Mountain waves and energy harvesting for UAVs using a DWL

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WG meeting, Boulder, CO

May 14, 2014

Overview

- General objectives of research
  - Atmospheric energy targets
- Team
  - SWA, lead (Emmitt, Greco and Wood)
  - Earthly Dynamics (Costello, Ward and Rogers)
  - Aurora (Chtangeev)
- Overview of energy harvesting strategy
- Mountain wave example

Objectives

- Equip UAVs and small piloted aircraft with lidar enhanced avionics to optimize detection of atmospheric features that will extend flight endurance and enable extended periods of “quite” operations.
- Incorporate lidar observations into flight path planning and aircraft flight control algortihms (e.g. thermal climbs and mountain wave surfing).

Potential atmospheric energy sources

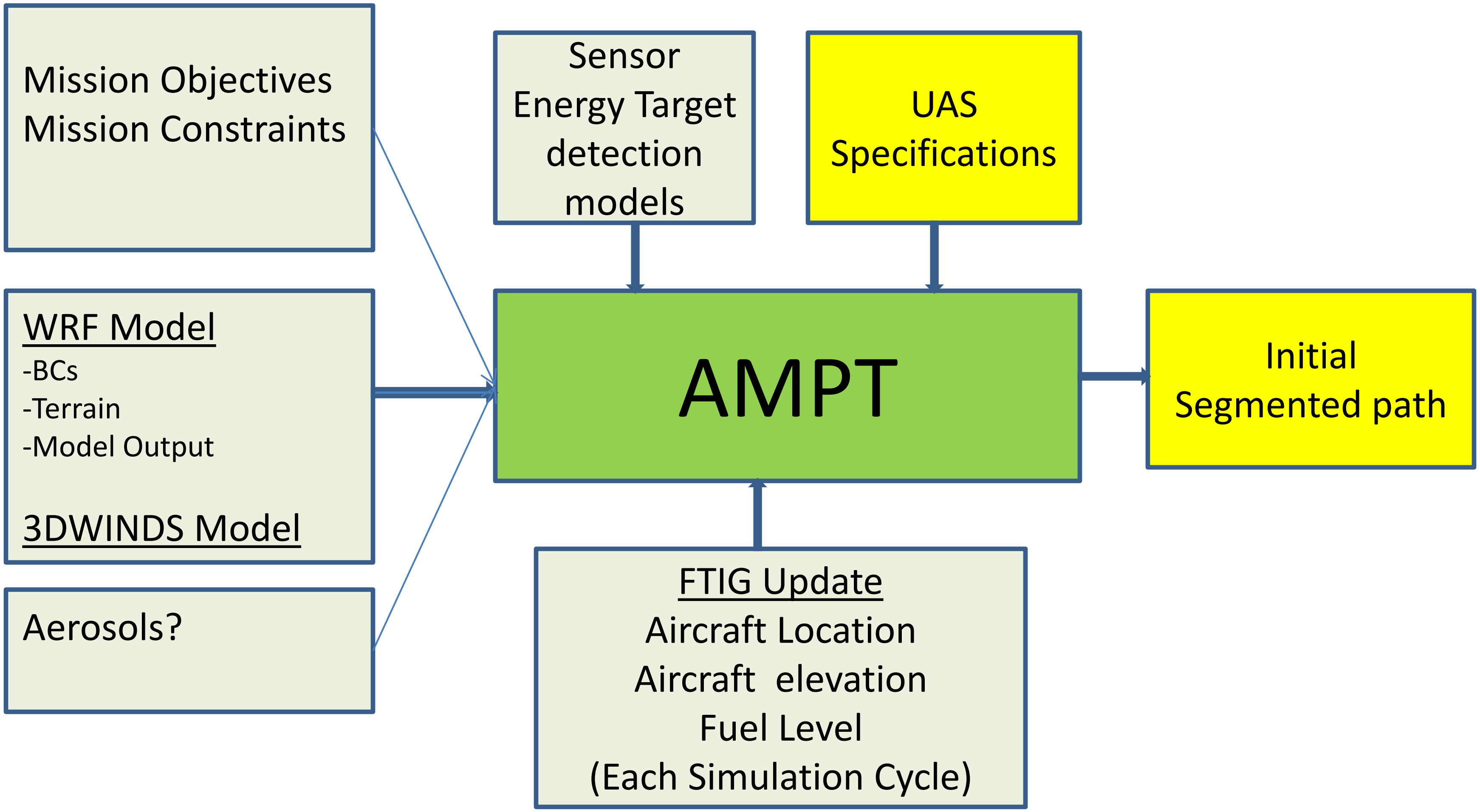
Phenomenology	Description (dimensions)	Nominal Magnitudes	Lifecycle Metrics	Remote Sensing Signatures
Thermals (non-orographic); triggered by differential surface heating	Few 100 meters in diameter; vertical extent controlled by environmental structure	1- 5 m/s	May last for large fraction of an hour; daytime features only	Convergence Optical depth Temperature Refractive turbulence
Thermals (slopes); driven by differential heating of sloped surfaces during direct solar illumination	100's meter diameter; vertical extent limited by environmental structure	1 -5 m/s	May last for hours during the daytime.	Convergence Optical depth Temperature Refractive turbulence
Organized Large Eddies (OLEs); upward branch of a semi-closed vertical circulation within the PBL	A few 100 meters in diameter; vertical extent defined by depth of PBL; organized in lines allowing "next AA" to be more easily predicted than thermals	1 – 3 m/s	May last for hours but with much variation in strength; Not much known about night-time characteristics	Convergence Optical depth Refractive turbulence
Obstacle flow; Strong horizontal flow deflected upward by orography and airmass collisions; (ridge soaring; frontal soaring)	Many miles in horizontal extent; vertical extent usually a few 100 meters above ridge line	1 – 10 m/s	May last for many hours and vary as the horizontal flow varies; Occurs at all hours of the day.	The obstacle Convergence Optical depth Refractive turbulence
Cloud updrafts; main targets are cloud base updrafts of non- or lightly precipitating cumuli.	Dimensions similar to thermals (a few 100's of meters); vertical extent can be 1000's of meters	1 – 5 m/s depending upon atmospheric stability.	A few minutes, maximum duration ~ 10 minutes.	The cloud Convergence Temperature Precipitation
Mountain Waves	Horizontal extent of many km; Vertical extent of 10's of km possible	Up to 10 m/s vertical velocities distributed in bands downwind of ridge line.	May last for hours throughout entire diurnal cycle	Vertical motions; visual wave clouds on occasion.
Gravity waves on density interface	Horizontal extent of many kms (50 – 500); Vertical extent of 5 – 10 km	1 – 3 m/s	1 – 3 hours	Vertical motions Inversions
Shear layers	Horizontal extent of many kms defined by surface topography and atmospheric structures; vertical extent a few 100 meters	10 – 25m/s with a maximum near 100 - 300 meters.	May persist for several days lasting through the nighttime	Horizontal wind speed; Optical depths

= features studied with airborne Doppler wind lidar

Source: SWA (Emmitt)

AMPT detailed

AEORA Mission Planning Tool



AMPT serves as the pre-launch mission planning tool using simulation with inputs from the FTIG regarding UAS performance. Post-launch, the AMPT would be used to update the PDFs and gridded wind fields. SWA patents on AEORA)

Case Study


N41.9°
N41.7°
N41.5°
N41.3°
N41.1°
N40.9°
Elko
W115.75°
W115.25°
W114.75°
N40.7°
N40.5°
N40.3°
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Weather Research Forecast (WRF) Model

- Three or four nested grid configuration

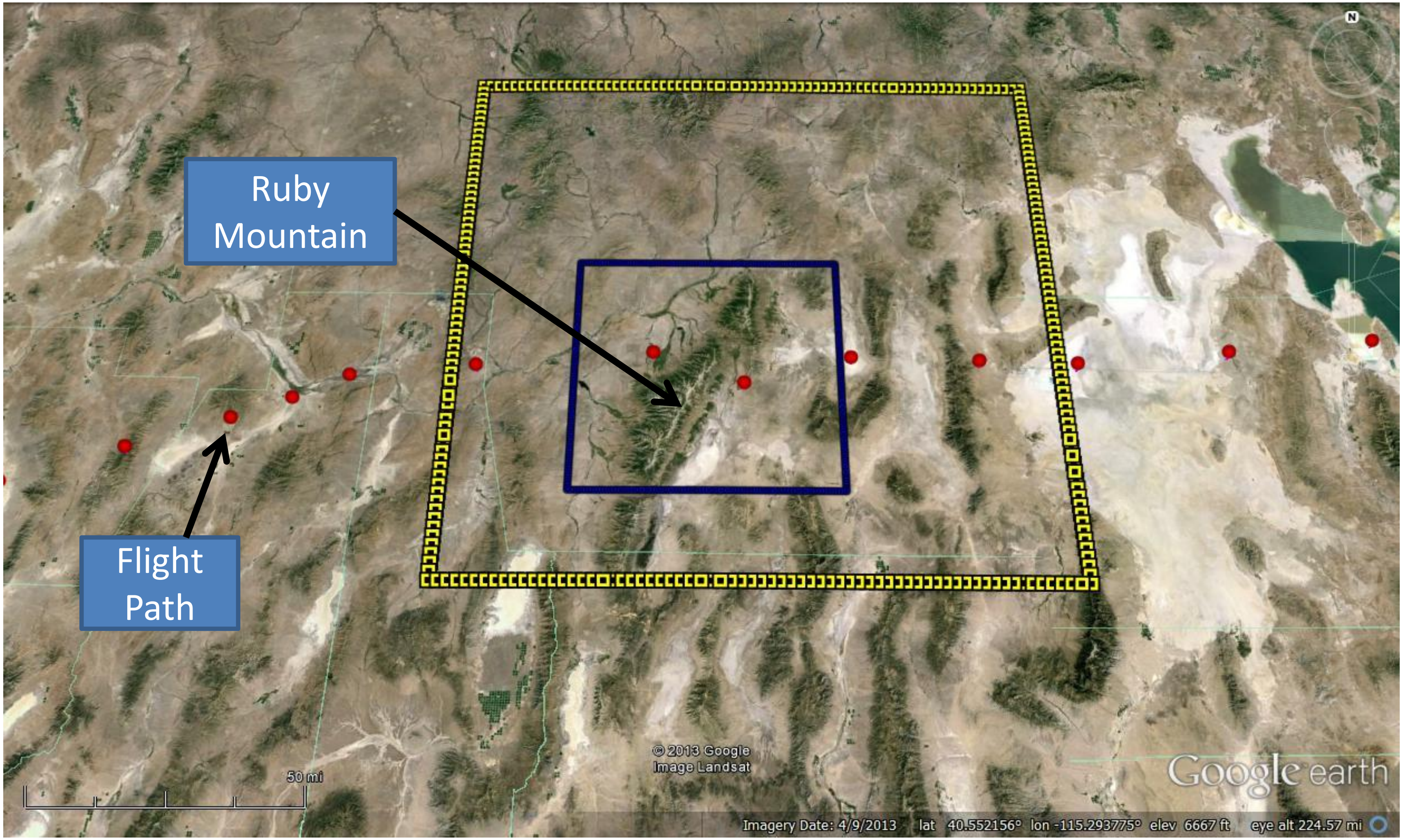
- Grid 1 with 9 km res.(540 km x 540 km domain)
- Grid 2 with 3 km res. (210 km x 210 km domain)
- Grid 3 with 1 km res. Up to 90 km x 90 km domain
- Grid 4 with 333 m res. over 35 km x 35 km domain

- 42 terrain-following vertical levels
- 200mb Model top
- NAM Analysis used as boundary conditions

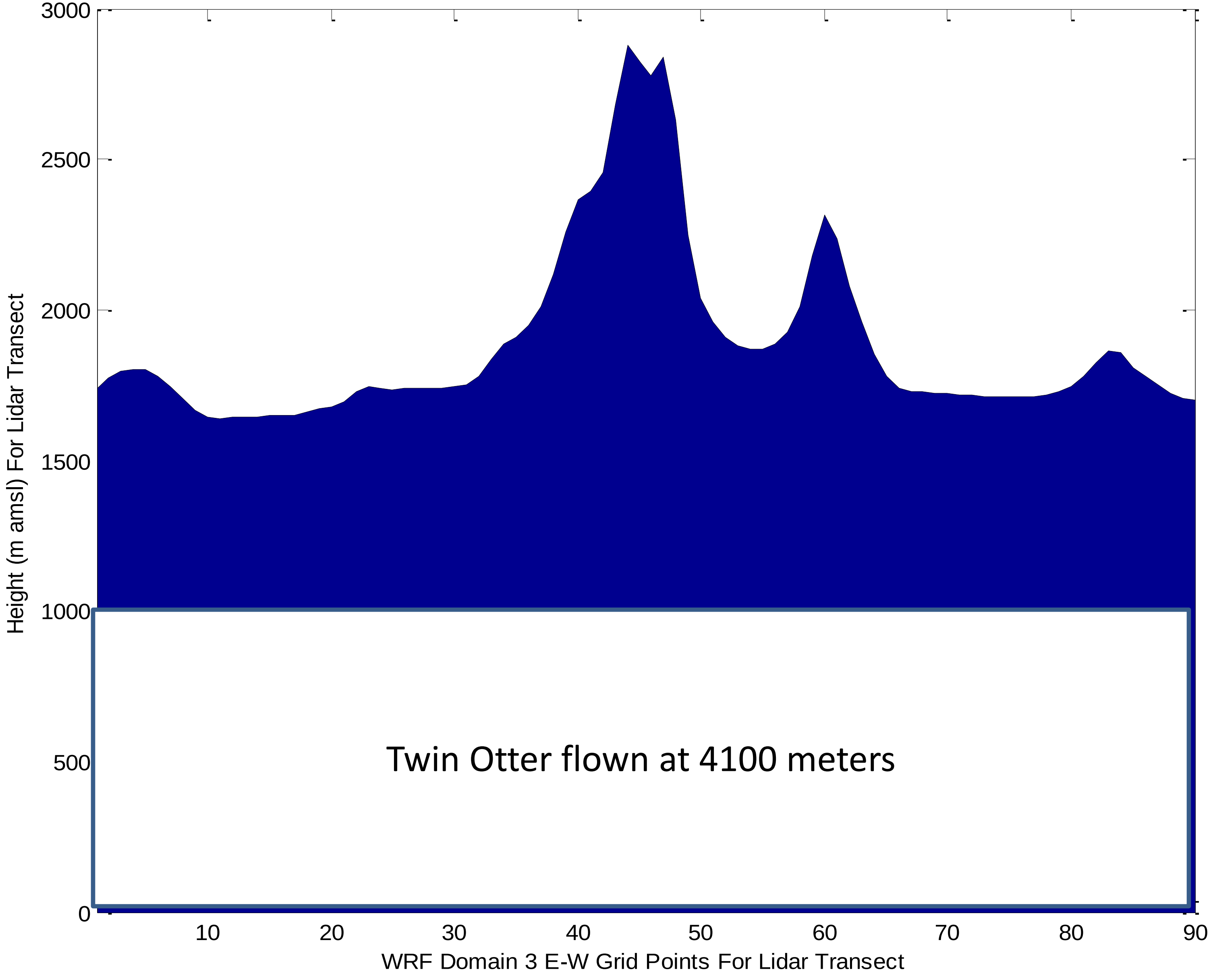
Weather Research Forecast (WRF) Model

- WRF V3.4
- LES options
- Lin Microphysics
- Surface layer physics based on M-O
- Surface physics – Noah Land Surface Model
- Mellor-Yamada Janjic scheme for BL Physics
- Betts-Miller Cum. Parameterization Scheme
- W-damping turned on

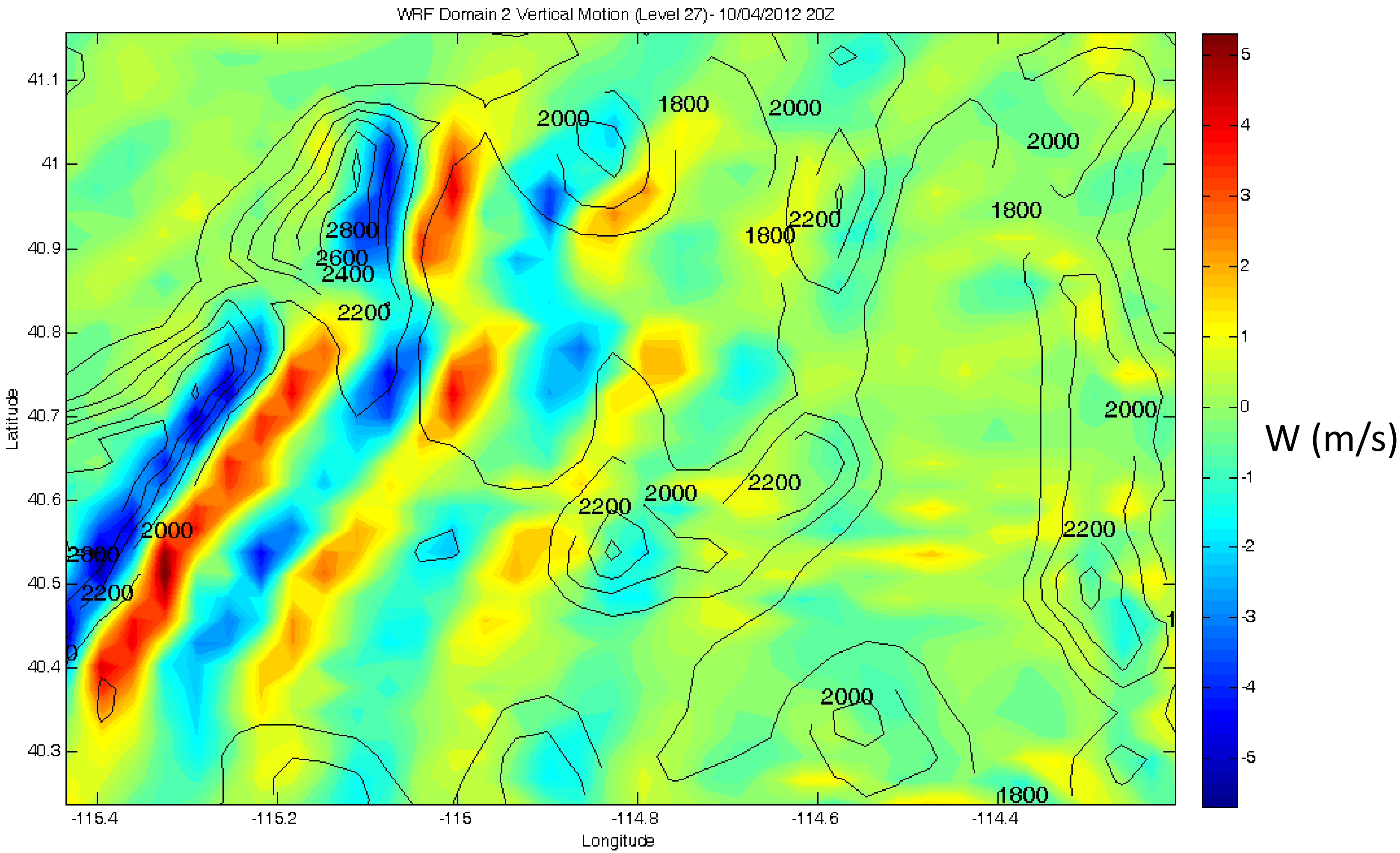
WRF Domains 2 (3 km res.) and 3 (1 km res) for 10/04/2012 20Z



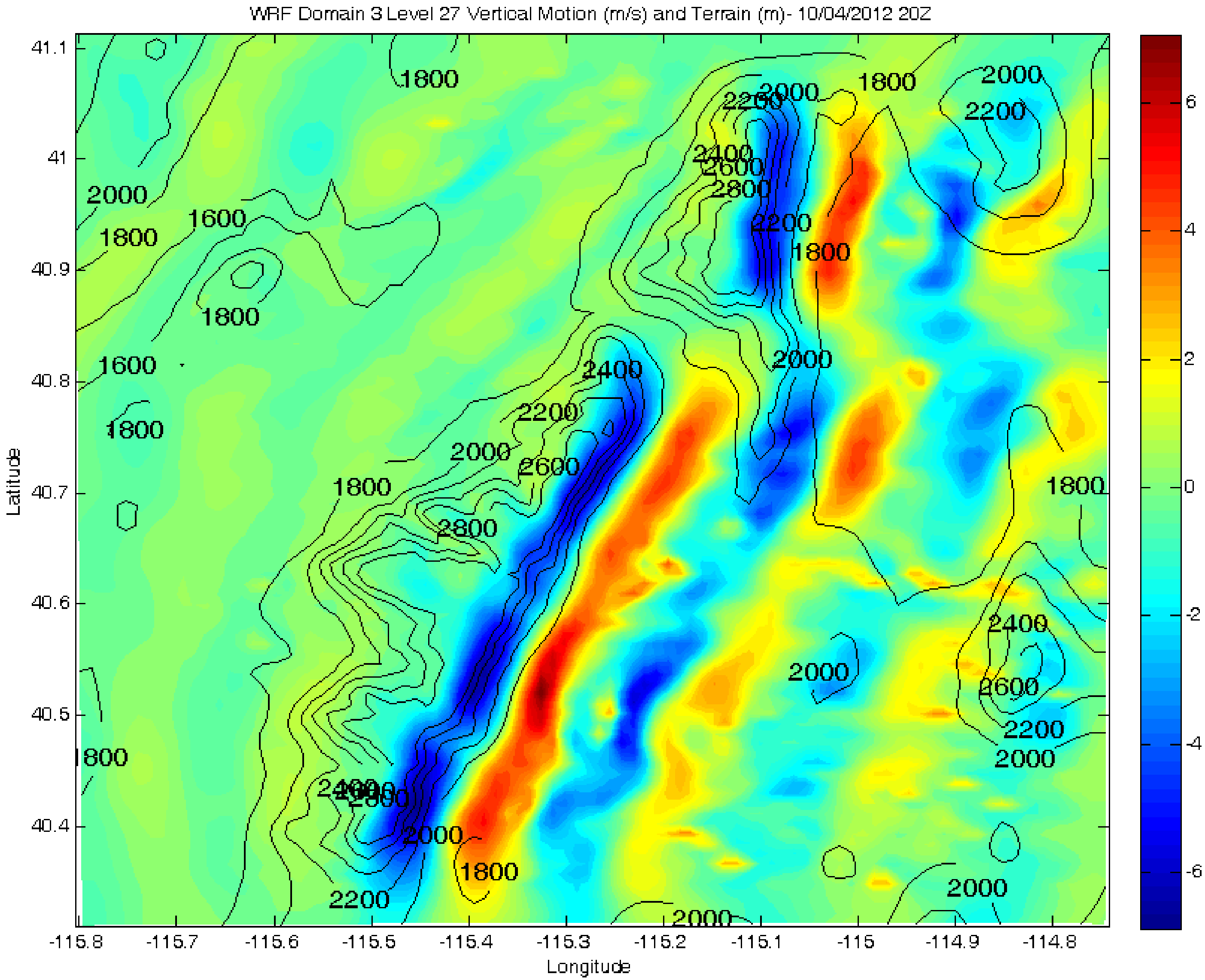
WRF Domain 3 Terrain (m) along E-W Points Chosen to Match Lidar Transect



WRF Domain 2 Level 27 Vertical Motion and Terrain – Zoom

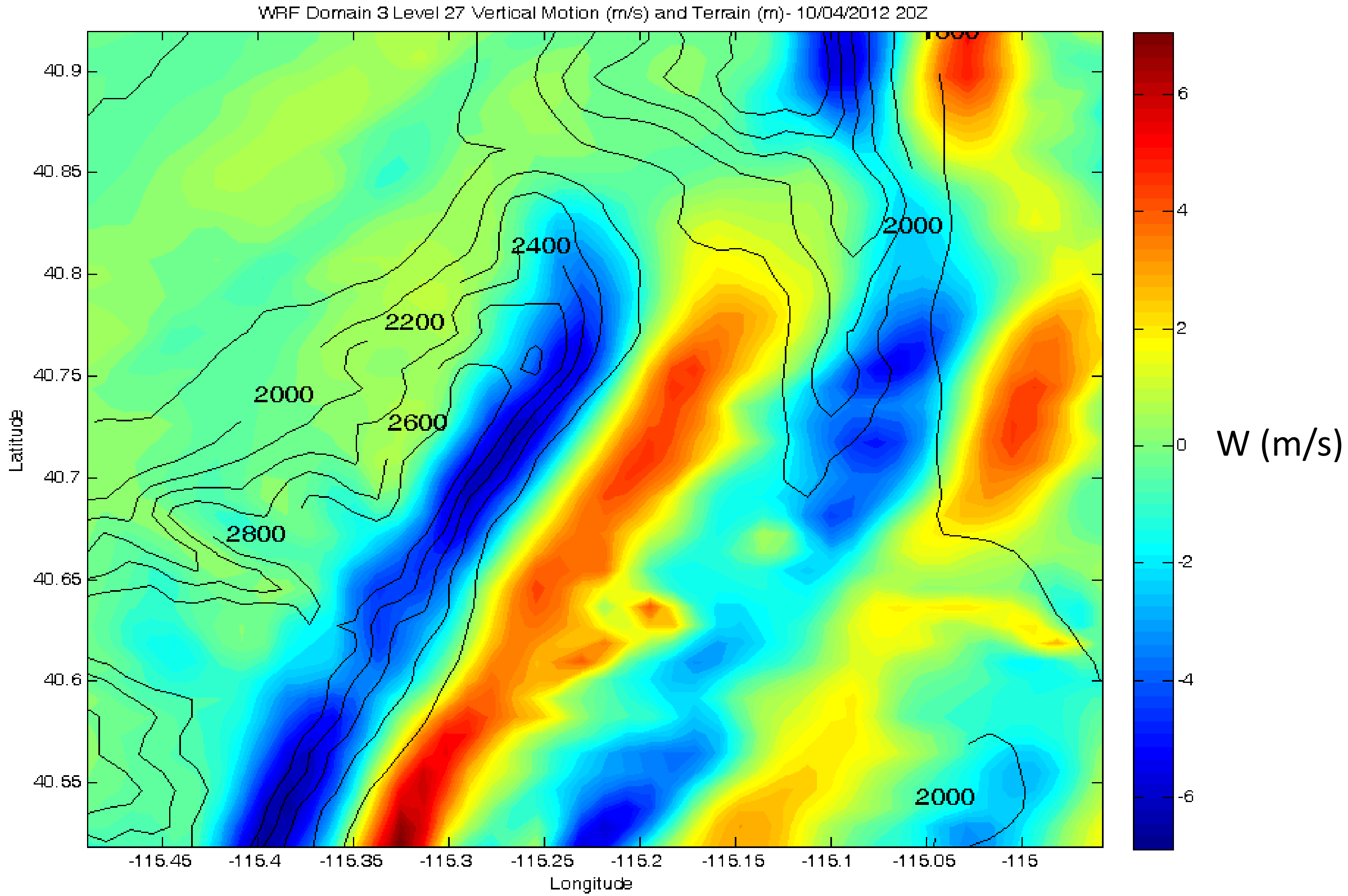


WRF Domain 3 Level 27 Vertical Motion and Terrain

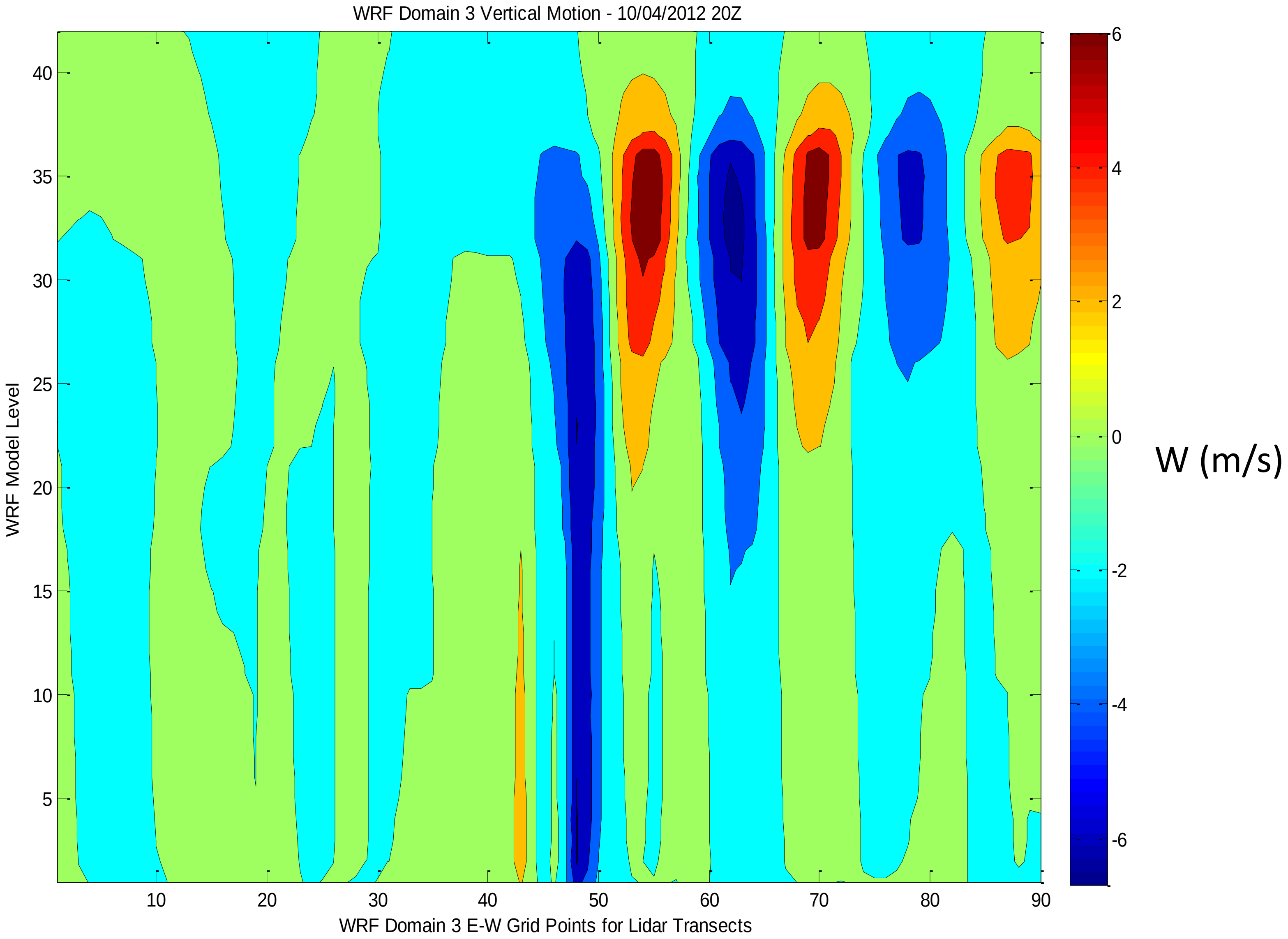


W (m/s)

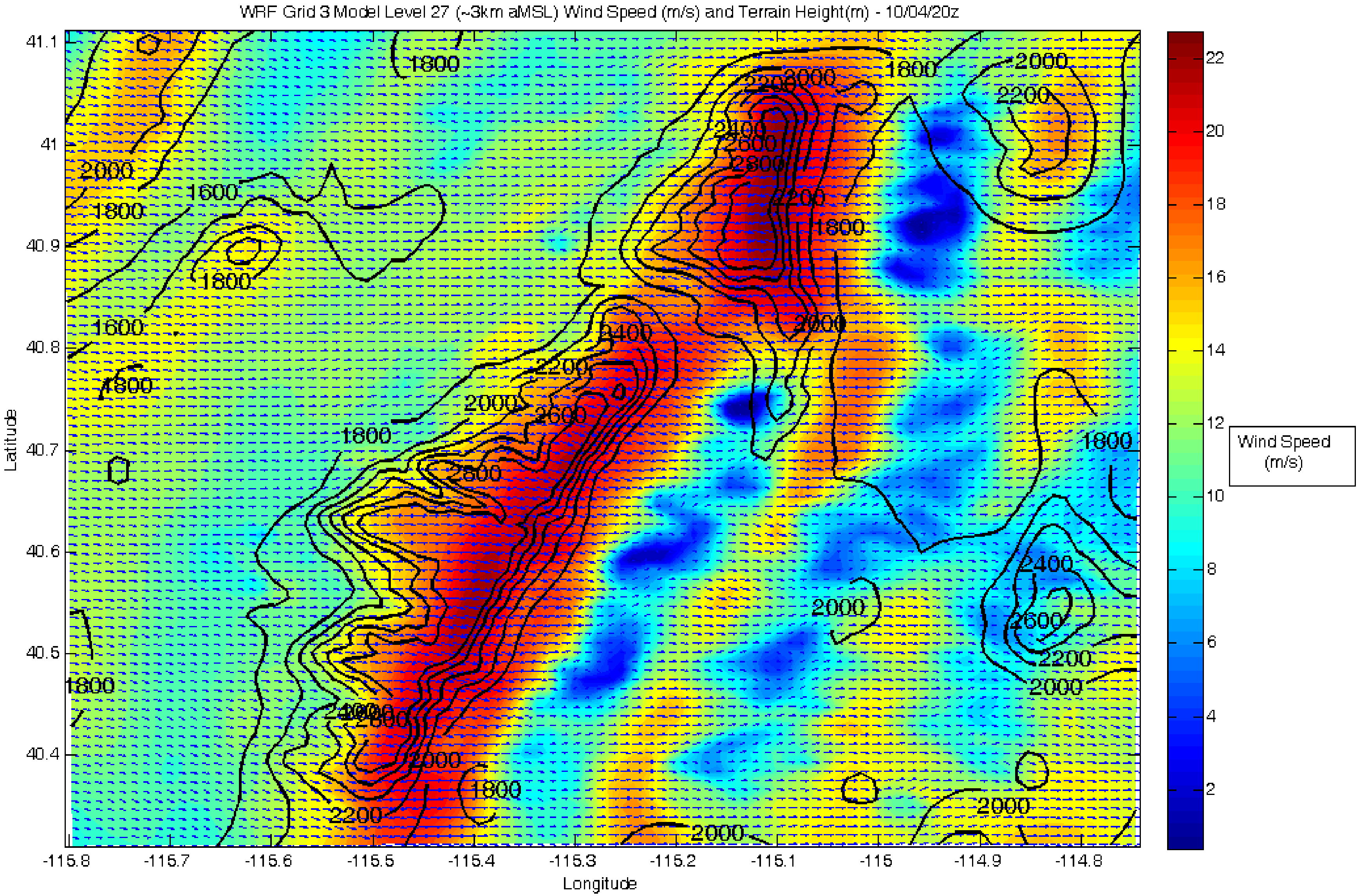
WRF Domain 3 Level 27 Vertical Motion and Terrain - Zoom



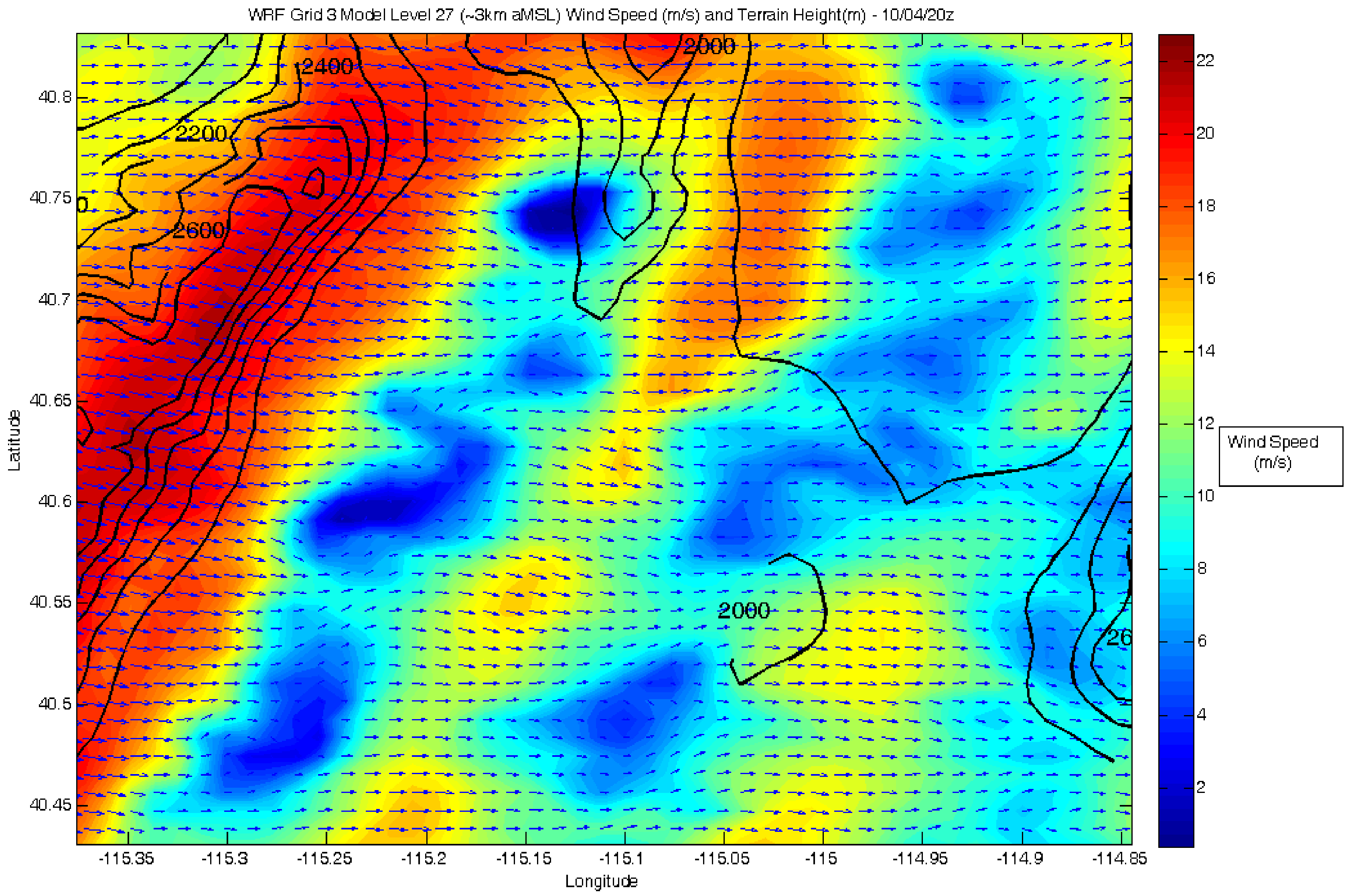
WRF Domain 3 Level 27 Z-X Vertical Motion Along Lidar Transect

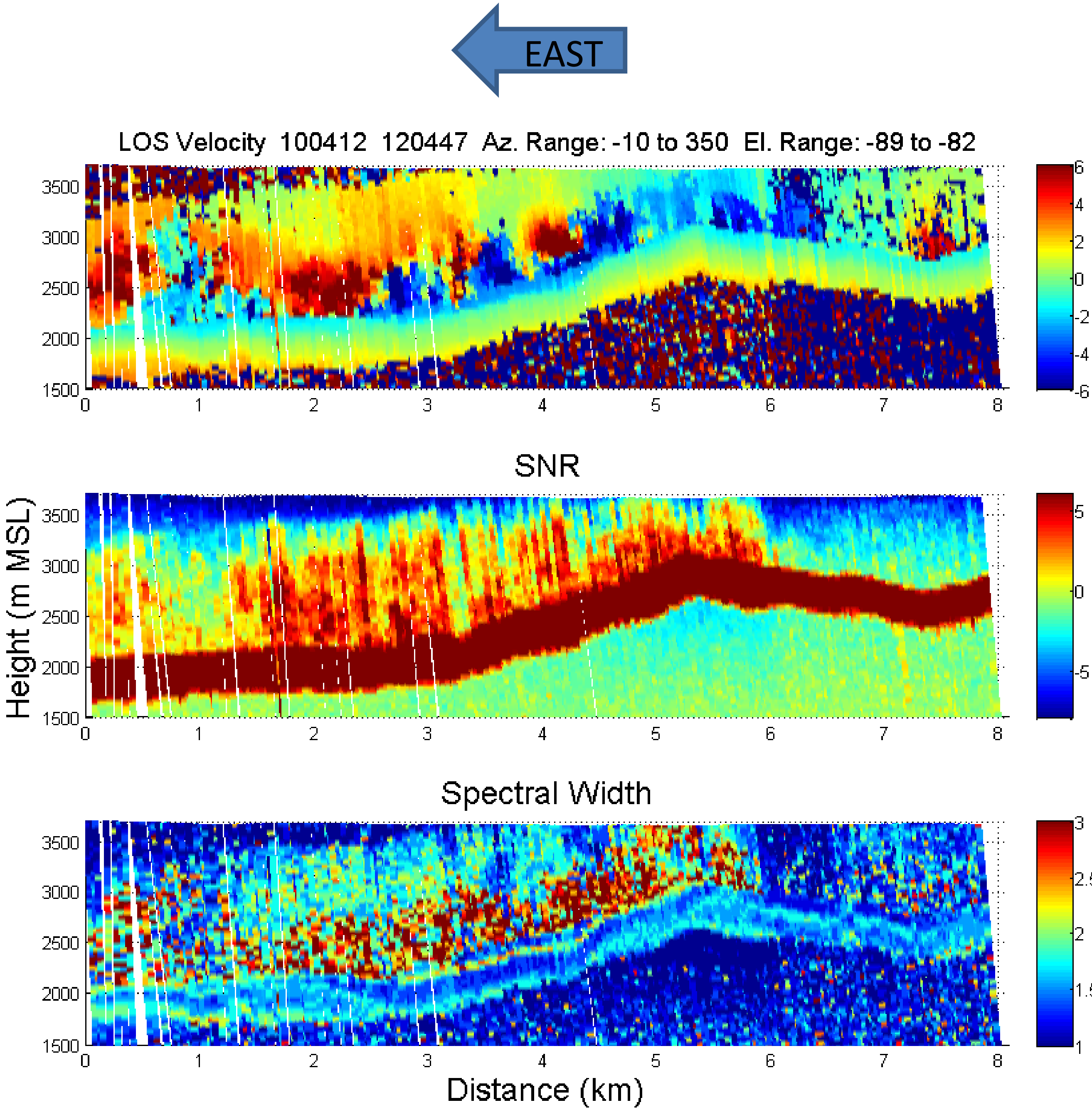


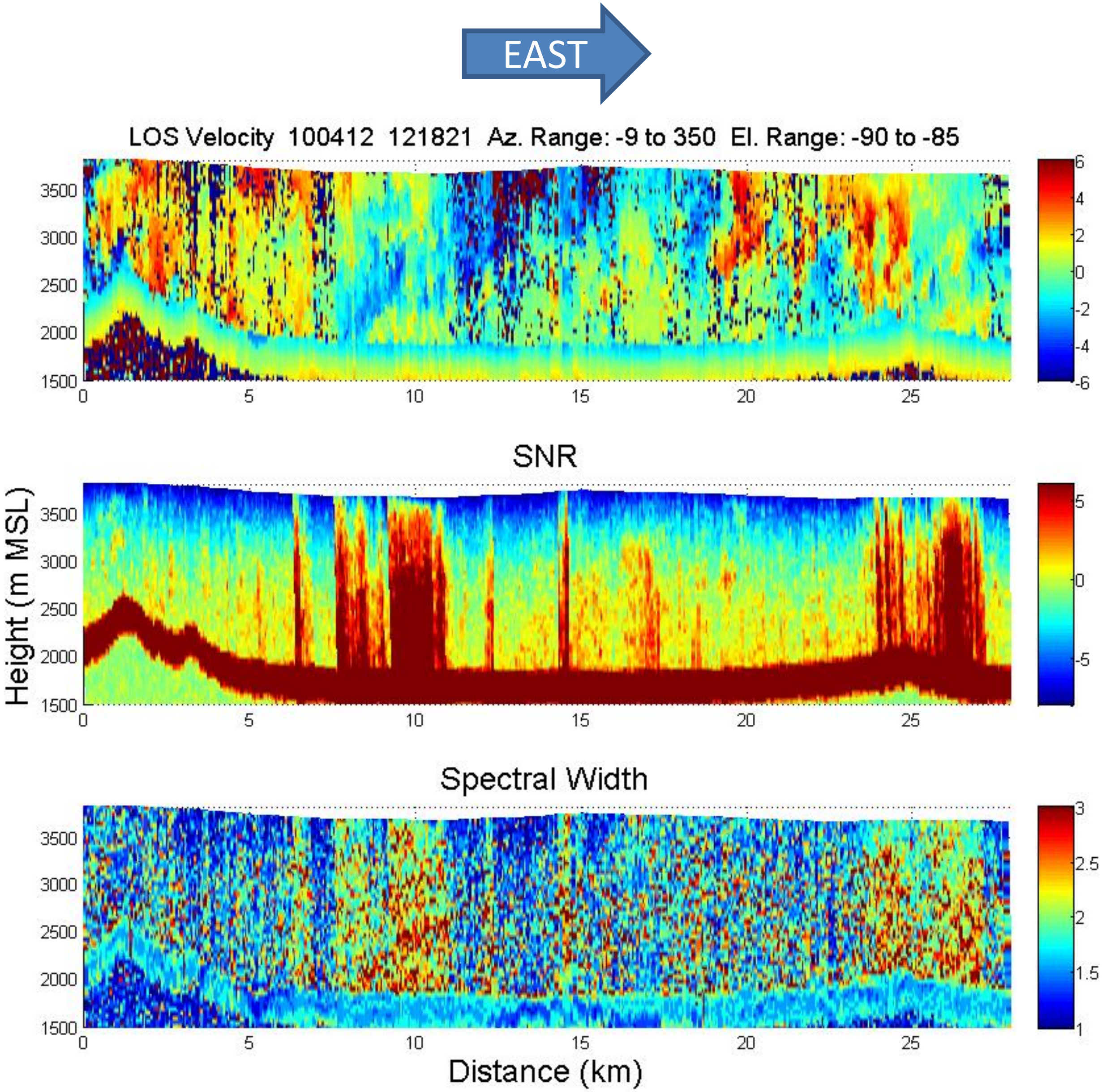
WRF Domain 3 Level 27 Wind Speed and Terrain



WRF Domain 3 Level 27 Wind Speed and Terrain - Zoom



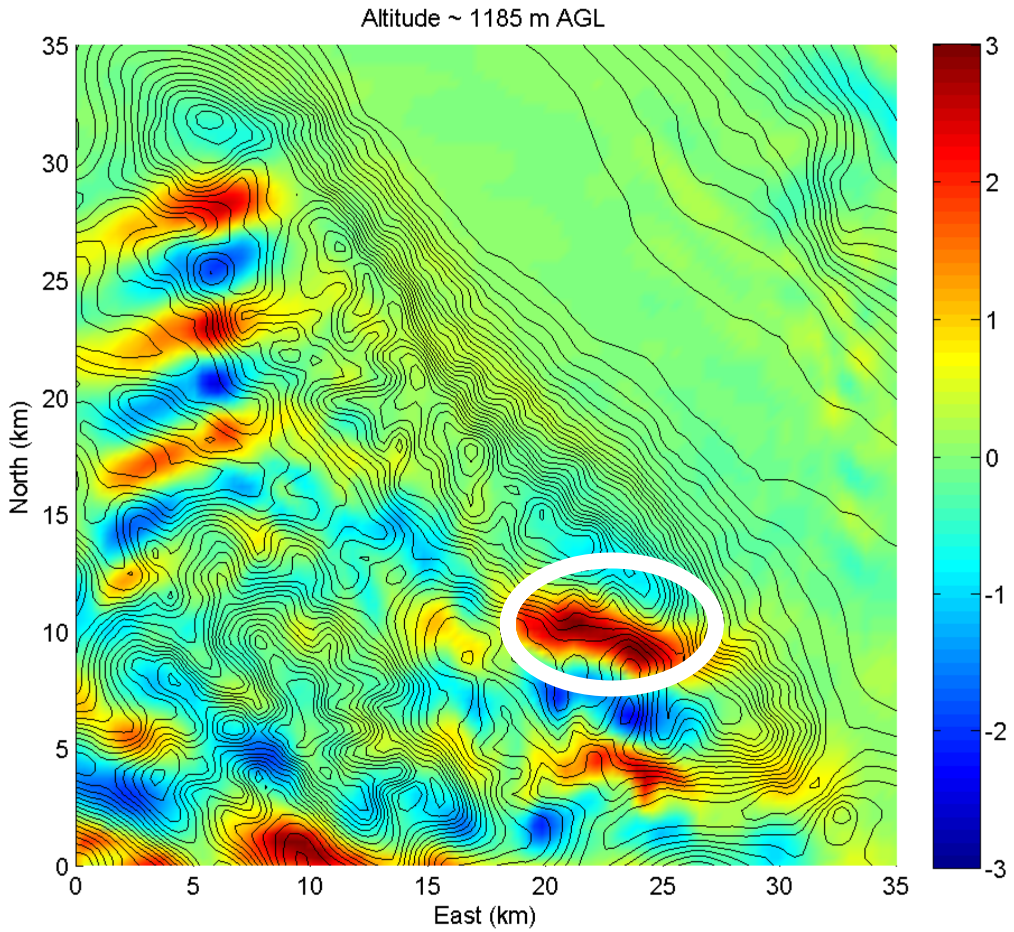

EAST
LOS Velocity 100412 120447 Az. Range: -10 to 350 El. Range: -89 to -82
SNR
Spectral Width
Height (m MSL)
Distance (km)
3500
3000
2500
2000
1500
0
1
2
3
4
5
6
7
8
6
4
2
0
-2
-4
-6
5
0
-5
3
2.5
2
1.5
1



EAST
LOS Velocity 100412 121821 Az. Range: -9 to 350 El. Range: -90 to -85
SNR
Spectral Width
Height (m MSL)
Distance (km)
3500
3000
2500
2000
1500
0
5
10
15
20
25
6
4
2
0
-2
-4
-6
5
0
-5
3
2.5
2
1.5
1

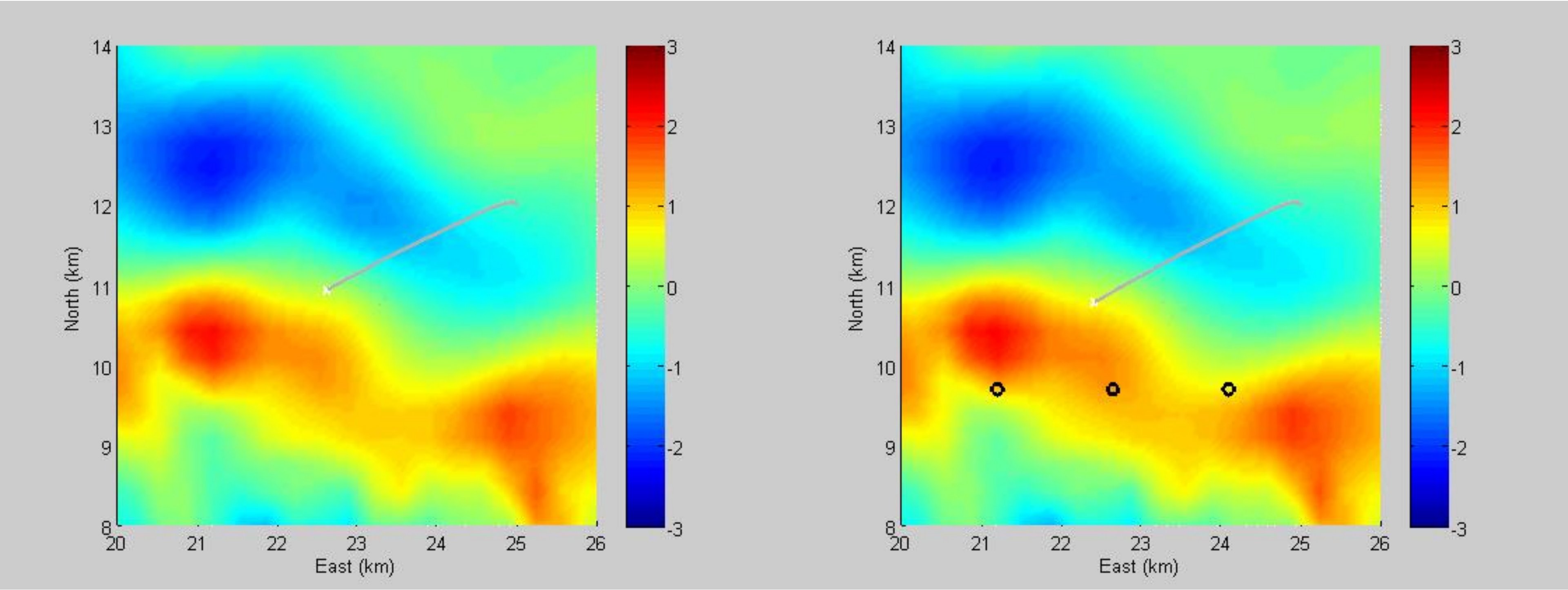
WRF Wind Field

- WRF data from a single instant in simulation time of a 35km x 35km grid using SWA's version of the WRF
- Simulation results presented here focus on the mountain wave circled below



Lift Line Controller

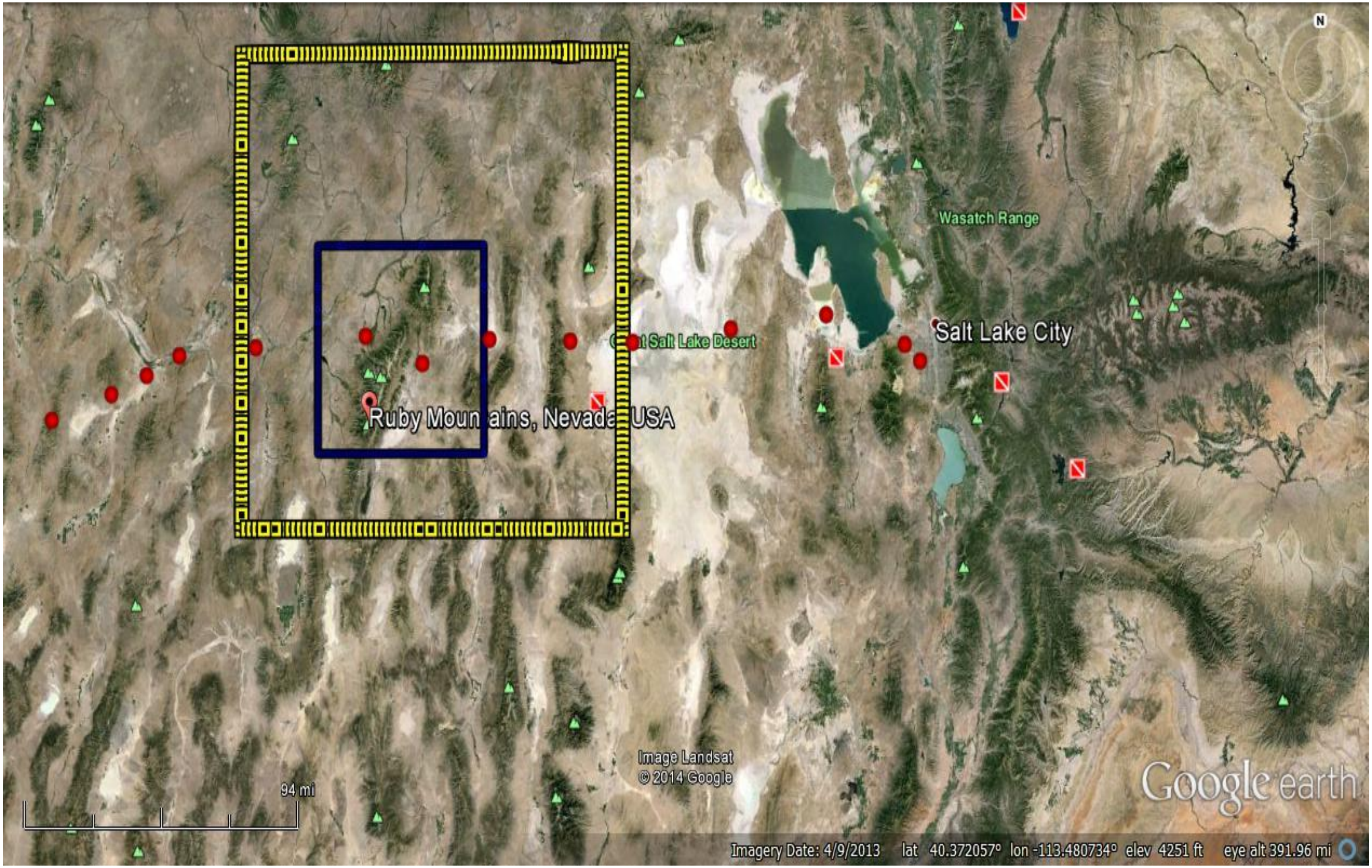
- Comparing Trajectories using Thermal Centering and Lift Line Controller flying Mountain Wave in WRF simulated wind field



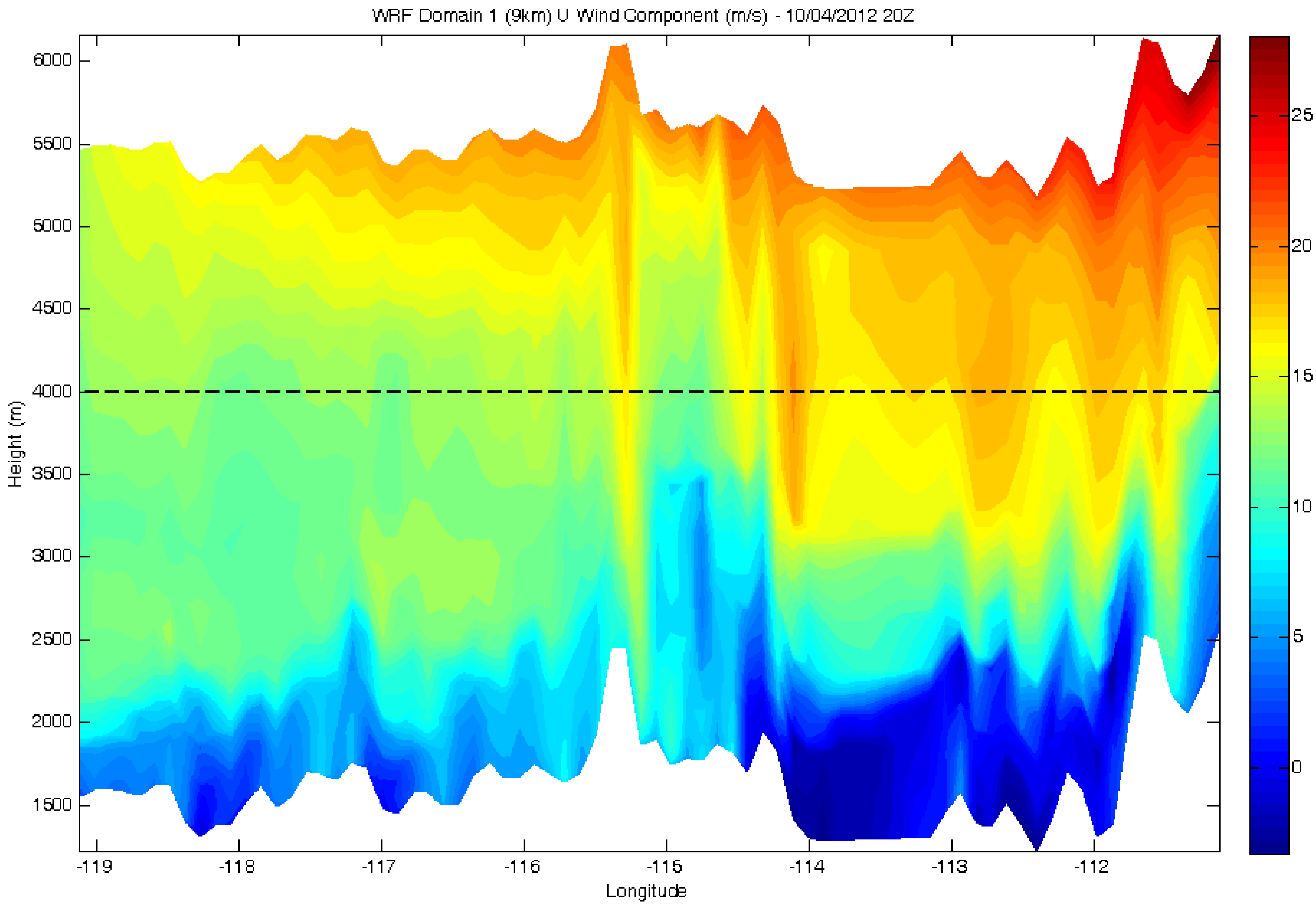
Summary

- The WRF model shows strong Ruby Mountain induced waves with amplitudes of +_ 6m/s and wave lengths on the order of 8 -10 km.
- The TODWL sampling in the nadir mode (vertical speed only) reveals two sets of waves: one with amplitude of +- 5-6 m/s and wavelength of 4 -5 km and a second set of energetic features on the leeward side, closer to the ground with amplitude of +- 6m/s and wavelengths of ~ 1 km.

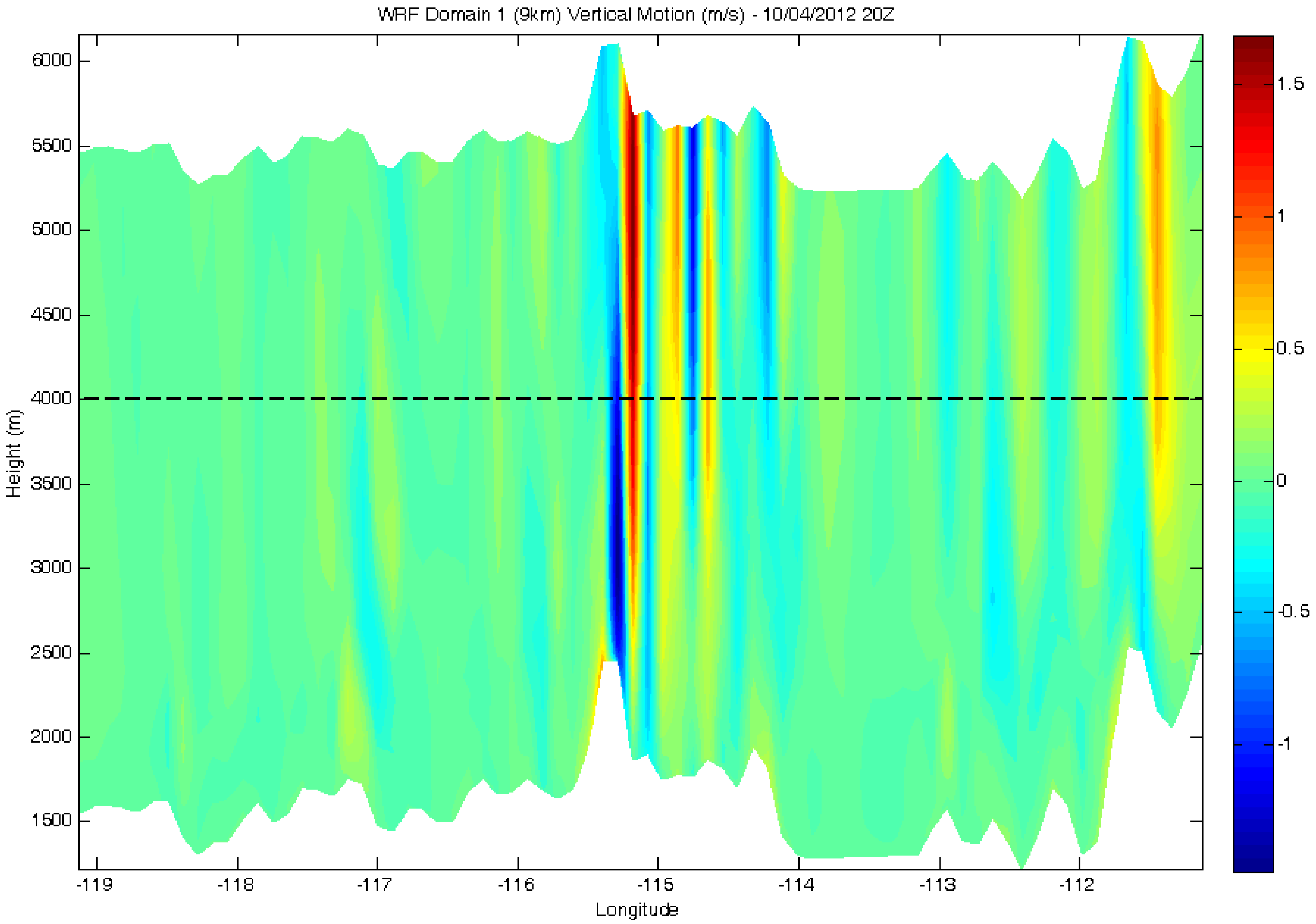
Extra Slides


Wasatch Range
Salt Lake City
Great Salt Lake Desert
Ruby Mountains, Nevada, USA
Image Landsat
© 2014 Google
94 mi
Google earth
N
Imagery Date: 4/9/2013 lat 40.372057° lon -113.480734° elev 4251 ft eye alt 391.96 mi

DOMAIN 1

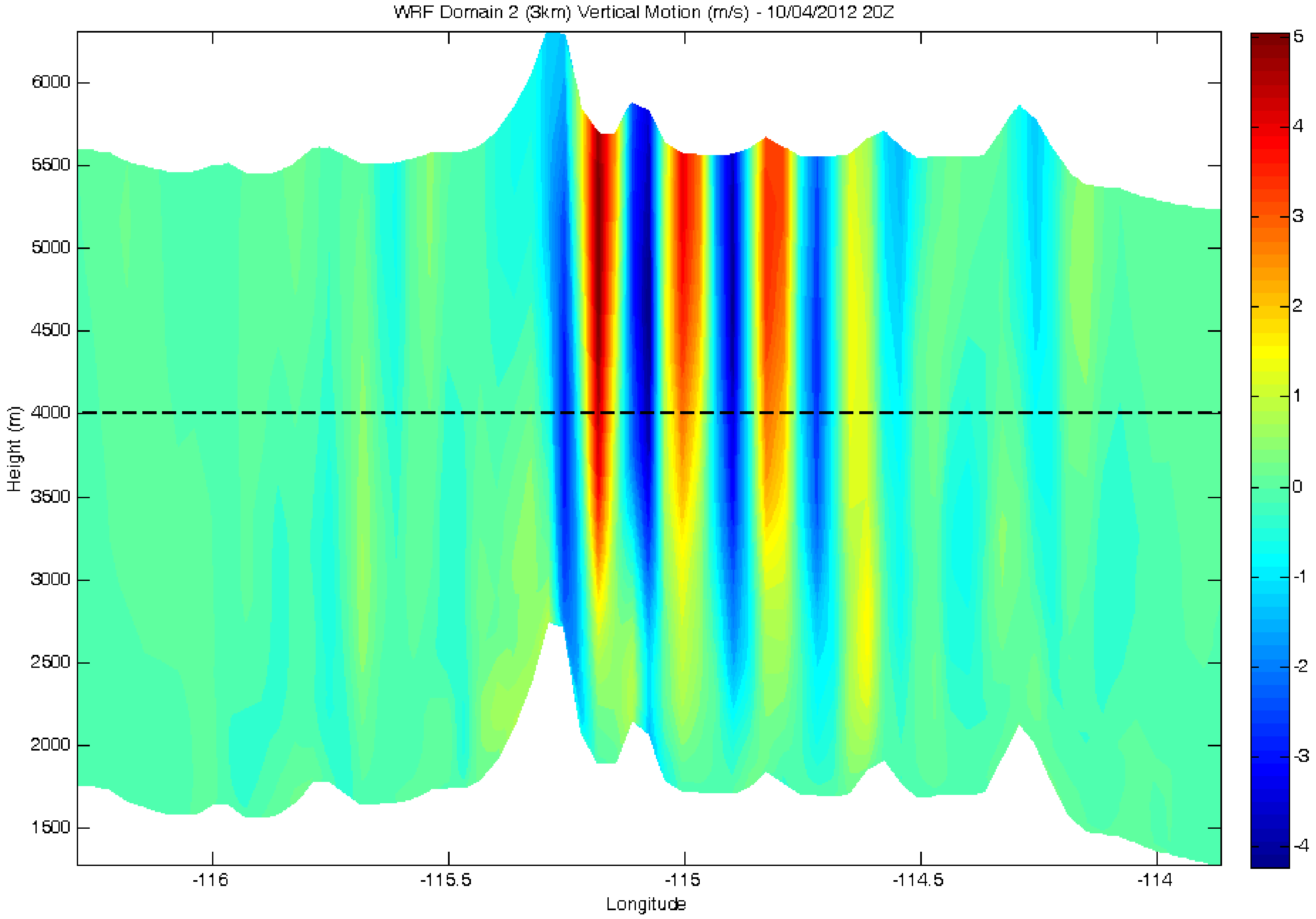


WRF Domain 1 (9km) U Wind Component (m/s) - 10/04/2012 20Z
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
Height (m)
-119
-118
-117
-116
-115
-114
-113
-112
Longitude
25
20
15
10
5
0

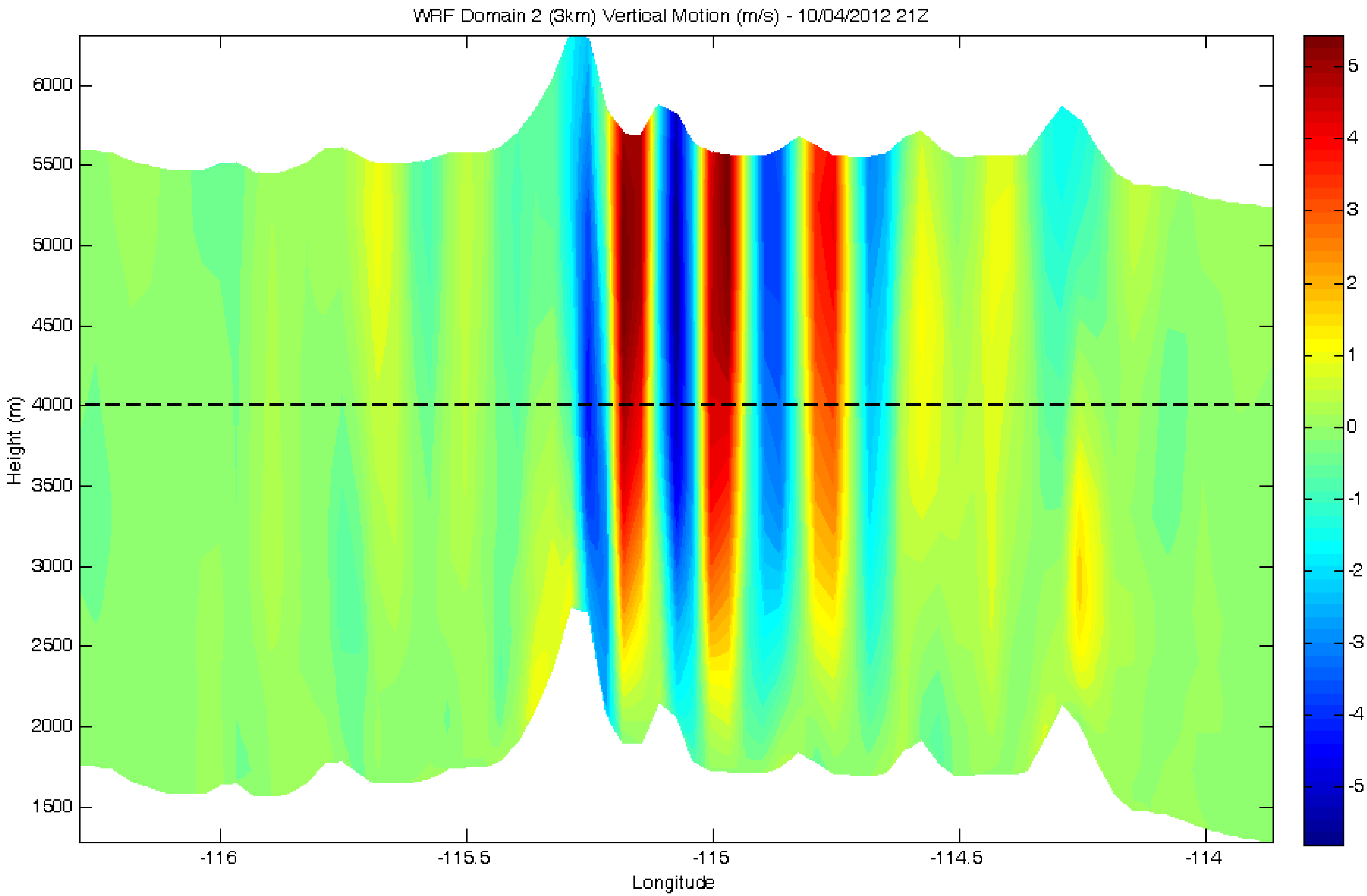


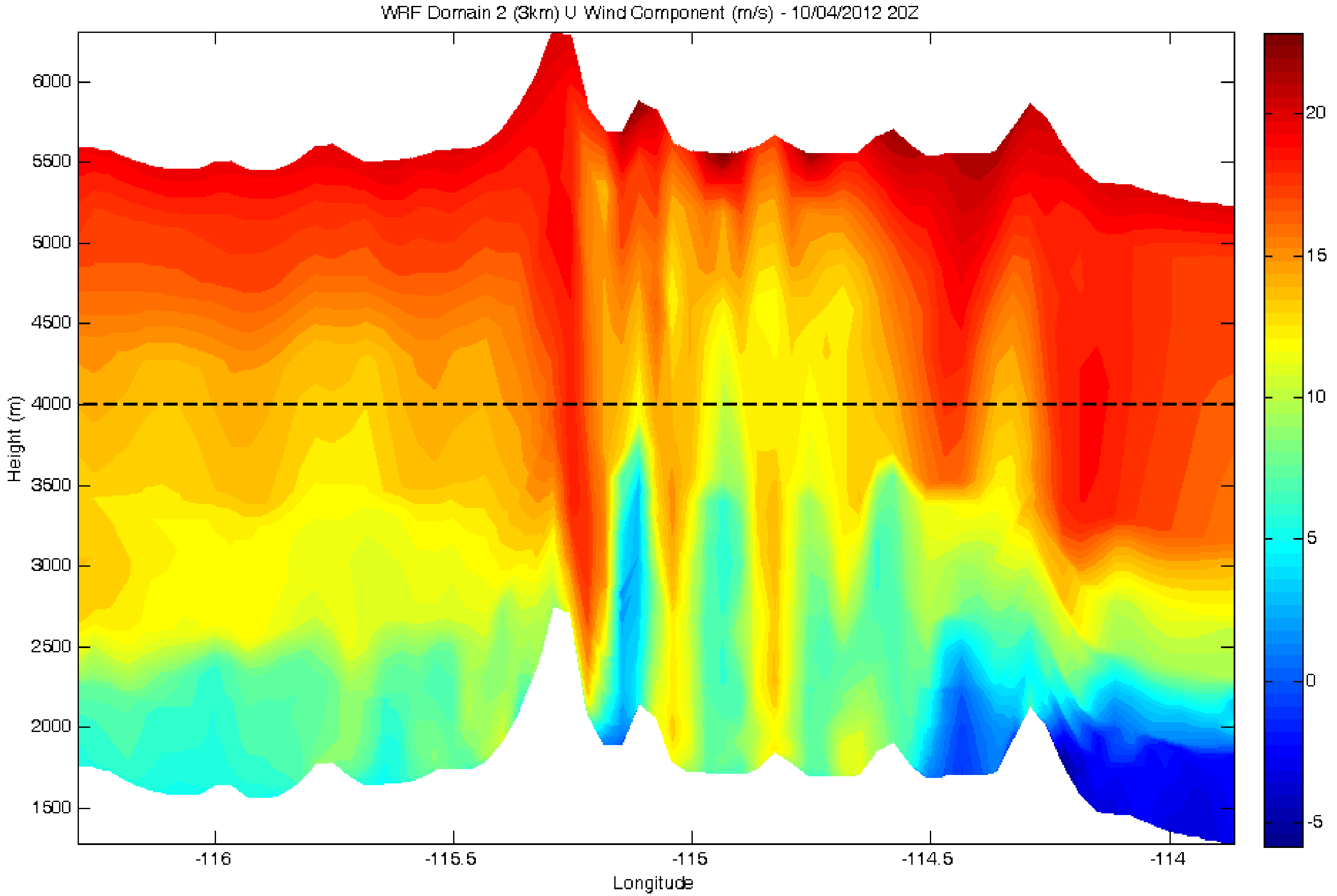
WRF Domain 1 (9km) Vertical Motion (m/s) - 10/04/2012 20Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
-119
-118
-117
-116
-115
-114
-113
-112
Longitude
1.5
1
0.5
0
-0.5
-1

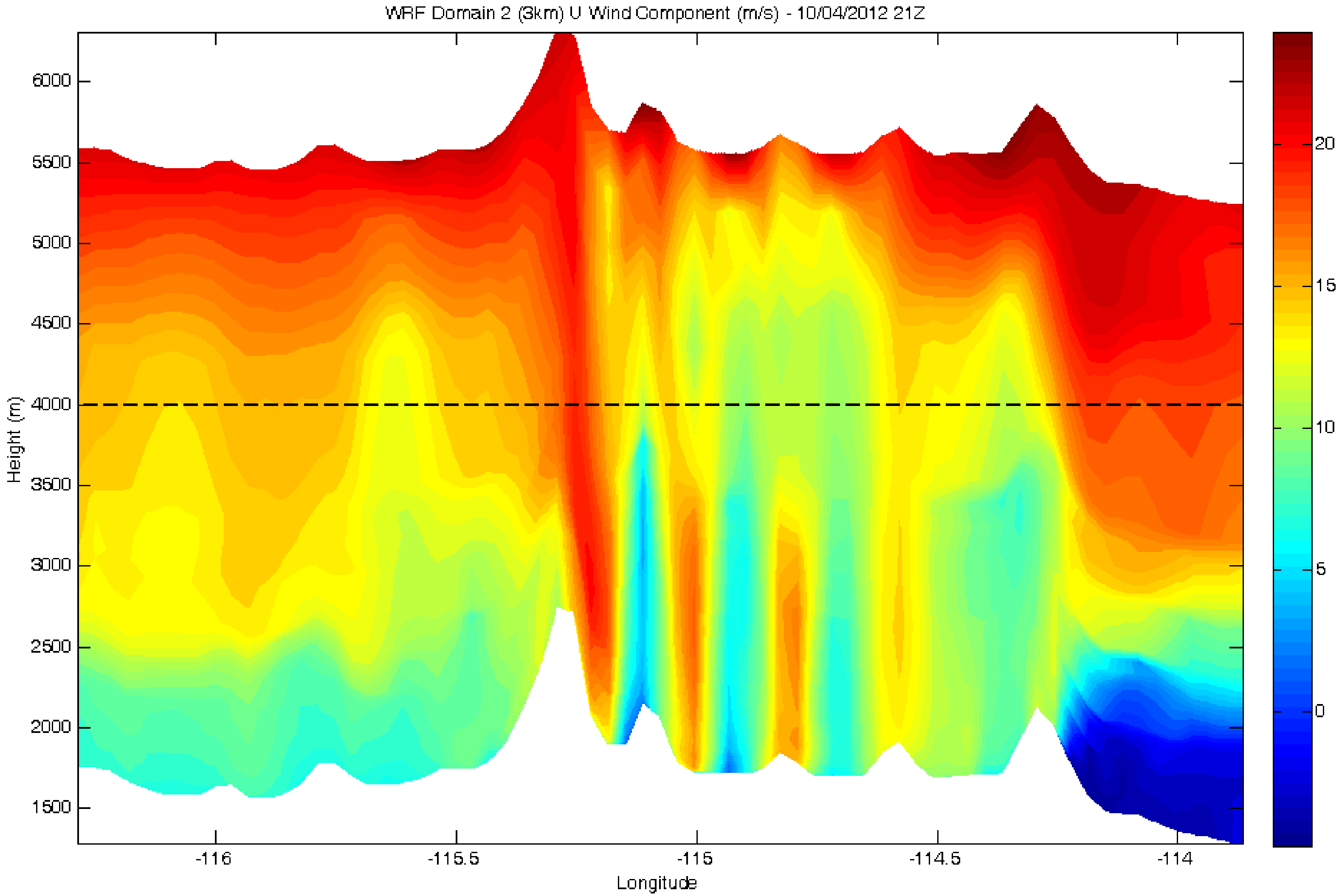
DOMAIN 2



WRF Domain 2 (3km) Vertical Motion (m/s) - 10/04/2012 20Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
-116
-115.5
-115
-114.5
-114
Longitude
5
4
3
2
1
0
-1
-2
-3
-4

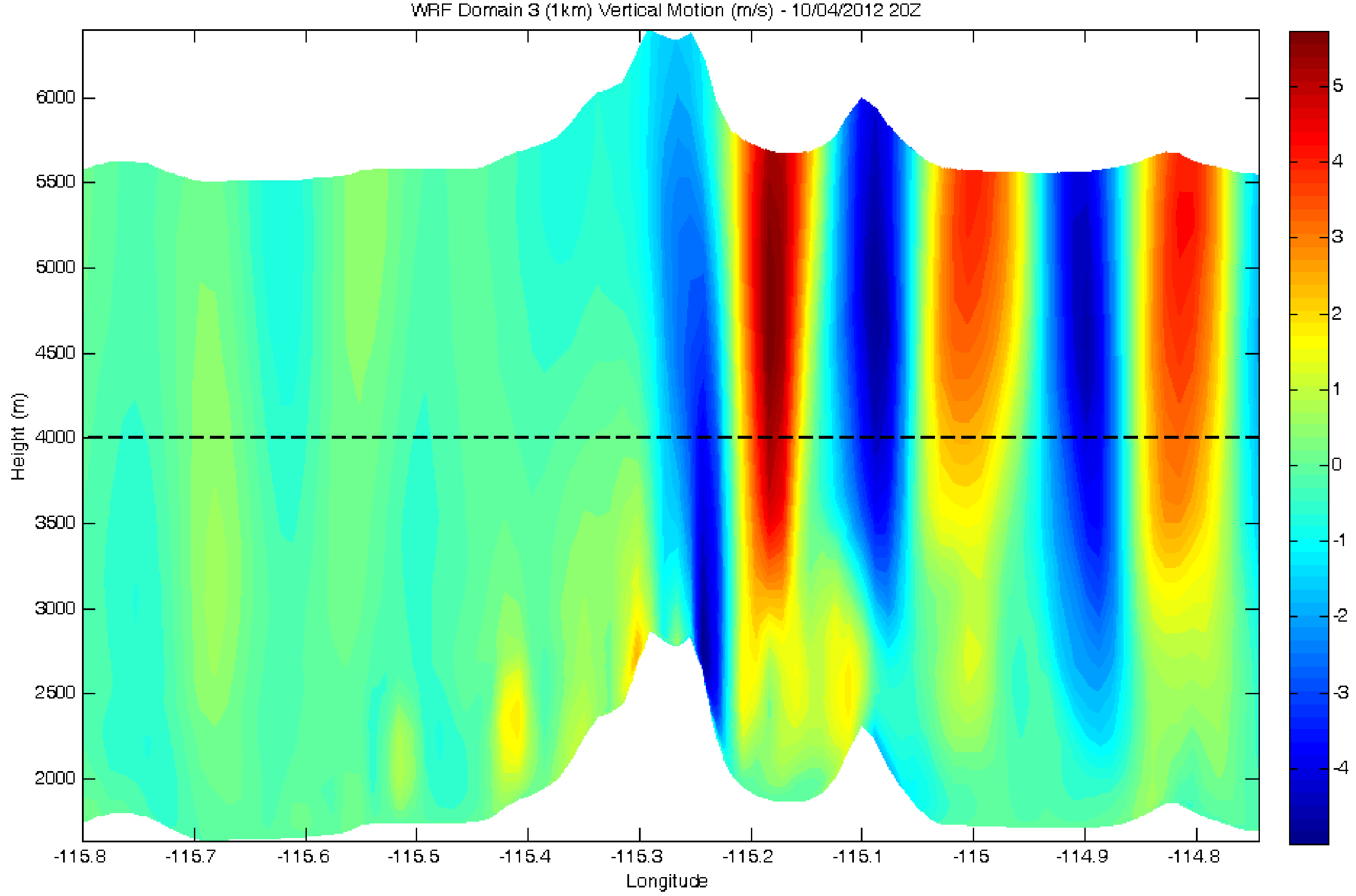

WRF Domain 2 (3km) Vertical Motion (m/s) - 10/04/2012 21Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
-116
-115.5
-115
-114.5
-114
Longitude
5
4
3
2
1
0
-1
-2
-3
-4
-5


WRF Domain 2 (3km) U Wind Component (m/s) - 10/04/2012 20Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
-116
-115.5
-115
-114.5
-114
Longitude
20
15
10
5
0
-5

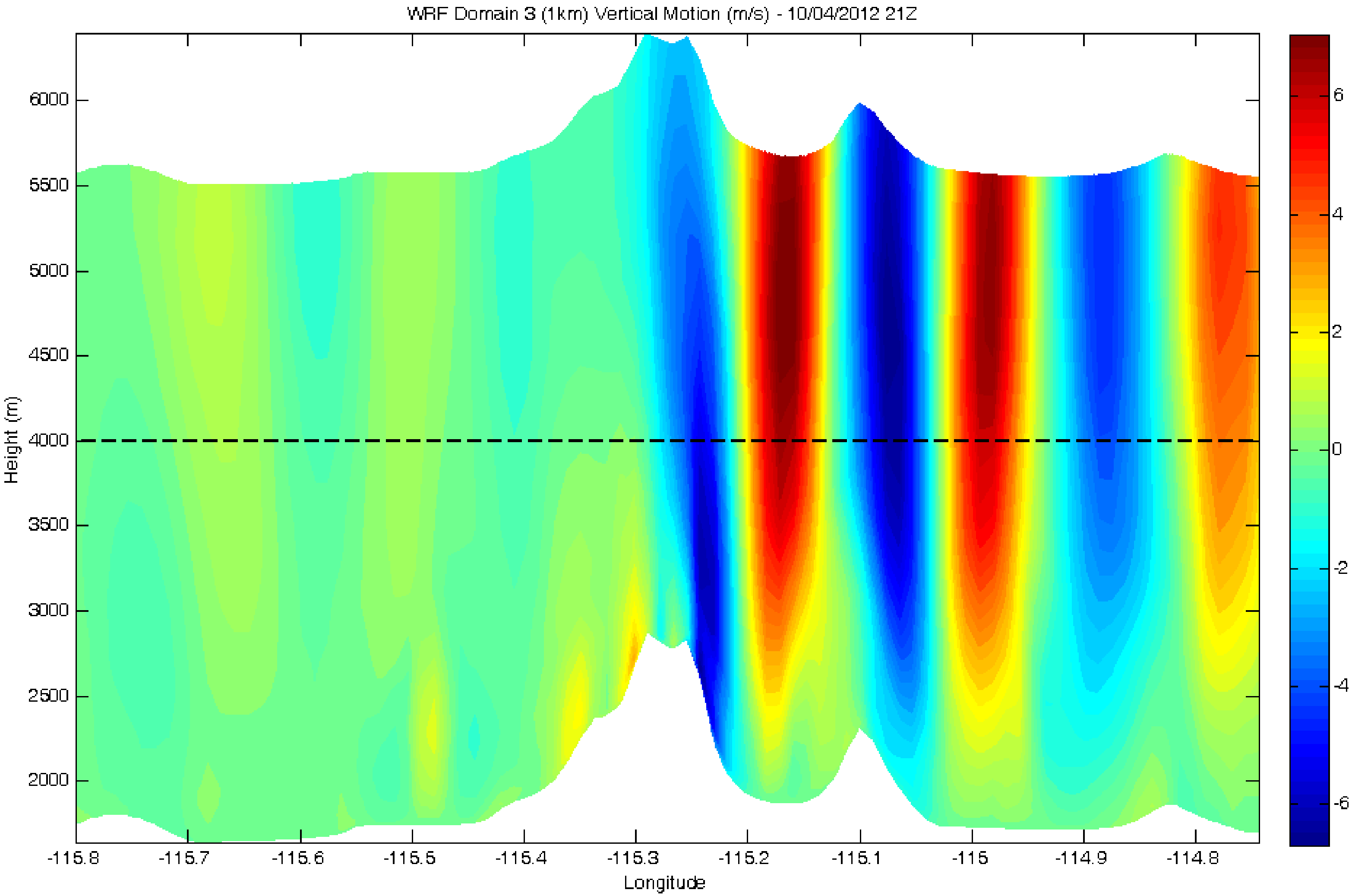


WRF Domain 2 (3km) U Wind Component (m/s) - 10/04/2012 21Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
-116
-115.5
-115
-114.5
-114
Longitude
20
15
10
5
0

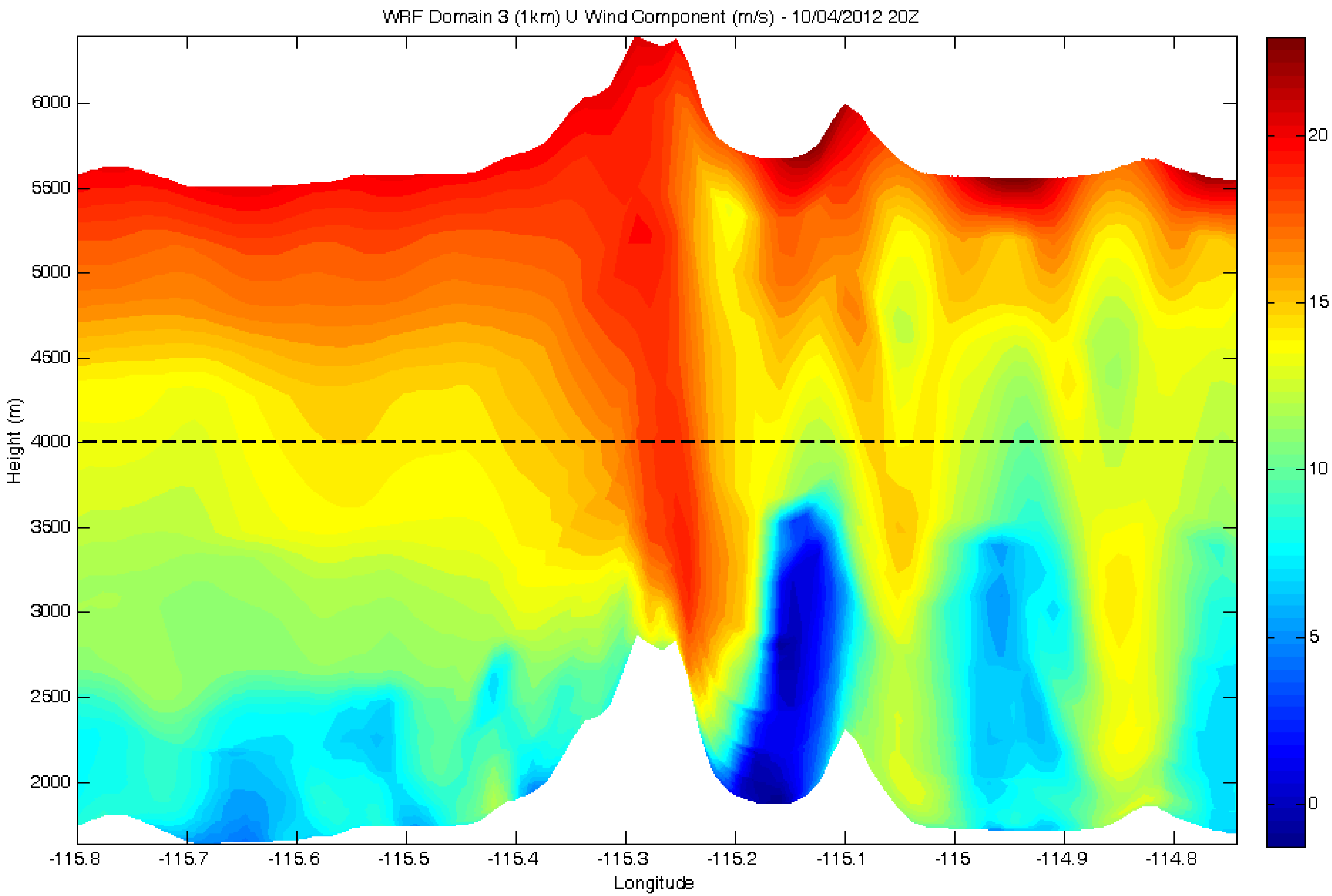
DOMAIN 3

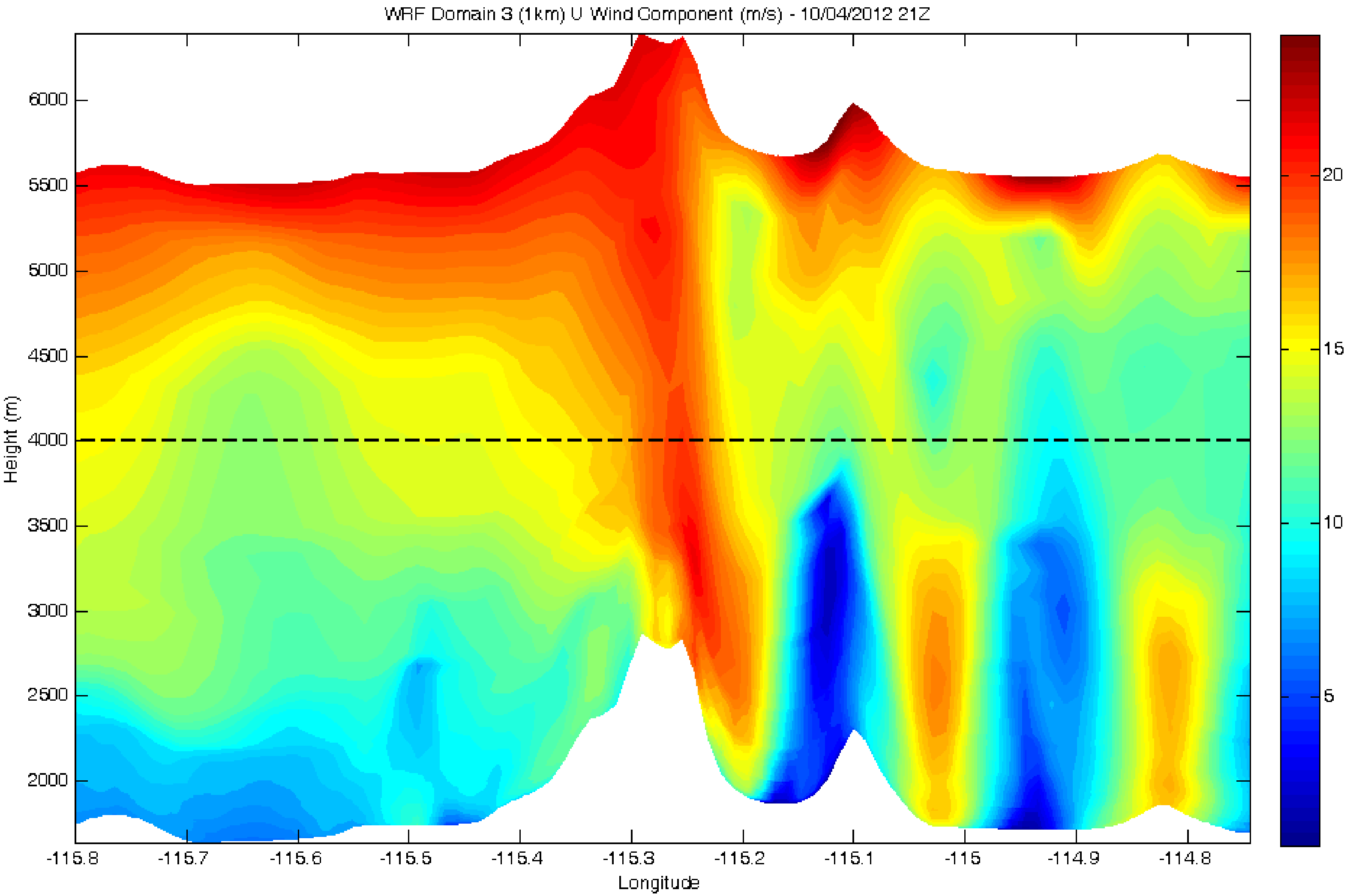


WRF Domain 3 (1km) Vertical Motion (m/s) - 10/04/2012 20Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
-115.8
-115.7
-115.6
-115.5
-115.4
-115.3
-115.2
-115.1
-115
-114.9
-114.8
Longitude
5
4
3
2
1
0
-1
-2
-3
-4



WRF Domain 3 (1km) Vertical Motion (m/s) - 10/04/2012 21Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
-115.8
-115.7
-115.6
-115.5
-115.4
-115.3
-115.2
-115.1
-115
-114.9
-114.8
Longitude
6
4
2
0
-2
-4
-6


WRF Domain 3 (1km) U Wind Component (m/s) - 10/04/2012 20Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
-115.8
-115.7
-115.6
-115.5
-115.4
-115.3
-115.2
-115.1
-115
-114.9
-114.8
Longitude
20
15
10
5
0


WRF Domain 3 (1km) U Wind Component (m/s) - 10/04/2012 21Z
Height (m)
6000
5500
5000
4500
4000
3500
3000
2500
2000
-115.8
-115.7
-115.6
-115.5
-115.4
-115.3
-115.2
-115.1
-115
-114.9
-114.8
Longitude
20
15
10
5