CEDAR 2010 Post-Doc Report

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Airglow signatures of gravity waves near the onset of dissipation

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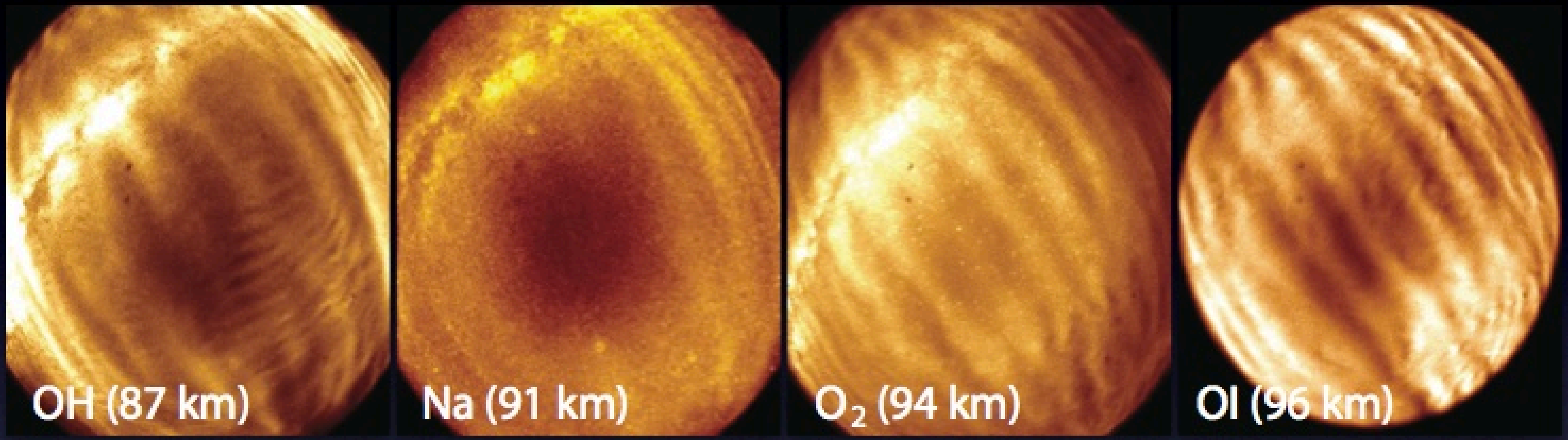
Contents

Airglow Imaging of Mesospheric Gravity Waves:

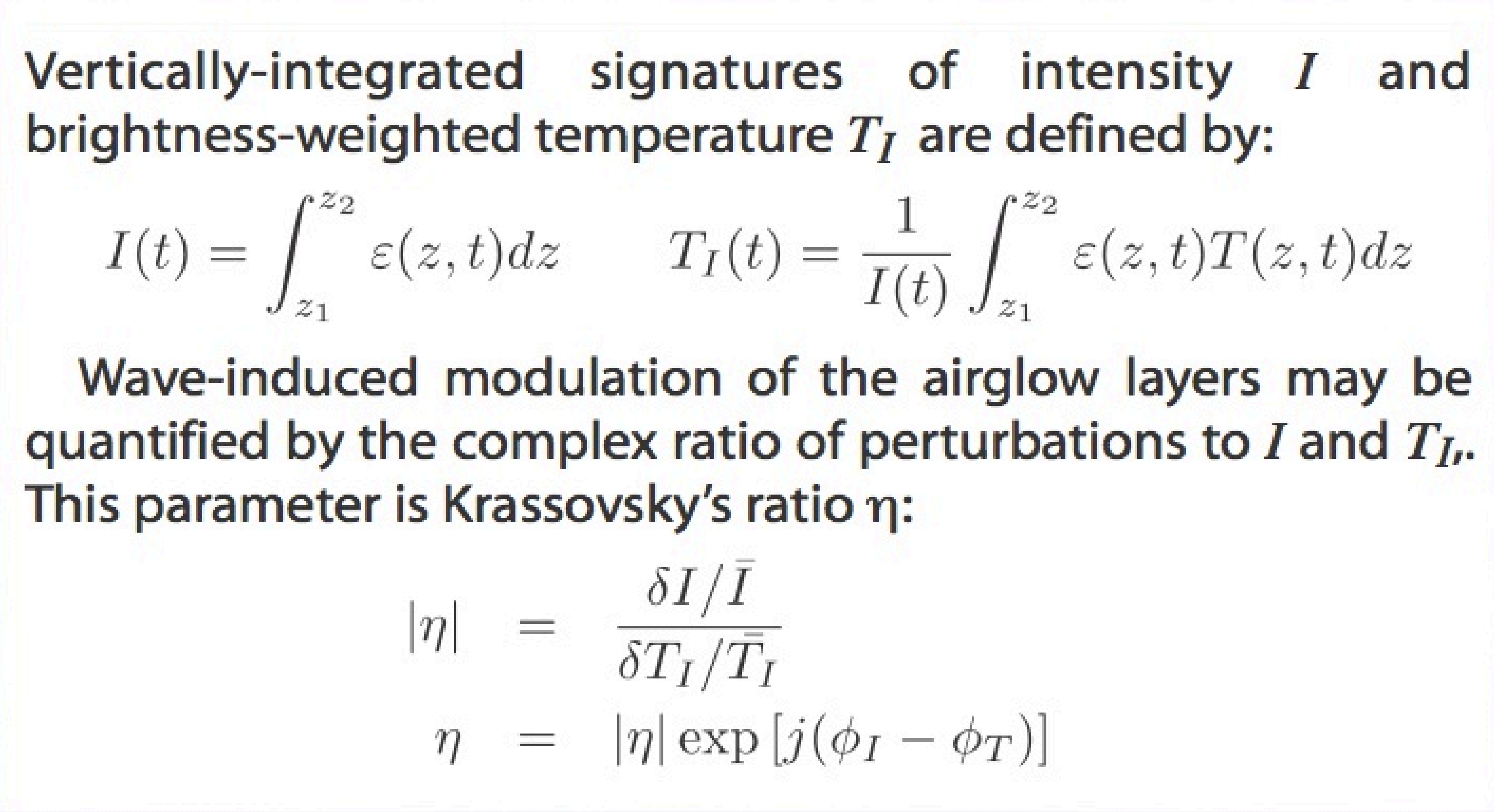


- OH(v) Meinel Bands (NIR filter passband 710-930 nm)
- Na D-line (589 nm)
- O_2 Atmospheric Band (NIR 865 nm)
- $O(^1S)$ green-line (557.7 nm)

Figure courtesy of M. J. Taylor.

Multiple airglow layer emissions allow assessment of gravity wave perturbations at a range of altitudes.

Column-Integrated Airglow Layer Measurements:

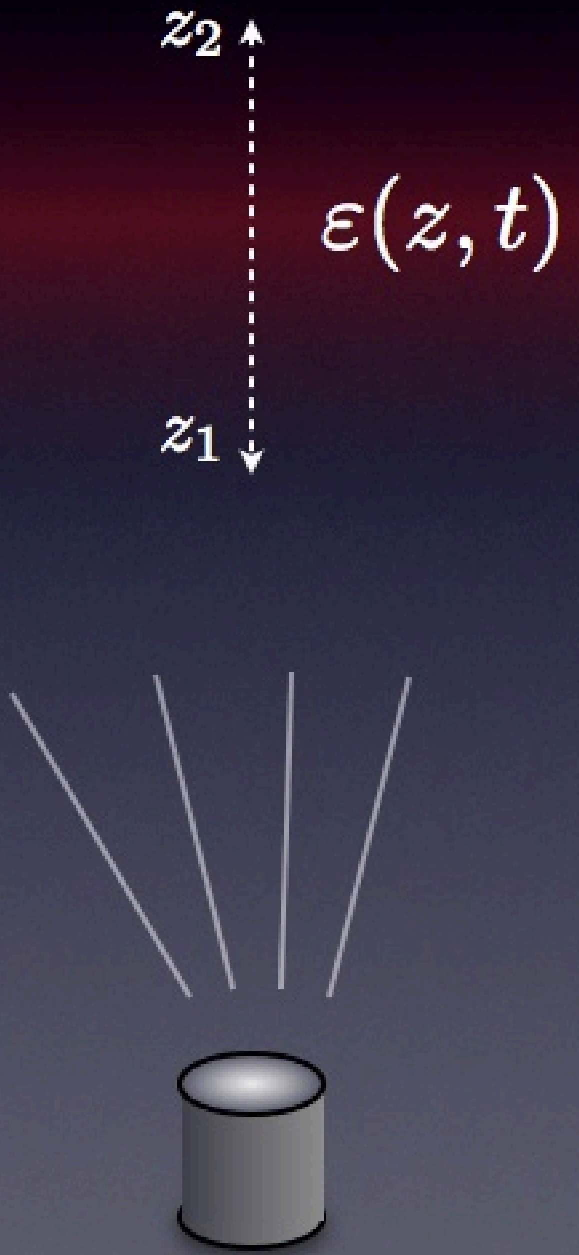


Vertically-integrated signatures of intensity I and brightness-weighted temperature T_I are defined by:

$$I(t) = \int_{z_1}^{z_2} \varepsilon(z,t)dz \qquad T_I(t) = \frac{1}{I(t)} \int_{z_1}^{z_2} \varepsilon(z,t)T(z,t)dz$$

Wave-induced modulation of the airglow layers may be quantified by the complex ratio of perturbations to I and T_I. This parameter is Krassovsky's ratio η:

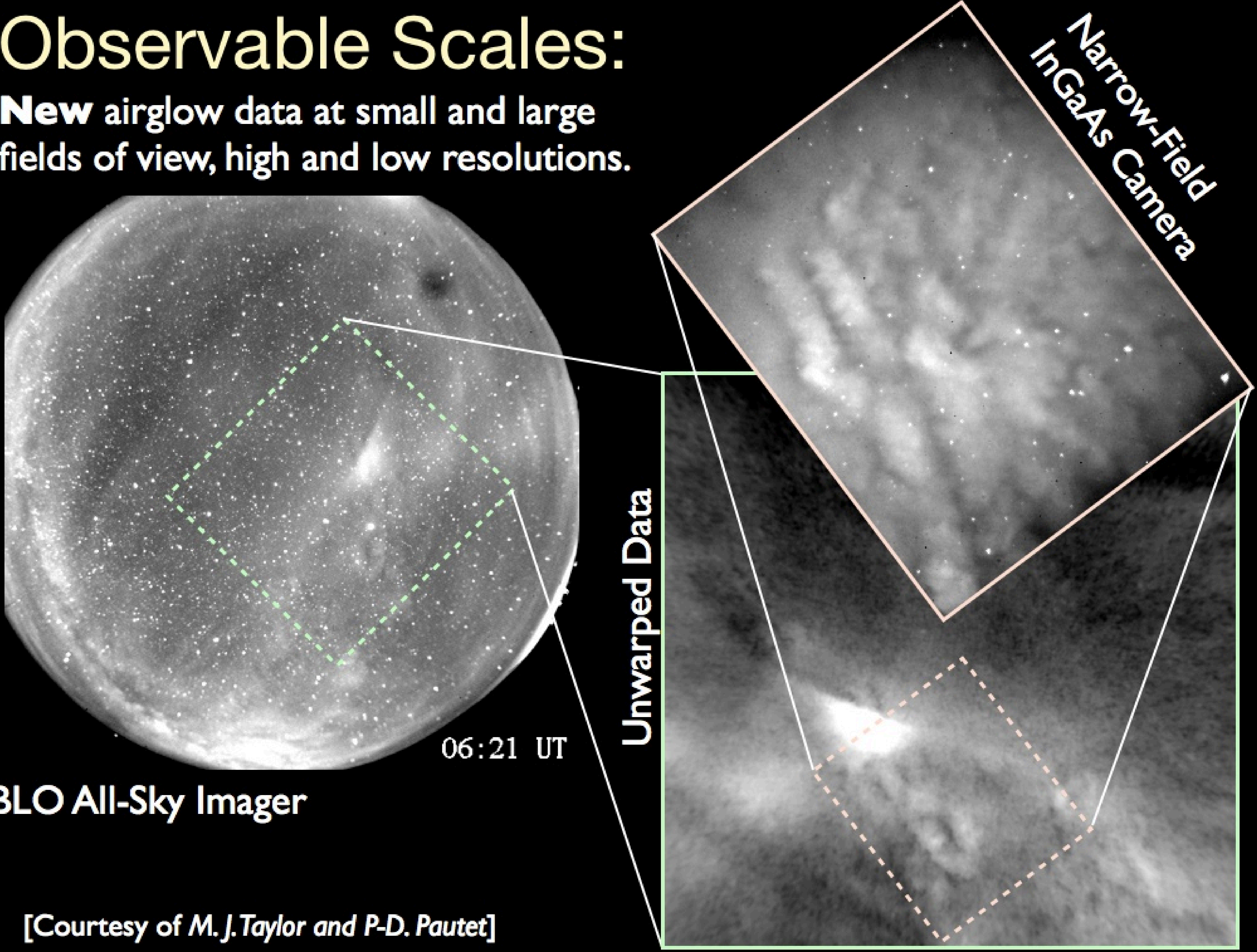
$$\begin{aligned} |\eta| &= \frac{\delta I/\bar{I}}{\delta T_I/\bar{T}_I} \\ \eta &= |\eta| \exp\left[j(\phi_I - \phi_T)\right] \end{aligned}$$



Filtered perspective into gravity wave dynamics:
Spatially (due to vertical integration and spatial resolution) and *temporally* (due to imager integration times and sampling rate).

Observable Scales:

New airglow data at small and large fields of view, high and low resolutions.



BLO All-Sky Imager

[Courtesy of *M. J. Taylor and P-D. Pautet*]

Numerical Models:

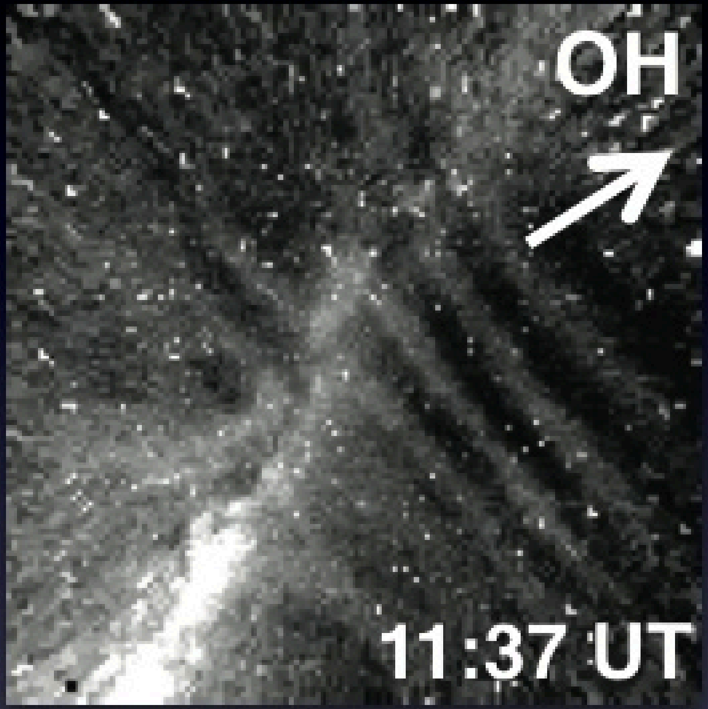
- **Gravity wave dynamics model:** Finite volume method (FVM) solution for compressible, stratified, and nonlinear Euler equations of gas dynamics, including viscosity and thermal conduction [e.g., *LeVeque*, 1997; *Snively and Pasko*, 2008].
- **OH (v) airglow model:** Time-dependent and nonlinear solution for OH(v) kinetics and resulting band emission intensities [e.g., *Adler-Golden*, 1997; *Snively et al.,* 2010].
- **OI 557.7 nm airglow model:** Solution for OI emission intensity [e.g., *Hickey et al.,* 1997*; Snively et al.,* 2010].

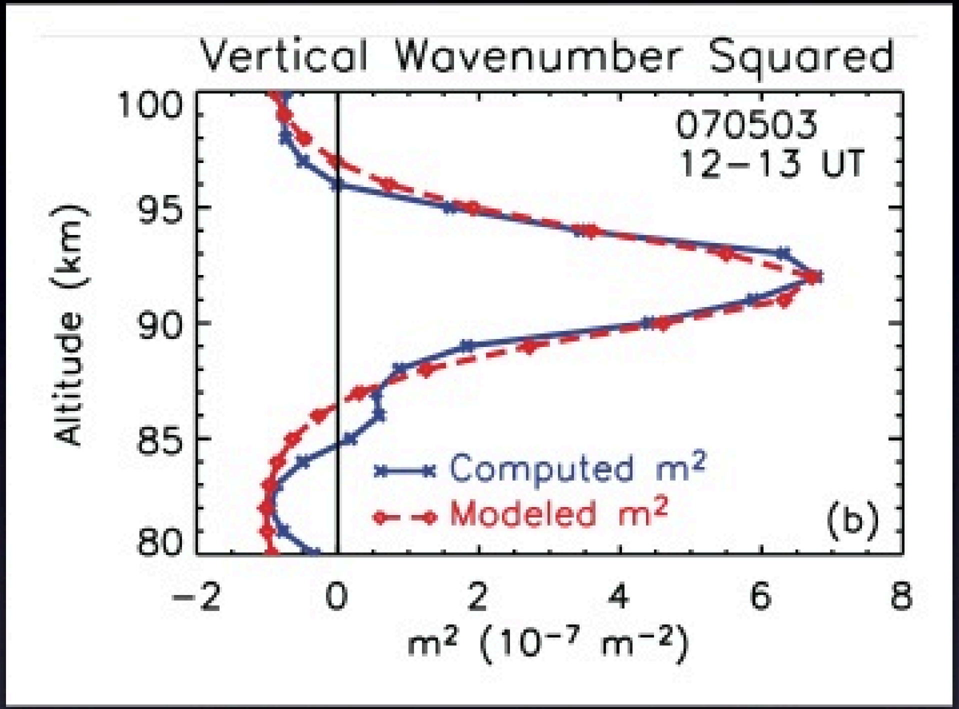
Models allow simulation of wave perturbations to airglow photochemistry, and resulting intensity and brightness-weighted temperature signatures.

Contents

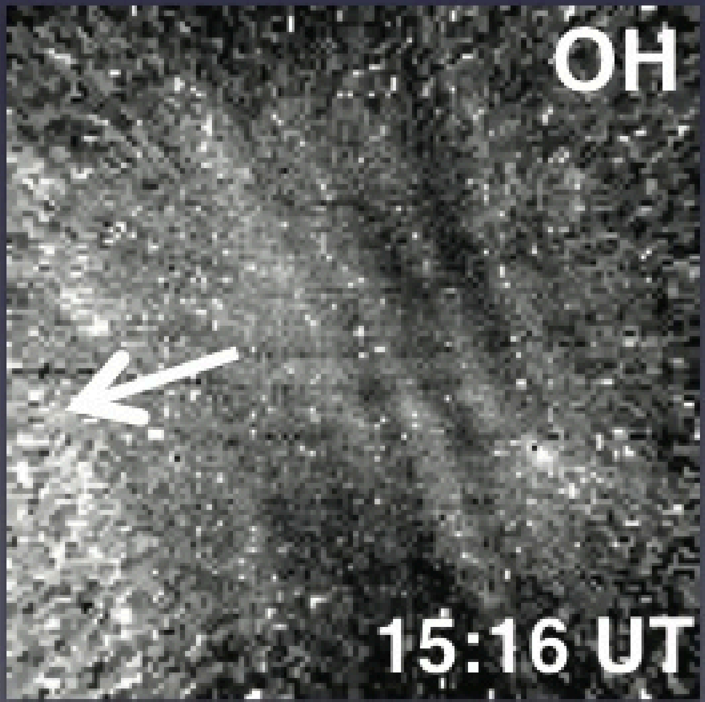
Ducting and Evanescence at Mesopause

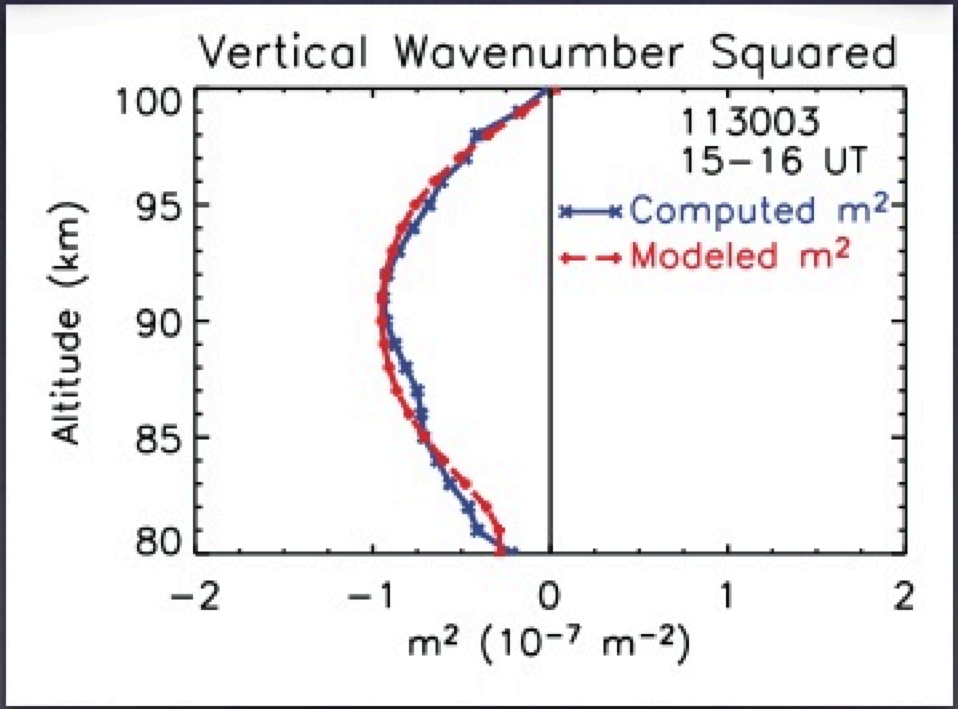
Variable tidal winds lead to layered regions of evanescence or trapping at mesospheric airglow layer altitudes [e.g., *Simkhada et al.*, 2009].





Ducted
Gravity Wave
(~35 m/s, 15 km)

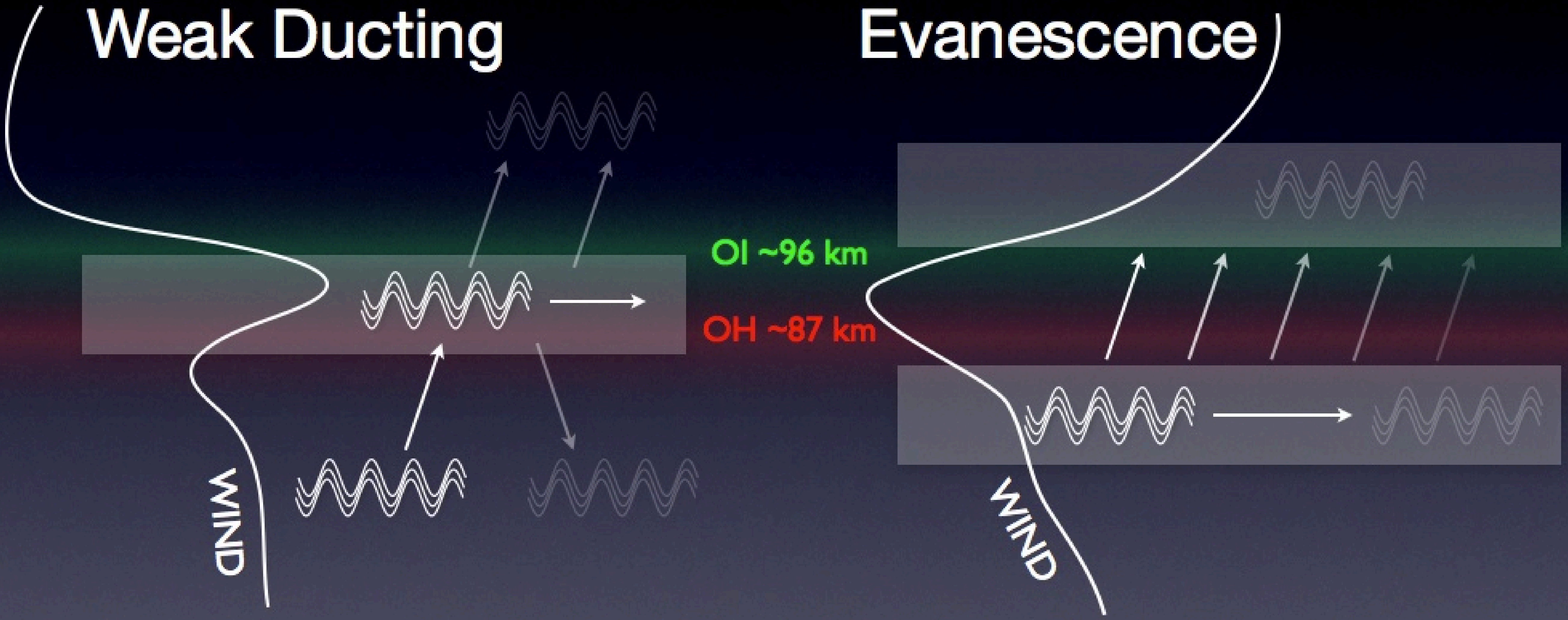




Evanescent
Gravity Wave
(~25 m/s, 17 km)

Ducting and Evanescence at Mesopause

Variable tidal winds lead to layered regions of evanescence or trapping at mesospheric airglow layer altitudes [e.g., *Simkhada et al.*, 2009].

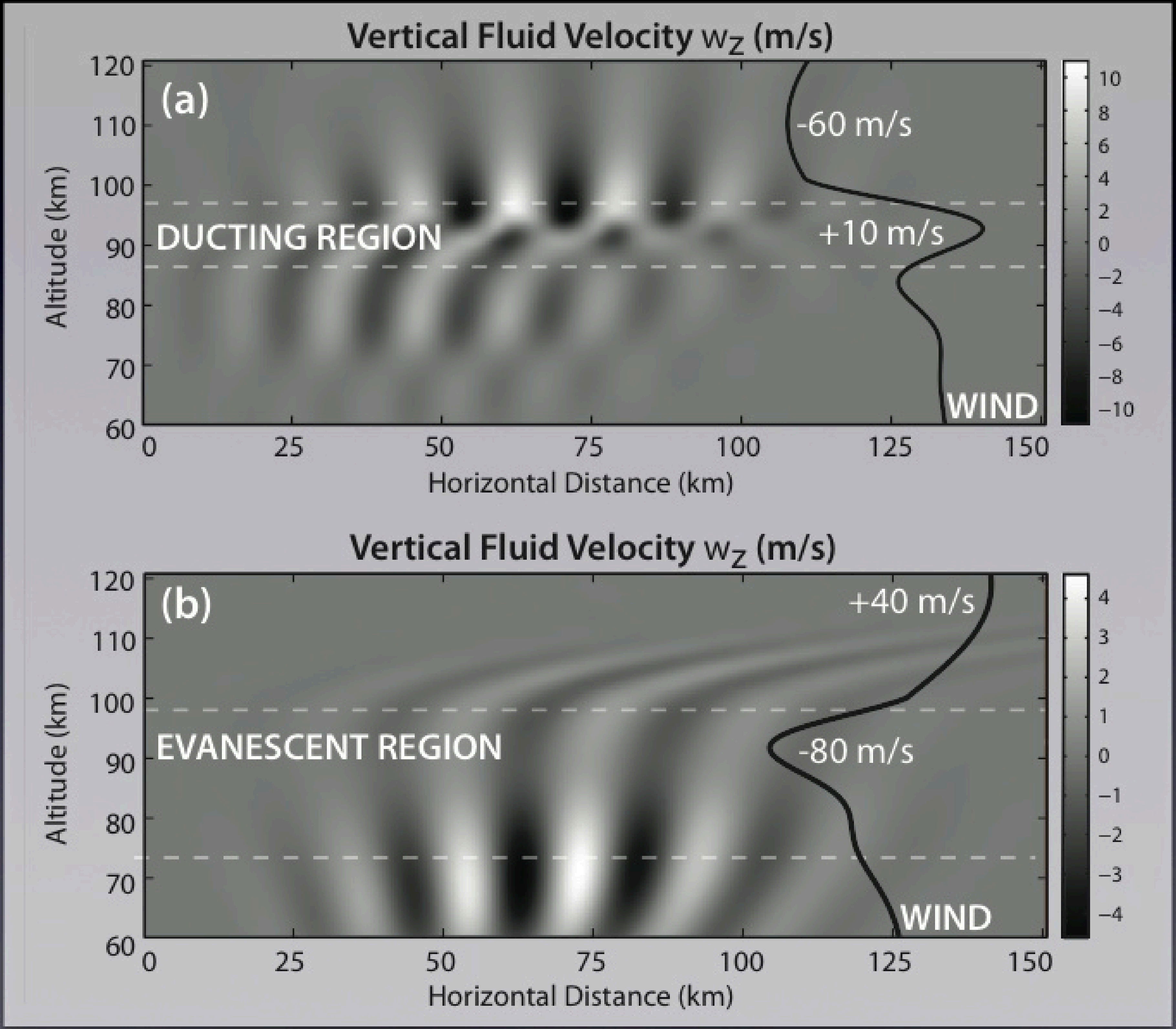


Leaky (non-ideal) ducting is common at mesospheric wind peaks, leading to alternating upward and downward fluxes [e.g., *Yu and Hickey,* 2007].

An alternate case arises when the wind flow opposes wave propagation, leading to evanescence. However, the wave still may propagate above and below.

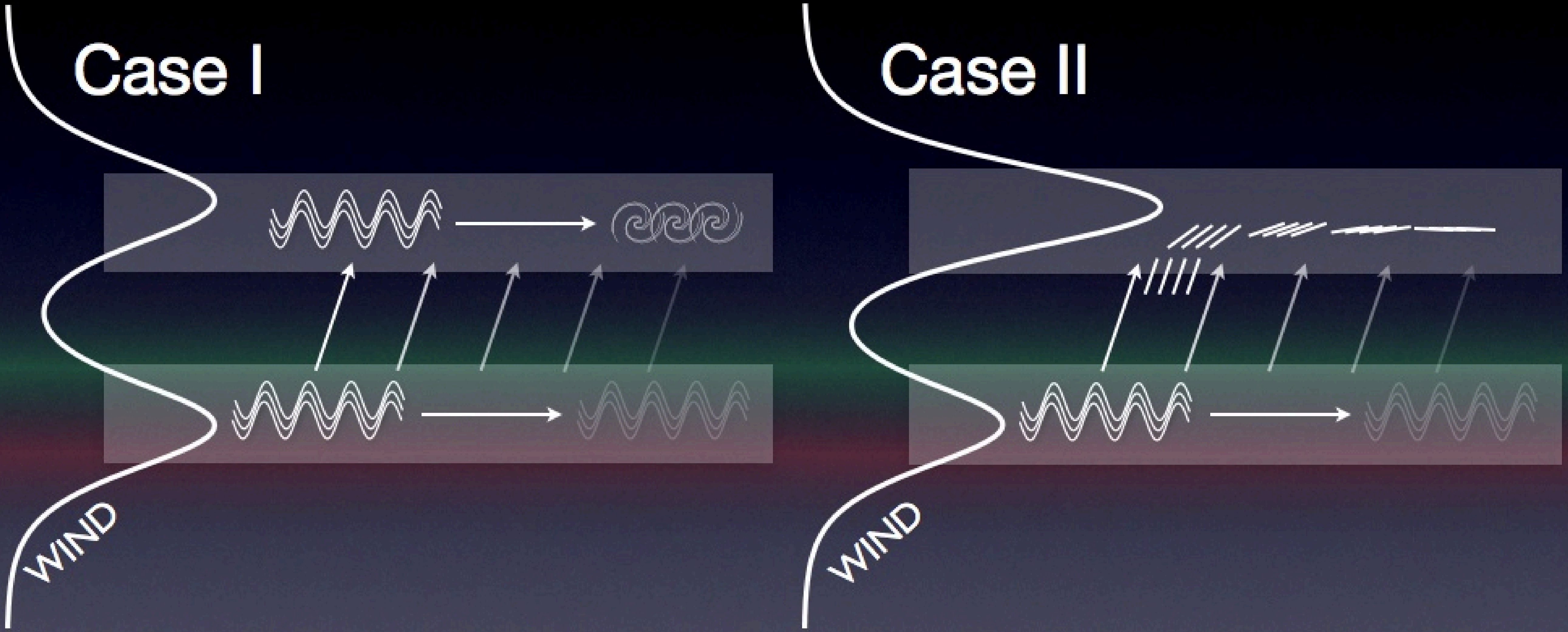
Ducting and Evanescence at Mesopause

Variable tidal winds lead to layered regions of evanescence or trapping at mesospheric airglow layer altitudes [e.g., *Simkhada et al.*, 2009].



Dissipation of Ducted Waves

Ducted gravity waves may dissipate as they tunnel to higher altitudes or into faster wind - This may (or may not) be detectable in airglow signatures.



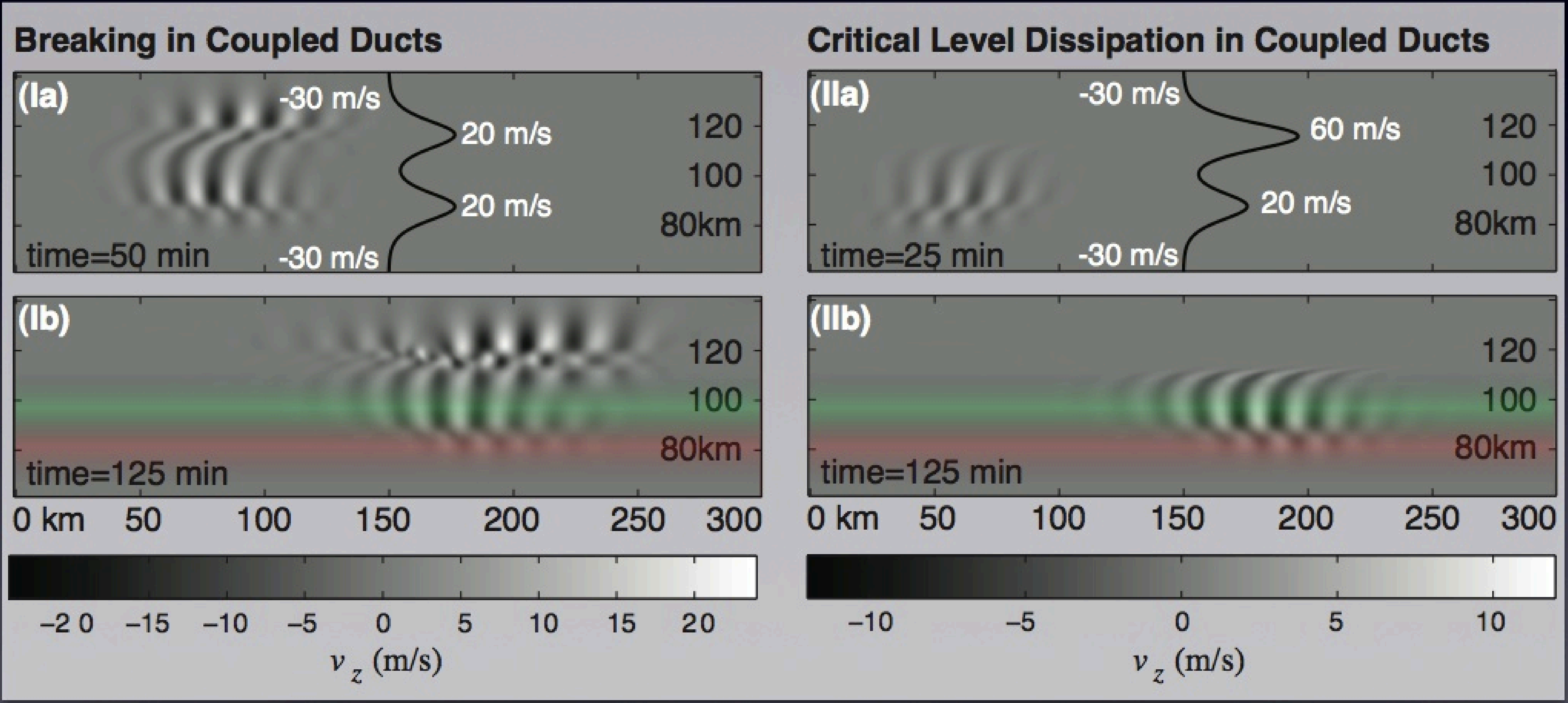
Tunneling to higher altitude leads to stronger velocity perturbations, and may lead to **breaking** for a wave that is stable at lower altitudes.

In the presence of stronger winds, the wave may tunnel into a **critical level**, rather than a Doppler duct. The wave thus dissipates as if it were untrapped.

Dissipation of Ducted Waves

(I) Breaking in a coupled two-duct system: As a consequence of vertical tunneling, wave magnitude is enhanced at higher altitude.

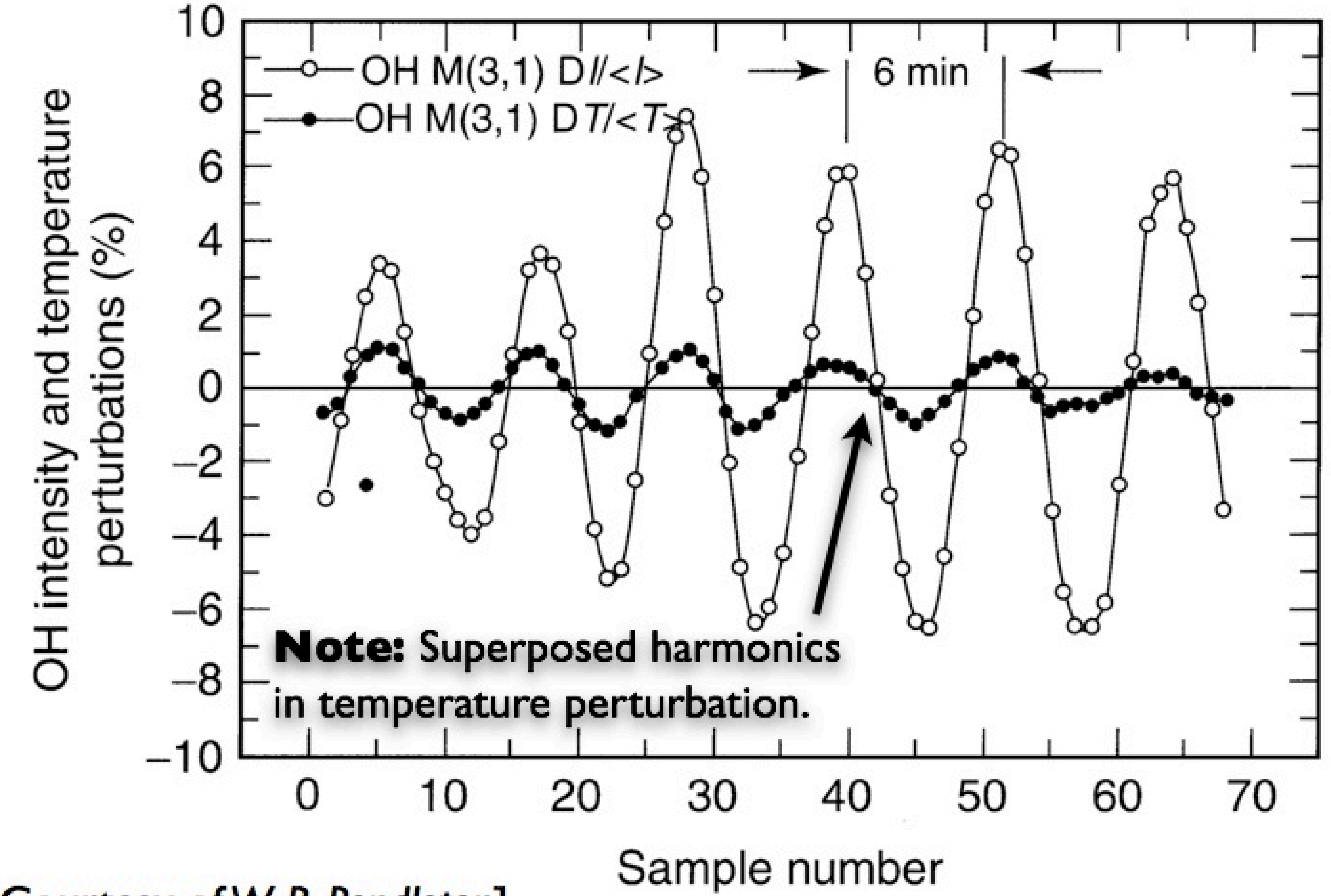
(II) Critical level dissipation in a two-duct system: The tunneled wave phase velocity is lower than peak wind velocity in upper duct.



Signatures of Strong (but Stable) Waves

Airglow signatures of T and I provide insight into **amplitude** and **duct altitude**

Due to steep density gradients (of H, O_3), nonlinear signatures may be present, exhibiting different cancellation effects during vertical integration.

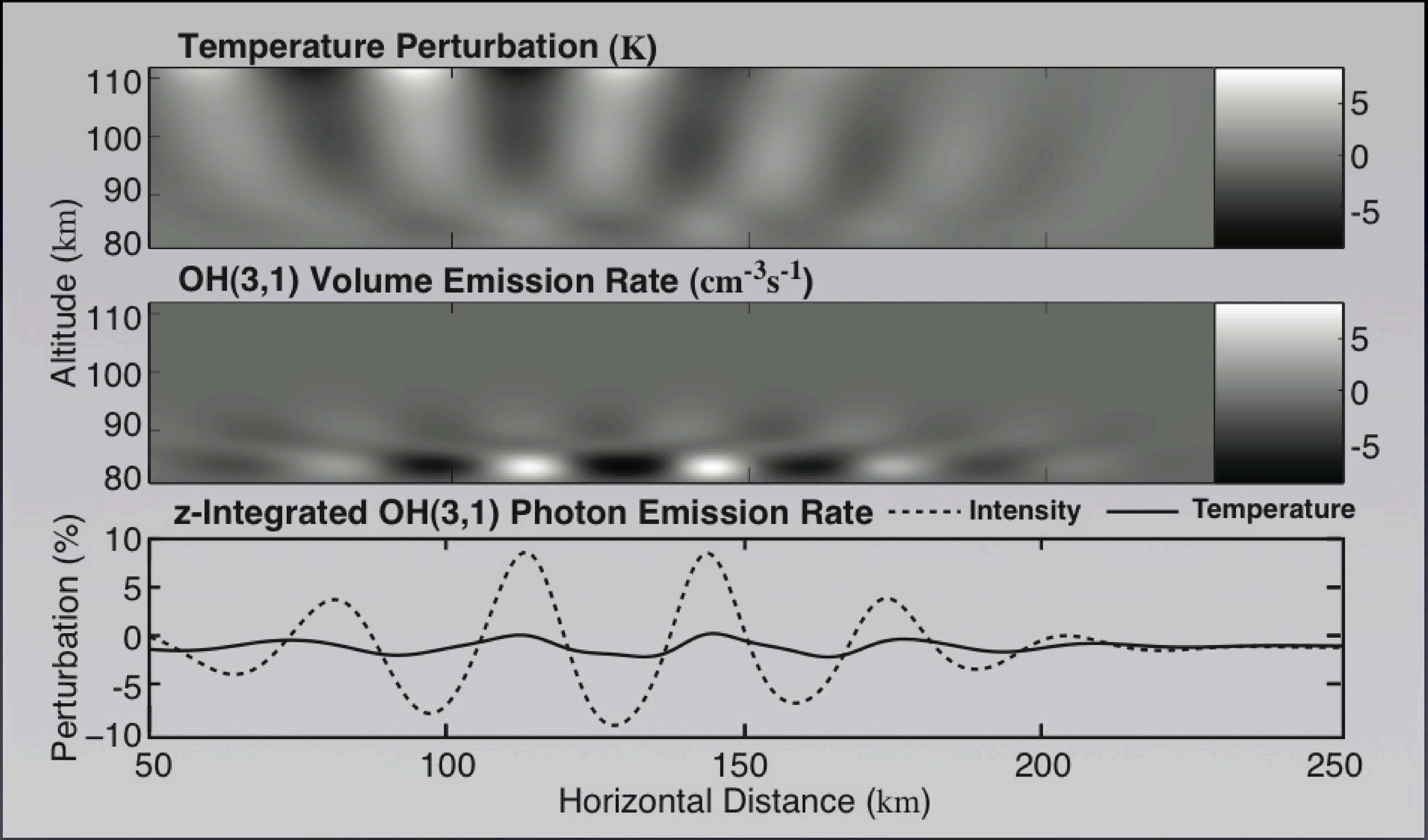


Note: Superposed harmonics in temperature perturbation.

[Courtesy of *W. R. Pendleton*]

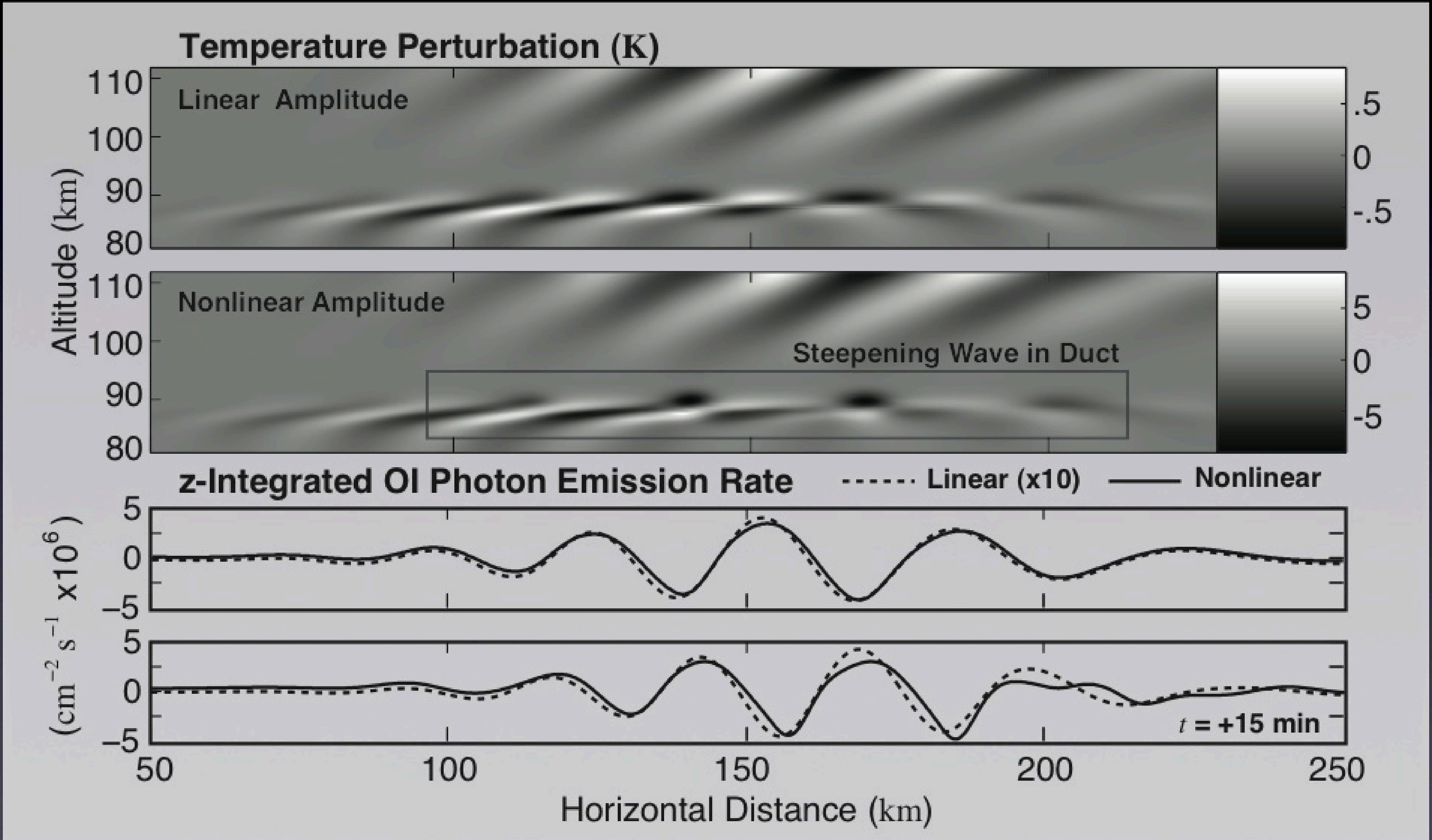
Airglow Nonlinearity and Strong Waves

Strong intensity indicates minimal cancellation of *linear* signature. Weak (but nonlinear) temperature indicates minimal cancellation of *nonlinear* signature.



Airglow Signatures of Nonlinear Waves

While nonlinear signatures may indicate nonlinear airglow response, waves may also exhibit significant nonlinearity in the MLT – Both are important!

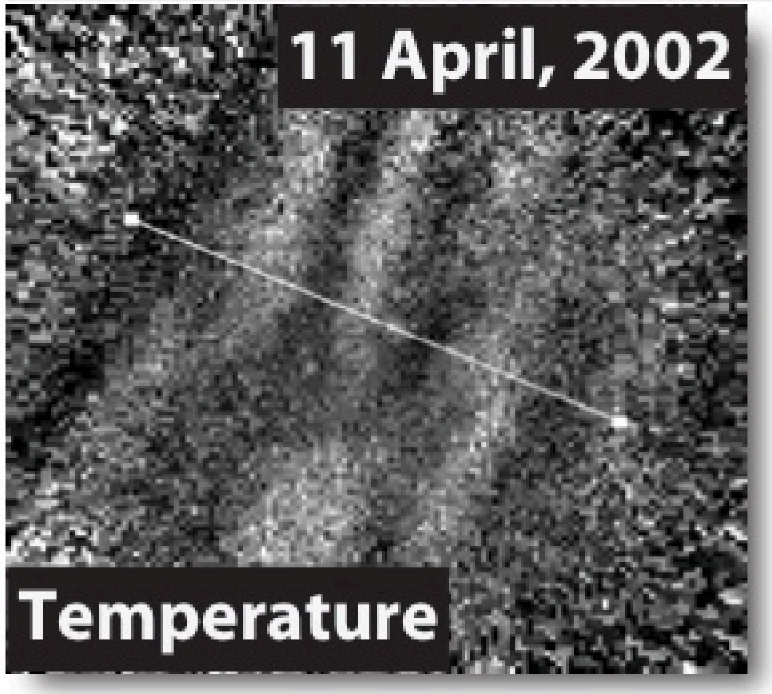


[Simulated ducted wave mode identified by *Walterscheid and Hickey*, 2009; based on *Smith et al.*, 2003]

Contents

Short-Period Wave Propagation:

MTM OH(6,2) intensity and temperature data.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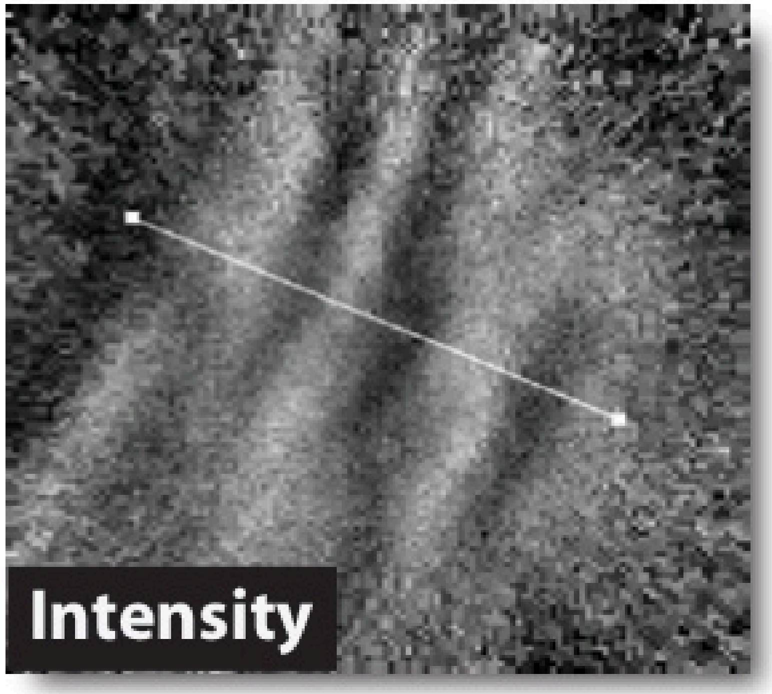
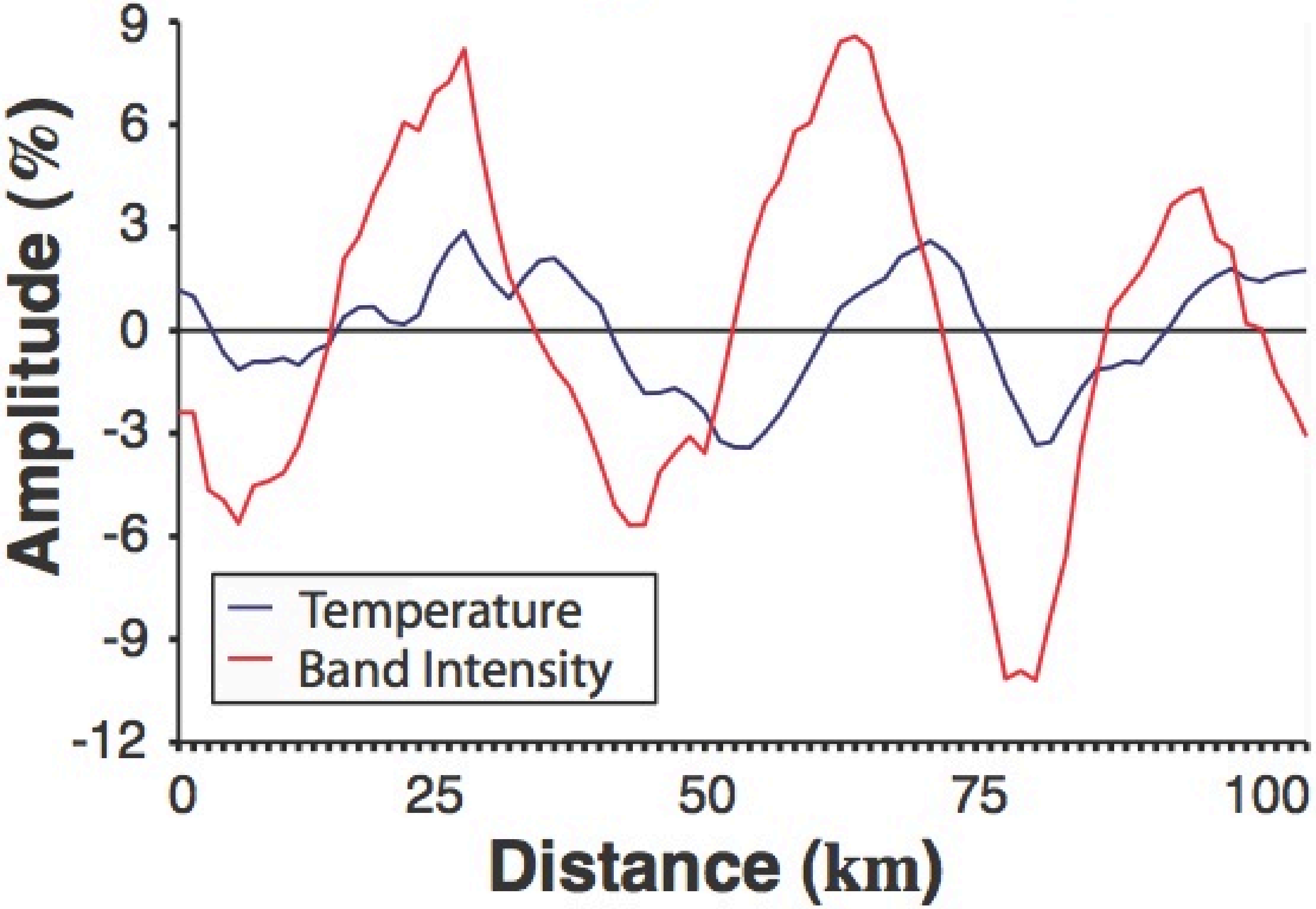


A large-amplitude short-period gravity wave was observed, with T=18 minutes and λ_x=37 km. OH intensity perturbations were large, ~10%, while the wave was *extremely weak in the O_2 data*.



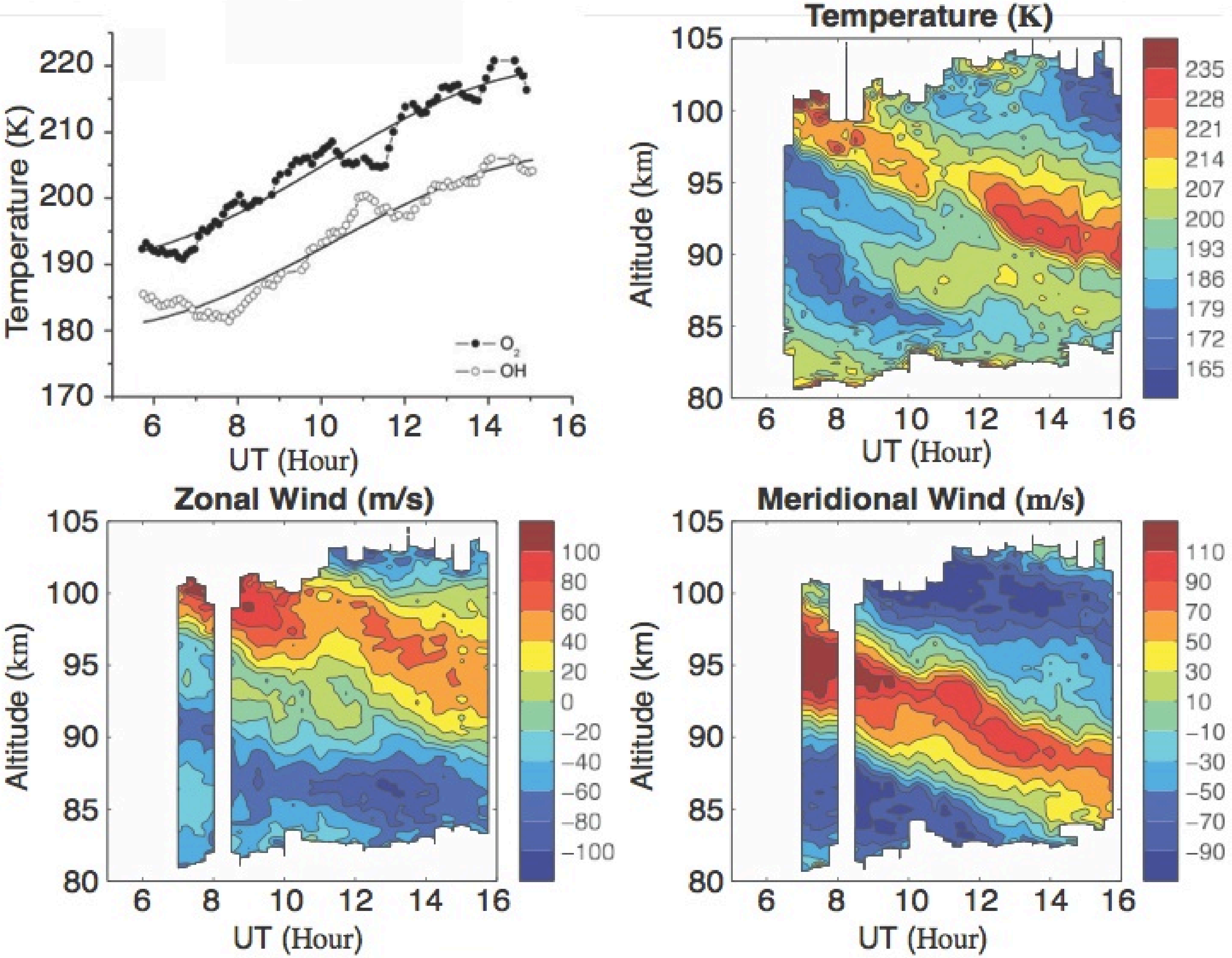
Short-Period Wave Propagation:

Ambient Conditions Observed via Lidar

Maui MTM and Lidar Data:

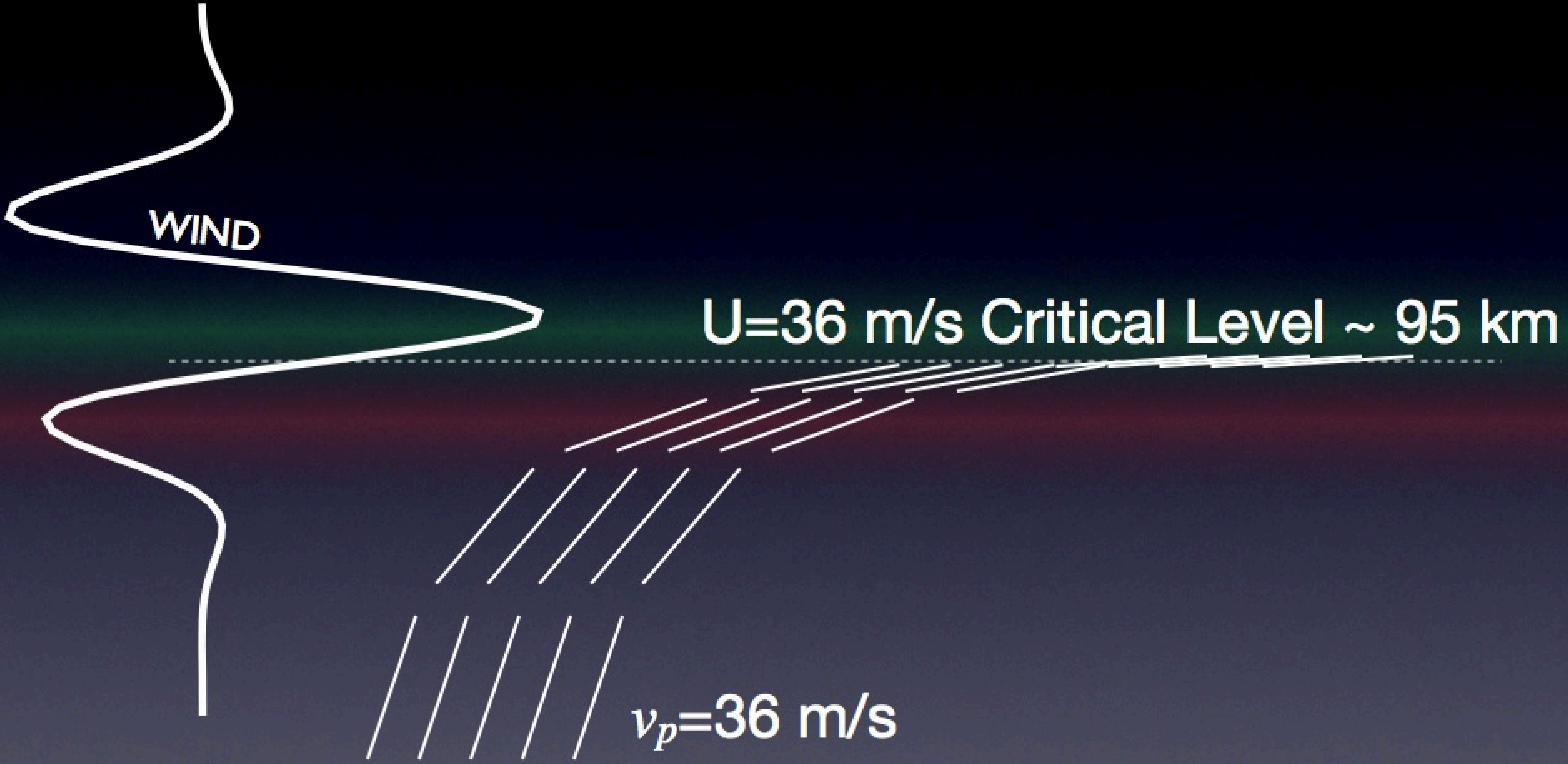
Zenith OH(6,2) rotational temperature is compared with zenith lidar temperature for the night of the event. *Data reveal a strong tidal signature.*

[adapted from Zhao et al., 2005, with additional figures from G. Swenson and A. Liu at University of Illinois].



Upward-Propagating Short-Period Wave:

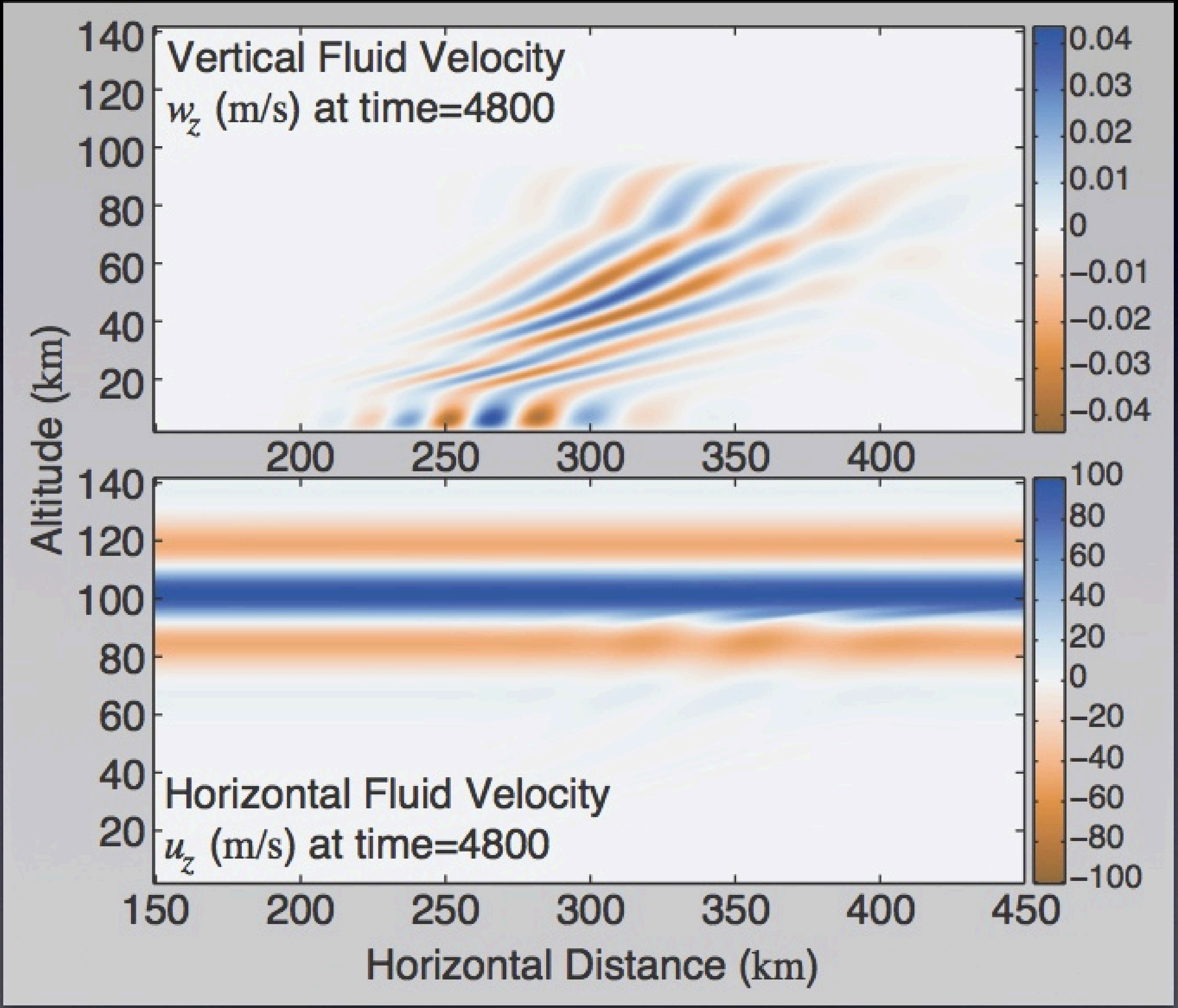
For this wave, tidal winds provide a critical level near the O_2 airglow layer.



For the observed wave, a critical level exists above 95 km altitude, which explains the strong OH signature but very weak O_2 signature.

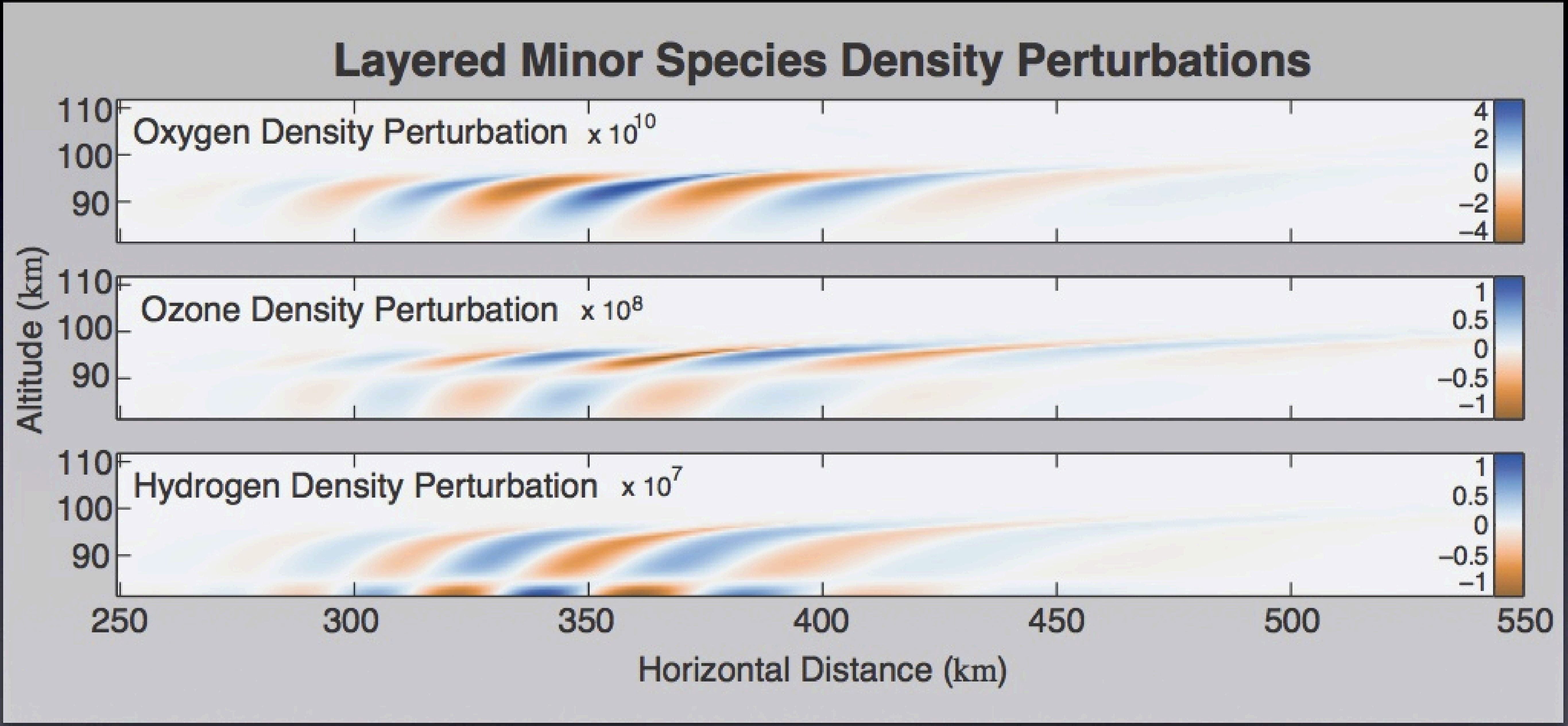
Upward-Propagating Short-Period Wave:

For this wave, tidal winds provide a critical level near the O_2 airglow layer.



Modeling of OH Reaction Minor Species

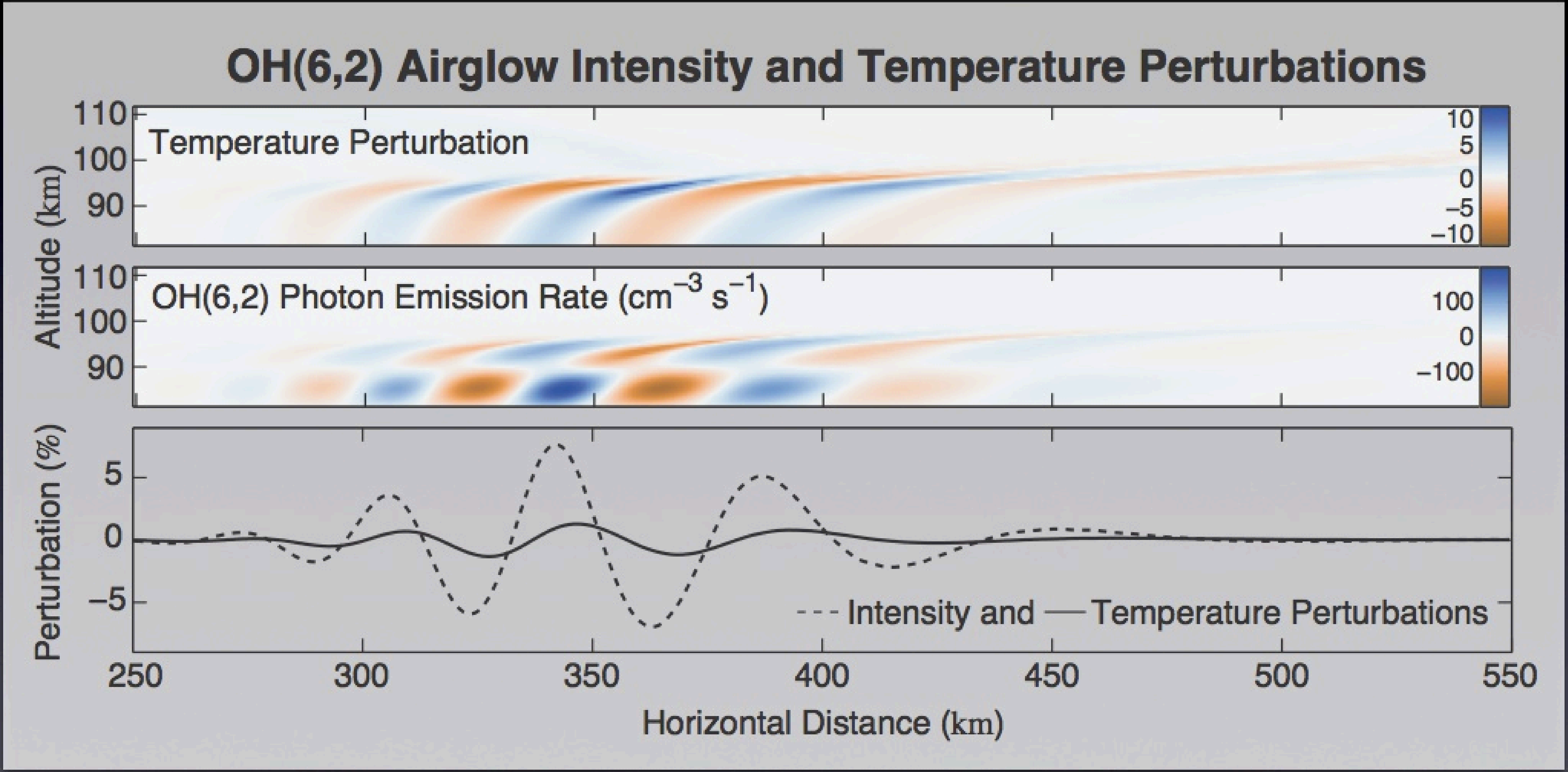
The wave produces significant perturbations to layered chemistry, enhanced by steep gradients above and below O, H, and O3.



Amplitudes of local perturbations of density are partially determined by the shapes of the chemical layer and steepness of gradients.

Modeling of OH Airglow Emission

Volume emission rates and resulting brightness-weighted temperature can be calculated to compare with observational data.



Phase shift between intensity and brightness-weighted temperature, along with relative magnitudes, are very similar to the observed wave!

Summary:

- Using the Mesospheric Temperature Mapper, intensity and rotational temperature images can be utilized to improve model reconstructions of wave events.
- Nonlinearities of the airglow signatures – associated with the wave itself, the chemical response, or both – provide important clues (and potential sources of confusion!) for modeling and understanding wave events.
- Ducted and freely propagating waves may be experiencing dissipation processes unobservable in airglow data. Modeling of atmospheric structure and wave propagation above and below the MLT are necessary to understand complex wave events.
- Numerical models of wave propagation and airglow perturbations can provide insight into gravity wave processes, and may serve as validation tools for future data analysis methods.