ABSTRACT

Atmospheric turbulence activity in the mesosphere and lower thermosphere (MLT) region is determined from narrowband Na lidar measurements obtained over 27 nights between 85-105 km altitude at the Andes Lidar Observatory (ALO) in Cerro Pachón, Chile (30°S, 70°W). Photocount fluctuations in the applicable spectral subrange are used as a tracer of turbulence activity. Mean altitude profiles reveal a log-scale linear increase in turbulence perturbation amplitude above 95 km. The observed trend is compared against global mean man-made transport profiles derived from SABER and SCIAMACHY satellite borne measurements.

OVERVIEW

Introduction

• Atmospheric gravity waves (AGWs) transport energy and momentum upwards to the mesosphere and lower thermosphere (MLT) regions.
• AGWs frequently become unstable near the mesopause, breaking into turbulence and dispersing energy and momentum to the surrounding atmosphere [2].
• The atmosphere is dominated by eddy diffusion below 95 km and molecular diffusion above 105 km [3].
• Turbulent mixing in the 95-105 km transition region drives the balance between eddy and molecular diffusivity via the eddy diffusion coefficient $K_{zz}$, altering net constituent diffusion profiles [4].
• Minor species such as Na are highly reactive, and their mass flux in the mesosphere can be written as [5]:

$$v = -\frac{1}{\rho} \frac{\partial}{\partial z} \left[ \frac{1}{\rho} \frac{\partial}{\partial \rho} \left( \rho \frac{u}{\rho} \right) \right]$$

• Thorough characterization of turbulence and gravity wave dissipation in the MLT region improves middle atmospheric model accuracy.

Background

• Narrow-band, three-frequency resonance fluorescence sodium (Na) lidar systems utilize the resident Na layer as a sensitive tracer of local wind, temperature, and density (TWD) in the 80-105 km regions [5].
• $K_{zz}$ is calculated from temperature and wind perturbation covariance and is related to the Brunt-Väisälä (BV) frequency, $N^2$ [6].

$$\frac{1}{\rho} \frac{\partial}{\partial \rho} \left[ \rho \frac{u}{\rho} \right] = -\frac{1}{\rho} \frac{\partial}{\partial z} \left[ \frac{1}{\rho} \frac{\partial}{\partial \rho} \left( \rho \frac{u}{\rho} \right) \right]$$

• Previous efforts (e.g., [7,8]) have measured $K_{zz}$ from 85 km to 100 km within ±10 m/s. Above 100 km, the power-aperture of the ALO lidar (∼1 Wms) is too weak for accurate calculation of $K_{zz}$.
• Turbulence activity can instead be measured from Na layer fluctuations following Kolmogorov's $\kappa^4$ power law at frequencies higher than $\kappa_0$.
• Temperature, wind, and density fluctuations are closely related to photocount fluctuations ($N^2/R^2$) [9]:

$$N^2 = \frac{1}{\rho} \frac{\partial}{\partial \rho} \left[ \rho \frac{u}{\rho} \right] = -\frac{1}{\rho} \frac{\partial}{\partial z} \left[ \frac{1}{\rho} \frac{\partial}{\partial \rho} \left( \rho \frac{u}{\rho} \right) \right]$$

METHOD

Turbulence-Scalne Scenarios

1. Raw vertical count profiles (25 m, 6 resolution) are averaged at each frequency assuming a mean temperature of $T = 185 K$.
2. Measurements with SNR <4 are regarded as erroneous and discarded. Remaining measurements are binned in time to 25 m, 12 resolution.
3. Photocount profiles are normalized against the pressure scale height, $H_{p}(z) = kT(z)/mg$:

$$N_c(z) = \frac{N(z)}{T(z)H_{p}(z)} \exp \left( \frac{H_{p}(z)}{T(z)} \right)$$

Detrending & Filtering

4. Normalized profiles are next detrended by applying a sliding 500, 150 m Hamming window.
5. The detrended profiles are bandwidth-filtered with cutoffs at the BV frequency and dissipative subrange (∼40 mHz).

Fitting & Normalization

6. Filtered profiles are fit to an $\kappa^4/3$ curve at 25 m resolution. Profiles are then combined to obtain the nightly turbulence power spectral density profile.
7. Nightly neutral density turbulence power profiles (conservative) are calculated from Na fluctuations (non-conservative) by [11].

RESULTS

Data

Twenty-seven (27) nights of lidar data were acquired at ALO, spanning 2500 hours and 275,700 hours of zenith and off-zenith measurements, respectively. Measurements are grouped near spring and autumnal equinoxes to leverage increased Na layer density.

Mean Trends

• Average Na fluctuation power over the 85-105 km region is 104.7±2/0.8/1.7% (0.08±2.17% amplitude).
• Na layer fluctuations are on average 5-10 times larger than neutral density fluctuations.
• Average turbulence power across the region is 2.3 ± 1.4 (80% confidence).
• A log-scale linear increase in turbulence power is present from 95 km to 104 km, with peak power of 26.78±7.11% (5.17±1.38% peak amplitude).

SABER & SCIAMACHY Data Comparison

• Total mesospheric $K_{zz}$ was determined from SCIAMACHY and SABER O and SABER CO$_2$ data [12].
• Turbulence power is related to turbulence-induced eddy diffusion by [11,13,14]:

$$K_{zz} = \frac{\sqrt{N^2}}{\rho} = \frac{\sqrt{H_{p}(z)\frac{\partial}{\partial z} \left[ \rho \frac{u}{\rho} \right]}}{\rho}$$

• The derived turbulence $K_{zz}$ profile indicates that wave-induced turbulence plays a significant role in defining eddy transport in the 100-105 km region.

CONCLUSIONS

Key Findings

• Mean turbulence-induced eddy diffusion is determined from Na layer fluctuations in the 85-105 km region.
• Atmospheric turbulence layer perturbations are 5-10 times more sensitive to turbulence than neutral density perturbations.
• Turbulence power exhibits a log-scale linear increase from 95-104 km with peak fluctuation amplitude of 5.17±1.38%.
• In the 100-105 km region, turbulence is a primary factor affecting total $K_{zz}$.

Limitations

• Mean temperature, $T$, is the largest measurement error source. Displayed uncertainties conservatively estimate a maximum temperature error of 2.50 K. At peak layer densities, an uncertainty of ±1 K is more realistic.
• Determination of turbulence $K_{zz}$ requires averaging thousands of lidar profiles. The current power-aperture product of the ALO Na lidar does not permit intra-nightly determination of $K_{zz}$ in the 100-105 km region under the method described.

Future Work

• Comparison between mean $K_{zz}$ profiles determined via the Na layer fluctuation and $\kappa^4$ methods in the 85-105 km region is essential for further validation.
• Detailed explanations of the developed methodology and key findings are covered in recent [15] and forthcoming [16,17] publications.

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