Accuracy assessment of MERRA-2 temperature and humidity profiles over the tropical ocean using AEROSE observations and ECMWF analysis

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Abstract

•Reanalysis model output is extensively used in atmospheric research to complement the satellite and in situ data. NASA's Goddard Earth Sciences Modern-Era Retrospective analysis for Research and Applications v 2 (MERRA-2) assimilates measurements from different sources to minimize bias errors. The model data must be rigorously evaluated to assess their suitability to study a variety of questions. Here, Sea Surface Temperature (SST) and profiles of temperature and humidity through the marine atmosphere from MERRA-2 are compared to independent ship-based measurements of radiosondes, and retrievals from the ship-based Marine-Atmosphere Emitted Radiance Interferometer (M-AERI), and also the analyses fields of the European Center for Medium - Range Weather Forecasting (ECMWF). The ship measurements include those from Aerosol and Ocean Science Expedition (AEROSE) cruises of the NOAA Ship *Ronald H. Brown* in the tropical North Atlantic Ocean, focusing on the representation of the spatial and temporal variability. The results reveal that temperature and water vapor profiles from the MERRA-2 are in good agreement with the in situ measurements. For part of the cruises, the atmosphere included a mid-level dry layer emanating from North Africa, the Saharan Air Layer (SAL). With respect to difference, MERRA-2 humidity profiles shows a big difference (40%) with RAOBs at high altitude (pressure level < 300 hPa). These results support the use of MERRA-2 fields in a variety of research applications, including those directed at improving the accuracies of satellite-derived SST_{skin} retrievals.

1. Data

➢ **MERRA-2 datasets:**

▪ The NASA MERRA-2 reanalysis data were generated using the Goddard Earth Observing System data assimilation system by NASA's Global Modeling and Assimilation Office Data Assimilation System V5.12.4.

▪Covering the earth observation data from 1980 to present.

▪MERRA-2 analysis data are computed on a latitude–longitude-altitude cubed sphere grid at the same spatial resolution as the 3DVAR algorithm atmospheric model based on the Grid-point Statistical Interpolation.

Data Name	MERRA-2 Variable used in this study	Spatial Resolution	Time resolution
tavg3_3d_cld_Np	Cloud fraction for radiation Relative humidity	0.5° * 0.625° 72 hybrid sigma-pressure layers	3-hourly
inst1_2d_asm	2m Temperature 2m Specific Humidity Sea Surface Temperature		1-hourly
inst3_3d_asm_Np	Ozone mass mixing ratio Mass fraction of cloud water Atmospheric air temperature East and West wind		3-hourly

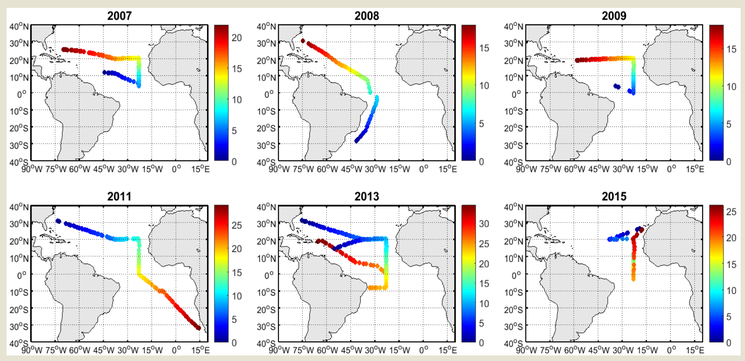
➢ **AEROSE:**

• A series of intensive field campaigns on the NOAA ship *Ronald H. Brown* in the Atlantic Ocean.

• AEROSE data include complementary measurements to study the transport of aerosols from the African continent across the Atlantic Ocean, including:

–Microphysical evolution and regional impacts

–Regional atmospheric chemistry and marine meteorology



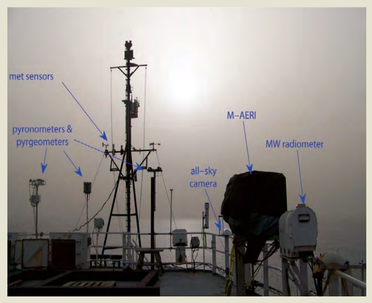
AEROSE tracks, color indicates the days since departure.

➢ **Independent Validation data:**

•Radiosonde (RAOB): Balloon-based instrument to make direct in situ measurements of air temperature, humidity, and pressure to about 30 km height.

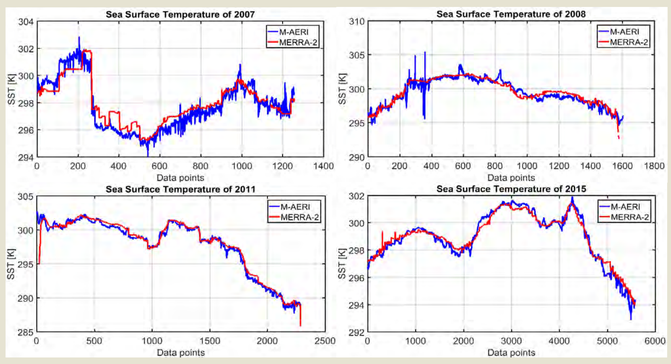
• ECMWF: Contains a set of atmospheric variables on a spatial horizontal grid of 0.5ox 0.5 o at 60 vertical levels. The ECMWF analysis is produced daily for 00, 06, 12 and 18 UTC. The four analyses per day are obtained by four-dimensional variational analysis (4DVAR) schemes.

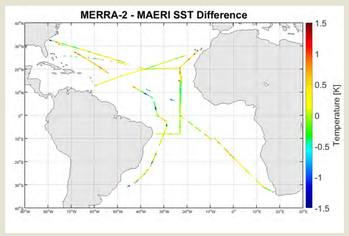
• M-AERI: An accurate, self-calibrating, Fourier transform IR spectroradiometer that measures emission spectra from the sea and atmosphere. (Minnett et al. 2001).



Unenhanced photograph of the forward level-2 of the NOAA ship Ronald H. Brown, taken during AEROSE-III, on the afternoon of 13 May 2007, during the major Saharan dust outflow pulse. (Nalli et al. 2011)

2. SST Validation





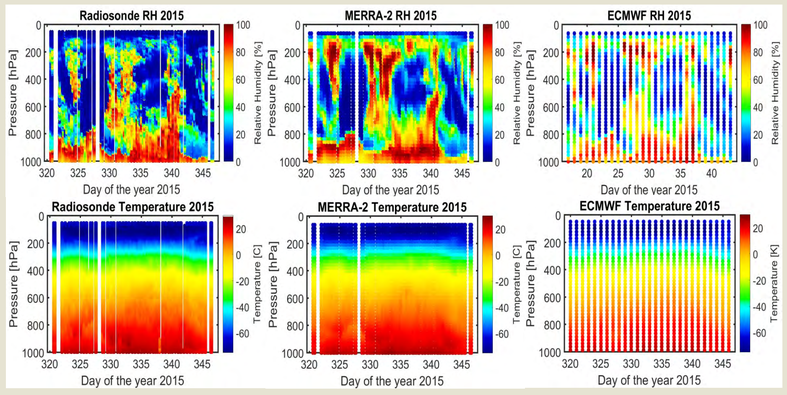
Upper: Time series of M-AERI (blue) and MERRA-2 (red) SST of each year. Left: Geo-locations of MERRA-2 minus M-AERI SST differences during AEROSE cruise.

The MERRA-2 SST agrees well with M-AERI, and it has a mean bias of 0.125 K and have the potential to provide a satisfactory contribution to studies involving SST. The SST difference distribution between them shows there is negative bias near equatorial region, effort is still required to provide better data especially some water vapor-contaminated data.

Year	Day					Night				
	N	Mean (℃)	Median (℃)	STD (℃)	RMS (℃)	N	Mean (℃)	Median (℃)	STD (℃)	RMS (℃)
2007	578	0.048	0.188	0.623	0.624	679	0.291	0.324	0.646	0.708
2008	786	0.125	0.222	0.617	0.629	817	0.151	0.187	0.527	0.548
2011	1190	0.212	0.212	0.373	0.429	1097	0.118	0.194	0.612	0.623
2013	3546	0.193	0.181	0.400	0.444	3584	0.198	0.177	0.350	0.402
2015	2729	0.017	-0.005	0.352	0.353	2854	0.073	0.027	0.366	0.374
Total	8829	0.125	0.116	0.433	0.450	9031	0.151	0.150	0.444	0.469

Table: Statistics of errors of MERRA-2 SST vs M-AERI

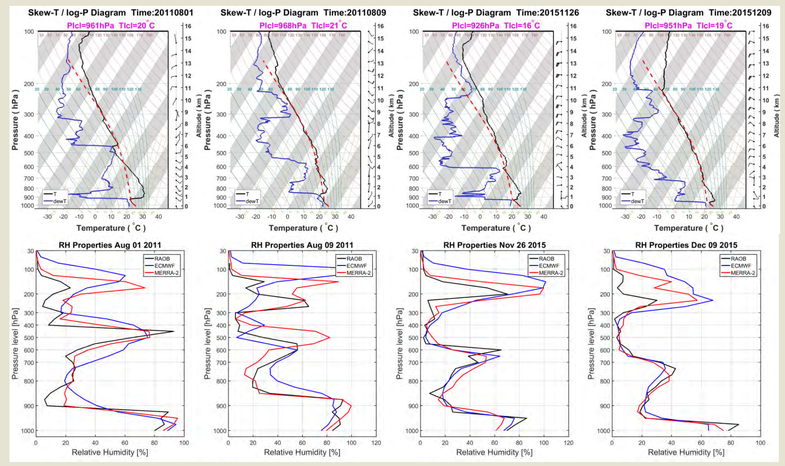
3. RH and Temperature Layer Validation



Relative Humidity and temperature layer properties of RAOB, MERRA-2 and ECMWF during 2015 AEROSE cruise, color indicates RH and temperature.

- AEROSE provided a coherent, unique and valuable source of data to the validation studies of the model data.
- Reanalysis data were bilinearly interpolated to the RAOB stations launch positions in the horizontal. RAOBs profiles profile were linearly interpolated in the vertical to model pressure levels.
- Both MERRA-2 and ECMWF temperature differences from RAOBs are less than 1K in the troposphere with MERRA-2 agreeing a little better for the whole cruise.
- With regard to the RH profile, both of the model data are in good agreement with the RAOBs except close to the surface and at high altitude region (RH bias is ~40%).

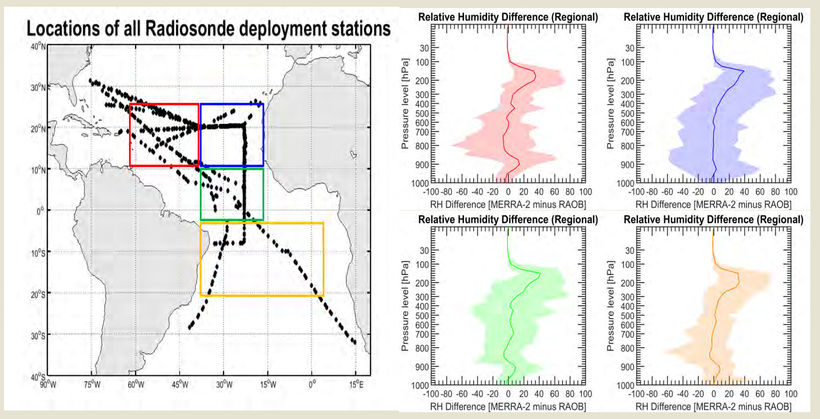
4. Special case - SAL



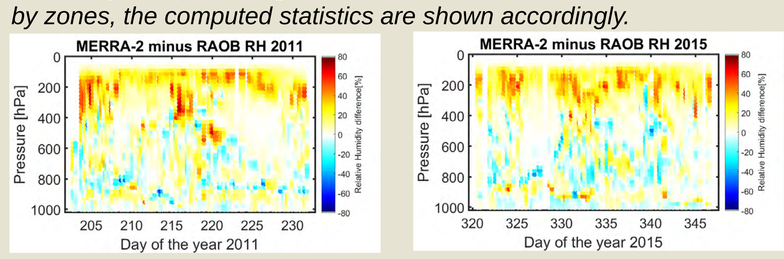
Skew-T and RH properties when R.H.B crossed SAL region.

- The extreme dry layers in Saharan Air Layer(SAL) result as airmasses that have lost moisture through condensation events descend over intervals of days to lower levels achieving low RH by adiabatic warming. We use the SAL case to validate the accuracy of MERRA-2.
- The upper dry air layer that were encountered during AEROSE is clearly visible in the cross-section of the RH data (Section 3). But the vertical height and thickness of SALs are not always well captured in reanalysis data.

5. MERRA-2 RH Error Distribution



To assess the reanalysis accuracies over tropics(green), midlatitudes (red and yellow), SAL region(Blue), subsets of MERRA-2 are stratified by zones, the computed statistics are shown accordingly.



RH difference between RAOBs and MERRA-2 according to height

- There are bias near dry layer, this is due to the vertical resolution between RAOBs and model data.
- For tropics and mid-latitudes, MERRA-2 transports too much water vapor to the upper troposphere, leading to a wet bias from 900 – 500 hPa.
- MERRA-2 is a valuable source of data for many applications, despite the noted issues.
- Note, some differences are due to shortcomings of RAOBs.

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7. References

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