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NEARCASTS: PROVIDING SHORT-RANGE FORECASTS OF CLEAR-AIR GEOSTATIONARY SATELLITE PRODUCTS

Short-range forecasts of clear-air observations from current and future geostationary satellite observations have been shown to provide forecasters with useful tools to help identify areas conducive for convective storm development.

Unlike Nowcasts, which generally provide 0-2 hour guidance based on extrapolations of radar and satellite observations after clouds appear, the NearCasting system uses multi-spectral infra-red geostationary satellite products to understand the detailed moisture and stability structure of the atmosphere 1-9 hours *before* storms form.

Action/Recommendation proposed: None

NEARCASTS: PROVIDING SHORT-RANGE FORECASTS OF CLEAR-AIR GEOSTATIONARY SATELLITE PRODUCTS

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Introduction – Future instruments (e.g., multi-channel geostationary imagers, hyper-spectral polar sounders, Wind Profilers, automated aircraft reports, etc.) will resolve atmospheric features with resolutions far beyond today's capabilities in both time and space. Although these data are expected to improve NWP guidance at 6-12 hours and beyond, a greater benefit from the detailed time/space-frequency satellite systems (e.g., GOES, SEVIRI) may come from objective systems that assist forecasters in identifying rapidly developing, extreme weather events during the 2-9 hour information gap which exists between Nowcasts and longer-range NWP guidance updates.

The NearCasting system shown here is designed to detect and retain extreme variations in the atmosphere (especially moisture fields) and to incorporate large volumes of perishable high-resolution a-synoptic data. This requires extremely computationally efficient numerical approaches that are notably different from those used in numerical weather prediction, where the forecast objectives cover longer time periods.

The objective approach uses parcel-following Lagrangian techniques (instead of the fixed-grid, Eulerian methods used in conventional NWP) to optimize the impact and retention of information provided by satellites, especially the large vertical and horizontal variations observed in the various data fields observed over time and localized maxima and minima. Nine-hour calculations take only minutes.

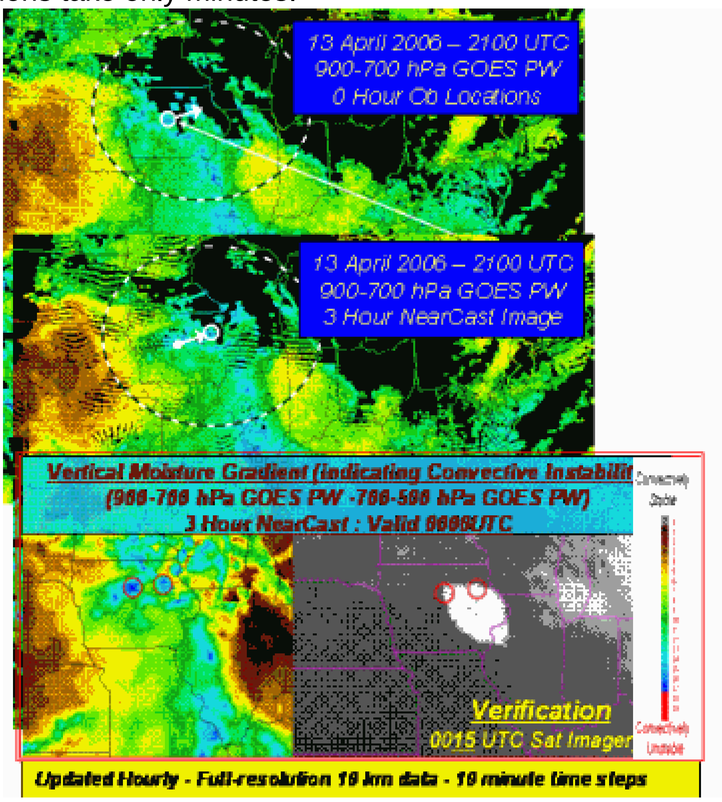

Figure 1 – Schematic of processes involved in producing a 3 hour satellite-based NearCast and producing output products. See text for details.

An example of how the Lagrangian approach retains data maxima/minima/gradients is shown in Figure 1. For each hourly-updated NearCast cycle, the system first interpolates NWP wind and geopotential gradient data to the locations of each of the full-resolution (10 km) GOES multi-layer moisture and temperature observations from multiple layers of the atmosphere (Fig.1 – top panel). Next, these high-definition data are moved to future locations, using dynamically changing winds with 'long' (10-15 min.) time steps (Fig.1 – middle panel). It should be noted that a long computational time step is possible in a Lagrangian model because, unlike Eulerian systems, the Lagrangian form of the equations of motion has no "CFL" time-step constraints. Finally (Fig.1 – bottom panel), the projected 'observation' values from each layer are transferred back to an 'image grid' for display. The forecasts of the satellite products can be displayed individually, combined in each layer to produce additional derived parameters, and merged between layers to obtain various "Stability Indices". The observed and derived product NearCasts have been used successfully to identify mesoscale areas where severe convection will develop - <u>even after the area of interest has become cloud covered and real-time GOES IR observations are no long available.</u>

Results using SEVIRI data – Recent efforts have focused on extending real-time testing and subjective evaluation of the NearCast products using both GOES and SEVIRI data. Outputs from the real-time NearCasting system are updated hourly and include two layers of Precipitable Water, derived layer Equivalent Potential Temperature, and Convective Instability calculated from that.

NearCasts results shown here are for an un-forecasted F-2 tornado event in southern Poland described by Pajek et al., 2007. The SEVIRI retrievals were used as a surrogate for future GOES-R ABI retrievals. This was a case of isolated severe summer-time convective when conventional NWP products gave no indication that convection was likely, much less to provide guidance as to the location and timing of the events. Although there were repeated instances during the day when convective clouds attempted to form over much of the area (see Fig. 2), the problem for forecasters was to determine which of these clouds would grow rapidly and when. This discussion traces the various parameters that are available from the SEVIRI observations and assess their usefulness in forecasting this case.

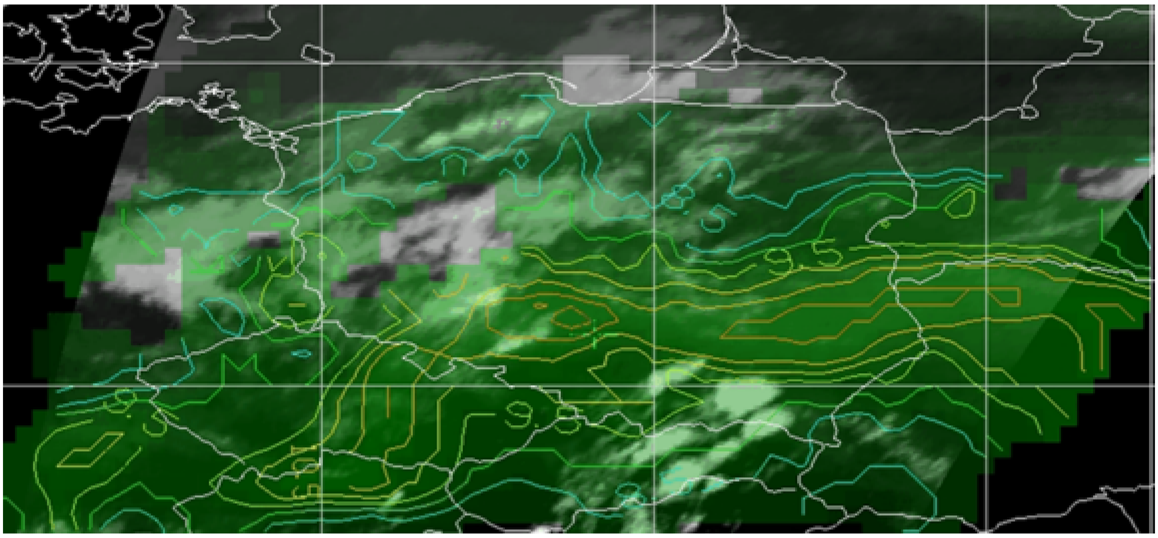

Figure 2 – Thermal IR image and NearCast of 840 hPa Mixing Ratio valid 1200 UTC on 20 July 2007, 3 hours prior to tornado formation.

Figure 3 shows the progression of low-level moisture and temperature for the 6 hour period before the tornado developed. It is noteworthy that, although the NearCasts move the surface front over the area of strongest storm formation by 1500 UTC, the area of greatest moisture, which was originally located just to the north of the surface front, passed the area of storm formation 3 hours too early.

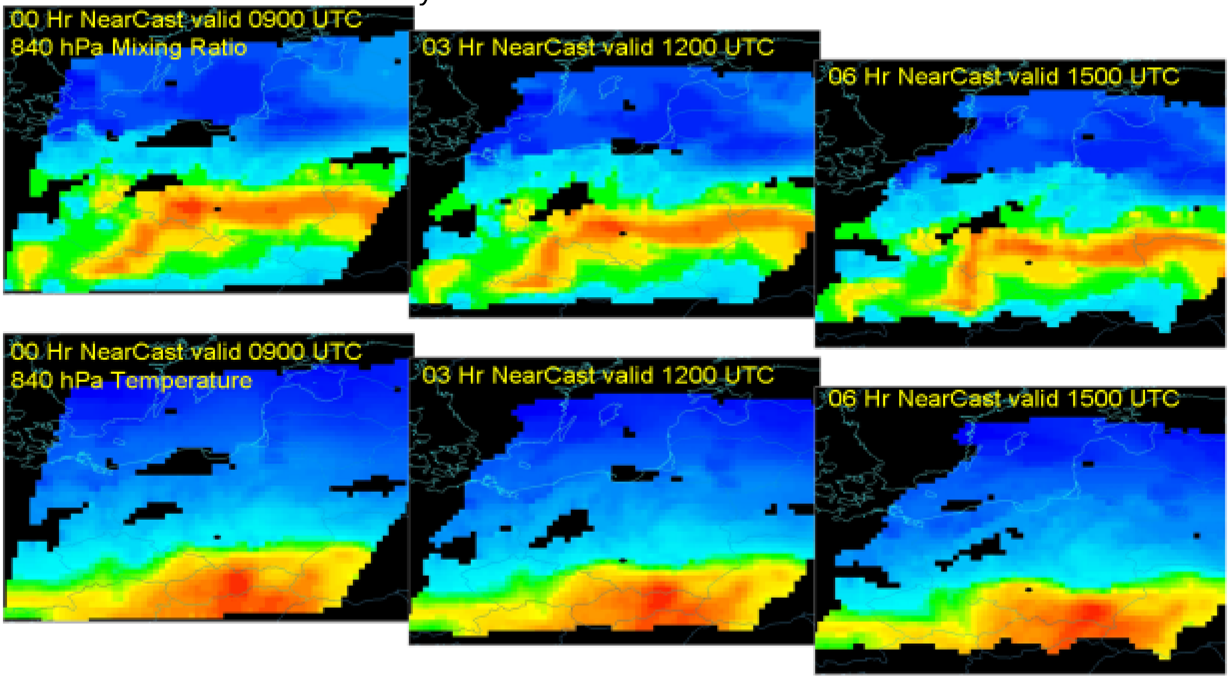

Figure 3 – Three-hourly interval NearCasts of low-level moisture and temperature during the 6 hours prior to formation of tornado at the end of the period at location noted by small black oval. NearCasts initialized at 0900 UTC 20 July 2007, with output presented at 0900, 1200 and 1500 UTC. Mixing Ratio for layer centered at 840 hPa in top row (Blue indicates low values, Red indicates high values), with Temperature in bottom row.

Although neither the temperature nor moisture fields alone provide information about the total thermal energy content of the low-level pre-storm environment, the derived Equivalent Potential Temperature (θ_e) fields readily shows the source of the thermal energy for the tornadic. As shown in the top row of Fig. 4, in contrast with the low-level moisture and temperature fields, the area of highest θ_e is initially located southwest of the later storm formation. This area moves east-north-eastward over the next 6 hours, just passing the tornadic formation area.

To address this question of where this low-level energy has the potential to be released quickly if sufficient lifting is present (e.g., along the surface front), the difference between the low- and mid-level θ_e fields can be computed to determine the Convective Instability. In this case, the mid-level θ_e fields showed large south-to north gradients. The differential movement of the low-level θ_e under the more rapidly moving mid-level fields coming from the west-north-west produces a distinct pattern of Convective Instability that changes shape and increases in intensity over time, reaching a maximum at the time and location of the rapid tornadic storm formation.

In addition to providing evidence of the location of the low-level moisture supply and stability, information about the timing of the release of the convective instability is also contained in the SEVIRI NearCasts. The evolution of the 840-480 hPa vertical lapse rate in the area of the storm formation in the top row of Fig. 5 show the movement of a small pocket of warm air near 480 hPa initially west-north-west of the tornadic storm formation increases mid-level stability in that area in first the 4 hours, acting as a cap to vertical storm growth. This is consistent with the inability of cumulus clouds that formed earlier in this area to grow.

In the next 2 hours, however, the NearCasts indicate rapid stability decreases as cold air infiltrates aloft. The lower-level temperature fields simultaneously positions the surface front at the location of the tornado intensified during the period, potentially contributing to the lifting required for releasing the Convective Instability.

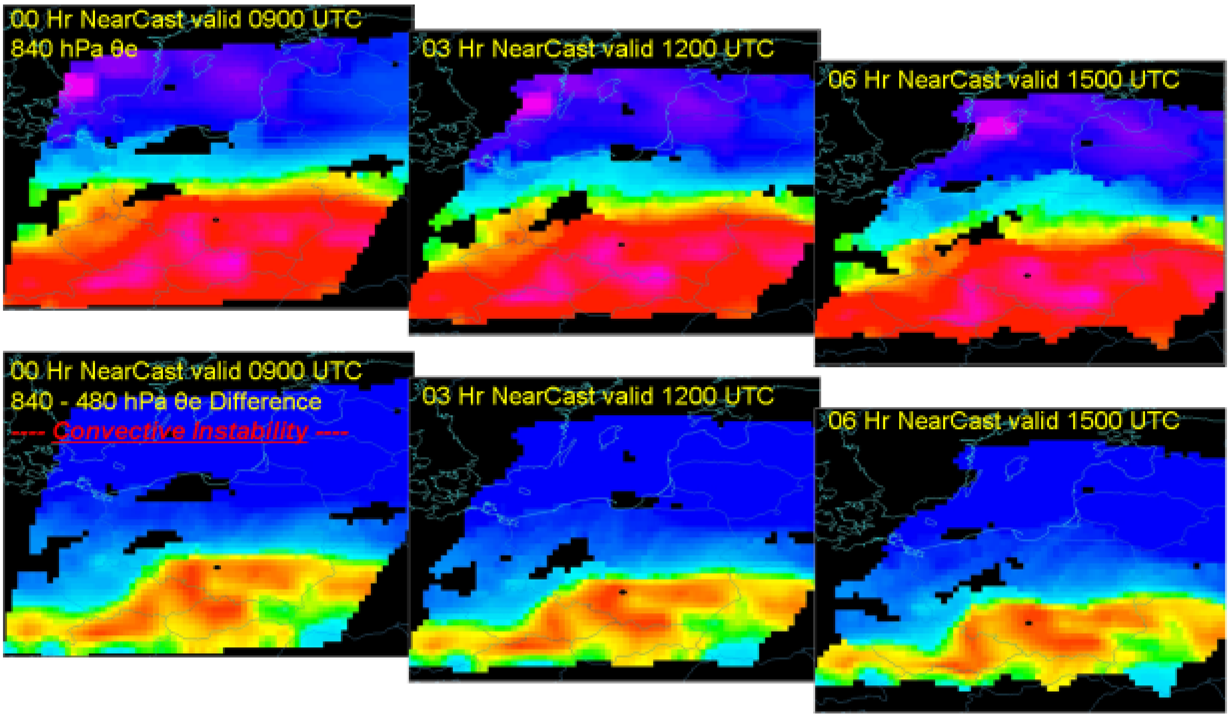

Figure 4 – Same as Fig. 3, except for 840 hPa Equivalent Potential Temperature (θ_e) in top row and vertical difference of θ_e between layers centered at 840 hPa and 480 hPa in bottom row. Largest values of θ_e difference indicate regions of Convective Instability (red areas).

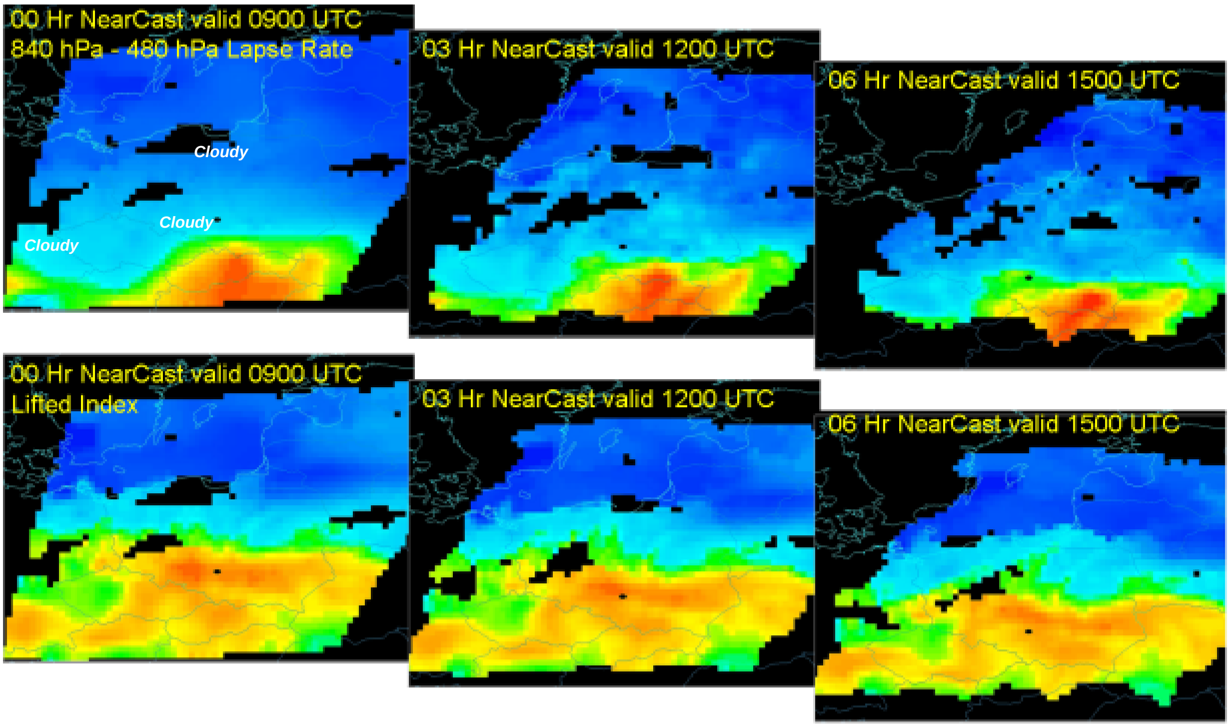

Figure 5 – Same as figure 3, except for 840-480 hPa lapse rate (top: red indicates weak lapse rates-large decrease of temperature with height) and Lifted Index (bottom).

Although the NearCasts of the Lifted Index (LI) for this case placed the weakest stability north of the surface front, away and ahead of the actual storm location, the use of this and other indicators in a multi-index ensemble shows promise and is be investigated further.

The NearCasting products can be combined further into a variety of physically meaningful combinations. For example, two of the major ingredients for rapid development and sustained support of severe convection are 1) the development of convective instability (θ_e decreasing with height or increasing with pressure) and 2) an abundant supply of total low-level thermal support. The product of the two fields (Fig. 6) further isolates the area conducive to rapid and continued development of severe convection very near the tornadic storms.

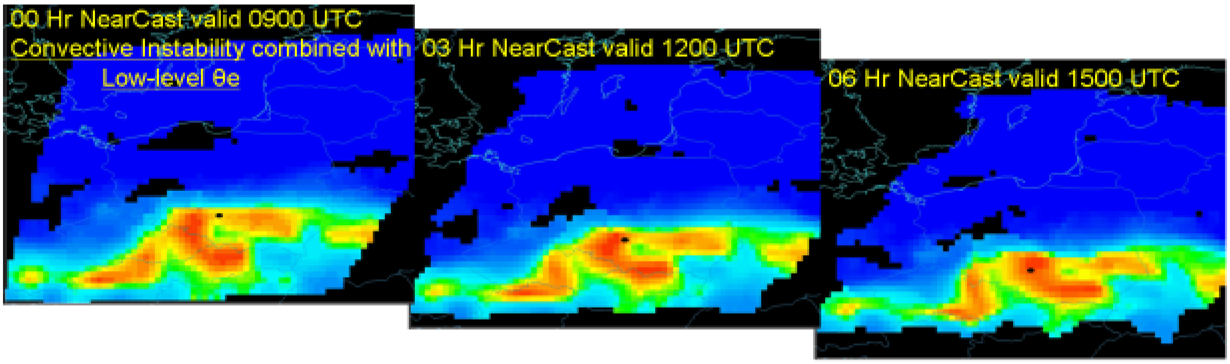

Figure 6 - Same as Fig. 3, except for product of 840 hPa Equivalent Potential Temperature (θ_e) and vertical difference of θ_e between layers centered at 840 hPa and 480 hPa. Largest values indicate regions of combined Convective Instability and large total low-level thermal energy (red areas).

The dynamically changing NearCast wind fields also show potential for assisting in isolating areas of low-level ascent needed to trigger the convective storms and areas of large vertical wind shear typical for more severe convection. For this case, the low-level divergence and moisture flux showed development of convergence immediately prior to the tornadic storms and supported by the formation of a low-level jet feeding additional moisture into the area. The 840-480 hPa shear vectors, a measure to differentiate more severe convective storms, also increased in the area of the tornado.

It should be noted that looping images of the NearCast geostationary satellite products output greatly enhance the understanding of the evolution of the pre-convective environment. Multi-panel display loops of the derived parameters further improves forecaster understanding of the physical processes supporting storm growth.

Summary and Recommendations – Tests results presented here show the utility of a simplified Lagrangian model to add forecast value to GOES and SEVIRI soundings data. The products augment conventional NWP output and help isolate areas that can support convection and become convectively unstable 1-9 hours in advance. Additional evaluation of the NearCasting system occurred in 2011 at the U.S. NWS Storm Prediction Center and Aviation Weather Center. The results show that:

1 - GOES Derived Product Image (DPI) NearCasts have been useful in detecting the pre-convective environment for hazardous weather in many US cases. The NearCasts are:

- Effective for detecting isolated convection and reducing warning area sizes,
  - Very helpful in indicating where convection will *not* form
- Important for predicting various type of Hazardous Convection,
- Useful in adding detail to Heavy Precipitation Forecasts,
- Helpful to forecasters in defining which precipitation areas forecast by longer-range NWP models are likely and not likely to verify, especially during summer.

2 - Projections of GOES Temperature Soundings provide additional information, further enhancing the moisture signal for detecting Convective Potential when using θ_e

3 - Tests with SEVIRI retrieval were positive.

- Projections of SEVIRI sounding data were useful in diagnosing the pre-convective environment evolution in a case of un-forecasted, isolated summer-time convection
- Information on stability changes was present in multiple forecasting indicators, which gave a far more complete image of the process of convective destabilization and when/where conditions would be most favorable for release of that instability
- Combined display of multiple physical meaning parameters that can be observed well by SEVIRI and GOES provide enhanced information and guidance for operational forecasters.

4 – Education and Training of the NearCasting approach and the forecast geostationary satellite products is critical for forecaster acceptance. This includes using displays (including careful choice of color display tables) which are constructed to help forecasters understanding of the physical processes involved in creating the pre-convective environment.

Recommendations include:

1 – Building upon the results of tests in the U.S., develop training for other portions of the globe covered by geostationary multi-spectral imagers/sounders and perform testing in other Meteorological services. (Real-time tests using SEVIRI data are being discussed with Eumetsat.)

2 – Perform tests in a variety of geographical and climatological areas, especially those without regular radar coverage.

3 – Expand applications areas to include aviation forecasts (especially in less-developed countries without radar), heavy precipitation forecasts and marine forecasts.

4 – Based on positive test results:

Include NearCasting training in the “Virtual Laboratory,” and
Make NearCast products readily available to all users via the internet.

References:

Pajek, M., R. Iwanski, M. Konig and P. Struzik, 2007: Extreme Convective Cases - The use of Satellite Products for Storm Nowcasting and Monitoring, Proceedings of the EUMETSAT Conference, Darmstadt, Germany.

Petersen, R., R. Aune and T. Rink, 2010: Objective short-range forecasts of the pre-convective environment using SEVIRI data. Proceedings of the EUMETSAT Conference, Cordoba, Spain.