

# Introduction of the Hyperspectral Environmental Suite (HES) on GOES-R and beyond

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## Abstract

The Hyperspectral Environmental Suite (HES), scheduled for implementation on the Geostationary Operational Environmental Satellite (GOES)-R, will be launched in approximately 2013. This is the next generation operational geostationary sounder. Presently in formulation phase, it will replace the filter-wheel sounder that flies on the current GOES satellites. The HES will provide dramatic improvements over current sounder data and products, including better spectral resolution, faster geographic coverage rate, and improved spatial resolution.

## Introduction

The Hyperspectral Environmental Suite (HES) on-board GOES-R (beginning in approximately 2013) will perform a number of functions with the data obtained in the infrared (Gurka and Dittberner 2001, Gurka and Schmit 2002). The two main tasks are to provide high-spectral resolution radiances for Numerical Weather Prediction (NWP) applications (Bayler et al 2001) and to provide temperature and moisture soundings (and various derived parameters) for a host of applications dealing with near or short-term predictions. Derived products include, but are not limited to: cloud-top information, winds, ozone, surface emissivity, and satellite-to-satellite inter-calibrations (Goerss et al 1998, Chung et al 2000, Li et al 2001a). There are actually two HES sub-tasks or modes. One mode is the HES - Disk Sounding (HES-DS) and the other is HES - Severe Weather / Mesoscale (HES-SW/M). The threshold spectral resolutions of these two tasks are 10 and 4 km, respectively. The coverage rate for the HES-DS is to cover the full "sounding disk" (less than 62 degrees view angle) is one hour, while the HES-SW/M will cover a 1,000 km x 1,000 km area in less than 4.4 minutes. This means the HES-DS will have a coverage rate approximately five times faster than the current GOES Sounder. The spectral coverage of the infrared portion of the HES will be 650 –1200  $\text{cm}^{-1}$ , 1650 -2150  $\text{cm}^{-1}$  or 1210 –1740 for the water vapor continuum and 2150 –2250  $\text{cm}^{-1}$ .

The infrared data from the HES instrument on-board GOES-R will complete a decade long march to both high-spectral and high-temporal operational sounding data. There have been many important steps along the way (Figure 1). This includes, but is not limited to, the first theoretical works, the pioneering low-earth orbiting sounders, the experimental, multi-spectral resolution geostationary VISSR Atmospheric Sounder (VAS) instrument (Smith 1983; Hayden 1988; Hayden et al 1996), the experimental high-spectral resolution low-earth orbiting sounders, the operational, low-spectral resolution GOES sounders (Menzel and Purdom 1994, Schmit et al

2002a) and finally the operational high-spectral resolution low-earth orbiting sounders. The HES on GOES-R will be the first operational, high-spectral resolution instrument in geostationary orbit (Li et al 2001b, Li et al 2002). Of course the geostationary orbit offers high temporal resolution to monitor a host of parameters.

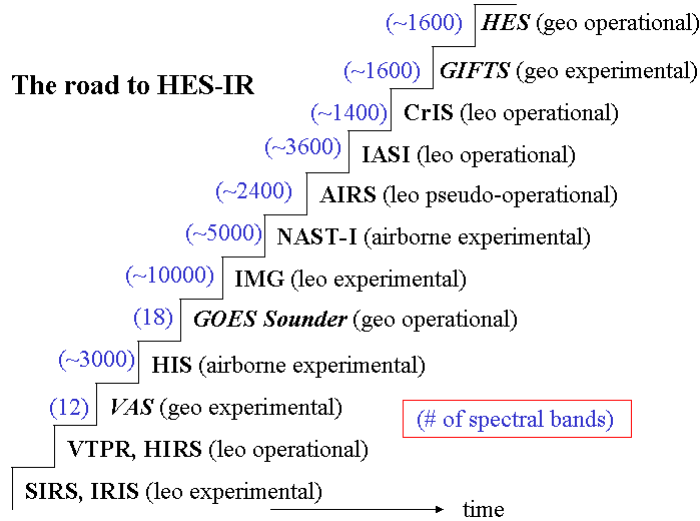


Figure 1: The path to the HES. The instruments in geostationary orbit are in italic.

The HES instrument will improve on the four key remote sensing areas. These are spatial resolutions, spectral coverage and resolution, temporal resolution and radiometric accuracy.

## Results for HES studies

### Water vapor information

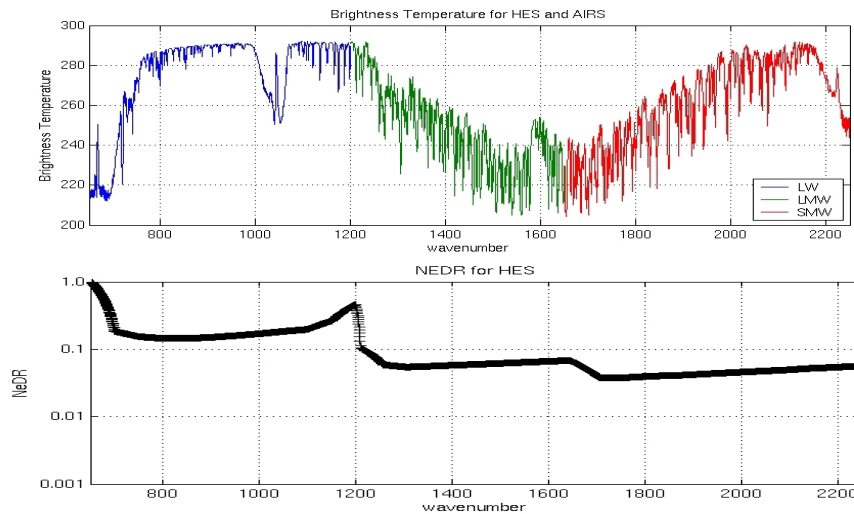


Figure 2: Example of BT spectral for HES LW, LMW, SMW (upper panel) and the noise in NEDR (lower panel).

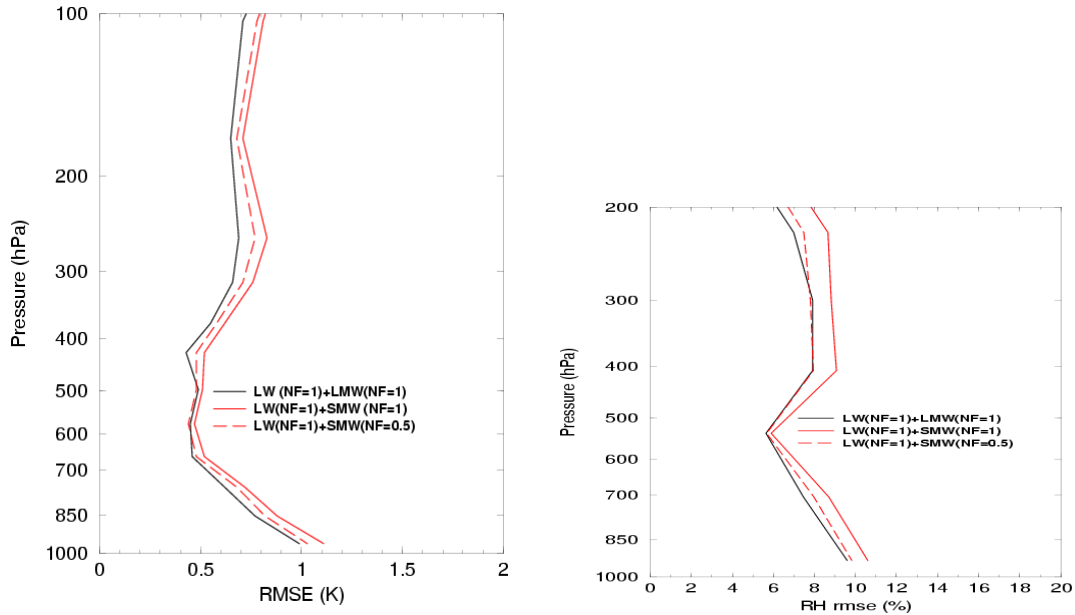


Figure 3: The temperature retrieval rmse at 1km vertical resolution and water vapor RH retrieval rmse at 2km vertical resolution LW + LMW, LW + SMW, and LW + SMW with the SMW noise reduced by half.

One important issue for the HES instrument is to select the water vapor spectral coverage. Usually the longwave coverage (LW, approximately  $650 - 1200\text{cm}^{-1}$ ) is selected for temperature, ozone and surface property retrievals. For the water vapor region, one can use either longer middlewave (LMW, approximately  $1200 - 1650\text{cm}^{-1}$ ) or shorter middlewave (SMW, approximately  $1650 - 2250\text{cm}^{-1}$ ). For example, AIRS uses the LMW while Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) uses the SMW region. Selection of both water vapor sides might be a better option in terms of information. For example, having both sides of the water vapor continuum would allow better trace gas measurements, and improved ABI back-up mode, better continuity for climate applications and improved retrievals. However, data volume will be increased. To compare the water vapor information from LMW versus SMW, a simulation study was carried out to simulate the retrieval performance for HES LW + LMW versus LW + SMW. Eigenvector regression followed by physical retrieval algorithm was used in the simulation (Li et al. 2003a); the spectral resolution for all spectral band channels is  $0.625\text{ cm}^{-1}$ . 523 global independent profiles were used in retrieval performance study, and 1 km temperature root mean square error (rmse) and 2 km relative humidity (RH) rmse were calculated to evaluate the retrieval difference between LW + LMW and LW + SMW. The 14bit HES instrument noise from the Technical Requirement Document (TRD) was used in simulating the HES radiances. Figure 2 shows an example of HES BT spectrum for LW (blue line), LMW (green line) and SMW (red line) (upper panel), the HES instrument noise in NEDR for LW, LMW and SMW is also shown in the lower panel. Figure 3 shows temperature retrieval rmse at 1km vertical resolution for LW + LMW, LW + SMW, and LW + SMW with SMW noise reduced by half (NF=0.5) (left panel), and the water vapor RH retrieval rmse at 2km vertical resolution (right panel). In general, the temperature retrieval difference between LW+LMW and LW+SMW is about 0.1K, while the water vapor retrieval difference is about 1%. With SMW noise reduced by half, both temperature and water vapor retrieval differences between LW+LMW and LW+SMW are reduced. Considering other factors for LMW (for example, lower spectral resolution than SMW, more trace gas other than water vapor, etc.), the temperature and moisture retrieval differences between LW + LMW and LW + SMW are very small.

## Spatial resolution study using MODIS data

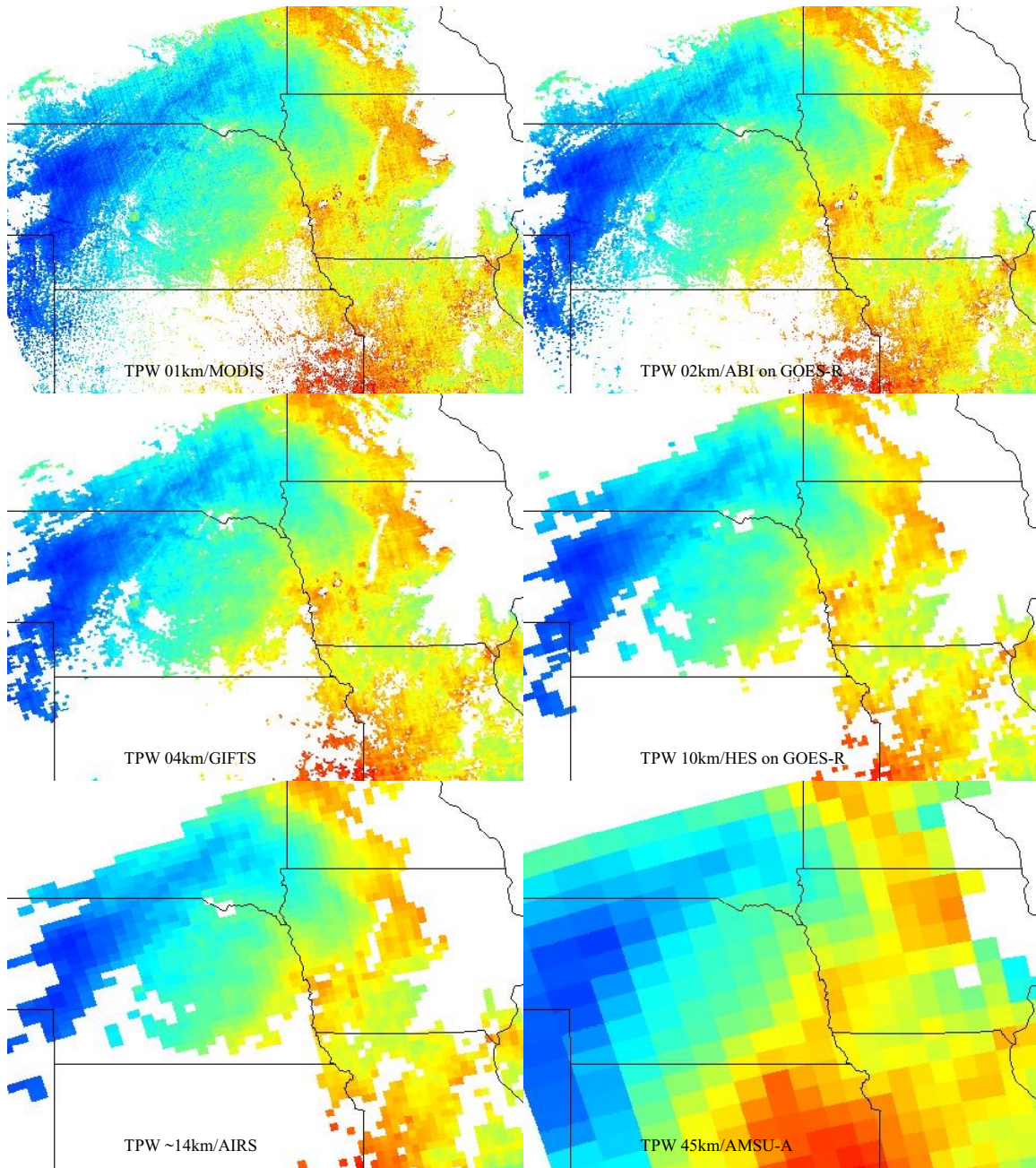


Figure 4: The 1km MODIS TPW (upper left panel) at 1900UTC on July 20, 2002 from the AQUA satellite, the simulated ABI resolution at 2km resolution (upper right panel), simulated GIFTS resolution at 4km spatial resolution (middle left panel), simulated HES resolution at 10km spatial resolution (middle right panel), simulated AIRS resolution at 14km spatial resolution (lower left panel), and simulated AMSU resolution at 45km spatial resolution (lower right panel), respectively, from the MODIS 1km TPW.

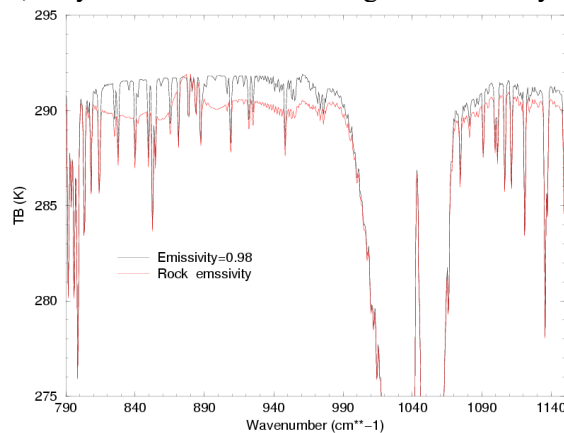
The spatial resolution for HES is very important because “hole hunting” will be the effective method to find clear pixels for atmospheric sounding without microwave sounding capability on the geostationary satellite. Fine spatial resolution allows a higher possibility of finding clear

pixels and maintaining spatial gradients. This is very important because (a) fine spatial resolution HES measurements will meet the mesoscale forecast requirement, and (b) fine spatial resolution enable to find more homogeneous fields-of-view (FOV) scenes for the cloud-clearing process.

Figure 4 shows the 1km MODIS TPW at 1900UTC on July 20, 2002 from EOS' AQUA satellite, and a number of reduced spatial resolutions for IR sounders. It can be seen that coarser spatial resolution results in smoothed TPW gradients and less clear coverage. The goal spatial resolutions of HES are 2 km.

### Spectral resolution study for non-sounding applications

A study has been carried to demonstrate that in the IR longwave window region, a spectral resolution of  $1\text{cm}^{-1}$  or better is necessary for accurately retrieving the non-sounding products such as IR surface emissivity and surface skin temperature by using the minimum local emissivity variance (MLEV) algorithm. Figure 5 shows the calculated LW BT spectrum at  $0.625\text{cm}^{-1}$  with two different IR surface emissivity spectra (one is from the constant emissivity of 0.98 and the other is from an observed rock emissivity spectrum). The BT difference between the two spectrum in the figure results solely from the different emissivity spectrum in the calculations. Figure 6 shows from upper to lower panels the BT spectrum with rock emissivity, true emissivity spectrum (black line), retrieved emissivity spectra with true surface skin temperature (green line) and surface skin temperature deviated by 1K (green and red lines). The noise factor indicates the noise added (e.g., 0.5 means half noise). The mean local emissivity variance is indicated. Both half noise and nominal noise will create emissivity variance contrasts between true skin temperature and wrong skin temperature, indicating that both surface skin temperature and IR emissivity spectrum can be retrieved. However, the emissivity variance contrasts are very small with doubled noise, indicating that the skin temperature and surface emissivity retrieval will be difficult with doubled noise. Figure 7 is the same as Figure 6 but with a spectral resolution of  $1.25\text{ cm}^{-1}$ , in this case, only half noise will create good emissivity variance contrasts in a lower



spectral resolution.

Figure 5. The calculated LW BT spectrum at  $0.625\text{cm}^{-1}$  with two different IR surface emissivity spectrum (black line shows the BT with a constant emissivity of 0.98 and the red line shows the BT with rock emissivity spectrum from observation).



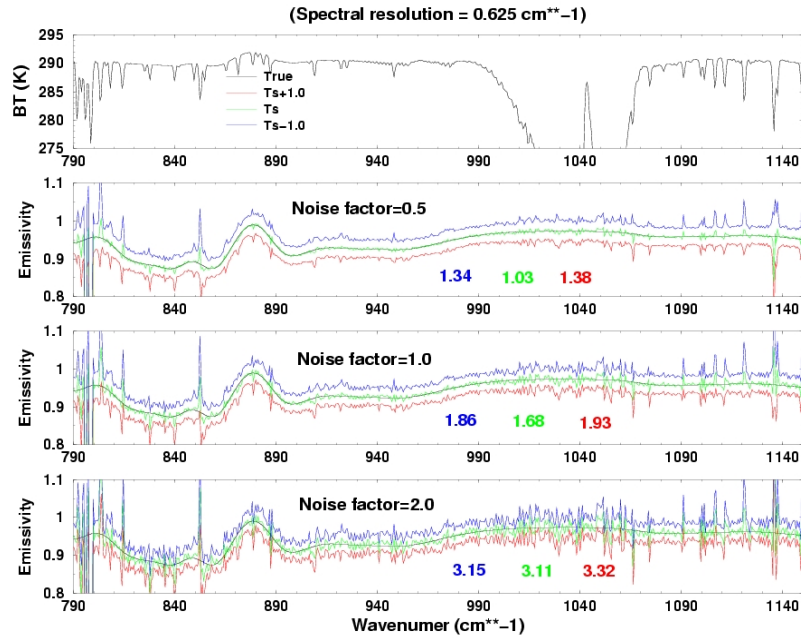


Figure 6. The BT spectrum with an observed rock emissivity spectrum, true emissivity (black line), retrieved emissivity spectra with true surface skin temperature (green line) and surface skin temperature deviated by 1K (green and red lines). The noise factor indicates the noise added in the simulation (e.g., 0.5 means half noise). The mean retrieved local emissivity variance is also indicated in each panel.

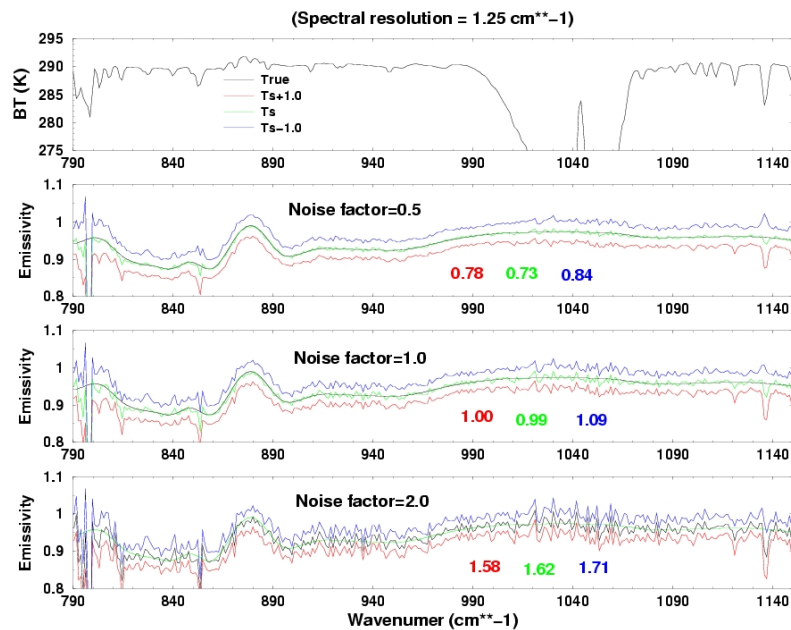


Figure 7. The same as Figure 6 but with a spectral resolution of  $1.25\text{cm}^{-1}$ .

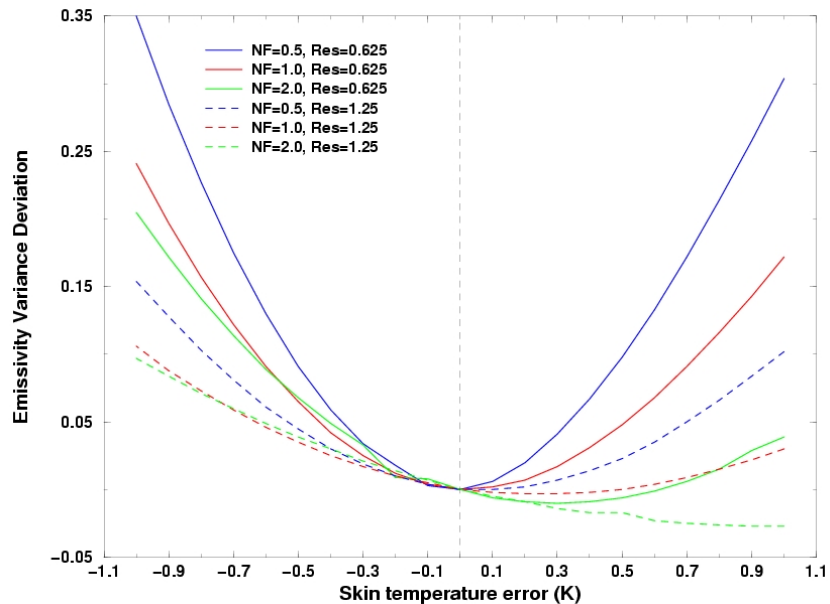


Figure 8. The emissivity variance difference between wrong skin temperature and true skin temperature as a function of skin temperature error, different lines correspond to various spectral resolutions and noise factors.

Figure 8 shows the emissivity variance differences between the wrong skin temperature and the true skin temperature as a function of skin temperature error, different lines correspond to various spectral resolutions and noise factors. It clearly indicates that a spectral resolution of  $0.625 \text{ cm}^{-1}$  with half noise and nominal noise will create an accurate emissivity and skin temperature retrievals, while only half noise will create good surface property retrieval with lower spectral resolution (e.g.,  $1.25 \text{ cm}^{-1}$ ). Note that this effect is not the only error source in estimating surface emissivity and skin temperature.

## Summary

The GOES-R HES will be launched in approximately 2013. This is the next generation operational geostationary sounder that is currently in the formulation phase and will replace the currently used filter-wheel instrument. The HES data and derived products will improve over the current operational instruments in many areas. These include more spectral bands, faster geographical coverage rate and potentially improved spatial resolutions. Of course the GOES-R HES instruments will not be acting alone, but should use nearly time co-incident measurements from the high spatial resolution ABI to improve GOES-R products (Li et al 2003a, Li et al 2003b, Schmit et al 2002b, Schmit et al 2004).

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## References

- Bayler, G. M., R. M. Aune, and W. H. Raymond, 2001: NWP cloud initialization using GOES sounder data and improved modeling of non-precipitating clouds. *Mon. Wea. Rev.*, 128, 3911-3920.
- Chung S., S. Ackerman, P. F. van Delst, and W. Paul Menzel, 2000: Model calculations and interferometer measurements of ice-cloud characteristics. *J. Appl. Met.*, 39, 634-644.
- Hayden, C. M., 1988: GOES-VAS simultaneous temperature-moisture retrieval algorithm. *J. Appl. Meteor.*, 27, 705-733.
- Hayden, C. M., G. S. Wade, and T. J. Schmit, 1996: Derived product imagery from GOES-8. *J. Appl. Meteor.*, 35, 153-162.
- Li, J., W. P. Menzel, F. Sun, T. J. Schmit, and J. Gurka, 2003a: AIRS sub-pixel cloud characterization using MODIS cloud products, *J. Appl. Meteorol.* (submitted)
- Li, J., W. P. Menzel, W. Zhang, F. Sun, T. J. Schmit, J. Gurka, and E. Weisz, 2003b: Synergistic use of MODIS and AIRS in a variational retrieval of cloud parameters, *J. Appl. Meteorol.* (submitted).
- Li, J., T. J. Schmit, and W. P. Menzel, 2002: Advanced Baseline Sounder (ABS) for future Geostationary Operational Environmental Satellites (GOES-R and beyond), SPIE proceeding, *Applications with Weather Satellites*, Oct.23 – 27, 2002, Hangzhou, China.
- Li, J., Menzel, W. P., and A. J. Schreiner, 2001a: Variational retrieval of cloud parameters from GOES sounder longwave cloudy radiance measurements. *J. Appl. Meteorol.* 40, 312-330.
- Li, J., T. J. Schmit, H. L. Huang, and H. M. Woolf, 2001b: Retrieval of atmospheric inversions using geostationary high-spectral-resolution sounder radiance information. *11<sup>th</sup> Conference on Satellite Meteorology and Oceanography*, 15 – 18 October 2001, Madison, WI.
- Goerss, J. S., C. S. Velden, and J. D. Hawkins, 1998: The impact of multispectral GOES-8 wind information on Atlantic Tropical Cyclone track forecasts in 1995. Part II: NOGAPS Forecasts. *Mon. Wea. Rev.*, 126, 1219–1227.
- Gurka J. J., and G. J. Dittberner, 2001: The next generation GOES instruments: status and potential impact”. Preprint Volume. *5<sup>th</sup> Symposium on Integrated Observing Systems*. 14-18 January, 2001, Albuquerque, NM., Amer. Meteor. Soc., Boston.
- Gurka, J. J., and T. J. Schmit, 2002: Recommendations on the GOES-R series from GOES users’ conferences, *SPIE Proceeding 4895*, 95 - 102.
- Menzel, W. P., and J. F. W. Purdom, 1994: Introducing GOES-I: The first of a new generation of geostationary operational environmental satellites, *Bull. Amer. Meteor. Soc.*, 75, 757-781.
- Schmit, T. J., et al., 2004: Study of ABI on GOES-R and beyond, *Proceeding of 20<sup>th</sup> International Conference on Interactive Information and Processing System (IIPS) for Meteorology, Oceanography, and Hydrology*, American Meteorological Society, Jan. 10 – 14, 2004, Seattle, WA, AMS
- Schmit T. J., W. F. Feltz, W. P. Menzel, J. Jung, A. P. Noel, J. N. Heil, J. P. Nelson III, G. S. Wade, 2002a: Validation and use of GOES sounder moisture information. *Wea. Forecasting*, 17, 139-154.
- Schmit, T. J., J. Li, W. P. Menzel, 2002b: ABI for future GOES-R and beyond, *SPIE Proceeding 4895*, 111-122.
- Smith, W. L., 1983: The retrieval of atmospheric profiles from VAS geostationary radiance observations. *J. Atmos. Sci.*, 40, 2025-2035.