J16.2 ATOVS DERIVED SOUNDINGS USING NOAA PRODUCT VALIDATION SYSTEM (NPROVS) DATASETS FOR COMPUTING FIRST GUESS AND SENSOR BIAS ADJUSTMENTS INDEPENDENT OF NWP

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1. INTRODUCTION

During the past 25+ years of NOAA operational polar satellites, the problem of providing reliable and consistent monitoring and scientific validation of operational measurements and derived meteorological products has been addressed through the compilation and analysis of collocated satellite and radiosonde observation datasets. The NOAA PROducts Validation System (NPROVS) (Reale *et al.* and Pettey *et al.* 2009) recently deployed at NESDIS Centere for Satellite Applications and research (STAR) now provides routine compilation of satellite and radiosonde collocations from multiple satellite derived sounding product systems operated by NOAA. In addition to validation, these datasets have also proved useful for deriving first guess and satellite measurement adjustments to compensate for radiative transfer model (RTM) bias.

The following report discusses the use of NPROVS sampling strategies and datasets for calculating regression coefficients for computing first guess temperature and moisture profiles and associated RTM bias adjustment prior to the retrieval of Advanced TOVS sounding products. Although independent of numerical weather prediction (NWP) observations, good consistency between regressed and NWP is observed.

2. BACKGROUND

Satellite derived sounding products are routinely produced by NOAA for a number of satellite platforms including GOES, NOAA-18, MetOp and NASA–EOS-Aqua. Although not currently used at most of the NWP centers, derived soundings remain a mainstay of NOAA ground processing systems and may yet play a key role as an efficient data compression mechanism for the assimilation of emerging hyper-spectral observations (Goldberg *et al.* 2003).

Derived soundings from legacy non-hyper spectral platforms such as ATOVS (Reale *et al.* 2008) are also important, particularly with respect to microwave observations in cloudy and precipitating regions and as a candidate first guess approach for deriving hyper-spectral soundings. The role of derived soundings, particularly a consistent blend of historical products connecting the TOVS, ATOVS and emerging hyper-spectral era remains to be exploited.

NESDIS STAR has been conducting experiments to replace the current operational Advanced TIROS Operational Vertical sounder (ATOVS) sounding products with a revised approach concerning the first guess and the use of the Microwave Humidity Sounder (MHS) (formerly the Advanced Microwave Sounding Unit-B) data. With the recent operational deployment of Microwave Integrated Retrieval System (MIRS) (Boukabara *et al.* 2007) soundings products from NOAA-18 and MetOp, a second action to combine the existing ATOVS and MIRS soundings into a single suite of products, taking advantage of the best aspects of each system, is now under way.

With the emergence of NPROVS, the integrated validation of the respective suites of ATOVS, MIRS and hyper-spectral soundings currently produced by NOAA has guided developments in each of these respective systems. Figure-1 shows a schematic diagram of NPROVS. As can be seen up to nine (9) processing suites from a variety of satellite platforms (green) are routinely compared against collocated radiosonde and NWP observations.

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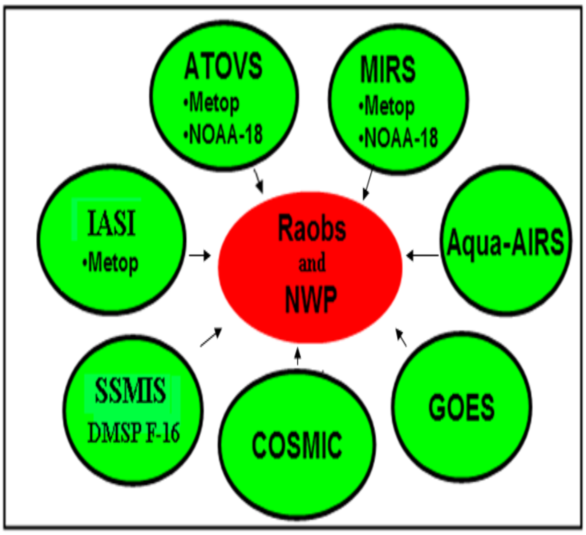

Figure 1: Diagram of NPROVS satellite data (green) access and collocation with ground truth (red)

The following report presents an ATOVS product approach based on a first guess regression compiled from NPROVS collocations of radiosonde and satellite (microwave) observations and presents results.

3. REGRESSION SAMPLING STRATEGIES

A series of inter comparisons for various sampling and coefficient predictor and predictand selection strategies culminated in a set of guidelines for generating regression coefficients from NPROVS collocation datasets. Guidelines include:

- Use 10-week running, global samples
- Update weekly
- Screen radiosondes for completeness up to 200 mb for $H_2$0 and 50 mb for temperature
- Screen water vapor profile if abrupt changes or unreasonable values observed
- Regressions for moisture are based on dewpoint temperature
- Segregate coefficients if in cold, dry atmosphere or over high terrain
- Screen satellite observation if “precipitating”

Collocation samples for NPROVS contain the single closest (in time and space) satellite sounding to a given radiosonde. The maximum time window is 6 hours and the maximum distance window is 150km. Radiosondes retained within NPROVS must attain at least 5 km with no gaps (1.5km). Retained radiosondes are assigned several screening flags depending upon the characteristics of the temperature and moisture profiles. For example, radiosondes with temperature inversions or moisture profiles with multiple abrupt variations are noted. Radiosondes collocated with satellite observations in precipitating or otherwise anomalous regions are also noted.

Three sets of first guess regression coefficients are generated for use under the following conditions:

- Normal
- Cold/dry
- High terrain

The first guess regression coefficients are based on the collocated radiosonde (predictand) versus microwave observations from the 15-channel Advanced Microwave Sounding Unit (AMSU) and 5-channel Microwave Humidity Sounder (MHS). The specific predictor channel combinations for the respective temperature and moisture profiles and conditions are outlined in Table-1.

Condition	Temperature	Moisture
Normal: NonSea	AMSU 5-14	MHS 3-5; AMSU 5, 6
Sea	AMSU 6-14	MHS 3-5; AMSU 6, 7
Cold/dry	AMSU 5-14	MHS 3; AMSU 5, 6
Hi-Terrain (> 1500m)	AMSU 7-14	MHS 3, 4; AMSU 7, 8

Table 1: Conditions and predictors for regression of the first guess Temperature and Moisture profiles

Cold/dry are defined as satellite observations for which calibrated radiance temperatures for AMSU channel 5 (53.7 gHz) and MHS channel 5 (190 gHz) are less than 245K and 250K, respectively. Each of these channels has sensitivity in the lower troposphere. High terrain is defined as sensor scenes for which the center terrain elevation exceeds 1500m. Otherwise the condition is considered normal.

The RT bias regression coefficients are regressed for each sensor based on the calculated radiance (OPTRAN reference) from the collocated radiosondes (predictand) versus the respective sensor measurements from the 15-channel Advanced Microwave Sounding Unit (AMSU), 5-channel Microwave Humidity Sounder (MHS) and 20-channel HIRS. Coefficients are sensor dependent and are derived using only atmospheric sensitive channels as indicated in Table-2.

Condition	Sensor	Channels
Non-Precipitating	AMSU	AMSU 4-14
Non-Precipitating	MHS	MHS 3-5
Clear	HIRS	HIRS 2-7; 10-16

Table 2: Conditions and predictors for statistical regression of the RT bias adjustments for selected sensor channels

4. COEFFICIENT GENERATION

The coefficient matrix R_{fg} for the first guess temperature and moisture is given in (1):

$$R_{fg} = (S_{yx})\ (S_{xx} + q*I)^{-1} \qquad \textbf{(1)}$$

where:

"R" defines the regression coefficients at a given level for a given channel (x),

"S" is the covariance matrix between a given channel (x) and level predictand value (y), and

"q" is the stabilization factor defined as 0.1K

The transpose of the coefficient matrix $R^T{}_{rt}$ for the RT bias adjustment is given in (2):

$$R^T{}_{rt} = (M^TM + \alpha I)^{-1}(M^TC + \alpha J) \qquad \textbf{(2)}$$

where:

"R" defines the regression coefficients for a given channel (x),

"M" is the matrix of measured radiances and additional predictors,

"C" is the matrix of calculated radiance (from RT), and

"α " is the rotation factor defined as 0.05.

"I" and **"J"** are identity and rectangular matrices, the latter required to account for additional (non-radiometric) predictors (Crone *et al*. 1996 and Fleming 1991).

The collocation samples for generating the respective First guess and RT bias adjustments coefficients are from the same 10-week period and are updated weekly.

5. RESULTS

5.1 First Guess Regression

Figures 2 and 3 provide vertical statistics for bias and standard deviation of satellite-minus-radiosonde temperature and moisture profiles. The satellite sounding platforms (color-coded) are sub-sampled among those shown in Figure 1, namely, Aqua-AIRS **(gold)**, the MetOp ATOVS operational soundings (blue), operational first guess (light blue), the regressed first guess profiles (**dark blue**) and associated NWP-minus-Radiosonde **(darkest blue** for temperature and **red** for moisture**)**. The collocations are from a 6-day period in January 2009 with pressure shown along the left side axis, sample size along the right side axis and the mean radiosonde profile values along the inner left side axis. The Bias curves are solid and standard deviation dashed. Units are deg K for temperature and H_20 vapor mixing ratio fractional difference (%) for moisture.

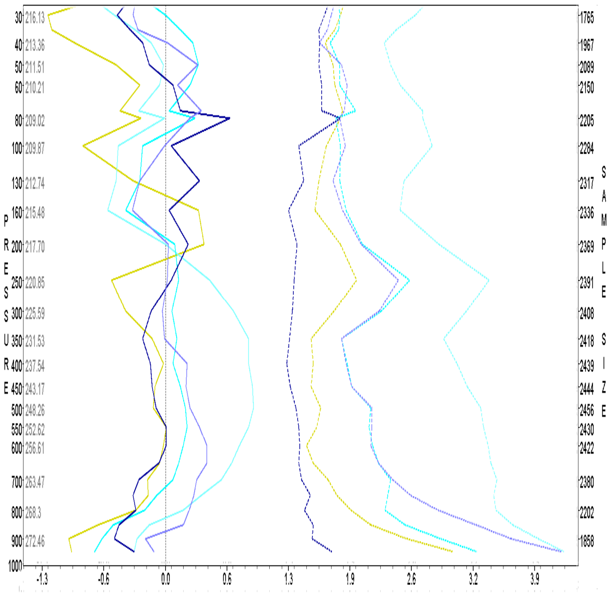

Figure 2: Vertical statistics of satellite-minus-radiosonde mean and standard deviation differences for Temperature (K)

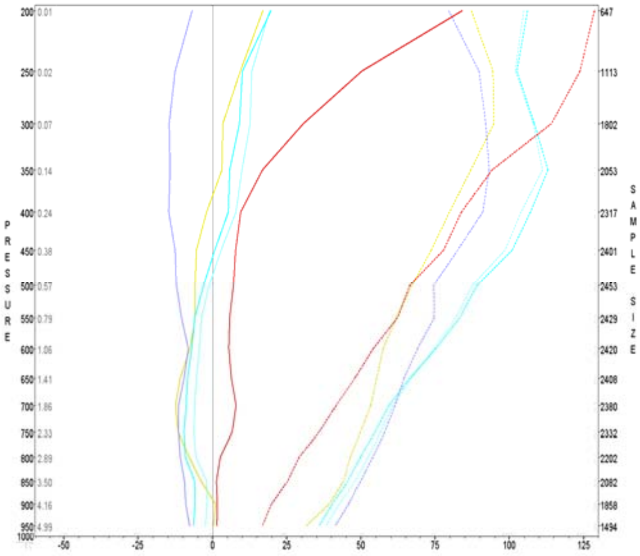

Figure 3: Satellite-minus-radiosonde mean and standard deviation fractional (%) differences for H_20 vapor (g/kg)

Significantly smaller mean and standard deviation differences from the radiosonde are observed for the ATOVS regressed first guess profiles compared to the current operational first guess for both temperature and H_20 vapor. The regressed first guess performs nearly as well as the ATOVS operational soundings for temperature above 700 mb and generally outperforms the operational H_20 vapor soundings profiles. The NWP-minus-radiosonde curves exhibit the smallest differences (particularly standard deviation) but this is not surprising since the radiosondes are directly assimilated into the NWP. A notable exception is for upper tropospheric moisture where the NWP exhibits an increased moist bias.

Overall, the ATOVS operational first guess exhibits the largest differences relative to the radiosonde compared to the regressed first guess which show differences comparable to the ATOVS final soundings. Hyper-spectral soundings show the smallest standard deviation differences although the temperature bias tends to be larger near the surface. A persistent dry bias (5% to 10%) in the regressed moisture is interesting given the tendency for dry bias in radiosonde (upper) troposphere humidity (see section 5.2 , figure 5c)

Figure 4 shows global, time composite, horizontal fields of ATOVS regressed first guess (right) and current operational (left) temperature (upper) and H_20 vapor (lower) and associated NWP 6-hour forecast observations (middle) at 500 mb. The respective color scales for the temperature (225K to 273K) and H_20 water vapor (0.0 to 6.0 g/kg) fields are identical.

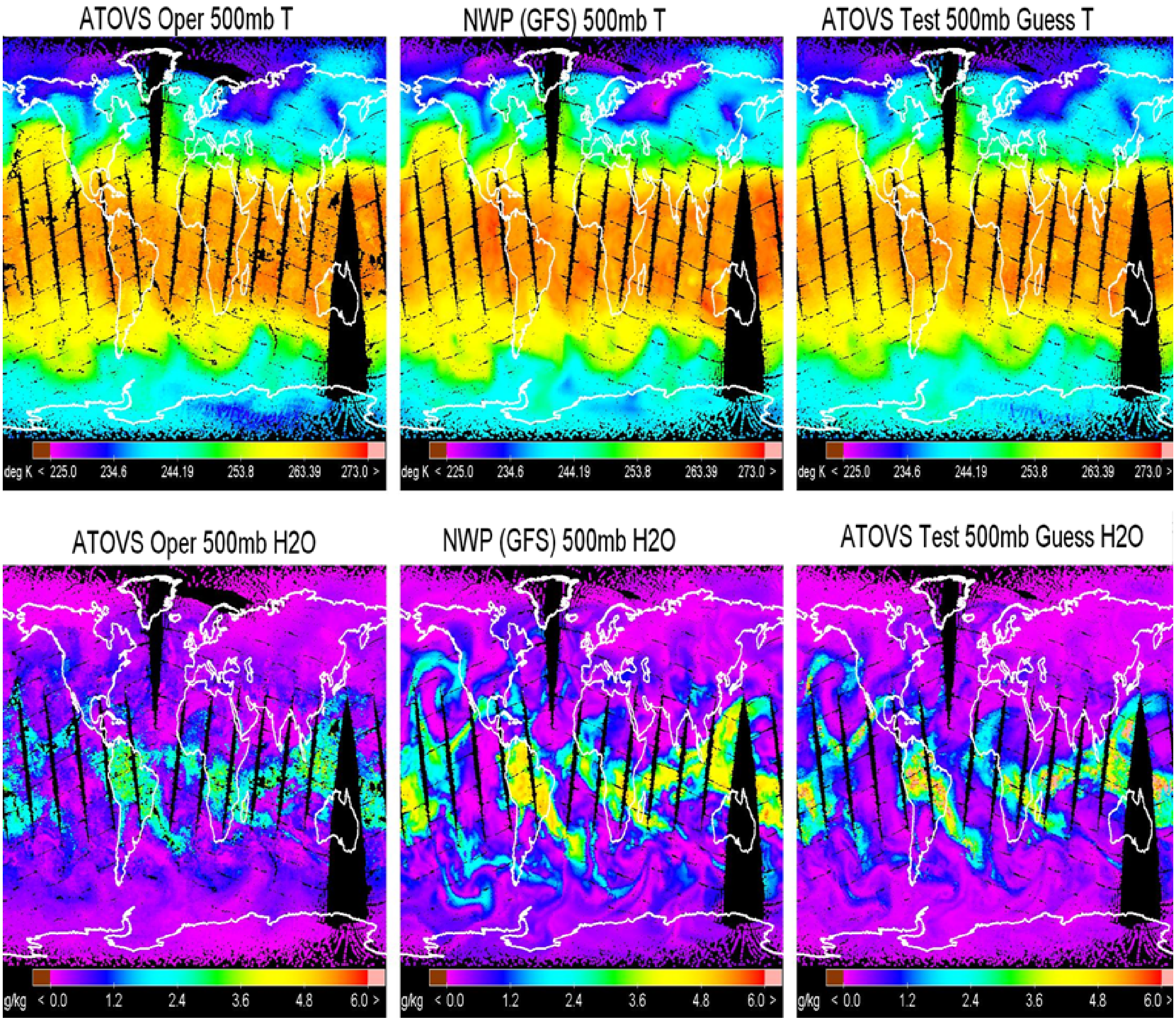

Figure 4: **Global, 12-hour time composite fields of ATOVS regressed first guess (right) and current operational (left) temperature (upper) and H_20 vapor (lower) and associated NWP 6-hour forecast observations (middle) at 500mb during January, 2009**

Immediately evident from figure 4 is the improved horizontal representation of the regressed (low right) versus operational (low left) H_20 vapor fields. Such characteristics are observed throughout the troposphere, whereas differences in the temperature fields are relatively small. This analysis also demonstrates the use of NWP to provide a reasonable target for “judging” the respective performances of satellite derived product systems.

Of particular interest is the NWP independent regressions produce global weather patterns that are overall consistent with NWP analysis in both radiosonde dense and sparse regions.

5.2 RT Bias Adjustment

RT bias adjustments are computed for each of the sensor channels that have sensitivity in the atmosphere. The predictors for adjusting each channel are exclusive to a given sensor as indicated in Table 2.

The bias adjusted sensor data are candidates for use in the retrieval step, and are intended to remove any systematic bias between the RT model calculated and observed sensor measurements, thus minimizing derived product bias.

Figures 5 (a-c) illustrate some preliminary features of the RT adjustments currently produced for microwave. As can be seen, the bias adjustment patterns and magnitudes for the three different channels are quite different.

Figure 5a illustrates orbital AMSU channel 6 sensitive to mid-tropospheric temperature. The adjustment pattern tends to be constant with a magnitude of about +1.5K and overall indicative of typical RT model bias for atmospheric sensitive temperature channels.

Figure 5b illustrates orbital MHS channel 3 sensitive to lower tropospheric moisture. The adjustment pattern shows the highest magnitude (10K) with a tendency to average out the dynamic range with relatively high values (dry) being lowered (moistened) and lower values (moist) being raised (dried).

Figure 5c illustrates orbital MHS channel 5 sensitive to upper tropospheric moisture. The adjustment pattern magnitude is about one-half as for MHS channel 3 and tends to correlate with the moisture burden with positive adjustments (drying) in the tropics and slight negative adjustments (moistening) toward the pole. This suggests a possible upper troposphere dry bias in the ground truth radiosondes (Sun *et al.* 2009).

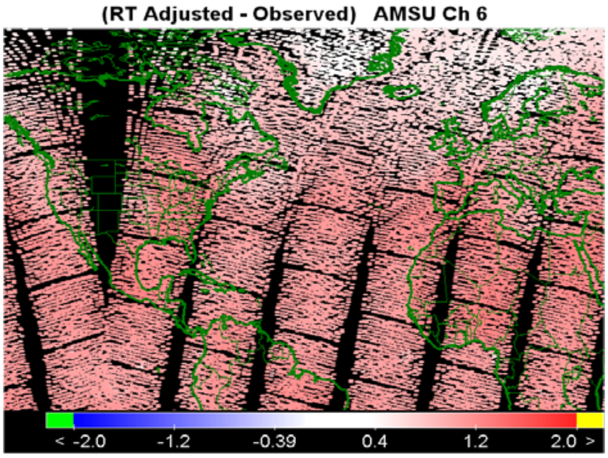

Figure 5a: Time composite orbital field of RT Bias adjusted-minus-original sensor data (K) for AMSU channel 6, sensitive to mid-troposphere temperature.

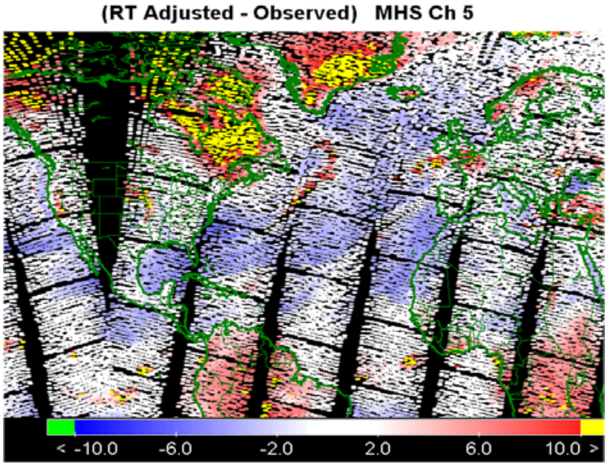

Figure 5b: Time composite orbital field of RT Bias adjusted-minus-original sensor data (K) for MHS channel 5, sensitive to lower troposphere moisture.

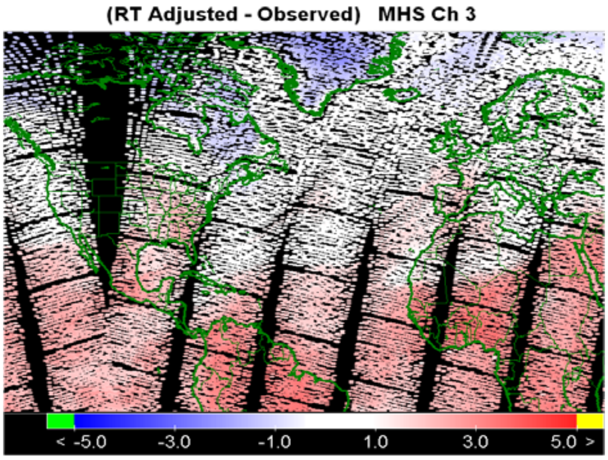

Figure 5c: Time composite orbital field of RT Bias adjusted-minus-original sensor data (K) for MHS channel 3, sensitive to upper troposphere moisture.

Further study is needed to better understand these characteristics (including for HIRS channels) and their subsequent impact on retrieval.

6. COLD/DRY, PRECIPITATING SCENES and OBSERVATION QUALITY

The designation and special treatment of cold/dry scenes, the need to identify and screen "contaminated" precipitating scenes and the emergence of the observational quality flag to summarize the confidence level of a given scene prior to retrieval were necessary steps that emerged during the development and analysis phases. Results outlining these respective techniques are illustrated in figures 6, 7 and 8 for the same region and period as figures 5a, b and c.

Figure 6 displays the cold/dry soundings (red), namely, those for which AMSU channel 5 is less than 245K and MHS channel 5 is less than 250K. Internal studies indicated that some segregation of "cold dry" atmospheres was needed concerning the selection of predictor channels and collocations for computing the first guess moisture coefficients. This led to the definition of "cold/dry" as defined as defined above for AMSU-A channel 5 (sensitive to lower troposphere temperature) and MHS channel 5 (sensitive to lower troposphere moisture). Under such conditions, MHS channels 4 and 5 are removed as predictors (see table 1) because the lack of moisture effectively transforms these channels into windows resulting in very cold values (normally indicative of high moisture).

However, even after removing these channels the relative humidity (RH) of the regressed profiles still exhibited supersaturated levels. It was decided to limit the RH for a given "cold/dry" scene to be no greater than 50%. Profiles requiring such adjustment(s) are indicated on the product output file and all original regressed moisture values are retained.

Precipitating scenes also required identification and screening prior to coefficient generation and potential user distribution. A "Sigma" screening approach was employed to identify MHS scenes contaminated by precipitation. The technique entails field analysis of the three MHS atmospheric channels (two at 183 and one at 190gHz) within each 10 degree latitude belt to identify "cold" outliers (> 1.5 sigma). Sigma values for each belt and channel are updated daily using the latest 14-days of observations.

Results are shown in Figure 7 in which the MHS Sigma flag for a given scene indicates

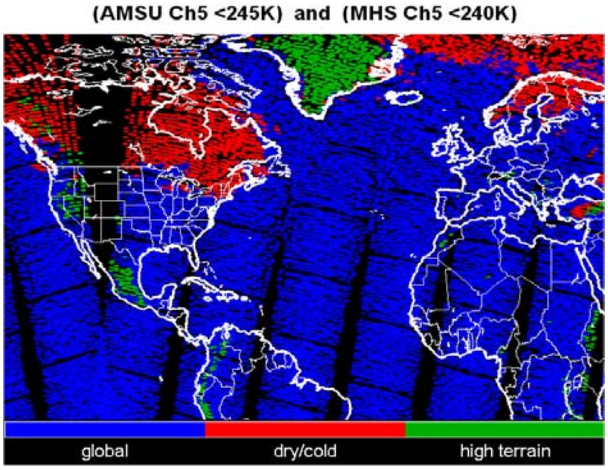

Figure 6: Satellite orbital composite indicating normal (blue), cold/dry (red) and high terrain conditions listed in table 1

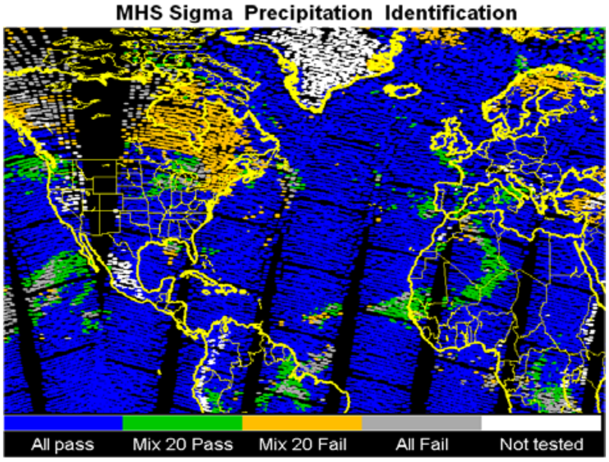

Figure 7: MHS Sigma flag indicating the presence of precipitation (orange and gray) in a given scene; scenes are not tested over high terrain

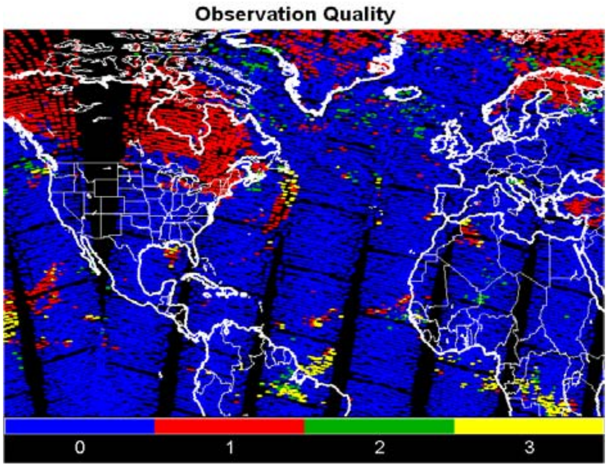

Figure 8: Scene observation quality with values of "0" (blue) indicating high confidence, "1" (red) and "2" (green) indicating reduced confidence, and "3" (yellow) low confidence.

whether all 3 MHS channels were cold, outlier (gray), at least 1 channel was cold, outlier including the lowest peaking MHS channel 5 (orange), at least one channel was cold, outlier but not including MHS channel 5 (green), all channels passed (blue) and not tested (white). Orange and grey indicate precipitating scenes.

Comparison of the cold/dry and precipitating scenes of figures 6 and 7 shows a common set of observations in the upper mid-latitude and polar regions. In such cases the cold/dry identification takes precedence (i.e., scene non-precipitating).

The observation quality illustrated in Figure 8 summarizes the overall confidence that the combined satellite sensor scene and associated first guess can result in a meaningful sounding retrieval. Values of zero (blue) indicate high confidence, one (red) and two (green) some concern for reduced confidence and three (yellow) indicates little or no confidence.

Collocations containing satellite scenes with an observation quality of 3 are screened from coefficient generation. Collocations containing cold/dry or high terrain are screened from the generation of “normal” (see table 1) coefficients.

7. SUMMARY

This report summarizes current activities under way to develop techniques for using collocated radiosonde and satellite observations to derive regression coefficients for computing global first guess temperature and moisture profiles and RT model bias adjustment of sensor observations. Procedures for compiling collocation datasets using NPROVS and related sampling strategies, including screening and special case analysis, are presented. Results show that although independent of NWP, the global patterns of the regressed first guess are consistent with NWP. The regressed first guess is significantly better than the ATOVS operation for moisture and comparable for temperature. Work to integrate the operational ATOVS, MIRS and methods in this report to retrieve final soundings is pending.

8. REFERENCE

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