ESPC Coupled Global Prediction System

James G. Richman
Oceanography Division, Code 7323
Naval Research Laboratory
Stennis Space Center, MS 39571
phone: (228) 688-4933 fax: (228) 688-4759 email: james.richman@nrlssc.navy.mil

Timothy R. Whitcomb
Marine Meteorology Division, Code 7532
Naval Research Laboratory
Monterey, CA 93943
phone: (831) 656-4812 fax: (831) 656-4769 email: timothy.whitcomb@nrlmry.navy.mil

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LONG-TERM GOALS

Develop and implement a fully coupled global atmosphere/wave/ocean/land/ice prediction system capable of providing daily predictions out to 10 days and weekly predictions out to 30-90 days. Initial Operational Capability is targeted as 2018. Predictions will provide environmental information to meet Navy and DoD operations and planning needs throughout the globe from undersea to the upper atmosphere and from the tropics to the poles. The system will be implemented on Navy operational computer systems, and the necessary processing infrastructure will be put in place to provide products for Navy fleet user consumption.

OBJECTIVES

Develop and implement a coupling infrastructure and interoperability layer to enable the component models to exchange information needed to make global earth system predictions. For each of the component models, develop and test coupled physical parameterizations and emphasize testing of new feedback loops that arise in the coupled system. Implement the tripolar grid for WaveWatch-III and wave forcing in the ocean. Incorporate time-dependent, radiatively active, and cloud-nucleating aerosols into NAVGEM for use in long-term simulations and forecasts and for use in the full coupled system.

APPROACH

There are five tracks for this project. Key performers for coupling infrastructure and interoperability layer extensions are Timothy Whitcomb (NRLMRY), Alan Wallcraft (NRLSSC), and James Chen

(SAIC). Oceanography and meteorology leads for coupled physical parameterizations for NAVGEM/HYCOM are James Richman (NRLSSC) and James Ridout (NRLMRY). Key performers for coupled physical parameterizations for NAVGEM/CICE/HYCOM are Pamela Posey (NRLSSC), Shouping Wang (NRLMRY), and Neil Barton (NRLMRY). Key performers for coupled physical parameterizations for NAVGEM/WaveWatch-III/HYCOM are Erick Rogers (NRLSSC), Alan Wallcraft (NRLSSC), Yalin Fan (ASEE/NRLSSC), and Dan Moore (Imperial College). Key aerosol physics performers are Ming Liu (NRLMRY) and Douglas Westphal (NRLMRY)

A necessary first step in the development of a coupled modeling system is the establishment of a coupling infrastructure. We use the Earth System Modeling Framework (ESMF) library as the foundation, and use additional capabilities from the "NUOPC Layer" (based on coordination work in the National Unified Operational Prediction Capability) that provides a set of conventions and shared routines to manage the model and coupler components, march model components in terms of the coupling time scale, conduct automated compatibility checking to ensure matched import/export fields, and to provide a platform to easily develop customized couplers. The synergistic development of the NUOPC layer and ESPC has allowed the NUOPC layer developers to respond to needs identified by ESPC and leverage ESPC as a testbed for NUOPC developments. The design strategy for ESPC is to limit the impact to the existing NAVGEM, HYCOM, and CICE forecast model systems's code structure and code flow as much as possible. This allows us to maintain agility while the component models are under development, and avoids additional errors due to extensive refactoring.

The Navy atmospheric forecast system (NAVGEM) and ocean-sea ice forecast system (HYCOM/CICE) have never been coupled at high resolution. The coupled processes will be incrementally tested by examining each step of the feedback loops. A range of physical processes will be included and excluded to ensure proper interactions between these processes. Both short term (10 day) and long term (30 day) tests will be conducted for this work. We will perform tests on NAVGEM and HYCOM in uncoupled, loosely coupled, and two-way coupled modes. The approach for FY14 has been testing different mixing and convection schemes in uncoupled NAVGEM (to address excessive cyclogenesis in extended runs that was identified earlier) and limited testing of the coupled NAVGEM/HYCOM system for the MJO events during the DYNAMO experiment in November, 2011. Initial experiments will occur with each component using its own flux computation which will lead to non-conservation and other undesirable effects. Addressing these issues will require implementation of alternate parameterizations and flux estimates in a new cycle of tests. In addition, the coupled system permits testing additional physical processes at the interface (such as sea-spray effect, dissipative heating, frictional velocity, and surface roughness) and accounting for momentum stress using shear of winds and currents across the interface.

The sea-ice component of this project requires modification of CICE versions 4 and 5 to run in the coupled ESPC global model with NUOPC tools, NCODA routines for sea ice concentration assimilation in the global coupled system, and the coupling algorithm for passing variables from CICE to NAVGEM. Summer seasonal forecasts (out to 5 months) have been run as part of the Study of the Environmental ARctic CHange (SEARCH) Sea Ice Outlook (SIO) effort, which is now managed as part of the Sea Ice Prediction Network (SIPN): these forecasts will be repeated with the fully coupled model.

Coupling the wave model requires integrating wave forcing from WaveWatch III into the ocean model as well as ensuring physical consistency of momentum budgets as atmosphere/ocean fluxes pass through the intermediate wave layer. Initial efforts of coupling wave forcing into HYCOM met with computational challenges. To mitigate the expense, Stokes drift is processed as a vertical profile that's integrated across fixed finite volume layers instead of sampled at fixed depths. New tests will also use a modified mixed layer parameterization (KPP instead of Mellor-Yamada). To ensure consistency with the ocean model, a global tri-pole grid will be implemented in WW3, which requires accounting for an "arctic seam" in the spatial propagation of wave energy. To allow for higher spatial resolution while maintaining scalability, test the proposed "hyper-scaling" (H. Tolman, poster presentation at Waves In Shallow Environments conference, April 2013) technique. Two-way coupled WW3 will be implemented into operational Global Ocean Forecasting System (GOFS) 3.5, thus making it the coupled HYCOM / CICE / WW3 component of ESPC. In addition to the wave-ocean coupling, ice coverage will be imported to WW3 from CICE.

We will incorporate time-dependent, radiatively active, and cloud-nucleating aerosols into NAVGEM for use in long-term simulations and forecasts for ESPC applications. We are relying on approaches, findings, lessons-learned from the NAAPS and COAMPS aerosol implementations. As in NAAPS, we will include the Navy-relevant species of dust, smoke, sea salt, SO_2 and sulfate. We utilize a library of microphysical parameterizations and source inventories and allow for run-time control of microphysical processes, radiative processes, and cloud-interactions.

WORK COMPLETED

We refactored NAVGEM top-level routines to support separate "initialize", "run", and "finalize" phases to be ESMF/NUOPC-compliant (HYCOM already used this structure) and developed top-level NUOPC-compatible drivers to control NAVGEM, HYCOM, and CICE. To avoid factorial growth in the number of couplers required as components are added and need to communicate with every other component, we developed a broker component (a "mediator") to scale the number of couplers as *2N* (where N is the number of components) and allow for operations like consistent flux computation and regridding (since simple interpolation is typically insufficient).

A series of loosely coupled simulations for November 2011 showed excessive cyclogenesis in the atmospheric model after approximately 10 days. We found that the problem persisted in the fully coupled system; it was evidenced in both wind animations and in the mean low-level cyclonic vorticity in the Indo-West Pacific region, which was adopted as a diagnostic for a series of follow-on tests. The coupled system was also found to be deficient in its representation of the MJO, a problem shared to varying degrees with other prediction systems. Tests were carried out with various changes in the NAVGEM physics to address these issues, including tests with the NAVGEM 1.2 physics, the new massflux component of the NAVGEM EDMF scheme, and changes in the treatment of convection and air-sea fluxes.

The coupled atmosphere-ocean system uses a different wind stress parameterization than the uncoupled system. NAVGEM was modified to using the HYCOM wind stress parameterization (COARE 3.0) with the same surface variables (SST and ocean surface velocity) exchanged. The impact of the wind stress change was explored in a series of near twin experiments with uncoupled HYCOM, where the air-sea interaction was mimiced in the stress calculation.

WAVEWATCH III (WW3) has been adapted by NRL to handle computations on a tripole grid for calculation of gradients in input fields (e.g. bathymetry, currents) and for propagation using the model's first order scheme (adaptation of the third order scheme is yet to be implemented). The primary challenge is to allow computations near and across the "Arctic Seam" which stitches the grid rows (with dissimilar grid indices) together at high latitudes. The new functionality is validated, and will will allow WW3 and HYCOM to both be applied on tripole grids together, reducing grid transformation errors during coupling. Work is ongoing to integrate Stokes drift from WW3 into HYCOM.

For the aerosols, we implemented the NAAPS dust source database of erodibility (fractional coverage of erodible area) and the NAAPS mineral dust emission source function. For sea salt we follow NAAPS and use a source that depends on ocean surface winds and relative humidity. In lieu of the relevant microphysical conversion and removal process (deposition, sedimentation, and wet removal) we used linear decay rates.

RESULTS

The impact of the coupled air-sea momentum flux on the ocean circulation has been investigated in a series of near twin experiments, where aspects of the coupled wind stress have been varied. The high resolution SST of HYCOM modifies the boundary layer stability increasing the wind stress by 8% globally. Requiring the stress at the bottom of the atmosphere match the ocean shear stress (inertially coupling the boundary layers) increases the wind stress by 5% globally. The number of eddies generated in HYCOM with the inertially coupled wind stress decreases by 28% compared to the classical wind stress. The decrease in eddy number is coupled with a decrease in the strength of the eddies as measured by their rotational velocity.

The coupled system using the NAVGEM default convection scheme (SAS) was found to exhibit excessive cyclonic vorticity development in our November 2011 reforecasts, as well as too weak eastward propagation associated with the two observed MJO events. We found that the excessive cyclogenesis improved significantly when the Simplified Arakawa Schubert (SAS) convection scheme was replaced using a physics suite that included a modified Kain-Fritsch convection scheme (to couple convection with boundary layer plumes from the NAVGEM eddy diffusivity-massflux mixing scheme) and the Xu-Randall cloud fraction parameterization for stable cloud cover. This physics combination also improved the MJO rainfall, particularly for the MJO event in late November. Changing the bulk air-sea flux scheme in NAVGEM to the HYCOM COARE parameterization improved the MJO rainfall further, as did an enhancement of the modified Kain-Fritsch convection to allow for concurrent deep and shallow convection. The coupled system does not reproduce the dual Kelvin wave structure of the late November MJO event, and other deficiencies persist, but the parameterization changes have shown significant improvements. Additional work is required.

During the summer of 2014, coupled HYCOM/CICE ran in forecast mode without assimilation, and initialized with an ice analysis at the beginning of each month (May 1, June 1, July 1 and August 1, 2014) and atmospheric forcing from Navy Operational Global Prediction System (NOGAPS) from 2004-2013 to determine a seasonal projection of the September 2014 Arctic sea ice minimum. Ice extent estimate was calculated using all grid cells with at least 15% ice concentration and averaged across all ensemble members. For the forecasts initialized from June 1, 2014, the sea ice extent estimates were 4.2 Mkm^2 ± 0.5 Mkm^2 from ACNFS and with a slightly higher estimate of 4.8 Mkm^2 ± 0.4 Mkm^2 from GOFS 3.1. The 2014 sea ice minimum was 5.2 Mkm^2 observed on September 17, which is very similar to the 2013 sea ice minimum.

NAVGEM versions 1.1, 1.2, and the developer's code can now be coupled with CICE version 4 and 5. Comparing the standalone NAVGEM and coupled ESPC global model shows that the ESPC system has a much more spatially variable and realistic sea ice albedo. The coupled system has been used to a short hindcast for 2013 similar to the SEARCH results with HYCOM and CICE. The initial results are encouraging with the coupled system performing well compared to the observed sea ice extent and the HYCOM/CICE only results for a short simulation.

Previous wave work compared the ocean responses to two different wind stresses (one from atmosphere model, the other from the wave model). All other components of the atmosphere forcing were the same with no feed back from the ocean to the atmosphere. During FY14, we enabled three way coupling, using a Gulf of Mexico test case which showed differences from all three components of the coupled system due to the use of the new wind stress for the ocean. Because we allow all three components of the model to envolve as a fully coupled system, we observe larger changes in the ocean currents, SST, and salinity even though the magnitude of surface wind is smaller in this test case compare to the previous Indian Ocean test. The strongest changes (stress, current, SST, wind, latent heat flux) not only occur where the wind is the strongest but also in the loop current and eddy region where the wind is weak. This suggests that strong current systems can modify the wave breaking and dissipation and thus affect stress calculations. COAMPS/NCOM/SWAN are still being used as a proxy here for NAVGEM/HYCOM/WW3, as the coupling infrastructure in the case of the latter models are less mature, and is being implemented and tested in separate efforts.

We conducted a 10-day simulation with 6-h update cycles and compared that with a pure 10-day forecast to test the aerosol restart capability. Atmospheric (not aerosol) data assimilation is included in the update cycle runs. Differences between the two runs are significant in both the dust and salt species, but not unexpected considering the differences in the dynamical forcing. Additional free-running 90-day integrations (to test mass conservation and numerical stability) produced features that appear to be physically reasonable. Tests with single and double-precision treatments in the semi-Lagrangian advection showed little difference in the aerosol mass change over long-term forecasts. Since semi-Lagrangian numerical techniques are non-conserving, additional efforts will be required to mitigate numerical growth or decay in total aerosol mass as a forecast progresses.

IMPACT/APPLICATIONS

The future impact of this project is to provide the Naval operational environmental prediction system that is targeted for IOC in 2018.

RELATED PROJECTS

This work is part of a larger ESPC project. Collaboration with the 6.1 ONR sponsored Unified Physics for Extended Range Prediction DRI, 6.2 MJO Key to Extended Range Forecasts and 6.2 Consistent Momemtum Balances for Surface Waves is acknowledged. Other 6.4 efforts in improving the current global atmosphere and ocean models will benefit the ESPC effort as well.