Deployment and Operational Status of the New ARM Lidars
Current ARM Lidar Inventory

- Raman (water vapor, aerosol backscatter, optical depth, temperature)
  - SGP
  - TWP-Darwin

- HSRL (aerosol backscatter, optical depth)
  - AMF2 (currently in Steamboat Springs)
  - NSA-Barrow

- Doppler (winds, aerosol attenuated backscatter)
  - SGP
  - TWP-Darwin
  - AMF1 (awaiting deployment to India)

- MPLs and Ceilometers at most sites
Ceilometer Update

- New ceilometers (Vaisala CL31) deployed at SGP/C1, NSA/C1, TWP/C1, TWP/C2, AMF1, AMF2

- All new ceilometers deployed and data available at ARM Archive before end of FY2010

- New ceilometers configured to improve detection of aerosol and mixing layers

- New boundary-layer cloud height algorithm not yet implemented
MPL Update?
Doppler Lidars
Doppler Lidar

• October 2010:
  – Three systems shipped from Halo Photonics to SGP for acceptance testing
    • SGPDL – The SGP Doppler lidar
    • TWPDL – The TWP-Darwin Doppler lidar
    • AMFDL – The AMF1 Doppler lidar
  – Thorough acceptance testing performed
    • Side-by-side intercomparisons
# Doppler Lidar Specifications

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Halo Photonics (UK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>85 kg</td>
</tr>
<tr>
<td>Aperture Diameter</td>
<td>75 mm</td>
</tr>
<tr>
<td>Pulse width</td>
<td>150 ns (22.5 m)</td>
</tr>
<tr>
<td>Pulse Energy</td>
<td>100 µJ</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1.5 µm</td>
</tr>
<tr>
<td>Pulse rate</td>
<td>15 kHz</td>
</tr>
<tr>
<td>Minimum range</td>
<td>75m (Typical value)</td>
</tr>
<tr>
<td>Range for data collection</td>
<td>Standard: 0.06-10km</td>
</tr>
<tr>
<td>Receiver bandwidth</td>
<td>± 15ms-1</td>
</tr>
<tr>
<td>Eye-safety</td>
<td>Class 1M</td>
</tr>
<tr>
<td>Range gate length</td>
<td>20-50m</td>
</tr>
<tr>
<td>Scanner</td>
<td>Fully programmable, two axis, step-stare scanner</td>
</tr>
<tr>
<td>Enclosure</td>
<td>Portable, rugged, sealed system with active and passive cooling</td>
</tr>
</tbody>
</table>

Uses heterodyne detection to measure Doppler shift of return. Sensitive to aerosol scattering, insensitive to molecular scattering, insensitive to solar.
Side-by-Side Intercomparisons

**AMFDL vs TWPDL**
- Period: 19 October 19:40 UTC to 20 October 2010 16:10 UTC.
- Location: Approximately 50 feet NW of RCF (next to fence).

**SGPDL vs TWPDL**
- Period: 18 October 21:40 UTC to 19 October 2010 17:30 UTC.
- Location: On the deck behind the GIF.

**AMFDL vs TWPDL**
- Period: 19 October 19:40 UTC to 20 October 2010 16:10 UTC.
- Location: Approximately 50 feet NW of RCF (next to fence).
Operating Modes

During the intercomparison periods the three lidar systems were configured as follows:

- Number of samples per gate = 10
- Number of range gates = 320
- Number of pulses averaged = 15000
- Points in FFT = 1024
- Vertical staring

The range resolution, or gate size, is determined by setting the number of the samples per range gate. Atmospheric returns are sampled at 50 MHz, which translates into 3 m between samples. The parameters listed above imply a gate size, or range resolution of 30 m, and a maximum measurement range of 9600 m. The pulse repetition frequency of the lidar is 15 kHz, so averaging 15000 pulses results in a temporal resolution of about 1 second. All intercomparisons were performed with the systems staring vertically. Thus, radial and vertical velocities are one and the same.
SGPDL vs TWPDL
22 UTC 18 October to 17 UTC 19 October 2010
This time gap is caused when the system acquires background data. This data is used to flatten the Doppler spectrum noise floor. Background data is taken automatically once per hour.
SGPDL vs TWPDL
22-23 UTC, 18 October 2010
Difference (top); bias (bottom left); RMS deviation (bottom middle); correlation (bottom right)

Mean difference or Bias (black)
Mean TWPDL
Mean SGPDL
Positive bias @ low signal levels
Velocity precision < 10 cm s⁻¹
SGPDL vs TWPDL
02-03 UTC, 19 October 2010
Vertical Velocity (left); Signal Intensity (right)

Strong but brief thunderstorm with heavy precipitation
SGPDL vs TWPDL

02-03 UTC, 19 October 2010

Difference (top); bias (bottom left); RMS deviation (bottom middle); correlation (bottom right)

Strong but brief thunderstorm with heavy precipitation
SGPDL vs TWPDL

11-12 UTC, 19 October 2010

Vertical Velocity (left); Signal Intensity (right)

twpdIC3 vs sgpdIC1, date_hour: 20101019_11
SGPDL vs TWPDL
11-12 UTC, 19 October 2010
Difference (top); bias (bottom left); RMS deviation (bottom middle); correlation (bottom right)
AMFDL vs TWPDL
20 UTC 19 October to 16 UTC 20 October 2010
AMFDL vs TWPDL
21-22 UTC, 19 October 2010
Vertical Velocity (left); Signal Intensity (right)

twpdIC3 vs sgpdIS01, date_hour: 20101019_21
AMFDL vs TWPDL
21-22 UTC, 19 October 2010

Difference (top); bias (bottom left); RMS deviation (bottom middle); correlation (bottom right)
AMFDL vs TWPDL
12-13 UTC, 20 October 2010
Vertical Velocity (left); Signal Intensity (right)

twpdIC3 vs sgpdIS01, date_hour: 20101020_12
AMFDL vs TWPDL
12-13 UTC, 20 October 2010
Difference (top); bias (bottom left); RMS deviation (bottom middle); correlation (bottom right)
Velocity Precision vs Signal-to-Noise Ratio (SNR)

- Velocity precision = standard deviation of the measurement noise

- Two methods were used to estimate velocity precision as a function of SNR
  - Method 1: Estimate velocity precision versus SNR by comparing measurements from two lidars
  - Method 2: Estimate velocity precision versus SNR from a single lidar using the autocovariance function.
Velocity Precision Estimates

- Two methods give very comparable results
- All three lidars show very similar behavior
- Velocity precision is better than 10 cm s\(^{-1}\) at high SNR.
- Saturation occurs at low SNR due to finite bandwidth (Nyquist velocity \(\sim 19.5\) m/s). This is typical for Doppler lidars.
DL side-by-side intercomparisons: Conclusions

• All three lidars produce very consistent measurements. Correlation coefficients between lidar measurements exceed 0.9 within the atmospheric boundary layer under convective conditions. Correlation coefficients decrease as vertical velocity fluctuations decrease, e.g. under stably stratified conditions.

• Velocity precision:
  • <10 cm s\(^{-1}\) at high SNR
  • < 20 cm s\(^{-1}\) within the atmospheric boundary layer (below ~2km)
  • Indicates < 50 cm s\(^{-1}\) for clouds between 2-5 km in altitude

• Velocity Bias:
  • All three systems show a positive bias in velocity at low SNR. The magnitude of this bias appears to be system dependent, and can exceed 1.0 m s\(^{-1}\).
  • AMFDL (a.k.a SGPDLS01 in this study) shows a negative bias in velocity at high signal levels. It is possible, however, that this bias may have been caused by improper leveling of the lidar. This is currently under investigation.
SGPDL

- Operated from the GIF deck from 15 October to ~20 December 2010
- November 2010: Dual-Doppler measurements conducted with AMFDL
- Initially operated without a problem, and exhibited good range performance
- Problems with instrument computer freezing up
  - Problems start in November, and become much more frequent in December
  - System moved indoors prior to Christmas for trouble shooting
  - Trouble shooting efforts from Jan-Feb 2011
    - New power supplies purchased and tested – didn’t solve problem
    - File system, HDD, and virus scans – didn’t solve problem
    - Registries cleaned – didn’t solve the problem
    - Shipped back to Halo for repair at the end of February
      - Vendor replaces instrument computer, and problem goes away
      - System is being shipped back this week
    - System should be back in operation by mid-April
- April 2011: Will be deployed next to new location of the 915 MHz radar wind profiler (and also very close to the MMCR and SWACR)
• 18 October to 30 November 2010:
  – Operated next to fence line just to the NW of RCF at SGP
  – Performed coordinated dual-Doppler scans with the SGPDL
  – System performed well while at SGP

• Early December 2010:
  – System shipped to AMF1 staging facility in Pagosa Springs, CO
  – Currently awaiting deployment to India
TWPDL Deployment

• October/November 2010
  – Shipped from SGP to TWP-Darwin
  – Arrived in Darwin in mid-November 2010

• Early December 2010
  – System installed on top of ‘D’ Van at Darwin facility (next to MMCR) by Dave Turner, and others…
  – Data flow to DMF initiated ~ 13 December
TWPDL Issues

• Range performance was slightly disappointing
  – Probably due to shallow boundary layer and very clean free troposphere
  – Focus adjusted improved near range performance
  – Configuration adjusted to 2 second averages, 48 m range bin

• Internal humidity has been gradually increasing inside the box since January
  – May replace entire with new unit that has a valve dry-air purge retrofit
# Data Lidar Datastreams

<table>
<thead>
<tr>
<th>Datastream Name (specific to Darwin)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>twpdlC3.00</td>
<td>Raw Data (prior to ingest)</td>
</tr>
<tr>
<td>twpdlfptC3.a0</td>
<td>Fixed beam stare (Vertical or slant path)</td>
</tr>
<tr>
<td>twpdlrhiC3.a0</td>
<td>Single pass, 180° RHI scan</td>
</tr>
<tr>
<td>twpdlrhi2C3.a0</td>
<td>Single or multi-pass, limited sector RHI scan</td>
</tr>
<tr>
<td>twpdlppiC3.a0</td>
<td>Single pass, 360° PPI scan</td>
</tr>
<tr>
<td>twpdlppi2C3.a0</td>
<td>Single or multi-pass, limited sector PPI scan</td>
</tr>
<tr>
<td>twpdlusrC3.a0</td>
<td>User defined scan, could be anything</td>
</tr>
<tr>
<td>twpdlcal1C3.a0</td>
<td>Near horizontal stare for backscatter calibration</td>
</tr>
<tr>
<td>twpdlcal2C3.a0</td>
<td>Hard target scans used for azimuth calibration</td>
</tr>
</tbody>
</table>
Doppler Lidar VAPs

• Azimuth angle calibration (done but not operationally implemented)
• Horizontal wind profiles (done but not operationally implemented)
• Vertical velocity statistics (not started)
  – Variance, skewness, kurtosis
  – Mixing layer heights
  – CBH
Raman Lidars

Darwin, AU

Oklahoma, US
Raman Lidars

• ARM now has two Raman Lidars
  – SGP, SGPRRL (aka CARL)
  – TWP-Darwin, TWPRRL (aka DARL)
• Essentially identical designs (TWPRRL doesn’t have a liquid water channel)
  – 355 nm, 300 mJ, 30 Hz
  – Two FOVs (WFOV and NFOV)
  – 9 detection channels (10 for the SGPRRL)
    • 3 Elastic, 355 nm (WFOV unpolarized, NFOV copol and depol)
    • 2 Nitrogen, 387 nm, (WFOV and NFOV)
    • 2 Water, 408 nm, (WFOV and NFOV)
    • 2 Rotational Raman (NFOV only)
      o 353 nm
      o 354 nm
TWPRL (aka DARL)

- Installed in Darwin in December by John Goldsmith and Dave Turner
- Data flow to DMF initiated ~15 December
- Initial results look really good
- A few relatively minor issues
  - “CPU creep” caused periodic computer crashes. Problem was fixed in February
  - Mode 0 data corrupted during last few days of February due to malfunction with the “flippers”. This issue has been resolved.
  - Background light contamination in WFOV mode 0 signals. Cardboard installed in late February improved the shielding.
  - Truncated header lines in raw data cause ingest at DMF to crash. Revised ingest code is being implemented.
  - As of 24 March the system has been down since March 7 when a high-voltage power supply in the laser failed. Replacement has been ordered and should be installed soon.
Results from TWPRL

Raman lidar moisture data
31 Dec 2010

RL VAPS were modified to accommodate new site
Results from TWPRL

Raman lidar moisture data
26 Jan 2011

Mixing ratio

Relative humidity

No Temperature Data Available

Temp from brpwind3rps03.a1
Created on: 11 Feb 2011
SGPRL Recent History

• The SGPRL has experienced a gradual loss in sensitivity over the past couple of years
• Primary culprit is optical damage in the laser beam expander
• In January 2011 an initial attempt was made at replacing the beam expander
  – Met with limited success
  – Sensitivity initially increased by 2x. But then …
  – Sensitivity rapidly degraded again
  – Aperture of the replacement expander was too small. Ablation of material from the edge of the aperture caused optical damage.
  – A new beam expander with a larger aperture was ordered
SGPRL Upgrade

- Implemented by John Goldsmith and Chris Martin in early March 2011.
- Replaced laser heads and power supplies. Laser system installed and tested by Continuum tech.
- Control PC completely reworked
  - Replaced HDD
  - Added additional RAM
  - Replaced CD-RW with a DVD-RW
  - Upgraded OS from Windows 2000 to Windows XP
  - Upgraded to LabVIEW 2010. So the SGPRL now uses exact same Labview code as the TWPRL.
- Installed new "flippers" to block the signals to record backgrounds (previously done using old filter wheel).
- Replaced the input lens assembly in the laser-beam-expanding telescope with an assembly that has a larger input aperture
- Modified the altitude range used for the boresite controller (brought it closer to the ground, which is working well in Darwin)
Before and After SGPRL Upgrade

Raman lidar moisture data
22 Feb 2011

Raman lidar moisture data
11 Mar 2011

Relative humidity

Mixing ratio

km AGL

hour of day (UTC)

0.01 0.10 1.50 10.00

0 10 20 30 40 50 60 70 80

Relative humidity (%)
SGPRL vs TWPRL

Raman lidar moisture data
11 Mar 2011

SGPRL

TWPRL

Relative humidity

13 min data
Created on 25 Mar 2011

Raman lidar moisture data
31 Dec 2010

Relative humidity

13 min data
Created on 11 Feb 2011
High Spectral Resolution Lidars (HSRL)
HSRL Deployments

• AMFHSRL
  – Deployed to Steamboat Springs in January 2011
  – Data “flowing” to DMF on 21 January 2011

• NSAHSRL
  – Deployed to NSA-Barrow on ~18 March 2011
  – Data “flowing” to the DMF on 20 March (just in the nick of time)
HSRL Issues

• Laser Issues
  – Vendor (Photonics) supplied lasers didn’t meet specs
    • Seed laser problems
    • Servo loop problems
  – Resulted in significant delays in the development of the lidar system
  – Inadequate testing prior to shipping to Barrow in order to meet milestone deadline (31 March)

• Integration of the existing HSRL data processing system into the DMF
Standard ARM Data Flow

On-site Instrument computer

DMF at PNNL
- Raw data ingest
- Raw data processing (VAPs)
  - Mentor sets VAP configurations

Archive at ONR
### HSRL Data Flow

#### ARM Site
HSRL Instrument Computer
- Creates and maintains netCDF raw data files
- Pushes netCDF raw data to server

#### Univ. Wisc. SSEC
**HSRL Server**
- Raw data archival and processing
- “c1-level” data products
- Retrieves NWS sonde data from the web
- Web-based “on-demand” data processing

#### Issues
- This is an unacceptable long term solution
- **Issues**
  - Server function should be handled within the DMF
  - Data should only be accessible through the ARM web site
  - Limited control over instrument-to-server communications
  - Server should use internal ARM sonde or AERI data
Possible HSRL Data Flow

ARM Site

- HSRL Instrument Computer
  - Creates and maintains netCDF raw data files
  - Pushes netCDF raw data to server

On site Server
- Raw data processing
- “c1-level” data products
- Retrieves NWS sonde data from the web
- Web-based “on-demand” data processing

Internet

PPNLM DMF

• Issues
  - On-site server should not be pulling in external data
  - Reprocessing would require pushing raw data back to the on-site server (unless the server archives ALL raw data)
  - Big problem with “on-demand” processing
Another Possibility

**ARM Site**
- **HSRL Instrument Computer**
  - Creates and maintains netCDF raw data files
  - Pushes netCDF raw data to server
- **On site Server**
  - Only receives raw data from instrument computer
  - Doesn't do anything else

**PNNL DMF**
- **HSRL Server**
  - Raw data processing
  - “c1-level” data products
  - Retrieves temp/pres data from the other ARM datastreams
  - Web-based “on-demand” data processing
On site Server
• Only receives raw data from instrument computer
• Doesn’t do anything else

ARM Site

HSRL Instrument Computer
• Creates and maintains netCDF raw data files
• Pushes netCDF raw data to server

PNNL DMF

HSRL Server
• Raw data processing
• “c1-level” data products
• Retrieves temp/pres data from the other ARM data streams
• Web-based “on-demand” data processing
HSRL web-based on demand data processing

- Allows external users to select
  - Resolution
  - Quality control
  - Variables to output
  - netCDF output

Would like to implement something similar for the Raman lidar in order to get rid of the plethora of datastreams.
HSRL On-demand Processing

• HSRL user community has gotten accustomed to the Univ. Wisc. ‘on-demand’ processing capability.

• Direct access to ARM data on the Univ Wisc. server will be disabled.

• ARM should offer something similar.
Questions?
Concerns?
Issues?