Channel Islands National Park: Design Considerations for Weather and Climate Monitoring

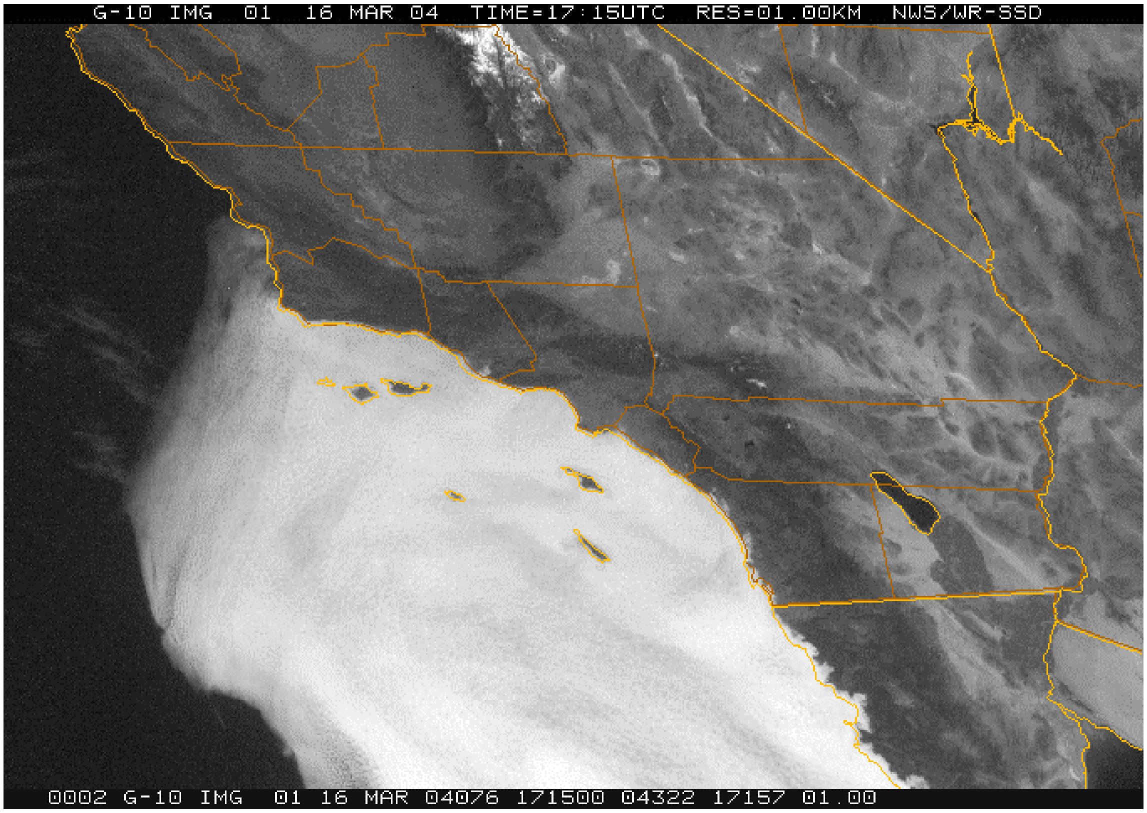

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Table of contents

Executive Summary

Channel Islands National Park has been designated as a prototype park for development of methodologies to utilize the national park system to characterize and understand variability and change in natural environments. The purpose of this report is to highlight how Channel Islands can contribute to better approaches to monitoring of climate as part of the Inventory and Monitoring Program. As with all parks, there are generic and specialized issues to consider, and this report has attempted to separate these in many of its sections.

Climate is a fundamental driver of biological and physical systems. This particular park is located very close to a major transition in climate that begins at the California coastline. Winter precipitation shows more relative year-to-year variation along the Los Angeles to San Diego coast than anywhere else in the United States. Evidence is accumulating that California's climate is changing, for whatever reasons. However, a major unresolved question is whether, and how, variations and trends in its rich marine upwelling systems ought to, and do, track variations on the mainland. Channel Islands National Park is well situated to help answer this important question.

The main purposes of the climate observational system are to characterize the variability of each island's climate in time and in space, provide daily updates to park personnel to inform operational needs, provide vital safety information regarding air, water and land transportation, provide interpretive information for visitors, and to help tie climate to variations in biological communities.

For purposes of tracking climate, a paramount need is for long-term consistency in methodological practices and constancy of instrumental exposure, or methods to bridge unavoidable changes.

A correlation analysis revealed there is enough variation among the islands that each island should have at least one automated station designated to track climate through time. These key stations should report in real time. San Miguel is the only island without a long-term automated site, and opportunities to address this should be explored.

There is no particular reason to move any of the existing automated stations.

These data rapidly begin to lose their value if they are not continuous. The present automated observing system still needs more protection against disruptive data gaps. The two main islands have acquired records of 10-15 years, and are starting to be able to provide additional kinds of information about variability through time as a consequence.

A systematic program of preventive maintenance is needed to insure that data are reliably received, accurate, and complete, with visits at least once or twice a

year. This approach has a high payoff. The interagency RAWS (Remote Automated Weather Station) program is a good choice for present and future key stations because many factors are automatically included.

Each automated station should measure, at least hourly, temperature, precipitation, wind speed and direction, relative humidity, and solar radiation. Fuel stick temperature (for fire purposes), soil temperature and soil moisture are very useful in additions. Barometric pressure would be of use to forecasters, especially at San Miguel and Anacapa, which span the main four islands.

Automation does not mean an end to the need for humans, but rather a change in the skill set needed to keep the observations coming in. This may require joining forces among nearby parks.

The ranger data constitute a useful supplement for two reasons: 1) as backup when automated systems have problems and cannot be serviced quickly, and 2) to better define the detailed spatial patterns of climate on the islands. This should be facilitated by a modest investment in a low-tech, less expensive, partly-manual system that records the most desired information (precipitation and temperature), and that can tolerate interruptions as human observers react to higher priorities.

A hybrid system of key benchmark stations, to which a set of supplemental stations are referenced, a kind of “hub and spoke” approach, appears to be the best model for the National Park System to adopt for networks or park units with internal climate diversity. At Channel Islands, at least one site per island would be considered as the benchmark, and ranger data locations or other sites could act as valuable supplements and backup.

The Main Ranch on Santa Cruz appears to have an excellent precipitation record that is well-correlated with mainland sites over the past century. Missing records in later years are worth locating. A good precipitation record as close to this site as practical should be maintained indefinitely.

It is recognized that the salty environment poses added burdens on electronic equipment, and that logistics and transportation constraints pose a considerable challenge. However, these observations are critical to operational and scientific needs and are always in demand. These islands are an inherently more difficult setting to maintain an observational network, and there should be provisions nationally for addressing such imbalances associated with specific elements of a comprehensive nationwide monitoring program.

1. About this document

The main purpose of this document is to provide advice and information on establishing and augmenting a network of systematic observations of weather and climate for Channel Islands National Park.

However, Channel Islands National Park (or "CHIS" as abbreviated by the National Park Service, NPS) also has a role as a prototype in this regard, in terms of how other NPS units approach the same subject. The activities and issues represented in this report have arisen frequently in many settings, within the NPS, elsewhere in other Department of Interior resource management agencies, in federal agencies in other departments, and in state and regional and local organizations. There are some factors that must be considered in all such settings, and there are others that are only germane to the specific setting addressed.

Because these issues arise so often in other administrative or organizational settings, we have attempted to separate the general from the specific, where this seems practical and appropriate. The general case is intended to apply anywhere in the U.S. including Alaska and Hawaii. In some cases, where the Western Regional Climate Center (WRCC) has developed potential workable approaches or solutions, those are highlighted for possible consideration in other venues. Over many years, we have encountered a great deal of interest in this subject, and there have been a number of publications dealing with aspects of weather and climate monitoring. The hope here is that this approach will be useful enough to emulate in other contexts.

With respect to the organization of this report, there are a large number of intersecting factors. Many subjects could be discussed under a variety of different headings, and in different order. As a result, the manner of grouping of comments is to some extent arbitrary

2. Background

As part of their overall mission, most national parks observe weather and climate elements. Many have been doing this for decades, and others are just getting started. The main purposes are stated here in abbreviated form and in more detail in Section 6.1

- Establishment of engineering and design criteria for structures, roads, culverts, wind/solar power, for comfort, safety, and economic needs.
- Real-time operations and maintenance needs, early warnings of potential hazards (landslides, mudflows, washouts, fallen trees, plowing, fire conditions, aircraft and watercraft conditions, road conditions, rescue conditions, fogginess, restoration and remediation efforts, etc)

- Long-term consistent monitoring for detection of changes in environmental drivers of park ecosystems, both slowly evolving and disturbance events.
- Visitor education and interpretation, expected and actual conditions while present and when deciding whether and when to visit the park unit.
- Retrospective data to understand and explain changes seen after-the-fact in park flora and fauna
- Documentation for posterity of physical conditions in / near the park, means, extremes, and variability (in time and space), for all applications.

Weather and climate constitute a prominent and widely-requested component of the Vital Signs Inventory and Monitoring Program. Some smaller park units, or units without sites that have good exposure, may benefit more from using nearby measurements made by some other group for their own purposes. Oakley et al. (2003) provide guidelines for development of monitoring protocols. The National Park Service currently maintains a web page that provides updates on the status of the Inventory and Monitoring Program at http://science.nature.nps.gov/im/monitor.

Although there is near-universal recognition of the value of systematic weather and climate measurements, which always score high on priority lists, such measurements will not have much value if not made to accepted standards. There is no single source for such standards, nor a single standard that meets all needs, but for general purposes several have been put forward by the American Association of State Climatologists (1985), the Environmental Protection Agency (1987), and the World Meteorological Organization (1983). Another set of recommendations was offered by Finklin and Fischer (1990), with a supplement by the National Wildfire Coordinating Group (2004). The RAWS (Remote Automatic Weather Station) program also produced a set of standards (Bureau of Land Management, 1997). Variations have been also offered by instrument makers (e.g., Tanner, 1990) and are more accessible via the Web. As a group, these serve as conventions that are widely adhered to. Furthermore, most of the literature on this subject is hard to locate and has not been made web accessible in any one place. It is similarly difficult to locate "how-to" manuals. Blauvelt (2005) has developed a web-accessible document for the Automated Weather Data Network in Nebraska, but we have not encountered a comprehensive guide.

Quality control and quality assurance are issues at every step all the way through the sensing, communication, storage, retrieval and display process. Quality assurance is an umbrella concept that covers all processes ("start to finish") in order to insure that credible information is available for the final end use; quality control has more limited scope. An operational definition of quality control at WRCC is "the evaluation and improvement of imperfect data, by making use of other imperfect data." The most effective quality control is to make good measurements in the first place. Up-front emphasis on quality provides the biggest payoff in the long run.

There is also a widespread desire to use automated systems to reduce human involvement. This is admirable and understandable, but every automated weather / climate station or network requires significant human attention and maintenance oversight. A telling example is that the Oklahoma Mesonet (see Brock et al., 1995; and bibliography at www.mesonet.ou.edu), a network of about 115 high quality automated meteorological stations spread over 69,000 square miles, nonetheless allocates about 80 percent of its annual budget to people and only about 20 percent to equipment.

Climate. In this report, we consider "climate" to consist of the complete and entire ensemble of statistical descriptors of the temporal and spatial properties of the behavior of the atmosphere. This includes means, variances, frequency distributions, autocorrelations, spatial correlations and other patterns of association, temporal lags, and element-to-element relationships. These are all taken to have a physical basis in flows and reservoirs of energy and mass, even if we cannot discern how they arise and how they work. Climate and weather phenomena shade gradually into each other, and are ultimately inseparable.

For climate, consistency through time is vital, counting nearly as much as accuracy, and sometimes as much or more. Sensors record only what is happening at the sensor – this is all they can ever "know." It is the responsibility of the station or network manager to insure that the sensor readings and observational methodologies produce values that are representative of the spatial and temporal scales of climate one wishes to record. These scales could be very local within a specialized setting (a few centimeters, meters or tens of meters) where a particular plant or animal lives, or regional (kilometers to tens or hundreds of kilometers) for multiple purposes, the most common need.

Changes in instruments, site characteristics, and observing methodologies can lead to apparent changes in climate through time. Many of these are subtle and hardly noticeable from day to day, and others are abrupt. For this reason it is vital to document all the factors that can bear on the subsequent interpretation of measurements. This information ("metadata," data about data) has its own history, and a set of quality control issues that parallel those of the data themselves. There is no single standard for metadata, but a little rule will suffice:

- Record whatever will be needed to properly and correctly interpret the observations, by some person trying to decipher how this site functioned, long after you have retired and disappeared.

Documentation is greatly underappreciated, is seldom thorough enough (especially for climate purposes), and insufficient attention to this issue often lowers the present and especially future value of otherwise useful data. This topic is addressed in more detail below.

Siting and local factors can be critical to both quality and representativeness of observations for the desired application, and are explored further below. National parks, with their emphasis on preservation of natural conditions where possible, are usually excellent places to host long-term climate measurements. Many of the issues involved with climate monitoring have been summarized by Dr. Tom Karl, director of the NOAA National Climatic Data Center, and widedly distributed as the “Ten Principles for Climate Monitoring,” included here as **Appendix E**.

Finally, although the measurement of weather and climate sounds conceptually simple, with automated equipment the situation turns out to be anything but, and the skill set needed should not be underestimated.

3.1 Design – general considerations

There are several criteria we would like to utilize in deciding where to deploy new stations:

- Where are the existing stations?
- Where have data been gathered in the past (discontinued locations)?
- Where would a new station fill a knowledge gap about the basic long-term climatic averages for an area of interest?
- Where would a new station fill a knowledge gap about how climate behaves in time?
- As a special case of behavior in time, what locations might be expected to show a more sensitive response to climate change?
- How do the answers to the above questions depend on the climate element? Are the answers the same for precipitation, temperature, wind, snowfall, humidity, etc.?
- What role should manual measurements play? How should these interface with automated measurements?
- Are there special technical or management issues, either already present or anticipated in the next 5-15 years, requiring added climate information?
- What unique information is provided in addition to that from existing sites? “Redundancy is bad.”
- Because observing systems always have gaps and lose data, what nearby information is available to estimate for missing observations? “Redundancy is good.”
- How would logistics and maintenance affect these choices?

In this section we consider a variety of issues in a cursory or introductory manner, and return to many of them in more detail later.

<u>Robustness</u>. The most frequent reason for the loss of weather data is the weather itself, the very thing we most wish to record. The design of climate and weather observing programs should take into account the meteorological

equivalent of “peaking power” employed by utilities. Because environmental disturbances have such significant effects on ecological systems, sensors, data loggers and communications should be able to function during the most severe conditions that can be realistically anticipated over the next 50-100 years. Systems designed in this manner are much less likely to fail under more ordinary conditions, and much more likely to transmit continuous, quality data for both tranquil and very active periods.

Weather vs. Climate. For “weather” measurements, pertaining to what is approximately happening here and now, small moves and changes in exposure are not quite so critical. For “climate” measurements, where values from different points in time will be compared, siting and exposure are critical factors, and it is vitally important that the observing circumstances remain essentially unchanged over the duration of the station record.

Station moves can affect different elements to different degrees. Even small moves of a few feet, especially vertically, can affect temperature records. Hills and knolls act differently from the bottoms of small swales, pockets, or drainage channels (Geiger et al, 2003; Whiteman, 2000). Precipitation is probably less subject to change with moves of 50-100 feet than other elements (that is, it has less intrinsic variation in small spaces), except if wind flow over the gage is affected.

Physical setting. Siting and exposure, and their continuity and consistency through time, have significant influence on the climate records produced by a station. These two terms have overlapping connotations. We use the term “siting” in a more general sense, reserving the term “exposure” more for the particular circumstances that affect the ability of an instrument to obtain a measurement that is representative at the desired spatial or temporal scale, another topic taken up later.

Measurement intervals. Climatic processes occur continuously in time, but our measurement systems usually record in discrete chunks of time, seconds or hours or days, for example. These are often referred to as “systematic” measurements. Interval averages may hide active or interesting periods of high-intensity activity. Alternatively, some systems record “events,” when some threshold of activity is exceeded (examples: another hundredth of an inch of precipitation, another kilometer of wind has moved past, the temperature has changed by a degree, a gust higher than 39.9 mph has been measured) at which time measurements from all sensors are then reported. This is also known as “breakpoint” data. In relatively unchanging conditions (long calm periods, or rainless weeks, for example) event recorders should send a signal that they are still alive and looking. If systematic recorders are programmed to note and periodically report the highest, lowest and mean value within each time interval, the likelihood is reduced that interesting behavior will be glossed over, or lost. With the capacity of today’s dataloggers, it is a good idea to record and report extrema within the basic time increment (e.g., hourly or 10-minutely). This also assists with quality control.

There is usually a trade-off between data volume and time increment, and most automated systems are now set to record approximately hourly. A number of field stations maintained by WRCC are programmed to record in 10- or 5-minute increments, from which an hourly value can be readily constructed; however, this produces 6-12 times as much data. These systems do not typically record the details of events at sub-interval time scales, but can easily record peak values, or counts of threshold exceedance, within these intervals.

Thus, for each time interval at automated stations, we recommend that several kinds of information, means or sums, extreme maximum and minimum, sometimes standard deviations be recorded. These quantities are very helpful for quality control and other purposes. Modern data loggers and office computers have quite high capacity. Diagnostic information on the state of the solar charger or battery voltage and their extremes is of great value. This is discussed in more detail below.

Automation has also made possible adaptive or intelligent monitoring, wherein systems vary their recording rate according to whether behavior of interest has been detected with software. Sub-interval behavior of interest can be masked on occasion (e.g., a five-minute extreme downpour with high erosive capability that is hidden by an innocuous hourly total). Most users prefer measurements that are systematic in time because they are much easier to summarize and manipulate.

For breakpoint data produced by event reporters, there is also a need to periodically send a signal that a station is still functional, even though it has nothing more than that to report. “No report” does not necessarily mean “no data,” and it is important to distinguish between the fact of an observation and the content of that observation (e.g., an observation of “0.00” is different from “no observation”).

<u>Mixed time scales</u>. There are times when we may wish to combine information from radically different scales. For example, over the past 100 years, how has the frequency varied of 5-minute precipitation peaks, or of peak 1-second wind gusts? Over this time, has nearby vegetation gradually grown up to increasingly block the wind, or slowly improve the precipitation catch? Answers to these questions require knowledge over a large range of time scales.

<u>Elements</u>. For manual measurements, temperature extremes, precipitation, and snowfall / snowdepth are the typical elements recorded. A standard complement of automated data includes temperature, precipitation, humidity, wind speed and direction, and solar radiation. An exception is that precipitation is difficult to measure accurately in very windy locations. Automated measurements of

precipitation that is falling as snow are improving, but manual measurements are probably still the comparison standard, as long as shielding is present. Automated measurement of frozen precipitation presents numerous challenges that have not been fully resolved in a century of trying, and the best gages are quite expensive ($3-8 K). Soil temperatures are sometimes also included. Soil moisture is extremely useful, but is not made at many sites, and takes care in installation and maintenance. Soil properties vary tremendously in short distances as well, and it is often very difficult ("impossible") to accurately document these variations (without digging it all up!). In cooler climates, ultrasonic snow depth sensors are becoming commonplace.

Wind standards. Wind varies the most in the shortest distance, since it always decreases to zero near the ground and increases rapidly (approximately logarithmically) with height near the ground. Changes in anemometer height will obviously affect the wind speed distribution, as will changes in vegetation, obstructions such as buildings, and so forth. A site with a 10-foot mast will clearly be less windy than one with a 20-foot or 10 meter (33 ft) mast. Historically many U.S. airports (Federal Aviation Administration, FAA, and National Weather Service, NWS) and most current RAWS sites have used a 20-foot standard mast for wind. Some NPS RAWS use shorter masts. Over the last decade, as ASOS (Automated Surface Observing System, mostly NWS) and AWOS (Automated Weather Observing System, mostly FAA) have been deployed at most airports, the wind has been raised to 26 or 33 feet, depending on airplane clearance. The World Meteorological Organization recommends 10 meters as the height for wind measurements, and more groups are slowly migrating to this standard. The AASC recommendation (1985) for wind was 3 meters, at a time when automated stations were just becoming popular; this standard has become less popular since then, and a higher level is usually preferred. Different anemometers have different starting thresholds. For both sustained winds (averages over some short interval from 2-60 minutes) and especially for gusts, the duration makes a considerable difference. For the very same wind history, 1-second gusts are higher than 3-second-average gusts, which in turn are greater than 5-second averages, so that the same sequence would be described with different numbers (and all 3 systems and more are in use). Changes in averaging procedure, or in height, or in exposure, can lead to "false" or "fake" climate change with no change in actual climate. Changes in any of these should be noted in the metadata.

Wind nomenclature. Wind is a vector quantity, having a direction and a speed. Directions can be two or three dimensional, the latter if the vertical component is important. In all common use, winds are always denoted by the direction they blow from (a "north wind", a "southerly breeze"). This convention exists because wind often brings weather, and thus our attention is focused upstream. This contrasts with ocean currents, which are usually denoted by the direction they move towards (an "eastward current" moves from west toward east). In specialized applications (such as atmospheric modeling), wind velocity vectors point in the direction toward which the wind is blowing. Thus, a southeast wind (from SE) has both northward and eastward (to the north, to the east) components. Except near mountains, wind cannot blow up or down near the ground, so the vertical component of wind is often approximated as zero and the horizontal component is emphasized.

Frozen precipitation. Frozen precipitation is much more difficult to measure than liquid precipitation, especially with automated techniques. Goodison et al (1998), Sevruk and Harmon (1984), Yang et al (1998), and Yang et al (2001) provide many of the reasons why this is so. The importance of frozen precipitation varies greatly from one setting to another. This subject was discussed in more detail in a related Inventory and Monitoring report for the Alaska national parks (Redmond et al, 2005).

In climates that receive frozen precipitation, a decision must be made whether to try to record such events accurately. This usually means that the precipitation must be turned into liquid, either by falling into an antifreeze fluid solution that is then weighed, or by heating enough to melt and fall through a measuring mechanism such as a nearly-balanced tipper. Accurate measurements (to the nearest 0.01 inch) of the first type require quite expensive gages; tipping buckets can achieve this resolution readily, but are more apt to lose some or all of the precipitation. Improvements have been made to the heating mechanism on the National Weather Service tipping bucket gage used for ASOS, the Automated Surface Observing System, to the point where many of its numerous deficiencies have become less of a problem, but this is not a cheap gage either. If heat must be supplied to melt frozen precipitation, this is usually more than renewable energy (solar panels or wind recharging) can provide, meaning that AC power is needed, a considerable limitation in many western United States settings. Furthermore, recharging conditions during frozen precipitation or rime are often less than optimal, with heavy clouds, short days, low solar elevation angles and more horizon blocking, and cold temperatures causing other battery drawdown.

Save or lose? A second consideration with precipitation is whether it should be saved, as in weighing systems, or lost, as in tipping bucket systems. In the latter, after the water has passed through the tipping mechanism, it usually just drops to the ground. There is thus no checksum, to insure that the sum of all the tips adds up to what has been saved in a reservoir someplace. By contrast, the weighing gages continually accumulate until the reservoir is emptied, the value that is reported is the total reservoir content (for example, the height of the liquid column in a tube), and the incremental precipitation is the difference in depth between two known times. These gages do not always have the same fine resolution, often recording to the nearest 0.1 inch or whole centimeter, usually good enough for hydrology but not necessarily for other needs. (For reference: a hundredth of an inch of precipitation can get a person in street clothes quite wet.) This is how the NRCS-USDA Snotel system works, in climates that see up to 500-1000 inches of snow in a winter. (See www.wcc.nrcs.usda.gov/publications for publications, or www.wcc.nrcs.usda.gov/factpub/aib536.html for a specific description.) No precipitation is lost this way. A thin layer of oil is used to suppress evaporation, and anti-freeze insures that frozen precipitation melts. When initially recharged, the sum of the oil and starting antifreeze solution is treated as the zero point. The antifreeze is usually not environmentally friendly enough to discharge to the ground, and thus must be hauled in and back out. Other weighing gages are capable of measuring to 0.01 inch (0.25 mm) resolution, but do not have as much capacity and must be emptied more often. Day/night and storm-related thermal expansion and contraction, and sometimes wind shaking, of Snotel gages can cause fluid pressure from accumulated totals to go up and down by small increments (0.01 to 0.10 foot, commonly) leading to "negative precipitation" followed by similarly non-real light precipitation, when in fact no change took place in accumulated precipitation at all.

Time. Time should always be in Local Standard Time (L.S.T.), and under no circumstances should Daylight Savings Time ever be used with automated equipment and timers. The latter leads to one duplicate hour, one missing hour, and a season of displaced values, needless confusion, and a data management nightmare. Absolute time such as Greenwich Mean Time (GMT) or Coordinated Universal Time (UTC) can also be used, because they are unambiguously translatable. Since measurements only provide information about what already *has* happened or *is* happening, not what *will* happen, they should always be assigned to the *ending time* of the interval over which they apply, with hour 24 marking the end of the last hour of the day. In this system, midnight always represents the end of the day, not the start. We have encountered situations where police officers seeking corroborating weather data could not recall whether the time on their crime report from a year ago was the starting midnight or the ending midnight! Station positions should be known to within a few meters, easily accomplished with GPS, so that time zones and solar angles can be accurately determined.

Automated vs Manual. Most of this report is concerned with automated measurements. Historically, most measurements are manual, and typically once a day, and in many cases those continue because of habit, usefulness, and desire for continuity over time. Manual measurements are extremely useful and when possible should be encouraged. Automated measurements are becoming much more common. Manual and automated measurements form a good complement for each other. For either one it is important to record time in a logically consistent way.

It should not be automatically assumed that newer data and measurements are "better" than older data, or that manual data are "worse" than automated. Older or simpler manual measurements are often of very high quality, even if they are sometimes not in the most convenient digital form.

Manual conventions. Manual measurements are typically made once a day. Elements usually consist of maximum and minimum temperature, temperature at observation time, precipitation, snowfall, snow depth, and sometimes evaporation, wind or other information. Since it is not actually known when the extremes occurred, the only logical approach, and the nationwide convention, is to ascribe the entire measurement to the date of the end of the time interval, and enter it on the form that way. For morning observers (say, 8 am to 8 am), this means that the maximum temperature written for today is often from yesterday afternoon, and that sometimes the minimum temperature for the 24-hour period actually occurred yesterday morning, but this is completely understood and expected. It is often a surprise to observers how many maximum temperatures do not occur in the afternoon, and how many minimum temperatures do not occur in the predawn hours. This is especially true in environments that are colder, higher, northerly, cloudy, mountainous, or coastal. As long as this convention is strictly followed every day, it has been shown that truly excellent climate records can result (Redmond, 1992). Manual observers should reset equipment only one time per day, at the official observing time. Making more than one measurement a day is strongly discouraged; this results in a hybrid record that is too difficult to interpret. The only exception is for total daily snowfall. New snowfall can be measured up to four times per day, with no observations closer than six hours. It is well known that more frequent measurement of snow increases the annual total, because compaction is a continuous process.

3.2 Design -- Channel Island considerations

The purposes for the measurement program at Channel Islands National Park are similar to those given earlier in Section 2, and elaborated in Section 6, for all National Park Service units. Since this particular Park must be reached by private or public boat, and the islands are out of sight of mainland ports, wind and wave conditions are important for safety reasons. The NOAA buoys are especially useful for this because of the wave information they uniquely report, but they also supply other data on wind, temperature (air and sea) and humidity, over the water.

As at all parks, precipitation characteristics of interest are amount and frequency (how often), type (liquid or frozen), and sometimes rate, and how these vary with elevation, slope magnitude and direction, windward or leeward, or season. Temperature affects many processes and is likewise always of interest, even though is temporal variations are highly damped by proximity to the marine environment.

Wind and fog are major elements of the Park, and information about those is a priority. Fog and stratus can be uniform or spatially patchy, and have varying base and top altitudes, usually below 2500 feet above sea level. The presence of fog can be inferred or estimated from relative humidity, utilizing a measurement that is comparatively cheap and simple in contrast to measurement of the cloud ceiling with a vertically pointing light beam or laser. Solar radiation measurements in concert with relative humidity can help differentiate between fog (encompassing the station) and stratus (base is above the station).

Regional wind patterns are extremely diverse. Because of the bend in the coastline at Point Conception, a flow separation point and a large eddy in the airflow is often present in summer during the north wind regime (see photo gallery, **Appendix F**). Thus, Anacapa and San Miguel are often experiencing different conditions, sometimes significantly so, from each other. Examination of numerous satellite photos also reveals a tremendous diversity of small scale features on almost any typical day, and often the different islands are experiencing different degrees of fog or stratus at the same time. The base and top altitude of the fog or stratus varies from day to day as well. In addition, these complex spatial patterns can change rapidly in time. Many times, the highest elevations on Santa Cruz and Santa Rosa are in the sun, above the cloud/fog shrouded lower elevations (see cover photo). Therefore a station at a high elevation is a very good idea, like the one on Santa Rosa.

The plant and perhaps animal distributions (down to the microbial level) are certainly tied to the frequency of direct sunlight, and to the frequency of enveloping blankets of fog, and these likely vary with elevation, so measurements at different elevations (highest and lowest) that relate to fog and stratus (relative humidity or solar radiation) are certainly desirable.

One very nice thing about the Channel Islands is that frozen precipitation is rare, which greatly simplifies the measurement of precipitation. Ice pellets and hail likely occur with vigorous convection of the type strong enough to produce lightning. The higher elevations will likely see snow on occasion, perhaps as often as once a year, though the contribution of snow to the annual total will be small. Nevertheless, there will be ecological effects, since plants have to survive their icy covering.

With respect to snow, if unheated tipping bucket gages are used, the gage must contain a funnel to position the water drops directly over the tipper. Without a heater, snow will accumulate on the funnel and the sides of the gage, or else fly in and fly out and not stick at all. This snow will not flow through the tipper until the temperature climbs a short distance above the freezing point. Thus, precipitation that is recorded in this manner will almost always be less than the true amount, and will be reported on a delayed basis, and will not be the correct rate, because of the dependence on the rate of melt, not the rate of fall. Cold spells do not last long here, but there is potential for upper elevation snows to not pass through the tipping mechanism for a day or two, sometimes longer. Conversely, an extended period of frozen precipitation will appear as a measurement of “zero” so that two successive periods will have incorrect precipitation data.

A common clue to an occurrence of snowfall at an untended tipping bucket gage is the initiation of “precipitation” when the temperature warms past 32 degrees F and snow in the funnel begins to melt and flow into the tipper. Such situations will not happen often near sea level in the Channel Islands, but will happen on occasion at higher elevations. At the Santa Rosa RAWS site (1298 ft elevation), temperatures of between +2 and +32 F (-17 and 0 ^{o}C) occurred 0.04 percent of the time, or a mere 48 hours out of a total of 117218 hours with data, between April 1990 and October 2004. Fortunately, snow is thus not a significant issue, and Channel Islands is very lucky not to have to deal with it, a happy circumstance that simplifies precipitation collection a great deal.

3.3 Siting strategy for Channel Islands

General strategy. The climate conditions at Channel Islands National Park are generally maritime, so if there were only a single station it should make sure to be maximally subject to that influence. However, there is also considerable structure and variation, across the whole set of islands from east to west and (somewhat less) from north to south (to tiny Santa Barbara), and also across each of the bigger islands. A single station for the island group cannot encompass all this variability at one time. The main priority should be to have at least one site on each island, for a total of 5 sites. Islands with additional climate structure, primarily Santa Rosa and Santa Cruz, would benefit from stations that sample this within-island diversity (e.g. coastal versus elevated). The correlation analysis (**Appendix D**) provides much of the rationale for such a strategy.

The two big islands have considerable variation in climate across them, with small microclimates varying with proximity to the sea, protection from the wind, and with elevation, slope and aspect. For wind, good exposure is important. The Black Mountain ridge top site at 1300 ft on Santa Rosa has excellent fetch in every direction and is a very good location for wind and temperature and humidity and solar radiation. Because air is typically in movement at this site, the sampling volume for atmospheric measurements is relatively large. For precipitation, the Santa Rosa site is less than optimal, since the wind (frequent and strong) reduces the catch here unless the gage is well shielded. Because of orographic uplift (air flow uphill toward higher topography), this location would be expected to be quite wet, but the much higher winds here would reduce the gage catch efficiency and reduce the totals. Nonetheless, this site readily meets widespread standards for site exposure, and given the history that exists, the best approach is certainly to keep it at its present location and work around, or simply acknowledge, the undercatch problem. It is not a great precipitation site, but is excellent for everything else.

The current sampling seems to have captured much of the range of temperature behavior on the islands, from relatively restricted near-ocean conditions, to more locally variable conditions at sites somewhat protected from the ocean influence.

On Santa Cruz the Central Valley Main Ranch site (250 ft elevation) can get surprisingly warm or even hot, even just a short distance from the ocean. This is because it is in a channelized setting, an east-west valley protected from immediate maritime influence from the south and north. For the same reason it can cool off more at night, with the help of local drainage winds. Topographic steering of flow in this channel increases the frequency of east and west winds compared to a site that has equal exposure at all azimuths. This station has a greater diurnal range because of where it sits in this valley. It also receives some solar radiation reflected from hill slopes to the north and south, in effect, extra sunlight. Radiation effects here will differ between high and low sun months, and the azimuth of sunrise and sunset in winter and summer, and the different shadowing patterns through the day and year. On the north side of Santa Cruz, the Del Norte Site at 800 feet above the sea has good maritime exposure to the north; the mass of the island to the south has heating or cooling effects on this site during southerly winds on clear days. This site is about mid-depth in the marine layer, which typically is 1500-2000 feet thick. In summer, above the top of the marine layer, around the level of the highest ridges on the island, the temperature will be warmer, sometimes a lot warmer, and the air dramatically drier. The two present Santa Cruz stations complement each other well. If a third site were ever added, the top of one of the highest east ridges that form the spine of the island would be the next priority. After this would be a low elevation site near the west end of the Central Valley.

On Anacapa, San Miguel, and Santa Barbara Islands, the choices for locations are more restricted because of size and topography, but the variety across these islands is correspondingly reduced because of their smaller sizes.

As of this writing, the remaining island to be sampled is San Miguel, and the relatively exposed and more uniform mid-elevations at mid-island should probably constitute the highest priority for a single station. There are two high points on San Miguel, Green Mountain to the west, and the next hill to the east, nearly the same elevation at 830 feet. The latter location was the site of a Navy weather station that is now mostly gone. The exposure is excellent, but further discussions with NPS personnel led to the conclusion that a site near the airstrip would be logistically much easier to serve, and meteorologically better in a few respects and not quite as good in others. As for the airstrip site on San Miguel 1) it has practical value for aviation, 2) the slightly reduced elevation from the gradual hilltop to the west should not reduce the wind speeds by too much, 3) the wind has good fetches and exposures from all directions there, and 4) the site is relatively easy to service. A slight drawback is its visibility and slight increase in potential for human tampering, whether well- or ill-intended. If an airstrip station were deployed and resources permitted, a second temporary site at the old Navy station location could be erected to develop an overlap with the older Navy records. Unfortunately WRCC does not have good access to these records.

Almost any site at Anacapa will do, since the island is long and narrow. A location near the lighthouse, subject to siting conditions mentioned elsewhere, would be slightly more suitabile. For one thing, all historical measurements have been made near the lighthouse on the east end. In addition this site is routinely visited, and can be better serviced, in contrast to the other parts of Anacapa that have high cliffs or steep slopes falling directly into the ocean, and potentially dangerous landing zones

Santa Barbara poses a special challenge. Highly isolated, with a single landing zone, and ships following strict schedules, and with short stopovers only approximately every week, there is limited time to service a station. A site near the landing zone would be better from a logistics standpoint, but the existing site on the north end of the island has a much better exposure, and the recommendation is to leave it where it is. This reduces the length of a maintenance visit, and means that unexpected problems typically encountered with networks and stations that are normally solvable with open-ended time available might not have time for completion and checking out, unless an unplanned eight-day vacation is acceptable. Problems could thus linger on for months, as experience has already shown. It is not highly practical for NPS personnel to visit with their own boat. Waiting for the right combination of ranger time, ship time, and visit duration results in many delays to servicing the station. Ignoring the reality of resource constraints, budgeting for 1-3 trips per year to service this station and perhaps attend to other island priorities, with an overnight layover and internal coordination to maximize efficiency, would be desirable.

Another factor at Channel Islands is salt, which is extremely corrosive on instruments, electronics, and circuitry, usually shortening their lifetime and swap-out intervals. Elevation helps in this regard, but there will usually be some salt in the air no matter what. The small islands of Santa Barbara and Anacapa would probably be expected to see the worst salt conditions because the salt source is so close and constant. The consequences are more frequent parts replacement than the manufacturer suggests, and more frequent needs for visits. This is especially problematic at seldom visited Santa Barbara Island.

Recommendation for existing stations. Our preliminary assessment of the existing stations is that there is no compelling reason to move them. In addition, station records from relocated stations should not be combined, so any move would effectively end one record, and delay even further the time needed to obtain the multi-year records of greatest utility.

3.4 Channel Islands siting -- additional specific information

The nearby presence of marine air, and the fact that it is usually in motion (calm conditions are less frequent than inland on the continent) helps reduce the amount of temporal variation associated with local heating fluctuations. When wind becomes nearly calm on sunny days, heating differences will result in larger local spatial variations in temperature, and thus temporal variations as well. Because these are islands, temperature does not typically span a very large absolute range, especially for sites within a mile or so of the coast. However, the presence of land of almost any consequence does cause the range of observed temperatures to be larger. Air is heated and cooled mostly from below, and land heats and cools much more readily than does ocean water.

From December 1999 through October 2004, NOAA Buoy 46053, in the Santa Barbara Channel north of Del Norte, reported wind “calm” speeds of 0-1 mph just 2.8 percent of the time, while the Del Norte RAWS site, at 800 feet and about a mile from the water on the north side of Santa Cruz, reported 7.6 percent of the hours in this nearly-calm range. Including very light winds that encompass potential differences in anemometer starting thresholds, the buoy reported 18.7 percent of its winds between 0 and 4 mph, and the Del Norte RAWS reported 62.3 percent of its winds in the same speed range, indicating a much higher incidence of quiet winds on land. The average annual wind speed at the buoy is 9.8 mph, and at Del Norte is only 4.1 mph.

An ocean site, NOAA Buoy 46025, 35 nautical miles WSW of Santa Monica, shows a rather small total temperature range from 41 F to 79 F over a 20 year period from April 1982 thru October 2004. In a shorter period with common data, the same buoy previously mentioned (46053, in the Santa Barbara Channel north of Del Norte) ranged from 43-73 F. For that same latter period (December 1, 1999 through October 2004), the well-exposed site at Del Norte ranged from 38-95 F, showing the effect of the land surface on temperature. The hilltop site on Santa Rosa from April 1990 through October 2004 ranged between the mid teens (disregarding some unrealistic and erroneous very low values) to 96 F (disregarding some very high values in the several hundred degree F range). From April 1990 through October 2004, the temperature at the Central Valley site on Santa Cruz has ranged from 15 to 102 F, a rather robust range for this area, but believable. This inland site, in a long and narrow east-west valley, is one of the locations most protected from the ocean influence. Highly exposed Anacapa ranged from 46 to 87 F in its short record from January through October 2004 (with 49 percent of its hourly temperatures between 58 and 61 F!), and the exposed Santa Barbara Island site ranged from 42 to 89 F from April 1995 thru October 2004 (about half of the hours reporting).

What the foregoing indicates is that the presence of even a moderate sized island introduces possibilities for significant departures from the relatively unchanging environment of the open water. The presence of sheltered areas on the islands, and thus wider temperature fluctuations, will have implications for types of habitats available for plants and animals to live in and adapt to, and might introduce the possibility of specialized species restricted to very small scale habitats.

The general considerations mentioned above for all sites and parks also apply to Channel Islands. One particular caution with respect to specific locations would be to generally try to avoid the near-ocean environment because of salt corrosion.

However, having noted this, since there are studies of the kelp beds and the tidal environment ongoing, as one exception it would be worth considering one site that is near the shore, and has equipment capable of measuring ocean water temperatures in the shallow near-shore and surf zone, unless the NOAA buoys suffice. The growth of plant and animal sea life might depend on these temperatures in these specific locations. And do we know if kelp production variations (for example) from one year to the next are driven by climate variations? An altitudinal transect of solar radiation would give a sense of whether the tops of the ridges stuck out in the sun, and above the marine inversion more often than their low-elevation counterparts. This could tie in to the kelp project, which is itself already making a large number of underwater temperature measurements with Hobo-type devices.

4.1 Inventory information -- general considerations

A basic starting point in program design is to establish what kinds of observations have been taken over time, by whom and in what manner, and whether these continue through today. It may also be of value to "re-occupy" an inactive station to provide some measure of continuity. This information (metadata) generally consists of a series of snapshots that apply to intervals of time, and therefore is really a history. There are two types of metadata information of interest:

1) Station inventories: information on the station itself, how it operated, latitude/longitude, elevation, elements measured, measurement frequency, sensor types, exposures, ground cover and vegetation, data processing details, network, purpose, and managing individual or agency, and

2) Data inventories: information on the measured data values themselves, their completeness, general quality, how missing data are represented, flagging systems, how special circumstances are denoted in the data, and the like.

Unfortunately, these two types of information are often stored and managed independently, if indeed both even exist. Similarly unfortunately, station metadata histories are often stored separately from the data the station generated. Data inventories derived from actually reading through the data are much better than those derived from station inventories that generally cover what data are thought to exist. Metadata and station inventories often gloss over or ignore, or simply do not know about, gaps in the data.

Although it is important to do so, the development of historic station or data inventories usually involves a large amount of detective work and requires a dogged persistence and an unflappable disposition. The source information is many times filed in old filing cabinets, poorly marked boxes, on old computer disks in formats no longer used, or quite frequently carried around in portable organic computers in people's heads, that may or may not prove accessible or reliable.

Most measurements are made as part of some kind of network. The limiting case is a network of one, made by an interested observer or group. Larger networks usually have more and better inventory data and station tracking procedures, but not always. There are a variety of typical national networks that are easiest to search first, including the NOAA cooperative network, airports and hourly meteorology readings and upper air balloon soundings. Other widespread networks include the RAWS (Remote Automatic Weather Station) network, the USDA / NRCS Snotel and snow course snowpack network, air quality networks, transportation networks, ALERT precipitation and wind networks, and along coasts the NOAA buoy system, CMAN (Coastal Marine Automated Network) stations, lighthouses, and specialized research or private observations, some of which may have long histories.

4.2 Inventory information – Channel Islands

The following observations can be found in the Channel Islands area.

NOAA Cooperative Network. Along the coast there is a set of daily climate measurements that range from decades to over a century. These include locations such as Long Beach, Los Angeles Airport and Downtown, Oxnard, Ventura, Santa Barbara Airport, Santa Barbara City, and Lompoc. On the five islands themselves, only Anacapa has hosted a NOAA cooperative station at times (not recently). San Nicholas and Santa Catalina have also had cooperative stations at times.

Hourly airways. These are measurements made at airports, and include wind, humidity, sky and visibility conditions, present weather, and are often hourly for at least part of the day if not all. We do not find such measurements on these five islands, though they have been taken at Santa Catalina and San Nicholas. There are a number of airports along the coast from Long Beach, Los Angeles, Oxnard, Camarillo, Santa Barbara, and Vandenberg.

RAWS. In its capacity as official archive of the entire RAWS network, WRCC automatically keeps track of these. There are four RAWS stations on three islands (Santa Rosa, Santa Cruz Main Ranch, Santa Cruz Del Norte, and Santa Barbara).

Snotel. None. Too close to sea level, no snowfed streams.

Transportation. No stations of this type on the islands.

Local or private. Anacapa now has an hourly station that WRCC is ingesting in real time. The Navy ran a station on San Miguel for a time, but we have not yet been able to locate the records. The Vail Ranch near Bechers Bay on Santa Rosa Island has a precipitation history stretching from about the 1940s to the present, but we were unable to ascertain the character, the completeness or adequacy of those records. We do have records from a station near there from 1988 onward.

Main Ranch. This is of special note. The Main Ranch on Santa Cruz Island has a monthly precipitation record that stretches back from January 1904 up though at least 1993. Although we do not know the exact GPS location of the precipitation gage, or its type, it appears to have been within a few hundred meters of the Santa Cruz RAWS station, probably at valley bottom to the northwest of the 2005 RAWS site. Records since 1993 are thought to exist for at least several more years. As will be seen below, this record correlates very highly with coastal stations, and a variety of tests show that this appears to be a very good record. As such it is well worth continuing, and locating the missing months.

Ranger data. Some of the rangers on duty on the islands have maintained daily records, and have been filling out forms with their daily observations. These range from quite complete to quite sporadic, depending on season and ranger schedules. These have recently been entered at WRCC and are updated as they arrive. This can serve as important supplemental information. Even if measurements cannot be made every day, occasional sums for precipitation can be entered in a standard way, and we are able to add these to get monthly totals to check against automated equipment.

NOAA Buoys. There are at least three buoys nearby, and others that are a little farther away. These are in deep water, but attached to the bottom with cables and anchors. They record hourly wind directions, speeds, and gusts, air and water temperatures, relative humidity and wave height. These are ingested live at WRCC, and the entire hourly history is available online. Two of the buoys started in 1993, and the other in 1982, so there is at this writing 23 years of hourly data available from on the water.

Profiler. Though not part of the National Park System instrumentation, the Navy facility on the nearby channel island of San Nicholas had, at the time of this report, been recently hosting a vertical profiler, installed by NOAA's

Environmental Technology Lab in Boulder CO. Using electromagnetic pulses this device is capable of detecting the varying wind speeds and directions and the temperature profile, inversion height, and freezing level (with precipitation) every 5 minutes or so up to 1-3 kilometers above the ground. This furnishes unique information about the vertical structure, which is such an important factor in the Santa Barbara Channel, the entire Los Angeles Bight south of Point Conception to San Diego, and the Santa Catalina Eddy often seen in the fog patterns (see gallery in **Appendix F**).

Access to data. Through a special project with the California Energy Commission, WRCC is developing a California Climate Data Archive, as well as a California Coastal Climate Data Archive. The data for this are available at www.calclim.dri.edu. A special web page for Channel Islands has also been developed at www.wrcc.dri.edu/nps that allows access to the Ranger and the RAWS and NOAA Buoy data, as well as mainland data.

Information on these stations is shown in **Appendix B**.

5.1 The climate background of Channel Islands

This description is not intended to be comprehensive, but rather to convey the overall climate. At latitude 34 degrees the Channel Islands experience the same winter-dominated precipitation regime as all of southern coastal California. The cool season accounts for nearly all of the annual precipitation. The active storm track expands southward in winter and intensifies, bringing occasional storms. At the long term Main Ranch station on Santa Cruz Island, the annual average from 1904-05 through 1992-93 is 19.90 inches (506 mm). There is considerable variation in annual precipitation on each island, and between islands. These variations are primarily related to elevation and the size of the elevated area, with higher and windward slopes getting more rain, and occasional snow. The steep west-facing and elevated portions of Santa Rosa and Santa Cruz likely see 25-30 inches (635-750 mm) or more, and amounts are likely more near 12-16 inches (300-400 mm) on the eastern low plains of the islands, values more comparable to Los Angeles. A general rule in this area is that less precipitation falls over the ocean than over land; an anchored ship would over time record significantly less precipitation than would a land-based site.

Also like southern coastal California, there is significant variation from one winter to the next (**Figure 1**), varying at the Main Ranch location on Santa Cruz from 6.35 (1989-90) to 56.15 (1940-41) inches (161-1426 mm) for the interval from July through June, a factor of nearly 9 in this 89-year record. The standard deviation of annual winter precipitation is 44 percent of the annual mean. This is very high; a typical figure in northern coastal Oregon would be 16-19 percent.

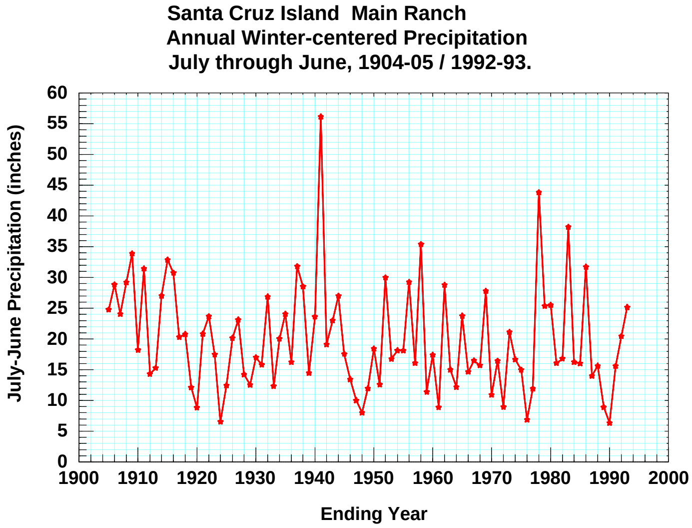
The river systems in south coastal California that are driven by this high degree of fluctuation in precipitation are the most variable in the United States. Shown also in **Figure 1** for comparison is a longer record from the relatively uniform topography near downtown Los Angeles, starting from the winter of 1877-78 and extending most of the way through the dramatically wet winter of 2004-05. The correlation exercise described below shows that these two annual time series have very good correspondence.

The mean annual temperature at Anacapa Island of about 60 F (15.5 C) is not greatly different from the mean annual ocean temperature of 59.3 F / 15 C measured at Buoy 46053 from 1994 through 2004 (in the Santa Barbara Channel). During this time at Buoy 46053 water temperature has ranged between 50-73 F (10-23 C), with 56 percent of the hourly water temperatures between 56-62 F (13-17 C). The daily range of temperature (max/min) near the water is about equal to the annual range of monthly mean temperature (10 F, 5-6 C) during the year. The highest elevations of the islands may poke above the marine inversion enough to warm considerably more than at lower elevations in summer. The exposed site at Santa Rosa has reached 96 F (36 C). The slightly sheltered RAWS site on Santa Cruz (near the Main Ranch) has fallen to about 15 F (-9 C) and been as warm as 103 F (40 C).

On occasion, offshore (from land to ocean) Santa Ana winds can bring very warm temperatures out to the islands. Ranger data show that Santa Barbara Island has recorded 105 F / 40.6 C, and the Main Ranch on Santa Cruz 109 F / 42.8 C. The Santa Ana wind analog in this area is the Sundowner, seen near Santa Barbara city. A fantastic account of an extremely warm Sundowner in 1859 is quoted by Blier (1998), with overnight temperatures so warm they resulted in burned skin on fishermen at night in the Santa Barbara Channel.

The wind regime along the coast of California is generally southerly in winter and northerly in summer as the subtropical high pressure system sets up in the eastern Pacific to the west of San Francisco. These cool (“cold” to many coastal residents) northerly along-shore winds drive the ocean upwelling that helps keep the temperatures cool. Wind roses at the well-exposed RAWS site on Santa Rosa are shown in **Figure 2**. At this site the wind is typically out of the northwest in summer as the northerly flow bends to the east to partially align with the mountainous shoreline. In winter a greater fraction of winds blow from the southeast compared with summer. Thus the predominant winds during this season also somewhat align with the shoreline. At times when broad northerly flow is under way along most of the California coastline, a giant swirl referred to as the Catalina Eddy is often seen to the south of Point Conception in the Los Angeles Bight, with winds circulating counterclockwise around the basin.

Figure 1. Santa Cruz annual winter-centered precipitation (top) and Downtown Los Angeles annual winter-centered precipitation, 1878-2005 winters (bottom), aligned approximately for common years.



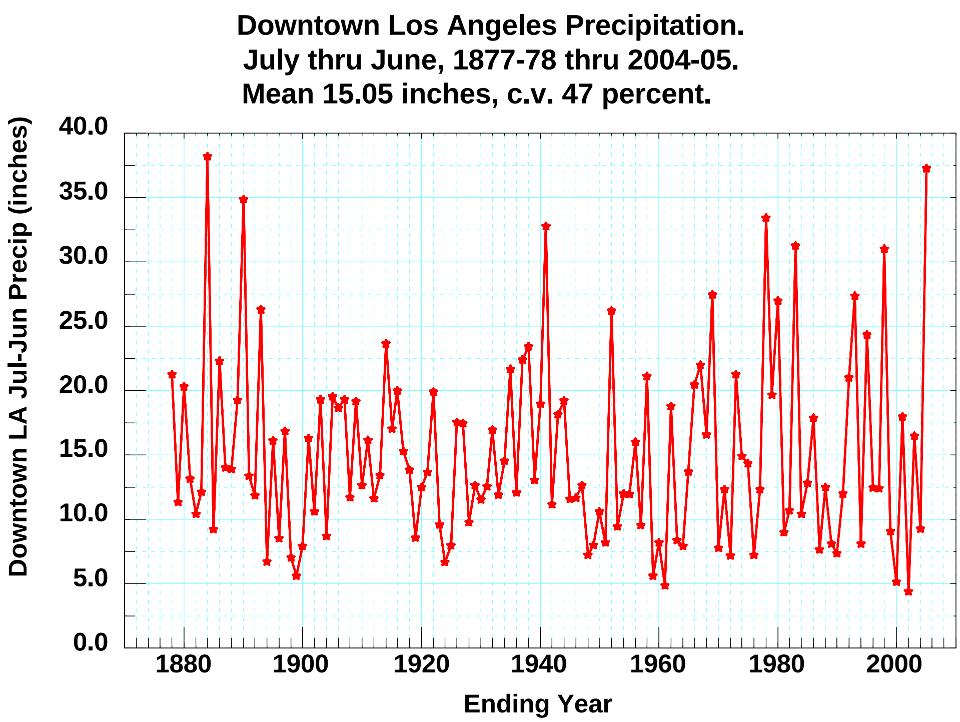
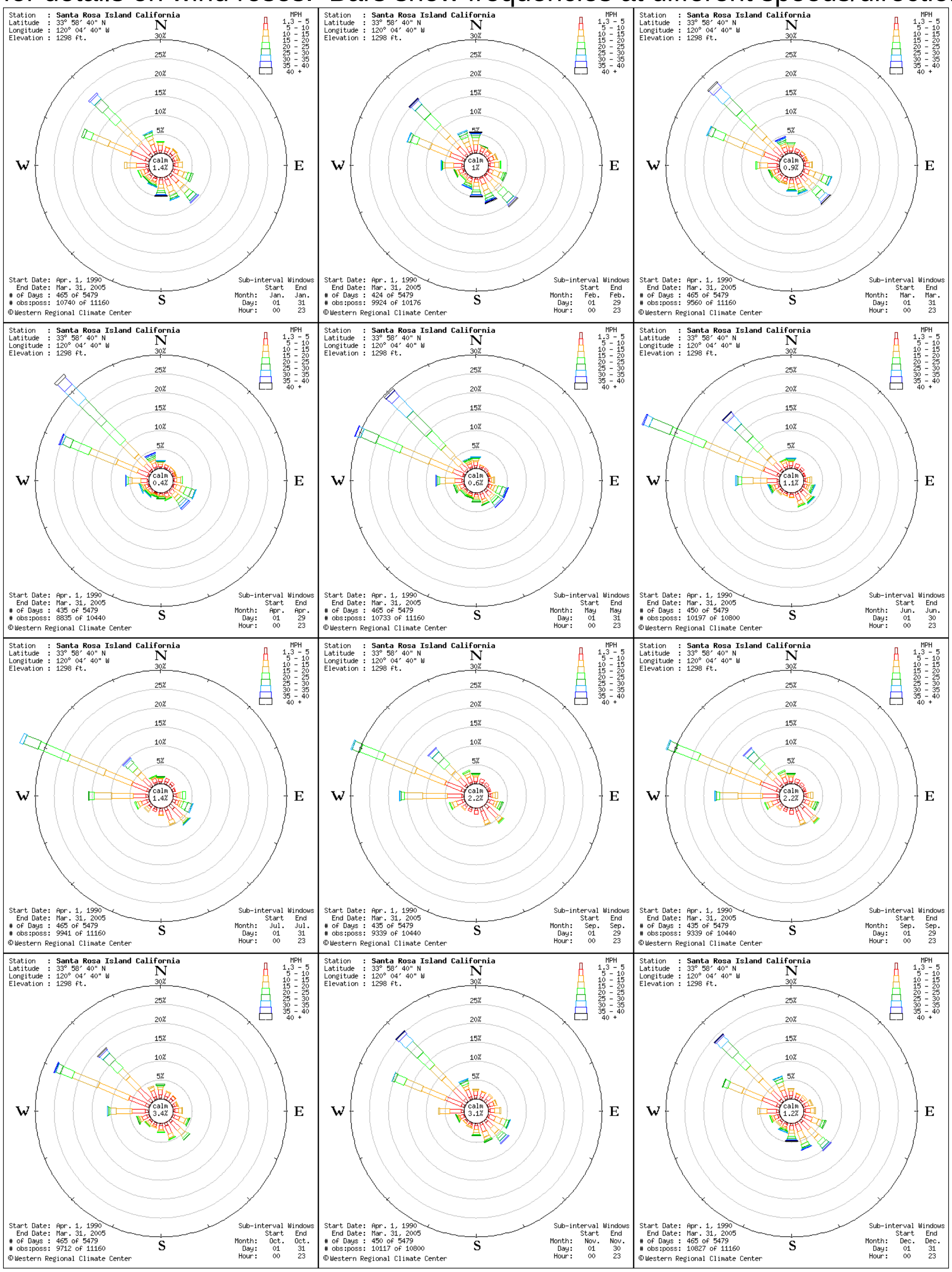


Figure 2. Wind Roses, all hours, Santa Rosa RAWS hilltop site, 1300 ft, from within the period April 1990-March 2005. About 10,000 observations for each month. All to the same scale, with 30 % maximum. From top left to bottom right: Jan, Feb, Mar; Apr, May, Jun; Jul, Aug, Sep; Oct, Nov, Dec. All hours. See text for details on wind roses. Bars show frequencies at different speeds/directions.



The other notable element is fog and marine stratus, more prevalent in summer than winter. The bottom of the stratus deck is most typically 500-1000 feet (150-300 meters) above sea level, but can range from sea level to higher than this. The top is typically at 2500-3500 feet (700-1100 meters above sea level), with typical thicknesses of anywhere from 0 to 2500 feet (0-800 meters). Dorman and Winant (2000) and references therein give many more details. Marine stratus is experienced as fog where the land rises into the cloud layer, and on many occasions fog is seen at sea level. Filonczuk et al (1995) discuss both the climatology of fog along the coast of California and also the significant variability it shows from year to year. The understanding and prediction of sea fog remains one of the most difficult problems in meteorology, depending as it does on fine nuances in flow, thermodynamics, atmospheric structure, ocean conditions, droplet microphysics, and radiation, as it hovers between existence and absence (Lewis et al, 2004). Just a few days of watching from any vantage point in the area, or consideration of the selection of satellite photos in **Appendix F** gives an appreciation of the incredible complexity of this phenomenon. The statistics associated with fog and stratus are important ecological drivers on the Channel Islands.

Above the marine inversion in summer, the air is much drier and warmer. On many occasions the higher peaks on the Channel Islands will be seen to protrude into this layer, especially on satellite photos. Wind flow in the dry air above is often different in speed and direction across the top boundary of the flow in the marine layer below.

Atmospheric flow is driven by differences in density, which in turn are produced by differences in heating rates from one place to another. There are such large gradients in heating rates along the California coast, especially between the ocean and continent, and especially during the summer half of the year, that the air is seldom still anywhere in this area. Consequently, fog and stratus conditions on many days are constantly fluctuating.

5.2 Climate background – Channel Island correlation analysis

As noted elsewhere in this report, to the extent that measurements are representative of larger circumstances the more cost-effective and useful they become. A measurement is temporally representative if its time series correlates well with similar time series in a large number of other locations of interest. A special correlation analysis was undertaken to acquire insights into this subject. This is of particular interest in the Channel Islands vicinity, as it is obvious that there are large differences in the marine and terrestrial climates even though they are separated by only a short distance.

Correlations also give important information on how well one can perform quality control. Redundant and correlated information is essential for quality control procedures to screen data and identify questionable or bad values, and to go further and offer edits and replacements for bad or missing data. For this reason we want observations that are not fully independent of all surrounding behavior, since there is no way to check their truthfulness.

In this regard, there are very few atmospheric specialists who are comfortable with providing replacements at hourly or finer time scales. At daily time scales, for extremes (daily max or min) or means, there is much less reluctance, and in most situations this is quite possible if there is sufficiently dense and nearby information from other sources. Note that "nearby" means in behavioral terms, not necessarily physical proximity, though those two metrics are often correlated themselves. There is similarly much less reluctance to estimate values at monthly and seasonal time scales, along with the added practical issue that there are far fewer values to examine and edit. There is always the unresolved problem that edited summary data are no longer self-consistent with the higher resolution data from which they may have been constructed (as with many automated data sets), and this typically means multiple and incompatible versions of a given data set. In such cases the derived data (daily or monthly values) in operational use cannot any longer be derived from the original hourly data. Though unfortunate, this is often a fact of life in data management.

Correlation analyses require assembly of the requisite time series. The latter are often hard to find, and must be created from source material, or have unknown origins and properties, and contain gaps and inhomogeneities. The analysis can also be done on several time scales, ranging from hours to decades. Time and resources did not permit a comprehensive analysis, but we were able to look at precipitation, temperature, wind and humidity. The records used were from shore stations from Point Conception around to Long Beach, from island RAWS stations, from the Main Ranch, and from the NOAA buoys. The RAWS records are quite short, only a dozen years or less, and barely usable at Santa Barbara Island because of their short record. Thus most of the attention was given to Santa Cruz and Santa Rosa. Correlation coefficients with short records must be viewed with proper skepticism, but do give some idea of strength of association, the main goal sought here, so the number of years was included to help with this assessment.

Data are shown in tables in **Appendix D,** and selected monthly correlations are shown with bar charts also in **Appendix D**.

Aside from local drizzle, precipitation processes are driven primarily by large spatial scale winter storms, sometimes with embedded convection, and to a first approximation we would expect that monthly, seasonal, and annual precipitation might be reasonably well correlated. This was indeed the case, and to a greater extent than anticipated. Also the Main Ranch monthly precipitation record correlates quite well with surrounding mainland sites, a most pleasing discovery. This record has a number of winter-time zeroes, which in many data sets arise from no data rather than from no precipitation. All of these zeroes were examined and found to be well supported. It is thus very much worth maintaining a record as near to this site as practical, and in finding values from the 1990s that may be in an obscure filing cabinet or old computer. Summer precipitation values do not correlate well from place to place, an expected finding. There are occasional poor or negative correlations in winter months.

Poor correlations can arise from two sources: poor physical connection between two locations, or poor data. There was not enough time to track down and evaluate all the poor-data possibilities, but when we see large negative correlations surrounded by adjoining months with high correlations, this does give reason to suspect a data issue. In many cases poor correlations arise because monthly averages are not based on full data, or have different missing periods at the two correlating sites and have too much missing data.

For temperature, the picture was more mixed as expected, but nonetheless there Is surprisingly greater correspondence across the open water than had been expected. The airports are usually right along the coast and thus may have local marine influences of their own. There were numerous hints that island RAWS temperature averages seem to fit better with NOAA cooperative observations than with those from airports, located close to the shore, and also these cooperative sites are a little further inland, a finding that might seem counterintuitive. However, perhaps the correlations are arising because certain situations (like offshore flow, or hot days) are best manifested a little further inland, and offshore flow might reach the islands preferentially at higher elevations, with little correlation nearer to sea level. The two RAWS sites on Santa Cruz and Santa Rosa have rather different exposures and elevations, and it is not surprising that they are not highly correlated in any month. (Correlation coefficients must be squared to determine common variance.)

As might be expected winds do not correlate more than modestly between any of the pairs examined. Somewhat surprisingly, even the two buoys near each other in Santa Barbara Channel, 46053 and 46054, did not correlate strongly at monthly time scales for wind speed. This simply reinforces the notion that the variety of behaviors seen in the Southern California Bight represents both connectedness and independence, that there is no surfeit of information or excessive number of stations, and that additional stations and data will contribute unique information.

Relative humidity is nearly always high near the ocean. Higher elevation island stations have a greater opportunity to sample different and non-marine air than do lower elevation stations. In winter, the monthly mean relative humidity variations associated with large scale winter storms are reasonably well correlated between Santa Rosa and Santa Cruz, but in the summer part of the year from April through September there is essentially no correlation in humidity between the stations on the adjoining islands. To some extent this may arise from site locations at different elevations and positions within the marine layer. Another reason for differential relative humidity could be terrain blockage south of the RAWS site at Santa Cruz, so that this somewhat sheltered (from north-south winds) site can get quite warm and thus experience low relative humidities, whereas Santa Rosa RAWS is well exposed and does not get as warm.

The main conclusion from the correlation analysis is that only precipitation is well enough correlated at monthly and seasonal scales that we can confidently estimate missing values. Other elements are only modestly correlated, and this reinforces the idea that stations located on each of the five islands, and even more than one on the bigger islands, are not likely to be providing excessively redundant information.

6.1 Purpose of measurements -- general considerations

People seem to have an almost reflexive need to measure precipitation and to a lesser extent temperature, for the same inscrutable reasons that dogs chase cars. These reasons span a broad range, from utilitarian to curiosity-driven. Although there are well-known recurrent patterns of need and data usage, there are always in addition new uses coming along. The number of such uses ranges into the thousands. Attempts have been made to categorize such uses (see NRC 1998, 2001). Climate measurements take so long to accumulate that they should be treated as multi-purpose, and should be undertaken in such a manner that they serve the widest possible assortment of applications. Some applications remain constant, others rise and fall in importance. Today's insistent issue may subside, and tomorrow's burning issue may be barely anticipated. The notion that humans might affect the climate of the entire Earth was nearly unimaginable when the national USDA (later NOAA) cooperative weather network began in the late 1800s. Abundant experience has shown, however, that there will always be a demand for a history of such measurements and their properties, and an expectation that somehow or other those measurements will have been taken, by somebody, and will be available.

An exhaustive list of uses for data would fill many pages and still be incomplete. In broad terms, however, there are needs to document environmental conditions that disrupt or otherwise affect park operations (e.g., storms and droughts). Design and construction standards are determined by climatological frequencies of events that exceed certain thresholds. Climate is a determinant of visitorship, sometimes attracting, sometimes discouraging attendance. The climate itself may be a large part of the park experience (e.g. Death Valley and heat are nearly synonymous). Some parks are large enough to encompass spatial or elevational diversity in climate, and the sequence of events can vary considerably inside or close to park boundaries. That is, the temporal trends and statistics may not be the same everywhere, and this spatial structure needs to be sampled. The granularity of this structure depends on the presence of topography or large climate gradients or both, such as that found along the West Coast in summer in the rapid transition from the marine layer to the hot interior.

Plant and animal communities, and the entire ecosystem in which they and we exist, react to every nuance of their physical environment. No aspect of weather and climate goes undetected in the natural world. Wilson (1998, p. 52) proposed "an informal rule of biological evolution" that applies here: "If an organic sensor can be imagined that picks up any signal from the environment, there exists a species somewhere that possesses it." Every weather and climate event, whether dull or extraordinary to us as humans, matters to some organism. Dramatic events and creeping incremental change both have consequences to living systems. Extreme events, or disturbances, can "reset the clock" or "shake up the system" and lead to reverberations that last years to centuries or longer. Slow change can carry complex nonlinear systems (e.g., any living assemblage) into states where chaotic transitions and new behavior can occur. These changes can seldom be predicted, and are typically observed after the fact and understood only in retrospect. They may not be exciting, but as the well known atmospheric scientist Mike Wallace at the University of Washington once noted, "subtle does not mean unimportant" (July 14, 1997, Seattle WA).

Thus, our recorders of the state of the climate need to be able to accurately record and depict both rapid and slow changes. In particular, an array of artificial influences can easily confound the detection of slow changes. The record as provided to us can contain both real climate variability (that took place in the atmosphere) and fake climate variability (that arose from changes in the way we observed and recorded the atmosphere). As an example, trees growing near a climate station with an excellent anemometer will make it look like the wind gradually slowed down over many years. We have to take great care to protect against sources of fake climate variability on the longer time scales of years to decades. The processes that lead to the observed climate are not stationary, because they draw from time-varying probability distributions, and for this reason climatic time series do not exhibit statistical stationarity. The implications are manifold. There are no true climatic "normals" to which the climate must inevitably return. Rather, there turn out to be broad zones within which we usually find the climate. There is not exact repetition of climate, but instead continual fluctuation and sometimes approximate repetition, and in addition there is always new behavior waiting to happen. For these reasons, the business of monitoring is never finished, and there is no point at which we can confidently and definitely say that we know "enough."

6.2 Purpose of measurements – Channel Islands

Channel Islands National Park faces many of the same issues as other parks and resource managers. There are a few specific issues, however.

Land use has primarily been for ranching and grazing. Attempts are now being made to restore the islands to prior conditions through both active and passive means. This evolution is affected by climate and weather events and these need to be monitored. An extensive program is also under way to remove feral pigs as a part of this effort. This program doubtless has operational needs for weather data, as well as for conditions affecting the animals and the ecological communities that are the subject of the restoration. Invasive species are attempting to secure a foothold in many ways. The associated ecological trajectories are affected by climate.

Though the Channel Islands share many aspects of southern California climate, the fact remains they are islands and because of the presence of fog and stratus, and of all the surrounding water acting as a temperature buffer, they do not correlate especially well with the nearby mainland for many elements. They do not necessarily correlate well among themselves. Because they thus have in effect a somewhat separate existence, they need to be monitored independently. That is, we cannot simply extrapolate measurements from the mainland. We also want very much to know how climate variations on the islands track those on the mainland, if climate changes or if it does not. Because the oceanic environment is so different from that of the mainland, they may follow different paths.

There is a large study under way of the kelp beds, and surface information gathered on the islands would constitute part of a more comprehensive environmental monitoring that tracks the terrestrial and marine environments at once, along with their meeting place in the tidal areas. In addition, there is widespread interest in monitoring the entire coastal environment of the West Coast (Pew Ocean Commission, U.S. Ocean Commission, Coastal Ocean Observing System networks).

It is well known that cities influence their local climate. We have in this case a relatively unusual circumstance of nearly unpopulated areas quite close to major urban centers, and the opportunity to obtain measurements uncorrupted by all of the usual urban influences, except those that relate to air transport of atmospheric constituents.

Operationally, because the islands must be reached by boat or by air, and are out of sight of the mainland when on the water, weather and climate information has important utility for transportation safety, and day to day logistics and operations. For this reason, the information is also needed with relatively little delay.

7.1 Representativeness of measurements – general considerations

Measurements can be made to emphasize specific phenomena or locations, or for general purposes. It is assumed here that the latter is the primary goal of most climate measurement programs. A common desire is that measurements be "representative" in some manner, whether of a specific location or of an area. Because variations in weather, and even climate, in separated locations do not track each other perfectly, we need to consider the difference between *spatial* and *temporal* representativeness, and decide which one we most want to emphasize. These are not the same thing, especially in areas where there is strong local diversity in climate, arising from topography or proximity to water bodies. These circumstances occur very frequently in the western United States.

<u>Spatial representativeness</u>: Is it desired that the absolute and time-averaged measurements at a given location in space be similar to those at other locations? That is, rainfall at unmeasured point B is typically about the same as at measured point A.

<u>Temporal representativeness</u>: Is it desired that the variations in time at a given location be similar to the variations in time at other locations? That is, points A and B have different (perhaps very different) rainfall, but their variations track each other in proportion to their own typical variability. Said differently, their time series show high correlation.

For basic characterization of climate, we focus on both of these issues. For climate monitoring, we focus more on the second.

Examples may help make this less abstract. Station A may be in a valley a kilometer wide, and Station B may be on a nearby ridge three kilometers away from A and 1000 meters higher. Higher elevations are traditionally wetter, and one of these stations may thus average 1.05, 1.2, or 1.5, or 2.0 (or more) times as much monthly or annual precipitation as the other. (In some western United States locations, for stations separated by 10-50 km, the above high:low elevation precipitation ratios may reach 10:1 or 20:1 or more for a given month, and can easily reach 10:1 or more on an annual basis.) In such instances, a wet month at one station is likely to be a wet month at the other station. We see this very often in the Coast Range or western Cascade Range of Oregon or Washington. Quite clearly, in this example the value at one station cannot be freely substituted for the other station. However, the percentage of its own long-term average at each of the stations may be similar (i.e., each might report 85 percent of their respective long-term mean, over the time period of interest).

The degree of similarity in percentage of average at closely spaced stations will be governed by the cause of the precipitation, large-scale cyclonic storms or small-scale summer-time convection. For the preceding case the absolute value (e.g., inches or mm) at one station does not represent the value at the other station. In a coastal setting, the time series of precipitation from one station would likely correlate highly (probably very highly) with nearby stations, even if their means were different. (Correlation between two variables is not affected by means themselves, only by variation about the means, and the linearity of this variation.) In this example, absolute numbers might be very different, but percentages of average might be similar. By contrast, in an arid setting, where sub-cloud evaporation or the frequent presence of small-scale convection dominates, values at Station A may show little correspondence (correlation) with values at Station B. An example might be the relation between valley and mountaintop precipitation in the Great Basin in summer. Thunderstorms over the mountains may give very little precipitation to adjoining valleys. In this latter case, Station A and Station B thus may have both very different means <u>and</u> poor temporal correlation.

Stated in another way, representativeness can be thought of as the extent to which information from one location can be used to estimate unknown values for any other arbitrary point out to some arbitrary distance.

The degree of representativeness can vary from *element to element*. Site A may reasonably represent the spatial or temporal behavior of precipitation at Site B, but not temperature or wind or some other atmospheric element. In topographically diverse locations, annual or monthly mean precipitation can vary over horizontal distances of a few hundred yards (or less), or over elevation differences of a few hundred feet. Temperature can vary systematically over even shorter distances, down to a few tens of feet horizontally or vertically.

Consider two sites separated by 100 feet horizontally, and 30 feet vertically. One is in a small valley next to a stream, and the other is atop a small knoll, and both have similar vegetation. In this case, there is high likelihood that both stations will have very similar precipitation climatologies. However, for temperature the picture may be quite different. Cool air will preferentially pool in the valley each night (more on nights that are clear and calm and low humidity, less on nights that are cloudy and windy and high humidity). The knoll will typically not cool as much (because cool and therefore more dense air that is forming there is sliding downhill), or take longer to begin experiencing cooling that is taking place on larger scales. The net effect is that the lower station will typically experience lower nighttime temperatures, and thus lower minimums. During daytime, the lower station will typically warm a little more than the station on the knoll. Differences in vegetation between the two sites can affect how the wind vertically mixes the air, or lead to differences in solar shading and thus daytime heating, or lead to differences in how much infrared radiation is emitted downward (by leaves, branches, and tree trunks) toward the vicinity of the thermometer. A well-known text by Geiger et al. (2003) has hundreds of examples; Fiebrich and Crawford (2001) document others in the seemingly simple terrain of Oklahoma.

As a rule, local low spots experience more numerous and varied temperature effects than do local elevated spots. Greater areal representativeness is obtained for sites that are atop slight rises in topography, or are on uniformly sloping ground. Areas to avoid are hollows and sinks, low spots or small valley bottoms that act as concentrated drainage channels at night (unless, that is, one is interested in measuring those very factors, which are a legitimate subject of study). It can be surprising how little variation in topography it takes to lead to temperature differences. Even ground that looks absolutely flat to the eye can exhibit differences of several degrees F, to as much as 10-20 degrees F, over the length of an airport runway, in clear and calm conditions, and especially with snow cover.

Stations should be placed on natural ground surface cover representative of the area. Artificially moistened surfaces (watered lawns) should usually be avoided, especially in arid climates, where evaporation acts to cool the overlying air. Sprinkler systems can in addition augment the "precipitation" reported from a site. In more moist climates, where surface cover remains naturally green, this is less of an issue. Likewise, paved or artificially dark surfaces absorb solar radiation by day, heating the air an additional increment, and may cool more slowly at night because of differences from natural ground cover in thermal conductance and heat capacity. Both maximum and minimum temperatures can separately be affected, and in different ways.

<u>Continue or not</u>? One dilemma that often arises is the following: A station has been operating with a less than optimal exposure for many years or decades. This is pointed out, and the station is moved to a more standard exposure. The reported climate may very well be different at the new location. Should the station be moved or not? This is not an easy decision. One can argue that the new location is "more accurate" but it is also "not the same". Is it more important to be accurate, or consistent? Like disturbing asbestos insulation, some would argue to leave the station "as is" for the sake of long-term consistency (most climatologists would fall in this camp), and others would argue to change the station, so as to be "more accurate." There is no easy answer. In either case, the situation should be documented. If an action (relocation) is undertaken, then that should be thoroughly documented, and a common third measurement (itself unchanging) should be sought to help calibrate an adjustment bridge across the gap in data consistency.

<u>Desirable non-representative sites</u>. All of the above comments refer to measurements intended to obtain the most generic and spatially and temporally representative conditions in some geographic or administrative unit of interest. However, there are sometimes reasons for knowing what is occurring in locations of special interest, or for learning the degree of departure of such places from the more generic locations commonly used for weather and climate observations. As an example, a particular national park may want to sample an often visited location (a prominent mountain, hiking destination, glacier, etc), or compare two

elevations (the rim and bottom of Grand Canyon), or monitor recovery of a disturbed area (burns, restorations, windfalls, infestations, etc), or conditions in some sensitive area, or the specialized micro-habitat of an endangered plant or animal species, or simply span the range of climates in the area of interest.

7.2 Exposure – general considerations

The best exposure for instruments varies according to element. For temperature, we like ventilation and air movement. For wind we like unobstructed upwind fetches in every direction, more open than is needed for temperature. For precipitation, we dislike wind and open exposures, and prefer some nearby vegetation to slow down the wind, a small clearing usually being the best, especially when snow is important. (Without shielding, it is easy to lose 50-70 percent of the precipitation in a medium wind (10-15 mph), through aerodynamic effects, when it is snowing.) Solar radiation needs an unobstructed horizon, especially the south side of the celestial hemisphere. These needs can be somewhat in conflict with each other. Though no strong consensus exists, the NOAA Climate Reference Network has adopted a version of an exposure rating proposed by Leroy (1998). The exposure considerations for different elements are discussed in greater detail next. This is not a comprehensive discussion of all aspects of each element; additional comments can be found in the Alaska report of Redmond et al. (2005).

7.3 Exposure – considerations by element

Temperature. Air in a confined region can heat or cool more rapidly, so factors that promote ventilation and movement are generally preferred. Vegetation and artificial obstructions (buildings and structures) that inhibit air movement should be avoided. The sides of buildings, hills, and cliffs will radiate additional infrared radiation downward toward a thermometer location. Heated or cooled structures need to be farther from thermometers. A suggested distance is 15-30 meters at a minimum. The NOAA Climate Reference Network, for example, typically looks for a minimum of 100 meters from the nearest structure, pavement, or other artificial influence, preferably 200-300 meters.

Minimum temperatures show much greater variation in space than do maximum temperatures, and much of this is related to topography. On any clear calm night over relatively flat surfaces, temperature inversions (temperature is warmer higher above the surface) will begin to form. In the western U.S. especially, this is the rule rather than the exception. It is not uncommon to see frost on the ground when a sheltered eye-height thermometer falls to only 36-37 F (2-3 C). For historical reasons, this height of 1.5-2.0 meters is the reference standard for surface observations. Note that bare thermometers can act as heating and cooling surfaces of their own; protection inside a louvered shelter (usually called a Cotton Region Shelter) or a stacked-plate shield (in appearance, like a stack of upside-down coffee saucers) is necessary to avoid the resulting bias. These plates are usually shaped to prevent sunlight from bouncing up from light-colored ground or snow into the housing from below. Thermometers ***always*** need to be in white shelters; yellowing or loss of paint can cause solar absorption and warming.

Maximum temperatures are usually associated with larger volumes of air than minimum temperatures, and thus show greater spatial coherence. Nonetheless, nearby heat sources (warm ground, pavement, sides of houses, rock cliffs) can artificially warm a thermometer. At the new Climate Reference Network site in Death Valley, the surface temperature 1.5 meters below the thermometer is often 140 to 160 F (60-71 C), so it is important to keep the thermometer at constant height throughout its measurement career.

Snow effects on temperature. Snow on the ground is superb at promoting local cooling: it absorbs and radiates infrared energy very well, it reflects solar radiation very well, and it is excellent as an insulator atop relatively warm ground. The presence of a layer of snow can thus greatly accentuate local temperature differences, and magnify small local differences commonly seen over bare ground. Snow covered ground can also promote the rapid development of temperature inversions (warmer air overlying colder air) and thus can cause pronounced vertical temperature differences near the surface. It is not unusual to see temperatures an inch or two above the surface at night that are 2-5 degrees F cooler than temperature at eye height. Thermometers in locations that habitually or preferentially retain snow can be unduly biased toward cool temperatures.

Precipitation. Precipitation is the melted liquid equivalent of all phases of water that fall from the sky. Precipitation, by definition, includes snow, hail, and sleet. Water in the gage that is caused by the gage itself (dew, frost) is not precipitation, and should not be counted as such. It can be difficult to distinguish fine drizzle (true precipitation) from fog droplets impacting a gage side and running down into the collection point (not precipitation).

All precipitation gages under-measure the true precipitation, except in rare circumstances. This is because of wind. In calm conditions, precipitation can fall straight down into the gage; though even then some can get lost by evaporating. Aerodynamic effects from wind blowing over the tops of precipitation gages lead to water drops or flakes falling elsewhere, and loss of measured precipitation. Effects are systematic, but relatively small for rain, typically less than 10 percent. Stronger winds lead to less recorded rain. For snow, the effects of wind are dramatic. Modest winds of 10 mph can cause the measured snowfall to be 30-70 percent of the actual snowfall. Heavy wet snow is less under-measured than fluffy, powdery snow. Slight changes in shielding and exposure can cause changes in measured precipitation with no change in true precipitation.

The main goal with precipitation is thus to slow down the wind. This can be done artificially with shielding, or by taking advantage of natural sheltering. Since wind increases with height, the higher the gage above ground, the greater the issues of exposure to wind. Some wet or snowy locations need a tall rain gage to hold the large amounts or to clear deep snowpacks and drifting snow. The usual way to slow the wind is to encircle the gage with a ring of swinging flaps. Made of metal or (now) plastic mounted slightly higher than the gage and about 12-18 inches (30-50 cm) away from the rim, these wedge shaped (foot-long, tapered toward the bottom) flaps slow the wind and introduce turbulence to disturb the smooth flow over the nearby orifice. Years of tests have shown that to completely eliminate wind effects takes a very large shield, and actually two or three of them arranged in concentric circles, the largest diameter typically being about 26 feet in diameter (8 meters), about 8 feet (2.5 meters) off the ground at the top and with 2-3 feet (60-100 cm) of clearance below to clear drifting snow.

Vegetation is highly effective as a natural shield, and small copses of trees or shrubs are very helpful. Shielding needs to be not too close nor not too far. Trees that are too close can shed rain or snow onto a gage; trees that at a distance are too far to have much effect. A common rule is for nearby vegetation to be at least about 4 tree/bush heights away from the gage. Many Snotel gages are closer in to trees than this, because the undercatch problem with snow is so great that the danger of some snow blowing from branches is more than balanced by allowing precipitation to fall straight down into a gage.

Gages too close to the surface will experience splash. Gage tops that are slightly different from level can lead to significantly more or less precipitation, depending on orientation. Funnels are used to herd the precipitation into an Interior measurement tube (for standard manual gages), and need to be removed in cold weather to allow snow to fall in. Heaters can be used, but there is a delicate balance between too much (fries the snow, and it evaporates) and too little (will not melt). Gages with weak or no heaters will accumulate a cap of snow that can melt at a later time and appear to be new precipitation.

Distilling the above, changes in the way precipitation is measured can easily appear to be changes in climate.

<u>Wind</u>. Wind probably shows the greatest amount of variation in a short distance, among any of the principal meteorological elements. No matter what the speed, wind always decreases to zero at or near the ground surface. The rate at which wind increases with height is very dependent on frictional elements in the landscape (vegetation, rocks, fences, structures, others) and on the temperature stratification near the surface. Cold air near the surface represents a stable situation, where vertical movement of air is resisted by buoyancy effects. The opposite is true when warm air is near the surface, as on a sunlit day where the lower atmosphere is mixed vertically very well, so that faster winds aloft are more readily mixed down to the surface, speeding up the surface wind and causing

temperatures to be more horizontally uniform. Vegetation can slow the wind for horizontal distances that are many times its vertical height. Growth of vegetation can gradually slow the measured wind with no real change in regional speeds. Examples from high quality instrumentation at the Oklahoma Mesonet show that small groves of a few trees a quarter mile away can have effects on a station's records. Raising and lowering the anemometer can greatly affect wind speed. As a (usually) mechanical device, bearings can wear and internal friction can increase the minimum speed threshold required to initially turn the cups or propeller, creating more measurements of zero and thus reducing the average speed. Sonic anemometers have no moving parts, and generally work well except where icing and salt crusting are present.

Gusts are caused by the turbulent mixing of regions of greater wind speed (higher off the ground) into regions with lesser wind speed (near the surface). Sustained winds are usually averaged over 2-10 minutes for aviation and forecasting purposes, but for many research applications wind is often averaged over a full 60 minutes. Gusts are usually measured over 1-5 seconds. Longer averaging periods produce lower gusts and should be avoided. Lightweight anemometers will respond more quickly to gusts, and thus generally record higher gust values for the same wind sequence than heavier instruments, but then are often less durable. A recent four-year period under the deep canopy of the Quinault rain forest in the Olympic National Park remarkably showed no winds speeds higher than about 7 mph (3 m/s), even with many large and windy storms passing over, so protected is this area by the towering vegetation. Exposed ridges, on the other hand, will usually see gusts to 100-150 mph (50-70 m/s) during their lifetime and rugged, dependable equipment is necessary. Higher elevations can easily exceed even these values. Anemometers should be sized according to the expected maximum gust. Changes in equipment or height or vegetation or obstructions or averaging period can all lead to changes in gust speeds, and to changes in the ratio of gust speeds to sustained speeds. This ratio often furnishes good clues about changes in observing methodology or equipment or local vegetation.

If climate time series (that is, sequences of values that will be compared over years or decades) of wind are desired, great care must be taken to measure and report values in a consistent manner, and to insure that vegetation and obstructions and anemometer height and other factors are maintained in a constant state. Grazing, logging, fires, species changes and other factors that affect local vegetation can show considerable variation from year to year. Furthermore, measured changes can reflect azimuthal differences at certain points of the compass, and the importance of these changes can in turn be a function of how often the wind blows from those directions, and the changing nature of obstructions in those directions. For this reason, full photodocumentation, taking special precautions to include nearby vegetation, should be repeated every 2-3 years.

Consequently, the best wind exposures feature little vegetation for 100-200 meters in any direction (300-400 meters is better), short vegetation if it must be present (the shorter the better), flat or elevated sites, with good exposure and vistas in all directions if possible. Excessive speed or highly preferred directions can result from channeling by nearby topography in both high wind and in nearly calm situations. Gentle nocturnal drainage winds flowing downslope can affect the directional frequency distribution.

Solar Radiation. Radiant energy from the sun (characteristic temperature 5800 K) drives the entire climate system, and the earth sheds this energy back to space by radiating at its own characteristic temperatures (circa 250-300 degrees K). The large amounts of energy that flow essentially instantly in the form of radiation are arguably the most important in the climate system. Solar emission peaks near wavelengths of 0.5 microns ("shortwave"), and earth emissions peak near wavelengths of 10-15 microns ("longwave"). Of the various forms of radiation, total solar radiation downward from the sky is the easiest to measure and most commonly observed and reported. The main requirements are a level surface, minimal horizon obstructions, avoidance of shadows from other instruments and supports, or from vegetation or topography. A small instrumental footprint (as small as possible, and with maximum wind exposure) helps avoid snow accumulation on the bulb, deters birds, and helps reduce dust accumulation. Instrumental drift is hard to determine "just by looking" and periodic recalibration to at least field standards (typically once a year) is required to be sure. As just one example of how this might matter, evidence has recently begun to accumulate that global changes in atmospheric transparency have in recent years reduced the amount of sunlight reach the surface by several percent, a phenomenon called solar dimming (UNEP, 2002). How can we distinguish this from instrumental drift? Typical accuracy for moderately priced sensors is within 5 percent. Accuracy within 3-4 percent is attainable from high quality solar sensors, but at much greater cost.

Humidity. Most of the same considerations that apply to exposure and siting for temperature also apply to relative humidity. Relative humidity is a fair proxy for the presence of cloud conditions (in mountain environments) or fog (typically when relative humidity is greater that 95 percent). True fog will be at 100 percent relative humidity, but the instruments themselves may "max out" at reported values of anywhere from 98 to 102 percent, and some as low as 92-95 percent. It is worth retaining these values in the data archive, because many products will first set these values to 100. Relative humidity measurements are most accurate (in terms of percentage points) in the middle ranges, and slightly less accurate at very high, and especially, very low relative and absolute humidities, and more so when the temperature is below freezing, especially well below freezing. The effect of a 1 percentage-point change (i.e., in units of percentage) in relative humidity at low temperatures has a considerable effect on the implied dewpoint, the temperature to which air must be cooled at constant pressure to begin to condense out its moisture. Dewpoint measurements, or other measures of absolute humidity, require specialized instruments, and usually AC power, and are more expensive and temperamental. The typical approach is to start with relative humidity, utilize the concurrent temperature measurement (and estimated pressure, though the pressure sensitivity is not great), to obtain dewpoint or mixing ratio (grams of water per gram of moist air) or other absolute measures of humidity as calculated quantities if such are desired.

Atmospheric Pressure. Barometric pressure is often not of direct biological interest, and is often considered an optional quantity to measure, but can be very useful in correcting or adjusting other measurements that are pressure-sensitive for variations (or "contamination") introduced by atmospheric disturbances. One example is river or lake stage measurements based on pressure transducers placed on streambeds. One millibar (about 0.03 inch of mercury) is equivalent to about one centimeter of water depth in a stream or a monitoring well. For comparison, sea level pressure is about 1000 mb, at 5,000 feet is about 850 mb, at 10,000 feet is about 700 mb, and at 14,000 feet is about 600 mb.

Note: We would strongly advocate that *station* pressure be measured and reported, never *sea level* pressure. There are many ways to reduce observed pressure to sea level, and the exact method depends on temperature and its recent history, and this is seldom documented, even though it is very important for this element. By contrast, there is only one station pressure. If sea level pressure *is* reported, it should *always* be accompanied by station pressure.

Different needs for different instruments. From this brief discussion, it can be seen that often compromises must be made, when an entire complement of instruments is deployed on a tower. What is good exposure for one element may not be that great for other elements. For example, precipitation is best measured when shielding from the wind is present, but temperature is best measured when there is free movement of air, and wind itself is best measured when no obstructions whatever are present for a long distance.

8.1 Documentation and metadata – general considerations

A good rule of thumb is to not allow a station to operate until its metadata have been entered.

A methodology for documenting conditions at meteorology and climate monitoring sites should be in place (NPS, 2003). The entire history should be included. The circumstances surrounding the observational process can have very significant effects on the reported climate, and changes in these circumstances can masquerade as climate change. We want to be able to distinguish between artificial changes, and real climate change, and for the latter, between climate changes that are real but very local and site-specific, and changes that are real and regionally representative. The purpose of metadata is to serve as the surrogate for human corporate memory about site circumstances and other factors. However, corporate memory is fallible, often moves to another location, or retires, or goes to the grave, and thus becomes inaccessible. An adequate documentation program will preserve this knowledge for future generations.

What to include? Broadly speakjng, the metadata information that should be gathered and preserved includes anything about the site that would affect the way future researchers would interpret the climate and weather records produced by the station. There is some judgment involved in what might be of greatest interest to those who many years hence will be poring over the data generated today. But better safe than sorry; it is practically impossible to over-document a station that will be used to track climate.

In general, the needs for documentation separate out into three main areas: 1) observational methodologies, 2) sensors and equipment, and 3) site exposure and environment.

1) Observational methodologies

This category of documentation includes how measurements are taken. For example, is the temperature an hourly average? Or a 10-minute period just before data transmission (common with RAWS, but not with many other networks)? Or an n-minute period at some other portion of the hour? Or a one-second grab sample at the moment of transmission? Or something else?

The same question applies to wind. Winds are typically described by the "sustained speed" and direction, and by gust values. These can each be estimated from a variety of different sampling strategies. The exact details will influence the resulting statistical properties of wind. Shorter averaging periods produce records with greater fluctuations. It is easier for a 10-minute wind average speed to deviate about the mean than it is for 60-minute averages. How the peak gust is determined can greatly affect the reported value: is this the highest n-minute reading during the hour, the highest m-second average, or the highest instantaneous one-second sample? Is every second of the hour a candidate, or does sampling just take place for part of an hour, or is every n-th sample retained for wind calculations, or is some other method in place?

Importantly, wind is a vector quantity. Averages can be obtained by initially using trigonometry to decompose the wind speed and direction into its two components (east-west and north-south), finding the average of the components, and recombining to obtain the vector mean. The alternative is to simply average the speed and the direction separately. Suppose that the wind is approximately out of the north. The average of a north-northwest wind from 338 degrees and a north-northeast wind from 22 degrees could either be from 360 degrees (the logical choice) or from (338+22)/2 or 180 degrees (from the south!).

What is the height of the anemometer above the ground? Has it been allowed to vary over the years? If so, do we know about those variations? If we want to compare the incidence of extreme events over periods of decades (like peak wind gust), can we be sure that the measurement recording process has been the same over this entire time period? If it has not, is there sufficient information that a dedicated researcher could develop adjustments based on recent process-based measurements designed to inform such an adjustment and homogenization process? These activities are possible, but need careful attention to detail.

Similar considerations apply to precipitation, humidity, solar radiation, evaporation, soil temperature and moisture, snowfall and snow depth, and any other atmospheric element.

For manual measurements there are different issues. For example, with daily temperature extremes, it is important to know what time of day the thermometer was reset, because morning observations yield cooler climates than do evening observations, a methodological effect on the reported climate. These effects can change reported mean monthly temperatures by several degrees F.

2) Instrumentation.

Have there been changes in the instrumentation package or the manufacturer? When has the instrumentation been re-calibrated, maintained, or swapped out in a systematic replacement process? For example, on anemometers, bearings may gradually gum up and slowly reduce the wind speed, or more typically the starting threshold. Very frequently, we see changes in the behavior of instruments that mysteriously started and stopped after known maintenance visits. Were cables changed or moved? Were all connections retested? Were plug-ins reversed? Were datalogger programs re-entered or modified? These are frequent sources of changes in data. Were units correctly entered? Was a precipitation gage that operates on a different principle substituted for an older precipitation gage? Does that gage work on the same principle? (Example: a switch from a weighing precipitation gage to a tipping bucket gage) Have there been changes in the way gages have been heated? Has the rain gage shielding varied through time? Have we recorded the exact date of change of equipment? Was the solar radiation dome dusted off, or had salt films removed? Has temperature or precipitation equipment gotten out of level, and has it been restored if so? Is this documented? Have various pieces of equipment been raised or lowered, or changed in relation to each other? For soil moisture, is there a systematic swap-out program? What is the replacement cycle for instrumentation? A well-designed high-quality observational program should plan on a complete replacement of all parts after about 5 years.

One thing that can help a great deal with detective work to track down problems with automated systems is to use the data logger to record information about the observations. For example, the battery voltage (max and min every hour (or whatever the sampling period)), the solar panel or other recharging output, and the maximum and minimum of each principal element for each hour (or sub-hour if 10- or 5-minute data) are extremely helpful diagnostics, and the associated data volume is well within the capabilities of a modern data logger.

As a significant by-product, recording the extreme maximum, minimum and mean of each individual time increment (no matter whether this interval is 5 or 10 or 60 minutes) allow an observation day to be constructed according to any desired definition (9 pm to 9pm, or 8 am to 8 am, for example), something that greatly facilitates comparison with long-term manual daily cooperative National Weather Service measurements. The "observation day" for most NWS volunteer observers has not been midnight to midnight, but more typically sunrise to sunrise, or sunset to sunset, or other intervals. The reported climate can vary (artificially) by several degrees, merely by changing the time of observation, but with no change in the hourly sequence of temperatures. So, such additional information can be immensely helpful with interpreting past records, or relating manual to automated measurements, bridging manual-to-automated transitions, or with quality control.

3) <u>Siting and environmental conditions</u>

For climate purposes, the observing conditions and exposure of each instrument to the prevailing conditions can be critical. For climate monitoring the main goal is <u>consistency through time</u>, and that station exposure not change throughout the lifetime of the station. Local conditions (from a few inches to a few hundred yards from the equipment) can exert very large effects that are comparable to variations in climate, but that are unfortunately totally artificial and introduced by the observing process. Any factor which changes the energy balance near the station should be avoided. This includes buildings and obstructions, the growth of tree trunks and tree canopies, changes in ground cover, avoidance of paved areas (several tens of yards at least, 50-100 yards is better), changes from grass to gravel or bare soil or vice versa, the growth of bushes and other vegetation, changes in mowing patterns for grass, changes in irrigation practices (natural settings are best), fires or windstorms or vegetation management changes from one year to the next, clearcutting near a station, yellowing of paint on radiation-sensitive housings (such as temperature), addition of cyclone fencing or other fencing that changes the vertical wind profile, "slight" moves that change the local micro-climate (a few tens of feet can be sufficient), changes in the proximity to ponds or lakes, changes in slope, removal of nearby grass for some purpose, changes in the sky coverage seen by global solar radiation equipment, changes in tillage patterns of plowed fields or in irrigation practices up to a mile or two away, changes in regional agricultural patterns (such as the large scale growth of pivot irrigation in the High Plains) that cool the local region through changes in evaporation, and a variety of other factors.

Many of these can be avoided through prudent site selection and consideration of future changes. A few (fires, windstorms, ice storms) can only be anticipated statistically.

Document! It is nearly impossible to find a site that is perfect for every element, so the next rule should be: document as thoroughly as possible, and preserve this information and make it accessible along with the data from the platforms themselves. We know from experience that it is not possible to over-document a weather or climate site.

Photographic documentation. To a great extent, documentation can be facilitated by photography, to serve as a memory aid long after the individual site manager-of-the-moment has departed. Photo-documentation itself is an art. A slide presentation on how this is accomplished for the Climate Reference Network is attached as an **Appendix G**.

Issues with documentation and metadata can be as complicated as the climate measurements themselves, and there is a parallel set of considerations to the actual monitoring of climate. Metadata are not fixed in time, but rather have a time history of their own that needs to be maintained. Metadata are themselves frequently in error, and require a quality control process of their own. Photos and other descriptors should be updated once every year or two, to record slow changes (vegetation growth and status, changes in roads or pavement or buildings or surrounding land use, condition of sensors and equipment), and to record maintenance activities.

As a rule, documentation is really mostly a matter of developing good habits, and the discipline to incorporate such activities into a routine, and to record and transfer such information into a form useful for posterity.

It is a fact of life that this entire set of considerations is often swept under the rug, and relegated to second-class status in the press to accomplish more than we can realistically do well. It is often tedious and seemingly unproductive. This should be acknowledged up front and dealt with from the start. The best generic approach is to ask "What will a future potential user of this information want to know about the circumstances surrounding how the information was obtained?"

A new baby is a grand thing, but an accompanying commitment to maintenance and care are needed for it to reach its full potential.

8.2 Documentation and metadata – Channel Islands

As with numerous other locations, documentation and metadata for Channel Islands are located in many locations and forms and formats. In this respect, this NPS unit seems reasonably representative of the more general situation. It is particularly beneficial to move toward a self-describing approach, to circumvent or minimize issues related to personnel career movements. The primary issue is insuring the accurate preservation of corporate memory. Methods to do this that involve use of the Web to promote greater ease of access and entry of additional and corrected information seem to offer the most promise.

The Main Ranch seems to have a particularly good precipitation record, already 90 years long. This is extremely valuable. Efforts to locate more information about this station, pictures and photos of the observing equipment and its exact location, and the precipitation data themselves (missing in the mid-1990s) are worth undertaking.

Organizing all this is a demanding chore and involves a combination of technology and detective work, a passion for detail, and there is no substitute for prior personal historical involvement. New technological systems can help re-organize existing digital databases. However, the key thing is to put the various records (both data and metadata) into digital form so that further manipulation is enabled. The most perishable component is that which resides in human memory.

In the case of Channel Islands, it took quite a while to determine the existence and usefulness of various kinds of metadata, and there may still be more that has not found its way into the system.

9.1 Communications – general comments

Weather and climate data have far more value, enjoy a bigger and more supportive constituency, and usually yield better data, if the information can be obtained, viewed, summarized and disseminated in as close to real time as possible. Access in real time to recent data, and to methods that can immediately place this information into historical context, allow a much wider variety of uses, both in practical operations decisions, and in research projects that may benefit from adjusting or switching strategies as a reaction to current and recent conditions. The happenstance events that Nature throws at us may be used to advantage to learn something important, if we can act quickly enough. Other ecological or environmental monitoring may kick into gear if certain weather or climate fluctuations occur (wind/rain/snow storms, freezes, heat spells, etc). Hazards associated with wind or heavy precipitation can be better anticipated. Problems arising from recent site visits can be identified and addressed. It is dismaying to find that a wind or precipitation sensor began to act badly several months ago, rather than yesterday, especially if crucial for some kind of study. Data errors that are caught earlier can be fixed earlier.

When possible, two-way communications are better, so that data loggers can be interrogated after communications breakdowns to assist with data recovery. WRCC relies on heavily on this method, and even with frequent breakdowns in a myriad of communications pathways, most data archives are kept complete and up to date because of this capability. Two-way communications also allow data loggers to be re-programmed without needing a site visit, or if additional diagnostic information needs to be added for troubleshooting a problem, or perhaps in anticipation of a significant forecast event. However, this can be risky, by disrupting a functional system, and should be undertaken only by experienced personnel. Some newer data loggers have capabilities to add diagnostic information to the data stream without endangering the original program.

The options for communications are manifold. In some cases, piggybacking onto existing agency infrastructure can be both easier and more cost effective. In other cases, separate pathways might make more sense. Direct hardwired land connections and connections to the internet are always beneficial and allow further routing options for dissemination and storage. Radio, cell phone, satellite and meteor-burst technologies are in widespread use, but the utilization of these depends on whether associated agency or commercial infrastructure is in place and is itself robust against weather and climate disruptions. The communication world is in constant flux, as technologies rise and fall. The best advice here is to pick methods that appear to be stable for the next 3-5 years, and try to remain near mainstream; beyond this time frame, developments occur too rapidly for solid planning.

When safety is an issue, reliability of communication matters. Ironically, the most common source of communications loss is the weather that the station is deployed to record, and the worst conditions are the ones of greatest immediate interest, particular if health and safety, even rescue, issues are present. As much as possible and unless heroic or extremely expensive efforts are needed, real time access (within an hour or two) is highly recommended.

Once received at a central gathering point, data can be made accessible to various key partners, and automated “watchdog” programs -- that are literally looking for trouble -- can be used to flag suspect operational values. These can pipe into quality control routines of arbitrary complexity, particularly ones that compare fields of data and try to find corroborating evidence to support or reject a value, or assign a confidence.

One-way communication (typical satellite uplink) can be used if two-way is not practical. With one-way methods there is no way for the sender to know if the receiver obtained the full and intact message. Satellite is fairly reliable, but there are occasional glitches. The data logger cannot be reprogrammed or asked to repeat a crucial transmission. Even a system that is 99 percent reliable will lose 88 hours a year, or nearly 4 days, which may include critical values. With two-way communications, each end knows what was last received, so that when communication is restored after a break, all data since last successful transmission can be obtained. At WRCC this method is used for all stations for which two-way communications are possible. After a break, an intense catch-up period ensues. Sometimes this is totally automated, and at other times some degree of human intervention is required to initiate the update. One-way communications also require that a visit take place to download data that were not successfully transmitted and insure a complete record.

For all communications options, data should be stored on-site in the data logger. With hourly data and a modest number of saved quantities, typically several weeks to several months can be stored in a rotating archive on a modern data logger. During site visits, these can be manually downloaded as an independent backup and later merged with data received in real time.

Power to communications systems should be separate from power to the weather instruments, if possible. Communications often require more power than do weather sensors. Sensors are typically fairly low consumption devices, often working for many months on a battery. The loss of communication should not jeopardize the collection of data. Data can always be recovered later. As a practical factor, it should be noted that it often proves hard to separate such systems at remote stations.

Every effort within reason should be made to record each and every hour of the year, even if it cannot be entered into the record until after the next site visit. Deep cycle batteries are recommended for remote or seldom visited locations. Charging systems (typically solar panels) must be designed for the worst combination: lowest sun (December), cloudy, and cold. In snowy climates, the solar panel should remain above the snowpack, even if some of the instruments are buried in the snowpack.

For precipitation systems that save the liquid water content through an accumulation process and report that accumulation, total precipitation during a communications break can be ascertained simply through subtraction of the last known accumulation value. For precipitation systems that count increments and then dump the liquid water to the ground, the total precipitation is irretrievably lost, unless the values can be obtained later by downloading the data logger contents. The data logger could also be instructed to accumulate and report counts of tips since some arbitrary point in time. Currently, all RAWS stations work this way, but we have encountered very few other networks that do this routinely, outside of stations maintained by WRCC.

9.2 Communications – Channel Islands

In the Channel Islands, there are additional issues, since the area is separated from the mainland and its administrative nerve center and visitor concentrations. Aircraft and boat operations to the islands can be made safer if current data of adequate quality are available. Visitors are constantly asking about current conditions, especially for locations that are out of sight from their embarkation point if using either concessionaire or private boats or planes. Information on water and wave conditions, and sky ceilings, are of great interest to boating and aviation operations. Certain rain rates are tipoffs to possible landslide impacts on the steep island roads.

Thus it is quite desirable to communicate station data to collector points in real time. Several technologies are now being widely used nationally for this. We were not sure where cell phones would work or not work on the islands, or work anywhere at all. These would likely be the preferred route if it could be reliable and cheap enough. Radio links to shore might also work, or to NPS repeaters, but shore links might need to be elevated because the islands are over the horizon. Radio communications can work over several tens of miles with the right kinds of radios. Other short-haul radios to a local broadcast site can also work. Many radio systems have no, or small, recurring costs. GOES satellite links are more expensive, though with no recurring costs, and are only one-way, but are a proven, reliable and widely used technology if two-way communications cannot work or are too expensive.

10.1 Calibration and maintenance – general considerations

Immediately upon deployment sensors, cables, connectors, physical support, begin to degrade at varying rates, depending on the environment they are immersed in, and the care and protection provided. Rain and sun and snow and wind and salt and spiders and wasps and gophers and mice and cows and elk and birds and perhaps other human beings discover the playground you have erected for them, while you try to record some aspect of the environment. Slow drift and sudden change begin to affect the measurements.

In the meantime, other duties and responsibilities begin to require our attention.

Automation does not mean the end of human involvement, but rather changes the role of the human and the type of skills needed. Abundant experience shows that it is simply a mistake to believe that automated equipment runs itself and that people are out of the picture and freed up for more productive activities. Things just happen, and these will need attention at both scheduled and inconvenient times.

Careful attention to detail during deployment and servicing, making sure that all connections are secure and hazard-proofed, have a payoff in reduced emergency visits. Observing programs should be viewed in terms of life-cycle costs. Cheap equipment does not mean an inexpensive observing program if extra attention to maintenance is needed, or if one cannot be sure whether the resulting data can be trusted when interesting and unusual phenomena emerge down the road (something nearly guaranteed). Parts need to be swapped out on schedules that vary according to type of equipment and cost of repair or replacement. It is a good idea to begin to acquire spare parts as soon as several stations have been deployed. Internal diagnostics, and some level of redundancy or corroboration from other sensors, are helpful in deciding whether we can stick our neck out in trusting observations to support some claim of behavior in the physical or biological environment.

Furthermore, many significant environmental events are only recognized as such well after the fact, in retrospect and through after-analysis. At this point it is too late to change anything.

Most atmospheric measurement devices should be visited at least once and preferably twice a year. Cheaper parts should be swapped out once every year or two, and more expensive equipment checked during such visits and rotated out on somewhat longer time scales. Sensors with moving parts, such as anemometers and precipitation gages, need extra attention in this regard.

Sites need maintenance as well: vegetation should be maintained in a relatively constant state, brush cleared, trees kept in approximately the same condition, and so forth, unless the goal is to record the effect of vegetative growth on the local climate. Ideally, site conditions should be kept constant within 50-100 yards of most stations. Sometimes this is not practical, but in such cases one should expect some degree artificial “climate change”. This is actually real change, but it is confined to a small area.

Field calibration kits are very helpful to check whether sensors are reporting values that are reasonable at the time of a maintenance visit. Is the wind reading about the right speed and direction? Are temperature and humidity close to values shown by reliable and portable calibration equipment? Some equipment is hard to calibrate on the spot, and needs more attention back in the laboratory, and might be best handled by swapping with recently calibrated equipment.

There is some necessary risk involved with maintenance visits, if connections that were working fine are disturbed or not sufficiently restored. This is an inherent problem with site visits, and the only way around it is with extra care. There is also something of an art to making sure that testing and calibration values during field visits are not accidentally transmitted as real data, and a need to insure that all instrument checks are documented. Problems with observations can be traced to accidental effects of recent field visits a surprising percentage of the time.

Looking for problems, rather than waiting for problems, usually results in the best climate records.

Field visits are more productive if the readings can be checked against calibration equipment carried to the site. A complete and accurate field calibration kit can be somewhat expensive, and may not be practical if a network consists of just a few sites. Adjoining maintenance efforts might consider joining forces to obtain such field kits. Relatively inexpensive commercially available equipment can be used for gross checks, if due recognition is given to limitations on their accuracy and on how closely the actual observing conditions can be simulated. Some comparison equipment can be obtained at low cost (such as for temperature), and other equipment practically calls for a duplicate of the device for that element (humidity, solar, pressure). Hand-held wind devices of intermediate cost are available, although reaching the position of the anemometer requires a ladder or climbing (wind increases with height). A stethoscope to listen to ball bearings can be quite useful. Precipitation gages are generally calibrated by providing them with a known quantity or weight of water to measure, and performing the tests slowly enough that drops are not lost during tipping transitions (for tipping bucket gages). A representative cost for a typical field calibration kit is around $3-6 K.

Subsurface conditions, such as soil temperature and moisture, are very difficult to check in a routine manner like air measurements. Actual examination requires such a degree of disturbance that replacement equipment might as well be put in, and soil disturbed to examine or replace instruments takes time to return to "normal" (see Basara and Crawford, 2000). Equipment thus removed can be checked in a local calibration lab or parts depot. Calibration labs are not necessarily low cost (typically $10-20 K to set up) and may benefit from joining forces. A related alternative to acquiring the necessary expertise is a dedicated individual or two who works with multiple administrative units and visits many sites during the course of a year.

Maintenance and calibration visits bring an element of danger. Functioning equipment often must be temporarily disturbed, or shut off, connections undone, communications stopped, batteries replaced, electronics shut down, data loggers re-programmed, fluids replaced, values reset, and the like. All of these provide great opportunities for new problems to be created. At WRCC we have frequently noted that changes in wind direction (e.g., shifts of 180 degrees) or in engineering-to-science unit conversions, in how means or extremes are recorded, and other changes, have coincided with site visits to automated stations. The lack of on-site feedback or inability to make a final pre-departure check that all quantities are being correctly recorded and transmitted in the proper units can constitute significant obstacles to quality assurance. Particularly with remote locations, the next visit may be a long time off.

Many resource management agencies in the western states and, increasingly in the remaining part of the country, are choosing to install RAWS (Remote Automatic Weather Stations) stations and pay an annual per-station fee for centralized maintenance. We have noted that some agencies balk at the cost (typically $1-2 K per year), but in relative terms, and given the widespread value and utility of the information, and as importantly the costly effects of missing or incorrect information, this is actually a relatively small expense when contrasted with the value of the information.

The true barriers may be as much psychological as physical or resource limitations. Maintenance and calibration are often considered as "extra" expenses, afterthoughts to equipment purchase and setup. In reality, acquisition and deployment are the easy part. Maintenance and all of its associated salary and equipment needs are integral to the sustained operation of a network, whether of 1 or 1000 sites. This also requires technical skills and mechanical aptitudes, and on-the-ground experience is invaluable. Dedication, intrinsic interest, and personal time are often observed to play a key role in the operation of observing equipment. The process can be made more efficient, but a certain irreducible minimum level of resources and attention are absolutely necessary, if an environmental observing network is to provide information of the quality needed to understand atmospheric variations and their impacts on the functioning of natural systems, and human operational and management decisions. Decisions and understanding can be no better than their inputs.

The bottom line is that if one cannot trust the information received, it has little or no value.

10.2 Calibration and maintenance – general training issues

The type of knowledge needed to maintain a quality observing program is acquired both from books and manuals, and the unfortunate bitter experience of trial and error. There are many dimensions to running a monitoring program, and proper training can greatly reduce the number of painful experiences and improve the quality of the output. The more one knows about the theory of how sensors and the other physical components of an observing system work, the better the end product. The more one understands the ever-present pitfalls and problems, the better the end product. The greater the mechanical and electronic aptitude, the better the end product.

Over the course of time, and in almost any type of climate, every conceivable problem will occur and should be anticipated: weather, animals, plants, salt, sensor and communication failure, windblown debris, corrosion, power failures, vibrations, avalanches, snow loading and creep, data logger program corruption, and many other exotic and cleverly maniacal gremlins that will visit the station. An ability to anticipate and forestall such problems, a knack for innovation and improvisation, the ability to think on one's feet, "street smarts," knowledge of electronics, practical and organizational skills, and the presence of mind to remember to bring all the myriad small but vital parts and spares and tools and diagnostic troubleshooting equipment and not lose them in the moss, are all qualities to be highly valued. Especially when logistics are expensive, a premium should be placed on using experienced personnel, since the slightest and seemingly most minor mistake can render a station useless, or even worse, uncertain. Exclusive reliance on individuals without this background can be very costly and will almost always eventually result in unnecessary loss of data. Skilled labor, and an apprentice system to develop new skilled labor, will greatly reduce (but not eliminate) the types of problems that can occur in running a climate network. The rather specialized and detailed knowledge needed to maintain an observing network is hard-won and often the product of a long career.

This kind of resource is beyond the means of many small administrative units in need of such capability. For this reason there is some rationale in joining forces to develop such personnel, and then share them. Within the National Park Service Inventory & Monitoring Program, the networks might consider this approach. Depending on access difficulty, travel scheduling, logistics and dependence on other forces, a single person might be able to handle 20-50 stations, if they have no other responsibilities. The geographic scope should not be too large, because problems arise frequently and spontaneously, and such people, as specialists, are almost constantly in stand-by mode. For many problems, any small deviation from routine can lead to a need to summon up some small item from a vast reserve of experience.

Technology, whether sensors, communications, storage, or other, is increasing in complexity and capability by leaps and bounds, and some way needs to be found to keep abreast. As an example, certain widely used data loggers are about to end production, and new data loggers require new programming languages. There is thus an associated need for training updates. We have often found it productive to stay a step back of the advancing crest of technology, to let others help find the problems in new software and sensors, and be able to tap the knowledge of a broad base of measurement technicians, but do (carefully) try out the latest technology when feasible.

To acquire and retain the necessary experience in comfortably working with automated stations locally, there are potentially several routes. One that suggests itself more strongly is a kind of apprenticeship with the National Interagency Fire Center (NIFC) in Boise, which has had extensive experience for many years with all aspects of the RAWS (Remote Automatic Weather Stations) program. These platforms are used by many federal resource management agencies, including the National Park Service (currently about 140 sites), and Channel Islands among those. They have also produced documents on siting and maintenance of meteorological stations. Furthermore, these automatically link into a system of storage and retrieval and display.

NIFC is probably one of the best resources available to federal and state resource management agencies for off-site calibration of instruments. Many of the participating groups are sister agencies to the National Park Service, in the Department of Interior: Bureau of Land Management, Fish and Wildlife Service, USGS, and Bureau of Indian Affairs.

10.3 Calibration and maintenance - Channel Islands specifics

On the Channel Islands, maintenance has additional dimensions, because one cannot just drive to the location of interest on a whim. Boat transportation must be arranged, and usually a vehicle must be waiting. Other parties that have business on the islands are in the same boat (literally and figuratively). Almost always, therefore, advance coordination is needed. Furthermore, each island must be reached independently. Thus, the need for coordinated schedules means that site visit activities must to be on the calendars of several people. The outer islands are visited less frequently, especially Santa Barbara Island, so more must be accomplished, and the pressure becomes greater to not make small mistakes at visitation time that require several months to redress. The salty and corrosive environment can lead to a need for more frequent visits to the smaller and lower islands. However, this is the nature of this park.

Consideration of these factors leads one to conclude that putting extra effort into insuring that stations are robust against failure, and having good backup sensors or procedures, are good steps toward insuring reliable data when visits are few and far between. A swap-out program to recalibrate or examine instruments as a form of preventive maintenance also makes good sense.

11.1 Data display and access – general considerations

The issues here were expressed most cogently by Laurie Kurilla (Peace of Mind Technologies), currently working with USGS and Channel Islands National Park to improve web pages and data access, who during a visit in November 2004 relayed an old observation about software and interfaces : "If it is easy to use, it was hard for the programmer, and if it is hard to use, it was easy for the programmer."

Weather and climate observations and products are in high demand at all times, and it is important that there be easy access to them. Furthermore, most users are not as much interested in looking over reams of data values as they are in obtaining the information content they contain with respect to their own particular application. Thus, systems that offer *products* -- summaries, distillations, manipulations, composites, selective listings, and many more -- are especially desirable.

However, no data set is without "traps" and idiosyncracies, many of them obscure or hidden, that must be accounted for when software is written to generate some product of interest. This process can be very involved and require specialized knowledge and a considerable degree of exception coding, usually one of the most time consuming parts of algorithm development. For many issues where there is economy of scale (and climate and weather mostly fit this category), enlisting the assistance of those who are familiar with such factors, or where "canned" or existing software can be immediately harnessed, is a very productive route.

Two other processes seem to take an inordinate amount of time. One has to do with assembling and fixing the metadata, as well as the preparing the data for routine access, activities that are closely linked. The second is the development of simple and intuitive interfaces (to the Web, these days) that can span the enormous diversity in user capability.

Several guiding thoughts seem relevant:

- Prefill forms and interfaces with intelligent guesses at what the largest number of users might want. For example, the latest available data date as the ending point.
- Lots of options for repeat users who have learned their way around.
- Verbose options for first time users, sparse commentary for experienced users, and the ability to avoid the former during repeat visits.
- Minimal need for clicking, scrolling, and re-typing of inputs.
- Short cuts across decision trees, to avoid going back to square one each time.
- The ability to run multiple analyses by changing only a few parameters at a time.
- Approaches that allow the opportunity for learning and for increasingly sophisticated usages and users.
- Opportunities for products to be piped into local and familiar analysis or report generation software.
- Methods that allow detailed options to help internal users debug problems with data, metadata, or other parts of the data flow path.
- Minimal use of proprietary software.

Most of the initial products available at WRCC were developed to deal efficiently and rapidly with a range of questions that have been asked repeatedly (thousands of times). These decisions involve determination of the right combinations of local autonomy, external dependence, and mutual interdependence, and some degree of redundancy for times of system failure.

Especially in the field of climate, there is a large and diverse activity known as the “climate services sector” that is devoted to catering to just such problems. These should be engaged as part of any systematic large-scale approach. The world of data and information about climate is every bit as complicated as climate itself. The problems and issues under discussion in this report have a long history and have been and are now the subject of concerted attention by a large number of people. However, it is also worth noting that in and of itself, this attention does not always insure processes that are optimal to the needs of particular user groups, such as NPS, so this needs to be monitored closely.

An important role of those in the climate services sector consists of helping people distinguish what they want from what they need. Once this is sorted out, the problem turns into one of matching these needs to available data and information. For important or new problems, perhaps additional data may be needed. However, by their nature, climate data sets take a long time to accrue. But the usual situation is that some kind of extant information must be harnessed to address the issue of interest. In the general case, none of these steps are simple or straightforward, and some are very complex. There is seldom a problem for which there is no useful information whatever. Rather, there is usually a practical dimension involving the cost of obtaining or further developing relevant information.

11.2 Data display and access – Channel Islands

A web interface has been developed at the Western Regional Climate Center to display data and summary products for the Channel Islands, found at the web site www.wrcc.dri.edu/nps. This site provides access to the daily data from the rangers ("Ranger Data") and from the automated RAWS platforms and NOAA buoys. All of the original hourly historical data are available from the latter two sets of stations, and the stations are updated every hour or so. Currently there are five RAWS-like (Anacapa is not strictly RAWS) stations on four islands, with the exception of San Miguel, and three nearby NOAA buoys are also shown. Other mainland and buoy data are now accessible through a new set of pages that have been produced as part of another project funded by the State of California, at <www.calclim.dri.edu>. The Channel Islands map interface is shown in **Figure 3**.

Clicking on a pin brings up the associated station for products or data. The left hand frame will display types of products available for the station, and the right hand frame will typically display either a monthly indicator of data availability or the hourly data for the current calendar date. The product list in the left hand frame is intended to grow. This software is developed under the auspices of different projects and then permanently added to the product suite. The general philosophy is to allow the user to control a variety of options, but to provide reasonable default values if they don't have the time or inclination to do so themselves. (Users are assumed to be as busy as those preparing the web pages!) Options are constantly being added, as time and needs allow. A brief description of each, as of this writing, follows:

Daily Summary – This gives an hourly listing of the reported quantities from the station, and provides sums, averages, and extreme values for the day. A variant on this gives wind chill and heat index information. Any day in the record can be chosen.

Monthly Summary – This shows summarized daily information for each day of the month, and provides sums, averages and extreme values of those quantities for the month as a whole. Values are converted internally into days, and data from days so defined is then summarized. A variant on this provides reference evapotranspiration values. Any month in the record can be chosen.

Time Series Graph – This allows the user to plot hourly values (or 5 or 10 minute data if available) for the past day or two, up to the past 732 days (2 years). Options control which elements are displayed, whether they are overlaid or on a series of charts, scaling, the size of the graph, and marker types. A future version will allow more graph scaling and zero-point options.

Graph of the Last 7 Days – As above, but quick look with no options or need for thinking, for selected elements, currently: air temperature, relative humidity, precipitation, wind speed, wind gust, and wind direction.

Wind Rose Graph and Hourly Tables – A "wind rose" is a pictorial representation of how often the wind blows from different directions at different speeds (see examples in **Figure 2**). The displayed quantity is frequency (in percent, or in actual numbers of observations). A number of options allow the user to control the overall period, sub-windows (for example, only use data from July 7-August 3 each year, and only the hours of 9 p.m. to 3 a.m.), the bin sizes and category boundaries, wind speed categories, 16 or 36-point compasses, output formats, accompanying tables, graph size and scales, what constitutes "calm," and other options under continual revision.

Hourly Frequency Distribution/Histograms – This shows how often, by hour of the day and daily, values of individual elements are within selected frequency categories. The user has control of the bin sizes (must all be the same size), and bin boundaries, whether frequencies (percentages) or counts are desired, the overall period, data windows within the year and within the day, whether to display hourly averages, upper and lower values to ignore (bad data), and the number of decimal places to show (so that the output can fit on one screen). Other options will be added as necessary.

Data Lister – This allows a user to display the original data, in a variety of formats, for an overall period and with various sub-intervals (for example, all Christmas Day values between 8 and 11 a.m.), with control of flag display, missing data representation, and delimiters for spreadsheets. Different export formats (delimited, ASCII, html, etc) are available. Future options will allow screening on values of one or more elements referred to Boolean operators (Example: display all hours with temperature between 35 and 48 degrees F and with wind from the northeast at 9-17 mph between July 18 and September 17 for years between 1987 and 1996).

Data Inventory – Shows all months with at least one observation, in red.

Data Inventory (Monthly) – By month (select by clicking), shows every hour that has data with a colored pixel, for a given element. This is a rapid way of assessing how reliably a station has been reporting values.

Figure 3. Channel Islands web interface at the Western Regional Climate Center.

www.wrcc.dri.edu/channel_isl/index.html

Channel Island National Park Stations

RAWS/NDBC Buoy/Manual Ranger Stations

Recent web page changes:

- Composite Daily Summaries added. (Link found below the map.)

Click on site of interest for more information.
Data is subject to review and verification.

Composite Daily Summaries

Historical Climate Data

Anacapa Island
Santa Barbara Island
Santa Cruz Island
San Miguel Island
Santa Rosa Island

Cooperating Agencies:

Desert Research Institute | National Interagency Fire Center | Western Regional Climate Center | National Park Service | National Data Buoy Center | U.S. Geologic Survey

Station Metadata – Shows position (latitude, longitude, and elevation) and station photos if available. This information could be conceivably linked to a GIS or other data system, to show other information about the station.

Under development - The current selection represents what users have wanted to see most, but the staff at WRCC is open to suggestion regarding other useful software. At this writing, one program under development but not yet on the web, will allow users to show a monthly time series of some quantity, such as the number of days each month over each of the past 15 years with a maximum temperature over 88.3 degrees, or the mean monthly temperature, or the total precipitation. There are numerous subtleties regarding how a "day" is formulated from potentially sparse hourly data, how a "month" is formulated from such days, and how a long term mean is formulated from such months. The plan is to allow the user to control these decisions as much as possible, but with defaults supplied.

12.1 Storage and retrieval – general considerations

Historical climate and weather data are unique and irreplaceable. For peace of mind we would always advocate local or intra-institutional storage for safekeeping and backup. This might not form the primary working data base; archival data sets are not necessarily the best working data sets, though well-designed systems can work simultaneously in both modes. In addition, no matter how capable a centralized facility might be, there are always and inevitably local data sets and activities that are harder to incorporate in a general scheme, or of interest just locally. Although the web is increasingly fast and reliable, there are times when it is not working or otherwise unavailable. If vulnerability to such disruption is unsatisfactory, local alternatives need development.

Because there is considerable commonality throughout the country in weather and climate data needs, it does make sense to take advantage of large scale programmatic activities. Regional and state climate centers are one example. For federal organizations, another strategy is to utilize agency-specific or government-wide approaches. For example, the RAWS program is widely used by resource management agencies in the West and increasingly, nationally. Currently about 1200 sites are reporting, with all sites reporting through the National Interagency Fire Center automatically going into the data base. Once there, standard products from a steadily growing list can be readily generated. This is a popular option, but not the only route available.

For the best-designed systems, no data are accessible until the metadata are available. Unfortunately, this latter activity is a major chore and often constitutes a considerable headache, so most systems provide access to data by making use of less than perfect metadata.

Related to metadata is the notion of traceability and journalizing, tracking the path of each datum so that we know its history. This is typically handled with flags that accompany every datum. A well-designed system will have more flags than actual data values. These are very helpful when quality control procedures have provided a stamp of approval or disapproval, or a confidence level, or an indicator of an edited value, or a description of how that edited value was derived. Many data with legal or regulatory functions utilize flagging systems. Most of these systems retain the original values in perpetuity, though perhaps off to the side. With improved quality control procedures, computers, and corroborating data, prior quality control decisions can always be revisited.

As with every other decision about data management, there are a variety of tradeoffs. Most of these center around trading away a workload (doing it yourself) but obtaining a vulnerability or a dependency (letting somebody else handle it) in so doing. It seems preferable to not be completely in either camp. However, there are also issues of access to necessary disciplinary expertise (computers, climate, measurement and sensing, web interfaces, etc), the reliability of this access, and the minimum skill levels that are needed (typically at least intermediate to advanced). Small work units may not have this level of expertise and might find it beneficial to partner.

12.2 Storage and retrieval – Channel Islands

Data from Channel Islands are currently produced on hourly and daily time scales. Historical data also exist on monthly time scales.

The daily values ("ranger data") are generated by rangers on the islands. Data are sporadic, especially in winter. Some summer months have fairly complete records. Many of these have been taken in some form or other for 10-20 years. These would have greater value if they were more complete, although the rangers are not always present. Given their variable schedules, only automation (electronic or paper traces on wind-up clocks) could produce more complete records. It would be best if standard louvered thermometer housings were employed, and that standard widely used rain gages were employed. Fortunately, snow is very rare at the ranger location elevations, so ordinary rain gages should suffice.

Manual measurements do have a role and are useful to the degree that standard, and unchanging, methodologies are employed. If this is difficult to achieve, and even if not, documentation of methods helps greatly, and of individual departures from whatever methodology is employed (for example, a reading at a non-traditional time of day). Standard, well-calibrated instruments are best, but more commonly available equipment can provide very useful measurements for many purposes. For temperature, inexpensive supplemental electronic instruments, and especially those capable of internally storing data from many days, placed inside a white shelter, could provide readings accurate to within a degree or two

F (about a degree C), which would be sufficient for many ecological studies, for example. Knowledge of a particularly hot or cool day can be beneficial. (We noted one July day at Santa Cruz with 109 F / 42.7 C, and another at Santa Barbara Island of 105 F / 40.6 C, which, though extreme, are not unbelievable. The Santa Cruz temperature occurred in a month with only 6 days of available data, so even a sporadic record is useful.) Such instruments can serve as backups for fully automated weather stations more remotely located in the event they malfunction. Not to be overlooked, they can also provide the rangers with an immediate sense of current conditions, or of recent deluges that may portend trail or road problems, and for some even a sense of engagement with monitoring. But it is recognized that other duties or emergencies interfere, and to the degree that such is likely to happen, the less intrusion on daily schedules the better. No matter what, and whether standard or not, the main need is to document procedures and practices, and note any changes through time. Again, a systematic approach is always best, but just a simple log book or log file on a computer can be very helpful, and is transferable in the future.

Electronic thermometers have become quite reliable, and are fairly inexpensive, but automated precipitation gages are more prone to problems, and a simple manual daily or multi-day measurement of precipitation can be a good check on an automated gage. Unfortunately most automated gages let precipitation pass through and do not save the water for later consistency checks (does the sum of the increments from an automated gage add up to what is in a nearby accumulated collector?). For reports of major events, any kind of corroborating information is useful for quality control purposes, no matter how “unofficial.”

These types of gages suffice for “weather” observations, but may not be adequate for “climate” observations, if the intent is to monitor for slow long-term change. For climate, subtle biases of many kinds can negate the accurate detection of trends, and more particularly *changes through time* in those biases, and considerable care must be taken to enable strict comparison through time of measurements made in a self-consistent way. This is the hallmark of a scientific observing program. An oft-repeated progression is that the systematic collection of “weather” data over a long period produces a strong temptation to treat the resulting values as “climate” data, with the inevitable regret that the process was not documented more thoroughly at the start and along the way. This dilemma nearly always revolves around the willingness to make individual and institutional commitments to a systematic process, and to leave a documentation trail.

For automated data, the path taken at Channel Islands is to use RAWS stations, which automatically go through the National Interagency Fire Center in Boise and are sent immediately to WRCC, stored, and made available for viewing, usually within the hour. By a different pathway, the NOAA buoy data become similarly available. The menus also provide access to summary products and data listings.

For data listings only, and as a “least undesirable” option, an access code was implemented at WRCC. Though inconvenient, this does provide an effective deterrent to corporate web crawlers and certain other sectors from bringing the WRCC data access system to a standstill through constant large data downloads. An as-yet-unrealized long-term goal at WRCC is to circumvent this by acquiring the high-end computers that can deal with multiple major data downloads. Other products that utilize the entire data set for a station are not subject to this restriction, since all the access and computation take place internally at WRCC.

Many users like to manipulate data according to their own experience and software, so options are available to download data in a variety of formats, delimited and otherwise. One of these formats is Microsoft Access, which has been adopted by a number of National Park Service users. Although the WRCC data are well backed up (these are part of the main national fire weather data base), an occasional download to a local machine as an added safety measure is still a good idea even if not necessary.

13. Summary

We have tried to provide both a flavor and some of the details of what is needed to run an end-to-end climate and weather monitoring program. Though at first this sounds simple, a large body of experience has shown that there are many complexities and a long list of arcane details through all the steps. We have tried to highlight the most important, but others remain. The reason for paying such close attention to all these details is that in the end we want to be confident that the information from which we make inferences is actually what we think it is, and that mechanisms for access, manipulation, and display are efficient and usable. The former is fundamental to the scientific discovery process, and the latter is necessary to make such efforts practical or even possible.

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Appendices:

Appendix A. Island maps.

Appendix B. Station locations.

Appendix C. Listing of monthly precipitation at Main Ranch, Santa Cruz.

Appendix D. Correlation analysis.

Appendix E. Ten Principles for Climate Monitoring.

Appendix F. Satellite images of Channel Island meteorology / cloud patterns

Appendix G. Photographic documentation. A slide presentation.

Appendix A. Island Maps.

Figure A.1. The five islands in Channel Island National Park. Clockwise from left: San Miguel, Santa Rosa, Santa Cruz, Anacapa, Santa Barbara (lower right).

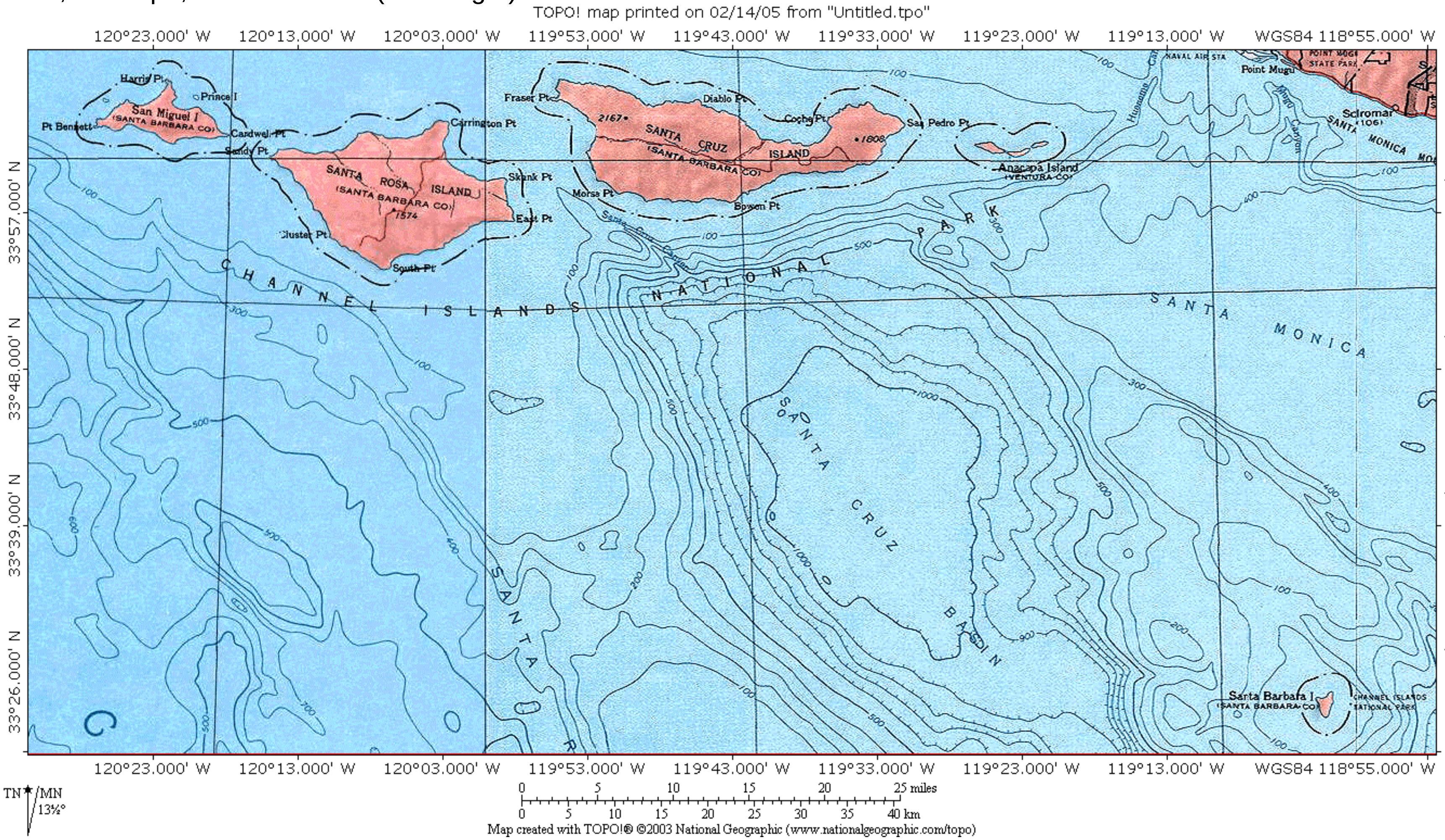


Figure A.2. San Miguel Island.

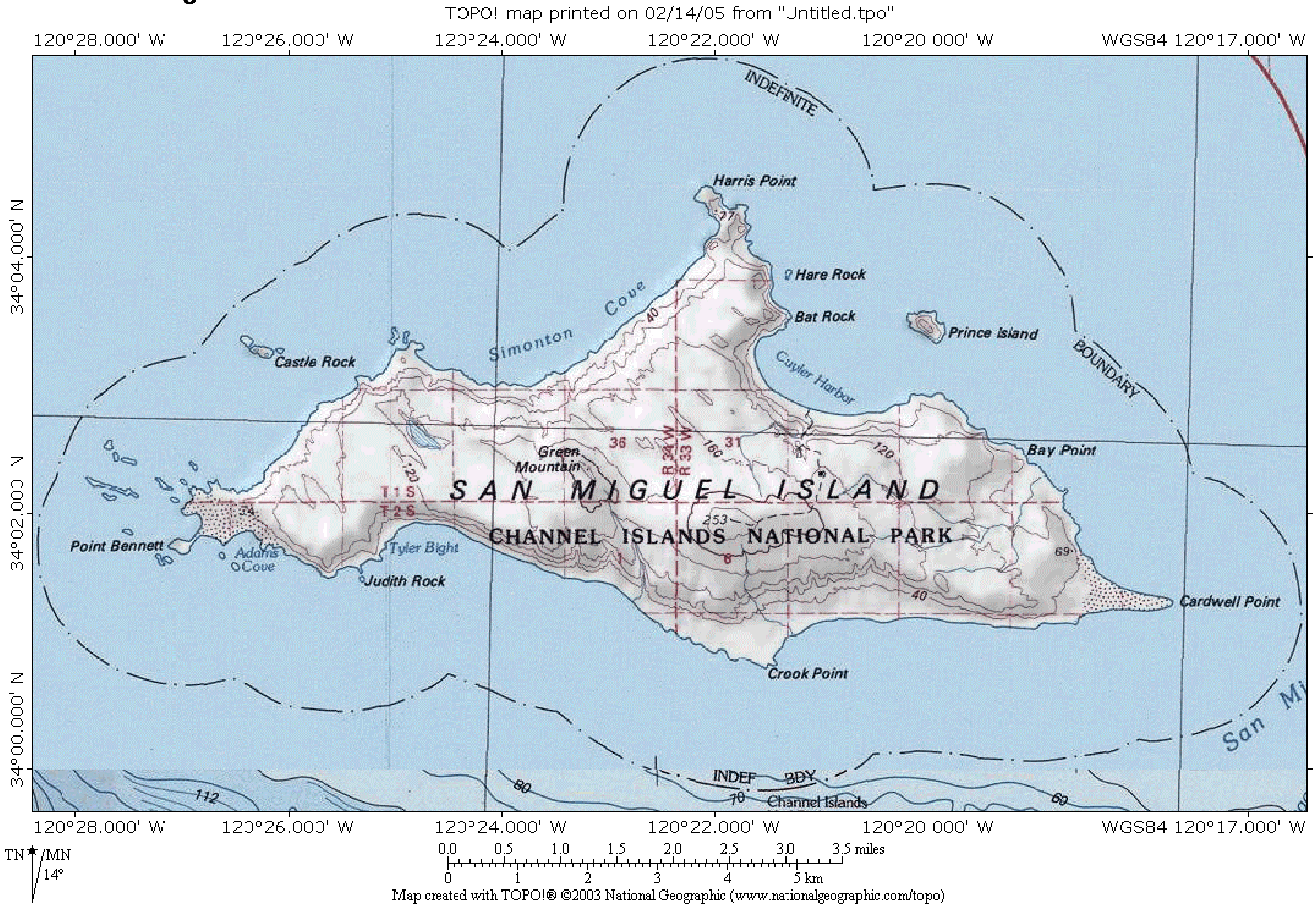


Figure A.3. Santa Rosa Island.

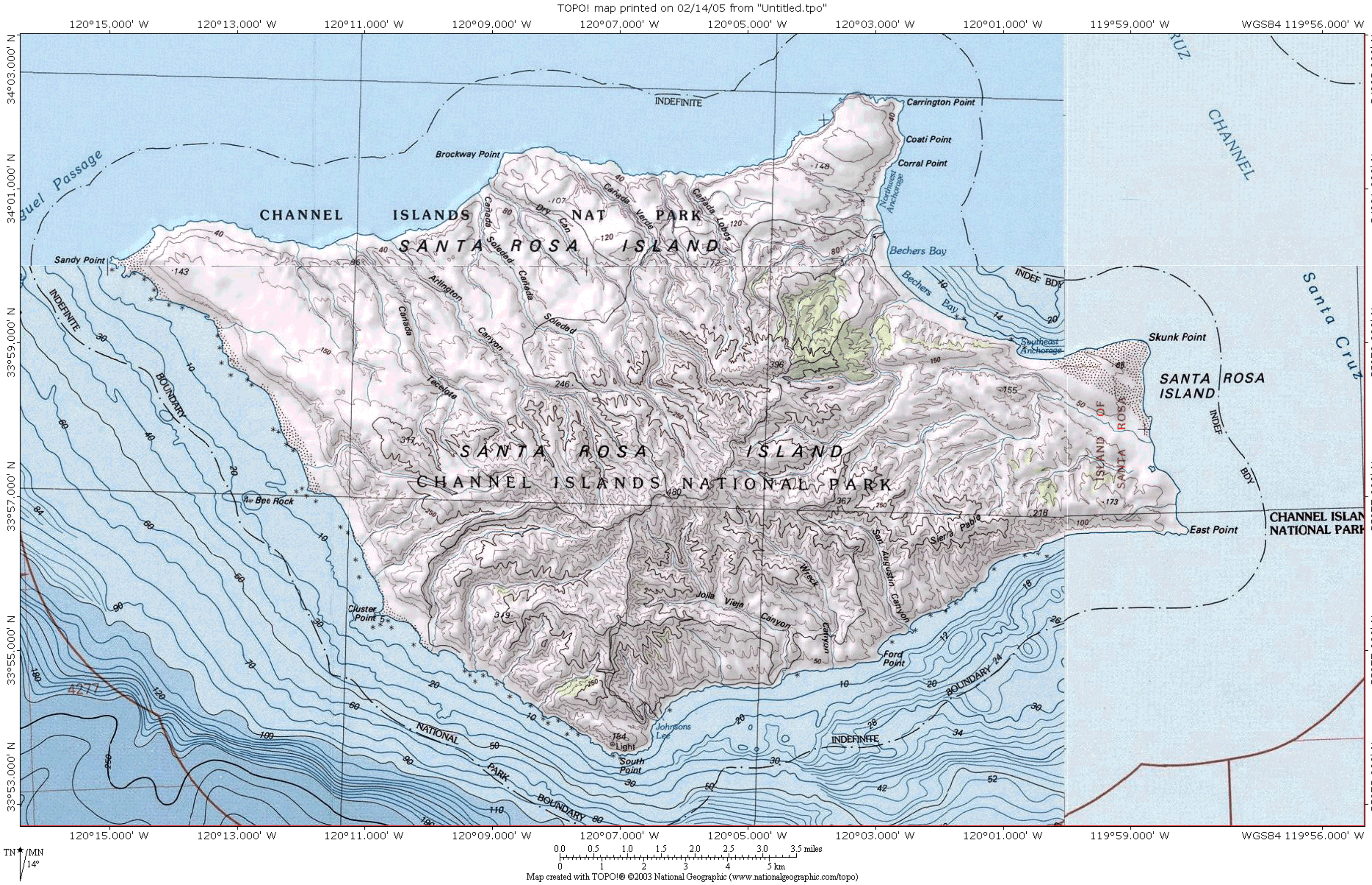


Figure A.4. Santa Cruz Island.

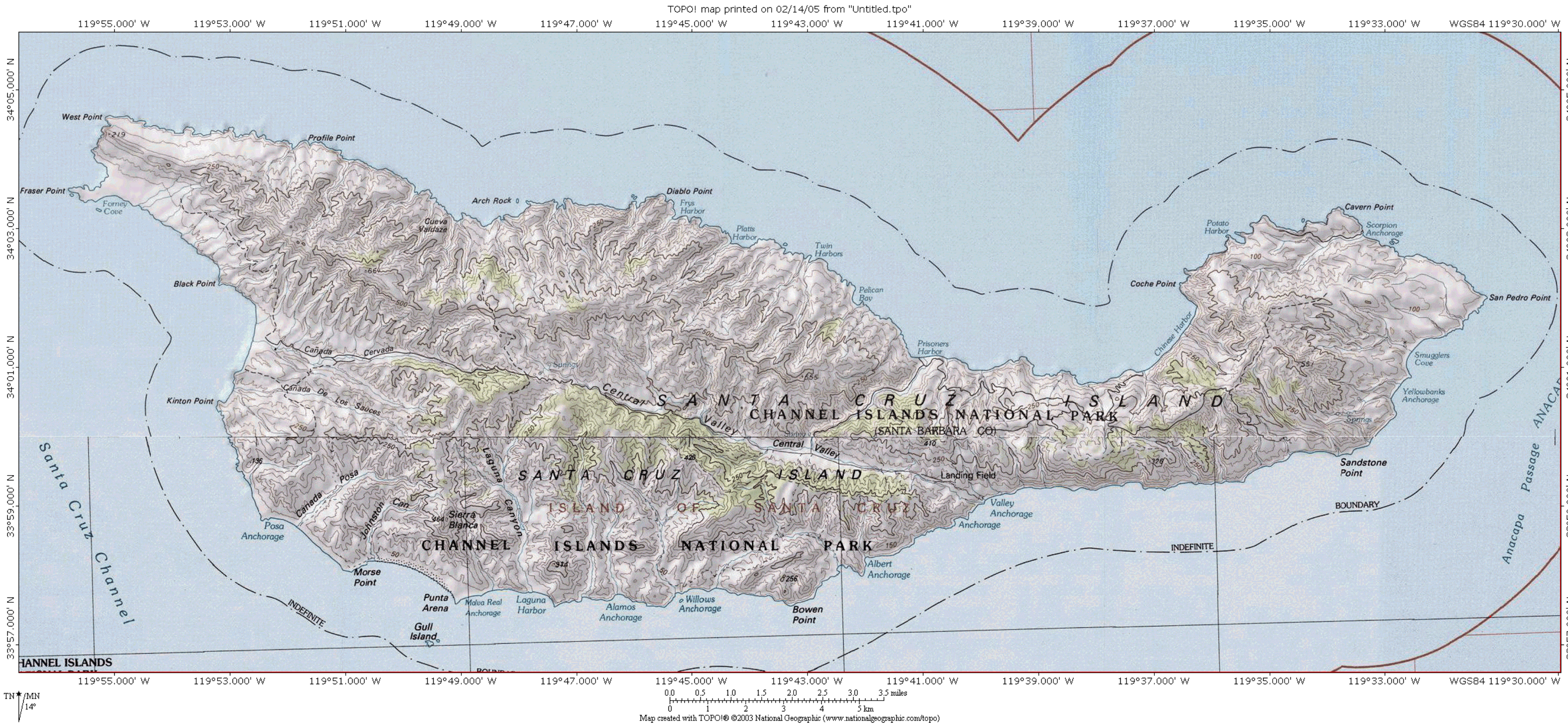


Figure A.5. Anacapa Island.

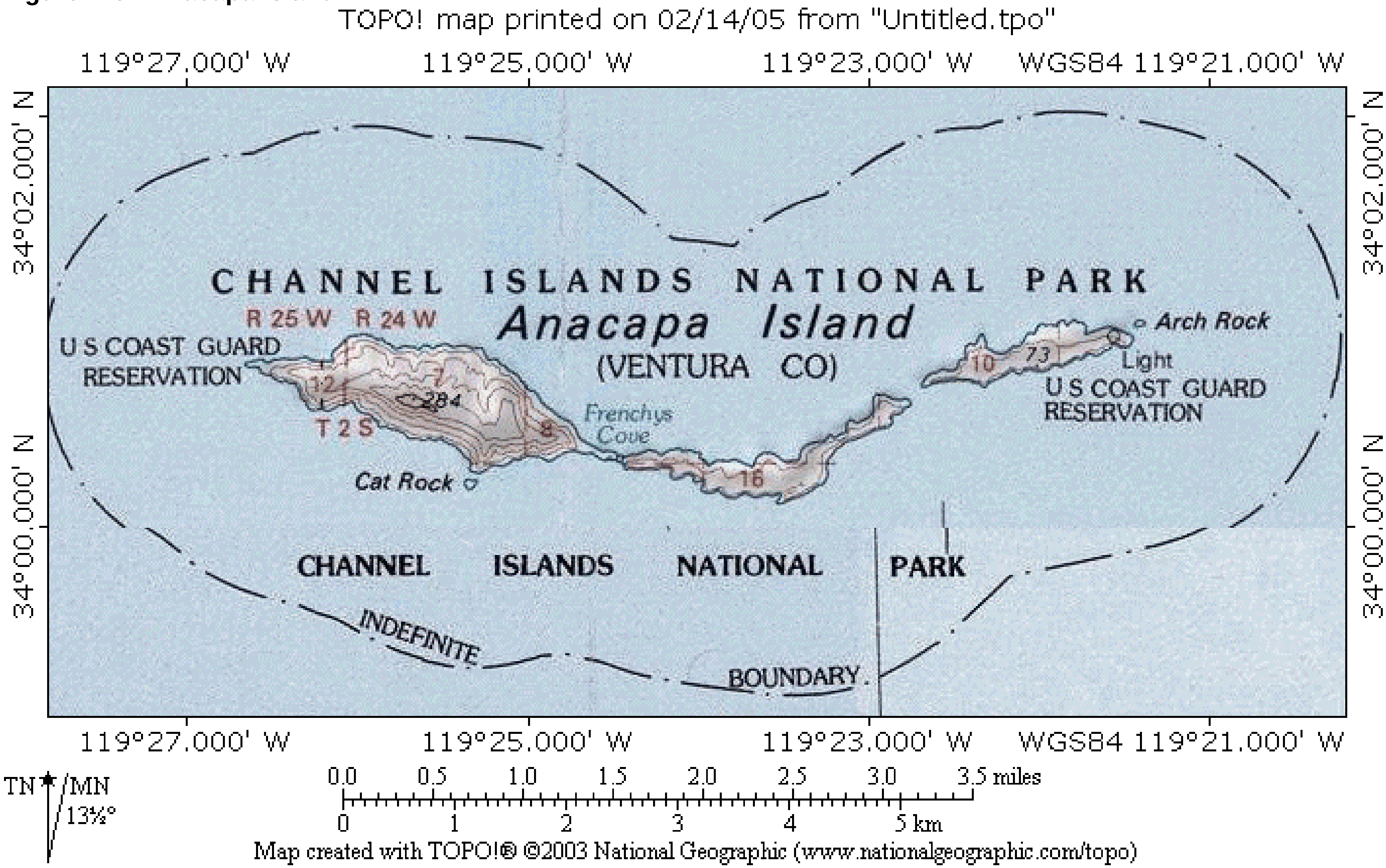
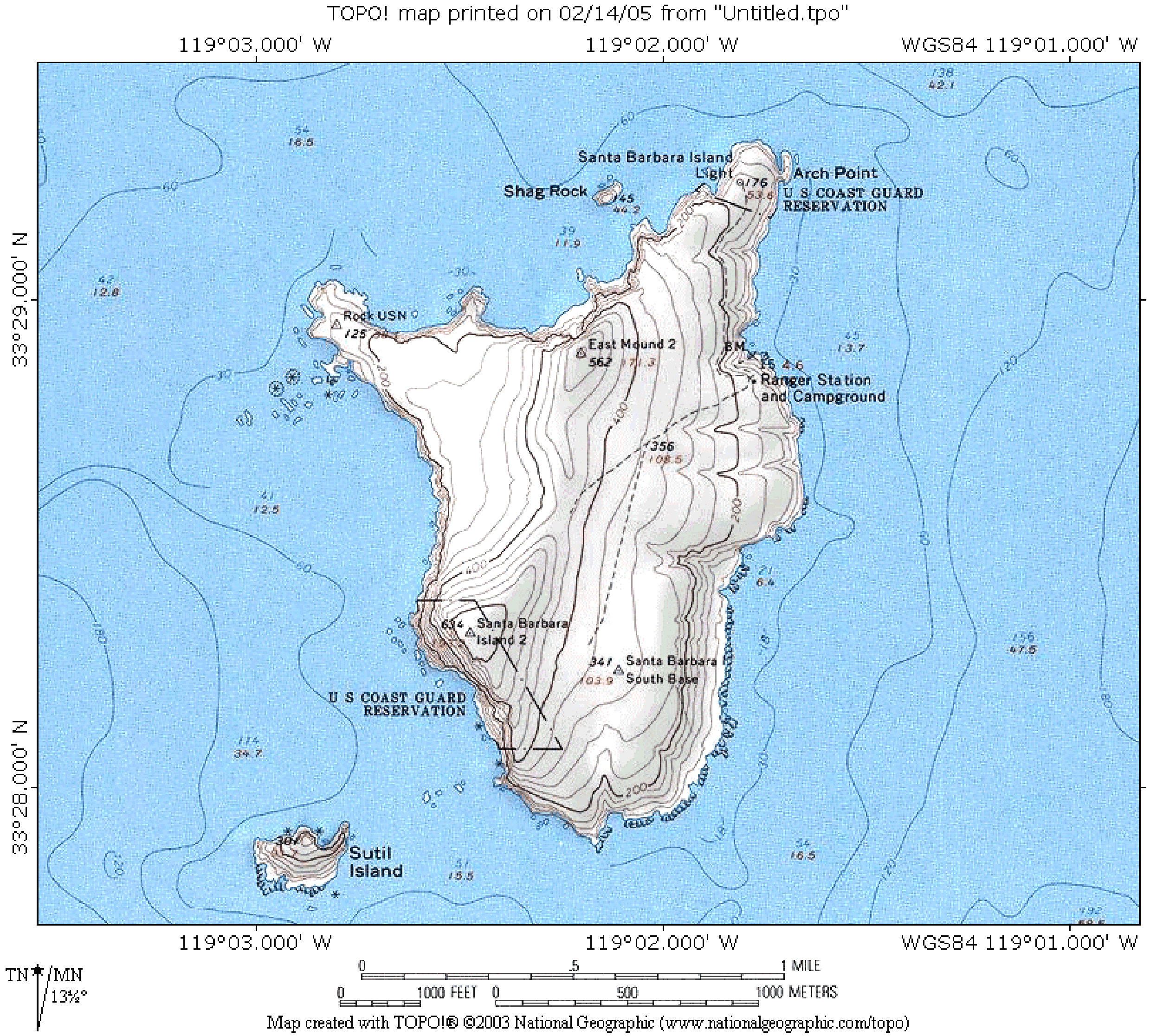


Figure A.6. Santa Barbara Island.



Appendix B. Station Locations.

Locations for the Ranger Data are taken from information supplied by Channel Islands National Park. RAWS positions are taken from the National Interagency Fire Center in Boise Idaho. NOAA buoy positions are taken from the National Buoy Data Center. The Anacapa site is technically not a RAWS station, but rather an Automated Weather Station funded by a different group.

Maps in this appendix are primarily to show station locations. They do not show as detailed geographic information as those in **Appendix A**.

Table B.1.

Ranger Data.

wrcc id		Station	Lat dd mm	Lon ddd mm	Elev ft	start year mo	end year mo
96 7801	X	SANTA BARBARA ISL. (CHIS)	33 29	119 02	9999	1980 10	9999 99
96 7802	X	SANTA CRUZ I. SCORPION	34 03	119 32	9999	1984 01	9999 99
96 7803	X	SAN MIGUEL ISL. (CHIS)	34 02	120 21	9999	1981 09	9999 99
96 7804	X	SANTA ROSA I. BECHERS BAY	33 58	120 05	9999	1993 07	2001 12
96 7805	X	SANTA ROSA I. RANGER STN	99999	999999	9999	2002 01	9999 99
96 7806	X	SANTA ROSA I. JOHNSON LEE	99999	999999	9999	1987 06	1991 12
96 7807	X	SANTA CRUZ I. MAIN RANCH	34 01	119 05	9999	2004 01	9999 99
96 7808	X	SANTA CRUZ I. NAVY SITE	99999	999999	9999	2004 01	9999 99
96 7809	X	SANTA CRUZ I. SMUGGLERS COVE	34 01	119 32	9999	2004 01	9999 99

RAWS and NOAA Buoy Locations.

Station	Lat dd mm ss	Lon ddd mm ss	Elev ft	start yr mo	end yr mo
NOAA Buoy 46025	33 44 42	119 05 02	0	1982 04	9999 99
NOAA Buoy 46053	34 14 10	119 51 00	0	1993 12	9999 99
NOAA Buoy 46054	34 16 08	120 26 54	0	1993 12	9999 99
Santa Barbara Island RAWS	33 29 00	119 02 00	176	1995 04	9999 99
Santa Rosa Island RAWS	33 58 40	120 04 40	1298	1990 04	9999 99
Santa Cruz Island RAWS	33 59 45	119 43 20	250	1990 04	9999 99
Del Norte RAWS	34 00 33	119 39 15	800	1999 04	9999 99
Anacapa Island AWS	34 00 57	119 21 35	277	2004 05	9999 99

Table B.2. Positions from various sources. Differences with positions in Table B.1 have not been resolved as of July 2005. For completeness, all are listed.

Location positions supplied by Kathryn McEachern 2001 Oct 22. They are approximate and not based on GPS readings. Datum NAD27. Easting of site E changed from 722388 to 772388.

Channel Islands National Park Weather Stations and Observation Locations – Approximate, not from GPS				
Island/Station	Easting	Northing	UTM Zone	Comments
A - SMI Old Ranger Stn	744,394	3,769,745	10	Nidever Canyon
B - SMI New Ranger Stn	744,597	3,769,431	10	Airstrip
C - SMI Handar (Navy)	743,395	3,768,730	10	San Miguel Hill
D - SRI Handar	769,979	3,763,421	10	Black Mountain
E - SRI Old Ranger Stn	772,388	3,766,231	10	Becher's Bay
F - SRI New Ranger Stn	771,192	3,765,737	10	New housing area
G - SCI Del Norte area	254,831	3,766,076	11	location is Del Norte area; specific weather station location unknown
H - SCI Handar	249,170	3,764,602	11	Main Ranch
I - SCI Ranger – Scorpion	263,894	3,770,315	11	Scorpion Ranch
J - SCI Ranger – New Housing	263,648	3,770,495	11	Temporary housing area
K - AI Ranger	281,843	3,766,248	11	
L - AI Lighthouse	282,195	3,766,226	11	Location of lighthouse
M - SBI Handar	311,466	3,706,976	11	
N - SBI Ranger Stn	311,513	3,706,222	11	

Values in table above converted to Latitude / Longitude, datum WGS84:

Station	Latitude	Longitude	Elev (ft)	
A – SMI Old Ranger Stn	34 02.504 N	120 21.217 W	410	
B – SMI New Ranger Stn	34 02.332 N	120 21.083 W	543	
C – SMI Handar Navy	34 01.964 N	120 21.885 W	836	
D – SRI Handar	33 58.683 N	120 04.734 W	1262	
E – SRI Old Ranger Stn	34 00.187 N	120 03.107 W	95	
F – SRI New Ranger Stn	33 59.942 N	120 03.899 W	355	
G – SCI Del Norte area	34 00.506 N	119 39.339 W	770	
H – SCI Handar	33 59.631 N	119 42.579 W	308	
I – SCI Ranger – Scorpion	34 02.927 N	119 33.519 W	58	
J – SCI Ranger New Housing	34 03.009 N	119 33.686 W	138	
K - AI Ranger	34 00.995 N	119 21.807 W	147	
L – AI Lighthouse	34 00.949 N	119 21.571 W	148	
M – SBI Handar	33 29.254 N	119 01.805 W	156	
N – SBI Ranger Stn	33 28.843 N	119 01.766 W	70	

RAWS Station Locations from ASCADS BLM and from NPS and WRCC visits. Datum WGS84.

D – Santa Rosa RAWS	33 58.670 N	120 04.670 W	1298 ft	ASCADS
H – Santa Cruz RAWS	33 59.750 N	119 43.330 W	250 ft	ASCADS
G – Del Norte RAWS	34 00.550 N	119 39.250 W	800 ft	ASCADS
L – Anacapa RAWS	34 00.950 N	119 35.580 W	277 ft	ASCADS
C – San Miguel Navy	34 01.981 N	120 21.839 W	627 ft	NPS GPS
H – Santa Cruz RAWS	33 59.576 N	119 42.976 W	363 ft	WRCC
G – Del Norte RAWS	34 00.725 N	119 39.179 W	701 ft	WRCC

Figure B.1. San Miguel Station Locations, using above coordinates.

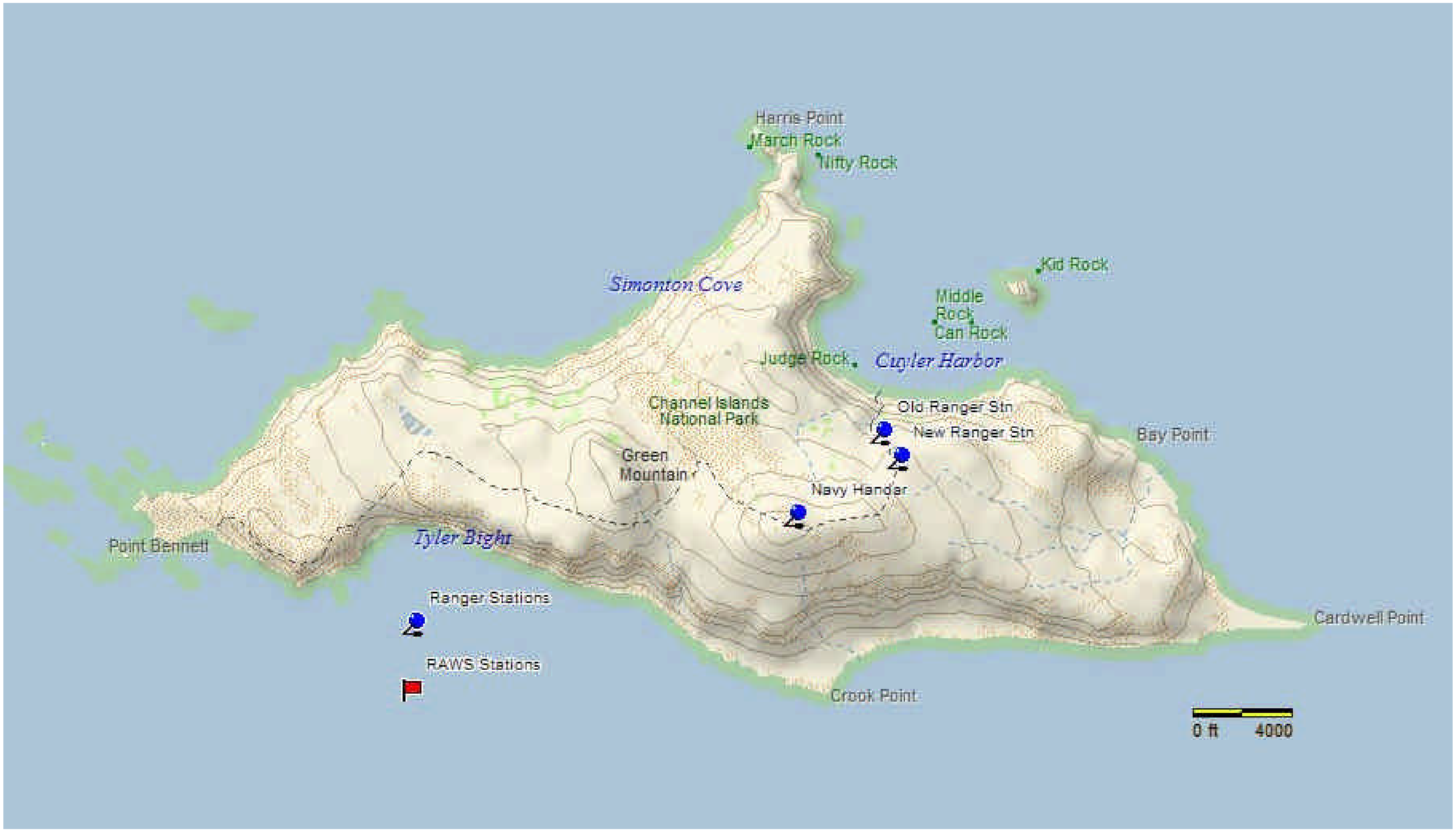


Figure B.2. Santa Rosa Station Locations, using above coordinates.

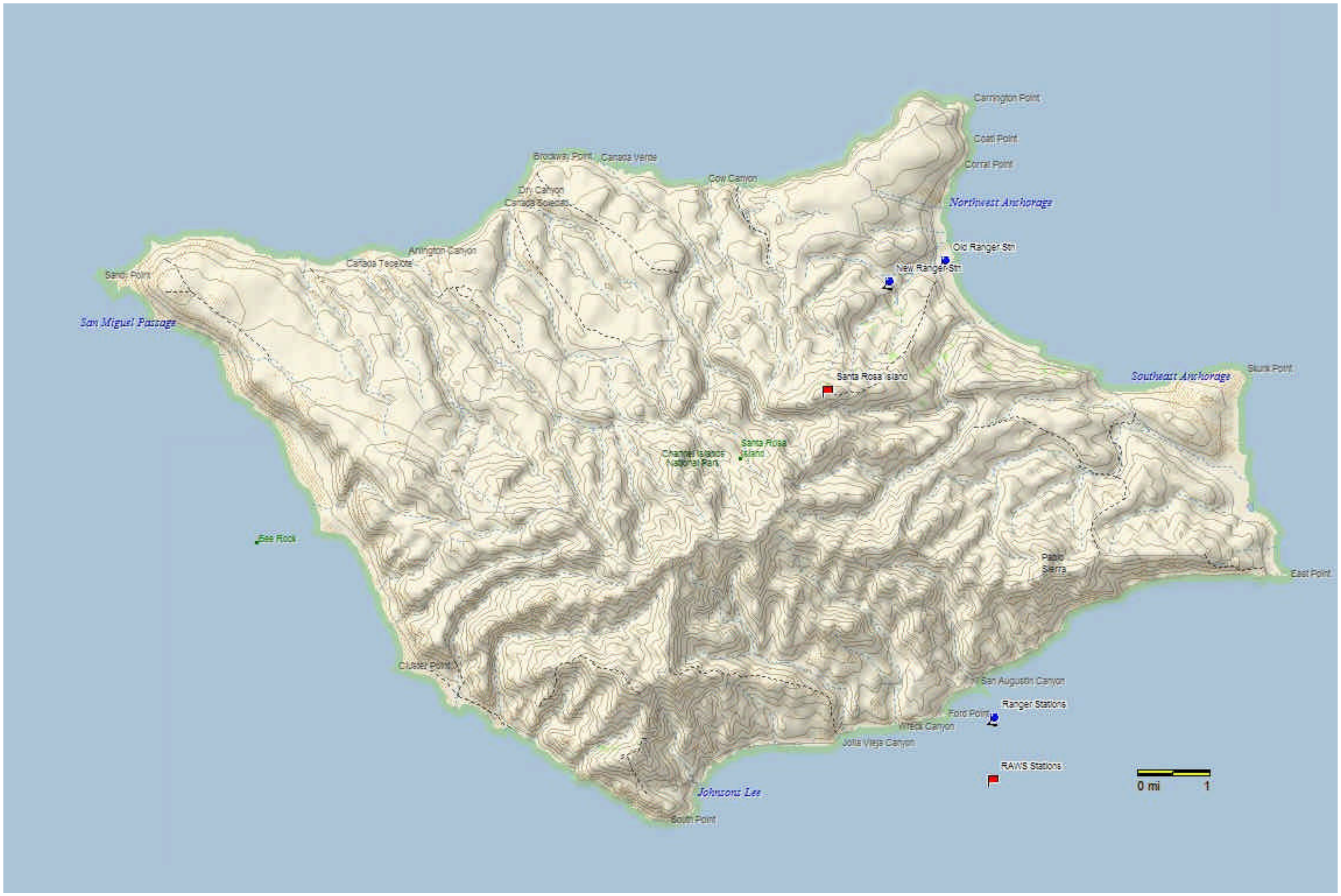


Figure B.3. Santa Cruz Island station locations, entire island, using above coordinates.

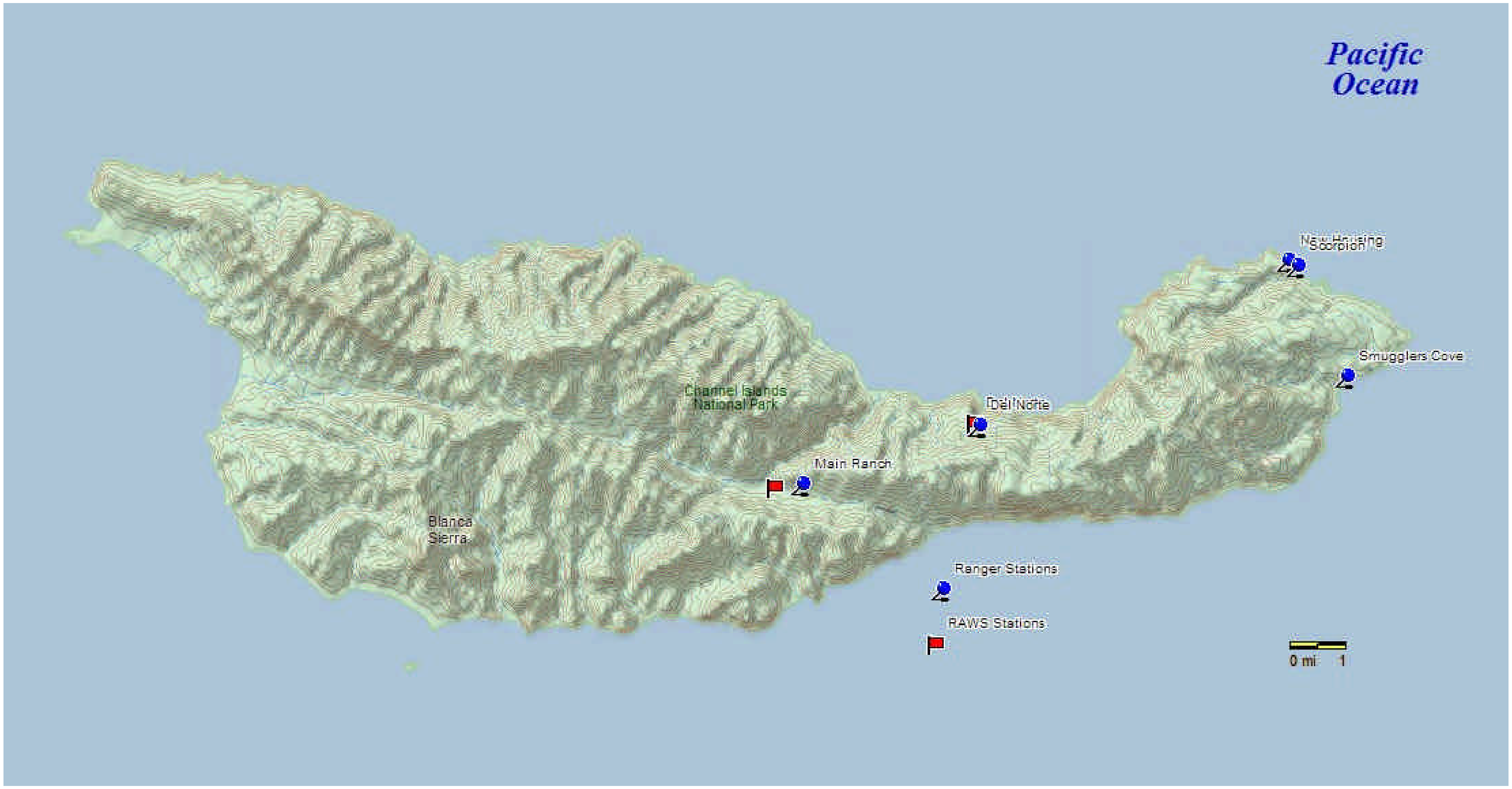
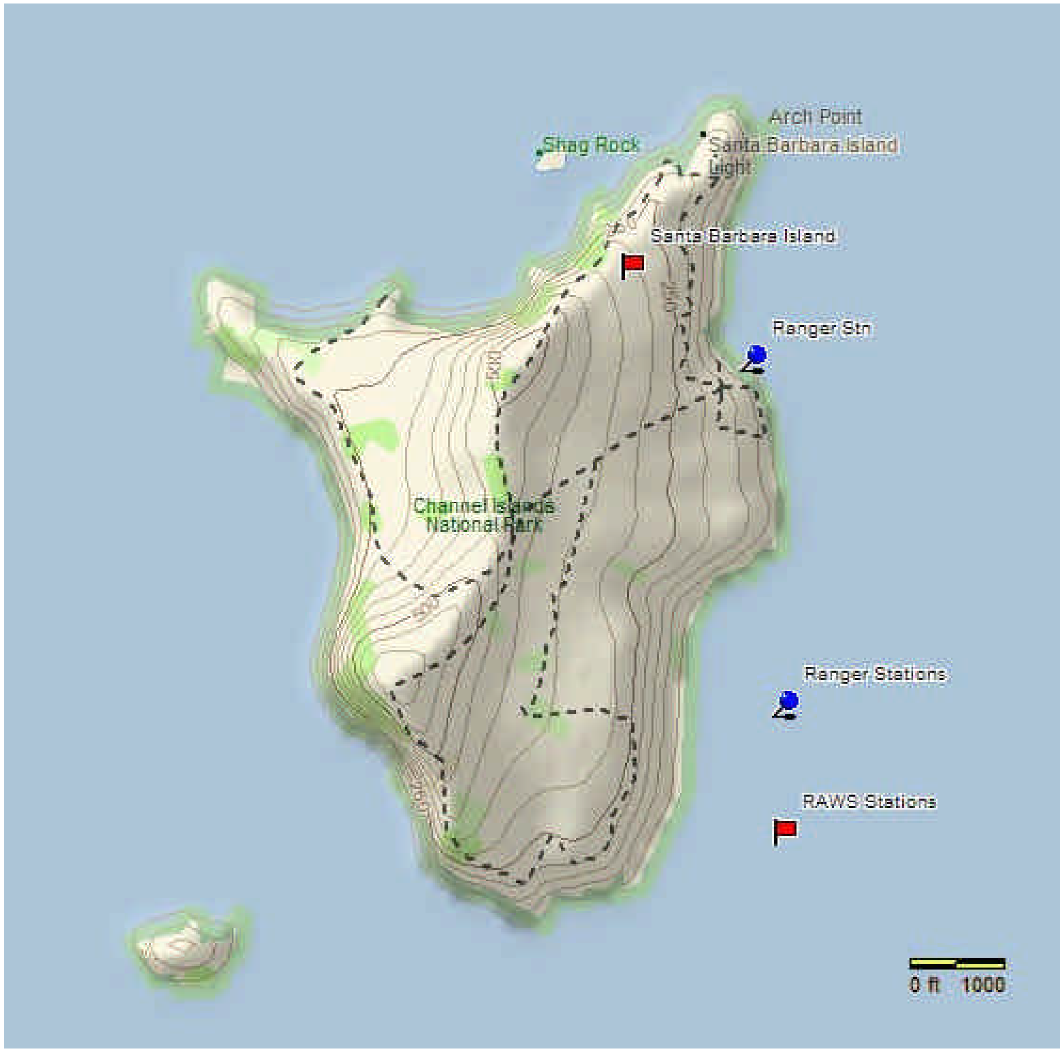


Figure B.4. Santa Cruz Island station locations, east side of island, using above coordinates.

Figure B.5. Anacapa Island station locations, using above coordinate information.

Figure B.6. Santa Barbara Island station locations, based on above coordinates.



Appendix C. Monthly Precipitation Data, Main Ranch, Santa Cruz Island.

Monthly precipitation at Main Ranch, Santa Cruz Island. Fixed format, with room for 2 alphanumeric data flags (both usually blank) following each value. Units: Hundredths of inches. 123 = 1.23 inches, 4 = 0.04 inches. Supplied by Channel Island National Park. 9999 = missing. Values of 0 in the middle of the rainy season appear suspect. Original forms were not available, and therefore it was not possible to distinguish zero from no data (missing).

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1904	72	472	361	155	0	0	0	0	222	44	0	137
1905	469	789	624	19	175	0	0	0	0	0	178	0
1906	657	544	1149	49	302	6	0	0	0	0	50	448
1907	768	228	913	0	0	0	0	0	0	428	0	310
1908	690	1365	10	120	0	0	0	0	140	0	131	317
1909	1438	996	366	0	0	0	0	0	0	28	194	959
1910	318	0	297	25	0	0	5	0	255	36	52	161
1911	1294	456	605	274	0	5	0	0	17	0	10	99
1912	50	0	847	288	119	0	0	0	0	37	5	0
1913	388	871	30	154	0	43	3	6	0	0	200	574
1914	1085	595	102	121	0	17	23	0	0	0	21	642
1915	608	1092	351	391	159	0	0	0	20	0	56	293
1916	2203	270	232	0	0	0	0	0	250	269	22	497
1917	342	598	19	34	0	0	0	0	8	0	18	5
1918	59	682	1282	0	24	0	0	10	160	0	355	72
1919	94	273	141	0	103	0	0	0	0	0	7	76
1920	0	361	370	68	0	0	0	0	0	33	197	183
1921	976	142	265	26	261	0	0	0	42	73	5	1021
1922	360	663	177	0	27	0	0	0	0	35	191	973
1923	59	201	18	268	0	3	0	0	19	0	53	77
1924	122	0	242	140	0	0	0	0	0	78	76	195
1925	69	227	210	85	290	15	0	0	0	0	70	270
1926	268	618	39	750	0	0	0	0	0	0	480	260
1927	264	1111	196	0	0	0	0	0	0	254	372	323
1928	0	175	257	42	0	0	0	0	0	32	197	282
1929	157	244	280	0	0	60	0	0	33	0	0	0
1930	713	361	326	35	232	0	0	0	0	0	264	0
1931	495	480	0	223	120	0	0	10	0	0	194	1159
1932	467	807	24	23	2	0	0	0	101	6	0	117
1933	696	0	66	46	4	199	0	38	0	111	0	763
1934	150	694	0	0	0	249	0	0	0	92	443	261
1935	513	117	543	436	0	0	0	0	14	53	160	0
1936	216	878	182	120	0	0	0	36	0	399	0	459
1937	328	1337	623	0	0	0	0	0	0	0	0	530
1938	157	1145	1020	0	0	0	0	0	0	65	15	465
1939	395	225	268	15	0	0	0	0	0	342	52	0
1940	152	640	1043	88	44	0	0	0	0	163	73	1442
1941	1581	891	910	549	6	0	0	0	0	228	37	796
1942	106	143	236	368	0	0	0	0	0	55	20	205
1943	1236	319	302	162	0	0	0	0	0	92	22	978
1944	361	801	335	110	0	0	0	0	0	0	388	67
1945	94	487	719	0	0	0	0	0	0	32	0	896
1946	22	70	324	0	0	0	0	0	0	24	455	270
1947	42	62	148	0	0	0	0	0	0	49	0	110
1948	0	50	356	223	12	0	0	0	0	0	0	252
1949	462	150	272	0	59	0	0	0	0	0	107	718
1950	435	433	111	38	0	0	0	0	30	110	149	72
1951	315	225	98	241	18	0	0	0	0	38	133	659
1952	1127	149	629	262	0	0	0	0	0	10	382	725
1953	223	27	101	208	0	0	0	0	0	0	178	0
1954	601	528	433	72	0	0	0	0	0	0	294	222
1955	378	189	249	373	105	0	0	0	0	0	25	1133
1956	1304	132	0	240	90	0	0	0	0	0	0	0
1957	693	481	117	200	114	0	0	0	0	158	11	334
1958	460	969	1095	463	51	0	0	0	10	0	0	22
1959	166	744	0	200	0	0	0	0	33	0	0	261
1960	506	696	35	211	0	0	0	0	0	0	596	48
1961	160	0	71	7	5	0	0	0	9	0	440	162
1962	262	1622	382	0	2	0	0	0	0	46	2	42

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1963	367	531	279	219	7	8	0	12	86	25	366	3
1964	303	4	353	44	7	15	0	2	0	72	200	1044
1965	97	41	265	655	0	0	0	0	0	0	955	113
1966	272	108	17	0	0	0	0	0	5	0	172	315
1967	528	37	95	496	0	0	0	0	0	0	467	115
1968	134	236	563	53	0	0	0	0	0	140	105	193
1969	1424	747	50	118	0	0	0	0	0	8	230	20
1970	414	266	154	0	0	0	0	0	0	3	641	591
1971	115	118	63	60	53	0	0	0	0	0	31	744
1972	82	22	0	14	0	2	0	0	0	21	371	131
1973	654	735	202	0	0	0	0	0	24	92	206	176
1974	805	322	40	0	0	0	0	0	0	65	23	538
1975	68	346	329	127	0	0	0	0	0	36	37	6
1976	0	348	118	85	3	54	0	6	243	0	47	95
1977	364	19	130	0	285	2	0	74	70	0	15	479
1978	791	1106	1545	303	0	0	0	0	109	1	258	304
1979	970	342	554	0	0	0	0	0	6	30	265	157
1980	927	903	243	22	0	0	20	0	0	0	0	281
1981	206	546	524	29	0	0	0	0	16	50	288	92
1982	528	47	469	187	0	0	0	0	140	76	462	260
1983	976	638	807	463	0	0	0	129	136	165	578	582
1984	0	4	9	23	0	0	0	78	176	79	338	500
1985	153	157	118	2	0	0	0	0	2	69	646	227
1986	478	1177	544	28	0	0	0	0	191	0	53	138
1987	212	314	473	9	0	9	7	0	0	204	68	530
1988	247	137	12	358	0	0	0	0	0	0	147	255
1989	131	240	77	22	20	0	0	0	0	53	32	0
1990	250	112	0	88	100	0	0	1	48	0	31	28
1991	147	376	863	3	0	61	0	0	0	28	21	429
1992	205	774	588	0	0	0	46	0	0	91	1	468
1993	970	563	340	0	0	38	9999	9999	9999	9999	9999	9999

Appendix D. Correlation Analysis Tables and Figures.

Correlations between stations were calculated for monthly precipitation, monthly mean temperature, monthly mean relative humidity, and monthly wind speed.

These are shown in the following tables and graphs. Station abbreviations are as follows:

SCI – Santa Cruz Island RAWS, SRI – Santa Rosa Island RAWS, SBI – Santa Barbara Island RAWS, SCID – Santa Cruz Island Daily Historical from Main Ranch, LOM – Lompoc NWS Coop Station, SBA – Santa Barbara Airport, SBC – Santa Barbara NWS Coop Station, VEN – Ventura NWS Coop Station, OXN – Oxnard NWS Coop Station, LAX – Los Angeles Airport, LAD – Los Angeles Downtown NWS Coop Station, LGB – Long Beach Airport.

For each station pair, the top line gives the Pierson correlation coefficient, and the second line gives the number of years. Many of these are not statistically significant. This exercise is intended to discover the approximate degree of coherence in the time domain at monthly time scales.

Table D.1. Station records used for the correlation analysis are from within the following periods, with at least one month of data in starting and ending year. Some records such as Santa Barbara Island are very fragmented.

Station	**Precipitation**	**Temperature**	**Rel Humidity**	**Windspeed**
Santa Cruz Island RAWS	1990-2003	1990-2003	1990-2003	1990-2003
Santa Cruz Del Norte RAWS	1999-2003	1999-2003	1999-2003	1999-2003
Santa Rosa Island RAWS	1990-2003	1990-2003	1990-2003	1990-2003
Santa Barbara Island RAWS	1996-2003	1996-2003	1996-2003	1996-2003
Santa Cruz Main Ranch	1904-1993			
Lompoc NWS Coop	1950-2001	1950-2002		
Santa Barbara Airport	1941-2002	1941-2002		
Santa Barbara NWS Coop	1867-2002	1931-2002		
Ventura NWS Coop	1931-2002			
Oxnard NWS Coop	1931-2002	1931-2002		
Los Angeles Airport	1944-2002	1944-2002		
Los Angeles Downtown	1877-2002	1950-2002		
Long Beach	1958-2001	1958-2002		
Buoy 46025		1982-2003		1982-2003
Buoy 46053		1994-2003		1994-2003
Buoy 46054		1994-2003		1994-2003

Table D.2. Monthly total precipitation correlations for different month/season combinations. Number of years used is given below the correlation.

Site Precip.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Oct-Mar	Nov-Apr	Oct-Sep	Jul-Jun	Jan-Dec
SCI/SBA	0.94	0.74	0.82	0.87	0.19	0.61	0.89	1.00	0.42	0.55	0.86	0.94	0.76	0.92	0.92	0.85	0.90	0.90	0.91	0.91	0.83
	6	6	7	7	8	7	7	8	8	8	8	8	6	6	7	7	6	6	6	5	5
SCI/SBC	0.98	0.98	0.95	0.53	0.92	0.71	-0.28	0.93	0.40	0.59	0.98	0.96	0.94	0.89	0.74	0.78	0.96	0.95	0.97	0.97	0.84
	10	9	10	11	12	11	10	12	12	1	9	11	9	10	10	9	7	7	6	7	6
SCI/SBI	0.99	1.00	1.00	0.92	NA	-0.50	NA	NA	0.06	-0.35	1.00	1.00	1.00	0.00	-0.50	1.00	0.00	0.00	0.00	0.00	0.00
	3	2	2	4	3	3	3	3	3	3	3	4	2	1	3	2	1	1	0	0	1
SCI/VEN	0.88	0.97	1.00	0.65	0.76	0.88	0.29	0.45	0.75	0.83	0.97	1.00	0.95	0.93	-0.22	0.79	0.97	0.96	0.99	0.99	-1.00
	6	6	5	6	7	5	6	8	7	8	6	6	5	5	5	5	4	4	3	3	2
SRI/LOM	0.98	0.72	0.76	0.85	0.98	-0.26	0.32	0.20	0.52	0.81	0.85	0.93	0.83	0.76	-0.37	0.66	0.87	0.84	0.87	0.87	0.68
	11	11	11	11	12	11	11	12	11	10	12	12	11	11	11	10	9	11	8	8	9
SRI/SBC	0.99	0.79	0.80	0.92	0.94	0.68	-0.12	0.82	0.54	0.85	0.73	0.87	0.83	0.76	0.47	0.52	0.82	0.80	0.84	0.83	0.63
	12	11	12	12	13	12	11	13	12	11	11	12	11	12	11	9	8	10	7	7	8
SRI/OXN	0.97	0.80	0.89	0.97	0.98	0.49	0.15	0.45	0.75	0.90	0.69	0.91	0.84	0.91	-0.18	0.61	0.84	0.84	0.82	0.85	0.68
	11	12	12	12	13	12	12	12	11	10	12	12	11	12	11	10	10	11	8	9	8
SRI/SBA	0.90	0.94	0.68	0.97	0.82	0.60	0.85	0.89	0.70	0.95	0.90	0.92	0.82	0.77	0.65	0.83	0.81	0.81	0.81	0.90	0.71
	7	7	8	7	8	8	8	8	8	7	8	8	7	7	8	6	6	7	6	5	5
SRI/SCI	0.97	0.73	0.92	0.64	0.92	0.62	0.90	0.87	0.37	0.78	0.76	0.93	0.74	0.86	0.83	0.66	0.77	0.77	0.79	0.79	0.63
	11	10	10	11	12	11	11	12	12	11	11	12	10	10	11	10	8	9	8	7	8
SRI/VEN	0.78	0.91	0.95	0.93	0.90	0.67	0.24	0.46	0.67	0.91	0.70	0.98	0.97	0.93	-0.31	0.30	0.97	0.97	1.00	1.00	0.97
	8	8	6	7	8	6	7	9	7	7	8	7	7	6	6	6	5	6	3	3	3
SRI/LGB	0.93	0.82	0.71	0.91	0.84	0.46	0.35	0.87	-0.27	0.82	0.62	0.75	0.75	0.66	-0.01	0.36	0.73	0.72	0.73	0.72	0.57
	11	11	11	11	12	11	11	12	11	10	12	12	11	11	11	10	9	11	8	8	9
SRI/LAD	0.87	0.81	0.80	0.88	0.93	0.39	0.54	-0.02	-0.06	0.92	0.66	0.70	0.74	0.78	-0.02	0.51	0.75	0.76	0.76	0.76	0.69
	12	12	12	12	13	12	12	13	12	11	13	13	12	12	12	11	10	12	9	9	10
SRI/LAX	0.92	0.82	0.85	0.93	0.94	0.36	0.84	0.09	-0.20	0.85	0.68	0.79	0.80	0.82	0.06	0.44	0.76	0.77	0.78	0.78	0.72
	12	12	12	12	13	12	12	13	12	11	13	13	12	12	12	11	10	12	9	9	10
SCD/LOM	0.83	0.88	0.79	0.91	0.94	0.41	0.07	0.60	0.66	0.66	0.85	0.80	0.84	0.84	0.66	0.78	0.87	0.88	0.88	0.87	0.91
	43	43	43	43	42	43	43	43	43	43	43	43	43	43	41	43	43	43	41	42	41

SCD/SBA	0.93	0.92	0.85	0.97	0.86	0.53	0.36	0.93	0.83	0.69	0.88	0.86	0.88	0.87	0.79	0.84	0.89	0.90	0.90	0.90	0.93
	52	52	52	52	52	52	52	52	52	52	52	52	52	52	51	52	52	52	51	52	51
SCD/SBC	0.90	0.89	0.85	0.93	0.88	0.70	0.12	0.58	0.78	0.79	0.90	0.88	0.88	0.86	0.60	0.82	0.89	0.90	0.89	0.89	0.91
	87	87	87	87	90	90	88	88	87	87	86	88	84	86	87	85	82	82	80	82	82
SCD/VEN	0.89	0.91	0.84	0.92	0.80	0.64	0.12	0.84	0.73	0.48	0.93	0.86	0.90	0.87	0.68	0.87	0.92	0.93	0.92	0.92	0.93
	62	62	61	61	61	60	60	61	60	61	61	59	59	61	60	60	59	59	58	58	59
SCD/OXN	0.96	0.92	0.90	0.95	0.91	0.39	0.02	0.85	0.73	0.88	0.95	0.84	0.92	0.92	0.67	0.91	0.94	0.94	0.93	0.93	0.95
	43	44	44	44	44	44	43	43	43	43	43	43	42	44	43	43	42	42	41	42	42
SCD/LGB	0.92	0.87	0.80	0.93	0.96	0.43	0.16	0.61	0.77	0.79	0.88	0.65	0.86	0.82	0.54	0.85	0.89	0.89	0.90	0.89	0.87
	35	35	35	36	36	36	35	35	35	35	35	35	35	35	35	35	35	35	34	35	34
SCD/LAD	0.84	0.83	0.82	0.88	0.76	0.57	0.25	0.66	0.33	0.65	0.83	0.71	0.83	0.83	0.48	0.75	0.83	0.84	0.83	0.82	0.85
	90	90	90	90	90	90	89	89	89	89	89	89	89	90	89	89	89	89	88	89	89
SCD/LAX	0.93	0.91	0.83	0.92	0.93	0.58	0.71	0.76	0.80	0.55	0.65	0.63	0.86	0.83	0.72	0.63	0.85	0.87	0.87	0.86	0.81
	49	49	49	49	49	49	48	49	49	49	49	49	49	49	48	49	49	49	48	48	48

Table D.3. Monthly mean temperature correlations for different month/season combinations. Number of years used is given below the correlation.

Site Mean Temp.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Oct-Mar	Nov-Apr	Oct-Sep	Jul-Jun	Jan-Dec
SCI/OXN	-0.30	0.65	0.59	0.70	0.90	0.74	0.39	0.28	0.53	0.45	0.55	0.49	0.13	0.79	0.47	0.54	-0.09	-0.01	0.42	-0.08	0.43
	10	10	10	11	12	11	10	11	11	11	11	12	10	10	9	10	9	9	7	7	7
SCI/LOM	0.183	0.66	0.53	0.61	0.73	0.5	0.29	-0.11	0.37	0.27	0.56	0.29	0.2	0.695	0.17	0.4	-0.197	-0.033	0.241	-0.041	0.165
	10	10	10	11	12	11	10	12	12	12	11	12	10	10	10	11	9	9	8	7	8
SCI/SBA	0.36	0.52	0.57	0.62	0.62	0.77	0.61	0.10	-0.59	0.27	0.16	-0.43	0.00	0.67	0.49	-0.46	-0.55	-0.34	0.12	-0.22	-0.06
	6	6	7	7	8	7	7	8	8	8	8	8	6	6	7	7	6	6	6	5	5
SCI/SBC	0.65	0.93	0.84	0.85	0.88	0.87	0.76	0.50	0.53	0.13	0.75	0.70	0.93	0.93	0.71	0.67	0.64	0.80	0.56	0.75	0.87
	10	9	10	11	12	11	9	12	12	12	9	11	9	10	9	9	7	7	5	6	5
SCI/SBI	0.00	0.00	0.00	1.00	1.00	-1.00	0.00	-1.00	-0.99	1.00	0.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	1	1	1	2	2	2	1	2	2	2	1	2	1	1	1	1	0	0	0	0	1
SCI/LGB	0.08	0.77	0.62	0.61	0.83	0.64	0.64	0.60	0.52	0.62	0.53	0.40	0.42	0.78	0.54	0.55	0.09	0.12	0.33	0.28	0.41
	10	10	10	11	12	11	10	12	12	12	11	12	10	10	10	11	9	9	8	7	8
SCI/LAX	-0.05	0.72	0.75	0.68	0.88	0.68	0.63	0.47	0.34	0.51	0.43	0.37	0.25	0.82	0.52	0.36	-0.12	0.09	0.27	0.10	0.30
	10	10	10	11	12	11	10	12	12	12	11	12	10	10	10	11	9	9	8	7	7
SCI/B53	0.46	0.45	0.62	0.59	0.61	0.43	0.54	0.68	-0.62	0.69	0.83	0.58	0.66	0.57	-0.19	-0.15	0.85	0.92	1.00	0.68	0.06
	6	5	5	6	7	7	6	7	6	6	6	7	4	5	6	6	3	3	2	3	4
SCI/B54	0.44	0.53	-0.03	0.32	0.60	-0.18	0.42	0.87	0.25	0.72	0.85	0.27	-0.74	-0.21	-0.26	0.09	-0.99	-1.00	1.00	0.00	0.41
	8	5	6	7	7	8	7	8	8	7	6	8	4	6	7	6	2	2	2	1	3
SRI/LOM	0.45	0.86	0.74	0.83	0.85	0.50	0.53	0.63	0.59	0.90	0.89	0.81	0.73	0.83	0.51	0.85	0.80	0.78	0.69	0.78	0.81
	11	11	11	11	13	12	12	13	12	10	13	13	11	11	12	10	8	10	7	7	7
SRI/SBC	0.23	0.88	0.88	0.85	0.85	0.64	0.52	0.90	0.42	0.81	0.75	0.69	0.52	0.95	0.49	0.82	0.92	0.74	0.90	0.88	0.76
	11	10	11	11	13	12	11	13	12	10	11	12	10	11	11	8	6	8	5	5	5
SCI/B25	0.45	0.23	0.03	0.57	0.81	0.68	0.61	0.53	-0.43	0.26	0.25	0.21	-0.07	0.56	0.62	-0.15	-0.55	-0.35	-0.24	-0.19	-0.42
	11	10	9	11	12	11	9	10	11	11	10	12	10	9	9	10	7	7	5	6	6
SRI/OXN	0.78	0.92	0.87	0.76	0.88	0.72	0.50	0.84	0.76	0.83	0.89	0.91	0.84	0.88	0.43	0.89	0.85	0.82	0.84	0.78	0.82
	11	11	11	11	13	12	12	12	11	9	13	13	11	11	11	9	8	10	6	7	6
SRI/SBA	0.45	0.74	0.62	0.72	0.69	0.66	0.55	0.82	-0.39	0.87	0.80	0.39	0.60	0.68	0.68	0.55	0.58	0.65	0.70	0.91	0.96
	6	6	7	6	8	8	8	8	8	6	8	8	6	6	8	5	4	5	4	3	3

Site Mean Temp.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Oct-Mar	Nov-Apr	Oct-Sep	Jul-Jun	Jan-Dec
SRI/SCI	0.61	0.75	0.67	0.72	0.85	0.75	0.54	0.61	0.63	0.67	0.68	0.38	0.24	0.89	0.63	0.68	0.80	0.66	0.78	0.55	0.11
	10	9	9	10	12	11	10	12	12	10	11	12	9	9	10	9	6	7	5	4	4
SRI/LGB	0.59	0.85	0.83	0.80	0.82	0.47	0.37	0.93	0.58	0.89	0.91	0.78	0.71	0.86	0.51	0.88	0.79	0.77	0.84	0.85	0.61
	11	11	11	11	13	12	12	13	12	10	13	13	11	11	12	10	8	10	7	7	7
SRI/LAD	0.88	0.90	0.93	0.81	0.85	0.50	0.59	0.89	0.33	0.95	0.91	0.57	0.84	0.88	0.54	0.81	0.90	0.91	0.96	0.98	0.85
	11	10	11	11	13	12	12	13	12	10	13	13	10	11	12	10	7	9	6	6	7
SRI/LAX	0.68	0.90	0.86	0.78	0.77	0.60	0.44	0.77	0.35	0.91	0.89	0.87	0.83	0.82	0.41	0.83	0.92	0.82	0.81	0.84	0.77
	11	11	11	11	13	12	12	13	12	10	13	13	11	11	12	10	8	10	7	7	7
SRI/B53	0.92	0.84	0.92	0.64	0.69	0.51	0.32	0.90	-0.84	0.83	0.92	0.57	0.83	0.80	0.17	0.05	0.89	0.88	0.85	0.82	-0.05
	7	6	6	6	8	7	7	8	6	6	8	8	6	6	7	6	3	5	3	3	4
SRI/B54	0.78	0.81	0.75	0.73	0.86	-0.16	0.54	0.81	0.28	0.84	0.97	0.54	0.50	0.76	0.34	0.27	0.83	0.76	1.00	1.00	0.62
	9	6	7	7	8	8	8	9	8	7	8	9	6	7	8	7	3	4	2	2	3
SBI/B25	1.00	0.99	0.59	0.96	0.92	0.95	-0.99	0.84	0.92	0.90	1.00	0.85	0.99	0.87	0.79	-1.01	1.00	1.00	0.00	0.00	-0.98
	3	3	3	3	3	3	3	3	3	3	2	3	3	3	3	2	2	2	1	1	2
B25/B53	0.98	0.95	0.97	0.99	0.89	0.86	0.78	0.96	0.77	0.83	0.82	0.84	0.92	0.94	0.87	0.74	0.93	0.95	0.91	0.93	0.91
	8	7	7	7	8	8	8	8	7	7	8	8	6	7	8	7	5	6	5	5	7
B54/B53	0.96	0.96	1.00	0.97	0.76	0.42	0.86	0.91	0.99	1.00	0.96	0.97	0.95	0.97	0.69	0.97	1.00	0.98	0.69	0.99	0.94
	8	5	6	6	7	8	8	8	7	7	8	8	4	6	8	7	3	4	3	3	5
B25/B54	0.95	0.87	0.93	0.80	0.71	0.26	0.69	0.84	0.80	0.79	0.79	0.84	0.89	0.78	0.47	0.78	0.78	0.85	0.81	0.75	0.90
	10	7	8	8	8	9	8	8	8	8	8	9	6	8	8	8	5	5	4	5	6

Table D.4. Monthly mean wind speed correlations for different month/season combinations. Number of years used is given below the correlation.

Site Mean Wind Speed	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Oct-Mar	Nov-Apr	Oct-Sep	Jul-Jun	Jan-Dec
SCI/B25	0.16	0.30	0.83	0.09	0.46	0.45	-0.10	0.23	-0.34	0.05	0.60	0.16	-0.02	0.23	-0.04	0.20	0.18	0.45	0.40	0.17	-0.30
	11	10	9	11	12	11	10	11	11	11	10	12	10	9	10	10	7	7	6	7	7
SCI/B53	0.89	0.56	0.63	0.65	0.33	0.54	0.55	0.36	0.75	0.82	0.91	0.80	0.74	0.72	0.76	0.88	0.98	0.83	0.94	0.97	0.55
	6	5	5	6	7	7	7	7	6	6	6	7	4	5	7	6	3	3	3	3	5
SRI/B25	0.64	0.84	0.39	-0.19	0.81	0.63	0.02	0.04	-0.01	0.77	0.64	0.49	0.81	0.46	0.23	0.83	0.70	0.72	0.84	0.72	0.76
	13	12	10	11	13	12	11	12	11	10	12	13	12	10	11	10	7	9	5	6	8
SRI/B53	0.84	0.72	0.77	0.47	0.89	0.39	0.37	-0.26	-0.45	0.83	0.78	0.84	0.44	0.71	-0.34	0.74	-0.35	0.82	-0.90	-0.41	-0.11
	8	7	6	6	8	7	7	8	6	6	8	8	6	6	7	6	3	5	3	3	5
SRI/SCI	-0.06	0.46	0.77	0.36	0.47	0.39	0.56	0.75	0.10	0.05	-0.03	0.20	-0.12	0.82	-0.02	0.06	-0.19	-0.60	-0.16	0.64	0.72
	11	10	9	10	12	11	11	12	12	11	11	12	10	9	11	10	7	8	7	6	7
B53/B54	0.62	0.75	-0.08	-0.79	0.64	0.53	0.74	0.51	0.34	0.79	0.69	0.83	0.70	-0.16	0.77	0.62	-0.40	0.14	0.49	0.78	0.59
	8	5	5	6	7	8	8	8	7	7	8	8	4	5	8	7	3	4	3	3	5

Table D.5. Monthly mean relative humidity correlations for different month/season combinations. Number of years used is given below the correlation.

Site Mean RH	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	DJF	MAM	JJA	SON	Oct-Mar	Nov-Apr	Oct-Sep	Jul-Jun	Jan-Dec
SRI/SCI	0.81	0.78	0.89	0.33	0.43	0.22	-0.06	0.37	0.50	0.73	0.74	0.84	0.66	0.67	-0.10	0.61	0.91	0.59	0.27	-0.24	-0.18
	10	9	9	10	12	11	11	12	12	10	10	11	9	9	11	9	6	7	6	5	5

Figure D.1. Selected monthly total precipitation correlations by month, from Table D.2

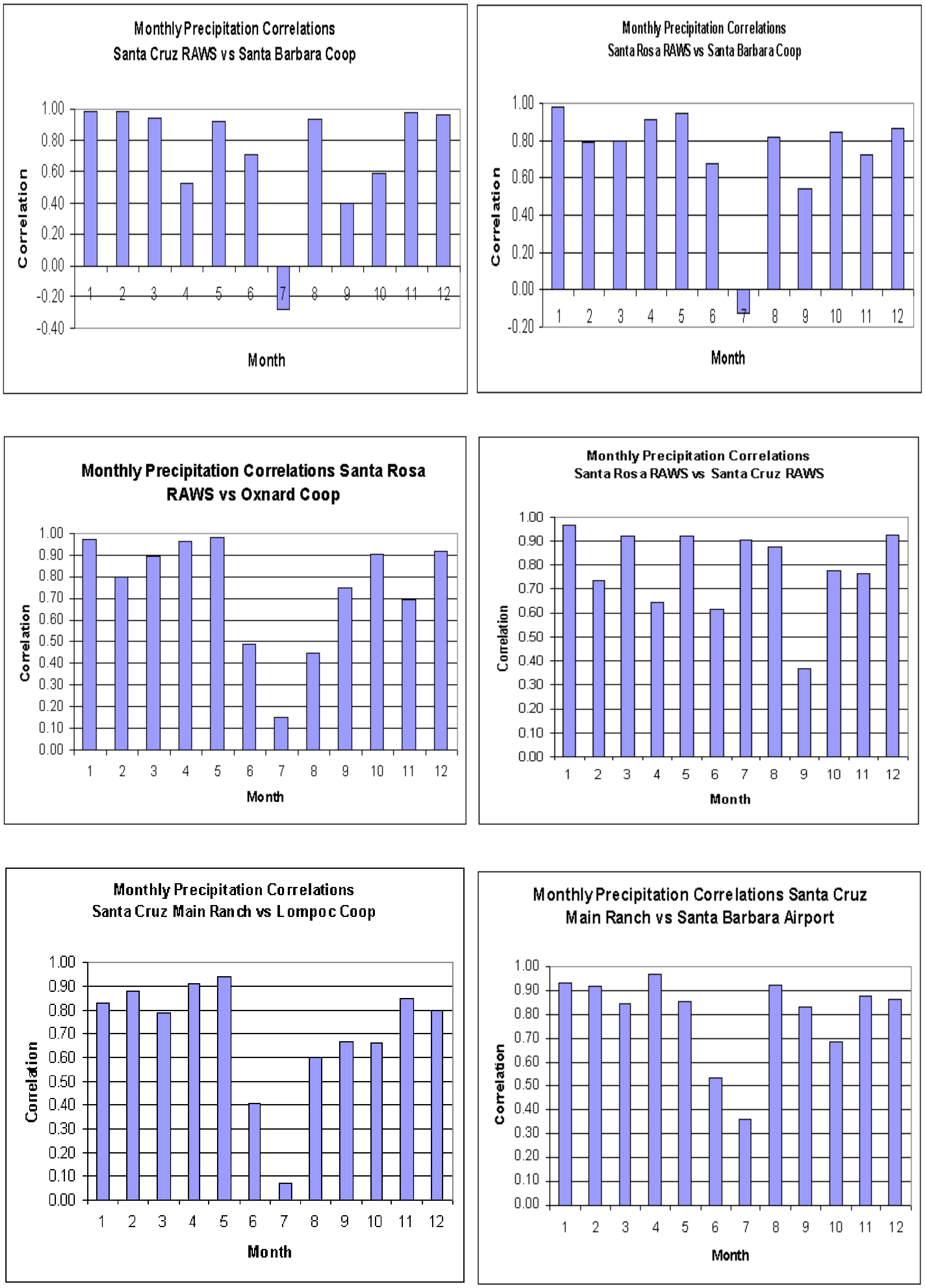
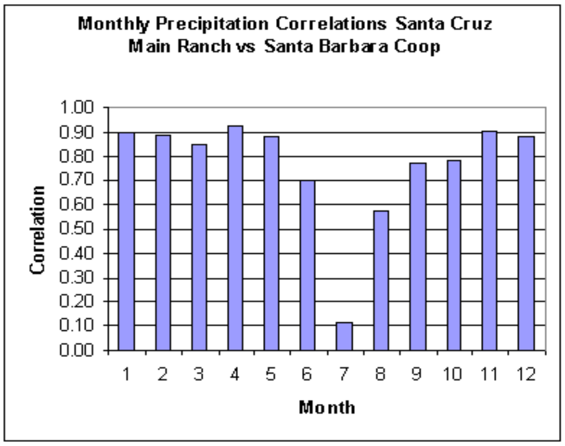
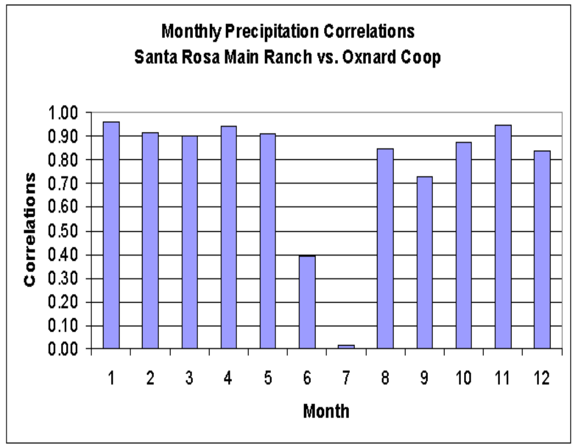
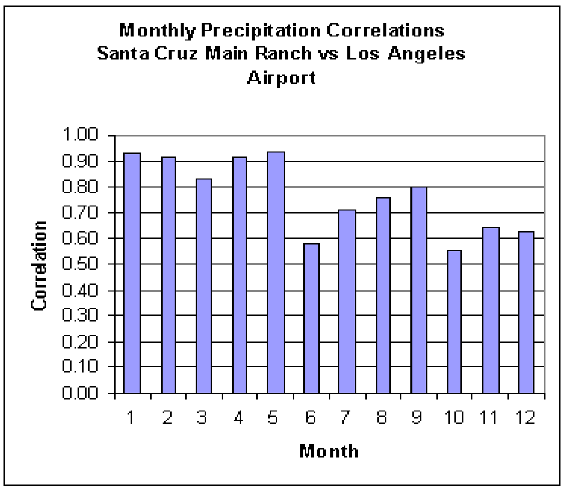
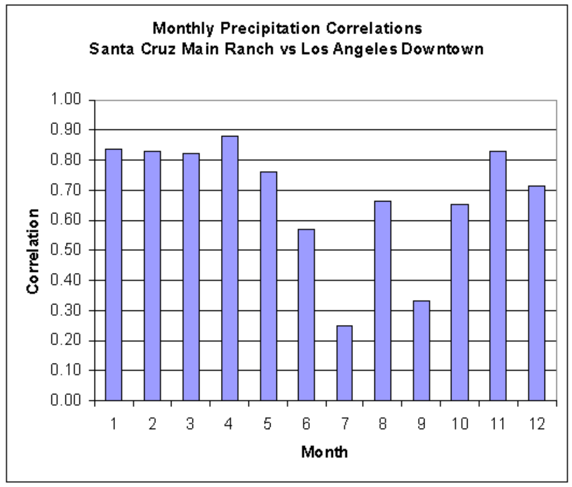


Figure D.1, continued. Selected monthly total precipitation correlations by month, from Table D.2









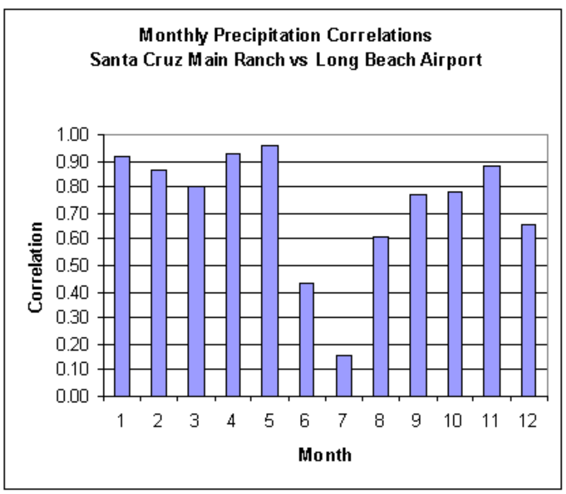


Figure D.2. Selected monthly mean temperature correlations by month, from Table D.3

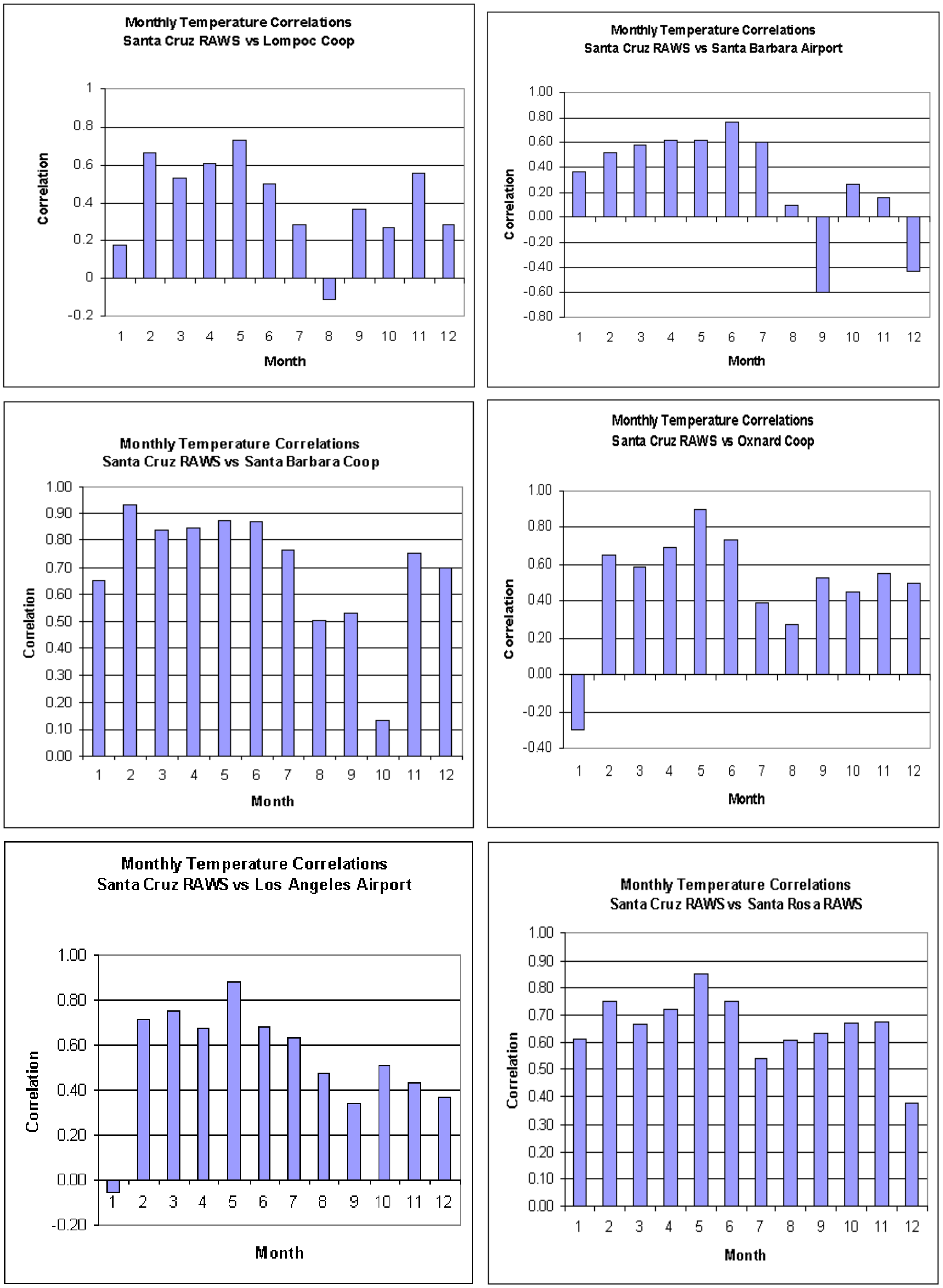


Figure D.2, continued. Selected monthly mean temperature correlations by month, from Table D.3

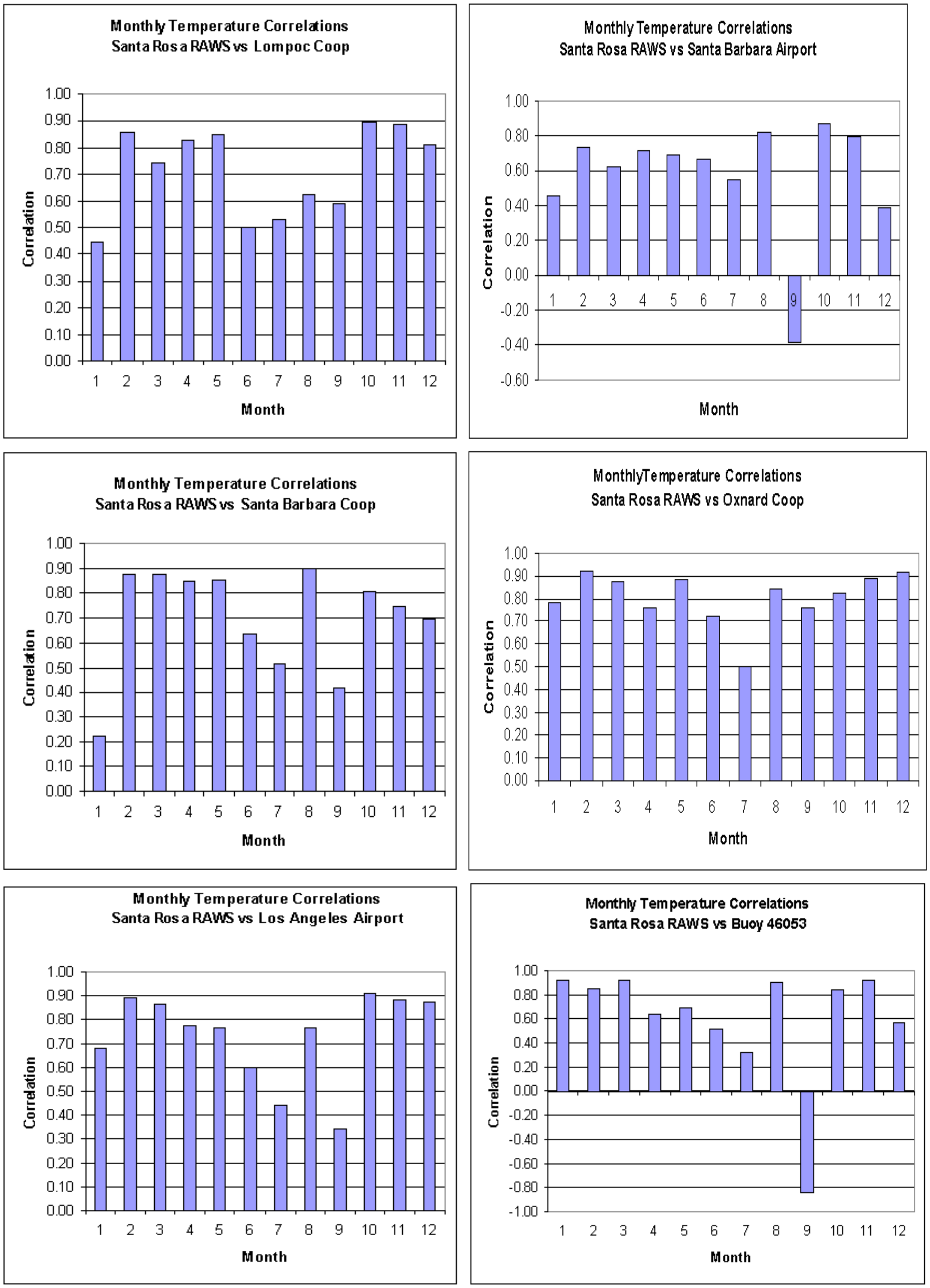


Figure D.2, continued Selected monthly mean temperature correlations by month, from Table D.3

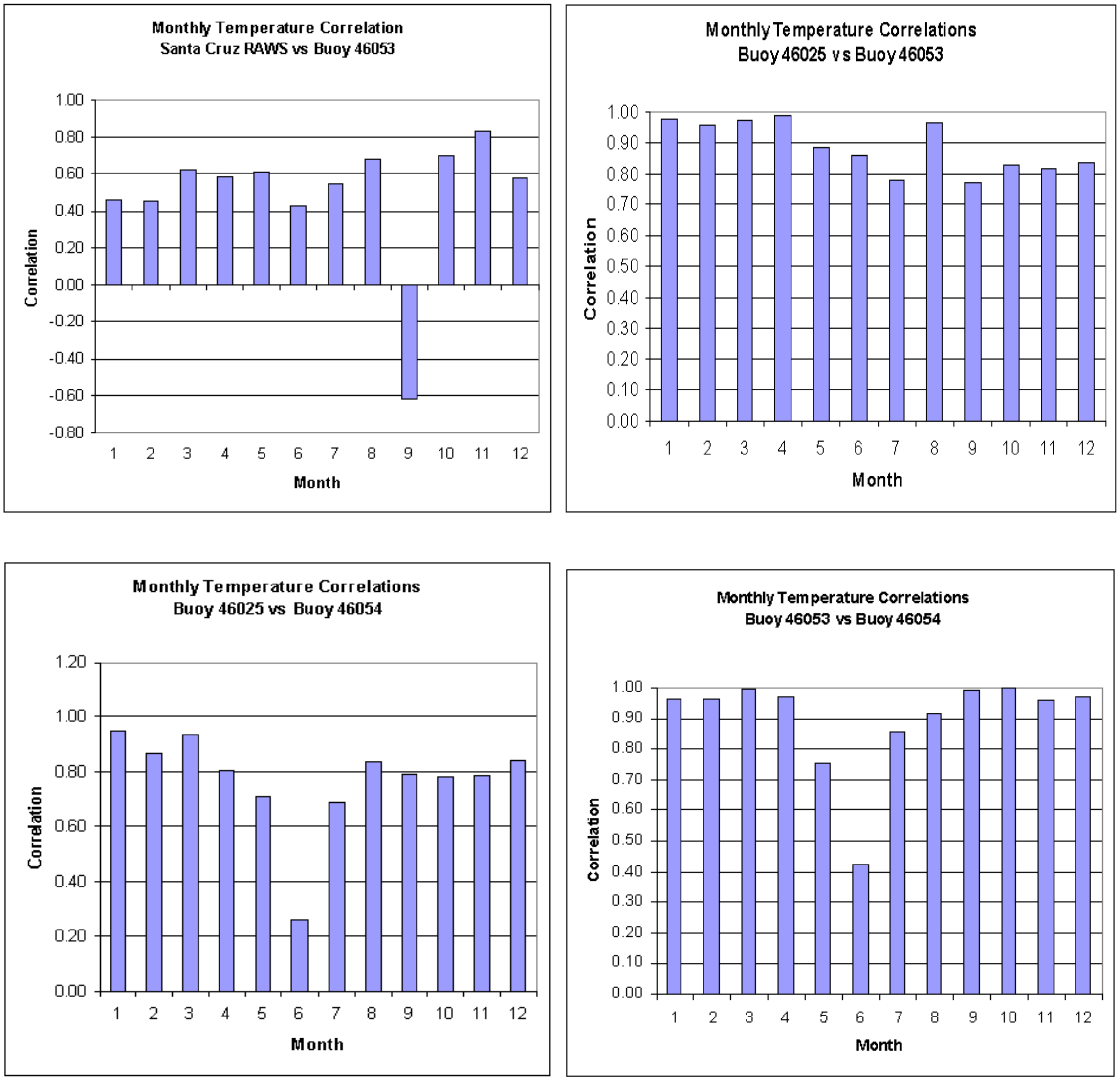


Figure D.3. Selected monthly mean wind speed correlations by month, from Table D.4

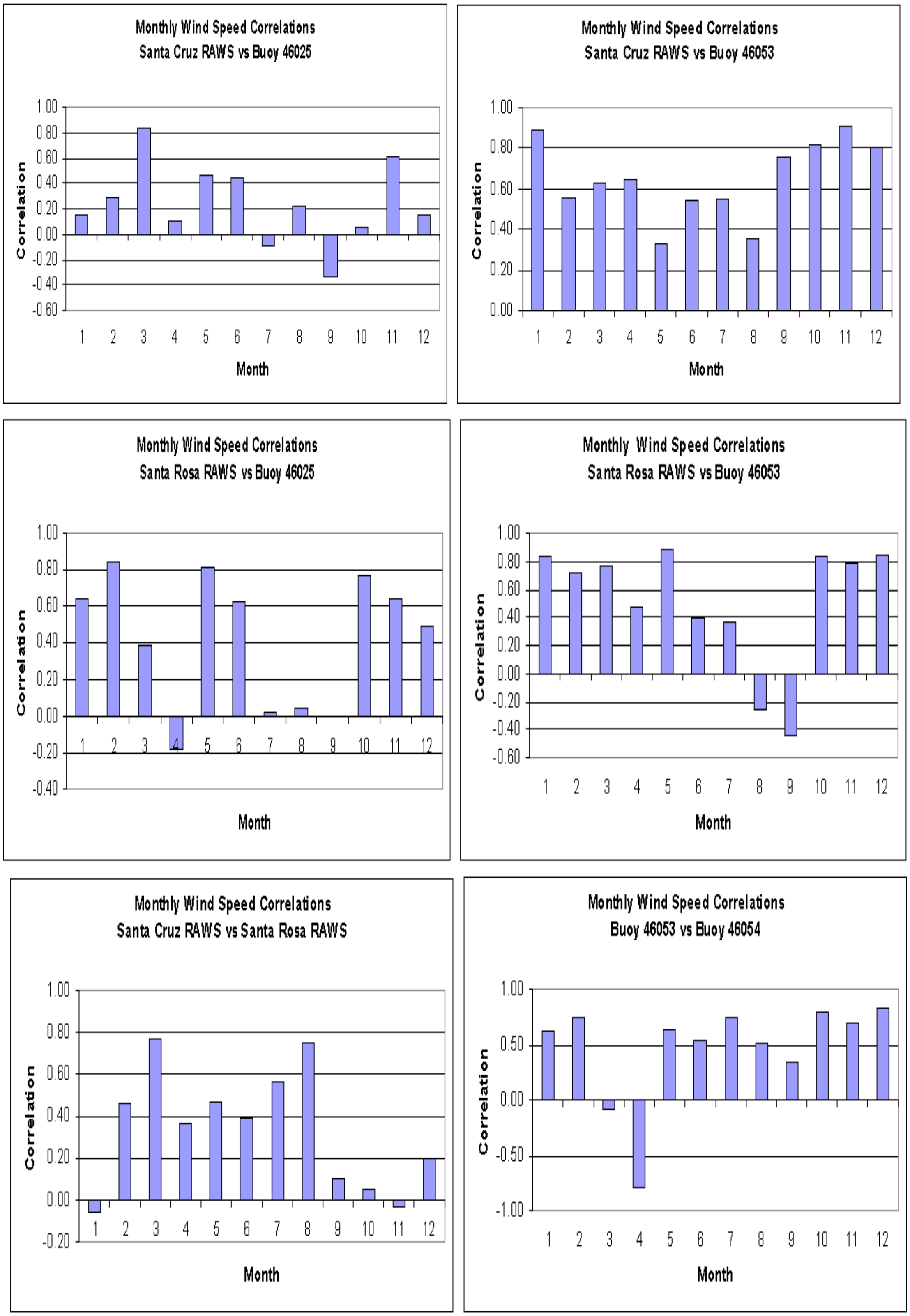
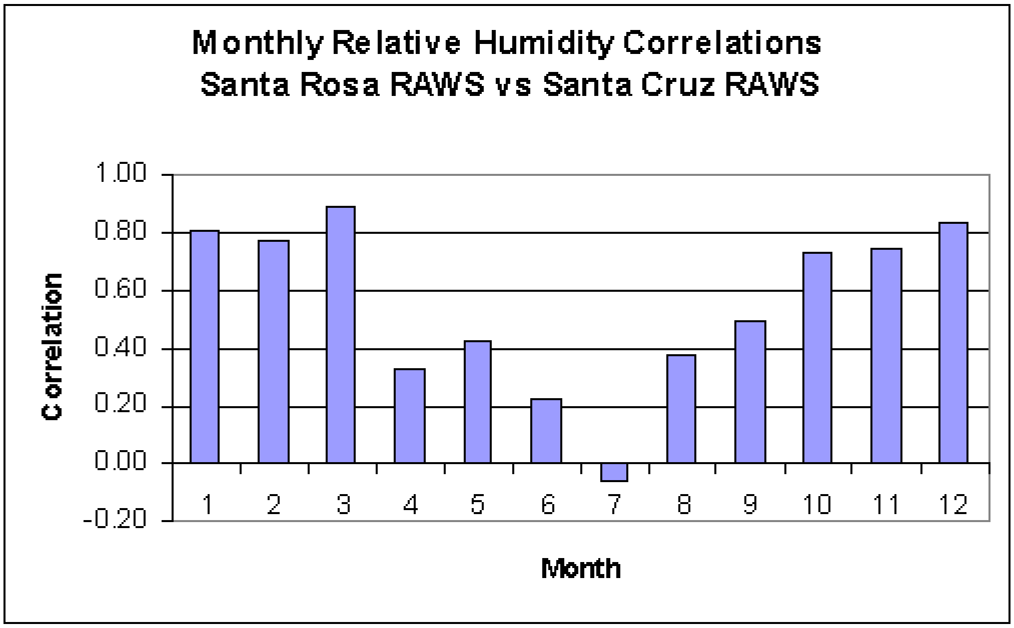


Figure D.4. Selected monthly mean relative humidity correlations by month, from Table D.5



Appendix E. Ten Principles for Climate Monitoring

Ten Principles for Climate Monitoring

Since the late 1990s, frequent references have been made to a set of climate monitoring principles enunciated in 1996 by Tom Karl, director of the NOAA National Climatic Data Center in Asheville North Carolina. In many quarters they have also been informally referred to as the "Ten Commandments of Climate Monitoring". Both versions are given here. Collated by Kelly Redmond, Western Regional Climate Center, Desert Research Institute, August 2000.

<u>Cliff's Notes version. "Ten Commandments of Climate Monitoring"</u>

1. Assess the impact of new observing systems or changes to existing systems prior to implementation.

> "Thou shalt properly manage network change." (Assess effect of proposed changes.)

2. Require a suitable period of overlap for new and old observing systems.

> "Thou shalt conduct parallel testing." (Of old and replacement systems.)

3. Treat the results of calibration, validation, algorithm changes, and data homogeneity assessments with the same care as the data.

> "Thou shalt collect metadata." (Full documentation of system and operating prodecures.)

4. Ensure a capability for routine assessments of quality and homogeneity, including high resolution data for extreme events.

> "Thou shalt assure data quality and continuity." (Assess as part of routine operating procedures.)

5. Integrate assessments, like those of the International Panel on Climate change, into global observing priorities.

> "Thou shalt anticipate use of the data." (e.g., integrated environmental assessment; anticipate data use as part of operating system plan.)

6. Maintain long-term stations.

> "Thou shalt worship historical significance." (Maintain long term observing systems which provide homogeneous data sets.)

7. Put a high priority on increasing observations in data-poor regions and regions sensitive to change and variability.

"Thou shalt acquire complementary data." (New sites to fill in observational gaps.)

8. Provide network operators, designers, and instrument engineers with long-term requirements at the outset of the design and implementation phases of new systems.

"Thou shalt specify climate requirements." (Designers of networks be aware of monitoring requirements for climate usage.)

9. Think through the transition from research observing systems to long-term operations carefully.

"Thou shalt have continuity of purpose." (Stable, long-term commitments.)

10. Focus on data management systems that facilitate access, use, and interpretation of weather data and metadata.

"Thou shalt provide data and metadata access."

<u>From Karl et al 1996. Full version:</u>

1. The effects on the climate record of changes in instruments, observing practices, observation locations, sampling rates, etc. must be known prior to implementing such changes. This can be ascertained through a period of overlapping measurements between old and new observing systems or sometimes by comparison of the old and new observing systems with a reference standard. Site stability for in-situ measurements, both in terms of physical location and changes in the nearby environment, should also be a key criterion in site selection. Thus, many synoptic network stations, primarily used in weather forecasting but which provide valuable climate data, and all dedicated climatological stations intended to be operational for extended periods, must be subject to such a policy.

2. The processing algorithms and changes in these algorithms must be well documented. Documentation of these changes should be carried along with the data throughout the data archiving process.

3. Knowledge of instrument, station and/or platform history is essential for data interpretation and use. Changes in instrument sampling time, local environmental conditions for in-situ measurements, and any other factors pertinent to the interpretation of the observations and measurements should be

recorded as a mandatory part of the observing routine and be archived with the original data.

4. In-situ and other observations with a long uninterrupted record should be maintained. Every effort should be applied to protect the data sets that have provided long-term homogeneous observations. "Long-term" for space-based measurements is measured in decades, but for more conventional measurements "long-term" may be a century or more. Each element of the observations system should develop a list of prioritized sites or observations based on their contribution to long-term climate monitoring.

5. Calibration, validation and maintenance facilities are a critical requirement for long-term climateic data sets. Climate record homogeneity must be routinely assessed, and corrective action must become part of the archived record.

6. Where feasible, some level of "low-technology" backup to "high-technology" observing systems should be developed to safeguard against unexpected operational failures.

7. Data poor regions, variables and regions sensitive to change, and key measurements with inadequate spatial and temporal resolution should be given the highest priority in the design and implementation of new climate observing systems.

8. Network designers and instrument engineers must be provided long-term climate requirements at the outset of network design. This is particularly important because most observing systems have been designed for purposes other than long-term climate monitoring. Instruments must have adequate accuracy with biases small enough to document climate variations and changes.

9. Much of the development of new observation capabilities and much of the evidence supporting the value of these observations stem from research-oriented needs or programs. A lack of stable, long-term commitment to these observations, and lack of a clear transition plan from research to operations, are two frequent limitations in the development of adequate long-term monitoring capabilities. The difficulties of securing a long-term commitment must be overcome if the climate observing system is to be improved in a timely manner with minimum interruptions.

10. Data management systems that facilitate access, use, and interpretation are essential. Freedom of access, low cost, mechanisms which facilitate use (directories, catalogs, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.) and quality control should guide data management. International cooperation is critical for successful management of data used to monitor long-term climate change and variability.

Sources:

Thomas R. Karl, V.E. Derr, D.R. Easterling, C.K. Folland, D.J. Hoffman, S. Levitus, N. Nicholls, D.E. Parker, and G.W. Withee, 1996. Critical Issues for Long-Term Climate Monitoring. pp 55-92, in "Long Term Climate Monitoring by the Global Climate Observing System", T.R. Karl, ed, Kluwer, 518 pp.

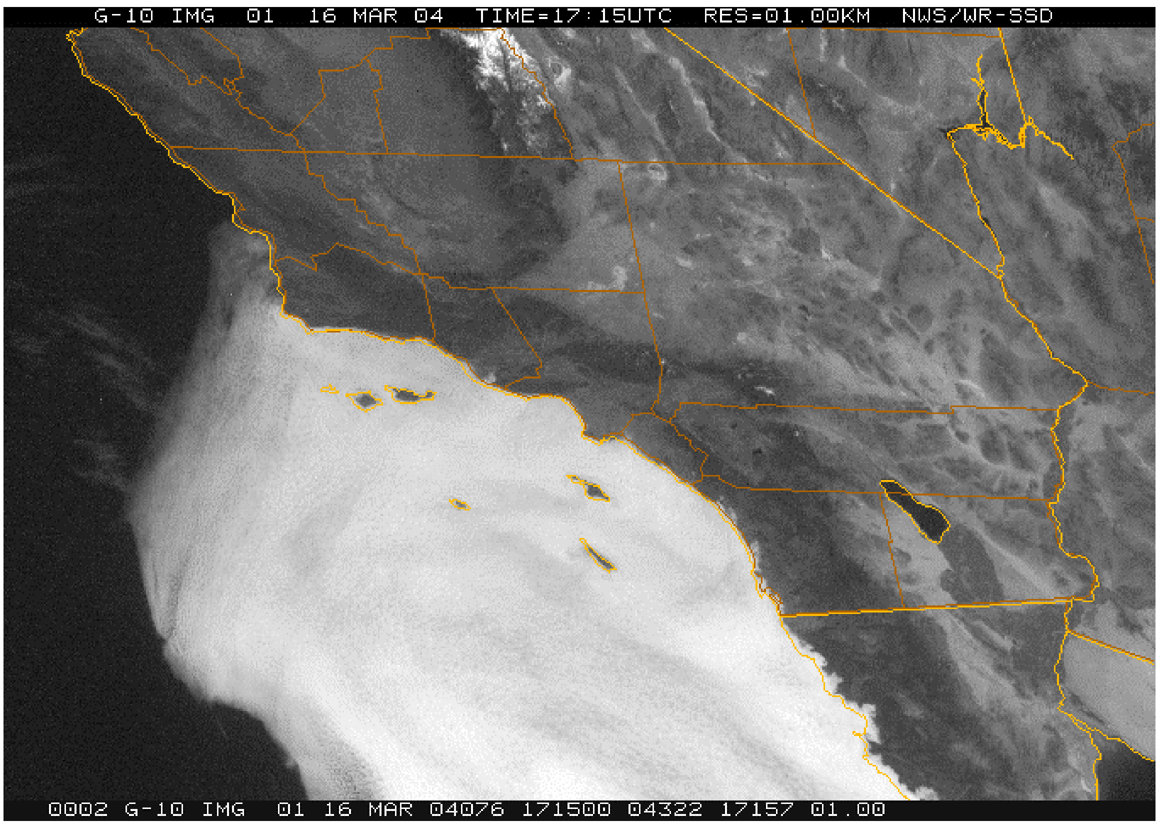
National Research Council, 1998. Guidelines and Principles for Climate Monitoring. Appendix F, p 63, in Future of the National Weather Service Cooperative Observer Network. National Academy Press, 65 pp.

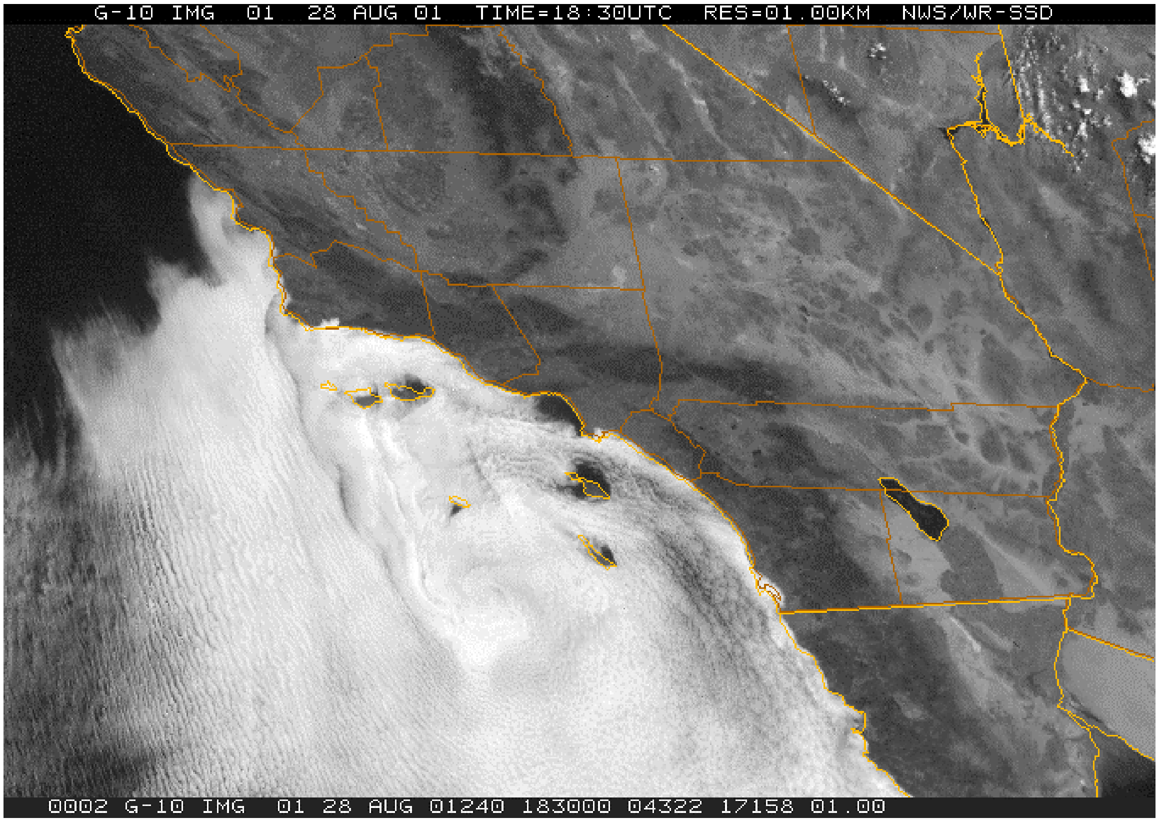
Eugene Rasmusson, 2000. Workshop notes. Climate Services: A vision for the future. NAS/NRC/BASC, Woods Hole MA.

Appendix F. A Gallery of Selected Satellite Photos of Channel Islands Meteorology / Cloud Patterns

These satellite photos are intended to illustrate just a small portion of the degree of diversity of cloud and meteorological patterns experienced by the Channel Islands. They also show that measurements from one island may be completely unrepresentative of what other islands are experiencing.

The date and time are shown on the bottom line. For example, the string
29 APR 04120 153000 is interpreted as
29th of April, 2004, 120th day of the year (Julian Day), 1530 Greenwich Mean Time (subtract 8 hours to obtain 0730 PST)

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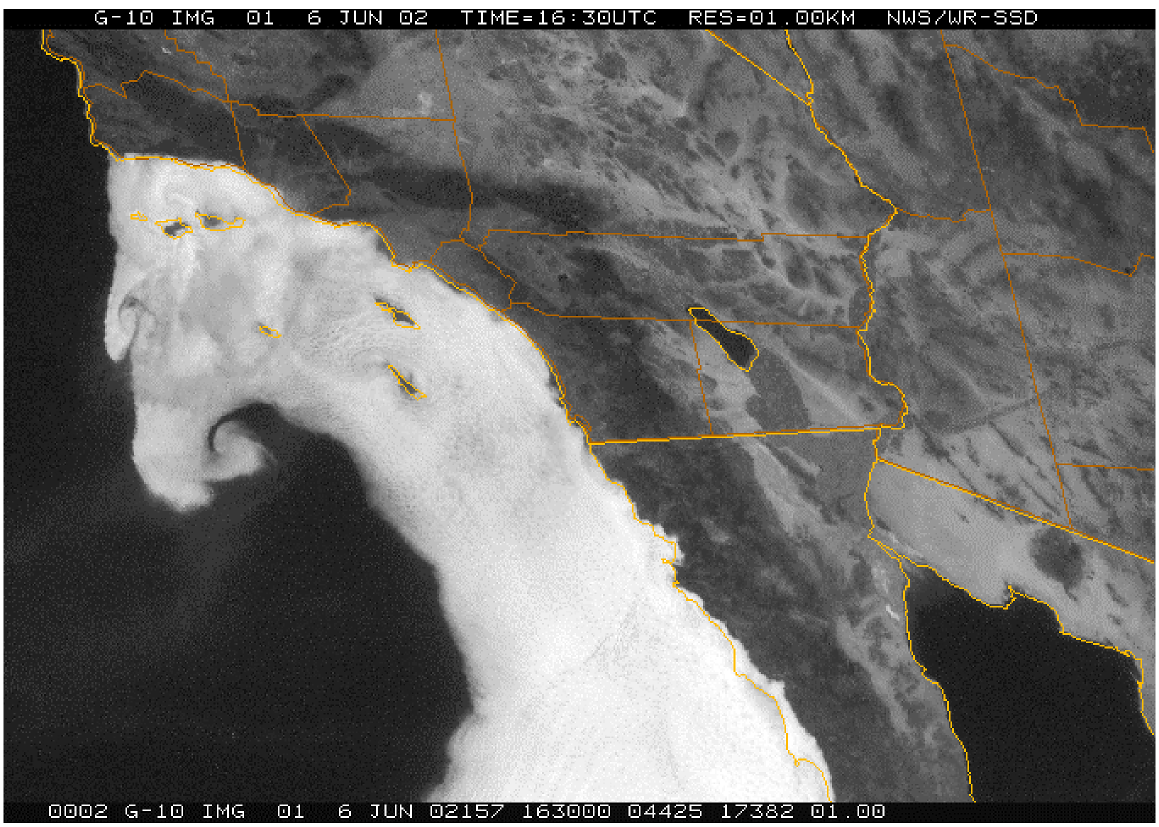
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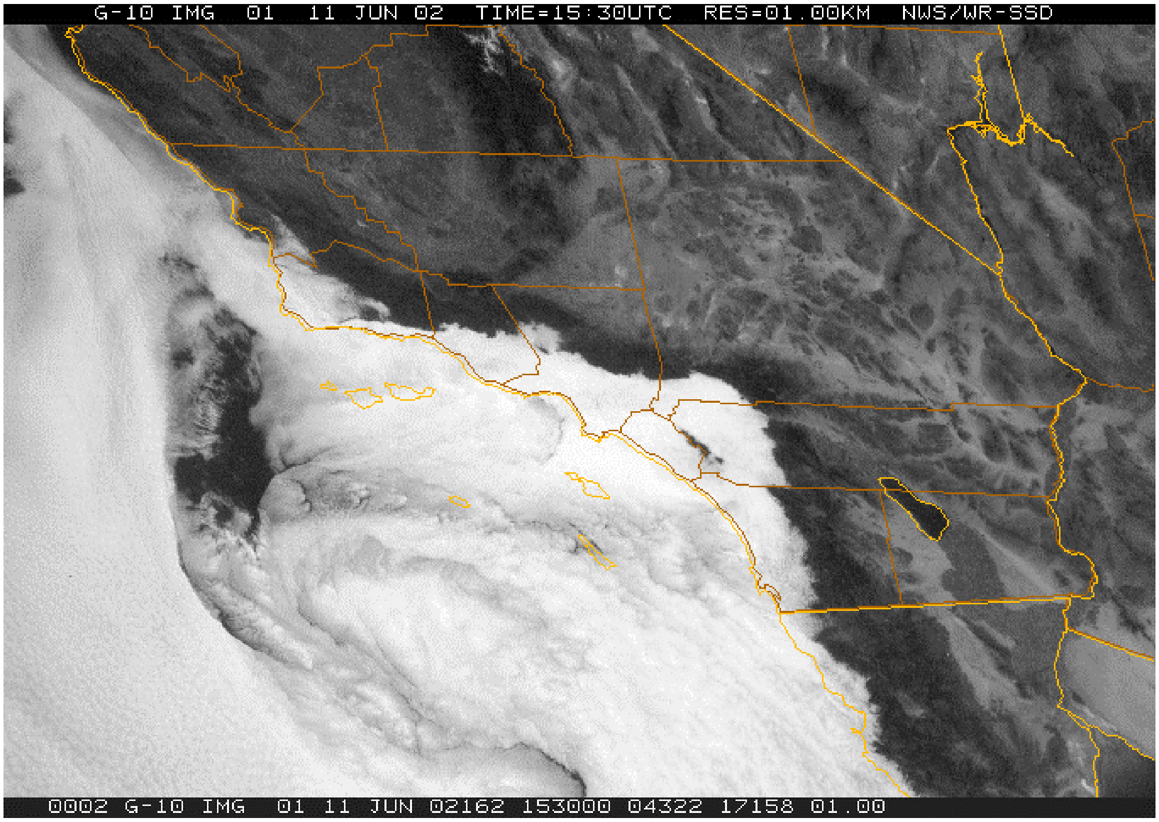
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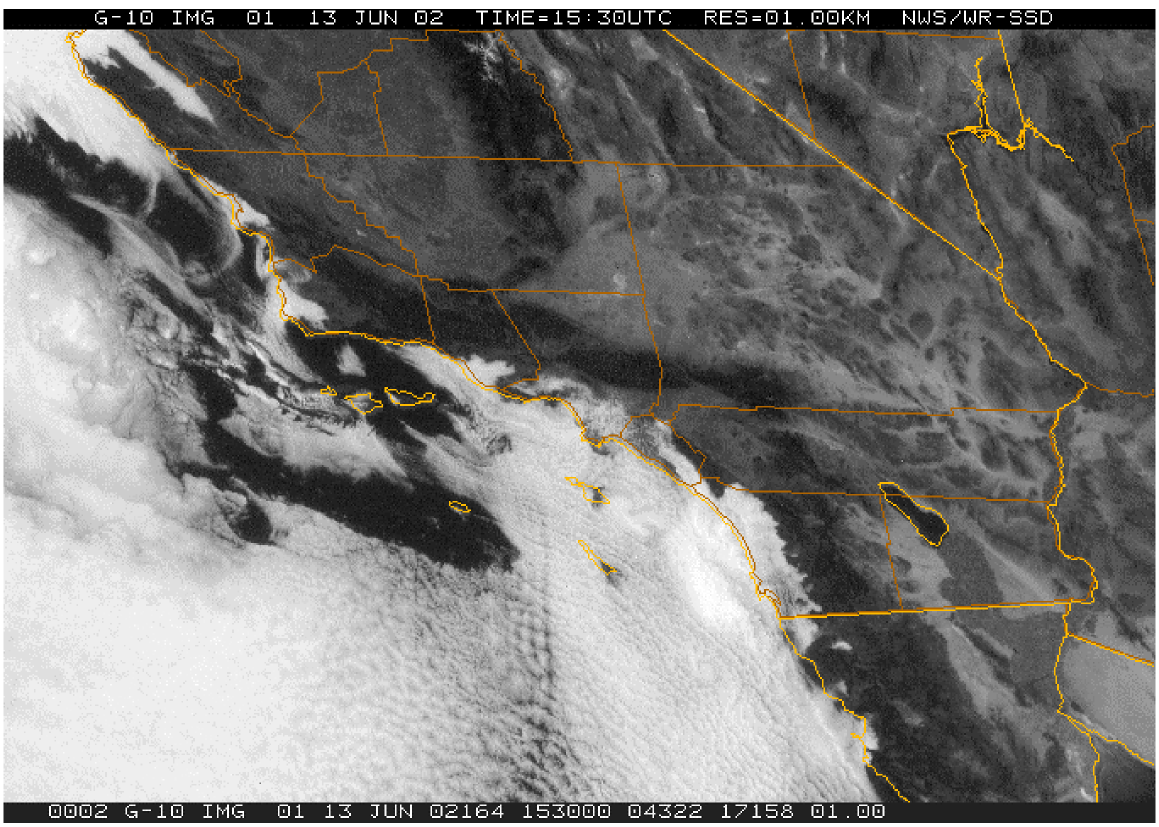
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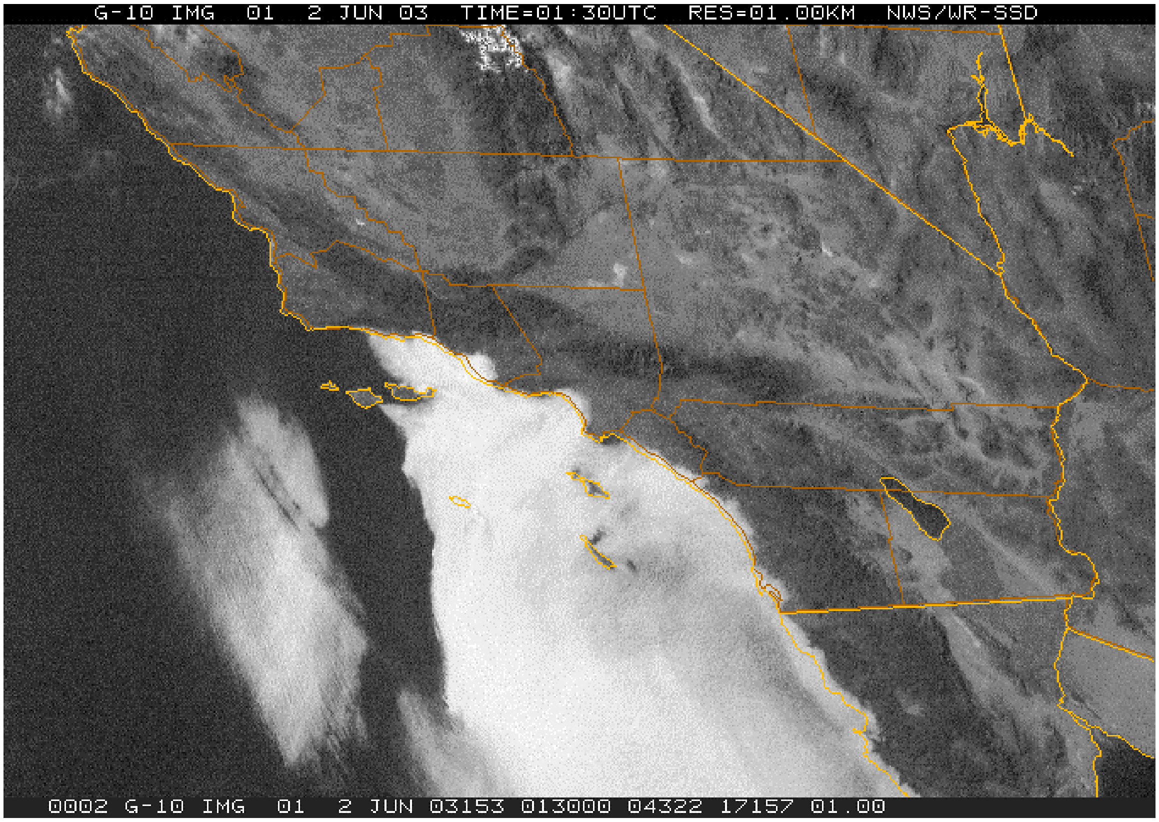
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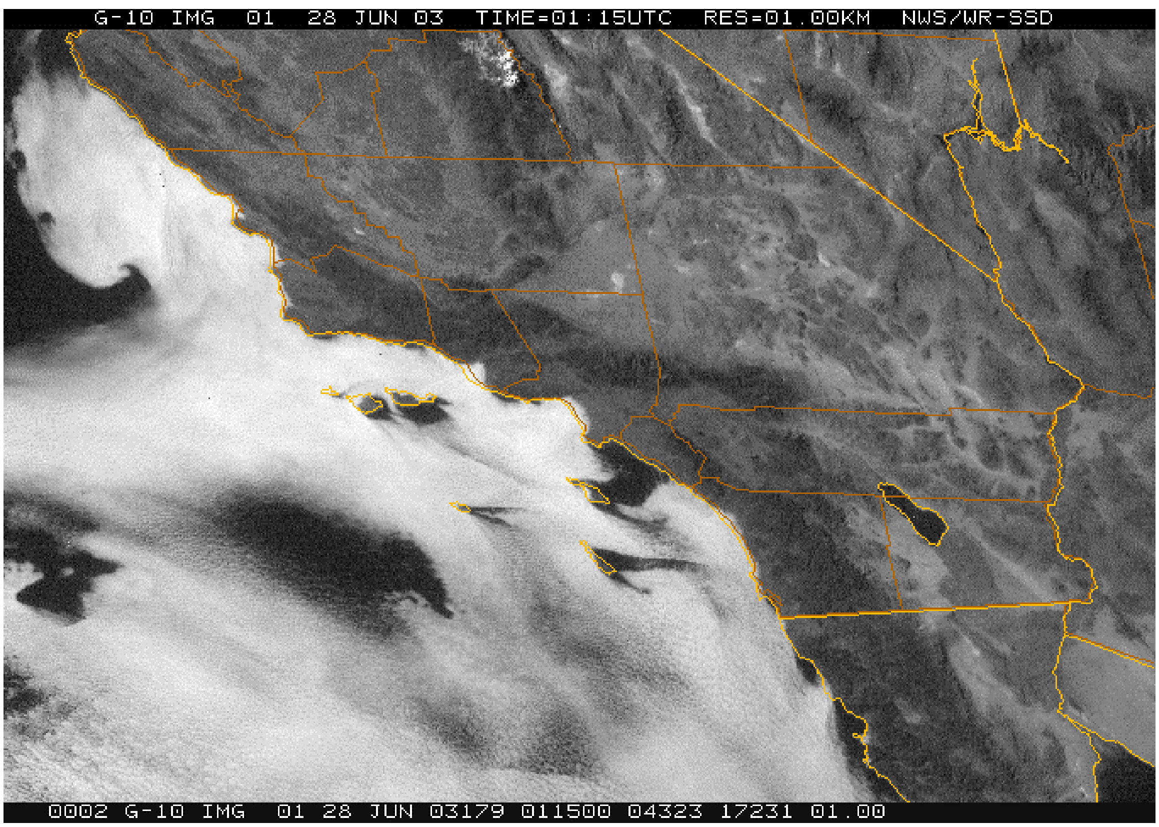
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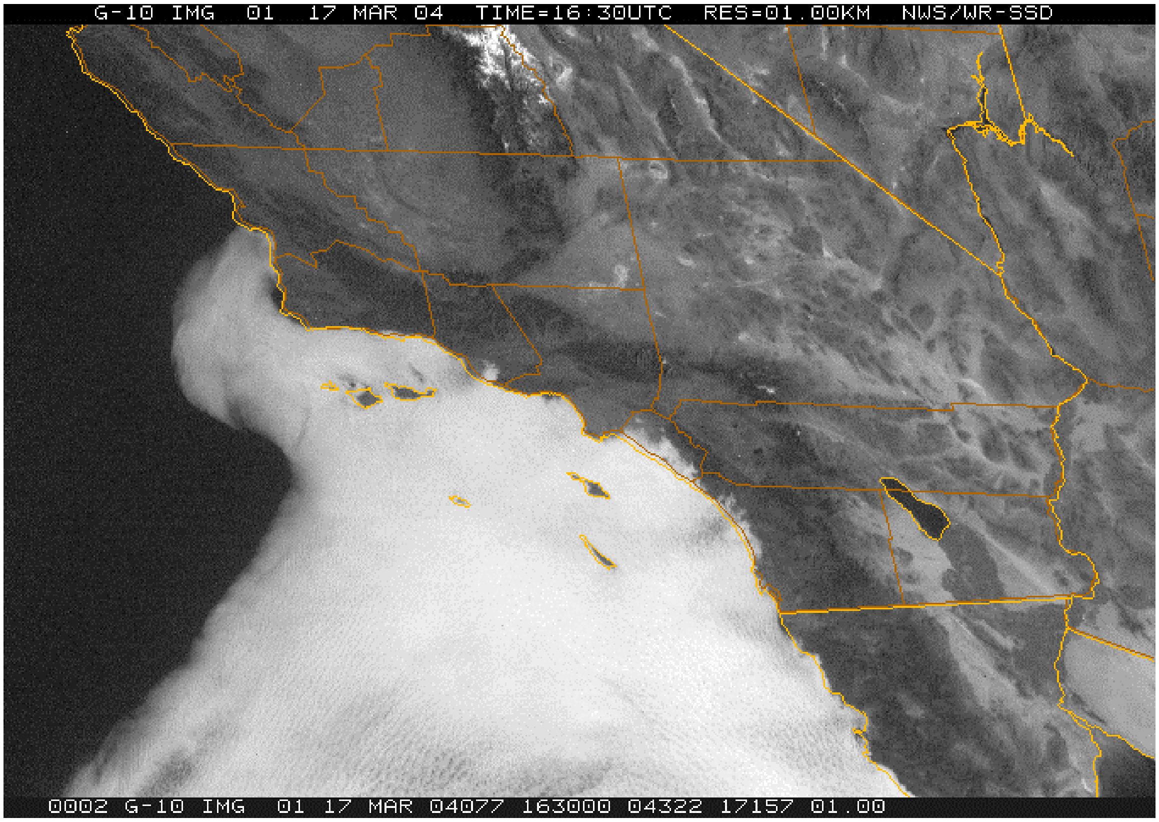
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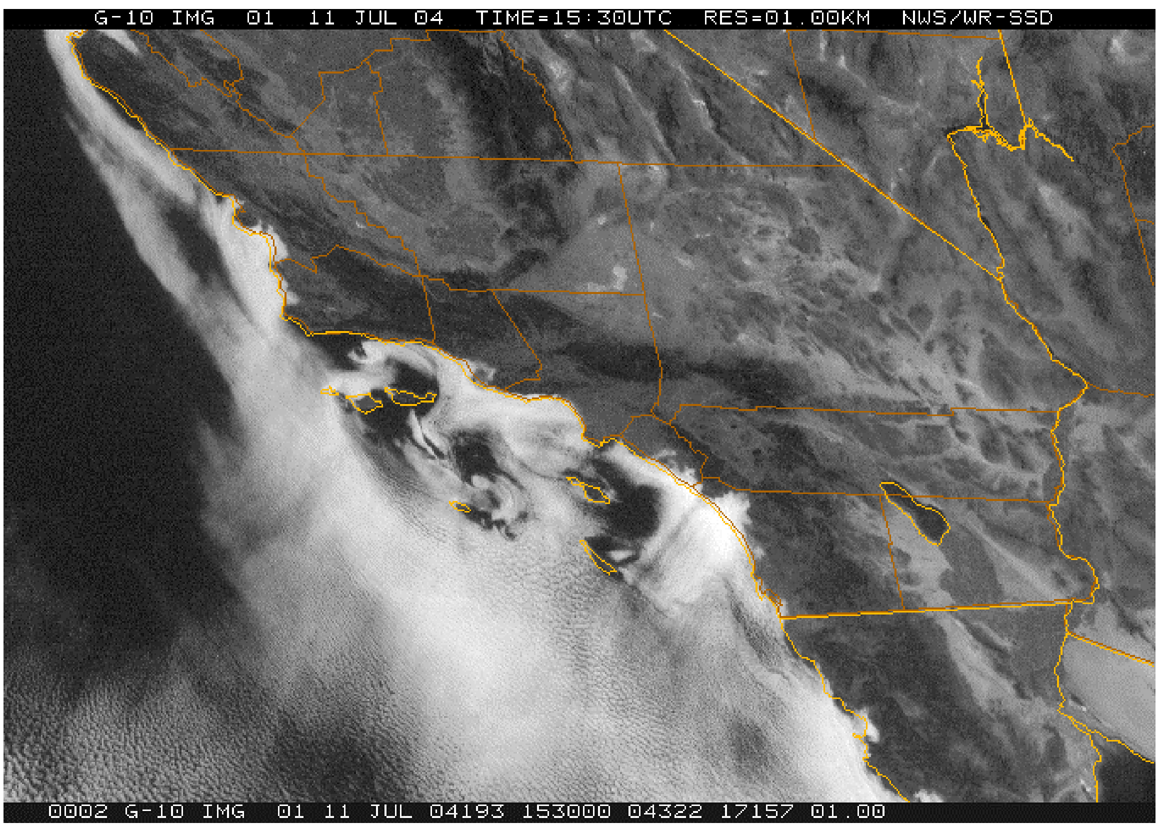
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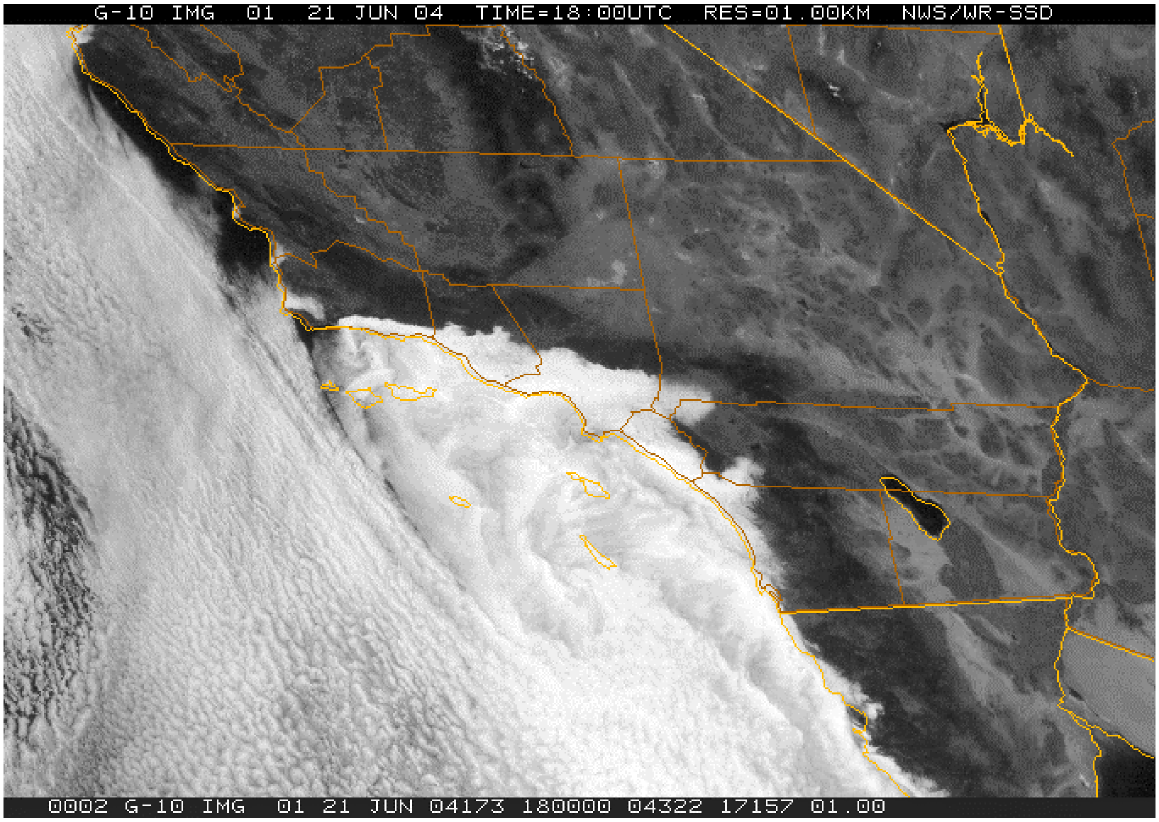
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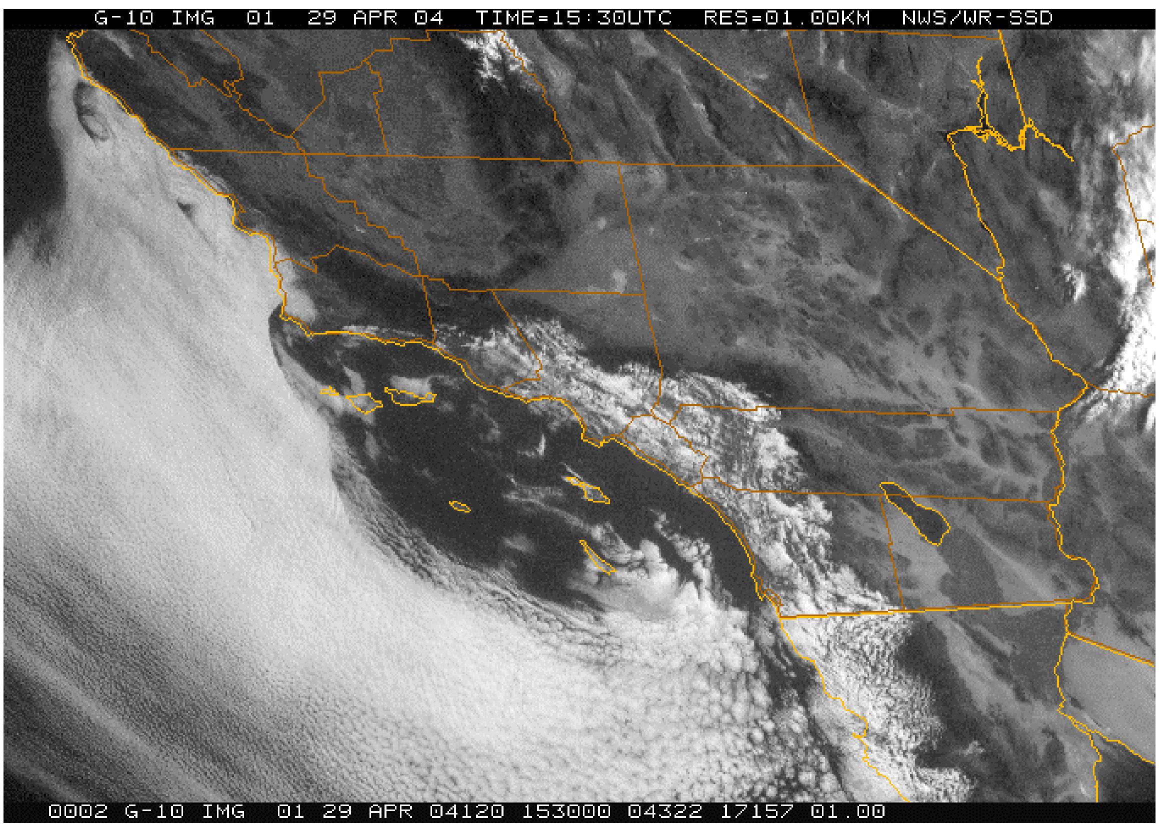
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Appendix G.

Photodocumentation of Climate Reference Network sites.

Prepared August 15, 2004, by Kelly Redmond, Western Regional Climate Center, Desert Research Institute, Reno Nevada.

Slides adapted from a presentation in Powerpoint.

This is based on many years behind a camera, and on the experience of documenting several hundred potential sites for the NOAA Climate Reference Network program from 2001 through 2005. About 35-40 sites visited were in national parks of the western United States.

Photographic Documentation of Long-Term Climate Stations

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Version 20040815

Why photo-documentation ?

- To leave a permanent archive record of site conditions
- Photos can be transmitted, mental images cannot
- Memories change, not always reliable
- To show relationships between instrumentation and the factors that affect what they observe and record
- To record the condition of instruments
- To record the setting at all scales
  - Within a few cm to a few m of the sensors
  - Within a few tens of meters
  - Within a few hundreds of meters
  - Within a few kilometers to tens of kilometers

What to record, in general:

Any factor relating to site conditions that could affect the interpretation of the historical climate sequence from this station.

The main purpose is to document conditions and relationships.

What to record (1)

<u>For all stations:</u>
Systematic views <u>of</u> a station over all azimuths all done in same manner
Systematic views <u>from</u> a station over all azimuths done in same manner
<u>Station dependent characteristics:</u>
Whatever is needed to record special circumstances

Almost every site has a bias arising from its situation
 We need to record such biases for posterity

Factors that can affect readings
Factors that can change with time

- **Status of vegetation**
- **Growth of vegetation**
- **Obstructions to wind, solar radiation**
- **Depth and condition of grass**
- **Height of vegetation that affects wind profile**
- **Death of vegetation from disease or fire**
- **Fire recovery**

What to record (2)

Factors that can affect readings and
Factors that can change with time (continued)

- **Vertical surfaces that emit infrared radiation, or bounce solar radiation**
    - **Building sides**
    - **Trees, forest canopy and trunks, and other vegetation**
    - **Rock walls and cliffs and canyons (within a mile or two)**
- **Intermittent or seasonal wetlands**
- **Surface conditions immediately adjacent to sensors**
    - **Rock, cobbles, grass, gravel, pavement, etc**
- **Health of vegetation**
- **Effects of artificial watering**
- **Nearby fields that are fallow one year, growing the next**
- **Nearby factors that change regional energy balances**
    - **Large scale agriculture**
    - **Pivot irrigation (operate some years, others not)**
    - **Trees within a quarter mile can affect sensible/latent fluxes**
    - **Growth or loss of vegetation**
    - **Addition of pavement**

What to record (3)

Factors that can affect readings and
Factors that can change with time (continued)

- **Orientation of instruments**
  - **Out of level (radiation, precipitation gages)**
  - **Loose clamps**
  - **Out of level temperature shielding plates**
- **Faded, discolored, darkened "white" surfaces**
- **Bird goop, dust, snow on top of transparent solar bubble**
- **Frost or condensation inside of transparent solar bubble**
- **Condition of precipitation gages**
  - **Presence or absence of shielding**
  - **Proximity to vegetative shielding**
  - **Overhanging vegetation**
  - **Insects and junk on screens**
  - **Insects, nests, on interior mechanisms**
- **Evidence of rodents chewing on cables**
- **Evidence of presence and activities of large animals**
  - **Scratching, tasting fluids, punctures, breakages**

What to record (4)

Factors that can affect readings and
Factors that can change with time (continued)

Topographic features that affect sensor readings

- **Slopes (hold camera exactly horizontal to show these)**
- **Small hollows and bumps**
- **Concave and convex upward surfaces**
- **Distance to**
  - **Cliff edges**
  - **Water surfaces**
  - **Nocturnal drainage channels (a meter is enough)**
  - **Canyon walls**
  - **Changes in slope above or below instruments**
  - **Wind channeling influences**

The primary purpose is to convey site information

… Scientific content takes precedence over artistic qualities

Many photographs expose for the sky at the expense of other portions of the image. Digital images do not always have the latitude (dynamic range of recorded brightness) of high quality slide film (eg, Kodachrome).

A common problem: The sky is properly exposed but instruments and their circumstances are dark or barely visible.

The sky is constantly varying and will be different on the next visit. Our interest is in the instruments and sensors. Whatever shows them in the best manner is the goal. A washed-out sky may not be pleasing, but if the desired object is correctly exposed, the purpose has been achieved.

Showing the same picture with two different image manipulations is perfectly acceptable. Just be sure to mention this.

Day-end lighting (morning/evening) shows subtle landscape variations best. However, azimuthal differences (into/away from sun) can be very pronounced. Early / late in the day, into the sun, important detail can be lost. In general, morning thru mid-day to afternoon lighting is best.

Cloudy days often have more uniform lighting.

Consider using familiar objects to show scale. Friends or visitors can suffice for this, but they will be immortalized for all time.

In general, use the widest angle lens setting available at all times, except for distance photos designed to compress distance and show spatial relationships. The best is the equivalent from a 35 mm film camera of a 28 mm focal length lens. These wide angles are not yet available on many digital cameras. Typically the best that is currently available is equivalent to a 35 mm focal length lens, a moderate wide angle.

A 35 mm focal length lens typically requires about 12 overlapping photos to pan around the horizon and back to the starting point.

The eight-point method will not yield overlaps, so it is important to keep track of directions. The best approach is to always take the photos in the same sequence, such as starting from north and working clockwise around the compass.

Take notes on paper or digital device to document the documentation process, special conditions, circumstances of note, etc.

Download to laptop daily, backup on second medium. It is helpful to carry a regular 35 mm film camera as backup.

Resolution:

With digital cameras, typically medium resolution is a good compromise. This results in photos that are about 250-300 Kb in .jpg format that can be enlarged somewhat.

High resolution can be useful for archive and further enlargement, but camera optics can become limiting, and email size. High resolution photos are often 600-1000 Kb or more, so that a full set can be 20-50 Mb.

Low resolution are sufficient for some purposes, but these can also be created with software by degrading from high/medium resolution.

Memory:

Enough to store 300-400 medium resolution images. A day's work will typically yield 100-200 photos.

Number for a standard set:

A typical site might require the basic 8 views, or 16 if two sets are taken (through and from the site), several panoramas side to side and some up-down, photos of specific instruments and their condition, ground surface and vegetation, and the overall setting. Total number is typically a minimum of about a dozen photos up to about 50 or 60, more for complex stations or settings. Time needed is 10-30 minutes.

Panoramas … a little more.

The term *panorama* here means an overlapping sequence of photos.

Although there are 8 main compass points, with typical focal length lenses (50 mm lens equivalent for 35 mm film) it generally takes about 12 pictures to make a complete 360-degree panorama.

This can be done, separately from a directionally-anchored panorama, by making sure that there is overlap from one from to the next (typically 5-15 percent of the frame width), so that it is clear that this is a panorama, and so that the sections can be adequately pieced together. It is helpful that the first and last picture overlap as well, to insure that the full circuit has been completed and to be able to reconstruct what you did many weeks or months later.

Panoramas can be side to side, or up and down, or both. These can later be combined to form mosaics, so that all of the main features relevant to how a sensor will respond can be shown at once.

Software exists to patch together pieces into a single image. This is nice, but might need a special viewer, or be hard to email easily.

The Setting

On the way in or out of the station location, find vantage points that illustrate the overall setting. Take panoramas if necessary. Use the widest angle lens available. Zoom in on the station location for one or two if this illustrates a feature of interest, or shows a spatial relation.

Photos of the setting can be taken from as close as 100-200 meters, but are often taken from distances of 1-10 miles. Be sure to situate yourself so that spatial relationships speak for themselves through the image. If you are driving out a different way than you arrive, consider stopping to record the setting from that vantage point. Often, just one or two vantage points will be very useful.

Try to record all relevant elements at once. For example, a river, a plowed field, a sagebrush alluvial fan, and a mountain slope, all in the same image containing the station of interest.

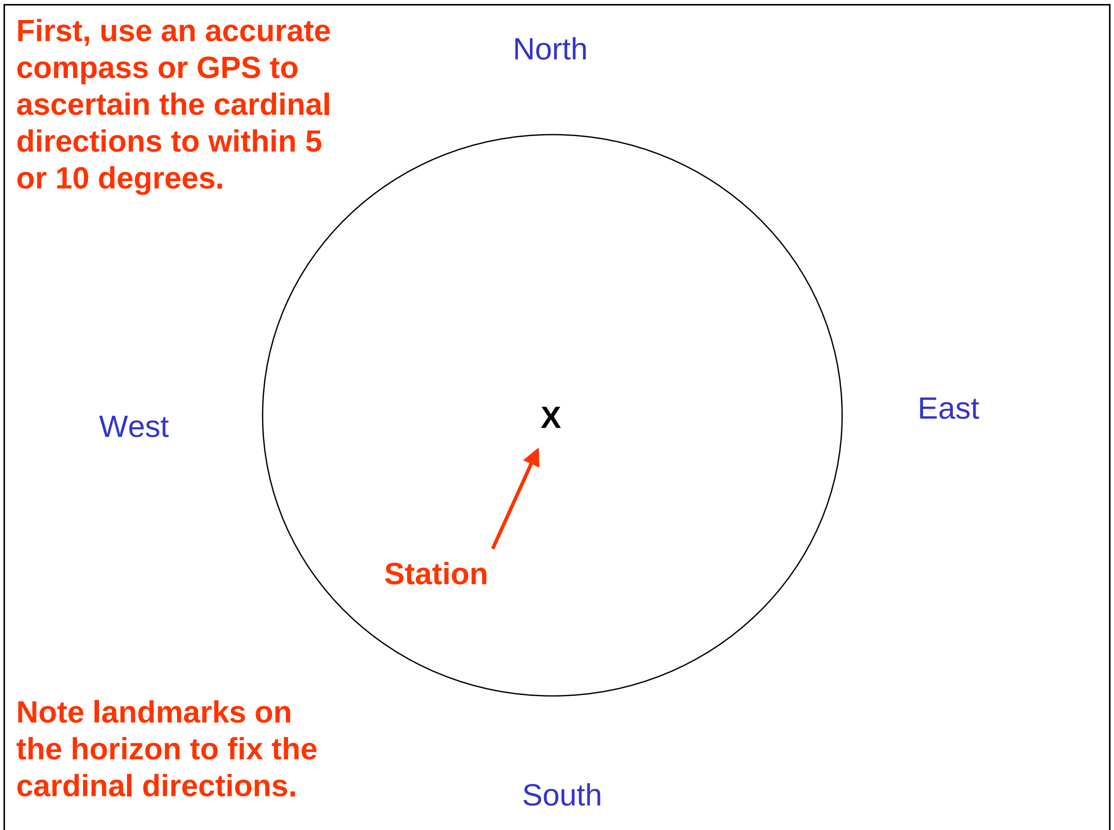
Photos of opportunity from commercial airline windows and small private planes or helicopters in the course of other business can be very helpful.

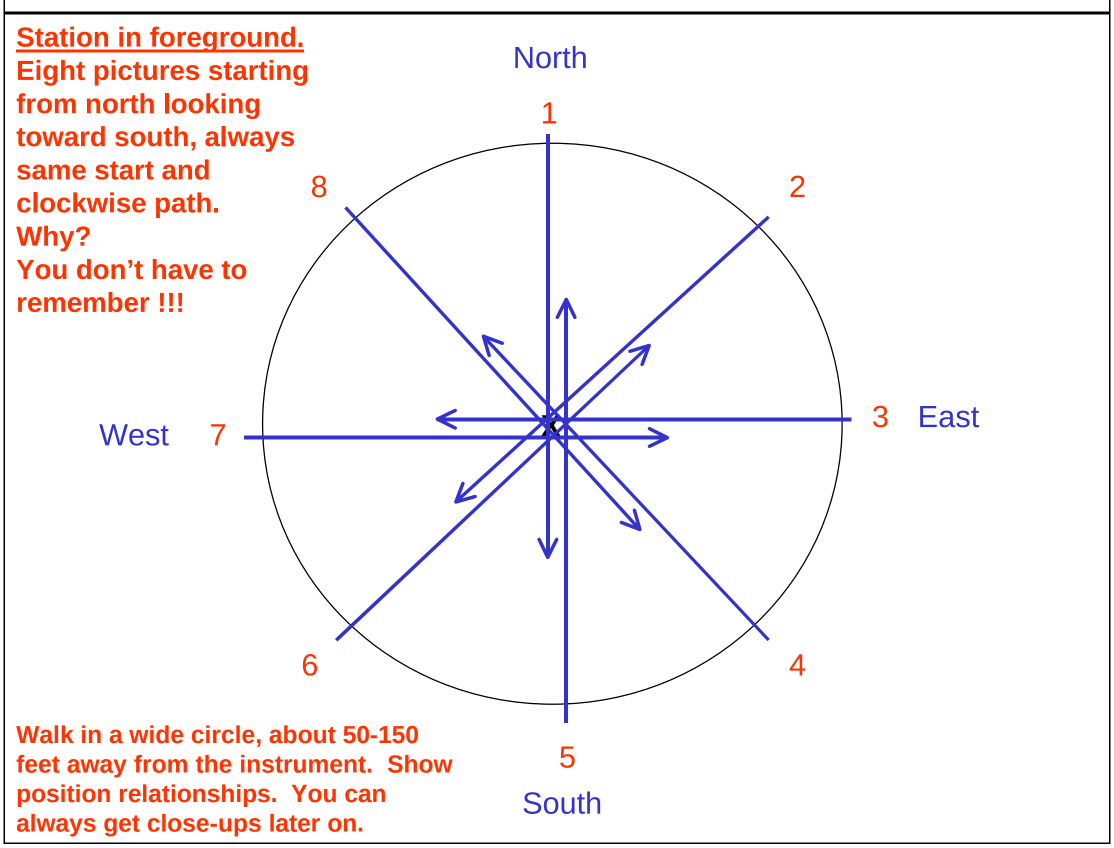
The Setting (2)

It is useful to show what can be seen from the site, in the surrounding area, and conversely, from where in the surrounding area the site can be seen.

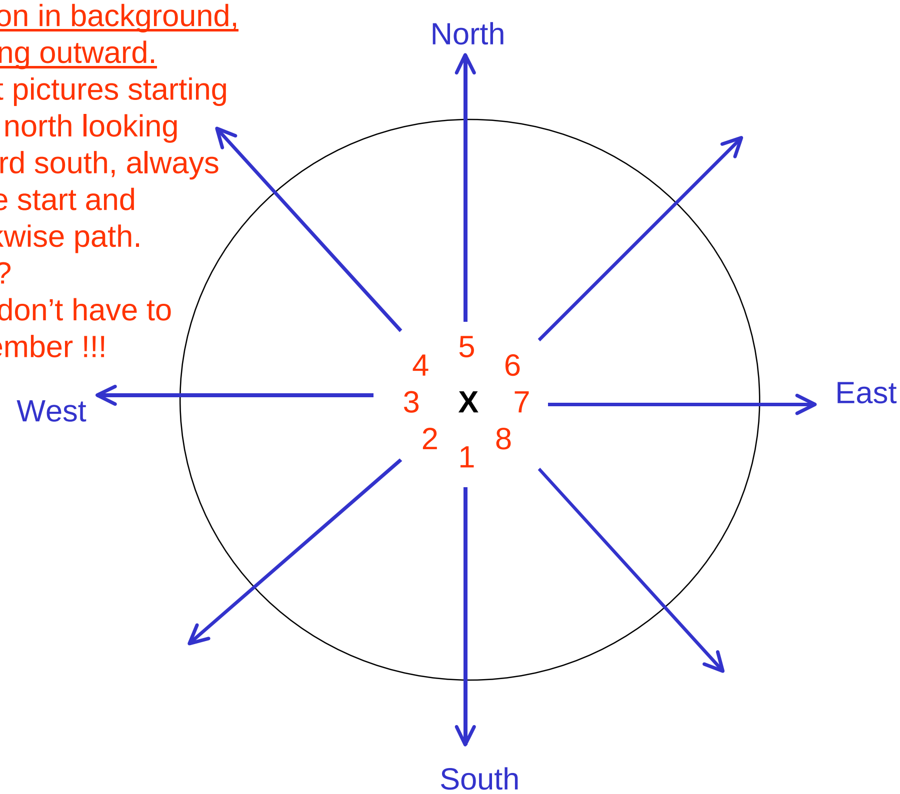
Also, there is more pressure to make sites less visible, for both aesthetics and to protect from vandalism. Use circles and arrows to point out sites that are hard to distinguish from the background. Some sensors must be visible: thermometer shielding must always be white, and anemometer cups and vanes will move and attract attention.

As a generality, the setting can be just as important as the station itself.


First, use an accurate compass or GPS to ascertain the cardinal directions to within 5 or 10 degrees.
North
West
X
East
Station
Note landmarks on the horizon to fix the cardinal directions.
South

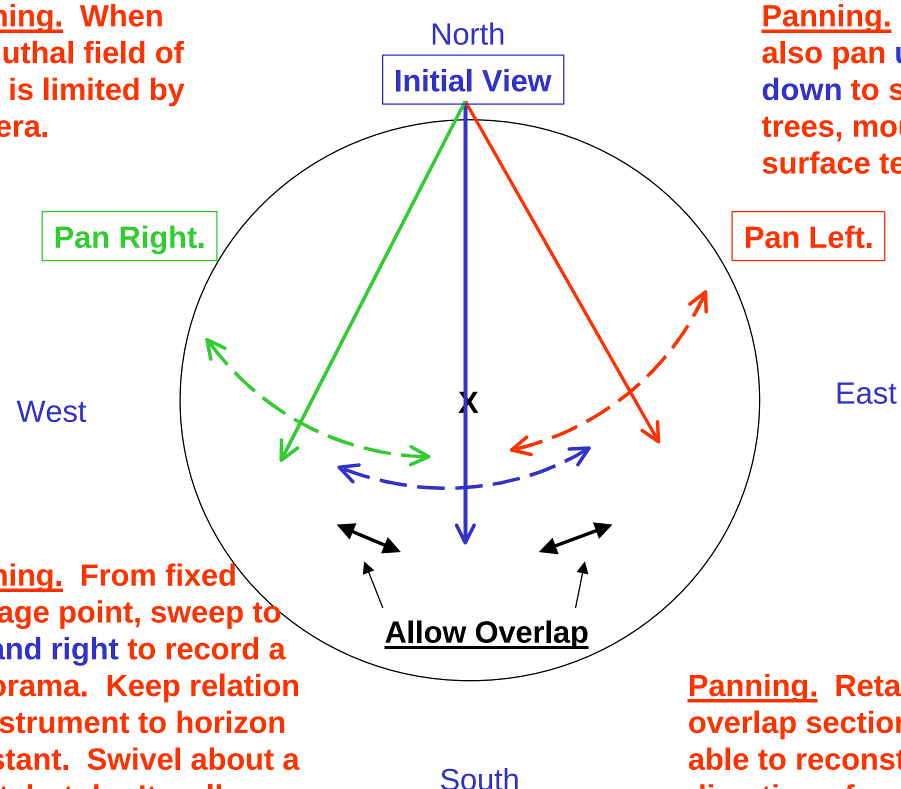

Station in foreground.
Eight pictures starting from north looking toward south, always same start and clockwise path.
Why?
You don't have to remember !!!
North
1
8
2
West
7
3
East
6
4
5
South
Walk in a wide circle, about 50-150 feet away from the instrument. Show position relationships. You can always get close-ups later on.

Station in background, looking outward.
Eight pictures starting from north looking toward south, always same start and clockwise path.
Why?
You don't have to remember !!!



Panning. **When azimuthal field of view is limited by camera.**

Panning. **Can also pan up and down to show trees, mountains, surface texture.**



Panning. **From fixed vantage point, sweep to left and right to record a panorama. Keep relation of instrument to horizon constant. Swivel about a point, but don't walk.**

Panning. **Retain an overlap section to be able to reconstruct direction of pan.**

What cameras do <u>not</u> record, at all or very well:

Your state of mind.

Anything outside the field of view.

What is behind, beside, above, or below you.

The full brightness range routinely discerned by the human eye.

Shadow details.

Highly contrasty situations, such as looking toward the sun.

Depth. 3 dimensions will be recorded on a 2-dimensional medium.

What happened prior to, or after, the shutter is snapped.

Shaded detail in bright sunlight, or with snow-covered ground.

Dark areas, when brighter conditions influence the light meter.

The fact that you are standing in a marsh or a mud pit or on bare rock.

<u>Once is not enough.</u>

Things change. Memory cannot be trusted.

A single set of photos is not sufficient for all time.

Perform repeat photography at some practical interval.

> **A very basic set once every year or two can be enough.**
> **Consider a full repeat every several years.**

More often when rapid change is present.

> **Urbanization and sprawl nearby**
> **Land is being de-vegetated**
> **Land is going back to nature, re-vegetation.**
> **Effects of recent fire, as soon as possible, and during recovery.**

Record the date and time of day of a visit.

To keep the size of this file small, no examples are included.

Examples can be found at:

[http://xxxxxxx or ftp://xxxxxxxxxxx]

Currently, some powerpoint files can be found at

ftp.wrcc.dri.edu/aasc/photodocument

Examples (actual photographs) will be added later on.