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# ANALYSIS OF CONVECTIVE CLOUDS AND TURBULENT BOUNDARY LAYERS USING HYPERSPECTRAL DATA

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## 1. INTRODUCTION

The focus of this research is to demonstrate new techniques in the analysis of convectively generated clouds and convective boundary layer (CBL) turbulence using high spectral resolution (i.e. hyperspectral) data.

Atmospheric convection is being studied using simulated hyperspectral data from the future Geostationary Imaging Fourier Transform Spectrometer (GIFTS) instrument, as recently produced at UW-CIMSS. Data from the GIFTS instrument will be an invaluable resource in the analysis of convective clouds due to the combination of its high temporal (5-10 min), spectral (~.5 $cm^{-1}$), and spatial (1-4 km) resolutions, which is much greater than achievable with current operational geostationary weather satellites (i.e. GOES). The GIFTS instrument will improve upon the 3-dimensional observation of all three basic atmospheric state variables (temperature, moisture, and wind) in addition to improved observations of cloud properties (i.e. microphysics, cloud height and optical depth). In this study, we combined the use of spectral band-differencing techniques and cloud-top temperature trend monitoring to demonstrate the utility of hyperspectral data in analyzing convective storm initiation and growth. A description of the datasets and the results completed-to-date will be presented in the sections below and within the conference poster presentation.

High temporal-resolution hyperspectral data from the Atmospheric Emitted Radiance Interferometer (AERI) has been used to study the CBL. Profiles of water vapor mixing ratio at 40 s resolution have only recently become available, allowing for unique analyses of CBL turbulent structures. Through the analysis of AERI water vapor profiles, GOES-8 1 km visible satellite imagery, and radiosonde data, we have discovered evidence for the presence of boundary layer roll structures during one day during the Cirrus Regional Study of Tropical Anvils and Cirrus Layers-Florida Area Cirrus Experiment (CRYSTAL-FACE). Details of this analysis and the corresponding results will also be described in the following sections and within the conference poster presentation.

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## 2. DATASETS AND METHODOLOOGY

### *2.1 Simulated GIFTS Data Analysis*

The simulated GIFTS data used in this study was produced from a 4 km horizontal resolution numerical model simulation, using the 5th generation Penn State/NCAR Mesoscale Modeling system (MM5), of convective storms that occurred during the International $H_2O$ Project (IHOP) intensive observing period over the U.S. Southern Great Plains (Posselt et al. 2003). Vertical profiles of MM5 simulated atmospheric temperature, water vapor, cloud ice and liquid droplet mixing ratios, and ozone were used as inputs to a fast forward radiative transfer model to produce GIFTS top-of-the-atmosphere radiances. These radiances were then converted into brightness temperatures over the GIFTS spectral range (~4.5-6 and ~8.5-15 µm) via the Planck function.

The techniques used for the satellite analysis of convective storms in this study have been adapted from those developed using GOES and MODIS data. Spectral band differencing techniques have been used to assess cloud-top height relative to the tropopause (~6.06 – 11 µm) and cloud-top microphysics (~8.5 – 11 µm). The results of these band-differencing techniques, performed with simulated GIFTS data, were related to MM5 simulated cloud ice and precipitation fields to assess their use in monitoring convective storm initiation (first detection of precipitation at the surface) and development. In addition, the sensitivity of these band-differencing techniques to selected wavelength is demonstrated.

### *2.2. AERI Data Analysis*

The AERI, as developed over the past 13 years at the University of Wisconsin, is designed to retrieve boundary layer moisture and temperature structure from the ground-based hyperspectral infrared measurements it collects. Feltz et al. (1998, 2003) and Smith et al. (1999) provide much of the overview for the AERI instrument design and physical retrieval algorithm. A suite of AERI instruments, five deployed at static locations across Oklahoma and Kansas surrounding the SGP ARM site, typically measure both temperature and water vapor at 10-minute resolution in real-time.

New high temporal resolution (40 s) AERI data, collected by a mobile AERI system, has been used to assess the presence and spacing of CBL roll structures, as present during the CRYSTAL-FACE experiment (one day for which 40 s AERI data was available). These data, collected within a hot, humid air mass with southeasterly wind flow in SW Florida on 29 July 2002, reveal the presence of periodic moisture fluctuations as the CBL deepened through strong solar heating. 40-s resolution water vapor perturbations ($q'$ ) were calculated at 315 m AGL, as convective roll structures were observed in GOES-8 visible satellite imagery from 1700-2100 UTC. A power spectrum analysis was performed on the $q'$ time series in order to extract the periodicity induced by the passage of turbulent structures over the AERI instrument site. Satellite analysis reveals that convective rolls were the dominant form of organized turbulence on 29 July. This roll-induced periodicity was corroborated with an analysis of theoretical roll periodicity derived from satellite imagery and radiosonde data incorporating the roll motion, orientation, wavelength, and width.

## 3. RESULTS

### *3.1 Analysis of Convective Clouds*

Figure 1 demonstrates the use of GIFTS hyperspectral data in diagnosing cloud microphysics and convective precipitation. In Fig. 1a, cloud features highlighted in blue have cloud-top brightness temperatures below freezing. Roberts and Rutledge (2003) have shown, using GOES-8 data, that monitoring the drop to below freezing cloud-top temperatures (in addition to the rate of cloud-top cooling) can provide up to a 30 min. lead time in forecasting convective initiation. Therefore, we monitor cloud top temperature trends as a first analysis field for convective clouds.

The next example of this analysis involves the use of the 8.5-11 µm technique for cloud-top microphysical assessment. The cloud features highlighted in green in Fig. 1a have 8.508-10.98 µm differences greater than 0, which indicate the presence of cloud tops composed of ice (Strabala and Ackerman, 1994). A comparison of the GIFTS-derived microphysical assessment to the MM5 cloud ice field (blue, Fig. 1b) demonstrates the strength of this technique in diagnosing cloud tops composed of ice. Animations of this technique in time show that the satellite-observed transition from liquid to ice cloud tops (i.e. glaciation) often signaled the onset of convective precipitation in the MM5 model simulation (Fig. 1b).

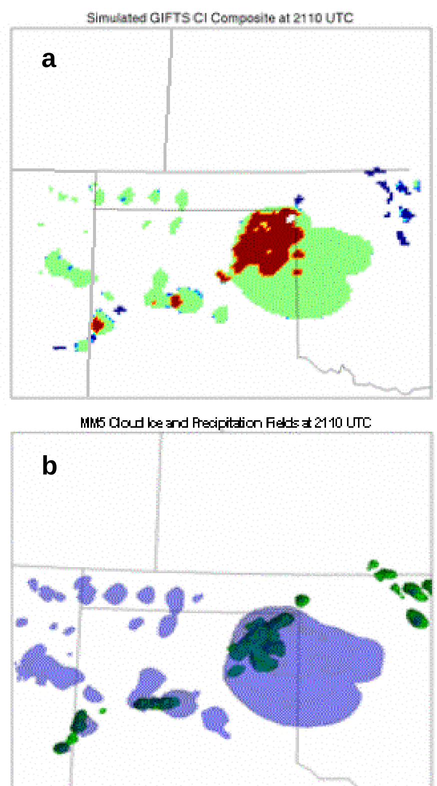


*Figure 1: (a) A composite image using illustrating below freezing cloud tops at 10.98 µm (blue), cloud tops composed of ice crystals (green, from the ~8.5-11 µm difference), and cloud tops at/above the tropopause (red, from the ~6.06-11 µm difference). (b) MM5 simulated cloud ice (blue) and precipitation fields (green).*

Positive values of the 6.06-10.98 µm technique (red, Fig. 1a) are indicative of cloud tops that are at or above the tropopause (i.e. “overshooting” tops). A similar technique was performed in Schmetz et al. (1997) using the 7 and 11 µm bands with data from the METEOSAT satellite. The 6.06 µm band was used in place of the 7 µm band because the GIFTS instrument will not detect radiation at 7 µm. The results from using the 6.06 and 7 µm are comparable because the GIFTS 6.06 µm weighting function peaks at approximately the same height as the METEOSAT 7 µm weighting function. Positive values of this technique correspond well with the MM5 simulated precipitation field (green, Fig. 1b).

The aforementioned band differencing techniques are very sensitive to subtle changes in chosen wavelength, as illustrated in Figure 2. When using the 8.5-11 µm technique with MODIS data, one is actually performing this difference with radiances detected over broad bands (8.4 to 8.7 µm for the 8.5 µm MODIS band) centered at 8.5 and 11 µm. When performing this technique with hyperspectral data, detected radiances are nearly monochromatic, allowing for much greater precision in performing these differences. Fine absorption lines are resolved through the high spectral resolution of ~.5 $cm^{-1}$ of the simulated GIFTS data and are responsible for the difference in results between Fig. 2a and 2b. Hence, one must carefully select the appropriate channels when performing band differences with hyperspectral data.

Future work in the analysis of convective clouds using hyperspectral data will involve the use of GIFTS derived cloud motion vectors to determine cloud top temperature/microphysical trends. Through the use of these vectors, we can determine the locations of individual cloud features in previous images to perform a “real-time” assessment of cloud-top cooling rates and microphysical changes. Monitoring these time trends should result in a better satellite-based assessment of the convective initiation process.

### *3.2 Analysis of Boundary Layer Turbulence*

A GOES-08 satellite image from 1925 UTC on 29 July 2002, provided in Fig. 3, illustrates the presence of convective roll structures near the AERI instrument site (denoted by the yellow square). These rolls were oriented along a 135º axis (southeast to northwest) and moved with a speed of 7 $ms^{-1}$ along the geostrophic wind vector of 120º (from radiosonde). A more detailed analysis of this image reveals that the roll wavelength and roll widths were 4.5 and 2 km, respectively. A geometric analysis incorporating roll motion, orientation, and wavelength dictates that rolls passed over the AERI instrument every 23 minutes.

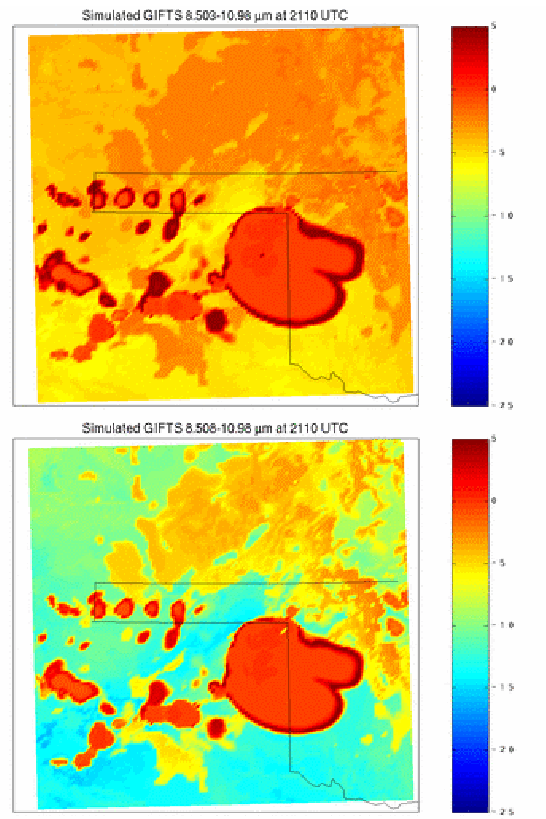


*Figure 2: (a) 8.503-10.98 µm difference (b) 8.508-10.98 µm difference. A comparison of these images illustrates the sensitivity of the 8.5 – 11 µm band differencing technique to subtle changes in wavelength (.005 µm).*

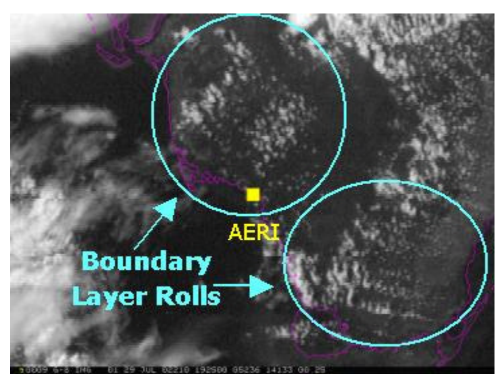


*Figure 3: GOES-08 1 km visible satellite image at 1925 UTC on July 29, 2002. The AERI instrument site is highlighted by the yellow square.*

AERI boundary layer water vapor mixing ratio profiles from the 17-21 UTC are provided in Fig. 4. Being that the AERI instrument is a passive upward-looking interferometer, precipitation and low clouds inhibit atmospheric profiling, resulting in gaps (shown in white) in the water vapor profiles. It was assumed that *q'* was constant during these periods so that the time series would remain continuous.

The q' time series at 315 m is presented in Fig. 5. The 315 m height was selected because it fell close to the middle of the boundary layer depth (700 m). Water vapor perturbations (red) were calculated by subtracting the 40 s signal from a 60 min. running mean. A 5-minute running mean (black) was performed on these perturbations in order to eliminate noise from both the instrument and cloud scale (< 1 km) turbulence.

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Figure 6 provides the results of a power spectrum analysis which was performed on the *q'* time series in order to extract the roll induced *q'* periodicity. A 99 % confidence curve (green) was calculated using a chi-squared significance test. Spectral peaks (blue) above the 99% level are produced by coherent boundary layer roll structures. A broad time interval of 16-28 minutes was found to be of 99% significance. The authors believe that variations in roll width are responsible for producing this broad spectral peak. Nevertheless, the satellite/sounding derived periodicity (23 mins) corresponds well with that derived through power spectrum analysis (16-28 mins). Therefore, the authors are confident that one-dimensional water vapor profiles can be used to infer the presence of three-dimensional CBL turbulent structures. Results from this study can be found in Mecikalski et al. (2004) and will be highlighted in the poster presentation.

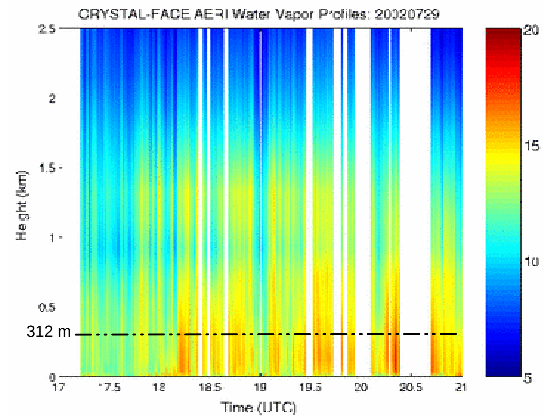


*Figure 4: AERI 40-second resolution water vapor mixing ratio profiles from 17-21 UTC on July 29th. Missing data is caused by passages of low clouds over the instrument.*

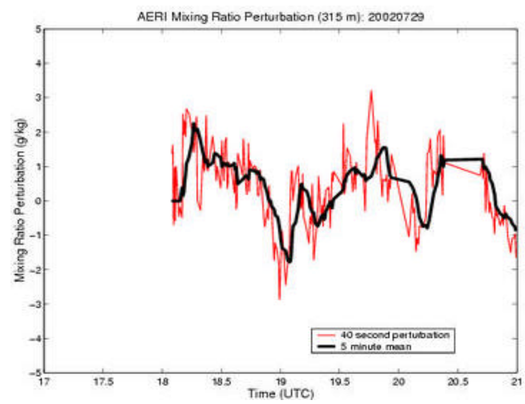


*Figure 5: A time series of q' from 17-21 UTC on July 29th. 40-s (5-min running mean) perturbations are provided in red (black).*

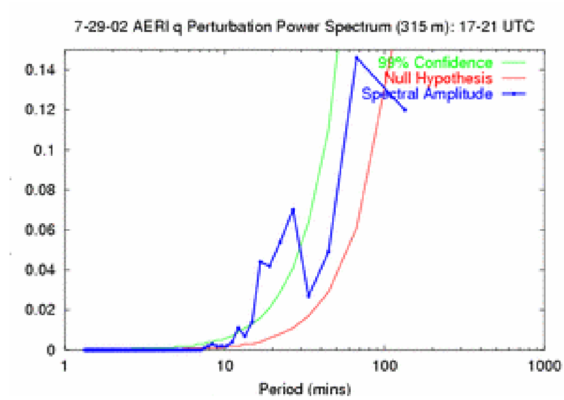


*Figure 6: A power spectrum analysis of the 5-min running mean of q' used in this analysis. The red-noise null curve (99% confidence curve) is provided in red (green). Spectral peaks above the green line are induced by meteorological phenomena.*

## 4. ACKNOWLEDGEMENTS

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