Enhanced Use of Radiance Data in NCEP Data Assimilation Systems

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Introduction

There have been significant changes in the use of radiance data at NCEP over the last few years. These changes have included a substantially increased volume of radiance data, an improved radiative transfer system, an improved forecast model (vertical/horizontal resolution, higher model top, improved physics), and improved quality control and bias correction techniques. Within an operational environment, it is necessary to continually maintain and enhance the system to improve the utilization of data. In addition, several new developments to utilize additional sources of radiance data (e.g., AIRS, SSM/IS, and geostationary/polar imagery) are under development. Enhancements in the use of the satellite data along with the current usage of satellite data will be discussed below. Experiments underway at NCEP directed towards the use of AIRS radiances, SSM/I radiances, GOES imager radiances and the use of radiances directly in the SST analysis will be briefly described.

Changes in the use of radiance data at NCEP

The changes to NCEP's use of radiance data can be divided into three main groups: updates to radiative transfer, modification to data selection and quality control, and enhancements to data assimilation and forecast systems. Of course these changes interact with each other within the data assimilation system. None of the changes produced large impacts on the quality of the resultant forecasts and analyses, but each represents a small incremental enhancement of the system. These modifications were implemented into the NCEP operational system on or before 20 Nov. 2003.

The radiative transfer used in the NCEP analysis system uses transmittances calculated using OPTRAN as modified by VanDelst et al.(2002). In addition, the radiative transfer calculations have been updated using new microwave and IR Line-by-Line (LBL) calculations and recalculating the OPTRAN coefficients. The system has been set up to incorporate the water vapour continuum both explicitly and implicitly as part of other calculations. Also, a new high spectral resolution algorithm for estimating the IR surface emissivity over the ocean has been included. This surface emissivity algorithm is described more completely in another ITSC-13 presentation (VanDelst, 2003).

The data selection has been enhanced to allow more control over which observations are selected and to extract more information from the data. In the new system, the data selection is based on a score related to how close the observation is to the center of the selection box, the time difference from the analysis time, and a measure of the likelihood that the data will pass later quality control. This change

in the data selection allowed many more IR and a few more microwave observations to pass the quality control. The IR quality control was also modified (primarily because of the large number of channels available from the AIRS instrument) to base the cloud detection on an estimated cloud percentage and cloud height from the differences in the observed and simulated brightness temperatures. This cloud detection change was discussed in a previous ITOVS meeting (Derber et al., 2002).

General changes to the assimilation system have also been made to enhance the use of all types of data. Previously the atmospheric forecast was assumed to be available either every three hours or just at the analysis time. The surface fields could only be used at the analysis time. Now, the capability to interpolate atmospheric fields and surface fields in time regardless of the frequency of the model output has been included. The analysis is performed twice in the NCEP operational system. There is an early data cut-off (2:45 after the analysis time) from which the aviation and long-range forecast is run. There is also a later data cut-off (6:00 after the analysis time) from which the 6hr forecast is created for use as a background in the next analysis. The analysis from the early cut-off can be used as a guess at the solution (not a background field) for the later analysis. This essentially has the effect of reducing the number of necessary iterations to reach convergence and increasing the number of outer iterations. Note that assuming complete convergence and the same quality control decisions in the outer iteration, the results in the later analysis would be identical whether or not a guess is used. Unfortunately, the option for using a guess field is not currently being exercised in the operation run suite. Finally, considerable effort has been expended to simplify the data handling, streamline the code and fix a few minor bugs.

These changes were all in preparation for major upgrades to the analysis system currently being tested or under development. These upgrades include the inclusion of new types of radiance data (as discussed below) and a new formulation of the background term in grid-space rather than spectral-space. By performing the calculations in grid-space, we will be able to introduce situation dependent background errors and hopefully be able to extract substantially more information from the observations.

Development of new radiance data usage at NCEP

AIRS data

The current trend in infrared satellite systems is to deploy instruments which produce many high spectral resolution channels. The first mega-channel instrument available was the AIRS instrument on the AQUA satellite. For instruments which produced on the order of 20 channels, it was possible to tailor bias correction and quality control decisions for individual channels. For the mega-channel instruments, it has become necessary to develop automated algorithms which can be applied successfully to large numbers of channels without manual intervention. This has been the major difference using AIRS versus HIRS data.

The real-time data stream used by NCEP comes from NASA through NESDIS and has been discussed extensively at ITOVS meetings (Wolf et al., 2002). The 281 channel version of the AIRS data stream is currently being used. Of the 281 channels, 254 were found to be usable. Channels 73-86 were not

used because they peak too high in the atmosphere. (Note specific channel numbers here refer to the original AIRS channel numbers). Channels 1937-2109 were not used since they appear to have non-LTE effects not incorporated in our radiative transfer. Finally, channel 2357 was not used due to large observational-background differences which could not be explained by model forecast errors. In addition, shortwave channels with wavenumbers above 2000 were down weighted and above 2400 removed during the day due to inadequacies in the modeling of reflected solar radiation.

The inclusion of the AIRS data within the NCEP assimilation system was tested in parallel during the Fall of 2003. During this testing, several modifications were introduced into the system including a change in the thinning distance from 150 to 225 km and an increase of the specified observational errors for each channel by .2K to an average of about 1K. These changes were introduced because the AIRS data was producing very large penalties relative to the other data and was slowing the minimization procedure. With the use of the new data selection algorithm, which attempts to choose the clearest field of view available, 38% of the selected radiances passed the quality control and were used in the assimilation. Further updates to the system have since been introduced based on the Fall 2003 experiments, and additional tests of the AIRS data impact are currently underway.

The Fall 2003 experiments showed little impact from the inclusion of the AIRS data. For example, in Figs. 1 and 2, the average fits to the radiosonde temperatures and the daily 5-day Southern Hemisphere forecast skill for the control and AIRS assimilation are shown respectively. Similar results are produced for different observation types and different regions. These figures show the impact was very small. We believe this is primarily due to the presence of clouds where the data potentially would have had the largest impact.
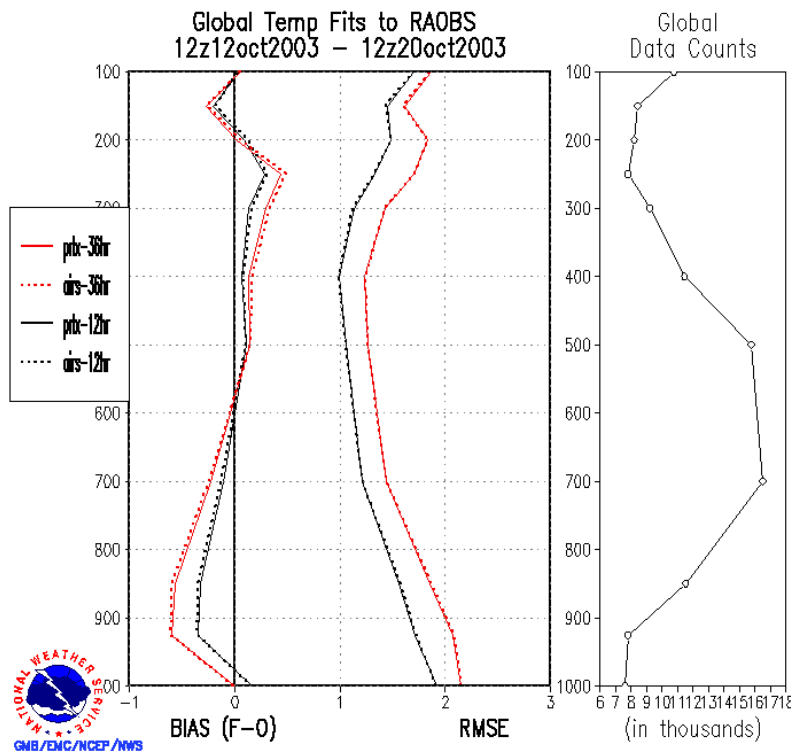

Fig. 1: RMS and bias for fit to radiosonde temperatures with (dashed) and without (solid) using AIRS data. Figure on right gives number of comparisons at each level.
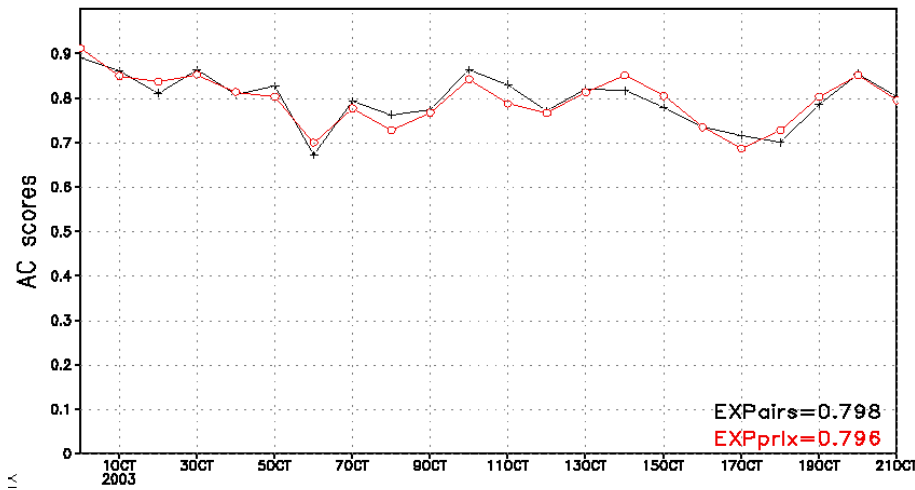
Fig. 2: Southern Hemisphere 500hPa geopotential anomaly correlation with (black) and without (red) AIRS data

GOES Imager data

Experiments are underway to use the GOES imager data in the NCEP global data assimilation system. The inclusion of the GOES imager data is intended to improve the moisture fields. The data is being
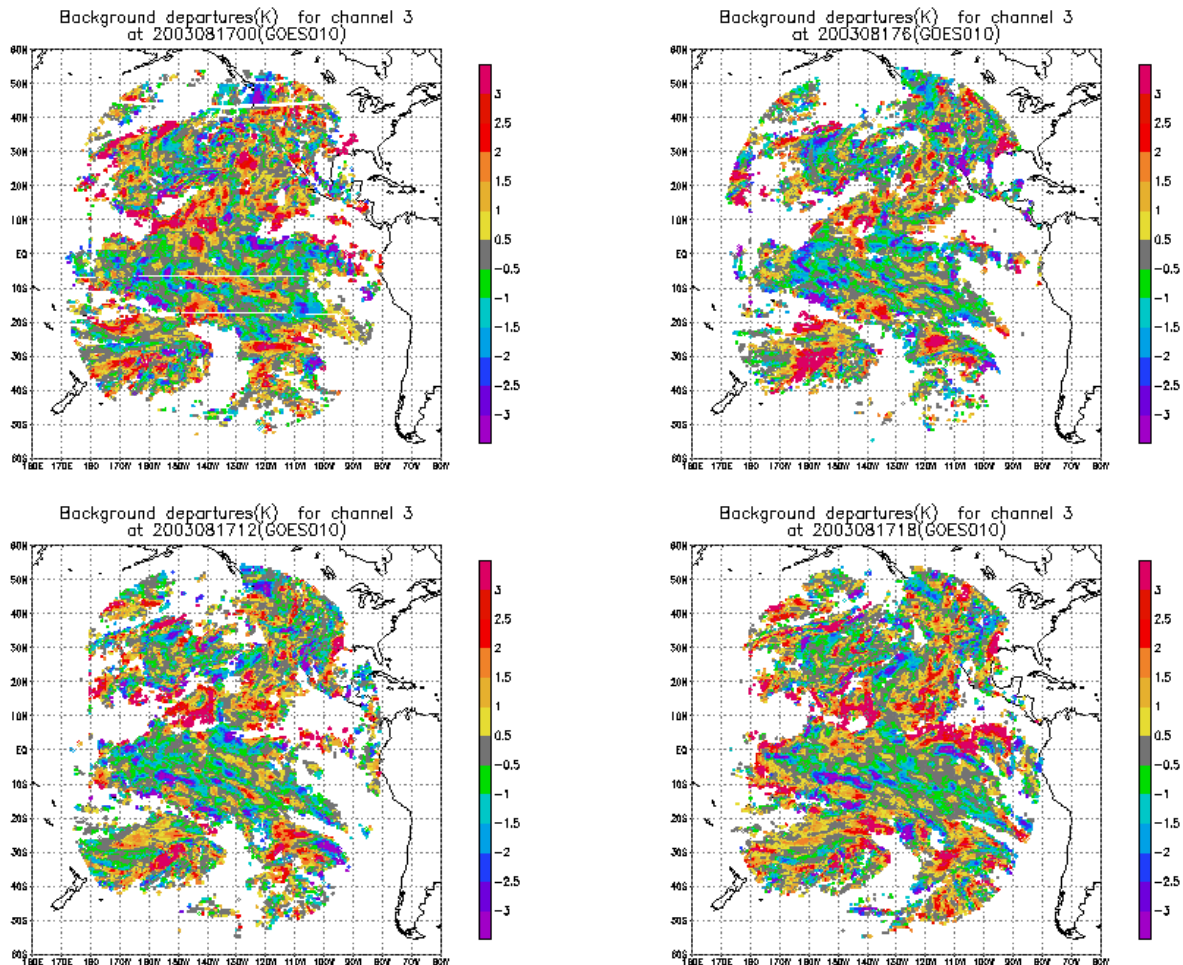

Fig. 3: Brightness temperature difference between observations and simulated observations prior to quality control.
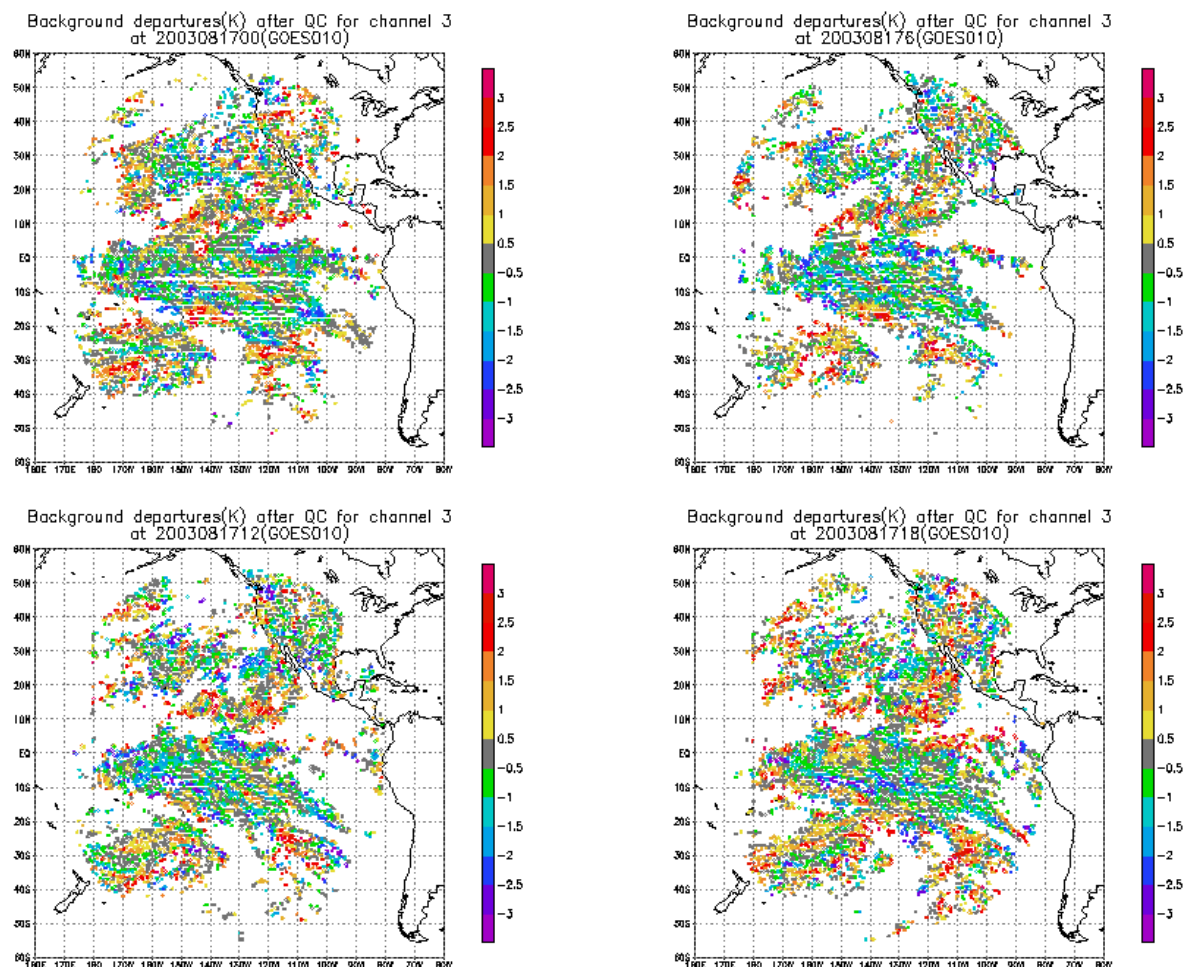
Fig. 4: Brightness temperature differences between observations and simulated observations after quality control

produced by NESDIS and is a 11x17 box average of observations which pass the NESDIS cloud detection quality control procedures. Initially only channel 3 is being used in the assimilation, while window channels 4 and 5 are used in the quality control procedures.

In addition to the standard quality control procedures within our analysis system, three additional quality checks are made to the data. For GOES-12, only box data with greater than a 25% clear sky fraction are being used while for GOES-10 greater than 10% is necessary. Also, the brightness temperature standard deviation within a box is required to be less than 1.5 degrees. Finally, GOES-12 data from 06UTC is not used due to the midnight effect.

In Figs. 3 and 4, the distribution of differences between observations and simulated observations from the background is shown before and after quality control respectively. There is a substantial reduction in the number of observations used by the analysis because of the quality control. However the basic large scale structure remains the same.

Assimilation and forecast experiments have been performed using this data showing a small positive impact on the moisture fields in the analyses and forecasts. Further experiments are currently underway, prior to possible operational implementation.
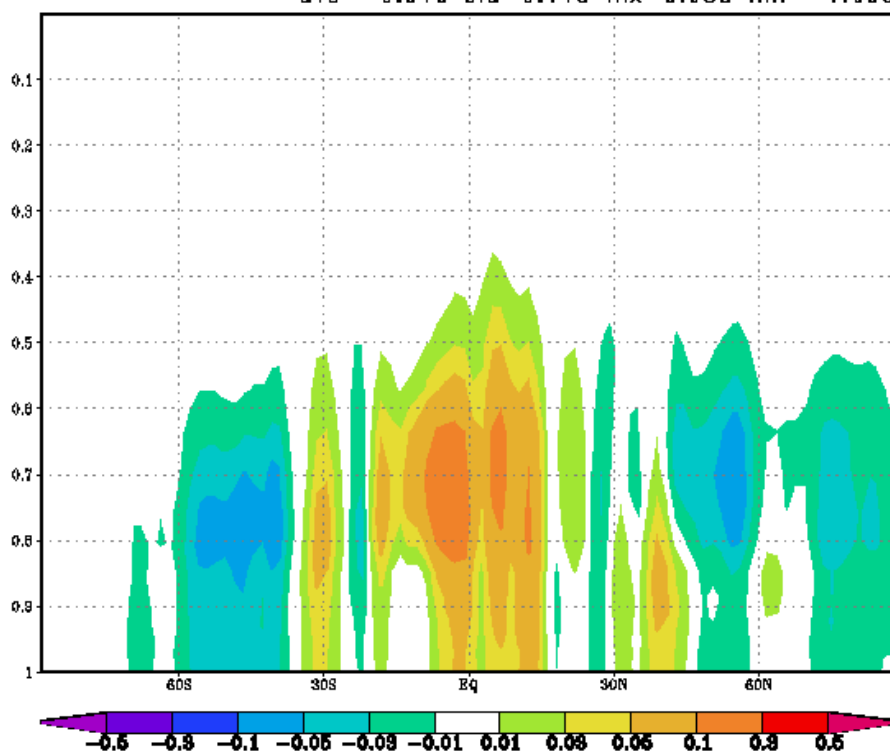
Fig. 5: Specific humidity differences between simulation with and without SSM/I data.

SSM/I data

In order to better use the information in the SSM/I data and to prepare for new conically scanning microwave instruments(e.g., SSM/IS and CMIS), experiments are being performed attempting to directly use the SSM/I observations within NCEP's analysis system. Initially, we are only attempting to use the data over the ocean where the surface emissivity is better known. Again, necessary bias correction and quality control procedures have been developed for this data.

In Fig. 5, the mean differences between the analyses with and without the SSM/I data are shown after several days of assimilation. Note the general increase in moisture in the tropics and decrease in the mid-latitudes. This signal is consistent with known biases in the forecast/analysis system. Experiments continue examining the usefulness of this data.

SST analysis using radiances

The SST plays an important role in atmospheric and oceanographic forecast and analysis systems. While our current operational system using U.S. Navy SST retrievals is able to attain a fairly high degree of accuracy in the SST analysis, future usage will require enhanced accuracy and time resolution. NCEP has begun a project to improve the SST analysis and to allow the use of all types of radiance observations directly in the analysis of the SST. The first step of the project is to examine the impact of using a real atmosphere above the SST field. Since we have a fairly accurate depiction of

the atmosphere above the surface in our atmospheric analyses and short term forecasts, we believe that we can remove a substantial portion of the atmospheric signal in the data (and possibly use the information in the atmospheric analysis) and extract more SST information from the data.

To test this idea, we have produced physical retrievals of SST based on the Community Radiative Transfer Code, the atmosphere from the NCEP's Global Data Assimilation System, the SST analysis from the previous day (as a background SST) and the U.S. Navy Brightness temperatures used to produce their retrievals. In the physical retrieval, 3 quantities are found; the SST increment, atmospheric moisture increment, and atmospheric temperature increment. The atmospheric moisture and temperature are assumed to not vary with height. Since, the AVHRR channels used are window channels and primarily sensitive to the near surface temperature and moisture, this should be a good assumption. However, if sounding channels are used, this assumption will have to be relaxed.

As with other radiance data, it was necessary to develop bias correction and quality control procedures for the AVHRR radiance data. The quality control currently only rejects a few observations since extensive quality control is already performed on the data by the U.S. Navy. Also, there is averaging of fields of view after the quality control which will further smooth out differences and make it less likely to fail the quality control. Since the data is averaged over several fields of view, it is also
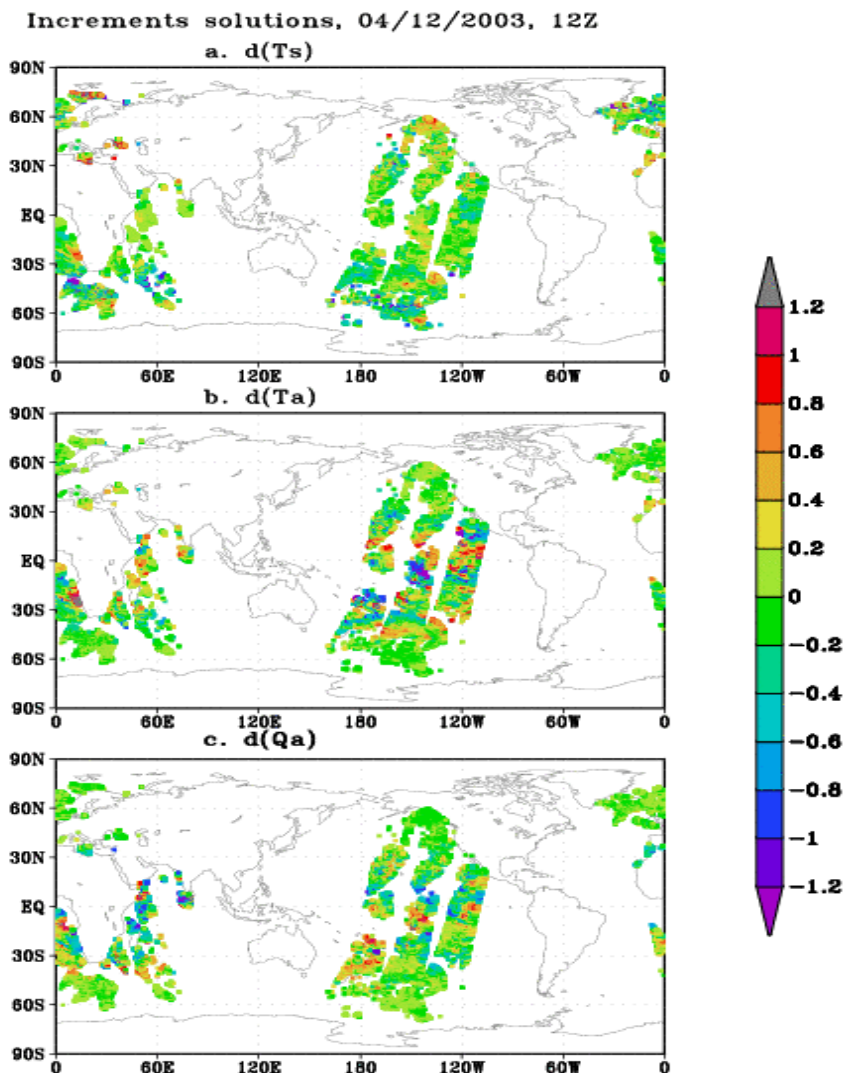

Fig. 6: Physical retrieval of SST (a), atmospheric temperature (b) and atmospheric moisture increments(c).

difficult to perform an angle dependent bias correction. For these reasons, the original observations will be used to attempt to improve the bias correction and quality control procedures.

An example of the SST and atmospheric temperature and moisture retrievals are show in Fig. 6. Note the larger moisture increments and temperature increments in the tropics. This is because of an increased sensitivity to the atmosphere as the amount of moisture increases for channels 4 and 5. The retrievals appear to be relatively insensitive to the background error given the background temperature but are sensitive to the error supplied to the background moisture. Preliminary assimilation experiments show some consistent improvement in the SST analysis from the use of these SST retrievals and a reduction of unrealistic variation between consecutive analyses in the tropics. With the encouraging results from these experiments, the direct inclusion of the radiances in the SST analysis and the meshing of the full 3-D atmospheric analysis with the SST analysis is continuing.

Summary and Future

NCEP has continued to enhance the use of satellite radiance data through improved data assimilation techniques and the incorporation of additional satellite data. Current ongoing new data investigations include AIRS, SSM/I, GOES imager and AVHRR (for use in SST analysis). Of course, there are many new observations from new instruments that will become available over the next five years. However, it is becoming increasingly difficult to get a positive impact from incorporating new satellite data. This limited impact results because many components of the analysis are already well defined by the current observing system, and for other components, the impact is limited by inadequacies in the assimilation system. Thus,successful utilization of all the information in the observing system requires substantial development of the data assimilation systems, not just the inclusion of additional data. NCEP is developing a new unified global/regional data assimilation system which calculates the background error in grid space rather than in spectral space. In this system, we anticipate that local situation dependent background errors can be utilized and substantial improvement in the usage of information in all types of data will result.

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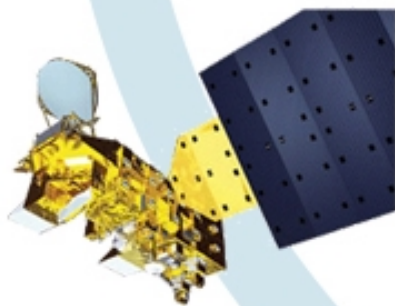
Sainte-Adèle, Québec, Canada
29 October – 4 November 2003