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Physical processes in present and future large-scale models

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Summary

Parametrized convective heating and large-scale waves - Peter Bechtold

Convection and wave interaction

The tropical linear waves can be described by the shallow water equation system. In model and observational practice, one does not use the shallow water system directly, but mostly extracts the tropical wave characteristics from the outgoing longwave radiation (OLR) with the aid of a 2D FFT, to obtain the so called wavenumber frequency diagrams (Wheeler and Kiladis, 1999). It is first shown that the wavenumber frequency spectra form long integrations with the ECMWF Integrated Forecast System (IFS) reproduce those obtained from 6 years of analysis data. The latter also confirms the theoretical dispersion relations obtained from the shallow water system with exception of the Madden-Julian oscillation (MJO) which is not a wave.

Real-time monitoring of the different modes (Kelvin, Rossby and MJO) can be performed following Wheeler and Weickman (2001) by filtering the OLR in the respective wavenumber-frequency band and transforming back to real space. As a long time series is required for the low-frequency waves, we decided to retain 90 days of analysed OLR beyond the current date and add to it the current medium-range or monthly forecast. Comparing the filtered OLR time series to the observations reveals that Kelvin and Rossby waves strongly modulate convective activity including continental diurnal cycle convection, and that the MJO is composed of both Rossby and Kelvin modes with the Rossby dominating. This also explains the frequent generation of equatorially symmetric pairs of tropical cyclones by the MJO.

However, in order to recover the full 3D structure of the global circulation one needs to project the data (temperature, wind and geopotential) onto the full normal mode system. The latter has been first derived by Kasahara and Puri (1981) and later further developed and applied to the IFS by Žagar et al. (2015a,b). It is similar to the shallow water system but uses the full IFS spherical harmonics structure together with the full set of model levels. We are only beginning to use this powerful tool for studying the atmospheric circulation and energetics in modal space. However, the example we prepared confirms the dominance of rotational modes in tropics explaining large parts of local jets in the lower troposphere and the MJO when it is positioned over the Pacific.

The convection wave interaction is discussed for the Kelvin wave using radiosonde data, ERA-Interim reanalysis data and an ensemble of annual integrations with the IFS. In agreement with the linear model by Raymond and Fuchs (2007) it is shown that ahead of the precipitation maximum associated with the Kelvin wave, the boundary-layer moist entropy increases and the convective inhibition above the boundary-layer decreases (Herman et al. 2015).This suggest that the major control of the wave onto the convection is by subsiding gravity motions suppressing convection ahead of the wave. The action of the convection onto the wave can be understood by the tilted baroclinic structure of the Kelvin. The wave anomalies can be extracted by regressing the observed or simulated temperature time series at every vertical level onto the Kelvin filtered OLR. As the convective heating coincides with the upper-level warm anomaly (it does in the observations and in the recent versions of the IFS – but not necessarily in models with deficient convection parametrizations!) there is generation of potential energy and conversion of potential energy into resolved wave kinetic energy (Steinheimer et al. 2008, Shutts 2006). The top-heavy heating mode shows largest energy growth (Raymond and Fuchs, 2007).

Toward higher resolution

With increasing horizontal resolution the convective fluxes become better resolved by the grid-scale dynamics and condensation. The transition from parametrized to resolved deep convective motions is supposed to occur in the 10 km – 500 m resolution range. Continuing with a spectral view on convection, one can also use the native spectral representation of the IFS to compute the resolved kinetic energy spectra at different spectral truncations with and without deep convection. The result of this study is that at both 5 and 16 km equivalent horizontal grid-spacing, the simulations without a deep convection parametrization show significantly more kinetic energy for scales smaller than roughly 200-400 km. Furthermore, following Augier and Lindborg (2013) it is possible to compute the spectral energy transfer, showing that without a deep convection parametrization the energy transfer in the aforementioned scale range is upscale while it is downscale with the deep convection parametrization. The question is then if this upscale energy transfer (and possibly associated error growth) poses a problem for predictability, the answer is probably yes.

From the parametrization point of view the challenge is to appropriately scale the convective mass flux with decreasing resolution. In collaboration with the Deutsche Wetterdienst (DWD) we established an empirical scaling of the mass fluxes so that at 5 km resolution roughly 60% of the nominal mass flux is retained while this proportion reduces to less than 20 % at 1 km. Furthermore an absolute mass flux limit of 2 kg m^{-2} s^{-1} is imposed. The scaling could also involve recomputing the environmental values in the full mass flux equations, but we have not done so yet as this would require knowledge of the updraught area fraction. Certainly the biggest approximation in the current parametrized deep convection is the column independent assumption and that updraught and downdraught are not spatially separated. However, preliminary tests with this mass flux scaling at equivalent horizontal resolutions of 5 km are very encouraging and confirm through good precipitation and wind scores in both the tropics and extra-tropics the robust and appropriate formulation of the deep convection scheme with its Convective Available Potential Energy (CAPE) type closure (Bechtold et al. 2014). Parallel tests without the deep convection parametrization at 5 km were less satisfactory, increasing the tropical upper-level wind errors by 30% compared to the analysis, while producing too intense and too localised precipitation.

Our immediate challenge will be to improve the microphysics formulation in the convection concerning the mixed-phase and therefore make it more consistent with the prognostic grid-scale cloud scheme.

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