Mountain waves and energy harvesting for UAVs using a DWL

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Overview

• General objectives of research
  – Atmospheric energy targets

• Team
  – SWA, lead (Emmitt, Greco and Wood)
  – Earthly Dynamics (Costello, Ward and Rogers)
  – Aurora (Chtangeev)

• Overview of energy harvesting strategy

• Mountain wave example
Objectives

• Equip UAVs and small piloted aircraft with lidar enhanced avionics to optimize detection of atmospheric features that will extend flight endurance and enable extended periods of “quite” operations.

• Incorporate lidar observations into flight path planning and aircraft flight control algorithms (e.g. thermal climbs and mountain wave surfing).
<table>
<thead>
<tr>
<th>Phenomenology</th>
<th>Description (dimensions)</th>
<th>Nominal Magnitudes</th>
<th>Lifecycle Metrics</th>
<th>Remote Sensing Signatures</th>
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</thead>
<tbody>
<tr>
<td><strong>Thermals</strong> <em>(non-orographic)</em>; triggered by differential surface heating</td>
<td>Few 100 meters in diameter; vertical extent controlled by environmental structure</td>
<td>1–5 m/s</td>
<td>May last for large fraction of an hour; daytime features only</td>
<td>Convergence</td>
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<td>Optical depth</td>
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<td>Temperature</td>
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<td>Refractive turbulence</td>
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<tr>
<td><strong>Thermals</strong> <em>(slopes)</em>; driven by differential heating of sloped surfaces during direct solar illumination</td>
<td>100’s meter diameter; vertical extent limited by environmental structure</td>
<td>1–5 m/s</td>
<td>May last for hours during the daytime.</td>
<td>Convergence</td>
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<tr>
<td><strong>Organized Large Eddies</strong> <em>(OLEs)</em>; upward branch of a semi-closed vertical circulation within the PBL</td>
<td>A few 100 meters in diameter; vertical extent defined by depth of PBL; organized in lines allowing “next AA” to be more easily predicted than thermals</td>
<td>1–3 m/s</td>
<td>May last for hours but with much variation in strength; Not much known about night-time characteristics</td>
<td>Convergence</td>
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<td>Refractive turbulence</td>
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<td><strong>Obstacle flow</strong>; Strong horizontal flow deflected upward by orography and airmass collisions; (ridge soaring; frontal soaring)</td>
<td>Many miles in horizontal extent; vertical extent usually a few 100 meters above ridge line</td>
<td>1–10 m/s</td>
<td>May last for many hours and vary as the horizontal flow varies; Occurs at all hours of the day.</td>
<td>The obstacle</td>
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<td>Refractive turbulence</td>
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<tr>
<td><strong>Cloud updrafts</strong>; main targets are cloud base updrafts of non- or lightly precipitating cumuli.</td>
<td>Dimensions similar to thermals (a few 100’s of meters); vertical extent can be 1000’s of meters</td>
<td>1–5 m/s depending upon atmospheric stability.</td>
<td>A few minutes, maximum duration ~ 10 minutes.</td>
<td>The cloud</td>
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<td>Precipitation</td>
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<td><strong>Mountain Waves</strong></td>
<td>Horizontal extent of many km; Vertical extent of 10’s of km possible</td>
<td>Up to 10 m/s vertical velocities distributed in bands downwind of ridge line.</td>
<td>May last for hours throughout entire diurnal cycle</td>
<td>Vertical motions; visual wave clouds on occasion.</td>
</tr>
<tr>
<td><strong>Gravity waves</strong> on density interface</td>
<td>Horizontal extent of many kms (50 – 500); Vertical extent of 5 – 10 km</td>
<td>1–3 m/s</td>
<td>1–3 hours</td>
<td>Vertical motions Inversions</td>
</tr>
<tr>
<td><strong>Shear layers</strong></td>
<td>Horizontal extent of many kms defined by surface topography and atmospheric structures; vertical extent a few 100 meters</td>
<td>10–25 m/s with a maximum near 100 - 300 meters.</td>
<td>May persist for several days lasting through the nighttime</td>
<td>Horizontal wind speed; Optical depths</td>
</tr>
</tbody>
</table>

= features studied with airborne Doppler wind lidar

Source: SWA (Emmitt)
AMPT detailed
AEORA Mission Planning Tool

- Mission Objectives
- Mission Constraints
- WRF Model
  - BCs
  - Terrain
  - Model Output
- 3D WINDS Model
- Aerosols?
- Sensor Energy Target detection models
- UAS Specifications
- FTIG Update
  - Aircraft Location
  - Aircraft elevation
  - Fuel Level
  - (Each Simulation Cycle)
- Initial Segmented path

AMPT serves as the pre-launch mission planning tool using simulation with inputs from the FTIG regarding UAS performance. Post-launch, the AMPT would be used to update the PDFs and gridded wind fields. SWA patents on AEORA)
Case Study
Weather Research Forecast (WRF) Model

- Three or four nested grid configuration
  - Grid 1 with 9 km res. (540 km x 540 km domain)
  - Grid 2 with 3 km res. (210 km x 210 km domain)
  - Grid 3 with 1 km res. Up to 90 km x 90 km domain
  - Grid 4 with 333 m res. over 35 km x 35 km domain

- 42 terrain-following vertical levels
- 200mb Model top
- NAM Analysis used as boundary conditions
Weather Research Forecast (WRF) Model

- WRF V3.4
- LES options
- Lin Microphysics
- Surface layer physics based on M-O
- Surface physics – Noah Land Surface Model
- Mellor-Yamada Janjic scheme for BL Physics
- Betts-Miller Cum. Parameterization Scheme
- W-damping turned on
WRF Domains 2 (3 km res.) and 3 (1 km res) for 10/04/2012 20Z
WRF Domain 3 Terrain (m) along E-W Points Chosen to Match Lidar Transect

Twin Otter flown at 4100 meters
WRF Domain 3 Level 27 Vertical Motion and Terrain
WRF Domain 3 Level 27 Vertical Motion and Terrain - Zoom
WRF Domain 3 Level 27 Z-X Vertical Motion Along Lidar Transect
WRF Domain 3 Level 27 Wind Speed and Terrain
WRF Wind Field

- WRF data from a single instant in simulation time of a 35km x 35km grid using SWA’s version of the WRF
- Simulation results presented here focus on the mountain wave circled below
Lift Line Controller

• Comparing Trajectories using Thermal Centering and Lift Line Controller flying Mountain Wave in WRF simulated wind field
Summary

• The WRF model shows strong Ruby Mountain induced waves with amplitudes of +_ 6m/s and wave lengths on the order of 8 -10 km.

• The TODWL sampling in the nadir mode (vertical speed only) reveals two sets of waves: one with amplitude of +/- 5-6 m/s and wavelength of 4-5 km and a second set of energetic features on the leeward side, closer to the ground with amplitude of +/- 6m/s and wavelengths of ~ 1 km.
Extra Slides
DOMAIN 1
DOMAIN 2
DOMAIN 3