CLIMATE MONITORING USING TOVS DATA

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1. INTRODUCTION

Data from the TIROS Operational Vertical Sounder (TOVS) and other satellite remote sensing observations have gained increased importance in view of the heightened interest in Climate and Global Change (CGC) research. Interannual variability in all fields in the tropics and subtropics is dominated by El Niño-Southern Oscillation (ENSO) periods (2-7 years) and by sporadic volcanic events Work has recently begun on reprocessing the historic TOVS data set in order to minimize satellite to satellite biases and to perform retrievals of interest to CGC researchers. This talk will provide an overview of the current status of CGC research using TOVS and other complimentary satellite remote sensing data sets. It will also outline plans for the reprocessing of the TOVS data set and plans for new launch criteria for the NOAA polar orbiting spacecraft.

2. CLIMATE MONITORING AND DIAGNOSIS USING TOVS DATA

2.1. Retrieval of Sea Surface Temperature from AVHRR/2 Observations

Large-scale sea surface temperature anomalies during ENSO have been linked to large anomalies in atmospheric temperature, precipitation, and flow patterns globally. Figure 1 shows the normalized sea surface temperature (SST) from a 30-year mean of the Comprehensive Ocean Atmosphere Data Set (COADS; Woodruff et al., 1985) in situ data from 1956 through 1992. This region, called Niño 4, is of particular interest to climate researchers studying tropical/mid-latitude interactions during ENSO warm and cold events. ENSO warm events are defined by times where the normalized departures are greater than 1, and ENSO cold events are defined by periods where the departure is less than -1. Data sets like this are helpful for defining the large-scale seasonal evolution of ENSO SST, but satellite data should be able to offer a much more detailed picture of the ENSO evolution in space and time.

Since 1982, a multi-channel sea surface temperature (MCSST) retrieval has been performed operationally by NESDIS (McClain et al., 1985). The MCSST method uses thresholds and spatial and spectral uniformity tests to determine clear only spots. Then multichannel retrieval algorithms are used to correct for tropospheric water vapor attenuation and obtain an accurate absolute surface skin temperature. Figure 2 shows the zonally-averaged difference between the MCSST analysis and COADS as described by Bates (1993). During this ten-year record, two major bias events are very evident. Both events are due to the injection of volcanic aerosols into the stratosphere. The first event occurs in March of 1982 and is associated with the eruption of El Chichón in central Mexico. The maximum anomaly is approximately 2°C immediately after the major eruptions. The biases expand latitudinally and biases of 1°C remain throughout 1983. In March through May 1991, a series of eruptions occurred on Mt. Pinatubo. Biases immediately after the eruptions exceed 5°C. In late summer 1991, NESDIS implemented a new multichannel algorithm in an attempt to correct for the volcanic aerosols. Some improvement is evident from this change, but smaller biases (about 0.5-1.0°C) remain in the tropics. However, late in 1991, another significant bias appears in the southern hemisphere. This bias is apparently associated with the Mt. Hudson eruption.

Although less evident than the volcanic bias episodes, a third bias event occurs in the first half of 1987. This bias event , however, is very different from the volcanic events in that it appears to be zonally symmetric. This event is associated with the use of the wrong calibration tables for the AVHRR/2. This is a scene temperature-dependent bias and has a zero crossing at a temperature of about 15°C. At MCSST temperatures above this there is a slight positive bias, at temperatures below this there is a negative bias.

Sea surface temperature observations are probably one to the best fields to validate against in situ observations since SSTs are often homogeneous over large areas and show only small diurnal cycles. Yet very large interannual biases exist due to volcanic aerosol contamination and these biases make it difficult to use these data for ENSO studies. It is even more difficult to identify and track the effects of stratospheric aerosols in retrievals of temperature and water vapor using TOVS data.

2.2. Volcanic Aerosol Effects on NOAA Satellite Observations

Although none of the instruments on the TIROS-N series of NOAA polar-orbiters was designed to measure volcanic aerosols, such aerosols have had a major impact on the climate and our ability to monitor climate using satellite remote sensing. Figure 3 shows a zonally-averaged time-latitude plot of 525 nm stratospheric optical depth from the Stratospheric aerosol and gas experiment (SAGE II) courtesy of McCormick et al. (1992). At the beginning of the SAGE II record in late 1984, the stratospheric optical depths were still relatively high due to the lingering effects of the eruption of El Chichón in March 1982. In early 1986, Mt. Ruiz erupted sending a moderate amount of aerosols into the stratosphere and in the middle of 1990 Mt Kelmut sent a minor amount of aerosols into the stratosphere. The major event of this timeseries, however, is the eruption of Mt. Pinatubo in 1991. Stratospheric aerosol optical depths shortly after the Mt. Pinatubo eruptions went off scale for the SAGE II instrument indicating quantities over 0.2. The long-term interannual record from the TOVS and the AVHRR on the NOAA polar orbiters shows mounting evidence that stratospheric aerosols contribute both directly and indirectly to large-scale interannual variability particularly in the tropics.

2.3. Retrieval of Lower Troposphere Mean Temperature Using MSU Observations

The broad weighting functions of the MSU channels 2, 3, and 4 respond approximately to the mean temperature of the troposphere, the upper-troposphere lower-stratosphere, and the lower stratosphere. Initially, Spencer et al. (1990) analyzed only the MSU channel 2 brightness temperature observations as a surrogate for the mean global tropospheric temperature. The MSU brightness temperature record is very stable over time and high correlations were found between MSU 2 brightness temperature anomalies and mean tropospheric temperature anomalies from radiosonde observations. However, upon closer examination of the interannual record, especially after the Mt. Pinatubo eruption, it became clear that the MSU 2 weighting function was picking up substantial brightness temperature anomalies due to the contribution of its weighting function in the stratosphere. This led to Spencer and Christy (1992) to retrieve the lower tropospheric temperature using a weighted combination of MSU 2 observations near nadir with those further toward the limbs.

Figure 4 shows the resultant retrieval of MSU 2 lower tropospheric temperature anomalies from 1979 through the first half of 1992. The largest coherent interannual variability is clearly associated with El Niño-Southern Oscillation (ENSO) warm and cold events in the tropics. A warmer than normal lower troposphere is associated with the latter stages of the ENSO warm events of 1979-80, 1982-83, and 1987-88. A colder than normal lower troposphere is found at the latter stages of the ENSO cold events in 1983-84 and 1988-89. After the warm events, the is often the suggestion of a poleward propagation of the warm troposphere anomalies. This poleward progression is predicted by simple model response to an equatorial heat source.

The evolution of the ENSO warm events in the tropics may have been damped following the volcanic eruptions of El Chicnón in March of 1982 and Mt. Pinatubo, beginning on March 1991. This has important implications for both reprocessing the TOVS data set and for GMC modeling of the past 10-15 years. On the interannual time scale, the effects of volcanic aerosols most be explicitly accounted for in both the TOVS retrievals and in GCM simulations.

2.4. Retrieval of Mean Precipitable Water Content Using HIRS

Water vapor is integrally involved in many of the major energy transfer processes that determine weather and climate. Water vapor is the key greenhouse gas in general circulation model simulations of future climate change. Until recently, however, most models contained only a very crude representation of the hydrological cycle. Recognition of the importance of water vapor in climate and global change, and improvements in model representations of the hydrological cycle, have renewed interest in retrieval of water vapor from HIRS.

The ability of the TOVS low-level moisture channel (channel 10) to retrieve the near surface water vapor mixing ratio depends on the relative contrast between the surface temperature and the brightness temperature of the lower atmosphere (Wu et al., 1993). Over the ocean, under most conditions, the contrast between the surface temperature and the lower atmosphere brightness temperature is small, and thus TOVS is not sensitive to variations in low-level moisture. Over land, the situation is highly variable. During the afternoon, there may be a large contrast between the surface temperature and the lower atmosphere brightness temperature. Under these conditions, TOVS may provide very accurate observations of low level moisture. Conversely, microwave observations provide accurate low level moisture estimates over the oceans, but the high and variable microwave emissivity over land prevents mirowave data from being useful over land.

Figure 5 shows a comparison of the differences in precipitable water content (PWC) between the NMC and ECMWF analysis and observations from TOVS and SSM/I for the season DJF 1988-1989. Compared to the SSM/I data over the oceans, the ECMWF analysis shows a systematic pattern of underestimating PWC in the tropical convergence zones and overestimating PWC in the subtropical subsidence regions. The NMC PWC analysis is closer to the SSM/I PWC values in the convergence zones, but overestimates the PWC more than ECMWF in the subsidence areas. The comparison with TOVS data suggests that both NMC and ECMWF underestimate the PWC particularly in the subtropical jet region across northern Africa eastward through India and into southeast Asia. This cursory assessment of PWC analysis from the operational centers suggests that there is room for considerable improvement in how these centers use satellite-derived moisture data.

3. OVERVIEW OF THE TOVS PATHFINDER

3.1. TOVS Pathfinder Science Working Group Report

The TOVS Pathfinder Science Working Group (SWG) met several times under the auspices of the NASA-NOAA Pathfinder program. The Pathfinder effort has the objectives of placing the level 1b data on readily accessible working storage and ensuring its long-term availability. Additionally, NASA and NOAA will involve the research community and agency scientists in the definition, production and verification of community consensus derived products relevant to Global Change research. The scope of work defined in the TOVS Pathfinder Charter includes:

1) Determine the best method for calibration of the long-term dataset, keeping in mind the intercalibration of the satellites;

2) Determine the steps that must be taken in order to decide on and generate geophysical parameters datasets that will be useful for the study of Global Change. Conditions for usefulness may include data stability and accuracy. In addition, such datasets may be of reduced spatial or temporal resolution;

3) Determine the need for reconvening, or, if necessary, set a schedule to convene on a periodic basis. Such issues as the need for reprocessing the entire archival are salient.

After extensive discussion and rewriting, the recommendations of the TOVS Pathfinder SWG were grouped into three major themes whose priorities for initiation are in the order given:

1) Radiance Datasets

2) TOVS Retrieved products;

3) Validation and intercomparison of Pathfinder datasets and retrieval methods.

The flow of reprocessing the TOVS (and other) Pathfinder datasets is schematically illustrated in Figure 6. The Level 1b TOVS dataset is currently being copied and stored in a more compact form using IBM square tapes. This will preserve the basic TOVS historical record, but will not necessarily make the database any easier for the broad research community to use. The next level of data envisioned by the TOVS Pathfinder SWG was a time-ordered and space-ordered set of earth located, calibrated radiances (ELCR). At full resolution, however, such a dataset would be larger than the original level 1b dataset. The TOVS Pathfinder Implementation Team (a subset of the TOVS Pathfinder WSG) decided that it would not be practical at this time to produce such a dataset. Unfortunately, this has also left the production of the spatially and temporally composited ELCR and clear column radiances from the default cloud clearing scheme in limbo. I feel that this dataset is still of primary importance to the TOVS Pathfinder and that real progress in understanding climate variability will be made through analysis of the radiance dataset, not in any of the retrieval paths. A radiance dataset with even 5-day, 100-km averages would readily used by many climate researchers.

At a lower priority, beneath the radiance databases, are the Paths for producing retrievals from the TOVS data. Path A is hydrodynamic model dependent and a priori data dependent, Path B is hydrodynamic model independent and a priori data dependent, Path C is hydrodynamic model independent and a priori data independent. The lack of concensus within the TOVS Pathfinder SWG underscores the insufficient experience and lack of difinitive results regarding derivation of long-term climate and global change products from satellite data. It also emphasizes the importance of producing a reduced resolution TOVS radiance dataset that will be widely distributed to the climate community. There is much to be learned in the three path approach, but it concerns mostly retrieval methodology and not climate. It is much more important for the climate community to have a radiance dataset to analyze than to wait for retrievals. Producing and widely distributing a TOVS radiance dataset to the climate community will immediately make the data useful for a wide range of new and innovative uses.

3. DATA CONTINUITY/SCIENCE ISSUES FOR FUTURE NOAA POLAR SATELLITE LAUNCH DICISIONS

The next polar-orbiting satellite ready for launch, NOAA-I, has been placed in storage subject to a 120-day call-up. The present launch criteria does not take into consideration data continuity and science issues, only requirements for numerical weather prediction. Because of this, an ad hoc working group of all NOAA Line Offices and major Program Offices was convened to consider such issues. In particular, an earlier than normal call-up would include the opportunity to have an overlap period between the two afternoon satellites thus assuring continuity of measurements with like instruments because of no gap in coverage and would offer the opportunity for intercalibration between the old and the new instruments in space. Science issues discussed identified at least ten variables of critical interest to CGC researchers. These include: ozone, MSU retrievals of mean temperature, stratospheric temperatures, vegetation index, clouds and radiation, sea surface temperature, upper tropospheric moisture, snow and ice cover, aerosols, and coastal resources.

Based on these data continuity and science issues, the working group recommended the following:

PRIMARY

1) NOAA should call up the launch of NOAA-I in the September/October 1992 time frame for launch no earlier than January/February 1993 (NOAA-I launch is now scheduled for June 1, 1993). This recommendation accounts for various schedule impacts of launch and ground systems, yet recognizes the importance of minimizing a potential gap in NOAA afternoon orbit polar satellite data for scientific purposes, including global climate monitoring and research.

2) NOAA establish a formal, standing working group comprised of representatives from all NOAA Line and Program Offices to consider future (post NOAA-I) data continuity/science issues on a case-by-case basis that could lead to earlier than normal launch call-ups.

SECONDARY

3) NOAA should consider implementation of a more precise orbital insertion for future polar satellites in order to minimize orbital drift over the lifetime of the satellite mission.

4) NOAA should consider upgrades to the Command and Data Acquisition (CDA) stations that would permit near simultaneous command, acquisition of data from two or more satellites.

References

Bates, John J. , 1993: A decade of multispectral sea surface temperature observations from space. Accepted *Adv. Space Res.*

Hussey, W. John, 1992: Report of the NOAA working group on data continuity/science issues for NOAA-I and future polar satellite launch decisions. Available from NOAA NESDIS Office of Systems Development.

McClain, E. P., W. G. Pichel, and C. C. Walton, 1985: Comparative performance of AVHRR-based sea surface temperatures. *J. Geophys. Res.*, **90**, 11,587-11,601.

McCormick, M. P. and R. E. Veiga, 1992: SAGE II measurements of early Pinatubo aerosols. *Geophys. Res. Let.*, **19**, 155.

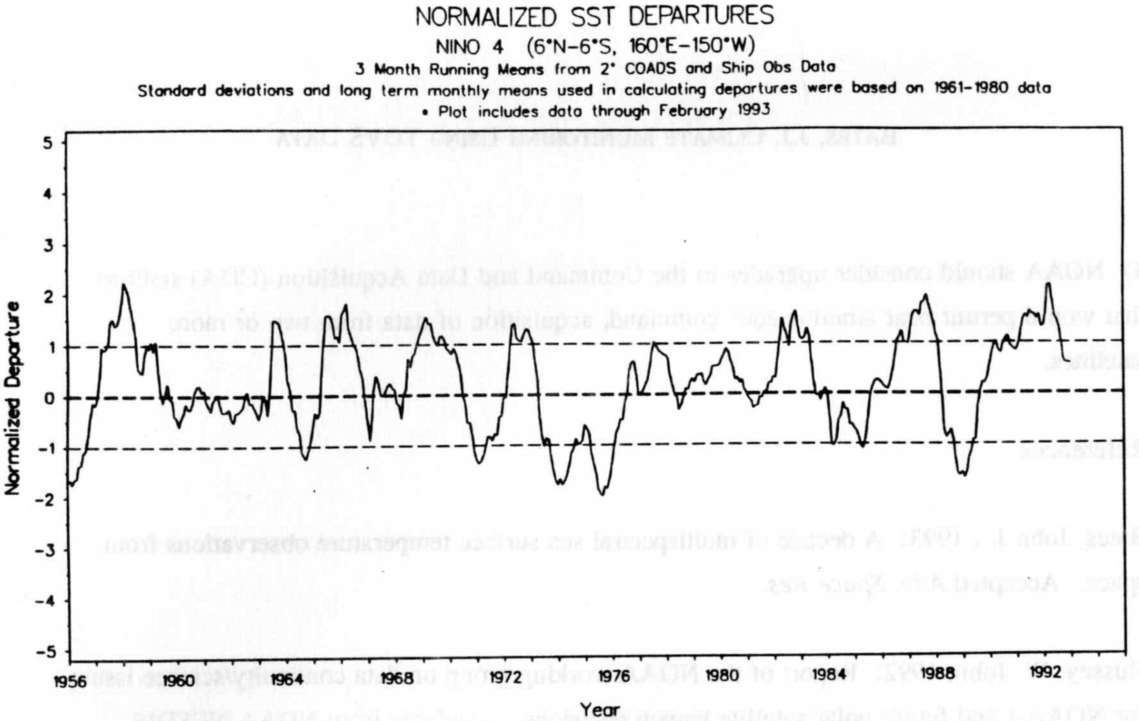
Spencer, R. W., and J. R. Christy, 1992: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part II: a tropospheric retrieval and trends during 1979-1990. *J. Climate*, **5**, 858.

Spencer, R. W., J. R. Christy, and N. C. Grody 1990: Global atmospheric temperature monitoring with satellite microwave measurements: Method and results. *J. Climate*, **3**, 1111-1128.

Thompson, O. E., 1991: Revised final report of the TOVS Pathfinder Scientific Working Group. Available from O. Thompson, University of Maryland at College Park.

Woodruff, S. D., R. J. Slutz, R. L. Jenne, and P. M. Steurer, 1987: A comprehensive ocean-atmosphere data set. *Bull. Amer. Meteor. Soc.*, **68**, 1239-1250.

Wu, X., J. J. Bates, and S. J. S. Khalsa, 1993: A climatology of water vapor band brightness temperatures from NOAA operational satellites. Accepted *J. Climate*.



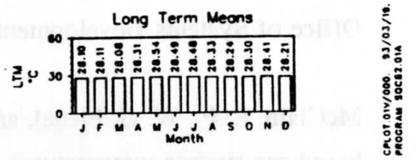


Figure 1. Sea Surface temperature departures in Niño 4.

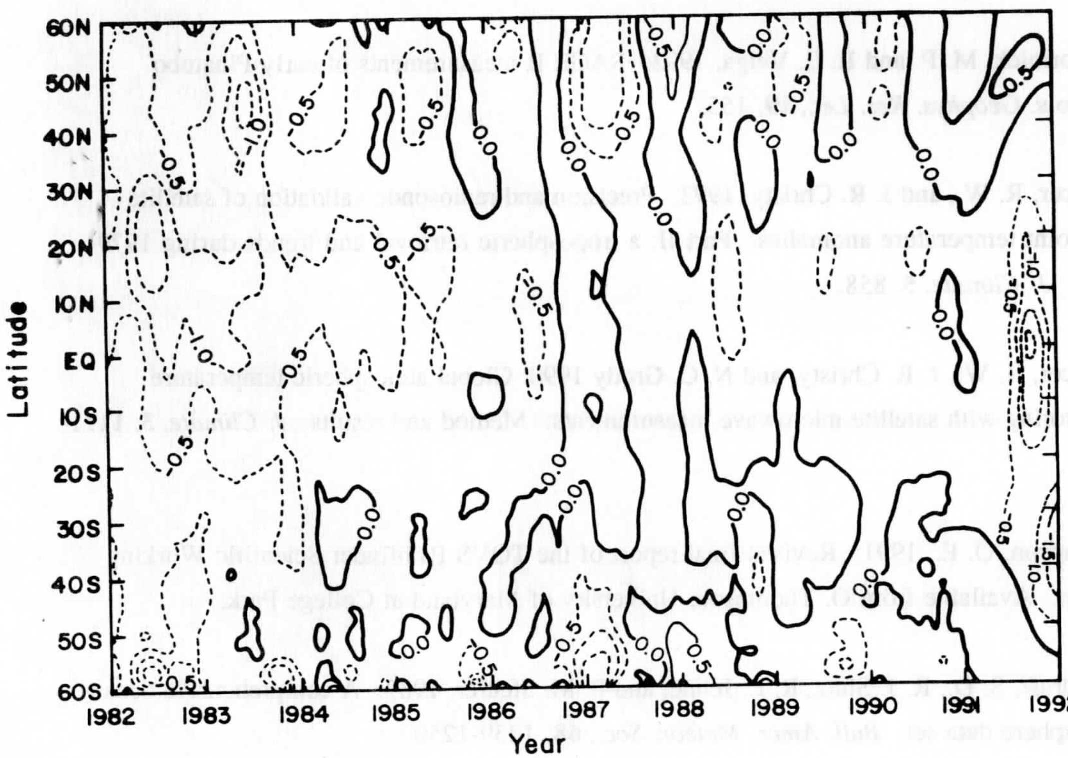


Figure 2. Zonally-averaged mean monthly difference between MCSST and COADS sea surface temperatures (from Bates, 1993).

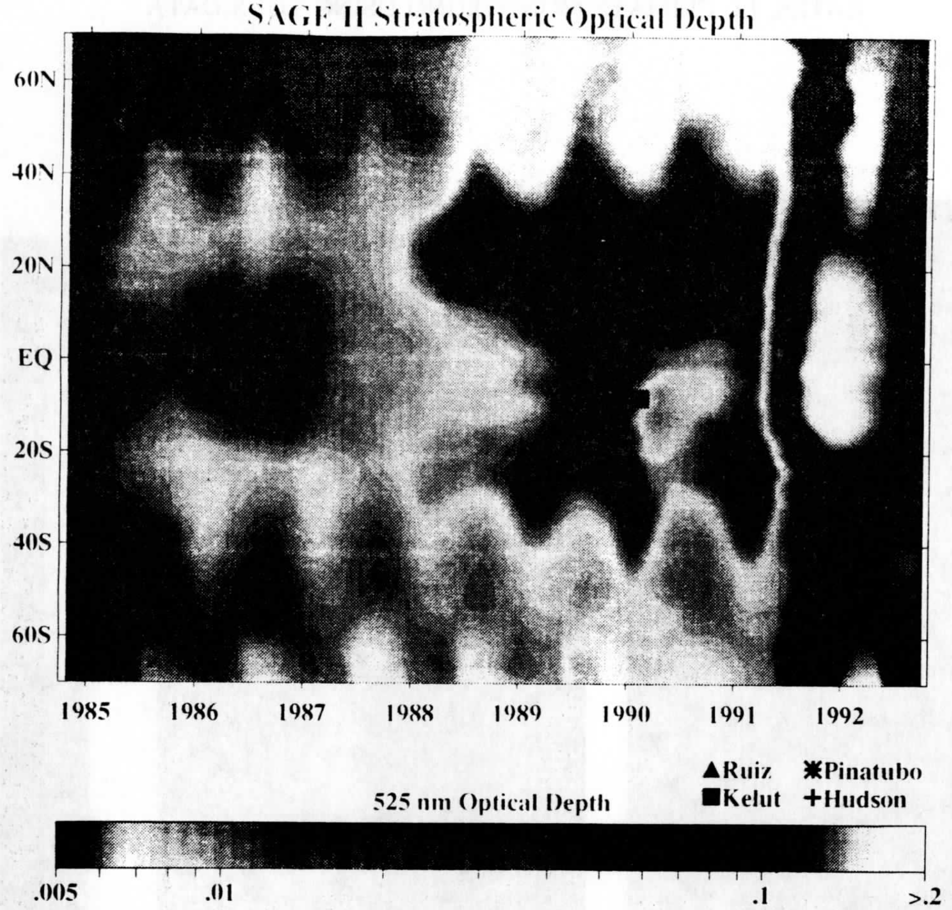


Figure 3. Zonally-averaged mean monthly SAGE II 525 nm optical depth (courtesy McCormick and Veiga, 1992).

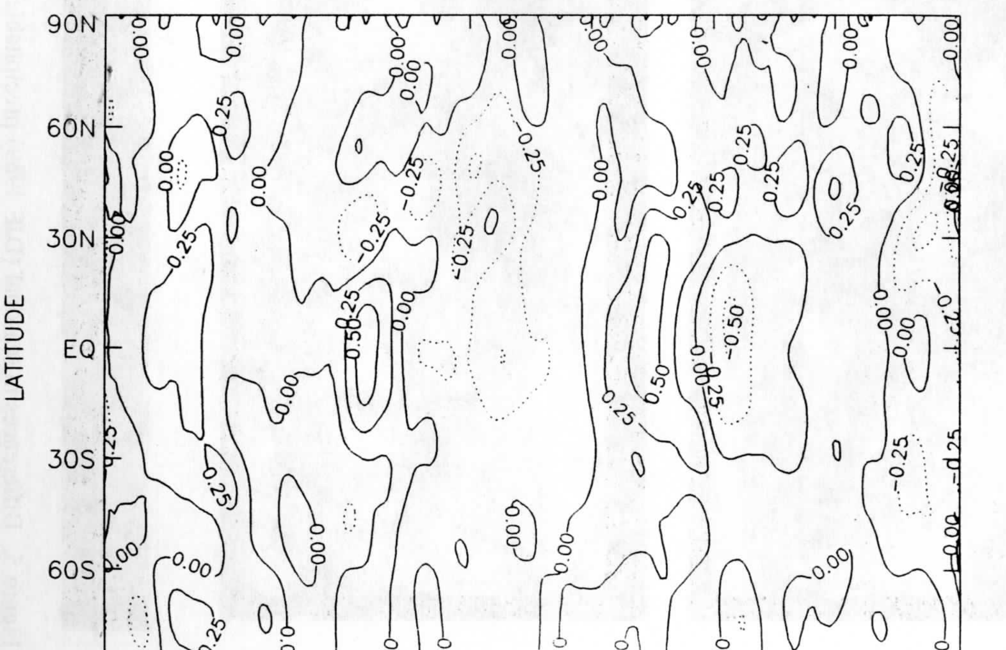


Figure 4. Zonally-averaged mean monthly MSU2R anomalies (courtesy Spencer and Christy, 1992).

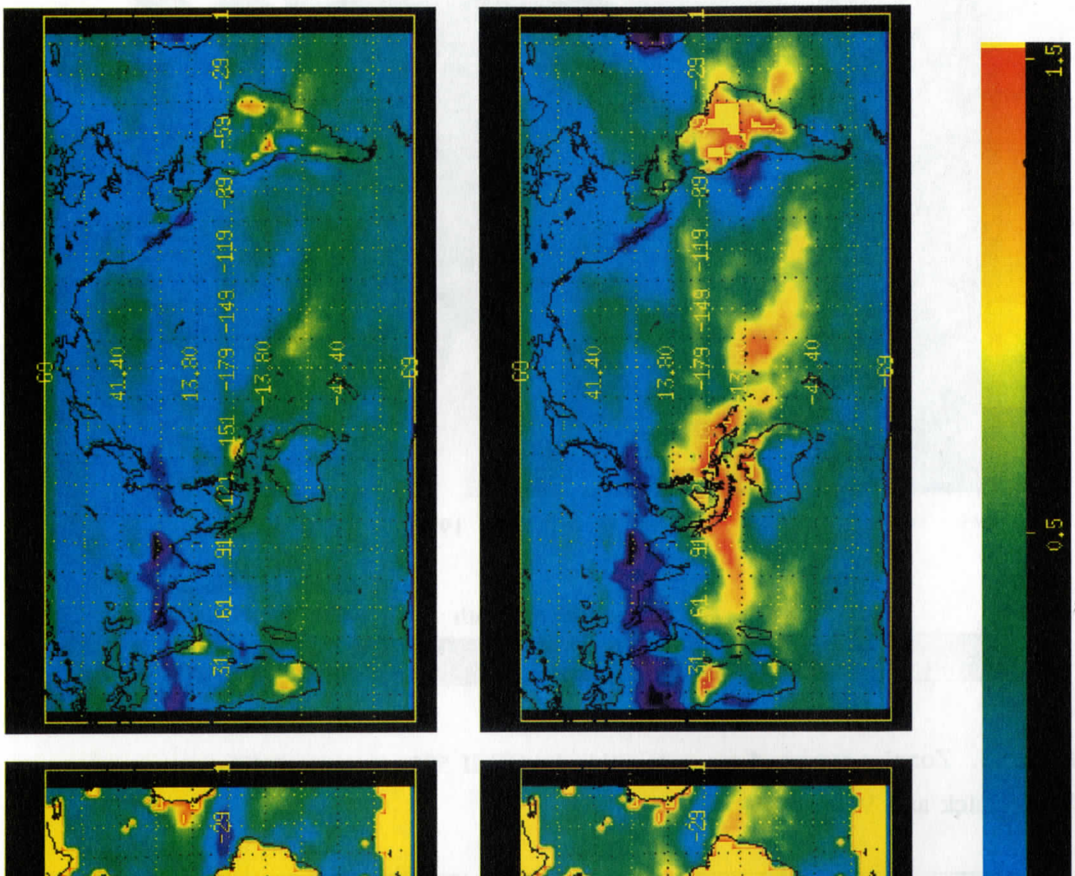


Figure 5. Differences in seasonal (DJF 1989) precipitable water content between operational centers and satellites: ECMWF - SSM/I (upper left), ECMWF - TOVS (upper right), NMC - SSM/I (lower left), NMC - TOVS (lower right).

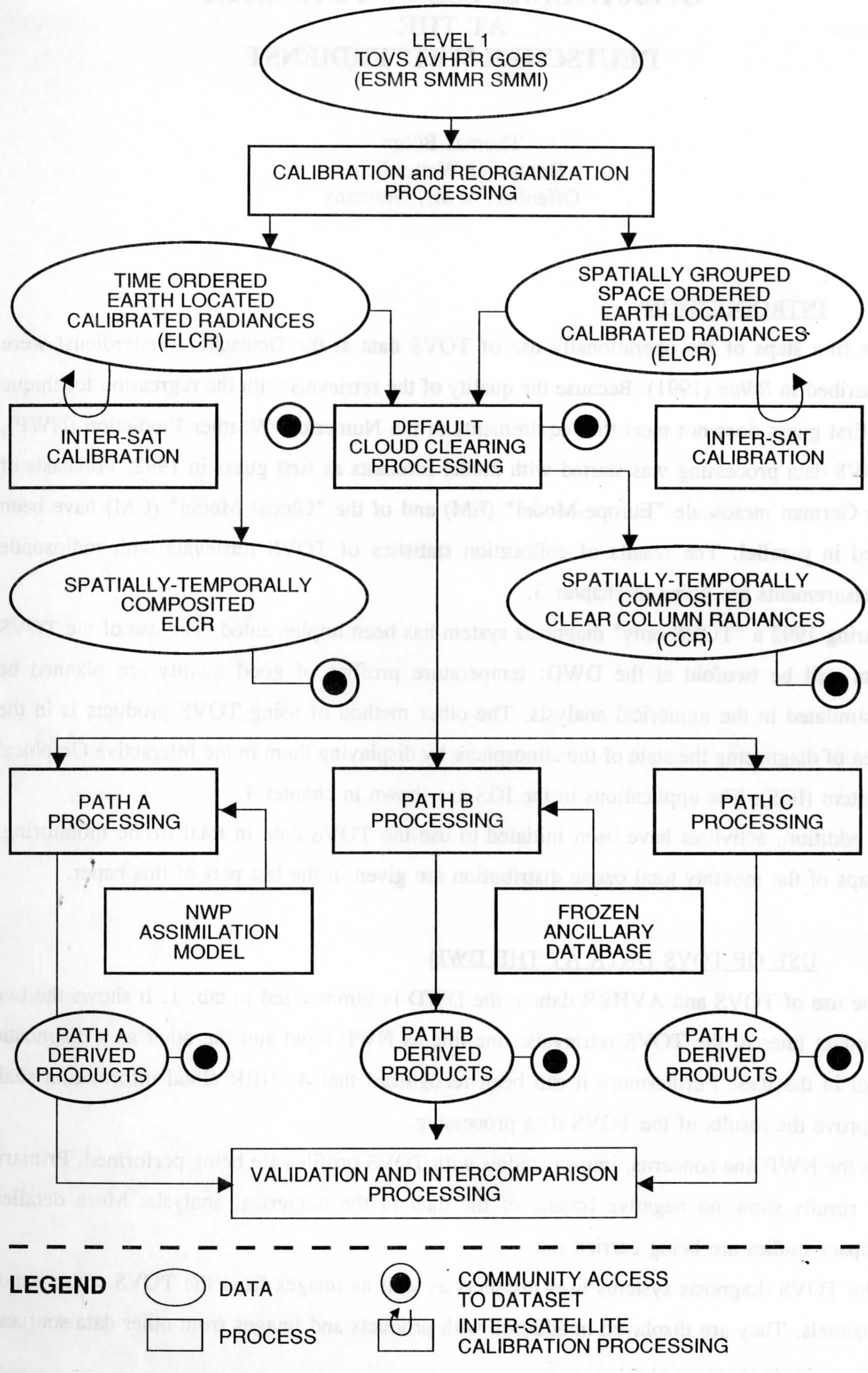


Figure 6. Flow chart of proposed TOVS Pathfinder processing (from Thompson, 1991).

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