Analysis of Observed and Modeled Surface Fluxes, Cloud Forcing, and Convective Processes for Improving The Meteorological And Oceanographic Modeling And Prediction Systems

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LONG TERM GOAL

The United States Navy is the Department of Defense's main source for standard meteorological and oceanographic (METOC) predictions. At the heart of these predictions are the short-to-medium range weather forecasts produced by the Navy Operational Global Atmospheric Prediction System (NOGAPS; Hogan and Rosmond, 1991). Surface flux fields from NOGAPS forecasts are used as input to the oceanographic prediction systems. These systems include: 1) the Thermodynamic Ocean Prediction System, 2) the Polar Ice Prediction System, and 3) the Third Generation Wave Model. Given the prominent role surface fluxes play in these systems, it is clear that their proper simulation by NOGAPS is vital. Presently, there are significant shortcomings in the NOGAPS simulation of most ocean surface heat flux components (long-term mean biases greater than 50 Wm^{-2} in many tropical/subtropical areas). The long term goal of this research is to determine the underlying causes for these shortcomings in order to: 1) enhance NOGAPS physical representation of the atmosphere and extend the skill of its medium range weather predictions, and 2) improve the skill of the oceanographic and coupled prediction systems via the improved simulation and prediction of the surface energy budget.

OBJECTIVES

The objectives of this research are to analyze and improve the model representation of ocean surface fluxes and the associated convective/radiative processes. Meeting these objectives includes the following: 1) Compare and analyze observations and NOGAPS model output of cloud characteristics, rainfall, precipitable water, surface latent heat flux, and top of the atmosphere (TOA) and surface radiative fluxes to help identify the parameterizations and processes which underlie the model surface heat flux biases; 2) Identify, develop and improve observational data sets over the ocean, particularly shortwave data, that can be used for model-data diagnostics studies; 3) Use the observed data sets in conjunction with research versions of NOGAPS, high resolution cloud-resolving models [e.g., Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS)], and/or single-column models to diagnose the shortcomings in the physical parameterizations, to help focus model development efforts, and even help assess the observational strategies associated with extensive atmospheric field programs, such as the Atmospheric Radiation Measurement (ARM) program and the Coupled Ocean Atmosphere Response Experiment (COARE).

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APPROACH

The approach taken in this research effort can be broken down into the following parts:

1) Assemble satellite-based and ground-based verification data sets for diagnostics comparison of NOGAPS simulation output. Such data sets include the ERBE products, ISCCP cloud products, MSU precipitation, SSM/I precipitable water, analysis-based dynamic fields, ship-based surface heat flux climatologies, as well as satellite surface shortwave data sets. Perform the analysis/comparison on the climatologies of the NOGAPS output and the available observations. Focus the analysis on those areas that show greatest discrepancies with observed data and consider the linkages between the hydrologic, energy and dynamical components of the system in order to try and identify the underlying causes for the surface flux biases in the model.

2) Using buoy-observed values of surface shortwave flux and a single-column version of the NOGAPS radiation code, validate the modeled clear-sky surface solar radiation flux values. This comparison will help to isolate the causes of the shortwave flux biases. The principle reason for focusing on the clear-sky values is that the (large) uncertainty in specifying the observed cloud amount is removed, and thus the results from the comparisons are easily interpreted. One of the main steps in accomplishing this task is assembling a robust open-ocean set of shortwave observations, necessarily from moored buoys, and to filter out the cloudy periods from these buoy-observed records of shortwave flux.

3) Use the high-resolution cloud-resolving COAMPS model as a form of synthetic observations in conjunction with the variational analysis of Zhang and Lin (1997) to examine the sensitivity of atmospheric field program data on spatial and temporal sampling characteristics. Typically, data from field programs such as ARM and COARE are used to calculate vertical velocities and advective tendencies that can then be used to study large-scale processes and budgets, examine the subgrid-scale influence on the resolvable fields, or assess model parameterizations, usually in conjunction with single-column models. The variational scheme analysis produces the "best" adjustments to the observed data (which are influenced by small-scale variability and sampling errors) so it conserves mass, moisture, momentum and energy. Used in conjunction with COAMPS output, sampled in a manner consistent with a field program (i.e. sounding array), one can examine the sensitivity of the data adjustments and determine the optimal temporal and spatial sampling strategies for the processes under study, and thus obtain the most utility from the data.

4) From the model-observation comparisons described above, and in collaboration with the NRL modeling teams, determine the underlying causes for the NOGAPS parameterization deficiencies that underlie the surface flux shortcomings, suggest improvements in the model formulations, and re-analyze the new simulations based on the improved physical parameterizations.

WORK COMPLETED

All of the tasks associated with Part 1) of the APPROACH have been completed. This analysis was performed on a 15-year simulation from the NOGAPS model (Version 3.4) conducted by Dr. Timothy Hogan (NRL).

All of the tasks associated with Part 2) of the APPROACH have been completed. This analysis was performed on five two-year time series of buoy-recorded surface shortwave from the ONR-supported Subduction Experiment (Moyer and Weller, 1997) conducted in the tropical Atlantic.

The research team necessary to undertake the tasks associated with Part 3) of the APPROACH has been assembled and preliminary, high-resolution (1-km) COAMPS simulations and associated variational analyses on the "synthetic soundings" have been completed. Besides the PI, the research team includes Dr. James Ridout (NRL), Dr. Shaocheng Xie (LLNL), Dr. Minghua Zhang (SUNY).

With respect to Part 4) of the APPROACH, collaboration with Dr. James Ridout (NRL) has resulted in the analysis of a number of convection parameterization sensitivity tests in a research version of NOGAPS to try and correct the shortcomings in the convective parameterization. While a number of cases show noteworthy improvements (see WWW address), continuation and implemen-tation of this work has awaited more elaborate testing in an operational-like setting of NOGAPS which can only be performed by the Global Modeling Section. This additional testing is to ensure that in addition to improvements obtained by the given changes in the convective parameterization, no other aspects of the model predictive skill suffer (e.g., tropical cyclones, frontal systems, etc.).

RESULTS

The results pertaining to Part 1) of the APPROACH were described in previous reports and can now be found in Waliser and Hogan (1999).

The results pertaining to Part 2) of the APPROACH are reported in Waliser et al. (1999a). This article describes the method developed to filter out cloudy samples from buoy-observed shortwave records using International Satellite Cloud Climatology Project (ISCCP) DX cloud data, along with additional constraints, and then demonstrates how the resulting clear-sky values can be used to help validate radiation parameterizations from a numerical model. At present, the validation has been done for both the National Center for Atmospheric Research Community Climate Model (Version 3) and for NOGAPS using five two-year buoy records from the Subduction Experiment (see ONR grant N00014-90-J1490; PI: R. Weller). The results of the direct model-data comparisons were reported in the previous report. Additional results stemming from this study include support for the suggestion that current atmospheric radiation theory does not properly account for the amount of shortwave absorption in the cloudy atmosphere (e.g., Cess et al., 1995). Figure 1 shows the ratios of the shortwave cloud forcing at the surface and the TOA at four Subduction Experiment buoy sites. The former is derived using the methodology and analysis in Waliser et al. (1999a), while the latter is derived from the Earth Radiation Budget Experiment (ERBE). Note that most current general circulation models (GCMs) have ratios on the order of 1.1 to 1.2 (including NOGAPS), implying that too little shortwave energy is being deposited directly into the model atmosphere. In addition, the method developed to filter out cloudy samples from buoy-observed shortwave records, in conjunction with the good agreement found between modeled and observed clear-sky surface shortwave values (~1%), provides the capability to remotely monitor the working condition of ocean buoy-mounted shortwave radiometers in real-time by using clear-sky model calculations and satellite retrievals of cloudiness and water vapor along with other surface meteorological parameters. The latter of which can be obtained via global analyses or from the buoy if they are available and transmitted in real-time.

Preliminary results pertaining to Parts 3) and 4) of the APPROACH can be found at the WWW address listed above.
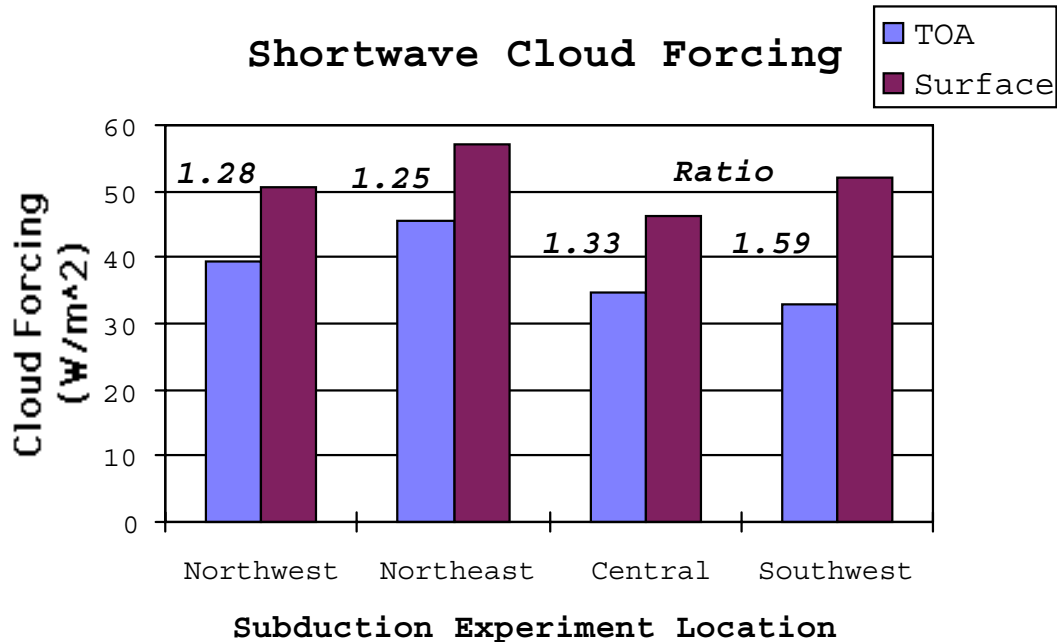
Shortwave Cloud Forcing

Figure 1. Surface and top of the atmosphere mean shortwave cloud forcing values for the Northwest, Northeast, Central, and Southwest Subduction buoy locations. Surface values are derived from the all-sky buoy observations and modeled clear-sky values. TOA values are derived from a weighted-mean of ERBE climatology, where the weighting is based on the data periods available from the buoys. Number listed for each buoy is the ratio between the surface and TOA cloud forcing values. The locations of the Northwest, Northeast, Southwest, and Central buoys are: $33^oN, 34^oW; 33^oN, 22^oW; 18^oN, 34^oW; $ and 25.5^oN and 29^oW.

IMPACT

The results from the NOGAPS analysis point to the convective parameterization as the major shortcoming underlying the model biases in the surface heat fluxes, and indicate how it also negatively impacts the large-scale circulation, the rainfall, surface wind, and cloud fields, and possibly even the simulation of intraseasonal variability. Remedying these shortcomings will: 1) improve NOGAPS physical representation of the atmosphere and extend the skill of its medium range weather predictions, and 2) improve the skill of the oceanographic predictions via the improved simulation and prediction of the surface fluxes.

The added observational support for the suggestion that shortwave absorption by clouds is not properly treated in GCMs intensifies the need for immediate and continued study into this issue, especially since artificial inclusion of this effect into GCM climate simulations shows significant effects on the general circulation of the atmosphere and the surface energy budget (Kiehl et al. 1995).

When implemented in an operational setting, the methodology developed to remotely monitor the working condition of moored shortwave instruments in real-time can help detect instrument failure, degradation or bio-fouling that would necessitate immediate maintenance and/or prevent routine maintenance on the sensor when unnecessary.

TRANSITIONS

The success and utility of the buoy-based shortwave analysis has led to the application of this study's techniques to the assessment of the overall, in-field working condition of nearly all of the available high-quality, open-ocean, buoy shortwave records (e.g., Frontal Air-Sea Interaction Experiment (FASINEX) [Weller, 1991], BioWatt [Dickey et al., 1993], Marine Light Mixed Layer Experiment (MLML) [Plueddemann et al., 1995], Coupled Ocean Atmosphere Response Experiment (COARE) [Weller and Anderson, 1996], TOGA TAO [McPhaden, 1995]). Collaborators on this continuation study include R. Weller (WHOI), M. McPhaden (PMEL/NOAA), and B. Wielicki (NASA).

RELATED PROJECTS

The PI has also investigated the simulation quality of the Madden-Julian Oscillation (MJO) in the NOGAPS model. This intraseasonal phenomenon has significant influence on tropical rainfall variability and the onset and breaks of the Asian-Australian monsoons, as well as minor influence on long-range mid-latitude weather forecasts. Dr. Hogan (NRL) has supplied daily output for a number of variables from the same NOGAPS simulation described above in order to assess the simulation of this process. Preliminary study indicates the NOGAPS model performs poorly with respect to the simulation of this phenomenon, although Slingo et al. (1996) has found that a majority of atmospheric models examined exhibit equally poor MJO simulations.

To help address the shortcomings in model simulations of the MJO, a statistical model for extended-range tropical rainfall has been developed using outgoing longwave radiation (OLR) in an effort to provide a benchmark for the skill of long-range predictions of the MJO (Waliser et al. 1999b). Comparison of this statistical benchmark with extended-range forecasts from the NOAA/NCEP medium-range forecast (MRF) model shows that the statistical model performs considerably better. These results indicate that considerable advantage might be afforded from the further exploration and eventual implementation of MJO-based statistical models to augment current operational long-range forecasts in the tropics. The comparisons also indicate that there is considerably more work to be done in achieving the likely forecast potential that dynamic models might offer if they could suitably simulate MJO variability (Jones et al., 1999). In addition, the PI has investigated the influence of ocean surface coupling on the simulation of the MJO and found that considerable improvement can be afforded by such coupling (Waliser et al. 1999c). These improvements include: 1) increased variability associated with the MJO, 2) a tendency for the MJO time scales to more closely match those found in the observations, 3) a reduced eastward phase speed in the eastern hemisphere, and 4) an increased seasonal signature in the MJO. Efforts are now underway to examine the influence of this ocean coupling in extended-range forecasts from the NOAA/NCEP MRF model.

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