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Aerosol Impact on Infrared METOC Data Assimilation

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LONG-TERM GOALS

This work addresses the impact of radiatively-important aerosol particle features on radiance assimilation procedures used in ESPC model components (NAVGEM and HYCOM). Mineral dusts, in particular, are active infrared absorber/emitters, with layer heights regularly reaching to and above 5 km above mean sea level. Our effort focuses on characterization of dust impact on thermal/water vapor profile radiance-based retrievals in the tropical Atlantic, which is frequently subject to large dust storm intrusions from the nearby Saharan Desert. We further examine the impact of optically-thin cirrus clouds on these processes, including sea surface temperature bias consistent with previous work, as ancillary unscreened and uncharacterized components of the column-integrated radiance profile.

OBJECTIVES

The primary objective of this research is to develop quantitative estimates for aerosol particle radiance bias on infrared retrievals used as data assimilations inputs for ESPC model components. These results will serve as the basis for a VTR for radiatively-active aerosol particles in NAVDAS and NAVDAS-AR assimilation systems for COAMPS and/or NAVGEM and NCODA for HYCOM. We focus our experiments on mineral dusts, given their relative global frequencies of occurrence, their relatively

high corresponding optical thickness, and common layer top height depths near/above 5 km MSL that enhances their activity at infrared wavelengths.

A secondary task is the concurrent analysis of optically-thin cirrus cloud contamination of infrared METOC radiance-based retrievals. Exhibiting visible optical depths < 0.3, these clouds are transparent in satellite-based radiometric imager and sounder datasets, and thus go unscreened in datasets used for current radiance assimilation procedures in NAVGEM and HYCOM. Similar to aerosols then, though clearly unresolvable by current METOC models, they represent an inherent signal that can be conceptualized and reported for ranges of potential bias in unfiltered assimilation-input datasets. Consistent with previous work investigating the impact of unscreened dust particle presence on sea surface temperature retrievals, we solve corresponding SST-retrieval bias for unscreened optically-thin cirrus presence using a forward radiative transfer model.

This work will establish the "limits of detection" from hyperspectral infrared sensors with respect to aerosol and optically-thin cirrus presence. A next step toward a fully interactive system, which is beyond the scope of this project, requires additional development of radiative transfer, requiring an examination of the translation of infrared radiance to temperature and moisture with respect to various dust parameters such as particle size. These sensitivities, called Jacobians, provide derivatives describing changes of radiance caused by changes in the particle size, type, and amount. Some simple approximations to these Jacobians can be performed within the limits of the experimental design.

The first year of this project was dedicated to an analysis of satellite and surface-based observations of dust plume occurrence and advection over the tropical Atlantic, and thus an aggregation of datasets collected by the CALIPSO satellite lidar, MODIS and VIIRS satellite radiometric imagers, IASI, AIRS and CrIS hyperspectral infrared satellite profilers, AERONET sun photometer network and the Micropulse Lidar network. These data have then been paired with NAVGEM and NAAPS output to develop a 1D-VAR experimental assimilation procedure that evaluates the limits of detection for dust presence and sensitivity of thermal/moisture profiles to dust infrared bias. Further analysis was conducted for SST bias in the presence of unscreened thin cirrus.

The second year of the project is focused on conducting experiments using the 1D-VAR radiance assimilation procedure using case study datasets compiled in Year 1. Further, a control dust aerosol profile case is built from CALIPSO climatological observation to establish a background for simultaneous evaluation and comparison. Tests will be conducted to determine if biases in surface temperature, boundary layer height, and temperature or moisture profiles can be attributed to dust radiative effects, dynamics, or both, and how these vary in magnitude versus background. Dust Jacobians will be approximated relative to NAAPS for the composite infrared satellite sounding profilers. We will then pair NAAPS with NAVGEM/NAVDAS-AR to evaluate basic implementation of a coupled system, and a comparison of orders of magnitude for operational impact of thermal/moisture profile bias compared with our experimental results.

APPROACH

We apply a three-phase approach to solving and evaluating dust infrared bias on thermal infrared sounder profile assimilation for NAVDAS and NAVGEM. The first phase considers field datasets generated from combined satellite/ground-based measurements. An example for this is shown in Fig. 1 for 29 July - 7 August 2012. A ground-based Micropulse Lidar Network instrument at Tenerife Island, just off the West African coastline, profiled a nearly ten-day dust propagation event (Fig. 1a).

Superimposed on these data are virtual potential temperature contours, which allow for simply depicting the depth of the Saharan Air Layer. We then pair with this multi-day composite information from the CALIPSO and MODIS satellites (Figs. 1b-c; 2 August), which provides three-dimensional perspective on the spatial extent of the plume. These data, now including DEBRA geostationary dust identification composites (Fig. 1d; 31 July), are paired with NAAPS, both as verification of model fidelity at the time of dust mobilization, and to conceptualize the spatial/temporal extent of the event.

The second and third phases of the analysis reflect the consideration of NAAPS analyses and background climatological profiles for regional dust in the tropical Atlantic. Whereas the first phase provides our best estimates of truth, NAAPS skill and representativeness can be evaluated, and thus practical recommendations made toward a proper coupling of NAAPS with NAVDAS in potential operations. Further, both the model and case study datasets can be considered in context relative to background climatology. In other words, for a given case study, and series of results derived, we can determine how conditions compare with expectation, and therefore report our findings relative to control and likely persistence.

A 1-Dimensional Variational (1D-Var) retrieval is developed as a practical and reasonable proxy for the operational system assimilating thermal sounder data. The retrieval can use observation and background errors from the operational assimilation system (NAVDAS or NAVDAS-AR) to assess how a given profile of dust affects surface temperature, and the temperature and moisture through the atmospheric column. Each of the three-phase inputs to such a system can be co-located with NAVGEM model atmospheric profile and surface state, and IR hyperspectral radiances from IASI, AIRS and/or CrIS. This tool will be a major step towards the development of a fully interactive dust assimilation system combining AOD assimilation with that of the IR radiances.

The areas of highest interest will be at the dust boundary where a subset of IR radiances both with and without dust contamination can be examined. The fundamental goal of the project is to quantify and understand the impact of assimilating dust-contaminated radiances when the radiative effects of the dust (and/or thin cirrus) have not been taken into account. An examination of these cases with the 1D-Var system will provide the quantification needed to define temperature and moisture error in the vertical in the presence of dust. Further, the examination of the observations themselves will give an estimate of ranges of radiance deviations as a function of aerosol loading.

The work described to this point utilizes only the NAVGEM and NAAPS models and forecasts, due to the development status of NAVDAS for COAMPS. However, we will seek to integrate COAMPS within the verification paradigm (i.e., paired with satellite and ground observation) in anticipation of future DA developments and for comparison with NAAPS. Saharan dust storms will be simulated at 1/3 degree resolution with NAAPS for each of the case studies applied. COAMPS will be used at 18 km resolution for detailed simulations of the dynamics and dust of the same period. This period will allow verification of the models over a number of dust events during the peak impact time of the year and take advantage of the NRL/NASA HS3 mission dataset. This notably includes evaluation of thermodynamic characteristics corresponding with the Saharan Air Layer. Our expectation is that inclusion of direct aerosol effects in DA systems will produce measurable improvement in NAVGEM skill. We seek to identify and quantify corresponding mechanisms for model improvement where applicable.

WORK COMPLETED

FY14 activities focused on case study identification for significant dust propagation over relatively clear skies and at significant altitude, so as to evaluate potential radiance bias in thermal sounder profiling datasets. A 1D-Var radiance assimilation model coupled with a forward radiative transfer model was also developed to conduct experiments in FY15 evaluating dust mass concentration profiles relative to thermal radiance contamination. Further, as follow-on to previously-funded research, we brought optically-thin cirrus cloud contamination calculations up-to-speed with previous evidence for radiance bias in sea surface temperature retrievals over the tropical Atlantic. Two publications came out of this effort: *Bogdanoff et al.* (2014) and *Campbell et al.* (2014).

1. As shown in Fig. 1, we have identified 26 July – 10 August 2012 as our primary case study for this project. To that end, and consistent with our Work Plan proposed, we have compiled available ground, satellite and model-based observational analyses to best characterize the dust transport event off the West African coast over the eastern Tropical Atlantic. This includes CALIPSO, MODIS, VIIRS, CrIS, IASI, DEBRA, AERONET, MPLNET, NAVGEM, NAAPS datasets and local radiosonde profiles. Dust mobilization is characterized by satellite radiometer measurements (MODIS, VIIRS and DEBRA) over Sahara beginning the 26th. By, the 29th, ground observations at the Tenerife site begin for profiling the advecting layer, including satellite profiling via CALIPSO. The event continues at Tenerife through the 8th. We have developed a working relationship with the Spanish Instituto Nacional de Técnica Aeroespacial (INTA; C. Cordoba-Jabonero), allowing us access to raw ground-based lidar and sun photometer measurements aside from those products made available publicly through MPLNET and AERONET. Presently, we are providing CALIOP-based satellite lidar profiling to help INTA calibrate the Tenerife lidar, in order to have more accurate mass concentration profiles than their current calibration suite has provided.
2. We designed a coupled forward radiative transfer model and sea surface temperature retrieval system for evaluating the potential bias due to unscreened optically-thin cirrus clouds. The system considers a hypothetical cirrus cloud 1.75 km thick with cloud top heights varying between 10.5 and 16.5 km above mean sea level and optical depths between 0.0-0.3 (Fig. 2). This conceptual model thus evaluates potential bias for any number of possible cloud occurrence scenarios in the tropics. Such optically-thin cirrus occur upwards of 70% in the tropics, with most cloud going unscreened in passive radiometer composite datasets.

RESULTS

FY14 results based on work completed are as follows

1. Pending. Through the work plan, applying 1D-Var assimilation system and conducting experiments evaluating potential radiance contamination from Saharan dust event will be FY15 priorities.
2. We have solved radiance bias in sea surface temperature retrievals for hypothetical cirrus cloud in tropics, 1.75 km deep with effective ice crystal radius of 20 and 40 μm, as function of cloud top height and optical depth (0.0 to 0.3 for optically-thin clouds). Bias ranges between 0-8 K within this range if the clouds and or retrievals themselves are not flagged. This bias propagates through assimilation systems and potentially into METOC models like HYCOM. We are awaiting public release on *Geophysical Research Letters* paper before submitting,

which conceptualizes this problem. We use Aqua MODIS collocated with CALIOP to describe the frequency of optically-thin cirrus cloud occurrence in tropics relative to number of unscreened aerosol optical depth retrievals. These data provide a proxy estimate of contamination potential in sea surface retrieval datasets available for assimilation. Approx. 92% of all MODIS 10x10km pixel composites contain cloud. Optically-thin clouds go unscreened, however, roughly 15% of the time over water, at a median cloud optical depth near 0.05. This suggests that the majority of unscreened cases for optically-thin cirrus produce a sea surface temperature bias of between 1-3 K, which is reasonably low enough so as to escape any supplemental QA applied to these data before assimilation.

IMPACT/APPLICATIONS

Current NAVO sea surface temperature retrievals used for HYCOM come from VIIRS, which is difficult to evaluate for potential cloud contamination (no collocated lidar instrument, as opposed to Aqua MODIS). We are communicating with product developers there to investigate potential strategies for bias mitigation.

TRANSITIONS

n/a

RELATED PROJECTS

n/a

PUBLICATIONS

Bogdanoff, A, D. L. Westphal, J. R. Campbell, J. A. Cummings, E. J. Hyer, J. S. Reid, and C. A. Clayson, 2014: Impact of airborne dust on sea surface temperature retrievals, *Rem. Sens. Environ.*, *in revision*.

Campbell, J. R., A. Bogdanoff, D. L. Westphal, R. E. Holz, M. Oo and J. A. Cummings, 2014: Conceptualizing sea surface temperature retrieval bias from unscreened optically-thin cirrus clouds, *Geophys. Res. Lett.*, *pending public release*.

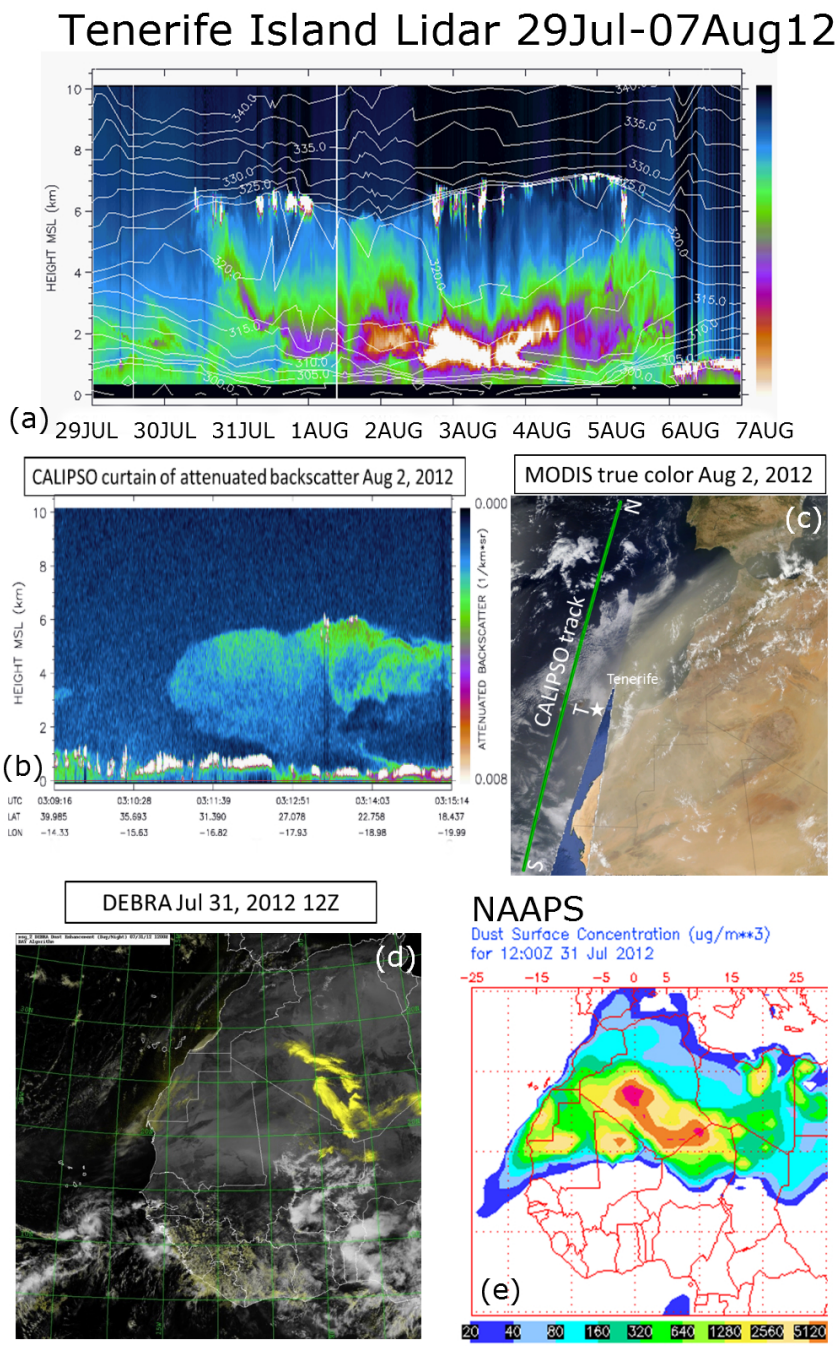

Figure 1: (a) NASA Micropulse Lidar Network measurements of Level 1 normalized backscatter at the Tenerife site for 29 July – 7 August 2012, including virtual potential temperature contours solved from local radiosonde profiles superimposed in 5 K increments. (b) NASA CALIPSO satellite lidar profile of Level 1 attenuated backscatter for a nighttime pass off the West African coast on 2 August 2012. Levels of enhanced backscatter through 6 km MSL reflect a dust layer consistent with that seen in (a). (c), NASA MODIS radiometric true-color image corresponding with morning after CALIPSO pass (superimposed) on 2 August 2012. (d) DEBRA geostationary satellite retrievals of enhanced dust presence (yellow). (e) NAAPS dust surface concentration alaysis for 12 Z 31 July 2012 over wsest Africa.

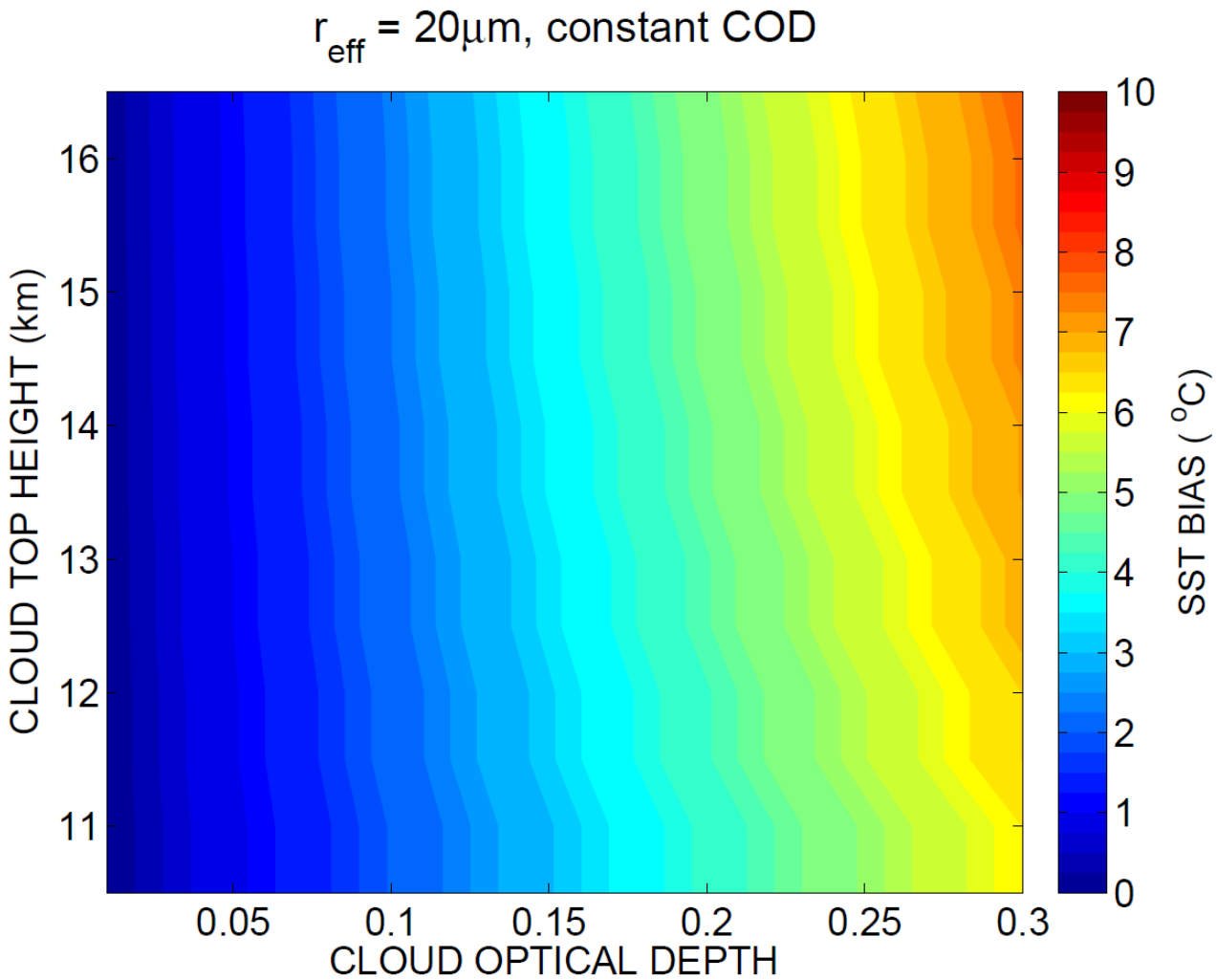

Figure 2: Conceptual estimates of sea surface temperature bias (see color bar) for a hypothetical cirrus cloud 1.75 km deep with 20 µm effective radius using a tropical standard atmosphere, based on Bogdanoff et al. (2014) and Campbell et al. (2014). Solutions vary as function of cloud top height and optical depth, as shown. The range of optical depths chosen coincides with optically-thin cirrus clouds that regularly go unscreened in passive satellite imager datasets, and thus propagate as noise through NWP/METOC infrared radiance assimilation procedures.