Dynamics Around Turbopause

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Calculation of Eddy Diffusion

- Eddy Diffusion: Turbulence.
- When a gravity wave becomes unstable, the flow become turbulent: 1. energy is efficiently dissipated through cascading; 2. constituents are effectively mixed.
- According to Eliassen-Palm's second theorem, deposition of wave momentum is closely associated with dissipation or other non-conservative force. This is the theoretical base for Lindzen's formulation, which ties diffusion and forcing (momentum deposition).

Momentum Deposition and Eddy Mixing

- More specifically:

$$F_{GW} = -\frac{1}{\rho}\frac{\partial \tau}{\partial z} = \frac{k(c-u)^3}{2NH}$$

$$Kzz = F_{GW}(c-u)/N^2$$

- According to this formulation, wind reversal can be used to constrain eddy diffusion.

Problems and Uncertainties (1)

- In Lindzen eddy thermal diffusion was what's calculated, but it is assumed to be equal to eddy viscosity (Pr_T=1).
- Eddy diffusion for constituents depends on Pr_C.
- Wave breaking and turbulent dissipation also induces a net heat flux and constituent flux (e.g. Walterscheid, 1981). The former could be responsible for the MIL (Liu and Hagan, 1998). The fluxes are not included in the original formulation.

Problems and Uncertainties (2)

A typical GW breaking at ~110 km
(F_{GW} doesn't depend on any parameterization)

$$\rho \sim 10^{-7} kg/m^3$$

$$\tau \sim 10^{-3} Pa$$

$$\Delta z \sim H \sim 10 km$$

$$F_{GW} \sim 1 m/s^2 \sim 8.6 \times 10^4 m/s/day$$

$$N \sim 0.03 s^{-1}$$

$$Kzz \sim 10^4 m^2/s \quad (if\ c - u \sim 10 m/s)$$

Of course we never see wind change by 86000m/s every day, probably because (1) GW occurrence is highly intermittent. According to momentum balance, GW forcing on the order several hundred m/s/day is needed. So the "intermittency" factor should be ~ 0.01. This will give us a mean Kzz ~100m^2/s. (2) momentum flux of GW there is much smaller (or both).

Side note: 1m/s^2 is a very significant forcing even if only last for 10 minutes. Large body forcing could be very significant (works by Sharon Vadas and Dave Fritts)

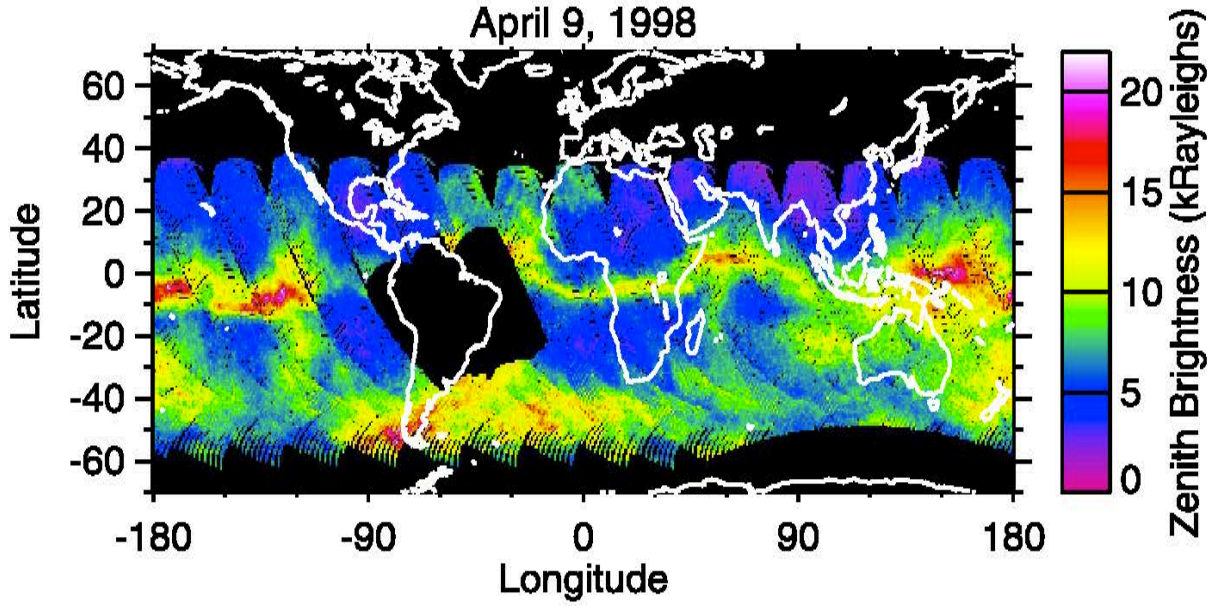
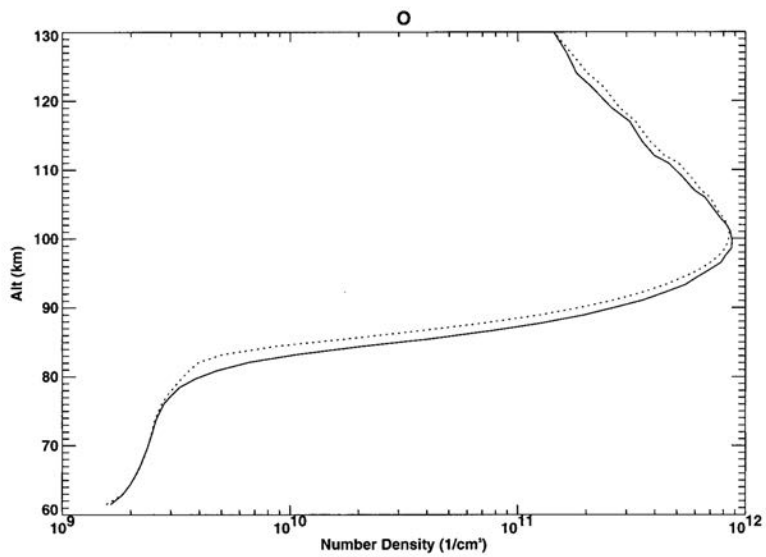


Figure 5. O_2 atmospheric band nightglow for 9 April 1998. This map is a 24-hour composite of data from all 15 orbits on that day. Only data from the descending node of the orbit are included, and the local time coverage is mostly in the evening hours. The coverage starts along the edge of evening twilight in the Northern Hemisphere, ranging over 2024–2048 LT at 38°N, and extends to 0230 LT at 63°S. Data have been discarded within the South Atlantic Anomaly region and southern auroral zone.

Hays et al., 2003



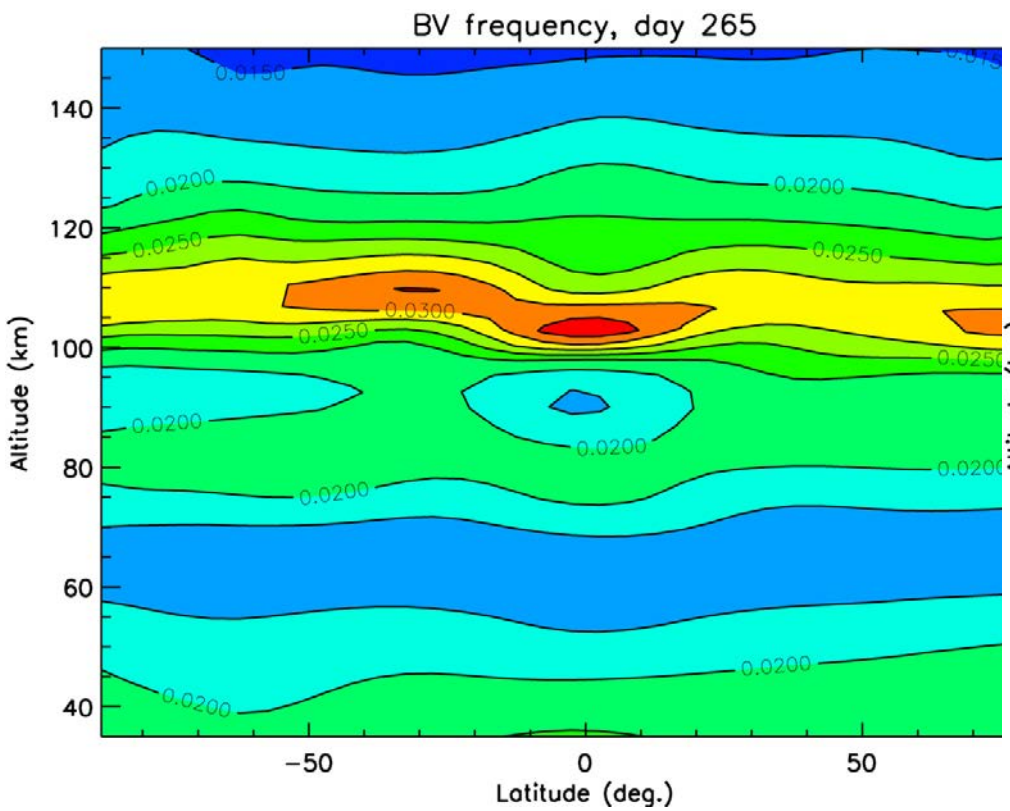
Liu et al, 1999

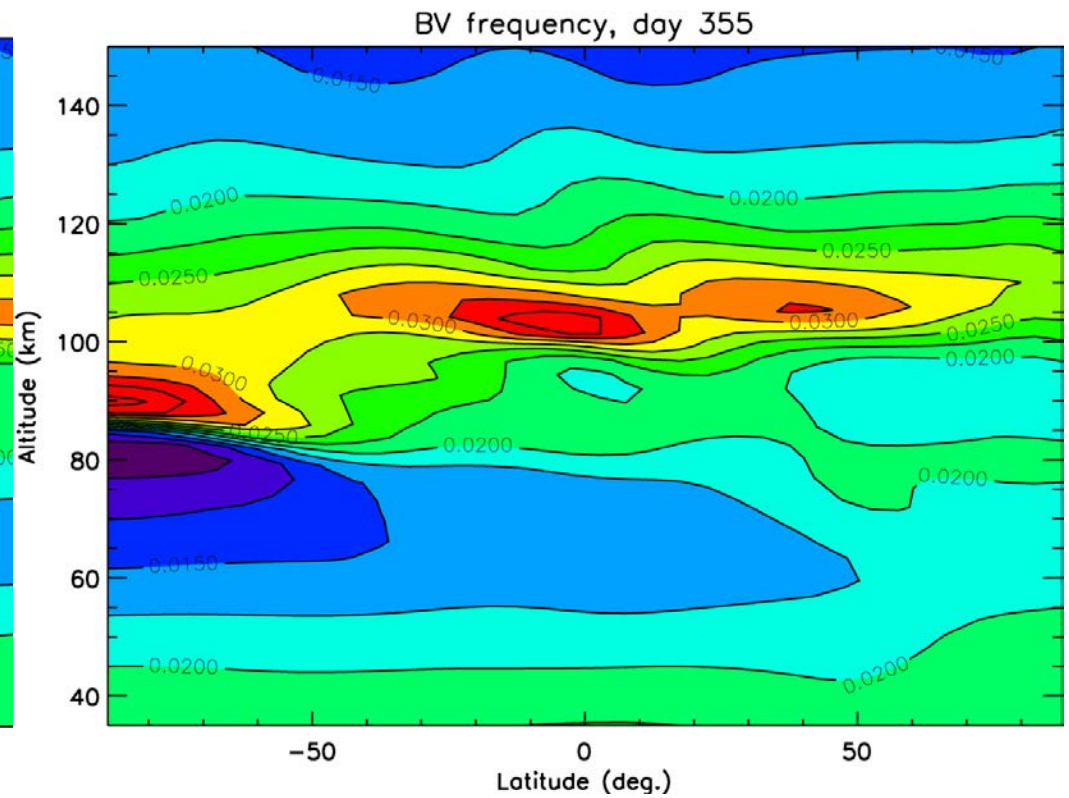
Problems and Uncertainties (3)

- GW sources: strengths/momentum fluxes; wave characteristics; intermittency.
- Considering the large variability of wave sources, characteristics, and the intermittency nature, eddy diffusion is likely highly variable. So the crossing of molecular and eddy in defining turbopause is probably just in the mean sense.
- What's the implication for turbopause? Is it highly dynamic? Or is it only meaningful in a mean sense?
- Wave sources tied to weather systems are now being considered in WACCM.
- Observations of wind, temperature and constituents can help constrain these quantities.

Temperature Structure: Maximal N above mesopause

$$N^2 = \frac{g}{T}\left(\frac{dT}{dz} + \frac{g}{c_p}\right)$$

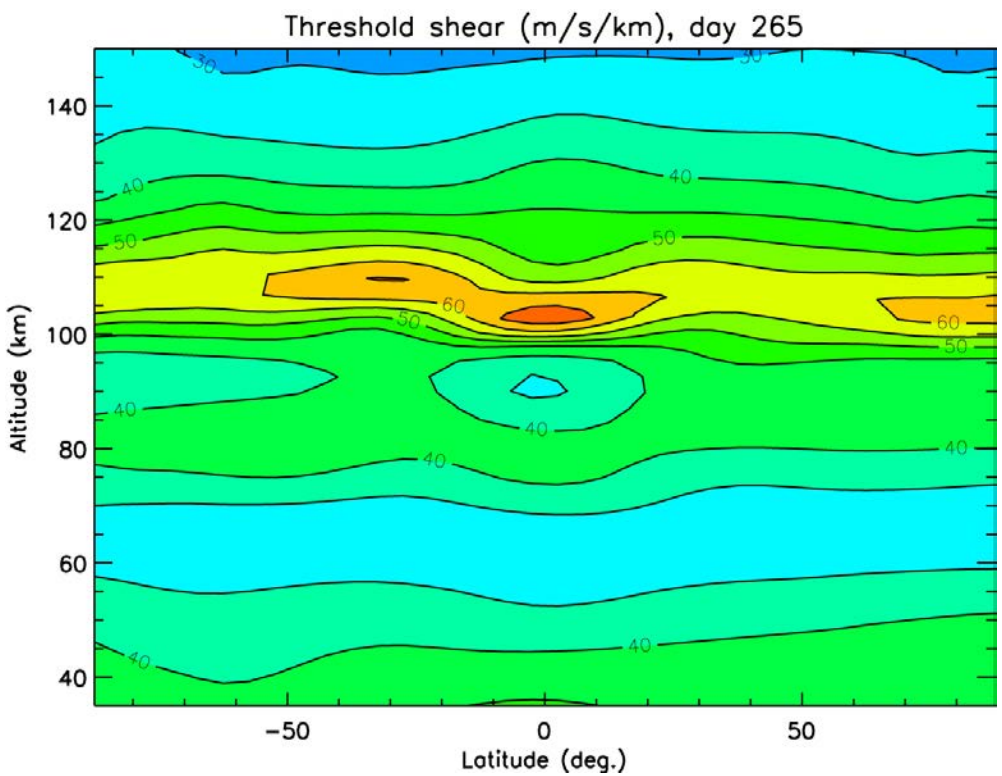


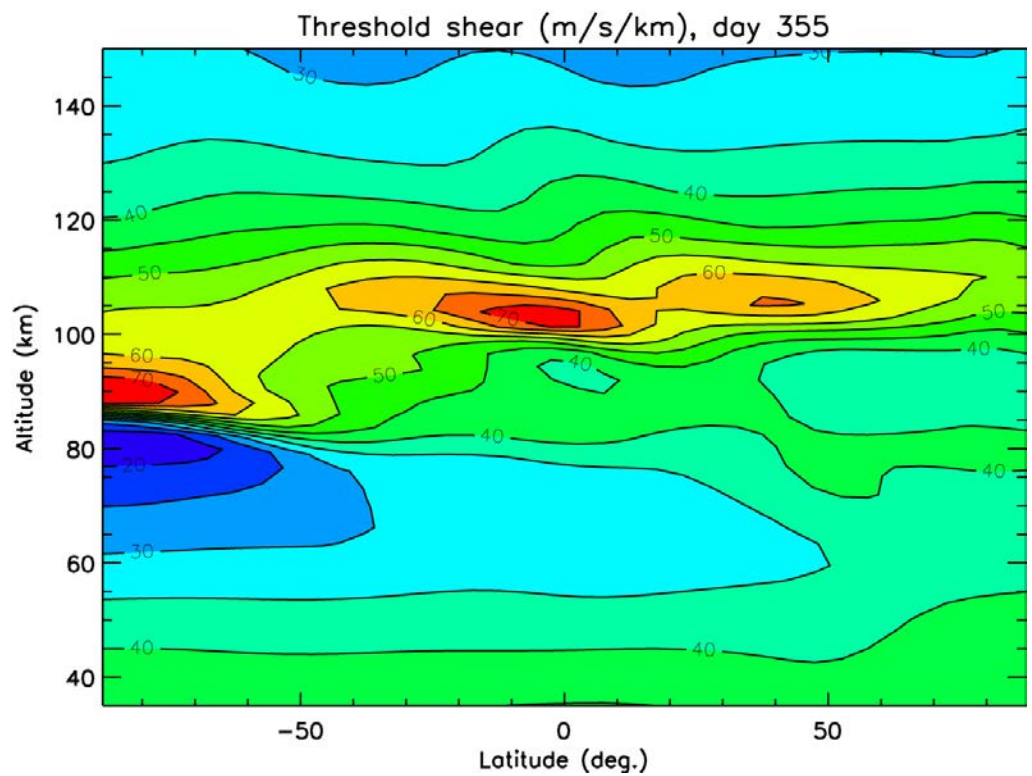


Implication for Wind Structure

- Stronger static stability can support larger wind shear, before the atmosphere becomes dynamically unstable:

$$|\partial u / \partial z|_{\max} = N / \sqrt{Ri_c} = 2N$$





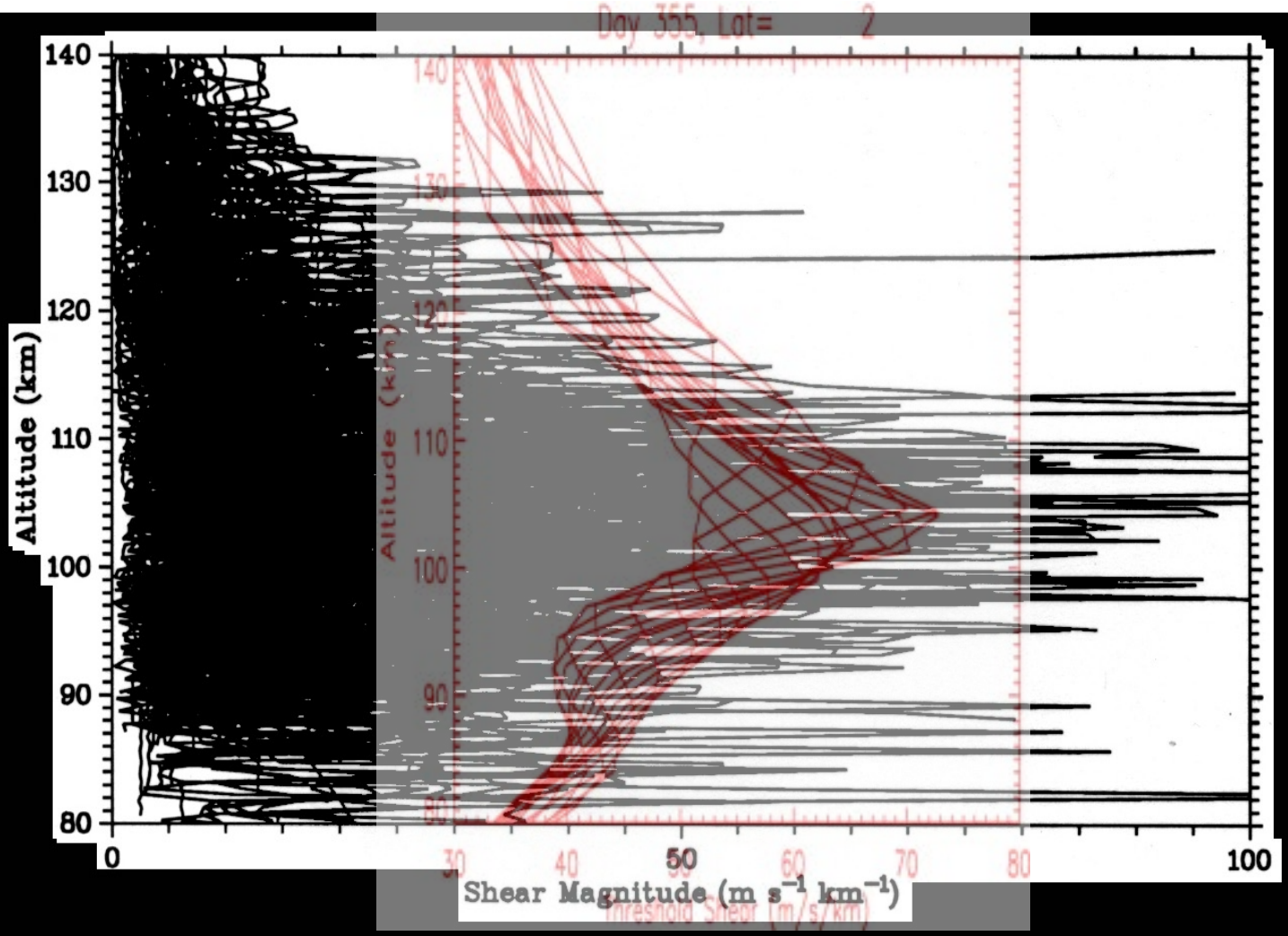


Figure 11. Superposition of the shear magnitude profiles for all of the low-latitude and midlatitude data.

Larsen, 2002