Workshop on the Quality and Continuity of Environmental Data

April 11-12, 1991
Silver Spring, MD

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Office of the Chief Scientist
Earth System Data and Information Management Project Office

ACKNOWLEDGMENTS

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ASSURING THE QUALITY AND CONTINUITY OF NOAA's ENVIRONMENTAL DATA

Silver Spring, MD - April 11-12, 1991

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Friday, April 12

8:30 am	Working Group Meeting (continued)	
11:00	Lunch (Draft of policy will be prepared)	
1:00 pm	Final Discussion & Future Actions	Vernon Derr
2:00	Adjourn	

Workshop Participants

John Knauss	OA
William Hooke	OA
Vernon Derr	OA
Robert Reeves	OA
Ann Georgilas	OA
John Wickham	OA
Joseph Golden	OA
William Sprigg	OA
Jerry Mahlman	OAR
Abraham Oort	OAR
Maurice Blackmon	OAR
Barry Schwartz	OAR
Pieter Tans	OAR
Fred Fehsenfeld	OAR
John DeLuisi	OAR
Dana Kester	NOS
William Woodward	NOS
Bruce Douglas	NOS
William Schramm	NOS
Millington Lockwood	NOS
Dan Basta	NOS
Jim Sargent	NMFS
Glenn Flittner	NMFS
John Withrow	COPO
Donald Scavia	COPO
Thomas Karl	NESDIS
Walter Planet	NESDIS
George Ohring	NESDIS
Michael Weinreb	NESDIS
Greg Withee	NESDIS
Kenneth Hadeen	NESDIS
Michael Chinnery	NESDIS
Carl Fisher	NESDIS
Alan Strong	NESDIS
Levin Lauritson	NESDIS
Dan Tarpley	NESDIS
Robert Mairs	NESDIS
Sydney Levitus	NESDIS
Bud Booth	NESDIS
Chester Ropelewski	NWS
David Rodenhuis	NWS
Ronald Lavoie	NWS
Richard Thomas	NWS
Robert Leffler	NWS
Fred Zbar	NWS
Ronald Alberty	NWS
Thomas Kaneshige	OGP
Roy Jenne	NCAR

The Data Quality and Continuity Issue

Introduction

Environmental issues are increasing in importance globally, and the United States is facing increasing pressure to play a more active leadership role. Recently, Prime Minister John Major of Great Britain, traditionally one of our staunchest allies in the political arena, announced his nation's intentions to move ahead independently to adopt measures to limit greenhouse gas emissions. Some in the United States consider an appropriate stance on the issue is to pursue further study until we can establish beyond some reasonable doubt that greenhouse warming has occurred, and is a result of human activities. Regardless of our political stance, accurate and thorough documentation of the climate record is vital, and this has put increased emphasis on the National Oceanic and Atmospheric Administration's (NOAA) responsibilities to monitor the oceanic, atmospheric, and solar environment and to predict its future state.

NOAA as Data Steward

NOAA's credibility as the agency responsible for collecting, processing, archiving, and distributing environmental data must be maintained. As we focus some of our attention on new and exciting programs, we must not lose sight of activities that have been a vital part of our tradition, that are unique to NOAA, and must continue with the same care and dedication as before. Above all, we must continue to act as responsible stewards of environmental data. The scientific community has stressed the important role NOAA has to play in this regard through reports and documents published by National Academy Panels (e.g. Atmospheric Climate Data Problems and Promises, Panel on Climate-Related Data, Board on Atmospheric Sciences and Climate, National Academy Press, Washington, D.C. 1986), ad hoc working groups, and a Presidential commission.

Under circumstances of frequent platform and sensor changes, it is difficult to maintain consistently uniform monitoring standards over time and space. This is particularly true in the case of platforms with finite lifetimes, such as satellites. Some of the questions our colleagues have been posing are: How accurate are initial calibrations? How stable are calibration procedures during instrument lifetimes? How can we prevent loss of important data during platform and instrument changeover? In response to this growing concern, the Office of the Chief Scientist, NOAA, sponsored a workshop in April 1991 to address the issues surrounding the quality and continuity of the environmental data record. The summary and recommendations from the workshop will be discussed below.

Data Issues are Pervasive

While many of the recommendations that have appeared in reports over the past decade concern climate-related data, the problems of data quality/continuity are global in extent, reaching beyond monitoring for climate assessment to all environmental concerns. Some of the concerns that have been identified are:

* Calibration and validation of satellite sensors
* Long-term calibration of surface sensors
* Modifications in measurement and recording practices with new surface and upper air systems
* Changes in frequency of measurement or location of sensors
* Data gaps due to sensor malfunction or funding restrictions
* Modifications to sampling procedures (e.g. fisheries collection methodologies)
* Deterioration of existing magnetic tape archives
* "Inaccessible" archives of hard copy data
* Inadequate "side-by-side" measurements of existing and replacement sensors

The Complications Introduced by New Technology

Some of the issues mentioned here are related to the development and implementation of new technology. The scientific community is always ready to exploit new, exciting technological advances that provide alternative instrumentation for monitoring the environment. In some cases new technology has allowed us to examine our environment in ways that were impossible before. The coverage provided by satellites is one such example. In other cases, alternative monitoring techniques have been developed which result in substantial savings. In many cases, the development of new technology has led to unforeseen problems. However, the difficulties of the past may be minor compared to the issues we face in the future, as significant changes are made in the observing methods or platforms on which new instruments reside.

Research Demands/Monitoring Requirements

Future research and monitoring will make greater demands for accuracy, precision, and representativeness than we believed necessary in the past when we largely studied processes on scales much smaller than global. Further, the necessity to compare measurements from instruments separated in time and space and developed by different scientists, perhaps from different countries, produces unprecedented demands for initial calibrations traceable to international standards, and for the maintenance of those calibrations in field (including space) usage. In addition, the necessity for determining subtle environmental trends over long periods of time requires that the quality of the data not be affected by political/technological changes. The need to compare regions and investigate trends over decades places a major burden on those responsible for monitoring the earth system. The term "continuity of measurement" applies both to spatial and temporal measurements. Finally, a very basic problem is that we do not know exactly the full complement of observations necessary to define the earth's system, nor do we know exactly the quality of observations required. We may have to adopt a philosophy that all measurements must exceed present requirements. For many applications, but particularly for global or regional climate assessment, there seems to be an insatiable appetite for data, caused by the uncertainty of predictions.

Researchers will use whatever data they can obtain, and it is a fact that operational data for weather analysis and prediction will continue to be used for research purposes, particularly since installation of duplicative systems is prohibitively expensive. Although operational data may be adequate for routine monitoring and prediction, in many cases they may prove to be unacceptable for more exacting research applications. This does not mean that simply because the primary purpose of the data is for day-to-day operations, one should not strive for quality. But where does one draw the line between cost and quality? What responsibilities does the operational segment have toward the research community, and vice-versa? What mechanisms, if any, exist to foster communication and cooperation between the research and operational interests? Who has the responsibility to consider the broader scientific requirements when new instrumentation is proposed? Are instrument calibrations traceable to the National Institute for Standards and Technology? Could we commission NIST to embark on programs to aid us in developing sensors for the measurement of crucial parameters such as water vapor?

Who Has the Responsibility?

Many of these questions could be addressed to the broader scientific community, including other government agencies and other nations. The interagency coordination for many of the issues related to new atmospheric instrumentation is handled by the Federal Coordinator for Meteorological Services and Supporting Research. To what extent can we also utilize existing structures within such organizations as the National Academy of Sciences, World Meteorological Organization, the Intergovernmental Oceanographic Commission, and the University Corporation for Atmospheric Research? What organizations could assist with oceanic measurements? Unfortunately, the ocean community does not possess a similarly extensive array of corporate bodies for standardizing measurement practices. Although mechanisms exist that should mitigate the problems, they have not always succeeded.

Fundamentally, NOAA, and all agencies, must adopt policies and procedures that ensure the continuity and quality of the environmental measurements. At the present time, there is no oversight mechanism to coordinate measurement activities across NOAA. This problem is complicated because there is no NOAA-wide authority cognizant of the monitoring activities in the whole agency. The present review process for monitoring efforts involving new instruments or sensors contains no provision for agency-wide review to maintain a program of comparison with existing sensors, or sensitivity to the needs of other disciplines. The extent to which calibration programs exist is a reflection primarily of the concern of individual program managers. There may be a natural reluctance to avoid the question of the use of measurements by other disciplines because to take into consideration all potential users may result in increased costs that may be intolerable in present budget circumstances. It may be necessary to accept undesirably low quality data in the face of budget constraints, but the decision should be made consciously and should be documented.

Awareness and Communication

NOAA must remain aware of those changes that may endanger data continuity, and seek to bring together all parties interested in the monitoring of significant parameters. All elements of the agency must also be aware of the monitoring needs of others. However, there is a serious danger that, carried to extremes, such an oversight procedure would introduce lags and inefficiencies, if it were required to sign off on every instrument development in the agency. We need to delineate crucial categories of measurements and to require that, in planning for replacement of instruments or platforms, the program plan show that consideration has been given to these concerns.

NOAA should sponsor further meetings involving the broader scientific community of agencies, academia, and industry in the United States. We must depend on the NIST for guidance on existing standards, their applicability to current measurements, and the development of new standards rugged enough for field use. After these meetings, we must ask our scientific allies in other countries to join us in assuring the integrity of present and future data.

Suggestions for solutions to the problem have ranged from "do nothing, just call it to the attention of those concerned" to "establish a data czar". The most recommended was the establishment of a panel of technical personnel, representing each major element of NOAA, to meet periodically to consider problems of data quality/continuity and to suggest a course of action. The details of the charge to the panel are contained below in the workshop recommendations.

Workshop Summary

Data Quality/Continuity Workshop

The important first step to address the issue of data quality/continuity was the convening of an agency-wide workshop on April 11-12, 1991. More than 40 individuals participated, selected from a mix of experts in data/sensors and NOAA policy formulation, representing each of the Line Offices and major programs. It was not the intent of the workshop to be an exhaustive examination of issues surrounding all of NOAA's data holdings, but rather to concentrate on some of the key problems and articulate a policy to address some of these issues on a continuing basis. Vernon Derr, Director-designee of the ESDIM Project Office, presided.

The Workshop objectives were to:

(1) Identify those parameters that require special attention of NOAA management with respect to data continuity

(2) Prepare a draft policy statement for data continuity to be submitted to the NOAA Administrator for approval

(3) Specify a process and responsibility to identify and address issues on a continuing basis

(4) Outline a process for extending the effort beyond NOAA to other agencies and to the international community.

Most of the first day was devoted to presentations and identification of problems in a number of broad categories, including surface measurements for climate, upper air, ocean measurements, satellite measurements and calibrations, atmospheric chemistry, fisheries data sets, and geophysical measurements. A summary of outstanding problem areas is appended.

An unstructured working session followed the formal presentations, allowing all participants an opportunity to present their ideas openly. As expected from the eclectic mix of NOAA scientists, the free discussion produced a rich assortment of ideas, suggestions, proposals, and data problems. One of the recurring themes throughout the 1½-day workshop was the need to have first-rate scientists working continuously with data, regardless of whether NOAA establishes some formal mechanism to address data quality/continuity. That theme was translated into one of the recommendations presented here to give greater recognition to researchers who work extensively with data.

The issue of how much authority NOAA possesses on its own to establish measurement standards was raised in a subtle way. Interagency coordination of such issues is handled by the Federal Coordinator for Meteorological Services and Supporting Research. Other groups active in the data quality/continuity issue are: WMO, IOC, UCAR, OFCM, NAS, and the community of users (for example, aviation interests, state climatologists, engineering groups). The requirements-setting function represents a balance of need, politics, feasibility (technological), and cost.

Workshop Recommendation

> ***Form a standing committee, composed of scientists from a broad spectrum of backgrounds, including research, operations, and data management, to address issues related to data quality and continuity involving major environmental parameters.***

Discussion

This recommendation reflects the opinions expressed at the workshop to establish a formal mechanism within the agency to deal with the issue of data quality/continuity, although there was not unanimity of opinion on the need for a formal reorganization or restructuring.

The functions and attributes to satisfy the requirements of the NOAA Data Quality/Continuity activity are:

o To report its findings and recommendations to the Assistant Administrators, Program Directors, and the Data Management Advisory Council.

- To determine which data sets being developed in NOAA have achieved a status of special importance to the scientific community, and make recommendations to the Deputy Assistant Administrator for Information Services as to how quality and continuity of these data can be maintained.

- To participate early in the requirements-setting process for NOAA programs.

- To provide an environmental data conscience to foster standards and ensure integrity in our data bases.

- To provide a NOAA focus for data quality/continuity issues for the community of scientists external to the agency.

In addition:

- The membership shall consist of scientists or engineers from a broad spectrum of backgrounds and organizations. (Funding mechanism to be resolved)

- The committee would report to either the Deputy Assistant Administrator for Information Services, NESDIS, or to the Chief Scientist.

- Special issues for consideration will be the needs and functions of networks, such as those established for surface solar measurements, turbidity measurements, and global ocean measurements.

- Signature approval by the Deputy AA for Information Services should be considered for observation systems that measure major environmental parameters.

- We recommend that the National Academy of Sciences be asked to form a similar committee to advise NOAA and other federal agencies on issues of data management, data quality, and continuity. (There exists now the National Weather Service Modernization Committee of the National Research Council)

The recommendation proposes Line Office involvement at the policy level, through a committee of scientists. Who presides over this activity is a further consideration. While this is a data issue that is of considerable concern to the Deputy Assistant Administrator for Information Services, NESDIS, placing lead responsibility with the Chief Scientist Office could provide an assurance of objectivity for the other LO's. There was some discussion at the workshop concerning the representation on such a body. One certainly needs the views of the working scientist, but decisions will need to be made by individuals who are placed high enough that they can speak for the Assistant Administrator on policy. Thus, a strong argument could be made for including a good mix of headquarters and field personnel on the committee. An option to the standing committee in this recommendation is the creation of a separate Office of Data Quality/Continuity within each Line Office. While this adds to the "bureaucracy", it would provide a focus within each Line Office for this important issue, and would officially represent Line Office policy. This option implicitly recognizes the important role that each Line Office plays in monitoring.

In addition to developing options for addressing data issues institutionally, the workshop expressed a need to maintain a healthy agency-wide awareness of the importance of the monitoring mission. Some of the participants expressed the view that high quality data will be produced only when demanding scientists are strongly involved - both in the requirements-setting for monitoring, and in the subsequent studies and careful editing in the course of performing serious research. There was a clear plea to provide proper rewards for researchers who perform extensive data analyses. The workshop recommended that the Administrator reserve some research positions, utilizing the vacancies created by annual turnover, for such talented researchers who work extensively with data. The ideas were folded into the following:

Workshop Recommendation

> ***That the NOAA Administrator reserve positions from the annual turnover for scientific positions to dedicated research and development groups in each Line Office whose work requires extensive data reduction and analysis.***

Discussion

Much NOAA data have application to important national and international issues that are beyond immediate operational program needs. The greater value of NOAA data and the requirements for maintaining continuity and quality will largely come from in-house research with that data, including participation by the broader international scientific community. Each NOAA program needs a critical mass of research personnel. One of the workshop participants suggested that as many as 50 positions over a 3-5 year period should be a goal. Performance in these positions would be evaluated with respect to <u>both</u> the research they accomplish and the contribution (peer-reviewed) they make to the construction of high quality data sets.

KEYNOTE ADDRESS

John A. Knauss
Under Secretary for Oceans and Atmosphere

I have had many opportunities since I have come to NOAA to give the opening remarks, but I am particularly delighted to be asked to address this workshop. There is general agreement that this is a most important subject, and one with a long history. Back in 1969 the Stratton Commission on which I served said: "At present, there is a wealth of data within the Nation that is of limited value because of low confidence in the data quality or because the data came from diverse sources and are not comparable. This is not only a national problem, but it increasingly is becoming an international one.

"Standard instruments are not desired; in fact, the process of measuring environmental characteristics is changing so rapidly that any attempt to standardize design would inhibit technological progress. What is needed is the definition of standards against which instruments can be calibrated, the definition of performance and test criteria, and the development of field and laboratory facilities and techniques to test instruments against these standards."

Some ten years later, the National Climate Program Act of 1978 called for specific program elements regarding global data collection, monitoring, and analysis, management and dissemination of climatological data, and international cooperation in data dissemination.

About the same time, the National Research Council's Board on Atmospheric Sciences and Climate (BASC) published a report, "A U.S. Climate Program Plan (Climate Research Board of 1979)" which recommended that the federal government "formulate a conceptual framework for a Climate Information System as a basis for future planning of the climate data, information, and services component of the U.S. Climate Program. The framework should provide for the effective management of climatic data, the transformation of these data into useful climate information, and the rapid delivery of data and information to users."

A later report by the Climate Research Board, "A Strategy for the National Climate Program," issued in 1983 identified data management needs at both the national and international levels.

The National Climate Program's Report of the Woods Hole Workshop that took place in July of 1985 under the National Research Council's sponsorship identified "Data management issues requiring attention [to] include the following: (a) Timely release of data collected at public expense after the use for its collection is met; (b) Easy access, by other users and researchers, to data used in preparing climate products and reports for public dissemination; (c) Data management to handle increase data loads; and (d) New instrumentation requires adequate documentation, calibration, and possible changes of quality control procedures."

And the American Meteorological Society has just issued a policy statement on Global Climate Change. Contained within that policy statement are a number of points that are relevant to the deliberations at this workshop:

"At present, observations suggest, but are insufficient to prove, the atmospheric warming caused by human activities has already occurred. The evidence is insufficient to state conclusively that human-induced global warming has occurred. The nature of the current uncertainties defines the priorities for research needed in the atmospheric sciences if we are to better understand the likely future of our planet's climate."

In that policy statement two of the primary needs are: "(1) comprehensive, long-term, consistent observations of the key variables, such as cloud properties, that describe and influence the state of the atmosphere;" and (2) "studies which focus on the climate variability, to gain better understanding of the presumable natural, background fluctuations as the North American dust bowl...."

Environmental data management is like motherhood and apple pie; there are few dissenters concerning its importance, but it is not glamorous. It is often ignored and often starved for funds. It has been a top priority for me since I came to NOAA. We are pumping more money into the data management activities.

The first priority is to rescue old data, to make our data holdings readily available. The planning of this effort has been led by your chairman for this meeting, Vernon Derr, who has functioned as a one man advisory committee to me. Vern has led a study group to consider both program needs and organizational options. They have just reported on the latter. They listed four options,

> The preferred option is a separate line office for data management. They have also recommended a number of details as to how that line office should be organized.
>
> The number 2 option was a reorganized NESDIS with a Deputy Assistant Administrator, for data management.

I have accepted the second option and am appointing Greg Withee to the Deputy Assistant Administrator position. Greg's mandate is to organize the data management program within NESDIS exactly as it would be if it were a separate line office. At the same time I am announcing that it is highly probable that we will be coming forward with a request for a separate line office in line with the preferred option of the Derr group. My reason for this two step approach is one of efficiency; I can do option 2 immediately. It can be done within NOAA and does not require a sign-off from either OMB or Congress. I am told it could take from six months to a year to clear a separate line office through OMB and Congress.

Having set the organizational structure in place, and having started the massive effort to rescue old data and make it readily available, it is now time to tackle the more interesting and more intellectually challenging task of what data to save and how to insure its quality and consistency. I have read the report of the group that met in Boulder last June, the forerunner of this meeting. I gather that the issues raised in June were only the tip of the iceberg. Some matters can be resolved quickly and expeditiously. Some are expensive; some are nearly intractable; some go to the heart of the scientific enterprise.

Once you have resolved the easy problems of internal calibration and documentation, you come face-to-face with the age-old problem of the responsibility of those collecting data for one purpose insuring that they will be useful to those who may need it for other purposes. In many cases, no one can be certain what those other purposes might be.

Let me remind you of a few of the more obvious examples. The primary purpose of tide gages is to record short term changes in sea level, the tides; not to track decadal changes, and longer, in sea level. Positions of tide gages are changed as port development changes. In the past, positions were seldom tied to our first order leveling network. In spite of all the tide gages in the world, there are few that can be used for tracking sea level change for as long as a hundred years.

The primary purpose of the world's surface meteorological network is to provide data for the daily forecast. The primary observational requirement for the daily forecast is to record horizontal gradients - pattern recognition to the human forecaster, quantitative gradient analysis to the computer. The observational requirements for the daily forecast, which are primarily spatial analyses, are not identical, and are often not well served by the requirements of the climatologist whose requirements are primarily in the time domain. I could give more examples, as I expect could each of you.

Finally, there are the observations we didn't make in the past, that we wish we had. We might have saved many millions of dollars and much acrimonious debate on the subject of the effects of acid rain, if someone had only had the foresight to keep track of the pH of a series of Adirondack lakes for the past fifty years. What measurements should we be making now that we are not, that we will wish we had in 2050? And what about the data streams of the future? Must all data be saved? Back when data streams were a mere trickle, we could duck that issue. Can we do so any longer? Do we need to save all the data from continuously recording instruments? Can we satisfy the long term needs from such instruments and from satellites with a relatively small statistically chosen sample? If the answer is no, how are we going to cope? If the answer is yes, who determines the sampling protocols?

I return to where I started. The easy problems of data management are on the way to being resolved. We will save the old data; we will make them more easily available. We will organize NOAA so that data management has more visibility and more clout within the organization. But the challenging environmental data issues of our time remain to be addressed. This workshop is a step in that direction. I wish you well.

Modeling Perspectives on Global Monitoring Requirements

Jerry D. Mahlman
OAR/Geophysical Fluid Dynamics Laboratory

Introduction

Recognition that earth's climate and biogeophysical conditions are likely changing due to human activities has led to a heightened awareness of the need for improved long-term global monitoring. The present long-term measurements efforts tend to be spotty in space, inadequately calibrated in time, and internally inconsistent with respect to other instruments and measured quantities. In some cases such as most of the biosphere, most chemicals, and much of the ocean, even a minimal monitoring program is not available.

Recently, it has become painfully evident that emerging global change issues demand information and insights that the present global monitoring system simply cannot supply. This is because a monitoring system must provide much more than a statement of change at a given level of statistical confidence. It must describe changes in diverse parts of the entire earth system on regional to global scales. It must be able to provide enough input to allow an integrated characterization of the changes that have occurred. Finally, it must allow a separation of the observed changes into their natural and anthropogenic parts. The enormous policy significance of global change virtually guarantees an unprecedented level of scrutiny of the changes in the earth system and why they are happening.

These pressures create a number of emerging opportunities. They virtually demand an evolving partnership between the observational programs and the theory/modeling community. Without this partnership, the scientific community will fail in the monitoring effort.

In NOAA the current monitoring "program" leaves us far short of the required capability. This is true for two reasons. First, the magnitude of the global monitoring problem vastly exceeds the scope and capability of any one agency, or even any country. Second, even within NOAA's mission priorities, we are far from a strong monitoring program.

This is particularly so for the oceans. It is now recognized that the oceans play a major role in determining and regulating global change and climate variability. Unfortunately, the state of monitoring for the oceans is in bad shape relative to the demands. At the present rate, the prospects for improvement are not encouraging, with the possible exception of the ocean surface through use of satellite remote sensing.

Despite of these formidable difficulties, the need for improved monitoring and understanding the oceans represents a major opportunity for NOAA. No other agency or country appears to be better configured than NOAA to forge genuine progress in this emerging frontier.

NOAA has historically given high priority to oceanic issues and problems. NOAA has been committed to systematic long-term oceanic measurements for decades. NOAA has shown that it possesses the institutional will and patience to address difficult, long-term problems. This is no small achievement; most "science"-oriented agencies have avoided these kinds of hard problems. Finally, NOAA has developed major theoretical and modeling-based approaches to the characterization of global change, almost uniquely so for the ocean and for the coupled ocean-atmosphere system.

These attributes provide an enormous potential for NOAA to become a world leader in the emerging monitoring/interpretation system for the oceans in the context of global change. This opportunity and these institutional strengths do not by themselves imply that NOAA is currently on track to address these problems at a level commensurate with the obvious need. Clearly, a major enhancement of effort will be required.

This does not suggest that NOAA needs to panic or to institute a crash program. The creation of an oceanic monitoring/interpretation program will of necessity require a decade or more to set in place. Thus, the challenge before us is not to solve the problem now, but rather to set appropriate actions in place so as to create the required framework for solution. Each individual piece needs to visualize its role in the larger problem and how the required interactions are to take place.

Below we emphasize some of the needs and opportunities that could and should be addressed through participation by the theoreticians and modelers in the global change monitoring problem. Although the principles and possibilities are applicable to the entire climate system, the emphasis here will be on the role of theory/modeling in an emerging global ocean observing system. This is because the need and the value of improved monitoring are particularly compelling for the ocean.

Requirements for Theory/Modeling Support for Ocean Monitoring

a. Context

All observing systems are incomplete in the sense that they will never be able to measure everything, everywhere, all the time with perfect accuracy and sustained calibrations. Moreover, even if this impossible goal could be achieved, the changes recorded by the "perfect" measurements would still need to be interpreted in the context of previous predictions and to be explained scientifically. Thus, the challenge before use is to seek the mechanisms by which models can be used in cooperation with observational systems to yield the maximum information and to produce the required synthesis.

b. Information Content of Observational Networks

One of the most straightforward ways to utilize models in a monitoring context is in the evaluation of existing or hypothetical networks. For the atmosphere, successful examples of NOAA research include evaluations of the global radiosonde network, the Dobson total ozone network, global surface temperature measurements, and satellite temperature soundings. In such approaches, time-dependent three-dimensional model output statistics are sampled in ways identical or similar to that of a given network. The advantage of using the model is that the "right" answers in this context are readily available for comparison against the answer inferred from the network subsample. Such research has revealed a number of significant and, occasionally serious, deficiencies in the existing networks.

An often voiced objection to using models for research in this context is that the models tend to be seriously incomplete depictions of reality. True enough. However, models have the virtue of constituting a self-consistent global data set. Moreover, the typical model problem is that they produce only a restricted version of the much richer spatial and temporal structure in nature. Thus, model diagnoses of network information tend to err on the conservative side; problems identified in networks through use of models are likely to be even worse in the real world.

c. Evaluation of Models from Sparse Observational Data

The other side of the coin is that even the current monitoring networks can be very powerful tools for evaluating strengths and weaknesses of models. Surprisingly, this is still true for even the seriously undermeasured ocean. It is a common misconception that 3-D global models can only be tested through use of 3-D global data sets. Just the opposite is true. Even individual local time series can (and often do) demonstrate that a global model is deficient in certain respects. This is because a 3-D model attempts to capture both regional and global structures. Thus, if a global model exhibits local structure and temporal variations quite unlike the real world, the model has already been determined to be deficient. Thus, observed data properly taken at local sites can provide a powerful tool for model evaluation. In turn, improved models can provide a powerful tool for filling in the inevitable gaps in monitoring systems. We shall return to this theme later.

d. Design of Observational Networks

A particularly attractive possibility is to use models to design optimum networks at the onset. The attractiveness of this concept is almost irresistible because of the prodigious expense of constructing dense sampling networks. In principle, models can provide perspective and predictions on the value of data at various accuracies and sampling densities. In practice, this approach will be somewhat limited by the accuracy and credibility of the model employed. Models themselves undersample the environment because their data density is also limited by costs, in this case computational.

An intriguing example might be in application to the proposed use of acoustical techniques for ocean monitoring. Models, in addition to evaluating information content, can provide information on the required location and density of sending and receiving sites. Moreover, models should provide insights into the power and the limitations of path-integrated, density-centered (not temperature and salinity) measurements.

It is becoming increasingly common to hear that a new proposed monitoring network can be designed in advance using model-based insights. In principle, this is true; in practice, serious barriers remain. The most serious barrier seems to be the lack of properly focussed human talent. Each potential network design problem represents a serious and major research problem that typically requires several years of concentrated research to provide appropriately useful answers. Currently, there is a major deficiency of properly trained and focussed talent, backed by serious <u>commitment</u>, both personal and institutional, to solve such problems. The design of observational networks has the potential to become a significant new priority area in the context of global change monitoring and assessment.

e. <u>Model Identification of Global Change "Fingerprints"</u>

It is clear that global change is a major challenge for our long-term observing systems. Questions on what the monitoring networks are capable of measuring are strongly influenced by the presence of an evolving theoretical/modeling perspective on what the expected changes <u>should</u> look like. Unfortunately, the issue is clouded by the presence of significant uncertainty in the model predictions. Even though they are uncertain, the models still can provide major guidance to the kinds of signals that a network needs to be able to detect.

As examples, can the network detect a global warming signal in the ocean? How about CO_2 uptake? How will the warming signal differ from the expected low frequency variability operating on time scales similar to the expected anthropogenic climate signal? Can the signals be separated and understood independently? Will the regions of oceanic resistance to surface climate change be consistent with current model predictions? Will the model-predicted presence of very low-frequency natural variability in the same regions (e.g., Antarctic Ocean, North Atlantic) undermine the attempt to separate and analyze the signals?

Clearly, we do not know the answers to such questions at this time. However, it is a very safe prediction that we will have to deal with them in the context of an ocean monitoring system. At the very minimum, we must design our systems so that we at least deal with the difficult interpretative questions that are already before us. We must take on the natural variability question head on as a concomitant part of global change. We also must address the global ocean sampling and long-term calibration question with sufficient skill to address adequately the proper monitoring identification of the climate change signals that are already predicted for the oceans. This includes not only changes in temperature and CO_2 amount, but also salinity, currents, and sea level. In each case the models are already predicting decidedly significant regional structures in the expected changes.

f. Model Assimilation of Data in the Context of Climate Change

One of the inevitable aspects of expanded global monitoring systems is that they will be composed of data from heterogenous sources. The data will be heterogenous in terms of types of instruments and the nature of the data obtained. The sampling will frequently be spotty in space and sporadic in time. Some systems will be dynamically incomplete; temperature and salinities may be available, but currents may not be. Some data will be field experiment oriented while other data will be in the form of extended time series.

All of these data inconsistencies create the need for a unified approach for combining and synthesizing the data. Fortunately, over the past decade or so, viable approaches for accomplishing this have been developed for both the atmosphere and the ocean. This is the so-called four-dimensional data assimilation method (4DDA).

The 4DDA approach uses comprehensive numerical models to provide a physically consistent synthesis and global analysis. In effect, 4DDA uses a global general circulation model to accept input data in a dynamically consistent manner. The model serves as a "traffic cop" determining which data in which forms are acceptable for inclusion. The data are incorporated in such a way as to "nudge" the model closest to a self consistent analysis of the data. In this context, the model serves also as a non-linear interpolator to fill in missing spatial and temporal information as well as missing variables (such as currents or chemical tracers).

A great strength of this approach is the production of a self consistent final analysis. A great weakness is that the quality of analysis can be quite sensitive to the quality of the model used. This is a particular concern for the ocean where the data coverage is extremely coarse, the model resolutions are insufficient, and model quality remains relatively low. However, it is now recognized that the insightful use of 4DDA techniques holds great promise to improve the ocean models as well as the data analysis.

In the monitoring context, perhaps the most promising use of 4DDA is in the retrospective analysis of historical data sets as is now in preparation at the National Meteorological Center. This approach may be able to yield analyses over decades that are appropriately time calibrated for monitoring use and evaluation. An unsolved problem with this approach is a limited ability of the data checking procedures to filter out small apparent "trends" due to calibration drift or instrument changes. For a given analysis, this is a small effect; for climate change analysis, it can be as large as the signal itself. However, the advantage of the reanalysis procedure is that it can be redone as many times as necessary to glean the maximum information from the data set. A major hurdle in reanalysis (and re-reanalysis) is that it is computationally and labor intensive. Obviously, there will be tradeoffs between the quality of the analyses and resources available, just as in the monitoring networks themselves.

Another major use for 4DDA is in the emerging need to predict the transient evolution of climate from today's conditions. It is now being realized that climate predictions over the next few decades may depend importantly upon the state of today's ocean. Because the ocean has sufficient thermal memory to produce decadal-scale climate variations that are as large in magnitude as the increasing greenhouse forcing, it is very desirable to "start up" the ocean from today's conditions when performing transient climate change model experiments. Interestingly, this appears to be true whether or not the decadal scale fluctuations are found to be predictable in any useful sense. A model ocean that has eliminated all low-frequency fluctuations from its structure most likely will exaggerate the statistical significance of its own greenhouse warming signal.

These considerations raise the question as to whether the present ocean observational network is even able to characterize properly the state of the ocean for climate prediction purposes. For example, if we are presently in the midst of a natural global warming cycle (thus amplifying the apparent global warming), is the present data/modeling capability adequate to even identify it? Right now, we just do not know. Again, it must be an emerging partnership between the ocean data system and modeling/prediction research if the answer is to be found.

Final Comments

It is clear that success in the monitoring problem will require a growing partnership between theory/modeling and the observational data systems. It is equally clear that the task will be extraordinarily difficult. It will take a long time, perhaps decades, and will require a new generation of scientific talent, institutional resolve, and financial resources.

Finally, some will counter argue that the problem is too difficult and too unglamorous to command the sustained resources and commitment required. When such counter arguments are advanced, it will be important to remember the challenge facing us all:

> We are faced with nothing less than the need to identify how the earth system is changing over the next century, explain why the changes are occurring, separate natural from anthropogenic change, and learn if our predictions were correct or incorrect.

If we in NOAA cannot step up to this exciting challenge, it is a safe prediction that all of us will be held accountable.

Data Continuity and a Global Ocean Observing System

Dana Kester
Office of the Chief Scientist

Ocean Observations for Global Change

There is considerable evidence that human activities could lead to global change. Figure 1 identifies some of the ocean-related aspects of global change that encompass nearly all scientific disciplines and the full range of NOAA's activities.

The present ocean observing efforts are inadequate to provide reliable assessments (nowcasts) or predictions of future states of the issues listed in Figure 1. Over the past couple of years there have been discussions of the need to establish a Global Ocean Observing System (GOOS). Figure 2 states a basic premise for GOOS and lists its major elements. In formulating a design for a GOOS, careful consideration must be given to the requirements of the system. If all possible requirements are blended together, the specifications for the system will become unwieldy and unmanageable. One approach to this problem is to formulate a set of modules within the GOOS, each of which will have identifiable requirements (Figure 3). Data can be shared across the modules to avoid duplication of effort. Each module can be implemented at the pace determined by available resources. A rudimentary Ocean Service GOOS module currently exists with coordination provided by organizations such as the Intergovernmental Oceanographic Commission and the World Meteorological Organization. The Ocean Services subsystem supports (1) marine, regional, and global, weather forecasts, (2) safety in maritime operations, and (3) some international ocean and atmosphere research programs. The activities within this subsystem include a Volunteer Observing Ships program, a Global Sea Level network, an ocean drifting buoy program, and an International Ocean Data Exchange program. This module makes use of the Global Telecommunications Network to transfer data on a timely basis.

At the present time there is substantial interest in developing a climate subsystem in a GOOS. Figure 4 lists four objectives for this GOOS module. From these objectives specific goals can be stated (Figure 5). The three sets of goals listed for the climate subsystem correspond in part to three ongoing international research programs WOCE, TOGA, and JGOFS. The research programs are designed with a finite life time of 7-10 years: WOCE, 1990-1997; TOGA, 1985-1995; and JGOFS, 1988-1998. It is likely that these research programs will result in understanding of ocean processes, in observational capabilities, and in predictive models that will warrant long-term, ongoing activity to support assessments of global change.

Figure 6 provides a schematic illustration of what the climate subsystem of GOOS might look like later in this decade. The key features include a combination of satellite remote sensing and in situ observations to provide sea truth for satellite data and to reveal internal ocean conditions. All of the components shown in this hypothetical system exist today as parts of research programs and scheduled experimental satellite missions. With the oceans covering 70% of the earth's surface and with their remoteness from human habitation, global ocean observations will be inherently expensive. We must make maximum use of our understanding of ocean processes and of ocean-atmosphere models to design an efficient and cost-effective climate subsystem of the GOOS.

The GOOS differs from research programs such as TOGA, WOCE, and JGOFS in the following ways:

1. It will be designed to meet specific requirements that go beyond increasing our understanding of the oceans.

2. We will have to make a long-term commitment to acquiring the data and assuring its quality over decades.

3. The GOOS must produce information and products that are useful to its clients whether they are predicting ENSO events, seasonal weather conditions, climate change, or formulating future energy and food production requirements.

A well-designed GOOS will also provide future research scientists with a wealth of information about the oceans. Data continuity will clearly be required within the GOOS.

Examples of Data Continuity Issues

Sea level data obtained by the National Ocean Service and its predecessor organizations provide a good example of the value of data continuity. We have a nearly 140-year record of sea level at San Francisco (Figure 7). These data show variability on a wide range of time scales; they show a rising trend of water level relative to the land over the past 100 years; they demonstrate continuity of data over many generations of observers and measurement technologies. A similar record is available from New York (Figure 8) with less variability relative to the 100-year trend, but with a 15-year gap in the data from 1878-1893. Gaps are a threat to data continuity. We must be committed to continuity over time, even when it may be inconvenient. Systems must be designed either with backup capability or with timely repair and replacement upon failure. This is a particularly important issue with regard to satellite data. During the 1980s we lost the opportunity for data continuity of ocean color, of sea surface elevation, of scatterometer winds, and of synthetic aperture radar of surface characteristics. We will never know how valuable these data sets might have been in our present deliberations of global change, and how costly this lack of data continuity will be.

Data continuity has been a long-standing concern in marine science. One hundred years ago oceanographers needed a property to trace water masses and to calculate the density of seawater. Salinity was difficult to measure routinely, so they applied the constancy of composition of seawater and measured the most abundant anion--chloride. For procedural reasons chlorinity was not simply the amount of chloride in seawater; it was formally defined in 1901 to reflect the fact that it was measured by titration with silver (Figure 9). By the late 1930s oceanographers realized they had a data continuity problem. The chlorinity scale was shifting as values for the atomic weights of silver and the halogen elements were determined more accurately. This led to a redefinition of chlorinity in 1940. The definition, which is still in force, equates chlorinity to the mass of pure silver that will precipitate the halides from a specific quantity of seawater. The property can be determined solely from measurements of mass and the ability to detect when all the halides (excluding fluoride) have been precipitated from a sample of seawater. It is no longer a measure of the chloride content of seawater, or of the chloride, bromide, and iodide content of seawater. The mass of seawater in the 1940 definition was selected to provide data continuity with the previous chlorinity values.

There was further evolution of the salinity-density properties as we shifted from chlorinity titrations to laboratory salinometers (inductive and conductive) and in situ salinity sensors (inductive and conductive). Considerable attention has been given to the data continuity problem during this evolution.

Multiple Measurement Technologies

During the first half of the 20th century oceanographers were lucky if they had one good method to determine a particular property of seawater. In the intervening years and today we are blessed with a multitude of measurement technologies. Figure 10 lists some of the methods that have been used or are available for three ocean properties. (In the case of the XCTD, refractive index, LIDAR, and solid state pH sensors I am anticipating future developments by a few years.) An issue of data continuity is whether these different technologies provide the same measure of surface and mixed layer temperature, ocean salinity, or pH. As new or multiple technologies are applied to ocean measurements, it is essential that we determine their consistency, or inconsistency, with earlier technologies. This documentation must become part of the ocean database so that future users of the data will know how the values were obtained. It is not sufficient to report that the ocean temperature is 23.45 Celsius at a particular latitude, longitude, and depth without knowing whether that is based on a reversing thermometer, a bucket thermometer, an XBT, a CTD, an XCTD, or a satellite image.

Precision and Accuracy: Random and Systematic Errors

The following issue related to data continuity is elementary, but we must not overlook the need to determine and document the nature of errors associated with long-term measurements.

Figure 11 illustrates a hypothetical set of a large number of observations of a fixed property. The mean value of the precision are readily established. In this case the property has been determined to within 3% of its magnitude with 98% confidence. Assume that the true value is 33.5. The observing system has done a pretty good job. We rarely know the true value for a quantity, but we often work with defined standards to assure continuity among observers.

Now consider implementing a new generation observing system for this property, which yields a five fold improvement in precision. One possible outcome is illustrated in Figure 12. In this case we have achieved data continuity with the next generation system--the mean is the same as the previous system. Now, however, the observations are a poor representation of the true value. This is due to the presence of systematic errors in the observing systems. As precision improves, systematic errors become more important. Reproducibility does not reveal systematic errors.

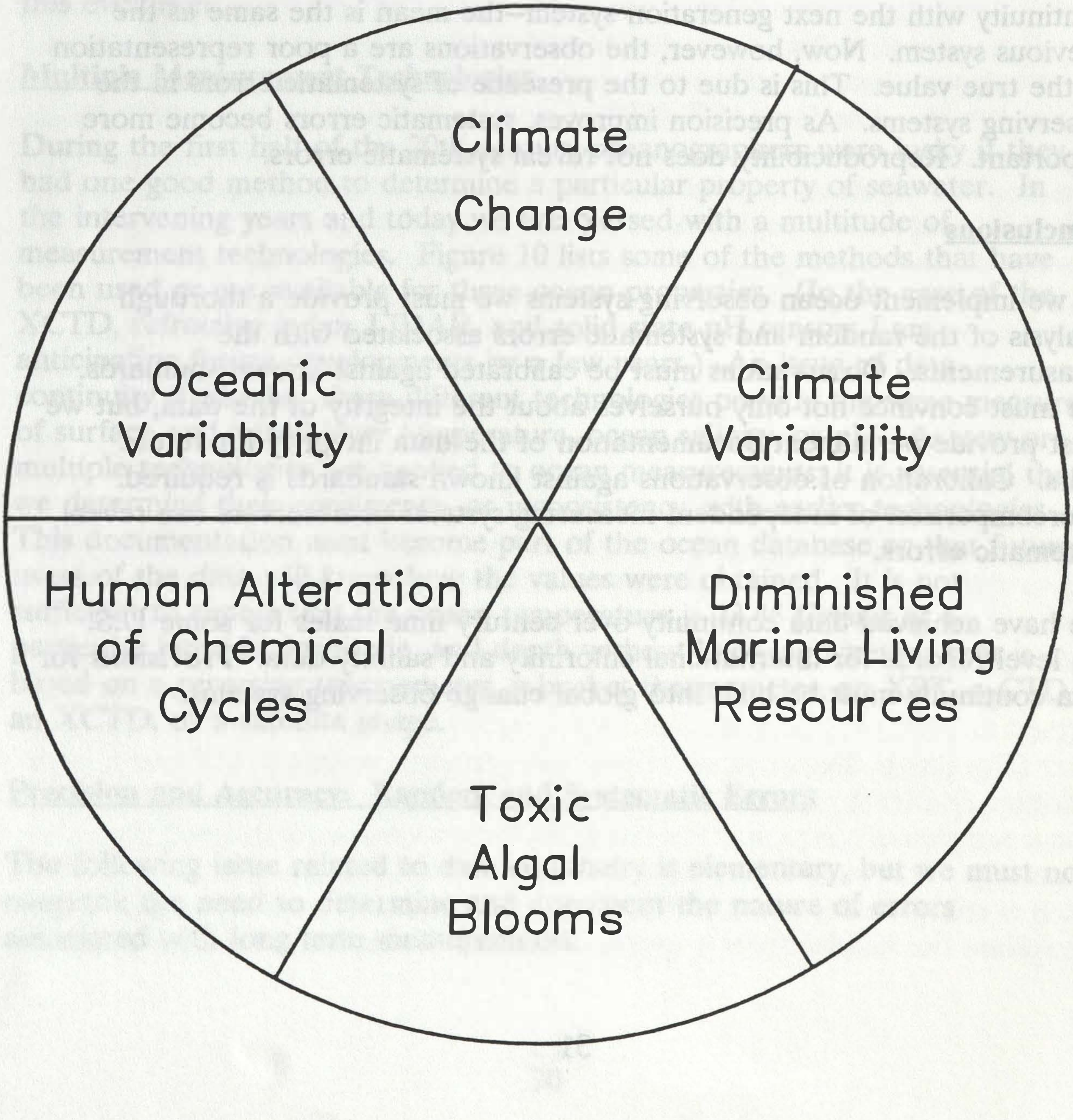
Conclusions

As we implement ocean observing systems we must provide a thorough analysis of the random and systematic errors associated with the measurements. Observations must be calibrated against known standards. We must convince not only ourselves about the integrity of the data, but we must provide permanent documentation of the data integrity for future users. Calibration of observations against known standards is required. Intercomparison of independent measuring systems or observers can reveal systematic errors.

We have achieved data continuity over century time scales for some U.S. sea level records for international chlorinity and salinity data. Provisions for data continuity must be built into global change observing systems.

Figure 1.

Ocean–Related Aspects of Global Change



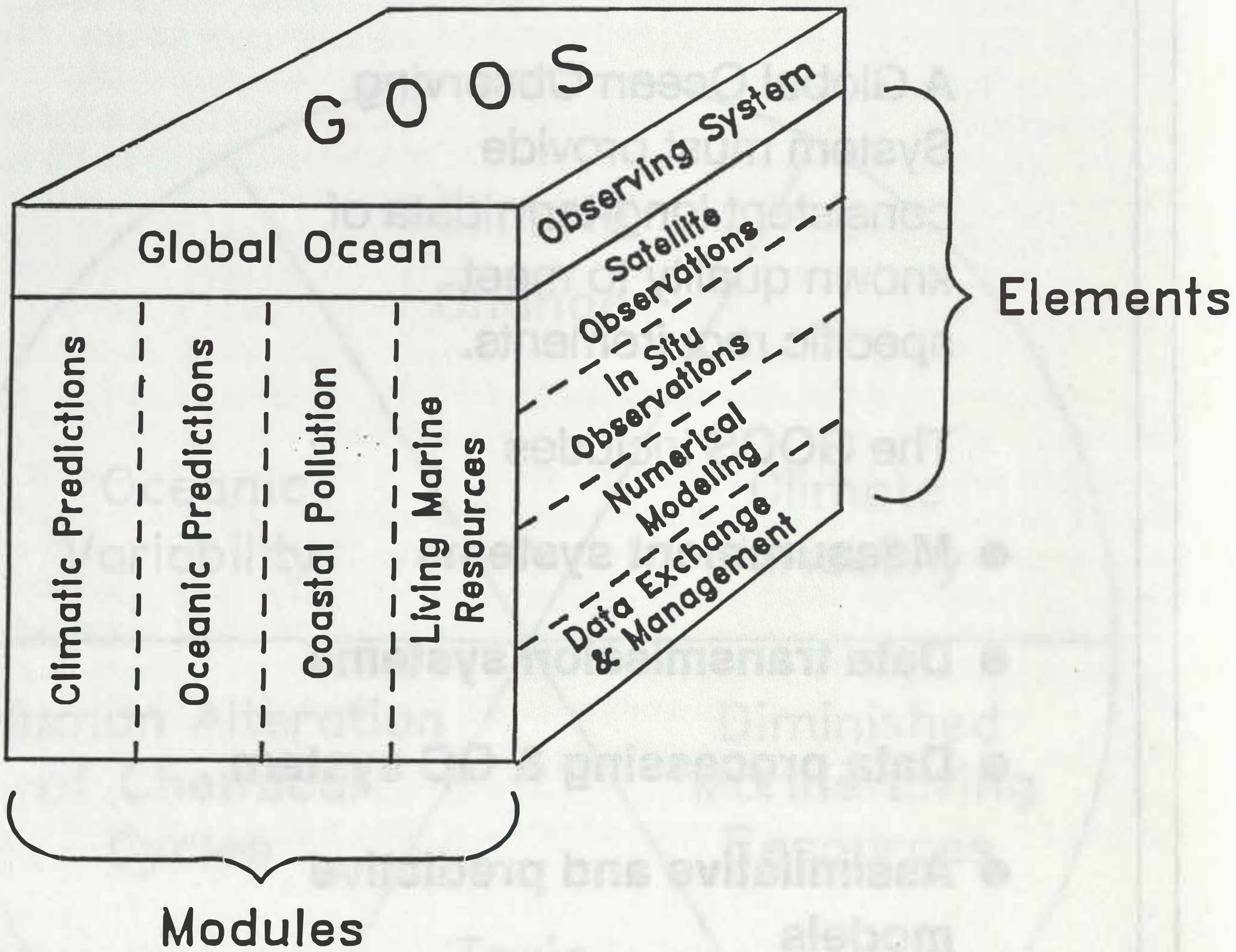
The Premise

A Global Ocean Observing System must provide consistent long-term data of known quality to meet specific requirements.

The GOOS includes

- **Measurement systems**
- **Data transmission systems**
- **Data processing & QC system**
- **Assimilative and predictive models**

Figure 3.



GOOS
Global Ocean
Observing System
Climatic Predictions
Oceanic Predictions
Coastal Pollution
Living Marine Resources
Satellite Observations
In Situ Observations
Numerical Modeling
Data Exchange & Management
Elements
Modules

Figure 4.

A Global Ocean Observing System Objectives

- Provide an ocean climatology database
- Detect climate change in the ocean
- Identify oceanic impacts of climate change
- Provide input data for ocean–atmosphere models

Global Ocean Observing System
Climate Module
Specific Goals

- **Monitor ocean heat budget**
  - *upper ocean thermal structure*
  - *latitudinal heat and water fluxes*
  - *thermohaline circulation*
  - *global sea level*
- **Monitor ocean variability**
  - *tropical Pacific ENSO*
  - *heat, salt, chemical choke point fluxes*
- **Monitor climate biogeochemical cycles**
  - *ocean-atmosphere CO_2 fluxes*
  - *balance the fossil fuel carbon budget*
  - *oceanic sources and sinks of methane*
  - *chemical and biological time series*

Hypothetical Late 1990s Global Ocean Observing System

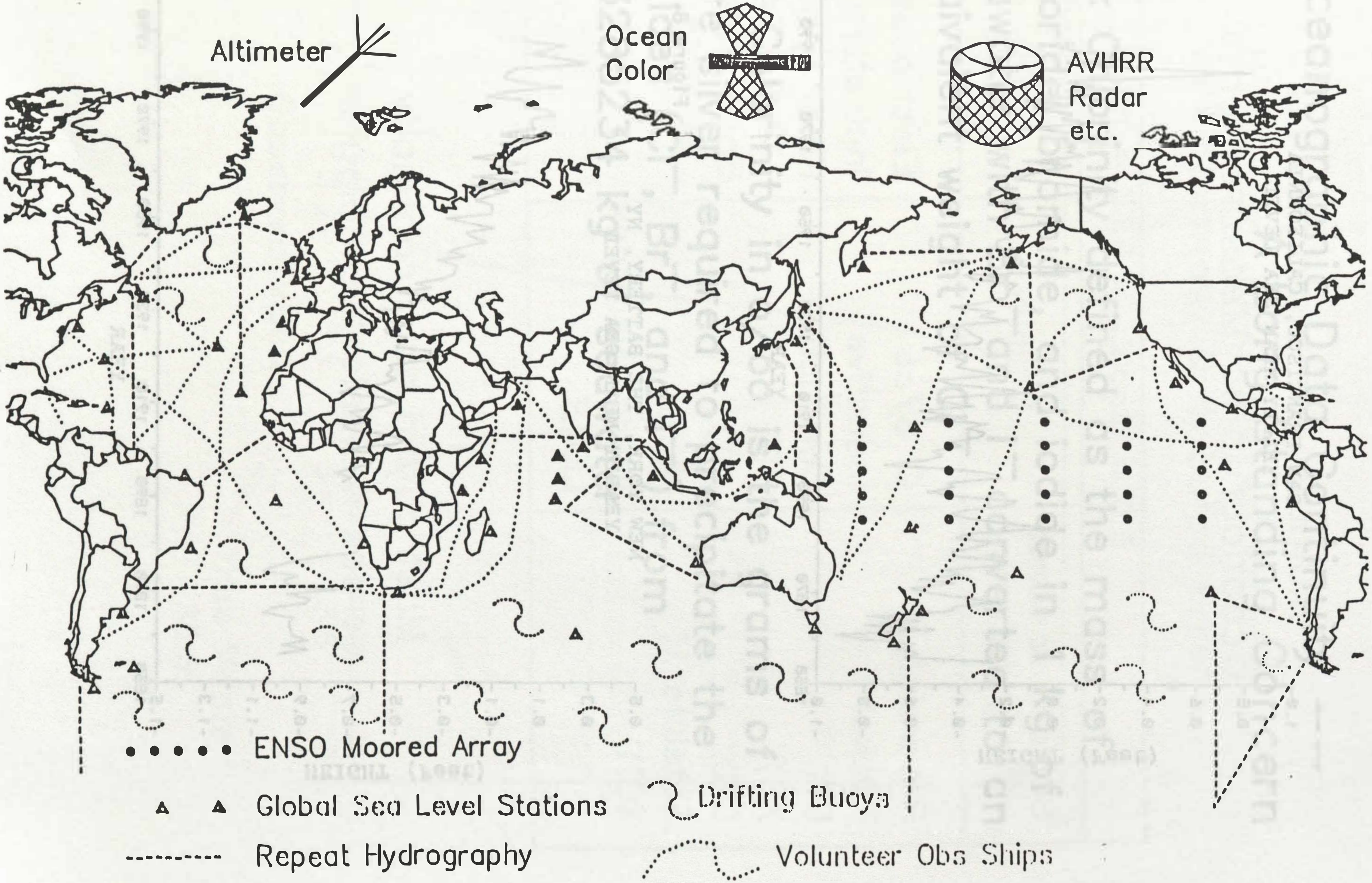


Figure 6.

Figure 7.

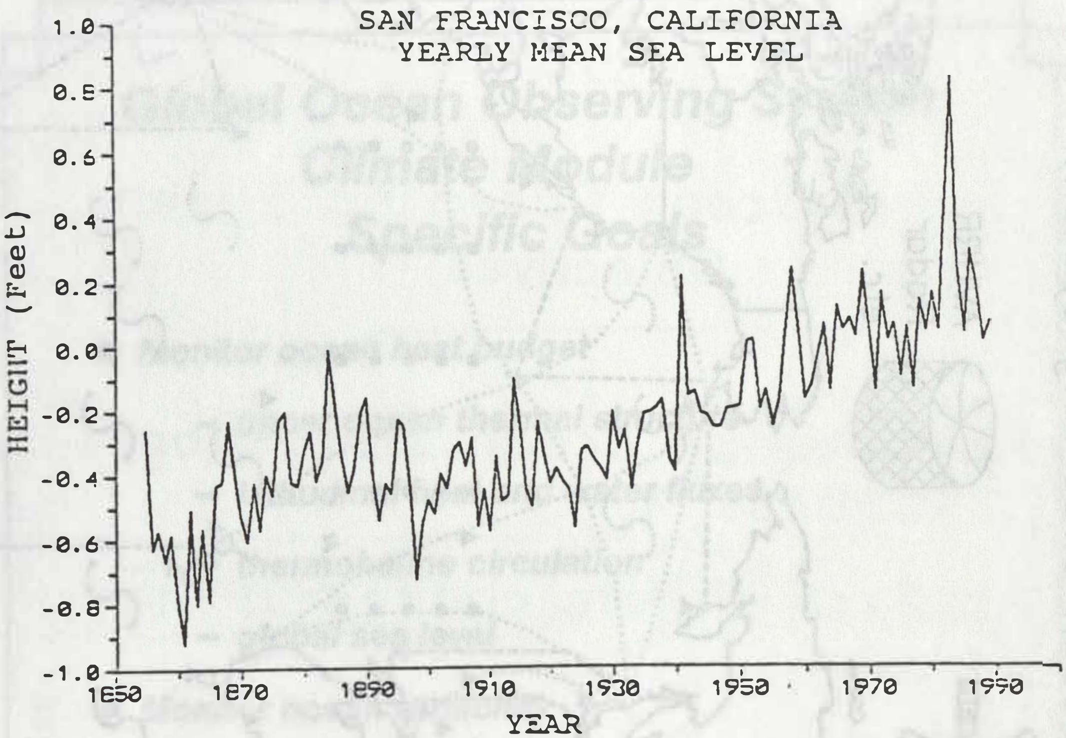
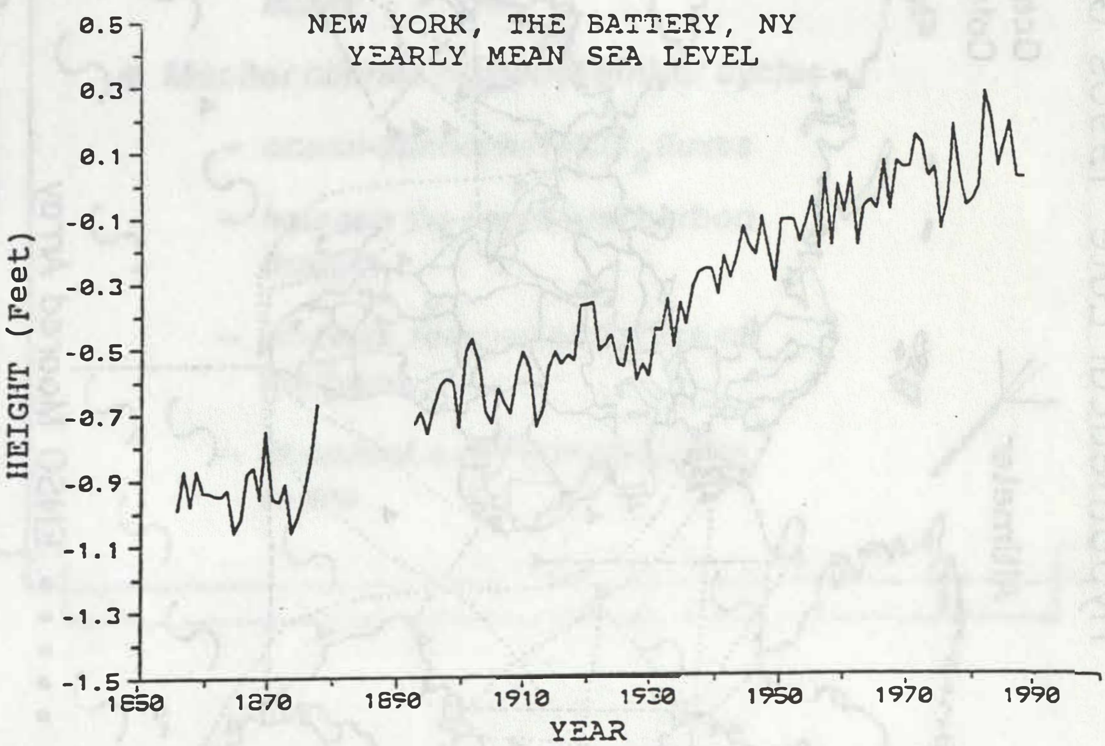


Figure 8.



Oceanographic Data Continuity —— A Long Standing Concern

1901: Chlorinity defined as the mass of chloride, bromide, and iodide in 1 kg of seawater with Br^- and I^- converted to an equivalent weight of Cl^-

1940: Chlorinity in o/oo is the grams of pure silver required to precipitate the halides (Cl^-, Br^-, and I^-) from 0.3285234 kg of seawater

Multiple Technologies for Oceanographic Measurements

Property		
Surface & Mixed Temperature	Salinity	pH
Reversing T Bucket T BT XBT CTD Satellite IR XCTD	Cl o/oo Inductive Conductive STD CTD XCTD Refractive Index LIDAR	Electrodes Indicators Fiber optic fluorescence Solid state sensors

Must obtain data continuity across multiple technologies

Figure 11.

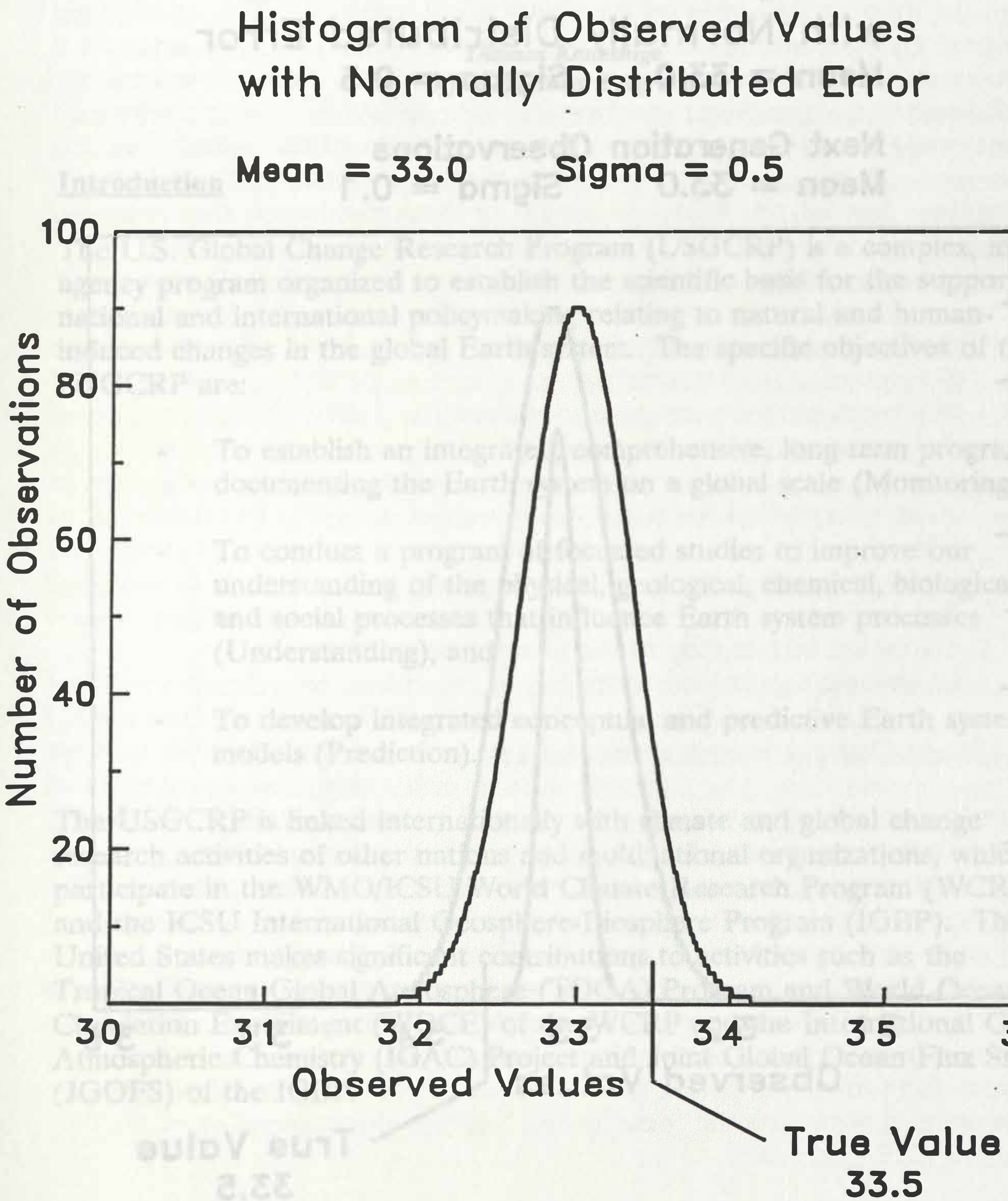
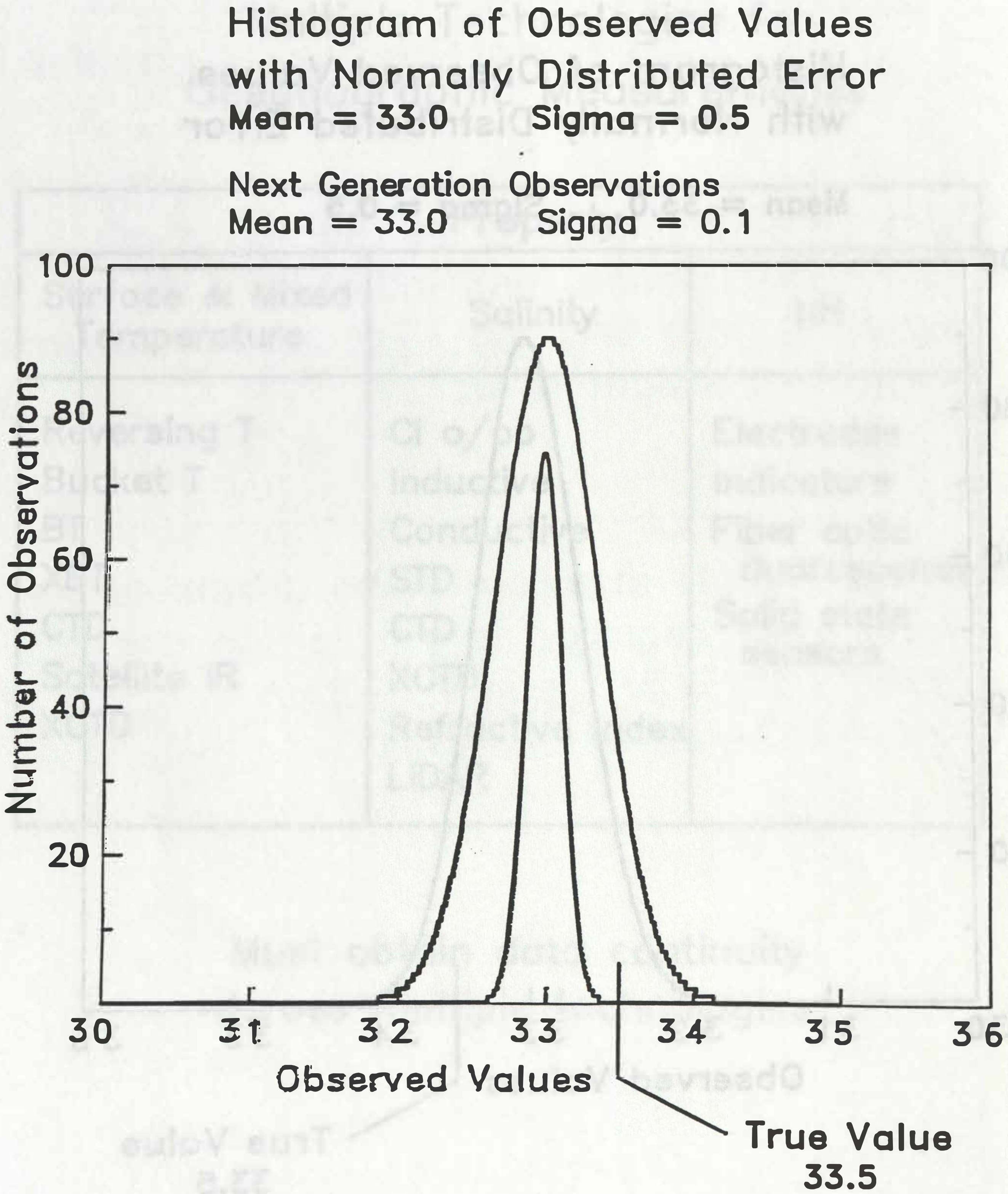

Histogram of Observed Values
with Normally Distributed Error
Mean = 33.0 Sigma = 0.5
100
80
60
40
20
Number of Observations
30
31
32
33
34
35
36
Observed Values
True Value
33.5

Figure 12.


Histogram of Observed Values
with Normally Distributed Error
Mean = 33.0 Sigma = 0.5
Next Generation Observations
Mean = 33.0 Sigma = 0.1
Number of Observations
100
80
60
40
20
30
31
32
33
34
35
36
Observed Values
True Value
33.5

Global Monitoring Requirements for the NOAA Climate and Global Change Program

Thomas Kaneshige
Office of Global Programs

Introduction

The U.S. Global Change Research Program (USGCRP) is a complex, multi-agency program organized to establish the scientific basis for the support of national and international policymaking relating to natural and human-induced changes in the global Earth system. The specific objectives of the USGCRP are:

- To establish an integrated, comprehensive, long-term program of documenting the Earth system on a global scale (Monitoring);

- To conduct a program of focussed studies to improve our understanding of the physical, geological, chemical, biological, and social processes that influence Earth system processes (Understanding), and

- To develop integrated conceptual and predictive Earth system models (Prediction).

The USGCRP is linked internationally with climate and global change research activities of other nations and multinational organizations, which participate in the WMO/ICSU World Climate Research Program (WCRP) and the ICSU International Geosphere-Biosphere Program (IGBP). The United States makes significant contributions to activities such as the Tropical Ocean-Global Atmosphere (TOGA) Program and World Ocean Circulation Experiment (WOCE) of the WCRP and the International Global Atmospheric Chemistry (IGAC) Project and Joint Global Ocean Flux Study (JGOFS) of the IGBP.

Global Monitoring Requirements

The issue of data continuity is paramount to the long-term (decades to centuries and beyond) monitoring objectives of the program. The signals that we are trying to document are, for the most part, so small that artifacts introduced in the measurement or derivation process could easily mask the variabilities and changes we are looking for. The USGCRP is so complex that one could not even begin to list all of the parameters that should be monitored to adequately support the seven science priorities that make up the program. Instead, the following is a list of those parameters that are more familiar and for which NOAA has the capability to monitor, using both in situ and satellite observing systems:

- Surface temperature (land, ocean)
- Precipitation (and evaporation)
- Tropospheric temperature and moisture
- Subsurface ocean temperature and salinity
- Cryospheric parameters (snow, sea ice, land ice, permafrost)
- Atmospheric circulation
- Cloudiness
- Land cover
- Sea level
- Radiation budget (top of the atmosphere, surface)
- Greenhouse gases and aerosols

Difficulties in Creating Long-term Data Bases

The need for long-term continuity and the need to keep up with the state of the art in technology tend to be in conflict with each other. Observing systems and the equipment needed to communicate and process the raw data into geophysical quantities are constantly being improved and changes from time to time are absolutely essential. With each change, however, there is a potential for introducing problems for monitoring programs in that the "old" and "new" systems frequently provide significantly different values of the same quantity being observed at the same time. It is essential that a sufficiently long transition period for simultaneous observing be introduced to calibrate and normalize the "new" to the "old" for the purpose of maintaining data continuity.

To a large extent, the USGCRP depends on the observing systems which have been deployed to support objectives that are not necessarily compatible with those for climate and global change purposes. Observations taken to support operational weather forecasting are "highly perishable" in the sense that if they are not available at the time the analysis/forecast cycle is run, the data are not used. Because of the time constraints imposed by operations, only a limited amount of quality control checking of data is possible, and there is really no strong operational need for retrospective processing of the data to ensure the long-term consistency of the data record.

The need to monitor the Earth system on regional-to-global scales further complicates the data monitoring problem. Despite the standards recommended by international observing programs such as the WMO World Weather Watch (WWW) and the joint IOC/WMO Integrated Global Ocean Services System (IGOSS), participating countries do utilize different types of equipment to measure the same variable, and this introduces the possibility of measurement differences due to the instruments themselves rather than to the variability of the parameter being measured. Additional complications that affect accuracies and precisions arise from changes in the locations of observing sites, changes in land use of the surroundings of a station, and changes in instrumentation.

Satellite observing systems have the capability to provide global observations on a regular basis, but suffer from temporal and spatial resolution deficiencies and problems due to "contaminants" in the field of view. Satellite instruments also suffer from degradation with age. Operational gain changes, while apparently improving the data for operational purposes, introduce discontinuities in the long-term data records. In the past, these deliberate changes have not been documented sufficiently well or the information has not been easily obtainable so that some interesting "jumps" in the data records have been uncovered (e.g., ISCCP). The worry is that some of these changes have been less obvious and are not as easy to discover.

USGCRP Data and Information Management Needs

The climate and global change program recognizes the need to introduce new instrumentation and ground processing equipment to provide the best information needed by scientific and policy users. At the same time, however, there is a need to document and archive the information that describes these changes and permits the user to "calibrate" the new with the old to ensure data continuity. Included among these types of information are:

In situ:
- changes in instruments and their characteristics
- changes in locations of observing sites and instrument exposures
- changes in land usage of the area surrounding the observing site
- differences in instrument characteristics from one site to another

Satellite:
- changes in instruments and their characteristics
- changes in on-board and ground processing algorithms
- changes in corrections applied to measurements

This supplementary information must be archived with the data to ensure that the user will have access to both types.

The task for monitoring long-term continuity of measurements is a difficult one, but a necessary one if the goals of the climate and global change program are to be achieved. The key ingredients for high-quality sustained monitoring are credible assessments of measurement accuracies, scientific involvement in the design of a monitoring strategy and in the interpretation of the data, and long-term professional and institutional commitments.

Enhancing Weather Observing and Data Management Systems to Reduce Uncertainties Regarding Climate Change

T. R. Karl
NESDIS/National Climatic Data Center

Past observing networks were built primarily to support weather prediction and assessment efforts or document climates which were thought to be invariant. Similarly, operational quality control and data management algorithms have focused on identifying outliers, and only rarely incorporate checks for data homogeneity. Furthermore, much of the information gleaned from near-real-time assimilation and analysis has not been used by retrospective data management systems. Nonetheless, scientists interested in quantifying changes of climate have made extensive use of these data. Unfortunately, unresolved inhomogeneities in the data have often subjected analyses of climate variation and change to criticism. Figures 1 and 2 show the effects of instrument changes in precipitation and temperature records. Inhomogeneities in the record are often as large or larger than past or projected climate variations.

Over the past decade, a surge of interest in climate change has occurred, primarily as a result of concerns over increases of greenhouse gases. Serious discussions now center on the cost of curbing our emissions of anthropogenic gases. Up to 150 billion dollars per year is the recent estimate of the cost of taking action in the USA to the extent proposed by many European countries and Japan (United States Congress, Office of Technology Assessment, 1991). Given these potential costs alone, it seems prudent to invest a tiny fraction of such an enormous expenditure in strengthening the operation of weather networks and data management practices throughout the globe so they will provide robust information about climate change throughout the rest of this Century and the next. The question is, "What would be needed and how much would it cost?"

It is feasible to outline many of the essential improvements required in operational surface observations and data management practices. The cost of these improvements in the United States should be modest compared to programs such as EOS, but it should be emphasized that such a system must be more than any one nation's commitment. An international organization such as the World Meteorological Organization (WMO) would have to take the leadership. These changes should be a cornerstone of the Global Climate Baseline Data Set Development, the Global Climate Change Detection, and the Global Climate Observing System Projects now in various stages of development within the WMO.

A number of basic principles of observation and data management must be adopted to broaden the mission of existing observing networks to include monitoring for climate change and variations. Such a mission is consistent with the call made by the IPCC (1990) to narrow the uncertainties related to documenting and understanding climate change and variation. These principles include:

1) Establish standard procedures for collecting overlapping measurements for all significant changes made in instrumentation, observing procedures, or the location of the instruments;
2) Make routine assessments of ongoing calibration, maintenance, or homogeneity problems for the purpose of taking corrective actions when necessary;
3) Develop standard station histories with routine monthly dissemination of changes (or initial status for new stations);
4) Develop standard data packages for important climate variables at various time and space-scales, which include a full discussion of processing procedures and algorithms used to reduce data;
5) Archive raw instrumental data prior to transformation into standard atmospheric variables or products along with the processed data and processing algorithms;
6) Establish closer working relationships between network designers and climatologists at the outset of network design, implementation, and changes; and
7) Maintain redundancy in observing networks to add robustness to data analyses.

Ideally, when changes occur in the network, side-by-side simultaneous measurements need to be conducted. The simultaneous measurements could be discontinued when the impact of the change can be quantified. This is not a new concept. The U.S. National Weather Service Operations Manual

(Section B-11) recommends overlapping observations for a period of 1 to 3 years. At present, infrastructure is lacking within weather services to support such procedures in the United States and much of the world. These procedures need to be established and supported at least for a representative subset of the existing global weather observing stations. In the future, portable automated climate stations may be used to help ensure that suitable transfer functions between new and old observing sites can be developed to account for changes in microclimate. Dual observations could be made with identical portable automated stations at both the new and old observing sites, while the more permanent station operates side-by-side with one of the portable automated stations.

To avoid uncertainties regarding changes in instrument biases, it would be desirable to establish a working museum of old decommissioned instrument types. One such museum of hydrological instruments exists in the Valdai branch of The State Hydrological Institute in the former USSR. It stores and tests scores of hydrological instruments (some from the 19th Century). Extension of this museum for precipitation gauges has been supported by the International Organizing Committee for the WMO Solid Precipitation Intercomparison Project (WMO 1991). Old gauges from various countries will be put into operation to gain knowledge about the biases of historical precipitation measurements. The creation of such museums could be an important asset toward resolving present and future in-situ measurement problems.

In an operational environment it may not always be possible to allow for simultaneous side-by-side measurements. For this reason it is advisable to operate a dense network of weather stations, scientifically designed so that occasional station losses will not badly degrade climatic analyses. This will allow comparisons among and between stations when simultaneous observations are not possible.

An aggressive program is required for near-real-time homogeneity assessment. This can best be accomplished by using both data and metadata. If the information about changes in biases can be relayed to network managers in a timely manner, the quality of the data for early warnings of climate change and variations should be significantly increased. In addition, real-time analysis fields (00 hr forecast) of numerical weather prediction models should be used to identify and investigate stations which consistently report values outside of an expected range. Mechanisms for archiving and effectively utilizing this information should be developed and implemented. It should be clearly understood, however, that even the best long-term data assimilation and re-analysis projects are not substitutes for long-term homogeneous observations.

Just as the WMO has developed standard practices for observing and reporting synoptic weather information, a similar scheme needs to be developed and implemented for the exchange of climate data (e.g., a uniform summary message for daily data and monthly extremes) and information on each station's history (current observing practices, instrumentation, sensor locations, exposure, the surrounding environment, etc.). The advantages of a standard report are many: facilitating the exchange of information among countries, lowering the probability of neglecting important information, and increasing the probability that the information is correctly recorded and distributed.

Computer software and hardware for on-line Data Base Management Systems will be important aspects of the data delivery system in the years to come. Just what that delivery system provides the scientist is dependent on adequate metadata. This is particularly important with respect to documenting the processing procedures associated with data reduction. All algorithms, averaging procedures, quality control, homogeneity checks, and corrections must be well documented and packaged to allow straightforward scientific analysis. Furthermore, those responsible for data reduction algorithms must work toward ready access of important climate characteristics beyond the usually reported mean anomalies integrated over large time and space scales. All this can be time-consuming, but its importance to the proper interpretation of the data cannot be overemphasized.

Fewer and fewer observations are direct measurements of basic climatological variables. Pre-processing of electronic measurements is rapidly becoming the standard. Not only must an effort be made to maintain adequate metadata, but data archives should be striving to preserve data in its most basic form. This would enable reprocessing should more appropriate transfer functions be developed (and they will if we use remote-sensing as an analogy).

Finally, over the past several decades observational networks have been designed for a variety of purposes, but rarely have they been designed to detect and monitor climate change and variations. This requirement can best be incorporated into network design by inclusion of climate change monitoring requirements in the earliest stages of network design. Climatologists and other scientists cannot afford to take only a passive interest in this area, as has so often been the situation in the past. Failure in this area will mean that future generations will still have to contend with many of the data uncertainties associated with the homogeneity issue we are addressing today. An institutional climate requirements infrastructure is needed to quantitatively, scientifically, and authoritatively deal with climate issues on an equal footing with weather reporting and weather prediction interests. These steps will allow us to resolve many of the important aspects of climate change. Knowledge of the precision and biases of measurement and processing can mean the difference between science and speculation.

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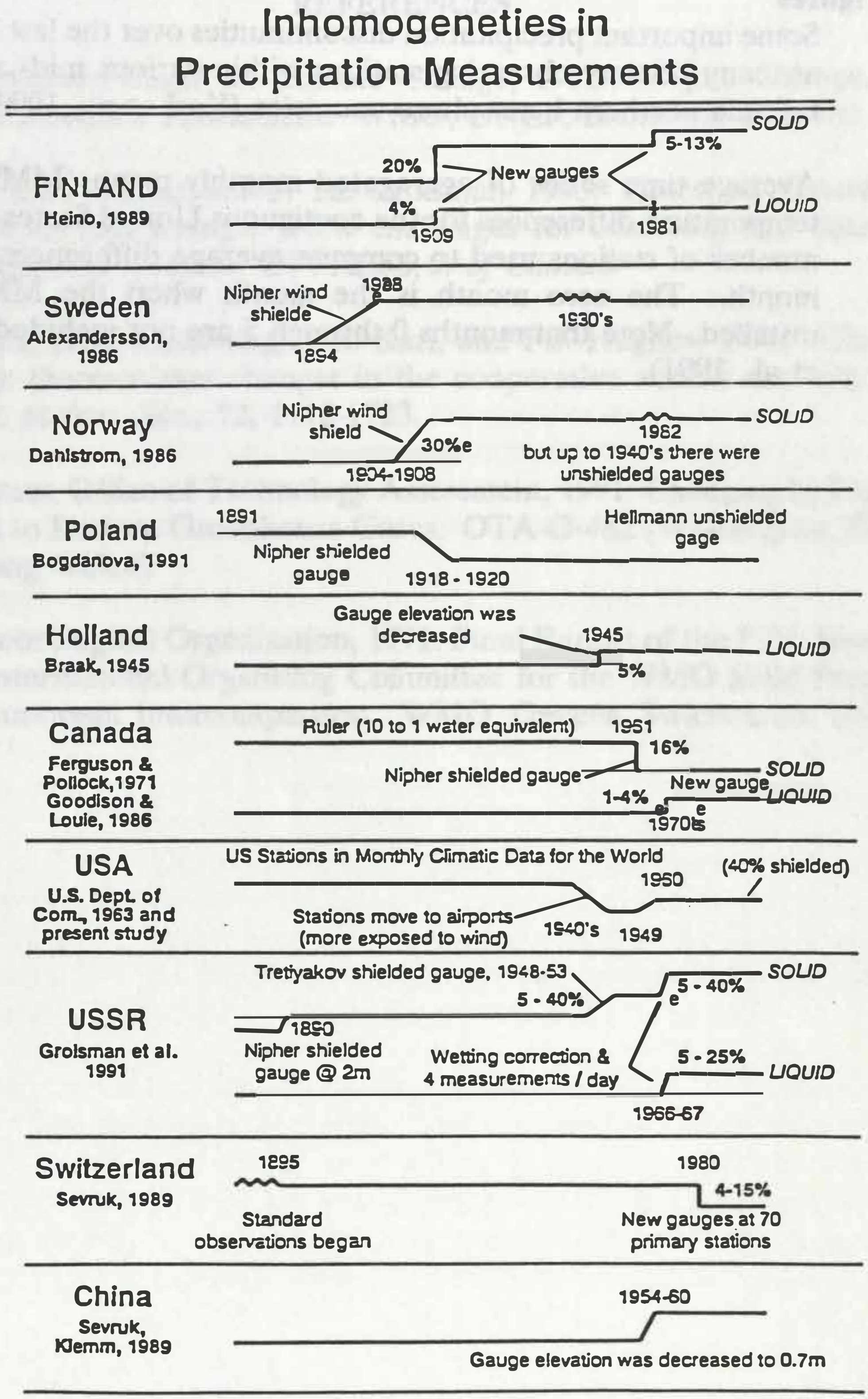

Figure 1 Some important precipitation discontinuities over the last 100 years at many primary observing stations within various mid- and high-latitude northern hemisphere countries (Karl et al., 1992).

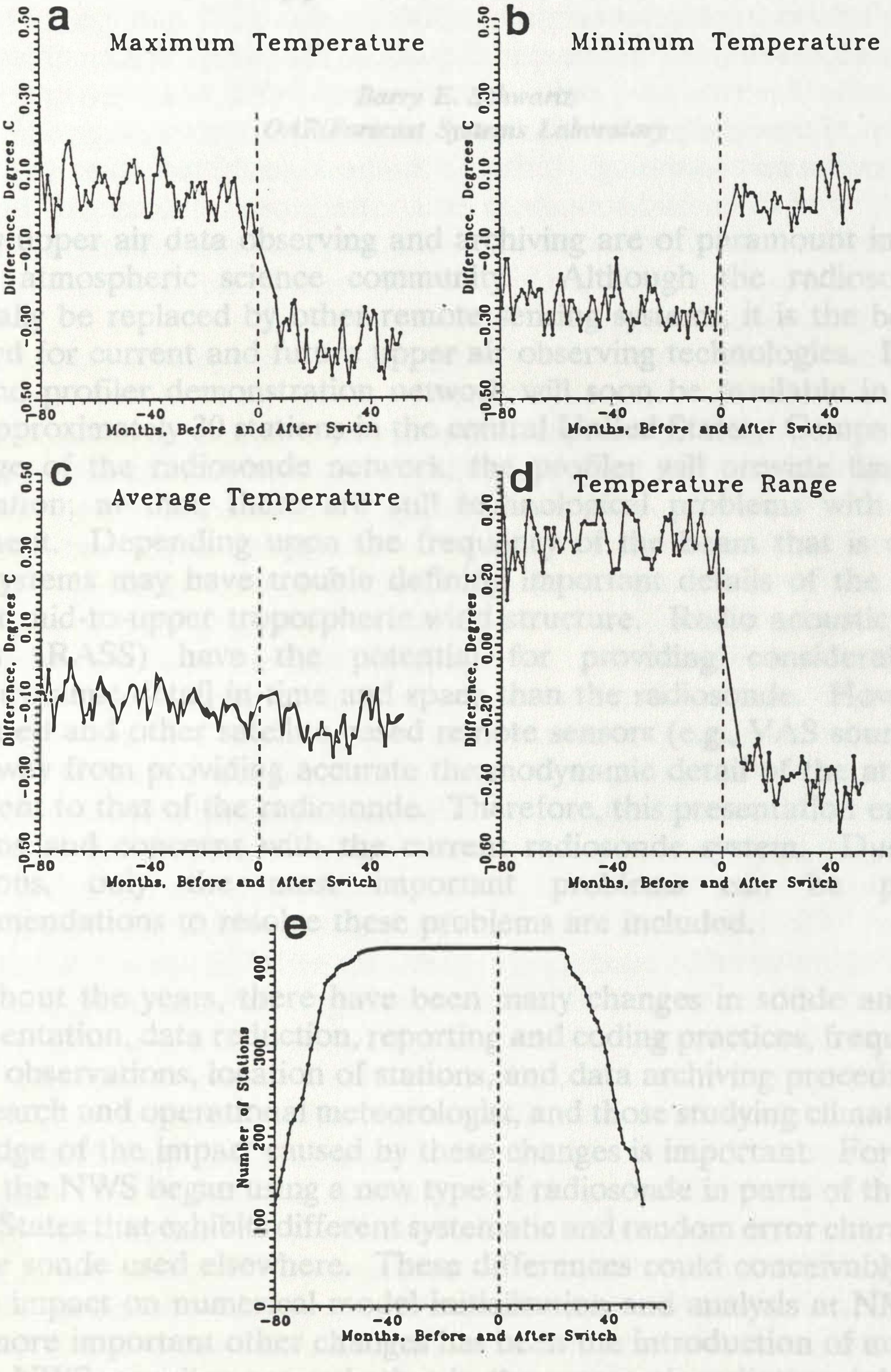

Figure 2 Average time series of aggregated monthly mean (MMTS-CRS) temperature differences for the contiguous United States and total number of stations used to compute average differences for each month. The zero month is the month when the MMTS was installed. Note that months 0 through 5 are not included (Quayle et al., 1992).

Upper Air Measurements

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Quality upper air data observing and archiving are of paramount importance to the atmospheric science community. Although the radiosonde may eventually be replaced by other remote sensing systems, it is the benchmark standard for current and future upper air observing technologies. Data from the wind profiler demonstration network will soon be available in real-time from approximately 30 stations in the central United States. Compared to the coverage of the radiosonde network, the profiler will provide limited wind information; at that, there are still technological problems with this new instrument. Depending upon the frequency of the beam that is employed, these systems may have trouble defining important details of the boundary layer or mid-to-upper tropospheric wind structure. Radio acoustic sounding systems (RASS) have the potential for providing considerably more thermodynamic detail in time and space than the radiosonde. However, this land-based and other satellite-based remote sensors (e.g., VAS sounders) are years away from providing accurate thermodynamic detail of the atmosphere equivalent to that of the radiosonde. Therefore, this presentation emphasizes problems and concerns with the current radiosonde system. Due to time limitations, only the most important problems can be presented. Recommendations to resolve these problems are included.

Throughout the years, there have been many changes in sonde and ground instrumentation, data reduction, reporting and coding practices, frequency and time of observations, location of stations, and data archiving procedures. For the research and operational meteorologist, and those studying climate change, knowledge of the impact caused by these changes is important. For example, in 1989 the NWS began using a new type of radiosonde in parts of the western United States that exhibits different systematic and random error characteristics than the sonde used elsewhere. These differences could conceivably have an adverse impact on numerical model initialization and analysis at NMC. One of the more important other changes has been the introduction of automation into the NWS sounding network; that is, the automatic radiotheodolite system

(ARTS). This effort was undertaken to standardize procedures, improve data consistency, and cut personnel costs. Although this goal has been at least partially accomplished, the automated system as currently implemented has resulted in a decrease in data quality, quantity, and NWS observer interest in data integrity. Ground equipment failures have resulted in missing soundings. Moreover, erroneous soundings continue to be transmitted over the data network. Some of these bad soundings occasionally pass undetected through automated quality control procedures and affect numerical weather prediction output.

A few problematic and antiquated observing and reporting practices are worthy of mention. Relative humidities <20% are routinely set to 19% (reported in the United States as a 30^0C dew point depression), when in fact, the current hygristor has resolution below 20%. In addition, U.S. data also exhibit a low bias for relative humidities >96% because the NWS has yet to implement a 1983 VIZ corporation correction algorithm to adjust high end relative humidities. In Europe, many stations report four times a day, while in this country, soundings are limited to twice a day. With an increase in emphasis being placed upon forecasting mesoscale weather disturbances in the modernized NWS of the 1990's, it seems logical that more observations in both time and space are essential.

As part of the NWS restructuring and modernization, many sounding stations have moved (or are planning to move), which effectively ends long-term climatological records at these sites. These moves, which are not being done in accordance with any known scientific considerations, also have a negative impact upon operational forecasting. In addition, the NWS has cut funding to the government of Mexico for 0000 UTC soundings. This too has resulted in numerous negative impacts upon forecasting and research.

There are many problems with how upper air data are archived at the National Climate Data Center (NCDC). Most noteworthy is the fact that NCDC does not archive the full resolution of the radiosonde report. NCDC data are different from the original observations and those coded for global dissemination (Global Telecommunications System (GTS) data). Original 1-minute wind data are interpolated to the significant levels, effectively smoothing the original wind profile. Information originally contained within the GTS data (e.g., maximum wind and mandatory level heights below the surface) are not archived. There are missing and erroneous significant level data for certain stations during the 1950's and 1960's. Original station records have been discarded for these early data, making it impossible to reconstruct older data for the archive. In addition, there have been problems with the humidity instrument itself (1968-1973) and the wind algorithm that interpolates the 1-minute data to the significant levels (1970-1979) that also potentially impact the archive. Moreover, a complete and accurate station history (containing latitude, longitude, elevation, and station identifiers) and instrumentation history are not available to users of NCDC data. Data are expensive to access because they are not sorted by time, effectively limiting operational NWS researchers access to their own data.

Solutions to these problems will require a concerted effort by various agencies; however, we could start by taking a close look at our observing systems and policies. Past experience suggests that those responsible for the implementation of new sensors, sondes, or ground-based equipment into operations could be more careful in the future to test and validate these systems adequately <u>before</u> they are implemented. Automation only <u>appears</u> to demand less of the observer; in fact, observer intervention and knowledge is more important than ever. Observers need to be better educated and trained; and there should be clear incentives for observers to carry out a quality observing program at their station (as there used to be) . Decisions concerning the location, time and frequency of observations, instrumentation type and precision, and data archival should be made using <u>primarily scientific</u> considerations.

The wide diversity of instrumentation and data reduction software and hardware in use indicates that coordination leading to standardization (e.g., development of a "reference" radiosonde and more intercomparison radiosonde flights) is needed to ensure some reasonable consistency among reports. The NWS should eliminate the automatic 30^{0}C dew point depression reporting practice and adopt the VIZ humidity algorithm for correcting high relative humidities. This would be a relatively simple way to improve the accuracy of humidity measurements, at least at the exteme values. A concerted effort should be undertaken to document a complete station and instrumentation history for upper air. Finally, the United States needs to reconsider its policy of funding the government of Mexico for their radiosonde program. Our government should be supporting efforts to enhance our observational capabilities.

Data from new upper air technologies will soon become available. We need to consider how and what we archive from these new systems now, so that we will not repeat the same mistakes made during the radiosonde era. Smoothing or revision of data should be left to the user and not the archiver of the data. Efforts to obtain and repair, if available, older erroneous and missing data in the archives at NCDC should begin. With the advent of highly efficient mass storage technology, we should be striving to obtain an archive, for both radiosonde and profiler era data, that contains the highest resolution possible, with minimal revision to the original records.

Upper Air Measurements

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Introduction

Practically all our present knowledge on the climate and its year-to-year variability in the free atmosphere is based on the historical data from the rawinsonde network. The network has grown from a sparse network of a few hundred stations after World War II to the present global network of about 800 to 900 regularly reporting stations (see Fig. 1).

Angell (1988) and his coworkers at NOAA's Air Resources Laboratory have been pioneers in determining the long-term temperature trend based on a carefully selected subset of 63 stations (see Fig. 2). At GFDL we have recently completed a thorough global objective analysis (Oort, 1983, updated) of many atmospheric quantities, including temperature, on a monthly basis using the entire available network at 11 levels in the vertical ranging from the surface to 50 mb height. In this note, some comparisons will be shown between the GFDL hemispheric mean temperature series and three other independently derived time series to evaluate the representativeness of the global rawinsonde network for climate trend studies. The three time series are the Angell series, a series based on the operational numerical weather prediction (NWP) model of the National Meteorological Center (NMC), and a microwave satellite-derived time series. For further details the reader is referred to Oort and Liu (1993).

Representativeness of the rawinsonde network

The seasonal time series for the period 1958 through 1989 for the troposphere (850-300 mb) and lower stratosphere (100-50 mb) based on the GFDL and Angell analyses are shown in Figs. 3 and 4, respectively. No clear trend is discernible in the troposphere, whereas a significant cooling trend is found in the lower stratosphere. There is excellent agreement between the two analyses as shown by the high degree of correlation.

Model-derived synoptic daily analyses such as those made at the National Meteorological Center are another possible source of climate statistics. However, they are generally thought to be unusable for climate trend studies because of the frequent changes in analysis schemes and data input made in attempts to improve the daily weather forecasts. Although the intercomparison for the 850-830 mb layer between GFDL and NMC as shown in Fig. 4a is not bad, the results for individual levels (see e.g., Fig. 4b) show the inherent problems in using the historical NMC analyses.

However, in the near future we can look forward to a new consistent set of historical analyses using a "frozen" general circulation model (GCM). This type of interpolation scheme between data points using the basic laws of physics must be, in the long run, superior to our analyses based on a purely statistical interpolation scheme. The so-called "re-analysis" project in preparation at NMC for a possible period of 30 years is of great importance; it should eventually be pursued much further back in time before the 1950's.

A promising, completely independent check on our analyses can be obtained by considering the recently published satellite temperature statistics by Spencer et. al., (1990) based on the microwave sounding unit (MSU) and available for the last decade. Fig. 5 shows excellent agreement between the satellite and the 850-300 mb rawinsonde curves, supporting the validity of both data sets.

In summary, we may conclude that the rawinsonde network provides an adequate and reliable measure of the year-to-year and interdecadal large-scale, hemispheric temperature variations during the last 30-50 years in the atmosphere below about 20-25 km height.

Recommendations

It should be a very high priority in NOAA to safeguard all daily soundings taken before May 1958, to make these data accessible to scientists, and to attempt objective monthly analyses of all available climatic variables in the free atmosphere for those years. No doubt, we can go back to the late 1940's to do analyses over the Northern Hemisphere, as shown by the map of station coverage in the NCAR archives (see Fig. 6). But even regional analyses using only the dense pibal data network over North America during the 1920's, 1930's (the "dust bowl" era), and 1940's, would be extremely valuable.

My specific recommendations are:

1. Make inventory of daily upper air soundings (radiosonde, pilot balloon, etc.) for 1920's, 1930's, 1940's and 1950's.

   - o What data are available, where and in what form (manuscript, punch card, magnetic tape) at NCDC, ETAC of U.S. Air Force, U.S. Navy....?

2. Make these early upper air data accessible to researchers.

   - o What resources are needed to make the data easily accessible and available on magnetic tape?
   - o Even single station records going back in time are invaluable
   - o All early data should be saved, since they can be used as an aid in reconstructing the past climate of the atmosphere or, at least, as a measure of local climate change.

3. Make rawinsonde data improvements.

   - o Present frequency of station reports for lower and middle stratosphere (50 mb level and higher) is insufficient.
   - o Humidity measuring techniques should be improved in upper troposphere. Is there any reliable method (e.g., SAGE satellite data) to measure the very low humidities in the stratosphere?
   - o Reporting practice for missing humidity should be standardized worldwide (see efforts by D. Gaffen, W. Elliott in ARL).

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Figure Legends

Fig. 1 Global distribution of the regular reporting ($\geq$ 10 reports during a month for OOGMT or 12GMT) rawinsonde stations for January of 1974 (774 stations) and 1989 (849 stations). These stations were used in the monthly objective analyses made at GFDL for the period May 1958 through December 1989 (Oort, 1983, updated).

Fig. 2 Global distribution of the 63 rawinsonde stations used by Angell (1988). Geopotential thickness anomalies for the stations were averaged in belts (e.g., 10S - 10N, 10 - 30N, 30 - 60N, 60 - 90N), and the resulting values were then averaged (with appropriate area weights) to obtain hemispheric and global mean thickness values. The thickness can be used as a measure of the mean layer temperature.

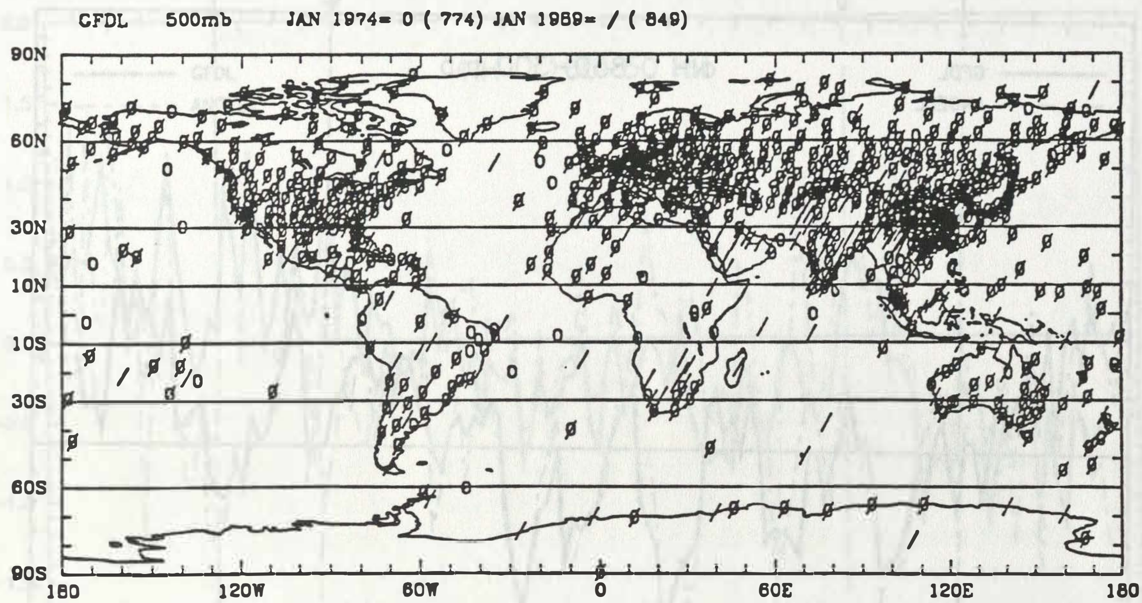
Fig. 3a Time series of the seasonal-mean temperature anomalies for the 850-300 mb layer in the GFDL (solid lines) and Angell (dashed lines) analyses for the Northern (top; NH) and Southern Hemisphere (bottom; SH). As expected due to the smaller number of stations the interseasonal variability is larger in the Angell curves. The correlation coefficients between the two analyses are r=0.88 for the Northern Hemisphere and r=0.82 for the Southern Hemisphere.

Fig. 3b Same as in Fig. 3a except for the layer 100-50 mb in the lower stratosphere. The correlation coefficients for the Northern and Southern Hemispheres are r=0.61 and r=0.76 respectively. The trends are -0.38 ± 0.12^{0}C/10yr (-0.23^{0}C/10yr) for the NH GFDL (Angell) data, and -0.45 ± 0.18^{0}C/10yr (-0.64^{0}C/10yr) for the SH GFDL (Angell) analyses.

Fig. 4 Intercomparison of the mean temperature analyses between the GFDL statistically-interpolated analyses and the NMC model-interpolated analyses for the 850-300 mb layer (a) and the 700 mb level (b). Some minor differences may be expected because of the differences in area, i.e., the entire NH in the GFDL case and the 20^0-90^0N area in the NMC case. However, the sudden 1^0C drop in the temperature of the NMC analyses at 700 mb between about Sept.-Nov., 1975 an Dec.-Feb., 1979 must be spurious.

Fig. 5 Intercomparison of the global mean temperature analyses between the MSU Channel 2 satellite data (solid line; after Spencer et al., 1990) and the 850-300 mb GFDL rawinsonde data (dashed line) for the 1979-1990 period (adapted from "Climate Assessment, Decadal Review 1981-1990" M.S. Halpert and C.F. Ropelewski, editors (1991), Climate Analysis Center/NMC/NOAA, see their Fig. 39).

Fig. 6 Global distribution of the regularly reporting rawinsonde stations during the period 1950-1958, that are available in the NCAR archives (open circles indicate NCAR time series, crosses U.S. Air Force ETAC time series; courtesy R. Jenne, NCAR).



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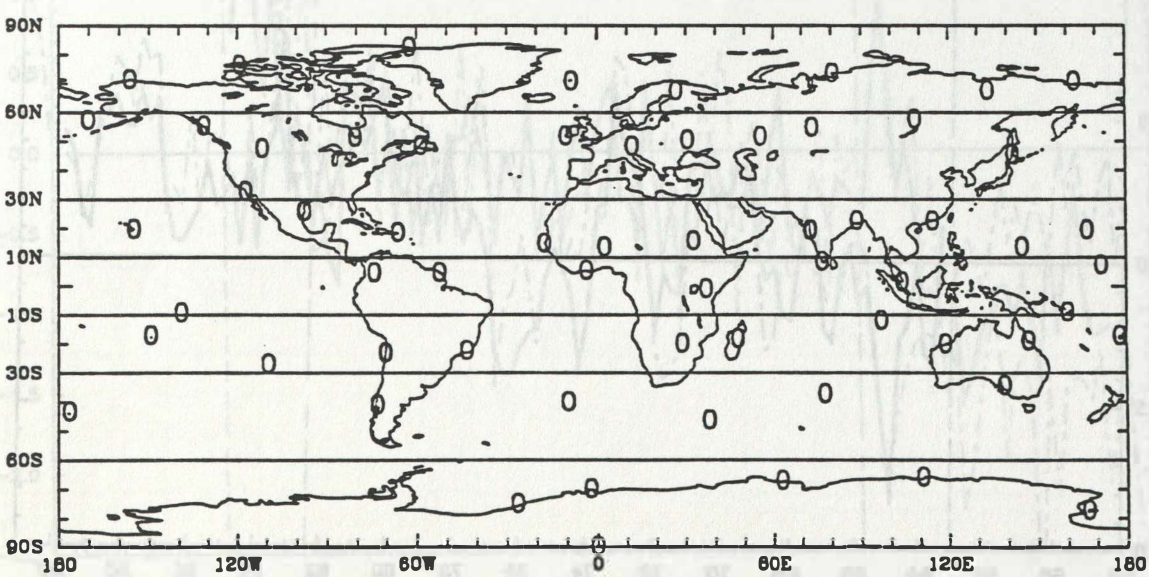

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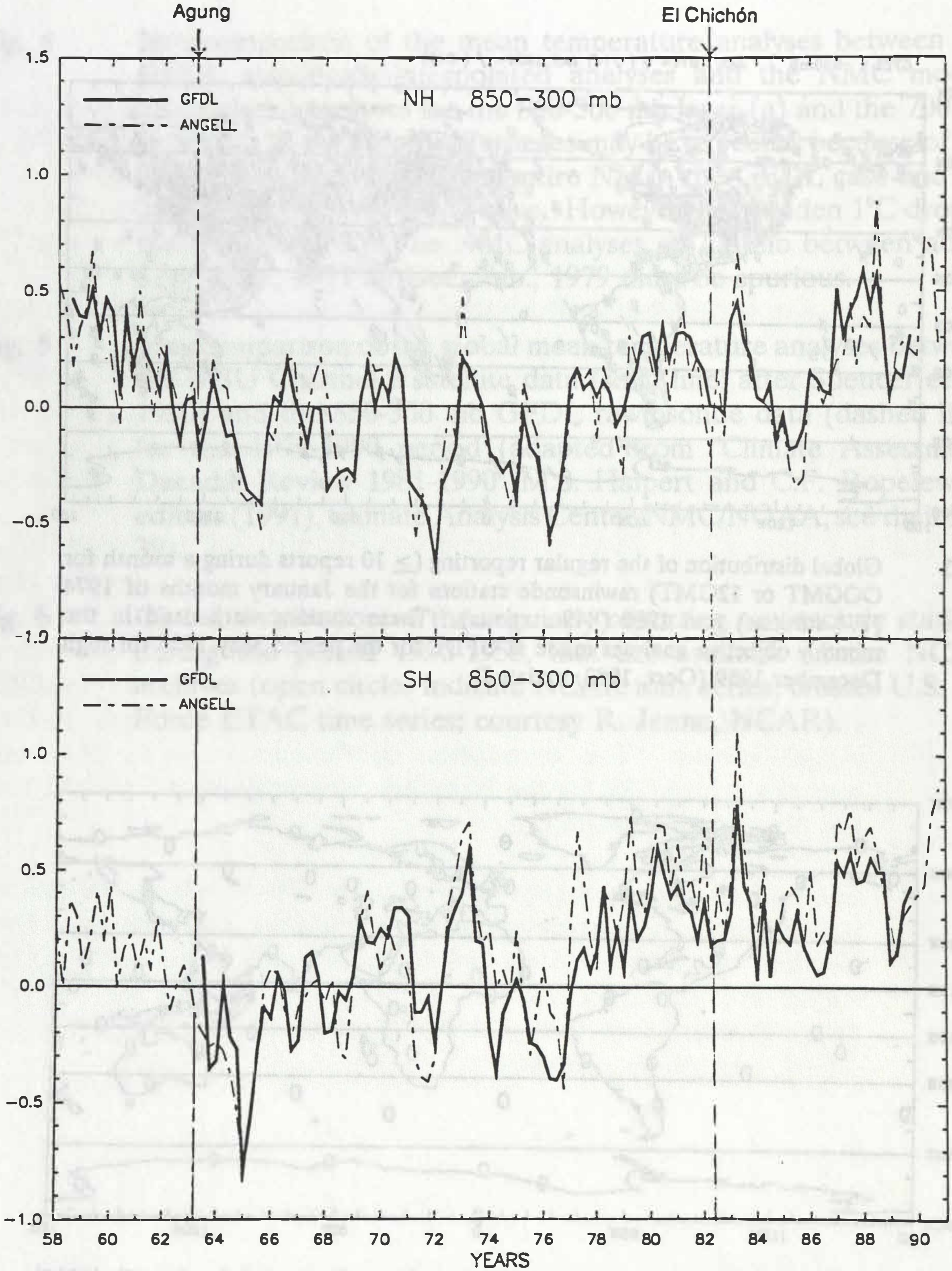

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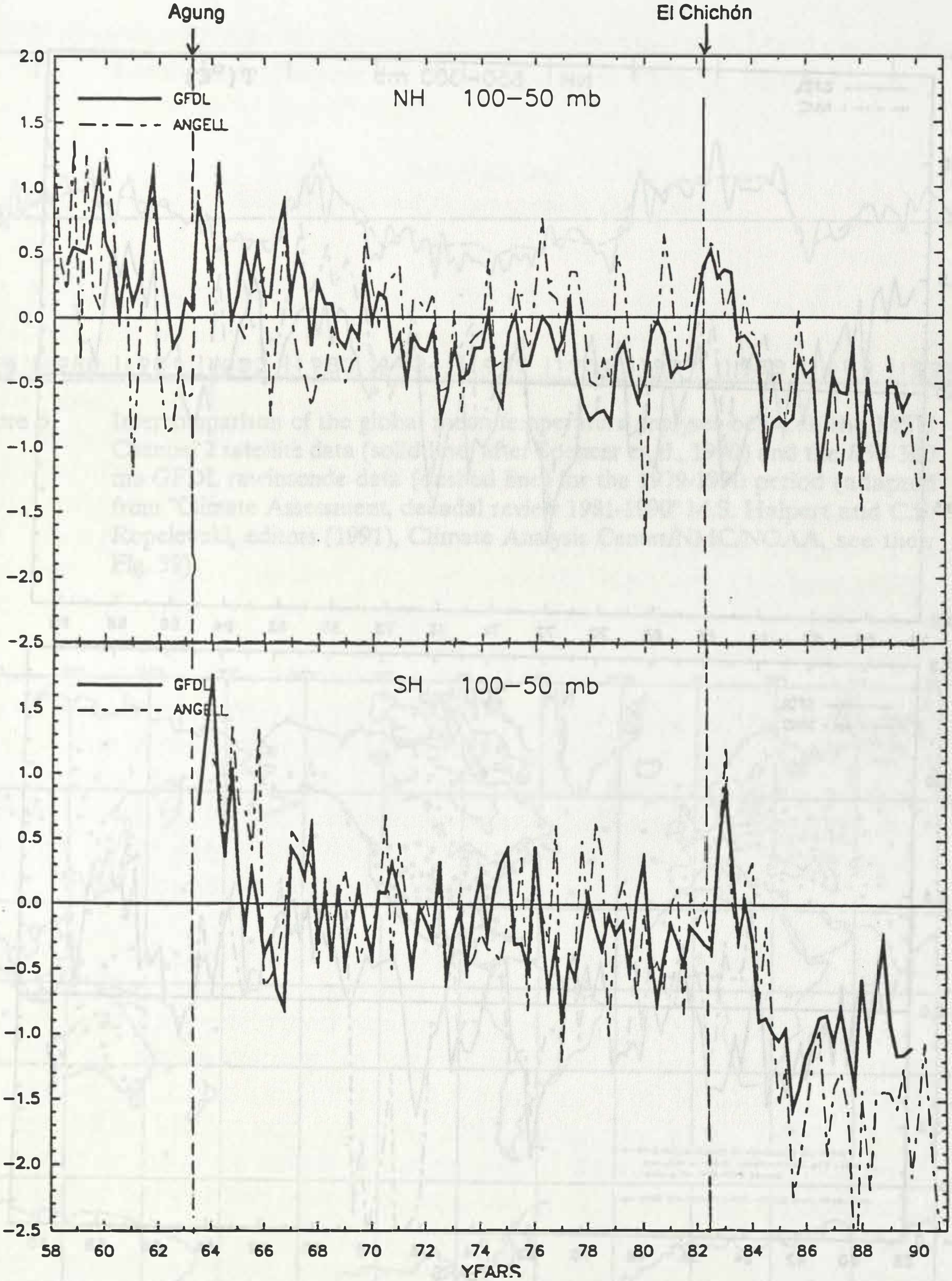

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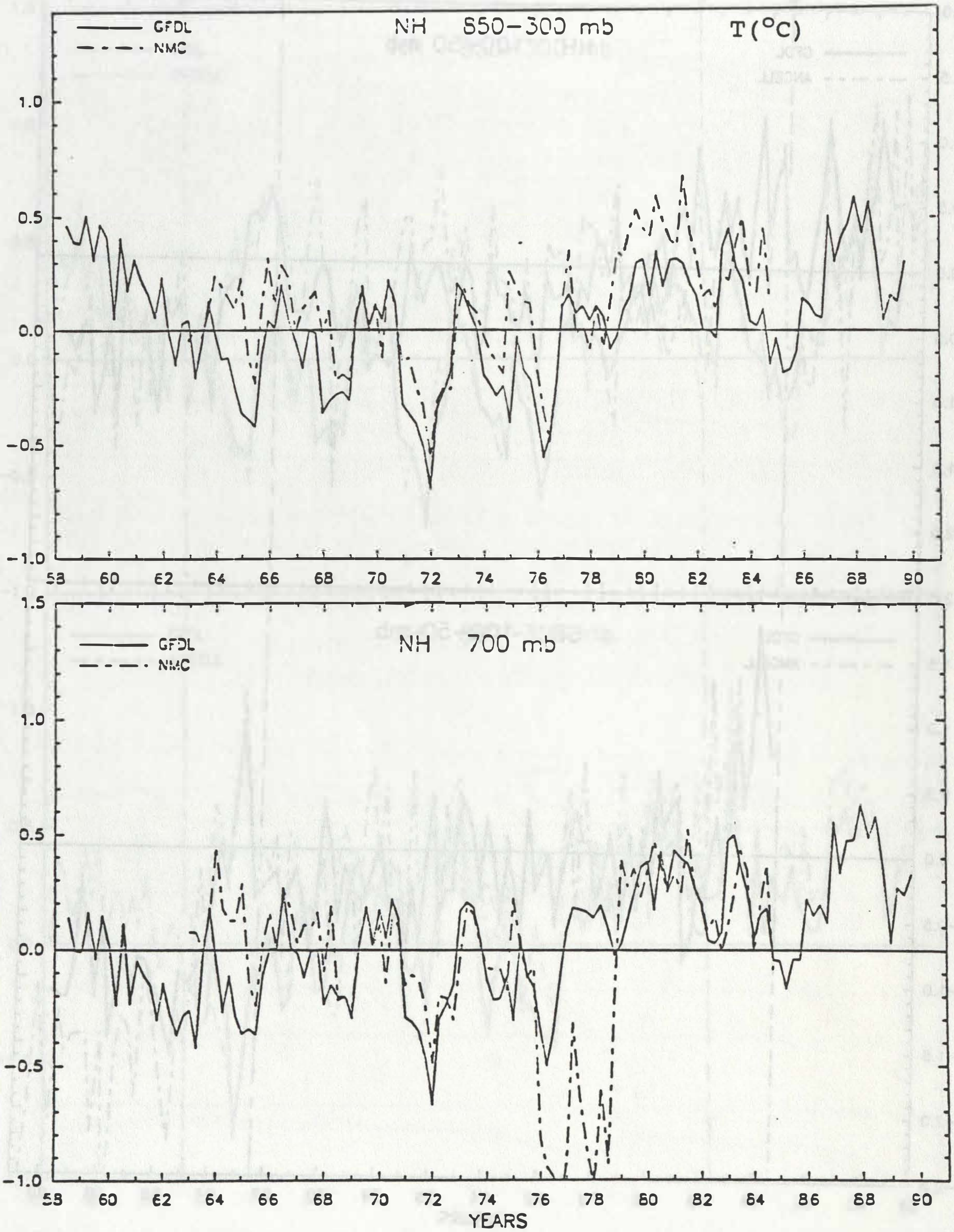

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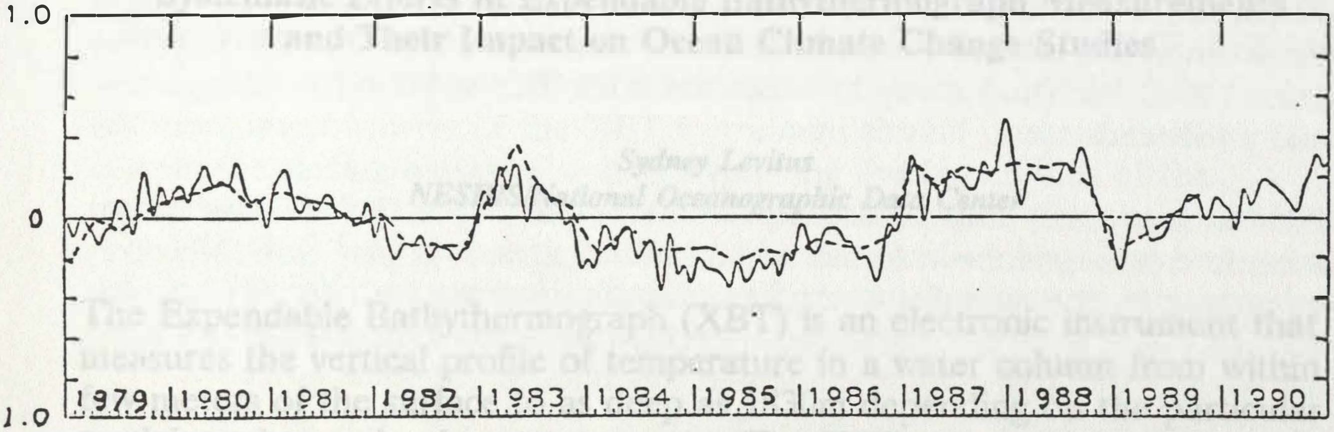

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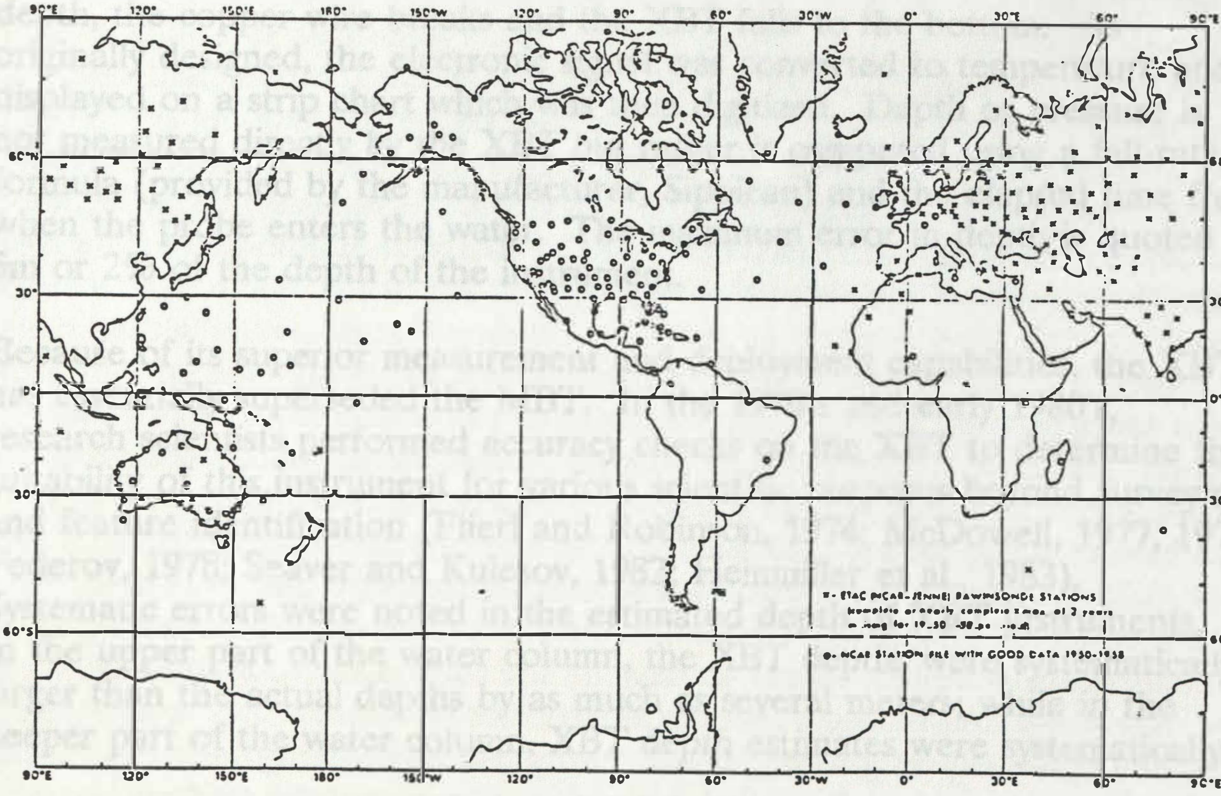

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Systematic Efforts in Expendable Bathythermograph Measurements and Their Impact on Ocean Climate Change Studies

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The Expendable Bathythermograph (XBT) is an electronic instrument that measures the vertical profile of temperature in a water column from within a few meters of the surface to as deep as 1830m depending on the particular model used to make the measurement. The XBT was developed by the U.S. Navy in the early 1960's to provide an improved temperature survey tool over the Mechanical Bathythermograph (MBT), which had a maximum depth range of 295m. The MBT was lowered and recovered with a winch and required a substantial decrease in ship speed when the instrument was deployed. The XBT transmits its signal to the deploying platform (ship, aircraft, helicopter) via a thin copper wire that is spooled out from the XBT as the instrument sinks in free-fall. When the XBT reaches its maximum depth, the copper wire breaks and the XBT falls to the bottom. As originally designed, the electronic signal was converted to temperature and displayed on a strip chart which was then digitized. Depth or pressure is not measured directly by the XBT but rather is computed using a fall-rate formula (provided by the manufacturer, Sippican) and the elapsed time from when the probe enters the water. The maximum error in depth is quoted as 5m or 2% of the depth of the instrument.

Because of its superior measurement and deployment capabilities, the XBT has essentially superseded the MBT. In the 1970's and early 1980's, research scientists performed accuracy checks on the XBT to determine the suitability of this instrument for various scientific purposes beyond surveying and feature identification (Flierl and Robinson, 1974; McDowell, 1977, 1978; Federov, 1978; Seaver and Kulesov, 1982; Heinmiller et al., 1983). Systematic errors were noted in the estimated depth of XBT instruments. In the upper part of the water column, the XBT depths were systematically larger than the actual depths by as much as several meters; while in the deeper part of the water column, XBT depth estimates were systematically less than the actual depths by as much as 15 meters at 700m depth. These errors were at the limit of accuracy stated by the manufacturer. Seaver and Kulesov (1982) outlined a way in which the systematic error might be partially reduced.

In the last few years, additional comparisons have been carried out and systematic errors have been found to substantially exceed the 2% depth error quoted by the manufacturer. For example Hanawa and Yoritaka (1987), Bailey et al. (1989), Szabados (1991), and Rossby and Lillibridge (pers. comm., 1991) have all documented this finding. In some cases the error in depth exceeds 25m at 750m depth.

It would be valuable to be able to use XBT data for studies of the interannual variability of the thermal structure of the ocean throughout the entire depth range over which the XBT instrument makes measurements. Levitus (1989) has recently documented that the main thermocline (400-1200m) of the subtropical gyre of the North Atlantic was displaced upwards by 25-50m between the 1950's and 1970's. These results were based solely on hydrographic cast data (reversing thermometers and C/STD's). These results are supported by the analysis of time series data from the Station "S" located near Bermuda (Roemmich, 1985). It is obvious that systematic errors of 15m and larger (in fact any systematic errors) make it inappropriate to directly merge XBT data in with hydrographic data to build the most complete data base for studying interannual variability. It is hoped that corrections to the systematic error can be made to enable these data to be used for studies of interannual variability.

The reason for the "increase" in the systematic error is being studied by various investigators. It may in part be related to the fact that, as originally designed,"The manufacturer corrects for the loss of weight and decrease in fall rate due to the unreeling of the wire by increasing the chart paper grid size with increasing time and descent" (from Seaver and Kulesov, 1982). Many XBT profiles are now digitally recorded on cassette and thus no longer are digitized from chart paper. Could this difference in recording technique be responsible for the increase in the magnitude of systematic error over time? A thorough investigation of this problem needs to be performed by an expert group and the results published along with suggested ways to correct historical data. Great care must be undertaken to ensure that "corrected" data are not merged with "uncorrected" data. Such an expert panel might be drawn from NOAA, TOGA, and WOCE principal investigators who deploy XBT's as well as instrument specialists. In addition, improvement of the XBT instrument should proceed both to correct the known biases as well as improving the capabilities of the instrument. For example, the elimination of the copper wire and attendant problems with weight change of the instrument (and fouling of the wire on ship superstructure) might be possible using acoustic means to transmit data from the XBT to its deployment platform.

It is clear that XBT instrument is now a major tool of the oceanographic research and monitoring communities. Substantial funding has been provided for Volunteer Observing Ship Programs to deploy XBT's over large areas of the world ocean. Data from these instruments are being used or are planned for use in quantitative diagnostic studies and in a forecasting models via incorporation into ocean or ocean/atmosphere general circulation models. Yet we are deploying instruments with large systematic biases!

To avoid problems like this in the future, we suggest a thorough and continuing process of calibration of any instrument to be deployed for climate change studies. For example, the Acoustic Doppler Current Profiler (ADCP) is an instrument now being deployed on research ships, and proposals exist to mount these instruments on merchant ships. These instruments can measure upper ocean velocity fields on a near continuous basis, but biases and errors due to ship roll and the presence of bubbles etc., must be accounted for in the processing of these data. A panel of experts must help whatever data center that is going to archive these data to make sure that all relevant parameters describing the processing of these data be saved as part of the data archive. This determination is not solely the role of the archiving center, where appropriate expertise may not exist. This function suggests joint cooperation between scientists and data centers. If this level of cooperation and scientific responsibility cannot be obtained in a particular program, there seems little point in funding such a program. Responsibility must be taken. Documentation of such activities might be published in a journal such as the Journal of Ocean and Atmospheric Technology. Substantial amounts of important information regarding oceanographic instrumentation appear in the grey literature or in somewhat obscure publications.

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Satellite Calibrations

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Introduction

A primary objective of NESDIS is to provide measurements from environmental satellite sensors from which properties of the Earth's surface and atmosphere are inferred. One of the factors determining the accuracy and stability of the measurements, and hence their usefulness, is the radiometric calibration of the instruments. The calibration establishes the relationship between the output of an instrument (e.g., in digital counts) and the intensity of the radiation incident on it. The satellite instruments operating in the infrared and microwave parts of the spectrum are calibrated in orbit from data acquired when the instrument views space and an on-board calibration target. The instruments currently operating in the visible and near-infrared are calibrated before launch but not in orbit.

This presentation focuses on satellite-instrument calibration as it affects our ability to detect long-term change in the environment. The first section covers improvements that might be made in handling calibration of currently operational instruments, and the second deals with the problem of obtaining budget authority to enhance the calibration capabilities of future sensors. The examples presented are drawn from our experience with the Advanced Very High Resolution Radiometer (AVHRR), but the conclusions apply generally.

Currently Operational Sensors

The currently operational instruments, as well as those planned for the near future (e.g., the NOAA-KLM series), were designed before we recognized the importance of long-term measurement continuity. Nevertheless, these instruments are providing a long-term data record from which climate information can be extracted. However, some difficulties need to be dealt with. For example, the visible and near-infrared channels of the AVHRR instruments on some of the NOAA-series satellites experience long-term changes in sensitivity of the order of 5%/yr. There are calibration discontinuities of several percent between AVHRRs on successive satellites. On occasion, artificial discontinuities are inserted into the time series of visible-channel data when NESDIS revises the calibration coefficients to optimize image quality. These problems, documented by numerous researchers at NASA and elsewhere, confound efforts to determine long-term change from AVHRR data. There is also evidence suggesting that similar problems affect the infrared channels of the AVHRRs (although to a much lesser extent, since those channels are calibrated in orbit).

No major policy initiatives are needed to enable NESDIS to make better use of the calibration data from the current series of instruments. It is only a matter of recognizing the need and committing the resources to satisfy it. Some recommended steps are supplied in a recent report (Abel, 1990). A few examples: In the area of the pre-launch instrument characterization, testing is often incomplete and test procedures outdated. NESDIS should require its instrument contractors to test its instruments more carefully and completely and to use more advanced test procedures, such as those recommended in an unpublished report from the National Institute of Standards and Technology. NESDIS should establish an in-house capability for monitoring in-orbit calibration. This would include continuous monitoring of relative gain changes, periodic absolute calibrations (via, e.g., aircraft underflights or "vicarious" calibration experiments), and complete documentation and dissemination of information. It is important that NESDIS have its own cadre of scientists who use the data and are cognizant of the calibration. Because of their interest in the quality of the data available to study the environment, they can act as liaison between the science community and NOAA; for example, advocating NOAA actions to meet the requirements of data accuracy, continuity, timeliness, etc.

Future Sensors

Because of the long lead times between the formulation of performance requirements and the launch of the first of a series of satellites, the design of our current and near-future satellite instruments was not motivated by the need to monitor climate change. For example, the specifications for both the current AVHRRs and the AVHRRs for the NOAA-KLM satellite series lack a requirement for measurement stability over time. The requirements for the satellite instruments that will operate for the decade beginning in the late

1990's are being formulated now. Now is the time, therefore, to write the enhanced performance requirements for detection of climate change into the requirement documents.

Obtaining budget authority to enhance an operational instrument, has two prerequisites. First, the enhancement must be required by an "operational" user (not just a research scientist, whether in or out of NOAA), preferably one who can back the requirement with a legislative mandate. For example, performance requirements on meteorological satellite instruments are based primarily on the needs of the National Weather Service. Second, the technology must be proven. Development of new technology should not be part of a contract for procurement of operational instruments; it should be done separately. In the past, NOAA relied on NASA's Operational Satellite Improvement Program (OSIP) for technology development. However, OSIP no longer exists, and no successor has emerged.

Apparently, requests for stringent climate-based capabilities, such as 1-2% stability per decade, are in jeopardy of not qualifying for budget authority because they lack both prerequisites. There are no requirements from an operational user, and the technology needs further development. Therefore, the following issues must be confronted:

1. How can NOAA obtain requirements from the climate community that will support budget requests for enhanced operational capabilities?

2. A consistent program to develop improved technology for operational instruments is needed. How can NOAA make it happen?

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Abel, P. (Ed.), 1990: Report of the Workshop on Radiometric Calibration of Satellite Sensors of Reflected Solar Radiation, March 27-28, 1990, Camp Springs, MD. NOAA Technical Report NESDIS 55, NOAA/NESDIS, U.S, Department of Commerce, Washington, D.C., 33 pp.

Satellite Measurements (Atmosphere)

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An abundance of environmental parameters related to the NOAA Climate and Global Change Program are or will be inferred from observations by instruments on NOAA operational satellites. Some of these are shown in Figure 1 with their importance to climate studies indicated by asterisks, with three being the greatest importance.

Associated with these parameters are a variety of problems affecting the quality and continuity of the derived data sets. These are shown in Figure 2 for several specific parameters. A general statement of the accuracy requirements is shown for each parameter along with an identification of specific problems associated with the observations of the parameters. It is clear from Figure 2 that to meet these requirements, there must be continuing efforts to improve the accuracy and long-term stability of instrument calibrations, to validate the satellite products and to maintain continuity from instrument to instrument over an extended series of satellite operations.

Of particular interest in climate research are the long-term trends in stratospheric ozone and temperature. Based on model forecasts of these trends, observational requirements can be given for the magnitude of detectable trends. These requirements are shown in Figure 3. (Trends of these magnitudes must be observable in order to be compared to the model results.)

Illustrative of the problems in data continuity associated with stratospheric temperatures, Figure 4 shows the corrections that need to be applied to satellite-derived temperatures based on comparisons with rocketsonde measurements. This tuning of the satellite data to improve accuracy and continuity is necessary due to the uncertainties in the satellite measurements at the higher stratospheric levels. Each horizontal segment is associated with a single satellite instrument. The need for a continuing validation with rocketsonde information is apparent, yet the national rocketsonde network, which once was robust, is on the verge of extinction.

In a similar manner, validation of satellite-derived cloud and aerosol properties to the level of the measurement requirements requires supporting information from sensors that are generally outside NESDIS (and maybe even NOAA) control. Figures 5 and 6 show the cloud and aerosol properties, their accuracy requirements, and method of validation. A summary of the issues specific to cloud and aerosol but general enough to be applicable to many other products is shown in Figure 7.

The degree to which the orbital parameters of the satellites can affect the continuity of a data set is illustrated in Figure 8, which shows the spacecraft sun angle histories for NOAA-9 and NOAA-11. (Spacecraft sun angle can be directly related to the solar zenith angle at the observed scene; e.g., sun angle of 0° corresponds to a zenith angle of 90°.) Due to orbital drift, solar zenith angles can change markedly over the lifetime of a single instrument and can vary significantly for two instruments flying at the same time. The algorithms developed to retrieve parameters dependent on solar angle must be sufficiently robust to accommodate a wide range of angles.

Another example of data accuracy problems is shown in Figure 9, which gives the average trend in the difference between total ozone amount derived from satellite measurements and that derived from several ensembles of ground-based observations. For example, ALL refers to a global distribution of about 45 locations of Dobson spectrophotometers, which is the total ground network used in this comparison study. The number of stations is reduced at each step; for example, ALL 20 means all stations minus the observations from the locations believed to be least accurate. Finally, the BST 30 corresponds to the best data set, which is compiled from seven stations having the best histories of calibration and observation. Note that there is essentially no change in the average differences (the asterisks) although the noise in the comparisons (represented by the vertical bars) varies. The point to be made is that there is a need to have a well-calibrated, stable, and uniform network for validation.

The need for good science is represented in Figure 10, which is a time history of global total ozone amount derived from a series of satellite measurements using a common instrument. Changes of varying magnitudes are noted as well as varying year-to-year differences. Folded into the record are effects such as solar events, atmospheric changes, and subtle changes in instrument behavior. Good science has to be developed and applied to all data records to extract the natural variability so that real long-term changes can be determined.

In sum, the observational issues center around instrument calibration (pre-launch absolute accuracy and post-launch stability), validation of the resultant data products (requiring concurrent ground-truth data from other sources), instrument-to-instrument continuity, and the quality of the science. To confront these technical issues, the following policy issues need to be addressed.

In order to assemble credible satellite data sets, there must be strong intra-NOAA coordination that supports the NOAA program for Climate and Global Change (C&GC) or any other long-term program. There must also be cooperation between NOAA and other agencies that either supports or complements the NOAA efforts. If climate is a NOAA program, the several line organizations (LOs) having common interest or activities should participate jointly rather than as separate entities. Several projects already do this; for example, the core projects of the C&GC program. Sources of auxiliary data (ground truth) in one LO should not unilaterally cut off a program when such data is of importance to another LO.

NOAA should be a conduit to other agencies and make them aware of the need for continuing support to national programs of which NOAA is one of the players. The national rocketsonde network for upper atmosphere measurements is a good example. Remotely-sensed parameters, especially temperature, continue to require rocketsonde data for data quality and continuity purposes.

Major programs in climate and global change are being initiated that will eventually require extensive data validation efforts. Generally, the sources of such data are external to the principal program. Plans have to be made in advance to fund acquisition of the data as well as to insure that the sources of such data will continue to do so during the lifetime of the principal program.

Finally, the necessity for excellent science is clear for all NOAA programs. NOAA has to support the continued acquisition of good young scientists in the years to come. Without this, we will stagnate and become only a collector of data.

Figure 1.

CLIMATE/GLOBAL CHANGE VARIABLES ACCESSIBLE FROM U.S. OPERATIONAL SATELLITES

VARIABLE	IMPORTANCE
OZONE	***
SURFACE VARIABLES	
VEGETATIVE INDEX	***
SNOW	*
SURFACE ALBEDO	*
TEMPERATURE	*
SOIL MOISTURE	***
RADIATION BUDGET	
TOP OF ATMOSPHERE	
LONGWAVE RADIATION	**
PLANETARY ALBEDO	**
SURFACE	
INSOLATION	*
PRECIPITATION	***
OCEAN VARIABLES	
SEA SURFACE TEMPERATURE	***
SEA SURFACE WIND	***
SEA ICE	**
CLOUDS AND AEROSOLS	
CLOUDS	**
AEROSOLS	*
WINDS	
TROPICAL	**
EXTRATROPICAL	*
WATER VAPOR	**
TEMPERATURE	***

GENERAL DATA PRODUCT PROBLEMS

PARAMETER	PROBLEM
OZONE (1%/10YR.)	A,B,C
VEG. INDEX (±5%)	A
SOIL MOISTURE (?)	FUNDAMENTAL
RADIATION BUDGET (±2%)	A,B,C
PRECIPITATION (±5MM/HR.)	B,C
SST (0.25K NMS)	B
CLOUDS/AEROSOLS (COVER ±5%@ 50KM RES; 5 LEVELS;TC,±3K[½KM]) (OPTICAL DENSITY 10% OF CLEAR SKY)	B,C
WINDS (LO ± 4M/SEC) (HI ±6M/SEC)	FUNDAMENTAL
WATER VAPOR (?)	FUNDAMENTAL
TEMPERATURE (1K/1KM)	C

A - ABSOLUTE CALIBRATION ACCURACY/STABILITY

B - VALIDATION

C - CONTINUITY (1 INSTRUMENT OVER TIME)
(2+ INSTRUMENTS OVER S/C)

Stratospheric Products Requirements

Quantity	Detectable trend magnitude
Total ozone	1-1.5 %/decade
Ozone profile	3-5 %/decade
Temperature	1-1.5 K/decade

Figure 3.

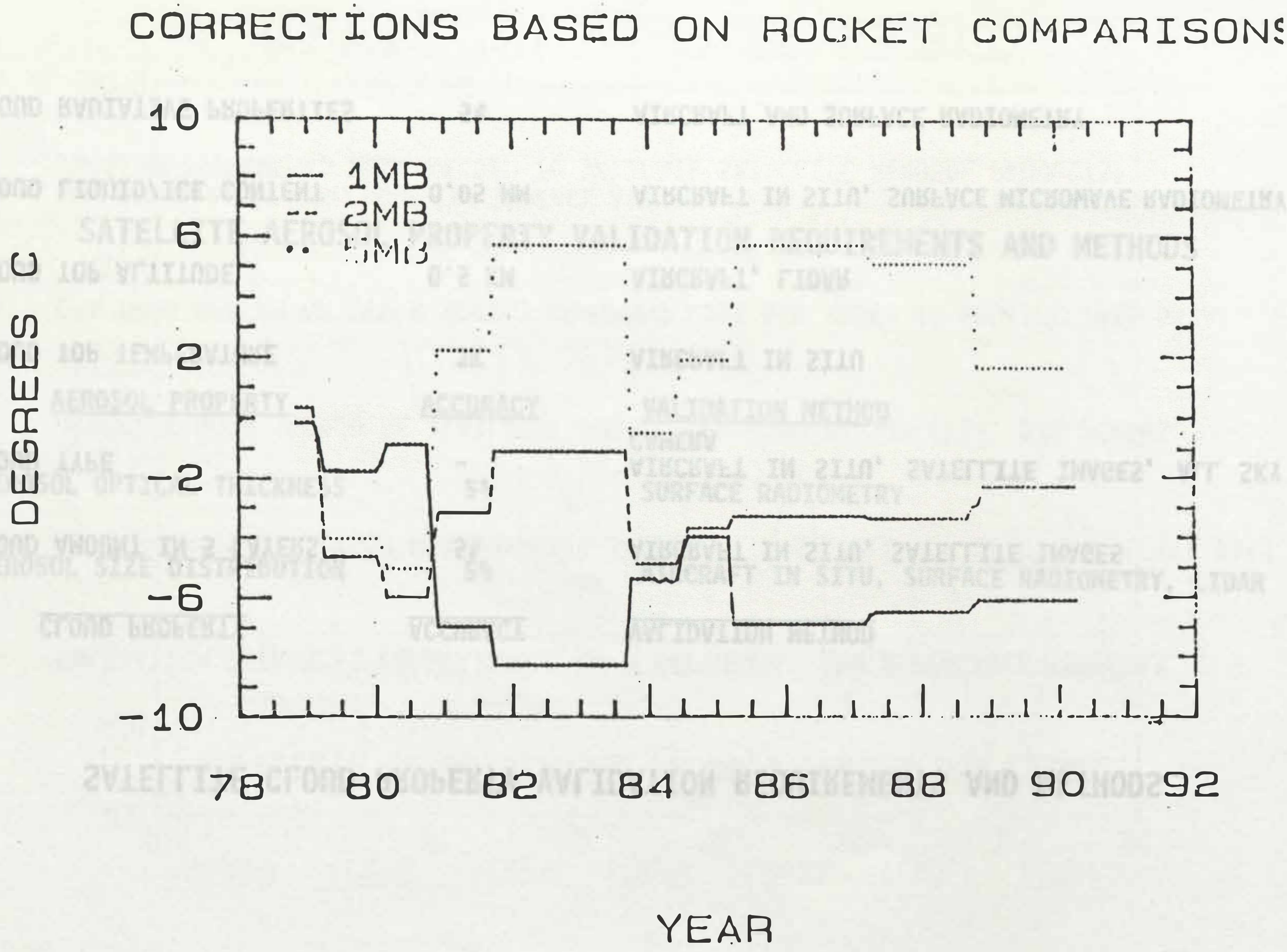
CORRECTIONS BASED ON ROCKET COMPARISONS
DEGREES C
10
6
2
-2
-6
-10
1MB
2MB
5MB
78
80
82
84
86
88
90
92
YEAR

Figure 4.

SATELLITE CLOUD PROPERTY VALIDATION REQUIREMENTS AND METHODS

CLOUD PROPERTY	ACCURACY	VALIDATION METHOD
CLOUD AMOUNT IN 5 LAYERS	5%	AIRCRAFT IN SITU, SATELLITE IMAGES
CLOUD TYPE	-	AIRCRAFT IN SITU, SATELLITE IMAGES, ALL SKY CAMERA
CLOUD TOP TEMPERATURE	3K	AIRCRAFT IN SITU
CLOUD TOP ALTITUDE	0.5 KM	AIRCRAFT, LIDAR
CLOUD LIQUID/ICE CONTENT	0.05 MM	AIRCRAFT IN SITU, SURFACE MICROWAVE RADIOMETRY
CLOUD RADIATIVE PROPERTIES	5%	AIRCRAFT AND SURFACE RADIOMETRY

Figure 5.

SATELLITE AEROSOL PROPERTY VALIDATION REQUIREMENTS AND METHODS

AEROSOL PROPERTY	ACCURACY	VALIDATION METHOD
AEROSOL OPTICAL THICKNESS	5%	SURFACE RADIOMETRY
AEROSOL SIZE DISTRIBUTION	5%	AIRCRAFT IN SITU, SURFACE RADIOMETRY, LIDAR

Figure 6.

SATELLITE CLOUD/AEROSOL PRODUCT VALIDATION ISSUES:

1- VALIDATION DATA MUST BE AVAILABLE ON A DEPENDABLE AND REPEATABLE SCHEDULE.

2- SOME SURFACE RADIATION MEASUREMENTS SHOULD BE AVAILABLE FOR EVERY SATELLITE PASS.

3- AIRCRAFT DATA SHOULD BE AVAILABLE FOR A WEEK LONG PERIOD EVERY SIX MONTHS.

4- CAN NOAA DEPEND ON OTHER AGENCY PROGRAMS LIKE ARM (DOE) TO PROVIDE THIS DATA?

5- WHY DID NOAA DISCONTINUE ITS SURFACE AEROSOL OPTICAL THICKNESS MEASUREMENT PROGRAM WHEN THOSE MEASUREMENTS WERE NEEDED TO VALIDATE SATELLITE AEROSOL PRODUCTS?

Figure 7.

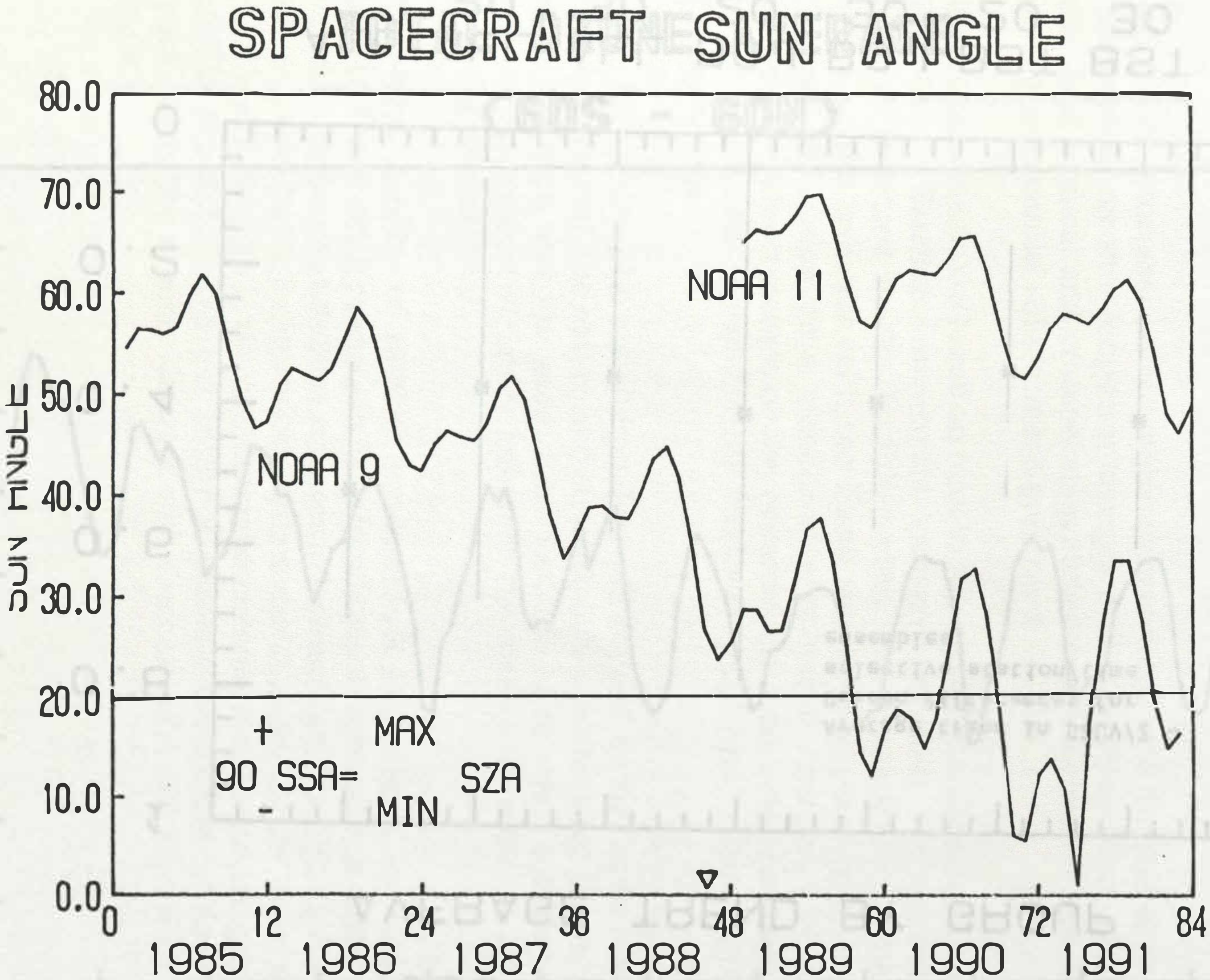
SPACECRAFT SUN ANGLE
SUN ANGLE
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NOAA 11
NOAA 9
+ MAX
90 SSA= SZA
- MIN
0
12
24
36
48
60
72
84
1985
1986
1987
1988
1989
1990
1991

Figure 8.

SATELLITE CLOUD/AEROSOL PRODUCT VALIDATION ISSUES:

1- VALIDATION DATA MUST BE AVAILABLE ON A DEPENDABLE AND REPEATABLE SCHEDULE.

2- SOME SURFACE RADIATION MEASUREMENTS SHOULD BE AVAILABLE FOR EVERY SATELLITE PASS.

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Figure 7.

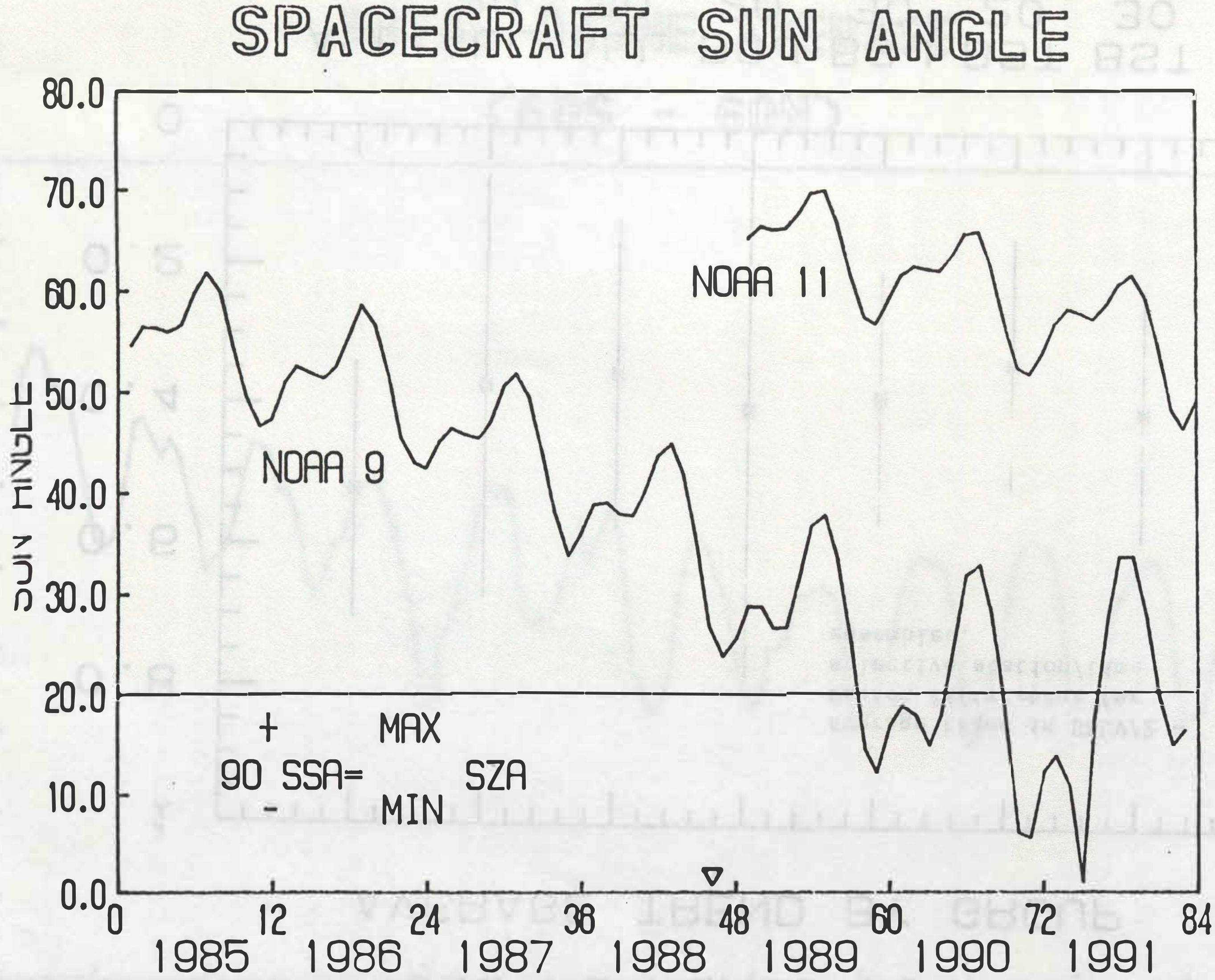
SPACECRAFT SUN ANGLE
SUN ANGLE
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
NOAA 11
NOAA 9
+ MAX
90 SSA= SZA
- MIN
0
12
24
36
48
60
72
84
1985
1986
1987
1988
1989
1990
1991

Figure 8.

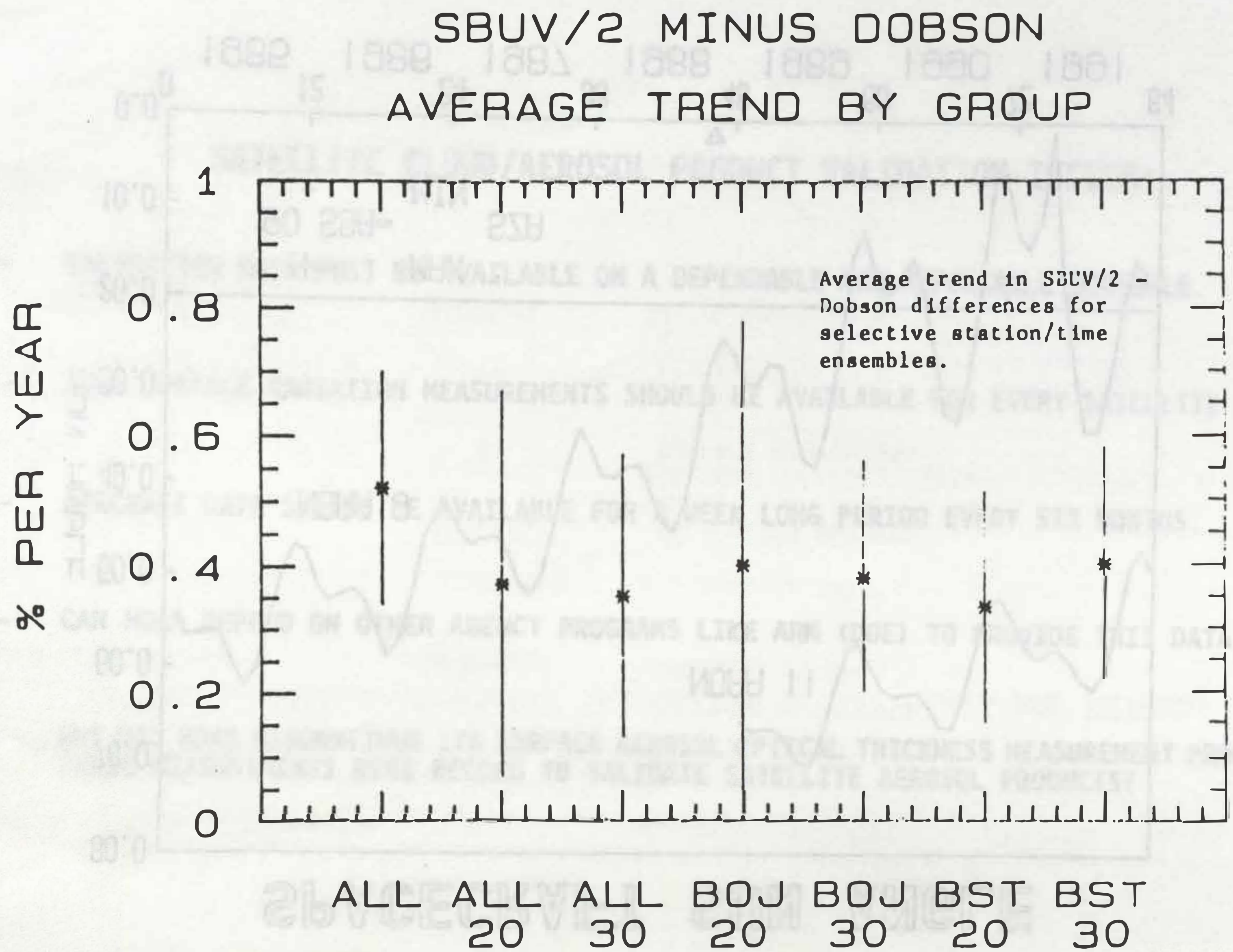
SBUV/2 MINUS DOBSON
AVERAGE TREND BY GROUP
% PER YEAR
1
0.8
0.6
0.4
0.2
0
Average trend in SBUV/2 - Dobson differences for selective station/time ensembles.
ALL
ALL 20
ALL 30
BOJ 20
BOJ 30
BST 20
BST 30

Figure 9.

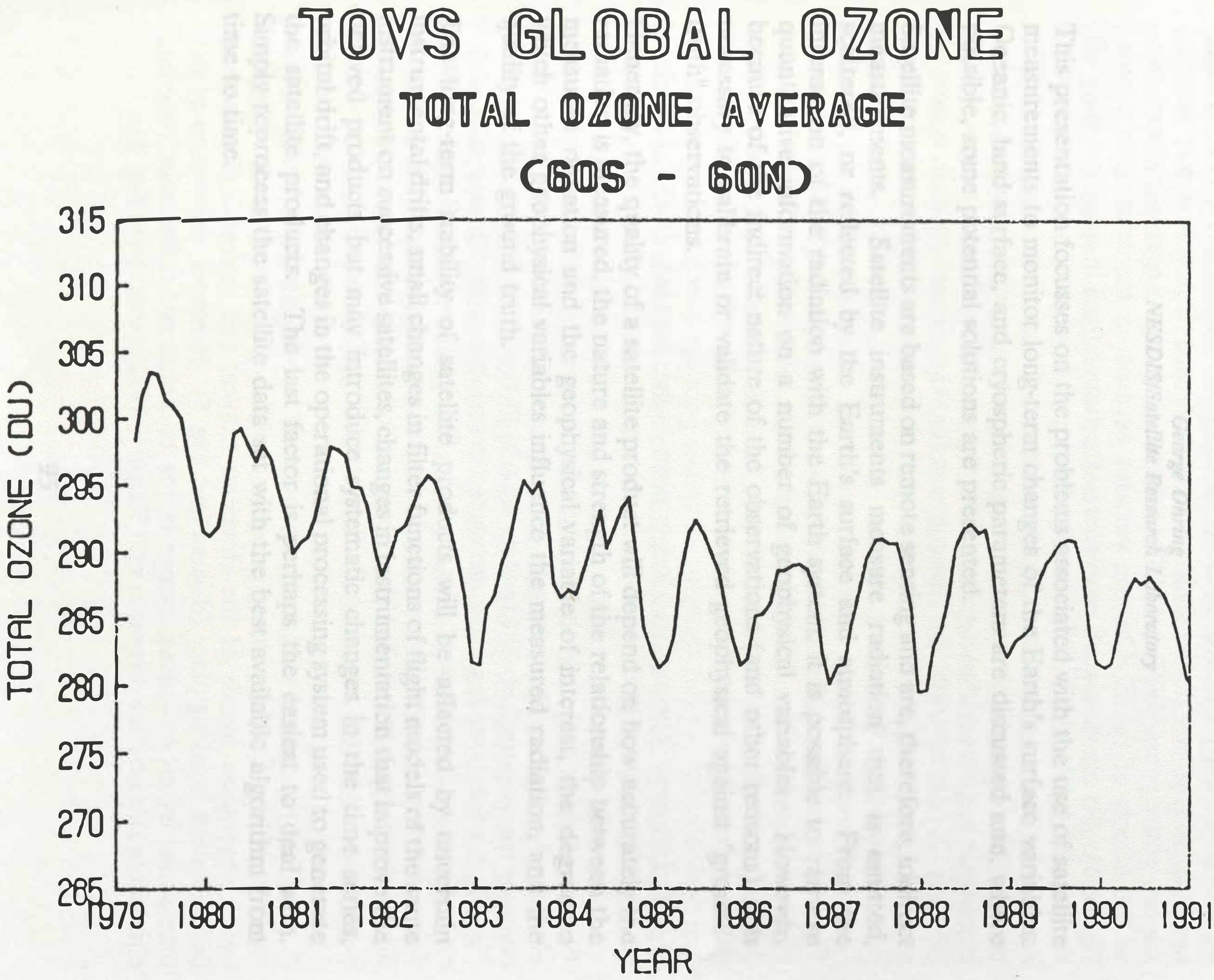
TOVS GLOBAL OZONE
TOTAL OZONE AVERAGE
(60S - 60N)
315
310
305
300
295
290
285
280
275
270
265
TOTAL OZONE (DU)
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
YEAR

Figure 10.

Satellite Measurements (Land, Ocean)

George Ohring
NESDIS/Satellite Research Laboratory

This presentation focusses on the problems associated with the use of satellite measurements to monitor long-term changes of the Earth's surface variables. Oceanic, land surface, and cryospheric parameters are discussed and, where possible, some potential solutions are presented.

Satellite measurements are based on remote sensing and are, therefore, indirect measurements. Satellite instruments measure radiation that is emitted, scattered, or reflected by the Earth's surface and atmosphere. From the interaction of the radiation with the Earth system, it is possible to retrieve quantitative information on a number of geophysical variables. However, because of the indirect nature of the observations (and other reasons), it is necessary to calibrate or validate the retrieved geophysical against "ground-truth" observations.

Generally, the quality of a satellite product will depend on how accurately the radiation is measured, the nature and strength of the relationship between the measured radiation and the geophysical variable of interest, the degree to which other geophysical variables influence the measured radiation, and the quality of the ground truth.

The long-term stability of satellite products will be affected by uncertain instrumental drifts, small changes in filter functions of flight models of the same instrument on successive satellites, changes in instrumentation that improve the derived products but may introduce systematic changes in the time series, orbital drift, and changes in the operational processing system used to generate the satellite products. The last factor is perhaps the easiest to deal with. Simply reprocess the satellite data set with the best available algorithm from time to time.

When time series of global or hemispheric mean monthly or annual satellite-based sea surface temperatures have been compared with similar data from ship observations, they have agreed reasonably well (Strong, 1990). However, to obtain such good agreement, Strong had to discard the satellite observations for two entire years--1982 and 1983-- because they were negatively biased due to the effects of the El Chichon volcanic aerosols in the stratosphere (see Figure 1). To alleviate such problems in the future (and in a reprocessing of the past data), Walton (1985) recently developed an algorithm that eliminates most of the bias due to the stratospheric aerosol. Comparison of satellite SSTs with collocated and coincident drifting buoy observations indicate that the monthly mean bias of the satellite SSTs is generally within the range +/-0.2° (see Fig. 2; McClain, 1991). This suggests that the current satellite system is probably capable of detecting a long-term change in ocean temperatures of 0.5°C or more.

The visible sensors on the NOAA satellites are not calibrated in-flight and tend to degrade with time. Such degradation will introduce artificial trends in derived products such as surface albedo, for example. A stop-gap solution is to characterize the degradation by monitoring surface features and assuming that their albedos are not changing - a rather poor approach to the monitoring of global change. The required longer term, higher cost solution is to develop and install on-board calibration for these sensors.

As a result of orbital drift, the local time of observation increases during the lifetime of a satellite. For example, in the case of NOAA 9, the observing time changed from about 2:30 PM to close to 4:30 PM over a four-year period (see Fig. 3). Artificial trends will be introduced in variables with diurnal cycles, such as land surface temperatures. For example, Fig. 4 (Gutman and Tarpley, 1992) shows an apparent downward trend in summer temperatures for Lebanon during the period 1985-1988; this apparent trend results from a gradual change in satellite observing time, from 2:30 pm to 4:30 pm, during the period.

A more subtle effect is the dependence of the bi-directional reflectance function of the Earth's surface on solar zenith angle. Analysis of NOAA 9 based vegetation trends of the Brazilian tropical rain forest indicates that deforestation is taking place (dashed line, Fig. 5). However, correction of the time series by an estimated change in the bi-directional reflectance function eliminates this artifact (Gutman and Tarpley, 1992) (solid line, Fig. 5).

The short-term solution to the problem of satellite drift is to launch the satellite into an orbit closer to noon, which, while minimizing the drift problem, could create overheating of the spacecraft in the event of a launch error. The required long-term, high-cost solution is installation of station keeping motors on the spacecraft (such as for the NASA NIMBUS series).

An instrumentation change is currently being proposed to improve the measurement of the Normalized Difference Vegetation Index (NDVI). This index is computed from the observations of the visible (channel 1) and near-infrared (channel 2) channels of the Advanced Very High Resolution Radiometer (AVHRR). The near-infrared channel is affected by atmospheric water vapor, whose variations introduce noise in the NDVI. The proposal is to eliminate the water vapor absorption feature by spectrally narrowing this channel. While this will accomplish the desired effect, it will also introduce a sudden greening of the Earth, as can be seen from the simulations in Fig. 6 (after Justus, 1987), and perhaps other more subtle changes in the NDVI of different surface types. How can we best deal with such improvements in instruments? Ideally, one would want sufficient overlap of the records of the two instruments to permit the results to be related to each other.

Perhaps one of the success stories of satellite surface products is the relatively long-term (in satellite years) cryospheric time series that is now available. Maps of snow cover (since 1966) and sea ice (since 1973) have been produced by human analysts examining satellite images to differentiate cloud from snow/ice and draw in the snow/ice lines. NOAA's Climate Analysis Center monitors these observations as part of its climate diagnostic activities. Figure 7 (Halpert and Ropelewski, 1991) shows time series of satellite-derived Eurasian snow cover for spring and summer and their correlation with similar time series of surface temperatures from weather station observations. Figure 8 (Halpert and Ropelewski, 1991) illustrates time series of satellite-based sea ice area for the Arctic and Antarctic for both summer and winter. But with the introduction of satellite microwave instruments, a new snow/ice product will be available, and, once again, we will have to compare the older methodology with the newer one during a suitable overlap period.

Solutions to some of the problems discussed above are costly. But the cost of not knowing what is happening to the Earth's climate is many orders of magnitude greater. The issue is: What is the mechanism for the climate community to make its requirements known to NOAA, and how will NOAA respond?

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Figure Captions

Figure 1. Satellite and in-situ sea surface temperature trends. (After Strong, 1990)

Figure 2. Monthly mean bias errors of satellite sea surface temperature measurements. (McClain, 1991)

Figure 3. The local observing times for the NOAA-9 and NOAA-11 satellites. (Gutman and Tarpley, 1992)

Figure 4. Monthly mean clear-sky brightness temperatures for Lebanon. (Gutman and Tarpley, 1992)

Figure 5. Time series of weekly Normalized Difference Vegetation Index (NDVI) for Brazilian tropical rain forest. (Gutman and Tarpley, 1992)

Figure 6. Simulations of Normalized Difference Vegetation Index (NDVI) for current and proposed satellite instruments as a function of precipitable water and observation angle (scan pixel number). (Justus, 1987)

Figure 7. Time series of Eurasian snow cover area derived from satellite data (dashed) and Eurasian temperature anomaly (solid) derived from an analysis of surface weather stations for spring and summer. (Halpert and Ropelewski, 1991)

Figure 8. Time series of sea ice area anomalies. Upper panel: Arctic winter (January/February) and summer (August/September). Lower panel: Antarctic winter (August/September) and summer (January/February). (Halpert and Ropelewski, 1991)

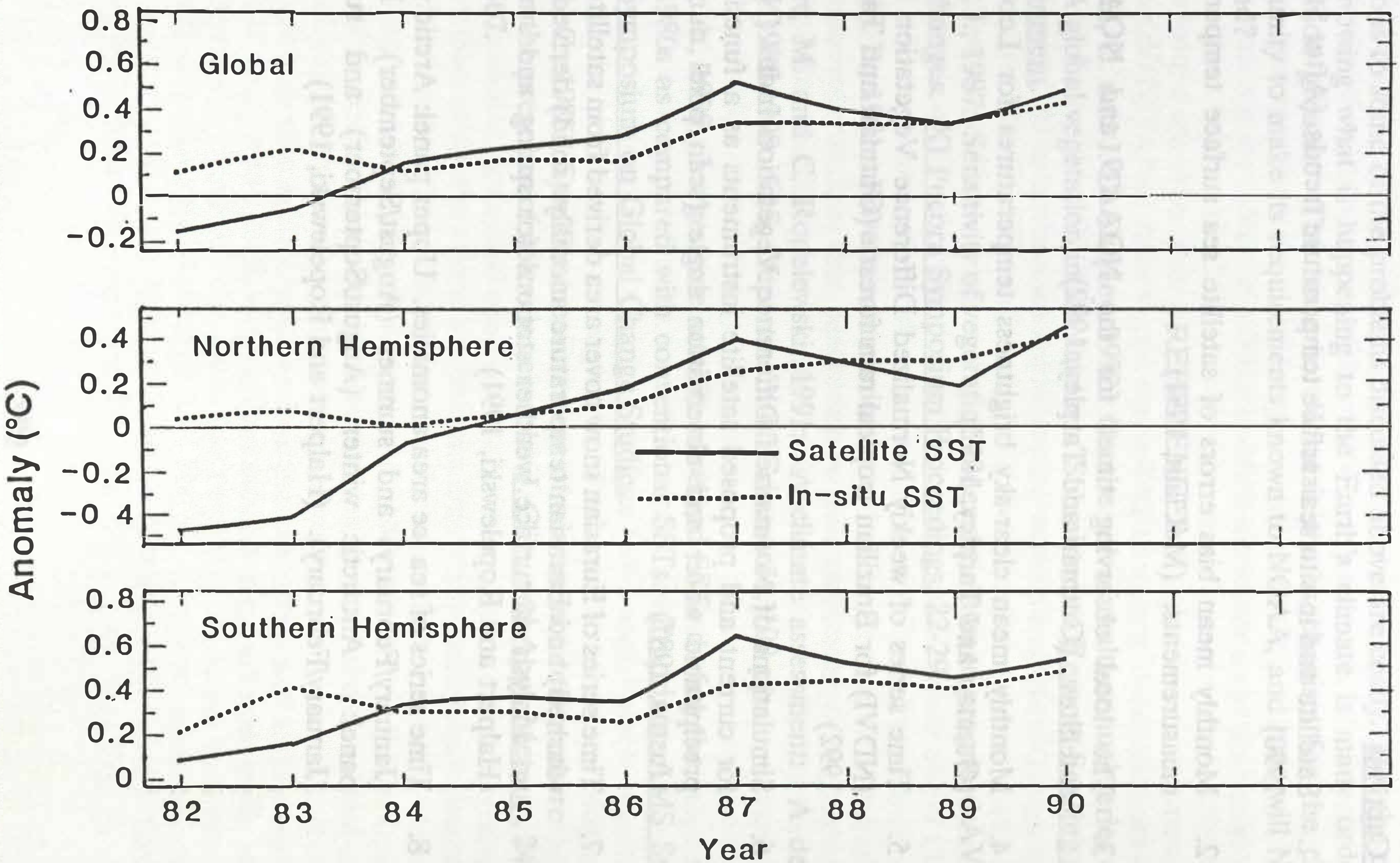

Figure 1 Satellite and in-situ sea surface temperature trends. (After Strong, 1990)

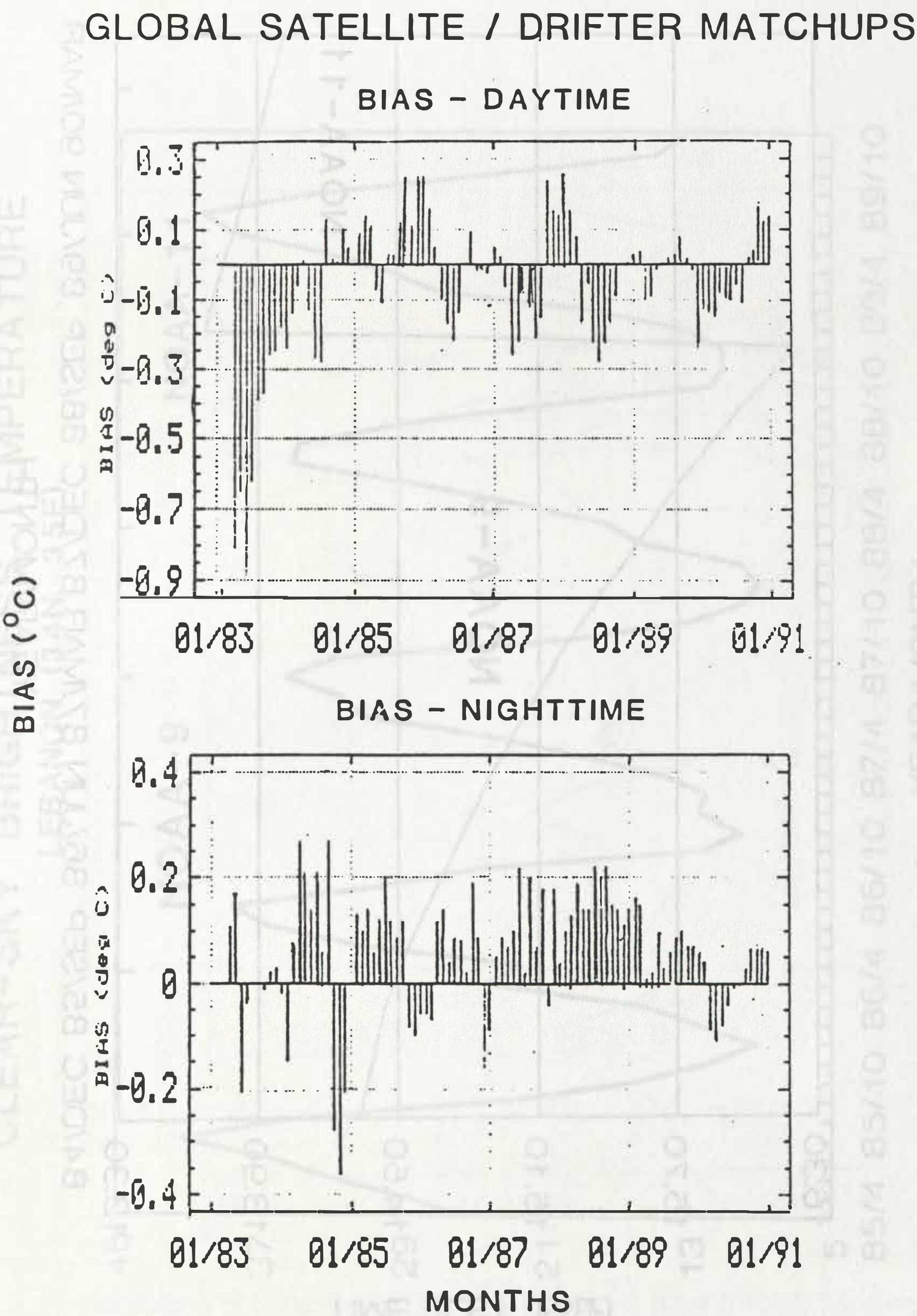

Figure 2 Monthly mean bias errors of satellite sea surface temperature measurements. (McClain, 1991)

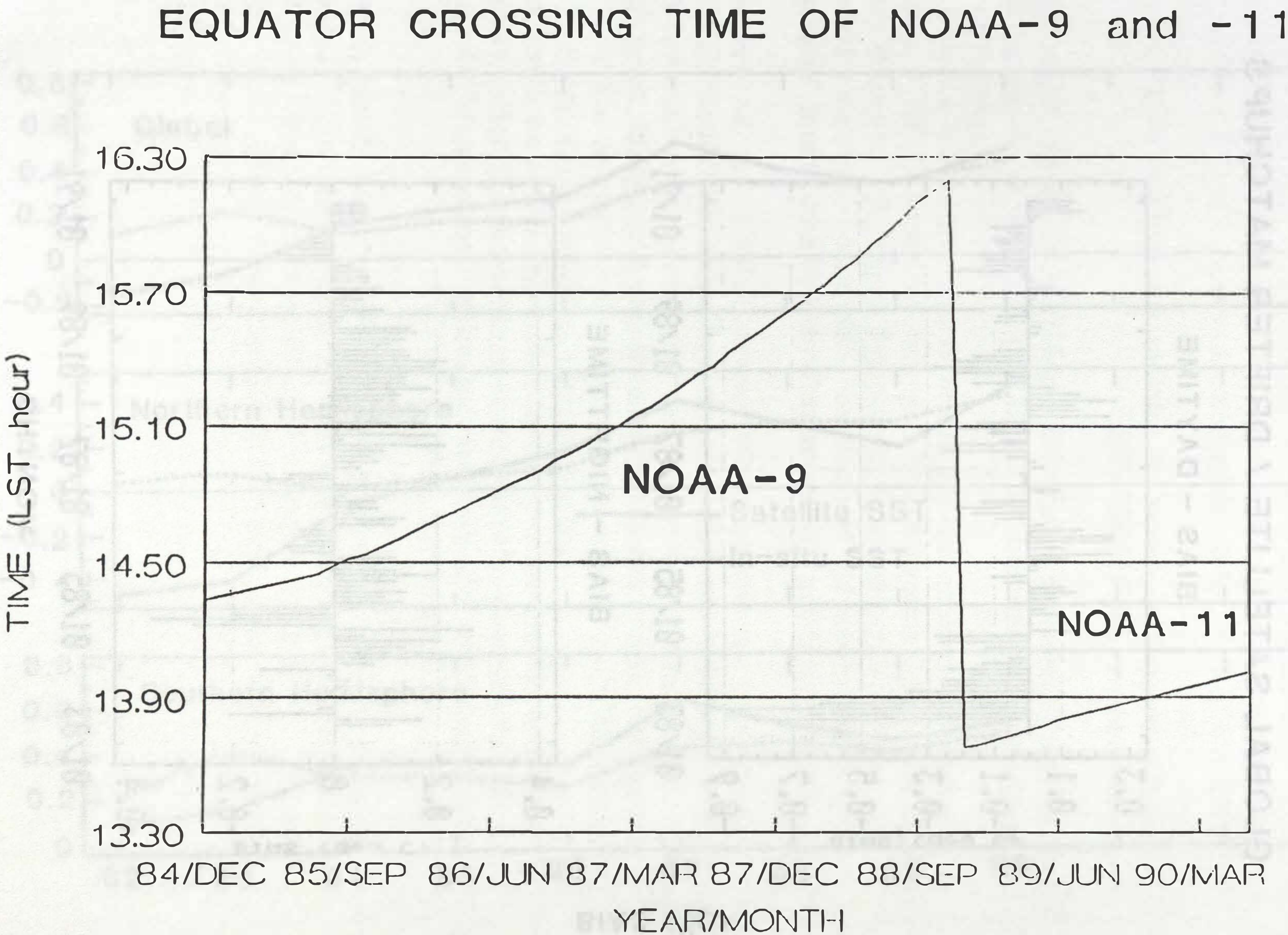

Figure 3 The local observing times for the NOAA-9 and NOAA-11 satellites. (Gutman and Tarpley, 1992)

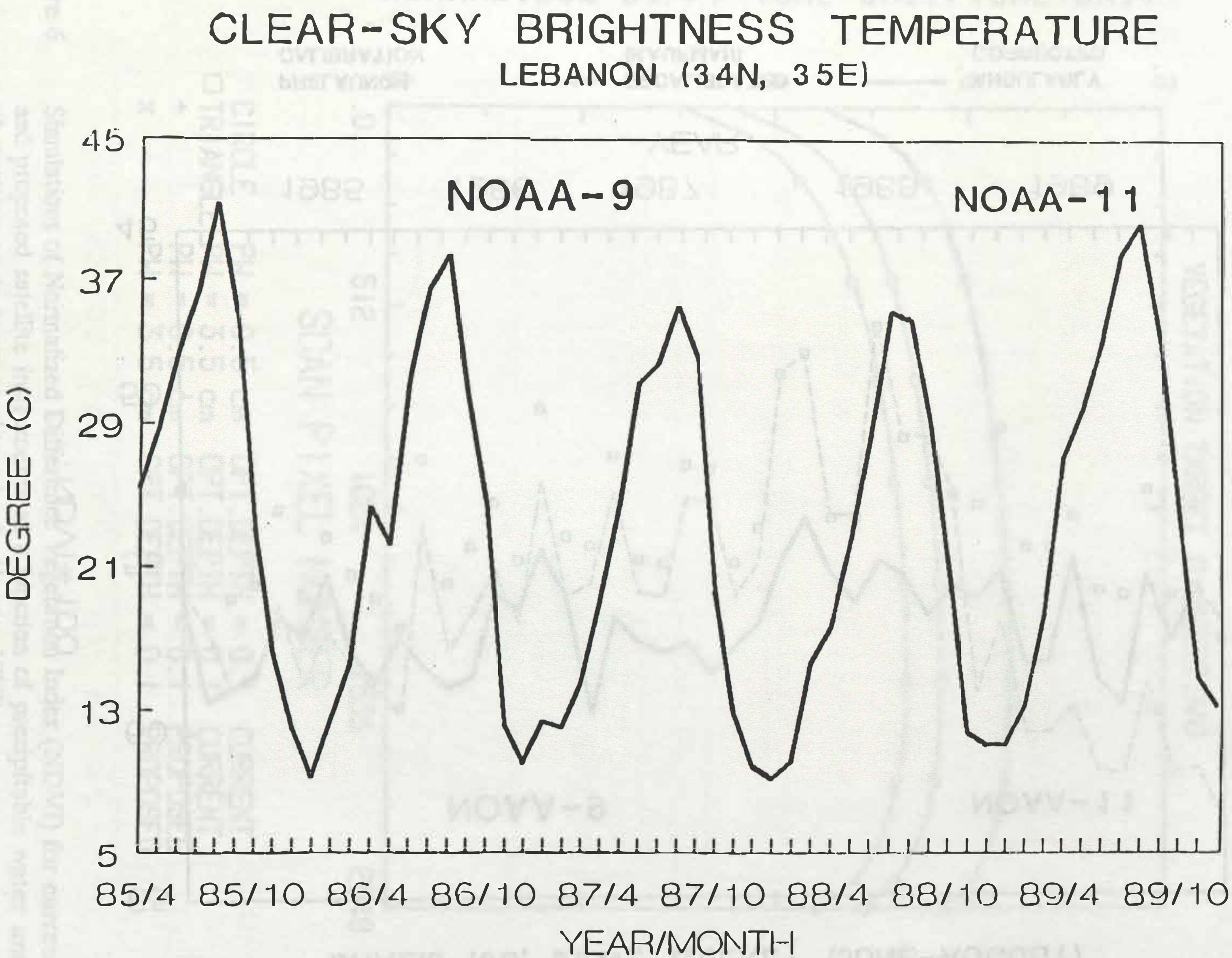

Figure 4 Monthly mean clear-sky brightness temperatures for Lebanon. (Gutman and Tarpley, 1992)

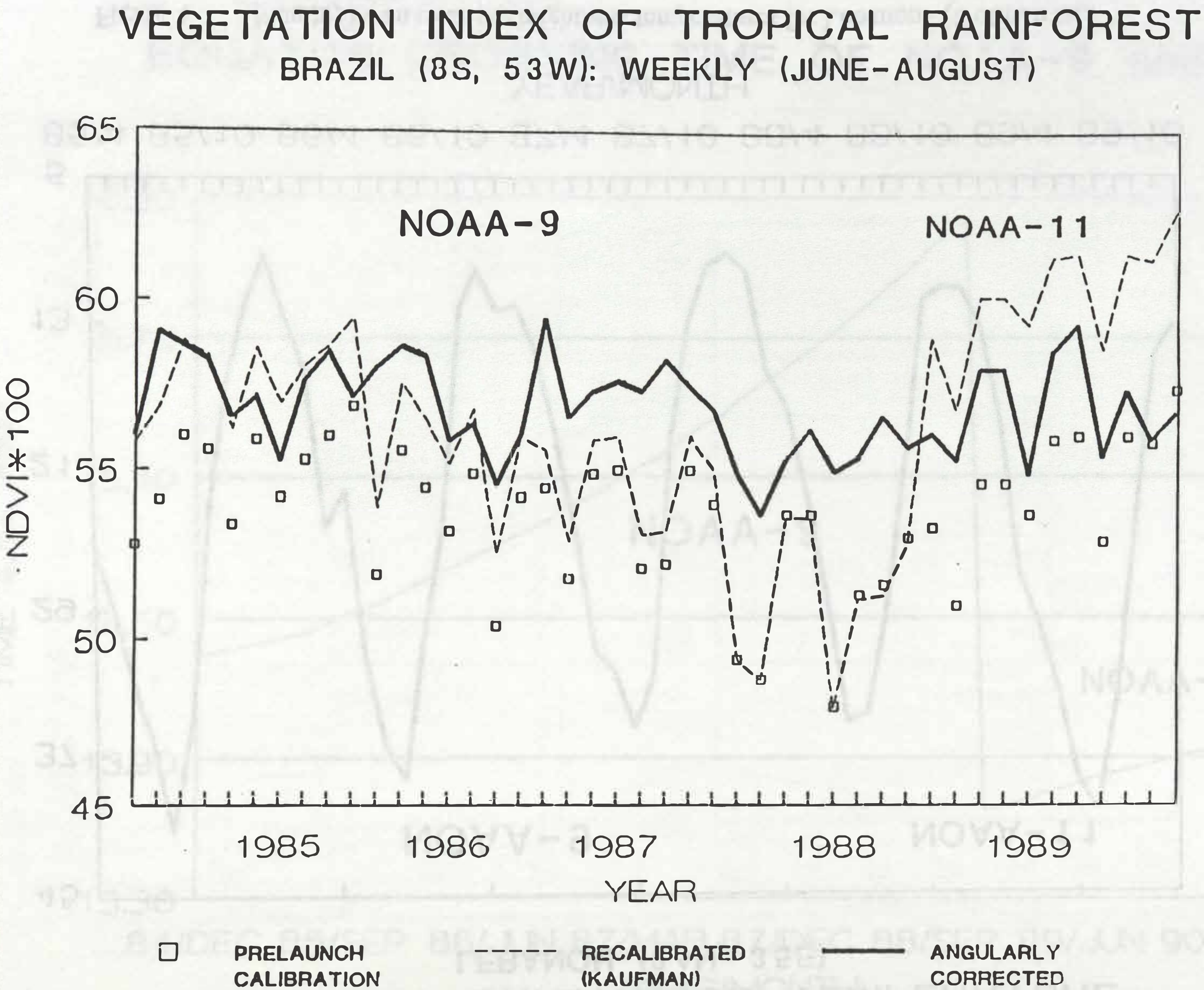

Figure 5 Time series of weekly Normalized Difference Vegetation Index (NDVI) for Brazilian tropical rain forest. (Gutman and Tarpley, 1992)

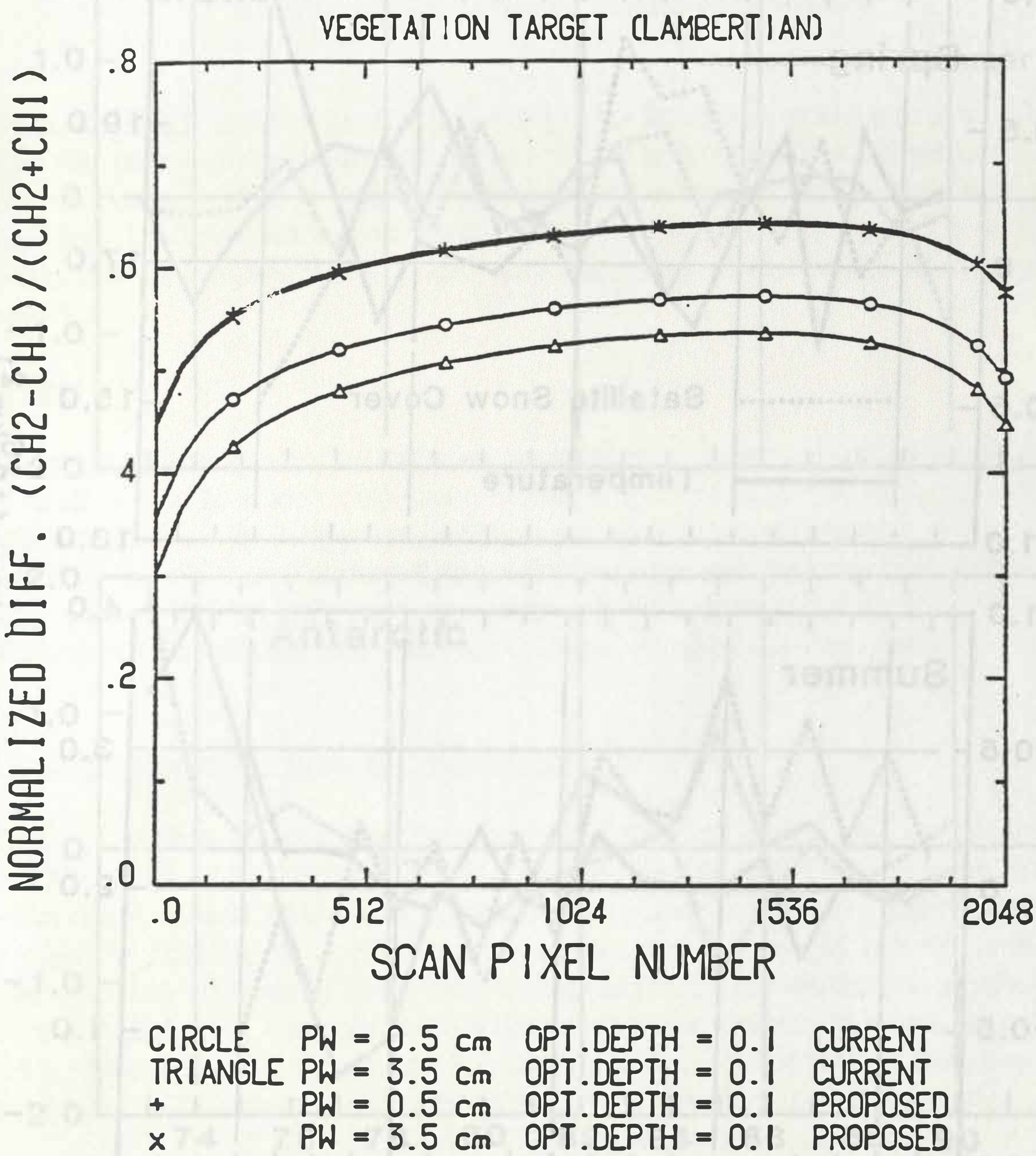

Figure 6 Simulations of Normalized Difference Vegetation Index (NDVI) for current and proposed satellite instruments as a function of precipitable water and observation angle (scan pixel number). (Justus, 1987)

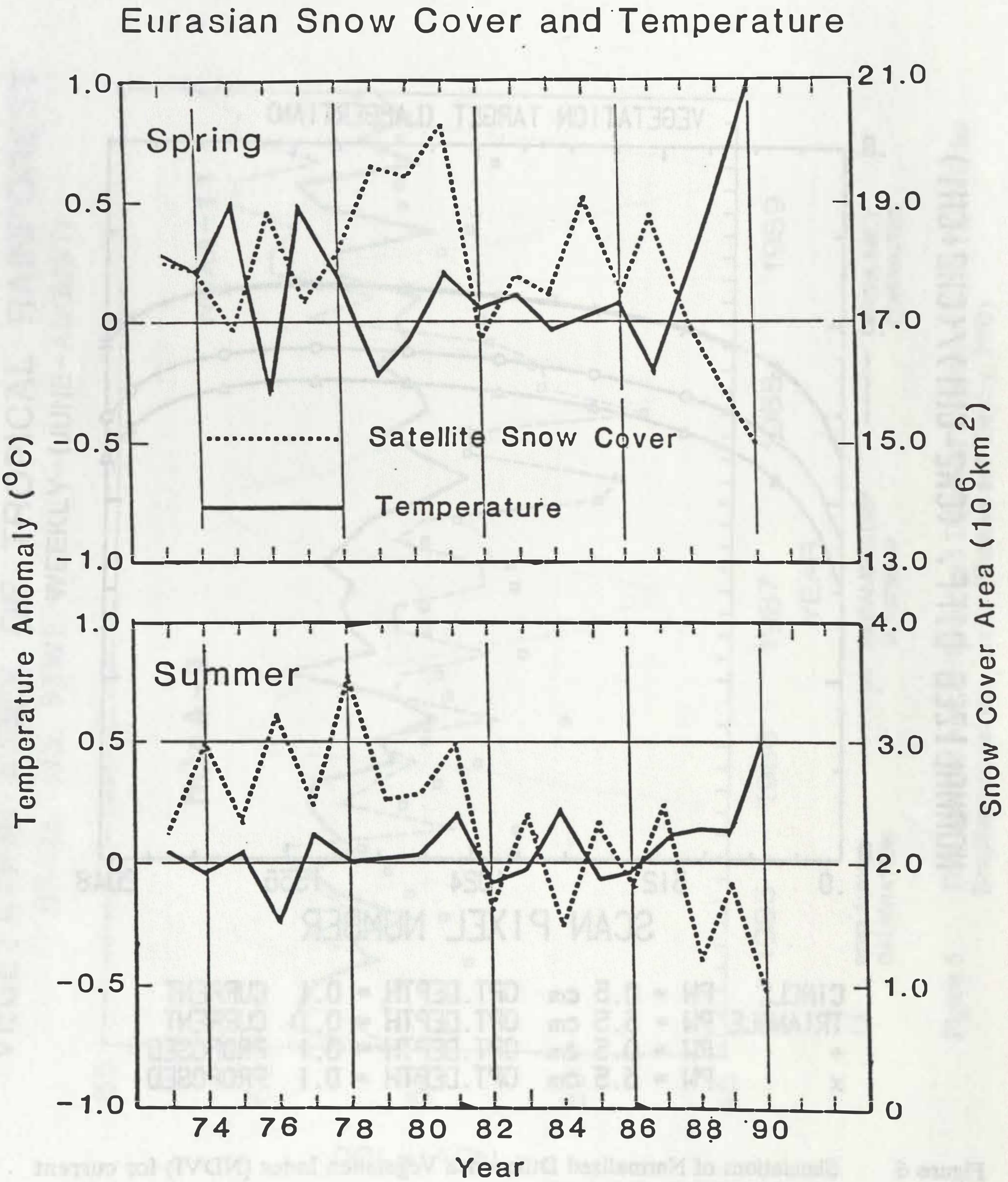

Figure 7 Time series of Eurasian snow cover area derived from satellite data (dashed) and Eurasian temperature anomaly (solid) derived from an analysis of surface weather stations for spring and summer. (Halpert and Ropelewski, 1991)

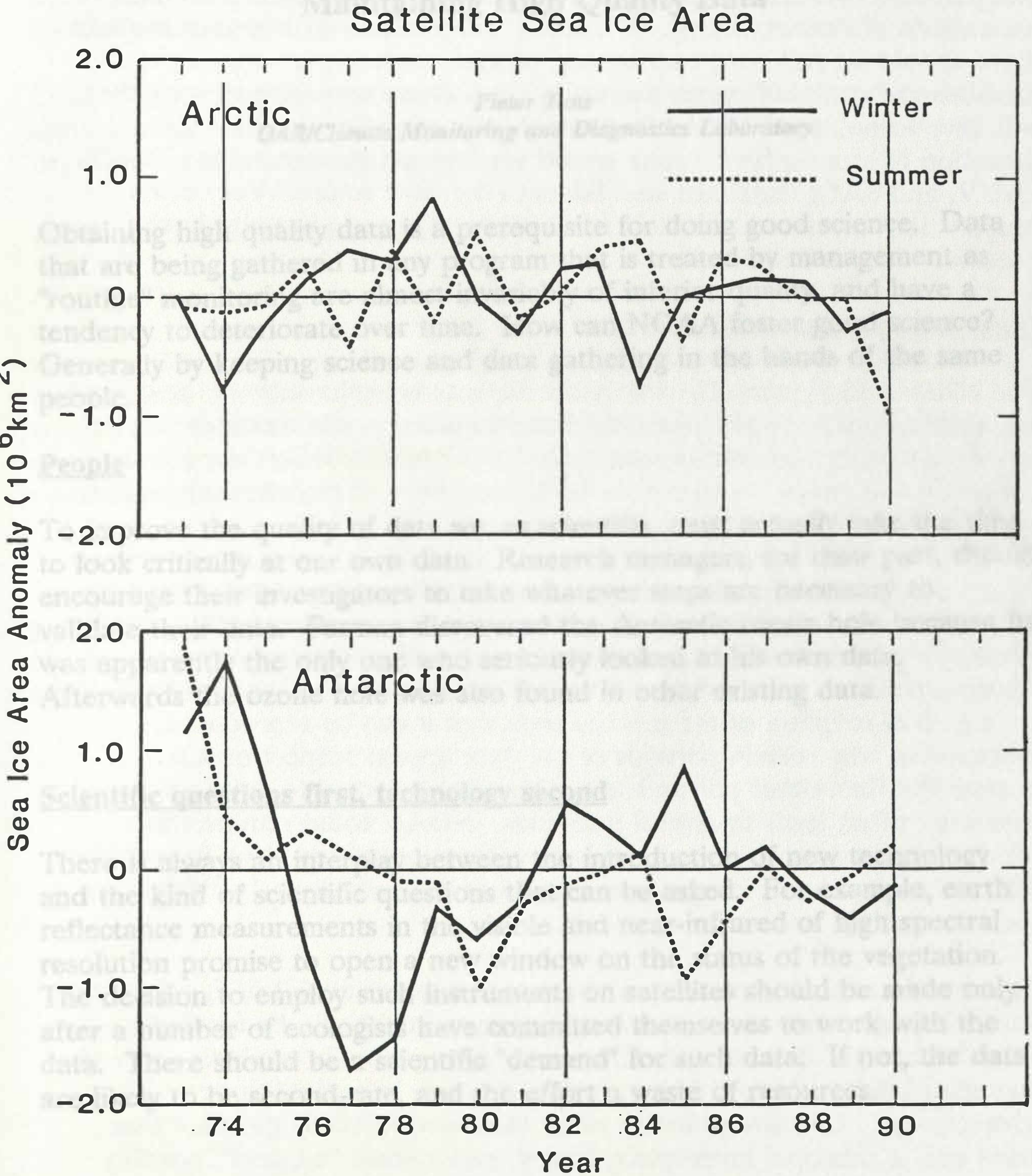

Figure 8 Time series of sea ice area anomalies. Upper panel: Arctic winter (January/February) and summer (August/September). Lower panel: Antarctic winter (August/September) and summer (January/February). (Halpert and Ropelewski, 1991)

A Few Suggestions for Achieving and Maintaining High Quality Data

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Obtaining high quality data is a prerequisite for doing good science. Data that are being gathered in any program that is treated by management as "routine" monitoring are almost invariably of inferior quality, and have a tendency to deteriorate over time. How can NOAA foster good science? Generally by keeping science and data gathering in the hands of the same people.

People

To improve the quality of data we, as scientists, must actually take the time to look critically at our own data. Research managers, for their part, should encourage their investigators to take whatever steps are necessary to validate their data. Farman discovered the Antarctic ozone hole because he was apparently the only one who seriously looked at his own data. Afterwards the ozone hole was also found in other existing data.

Scientific questions first, technology second

There is always an interplay between the introduction of new technology and the kind of scientific questions that can be asked. For example, earth reflectance measurements in the visible and near-infrared of high spectral resolution promise to open a new window on the status of the vegetation. The decision to employ such instruments on satellites should be made only after a number of ecologists have committed themselves to work with the data. There should be a scientific "demand" for such data. If not, the data are likely to be second-rate, and the effort a waste of resources.

Related is the exceedingly important issue of independent evidence. The comparison of results obtained via independent methods offers the best assessment of their reliability. Whenever new technology becomes available there should be sufficient overlap and careful intercomparison. If the methods are really different, and we really want to know the answer, they will have to be employed simultaneously. An example would be the detection of stratospheric ozone trends via Dobson spectrometers, TOMS, SBUV, and SAGE satellites, and lidars in the near future. Very often "duplication" of measurements is not a waste of money, but absolutely necessary for good science.

Documentation and archival

The Montsouris 0_3 data, obtained near Paris around the turn of the century, are an excellent example of careful documentation -- the methods can be reproduced and re-evaluated today. In today's scientific literature there appears to be undue emphasis on the presentation of results, explanations and conclusions rather than methodologies.

The status of NOAA data reports and technical memorandums should be enhanced -- they should count more heavily in career advancement relative to today's preponderance of papers in the open literature. Rules or recommendations on what should be included in data reports can be drawn up, e.g., a description of the method such that it can be reproduced, calibrations, why certain portions of the data appear suspect or less trustworthy than other portions, etc. Also, being forced to write up one's own work often leads to critical questions. NOAA could require this activity as part of any research initiative. This sort of reporting is not time frittered away, but an integral part of all scientific activity -- "what has not been written up, has not been done".

Data archival should be incorporated into the experimental design from the start. This is obvious for monitoring activities, but should be applied to many "campaign" data as well. Data should be generally available soon after they have been gathered. If not, it should weigh in against career advancement. It is always better when more people study the data than when only a principal investigator tries to select some "nuggets", possibly cultivating his/her preconceptions, while tending to neglect the rest. Certain ground rules about formats and other requirements for archival can be established, e.g., compatibility with emerging database technologies. It should be required to always include this activity in the research budget.

Data archival facilities and activities that have scant or no interaction with the scientists responsible for the quality of the data may look good on an organization chart, but are doomed to fail.

Standards and intercomparisons

An important management principle for accurate and precise standards for long-term measurements is that the users -- the people really motivated to answer the scientific questions -- should also be responsible for the creation, maintenance and documentation of the standards. The requirements for standards depend on the type of scientific questions being asked. These scientists may, of course, decide that the standards they require can be achieved commercially.

Standards are also usually the key to the proper characterization of instruments; for example, non-linearity, another requirement for obtaining good data. This process too should be science-driven. It is not practical to enumerate specific requirements for standards that apply to all the various measurements that are being made.

Fishery Data Sets

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The National Marine Fisheries Service collects, analyzes, and archives gigabytes of current and historical biological and environmental data to fulfill its mission of "Stewardship of America's Living Marine Resources." The ultimate usefulness of these data is impacted by data quality and continuity problems. Data sets with problems include the historical resource trawl surveys, commercial and recreational fisheries statistics, ecosystems monitoring programs, fishery habitat studies, marine mammal investigations, contaminants in food fish investigations, and environmental data. Key quality and continuity problems include loss of data collection platforms, changes in data acquisition instrumentation, reliability of data sources, and data management issues. Relevant data management issues are data quality control, conversion factors for fish weights, multiple data formats, variable parameter codes, and data documentation.

NMFS has lost data collection platforms, which had an immediate effect on data continuity. The loss of the Albatross IV research vessel in the Northeast, due to budgetary constraints, caused the curtailment of the MARMAP survey, one of the world's most comprehensive and large marine ecosystem monitoring programs. The Northeast Bottom Trawl Survey is now dependent on the R/V Delaware II and is therefore vulnerable to vessel breakdowns. Additionally, these losses have resulted in significant reductions in surveys for fishery habitats, marine mammals, and other Climate Global Change and Coastal Ocean Program initiatives. Similar reductions have occurred for the West Coast CALCOFI research program, in which surveys have been reduced twelve-fold in space and three-fold in time. Reductions in the Northwest and Alaska surveys have cut the number of sea days in half since 1980. Several NDBC meteorological data buoys are scheduled to be removed in FY 91 which will affect the reliability of West Coast rockfish assessment.

Changes in data acquisition instrumentation have created difficulties in relating data from different segments of time series. Water column profile data have been collected by Nansen cast bottles, XBTs, SDTs, and CTDs. Different trawl door designs affect the catch coefficients of trawl nets. Different types of plankton collection devices create a bias in the number and weights of plankton sampled. Calibration between the different collection devices requires significant resources and research to guarantee reliable data comparison.

NMFS commercial and recreational fisheries statistics are highly dependent on information obtained from fishermen. These data are subject to inaccuracies caused by intentional and unintentional erroneous reporting regarding the volume, location, and other catch parameters. Much cross checking is required to eliminate major biases.

Data entry quality control has increased significantly with the utilization of desktop computers with easy to use "off the shelf" data base management software that facilitates data quality controls. Some early experiments with quality control software have been positive. Quality control algorithms should be standardized and shared among systems using common elements.

Correction factors used to convert landed to live catch weights need continued research to ensure accuracy. Changes in ratios of shell fish meat weight to shell weight are variable and can bias fishery statistics.

The plethora of different data formats for time series data sets continues to pose challenges in relating data from different time segments. Also, many different parameter codes exist for the same elements. There are 10 or more different species codes in use in different regions, offices, and investigations. Fishery statistics data collected from different states and agencies have different area codes for the same area. Similar situations exist for other key data elements.

Documentation is needed to relate data from different systems. Standard element names, definitions, and formats should be established and documented, along with other metadata, in data dictionary/directory systems.

NOAA has made a good effort in developing the NOAA Earth Systems Data Directory, which establishes a standard method of documenting data files. We should go further and develop procedures to capture metadata at the system, experiment, and data element levels in order to ensure compatibility and relativity of data. Also, data quality indicators should be included in the data directory.

Data Quality and Continuity Issues for NOAA and Non-NOAA Data and Products Held by NOAA

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Among global observations and derived data products for which NOAA's National Geophysical Data Center (NGDC) is responsible are some spanning hundreds to thousands of years, for example, international sunspot numbers and paleoclimate data such as tree rings. Often, older values were derived from data of uncertain quality. Most surely, however, even flawed knowledge about long-term geophysical conditions in the coupled Sun-Earth system is better than an empty void to be filled only by results of extrapolating models. Some data sets once measured only on Earth's surface are recorded on space platforms . Ground-based sensors may still provide "ground truth." Other values measured in space lack a counterpart on Earth. Each type provides challenges that we must meet to provide data for present research and future studies. This presentation gives examples of parameters held by NGDC that need attention with respect to maintaining data continuity/integrity over changing measurement techniques and types of data processing. It raises issues involved if we are to "correct" data from the past which we did not collect, and others that arise when we accept responsibility for data and derived products collected/created by other agencies and institutions in the United States and foreign countries. All examples presented are important, but each only represents many others that could have been used.

Questions regarding changing global parameters which we should be able to address include:

- o How has solar activity varied over the period of observation?
- o How does the "solar constant" vary with time, and what is its value?
- o What is the speed and composition of the "solar wind" in interplanetary space: today and averaged over periods of days,

months, and years?

o How has the solar plasma input into the near-Earth space (magnetosphere) varied with time over the period of record monitored by NOAA's GOES?

o How can energy inputs measured at geostationary orbit altitude (6.6 Re) be reconciled with those measured by Low Earth Orbiters?

o How has the global geomagnetic field changed with time as reconstructed from paleomagnetic measurements, early 18th-19th Century measurements, and as modeled from the present global array of magnetic observatories?

o At what rate is the Earth's protective magnetic field declining toward zero and possible reversal? What will be the effects during transition?

o Galactic cosmic rays, solar cosmic rays, and magnetic storms damage orbiting satellites or cause them to malfunction. They also affect the operation of chip-based technology in the air and on Earth's surface. <u>How do magnetic storms today compare with those of the past?</u>

o <u>How many earthquakes occur worldwide during a given time interval?</u> How much stored seismic energy is released over time? Is the rate about constant worldwide and over large regions of Earth?

NGDC is responsible for maintaining data collections that, in principle, can be addressed to provide at least partial answers to these questions. However, there are issues that affect the databases which would be accessed. Some are:

o <u>Conversion from analog to digital sensors</u>

Geomagnetic observatories worldwide are converting from photographic analog sensors to digital instruments. This change introduces problems of cost of processing, more frequent data gaps due to power failures, and inability of computer processing to replicate important indices previously scaled by hand from continuous analog records. Analog to digital sensor conversion is also taking place in the worldwide network of ionospheric sounders.

o Errors introduced on site by key-entry of tabular data

Cosmic ray return neutron monitor records are usually reported as relative percentages of flux variation. There are substantial errors in the absolute digital record arising from different causes, including poor data entry. It is often impossible to return to the original source for corrections, yet we feel some effort should be made to "adjust" obviously bad values.

Geomagnetic records include major "shifts" which are probably artificial in origin. If they can be identified, how should they be "corrected"? Some are substantial and affect the continuity of long-term models derived from the global geomagnetic database.

o Errors introduced by data processing or in deriving key products

Large earthquakes should be well-observed worldwide, and their frequency within large regions of similar seismicity should be relatively constant over longer periods of time. Lists of earthquakes having mb>5.5 from three different sources are compared for large regions of Earth and shown to be most consistent for carefully derived magnitudes. This is important if time rates of change in seismic activity are to be sought. These results suggest that the derivation of earthquake magnitude is of fundamental importance.

NOAA processes energetic particle records from the GOES Space Environment Monitors. These data are critical for design of aerospace instruments to function correctly in all conditions, and for other research applications. In January 1990, a significant change was made in the processing algorithm for proton fluxes to remove counts of higher-energy protons that penetrate the sides of lower-energy sensors and inflate their readings. This introduced a step-function in the historical record that negates long-term comparisons to derive multi-year trends. GOES proton data deposited monthly with NGDC are now in two formats: old and new algorithm results. We continue to disseminate the old-algorithm values at the requests of users who do not have the details from NOAA needed to apply the improved algorithm to values from earlier years.

We take as axiomatic that global data kept for long-term applications should be of the highest possible quality and fully documented. This ignores the practical questions of how important are different levels of error and in how many versions data should be retained. How much documentation is enough?

OBSERVED SOLAR VARIABILITY SINCE 1600

How has solar activity varied over the period of observation (1610-present)?

- **Sunspot numbers vary with observed regularity, average period 11.1 years**
- **Solar flares show similar periodicity but different amplitude and phase for recent cycles**
- **Magnetic activity indices show rising trend with sunspots since about 1900**

Does the "solar constant" vary with time and what is the sun's total luminosity?

- **Total solar irradiance measurements from five different satellites span, at most, about one 11-year cycle and differ in absolute level by an amount equal to the average range of variation**

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CHANGES OF OBSERVED PARAMETERS ARISING FROM USE OF NEW TECHNOLOGY

Solar radio frequency emissions at 10.7 cm wavelength introduced in 1940s can substitute for sunspot numbers

- Advantages of electronic observations not obscured by optical viewing - minimizes observer subjectivity
- Good correlation but differences near peak and minimum inherent from definitions
- Observations at one site vs. worldwide network; change of 10.7-cm site in 1991 may affect continuity

Apparent systematic increase in sunspot magnetization

- New look at Mt Wilson observations of magnetic intensity of sunspot regions shows a systematic increase over last three cycles

EFFECTS OF CONVERTING FROM ANALOG TO DIGITAL RECORDING

Derivation of geomagnetic activity indices affected by change to digital sensors

- **Digital magnetometers introduced worldwide (except USSR) ends continuous analog recording on film and changes activity index derivation**
- **Digital ionosondes raise question of how to derive scaled parameters produced by hand in past**

Photographic records being replaced by digital imagery

- **Sunspots photographed in white light would look familiar to Galileo after almost 400 years**
- **Today solar images are increasingly recorded digitally and stored on magnetic or optical media**

CORRECTION OF ERRORS INTRODUCED AT RECORDING SITE OR DURING KEY-ENTRY

"Traditional" reporting of cosmic ray-produced neutrons overlooked errors in absolute counts

- Cosmic rays reaching Earth's atmosphere from galactic sources are modulated by solar activity (negative sunspot cycle)
- "Adjusted" values introduced at NGDC correct most likely errors but must be reviewed

Obvious errors in key-entered geomagnetic and ionospheric hourly values are being corrected at NGDC

- Visual survey essential to identify data "busts"
- Changes flagged in data record
- Quality control software provided to foreign sources of data

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DIFFERENCES ARISING FROM PROCESSING OR IN DERIVATION OF KEY PARAMETERS

How many earthquakes per month in large regions?

- **Two major lists of global earthquakes differ widely in the number and frequency of large earthquakes**
- **Changes by factor of three in number of events per month in both lists but at different times and some in opposite directions**
- **Maximum likelihood estimation of magnitudes resolves differences in ISC list of mb>5+ earthquakes**

Changed processing algorithm for energetic protons measured by GOES sensors

- **Consistent values over time important for comparison of major events**
- **Changed algorithm in Jan 1991 will inhibit long-term trend identification unless applied to earlier observations**

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