

USING AEROSE-DOMAIN SEVIRI DATA FOR LEGACY SOUNDING PRODUCTS FROM THE GOES-R ADVANCED BASELINE IMAGER

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Abstract

The Advanced Baseline Imager (ABI) to be flown on the U.S. National Oceanic and Atmospheric Administration Geostationary Operational Environmental Satellite R-series (GOES-R) will have a set of 10 narrowband infrared channels suitable for continuing GOES legacy sounding products, namely vertical temperature and moisture profiles, total precipitable water (TPW), surface skin temperature, and atmospheric stability indices. To facilitate the development, validation and demonstration of the proposed ABI sounding products, we have built a multiyear, ocean-based, empirical proxy-dataset, that is, one based upon actual satellite measurements taken over the tropical Atlantic, including data from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard Meteosat in GEO orbit. This proxy dataset is unique in that the satellite measurements will be supplemented by ship-based measurements acquired at sea during several trans-Atlantic Aerosol and Ocean Science Expeditions (AEROSE). We have collected satellite data within the AEROSE space-time domains [10°S, 35°N; 80°W, 10°W], rather than merely at the ship locations/times, so that dynamical features over the tropical Atlantic (e.g., SAL, dust outflows, tropical convection, etc.) can be observed and studied. The multi-year AEROSE datasets will be extremely useful for studying the impact of GOES-R for observing these and other interesting mesoscale and synoptic scale phenomena over the Atlantic Ocean. This paper presents some initial SEVIRI retrieval validation results based upon radiosonde matchup locations obtained during the AEROSE campaigns.

INTRODUCTION

The U.S. National Oceanic and Atmospheric Administration (NOAA) Geostationary Operational Environmental Satellites (GOES) are the primary tools for the detection and tracking of mesoscale (hurricanes and other severe weather) for the Western Hemisphere and Continental U.S. (CONUS). The next generation GOES series, GOES-R, is planned for launch in 2015. In preparation for GOES-R, Algorithm Working Group (AWG) Application Teams were established at NOAA's National Environmental Satellite and Data Information Service (NESDIS) Center for Satellite Applications and Research (STAR) to recommend, demonstrate and validate algorithms for user products that satisfy requirements specified in the Mission Requirements Document (MRD).

The GOES-R Advanced Baseline Imager (ABI) will have a set of 10 narrowband infrared (IR) channels (Schmit et al., 2005) suitable for continuing GOES *legacy sounding* products¹ (Schmit et al., 2008). Retrieval algorithms for these products have been under development by the GOES-R AWG Soundings Application Team (SAT) (Jin et al., 2008). To facilitate the development, validation and demonstration of the proposed ABI sounding products, we have built a multiyear, ocean-based, empirical proxy-dataset, that is, one based upon actual satellite measurements taken over the tropical Atlantic, as opposed to radiative transfer model simulations. Our proxy dataset is unique in that the

satellite measurements will be supplemented by ship-based measurements acquired at sea during several trans-Atlantic Aerosol and Ocean Science Expeditions (AEROSE) (Morris et al., 2006). The AEROSE campaigns constitute one of the most comprehensive collections of *in situ* measurements of the Saharan air layer (SAL) and associated dust outflows over the tropical Atlantic. We have collected satellite data within the AEROSE space-time domains [10°S, 35°N; 80°W, 10°W], rather than merely at the ship locations/times, so that synoptic and mesoscale phenomena over the tropical Atlantic (e.g., SAL, dust outflows, tropical convection, etc.) can be observed and studied. These include data from the Spinning Enhanced Visible and Infrared Imager (SEVIRI) onboard Meteosat in GEO orbit (Schmetz et al., 2002), and the Infrared Atmospheric Sounding Interferometer (IASI) (e.g., Cayla, 1993) onboard MetOp-A and Atmospheric Infrared Sounder (AIRS) onboard EOS-Aqua (e.g., Aumann et al., 2003), both in LEO orbit. The SEVIRI radiometer has spectral channels similar to the ABI, and because it is in GEO orbit, it possesses similar temporal resolution and view geometry. We present some initial SEVIRI retrieval validation results based upon radiosonde observations (RAOBs) at matchup locations obtained during the AEROSE campaigns. As will be illustrated in this preliminary work, the multi-year AEROSE datasets will be useful for validating and studying the impact of GOES-R for observing these unique mesoscale weather phenomena over the tropical Atlantic Ocean.

GOES-R LEGACY SOUNDING ALGORITHM AND PRODUCTS

The ABI Legacy Sounding (ALS) products have been developed at the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMSS) and are a continuation of the current GOES Sounder products (Schmit et al., 2008). The ALS products include retrieved vertical temperature and moisture profiles, surface skin temperature and emissivity, along with products derived from the retrieved profiles, namely total precipitable water (TPW), layered PW in 3 layers, along with atmospheric stability indices, namely the Lifted Index (LI), Convective Available Potential Energy (CAPE), K-Index, Total-Totals Index and Showalter Index.

The ALS algorithm is a two-step retrieval algorithm, the first step being statistical regression, the second step being an optimal estimation physical retrieval; for algorithm details, the reader is referred to Jin et al. (2008) and Li and Huang (1999). The algorithm operates on clear-sky (cloud free) fields-of-view (FOVs), obtained from AWG cloud mask product, providing a retrieval for a 5 x 5 field-of-regard (FOR). The predictors used in the statistical regression consist of the ABI (or SEVIRI) channel brightness temperatures, the surface pressure, the ECMWF forecast air temperature and water vapor, the local latitude, satellite zenith angle and month. The forecast predictors were found to be necessary owing to the lack of vertical resolution and information afforded by the ABI narrowband channels alone. The solution obtained by the regression is then used as the first guess in the physical retrieval.

AEROSOL AND OCEAN SCIENCE EXPEDITIONS (AEROSE)

The Aerosol and Ocean Science Expeditions (AEROSE) are a series of intensive field campaigns-of-opportunity conducted aboard the NOAA Ship *Ronald H. Brown*, supported by NESDIS/STAR in collaboration with the Howard University NOAA Center for Atmospheric Sciences (HU/NCAS)², the University of Miami Rosenstiel School of Marine and Atmospheric Science (UM/RSMAS), and NOAA's Oceanic and Atmospheric Research Atlantic Oceanographic and Meteorological Laboratory (OAR/AOML) and Earth System Research Laboratory Physical Sciences Division (ERSL/PSD). The ongoing AEROSE mission focuses on providing a set of measurements that characterize the impacts and microphysical evolution of aerosols from the African continent as they transit the Atlantic Ocean (Morris et al., 2006). The AEROSE shipboard data complement to date includes Vaisala rawinsonde observations (RAOBs) (Nalli et al., 2005; Nalli et al., 2006), calibrated IR spectra and high accuracy sea surface skin temperature (skin SST) from Marine Atmospheric Emitted Radiance Interferometers (M-AERI) (Minnett et al., 2001), Microtops sunphotometers, ozonesondes, micropulse lidar (MPL) (Morris et al., 2006), ceilometers, Multi-Filter Rotating Shadowband Radiometers (MFRSR), surface radiative fluxes, among others.

To date, there have been 4 campaigns consisting of 5 separate 3-4 week legs executed during the Northern Hemisphere spring and summer (see Figure 1). AEROSE-I was a 27-day cruise conducted

during March 2004. This was followed up with AEROSE-II, a two-leg, 55-day “piggyback” mission conducted May–July 2006 in concert with the African Monsoon Multidisciplinary Analysis (AMMA) and the Pilot Research Array in the Tropical Atlantic (PIRATA) Northeast Extension (PNE) project³ (Servain et al., 1998; Bourles et al., 2008). The third AEROSE campaign was also subsequently executed as a 26-day piggyback mission during the May 2007 PNE/AMMA Cruise. The fourth and most recent piggyback campaign mission as of this writing was the 22-day RB-08-03 Interhemispheric Transit, which took place in April-May 2008. Fortuitously, NOAA has committed to maintaining the PNE array, thereby requiring annual PNE cruises onboard the *Ronald H. Brown* within the AEROSE study region, so two more cruises and piggyback campaigns are tentatively planned for the early summers of 2009 and 2010.

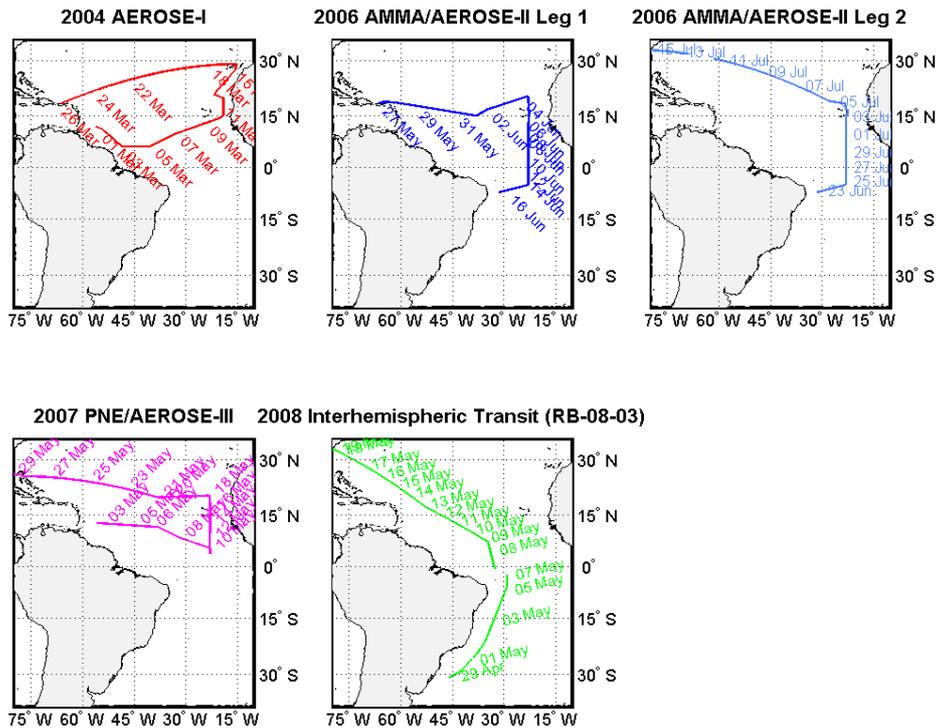


Figure 1: Location and dates of the NOAA Ship *Ronald H. Brown* within the AEROSE bounding box [10°S, 35°N; 80°W, 10°W] during the five AEROSE cruises to date. Map projections are Mercator.

The AEROSE study region is a region of great meteorological interest. Approximately 2 billion metric tons of mineral dust is injected into the atmosphere from the Sahara annually, with dust aerosols often transported well across the Atlantic. Smoke from biomass burning sites (e.g., savanna grasslands in sub-Saharan Africa) is also a major contributor to the aerosol climatology of the tropical Atlantic. Figure 2 shows the 16-year aerosol climatology as derived from the NOAA Advanced Very High Resolution Radiometer (AVHRR) Pathfinder Atmospheres (PATMOS) dataset (Jacobowitz, et al., 2003) for the month of May. Accompanying the Saharan dust aerosols is the Saharan air layer (SAL), a layer of dry, warm stable, air which also advects over Atlantic (Carlson and Prospero, 1972). The SAL was directly observed and characterized in 3 coherent cross-sections by Nalli et al. (2005) during the 2004 AEROSE-I campaign. These conditions may act to suppress hurricane formation over the Atlantic (e.g., Dunion and Velden 2004; Evan et al. 2006). Geostationary imagers (e.g., ABI, SEVIRI) are tools whereby the SAL can be observed (e.g., Dunion and Velden, 2004); validation in this region is therefore all the more important (e.g., Nalli et al. 2006).

Of direct interest for our validation of the GOES-R ALS products are the Vaisala RS92 GPS rawinsondes (RS80/90 in 2004). While these sondes were, for the most part, launched to coincide with AIRS (and later, IASI) overpasses (4/day at ~01:30, 09:30, 13:30, 21:30), practically all launches qualify as a matchup with the Meteosat SEVIRI. There have been a total of 423 AEROSE RAOBs acquired to date, which is a sample large enough for assigning statistical significance.

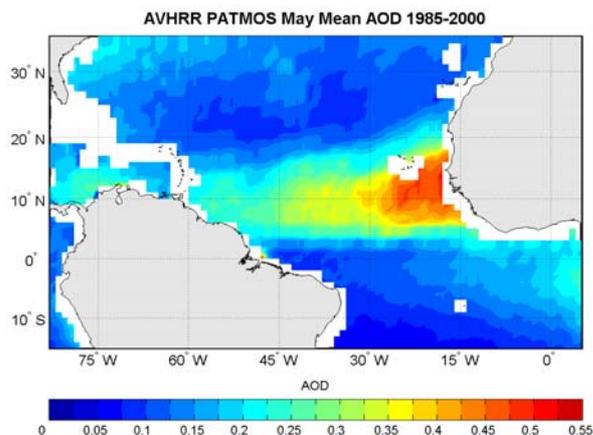


Figure 2: AVHRR Pathfinder Atmospheres (PATMOS) (Jacobowitz et al., 2003) climatological (1985–2000) mean aerosol optical depth (AOD) derived from cloud-free, grid-cell mean AVHRR channel 1 ($\lambda = 0.63 \mu\text{m}$) normalized reflectances. Map projection is Mercator.

INITIAL RESULTS: 2007 PNE/AEROSE-III FOCUS

The 2007 PNE/AEROSE-III campaign took place 3–29 May 2007, from Bridgetown, Barbados to Fort Lauderdale, Florida, USA. A total of 96 sondes were launched, resulting in a total of 60 clear-sky matchups with SEVIRI. During the 2007 campaign, the *Ronald H. Brown* encountered a major SAL and dust outflow event just prior to and during the northbound 23°W transect. Figure 3 shows SEVIRI solar-spectrum imagery ($0.6 \mu\text{m}$) with the concurrent location of the sonde launch matchup. Figure 4 shows a photograph of the dust outflow as viewed from the *Ronald H. Brown* while holding station along 23°W , indicating the presence of dust in the surface layer. For comparison against Figure 3, Figure 5 shows an image derived from an *ad hoc* “SAL tracking” method, where possible SAL environments are identified by taking the difference of the split-window (12.0 and $10.8 \mu\text{m}$ channels) brightness temperatures and plotting those falling within a symmetric range about zero (i.e., analogous to the algorithm for the NOAA GOES-8 Imager; Dunion and Velden, 2004). We found the range of $[-2, +2]$ K to work well with our SEVIRI imagery, thus $-2 \leq T_B(12) - T_B(10.8) \leq +2$ K. In Figure 3 it is clearly seen that the *Ronald H. Brown* was located within a very dusty, yet relatively cloud-free, air layer. However, the split-window SAL tracking in Figure 5 apparently suggests SAL presence in a relatively clearer area to the north of the main plume.

The AEROSE GOES-R proxy dataset offers a unique opportunity to evaluate the performance of the GOES-R ALS product within this challenging environment. Figure 6 shows a comparison of water vapor mixing ratio profiles derived from RAOB, the European Centre for Medium-Range Weather Forecasts (ECMWF) model forecast, and the ALS SEVIRI retrievals (statistical and physical), for the UTC 13:30 13 May 2007 RAOB matchup shown in Figures 3 and 5. The RAOB shows the presence of the SAL as two distinct dry layers at ~ 950 and ~ 900 hPa. While none of the products (ECMWF or SEVIRI retrieval) were able to resolve the dual layers, all nevertheless were able to detect the SAL, and the SAL retrieved by SEVIRI was in very good agreement with the RAOB.

This single case is meant to illustrate the potential utility of the AEROSE GOES-R proxy dataset. By looking at all available RAOB matchups, we plan to obtain a statistical evaluation of the ALS algorithm in this region, hopefully providing some measure of confidence of the algorithm for detecting the SAL. Figure 7 shows an image of the SEVIRI ALS-derived total column precipitable water (TPW) in mm, defined as the integral of water vapor mixing ratio over the entire atmospheric column, for the AEROSE domain at UTC 13:30 13 May 2007 (the SEVIRI-RAOB matchup case as in Figures 3, 5 and 6). Here we can confirm that the *Ronald H. Brown* was just entering the SAL at this time, even though it was located fully within the main dust plume (cf. Figure 3). The expanse of the dry region is in general agreement with that shown in Figure 5. The driest air is located to the north of the main dust plume, thereby corroborating findings by previous investigators that Saharan dry air outbreaks do not always necessarily correlate directly with dust quantity (e.g., Zhang and Pennington, 2004). It should

be noted that, unlike the simple split-window temperature difference used for generating Figure 5, the ALS TPW product is derived physically, and the result, the TPW in mm, is a conservative atmospheric physical quantity.

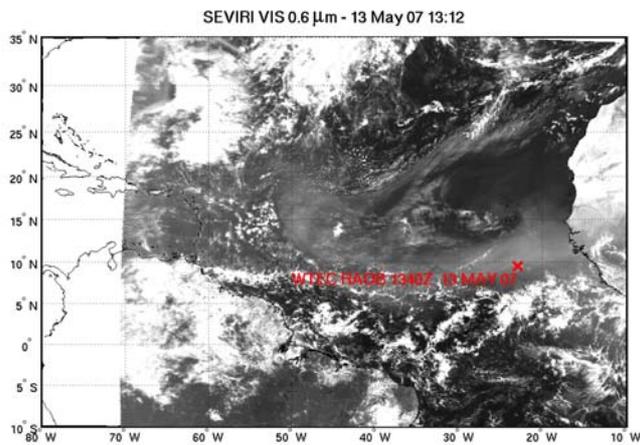


Figure 3: SEVIRI solar-spectrum imagery (0.6 μm), UTC 13:12 13 May 2007. The red \times shows the location of a coincident RAOB launched at 13:40 UTC from the *Ronald H. Brown* within a major Saharan dust outflow event.



Figure 4: Saharan dust outflow as photographed from the *Ronald H. Brown* while holding station along 23°W longitude. The very low visibility near the horizon indicates the presence of dust within the surface layer. Given the visibility of the solar disk, there are apparently very few if any detectable low- to mid-level clouds within the camera FOV. Color photo courtesy of V. Morris (HU/NCAS).

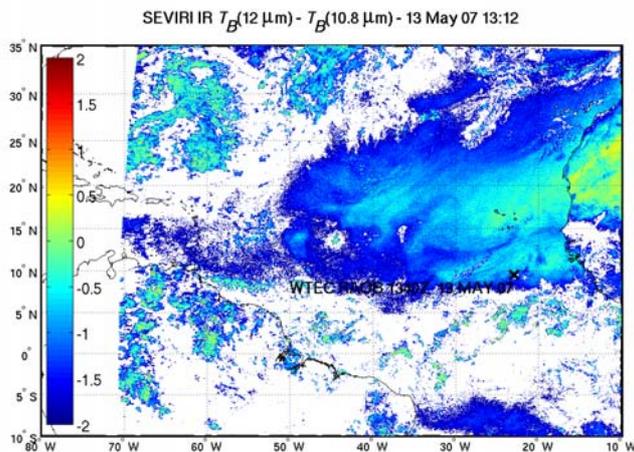


Figure 5: As Figure 3, except showing *ad hoc* SEVIRI “SAL tracking” as the brightness temperature difference between SEVIRI channels 6 and 7, with $-2 \leq T_B(12) - T_B(10.8) \leq +2$ indicating a possible SAL environment (analogous to the algorithm for the NOAA GOES-8; Dunion and Velden, 2004).

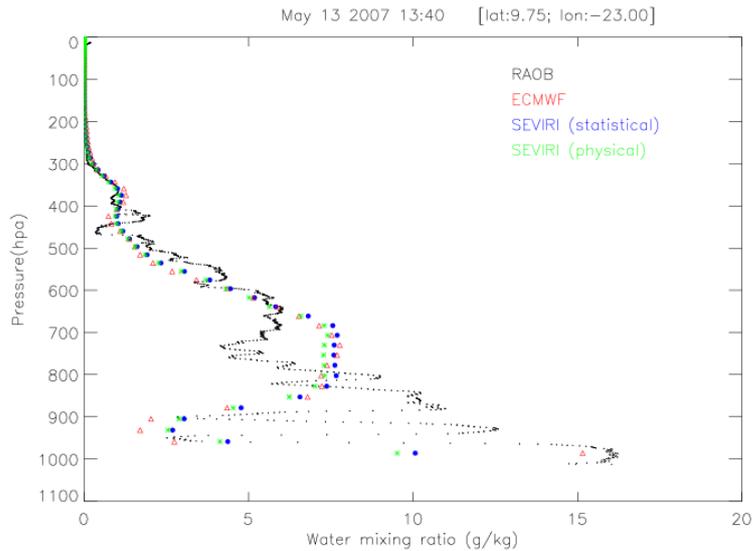


Figure 6: Water vapor mixing ratio sounding comparisons for the UTC 13:30 13 May 2007 RAOB matchup (shown in Figures 3 and 5): RAOB (black dots), the ECMWF model 6 hour forecast (red triangles), the SEVIRI ALS statistical retrieval (blue circles), and the SEVIRI ALS physical retrieval (green squares). Note the presence of the SAL as two distinct dry layers seen in the RAOB at ~950 and ~900 hPa.

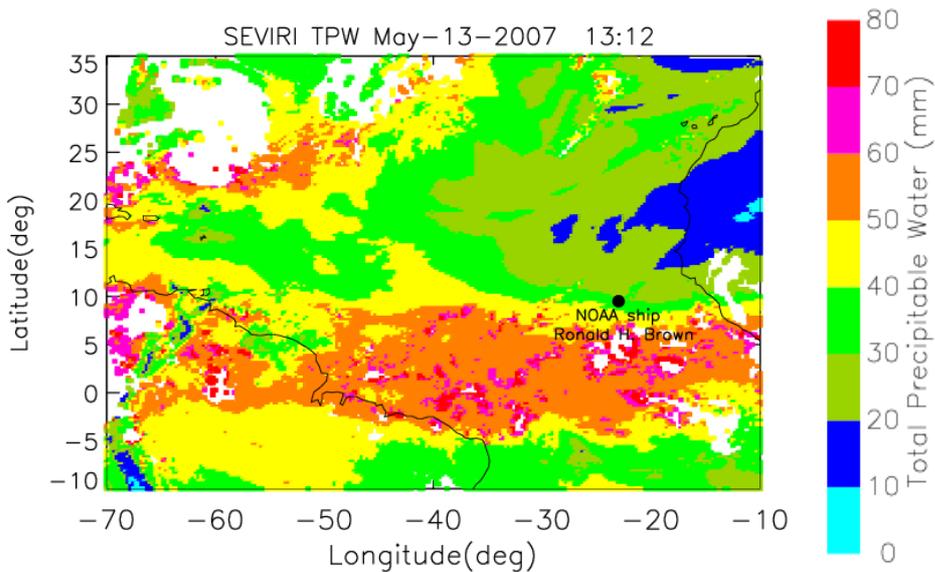


Figure 7: SEVIRI ALS derived total precipitable water (TPW) in mm, defined as the integral of water vapor mixing ratio over the entire atmospheric column, for the UTC 13:30 13 May 2007 SEVIRI-RAOB matchup case (as above). Location of the *Ronald H. Brown* sonde launch is shown, and clouds are screened as white.

SUMMARY AND FUTURE WORK

In this preliminary work, we have briefly described the ocean-based GOES-R AEROSE proxy dataset that we have developed based on multi-year satellite observations that have been supplemented by ship-based measurements during the AEROSE trans-Atlantic campaigns. The simple case study from the 2007 PNE/AEROSE-III cruise presented in this paper illustrated that the ALS statistical regression and physical retrieval agree reasonably well with RAOB measurements over the entire column. These initial results suggest that the derived TPW legacy product holds promise for a physically-based day and nighttime SAL tracking tool. Future work on ABI Legacy Sounding validation using AEROSE proxy datasets will focus on obtaining SEVIRI error statistics based on all the clear-sky RAOB matchups obtained from for all 4 AEROSE campaigns. The results of a more extensive evaluation of this application is planned to be the subject of a forthcoming paper.

While SEVIRI provides narrowband imager data from a geosynchronous platform, the channel bandpasses nevertheless do differ from those planned for ABI. Therefore, to derive proxy data that emulate better the ABI channels, we intend to convolve reprocessed IASI data with the appropriate ABI spectral response functions (with D. Zhou, NASA/LaRC). As with the SEVIRI, we plan then to test the UW/CIMSS ABI codes using the IASI-simulated ABI proxy data from the 2007, 2008, and potential future cruises-of-opportunity.

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1. Note however that because ABI has only 1 CO₂ band, the retrieved upper-level temperature will nevertheless be *degraded* compared to the *current* GOES Sounder. Improved soundings from the next generation GOES were originally planned from the GOES-R Hyperspectral Environmental Suite (HES). Unfortunately, HES was descoped from the GOES-R series in 2006, and the advanced sounding products that were originally envisioned for GOES-R cannot be realized. Nevertheless, legacy sounder products that are used by the NOAA National Weather Service (NWS) and others must still be continued.
2. HU/NCAS is one of four NOAA cooperative centers established in 2001 under the NOAA Educational Partnership Program with Minority Serving Institutions (EPP/MSI) Cooperative Agreement No. NA17AE1623 (Morris et al., 2007).
3. The PIRATA Northeast Extension (PNE) project is a collaborative effort between the U.S. (NOAA/AOML), France, and Brazil to maintain an array of moored buoys to collect meteorological and oceanographic measurements for weather and climate prediction (Bourles et al., 2008).