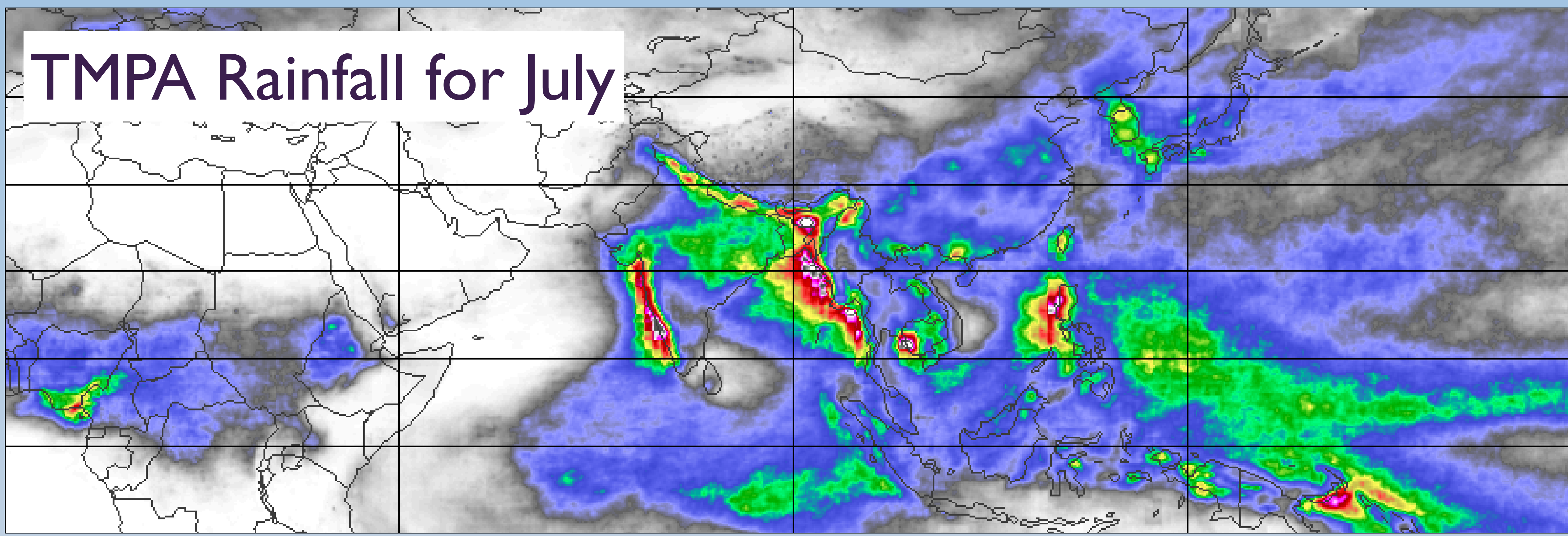
Variability of Transport through the Asian Summer Monsoon Anticyclone



Kenneth P. Bowman and Leong Wai (Chris) Siu
Department of Atmospheric Sciences
Texas A&M University

Thanks to NSF CLD and PDM Programs

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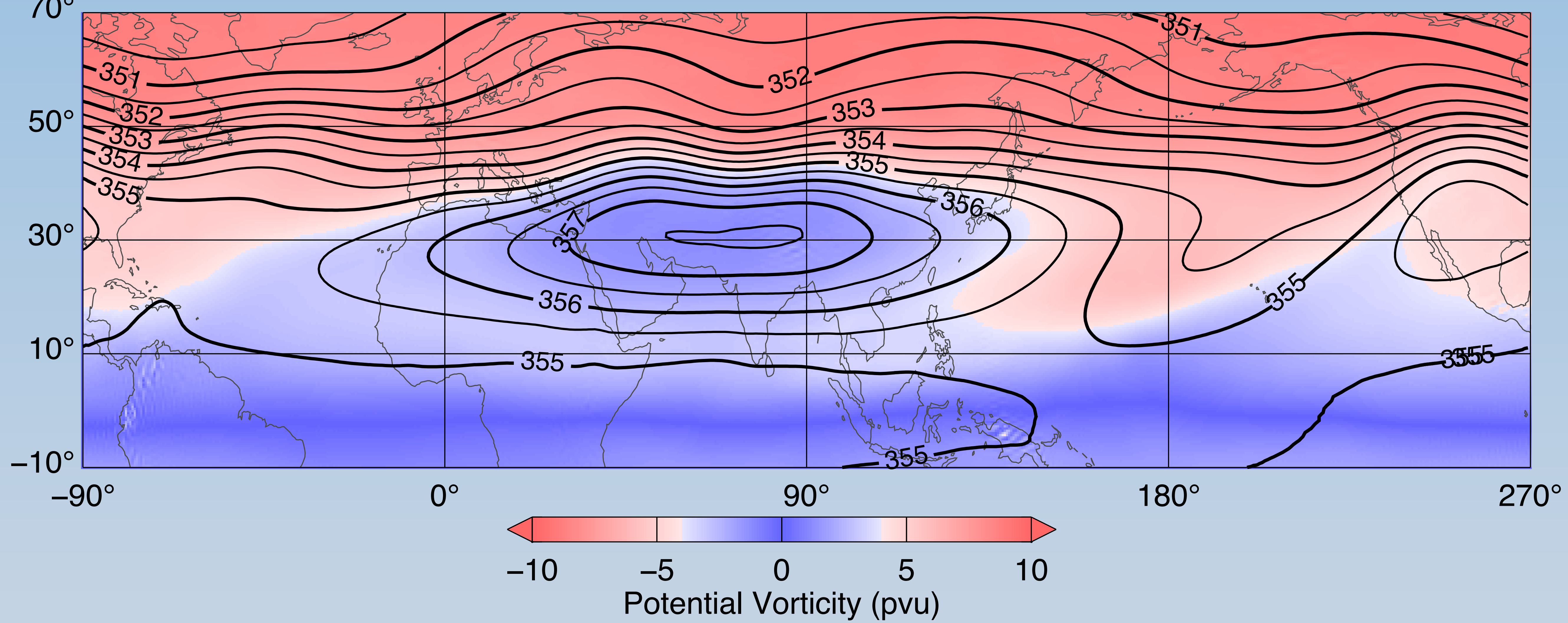
ATMOSPHERIC SCIENCES

Climatology of Transport

- Goals of this sub-project are
  - to develop methods to quantify the Lagrangian transport into and out of the Asian monsoon anticyclone
  - produce a Lagrangian climatology of transport as a function of time of year and altitude
  - examine interannual and intraseasonal variability and relationship to dynamical forcing

370 K PV and Streamfunction

Climatological ERA-Interim Reanalysis for July



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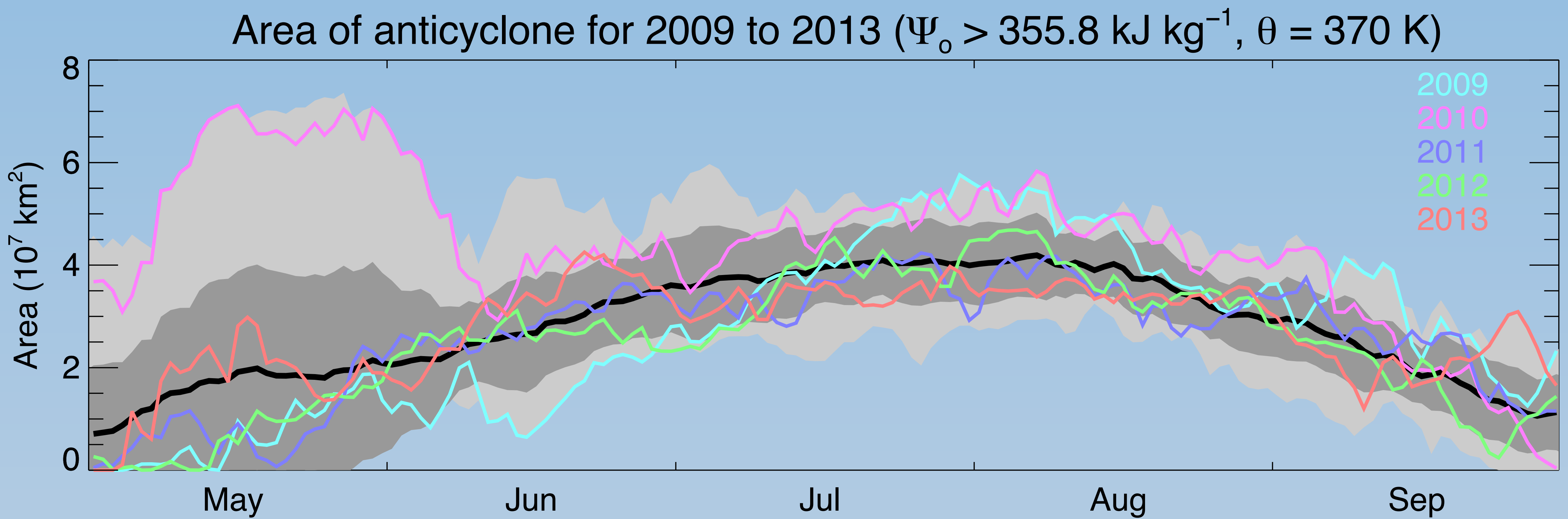
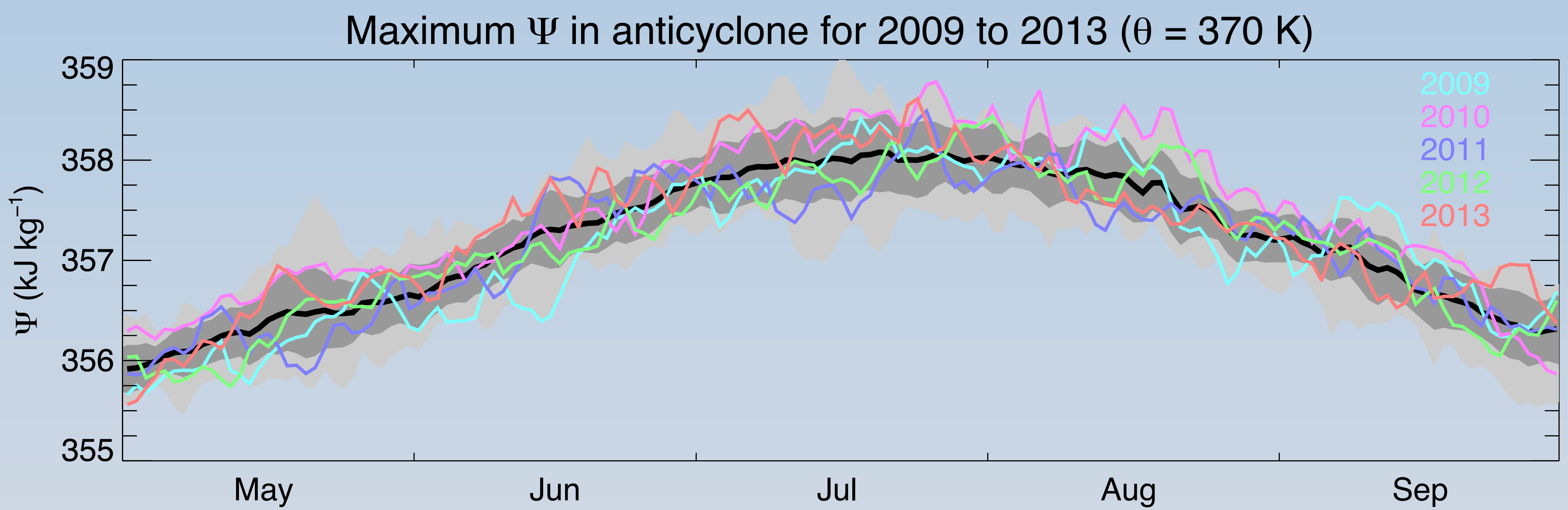
Monsoon Anticyclone Climatology





gray is 1998-2014 std. dev and max/min

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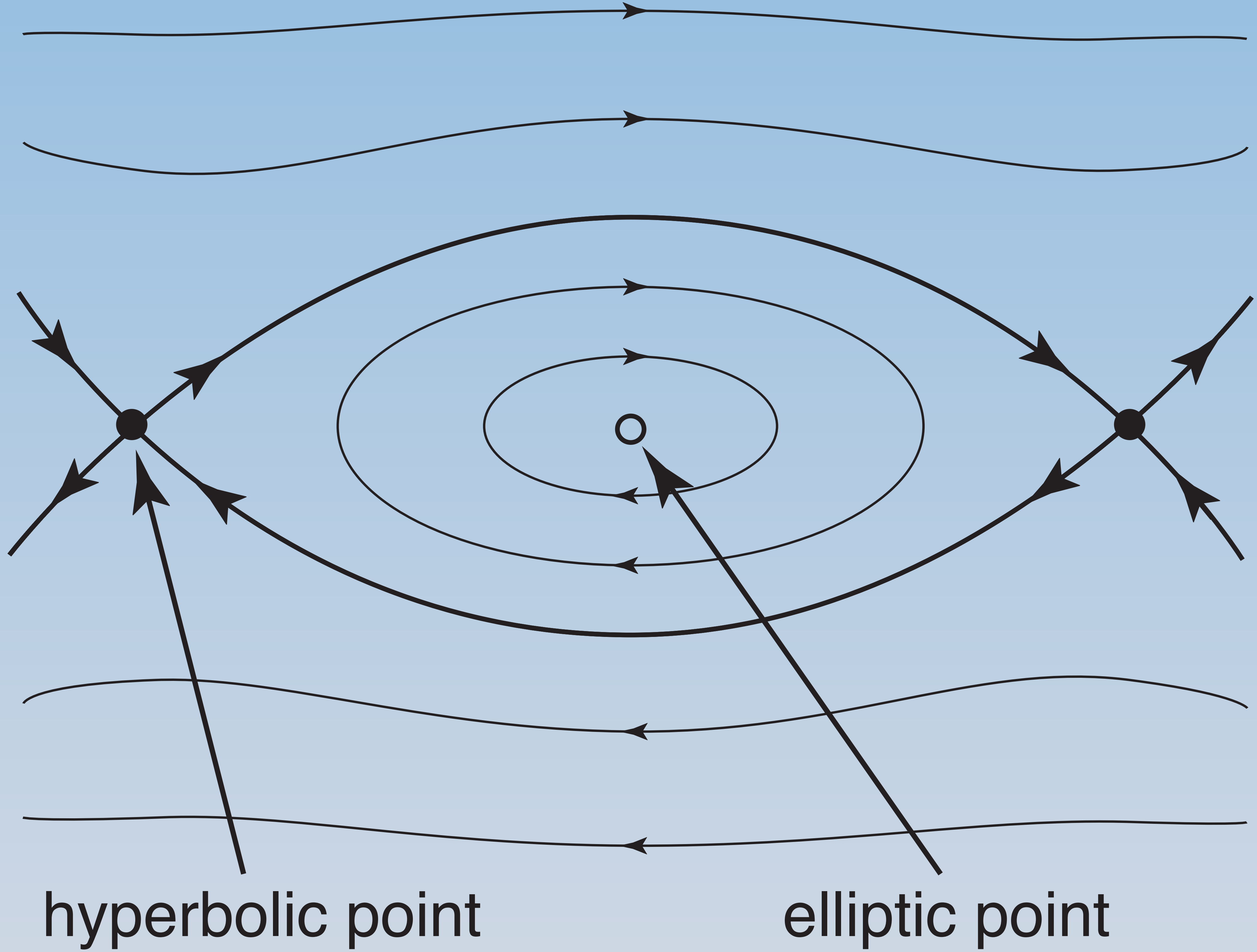
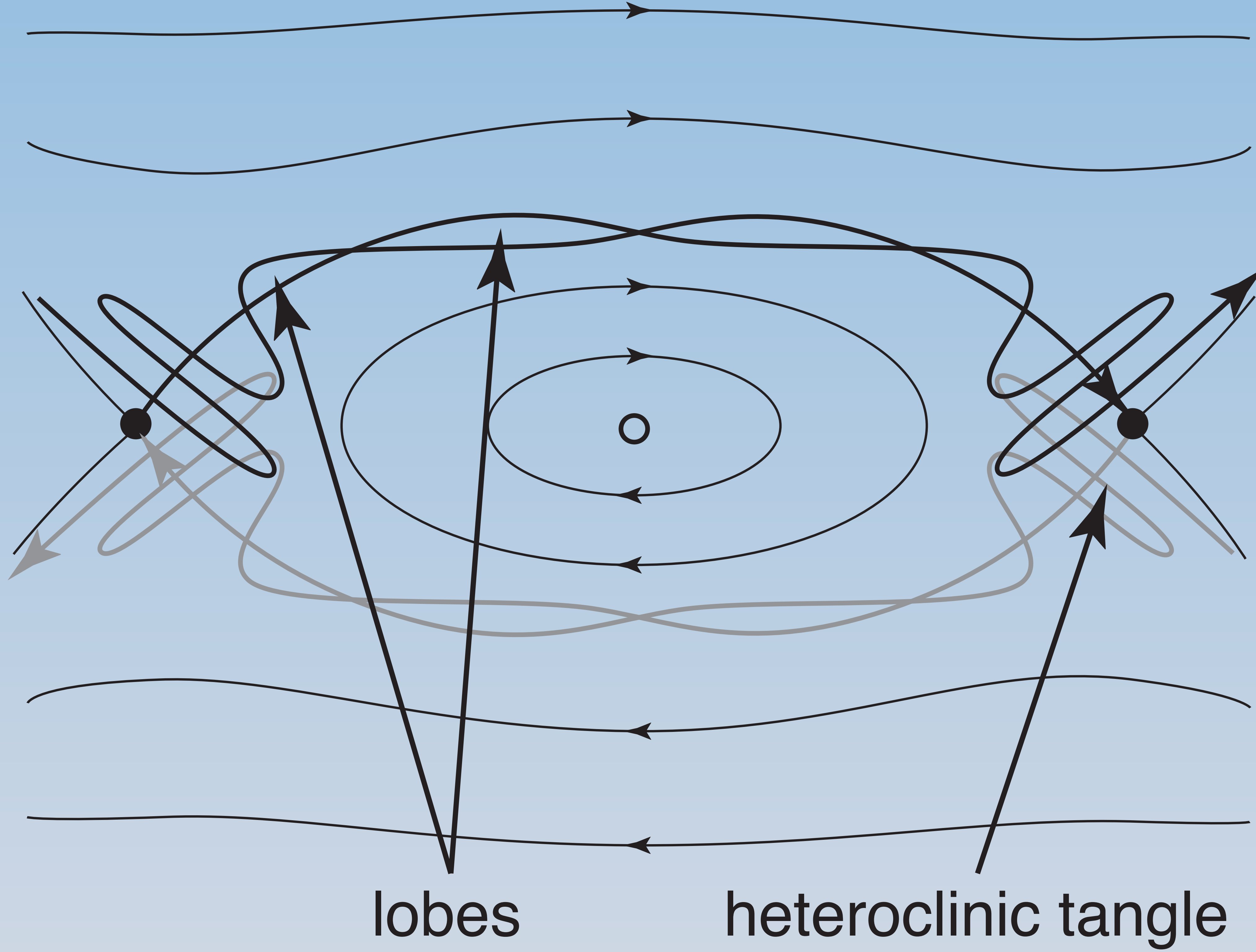
Steady Flow - Wave on Shear



Unsteady Flow



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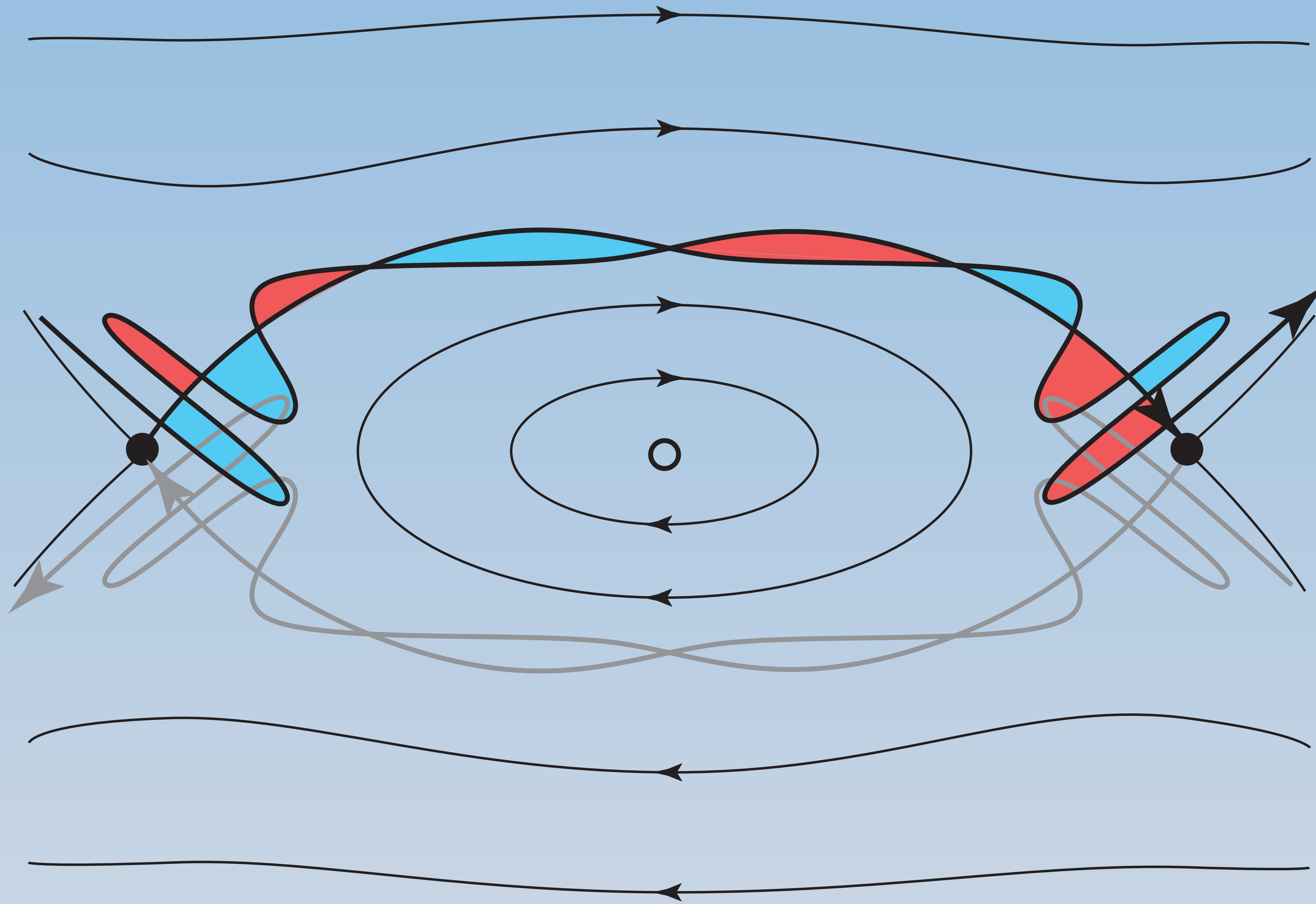
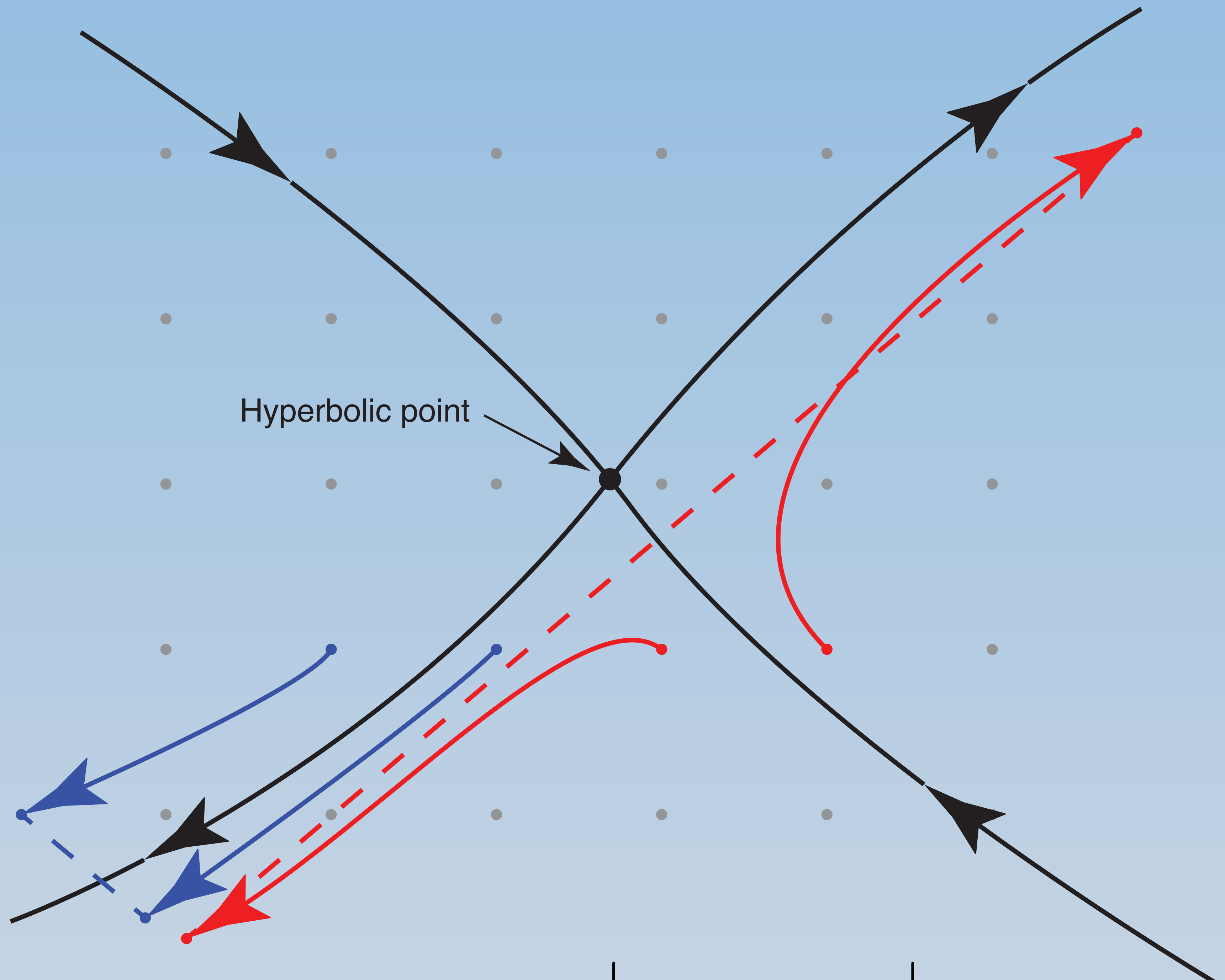
Lobes and Filaments



Finding the Underlying Geometric Structure



$$\text{stretching} = \frac{\left|\mathbf{x}_i - \mathbf{x}_{i+1}\right|_{t+\tau}}{\left|\mathbf{x}_i - \mathbf{x}_{i+1}\right|_t}$$

Manifolds or Lagrangian Coherent Structures (LCS)

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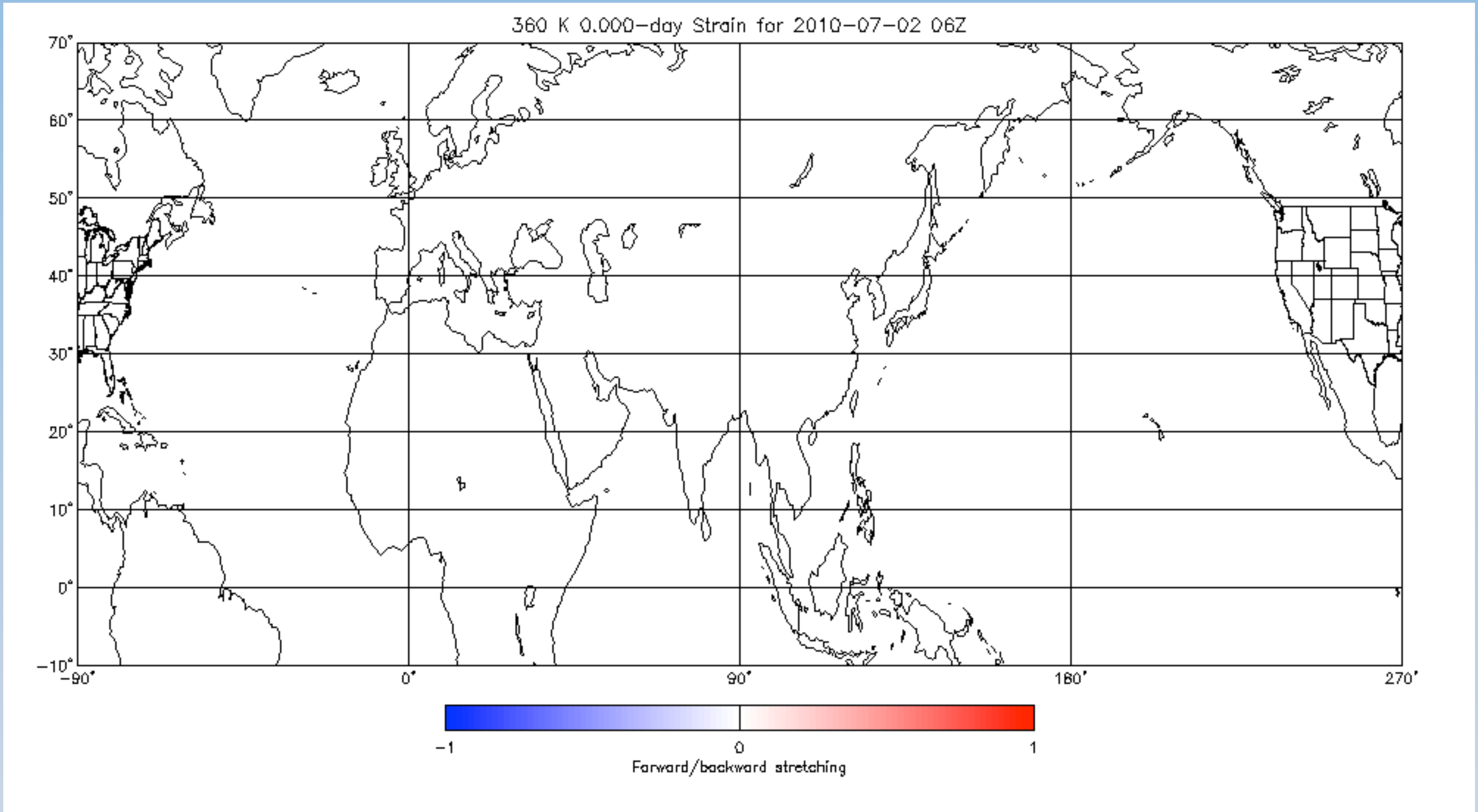
Stable and Unstable Trajectories



Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

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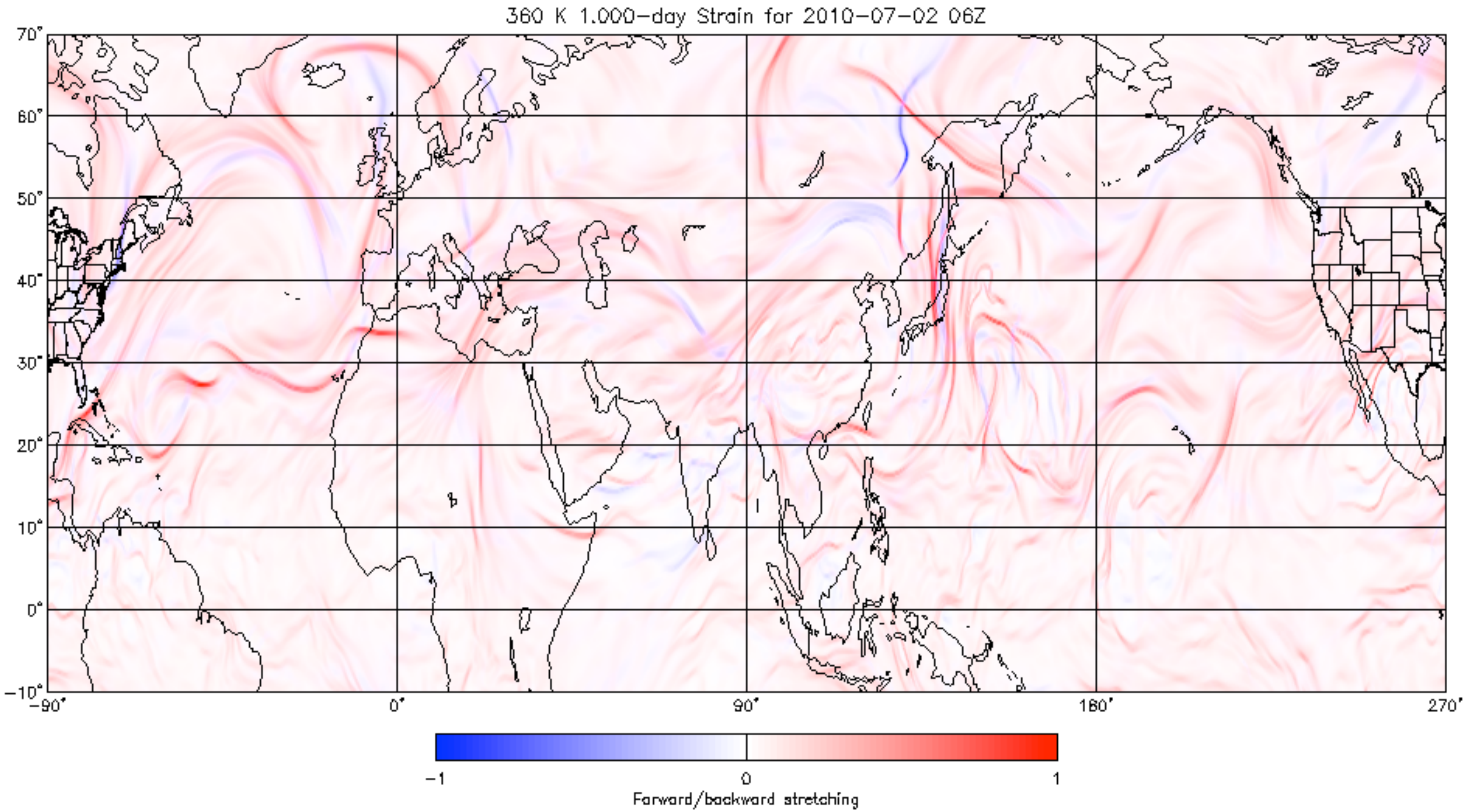
Finding Stable and Unstable Trajectories



Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

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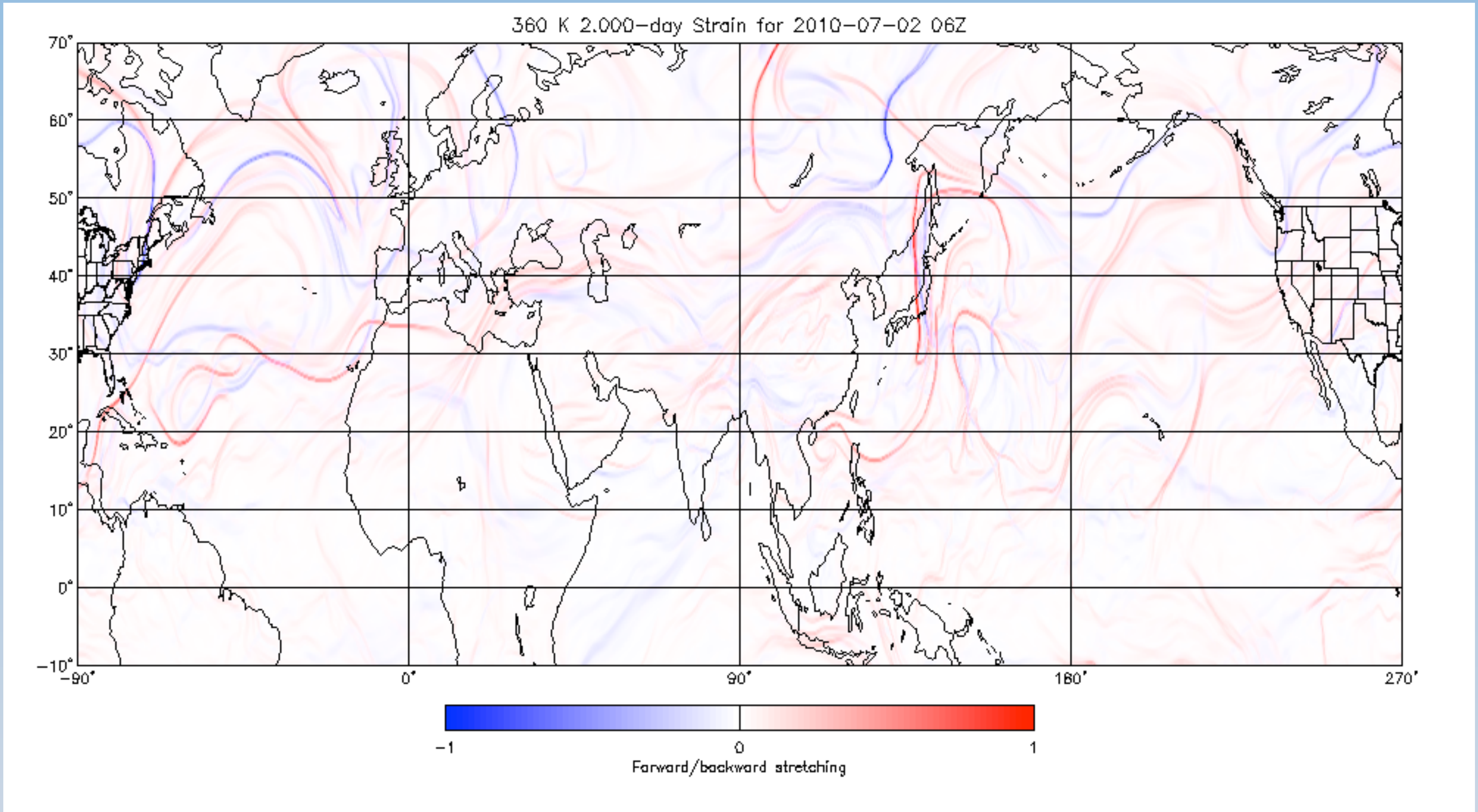
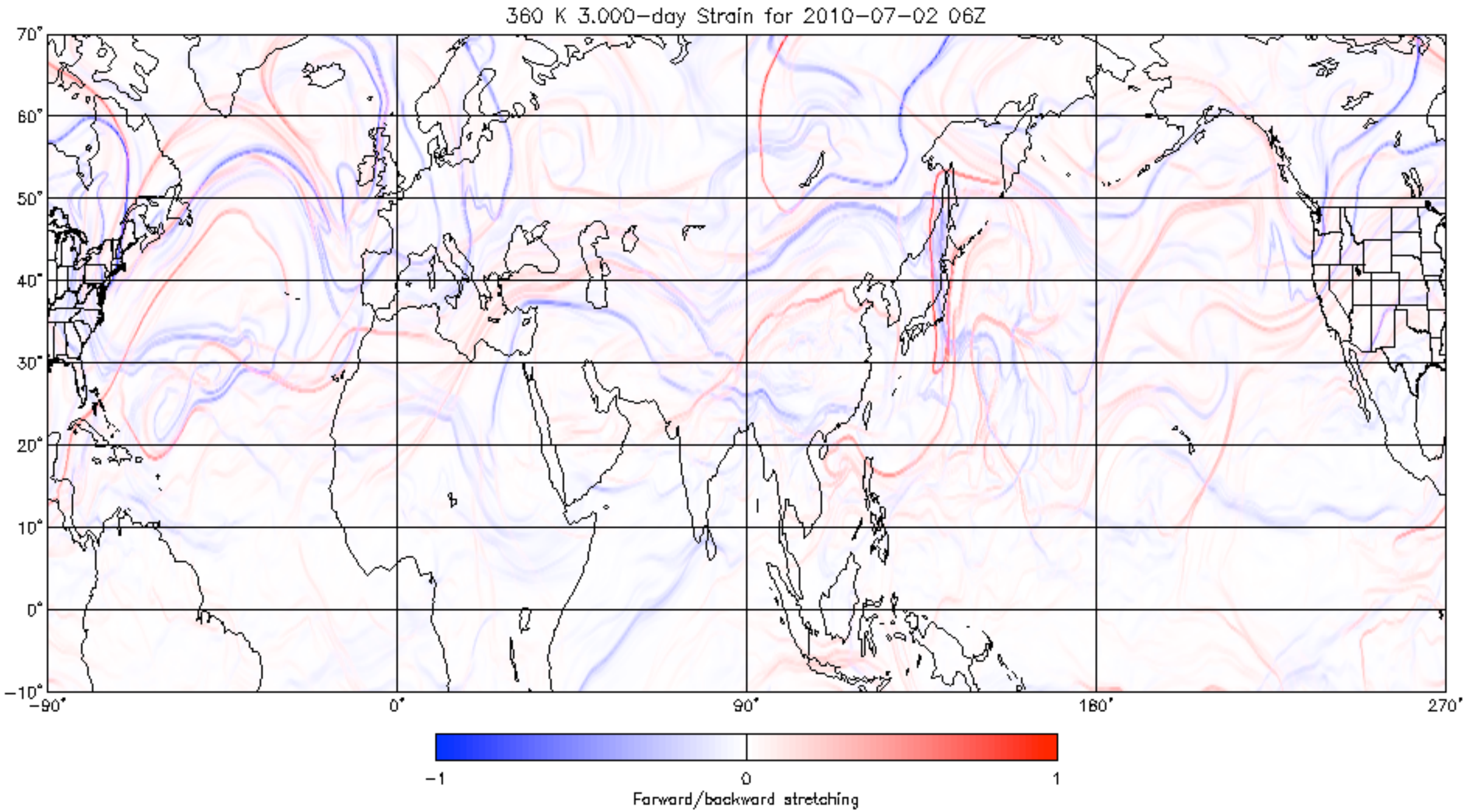


Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

Finding Stable and Unstable Trajectories



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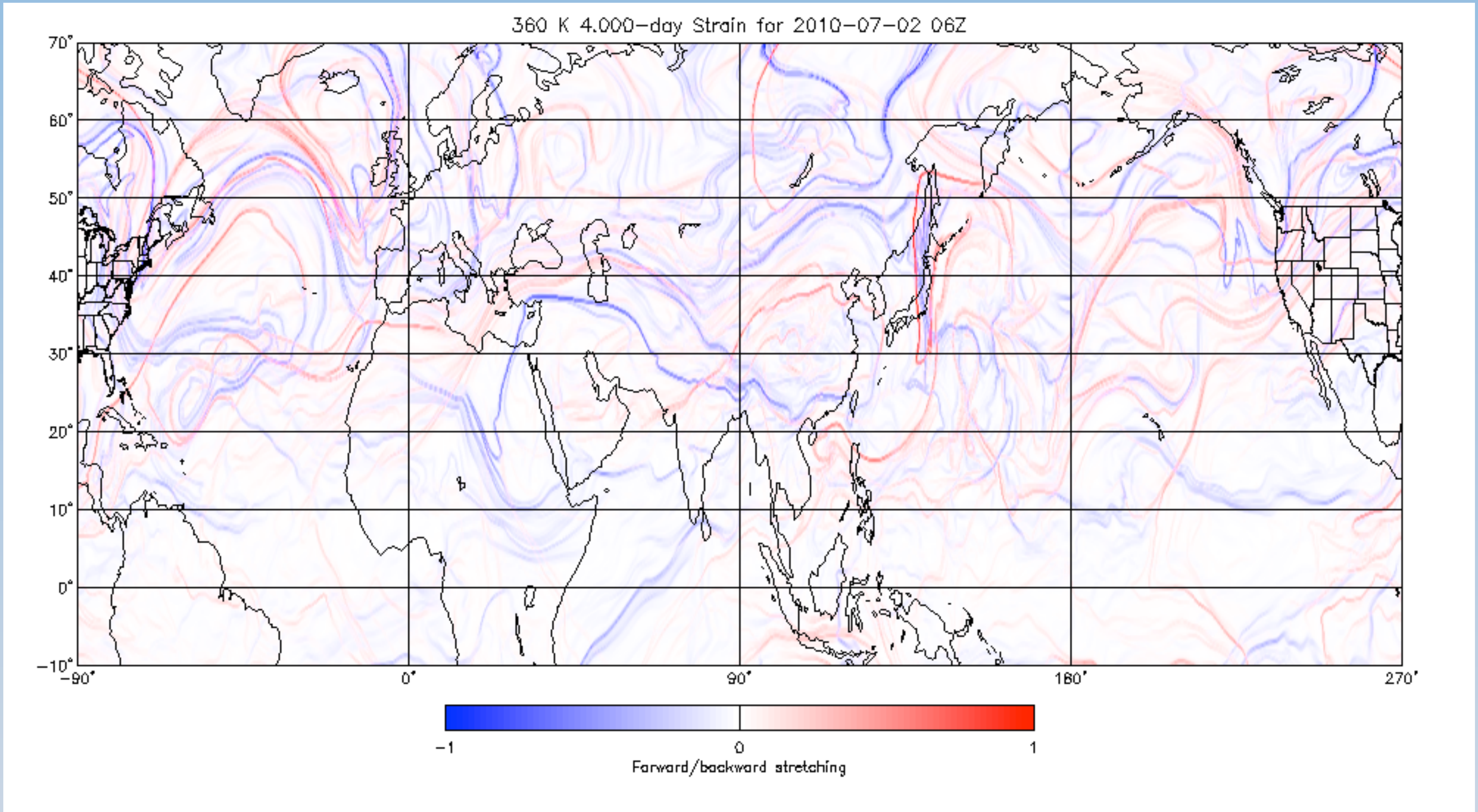
Finding Stable and Unstable Trajectories



Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

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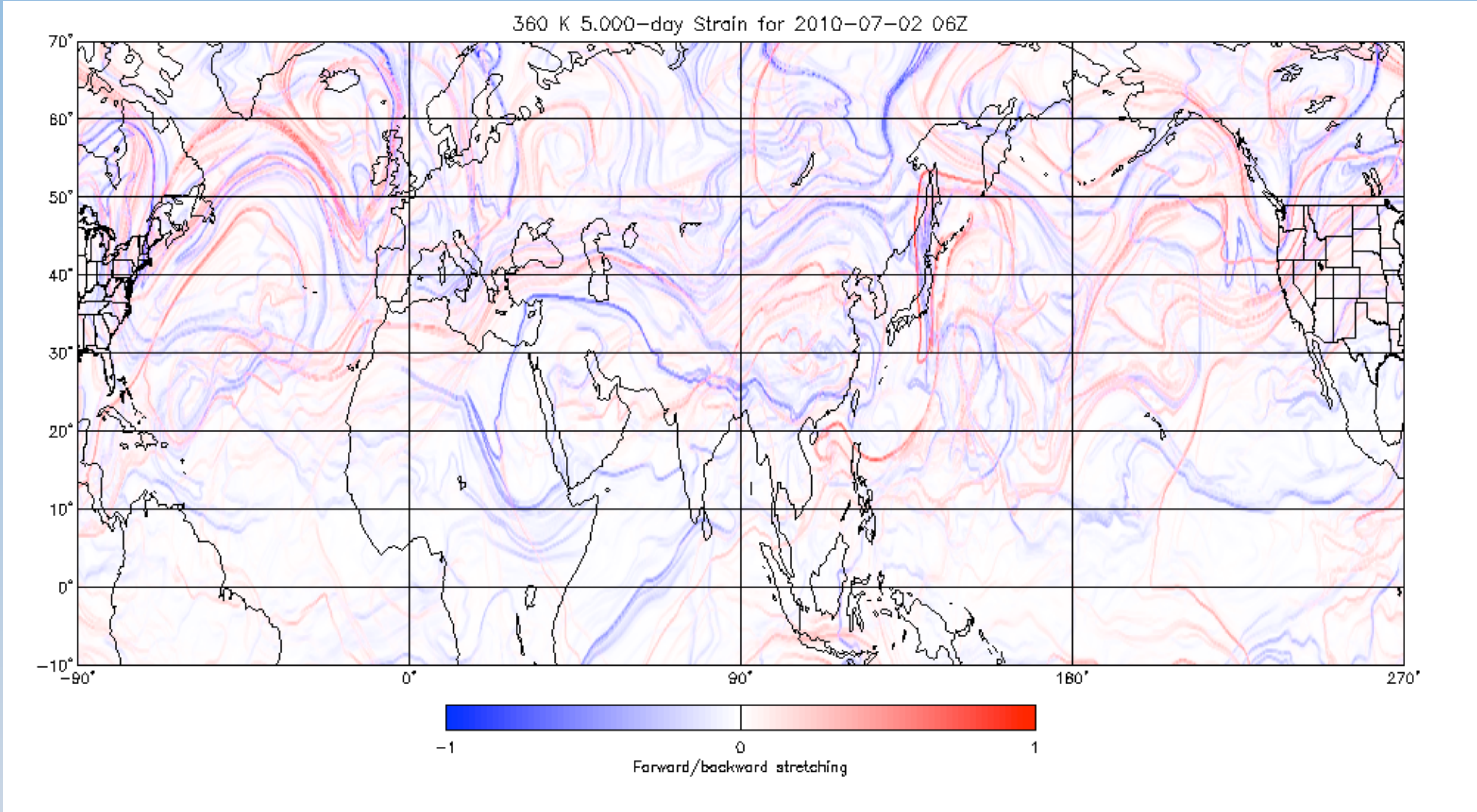

Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

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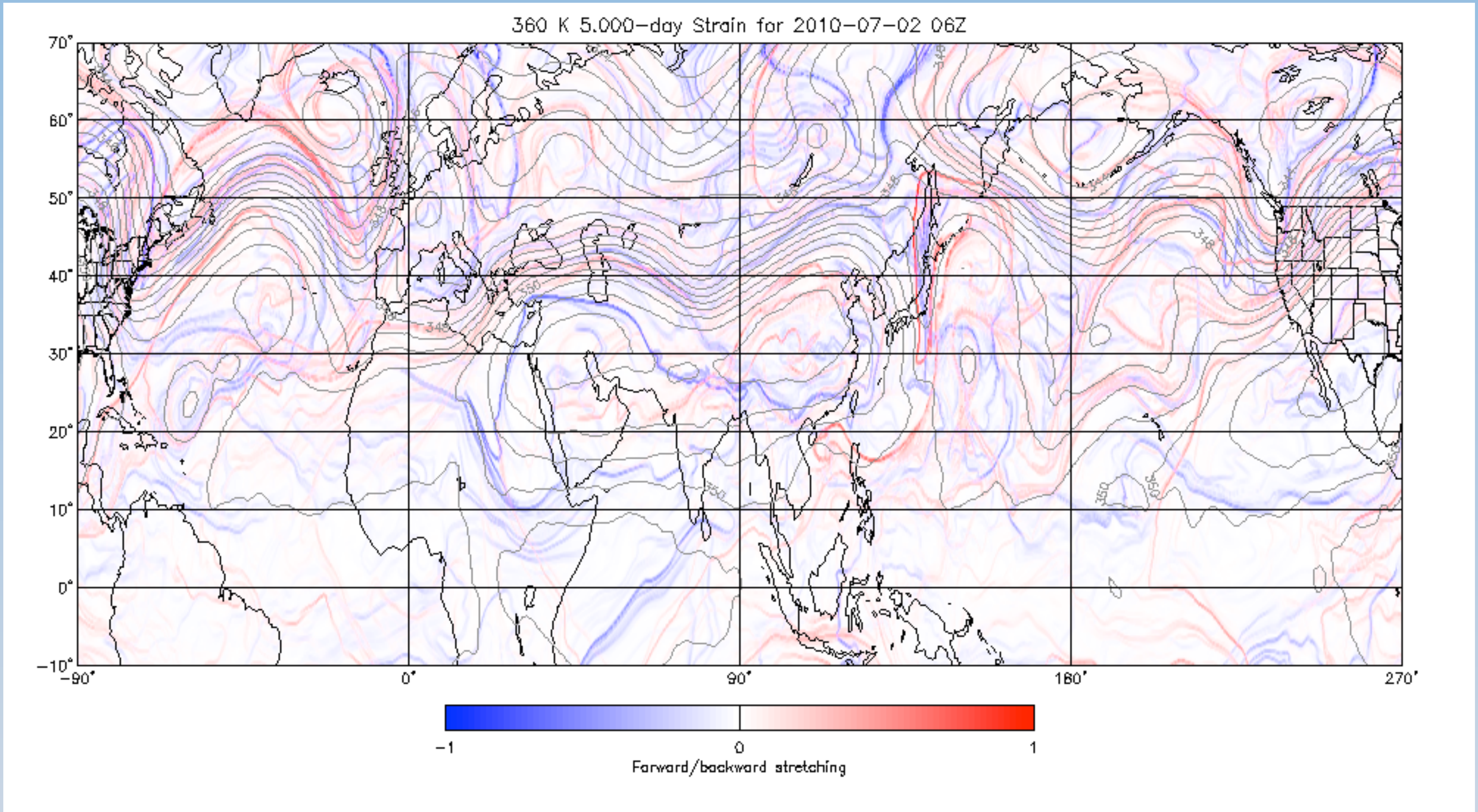
Finding Stable and Unstable Trajectories



Bowman, 2000; Haller, 2000, 2001, 2002; Lekien et al., 2007

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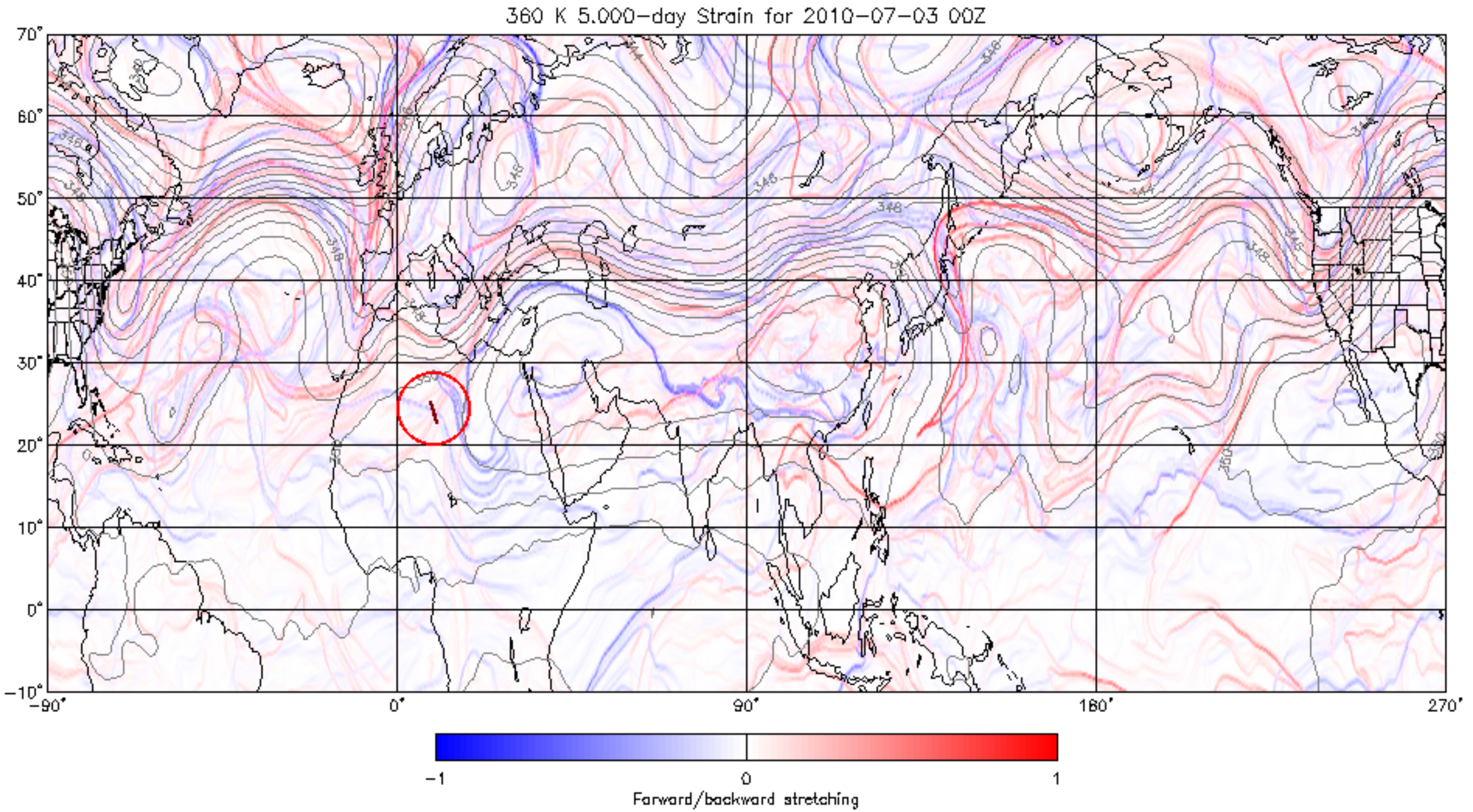
Straddling a Hyperbolic Point



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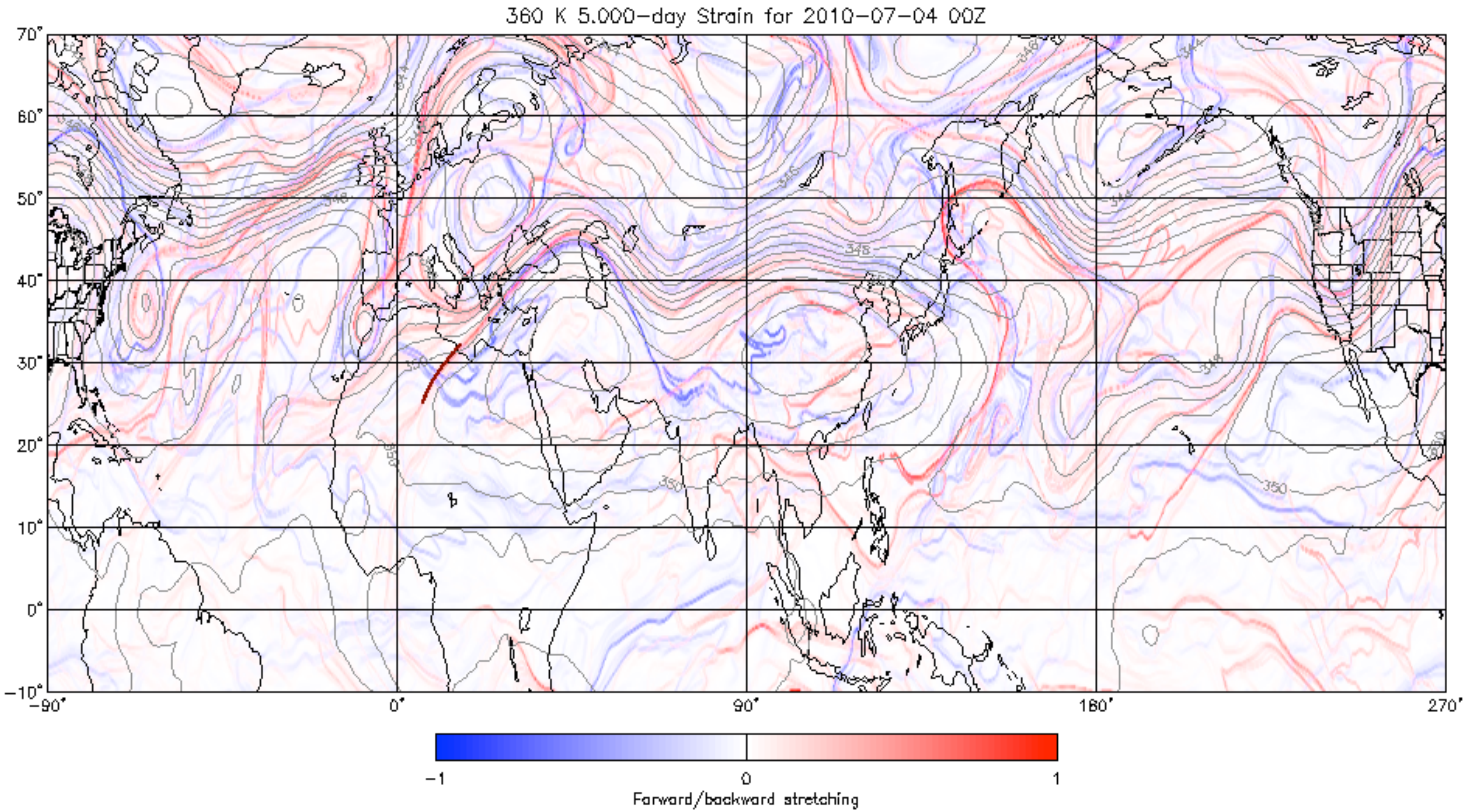
Straddling a Hyperbolic Point



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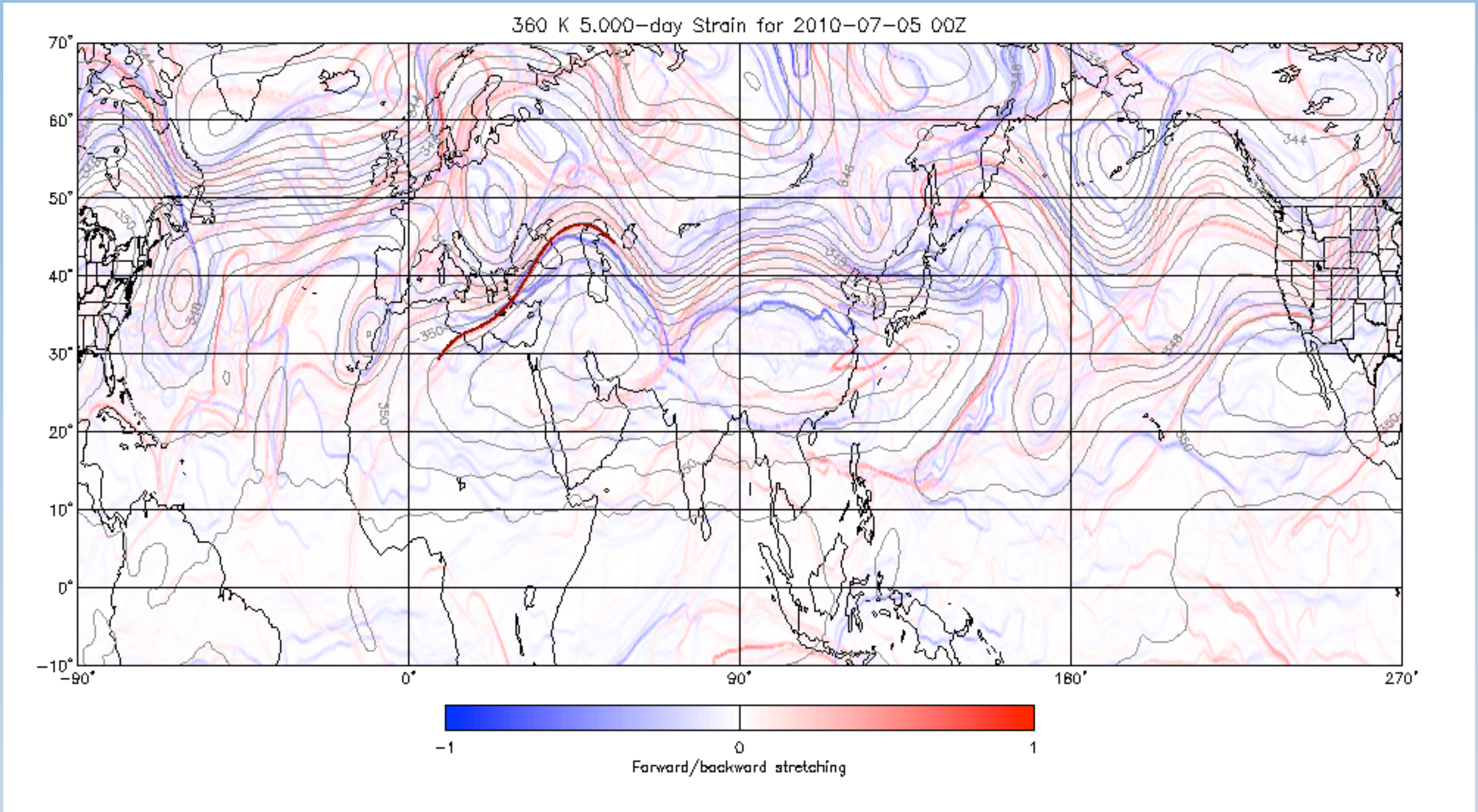
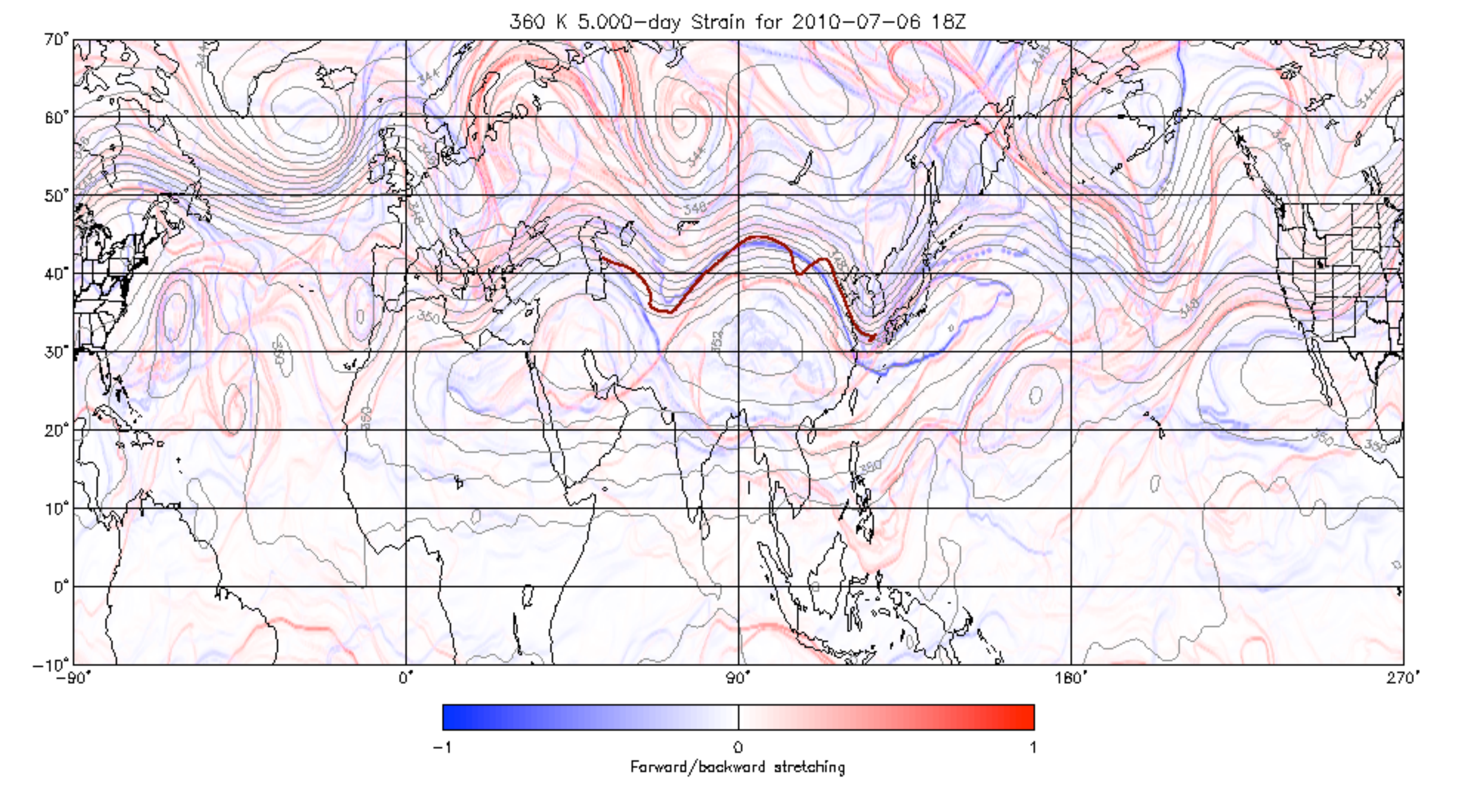
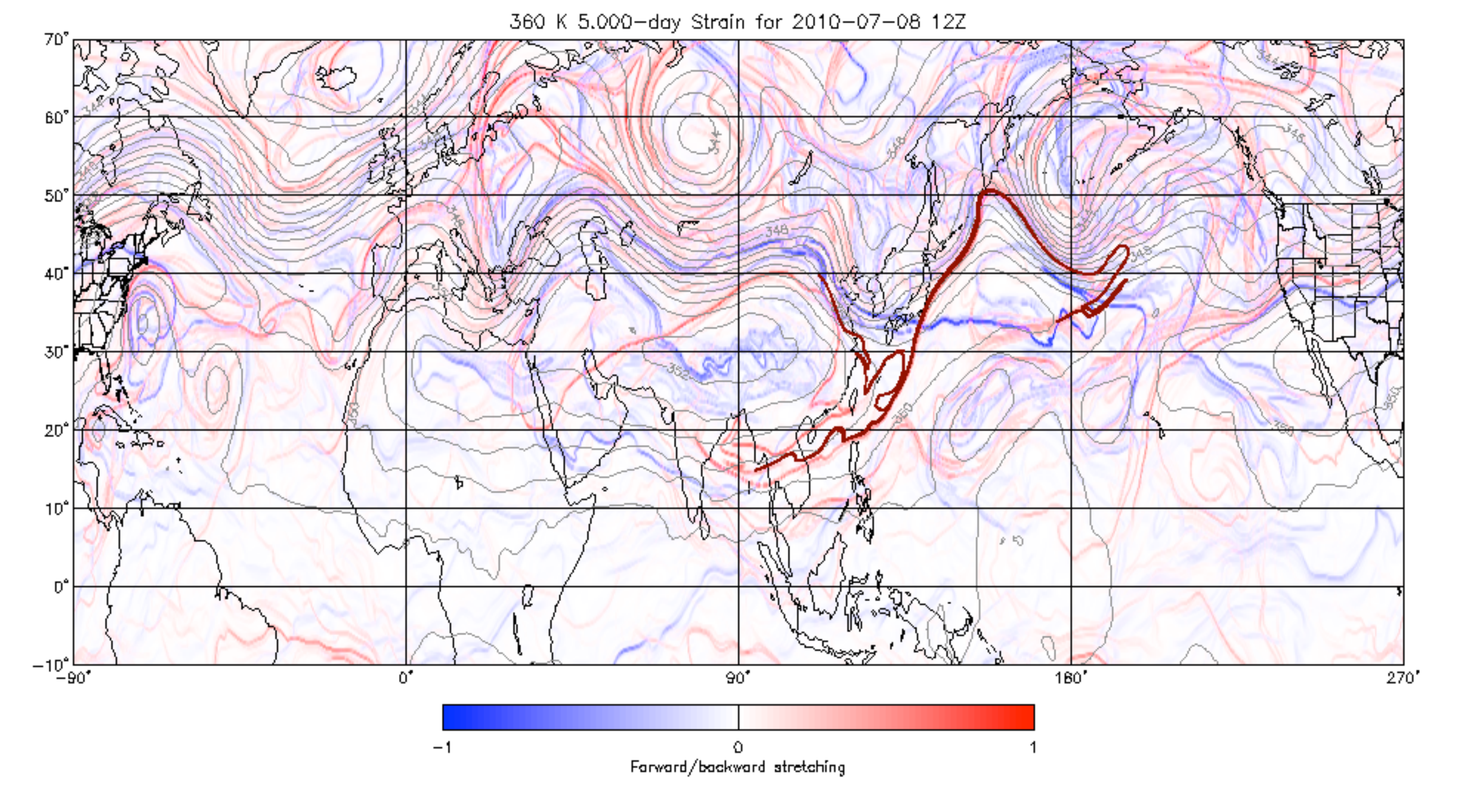
Straddling a Hyperbolic Point



Straddling a Hyperbolic Point



Straddling a Hyperbolic Point



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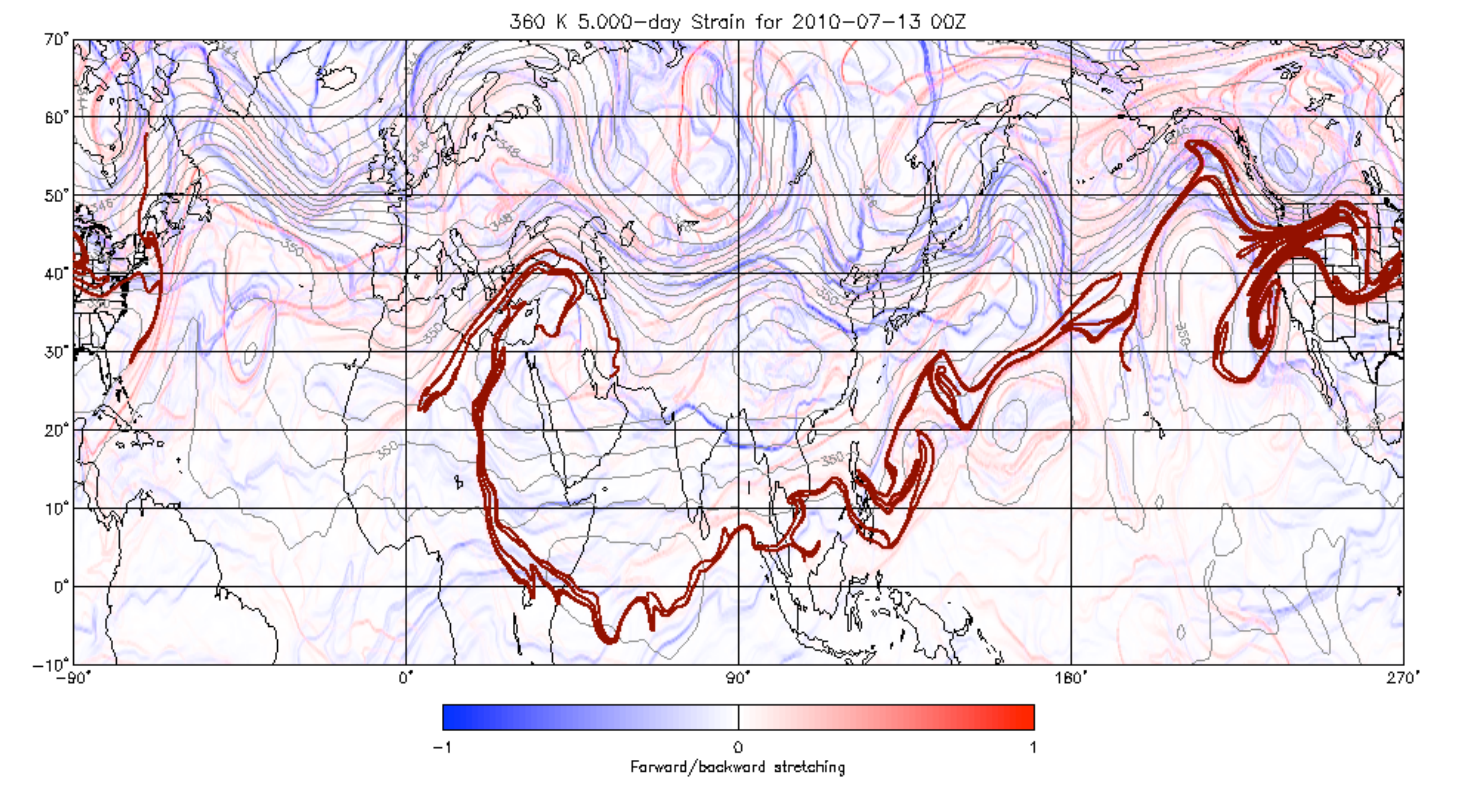
Straddling a Hyperbolic Point



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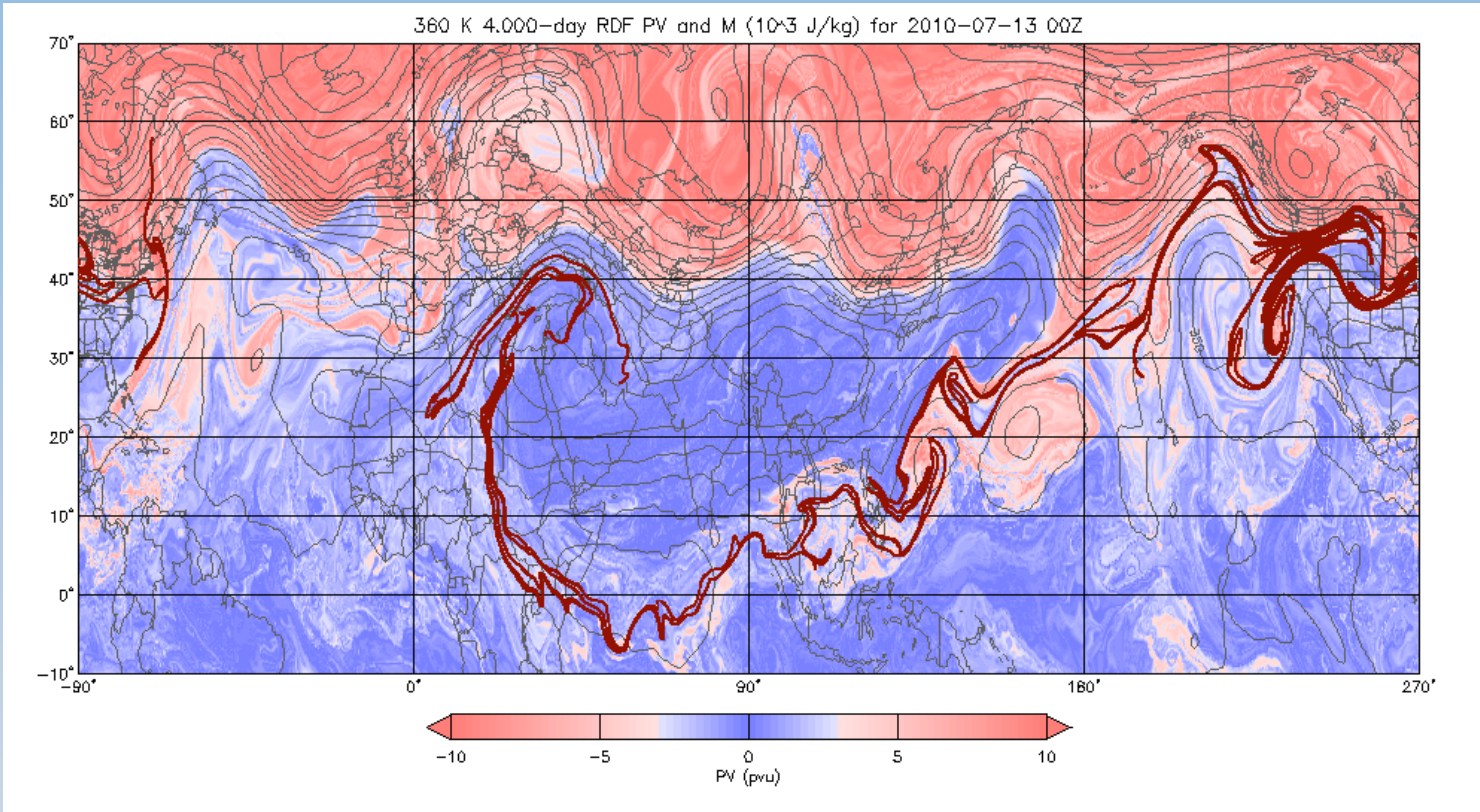
Straddling a Hyperbolic Point



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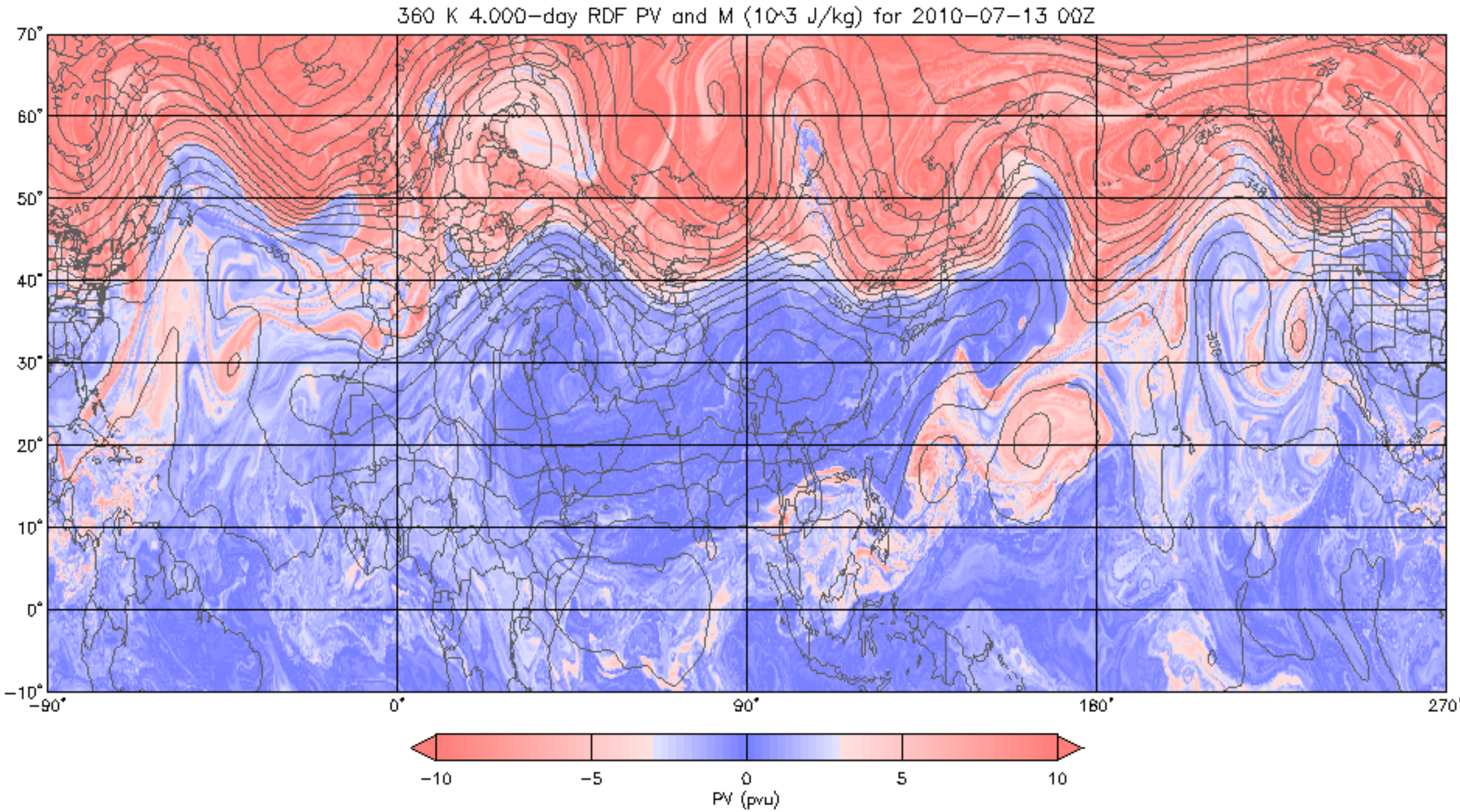

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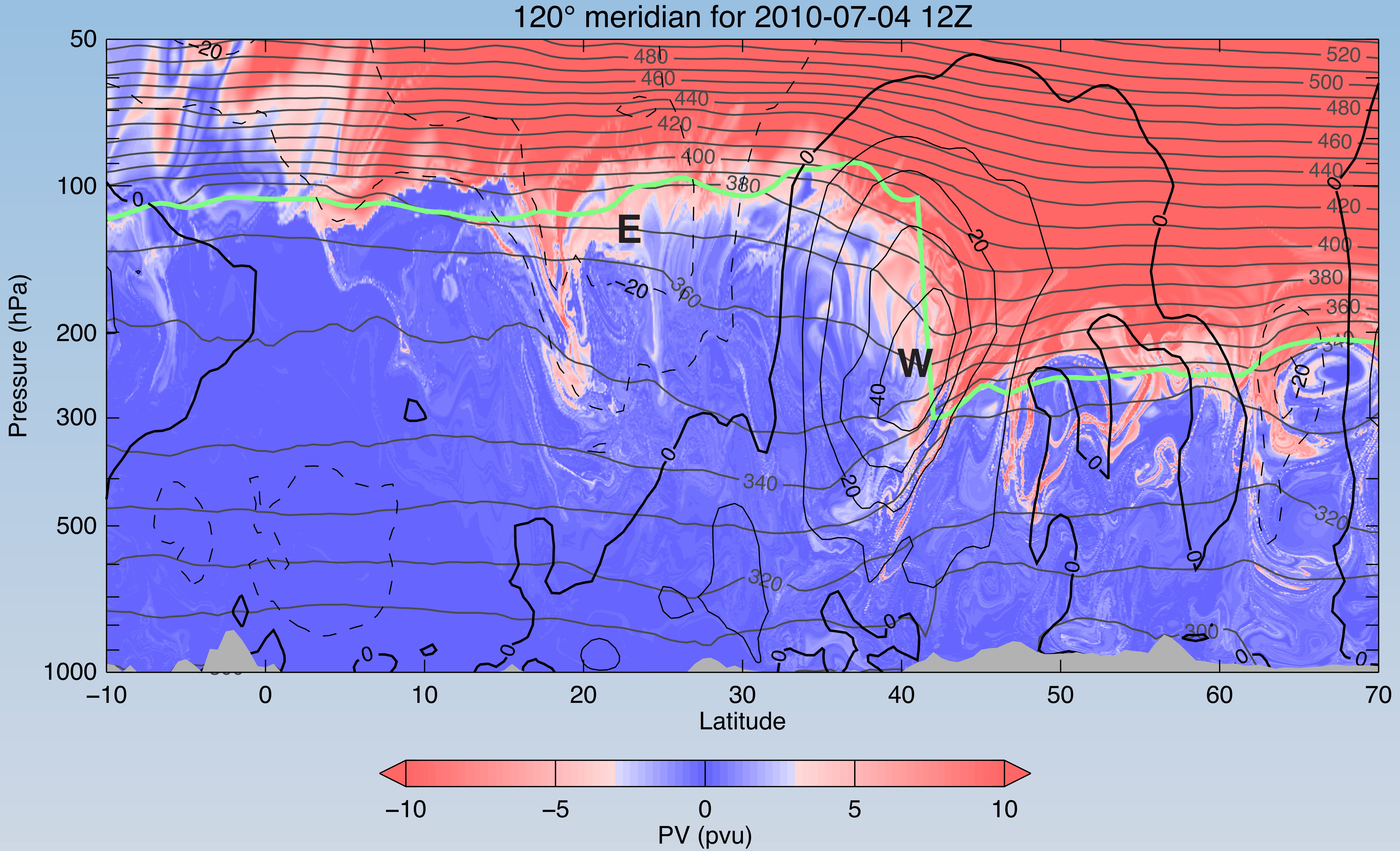
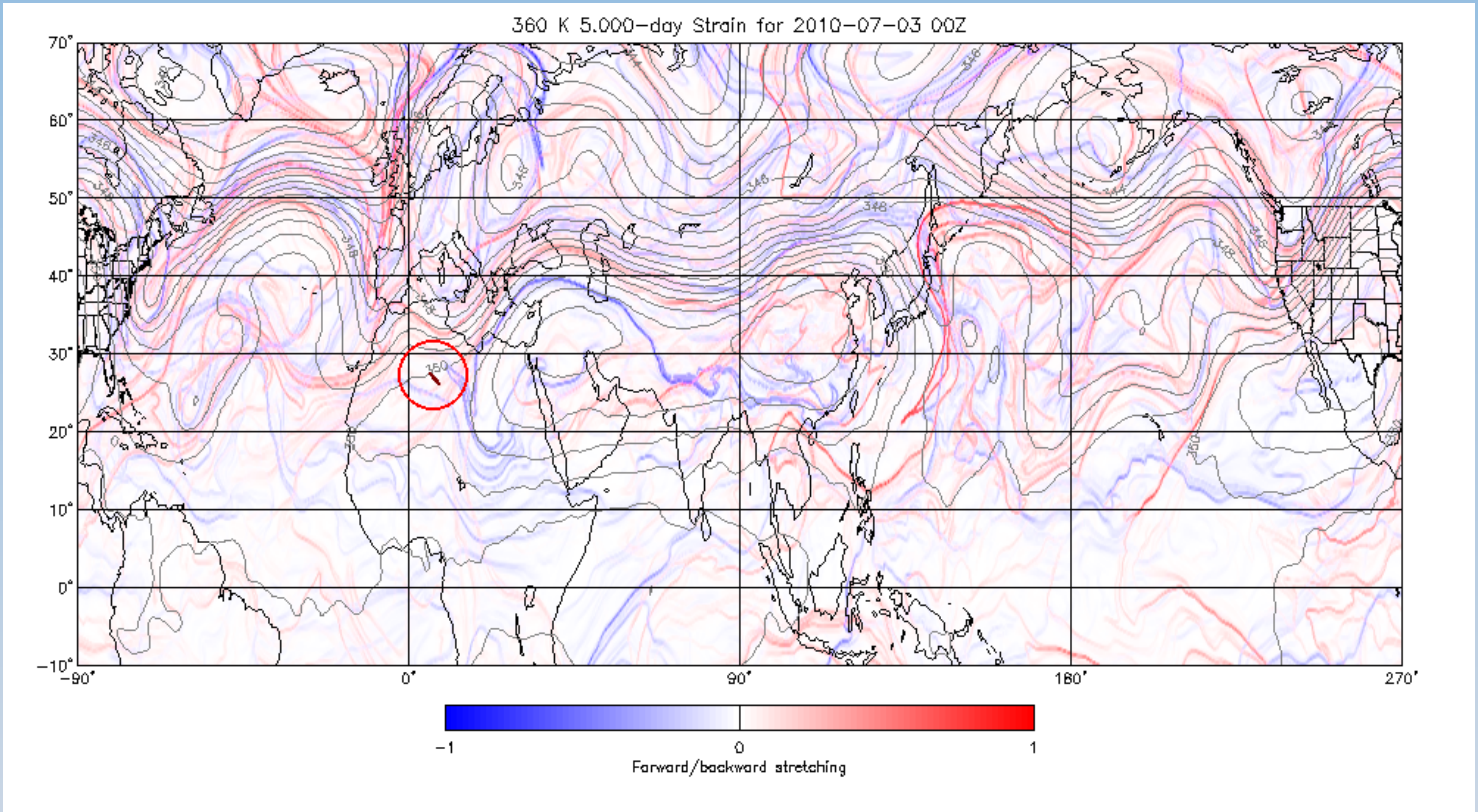
RDF Vertical Section



Not Straddling a Hyperbolic Point



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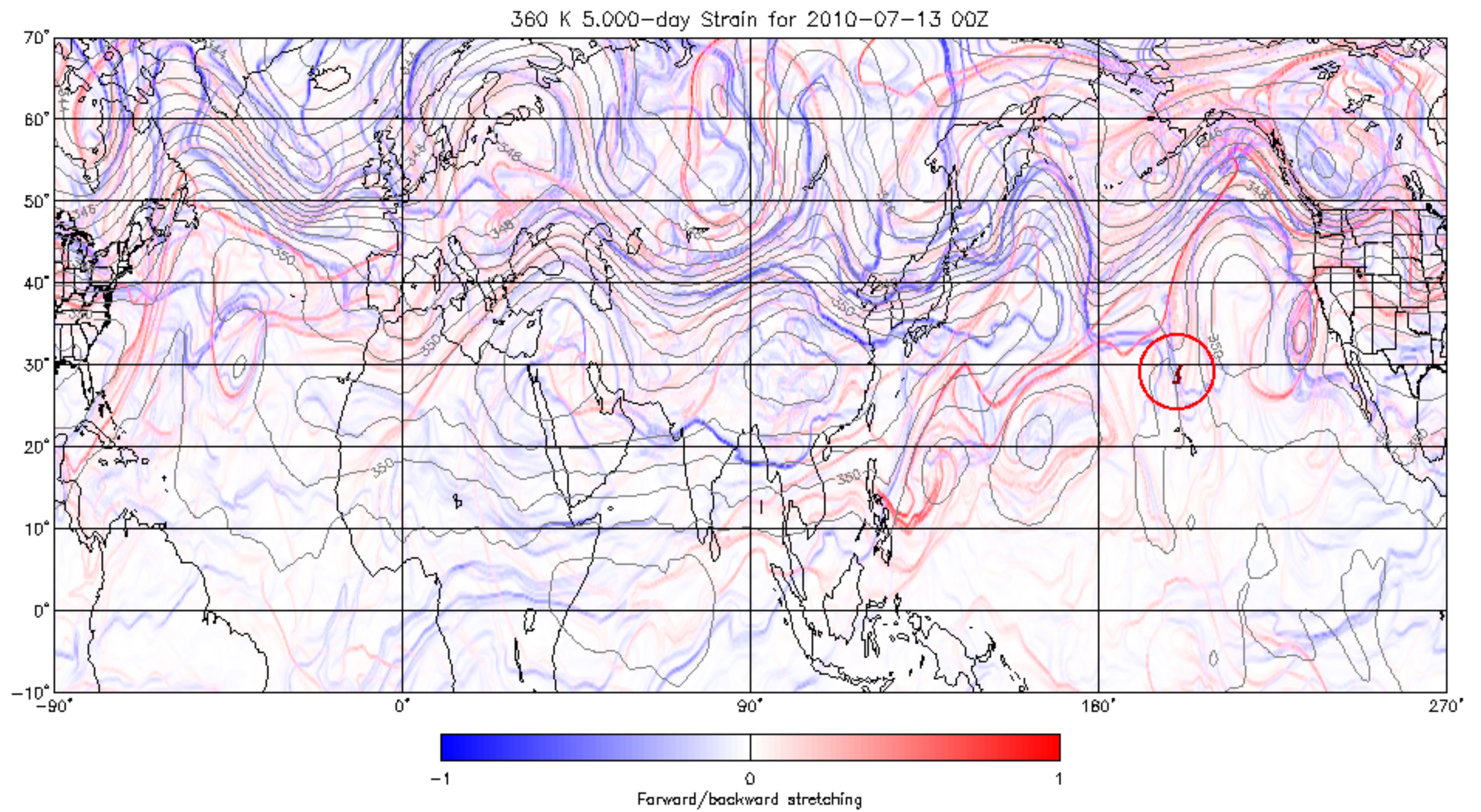
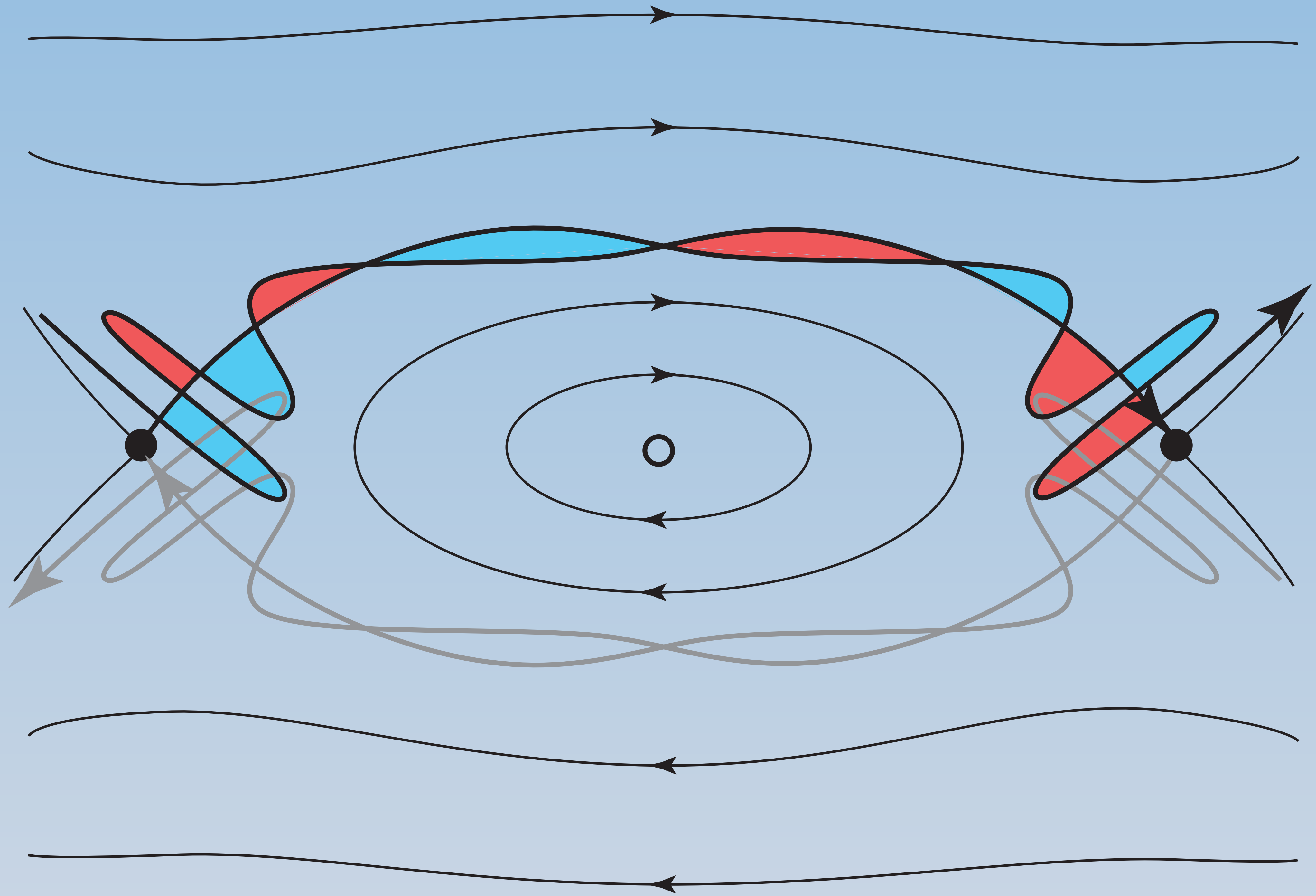
Not Straddling a Hyperbolic Point



Where is the 'Boundary' of the Anticyclone?



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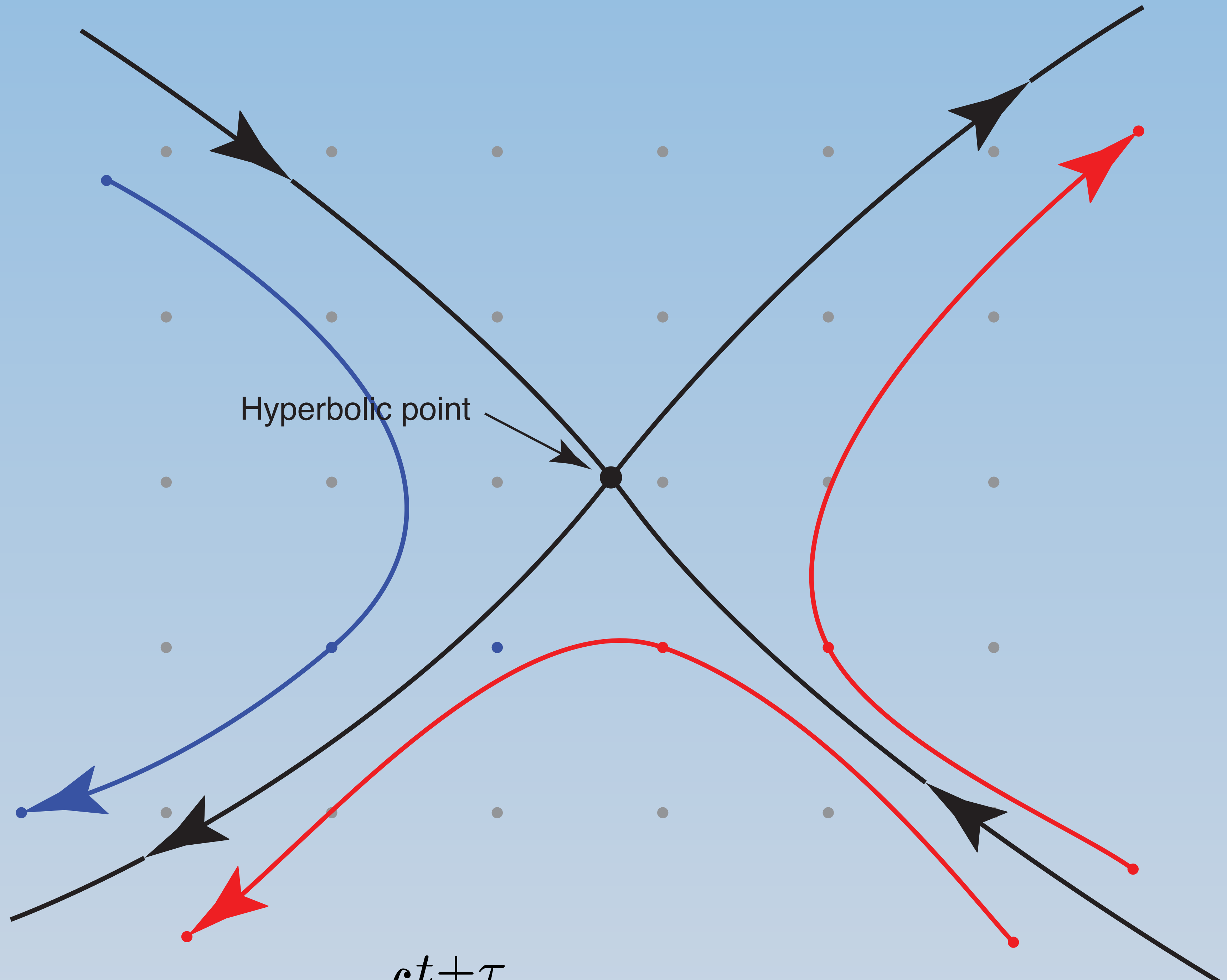
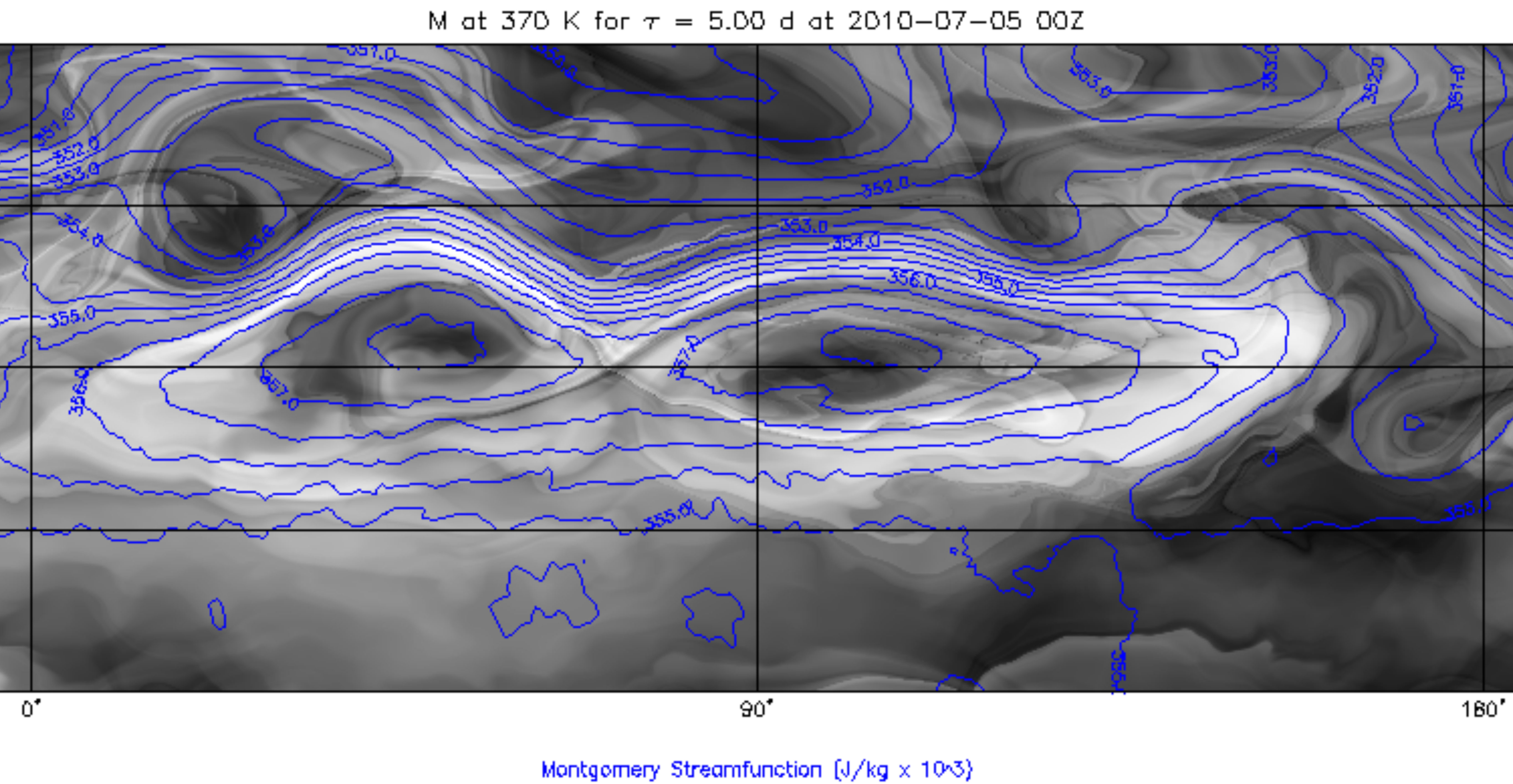
Alternative Method — M-function



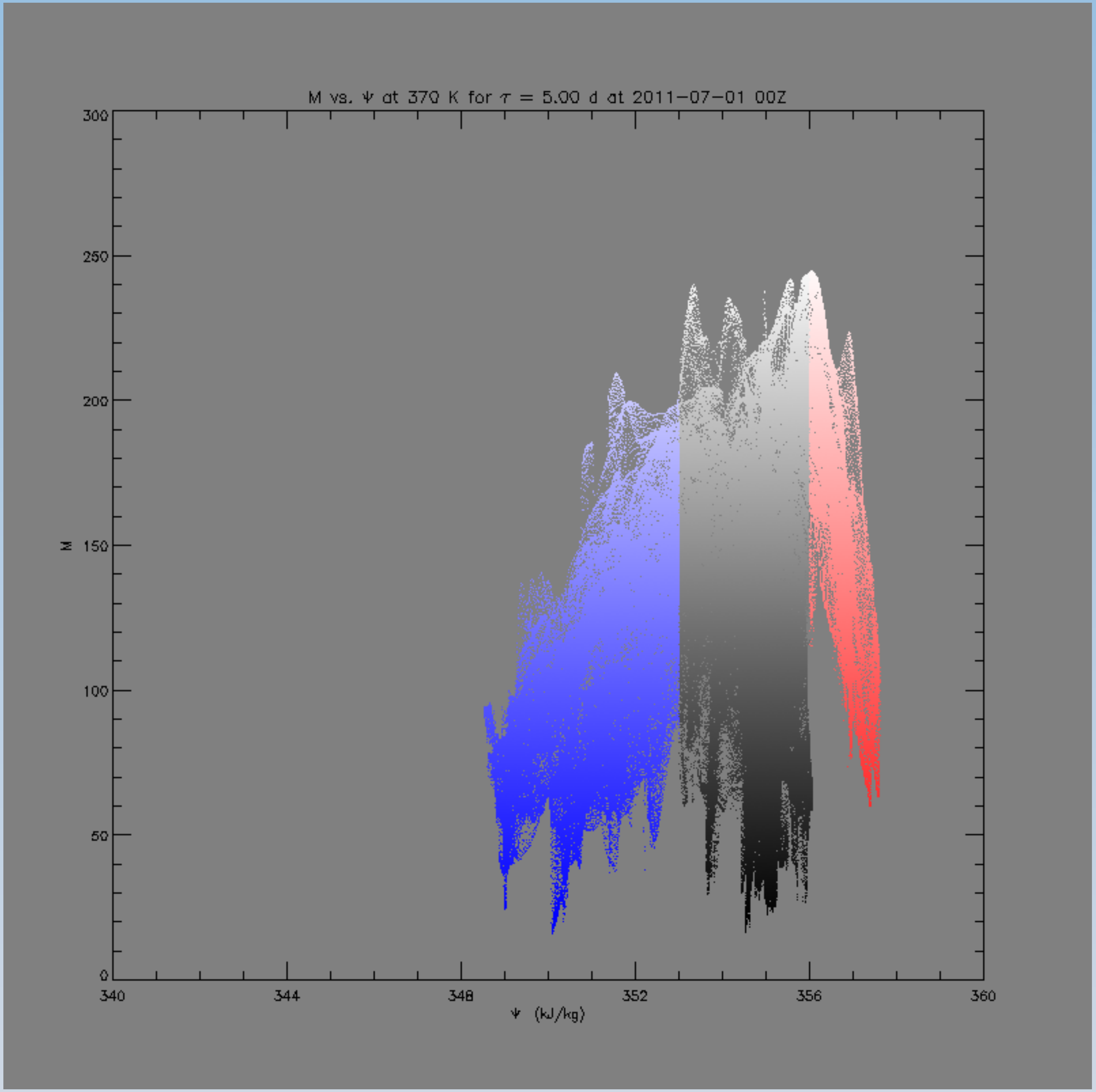
$$M(\mathbf{x_0}, t) = \int_{t-\tau}^{t+\tau} \mathbf{v}(\mathbf{x}, t)\ dt = \text{path length}$$

Madrid & Mancho, 2009; de la Camara et al., 2011, 2013

M and Streamfunction Ψ



Scatterplot of M and Ψ



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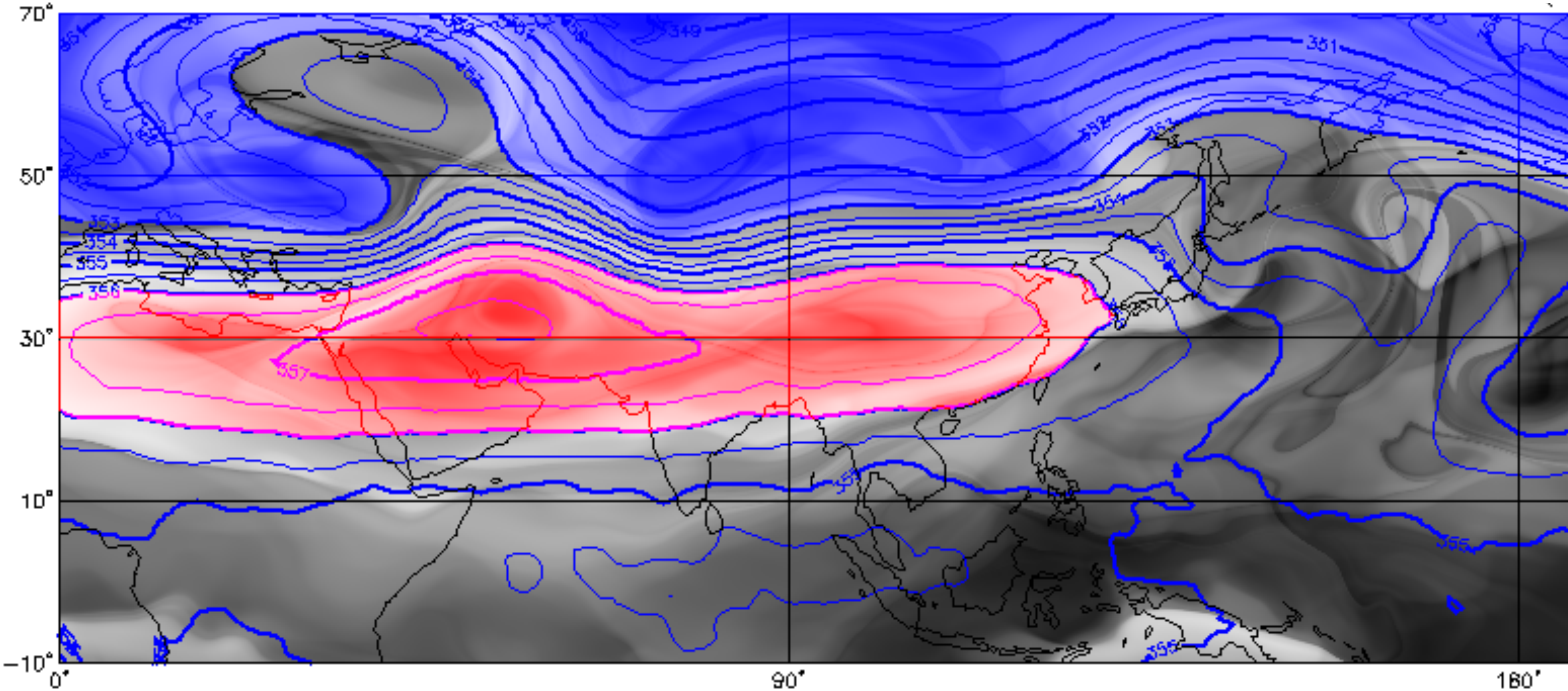
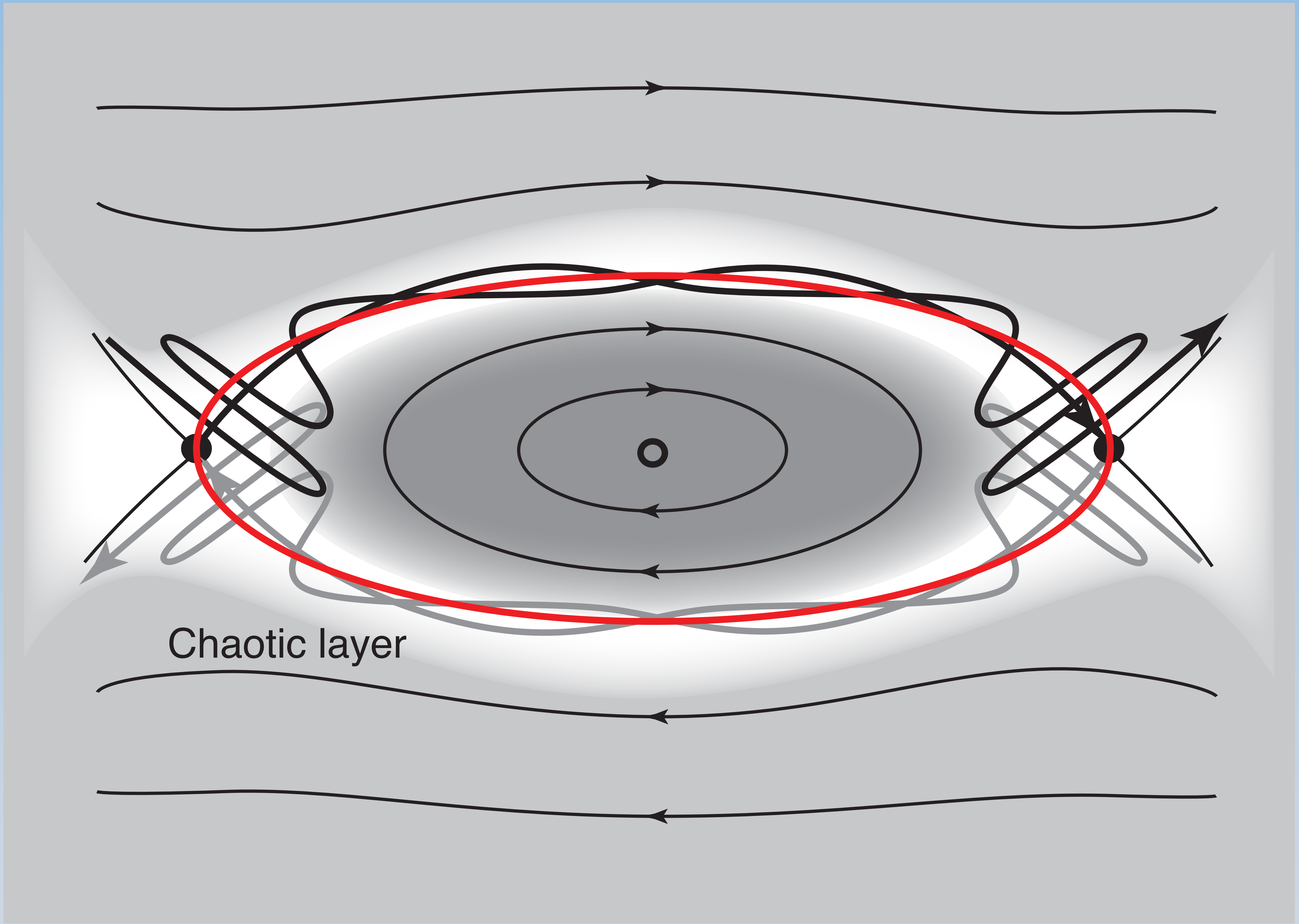
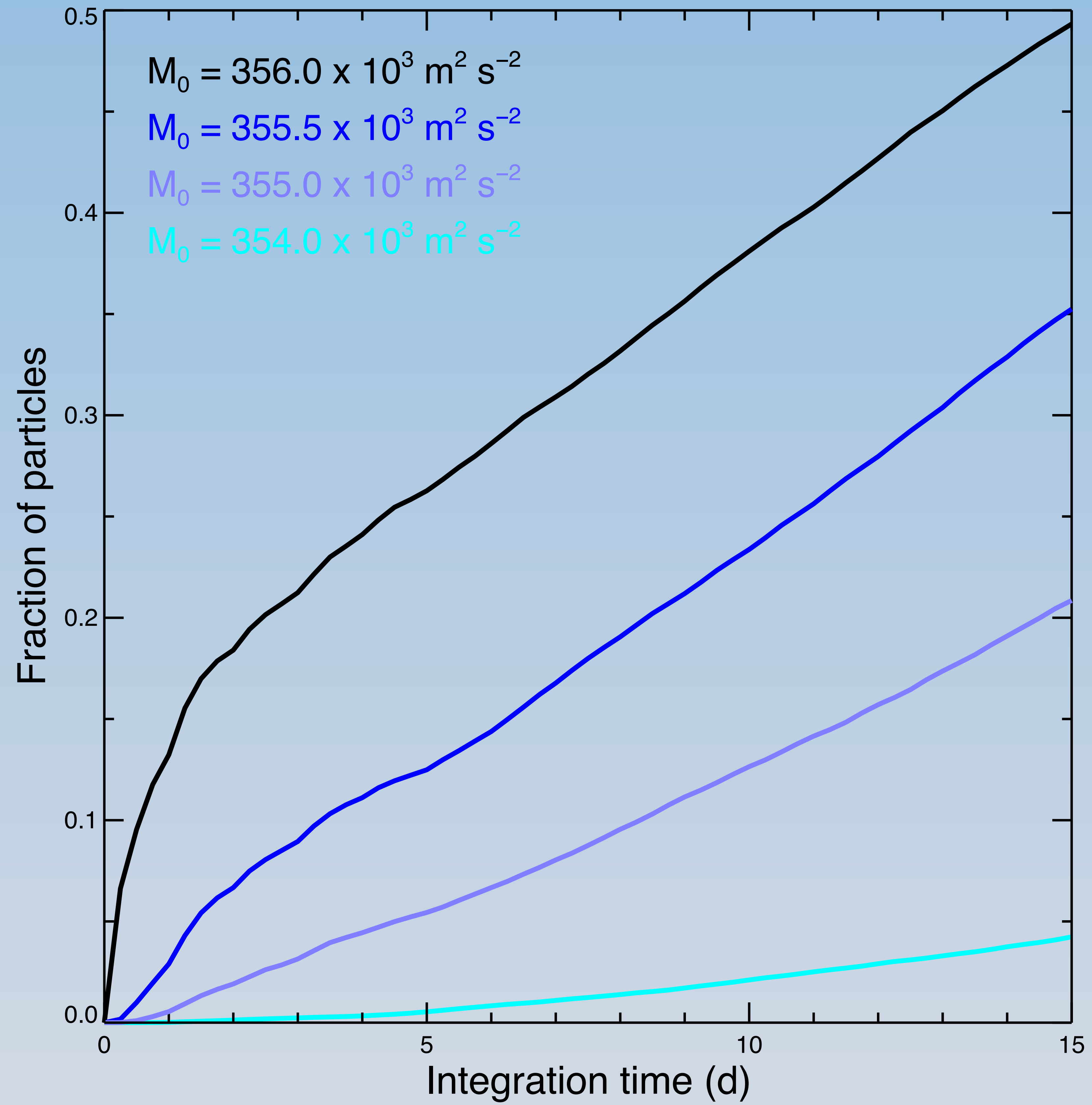
Parcels partitioned by ψ



Anticyclone Boundary Defined by ψ



Average Outward Particle Flux - July 2010



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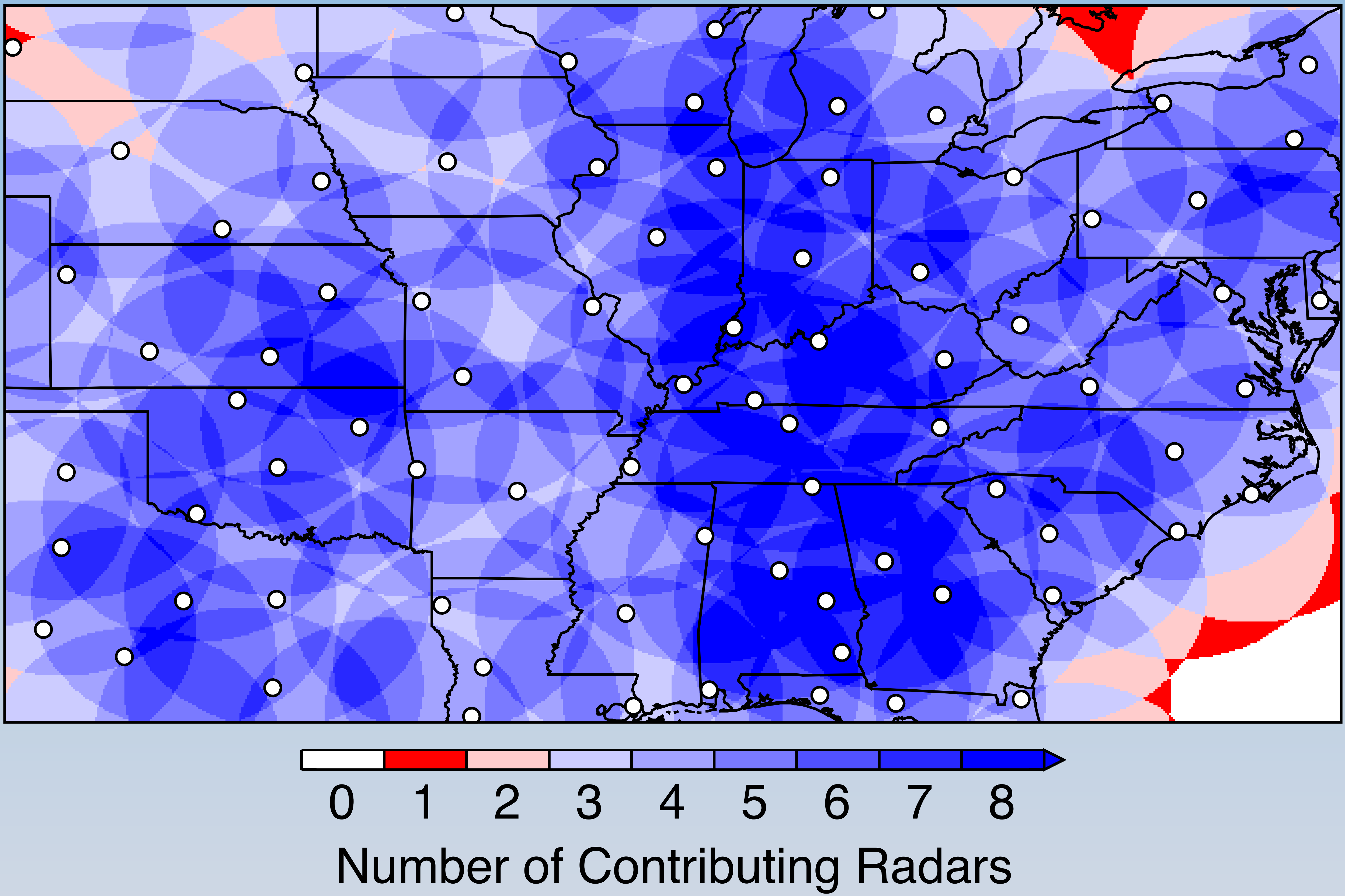
Overshooting Convection in N. America

- Solomon, Bowman, and Homeyer, 2016. Tropopause Penetrating Convection from Three-Dimensional Gridded NEXRAD Data, *JAMC*.
  - Overshooting convection from NEXRAD for 2004
  - Annual, diurnal, and geographic variation

NEXRAD Network



3-hourly analysis for 1 year

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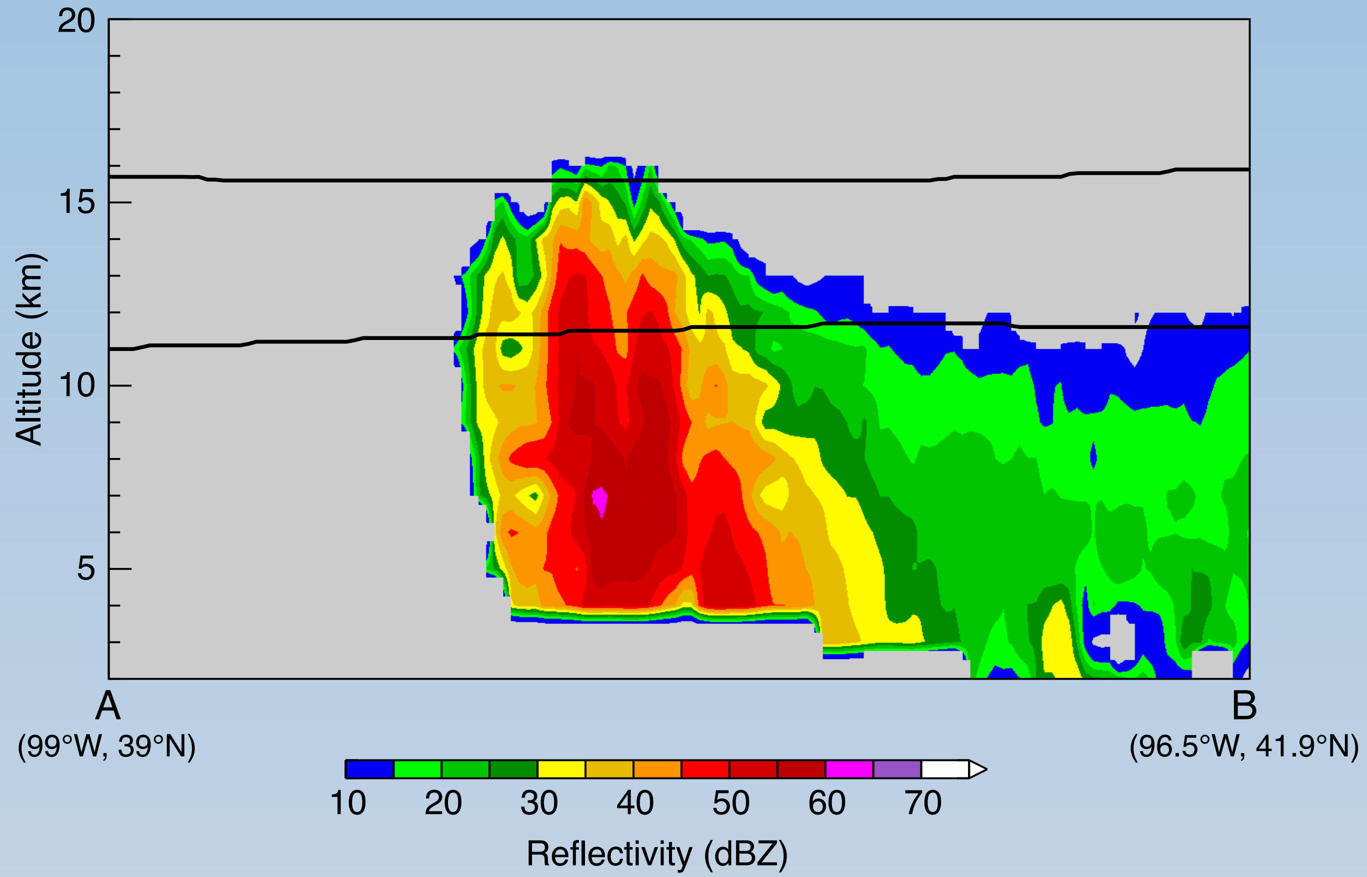
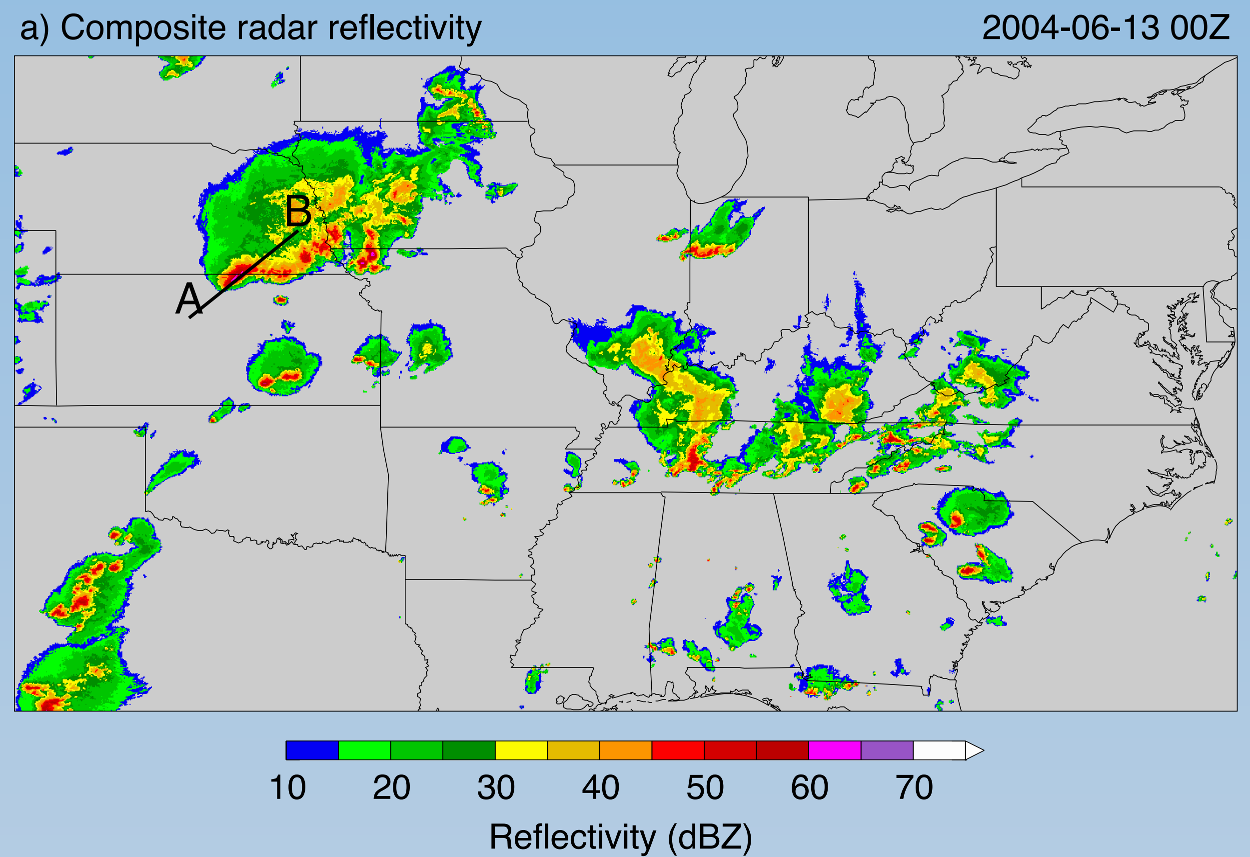
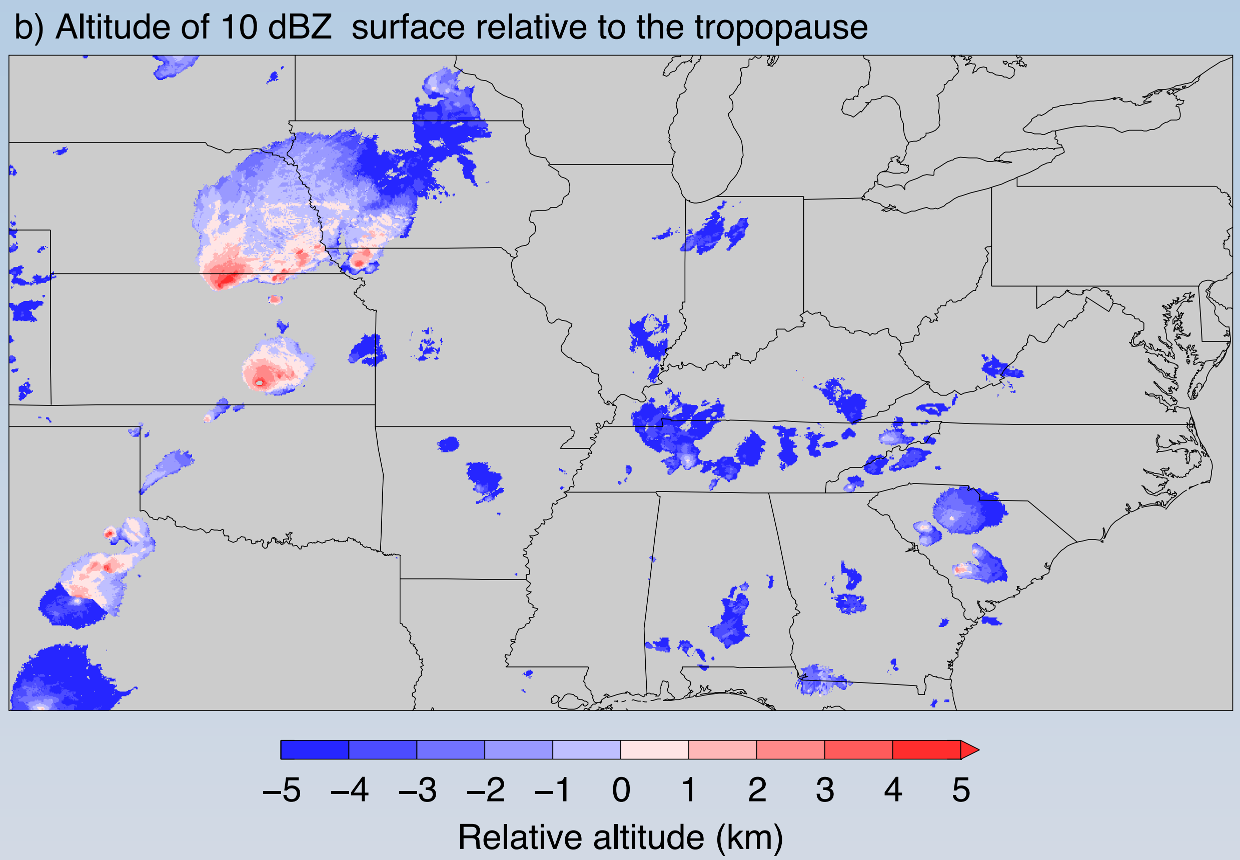
Overshooting Convection in N. America







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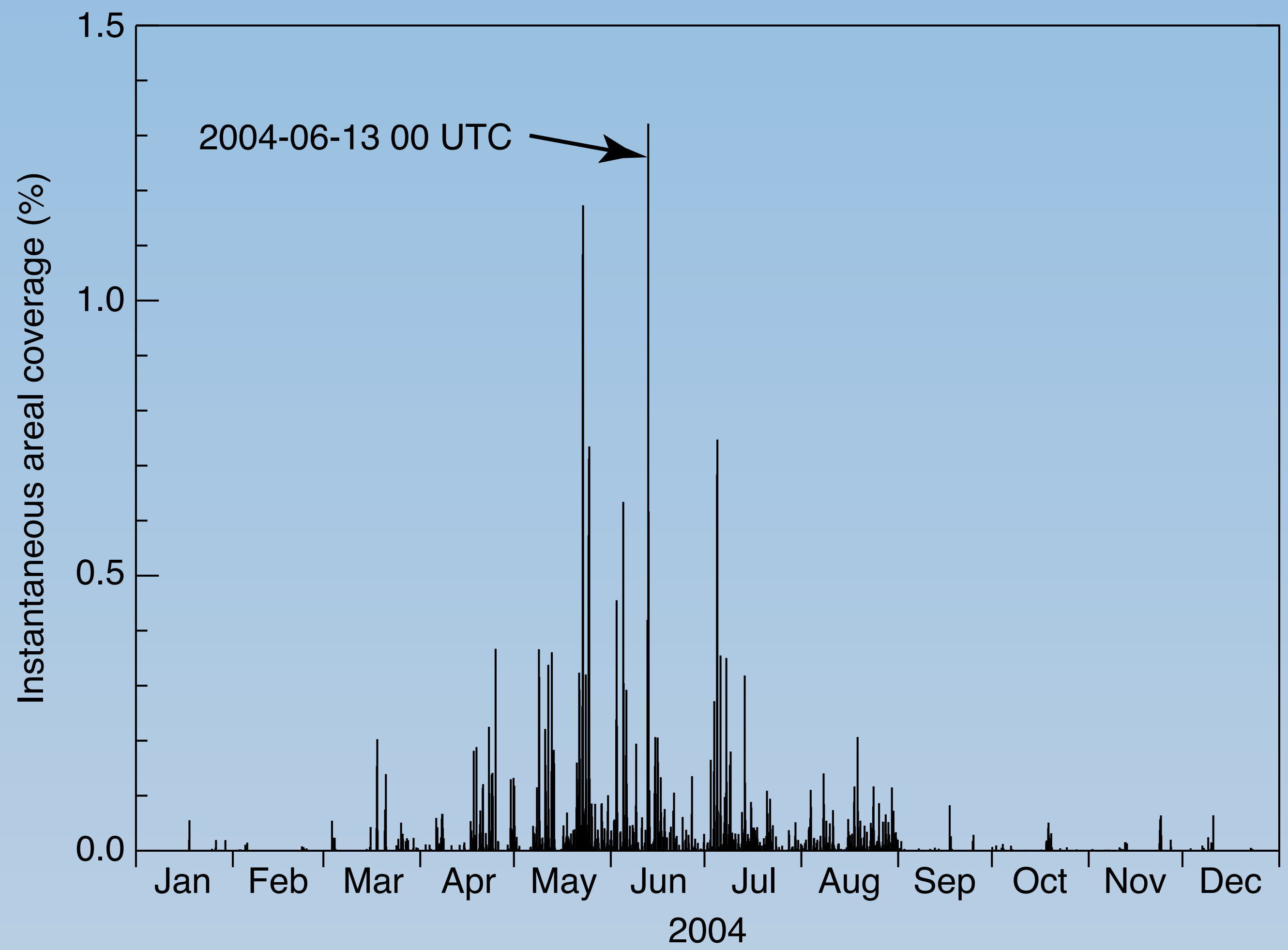
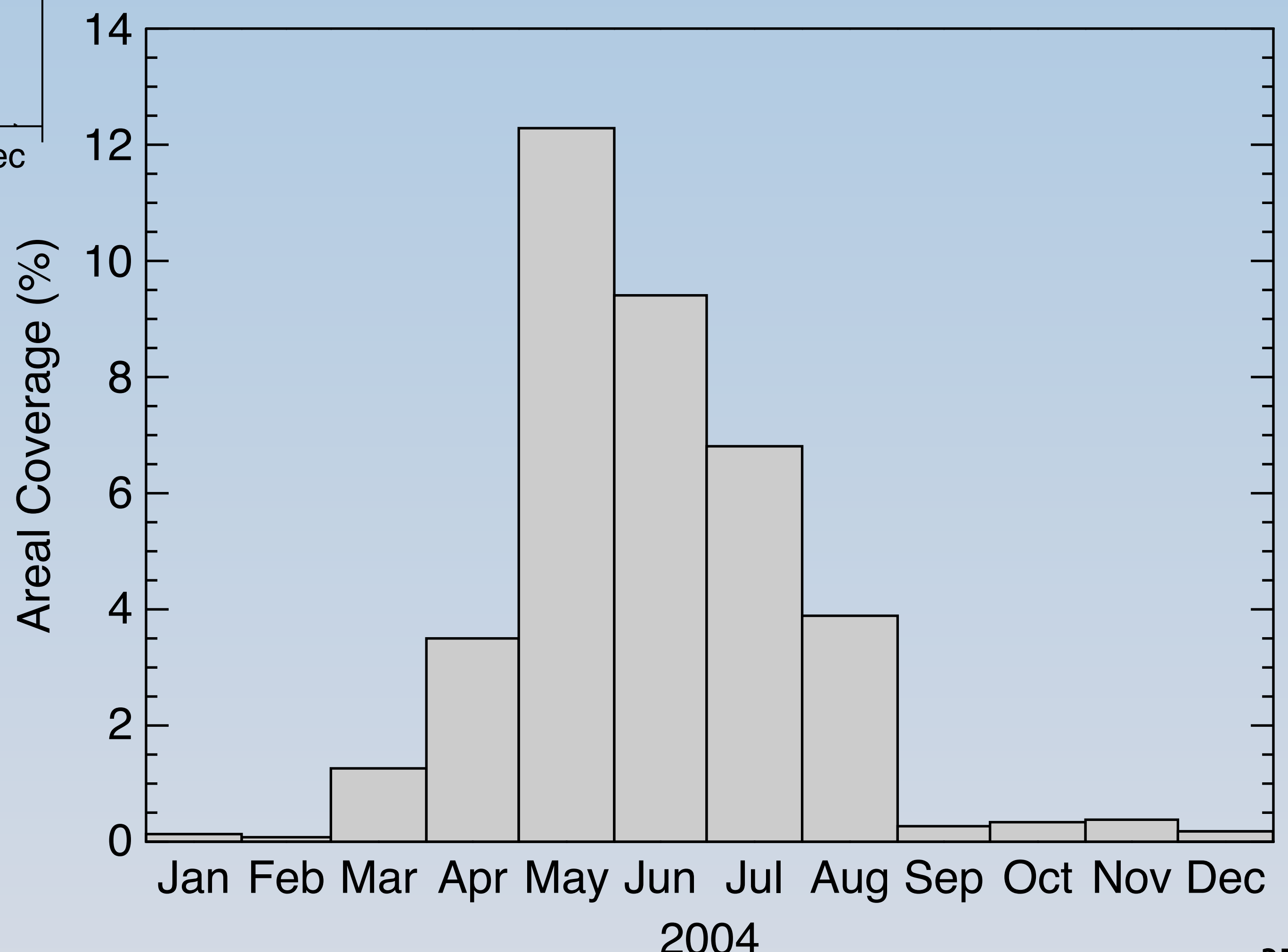
Occurrence during the Year





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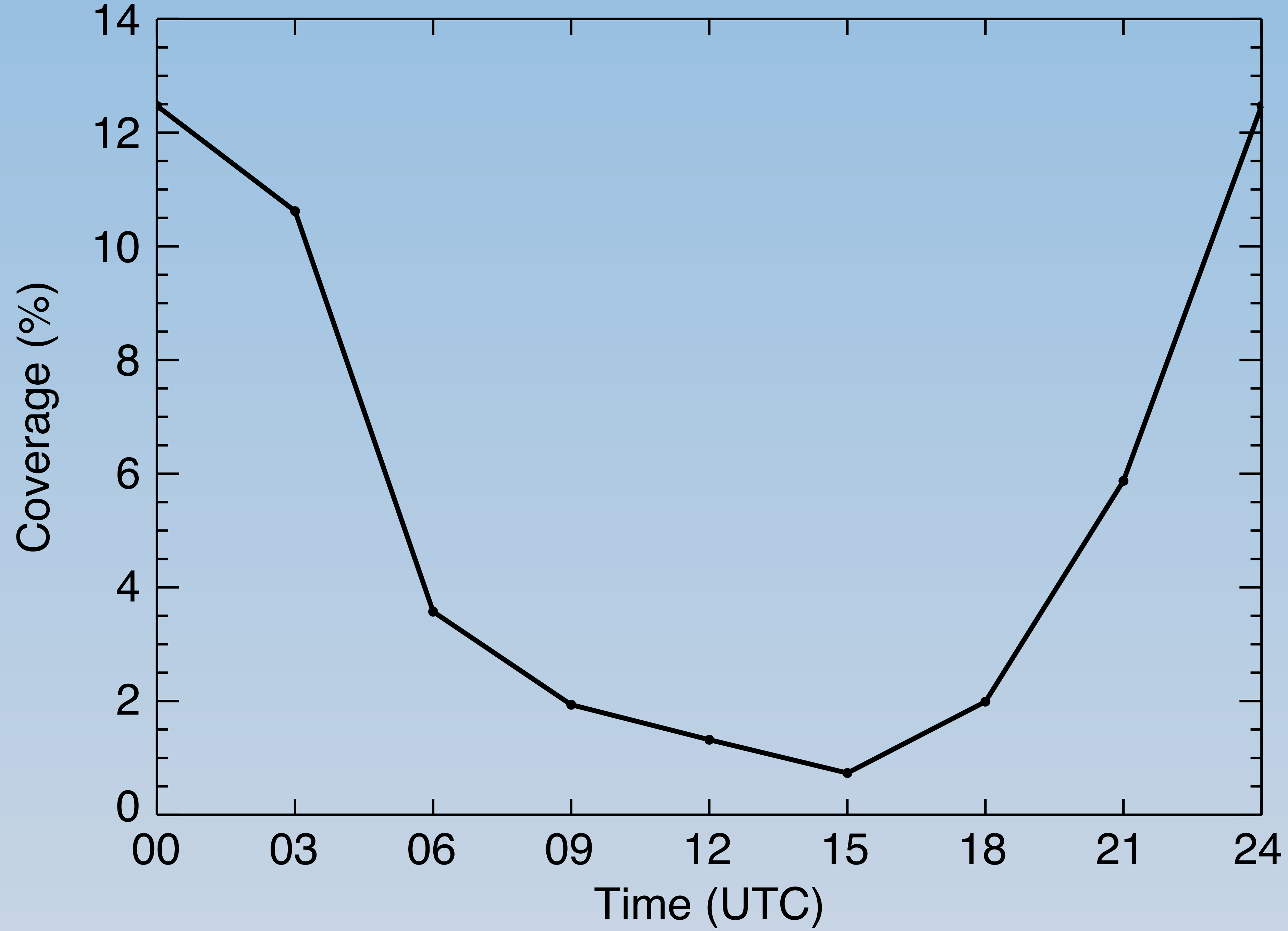
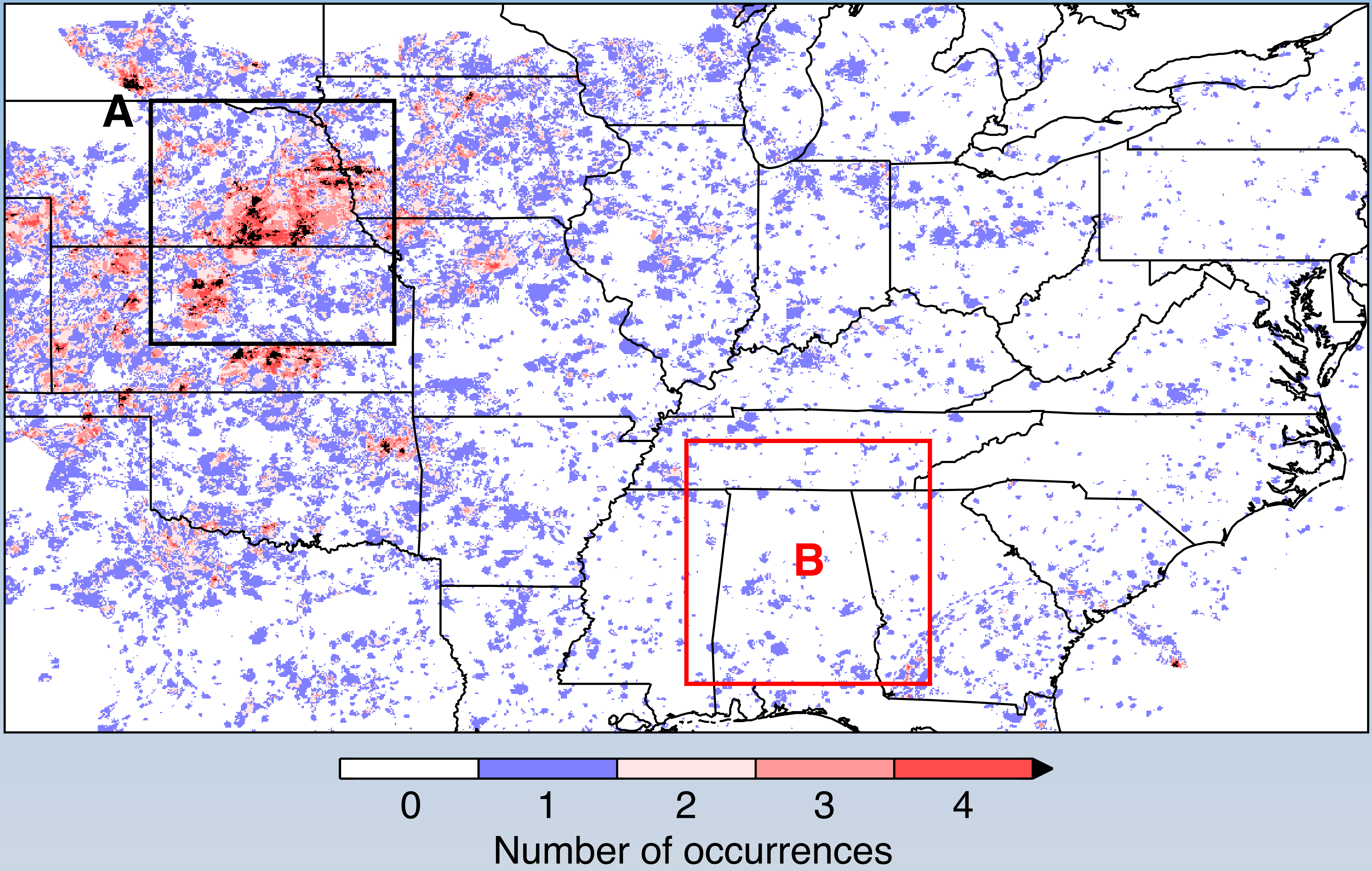
Diurnal Variation



Annual Occurrence



Note: results very different from Bedka analysis