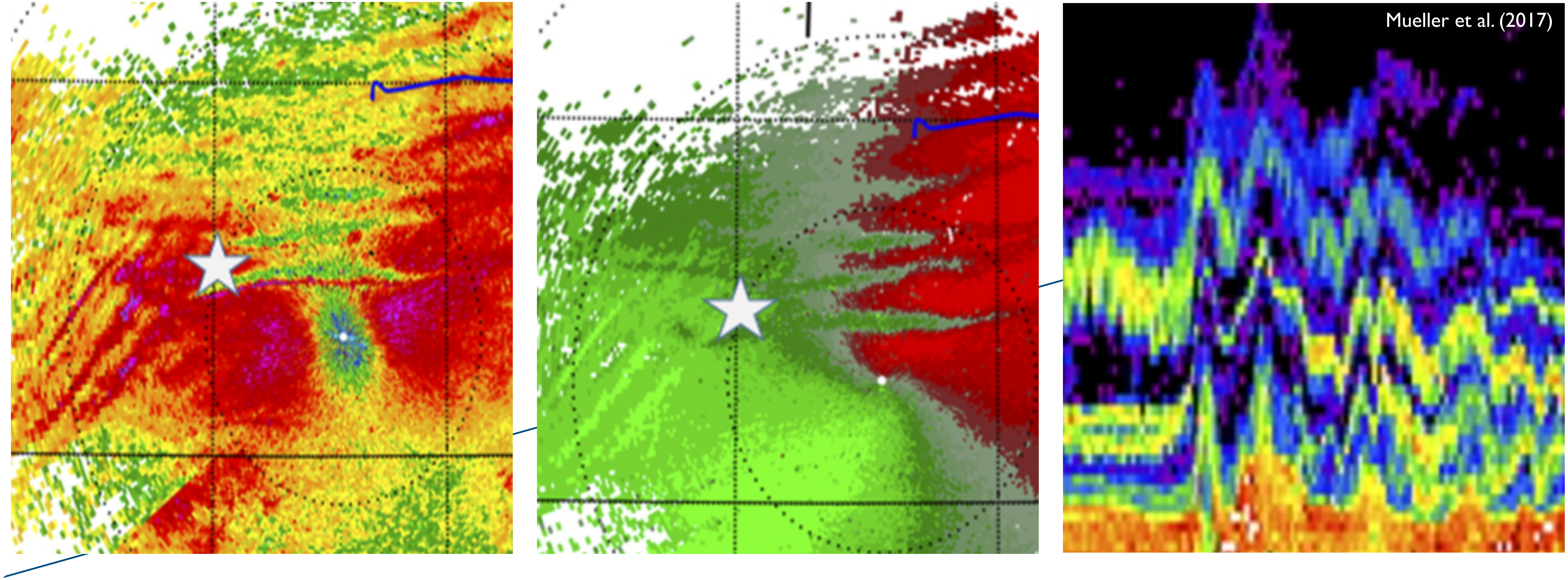


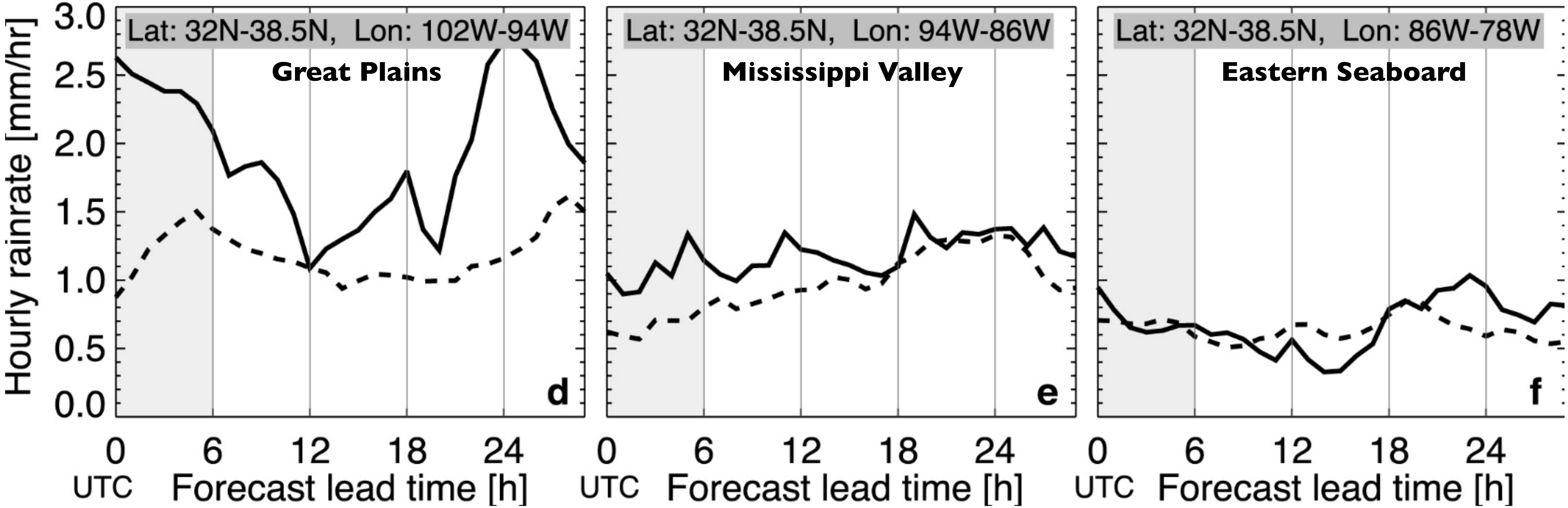
Mueller et al. (2017)

The Potential Role of Atmospheric Bores and Gravity Waves in the Initiation and Maintenance of Nocturnal Convection over the Southern Great Plains

Parsons, Haghi, Halbert, Elmer (OU), and Wang (SUNY Albany)

GCMs cannot accurately represent Great Plains nocturnal precipitation!

Surcel et al. (2010)



West — : Radar-derived hourly rain rate - - - : GEM (CMC) hourly rain rate **East**

Insufficient understanding of nocturnal MCSs contributes to such bias

Nocturnal MCS

1. "Weakly forced" weather regime
2. Correlated with NLLJ above boundary layer (Trier and Parsons 1993)
3. Bores could rejuvenate (Crook et al. 1990) or initiate (Wilson and Roberts 2006) convection by inducing ascent
4. Bores could determine propagation speed of simulated N. MCSs (French and Parker 2010)
5. "Partially blocked" flow -> Interaction between convective outflow and environment -> Bores (Haghi et al. 2017)

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Other potential mechanisms…

1. Ascent driven by NLLJ (Pu and Dickinson 2014; Shapiro et al. 2018)
2. Pressure Tides (Dai et al. 1999)
3. Propagating GWs from the Rockies (Carbone and Tuttle 2008)
4. Eastward-moving PV anomalies (Li and Smith 2010)
5. NLLJ overrunning an zonal stationary front (Trier and Parsons 1993)

IHOP_2002 (Weckwerth et al. 2004) **Observational Dataset**

Analysis Period:

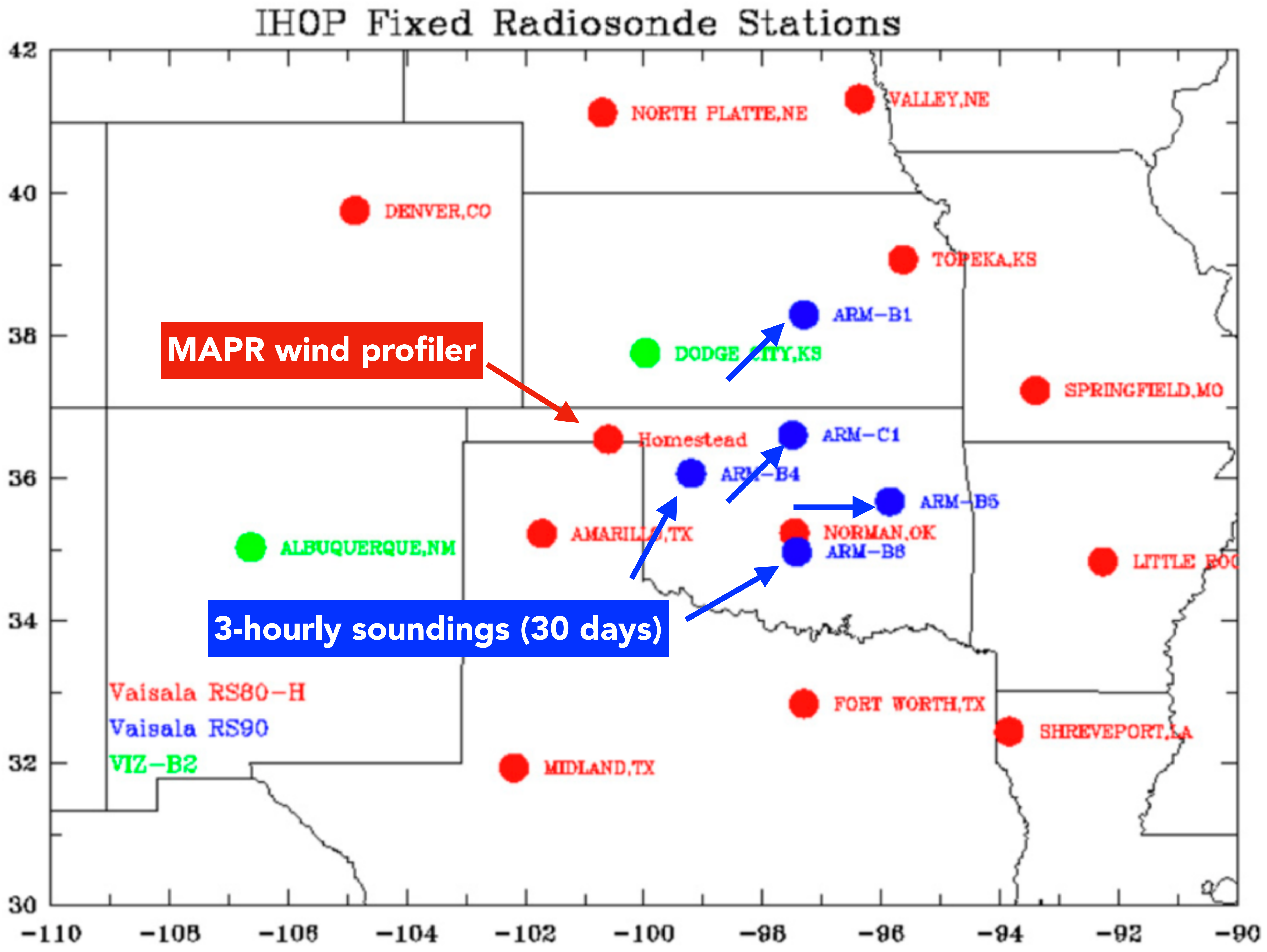
Suppressed Phase

13 May 2002

2 June 2002

25 June 2002

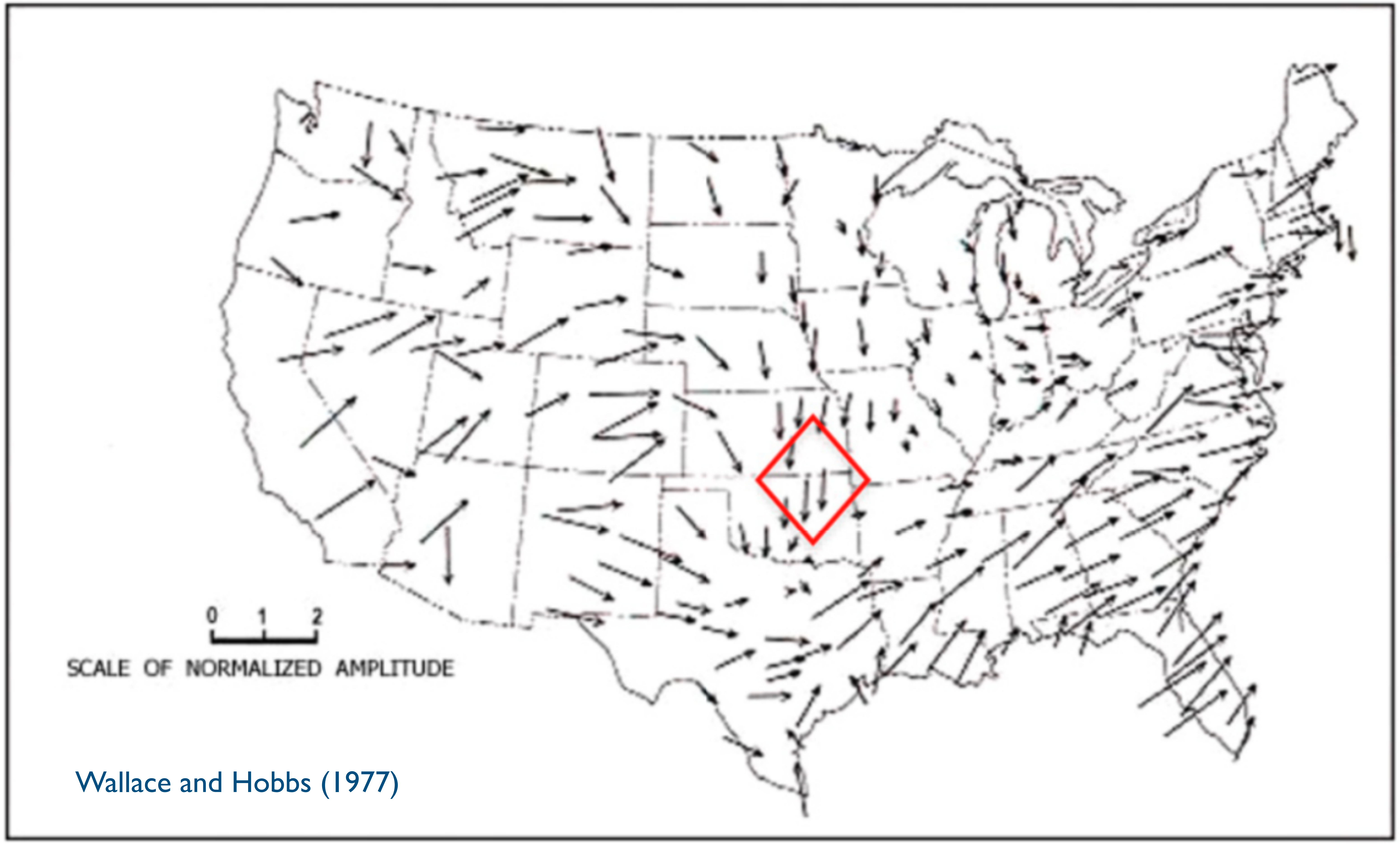
Analysis Domain:



MAPR wind profiler

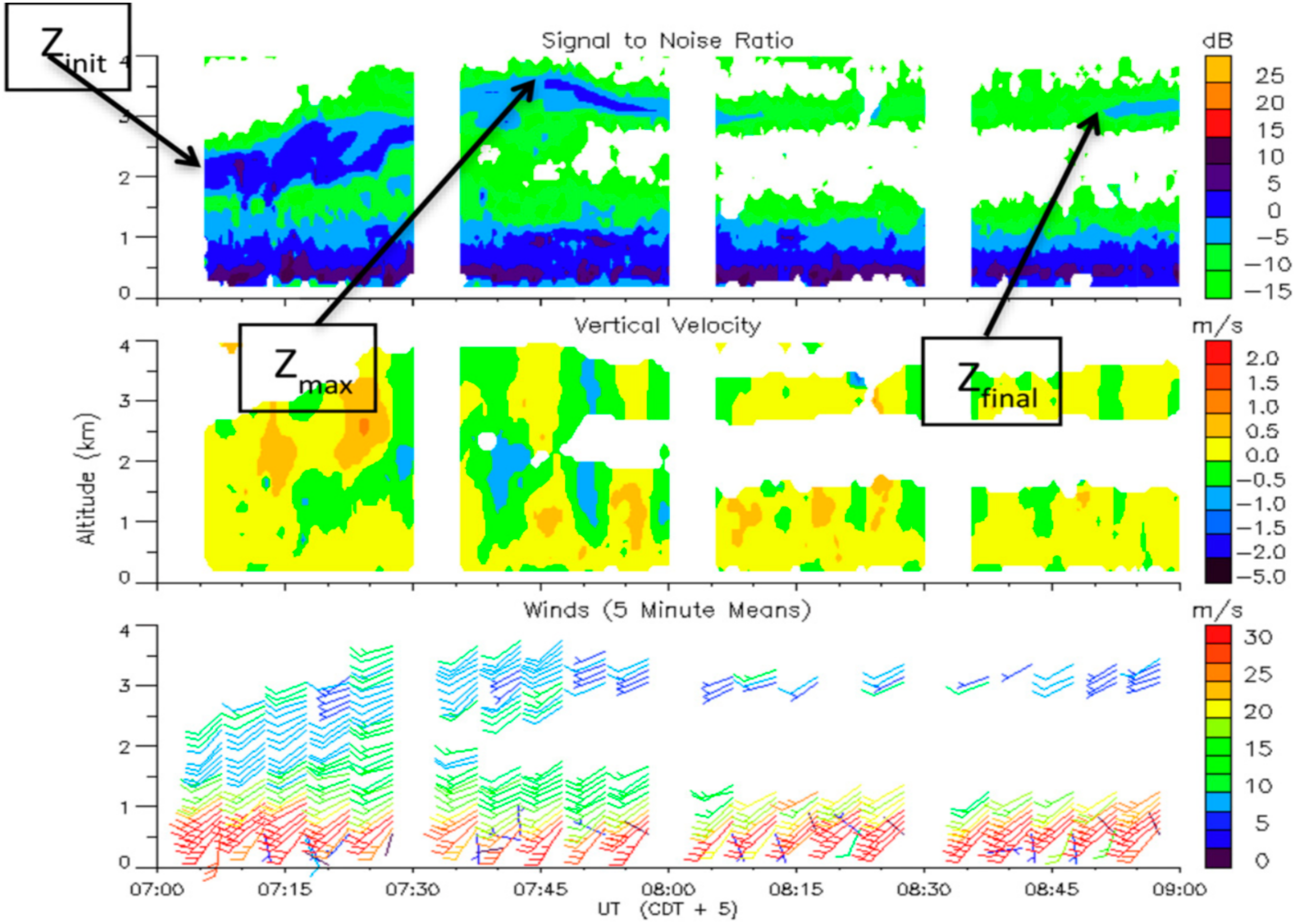
3-hourly soundings (30 days)

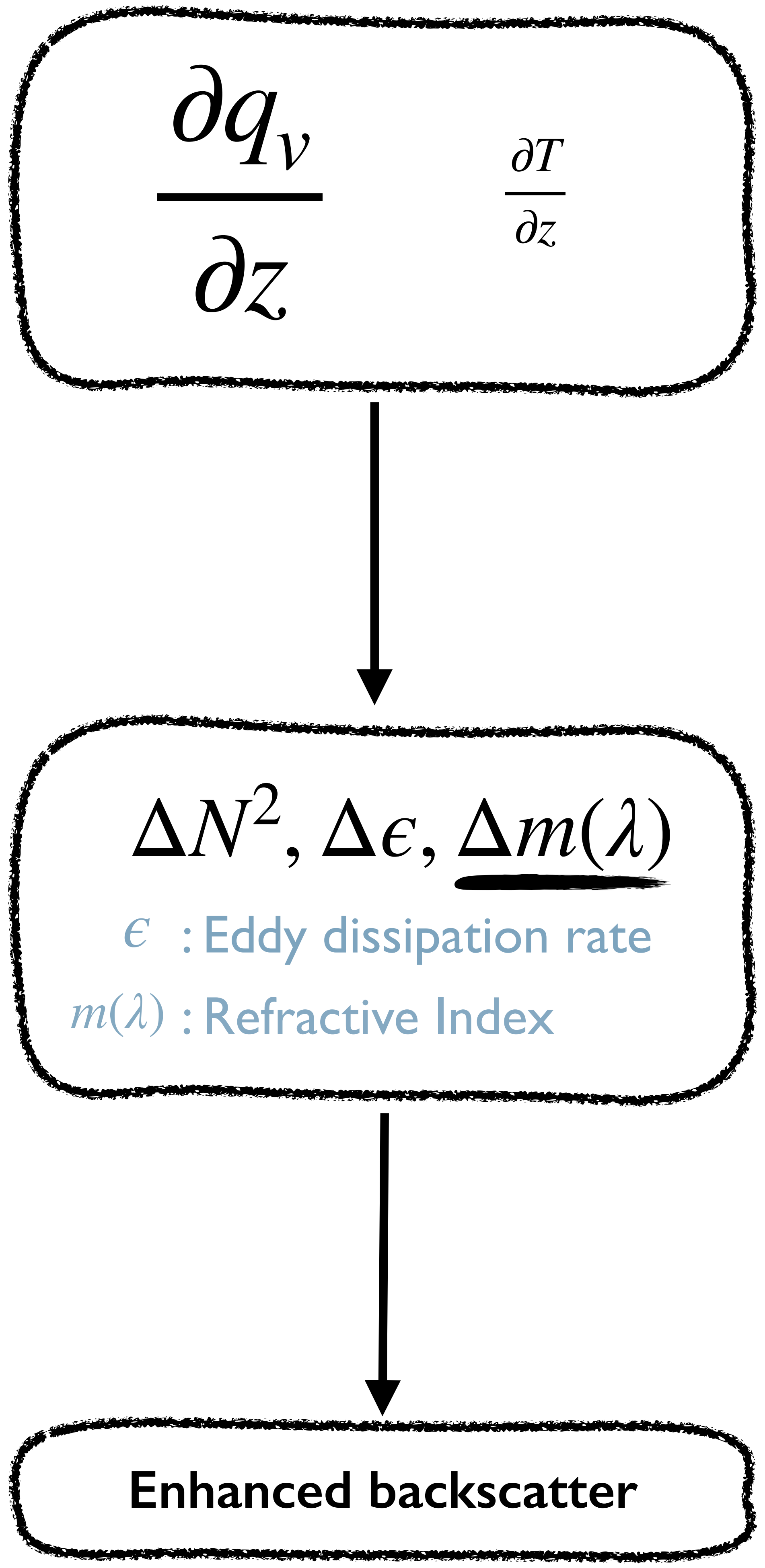
Hotspot for Nocturnal Convective Development



Wallace and Hobbs (1977)

Estimating Layer Displacement with MAPR





$$\frac{\partial q_v}{\partial z} \quad \frac{\partial T}{\partial z}$$

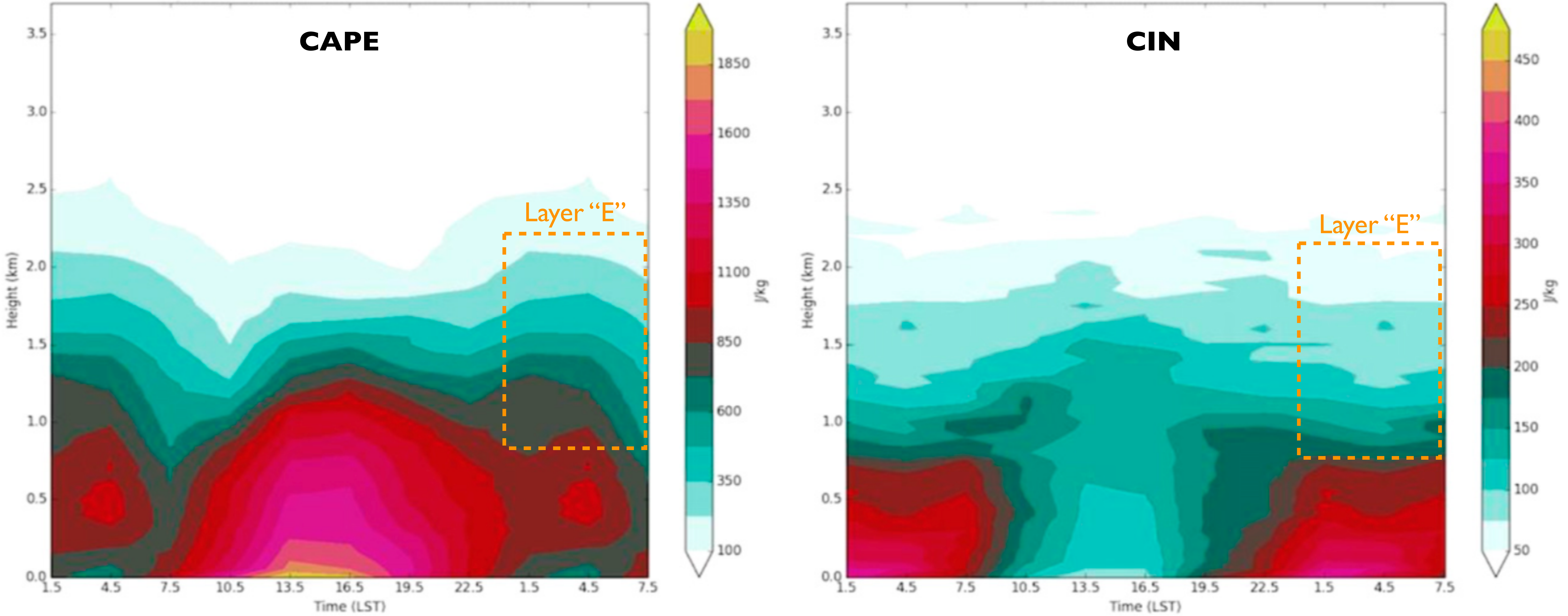
$$\Delta N^2, \Delta\epsilon, \underline{\Delta m(\lambda)}$$

ϵ : Eddy dissipation rate

$m(\lambda)$: Refractive Index

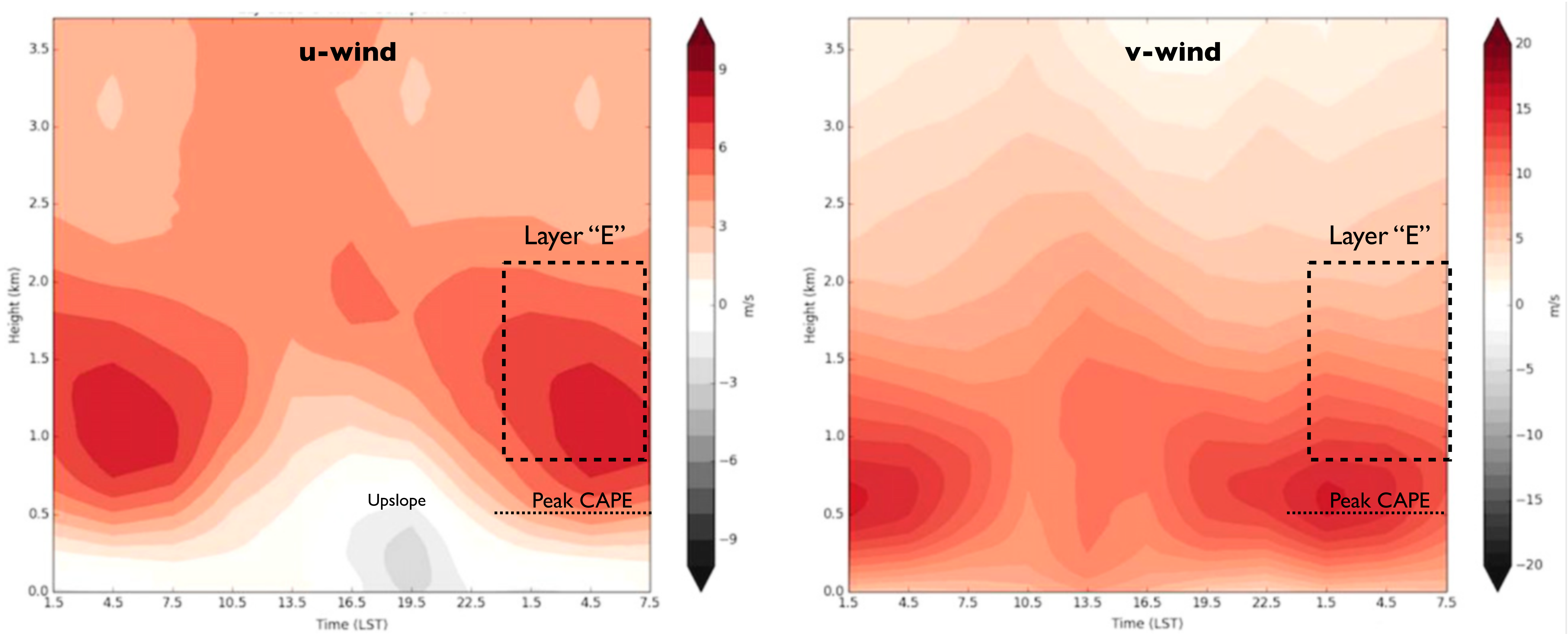
Enhanced backscatter

Diurnal Variations in Convective Instabilities



Composite diurnal cycles for days when $\boldsymbol{v_{<1km} > 15\ m\ s^{-1}}$

How do they stack up with wind profiles?



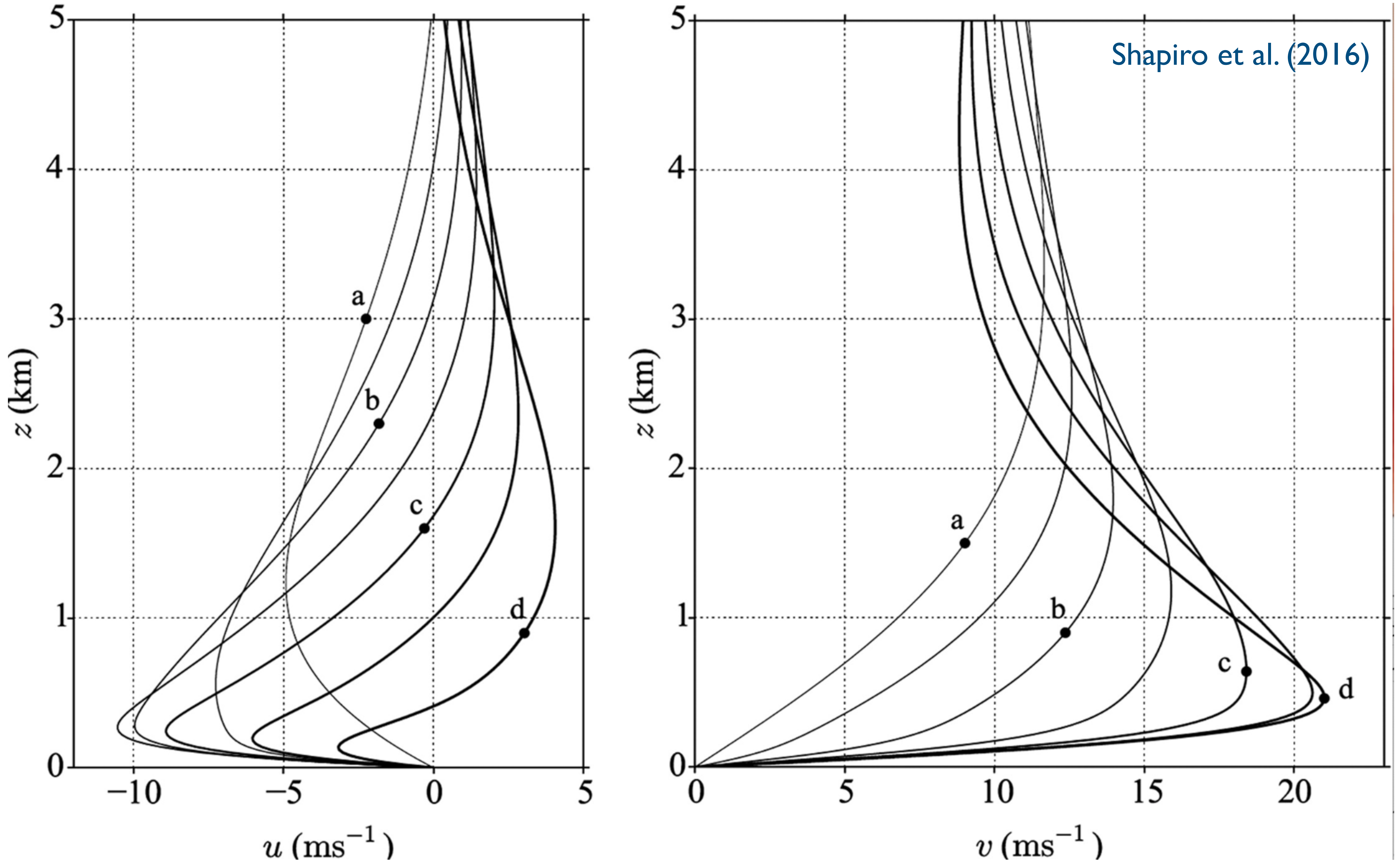
Composite diurnal cycles for days when $v_{<1km} > 15\ m\ s^{-1}$

The observed wind evolution agrees with theoretical calculations

Inertial oscillation in the NLLJ ageostrophic component
(Blackadar 1957)

⊕

Thermal forcing over sloped terrain
(Holton 1967)



Shapiro et al. (2016)

Can the Great Plains nocturnal precipitation be purely caused by large-scale factors?

1. Ascent driven by NLLJ (Pu and Dickinson 2014; Shapiro et al. 2018)
2. Pressure Tides (Dai et al. 1999)
3. Propagating GWs from the Rockies (Carbone and Tuttle 2008)
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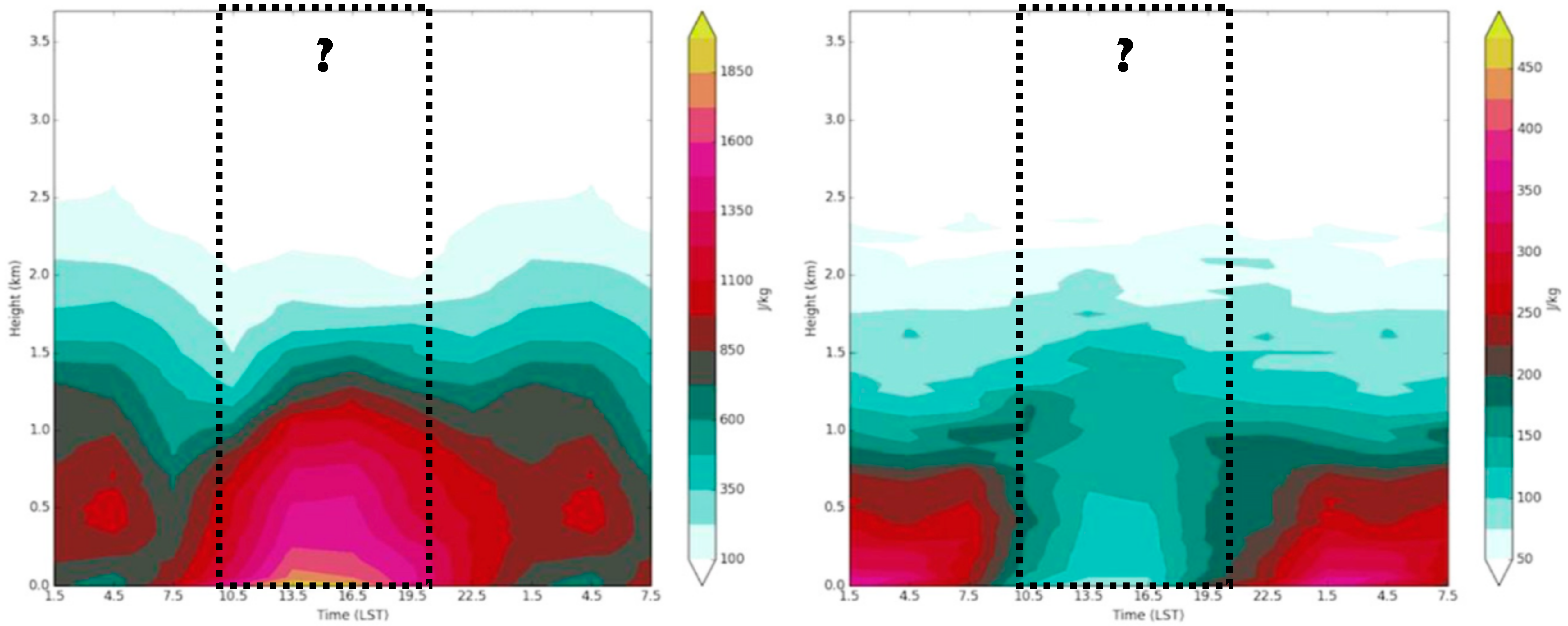
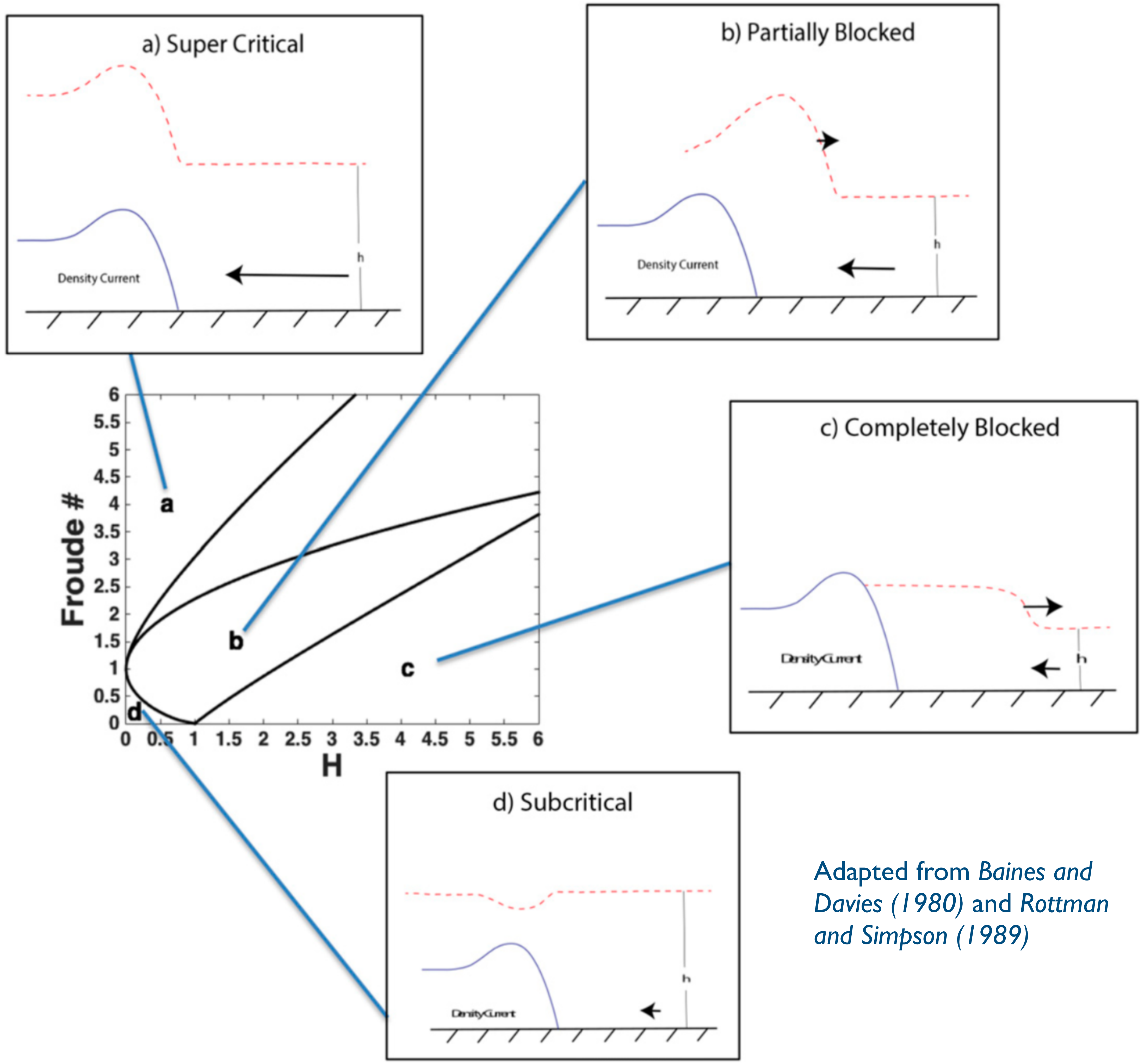


Large-scale factors could not create a ***particularly unstable*** environment!

Overview of Fluid Regimes in the *IHOP_2002* dataset



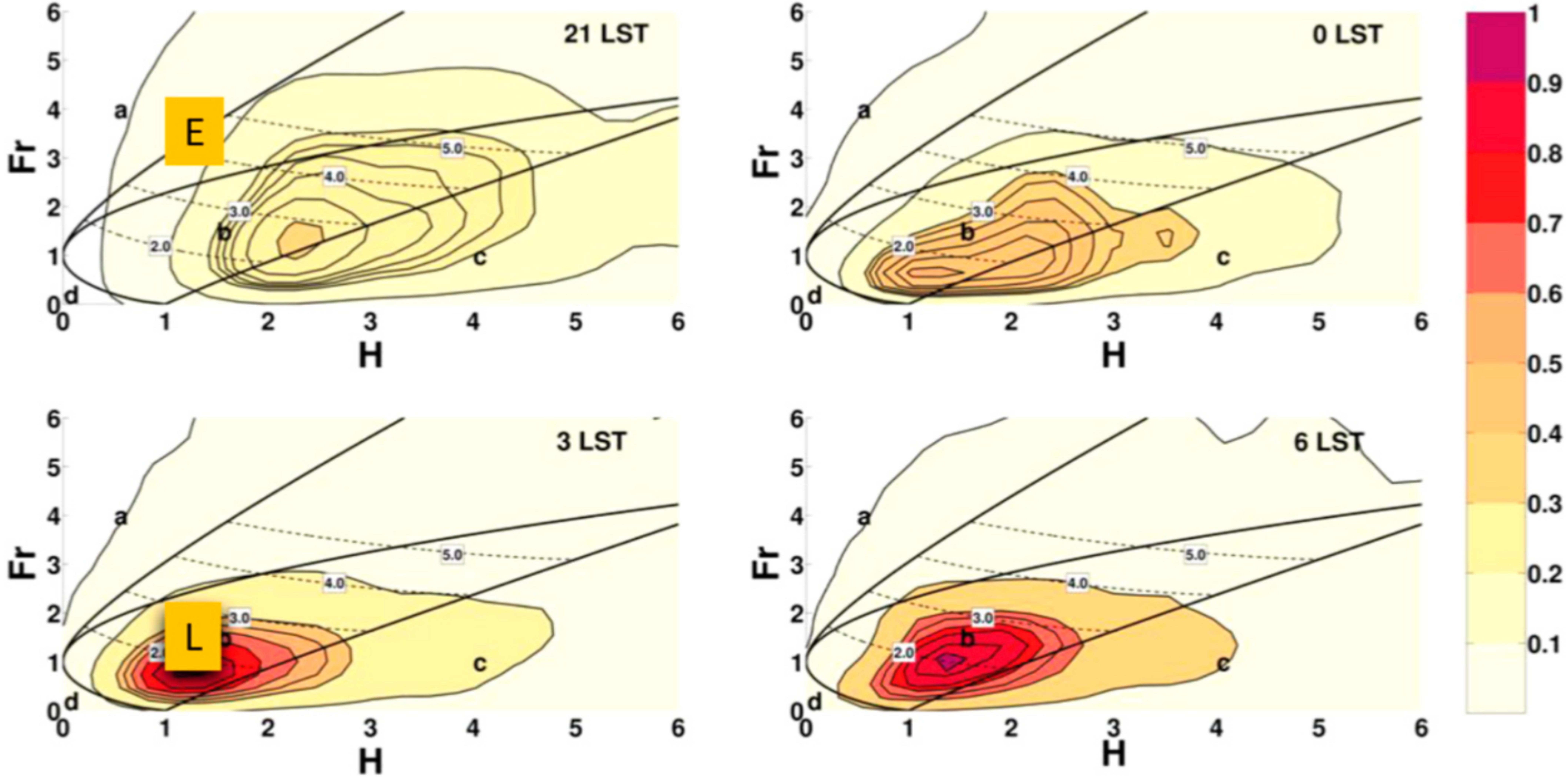
Adapted from Baines and Davies (1980) and Rottman and Simpson (1989)

$$Fr = \frac{U_{inv} - C_{dc}}{\sqrt{g\frac{\Delta\theta}{\theta_{vw_{inv}}}h_0}}$$

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

Fluid Regime Evolution during *IHOP_2002* (Haghi et al. 2017)

⬭ : Time evolution of ***Fr***, ***H*** during *IHOP_2002*



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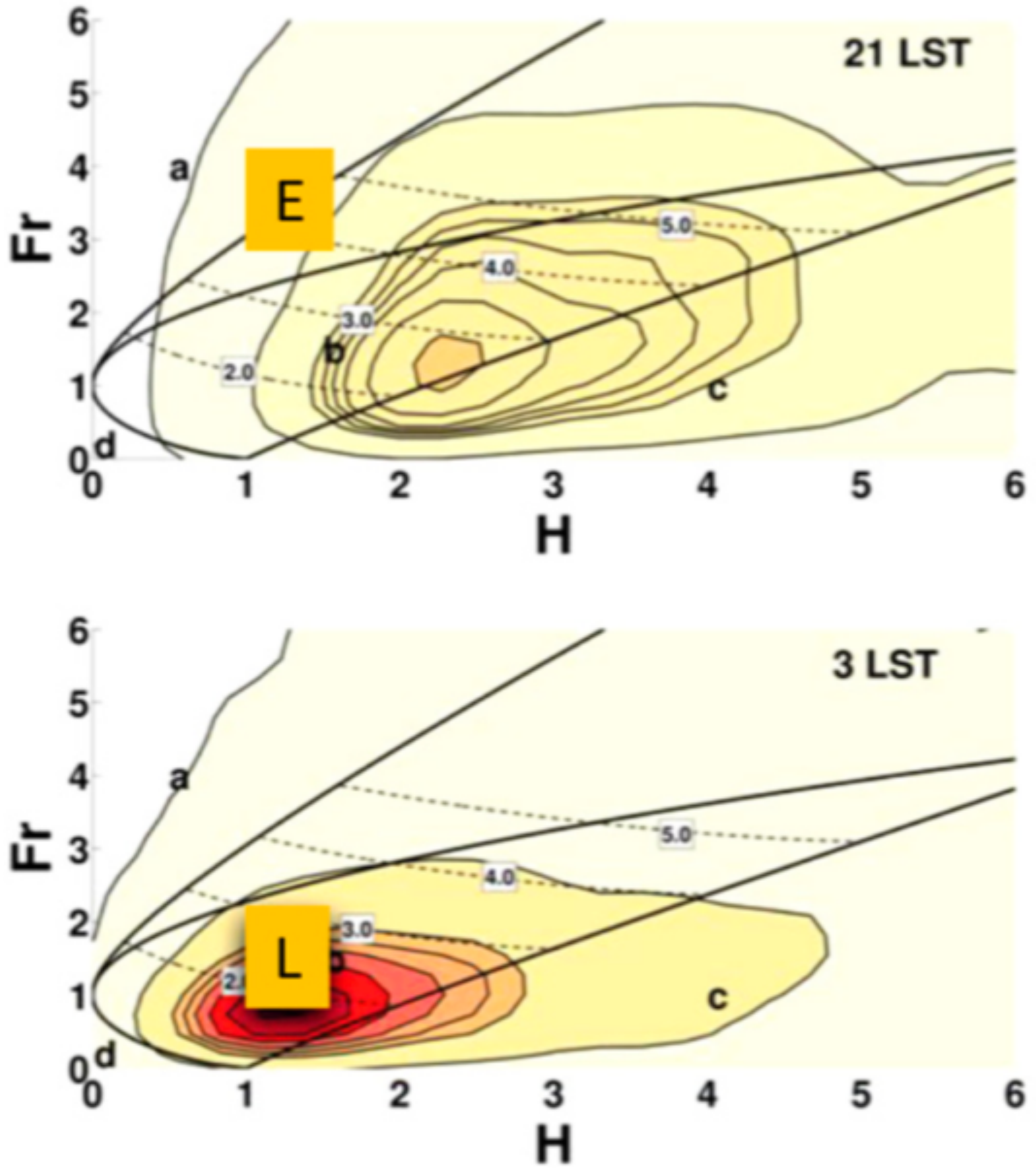


Differences from H17

1. P08, FP10: Bore speed~20-30 ms^{-1}

   H17: Median Bore speed~11 ms^{-1} (59 cases)

2. P08, FP10: Small CAPE in the lowest 1.5 km, high CAPE between 1.5-2 km

   H17: Positive CAPE in the boundary layer, smaller CIN aloft

Lifting observed by the MAPR

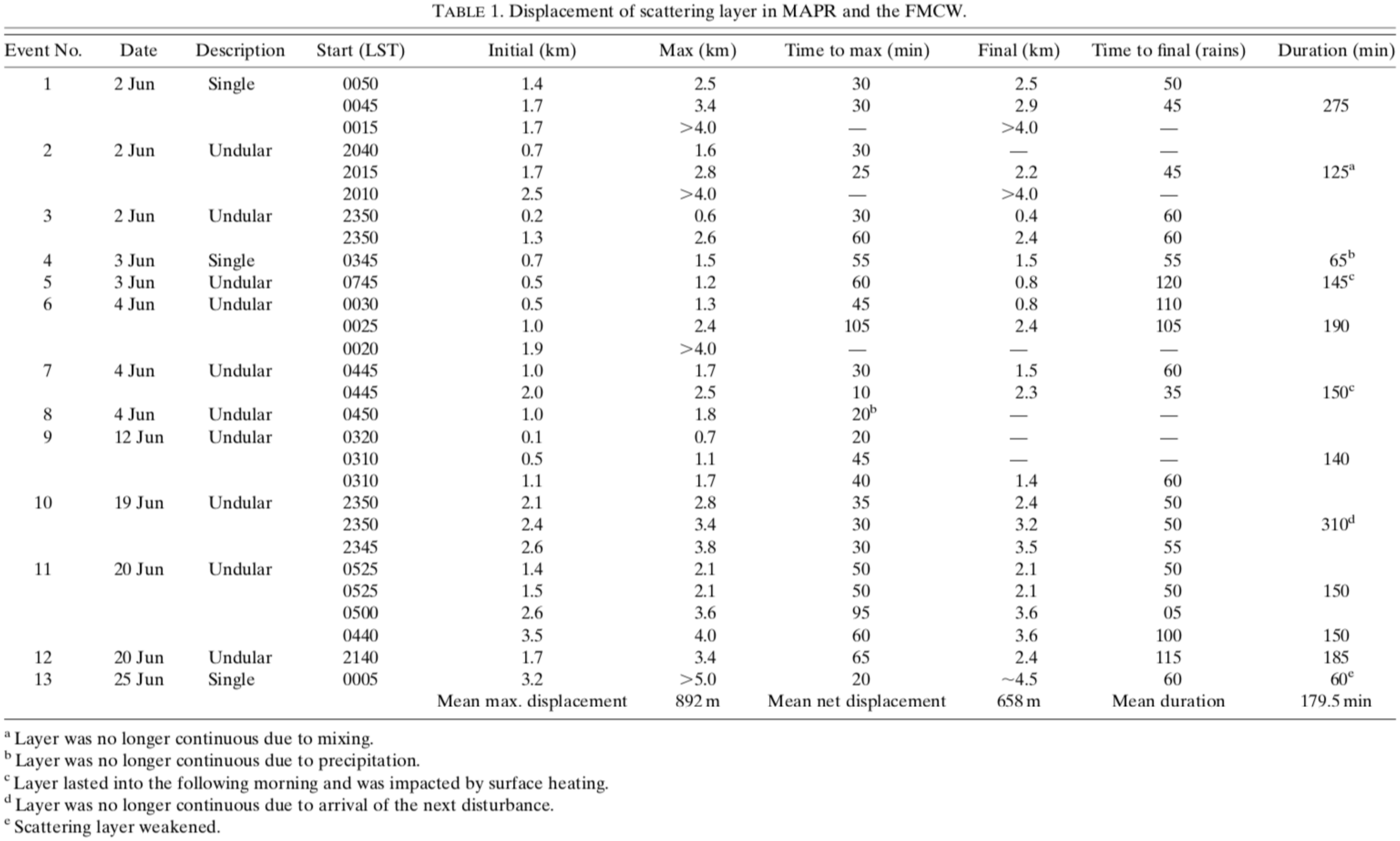


TABLE 1. Displacement of scattering layer in MAPR and the FMCW.

Event No.	Date	Description	Start (LST)	Initial (km)	Max (km)	Time to max (min)	Final (km)	Time to final (rains)	Duration (min)
1	2 Jun	Single	0050	1.4	2.5	30	2.5	50	
			0045	1.7	3.4	30	2.9	45	275
			0015	1.7	>4.0	—	>4.0	—	
2	2 Jun	Undular	2040	0.7	1.6	30	—	—	
			2015	1.7	2.8	25	2.2	45	125^{a}
			2010	2.5	>4.0	—	>4.0	—	
3	2 Jun	Undular	2350	0.2	0.6	30	0.4	60	
			2350	1.3	2.6	60	2.4	60	
4	3 Jun	Single	0345	0.7	1.5	55	1.5	55	65^{b}
5	3 Jun	Undular	0745	0.5	1.2	60	0.8	120	145^{c}
6	4 Jun	Undular	0030	0.5	1.3	45	0.8	110	
			0025	1.0	2.4	105	2.4	105	190
			0020	1.9	>4.0	—	—	—	
7	4 Jun	Undular	0445	1.0	1.7	30	1.5	60	
			0445	2.0	2.5	10	2.3	35	150^{c}
8	4 Jun	Undular	0450	1.0	1.8	20^{b}	—	—	
9	12 Jun	Undular	0320	0.1	0.7	20	—	—	
			0310	0.5	1.1	45	—	—	140
			0310	1.1	1.7	40	1.4	60	
10	19 Jun	Undular	2350	2.1	2.8	35	2.4	50	
			2350	2.4	3.4	30	3.2	50	310^{d}
			2345	2.6	3.8	30	3.5	55	
11	20 Jun	Undular	0525	1.4	2.1	50	2.1	50	
			0525	1.5	2.1	50	2.1	50	150
			0500	2.6	3.6	95	3.6	05	
			0440	3.5	4.0	60	3.6	100	150
12	20 Jun	Undular	2140	1.7	3.4	65	2.4	115	185
13	25 Jun	Single	0005	3.2	>5.0	20	~4.5	60	60^{e}
				Mean max. displacement	892 m	Mean net displacement	658 m	Mean duration	179.5 min

[a] Layer was no longer continuous due to mixing.

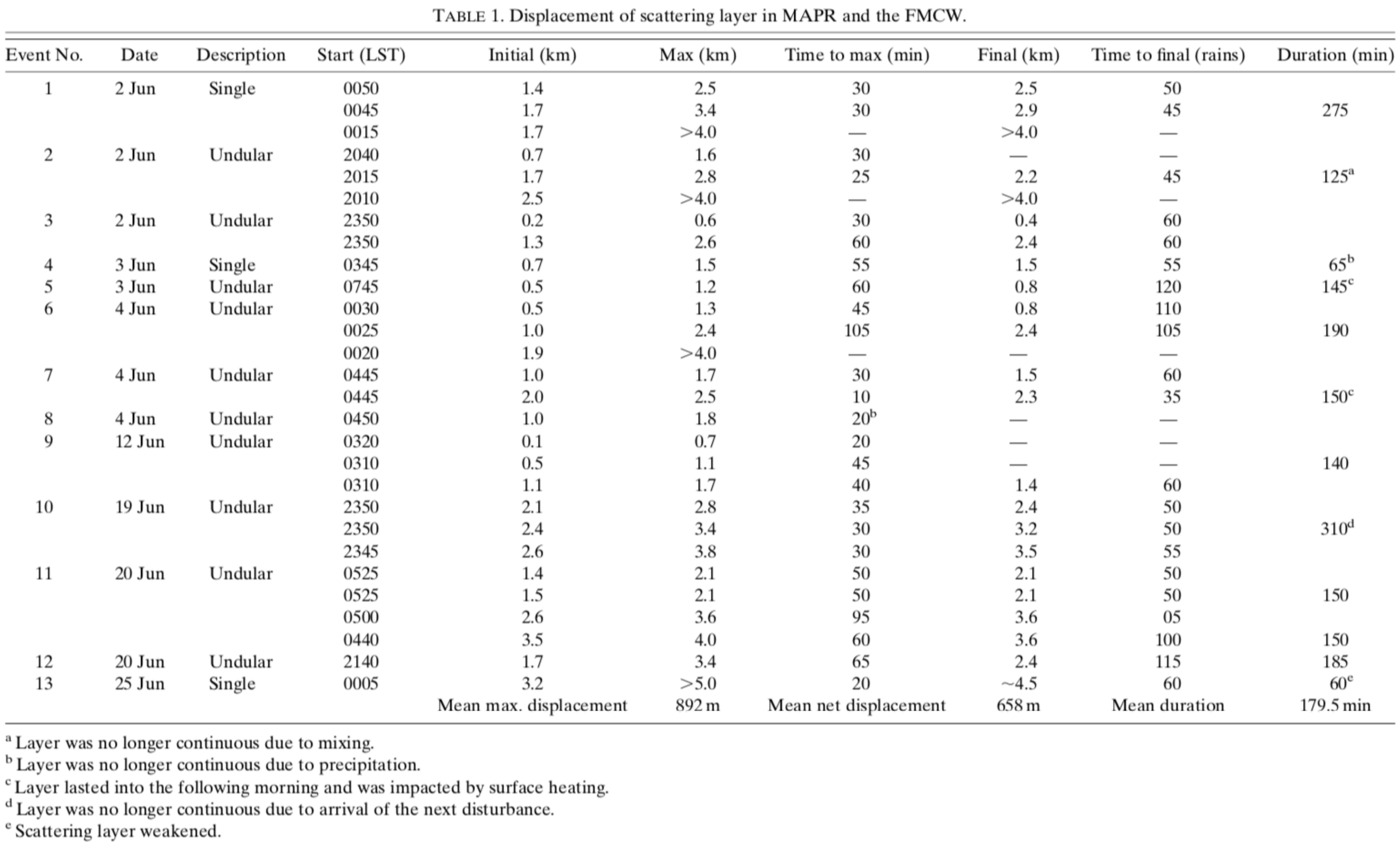
[b] Layer was no longer continuous due to precipitation.

[c] Layer lasted into the following morning and was impacted by surface heating.

[d] Layer was no longer continuous due to arrival of the next disturbance.

[e] Scattering layer weakened.

Lifting observed by the MAPR



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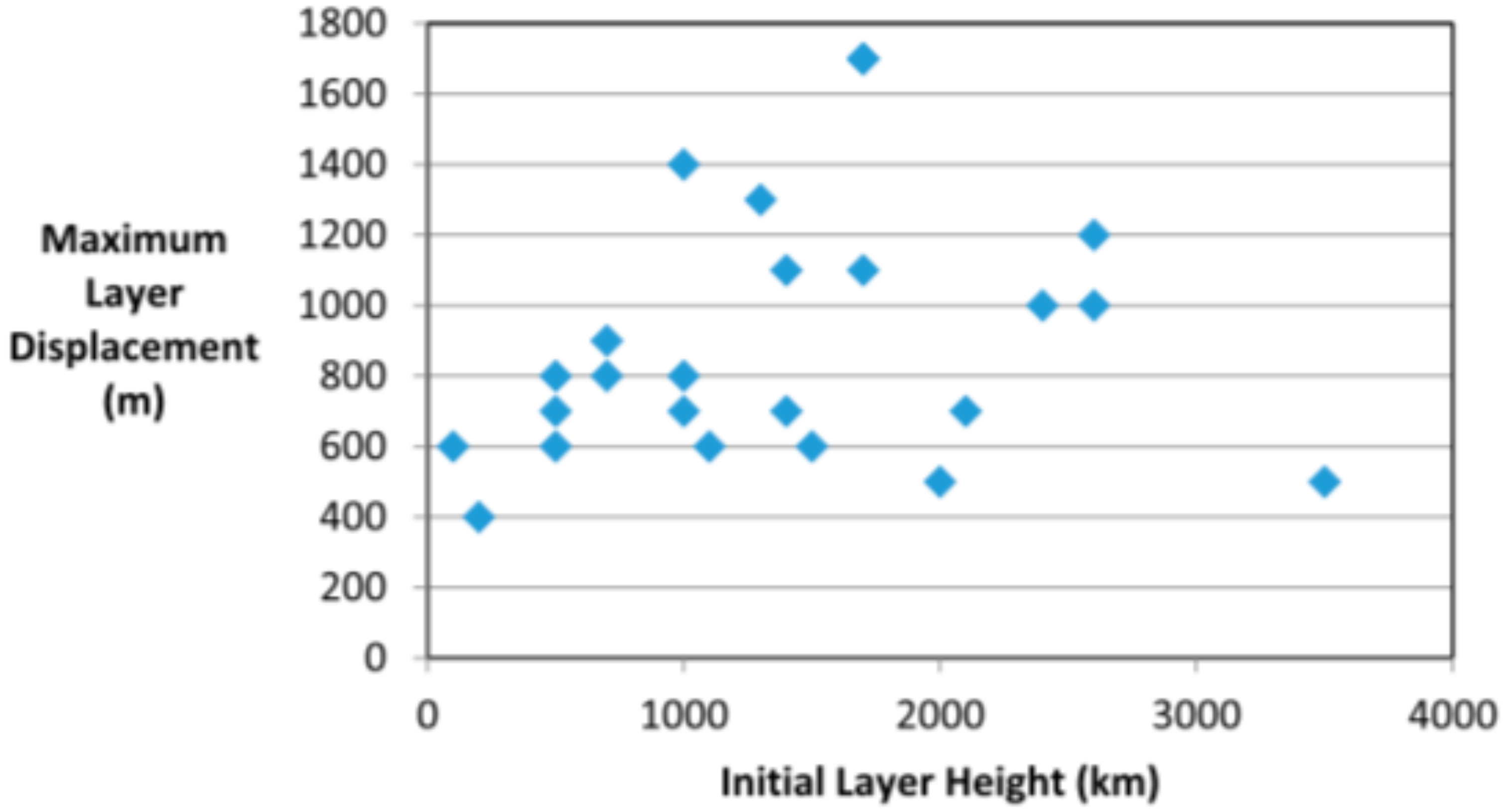
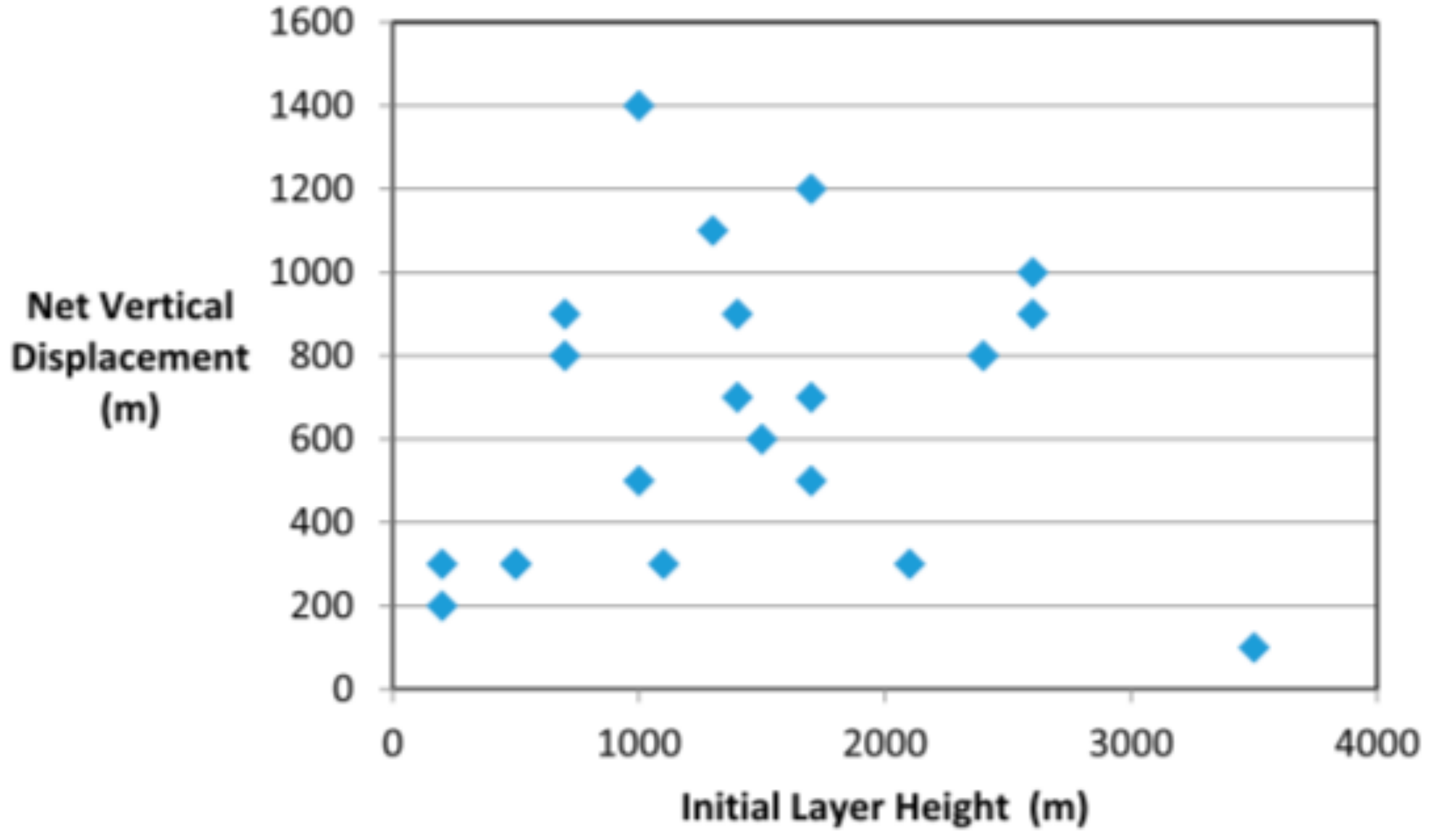
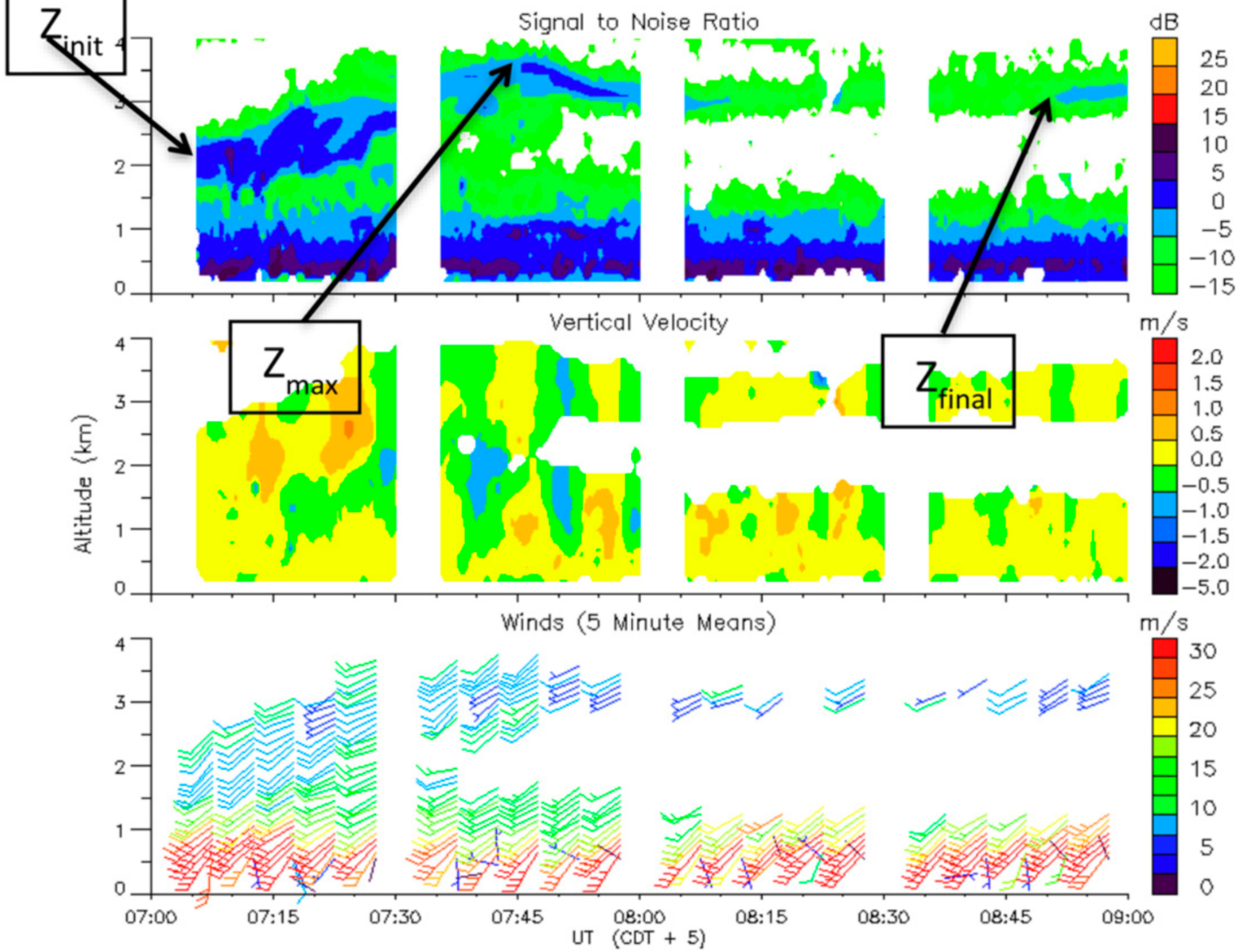


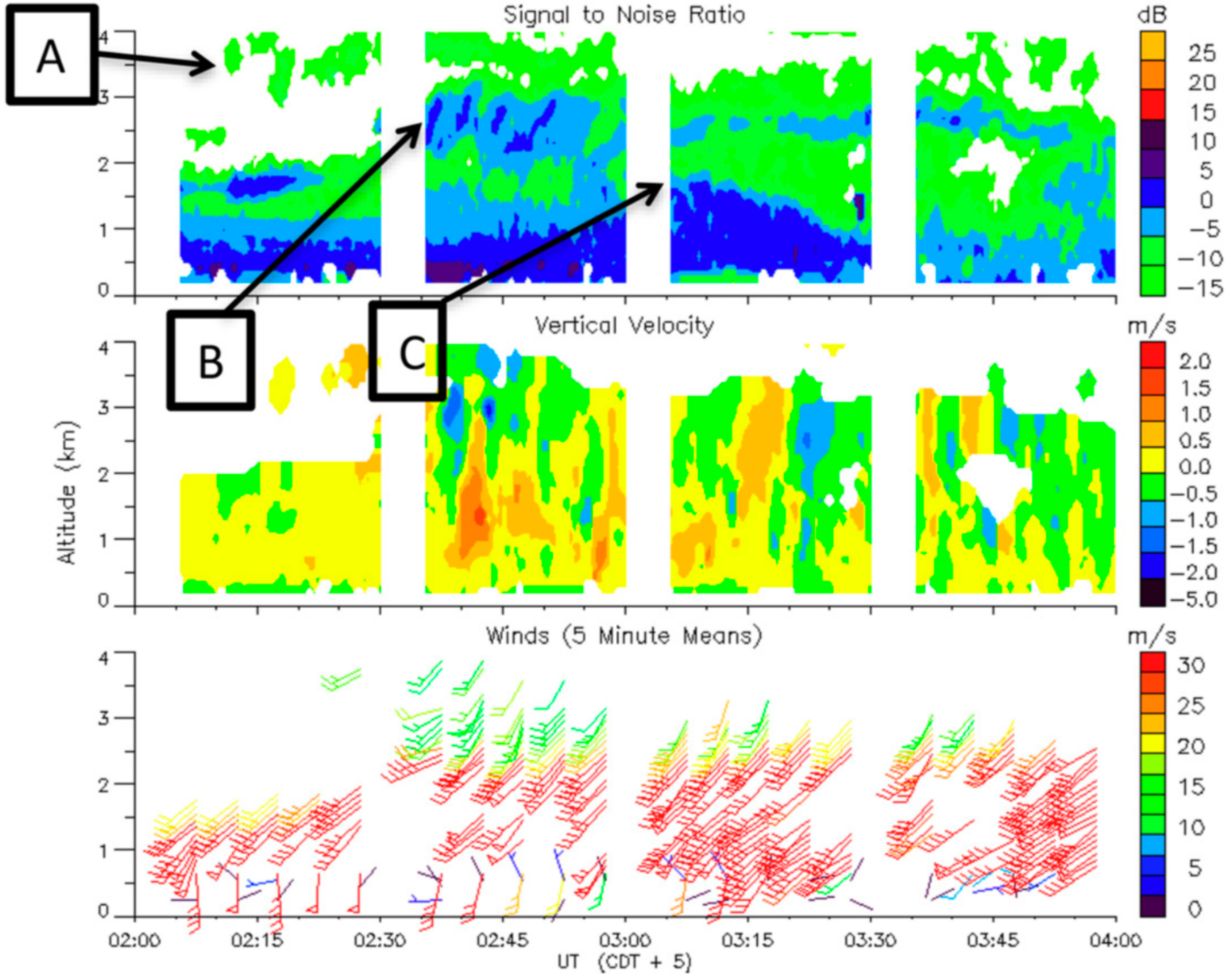


Examples of Observed Wave Events during *IHOP_2002*

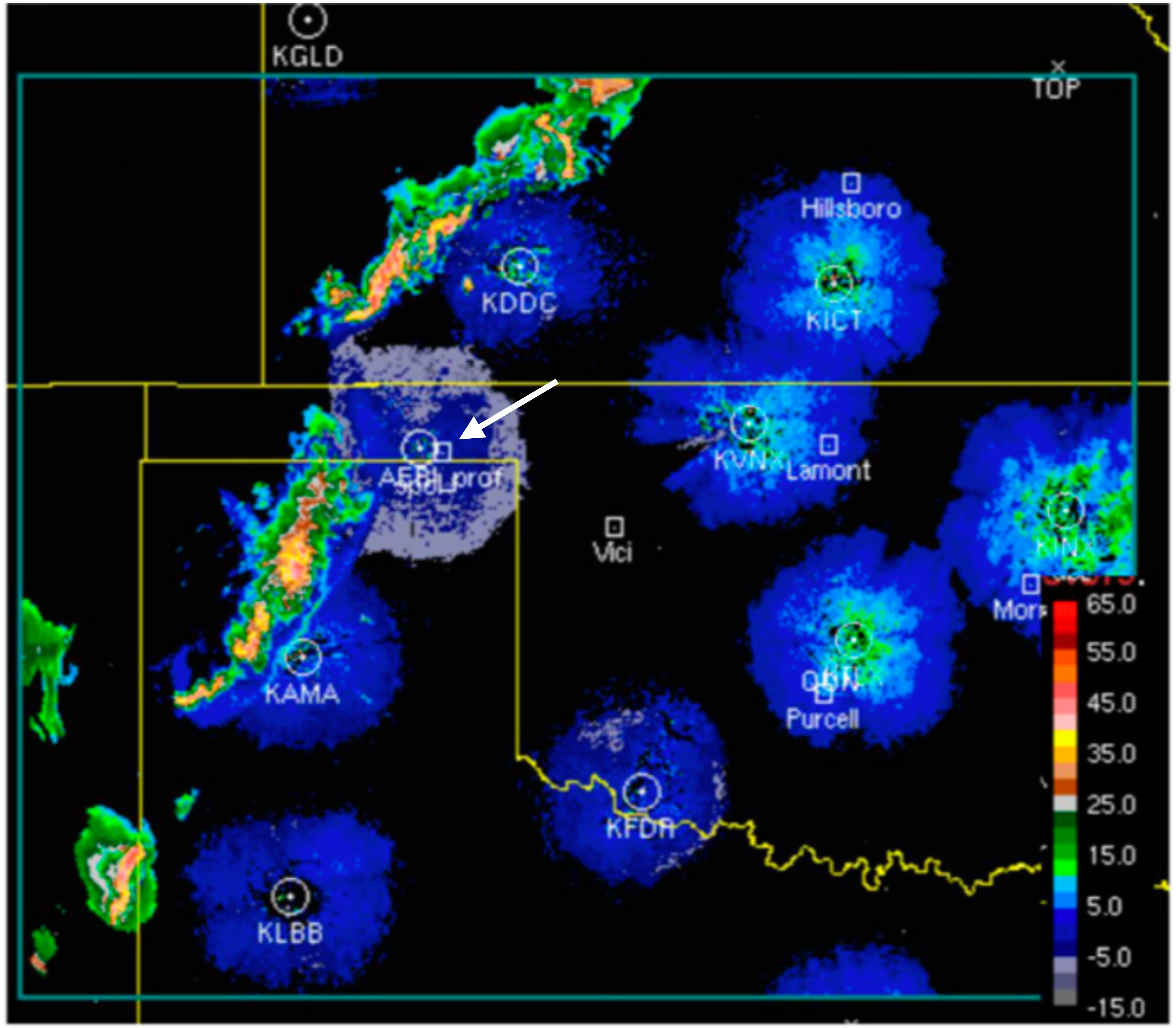
06-02



06-03

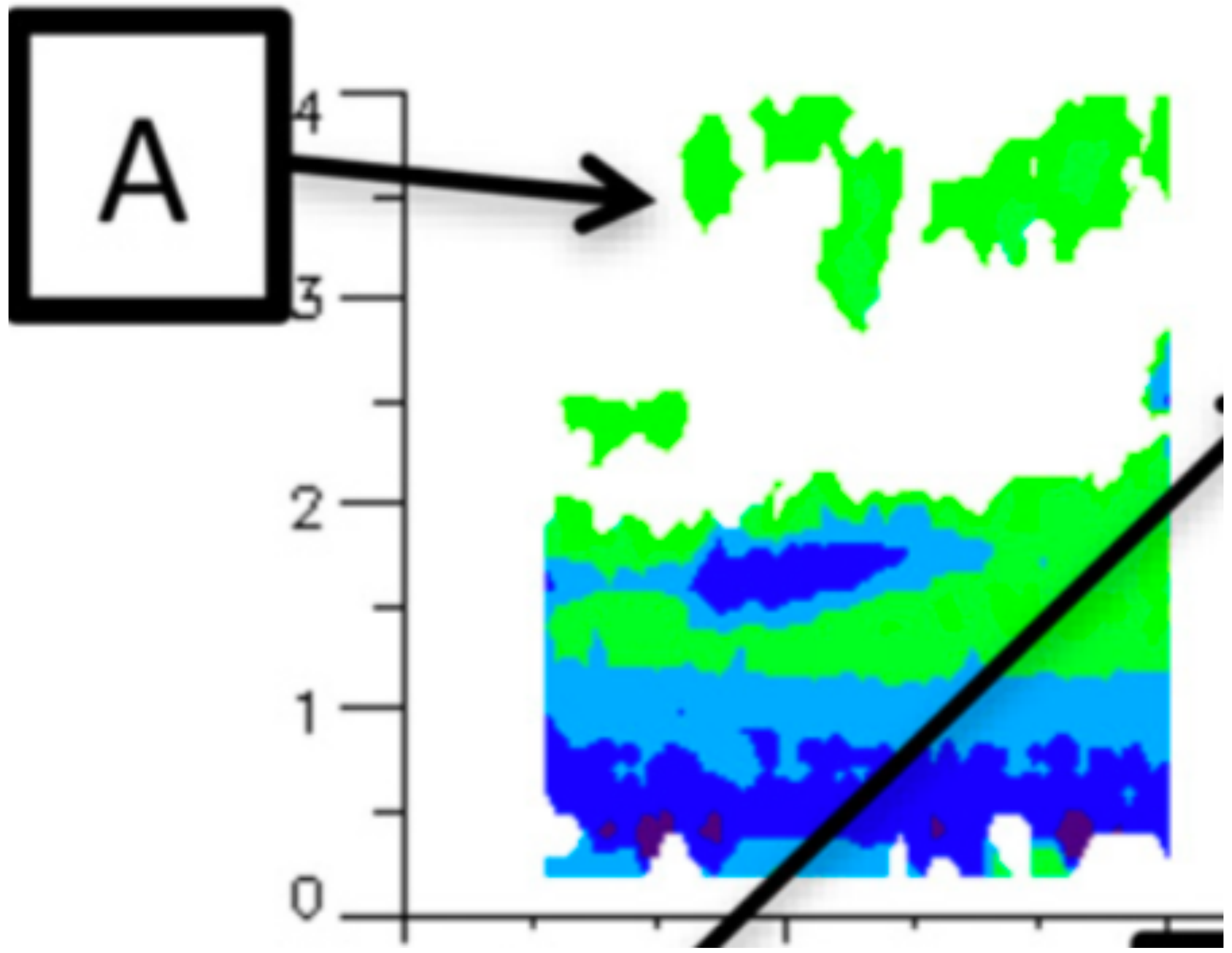


Examples of Observed Wave Events during *IHOP_2002*



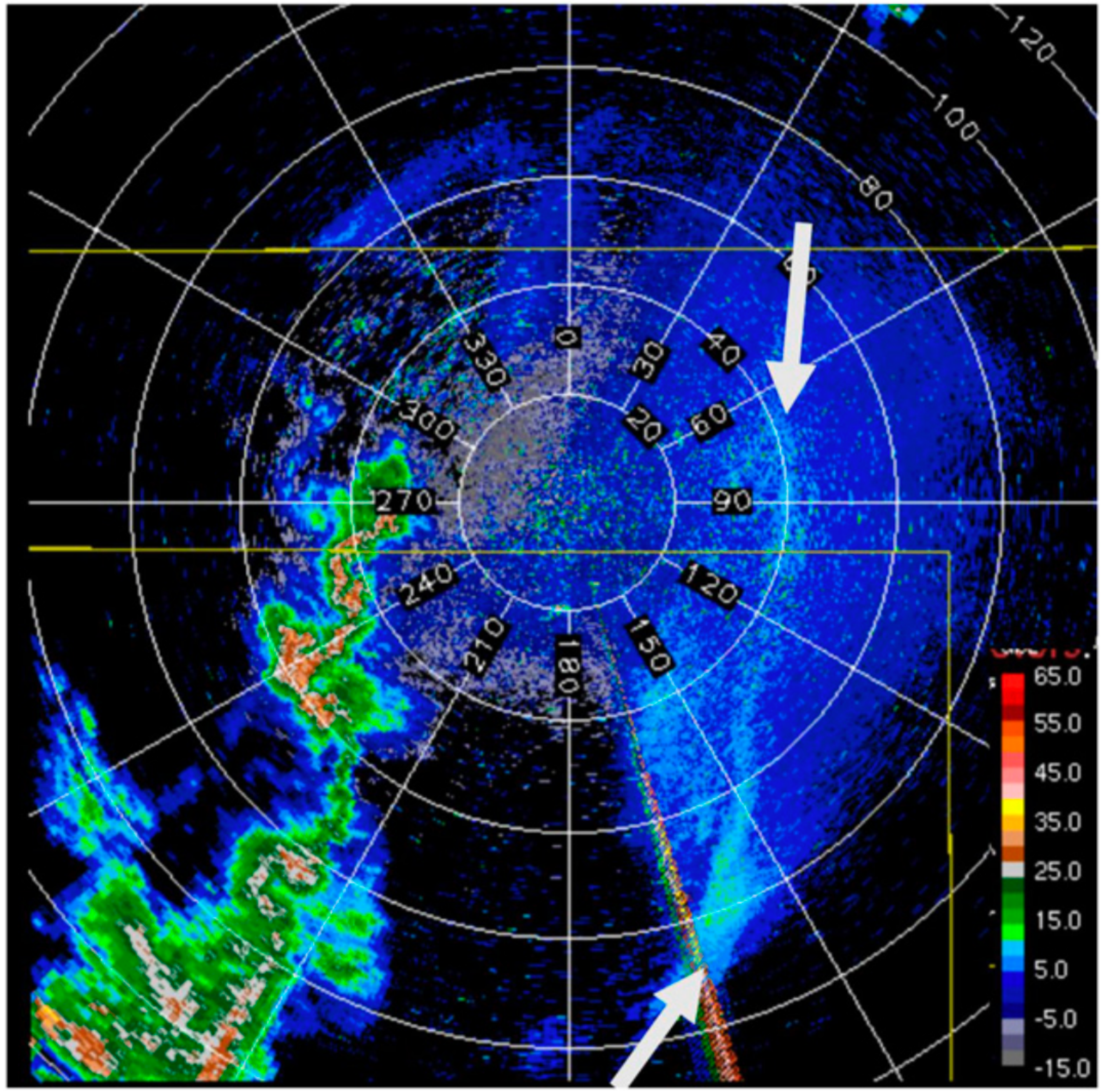
⬭: Radar Reflectivity (dBZ) at 2015 LST 3 Jun 2002

Case 2: 2002-06-03



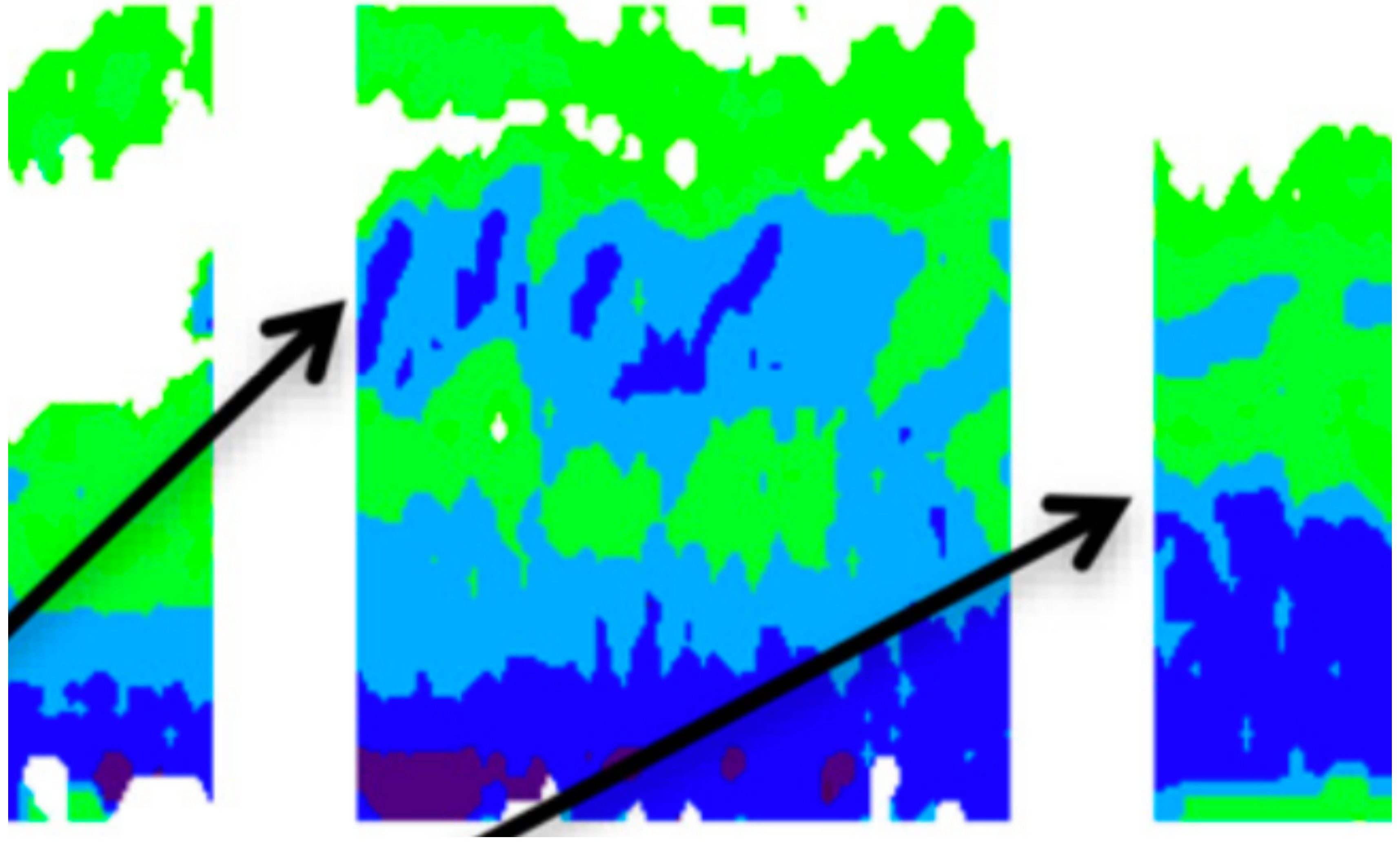
Low-frequency GWs generated by buoyancy convection (Nicholls et al. 1991; Fovell 2002)

Examples of Observed Wave Events during *IHOP_2002*



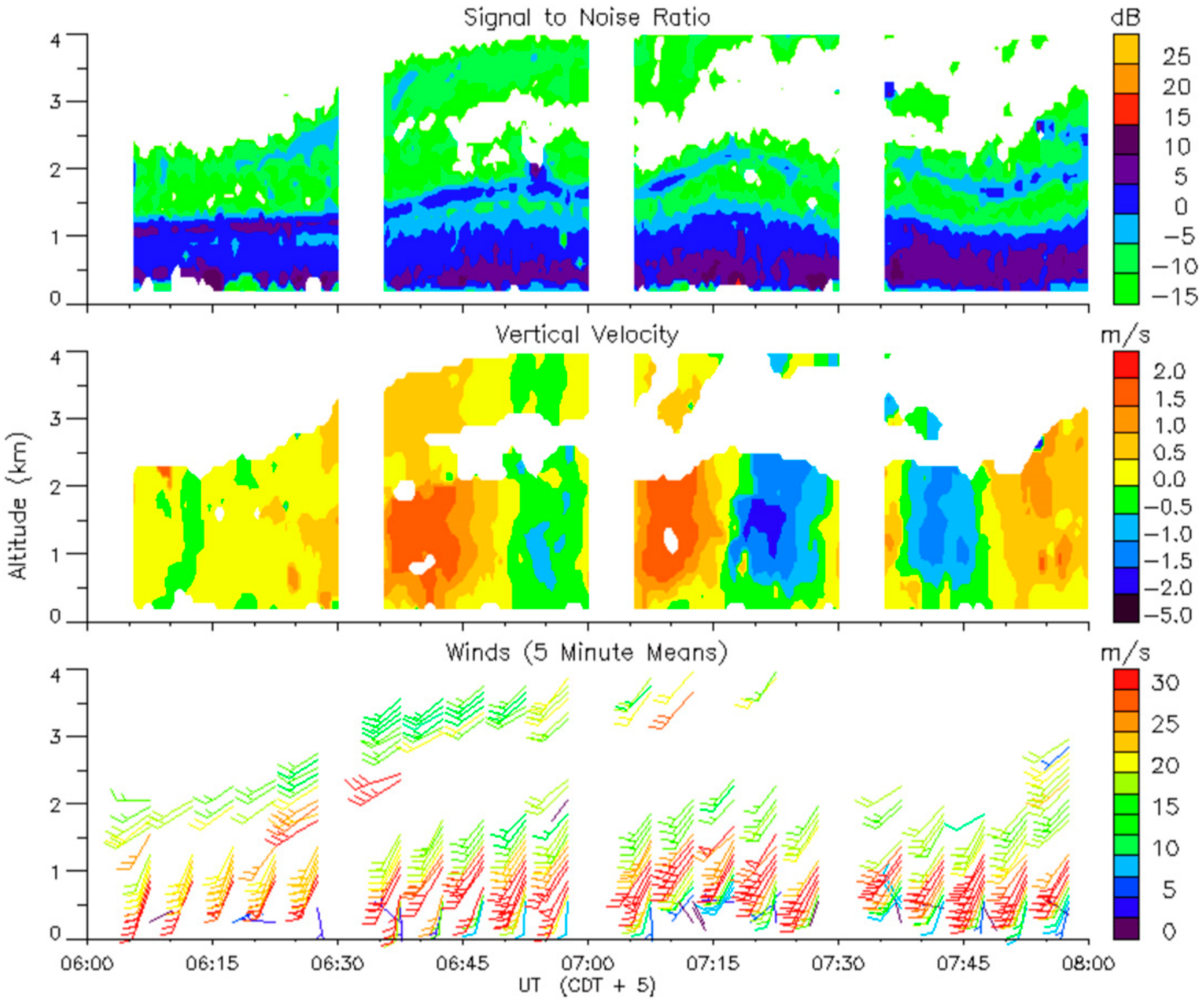
⬭: Radar Reflectivity (dBZ) at 2130 LST 3 Jun 2002

Case 2: 2002-06-03



Most likely bore lifting.

Examples of Observed Wave Events during *IHOP_2002*



Case 8: 2002-06-04

- Lifting at three distinct heights
- Wave amplitude increased with time
- Lifting aloft in phase with bore lifting
- Wave structure aloft: “indirect influence” of bore (Koch et al. 2008)? Multiple wave ducts (Haghi et al. 2017)?
- Ascent associated with wave features could enhance deep-layer shear -> maintain lifting (Parker 2008)

Wave ducts and energy trapping associated with lifting events

Taylor-Goldstein Equation (Governs the vertical structures of wave perturbation)

$$\frac{\partial^2 w}{\partial z^2} + m^2 w = 0$$

Vertical Wave Number

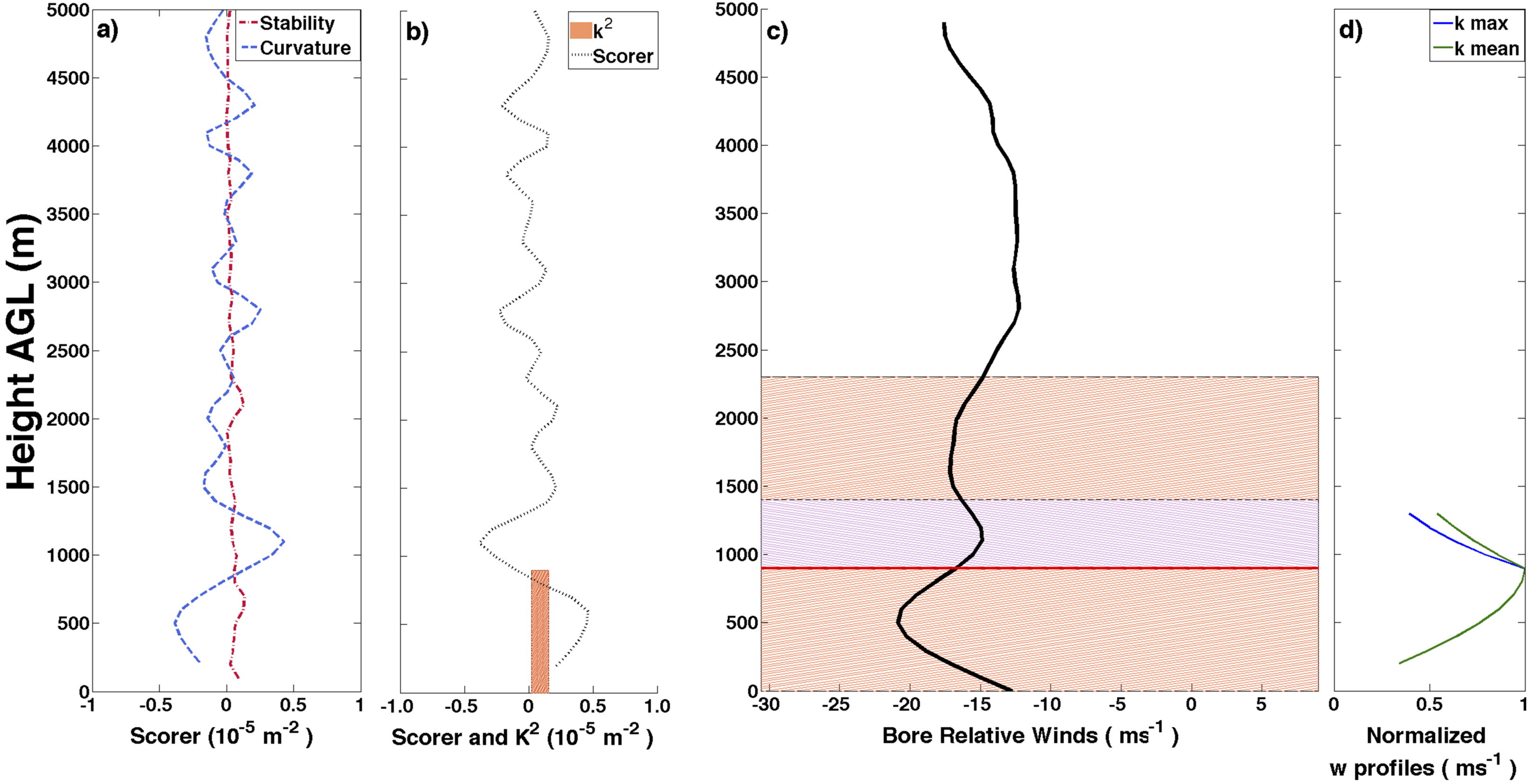
$$m^2 = l^2 - k^2 = \frac{N^2}{(U - C_b)^2} - \frac{\frac{\partial^2 U}{\partial z^2}}{(U - C_b)} - k^2$$

Stability Term

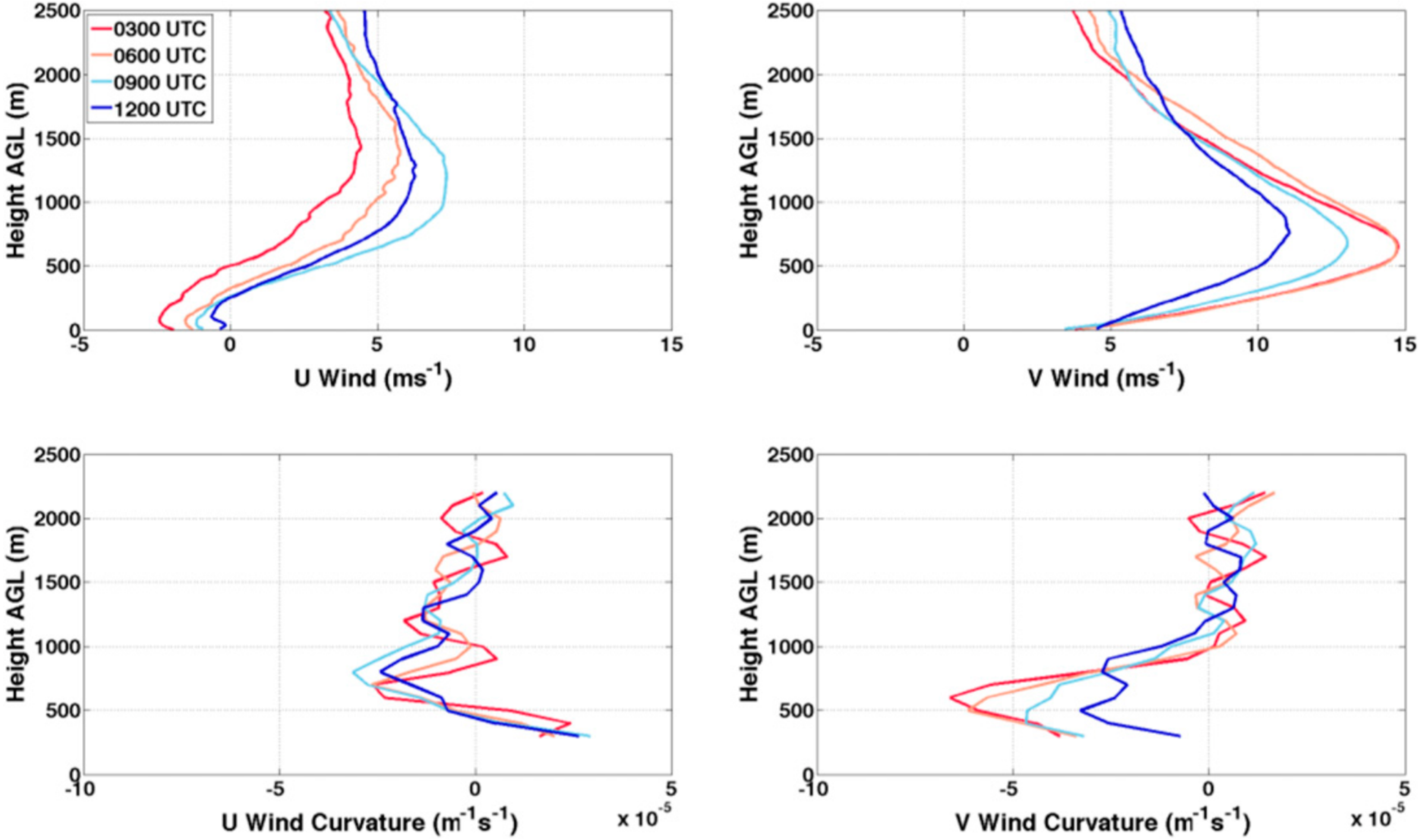
Curvature Term

Wave ducts and energy trapping associated with lifting events

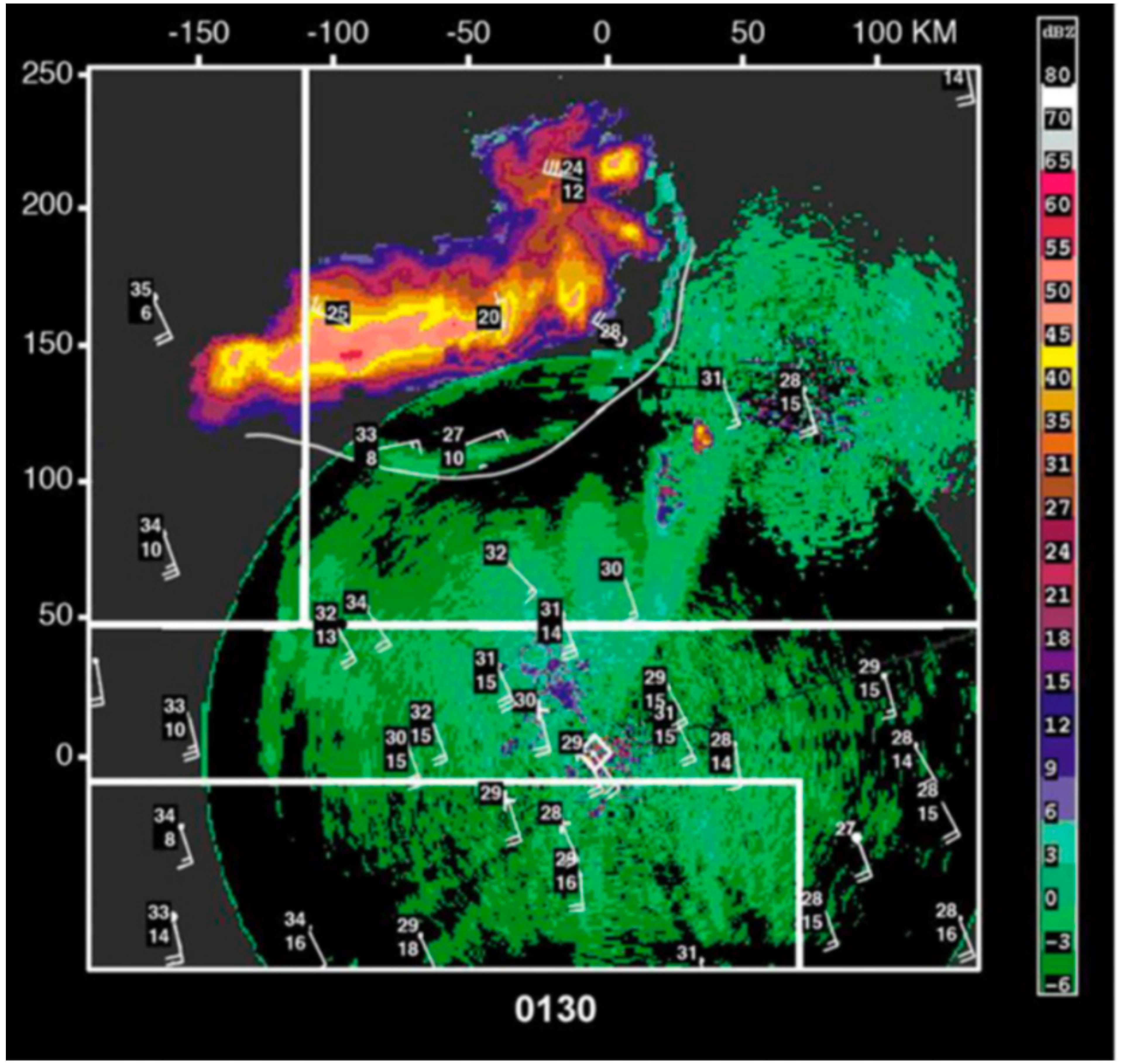
Case 8 (Haghi et al. 2017)



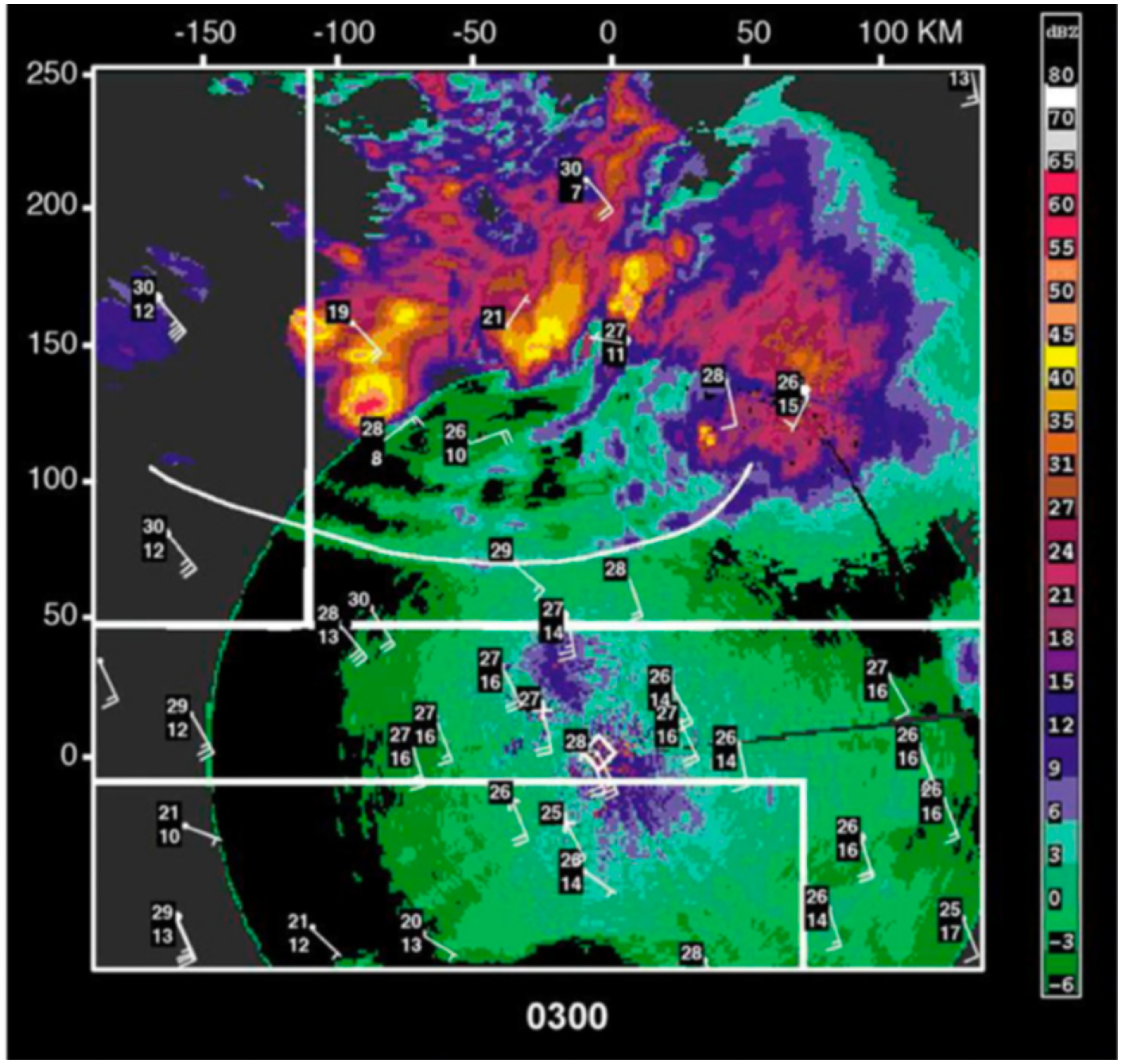
Wave ducts and energy trapping associated with lifting events



Waves and Convection (20 Jun 2002 Case)

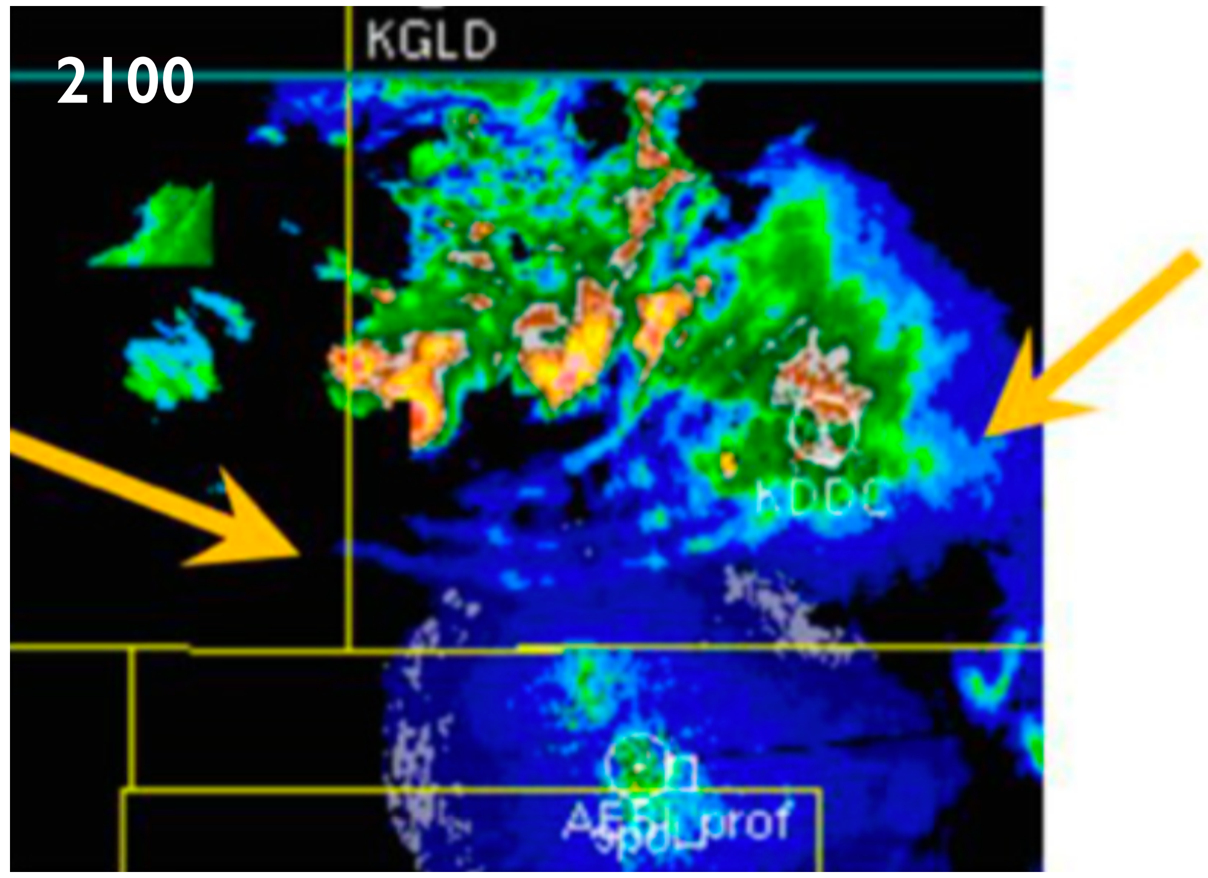


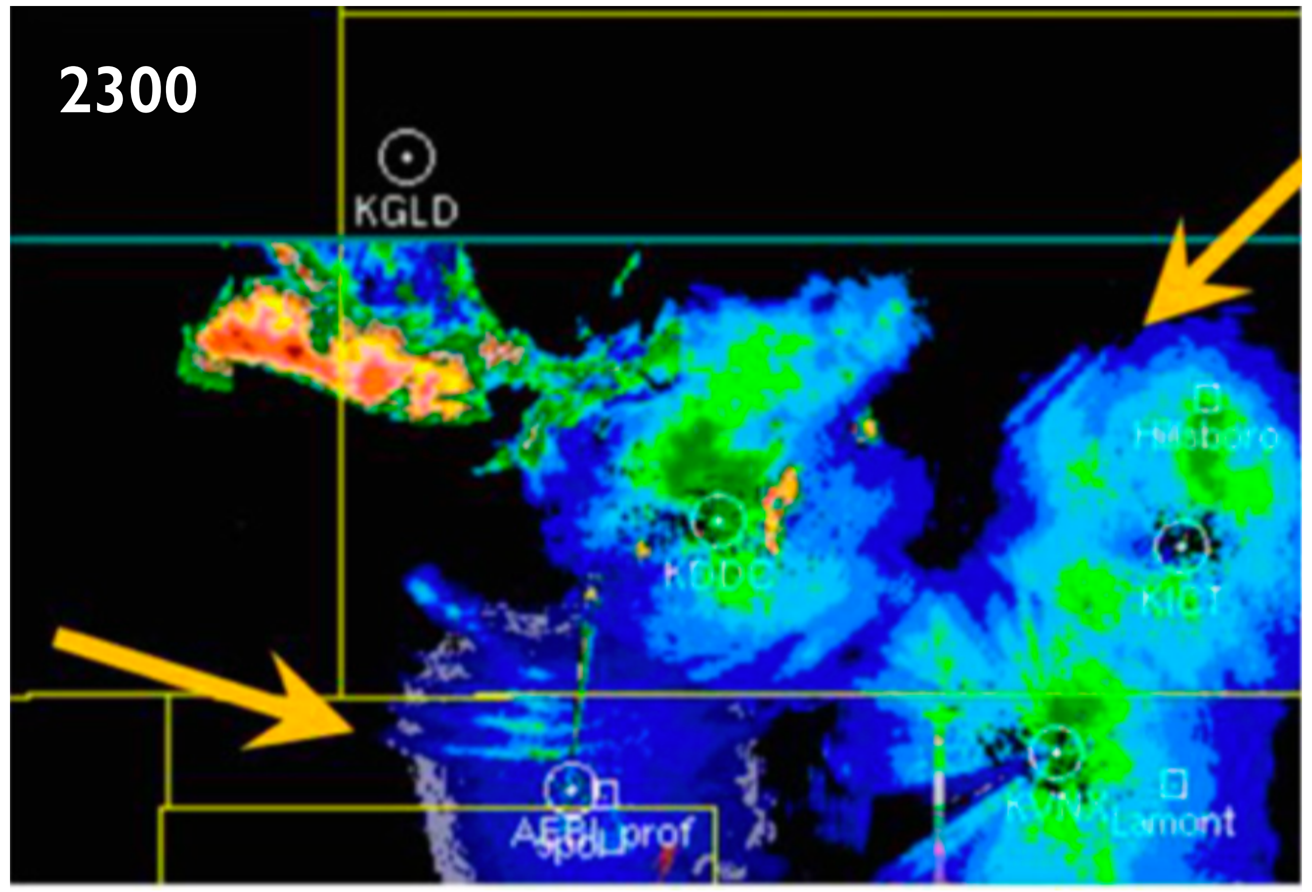
1930LST

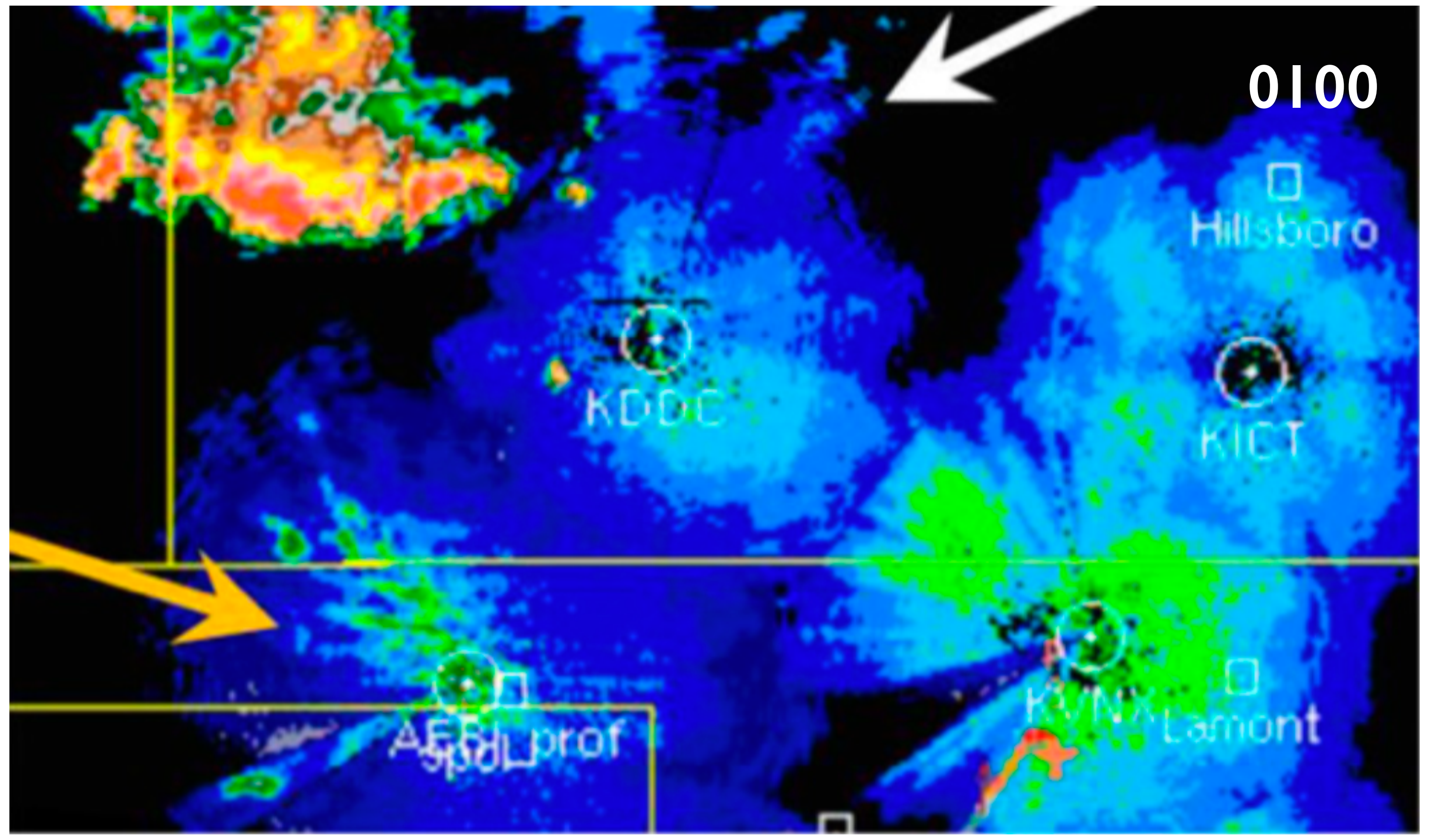


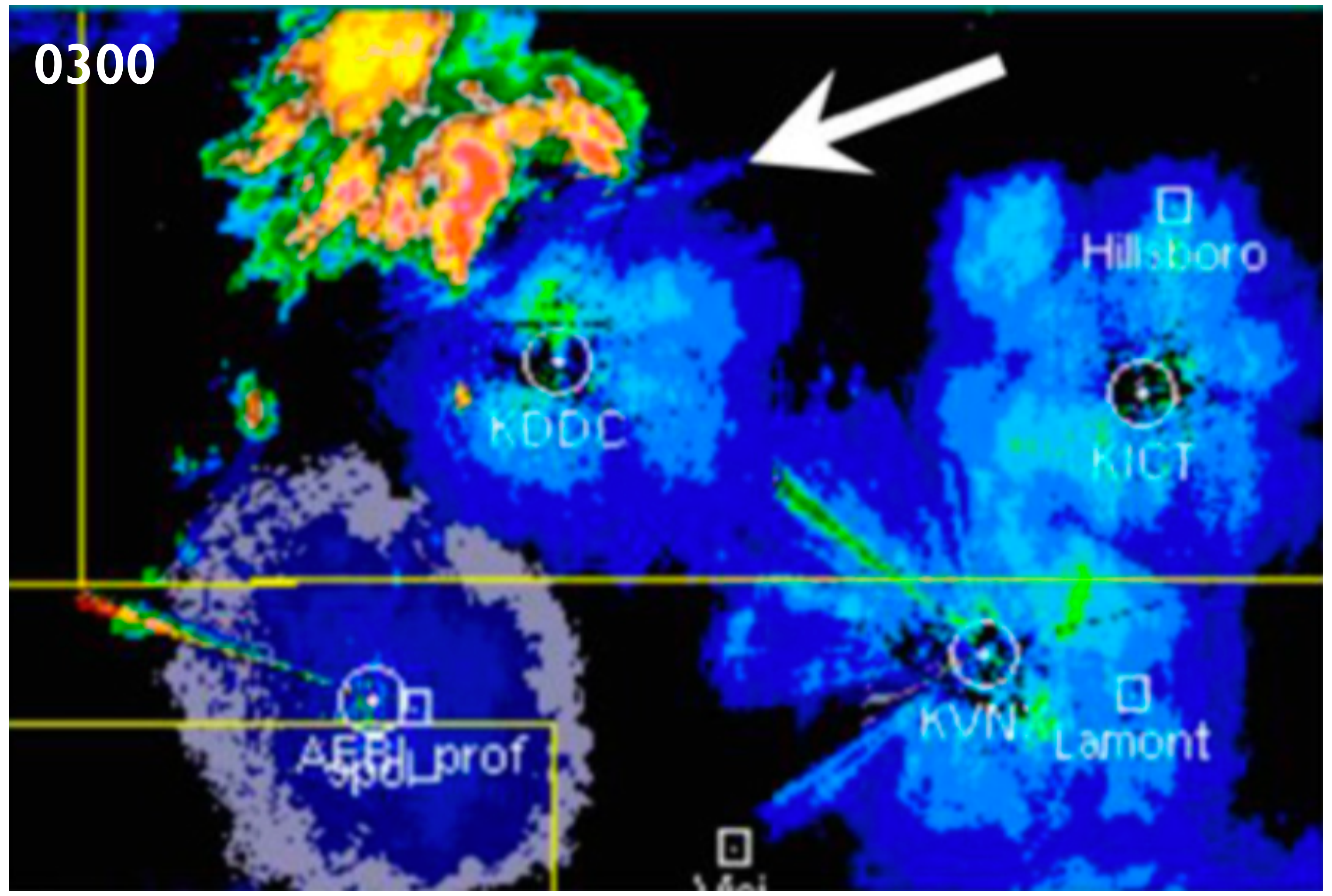
2130LST

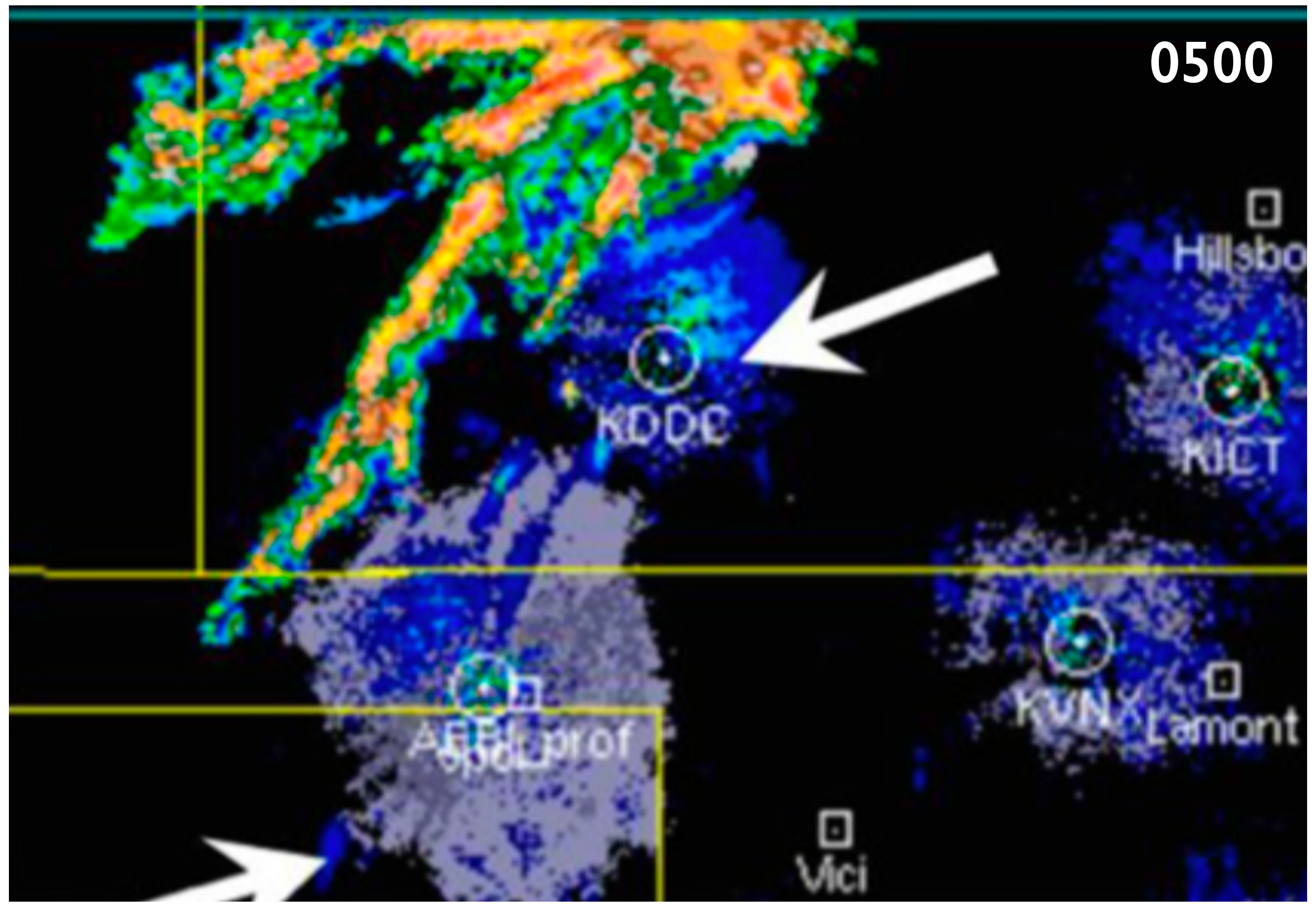
Waves and Convection (20 Jun 2002 Case)

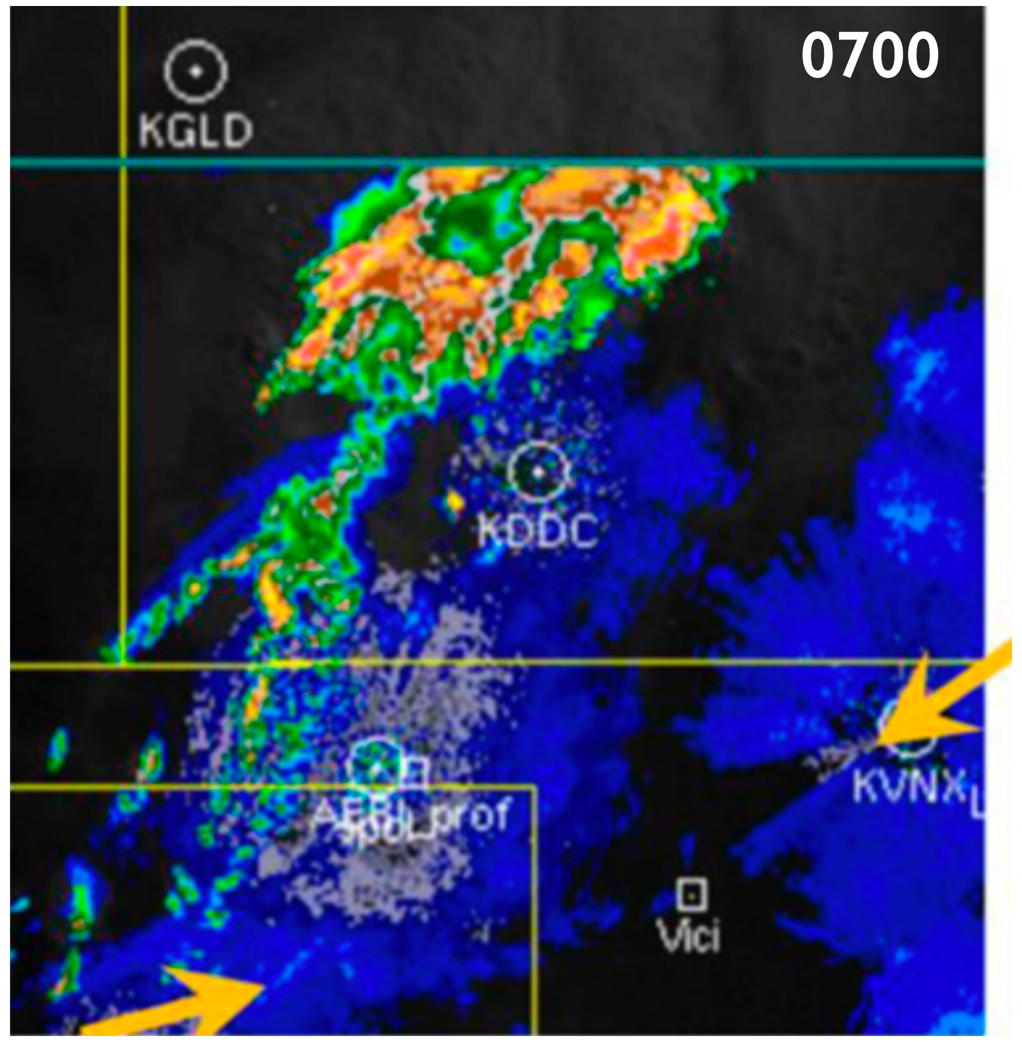




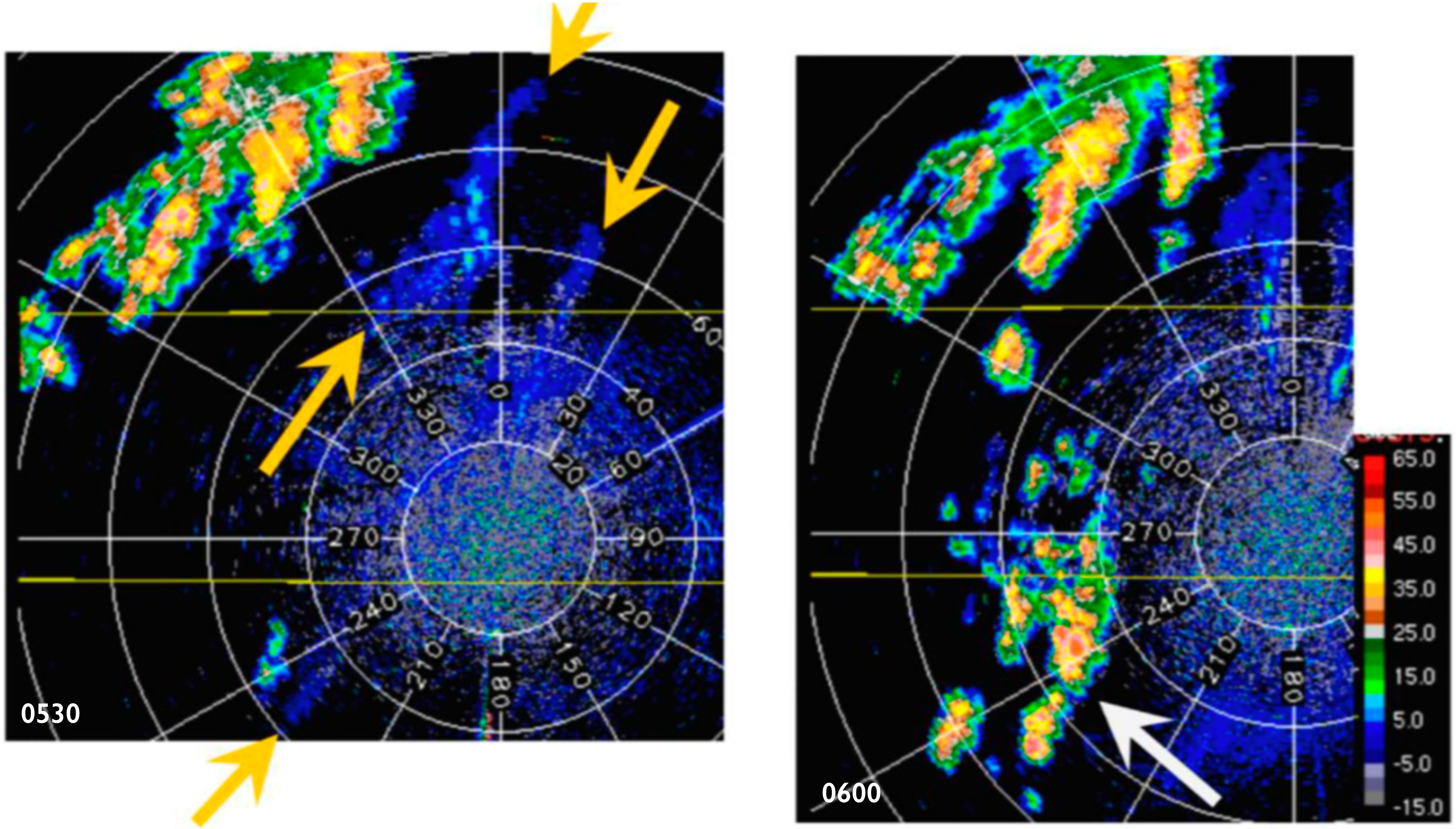




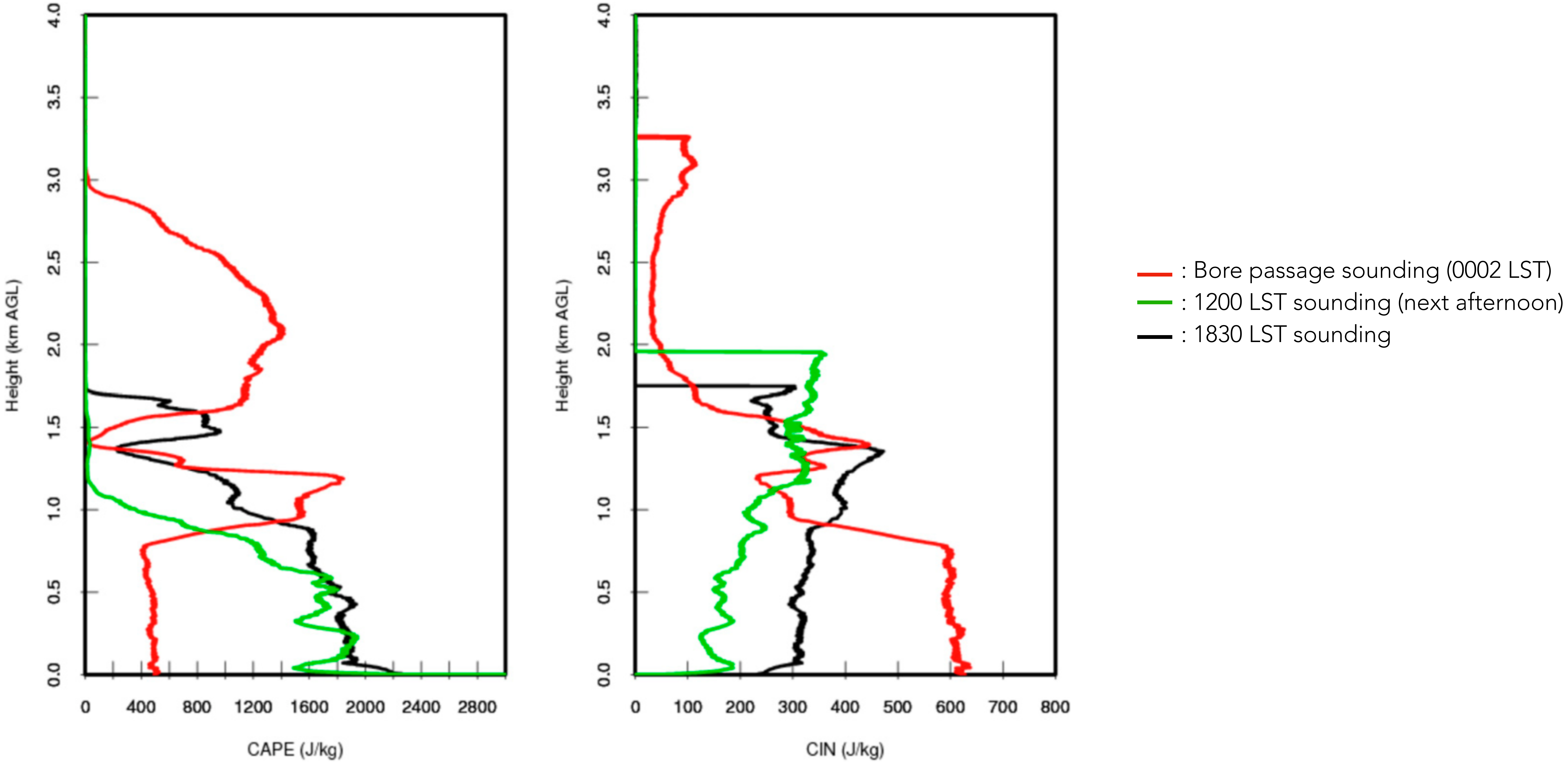




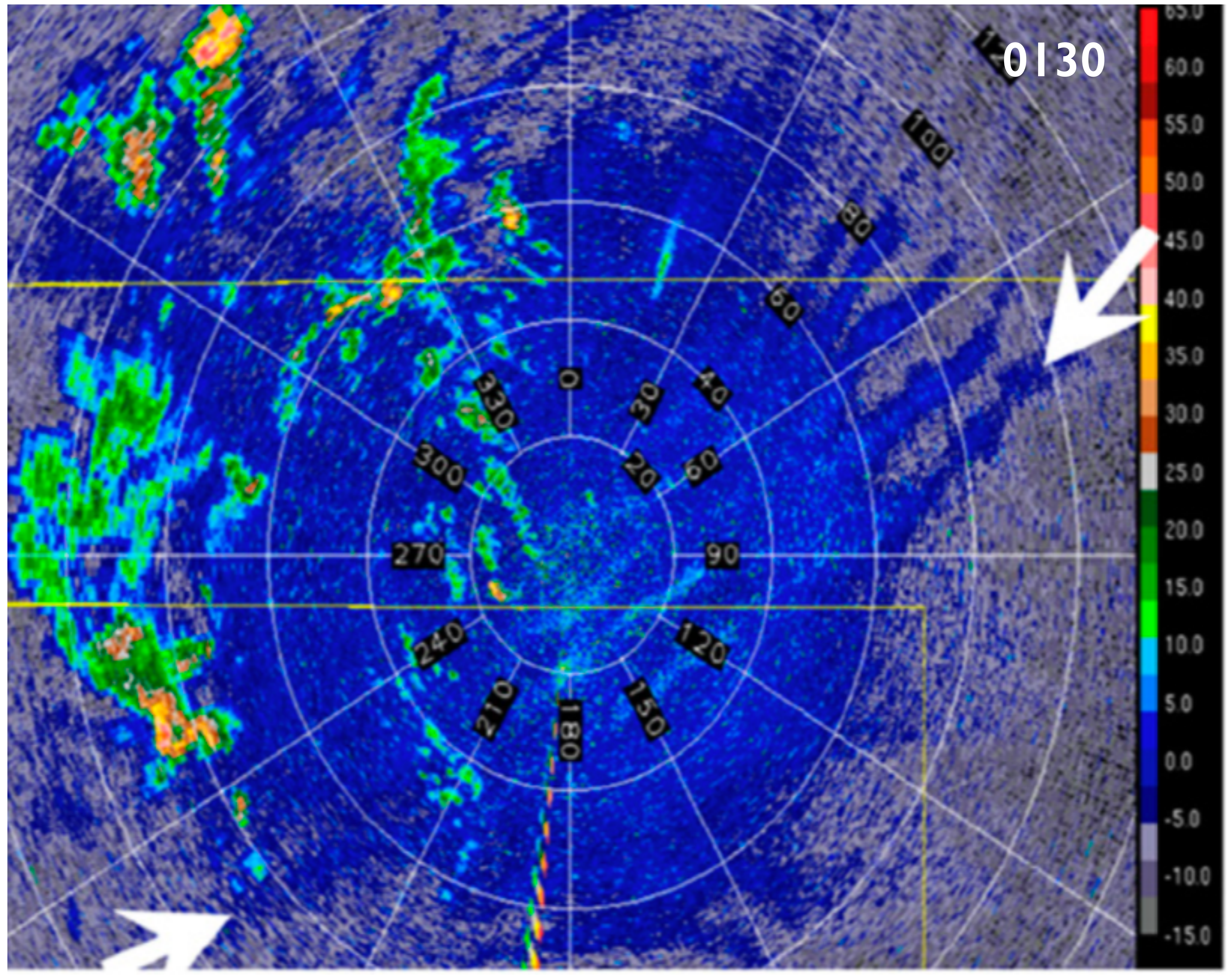
Waves and Convection (20 Jun 2002 Case)

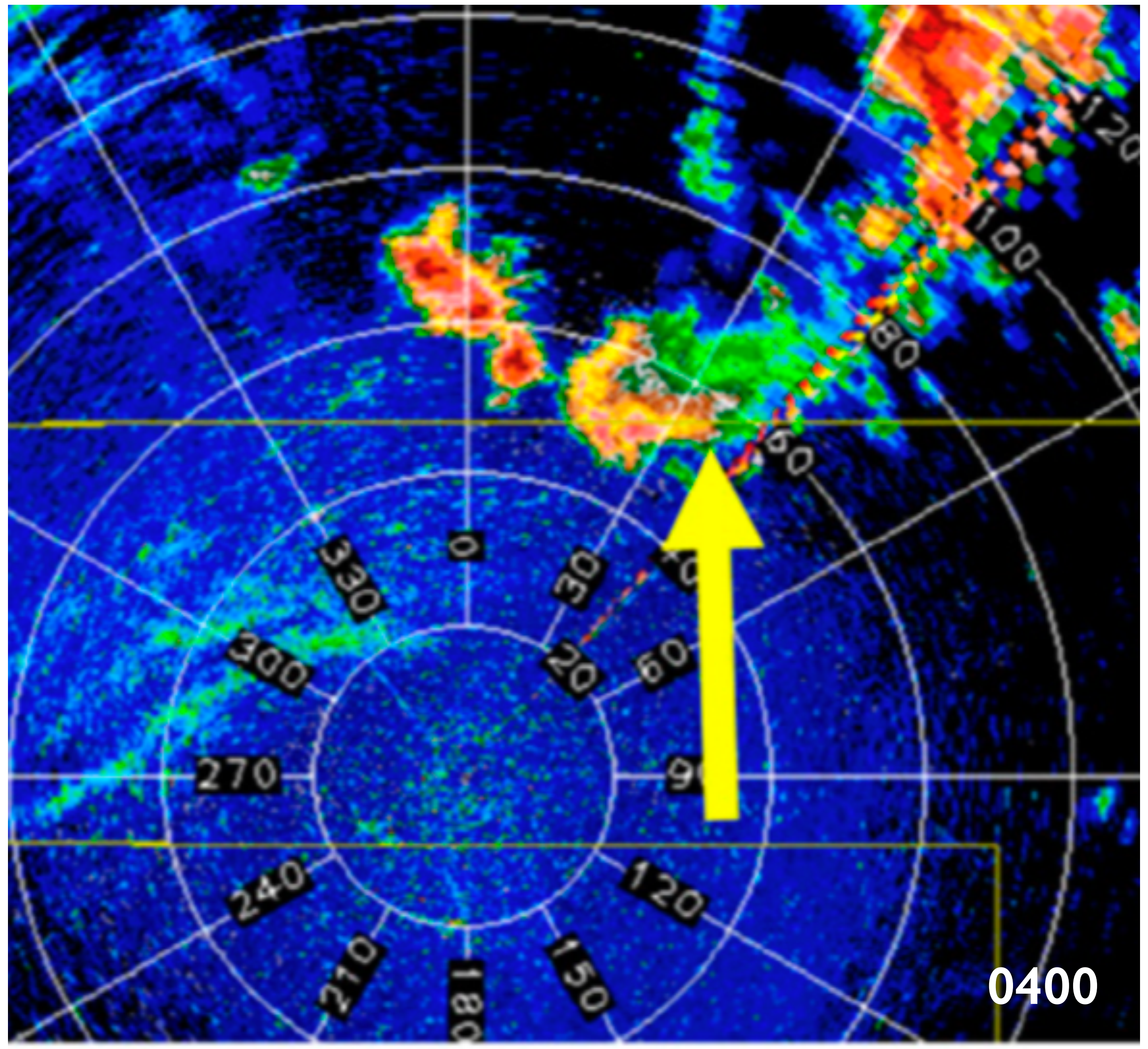


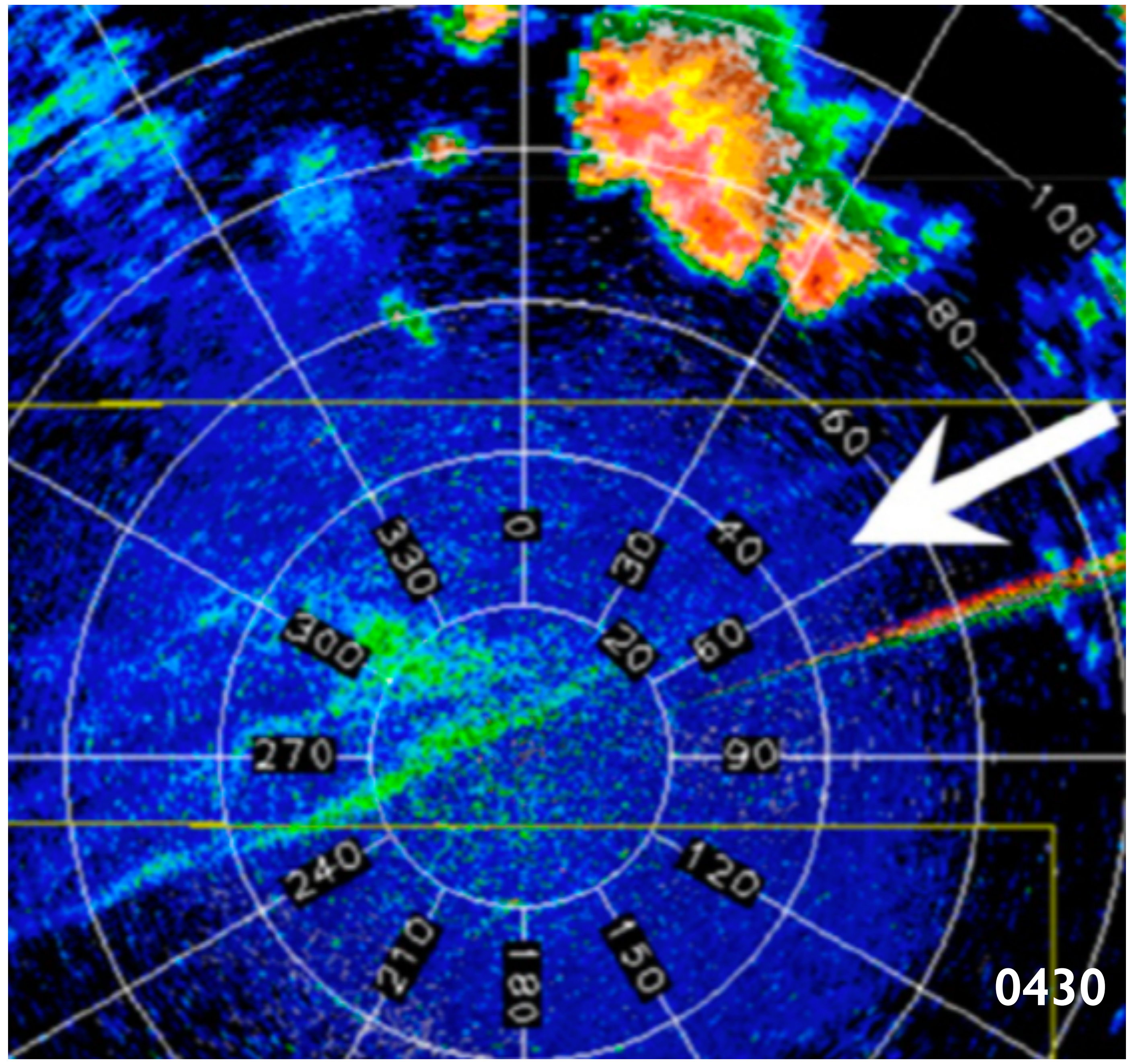
Waves and Convection (20 Jun 2002 Case)



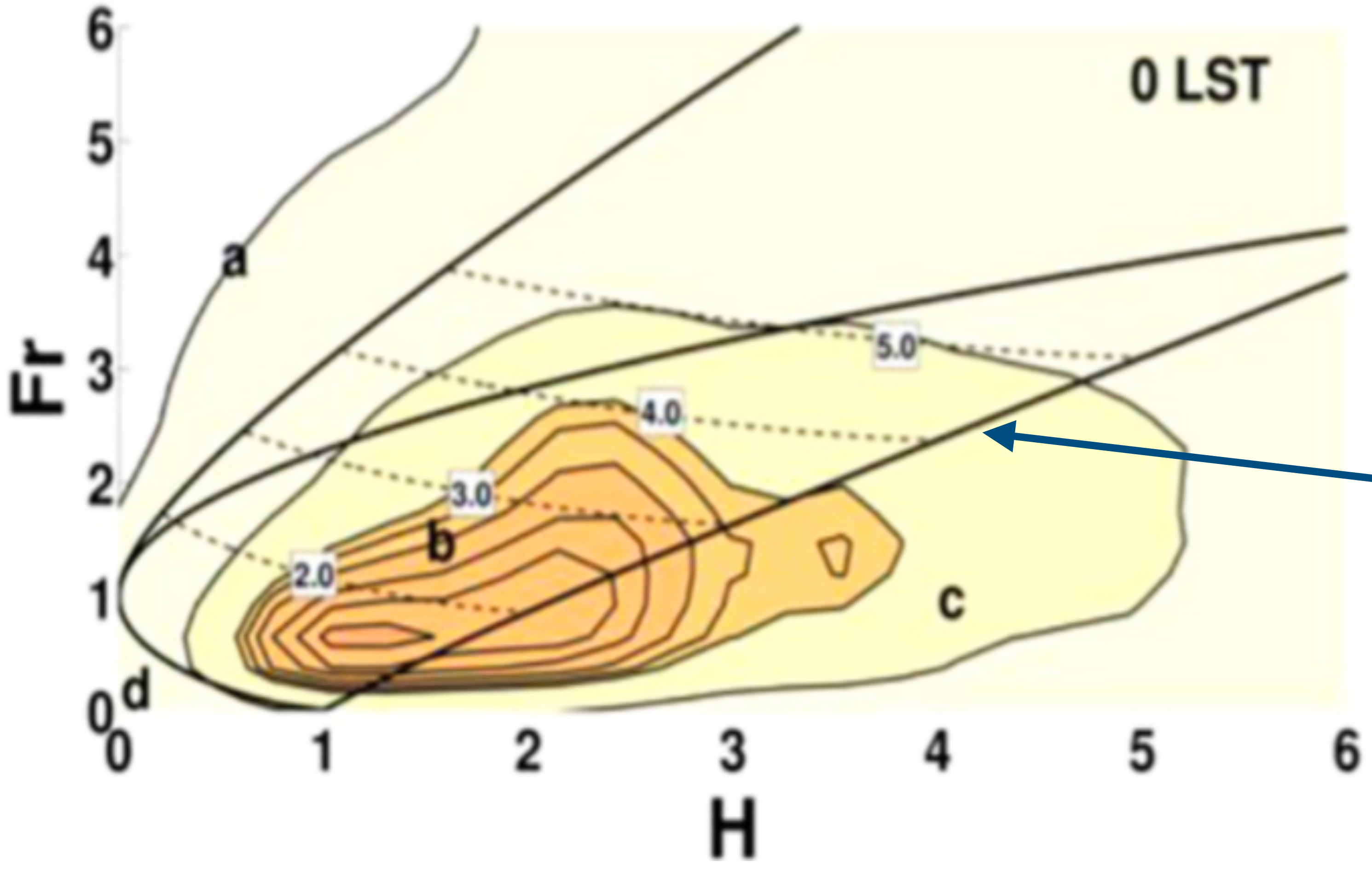
Waves and Convection (4 Jun 2002 Case)







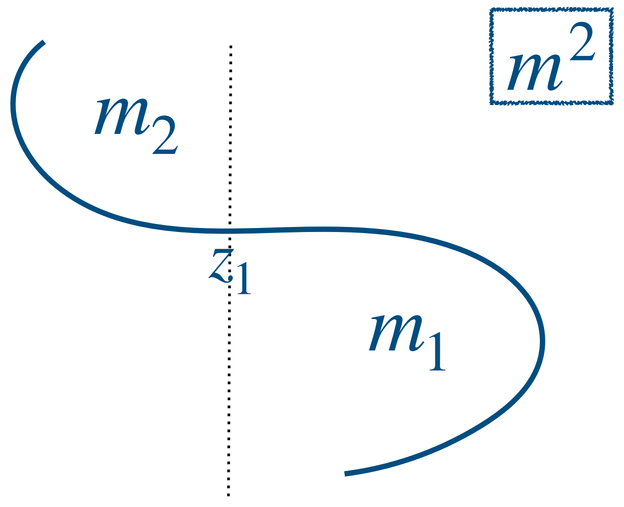
Quantified the impact of bore lifting on stability profiles



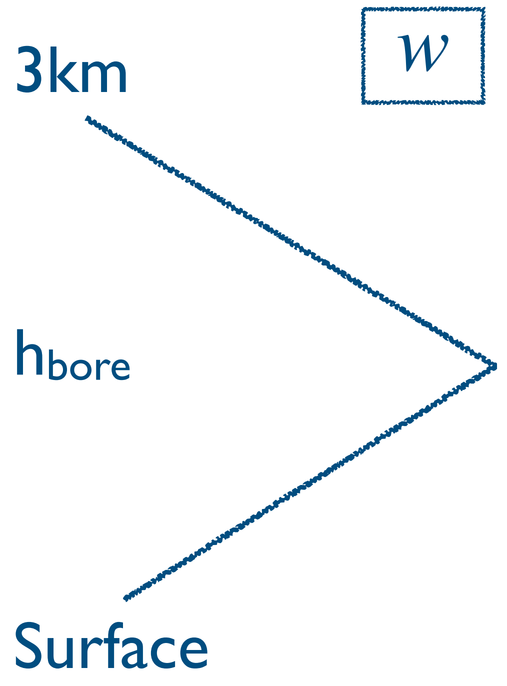
$$\left\{\begin{aligned}
\frac{h_{bore}}{h_{NBL}} &= H - \frac{1}{2}\frac{u_1^2}{g'h_0} + \frac{3}{2}(\frac{h_1}{h_0}\frac{u_1}{(g'h_0)^{\frac{1}{2}}})^{\frac{2}{3}} \\
\frac{C}{(g'h_0)^{\frac{1}{2}}} &= [\frac{1}{2}(\frac{h_{bore}}{h_{NBL}})(1+\frac{h_{bore}}{h_{NBL}})]^{\frac{1}{2}} \\
\frac{u_1}{(g'h_0)^{\frac{1}{2}}} &= Fr - (1-\frac{h_{NBL}}{h_{bore}})\frac{C}{(g'h_0)^{\frac{1}{2}}}
\end{aligned}\right.$$

Rottman and Simpson (1989)

Determine Bore Height



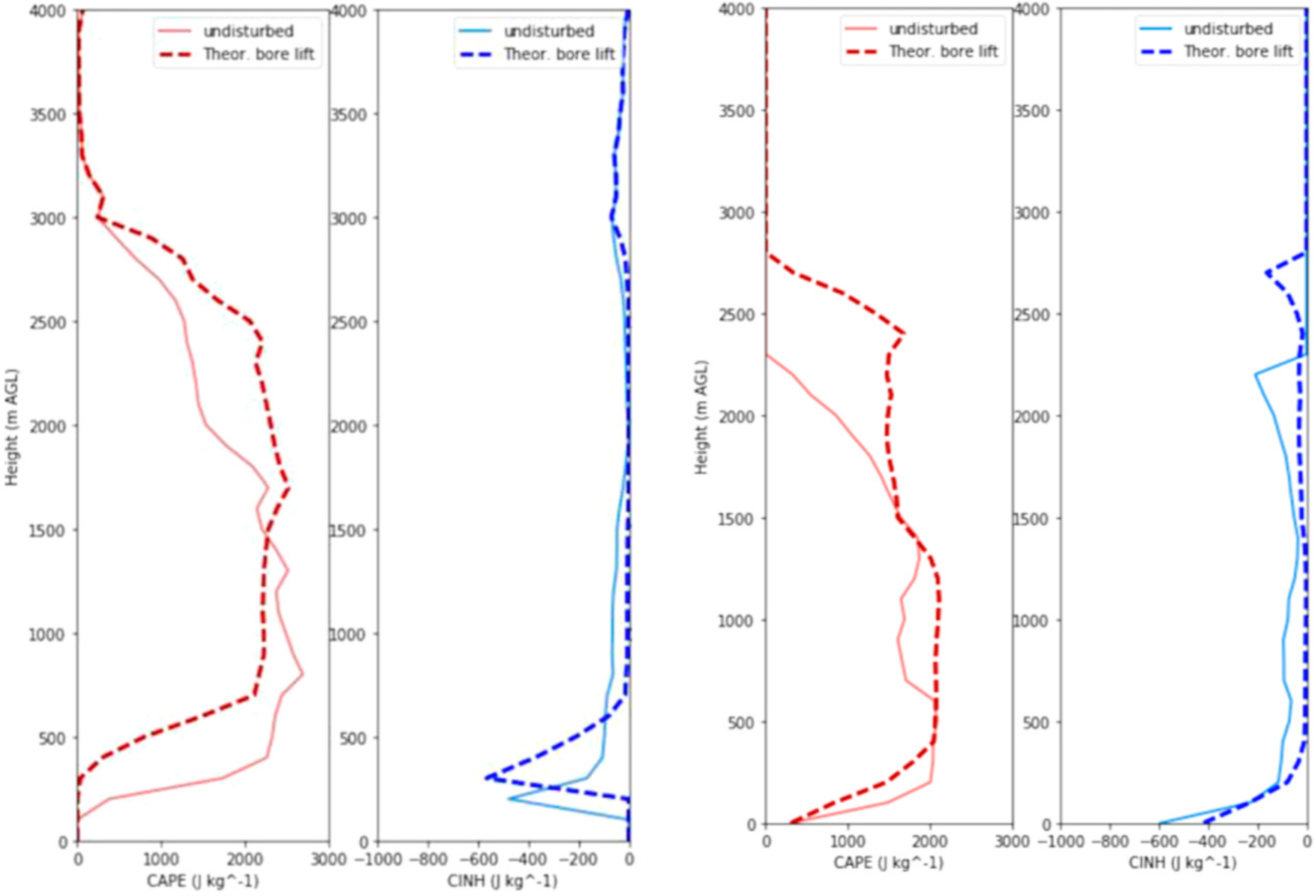
$$\begin{aligned} w &= sin(m_1 z) \\ &= sin(m_1 z_1 e^{-m_2(z-z_1)}) \end{aligned}$$



Alter sounding profiles

Calculate CAPE/CIN for every height level

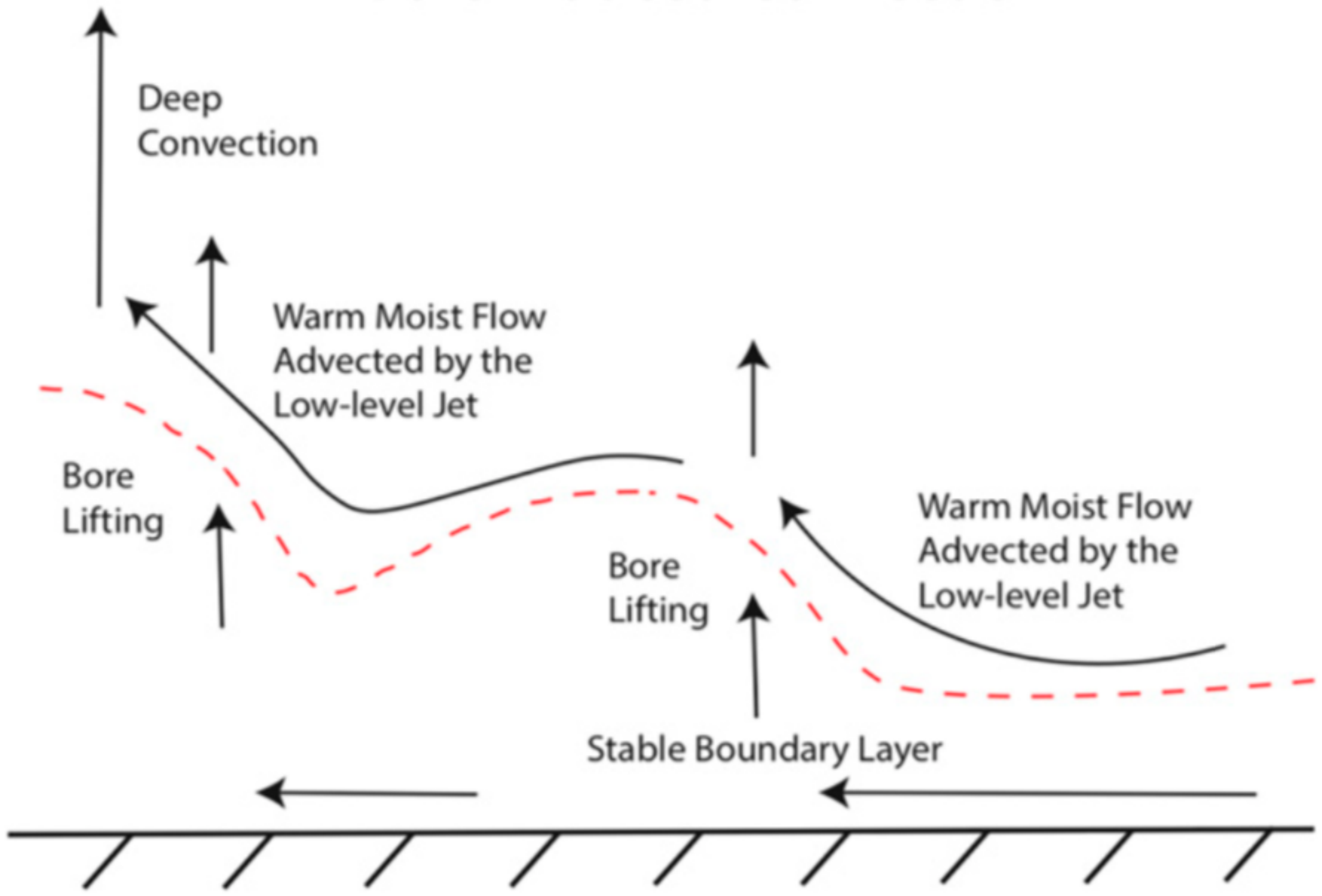
Quantified the impact of bore lifting on stability profiles (4 Jun 2002 Case)



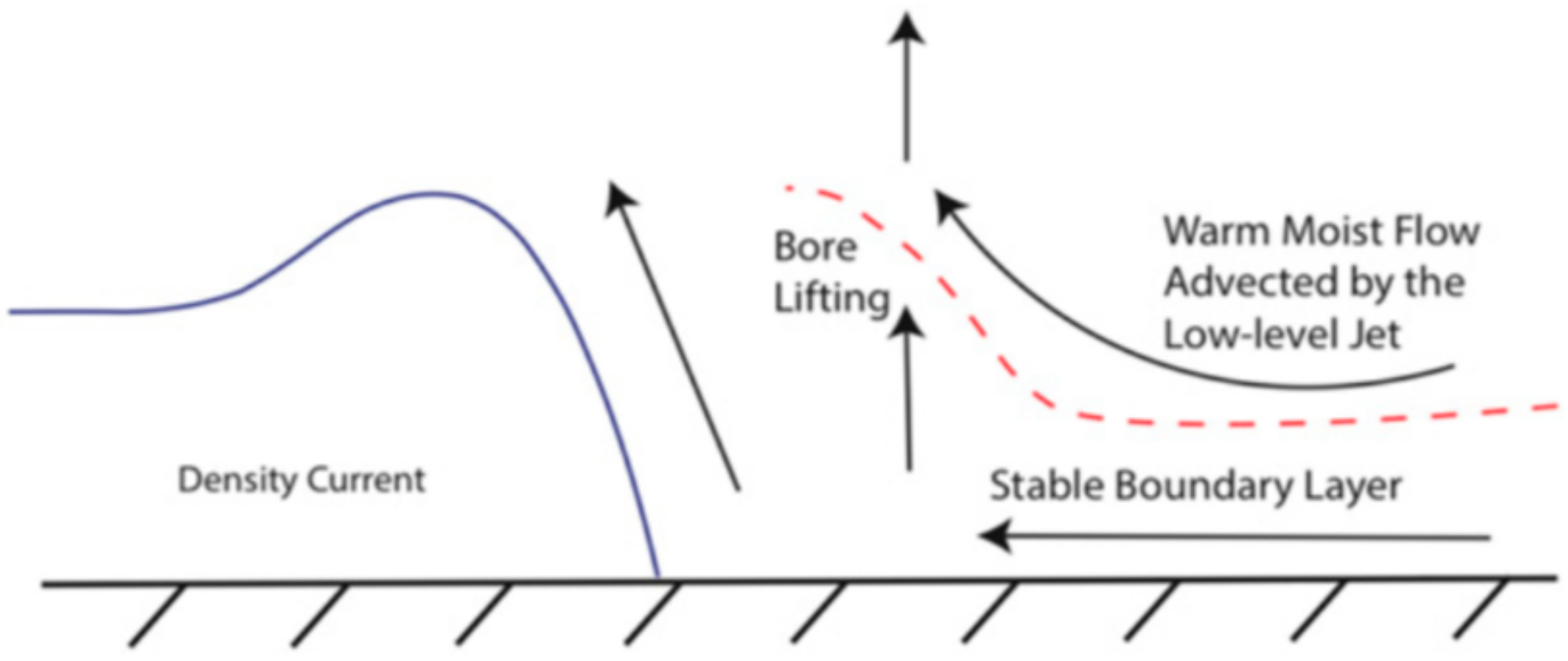
Convective-Environment Interaction via Wave Dynamics

- Lifting of elevated layer(s) with substantial CAPE/***low CIN*** common during the *IHOP_2002* field campaign
- Co-existence of bore and low-frequency GWs. Role of GWs possibly more important than previously expected.
- Sustained layer displacement in the wake of bore fronts

Bore Induced Convection



Bore Lifting Aiding the Maintenance of Convection



- ***Critical*** moisture layer in response to stabilizing NBL?
- Suitable observational technique on detecting elevated GW lifting event?
- Nocturnal convection in other weather regimes. (e.g. nocturnal convection over closed/semi-closed water surfaces)
- Bore generation between colliding MCS outflow and land/sea breeze?
- Role of wave-induced ascent for Mei-yu systems? *(Liu and Moncrieff 2017)*

Holle and Murphy (2017)