GOES-R Progress Report for April -June 2005
University of Wisconsin-Madison
Cooperative Institute for Meteorological Satellite Studies

Project Title: CIMSS Participation in GOES-R Risk Reduction
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Remaining Funds: $0

Task 1. Soundings Algorithm Development

Significant Inputs in the last three months
- ❑ *Algorithms:*
  - ○ **Emissivity impact on sounding retrieval found using AIRS data**

There are two basic approaches to handle IR ocean and land surface emissivity in hyperspectral sounding retrieval: (1) simultaneous retrieval of the sounding and IR surface emissivity spectrum, in such a way that only emissivities at some spectrally sensitive window channels are retrieved. Because the number of unknowns in the retrieval is increased with each spectrally dependent emissivity that need to be simultaneously determined along with other unknowns, the retrieval solution becomes an ill-posed problem. The other approach is to predetermine the surface IR emissive spectrum before the physical retrieval starts. For example, use regression for emissivity estimation in such a way that the solution will be stable since the emissivities are predetermined and the number of unknowns is significantly reduced. In the regression approach, the training database contains physically realistic emissivity information of high spectral resolution that is critical for emissivity predetermination. Study shows the high spectral resolution emissivity spectrum needs to be assigned to each profile of the training data to account for the natural variation and be representative of global surface spectral signature. Figure 1 shows one of the examples of low and high resolution emissivity spectrum modeled in the training desert region; the respective AIRS total precipitable water (TPW) retrieval derived from low and high spectral resolution emissivity training database are shown for comparison. The TPW retrieval difference between these two retrievals over desert region is significant. This demonstrates that high spectral resolution emissivity contributes greatly to the retrieval sensitivity over the desert and other land areas as well. Accurate treatment and modeling of emissivity with high spectral resolution will be a key factor for accurate atmospheric profile retrievals such as the TPW shown.
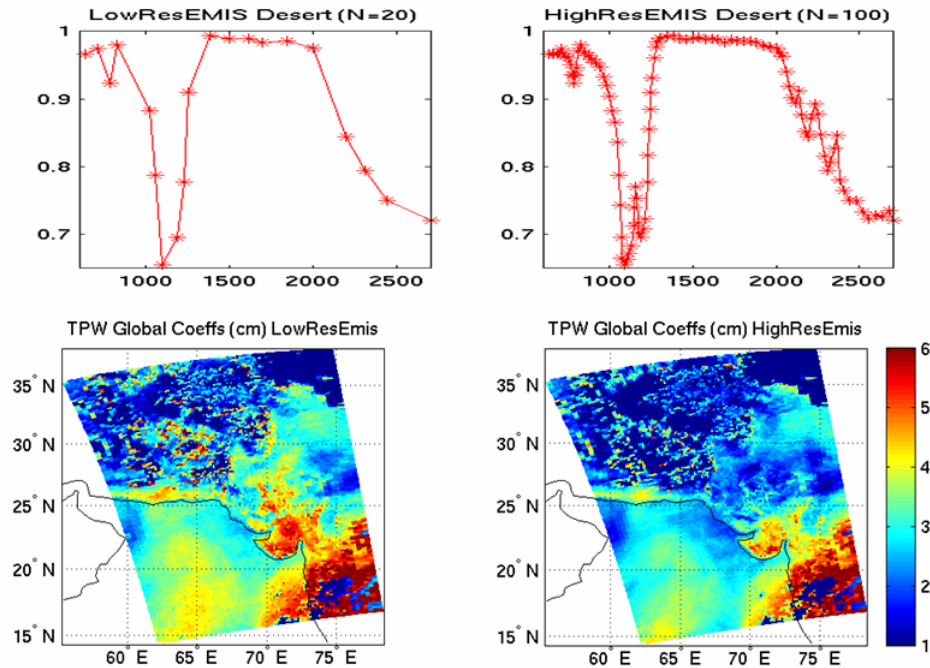
Figure 1: Example of low (upper left), and high (upper right) spectral resolution surface emissivity training database used to derive a regression retrieval of AIRS TPW. The respective TWP retrievals derived from the low (lower left) and high (lower right) spectral resolution emissivity database are shown.

- o **Synergistic Cloud-clearing Algorithm Development**

The ABI/HES cloud-clearing study uses MODIS/AIRS data as proxy. The methodology of cloud-clearing a two-layer cloudy HES footprint is under investigation. The refinement of viewing angle effects on the cloud-clearing performance is also under analysis. Preliminary results show that without a viewing angle correction there might be up to 0.4 K error that can degrade the cloud-clearing quality. The angle effect needs to be corrected using a statistical approach before cloud-clearing or using pairs of the same view angle data to perform cloud-clearing. The impact of cloud-clearing in sounding retrieval is also underway. Figure 2 is an example of retrievals of clear, cloud-cleared and cloudy FOVs, respectively. The collocated ECMWF analysis profile is also displayed for reference.
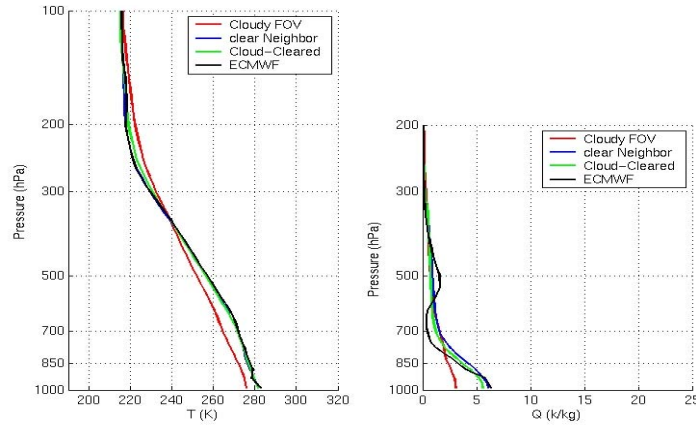
Figure 2: Example retrieval profile of temperature (left), and water vapor (right) of clear, cloud-cleared, and cloudy FOVs and the collocated ECMWF are shown to demonstrate the impact of cloud-cleared radiances on profile retrieval.

- **Cloudy Sounding Retrieval Algorithm Development**

In cooperation with Dan Zhou and Bill Smith Sr. a cloudy sounding retrieval paper entitled *"Thermodynamic and cloud parameter retrieval using infrared spectral data"* has been published. In this paper it was demonstrated that some success was achieved in the ability to retrieve information below scattered and partially transparent cirrus clouds (i.e., clouds with effective optical depths of less than one). The thermodynamic profile information might be obtained by a combination of cloud clearing and by direct retrieval from the clouded radiances using a realistic cloud radiative transfer model. Results achieved with airborne NAST-I observations show that accuracies close to those achieved in totally cloud-free conditions can be derived down to cloud top levels. The accuracy of the profile retrieved below cloud top level is dependent upon the optical depth and fractional coverage of the clouds.

- **NWP Modeling for Geostationary hyperspectral resolution measurement simulation**

The use of the Weather Research and Forecasting (WRF) model to support GOES-R Risk Reduction algorithm development continues to evolve. For now, using our new computing resources, a SGI Altix with 192 GB RAM and 32-64 bit CPUs, and more than 30 Tb of storage, allows us to generate simulations with relatively fine horizontal resolution over a geographic domain comparable in size to what a geostationary satellite will observe from space. Most recently, we have successfully performed a WRF model simulation with 1600x1600 grid points and 50 vertical levels at 8-km horizontal resolution that covers the region from 50 S to 50 N and 130 W to 20 W (figure 3). In the future we should be able to perform even larger simulations with finer horizontal resolution. We can also run the model at any smaller domain with finer spatial resolution that reflects all modes of GOES-R scanning and viewing. Fine temporal resolution ranging from a few minutes to hourly can also be generated to support wind product demonstration. (Note that this modeling capability is a result of many years of model development under the efforts of DOD MURI project. At the end of MURI project we hope through the GOES-R Algorithm Working Group (AWG) we can continue to

advance our model simulation capability to support both GOES-R Risk Reduction and the AGW algorithm prototyping).
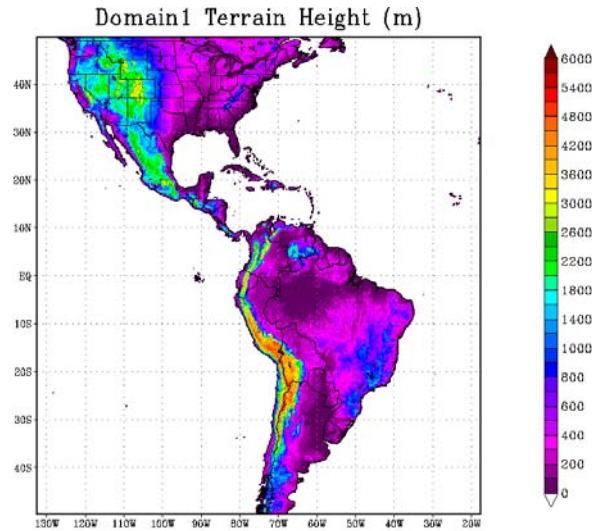

Fig. 3. Geographical region covered by the 1600x1600 grid point domain used for the WRF simulation and can be run at 8-km horizontal resolution.

o Cloudy Forward Model Development

We are continuing to leverage the MURI project in this endeavor. During this quarter the progress is summarized below:

❑ We have continued to refine the implementation of the two-layer cloud. An AMS 2006 presentation will feature the latest progress and model results. A fast and accurate hyperspectral infrared clear/cloudy radiative transfer model is developed to simulate the Top-Of-Atmosphere (TOA) radiances and brightness temperatures over a broad spectral band (~3-100μm). The principal use of this work is to generate TOA brightness temperatures, radiances, and surface to space transmittance over large spatial domains for realistic surface states and atmospheric conditions to assist in retrieval algorithm development for next-generation hyperspectral IR sensors. A two-layer cloud model in the framework of the GIFTS fast model (LY2G) has been implemented and an ecosystem surface emissivity model (MODIS band resolution) has been included. An automatic selection of cloud layer type, top height, optical depth (OD), and effective diameter (De) from mesoscale model outputs and/or from the atmosphere profiles with a two-layer cloud formation model has been developed and incorporated into LY2G. Overall, this model (LY2G) runs in less than 1 second per GIFTS spectrum (3000+ channels) and yields more accurate results in comparison to a one layer cloud model in reference to a complete and sophisticated radiative model, i.e. LBLDIS. For the purpose of comparison and validation, a range of simulations were performed for generating LY2G and LBLRTM/DISORT simulated brightness temperatures for GIFTS channels and equivalent cloudy profiles. Results show that adopting two-layer cloud model at least doubles accuracy of simulations in comparison to one layer-cloud model, which will

eventually increase retrieval algorithm accuracy. A netCDF interface option was added to make easier the visualization of inputs/outputs with Unidata's Integrated Data Viewer (IDV).

❑ We have prepared a manuscript for publication, entitled: *"High-resolution infrared spectral signature of overlapping cirrus clouds and mineral dust"*. In this effort we have amalgamated the clouds and aerosol/dust modeling work into the forward modeling study. Figure 4 is an example simulation spectra affected by the cloud and its underlying dust.
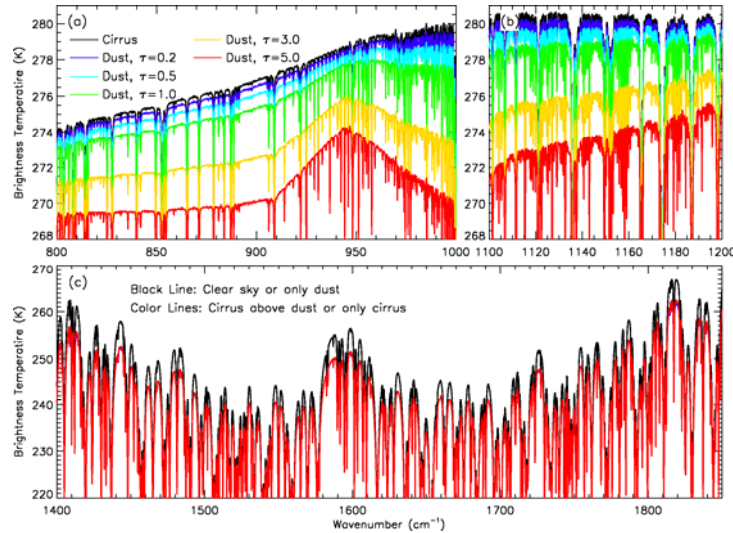

Figure 4. Simulated spectral brightness temperatures at the top of atmosphere as a function of wavenumber for cirrus cloud contaminated by underlying mineral dust with different loading of $\tau = 0.2, 0.5, 1.0, 3.0,$ and 5.0. The cirrus cloud is with a homogenous layer of 10–11 km an effective particle size $D_e = 30$ µm, and an optical thickness $\tau = 0.5$. The mineral dust is with a homogenous layer of 0–5 km and an effective particle size $D_e = 4.0$ µm.

❑ ***Recent Publications:***
Gang Hong, Yang Ping, H-L Huang, S. Ackerman, 2005: High-resolution infrared spectral signature of overlapping cirrus clouds and mineral dust. Submitted to *Geophysical Research Letters*.

Plans for Next Three Months
❑ Conduct routine algorithm working group meetings to coordinate work load and optimize resources.
❑ Improve quarter report coordination and document progress.
❑ Revised newly submitted publication papers.
❑ Refine new two-layer cloudy forward model performance and verify its performance.
❑ Continue work on deriving the cloud-clearing algorithm and design approaches to perform more than one-layer of cloud-clearing.

❑ Investigate design potential approaches to consider the time continuity aspect of the geo sounding and imaging measurements

❑ Continue to refine ATBDs and use the latest ATBDs to guide algorithm development and implementation.

❑ Complete a version 1.0 dataset and algorithms for the ground system data processing team to test their system performance and run through the system for prototyping demonstration.

Task 2. Preparation for Data Assimilation

Significant Inputs in the last three months

Work completed by Professor Xiolie. Zou (Florida State University), our GOES-R Risk Reduction data assimilation subcontractor during this quarter is summarized below. We have completed a high-resolution simulation of the severe convective initiation that occurred on 12 June 2002 during the International H_2O Project (IHOP) intensive observing period to an extended 4-km forecast domain (Fig. 5), with 300 x 300 horizontal grid points and 54 vertical layers. A simple ice explicit moisture scheme (Dudhia scheme with no cumulus parameterization), MRF planetary boundary layer scheme and RRTM radiation scheme were used in the model integrations. Similar parameterization schemes have been used to simulate the same case by Otkin (2004) except using the OSU land surface model scheme.
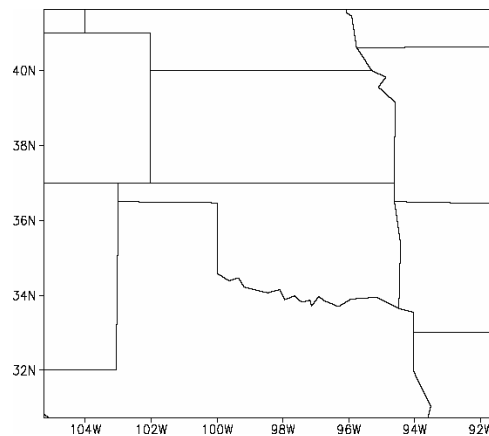

Figure 5. Single model domain for simulating IHOP convective initiation case at 4-km horizontal resolution.

Figure 6 shows the accumulated 6-hours NCEP observed and MM5 model predicted rainfall distribution ending at 0300 UTC 13 June (the first 6 hours rainfall after the convective initiation started at 2100 UTC12 June 2002) and 0900 UTC 13 June (the second 6 hours rainfall after the convective initiation). It can be seen from Figs. 6a and 6b that the model captures the rainfall line form north of Texas to Oklahoma, which is similar to the observed severe precipitation area, while the model produced more precipitation near the center of Oklahoma instead of around the borders of Oklahoma and Kansas (because the model predicted the rainfall one or two hours earlier than the

observed precipitation). It is apparent from Fig. 6 that the movement of the model predicted precipitation from the north of Oklahoma to the southeast of Oklahoma is consistent with the movement of the observed precipitation bands.
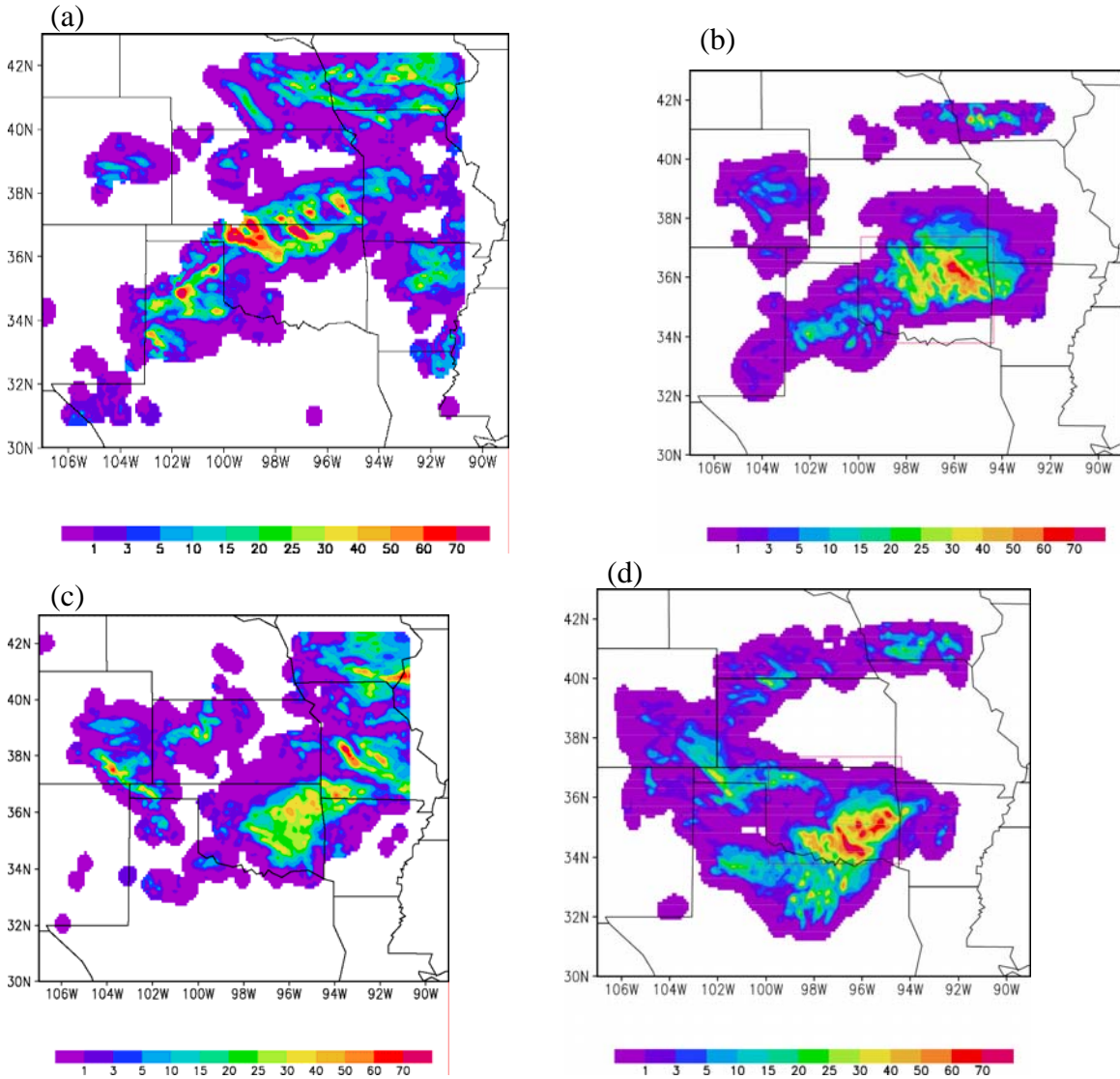

Figure 6. (a) Observed 6-hours accumulative rainfall, (b) Model predicted 6-hours rainfall ending at 0300 UTC June 13. (c) Observed 6-hours accumulative rainfall, (d) Model predicted 6-hours rainfall ending at 0900 UTC June 13.

Toward assessing the impact of clear-sky GIFTS measurements to convective QPFs

In order to assess the potential impact of clear-sky GIFTS measurements, the spatial and temporal characteristics of clear-sky atmospheric conditions around cloudy areas will be investigated. Results will be shown in the next report.

Simulation of GIFTS clear-sky radiance

The MM5 model forecasts are used as the "true" atmosphere to generate the simulated top of atmosphere radiance by the GIFTS clear-sky forward model. Figure 7

shows the clear-sky brightness temperature at 2200 UTC 12 June for the four GIFTS channels: 713.6065 cm^{-1} (CO_2 channel), 892.5818 cm^{-1} (IR window channel), 1030.8287 cm^{-1} (O_3 channel), and 1774.2645 cm^{-1} (water vapor channel). Interesting, mesoscale features are noted in all channels. Among these four channels at different absorption regions, it seems that the water vapor and the IR window channel will provide useful information about the development and location of the storm.
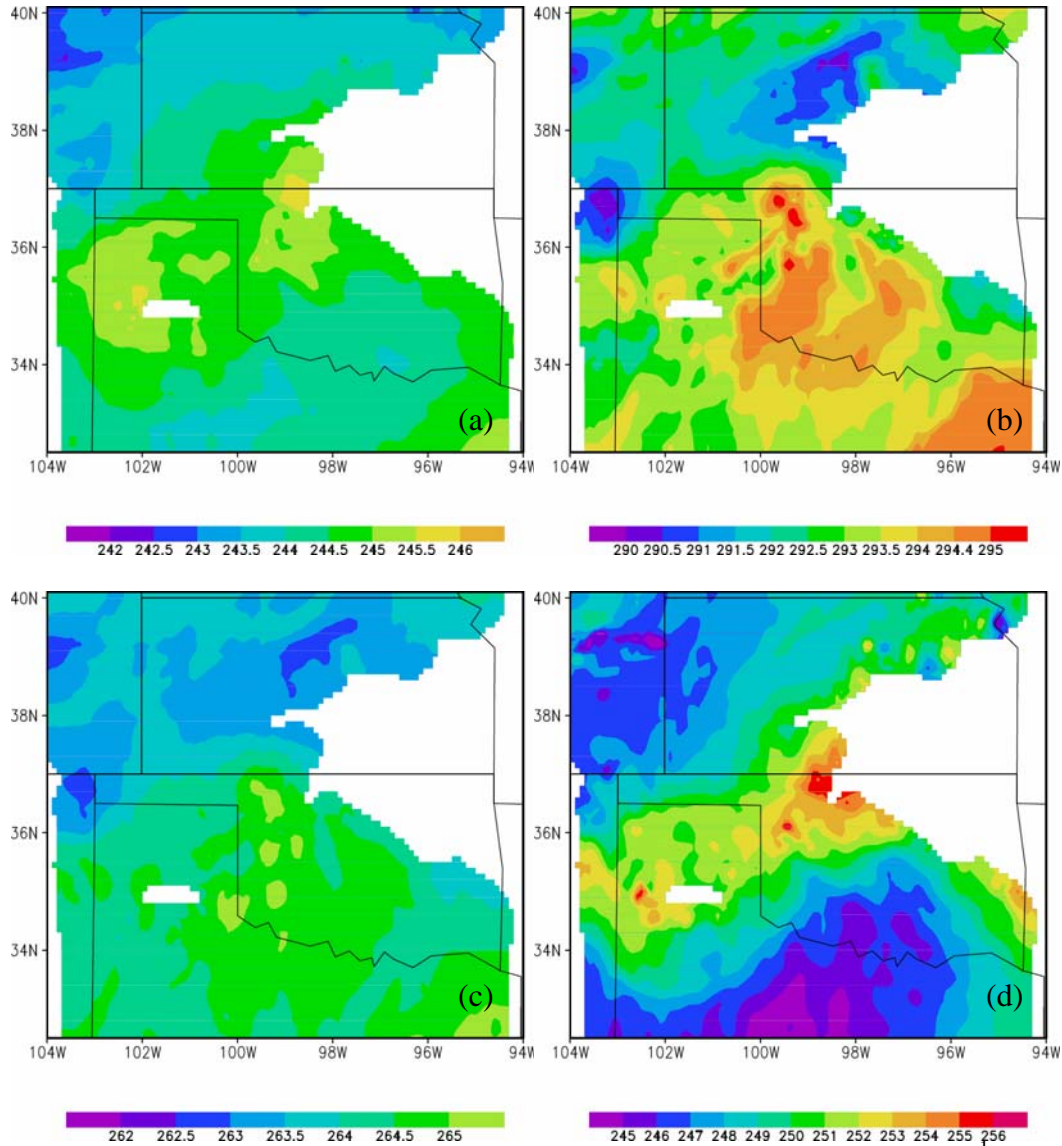

Figure 7. Simulated brightness temperature images of channel (a) 713.6065 cm^{-1}, (b) 892.5818 cm^{-1}, (c) 1030.8287 cm^{-1}, and (d) 1774.2645 cm^{-1} for the clear sky points at 2200 UTC 12 June 2002.

4. Adjoint sensitivity analysis

The temperature and water vapor mixing ratio profiles extracted from the MM5 model forecast are used as input to the GRTM. In order to access the relative sensitivity of radiance to temperature and water vapor mixing ratio at different vertical levels, the sensitivity experiments are performed by the use of GRTM and its adjoint model. The

magnitude of the relative sensitivity can rank the relative importance of the input variables (mixing ratio and temperature at different vertical levels) in the computation of radiance at the top of atmosphere for a selected channel (Amerault and Zou 2002). It is noted that positive sensitivities indicate that an increase in the variable will lead to an increase in radiance, while a negative sensitivity will result in a reduced radiance if the variable is increased. Examples showing the relative sensitivity of radiance at GIFTS channels to the temperature and water vapor mixing ratio profiles will be presented in the coming report.

❑ *Publications:*
   N/A

Plans for Next Three Months
❑ To analyze MM5 adjoint capabilities to study the sensitivity of hyperspectral measurements.
❑ Prof. Zou of FSU, under subcontract agreement, will continue to perform the following activities during the next few quarters:
  • Channel selection for improved convective QPF - one way to optimize data assimilation approaches for HES;
  • Development of the tangent linear and adjoint operators of a cloudy radiative transfer model (RTM); and
  • Observing system simulation experiments (OSSEs) (e.g., data assimilation using simulated HES data), aiming at assessing full information content of HES for NWP data assimilation by taking advantage of time continuity of HES, and identifying risks and potential problems associated with assimilation of HES data.

Task 3: GOES R Winds

Winds Work Summary

Very little work was done on GOES-R winds in this reporting period. The winds group is waiting for the retrieval group to provide a new set of AIRS cloud-cleared or flagged retrievals so we can better depict clouds in the moisture fields when tracking features. This dataset was recently provided, and we will attempt to re-derive AIRS winds with these new retrieved moisture fields in the next quarter.

Significant Accomplishments in the last three months

None this quarter

Plans for Next Three Months

The new set of cloud-cleared AIRS retrieval moisture fields for the case study completed in the last reporting period will be used to re-derive the winds and assess the differences.

Task 4: GOES-R Ground System Design and Studies

Significant Accomplishments in the last three months

Proposed activities for second quarter of 2005 involved preparation for processing of thermal vacuum testing data from the GIFTS instrument, continuing work on prototype data system components and demonstrations, and developing principles and prototypes for large- scale process metadata for a full-scale GIFTS system.

Work during second quarter focused on continuing the implementation of a prototype data processing pipeline in C++, with focus on computational efficiency and sufficient design flexibility to allow thermal vacuum and instrument simulation data to be processed through a variety of algorithm pipelines for purpose of algorithm validation and instrument characterization.

During this quarter, large scale simulation data generation continued, updating and expanding our capability to create plausible input data sets of sufficient size to demonstrate data processing for a GIFTS or HES-like instrument. The new computing hardware (SGI - Altix) successfully completed a large scale WRF model simulation for the Atlantic - THORPEX Regional Campaign (ATReC). This simulation contains data at two different horizontal resolutions, one part at 2 km resolution and another section of 4 km resolution data. The 4 km resolution dataset contains hourly data from December 5th, 2003 at 12 UTC to December 6th, 2003 at 00 UTC and covers a spatial domain large enough to model an area 4 GIFTS cubes by 4 cubes. The 2 km resolution dataset was produced at 5 minute intervals from 16 UTC to 18 UTC December 5th, 2003 and covers the same spatial footprint as the 4 km dataset. Pipeline stages demonstrating the first stages of processing this data were created based on the existing pipeline code, run through testing, and distributed on the SSEC web site. Figure 8 shows the a recent iteration of the software concept map for the GIFTS information processing system.

In reviewing the results of this and previous design cycles, we concluded that a simplification of the component design principles was needed in order to speed development. Module interfaces were systematically made less complex and more C-like. This factoring of the design made the programming process more efficient while opening the system to automatic generation of tedious data transport code. Standard POSIX practices for inter-process interaction were applied in order to maintain efficiency and flexibility. Stemming from these and other decisions we began developing a toolset to manage data flow among the processing algorithms. This tool will use system metadata definitions to efficiently build connections between individual algorithm modules.
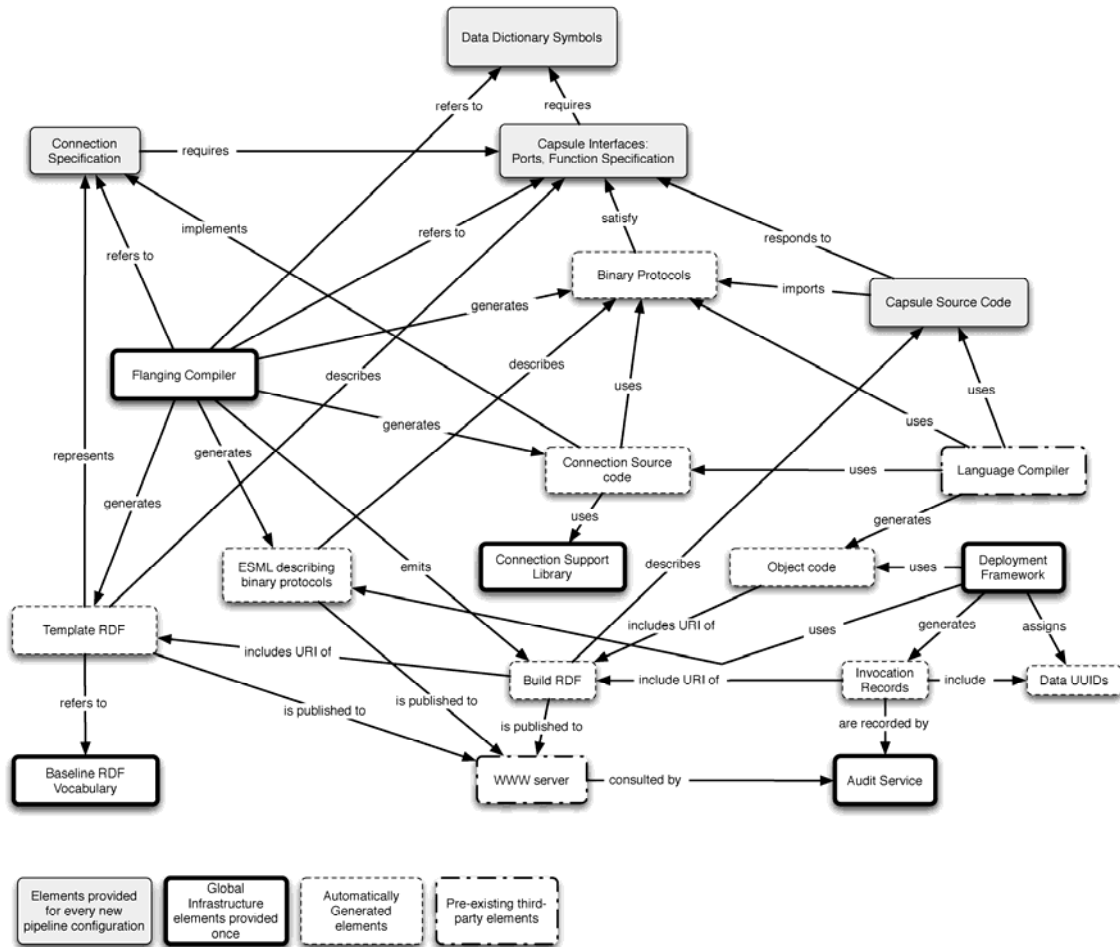
Figure 8. a recent iteration of the software concept map for the GIFTS information processing system.

Researching metadata - which in our case is the generation and management of process and provenance records - began in earnest during the quarter. Two existing metadata standards were identified as being appropriate for long-term use. The W3C Resource Description Framework (RDF) can be used to provide syntax and underlying vocabulary for describing a data system configuration. This can be archived and managed in XML format or captured in a relational database as needed by a given query engine; several query engines for RDF repositories are readily available and are being evaluated in the context of GIFTS metadata management. Also, the Earth Sciences Markup Language (ESML) is being evaluated for describing binary data protocols that are used by data processing software, thus combining the efficiency of binary data formats with the literacy of XML format description.

In the third quarter of 2005, development of the toolset for automatic generation of processing code will continue, along with a final development push for the various algorithms making up a demonstration GIFTS pipeline. An experiment evaluating several approaches to radiometric calibration will be carried out using the code thus generated, and related activities will involve generating the needed test data and tweaking

the calibration algorithm variants for this experiment. Also, a manuscript will be submitted and a poster will be presented at the August 1-3 Earth Observing Systems X session of the SPIE meeting in San Diego, summarizing the detailed design activities carried out in this quarter.

Finances Summary: GOES-R Funding and Spending Plan

GOES R Risk Reduction Funding

Through 2/2004	$1,270K
Through 2/2005	$ 750K
Through 2/2006	$ 910K
Total funding to date	$2,930K

GOES R Risk Reduction Spending

Through 2/2004	$1,299K
3/2004 - 2/2005	$ 880K
March 2005	$ 68K
April 2005	$ 145K (includes $75K subcontract payment),
May 2005	$ 49K
June 2005	$ 56K
Total spending thru 6/30/05	$2,497K

The 2004 funds budget period ended 28 February 2005. The 2005 funding recently arrived. For the next three months, spending is estimated to be:

July 2005	$50K
August 2005	$50K
September 2005	$60K

end