Geophysical Research Abstracts
Vol. 12, EGU2010-6729, 2010
EGU General Assembly 2010

A Comparison of Vertical Staggering for Coupling Large Scale Dynamics to the Planetary Boundary Layer.

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One of the current challenges in numerical weather prediction is in obtaining accurate coupling between models formulated for sub grid scales and those formulated for resolved large scales. Previous emphasis has been on the temporal aspects of this so called physics-dynamics coupling problem, with little attention towards the spatial aspects. When designing a model for numerical weather prediction there is a choice for how to vertically arrange the required variables, namely the Lorenz and Charney-Phillips grids, and there is ongoing debate as to which is the optimal. The Charney-Phillips grid is considered good for capturing the large scale dynamics and wave propagation whereas the Lorenz grid is often beneficial for sub grid scale parametrisations and conservation but supports a computational mode.

We use the normal mode analysis approach, as used in previous work of a similar nature. This is an attractive methodology since it allows one to pin down exactly why a particular configuration performs well. In order to apply this method we set up a one dimensional column model, where we assume horizontally wavelike solutions with a given wave number. Applying this method encounters issues when the problem is non normal, as it will be when including boundary layer terms. We have shown that when addressing the question for the boundary layer only, i.e. without horizontal dependency and without the vertical component of velocity, the lack of orthogonality between eigenvectors causes mode analysis to break down. We have shown that one can recover some of the usefulness of the methodology by examining singular vectors and singular values; these retain the appropriate physical interpretation and allow for valid comparison due to orthogonality between singular vectors. We have shown that the Lorenz grid is the preferred configuration for the boundary layer. Using it enables better representation of the structure of a given singular vector than when using the Charney-Phillips grid. Additionally, when using the Charney-Phillips grid, eigenvalues and singular values reveal that eigenmodes will generally be damped too slowly, meaning any inaccuracies will be longer lived and more likely to produce further errors.

When resolved scale dynamics is included, along with the boundary layer parametrisation, the usefulness of eigenvectors is somewhat recovered; although not orthogonal, behaviour remains physical. Using this, along with the techniques established for the boundary layer only, a thorough comparison between the Lorenz and Charney-Phillips grid has been possible. Each type of grid can be shown to have advantages and it generally depends on the mode type. For example the dispersion property of a large scale Rossby mode may still be better approximated using Charney-Phillips whereas a boundary layer type mode, on the same grid, could be damped too slowly. We have shown that particular eigenmodes can be tracked as the boundary layer is switched on, showing which structures are most affected by the the extra diffusion mechanism. Acoustic waves are fast enough that they are not altered by adding in boundary layer structure but inertia-gravity and Rossby waves can be distorted. The computational mode associated to the Lorenz grid remains intact for the full coupled system but can only exist where no shear or boundary layer diffusion occurs: everywhere above the boundary layer we find a two grid wave that is advected at the speed of the background flow.