IMPROVING VERY-SHORT-RANGE FORECASTS OF THE PRE-CONVECTIVE ENVIRONMENT USING CLEAR-AIR SEVIRI PRODUCTS

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Abstract

The overall objective of this effort is to provide data driven tools to help forecasters expand their use of moisture and temperature soundings/products from geostationary satellite instruments like SEVIRI by 1) enhancing and expanding existing observations using clear-air variables that GOES observes and 2) adding new products to understand the near-future state of the pre-storm environment. (It should be remembered that few clear-air sounder data are used in any operational NWP model over land.)

The project has four primary tasks:

1) Determining how information contained in ancillary asynoptic data sets (including GPS-Total Precipitable Water (GPS/TPW), AMDAR aircraft profiles, Raman Lidar observations from the ARM CART site and hyperspectral POES retrievals) can be used to enhance GOES-R/SEVIRI products by identifying and removing biases and also facilitating combination of future GOES-R data with soundings from existing GOES satellites and then using these products in NearCasts covering the next 6-9 hours (This aspect is reported in detail in Dworak et al (2013) also in this volume),
2) Incorporating these enhanced sounding products in a multi-layer and isentropic version of the NearCasting analyses and short-range forecasts (This aspect is reported in detail in Line et al. (2013) also in this volume),
3) Performing assessments and validations of the NearCasting products using existing GOES sounder products at participating GOES-R Proving Ground sites, and
4) Testing the system using SEVIRI data over Europe as a surrogate for GOES-R.

Introduction: This paper provides an update to presentations made by Petersen et al. (2010, 2011, 2012) at previous EUMETSAT Users' Conferences. A brief summary of major development areas that have been addressed during the past year follows. It includes results of several of the many new case studies that have been performed since the last meeting. This is followed by a discussion of results of tests of the NearCasting using GOES sounder data over the US at GOES Proving Ground sites and using SEVIRI data over Europe in 2013 and at European Severe Storms Laboratory (ESSL).

Improving the quality of GOES moisture retrievals: The initial developmental effort for the first task of this project was designed to improve existing GOES moisture retrievals by melding information from GOES products and information from other existing ancillary data sources. Approaches have been developed to calibrate the GOES retrievals using other surface-based systems including GPS /TPW across the US and research-quality Raman Lidar profiles and microwave TPW data profiles from the ARM CART site. These statistical inter-comparisons between the GOES retrievals and GPS/TPW data were also used by NESDIS operations in justifying for the implementation of the "Li" retrieval scheme NESDIS operations in 2013. This is the same processing methodology used to produce SEVIRI Global Instability Index (GII), except that it uses the data from the NWS Global Forecast System (GFS) as a first guess for the retrievals instead of output from the European Center for Medium Range Forecasting (ECMWF). Highlights of the efforts by Dworak et al. (2013) follow.

Results of the GOES-GPS/TPW for the entire year of 2011 showed distinctly that the systematic errors in the GOES TPW products are largely the result of biases in the NWP first guess fields from the NCEP-GFS used during the retrieval reprocess. Vertically integrated GOES sounding products mirror biases in TPW from the short-range GFS forecasts. Biases in the 3-layer GOES PW products as determined by comparisons with Raman Lidar profiles also reflect the vertical variation in errors in the GFS in those layers. Biases in the GFS fields show strong systematic biases in moisture from one forecast cycle to the next. In terms of random errors, GOES moisture data also showed that the greatest improvement in Standard Deviation (StDev) over NWP products occurred during the warm months, a time of year when short-range NWP precipitation forecasts have their least skill (See figure 1).

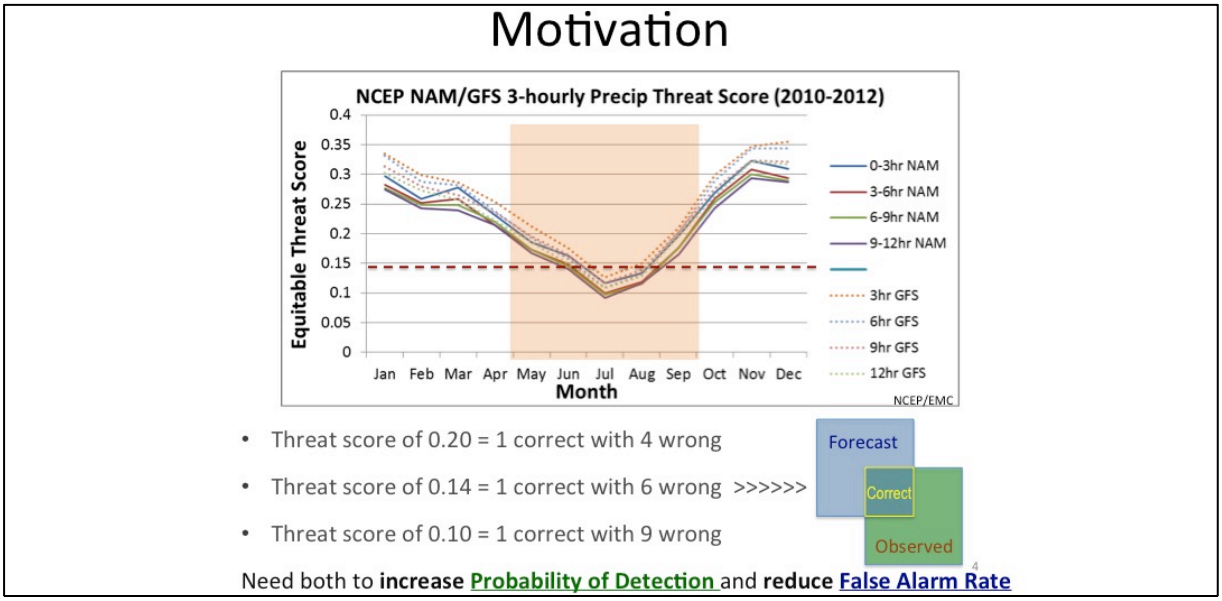

Figure 1 - Precipitation forecast Skill from NCEP operational global and regional models for 00-03, 03-06, 06-09 and 09-12 hours after analysis times. Notes at bottom of figures relate Skill Scores to Correct Forecasts, Incorrect forecasts and False Alarms.

A bias removal method for the multi-layer GOES moisture data has been developed based on normalized bias statistics. Although a strong seasonal signal is present in both the GFS and GOES TPW and the 3-layer PW products (Fig. 2 left), statistics for the relative random error in the 3-layers of GOES PW (Fig. 2 right) remain relatively constant throughout the year. Based on these finding, it is proposed that a constant relative bias correction be added to the GOES products before the data are used in the NearCast analyses and forecasts. Different corrections will be used for each of the 4 GFS cycles that are used as first guess field. Additional tests showed that the same corrections could be used for both GOES-East and GOES-West. A unified NearCast product is being also planned covering the entire CONUS and surrounding oceans at the requests of the NWS Western and Southern Regions and the SPC, AWC and OPC Proving Grounds.

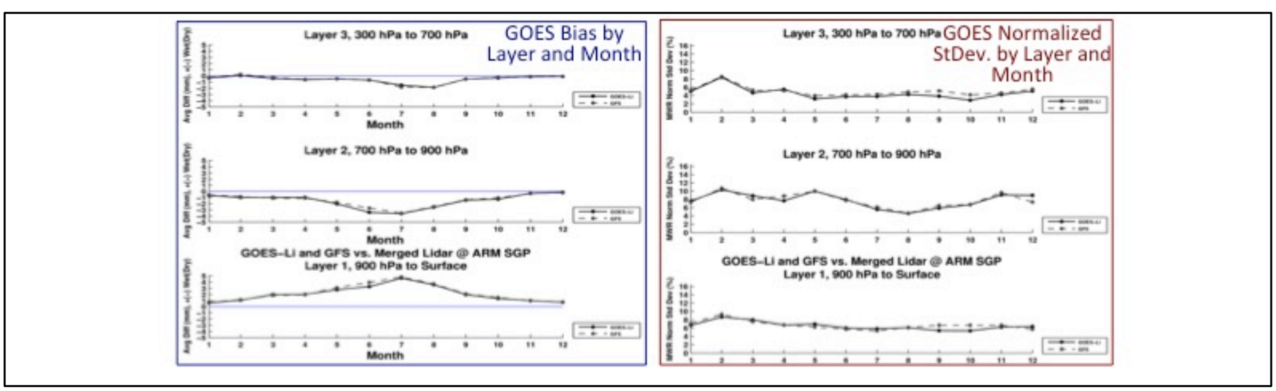

Figure 2: Left: Monthly Biases in 3-layer moisture from GOES-East (solid) and GFS first-guess (dashed) for 2011. Right: Same as left, except biases normalized by amount of moisture observed in each layer. (Note - data from November and December are being reprocessed).

Case study showing the benefits of converting the NearCasting system from an Isobaric to an Isentropic framework: This part of our effort was designed to enhance the importance of the clear-air satellite products in short-range forecasts and to provide forecasters a more complete picture of the total amount of moisture and energy being transported adiabatically into areas of interest and an improved understanding of near-term vertical motions. The reformulation of the diagnostic/predictive NearCasting model to a many-layer isentropic version has been completed and tests have been completed using a variety of case studies. Results are being compared with output from the conventional isobaric version. The case study example that follows is described in more detail in Line et al. (2013, also in this volume).

A comparison between the original isobaric and new isentropic versions of the NearCast model is shown in Fig. 3. The upper panels shows 'conventional - Isobaric' 6- and 9-hour NearCast of the pre-storm environment that developed in advance of a tornadic thunderstorm complex that formed around 2300 UTC over far west-central IA. Note that by 0000UTC, the NearCasts had predicted the dry/cool air aloft (lower θe values in upper left graphics in each panel) to move over lower-level warm/moist air (higher θe values in lower left graphics), creating an area of increasing convective instability over far western IA (blue area in right-side graphics) at the time and location of the rapid storm development.

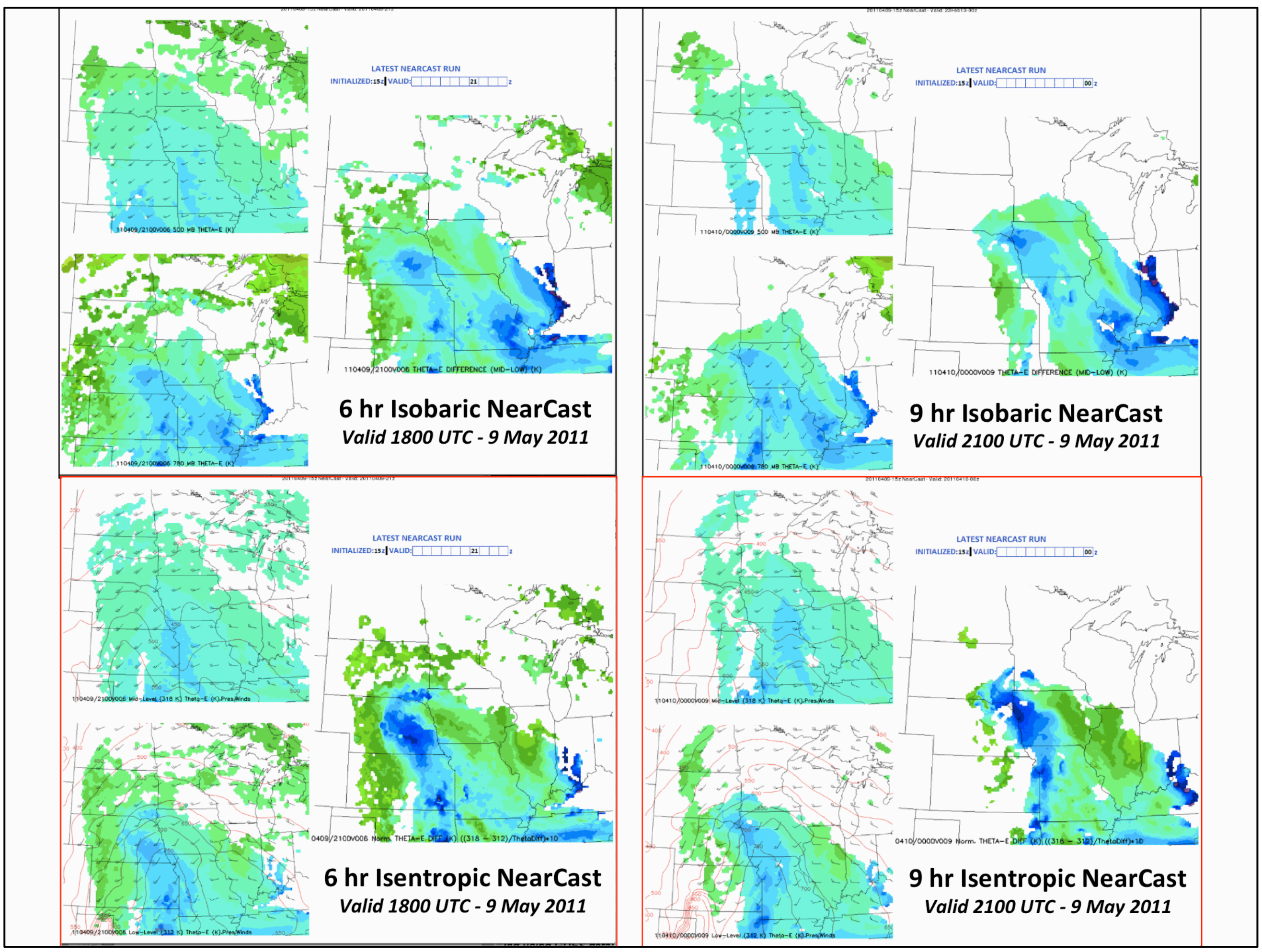

Figure 3: Upper Half –Two panels show 6- and 9-hour Conventional Isobaric NearCast predictions Lower-level θe from 1500 UTC valid at 2100 UTC and 0000 UTC, Mid-level θe NearCast in top left of each panel and derived Convective Instability (vertical θe difference between isobaric surfaces) on right half of each panel. Bottom Half – Same as top half, except Isentropic NearCasts of Lower-level (centered at 312K) θe, Isentropic Lower-level (centered at 318K) θe NearCast, and derived Convective Instability (vertical θe difference between isentropic surfaces). Pressure topography of isentropic surfaces included in Isentropic results.

Corresponding results from an isentropic version of the NearCast system are shown in the bottom half of Fig. 3. Although the isentropic NearCasts show a similar area of destabilization moving into far western IA, the depictions of the lower-level moisture supply moving northward from the Gulf and upper-level dryness overlaying it from the southwest are more distinct and well defined. The isentropic output also adds information showing that the lower-level parcels that have been moving relatively horizontally from their source in the Gulf are suddenly lifted and brought closer to the drier/cooler air aloft as they reach western IA where the convective destabilization is occurring (right graphic in lower panels). The intrusion of cooler/drier air from the west is also more pronounced along the sloping isentropic surface. As a result, the strength of the vertical θe difference is greatly enhanced, showing tendencies that are nearly twice those observed in the Isobaric run. The transition from convectively stable to unstable environment in the 3-hours before the initiation of the severe convection was also more pronounced in the isentropic outputs. Finally, the wind fields show the development of a much stronger sheared environment at the time of the convective development, more indicative of severe weather here. This was due primarily to the additional accelerations of the lower-level air parcels as they ascended upward to elevations with stronger pressure gradient forces.

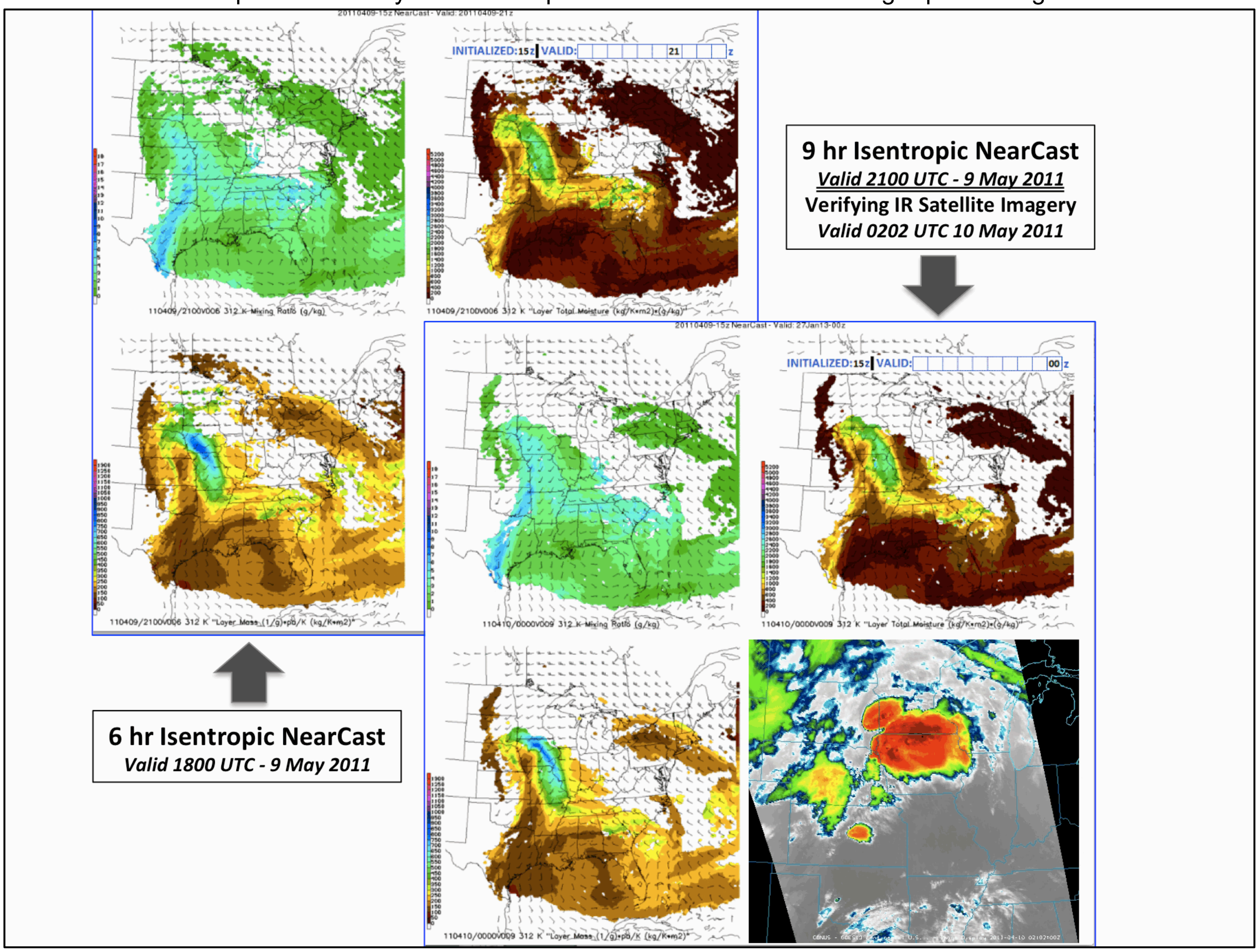

Figure 4: Diagnostic outputs from same 6- and 9-hour Isentropic Nearcasts shown in Figure 3. From each panel, upper-left graphic shows Mixing Ratio in isentropic layer surrounding 312K, lower left graphic shows Isentropic Mass in the same layer and upper right panel shows the Total amount of Moisture being transported adiabatically. Lower-right-most panel shows verifying satellite IR imagery at 2 hours after end of NearCast after convection formed over Minnesota and Wisconsin.

Output from the isentropic version of the NearCasting model also provided unique information for differentiating the areas of rapidly developing severe convection observed over north-west Iowa from the regions of heavy precipitation associated with the less severe convection that formed later across southern

Minnesopa and Wisconsin. Information about the average Mixing Ratio and Isentropic layer Mass (inverse static stability) for the lower isentropic layer can be combined to depict the total moisture being transported adiabatically. These parameters, as well as a verifiying satellite image of the initial development of the heavily precipitating convection are shown in Figure 4. It is noteworthy 1) that only a relatively small amount of total moisture was available through adiabatic flow in the area of the severe, but short-lived storms that was observed over north-western Iowa, while 2) the combination of higher mixing ratios and weaker static stability to the east produced a well-defined area of high total moisture moving northeastward across central Iowa capable of supporting the more long-lived, though weaker convection that developed thereafter first over southern Minnesota and then over north-western Wisconsin.

These results and other presented by Line et al. (2013, also in this volume) point to several advantages of the Isentropic configuration for very-short-range forecasting of the pre-convective environment using SEVIRI data. In particular, the isentropic version can 1) depict adiabatic lift, 2) give more details into the shear environment, 3) more accurately predict the movement of θe through the atmosphere on each level and 4) provide more accurate predictions of convective instability and destabilization. Additionally, the isentropic model provides extra information derived from the SEVIRI observations, including total layer moisture. This information can be used to identify 1) whether there will be enough moisture to support convective growth, 2) the longevity of potential convection and convection that has already formed and 3) whether a convective event will product heavy rainfall or be relatively dry.

Validation and Testing using GOES data: For a second year, the project has participated in (and received feedback from) validation efforts at the GOES Proving Grounds (GOES-PG) sites at NCEP's Storm Prediction Center (SPC) and Aviation Weather Center (AWC). This included a major development of new education and training materials for use by the GOES-PG prior to forecaster arrival. This included both PowerPoint and Visit-View training (copies are available upon request). Many of the recommendations provided by forecaster feedback at the GOES-PG have already been included in revisions/enhancements to the system. Forecaster feedback using GOES sounder data over the US from SPC included:

2011-2012:

- ***Helped understand*** *why convection occurred and where it would occur*
- *There was a strong theta-e gradient that the storm was moving into and that* ***gave me confidence*** *that the storm would intensify.*
- *I used it both as a* ***forecast tool and an analysis tool****.*
- *It really had a* ***clear picture*** *of the gradient of moisture and showed a strong push of cooler/dryer air where storms did not end up forming.*
- *Theta-e difference used extensively when storms were already mature... monitored what environment the storms were moving into...* ***helpful in identifying intensification.***
- *The forecast parts tended to build areas of increased instability that helped* ***provide guidance*** *on what was going to happen later on.*
- *That was my* ***favorite product****... it really seemed to capture the motion of the atmosphere than any of the products we had been looking at.*
- *Would definitely like to see this in my home WFO.*

2013:

- *The theta-e difference showed unstable air. When the storms entered this unstable air they did strengthen quite a bit, several becoming severe.*
- *The initial development to the west was associated with marginal moisture (as indicated by the PW fields], but just to the east there was more moderate moisture and as soon as that development moved into the area it lit up like a Christmas Tree.*
- *The product* ***helped a lot*** *to focus on the anticipated area of* ***initiation****.*
- *The storms on Wednesday formed right on the low-level maximum of theta-e, so* ***it did very well.***
- *The theta-e difference is a* ***good product****… shows exactly what you want it to.*
- *This information was very* ***beneficial*** *to have.*

Many forecasters also noted the importance of monitoring not only the areas of greatest lower-level θe and convective stability, but also the tendencies of these parameters, especially in situations where the NearCasts are anticipating that the middle troposphere will change rapidly from being stable to unstable.

Since mid-summer, NearCast model output has started to be included in training/use by operational forecasters at SPC. Comments to date include:

- *This is great because it is information we do not already have available*
- *I like that it is observation-based.*
- *This could be particularly useful in the south, where we have pulse thunderstorms, to show the moisture gradients.*
- Forecasters really like to view the analysis fields (especially theta-e difference) with satellite imagery overlaid, an approach also used in testing at ESSL and to be discussed later.

From AWC, where the testing has been more preliminary, comments from Proving Grounds participants have included:

- *The product was **VERY useful** in terms of assessing where the atmosphere would be most favorable for convection should there be a trigger and/or broad-scale lift support.*
- *It may aid in evaluating the evolution of mid-level instability in **data void areas** and between rawinsonde launches in both space and time.*
- *This was of particular use over **off shore regions** where flight routes exist, but observations are much more sparse.*
- *… it was used to provide **situational awareness** for convective initiation and behavior later in the afternoon*

The NearCast system was also tested as part of the European Severe Storms Laboratory's 2013 Summer Experiment using SEVIRI data. Due to a number of technical limitations, the same soundings that are used to generate the EUMETSAT GII products were not available for use in these tests. Instead, the NearCast was supplied with retrievals generated using the standard product suite available for export from CIMSS/SSEC. As such, a number of differences from previous tests over the US should be noted. Because SEVIRI has fewer temperature channels, more of the retrieval temperature information comes from NWP 'first guess' fields. However, the SEVIRI products are available at higher spatial (3-5km vs. 10-15km 'pixel size') and temporal (15-minute vs. 1-hour refresh) resolution than from the current GOES. Although hourly frequency SEVIRI retrievals were used this year, off-line tests using sub-hourly updates showed the additional data were effective in removed gaps in analysis. For technical reasons, the SEVIRI products used at ESSL were generated at CIMSS using NCEP/GFS fields as retrieval 'first guess profiles' instead of ECMWF fields employed in EUMETSAT GII products. Likewise, initial winds used in NearCasts come from 3-hour frequency GFS outputs, which are updated every 6 hours.

Early in the experiment, the ESSL tests disclosed a software problem (array overflow) in using the higher-resolution SEVIRI data that caused 'jumpy' NearCasts. That, however, did not preclude a successful demonstration of NearCasting concepts. As with previous tests in the US, it become quickly apparent that forecasters needed more training before and during the experiment. As with any new concept, users need time to grasp the processes involved and the meaning of the new products. Additional display improvements are also needed in color bar selections, etc., as well as a better means of integrating 3-panel product graphics (similar to those shown in previous figures and available on the CIMSS web page) with other ESSL displays. There was also a strong desire to have both θe and Precipitable Water products available, so that the latter could be used for more direct comparisons with NWP output.

Although the ESSL experiment was conducted during a period that was dominated by an unusually strong and persistent high-pressure system covering most of EUROPE that inhibited most convection, some important observations were made, including:

- *European forecasters rely heavily on NWP products and focus on CAPE as a primary parameter for identifying areas of convective potential*
    - *They expected other objective forecasting tools to 'look and feel' like traditional NWP tools*
    - *Forecaster were already frustrated over lack of consistency in NWP output definitions from one model to another, leading to reluctance in accepting other 'new' parameters.*
        - *E.g., CAPE definitions differ between ECMWF, GFS, DWD and . . .*
        - *Adding new products that look 'different' complicates/delays acceptance*
- *Forecasters quickly learned to use the NearCast layer θe products to monitor NWP performance*
    - *They were especially interested in Lower-Level θe NearCast analyses and forecast*
    - *They detected significant deficiencies discovered in forecasts from <u>all</u> NWP models*
- *The NearCasts helped forecasters decide which storms would continue to grow after initiation*
- *Possibly most importantly for EUMETSAT, a strong desire was expressed for higher vertical resolution reaching lower into boundary layer, a capability that should be available from the geostationary sounder planned for MTG.*
    - *Quoting Pieter Groenemeijer (leader of the ESSL tests), "I support whatever you can do to raise attention to this at EUMETSAT!"*

Case Study using SEVIRI data: Although little convection developed during the NearCasting evaluation period at ESSL, forecasters from Germany and Poland identified an extremely difficult forecast event from the late afternoon and evening of 20 June 2013 for which they wanted to test the utility of NearCasts of SEVIRI observations. While COSMO-DE and COSMO-EU NWP guidance picked up the MCS, which reached western Germany in the morning hours of that day, the development of new cells at the southern edge of the outflow boundary was missing in all of local models and in the COSMO-DE EPS, as well as global models. As a result, the new squall line that spread into eastern Germany was missed in <u>all</u> of the model prediction. The southern MCS was also absent, with no convection predicted for Bavaria. The strong convection over eastern parts of Germany was totally absent in the model predictions from 0000 to 0900UTC. Only the COSMO-DE EPS 1200UTC run showed the northern part of the squall line, possibly due to latent heat nudging in that model. Even then, however, the model squall line weakened too quickly and dissolved around 1800UTC, possibly a sign of too little moisture.

A case study was run for this case incorporating SEVIRI retrieval generated at CIMSS using the same protocols as during the ESSL experiments. The resulting sequence of NearCast analyses of lower-level θe is shown in figure 5, along with corresponding satellite and radar observations. For reference, the 18-hour forecast of 3-hour precipitation accumulation from the 0000UTC run of the COSMO-EU model is also shown. As mentioned earlier, the NWP products persisted to maintain the area of precipitation in western Germany in the afternoon, at a time when radar and satellite observations showed strong development in eastern Germany and sparse precipitation to the west. By contrast, the lower-level θe NearCasts show several areas of moist/warm air initially located in southeastern Germany and moving to the north throughout the day.

Nearcasts predictions were produced from SEVIRI retrievals generated hourly throughout the day. The 1- to 9-hour forecasts showed good consistency from run-to-run, with later runs showing progressive improvement from the repetitive data updates. A sample of results from the NearCast generated from 1200UTC (based on retrievals from 0300 through 1200UTC) is shown in Figure 6. Forecasters reported that:

- *"The NearCast gave a very good indication of where convection was started.*
- *It's really impressive to see that the convection was initiated at the northern edge of the θe maximum over northeaster Bavaria and at another smaller θe maximum located at the alpine foothills in the southwest of Bavaria.*
    - *There are some hills around 600 - 1000 m high, which possibly could have helped to trigger convection.*
    - *Out of these cells, only the MCS over eastern Germany developed. (Note: This was the area where the NearCasts showed maximum θe and strongest vertical gradients.)*
- *Because the operational models missed this convective initiation there, they also missed the development of the MCS.*

- *If we had had NearCast, we would have been able to make a first estimation of the position where the convection would be most probably initiated.*
- *The NearCast would have improved the forecast of this day."*

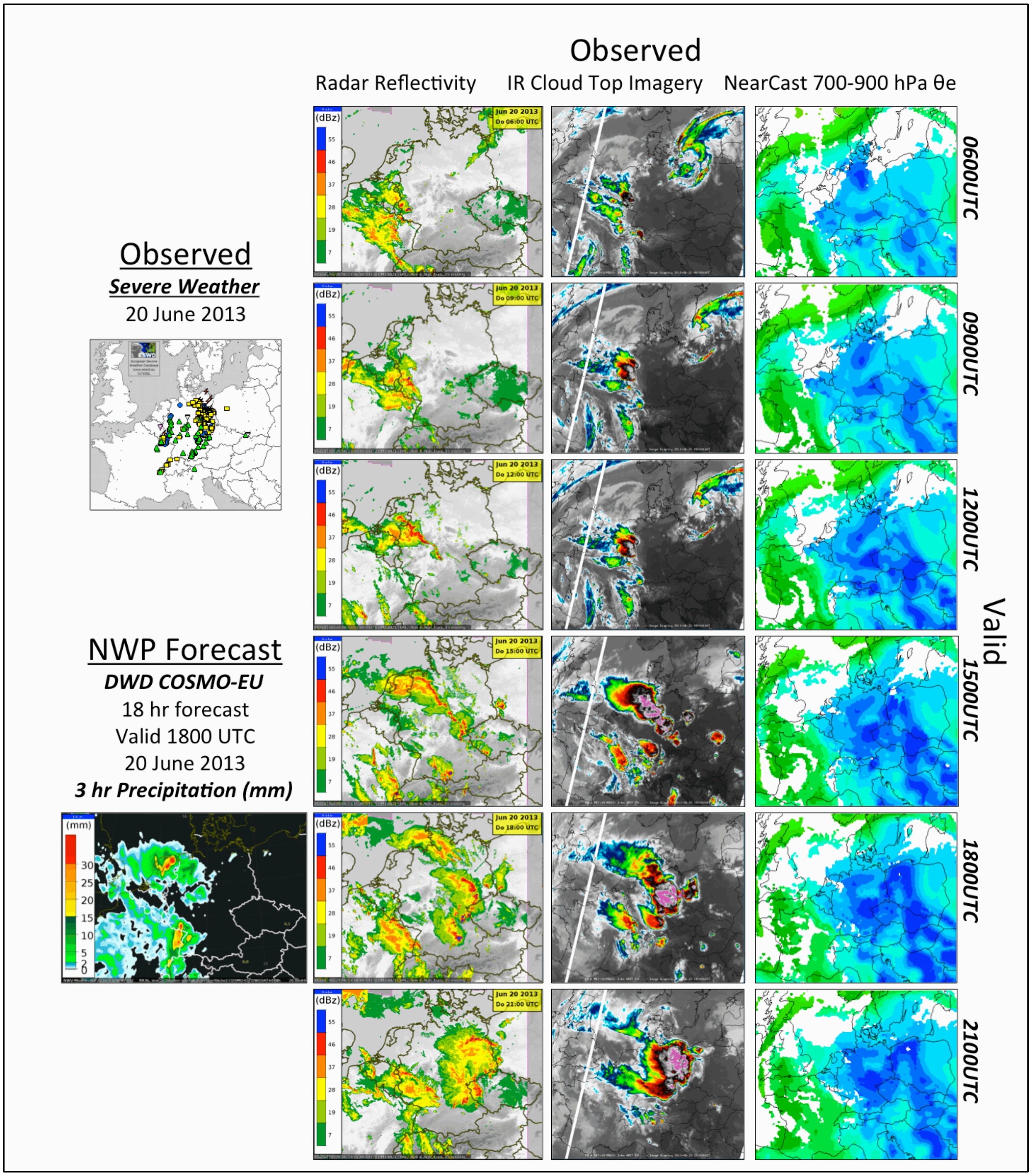

Figure 5: 3-hourly radar (left column) and satellite (center column) observations, and NearCast SEVIRI analyses (Right column) of lower-level θe for 20 June 2013. Locations of severe weather from the day shown in upper left panel. 18-hour DWD COSMO-EU 3-hour precipitation accumulation forecast shown at lower left, next to verifying radar/satellite/SEVIRI observations.

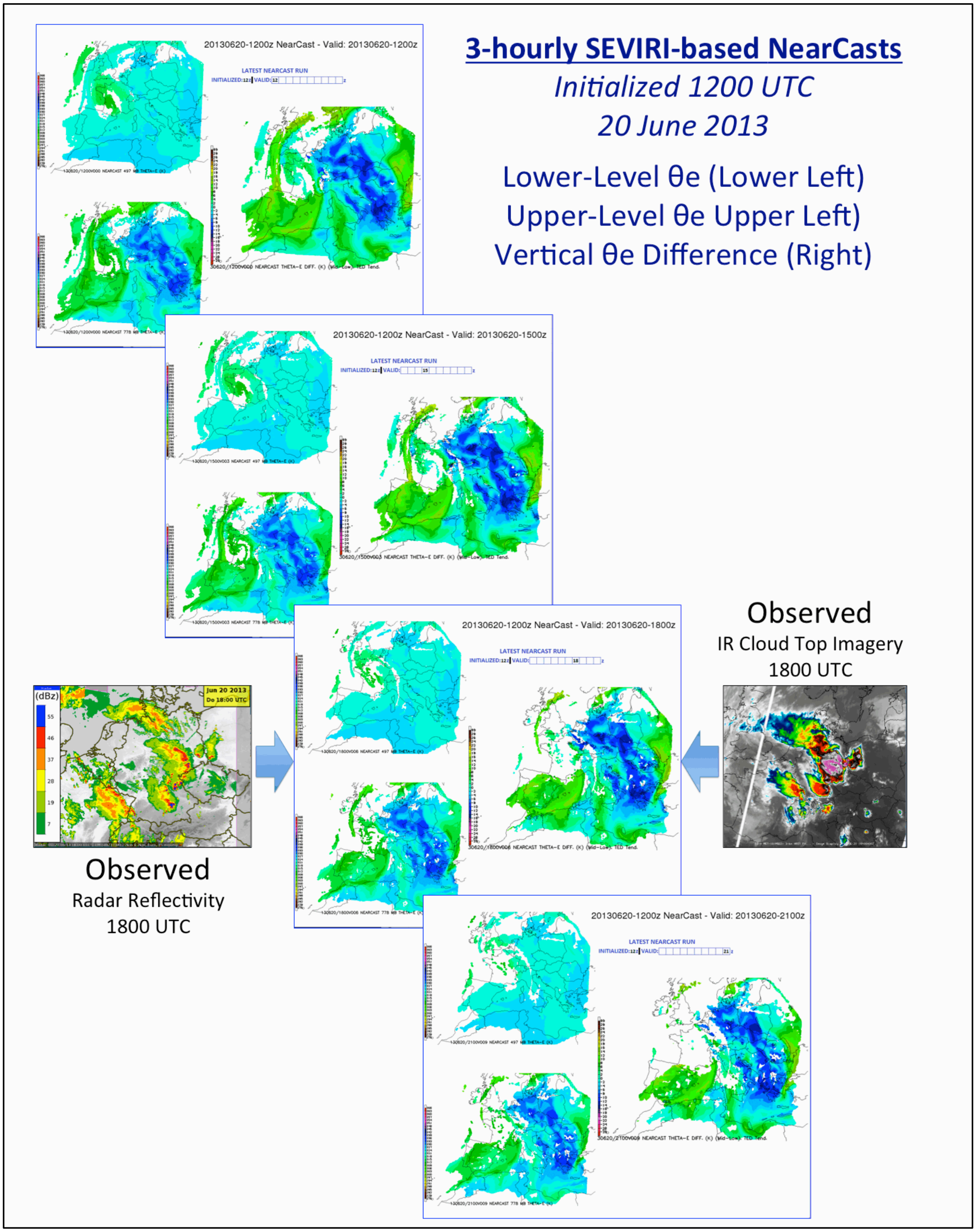

Figure 6: Lower-level θe (lower-left in each panel), mid-level θe (upper-left in each panel) and θe difference (right graphic in each panel) for 0-, 3-, 6- and 9-hour NearCasts from 1200UTC 20 June 2013. Radar and Satellite verification data are included for time of peak convective development at 1800UTC, a time when conventional NWP products predicted little precipitation in eastern Germany.

Summary of Forecaster Comments regarding the utility of NearCasts: Overall, forecaster impressions of the potential for NearCasts to help improve short-range forecasts for hazardous convection have been positive, although substantial training and exposure to these new products and concepts is essential for their full acceptance. Specifically, it was noted that:

- ✓ *The GEO Satellite observations in clear air add fine horizontal scale information to NWP background (esp. in warm season) and represent a fusion of NWP first guesses, conventional surface observations and a-synoptic satellite data*
- ✓ *Trends in local maxima/minima of low-level moisture and θe observed in GEO soundings are validated using GPS-TPW observations*
- ✓ *Lagrangian transport tools provide realistic projection of the movement of moisture anomalies – in real-time*
- ✓ *NearCast products are useful tools in monitoring the performance and providing corrections to short-range NWP products*
- ✓ *Overlays of upper- and lower-level θe fields can be used to mimic areas where convection forms along upper-level dry streaks*
- ✓ *Areas transitioning from convectively stable to unstable are most favorable for convection – Little convection forms in stable regions*
- ✓ *Intense convection observed in areas also developing strong shear*
- ✓ *From ESSL in particular:*
  - ✓ *Likes the concept NearCasts and supports the enhanced use of satellite, but wants higher vertical resolution moisture profiles*
  - ✓ *Views NearCasts using SEVIRI as a good tool to monitor and update NWP performance, but*
    - ✓ *Wants profiles of both moisture and temperature with increased vertical gradients - extending near earth's surface*
    - ✓ *Also interested in tools to monitor/predict vertical wind shear in lowest 3-6 km.*

Although the proper way to use full time and space resolution MSG/MTG clear-air moisture information will be within improved NWP systems, these will not be available for many years. Even then, it is likely that the model output will lag observations by an hour of more. In the interim, data-driven NearCasts provide a simple, fast means of delivering objective short-range forecasts of detailed horizontal moisture and stability structures immediately after the SEVIRI observations are made, as well as providing an excellent means to monitor model performance and moisture/precipitation forecasts in real-time.

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