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SIMULATION OF GIFTS DATA CUBES

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1. Introduction

The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) represents a revolutionary step in satellite based remote sensing of atmospheric parameters, and poses a challenge in terms of being able to process and understand the large amount of data it will collect. Using the combination of a Fourier Transform Spectrometer and Large Area Focal Plane Arrays, GIFTS will measure the Earth emitted radiance at the top of atmosphere from geosynchronous orbit. In its nominal operating mode, GIFTS will measure the infrared spectrum in two bands (a 14.6 to 8.8 μm longwave band and a 6.0 to 4.4 μm short/midwave band) at a spectral resolution of ~0.6 cm^{-1} for a 128x128 set of ~4 km footprints (a ~512 x 512 km area) every eleven seconds. Successive measurements of such data will be collected to cover desired regions of the globe. In terms of interferograms, the high rate data from the FPAs is numerically filtered and decimated to produce a raw “data cubes”, consisting of a 128 × 128 array of 2048 point interferograms for the longwave band and a 128 × 128 array of 4096 point interferograms for the short/midwave band. These data are then passed through an on-board lossy data compression algorithm, and the raw and compressed data streams (as well as 512×512 arrays of visible data collected and associated metadata collected during the eleven seconds) are telemetered to the ground at a rate of ~65 Mb/s. In the project's formulation phase, these infrared “data cubes" have been simulated in order to support algorithm development efforts and instrument trade studies. In particular, the simulated data has been used to develop and test the lossy data compression algorithms, which operate on the numerically filtered and decimated interferograms. This poster presents an overview of the simulation methodology and gives some examples of the simulated GIFTS data.

2. Simulation Methodology

The simulated data includes radiometrically calibrated spectra, uncalibrated spectra, and uncalibrated interferograms, with or without various instrumental effects. These can be for Earth views or of views of the internal calibration blackbodies, and can be noise-free or including instrumental noise. The general simulation methodology includes three general steps: 1) creation of the atmospheric state on the appropriate temporal and spatial scales and resolution, 2) calculation of the high spectral resolution top-of-atmosphere (TOA) radiance spectra from the atmospheric state, and 3) inclusion of various instrumental effects. The following sub-sections describe these steps in more detail.

2.1. Generation of Atmospheric State

The atmospheric state parameters (profiles of temperature and gaseous absorber profiles, cloud properties, surface properties, and wind vectors) are generated using a high spatial resolution model. As opposed to observed quantities, the use of model data allows all variables to be known exactly when performing studies such as temperature retrieval studies using the simulated data. We use the University of Wisconsin Nonhydrostatic Modeling System (UW-NMS version 6a, released February 2000) developed by Greg Tripoli at UW-Madison. Input to the NMS model includes skin temperature, water vapor mixing ratio, ozone concentration, surface elevation, and liquid and ice water paths. A cloud-top height (set to the altitude at which the logarithm of the density of the cloud’s liquid or ice content exceeds 0.25) is also input to the UW-NMS. Some features of the UW-NMS model include:

- Arbitrary spatial resolution in all directions
- Local spherical coordinate system in the horizontal
- Height coordinate system with step topography using a terrain following variable grid spacing near the ground
- Multiple two-way interactive grid nesting, with moveable inner grids
- Gridscale microphysics parameterization with cloud water, rain, pristine crystals, snow, aggregate crystals, and graupel
- Modified Emanuel convective parameterization scheme
- Long/Short wave radiation parameterization with clouds
- Diffusion based on TKE prediction.

For the GIFTS simulations, a 24 hour spin-up using a nested grid, with a 4km resolution inner grid, is performed using initial conditions from a global model. Forecasts are then performed with 15 to 30 minute time steps for a duration of several hours. The end result is realistic and coherent atmospheric state, surface, and cloud variables at 4km resolution for ~512 x 512 km areas with time steps of ~30 minutes. Larger spatial domains (~4 times larger) are also possible. Additional information on UW-NMS is available at http://mocha.meteor.wisc.edu/uw-nms.html.

2.2. Calculation of TOA radiance spectra

A forward model takes atmospheric state parameters (such as temperature, water vapor and other gas concentrations, and clouds) and derives satellite-altitude radiances. The major components

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include computaion of the clear sky transmittances, cloudy sky transmisttances, and performing radiative transfer.

For the gaseous absorption, a clear sky fast model for GIFTS was generated by applying a PLOD regression (Hannon et al., 1996) to line-by-line calculations obtained with LBLRTM (Clough and Iacono, 1995), using HITRAN96 (Rothman et al.,1992) and the CKDv2.4 water vapor continuum module (Tobin et al., 1999). The line-by-line transmittances were mapped to the GIFTS spectral domain using a maximum optical path difference of ~0.87 cm, with an effective spectral resolution of approximately 0.6 cm^{-1}, and apodized (6th order Kaiser-Bessel) prior to performing the regression analysis.

Cloud effects are incorporated into the fast model via an optical thickness parameterization scheme developed by Dr. Yong Hu of NASA Langley Research Center:

$$OT_l = WP_l\left(C_0 r_{e,l}^{\ \ C_1} + C_2\right) \qquad \text{(liquid cloud)}$$

$$OT_i = WP_i\left(C_0 r_{e,i}^{\ \ C_1} + C_2\right) \qquad \text{(ice cloud)}$$

where C_0, C_1 and C_2 are parameterization coefficients, WP is the water path, and r_e is the effective radius of the cloud particle. Subscripts *l* and *i* denote liquid and ice cloud, respectively. The cloud transmittance is then

$$t_{cloud} = \exp\left(-OT\right).$$

Above the cloud level $t_{cloud} = 1$.

The clear and cloudy sky transmittance profiles are then multiplied and used along with the atmospheric temperature profiles and surface properties to compute the top-of-atmosphere radiances using the radiative transfer equation. The surface is represented as black (unit emissivity) with skin temperatures as given by the numerical model. At this point, the Kaiser Bessel apodization is removed from the calculated radiances, effectively producing top-of-atmosphere radiances with spectral resolution of that of an ideal (on-axis) FTS with a maximum optical path difference of ~0.87 cm.

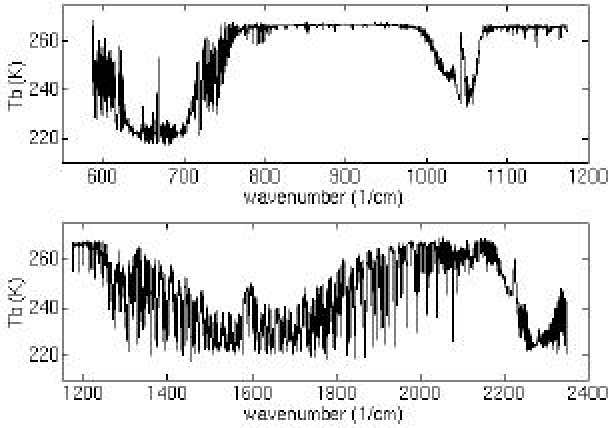

Figure 1. A sample TOA brightness temperature spectrum produced by the GIFTS fast model.

2.3. Instrumental Effects

A Fourier Transform Spectrometer (FTS) simulator has been developed to model the significant instrumental effects of the GIFTS interferometer on the top-of-atmosphere simulated radiances. For each pixel in the GIFTS focal plane array, the simulator produces an interferogram (or spectrum, if desired) of an Earth scene or calibration blackbody view. The instrumental effects included in the simulations are:

- Addition of background, instrument emission
- Application of the responsivity (gain)
- Application of the numerical filter
- Application of the complex phase due to beam splitter dispersion
- Inclusion of finite detector size, leading to self-apodization and ILS variations across the FPA.
- Inclusion of off-axis (from the FTS axis) detector, leading to different optical path difference sampling points for each FPA pixel.
- Inclusion of pixel-to-pixel offset and gain variations
- Inclusion of pixel operability
- FTS axis not aligned with FPA center
- Inclusion of random (thermal) detector noise
- Inclusion of photon generated noise
- Inclusion of integrated circuit readout noise
- Inclusion of quantization noise

Any, all, or none of the effects can be included depending on the particular use of the simulated datacube. Particular effects which are not currently included are:

- Phase variations across the FPA
- Non-linear detector response
- Interferometric (scan mirror tilt and velocity variation) noise
- Diffraction and jitter blur
- Consecutive data cube spatial misalignment

The logic behind the inclusion/exclusion of each effect, and how the effects were simulated will be presented at the conference. In addition, two GIFTS project documents, references 1 and 2, describe the simulation process in detail. Reference 1 gives an overview of the simulations and information (times, locations, meteorology) of the data cubes simulated to date, and Reference 2 gives details on the simulated instrumental noise.

2. Examples of Simulated Data Cubes

The following three figures show examples of the simulated data cubes. Figure 2 shows the dramatic effect of the variation of optical path difference point sampling in the interferogram domain for the off-axis FPA pixels. This is due to the different optical path differences which are experienced for beams of light which propagate through the FTS at different angles with respect to the FTS axis. In this figure, the top panel shows the interferfogram values for zero optical path difference (ZPD), which are not affected by the off-axis angles. The x and y axes are pixel indices (ranging from 1 to 128) representing the horizontal spatial dimensions. The z-axis represents the interferogram value and is proportional to the total energy reaching the

FPA for each pixel. The lower values are due to clouds. (Note the direction of the z-axis limits). The bottom panel of Figure 2 shows the interferogram values for the same Earth scene but for an optical path difference of ~0.6 cm. In this case, the off-axis OPD sampling causes the underlying signal to vary smoothly. This effect is easily removed using ground-based computing hardware and algorithms, but is a challenge to the on-board compression algorithms.

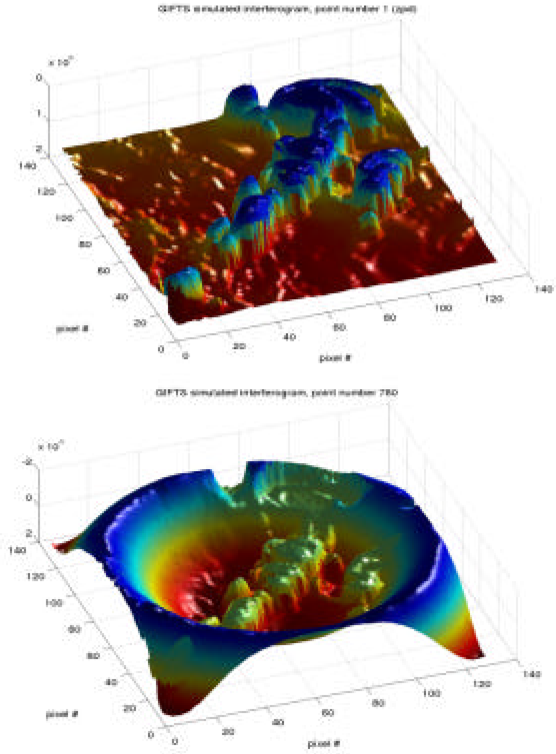

Figure 2. Effects of off-axis OPD sampling, as discussed in the text. Top panel: interferogram values for ZPD; bottom panel: interferogram values near the CO_2 resonance region (~0.6 cm).

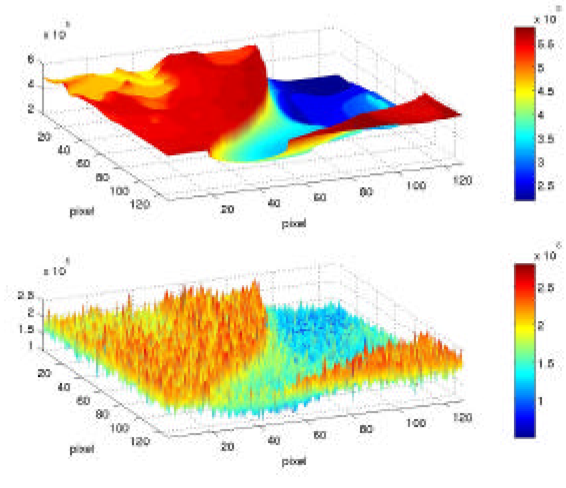

Figure 3. Effect of FPA pixel-to-pixel gain and offset variability, as discussed in the text.

Figure 3 shows the effect of pixel-to-pixel variations in the FPA detector gains and offsets. This is due to the inherent variability in the characteristics of individual pixels within the FPA. The top panel shows the (uncalibrated) interferogram values without the effects included, and the bottom shows the interferograms, but with variable offsets and gains applied. Pre-launch characterization of the FPAs and on-board blackbody and space views will allow for these effects to be removed via the radiometric calibration, but this is an effect that the on-board compression algorithms need to account for.

The last example (Figure 4) shows the ~1650 cm^{-1} calibrated brightness temperatures for data cubes produced for three time steps (00:00, 00:30, 01:00 UTC) for the upper Midwest region. This shows the variability in time and space of the mid to upper level water vapor and clouds present in the model runs.

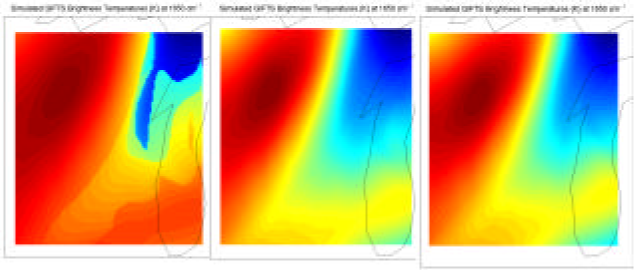

Figure 4. ~1650 cm-1 brightness temperatures for simulated cubes of the upper Midwest region at 0000, 0030 and 0100 UTC on 3 April 2000.

3. Acknowledgements

Thanks to Gail Bingham, John Elwell, and Alan Thurgood of the Space Dynamics Lab, Utah State University for their contributions to this work. Thanks to the supporting GIFTS Project personnel including Mike Blythe, Wallace Harrison, and Jim Miller.

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