Mixed layer height measurements from Doppler lidar using a composite method

T. A. Bonin$^{1,2}$, B. J. Carroll$^3$, R. M. Hardesty$^{1,2}$, W. A. Brewer$^2$

$^1$Cooperative Institute for Research in Environmental Sciences
$^2$National Oceanic and Atmospheric Administration, Chemical Sciences Division
$^3$Joint Center for Earth Systems Technology/Univ. of Maryland Baltimore County
INFLUX Doppler lidar deployment

- Halo Streamline lidar deployed on roof of Ivy Tech Building (4 stories above ground) in Aug 2013 until June 2015
- Lidar was upgraded at the end of 2015, and Halo Streamline XR was redeployed at same location in January 2016 to present
- Motivation: Measuring greenhouse gas emissions from city
  - Need wind profile and MH
Motivation for composite fuzzy-logic technique

- Backscatter alone is not always sufficient to determine mixing height, especially when residual layer is present.
- Variance alone may lead to a high determination of the mixing height, especially when non-turbulent wavelike motions are present.
- Need to use information from multiple scans to overcome minimum range issues.
<table>
<thead>
<tr>
<th>Day:</th>
<th>Night:</th>
</tr>
</thead>
<tbody>
<tr>
<td>3°</td>
<td>3°</td>
</tr>
<tr>
<td>10°</td>
<td>10°</td>
</tr>
<tr>
<td>35°</td>
<td>35°</td>
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<tr>
<td>60°</td>
<td>60°</td>
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<tr>
<td>PPI</td>
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</table>

**Scanning strategy for INFLUX**

**20 minute repeating cycle**

<table>
<thead>
<tr>
<th>Vertical Stare</th>
<th>Vertical Stare</th>
</tr>
</thead>
<tbody>
<tr>
<td>S/E 20° EL Stares</td>
<td>Vertical Stare</td>
</tr>
</tbody>
</table>

**Key Variables:** $u, v, \sigma_{vr}^2, \text{TKE}$

<table>
<thead>
<tr>
<th>$\sigma_u^2, \sigma_v^2$</th>
<th>$\sigma_u^2, \sigma_v^2, \text{SNR, } \sigma_{SNR}^2$</th>
<th>$\sigma_w^2, \text{SNR, } \sigma_{SNR}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 m – PBL top</td>
<td>0 – 200 m</td>
<td>60 m – $\approx$1000 m</td>
</tr>
</tbody>
</table>

**Images:**
- S/N images with color scales indicating intensity.
- Data plots showing height versus range with annotations and measurements.
MLH Detection Overview

1) Detect gravity waves and other non-turbulent sub-meso motions

Use relation between HF $w'^2$ ($T<1$ min, $f>0.017$ Hz) to total $w'^2$ to differentiate turbulent and non-turbulent motions
MLH Detection Overview

1) Detect gravity waves and other non-turbulent sub-meso motions

2) Combine data from all useful scans using fuzzy logic:
   - $\sigma_{vr}^2$ from each VAD scan
   - $\sigma_u^2, \sigma_v^2$ from shallow stares
   - $\sigma_u^2, \sigma_v^2$ from RHI scans
   - $\sigma_w^2$ from vertical stares

3) Identify a first guess for the top of the mixed layer ($z_{fg}$) based on fuzzy aggregation

4) Fuzzify proxies for mixing if it is near $z_{fg}$
   - Peaks in wind shear
   - Large variance or gradients in SNR

5) Determine final estimate for top of mixed layer

6) Flag the final estimate:
   - Is it raining?
   - Can we see the top of the ML?
   - Is the ML cloud-topped?
   - Is ML below minimum height?

$\sigma_w^2 \text{[m}^2 \text{s}^{-2}]$

$\sigma_u^2 + \sigma_v^2 \text{[m}^2 \text{s}^{-2}]$

$10^\circ$ VAD $\sigma_{vr}^2 \text{[m}^2 \text{s}^{-2}]$
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3) Identify a first guess for the top of the mixed layer ($z_{i_{fg}}$) based on fuzzy aggregation

![Chart showing fuzzy logic multi-method PBL membership with a first guess for PBL height]
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5) Determine final estimate for top of mixed layer & uncertainty
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Verification of MLH with aircraft observations 5/13/16 in Indianapolis

We thank Paul Shepson, Olivia Salmon, and the entire Atmospheric Chemistry group Purdue University for taking profiles over the lidar site and providing the independent observations for comparison.
Annual Variation of MLH

2016 Month

2017 Month
Normalized Diurnal variability in MLH in Indianapolis

Morning transition

Evening transition
MLH evolution depends on mean wind speed

Morning transition

Evening transition
A composite fuzzy logic algorithm has been developed and applied to different Doppler lidar systems to continuously detect the MLH at high temporal resolution (15-20 min)

- Uses inputs of velocity variances (turbulence), backscatter intensity, and wind profiles from all scans
- Gravity waves and other non-turbulent motions are identified and flagged for exclusion from analysis

We have applied this algorithm to other Doppler lidars at in different locations (Oregon, California, Las Vegas, Alaska)

- Algorithm adjusts to use whatever data it can get; do not need the scanning pattern discussed here

Ongoing efforts to validate MHs through intercomparison with other instruments and NWP output