IMPROVEMENT OF RETRIEVAL SKILL FOR THE ADVANCED MICROWAVE SOUNDING UNIT/MICROWAVE HUMIDITY SOUNDER AND THE ADVANCED TECHNOLOGY MICROWAVE SOUNDER BY FOOTPRINT MATCHING

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Abstract

This paper presents the results of a simple information content study between the AMSU/MHS and the ATMS. When a single field of view is considered for both instruments, the AMSU/MHS generally out-performs the ATMS for temperature and moisture information due to its better noise performance. However, when footprint matching is employed to use over-sampled ATMS observations, the ATMS consistently shows improvement in temperature and moisture information over the AMSU/MHS.

MOTIVATION

There is considerable concern in the numerical weather prediction (NWP) community that the Advanced Technology Microwave Sounder (ATMS) is merely being built to the noise specifications of the Advanced Microwave Sounding Unit (AMSU) and the Microwave Humidity Sounder (MHS). Since the AMSU/MHS have greatly exceeded the instrument noise specifications, the NWP community is worried that the ATMS in fact would be a step backwards. The International TOVS Study Conference-XIV Working Group on The Use of TOVS/ATOVS Data in Data Assimilation/Numerical Weather Prediction noted (ITSC, 2005) : "The WG is concerned that the instrument specification for ATMS channel noise exceeds current AMSU performance and that the choice of polarisations may not be optimal for sounding the lower troposphere. The WG were keen to do more scientific studies to provide good evidence for the impact of different choices in microwave sounder design on microwave sounder impact in NWP. When these studies are complete, the WG will be in a stronger position to formulate a recommendation to satellite agencies concerning future microwave sounding missions." The purpose of this paper is to document the initial results of one such study. The basic methodology of Kleespies and Watts (2006) will be used for this study.

DIFFERENCES BETWEEN THE ATMS AND THE AMSU/MHS

The AMSU is actually composed of two separate instruments, the AMSU-A1 and the AMSU-A2 which cover frequencies from 23.8 to 89 GHz. They are teamed with the MHS which has channel frequencies from 89 to 191 GHz. The ATMS is a single instrument that is intended to provide similar channel coverage to the combination of the AMSU and the MHS. It also has three new channels. Table 1 summarizes the channel frequency differences between the two instrument suites for NOAA 18 AMSU/MHS and the ATMS Proto-flight Model to be flown on the National Polar Operational Environmental Satellite System (NPOESS) Preparatory Mission. This paper will not discuss polarization differences.

RADIANCE AND JACOBIAN COMPARISONS

The radiative transfer model used in this study is the Joint Center for Satellite Data Assimilation Community Radiative Transfer Model v1.4.2.2 2005/10/20 (Weng et al., 2005). The atmospheric state was taken from a fifty-two profile subset of the European Centre for Medium Range Weather Forecasts (ECMWF) profile set (Chevallier, 2002). The surface emissivity was treated in two ways. In the first, two fixed values of 0.6 and 0.9 were used for all atmospheres. In the second, the surface emissivity was allowed to vary randomly. Basic statistics were computed from the ensemble of calculations with these emissivities. Only a cloud free, nadir view with no terrain variations was considered. Table 2 gives the mean difference and the standard deviation of the difference for this simulation. Note that only corresponding channels are presented. New channels are not shown. The greatest differences are in the AMSU/MHS vs. ATMS channel pairings 3-3, 4-5, 17-17 and 20-18. The large differences between the first two pairs is probably due to differences in the bandwidths. The large differences between the last two sets are due to the frequency change of channel 17 from 157 to 165.5 GHz, and the change of channel 20 from a single sideband on MHS to a double sideband on ATMS, as was the AMSU-B. The mean difference and standard deviation of the difference for the pairs 17-17 and 20-18 are comparable to those presented by Kleespies and Watts (2006) for similar channels.

The temperature and moisture Jacobians for selected channel pairs are shown in Fig. 1. The Jacobian is the matrix of partial derivatives of the brightness temperatures with respect to the elements of the state vector, here limited to temperature and moisture. Jacobians are different between the two channels where both red and green are evident. Jacobians are the same where only green is perceptible. It is apparent that for some channel pairs, one instrument channel senses different parts of the atmosphere than its nominal counterpart. This will have implications in the following section on information content.

INFORMATION CONTENT

A statistical estimation of the retrieval error covariance is defined by Rodgers (1976) as

$$\mathbf{S} = \left(\mathbf{B}^{-1} + \mathbf{K}(\mathbf{x})^{\mathrm{T}} (\mathbf{O} + \mathbf{F})^{-1} \mathbf{K}(\mathbf{x})\right)^{-1} \qquad (1)$$

where **B** is the ECMWF background error covariance, which was estimated from an ensemble of data assimilation experiments where the members differed because of random perturbations to the observations. **O** is the observational error covariance, determined from the on-orbit NEDT from AMSU/MHS, and from thermal vacuum testing for the ATMS. Figure 2 gives these values for the various instruments. Note that the ATMS matches the noise characteristics of the AMSU/MHS for only a few channels. **F** is the forward modeling error, which is set to a diagonal matrix with 0.2K on the main diagonal, as per Fourrié and Thépaut (2003). **K(x)** is the Jacobian. Equation (1) is derived by taking the Hessian of a cost function, where the Hessian is a matrix of second order derivatives.

Figure 3 illustrates the percentage of the error covariance reduction of the AMSU/MHS (red) over the ATMS built to specification, for a hot and wet, a cold and dry, and a moderate atmosphere. These atmospheres have pressure weighted temperatures of 285.6 K, 216.1 K, and 263.6 K, and precipitable water amounts of 10.54, 0.007 and 3.45 cm respectively. The percentage of the error covariance reduction is expressed as $100*(S_{amsu}-S_{atms})/B$, where S_{amsu} and S_{atms} are the diagonal elements of the error covariance from (1) for the AMSU/MHS and ATMS respectively, and B is the background error covariance from above. If the percentage improvement is negative, ATMS performs worse than AMSU/MHS, and vice versa if it is positive. The top panels are for temperature and the bottom panels are for moisture. It seems that if the ATMS were to only meet its specification, it would indeed be a step backward from the AMSU/MHS. Figure 4 is the same as Fig. 3, but for the ATMS proto-flight model (PFM). Here, green shows cases where the ATMS-PFM performs better than the AMSU/MHS. In this case the ATMS-PFM does improve over the AMSU/MHS for some parts of the atmosphere. Given the poorer noise performance of the ATMS, this improvement is due to the additional three channels.

Thus far this study has examined the case of using only a single field of view. However, the ATMS is spatially over sampled, especially at the lower frequencies. These overlapping fields of view can be composited to reduce the noise, improving the performance of the ATMS. Consider a simple field of view mapping procedure where the higher resolution fields of view that lie predominantly within the lowest resolution field of view are combined. If any systematic noise is removed by de-biasing procedures, then the random noise would be reduced by the reciprocal square root of the number of independent samples. Figure 5 illustrates how this compositing would work for the AMSU/MHS and the ATMS. We do not consider the effects of scene inhomogeneities.

Figure 6 illustrates the percent improvement of the ATMS over the AMSU/MHS for composite fields of view near the edge of scan and near nadir as shown in Figure 5. Since the ATMS has a wider scan swath, the outermost scan angle of the AMSU and its equivalent on the ATMS were used. In this case the ATMS shows substantial improvement over the AMSU/MHS for both the temperature and the moisture error covariance and all three atmospheric conditions.

CONCLUSIONS

It will be necessary to perform some kind of footprint matching or compositing in order for the ATMS to consistently perform better retrievals than the currently flying AMSU/MHS. Numerical weather prediction centers are cautioned to be careful about thinning of the over-sampled data and to consider combining fields of view when using the ATMS data.

ACKNOWLEDGMENTS

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http://www.orbit.nesdis.noaa.gov/smcd/spb/CRTM/index.html

Frequency (GHz)	BandWidth (MHz)	Channel	Frequency (GHz)	BandWidth (MHz)
23.8	251	1	23.8	258
31.399	161	2	31.4	172
50.299	160	3	50.3	173
		4	*51.76*	381
52.8	380	5	52.8	366
53.596 ±0.115	2x167	6	53.596±0.115	2x162
54.4	380	7	54.4	387
54.94	380	8	54.94	387
55.5	309	9	55.5	317
f_0=57.290344	310	10	f_0=57.290344	151
f_0±0.217	2x76	11	f_0 ± 0.217	2x76
f_0±0.3222±0.048	4x35	12	f_0 ±0.3222±0.048	4x35
f_0±0.3222±0.022	4x15	13	f_0 ±0.3222±0.022	4x15
f_0±0.3222±0.010	4x8	14	f_0 ±0.3222±0.010	4x8
f_0±0.3222±0.045	4x3	15	f_0 ±0.3222±0.0045	4x3
89	1994	16	*88.2*	1928
89	2190	16	*88.2*	1928
157	2192	17	*165.5±7.55*	2x1125
190.31	1932	18	183.310± 7.0	2x1930
		19	*183.310± 4.5*	2x1951
183.310± 3.0	2x909	20	183.310± 3.0	2x980
		21	*183.310± 1.8*	2x982
183.310± 1.0	2x460	22	183.310± 1.0	2x494

***Table1*: Comparison of the AMSU/MHS (left) with the ATMS (right). Significant channel differences are indicated with italics. NxW indicates number of passbands and bandwidth of each. AMSU channels 1-15 ARE 3.3º BEAMWIDTH, MHS channels 16-20 are 1.1º. ATMS channels 1&2 are 5.2º, channels 3-16 are 2.2º, and 17-22 are 1.1º.**

AMSU Channel	ATMS Channel	Mean Difference (K)	Standard Deviation of the Difference (K)
1	1	-0.0157	0.1306
2	2	-0.0531	0.1041
3	3	0.3069	1.0698
4	5	0.2172	0.7327
5	6	0.0112	0.0155
6	7	-0.0233	0.0225
7	8	-0.0287	0.0340
8	9	-0.0175	0.0278
9	10	0.0049	0.0249
10	11	-0.0019	0.0041
11	12	-0.0003	0.0070
12	13	0.0295	0.0316
13	14	0.0255	0.0418
14	15	0.0056	0.0647
15	16	0.0204	0.2767
16	16	0.0005	0.3052
17	17	-1.2654	3.7747
20	18	0.2202	1.0355
19	20	-0.0270	0.0541
18	22	-0.0588	0.1002

***Table 2:* Differences between AMSU/MHS and ATMS brightness temperatures.**

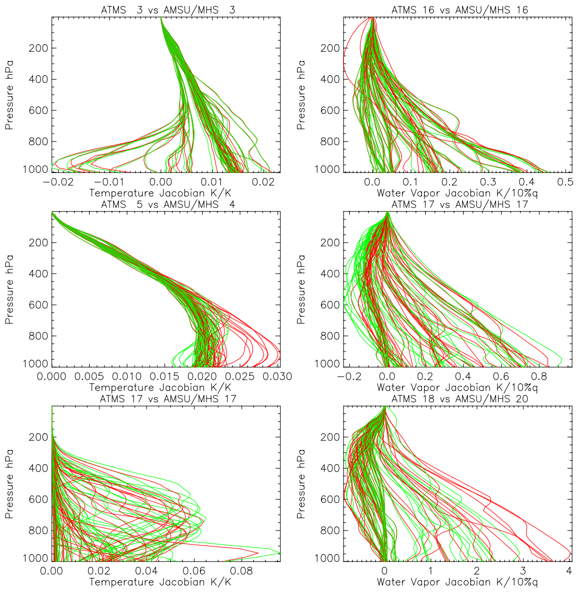

***Figure 1*. Selected channel pair Jacobians for the 52 ECMWF atmospheres. Temperature (left) Moisture (right). The AMSU/MHS is drawn first in red, and the ATMS is overdrawn in green. Jacobians are different where both red and green are evident. Jacobians are the same where only green is perceptible.**

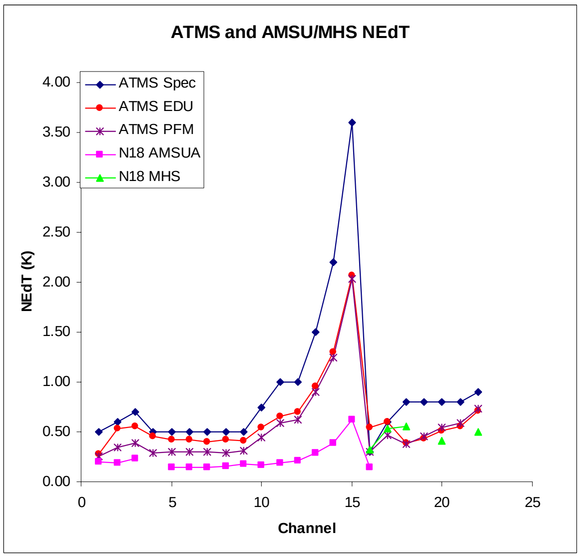

***Figure 2.* NEDT for the ATMS specification, the ATMS Engineering Design Unit, the ATMS Proto-Flight Model, and the AMSU/MHS flown on NOAA-18. The**

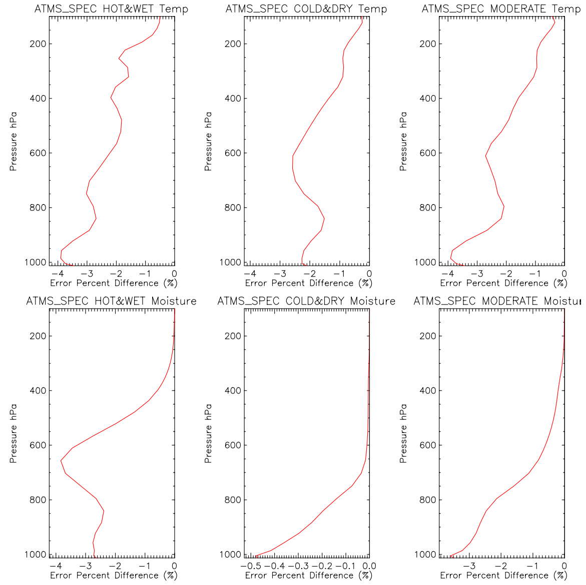

Figure 3. **Percent improvement of the ATMS built to specification over the AMSU/MHS for a single field of view. Negative values indicate AMSU/MHS better than ATMS, and positive values vice versa. The top panel is temperature improvement, the bottom panel is moisture improvement. Left to right is for a hot and wet, cold and dry, and moderate atmosphere, respectively.**

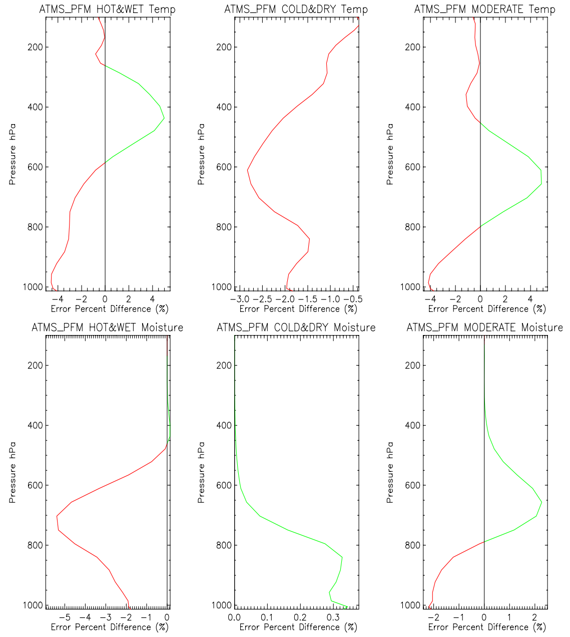

Figure 4. **Percent improvement of ATMS Proto-Flight Model over AMSU/MHS for a single field of view, where the smaller field(s) of view is nearest to the center of the largest field of view. Red (negative) is where the AMSU/MHS performs better than the ATMS, and green (positive) is where the ATMS performs better than the AMSU/MHS. Top is temperature improvement, bottom is moisture improvement. Left to right is for a hot and wet, cold and dry, and moderate atmosphere, respectively.**

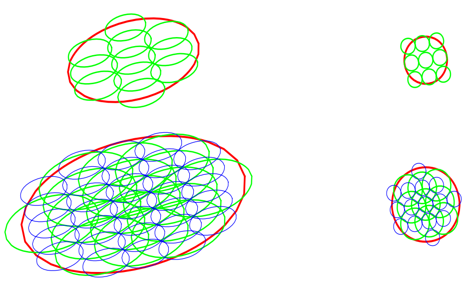

Figure 5. **Layout of composite fields of view for AMSU/MHS (top) and ATMS (bottom). AMSU is red and MHS is green. For ATMS, red is 5.2º , green is 2.2º and blue is 1.1º fields of view. Left pair is for near edge of scan, and right pair is near nadir.**

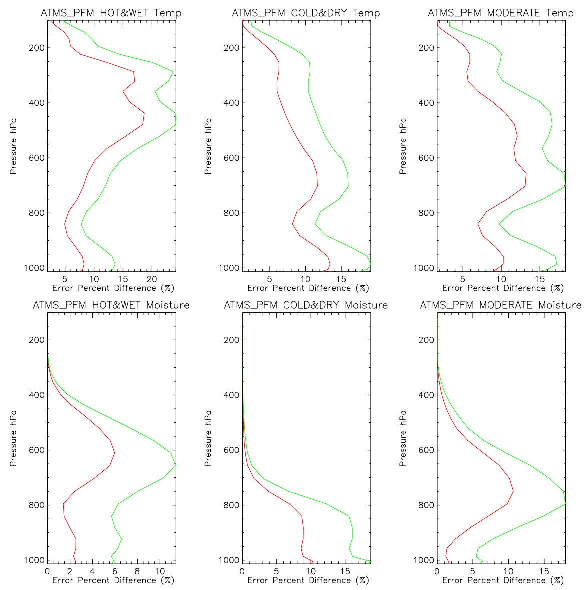

Figure 6. **Percent improvement of ATMS Proto-Flight Model over AMSU/MHS when all fields of view within the largest are used. Red is for near nadir, green is for near edge of scan. Top is temperature improvement, bottom is moisture improvement. Left**