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Fabio Vargas and Gary Swenson

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Uncertainties in gravity wave parameters, momentum fluxes, and flux divergences estimated from multi-layer measurements of mesospheric nightglow layers

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Abstract

Measurements of dynamic parameters of atmospheric gravity waves, mainly the vertical wavelength, the momentum flux and the momentum flux divergence, are affected by large uncertainties crudely documented in the scientific literature. By using methods of error analysis, we have quantified these uncertainties for frequently observed temporal and spatial wave scales. The results show uncertainties of ∼10%, ∼35%, and ∼65%, at least, in the vertical wavelength, momentum flux, and flux divergence, respectively. The large uncertainties in the momentum flux and flux divergence are dominated by uncertainties in the Brunt-Väisälä frequency and in spatial separation of the nightglow layers, respectively. The measured uncertainties in fundamental wave parameters such as the wave amplitude, intrinsic period, horizontal wavelength, and wave orientation are ∼10% or less and estimated directly from our nightglow image data set. Other key environmental quantities such as the scale height and the Brunt-Väisälä frequency, frequently considered as constants in gravity wave parameter estimations schemes, are actually quite variable, presenting uncertainties of ∼4% and ∼9%, respectively, according to the several solar activity and seasonal atmosphere scenarios from the NRLMSISE-00 model simulated here.

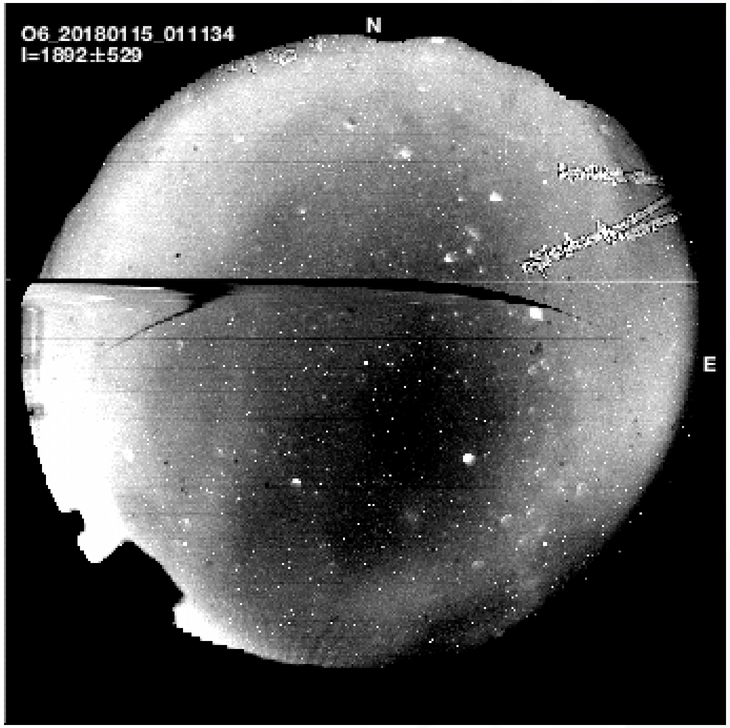
Keywords: Atmospheric gravity waves; Nightglow; Momentum flux; Momentum flux divergence; Uncertainty estimations; Nightglow imagers

Motivation and Goal

- **Motivation**
  - GW parameters uncertainties from nightglow images are rarely reported in the literature

- **Goals**
  - To quantify the uncertainties on these GW parameter
  - Encourage other colleagues to report uncertainties on their publications via the presented methodology

Derivable GW Quantities



Vertical Wavenumber

$$m^2 = \left(\frac{N^2}{\omega^2} - 1\right) k^2 - \frac{1}{4H^2}$$

Momentum Flux

$$F = \langle w' u'_\theta \rangle = -\frac{1}{2} \frac{g^2}{N^4} \frac{m}{k} \omega^2 \left(\frac{A}{CF}\right)^2$$

Flux Divergence

$$D \approx -\frac{1}{\bar{\rho}} \left(\frac{\Delta \bar{\rho}}{\Delta z} F + \frac{\Delta F}{\Delta z} \bar{\rho}\right)$$

Errors on Derivables Quantities

Error Propagation

$$\sigma_f^2 = \sum_{i=1}^{n} \left(\frac{\partial f}{\partial x_i}\right)^2 \sigma_{\bar{x}_i}^2$$

Vertical Wavenumber

$$\sigma_m^2 = \left(-\frac{N^2k^2}{m\omega^3}\right)^2 \sigma_\omega^2 + \left(\frac{k}{m}\left[\frac{N^2}{\omega^2} - 1\right]\right)^2 \sigma_k^2 + \left(\frac{Nk^2}{m\omega^2}\right)^2 \sigma_N^2 + \left(\frac{1}{4mH^3}\right)^2 \sigma_H^2$$

Momentum Flux

$$\sigma_F^2 = \left(\frac{F}{m}\right)^2 \sigma_m^2 + \left(\frac{2F}{\omega}\right)^2 \sigma_\omega^2 + \left(\frac{2F}{A}\right)^2 \sigma_A^2 + \left(\frac{F}{k}\right)^2 \sigma_k^2 + \left(\frac{2F}{CF}\right)^2 \sigma_{CF}^2 + \left(\frac{4F}{N}\right)^2 \sigma_N^2$$

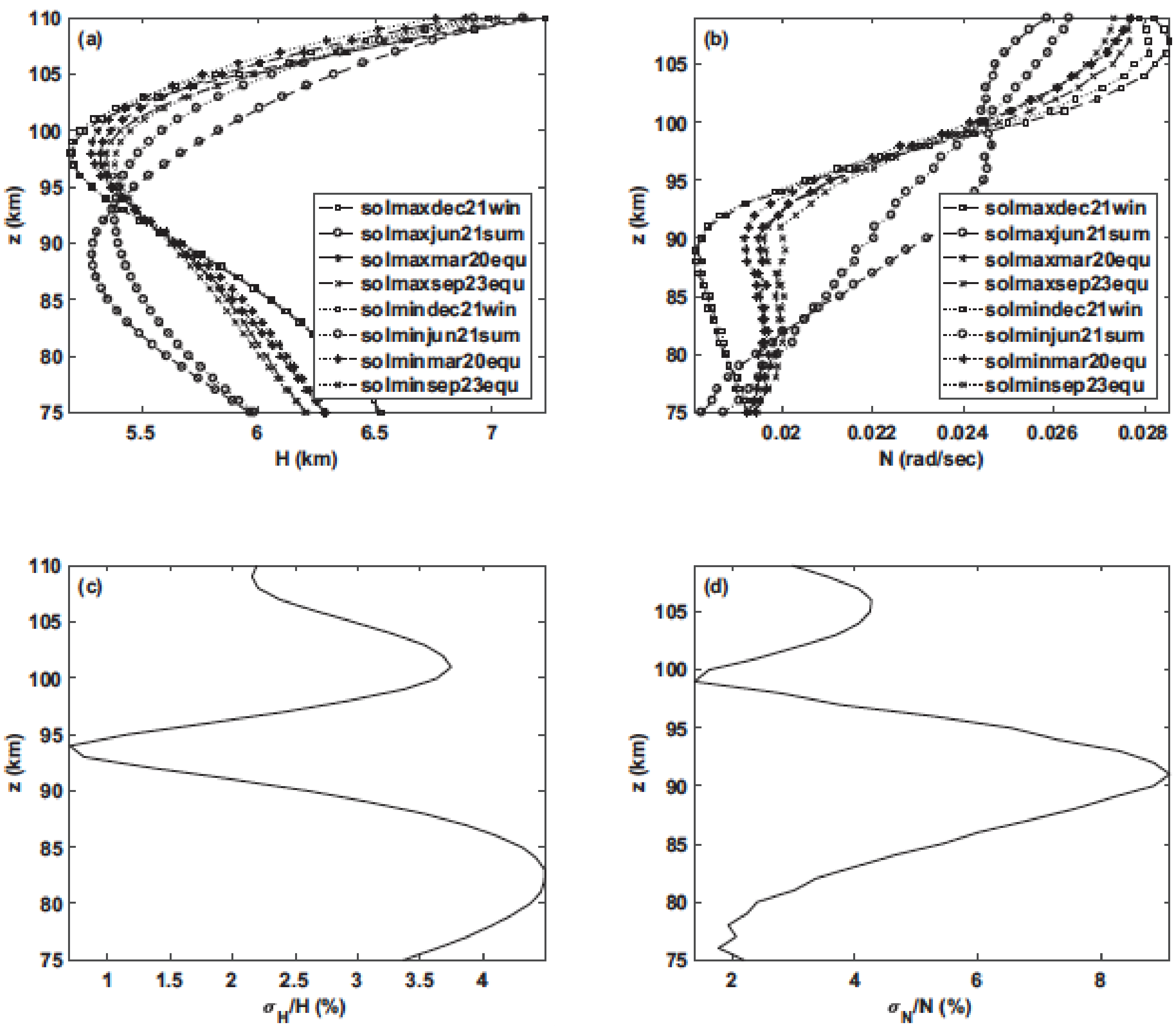
Flux Divergence

$$\sigma_D^2 = \left(\frac{\Delta\bar{\rho}}{\bar{\rho}}\frac{F}{\Delta z^2} + \frac{\Delta F}{\Delta z^2}\right)^2 \sigma_{\Delta z}^2 + \left(\frac{1}{\Delta z}\right)^2 \sigma_{\Delta F}^2 + \left(\frac{1}{\bar{\rho}}\frac{F}{\Delta z}\right)^2 \sigma_{\Delta\bar{\rho}}^2 + \left(\frac{1}{\bar{\rho}}\frac{\Delta\bar{\rho}}{\Delta z}\right)^2 \sigma_F^2 + \left(\frac{\Delta\bar{\rho}}{\bar{\rho}^2}\frac{F}{\Delta z}\right)^2 \sigma_{\bar{\rho}}^2$$

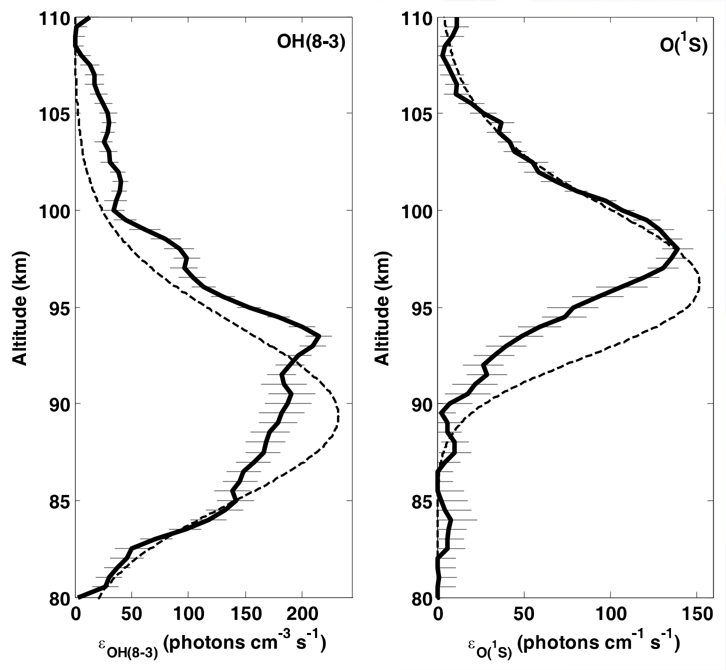
Specifying the Uncertainties in Primary and Environmental Parameters

Uncertainties in Geophysical Quantities

$$m^2 = \left(\frac{N^2}{\omega^2} - 1\right) k^2 - \frac{1}{4H^2}$$



Uncertainty in the layer altitude

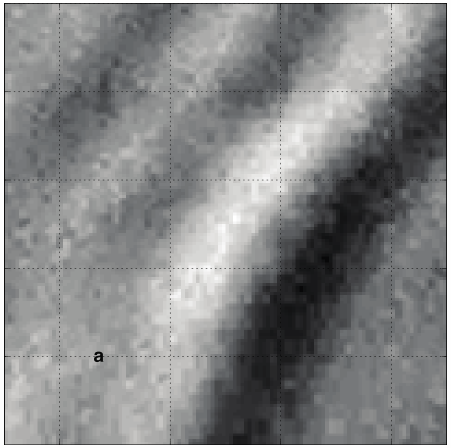


The uncertainty on the layer centroid position is about 2.5 km (Zhao et al. (2005)

The uncertainty on the distance between layers (Δz) is then 50 %

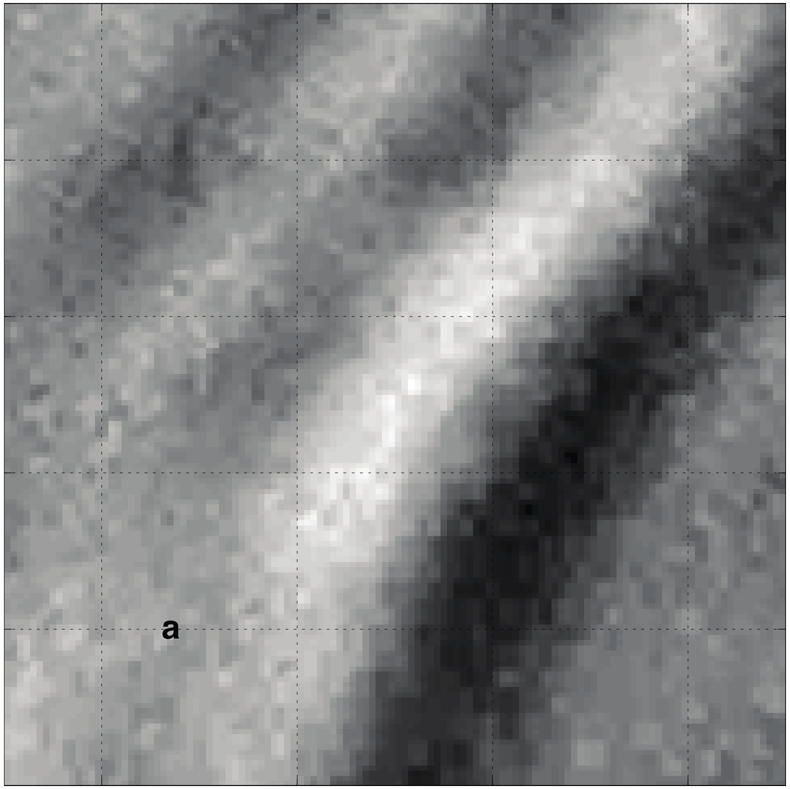
Zhao, Y., M. J. Taylor, and X. Chu (2005), Comparison of simultaneous na lidar and mesospheric nightglow temperature measurements and the effects of tides on the emission layer heights, *Journal of Geophysical Research: Atmospheres*, *110*(D9), n/a–n/a, doi:10.1029/2004JD005115.

Uncertainties in Wavenumber and Direction

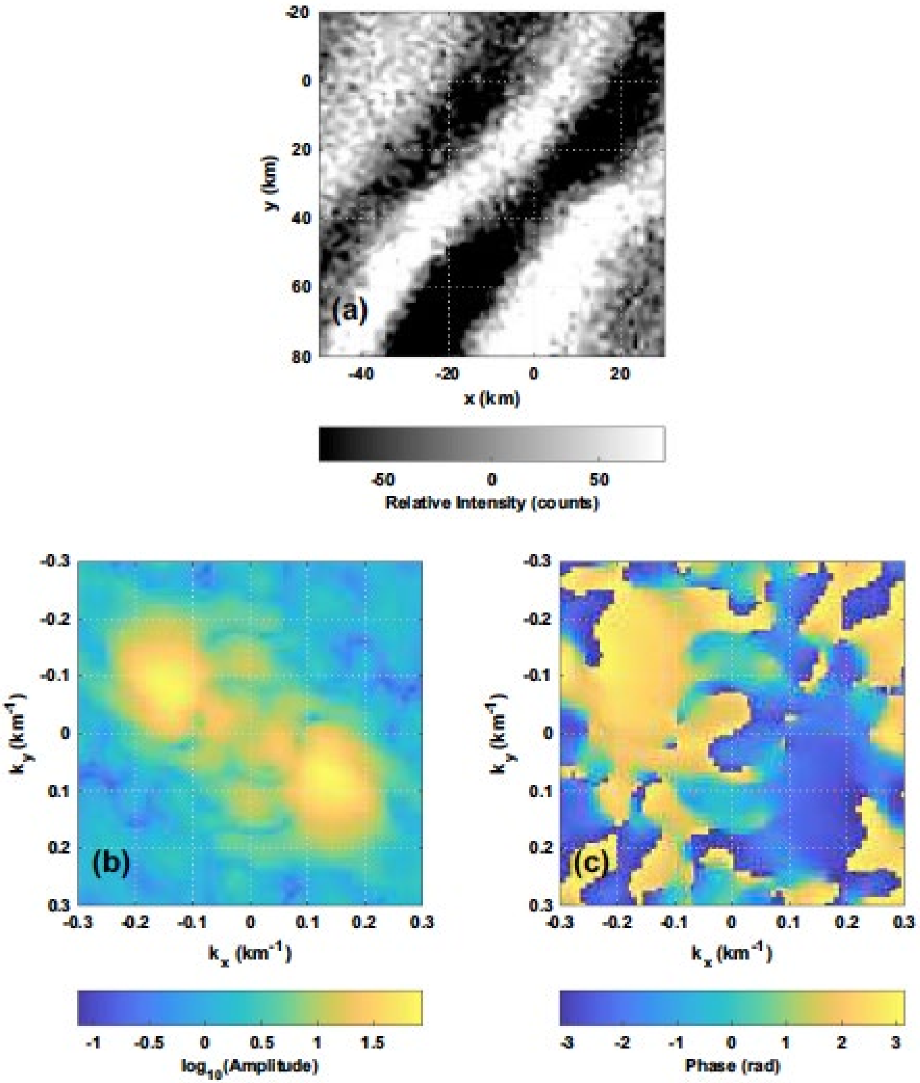


Uncertainties in Wave Amplitude

Uncertainty in the wave amplitude is the **Variance** of the raw image



Uncertainty in the Wave Period



Phase Speed

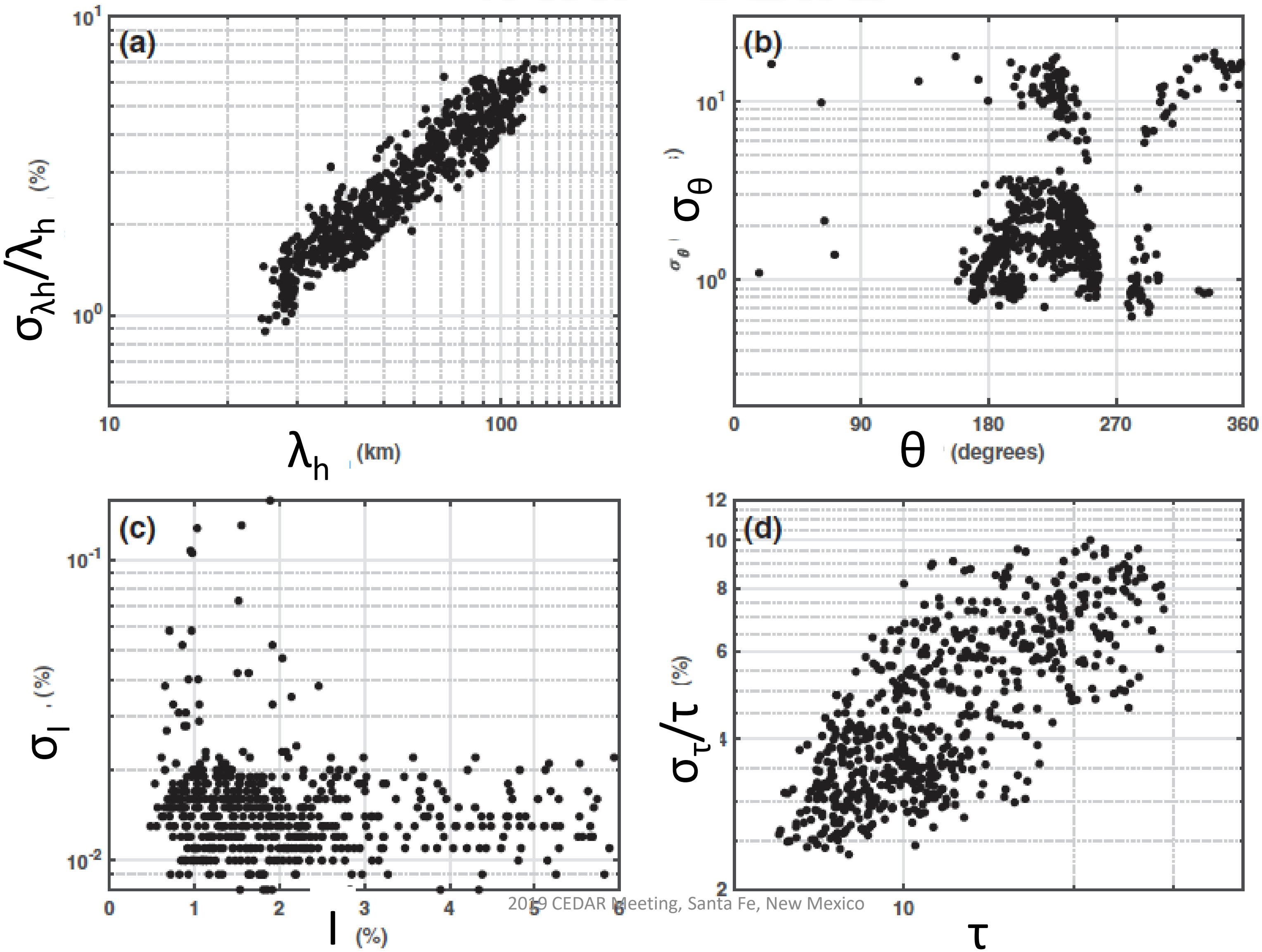
$$c = \frac{\lambda_h}{2\pi}\frac{\Delta\phi}{\Delta t}$$

Uncertainty in the wave phase velocity

$$\sigma_c^2 = \left(\frac{c}{\lambda_h}\right)^2 \sigma_{\lambda_h}^2 + \left(\frac{c}{\Delta\phi}\right)^2 \sigma_{\Delta\phi}^2 + \left(\frac{c}{\Delta t}\right)^2 \sigma_{\Delta t}^2$$

Measured Uncertainties

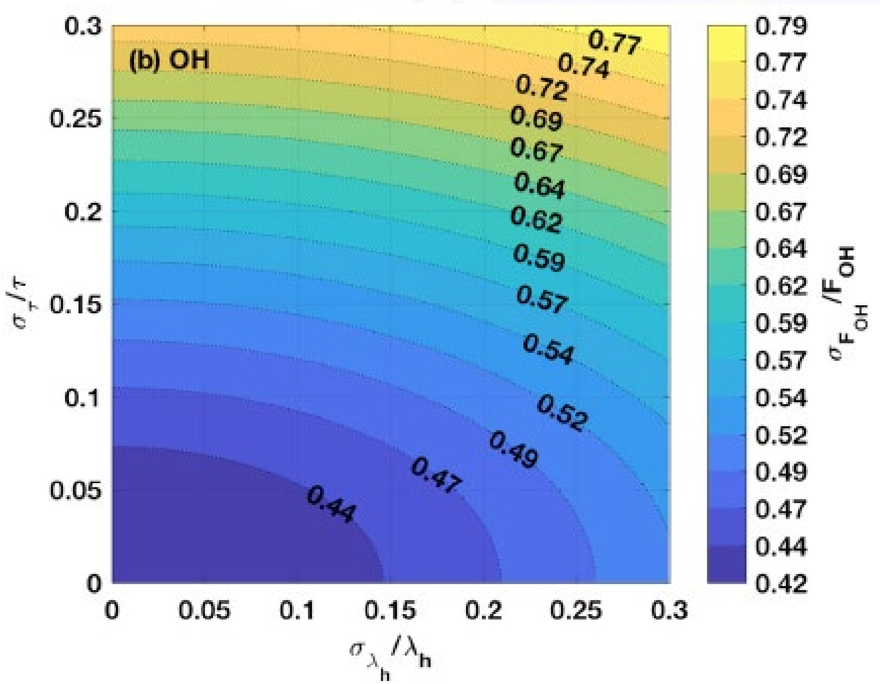
in Primary Parameters



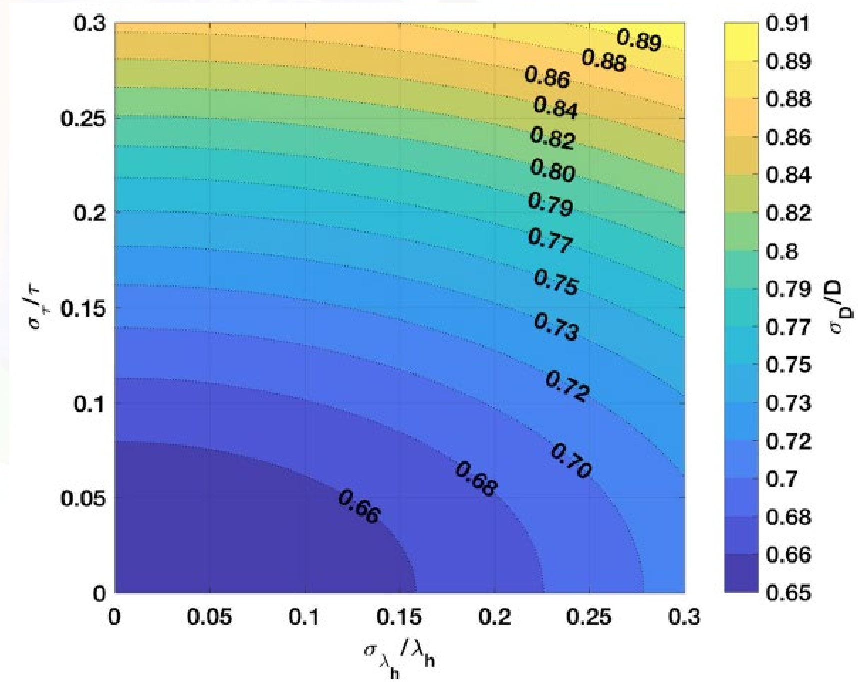
$$F = \langle w' u'_\theta \rangle = -\frac{1}{2}\frac{g^2}{N^4}\frac{m}{k}\omega^2\left(\frac{A}{CF}\right)^2$$

$$D \approx -\frac{1}{\bar{\rho}}\left(\frac{\Delta\bar{\rho}}{\Delta z}F + \frac{\Delta F}{\Delta z}\bar{\rho}\right)$$

Momentum Flux



Flux Divergence



Summary

Most wanted **GW parameters are affected by large uncertainties**;

To beat down the uncertainties, averaging multiple measurements of the same wave scale;

Uncertainties in N and Δz are the dominant sources of errors in GW parameters from nightglow imagery;

Use techniques **to estimate better Δz** (triangulation, tomography), and **collocated lidar measurements to estimate better N** throughout the MLT.

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