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STUDIES ON THE GOES-R HYPERSPECTRAL ENVIRONMENTAL SUITE (HES) ON GOES-R

Jun Li[*], Timothy, J. Schmit[@], Chian-Yi Liu[*], W. Paul Menzel[@], and James Gurka[#]

[*]Cooperative Institute for Meteorological Satellite Studies (CIMSS)
University of Wisconsin-Madison, Madison, WI
[@] NOAA/NESDIS, Office of Research and Applications, Madison, WI
[#] NOAA/NESDIS, Silver Spring, Maryland

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) 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. HES data applications investigated include sounding temperature/moisture retrievals, trace gas estimation, cloud retrieval and surface property retrieval. The accuracy and vertical resolution of atmospheric temperature, moisture and trace gas associated with HES are investigated. These will be contrasted with capabilities from current sensors.

Corresponding author address: Jun Li, Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison, 1225 West Dayton Street, Madison, WI 53706
E-mail: Jun.Li@ssec.wisc.edu

2. WATER VAPOR INFORMATION FROM IR LMW AND SMW.

One important issue for HES instrument design is to select water vapor spectral coverage. Usually longwave (LW, 650 – 1200 cm^{-1}) is selected for temperature, ozone and surface property retrieval. The water vapor region can be either a longer middlewave (LMW, 1200 – 1650 cm^{-1}) or a shorter middlewave (SMW, 1650 – 2250 cm^{-1}). For example, AIRS uses LMW while GIFTS uses SMW. Selection of both water vapor sides might be a better option in terms of water vapor and trace gas information, however, more data volume will need to be stored and processed. 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 approaches. Regression (EV - eigenvector) followed by physical retrieval algorithm was used in the simulation (Li et al. 2003a); the spectral resolution for all channels is 0.625 cm^{-1} in the simulation. 523 global independent profiles are used in retrieval performance study, and 1 km temperature rms and 2 km relative humidity (RH) rms were created 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), and the HES instrument noise in NEDR for LW, LMW and SMW (lower panel). Figure 2 shows temperature rms at 1km vertical resolution from HES simulated radiances for LW + LMW, LW + SMW, and

LW + SMW with the SMW noise reduced by half. Figure 3 is the same as Figure 2 but for water vapor RH rmse at 2km vertical resolution. In general, the temperature difference between LW+LMW and LW+SMW is about 0.1K, while the water vapor difference is about 1%. With reduce SMW noise, both temperature and water vapor differences between SMW NF=1 and SMW NF=0.5 are significant. Considering other factors for LMW (for example, lower spectral resolution than SMW, more trace gas other than water vapor, etc.), the difference between LW + LMW and LW + SMW should be very small for both water vapor and temperature retrievals.

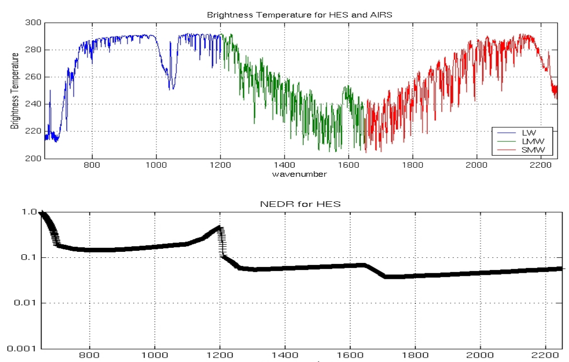


Figure 1. Example of BT spectral for HES LW, LMW, SMW (upper panel) and the noise in NEDR (lower panel).

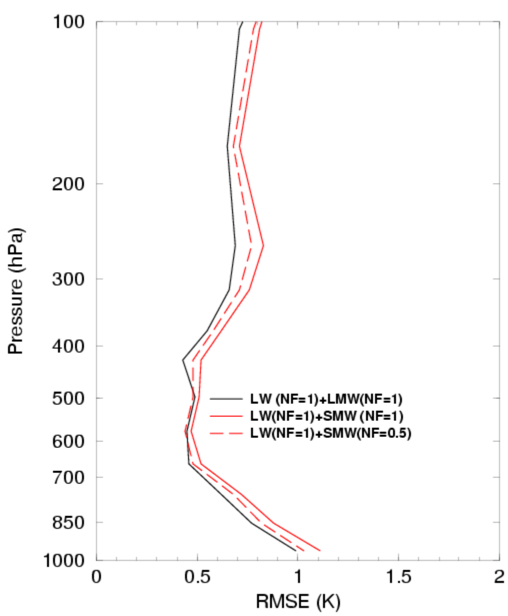


Figure 2. The temperature rms at 1km vertical resolution from HES simulated radiances for LW + LMW, LW + SMW, and LW + SMW with the

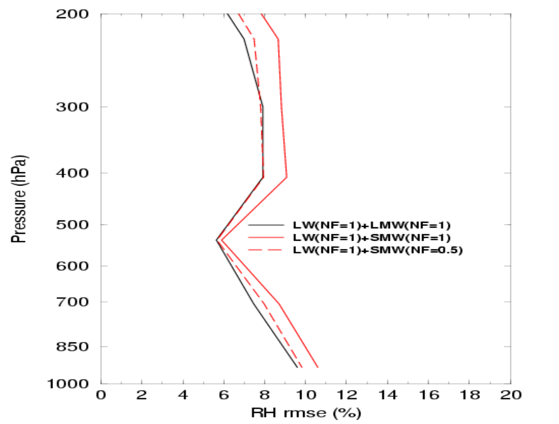
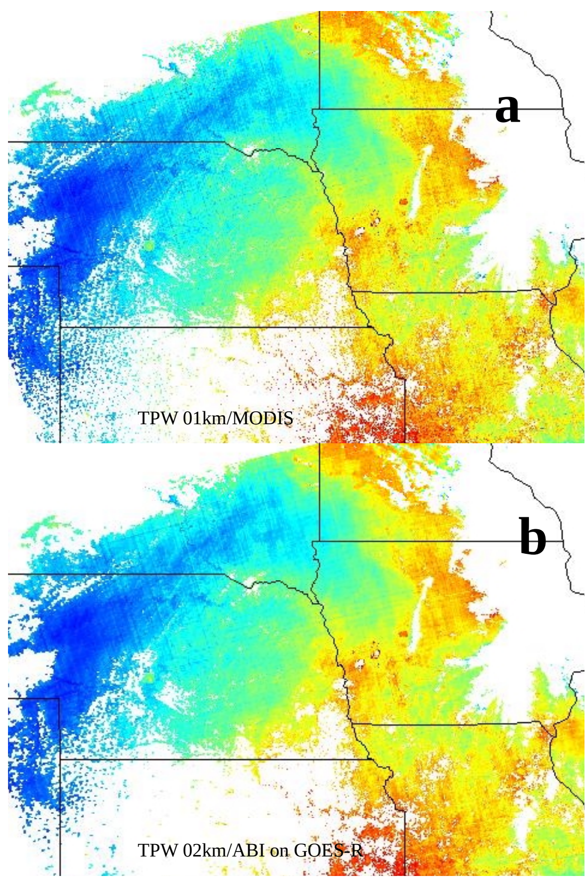


Figure 3. The water vapor RH rmse at 2km vertical resolution from HES simulated radiances for the following configurations: LW + LMW, LW + SMW, and LW + SMW with the SMW noise reduced by half.

3. SPATIAL RESOLUTION STUDY USING MODIS 1km DATA



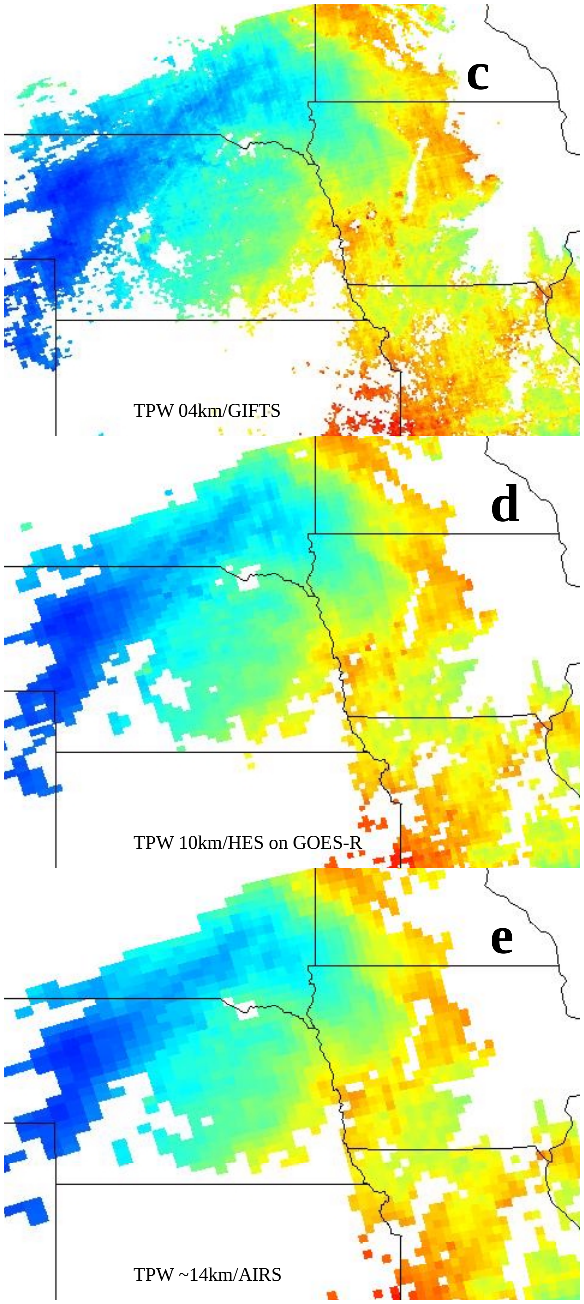


Figure 4. The 1km MODIS TPW (a) at 1900UTC on July 20, 2002 from EOS' AQUA satellite and 20, 2002, simulated ABI TPW at 2km resolution (b), simulated GIFTS TPW at 4km spatial resolution (c), simulated HES TPW at 10km spatial resolution (d), and simulated AIRS TPW at 14km spatial resolution (e), from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

A spatial resolution for HES is very important because "hole hunting" will be the effective way to find clear pixels for atmospheric sounding with out microwave sounding capability on the geostationay satellite. Fine spatial resolution allows high possibility of find clear pixels. This is very important because (a) fine spatial resolution HES measurements will meet the requirement of musicale application of geostational sounder data, and (b) fine spatial resolution enable to find more homogeneous 2 by 2 or 3 by 3 fields-of-view scenes for the possible cloud-clearing process with ABI/HES synergism,

Figure 4 shows the 1km MODIS TPW (a) at 1900UTC on July 20, 2002 from EOS' AQUA satellite, simulated ABI TPW at 2km resolution (b), simulated GIFTS TPW at 4km spatial resolution (c), simulated HES TPW at 10km spatial resolution (d), and simulated AIRS TPW at 14km spatial resolution (e), from retrieved MODIS TPW at 1km spatial resolution shown in panel (a). It can be seen that coarser spatial resolution results in smoothed TPW gradient and less clear coverage. A spatial resolution of 10km or better is being 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, and the middle-wave spectral resolution on the water vapor sounding retrieval. Studies have been conducted 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, cloud emissivity by using the local minimum 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 the rock emissivity spectrum from observation). The BT difference between the two spectrum in the figure results solely from the difference emissivity spectrum in the calculations. Figure 6 shows (from upper to lower panels) the BT spectrum with rock emissivity, true emissivity (black line), retrieved emissivity 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. Both half noise and nominal noise will create emissivity variance contrast between 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 contrast in a lower spectral resolution. 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 with lower spectral resolution (e.g., 1.25 cm^{-1}), only half noise will create good surface property retrieval.

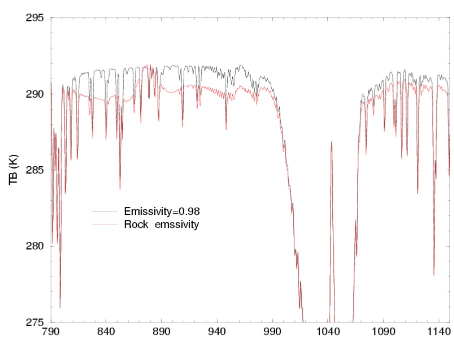


Figure 5. The calculated LW BT spectrum at 0.625cm^{-1} with two different IR surface emissivity spectrum (black line shows the BT with a constant emissivity of 0.98 and the red line shows the BT with rock emissivity spectrum from observation).

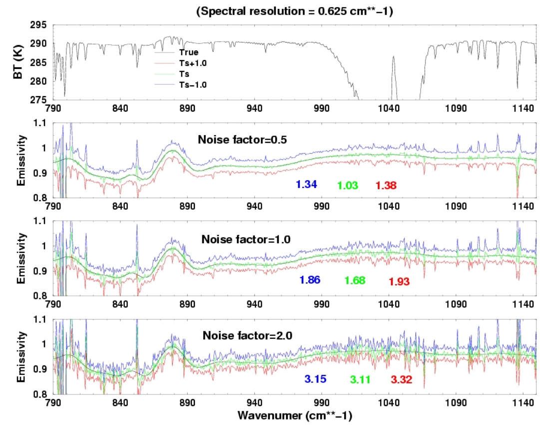


Figure 6. The BT spectrum with rock emissivity, true emissivity (black line), retrieved emissivity with true surface skin temperature (green line) and surface skin temperature deviated by 1K (green and red lines). The noise factor indicates the noise added in the simulation (e.g., 0.5

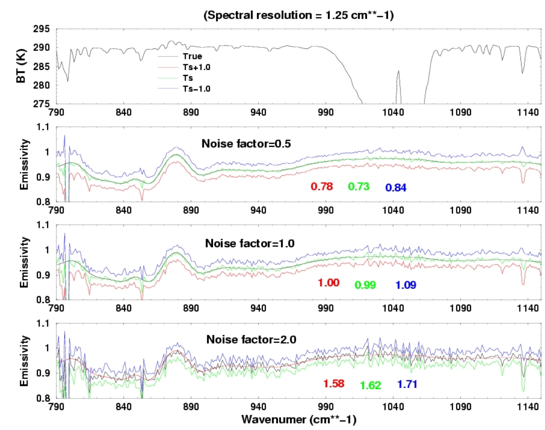


Figure 7. The same as Figure 6 but with spectral resolution of 1.25 cm^{-1}.

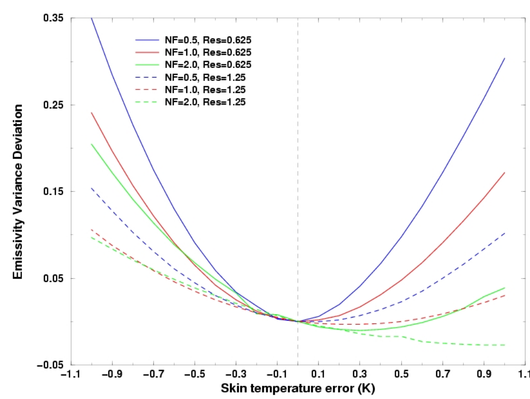


Figure 8 shows the emissivity variance difference between wrong skin temperature and true skin temperature as a function of skin temperature error, different lines correspond to various spectral resolutions and noise factors.

Spectral resolution also determines the vertical resolution of temperature and moisture soundings. Higher spectral resolution corresponds to higher vertical resolution. Figure 9 shows the temperature vertical resolutions from HES two-band option (LW+SMW) with spectral resolution of 0.625, 1.25 and 2.5 cm^{-1}, respectively.

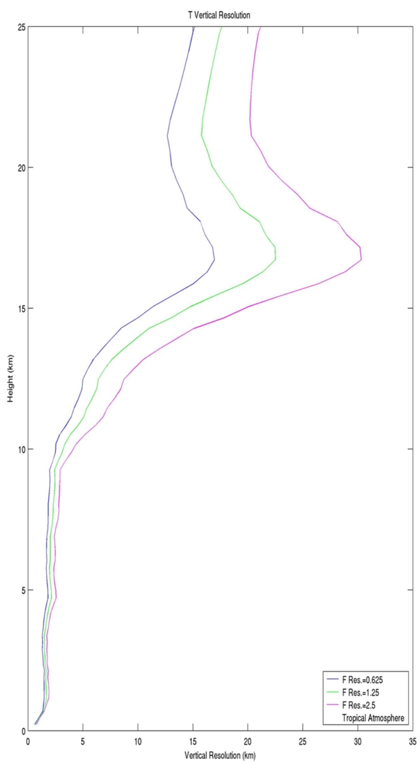


Figure 9. The temperature vertical resolutions from HES two-band option (LW+SMW) with spectral resolution of 0.625, 1.25 and 2.5 cm^{-1}, respectively. The Tropical atmosphere is used in the calculations.

5. ABI/HES SYNERGISM

Advanced Baseline Imager (ABI) (Schmit et al. 2004) will provide cloud mask, cloud phase, classification mask etc. with high spatial resolution (~ 2km). Those products are very useful to characterize the HES sub-pixel (~ 10km) cloud property. An imager/sounder collocation algorithm and software were created, for a given sounder footprint, all the imager pixels within the footprint are found. MODIS data and AIRS data were used for demonstrating sounder sub-pixel cloud characterization (clear/cloud detection, cloud phase determination, single/multi-layer cloud determination) using high spatial resolution imager cloud products (Li et al. 2004a). In addition, imager products serves as background information, the atmospheric and cloud properties such as cloud-top pressure (CTP), effective cloud amount (ECA), cloud optical thickness (COT), and cloud particle size (CPS), can be derived from sounder radiances with much better accuracy, this is demonstrated by cloud property retrieval from synergistically MODIS/AIRS data (Li et al. 2004b, 2004c).

Figure 10 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 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.

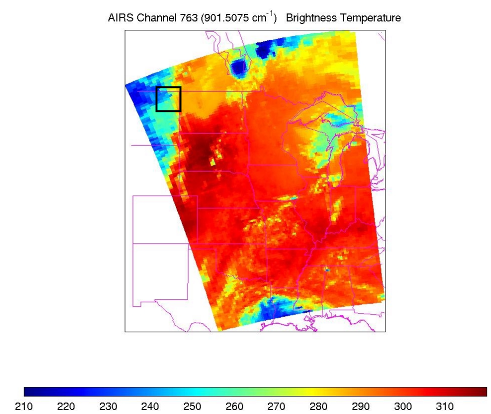


Figure 10. An AIRS BT image at a window region at 19:17UTC on 06 September 2003 (granule 193). The upper left square indicates the small area for AIRS sub-pixel cloud characterization and MODIS/AIRS synergistic retrieval study.

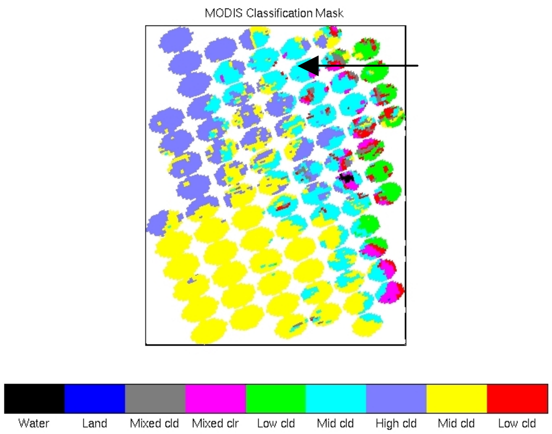


Figure 11. The study area (see Figure 9 for the location of the study area) of the MODIS classification mask collocated to AIRS footprints.

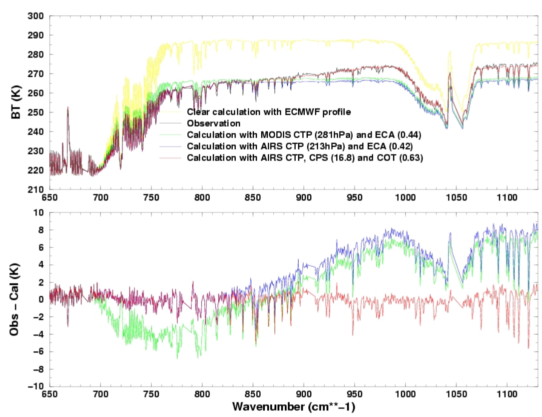


Figure 12. The AIRS longwave clear BT calculation from the ECMWF forecast model analysis (yellow line), the cloudy BT calculation with the MODIS CTP and ECA (green line), the BT calculation from the AIRS retrieved CTP and ECA, and the BT calculation with AIRS retrieved CTP as well as CPS and COT (redline), 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 11 shows the MOIDS classification mask (Li et al. 2003b) 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 arrow in this figure is used to show the MODIS/AIRS synergistic cloud retrieval. This pixel is identified by 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 12 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 12 shows the corresponding BT difference between observation and calculation. As described, the MODIS cloud products serves as the background information in the AIRS retrieval; a variational (1DVAR) approach is used for MODIS/AIRS synergistic retrieval CTP, ECA, CPS and COT products (Li et al. 2004b, 2004c). It shows that there is a large difference between calculation with the MODIS cloud products and observation in the CO_2 region. However, 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. 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.

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 1 cm^{-1} or better should be consider at window region along with a good signal-to-noise ratio is needed for surface property

retrieval. Higher spectral resolution corresponds to higher vertical sounding resolution.

(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 products than that from either system alone. MODIS/AIRS data has been used for demonstrating this.

Future works will focus on more HES trade-off study for HES formulation, and more ABI/HES synergism study for better atmospheric sounding and non-sounding products.

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