Multiscale Modeling and High Performance Computing of Mountain Waves using WRF Version 3.2 with Vertical Nesting and Beyond

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Multiscale Dynamics in the Upper Troposphere and Lower Stratosphere (UTLS)

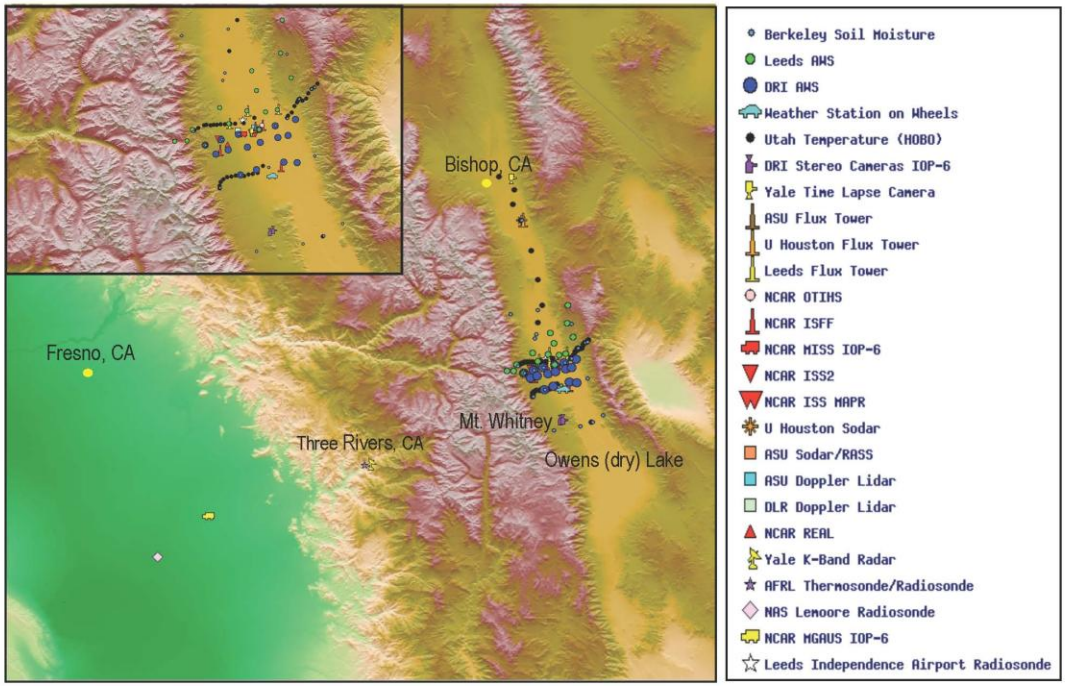
Numerical Setup

- The WRF simulations were performed with three nested domains using two-way horizontal nesting. The three WRF domains have the horizontal resolutions of 27 km, 9 km and 3 km. The number of vertical sigma pressure levels used in all these nests is 61.

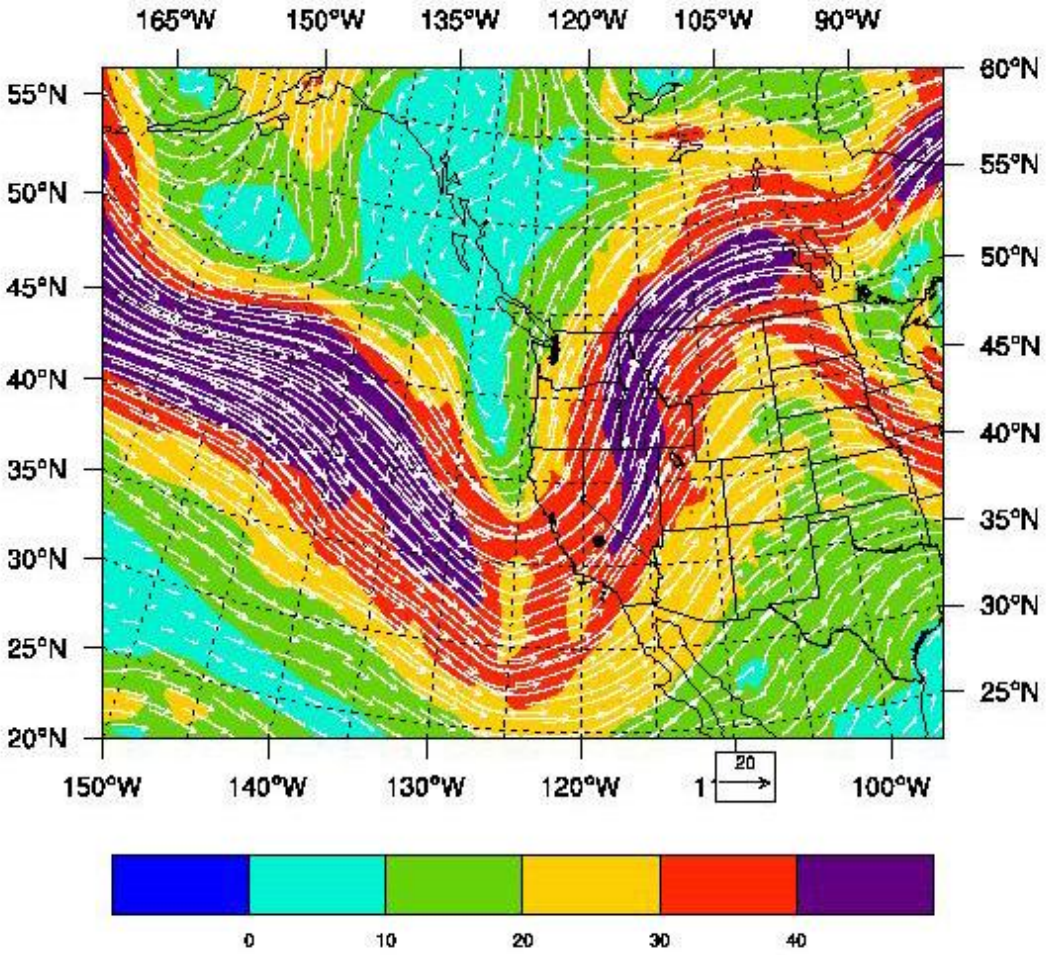
- Another one-way nested WRF simulation is conducted using a horizontal resolution of 1 km and a vertical refinement factor of 3, which gives 181 vertical levels.

- The simulations were conducted for the period from 00 UTC March 31, 2006 to 0000 UTC April 2, 2006, and the period from 1200 UTC March 24, 2006 to 12 UTC March 26, 2006 which fall within IOP 8 and IOP 6 of the T-REX campaign, Owens Valley CA.

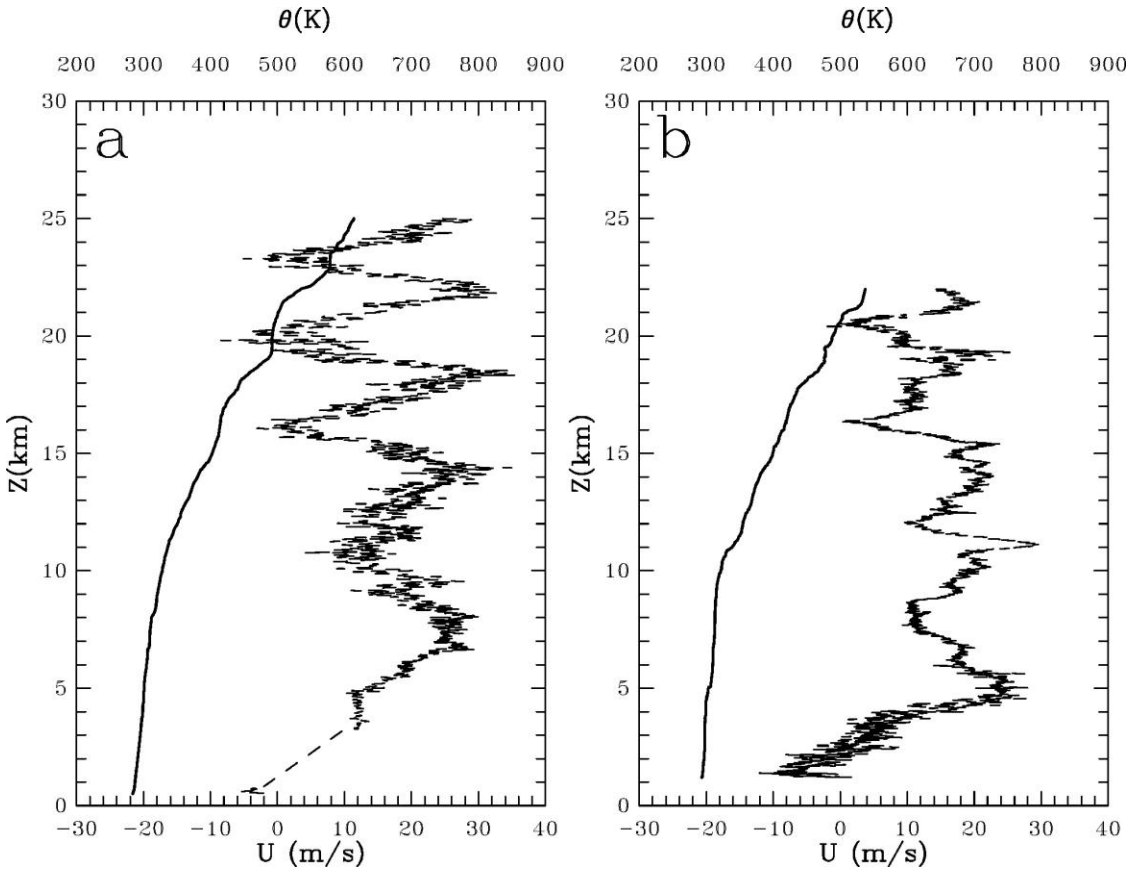
- The WRF simulations were initialized by the high-resolution data provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) global spectral model T799L91.



T-REX field campaign area and ground-based instrumentation layout

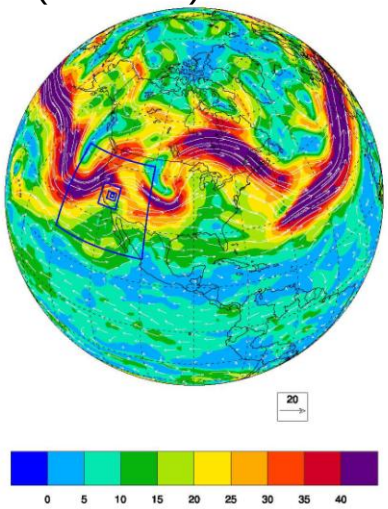


Distributions of vector wind speed fields from ECMWF on 320 K isentrope on April 1, 2006. The dot indicates the location of balloon launching site.

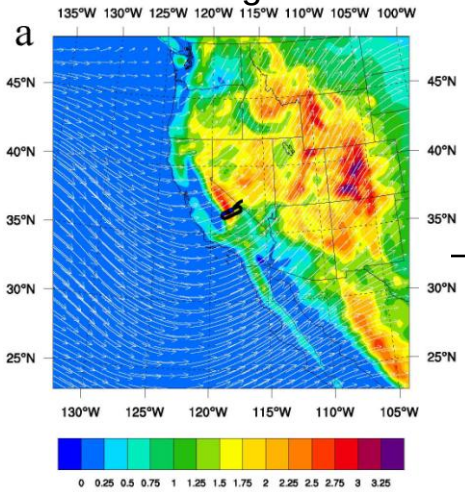


Vertical profiles of potential temperature (solid) and eastward wind (dashed) from GPS radiosondes launched from (a) Three Rivers (36.49 N, 118.84 W) at 10 UTC and (b) Owens Valley (36.78 N, 118.17 W) at 08:00 UTC on April 1, 2006.

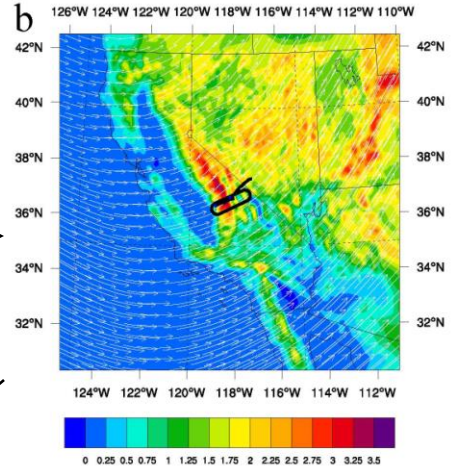
Global model (ECMWF)



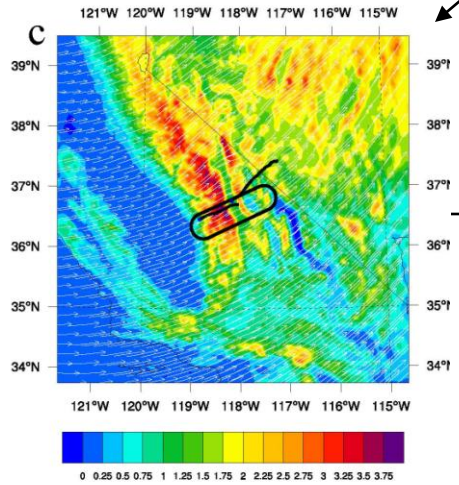
Domain 1: Nested to the global model



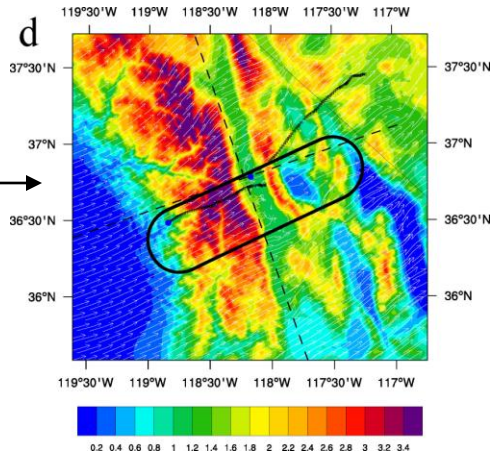
Domain 2: Nested to domain 1



Domain 3: Nested to domain 2



Domain 4: Nested to domain 3



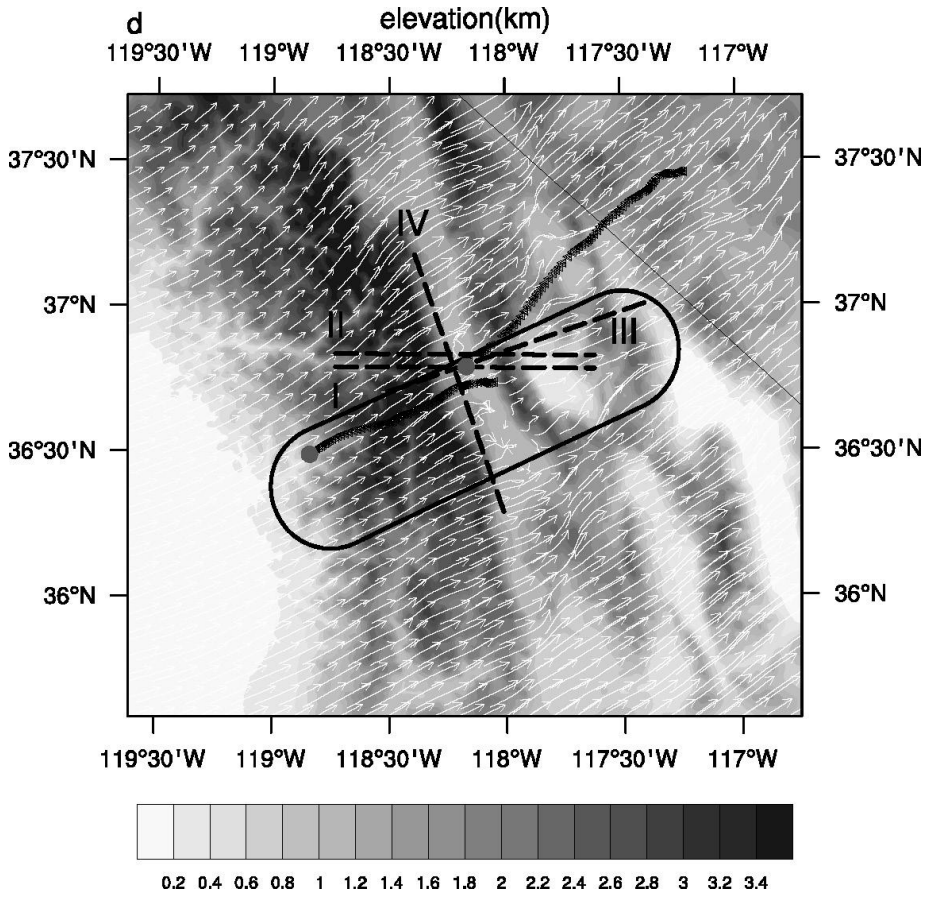
❖WRF is initialized with analysis from ECMWF.

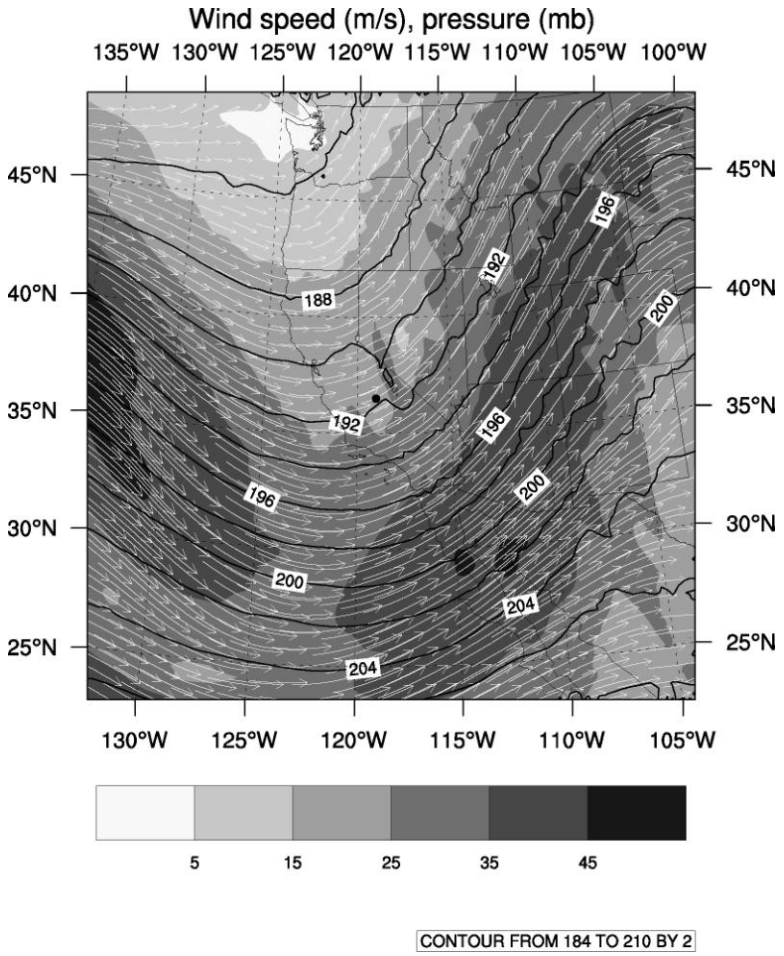
❖WRF uses 4 nested domains with horizontal gridding of 27km, 9km, 3km (61 vertical levels) and 1km (181 vertical levels).

❖NCAR HIAPER Research aircraft and balloon trajectories.

❖Topography and geographical locations of the domains used for finest WRF domain. The wind vector fields simulated on April 1, 2006 at 8 UTC near the tropopause (z =12km) are superimposed in these figures. The solid curves indicate the paths of the two balloons.

❖The balloons are launched from Three Rivers (36.49 N, 118.84 W) and Owens Valley (36.78 N, 118.17 W). The curve shaped like an ellipse is the trajectory of the NCAR HIAPER research aircraft. The dashed lines I, II, III, IV indicate the locations where various vertical cross-sections are taken.

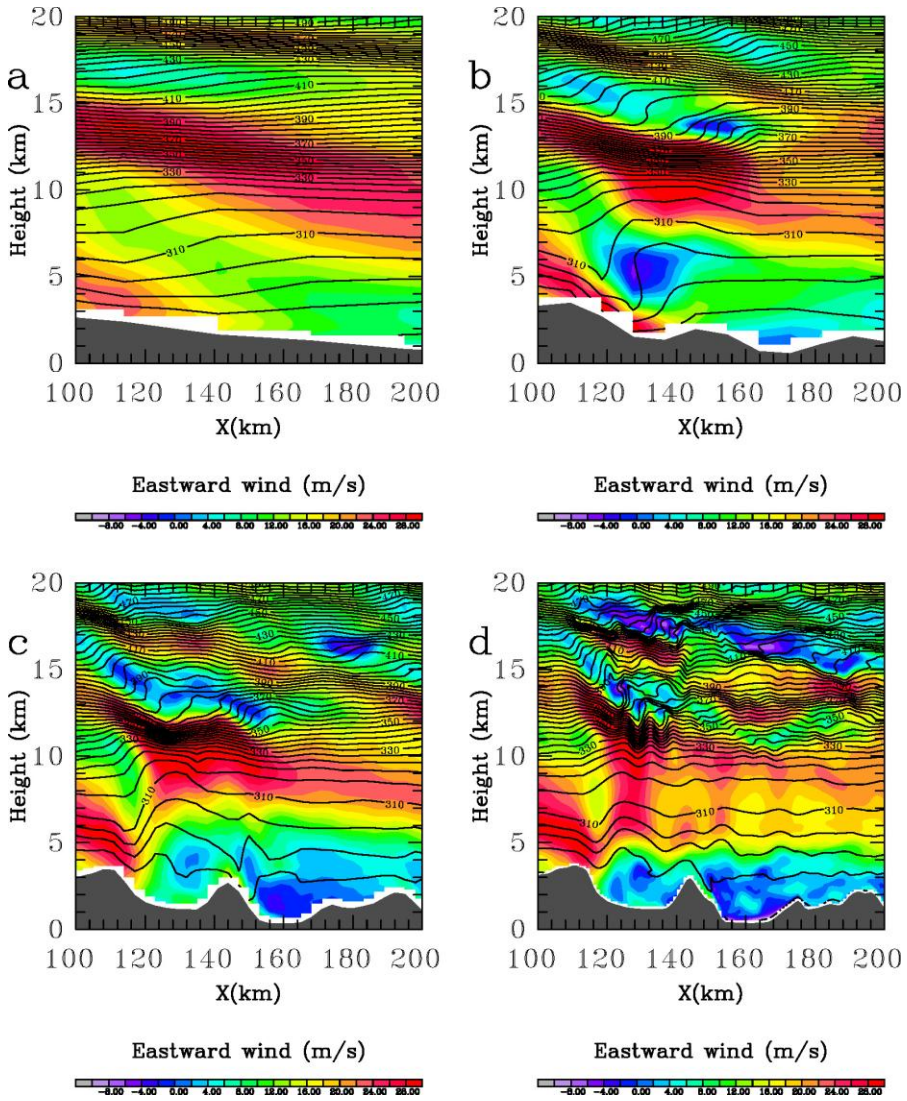




Wind speed (shaded, m/s) and pressure (contours, mb) fields at z = 12 km obtained from WRF simulations using the largest domain (27 km) on April 1 at 8 UTC.

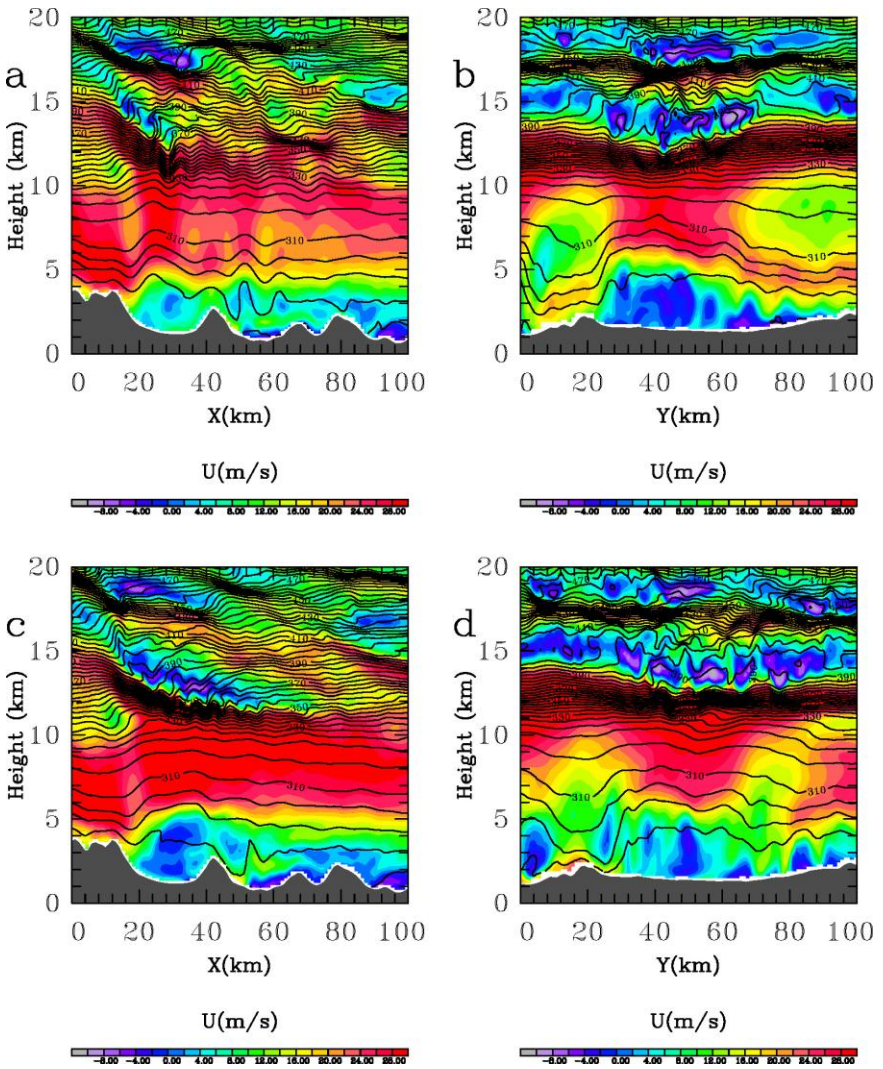
❖Vertical cross-sections of potential temperature (contour, K) and eastward wind (color, m/s) from the four WRF domains.

❖The time is 0800 UTC April 1, 2006. The cross-sections are taken along the horizontal dashed line (I) superimposed in the finest WRF domain. The horizontal axis indicates the distance with respect to the location (36.79 N, 118.73 W).



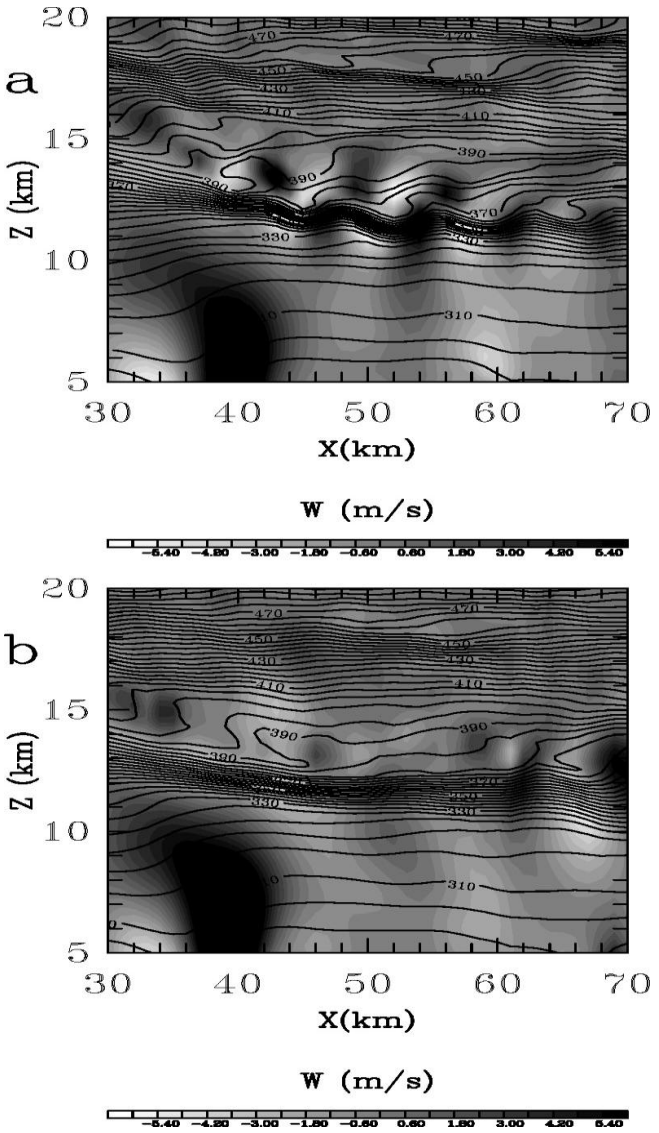
❖Vertical cross-sections of horizontal wind component transverse to the valley (color, m/s) and potential temperature (K) from the finest WRF domain on April 1, 2006 at 8 UTC: (a) across and (b) along the valley. (c) and (d) are the same as (a) and (b) respectively but at 6 UTC.

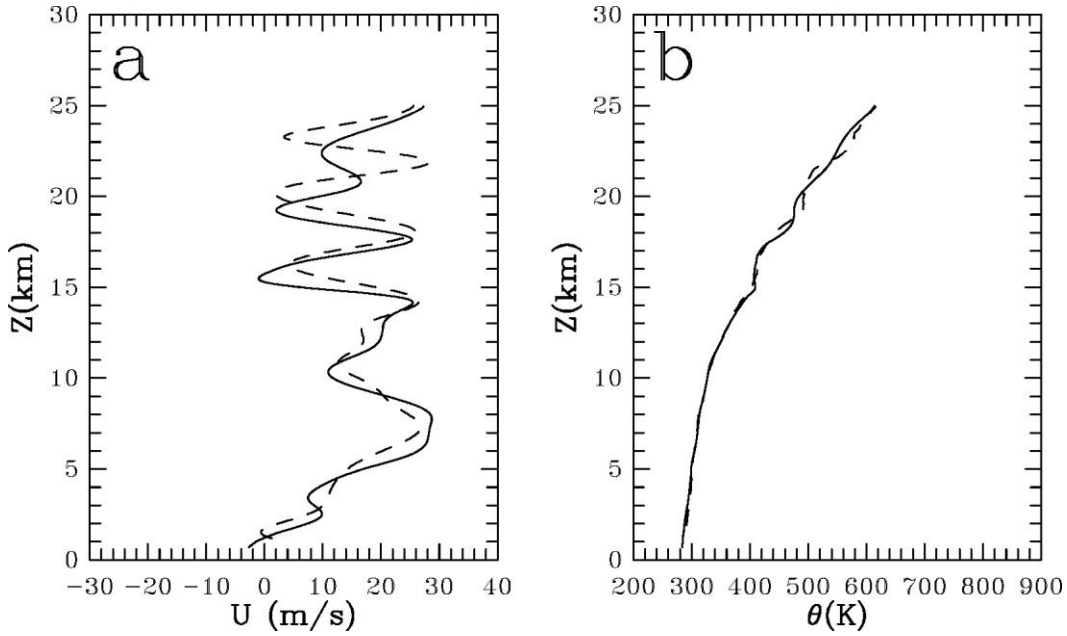
❖The locations of the cross-sections across and along the valley are indicated in the finest WRF domain by the dashed lines III and IV. The horizontal axes X and Y indicate the distance with respect to the location (36.70 N, 118.50 W) and (36.29 N, 118.01 W) respectively.



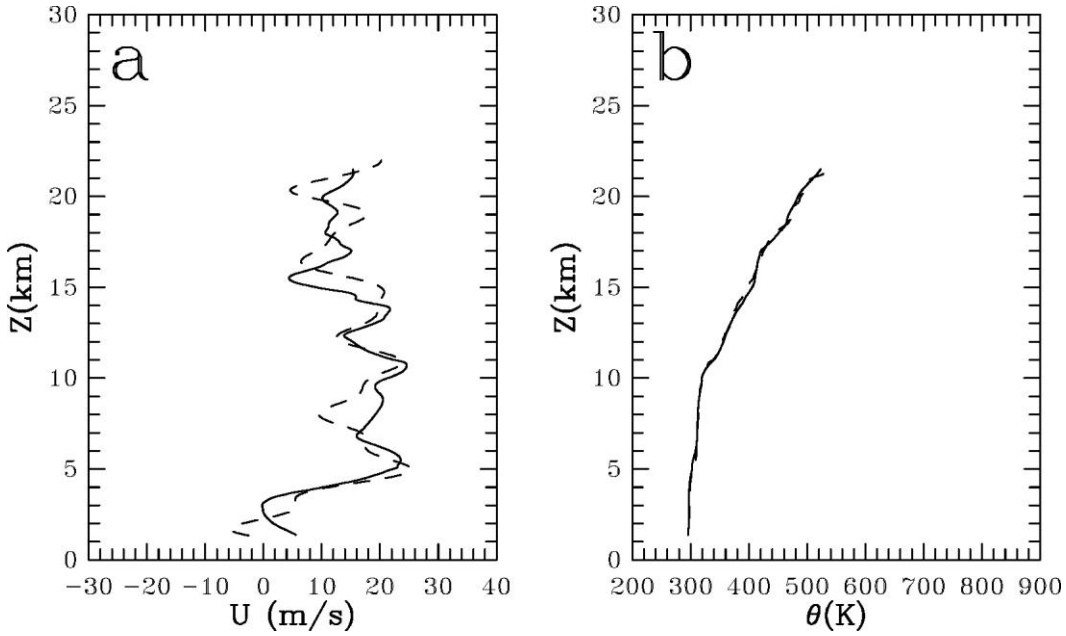
❖Vertical cross-sections for potential temperature and vertical velocity zoomed in the UTLS from the finest WRF simulations with (a) and without (b) vertical refinement.

❖The horizontal resolution is 1 km in both cases. The time is April 1, at 06 UTC. The cross-sections are taken along a portion of the dashed line II superimposed in the finest WRF domain. The horizontal axis indicate the distance with respect to the location (36.83 N, 118.73 W).



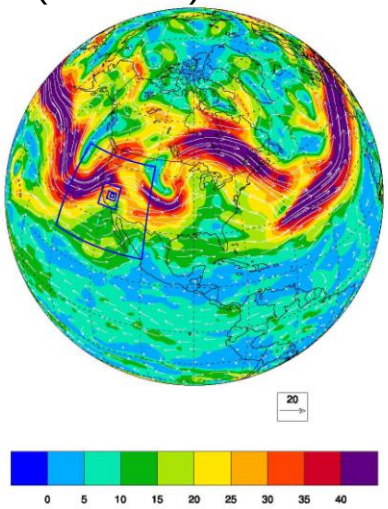


❖Vertical profiles of eastward wind (a) and potential temperature (b) from observations (dashed) and simulations (solid). The observations are from a radiosonde launched from Three Rivers (36.49 N, 118.84 W) at 10 UTC after smoothing out the noise in the wind profile. The simulated profiles are obtained by interpolating in time and space the fields to the slanted path of the balloon.

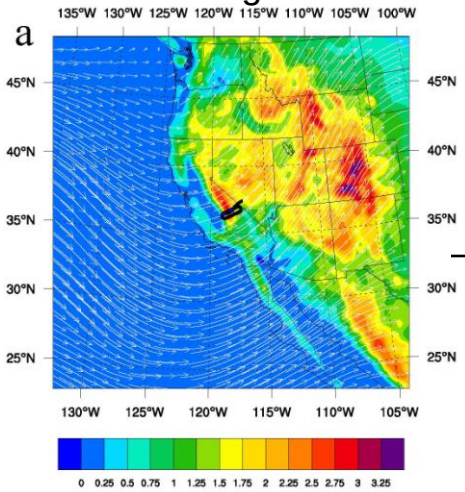


❖Vertical profiles of eastward wind (a) and potential temperature (b) from observations (dashed) and WRF simulations (solid). The observations are from a radiosonde launched from Owens Valley (36.78 N, 118.17 W) at 8 UTC after smoothing out the noise in the wind profile. The simulated profiles are obtained by interpolating in time and space the WRF fields to the slanted path of the balloon.

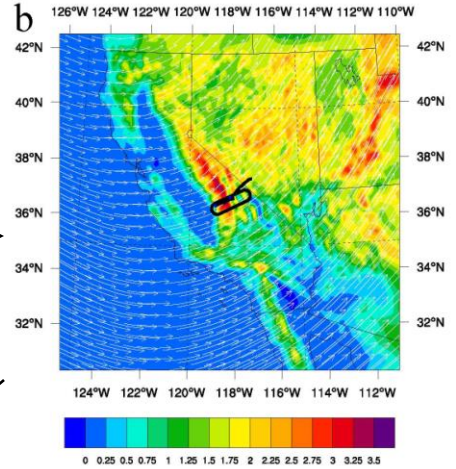
Global model (ECMWF)



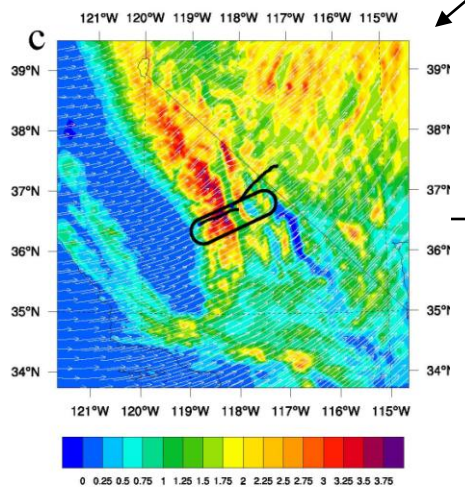
Domain 1: Nested to the global model



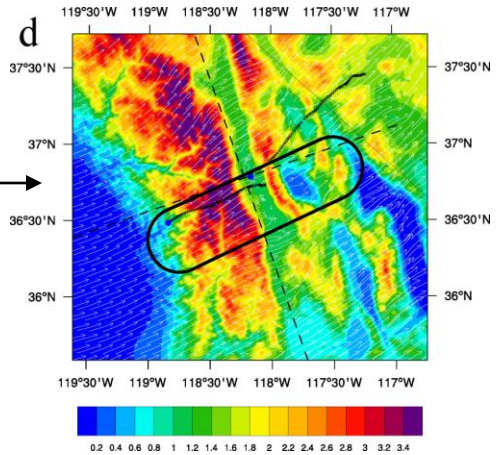
Domain 2: Nested to domain 1



Domain 3: Nested to domain 2



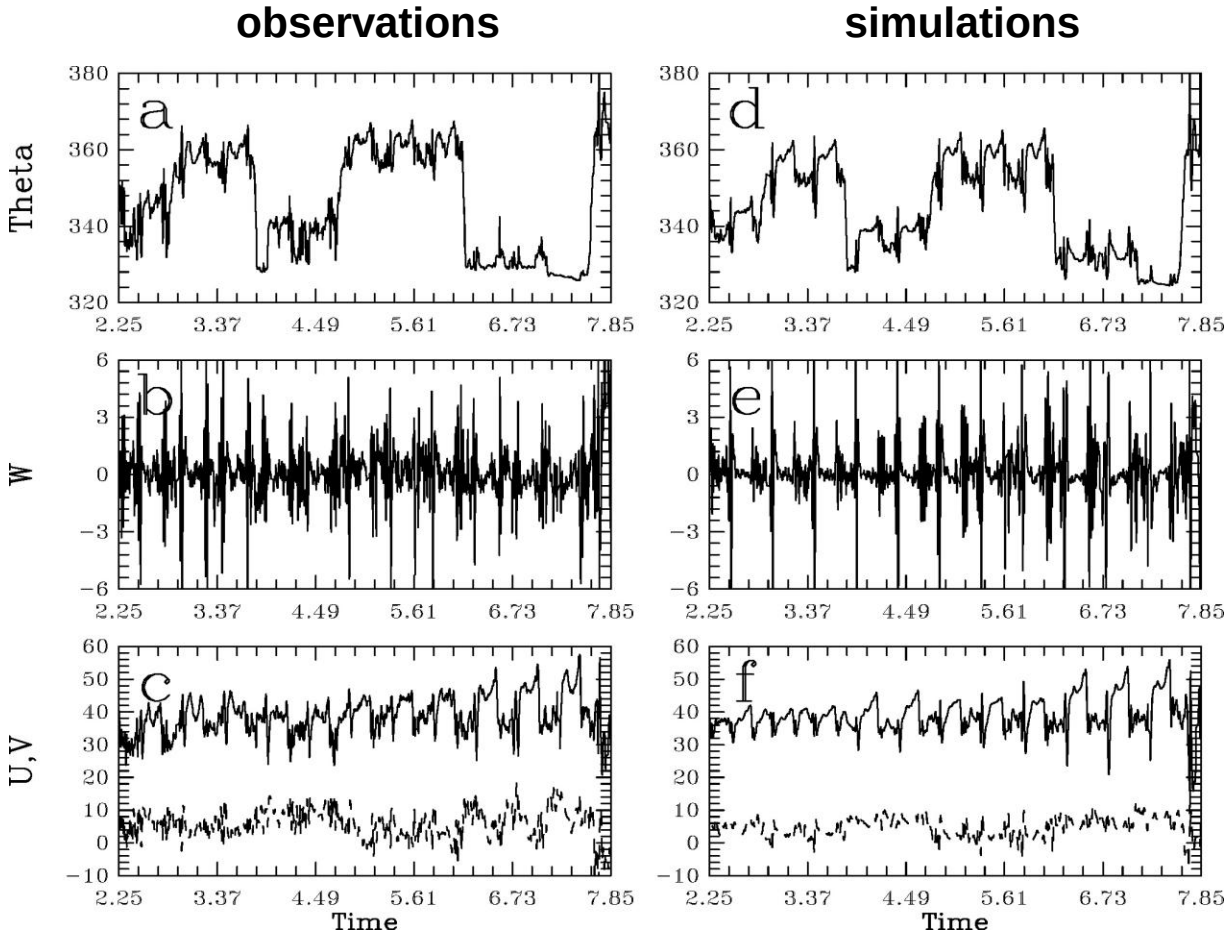
Domain 4: Nested to domain 3



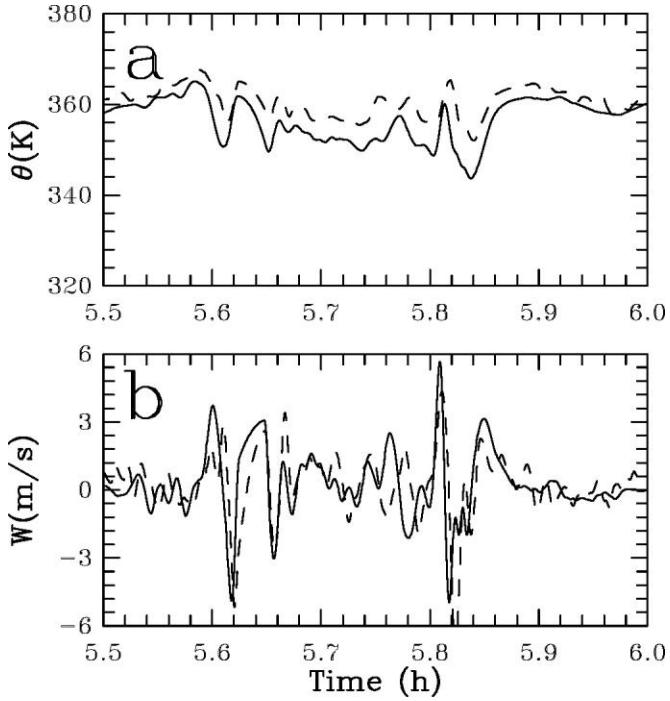
❖WRF is initialized with analysis from ECMWF.

❖WRF uses 4 nested domains with horizontal gridding of 27km, 9km, 3km (61 vertical levels) and 1km (181 vertical levels).

❖NCAR HIAPER Research Aircraft.



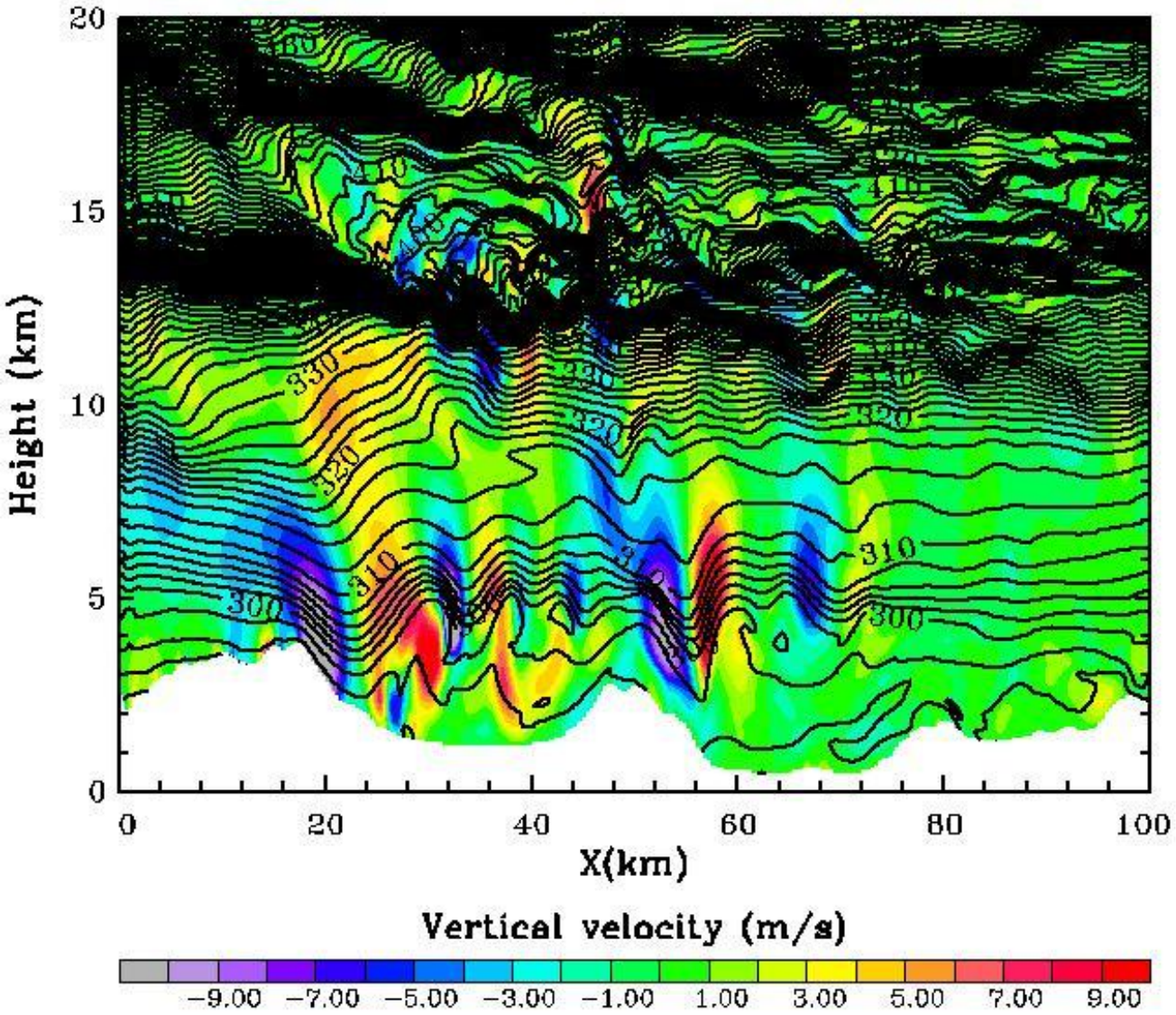
Profiles of (a) potential temperature, (b) vertical velocity , and (c) eastward (solid) and northward (dashed) winds (c) from aircraft measurements. (d)-(f) are the same as (a)- (b) but from WRF simulations.



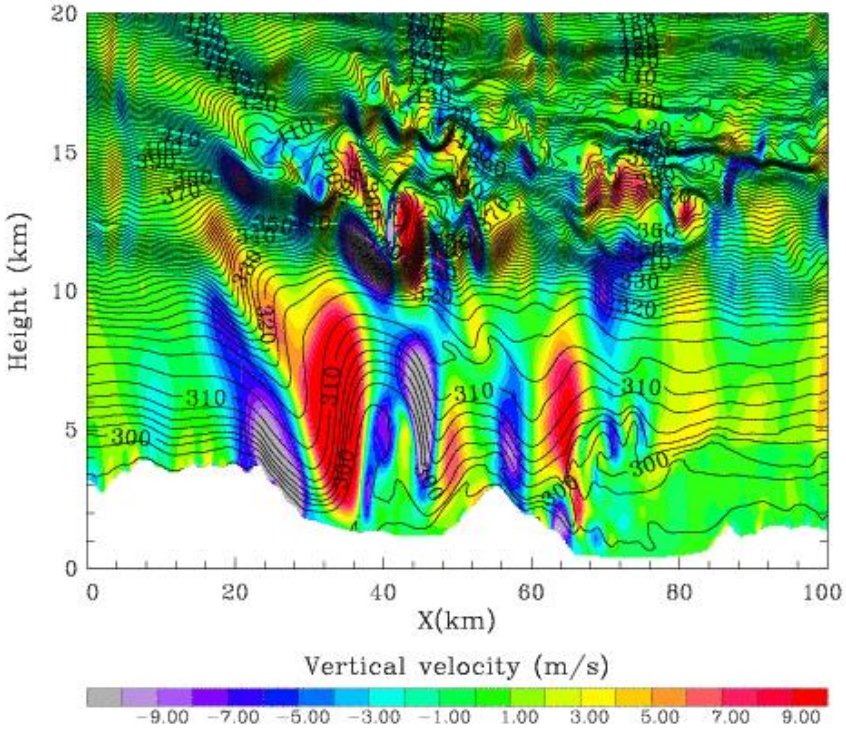
Zooms for (a) potential temperature and (b) vertical velocity as a function of time from aircraft HIAPER observations (dashed) and from interpolated WRF simulations (solid). The time is relative to March 25, 15 UTC.

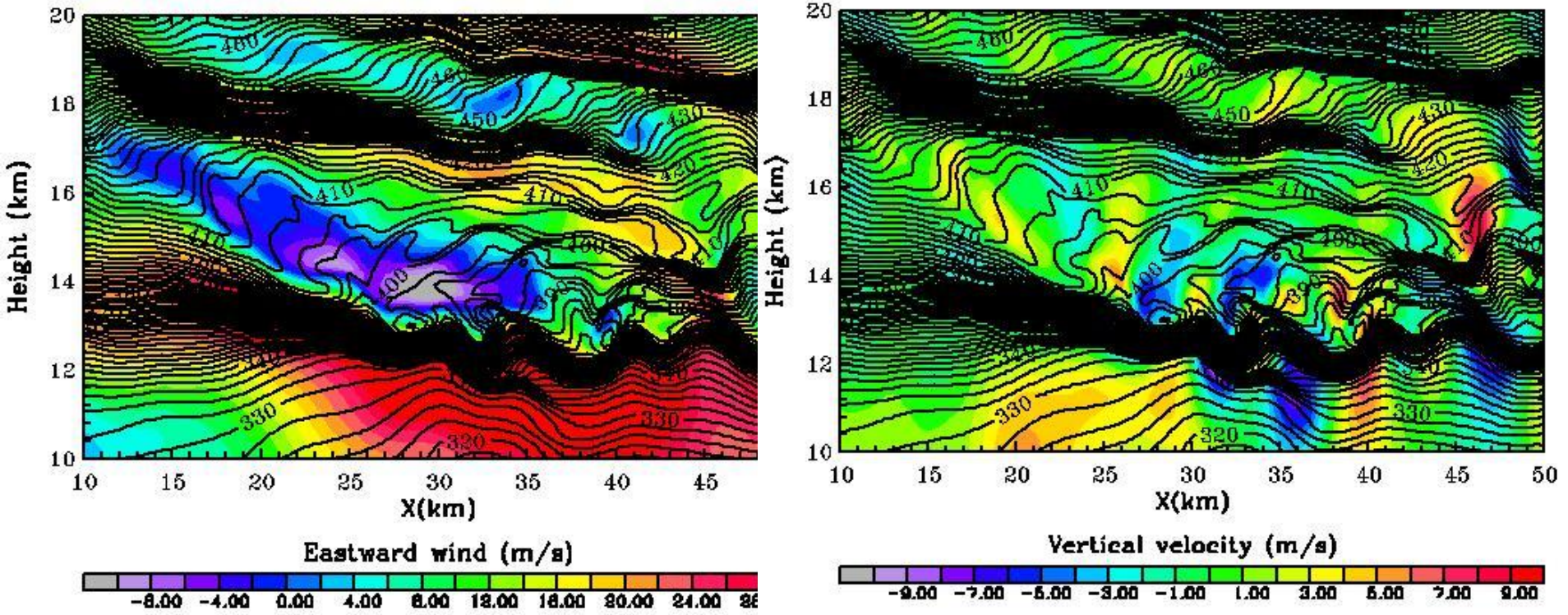
Multi-Nested WRF Microscale Simulations

Terrain-induced Rotor Experiment (T-REX) campaign of measurements, *Owens Valley, CA* March-April 2006

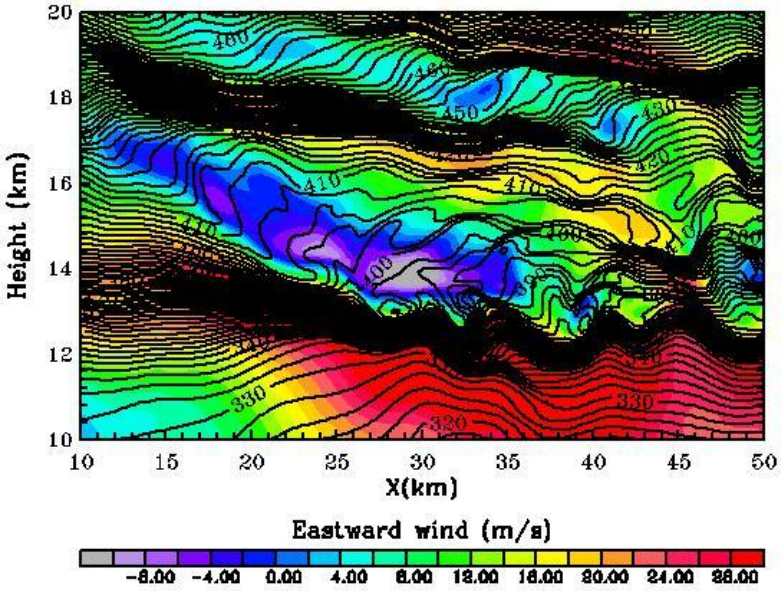


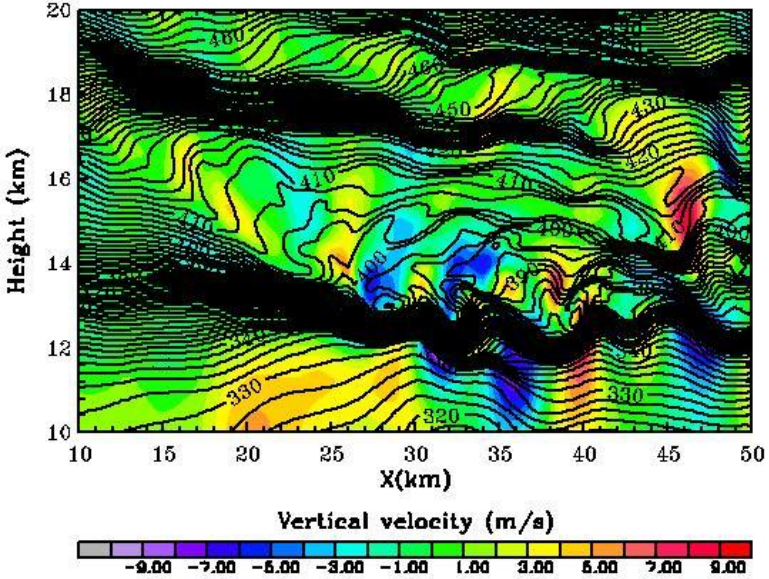
TREX campaign of measurements Owens Valley, CA. Longitude (118.56 W, 117.42 W)-altitude cross-section at latitude 36.82 N for potential temperature (contour) and vertical velocity (color) for the innermost microscale domain (333m grid); 300 grid points in horizontal directions, 450 vertical levels.. Both upper and lateral boundary conditions are relaxed to the finest WRF nest.


Height (km)
X(km)
Vertical velocity (m/s)
-9.00 -7.00 -5.00 -3.00 -1.00 1.00 3.00 5.00 7.00 9.00

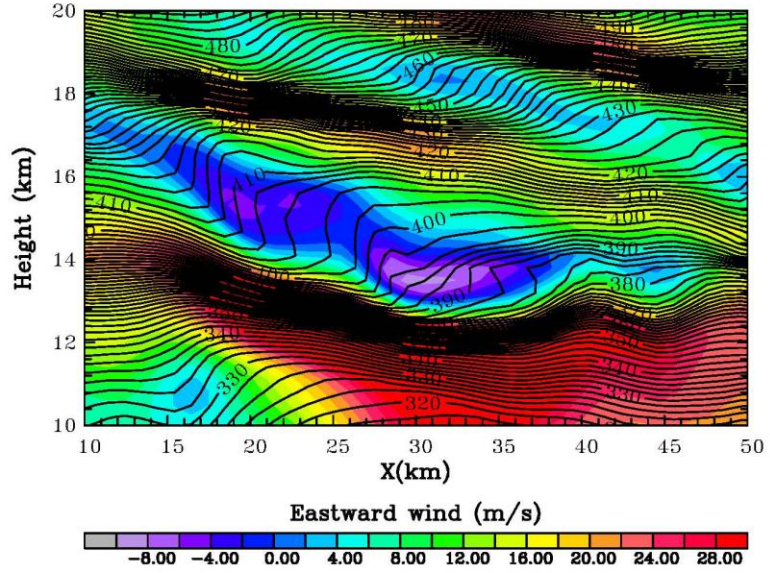


Longitude-altitude cross-sections. Left panel: potential temperature (contour) and eastward wind (color); right panel: potential temperature (contour) and vertical velocity from the innermost microscale domain (333m grid); 300 grid points in horizontal directions, 450 vertical levels. The time is 8:00 UTC, April 1, 2006.





Microscale (450 levels)



150 levels

Longitude-altitude cross-sections for: upper left panel: potential temperature (contour) and eastward wind (color); upper right panel: potential temperature (contour) and vertical velocity from the innermost microscale domain (333m grid); 300 grid points in horizontal directions, 450 vertical levels. The time is 8:00 UTC, April 1, 2006.

Multi-Nested WRF Microscale Simulations Terrain-induced Rotor Experiment (T-REX) campaign of measurements, *Owens Valley, CA* 3/24/2006 12UTC to 03/26/2006 12UTC

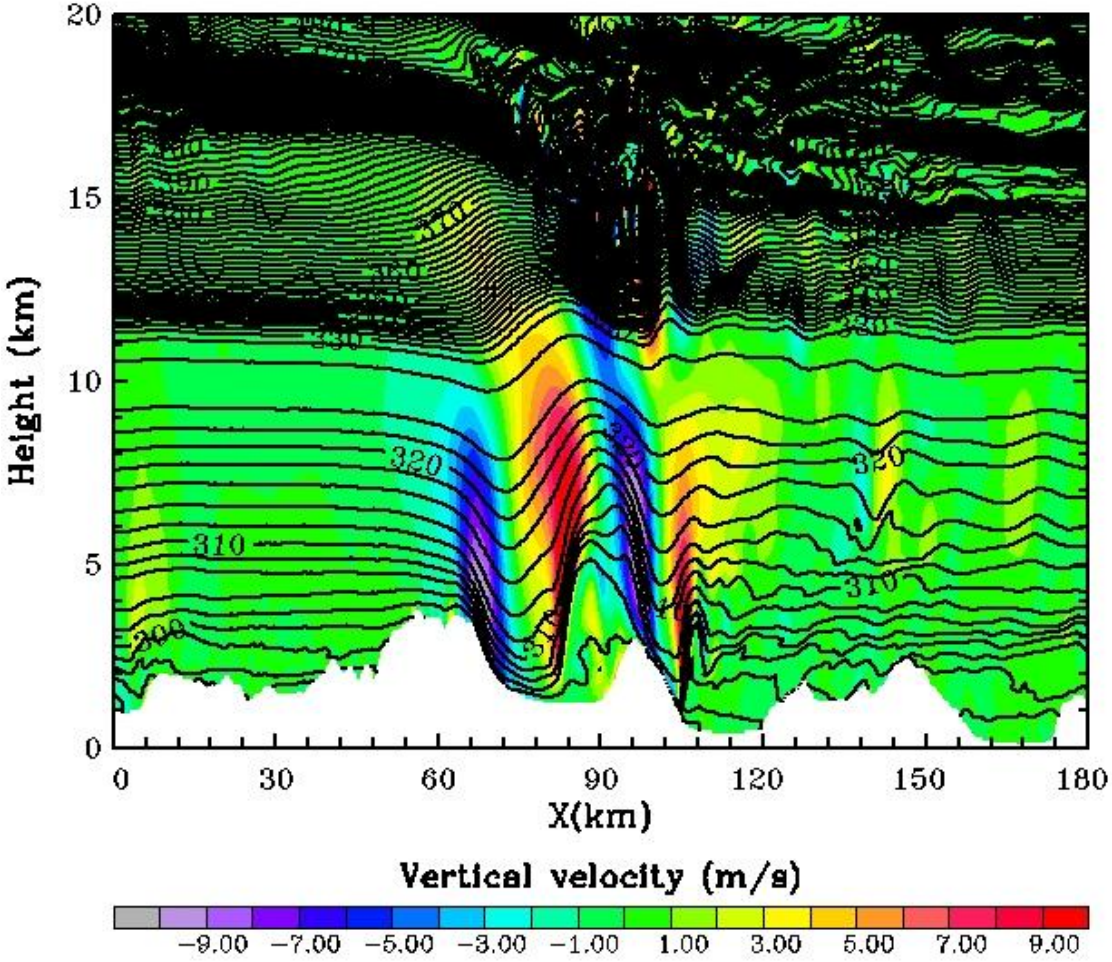
WRF simulations conducted for the period from 03/24/2006 12 UTC to 03/26/2006 12 UTC.

WRF domains are centered over (36.2 N, 118.5 W).

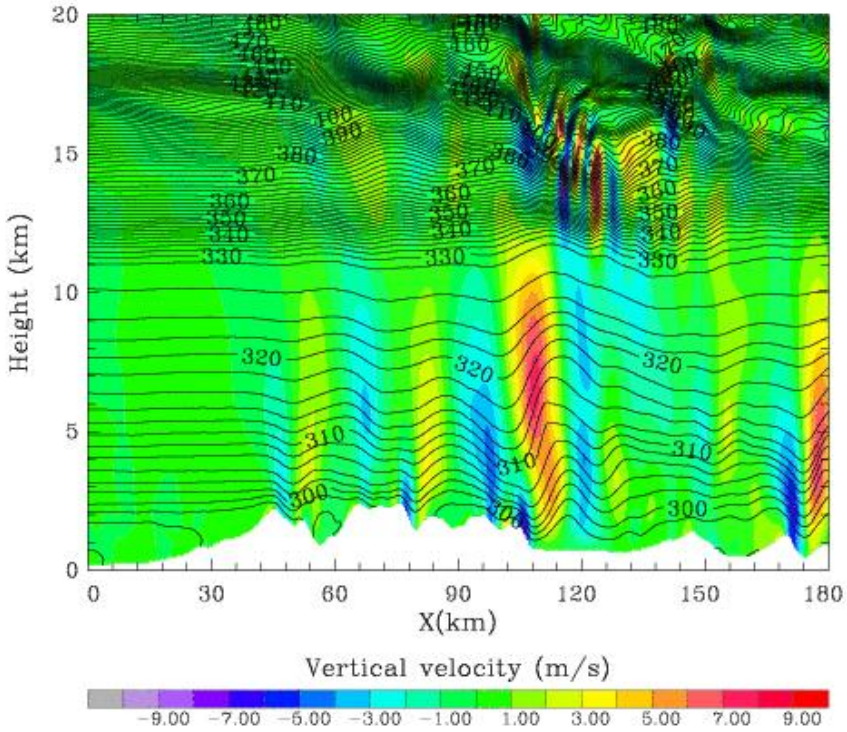
Three WRF domains (two way nesting) are used with horizontal resolutions of 9km, 3km and 1 km, and 150 vertical levels.

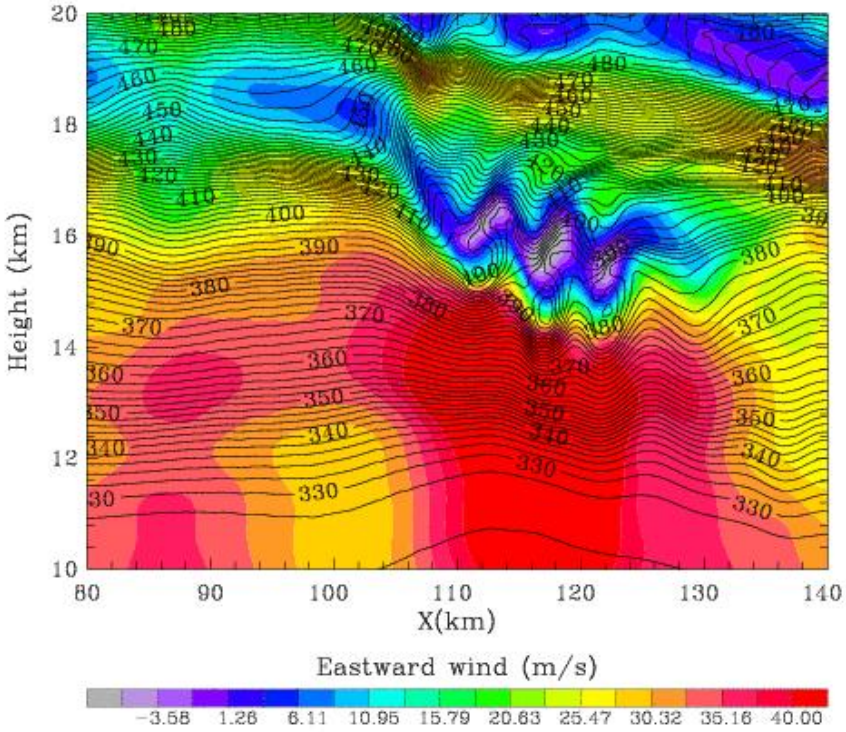
WRF simulations are initialized with ECMWF T799L91 analysis (25 km horizontal resolution and 91 vertical levels).

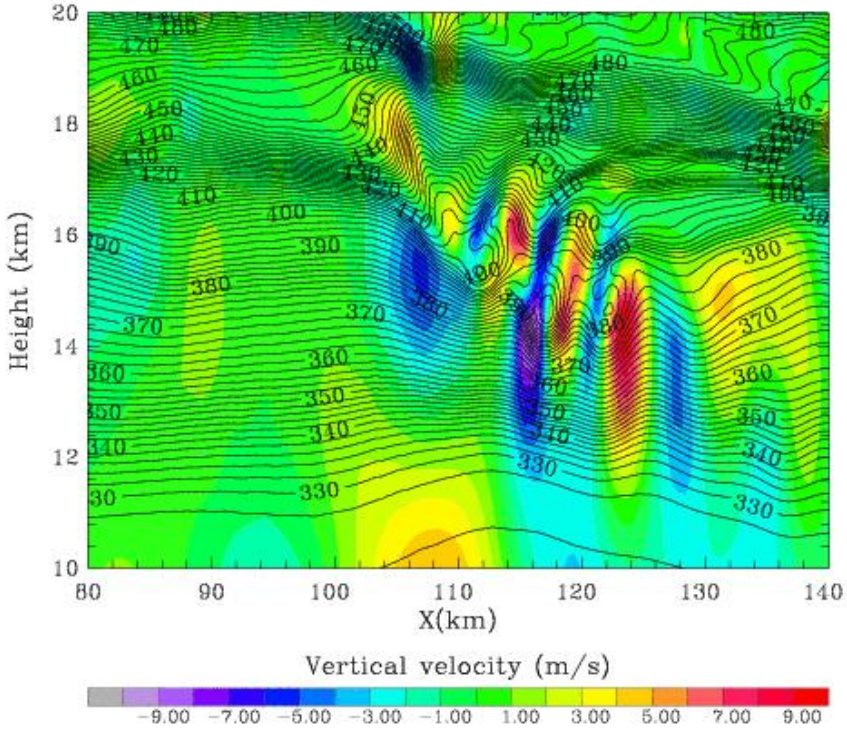
Microscale domain (4^{th} nest) is done using 559 X 469 grid points in the horizontal (333m grid spacing) and 450 vertical levels up to 10 mb. One way horizontal and vertical nesting with boundary conditions and initialization from the finest WRF nest.



Longitude-altitude cross-section at latitude 36.8 N for potential temperature (contour) and vertical velocity (color) for the innermost microscale domain. Both upper and lateral boundary conditions are relaxed to the finest WRF nest. The time is 20:00 UTC, March 25, 2006.


Height (km)
X(km)
Vertical velocity (m/s)
−9.00 −7.00 −5.00 −3.00 −1.00 1.00 3.00 5.00 7.00 9.00


Height (km)
X(km)
Eastward wind (m/s)
-3.58
1.26
6.11
10.95
15.79
20.63
25.47
30.32
35.16
40.00


Height (km)
X(km)
Vertical velocity (m/s)
−9.00 −7.00 −5.00 −3.00 −1.00 1.00 3.00 5.00 7.00 9.00

Conclusions

- High-resolution simulations in real atmospheric conditions of mountain waves in the upper troposphere and lower stratosphere (UTLS) for two Intense Observational Periods (IOP6 and IOP8) of the Terrain-induced Rotor Experiment (T-REX) were presented.

- Nesting and refined vertical gridding have been applied within the finest nest of WRF, with a vertical refinement factor of 3 (181 vertical levels)

- WRF simulations with vertical grid refinement are able to improve the resolution of small scale processes associated with mountain waves in the UTLS and to bring up new details in the simulated fields as opposed to horizontal nesting alone.

- New dynamics associated with local generation of secondary motion in the UTLS and inversion layer formation related to lee waves at lower levels are better resolved.