Sensitivity of Global Mixing and Fluxes to Isolated Transport Barriers

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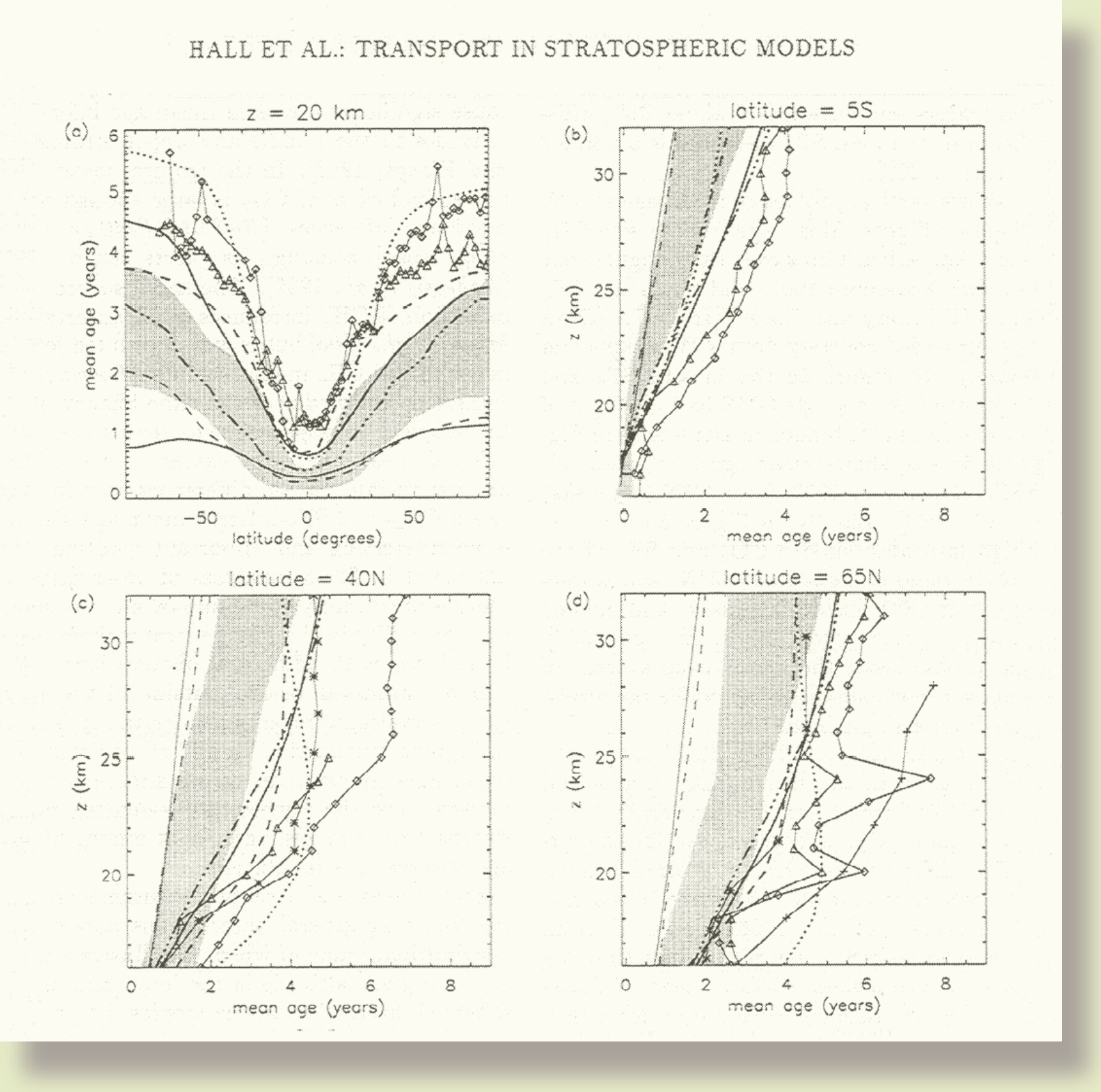
Background: model disparity

Even though the advecting eddy is large (~1000's km) and thus well resolved, estimates of hemispheric mixing in the upper troposphere and lower stratosphere (UTLS) vary considerably among models, depending on the advection scheme and subgrid-scale parameterization (Hall et al. 1999, Rind et al. 2007).



Is this just the problem with the models, **or is it that something about the large-scale transport and mixing in the UTLS makes it *inherently* difficult to quantify?** We suspect the latter and hypothesize that global mixing is sensitive to the properties of isolated transport barriers such as jets. To assess this sensitivity is the goal of this research.

Theory: 1D analytical model

$$\frac{\partial}{\partial t}q(y,t)=\frac{\partial}{\partial y}\left(K(y)\frac{\partial q}{\partial y}\right), \qquad y\in[0,L]$$

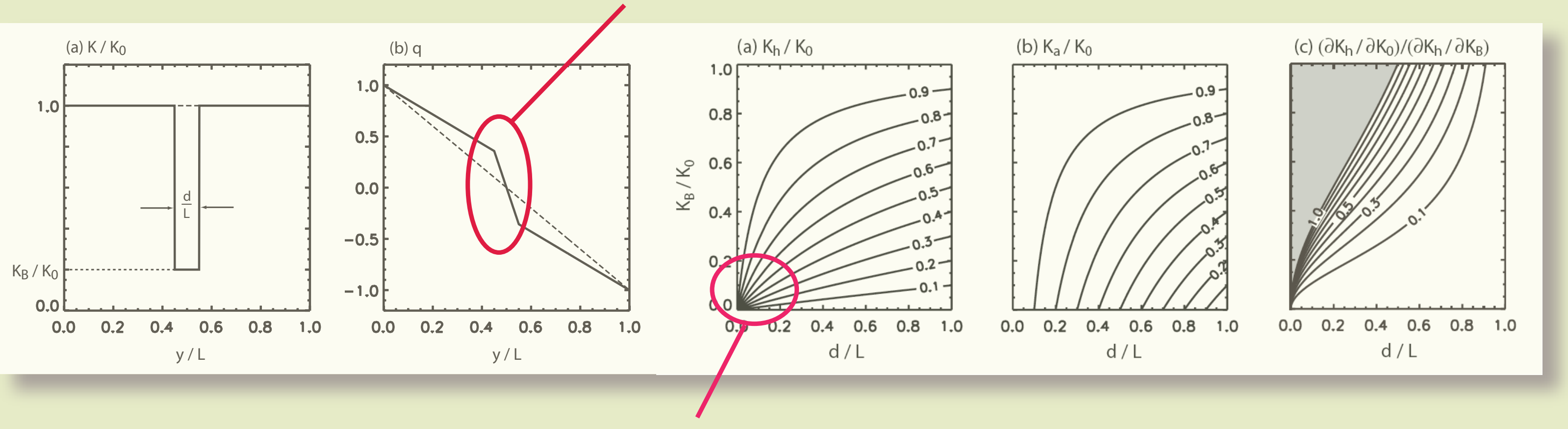
A barrier is represented by a local minimum in $K(y)$.

(1) Fixed boundary values: $q(0)=q_0,\ \ q(L)=q_L$

$$-K(y)\frac{\partial q}{\partial y}=F_0\ \ (const)\ \ \rightarrow\ \ \frac{\partial q}{\partial y}=\frac{-F_0}{K(y)}\ \ \rightarrow\ \ F_0=\frac{q_0-q_L}{L}\underline{\left\langle K^{-1}\right\rangle^{-1}}$$

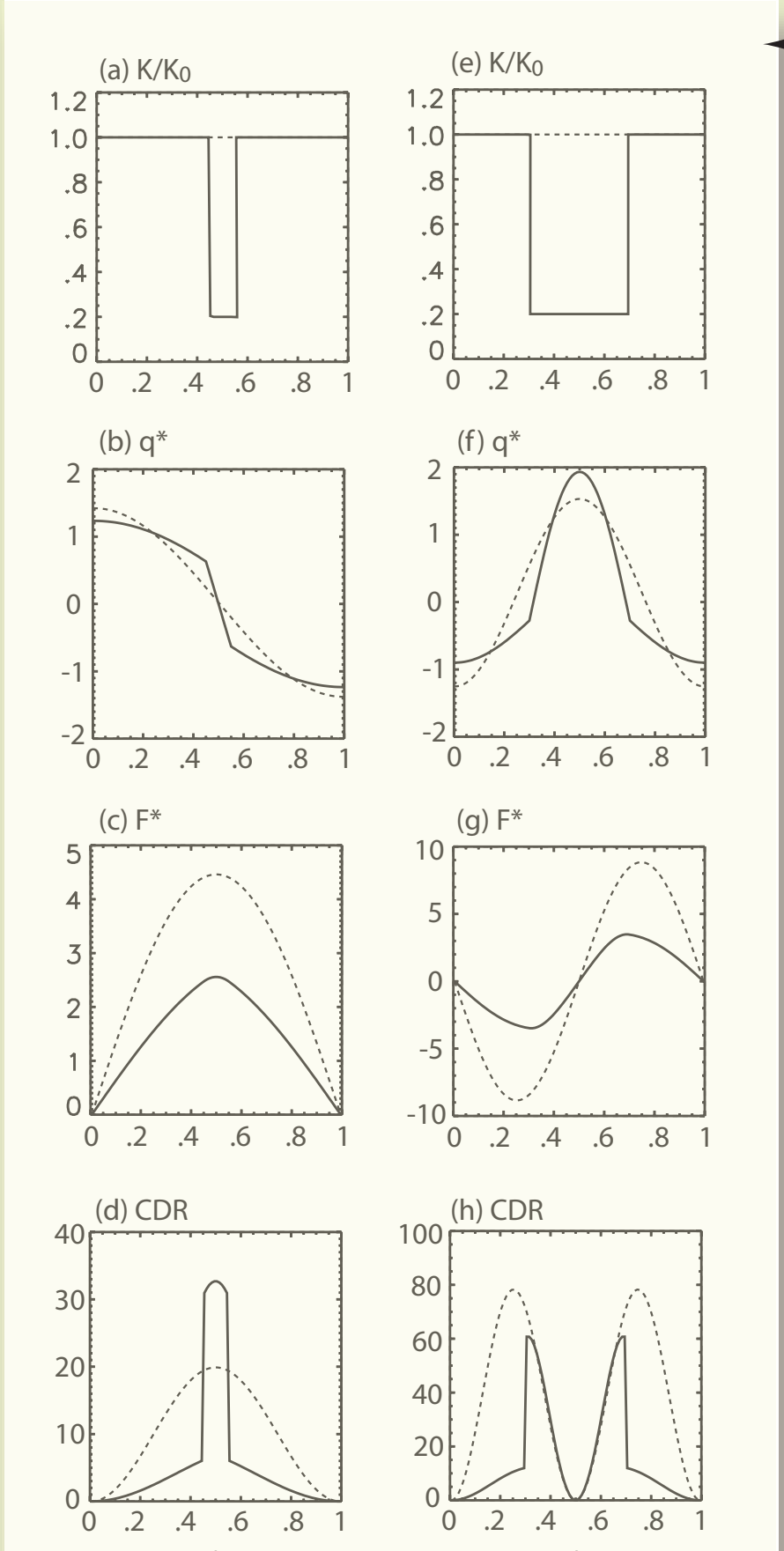
Gradient is larger in the barrier region.

harmonic mean of K = K_h



Flux is proportional to the harmonic mean of K (= K_h), which is sensitive to the width and depth of the barrier when the barrier is narrow and deep.

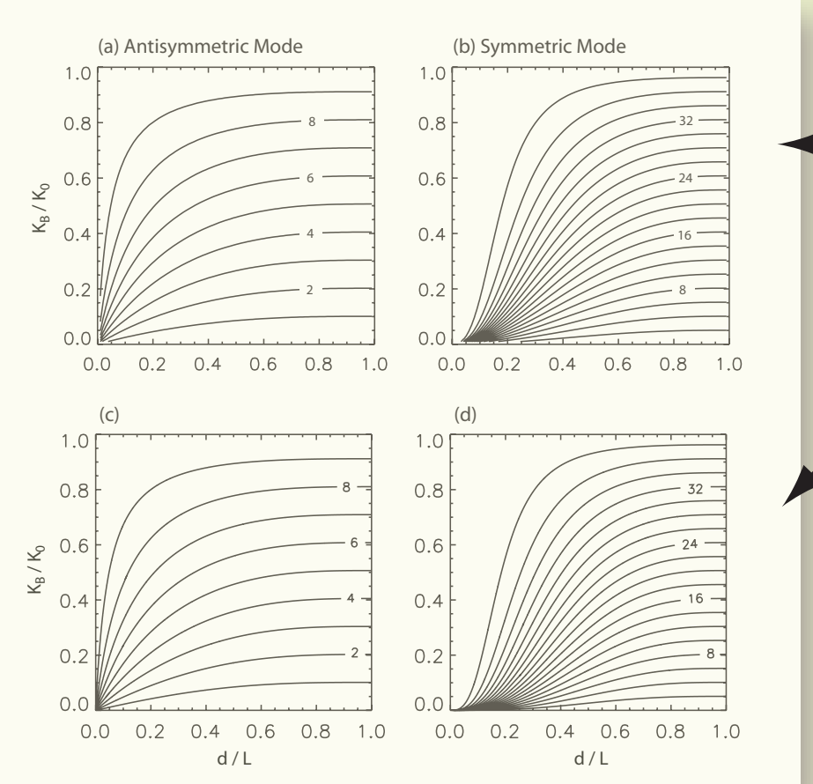
(2) Zero boundary fluxes (freely decaying eigenmodes)



diffusivity and mode structures

Though the gradient and dissipation are focused in the barrier region, the flux decreases globally.

damping rates as functions of barrier width and depth



numerical solutions

approximate formulae

$$\alpha_A=\frac{\pi^2}{L^2}K_h(1-0.5\varepsilon_1)^{-1}$$

$$\alpha_S=\frac{4\pi^2}{L^2}K_h(1-0.5\varepsilon_2)^{-1}$$

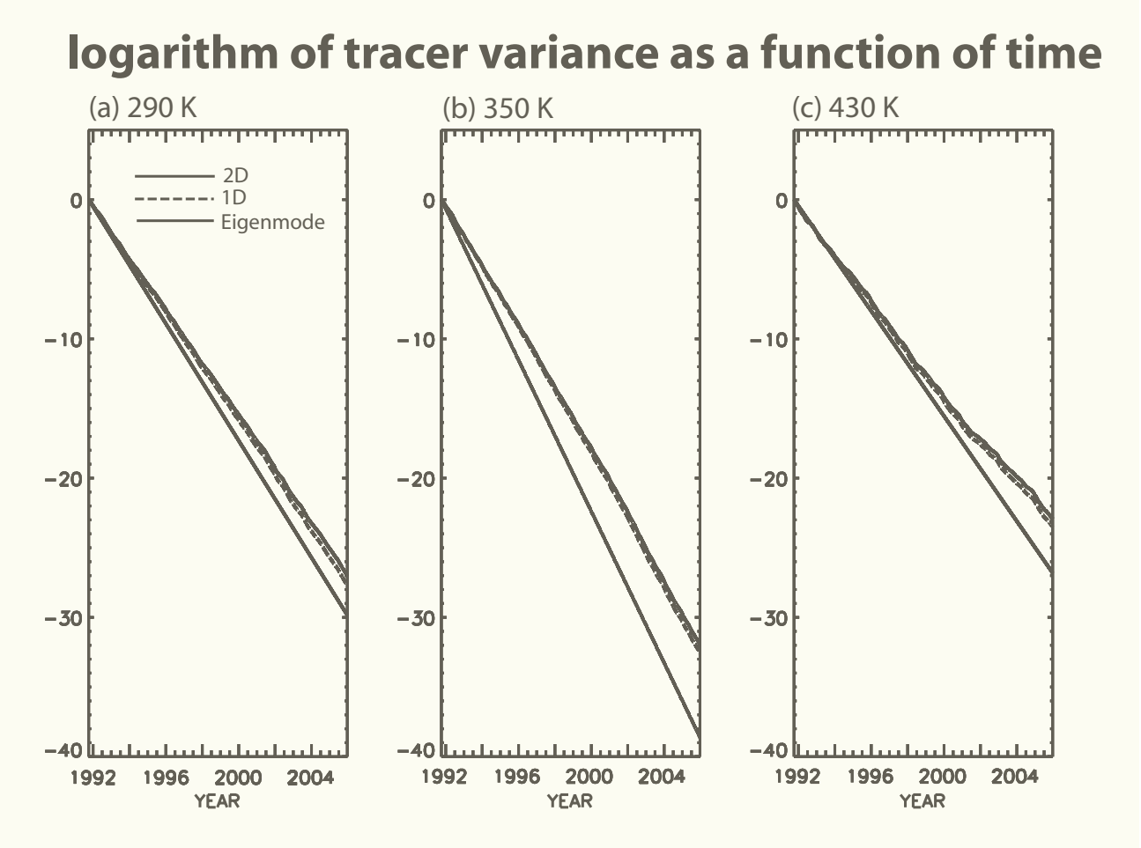
ε_1, ε_2 are the projection of K/K_0 on the first and second cosine functions, respectively.

K_h is a first-order predictor of the damping rates.

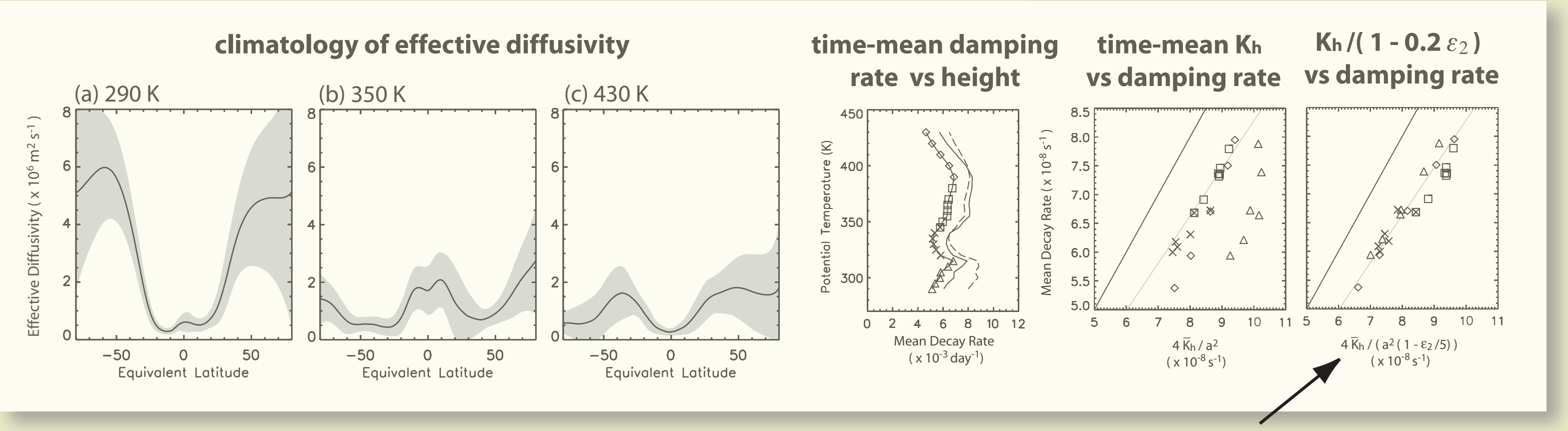
Most contributions to damping come from the barrier region.

Application: UTLS isentropic mixing

To test the role of barriers in the UTLS, we diagnose the tracer field obtained as a numerical solution of isentropic advection-diffusion calculations driven by the Met Office Stratospheric Analysis winds. The tracer is initialized as sine of latitude on each isentropic surface on 17 October 1991, and integrated forward through 2005 (the truncation of the tracer is T105). The tracer is allowed to decay freely.

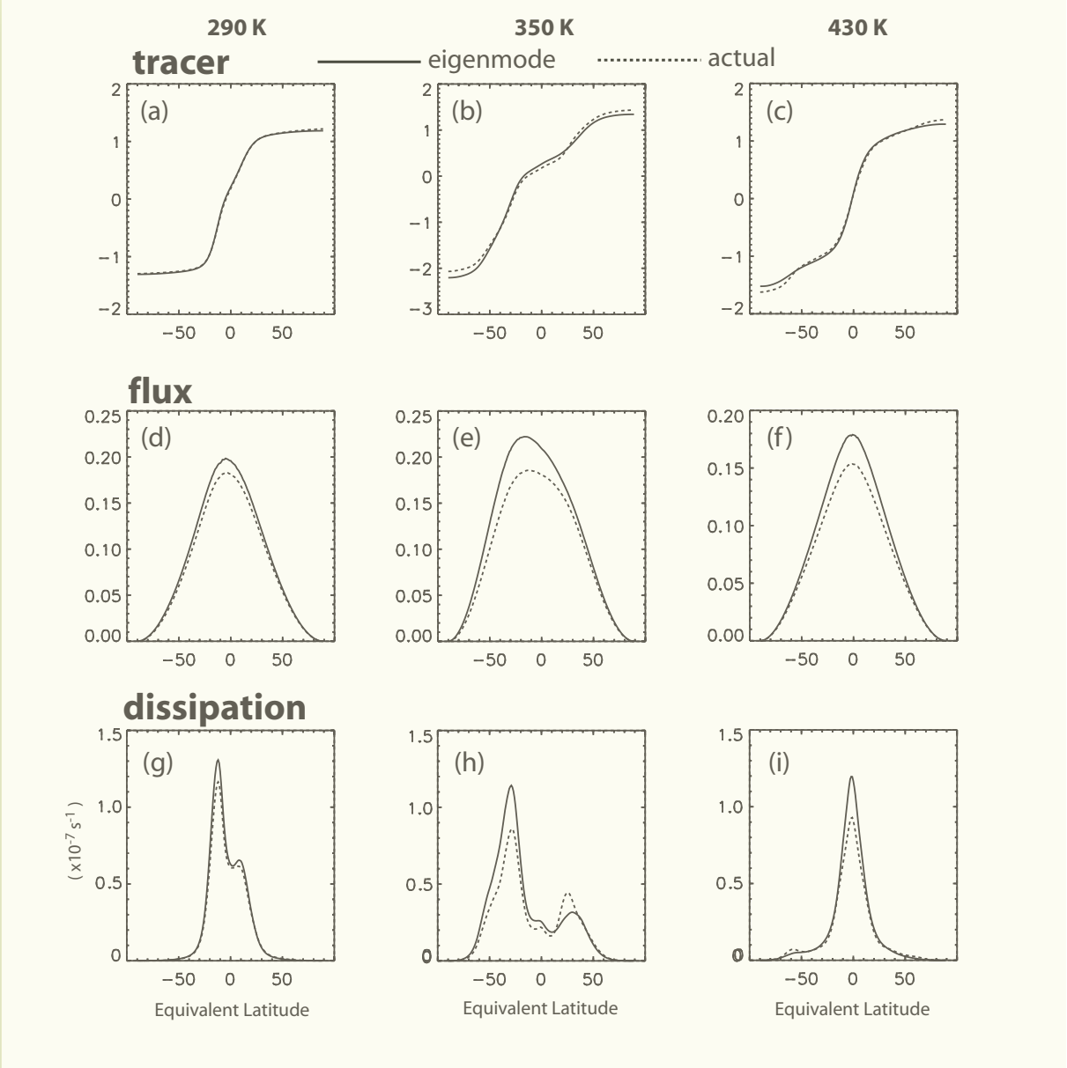


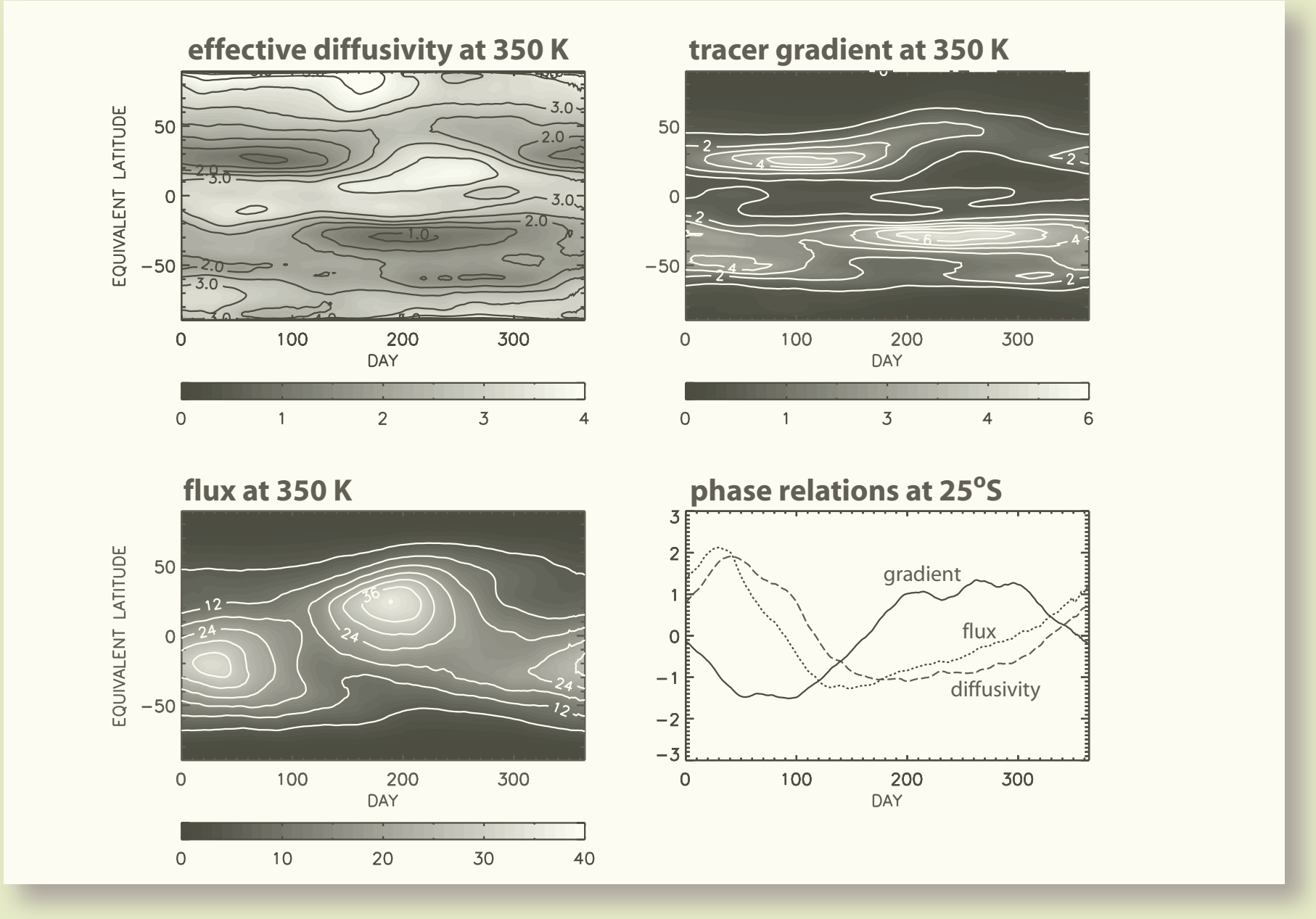
The decay of tracer variance is found to be exponential, and despite the seasonality and daily fluctuations in the advecting winds, the damping rates are remarkably constant over the years. This supports the relevance of the "eigenmode" concept.



ε_2 is the projection of K/K_h on the second Legendre polynomial.

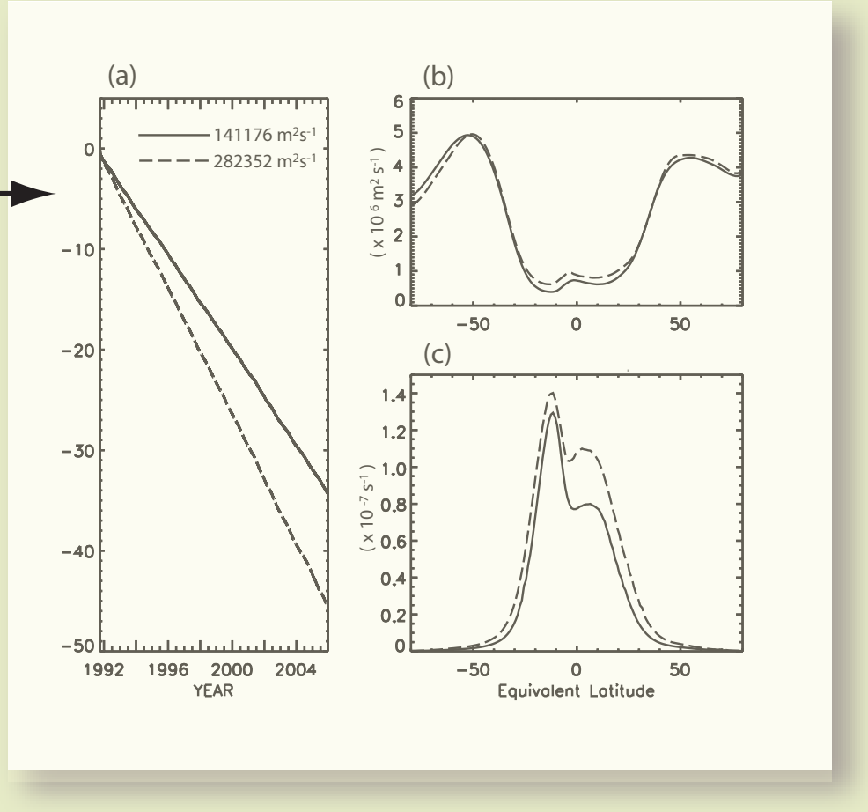
Time-mean damping rates vary with height, which we associate with height variation of the barrier geometry. The theoretical prediction of the damping rates based on the adjusted K_h produces a good fit to a linear relationship, but it overestimates the rates by ~15 percent.





The slight departure from the eigenmode is associated with temporal anticorrelation between the effective diffusivity and tracer gradients.

When the model's numerical diffusion is doubled, the effective diffusivity in the barrier region changes only modestly, but it has a disproportionately large impact on global mixing: the damping rate increases nearly 30 percent!



Conclusion: barriers rule

The global mixing and fluxes of a passive tracer are very sensitive to the properties of the barrier, when it is narrow and deep. To the extent that the barrier properties are sensitive to the errors in winds and details of the models, transport calculations for the UTLS region will remain a challenge. This seems to explain, at least partially, the disparate results reported in the literature. Future transport modeling should pay close attention to the representation of transport barriers.

Sponsor: NSF   For more info: http://geosci.uchicago.edu/~nnn/Nakamura_r2.pdf