Why use wavelet decomposition with stellar occultations?

Breaking gravity waves affect Jovian upper atmospheres.

Because gravity waves in jovian atmospheres can travel large vertical distances, they form an important means for coupling between different atmospheric regions. These waves become convectively unstable at higher altitudes, and "break" (each wave at its own breaking altitude). When this happens, the breaking waves can interact with the background atmosphere, and can:

• Force the global circulation, by depositing their momentum.

Lindzen, 1981. Turbulence and stress due to gravity wave and tidal breakdown. *JGR* **86**, 9707-9714.
McLandress, C., 1998. On the importance of gravity waves in the middle atmosphere and their parameterization in general circulation models. *J. Atmospheric and Solar-Terrestrial Physics* **60**, 1357–1383.
Young *et al.* 2001. Uranus after solstice: results from the 1998 November 6 occultation. *Icarus*, in press.

• Heat the upper atmosphere, by depositing their energy.

Roques *et al.* 1994. Neptune's upper stratosphere, 1983-1990: ground-based stellar occultation observations. *A&A.* **288**, 985-1011.
French and Gierasch 1974. Waves in the Jovian upper atmosphere. *J. Atmos. Sci.* **31**, 1707-1712.

- Cool the upper atmosphere, by convecting heat downward.

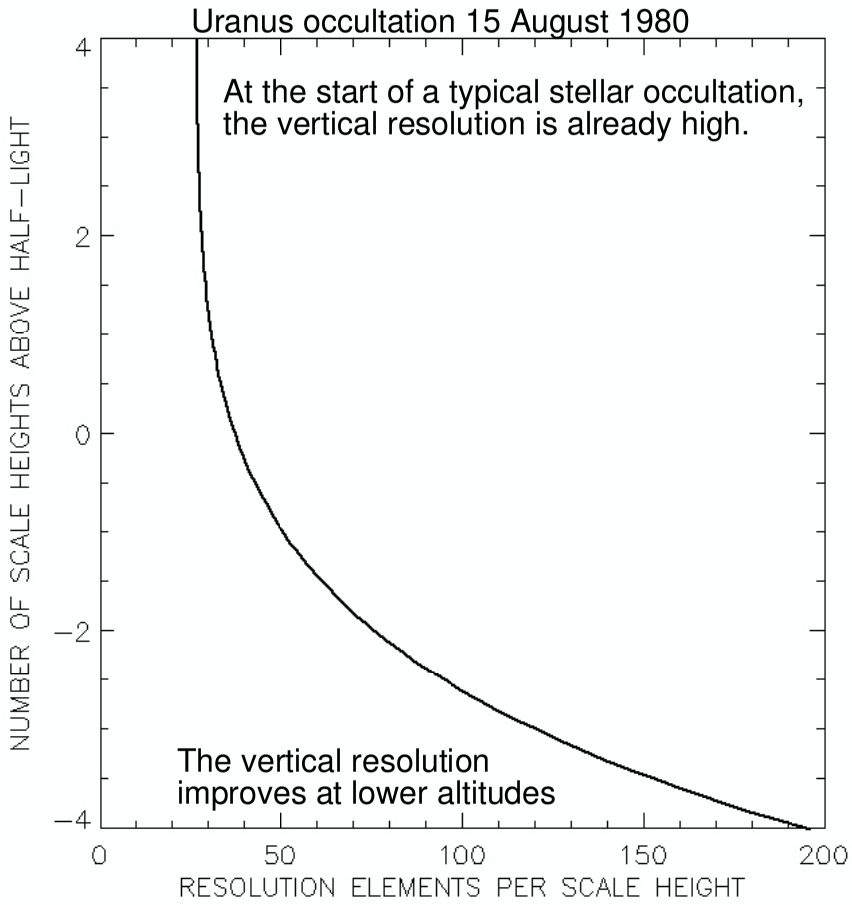
Strobel *et al.* 1985. Energy balance constraints on gravity wave induced eddy diffusion in the mesosphere and lower thermosphere. *JGR* **90**, 13067-13072.
Fritts and Dunkerton 1985. Fluxes of heat and constituents due to convectively unstable gravity waves. *J. Atmos. Sci.* **42**, 549-556.

- Affect abundances of photochemical species by changing the eddy diffusion coefficient.

Garcia and Solomon 1985. The effect of breaking gravity waves on the dynamics and chemical composition of the mesosphere and lower thermosphere. *J. G. R.* **90**, 3850-3868.
Gladstone *et al.* 1996. Hydrocarbon photochemistry in the upper atmosphere of Jupiter. *Icarus* **119**, 1-52.

Occultations have the resolution needed to measure gravity waves

To quantify the effect of gravity waves, we want to measure their amplitudes and wavelengths. Because the small vertical scales of upper atmospheric gravity waves make them difficult to study spectroscopically, measurements of gravity waves in jovian upper atmospheres comes mainly from stellar occultations.

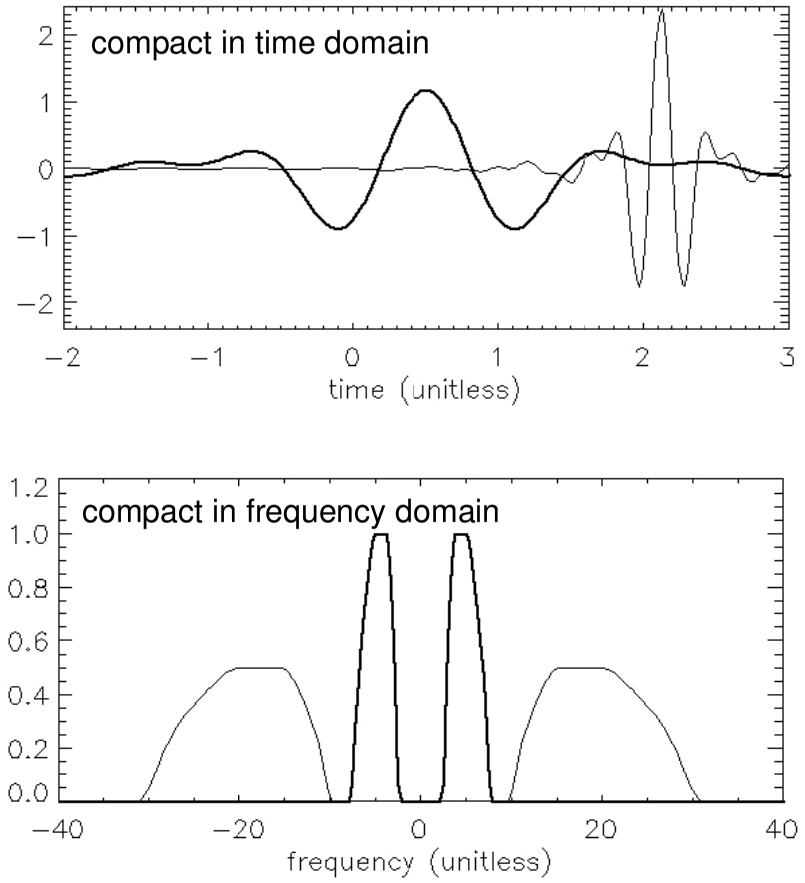


Stellar occultations provide high vertical spatial resolution from Earth-based or near-Earth telescopes, rivaling or exceeding that of in-situ probes. The vertical spatial resolution is limited by signal-to-noise, the Fresnel scale of the atmosphere, the finite angular size of the star, and the time resolution of the observations.

Fig. 1. Typical resolutions achievable by stellar accultations.

Wavelet transforms can characterize the location and wavelength of waves

The temperature and density structures derived from stellar occultations (or the Galileo probe) do not show simple, quasi-monochromatic waves.



Fourier analysis is well suited to stationary signals, but ill suited to signals which change with time (or, in this case, altitude). An alternative is wavelet analysis, where a function is described a sum of basis functions that are compact in both time and frequency (or, in this case, altitude and vertical wavenumber).

Fig. 2. Example of a wavelet (Sato and Yamada 1994). A mother wavelet (thick lines) is shifted and scaled (thin line) to make a family of wavelets.

Wavelets are widely used for studying gravity waves & turbulence on Earth

Wavelets have been used to:

- study the vertical evolution of the gravity wave power spectra

Sato, K. and M. Yamada 1994. Vertical structure of atmospheric gravity waves revealed by the wavelet analysis. *JGR* **99**, 20,623-20,631.

- measure the exponent of a power-law power spectrum

Yamada. M. and K. Ohkitani 1990. Orthonormal wavelet expansion and its application to turbulence. *Prog. Theor. Phys.* **83**, 819-823.

- distinguish turbulence from phase-randomized signals

Yamada. M. and K. Ohkitani 1991. An identification of energy cascade in turbulence by orthonormal wavelet analysis. *Prog. Theor. Phys.* **86**, 799-815.

- identify isolated waves, and measure the vertical dependence of their amplitude and wavelength.

Chane-Ming, F. *et al.* 2000. Analysis of gravity waves in the tropical middle atmosphere over La Reunion Islan (21°S, 55°E) with lidar using wavelet techniques. *Ann. Geophysicae* **18**, 485-498.

Because it is not straightforward to derive the statistical properties of waves in the atmosphere from stellar occultations. In this poster, we present three methods of analysis.

"It is as natural to study turbulence using wavelets as it is to explore the night sky with a telescope."
Yves Meyer, in *Wavelets: algorithms and applications*,