A Study of Intermittent Turbulence in Stable Arctic Boundary Layers

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1. Introduction

Stable ABLs are difficult to simulate due to the existence of intermittent turbulence within them. Here we present a case study evaluation of intermittent turbulence in a stable ABL observed during the ERASMUS (Evaluation of Routine Atmospheric Sounding Measurements using Unmanned Systems) field campaign. We ask:

- Are downward cascades of intermittent turbulence observed in the stable ABL?
- What is the vertical extent of these layers of intermittent turbulence?
- How are these layers propagating and what is their propagation velocity?

2. Methods

- 5 UAV (DataHawk2) flights on 10/19/16
- Oliktok Point, Alaska
- 57 profiles
- 3.2 hours of measurements
- 800Hz temperature (T) & wind (U)
- Clear, cold conditions
- Strongly stable ABL

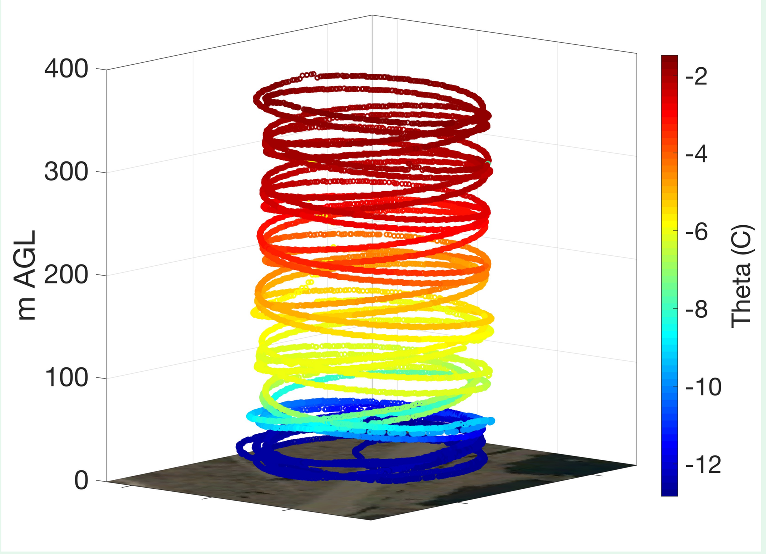

Figure 1. Circular potential temperature (θ) profiles measured from 17:26 – 17:58 UTC on 10/19/16 at Oliktok Point, Alaska.

Turbulent layers were identified using the **Bulk Richardson Number** - a ratio of buoyancy forces measured with T profiles and shear forces measured with U profiles:

$$R_B = \frac{g\, \Delta\theta_v\, \Delta z}{\theta_v\, [(\Delta U)^2 + (\Delta V)^2]}$$

3. Results

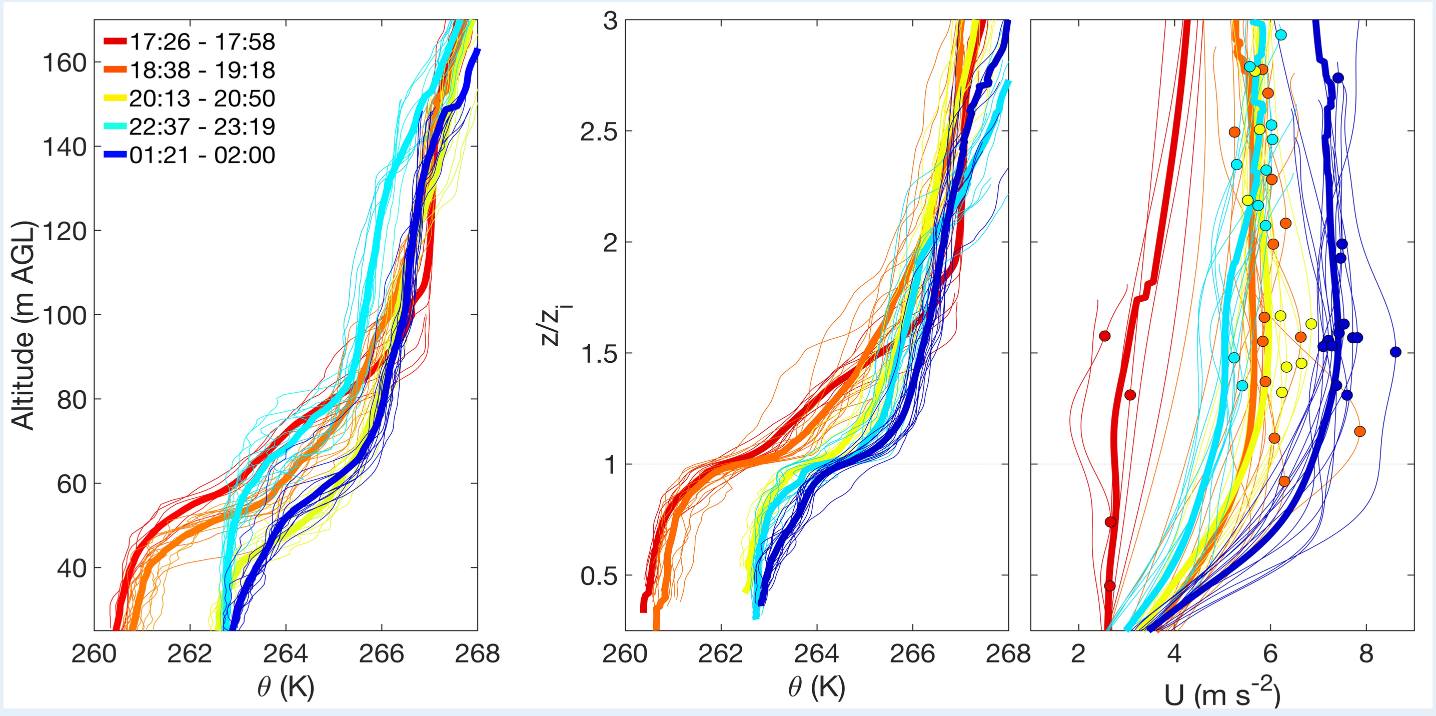

Figure 2. Potential temperature (θ) profiles for 5 flights (left), ABL height-adjusted θ profiles (middle) and U profiles (right). Dots indicate height of minimum shear.

Potential temperature profiles showed variation both within flights (~40 minutes) and throughout the day. U profiles showed that shear was generally strongest below the inversion separating the ABL from the free atmosphere. Dots on the U profiles represent the height of minimum shear, the majority of which occurred above the ABL.

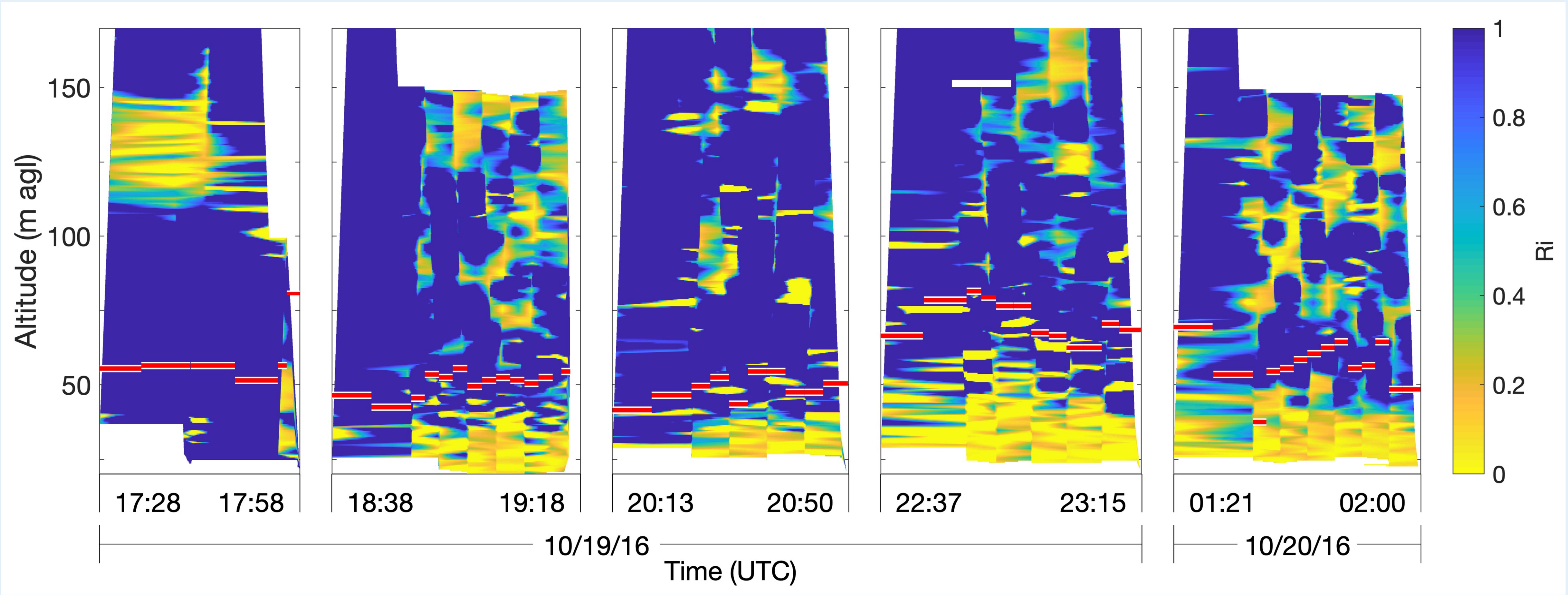

Figure 3. Time-height cross sections of Richardson number interpolated from profiles. Yellow represents turbulent layers, blue represents stable layers. Red dashes represent the height of maximum squared Brunt–Väisälä frequency – roughly the inversion height and an estimate of ABL height. Turbulent layers are defined as regions with Ri below 0.25.

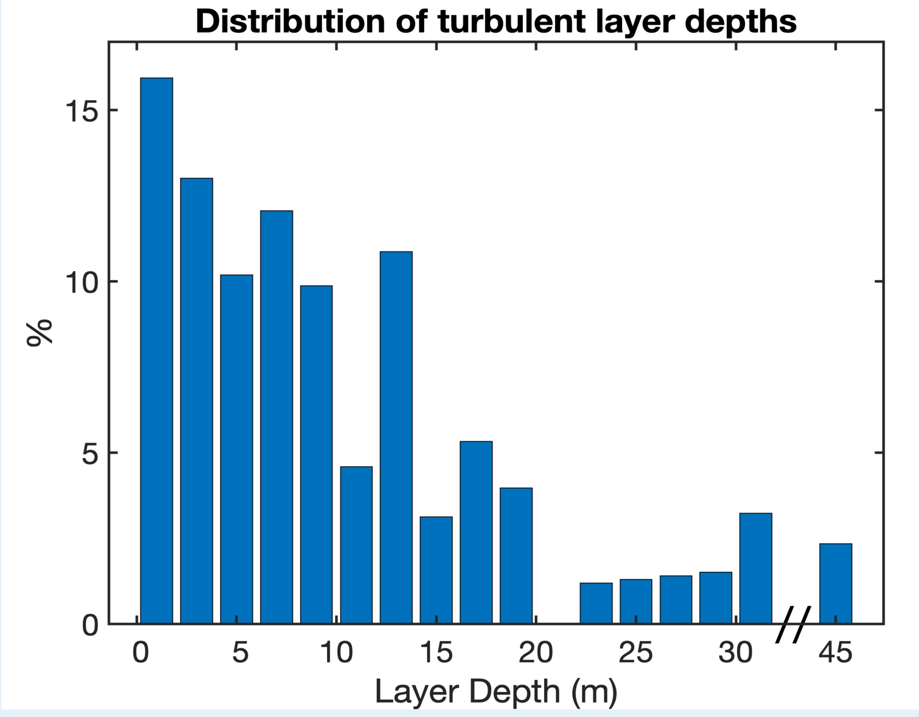

Figure 4. Percent distribution of turbulent layer depths was calculated as the frequency of occurrence of each layer depth multiplied by the layer depth divided by the cumulative depth of all turbulence.

The majority (60%) of turbulent layers were < 2 m deep. Depth-weighted fraction of all turbulence showed that 50% of turbulence occurred in layers < 7 m deep.

An assessment of the time-height cross sections found that turbulent layers appear to propagate both upward and downwards. The median magnitude of propagation vertical velocity was 1.4 cm s^{-1}. This is equivalent to typical vertical wind speed magnitudes in the ABL. It is much lower than propagation velocities proposed by the LES findings of Sullivan et al. (2016).

4. Conclusions

- Turbulent layers exist within the stable boundary layer
- Turbulent layers propagate both upwards and downwards
- Vertical extent of turbulent layers ranged from 1 – 45 m
- Majority of turbulent layers < 2 m deep
- Half of all turbulence existed as independent layers < 7 m deep
- Layers propagate vertically at a median speed of ±1.4 cm s^{-1}
- Turbulence within the ABL was generally initiated by shear, while above the ABL it was often buoyancy driven

5. Future Work

- Use high frequency T & U data to obtain more direct measurements of turbulence:
  - Temperature Structure Function Parameter (C_T^2)
  - TKE Dissipation (ε)
- Use spectral characteristics of 800Hz T & U data to confirm Ri-identified turbulent regions
- Investigate the processes responsible for the vertical propagation of turbulence within stable boundary layers
- Investigate the relationship between wind speed, ABL height, and turbulence

References

Sullivan, P. P., Weil, J. C., Patton, E. G., Jonker, H. J. J. and Mironov, D. V.: Turbulent winds and temperature fronts in large-eddy simulations of the stable atmospheric boundary layer, J. Atmos. Sci., 73, 1815–1840, doi:10.1175/JAS-D-15-0339.1, 2016.

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