How do we maintain sustainable high-quality climate observation networks that can answer the question: How has the climate changed over the past 50 years?

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Abstract

As we experience a new era in which the Earth's climate is forced by human activities, it is critically important to maintain an observing system capable of detecting and documenting global climate variability and change. Policy makers and the general public require climate observations to assess the present state of the ocean, cryosphere, atmosphere, and land, and place them in context with the past. To be of widespread value to scientists and society, these observations must be sustained over many decades and remain of the highest quality. Climate observations are needed to evaluate and initialize climate models and to improve predictions of climate change. Such efforts are essential for guiding national and international policies that govern climate-related resources, and for building agreements aimed at mitigating long-term climate change. Climate researchers have used existing, operational networks because they gave been the best, and sometimes only, source of data available. Guidelines have been developed for climate observing systems, specifically the ten climate monitoring principles. These principles should be considered in the design of new networks.

1. Introduction

Climate Observing system needs

Most observing systems that monitor climate were established to provide data for defined purposes, such as predicting daily weather; advising farmers; warning of hurricanes, tornadoes and floods; managing water resources; aiding ocean and air transportation; and understanding the role of the ocean in climate change.. The purpose of these observations continues to evolve with changes in mission, with the development of new technologies, and more recently with restrictions on budgets. The priorities to maintain the observation networks vary widely from country to country. In general, management of the programs has not recognized the importance of the observations for detection and attribution of climate change. Climate researchers have used existing, operational networks because they have been the best, and sometimes only, source of data available. They have succeeded in establishing basic trends of several aspects of climate on regional and global scales. Deficiencies in the accuracy, quality, and continuity of the records, however, still place serious limitations on the confidence that can be placed in the research results.

The ten climate monitoring principles that should be applied to climate monitoring systems are:

Management of Network Change: Assess how and the extent to which a proposed change could influence the existing and future climatology obtainable from the system, particularly with respect to climate variability and change. Changes in observing times will adversely affect time series. Without adequate transfer functions, spatial changes and spatially dependent changes will adversely affect the mapping of climatic elements.

Parallel Testing: Operate the old system simultaneously with the replacement system over a sufficiently long time period to observe the behavior of the two systems over the full range of variation of the climate variable observed. This testing should allow the derivation of a transfer function to convert between climatic data taken before and after the change. When the observing system is of sufficient scope and importance, the results of parallel testing should be documented in peer-reviewed literature.

Metadata: Fully document each observing system and its operating procedures. This is particularly important immediately prior to and following any contemplated change. Relevant information includes: instruments, instrument sampling time, calibration, validation, station location, exposure, local environmental conditions, and other platform specifics that could influence the data history. The recording should be a mandatory part of the observing routine and should be archived with the original data. Algorithms used to process observations need proper documentation. Documentation of changes and improvements in the algorithms should be carried along with the data throughout the data archiving process.

Data Quality and Continuity: Assess data quality and homogeneity as a part of routine operating procedures. This assessment should focus on the requirements for measuring climate variability and change, including routine evaluation of the long-term, high-resolution data capable of revealing and documenting important extreme weather events.

Integrated Environmental Assessment: Anticipate the use of data in the development of environmental assessments, particularly those pertaining to climate variability and change, as a part of a climate observing system's strategic plan. National climate assessments and international assessments, (e.g., international ozone or IPCC) are critical to evaluating and maintaining overall consistency of climate data sets. A system's participation in an integrated environmental monitoring program can also be quite beneficial for maintaining climate relevancy. Time series of data achieve value only with regular scientific analysis.

Historical Significance: Maintain operation of observing systems that have provided homogeneous data sets over a period of many decades to a century or more. A list of protected

sites within each major observing system should be developed, based on their prioritized contribution to documenting the long-term climate record.

Complementary Data: Give the highest priority in the design and implementation of new sites or instrumentation within an observing system to data-poor regions, poorly observed variables, regions sensitive to change, and key measurements with inadequate temporal resolution. Data sets archived in non-electronic format should be converted for efficient electronic access.

Climate Requirements: Give network designers, operators, and instrument engineers climate monitoring requirements at the outset of network design. Instruments must have adequate accuracy with biases sufficiently small to resolve climate variations and changes of primary interest. Modeling and theoretical studies must identify spatial and temporal resolution requirements.

Continuity of Purpose: Maintain a stable, long-term commitment to these observations, and develop a clear transition plan from serving research needs to serving operational purposes.

Data and Metadata Access: Develop data management systems that facilitate access, use, and interpretation of data and data products by users. Freedom of access, low cost mechanisms that facilitate use (directories, catalogs, browse capabilities, availability of metadata on station histories, algorithm accessibility and documentation, etc.), and quality control should be an integral part of data management. International cooperation is critical for successful data management.

2. What Characteristics does a Climate Observing System need to produce useful climate data?

Observational systems are composed of an entire sequence of process steps. An observing system is operational for climate purposes only if this entire sequence exists in a robust condition. The present study assesses the condition of the physical measuring system for a given variable and the characteristics that turn a set of measuring devices into a climate observing system.

A climate observing system should have the following characteristics:

1. measurements are taken with accurate, calibrated instruments and converted into geophysical data and stored;
2. data are collected and quality controlled;

3. data are put in standard format and compiled into useful data products; and
4. data and metadata[1] are stored in a repository that is readily available to users.

Additionally, for such an observing system to be useful for detection of climate trends and attribution to a cause, the resulting data sets must:

1. be precise and accurate enough for the early detection of trends over the next decade or so, and for continued monitoring;
2. be homogeneous in location, time, and method;
3. be long enough and uninterrupted in time for decadal trends to be resolvable; and
4. have sufficient spatial coverage and resolution to allow spatial patterns and their time dependence to be evaluated.

The concept of homogeneity introduced above depends on quality climate observations. A homogeneous data base contains no discontinuities introduced by a change in instrument location, human-induced environmental changes in the immediate vicinity of an instrument, an undocumented change in instrumentation, an uncorrected change in instrument calibration or other operating procedures, uncorrected instrument drift, or any other change that is an artifact of changing the measurement technique. Any data base obtained from an observing system not specifically designed and operated for climate observing purposes is likely to contain inhomogeneities that must be removed before the data can be used with confidence for climate analyses

3. **Infrastructure for climate monitoring and prediction**

Essential infrastructure has to be established to ensure the integrity and continuity of the observations, their analysis into products, and links to modeling and research activities. The need is for systematic, objective, continuous observations of both state variables and forcings of the climate system. There should be oversight of the health of the observing system and resources to build and sustain a climate observing system operating under the 10 guideline principles. It would have a new management structure, authority and infrastructure and should be responsible for a line of products for use in all aspects of climate. The infrastructure should:

1. Ensure the integrity and continuity of the observations.
2. Have Systematic, objective continuous observations of state variables and forcings with a commitment to the continuity of record.
3. Have Strong links to research and development**.**

4. A Scientific Strategy for Climate Monitoring

There is compelling evidence that the climate is changing. The degree, nature and cause of the climate variations and whether there is a change requires solid information.

This requires

- improved observations of the state variables and forcings,
- the means to process these and understand them,
- the ability to set them in a coherent physical (and chemical and biological) framework with models.

Meanwhile, the information is also extremely valuable for other purposes including a myriad of practical applications for business, industry, government, and the general public. *Climate monitoring requires a long-term commitment to quality and stability*. Many of the climate-related signals are small, obscured by natural variability. There must be an active program of research and analysis utilizing climate data sets to ensure the data are state-of-the-art and meet requirements. Climate research and monitoring requires an integrated strategy of land/ocean/atmosphere observations, including both in situ and remote sensing platforms, and modeling and analysis. I

Important operating principles include:

1. Adequate support should be available for changes to instrumentation in the context of maintaining a long-term climate record.
2. Stable support is an essential characteristic of a climate observing system. Since this is to be a sustained activity, inflationary increases should be programmed into budget requests.
3. Contingency plans should be made for resource shortfalls so that operation of the system is not compromised.
4. Observing system activities should be regularly reviewed.
5. Activities should produce annual plans documenting accomplishments, future activities, and projected spending.
6. Operating cost increases or other factors often require flexibility and adjustments by the system operators to maintain data flow while long-term solutions are sought. In making such adjustments, priorities, from highest to lowest, should be:
   a) Data collection and archiving
   b) Distribution of the raw data in near-real time
   c) Quality control in delayed mode and archiving of data sets
   d) Development and maintenance of data access tools (e.g. web sites)

5. Conclusion

We need a comprehensive Climate Observing information system to:

1. Follow the Ten Monitoring Principles for Climate Observing Systems
2. Extend standardization of Climate Monitoring Networks Internationally
3. Develop International test beds to evaluate new technology and preserve data continuity in the climate record.
4. Have one common entry point for monitoring of climate state variables on a global scale.
5. Assess impacts regionally: on environment, human activities and sectors such as agriculture, energy, fisheries, water resources, etc.