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STUDY OF THE HYPERSPECTRAL ENVIRONMENTAL SUITE (HES) ON GOES-R

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1. INTRODUCTION

High spectral resolution infrared radiances from the Hyperspectral Environmental Suite (HES) on Geostationary Operational Environmental Satellite (GOES-R and beyond) will allow for monitoring the evolution of atmospheric profiles and clouds. The HES is currently slated to be launched in 2013. HES, together with the Advanced Baseline Imager (ABI) (Schmit et al. 2004.; Schmit et al. 2002) will operationally provide enhanced spatial, temporal and vertical information for atmospheric soundings and clouds. Trade-off studies have been done on the spectral coverage, spectral resolution, spatial resolution, temporal resolution, band-to-band co-registration and signal-to-noise ratio (Li et al. 2003b). HES data applications investigated include sounding temperature/moisture retrievals, trace gas estimation, cloud retrieval and surface property retrieval. Synergistic uses of ABI and HES data for better atmospheric and cloud retrievals are also under investigation. Moderate Resolution Imaging Spectroradiometer (MODIS) and Atmospheric InfraRed Sounder (AIRS) measurements from Earth Observing System's (EOS) Aqua platform are used to demonstrate the ABI/HES system capability of deriving atmospheric, cloud and surface parameters with high accuracy.

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2. WATER VAPOR INFORMATION FROM IR LMW AND SMW.

One important issue for HES instrument design was the selection of water vapor spectral coverage. Usually longwave coverage (LW, approximately 650 – 1200cm^{-1}) is selected for temperature, ozone and surface property retrievals. For water vapor region, one can use either longer middlewave (LMW, approximately 1200 – 1650cm^{-1}) or shorter middlewave (SMW, approximately 1650 – 2250cm^{-1}). AIRS, for example, uses LMW while the Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) uses SMW. 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 would be increased. In order to compare the water vapor information from LMW verus SMW, a simulation study was carried out to simulate the retrieval performance for HES LW + LMW versus LW + SMW. Eigenvector regression followed by a physical retrieval algorithm was used in the simulation (Li et al. 2003b); the spectral resolution for all spectral band channels is 0.625 cm^{-1}. 523 global independent profiles are 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 1 shows an example of HES brightness temperature (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 2 shows temperature rmse at 1km vertical resolution for LW + LMW, LW + SMW, and LW + SMW with SMW noise reduced by half (NF=0.5). Figure 3 is the same as Figure 2 but for the water vapor RH rmse at 2km vertical resolution. In general, the temperature retrieval difference between LW+LMW and LW+SMW is about 0.1K, while the water vapor retrieval difference is

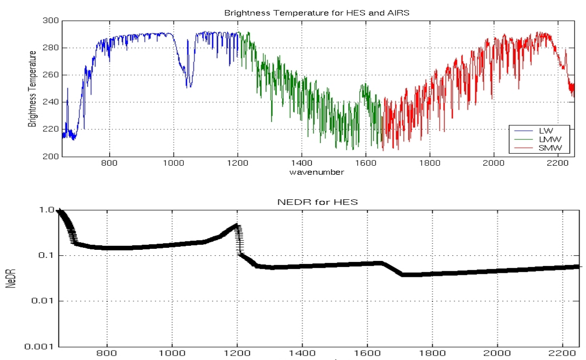


Figure 1. Example of BT spectral for HES LW, LMW, and SMW (upper panel). The noise in NEDR is shown in the lower panel.

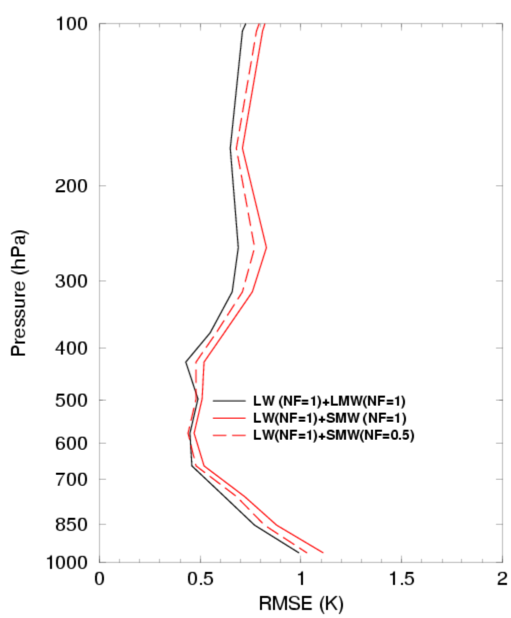


Figure 2. The temperature retrieval rmse at 1km vertical resolution for LW + LMW, LW + SMW, and LW + SMW with SMW noise reduced by half.

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, etc.), the temperature and moisture retrieval differences between LW + LMW and LW + SMW are very small.

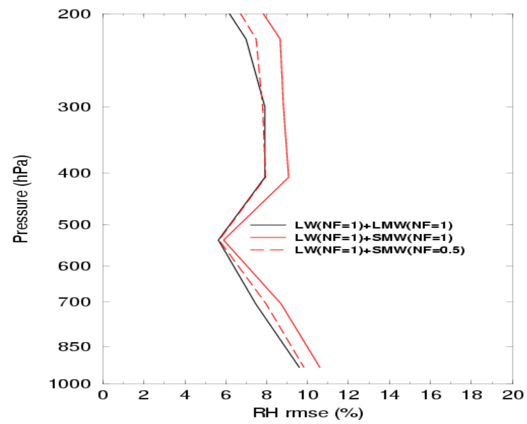
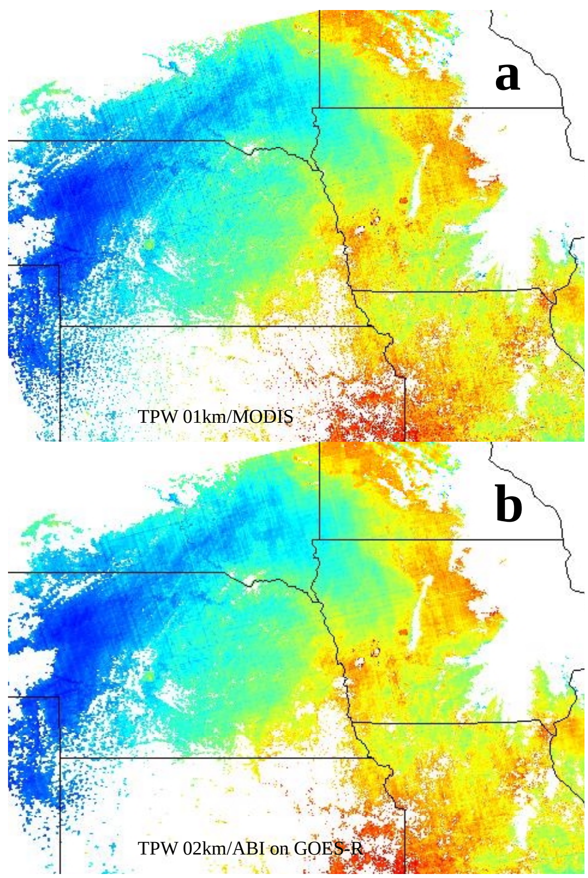


Figure 3. The same as Figure 2 but for water vapor RH rmse at 2km vertical resolution.

3. SPATIAL RESOLUTION STUDY USING MODIS 1km DATA



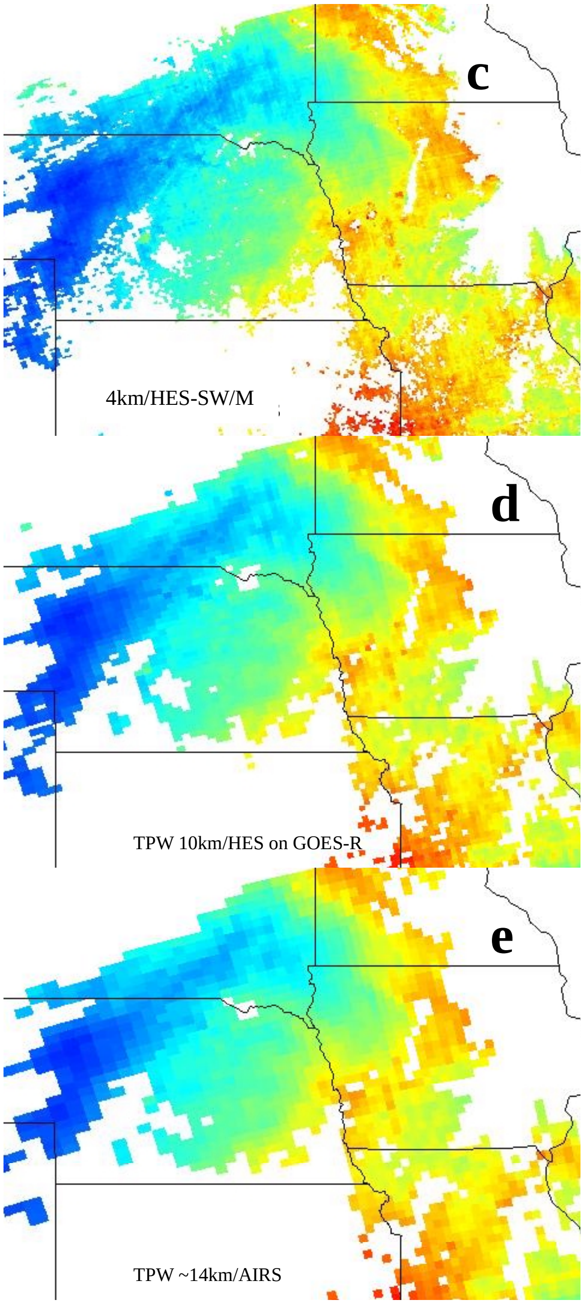


Figure 4. The 1km MODIS TPW (a) at 1900UTC on July 20, 2002 from EOS' AQUA satellite, simulated ABI TPW at 2km resolution (b), simulated HES-SW/M TPW at 4km spatial resolution (c), simulated HES-DS TPW at 10km spatial resolution (d), and simulated AIRS TPW at 14km spatial resolution (e), from the retrieved 1km MODIS TPW.

The spatial resolution for HES is very important because "hole hunting" will be the effective way to find clear pixels for atmospheric sounding without microwave sounding capability on the geostationay satellite. Fine spatial resolution allows for a higher possibility of finding clear pixels. This is very important because (a) fine spatial resolution HES measurements will meet the mesoscale forecast requirement, and (b) fine spatial resolution enables one to find more homogeneous 2 by 2 or 3 by 3 fields-of-view (FOV) scenes for the possible ABI/HES cloud-clearing.

Figure 4 shows the 1km MODIS TPW at 1900 UTC on July 20, 2002 from the EOS' AQUA satellite, and a number of reduced spatial resolutions for IR sounders. It can be seen that the coarser spatial resolution results in smoothed TPW gradients and less clear coverage. The spatial resolution of 10km or better should be considered for HES.

4. SPECTRAL RESOLUTION REQUIREMENT FOR NON-SOUNDING

In order to help define the requirement for HES spectral coverage and spectral resolution, trade-off studies are necessary to investigate the impact of long-wave window spectral resolution on non-sounding products. A study has been performed to demonstrate that in the IR longwave window region, a spectral resolution of $1cm^{-1}$ or better is necessary for accurately retrieving the non-sounding products such as IR surface emissivity and surface skin temperature by using the local minimum emissivity variance algorithm. Figure 5 shows the calculated LW BT spectrum at $0.625cm^{-1}$ with two different IR surface emissivity spectrum (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 spectra 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 spectrum 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 local emissivity variance is also indicated in each panel. Both half noise and nominal noise will create emissivity variance contrast between the true skin temperature and the wrong skin temperature, indicating that both surface skin temperature and IR emissivity spectrum can be retrieved. However, the emissivity variance contrast is very small with doubled noise, indicating that the skin temperature and surface emissivity retrieval will be difficult with doubled noise. The spectral resolution in the figure is 0.625 cm^{-1}. Figure 7 is the same as Figure 6 but with a spectral resolution of 1.25 cm^{-1}, in this case, only half noise will create a good emissivity variance contrasts in a lower spectral resolution.

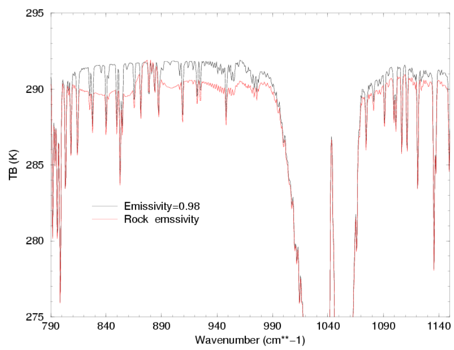


Figure 5. The calculated LW BT spectrum at 0.625cm^{-1} with two different IR surface emissivity spectrum (black line shows the BT with a constant emissivity of 0.98 and the red line shows the BT with rock emissivity spectrum from observation).

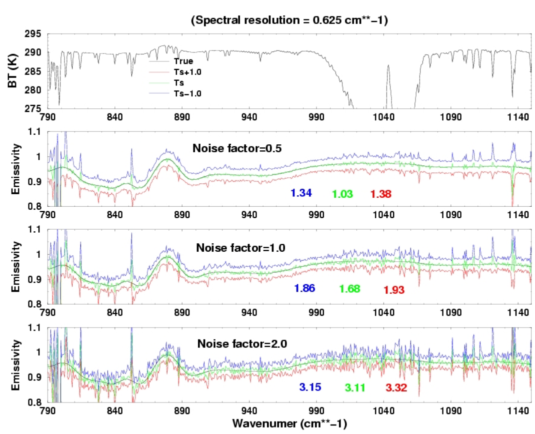


Figure 6. The BT spectrum with rock emissivity spectrum, true emissivity (black line), retrieved emissivity spectrum with true surface skin temperature (green line) and surface skin temperature deviated by 1K (green and red lines). The noise factor indicates the noise added in the simulation (e.g., 0.5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

Figure 8 shows 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. It clearly indicates that a spectral resolution of 0.625 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 cm^{-1}). Note that this effect is not the only error source in estimating surface emissivity and skin temperature.

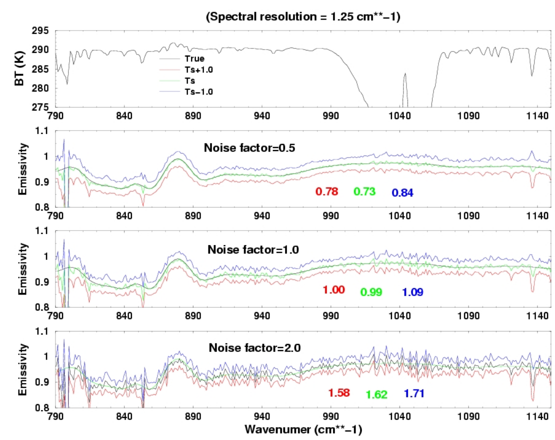


Figure 7. The same as Figure 6 but with a spectral resolution of 1.25cm^{-1}.

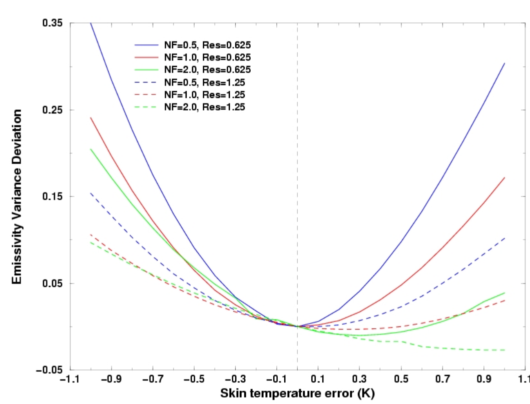


Figure 8. The emissivity variance difference between wrong skin temperature and true skin temperature as a function of skin temperature

error, different lines correspond to various spectral resolutions and noise factors.

5. ABI/HES SYNERGISM

ABI will provide a cloud mask, cloud phase, and classification mask with high spatial resolution (~ 2km). Those products are very useful for characterizing the HES sub-pixel (~ 10km) cloud properties. An imager/sounder collocation algorithm and software was created, for a given sounder footprint, all the imager pixels within the footprint are found. MODIS data and AIRS data was used to demonstrate sounder sub-pixel cloud characterization using high spatial resolution imager cloud products (Li et al. 2003c). In addition, imager products serve as background information, and the atmospheric and cloud parameters can be derived from sounder radiances with much better accuracy. This is demonstrated by cloud property retrieval from collocated MODIS/AIRS data.

Figure 9 shows an AIRS BT image at a window region at 19:17UTC on 06 September 2003 (granule 193). The upper left square indicates the small area for the AIRS sub-pixel cloud characterization and MODIS/AIRS synergistic retrieval study. Figure 10 shows the study area (see Figure 9 for the location of the study area) of the MODIS classification mask collocated to AIRS footprints.

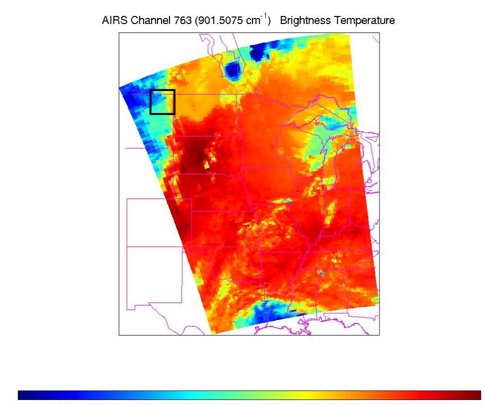


Figure 9. An AIRS BT image at a window region at 19:17UTC on 06 September 2003 (granule 193). The upper left square indicates the small area for AIRS sub-pixel cloud characterization and MODIS/AIRS synergistic retrieval study.

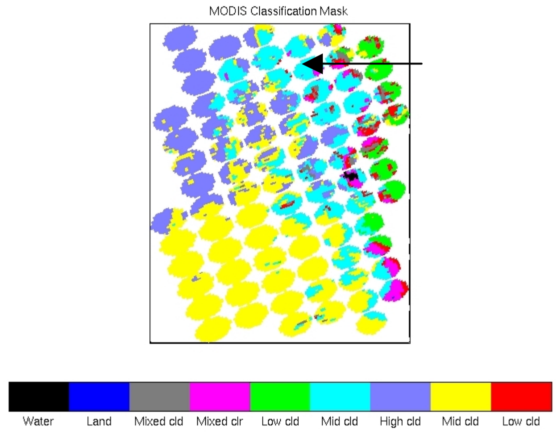


Figure 10. The study area (see Figure 9) of the MODIS 1km classification mask shading to the AIRS footprints.

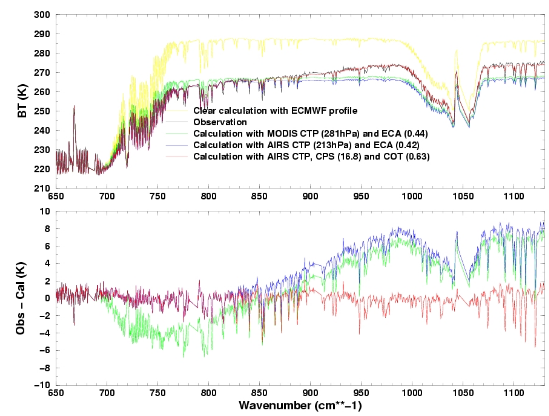


Figure 11. The AIRS longwave clear BT calculation from the ECMWF forecast model analysis (yellow line), the cloudy BT calculation with the MODIS CTP and ECA (green line), the BT calculation from the AIRS retrieved CTP and ECA, and the BT calculation with AIRS retrieved CTP as well as CPS and COT (redline), along with the cloudy BT observation (black line) spectra for footprint indicated by Figure 10; the lower panel shows the corresponding BT difference between observation and calculation.

Figure 10 shows the MODIS classification mask (Li et al. 2003a) at 1km spatial resolution superposed to the AIRS footprints. Different types of clouds are well identified by MODIS classification mask at 1km spatial resolution. The AIRS footprint indicated by an arrow in this figure is used to show the MODIS/AIRS synergistic cloud retrieval. This pixel is identified by the MODIS classification mask as middle level clouds and the clouds belong to ice clouds according to the MODIS cloud phase mask at 1km resolution. The upper panel of

Figure 11 shows the AIRS longwave clear BT calculation from the ECMWF forecast model analysis (yellow line), the cloudy BT calculation with the MODIS CTP and ECA (green line), the BT calculation from the AIRS retrieved CTP and ECA, and the BT calculation with AIRS retrieved CTP as well as cloud particle size (CPS) and cloud optical thickness (COT) (redline), along with the cloudy BT observation (black line) spectra for footprint indicated by Figure 10. The lower panel of Figure 11 shows the corresponding BT difference between observation and calculation. As described, the MODIS cloud products serve as the background information for the AIRS retrieval; a variational (1DVAR) approach is used for MODIS/AIRS synergistic retrieval of CTP, ECA, CPS and COT products (Li et al. 2003c). It shows that there is a large difference between calculation with the MODIS cloud products and observation in the CO_2 region, the difference in the CO_2 region is almost removed by the calculation with the AIRS retrieved CPT and ECA; AIRS adjusted the MODIS CTP by 68 hPa. However, the slope of the BT in the spectral window region for the AIRS footprint is still significantly large because of CPS effects. With AIRS retrieved CPS and COT for this footprint, the calculation (red line in this figure) fits the slope very well, indicating that the cloud microphysical properties can be retrieved effectively by the AIRS radiance measurements (Li et al. 2003d).

Given that the ABI will scan the full disk in approximately 5 minutes, the time difference between the ABI and HES observations should be less than 2.5 minutes, this will make good ABI/HES collocation for synergism.

6. CONCLUSIONS

Some conclusions for HES can be drawn from this study.

(1) LMW and SMW provide similar water vapor information along with the LW spectral band; either LMW or SMW can be chosen for HES water vapor band for moisture sounding retrieval.
(2) Spatial resolution is very important for clear “hole hunting” without a microwave sounder. A spatial resolution of 10km or better is required.
(3) A high spectral resolution of 1 cm^{-1} or better, should be considered for the window region along with a good signal-to-noise ratio. Both are needed for surface property retrieval.
(4) ABI high spatial resolution cloud products can help HES sub-pixel cloud detection and characterization. Synergistic use of ABI and HES data will provide products with better accuracy than that from either system alone. MODIS/AIRS data has demonstrated this.

Future work will focus on trade-off study for determining the HES specification based on users’ requirements. Further ABI/HES synergism studies for better atmospheric sounding and non-sounding products will also be performed.

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