Satellite Upper Air Network

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INTRODUCTION

The following report proposes a network of about 40 upper-air sites (and available ships) that would routinely launch reference radiosondes coincident with polar satellite overpass, referred to as the Satellite Upper Air Network (SUAN). The candidate SUAN sites are presented, along with the potential mutual benefits of SUAN on satellite data systems, climate, numerical weather prediction (NWP), radiative transfer (RT) models, future advanced sounders, and the radiosondes, and the growing support for SUAN as an important step toward insuring that past mistakes are not repeated.

BENEFITS OF SUAN:

Satellite Data and Products

Operational polar satellite measurements and derived products utilize collocations of satellite data and radiosondes for validation and also for direct product tuning during retrieval (Reale, 2002). Troubling degrees of inconsistency among the global distributions of collocations available per satellite, and the need for broad time windows to achieve large enough global samples has raised questions concerning their suitability for these purposes. Typical global distributions of collocations for NOAA-15 (top) and NOAA-16 (middle) operational Advanced-TOVS satellites (Tilley et.al., 2000) are shown in the 2 panels of Figure 1. The two panels of Figures 2 show corresponding vertical accuracy statistics per satellite for the 30N to 30S land regions, respectfully. As can be seen the accuracy curves show significant differences particularly for bias, but these are much more indicative of systematic uncertainties due to sampling inconsistencies than actual satellite dependent product structures.

A projection of the problem in “radiance” space is illustrated in the two panels of Figure 3, which show examples of RT bias adjustments derived for the AMSU-B channel 3 (183 +/-1 GHz) from NOAA-16 (top), and NOAA-15 (bottom). It can be seen that although correlated, there are satellite dependent differences in the magnitudes of the adjustments, in some cases exceeding 5K. Since the samples of data used to compute “bias-adjustment” coefficients are the collocation data-sets as shown in Figures 5, it is uncertain whether the differences per satellite are indicative of actual radiometer sensitivity or sampling difference. These are discussed further in Section 2.4.

Figures 4 shows collocations for N-16 using a 1-hour time window. As can be seen the coverage and sample size is certainly too small and isolated to be meaningful for purposes as shown in Figures 2 and 3. Sampling characteristics of collocations within 1 hour of NOAA-15 (as well as NOAA-17) reveal similar problems, along with their being mutually exclusive per satellite.

The resolution of global sampling problems described in Figures 1 through 4 would have positive impacts for not just satellite products, but all scientific areas as addressed in the following sections.

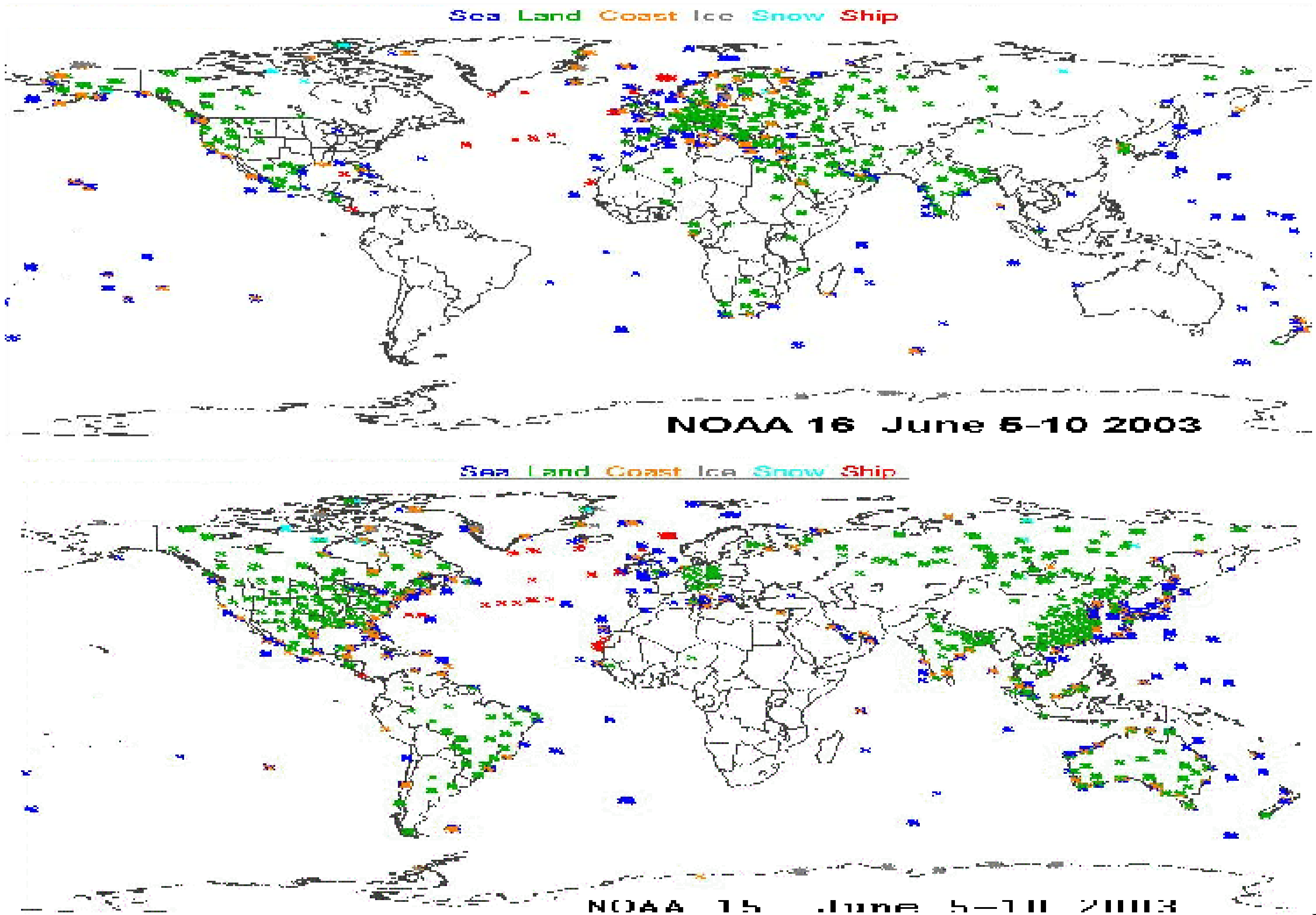


Figure 1: **Co llocated radiosonde and satellite observation samples compiled by NESDIS for NOAA-16 (upper) and NOAA-15 (lower) using 3-hour (land) and 5-hour (sea) time windows.; Sea, Land, Coast, Ice, Snow and Ship.**

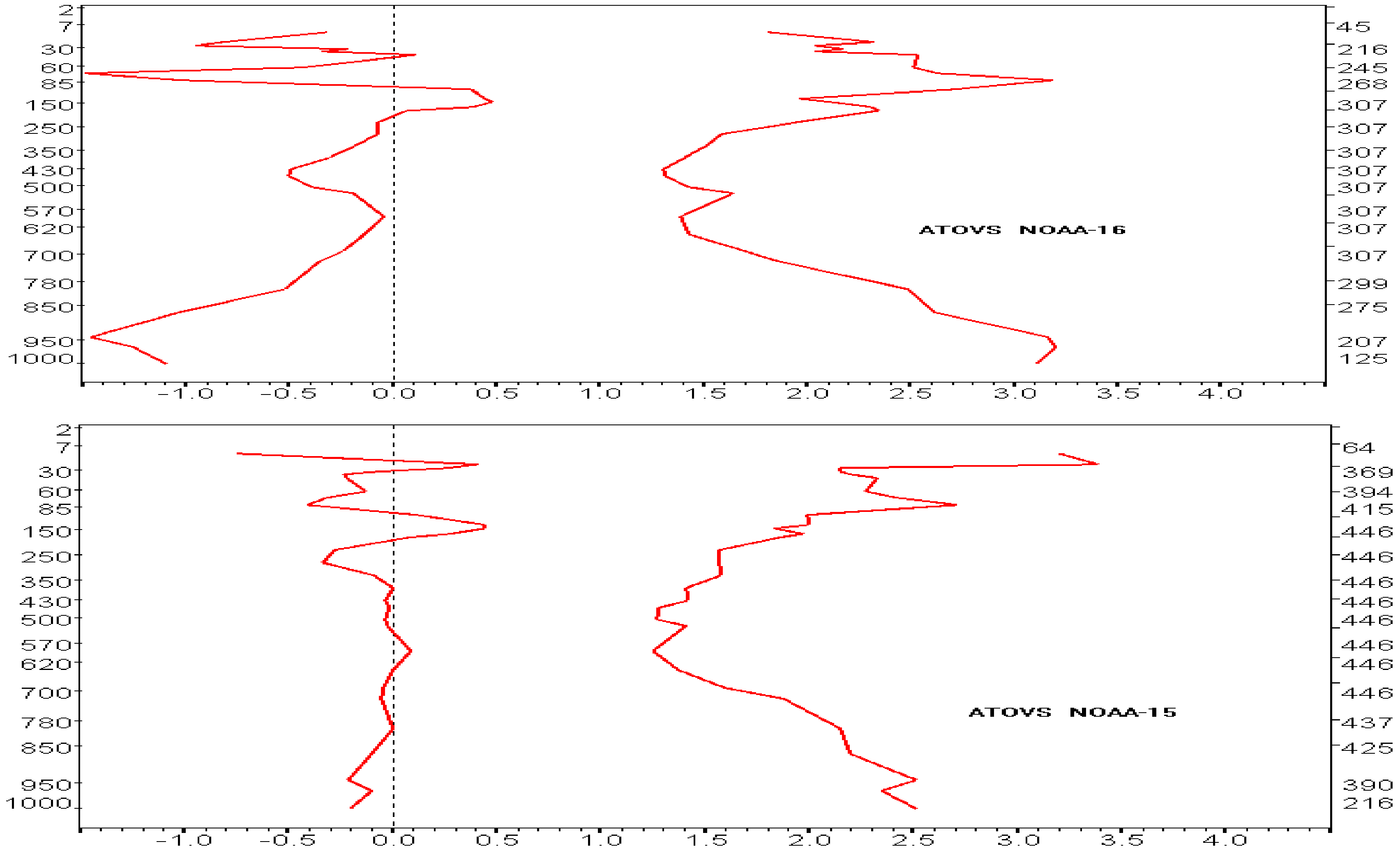


Figure 2: **Vertical accuracy statistics of mean (left) and standard deviation (right) satellite minus radiosonde differences for NOAA-16 (top) and NOAA-15 (bottom) using samples corresponding to Figure 5.**

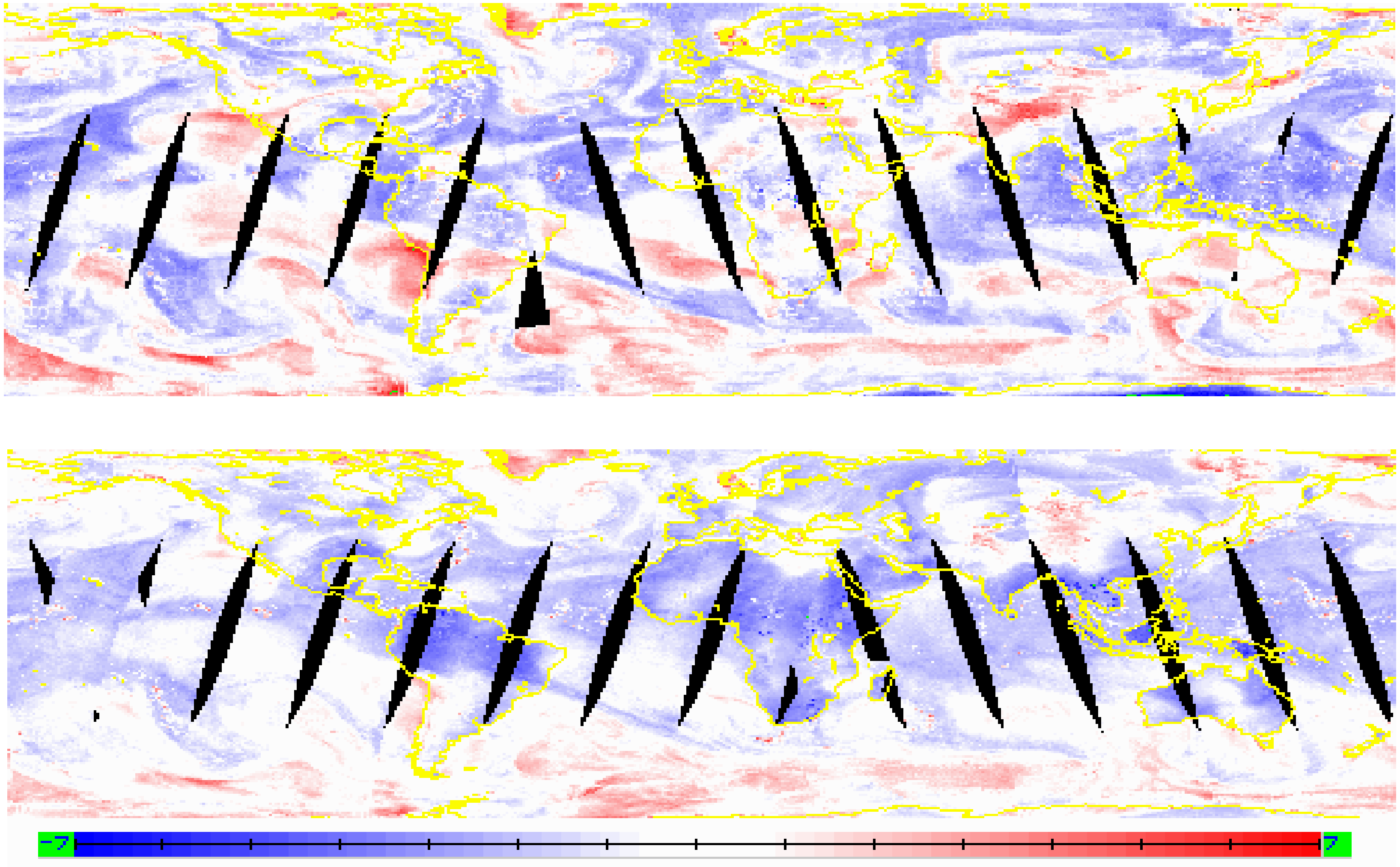


Figure 3: **RT bias adjustments for NOAA-16 (top) and NOAA-15 (bottom) for AMSU-B Channel-1 (183 +/- 1 GHz) on October 13, 2003.**

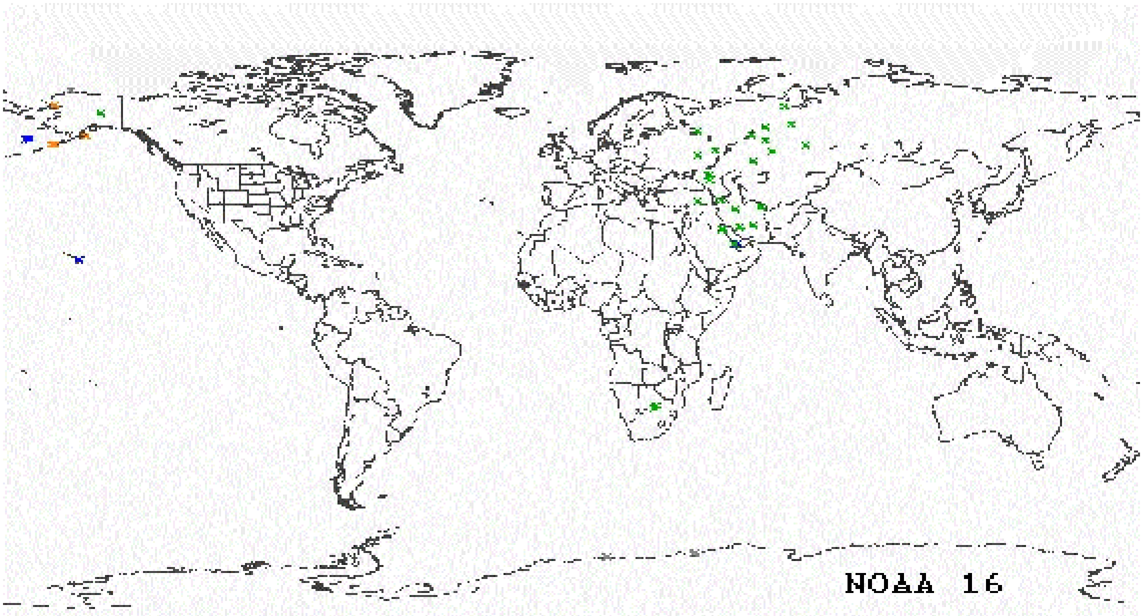


Figure 4: Collocated radiosonde and satellite Observations for NOAA-16 using a minus 1 hour time window; Sea, Land, Coast, Ice, Snow and Ship.

Climate

The problems of detecting global climate change from operational satellites and radiosonde observations has been addressed by a number of researchers with often conflicting results or a conclusion that the data available are not suitable for detecting the extremely small climate signals. Examples can be found, for example, of several attempts to use the 20+ years of historical TOVS-MSU data and radiosondes to detect climate changes with several publications citing results with little overlap. The bottom line is that recent constructions of a number of tropospheric temperature climate data-sets has nominally served only to increase our uncertainty in the true multi-decadal trends (Seidel et.al., 2004).

Examples of these kinds of problems are illustrated in the two panels of Figure 5 using the relatively short term data set of AMSU-B measurements from NOAA-15. The top panel shows AMSU-B, 183 +/-1 GHz measurements and associated RT bias adjustments for NOAA-15 from September 2000. Comparing the lower panels of Figure 5 and Figure 3 indicates an apparent drift in this channel, however, it is uncertain whether this drift is real or a manifestation of sampling differences and/or radiosonde instrument changes over that time.

A potentially significant portion of such uncertainty could disappear in the presence of a sufficiently robust and consistent transfer standards, most critical for example for free-troposphere variables such as those observed by the radiosondes and satellites. Any transfer standard would optimally need to be a two-point calibration system. For one of the points, the potential of using SUAN sites is quite high, and perhaps sufficient under ideal circumstances. As needed, a second calibration point could be derived from a future middle earth orbit (MEO) satellite (operating between polar orbiting and geostationary altitudes) as a transfer standards for polar orbiting retrievals and synoptic radiosondes.

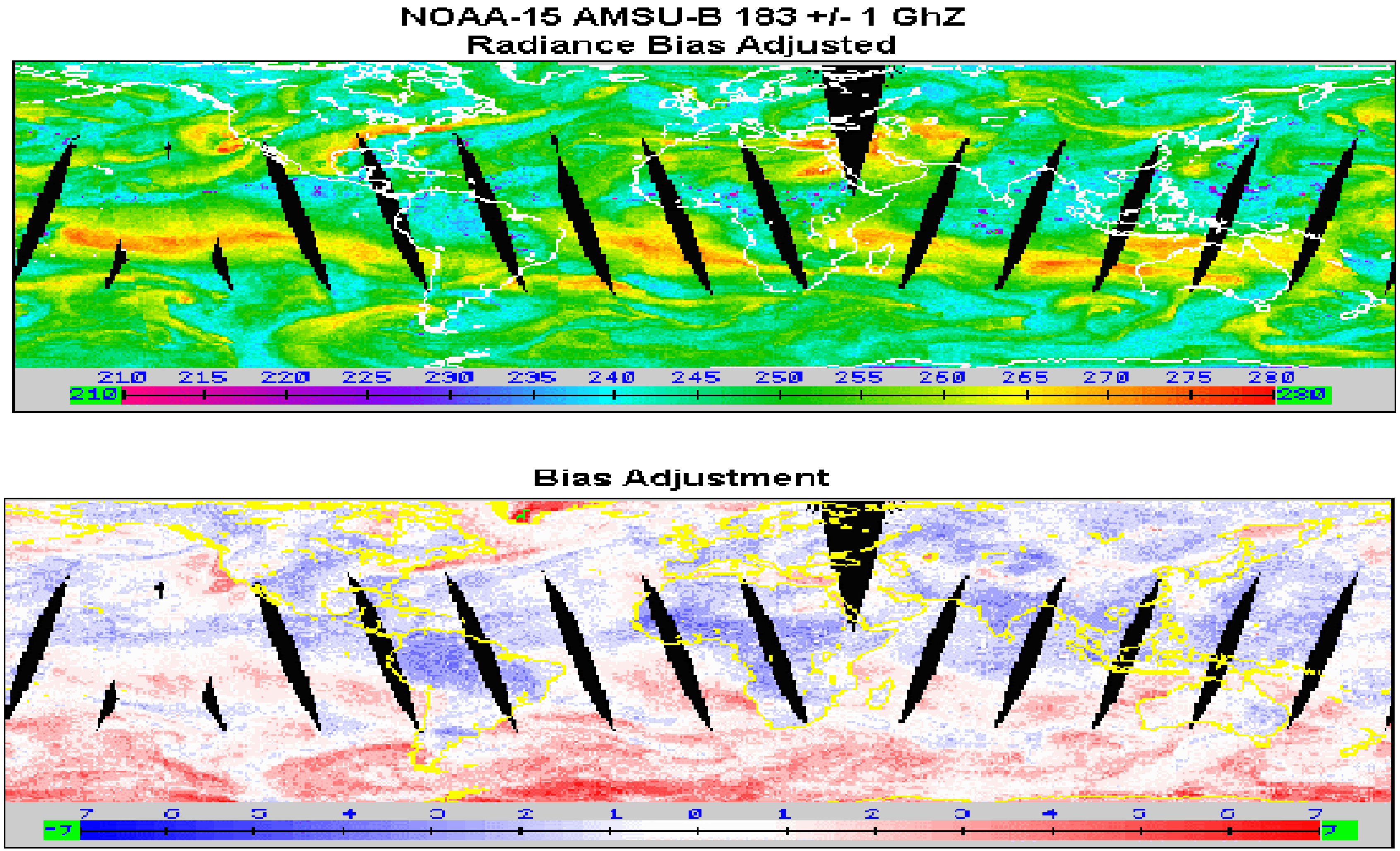


Figure 5: **AMSU-B measurements (upper) and associated RT bias adjustments (lower) for NOAA-15 from September, 2000.**

Numerical Weather Prediction (NWP)

Scientist from the NWP community have cautiously supported the potential for positive impacts using SUAN, recognizing that the radiosondes are very important to the effective use of satellite sounding data in NWP and that a well-distributed network of radiosonde stations providing high quality data coincident with satellite overpass could play a valuable role in improving these processes and ultimately the impact of satellite data on NWP. Under ideal circumstances, SUAN could provide a data platform to segregate the residual NWP error from the RT bias. However, this could also resurrect the difficult background error problem for NWP, which became somewhat more manageable when using the NWP to compute the observational data adjustments (McNally et.al., 2000). It becomes a (nasty) question of tradeoffs and whether it would be worth the effort?

Figures 6 provides some insights through analysis of derived satellite (SAT) sounding (tuned using radiosondes) minus NWP (“cooked” as described above) forecast fields. The two upper right panels of each Figure illustrate such differences for 500mb to 300mb (upper) and 1000 to 700mb (middle) layer mean virtual temperatures (T*), respectively. A red, white and blue color scale is used to denote differences, with red indicating that the satellite (SAT) was warmer; white indicating that differences were between +/- 1K, and blue indicating that the satellite was colder. To the left of each panel are the corresponding AMSU-A channels 6 and 4, shown in spectral color scales, which have sensitivity in these layers. The bottom two panels of Figure 10 show corresponding AVHRR channel 4 measurements denoting clouds, and NWP 12-hour forecast minus verifying Analysis differences scaled identical to the SAT-NWP differences. The region shown is a large portion of the remote (and data devoid) Pacific Ocean off the northwest US coast on January 15, 2004.

Figure 6 demonstrates that differences between the SAT and NWP data serve as good tracers of frontal zones, precisely where NWP is most prone to error. Outside these zones, for example in the warm and cold core sectors, differences tend to zero. It can also be seen that the signature of the differences in the lower layer tend to be correlated with the advection, with the satellite soundings typically colder in cold advection zones and warmer in warm advection zones. The relationship in the upper layer shows more of a tendency for the satellite data to be colder than the NWP when differences occur. Together, these suggest a more destabilizing pattern for the satellite soundings in the warm air and a more stabilizing pattern in the cold air relative to the NWP, in each case a more dynamic pattern. The bottom right panel shows that the initializing 12-hr NWP forecast and verifying Analysis agree quite closely, with little or no impact from the assimilated satellite data in the frontal regions, where one would expect to see changes.

Radiative Transfer (RT) Models

RT models represent a scientific area shared among satellite, climate, NWP, and radiosonde data platforms, and is the critical process for achieving absolute accuracy. Unfortunately, combined/unresolved errors in the satellite, meteorological and/or RT model itself makes absolute validation nearly impossible; catch-22. However, a carefully designed SUAN data-set which minimizes unresolved errors in the collocated spectral and meteorological (radiosonde) data would provide the robust and reliable information for validating RT models, the key for ascertaining and maintaining the “absolute” accuracy of the operational satellite and radiosonde data.

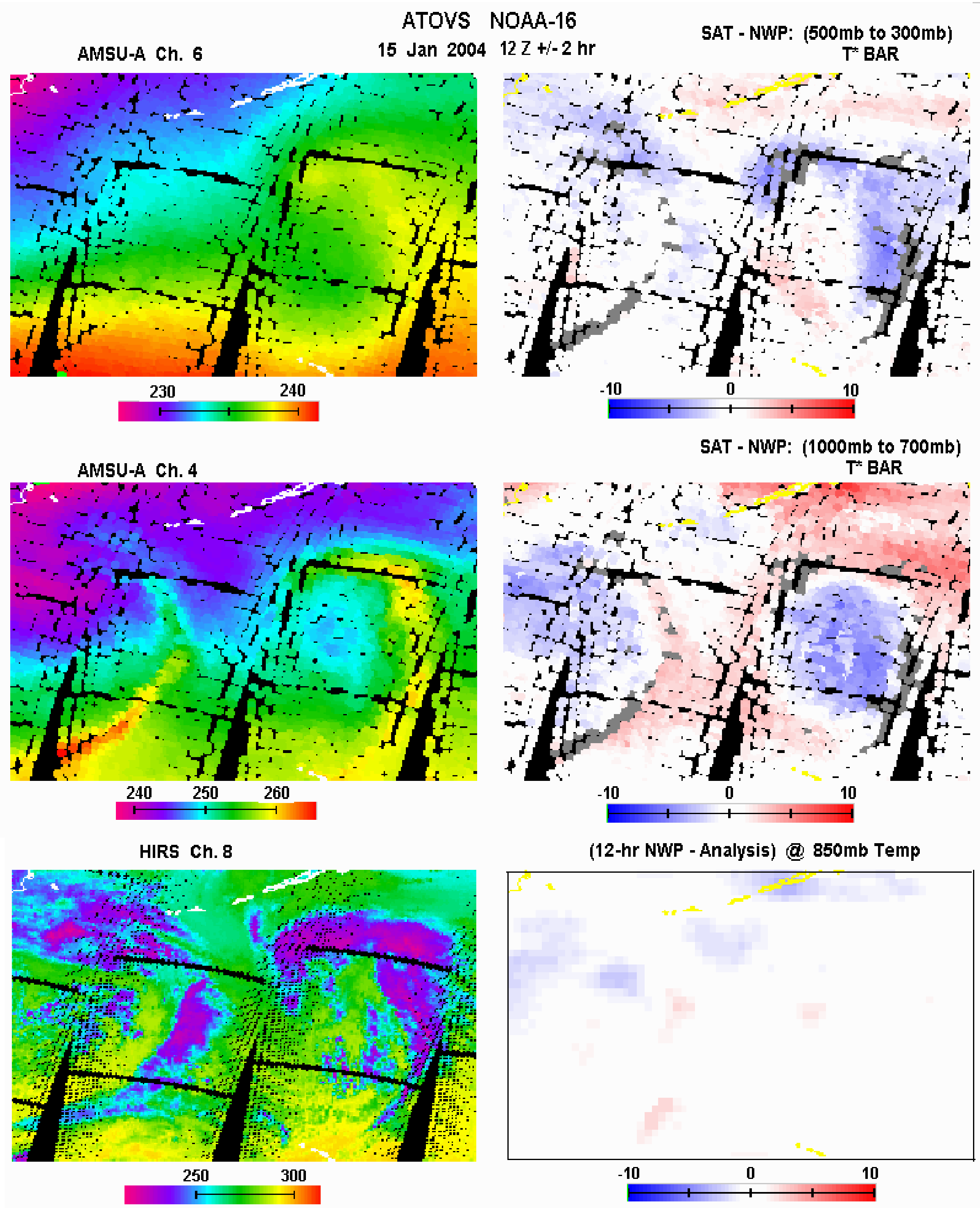


Figure 6: NOAA-16 (SAT) minus NWP difference fields for 500mb to 300mb and 1000mb to 700mb layer mean temperatures (T*), associated AMSU-A Channel 4 and 6 measurements, HIRS Channel 8 measurements (Clouds), and 12-hr NWP minus verifying Analysis differences

SUAN would provide a great data-set in support of RT development and validation exercises supporting the continued evolution of satellite and radiosonde instruments. SUAN would be useful to resolve problems as shown in Figure 3, in which the spectral adjustments (for the AMSU-B 183+/- 1 GHz data sensitive to upper level moisture) are far greater than one would expect given the expected accuracy of these measurements. SUAN would also support associated surface and atmospheric emissivity algorithms and the generation of global atlas data (ie, for surface temperature and emissivity) of the earth from polar satellites.

Future Advanced Sounders

Having a SUAN in place several years prior to next generation satellites (NPOESS), would represent an enormous advantage to future users of these data. SUAN sites would provide attractive locations in support of ongoing CALVAL activities currently underway in support of the next generation advanced instruments (ie, EOS/ AQUA) and would ultimately accelerate their operational deployment, as well as insuring the continuation of ongoing records, for example the AMTS with AMSU-A and MSU (Aumann et.al., 2003).

The WG on Advanced Sounders of the **ITSC-13** has documented the need for high quality global in-situ measurements concurrent with next generation sounder data, and support the Satellite Upper Air Network (SUAN) initiative as a mechanism for achieving this.

Radiosonde Monitoring

The problem of global radiosonde measurement errors is an underlying problem across the satellite, climate, NWP and RT model landscapes since they are often used directly or indirectly for scientific tuning/cooking and/or validation. Such errors typically occur as either systematic, for example, due to a specific radiosonde type or correction procedure, or in a less predictable random manner due to the need for better measurement technologies. A component of this problem can also be traced to bookkeeping type errors, for example, uncertainties concerning the radiosonde types flown, launching protocols, corrections applied and other deficiencies concerning available meta-data records from long-term archive centers.

The deployment of SUAN would provide a manageable program for monitoring radiosondes, not only SUAN radiosondes but also the greater radiosonde network, as well as providing a very good network for radiosonde instrument testing, new technology research and development. For example, SUAN sites located in the vicinity of existing synoptic sites would offer ample opportunities for a variety of studies ranging from straightforward inter-comparisons of the radiosonde measurements to the modeling of localized effects such as frontal passage, local weather features, terrain, and balloon drift. Appropriately planned multi-instrument launches at satellite overpass would provide useful information for testing radiosonde instrument bias, and attractive locations for long-term studies of instrument performance, data corrections, new technologies (ie, drift-sondes) and integrated ground based spectral measurements. Finally, and perhaps most important, deploying SUAN could ultimately provide information for determining absolute radiosonde accuracies by using the satellite observations as a transfer standard for radiosonde corrections (McMillin et.al., 1988).

THE SUAN NETWORK

Candidate Sites

The current candidate stations for SUAN consist of the 43 radiosonde sites illustrated in Figures 7. The stations were selected so as not to interfere with ongoing, long-term climate records. Climate record scores (provided by Dr Peter Thorne) rank each site according to its' contribution to the long-term Climate record. A score or 1 or 0 indicates that the site has no climate record, a score of 2 or 3 indicate an insignificant climate record, and a score of 4 or more indicates a potentially significant climate record; the maximum possible score for a site is 11.

Figure 7 shows the global distribution of the 43 candidate SUAN sites color coded:

- Green are sites with no climate record and acceptable radiosonde type (24)
- Yellow are sites with little or no climate record and acceptable radiosonde type (11),
- Red are sites with a climate record and acceptable radiosonde type (4), and
- Blue are sites with little or no climate record but unacceptable radiosonde type (4).

Other factors considered in the establishment of the candidate network included the radiosonde instrument type, global distribution, and a desire to avoid sites at coastal and high terrain locations, for example, no site exceeds 456m. There are a total of 20 Land, 20 Sea, and 3 Sea-Ice locations.

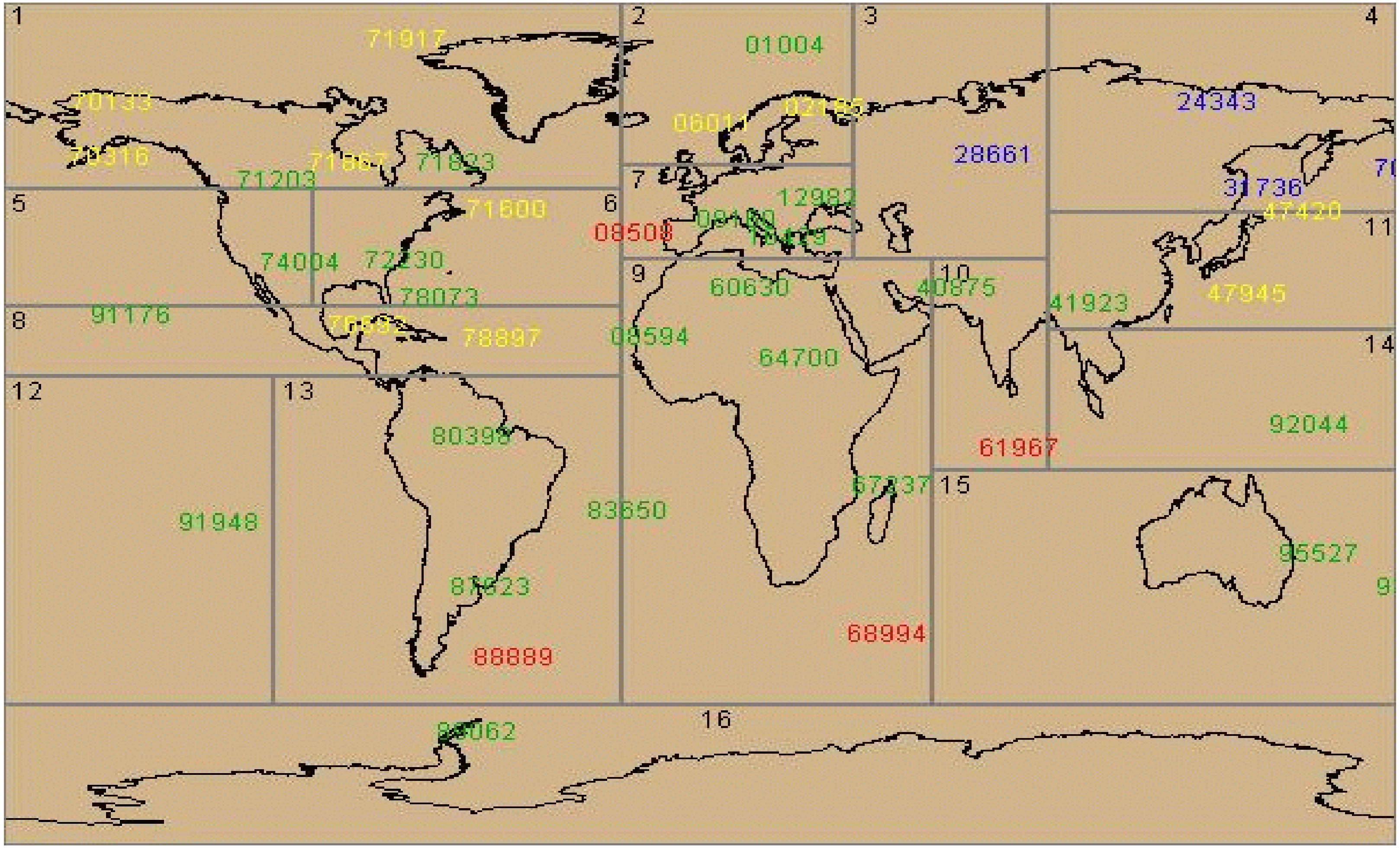
Global Robust Network: How Much is Enough?

The premise is that if each station would provide at least one launch per day, and that this would be enough to adequately monitor a two satellite operational configuration. An obvious question is whether these target numbers are enough? The answer to a large extent depends on the quality of the "standardized" measurements. Assuming good quality, then a simplified look at the number of observations from the proposed SUAN network can provide some insight. If each of the 43 stations provide one launch per day, and assuming a two-polar satellite configuration, then a 4-day cycle of observations per site that coincident with each satellite and orbital node would occur (two satellites times two orbital nodes). Over the course of one month (30 days), this would provide approximately fifteen collocations per satellite and site, equally distributed among the ascending and descending orbital nodes. Globally, this would provide over 600 observations per month per satellite (equally divided among the ascending and descending nodes), and over 7000 satellite dependent observations per year. This would appear to be enough.

Endorsements

The following are summary listings lists of endorsements:

- Workshop to Improve Usefulness of Operational Radiosondes (Durre et.al., 2003)
- ITSC-13, with specific endorsements from following WG:
  - Satellite Sounder Science and Products
  - TOVS/ATOVS Data in Climate
  - Advanced Sounders
  - International Affairs



<u>*Acceptable Raob Types:*</u> *Mesei RS2-91* *VIZ MARK II and B2;* *Vaisala RS80/90*

Figure 7: **Candidate SUAN sites listed according to their geographic Box location (1 thru 16) and color coded: *Green* are sites with no climate record, *Yellow* are sites with little or no climate record, *Red* are sites with a significant climate record, and *Blue* are sites with an un-acceptable radiosonde type.**

Additional support for SUAN can be found in recommendations specified in

- *The White Paper on Climate Data Records from NOAA Operational Satellites* (Goldberg and Bates, 2003), and
- *NOAA Council on Long-term Climate Modeling* (January, 2003).

WMO Report

The World Meteorological Organization (WMO) must play a pivotal role in the deployment of SUAN. A report to the WMO describing SUAN, and associated resources, protocols and perceived benefits to users and researchers of global environmental data is planned by early 2004.

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