NOAA Technical Memorandum OAR GMD-17

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UNITED STATES DEPARTMENT OF COMMERCE

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Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

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Table of Contents

Scientific Rationale for the Placement of Sites to Monitor the Surface Energy Budget for Climate Applications

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1. Introduction

Long-term monitoring of climate forcing and associated climatic signatures at acceptable levels of accuracy is necessary to not only detect climate change but to help in understanding the fundamental processes that enable regional and global modeling activities to provide credible future predictions. By observing actual components of the surface energy budget (SEB), comparisons can be made with theoretically predicted values for parameters responsible for driving the entire global atmospheric and oceanic circulation system. In a recent book from the National Academy of Sciences Board of Atmospheric Science and Climate (BASC), one of the recommendations for improving the observational record was to “Explore the value of creating a network of surface sites that provide representative monitoring of the surface energy budget” (NRC, 2005). This recommendation stems from an understanding that climate forcing can be due to non-atmospheric factors such as land use changes and responses directly affect how much energy, and in what form (sensible or latent), is transferred to the atmosphere. The fundamental forcing of climate and the driving components of the surface energy budget, solar and thermal radiation, have been identified as essential climate variables by the Global Climate Observing System (GCOS) and adopted by the Global Earth Observation System of Systems (GEOSS). It is, therefore, imperative that appropriate and adequate observations of these variables be made by NOAA to fulfill the nation's commitment to these international efforts.

A network of high-quality climate stations fully characterizing the components of the surface energy balance would lead to an improved understanding of both radiative and non-radiative forcing of climate. The network has the potential to provide an unprecedented level of detail through the selection of sites based not only on various climate regimes, but on local land use and vegetation dynamics that result in regionally representative surface temperatures, surface albedo, and energy partitioning of sensible, latent and ground heat fluxes. This study demonstrates requirements for the placement of surface energy budget measurement systems by NOAA for the purpose of addressing some of the most pressing and critical issues of NOAA’s climate program. The geographical domain for this study includes the 50-state region and territories of the U.S. along with globally remote locations where the U.S. has an established scientific and logistical presence.

In considering placement of monitoring sites, the adequacy and completeness of an observation depends not only on the accuracy with which it can be made and sustained over time, but also on the spatial and temporal extent to which a single observational site can be considered representative. The complexity of this issue increases as the siting criteria for the various energy budget components are considered, as each component, whether atmospheric or ground based, has a characteristic spatial footprint. For example, a downwelling solar measurement may be representative of a large region surrounding the measurement, but upwelling solar and surface energy fluxes strongly depend on the surface type, growth stage of the vegetation, and soil moisture availability. In most cases, the upwelling flux measurements would represent a smaller area. The major criteria for determining the distribution of surface energy budget network stations are:

- representativeness of the various climate regions in order to reflect the atmospheric forcing factors (i.e., aerosols, water vapor, clouds) that regulate incoming solar and thermal radiation,
- representativeness of the various land use types within each of the climate regions to reflect the seasonal and annual land surface processes that regulate the partitioning of radiation at the surfaces into sensible, latent, and ground heat fluxes, and
- locations that can be linked with satellite observations not only for calibration/validation studies for extrapolation to the spatial domain, but also to provide additional data on identifying trends and potential causes and feedbacks to regional climate changes.

In short, our goal is to acquire detailed, state-of-the-art, and accurate observations at sites that are carefully chosen to be representative of the various climate regimes and predominant land surface types within the major climate regimes of the U.S. An additional part of this task is to further contribute to international global climate observational efforts by identifying appropriate and accessible global sites for energy budget component observations. The challenge is to maximize spatial and geo-climate-region representativeness with a sufficient number of stations. For example, in the site selection process for The U.S. Surface Radiation Budget Network (SURFRAD) (Augustine *et al*. 2000), consideration was given to locations where the land surface and vegetation were homogeneous over an extended region so that all of the measurements would be representative of at least pixel- or grid-sized areas of satellite measurements and climate models, respectively. As with SURFRAD sites, SEB network sites would have requirements that the stations should not be located near concentrated sources of anthropogenic aerosol emissions, nor should they be near large bodies of water so that their measurements are not overwhelmed by point-source or local influences. For the SEB network, in addition to the criterion of land surface uniformity over pixel-sized regions, we base the national network design on annual variations of quantities affecting the surface energy budget, such as cloud cover, aerosols, moisture availability, temperature, land use and vegetation dynamics, which affect surface albedo, emissivity, etc. Another useful application of the SEB data is for comparisons on short-time frames of the same quantities either inferred from satellite observations or derived from fully coupled numerical weather prediction models. These can range in complexity from full line-by-line spectral radiation calculations in a realistic atmosphere, to more coarse parameterizations in global climate models. The locations of network sites must reflect these interests with a long-term goal of improving both atmospheric and land surface models (LSM) for improved predictions of climate on regional and global scales.

2. Role of the surface energy budget in climate and its impact on site selection

The complete surface energy budget (SEB) consists of radiative and non-radiative components. Changes in the downward solar and infrared radiation produce atmospheric forcing. The reflected solar and the upwelling longwave radiation are in part determined by the land surface type and moisture availability. The sum of the incoming and outgoing radiative components constitutes the so-called available energy or *net radiation*. This flow of energy is then partitioned into the non-radiative constituents; the vertical transport of sensible heat and water vapor into the atmosphere and storage of heat in the ground. It also drives many of the complex processes of vegetated surfaces such as photosynthesis and emissions of some trace gases, for example, isoprene.

It is widely understood that changes in climate forcing constituents will first be realized in changes in the SEB, which will in turn also be affected by the resulting climate change. That direct role of the SEB, and its sensitivity to climatic feedback, not only emphasizes its importance for long-term climate studies, but also considerably complicates the expected measurable variations and interpretation of these changes in the SEB over time. It is, therefore, important to know how the differing anticipated events, e.g., changing atmospheric composition, are expected to affect each of the separate components of the SEB. Climate models and satellite retrieval algorithms do not have the complete physics or process level details to accurately simulate or infer the actual SEB changes. It is these uncertainties that reinforce the need for actual measurements of the SEB at optimally chosen locations.

In order to advance our understanding of climate feedbacks and to detect radiatively driven climate change, certain criteria for the measurement of surface radiation and energy budgets must be met. To determine where SEB observations are needed, we must first determine how well our current stations sample with respect to the geographical distribution of climate forcing parameters that affect radiative transfer in the solar and thermal infrared, such as clouds, aerosols, and moisture. Based on those analyses, new station locations are recommended to improve the spatial representativeness of the network.

We have considered the largest potential sources of climate variations and assessed their impact on the SEB over the continental U.S. (CONUS; lower 48 states) as well as assessed the need for related observations on the international global scale. Determining the location of an optimal number of SEB sites provides information for detecting climate variations, improving our representation of land surface processes for improved predictability, and supporting model and satellite retrieval validation by optimizing the versatility of station environments.

3. Rationale for the proposed network

We are proposing a SEB network strategy that will adequately sample the primary ecoregions of the conterminous U.S. and contribute to global efforts to sample representative climate zones in remote regions. Ecoregions, defined as large areas of similar climate regimes where ecosystems recur in predictable patterns, reflect both climate and land-use patterns. Also, we consider certain oceanic sites (on small islands) in otherwise under-sampled climatic regions where only the surface radiation portion of the SEB measurements are feasible. Also, a few sites are considered where specific land-use regimes will reflect and be responsive to climate change, but may not necessarily contribute to the overall regional representativeness of some of the SEB component measurements.

Here, the rational and specific applicability and usefulness of the selected sites will be discussed. Guidance for site selection will also be taken from existing networks that monitor other atmospheric variables, but which have comparable long-term climate goals and objectives (Baldocchi *et al.*, 2001; Hicks *et al.*, 2001). The network will be assembled from existing sites with data records of more than ten years duration (Augustine *et al*., 2005). These stations were selected with ecosystem or climate diversity as the primary rationale (Augustine *et al*., 2000;

Hicks *et al*., 1996). Preserving these carefully chosen observing sites with existing, high-quality, long-term records is a key consideration for the observations of essential climatic variables. The proposed SEB network will leverage the integration of three existing networks that have goals related to, but not as comprehensive as, concepts and objectives of a broader, more comprehensive SEB network.

4. Site selection

To identify sites that will give adequate representation over the continental U.S. and contribute incrementally to international global baseline observations of the SEB, it is desirable to build upon the merits of the existing sites of related NOAA programs. Here we evaluate the geographic, climatic, and ecoregion representativeness of current NOAA OAR laboratory research networks for radiation and surface energy budget measurements. After the discussion of current network sites and their contribution to the proposed SEB network goals, we identify needed extensions of measurements at some existing sites, and additional new site locations that will achieve the sampling goals of a dedicated SEB network.

4.1 Continental U.S. (CONUS) sites

In the continental U.S., several NOAA sites exist for the continuous long-term measurement of surface radiation budget, and at a few of those sites the total surface energy budget is measured. The criteria used to select those sites, as well as network expansion locations, depend on a large number of climate-related variables, however, four: 1) climate classification, 2) clouds and surface solar radiation, 3) aerosols, and 4) land use were considered in this site selection process for the proposed U.S. network. Climate classification is determined from the Köppen system (http://www.geofictie.nl/ctkoppen.htm), shown for the lower 48 states in Figure 1. The Köppen system is the most widely used method for classifying the climate. It has 5 major categories that are based on the annual and monthly averages of temperature and precipitation. Each major climate type is designated by a capital letter as described below.

A	Tropical Moist Climates: all months have average temperatures above 18 degrees Celsius
B	Dry Climates: with deficient precipitation during most of the year
C	Moist Mid-latitude Climates with Mild Winters
D	Moist Mid-Latitude Climates with Cold Winters
E	Polar Climates: with extremely cold winters and summers

Subdivisions of these fundamental climate types further refine the seasonal moisture and temperature. The Cfa designation, for example, is defined as “humid subtropical-mild with no dry season, hot summer,” which covers much of the southeastern quadrant of the U.S. The Dfa designation, which covers much of the Midwest, is defined as “humid continental-with severe winter, no dry season, hot summer.” Much of the intermountain west is designated Bsk for “mid-latitude steppe-mid-latitude dry.” The only A designated area for tropical humid climates is in the southernmost part of Florida.

Currently, many climate types are sampled with the existing radiation network, but obvious gaps are also apparent, especially in the western and eastern U.S. The proposed network expansion shown in Figure 1 improves the overall coverage of climate regimes.

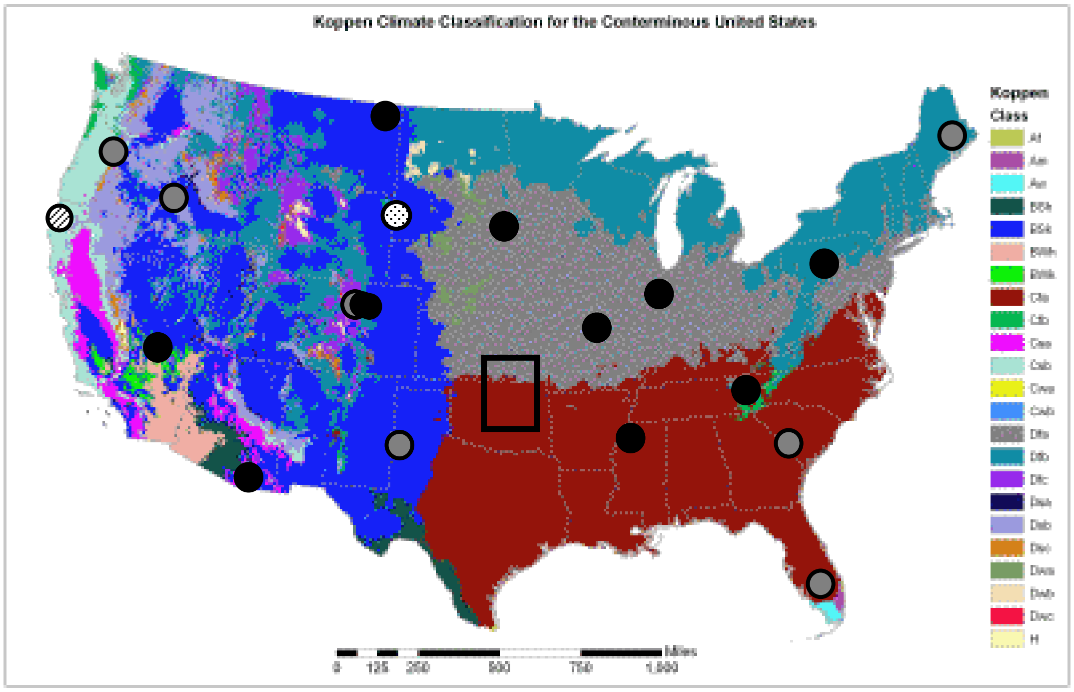

Figure 1. Köppen classification of climate for the U.S. The fundamental variables contributing to this mapping are temperature and precipitation. The first letter designations (A through D) on the right are for tropical humid, dry, mild mid-latitude, and severe mid-latitude conditions, respectively. Mild and severe refer to the harshness of the winter season. Plotted symbols represent existing and potential SEB observing sites given in Table 1. The black dots are the current stations that either have complete radiation budget measurements, heat flux measurements, or both, and gray dots are proposed SEB sites. The hatched dot on the west coast represents the Trinidad Head site of GMD/ESRL that will only have downwelling solar measurements, the dotted circle is a heat flux only site in the Black Hills, and the rectangle is the DOE ARM site. Base map is courtesy of Bruce Godfrey, University of Idaho.

Figure 2 illustrates the average daily solar radiation over one year for all of the U.S. The values represent the solar radiation received on a horizontal surface and are based on surface measurements (7%) and on models (93%) using correlations with measurements plus supplemental data (mostly cloud-cover). The pattern of received solar radiation over the U.S. is primarily dependent on latitude and cloud cover. Although the spatial resolution is low, the pattern demonstrates the north to south gradient in radiation and also a generally northeast to southwest increase associated with decreasing cloud cover. As in Figure 1, the existing and potential GMD/ESRL sites and the ARM SGP site, a mesonetwork of SEB stations, are over-plotted to visualize the extent of the existing sampling of this climate variable, and its improvement following network expansion.

The annual average of aerosols, one of the key and most variable climate-forcing agents, is shown in Figure 3. The smallest aerosol extinction of solar radiation is in the inter-mountain west and the largest is in the Ohio River valley. The differences in the U.S. range over an order of magnitude and clearly have different distributions than surface solar radiation, clouds, and climate type indicated in Figures 1 and 2. Aerosols depicted in Figure 3 are not well sampled over their complete range by the current network, but the additional stations will complete the

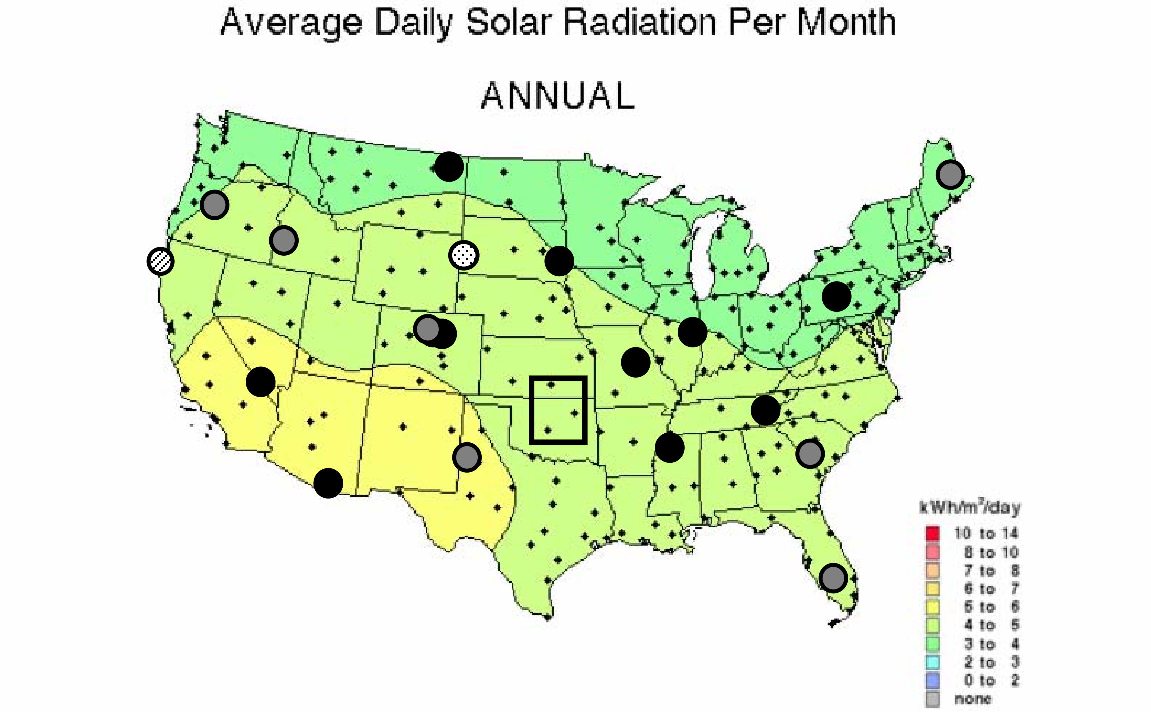

Figure 2. Annual average of the daily radiation received on a horizontal surface. This figure is available from http://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/. The large dots represent the existing and potential SEB stations as described in Figure 1. Small dots represent the old SOLRAD network plus modeled stations on which the solar radiation distribution shown is based.

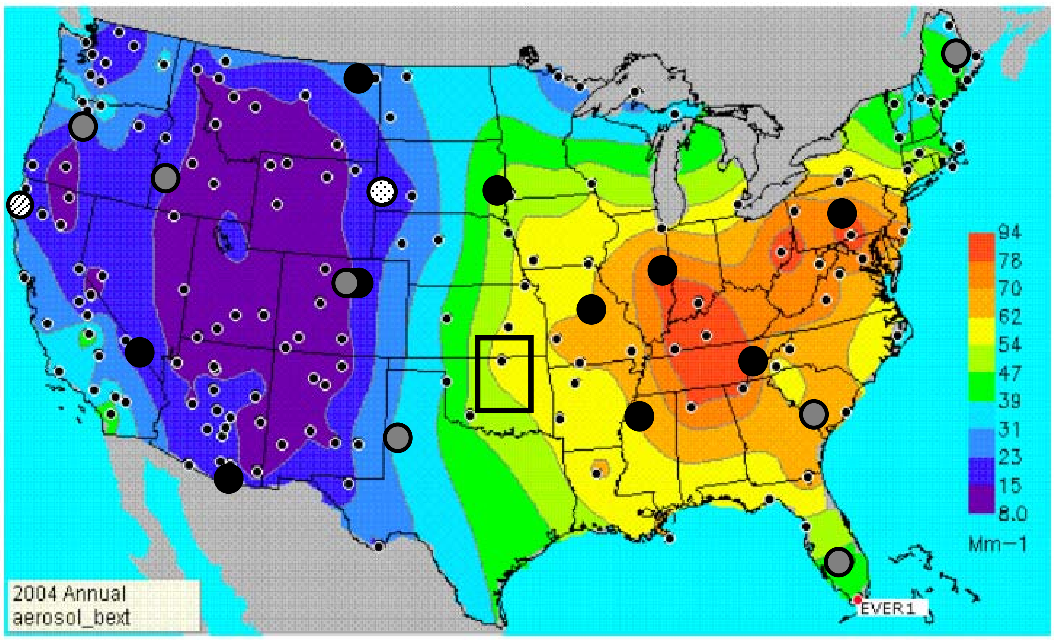

Figure 3. Annual averaged aerosol extinction for the continental U.S. in inverse megameters. For example, 10 Mm^{-1} (in the purple range) is approximately equivalent to a column aerosol optical depth of 0.08. Small dots represent the network that was used to generate the aerosol distribution shown. For this map and seasonal aerosol extinction maps see http://vista.cira.colostate.edu/views/Web/AnnualSummary/ContourMaps.aspx. Current and proposed SEB station locations are indicated by the large dots.

range of aerosol loading experienced in the U.S. Regions that need additional coverage are clearly in the northwest, intermountain west, the southwest, the southeast coastal plain, and upper New England. The over-plot of current GMD/ESRL sites indicates that the range of aerosol extinction in the U.S. is currently under-sampled with only about 50% of the divisions sampled by the present network. Addition of the expanded stations (gray dots) will better characterize the aerosol loading in many parts of the U.S.

Figure 4 is an ecoregion depiction of the U.S. relating both land cover and climate. This map is closely tied to solar reflectivity, thermal emissivity, latent and sensible heat fluxes to the atmosphere, and heat flux into the ground. The current locations of the GMD/ESRL and ARM sites indicate that although some key ecoregions are sampled (black dots and rectangle), additional sites (gray dots) will be required to more fully capture the ecosystem variation in the U.S. Figures 1 through 3 illustrate the major factors determining the number and distribution of sites that will achieve a goal of representing most (90%) of the contiguous U.S. for cloud cover, solar irradiance, climate and aerosols. Given the large diversity of ecoregions shown in Figure 4, the proposed network will represent slightly more than 75% of the ecoregions in the CONUS. Currently, the GMD/ESRL sites represent about 33% of the ecoregions of the CONUS.

In Figure 5 the International Satellite Cloud Climatology Project Flux Dataset (ISCCP FD) of derived annual downwelling solar irradiance from satellite data (Zhang *et al.*, 2004) are used to establish cross correlations between ISCCP grid points near surface sites and the rest of the area shown, using nominal 280 km by 280 km grid density. It has been previously shown (Dutton *et al.*, 2006) that annual average solar irradiance from single surface sites can be highly correlated with the FD irradiance data for large areas surrounding the site. This correlation analysis is useful to establish an area whose downwelling solar radiation is reasonably represented by a single station. Figure 5 shows contours of the correlation coefficient divided by the standard error uncertainty in the correlation coefficient for the SURFRAD station near State College, Pennsylvania. The correlation to uncertainty ratio of four is represented by the dark yellow contour. The pattern shown suggests that measurements from this single station correlate well with surface solar radiation and cloud cover from the mid-Atlantic to parts of New England.

In Figure 6 we composite the cross correlations for all seven of the current SURFRAD sites, the Department of Energy’s Atmospheric Radiation Measurement (ARM) site in Oklahoma and Kansas, and STAR’s Trinidad Head station. The shaded area represents regions where at least one of the plotted sites had a correlation ratio of greater than 4. This map clearly illustrates that the surface solar radiation of a large part of the lower 48 states is well represented by the current network, but also shows where gaps in coverage lie.

Based on the analysis presented in this section, an expanded NOAA SEB CONUS network is presented in Figure 7. Considering the ISSCP downwelling solar cross correlation analysis composite results in Figure 6, six new stations would likely extend adequate coverage for solar radiation and cloud sampling to more than 90% of the U.S. The only gaps would be in the intermountain west and south Texas. Depending on where the proposed new stations are situated in the northwest and southern Arizona, a few additional Köppen climate types would be sampled. The new station in Tennessee would serve two purposes. It would sample the region of the U.S. with the highest aerosol loading, and it would also be located at the top of a deciduous forest canopy. The latter is a surface type not represented in the current network, and a station of this type has been requested by NESDIS.

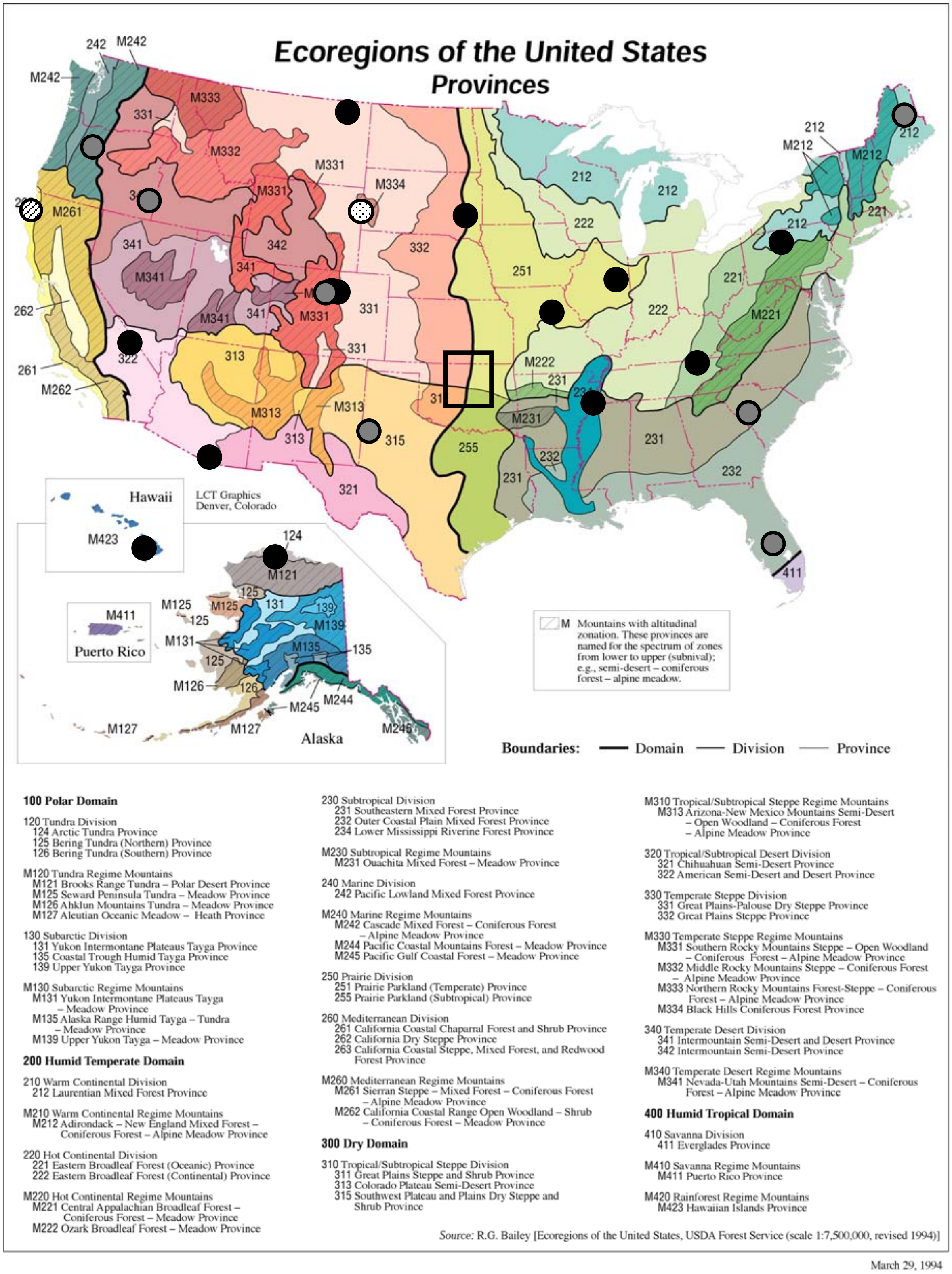

Figure 4. Ecoregions of the U.S. (R.G. Bailey, Ecoregions of the United States, USDA Forest Service). Station locations are shown as in Figures 1, 2 and 3.

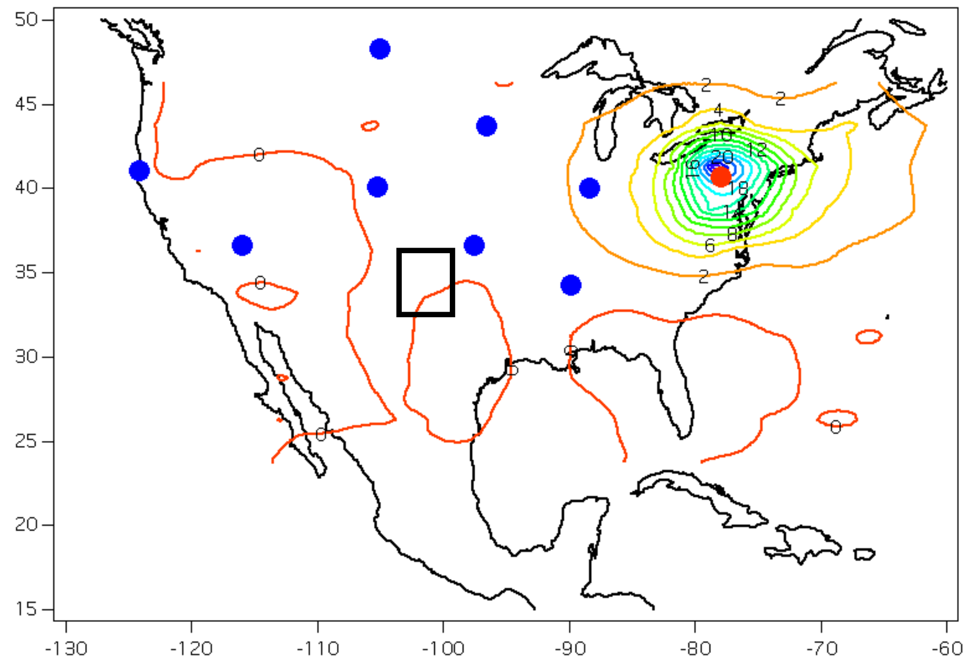

Figure 5. Map of the correlation of the ISCCP FD (satellite) derived values of annual solar irradiance received at the surface near State College, Pennsylvania, compared with the surrounding region. The contours represent the significance of the derived correlation in terms of the ratio of the cross correlation to its standard error of determination. Note that perfect correlation is forced at the central data point as it is correlated with itself. The contour value of four includes areas from the mid-Atlantic to New England. Station locations depicted are those currently measuring downwelling solar irradiance.

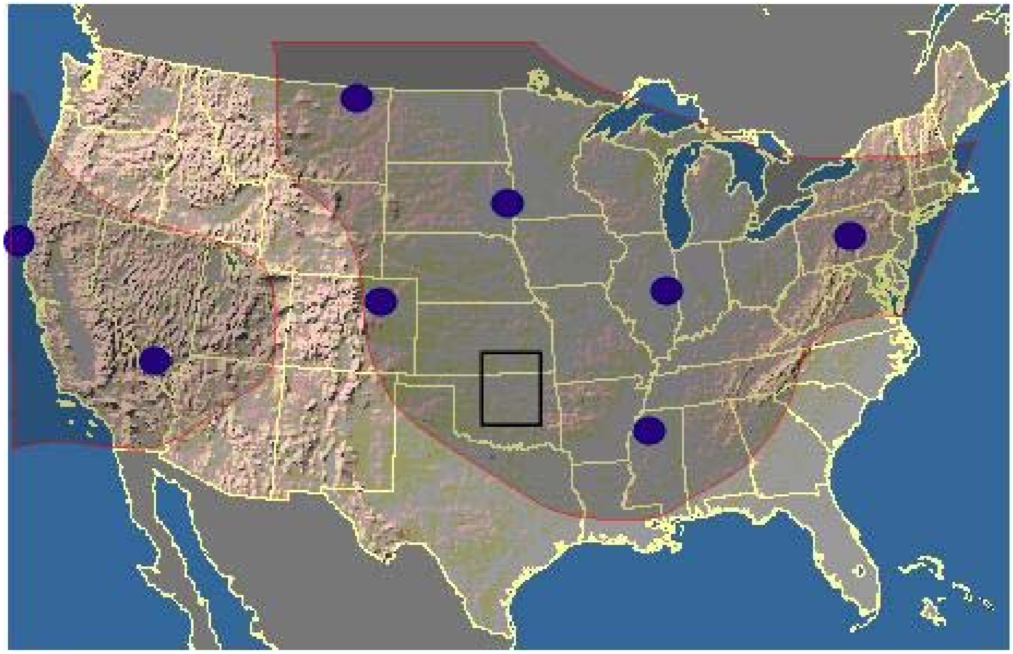

Figure 6. The shaded area is the areal coverage of the annual variation in solar irradiance received at the surface that can be correlated with one of the current GMD/ESRL or ARM sites where the ratio of cross-correlation to its standard error exceeds 3. Stations shown are those that currently have downwelling solar measurements.

In comparing the ecosystem distribution in Figure 4 with the proposed expansion shown in Figure 7, each of the new stations would be located in an ecosystem presently not sampled. Also, many of the stations, existing and proposed, are located on borders of ecoregions. Because climate defines the type of ecosystem that can be sustained, these stations are, or will be, ideally poised to detect climate change. The addition of two more stations in Texas and the intermountain west (e.g., western Colorado or central Utah) would likely achieve more than 90% coverage according to the distribution of aerosols, clouds, and downwelling solar radiation. Land use, which modulates surface fluxes, is too diverse over the U.S. to be represented completely by our planned expansion. Therefore, a few more heat flux stations will be needed to supplement the surface sampling of those variables. For example, trees and forests are adapted to specific climate conditions, and are particularly susceptible to climate change. Climate change induced modifications to the land surface response include changes in species composition, geographic range, and health and productivity of the forest stand. If conditions become drier, the current range and density of the forests could be reduced and replaced by grasslands and pasture. All of these changes would cause changes in the regional surface albedo, and energy partitioning at the surface. The vast ponderosa pine forest of the Black Hills is a good example of a bio-indicator species. Here, less accurate measures of the surface radiation budget will have to suffice because the location is remote (for sensor maintenance) and there is no A/C power.

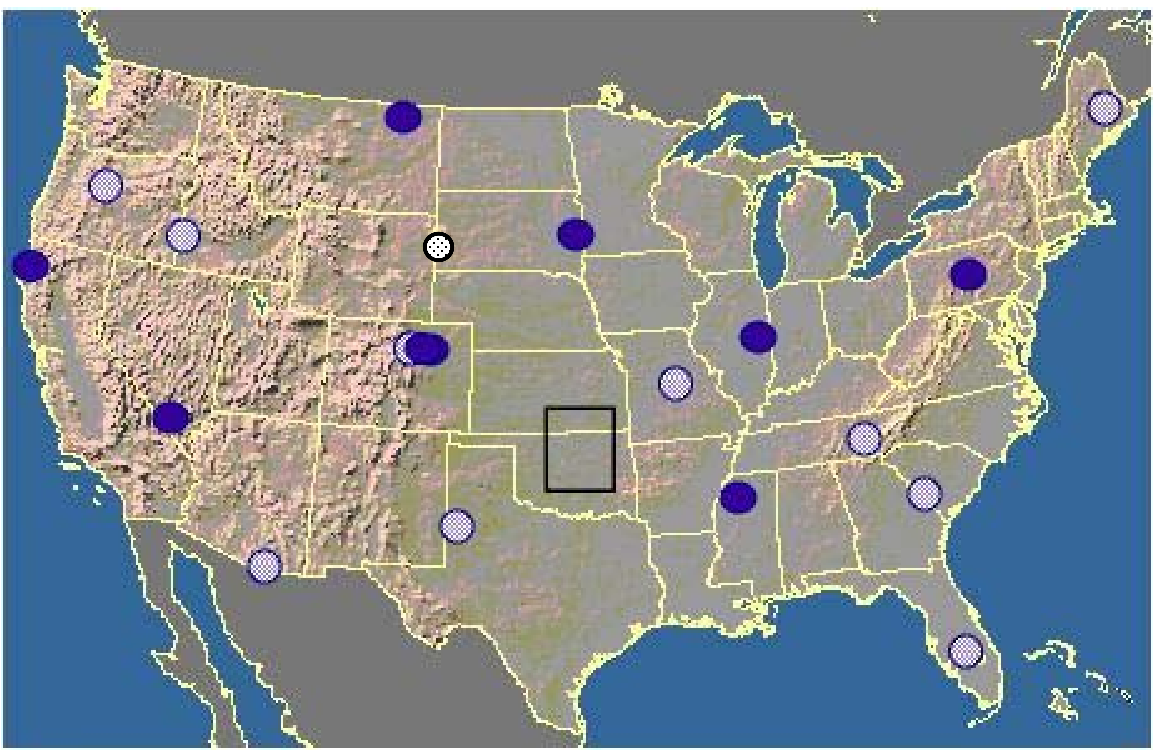

Figure 7. Potential expansion of a SEB network over the continental U.S.

4.2 Baseline Surface Radiation Network (BSRN) and Air Resources Laboratory Global Water and Energy Experiment (ARL/GEWEX) CONUS sites

It is desired that surface radiation-only stations that are favorably located be enhanced with surface energy flux measurements, and also that favorably located energy flux stations be enhanced with BSRN-approved radiation instrumentation. Currently, complete SEB instrumentation suites are co-located at Bondville, Illinois, Fort Peck, Montana, and Goodwin Creek, Mississippi. Adding heat flux instruments to current radiation-only stations at Desert Rock, Nevada; Boulder, Colorado; Sioux Falls, South Dakota; and Penn State University, Pennsylvania, and adding BSRN radiation instrumentation to ARL/GEWEX sites at Chestnut Ridge, Tennessee, Columbia, Missouri, and Audubon Ranch, Arizona would achieve a 50% level of ecoregion representation (Figure 8). To achieve 75% ecoregion representation (by area), it is recommended that sites be added to 7 more ecoregions (Figure 8). These would include 4 new sites in the western U.S., two forested plus two grassland, and 3 new sites in the eastern U.S., including one in central Florida, one in central Maine, and the other in South Carolina. For the 2 western grassland sites, we leverage the existing U.S. Climate Reference Network (USCRN) by selecting 2 of those stations in ecoregions currently not represented in the current radiation network—one in Idaho (near Murphy), and the other in Texas (near Muleshoe). Both have site characteristics and infrastructure that would support a SEB network's activities and objectives. The two newly proposed forested western U.S. locations would have collocated Ameriflux towers. One is at Niwot Ridge, Colorado, and the other is near Metolius, Oregon.

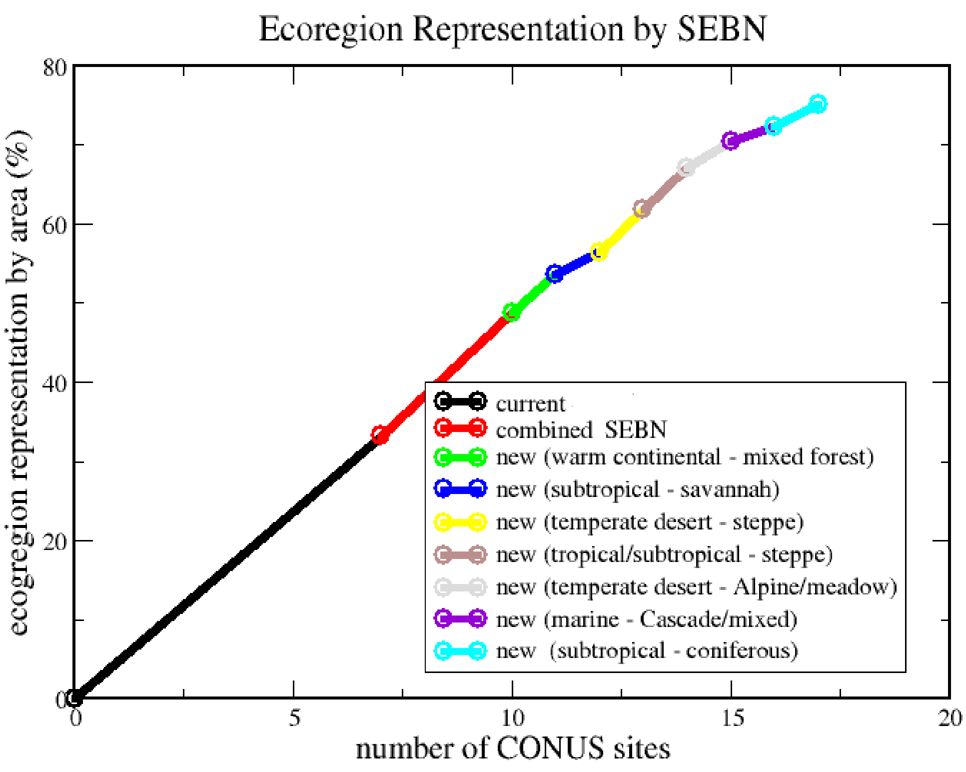

Figure 8. Percent of CONUS ecosystem area represented as the number of sites are increased.

The three newly proposed eastern U.S. stations were chosen based on their downwelling solar and land use characteristics. The Archbold Biological Station, near Lake Placid in central Florida is an independent, non-profit research facility devoted to long-term ecological research and conservation. That facility owns and manages a 5,193-acre, globally-significant natural preserve. The second recommended eastern U.S. site is at the Department of Energy's Savannah River Laboratory in Aiken, South Carolina. Although in the same ecoregion as Florida, the solar characterization, aerosols, and land use (predominantly loblolly pine) of South Carolina are very different from Florida. The recommended new site in the northeast is near Howland, Maine. This Ameriflux study site is located in a boreal transitional forest and is dominated by mixed spruce, hemlock, aspen and birch stands ranging in age from 45 to 130 years.

4.3 Non-CONUS global baseline sites

Because climate change can result from global scale phenomena, and geopolitical regions are affected in various ways (e.g., biomass burning), there is a need for both the understanding of the global causes and regional consequences of climate change. Likewise, there are global consequences from regional influences. Therefore, our approach is to provide an observing network where the density is not only adequate for determining the regional (CONUS) influences on, and consequences of, climate variability, but also where SEB component observations from a globally sparse set of sites will contribute to understanding the global scale causes and consequences of climate processes. The U.S. has ready access to several such globally remote sites where measurements are representative of globally under-sampled climate regimes and at which sustained observational programs are practical. NOAA's globally remote sites contribute to ongoing similar efforts of other countries. International coordination of those efforts is through such programs as the World Climate Research Program's Baseline Surface Radiation Network (BSRN) and other Global Water and Energy Experiment (GEWEX) surface energy budget projects. The SEB measurement sites will contribute to the BSRN, which was established in support of global climate research as discussed in WCRP (1989) and Ohmura *et al.* (1998).

Between about 15 and 30 climatic zones have been identified on the planet that define conditions relative to suitability for habitation and agricultural productivity. However, it is the total area of the planet, including oceans and other under-sampled desolate regions, that accounts for the annual average surface energy budget and that is ultimately responsible for potential modifications of the climate of any given region. For that reason, a few sites are suggested in regions that would otherwise be unobserved, and large gaps in the global picture can be filled with information from these sites. Cooperative international projects such as BSRN are attempting to acquire SEB component observations from available sites in such regions. These few sparse and remote sites will not have the capability to provide true spatial averages for climate research, such as the density of stations in the U.S. will permit, but instead will allow for satellite and model validation over the oceans and in inhospitable regions.

Using the same method as shown in Figures 5 and 6 for the U.S., Dutton *et al*. (2006) has shown an estimate of the spatial representativeness of several of the proposed globally remote sites (see Figure 9). In that figure the cross correlation is given between the sites' solar irradiance records and that derived from a satellite record (ISSCP FD). Here the extended value of the stations is indicated; although falling well short of the entire globe, it provides a substantial contribution to the entire planet's coverage. The merit of the remote sites' contributions to the global picture is realized when combined with about 30 more international BSRN sites operated by other countries.

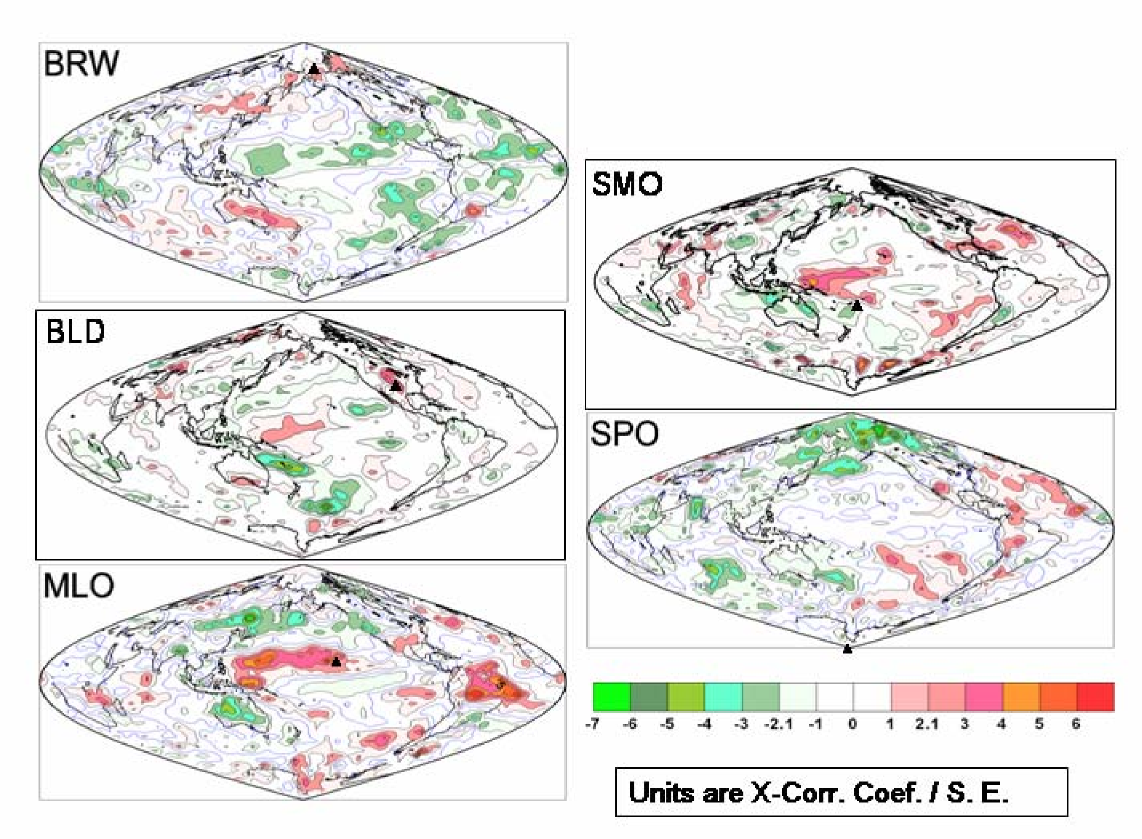

Figure 9. ISSCP-based cross correlation ratios for five of the proposed baseline sites, as in Figures 5 and 6, except satellite data were correlated with 17 years of existing ground-based observations at each site. Site location is indicated with ▲. BRW is Barrow, Alaska, BLD is the Erie, Colorado site near Boulder, MLO is Mauna Loa, Hawaii, SMO is American Samoa, and SPO is the South Pole.

The stations at globally remote locations with the special purpose of enhancing the U.S. contribution to international and global SEB related programs are given below with a brief description of the particular merits of each.

Pt. Barrow, Alaska (BRW) - This site on the north slope of Alaska is located in the Arctic and has a long established record of surface radiation budget measurements. It is also a sentinel site for climate change. We propose adding heat flux measurements (latent and sensible heat) to the site.

Bermuda - This site is the only oceanic site directly downwind from the majority of land area of the U.S. It also is the only suitable site for continuous surface measurements in the entire north central Atlantic Ocean. The site is inherently representative of a large portion of that part of the globe and its associated climate zone. Surface heat flux measurements on this small island are not feasible and are not proposed as such measurements would be adversely affected by the underlying surface of the island and not representative of the open ocean. Downwelling radiation and aerosol optical property measurements are recommended for this location.

Mauna Loa, Hawaii (MLO) - This site is a unique and historic reference site for atmospheric measurements representative of the mid to upper troposphere and stratosphere. Surface budget component measurements at this site have been used as proxy indicators of the climatic impact of hemispheric- and global-scale atmospheric events such as major volcanic eruptions and major dust storm outbreaks. Because of the influence of unrepresentative surface characteristics, surface heat flux measurements at this, as with other island sites, are considered of little use. However, measurements of downwelling radiation and aerosol loading provide valuable information at this site.

Kwajalein, Marshall Islands - This location is an exceptional mid-oceanic site for observations of the downwelling irradiance components of the surface energy budget, but with the surface influenced flux components again being unrealistically biased by the island itself. The downwelling irradiances and supporting ancillary data, as from other islands in this network provide extraordinarily valuable information of the solar and thermal irradiances for the purpose of uniquely contributing to satellite and model investigations of the surface radiation budget at this remote site.

American Samoa (SMO) - This site is similar to Kwajalein, but is located in the southern hemisphere where any comparable observations for global scale investigations are extremely rare. Also, Samoa is substantially displaced from Kwajalein with respect to the location of the inter-tropical convergence zone and therefore represents an entirely different climate realm and again is similar to that of a large portion of the surrounding regions as seen in Figure 9. Both downwelling radiation and aerosol optical measurements are recommended at this site.

South Pole (SPO) - Set in the high dry polar plateau, the South Pole site is truly representative of hundreds of surrounding square kilometers with respect to components of the surface energy budget. The site is one of the longest running continuous climate monitoring observatories in the world, but operating conditions at this location can be difficult and to date no routine ongoing surface heat flux measurements are conducted; they could be added as part of a SEB network. The value of the SEB observations at the South Pole is further enhanced by the difficulty that both the satellite observations and climate model calculations have dealing with this environment, which is representative of a substantial portion of Antarctica. Complete vertical energy flux measurements are recommended for this location.

Alert, Canada - This site provides a pristine deep arctic site in a region of suspected high climate sensitivity. Existing infrastructure along with fledgling SEB observations as part of NOAA's SEARCH program make this a highly desirable site to maintain. The surface energy budget is known to play a significant role in currently observed Arctic change and continuing to quantify its variations will greatly contribute to understanding this region's contributions to the global scale.

An additional yet to be identified site – On the global scale, many other nations are contributing to filling in the spatial coverage. Nonetheless, a remote monitoring site supported by NOAA in addition to those identified above would contribute considerably to extending the global coverage and contributing to the various international programs related to GEOSS. Determination of a location for such an additional site would require considerable investigation and commitment of resources that cannot be undertaken until such time that at least some portion of those resources would become available.

> Therefore, we are recommending that an additional globally remote baseline site be included in the planning of an extended program and the work to identify such a site begin at the onset of the program. Wake or Easter Island would be good candidate sites to address the needs of the BSRN and a new SEB network.

4.4 Turbulent heat fluxes at global baseline sites

The remoteness along with the geographic and land surface features of many of the globally remote sites identified in Section 4.3 make them very challenging for turbulent heat flux measurements. Nonetheless, the complete surface heat budget at and in the vicinity of these sites is part of the global climate system, and efforts should be taken to obtain related observations as conditions permit. Of the sites identified, Barrow, Alert, and South Pole have potential for surface turbulent heat flux measurements that are representative of the surrounding region. The other sites are located on relatively small oceanic islands where regionally representative observations would need to be made over the open ocean. These observations could best be made on readily accessible ocean moorings outside any local influences on the SEB by the island topography or ocean bottom. Addition of the turbulent flux measurements at the three identified polar sites will require additional characterization and hardening of the related instrumentation, but will provide highly valuable information for climate sensitive regions, and for regions where little other data exist.

5. Summary and conclusions

Although the goals of this report address three different spatial distributions and have varying emphases for applications of the SEB observations, the primary logistics, scientific and technical expertise, support facilities, and administrative requirements are nearly identical. The integration of these efforts into a single central project is an efficient and expedient undertaking. Table 1 provides a list of recommended sites based on their potential contribution to CONUS representativeness or potential for contributions from globally important, but data-poor regions. We believe that the CONUS sites would provide surface energy budget coverage representative of approximately 75% of the continental U.S., and the globally remote sites contribute to a global understanding of specific critical energy budget components at global baseline locations not otherwise observed. The table indicates what types of measurement categories would be desirable and feasible at these sites utilizing existing NOAA infrastructure and in many cases extending unique existing long-term climatological records of certain energy budget components. Not only can significant temporal variations in the SEB quantities at these sites be considered indicative of real climate variability and be used for verification of predicted changes in those quantities, but the ongoing development of diagnostic and predictive models can also be further improved in matching these observations, after consideration of spatial differences, in the initialization and predictive stages. The denser continental network will provide valuable insight to the changing conditions affecting most of the country while the specialized land-use sites will provide supplements to that analysis and valuable information for process parameterization refinements. The globally remote sites contribute extensively to international programs and will help identify changes that could otherwise be completely undetected, but which can be indicative of global scale influences in the system.

Table 1. Candidate Sites and the General Climate and Land Use Representativeness.

Site #	Climate Type (Köppen)	Land Use or Regional Representativeness	SEB Measures	SEBN Candidate Site	Current Obs System	Existing Meas.
1	Dfa	Prairie Parkland	S	Bondville, IL	SURFRAD	Y
2	Dfb	Central Appalachian Broadleaf/Conifer/Meadow	S (r)	Rock Springs, (Penn State), PA	SURFRAD	P
3	Bsk	Great Plains Steppe	S	Table Mountain, CO	SURFRAD	P
4	Bw	American Semi-Desert	S	Desert Rock, NV	SURFRAD	P
5	BSk	Great Plains Dry Steppe	S	Fort Peck, MT	SURFRAD and GEWEX	Y
6	Cfa	Low Miss. River Forest	S	Goodwin Creek, MS	SURFRAD and GEWEX	Y
7	Dfa	Prairie Parkland	S	Sioux Falls, SD (Moving GEWEX from Brookings, SD to Sioux Falls, SD)	SURFRAD and GEWEX (FY 08)	Y
8	Cfa	Eastern Broadleaf Forest	S	Chestnut Ridge, (Oak Ridge), TN	GEWEX	P
9	BWh	Semiarid Grassland	S	Audubon Ranch, AZ	GEWEX	P
10	Dfb	Forested/Conifer	s	Black Hills, SD	GEWEX	Y
11	Dfa	Broadleaf Forest	S	Columbia, MO	GEWEX	P
12	Csb	Pacific Coastal Steppe/Forest	RA	Trinidad Head, CA	STAR	Y
13	ET	Arctic Coastal Tundra	S	Barrow, AK	STAR	P
14	Cf	N.Hem. Subtropical High Alt	RA	Mauna Loa, HI	STAR	Y
15	Bsk	Great Plains Dry Steppe	S (r)	Erie, CO (BAO Tower)	STAR	P
16	Af	S. Pacific Oceanic, S. Hem.	RA	American Samoa	STAR	Y
17	EF	Antarctic Plateau (ice cap)	S	South Pole	STAR	P
18	Af	S. Pacific Oceanic, S. Hem.	RA	Kwajalein, M. Is.	STAR	Y
19	Cfb	West Central Atlantic Ocean	RA	Bermuda	STAR	Y
20	ET	Arctic Coastal Tundra	S	Alert, Canada	STAR	Y
21	Cfb	Oceanic	RA	Wake or Easter Is.		New
22	Cab	Pacific Lowland Mixed Forest	S	Corvallis, OR		New
23	BSk	Intermountain Semi-Desert	S	Murphy, ID		New
24	BSk	SW Plateau and Dry Plains Steppe and Shrub	S	Muleshoe, TX		New
25	Cfa	SE Mixed Forest	S	Aiken, SC		New
26	Cfa	Outer Coastal Plain Mixed Forest	S	Lake Placid, FL		New
27	Df	S. Rocky Mt. Steppe Woodland	S	Niwot Ridge, CO		New
28	Dfb	Laurentain Mixed Forest	S	Howland, ME		New

Table 1 Notes:
"SEB Measures" column indicates what measurements are recommended for the site.

"Existing Measures" column indicates to what extent SEB measurements currently exist at the site.

Abbreviations:
a. "SEB Measures" column -
  S = Complete vertical Energy Fluxes including BSRN radiation
  RA = Downwelling BSRN radiation and aerosol optical measurement
  s = Heat Fluxes and Net Radiation without BSRN radiation
  r = BSRN Radiation Budget without Heat Fluxes
b. "Existing Meas." column
  P = Partially developed SEB site
  New = No permanent recommended measurements exist at the site – Establish New Site
  Y = All recommend observations currently exist at the site
(Note: Supporting ancillary observations of atmospheric state and clouds are desirable at all sites.)

c. Köppen Climate Classification System (http://www.geofictie.nl/ctkoppen.htm) is the most widely used method for classifying the world's climates. It has 5 major categories that are based on the annual and monthly averages of temperature and precipitation. Subdivisions of these fundamental climate types further refine the seasonal moisture and temperature. Each major climate type is designated by a capital letter and is described below.

A	Tropical Moist Climates: all months have average temperatures above 18 degrees Celsius
B	Dry Climates: with deficient precipitation during most of the year
C	Moist Mid-latitude Climates with Mild Winters
D	Moist Mid-Latitude Climates with Cold Winters
E	Polar Climates: with extremely cold winters and summers

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