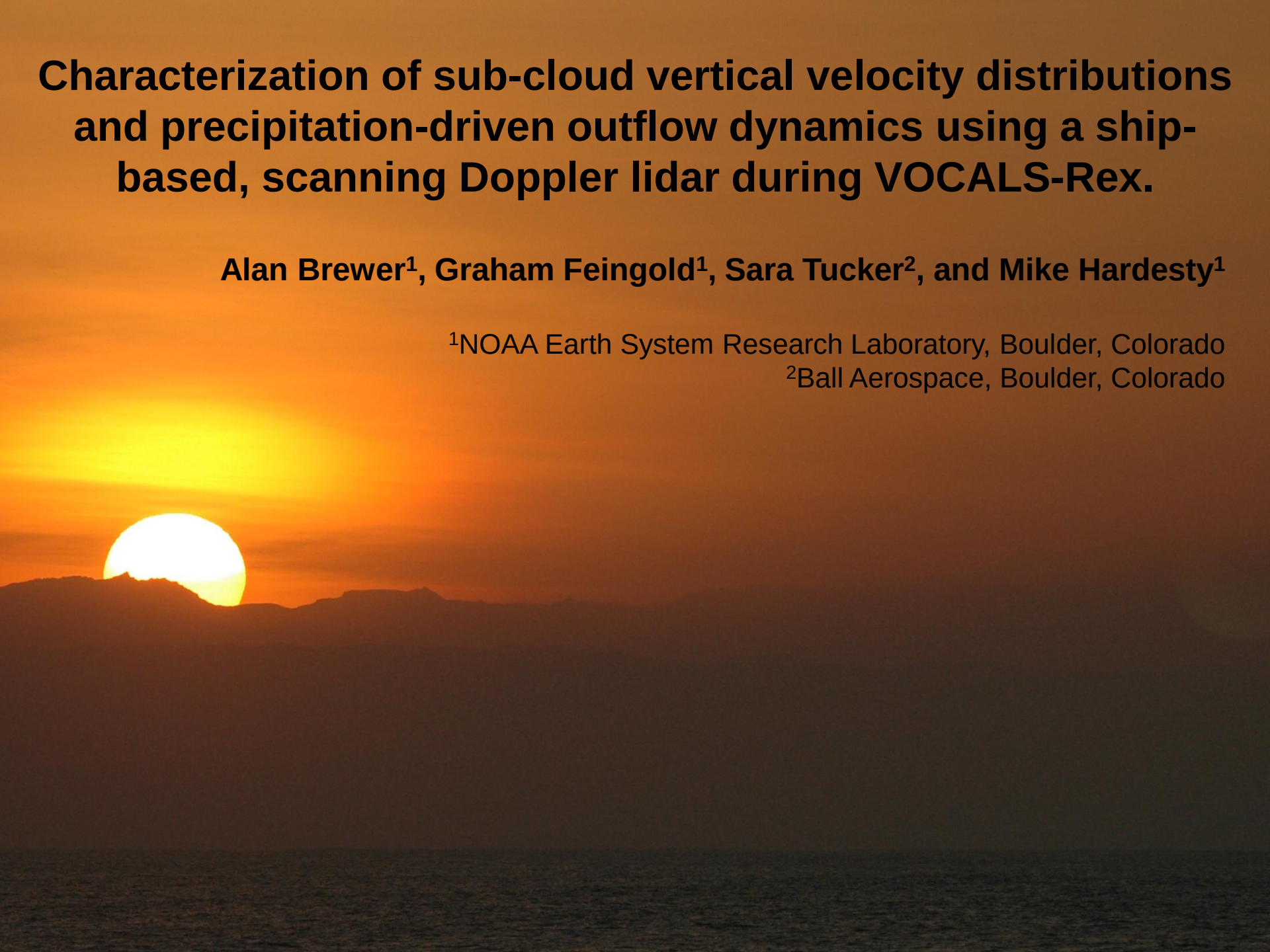
Characterization of sub-cloud vertical velocity distributions and precipitation-driven outflow dynamics using a ship-based, scanning Doppler lidar during VOCALS-Rex.

Alan Brewer[1], Graham Feingold[1], Sara Tucker[2], and Mike Hardesty[1]

[1]NOAA Earth System Research Laboratory, Boulder, Colorado
[2]Ball Aerospace, Boulder, Colorado



Characterization of sub-cloud vertical velocity distributions and precipitation-driven outflow dynamics using a ship-based, scanning Doppler lidar during VOCALS-Rex.

Alan Brewer[1], Graham Feingold[1], Sara Tucker[2], and Mike Hardesty[1]

[1]NOAA Earth System Research Laboratory, Boulder, Colorado
[2]Ball Aerospace, Boulder, Colorado

Acknowledge:

- Chris Fairall, Bob Banta, Dan Wolfe, Ludovic Bariteau (NOAA ESRL PSD, CSD & CIRES Univ of Colorado)
- Sandra Yuter &, Casey Burleson, Northern Carolina State University
- Simon de Szoeke, Oregon State Univ
- David Mechem, Univ of Kansas
- Paquita Zuidema, Univ of Miami
- Dave Covert, Univ of Washington

Using ship-based Doppler Lidar observations to compare with LES models

Two approaches :

- Continuous observations, build statistics of turbulence profiles, and composite the results.

- Combine high temporal and spatial resolution remote sensing data to study evolution specific examples.

This talk :

Preparing Lidar data for comparison

- Combine vertical and horizontal velocity measurements to create turbulence profiles.
  - Strength of the turbulence
  - Driving mechanism

- Compositing turbulence profiles to investigate
  - Diurnal cycles
  - Impact of decoupling and drizzle occurrence

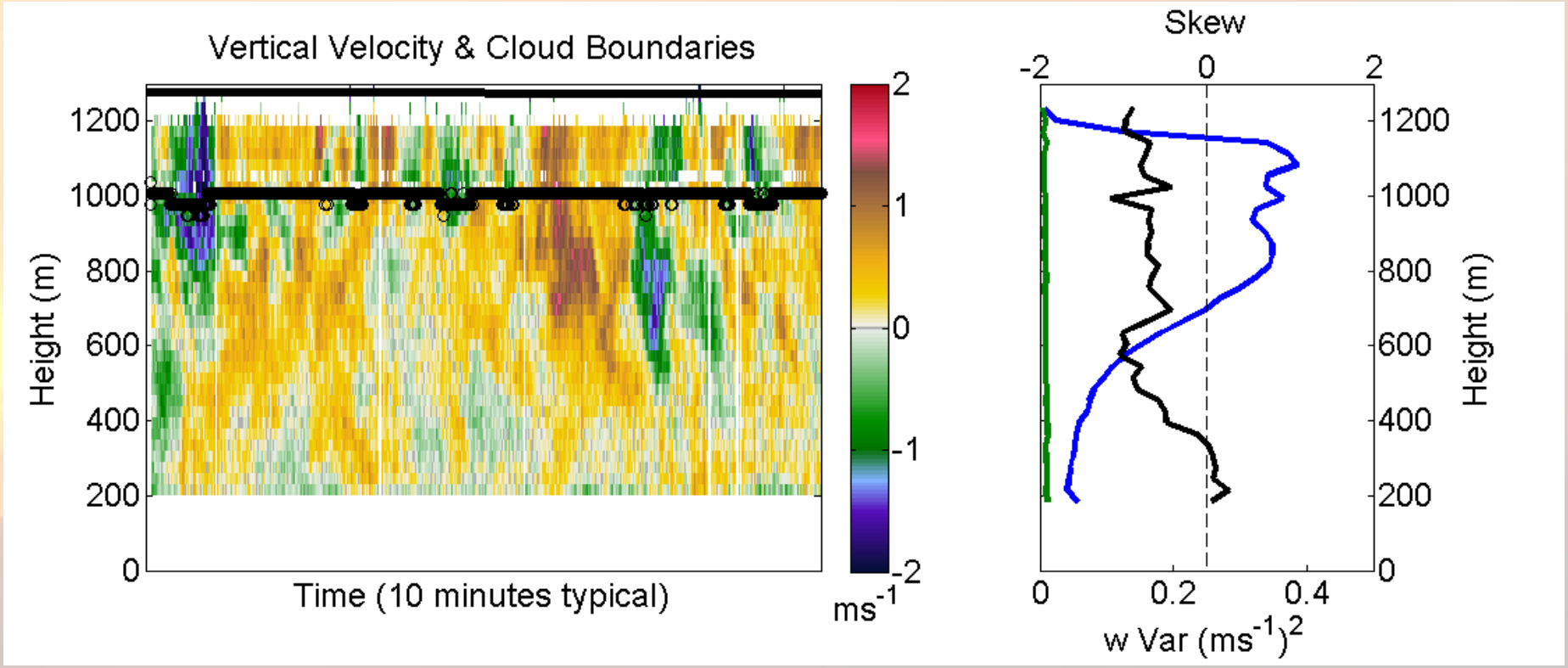
- Anatomy of an outflow

- Summary

Turbulence profiles

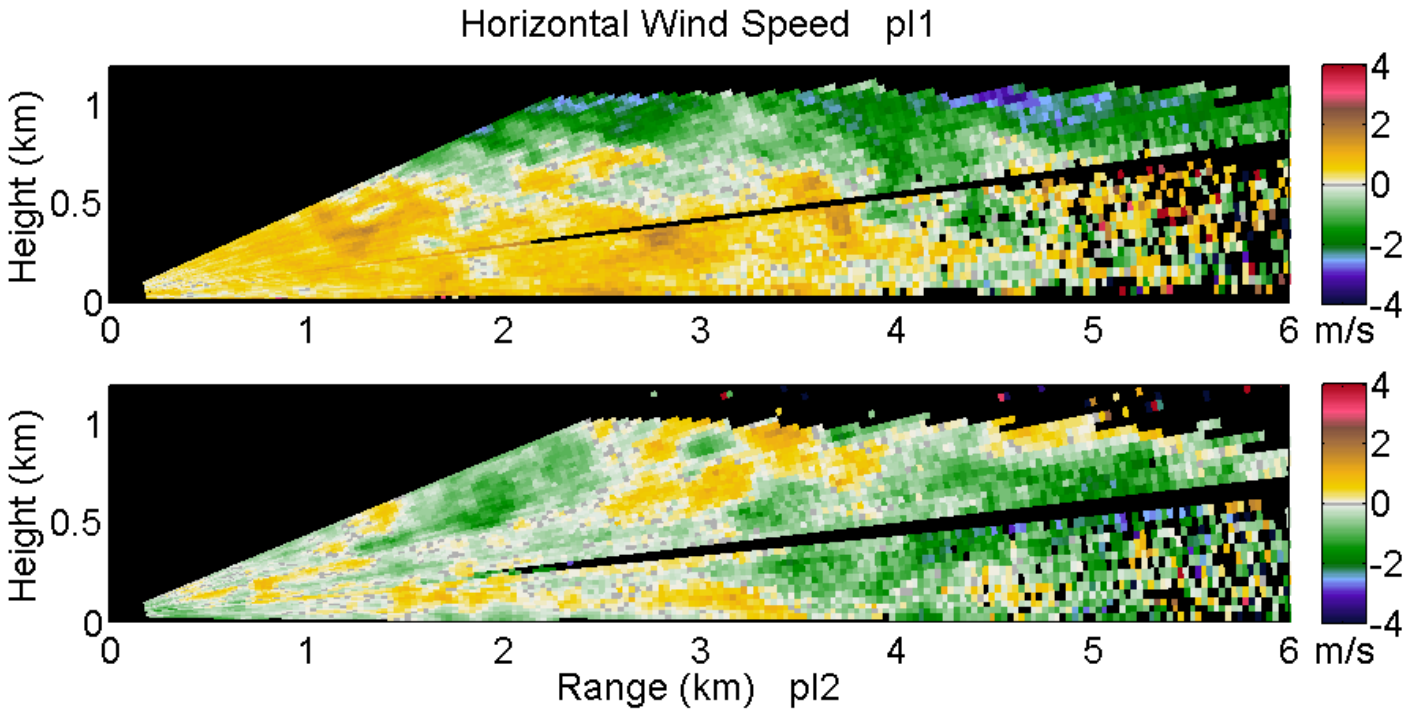
- Vertical variance
- Skewness
- Horizontal variance
- TKE
- Isotropy Ratio (vertical vs horizontal variance)
- Eddy Dissipation Rate
- Mean wind speed and direction
- Aerosol backscatter strength

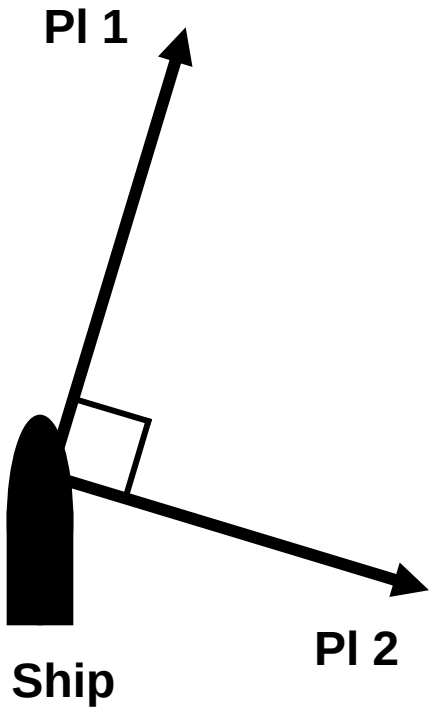
Vertical velocities : form statistics from repeating 10 minute collection periods



Strongest vertical motion at cloud base, negative skewness consistent with top-down mixing driven by cloud-top cooling

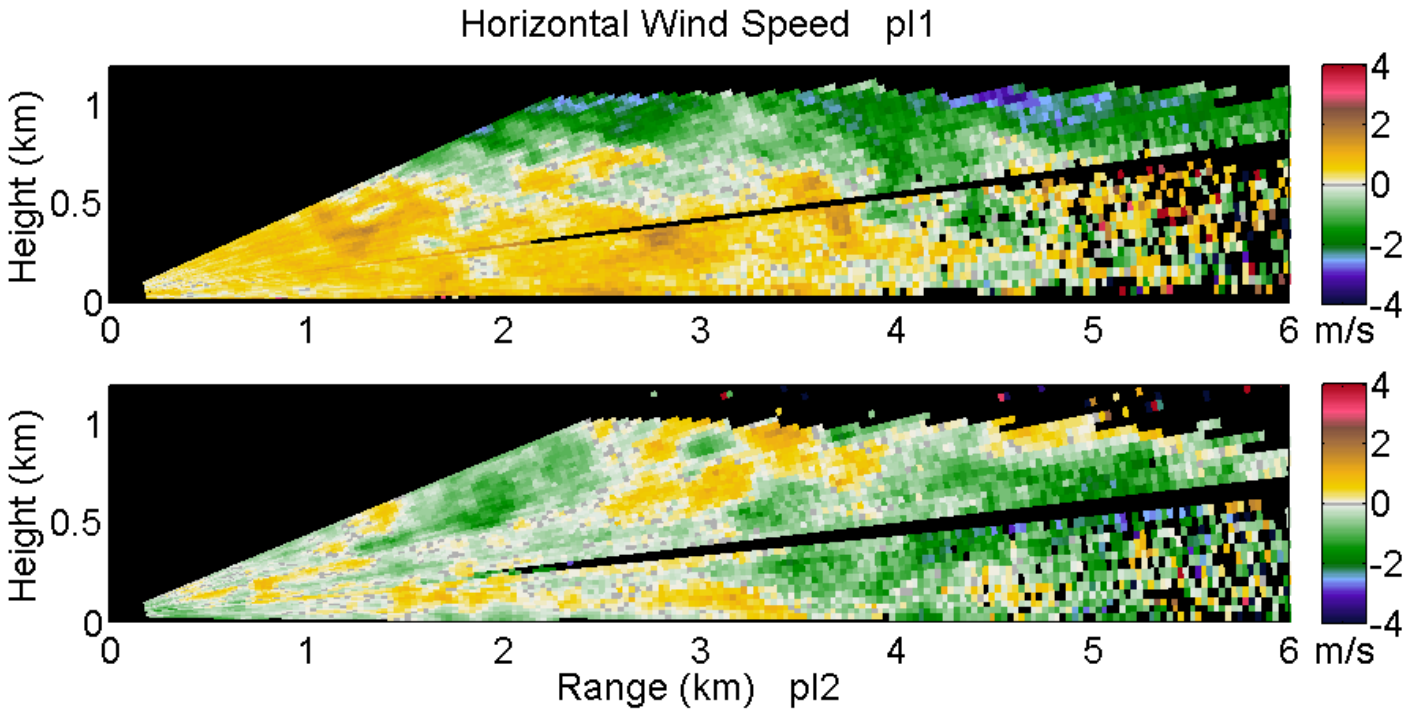
Horizontal velocities : Spatial variability

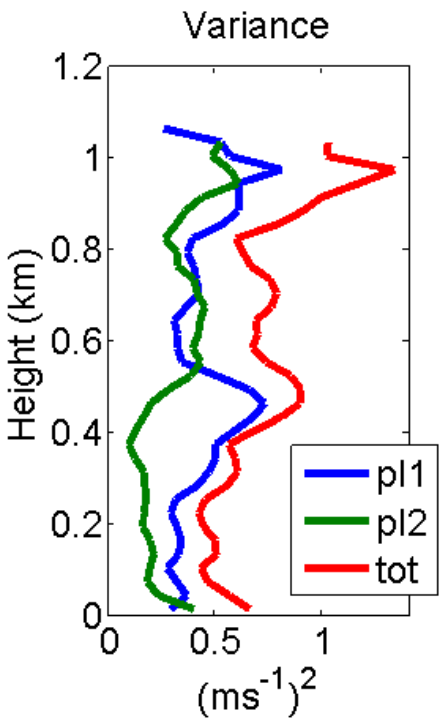




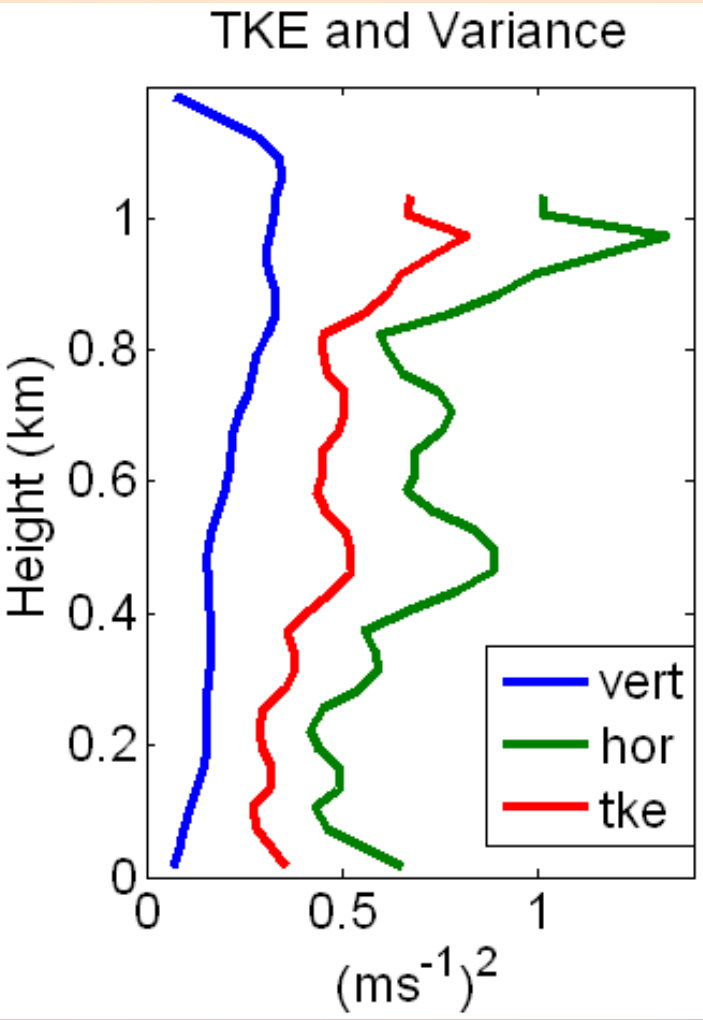
Scanning measurements along two orthogonal axes combined to create total horizontal variance.

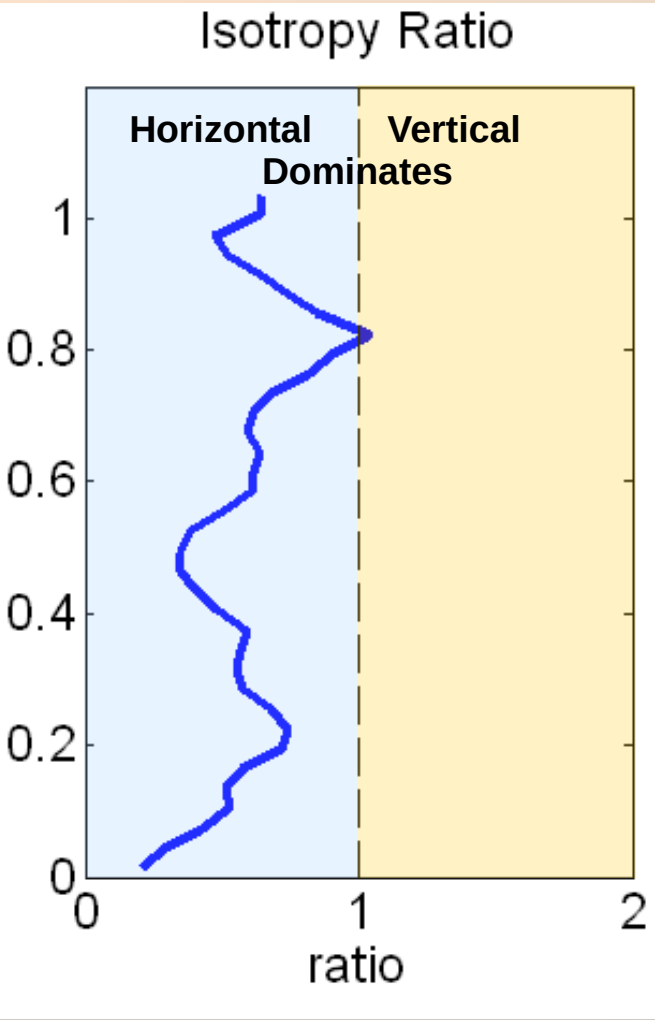
Horizontal velocities : Spatial variability





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



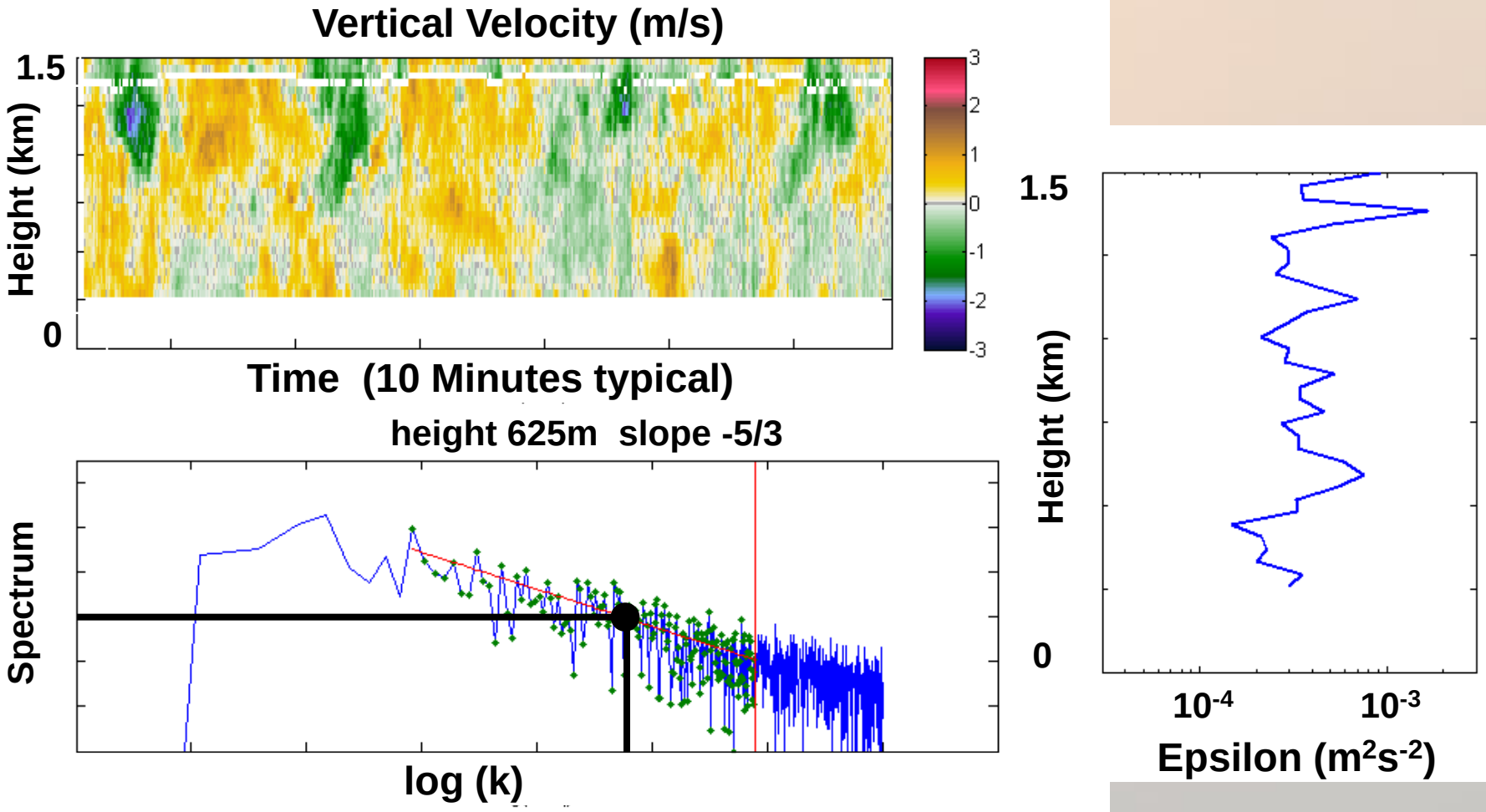


$$TKE = \frac{1}{2}(\sigma_{vert}^2 + \sigma_{hor}^2)$$

$$\frac{2\sigma_{vert}^2}{\sigma_{hor}^2} = \frac{2\sigma_w^2}{(\sigma_u^2 + \sigma_v^2)}$$

The Isotropy ratio is one for isotropic turbulence

Eddy Dissipation Rate

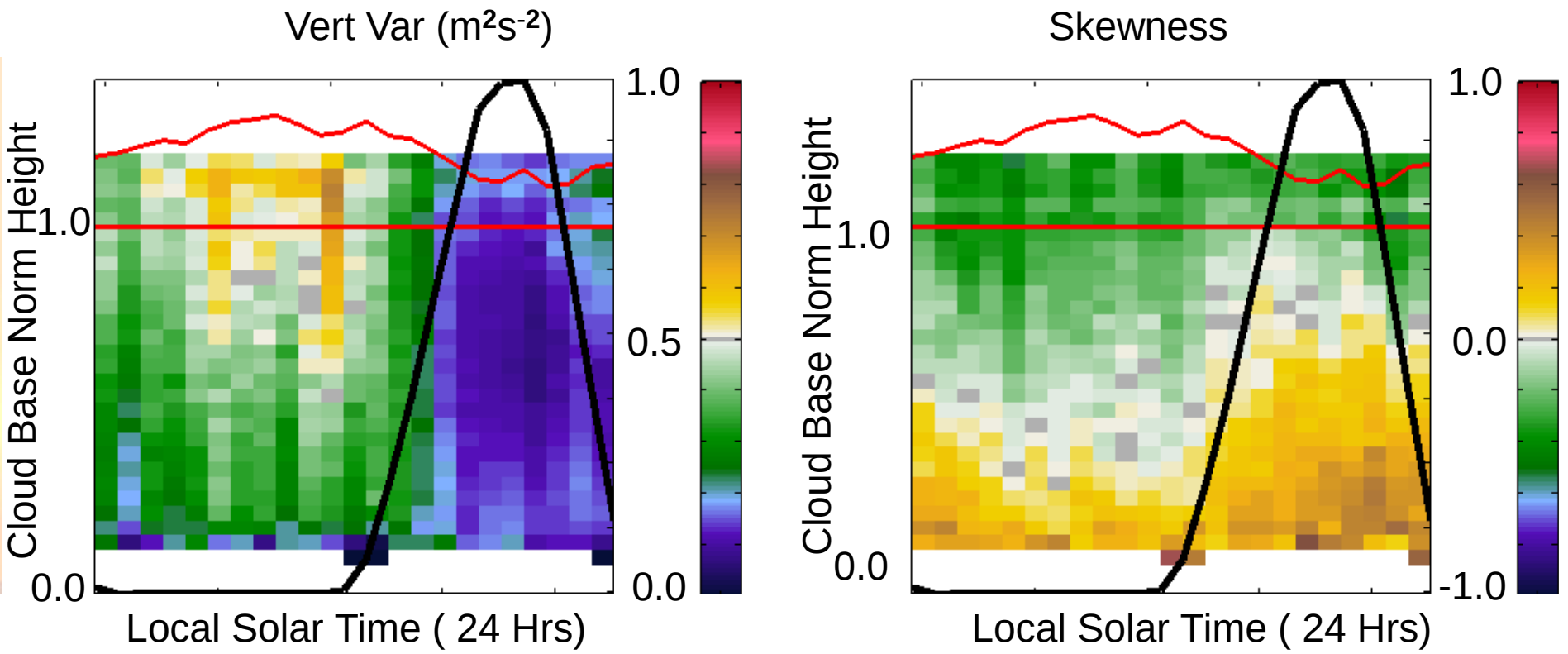


$$S(k) = \alpha \varepsilon^{2/3} k^{-5/3}$$

Composite Turbulence Profiles

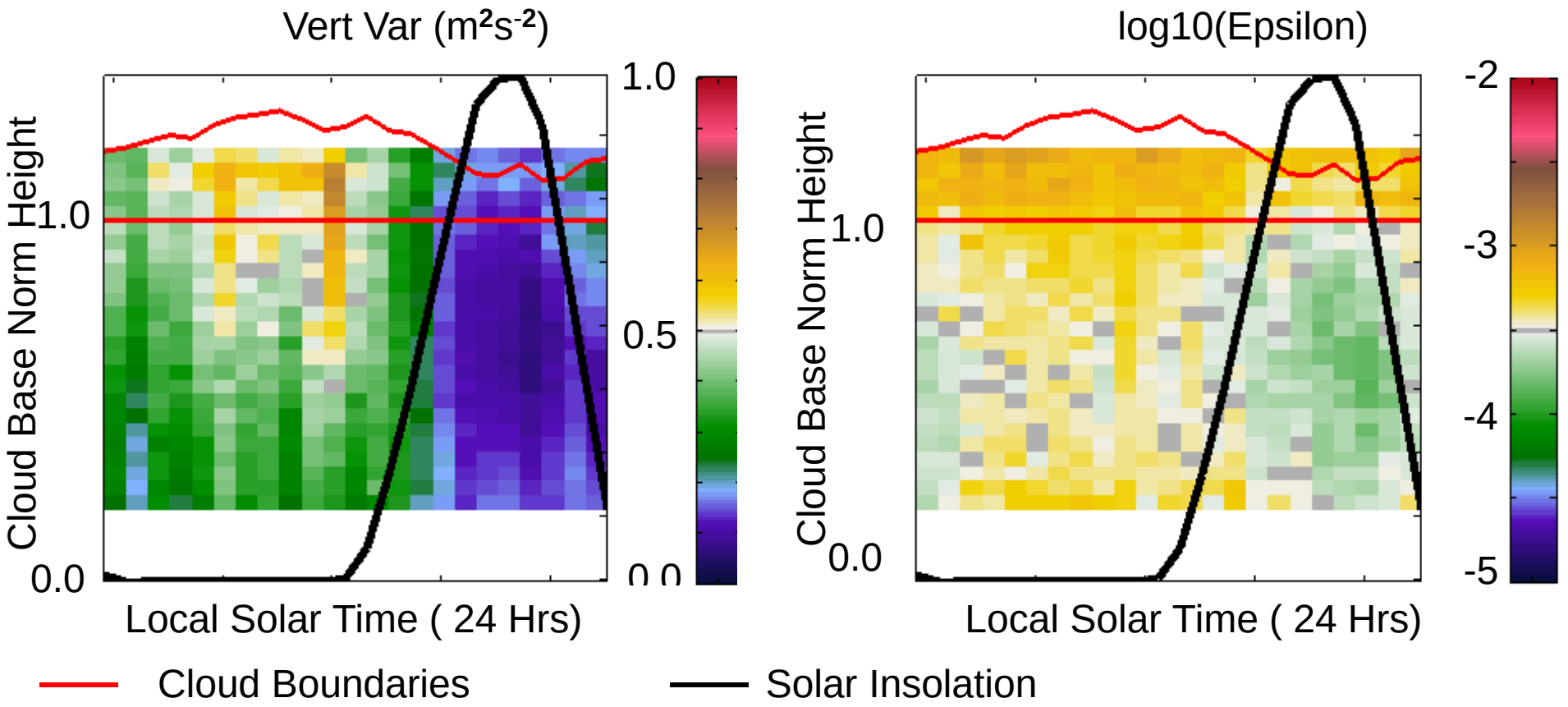
- Form cloud base normalized profiles
- Combine data from entire experiment
- Investigate
  - Diurnal cycle
  - Connection to decoupling and drizzle occurrence

Vertical Velocity Variance and Skewness



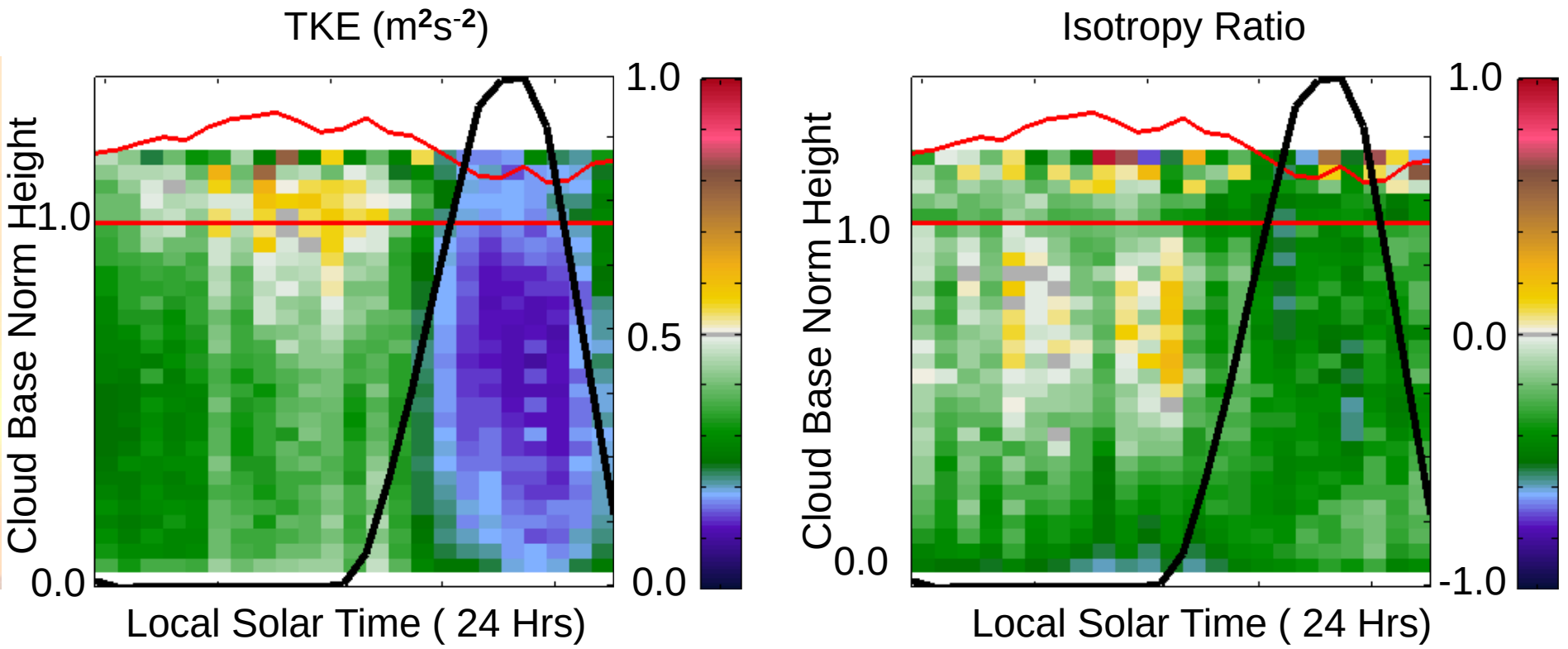
Vertical variance is max at night, skewness consistent with top-down mixing driven by cloud top cooling.

Eddy Dissipation Rate



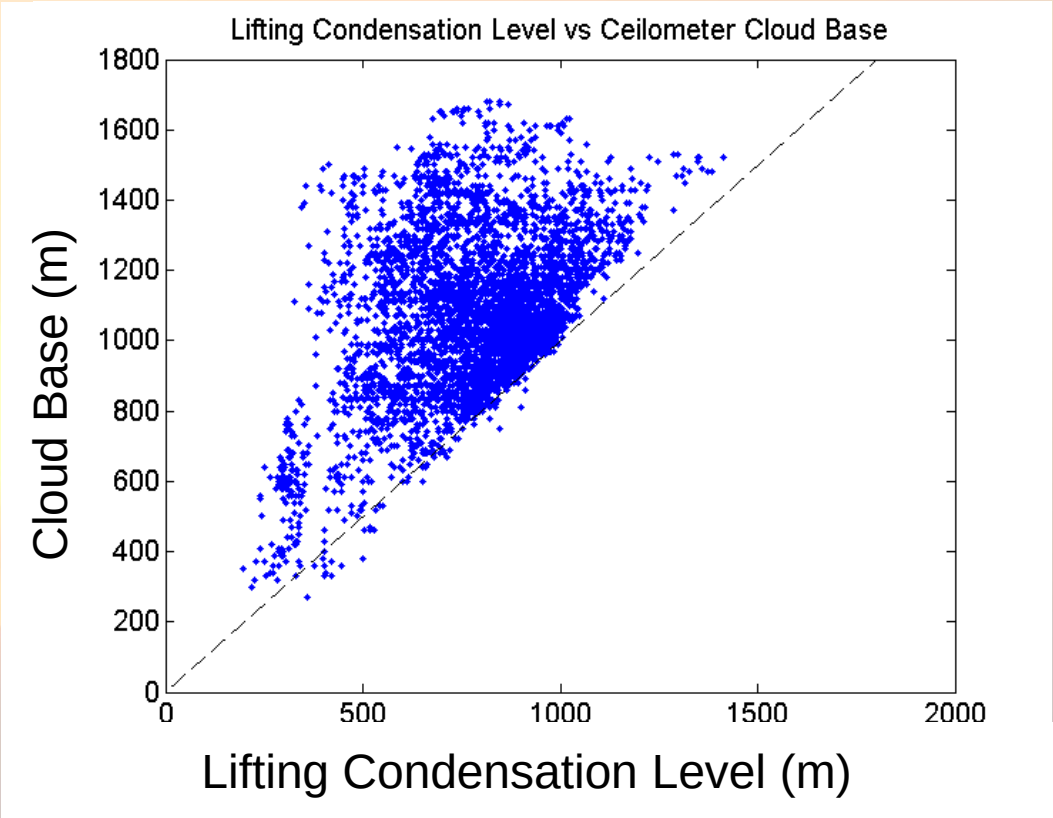
Epsilon has a diurnal pattern with a maximum at cloud base and at the surface

TKE and Isotropy Ratio



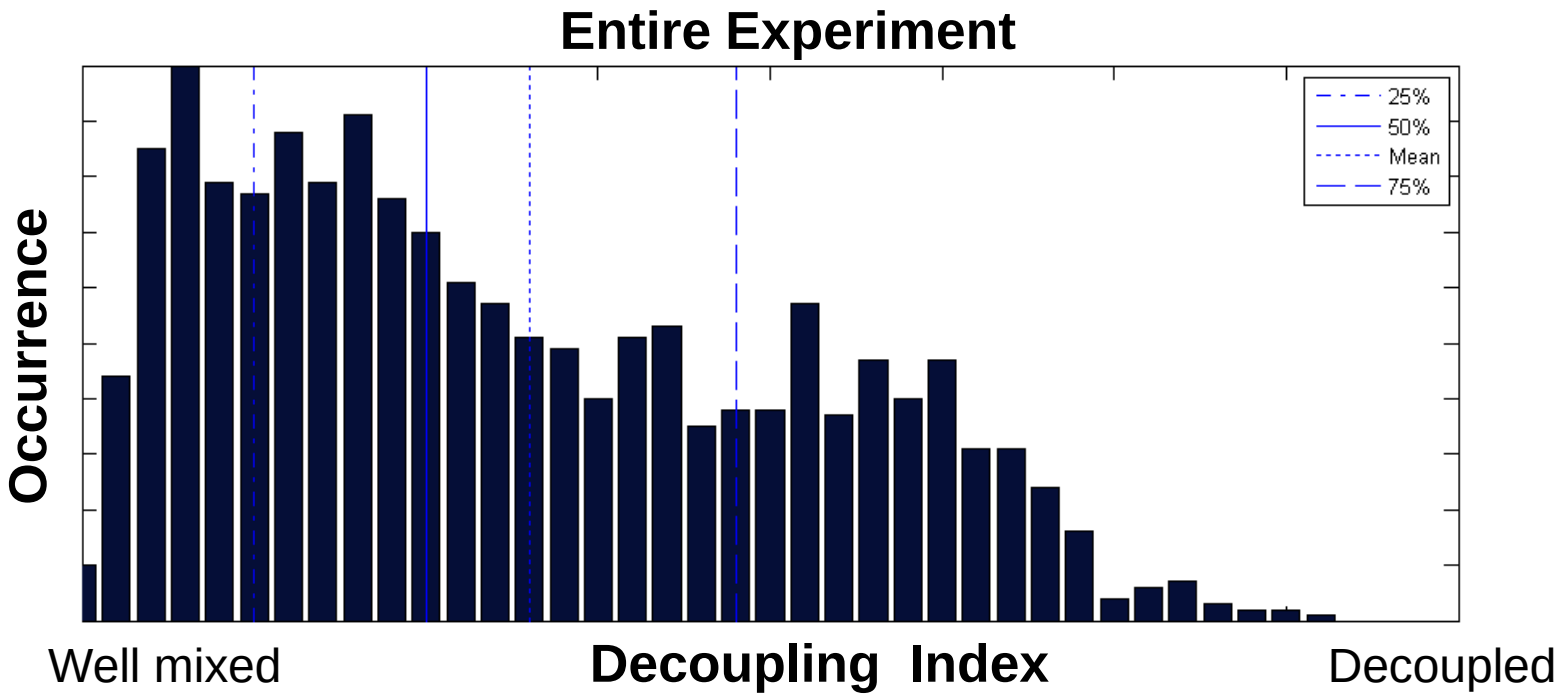
TKE has diurnal pattern with max at cloud base. Isotropy ratio indicates vertical motion most important near center of BL at night. Horizontal motion dominates during day.

Decoupling



$$\text{Decoupling Index} = \frac{\text{Cloud Base} - \text{LCL}}{\text{Cloud Base}}$$

Decoupling and Drizzle Occurrence

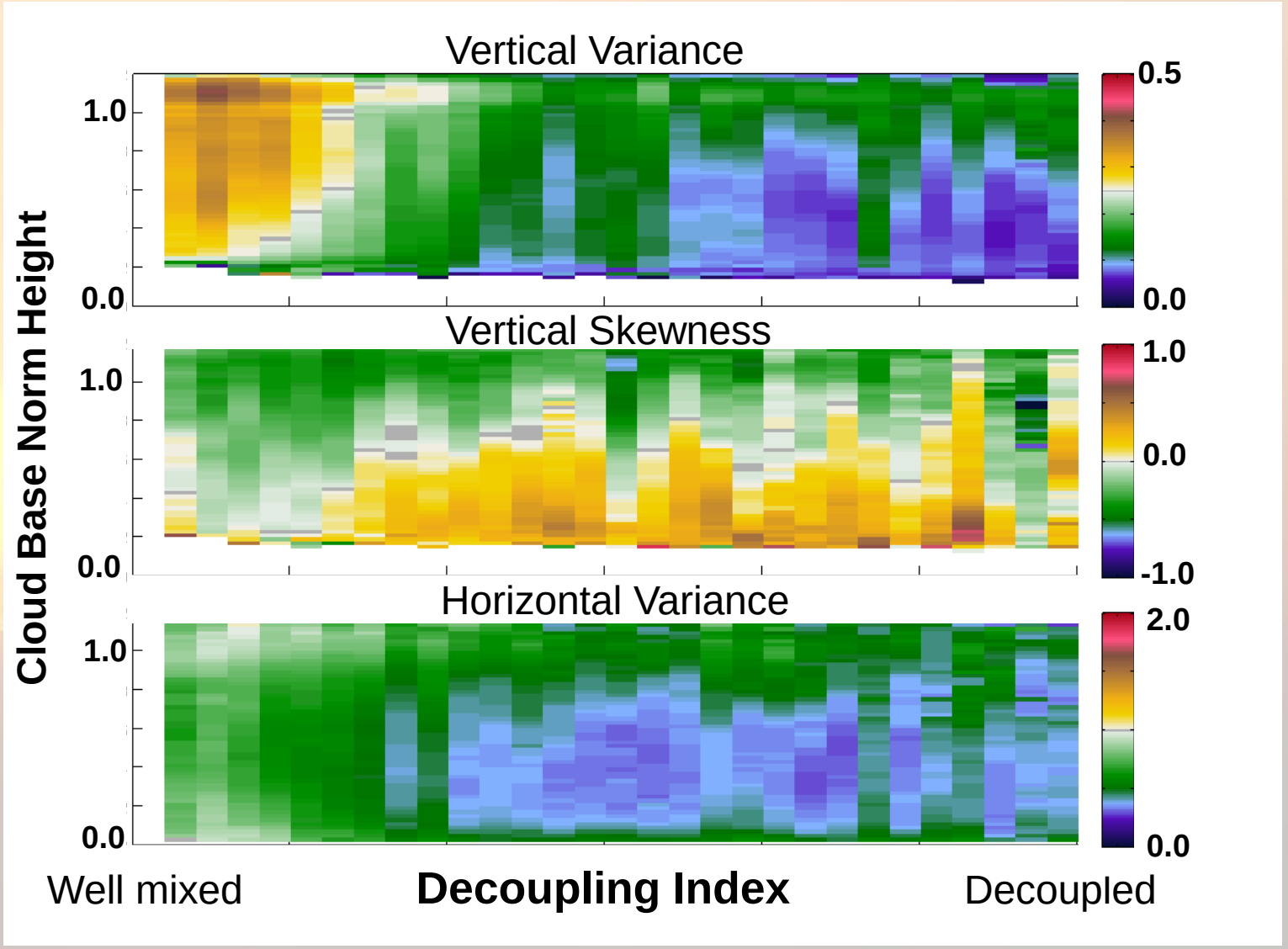


Drizzly Proxy derived from C-Band Radar

Eastern portion relatively well mixed, western portion had more decoupling

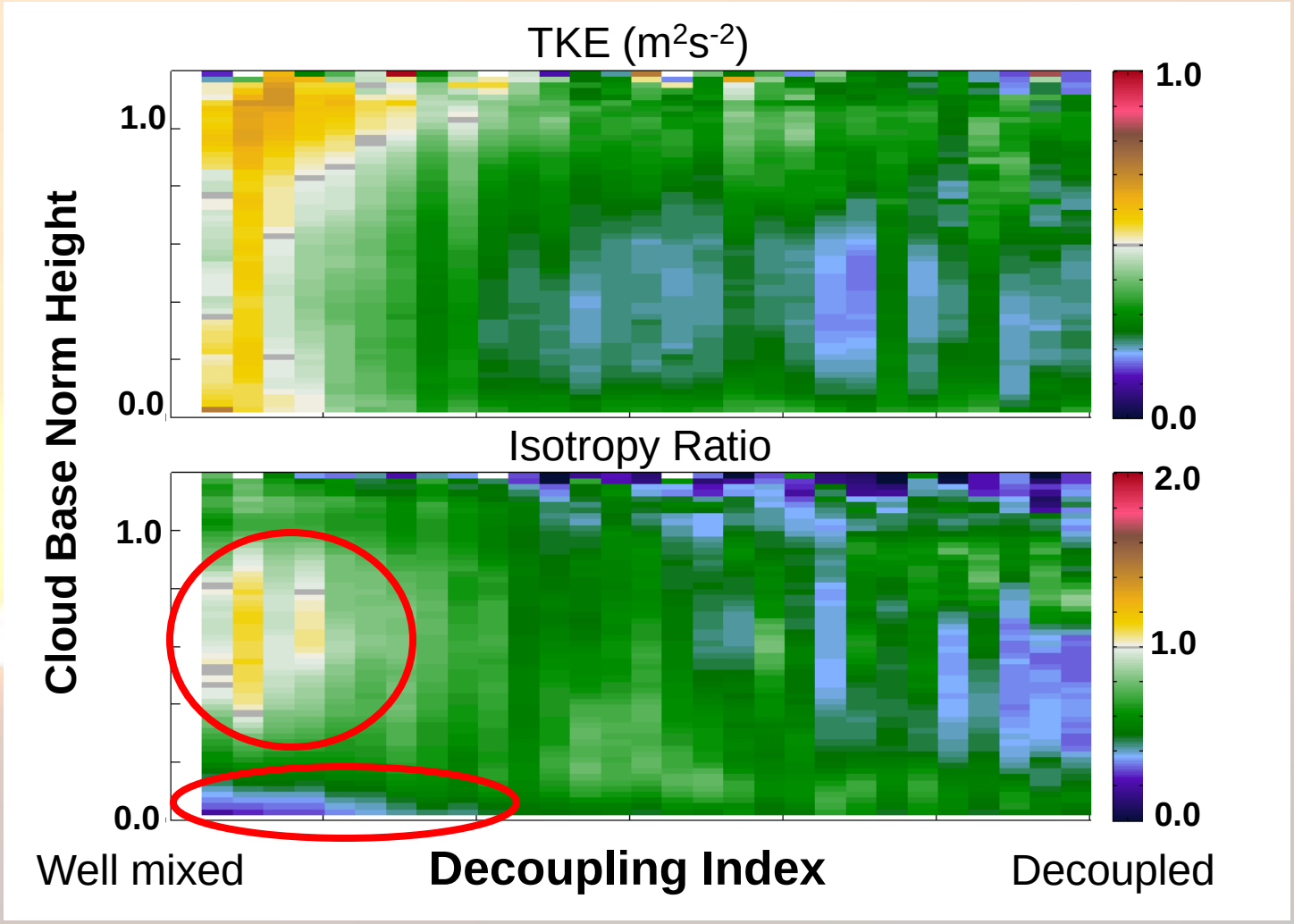
Periods of stronger decoupling are associated with higher drizzle rates

Turbulence Profiles as a function of Decoupling Index



Vertical variance strongest for well mixed BL. Horizontal variance maximum at surface and cloud base.

Turbulence Profiles as a function of Decoupling Index

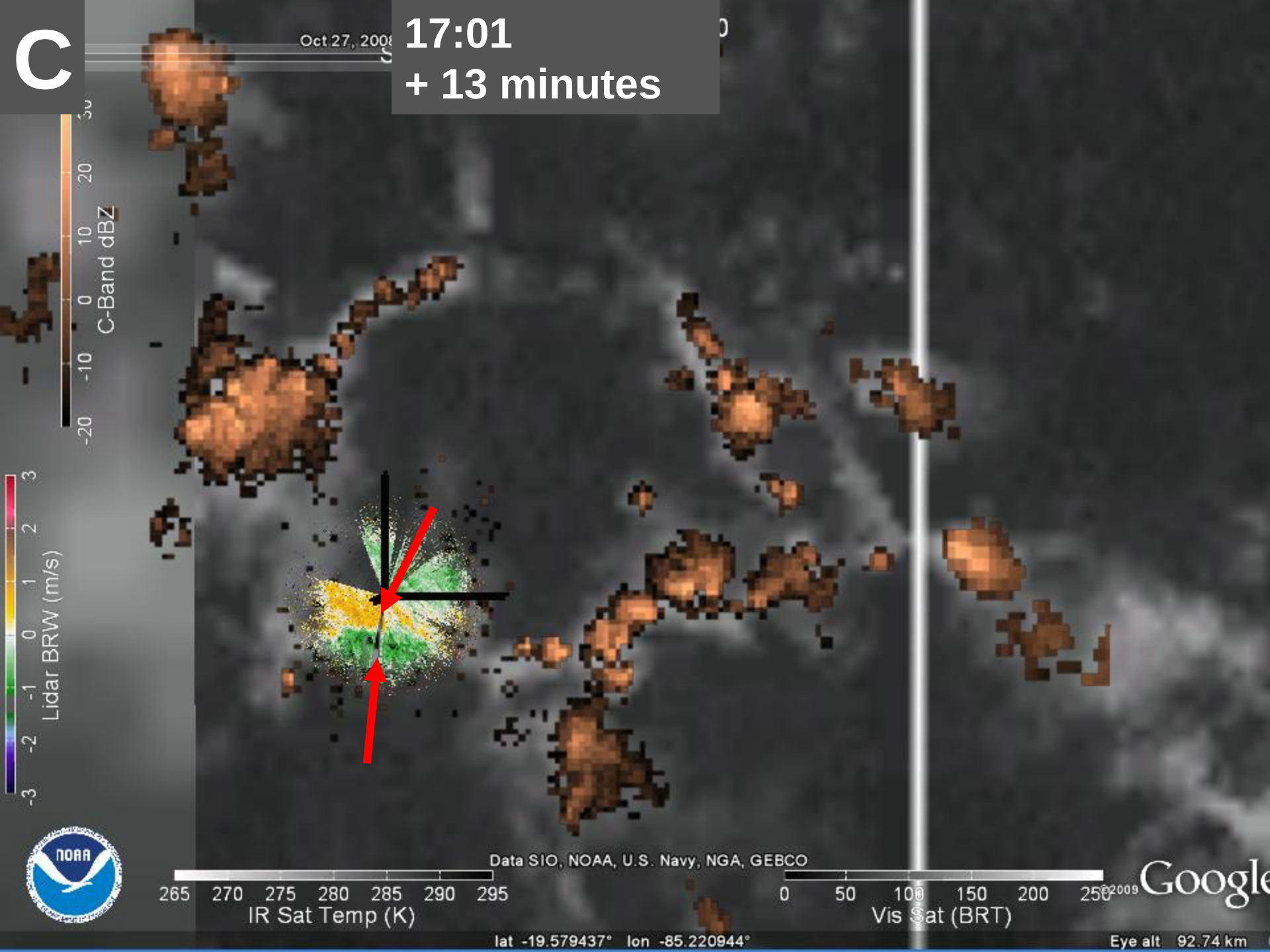


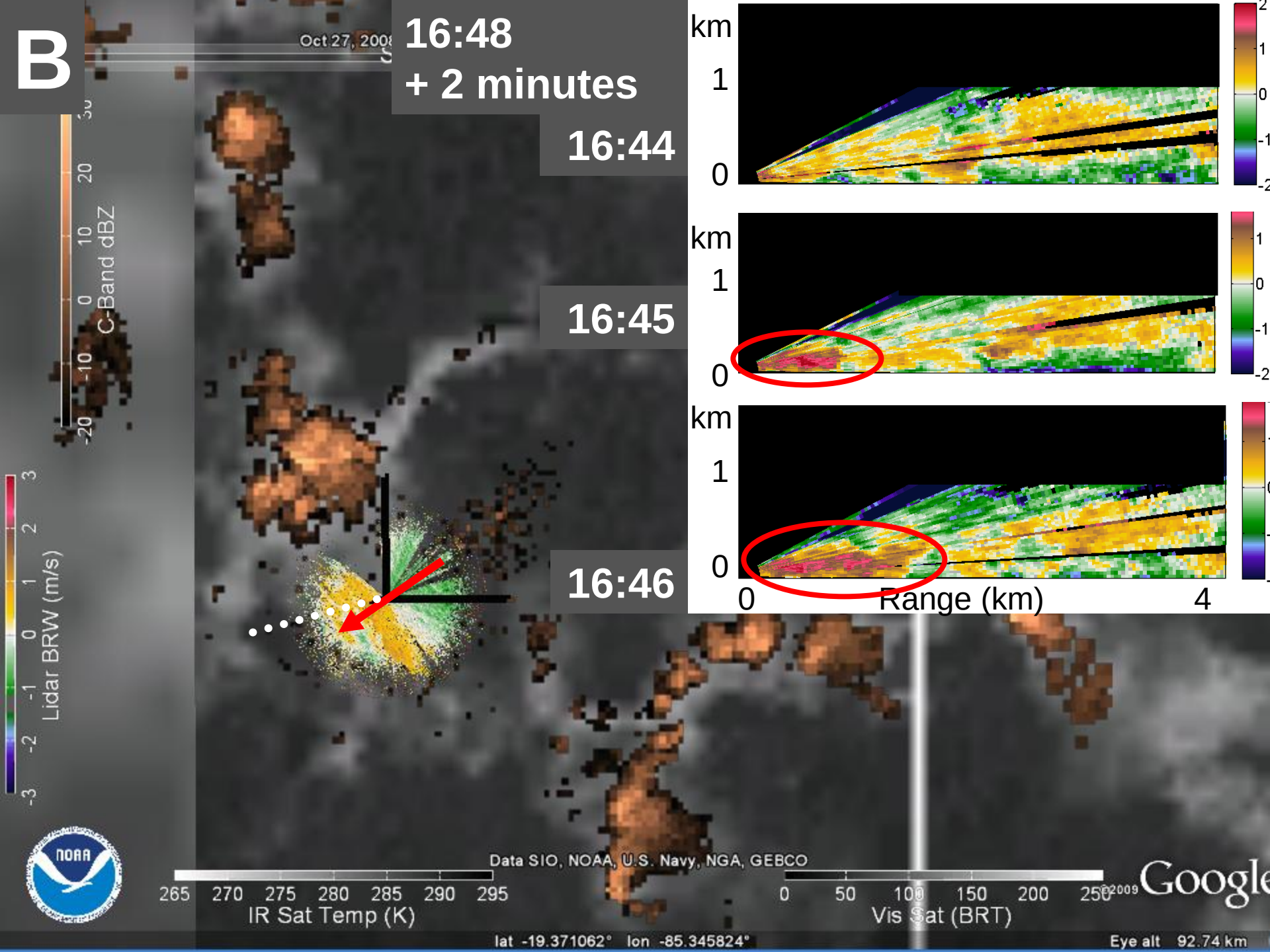
Strongest TKE associated with well mixed BL near cloud base. Ratio: vertical motion important at mid BL with horizontal variance being more important at surface.

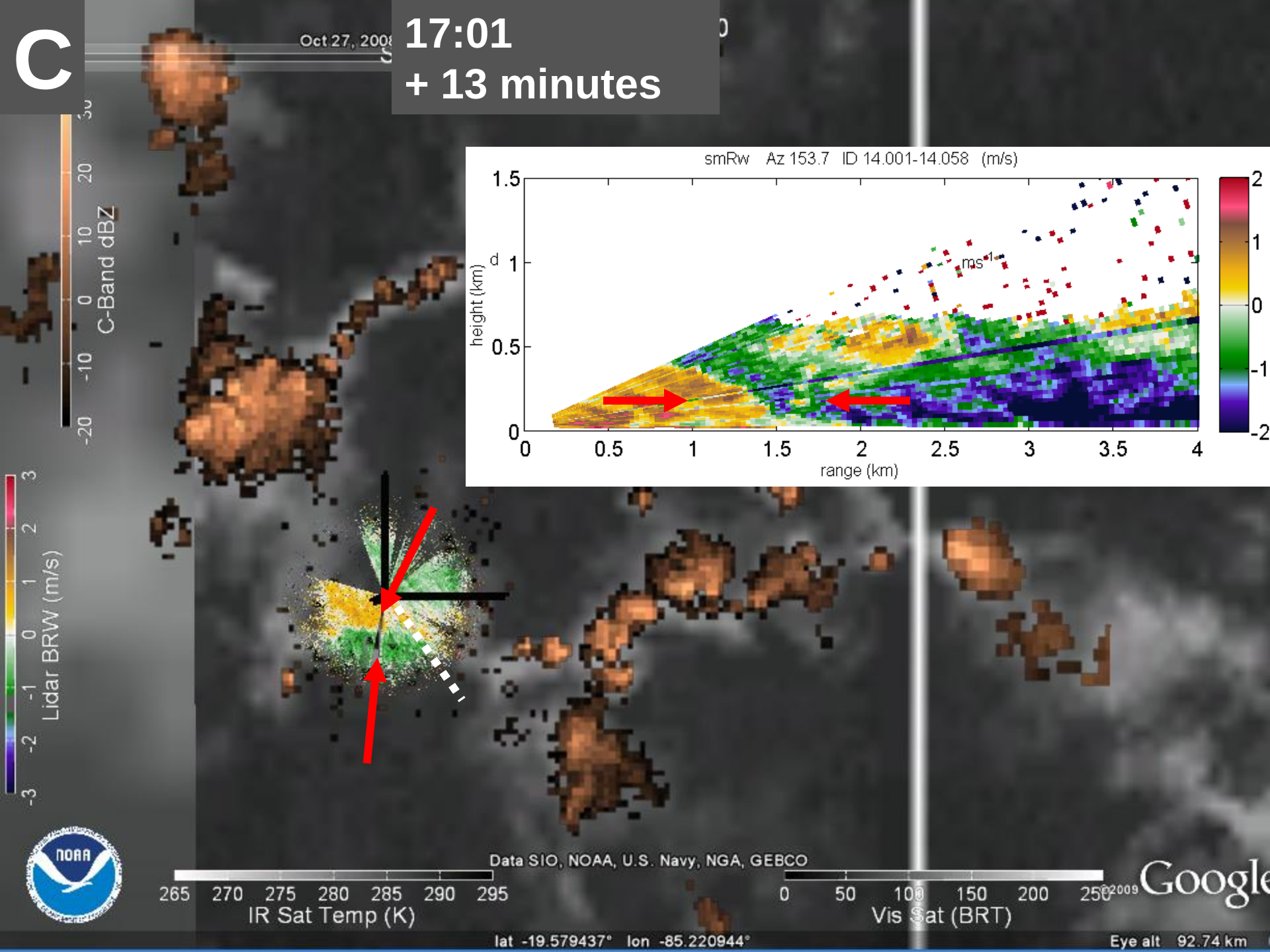
Anatomy of an Open Cell

- Combine scanning remote sensor data
  - Lidar residual velocity
  - C-Band reflectivity

- Temporal resolution : 0.5 - 3 minutes to complete a scan


C
Oct 27, 200
17:01
+ 13 minutes
C-Band dBZ
30
20
10
0
-10
-20
Lidar BRW (m/s)
3
2
1
0
-1
-2
-3
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
265 270 275 280 285 290 295
IR Sat Temp (K)
0 50 100 150 200 250
Vis Sat (BRT)
©2009 Google
lat -19.579437° lon -85.220944°
Eye alt 92.74 km

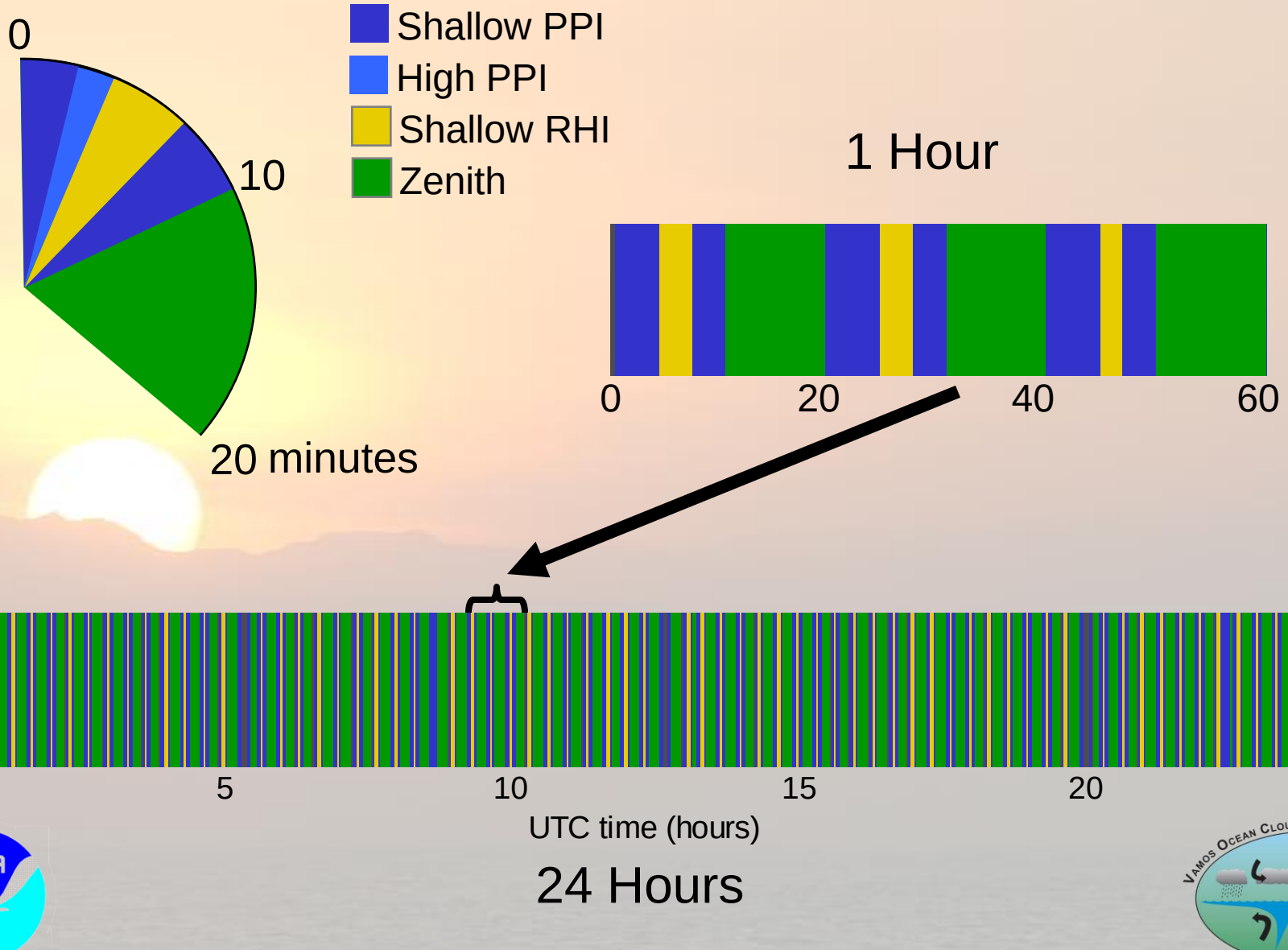

B
16:48
+ 2 minutes
16:44
16:45
16:46
C-Band dBZ
Lidar BRW (m/s)
km
1
0
Range (km)
0
4
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
IR Sat Temp (K)
265 270 275 280 285 290 295
Vis Sat (BRT)
0 50 100 150 200 250
Google
lat -19.371062° lon -85.345824°
Eye alt 92.74 km


C
17:01
+ 13 minutes
Oct 27, 200
C-Band dBZ
30
20
10
0
-10
-20
smRw Az 153.7 ID 14.001-14.058 (m/s)
height (km)
range (km)
ms-1
1.5
1
0.5
0
0.5
1.5
2
2.5
3
3.5
4
2
1
0
-1
-2
Lidar BRW (m/s)
3
2
1
0
-1
-2
-3
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
265 270 275 280 285 290 295
IR Sat Temp (K)
0 50 100 150 200 250
Vis Sat (BRT)
©2009 Google
lat -19.579437° lon -85.220944°
Eye alt 92.74 km

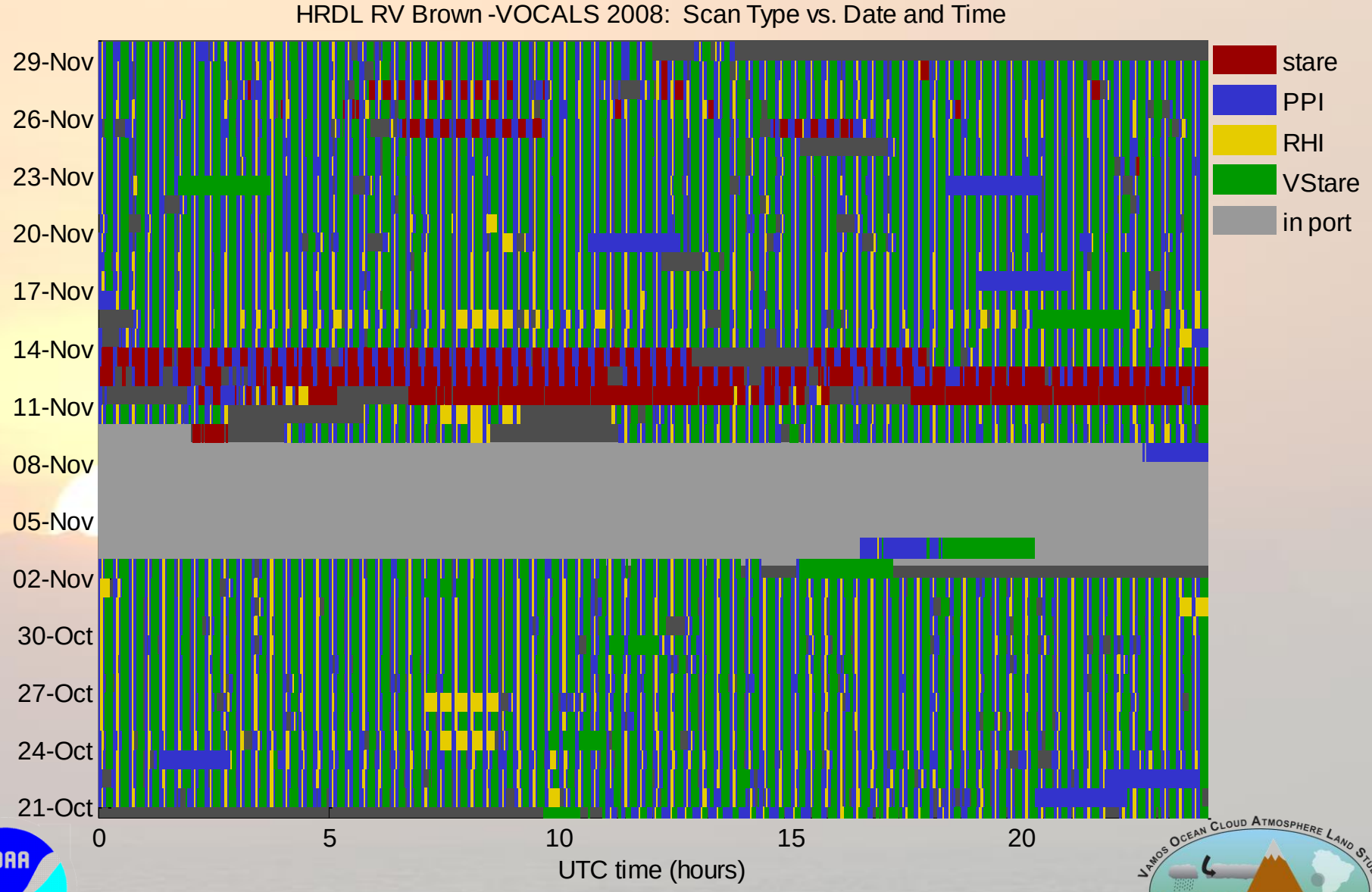
Summary

- Lidar observational data used to create statistical accumulations of turbulence quantities
- Scanning remote sensing data used to study structure and time evolution of open cell boundaries.
- Results from both approaches are being be used to compare to LES models.

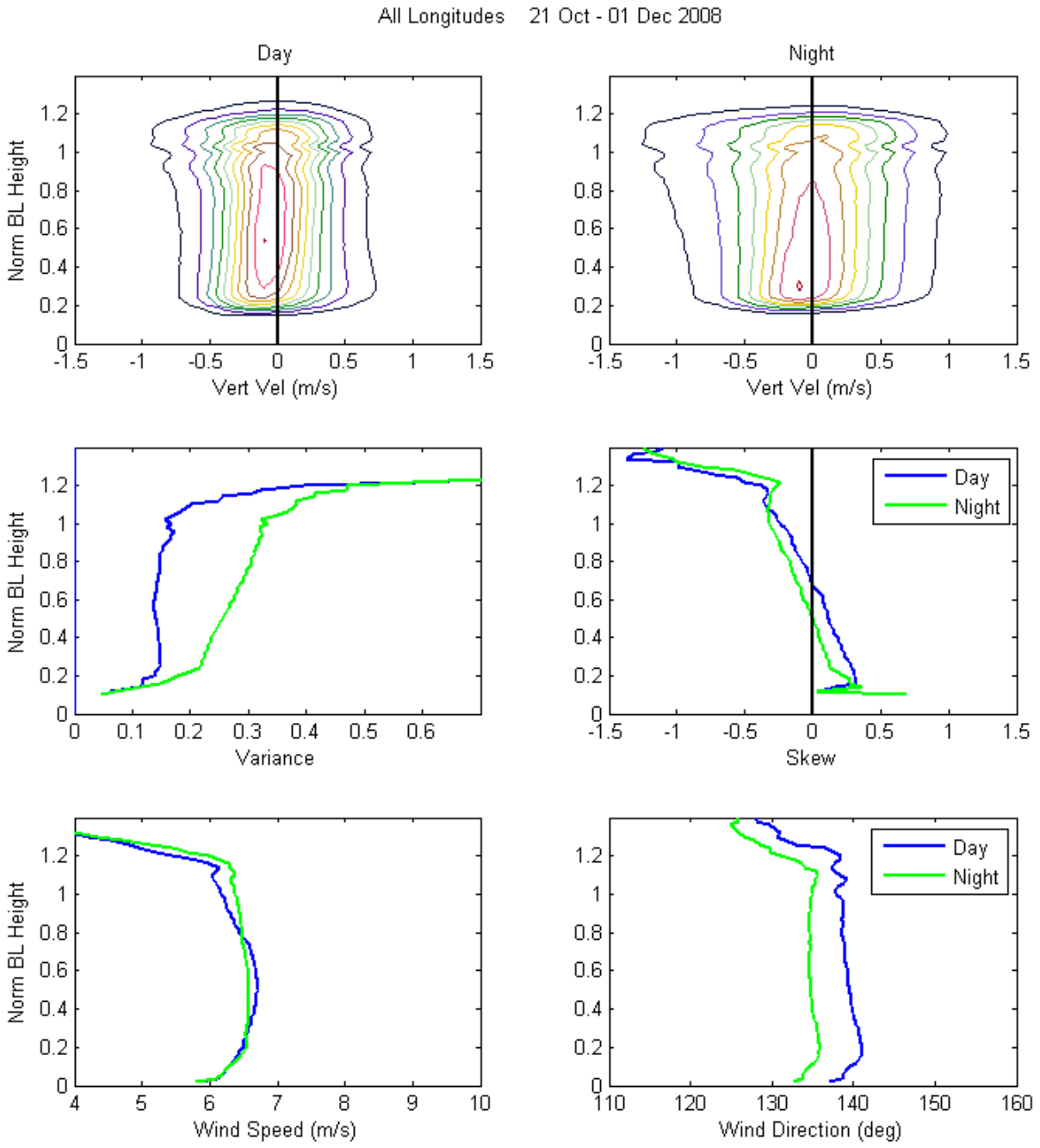
Repeating 20 minute scan sequence



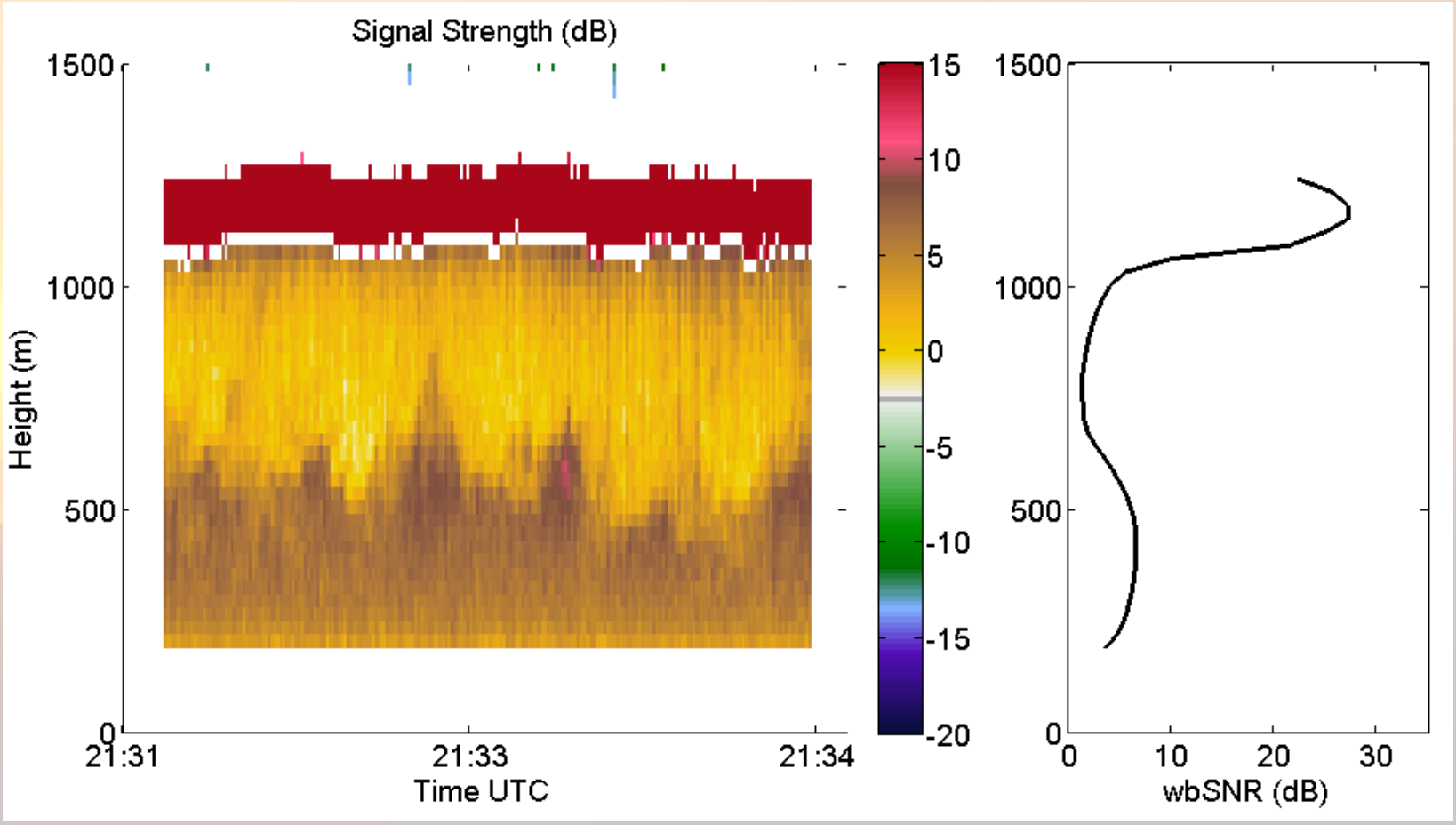
Continuous operation 21 Oct – 30 Nov 2008

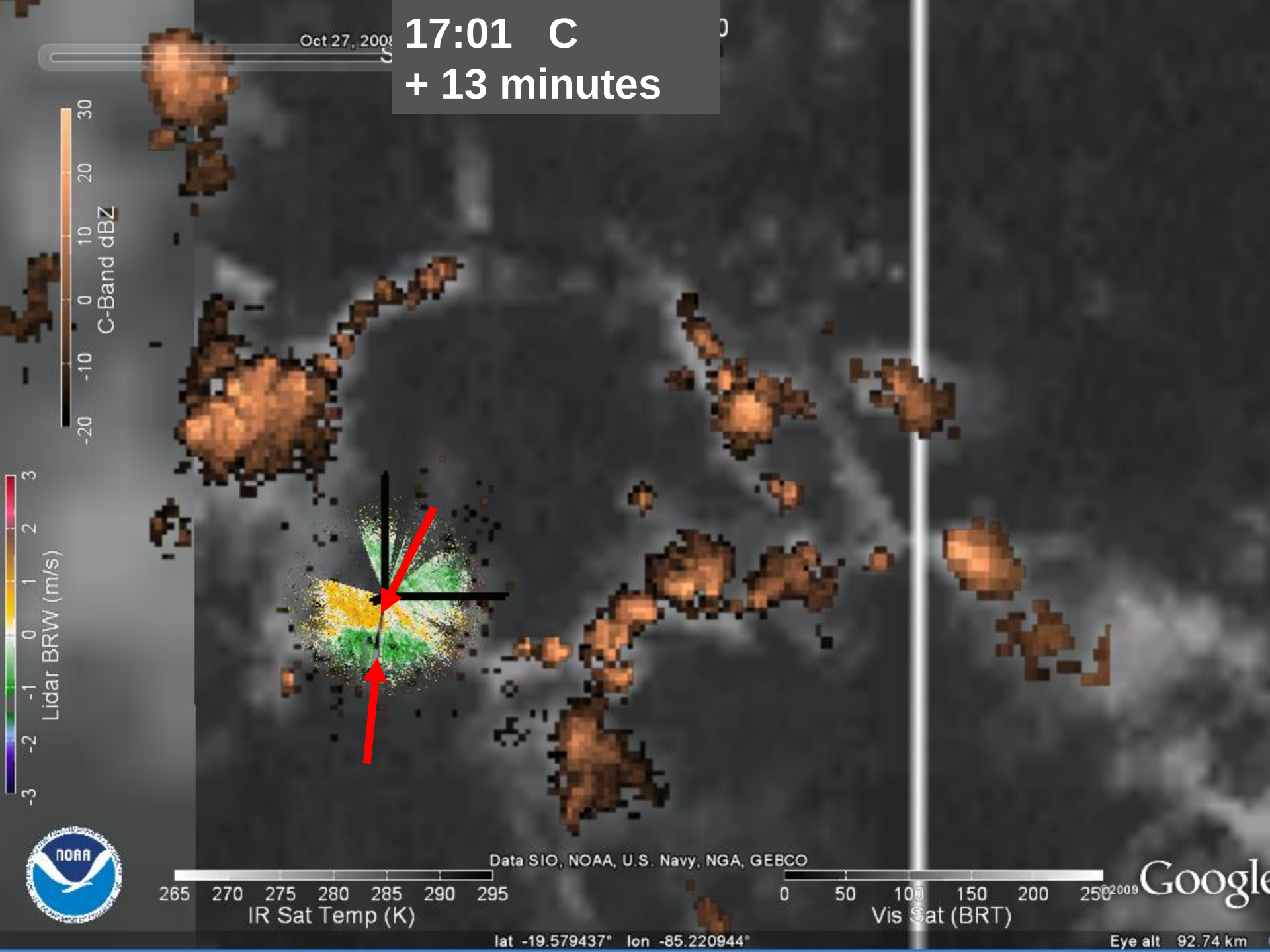


Average profiles from entire experiment: day vs night



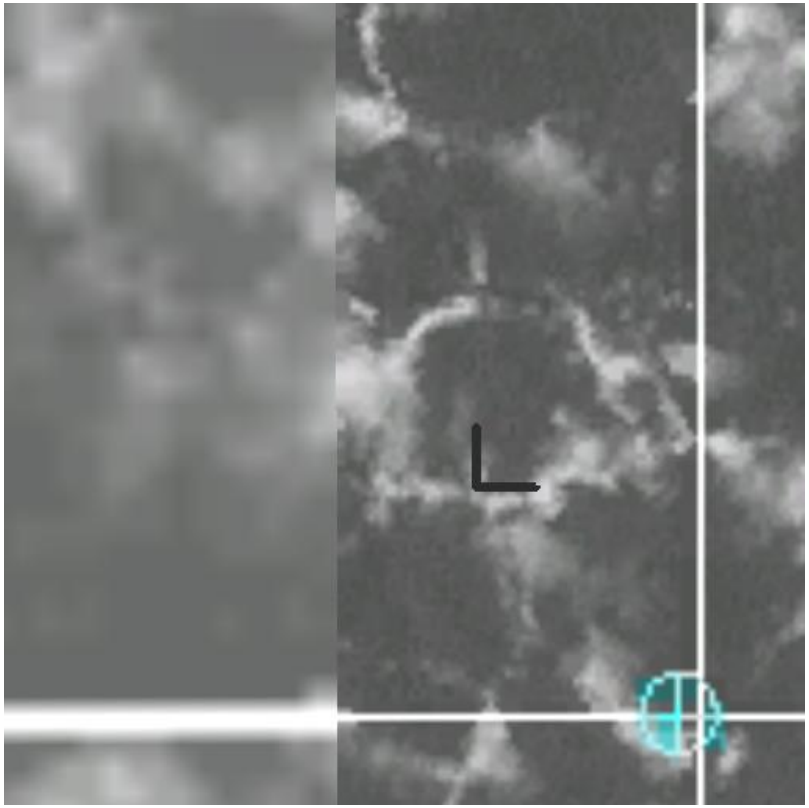
Combining vertical and horizontal velocity data to form turbulence profiles.




17:01 C
+ 13 minutes
Oct 27, 200
C-Band dBZ
30
20
10
0
-10
-20
Lidar BRW (m/s)
3
2
1
0
-1
-2
-3
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
265 270 275 280 285 290 295
IR Sat Temp (K)
0 50 100 150 200 250
Vis Sat (BRT)
©2009 Google
lat -19.579437° lon -85.220944°
Eye alt 92.74 km

GOES Imagery: VOCALS

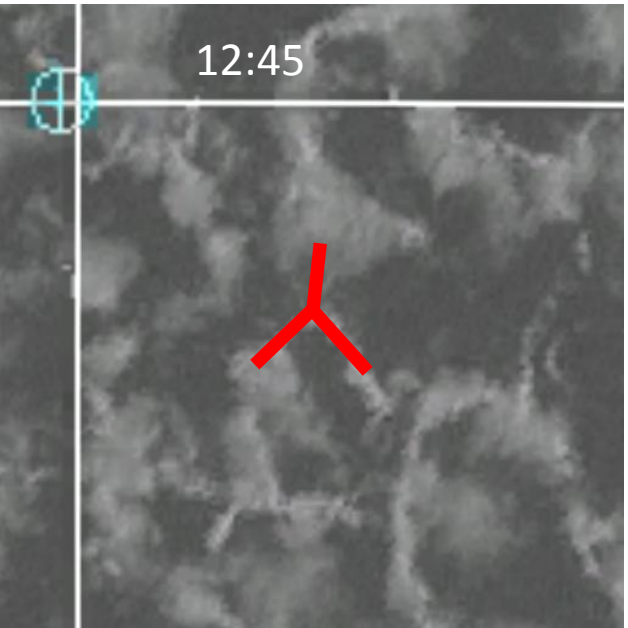
October 27 2008

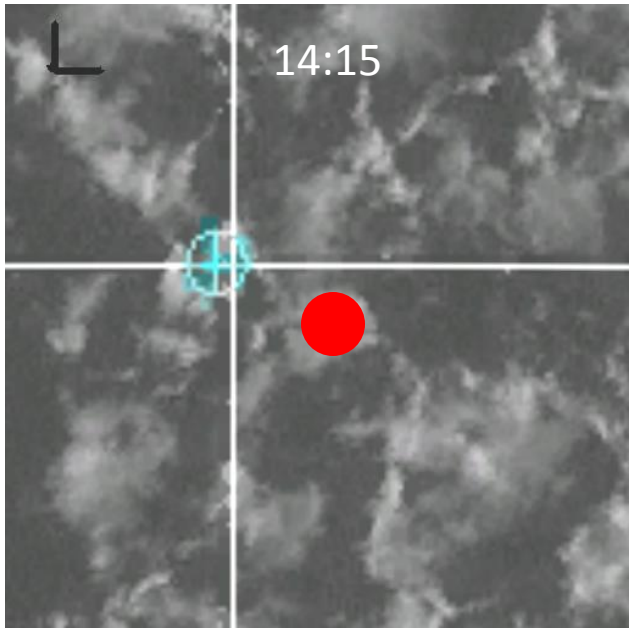


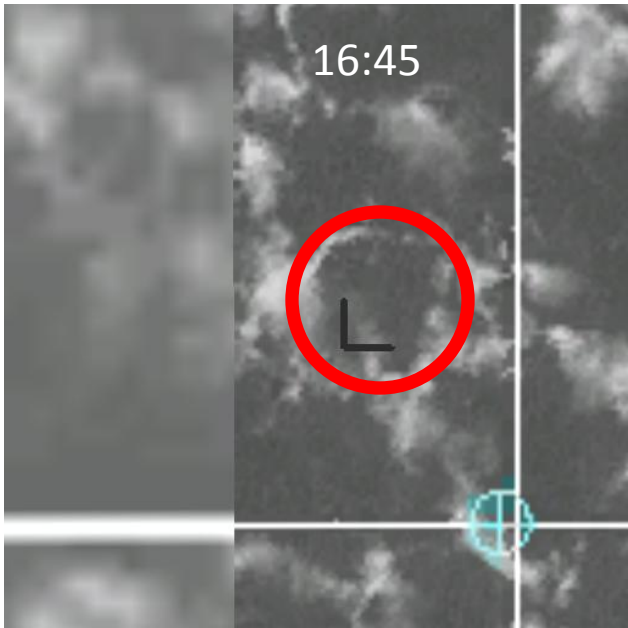
15 minute time steps
Advection removed

25 km

Ship location







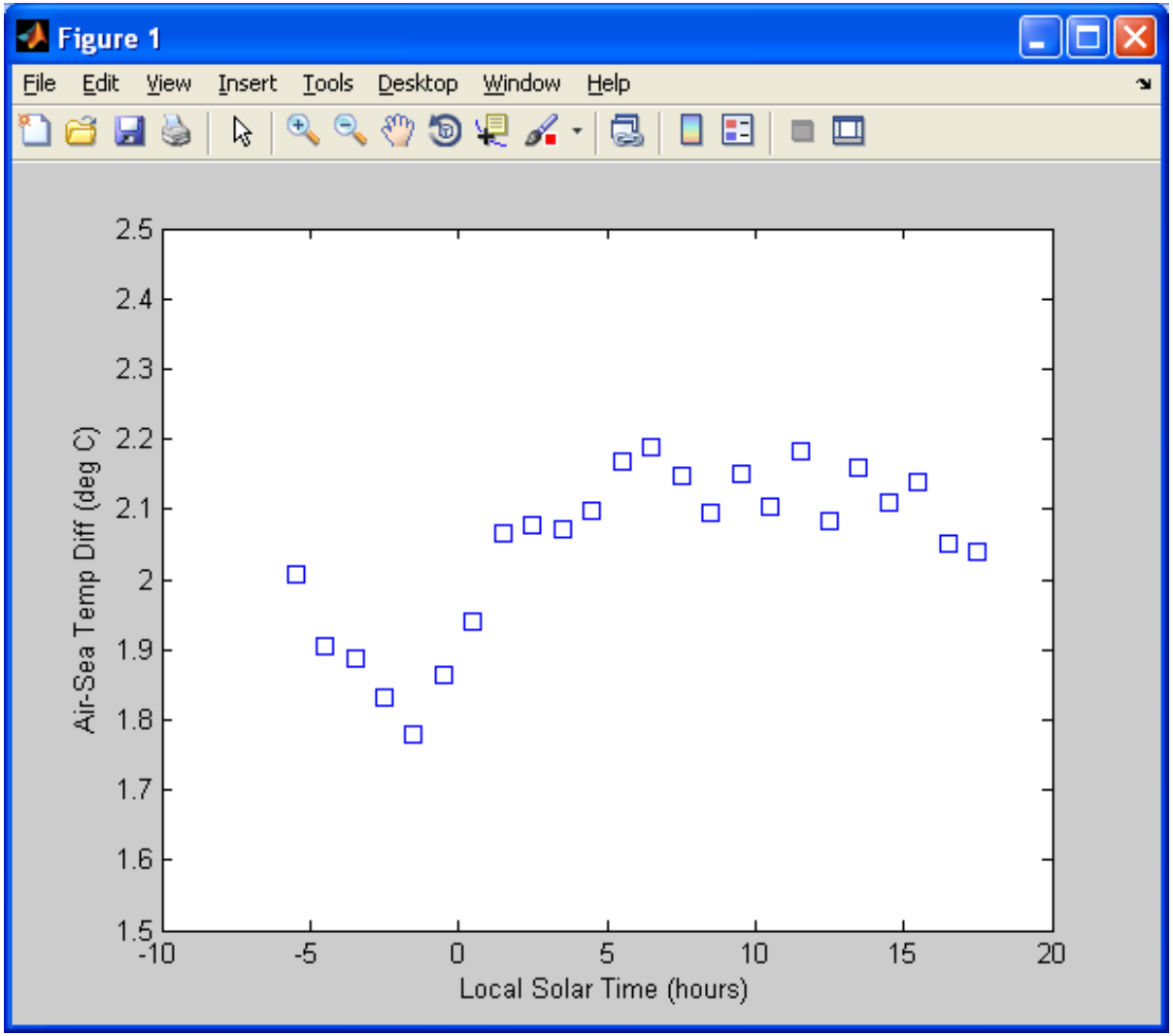


Figure 1
File Edit View Insert Tools Desktop Window Help
Air-Sea Temp Diff (deg C)
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
-10
-5
0
5
10
15
20
Local Solar Time (hours)