Bimodal Representation of Convection with a Modified Kain-Fritsch Cumulus Scheme

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Convective Scheme Development – Modified Kain-Fritsch

Extension of Modified Kain-Fritsch Scheme of Ridout et al. (2005)

Closure relation based on an assumed quasi-balance in updraft parcel buoyancy at cloud base. Constraint imposed to ensure that available buoyant energy does not entirely vanish.

Changes since publication include:

1) Added convective momentum transport (similar to treatment of Gregory et al. (1997), as in the Emanuel convection scheme (Emanuel 1991; Emanuel and Zivkovic-Rothman 1999)).

2) Modified mixing rate based on the updraft mass flux and parcel buoyancy (in part, adopting an approach described by Peng et al. (2004)).

3) Enhanced capability to represent shallow convection, with inputs from boundary layer plumes modeled in the NAVGEM EDMF scheme (Sušelj et al. 2013).

Turbulence-Forced and Dynamically-Forced Modes

The scheme provides for simultaneous representation of two modes of convection. "Shallow convection" is forced by turbulent plumes, and is perhaps better described as "turbulence-forced" (TF), since there is no height limit applied. The "deep convection" mode is forced in a manner like the Kain-Fritsch scheme (Kain and Fritsch 1990; Kain 2004), in which the updraft cloud base temperature perturbation is computed based on the grid-scale vertical velocity (assumed to represent mesoscale uplift) as in Fritsch and Chappell (1980)); this mode is hence referred to as "dynamically-forced" (DF).

The separation of convection into two modes based on triggering types – boundary layer turbulence and dynamical lifting - is motivated by work of Mapes (2000).

Benefits of the dual mode formulation include:

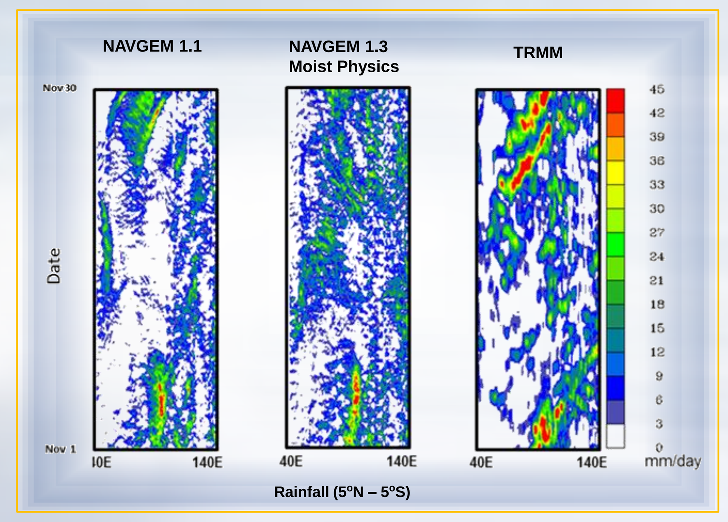
1) Inclusion of both types simultaneously.
2) Accomodation of type-specific parameterization differences - for example, in the current scheme, precipitation-driven downdrafts are occur only with the DF mode.

Challenges:

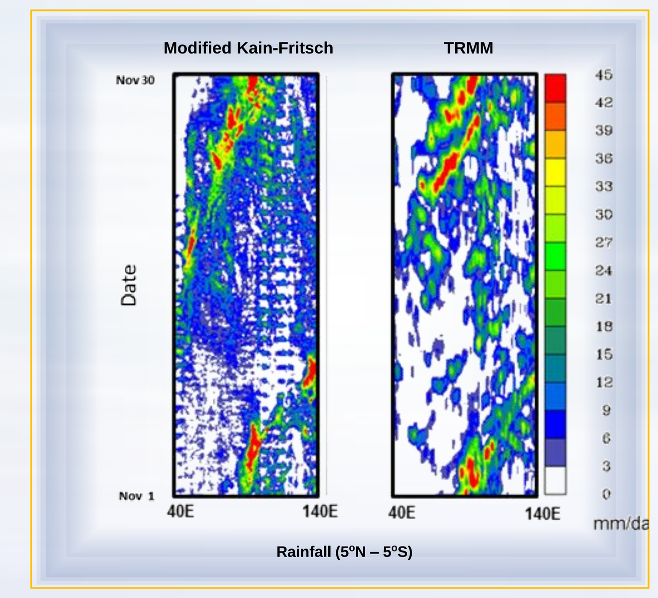
1) Improve parameterization of the triggering mechanisms.
2) Improve parameterization of type-specific differences in convection.

Impact on DYNAMO Hindcasts from 1 Nov, 2011

Rainfall

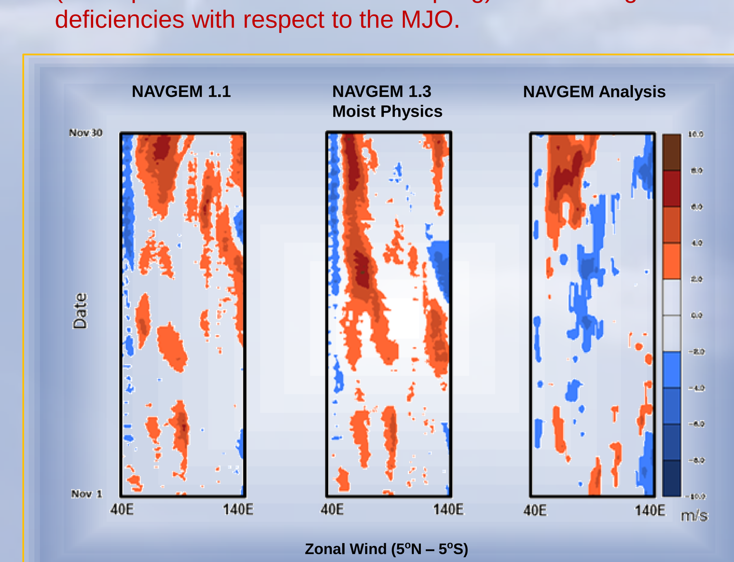


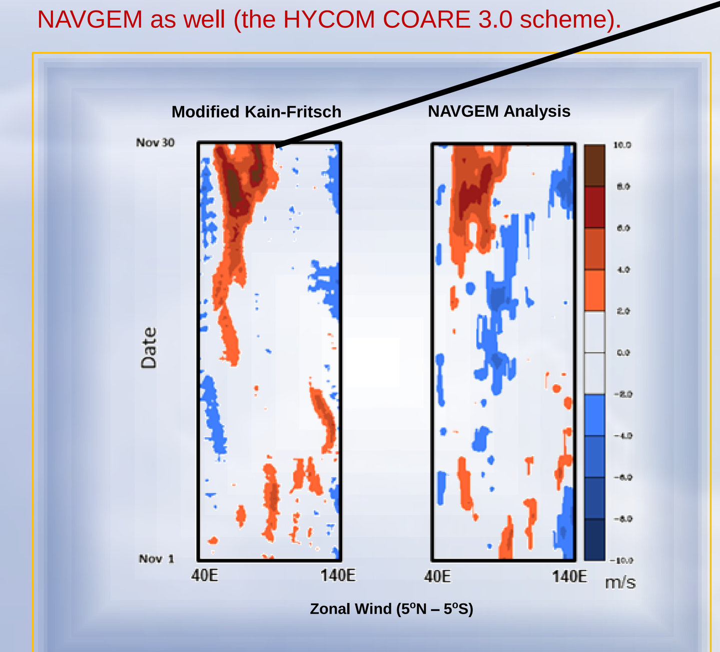
The Navy Global Environmental Model (NAVGEM) is an atmospheric NWP model that uses the Simplified Arakawa-Schubert convection scheme (Han and Pan 2011) operationally. Hindcasts using the operational NAVGEM moist physics in the Navy's Earth System Model (NESM) (atmosphere-ocean-sea ice coupling) exhibit significant deficiencies with respect to the MJO.



Significant improvement is obtained using the modified Kain-Fritsch convection scheme in NESM. Comparison here includes a modified treatment of air-sea fluxes in NAVGEM as well (the HYCOM COARE 3.0 scheme).

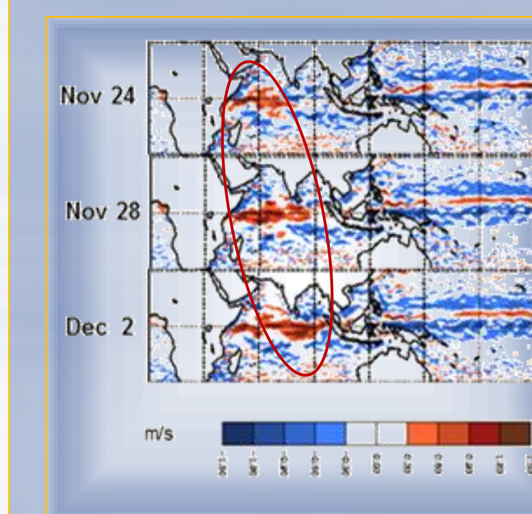
Zonal Winds





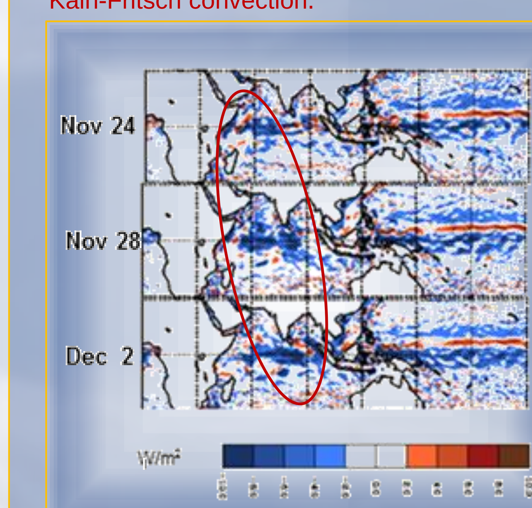
Simulated Ocean-Current Feedbacks

Zonal Surface Current



above) Surface currents in NESM respond to the westerly wind burst of the second MJO event.

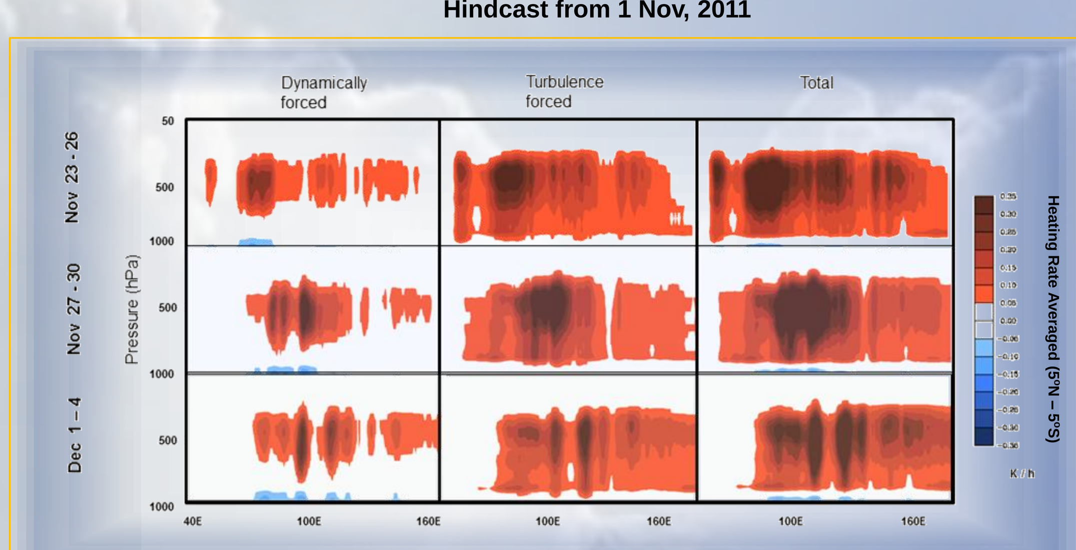
below) Impact of currents on surface latent heat flux in hindcasts with the modified Kain-Fritsch convection.



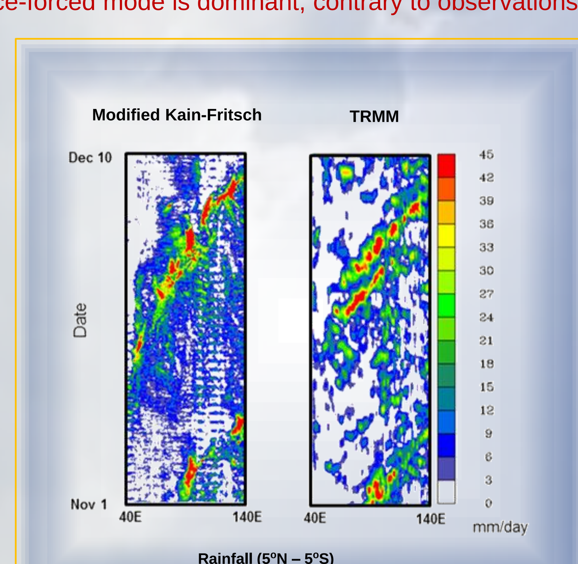
Impact of Currents on Surface Latent Heat Flux

Convective Heating Rate - Modified Kain-Fritsch

Hindcast from 1 Nov, 2011



The turbulence-forced mode is dominant, contrary to observations (cf. Mapes 2000).



Hindcast precipitation has similarities with TRMM data extending out 40 days, though further improvement is desired.

Improved Convective Mode Partitioning

Mixed Layer Richardson Number Constraint

Address Unrealistic Dominance of Turbulence-Forced Mode

Mixed Layer Richardson Number Constraint

The NAVGEM EDMF scheme parameterizes transports associated with "plumes" (thermals) in the convective boundary layer. In the modified Kain-Fritsch convection scheme, these plumes are used to force the turbulence-forced convection component.

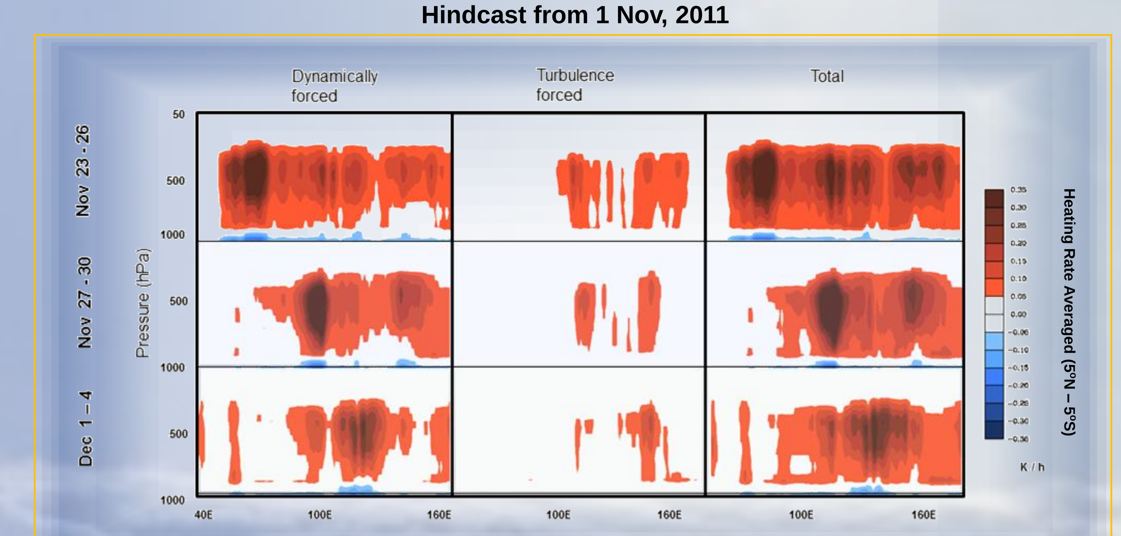
Stull (1994) cites evidence that wind shear can play an important role in the growth of such eddies (e.g., Noonkester (1979), Eloranta and Forrest (1992), Schols and Eloranta (1992)). Work by Grossman(1982), as well as more recent work, e.g., Zheng et al. (2015) can also be cited.

Based on such evidence, Ridout and Reynolds (1998) proposed a "thermal growth parameter" t_g that scales between 0 (forced convective boundary layer) and 1 (free convective boundary layer) based on the "mixed layer Richardson number" introduced by Stull (1994) for boundary layer regime classification. The parameter t_g was used as a type of trigger for boundary layer turbulence generated convection.

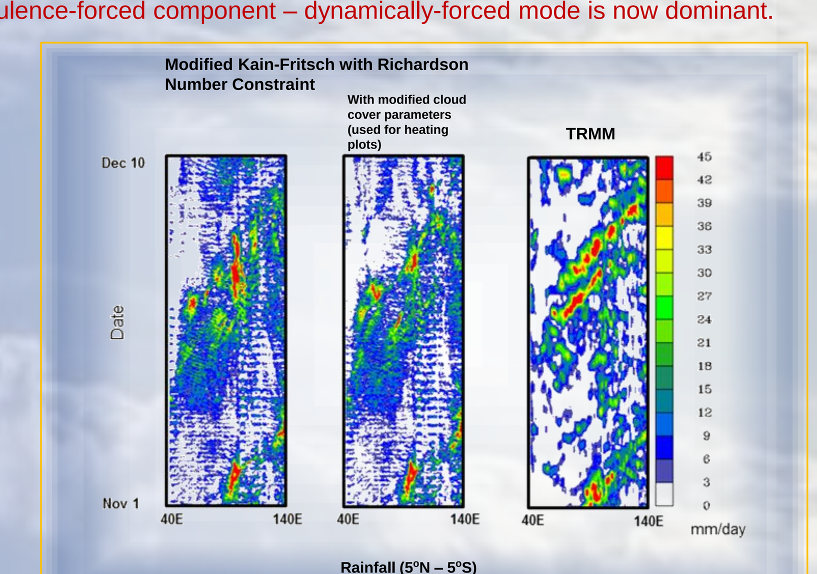
The parameter t_g is being tested now with the modified Kain-Fritsch scheme in NAVGEM to:
1) scale the cloud base mass flux for turbulence-forced convection.
2) limit EDMF plume height for forced convection conditions to the top of the boundary layer.

Convective Heating Rate - Modified Kain-Fritsch with Mixed Layer Richardson Number Constraint

Hindcast from 1 Nov, 2011



The Richardson number constraint reduces the heating associated with the turbulence-forced component – dynamically-forced mode is now dominant.



Improved eastward propagation. Peaks somewhat underrepresented.

Further Work in Progress

1) Cloud model modifications of precipitation efficiency, buoyancy sorting.

2) Validation / Testing - DYNAMO observations, extended coupled integrations for other periods, diagnostics from the MJO intercomparison project Vertical Structure and Diabatic Processes of the MJO (WCRP-WWRP/THORPEX MJO Task Force and YOTC, and the GEWEX GCSS) (e.g., Klingaman et al. 2015)

Key Process Issues

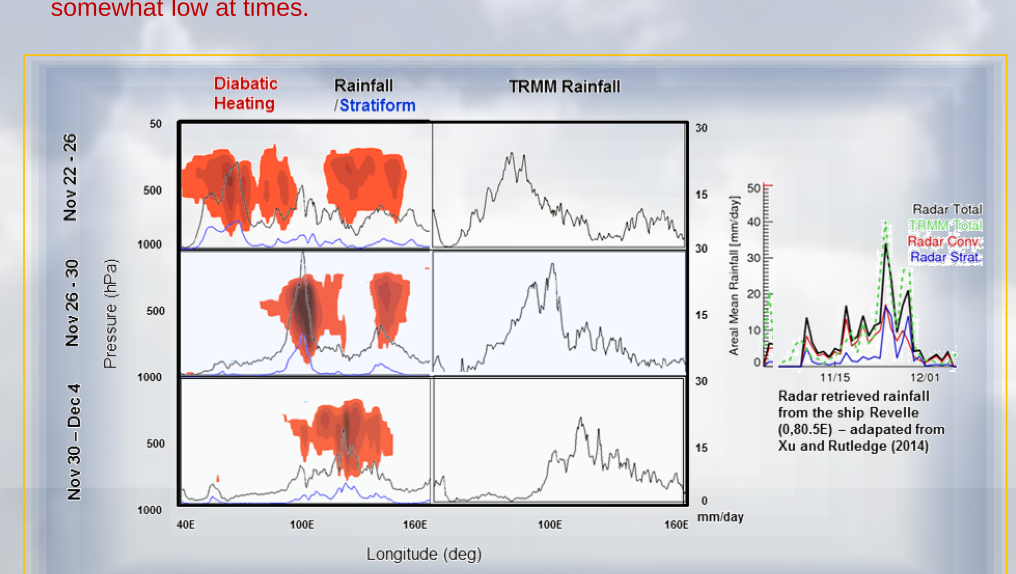
1) Role of shear in modulating convective boundary layer plume transports and convective triggering (and more generally, impacts on convection).

2) Downdraft characteristics and precipitation efficiency for various convection modes, and impacts on large-scale convective organization.

3) Air-sea interactions – impacts of feedbacks associated with ocean currents.

Diabatic Heating, Convective/Stratiform Partitioning

Further diagnostics are in progress for the DYNAMO period. Shown here are the simulated diabatic heating and the partitioning of rainfall between convective and stratiform. The convective/stratiform ratio appears to be fairly well represented in general compared with radar data, though the stratiform percentage is possibly somewhat low at times.



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