SCIENTIFIC STATUS OF NESDIS ADVANCED TOVS SOUNDING PRODUCTS

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1. INTRODUCTION

The National Oceanic and Atmospheric Administration deployed the new Advanced TIROS Operational Vertical (ATOVS) sounder configuration onboard the NOAA-15 polar orbiting satellite in May of 1998. Six months later, in November 1998, the National Environmental Satellite Data and Information Service (NESDIS) began making test sounding products from ATOVS available to users for their evaluation. In April 1999, the ATOVS sounding products from NOAA-15 were implemented into the NESDIS operation, replacing NOAA-12.

The following report provides the current status of the scientific algorithms and operational sounding products for NOAA-15. The report addresses preliminary feedback from users and problems areas identified and corrected since April. Sounding product evaluation against existing NESDIS operational systems and radiosondes are included. Excellent consistency among sounding products from all NESDIS operational systems is observed.

2. BACKGROUND

The NESDIS operational sounding systems for ATOVS NOAA-15 (Reale, 1999) are in fact two distinct systems. For this report, ATOVS refers to the 20-channel High-resolution Infrared Radiation Sounder (HIRS/3), the 15-channel Advanced Microwave Sounding Unit-A (AMSU-A), and the 5-channel Advanced Very High Resolution Radiometer (AVHRR). AMSU-A essentially replaced the 4-channel Microwave Sounding Unit (MSU) and 3-channel Stratospheric Sounding Unit (SSU) onboard previous NOAA polar orbiting satellites. Product systems for the "new", high resolution moisture soundings from AMSU-B are operated separately, and at this time independently from the ATOVS data (Reale, 2000).

Sounding products from NOAA-15 consists of a newly designed suite of radiometric and derived products to meet the variety of user needs. For example, radiometric products now include the initially calibrated data at the instrument field-of-view (fov).

3. SCIENTIFIC ALGORITHMS

Figure 1 illustrates the organization of the online and offline systems for ATOVS to derive operational sounding products. Solid lines indicate "orbital" processing sub-systems, and the dashed and dotted lines are "offline" support systems which operated on a daily or weekly basis.

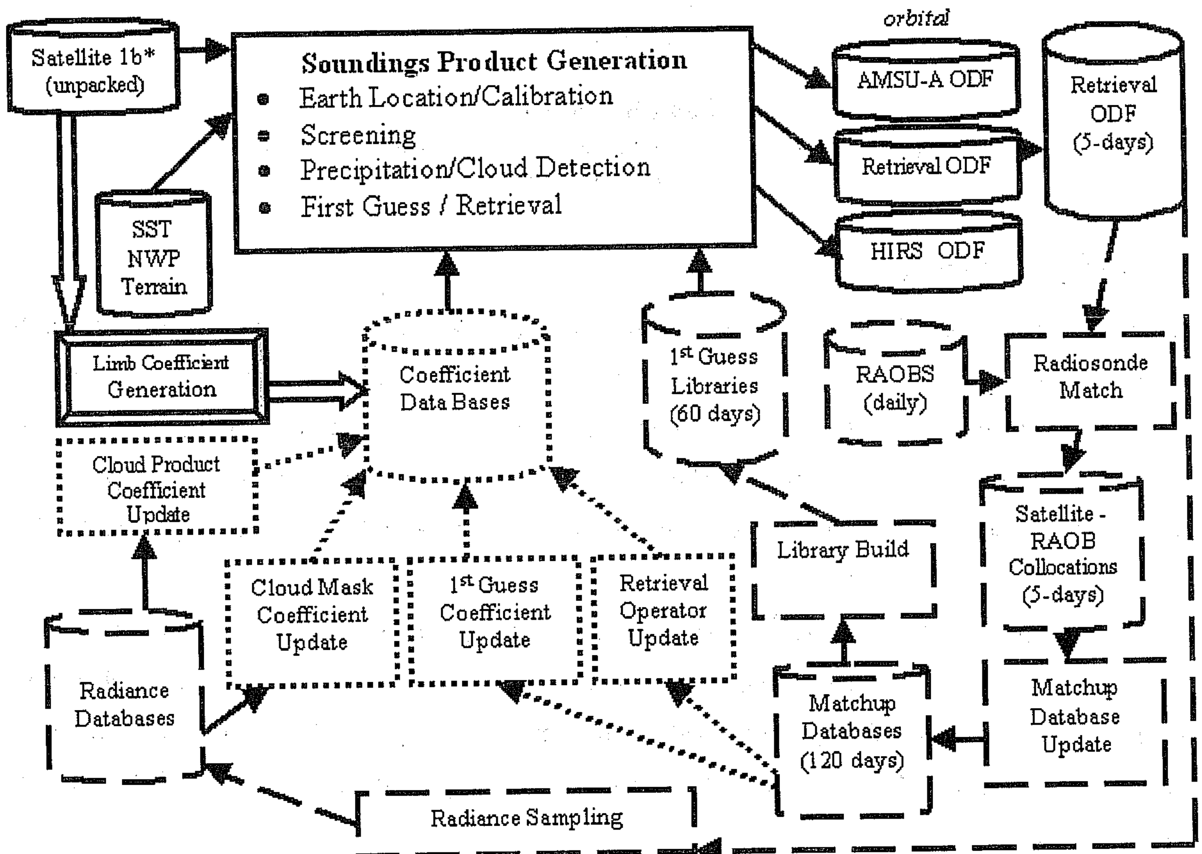

Figure 1 – **ATOVS Processing System, showing the On-Line (orbital) processing [solid lines], the Off-Line Daily jobs [dashed lines], the Off-Line Weekly jobs [dotted lines], and As Needed jobs [blocked arrows and box].**

3.1 Orbital

The orbital processing system outlined in the solid box in Figure 1 includes:

- preprocessing
- radiance temperature adjustments
- contamination detection
- first guess and retrieval.

Preprocessing consists mainly of instrument calibration, gross error checks, and the interpolation of the AMSU-A observations to the HIRS footprint as required for deriving soundings.

Radiance temperatures adjustments consist of corrections to the nadir view (Allegrino, 1999). These are sounder dependent and are done independently for the HIRS and AMSU-A measurements. Monitoring determines the frequency of updating. Procedures for improved sampling and coefficient constraints are underway to correct residual limb effects in some of the channels.

Contamination detection includes effects due to precipitation and clouds. Precipitation contamination of microwave data is determined by comparing computed cloud liquid water (clw) to thresholds (i.e., 40 mm). Special techniques are also available over land (Grody and Ferraro, 1999). Cloud detection for infrared data consists of a series of tests applied to each HIRS fov (Ferguson, 2000). Cloud tests are integrated over a variety of geographical, seasonal, and solar conditions. If at least one test fails, the HIRS scene is designated as cloudy, and no HIRS tropospheric measurements are used in subsequent first guess and retrieval steps.

The first guess is determined for each sounding using an eigenvector/library-search. The libraries searched contain recent global samples of satellite and radiosonde collocations (Tilley, 2000). The libraries and eigenvectors are segregated for clear and cloudy soundings, and routinely updated (see Section 3.2).

The current channel combination used in the first guess search for clear soundings are:

- HIRS 7, and 10-12
- AMSU-A channels 4-14

and for cloudy soundings are:

- AMSU-A channels 5-14
- the surface layer temperatures from operational NOAA global weather forecasts.

The first guess temperature, moisture and radiance temperature profiles for each sounding are computed by averaging selected collocations. For ATOVS channels peaking above 50 mb (defined as HIRS channel 2 and AMSU-A channels 11-14), the first guess radiance temperatures are calculated (McMillin, 1995) based on the first guess temperature profile. This is consistent with offline procedures to extend radiosonde profiles in the upper stratosphere, above the highest reported level (Gelman, 2000).

The retrieval approach is the minimum-variance, simultaneous technique given by:

$$T - T_g = S A^t (A S A^t + N)^{-1} (R - R_g) \qquad (1)$$

where the subscript t indicates the matrix transpose, -1 the inverse, and

T: final soundings products vector, (132 x 1)

Tg: first guess products vector, (132 x 1)

S: first guess covariance matrix, (132 x 132)

A: sounder channel weighting matrix, (35 x 132)

N: noise covariance matrix, (35 x 35)

R: observed radiance temperature vector, (35 x 1)

Rg : first guess radiance temperature vector, (35 x 1).

The (internal) products vector (T) includes 100 levels of atmospheric temperature, 31 levels of moisture, and surface temperature. The dimension 35 denotes the complete array of ATOVS channels (not all are used).

The retrieval channel combinations for clear soundings are:

- AMSU-A channel 4-14
- HIRS channels 2-7, 10, 12, 14 and 15

and for cloudy soundings are:

- AMSU-A channels 5-14
- HIRS channel 2.

Soundings over high terrain (> 1000m) are retrieved using the cloudy combination but without AMSU-A channel 5. Over Antarctica AMSU-A channel 6 is also excluded.

The A, S, and N matrices of the retrieval operator are computed offline and updated weekly. Up to 46 separate operators, stratified by terrain, latitude and sounding type (i.e., clear versus cloudy) are possible. At this time, nine separate operators stratified by latitude are applied and updated weekly (see 3.2).

The result of orbital processing are the operational atmospheric sounding products which include:

- initial radiometric observations (AODF and HODF)
- adjusted radiometric observations (RODF)
- derived temperature and moisture soundings (RODF)
- cloud products, total ozone and radiation budget (HODF and RODF).

The AODF(AMSU-A Orbital Data File) and HODF (HIRS Orbital Data File) data sets essentially represent the original sounder measurements, as requested by some advanced weather prediction centers for direct assimilation into numerical weather prediction (nwp). However these datasets also include cloud and precipitation parameters, collocated AVHRR (up to 6 channels), and other information not available to ô1b levelö data users.

The RODF(Retrieval Orbital Data File) stores the more traditional sounding products data, including: the adjusted radiometric vectors used to compute soundings, the derived temperature and moisture soundings, first guess and ancillary information, and non-sounding products such as cloud liquid water, total precipitable water, cloud top pressure, total ozone, and radiation budget.

Approximately 150,000 ATOVS soundings are processed daily by NESDIS, with routine distribution over dedicated, including:

- National Weather Service (NOAA)
- United Kingdom Meteorological Office
- Global Telecommunications System
- Shared Processing Network.

Raw satellite data and derived operational products are routinely archived by National Climatic Data Center.

3.2 Offline

As shown in Figure 1, the Offline systems provide a major component of the sounding products systems. Offline systems contribute to the tuning and evaluation functions required to ascertain and maintain the scientific integrity of the orbital sounding products.

Offline systems routinely compile and update:

- satellite radiance databases
- collocated radiosonde and satellite product databases
- first guess and retrieval coefficients.

All are directly utilized in the orbital processing subsystem.

The radiance databases include the clear scene, limb adjusted ATOVS measurements for generating the variety of regression coefficients used to detect clouds (Ferguson, 2000).

Collocated radiosonde and satellite observation data sets are compiled daily (Tilley, 2000). These are used to update longer term data sets of collocations referred to as Matchup Data Bases (MDBs). MDB updating includes special procedures to maintain optimal spatial and temporal distribution of the collocations over time. Separate MDBs are maintained for clear and cloudy soundings.

The MDBs are used to update the

- first guess libraries
- first guess coefficients, and
- retrieval operator coefficients.

The first guess libraries are updated daily, with separate libraries for clear and cloudy collocations. Library samples typically span the latest 30 to 120 days, with regional time periods inversely proportional to radiosonde report density.

The first guess coefficients consist of eigenvectors and eigenvalues based on the adjusted radiance temperature data stored on the MDB. Coefficients are global, and segregated for clear, cloudy, sea and nonsea sounding types, resepctively, and consistent with the first guess channels combinations and orbital processing applications. (see Section 3.1).

The retrieval operator coefficients primarily consist of the "A" (sensor weighting function) and "S" (first guess covariance) matrices (see section 3.1). Nine separate A matrices corresponding to specific latitude belts, and a single global S matrix are combined to compute the nine separate retrieval operators for deriving all soundings. The S matrix is based on "first guess minus radiosonde" differences for temperature and moisture. Software flexibility to uniquely combine up to 46 separate A matrices and 6 latitudinal based S matrices is available.

4. RESULTS

Figure 2 presents results comparing ATOVS against collocated radiosonde observations (Tilley, 2000). The plots display mean and standard deviation differences of satellite sounding minus radiosonde profiles for the 60N to 60S latitude belt. Pressure is shown on the left axis, sample sizes are on the right axis, and temperature difference (K) is along the x-axis. Statistics are for a one week period in September of 1999. The ATOVS system demonstrates RMS values under 2o K through most of the atmosphere.

The NESDIS operational implementation of ATOVS sounding products has been highly successfully. Results indicate that these new products, along with the existing operational data, exhibit excellent consistency and scientific integrity, and meet requirements user requirements for nwp and other research applications.

5. ACTIVITIES AND PLANS

A number of problem areas and corrective actions have been resolved by NESDIS since the operational implementation of ATOVS in April 1999. Several of these were initially identified through user feedback to NESDIS. For example, a number of problem areas were found to be associated with poor cloud detection (mainly in polar regions), less than optimal first guess and retrieval channel combinations, and retrieval operator discontinuities across geographical boundaries (i.e., sea and ice). A series of corrective action tasks were defined and successfully concluded in many cases. Several improvements were implemented, but activity continues to fully resolve these problems.

The ATOVS operating system is generally accepted as a significant improvement over TOVS due to the replacement of the MSU and SSU. However, some detailed studies (Gelman, 2000) indicated that the new ATOVS profiles had some intrinsic shape problems very high in the stratosphere which were insensitive to the sounder measurement. New procedures were developed and preliminary results are positive

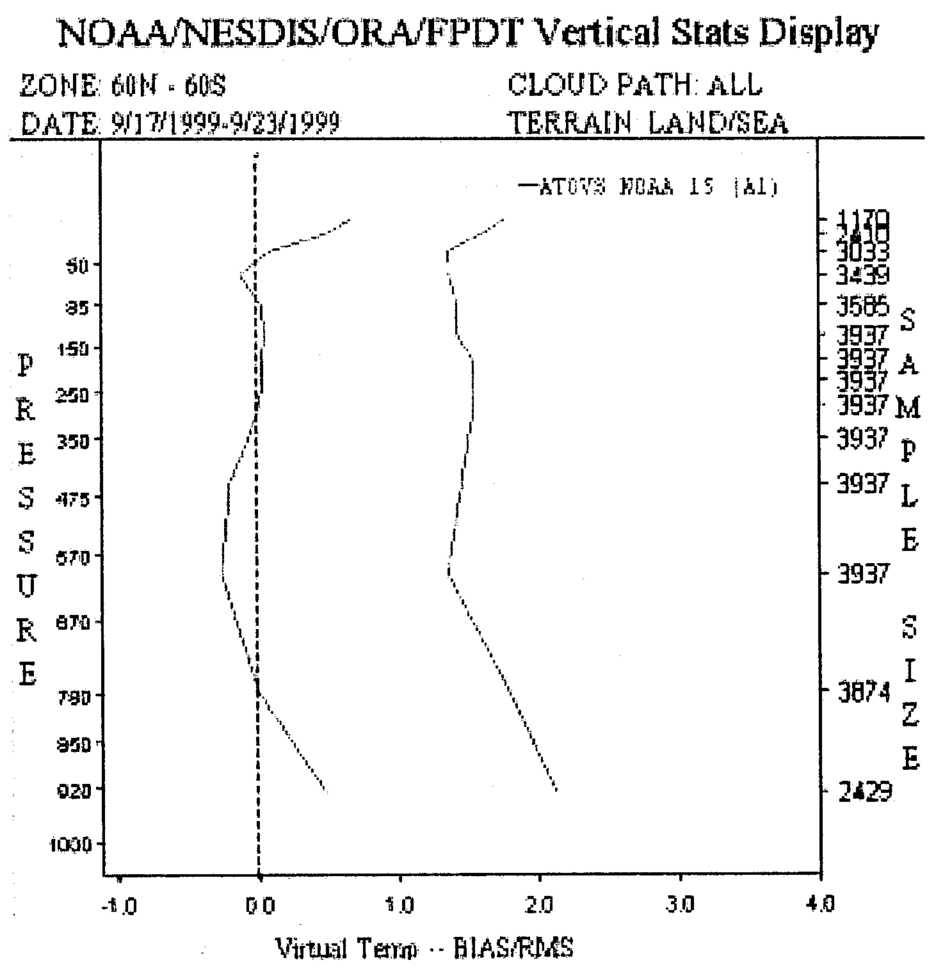

Figure 2 Vertical Accuracy Statistics

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