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POTENTIAL IMPROVEMENT AREAS FOR HYDROMETEOROLOGICAL OBSERVING AND FORECASTING IN THE GOES-R ERA. EMPHASIS: IMPROVING PRECIPITATION POTENTIAL ESTIMATES USING THE HES SENSOR

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1. INTRODUCTION

One of the key challenges with current hydrometeorological observing and forecasting is the ability to accurately characterize atmospheric water vapor in three and four dimensions. Additionally, observing atmospheric moisture characteristics over varying geographic regions adds to the challenge. The HES (Hyperspectral Environmental Suite) sensor on the next-generation GOES-R satellites will lead to a much improved capability to measure three and four dimensional atmospheric moisture on smaller horizontal, vertical and temporal scales. Improvements to atmospheric moisture field observations and forecasts will lead to more accurate precipitation forecasts and rainfall potential assessments over the entire HES sensor coverage. Furthermore, the capability of the HES sensor to more accurately characterize three and four dimensional temperature and wind fields on smaller scales will also provide better information for observing and forecasting mesoscale-driven precipitation processes such as convection. This paper will discuss some of the key moisture field and other observational advancements to be gained with the HES sensor in the GOES-R era and beyond that will lead to improved precipitation potential estimates and forecasts.

2. OBSERVATIONAL IMPROVEMENTS

Before precipitation forecasts themselves can be improved, we must first collect better observations of the most important atmospheric drivers of precipitation processes. This section briefly highlights several well-known precipitation forecasting challenges, the atmospheric drivers behind them, and how observational improvements in the GOES-R era will help address these problem areas.

2.1 Precipitation Forecasting Challenges

Whether forecasting the probability of precipitation (PoP), type, intensity, duration, or accumulation, qualitative and quantitative precipitation forecasting has long been one of the most challenging aspects of predicting the weather. Precipitation is the most important atmospheric variable to forecast and the most intermittent and chaotic in both time and space (Fritsch et al., 1998). A difficulty with precipitation forecasting is that the greatest intensity and variability often derives from mesoscale processes ranging from mesoalpha-scale (>500 kilometer) features such as frontal circulations to mesobeta-scale (~100 kilometer) bands and clusters such as mesoscale convective systems (MCS) to mesogamma-scale (1-10 kilometer) phenomena such as individual convective cells. An enhanced capability to observe four dimensional moisture (and temperature and wind) evolution over these scales is key to improving both our conceptual and numerical modeling of these often chaotic precipitation processes.

As a rule, the heaviest precipitation usually occurs when and where the highest relative and absolute moisture (and its transport) intersects the most thermodynamically unstable air under the right dynamic forcing conditions (i.e. low- and upper-level jets, frontal boundaries, etc.) The importance of tracking moisture availability, atmospheric instability, and external dynamic forcing has been well studied and documented for several decades (Maddox et al. 1979, Doswell et al. 1996, Junker et al. 1999). Operational forecasters will often look at the precipitation efficiency (PE)—typically defined as the ratio of average precipitation depth to average precipitable water for a

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given area—to assess whether the potential exists for heavy precipitation to occur. Some of the most important factors for yielding a high PE are strong low-level moisture transport in the sub-cloud layer, low cloud bases with a deep warm cloud (3-4 km) layer, high values of surface-500mb mean relative humidity, and weak vertical wind shear.

Along with looking for broad indicators like those listed above, forecasters also have to carefully assess the potential for convective initiation (CI), or thunderstorm development, as another key contributor to heavy rainfall. Here, such factors as surface diabatic heating, low-level instability and moisture convergence, boundary-induced forcing (dry line, gust front, sea breeze, convective rolls, etc.), mid-level moisture, and capping inversions all play a role in collectively determining whether deep convection will form or not. Of these, moisture (or a lack of it) almost always plays a deciding role. Because of its extreme importance, a field experiment called the International H2O Project (Weckwerth et al, 2004) was conducted over the Southern Great Plains (SGP) of the U.S. in 2002 to “improve the characterization of the four-dimensional (4-D) distribution of water vapor and its application to improving the understanding and prediction of convection.” IHOP employed both in-situ (mesonets, dropsondes, etc.) and high-resolution remote sensors (S-Pol radar, LIDAR, etc.) to observe the small scale variability of moisture, particularly within and just above the boundary layer. So far, studies conducted during IHOP confirm that moisture (or lack thereof) plays a significant role in both the successful initiation and failed initiation of convection.

Many of the sensors used during IHOP were deployed tactically in a highly specialized and controlled research environment. Practically speaking, however, one of the limitations of current operational observing systems, including GOES, is that the fidelity and resolution of the operational instruments isn’t good enough for monitoring the small scale variability of moisture and other determining factors for CI including low-level temperature (capping) inversions and atmospheric instability. Additionally, this lack of spatial and temporal fidelity also inhibits our ability to identify and track the broader, well-known indicators for heavy precipitation potential like those described earlier.

2.2 HES Capabilities

In comparison to the current GOES sounder, HES will provide greater spectral resolution (thousands of channels), greater temporal resolution (< 1 hour), greater horizontal (< 10 km) and vertical (< 1km) resolution, and greater radiometric accuracy (< 1K) for monitoring the evolution of detailed temperature and moisture structures in the atmosphere (Li et al., 2002). Specifically, HES temporal (15 min or less), spectral (0.5 cm-1), spatial (1-10km), and radiometric (0.1K) capabilities will depict water vapor as never before by identifying small scale variability of moisture horizontally and vertically in the atmosphere (Menzel et al., 2004).

Figures 1 & 2 provide a sample listing of some of the next generation products and resolutions that will be routinely available from GOES-R that will provide a leap-ahead operational capability for advancing our understanding of and ability to forecast precipitation-driven processes. Figure 1 shows those products that HES will either directly measure, or indirectly derive in concert with the Advanced Baseline Imager (ABI), a companion multispectral sensor. Figure 2 shows the HES threshold (T) and optimal (O) atmospheric vertical profile product resolution requirements.

Product Type	Sensor	New
Atmospheric Vertical Moisture Profile	HES	
Atmospheric Vertical Temp Profile	HES	
Derived Motion Winds	ABI / HES	
Cloud Base Height	HES	X
Cloud Layers / Heights and Thickness	ABI / HES	X
Cloud Particle Size Distribution	ABI / HES	X
Capping Inversion	HES	X
Derived Stability Indices	ABI / HES	
Moisture Flux	ABI / HES	X
Convective Initiation	ABI / HES	X
Rainfall Rate / QPE	ABI / HES	X
Rainfall Potential	ABI / HES	X
Probability of Precipitation	ABI / HES	X
Total Precipitable Water	HES	
Total Water Content	HES	X

Figure 1. Sample listing of planned GOES-R products generated from HES or ABI/HES. Check mark indicates if it is a new product compared to the current GOES operational suite.

Product Type	T/O	Horizontal Res.	Vertical Res.	Time Freq.
Atmospheric Vertical H^{2}0 & Temp Profiles (Full Disk)	T	10 km	0.3 – 0.5 km (Sfc–500 mb)	60 min
	O	2 km	0.3 – 0.5 km (Sfc–500 mb)	15 min
Atmospheric Vertical H^{2}0 & Temp Profiles (CONUS)	T	10 km	0.3 – 0.5 km (Sfc–500 mb)	60 min
	O	1 km	0.3 – 0.5 km (Sfc–500 mb)	5 min
Atmospheric Vertical H^{2}0 & Temp Profiles (SW/M)	T	4 km	0.3 – 0.5 km (Sfc–500 mb)	15 min
	O	2 km	0.3 – 0.5 km (Sfc–500 mb)	15 min

Figure 2. HES atmospheric profile resolution requirements for Full Disk, CONUS, and Severe Weather/Mesoscale (SW/M) scan modes.

3. MODEL QPF IMPROVEMENTS

Precipitation is arguably the one parameter that numerical weather prediction (NWP) models typically forecast with the least amount of skill, especially quantitatively. The reason for this is due in large measure to inadequate model initial conditions and an inability to model mesoscale variability.

3.1 Initial Conditions

As with all predictive models, the quality of the forecast is ultimately determined by the quality of the data used to initialize the model. Though this is true for all types of atmospheric variables, precipitation is particularly sensitive to the initial state—especially that of the moisture field—and improvements in QPF are currently limited by a lack of highly-resolved and accurate measurements of atmospheric water vapor. HES will deliver more resolute, accurate, and timely observations of water vapor and, in turn, provide a much better representation of the initial atmospheric state. Moreover, emerging data assimilation techniques, such as four-dimensional variation analysis (4DVAR), should be able to exploit the improved observational data from HES as well. Adjoint techniques like 4DVAR attempt to mitigate potential errors in the initial observational state that may lead to forecast errors later on.

3.2 Mesoscale Variability

The greatest variance in precipitation often derives from small scale processes, as stated earlier. Therefore, it is imperative to observe atmospheric variability on smaller scales as much as possible. The improved spectral, spatial, and temporal resolution of HES will more accurately capture the mesoscale state of the atmosphere in the initial conditions, both horizontally and vertically. Due to its limited number of spectral channels (18), the current GOES sounder only yields a very coarse 3 km vertical resolution when measuring water vapor and temperature atmospheric vertical profiles. HES, on the other hand, given its thousands of spectral channels, will have significantly more and sharper weighting functions compared to current GOES sounder and, therefore, moisture and temperature retrievals will have better vertical resolution (Figure 3, Menzel et al., 2004). This marked improvement in spectral resolution will allow HES to provide up to a 0.3 km vertical resolution— or a 100-fold increase.

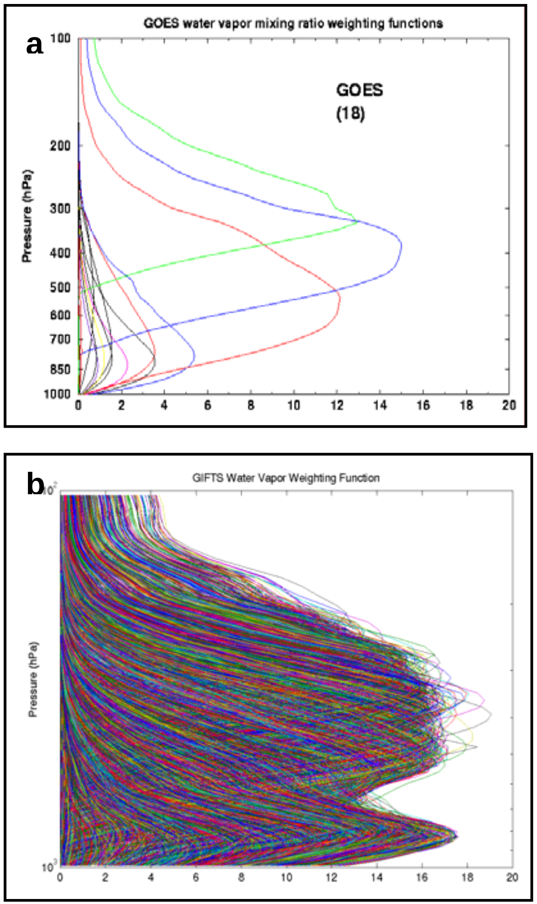
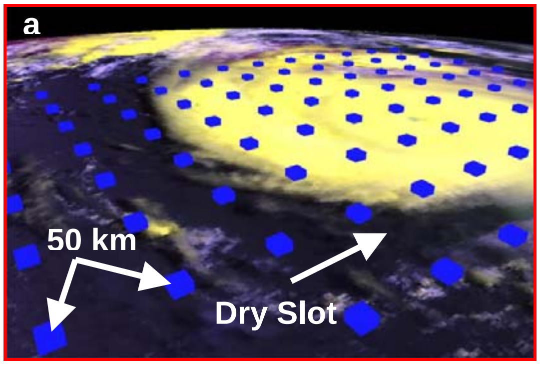
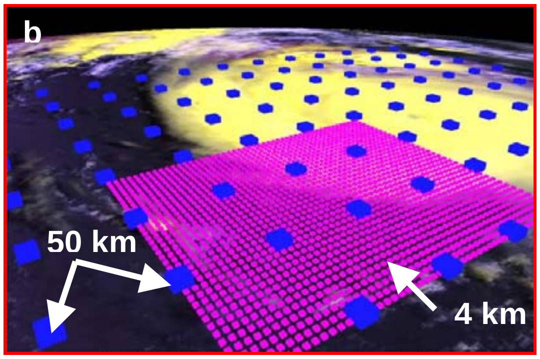


Figure 3. The number of spectral channels and resultant moisture weighting functions between the (a) current GOES sounder and (b) future HES-like sounder (from Menzel et al, 2004).

From an NWP perspective, it takes at least five distinct points to adequately model a wave—or a sampling resolution of at least one-fourth the size of the wave. The current GOES sounder can only generate atmospheric profiles at 50 km horizontal spacing and, as a result, can't fully resolve features less than 200 km in size. HES will generate atmospheric profiles at a threshold spacing of 4 km thus making it able to explicitly resolve features as small as 16 km in size. Figures 4a & 4b illustrate the threshold difference in horizontal resolution between the current GOES sounder and HES, overlaid on a false color image of Hurricane Charley for reference. Notice that HES provides more than enough sample points (>10) to fully resolve the structure of the "dry slot" intrusion into the backside of the hurricane whereas the current GOES sounder only offers a couple of sampling points at best. Figure 4c shows the difference in the vertical resolution as well. This vastly improved resolution will make it easier to detect and subsequently model the kinds of mesoscale variability affecting precipitation estimation, including that of moisture transport in the sub-cloud/boundary layer and low-level temperature and moisture inversions (i.e., atmospheric instability).





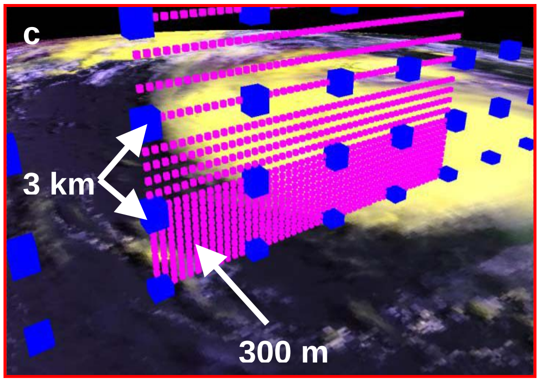


Figure 4. (a) Overlay of current GOES sounder atmospheric profile horizontal resolution (50 km blue) on a false color image of Hurricane Charley (8/13/04 1500 UTC), (b) Comparison of HES atmospheric profile horizontal resolution (4 km purple) vs. current GOES resolution, (c) Comparison of HES atmospheric profile vertical resolution (300 meter purple) vs. current GOES vertical resolution (3 km blue).

4. CONCLUDING REMARKS

The exploitation of hyperspectral data for environmental applications is relatively new. In fact, GOES-R will deploy the first ever hyperspectral sensor on an operational geo-stationary weather satellite to deliver unprecedented fidelity in measuring moisture and temperature in three and four dimensions, as described in this paper. Yet, hyperspectral data, through its vast numbers of spectral channels and improved spectral resolution will provide many benefits beyond what can even be imagined and planned for today. With potential access to the level one processed data from thousands of spectral channels, the opportunity to research and develop countless new algorithms for many additional products currently unforeseen shouldn't be discounted.

HES will provide a treasure trove of information to the satellite research community and a wide range of algorithm developers. With a greater emphasis being placed on openly and jointly working with the end-user community to provide greater access to the various levels of processed GOES-R data and products, a community development process should naturally evolve that can act as a force multiplier for the exploitation and application of the data itself and allow for quicker and timelier integration of new algorithms back into the operational product stream.

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