Techniques for Sampling Morning Boundary Layer Transitions Using Rotary-Wing Unmanned Aircraft Systems

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11 July 2018
Diurnal Cycle
Morning Transition – Fluxes

Fig. 3 Schematic of processes that affect the thermal structure of the PBL. Under certain conditions, temperature advection can be assumed to be constant through the PBL

Bonin et al., 2012
Figure 1. Averaged plots of 10-m wind speed, 1.2-m screen temperature and 10-m sensible heat flux at Cardington. Screen temperature is measured relative to its daily minimum and all plots are normalised to their maximum values. The plots are taken from 30 days before and after June 21 over a period of 6 years. SR is sunrise, MT is the morning transition, FC is the transition to a fully convective boundary layer, ET is the evening transition and SS is sunset. U/UM is wind speed related to the gradient wind; TEMP is screen temperature; WT is the 10-m turbulent heat flux.

Lapworth, 2006
Fedorovich et al., 2004

Entrainment

GS case, total heat flux
\( t=10000 \) s

- OU
- WVU
- NCAR
- BUW
- ARPS
Objectives

1. Develop a rotary-wing UAS for vertical thermodynamic and kinematic profiling
2. Optimize sampling capabilities
3. Collect observations in the field, validate against references
OU CopterSonde

- Hashtag carbon fiber frame, octo-rotor design
- 4 Temperature, 4 RH sensors for redundancy
- Pressure from autopilot barometer, winds derived from Euler angles
- 6 cell, 20,000 mAh, 22.2 V LiPo batteries yield flight times of ~25 minutes
- Takeoff weight: 6 kg
- Post-processing kinematics differential GPS ⇒ centimeter positional accuracy
Consolidating Data Streams

- Custom-built control board for iMet-XF temperature and PT-100 RH sensors, connects to PixHawk autopilot via I²C protocol
- Allows for on board synchronization in the autopilot resulting in singular optimized data stream to ground station
Sensor Placement

- When underneath peaks in wind speed, temperatures closely match environmental
- Underneath motor mounts, significant temp rises: motor heat
- Near tips of propellers: compressional & frictional heating

**Conclusion: Sensor placement matters!**

PBL Transitions

- Flights at KAEFS
- September 2017 – April 2018
- Maximum altitude 2500 feet (760 m)
- Flights every 15-20 minutes
UAVs

Fig. 1 Photograph of the SMARTSonde, the radio controller, and the ground control station (GCS)

Diagram showing a 3D representation with axes labeled E, S, and Z₀ (Surface).
Flux Estimation Algorithm

From Deardorff et al., 1980:

\[
\overline{w'\theta'}(z) = \int_z^{h_a} \left( \frac{\partial \theta}{\partial t} + w \frac{\partial \theta}{\partial z} \right) dz \approx \int_z^{h_a} \frac{\partial \theta}{\partial t} dz
\]

\[
H(z) = c_p \rho w' \theta'(z) = c_p \sum_z^{h_a} \rho \frac{\Delta \theta}{\Delta t}(z)
\]

\[
F(z) = L_v \rho w' q'(z) = L_v \sum_z^{h_a} \rho \frac{\Delta q}{\Delta t}(z)
\]

Bonin et al., 2012
Bonin et al. 2012

Fig. 7  Same as Fig. 5, except for EET on February 18, 2011
Datasets

<table>
<thead>
<tr>
<th>Date</th>
<th># Profiles</th>
<th>Average Δt (min)</th>
<th>Weather Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>21 Sep 2017</td>
<td>12</td>
<td>21</td>
<td>Warm and dry, partly cloudy with moderate southerly winds.</td>
</tr>
<tr>
<td>18 Oct 2017</td>
<td>18</td>
<td>13</td>
<td>Sunny, dew in morning, residual LLJ. Strong mixing in transition.</td>
</tr>
<tr>
<td>11 Nov 2017</td>
<td>8</td>
<td>23</td>
<td>Mostly sunny, near freezing, and humid. Light winds allowed for sharp inversion which mixed out.</td>
</tr>
<tr>
<td>04 Apr 2018</td>
<td>6</td>
<td>19</td>
<td>Chilly, dry, breezy, cloudy. Southerly winds. Gradual increase in T and Td.</td>
</tr>
<tr>
<td>24 Apr 2018</td>
<td>12</td>
<td>16</td>
<td>Calm and clear transitioning to sunny with some cirrus with light winds.</td>
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Washington Mesonet Site, 24 April 2018

**T, T\_d**

**P**

**Wind**

**Solar**
Potential temperature

Residual Layer

Nocturnal Inversion

Well Mixed

Background | Objectives | System | Methods | Results | Fluxes | Conclusions
---|---|---|---|---|---|---
Mixing Ratio

Background

Objectives

System

Methods

Results

Fluxes

Conclusions

Residual Layer

Nocturnal Inversion

Well Mixed
Sensible heat fluxes
Latent heat fluxes

Specific Humidity 24 April 2018 WASH

Dew Evaporation

Background | Objectives | System | Methods | Results | Fluxes | Conclusions
Conclusions and Future Work

• CopterSonde development completed
  • New designs for future generations
• Much insight gained in regime of morning transitions
• Flux estimation reasonable under right conditions
• Will investigate further on days with appreciable advection
  • Compare with ground-based instruments – tower, lidar, eddy covariance
• Analysis of data from ISOBAR – wintertime arctic PBL

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Extra slides
20180424
First Profile
KAEFS – 18 October 2017

Figures created using MetPy: https://github.com/Unidata/MetPy
Potential Temperature

Potential Temperature 18 Oct 2017 WASH

Altitude AGL (m)

Time UTC

Potential Temperature (K)
Wind Speed and Direction

Wind Speed (kts) and Direction 18 Oct 2017 WASH

Altitude (m)

Time UTC

0 100 200 300 400 500 600 700