CGMS-XXXI USA-WP-26
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Agenda Item: III.1

REPORT ON AUTO-CASTER RESEARCH

Summary and Purpose of Document

This paper summarizes the current auto-nowcasting research conducted at the NOAA/ NESDIS Cooperative Institute for Meteorological Satellite Studies. It is in response to action 30.30 "NOAA/NESDIS is invited to report on the 'auto-nowcaster' at CGMS XXXI.
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Action Requested: None

Report on Auto-Caster Research

Processing Meteorological Satellite Information to Nowcast Convective Initiation and Convective Character from Space for the Purpose of Increasing Aviation Safety

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1. Overview of Research

Work that has been done lies in three main areas: (1) processing real-time meteorological satellite imagery toward the assessment of convective initiation (CI) on scales of 1-4 km, (2) performing basic research in the use of data from the MODerate resolution Infrared Spectrometer (MODIS) for estimating convective cloud growth toward CI, and (3) performing a first assessment of the value that hyperspectral data has toward studying convective clouds and the CI process. For this work, CI is defined as the first occurrence of rainfall reaching Earth's surface from convective (i.e. cumulus) clouds.

2 Real-time Processing for CI Assessment

Geostationary Operational Environmental Satellite (GOES) provides three data sets for CI investigations: (1) 1 km resolution visible imagery, (2) 4 km resolution infrared imagery from the GOES Imager, and (3) 10 km resolution infrared imagery collected by the GOES Sounder. Each data set has a unique value for assessing the CI-potential of convective clouds as seen in satellite imagery. Each CI-relevant field is referred to as a "CI interest field" with the knowledge that each data set will contribute to a forecast of CI. Not all CI interest fields provide the same level of information (i.e. value) to a CI forecast, as will be explained below. Each CI interest field is evaluated in real-time through the use of NEXRAD radar data as provided through the Man computer Interactive Data Access System (McIDAS) at UW-CIMSS.

GOES Visible Imagery: At 1 km horizontal resolution, these data provide information on the cumulus cloud scale. Early efforts focused on using this information to detect the presence of daytime "active" cumulus from which a "cumulus cloud mask" was defined, with follow-on processing for CI. Cumulus clouds were identified in visible data via a simple two-dimensional brightness gradient and via a method based on a "critical" brightness across an image. The gradient technique identifies immature cumulus clouds, which are often precursors to the CI process. The critical brightness method assumes cumulus reflect a high percentage of incoming solar radiation and thus are some of the brightest clouds; this is useful for identifying mature cumulus clouds, many of which are very near to or have already begun precipitating.

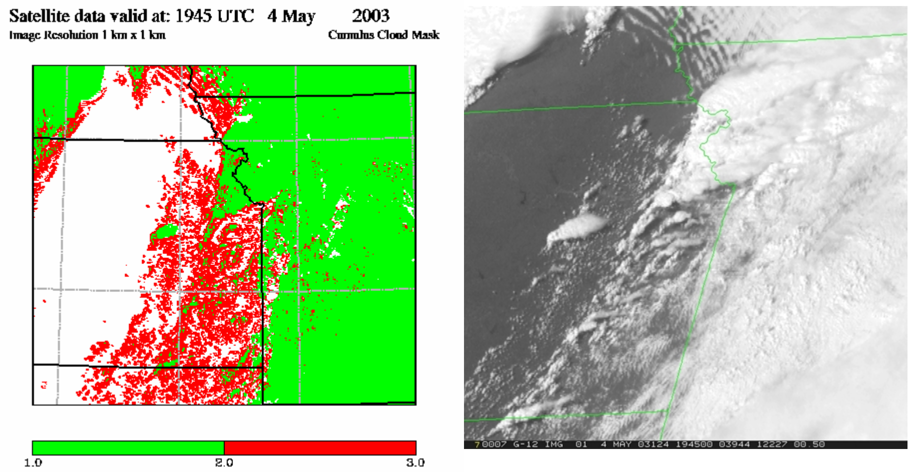

Figure 1: Convective cloud mask (left) and GOES-12 visible (right) 1 km images. Red pixels denote cumulus clouds as identified via the brightness gradient approach. Green pixels indicate clouds (some cumulus) identified by the "critical brightness" approach.

<u>GOES Imager Infrared Data</u>: It has been determined that all CI processing should occur on 1 km resolution (rather than 4-5 km). Thus, all 4 km IR data (channels 2-5 of the GOES Imager) are being interpolated to 1 km resolution. Through this process, the IR data can now be directly used with the 1 km visible data in ways that preserve the high-detail and value that the visible data provide to the CI assessment problem. The 1 km IR data are processed in two unique ways toward evaluating the character (e.g. growth and deepening, rates of development, and microphysics) as relevant to CI. These involve:

a. Tracking the Time-Rate of Change of the 10.7 μm Cloud-Top IR Temperature
b. Monitoring the 6.7-10.7 μm Cloud-Top IR Temperature Differences
c. Monitoring the 3.9-10.7 μm Cloud-Top IR Temperature Differences
d. Monitoring the 13.3 (12.0) –10.7 μm Cloud-Top IR Temperature Differences

For a), simply keeping track of the 10.7 μm cloud-top temperatures for cumulus identified by the cumulus mask indicates whether or not the cloud is deepening, or if glaciation is occurring or about to occur. Section 4 (presented below) provides a full description of how individual cumulus clouds are tracked. The IR band differences b)-d) help to reveal which cumulus cloud tops are close to the tropopause, composed of ice or water, and optically thick, respectively. Tracking individual cumulus to monitor these channel differences over time has proven critical in assessing if a cloud is about to produce precipitation. The most useful of the four techniques listed above have been found to be a) and b) described in the literature by Roberts and Rutledge (2003) and Schmetz et al. (1997), respectively. In effect, if a cloud's temperature can be tracked over a period of time, the time of glaciation can be estimted. In many cases, b) indicates where it is already raining based on comparison to NEXRAD data. IR differencing of the 10.7 and 3.9 μm channels is fraught with high-noise in the 3.9 μm channel at night and is very sensitive to solar zenith angle during the day. The channel difference involving the 12.0 (GOES-11 and before) or 13.3 μm (GOES-12 only) bands are somewhat redundant with the 6.7-10.7 μm difference, since deep cumulus are often optically thick. Figure 2 below overviews these channel differences for one convectively active day. Table 1 provides an overview of these CI assessment criteria and their critical values.

<u>GOES Sounder Infrared Data</u>: Data from the 10 km resolution GOES Sounder instrument offers the ability to produce satellite-based soundings of the troposphere. From these soundings, convection-related parameters such as convective available potential energy (CAPE), lifted index (LI), and convective inhibition (CIN) can be produced. Unfortunately, these parameters are only available in clear-sky conditions, and at 10 km resolution. In effect, the Sounder-based products tell us little in the way of new information. Specifically, since CAPE is often not a limiting factor for thunderstorm development in a convectively unstable atmosphere (i.e. one with active cumulus), LI's are very often negative across large regions of the U.S. during the convective season, and CIN are similarly ubiquitous components of warm-season atmospheres. Another GOES-derived product is the Cloud Top Pressure (CTP) based on the "CO2 slicing" (Schreiner et

al. 1993) technique; this has proven to be more useful in CI work than other derived products. Methods of interpolating the 10 km Sounder data to a 1 km resolution are being explored, which would enable use of the CTP product in CI analysis.

Cloud Motion Tracking: The ability to track the same cumulus cloud in two successive GOES images (15-30 minutes apart) is important. This was accomplished through the use of the same program that creates visible/infrared satellite derived winds for a variety of meteorological applications (see Velden et al. 1998). An “offset” vector, based on these satellite-derived winds, is used to approximate the location of a pixel in previous IR images. This enables monitoring trends in individual clouds on the 1 km scale across an entire GOES image.

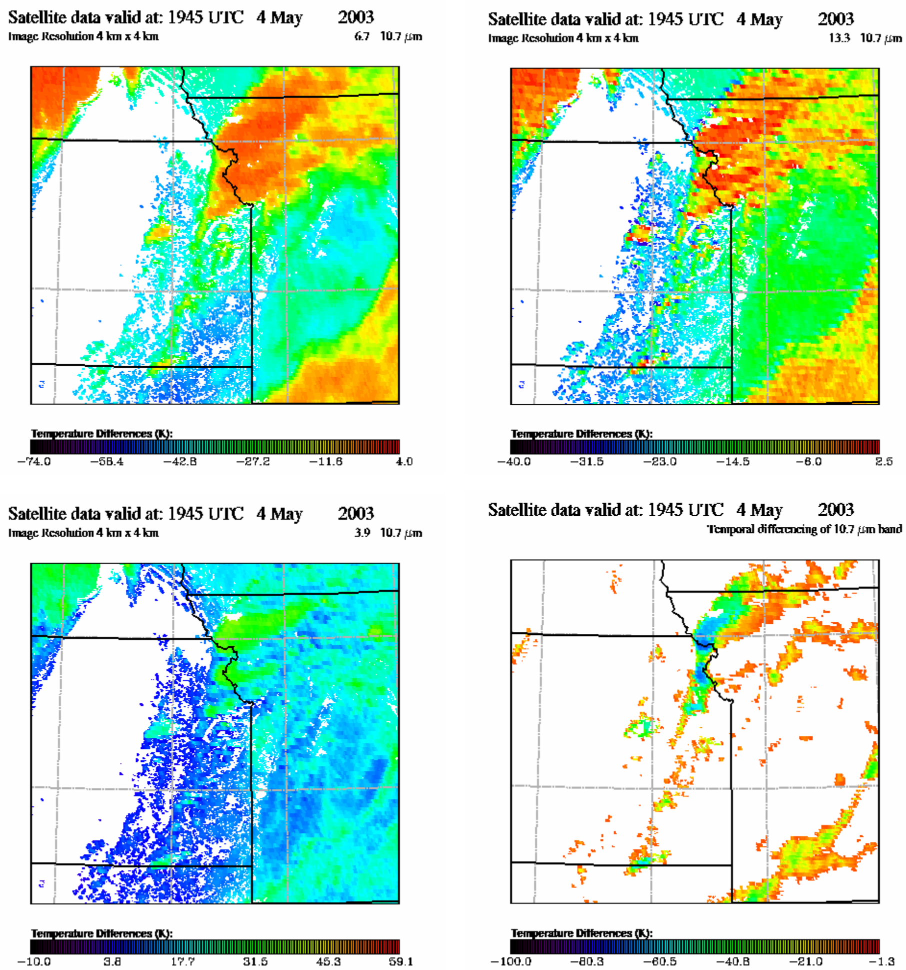

Figure 2: Various CI channel difference fields using GOES-12 data for a convective event on 19:45 UTC, 4 May 2003. The 6.7-10.7 μm channel difference for detecting “overshooting”/deepening clouds (red, upper-left), the 13.3-10.7 μm difference for detecting for identifying optically thick clouds (red, upper right), the 3.9-10.7 μm difference for cloud microphysics (green=ice, lower left) optically thick, and the time trend in cloud-top temperature. An accurate temporal trend assessment has been possible through the use of the “offset vector” technique.

CI Assessment Criteria (Listed in Subjectively-Determined Order of Importance)	**Critical Value**
10.7 µm T_B	< 273 K
10.7 µm T_B Time Trend	< -4 K/15 mins. (weak growth) < -8 K/15 mins. (vigorous growth) [based on Roberts and Rutledge (2003)]
Timing of 10.7 µm T_B drop below 273 K	within previous 30 minutes
6.7 – 10.7 µm difference	-35 K to –10 K
13.3 – 10.7 µm difference	> -20 K

Table 1: Specific CI channel "critical" differences used in our CI processing.

<u>Summary:</u> When processing for CI, the following methodology is followed toward the production of several CI products. Several of the well-tested methods are products available in real-time. Product development continues on 6 case study events of CI for which NEXRAD radar and the full suite of satellite data area available. To date products tested include:

- Cumulus cloud mask, combined with NEXRAD radar data [Real-time]
- The various IR channel differences [Real-time]
- Time differences of the 10.7 µm IR channel that relies on "offset" vectors [Real-time]
- An assessment of the timing of 10.7 µm temperature drop below freezing for cumulus [Experimental]
- An assessment of cumulus cloud motion and jet stream-level wind speed [Real-time]
- A scoring procedure that tabulates CI likelihood based on several CI interest fields [Experimental]

Efforts are underway to test a CI nowcast field that uses simple linear time-extrapolation of the scoring-based product (Fig. 3) toward estimating the time that CI should occur. Based on the information in Table 1, it is conceivable that some level of interpolation of trends in cloud-top IR temperature and temperature difference changes can be inferred from this processing. It is a goal to be able to nowcast the occurrence of CI, based on tests against NEXRAD information, from 30-60 minutes into the future with reasonable accuracy (~70 %) with little additional processing effort.

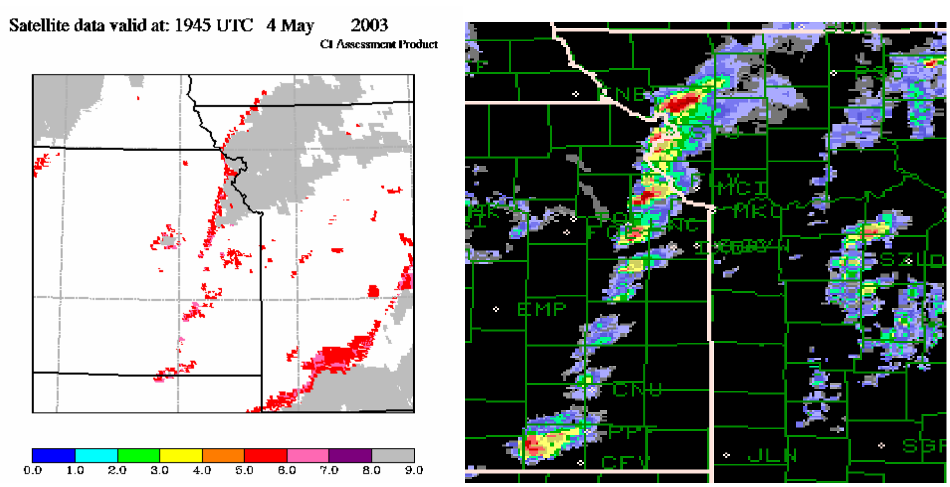

Figure 3: This product (left) represents the likelihood of CI based on the scoring of several CI interest fields as they are determined to contribute to predicting the occurrence of CI. The right-hand side image is NEXRAD data ~45 minutes later showing new convection near Topeka, KS in the same locations of the red pixels on the "CI Assessment Product". Grey pixels correspond to cirrus anvils.

3. MODIS Image Processing for CI

Given the availability of MODIS imagery (from the Aqua and Terra satellite platforms) at UW-CIMSS, capabilities of MODIS and GOES data in CI research were compared. Figure 4 demonstrates a few comparisons and capabilities of MODIS for a severe convective event over the southeastern US in spring 2003. One aspect of MODIS that GOES instruments do not possess is the number of available channels, MODIS offers 36 from 250 m—1 km resolution compared to the GOES Imager 1 visible (1 km), four IR Imager (4 km) and 18 Sounder (10 km) bands. Although MODIS offers enhanced spatial resolution, challenges facing its use in an evaluation of short-time scale phenomena involve the four times per day overpass frequency and issues related to view angle and image navigation. However, because of its advanced capabilities, MODIS data is expected to become a significant component in CI processing. Figure 4 demonstrates 8.5-11.0 μm channel differences (right, Strabala and Ackerman (1994)) achievable on MODIS (and not on GOES), a representation of cloud-top microphysics is seen for convection occurring over the southeast U.S. The MODIS 6.7-11.0 μm differences (left) are also shown. Better utilization of MODIS once data navigation is adequate enough to accurately use these data in quasi-real-time processing for CI.

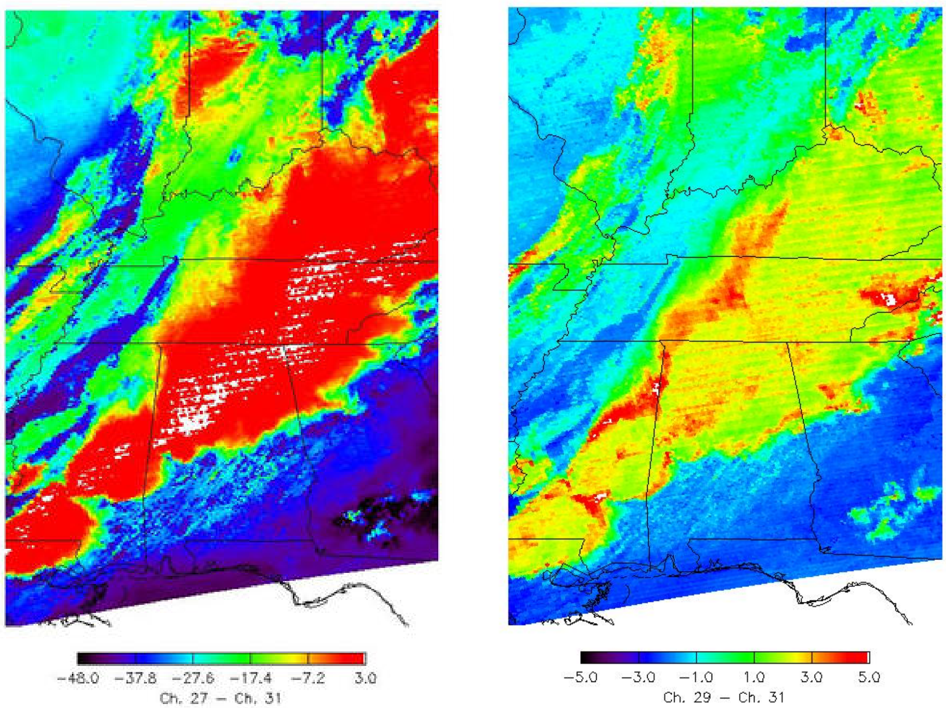

Figure 4: MODIS 6.7-11.0 μm (left) and 8.5-11.0 μm (right). On the left image, smaller scale (1 km) cumulus clouds (southern Alabama) are more easily seen in comparison to 4 km resolution IR from GOES. MODIS nighttime assessments of CI are expected to contribute more than GOES due to its higher resolution in the IR. The 8.5-11.0 μm difference will allow an estimate of cloud-top glaciation in wavelengths that GOES does not possess. Red areas highlight locations of high ice crystal concentration, yellow highlights mixed-phase clouds, and blue highlights liquid water clouds and clear sky

4. Use of Hyperspectral Data for Determining Convective Cloud Properties

Simulated GIFTS data are being used to develop retrieval algorithms, "fast" and forward model radiative transfer models, and meteorological applications that are enhanced by hyperspectral measurements. Simulated GIFTS data created at CIMSS for a 12 June 2002 case of CI over the International H2O Project (IHOP_2002) domain is comprised of over 3000 channels at 0.6 cm^{-1} wavenumber (~0.01 μm) resolution in the spectral ranges between 4 μm and 15 μm. Figure 5 demonstrates the "8.5 - 11μm" difference as available on many "broad-band" satellite sensors (e.g., MODIS and Meteosat Second Generation—MSG);

these represent an average of a range of channels (e.g., from 10.78 to 11.28 μm (MODIS) and from 10.2 to 11.2 (GOES) for the ~11 μm channel). GIFTS channel differences are the best approximation of a "true" channel difference. As demonstrated in Fig. 5, true channel differences enable better measurement of the cloud-top character of the convection (and CI).

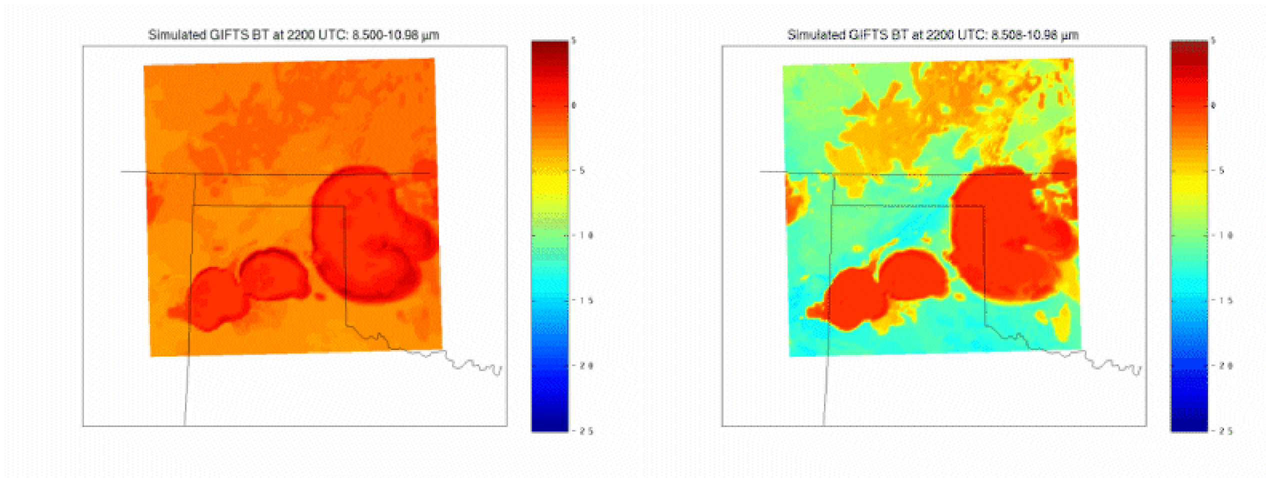

Figure 5: Simulated GIFTS ~8.5 – 11 μm difference. A high sensitivity in the difference exists as a result of fine water vapor absorption bands. The image on the right is closest to that from MODIS, where red represents ice cloud tops, orange represent mixed phase tops, and yellow/blue represents liquid water tops/clear sky.

5. Near term Plans

The near term plans are as follows:

- Submit and publish the *Journal of Applied Meteorology* paper detailing the work done to date;
- Refine the cumulus cloud mask;
- Develop this research to benefit the NCAR-based PDTs (Convective Weather and Oceanic Weather) so they may use CI diagnostic and nowcast products in their aviation safety applications work;
- Develop the use of lightning information in satellite-based CI processing systems;
- Work toward developing and publishing research on nocturnal CI, which is particularly challenging given that visible satellite data cannot be used;
- Further determine how MODIS imagery can be effectively utilized in CI processing systems.

6. Acknowledgments

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7. Bibliography

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