NOAA Technical Report NESDIS 29

The Complementary Roles of Microwave and Infrared Instruments in Atmospheric Sounding

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U.S. DEPARTMENT OF COMMERCE
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Abstract

Radiance measurements in the infrared and microwave regions respond differently to changes in the atmosphere. These differences in response lead to differences in the ability to derive profiles of atmospheric parameters such as temperature and moisture. A summary of the characteristics of each region is presented, followed by an evaluation of the results of simulation studies and extrapolations from existing instruments, both of which were designed to assess the relative advantages of the two wavelength regions. The studies show that the combination of the information from the two spectral regions leads to more accurate retrievals than can be obtained from either spectral region alone at all levels of the atmosphere. For levels where the microwave retrievals were clearly more accurate than the infrared, the combination of information from the two regions increased the accuracy by a minimum of 0.1 K. For other levels, the increase in accuracy is larger. The infrared information is particularly helpful in increasing the accuracy of microwave soundings in the lower atmosphere below the 700 mb surface. In this region, the combination increased the accuracy by 0.5 to 1.0 K, depending on the region and the particular study. This represents a reduction in error of about 25% of the error produced by microwave measurements alone.

1. Introduction

Atmospheric temperatures can be determined from radiance measurements in both the infrared and microwave regions of the spectrum. Measurements in the two spectral regions differ in several important ways, and these differences lead to differences in ability to derive profiles of temperature and moisture as well as other atmospheric parameters. Because of these differences, the best results for a single atmospheric parameter are produced by measurements in the infrared for some pressure levels and in the microwave region for other pressure levels. Retrievals based on both measurements demonstrate consistent increases in accuracy over the best results produced from either single wavelength region. This is true even for the case of a single feature at a single level where measurements in one of the two wavelength regions produce clearly superior results over the other one. A summary of the characteristics of both regions is presented followed by an evaluation of the results of simulation studies and extrapolations from real data, both of which were designed to assess the relative advantages of the two wavelength regions.

2. Sounding Instruments

Historically, temperatures have been derived from satellite measurements that emphasize the infrared region with the microwave gaining an increasing role with the inclusion of the Microwave Sounder Unit (MSU) on the TIROS Operational Vertical Sounder (TOVS) and the inclusion of an Advanced Microwave Unit (AMSU) on the next generation sounder. The infrared component of the TOVS is the High-resolution Infrared Radiation Sounder (HIRS). This instrument has 20 channels with a horizontal resolution of about 20 km. The channels consist of seven 15 μm temperature sounding channels (channels 1-7), one 11 μm window channel (channel 8), one 9.7 μm ozone channel (channel 9), three 6.7 μm water vapor channels (channels 10-12), five 4.3 μm temperature sounding channels (channels 13-17), two 3.7 μm window channels, (channels 18 and 19), and one albedo channel (channel 20). Weighting functions for the temperature sounding channels are shown as parts "c" and "d" of Figs. 1, 2, and 3. More details on this instrument are given by Smith et al. (1979), and Schwalb et al. (1978). From the list of channels it can be seen that the instrument has duplicate temperature sounding and window channels at two wavelength regions, 3-4 μm and 10-15 μm. This duplication is provided to take advantage of the greater vertical resolution at 3.4 μm near the earth's surface that results from the greater nonlinearity of the relationship between temperature and radiance given by the Planck function. Measurements at 15 μm are needed because in daylight at 4.3 μm, the solar radiation is of the same order of magnitude as the earth's radiation and must be removed. The 10-15 μm region also provides better performance in colder regions of the atmosphere where it has a better signal-to-noise ratio and is useful in correcting for cloud effects.

The Advanced Microwave Sounding Unit (AMSU) is a 20 channel instrument. It has 12 temperature sounding channels in the 50.3 - 58 GHz oxygen absorption band with horizontal resolutions of $\approx$50 km, three window channels with 50 km resolution at 23.8, 31.4, and 89 GHz to sense a variety of parameters including tropospheric water vapor, precipitation, ice and snow cover, and ocean wind stress, and five channels with 15 km resolution (one at 89, one at 166 and three at 183 GHz) to sense water vapor profiles and precipitating areas. Temperature weighting functions for the AMSU temperature sounding channels are shown as part "b" in Figs. 1, 2, and 3. More information about the AMSU can be obtained from the report of the AMSU Workshop (1982).

3. Sounding in the Different Spectral Regions

The combination of the HIRS and AMSU instruments provides the capability to sense atmospheric temperature and the surface in three spectral regions. The best retrievals result from the use of all spectral information because the responses to atmospheric changes differ in the three regions. One of the advantages of a combination of measurements is that even when channels at different wavelengths sense the same levels of the atmosphere, weighting functions for the different wavelengths have somewhat different shapes, and thus the measurements contain somewhat different information. This advantage is added to the usual reduction in error that results from combining independent estimates of the same parameter. Relative advantages of the different regions are discussed in the next paragraphs. Although the discussion treats factors affecting retrieval accuracy individually, it is important to recognize that the factors are coupled. For example, vertical resolution, noise, and number of channels are interrelated in the retrieval process. For a discussion of the relationships, see McMillin and Fleming (1985).

Vertical resolution has a significant effect on sounding accuracy. In the infrared, several instrument designs with different vertical resolutions are possible. The HIRS is a filter instrument in which spectral resolution is limited by filter technology. Because of this limitation, it is necessary for the filter to cover several absorption lines. This has the effect of making the vertical weighting functions wider than can be achieved in the microwave where a channel senses essentially monochromatic radiation between lines, or than can be achieved with alternative infrared designs such as spectrometers and interferometers. For the infrared, however, in an atmosphere with a typical lapse rate, the temperature increase near the surface combines with the nonlinear relationship between radiance and temperature given by the Planck function to produce a narrowing of the weighting function. This narrowing more than compensates for the difference due to the difference in the spectral regions, resulting in a net narrowing of the weighting functions for the infrared as compared to the microwave. The narrowing of the weighting functions is illustrated by Figs. 1-3 which show weighting functions for temperature (as opposed to weighting functions for radiance). Figures 1-b, 1-c, and 1-d show the temperature weighting functions for the AMSU (NOAA-KLM) channels, the 4.3 μm channels, and the 15 μm channels, respectively, for the cold sounding shown in Fig. 1-a. Figures 2 and 3 show the same features for a moderate and a warm sounding. Notice that the microwave weighting functions shown in Figs. 1-3 b change very little with profile while a substantial profile dependence of the temperature weighting functions is evident for the infrared in parts "c" and "d". The advantage of the infrared channels is illustrated by the narrow width of the weighting functions near the ground in Figs. 3-c and 3-d relative to the wider ones for the microwave channels shown in Fig. 3-b. The net result of these effects is that for most atmospheric conditions,

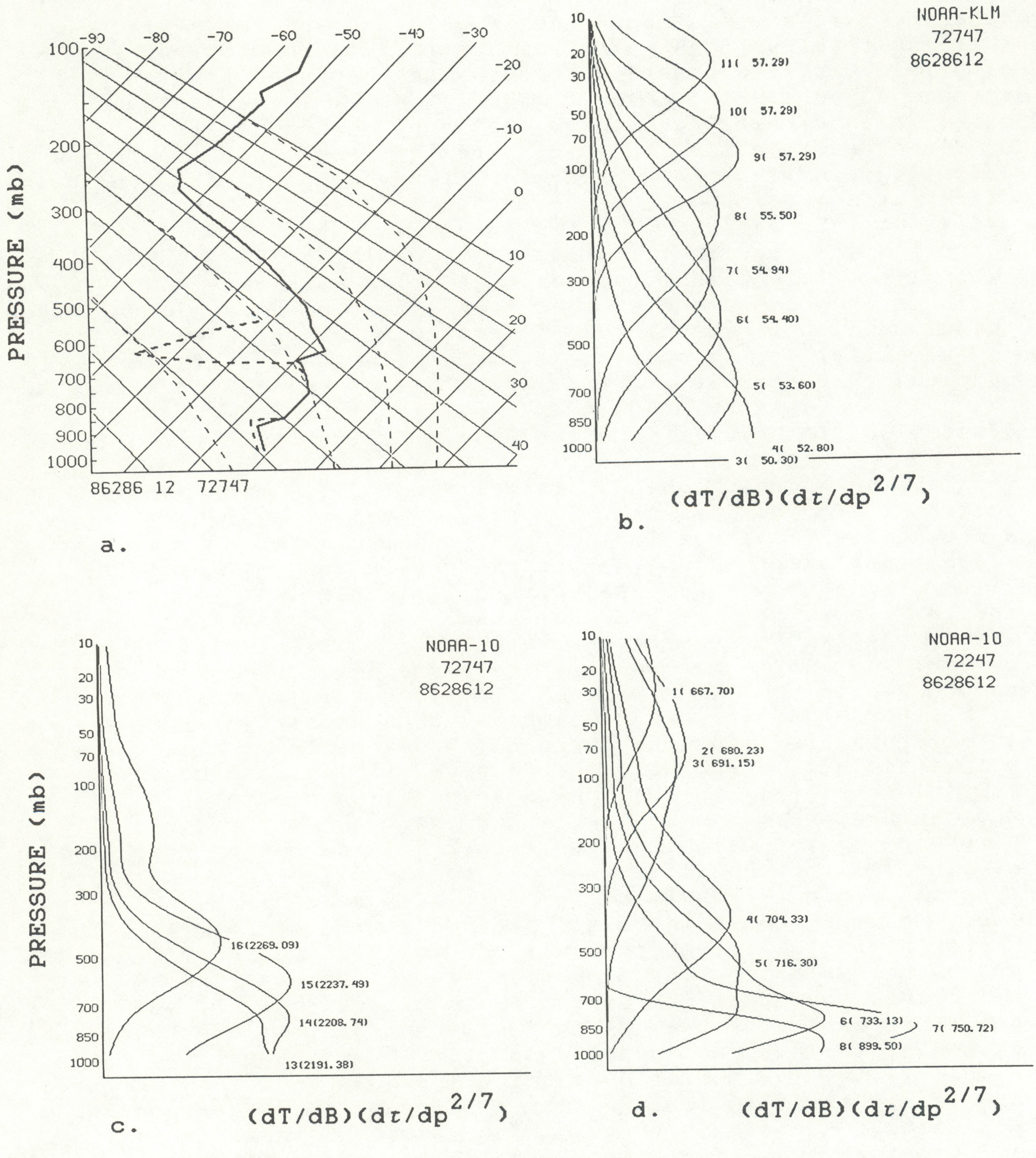

Figure 1. Weighting functions of brightness temperature for temperature sounding channels for a cold profile. Part "a" shows the profile and parts "b" - "d" show weighting functions for the microwave (b), 4.3 μm (c), and 15 μm (d), temperature sounding channels.

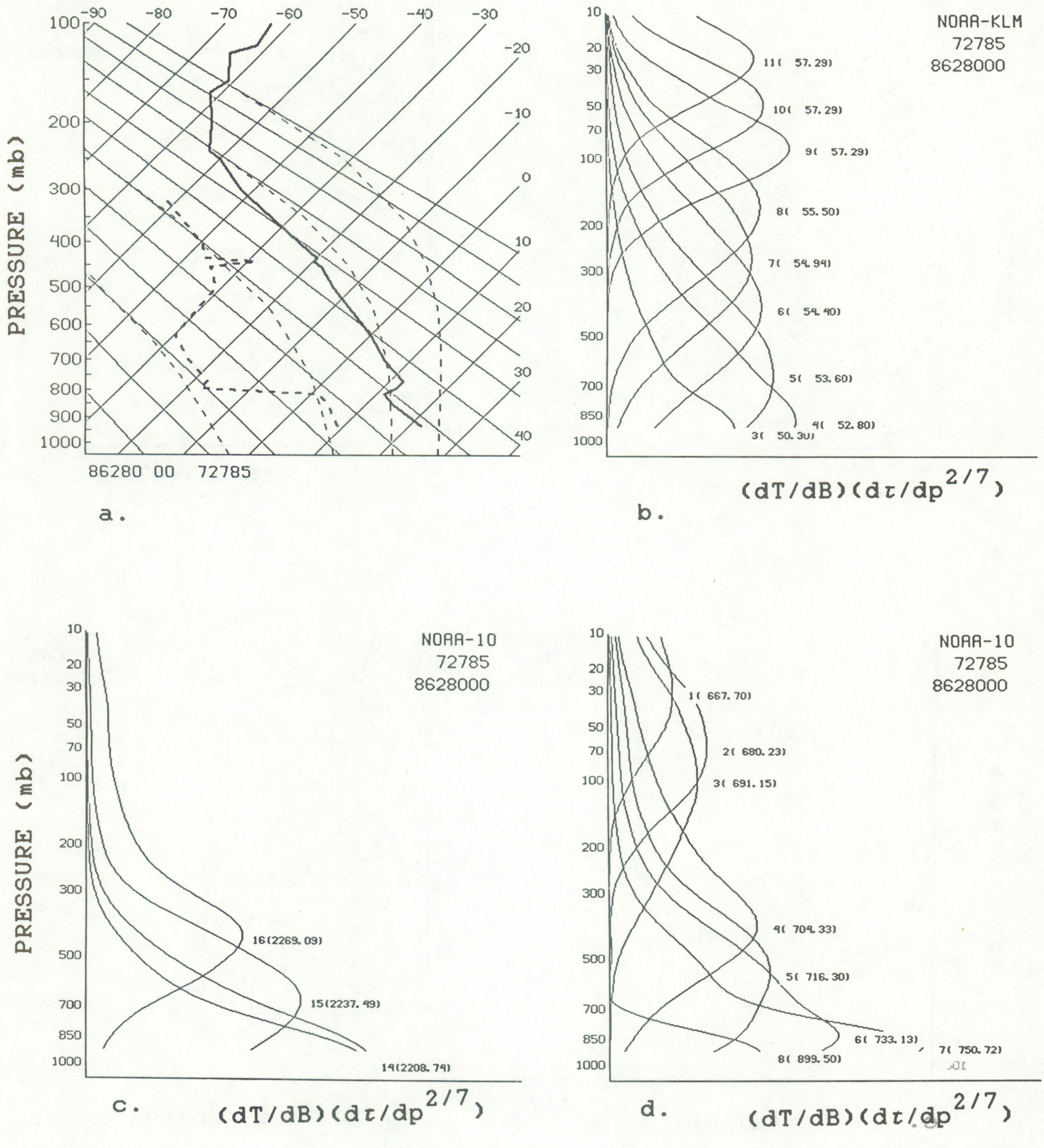

Figure 2. Weighting functions of brightness temperature for temperature sounding channels for a moderate profile. Part "a" shows the profile and parts "b" - "d" show weighting functions for the microwave (b), 4.3 μm (c), and 15 μm (d), temperature sounding channels.

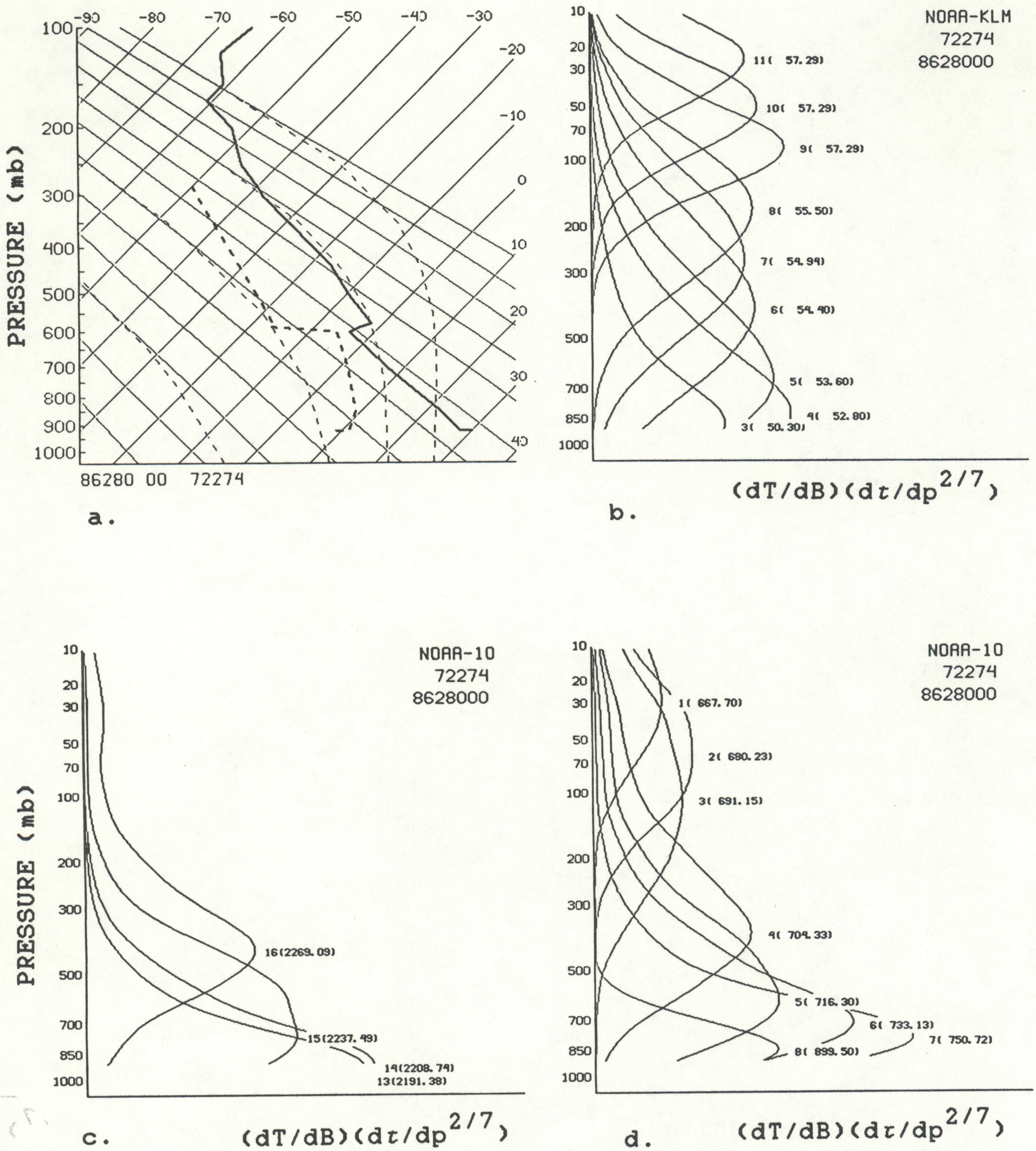

Figure 3. Weighting functions of brightness temperature for temperature sounding channels for a warm profile. Part "a" shows the profile and parts "b" - "c" show weighting functions for the microwave (b), 4.3 µm (c), and 15 µm (d), temperature sounding channels.

the microwave instrument has the best vertical resolution near the tropopause, the 4.3 μm channels provide the best results near the surface, and the 15 μm channels are used for correcting the 4.3 μm channels for solar radiation and for cloud clearing.

A closely related factor affecting accuracy is signal-to-noise level. This is affected by the same wavelength dependent nonlinearity between radiance and temperature that affects vertical resolution. In the 3-4 μm region, the nonlinearity causes the signal-to-noise ratio to be very good at warm scene temperatures and very poor at cold scene temperatures; while in the microwave region, the signal of the microwave instrument is linearly related to the scene temperature. In both regions, the noise is independent of scene temperature. To illustrate this effect, Noise Equivalent Temperatures (NEΔTs) for the temperature profile shown in Table 1 were generated using the noise equivalent radiances provided by Schwalb (1978) for the HIRS and by report of the AMSU workshop (1982) for the AMSU. The NEΔTs for the three wavelength regions are shown at the pressures corresponding to the peak of the weighting function in Table 2. It is obvious that the HIRS has a significant noise advantage between the ground and the 700 mb level. It should also be noted that HIRS instruments currently being delivered have NEΔTs significantly lower than the specified values.

Table 1. Temperature profile used for noise calculations.

Pressure (mb)	Temperature (K)	Pressure (mb)	Temperature (K)
0.1	228.5	115.0	198.7
0.2	241.7	135.0	202.8
0.5	255.6	150.0	206.2
1.0	256.8	200.0	219.2
1.5	255.1	250.0	230.8
2.0	253.4	300.0	240.7
3.0	256.4	350.0	249.4
4.0	251.2	400.0	256.6
5.0	247.0	430.0	260.1
7.0	242.7	475.0	265.0
10.0	230.8	500.0	267.6
15.0	225.7	570.0	273.6
20.0	222.3	620.0	277.7
25.0	220.2	670.0	281.4
30.0	218.3	700.0	283.5
50.0	211.3	780.0	287.9
60.0	208.0	850.0	291.4
70.0	204.0	920.0	294.4
85.0	199.8	950.0	295.9
100.0	198.2	1000.0	298.2

Table 2. Signal to noise ratios at different wavelength regions.

Pressure	Noise Equivalent Temperature		
	15 µm	4.3 µm	50 GHz
(mb)	(K)	(K)	(K)
10			.50
20			.35
30	.78		
60	.30		.35
90			.25
100	.30		
200			.25
300			.25
400	.21		
500			.25
600	.18		
700		.10	.25
800	.17		
900	.15	.05	
1000	.07	.03	.25

It has been suggested that the disadvantages of relying only on microwave measurements can be partly offset by using the sea surface temperature as additional information when deriving atmospheric temperatures over ocean areas. This suggestion is justified over large expanses of the ocean where the surface air temperature is tightly coupled to the sea surface temperature. The method must, however, be used with caution near land areas and near strong gradients in sea surface temperatures where the difference in the two quantities can be large and retrievals based on the sea surface temperature can produce large errors. If a single measurement of sea surface temperature is to add the same information to AMSU measurements as the HIRS, the one sea surface temperature must contain the same supplemental information as the multiple HIRS channels and must provide a sea surface temperature of the same accuracy as that which could be obtained from the simultaneous HIRS measurements. Although the first condition is difficult to evaluate, the second one can be evaluated by comparing the accuracy of the surface temperature to the accuracy of the surface temperature estimate that could be determined from a simultaneous infrared measurement. Typical errors of sea surface temperature run about 0.6 - 0.7 K for values at the time of the satellite passage. Maps of sea surface temperature proposed as the input are generated from data going back 15 days so some additional error is introduced by the time lag. In addition, sea surface temperatures are subject to a diurnal variation that is typically ±0.5 K in low latitudes, but can reach ±3.0 k. When these factors are considered, an error of ±1.0 K is a reasonable estimate of error for a value from the sea surface temperature field. If sea surface temperature is used to retrieve atmospheric temperatures, then the accuracy should be compared to accuracies that could have been obtained from simultaneous infrared measurements with the NEΔTs shown in Table 2. It should also be noted that while in daylight, the difference between channels 18 and 19 is primarily determined by the reflected solar radiation, at night it is possible to take advantage of the low noise level at 3.7 μm and use channels 18 and 19 as a split window to derive a sea surface temperature considerably more accurate than ±1.0 K. Although this capability is not being utilized in the current TOVS processing at NESDIS and thus is not reflected in current comparisons with radiosondes, 3.7 μm data are being utilized by NASA to derive sea surface temperatures in all lighting conditions (see Susskind et al. 1984 and Susskind and Reuter 1985) and this capability is included in plans for processing the HIRS-AMSU data.

A discussion of noise should include other uncertainties such as cloud contamination and uncertainties in surface emissivity which also have effects on retrievals. These effects also differ from instrument noise in a significant way in that instrument noise is random and makes one channel inconsistent with its adjacent channels, while clouds and surface emissivity have the same effect on all channels sensing the same region of the atmosphere. Different retrieval systems differ in their responses to these two types of noise and each retrieval system should be evaluated for its response to both, but there is a general tendency for correlated noise to produce a smaller error spread over a thicker atmospheric layer.

Surface emissivity characteristics differ in the infrared and microwave regions. In the infrared, surface emissivity is near 1.0, although it is somewhat smaller in the 3-4 μm region than in the 10-12 μm region, and restrahlen effects are present in channels near 9 μm over bare soils. These variations are minor compared to variations in the microwave region where the surface emissivity changes from ≈0.5 over water surfaces to ≈0.9 over dry soils. Although methods estimating the emissivity are available, retrievals based on microwave measurements contain an additional element of uncertainty due to the uncertainty in the correction for emissivity. This additional uncertainty produces an additional degradation in the accuracy of microwave retrievals near the ground relative to those obtainable from the infrared.

The response to clouds also differs greatly between the infrared and microwave regions. While infrared radiation does not penetrate clouds to a significant extent, the wavelength of microwave radiation is large compared to cloud drop sizes. As a result, microwave radiation passes through clouds of small and moderate water vapor content with minimal effects, although clouds with high water vapor content and precipitating clouds produce errors large enough to affect the resulting retrievals. Although the infrared can be used to produce retrievals over partly cloudy areas using cloud clearing approaches (McMillin and Dean, 1982, and Susskind et al., 1984), it is limited to clear and partly cloudy areas while the microwave can be used to extend retrievals into most, but not all, overcast areas.

Horizontal resolution also differs for the two instruments. In the case of the microwave instrument the resolution is diffraction limited, which means that the scan spot is not well defined in the sense that 50 km is the size of the area that contributes half the signal for a given field-of-view, but the spot must be expanded to 125 km to cover the area contributing 95 percent of the energy reaching the detector. This size is large compared to the 20 km resolution of the HIRS and resolutions of some forecast models. Figure 4 shows antennae pattern of a typical microwave instrument. It gives the percent of the total microwave energy within a cone as a function of angle. In the case of an infrared instrument, the wavelength is small compared to the dimensions of the optics and horizontal resolution is primarily limited by considerations of the amount of energy necessary at the detector to overcome noise; while in the microwave region, the wavelength is large compared to the dimensions of the optics and this ratio becomes a limiting factor for the horizontal resolution. In regions of high cloud moisture content, such as the tropics, the effects of thick broken clouds on the microwave channels can become significant while the narrow field-of-view in the infrared allows observations to be made in the clear areas between the clouds.

The two instruments differ in their ability to retrieve other parameters as well as their ability to retrieve profiles of water vapor and temperature. Many features that cause problems when solving for temperature are advantages for other applications. The variations in surface emissivity in the microwave region, which add error to atmospheric retrievals near the ground, allow a determination of the surface type to be made. Thus areas of snow and ice, and features such as ice age can be determined. The clouds, which block the infrared radiation below the clouds, are important meteorological parameters in themselves whose importance is beginning to be recognized. A number of papers have appeared discussing ways to retrieve cloud amount and cloud top height (McCleese and Wilson, 1976, Smith and Platt, 1978, Wielicki and Coakley, 1981, and Susskind et al., 1986) from infrared data. Many researchers are currently looking at HIRS data as a replacement to Earth Radiation Budget Experiment (ERBE) data to be used to verify radiation models that are being incorporated into numerical models. An estimate of the total outgoing radiative flux can be made from the infrared measurements which are sensitive to clouds, but not from the microwave measurements. Cloud information is useful in determining which microwave spots are contaminated by clouds or rain, and the cloud height and amount are parameters that are needed for the determination of ozone from the Solar Backscattered Ultra Violet (SBUV) measurements. The ozone channel can to used to determine total ozone both as a check and a backup to the SBUV, and as a means of extending measurements into polar regions in 24 hour darkness where the SBUV does not produce values for several months at a time.

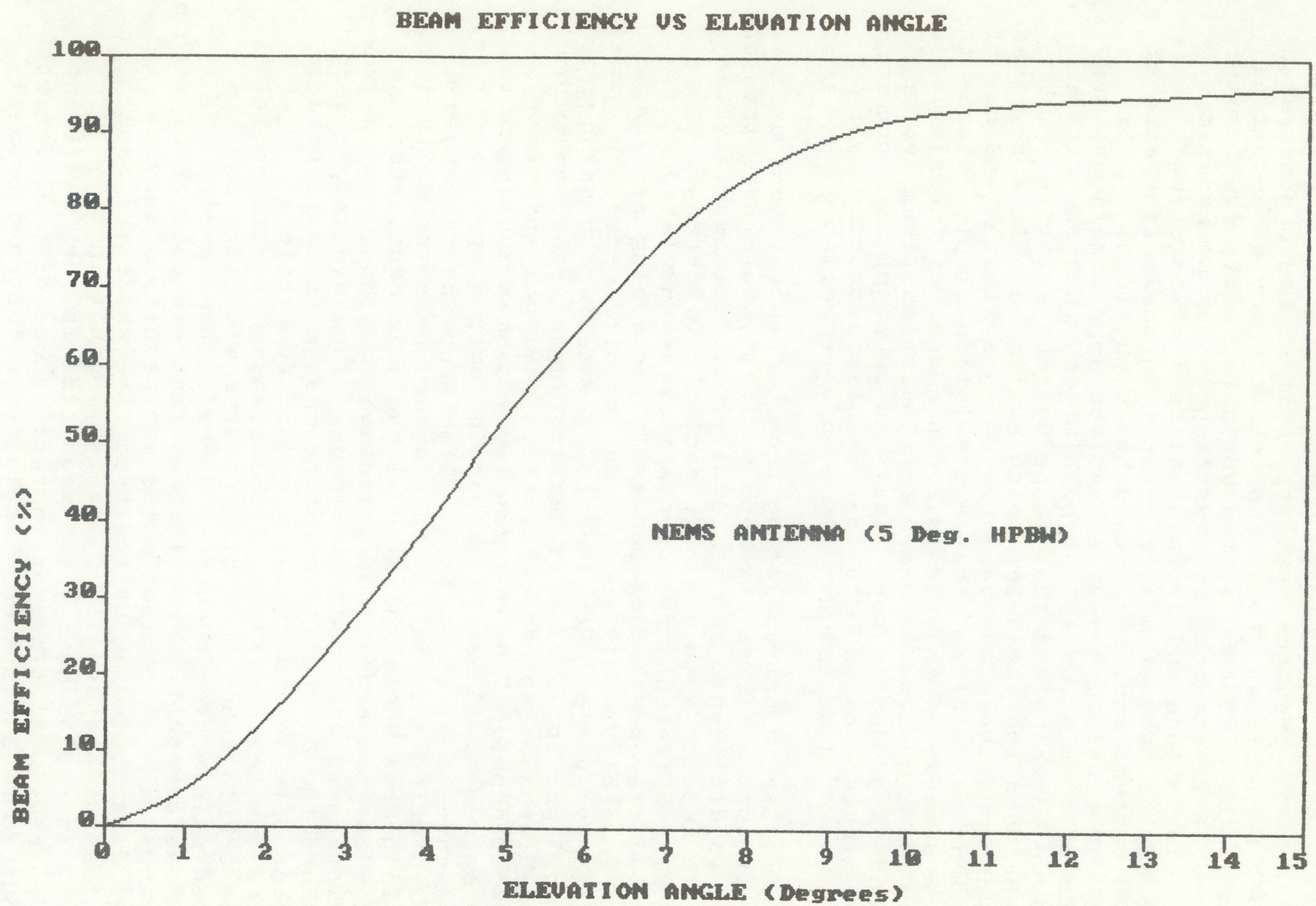

Figure 4. Beam efficiency of a typical microwave instrument. Notice that considerable energy comes from areas far removed from the half power point. The angle that includes 95% of the energy is about 2.5 times the angle that includes 50% of the energy.

4. The Roles of Simulations and Real Data in Assessing Future Capabilities

Experience with previous satellite systems has demonstrated that the most reliable way to assess the accuracy of a combined system such as the HIRS-AMSU system would be to fly it, but this is not desirable if the combined system provides no benefit. This leaves simulations and extrapolations from existing instruments as the two methods of estimating the performance of the combined system, and each method has significant limitations. A simulation always involves approximations, and the weakness of simulation is the possibility that one of the approximations is wrong and that it produces a relative difference between the variables being evaluated. In some cases the relationship between the variable being evaluated and one of the assumptions is so direct that a simulation simply returns the assumption. Because of the possible dependence of the simulation to assumptions, a conclusion based on simulations from two or more independent groups is more likely to be right than one based on a single simulation, and one that is also supported by comparisons based on actual data is even more reliable.

The difficulty in extrapolating from present systems arises from the fact that different systems typically have more than one factor that is different, and it is difficult to associate the difference in results with a single factor. Differences associated with different instruments include unrelated instrumental differences, differences in processing systems, and differences in orbits. Differences due to differences in orbits are particularly subtle. For example, a satellite passing over an area near 3 pm. local time is sensing any given spot at the peak of the diurnal temperature cycle in daylight and close to the minimum at night. Thus one retrieval system must predict both daily extremes. A satellite passing over a spot near 9 am. local time senses a given spot at a time when the temperatures for the am. passing and the pm. passing are near the daily average. In places where the diurnal cycle is pronounced, an orbit near 9 am. has a distinct advantage for those regions where the diurnal temperature change is large. The advantage extends to areas where the diurnal temperature change is small because channels sensitive to the change are used to retrieve temperatures for nearby levels of the atmosphere. In addition, radiosondes are launched according to Greenwich time and are concentrated mainly over populated areas in the developed countries. As a result, a requirement that radiosondes be within some tolerance of a given local time may result in many radiosondes distributed about the mean time while the same requirement about another local time may result in only a few radiosondes, in radiosondes whose mean time is very different from the desired local time, or in radiosondes of a different design produced by a different manufacturer launched by a different country and processed in a different manner. Since polar weather satellites are sun synchronous, some orbits produce better synchronization with the radiosonde launch times than others, and, as a result, better agreement with radiosondes at levels (especially near the surface and the ozone maximum) where diurnal temperature changes are significant. In the past, radiosonde collocation programs have been used to evaluate different processing systems on the same radiosondes so parameters such as the mean time difference between the radiosonde and the satellite and the standard deviation of the radiosonde temperature have not been required, are not available, and are not widely recognized as being important; but they are necessary to adequately assess differences between instruments on different satellites.

It is clear from the discussion of instrumental differences that measurements in the different wavelength regions have unique advantages for different situations, and a combination of measurements from all regions provides benefits that can not be achieved with measurements from any individual region by itself. This gives a qualitative, but not a quantitative, assessment of the advantages of a combined system.

5. Simulation Studies

Both NESDIS and NASA have done simulations which illustrate the relative advantages of the HIRS and AMSU instruments for temperature sounding. At NESDIS, a simulation was done that compared the accuracies using three sounding instruments:

A. HIRS channels 1-7 and 13-16, (13 temperature channels),
B. AMSU channels 3-14, (12 temperature channels), and
C. AMSU+HIRS, (23 channels).

Noise values typical of the instruments were simulated. For the HIRS instrument, the noise levels specified by the design specifications given by Schwalb (1978) were used with the assumption that the noise of channel 1 could be reduced to 0.27 mW/(m2 sr cm-1) by averaging over area since this channel does not "see" clouds. For the AMSU, the specified noise of 0.3 K was assumed.

Statistics of temperature accuracies were generated for three latitude belts (0-25N, 25-55N, and 55-90N) for two months (January and August). Initially, separate statistics were generated for land and ocean cases because the microwave channels have an emissivity of 0.9 over land and 0.5 over water and because surface temperature uncertainty was assumed to be ±1.2 K over land and ±0.9 K over water based on the assumption that the surface temperature could be obtained from the window channels. Over both land and water, the emissivity was assumed to have an uncertainty about its mean value of ±0.02.

Because there was some uncertainty about the accuracy of the assumption of a 0.02 rms. error in surface emissivity, a second test was run in which it was assumed that the 50.3 GHz channel could be used to obtain the product of the surface emissivity times the surface temperature and that this approach would yield an uncertainty in the product of ±1.5 K leading to an uncertainty in surface emissivity ±0.005 rms. Because the 50.3 GHz channel was used for the surface emissivity, it was not used for the air temperature retrieval and the number of channels in instruments B and C were both reduced by one to 11 and 22, respectively. The assumptions used in the first experiment may be considered to be pessimistic while the the ones used in the second experiment may be optimistic. In any case, it is likely that the uncertainty over oceans is less than the uncertainty over land and the values provided by an uncertainty of 0.02 rms. in surface emissivity over land and 0.005 rms. over water represent the extreme values. These extremes are shown in Figs. 5 through 8 with Figs. 5 and 6 showing the results for an uncertainty of 0.02 over land and Figs. 7 and 8 showing the results for an uncertainty of 0.005 over water.

Results from this simulation show that the AMSU+HIRS combination is more accurate than the AMSU alone combination at all levels with the greatest improvement coming near the surface where the 4.3 μm channels have the advantages of better signal to noise ratio and narrower weighting functions, while the difference is least in the upper levels where the AMSU was expected to do best. As expected, the improvement in accuracy that results from adding the HIRS to the AMSU is greater in Figs. 5 and 6 than in Figs. 7 and 8. However, improvements in retrieval accuracy in the lower atmosphere are significant in all figures. The increase in accuracy ranges from 0.1 to 0.2 K at the upper levels and up to 1.2 K at the lower levels. While the improvement in accuracy at the upper levels is small, the improvement is consistent over the whole atmosphere and reaches 25% of the expected AMSU error at the surface.

A similar comparison was done by NASA at Goddard Space Flight Center. Simulations were done for a set of 200 ocean mid-latitude winter soundings and another set of 200 land mid-latitude winter soundings. It should be noted that the NASA results compare HIRS with AMSU rather than HIRS+AMSU with AMSU. The results of this simulation are shown in Figs. 9 and 10.

Results from the NASA study are similar to those of NESDIS. Increases in accuracy of the HIRS over the AMSU of 0.5 - 0.8 K were obtained at the surface. If these are increased to allow for the HIRS+AMSU combination, accuracies comparable to the NESDIS results are obtained.

6. Extrapolations from Measurements from Current Instruments

Several attempts have been made to assess the expected performance of a HIRS plus AMSU system based on extrapolations from current systems. In these extrapolations, the measurements provide direct information about parameters that were estimated in the simulations, but the extrapolations involve assumptions

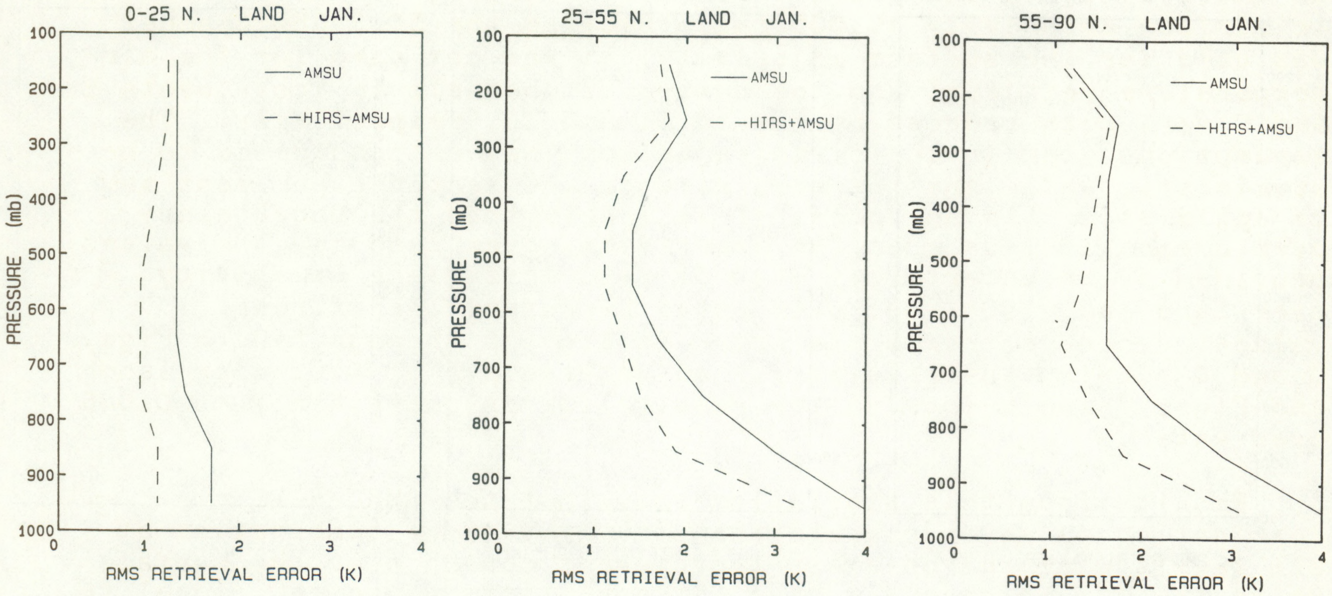

Figure 5. Comparisons of retrieval errors for AMSU only retrievals vs. AMSU + HIRS retrievals over land for three latitude zones for Jan. for a 0.02 rms. uncertainty in surface emissivity for the microwave channels.

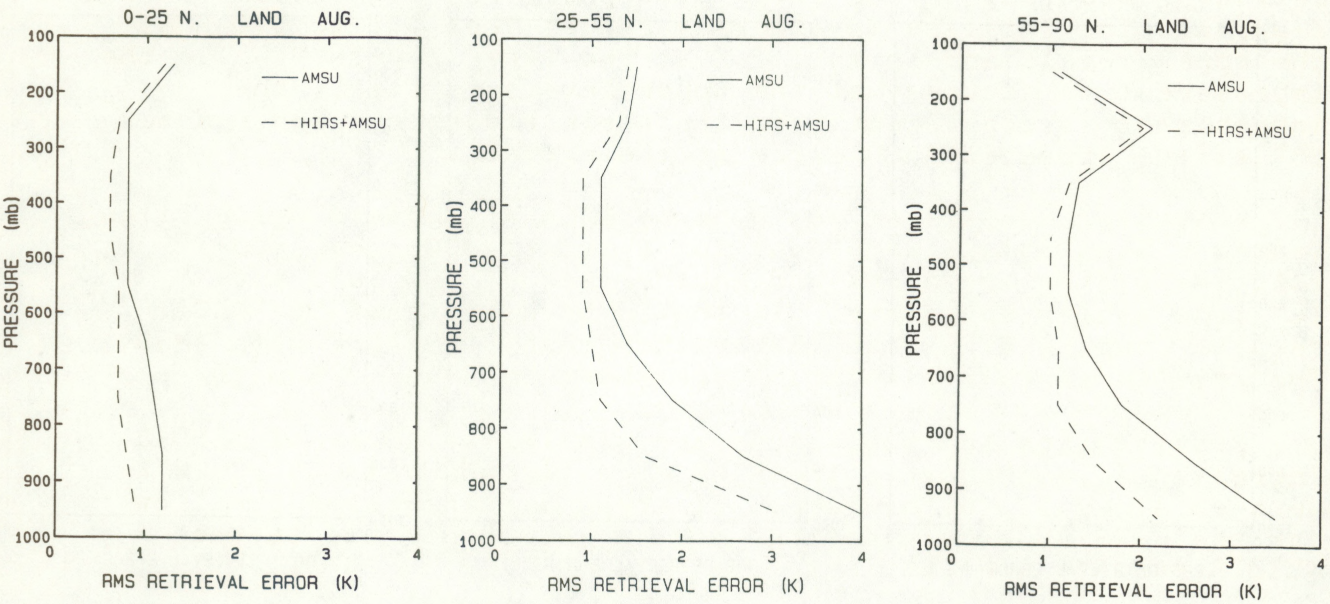

Figure 6. Comparisons of retrieval errors for AMSU only retrievals vs. AMSU + HIRS retrievals over land for three latitude zones for Aug. for a 0.02 rms. uncertainty in surface emissivity for the microwave channels.

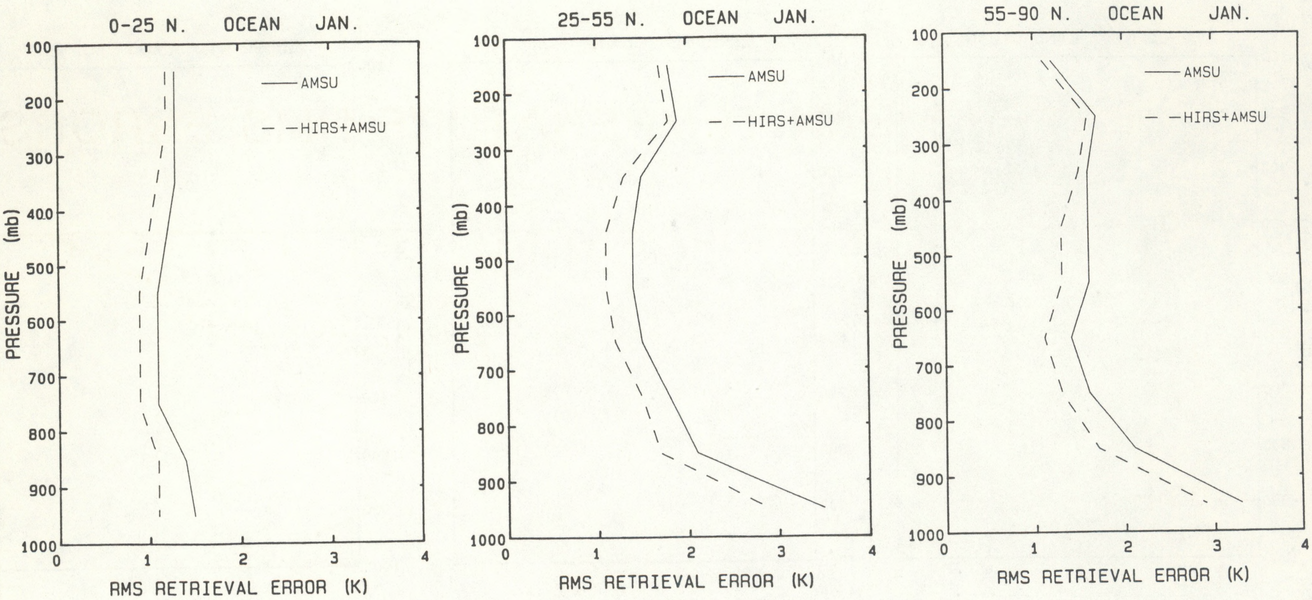

Figure 7. Comparisons of retrieval errors for AMSU only retrievals vs. AMSU + HIRS retrievals over oceans for three latitude zones for Jan. for a 0.005 rms. uncertainty in surface emissivity for the microwave channels.

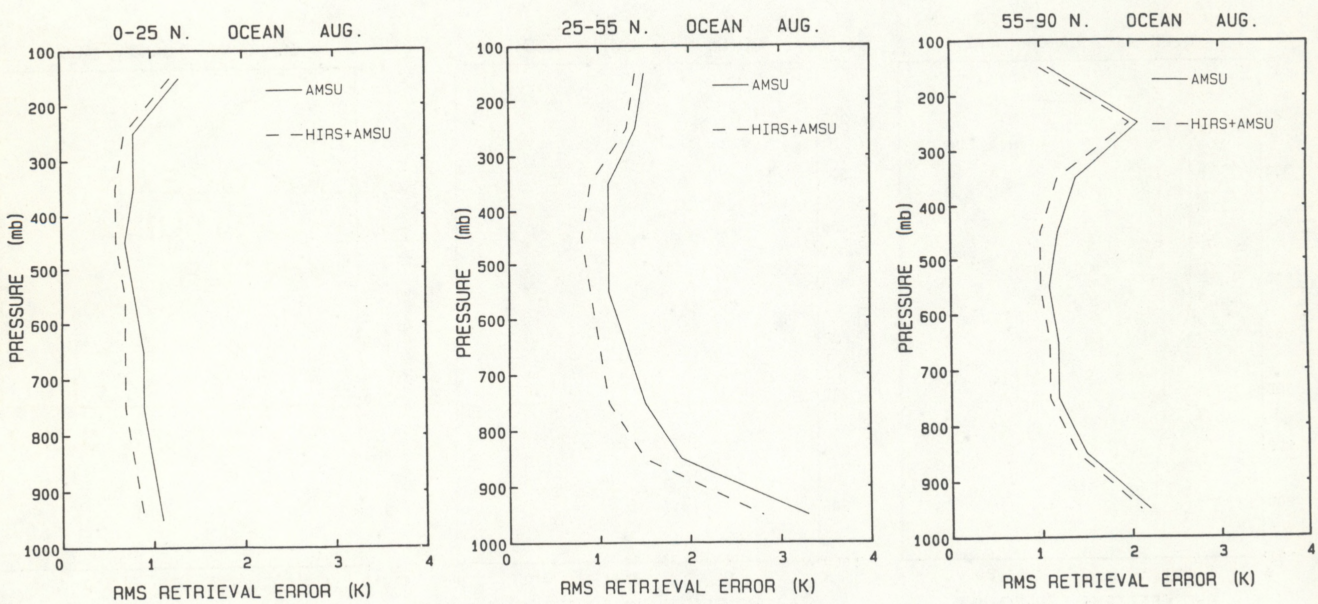

Figure 8. Comparisons of retrieval errors for AMSU only retrievals vs. AMSU + HIRS retrievals over oceans for three latitude zones for Aug. for a 0.005 rms. uncertainty in surface emissivity for the microwave channels.

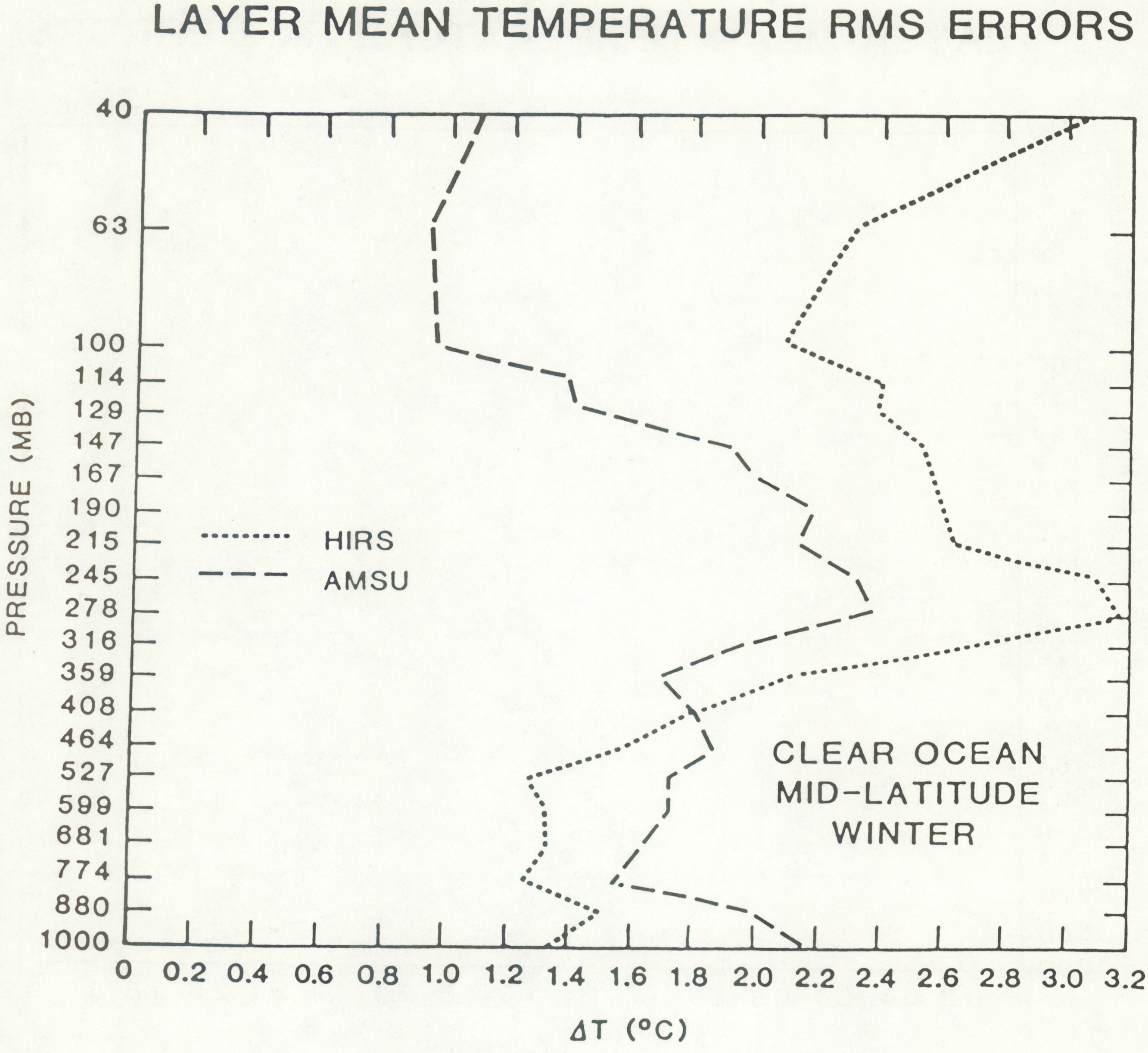

Figure 9. Comparisons of retrieval errors for AMSU only vs. HIRS only retrievals for 200 midlatitude soundings over oceans. These retrievals were done at Goddard Space Flight Center and thus are independent of figs. 4-7. They show the same improvement in retrieval accuracy for the HIRS over the AMSU in the lower atmosphere as was obtained at NESDIS.

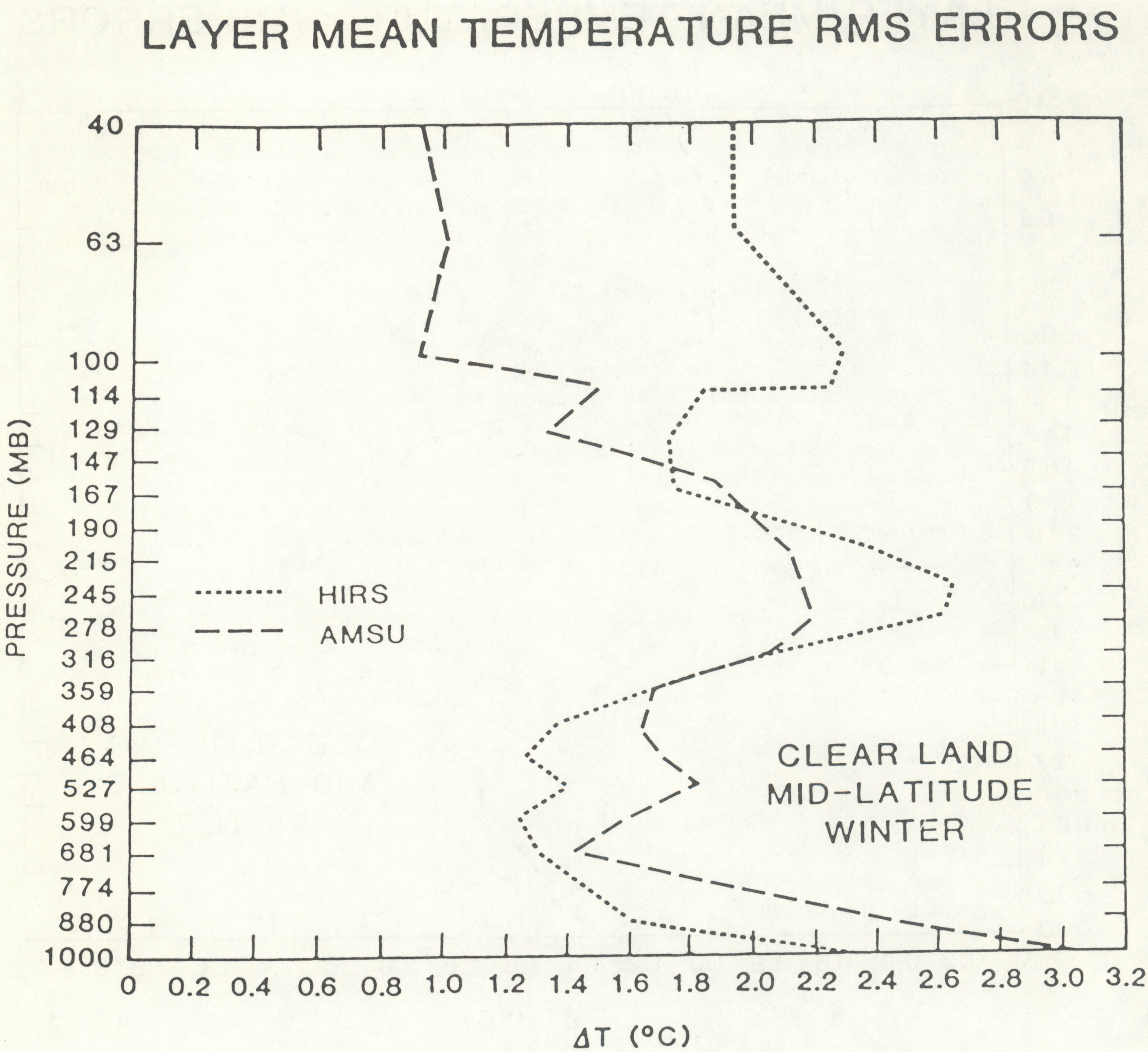

Figure 10. Comparisons of retrieval errors for AMSU only vs. HIRS only retrievals for 200 midlatitude soundings over land. These retrievals were done at Goddard Space Flight Center and thus are independent of figs. 4-7. They show the same improvement in retrieval accuracy for the HIRS over the AMSU in the lower atmosphere as was obtained at NESDIS.

about the effects of differences in other than the two instruments. These differences are easy to eliminate in the simulations. It would be very easy to ignore one or more of these effects and reach a conclusion different from those indicated by the simulations, while consideration of these effects would produce consistency between simulated and extrapolated results.

N. Phillips (see Appendix) was concerned that conclusions based on evaluations of the AMSU retrieval capability that did not include the ocean surface temperature as additional information could be misleading. There is a problem in including this factor in a simulation, because this a case where the accuracy of the retrieval of the lower atmospheric temperature is so tightly coupled to the assumed accuracy of the sea surface temperature that the simulation essentially returns the assumed value. To assess the effect of the use of the surface temperature, he used his collocation program to make the assessment given in his memorandum which is included in this report as an appendix. His assessment took advantage of the fact that NOAA 6 has an inoperative HIRS instrument and produces MSU + SSU soundings over the entire globe. He runs a special retrieval package to produce MSU retrievals over ocean areas using retrieval coefficients derived from a data set designed to optimize retrieval accuracy over oceans. By comparing the accuracy of these retrievals with those of the global TOVS system, he attempted to assess the effect of using the sea surface temperature to aid microwave-only retrievals. The assessment was hampered by the fact that the comparison included differences in retrieval types, processing systems, and orbits. He was concerned that the operational retrievals produced by NESDIS from HIRS and AMSU included only clear and partly cloudy retrievals, and not the presumably more difficult cloudy retrievals. To adjust for this difference, he used the difference between the accuracy of his retrievals from NOAA 6, which contained retrievals from areas that NESDIS considered to be clear, partly cloudy, and cloudy, with his retrievals from NOAA 9, which contained only overcast retrievals. In making this adjustment, he implicitly assumed that other differences between his NOAA 6 and NOAA 9 retrievals had no effect on accuracy. Other differences which could have had an effect include the differences in orbit and the fact that collocations used to generate coefficients accumulated at different rates resulting in a different coefficient "age" for the two satellites. Because of the many assumptions involved in this extrapolation, the results were subject to interpretation. Both the interpretation that the data supports the conclusion that HIRS provides a substantial increase in accuracy over an AMSU plus sea surface temperature, and the interpretation that the results support the conclusion that HIRS would provide little additional benefit, were made from the data with different, but reasonable assumptions about magnitudes of the differences caused by these extraneous factors. As a result, it was felt that a comparison with fewer assumptions was needed.

A second assessment was done with the TOVS system to determine how the addition of sea surface temperature data to microwave data would affect the benefit of adding HIRS to the system. In this study, NOAA 9 retrievals were produced with the normal complement of HIRS channels 1-15 (channel 16 is defective on NOAA 9), and MSU channels 2-4. A second set of retrievals was produced from MSU channels 2-4 plus the Sea Surface Temperature (SST). Retrievals were produced from data from the same satellite using the same collocations for evaluation, the same processing system, and the same data sets to produce retrieval coefficients. These steps eliminated the need for the many assumptions necessary in the previous extrapolation, since everything except the channels used was kept constant. The study was conducted over ocean areas between 30-60°N latitude. Results from the 47 clear and 20 partly cloudy cases included in this study are shown in Table 3. It is clear that even when the MSU has the benefit of a sea surface temperature to help retrievals near the surface, the HIRS + MSU produces a substantial improvement in accuracy. The one limitation of this assessment is that the MSU, with only three sounding channels, is far inferior to the 20 channel HIRS or the 20 channel AMSU.

Table 3. Satellite errors relative to radiosondes error for MSU + sea surface temperature vs. TOVS.

Level (mb)	MSU + SST (K)	HIRS + MSU (K)
700	2.08	2.08
780	2.31	2.26
850	2.74	2.55
920	3.15	2.73
950	3.52	2.92
1000	4.64	3.35

A closer representation of the AMSU is given by the Special Sensor Microwave for Temperature (SSMT) of the Defense Meteorological Satellite Program (DMSP). The SSMT is a 7 channel microwave instrument with 6 temperature sounding channels and 1 window channel. However, this advantage is accompanied by several disadvantages not present in the previous case due to differences in the retrieval systems, the fact that the outer scan angle of the SSMT is considerably less than the outer angle used by TOVS, and the fact that the satellites are in different orbits. Since the SSMT is in an orbit that places it over a location at 10 local time while the TOVS is in an orbit that places it over an area at 3 local time, the cautions discussed earlier about comparing retrievals from instruments on different satellites apply. The difference in their relationships with the radiosonde network is indicated by the large difference in sample size with the SSMT generating 6681 collocations over water compared to 3171 for the TOVS in the same period. It is currently undergoing evaluation for operational use, so comparisons against radiosondes are available. To be consistent with the other comparisons, results for areas between 30 - 60 N are shown in Fig. 11. This figure illustrates the advantage of the infrared retrievals near the surface where the TOVS retrievals are more accurate by about 0.5 K out of a total error of 3.0 K. Although there are differences in the pattern for other latitude zones, the pattern of roughly equivalent performance in the upper atmosphere and advantage of the infrared at the lower levels is consistent.

7. Conclusions

Several simulations and extrapolations from real data have been made in an attempt to evaluate the advantages of flying a HIRS instrument with AMSU. Although these assessments have been made in several different ways, they are complementary and all support the conclusion that infrared soundings have an advantage over microwave soundings in the lower levels (below 700 mb) of the atmosphere. The addition of an infrared instrument to the AMSU will produce increases in retrieval accuracy at these levels in the range of 0.5 to 1.0 K depending on the region and the particular study. When measurements from both instruments are used to produce a sounding, the resultant retrieval is always more accurate than that produced by either instrument alone. As a result, even in the regions where the infrared soundings are less accurate than those from the AMSU, the combination results in a retrieval that is more accurate than that produced by the AMSU alone by 0.1 to 0.2 K. In addition, the combination allows the derivation of additional meteorological parameters such as clouds and longwave radiation, which would not be available from AMSU alone. The conclusion that HIRS provides a substantial benefit when added to an AMSU was reached independently by the National Research Council (1986) and is supported by work being done in other countries as evidenced by the reports of the International TOVS Study Conferences (Menzel 1984,1985,1987) and a letter from Houghton (1986) containing a memorandum from Morgan and Eyre in which they state "Simulation studies performed at Oxford have shown the marked superiority of AMSU+HIRS over AMSU-only in temperature retrievals of the lower atmosphere."

Although most of the studies have concentrated on atmospheric temperature, the factors that affect the temperature will have similar effects on moisture retrieval accuracy. Since moisture is concentrated in the lower levels of the atmosphere where the advantages of adding the HIRS to the AMSU are largest, the improvement in ability to retrieve water vapor should be even more pronounced than the improvement in the ability to retrieve temperature.

The ultimate effect of these differences on weather prediction can depend as much on the forecast model and how it utilizes satellite data as it does on the accuracy of the

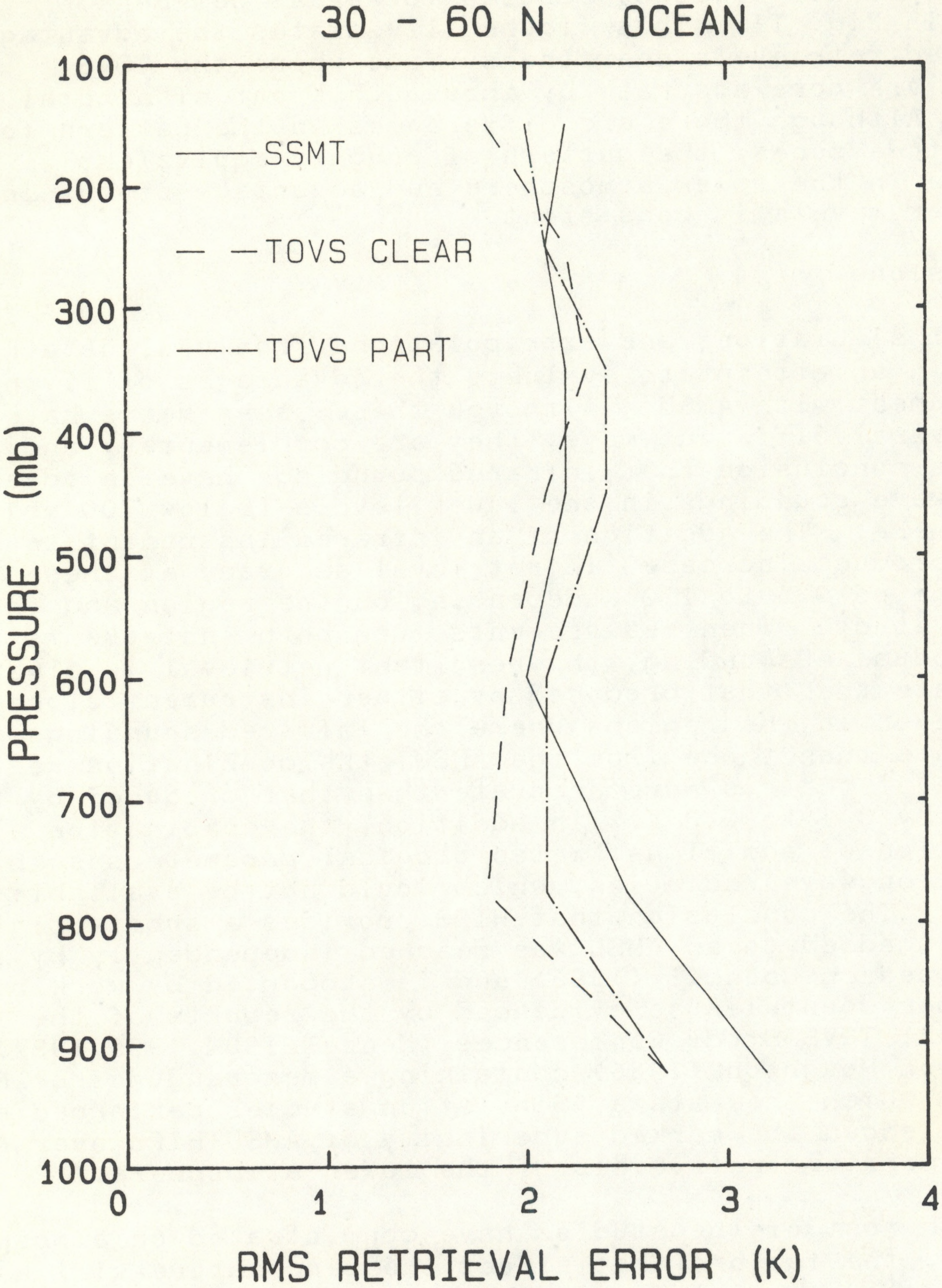

Figure 11. A comparison of SSMT and TOVS clear and partly cloudy mid-latitude retrievals over water. Accuracies are roughly comparable in the upper atmosphere, but TOVS is more accurate below 600 mb.

satellite data itself. However, a forecast model that uses data effectively should be sensitive to an increase in accuracy of lower atmospheric retrievals of 0.5 to 1.0 K out of a total error of 3.0 K.

8. References

Houghton, J.T., 1986: "Sounding Instruments on NOAA-K, L, and M." Private communication.

Menzel, W.P., 1984: "The Technical Proceedings of The First International TOVS Study Conference." Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706.

Menzel, W.P., 1985: "The Technical Proceedings of The Second International TOVS Study Conference." Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706.

Menzel, W.P., 1987: "The Technical Proceedings of The Third International TOVS Study Conference." Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin, 1225 West Dayton Street, Madison, Wisconsin 53706.

McCleese, D.J., and L.S. Wilson, 1976: "Cloud Top Heights from Temperature Sounding Instruments." Quart. J. Roy. Meteor. Soc., 102, 781-790.

McMillin, L.M., and C. Dean, 1982: "Evaluation of a New Operational Technique for Producing Clear Radiances," J. Appl. Meteor.,21, 1005-1014.

McMillin, L.M., and H.E. Fleming, 1985: "Trade-Offs in the Design of Satellite Sounding Instruments," J. Atmos. Oceanic Tech., 2, 278-284.

National Research council, 1986: "A letter from the chairman of the NOAA Review Panel, Board on Atmospheric Sciences and Climate, National Research Council to the Administrator, National Oceanic and Science Administration, U.S. Department of Commerce dated Sept. 24, 1986." private communication.

Smith, W.L., and C.M.R. Platt, 1978: "Comparison of Satellite Deduced Cloud Heights with Indications from Radiosondes and Ground-based Laser Measurements," J. Appl. Meteor., 17, 1796-1802.

Smith, W.L., H.M. Woolf, C.M. Hayden, D.Q. Wark, and L.M. McMillin, 1979: "The TIROS-N Operational Vertical Sounder," Bull. Am. Meteorol. Soc., 60, 1177-1187.

Schwalb, A., 1978: "The TIROS-N/NOAA A-G Satellite Series," NOAA Technical Memorandum NESS 95, 75 pp.

Susskind, J., J.Rosenfield, D.Reuter, and M.T.Chahine, 1984: "Remote Sensing of Weather and Climate Parameters form HIRS/MSU on TIROS-N. J. Geophys. Res., 89, 4677-4697.

Susskind, J., and D. Reuter, 1985: "Retrievals of Sea Surface Temperature from HIRS/MSU." J. Geophys. Res., 90C, 11,602-11,608.

Wielicki, B.A., J.A. Coakley, 1981: "Cloud Retrieval Using Infrared Sounder Data: Error Analysis," J. Appl. Meteor., 20, 157-169.

Workshop, 1982: "workshop on Next Generation Operational Satellite Sounding Systems," Science and Engineering Research Council, Rutherford Appleton Laboratory. Copies Available from Dr. D.L. Croom, Rutherford Appleton Laboratory, Chilton, Didcot, Oxfordshire OX11 OQX, U.K. 16 pp.

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
NATIONAL WEATHER SERVICE

National Meteorological Center
W/NMC2x2, WWB, Room 204
Washington, DC 20233

March 10, 1986 W/NMC2x2:NAP

MEMORANDUM FOR: Addressees

FROM: Norman A. Phillips
Principal Scientist

SUBJECT: Role of HIRS2 in improving temperature retrievals from a microwave sounder.

It seems to be generally accepted that in clear conditions, the AMSU microwave sounding instrument that is planned as the major sounding instrument for NOAA K, etc., cannot make temperature retrievals in the lower troposphere that are as accurate as those obtainable from the infrared sensors of HIRS. I believe that these conclusions do not take into account that over the ocean, where satellite retrievals are most useful, the temperature of the underlying surface is known fairly accurately. Since the water temperature is measured by both ships and by the AVHR, this should be considered in judging the importance of adding a HIRS sounder as a complement to the AMSU to improve low level temperatures in clear air.

A partial test of this is possible with the present operational retrievals from NOAA 6 and NOAA 9 because the failure of the HIRS on NOAA 6 has led to the production of temperature retrievals using only the 4-channel MSU on NOAA 6, <u>for all conditions of cloudiness</u>. NOAA 9, on the other hand, has both HIRS and MSU, and retrievals from it that are based almost solely on its MSU occur only under cloudy conditions.

I operate a colocation program that generates regression retrieval coefficients suitable for microwave retrievals over the oceans between 30N and 60N. These coefficients are used by NESDIS operationally for this latitude belt over water whenever the retrieval must be based on microwave radiances, either because it is cloudy or because there is no HIRS.

In addition to the 4 MSU brightness temperatures, my regression scheme uses sea-surface temperature obtained from the NMC SST analysis as an additional predictor. (HIRS channels 1,2,3,and 17 are also considered for NOAA 9, but they enter primarily in the upper troposphere.) The statistical correlations are obtained using brightness temperatures colocated with maritime raobs, but only when those brightness temperatures are associated with a retrieval that has been identified by NESDIS as having been made with a primarily microwave base (so-called paths 3 and 4). <u>All retrievals</u> from NOAA 6 therefore qualify with respect to "path" in my colocation system, whereas the only retrievals from NOAA 9 that qualify with respect to "path" are those that were made <u>under cloudy conditions</u>.

The following table reproduces the rms temperature difference between colocated retrievals and maritime radiosondes for the period February 4 - March 4 1986. I get these statistics every week when my coefficients are updated.

They are very consistent with individual weekly results extending back to the time in mid-1985 when NOAA 6 became a pure microwave sounder. The number of match-ups in this month for the bottom layer in the table was 69 for NOAA 9 and 206 for NOAA 6. (This is consistent with the usual percentage of retrievals that are "cloudy" over water at this time of year.) There are about 10% more matchups at higher levels.

RMS Temperature Differences of Satellite
Layer Temperatures with Colocated Maritime
Radiosondes. February 4-March 4 1985.
30N - 60N

Layer (mbs)	NOAA 6 (MSU only, all cloudiness conditions)	NOAA 9 (Only cloudy conditions)
1000 - 850	2.59°	3.20°
850 - 700	2.12	2.26
700 - 500	1.56	1.42
500 - 400	1.83	1.79
400 - 300	2.01	1.58
300 - 200	1.85	1.84
200 - 100	1.86	1.85

In the two bottom layers, the NOAA 6 "errors" are smaller. This is presumably because it is inherently more difficult to make retrievals under the cloudy conditions that characterize the NOAA 9 results than it is under the mix of cloudiness that characterizes the NOAA 6 values.

If it had been possible to consider only those cases in the NOAA 6 statistics that represented clear (or partly clear) events, the clear MSU errors would have been smaller than the values of 2.59 and 2.12 that are shown above. In the absence of this information, one can construct an estimate of what this might have been by combining the squared errors, e_6^2 for NOAA 6 and e_9^2 for NOAA 9, for the bottom layer according to the number of retrievals in that layer:

$$206\ e_6^2 = 69\ e_9^2 + (206 - 69)\ e_c^2 ,$$

e_c is the desired value of the error from a pure MSU retrieval under conditions when cloudiness was small enough to have permitted full use of the HIRS if it had been available. Using $e_6 = 2.59$ and $e_9 = 3.2$ gives

$$e_c = 2.2 \text{ degrees}$$

This is only slightly larger than I have seen in the past from the best HIRS retrievals over this part of the world.

This inferred smallness of errors in the lowest layers of the troposphere from a pure microwave retrieval in non-cloudy conditions is believable only if my use of the sea surface temperature has been a powerful help. The size of my retrieval coefficients does in fact assign an important role to the sea surface temperature for the layer 1000-850 mbs. (MSU channel 1, which is the near "window" channel, plays only a minor role at all levels, but MSU channel 2, as is well known, is a very important channel at most levels.)

Above 700 mbs, one can detect slightly better results from NOAA 9.

o I interpret these results as suggesting that an AMSU can make retrievals

o in clear or partly clear conditions in this part of the world that are

o almost as good as those obtainable from a HIRS, if the retrieval process

o makes use of independently derived values of the sea surface temperature.

There is a subtle meteorological criticism of the above conclusion. This is that sea surface temperature is also available to the NMC analysis codes, and could in principle be used as a guide in analysing air temperatures near the sea surface, in conjunction with any satellite temperatures, irrespective of whether sea surface temperature was or was not used in arriving at the satellite values. Under these circumstances, the improvement in satellite microwave retrieval of the 1000-850 mb temperature by use of the water temperature could be irrelevant; the important question might no longer be how accurate the satellite system can retrieve the 1000-850 mb air temperature, but rather

How accurate can the satellite system retrieve the difference between the water and air temperature if a good independent estimate of the water temperature is available to the retrieval process?

Unfortunately I know of no information that would answer this question for an AMSU versus an AMSU+HIRS combination.

Distribution:
NMC:
W. Bonner
J. Brown
R. McPherson
J. Gerrity
NESDIS:
R. Koffler
H. Yates
W. Planet
H. Fleming

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NESDIS 7 Fire Detection Using the NOAA--Series Satellites. Michael Matson and Stanley R. Schneider (NESDIS), Billie Aldridge and Barry Satchwell (NWS), January 1984. (PB84 176890)

NESDIS 8 Monitoring of Long Waves in the Eastern Equatorial Pacific 1981-83 Using Satellite Multi-Channel Sea Surface Temperature Charts. Richard Legeckis and William Pichel, April 1984. (PB84 190487)

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NESDIS 12 Utilization of the Polar Platform of NASA's Space Station Program for Operational Earth Observations. John H. McElroy and Stanley R. Schneider, September 1984. (PB85 1525027AS)

NESDIS 13 Summary and Analyses of the NOAA N-ROSS/ERS-1 Environmental Data Development Activity. John W. Sherman III, February 1984. (PB85 222743/43)

NESDIS 14 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Activity. John W. Sherman III, February 1985. (PB86 139284 A/S)

NESDIS 15 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Products and Services. Franklin E. Kniskern, February 1985. (PB86 213527/AS)

NESDIS 16 Temporal and Spatial Analyses of Civil Marine Satellite Requirements. Nancy J. Hooper and John W. Sherman III, February 1985. (PB86 212123/AS)

NESDIS 17 reserved

NESDIS 18 Earth Observations and The Polar Platform. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 177624/AS)

NESDIS 19 The Space Station Polar Platform: Integrating Research and Operational Missions. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 195279/AS)

NESDIS 20 An Atlas of High Altitude Aircraft Measured Radiance of White Sands, New Mexico, in the 450-1050 nm Band. Gilbert R. Smith, Robert H. Levin and John S. Knoll, April 1985. (PB85 204501/AS)

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NESDIS 24 Satellite-Derived Moisture Profiles. Andrew Timchalk, April 1986. (PB86 232923/AS)

NESDIS 25 reserved

NESDIS 26 Monthly and Seasonal Mean Outgoing Longwave Radiation and Anomalies. Arnold Gruber, Marylin Varnadore, Phillip A. Arkin, and Jay S. Winston, October 1987.

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