Integration and Ocean-Based Prelaunch Validation of GOES-R Advanced Baseline Imager Legacy Atmospheric Products

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ABSTRACT

An ocean-based prelaunch evaluation of the Geostationary Operational Environmental Satellite (GOES)-R series Advanced Baseline Imager (ABI) legacy atmospheric profile (LAP) products is conducted using proxy data based upon the Spinning Enhanced Visible and Infrared Imager (SEVIRI) on board the Meteosat Second Generation satellite. SEVIRI-based LAP temperature and moisture profile retrievals are validated against in situ correlative data obtained over the open ocean from multiple years of the National Oceanic and Atmospheric Administration (NOAA) Aerosols and Ocean Science Expeditions (AEROSE). The NOAA AEROSE data include dedicated radiosonde observations (RAOBs) launched from the NOAA ship Ronald H. Brown over the tropical Atlantic: a region optimally situated within the full-disk scanning range of SEVIRI and one of great meteorological importance as the main development area of Atlantic hurricanes. The most recent versions of the GOES-R Algorithm Working Group team algorithms (e.g., cloud mask, aerosol detection products, and LAP) implemented within the algorithms integration team framework (the NOAA operational system that will host these operational product algorithms) are used in the analyses. Forecasts from the National Centers for Environmental Prediction Global Forecasting System (NCEP GFS) are used for the LAP regression and direct comparisons. The GOES-R LAP retrievals are found to agree reasonably with the AEROSE RAOB observations, and overall retrievals improve both temperature and moisture against computer model NCEP GFS outputs. The validation results are then interpreted within the context of a difficult meteorological regime (e.g., Saharan air layers and dust) coupled with the difficulty of using a narrowband imager for the purpose of atmospheric sounding.

1. Introduction

Satellite-measured infrared (IR) spectral radiances and their derived products have been useful for improving numerical weather prediction (NWP) through data assimilation methods (McNally et al. 2006; Le Marshall et al. 2006). For example, high-spatial- and -temporal-resolution-derived products from the Geostationary Operational Environmental Satellite (GOES) sounders and imagers provide crucial data needed for identifying and predicting weather system development in its early stages, thereby facilitating advanced warning (Menzel et al. 1998; Schmit et al. 2002; Li et al. 2008; Li et al. 2012). Improving on the current imager, the next generation of GOES, the GOES-R series (GOES-R), that features the Advanced Baseline Imager (ABI) and a multichannel visible (VIS) and IR narrowband imaging radiometer will have much higher spatial resolution (2 km for IR) and much faster coverage rate [5 min if only scanning the full disk (FD); Schmitt et al. 2005].

In preparation for the GOES-R series, the National Oceanic and Atmospheric Administration (NOAA)
GOES-R Program Office (GPO) assigned the responsibility of managing the development, selection, and calibration/validation (cal/val) of product algorithms to the Center for Satellite Applications and Research (STAR), the research arm of the National Environmental Satellite, Data, and Information Service (NESDIS). STAR responded with the creation of the GOES-R Algorithm Working Group (AWG), which has provided oversight of the schedules, activities, and budget expenditures needed for an integrated program of algorithm development and cal/val that span the entire life cycle of the GOES-R program. The AWG consists of application teams, development teams, the algorithm integration team (AIT), the proxy data team, and the cal/val team.

To risk manage the loss of the hyperspectral sonde that was originally planned for GOES-R (Schmit et al. 2008), the AWG soundings application team (SAT) adapted the current GOES sonde operational retrieval algorithm for the GOES-R ABI to ensure continued availability of geostationary legacy atmospheric profile (LAP) products (Jin et al. 2008). The LAP algorithm retrieves 101-level atmospheric temperature and moisture profiles and surface skin temperature. Derived LAP products also include column-integrated products such as stability indices (viz., lifted index, convective available potential energy index, and Showalter index) and total column precipitable water vapor (TPW) under clear-sky or probably-clear-sky conditions as determined by the ABI cloud mask (ACM) (Heidinger 2011).

Several prelaunch validation efforts have been made to evaluate the GOES-R LAP retrieval algorithm using proxy data over land (Jin et al. 2008; Li et al. 2009; Lee et al. 2013, manuscript submitted to J. Atmos. Oceanic Technol.). In this paper, we extend the prelaunch validation of the LAP algorithm to cases over open ocean using Meteosat Second Generation (MSG) Spinning Enhanced Visible and Infrared Imager (SEVIRI) data as a proxy for the ABI, along with dedicated collocated RAOBs acquired over the tropical Atlantic Ocean during the 2007–11 NOAA Aerosols and Ocean Science Expedition (AEROSE) cal/val campaigns (Morris et al. 2006; Nalli et al. 2011). SEVIRI has spectral channels and spatiotemporal resolution similar to ABI, (e.g., FD scan within 15 min with 3-km spatial sampling), thereby making it well suited for proxy data, and the AEROSE campaigns have all taken place over the tropical Atlantic Ocean, making them ideally suited for correlative cal/val data. As has been pointed out by previous investigators (e.g., Hagan and Minnett 2003; Nalli et al. 2006; Nalli et al. 2011), ocean-based validation is advantageous given that the sea surface radiative properties (i.e., emission skin temperature and spectral emissivity) are well characterized and uniform (e.g., Smith et al. 1996; Nalli et al. 2008); ocean-based validation is also important because the oceans constitute about 70% of Earth’s surface area, being a source region for on-shore moisture flow (Rabin et al. 1992), and satellite data are known to make their biggest impact on NWP over the ocean (Nalli et al. 2011).

A brief overview of the AWG AIT and AWG AIT framework is presented in section 2, followed by a description of the LAP algorithm in section 3. The NOAA AEROSE GOES-R ABI proxy dataset is presented in section 4, and the results of the LAP algorithm validation against AEROSE dedicated RAOBs are presented in section 5. Finally, an application of the LAP retrievals to a Saharan dust outflow case in 2011 is shown in section 6.

2. Overview of the GOES-R AWG algorithm integration team framework

The GOES-R AWG AIT was formed to coordinate the algorithm development activities of all AWG teams. It is the primary interface between AWG application teams, development teams, and the Ground Segment Project (GSP). The AIT is mainly involved in developing and implementing a GOES-R product-processing-system framework that will allow the integration of product software received from each of the AWG development teams, and the AIT is responsible for preparing and submitting system deliveries to the GSP.

To make operational algorithm testing and verification more efficient, the AIT has designed, developed, and implemented the AWG product-processing-system framework, which enables the development and testing of the entire baseline and “future capability” ABI and Lightning Mapper products within a single system. The AIT framework is capable of testing the algorithms individually and as a complete system with all products.

Only C/C++ and FORTRAN 90 languages are used within the AIT framework, and all of the designed codes must meet a coding standards established at NOAA/NESDIS/STAR. A single standard data format [network Common Data Form (NetCDF4)] is required for all inputs and outputs. To facilitate algorithm integration, the AIT framework has been designed as a plug-and-play system for scientific algorithms. Each algorithm is configured and managed through a production control file where input, dependent products, output, and other pertinent information are specified. Common and interchangeable interfaces enable the algorithm to be developed and/or tested in both the framework and the scientist’s offline research system with little to no modification or addition to either system. This approach
enables both the algorithm developers (scientists) and algorithm integrators (programmers) to work on the same software since the algorithm now can be “dropped” into both systems, resulting in simple algorithm rollbacks.

To summarize, there are many advantages inherent in the AIT framework: 1) large volumes of all the radiance and ancillary data are stored in memory to decrease processing time by reducing input/output (I/O) redundancy; 2) the algorithm design does not have to conform to the AIT framework data structures; 3) products of one or more algorithms can be run as precedence for other algorithms; 4) it brings scientific consistency between all products by using the same Community Radiative Transfer Model (CRTM), same ancillary data, and the same software libraries; and finally, particularly germane to this paper, 5) the AIT framework enables the evaluation of the algorithms for scientific accuracy in a controlled environment using common libraries.

In this study, the ACM, aerosol detection products (ADP), and the LAP algorithm were run in the AIT framework. The ACM algorithm was designed at NOAA/NESDIS/STAR to provide a four-level cloud mask (clear, probably clear, probably cloudy, and cloudy) based on spectral, spatial, and temporal signatures (Heidinger 2011). The ADP algorithm was developed at NOAA/NESDIS/STAR to provide an initial estimate of the presence of smoke or dust within each ABI pixel over water and land (NOAA/NESDIS/STAR 2010). The LAP algorithm was developed by the SAT at the Cooperative Institute for Meteorological Satellite Studies at University of Wisconsin–Madison (CIMSS UW). An overview of the LAP algorithm is given in the next section.

3. Overview of the GOES-R LAP retrieval algorithm

Like most IR-based retrieval algorithms, the LAP algorithm relies upon clear-sky and probably-clear-sky observations. Within the AIT framework, these clear-sky and probably-clear-sky observations are obtained through tests of cloud and spatial heterogeneity within the ACM (Heidinger 2011). ABI spectral and spatial radiance signatures are used in the retrieval process. For complete details on the GOES-R LAP algorithm, the reader is referred to Li et al. (2010) and Jin et al. (2008); a brief overview follows below.

The ABI LAP algorithm combines a synthetic regression approach with a physical iterative retrieval approach that adjusts a first-guess profile based on brightness temperature (BT) residuals between IR-channel observations and CRTM model calculations. The first guess is used in the initial calculation. Li et al. (2010) found that a regression is usually better than a short-term forecast field since the regression uses combined forecast and ABI IR radiances as predictors, so the LAP algorithm starts with a statistical nonlinear regression technique. The regression coefficients can be obtained using the general least squares method with a global training database. The “SeeBor database” (Borbas et al. 2005) is composed of global temperature, humidity, and ozone profiles from the thermodynamic initial guess retrieval for the latest version (TIGR3), NOAA-88, and the European Centre for Medium-Range Weather Forecasts (ECMWF), supplemented by profiles from desert RAOBs and ozonesondes with the total number of training-set profiles totaling approximately 15,700. Since the forecast profile is used together with IR BTs as predictors, the regression should be no worse than the forecast (Li et al. 2010).

The LAP retrieval approach uses an optimal method of combining ABI observations along with a background term in the form of short-term forecasts from a NWP model, which accounts for the assumed error characteristics of both. The retrieval is expressed as

\[ J(X) = |Y_m - Y(X)|^2 + \gamma |X - X_0|^2, \]  

where \( X \) is the geophysical parameter to be retrieved (e.g., temperature/water vapor profiles and surface skin temperature), \( J(X) \) is the minimum-variance solution, \( X_0 \) is the first guess from nonlinear regression [regression based upon National Centers for Environmental Prediction Global Forecasting System (NCEP GFS) model output using the SeeBor training dataset], \( Y_m \) is the measured IR-channel radiance (i.e., the observation), \( Y(X) \) is the calculated IR-channel radiance using \( X \) as the input state parameter in the CRTM, and \( \gamma \) is the regularization parameter, which can be derived via the discrepancy principle (Li and Huang 1999). In the LAP physical retrieval process, the water vapor profile is expressed as a logarithm of the mixing ratio given that the logarithm varies more linearly with the IR radiances than does the base mixing ratio (Li et al. 2010), and the profile can be derived from Eq. (1) by using quasi-Newtonian nonlinear iteration (Li et al. 2000).

4. The NOAA AEROSE GOES-R ABI proxy dataset

A multiyear ocean-based proxy dataset, consisting of satellite observations and correlative ship measurements, has been created, regularly updated, and maintained at NOAA/NESDIS/STAR. Ship-based correlative
data have been collected during a series of NOAA AEROSE cruises on board the NOAA ship Ronald H. Brown to acquire simultaneous in situ and remotely sensed marine data. For more details on the AEROSE, the reader is referred to Nalli et al. (2011) for a summary of AEROSE (and details of all the campaigns through and including the 2010 cruise) and Morris et al. (2006) for a general overview of AEROSE objectives. The AEROSE campaign data used in this study were collected during May 2007, May 2008, July–August 2009, April–May 2010, and, most recently, July–August 2011. We have collected satellite data including the SEVIRI on board the first MSG satellite (Meteosat-8) from the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the second satellite of MSG (Meteosat-9). SEVIRI has the capacity to observe Earth in four visible and near infrared (VNIR) channels (0.4–1.6 μm) and eight IR channels (3.9–13.4 μm) with a baseline repeat cycle of 15 min. The VNIR channels include a high-resolution visible (HRV) channel, which contains nine broadband detection elements to scan Earth with a sampling distance at nadir of 1 km. All the other channels (including the IR channels) are designed with three narrowband detection elements per channel to scan Earth with a 3-km spatial resolution. To supplement the geosynchronous SEVIRI narrow-band imager data, low-Earth-orbit (LEO) hyperspectral sounder data from the Aqua Atmospheric Infrared Sounder (AIRS) and MetOp Infrared Atmospheric Sounding Interferometer (IASI) within each AEROSE domain have also been collected. For the GOES-R AEROSE proxy dataset, data in a wide variety of native formats have been converted to standard HDF/NetCDF along with attendant documentation for the users' convenience. The AEROSE campaign data provide a large number of high-quality in situ RAOB measurements including Vaisala RS92 rawinsondes and electrochemical concentration cell ozonesondes, all launched over the tropical Atlantic Ocean (Nalli et al. 2011), a region perfectly suited for ocean-based satellite cal/val using the Meteosat SEVIRI instrument. We have collected 678 RAOBs as of the submission of this paper, and the next AEROSE campaign is scheduled for January–February 2013.

A map of ship and satellite coverage of the AEROSE proxy dataset is shown in Fig. 1. According to the different cruise tracks (color symbols), we have selected various space domains for these series of AEROSE campaigns. Satellite data (viz., SEVIRI, AIRS, and IASI) within these entire AEROSE domains (rather than merely at the ship space–time coordinates) have been collected to construct a large GOES-R AEROSE proxy dataset. By doing so, critical tropical Atlantic meteorology, including the Saharan air layer (SAL), dust outflows, tropical convection, and so on can be observed and studied as an essential component of the GOES-R mesoscale mission.

5. Independent prelaunch validation of GOES-R LAP products over open ocean

In this section, we conduct an independent prelaunch ocean-based validation analysis of the GOES-R ABI LAP algorithm as it has been implemented within the AWG AIT framework at NOAA/NESDIS/STAR. This work is to be distinguished from earlier land-based work conducted offsite on “offline” systems. Furthermore, the AEROSE RAOBs that we employ as correlative data have not been assimilated into any NWP models (with the exception of possibly some from the 2007 campaign), so they constitute truly independent correlative data. Additionally, the AEROSE RAOBs are launched from ships remote from any continents or islands and are thus truly indicative of open ocean (as opposed to “ocean RAOBs” launched along coasts). Meteosat-9 data were selected to run in the AIT framework because the regression coefficients for Meteosat-9 were newly trained and delivered to the AIT in September 2011. For satellite matchup with RAOB, the data were first selected if the temporal distance between RAOB launching time and satellite capturing time is...
less than 15 min. Since RAOB has a very high vertical resolution, we reduced its original thousands of observations to 101 pressure levels by selecting the average of a thin layer having a pressure difference of less than 0.5 hPa to the corresponding LAP’s pressure level. The selection of spatial matchup is complicated given that the satellite pixel having the shortest spatial distance to the RAOB launching location may not be retrieved because of cloudy contamination. In this regard, we selected satellite pixels within a bounding box having latitude and longitude differences of less than 0.5° to the launching location. Among these pixels under clear-sky or probably-clear-sky conditions, we then selected the pixel having the shortest spatial distance to the RAOB as the RAOB–satellite matchup. For both regression calculation and comparison in the validation, 1° × 1° NCEP GFS forecast data were temporally and spatially interpolated to the satellite matched pixels. This resulted in 55, 36, 50, 51, and 60 matchup cases for the 2007, 2008, 2009, 2010, and 2011 domains, respectively, yielding a total of 252 dedicated RAOB matchups over the tropical Atlantic.

Root-mean-square error (RMSE) plots of the temperature (Fig. 2) show that NCEP GFS and SEVIRI physical retrieval have a relatively similar pattern, as expected given that retrieval depends on its first guess, which is from nonlinear regression based upon NCEP GFS forecasts; thus, the forecast model has constraints on LAP retrieval. It is noticed that temperature RMSE is large in the lower troposphere, and the locations of

Fig. 2. RMSE of temperature profiles using RAOB as reference. The solid line represents physical retrieval using SEVIRI, and the dotted–dashed line represents RMSE of NCEP GFS. Sample size of each year is given in the upper-right corner of each panel.
maximum RMSE change because of the different campaign observing periods of each year. For years 2008 to 2011, the retrieval (solid line) clearly shows a better agreement with RAOBs than NCEP GFS (dotted–dashed line) in general. For 2007, the forecast model has better agreement than the retrieval in some areas, possibly due to some of the 2007 data being assimilated into the NCEP GFS model. Plots in Fig. 3 show the RMSE of water vapor in the mixing ratio, where it is seen that the retrieval improves water vapor against NCEP GFS especially in the lower and midtroposphere where most of water exists in the atmosphere.

Since the NCEP GFS features prominently in the regression, the NWP model acts as a significant constraint on the retrieval. To establish the model’s capability relative to RAOBs, we compare the 2007–11 NCEP GFS forecasts at 6-h intervals within the AEROSE domains to the observations of soundings from the Integrated Global Radiosonde Archive (IGRA) at the NOAA National Climatic Data Center (NCDC). IGRA consists of quality-assured soundings at more than 1500 globally distributed stations with the most frequent observation times at 0000 and 1200 UTC. Within the AEROSE domain, 36 stations were found for 2007 and 2009, 74 stations for 2008, 38 stations for 2010, and 98 stations for 2011. More than 90% of these stations are over land. We calculate the means of temperature profiles from both NCEP GFS forecasts and IGRA observations and plot the temperature difference (solid line) between the mean of forecasts and the mean of soundings along with altitude (Fig. 4a). The dotted line displays the total number of soundings over 5 years at each level using
the $x$ axis on the top. It is seen that temperature is overestimated near the surface and above 500 hPa by the NCEP GFS, and it becomes underestimated between 950 and 500 hPa with a maximum around 700 hPa. We take the same approach to the water vapor mixing ratio, as seen in Fig. 4b. However, the pressure level is limited to 300 hPa for moisture given that there are no moisture data above 300 hPa in the archived data. As indicated by Fig. 4b, the NCEP GFS has a dry tendency below 820 hPa and a wet tendency above that level. The AEROSE data are collected over the tropical Atlantic downwind of the Saharan dust. To better understand if the presence of dust affects the LAP retrievals, we have conditioned the median and standard deviation on aerosol optical depth (AOD) $\tau_a(\lambda)$ at 870 nm. AOD $\tau_a(\lambda)$ has been measured from MICROTOPS handheld sunphotometers on board the Ronald H. Brown and processed using the Maritime Aerosol Network (MAN) methodology described by Smirnov et al. (2009). We have selected five bins and the four AOD bin edges are as follows: 0.19, 0.38, 0.56, and 0.75. Since AOD measurements have been only collected at daytime, we have selected 200 out of 252 RAOB/NCEP GFS/retrieval matchup cases. The numbers of matchup cases for each bin during each AEROSE are listed in Table 1.

The statistical comparisons of retrieved temperature and relative humidity (RH) to NCEP GFS in conditioned bins are presented in Fig. 5. The bias tendency is defined as the mean difference in each AOD bin minus the mean difference over all 200 accepted cases (cf. Maddy et al. 2012). Figures 5a and 5c are for temperature, and Figs. 5b and 5d are for RH. Both temperature and RH show a similarity of NCEP GFS outputs and SEVIRI LAP retrievals in vertical bias tendency oscillations. Additionally, the plots with smaller AODs (navy and blue) appear to show smaller bias tendencies.

**TABLE 1.** Number of matchup cases for conditioned AOD $\tau_a(\lambda)$ at 870 nm.

<table>
<thead>
<tr>
<th>AOD $\tau_a(\lambda)$</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2007–11</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&lt;0.19$</td>
<td>11</td>
<td>26</td>
<td>—</td>
<td>27</td>
<td>11</td>
<td>75</td>
</tr>
<tr>
<td>[0.19, 0.38)</td>
<td>18</td>
<td>4</td>
<td>18</td>
<td>8</td>
<td>23</td>
<td>71</td>
</tr>
<tr>
<td>[0.38, 0.56)</td>
<td>9</td>
<td>5</td>
<td>—</td>
<td>7</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>[0.56, 0.75)</td>
<td>4</td>
<td>—</td>
<td>9</td>
<td>1</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>$&gt;0.75$</td>
<td>8</td>
<td>—</td>
<td>—</td>
<td>5</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Sum</td>
<td>50</td>
<td>35</td>
<td>27</td>
<td>43</td>
<td>45</td>
<td>200</td>
</tr>
</tbody>
</table>
Interestingly, oscillations are much wider for AODs between 0.38 and 0.75 (cyan and yellow), with NCEP GFS displaying smaller oscillations. Near the surface, the retrieved temperature has bigger positive bias tendencies implying that the retrievals are responding to the warm dust layer by warming the temperature profile near the surface. It is also noted that the retrieved temperature and RH have smaller oscillations in the whole compared region overall in the dustiest case (brown).

6. Application to a Sahara dust outflow case (2011 AEROSE)

Although the existence of large-scale Saharan dust outflows over the tropical North Atlantic was first reported over four decades ago (e.g., Carlson and Prospero 1972; Prospero et al. 1981), it was the advent of operational environmental satellite imagers such as the GOES imager and the Moderate Resolution Imaging Spectroradiometer (MODIS) that has enabled global-to-synoptic and mesoscale observation of these key meteorological phenomena. These outflows can travel hundreds and thousands of kilometers over the North Atlantic within layers of dry desert air referred to as the SAL (e.g., Carlson and Prospero 1972; Zhang and Pennington 2004; Dunion and Velden 2004; Nalli et al. 2006, 2011). This massive large-scale transport of dust and smoke from Africa across the Atlantic Ocean has been among the primary subjects of the AEROSE (Morris et al. 2006; Nalli et al. 2011).

Given the potential difficulty of IR retrievals in the presence of large dust loading (e.g., Stowe and Fleming 1980; Nalli and Stowe 2002; Weaver et al. 2003; Zhang and Zhang 2008; Maddy et al. 2012), the large outflow of Saharan dust over the Atlantic during 2007 and 2011 AEROSE cruises is worthy of a more deliberate case study. Nevertheless, because an unspecified number of the 2007 AEROSE RAOBs were uploaded to the Global Telecommunications System (as part of collaboration with the African Monsoon Multidisciplinary Analysis project), we are restricted to select the dust pulse encountered during the more recent 2011 AEROSE in this study to preclude any possibility of assimilation into NCEP GFS model. This also provides us the opportunity

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**Fig. 5.** Bias tendency of temperature and RH conditioned and color coded as a function of AOD at 870 nm (cf. Maddy et al. 2012) from (a),(b) SEVIRI physical retrievals and (c),(d) NCEP GFS.
to highlight data obtained from the most recent AEROSE campaign not yet conducted at the time of the publication of the cited AEROSE papers.

The 2011 AEROSE-VII campaign consisted of an interhemispheric transit from Charleston, South Carolina, to Cape Town, South Africa, a cruise track very similar to the Aerosols99 campaign (e.g., Thompson et al. 2000) except taking place during boreal summer (July–August 2011) and farther east in the Atlantic basin (see Fig. 1). The cruise track encountered significant outflows of both Saharan dust and biomass burning smoke (Fig. 6). Owing to their large particle size, dust aerosols have a greater impact on IR radiances and thus direct our attention to these here. Figure 6 shows the daily AOD $\tau_\lambda(\lambda)$ approaches 1.0 and small Ångström exponents $\alpha$ during the dust pulse on 3 August 2011, thus giving an indication of its strength.

To locate the dust spatially, we select MODIS–Aqua granules falling within the 2011 AEROSE space domain ($35^\circ N$–$35^\circ S$, $80^\circ W$–$20^\circ E$) as proxy inputs to run the AWG ADP algorithm in the AIT framework. Since the ADP works only for daytime, only daily granules have been chosen to obtain the dust/smoke pattern. Moreover, only dust/smoke pixels with a confidence level of at least medium or higher are selected to rule out any false alarm of dust/smoke detection. We here show the dust/smoke pattern as a composite from 1 to 3 August 2011, on which days the ship clearly encountered a Saharan dust plume justified from the ADP results. As shown in Fig. 7, large smoke plumes resulting from biomass burning are identified over South America, and dust from the Sahara Desert is shown over the Atlantic.

There were nine matchups from 1 to 3 August 2011. We present the mean temperature and relative humidity profiles under these nine dust cases in Fig. 8. The $x$ axis on the bottom is for the direct measurement while the $x$ axis on the top is for the difference between model/retrieval and measurement. It is seen that observed tropospheric temperature (black line with dots in Fig. 8a) has the highest value and observed tropospheric RH (black line with dots in Figs. 8b) has the lowest value around 800 hPa, verifying the likelihood of the SAL and

![Fig. 6. Daily (top) AOD $\tau_\lambda(\lambda)$ and (bottom) derived Ångström exponents $\alpha$ for 2011 AEROSE. AOD $\tau_\lambda(\lambda)$ has been measured from MICROTOPS handheld sunphotometers and processed using the MAN methodology described by Smirnov et al. (2009).](image-url)
dust. In terms of temperature, both model and physical retrieval have less than 1-K difference mostly relative to RAOB below 200 hPa. For water vapor, the physical retrieval (red) obviously captures the variability of water much better than the NCEP GFS model results (blue).

Figure 9 shows SEVIRI retrieved temperature and RH fields at 850 and 700 hPa. Those values are calculated as the means of 13 SEVIRI outputs from 0000 UTC 1 August to 0000 UTC 4 August 2011 at 6-h intervals. It appears that temperature is higher over the dust region, and RH at 850 hPa is lower than RH at 700 hPa, implying a SAL dry air effect.

There were 10 days during the 2011 AEROSE where the ship was located within 25°–15°N, 55°–22°W, an important region for the development of tropical cyclones (Goldenberg et al. 2001). Among these 10 days, there were 3 days (10 cases) with AODs of less than 0.2, and there were 5 days (15 cases) with AODs of greater than 0.4. To provide the information of temperature as a response of the SAL, we plot the temperature anomaly profile in Fig. 10a. The temperature anomaly profile is defined as the difference of the averaged temperature of AODs greater than 0.4 and the profile for AODs less than 0.2. For RAOBs (black line with dots), there are warm anomalies between 950 and 600 hPa, with the maximum anomaly at around 820 hPa. Above the warm
anomalies lie the cold anomalies, with a maximum cold anomaly at about 500 hPa. Both physical retrieval (red plus) and NCEP GFS (blue triangle) capture the similar pattern with a better agreement of physical retrieval with RAOB overall.

The same approach is taken to compute the RH anomalies and the results are shown in Fig. 1b. As expected, we see dry anomalies and an inversion layer below 700 hPa associated with the dry air. It is noted that the maximum dry anomaly is about 820 hPa for RAOB while it falls to about 880 hPa for physical retrieval and NCEP GFS, indicating that NCEP GFS and retrieval possibly fails to simulate the elevation of the inversion layer because of the high variation of water associated with the SAL.

7. Summary

A powerful application framework has been designed and developed by the GOES-R AWG AIT at NOAA/NESDIS/STAR to handle the current list of level-2 algorithms for the GOES-R series. A large multiyear proxy dataset including various satellite observations supplemented by ship-based measurements during a series of AEROSE campaigns has been developed and maintained for the GOES-R validation over the tropical Atlantic Ocean. In this study, the state-of-the-art GOES-R ACM, ADP, and LAP algorithms have been run in the GOES-R AWG AIT framework.

In particular, this work has contributed to the pre-launch validation of the GOES-R ABI LAP–retrieved atmospheric profiles by utilizing an ABI proxy dataset consisting of Meteosat-9 SEVIRI spectral band IR radiances that have been matched with a relatively large sample of dedicated AEROSE RAOBs over the tropical Atlantic Ocean. Although the GOES-R ABI cloud mask algorithm was used to obtain clear-sky or probably-clear-sky observations, a large portion of these were “contaminated” by significant levels of Saharan dust aerosols. This region of the tropical Atlantic is of great meteorological importance, being the main development area of Atlantic hurricanes and thus a critical area germane to the mesoscale observing mission of the GOES-R series.

Fig. 9. The mean values of retrieved (a),(b) temperature and (c),(d) RH fields at (left) 850 and (right) 700 hPa from 0000 UTC 1 Aug to 0000 UTC 4 Aug 2011 at 6-h interval.
Using the RAOB measurements from 2007–11 AEROSE campaigns for reference and the NCEP GFS model outputs for comparison, it is clearly shown that physical retrievals improve both temperature and water vapor against NCEP GFS model outputs overall. It is understandable that the physical retrieval has a similar pattern to NCEP GFS given that the NWP model acts as a significant constraint on the retrieval. Agreement between measured temperature and water profiles and products obtained from the LAP algorithm run in the AIT framework indicates that the current LAP algorithm is suitable to provide atmospheric temperature and water profiles for the ABI imager on board GOES-R. In addition, 252 cases were run successfully in the AIT framework indicating LAP has been implemented successfully in the GOES-R AWG AIT framework, and it is ready for NOAA real-time processing.

It is noticed that there is larger temperature RMSE in the lower troposphere for both NCEP GFS and SEVIRI retrieval compared with RAOBs, this being a consequence of the strong inversions associated with the SAL that neither the satellite nor the model can resolve. Comparison of NCEP GFS to IGRA data shows that the temperature is overestimated near the surface and above 500 hPa by the NCEP GFS, and it becomes underestimated between 950 and 500 hPa with a maximum around 700 hPa. The temperature underestimation of NCEP GFS in the troposphere leads to larger temperature RMSE of both NCEP GFS and SEVIRI retrieval compared to RAOBs in that region. Comparisons of retrieved temperature and relative humidity in conditioned AOD bins show that both have relatively smaller bias tendencies for smaller AODs and the dustiest case, while oscillations are much wider for AODs between 0.38 and 0.75.

In addition, we carried out a case study for the most recent 2011 AEROSE. Figures of daily AODs and derived Angström exponents show that the 2011 AEROSE encountered dust, which is also justified from the ADP outputs using MODIS–Aqua data. Profile plots using the mean values of nine dust cases from 1 to 3 August 2011 show both NCEP GFS and the LAP retrievals capture the temperature and RH profiles well with a slightly better agreement from the retrieval. We also conducted an experiment of anomaly for 25°–15°N, 55°–22°W, an important region for the development of the tropical cyclone. The anomaly profile is defined as the difference between the profile of AODs greater than 0.4 and profile for AODs less than 0.2. The experiment of anomaly displays that the retrieval captures the variability of both temperature and relative humidity much better than NCEP GFS. It is seen that there is a warm anomaly from 950 to 550 hPa for AODs greater than 0.4, with a maximum located around 800 hPa.
While the GOES-R ABI LAP product produced reasonable results in our prelaunch validation study, there is nevertheless a fundamental limit in its vertical resolving power given that ABI is a narrowband imager, not a hyperspectral sounder. Thus, our work supports the position held by Schmit et al. (2009) in favor of a GEO hyperspectral IR sounder, which we think will be ultimately necessary for adequate vertical, spatial, and temporal resolution of critical meteorological phenomena over the tropical Atlantic Ocean.

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