Slope-limiting Diffusion in Simulations of Convection and Thermal Plumes

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JILA - University of Colorado - Boulder
GTP Workshop – May 20, 2013
Compressible Spherical Segment (CSS) Code

- Solves primitive compressible MHD equations using:
  - 3rd or 4th order TVD Runge-Kutta for time evolution
  - 4th or 6th order modified compact finite differences for spatial derivatives [Lele (1992)]
Multi-scale near-surface flows captured in CSS

Density stratification leads to expanding spatial scales with depth

Coalescing downflows begin to feel global-scale effects (rotation and geometry)

Interactions between the imposed global-scale flows and turbulent downflows become increasingly evident

**Q:** How might the nature of SLD influence the dynamics of this convection?
Slope-limiting Diffusion

• How does it fit into the overall picture of SGS/LES methods?
  – Slope-limiting
    Filtering of high wavenumbers
  – Flow-dependent diffusion coefficient
    SGS Model of diffusion, enhanced where flows are fast
  – This is foremost a numerical stabilization procedure

\[
\nu = 0 \neq \lim_{\nu \to 0} NS
\]

\[
F_r = c_r g_r \delta u_r
\]
Q1 -- How does SLD behave as a diffusion operator?

Laplacian

\[ \frac{\partial u}{\partial t} = \nu \frac{\partial^2 u}{\partial x^2} \]

Slope-limiting Diffusion

\[ \frac{\partial u}{\partial t} = -\frac{\delta F}{\Delta x} \]

Local operator

spectrally non-local
Q2 -- Can typical fluid prognostics and diagnostics be controlled or deduced?

Does the naïve approach sufficiently control Pr?
Q2 -- Can typical fluid prognostics and diagnostics be controlled or deduced?

*How might we improve it’s agreement?*
Q3 – How much lower is the apparent diffusion?

How much lower is the diffusion?

16 times less resolution!
Q4 – Can SLD reproduce or mimic fluid instabilities

*Thermal plumes (Pinch & Sinuous instabilities)*

Which is Laplacian?

MRI *(Does it match linear growth rates?)*

Q5 -- Can it also produce consistent boundary layers?

Q6 – Is there sufficient entrainment and detrainment?

*How does this depend upon the SLD “Pr”?*
Slope-limiting Diffusion

Q1 -- How does SLD behave as a diffusion operator?

+ *Local operator* spectrally non-local

+ *Implications for large-scale dynamos, instabilities, and cascades?*

+ *Could it excite instabilities that otherwise might not be present?*

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+ *Does the naïve approach sufficiently control Pr?*

+ *How much lower is the diffusion?*
Slope-limiting Diffusion

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