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PROCESSING REALTIME SATELLITE INFORMATION TO NOWCAST CONVECTIVE INITIATION AND ITS CHARACTERISTICS

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1 MOTIVATION AND GOALS

Accurately forecasting the initiation, temporal and spatial scales, and the immediate impacts of thunderstorms remains one of the more elusive problems in meteorology today. Improved methods must be developed for forecasting convective initiation (CI) and subsequent thunderstorm development. Techniques are needed to quantify the important precursors to CI over small spatial and temporal scales (on the order of 1-5 km and 0-3 hours) using the wealth of information contained in realtime meteorological satellite imagery (e.g., GOES, MODIS), in conjunction with other operational weather data (e.g., radar, numerical models). [‡]

Specifically, the goals of this project include:

1. Development of new satellite-based techniques to identify important precursors to convective initiation and growth.
2. Combining various convective initiation "interest fields" with other multisensor information to improve nowcasting of CI within expert systems (e.g., the National Convective Weather Forecasting, NCWF, and others).
3. Lay the foundation for using upcoming satellite technology (e.g., hyperspectral) to test these techniques on higher resolution data.

To be presented is new research that focuses on processing realtime GOES visible and infrared data to identify and isolate the temporal characteristics of cumulus clouds (e.g., new, expanding, deepening and persisting). The evaluation of patterns (lines and clusters) within realtime satellite imagery will be an area of concentration, along with the application of cloud phase information (e.g., first time glaciation of cumulus cloud tops). A unique aspect of this project is the combined use of all available data from a given geostationary instruments data (e.g., GOES) for evaluating CI. For GOES this included the 1 km visible imagery, 5 channels of 4 km Imager data, and 19 channels of Sounder data.

This project's goals coincide with those of the FAA Aviation Weather Research Program (AWRP) efforts at the National Center for Atmospheric Research (NCAR), to nowcast CI for the purpose of enhancing aviation safety. Thus, this presentation will highlight recent research progress on a collaboration between the University of Wisconsin-Madison, Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) and NCAR to routinely diagnose convection over land and ocean regions. As proven techniques are developed through this collaboration, they will be transfered into the forecast systems supported by the FAA for nowcasting convection over the land and ocean.

2 DATA TYPES AND PROCESSING

This research will fully exploit data from the series of GOES geostationary satellites (GOES-08, -10, -11 and -12, as of this writing in 2002) for nowcasting CI. Data from other such sensors (i.e. METEOSAT, MTSAT, FY3) are available for use within the CI nowcasting algorithms that will be developed. More exploratory research using data from the two current MODerate resolution Infrared Spectroradiometers (MODIS, on the Terra and Aqua

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platforms) will be also be done in preparation for the upcoming hyperspectral instruments such as the Geosynchronous Interferometer Fourier Transform Spectrometer (GIFTS, expected by 2006).

The UW-CIMSS/NCAR collaboration motivated by this research focuses on the development of new data analysis techniques for processing data in near-realtime, due to the short forecast timescales associated with CI. Henceforth, key to any nowcast of CI is the ability to capitalize on the low data latencies where available. In particular, at UW-CIMSS, GOES and MODIS data are available at latencies of 1-2 minutes given their direct receipt. For GMS and METEOSAT, latencies are on the order of 5-10 minutes.

Since this project's inception in 2001, a high emphasis has been placed on the use of memory-efficient compiled code for this processing. As a result, the simultaneous processing of up to 10 individual CI-interest fields over domains of several US states can occur four times per hour taking full advantage of low data latencies. In effect, processing over several US states means analyzing images with $>10^6$ pixels for 1 km GOES visible, $>10^5$ for 4 km GOES Imager, and >35,000 for 10 km GOES Sounder data. Time constraints on such processing are on the order of 10-minutes before the CI interest fields become dated.

The UW-CIMSS/NCAR collaboration has been mutually beneficial for several reasons. First, the legacy of nowcasting CI using "expert systems" at NCAR, which spans over 10 years, allowing the UW-CIMSS research team to gain much experience for their previous efforts. This experience comes by way of the direction UW-CIMSS received from the NCAR Convective Weather and Oceanic Weather AWRP Product Development Teams (PDTs). UW-CIMSS also receives direct and immediate feedback on the value of newly developed methods, which occurs through direct communication between the two institutions. Finally, NCAR obtains access to the low data latencies available at UW-CIMSS for the above datasets, as well as to the expertise for processing them for this type of scientific research.

3 PROCESSING METHODS

Three methods of satellite data processing are used currently in our CI processing:

1. **Spectral Techniques** which take advantage of how these satellites measure outgoing radiation from Earth, in particular, clouds and the changing character of clouds. Such methods are used to assess cloud growth, microphysical patterns and cloud temperatures (e.g., Schmetz et al. 1997).

2. **Pattern Recognition Techniques** which are designed to automatically identify those cloud features important to and associated with CI. In particular, such processing identifies cloud lines, surface-based convergent boundaries, the collision of such boundaries, and simply the location of active cumuliform clouds (e.g., Bow 1992, Chapter 9).

3. **Spectral-based Processing of CI-relevant Patterns** which represents the implementation of a combination of processing modes 1. and 2.

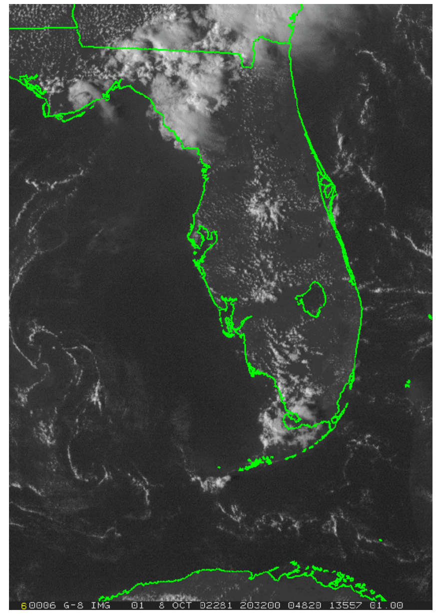

Figure 1: 1-km resolution GOES-08 visible image over Florida at 20:32 UTC 8 October 2002.

A fourth type of processing, one that is being explored, involves combining low-time frequency information with high-time frequency data. Specifically, an example of this will come when twice-per day MODIS information (e.g., cloud-top cooling rates) is used in conjunction with the latest GOES data to assess CI via this fourth technique over an area the size of a MODIS swath.

A key component to the research outlined above is its usability at NCAR, and within their convective diagnosis and nowcasting systems. One way of enhancing the usefulness of our data and analy-

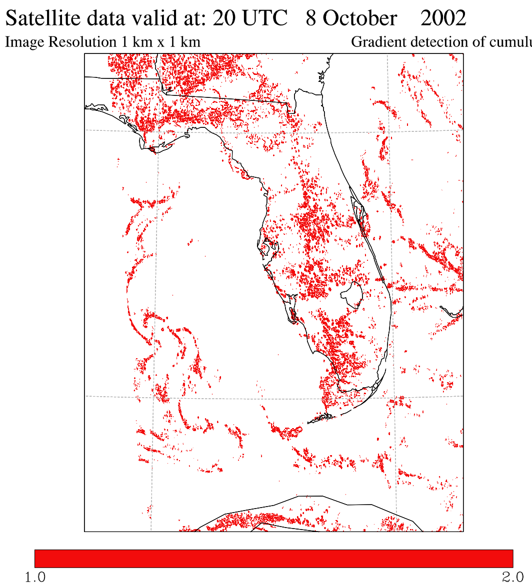

Figure 2: The automated detection of surface-based active cumulus over Florida using 1 km-resolution GOES-08 data for that shown in Fig. 1. The method employed is based on the computation of north–south and east–west gradients of time-relative brightness in the imagery.

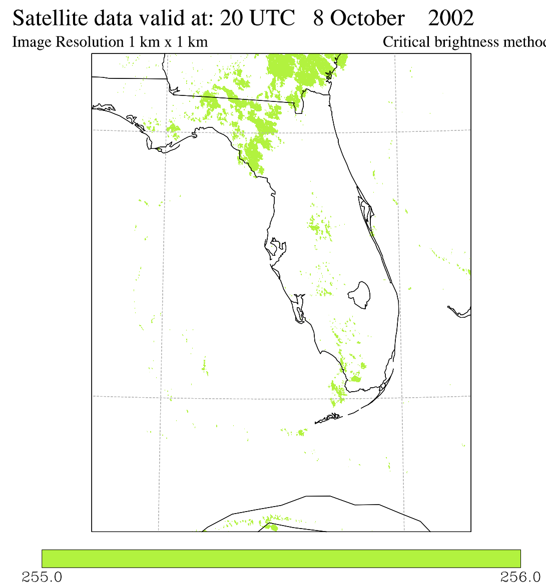

Figure 3: The detection of larger-scale (mesoscale) convective cloud features based on the selection of a time-of-day specified brightness value within the GOES-08 visible data. This simple method shows only cumulus that reflect significantly, and highlight cumulus congestus clouds versus individual cumulus clouds. Data are as in Fig. 1.

ses is through the development of so-called "confidence indicators" per CI interest field. Such confidence indicators can be used to appropriately weight a given interest field within an expert system like those run at NCAR. CI confidence indicators can provide a measure of error and uncertainty for a given CI interest field. For example, providing confidence to the use of the 6.7–10.7 μm CI interest field will include the uncertainty involved in differencing these two "broad" bands, the vertical spread of the weighting functions for each band, and the error of this interest field for identifying only growing convective clouds. Hence, considerable effort will include the formation of a unique confidence indicator for each CI interest field which requires an understanding of the weakness/strengths of a given analysis method and data type.

4 DEVELOPMENT OF CONVECTIVE INITIATION INTEREST FIELDS

This extended abstract presents examples of several CI interest fields that provide value-added information within the NCAR expert systems for nowcasting CI. This is work in progress and therefore even the examples shown are undergoing continual evaluation.

Figure 2 demonstrates the second processing method described above in which patterns of active convective clouds are highlighted in the imagery (centered over Florida), to accompany the satellite image in Fig. 1. This field is generated by taking the two-dimensional horizontal gradient of brightness, and is good at showing small-scale cloud features; values above a specific brightness gradient level are highlighted. Figure 3 uses a simple technique of only showing clouds above a time-dependent brightness value in the visible data (again at the same time as in Fig. 1). Fig. 3, in contrast to Fig. 2, identifies larger-scale features (the mature convection over northern Florida and Georgia) that are not identified by the gradient technique. Despite the simplicity of this field, it can be used within processing method 3 as our algorithms subsequently focus only on those relatively few satellite pixels containing cumulus that are most likely to be locations of CI in the near future.

The plan is to automatically assess the orientation and longevity of the cumulus lines shown in Fig. 2, which is work in development. Figures 4 and 5 highlight two multispectral methods as they pertain to the CI problem. In Fig. 4, GOES-08 channels 2 and 4 (3.9–10.7 μm) are differenced to provide an estimate of cloud top glaciation for the cumulus shown in Fig. 2; the greatest difference in Fig. 4 highlight

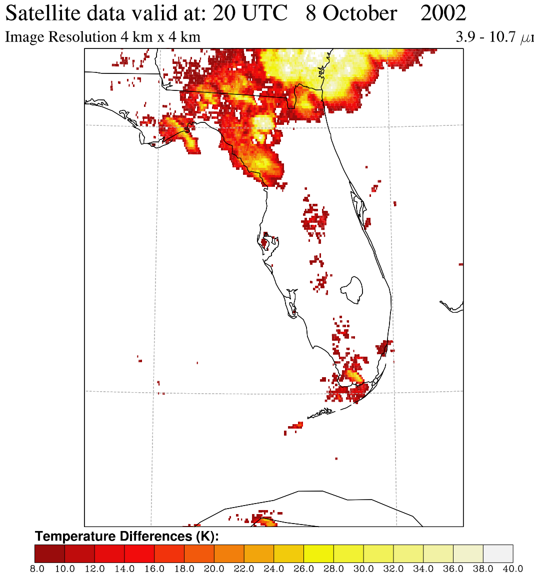

Figure 4: Spectral approach to detecting cloud-top glaciation of (new) cumulonimbus clouds. This figure, the difference of the 3.9–10.7μm broad bands of 4 km-resolution GOES-08 imagery, shows regions in which cumulus more likely possess ice crystal-dominated cloud tops (highlighted) versus liquid hydrometeors. These data will be used in conjunction with those in Fig. 2.

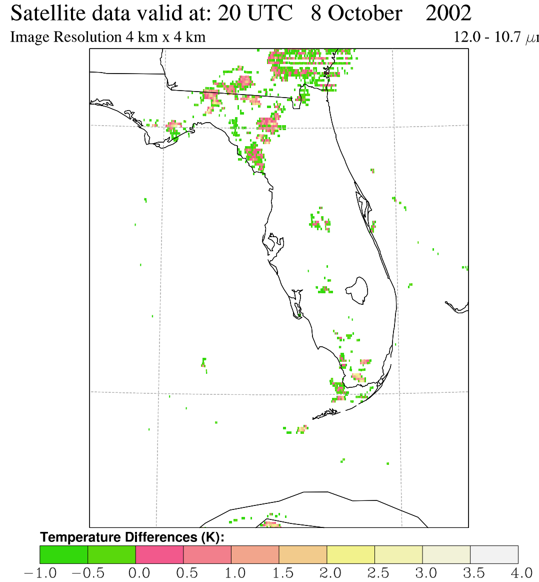

Figure 5: Spectral approach that delineates cirrus from non-ice clouds, and hence regions of new CI. This figure, the difference of the 12.0–10.7μm broad bands of 4 km-resolution GOES-08 imagery, highlights regions where optically-thin clouds (i.e. cirrus) are present. We plan to use this technique to identify precipitating convection, which in turn can help validate our nowcasting and/or help identify where new convection will initiation.

ice crystal-dominated cloud tops. In Fig. 5, the 12.0 and 10.7 μm channels are differenced which provide some information on the occurrence of ice (versus water) in cloud top hydrometeors. Another band subtraction technique (not shown) which is useful for identifying deepening convection is the 6.7–10.7 μm difference [slightly positive differences; Schmetz et al. (1997)]. A challenge of this effort will be to combine the 4 km and 10 km GOES infrared data sets with the 1 km information to formulate second-order CI interest fields. Additional CI interest fields and examples of the various processing methods will appear on the accompanying poster.

Aspects of this research that will soon be explored include the use of time series of GOES imagery as convective cloud longevity and movements are studied, the incorporation of other satellite-derived information (e.g., cloud-motion derived winds, GOES Sounder derived tropospheric stability information; Fig. 6), and non-satellite numerical weather predictions model fields (e.g., from the RUC2). As described above, we will also develop optimal ways of combining twice-daily MODIS data into our GOES-processing algorithms to help assess how these enhanced-resolution instruments can be used to assess CI so we may be prepared for hyperspectral data sets when they arrive toward 2006.

Our work will ultimately bifurcate into CI analysis for land and CI analysis over oceanic regions. Due to the different character in lower-tropospheric heating over these two regions, we expect that cloud analysis techniques for nowcasting CI will need also to be different over the two surfaces. This will especially be the case when existing cumulus cloud features are monitored as is the case of convective cloud lines over oceans (which may produce moderate precipitation for hours throughout the day and night) and over land (which may erupt into deep, heavy precipitation during afternoon hours, and disappear at night). Another significant difference between land and oceanic CI monitoring is the timing of CI as related to heating cycles.

In addition, aspects of nocturnal CI will be assessed in this project. Nocturnal CI remains one of the most difficult aspects of nowcasting (Parsons et al. 2001) and will this demand considerable time from this research effort. At this point, we expect that assessment of nocturnal CI will be similar over land regions and oceans as CI is not associated directly with solar heating or surface moisture/mass convergence, and thus is less a function of surface

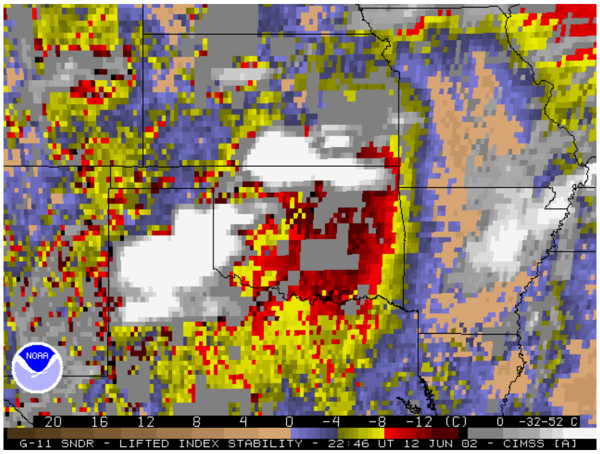

Figure 6: GOES-11 Sounder derived lifted index (LI). This represents an example of a GOES Sounder stability field that can be incorporated into our realtime CI diagnostic and nowcasting routines.

characteristics. The successful regional scale analysis of nocturnal CI would be a very significant outcome of this project.

5 SUMMARY

The CI interest fields developed from this research to be formed over the next three year will be transferred to the nowcasting systems run at NCAR. These include the Thunderstorm AutoNowCaster, the National Convective Weather Forecast, and the Oceanic Convective Nowcaster Demonstration. Work over the coming convective weather seasons will involve the development of new methods at UW, and the transfer of algorithms for further testing and evaluation at NCAR. This research effort will capitalize on a number of field experiments as unique data sets are utilized for evaluating CI in the presence of more routine information (e.g., GOES). Immediate field experiment data sets that will be used include those from the International H_2O Project 2002 (IHOP_2002), the CRYSTAL-FACE campaign, and the THunderstorm Operational Research (THOR) project to occur during summers 2003-2005 over the northeastern US.

Additional collaboration between the UW Machine Learning Research Group are expected to develop as state-of-the-art pattern detection methods are incorporated into the analysis of convection and CI.

6 ACKNOWLEDGEMENTS

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