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GIFTS SOUNDING RETRIEVAL ALGORITHM DEVELOPMENT

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1. INTRODUCTION

Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) will enable the measurement of temperature and moisture profiles with high spatial and temporal resolution for the purpose of producing wind profiles and observing thermodynamic and dynamic features related to the turbulent atmosphere and the evolution of severe storm systems, including tornadic storms and hurricanes. A sounding retrieval algorithm has been developed for processing the clear sky radiances. The algorithm is a statistical retrieval followed by a nonlinear iterative solution. In the statisitical retrieval procedure, the training data set of global radiosonde profiles used for establishing the synthetic regression algorithm was enhanced through the addition of more radiosonde observations, particularly in under-represented weather regimes. IR surface emissivity measurements sorted by ecosystem type are used to improve the surface characterization in the training data, and a more physical basis for assigning a skin temperature to each training profile has been investigated. Simulation of cube data with MM5 shows GIFTS is able to capture both the spatial and temporal features of atmospheric soundings (Sun et al. 2004, this volume). MODIS and AIRS data on EOS' Aqua satellite are also used for testing the algorithm for GIFTS sounding retrievals.

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2. FORWARD MODEL AND INVERSE MODEL FOR GIFTS RADIANCES

The atmospheric temperature and moisture sounding profiles are the primary level 2 product to be retrieved from GIFTS measurements. Other derived products such as stability indices, water vapor motion winds etc, are derived from the high spatial and temporal resolution sounding products. The purpose of this work is to provide a task description of the theoretical and practical aspects of the GIFTS temperature and moisture sounding retrieval algorithm. Most of the sounding expertise for this endeavor has been acquired with existing high spectral resolution infrared sounding instrument projects such as aircraft base High-resolution Interferometer Sounder (HIS), NPOESS Airborne Sounder Testbed Interferometer (NASTI) and space-based Atmospheric Infrared Sounder (AIRS). The sounding techniques developed for these existing sensors have been translated directly to the GIFTS sounding algorithm. For example, operational sounding algorithm (Li et al. 2000; Zhou et al. 2002; Seemann et al 2003), forward model for both clear and cloudy skies, will form the basis for GIFTS sounding algorithm development. The advantage of GIFTS for retrieving sounding profiles is its semi-continuous spectral measurements of more than 1600 infrared channels with spectral resolution of ~0.6 cm^{-1} and high spatial resolution of ~4 km at nadir.

GIFTS will produce a very large volume of data that needs to be acquired and processed efficiently for real-time data and products distribution. A prototype sounding processing scenario for GIFTS products will be on a "cube-by-cube" basis, meaning that the data will be processed as it is acquired. The processing will likely be parallel, since the basic sounding problem is 1-d and suitable for multiprocessing. Both simulated level-1 (calibrated top of the atmosphere radiances) and level-2 (atmospheric profile state) information are required to perform such sounding tasks. Since GIFTS only provides infrared measurements, clouds will greatly attenuate the radiance signal coming from below the clouds. The radiative transfer problem for clouds over the spectral region of GIFTS measurements will need to be tasked separately and GIFTS sounding retrieval algorithms developed for cloudy conditions.

To perform the regression retrieval, GIFTS radiances are calculated from the radiosonde observations of the atmospheric state, and the regression coefficients are generated from these calculated radiance/atmospheric profile pairs. The radiative transfer calculation of the GIFTS spectral radiances is performed using a transmittance model called Pressure layer Fast Algorithm for Atmospheric Transmittances (PFAAST) (Hannon et al. 1996); this model has 101 pressure level vertical coordinates from 0.05 to 1100 hPa. The calculations take into account the satellite zenith angle, absorption by well-mixed gases (including nitrogen, oxygen, and carbon dioxide), water vapor (including the water vapor continuum), and ozone. The temperature and moisture sounding retrievals are produced when the regression coefficients are applied to the actual clear sky GIFTS measurements. The advantage of this approach is that it does not need GIFTS radiances collocated in time and space with atmospheric profile data, it requires only historical profile observations. This statistical regression algorithm is computationally efficient, numerically stable, and simple.

In order to provide soundings with the required level of accuracy, proper treatment of surface and cloud emissivities in the forward radiative transfer model is very important. In the GIFTS sounding algorithm, IR surface emissivity measurements sorted by ecosystem type are used to improve the surface characterization in the training data, and a more physical basis for assigning a skin temperature to each training profile has been investigated.

To address forward model uncertainties that result in differences between observed and calculated radiances, radiance bias adjustments will be studied and implemented in the retrieval algorithm. Variations in these biases over the course of a year must be investigated. The GIFTS algorithm will include an advanced global bias scheme that uses a regression based on air-mass predictors (atmospheric layer thickness, surface skin temperature, and TPW) such as that employed on the TIROS Operational Vertical Sounder (TOVS) (Harris and Kelly, 2001).

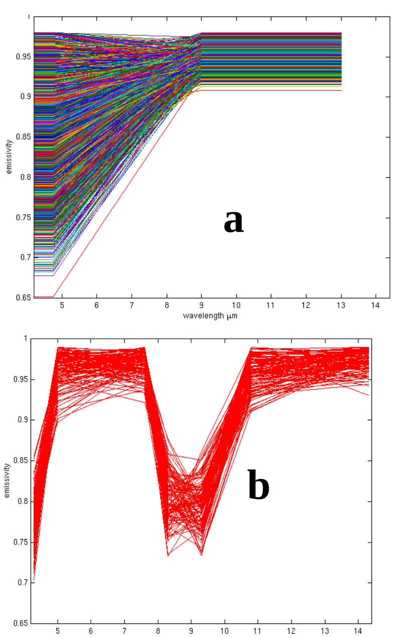
GIFTS has two bands that contain more than 1600 channels; however, it is not necessary to use all channels in the retrieval processing. A subset of channels (optimal channels) can be selected in the physical retrieval process. The reasons for GIFTS channel selection are: (a) there are information redundancies among all the GIFTS channels; and (b) the weighting function and inverse computation is very time consuming in each iteration when using all channels, so a set of optimal channels will significantly reduce the retrieval processing time. Channel selection has been studied to select a set of optimal GIFTS channels.

GIFTS cloudy FOV detection will be based on current GOES sounder cloud detection technique. In addition, spatial information, brightness temperature difference, along with the spectral information can be combined to better detect cloud (Li et al. 2003). A reliable GIFTS cloud mask algorithm is been developed developed for both sounding retrieval and cloud property retrieval.

Also, sounding retrieval error and error correlation will be quantized. Reliable knowledge on the error characteristics of retrievals is of absolute necessity for proper use of these data. Information on instrument noise and error, retrieval variable error and error correlations are necessary information for a data assimilation system to determine suitable reliability weights and achieve the optimum balance between the multiple inputs of in situ and remotely-sensed data. During the GIFTS assessment phase the following sounding algorithm tasks and processing procedures will need to be implemented and extensively tested to meet all the operational demands.

3. EMISSIVTY IN THE TRANING DATA

Previously, the emissivity assigned to the training data profiles was given a mean of 0.85 at 4µm and 0.95 between 9µm and 14µm, with a linear interpolation in between (see Fig. 1a). A standard deviation was applied to these values to simulate some variability. This approach did not properly represent actual emissivities, particularly in desert regions. A study using MODIS data shows that some problems existed over desert regions with the artificially assigned emissivity. Total Precipitable Water (TPW) from Aqua MODIS in Figure 1b shows along-track stripes of high moisture due to unstable retrievals on this hot day in August 2002. To address this problem, more representative emissivity values were assigned to each of the training profiles. Profiles were categorized as ocean, snow/ice, desert, and non-desert land, and an appropriate emissivity was derived for each profile based on measurements by Dr. Wan and the UCSB MODIS land surface temperature group (http: http://www.icess.ucsb.edu/modis/EMIS/html/em.html). The new emissivities used for the desert profiles are shown in Figure 1c, and the improvement in the TPW retrievals using the training data set with the new emissivity is in Figure 1d.



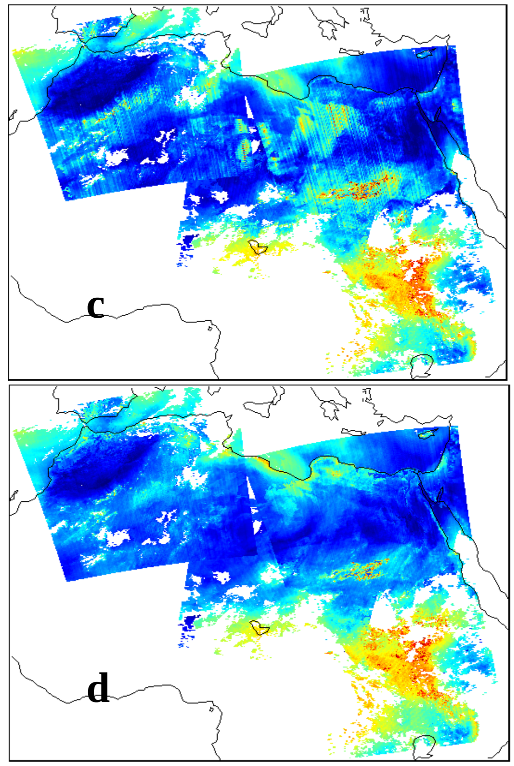


Figure 1. a) Emissivity spectra for all training data profiles used in the original algorithm. b) Aqua MODIS TPW (mm) for August 24, 2002 over the Sahara desert retrieved with coefficients derived using the emissivity spectra in (a). c) New emissivity spectra for desert profiles. d) As in (b) except retrieved with coefficients derived using different emissivity spectra for ocean, ice and snow, desert, and non-desert land such as those for desert shown in (c).

4. SIMULATIONS

In the simulation study, the GIFTS radiances are calculated with the forward model. The GIFTS instrument noise is added into GIFTS radiances, the regression followed by a nonlinear physical retrieval procedure (Li and Huang 1999; Li et al. 2000; Zhou et al. 2002) was applied to the simulated GIFTS radiances for atmospheric temperature and moisture profile retrievals. The temperature and moisture retrievals are then compared with the true radiosonde profiles used in the simulation for retrieval accuracy analysis.

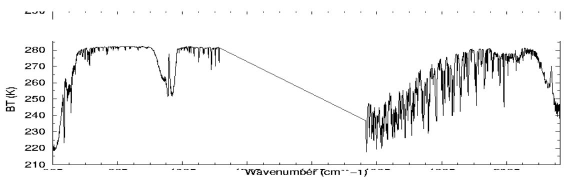


Figure 2, GIFTS brightness temperature spectrum calculated from radiosonde profile.

Figure 2 shows one example of a GIFTS brightness temperature spectrum calculated from radiosonde profile.

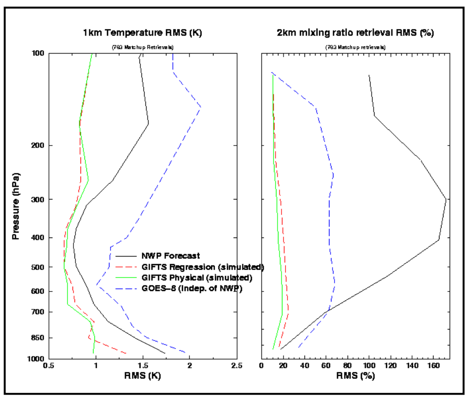


Figure 3, the 1km temperature and 2km water vapor mixing ratio retrieval RMSE (water vapor RMSE is in terms of percentage) from GOES-8 real radiance measurements, GIFTS simulated radiances with noise included, and forecast/analysis.

The physical non-linear iterative temperature/moisture retrieval algorithm for GIFTS (685 – 1150 cm^{-1} longwave band with 0.625 cm^{-1} spectral resolution for temperature, cloud and ozone retrievals, and 1650 – 2250 cm^{-1} short middle wave with 0.625 cm^{-1} spectral resolution for water vapor retrievals) has been applied to a subset of independent global radiosonde profiles. Temperature and moisture retrievals from current GOES-8 radiance measurements and simulated IOMI-GIFTS radiances are compared with time/space co-located radiosonde observations and numerical weather prediction (NWP) forecasts. Figure 3 shows the 1km temperature and 2km water vapor mixing ratio retrieval RMSE (water vapor RMSE is in terms of percentage) from GOES-8 real radiance measurements, GIFTS simulated radiances with noise included, and forecast/analysis. Note that 1) only data at 00UTC and 12UTC are used, 2) both GOES-8 real retrievals and GIFTS simulated retrievals are independent of forecast/analysis. Results show the large improvement of GIFTS boundary layer moisture retrievals over either the current GOES-8 sounder retrieval or the NWP/forecasts.

5. ALGORITHM TESTING WITH AIRS DATA

The algorithm developed has been tested using AIRS radiance measurements from the Aqua satellite. Figure 4 shows the AIRS brightness temperature of an AIRS window image (upper panel) and the clear AIRS brightness temperature image (lower panel) using the cloud detection algorithm. Figure 5 shows the AIRS temperature retrievals (upper left panel) along with MODIS temperature retrievals (lower left panel) at 850hPa. The upper right and lower right panels show the water vapor mixing ratio images from AIRS and MODIS measurements. The MODIS atmospheric product is validated with other observations (Seemann et al. 2003). The AIRS and MODIS retrievals show the similar patterns for both temperature and water vapor. The AIRS profiles have more vertical accuracy while MODIS has more spatial features.

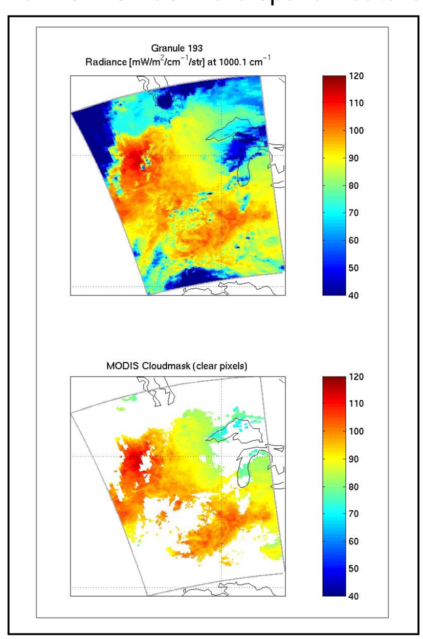


Figure 4, the AIRS brightness temperature of an AIRS window image (upper panel) and the clear

AIRS brightness temperature image (lower panel) using cloud detection algorithm.

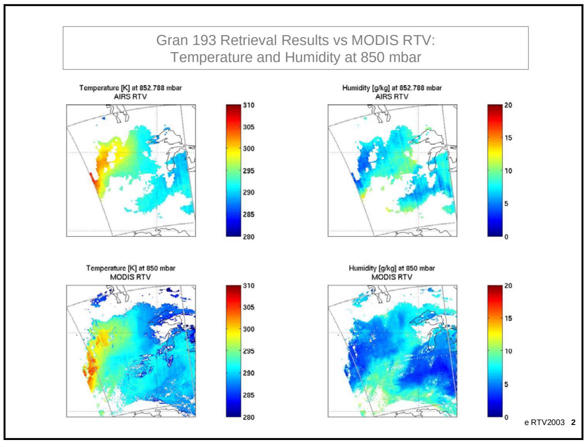


Figure 5, the AIRS temperature retrievals (upper left panel) along with MODIS temperature retrievals (lower left panel) at 850hPa. The upper right and lower right panels show the water vapor mixing ratio images from AIRS and MODIS measurements.

6. CONCLUSIONS

Retrieval simulations have been carried out to demonstrate the capability of GIFTS on temperature and moisture remote sensing. The algorithm has been tested using MODIS and AIRS data. The following conclusions can be drawn from this study.

(1) Surface emissivity and surface skin temperature assignment to the training profiles are very important for better retrieval results. This has been demonstrated with MODIS retrievals.
(2) A regression based temperature and water vapor retrievals can bed improved using a physical retrieval approach.
(3) Based on testing using AIRS data, the algorithm is stable for operational retrieval processing.

Future work will focus on more validation of the GIFTS sounding retrieval algorithm using Atmospheric Infrared Sounder (AIRS) radiance measurements, improving the training data set with more realistic surface emissivity and surface skin temperature assignment.

ACKNOWLEDGEMENT

This program is supported by NOAA GIFTSPAPE program NA07EC0676.

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