JP1.15

ADVANCED-TOVS (ATOVS) SOUNDING PRODUCTS FROM NOAA POLAR ORBITING ENVIRONMENTAL SATELLITES

Anthony L. Reale and Michael W. Chalfant
NOAA/NESDIS
Washington D.C.

Americo S. Allegrino, Franklin H. Tilley, Michael P. Ferguson and Michael E. Pettey
Raytheon Technical Services Company/ITSS
Lanham, Maryland

1. INTRODUCTION

The National Oceanic and Atmospheric Administration deploys a fleet of civilian, polar orbiting environmental satellites which provides users and researchers with a suite of operational atmospheric and environmental data. On May 13, 1998, the Advanced TIROS Operational Vertical Sounder (ATOVS) instrument configuration (Goodrum et al., 2000) onboard NOAA-15 was successfully deployed into a morning orbit, followed by NOAA-16 into an afternoon orbit, on September 21, 2000. The ATOVS sounders consists of the 15-channel Advanced Microwave Sounding Unit-A (AMSU-A), the 5-channel AMSU-B, the 20-channel High-resolution Infrared Radiation Sounder (HIRS/3), and the 6-channel Advanced Very High Resolution Radiometer (AVHRR/3). The following report summarizes the latest series of upgrades and current scientific status of the National Environmental Satellite Data and Information Service (NESDIS) operational sounding products. The report also addresses the requirement for ground truth, radiosonde observations concurrent with each satellite, and future plans to better meet user requirements.

2. CURRENT SYSTEM SYNOPSIS

Scientific procedures for processing NESDIS operational sounding, cloud (experimental), radiation and ozone products for ATOVS are briefly summarized below. These are divided into Orbital and Offline processing systems. A more detailed discussion is found in Reale, 2001 and at the web site: **http://poes.nesdis.noaa.gov**

---

* Corresponding author address: Anthony L. Reale, 5200 Auth Rd, Suitland Md, 20746; email: tony.reale@noaa.gov

The **Orbital** processing system provides:

- Pre-processing,
- Contamination detection,
- First guess and retrieval for soundings, and
- Cloud, Radiation, and Total Ozone products.

Pre-processing steps include instrument calibration, quality control (QC) of the sounder measurements, attachment of ancillary data such as terrain designation, Sea Surface Temperature and Numerical Weather prediction (NWP), the spatial interpolation of the AMSU-A measurements to the HIRS/3 field-of-view (FOV), and radiance temperature adjustments such as limb correction (Allegrino, 1999).

Contamination detection consists of the identification of effects due to precipitation for the AMSU measurements, and clouds for the HIRS/3 measurements. Cloud detection (Ferguson and Reale, 2000) is particularly critical as it constrains the use of the HIRS in subsequent first guess and retrieval calculations.

The first guess is uniquely determined for each sounding using a library search technique (Goldberg, 1988). The libraries consist of collocated radiosonde and satellite measurements, sorted by geographical category (see Table 2, and also Tilley et.al 2000) and are directly accessed during orbital processing.

The generalized form for the library search is given in equation (1):

$$D = (R - R_k)^t B^{-1} (R - R_k) \qquad (1)$$

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

D : scalar closeness parameter,
B : sounding channel radiance covariance matrix; dimension (35 x 35),
R : adjusted, observed radiance temperature vector; dimension ($N_{A,i}$), and
R_k : adjusted, library radiance temperature vector; dimension ($N_{A,i}$).

The dimension "35" for the B matrix in Equation (1) denotes the total number of sounder channels available from ATOVS[1], even though not all are used. The dimension ($N_{A,i}$) denotes the specific channel combination used to compute D, and the subscript "k" denotes the collocations searched. The channel combination for a given sounding varies depending on whether the sounding type is clear or cloudy, and sea or non-sea. The actual first guess temperature, moisture and radiance temperature profiles for a given sounding are computed by averaging the 10 closest collocations with the smallest D.

ATOVS soundings are retrieved using a Minimum Variance Simultaneous solution (Fleming, 1986), which is given by equation (2):

$$T - T_g = S A^t (A S A^t + N)^{-1} (R - R_g) \qquad (2)$$

where the subscript *t* indicates the matrix transpose, -1 the inverse, and:
T: final soundings products vector, (133),
T_g: first guess products vector, (133)
S: first guess covariance matrix, (133 x 133),
A: sounder channel weighting matrix, (35 x 133),
N: measurement uncertainty matrix, (35 x 35),
R: observed radiance temperature vector, ($M_{A,j}$),
R_g : first guess radiance temperature vector, ($M_{A,j}$).

The product vector (T) includes 100 levels of atmospheric temperature (1000mb to .1mb), 31 levels of moisture (1000mb to 200mb), and surface data. The dimension 35 for the A and N matrices denotes the available ATOVS channels; not all are used. The dimension ($M_{A,j}$) denotes the specific channel combination used to compute retrievals, depending on the sounding type. The S, A and N matrices of the retrieval operator are pre-computed offline and updated weekly, with nine unique sets of matrices combined depending on the sounding type and latitude.

[1] AMSU-B is not included in current ATOVS system, see Section 6.

The cloud products (Chalfant and Allegrino, 2001) are computed using a CO_2 Slicing algorithm, which is a slope-radiance technique for deriving the cloud parameters. This technique is based on the assumption that the observed radiance for any channel is a linear function of the effective cloud fraction which falls on a line between the totally clear and the cloudy radiance (Yang et. al., 1996). The algorithm uses the triple-pass approach described by McMillin et. al.(1994) to calculate the cloud products. The first and second iterations calculate products based on HIRS channels 7 and 8, with the third iteration using a HIRS channel pair based on the cloud top pressure. In all iterations, the cloud top temperature and corresponding derived sounding are used to determine the cloud top pressure, with effects due to $C0_2$ attenuation above the cloud accounted for in the second and third iterations.

Cloud products are available per HIRS/3 Field-of-View (FOV), per sounding, and on one equatorial degree global, grid fields. Cloud amount summary tables, similar to Menzel et.al., 2001, and based on the grid data are also produced daily.

The ATOVS derived cloud products consists of the following parameters:

- Cloud Amount (%),
- Cloud Top Pressure, and
- Cloud Top Temperature

Regression coefficients are used to predict the clear sky temperature (i.e., at the cloud top). These coefficients are derived offline, using selected HIRS and AMSU-A tropospheric channels (unaffected by clouds) from clear sky FOV (Chalfant and Allegrino, 2001). Coefficients are produced for five (5) latitude zones, with linear interpolation near latitude boundaries, and updated weekly.

NESDIS also has a long history of providing Outgoing Longwave Radiation (OLR) and clear-sky Layer Cooling Rates (LCR) from its polar orbiting satellites. The ATOVS system routinely provides the following radiation parameters at each of the HIRS/3 FOV and on grid:

- All Sky and Clear Sky OLR
- Clear Sky LCR1 (1000mb to 700mb),
- Clear Sky LCR2 (700mb to 500mb),
- Clear Sky LCR3 (500mb to 240mb), and
- Clear Sky LCR4 (240mb to 10mb)

OLR and LCR parameters are computed using a fixed set of regression coefficients as described in Ellingson et. al., 1994a and 1994b.

ATOVS Total Ozone is the final product produced, and are derived at each sounding location, except for cases of very thick, cold, clouds, using a physical, two-layer, transmittance-radiation model (Neuendorffer 1996).

The **Offline** processing system compiles and updates the respective data sets of sounder FOV, and the collocated satellite and radiosonde observations used to derive coefficients.

The sounder FOV observations used to update the cloud parameter and cloud test coefficients primarily consist of clear-sky HIRS FOV which are sub-sampled from each operational satellite on a daily basis. Samples are global, and typically span the most recent 30 to 60 days.

The collocated radiosonde and satellite observations, also updated daily, are directly used in orbital processing to provide first guess information, and are also the basis for computing the retrieval coefficients and for products validation (Tilley et al., 2000). Their use in product processing, referred to as "Tuning", attempts to compensate for the systematic differences among the scientific algorithms, ground truth, and satellite measurements, including seasonal changes and instrument drift. The primary data set of collocations used for these purposes is referred to as the Matchup Data Base (MDB), which is discussed later in Section 4.1.

3. RESULTS

The motivation for all scientific upgrades developed by NESDIS is to enhance the information content of the derived products in the context of NWP and Climate applications. Upgrades typically address improved consistency in products relative to the sounder measurements and ground truth, as well as expanded products, such as the increased coverage and accuracy of the global cloud products which are now available experimentally. Selected results from NESDIS operational product systems are discussed below, as provided through the Environmental Data Graphical Evaluation (EDGE) system, developed at NESDIS in support of operational products (Brown et.al., 1992).

The panels in Figure 1 illustrate the information content of the NOAA operational sounding products from ATOVS in the context of NOAA's Environmental Modeling Center (EMC) NWP data. The upper two panels illustrate difference fields for **SAT**ellite (NOAA-16) operational soundings minus EMC's **NWP** (6-hour "Aviation" forecasts) for the (500 to 300mb) layer mean virtual temperature, with the SAT-NWP time differences constrained to be within 2 hours. The middle two panels show EMC 400mb wind fields (m/s) corresponding to the same periods, and the lower panels illustrate concurrent AMSU-A channel 5 radiance temperature measurements (K) which are sensitive to middle tropospheric temperature. The region displayed is the remote South Indian Ocean region (see EMC panels for latitude and longitude boundaries), on March 23, 2002 (left) and 48 hours later on March 25 (right).

The high correlation between the maximum 400mb wind and the SAT-NWP departure patterns demonstrates the potential value of the NWP-independent, NESDIS sounding products to assist forecasters in identifying developing storm systems. This is the type of information which may be compromised in conventional NWP systems which assimilate radiance data based on a forecast first guess (Derber and Wu 1998). These patterns are not artifacts of the SAT minus NWP time differences, as the wave speed in Figure 1 is approximately 20 kph, which given the less than 2-hour time difference in observations is insufficient to account for the observed patterns. Such cases warrant further study to better understand the implications of these signature SAT-NWP difference patterns, found mainly in the vicinity of weather transition zones (also see Reale 1995).

Over the past few years, a number of users have expressed an increasing interest in Southern Hemisphere sounding products including those over Antarctica. Given its high terrain and global isolation, generating products over Antarctica is very challenging and requires some special considerations. For example, the use of infrared

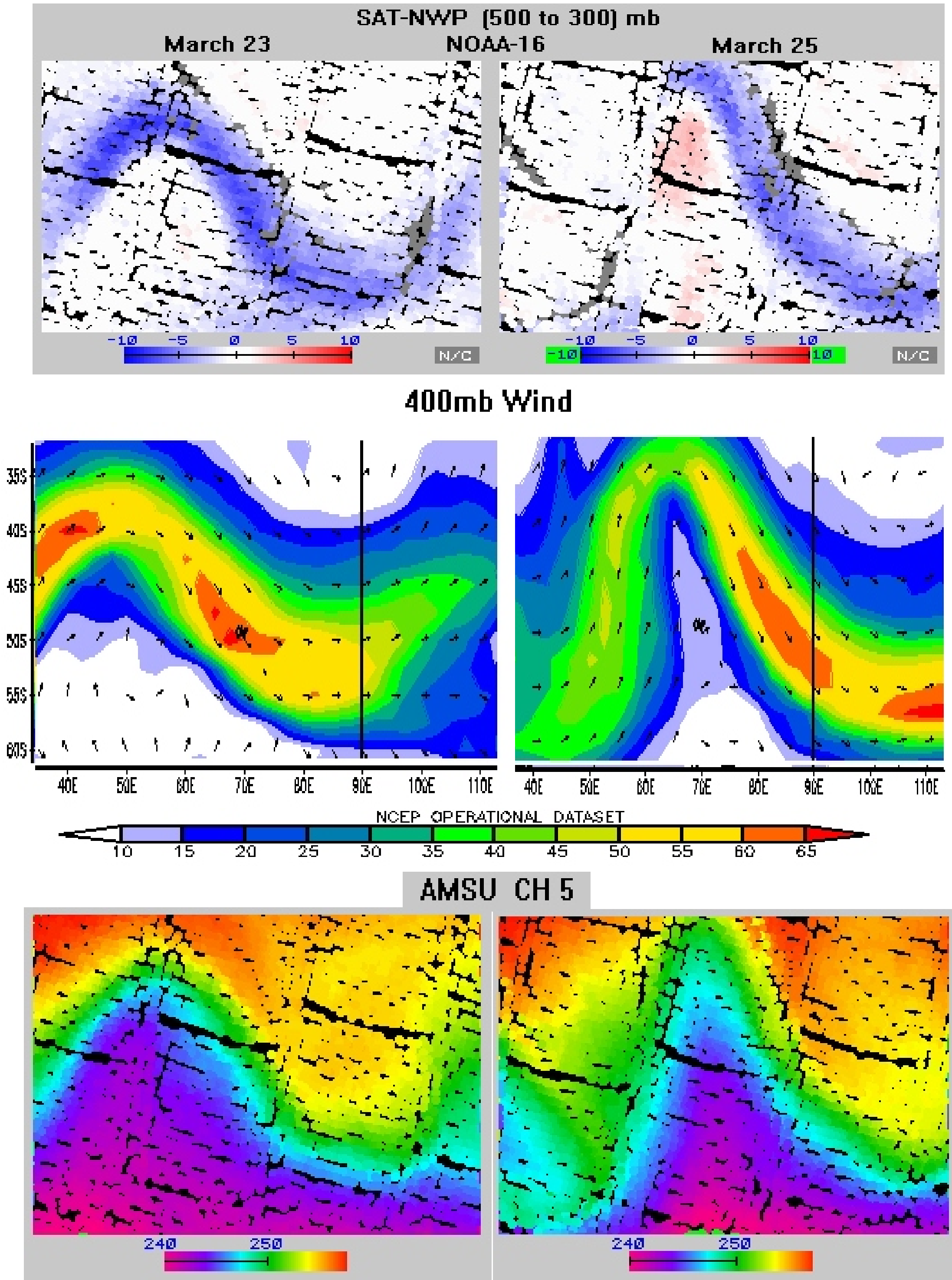

Figure 1: (SAT-NWP) differences (deg K) for the 500 to 300mb layer (upper), NWP Wind (m/s) Analysis at 400mb (middle), and AMSU-A channel 5 (deg K) data (lower) over the Indian Ocean on March 23, 2002 (left) and 48 hours later on March 25. (right).

observations and lower peaking microwave sounding channels in this region has been found to be prohibitive, and the sparsity of collocations (radiosondes are mainly limited to coastal regions) makes it difficult to operate and validate the NESDIS algorithms over inland Antarctica. Recent changes to further constrain the use of sounder data from Antarctica, along with increased monitoring of this region by NESDIS has significantly improved the product performance in Antarctica, particularly above the 500mb level.

An example of the improved southern hemisphere sounding products in polar regions is shown in the three panels of Figure 2. This illustrates AMSU-A channel 8, which is sensitive in the vicinity of 200mb (upper left), the NESDIS, derived 200mb temperature data from NOAA-16 and the corresponding terrain designation for the Antarctica region. The derived soundings and measurements show quite good agreement[2], with a relatively smooth transition across the sea, ice and land boundaries[3]. Users are encouraged to further consider the use of these data and to provide feedback to NESDIS on performance.

Of particular interest are the global Grid data-sets for Clouds, which were created to facilitate comparisons with other sources of cloud products (i.e., Menzel et.al., 2001). Grid data sets are provided daily, per satellite, and for the ascending and descending orbital node data, respectively. After sorting the products by cloud top pressure into High, Medium and Low cloud heights, the values in each grid cell are computed as a weighted average with respect to the effective cloud amount (or fraction). The Cloud Height Categories for grid data are:

- **ALL** (High. Medium and Low),
- **HIGH**, above 440mb,
- **MEDIUM**, from 440mb to 680mb, and
- **LOW**, below 680mb.

[2] Measurement and derived temperatures exhibit different dynamic ranges making direct color comparisons difficult.

[3] NESDIS products in the past have typically exhibited sharp discontinuities across the south polar sea, ice and Antarctic coastal boundaries.

Figure 3 shows examples of the Grid data sets for the experimental Cloud and Radiation products, illustrating (clockwise beginning upper left) the derived Cloud Top Pressure, Cloud Top Temperature, High Cloud Top Temperature[4], Clear-Sky Layer Cooling Rate for the 1000mb to 700mb layer, Outgoing Longwave Radiation (OLR), and AVHRR channel 4. Very good agreement is observed, for example, where the locations of high clouds correspond with the lower values of cloud top pressure, temperature and AVHRR measurement values.

NESDIS also provides “equal-area”, Cloud-Amount summary tables, again consistent with Menzel et.al, 2001, on a daily basis which are generated from the Grid data sets. Separate tables are provided for:

- 6 pre-defined latitude bands,
- two additional areas covering the continental U.S.,
- ascending and descending orbital node, and
- each operational satellite.

The Cloud-Amount summary tables report the cloud fraction for each of the Cloud Height Categories (above), where the cloud fraction is the average for all grids within a given latitude band, Height, and Thickness (or Amount) categories[5] defined as:

- **ALL** (Opaque, Thick, and Thin),
- **OPAQUE**, the Cloud Amount (fraction) is above 90%,
- **THICK**, the Cloud Amount (fraction) is between 90% and 50%,
- **THIN**, the Cloud Amount (fraction) is less than 50%.

[4] Black regions (other than orbit gaps) denote areas of Medium and Low Clouds.

[5] Or effective emissivity, see Menzel et.al., 2001.

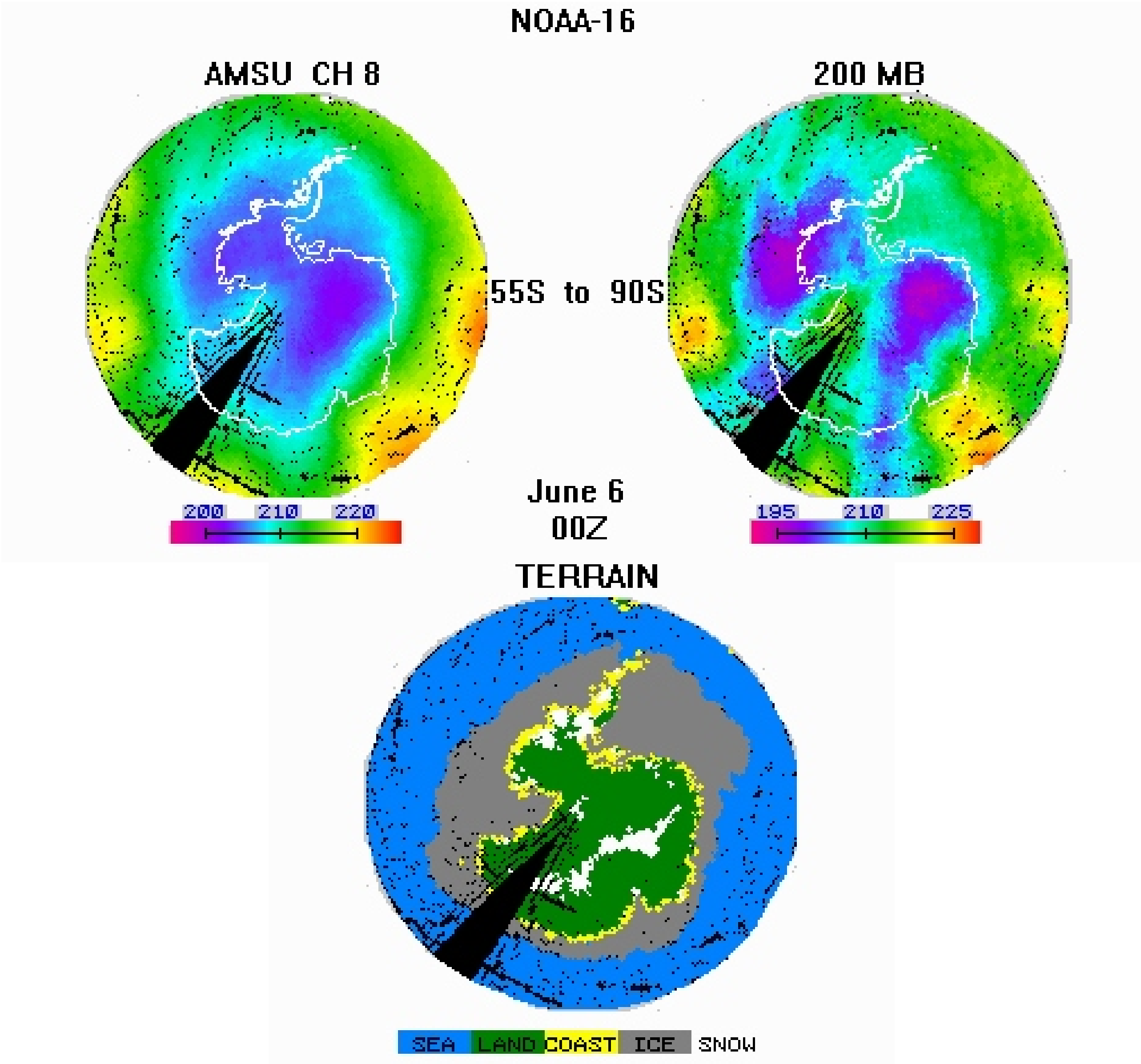

Figure 2: AMSU-A channel 8 (upper left) and corresponding 200mb derived temperature fields (upper right) for NOAA-16, and the corresponding terrain characteristics across the southern polar ocean, sea-ice and Antarctic regions (lower).

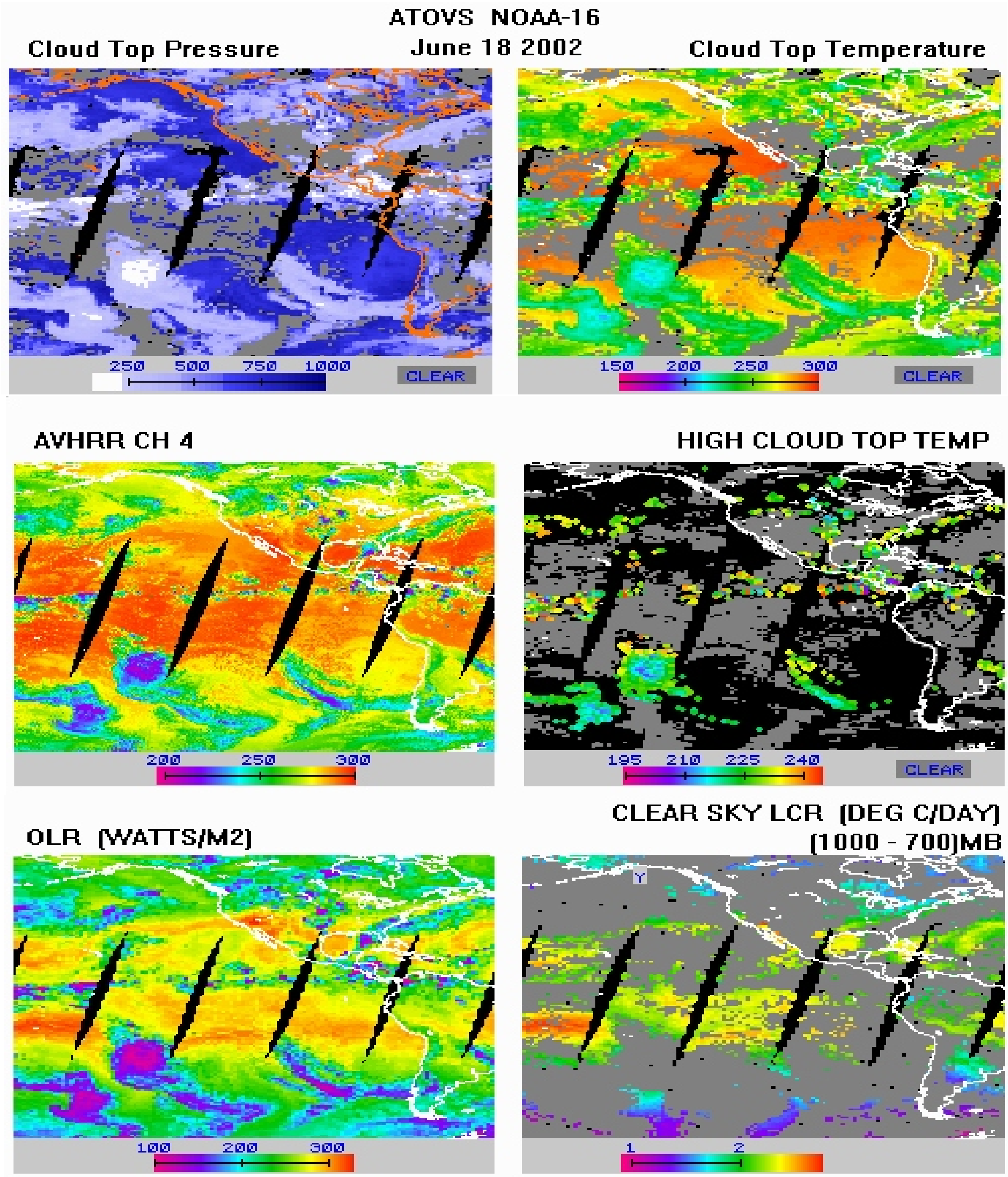

Figure 3: **Experimental Cloud and Radiation Grid Products for NOAA-16 ATOVS, illustrating (Clockwise beginning Upper Left) the derived Cloud Top Pressure, Cloud Top Temperature, High Cloud Top Temperature, Clear Sky Layer Cooling Rate (1000mb to 700mb layer), Outgoing Longwave Radiation, and AVHRR channel 4.**

CLOUD PERCENTAGES FOR (60N - 30N)

	ALL	HIGH	MED	LOW
ALL	34.7	18.8	6.2	9.7
OPAQUE	11.7	8.0	0.4	3.3
THICK	15.6	8.0	3.8	3.8
THIN	7.4	2.8	2.0	2.6

CLOUD PERCENTAGES FOR (30N - EQUATOR)

	ALL	HIGH	MED	LOW
ALL	36.0	30.0	2.8	3.2
OPAQUE	11.5	10.4	0.2	0.9
THICK	16.1	13.6	1.1	1.4
THIN	8.4	6.0	1.5	0.9

Table 1: Examples of Daily Cloud-Amount summary tables for the 60N to 30N (upper) and 30N to Equator (lower) regions showing the average cloud fraction for ALL, OPAQUE, THICK and THIN clouds, for ALL, HIGH, MEDIUM and LOW cloud top pressure.

Table 1 (above) provides examples of Cloud Amount summary tables for the 60N to 30N (upper) and 30N to the Equator (lower) latitude bands, respectfully. The values in Table 1 are interpreted as the average percentage of cloudiness for a given grid cell within the latitude belt, cloud-height, and thickness category. For example, on average, a given grid cell in the 60N to 30N band was 34.7 % cloudy, with 18.8 % covered by High clouds, 11.7 % by Opaque clouds, and 8.0 % by High, Opaque clouds on the given day.

4. GROUND TRUTH

4.1 Applications for NESDIS Sounding Products

The requirement for ground truth, namely the collocated radiosonde and satellite observations compiled in support of the NESDIS sounding product systems, is a critical element concerning both the processing and QC of the measurements and derived products provided by NESDIS (Tilley et al., 2000 and Reale, 2001). Subsequently, the QC of the collocations, and in particular the radiosonde observations, is a major concern. The lack of a dedicated, global program to provide ground truth data in support of NOAA's operational polar satellites has compounded this concern and (in the opinion of the authors) contributes a sizeable component of the current problems inhibiting the validation and use of polar products in NWP and climate applications.

One of the basic problems confronting NESDIS, which operates two operational polar satellites with a six-hour orbital separation, is to maintain a consistent data base of collocations for use in the processing and validation of products for each satellite. This data base is referred to as the MDB, which contain approximately 15,000 radiosonde and satellite collocations, stratified among 23 geographical categories. The MDB is updated daily, with approximately 75% overlap in sample from week to week, with the most recent data stored about 12 hours old, and the oldest up to 104 days. The MDB is archived by the National Climatic Data Center(NCDC).

Unfortunately, given that a majority of radiosonde observations launch at the 0Z and 12Z synoptic times, the collocations in support of each satellite are typically mutually exclusive (particularly over land), given the time window constraints required for reliable observations.

The three panels of Figure 4 illustrate typical 24-hour, global distributions of collocations for NOAA-15 (Upper) and NOAA-16 (Lower), as sub-sampled from the MDB, and the corresponding radiosonde observations that were available (Middle). The notable differences in the satellite distributions, particularly over (but not restricted to) land, underscore the need for considering at least a partial rededication of the global radiosonde network to insure adequate, consistent, and global ground truth in support of "each" polar satellite. Otherwise, the use of collocation datasets in the processing and validation of derived products, as well for monitoring the performance of the satellite borne radiometers will be potentially biased.

The two panels of Figure 5 illustrate the use of the collocation data to validate the derived sounding products for NOAA-15 (left) and NOAA-16 (right). Each panel shows vertical plots of the Mean and Standard Deviation of the Satellite minus Radiosonde differences for the satellite derived first guess (light) and sounding (**heavy**) temperatures, with atmospheric pressure and sample size indicated on the left and right vertical axes, respectively. The collocations for computing each set of curves are from the 60N to 60S regions, for combined clear and cloudy satellite soundings and all terrains, spanning a 7-day period in June, 2002. Although the curves for each satellite are similar, there are some differences, particularly near the surface and in the upper atmosphere – likely due to sampling differences as illustrated in Figure 4 – which ultimately reduces the reliability of comparing the accuracy of the products (and measurements) from each satellite using such statistics.

A series of actions by NESDIS over the past few years has caused changes to QC procedures for radiosonde data, particularly for moisture, and adjustments of the time and distance windows used to compile the MDB for each satellite.

The series of QC changes for the radiosonde reports covered a range of problem areas identified by NESDIS internal evaluations, including the

- interpolation and extrapolation of moisture profiles through data gaps,
- handling of missing moisture for temperatures below -40C,
- handling of "spikes" in observed dewpoint depression profiles,
- processing of reports with over 50 significant levels, and
- the need for better diagnostics.

The radiosonde moisture upgrades were significant, since over 30% of the radiosonde reports from the upper latitudes were being screened due to incomplete moisture profiles, even though the accompanying temperature data was complete into the stratosphere. Further study indicated that in many cases there was enough moisture information to provide a reasonable interpolation and/or extrapolation of the radiosonde moisture profile to 200mb, as required for the NESDIS ATOVS soundings [6]. However, it was also noted that the resident technique for extrapolating moisture profiles to 200mb, which used a "constant Dewpoint Depression" approach, was unreasonable, particularly in polar regions where the tropopause is below 200mb. A new extrapolation technique was developed based on a "constant dew point temperature lapse rate", derived from the uppermost levels of the moisture report.

Programs to routinely monitor, and as necessary to adjust the time and distance windows used to compile the collocations for each satellite are ongoing at NESDIS in an effort to maintain robust and consistent MDB sampling distributions per satellite over time, a challenge given the mutually exclusive sampling tendencies as illustrated in the upper and lower panels of Figure 4.

[6] For example, groups of radiosondes stop reporting moisture if the atmospheric temperature falls below -40C.

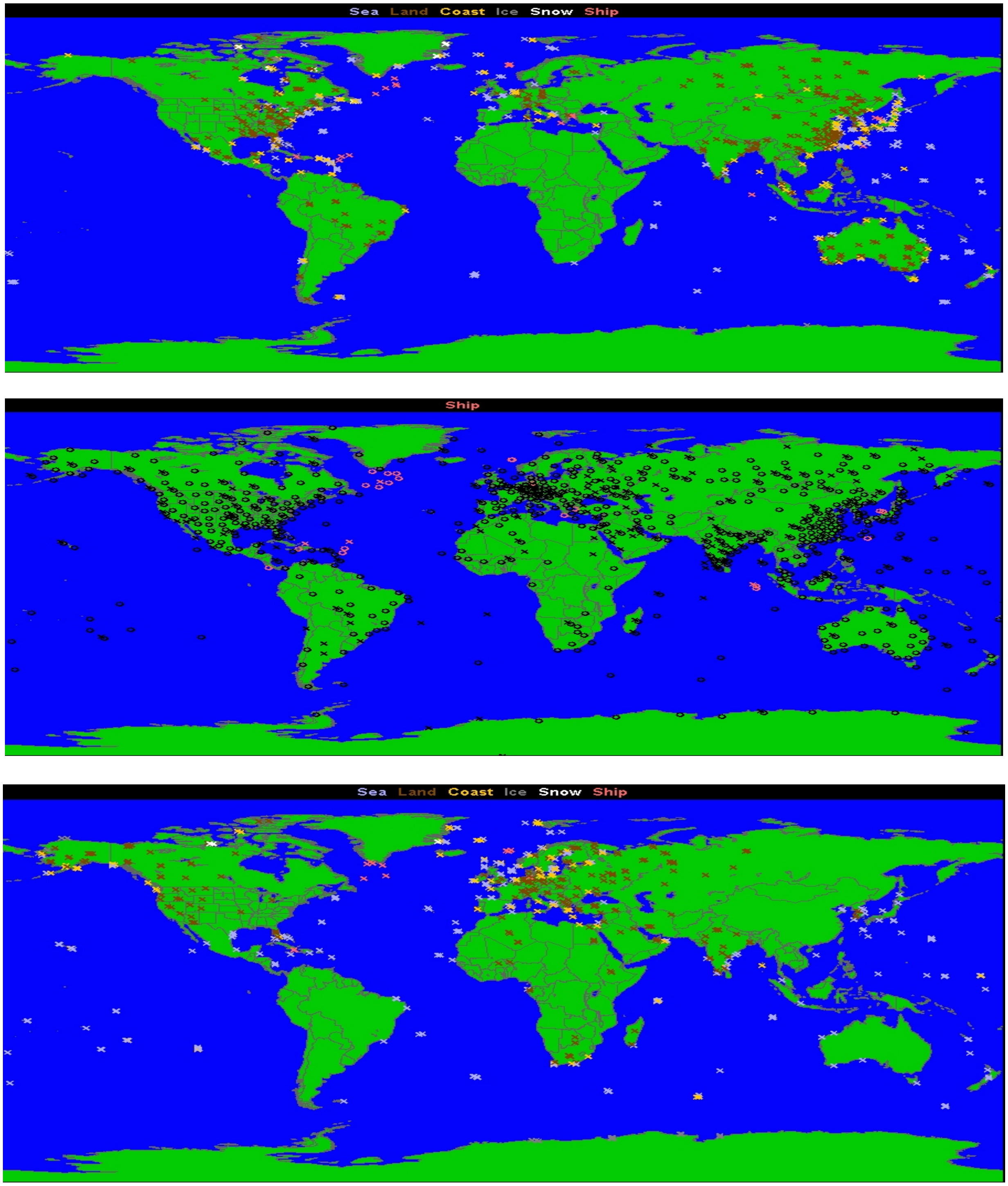

Figure 4: **Daily distributions of MDB collocations for NOAA-15 (upper) and NOAA-16 (lower), and available Radiosondes (middle) as observed on July 28 and 29, 2002, with collocations color coded based on the sounding type (Blue, sea; Brown, land; Yellow, coast; Grey, ice; and White, snow), with Ship data in red.**

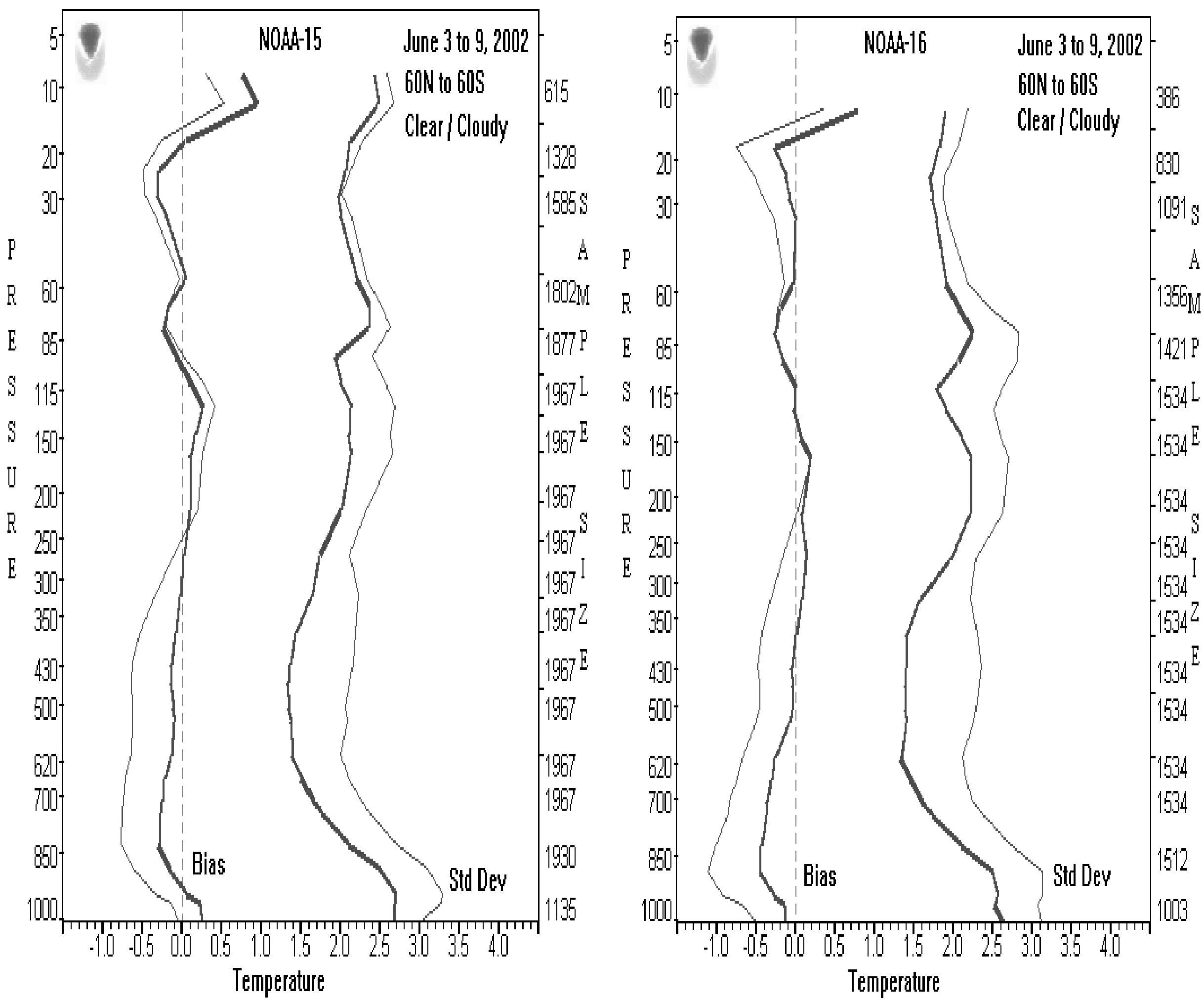

Figure 5: **Vertical accuracy statistics displaying the Mean Bias and Standard Deviation of ATOVS minus Radiosonde Temperature (K) profiles for NOAA-15 (left) and NOAA-16 (right) first guess (**light**) and final Soundings (dark), for combined Clear and Cloudy soundings from the 60N to 60S latitude band for the period June 3-9, 2002; the pressure level is shown on the left axis and the sample size for each level satellite on the right axis of each plot.**

CAT	LAT	TERR	NOAA-15 Samp	NOAA-15 Clear (km)	NOAA-15 Clear (hr)	NOAA-15 Clear Δt (day)	NOAA-15 Cloudy (km)	NOAA-15 Cloudy (hr)	NOAA-15 Cloudy Δt (day)	NOAA-16 Samp	NOAA-16 Clear (km)	NOAA-16 Clear (hr)	NOAA-16 Clear Δt (day)	NOAA-16 Cloudy (km)	NOAA-16 Cloudy (hr)	NOAA-16 Cloudy Δt (day)
	Ascend/Descend															
1	N	Ice/Coast	350	125	3	104	70	3	56	425	90	3	88	70	3	50
2	Ice-45N	Sea	700	90	4	67	80	4	80	600	80	4	30	80	4	42
3	45-30N	Sea	650	70	5	59	90	5	52	625	70	5	51	90	5	45
4	30-15N	Sea	650	70	5	78	90	5	67	525	80	5	53	100	5	46
5	15N-15S	All	650	60	3	55	60	3	34	550	90	3	55	70	3	49
6	15-30S	Sea	300	90	5	59	110	5	76	400	90	5	48	100	5	66
7	30-45S	Sea	300	100	5	97	100	5	80	300	100	5	62	100	5	75
8	45S-Ice	All	200	90	3	72	90	3	48	250	110	3	97	100	3	76
9	S	Ice/Coast	200	100	3	104	90	3	65	250	100	3	104	80	3	55
	Ascending															
10	90-60N	NonSea	225	125	3	100	60	2	55	400	100	3	41	50	2	31
11	60-45N	NonSea	500	80	2	48	50	2	42	500	60	2	27	40	2	44
12	45-30N	NonSea	550	50	2	34	40	2	34	450	80	2	36	70	2	54
13	30-15N	NonSea	400	60	3	55	70	3	23	400	80	3	48	100	3	63
14	15-30S	NonSea	150	70	3	23	100	3	34	150	100	3	81	110	3	104
15	30-45S	NonSea	200	80	3	28	100	2	38	150	110	3	100	110	3	104
16	60-90S	NonSea	50	100	3	-	100	2	-	25	100	3	-	100	2	-
	Descending															
17	90-60N	NonSea	225	125	3	90	80	2	48	375	100	3	62	90	2	81
18	60-45N	NonSea	500	70	2	48	40	2	51	500	60	2	48	40	2	27
19	45-30N	NonSea	550	60	2	34	40	2	41	450	70	2	55	60	2	34
20	30-15N	NonSea	350	80	3	37	80	3	25	350	100	3	61	100	3	60
21	15-30S	NonSea	125	100	3	35	100	3	76	150	110	3	104	110	3	104
22	30-45S	NonSea	125	100	3	27	100	3	42	150	110	3	104	110	3	104
23	60-90S	NonSea	50	100	3	-	100	2	-	25	100	3	-	100	2	-

Table 2: **Sampling characteristics of the ATOVS Matchup Data Base (MDB) showing the geographical category (CAT), definitions (LAT and TERR), and the corresponding sample size allocations (SAMP), time (hr) and distance (km) windows, and the time periods (Δt) spanned by the collocation sample within each category. Data are segregated for each operational satellite (NOAA-15 and NOAA-16) and sounding type (Clear and Cloudy), and are a snapshot as observed on June 8, 2002.**

Table 2 (above) shows the collocation sampling constraints, consisting of the time (hr) and distance (km) windows, and the sample size allocations (SAMP) for compiling the radiosonde and satellite collocations within each of the 23 geographical (LAT and TERR) categories (CAT). Constraint criteria are separately defined for each satellite, latitude region, sea and non-sea terrains, and for clear and cloudy satellite soundings, respectively.

The time periods (Δt) spanned by the collocation sample (or age of the oldest collocation retained) in each category are also monitored and shown[7]. As can be seen, the sample sizes retained for a given category vary significantly in proportion to the density of available radiosonde observation, despite the significantly smaller distance windows in the more radiosonde dense regions. However, the corresponding time period differences across the 23 categories is somewhat more balanced.

[7] The maximum age retained is 104 days; categories indicating this age have sample sizes less than SAMP.

The observed sampling differences among corresponding categories for each satellite largely depends on the radiosonde launch (ie, typically synoptic) versus the local satellite overpass times (as shown in Figure 5), as well as diurnal and regional differences in cloudiness.

4.2 Recommendations

Internationally coordinated efforts are needed to both recognize and promote the very basic requirement that reliable global radiosonde observations are needed to support and validate operational polar satellite measurement and product programs. It is time to acknowledge that the optimal use of radiosondes is shifting (has shifted) from an initial requirement to provide "synoptic" observations primarily in support of NWP, to a evolving (more modern) requirement to provide observations collocated with the satellite which are now providing a major component of the data for NWP and climate applications. Such actions must be taken carefully, and in full consideration of ongoing, long-term climate records and requirements for regional and local weather forecasts.

Several actions are also needed to improve the consistency of radiosonde reporting and transmission practices across the global community. Although these issues have been addressed in the past, more work is needed to unify reporting practices around the world.

NOAA can also pave the way toward realizing the significant benefits of a coordinated effort to provide ground truth data for satellite observations over the vast ocean regions of the earth. The NOAA flagship scientific vessel, RONALD H BROWN (RHB), which typically operates for over 250 days a year, provides both a radiosonde launch and a polar satellite data reception capability, along with other in-situ measurements capabilities (ie, for clouds, SST, etc). The RHB represents a cost-effective and potentially valuable resource for remote ocean sensing, which could provide valuable real-time weather and climate research data, and greatly enhance our understanding of ocean-atmosphere interactions as portrayed by remote satellite observations.

5. CURRENT PRODUCTS LIST

Table 3 lists the ATOVS operational and experimental products, with the **ATOVS Product** types in column 1, beginning with the radiometer/sounder measurements for each **AMSU-A, HIRS/3, AVHRR/3** and **AMSU-B**[8] channel, followed by the derived **Temperature** and **Moisture** soundings, **Outgoing Longwave Radiation (OLR)** and **Layer Cooling Rates (LCR)**, experimental **Cloud** products and **Total Ozone**. The **Units** of measurement, product **Levels (or Layers)**, the nominal (at nadir) **Horizontal Resolution** and additional **Comments** are tabulated for each Product.

Although the sounder measurements are not strictly a derived product, the **Calibrated** measurements, the series of radiometric **Adjustments**, and the **First Guess** measurement profiles computed in the NESDIS scientific algorithm have become a focal point of user interest over the past few years, along with the First Guess profiles from which the soundings are derived.

AVHRR channel measurements are available on selected operational files, comprised of the 17 Global Area Coverage (Goodrum et.al. 2000) pixels corresponding to the HIRS/3 FOV.

Many users receive and utilize secondary derived products, that is, products derived from the temperature and moisture soundings. The secondary products routinely distributed by NESDIS include the **Geopotential** height, Layer Mean **Virtual** temperature and the Total and Layer Precipitable Water (**TPW** and **LPW**). Secondary sounding products are typically computed for the standard, mandatory pressure levels.

---

[8] AMSU-B measurements and derived sounding products are currently not available as part of the ATOVS product suites, but are available separately from NESDIS, with pending work underway to integrate these measurements into ATOVS.

ATOVS PRODUCT	UNIT	LEVELS (LAYERS)	HORIZONTAL RESOLUTION	COMMENTS
AMSU-A	° K	15 CHANNELS	50km	Calibrated, Adjusted, and First Guess
HIRS/3	° K	20 CHANNELS	17km	Calibrated, Adjusted, and First Guess
AVHRR/3	° K	6 CHANNELS	1.2km	17 Pixels @ HIRS/3
AMSU-B	° K	5 CHANNELS	15km	(See footnote 10)
TEMPERATURE **Geopotential** **Virtual**	° K M ° K	40 @ 1000 - .1mb (18 @ 1000 -.1mb) (18 @ 1000 -.1mb)	35km	Includes First Guess Secondary Secondary
MOISTURE: **ATOVS** **AMSU-B** **TPW** **LPW**	G/KG mm mm	 17@ 1000 - 200mb 15@ 1000 - 300mb (Total) (1000 - 700mb) (700 - 500mb) (500 - 300mb)	 35km 15km	Includes First Guess (See footnote-1) Secondary Secondary
OLR: **ALL SKY** **CLEAR SKY**	WATTS/M2		17km, GRID	
CLEAR SKY LCR	° K /DAY	(1000 - 700mb) (700 - 500mb) (500 - 300mb) (300 - 100mb)	17km, GRID	
CLOUD TOP: **PRESSURE** **TEMPERATURE** **CLOUD AMOUNT**	 MB ° K %	Low; > 680mb, Med, 440-680mb, High, < 440mb	17km, 35km, and GRID	Experimental Opaque, > 90% Thick, 50 to 90% Thin, < 50%
OZONE	DOBSON	(TOTAL)	35km	

Table 3: **NESDIS Operational (and Experimental) Products**

Horizontal Resolution is a difficult parameter to define, particularly for the ATOVS sounders which are cross-track scanners with variable resolution from one side of the orbit to the other. In addition, the scientific processing techniques typically involve spatial interpolations of the sounder measurements (ie, for ATOVS all measurements are interpolated to the HIRS). The values listed for the horizontal resolution represent estimates of nominal values (at nadir), typically **17km** for the HIRS, **50km** for the AMSU-A, FOV (**15km** for AMSU-B), and **35km** for derived soundings.

Grid **(GRID)** data sets are also indicated for several of the Radiation and Cloud products, these are defined as **1 x 1 Degree** fields.

All **Cloud** products are currently **Experimental** and under evaluation for pending operational approval. GRID data sets are also segregated by cloud height (High, Med., Low).

6. FUTURE PLANS

A new series of scientific upgrades for NESDIS derived sounding products are planned for ATOVS over the next 2 years. The ultimate goal of these upgrades is to derive products with error characteristics that can be more easily defined by potential NWP users, while remaining independent of any particular NWP model.

The new upgrades planned by NESDIS include:

- use of AMSU-B measurements in ATOVS for the simultaneous computation of temperature and moisture soundings,
- replacement of the library search technique for computing the first guess with an AMSU based regression approach (Goldberg 1999),
- on-line use of radiative transfer (McMillin et al., 1995) to retrieve each sounding,
- radiance bias adjustment of sounder measurements used in retrieval,
- a convergence of “common” techniques resident in NESDIS atmospheric and microwave surface product programs (Grody et al., 2001), and
- improved diagnostic capabilities to compile and evaluate collocated Satellite, NWP and Radiosonde observations.

NESDIS will also be involved with the operational implementation of ATOVS products from NOAA-17 and the efforts to prepare for the METOP and NPOESS programs planned for 2005 and beyond.

7. SUMMARY

NESDIS provides routine sounding products from the ATOVS sounder data onboard NOAA operational polar satellites. Results demonstrating the information content of these NESDIS weather products in the context of real-time weather forecasting applications and global weather analysis are presented. The report also discusses the importance of ground truth radiosondes collocated with polar satellite observations in defining and maintaining both measurements and derived product accuracy, and problems with the current global radiosonde network to meet these requirements. The report concludes with future plans, consisting of the pending operational implementation of NOAA-M satellite (successfully launched on June 24, 2002), and a new series of ATOVS upgrades to utilize AMSU-B data and to upgrade the NESDIS retrieval approach.

8. REFERENCES

Allegrino, A., A.L. Reale, M.W. Chalfant and D.Q.Wark, 1999: Application of limb adjustment techniques for polar orbiting sounding data. Technical Proceedings of the 10th International TOVS Study Conference, Jan 26- Feb 2, Boulder, Colorado, USA., 1-10.

Brown, C.E., Caldwell, J., Sief, K. Carey, R., and Reale, A., 1992: EDGE: A pc based display system for visualizing NOAA environmental data. 8th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography and Hydrology. Preprint Volume, AMS, Atlanta Georgia.

Chalfant, M.W. and A.S. Allegrino, 2001: Advanced TOVS (ATOVS) Experimental Cloud Products Using HIRS/3 and AMSU-A Measurements. Technical Proceedings of the 11th International TOVS Study Conference, Sept 20-26, 2000, Budapest, Hungary.

Derber, J.C., and W.S.Wu, 1998: The use of TOVS cloud-cleared radiance in the NCEP SSI analysis system. Mon. Wea. Rev., 126, 2287-2299.

Ellingson, R.G., D. Yanuk, H. Lee and A. Gruber, 1994a: Validation of a Technique for Estimating Outgoing Longwave Radiation from HIRS Radiance Observations. J. Atmos.and Oceanic Technology, 11,357-365.

Ellingson,R.G., D. Yanuk, A. Gruber and A.J.Miller, 1994b: Development and Application of Remote Sensing of Longwave Cooling from the NOAA Polar Orbiting Satellites. J. Photogrammetric Eng. Rem. Sens., 60, 307-316.

Ferguson, M.P., and A.L. Reale, 2000: Cloud detection techniques in NESDIS Advanced-TOVS sounding products systems. 10th Conf. on Satellite Meteorology and Oceanography, 9-14 January, Long Beach, CA

Fleming, H.E., D.S. Crosby, and A.C. Neuendorffer, 1986: Correction of satellite temperature retrieval errors due to errors in atmospheric transmittances. Journal of Climate and Applied Meteorology, Vol 25, No. 6, 869-882.

Goldberg, M.D., 1999: Generation of retrieval products from AMSU-A: methodology and validation Technical Proceedings of the 10th International TOVS Study Conf., Jan 26- Feb 2, Boulder, Colorado.

Goodrum, G, K.B. Kidwell, and W. Winston, 2000: NOAA KLM users guide: September 2000 Revision. U.S. Department of Commerce, NOAA, NESDIS, NCDC, Climate Services Division, Satellite Services Branch, Suitland, MD.

Goldberg, M, J. Daniels and H. Fleming, 1988: A method for obtaining an improved initial approximation for the temperature/moisture retrieval problem. Preprints, 3rd Conference on satellite Meteorology and Oceanography, Anaheim, Ca, 16-19.

Grody, N., J. Zhao, R. Ferraro, F. Weng, and R. Boers, 2001: Determination of precipitable water and cloud liquid water over ocean from the NOAA 15 Advanced microwave sounding unit. J. Geophysical Res. ,106, 2943-2953.

McMillin, L.M., L. Crone and T.J. Kleespies, 1995:Atmospheric transmittances of an absorbing gas. 5. Improvements to the OPTRAN approach. Appl. Optt., 34, 8396-8399

McMillin, L.M., S.S. Zhou, and S.K. Yang, 1994: An improved cloud retrieval algorithm using HIRS2-MSU radiance measurements. J. Appl. Meteor., Vol. 33, pp 195-211.

Menzel, W. P., D.P. Wylie and R.A. Frey, 2001: Comparison of University of Wisconsin HIRS, MODIS and ISCCP D2 Cloud Studies. Technical Proceedings of the 11th International TOVS Study Conference, Sept 20-26,2000, Budapest, Hungary.

Neuendorffer, Arthur C., 1996: Ozone monitoring with TIROS-N operational vertical sounders. Journal of Geophysical Research, Vol. 101, No. D13, pp. 18,807-18,828.

Reale, A.L., 2001: NOAA operational sounding products from advanced-TOVS polar orbiting environmental satellites. NOAA Technical Report NESDIS 102, U.S. Dept. of Commerce, Washington D.C., 61 pp.

Reale, A.L. 1995: Departures between derived satellite soundings and numerical weather forecasts: present and future. Tech. proceeding of the 8th International TOVS Study Conf., Queenstown, New Zealand, 395-404.

Tilley, F.H., M.E. Pettey, M.P. Ferguson, and A.L. Reale, 2000: Use of radiosondes in NESDIS advanced-TOVS (ATOVS) soundingproducts. 10th Conference on Satellite Meteorology and Oceanography, 9-14 January, Long Beach, CA.

Yang,S.K.,S.S. Zhou,L. McMillin and K. Campana, 1996: Characteristics of the NOAA/NESDIS Cloud Retrieval Algorithm Using HIRS-MSU Radiance Measurements. J. Applied Meteorology.