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# Physics Parameterization for Seasonal Prediction

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## LONG-TERM GOALS

This 6.1 project is part of a long-term effort to identify and solve the major challenges of parameterizing the impacts of physical processes on atmospheric predictions extending out to seasonal time scales. Achievement of this goal will represent a significant step towards the development of an operational global earth system model targeted by the national Earth System Prediction Capability-Research, Development, and Operations (ESPC-RDO) effort, in which the United States Navy is a participant.

## OBJECTIVES

This project targets development of a "unified" treatment of atmospheric mixing processes, including interactions with clouds, within the Navy Global Environmental Model (NAVGEM) suitable for extended range prediction that includes not only boundary layer mixing, but mixing by shallow to mid-level convective clouds, as well as deep convection. The project will pursue a more consistent and realistic treatment of the relative magnitudes of these various mixing processes, focusing on the hydrologic cycle, but also addressing related momentum drag balance issues.

## APPROACH

We are focusing on ensuring a more comprehensive representation of key processes in the hydrologic cycle in NAVGEM. We continue to work towards improved fidelity of our physics codes to current understanding of atmospheric processes, and are seeking to adapt and test new physics treatments as well, particularly those developed under this DRI. A key question remains concerning the key physics requirements for simulation of important modes of predictability on extended timescales, particularly the Madden Julian Oscillation (MJO). We are continuing our participation in the project "Vertical Structure and Diabatic Processes of the MJO", a joint effort between the Year of Tropical Convection (YOTC) Program and the Global Energy and Water Cycle Experiment (GEWEX) Cloud System Study (GCSS). This large collaborative effort is investigating the sensitivity of the representation of the MJO to various model formulations, providing us an excellent opportunity to leverage our development efforts under this DRI project. Evaluation of progress achieved will include a range of global data sets,

and will be aided through analysis of errors on shorter timescales using the state-of-the art data assimilation component of NAVGEM.

The key performers on this project are Drs. James Ridout (PI) , Melinda Peng (Co-PI), Maria Flatau and Shouping Wang, all employed by NRL in the Marine Meteorology Division, and Dr. Piotr Flatau, a visiting scientist from Scripps Institute.

## WORK COMPLETED

**1) Modified Kain-Fritsch Convection Scheme Update.** Our parameterization effort this year focused on atmospheric convection. We worked to address key processes needed to improve the representation of the MJO and equatorial Kelvin waves in NAVGEM, and to improve the integration of the NAVGEM EDMF scheme with the convective parameterizations. A process that is not represented in NAVGEM's Simplified Arakawa Schubert (SAS) (Han and Pan 2011) deep convection scheme is the so-called "buoyancy sorting" involved in mixing of updraft air with the environment, though it does include a crudely parameterized sensitivity of the imposed updraft profile to atmospheric moisture. At NRL we have experience with two convective schemes that represent buoyancy sorting in different ways; the Emanuel scheme (Emanuel 1991; Emanuel and Zivkovic-Rothman 1999; Peng et al. 2004), and the Kain-Fritsch (1990) scheme. Since we have through the years carried out a considerable amount of testing with the Emanuel scheme in our global models, largely unsuccessful in regards to MJO simulation, we decided to begin testing with a familiar variant of the Kain-Fritsch scheme. In 2005, we published a modified version of the scheme (Ridout et al. 2005) in which we modified the closure relation, adopting a treatment similar to that employed in the Emanuel convection scheme, as supported by our quasi- cloud-resolving model experiments. The selection of updraft source level was also modified, adopting an approach approximating that in the NOGAPS Emanuel code as described by Peng et al. (2004).

**a) Changes to the deep convection scheme** We implemented the modified Kain-Fritsch code into NAVGEM and began testing with a series of hindcasts for an MJO event in December 2008 and January 2009. Initial test runs proved unsuccessful, but significant progress was achieved through addition of convective momentum transport as treated in the Emanuel convection scheme and modification of the updraft mixing rate $\delta M_{ek}$ (kg s$^{-1}$) based in part on the treatment described by Peng et al. (2004). In the Kain-Fritsch scheme (1990) the updraft mixing rate, the amount of environmental air that mixes with the updraft over a pressure interval $\delta p_k$ (Pascals), is represented as

$$\delta M_{ek} = M_{u0}\left(-0.03\,\delta p_k / R\right) , \qquad (1)$$

where $M_{uo}$ is the updraft mass flux (kg s$^{-1}$) at the cloud base level, R is the assumed updraft radius (m), and 0.03 is a parameter with units of m Pa$^{-1}$. The modified relation based on our testing is:

$$\delta M_{ek} = M_{u0}\left(-0.03\,\delta p_k / R_k\right) \min\left(1.0 + 0.4\left|\delta T_{vk}\right|, 2.0\right) , \qquad (2)$$

where $\delta T_{vk}$ is the virtual temperature difference (K) between the updraft and the environment at level k (in essence adopting the treatment described by Peng et al. (2004)), and where the radius $R_k$ varies with $M_{uk}$, the updraft mass flux at level k, following a simple power law relationship:

$$R_k = R_{LCL}\left(\frac{M_{uk}}{M_{u0}}\right)^n . \qquad (3)$$

Currently, the exponent n = 0.5, though a change to n=1.0 is planned, supported by recent observations by Giangrande et al. (2013) over the U.S. Great Plains.

The changes to the updraft mixing rate were applied to the downdraft as well (where the replacement of updraft quantities with the corresponding downdraft quantities in the equations is straightforward). Also, the downdraft initiation level is now constrained to lie below the melting level.

**b) Shallow convection** Another modification important for progress achieved in simulating MJO eastward propagation in our hindcasts is an enhancement of the modified Kain-Fritsch convection scheme to allow for treatment of shallow convection. Shallow convection is widely thought to be important in moistening the lower troposphere ahead of the main MJO convection, "preconditioning" the environment for succeeding deeper convection. It also has its own role as a source of latent heating that can contribute to the development of equatorial waves. The original Kain-Fritsch scheme did not treat shallow convection, but an update of the scheme (Kain 2004) does include such a treatment for grid columns where no deep convection is parameterized. The version of the scheme used in COAMPS® as well as the modified Kain-Fritsch scheme described by Ridout et al. (2005) have no treatment for shallow convection, requiring that clouds be at least 3 km in depth. In our work this year, we have relaxed the 3-km depth requirement considerably. Clouds in the current scheme need only be 200 m (measured from cloud base to cloud top) and 4 model levels deep. In the shallow convection treatment described by Kain (2004), the cloud base mass flux is parameterized based on the subcloud layer turbulent kinetic energy (TKE). An alternative treatment is adopted here in which the mass flux depends on the mass flux of plumes from the NAVGEM EDMF scheme that are determined to be associated with active convection. These plumes are those that are buoyant at or above the maximum of cloud base and the boundary layer top. At the lowest level for which this condition occurs, these plumes are capped when using the modified Kain-Fritsch convection scheme. This "cumulus capping" treatment allows the boundary layer plumes to transport surface layer air to the top of the boundary layer, but reserves the role of representing the associated cumulus clouds to the convection scheme. The mass flux of the capped plumes at the lifting condensation level (LCL) provides a preliminary value for the mass flux of the associated shallow cumulus. In cases where the deep convection component of the scheme (which is called prior to the shallow convection) parameterizes convection originating from the boundary layer, the mass flux of the shallow convection is reduced by the magnitude of the deep convective mass flux.

**2) Improved Integration of the EDMF scheme with NAVGEM Physics.** The cumulus capping treatment for the EDMF scheme described in connection with the shallow convection component of the modified Kain-Fritsch scheme merits some further discussion. The treatment is used not only with the modified Kain-Fritsch scheme, but is also included as an option for running with the SAS scheme in NAVGEM. As described above, the treatment identifies plumes that have characteristics associated with "active" cumulus, i.e., convective clouds that reach the level of free convection, and limits their top to the lowest level that is both above the boundary layer top and above the LCL where they are positively buoyant. The capping scheme thus allows mixing by the capped turbulent plumes, but reserves the role of representing the associated cumulus clouds for the model's convection schemes. There are a couple of supporting arguments for this treatment. First, currently the convection schemes are better equipped than our EDMF scheme to represent the full range of cloud processes. Another issue concerns the representation of the air inflow into turbulence forced convective clouds. As suggested by Bretherton et al. (2004) there is support from the LES simulations of Siebesma et al. (2003) for constraining the updraft source layer to lie at the boundary layer top in cases of shallow convection. Based on this reasoning and an effort to avoid competition between convection and

turbulence in stratocumulus-topped boundary layers, Bretherton et al. (2004) constrain cumulus updrafts to originate at the boundary layer top. Although currently our convection schemes do not enforce this restriction, the capping treatment, which acts to promote convection from the top of the boundary layer, is a step in this direction.

**3) Testing – NAVGEM and Beyond.** Our parameterization testing has continued to focus on key large-scale modes of variability, in particular the MJO and equatorial Kelvin waves. In FY14 we continued to carry out NAVGEM hindcast tests for the second of the two test cases from the MJO intercomparison experiment. We also carried out a three-year NAVGEM integration using a preliminary version of the modified Kain-Fritsch scheme. In addition, we have been working in collaboration with the 6.4 ESPC project and NRL 6.2 MJO to implement and test our parameterizations in the ESPC coupled system for the fall 2011 DYNAMO (Dynamics of the Madden Julian Oscillation) observational period.

**4) Coordination with Other DRI Projects.** An important component of our effort has continued to include implementation and testing of parameterizations from other DRI projects. In FY13 we implemented the EDMF scheme in NAVGEM. This past year we continued our collaboration with the group led by Dr. Joao Teixeira at JPL as the scheme has undergone further development. In addition, we continued to work with Dr. Ed Andreas with implementation and testing of his new air-sea flux scheme (Andreas et al. 2014). The full scheme with sea-spray effects included was found to have some issues on rare occasions, apparently with convergence of the sea-spray portion of the algorithm, that still need to be addressed before we can proceed further with testing.

**5) COAMPS Evaluation.** COAMPS-SCM and LES simulations were performed for the UPEFF-RF01 intercomparison case study. The SCM work involves a collaboration with Profs. Qing Wang of NPS and David Mechem of U. of Kansas, and Dr. Joao Teixeira of JPL. The effort seeks to evaluate mixing in the EDMF scheme and in COAMPS for this case study of the California central coast region near Monterey.

## RESULTS

**a) Modified Kain-Fritsch convection scheme update.** The modified Kain-Fritsh scheme was tested as part of a series of three-year (2004 – 2006) integrations of NAVGEM with SSTs and sea ice cover specified using the NCEP OI SST V2 weekly data. The physics configuration tested includes not only the modified Kain-Fritsch convective parameterization coupled to the latest version of the EDMF scheme, but also the Xu-Randall (1996) /Ridout cloud fraction parameterization that was found last year to improve tropical equatorial variability. The tested configuration was found to provide the best yet representation of tropical variability in NAVGEM, as evidenced in comparisons of Wheeler and Kiladis (1999) type wavenumber-frequency diagrams of simulated and observed (TRMM) rainfall (Fig. 1). The results for the 20-year run (Fig. 1b) is broadly representative of NAVGEM skill when the project started. Although there is a low-frequency signal that includes the MJO portion of the low-frequency spectrum, the low-frequency east/west signal ratio appears to be close to unity, in contradistinction to the observations (Fig. 1a). The results obtained with the modified Kain-Fritsch/Xu-Randall combination (Fig 1c) are significantly better. The Kelvin wave portion of the spectrum is also much improved. This comparison is complicated somewhat in that differing model resolutions were used. The 20-year run was carried out at t359l42 resolution, whereas the modified

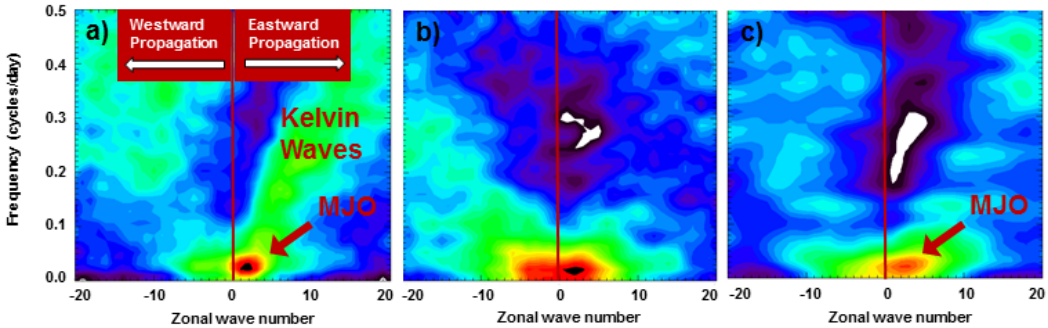


***Figure 1. Power spectra of total rainfall in zonal wavenumber / frequency space following the method of Wheeler and Kiladis (1999) for the years 2004 – 2006. Results are shown for: a) TRMM rainfall, b) NAVGEM 20-year run for the YOTC/GEWEX intercomparison project, and c) NAVGEM with modified Kain-Fritsch convective parameterization and Xu-Randall (/Ridout) cloud fraction scheme.***

Kain-Fritsch run was done at t425l60. We are planning a paper that will more carefully document the performance sensitivity.

Testing of the modified Kain-Fritsch scheme in the ESPC coupled system involved 30-day hindcasts beginning 1 November, 2011. These hindcast tests provide an important check on our

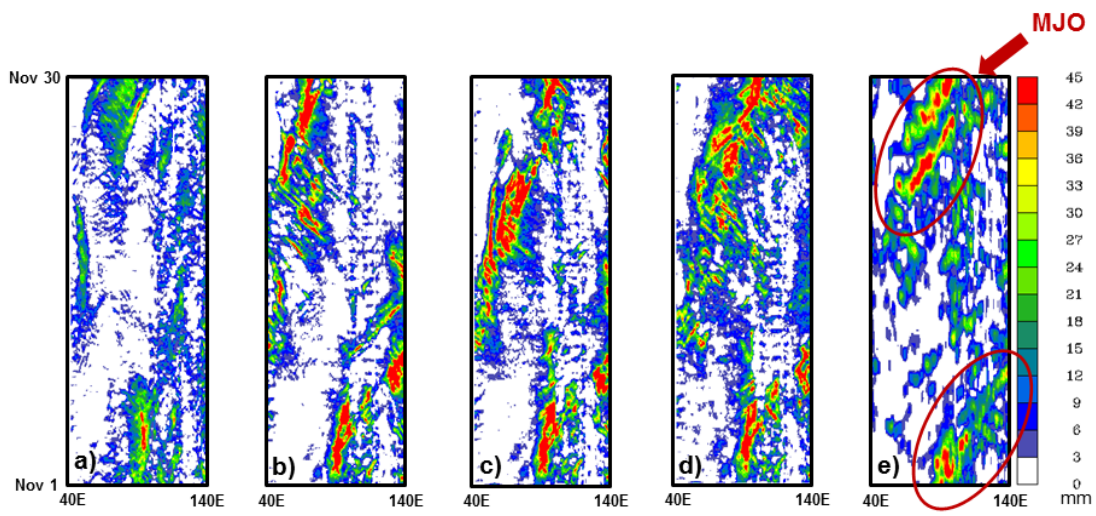


***Figure 2. Hovmöller plots of rainfall averaged between 5N – 5S for November 2011. Results are shown for a) NAVGEM 1.1 physics, b) modified Kain-Fritsch configuration , c) same as (b), but with HYCOM COARE 3.0 air-sea fluxes in NAVGEM, d) same as (c), but with a bimodal version of the modified Kain-Fritsch scheme. Panel (e) shows corresponding results based on TRMM rainfall data.***

evaluations of the MJO based on the AGCM runs described above. The MJO in these hindcasts was evaluated in terms of the temporal evolution of equatorial rainfall as it varied with longitude (Fig. 2). The results show clear improvements with the modifications to the NAVGEM 1.1 physics. All of the modified physics runs, for example, show improvements in the strength of the second MJO event. Also, the eastward propagation of the rainfall for the first MJO event is better represented in these

runs. The second MJO event is improved with both the change in the air-sea fluxes as well as the implementation of the bimodal version of the modified Kain-Fritsch convection scheme.

**c) COAMPS Evaluation.** The COAMPS-SCM was used to simulate a cloud dissipating case with well-defined large-scale and surface conditions. Consistent with observations and LES models, COAMPS-SCM produced dissipating cloud with decreasing boundary layer height and weakening turbulence kinetic energy. The COAMPS-SCM simulated clouds last about 8 h before they completely dissipate. This dissipation time scale is significantly longer than that obtained with EDMF (~ 4 h) (Fig. 3), suggesting that entrainment mixing in EDMF is significantly stronger than that in COAMPS-SCM. Further analysis will be conducted to understand the cause of this difference.

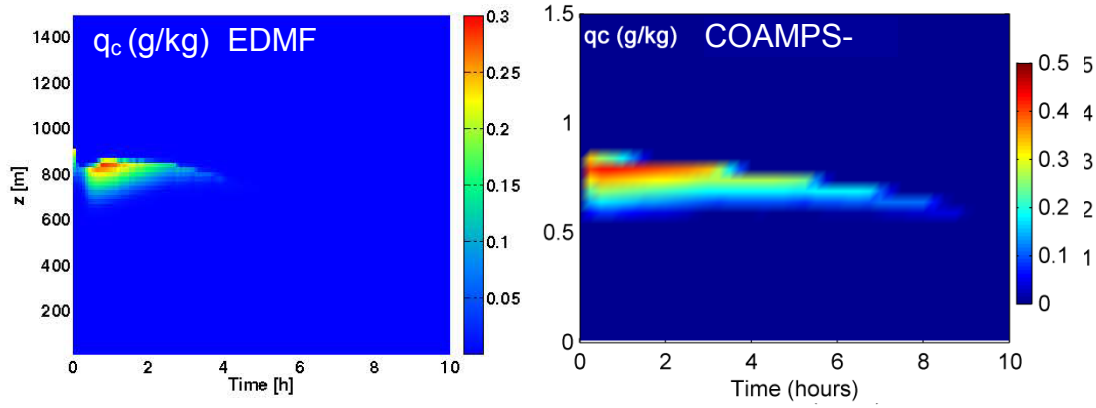


***Figure 3. Liquid water mixing ratio from EDMF (left) and COAMPS-SCM (right) UPPEF-RF01 case simulations.***

Three sensitivity simulations were performed. The first (S1) is run with reduced mixing length for cloudy conditions in the inversion; the 2nd (S2) is run with a reduced transfer coefficient based on the stability condition; the 3rd (Operation) is the same as the operational COAMPS.

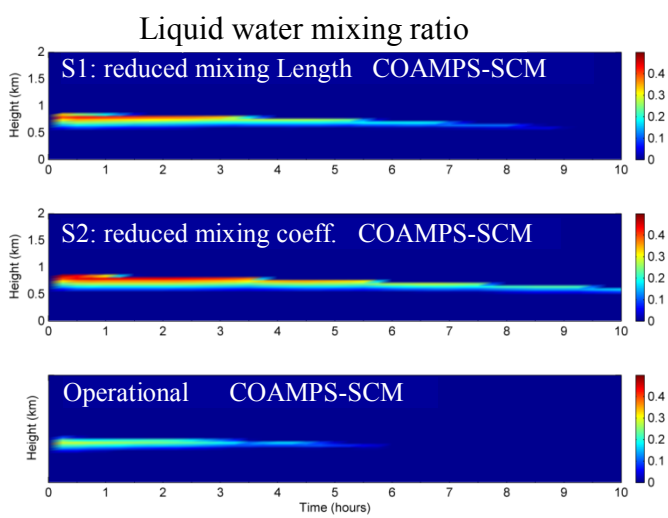


***Figure 4: Liquid water mixing ratio from sensitivity simulations using COAMPS-SCM. TOP: Reduced mixing length in the inversion; Middle: Reduced mixing coefficient based on Richardson number; Bottom: Operational version.***

Figure 4 shows that S1 and S2 have more cloud water and longer enduring clouds compared with Operation, a result of the weaker entrainment mixing in S1 and S2. S2, in particular, produced cloudy conditions for the duration of the simulation. Because operational COAMPS has a negative bias in

low-level cloud predictions, these results may help direct changes needed to improve COAMPS cloud prediction. We are testing these ideas in regional COAMPS.

COAMPS-LES was also used to simulate the UPPEF-RF01 case. Preliminary analysis shows that the results are generally consistent with observations and other models, though with more rapid cloud dissipation. Efforts are underway to understand this difference.

## IMPACT/APPLICATIONS

The parameterization development under this project is expected to contribute to future strategic planning capabilities of the United States Navy. In addition to helping enable skillful extended range prediction, benefits to current short- to medium range forecasting capabilities are also expected.

## RELATED PROJECTS

The NRL 6.2 project "The Madden Julian Oscillation: Key to Extended-range Predictability" (PI Dr. Carolyn Reynolds) and the 6.4 ESPC project (PI Dr. Melinda Peng) provide a transition pathway for this 6.1 project.

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Jiang et al. 2014: Vertical structure and physical processes of the Madden-Julian Oscillation: Exploring key model physics in climate simulations. Submitted to *J. Geophys. Res. – Atmospheres*.

Klingaman et al. 2014: Vertical structure and physical processes of the Madden-Julian Oscillation: Linking hindcast fidelity to simulated diabatic heating and moistening. Submitted to *J. Geophys. Res. – Atmospheres*.