

# **Physical Modeling for Processing Geosynchronous Imaging Fourier Transform Spectrometer-Indian Ocean METOC Imager (GIFTS-IOMI) Hyperspectral Data**

Dr. Allen H.-L. Huang, Principal Investigator (PI)  
Cooperative Institute for Meteorological Satellite Studies (CIMSS)  
Space Science and Engineering Center (SSEC)  
University of Wisconsin–Madison (UW)  
1225 West Dayton Street  
Madison, Wisconsin 53706-1695  
phone: (608) 263-5283 fax: (608) 262-5974 email: [allen.huang@ssec.wisc.edu](mailto:allen.huang@ssec.wisc.edu)

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## **LONG-TERM GOALS**

This Office of Naval Research (ONR), Department of Defense (DoD) research effort has three main long term goals. They are: 1) to bridge the physical principles of a hyperspectral data retrieval problem with the mathematical algorithms that try to solve it; 2) mathematically quantify the location of useful information to complete a physically-driven application in the electromagnetic spectrum, and 3) develop physically-based hyperspectral data processing applications for surface material classification and identification, atmospheric parameter retrieval formulation, and coastal water quality assessment.

## **OBJECTIVES**

The objective of this DoD research effort is to develop and demonstrate a fully functional GIFTS-IOMI hyperspectral data processing system with the potential for a transition to operational deployment in a centralized and/or shipboard real-time processing environment once GIFTS-IOMI is stationed over the Indian Ocean. The system will provide specialized methods for the characterization of the atmospheric and surface material components of the battlefield environment that will take good advantage of the revolutionary capabilities of the new GIFTS-IOMI mission.

## **APPROACH**

This project involves four primary components designed to address the key research objectives of this DoD ONR Multidisciplinary Research Program of the University Research Initiative (MURI). The plan is to chart an evolution of GIFTS-IOMI, from the information content, to describing the mesoscale (length scales 25–1000 km) and microscale (tens of meters) environment.

### *1. Mathematical Quantification of Useful Hyperspectral Information*

UW Co-Investigators (Co-I) Dr. Jun Li, Dr. Bormin Huang, Dr. Paul Lucey, Erik Olsen, and PI Dr. Allen Huang have developed a method that objectively identifies the information-rich radiance channels that possess the most useful information.

# Report Documentation Page

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2. *Radiative Transfer Modeling (Clear and Cloudy-Sky Emission/Absorption, Atmospheric Particulate Emission/Absorption, Surface Emission/Absorption)*

Dr. Dave Tobin and Leslie Moy have produced an improved clear-sky fast radiative transfer model for GIFTS-IOMI. Work on this aspect of the project involves subcontractors Dr. Ping Yang (Texas A&M Univ.), Dr. Gary Jedlovec and Dr. Sundar Christopher (Univ. of Alabama-Huntsville), and Dr. Irina Sokolik (Univ. of Colorado–Boulder).

3. *Mathematical Retrieval Algorithm Development (Atmospheric Parameters, Suspended Particulate Detection and Quantification, Sea Surface Temperature, Surface Material Identification)*

Co-Is Dr. Steve Ackerman, Dr. Allen, Dr. Jun Li, Dr. Paul Lucey (UH), Wayne Feltz, Chris Velden, Dr. Irina Sokolik, and Dr. John Mecikalski are developing parameter retrieval methods.

4. *Product Research (Ocean Surface Characterization, Lower Tropospheric Temperature, Moisture and Winds, Surface Material Products, Aerosols, Derived, Second Order Products)*

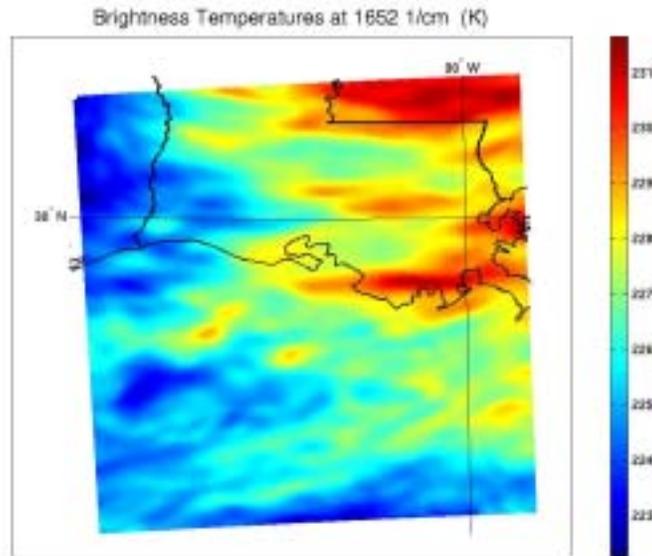
Co-Is Dr. John Mecikalski, Dr. Paul Lucey, Chris Velden, Wayne Feltz, Derek Posselt, and Dr. Steve Ackerman are using simulated GIFTS-IOMI data within retrieval algorithms.

## **WORK COMPLETED**

Funding over the period 1 October 2001–30 September 2002 through this MURI Topic #15: “*Physical Modeling for Processing of Hyperspectral Data*” has been used to perform basic research in the above four proposed research components. This research has involved all UW CIMSS investigators listed in the original proposal, as well as four subcontractors outside UW. The main reporting activity occurred on 14-15 May 2002 through the *Second MURI Workshop* at the UW CIMSS. This workshop brought together the DoD MURI program managers, ONR science advisors, NASA, NOAA and Naval Research Laboratory representatives, UW MURI subcontracted investigators [from the University of Alabama–Huntsville (UAH), Texas A&M University (TAMU), and the University of Colorado at Boulder (UCB)] and UW and University of Hawaii (UH) MURI investigators. During this two-day meeting, all non-MURI representatives were informed of progress made in the area of hyperspectral GIFTS data simulation and retrieval algorithm development. In addition, the UW PI, Program Manager (PM), and all Co-Is obtained a more complete understanding of this MURI program from the DoD perspective.

A main focus of UW-MURI’s first full year of funding has been developing simulated hyperspectral data sets for the following purposes 1) GIFTS-IOMI “fast” model development, 2) GIFTS-IOMI “forward” radiative transfer model development, and 3) GIFTS-IOMI “retrieval” algorithm development. Current efforts to model the output of the GIFTS-IOMI instrument involve three steps. First an atmospheric numerical model (e.g., the Penn State/NCAR MM5) is used to simulate the desired atmospheric conditions. This atmosphere is considered “truth” to which any subsequent algorithm test can be compared. Temperature and water vapor profiles, surface temperature, surface height, liquid water content, and ice water content are extracted from this simulation and used as input to a coefficient regression-based radiative transfer model. The GIFTS radiative transfer model produces interferogram information and top-of-the-atmosphere (TOA) radiance “cubes” of the quality expected from the GIFTS-IOMI instrument [128 x 128 (4 km) array at 0.57 cm<sup>-1</sup> spectral resolution

with 776 radiance channels between wave numbers 685-1130  $\text{cm}^{-1}$  and 1047 channels between 1650-2250  $\text{cm}^{-1}$ ]. From these radiance spectra, simulated atmospheric state variables are then “retrieved” (e.g., vertical temperature profiles), and quality tested against the original NWP data they were generated from. Figure 1 shows an example of the simulated brightness temperatures obtained from this GIFTS simulation procedure.



***Figure 1. Simulated GIFTS-IOMI brightness temperatures at wavenumber 1625  $\text{cm}^{-1}$  for a region possessing a mix of ocean and land surfaces.***

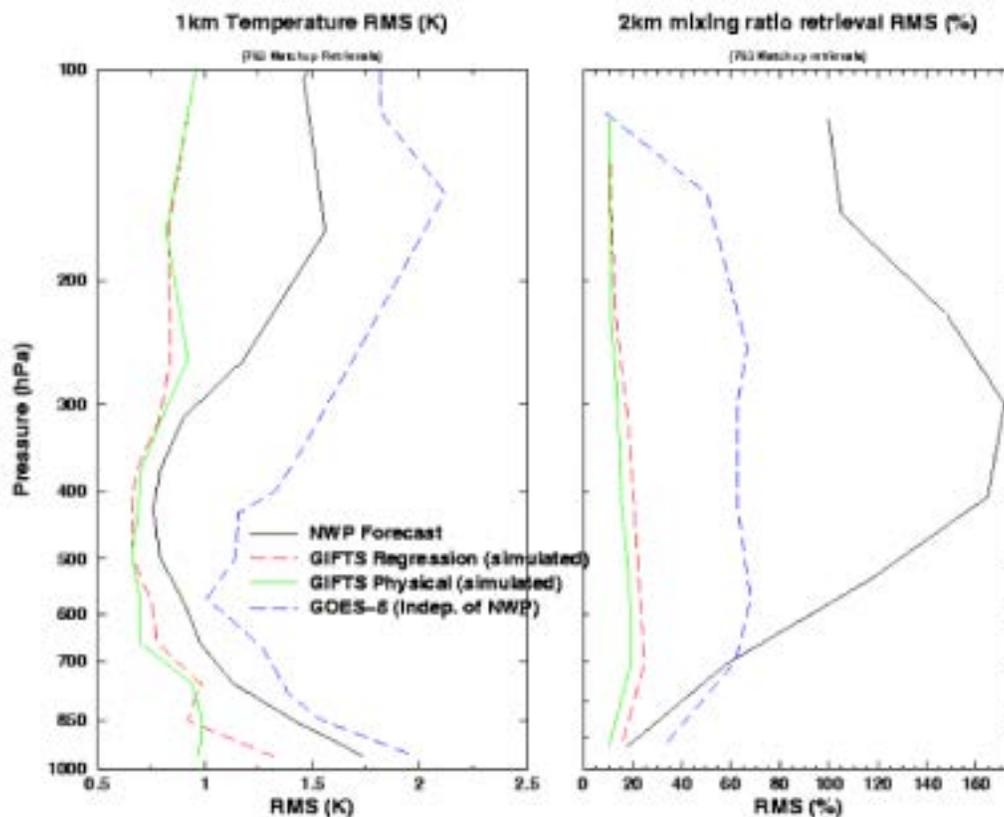
The final step in the GIFTS-IOMI simulation procedure involves computing instrument-specific effects for the given radiance spectrum, including apodization, off-axis effects, detector responses, background contributions from the instrument, and quantization of the signal for conversion to a digital stream. The importance of simulating GIFTS-IOMI data at this stage in the MURI research effort cannot be overstated as it allows all MURI investigators to formulate algorithms well in advance of the GIFTS-IOMI instrument launch.

Clear-sky forward model development for GIFTS-IOMI retrievals has received much attention within this MURI to date. It involves two tasks: 1) Adding functionality to the existing GIFTS-IOMI fast model, and 2) developing an improved “fast” forward radiative transfer model. UW-CIMSS has nearly completed the task of reproducing the current GIFTS-IOMI clear-sky regression fast model with new, more flexible software. This includes generation of monochromatic layer-to-space transmittances, degradation to GIFTS spectral resolution, computation of direct and derived gas components, computation of regression predictors, and computation of regression coefficients. This is a “LBLRTM based PLOD-type” model. We are currently characterizing the accuracy of this model with comparisons to LBLRTM calculations for the dependent profile set (e.g., analyzed data from the Atmospheric Infrared Sounder, AIRS).

A physical retrieval algorithm has been developed for temperature and moisture sounding retrieval from GIFTS-IOMI radiances. In the simulation study, GIFTS-IOMI radiances are calculated from

radiosonde observations of the atmospheric state using the fast radiative transfer model developed by the UW MURI team. The GIFTS-IOMI instrument noise is then added into GIFTS-IOMI radiances, and a regression followed by a nonlinear physical retrieval procedure (Li et al. 2000; Zhou et al. 2002) was applied to the simulated GIFTS-IOMI radiances for temperature and moisture profile retrievals.

Figure 2 shows the 1-km temperature and 2-km water vapor mixing ratio retrieval RMSE (water vapor RMSE is in terms of mixing ratio percentage) from GOES-8 real radiance measurements, GIFTS-IOMI simulated radiances with noise included, and forecast/analysis. Results show the large improvement of GIFTS-IOMI boundary layer moisture retrievals over both the current GOES-8 sounder and the NWP forecasts. The impact of contrast between surface skin temperature and surface air temperature on boundary layer moisture retrieval is also investigated; a contrast of 5 K or larger will help boundary layer moisture retrieval. Simulation shows that the significant spatial and temporal features of atmosphere are well identified from GIFTS retrievals.



**Figure 2. The 1 km temperature and 2 km water vapor mixing ratio retrieval RMSE (water vapor root mean square error, RMSE, is in terms of percentage) from GOES-8 real radiance measurements, HES simulated radiances with noise included, and forecast/analysis.**

Initial efforts have also focused on updating the existing cloud and water vapor tracking algorithm for wind generation to: 1) be independent of operating system byte order, and 2) to remove all satellite/sensor specific references. A recent study has shown that the CIMSS winds retrieval algorithm is model first-guess independent, providing the needed flexibility. Improvements are thus being made

to improve performance and reduce algorithm development/maintenance impact toward the formation of a sensor-independent code.

Work has also commenced on atmospheric parameter regression retrievals from the GIFTS-IOMI simulation cubes. Retrieved lifted index and equivalent potential temperature show that differences (“truth–retrieved”) are  $\pm 2.5$  for lifted index, and  $\pm 3.5$  for equivalent potential temperature. Additional new work is being done to evaluate boundary layer turbulence using hyperspectral capabilities.

Ongoing research at UH involves transitioning the UH longwave infrared (LWIR) Airborne Hyperspectral Imager (AHI) instrument to match the radiance spectra of the forthcoming GIFTS-IOMI instrument. Tests using the AHI at UH occurred during early 2002, with additional field experiments planned into 2003 to collect information over various land surfaces in Hawaii. The UH is establishing a methodology to accurately estimate surface spectral emissivity using a combination of high-resolution spacecraft data and library information, with the aim being to obtain surface emissivity information using GIFTS. This work allows UW and UH to collaborate fully as UW shares simulated GIFTS data with UH, and UH provides emissivity to algorithms to UW.

Other UW MURI subcontractor involvement during this period is summarized as follows: UAH is working to develop new algorithms suitable for processing GIFTS-IOMI measurements to differentiate cloudy regions from clear and identifying unique characteristics such as cloud type and height. Additionally, UAH will investigate the upper limits of wind tracking accuracy from geostationary satellite imagery derived from the detector arrays used by GIFTS-IOMI. Other work, by UCB, will involve the detection of aerosol and dust clouds and distinguishing these from water clouds. This UCB work requires the development of forward modeling capabilities to characterize spectral signature of dusts of different origin. UCB will analyze high spectral data collected during heavy dust conditions and develop appropriate models to interpolate and model its radiative effects. This modeling will improve GIFTS-IOMI ability to derive the high priority visibility product. Finally, the TAMU subcontract is working heavily on cloud-sky radiative modeling, with emphasis on both ice and water clouds. The development of a cloud-sky forward retrieval model by TAMU will complement the clear-sky radiative transfer modeling work at UW.

## **RESULTS**

The meaningful technical results since 1 October 2001 are summarized as follows:

- Full development of a robust approach to simulate GIFTS-IOMI data.
- Continued development of an improved clear-sky fast model for GIFTS-IOMI.
- First development and testing of a physical non-linear algorithm for the retrieval of atmospheric temperature and water vapor profiles simultaneously from GIFTS-IOMI radiance spectra.
- Improving estimates of surface emissivity using hyperspectral data.
- Cloud-sky radiative transfer modeling development at TAMU, UAH and UCB.
- First aerosol and dust modeling research from UCB that considers the use of GIFTS data sets.

## **IMPACT/APPLICATIONS**

The immediate application and impact of the basic research accomplished to date is the use of simulated GIFTS-IOMI data to formulate atmospheric parameter retrieval algorithms to form the meteorological products highlighted by DoD as valuable to Navy fleet operations.

## **TRANSITIONS**

The algorithms described above for GIFTS-IOMI continue to development. No person or institutions outside UW and UH are utilizing them. The basic research is being performed to form robust atmospheric parameter products to address the Year 3-5 proposed tasks. In addition, UH continues to coordinate UW on basic surface characterization research as improved surface emissivity estimates are obtained. All UW subcontractors will collaborate toward completion of a full (clear-sky, cloudy-sky, surface) suite of retrieval algorithms. Student sharing between UW and UH is forthcoming.

## **RELATED PROJECTS**

The projects that closely relate to the UW and UH MURI basic research initiative include: 1) the GIFTS development work at UW supported by NASA and NOAA, 2) student and basic research involvement with Prof. Morgan of UW for using GIFTS-IOMI for NWP, data assimilation and atmospheric parameter retrievals, and 3) the future value of this basic research to a number of UW CIMSS projects related to mesoscale nowcasting for aviation safety issues.

## **SUMMARY**

To date, this UW and UH MURI has provided to the scientific community the first procedures for simulating and using hyperspectral radiance information from GIFTS-IOMI instrument to form atmospheric products that will describe the mesoscale battlespace. These products will some day enhance the efficiency of Naval activities by providing to fleet highly-specialized meteorological information. The development of a first retrieval algorithm and a fast radiative transfer model for GIFTS-IOMI, the transitioning of the AHI instrument to GIFTS-IOMI spectral resolution, and the ability to simulate GIFTS data, highlight the progress that UW and UH have made to date.

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