Observing boundary layer properties with Doppler lidar for mass-balance estimates of greenhouse gas emissions

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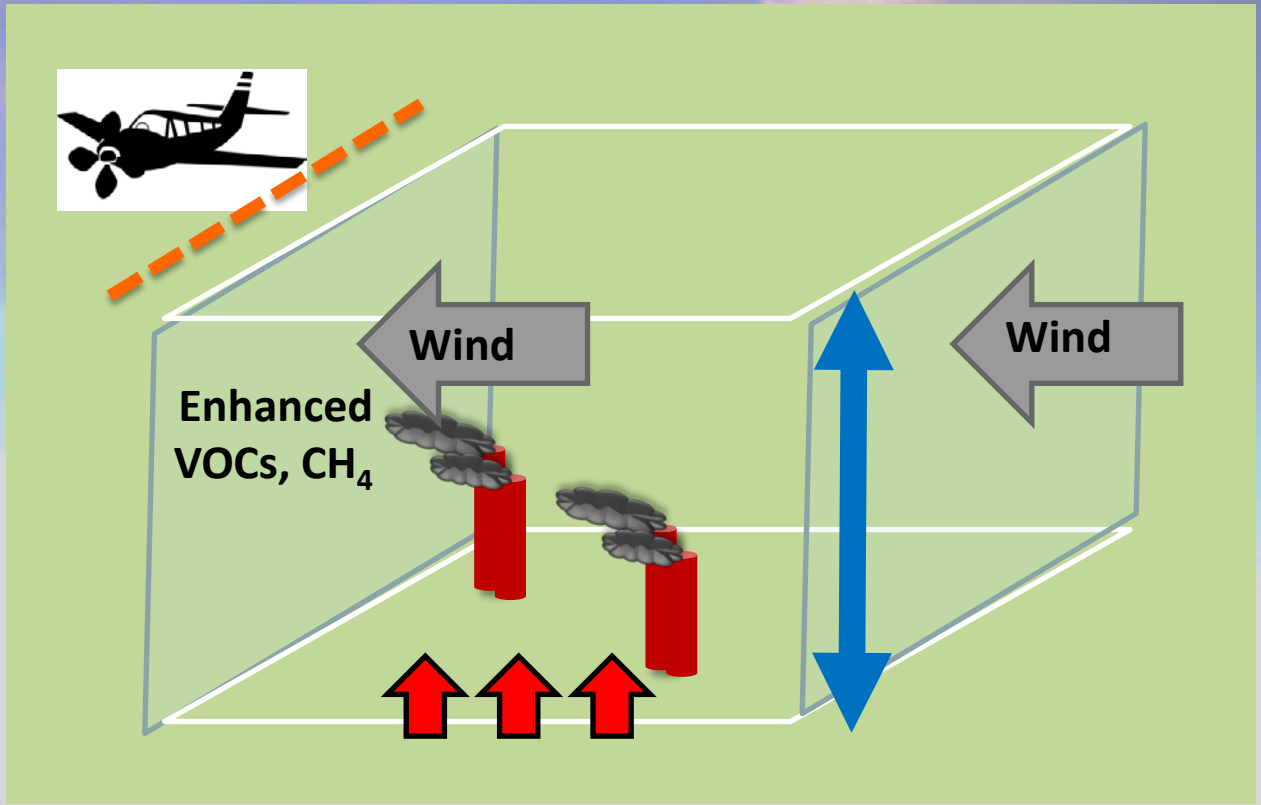
GMD Annual Meeting

22 May 2013

Mass-balance estimates of emissions: what boundary layer properties do we need to know?

Daily flight planning

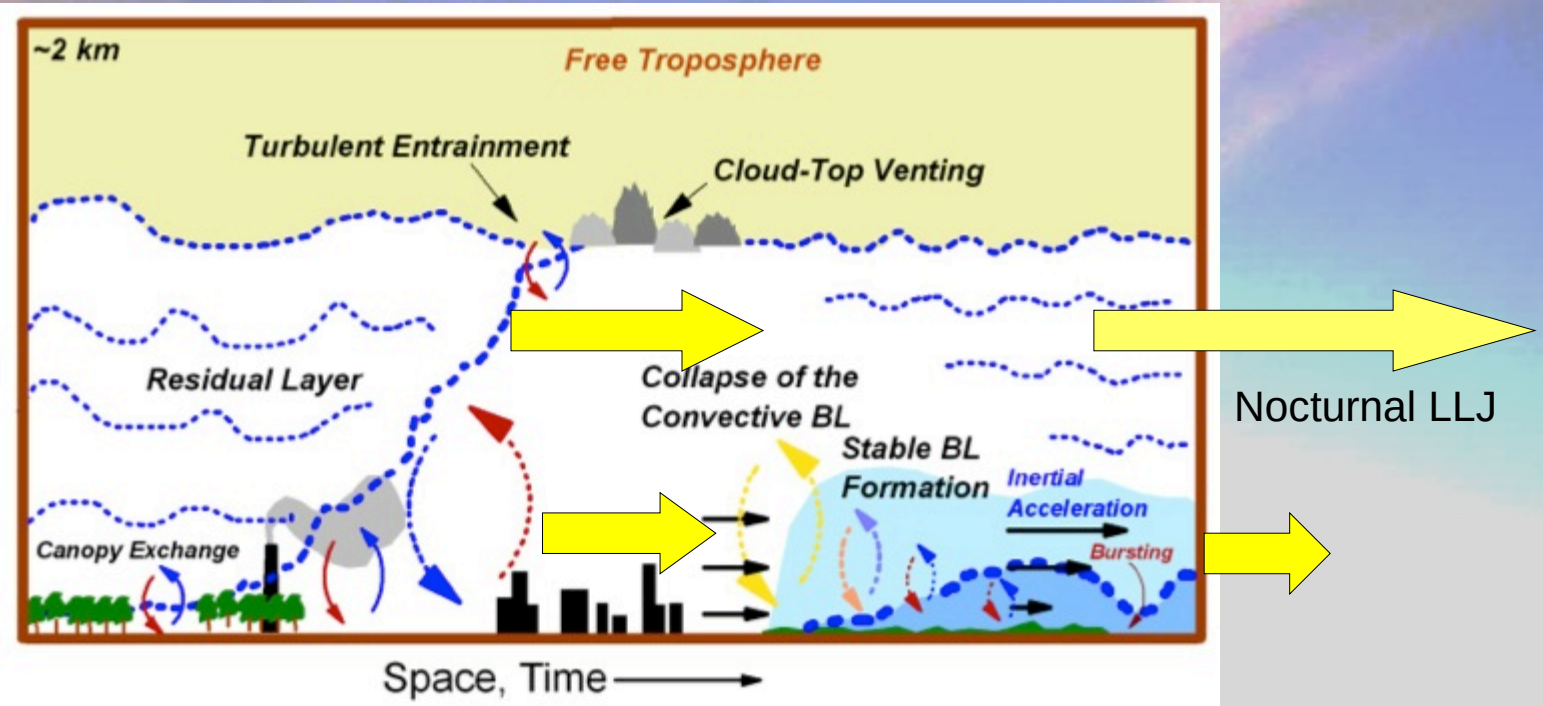
- Wind speed/direction
- Mixing layer depth



Computing emissions

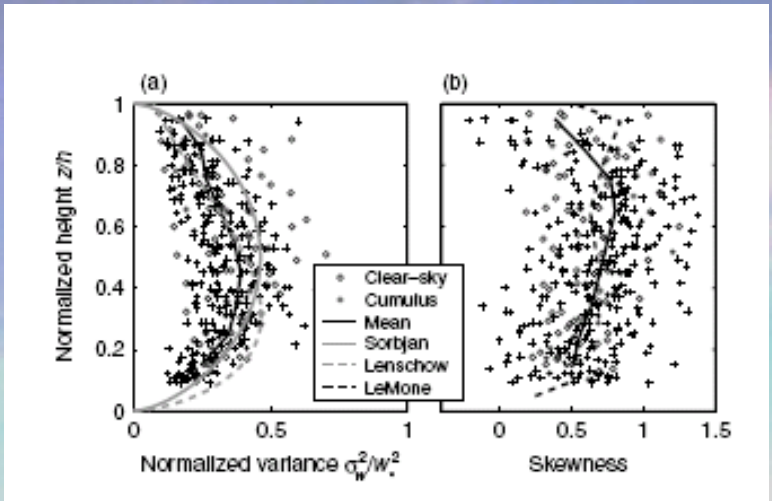
- Time history of the wind speed and direction
- Evolution of the mixing layer
- Presence of a residual layer

Mass-balance estimates and evolution of the boundary layer

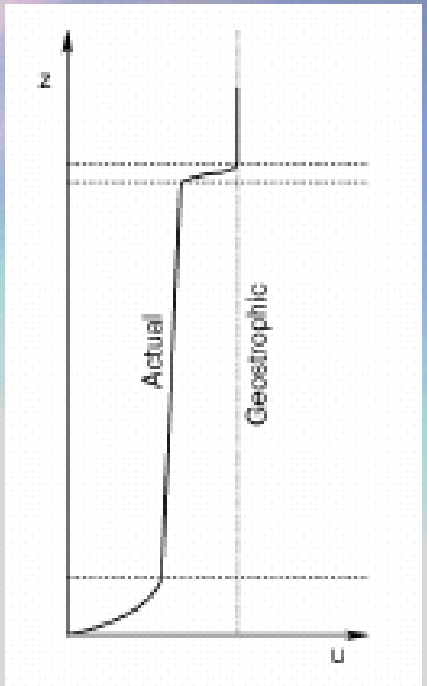


- Mixing layer depth is well-defined during morning and early afternoon as boundary layer grows and heating is maintained
- During middle to late afternoon heating diminishes and depth becomes more difficult as residual layers form
- Probably best to fly around mid-day

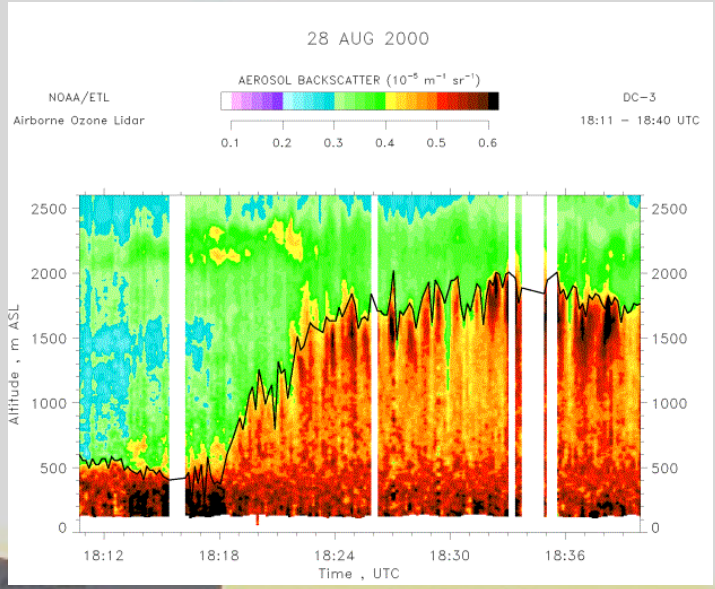
Doppler lidar sensing of mixing layer height



Vertical Velocity Variance
(Hogan et al, JAS)

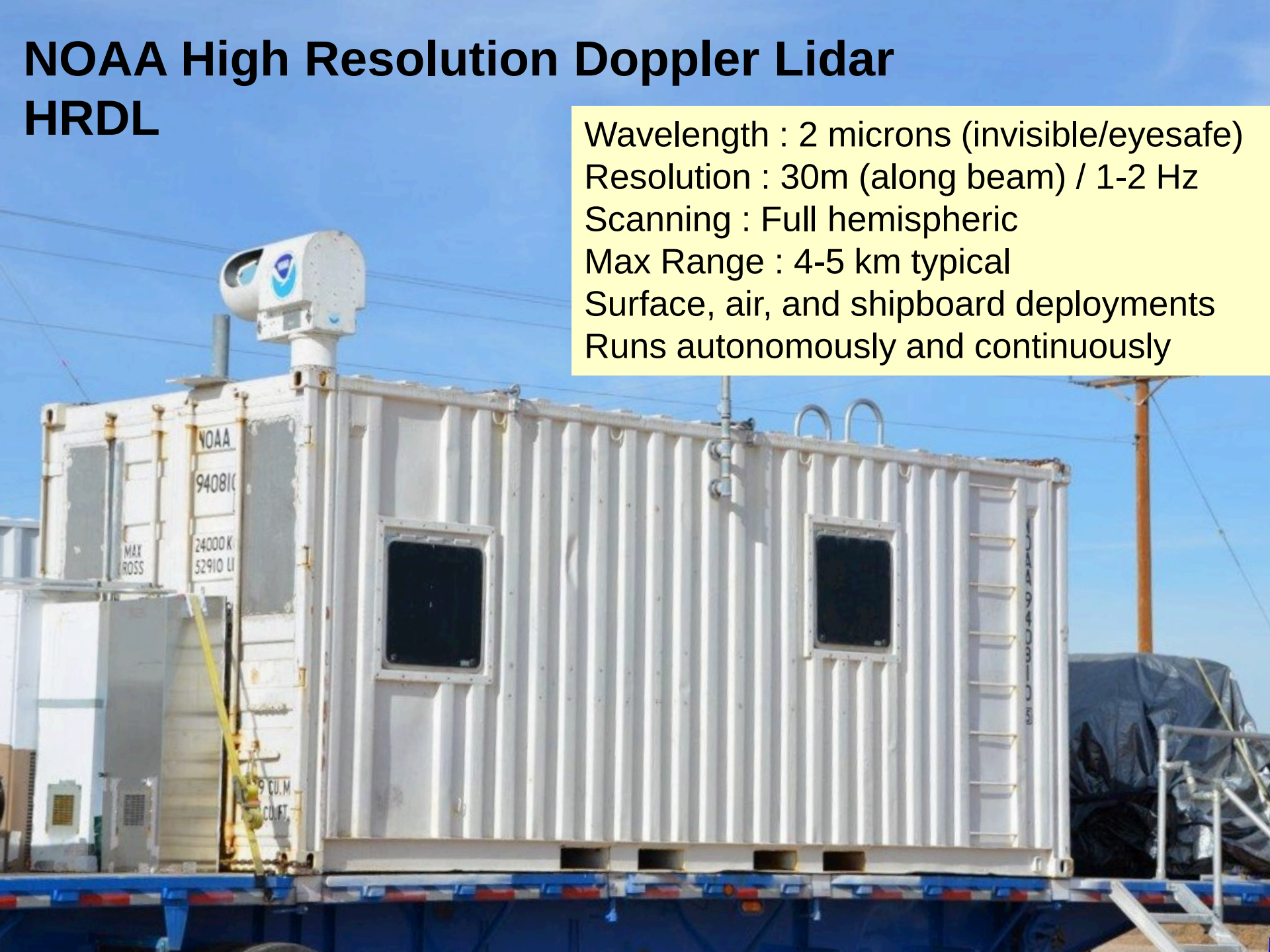


Horizontal wind profile



Aerosol structure

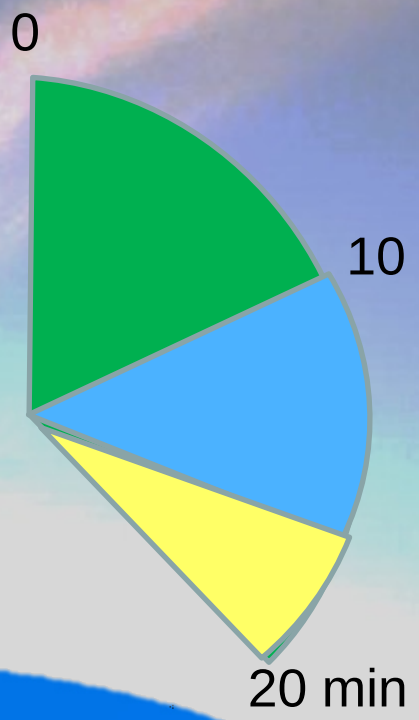
NOAA High Resolution Doppler Lidar
HRDL

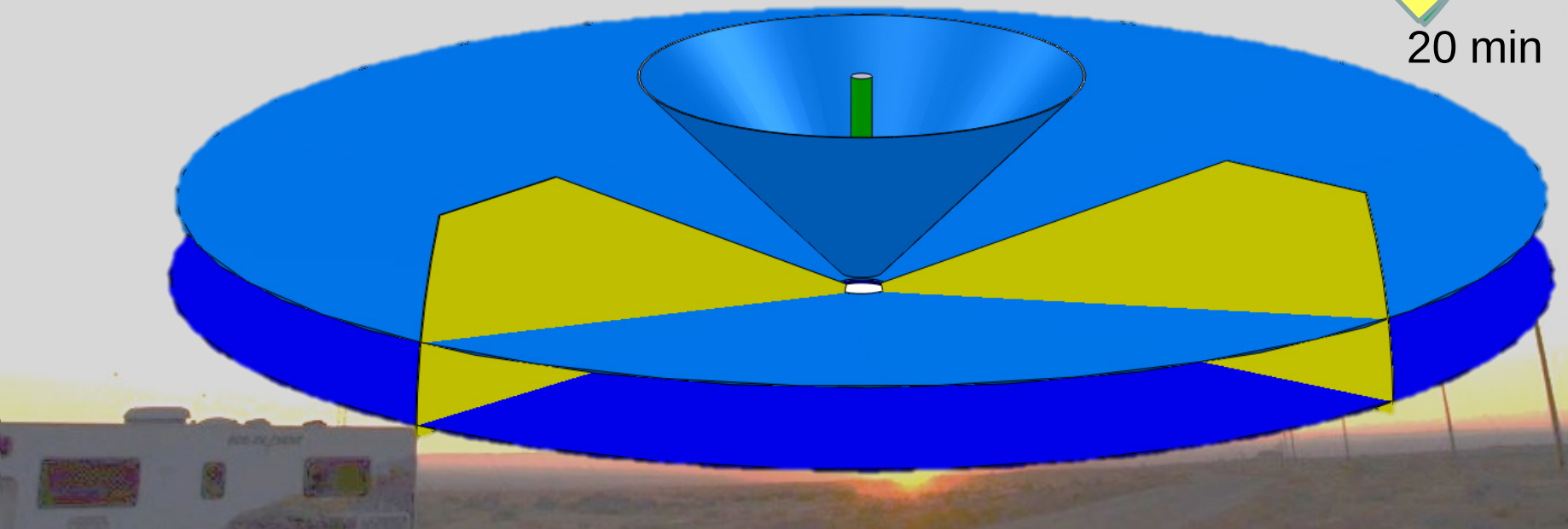


Wavelength : 2 microns (invisible/eyesafe)
Resolution : 30m (along beam) / 1-2 Hz
Scanning : Full hemispheric
Max Range : 4-5 km typical
Surface, air, and shipboard deployments
Runs autonomously and continuously

Scanning for boundary layer characterization

- Scan sequence repeats every 20 minutes
- Combination of scans and staring
  - -vertical stare (10 minutes)
  - -conical scans: 2°,4°, 25°, 45° (7 minutes)
  - -vertical scans: 2 orthogonal (3 minutes)

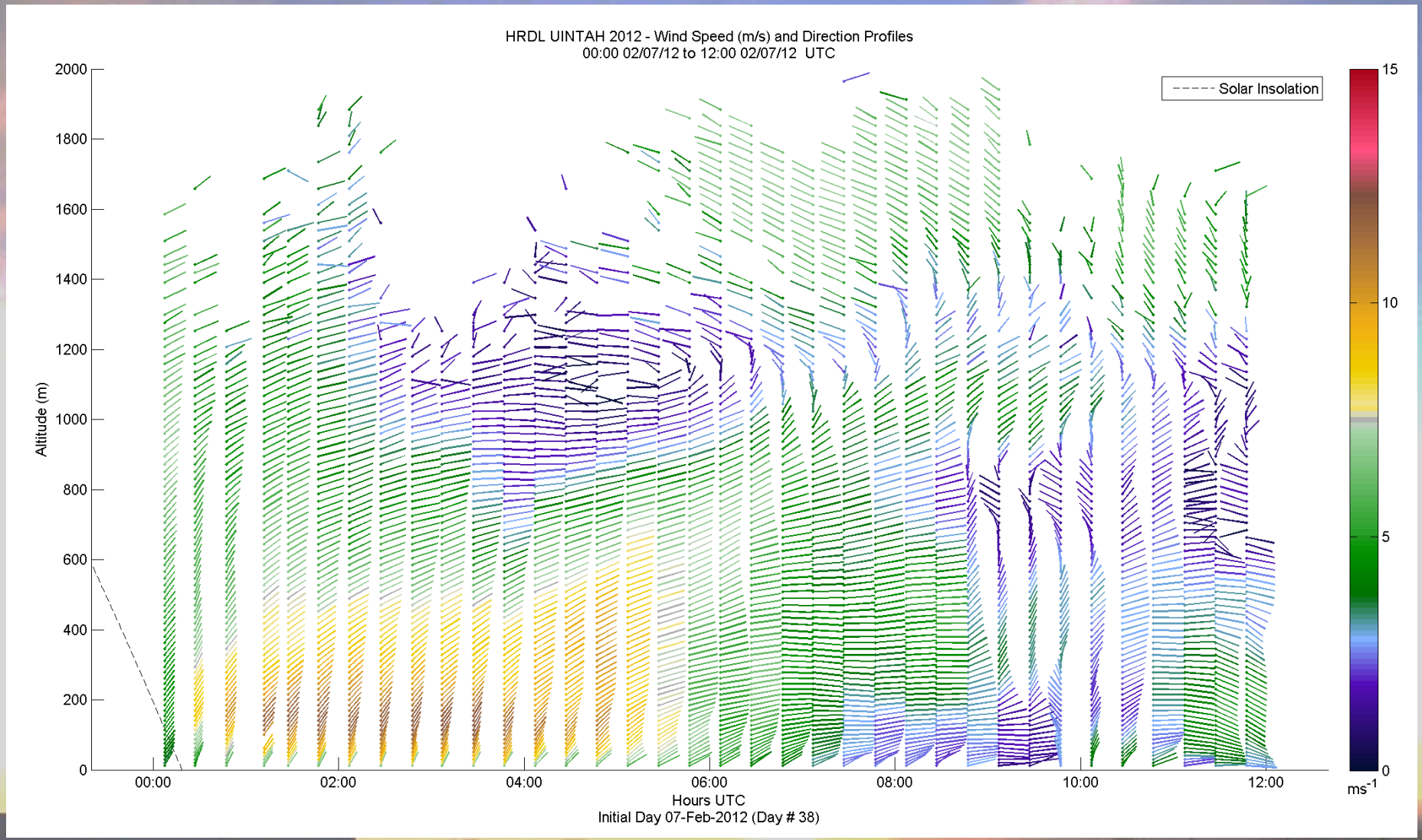




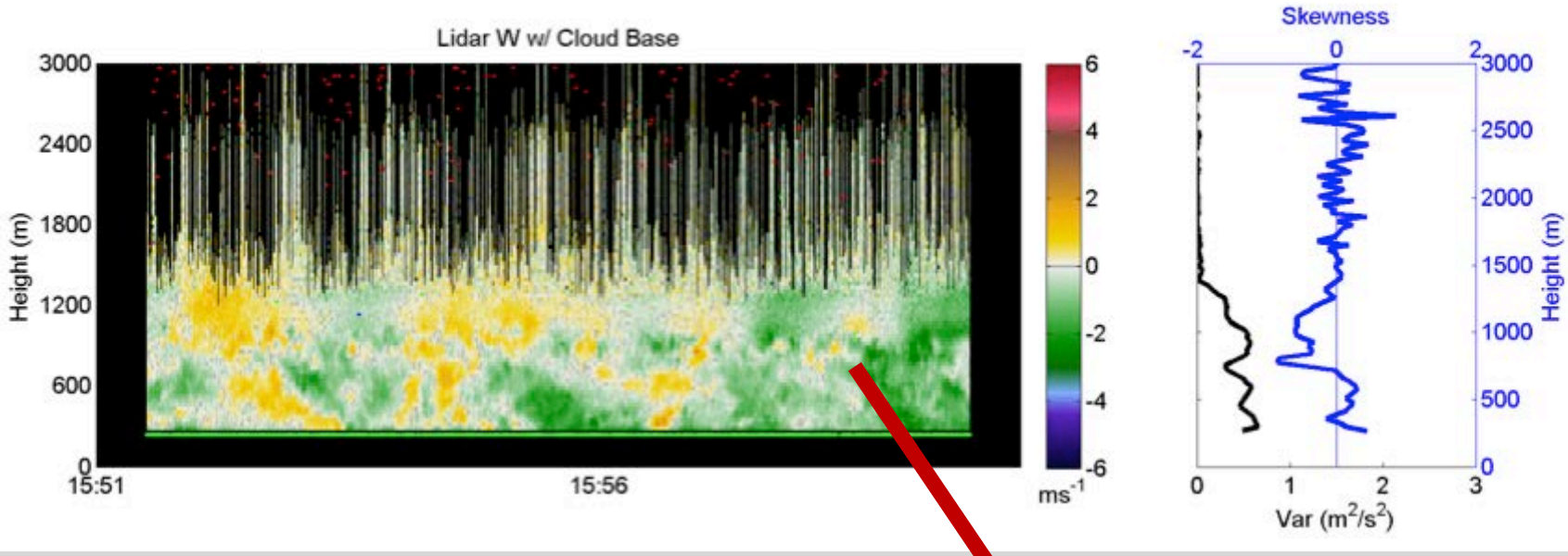
Wind profiles every 20 minutes -

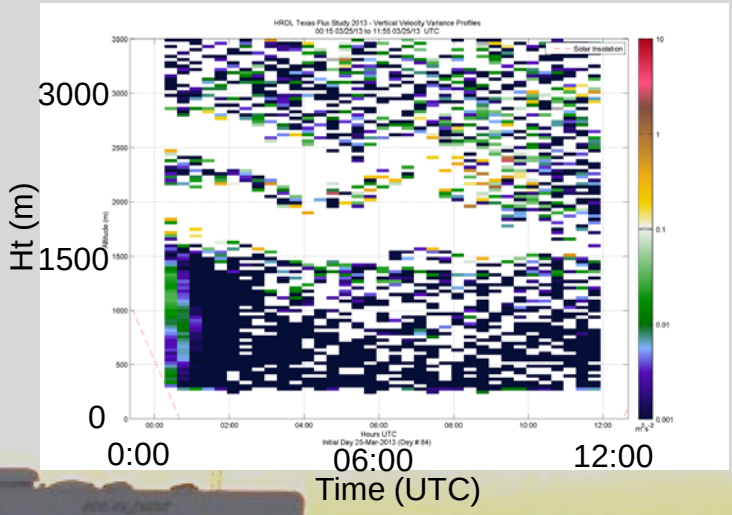
From within a few meters of the ground through the top of the BL

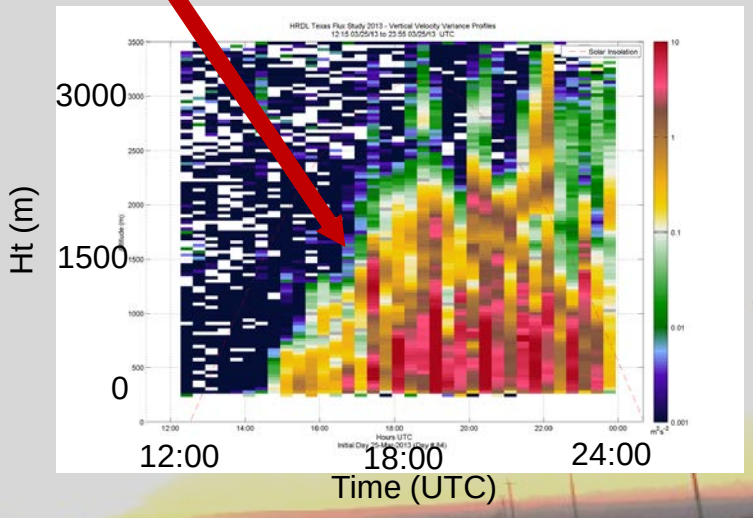
5-15 m vertical resolution



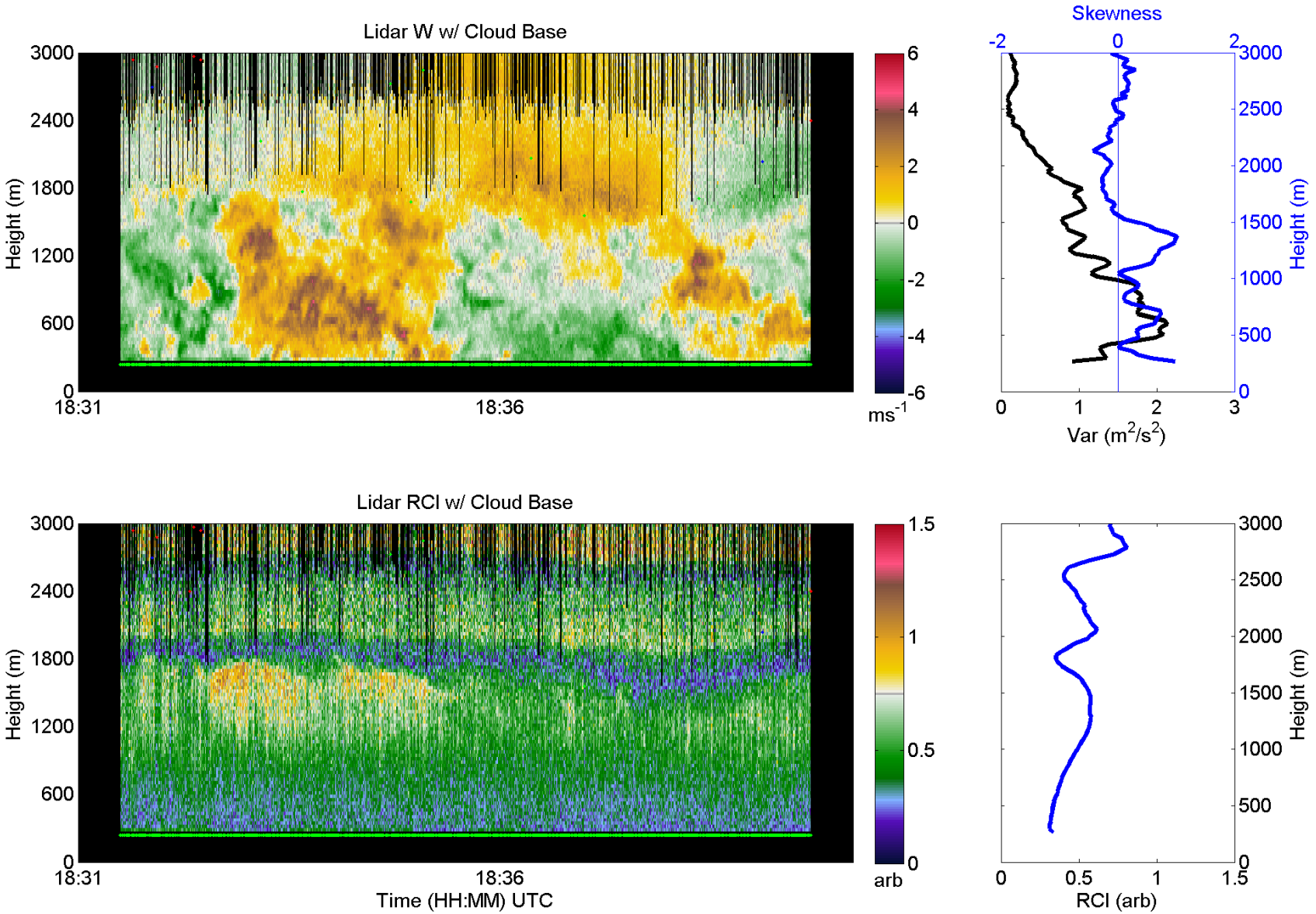
Vertical velocities : form statistics from repeating 10 minute collection periods







Boundary Layer Development



HRDL Vertical Data - B: +Grd, G: -Grd, R: Var Yel:BLH Mag :CB - Init day: 25-Mar-2013 (#84)

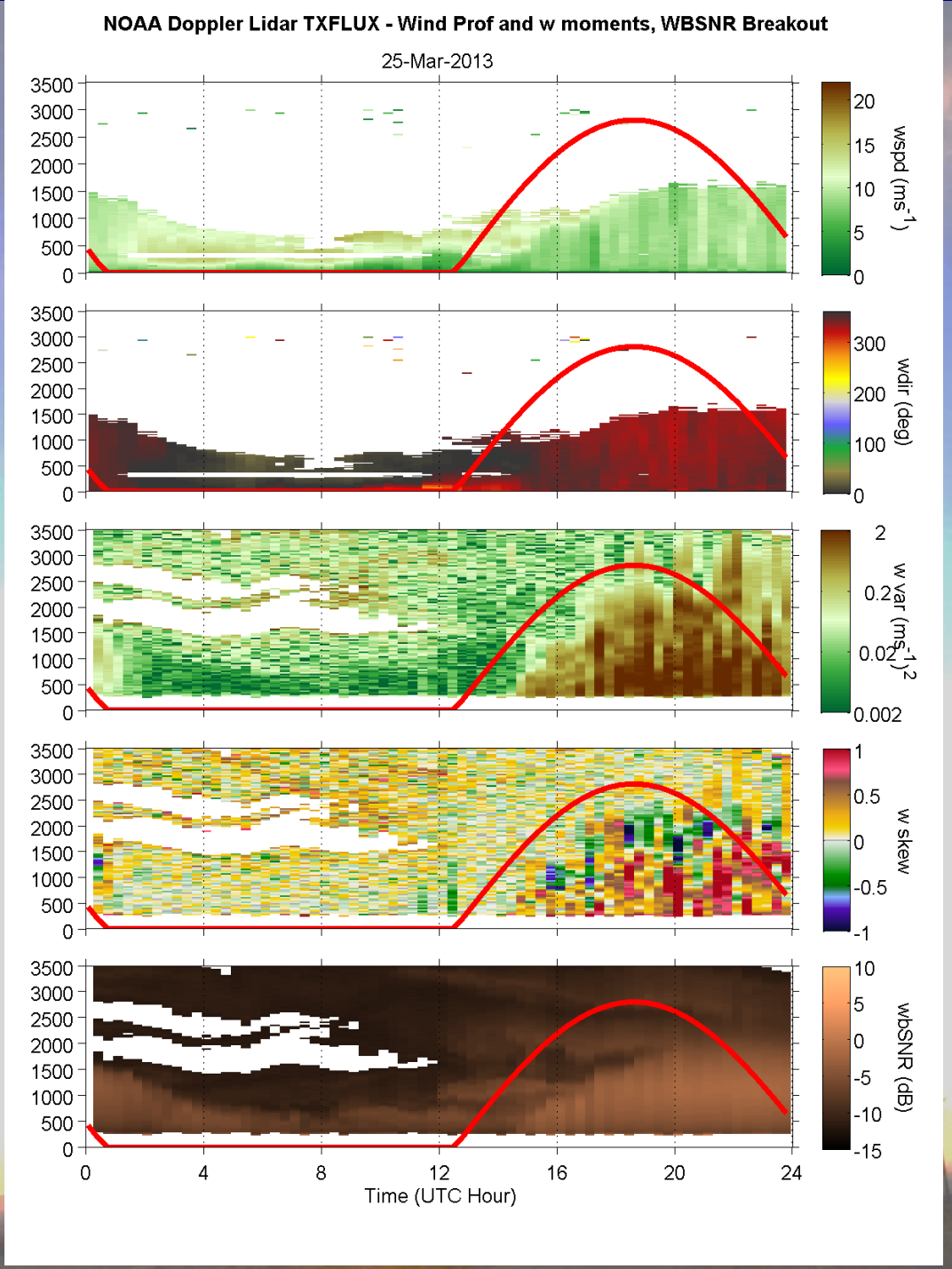
Wind Speed

Wind Direction

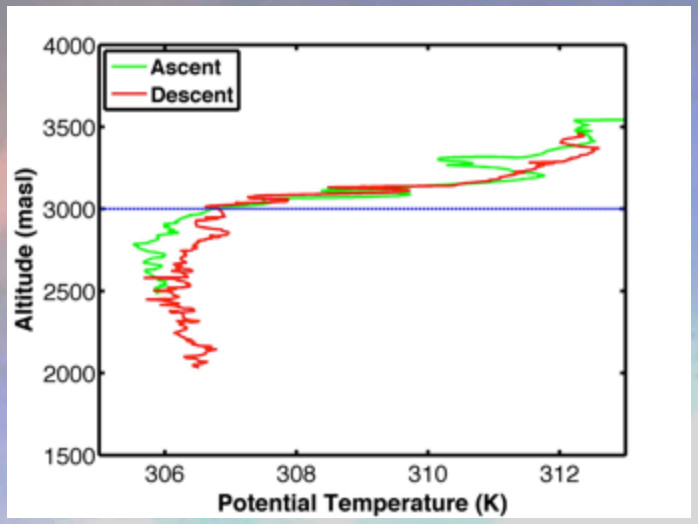
Vertical velocity variance

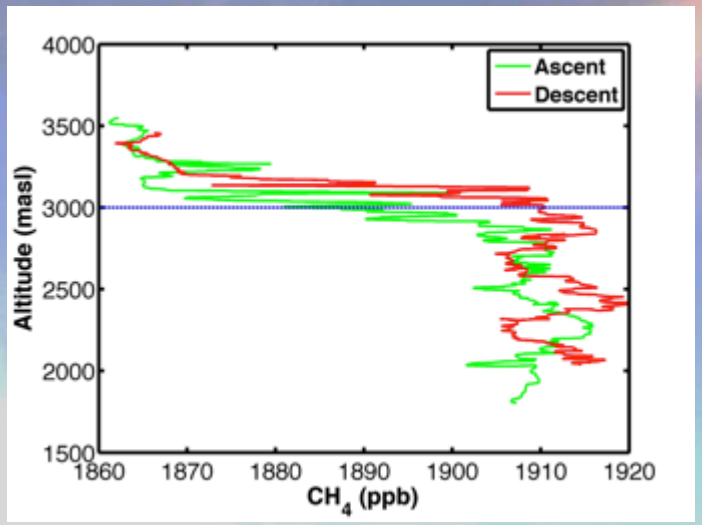
Vertical velocity skewness

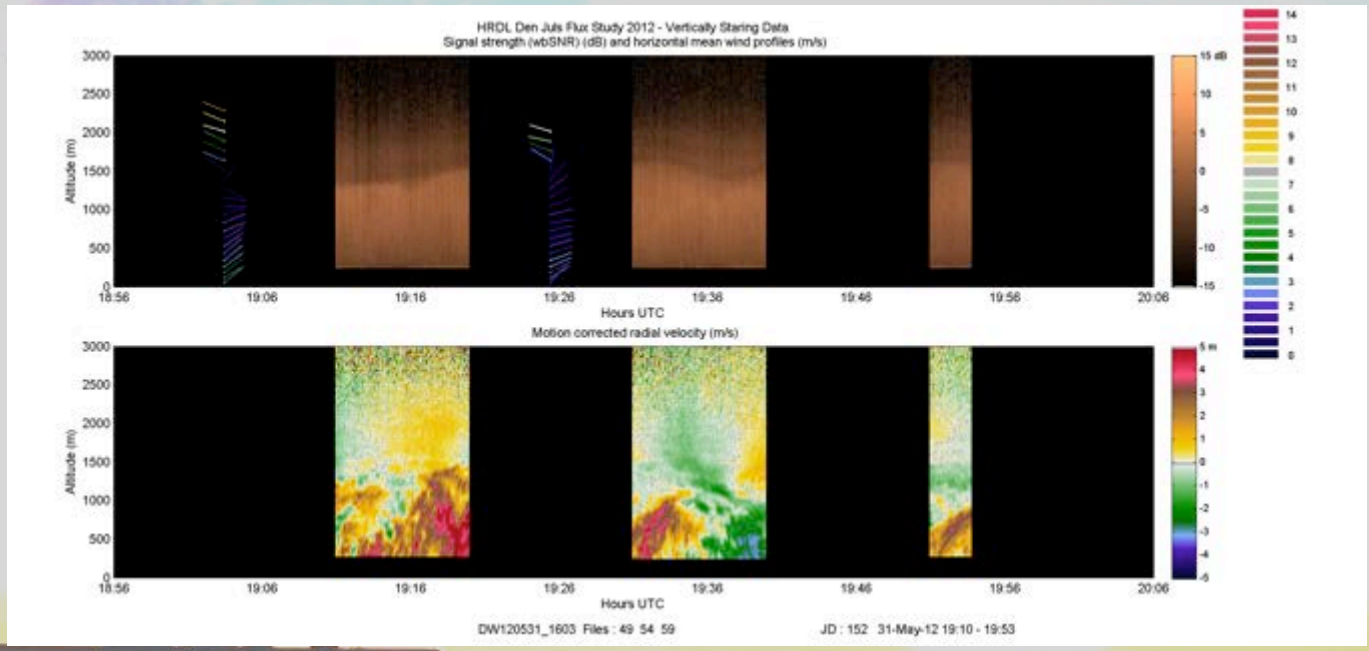
Aerosol

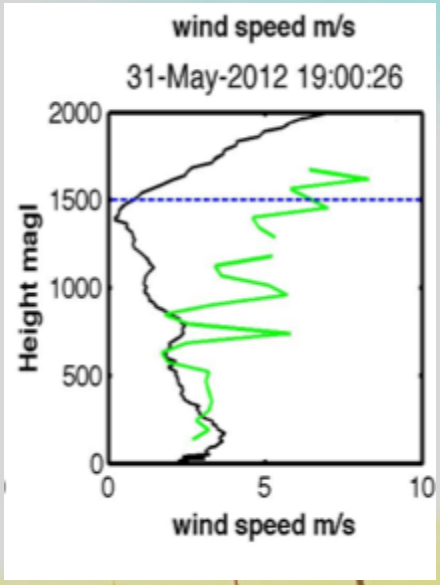


Residual layers: Denver-Julesburg

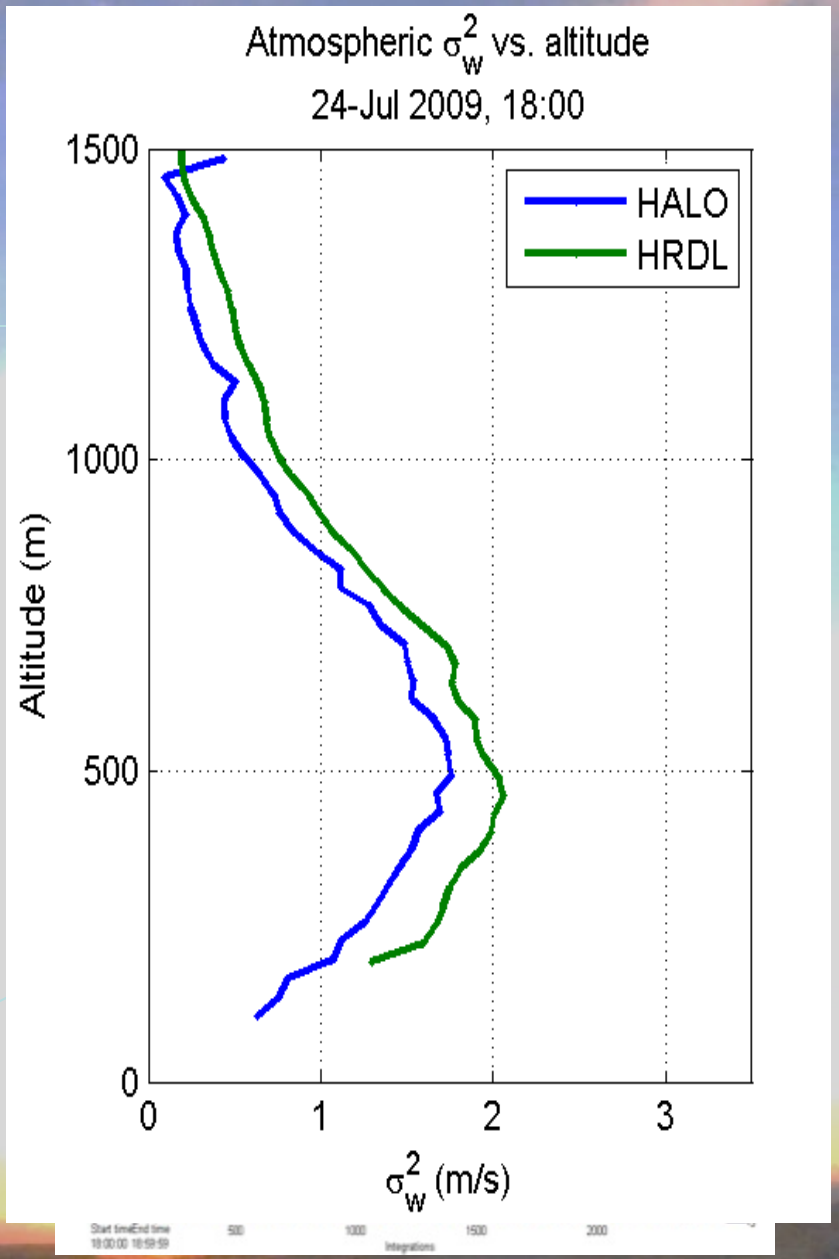








Lidar characterization of the boundary layer for INFLUX

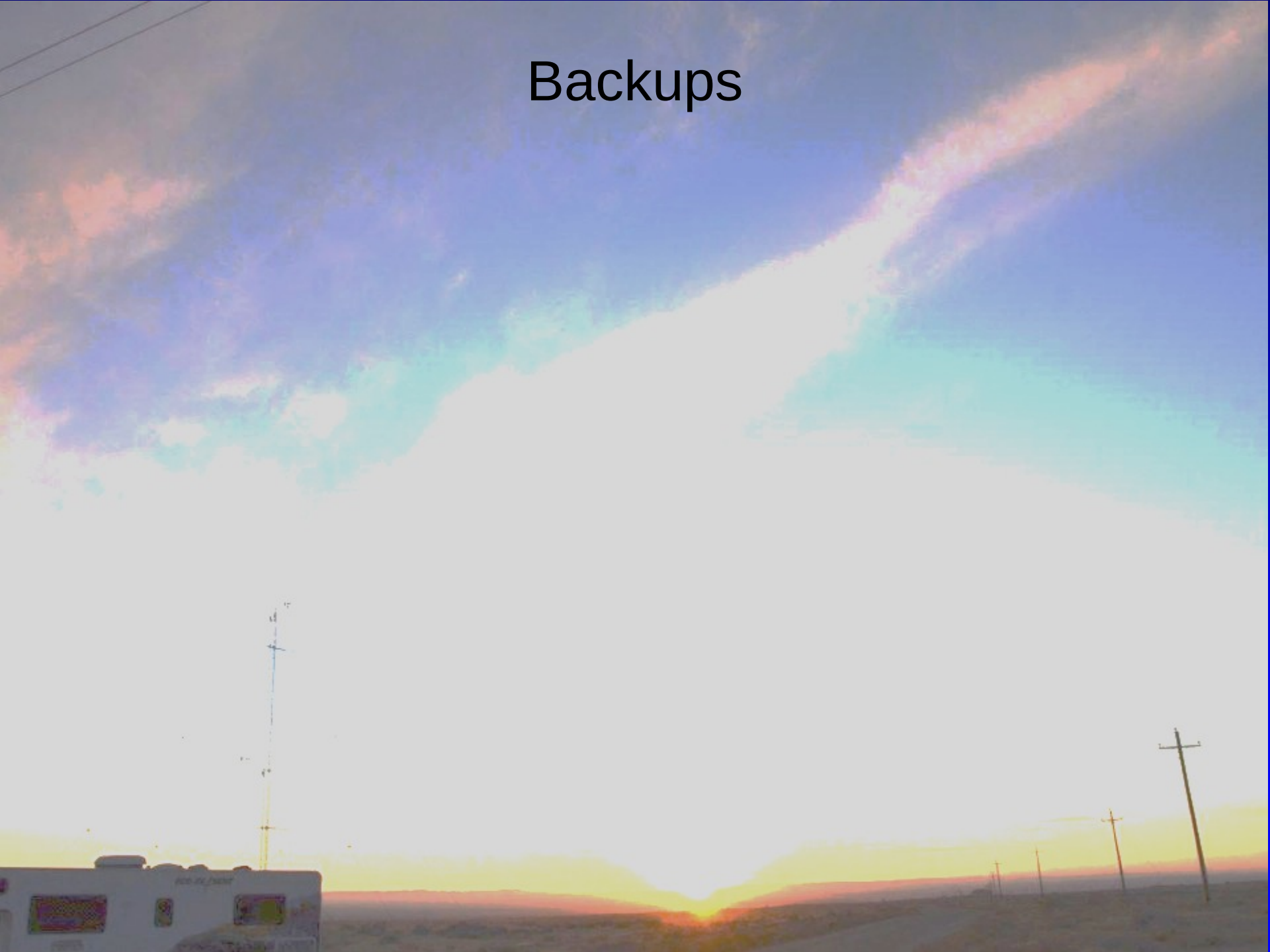


Installation at Ivy Tech Community College NE of Indianapolis

Current Status

- Doppler lidars have been deployed in 5 experiments to characterize boundary layer depth and dynamics for greenhouse gas emissions measurement
  - Unitah Basin 2012
  - Denver-Julesburg 2012
  - Uintah Basin 2013
  - Barnett Shale 2013
  - INFLUX 2012
- A commercial mini Doppler lidar is installed at Indianapolis for INFLUX and is operating
- Some receiver problems at low signal level are being investigated
- We’re currently pursuing algorithms for automated estimates of mixing layer depth

Backups



Acknowledgement

Coauthors:
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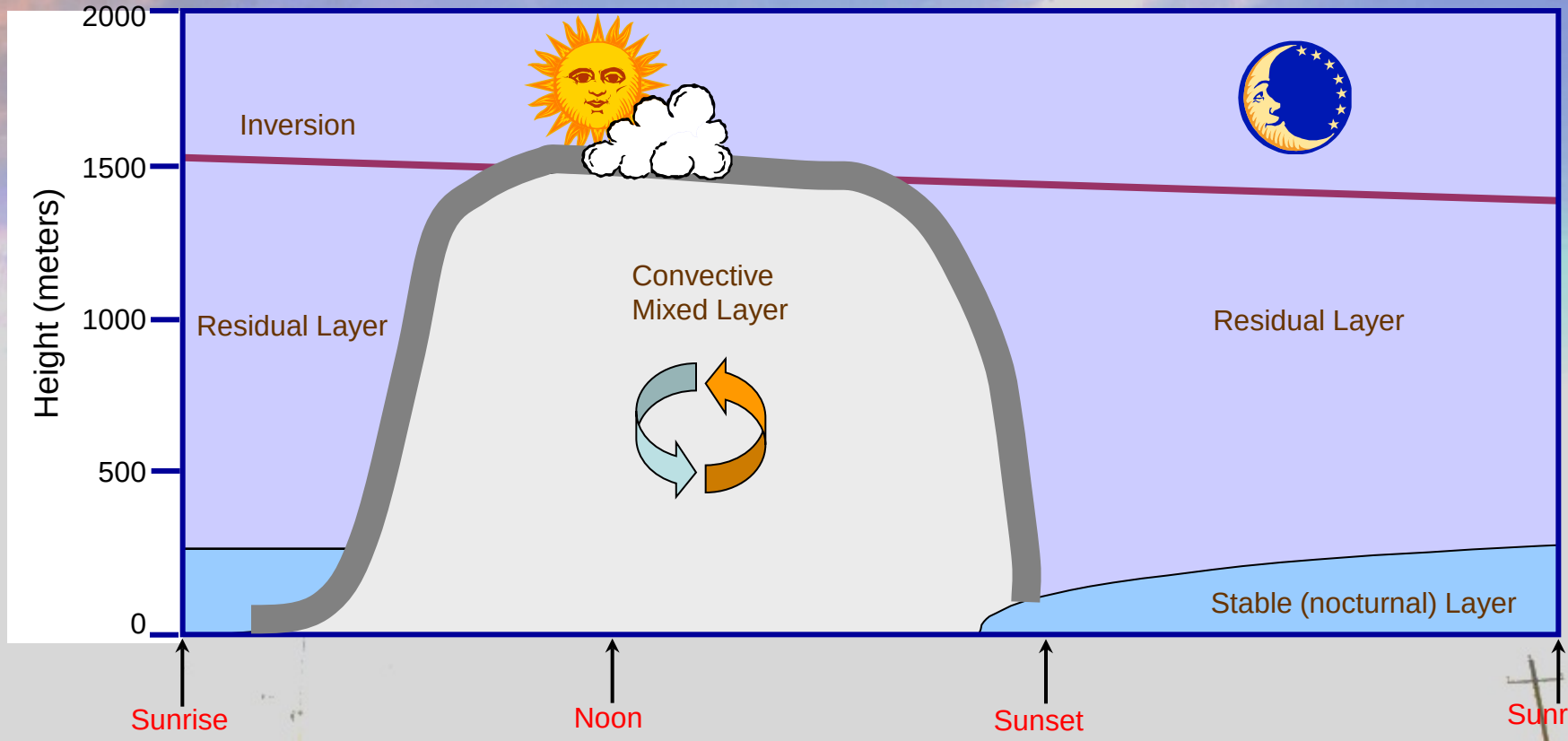
NOAA Twin Otter flight crews & NOAA Aircraft Operations Center

Steven Conley, UC Davis, Mooney AC Pilot

NOAA Health of the Atmosphere Program

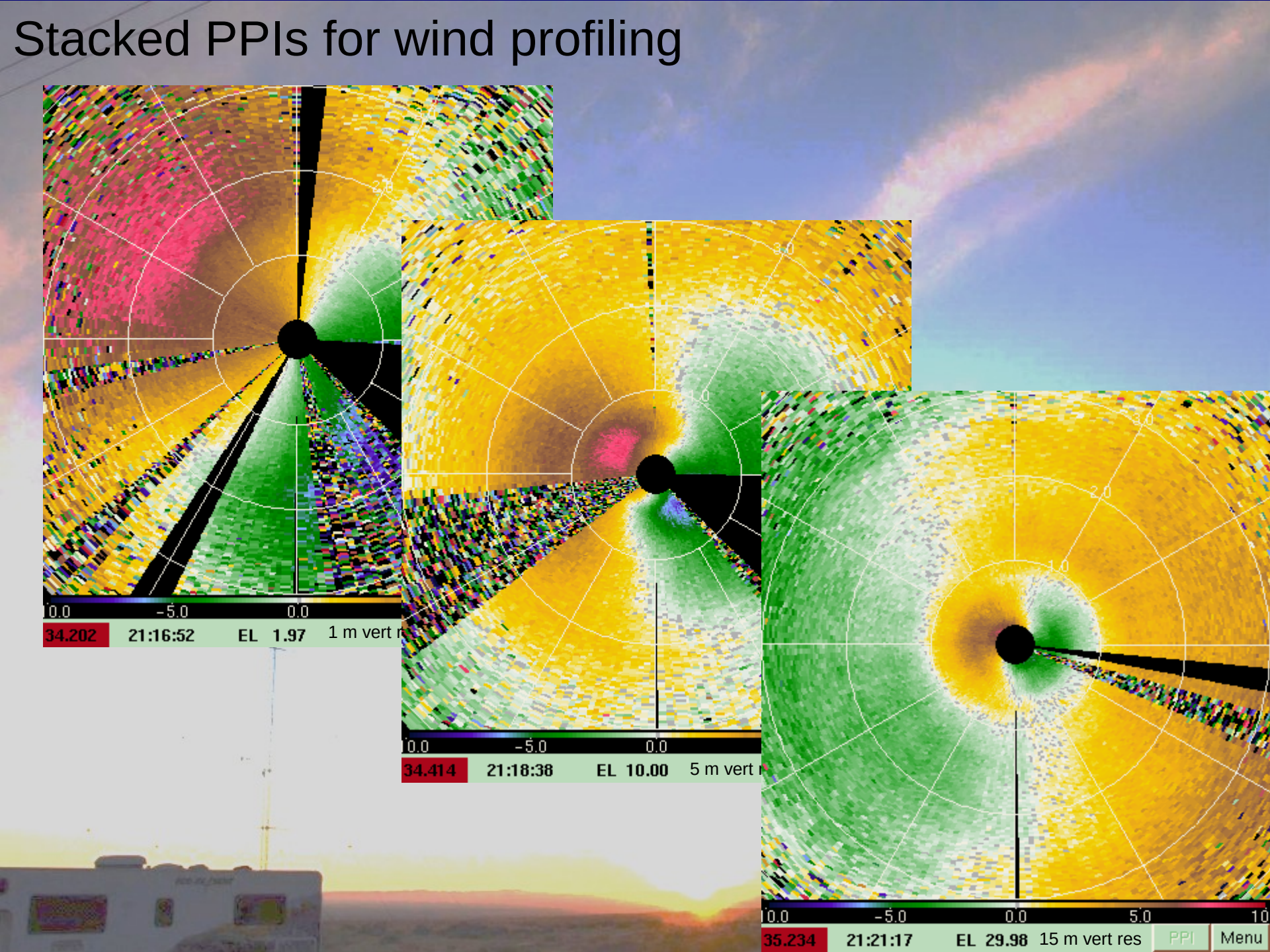
Uintah Impact Mitigation Special Service District, Western Energy Alliance, BLM, EPA, NSF, State of Utah

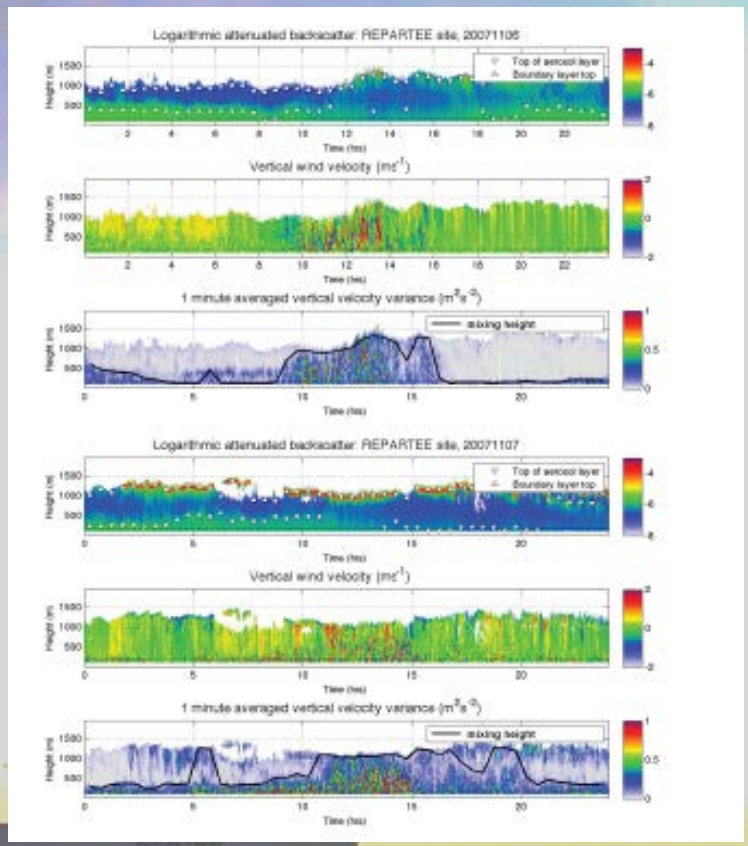
Atmospheric Boundary Layer Diurnal Variation

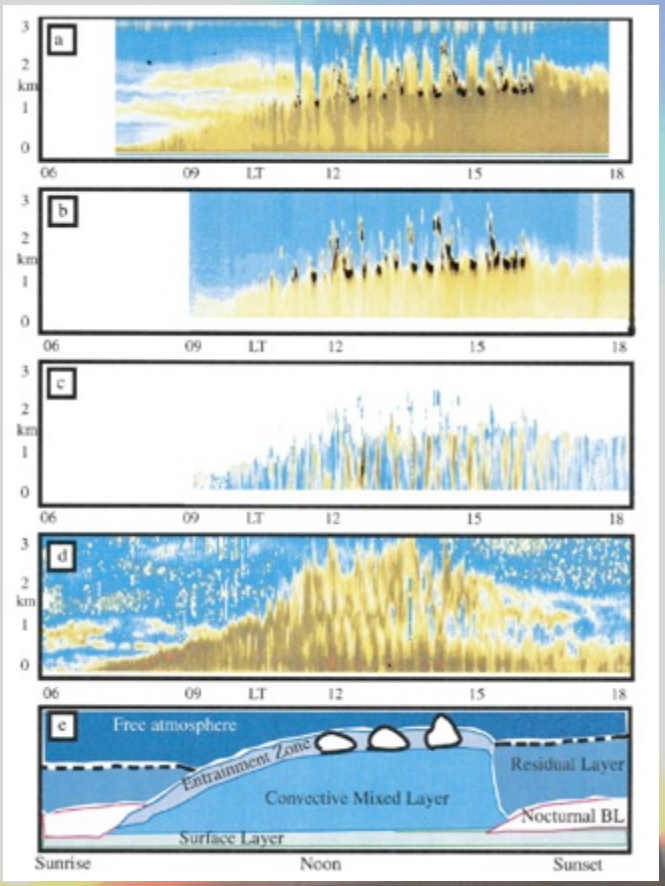


Adapted from Introduction to Boundary Layer Meteorology -R.B. Stull, 1988

Stacked PPIs for wind profiling




Logarithmic attenuated backscatter: REPARTEE site, 20071106
Top of aerosol layer
Boundary layer top
Height (m)
Time (hrs)
Vertical wind velocity (ms-1)
1 minute averaged vertical velocity variance (m2s-2)
mixing height
Logarithmic attenuated backscatter: REPARTEE site, 20071107
Top of aerosol layer
Boundary layer top
Vertical wind velocity (ms-1)
1 minute averaged vertical velocity variance (m2s-2)
mixing height


a
b
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09
12
15
18
Free atmosphere
Entrainment Zone
Residual Layer
Convective Mixed Layer
Nocturnal BL
Surface Layer
Sunrise
Noon
Sunset

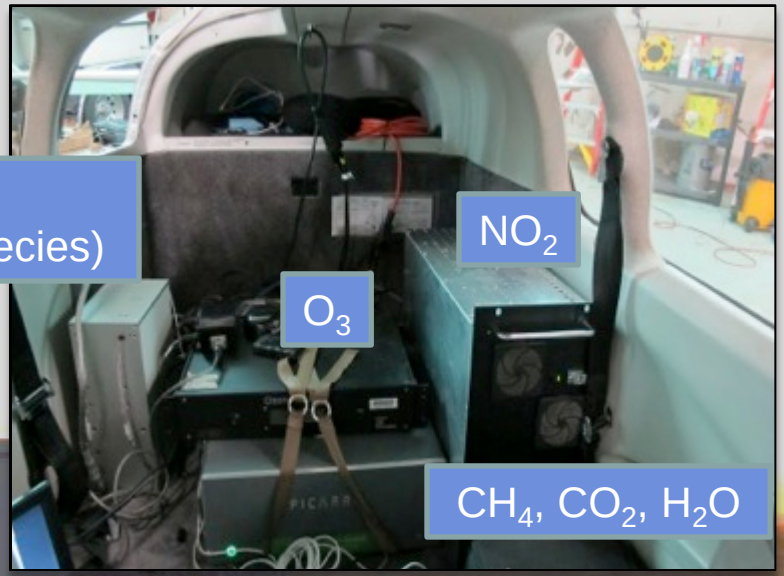
Methane Flux downwind of Oil & Gas Operations

(Uintah Basin Winter Ozone Study 2012)

Methane

Airborne in situ observations

Mooney TLS-20
Scientific Aviation, Inc.

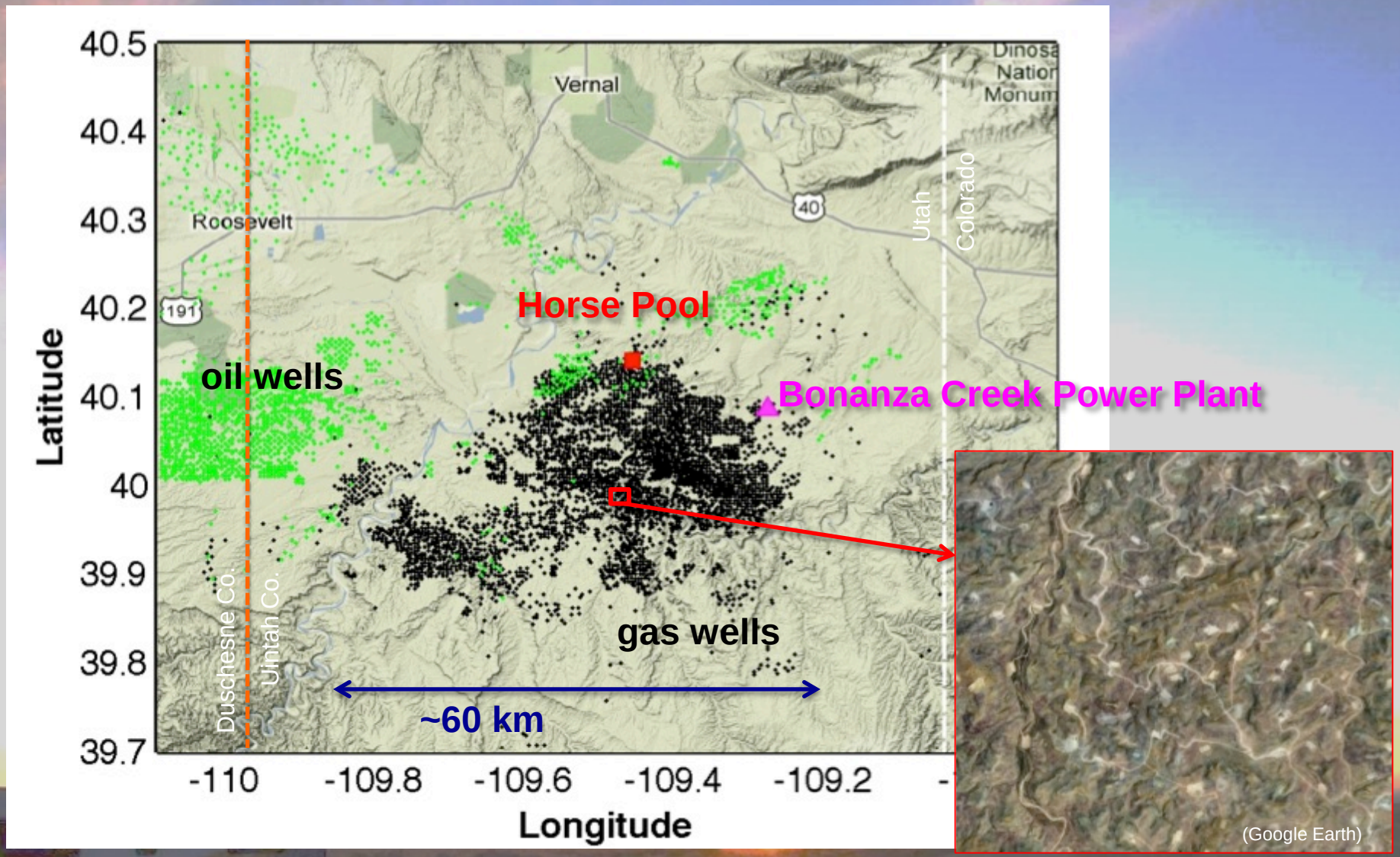


Flasks
(50+ species)

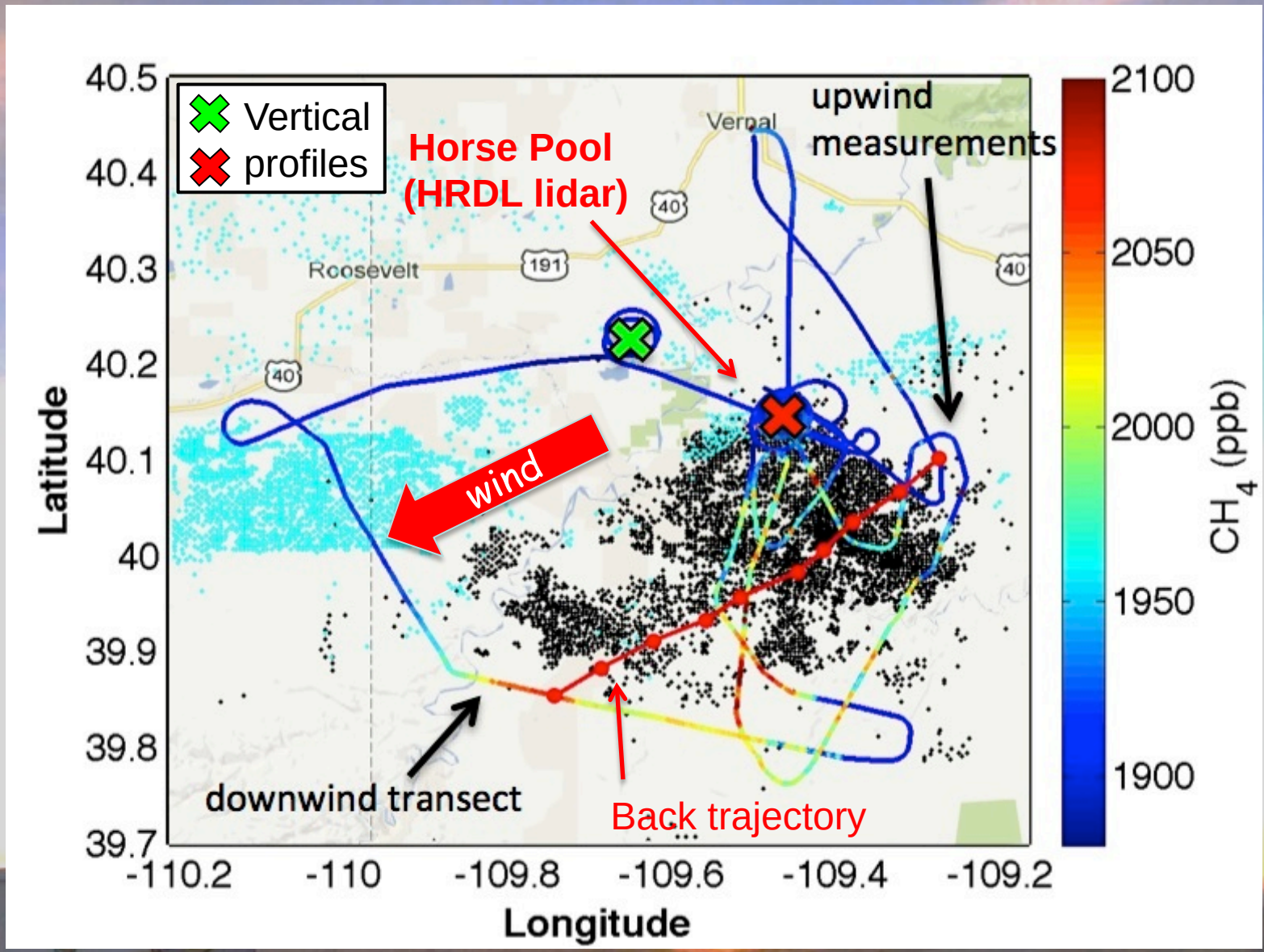
Wind profiles/Mixing height

Ground-based High Resolution Doppler Lidar (HRDL)

Uintah Basin, Utah



3 Feb 2012: Aircraft CH_4 measurements



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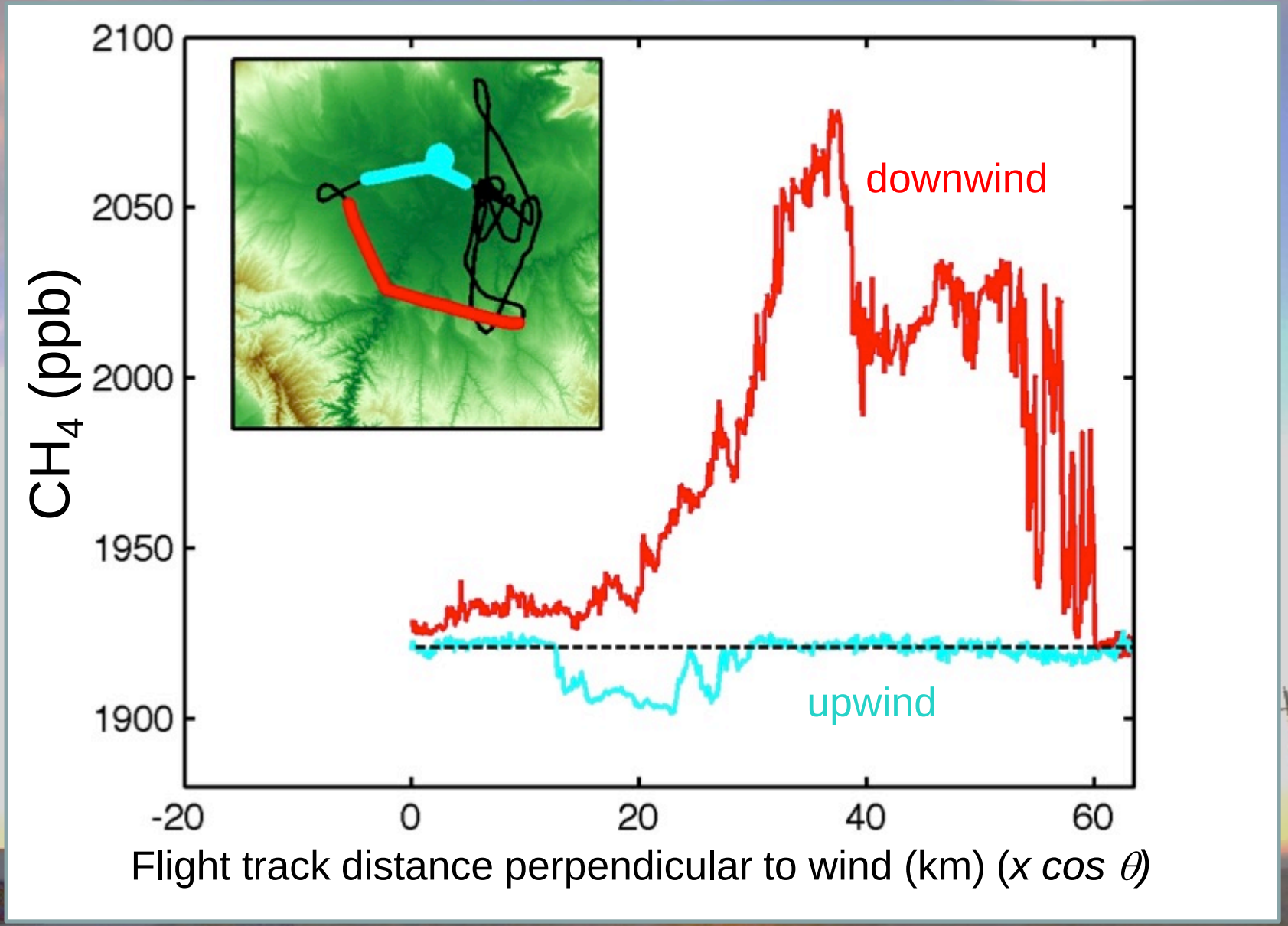
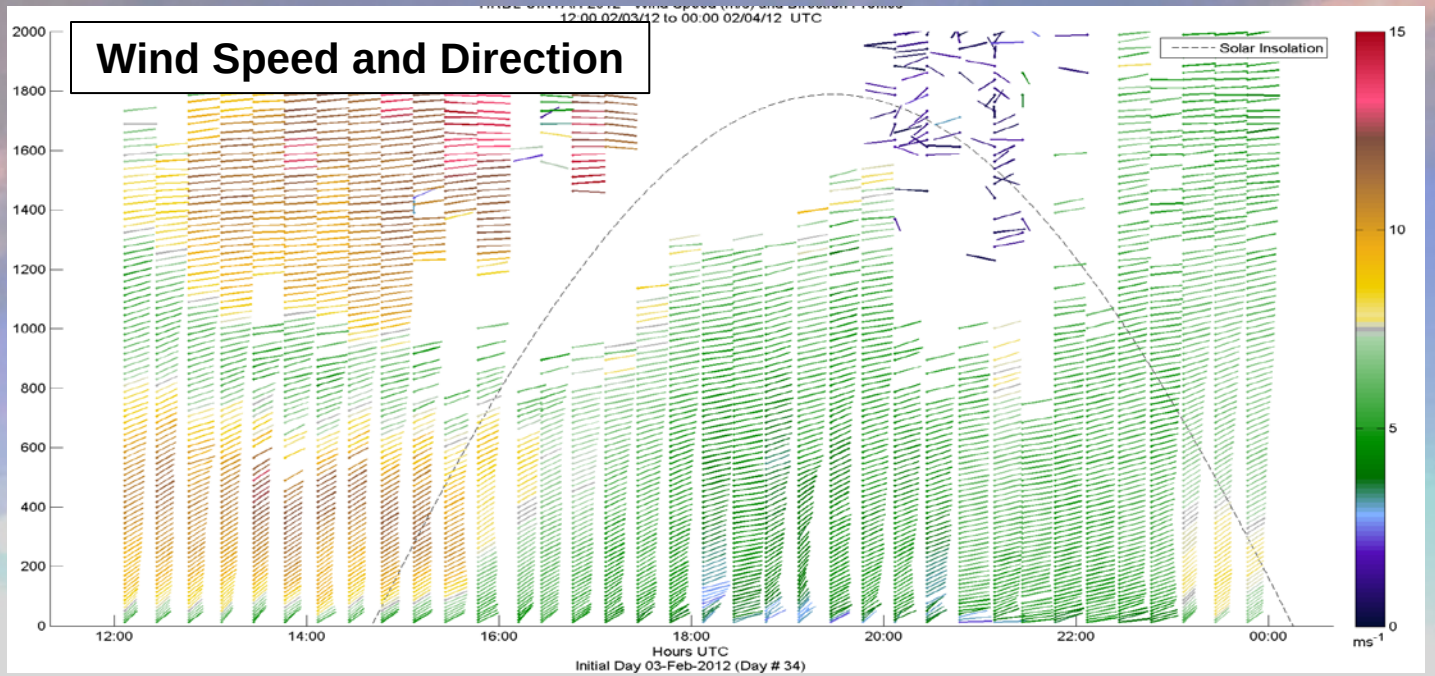
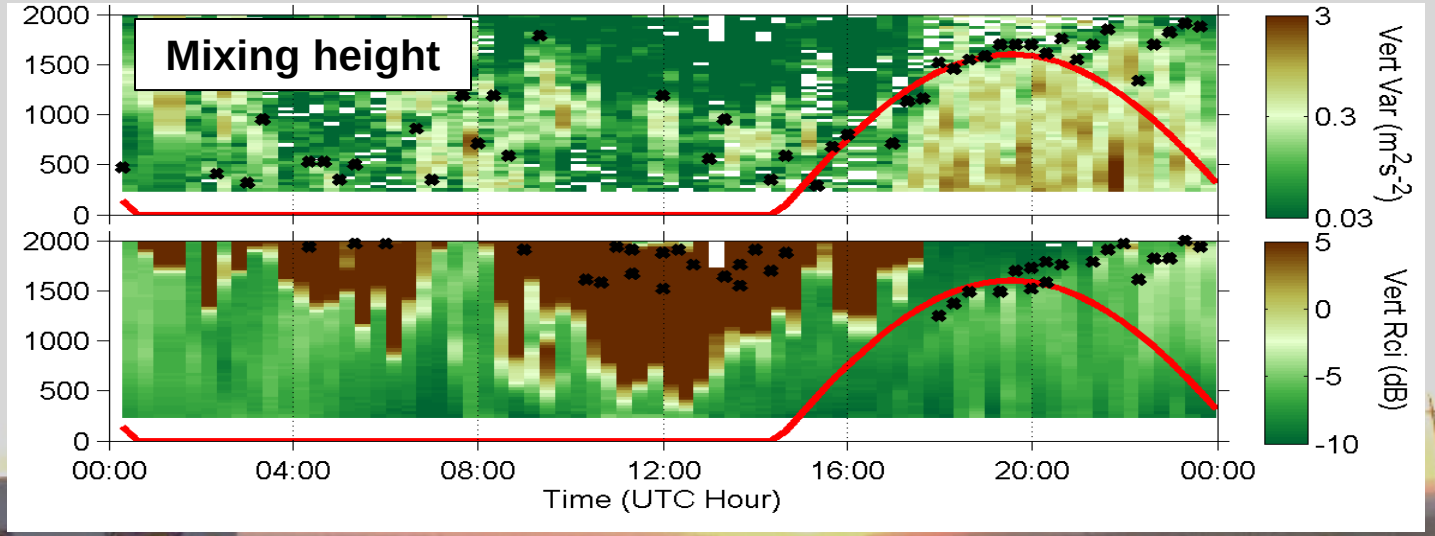


3 Feb 2012: HRDL lidar observations

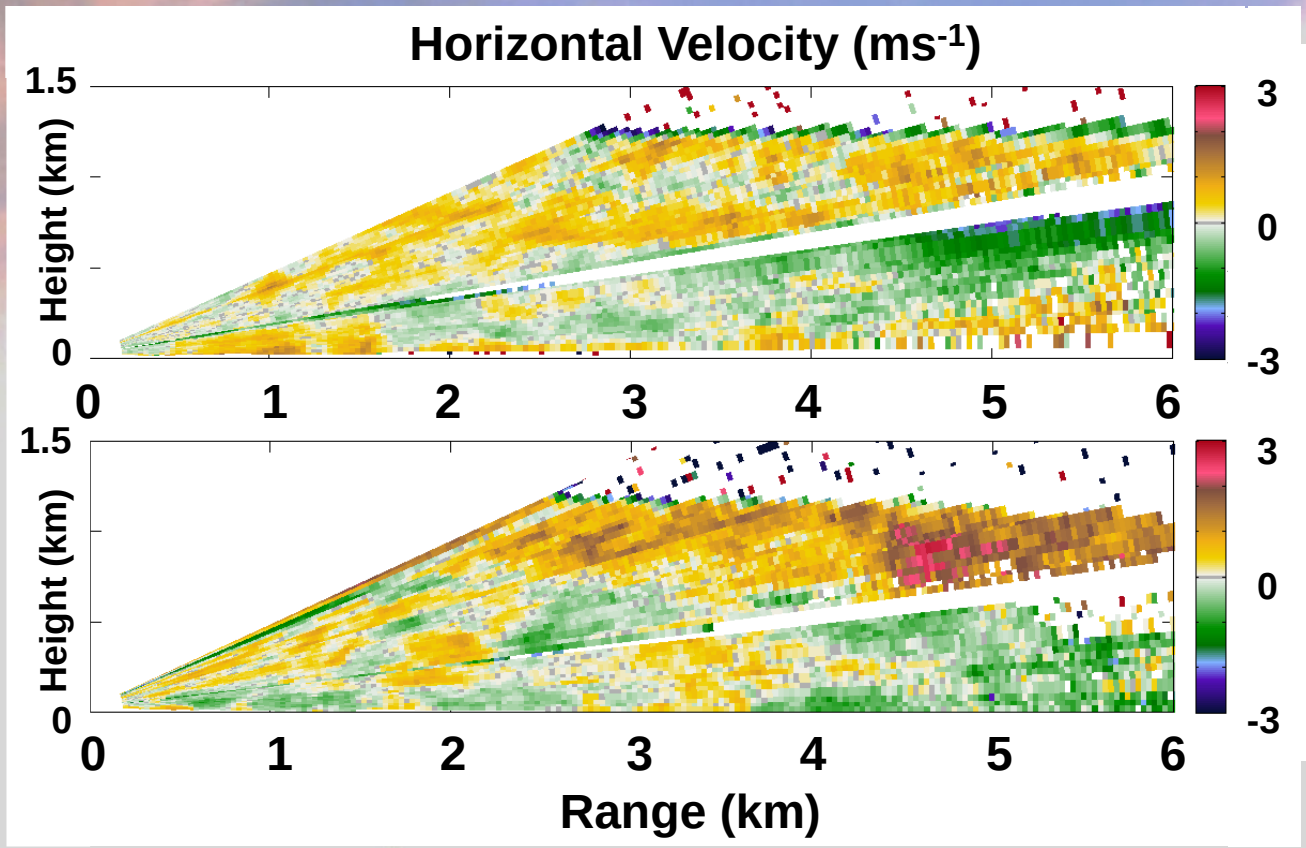


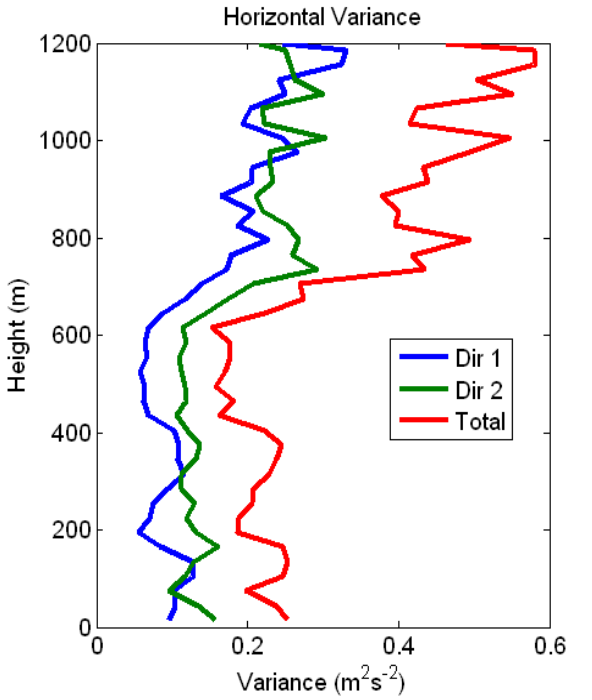


Uintah Basin: Methane emissions estimates

Date	ΔX_{CH4} , ppbv	Wind speed , m/s	PBL depth , m AGL	CH_4 mass flux , metric tons/h	Relative Uncertainty
3 Feb 2012	**56**	**5.2**	**1700**	**56±15**	**28%**
7 Feb 2012	245	1.2	700	30±19	62%

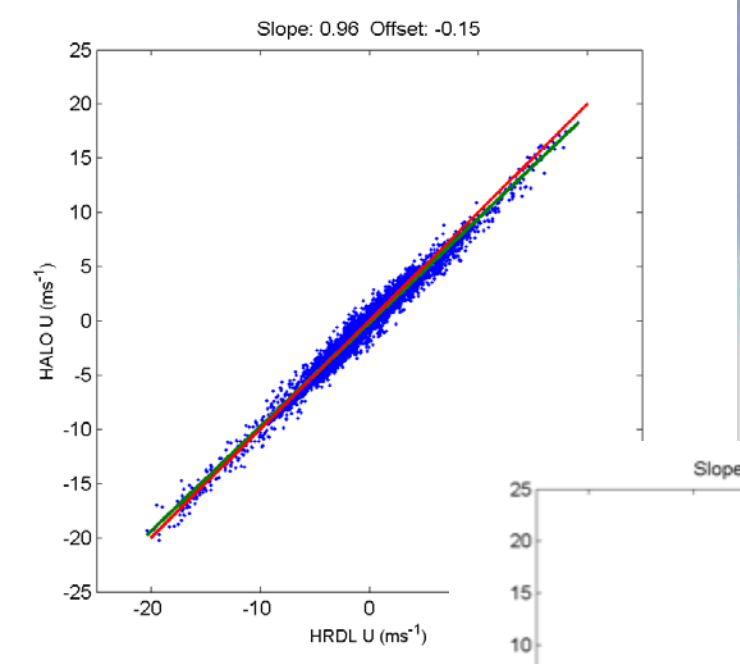
Horizontal Velocities : Spatial variability

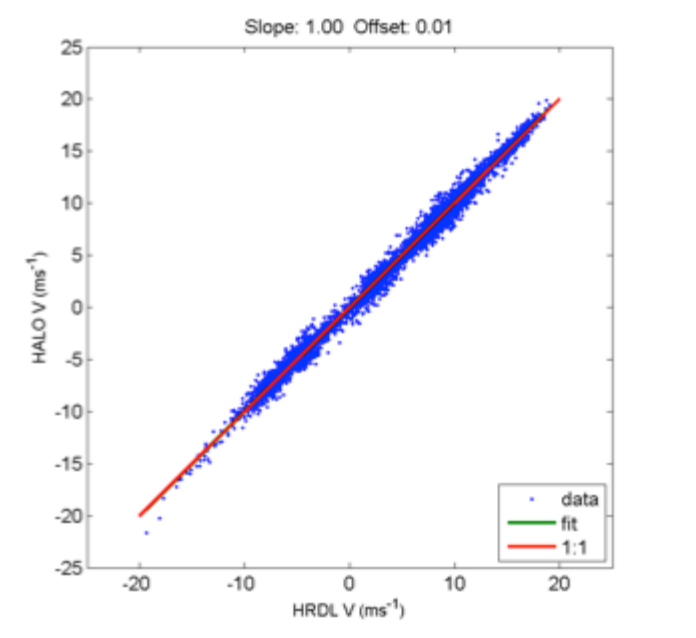


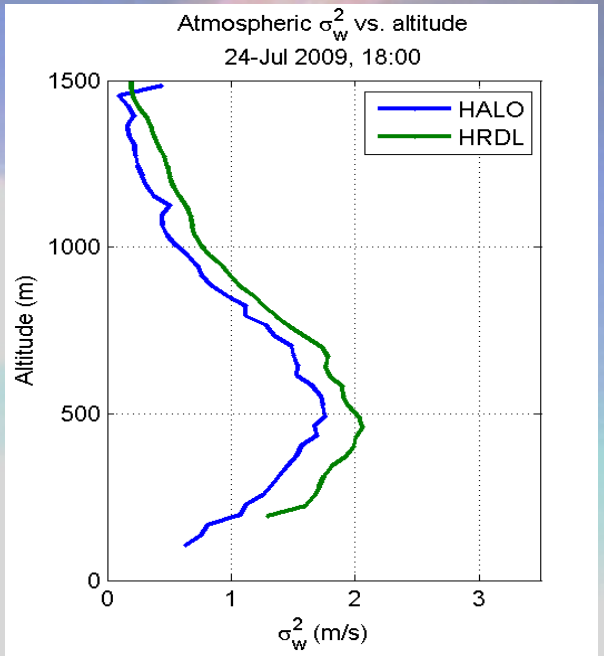


One minute to form horizontal variance profiles, cover from the ground though cloud base. Samples scales of 30m – 6km.

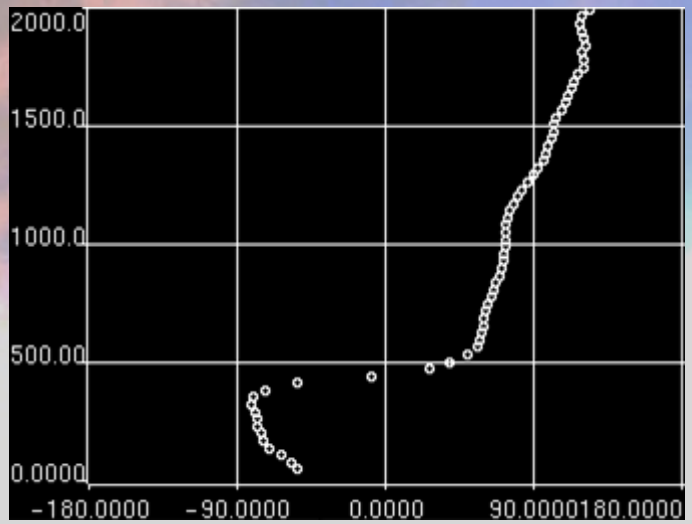
Halo – HRDL comparisons



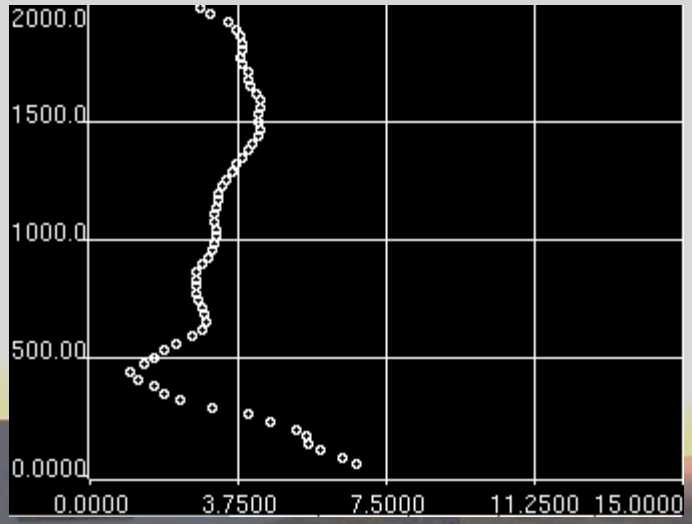




Calculating wind profile from PPI scans



Wind Direction



Wind Speed