**1.11** AN OBJECTIVE NOWCASTING TOOL THAT INCORPORATES GEOSTATIONARY SATELLITE MEASUREMENTS

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1. INTRODUCTION

The concept of nowcasting, or at least the term itself, has been around since the mid-1970s. Although the definition of nowcasting can vary due to different operational requirements, it generally refers to the process of identifying small-scale features in the atmosphere, projecting their behavior forward in the short term, and disseminating information that will influence the decision of a customer. Such a decision might involve public safety (warnings) or a choice affecting the economic outcome of an activity (transportation, agriculture). The time and space scales involved require the extensive use of high-resolution observing systems and the rapid distribution and analysis of the observations they generate. Remote sensing has to play a key role. Only satellites and radar can provide the spatial and temporal coverage needed to resolve mesoscale structures that are important to the nowcasting process. A detailed description of many aspects of the nowcasting problem is presented in the book *Nowcasting*, edited by Browning (1982).

Instruments placed in geostationary orbit have the advantage of sampling the atmosphere at short time intervals required for nowcasting. The current GOES series of satellites can sample at one-minute intervals for a short time under special circumstances (Menzel et al., 1988). This feature has been used to study developing thunderstorms. The imager samples the full earth disk using five spectral bands every 30 minutes at a horizontal resolution of one kilometer, while the sounder samples hourly, using 19 spectral bands over a more limited area at a horizontal resolution of approximately 10 kilometers. These specifications are essentially determined by communication bandwidth, i.e. the time it takes to transmit the information down to the ground station and then to the user.

There are some disadvantages with using a geostationary orbit. The altitude necessary to maintain a geostationary orbit (36,000 kilometers) requires that instrument detectors and optics need to be sensitive and carefully calibrated to achieve a useable signal-to-noise ratio. To date, current technologies will only allow sensors that detect in the visible and IR bands. Thus, temperature and moisture soundings can only be generated in clear fields-of-view (FOV). Cloud detection is very important because sounding retrieval algorithms are extremely sensitive to cloud contamination. Many of these limitations can be minimized with careful utilization of the data and by leveraging information from other observing systems. Forecasters have become very dependent on the GOES satellites for detecting both synoptic and mesoscale features in the atmosphere. The objective use of GOES data in numerical analysis and forecasting remains less common. Operational centers are currently using radiances and retrieved products from GOES in their assimilation systems. However, the full temporal and spatial resolution of the data is typically not utilized.

Recently, the issue of limited vertical resolution has been challenged with the launching of the Advanced Infrared Sounder (AIRS) (Pagano et al., 2001). Although in a polar orbit with limited temporal coverage, it uses a grating spectrometer to sample the atmosphere at 1200 narrow spectral bands at a horizontal resolution of 13.5 kilometers. The spectral resolution allows AIRS to detect vertical structures of one kilometer in depth, far

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better than the current GOES sounder. This vertical resolving power will allow for the detection of mesoscale features important to nowcasters. In the coming years hyper-spectral instruments will eventually make their way into geostationary orbit. One proposed instrument is the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) (Bingham et al., 2000). It will have the sensitivity to resolve atmospheric features above and beyond the capabilities of today's geostationary sounders. Although GIFTS data will most likely generate improvements in numerical forecast guidance out to 48 hours and beyond, a significant benefit will come from the use of GIFTS data in a real time objective nowcasting system designed to assist forecasters with identifying rapidly developing, small-scale extreme weather events. To satisfy nowcasting requirements such a system will need to detect and retain extreme variations in the atmosphere while assimilating large volumes of high-resolution asynoptic data from satellites. To accomplish this may require numerical techniques that are notably different from those used in numerical weather prediction where the forecast objectives cover longer time periods. Such a system will need to place an emphasis on observation accuracy, require frequent updates and will have minimal interaction with numerical prediction models.

It is our intent to develop an objective analysis system for nowcasting using a LaGrangian approach to optimize the retention of information provided by multiple observing systems. The system will give priority to preserving vertical and horizontal gradients in the observed fields with the goal of detecting extreme variations in atmospheric parameters and identifying the onset of significant weather events. A ystem is currently being developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin. Analytical tests have been performed to test the ability of the method to retain gradients and extremes in meteorological fields. These tests show that the technique is computationally efficient and is able to retain sharp gradients, observed maxima and minima, and is capable of providing updates to forecast guidance provided by operational forecast models. Tests with real data are currently being conducted using full resolution (10 km) derived layer moisture products from the GOES-12 sounder over an area in the Central U.S. These tests focus on the ability of the proposed system to retain and capture details important to the development of convective instability. The advantages of using a LaGrangian to updating short-range model guidance will be demonstrated for conditions that are dominated by differential advection.

## 2. OBSERVATION-INTENSIVE OBJECTIVE ANALYSIS

As stated by Browning (1982), the nature of nowcasting requires an "observation-intensive approach to local weather forecasting". Today's modern data assimilation systems do an amazing job of using a sparsely distributed collection of observations to generate initial conditions for numerical weather prediction (NWP) models. They do not necessarily produce accurate analyses of atmospheric parameters in the absolute sense, particularly in the 0-3 hour forecast period. Today's operational NWP centers use optimal statistical approaches to extract information from observations by fitting the model variables to the observations in a least-squared sense across three space dimensions over a discrete time intervals (Daily, 1991). Absolute accuracy is sacrificed to achieve the best overall spatial fit that satisfies the model numerics. Some of the information introduced in previous assimilation cycles (especially maxima and minima) is lost due to imperfections in the analysis and the prediction model: numerics, truncation, smoothing, interpolation, etc. Numerical constraints are usually imposed during the analysis phase that are required to maintain numerical stability, often at the expense accurately fitting the analysis background to a perfectly good observation. Consequently, initial model fields frequently contain unrepresentative gradients and reduced maxima and minima.

One obvious method for improving the absolute accuracy of gridded analyses is to increase the volume of observations available to the assimilation system within the assimilation window. Allowing off-time observations in the analysis is one method for increasing spatial coverage. If the assimilation time window is brief, time-space corrections are usually not performed.
One assimilation method that allows observations to influence the analysis over a wider time window is the 4-D variational approach like that used by the European Center for Medium Range Weather Forecasts (ECMWF) (Rabier et al., 1998). This system iterates toward a forecast model trajectory that best fits the model background and

observations for a given time interval, typically 6 to 24 hours in length. This approach is computationally expensive and, therefore, is usually implemented at a degraded spatial resolution. 4-D variational systems are also bound to the same physical and dynamical constraints that are required for model initialization and are complicated to maintain.

It is our goal to design an objective analysis system that takes advantage of positive attributes of geostationary observing systems in combination with in situ observations for the purpose of nowcasting. It will rely as little as possible on information generated by deterministic forecast models. It will optimize the use of non-perishable observations from previous observing times, projected along forward trajectories to augment spatial and temporal coverage and keep absolute errors in check. Maxima and minima in the analyzed fields will be preserved.

## 3. AN OBJECTIVE ANALYSIS FOR NOWCASTING

In theory, if the spatial coverage and density of observations are greater than the analysis grid, a model generated background field has less influence on the analysis and in the extreme may not be required. One observing system that comes close to having the ability to provide observations of atmospheric parameters at excellent spatial (at least horizontal) and temporal resolutions is the sounder onboard the Geostationary Operational Environmental Satellite (GOES) (See Menzel et al., 1998). The sounder measures the atmosphere at 19 spectral bands in real time with a 10 km footprint, at one-hour intervals. Retrieved temperature and moisture profiles are currently processed in real time by NESDIS at hourly intervals. Clear FOVs are required for the proper conversion of measured radiances to standard meteorological parameters. Figure 1 shows three layers of precipitable water (PW) retrieved from GOES-12 sounder radiances. The color enhancement is identical for all three images. Each layer contains differences in the horizontal gradients and in the amount of water vapor present. A nowcasting analysis scheme must be able to capture these features, track them, and diagnose significant changes in atmospheric stability.

We are currently using an analysis system based on a recursive filter (Hayden and Purser,

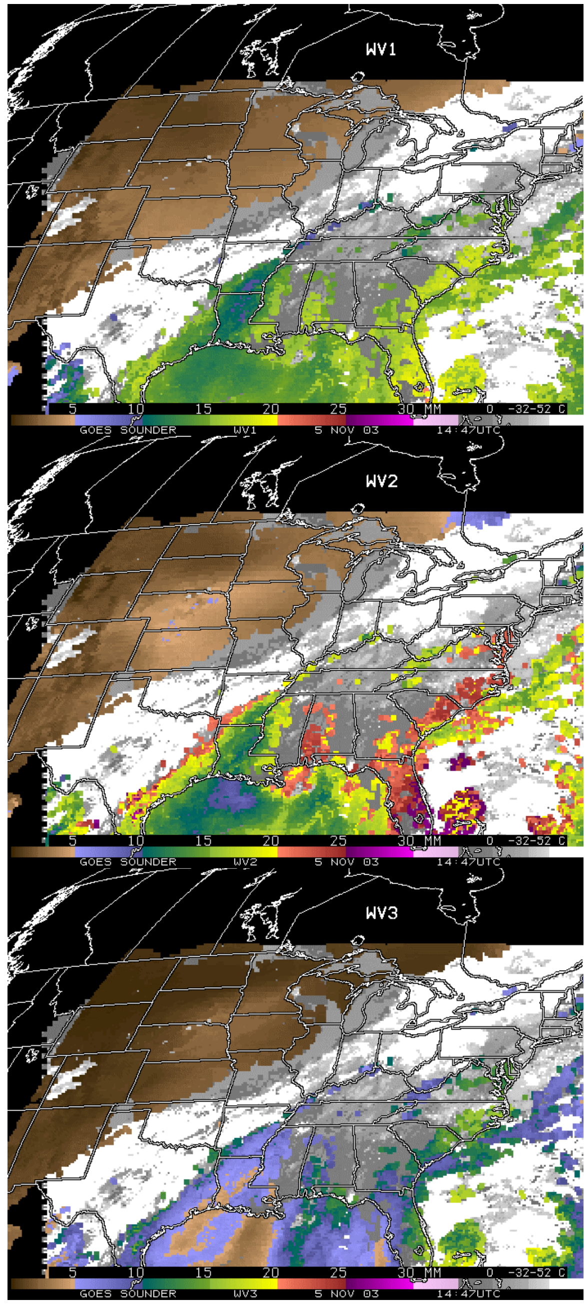


Fig 1. Three layers of precipitable water derived from GOES-12 sounder radiances valid 15 UTC November 5, 2003. Differences in gradients exist in each layer.

1995) to analyze hourly GOES-12 sounder observations to a 5 km grid centered over the Central U.S. (Figure 2). The technique is very fast and has proven to be reliable. Each retrieval data set is projected forward at one hour intervals using trajectories computed from winds obtained from

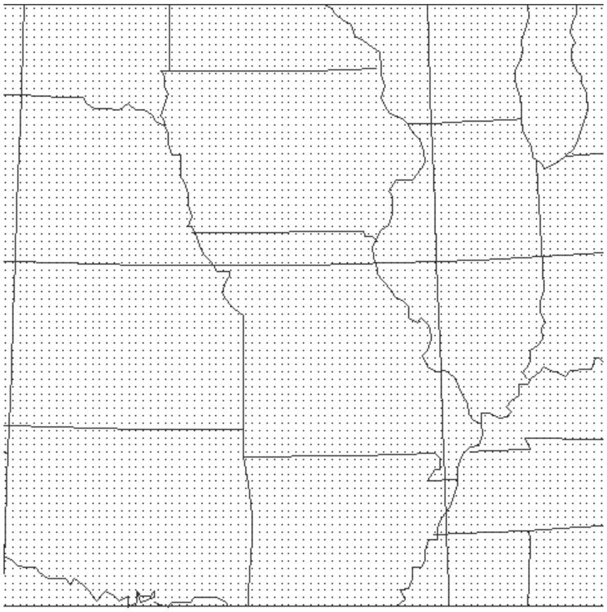

Fig 2. The 5 km domain currently used by the LaGrangian nowcasting scheme. Every third gridpoint is displayed.

the NCEP Rapid Update Cycle (RUC), producing pseudo-trajectory (PT) observation data sets at each of the hourly observation times. Eventually our system will incorporate wind observations from radar, aircraft, GOES and others. We have found that the accuracy of the PT observations decreases only slightly with time, retaining most of their value for up to four hours. Since the GOES-12 retrievals are available in clear air, it is hypothesized that values will remain unchanged as long as the atmosphere remains adiabatic. If this holds true, the total number of observations available to the analysis would grow with each hour as PT observations from previous hours would be joined by new retrievals. The accuracy of the PT observations has been assessed by statistically comparing them to the analyzed PW retrievals for each hour. Root mean square (rms) differences remain reasonable for the first four hours. Rms values at lower levels degrade faster because of diurnal boundary layer effects, which would be maximized in the morning hours.

## 4. PLANS

Ideally we want to configure an analysis system that incorporates all available observations. GOES retrievals from previous hours could be projected forward in time along isentropic trajectories to new locations since they generally exist where the atmosphere is adiabatic. The quality of the projected retrievals could be assessed dynamically and down-weighted as their accuracy becomes questionable. The resulting four-fold increase in the number of contributing observations every 4 hours would result in enhanced spatial coverage and a better chance at retaining horizontal gradients and detecting atmospheric extremes.

The amount of information defining the physical and dynamical state of our atmosphere, collected in near real time, is rapidly becoming unmanageable. The vast majority of these observations are coming from remote sensing platforms. An observation-based analysis system could serve as an intelligent data compression tool, generating detailed analyses that can be readily transmitted to nowcasters in the field. The visualization of these data is also an important issue. We intend to leverage the visualization expertise at the University of Wisconsin Space Science and Engineering Center (SSEC) to determine the best methods for displaying the resulting analyses.

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