P6.9 AN OBJECTIVE NOWCASTING TOOL THAT OPTIMIZES THE IMPACT OF GOES DERIVE PRODUCT IMAGERY IN VERY-SHORT-RANGE FORECASTS AND NOWCASTS

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1. BACKGROUND

Many future instruments (e.g., Wind Profilers networks, automated aircraft reports and the Hyperspectal Environmental Sounder planned for GOES-R) have the capability of resolving atmospheric features beyond today's capabilities in both time and space. Although these data are expected to generate improvements in numerical forecast guidance out to 48 hours and beyond, a greater benefit from these high-time-frequency and detailed data sources may come from their use in real time objective nowcasting systems designed to assist forecasters with identifying rapidly developing, small-scale extreme weather events.

These nowcasting systems will need to detect and retain extreme variations in the atmosphere, incorporate large volumes of high-resolution asynoptic data from satellites and other high-resolution systems, and be very computationally efficient. Accomplishing this will require numerical approaches and techniques that are notably different from those used in numerical weather prediction where the forecast objectives cover longer time periods. The nowcasting systems will need to place an emphasis on retaining the accuracy of individual observations and preserving the large gradients seen in these data through time. Speed, however, will be of the essence, since in many cases the detailed information provided in the observations is extremely perishable.

The basis for a new approach to objective nowcasting is presented that uses LaGrangian techniques to optimize the impact and retention of information provided by multiple observing systems. Real data tests are shown in which GOES Derived Product Imagers (DPIs) of multi-layer precipitable water observations are used with the goal of identifying horizontal and vertical details of the environments associated with the onset of significant weather events several hours in advance.

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2. THE LAGRANGIAN APPROACH

The LaGrangian Objective Nowcasting system described here is designed both to retain extreme variations in observed atmospheric parameters and preserve vertical and horizontal gradients observed in the various data fields throughout a 3 to 6 hr projection. Instead of relying on traditional Eulerian approaches which forecast the changes in parameters at fixed grid points and which require that observations be interpolated from their original locations to the fixed grid (and thereby lose some of their detail and data extremes), the approach used here applies the equations of motion to parcels originating at their points of observations.

The LaGrangian approach (based on the Discrete Model Theory developed by Greenspan, 1972) has been shown to be an effective diagnostic tool by Kocin et al., 1986. In this study, low- and upper-level trajectories were obtained during a pre-convective period based on analyses of

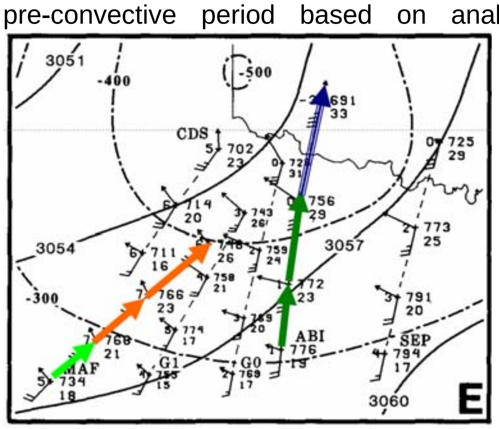

Figure 1 - Lower-tropospheric parcel flow preceding 10 April 1979 tornado outbreak.

special 3-hourly rawinsonde data. The result not only showed the ability of the LaGrangian approach to simulate the interplay between dry line approaching from west and transport of Gulf moisture from the south (repeated here in Fig. 1), but also the coincidence of the low-level moisture convergence with drying and the growth of divergence in the exit region of the jet streak aloft.

2.1 Model Formulation

In discrete form (See Petersen and Uccellini, 1979), the basic equations of motion become:

$$a_x^{(t)} = -\Delta\Psi^{(t)} / \Delta x + f^{(t)} v^{(t)},$$
$$a_y^{(t)} = -\Delta\Psi^{(t)} / \Delta y - f^{(t)} u^{(t)}, \quad \text{or}$$
$$v^{(t)} = 1/f^{(t)} [a_x^{(t)} + \Delta\Psi^{(t)} / \Delta x],$$
$$u^{(t)} = -1/f^{(t)} [a_y^{(t)} + \Delta\Psi^{(t)} / \Delta y].$$

In discrete model formulation (Greenspan (1972), the future momentum and location of parcels is calculated using energy conservative formulae:

$$u^{(t+1)} = u^{(t)} + \Delta t\, [\, 1.5\, a_x^{(t)} - 0.5\, a_x^{(t-1)}\,],$$
$$v^{(t+1)} = v^{(t)} + \Delta t\, [\, 1.5\, a_y^{(t)} - 0.5\, a_y^{(t-1)}\,], \text{ and}$$
$$x^{(t+1)} = x^{(t)} + 0.5\, \Delta t\, [\, u^{(t)} + u^{(t+1)}\,],$$
$$y^{(t+1)} = y^{(t)} + 0.5\, \Delta t\, [\, y^{(t)} + y^{(t+1)}\,],$$

where for the first time step

$$u^{(1)} = u^{(0)} + a_x^{(0)}\, \Delta t, \text{ and } v^{(1)} = v^{(0)} + a_y^{(0)}\, \Delta t.$$

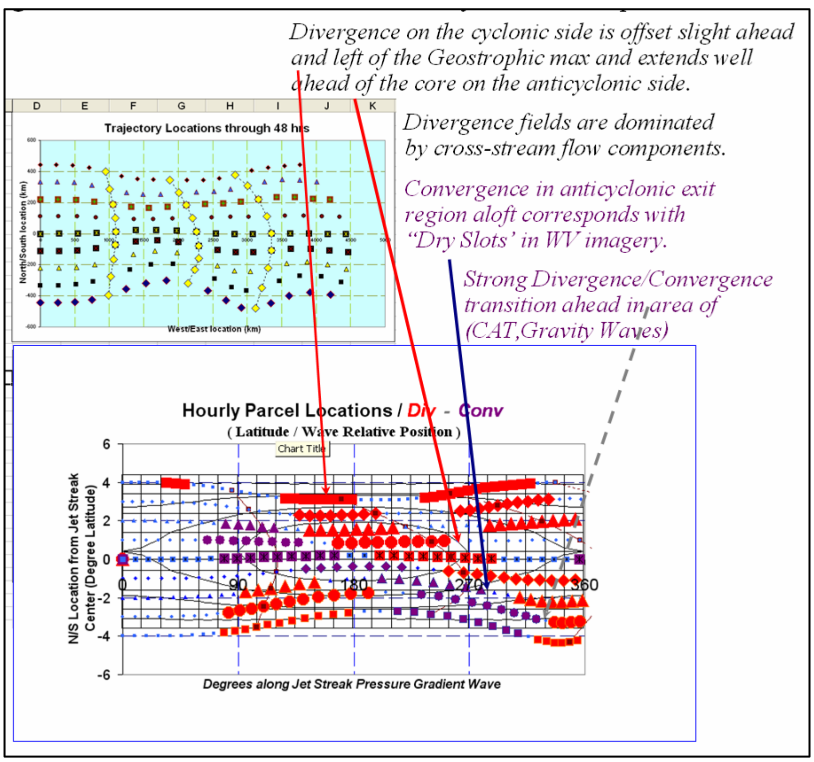

Figure 3 - Example of test of LaGrangian system with analytical Jet Streak, including annotations of specific findings.

At each time step, $a_x^{(t)}$ and $a_y^{(t)}$ are calculated by interpolating $\Delta\Psi/\Delta x$ and $\Delta\Psi/\Delta y$ bi-linearly from a regular grid to each parcel location, f is calculated from latitude location of the parcel, and the parcel accelerations are calculated arithmetically at time t and saved for time use in the next step as $t\text{-}1$.

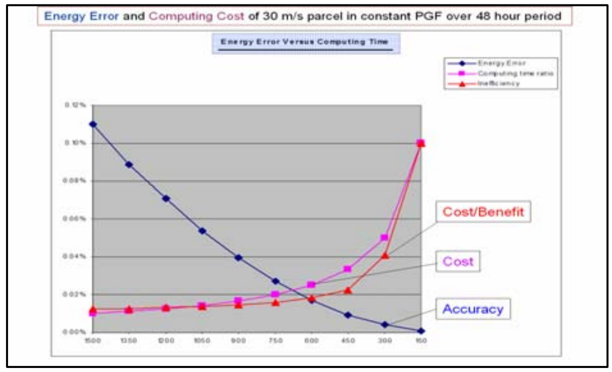

Figure 2 - Comparisons of errors in energy conservation and computational time step for idealized LaGrangian test cases.

2.2 Analytical Tests

An extensive series of analytical TESTS were performed to document the ability of the method to retain gradients and data field maxima/minima through advection. These tests not only quantified the computational efficiency of the LaGrangian approach and the ability of the approach to retain observed gradients and isolated maxima and minima, but also demonstrated that the technique eliminates amplitude and phase error biases associated with the advection of very small wavelength features which occur when using conventional Eulerian techniques. The cost/benefit diagram in Figure 2 also shows that an optimal time step for the LaGrangian technique is about 600-700 seconds, independent of data grid density.

Additional analytical tests have been conducted to determine the advantage of LaGrangian techniques to different dynamical processes especially relevant to nowcasting. Specific emphasis was placed on modeling the structure of the Jet Streak. The goals of these examples are two-fold: 1) to provide evidence of the advantage of the approach in a manner relevant to forecasters and 2) to provide a tools for teaching a more thorough understanding of the dynamical processes involved in mesoscale systems – especially those related to creating an environment conducive to severe storm development – and how the result of these dynamics is shown in rapidly changing GOES satellite data.

For example, analyses of parcels entering an idealized jet streak reveal a variety of features which modulate as the strength of the jet streak increases. Figure 3 shows a number of examples typical of more extreme shear conditions. Impacts include asymmetry in the divergence/convergence couplets around the jet streak, and enhanced upper-level convergence on the anticyclonic side of the jet streak divergence ahead of it.

It is noteworthy that the development of this feature has occurred using parcels which had been initially in complete dynamical balance and which were initially separated by 111 km. In the exit region, the separation decreases to less than 10 km. Producing such a simulation with an Eulerian system would have required grid resolutions of ~1-2 km – an extremely resource intensive effort – while the LaGrangian approach was done nearly instantaneously on a PC.

The analytical tests have shown that the LaGrangian approach is extremely computationally efficient (since the inertial advective terms needed in Eulerian models no longer dictate that the model time step must be a function of grid spacing), is able to retain sharp gradients and observed maxima and minima, and has the capability of providing timely updates to guidance provided by operational forecast models.

3. REAL DATA TESTS

Real data tests are currently being conducted at CIMSS - with the goals of identifying details of the environments associated with the onset of significant weather events several hours in advance. The tests use full resolution (10 km) derived layer moisture products from the GOES-10/12 sounders to update and enhance operational RUC forecasts. Initial tests are focusing on the use of multi-layer GOES Derived Image Product (DPI) moisture data, with the long-term goal of providing a basis for using GOES-R and NPOES data when they arrive.

The objective of these tests is to provide forecasters 3 to 6 hour forecasts of the DPI fields updated every hour. Initial application of the LaGrangian Nowcasts focuses on the optimal approaches for providing *updates of existing mesoscale model outputs in the free-atmosphere by combining the power of Short-Range NWP with strength of satellite observation updating* through matching of RUC-II wind analyses and geopotential analyses/forecasts with GOES Sounder (DPI) Water Vapor Data. (It should be noted that the GOES Sounder profiles are not currently used in RUC over land.) Individual air parcels are assigned to each GOES-DPI data location and marched forward in time at 15 minute intervals. Note that additional observations can be included as they arrive to provide additional data points since the satellite data arrive every 30-60 minutes.

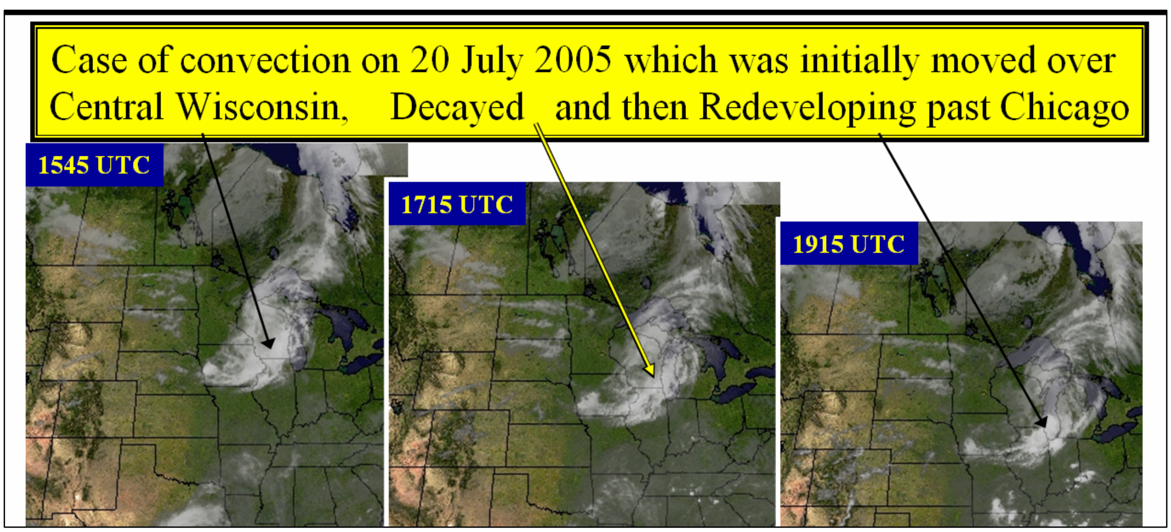

Figure 4 - Visible satellite images of Derecho moving across Wisconsin into northwestern Indiana on 20 July 2005.

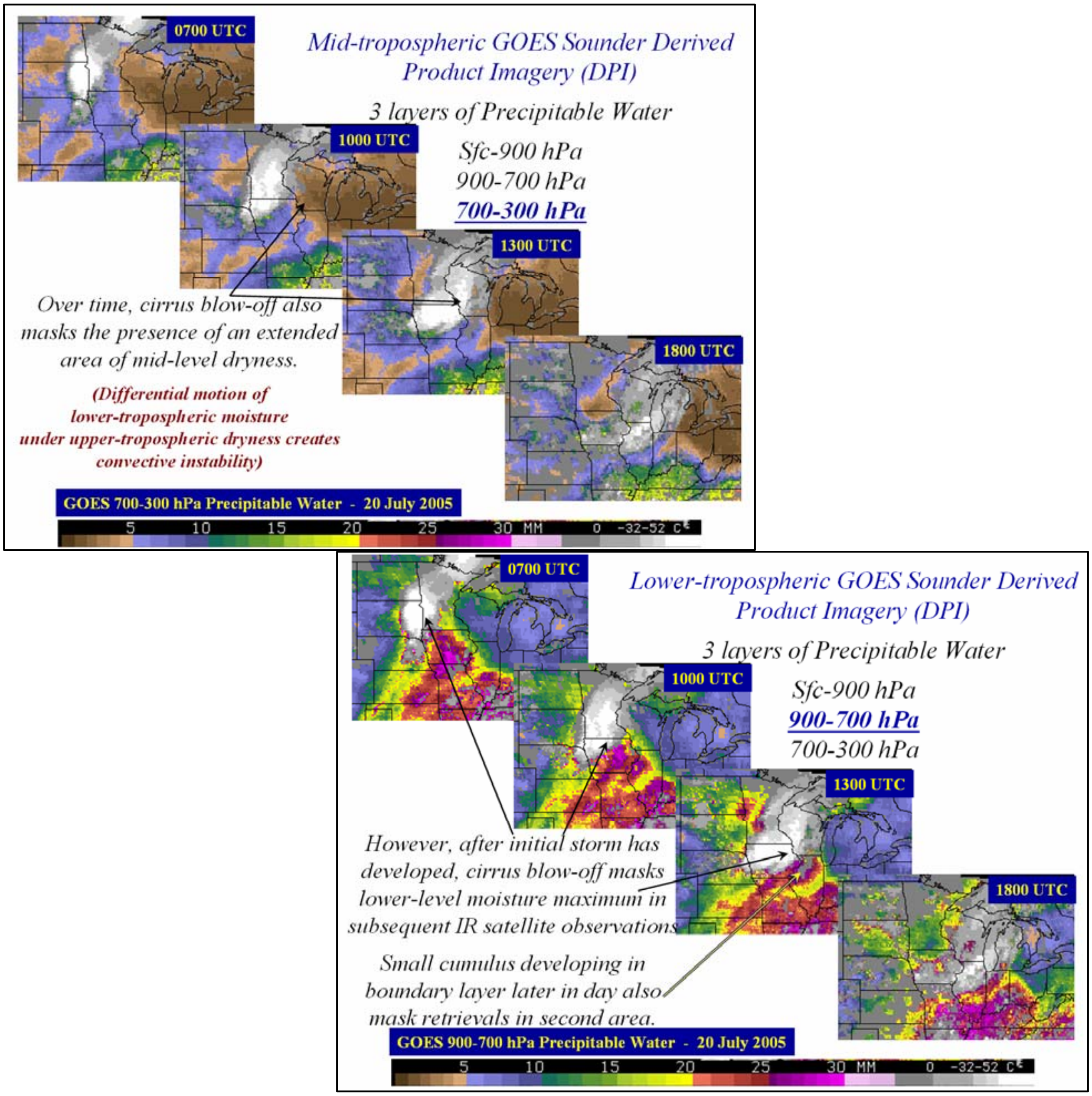

Figure 5 - Observed GOES DPIs of Middle - (top) and Lower- (bottom) Tropospheric Precipitable Water (PW) for 20 July 2005, with annotation of important features.

The case presented here considers the propagation and redevelopment of an unforecasted Derecho which progressed from central Minnesota, across Wisconsin and into north-western Indiana during the daylight hours of 20 July 2005. Visible satellite imagery throughout the day (Fig. 4) shows that the surrounding area was nearly devoid of other cloud features, making it optimal for satellite sounding retrieval.

Nevertheless, the evolution of the middle and lower-tropospheric moisture fields in Figure 5 shows that by the time of the redevelopment of the convection southeast of Chicago, the source of lower-level moisture which had been located over south-central Iowa at 0700 UTC was almost entirely obscured by clouds. Likewise, the area of middle-tropospheric dryness, needed to produce convective instability by overlaying the lower-level moisture, was also capped by cirrus blow-off near the tropopause in the area of concern. The masking of the middle and lower-troposphere by the cirrus clouds made the satellite data being viewed by forecasters immediately before the storm developments far less useful than it might have been had the cirrus clouds not been present.

In an attempt to assess whether the nowcasting system can project the satellite information available in clear areas earlier in the day into the areas of subsequent storm development (but without the limiting effects of cirrus contamination), the LaGrangian nowcasting system was initialize with parcels assigned to every observational point in the 10km resolution GOES DPI PW imagery (See Fig. 6) at 1200 UTC. RUC-II winds were interpolated to each parcel location and dynamic parcel trajectories were calculated using the initial RUC wind data and observed height field tendencies. Layer averaged data from 850-750 hPa and 550-450 hPa were used to initialize the movement of the parcels.

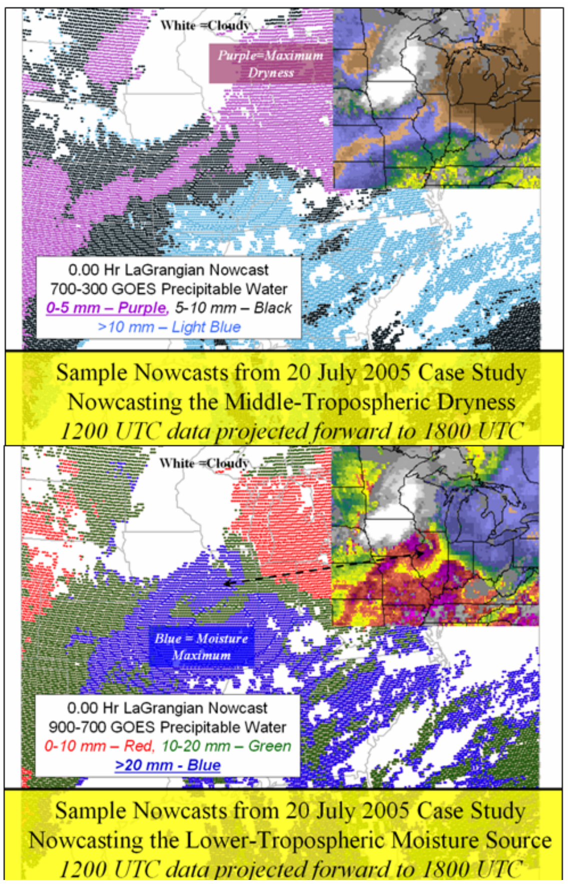

Figure 6 - Color Coded Initial Parcel locations for Middle- (top) and Lower- (bottom) tropospheric Precipitable Water with original DPI imagery for 1200 UTC 20 July 2005. PW banding conventions noted in figures.

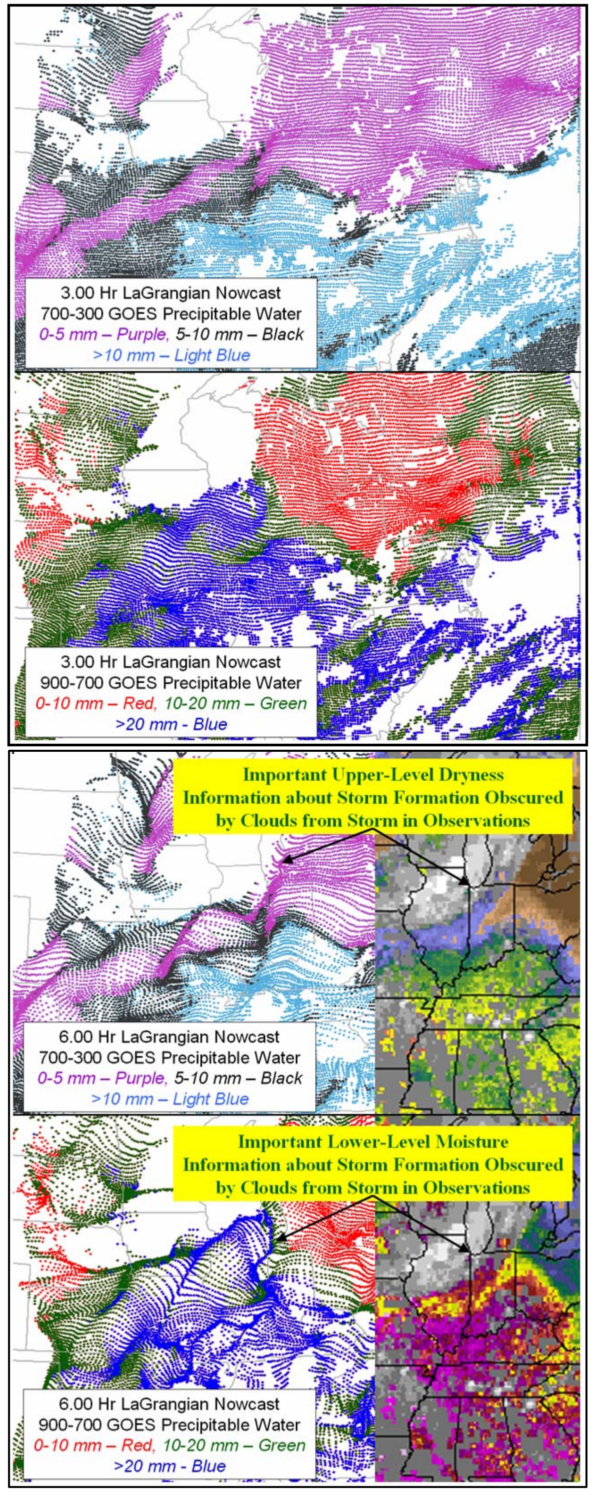

Figure 7 - Color Coded 3 hr (Top 2 Panels) and 6 hr (Bottom 2 Panels) Nowcasts of Parcel locations for Middle- and Lower - tropospheric Precipitable Water initialized at 1200 UTC 20 July 2005. Verification DPIs shown with 6 hr nowcasts

Three and six hour nowcasts of the middle- and lower-level PW shown in Figures 7 depict the translation of the parcels from morning into early afternoon. The nowcast images clearly show the movement of the moisture maximum initially along the Iowa/Illinois boarder across Illinois and into northwestern Indiana in the 6 hours between 1200 and 1800 UTC. In addition, the region of upper-level dryness has also moved into this area, showing a distinct concentration in the area when convection subsequently developed.

The development of convective instability is vital to the development of severe convective storms such as this. The process whereby mid-level warm dry air overlays moister air nearer the surface to create areas of convective instability is a complex one. Not only must there be a local concentration in moisture at low levels, but the moisture must first be capped by increasing subsidence of dry air from aloft during the time while the low level moisture is concentrating in an area. This creates the convectively unstable environment suitable for severe convection. For the convection to occur, however, the low level moisture must be able to break through the overlying subsidence inversion. This can occur by having sufficient low level convergence present to lift the inversion while convective clouds are forming below. To aid the low-level lifting process, it is advantageous to have the forcing for the upper-level subsidence and drying slightly out of phase (moving ahead of) the area of low-level moisture flux convergence.

Study of the nowcast images for this case show that was indeed the case for this example. The increase of low-level moisture is almost coincident with the development of convection, while the concentration of middle-level dryness occurs over northwestern Indiana approximately 1-2 hours before the convection redeveloped there, followed by a movement of the dryness extreme farther to the east.

4. SUMMARY

A new method for objective nowcasting has been presented which uses LaGrangian approaches to the numerical forecasting problem rather than the traditional Eulerian techniques. The method is advantageous in that is extremely computationally efficient, is able to retain sharp gradients and observed maxima and minima, and has the capability of providing frequent and timely updates to guidance provided by operational forecast models – using perishable observations that are not typically included in NWP systems. Both analytical and real-data tests have shown the potential usefulness of the system. The approach holds promise of extending the utility of GOES DPI products (which currently are not used in NWP models over land) from observational data into objective tools that can be used in anticipating details about the timing and location of convection 3-6 hours in advance, even after the IR observations themselves may no longer be available in the areas of severe weather due to cloud development.

In order to show consistency for operational forecasters between observations and nowcasting products, results of future DPI nowcasting tests are presented in the same form of forecast satellite images as the observed DPIs themselves.

Others areas of future work include:

- Optimizing wind level selection to match satellite channel weighting and using isentropic coordinates,

- Improving visualization tools to view predicted DPIs in formats identical to the observational products will require improvements to LaGrangian model, as well as ‘data aging' and ‘continuous successive image merger' algorithms to combine coincident output from successive nowcast runs into single images,

- Integrating Profiler, Aircraft and Cloud Tracked Wind data directly into the system to provide wind as well as moisture data updates, and

- Testing the impact of higher vertical resolution AIRS soundings in resolving the pre-convective environment.

5. REFERENCES

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6. ACKNOWLEDGMENTS

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