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Challenges in Modeling of the Global Atmosphere

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The massively parallel computer architectures require that some widely adopted modeling paradigms be reconsidered in order to utilize more productively the power of parallel processing. For high computational efficiency with distributed memory, each core should work on a small subdomain of the full integration domain, and exchange only few rows of halo data with the neighbouring cores. However, the described scenario implies that the discretization used in the model is horizontally local.

The spherical geometry further complicates the problem. Various grid topologies will be discussed and examples will be shown. The latitude-longitude grid with local in space and explicit in time differencing has been an early choice and remained in use ever since. The problem with this method is that the grid size in the longitudinal direction tends to zero as the poles are approached. So, in addition to having unnecessarily high resolution near the poles, polar filtering has to be applied in order to use a time step of decent size. However, the polar filtering requires transpositions involving extra communications.

The spectral transform method and the semi-implicit semi-Lagrangian schemes opened the way for a wide application of the spectral representation. With some variations, these techniques are used in most major centers. However, the horizontal non-locality is inherent to the spectral representation and implicit time differencing, which inhibits scaling on a large number of cores. In this respect the lat-lon grid with a fast Fourier transform represents a significant step in the right direction, particularly at high resolutions where the Legendre transforms become increasingly expensive.

Other grids with reduced variability of grid distances such as various versions of the cubed sphere and the hexagonal/pentagonal (“soccer ball“) grids were proposed almost fifty years ago. However, on these grids, large-scale (wavenumber 4 and 5) fictitious solutions (“grid imprinting”) with significant amplitudes can develop. Due to their large scales, that are comparable to the scales of the dominant Rossby waves, such fictitious solutions are hard to identify and remove.

Another new challenge on the global scale is that the limit of validity of the hydrostatic approximation is rapidly being approached. Having in mind the sensitivity of extended deterministic forecasts to small disturbances, we may need global non-hydrostatic models sooner than we think.

The unified Non-hydrostatic Multi-scale Model (NMMB) that is being developed at the National Centers for Environmental Prediction (NCEP) as a part of the new NOAA Environmental Modeling System (NEMS) will be discussed as an example. The non-hydrostatic dynamics were designed in such a way as to avoid over-specification. The global version is run on the latitude-longitude grid, and the polar filter selectively slows down the waves that would otherwise be unstable.

The model formulation has been successfully tested on various scales. A global forecasting system based on the NMMB has been run in order to test and tune the model. The skill of the medium range forecasts produced by the NMMB is comparable to that of other major medium range models. The computational efficiency of the global NMMB on parallel computers is good.