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# The GOES-R ABI (Advanced Baseline Imager) and the Continuation of GOES-N Class Sounder Products

The first of the next generation series of Geostationary Operational Environmental Satellite (GOES-R) is scheduled for launch-readiness in December 2014. One of the primary instruments onboard GOES-R is the Advanced Baseline Imager (ABI) that will offer more spectral bands, higher spatial resolution, and faster imaging than the current GOES Imager. Measurements from the ABI will be used for a wide range of qualitative and quantitative weather, environmental oceanographic, and climate applications.

However, the first, and likely the second, of the new series of GOES will not carry an infrared sounder dedicated to acquiring high vertical resolution atmospheric temperature and humidity profiles that are key to mesoscale and regional severe weather forecasting. The ABI will provide some continuity of the GOES-N class current sounder products in order to bridge the gap until the advent of the GOES advanced infrared sounder.

Both theoretical analysis and retrieval simulations show that data from the ABI can be combined with temperature and moisture information from forecast models to produce derived products that will be adequate substitutes for the legacy products from the current GOES Sounders. Products generated from SEVIRI (Spinning Enhanced Visible and InfraRed Imager) measurements also demonstrate the utility of those legacy products for nowcasting applications. However, due to very coarse vertical resolution and limited accuracy in the legacy sounding products, placing a hyperspectral resolution infrared (IR) sounder with high temporal resolution in the GOES-R series is an essential step toward realizing substantial improvements in mesoscale and severe weather forecasting required by the user communities.

# The GOES-R ABI (Advanced Baseline Imager) and the continuation of GOES-N class sounder products

## 1. Introduction

The Geostationary Operational Environmental Satellite (GOES) Sounders (Menzel and Purdom 1994) have provided quality hourly radiances and derived products over the continental U.S. and adjacent oceans for over a decade (Daniels et al. 2001; Hillger et al. 2003). The derived products include: clear-sky radiances; temperature and moisture profiles; Total Precipitable Water vapor (TPW) and layer PW; atmospheric stability indices such as Convective Available Potential Energy (CAPE) and Lifted Index (LI); cloud-top properties (Schreiner et al. 2001); clear-sky water vapor winds via radiance tracking (Velden et al. 1998); and total column ozone (Li et al. 2007; Li et al. 2001). These products are used for a number of numerical weather prediction (NWP) and forecasting applications (Menzel and Purdom 1994; Bayler et al. 2001; Dostalek et al. 2001; Schmit et al. 2002). The GOES-13/O/P Sounders will continue this mission of nowcasting and NWP support.

The next generation geostationary satellite series will enable many improved and new capabilities for imager-based products and provide an adequate substitute for legacy sounder-based products. The Advanced Baseline Imager (ABI) (Schmit et al. 2005) on the next generation GOES-R will improve upon the current GOES Imager with more spectral bands, faster imaging, higher spatial resolution, better navigation, and more accurate calibration. The ABI expands from five spectral bands on the current GOES Imagers to a total of 16 spectral bands in the visible, near-infrared and infrared spectral regions. There will be an increase of the coverage rate leading to full disk scans at least every 15 minutes. At the same time, the continental U.S. region will be scanned every five minutes. ABI spatial resolution will be 2 km at the sub-point for 10 infrared (IR) spectral bands, 1 km for select near-IR bands and 0.5 km for the 0.64 $\mu$m visible band (Schmit et al. 2005).

The current GOES Sounders have 18 infrared spectral bands to profile the atmosphere, while the current GOES Imagers have only four infrared spectral bands; most of which give surface and cloud information. With the advent of advanced imagers, like the ABI, 'legacy sounding type' products are possible. However, the broad-band imager spectral coverage can not match the performance of high spectral resolution advanced sounders. The imagers have spectral coverage on the order of 50 – 200 $cm^{-1}$ for single band, while advanced sounders have spectral coverage on the order of 0.5 $cm^{-1}$ for single channel. The finer resolutions enable measurements of important spectral changes that result from vertical structures and other phenomena. Never the less, with the current four IR spectral band imager, certain products like TPW, LI and skin temperature have been produced (Hayden et al. 1996, evolving from experience with the GOES VISSR (Visible and Infrared Spin-Scan Radiometer) and VAS (VISSR Atmospheric Sounder) data (Smith et al, 1985).

Without a high spectral resolution sounder on GOES-R/S, there is a need to continue legacy sounder products that are used by the National Weather Service (NWS) and others. Adequate substitute products can be generated from ABI data, in conjunction with the information from the short-term numerical model forecasts. The needed 'continuity' products (TPW, LI, skin temperature, clouds, and winds) from today's low-spectral resolution sounder can be adequately derived from ABI measurements.

The ABI has improved temporal (Figure 1) and spatial (Figure 2) attributes compared to those of the GOES-N class sounder. Both the ABI and the current GOES Sounder offer multi-spectral measurements (Figure 3). The corresponding weighting functions for the ABI and current sounder are shown in Figure 4; the current sounder has more $CO_2$ and shortwave bands that enable superior profile retrieval accuracies compared to those of the ABI. The ABI, along with forecast information will be comparable to the GOES-N class sounder, yet will still be substantially less capable than a high-spectral resolution sounder with respect to information content and retrieval accuracy. Current GOES sounder information clear-sky radiances in bands 1-15 (14.7 to 4.4 µm) are assimilated in the NWP models and will be replaced by ABI bands 7-16 (3.9 to 13.3 µm) which includes only one $CO_2$ sounding band. Information from the Cross-track Infrared Sounder (CrIS) and other polar-orbiting high-spectral polar-orbiting IR sounders in conjunction with the finer spatial resolution ABI data will provide a useful substitute for current sounder information for radiance uses within NWP. Regarding information content, both the ABI and current sounder have three broad “water vapor” ($H_2O$ absorption) bands and longwave window bands. However, a Hyper-spectral Environmental Sounder (HES)-type sounder (Wang et al. 2007) with faster scanning and high spectral resolution remains essential for regional Numerical Weather Prediction (NWP), surface emissivity, better nowcasting products, moisture profiles, moisture flux, better cloud heights, and many additional environmental applications.

Section 2 studies the legacy operational products and their accuracies achievable with ABI data. Section 3 introduces some experimental products that ABI will be able to offer. Section 4 discusses the benefits of using high spatial and temporal resolutions. A product demonstration using the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) measurements from the European Meteosat Second Generation (MSG) is given in Section 5. Conclusions are presented in Section 6.

## 2. Operational products

Moisture information (three layers of PW) and cloud heights from the current GOES Sounders have provided positive impact on NWP, while nowcasting at the forecast offices has benefited most from atmospheric stability trends. There are many papers documenting various applications and NWP impact of hourly GOES sounding data (for examples of applications see Menzel et al. (1998) and for a comparison of GEO/LEO/ radiosonde NWP impact see Zapotocny et al. (2002)).

The ABI will be required to continue the current GOES-N class operational services. The ABI has many of the necessary spectral bands and improves upon the spatial coverage rate of the current sounders. The required ‘continuity’ sounder products (radiances, TPW, LI, skin temperature, clouds, and moisture winds) can be provided by the ABI (Table 1). Some of these products, such as TPW are being produced from the Moderate Resolution Imaging Spectroradiometer (MODIS) data (Seemann et al. 2003). In view of this it is thought that the GOES-N class sounders (Schmit et al. 2006) do not offer enough extra capability to warrant inclusion in the GOES-R series. As the coverage rate of the ABI is more than 20 times faster than the current GOES Sounder, the ABI offers much greater spatial coverage and much reduced time latency between the satellite observation and delivery of derived product. The spatial resolution represented by the footprint size is more than 20 times finer (from approximately 10 km to 2 km with both directions) than that from the current sounders, although, some products may need spatial and/or temporal averaging to improve the signal to noise ratio.

*a. Theoretical analysis*

To compare the profile information between ABI and the current GOES Sounder, an error analysis method is used to demonstrate theoretically possible profile information achievable from ABI versus the GOES-N class sounder. While the retrieval of temperature and moisture profiles from IR radiances is an ill-posed problem, it can be resolved by the addition of background data from short-term forecasts. Variational retrievals provide an optimal method of combining observations with a background in the from a short-term forecast NWP model, accounting for the assumed error characteristics of both. The variational retrieval is performed by adjusting the atmospheric profile state, **X**, from the background, $\mathbf{X^b}$, to minimize a cost function (Rodgers 1990) of

$$J(X) = [Y^m - F(X)]^T E^{-1} [Y^m - F(X)] + [X - X^b]^T B^{-1} [X - X^b]. \qquad (1)$$

Where **B** and **E** are the error covariance matrices of background, $\mathbf{X}^b$, and the observation (radiances) vector, $\mathbf{Y}^m$, respectively, **F**(**X**) is the forward radiative transfer model operator and superscripts T and -1 are the matrix transpose and inverse, respectively.

By using the Newtonian iteration (solving equation $J'(X) = 0$)

$$X_{n+1} = X_n - [J''(X_n)]^{-1} \cdot J'(X_n), \qquad (2)$$

the following Quasi-Nonlinear iterative form is obtained

$$\delta X_{n+1} = (F_n'^T \cdot E^{-1} \cdot F_n' + B^{-1})^{-1} \cdot F_n'^T \cdot E^{-1} \cdot (\delta Y_n + F_n' \cdot \delta X_n), \qquad (3)$$

where $\delta X_n = X_n - X^b, \delta Y_n = Y^m - F(X_n)$, $F'$ is the tangent linear operative (Jacobian) of forward model **F**.

A fast radiative transfer model called Pressure layer Fast Algorithm for Atmospheric Transmittances (PFAAST) (Hannon et al. 1996) was used in this study for ABI and the GOES-N class sounder; this model has 101 pressure level vertical coordinates from 0.05 to 1100 hPa. The fast transmittance model uses line-by-line radiative transfer model (LBLRTM) calculations and the high-resolution transmission molecular absorption spectroscopic database HITRAN 2000. The calculations take into account the satellite zenith angle, absorption by well-mixed gases (including nitrogen, oxygen, and carbon dioxide), water vapor (including the water vapor continuum), and ozone. The ABI spectral response function (SRF) is assumed to be a combination of a “Gaussian” and “boxcar” functions; this means the wings fall off via a Gaussian distribution, but the top of the SRF is spectrally flat, similar to ideal ‘boxcar’ functions.

An estimate of the uncertainty on the retrieved profile can be derived by assuming that the errors are normally distributed about the solution and that the problem is only moderately non-linear. In such a case, the theoretically possible error covariance matrix of the analysis, **A**, is given by

$$A = (F_f'^T \cdot E^{-1} \cdot F_f' + B^{-1})^{-1} \qquad (4)$$

Where $F_f'$ is the evaluation at the solution (or final iteration), it is calculated analytically (Li 1994). Although **A** depends on the reference profile, it has been evaluated for ABI, GOES-N class Sounder and HES (final formulation) in a US standard atmosphere in Figure 5, only square root of diagonal values are shown. For the simulations, the HES specified PORD (product operation requirement document) noise values were used for HES. The coverage and spectral resolution (SR) used were 675 - 1200 $cm^{-1}$ with 0.625 $cm^{-1}$ SR, 1689 – 2150 $cm^{-1}$ with 1.250 $cm^{-1}$ SR, and 2150 - 2400 $cm^{-1}$ with 2.50 $cm^{-1}$ SR.

The background error covariance matrix is derived from a matchup data set containing spatially and temporally collocated radiosondes, GOES-12 Sounder radiances and forecast information over the Continental United States (CONUS). The radisosondes used in the analysis are independent of the training datasets. The left panel of Figure 5 shows that ABI barely provides additional temperature information to the forecast, and the current GOES Sounder provides slightly more temperature information over the forecast. High-spectral resolution data, on the other hand, provides significant temperature improvement over the forecast. The right panel of Figure 5 shows that for water vapor error covariance matrix, the analysis error of ABI is similar to that of the current GOES Sounder because both have three similar water vapor spectral bands; both instruments improve the forecast information that shows a large water vapor background error. Again, the high-spectral resolution data provides water vapor information of higher quality than either current GOES Sounder or ABI due to its high spectral resolution.

*b. Retrieval simulation*

However, matrix **A** presents a theoretical analysis for specific profiles to show the possible error achievable for a given sensor. **A** does not represent the retrieval error since the nonlinear and inverse errors are not included in **A** (Huang et al. 1992). In order to further demonstrate the retrieval performance with ABI, current GOES Sounder and HES, a retrieval simulation is carried out. The simulation used the matchup data set mentioned above. The GOES-12 Sounder radiance measurements, the "ABI radiances" selected from the GOES-12 Sounder radiance measurements, and high-spectral radiances simulated from radiosondes through radiative transfer calculations are used in the inverse for temperature and moisture profile retrieval. The instrument noise is randomly added to the HES simulated radiances. The radiosonde profiles are used as truth in the generation of all the statistics. The retrieval method is based on the statistical technique followed by a physical iteration approach (see Eq.(2) for physical iteration) (Li and Huang 1999; Li et al. 2000). The first guess from the statistical technique is based on a near global training dataset containing realistic surface emissivity and skin temperature assignment.

Figure 6 shows the 1 km vertical layer temperature retrieval root mean square error (RMSe) (left panel) and 2 km vertical layer relative humidity (RH) RMSe (right panel), the RMSe is based on the absolute differences between retrieval and truth, and the statistics are based on the approximately 300 independent retrievals. Simulation shows that there is slight temperature improvement of GOES-12 Sounder over forecast (approximately 0.1 ~ 0.2 K in troposphere). As expected, the ABI-like data has even less temperature information than the GOES-12 Sounder. For the RH retrieval, GOES-12 Sounder and ABI-like have the similar retrieval performance, both improve the forecast. Again, HES provides the best temperature and water vapor retrievals with much better accuracies than either the forecast, ABI-like or the current GOES Sounder retrievals. The retrieval simulation is consistent with the analysis discussed in section 2a.

The accuracy of several products would be slightly degraded when produced from the ABI as compared to the current GOES Sounder. Simulations (with using background information) imply that TPW and LI (see Figure 7) are estimated to have slight degradation between the ABI and GOES Sounder. TPW accuracy values show the ABI plus forecast and the Sounder plus forecast improve over that from the forecast alone (Figure 7). Simulations show that these have approximately double the error of those from a high-spectral resolution sounder. Spatial (and possible temporal) averaging of ABI data can help to improve profile accuracy, but the profiles are still degraded compared to those from the current Sounder. Both the ABI and the current GOES Sounder profiles are significantly inferior to those from a high-spectral resolution sounder. Similar results are found in the simulation of atmospheric stability (e.g., the Lifted Index). In the LI calculations, approximately 300 independent profiles were retrieved with Lifted Index <0 (unstable atmosphere).

Derived product images (Hayden et al. 1996) show that cloud height estimates from the current imager and current sounder are comparable (Fig. 1). Theory indictates that additional $CO_2$ sensitive bands should improve the height estimate, especially for optically thin/high clouds. The similarity of imager and sounder cloud-top height information for a limited number of co-locations compared to an aircraft lidar was documented by Bedka et al 2007. Information on the validation of GOES Sounder clouds to ground-based lidar data can also be found in Hawkinson et al (2005).

The skin temperature accuracy will be improved by the ABI over the current GOES Sounder; the ABI has an additional infrared window band (10.35 µm or 966.2 $cm^{-1}$). GOES Sounder moisture winds should also be improved by ABI due to the improved spatial resolution and improved image quality. In addition, the ABI will allow more flexibility of the time between images than the fixed hourly images from the current sounder.

## 3. Experimental products

Table 2 lists select current experimental products from the GOES Sounders. Some may become operational products well before the advent of the GOES-R series. Again, the ABI has improved temporal and spatial attributes, while the accuracy will be slightly degraded for some products (Total Column Ozone (TCO) (Jin et al. 2007), products that use the temperature and moisture profiles as inputs). Some products will be produced with a finer accuracy using ABI data (e.g., upper-level detection of $SO_2$ (Schreiner et al. 2003; Schmit et al. 2005) where the ABI has two bands that are sensitive to the detection of upper-level $SO_2$) and moisture winds.

## 4. Spatial and temporal benefits with ABI

The high spatial and temporal resolutions for ABI can benefit the legacy products. For example, the radiance noise can be reduced by an averaging process with a 5 by 5 field-of-view area. In such a case, products with 10 km spatial resolution can be achieved with better accuracy than single Field-Of-View (FOV) retrievals with 2 km spatial resolution. The radiance noise can also be reduced through temporal averaging. In order to quantify the beneficial impact realized from the improved spatial resolution on retrievals, approximately 600 independent near global (e.g., no polar data) retrievals were derived for various ABI product resolutions. Averaging of 2 x 2, 3 x 3, 4 x 4, and 5 x 5 FOV were investigated. Figure 8 shows the temperature (left panel) and RH (right panel) retrieval RMSe for different ABI spatial averages. Retrievals from GOES-N class Sounder and HES final formation are also included for comparisons. Note that the retrievals are based on the sensor information alone; no forecast information is included in the retrievals.

ABI Single FOV (SFOV) provides very limited temperature information; averaging the radiances slightly improves the temperature profile information; especially between 400 and 700 hPa. However, even 5 x 5 ABI radiance averages are worse than the current GOES Sounder SFOV since there is only one $CO_2$ absorption band on the ABI, although water vapor bands to provide some temperature information. For relative humidity, the 2 by 2 retrieval provide a significant improvement over the SFOV. The 5 x 5 and 4 x 4 are comparable; they both provide better moisture information than SFOV and 2 x 2. It is interesting to note that 5 x 5 retrievals ABI are slightly worse than the current GOES Sounder SFOV for moisture even though both the ABI and the current GOES Sounder have three water vapor absorption spectral bands. This is due to the fact that the water vapor retrievals also relies on temperature information since water vapor bands contain both atmospheric emission and absorption. The ABI has fewer $CO_2$ bands than the sounder. This results in worse moisture retrievals where ABI and Sounder are used alone. With forecast information included, ABI and the current GOES Sounder provide comparable moisture retrievals. The spatial averaging can improve the retrieval, as can temporal averaging.

## 5. Demonstration with SEVIRI and AERI

The Spinning Enhanced Visible and Infra-Red Imager (SEVIRI) onboard the first METEOSAT Second Generation Satellite (MSG-1), now called MET-8, provides temperature and water vapor information similar to ABI but with slightly lower spatial resolution (re-sampled to nominally 3 km). In spite of several differences, the SEVIRI has a similar band configuration to that specified for the ABI, see Table 3 for SEVIRI specification (Aminou et al. 2003); it has been used as a proxy to demonstrate ABI legacy estimates. However, ABI and SEVIRI differ in some important ways. ABI has two more IR bands than SEVIRI. ABI is designed for a 5 minute full-disk scan at a spatial resolution of 2 km while SEVIRI makes a full-disk scan in 15 minutes with 5 km sized samples regridded onto a perfect 3 km resolution projection. The spectral responses of the individual bands and the noise equivalent radiances (NEDR) are different and can lead to different retrieval performance. These differences were studied in numerical simulations, for example, in total column ozone study (Jin et al. 2007).

We have used SEVIRI measurements and ECMWF (European Center for Medium range Weather Forecasting) forecasts to demonstrate the legacy products. Figure 9 shows the TPW (left panel) and LI (right panel) retrievals from SEVIRI at 12 UTC on 14 February 2006, ECMWF 6 hour forecast are used as the first guess. The unstable atmosphere is clearly depicted by SEVIRI over central Africa, with a convective storm forming in this region a few hours later. Comparison between the analysis (at RAOB locations) and retrievals (Figure 10) from one month data (August 2006) shows that a combination of SEVIRI and the forecast provides reasonable nowcasting products such as precipitable water and atmospheric stability parameters such as the lifted index.

The Atmospheric Emitted Radiance Interferometer (AERI) (Knuteson et al. 2004b, 2004c) is an uplooking high spectral resolution (finer than 1 $\mu$m) infrared instrument that monitors planetary boundary layer thermodynamic structure at approximately 10 minute temporal resolution (Feltz et al. 2003). Uplooking AERI retrieved water vapor profiles from the 3 May 1999 Oklahoma/Kansas tornado outbreak (Feltz and Mecikalski 2002) are shown in top panel of figure Figure 11. Representative planetary boundary layer vertical resolution functions were both applied to the top panel water vapor field for both space-borne hyperspectral resolution GIFTS (Geosynchronous Imaging Fourier Transform Spectrometer) (Smith et al 2002) and current GOES sounders. The simulated water vapor fields were then differenced from the top panel to produce the center and bottom cross sections within figure 11. These two panels indicate the benefit of high-spectral IR data over the broad-band data for capturing the spatial and temporal variation in the PBL water vapor field important for NWP precipitation forecast improvement and short term atmospheric stability applications.

## 6. Summary

Both theoretical analyses and retrieval simulations show that data from the ABI can be combined with temperature and moisture information from a forecast model to produce sounding products that adequately substitute for those from the Sounders on current GOES satellites. Both the current GOES Sounder and ABI can provide additional useful moisture information over that from forecasts alone. The ABI adequately provides continuity of the current GOES Sounder operational products, however it does not meet advanced sounding requirements (Figs. 5 and 6) posted for future numerical weather prediction (hourly hemispheric radiances enabling profile retrievals with higher vertical resolution for both temperature and moisture). High spectral resolution observations are needed for these and many other applications. The ABI does not meet documented advanced sounding requirements needed for future severe weather applications. Without high-spectral resolution infrared geostationary sounding capabilities, forecasters and regional models will not have sufficient information regarding the fine scale 3-D structure of atmospheric water vapor and capping inversions. Numerical model simulation experiments have shown the benefit of high temporal with high vertical resolution data for regional models (Aune et al, 2000). A high spectral sounder (and hence vertical) resolution with faster scanning is essential to monitor important low-level information. The potential uses (atmospheric profiling, surface characterization, cloud information, total ozone, atmospheric motion vector winds, etc) of high-spectral resolution infrared data have been documented (Smith et al. 1990, Hayden and Schmit 1991, Leslie et al. 2002, Smith et al. 2002, Knuteson et al. 2004a, Schmidt et al. 2004, Revercomb et al. 2004, Velden et al. 2007). While the ABI provides a gap filler, the advanced sounder should be developed as soon as possible.

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**List of Tables**



**Figure captions**

Table 1. Operational Products from the current GOES Sounder and how the ABI measurements, along with ancillary data, could help produce legacy products.

| Product | Temporal/Latency | Spatial | Accuracy | Overall | Comments |
|---|---|---|---|---|---|
| | | | | | |
| **Radiances** | ABI ~ 20X faster | Comparable (when averaged) | Comparable | Adequate | Only 1 $CO_2$ band on ABI (5 bands on Sounder) |
| **TPW** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | ABI product quality helped with model info |
| **Lifted Index** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | ABI product quality helped with model info |
| **Skin Temperature** | ABI ~ 20X faster | Comparable (when averaged) | Comparable | Adequate | ABI has extra window band |
| **Profiles** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | Worse upper-level T and lower-level moisture |
| **CLOUDS** | ABI ~ 20X faster | ABI Finer | Sounder more precise | Adequate | More $CO_2$ bands gives a better height |
| **Moisture winds** | ABI ~ 20X faster | ABI Finer | Comparable | Adequate | - |

Table 2. Experimental Products from the current GOES Sounder and how the ABI measurements, along with ancillary data, could help produce legacy products.

| **Product** | **Temporal/Latency** | **Spatial** | **Accuracy** | **Overall** | **Comments** |
|---|---|---|---|---|---|
| | | | | | |
| **Total Column Ozone** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | Sounder better due to several $CO_2$ bands |
| **Microburst potential** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | Need profiles |
| **Other stability products** | ABI ~ 20X faster | Comparable (when averaged) | Sounder more precise | Adequate | Need profiles |
| **Upper-level SO2** | ABI ~ 20X faster | Comparable (when averaged) | ABI more precise | Adequate | ABI has additional band |
| **Cloud Climatology** | ABI ~ 20X faster | ABI Finer | Sounder more precise | Adequate | More $CO_2$ bands gives a better height |
| | | | | | |

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Table 3. Band number, central wavelength (µm), and NEDR in mW $m^{-2}$ $sr^{-1}$ $cm^{-1}$) of ABI, SEVIRI, and the GOES-12 Sounder. The ABI NEDR are specification values.

| GOES-12 | | | ABI | | | SEVIRI | | |
|---|---|---|---|---|---|---|---|---|
| **Band** | **NEDR** | **Wavelength** | **Band** | **NEDR** | **Wavelength** | **Band** | **NEDR*** | **Wavelength** |
| 18 | 0.0009 | 3.75 | | | | | | |
| 17 | 0.0022 | 3.98 | 1 | | 0.47 | | | |
| 16 | 0.0024 | 4.12 | 2 | | 0.64 | 1 | | 0.635 |
| 15 | 0.0066 | 4.45 | 3 | | 0.87 | 2 | | 0.81 |
| 14 | 0.0062 | 4.53 | 4 | | 1.38 | | | |
| 13 | 0.0062 | 4.57 | 5 | | 1.61 | 3 | | 1.64 |
| 12 | 0.11 | 6.5 | 6 | | 2.25 | | | |
| 11 | 0.059 | 7.01 | 7 | 0.0038 | 3.9 | 4 | 0.0046 | 3.92 |
| 10 | 0.099 | 7.44 | 8 | 0.058 | 6.19 | 5 | 0.0098 | 6.2 |
| 9 | 0.14 | 9.72 | 9 | 0.0827 | 6.95 | | | |
| 8 | 0.11 | 10.96 | 10 | 0.0958 | 7.34 | 6 | 0.0226 | 7.35 |
| 7 | 0.11 | 11.99 | 11 | 0.1304 | 8.5 | 7 | 0.0948 | 8.7 |
| 6 | 0.14 | 12.66 | 12 | 0.1539 | 9.61 | 8 | 0.0975 | 9.66 |
| 5 | 0.34 | 13.34 | 13 | 0.1645 | 10.35 | | | |
| 4 | 0.39 | 13.63 | 14 | 0.1718 | 11.2 | 9 | 0.1247 | 10.8 |
| 3 | 0.45 | 14.03 | 15 | 0.1754 | 12.3 | 10 | 0.1923 | 12 |
| 2 | 0.61 | 14.38 | 16 | 0.5237 | 13.3 | 11 | 0.4178 | 13.4 |
| 1 | 0.77 | 14.66 | | | | | | |

* These values are calculated from in-flight measurements of noise equivalent difference of temperature (NEDT) (Aminou et al. 2003).

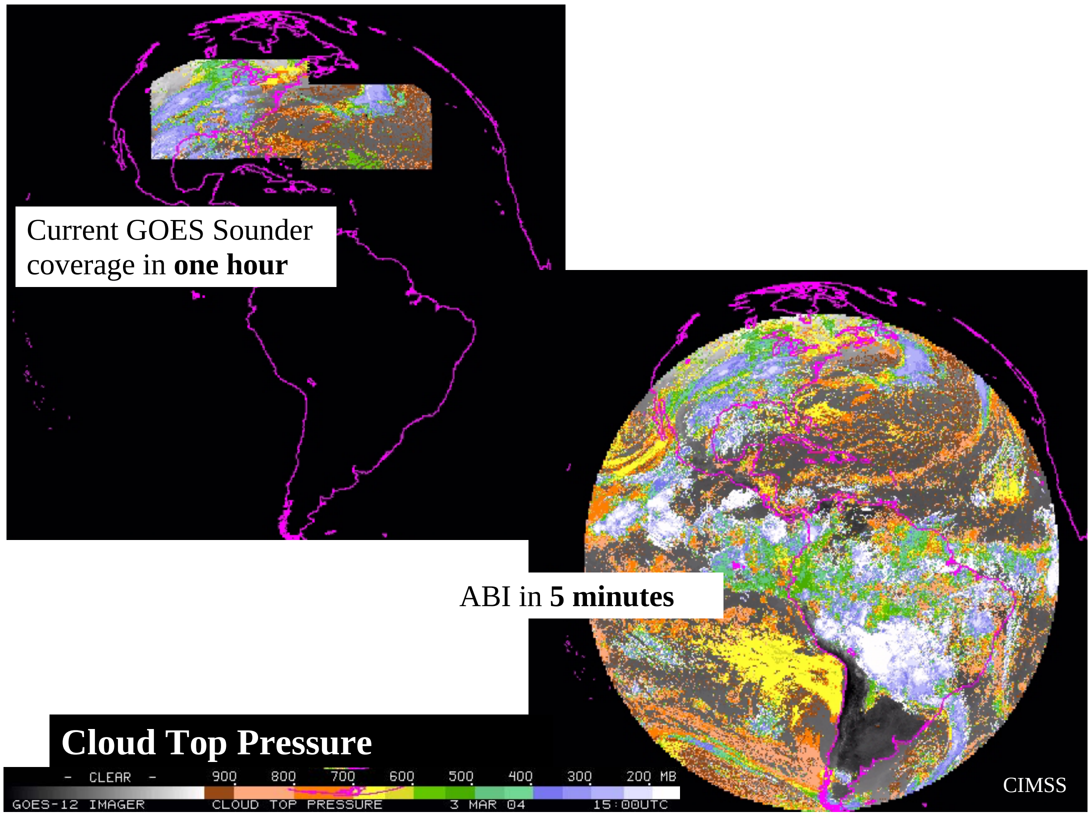


Figure 1. Cloud-top pressure (CTP) from GOES-12 Sounder and GOES-12 Imager. Much improved coverage (and hence total product latency) with ABI over the current GOES Sounder. The nearly full disk image is derived from GOES-12 Imager data.

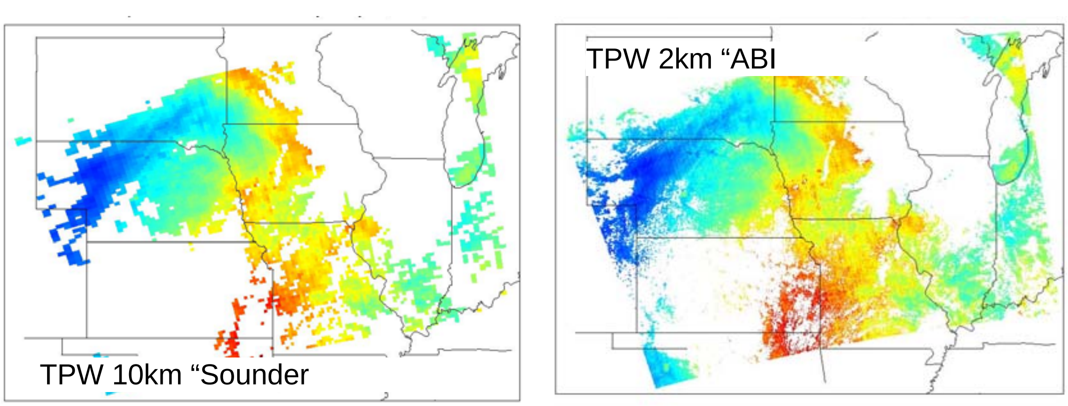


Figure 2. Simulated TPW retrievals with 10 km spatial resolution (left panel) and 2 km spatial resolution (right panel).  1 km spatial resolution MODIS data are used in the simulation. This shows improved spatial resolution with ABI over the current Sounder.

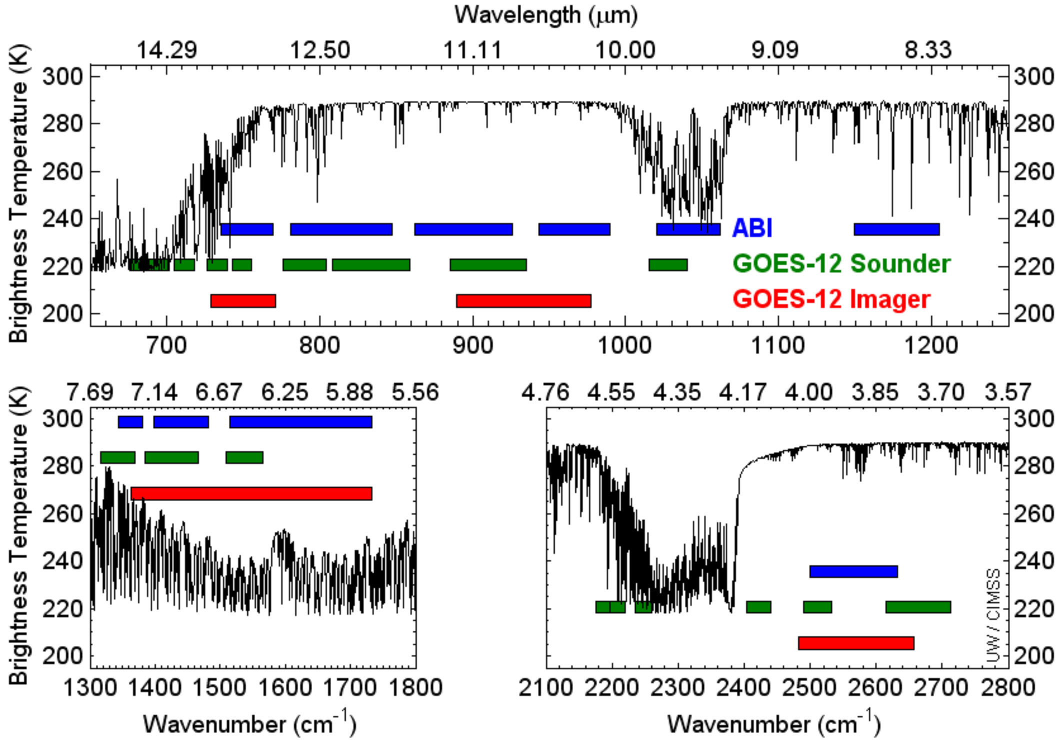


Figure 3. ABI (blue) and current GOES sounder (green) spectral coverage over a high spectral resolution brightness temperature spectrum.

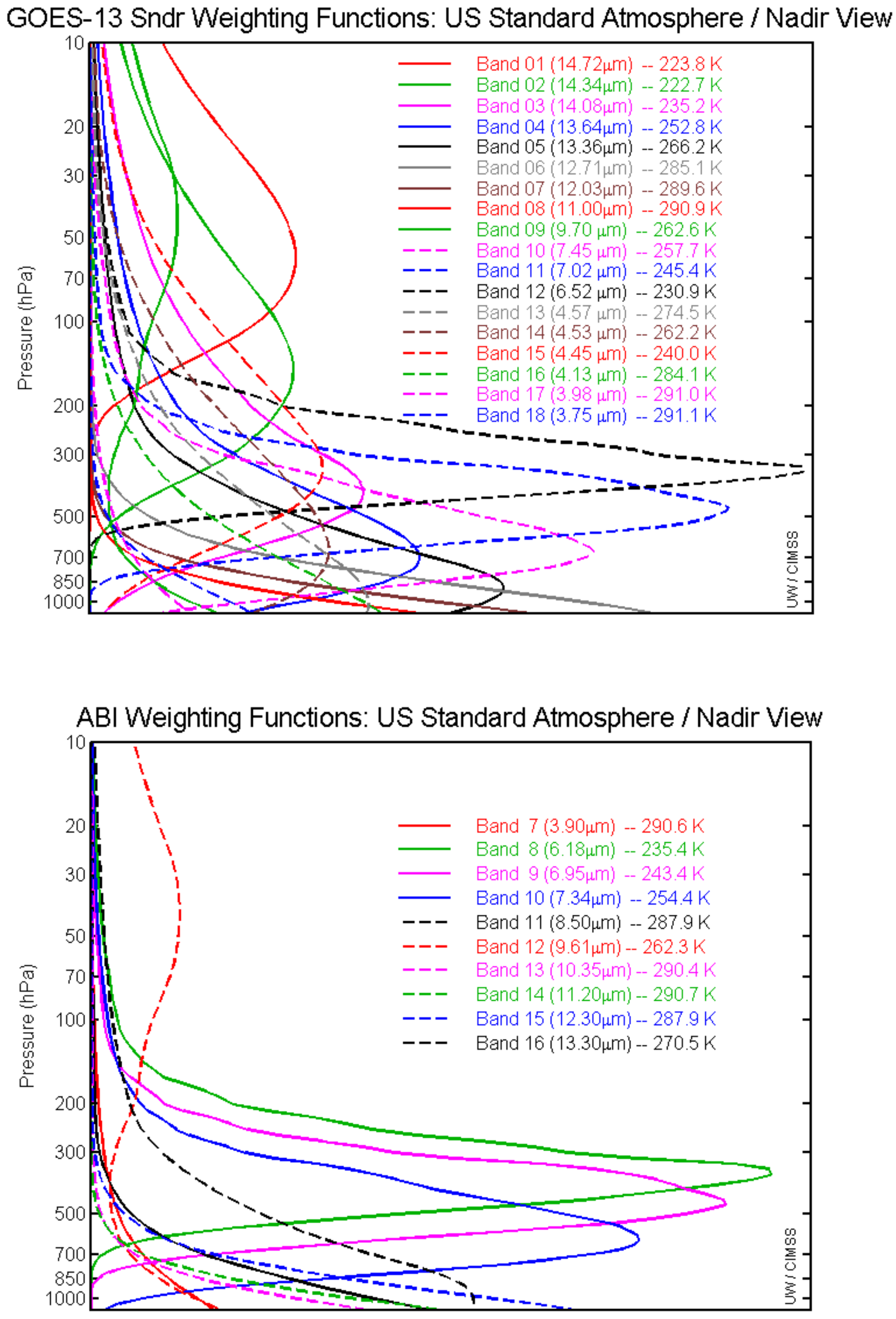


Figure 4. Weighting functions of the GOES-N Sounder (upper panel) and ABI (lower panel). The GOES-N sounder has 5 $CO_2$ bands, while the ABI only has one. The sounder also has more shortwave bands.

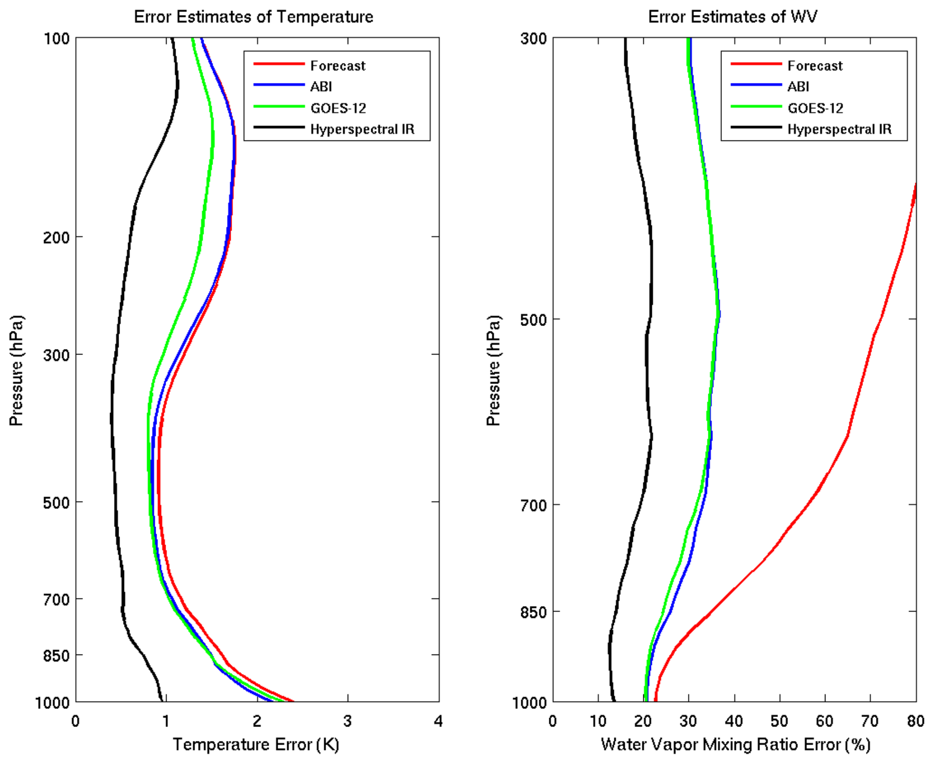


Figure 5. Temperature (left panel) and water vapor mixing ratio (right panel) background error convariance matrix from forecast model, **B**, and analysis error covariances matrix, **A**, with ABI, GOES-12 Sounder and HES final formulation.

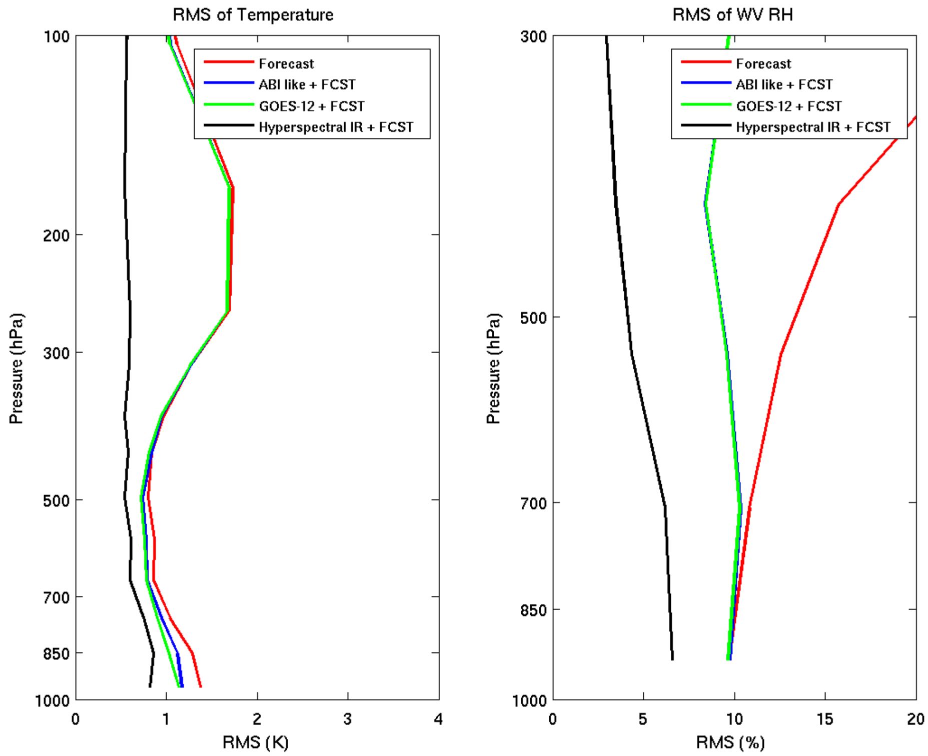


Figure 6. The 1 km vertical layer temperature (left panel) and 2 km vertical layer relative humidity (right panel) retrieval RMSe with ABI like, GOES-12 Sounder and HES. The forecast information is included in the retrieval.

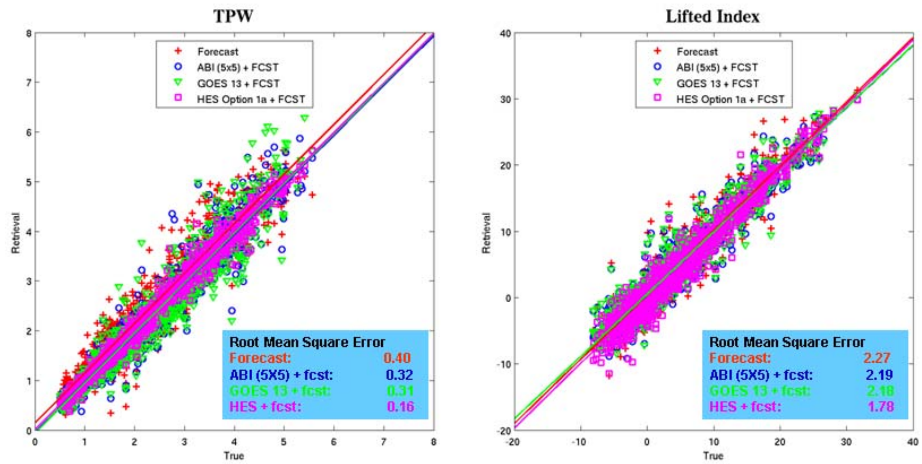


Figure 7. Simulations of GOES-N TPW (left panel) and LI (right panel) performance -- only cases with Lifted Index of less than zero are included.

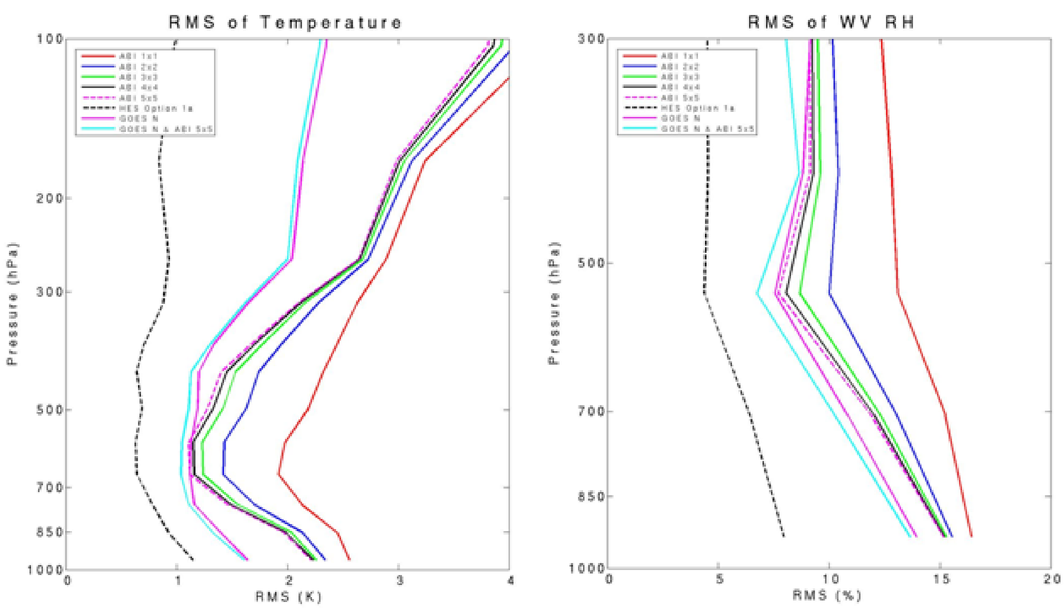


Figure 8. Simulations of GOES temperature (left panel) and RH (right panel) retrieval performance. Near global radiosonde observations (RAOBs) of 600 independent sounding retrievals. The retrieval algorithm is based on regression (first guess) followed by physical (final). “GOES-N” denotes the current Sounder.

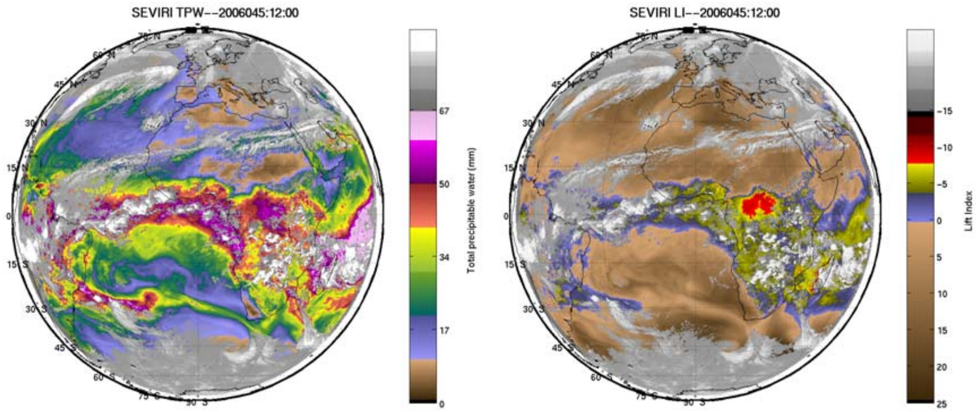


Figure 9. TPW (left panel) and LI (right panel) retrievals derived from SEVIRI at 12 UTC on 14 February 2006, the ECMWF 6 hour forecast are used as the first guess.

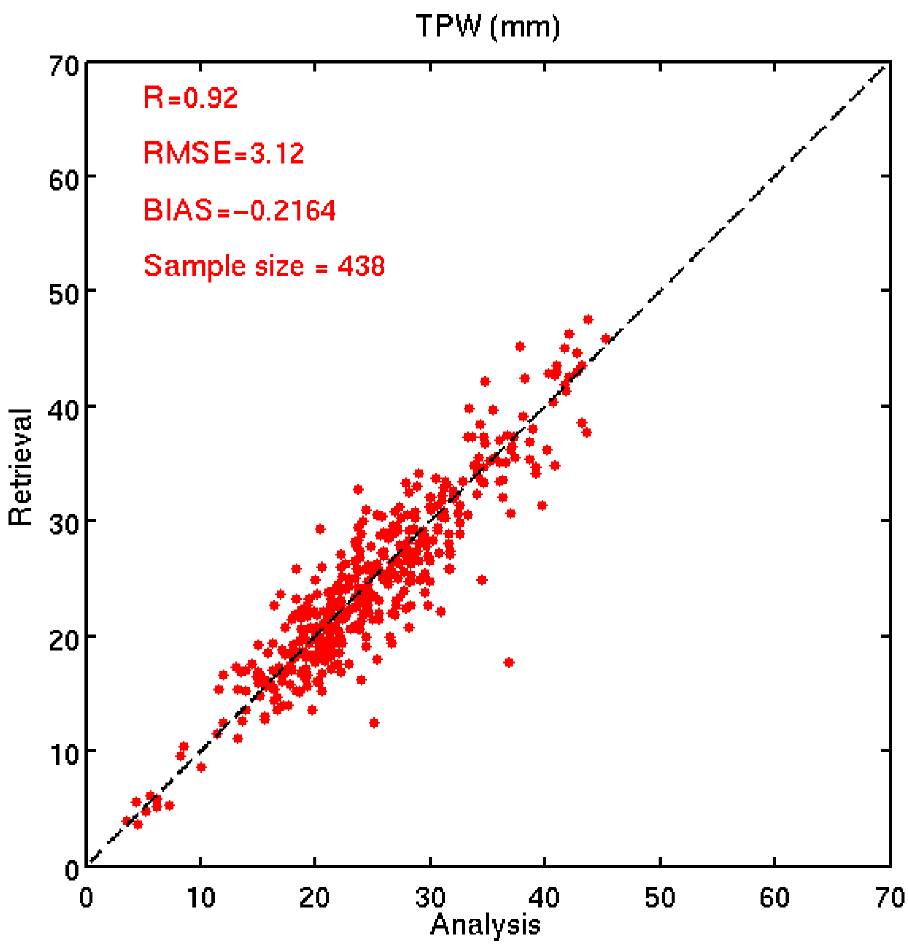


Figure 10. TPW scatterplot between the ECMWF Analysis (at RAOB locations) and SEVIRI for the the month of August 2006.

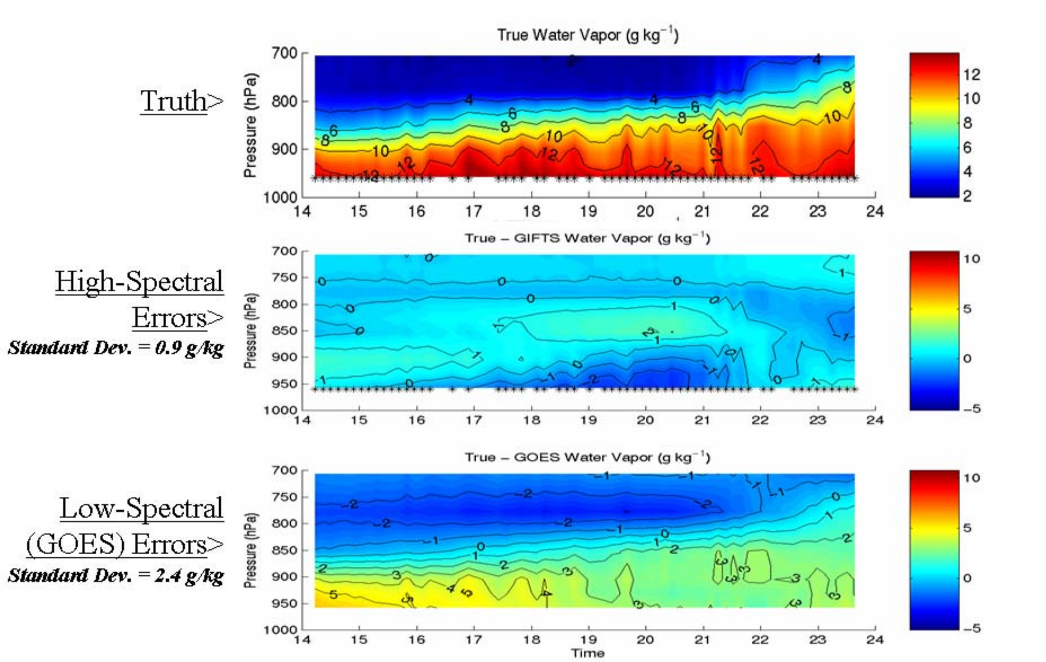


Figure 11. A time-height cross section of retrieved water vapor (g/kg) from an uplooking AERI on 3 May 1999 Oklahoma tornado outbreak (top panel). The center panel indicates the difference between the AERI  water vapor field (top) and simulated spaceborne hyperspectal water vapor field using representative vertical resolution functions.  The lower panel shows a similar set of differences except that GOES vertical resolution function was used. Note that the retrievals from the high-spectral measurements more correctly capture the important vertical moisture variations, not only are the errors reduced, but it captures low-level moisture peaks and vertical gradients.