2013-2014 GOES-R Proving Ground Activities at the Storm Prediction Center - Final Evaluation

Project Title: 2013-2014 GOES-R Proving Ground Activities at the Storm Prediction Center

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Evaluator(s): SPC

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Contents

1. Executive Summary

The SPC provides the GOES-R Proving Ground with an opportunity to demonstrate baseline and future capabilities products associated with the next generation GOES-R geostationary satellite system that have the potential to improve hazardous weather nowcasting and forecasting. After familiarization shadow shifts with SPC forecasters in operations, select GOES-R proxy products were identified as having potential to fit into the forecast process and to provide unique and complementary information to SPC operations. Initial experimental products implemented into the SPC operational N-AWIPS include the Cloud Top Cooling (CTC) algorithm, Overshooting Top Detection (OTD) algorithm, NearCast model analyses and forecasts of atmospheric moisture and instability, and the Lightning Threat algorithm for numerical weather prediction (NWP). Additionally, GOES-14 Super Rapid Scan Operations for GOES-R (SRSOR) 1-minute imagery was available to forecasters during periods in August 2013, May 2014 and August 2014, demonstrating the super rapid scan capability of the GOES-R Advanced Baseline Imagery (ABI).

Feedback from SPC forecasters comes in the form of verbal and email communication and survey completion. Forecasters have found the OTD product to be an objective and visually complementary means of monitoring the evolution of mature convective systems. The non-obtrusive overlay on satellite imagery allows users to easily and quickly spot OT features and their trends, and has proven to be especially valuable at night when it is significantly more difficult to subjectively identify small-scale storm top features in IR imagery. Similar to the OTD algorithm, forecasters appreciate the easy-to-understand display of the CTC product as an overlay on satellite imagery. This product has been utilized by forecasters when monitoring for initial convective development as it signals and quantifies the rate of rapid growth. The NearCast model provides SPC forecasters with an observation-based tool to help monitor the thermodynamic environment and fill spatial and temporal gaps that exist in moisture observations. They have found value in viewing the evolution of convection with respect to NearCast moisture and instability by overlaying NearCast analyses on satellite imagery. Although the Lightning Threat algorithm may aid in the preparation of a few SPC forecast products, some enhancements to temporarily match other SPC Probabilistic forecast products could increase its relevancy. Finally, SPC forecasters experienced many situations in which the 1-minute satellite imagery provided operationally-significant information not captured as well (or at all) in current 5-30 minute imagery. The products and capabilities under evaluation have been referenced in various SPC operational forecast products throughout the period.

2. Introduction

Current GOES-R Proving Ground activities within the Storm Prediction Center (SPC) began in June of 2013, shortly after William Line took over the GOES-R Liaison position. Proving Ground demonstrations in the SPC provide users with an early view into the capabilities, products and algorithms that will be available with the future geostationary satellite series, beginning with GOES-R which is scheduled to launch in 2016. The education and training received by SPC forecasters fosters excitement for satellite data and helps to ensure day-1 readiness for the receipt of GOES-R data. Initial activities included participation by the GOES-R

Liaison in shadow shifts with SPC forecasters to become familiar with various aspects of the SPC forecasting mission: operational procedures, observational and model products used in forecast decision-making, and the challenges faced by the forecasters. The one-on-one interactions revealed situations in which GOES-R and other satellite-related products have the potential to be useful to operations in unique and/or complimentary ways.

Once satellite-related products were identified as potentially benefiting SPC operations, the Satellite Liaison initiated data streams to bring the products into SPC and evaluate them first on a local development workstation. Relevant products were then moved into operations experimentally for real-time evaluation by SPC forecasters. In collaboration with algorithm developers, training material was organized in the form of brief PowerPoint presentations and one-page information sheets. Additionally, a webpage local to SPC containing additional training material and case examples was created and made available to forecasters for reference. One-on-one in-person training for each product was provided to the forecasters in operations at a spare forecast desk when time allowed. In addition to covering how the algorithm works and its relevance to SPC operations, examples (including very recent ones) were presented to the forecaster. The Liaison spent additional time in operations monitoring the products in real-time, helping the forecaster to properly utilize them, and answering any questions that would arise. A Stored Procedure File (SPF) in N-AWIPS dedicated to GOES-R demonstration products was developed to make it easier for forecasters to access the various tools under evaluation.

Feedback was primarily collected verbally through in-person conversation between the Liaison and forecasters. Additional feedback was collected via email correspondence and survey participation. The majority of feedback highlighted methods of effectively integrating the product into the SPC forecast process and using it to improve forecasts. The Liaison composed various blog posts to the “Satellite Liaison Blog” highlighting operational use of the GOES-R products in SPC. The SPC demonstrations and feedback collection continue year-round, allowing forecasters to become familiar with the products, integrate them into their forecast process, and evaluate them over a variety of seasons and weather regimes. Additional products continue to be evaluated by the Satellite Liaison for potential future integration into SPC operations. Feedback from GOES-R product evaluations taking place at SPC between August 2013 and December 2014 is summarized in this document.

3. Products Evaluated

Table 1. List of products demonstrated within the Storm Prediction Center

Demonstrated Product	Category
Cloud Top Cooling	GIMPAP
Overshooting Top Detection	Future Capabilities
NearCast Model	GOES-R Risk Reduction
Lightning Threat algorithm for NWP	GOES-R Risk Reduction
GOES-14 SRSOR 1-min Imagery	Baseline
Category Definitions: **Baseline Products -** GOES-R products that are funded for operational implementation **Future Capabilities Products -** New capability made possible by ABI	

GOES-R Risk Reduction - New or enhanced GOES-R applications that explore possibilities for improving AWG products. These products may use the individual GOES-R sensors alone, or combine data from other in-situ and satellite observing systems or models with GOES-R
GIMPAP - The GOES Improved Measurement and Product Assurance Plan provides for new or improved products utilizing the current GOES imager and sounder

3.1 Cloud Top Cooling

University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (CIMSS)

The CTC algorithm provides forecasters with a satellite-based tool for diagnosing initial convective development. The algorithm uses GOES IR brightness temperature and cloud phase data to identify immature convective clouds that are cooling and therefore growing vertically (Sieglaff, 2011). The final result is a satellite-based measure of vertical cloud growth rate that can be used to identify where and how rapid convective clouds are growing. Strong CTC rates correspond to more intense future precipitation cores (composite reflectivity, reflectivity at the minus10C level, maximum estimated size of hail, and vertically integrated liquid) when compared to moderate and weak CTC rates (Hartung, 2013). The product offers consistent day/night performance and is available over the full CONUS using the GOES-East and GOES-West satellites. The display not only indicates where rapid convective growth has occurred from the previous scan to current, but also color codes the degree of growth (K $(15\ \text{min})^{-1}$). The demonstration of the CTC algorithm seeks to learn whether such a tool might provide additional valuable information to the SPC forecaster when monitoring for new convective development.

Forecasters at SPC have been effectively integrating the CTC product into their nowcast process over the course of the evaluation period. Early on, they were encouraged to load the CTC product as an overlay on their routine visible or IR GOES imagery. In general, they found this display to be a non-obtrusive means of drawing the forecaster's attention to areas in the imagery where initiation is just beginning to take place. This is especially important during busy nowcast situations when any bit of lead time to initiation is valuable. Furthermore, forecasters appreciate the quantification of cloud growth this product provides, increasing their awareness to which developing storms might pose the greatest near-term threat. Finally, low to no cooling rates with developing storms provided just as much insight as higher rates, informing the forecaster that convective growth was relatively weak and the resulting storms likely not as threatening.

> "When looking at just imagery, it is hard to tell what's developing rapidly, so it is nice to be able to quantify it."
> *SPC Forecaster*

> "You can see cooling in the IR, but it is difficult to gauge the vigor of the cooling, which makes this product useful."
> *SPC Forecaster*

> "Lack of ctc rates over Florida confirmed only weakly developing storms, implying storms would be weak, which they were."
> *SPC Forecaster*

There has been a lot of discussion about the "fire hose" of data the modern forecaster faces. At SPC, forecasters have found that the CTC product overlay helped them to more quickly interpret the imagery with respect to convective development, actually allowing *more* time to move on and view other datasets. Used as an overlay on imagery the forecaster already views, the product didn't take time away from viewing other tools, and in many cases enhanced processes present in the imagery that were otherwise difficult to observe.

> "Tells you right away what is happening, making it obvious where cooling is occurring so you can spend less time analyzing the field. Easy product to understand."
> *SPC Forecaster*

When using the CTC product, forecasters were advised to view it in context with the broader environmental conditions. For example, a rapid CTC rate in a high instability, high shear and strongly forced supercell thunderstorm environment will have different meaning than the same rate of cooling in a weakly sheared and forced, pulse thunderstorm environment. Similarly, in situations where forecasters were not certain whether the environment would be conducive to widespread convective development, signals in the CTC product often proved to be a deciding factor. For example, a few weaker CTC rates would indicate that the environment was not supportive of rapid convective growth, and severe weather was less likely.

> "The fact that there were many storms exhibiting significant cooling gave me confidence that the environment would be conducive to the development of severe weather. One weaker cooling would not have been enough, but the many areas of cooling really told me that stuff was definitely going, and could be severe given other environmental factors (Fig 1)."
> *SPC Forecaster, regarding 2014 MD #1724*

> "THE MODERATE INSTABILITYAND -10 C 500 MB TEMPERATURES ARE PROVING SUFFICIENT FOR RAPID CLOUD TOP COOLING WITH MOST OF THE STORM CELLS IN THIS REGION PER GOES-R CLOUD TOP COOLING PRODUCT (Fig 1)."
> *SPC Forecaster, 2014 MD #1724*

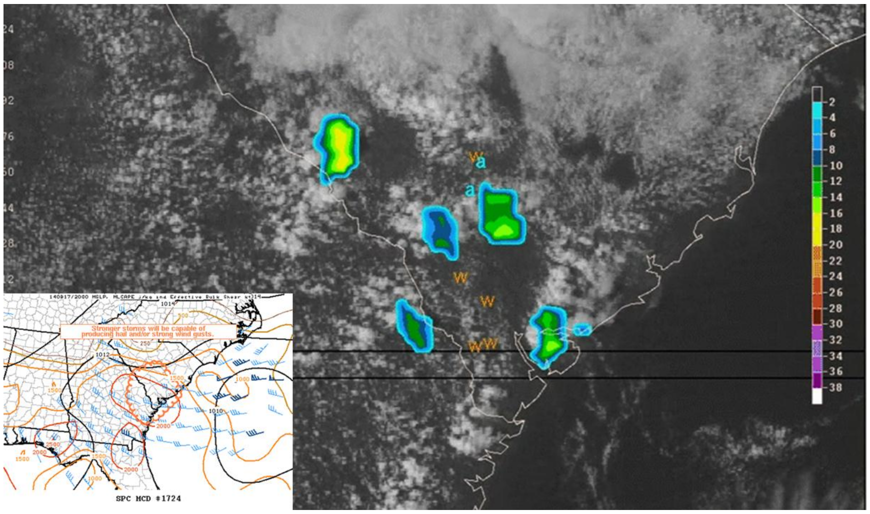

Figure 1: 1900z 17 September 2014 Cloud Top Cooling rates (overlay; K (15 min)$^{-1}$) and GOES-East visible satellite imagery, severe wind (w) and hail (a) reports over South Carolina and Georgia. SPC Mesoscale Discussion #1724 graphic (inset).

Forecasters expressed specific situations in which the product proved especially valuable. SPC forecasters generally have a good assessment on the approximate timing and location of anticipated development via other data sources. However, knowledge of exactly where along a boundary convection will first initiate often remains a challenge. In such situations, the CTC product has proven to be useful in indicating where along the boundary convection is first developing and expanding, including a quantification of the vigor of growth. As expected, the CTC product had exceptional utility at night (in the absence of visible satellite imagery) when convective growth is more difficult to discern subjectively from IR imagery alone. Additionally, the product had enhanced value in regions where radar coverage is lacking and forecasters must rely more on satellite-based products.

An event during which CTC was utilized in SPC operations occurred during the day on 28 May 2014 across parts of northern Utah and southwestern Wyoming, where mountainous terrain causes beam-blocking and radar coverage is limited. Severe winds were the anticipated severe threat for storms should they develop in the region, with a relatively low probability of 5% highlighted in the SPC Day 1 Convective Outlook. An SPC mesoscale forecaster was monitoring the region for initial convective development when strong cooling rates (~30 K (15 min)$^{-1}$) were observed by 1800 UTC in southwest Wyoming (Fig. 2), indicating rapid convective growth. Significant cooling continued to be detected further to the south through 2000 UTC. At 2002 UTC, the forecaster issued a Mesoscale Discussion (MD) for the region, highlighting the threat for locally strong wind gusts and noting "THE GOES-R CLOUD TOP COOLING PRODUCT INDICATED COOLING TOPS OVER SWRN TO WEST-CENTRAL WY AND ONGOING CLOUD TOP COOLING IN NERN UT" as evidence of continued widespread convective growth. Thunderstorms went on to produce damaging winds across the area.

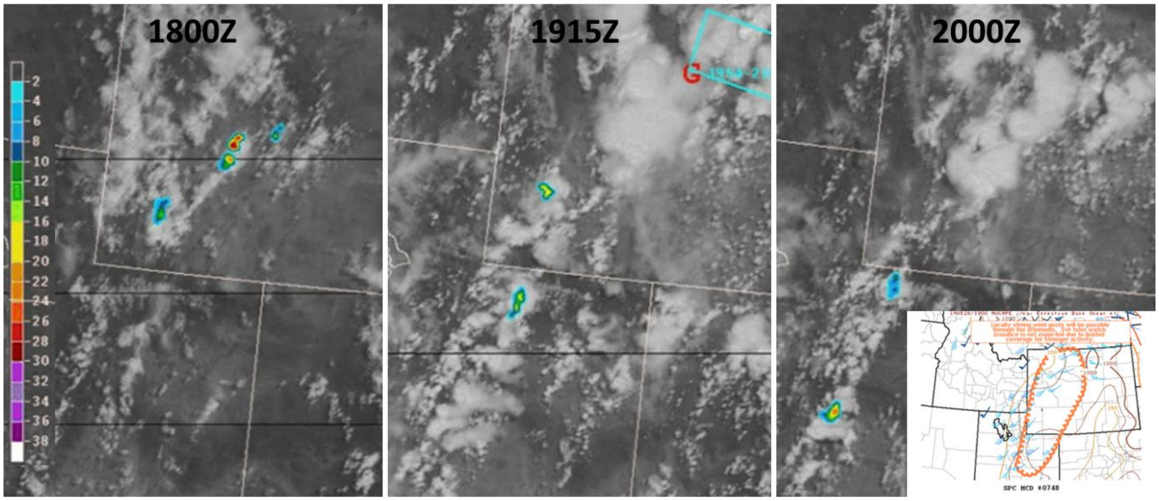

Figure 2:1800, 1915, and 2000Z 28 May 2014 Cloud Top Cooling rates (overlay; K (15 min)$^{-1}$) and GOES-West visible satellite imagery, severe wind gust reports (G) and severe thunderstorm warnings (polygons) over Utah and Wyoming. SPC Mesoscale Discussion #0748 graphic (inset).

SPC forecasters commented on some of the challenges facing the CTC product as well. Certain situations cause the algorithm to make false detections, though it is usually easy to differentiate these from actual convective growth. With a typical latency of 15-min after the timestamp, forecasters would appreciate a smaller temporal gap between satellite image arrival (5-7 minutes after timestamp) and CTC product arrival. Also, until forecasters gain experience in the use and interpretation of the CTC product, it will take a period of time for them to become properly calibrated to the magnitude of growth rates given a variety of weather situations. Although aspects of the algorithm are being fused with other datasets to produce probabilistic products, it is acknowledged that many users would still prefer to see the raw (CTC) data in some manner as well.

Forecasters look forward to the application of the CTC product and its fusion with other datasets in the GOES-R era using higher temporal and spatial resolution ABI data. The more precise data and potential to reduce false alarm will make the product more useful to the forecaster. Considering the positive response thus far, the CTC product will continue to be made available to SPC forecasters as long as it is provided.

3.2 Overshooting Top Detection algorithm

University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (CIMSS)

The OTD algorithm uses satellite-observed spatial gradients in the infrared window channel, GFS tropopause temperature, and satellite brightness temperature thresholds to identify and determine the magnitude of OTs (Bedka, 2010). The product offers continuous day/night detection capability and can be produced where sufficient satellite coverage is available. OTs signifiy the presence of deep convection with an updraft strong enough to vertically penetrate the tropopause into the lower stratosphere. Convection with OT signatures is often associated with nearby hazardous weather conditions such as frequent lightning, heavy rainfall, and severe weather (Dworak, 2011). The product provides a visual means for users to quickly identify OTs in animations of satellite imagery, which is especially important during busy nowcast situations.

The display of the binary product consists of a marker indicating the presence of an overshooting top, while the display of the magnitude product indicates the temperature difference between the OT and the surrounding anvil (strength of the OT). In response to Proving Ground feedback, the algorithm is currently being improved via GOES-R Risk Reduction, namely to incorporate visible satellite information during the day, make the algorithm probabilistic, and eliminate fixed brightness temperature thresholds. This demonstration seeks to gauge the benefit of the automated OTD algorithm in SPC operations.

Similar to the CTC product, the OTD algorithm provides a simple, non-obtrusive overlay for display with satellite imagery. Forecasters were advised to load the OT product on satellite imagery with the CTC product, since each algorithm has its utility during unique stages of convective evolution. Once again, forecasters did not feel that it took time away from viewing other tools, but instead enhanced the imagery by highlighting features that are otherwise difficult to identify subjectively and track quickly.

> "Useful even with visible imagery during day because it highlights the OT for me. I have so many products to look at, so it is nice to be able to glance quickly at the imagery to see this."
> *SPC Forecaster, 05/29/2014*

Forecasters anticipated/experienced enhanced application of the OTD algorithm at night, given the feature is more difficult to identify visually in coarser resolution IR imagery versus visible imagery. They also saw increased value in areas where radar coverage is limited and reliance on satellite-based information is increased. However, even during the day and in areas of adequate radar coverage, forecasters felt that the algorithm had its benefits. At the very least it would serve as confirmation tool, increasing confidence to what other observational data were showing.

> "I look forward to using it out west especially where radar coverage isn't as great, and there will be situations where I think it would be useful."
> *SPC Forecaster*

> "Could be useful at night and over the ocean to better quantify what is happening regarding where the strongest updrafts are."
> *SPC Forecaster*

> "Helps with situational awareness. It confirms some of what we already know during the day in areas of good radar coverage. "
> SPC Forecaster

It was discovered early in the demonstration period that the OTD algorithm might have its greatest utility in tracking the evolution of mature convective systems. Forecasters found that the presence of a persistent OT feature or group of OTs can signify an especially long-lived and potential hazardous weather producing storm or cluster of storms. Similarly, decreasing trends in the existence of previously persistent and abundant OTs may indicate the thunderstorm or convective system is weakening. This OT tracking process is expedited through use of the OTD algorithm as the user no longer needs to spend time manually identifying the feature in each successive satellite image.

> "Trends could help give some information about mature storm evolution."
> *SPC Forecaster*

> "It was helpful to look at trends in the OTD's (from scan to scan) to know which storms were staying strong and when certain storm clusters were beginning to weaken."
> *SPC Forecaster, 12/20/2013*

The benefit of monitoring trends in the OT detections was illustrated during a 24 April 2014 southeast U.S. severe weather event. A SPC mesoscale forecaster was monitoring the evolution of existing severe convection as it traversed across central Mississippi through the evening hours. A particularly long-lived thunderstorm with an associated algorithm-detected OT had a history of producing severe hail and wind along its path through 0230Z. The OT was last detected with this area of convection at 0202Z, 28 minutes before the final report of severe weather, after which the storm core descended and convection subsequently dissipated. The mesoscale forecaster issued an MD at 0344Z concerning the soon-to-expire severe thunderstorm watch, referencing the OTD trends as evidence that the overall severe threat was waning: "THE GOES-R OVERSHOOTING TOP PRODUCT INDICATED A DIMINISHING TREND OVER EAST CENTRAL MS SUCH THAT UPDRAFT INTENSITIES ARE LIKELY WEAKENING (Fig. 3)."

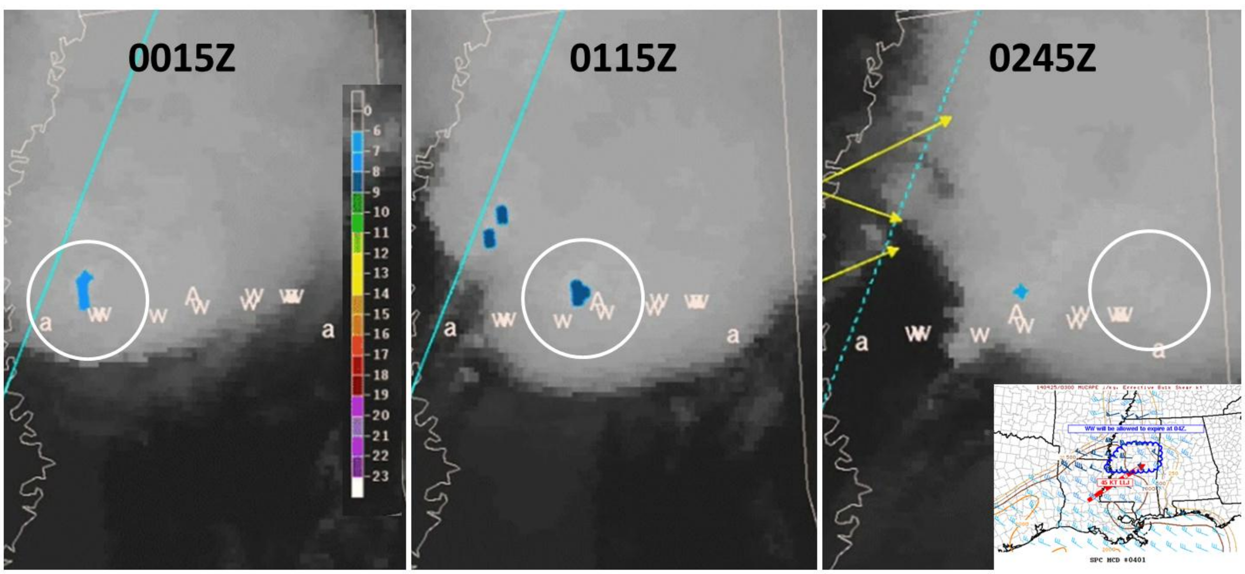

Figure 3: 0015Z, 0115Z, and 0245Z 25 April 2014 Overshooting Top Detection Magnitude (overlay; K) and GOES-East infrared satellite imagery, severe hail (a, A-significant) and wind (w) reports over Mississippi. SPC Mesoscale Discussion #0401 graphic (inset).

Criticisms of the OTD algorithm were also documented. Some situations were associated with false detections and/or missed detections. The false detections were usually obvious to the user given the location of the OT and utilization of other observational tools such as radar. Enhancements currently being made to the OTD algorithm plus increased spatial resolution with the GOES-R ABI will partially alleviate these issues. Several forecasters preferred to identify the

OTs manually during the day, though they acknowledged its availability at night provided unique value. Similar to the CTC algorithm, OTD would benefit from reduced temporal latency.

Given its use in storm monitoring, the OTD algorithm will remain available to forecasters in SPC operations as long as the product is generated. SPC forecasters look forward to seeing an updated OTD algorithm and using it in the GOES-R era when it will benefit from the higher temporal and spatial resolution data from the ABI.

3.3 NearCast Model

University of Wisconsin/Cooperative Institute for Meteorological Satellite Studies (CIMSS)

The GOES NearCast model was designed to increase the utility of GOES Sounder moisture and temperature retrievals for forecasters. Multi-layer products from the model are used to help determine where and when convective development is more (or less) likely to occur in the near future (0-9 hour forecast range), helping to fill the information gap that exists between observation-based nowcasts and longer-range (beyond 12 hours) numerical weather prediction (NWP) guidance. The NearCast model uses a Lagrangian approach to dynamically project GOES sounding temperature and moisture data forward in space and time in multiple layers of the atmosphere that are consistent with the observing capabilities of the GOES instrument. The technique preserves fine details present in the full-resolution observations such as horizontal gradients, maxima, and minima, which often provide the focus for convective development (Line, 2013).

Available to forecasters at SPC are analyses and 0-9 hour forecasts of: low- (centered around ~780 mb) and mid- (centered around ~500 mb) layer theta-e, vertical theta-e difference (mid-low), low (~900-700 mb) and mid (~700-300 mb) layer precipitable water (PW), and vertical PW difference (low-mid). Based on past forecaster feedback, a “CONUS” version of the NearCast model that combines data from both the GOES-East and West Sounders was developed and implemented. The main purpose of the NearCast demonstration is to determine if the guidance provided by the NearCast system using moisture and temperature information from the GOES Sounder (and planned ABI) provides forecasters with relevant and unique analysis and short-term forecast information about the thermodynamic structure of the atmosphere.

Very important to the forecast process at SPC is the availability of vertical moisture information when assessing the pre-convective environment. However, the lack of routinely observed vertical profiles of moisture data often requires forecasters to rely on NWP sources more than some prefer. Therefore, one aspect SPC forecasters appreciate most about the NearCast system is that it provides an observation-based source of vertical moisture information at relatively high temporal (hourly) and spatial horizontal (10-12 km) resolution. Additionally, the latency from when the observations are made to when the NearCast products are available is relatively short (~15 minutes), another attribute the forecasters value.

> “I like that it is observation-based, instead of model data, of which there are many products.”
> *SPC Forecaster*

Forecasters have expressed situations in which they feel the NearCast products have their greatest benefit. One such use is at the outlook desk, especially when preparing the 20Z Day 1 Convective Outlook (adjusting boundaries, etc.) given the models ability to capture the location and future movement of significant horizontal moisture gradients. This capability also benefits forecasters at the mesoscale assistant desk when defining the thunder probability boundaries.

> "This could be particularly useful in the south, in pulse thunderstorm situations, to show the evolution of moisture gradients."
> *SPC Forecaster*

The initial implementation of the GOES NearCast System into SPC included only the 0-9 hour forecast products. Early on, however, forecasters expressed a desire to also have separate analysis products made available for use as overlays on satellite imagery. This is similar to how SPC forecasters use NWP model analysis (GFS, RAP, etc) overlays on imagery. NearCast analysis overlays allow forecasters to visualize how convective activity (or lack thereof) has evolved to its current state with respect to the NearCast thermodynamic fields, as observed from the GOES Sounder. One can then, in turn, make an assessment of how activity might continue to evolve given the NearCast forecast fields. The NearCast system enhances the GOES sounder observations by filling in data gaps - that exist due to cloud cover - with previous forecast data that are valid at the same time.

The field most utilized by SPC forecasters has been the vertical theta-e difference. This field provides an objective means of identifying where mid-level cooling/drying is occurring over low-level warming/moistening, corresponding to where convective instability may be developing. As an example, NearCast model theta-e difference analyses were utilized at the SPC Outlook desk prior to the issuance of the 20Z Day 1 Convective Outlook on 1 October 2014. It was evident from the theta-e difference analysis field that a convective instability maximum was advancing northeastward along a southwest to northeast oriented instability/moisture boundary (Fig. 4). Based on past experience, one would expect convection to more likely initiate in the vicinity of the instability maximum and advance along the boundary. That turned out to occur, as the forecaster noted, "the satellite derived Convective Instability product from the NearCast Model highlighted the location of convective initiation in central Oklahoma about 1.5 hours in advance". He went on to say that "convection initiated and moved with a relative maximum in convective instability as shown in the NearCast analyses." This particular forecaster assisted in the development of a contouring scheme for the NearCast theta-e difference analyses that is now used as an overlay on satellite imagery. Experiencing events in real-time such as the one presented increases forecaster confidence in using the tool in a beneficial and complimentary manner.

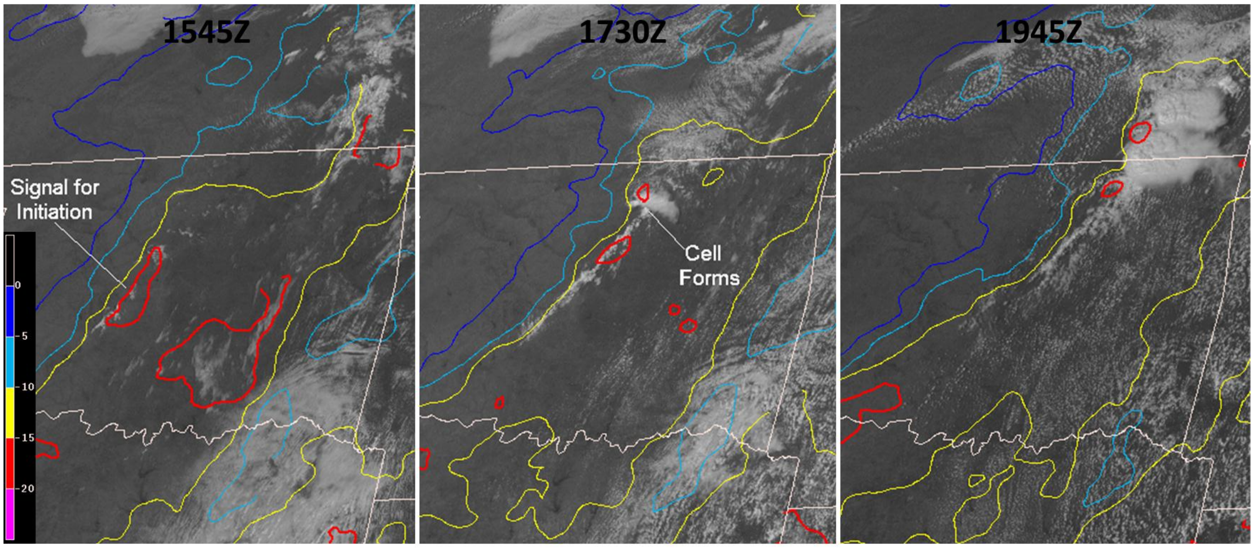

Figure 4: 1500, 1700, and 1900Z 1 October 2014 NearCast Model negative theta-e difference analyses (contours; K) and 1545Z, 1730Z, and 1945Z GOES-East visible satellite imagery over Oklahoma.

The NearCast Model will continue to be available to SPC forecasters in operations as long as it is provided. The vertical moisture information is unique in that it is highly observation-based at relatively high temporal and horizontal resolution, and has its utility extended into short term forecasts. The eventual migration of SPC to an advanced visualization system such as AWIPS-II will benefit the NearCast system in various ways, including but not limited to: blending of analyses and forecasts into one seamless animation, automatic updating of the hourly forecasts, improved color scheme, and multi-panel displays. These benefits have previously been realized in the Hazardous Weather Testbed (HWT) during the Spring Experiment (Line, 2014). Continued long-term use of the NearCast products in SPC will allow SPC forecasters to become more comfortable with the information it provides, and reveal additional situations in which it is operationally significant.

3.4 Lightning Threat algorithm for NWP

The Lightning Threat algorithm provides forecasters with a tool to differentiate areas of explicit convection in Convection-Allowing Model (CAM) guidance that are predicted to produce total lightning versus those that are not. A calibrated graupel flux at -15°C term is combined with a vertically integrated ice content term in a weighted average to produce the flash rate density product in flashes (5 min)$^{-1}$ km^{-2} (McCaul, 2009). This product is available to SPC forecasters in N-AWIPS from the NSSL-WRF and High Resolution Rapid Refresh (HRRR) numerical weather prediction (NWP) models. The purpose of this demonstration is to identify aspects of SPC operations that might benefit from the flash rate density forecast product.

Forecast products issued by SPC that are most relevant to the CAM-based flash rate density product include the Thunderstorm Outlooks, Convective Outlooks, and Dry Thunder Outlooks. Forecasters appreciate the additional thunderstorm guidance, and some have included it in their regular forecast decision-making process. However, in general SPC forecasters are not as concerned with knowing which individual storms in the forecast will produce lightning, but instead want to know about the broader overall lightning threat. Therefore, some enhancements to this product could make it more compatible and useful during the preparation of the aforementioned SPC forecast products.

The SPC Thunderstorm Outlooks are for 4-hour forecast periods (e.g., 12Z-16Z, 16Z-20Z, 20Z-00Z), so a 4-hour lighting density product would be an appropriate addition. Also, the thunderstorm outlooks are in the form of probabilities, so developing a probability-based lightning threat algorithm (in development) will be more pertinent. These additions would match other SPC forecast guidance, would allow for straightforward comparisons between products, and can provide forecasters with confidence in the model when compared with actual observations from the GLM (as with synthetic model radiances compared to actual ABI data).

3.5 GOES-14 Super Rapid Scan Operations for GOES-R 1-minute imagery

SRSOR 1-min imagery from GOES-14 demonstrates a capability of the GOES-R ABI when in the “flex mode” (mode 3) scan strategy, which will include 30 second imagery over one 1000x1000 km sector, or two 1000x1000 km sectors of 1-minute imagery (Schmit et al., 2005). The 1000x1000 km refers to the size at the satellite sub-point. Past GOES-14 1-minuite data collection experiments are documented by Schmit et al. (2013, 2014). In addition to familiarizing users with a future ABI capability with respect to its temporal resolution, this evaluation sought to understand how 1-minute imagery might benefit SPC forecasters. Acknowledging that 1-minute satellite data will likely play an important role as part of future data-fused products, these initial demonstrations focused on the potential utility of the super rapid scan imagery in SPC operations.

GOES-14 1-minute imagery was made available to SPC forecasters in N-AWIPS during parts of August 2013, May 2014, and August 2014. The 1-min imagery was available over a daily-changing approximately 1500x2000 km sector that was positioned over the region where the most active weather was expected to occur. During these periods, the imagery was used heavily (when located over convectively active regions) at the lead, mesoscale, mesoscale assistant and outlook forecast desks in SPC operations. Forecasters took note of specific features and processes observed in the 1-min imagery that were less obvious or not apparent at all in the corresponding routine geostationary satellite imagery. The benefits of the 1-min imagery to SPC operations were realized during all parts of the convective nowcast cycle, including pre- and post-convective initiation.

In addition to increased temporal frequency, each SRSOR image was available to the forecasters in a much timelier manner. While routine images via the direct feed arrive 6-10 minutes after the timestamp (depending on scan sector), the 1-min images were usually available in N-AWIPS with a 3-4 minute time latency (some of which was due to transfer of data over the internet). No N-AWIPS performance issues related to the 1-min imagery have been reported, even as forecasters sometimes load more than 200 SRSOR images (3+ hours) in one display loop.

There were many situations in which the 1-min satellite imagery aided SPC forecasters in assessing the pre-convective environment. The continuous nature of the 1-min imagery allowed for more precise monitoring of cloud character and growth trends, providing detailed information about the evolving state of the environment. Instead of inferring what might be occurring between successive satellite scans by waiting 5-30 minutes, the forecaster was able to observe various cloud processes as they occur in real-time.

> “[I found it very useful in] diagnosing the near-storm environment (NSE) through both convective trends and near-environment cloud character--for example, billows evolving into cumuliform clouds as indicators of NSE destabilization, or billows remaining billows as indicators of lack of instability.
> *SPC Forecaster*

> “The 1-min satellite imagery has afforded opportunity to more completely observe life cycles of individual convective updrafts. These data also provided greater visual continuity of convective cold pool evolution and nascent convective development along boundaries. The latter led to higher confidence in the timing and location of storm development.”
> *SPC Forecaster*

> “With weakly-forced, nebulous low-level boundaries over the Northeast today, the ability to see where boundary layer cumulus is deepening and clumping in this manner is quite striking.”
> *SPC Forecaster, May 22, 2014*

Similarly, the imagery allowed for easier identification and tracking of boundaries, which often play a vital role in forthcoming and already developed convection.

> “[I found it very useful in] using cloud character and trends to diagnose boundary locations and motion, and nowcast their potential for either CI or influences on upshear storms to interact therewith.”
> *SPC Forecaster*

> “The identification and evolution of mesoscale and storm-scale features, such as outflow boundaries and feeder cells, were very evident.”
> *SPC Forecaster*

As an example, the 1-min imagery aided the SPC forecaster at the mesoscale desk in his analysis of the pre-convective environment during a severe weather day on 22 May 2014 in Pennsylvania and New York. Explosive convective growth was not expected, so any signs of initiation, however subtle, would be of value to the forecaster. Areas of deepening and clumping cumulus were apparent in the imagery after 1500Z, helping to key the forecaster’s attention to the occurrence of upscale growth as it was occurring in an environment favorable for severe wind and hail (Fig. 5). The forecaster wrote in the MD text: “1-MIN RESOLUTION VISIBLE SATELLITE IMAGERY DEPICTS DEEPENING CU AND SMALL CBS FORMING ALONG/JUST AHEAD OF A COLD FRONT STRETCHING FROM AROUND 25 S ROC TO ZZV...WITH THE GREATEST CLUMPING NEAR THE NY/PA BORDER.” This convection would continue to grow upscale, eventually developing into storms that produced severe wind and hail.

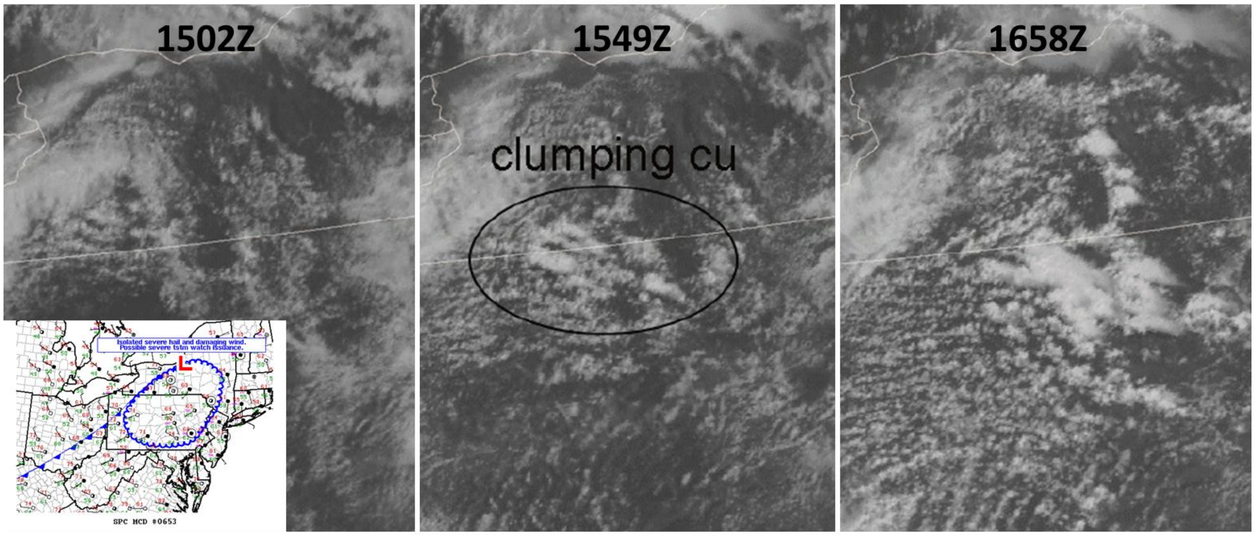

Figure 5: 1502Z, 1549Z and 1658Z 22 May 2014 GOES-14 SRSOR 1-min visible satellite imagery over Pennsylvania and New York. SPC Mesoscale Discussion #0653 graphic (inset).

Forecasters agreed that their enhanced ability to identify such processes and features when using the 1-min imagery led to increased confidence and lead-time to where and when convection would initiate. Accordingly, SPC forecast products such as Mesoscale Discussions and Watches were often issued earlier and with more precision (compared to using routine imagery), providing customers with more time to prepare for the event.

> "The greatest advantage to the 1-minute imagery is in detecting deep, moist convective initiation, with 15-30 minutes of lead-time advantage compared to current GOES scanning strategies."
> *SPC Forecaster*

> "It even helped with one or two watch decisions on my shifts, in terms of starting the process a little earlier (lead time) or focusing it tighter (less potential false-alarm area).
> *SPC Forecaster*

> "This has provided extra confidence and lead time for the issuance of two mesoscale discussions compared to the normal satellite update frequency/latency."
> *SPC Forecaster, 5/22/14*

In another case, the 1-min satellite imagery increased SPC forecaster lead-time to pinpointing when and where convective initiation was taking place prior to a 11 May 2014 tornado event in Nebraska. The SPC forecaster monitored the 1-min data at the Outlook desk while preparing the 20Z Day 1 Convective Outlook. Around 1848Z, an "orphan anvil" was generated signaling a convective initiation event that was not sustained (Fig. 6). However, this initial glaciation clued the forecaster to the likelihood of subsequent initiation in that particular area. The forecaster explained that the feature was not apparent in GOES-East imagery, which was in Rapid Scan Operations (RSO). In the outlook, the forecaster increased tornado probabilities over a small region surrounding the location of the orphan anvil. After the fact, it was mentioned that although the upgrade would have likely been made without SRSOR, the 1-min imagery did increase confidence in the decision to include it and where. Referring to the 1-min imagery in the outlook, the forecaster explains, “THE LATEST 1 KM VISIBLE SATELLITE IMAGERY SUGGESTS STORM INITIATION IS TAKING PLACE NEAR THE SFC TRIPLE POINT IN WEBSTER COUNTY NEB.” Storms began rapid development in the area within the next hour.

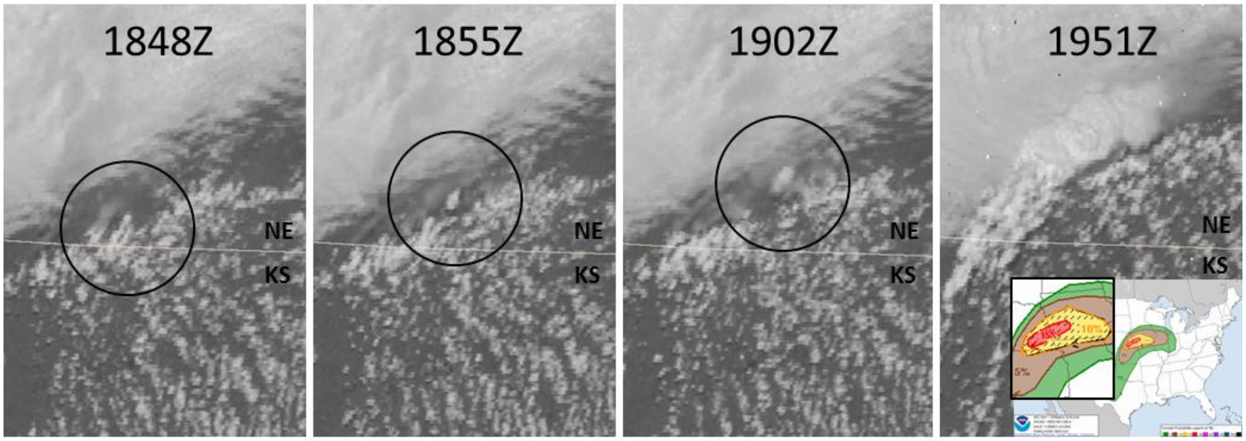

Figure 6: 1848Z, 1855Z, 1902Z and 1951Z 11 May 2014 GOES-14 SRSOR 1-min visible satellite imagery over Nebraska and Kansas. 20Z SPC Day 1 Tornado Outlook (inset).

The 1-min satellite imagery also aided SPC forecasters in the period after convection had developed and matured. Storm-top features and processes were more easily observed and tracked, allowing for more confident and timely identification of changes in storm intensity.

> “Post-storm initiation, the high-resolution data allowed for careful analysis of overshooting and collapsing thunderstorm tops, the character of the storm anvils (i.e. health of the storm) and the identification of convectively generated outflows.”
> *SPC Forecaster*
>
> “[I found it very useful in] assessing the trends of convection via evolution of cloud character in the storms themselves (overshooting tops, subjective visual assessment of storm-top divergence and flanking-line development, etc,)”
> *SPC Forecaster*
>
> “As deep convection encounters capping inversions, the spreading out of the convection can be seen. This may enhance our ability to assess capping strength with more experience.”
> *SPC Forecaster*
>
> “Flanking line convection is also clearly evident in the short time scans. Usually, this development is hard to visualize in longer time spans since anvil clouds often obscure this type of evolution rather quickly.”
> *SPC Forecaster*

In a final case example, the 1-min visible satellite imagery was used to monitor intensity trends of mature convection at the mesoscale assistant desk on 21 May 2014. A severe thunderstorm watch had already been issued for a large portion of western Texas for a hail and wind producing north-south oriented line of severe thunderstorms. The continuous imagery allowed for the precise monitoring of persistent robust updraft generation and for the identification of updrafts that were weakening (Fig 7). Additionally, new thunderstorms were identified as they developed rapidly in the southern part of the domain, instead of after they had already developed as is often the case with less-frequently updated satellite imagery. Referencing the 1-min imagery, the forecaster wrote in a watch update MD: “GOES 14 ONE-MINUTE IMAGERY SHOWS CONTINUED UPDRAFT GENERATION WITHIN A MORE MATURE CLUSTER JUST E OF AMA...AND ADDITIONAL TSTM DEVELOPMENT W OF MAF...SUGGESTIVE OF A CONTINUED SVR HAIL/WIND THREAT FOR AT LEAST THE NEXT 1-2 HRS.”

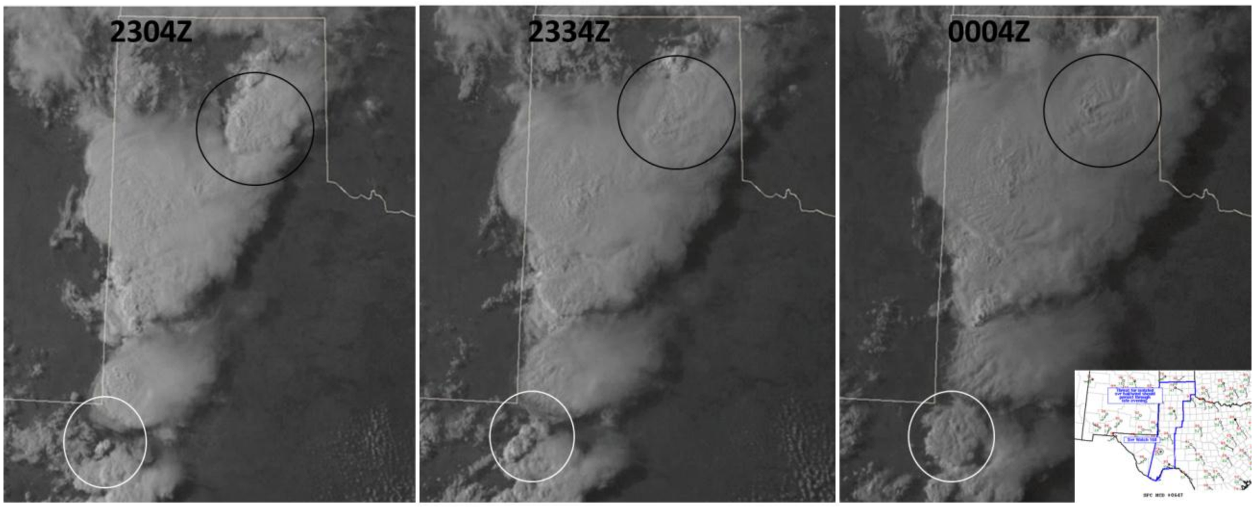

Figure 7: 2304Z, 2334Z 21 May 2014 and 0004Z 22 May 2014 GOES-14 SRSOR 1-min visible satellite imagery over west Texas. SPC Mesoscale Discussion #0647 graphic (inset).

Looking ahead, SPC forecasters anticipate educational benefits from the long-term use of high-temporal resolution satellite imagery. Never-before-seen features and processes related to convection may be revealed as current knowledge is enhanced and refined, helping to improve severe weather nowcasts.

> “Ability to observe thunderstorm (and other phenomena) development with temporal resolution that has not been available in the past --- potentially providing insight into processes important to storm development not currently recognized / diagnosable.”
> *SPC Forecaster*

> “I would add that having the data available routinely would very likely, over time, allow forecasters to gain a better understanding of processes related to convective initiation, as these processes occurring within a cu field would be visually revealed in high temporal-resolution data in a way that 15- or 30-minute imagery cannot as clearly depict.”
> *SPC Forecaster*

After three separate two-week periods of GOES-14 SRSOR data collection, SPC forecasters are able to make very insightful assessments regarding the utility of 1-min satellite imagery to severe weather forecasting. In addition to having more frequent images, the forecaster sees the images in a timelier manner when compared to current routine imagery. Through real-time use in operations during a variety of weather events, forecasters have experienced many situations pre- and post-convective initiation where the 1-min data has improved their nowcast/forecast process and enhanced their knowledge of various convective processes. In many cases, the imagery increased confidence in and lead-time to the issuance of forecast products, benefiting the public.

> "Satellite imagery at 1-min temporal resolution needs to become the new standard for severe weather operations."
> *SPC Forecaster*

4. Summary and Conclusions

As the 2016 launch date of the first GOES-R satellite approaches, year-round Proving Ground activities at SPC continue. In addition to exposing SPC forecasters to GOES-R products and algorithms, these demonstrations have provided an excellent opportunity to educate them on the advanced instrumentation and associated capabilities that will be available. Over time, SPC forecasters are realizing the significant benefits to hazardous weather forecasting that will be provided. This knowledge will help make the post-launch transition into the GOES-R era seamless, as SPC will be well-prepared to utilize the new data from day 1.

In order to make informed decisions regarding the scope of GOES-R demonstrations in SPC, the satellite liaison began by participating in shadow shifts with the forecasters. This familiarization period allowed for the identification of specific forecaster needs that could be addressed through the use of satellite data. Relatively mature Proving Ground products were identified as having potential to provide unique and complimentary information to the SPC forecast process. These initial products included Cloud Top Cooling, Overshooting Top Detection, NearCast Model analyses and forecasts, Lightning Threat algorithm and GOES-14 SRSOR 1-min satellite imagery. Over the last year and a half, SPC forecasters have been utilizing these tools in operations, discovering and documenting ways in which the products can be applied to their benefit.

The CTC and OTD products both provide a non-obtrusive, easy to understand overlay on satellite imagery, something the forecasters appreciate. The products enhance satellite imagery by highlighting and quantifying features, drawing out details and tendencies that are otherwise more difficult or time consuming to discern, which is especially important during busy nowcast situations. Forecasters are quite comfortable loading these GOES-R products with their routine satellite imagery, with some already viewing them regularly during severe weather operations. The CTC product has been valuable in alerting the forecaster to locations of initial convective development, while giving them an idea of how strong individual storms might become and how widespread the growth will be. Meanwhile, forecasters have found the OTD product to be beneficial when monitoring the evolution of mature convection, as trends in individual and groups of OTs have provided insight into whether an area of convection is maintaining strength or potentially weakening.

The NearCast model has provided forecasters with an alternative source of vertical moisture and instability analysis and forecast information that is observation-based. SPC forecasters recommended and helped develop the NearCast analysis displays for use as overlays on satellite imagery. The lightning threat algorithm has been identified as having potential utility during the creation of thunderstorm-related SPC forecast products. Finally, the 1-minute satellite imagery from GOES-14 has spawned great excitement from the forecasters. Every day during which the 1-min imagery was available over a convectively active region, SPC forecasters used it heavily in operations. There were many situations in which convective features and processes observed in the 1-min imagery were not apparent in the routine imagery, or were diagnosed significantly later in time. The products under demonstration have been referenced in many SPC mesoscale discussions and outlooks, evidence that they already provide valuable guidance to forecasters.

Other general takeaways from SPC demonstrations:

1) Forecasters are more open to trying out a new product in operations if the display is easy-to-understand, clean and non-obtrusive.
2) Forecasters need time to learn the proper methods of use and strengths and weaknesses of new forecast tools through real-time application in their home operational setting. They will not become experts with a new tool in a week, but instead need months of operational use to become comfortable with the tool over varying weather situations.
3) Some forecasters are more set in their ways and are not open to immediately trying new products. Initial attention must be given to those early adopters who are most interested in exploring new datasets, and their use will eventually spread through the forecaster ranks.
4) In SPC, low time latency in product arrival is of extreme importance.
5) SPC forecasters rely heavily on frequent and timely observation-based information, as observations provide them with “atmospheric truth”. While some forecasters may accept black box algorithms, many still prefer to also see the raw data.
6) A lot of attention (research, algorithm development) has focused on the initiation stages of convective evolution, with comparatively little attention paid to the convective dissipation stages. Improved/increased guidance for convective decay is arguably just as important, and something forecasters have expressed a desire in seeing.
7) Forecasters would prefer one holistic algorithm that provides diagnostic information throughout the entire lifecycle of a storm/storm system, from “when/where is the storm going to initiate” to “how strong is the storm going to be” to “when/where is the storm going to dissipate”.

The unique expertise SPC forecasters possess in the realm of severe weather forecasting is of considerable benefit to the GOES-R Proving Ground. Their comments should be valued for they have been utilizing these data in a real-time operational setting for a significant time period. SPC feedback helps to reveal how GOES-R products and capabilities can best be applied to improving convective forecasting, and what can be done to enhance existing tools. This information is valuable for decision-makers as baseline algorithms and modes of operation are chosen, and as we continue to prepare the broader user community for the receipt of GOES-R data.

Use examples of GOES-R products and capabilities at SPC can be found on the “Satellite Liaison Blog” at:
https://satelliteliaisonblog.wordpress.com/

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