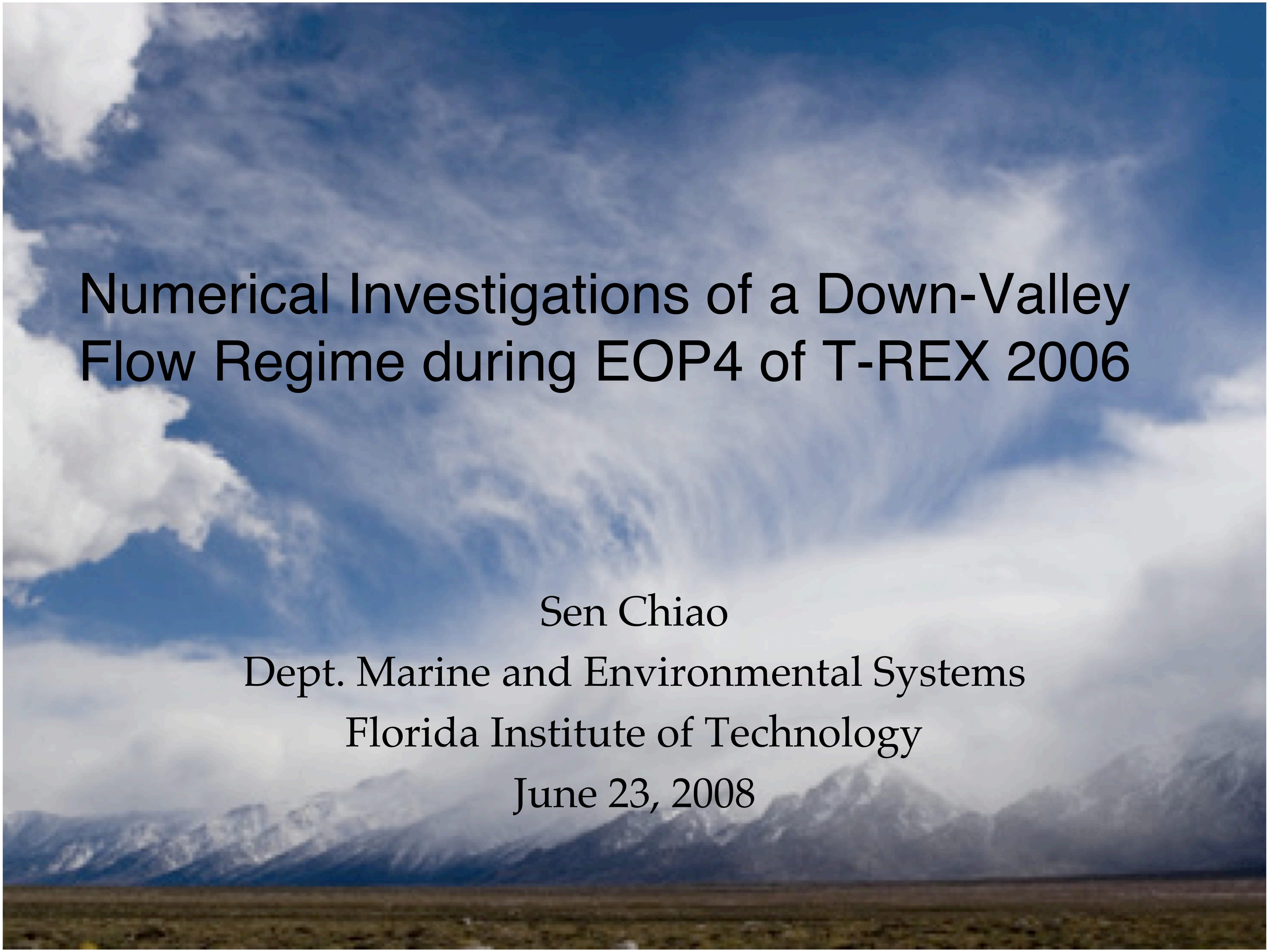

Numerical Investigations of a Down-Valley Flow Regime during EOP4 of T-REX 2006

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June 23, 2008

Outline

- Overview of the mountain-valley wind system
- Slope/along-valley wind cycle
- Terrain-Induced Rotor Experiment (T-REX) 2006
- Nocturnal Down-Valley Jet (DVJ) Formation during "T-REX"
- Summary

The Mountain Wind System

The mountain wind system is made up of four separate wind systems:

<u>Slope</u> - These winds occur along the mountain slopes (either upslope or down slope) and are driven by temperature differences between the air over the mountain sides and the air over the center of the valley.

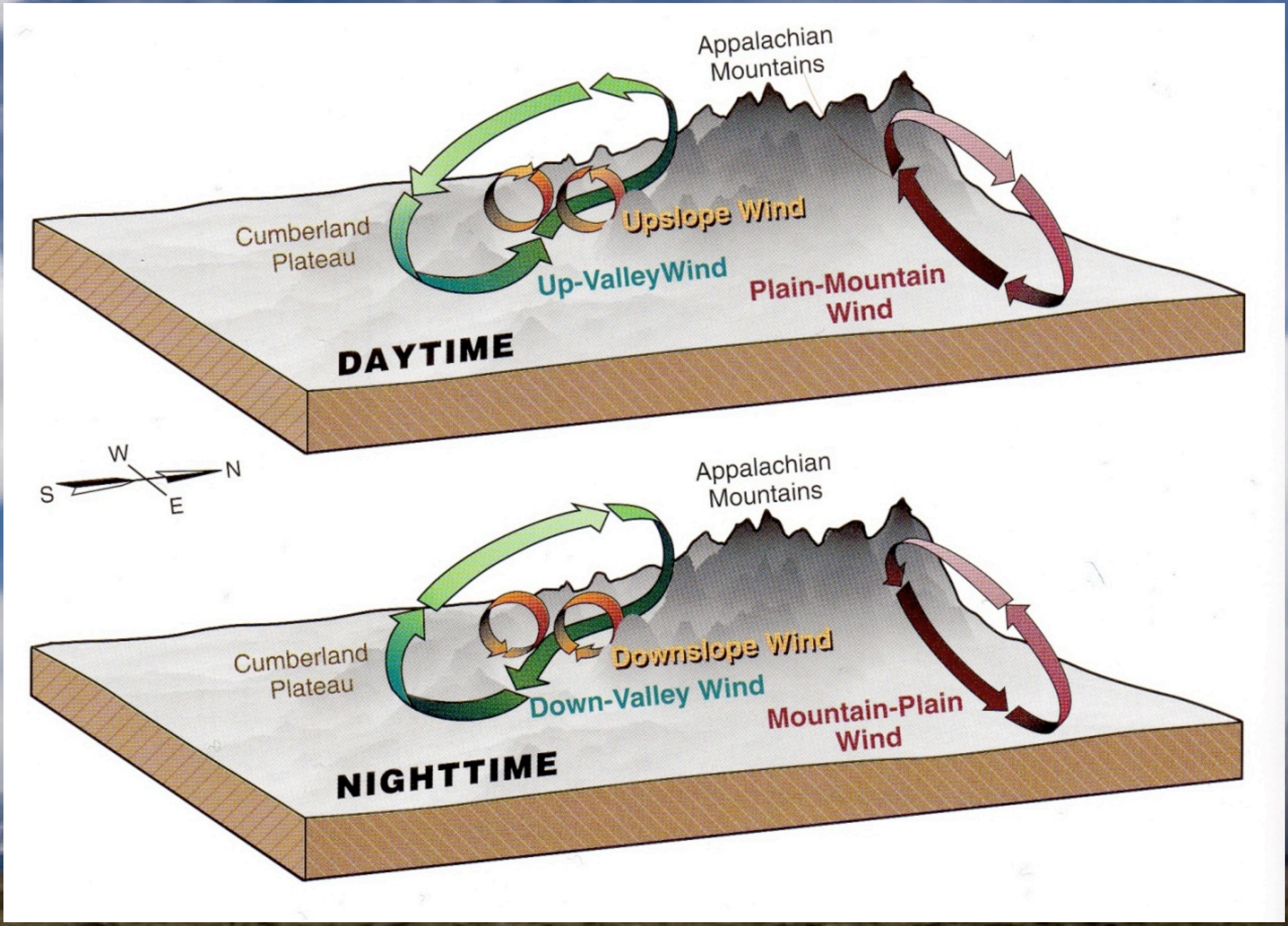
<u>Along-valley</u> - These winds flow parallel to the mountain sides in the center of the valley (either up-valley or down-valley) and are influenced by temperature variations along the valley axis. These winds may also be influenced by slope winds affecting by Coriolis force.

The Mountain Wind System

<u>Cross-valley</u> - These winds blow perpendicular to the valley axis from one sidewall to the other. They are driven by temperature differences between the two sidewalls.

<u>Mountain-plain</u> - These winds blow up-slope or down-slope of the mountain side on the outside of the valley. This system develops as a result of temperature differences between the mountain wall and the air over the adjacent plain.

Model of the diurnal variations of slope, along-valley, and mountain-plain wind systems (Whiteman 2000)



Slope/along-valley Wind Cycle

The slope/along-valley wind cycle is *simply* the diurnal evolution of the thermally-driven slope and along-valley wind systems. It is broken down into four phases:

→ Evening-transition phase
→ Nighttime phase
→ Morning-transition phase
→ Daytime phase

Slope/along-valley Wind Cycle

Evening-transition phase

- Slope winds transition from up-slope to down-slope
- Down-slope winds drain cold air into the valley
- Temperature inversion builds in valley as a result of the cold pool
- Along-valley winds change from up-valley to down-valley
- End of phase is marked by the absences of all up-valley flow

Slope/along-valley Wind Cycle

<u>Nighttime phase</u>

- Valley atmosphere is 'decoupled' from the atmosphere above the top of the mountains
- Prevailing down-valley and down-slope (drainage) flows
- Temperature inversion at surface → stable boundary layer
- Down-valley flow increases within the inversion layer → Nocturnal down-valley jet forms
- Jet reaches its maximum just before sunrise

Slope/along-valley Wind Cycle

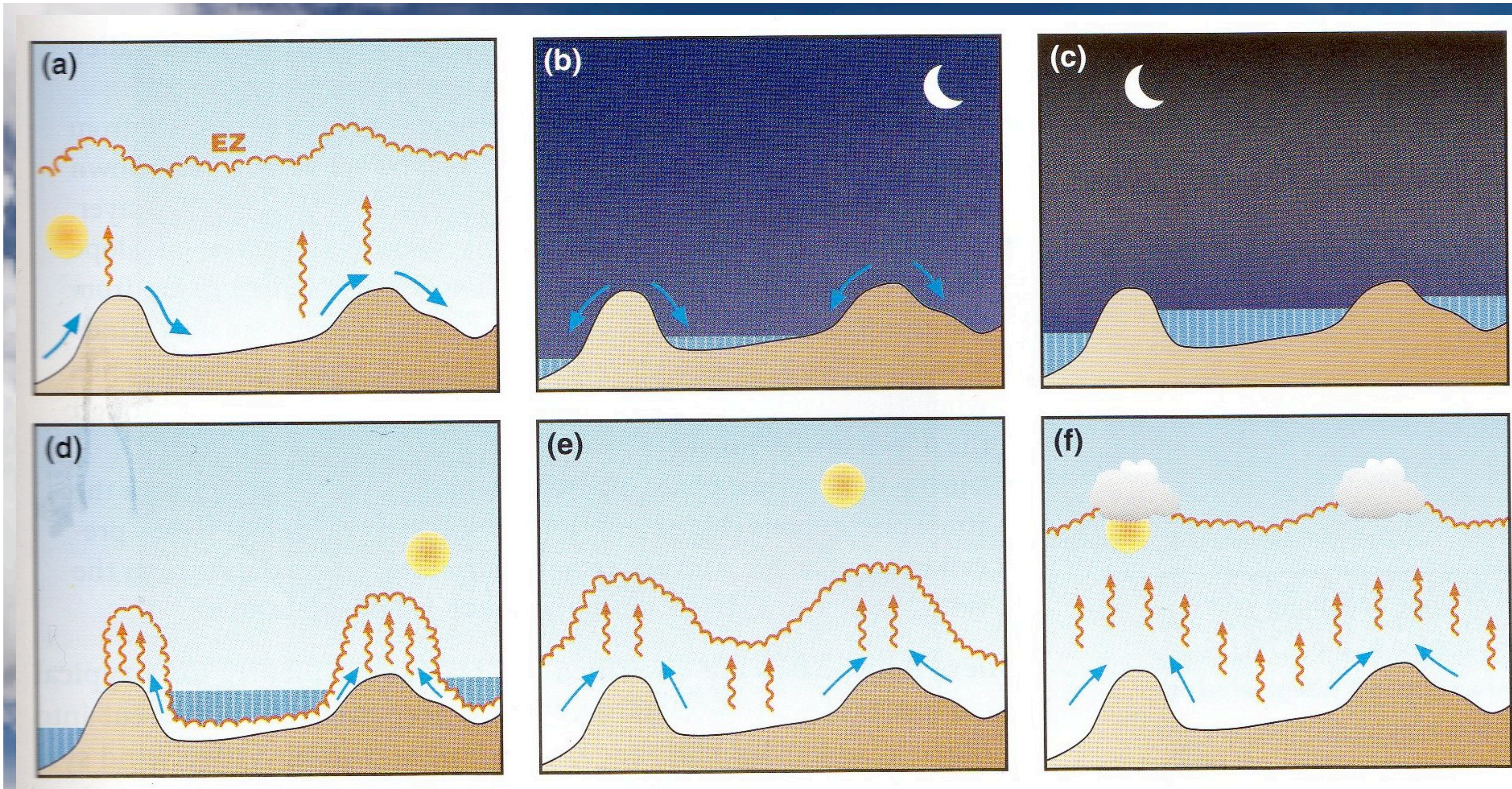
<u>Morning-transition phase</u>

- Slope winds begin to transition from down-slope to up-slope
- Up-slope winds bring warmer air to the mountain sides
- As valley surface heats up, rising currents lift and deteriorate cold pool
- Down-valley jet weakens as along-valley winds transition from down-valley to up valley
- End of phase is marked by the complete destruction of the temperature inversion and the absences of all down-valley flow

Slope/along-valley Wind Cycle

Daytime phase

- Valley atmosphere is coupled with the atmosphere above the mountain range
- Prevailing up-valley and up-slope flow
- Absence of temperature inversion → unstable boundary layer

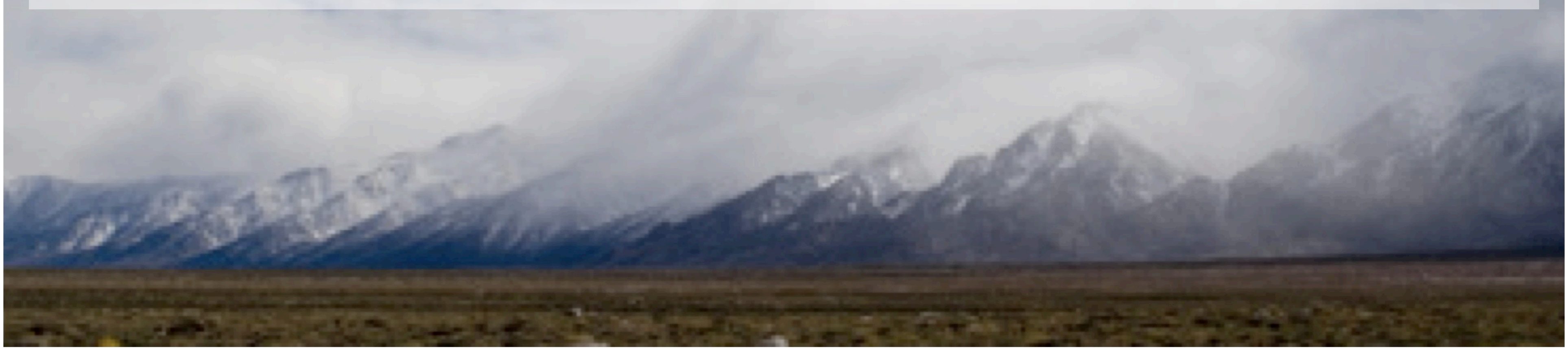


Model of the diurnal evolution phases of the slope/along-valley wind cycle (Whiteman 2000). The evening transition phase is shown in (a) and (b), the nighttime phase in (c), morning-transition phase in (d) and (e) and the daytime phase in (f).

Slope/along-valley Wind Cycle

Disruption

Disruption of the diurnal wind cycle can occur when there is an overlying synoptic scale condition such as a frontal system or a mid-latitude cyclone. Conditions such as these can cause what would have been down-valley nocturnal flow to become cross-valley or up-valley flow.



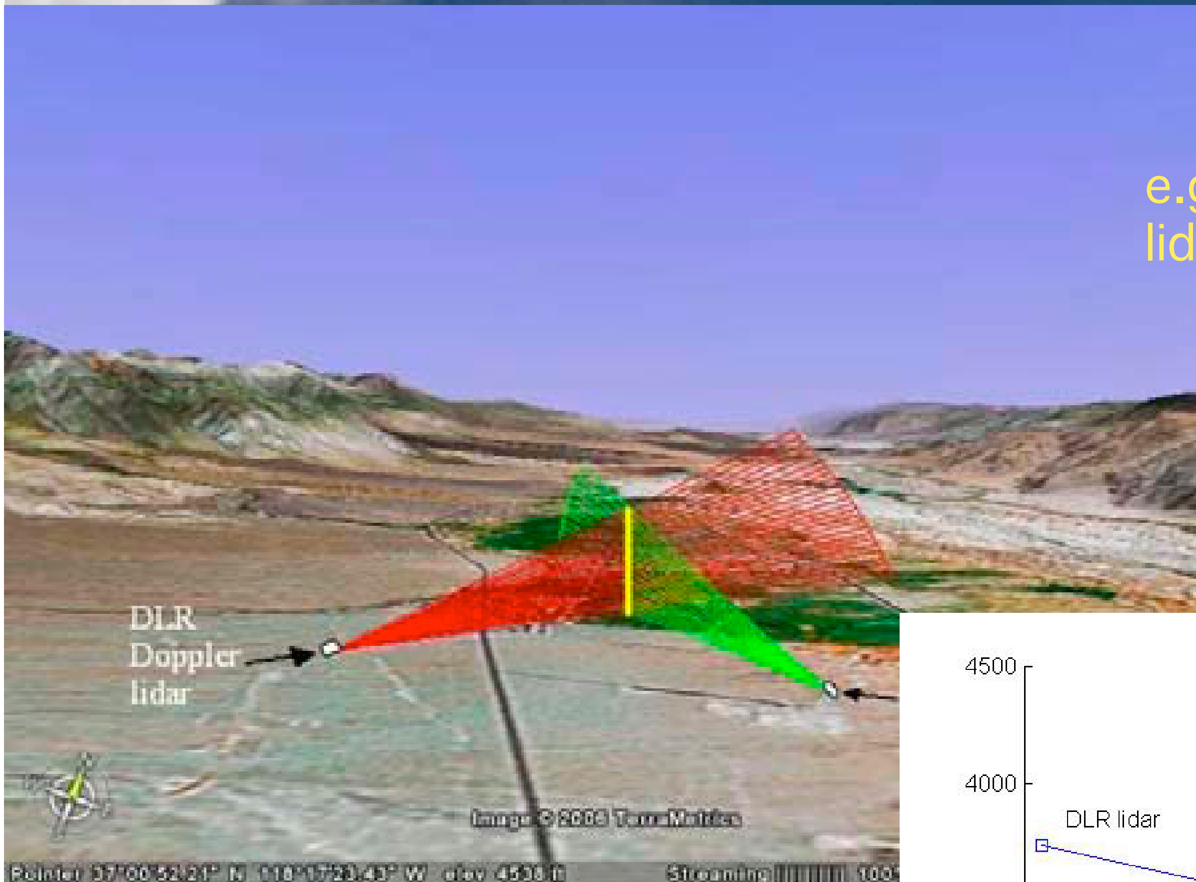
Forecast Challenges -- PBL

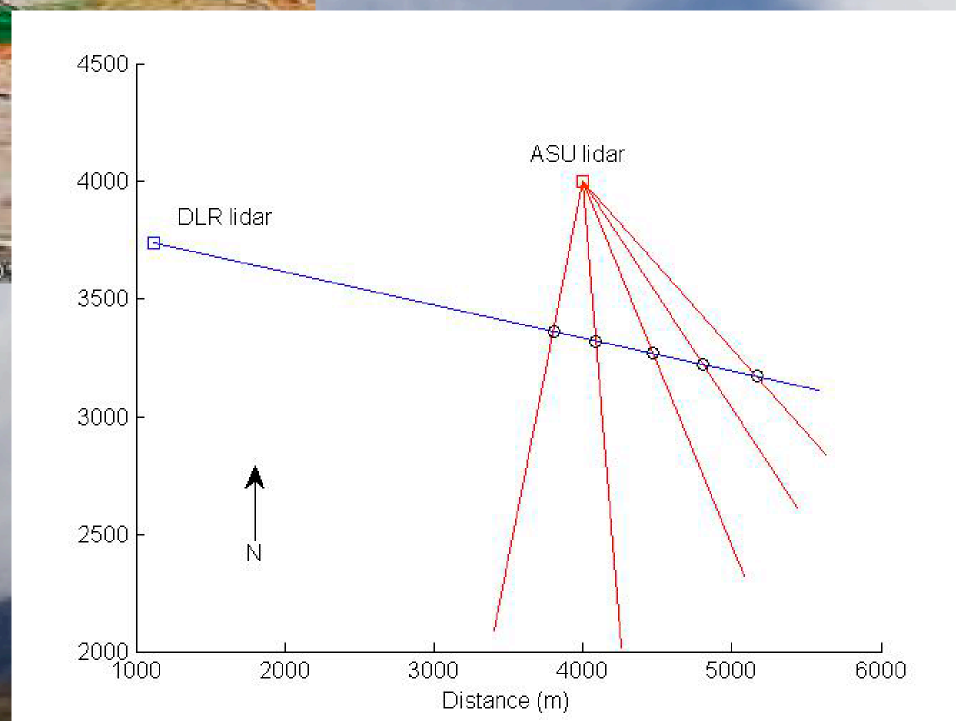
- Heterogeneity
- Surface Layer -- U*, Q*, H*, stability
- Vertical distributions of V, T, q, tke, e, Ri
- BL height -- Z_i, thickness of inversion
- Turbulence Parameterization
- Clouds/Radiation
- Precipitation
- Terrain -- elevation, soils, moisture
- Meeting user needs

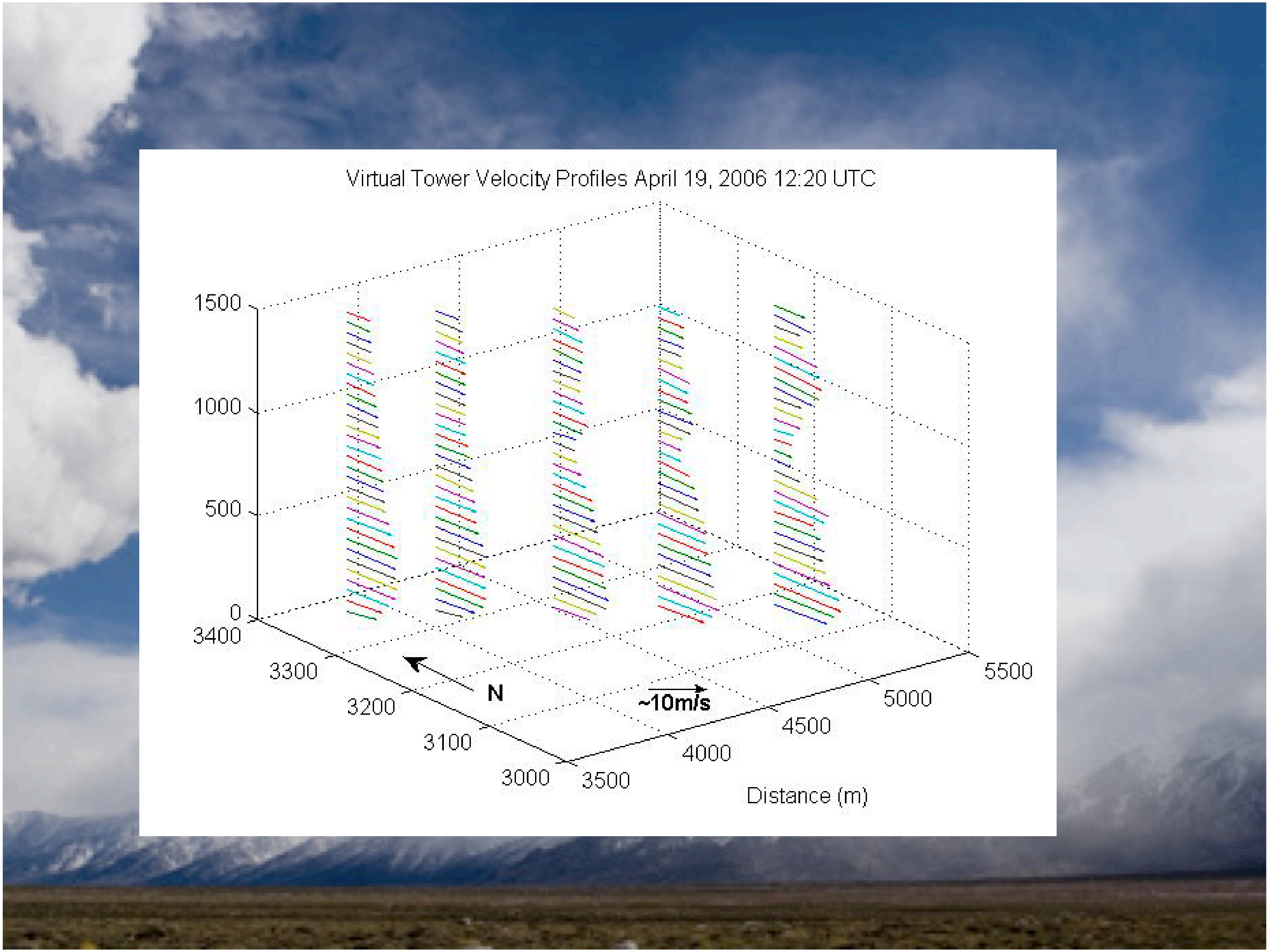
Look to Future Needs and Users

- Small scales ($0.01 < x < 10$km; $10 < t < 10^3$ sec)
  - Urban Meteorology
  - Wind Energy
  - CBRN Dispersion
  - Military Operations
  - Public Health/ Air Quality
  - Surface Transportation

e.g., Surface based Doppler wind lidars







Virtual Tower Velocity Profiles April 19, 2006 12:20 UTC
1500
1000
500
0
3400
3300
3200
3100
3000
3500
4000
4500
5000
5500
N
~10m/s
Distance (m)

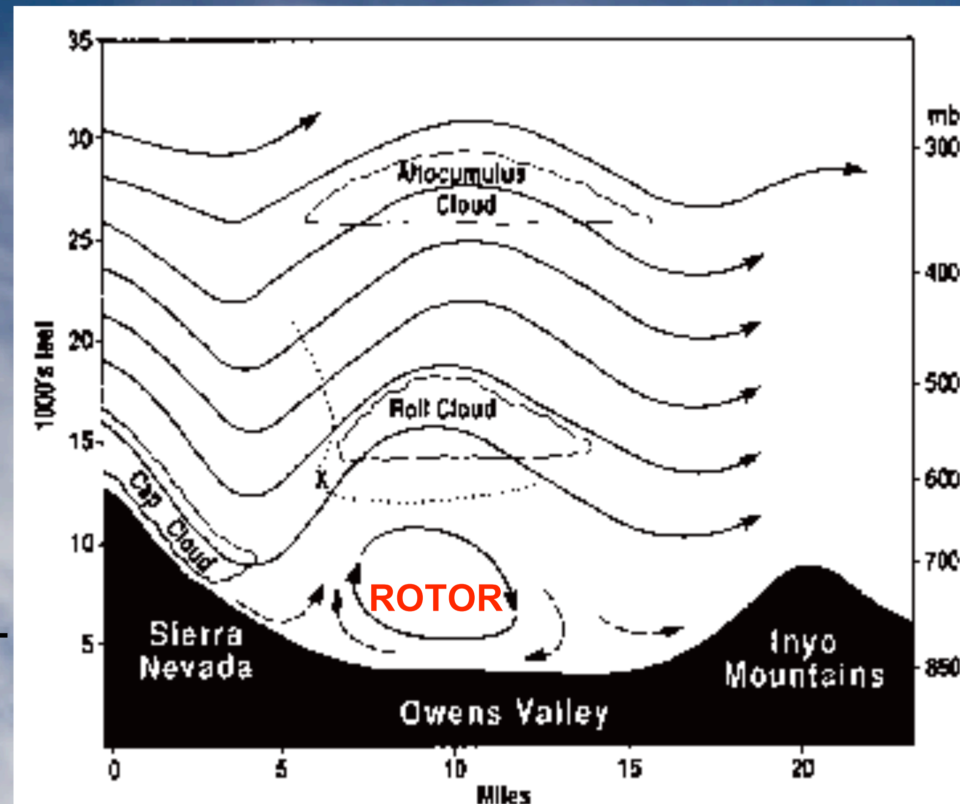

Project Overview
The Terrain-induced Rotor Experiment (T-REX) is the second phase of a coordinated effort to explore the structure and evolution of atmospheric rotors (intense low-level horizontal vortices that form along an axis parallel to, and downstream of, a mountain ridge crest) as well as associated phenomena in complex terrain.

Atmospheric Rotors:

Atmospheric rotors are caused by mountain waves or gravity lee waves.

In some cases, the waves become trapped by topography and rotors will form downstream of the flow.

Rotors are regions of turbulent air recirculating around a horizontal, cross-wind axis.



Nocturnal DVJ Formation During T-REX

- Although the project focuses on terrain-induced rotors (which occur during unstable boundary layer conditions), a large amount of data was also collected for periods of stable BL conditions. These are termed Enhanced Observation Periods (or EOPs) and last from two – three days.

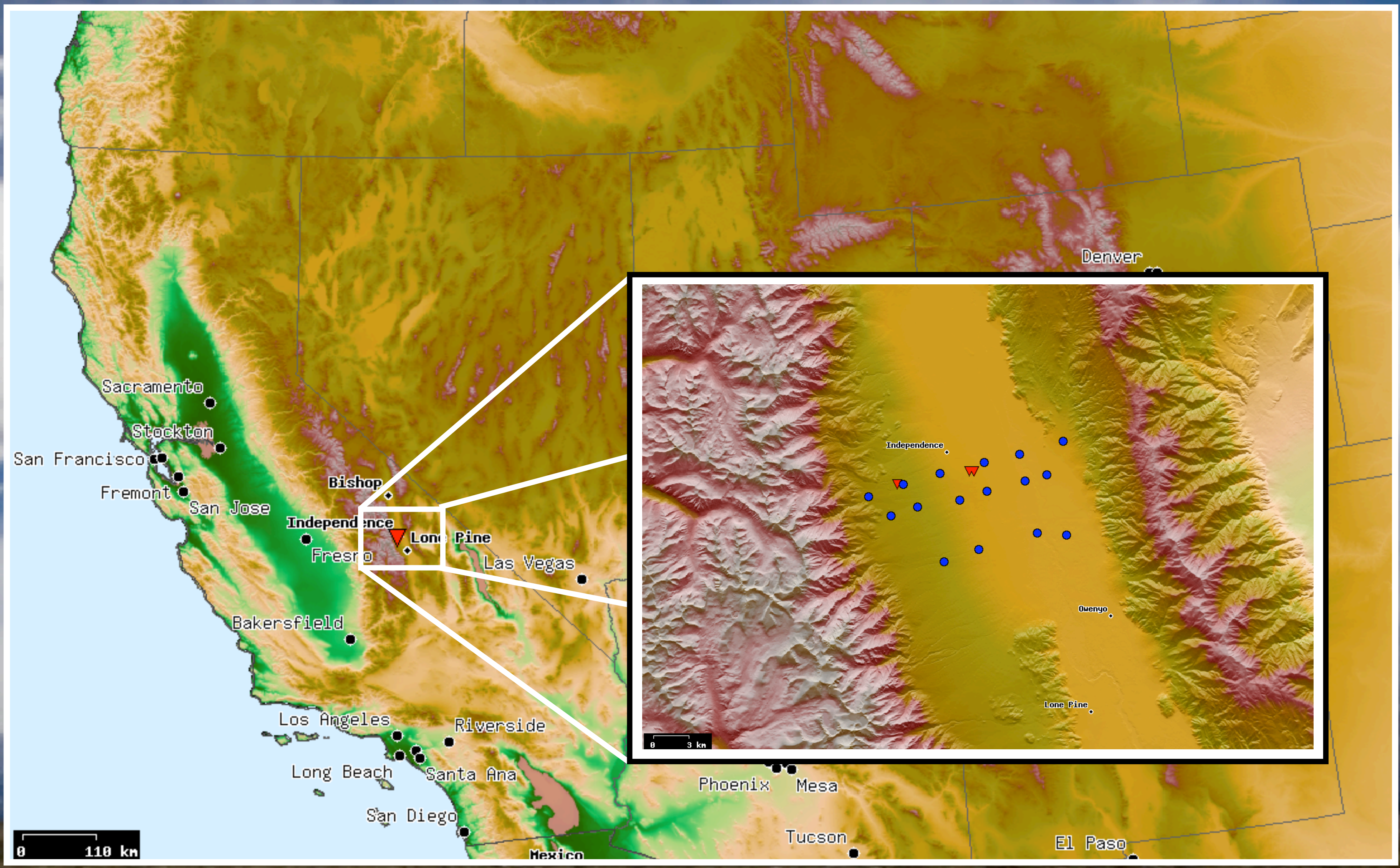
- Data was collected at 30 second intervals from 16 surface stations along the mountain valley. We will focus on the data collected from EOP3 and EOP4/5
  → the periods with the most significant down-valley jets.

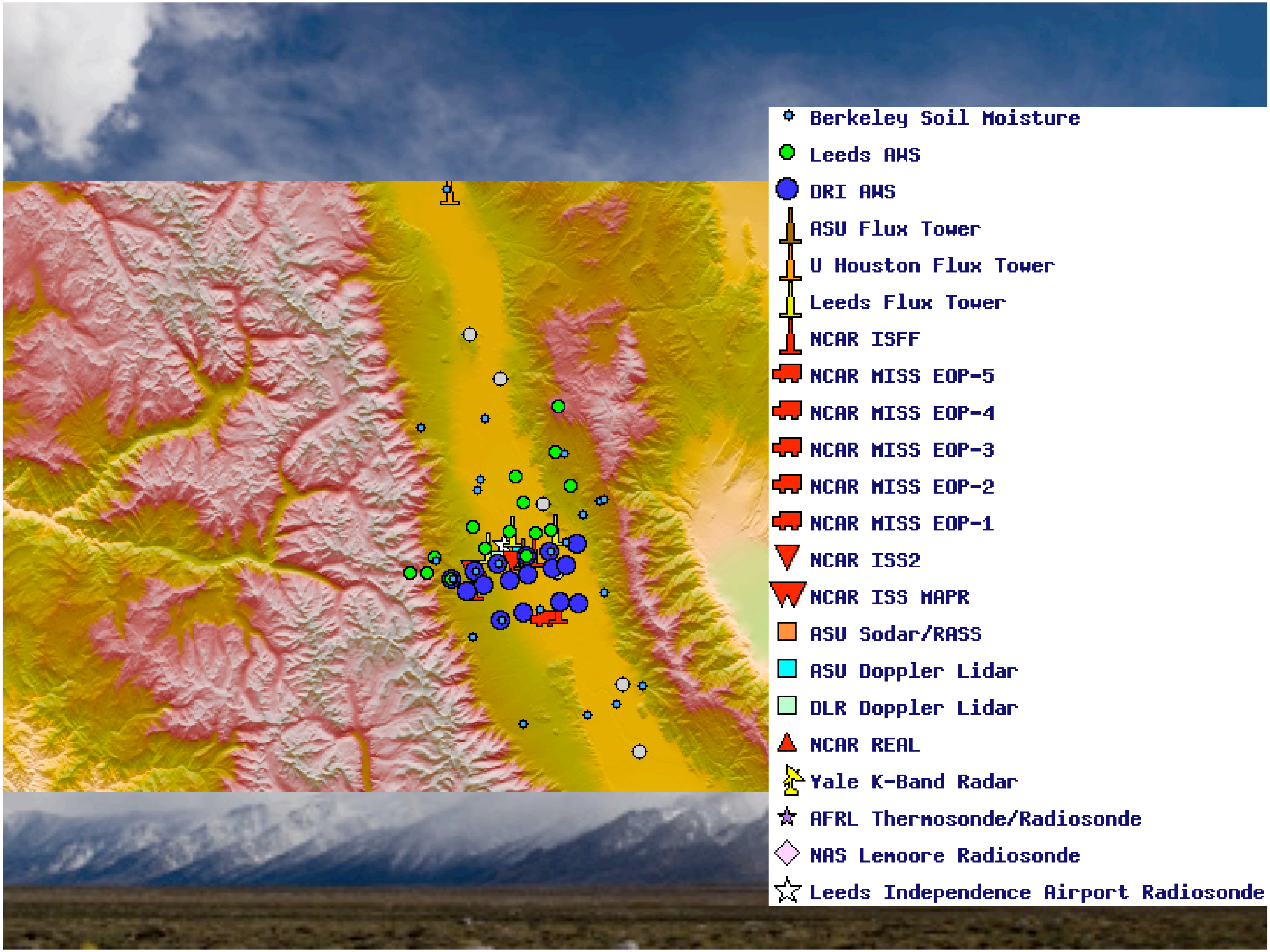
Working Hypotheses :

(1) the average error (bias) of modeled wind at 10 meters is within 10% of the measured wind at 90% confidence level; and

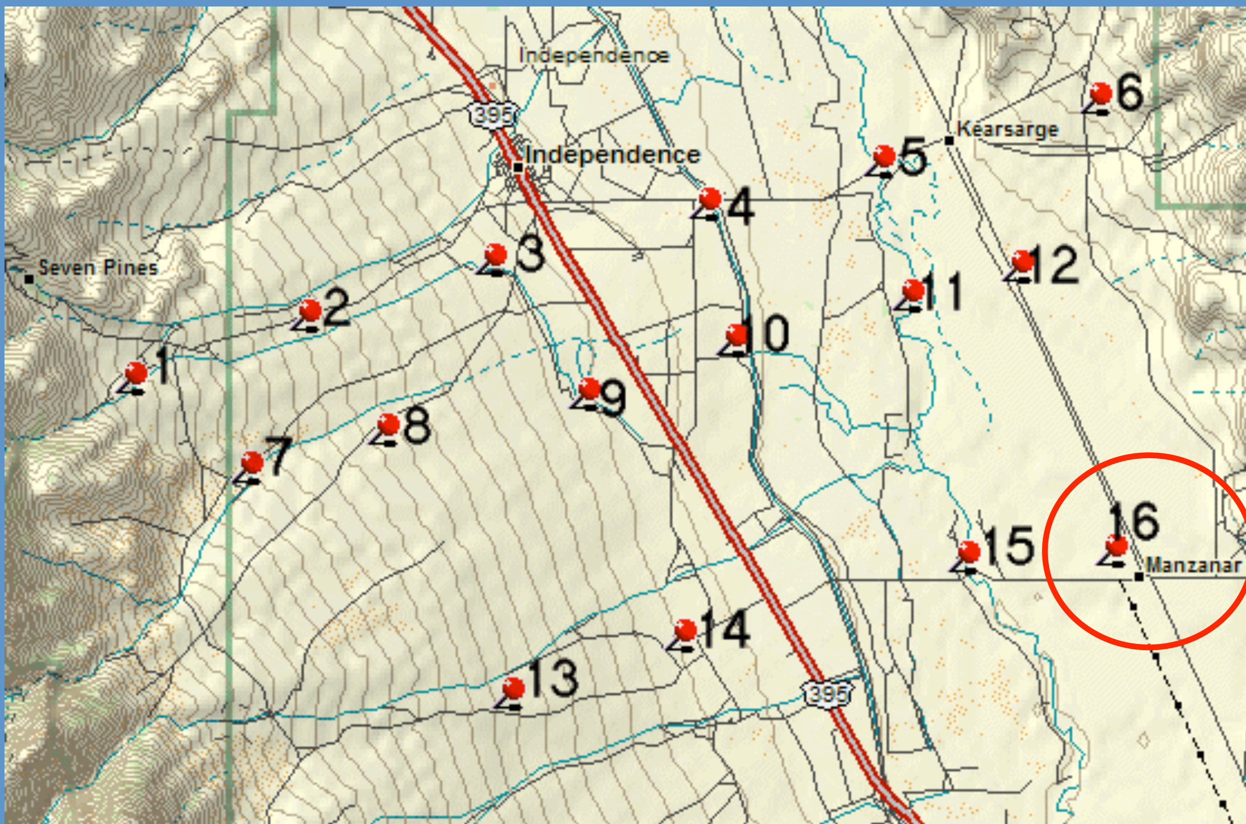
(2) the choice of subgrid terrain representation is not significant in the error of averaged winds at some height during stable conditions

Shown below is the 16 surface stations (in blue) utilized during T-REX 2006 in Owens Valley, California. The red triangles indicate the locations of where the wind profiles were taken. The second station in the first row is station#2, the red triangle under it is the ISS2 station. All graphs in the following slides were created using data collected at these stations.




Berkeley Soil Moisture
Leeds AWS
DRI AWS
ASU Flux Tower
U Houston Flux Tower
Leeds Flux Tower
NCAR ISFF
NCAR MISS EOP-5
NCAR MISS EOP-4
NCAR MISS EOP-3
NCAR MISS EOP-2
NCAR MISS EOP-1
NCAR ISS2
NCAR ISS MAPR
ASU Sodar/RASS
ASU Doppler Lidar
DLR Doppler Lidar
NCAR REAL
Yale K-Band Radar
AFRL Thermosonde/Radiosonde
NAS Lemoore Radiosonde
Leeds Independence Airport Radiosonde

Station Locations



Station	Elevation (ft)
1	5697
2	4842
3	4180
4	3836
5	3756
6	3989

Station	Elevation (ft)
7	5167
8	4724
9	4061
10	3868
11	3761
12	3731
Manzanar	**3726**

There are 16 automatic weather stations located between Independence and Manzanar in the central part of the Owens Valley (seen above).

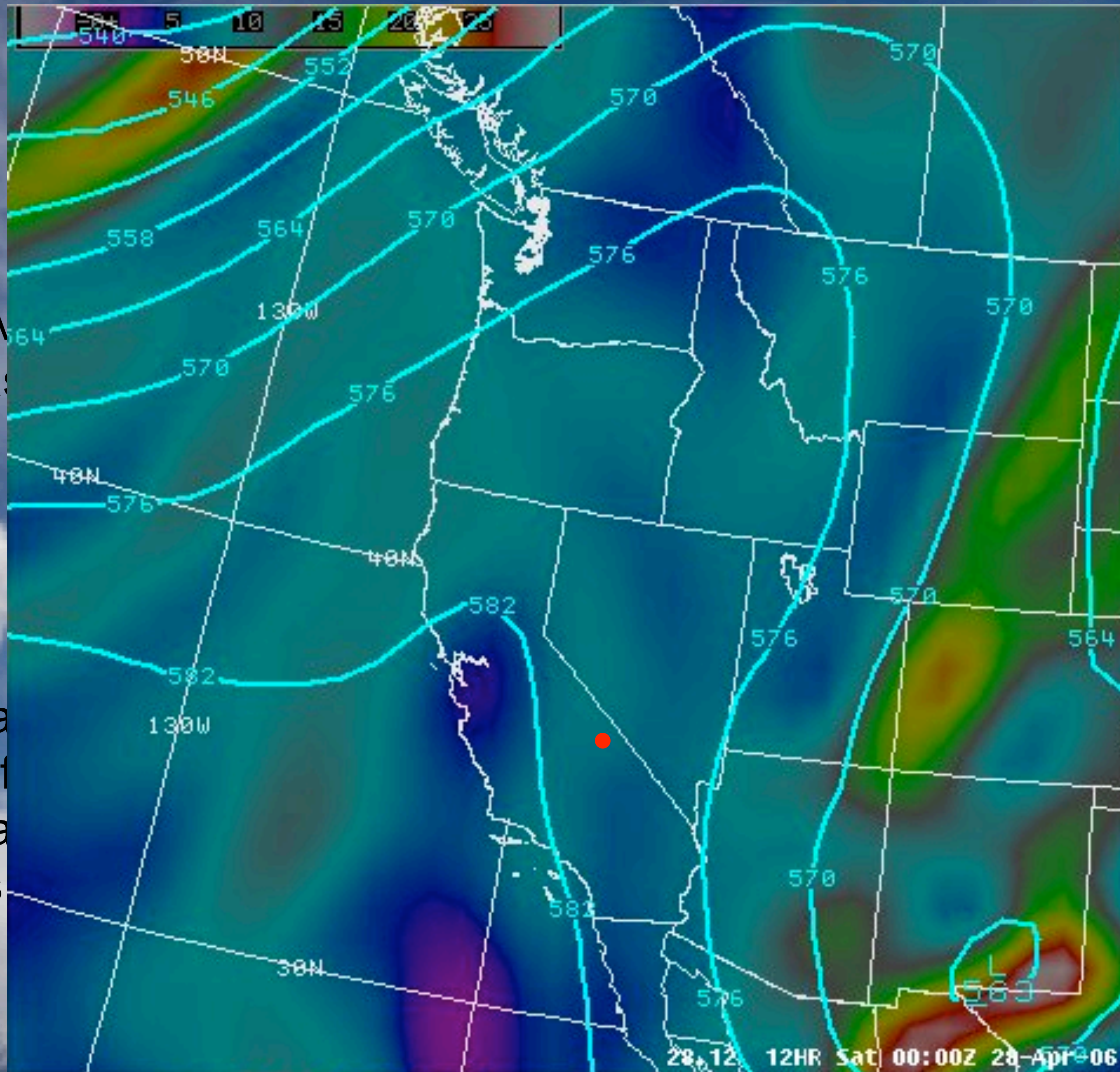
EOP4

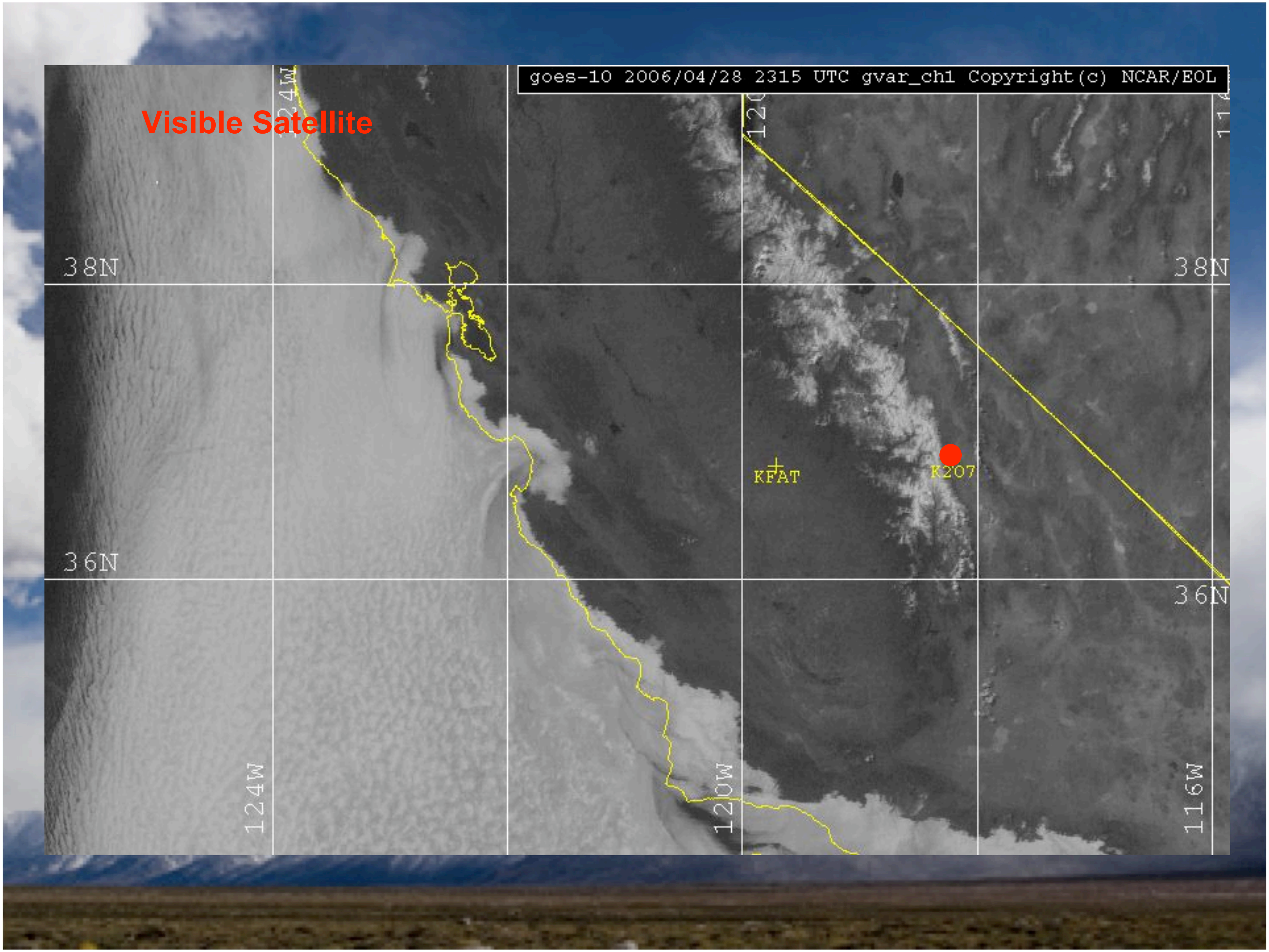
- April 28th – April 30th 2006 → We will focus on the 29th
- DVJ in this period began 21:00 (April 28th) and lasted until 7:00 PDT April 29th
- Maximum velocity reached was 12 m/s (27 mph)
- Down-valley jet extended from the surface to about 700m.

EOP4: Prev ng off with
both increas een before
the sunrise

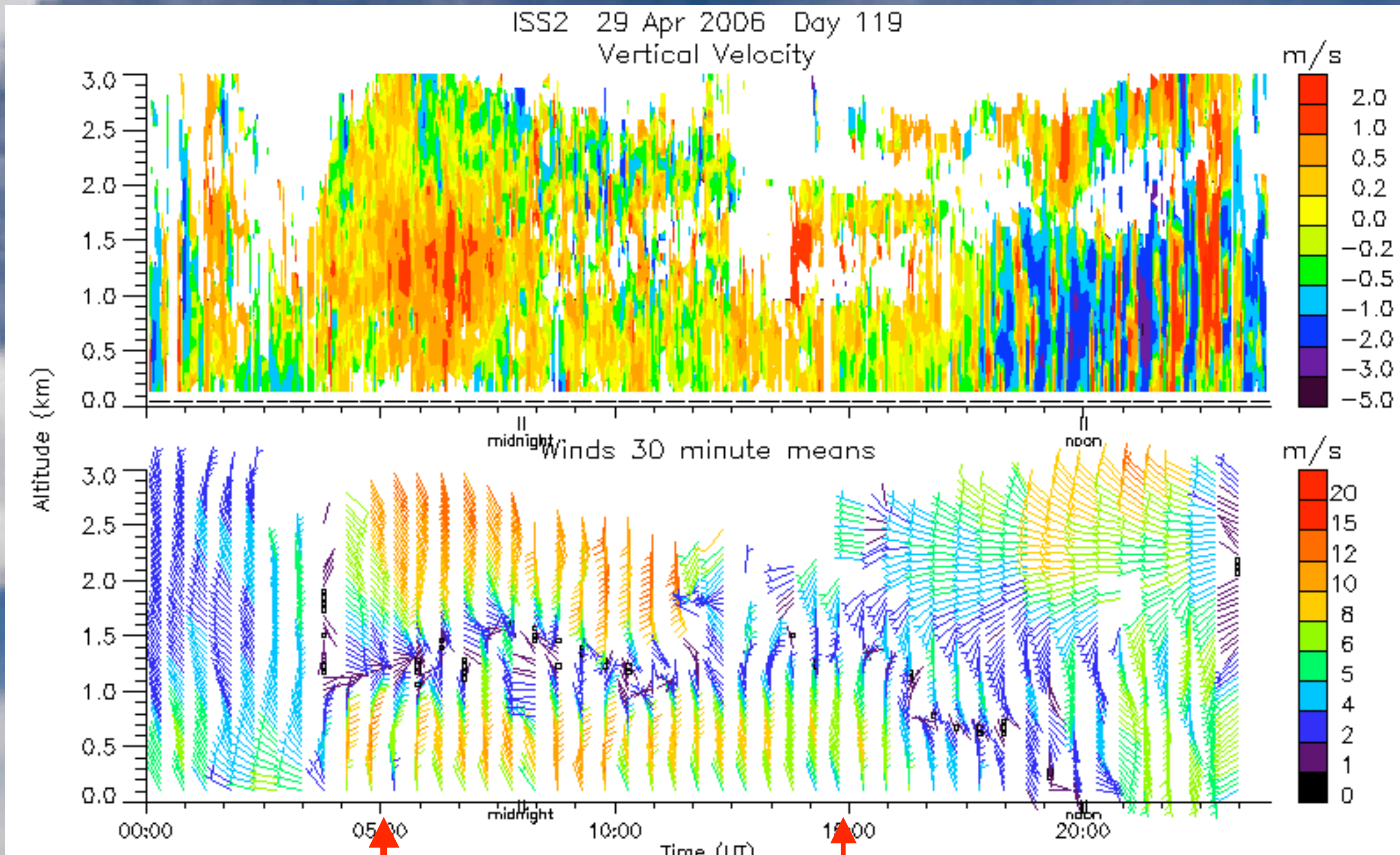
A mid-level ow is near El
Paso.

Surface gra NAM 625
hPa winds f rom
northwest a hed around
5 to 10 m/s





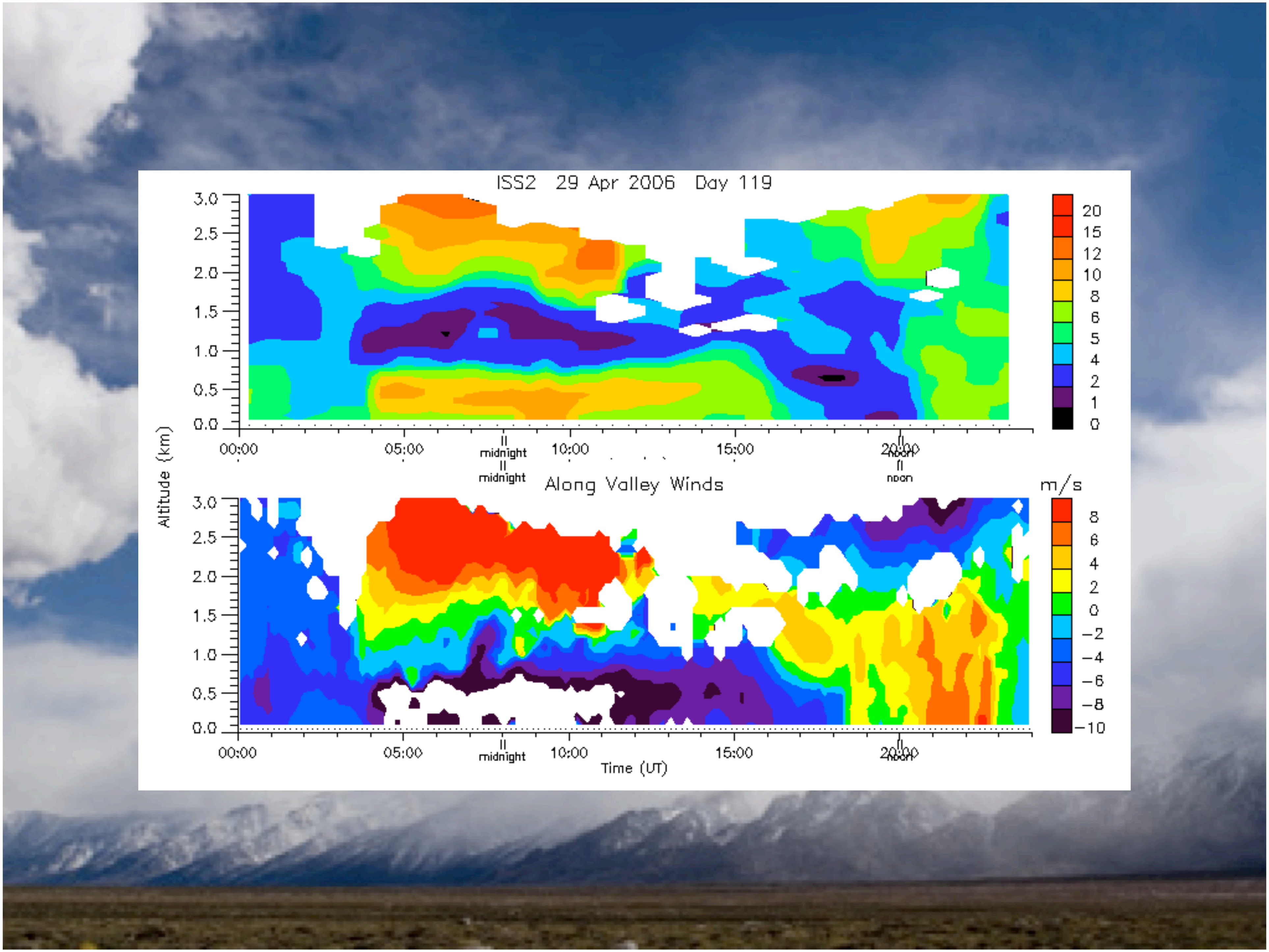
Visible Satellite
goes-10 2006/04/28 2315 UTC gvar_ch1 Copyright(c) NCAR/EOL
38N
36N
124W
120W
116W
KFAT
K2O7



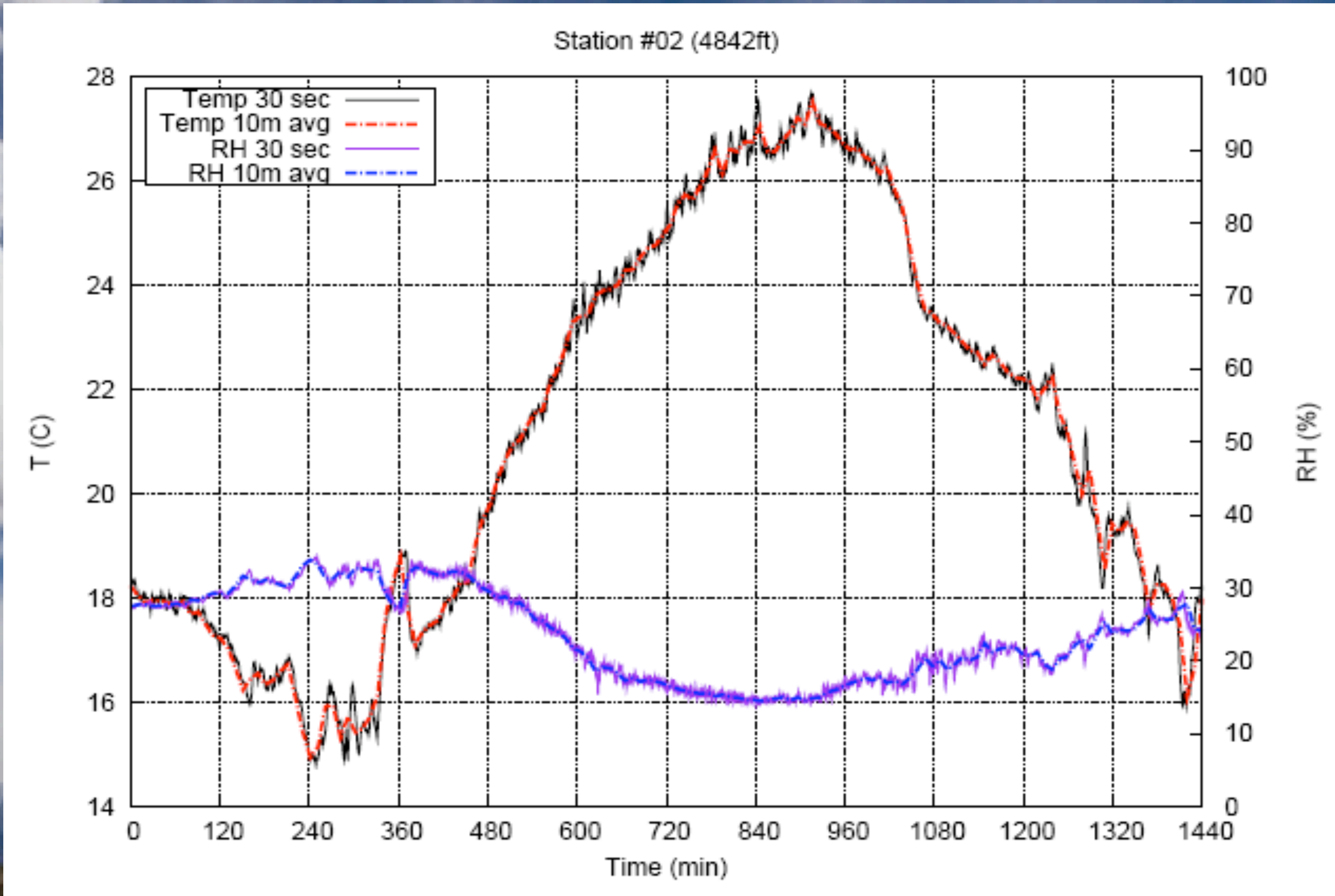
ISS2 Wind profile for April 28th – April 29th 2006.

2200 LST 28

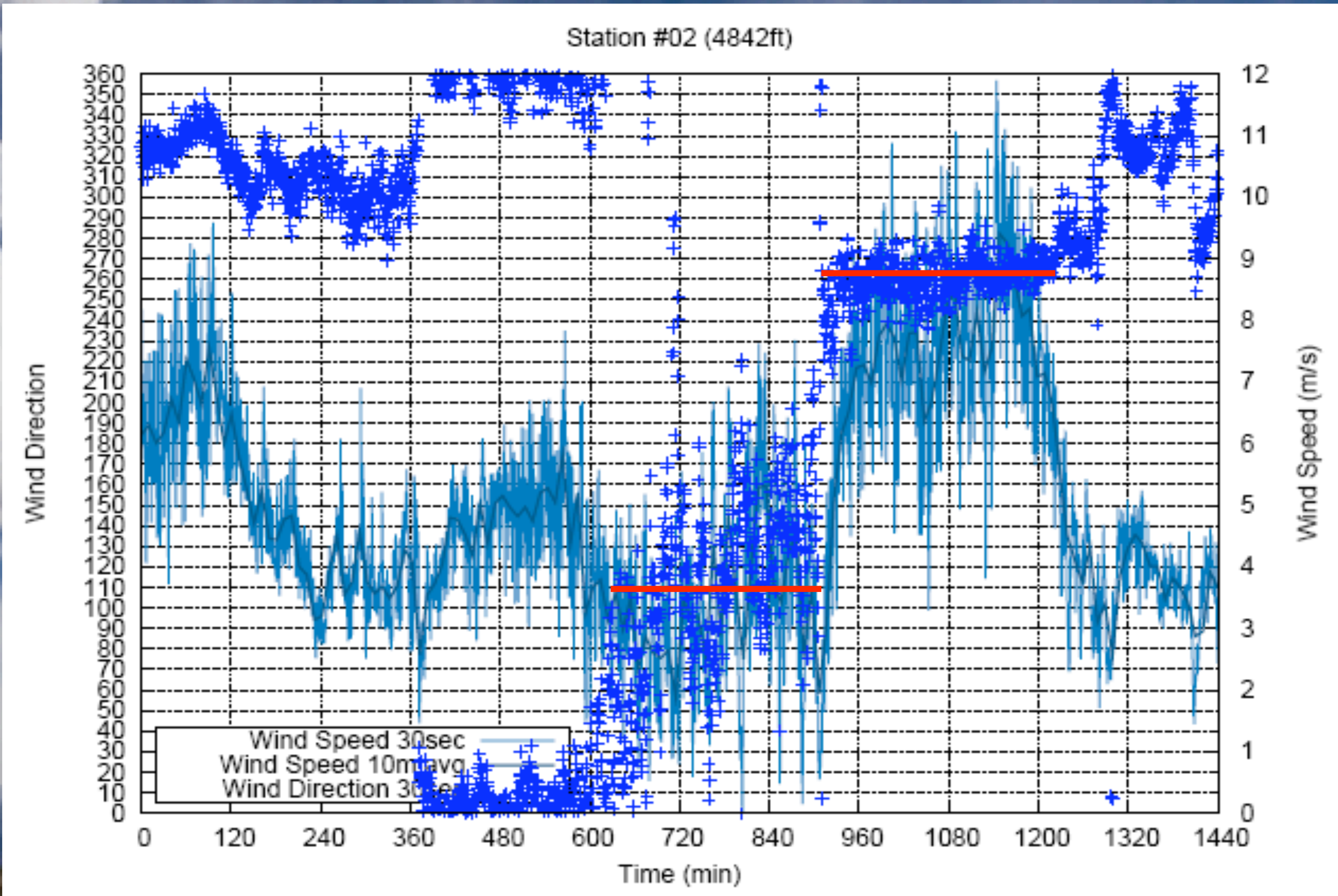
0800 LST/29


ISS2 29 Apr 2006 Day 119
Altitude (km)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
00:00
05:00
midnight
10:00
15:00
20:00
noon
20
15
12
10
8
6
5
4
2
1
0
Along Valley Winds
m/s
8
6
4
2
0
−2
−4
−6
−8
−10
Time (UT)

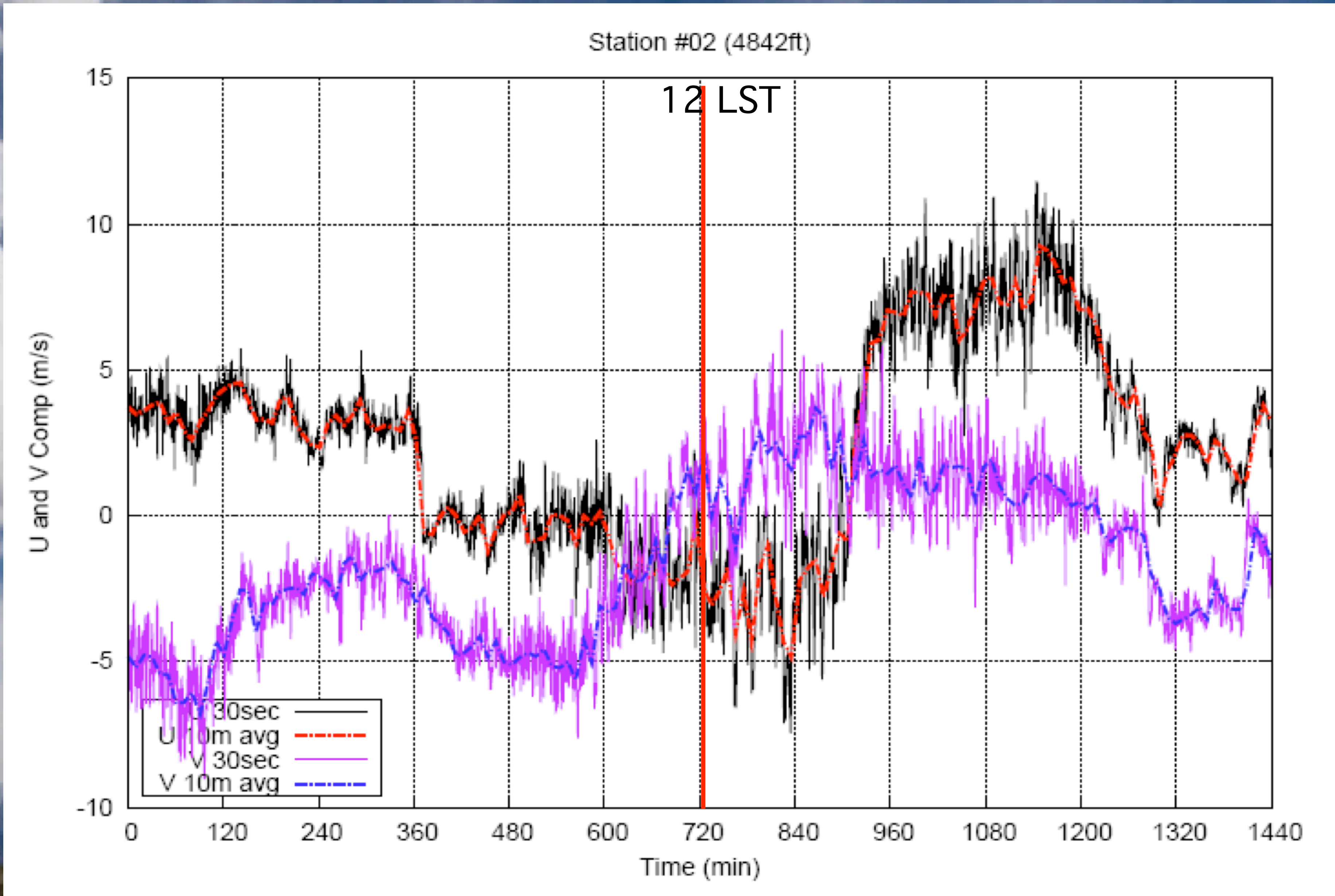
Station #2 Temperature and RH data for April 29h 2006 measured in Celsius. X-axis is in local time (PDT)



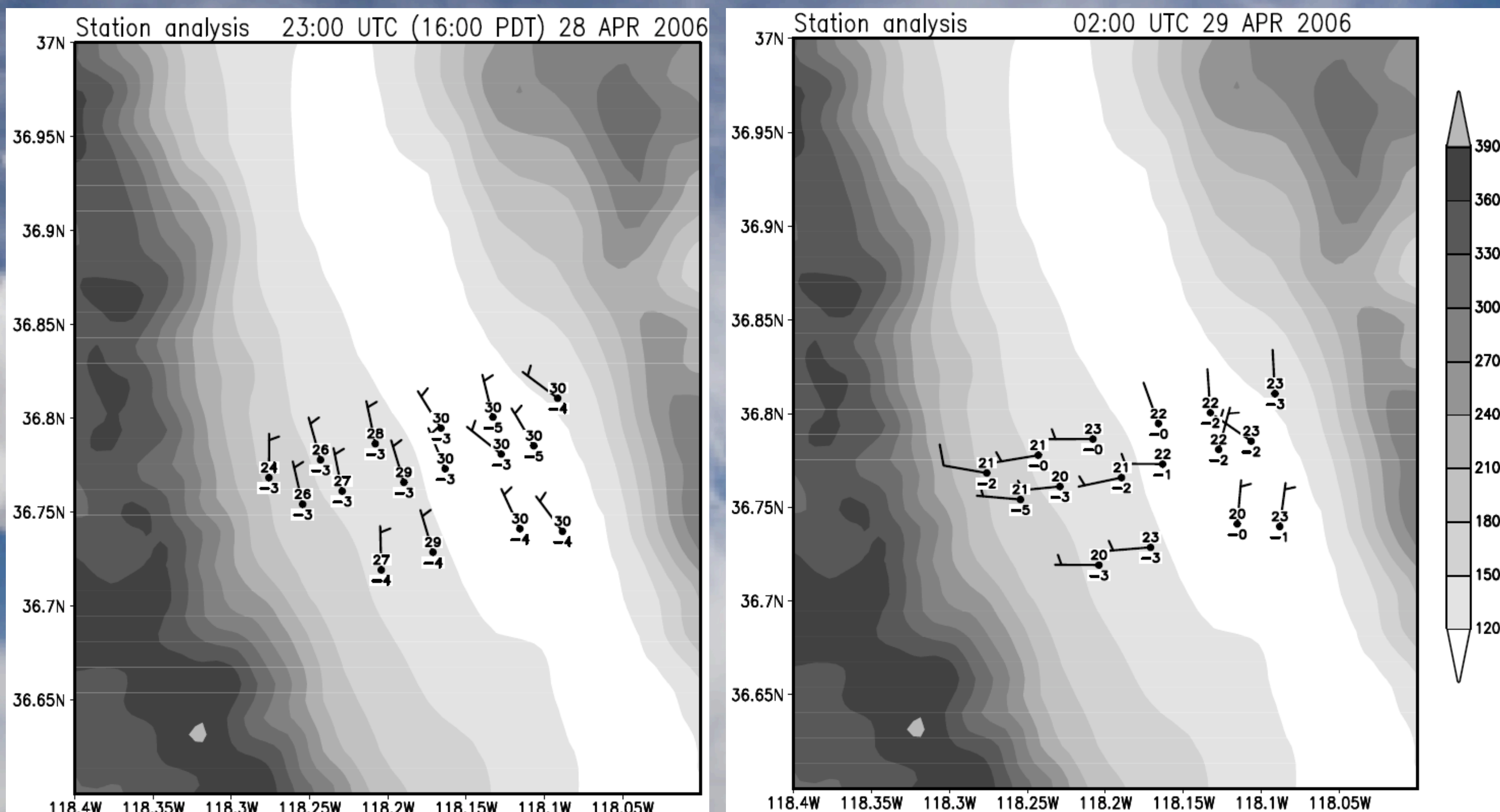
Station #2 wind speed/ direction data for April 29th 2006 measured in m/s. X-axis is in local time (PDT)



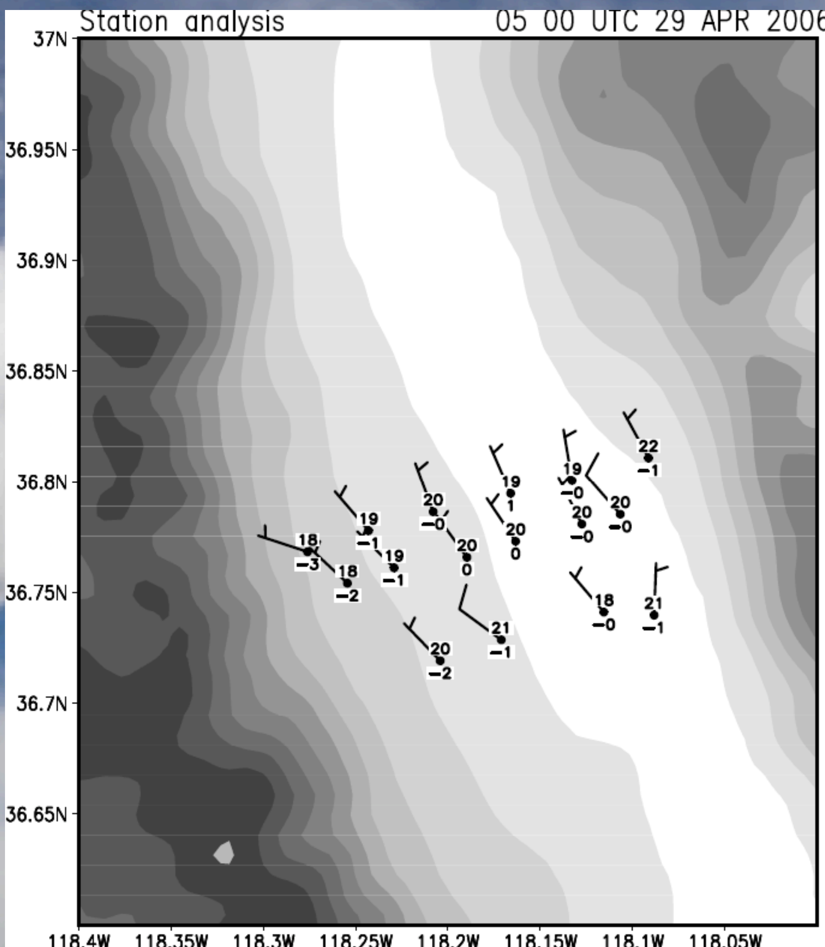
Station #2 UV component data for April 29th 2006 measured in m/s. X-axis is in local time (PDT)

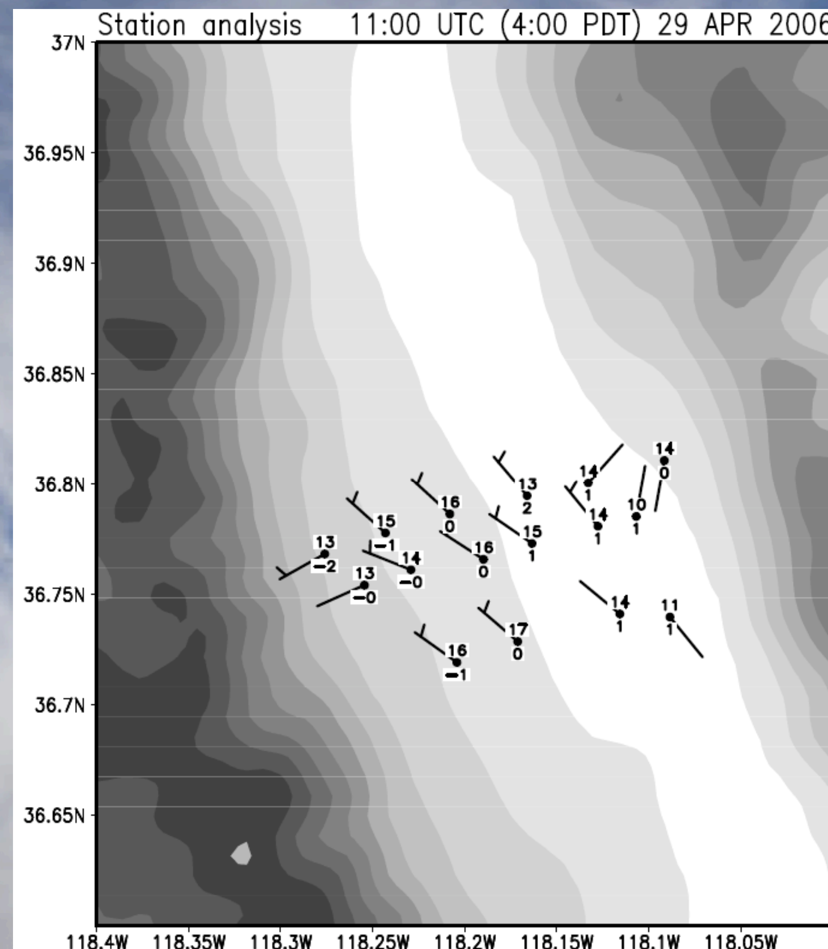


EOP4 DRI station analysis

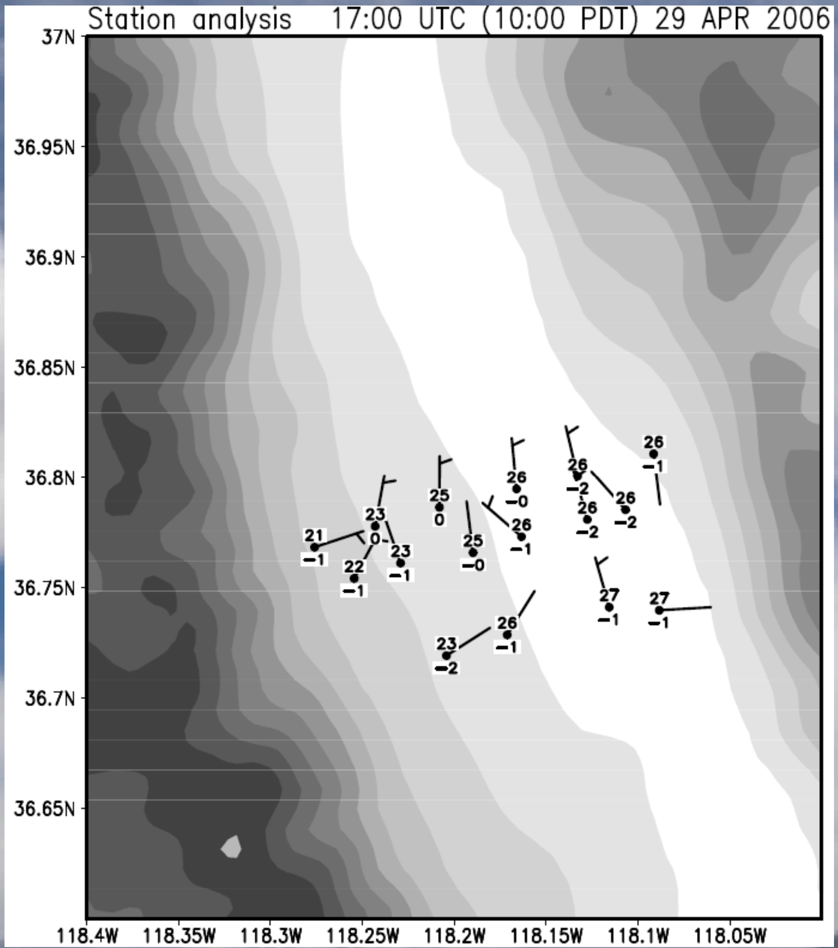


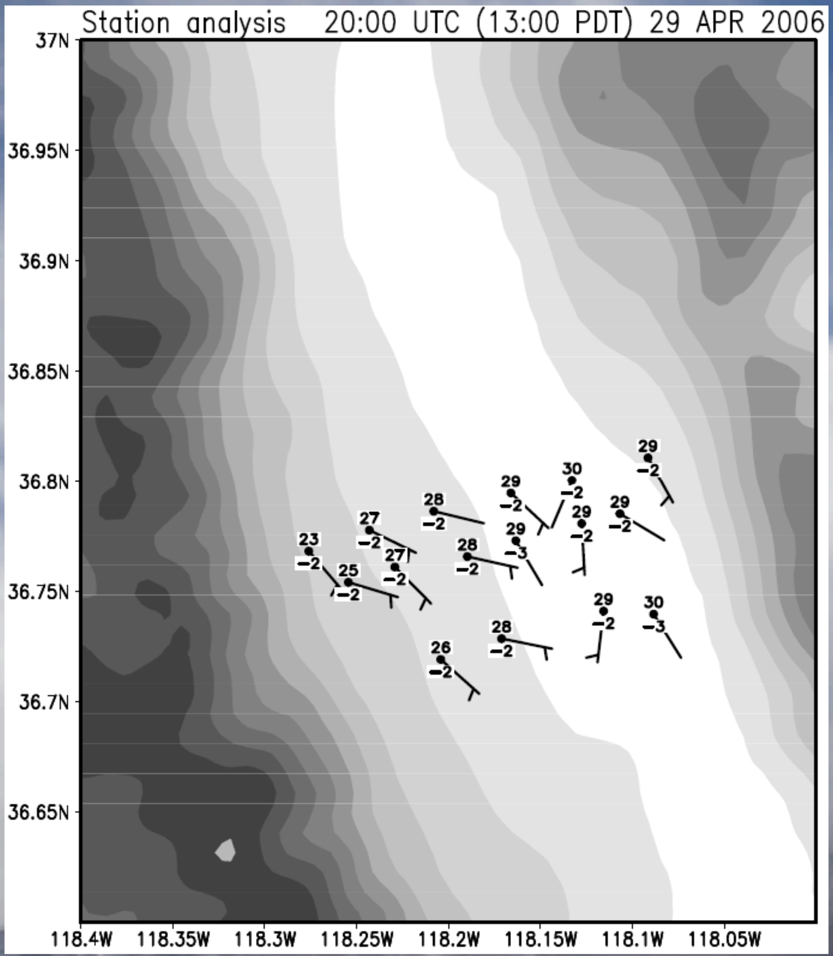
EOP4 DRI station analysis (Cont'd)





EOP4 DRI station analysis (Cont'd)





The setting of topography

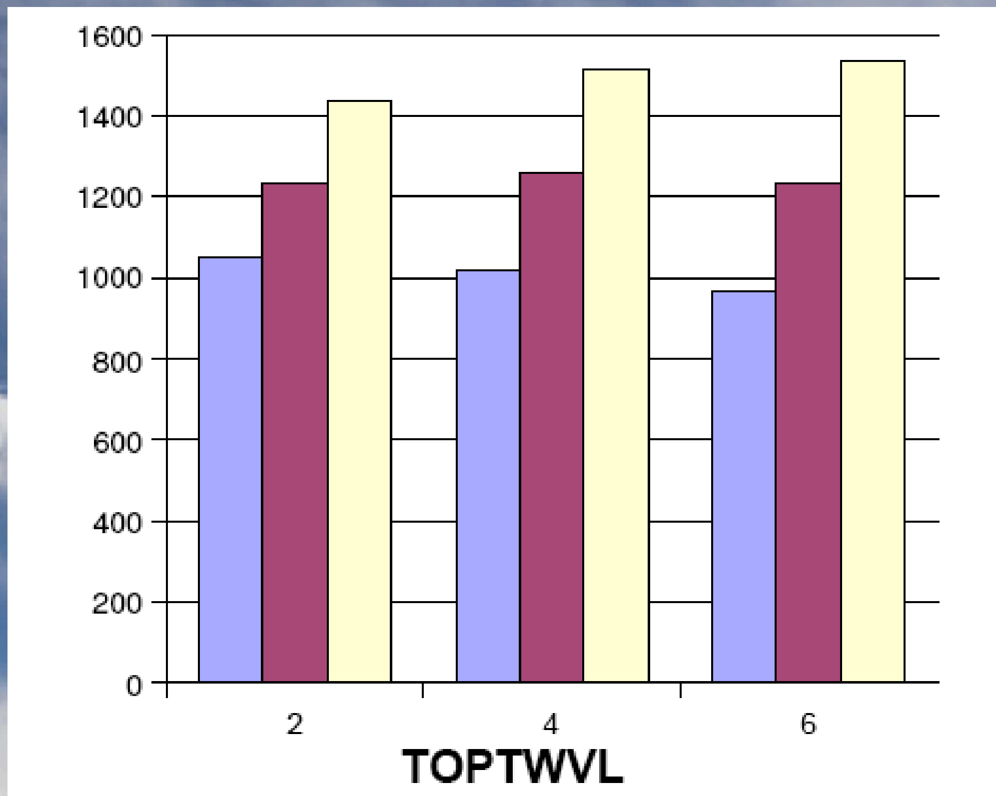


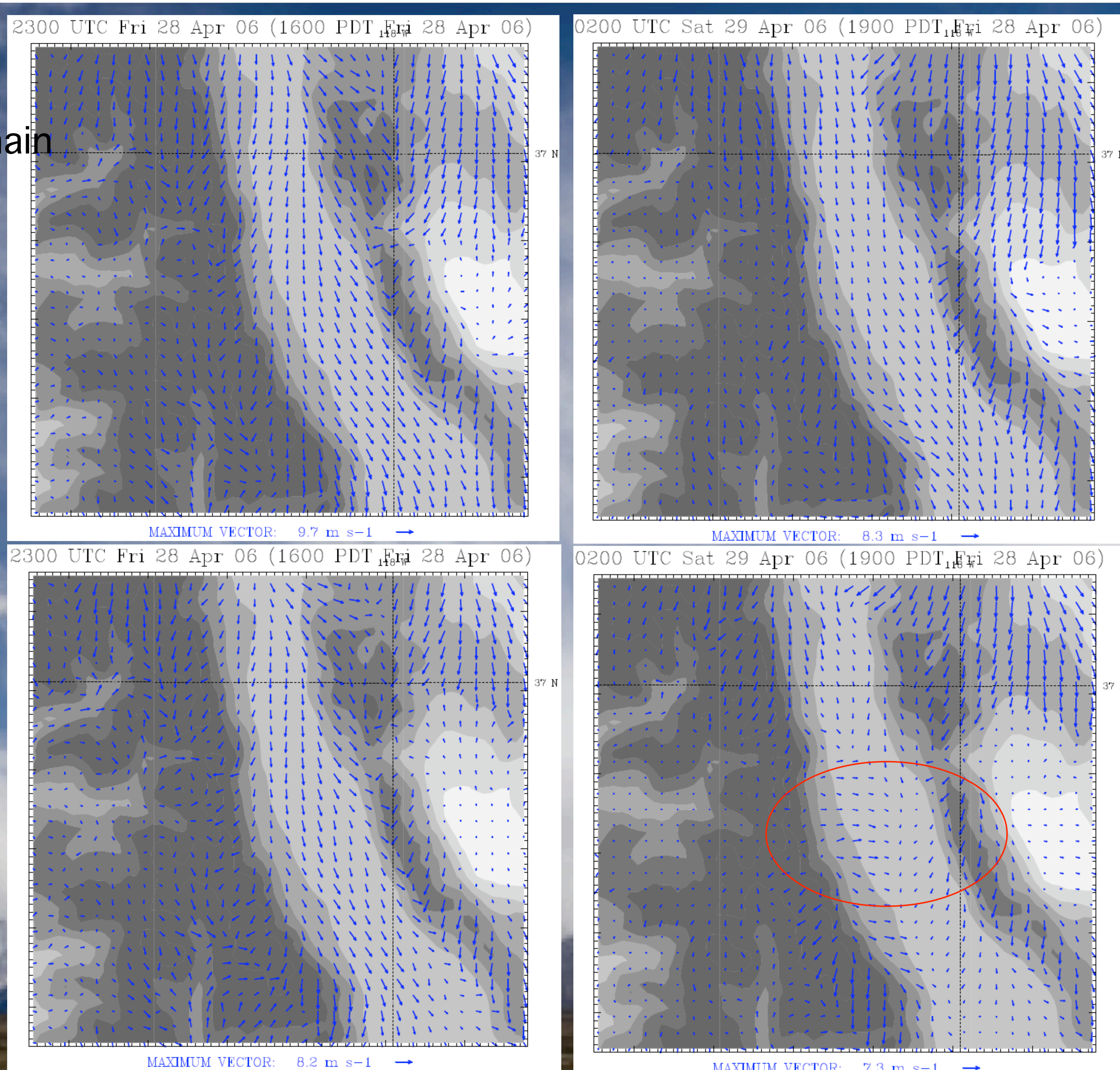
Figure 2: Maximum terrain height (meters) as a function of various settings for parameters toptwvl and silavwt (where silavwt=0=blue; 1=red; 2=tan) for domain d01.

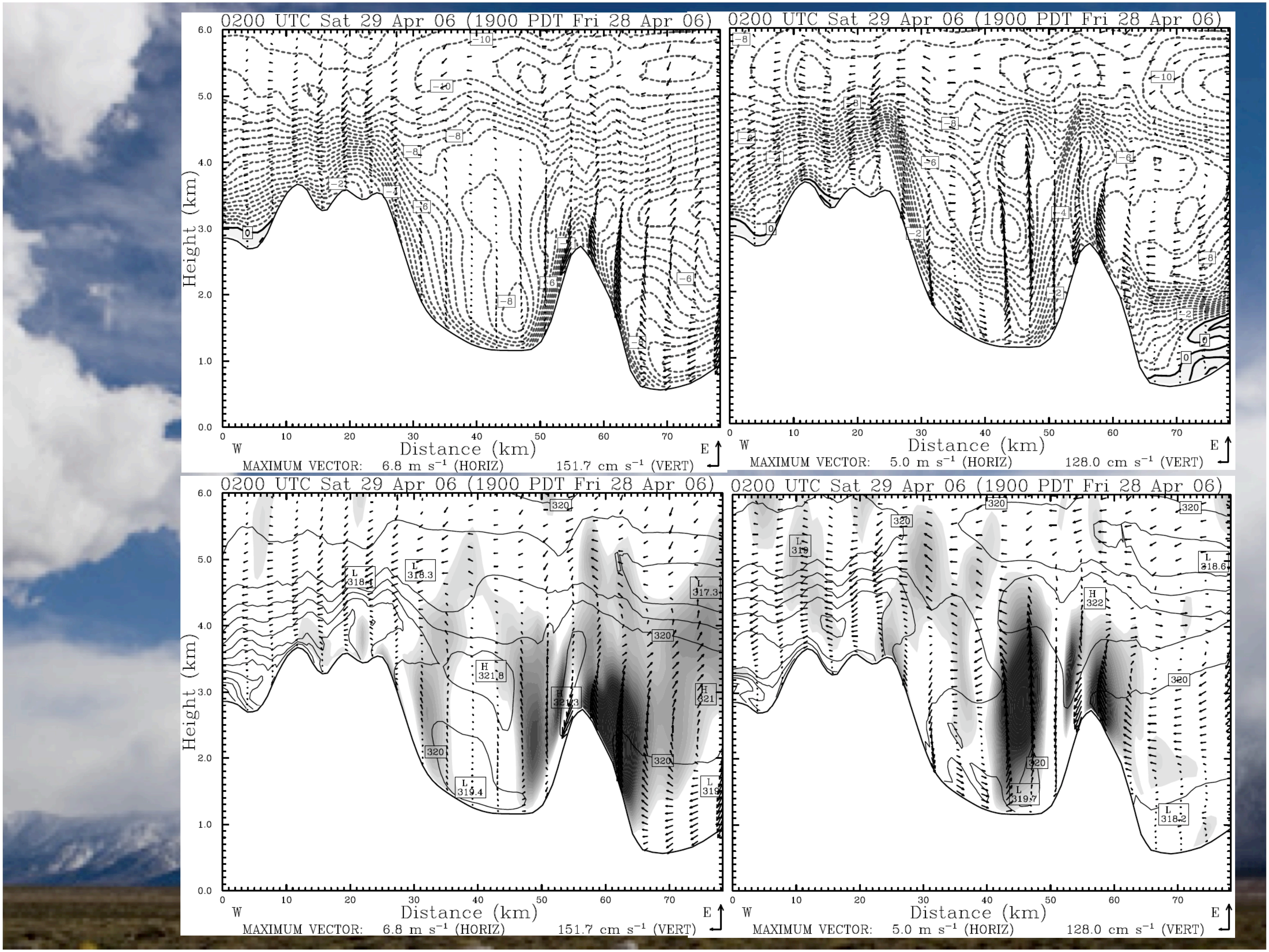
(Smart et al. Wrf workshop 2004)

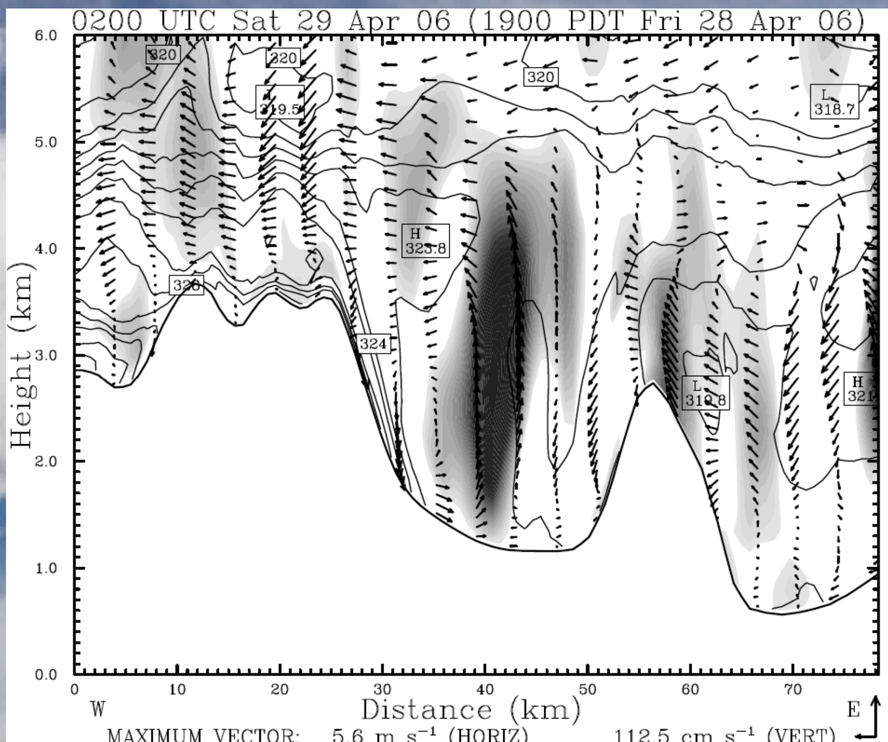
10-m wind from the 1.5 km domain

SILAVWT = 0

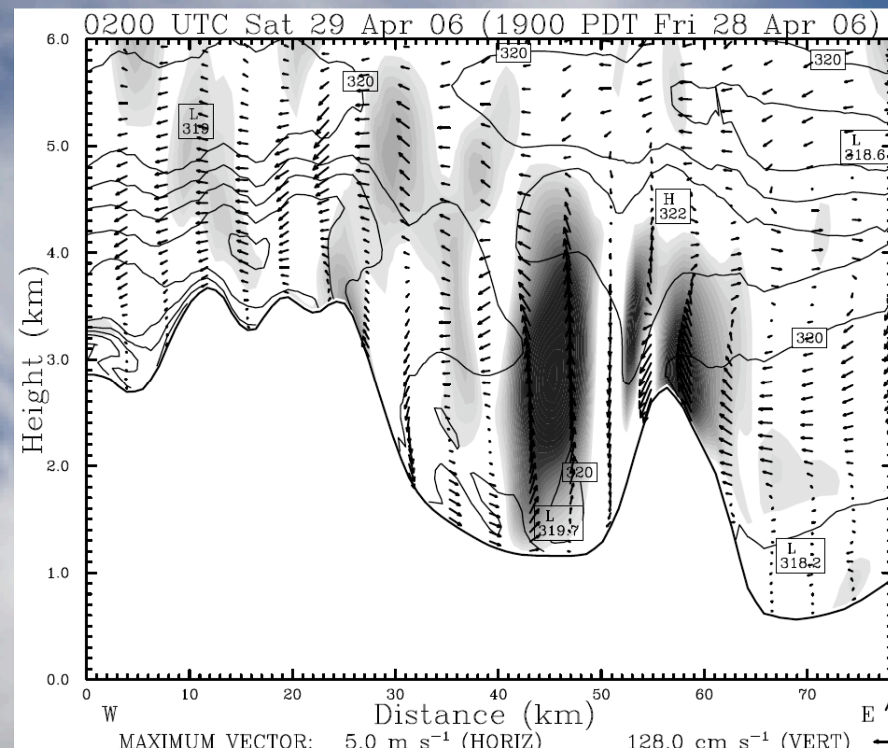
SILAVWT = 2



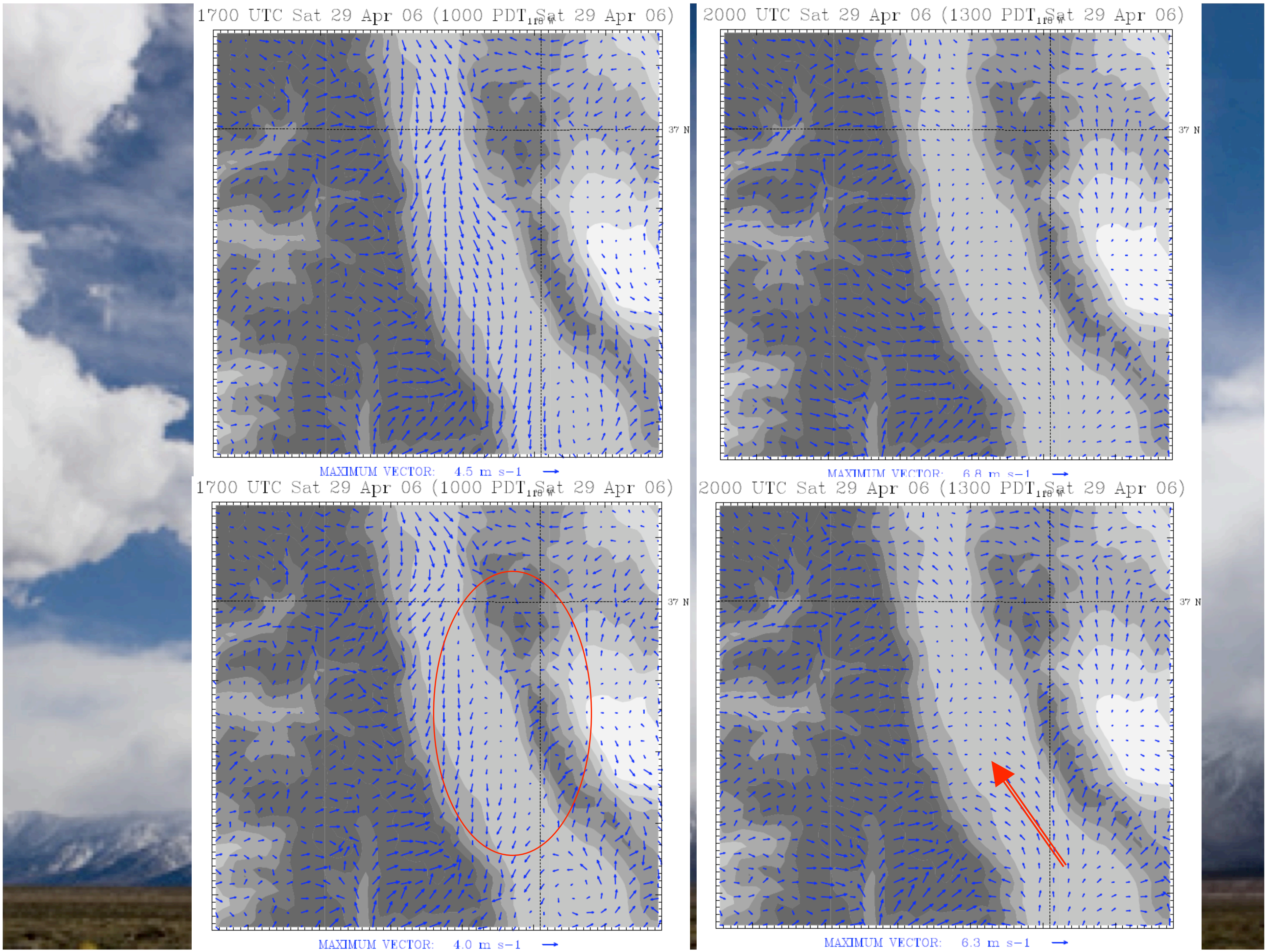

0200 UTC Sat 29 Apr 06 (1900 PDT Fri 28 Apr 06)
Height (km)
Distance (km)
W
E
MAXIMUM VECTOR: 6.8 m s^{-1} (HORIZ) 151.7 cm s^{-1} (VERT)
0200 UTC Sat 29 Apr 06 (1900 PDT Fri 28 Apr 06)
Distance (km)
W
E
MAXIMUM VECTOR: 5.0 m s^{-1} (HORIZ) 128.0 cm s^{-1} (VERT)
0200 UTC Sat 29 Apr 06 (1900 PDT Fri 28 Apr 06)
Height (km)
Distance (km)
W
E
MAXIMUM VECTOR: 6.8 m s^{-1} (HORIZ) 151.7 cm s^{-1} (VERT)
0200 UTC Sat 29 Apr 06 (1900 PDT Fri 28 Apr 06)
Distance (km)
W
E
MAXIMUM VECTOR: 5.0 m s^{-1} (HORIZ) 128.0 cm s^{-1} (VERT)

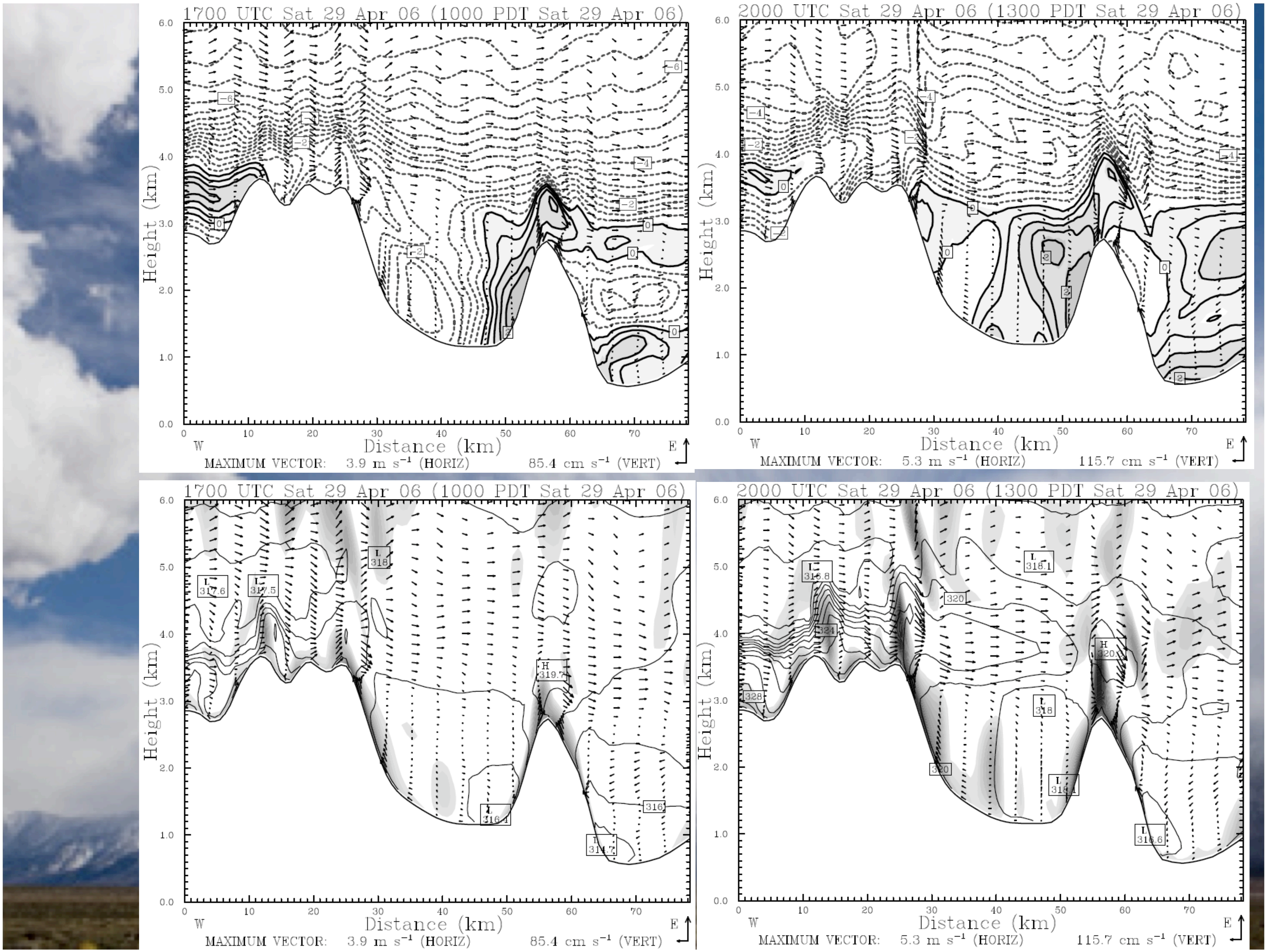


MYJ PBL scheme



YSU PBL scheme


1700 UTC Sat 29 Apr 06 (1000 PDT Sat 29 Apr 06)
118 W
37 N
MAXIMUM VECTOR: 4.5 m s-1
2000 UTC Sat 29 Apr 06 (1300 PDT Sat 29 Apr 06)
118 W
37 N
MAXIMUM VECTOR: 6.8 m s-1
1700 UTC Sat 29 Apr 06 (1000 PDT Sat 29 Apr 06)
118 W
37 N
MAXIMUM VECTOR: 4.0 m s-1
2000 UTC Sat 29 Apr 06 (1300 PDT Sat 29 Apr 06)
118 W
37 N
MAXIMUM VECTOR: 6.3 m s-1


1700 UTC Sat 29 Apr 06 (1000 PDT Sat 29 Apr 06)
2000 UTC Sat 29 Apr 06 (1300 PDT Sat 29 Apr 06)
Height (km)
Distance (km)
W
E
MAXIMUM VECTOR: 3.9 m s-1 (HORIZ) 85.4 cm s-1 (VERT)
MAXIMUM VECTOR: 5.3 m s-1 (HORIZ) 115.7 cm s-1 (VERT)
1700 UTC Sat 29 Apr 06 (1000 PDT Sat 29 Apr 06)
2000 UTC Sat 29 Apr 06 (1300 PDT Sat 29 Apr 06)
Height (km)
Distance (km)
W
E
MAXIMUM VECTOR: 3.9 m s-1 (HORIZ) 85.4 cm s-1 (VERT)
MAXIMUM VECTOR: 5.3 m s-1 (HORIZ) 115.7 cm s-1 (VERT)

Summary

- The EOP4 case shows the drainage flows (down-valley + down slope) with 3-layer structures.
- The results indicate the DVJ was well simulated by the WRF model. The layer structure of wind speed was possibly caused by entrainment.
- Different type of processing of topographic data does affect the simulated results, which is critical for mountainous regions. Preserving more slope information may help to improve the simulation.
- The use of PBL scheme for stable boundary layer condition still needs further investigation to better quantify the bias of each scheme.

Acknowledgements

- Dr. Walter Bach (ARO)
- Bob Dumais (ARL)
- NCEP and NCAR supercomputing resources


Questions?

Supplemental slides

EOP3

- April 18th – April 19th 2006 → We will focus on the 18th
- Jet began to develop just before 22:00 (April 17th) and lasted until just after 8:00 PDT April 18th
- Low-level jet extended from the surface to 800m
- Maximum velocity reached was 15 m/s (34 mph)

EOP3: April 18, 2006 (3:00 PM) – April 19, 2006 (12:00 PM)

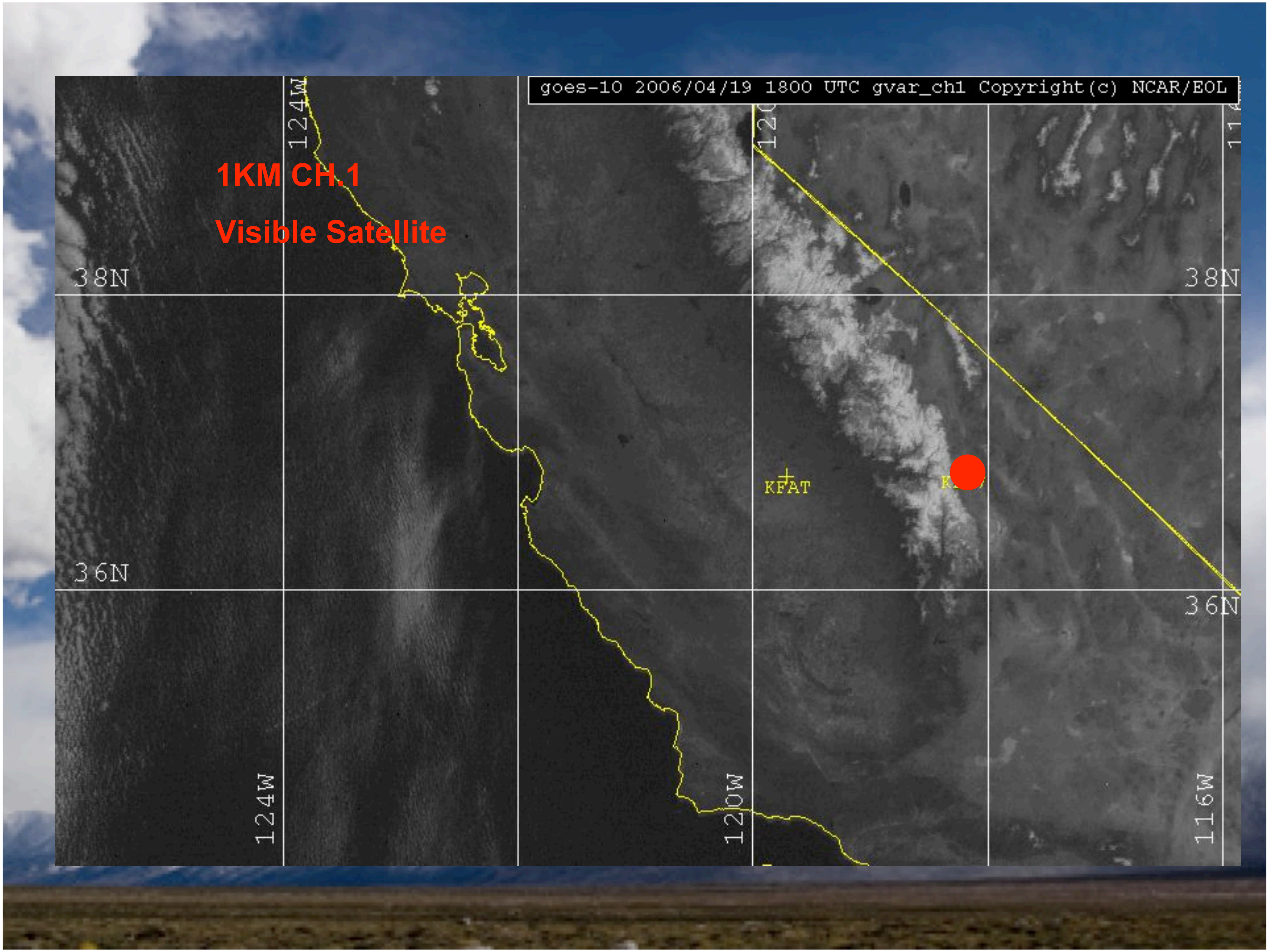
Observed Conditions:

The wind velocity profile for EOP3 shows nearly inverted conditions before sunrise. Winds are sustained from the north at about 6 m/s at elevations from 50m to 200m,10 m/s from the northwest below 50m, and above 200m to 600m at about 12 m/s. The inversion disappears as the sun rises.

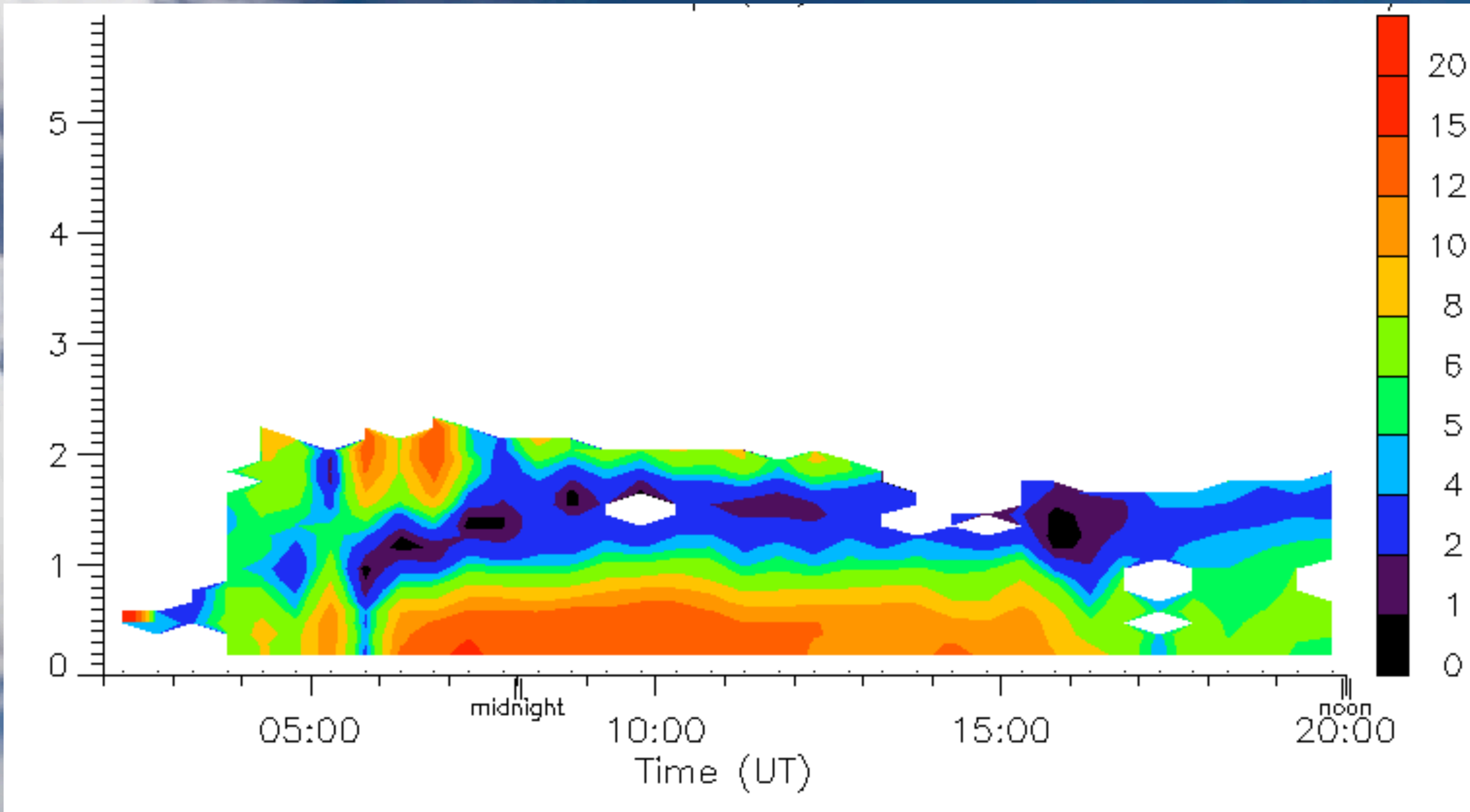
Throughout the day, there is a low off the coast of southern California, bringing more westerly and northwesterly winds.

There were slightly higher winds and higher moisture across the southern half of Inyo county than the north.

There were weak north to northwest flow at the beginning of the day and gradually becoming more northwest to westerly by noon.

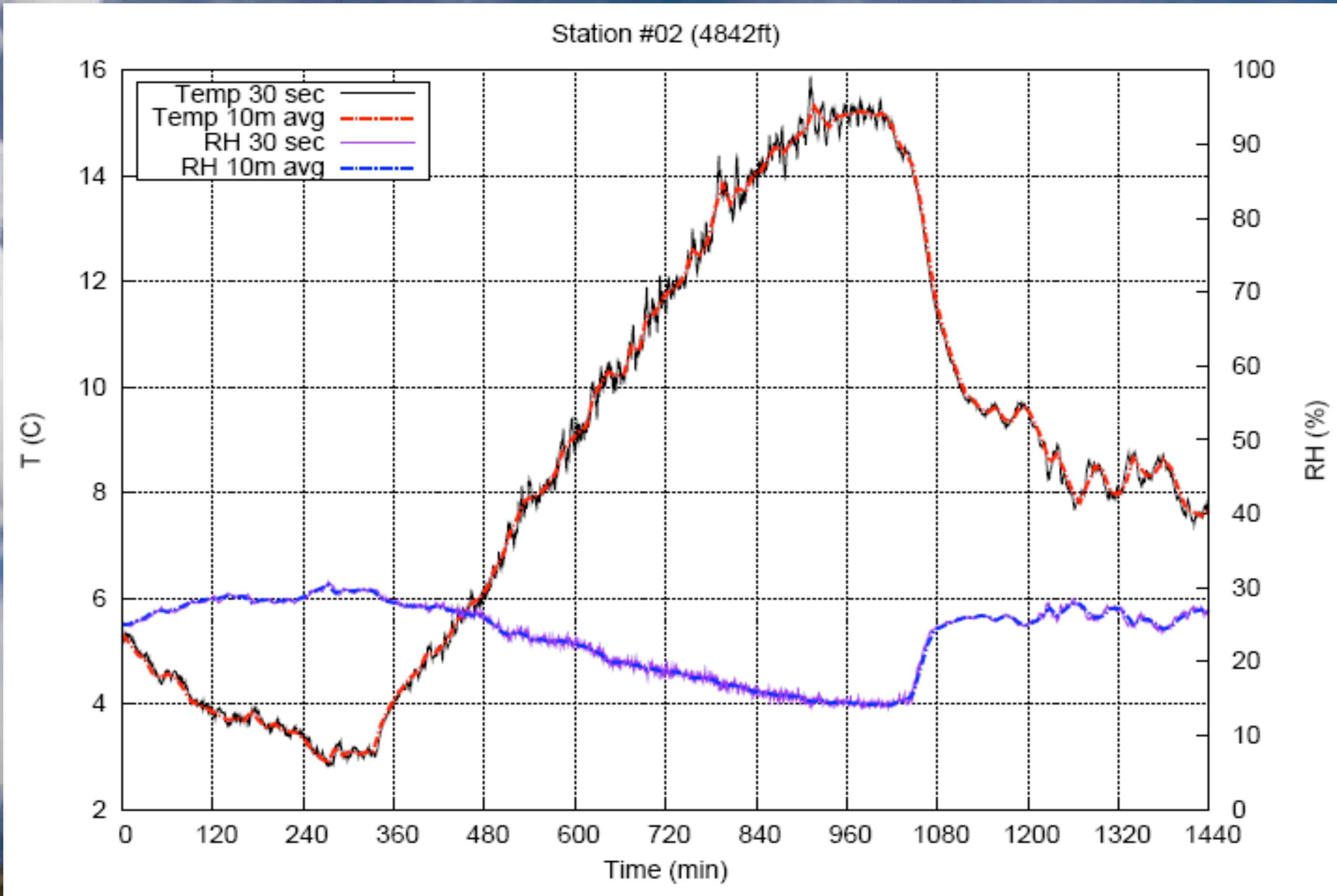


1KM CH.1
Visible Satellite
goes-10 2006/04/19 1800 UTC gvar_ch1 Copyright(c) NCAR/EOL
38N
38N
36N
36N
124W
124W
120W
120W
116W
KFAT

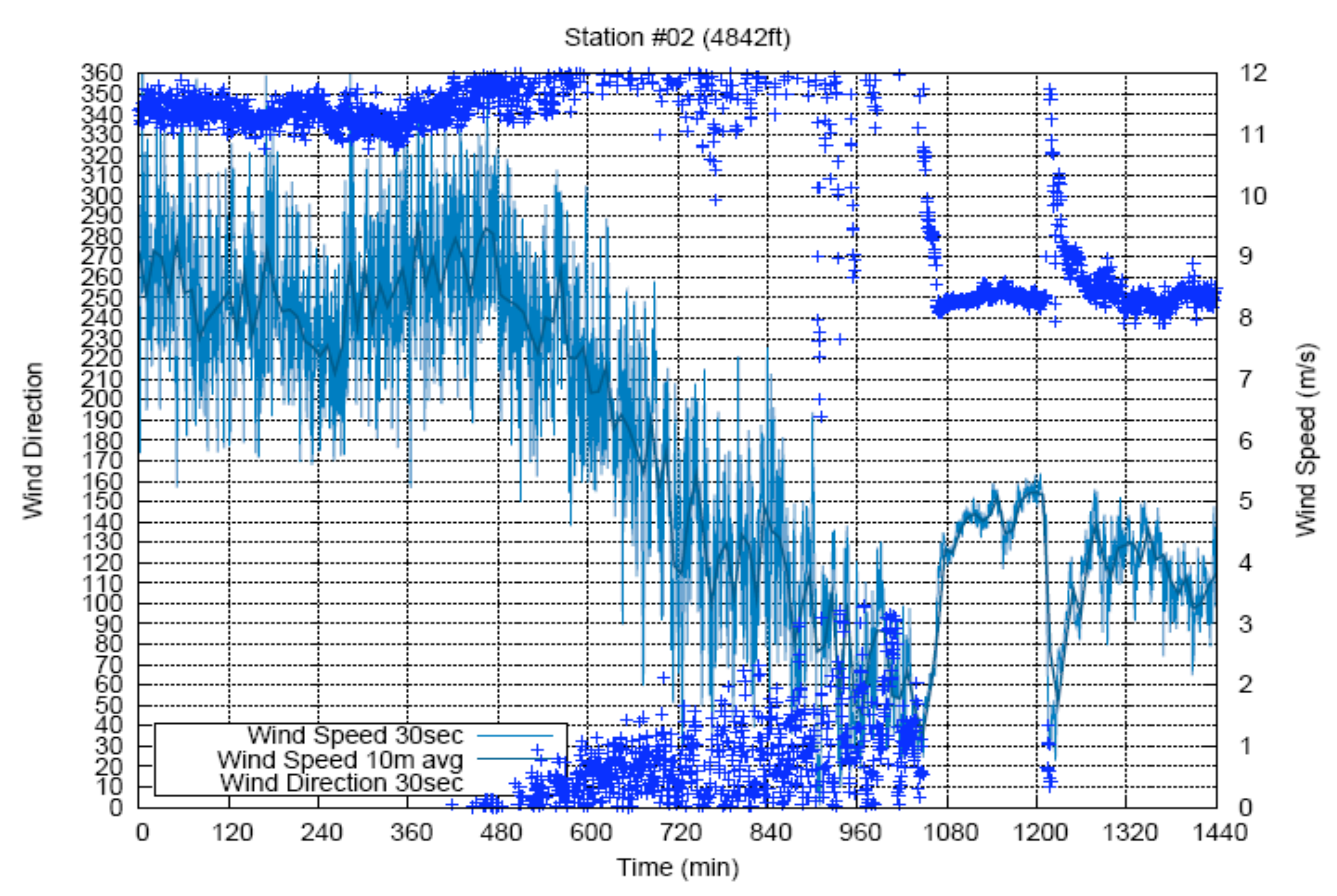


ISS2 Wind profile for April 17th – April 18th 2006. Color contours are along-valley velocities (m/s). Positive velocities indicate wind from the south. Y-axis is altitude measured in kilometers

Station #2 Temperature and RH data for April 18th 2006 measured in Celsius. X-axis is in local time (PDT)



Station #2 wind speed/ direction data for April 18th 2006 measured in m/s. X-axis is in local time (PDT)



Station #2 UV component data for April 18th 2006 measured in m/s. X-axis is in local time (PDT)