Improving Accuracy of Sea-surface Temperature Retrievals by Incorporating Optimal Estimation

Malgorzata Szczodrak and Peter J. Minnett

Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, USA

Email: goshka@rsmas.miami.edu, pminnett@rsmas.miami.edu

This research is funded by the NASA Physical Oceanography Program.

Objective:

To explore in what conditions Optimal Estimation (OE) can improve the accuracy of the MODIS Sea-Surface Temperature (SST) retrievals compared to the routine approach that uses the Non-Linear SST (NLSST).

Introduction

The current MODIS SST retrieval algorithm (NLSST) is based on a nearly linear combination of brightness temperature in two infrared channels with coefficients that are region and season dependent and are derived from match-ups with buoy measurements. The NLSST retrievals have global accuracy of about 0.5 to 0.4K in rms and mean bias of -0.15 to -0.2 K . This is good on average but still above the absolute temperature uncertainty of 0.1 K required for generation of Climate Data Records. Regional or seasonal biases may be much greater if local conditions depart from the 'average' that is represented in the statistical coefficients. Intrusions of the Saharan Air Layer (SAL) over the eastern Atlantic is an example of a seasonal phenomena that represents such departure from average atmospheric conditions and leads to large errors in the NLSST; but even without such special events there is a seasonal and regional variability in the accuracy and bias of the NLSST. The Optimal Estimation (OE) approach attemps to account for the actual atmospheric state at the time and place of the satellite measurement and therefore can lead to alleviating some of the NLSST bias. OE SST retrievals were performed for two years of AQUA MODIS match-up data for the Caribbean, North Atlantic and Mediterrean basins and the results of the OE and NLSST retrievals and are compared with in situ buoy and ship radiometer (M-AERI) measurements. We identify areas and condtions where incorporating OE can lead to improved accuracy of the retrieved SST.

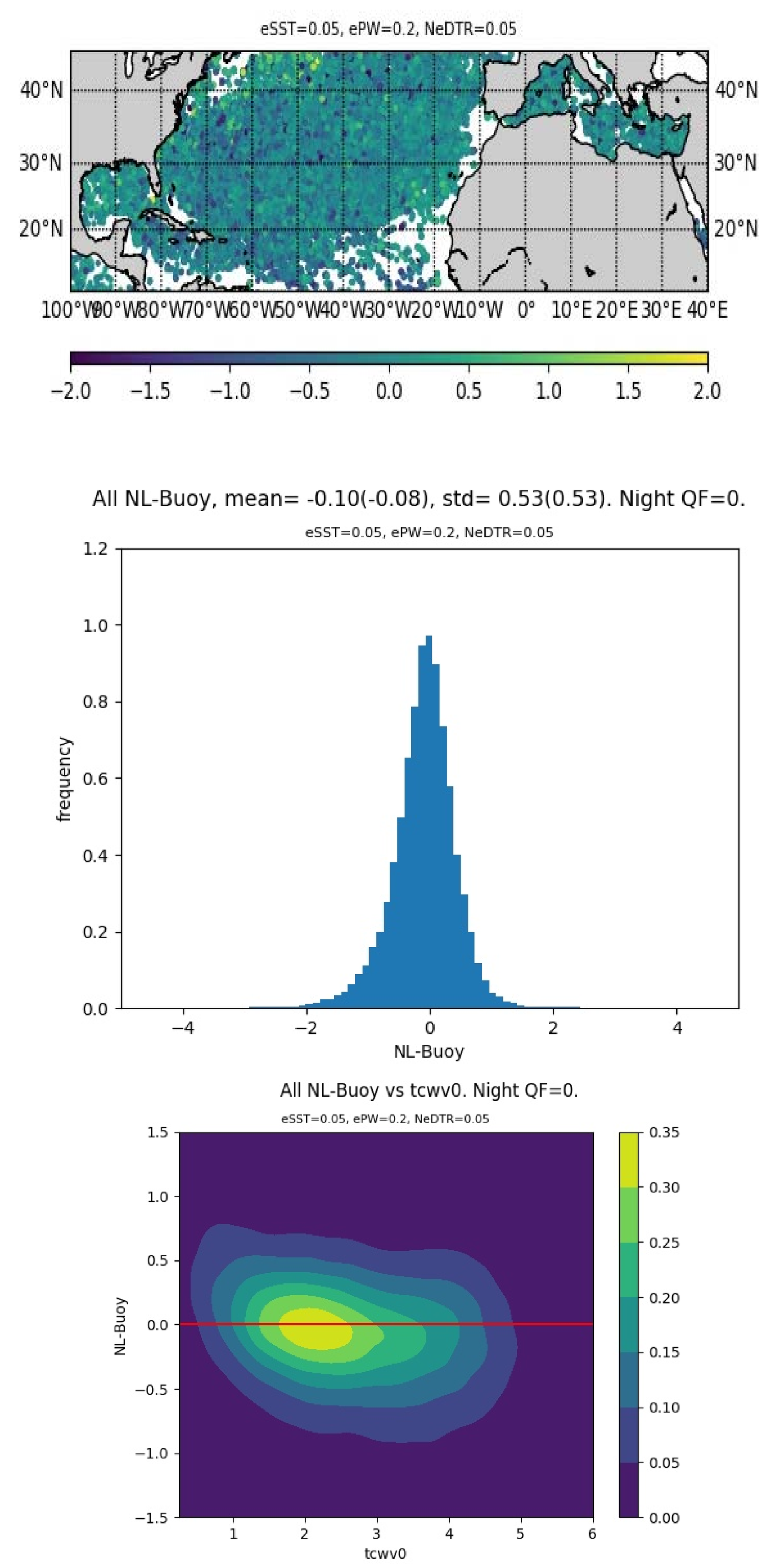
Elements of the OE approach:

OE is applied to retreival of sea surface temperature (SST) from MODIS AQUA radiance measurements in 11 μm and 12 μm channels. Prior knowledge is a state vector consisting of European Center for Medium Range Weather Forecast (ECMWF) ERA-5 reanalysis fields of sea surface temperature and column water vapor $\mathbf{x}$ = (SST, TCWV), and prior observations is a set of MODIS channel 31 (11 μm) and 32 (12 μm) radiances calculated using a radiative transfer model (RTTOV) for the a priori state vectors. RTTOV was also used to compute the partial derivatives of the channel radiances with respect to the elements of the state vector (Jacobian matrices). We treat the covariance matrix of forward modelling and observations, and covariance matrix of prior information as parameters of the retrieval. 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}.

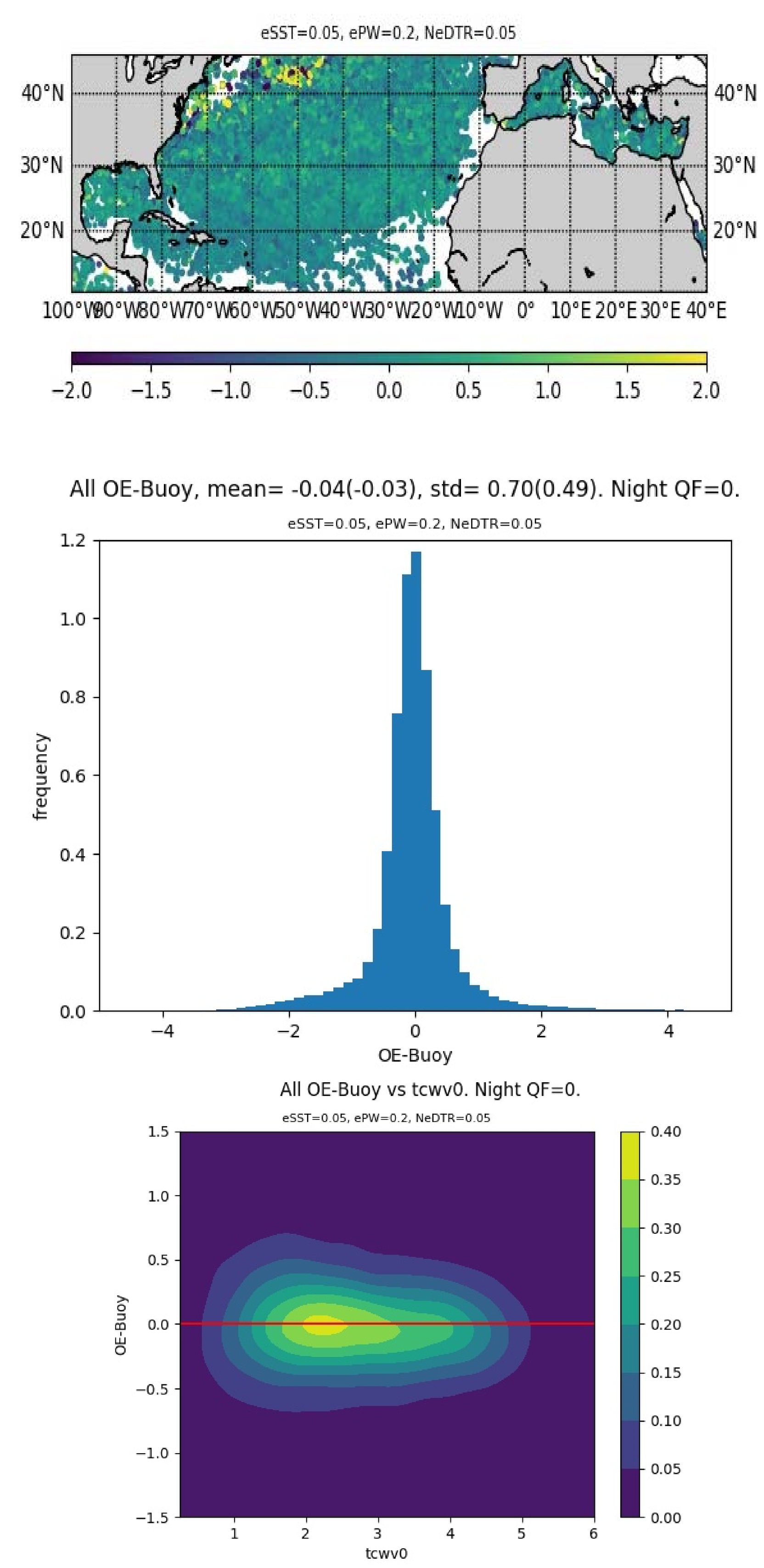
Results

The first panels of the figures below show maps of the difference between the MODIS SST_{skin} (NLSST or OESST) and a validation temperature measurement where buoy measurements are converted to skin temperature by subtraction of 0.17 K, and the radiometer measurements are unchanged. Only night-time measurements are considered. The second panel shows histograms of the temperature differences, and the third panel shows density distribution of the [ΔSST, TCWV] pairs where ΔSST is either NLSST - in situ (ΔNL) or OESST - in situ (ΔOE). The left pairs of figures shows the results for match-ups with quality flag QF = 0 (highest) and on the right are the results for QF = 1. Parameters of the OE model were $NE\Delta T$ = 0.05 K, e_{SST} = 0.05 K and e_{WV} = 0.2.

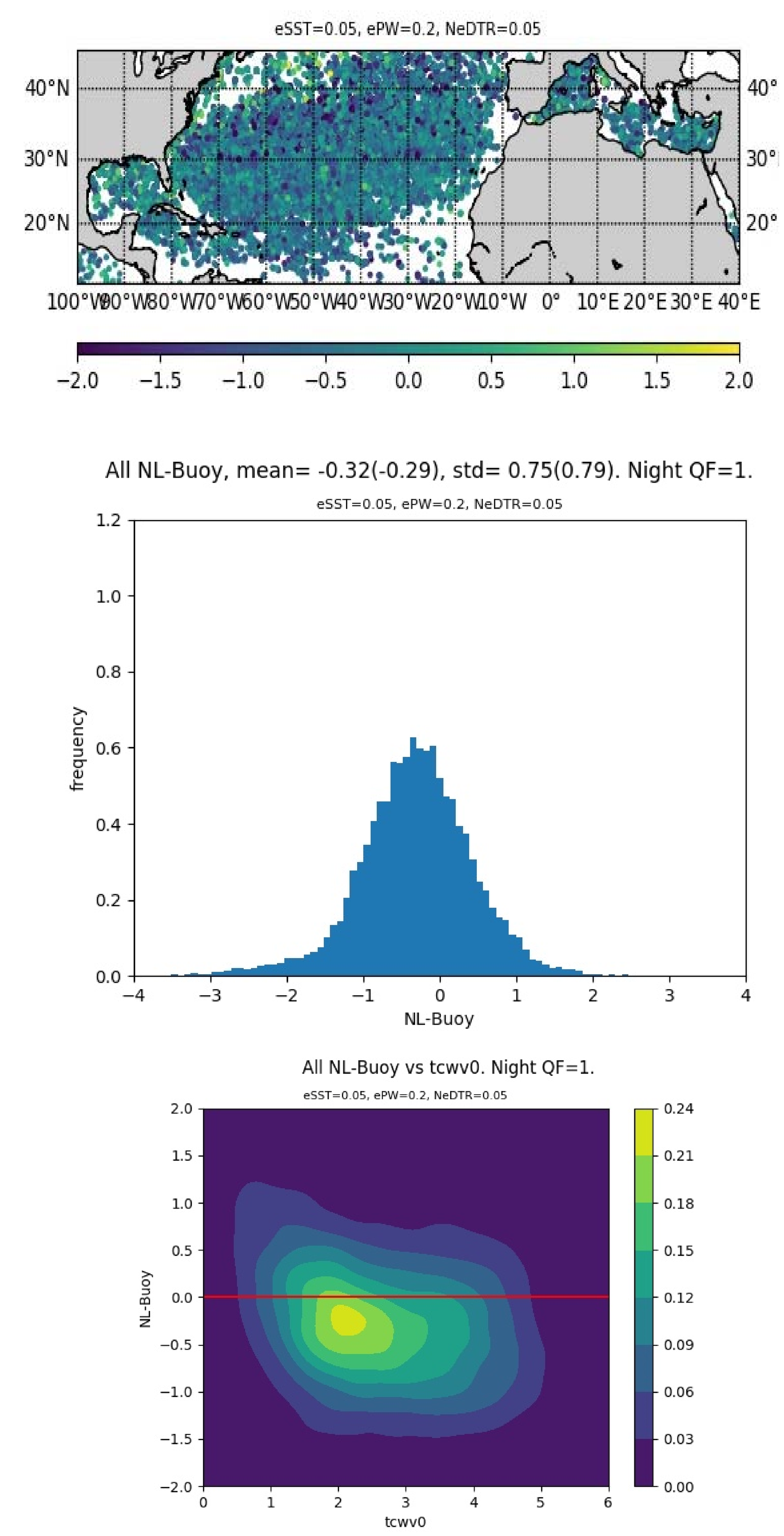
NLSST – Buoy, QF=0.



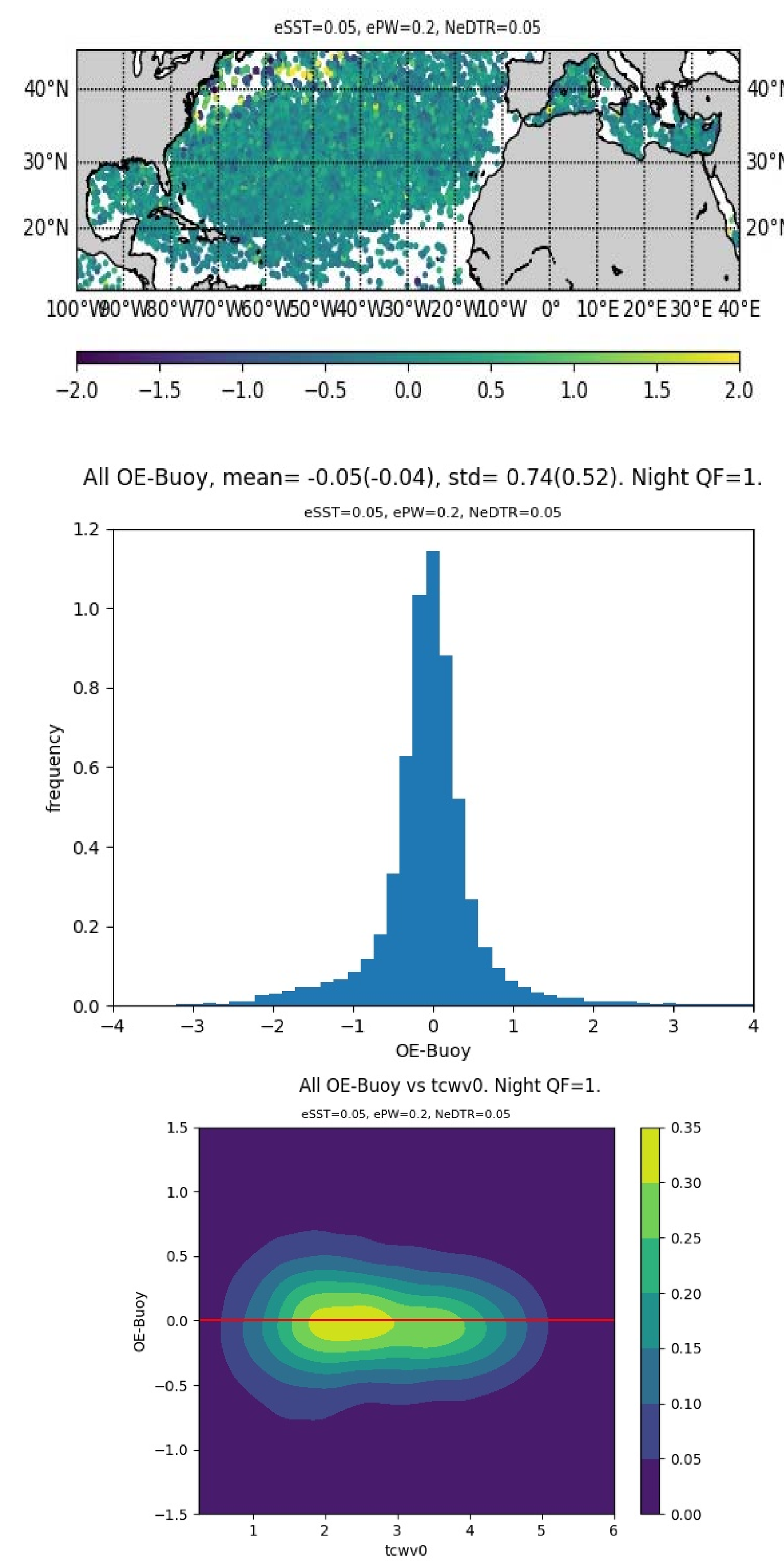
OESST – Buoy, QF=0.



NLSST – Buoy, QF=1.



OESST – Buoy, QF=1.



Mean and standard deviation of ΔNL and ΔOE are given in the histogram plots together with the robust values in parenthesis. There is a significant improvement in the accuracy of the retrieved SST when OE is used for QF=1 match-ups but only modest improvement for QF=0. If we define improvement in SST retrieval accuracy through use of OE as | ΔOE| < |ΔNL| then improvement is achieved for about 66% of QF = 1 match-ups but only for about 22% of matchups with QF = 0. Mean value of ΔNL for the QF = 0 match-ups that were not improved by OE is 0.03 K and mean value of those that were improved is -0.20 K.

The contour plots indicate that OE retrievals are largely independent of the TCWV but NL tends to retrieve warmer SST in dry atmospheres and colder SST in moist conditions both for QF = 0 and 1.

There is a observable warm bias in both NL and OE SST along the north-west edge of the considered domain. Although it appears in both ΔNL and ΔOE it seems to be stranger in ΔOE. It could be due to the ECMWF SST flied that underlies the OE retrieval not accurately capturing the northern branches of the Gulf Stream.

Summary and Conclusions

For the AQUA MODIS data considered in this study:

- For the best quality match-ups the OE SST estimates are only slightly more accurate than the NLSST.
- There is a significant improvement in accuracy for QF = 1 match-ups.
- The OE approach is much more computationally intensive than NLSST so maximum benefit would be achieved if it is used specifically when NLSST performs poorly i.e. extremely dry or moist atmospheres, QF = 1 conditions.
- The OE is sensitive to the a priori fields and large errors in the first guess will transfer to the retrieval (at least if only one iteration is performed).