Simultaneous Retrievals of Sea-surface Temperature and Column Water Vapor from MODIS measurements with Optimal Estimation

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Objective:

To explore if Optimal Estimation (OE) can improve the accuracy of the MODIS Sea-Surface Temperature (SST) retrievals during Saharan Air Layer (SAL) compared to the routine approach that uses the Non-Linear SST (NLSST) and to simultaneously produce accurate retrievals of Total Column Water Vapor .

Introduction

The current SST retrieval algorithm applied to MODIS data is built on the NLSST algorithm with a set of coefficients derived using collocated measurements of SST from drifting buoys (Match-Up Data Base – MUDB). NLSST produces accurate SST retrievals in conditions that are similar to those represented in the MUDB but when conditions deviate from typical, the errors can be larger. It has been postulated that algorithms based on the Optimal Estimation (OE) technique could be more accurate in such conditions. During SAL outbreaks in the northern tropical Atlantic, a typically moist tropical or sub-tropical maritime atmosphere is replaced by dry air from the African continent resulting in atypical conditions for the NLSST retrieval (Szczodrak et al, 2014). In the fall of 2015 the University of Miami group participated in a research cruise off the African coast on the NATO ship R/V Alliance. During a later part of the cruise we encountered SAL conditions. Figure 1 shows vertical structure of the atmospheric relative humidity from radiosondes along the cruise track with a very dry layers aloft starting with days ~327 and ~342 (surface level dust was also observed on these days). We use data collected on this cruise to derive OE estimates of SST (OESST) in and out of SAL conditions and compare OESST and NLSST with shipboard radiometer SST measurements.

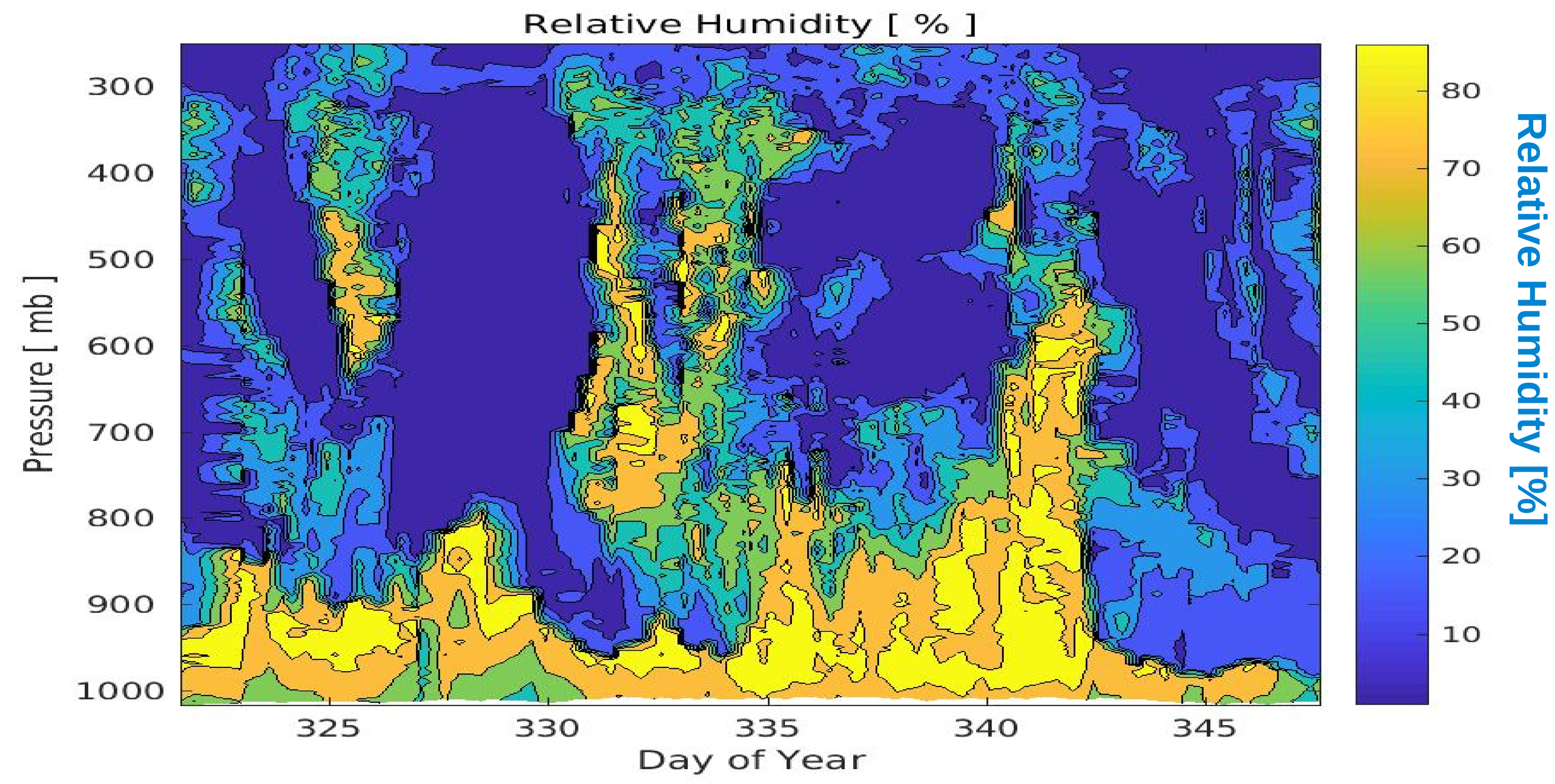

Figure 1. Vertical structure of relative humidity along the path of R/V Alliance.

Elements of the OE approach:

The ocean-atmosphere system is represented by a reduced state vector, **x** = (SST, TCWV), where TCWV is total atmospheric column water vapor. This choice of variables permits the retrieval of TCWV as well as the retrieval of SST. For an a priori state vector SST is that measured by shipboard Marine-Atmosphere Emitted Radiance Interferometer (M-AERI; Minnett et al. 2001), and TCWV comes from radiosonde measurements. During the cruise radiosondes were launched to coincide with AQUA satellite overpasses.

The forward model is the Line by Line Radiative Transfer Model (LBLRTM) of Clough, et al., (1995). The observation vector is the vector of radiances in MODIS 11 and 12 µm channels on AQUA.

We treat the covariance matrix of forward modelling and observations, and the covariance matrix of prior information as parameters of the model. These parameters represent uncertainties of MODIS measurements in the two channels ($e_{11} = e_{12} = NE\Delta T$) and uncertainties of the a priori fields of SST and TCWV e_{SST} and e_{WV}.

Results

The R/V Alliance cruise track is shown in Figure 2a. The color scale indicates TCWV as measured by a shipborne microwave radiometer (MWR). The black triangles mark positions of ship radiosonde launches (for clarity only first radiosonde launch of the day is labelled). Figures 2b and 2c show maps of the difference between the MODIS SST derived with the NLSST algorithm and the SST measured by M-AERI for (2b) and the MODIS SST derived with OESST algorithm (2c). Only MODIS quality 0 to 2 retrievals are indicated in Figure 2 and following figures. Parameters of the OE model were $NE\Delta T$=0.05K, e_{SST} a=0.05K and e_{WV} =0.1. Figure 3 shows time series of M-AERI SSTs and retrievals with different quality flags (QF).

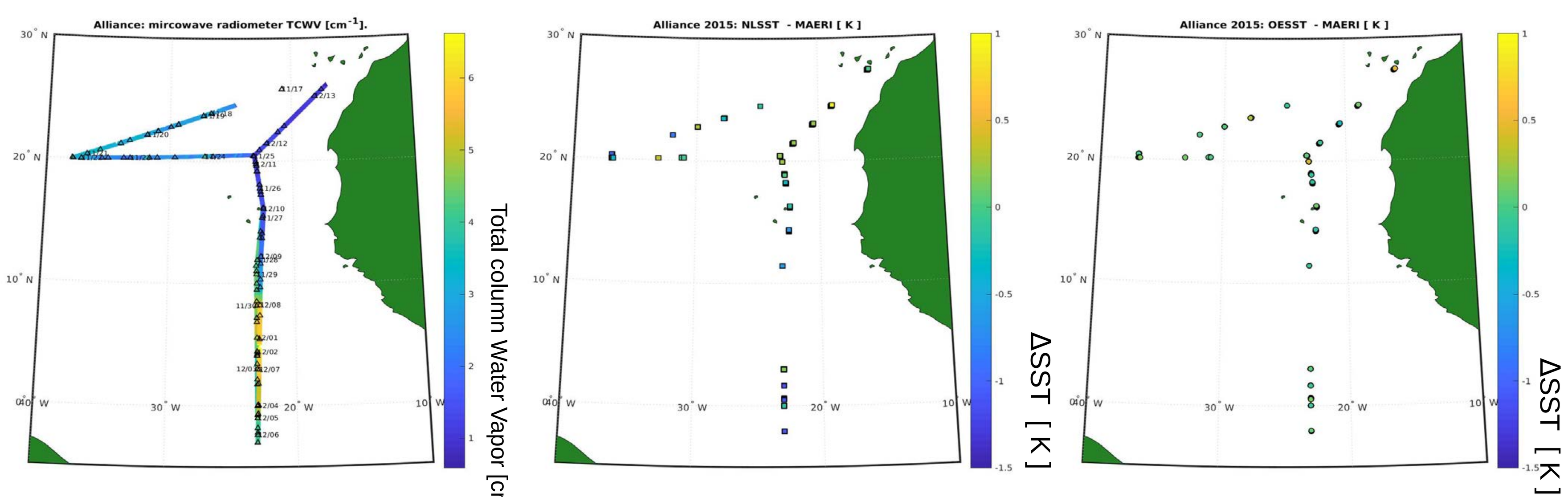

Figure 2. TCWV along the cruise track with SAL area marked on the map (a); difference between NLSST and M-AERI (b); and difference between OESST and MAERI (c).

References:

Clough, S. A. and M. J. Iacono, 1995: Line-by-line calculations of atmospheric fluxes and cooling rates II: Application to carbon dioxide, ozone, methane, nitrous oxide, and the halocarbons. *Journal of Geophysical Research*, 100, 16,519-516,535.

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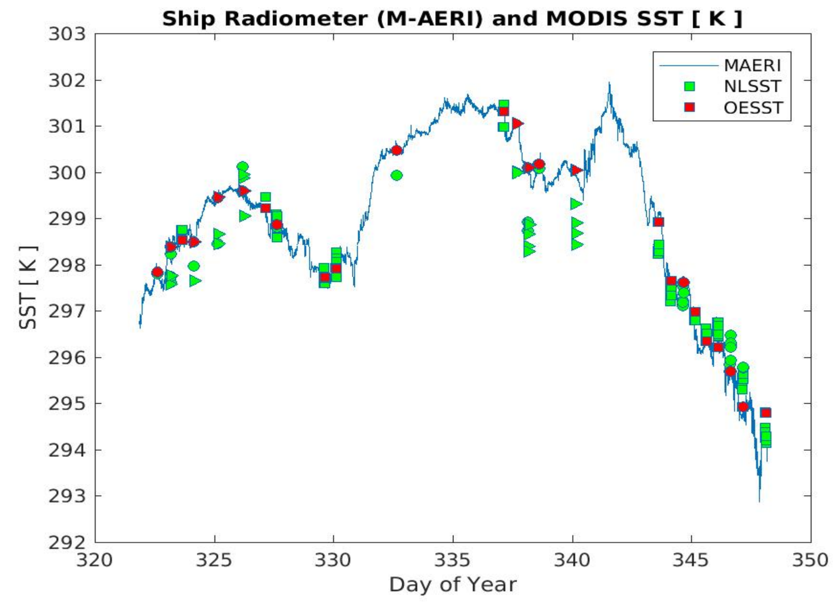

Figure 3. SST measured by M-AERI (blue line), NLSST retrievals (green symbols) and OESST retrievals (red symbols). Squares, circles, and triangles indicate QF=0, 1, and 2 respectively.

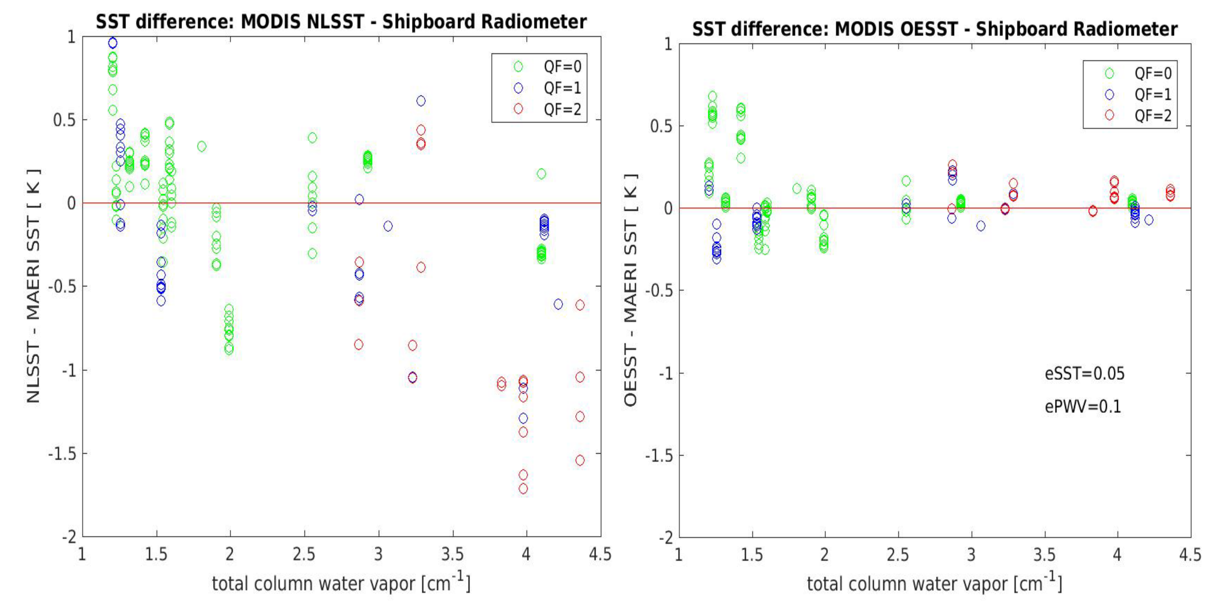

Figure 4. Difference between NLSST and MAERI SST (a) and OESST and MAERI SST as a function of TWVC. Colors correspond to different quality flags.

Table 1.

		NLSST – M-AERI Mean	RMS	StD	OESST – M-AERI Mean	RMS	StD	N Samples
All	QF=0	0.0526	0.3753	0.3733	0.0762	0.2408	0.2295	105
	QF=1	-0.1603	0.4978	0.4770	-0.0506	0.1438	0.1363	42
	QF=2	-0.8397	1.0381	0.6255	0.0828	0.1108	0.0754	21
Dry	QF=0							76
	QF=1	0.0564	0.4115	0.4104	0.0955	0.2816	0.2667	20
	QF=2	0.0066	0.4715	0.4837	-0.1316	0.1804	0.1265	0
Standard	QF=0	0.1753	0.2384	0.1658	0.0236	0.0492	0.0443	20
	QF=1	-0.4193	0.6720	0.5485	0.0721	0.1280	0.1104	12
	QF=2	-0.7731	1.0036	0.6596	0.0815	0.1151	0.0838	17
Wet	QF=0	-0.2514	0.2938	0.1612	0.0304	0.0344	0.0170	9
	QF=1	-0.1833	0.2330	0.1516	-0.0358	0.0462	0.0309	10
	QF=2	-1.1227	1.1736	0.3949	0.0884	0.0899	0.0188	4

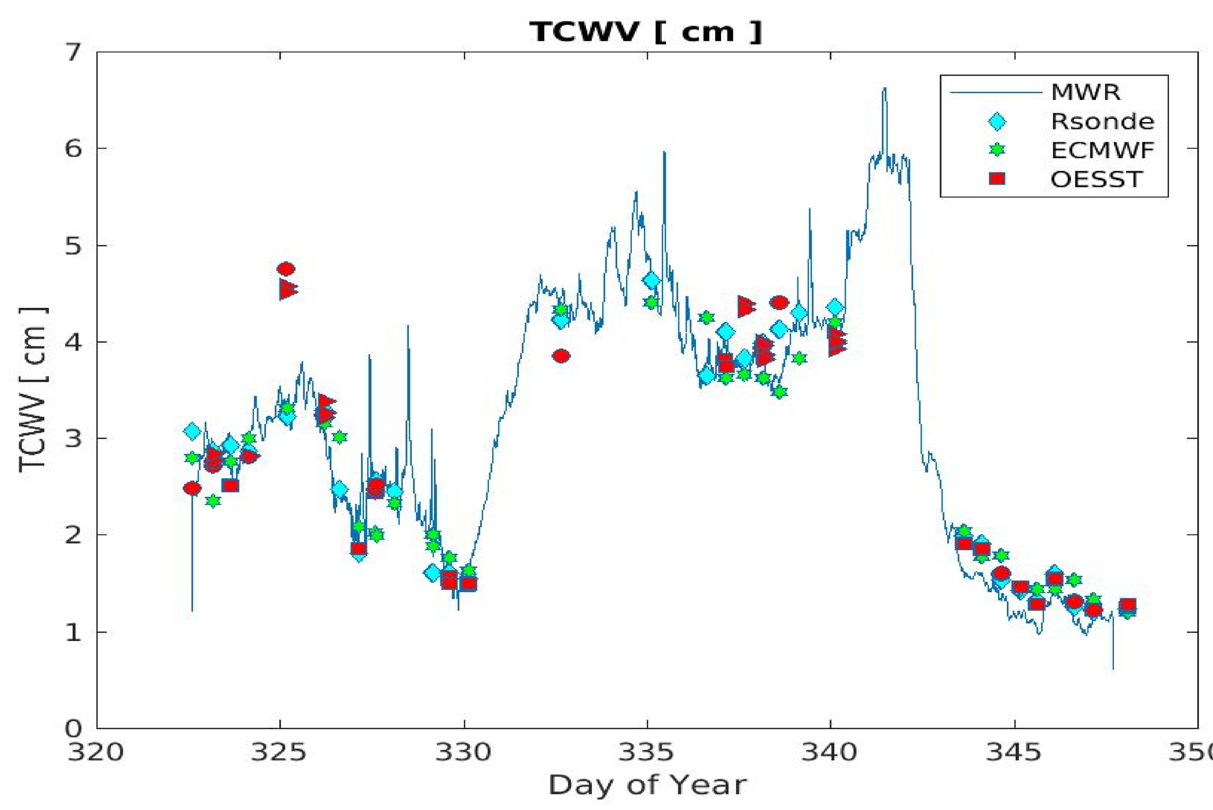

Figure 5. TCWV measured by MWR (blue line), radiosondes (light blue symbols), from ECMWF analysis (green), and from OESST retrievals (red symbols).Squares, circles, and triangles indicate QF = 0, 1, and 2 respectively.

QF	Dry	Standard	Wet
0	-0.03 (0.05)	-0.30 (0.16)	-0.30 (0.02)
1	0.05 (0.02)	0.00 (0.24)	0.21 (0.20)
2		0.17 (0.48)	-0.36 (0.06)

Table 2. Mean and Standard Deviation (in brackets) of OE TCWV - OE Radiosonde in cm.

Summary and Conclusions

For the data acquired during the 2015 R/V Alliance cruise the OE approach results in:

- decrease in RMS errors with respect to SST measured by M-AERI for all cases, not just under SAL conditions;
- improvements in RMS error are in fact greater for standard and wet conditions than for the very dry conditions, contrary to our expectations;
- scatter of OESST values around the M-AERI SST is also significantly smaller in all cases than the scatter of NLSST;
- lower quality data see greater improvement in the OE retrieval than the best quality data (QF=0) for all conditions;
- for QF=0 the mean bias is lower for NLSST than OESST;
- TCWV retrieved by OE is within 15% of the TCWV measured by radiosondes over the wide range of TCWC values encountered during the cruise. This is a promising result for the ability of OE to provide simultaneous TCWV and SST retrievals from MODIS IR measurements.