The Relation between Nocturnal MCS Evolution and Its Outflow Boundaries in the Stable Boundary Layer

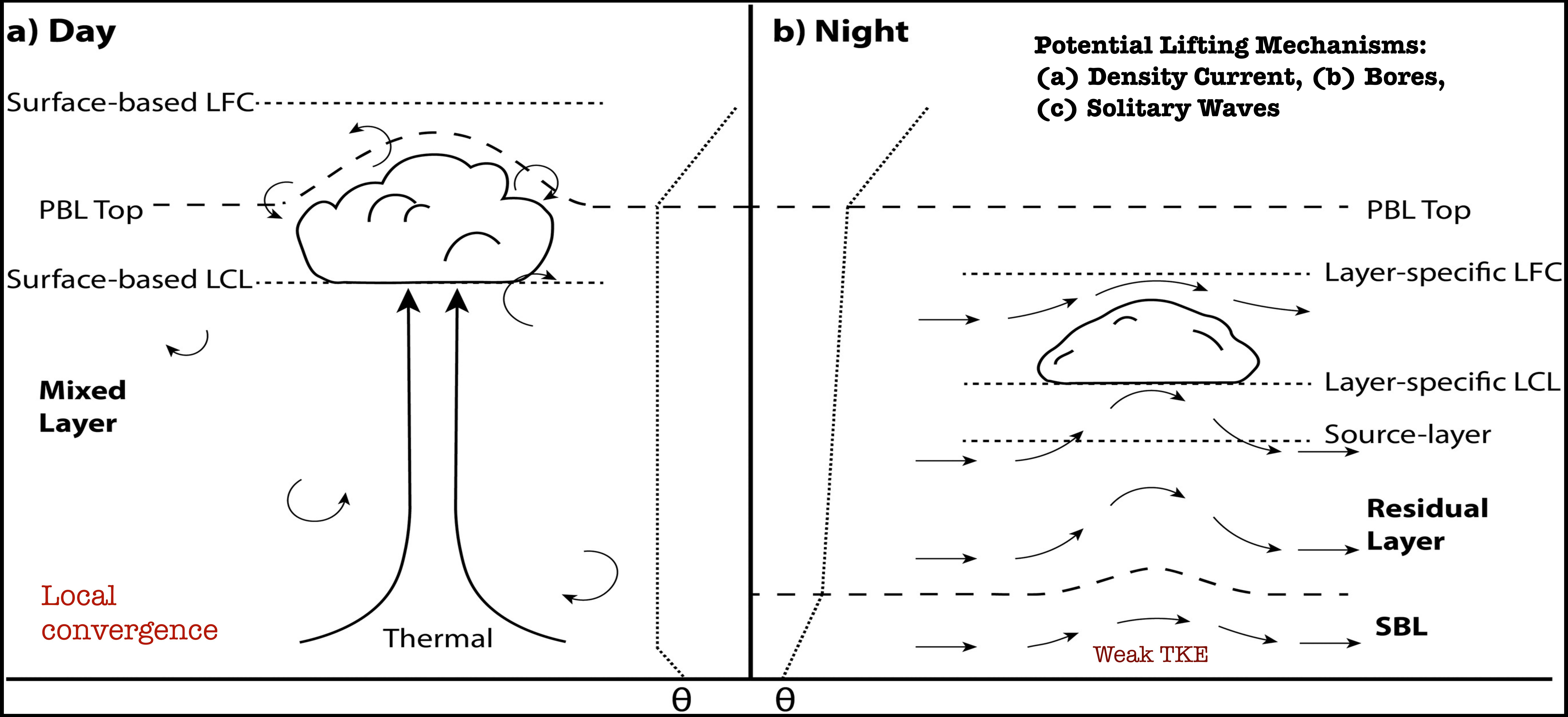
An Observational Study of the 15 July 2015 MCS in PECAN

(Grasmick, Geert, Turner, Wang, and Weckwerth; MWR 2018)

Keywords

- Bores
- Density currents
- Lifting mechanisms in the presence of Stable Boundary Layers
- Convective Initiation

Parcel Lifting and Layer Lifting



How to observe Potential Lifting Mechanisms?

- Surface observations
- Reflectivity maps
- Profiling instruments (Spatial coverage lacking)
- Transversing research aircrafts (Direct observations, rare)

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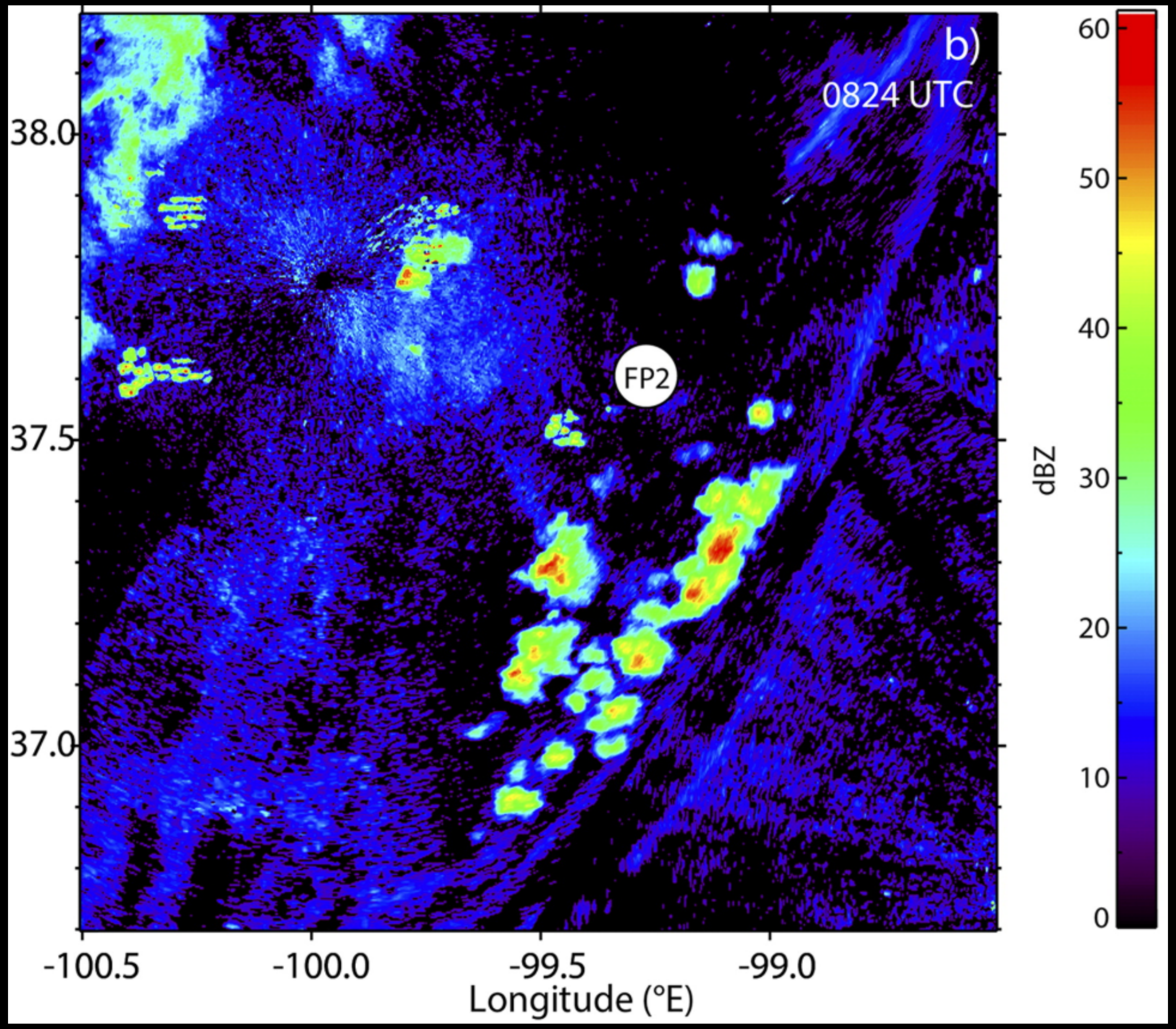


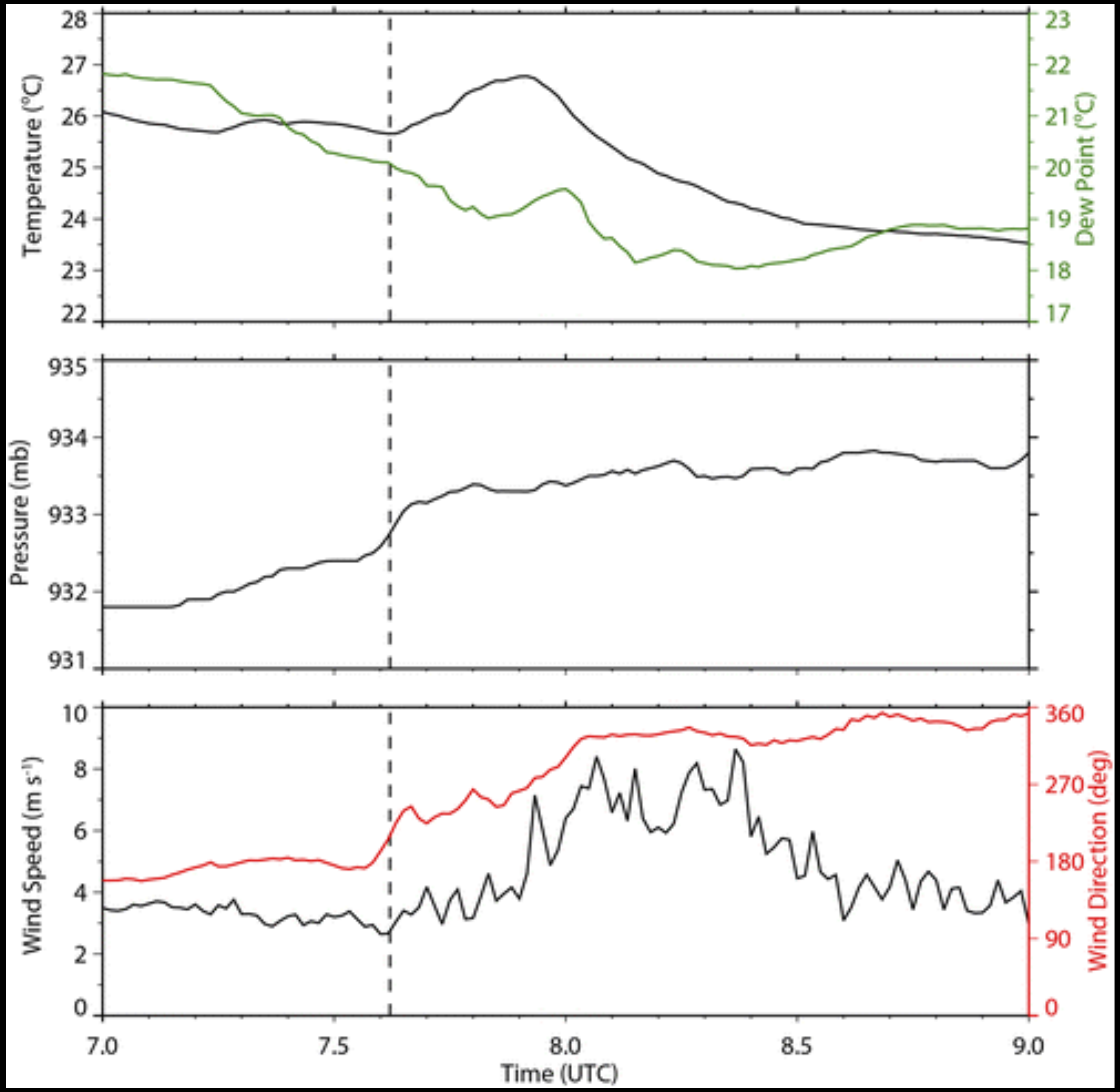


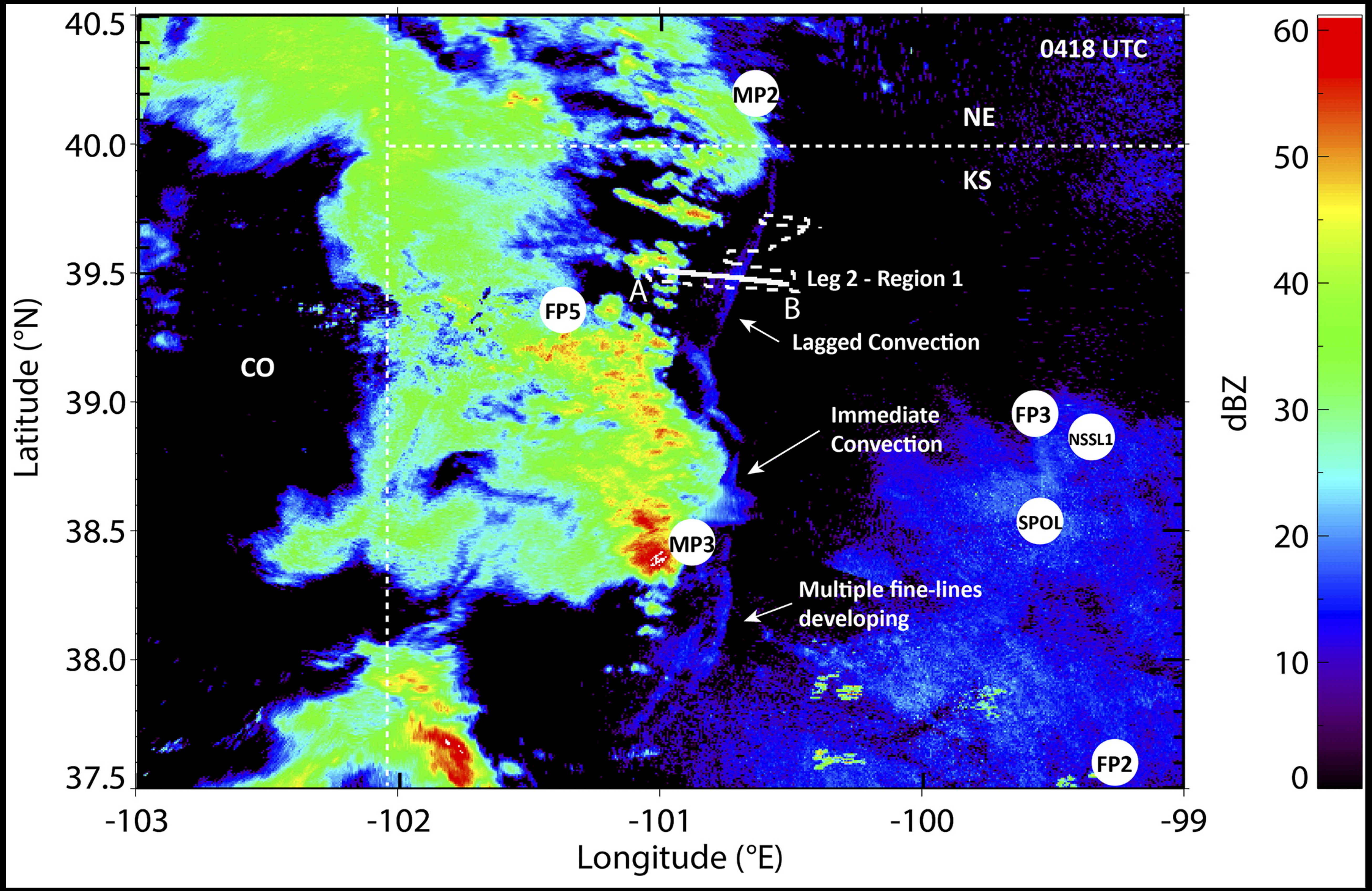
Fig. 16. Surface station data for FP2. The dashed line marks the arrival of the bore.

Instrumentation

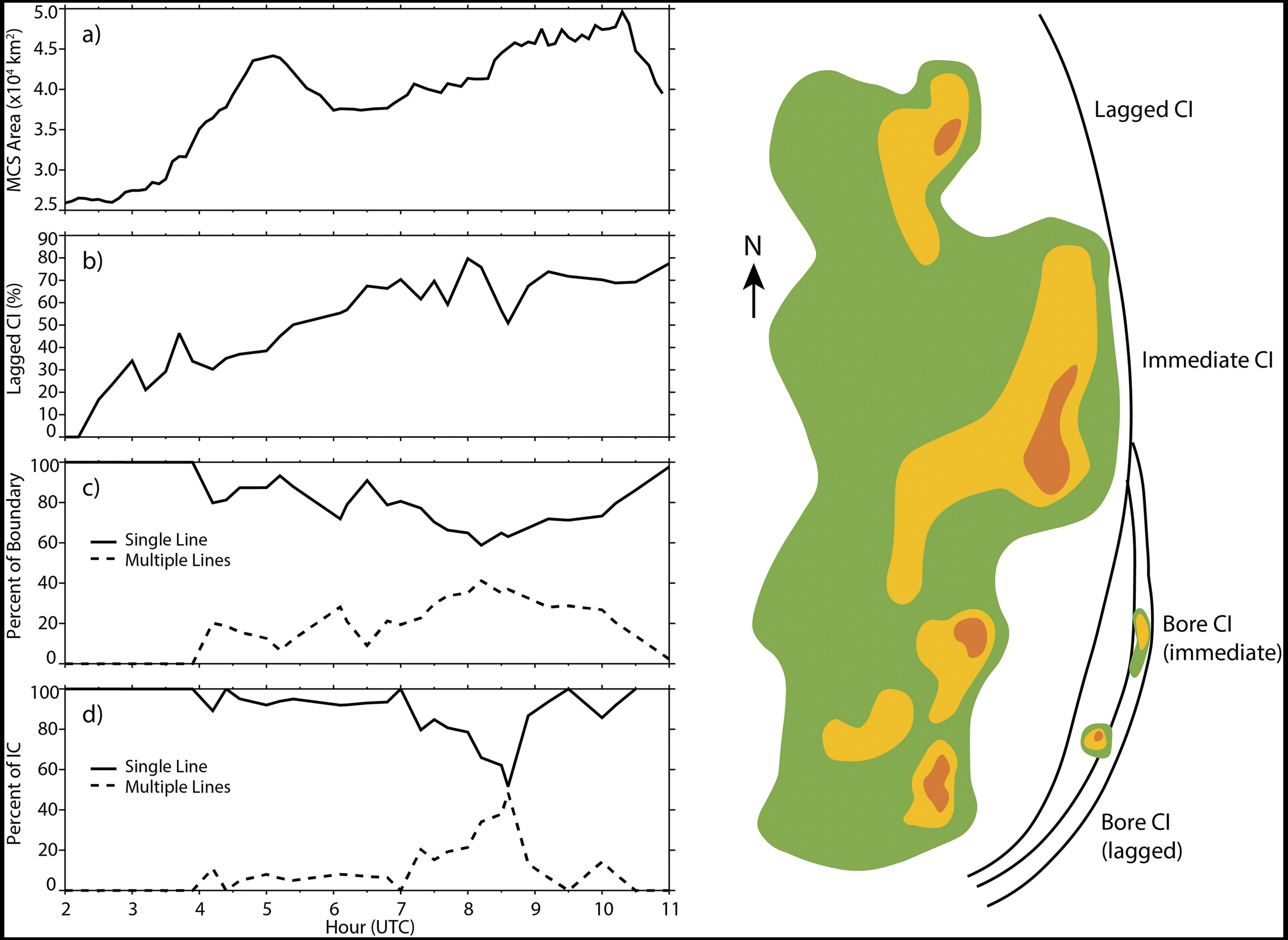
Platform and location	Instruments used	Outflow boundary passage
FP2—Greensburg, KS	Radiosonde (Vermeesch 2015), AERI (Turner 2016a), surface station (UCAR/NCAR–Earth Observing Laboratory 2016a)	0744 UTC
FP3—Ellis, KS	Radiosonde (Clark 2016), AERI (Turner 2016b), surface station (Clark 2015)	0602 UTC
FP5—Brewster, KS	Radiosonde (UCAR/NCAR–Earth Observing Laboratory 2016b), AERI (Turner 2016c), surface station (UCAR/NCAR–Earth Observing Laboratory 2016d)	0254 UTC
MP2—McCook, KS	Radiosonde (Knupp 2015)	0425 UTC
MP3—Scott City, KS	Radiosonde (Wagner et al. 2016a), AERI (Wagner et al. 2016c), surface station (Wagner et al. 2016b)	0348 UTC
NSSL1—Hays, KS	Radiosonde (Ziegler et al. 2016)	0623 UTC
UWKA	1-Hz flight-level data (University of Wyoming–Research Flight Center 2017a), CRL (Wang et al. 2016), WCL (UWRFC 2017b)	—
S-Pol—38.55°N, 99.54°E	S/Ka-band dual polarization dual wavelength Doppler radar (UCAR/NCAR–Earth Observing Laboratory 2016c)	0618 UTC

- AERI
- Radiosonde
- UWKA flight-level data, Cloud Lidar (WCL+CRL)

Event Overview



- Southerly LLJ (~22 m s-1) by 0600UTC
- Multiple "fine-lines", indicative of potential lifting mechanisms
- Signs of bores south of MP3
- Strongest convection -> Small gap between CI location, fine-line
- Weaker convection -> Large gap between CI location and

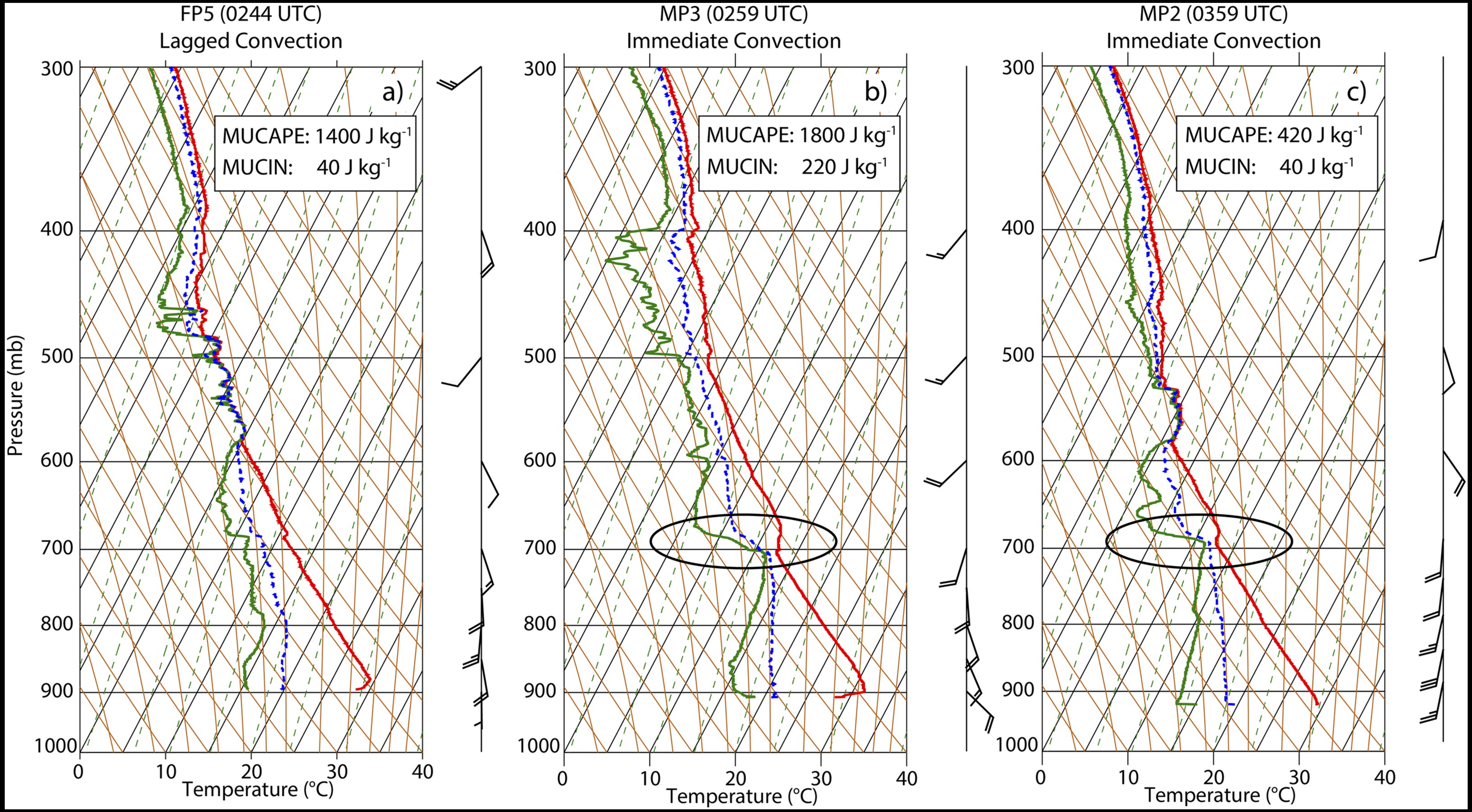


- Increased "Lagged-CI" coverage during strength stalling - weakening phase
- Multiple Lines **correlates with** MCS area expansion
- Direct CI by bores between 07-09UTC

Convergent boundary classification and ensuing vertical displacement

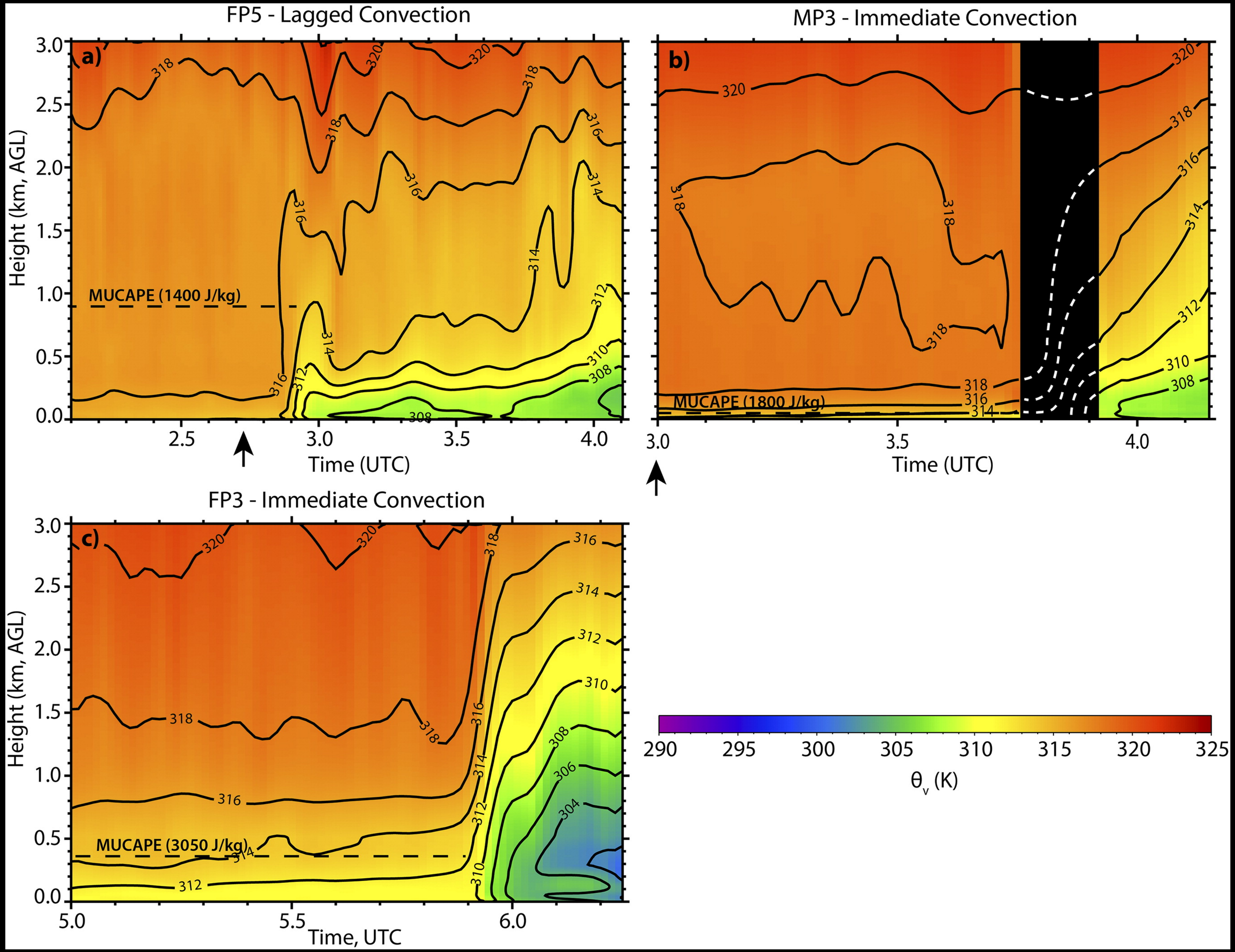
1. Lagged and immediate convection initiation
2. UWKA density current and bore transects
3. Bore-induced vertical displacements

Lagged and Immediate CI



Pre-line environments cannot differentiate Lagged CIs from Immediate CIs!

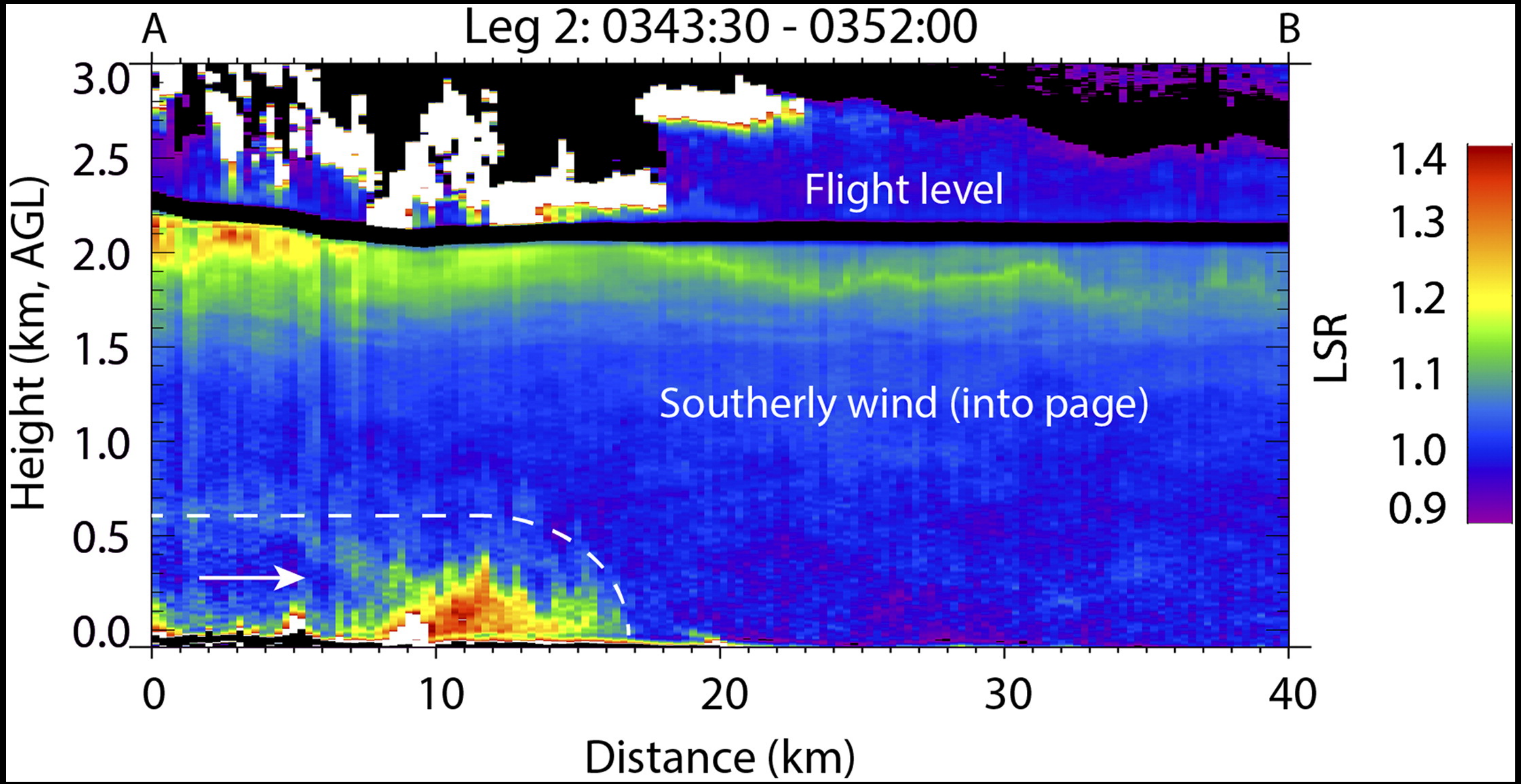
Lagged and Immediate CI

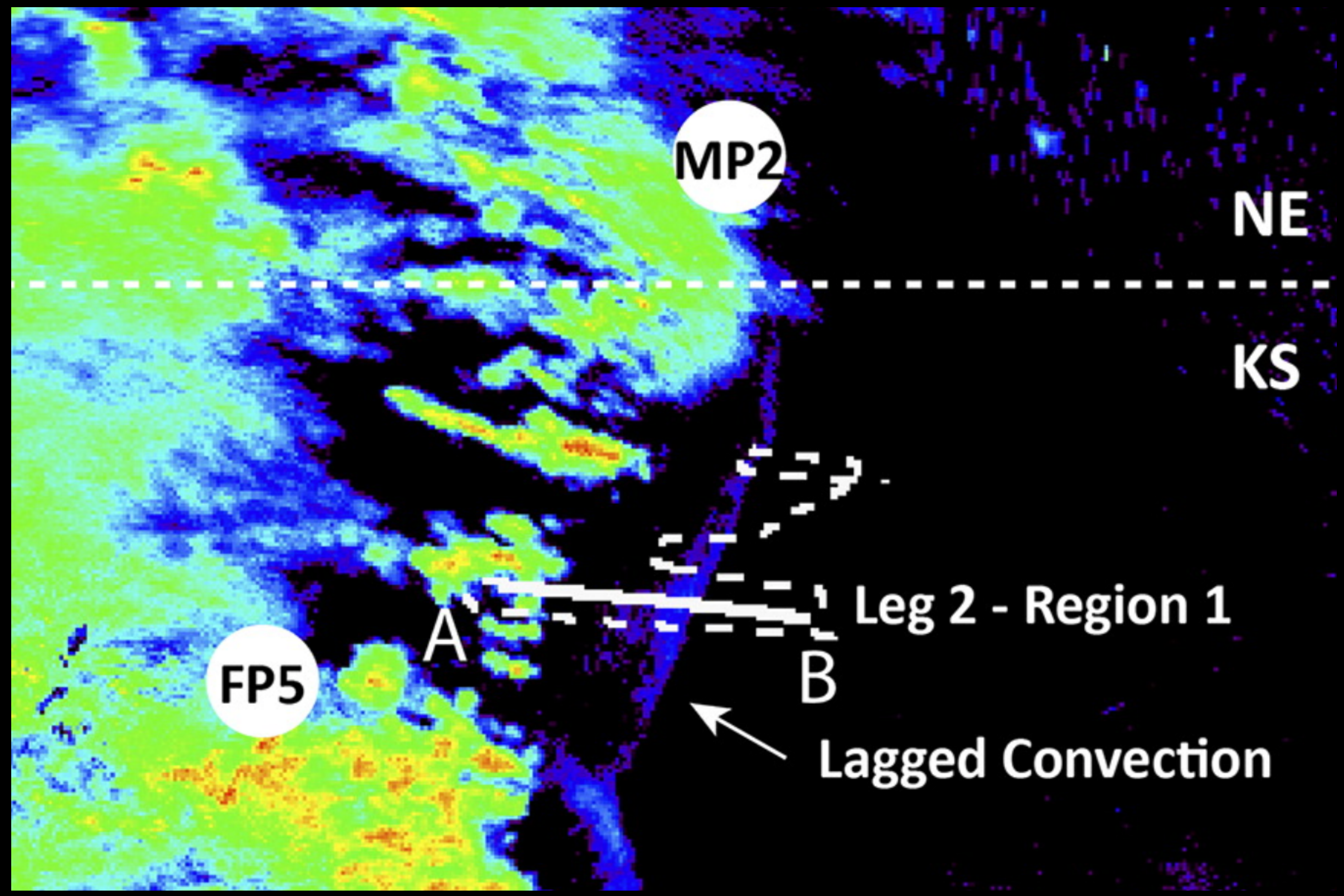


- **Lagged CI cold pools shallower than immediate CI cold pools** (not necessary stronger though: compare MP3 and FP5)
- **Greater lifting across boundary for immediate CIs**
- **Parcels above SBL was lifted by deep cold pools near FP3**

UWKA density current + bore transects

Region 1

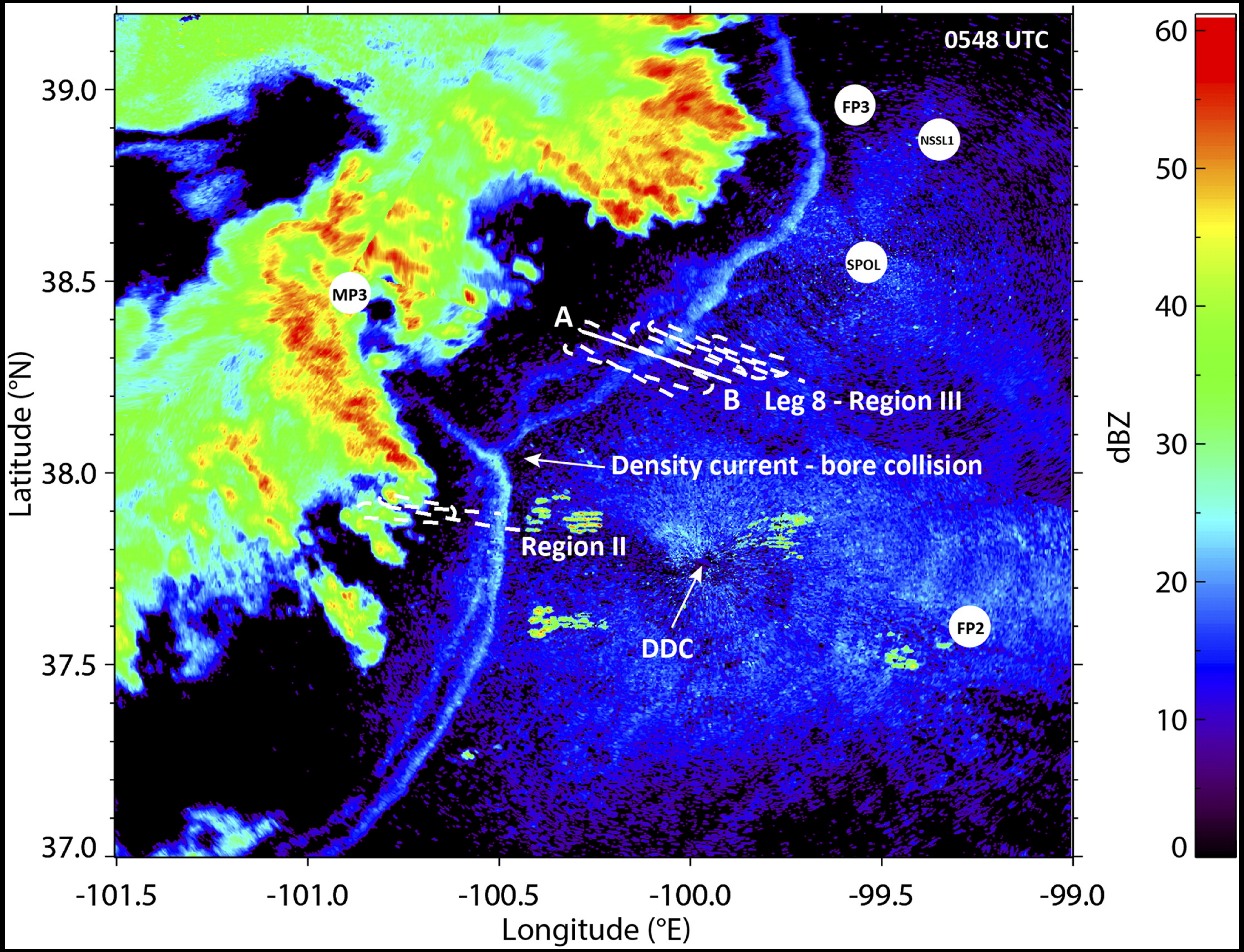




Shallow cold pool (depth ~600m), consistent with AERI

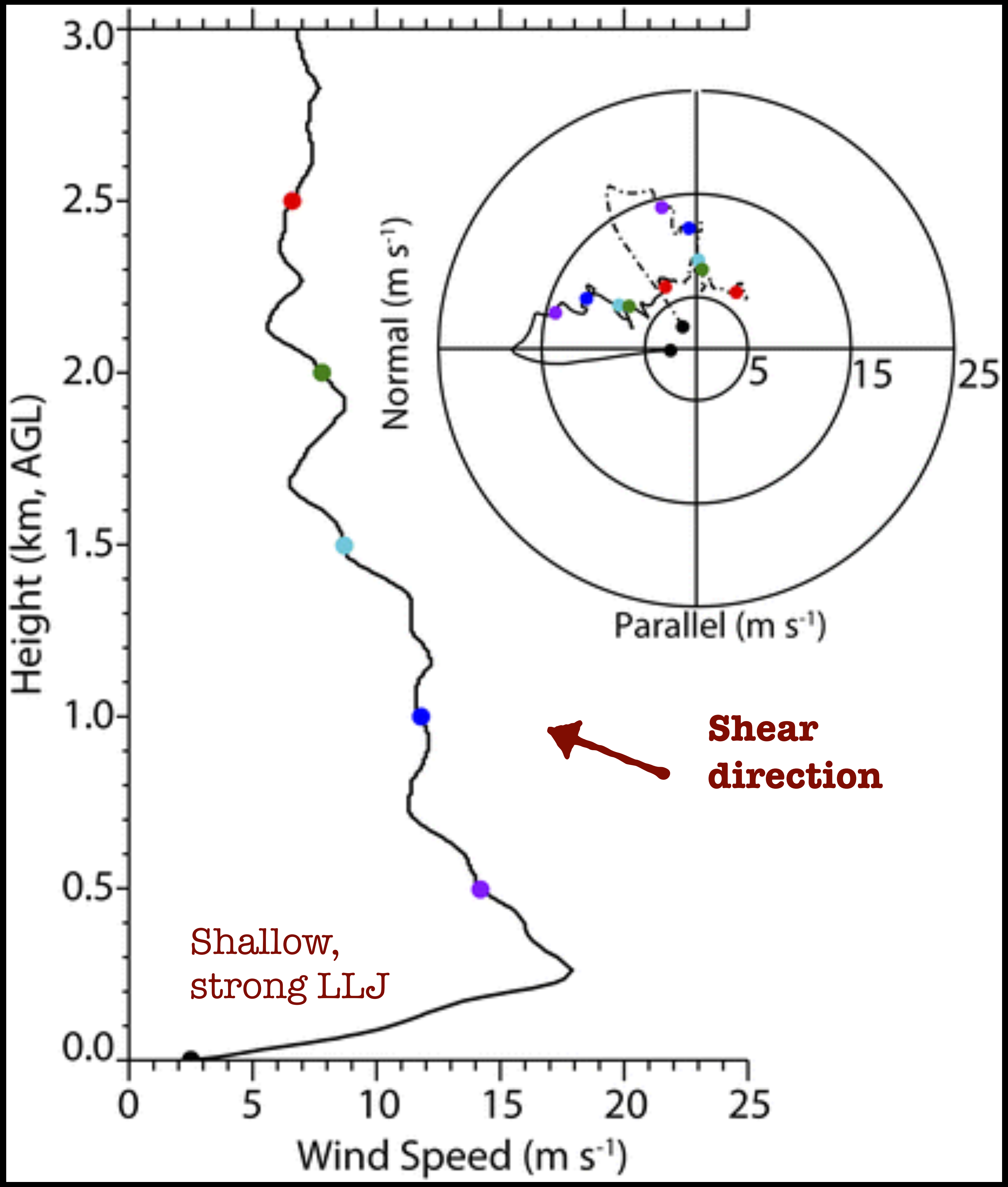
UWKA density current + bore transects

Region 2+3



UWKA density current + bore transects

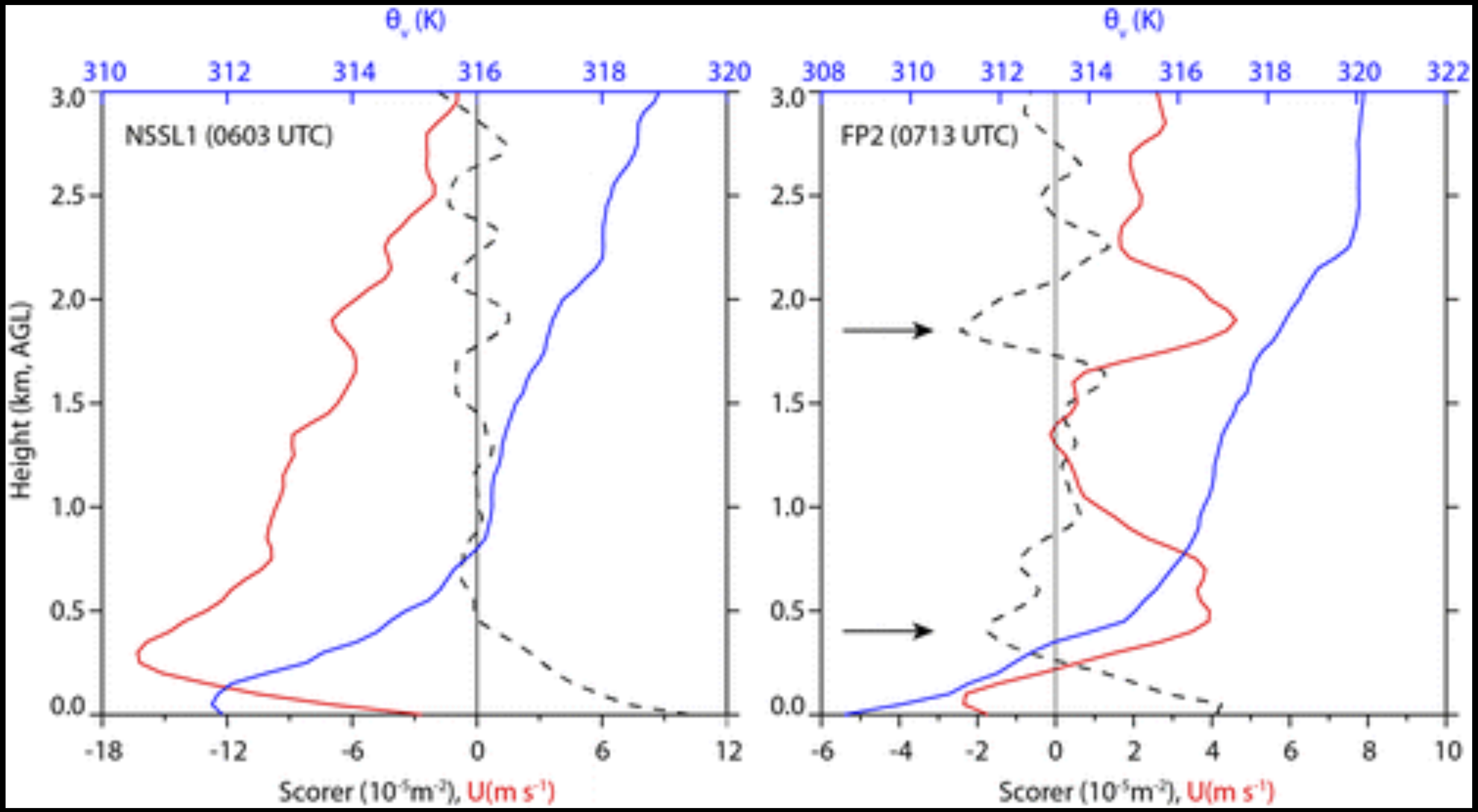
Are these bores?



NSSL1 0603 UTC sounding

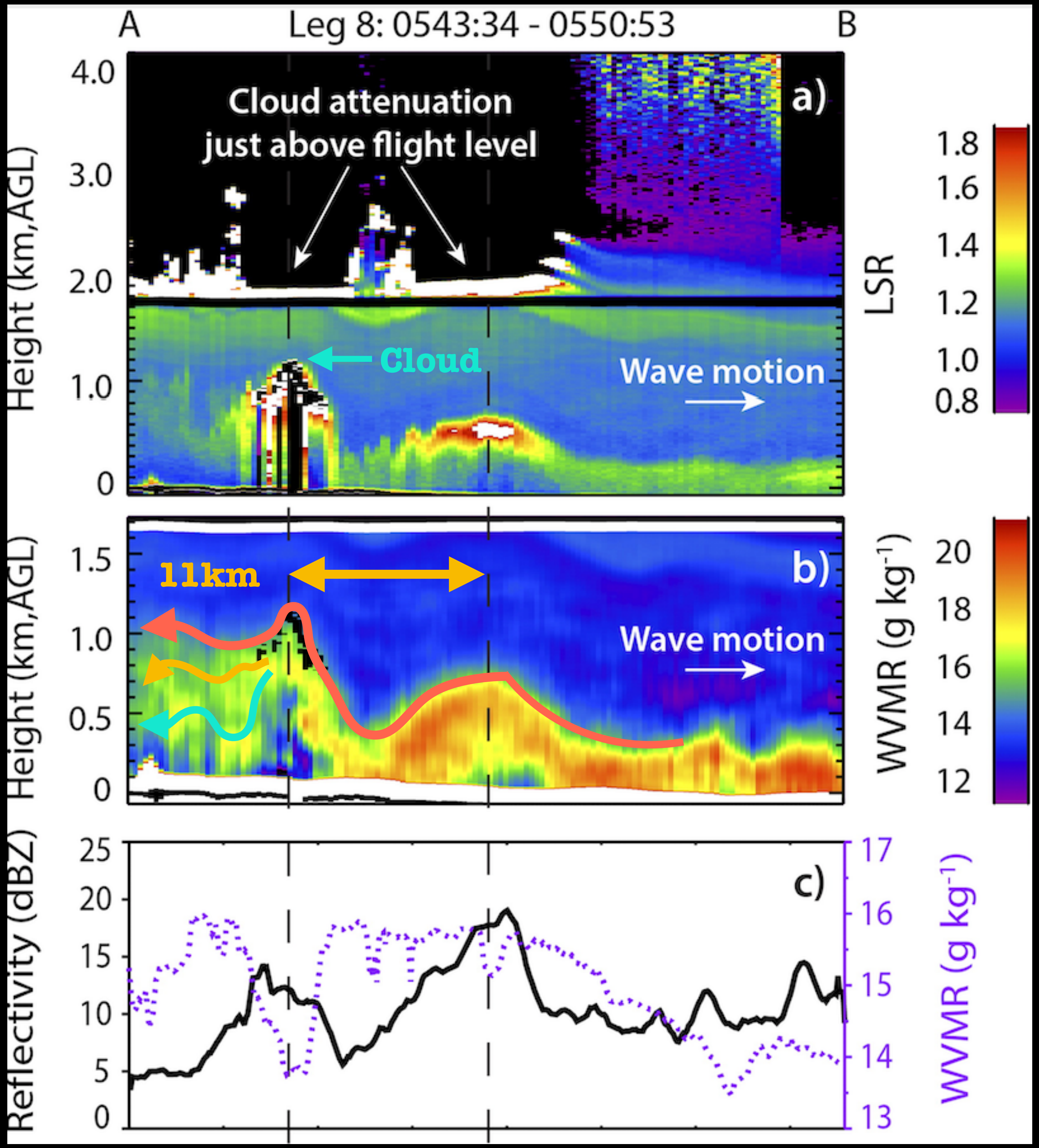
$$l^2 = \frac{N^2}{(U-C)^2} - \frac{\frac{\partial^2 U}{\partial z^2}}{(U-C)}$$

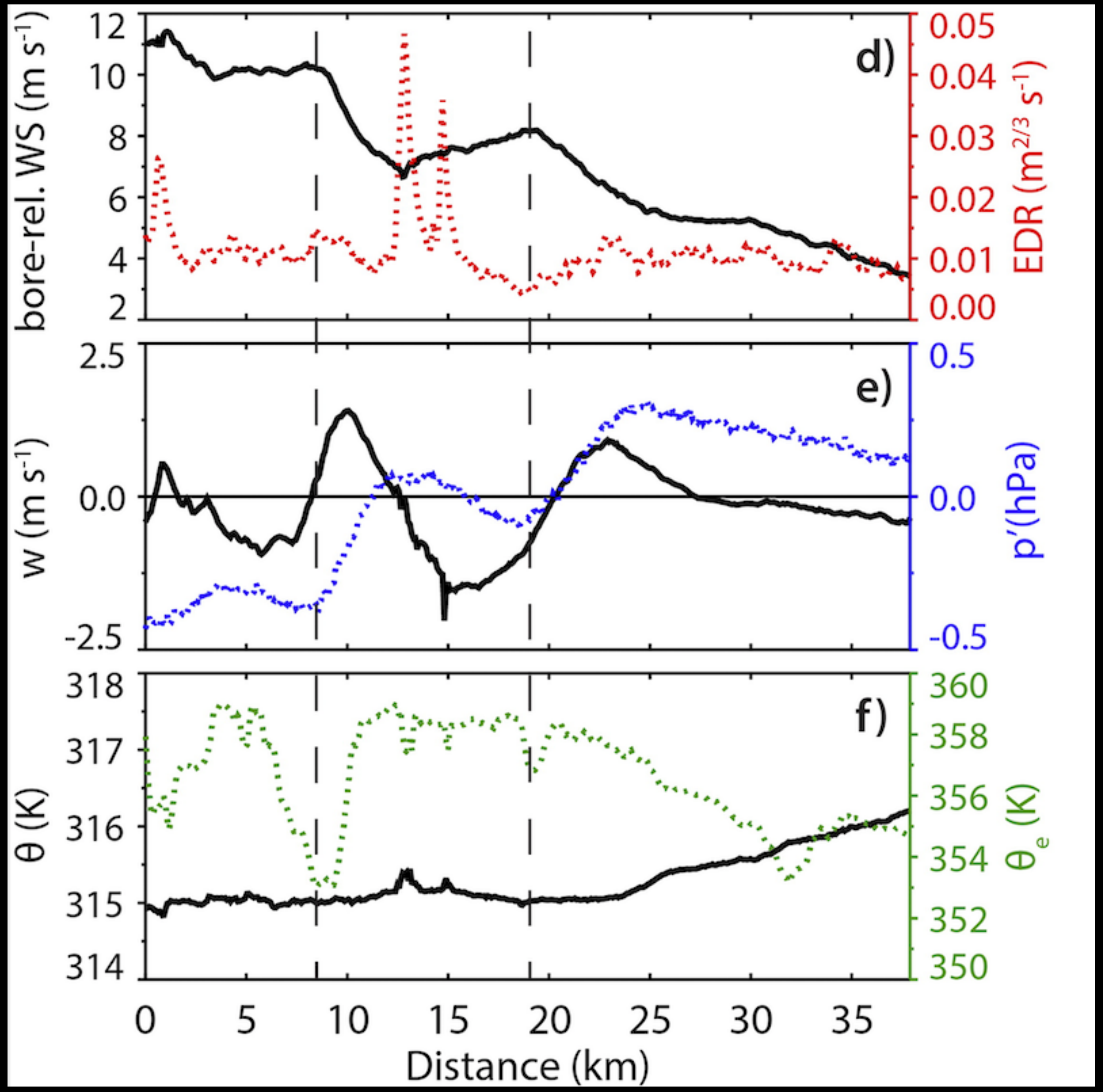
- **N:** Brunt-Vaisala frequency
- **U:** Environmental wind speed
- **C:** Boundary propagation speed



UWKA density current + bore transects

Bore transects

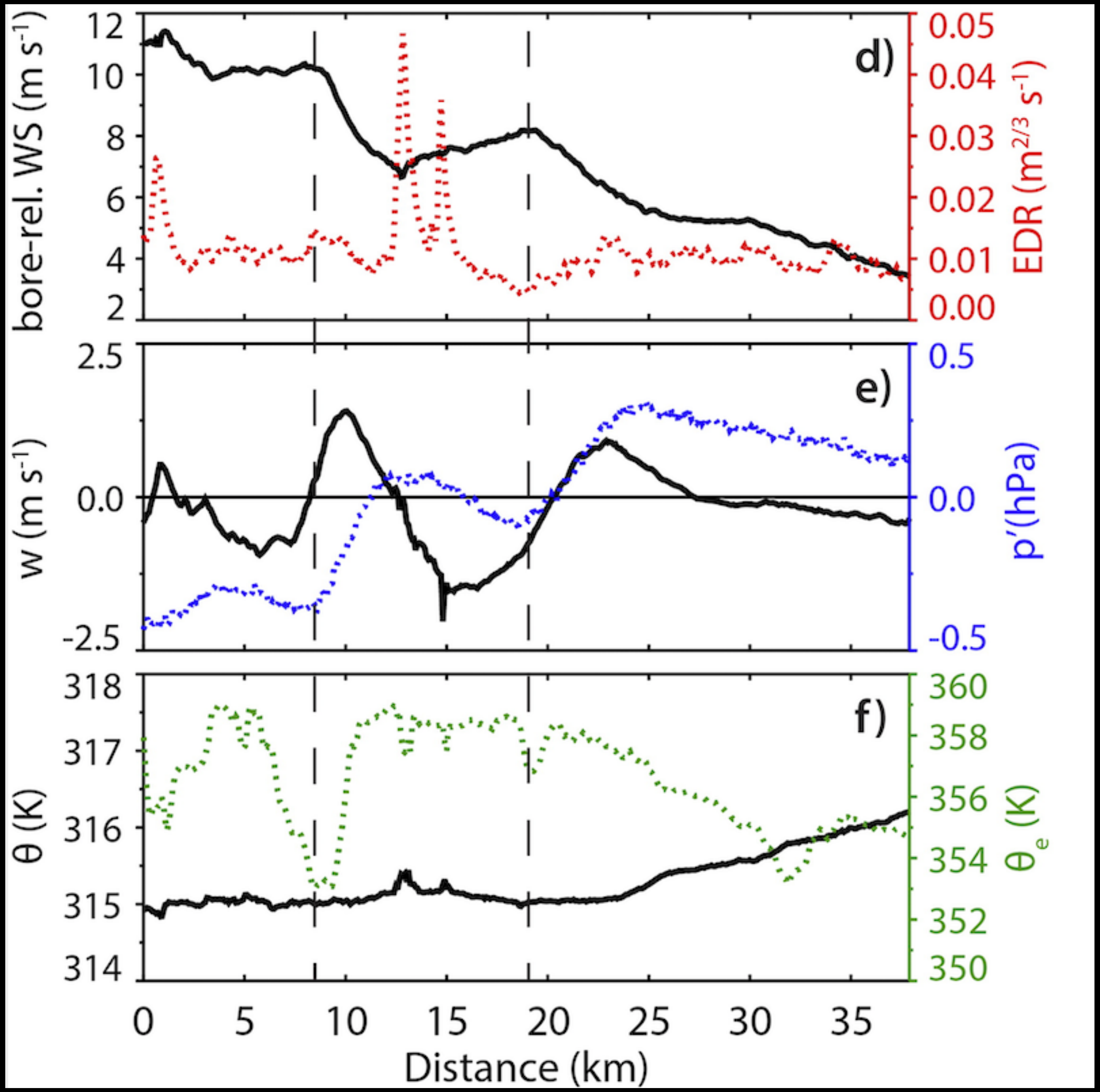




- Turbulent downstream -> Bore strength between 2 and 4 (Rottman and Simpson 1989)
- Reflectivity enhancement over wave crests
- Drier air was brought to the flight level (WVMR, theta-e) -> Indicative of updrafts

UWKA density current + bore transects

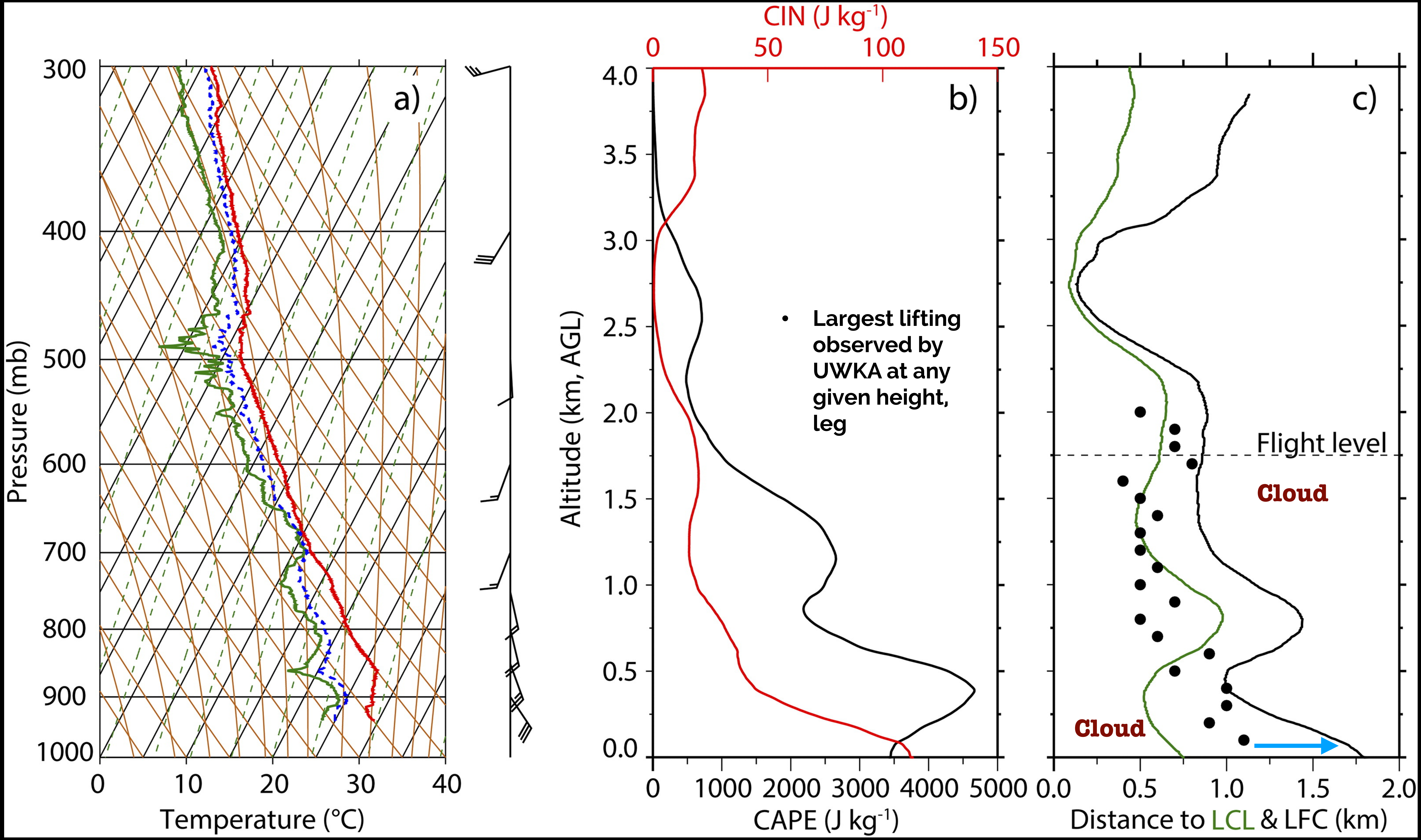
Bore transects



- Areas with upward (downward) motion correlates well to along-track flow divergence (convergence) upstream of wave crests.
- The amplitudes of pressure perturbation (0.31 mb for 1st wave) ~ dynamic pressure drop predicted by Bernoulli equation (0.25 mb)
- **Assumption: Air velocity representative of layers below flight level (OK because within residual layer)**

$$p_1' + \frac{1}{2}\rho v_1' = p_2' + \frac{1}{2}\rho v_2'$$

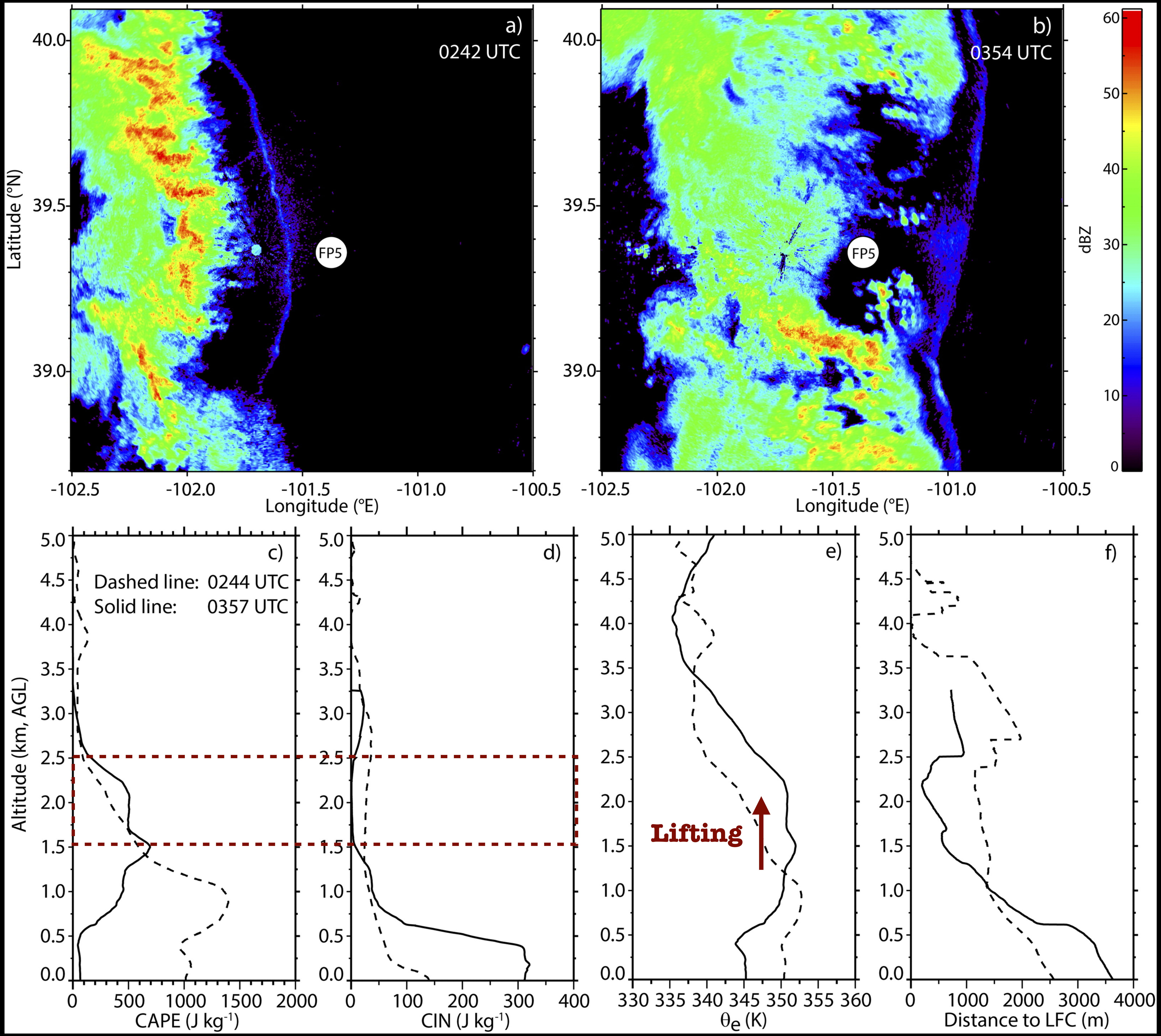
Bore-induced vertical displacements



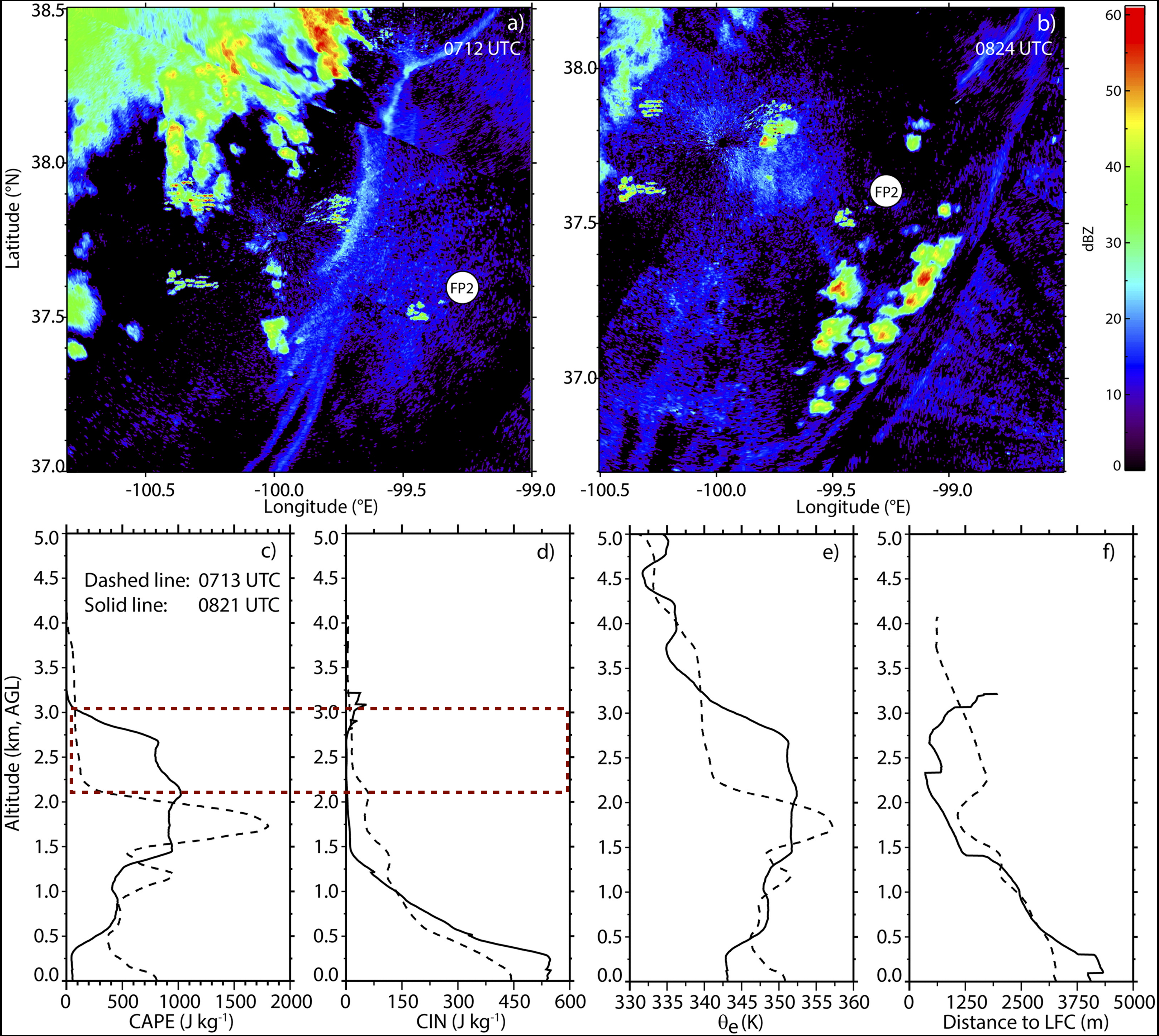
NSSL1 0603 UTC sounding

Modification of the thermodynamic profile: Density current versus bore

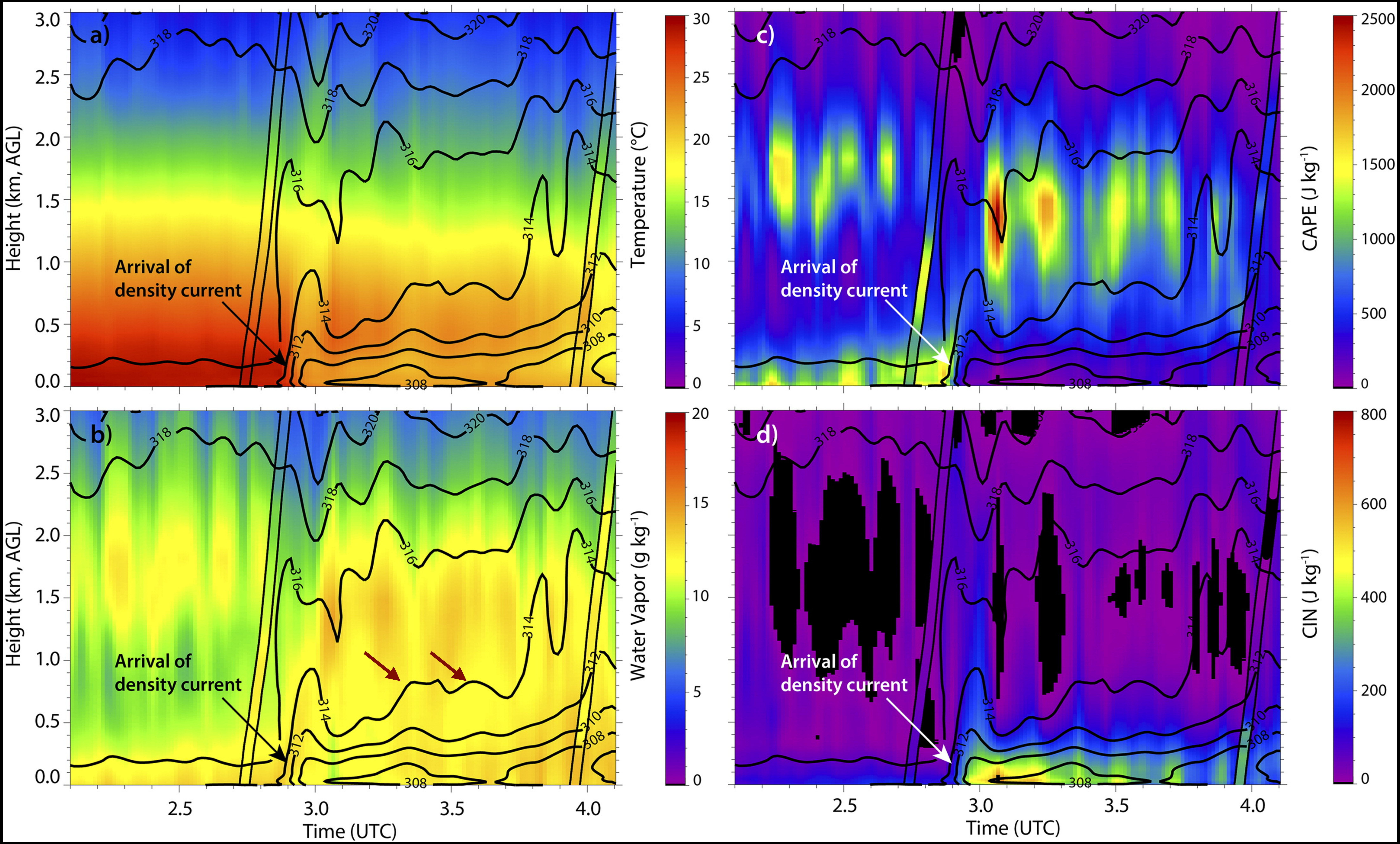
1. Sounding Analysis
2. AERI Analysis



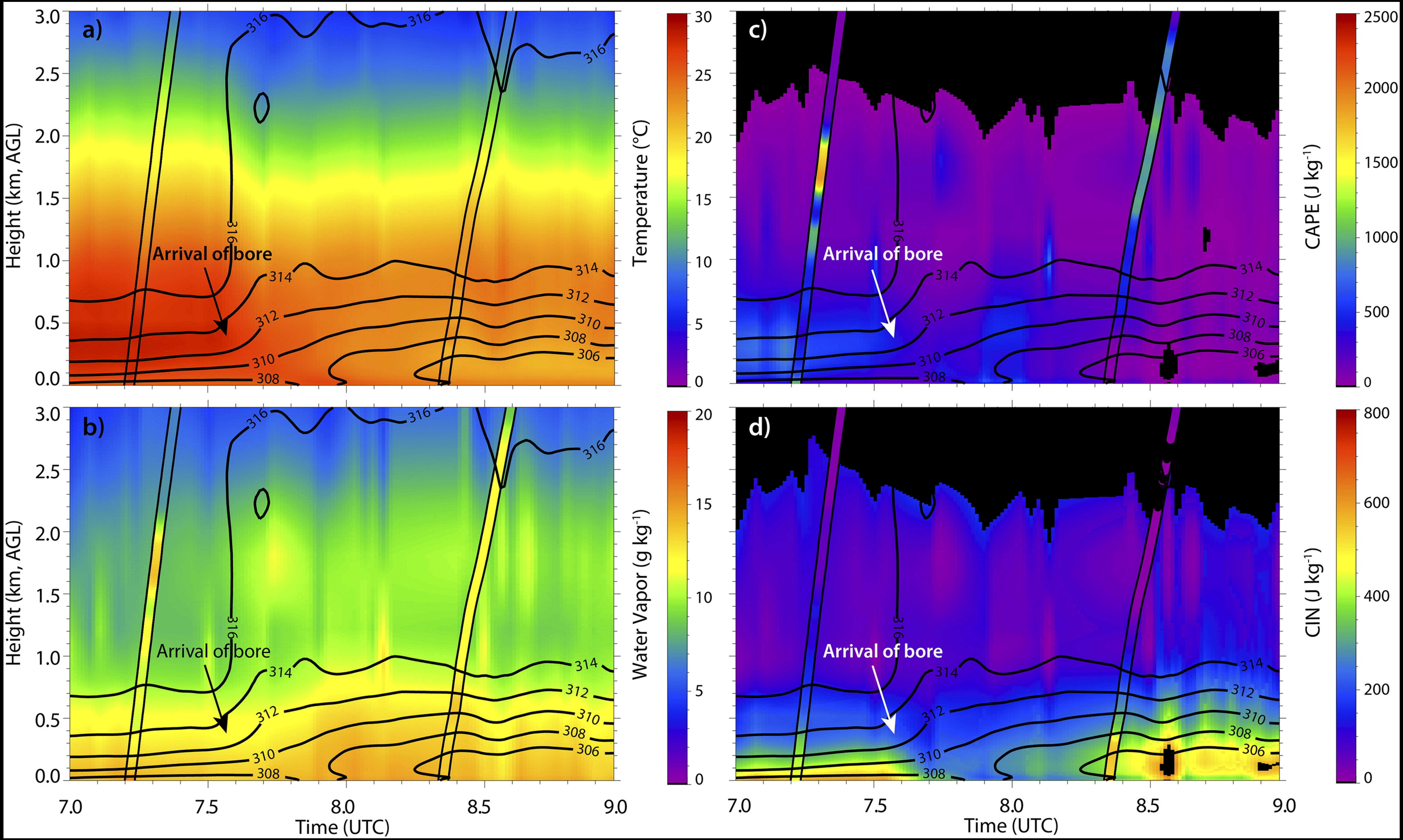
a)
0242 UTC
b)
0354 UTC
FP5
FP5
Latitude (°N)
Longitude (°E)
Longitude (°E)
dBZ
c)
d)
e)
f)
Dashed line: 0244 UTC
Solid line: 0357 UTC
Altitude (km, AGL)
Lifting
CAPE (J kg⁻¹)
CIN (J kg⁻¹)
θe (K)
Distance to LFC (m)



a)
0712 UTC
FP2
b)
0824 UTC
FP2
dBZ
Latitude (°N)
Longitude (°E)
Longitude (°E)
c)
Dashed line: 0713 UTC
Solid line: 0821 UTC
d)
e)
f)
Altitude (km, AGL)
CAPE (J kg-1)
CIN (J kg-1)
θe (K)
Distance to LFC (m)



a)
b)
c)
d)
Arrival of density current
Arrival of density current
Arrival of density current
Arrival of density current
Height (km, AGL)
Height (km, AGL)
Time (UTC)
Time (UTC)
Temperature (°C)
Water Vapor (g kg-1)
CAPE (J kg-1)
CIN (J kg-1)



a)
b)
c)
d)
Arrival of bore
Height (km, AGL)
Time (UTC)
Temperature (°C)
Water Vapor (g kg-1)
CAPE (J kg-1)
CIN (J kg-1)
316
314
312
310
308
306
0.0
0.5
1.0
1.5
2.0
2.5
3.0
7.0
7.5
8.0
8.5
9.0

Discussion

Hydraulic Theory (Rottman and Simpson 1989)

$$Fr = \frac{C_{dc}}{C_{gw}} = \frac{C_{dc}}{\sqrt{g'h_0}}$$

- **C_{dc}:** Density current propagation speed
- **C_{gw}:** Gravity wave propagation speed
- **h_o:** Depth of Stable Boundary Layer

$$DR = \frac{d_0}{h_0}$$

- **DR:** Depth Ratio
- **C_{gw}:** Depth of the density current

Supercritical flow | **Subcritical flow** | **Partially blocking** | **Completely blocked**

Bores and Solitons

Discussion

Hydraulic Theory (Rottman and Simpson 1989)

$$d_0 = \frac{\theta_{vw}\Delta p}{\rho_w g(\frac{p_c}{p_w}\theta_{vw} - \theta_{vc})}$$

Derivation in Koch et al. (1991)

- **w:** Measurement on the warm side of boundary
- **c:** Measurement on the cold side of boundary
- **Assumption: Pressure change across boundary is hydrostatic, density does not vary with height**

$$C_{dc} = \sqrt{\frac{g\Delta T d_0}{T_c}}$$

Simpson (1987)

Mesonet at KSRE

- **Temperature:** 5.6K drop
- **Pressure:** 1.5mb rise
- **d_o: 580m**
- **C_{dc}: 10.4 ms^{-1}**
- **h_o: 400m (KingAir lidar)**
- **Fr: 2.1**
- **DR=1.45**

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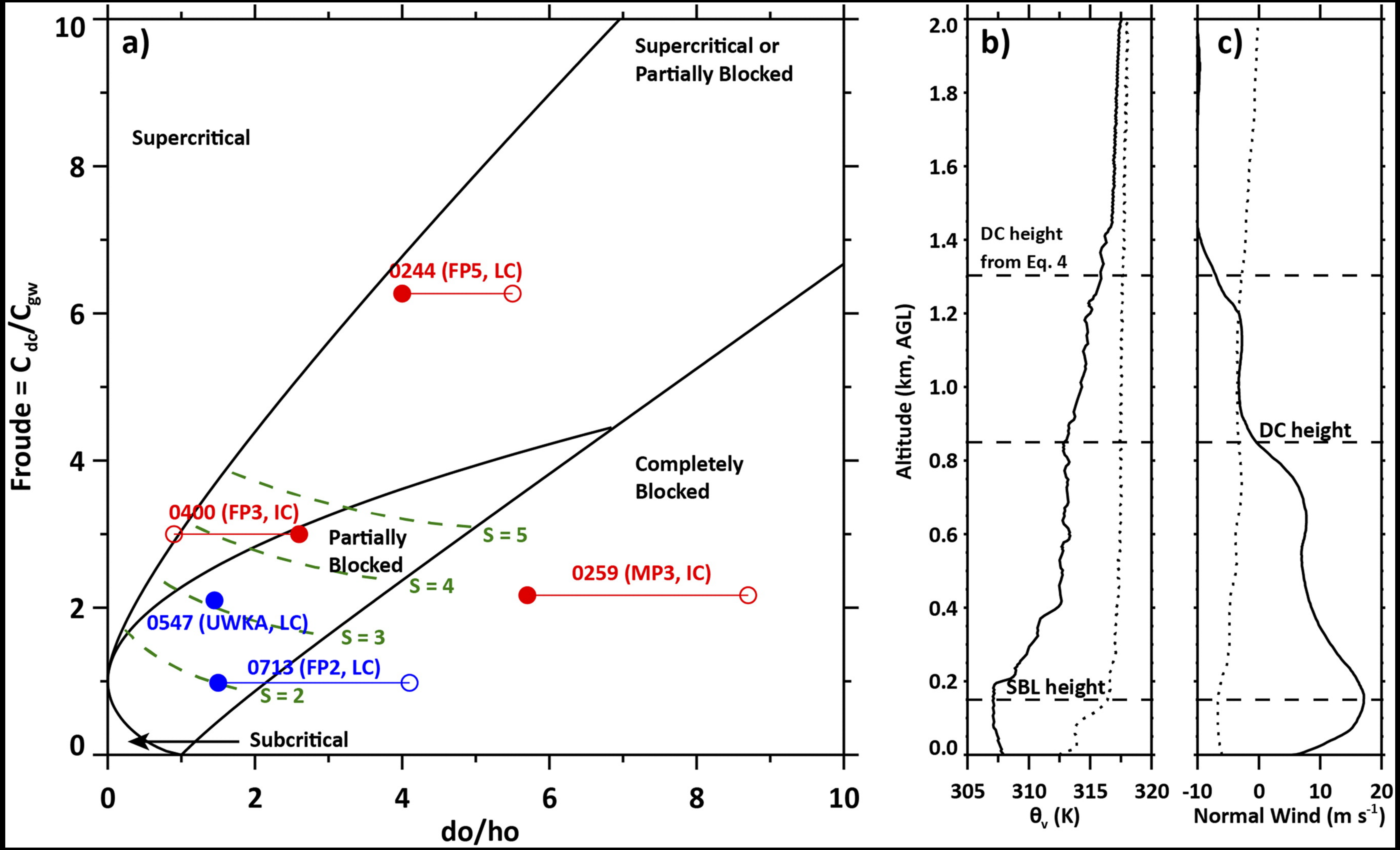
Partially blocked flow regime near multi-fine line structure

Discussion

Hydraulic Theory (Rottman and Simpson 1989)



Conclusion

1. Lagged convection -> not enough initial lifting (shallow cold pool)
2. DC, bore both improves likelihood for elevated CI through destabilization aloft
3. Structure of DC, bore determinative of whether lagged CI/immediate CI formed behind a certain boundary
4. As time goes by, nocturnal cooling initiated a transition from DC-dominated boundaries to a combination of DC and bore-generated boundaries
5. Propagation of solitary waves from MCS initiated short-lived secondary CI that are unable to sustain MCS (they dissipated at appro. same location)