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Challenges and Opportunities in Modeling of the Global Atmosphere

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Modeling paradigms on global scales may need to be reconsidered in order to better utilize the power of massively 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. Note that the described scenario strongly favors horizontally local discretizations.

This is relatively easy to achieve in regional models. However, the spherical geometry complicates the problem. 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 a reasonable size. However, the polar filtering requires transpositions involving extra communications as well as more computations.

The spectral transform method and the semi-implicit semi-Lagrangian schemes opened the way for application of spectral representation. With some variations, such techniques are currently dominating in global models. Unfortunately, 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 polar filtering is a 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. Relaxing the hydrostatic approximation requieres careful reformulation of the model dynamics and more computations and communications.

The unified Non-hydrostatic Multi-scale Model (NMMB) will be briefly 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 without modifying their amplitudes. The model has been successfully tested on various scales. The skill of the medium range forecasts produced by the NMMB is comparable to that of other major medium range models, and its computational efficiency on parallel computers is good.