Update of upper-level turbulence forecast by reducing unphysical components of topography in WRF

Sang-Hun Park[1]

Jung-Hoon Kim[2], Robert Sharman[1] and Joseph Klemp[1]

1. National Center for Atmospheric Research
2. CSU/CIRA, NOAA/Aviation Weather Center

Aviation turbulence

Cruising altitudes: FL250-450 (8~12 km AGL)

Clear-Air Turbulence (CAT)

Mountain Wave -induced Turbulence (MWT)

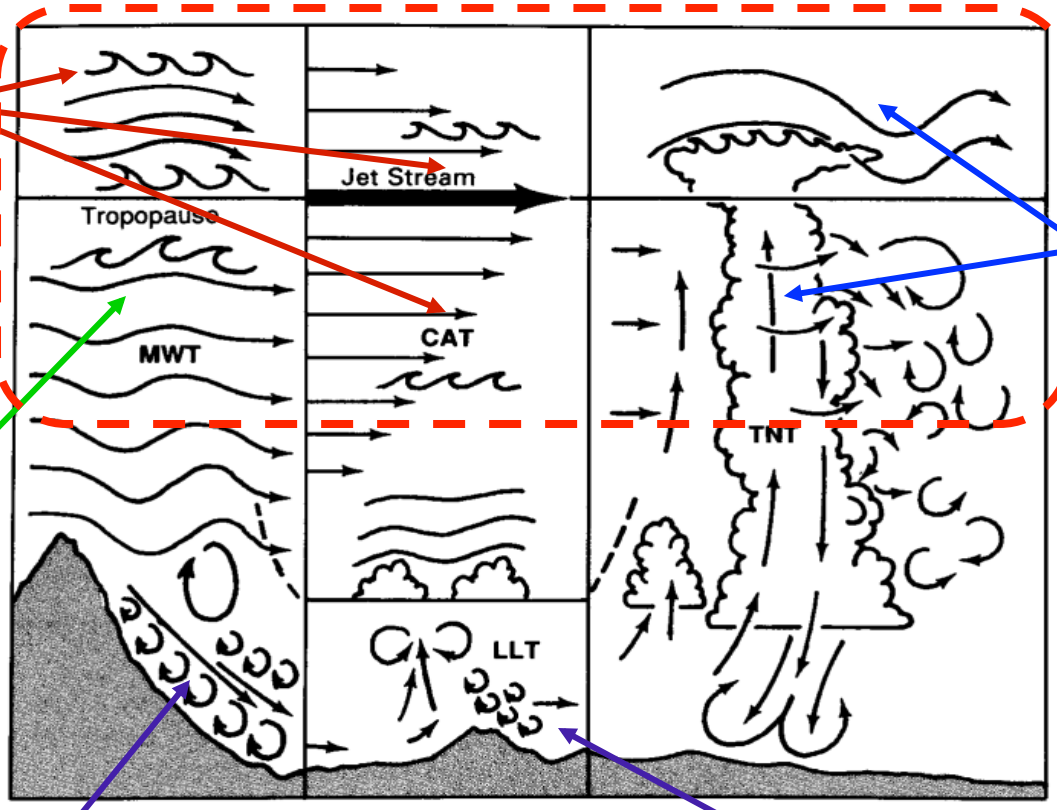


Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

Convectively-Induced Turbulence (CIT)

Low level Terrain-induced Turbulence (LLT)

Convective boundary Layer turbulence

Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

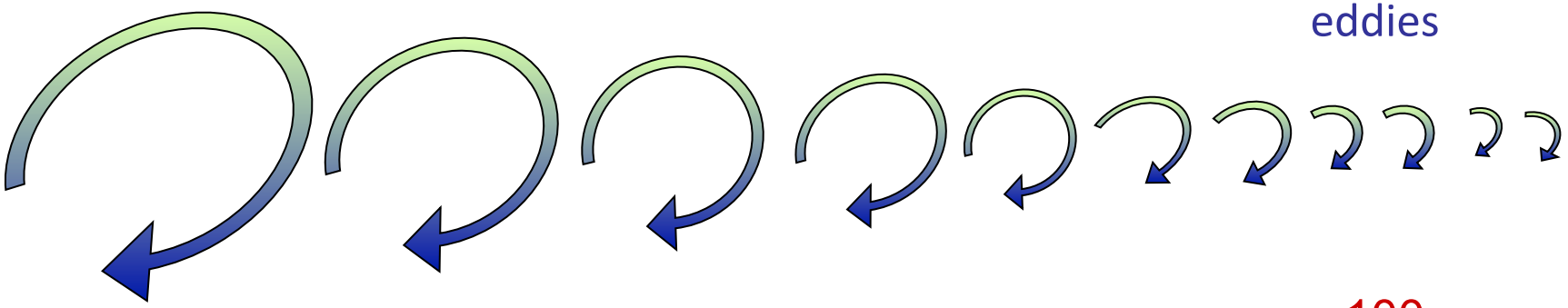
Slide by J.-H. Kim

Forecasting aviation turbulence

Large-scale disturbances

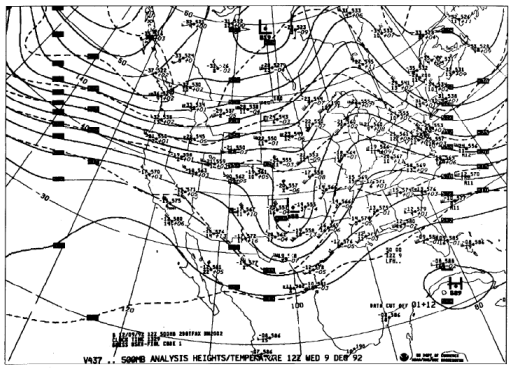
"Energy cascade down"

small-scale turbulent eddies

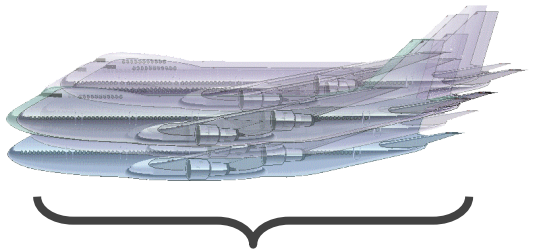


10s km

100s m



linkage



Aircraft responds to scales from ~100m – 3 km

NWP resolution
(RAP, Δ~13km)

NWP model

Post-processing for turbulence

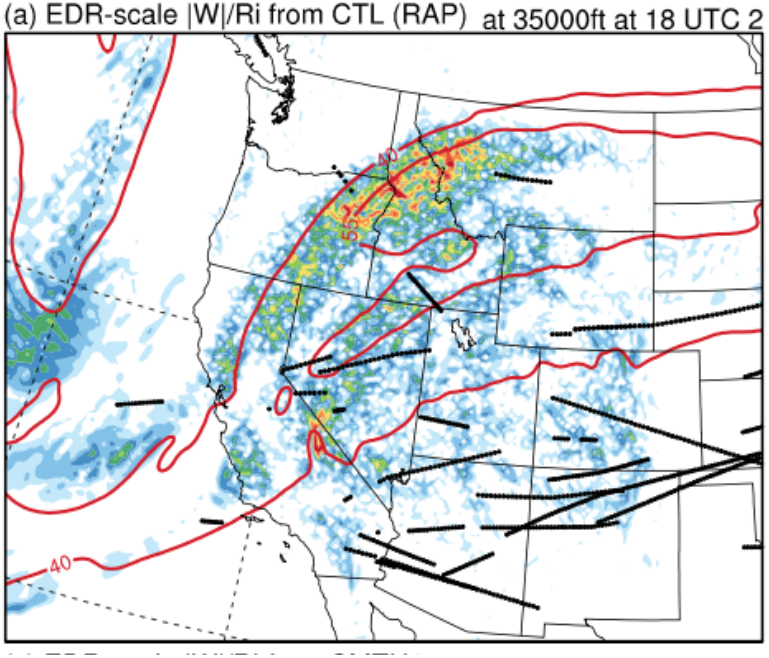
Aircraft Observation

Slide by J.-H. Kim

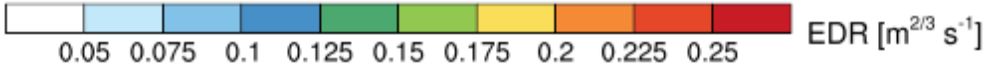
False Alarm of Air Turbulence

From Melissa Thomas (**Delta Airline**) *in personal communication*

… Many years ago, we used to have access to vertical cross sections of WRF for mountain wave forecasting. We stopped using them because we saw that WRF default was to ALWAYS show mountain wave. It was a rare day in the winter that it DID NOT show a wave over CO. Like you, I believe it is due to the fine resolution of the model and terrain. …



- Graphical Turbulence Guidance (GTG) – 2015.11.02. 18UTC
  : showing Eddy Dissipation Rate (EDR)-scale turbulence diagnostic (shading, based on $|w|/Ri$) and horizontal wind speed (40 and 55 m/s, red contours)



Motivation (Question)

- Can we reduce over-estimated of air-turbulence (connected to mountain waves)?

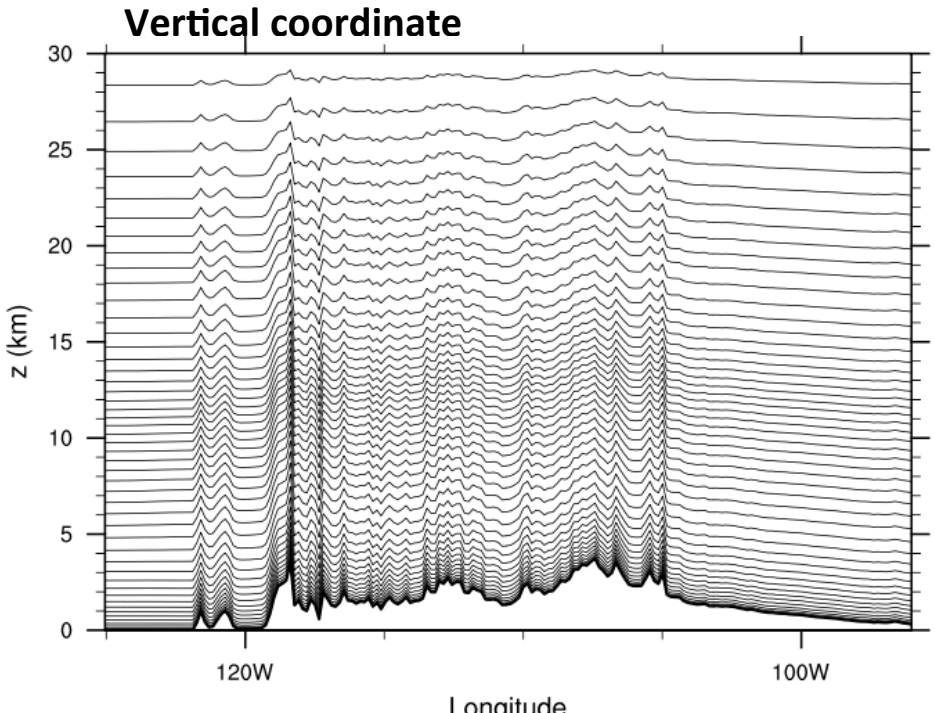
  If so…

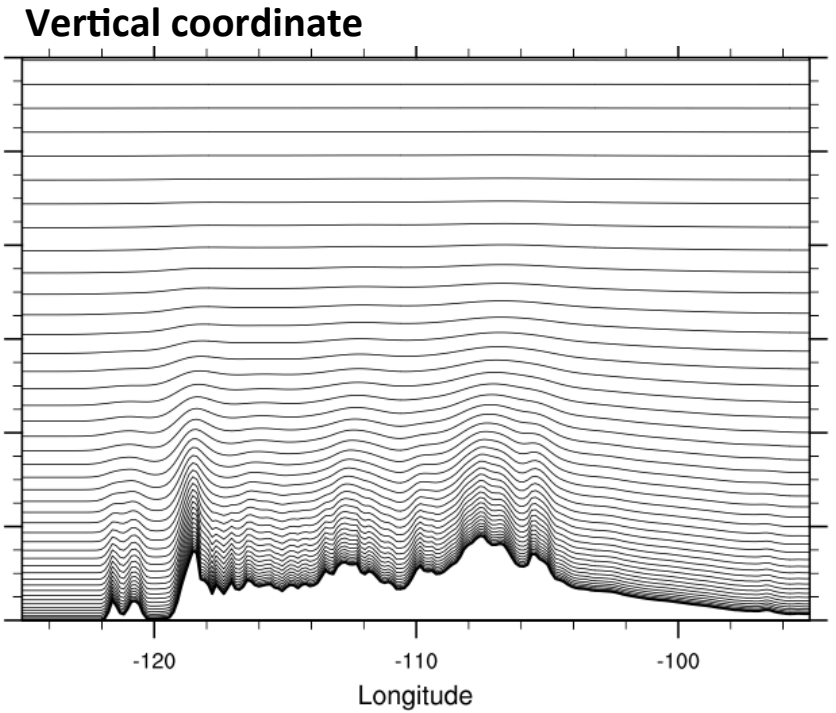
- What is the key to cause this issue?

  - terrain shape (need more complex data or less realistic data?)

  - vertical coordinate (need smoothed coordinate?)

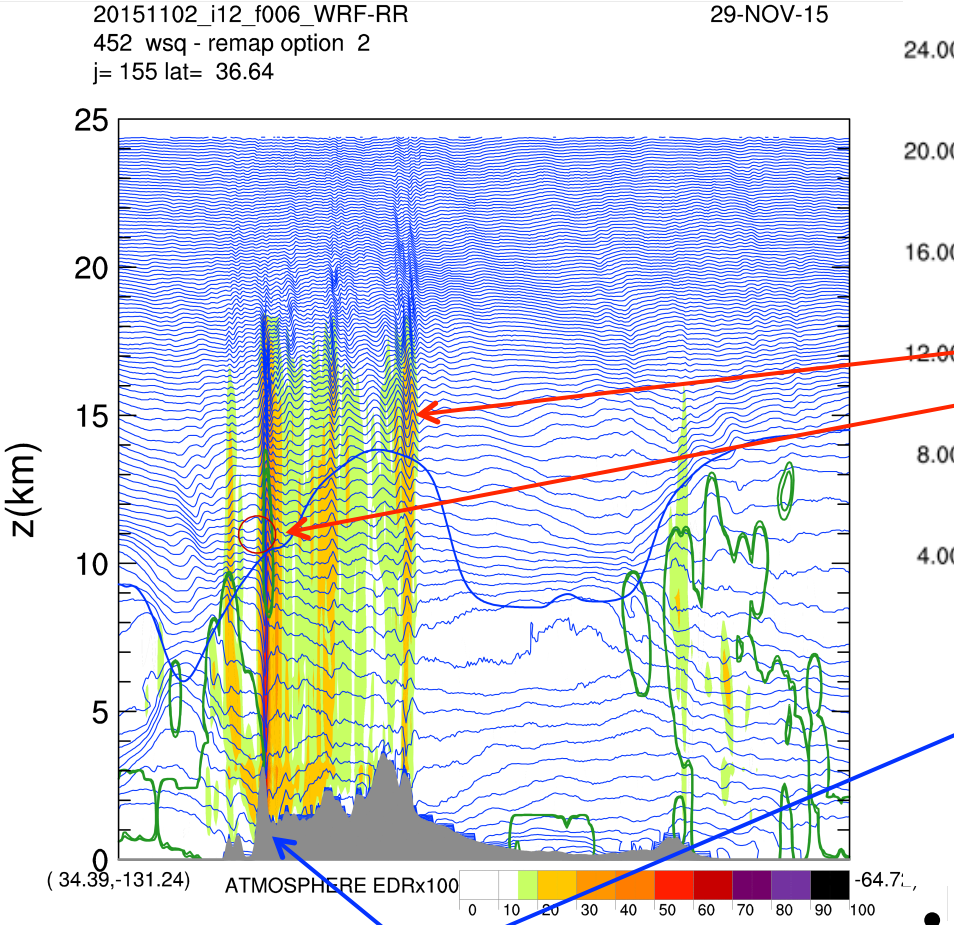
  - lack of vertical layers (need more high-vertical resolutions?)



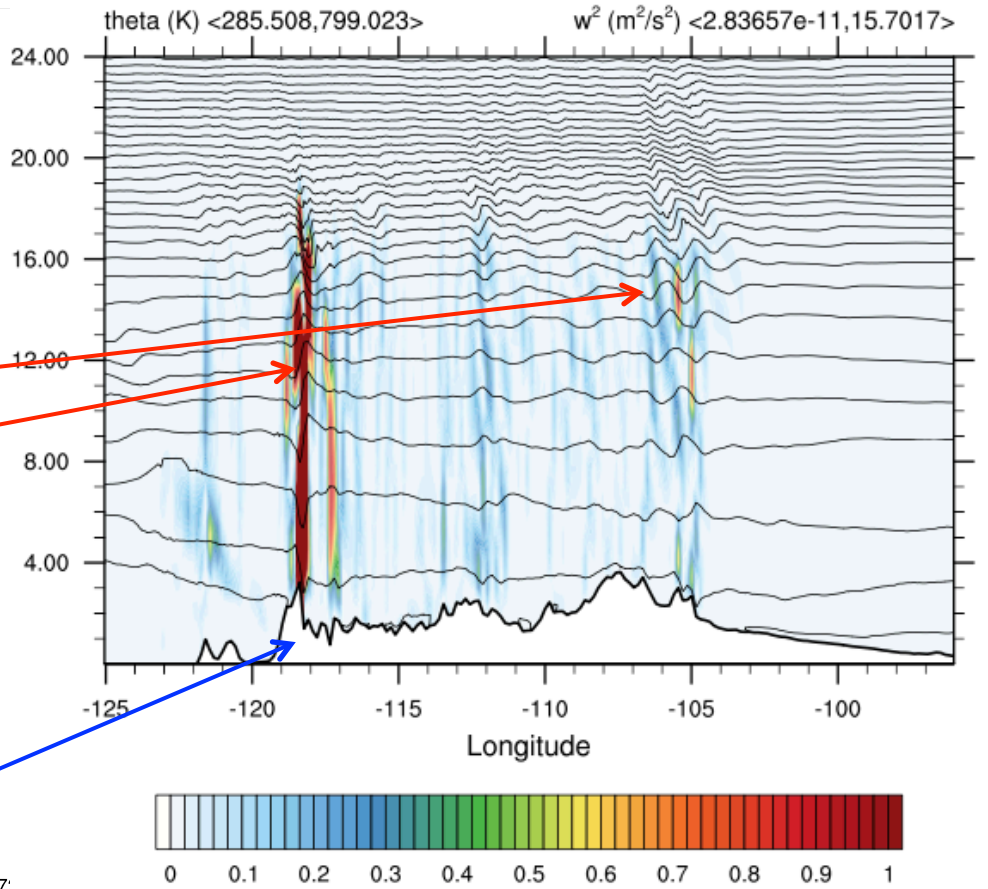


Reproduce of False Alarm

- EDR (x100) from RAP



- w^2 from WRF (Reproduced)



Sierra Nevada

- 2015.11.02.00UTC + 18hrs (initialized from .5 degree GFS)

- reproduced mountain wave structure is comparable
- distribution of vertical velocity is well matched with EDR spread

Topography in RAP & WRF

- Topography in RAP ($\triangle \sim 13km$) is a result from "NO-SMOOTHNESS" of TOPO.
- In WPS, smooth-terrain is setup with following calculation

do n=1,num_smoothness

$$\phi^*_{i,j} = \phi^n_{i,j} + \alpha \nabla^2 \phi^n_{i,j}$$

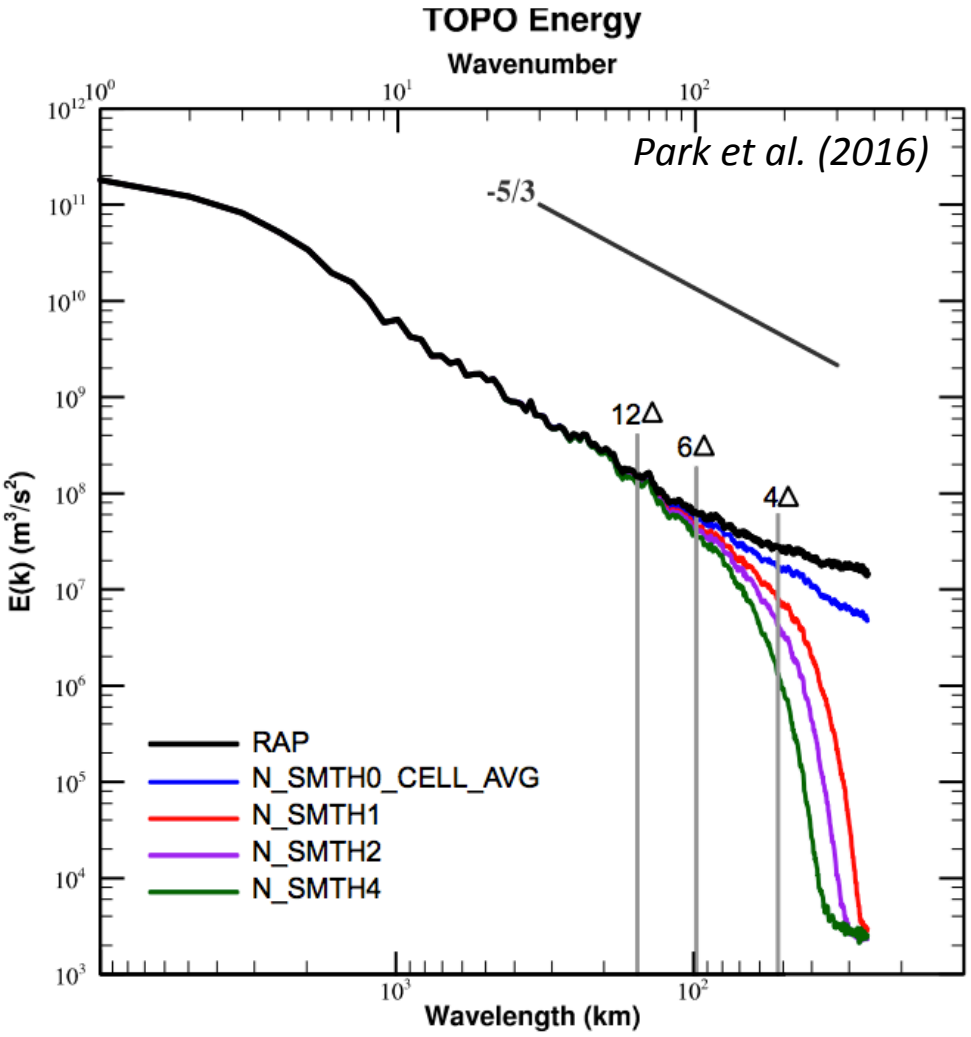
$$\phi^{n+1}_{i,j} = \phi^*_{i,j} - \alpha \nabla^2 \phi^*_{i,j}$$

end do

to remove $2\triangle$ scales (with $\alpha = 0.25$), which are relevant to computational modes.

TOPO. Source	INTERP. method	num_smoothness	Max. TOPO.
30s	cell avg	0	3643.7
30s	cell avg.	1	3629.0
30s	cell avg.	4	3618.2

Energy Spectra for Topography

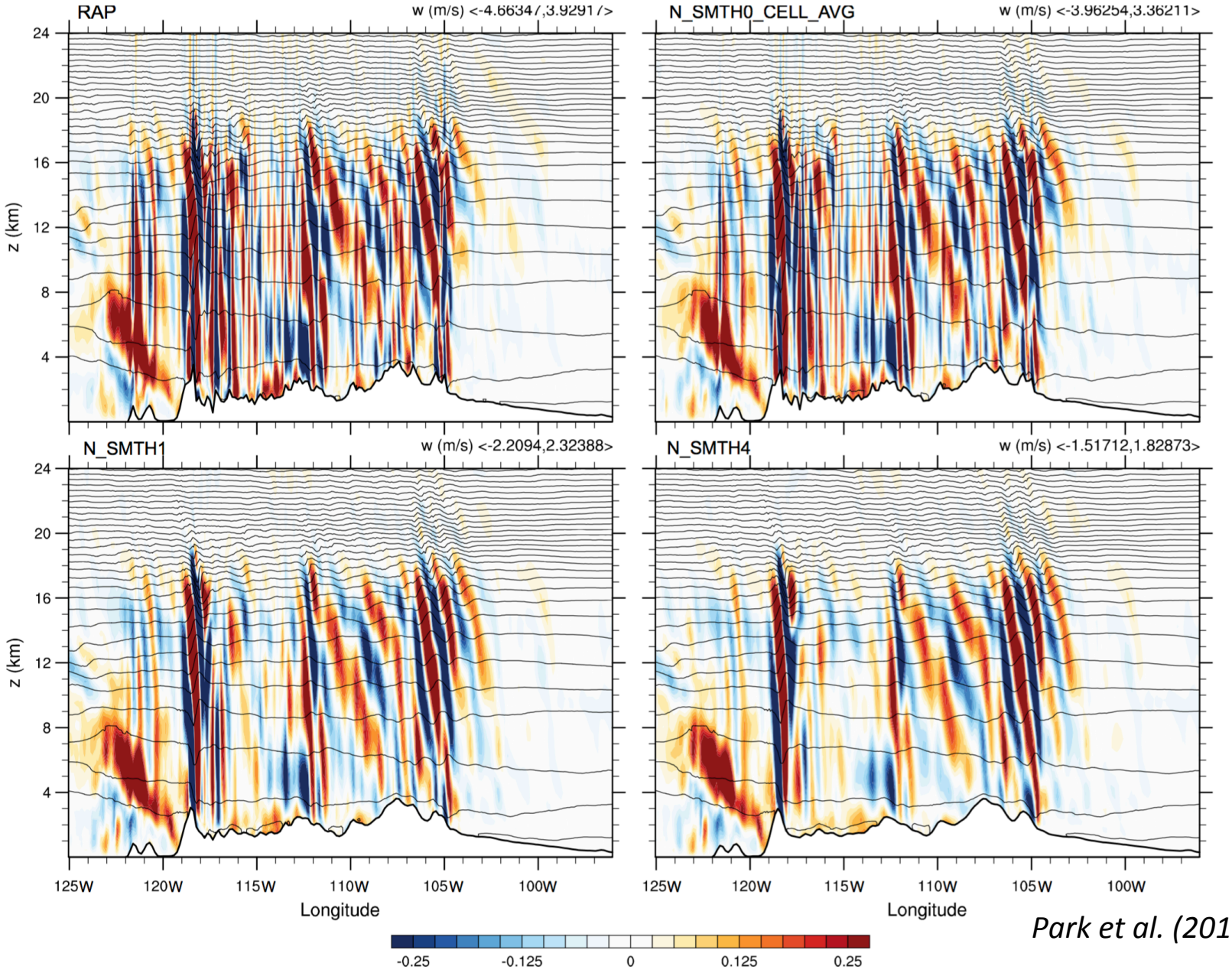


TOPO. Source	INTERP. method	num_ smoothness	Max. TOPO.
2m	4pt. Interp.	0	3768.4
30s	cell avg	0	3643.7
30s	cell avg.	1	3629.0
30s	cell avg.	2	3625.5
30s	cell avg.	4	3618.2

- 5 cases are tested to investigate sensitivity of terrain shape regarding to air turbulence

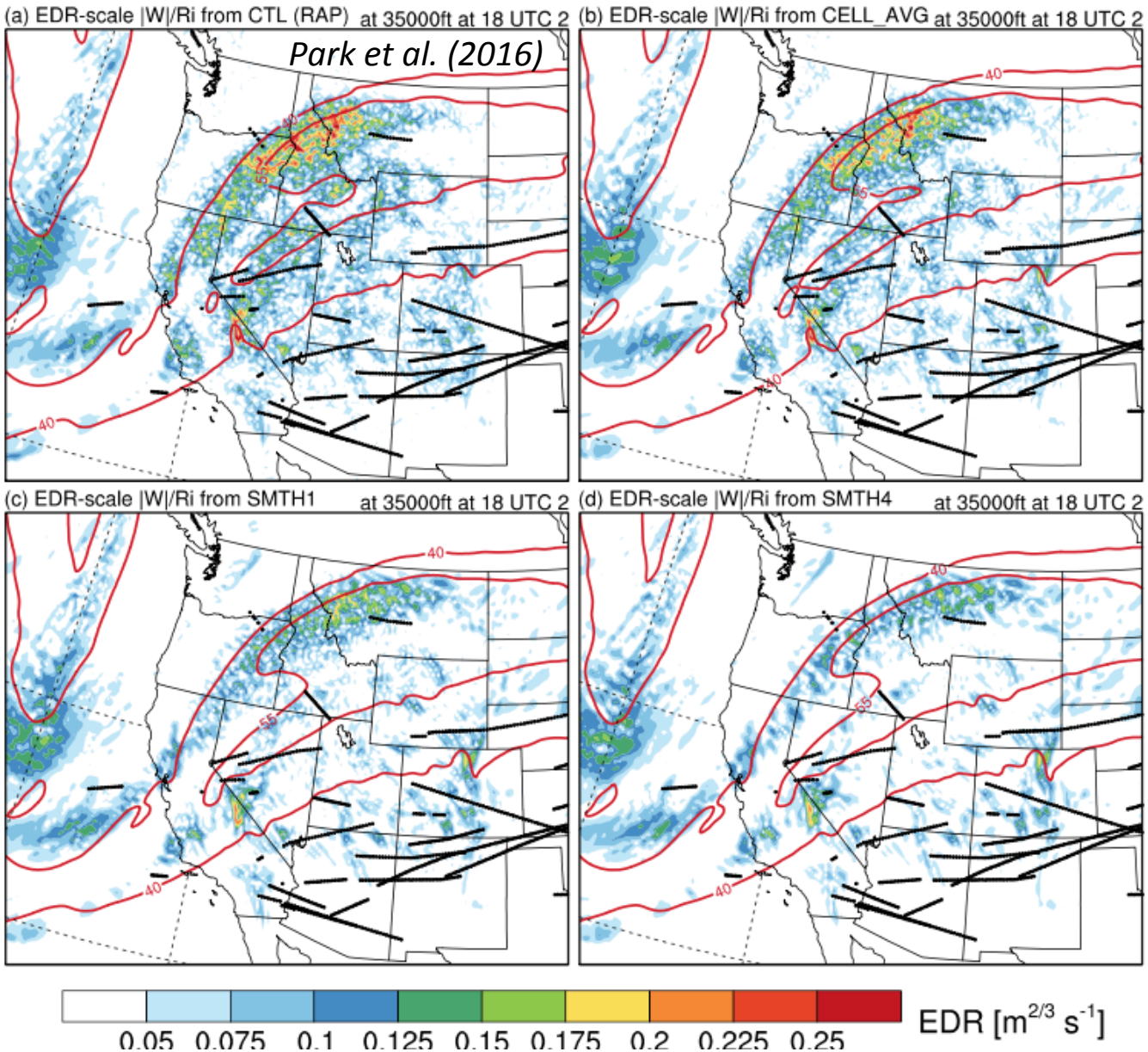
- Both of *no smooth-terrain option*, 2Δ modes are not removed regardless of interpolation method and source data of TOPO.

Sensitivity of Air Turbulences (w)



Park et al. (2016)

Sensitivity of Air Turbulences (EDR)

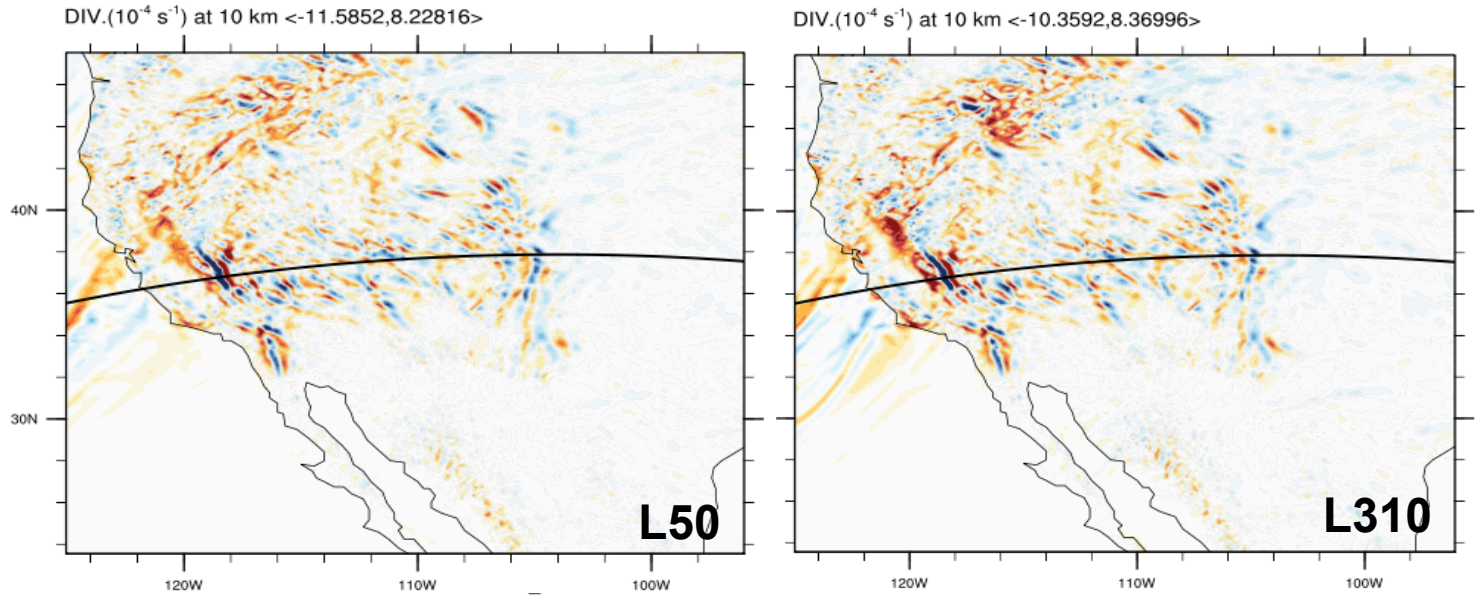


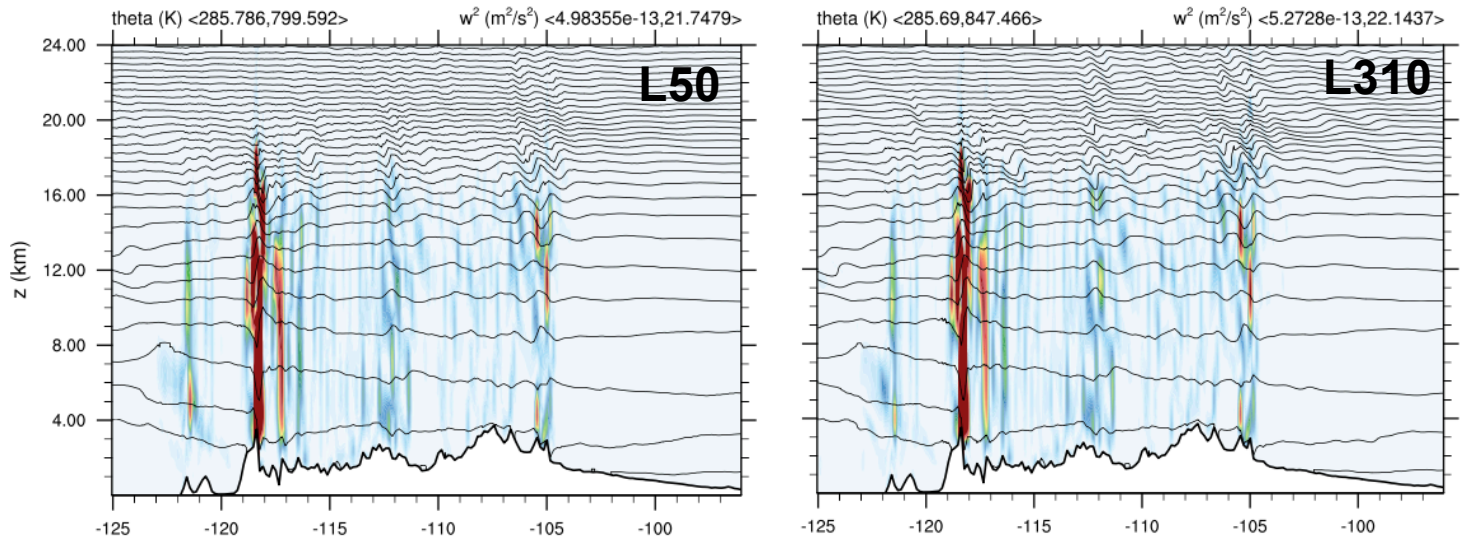
<0.05 EDR :: Obs. from aircraft

WSPD. contour (40,55m/s)

Other Possibilities to reduce False Alram

- *lack of vertical layers (need more high-vertical resolutions?)*
  try L50 -> L310



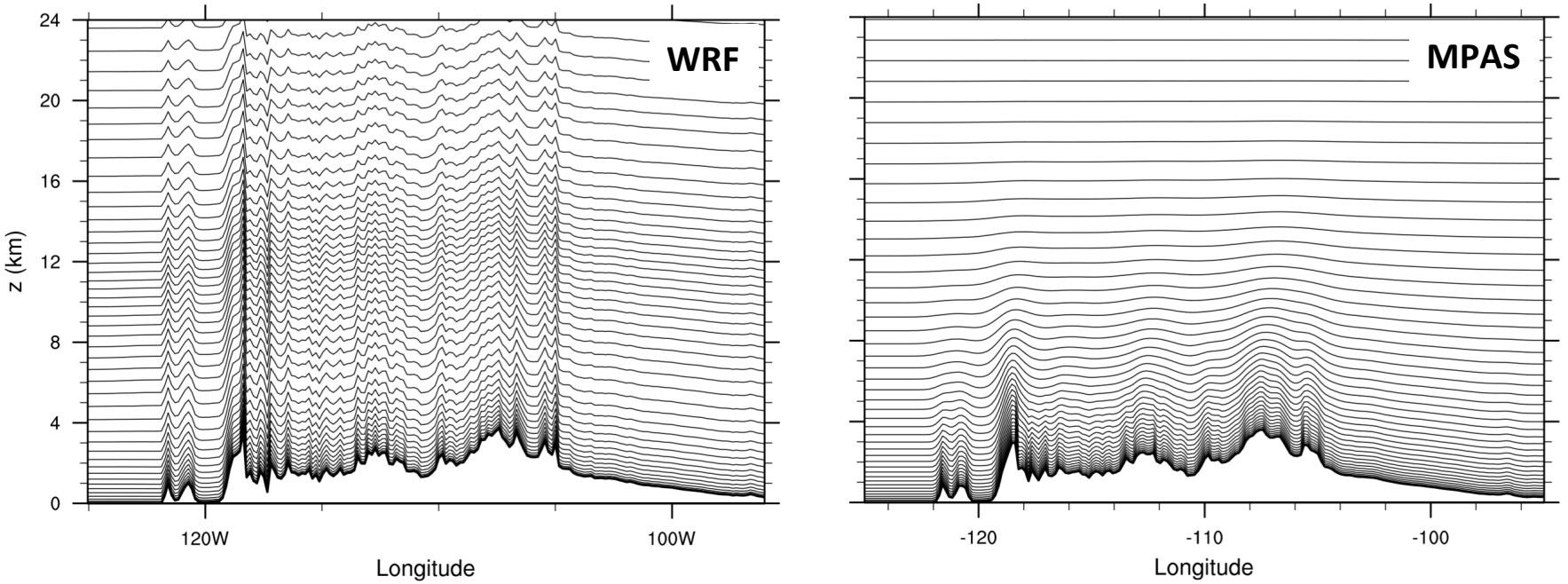


- Both are comparable!!

- Vertical resolution issue is not very sensitive around of tropopause!!

Other Possibilities to reduce False Alram

- *lack of vertical layers (need more high-vertical resolutions?)*
  try L50 -> L310
- *vertical coordinate (need smoothed coordinate?)*

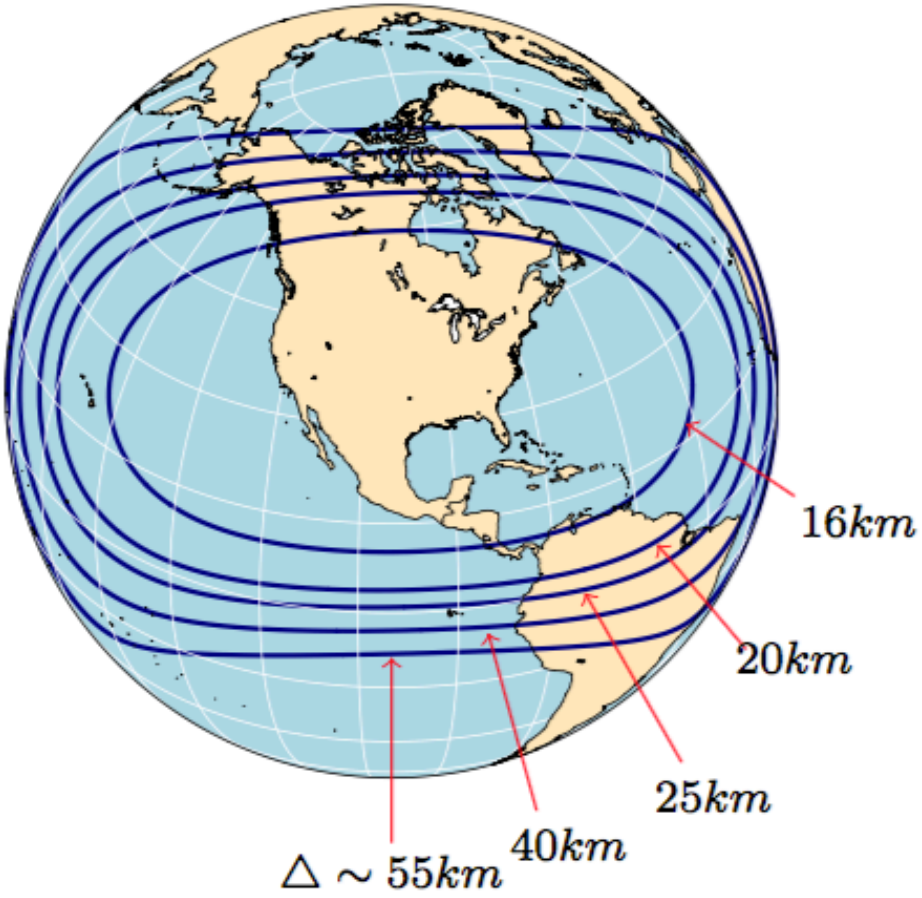


- Both of TOPO. include $2\triangle$ mode (*num_smoothness=0*), but in MPAS, hybrid-height coordinate option (*Klemp, 2011*) is turned on
- Even if there is computational mode in MPAS TOPO, it looks like hybrid option will be helpful for reducing of strong mountain waves (air turbulence)

MPAS Setup and Configuration

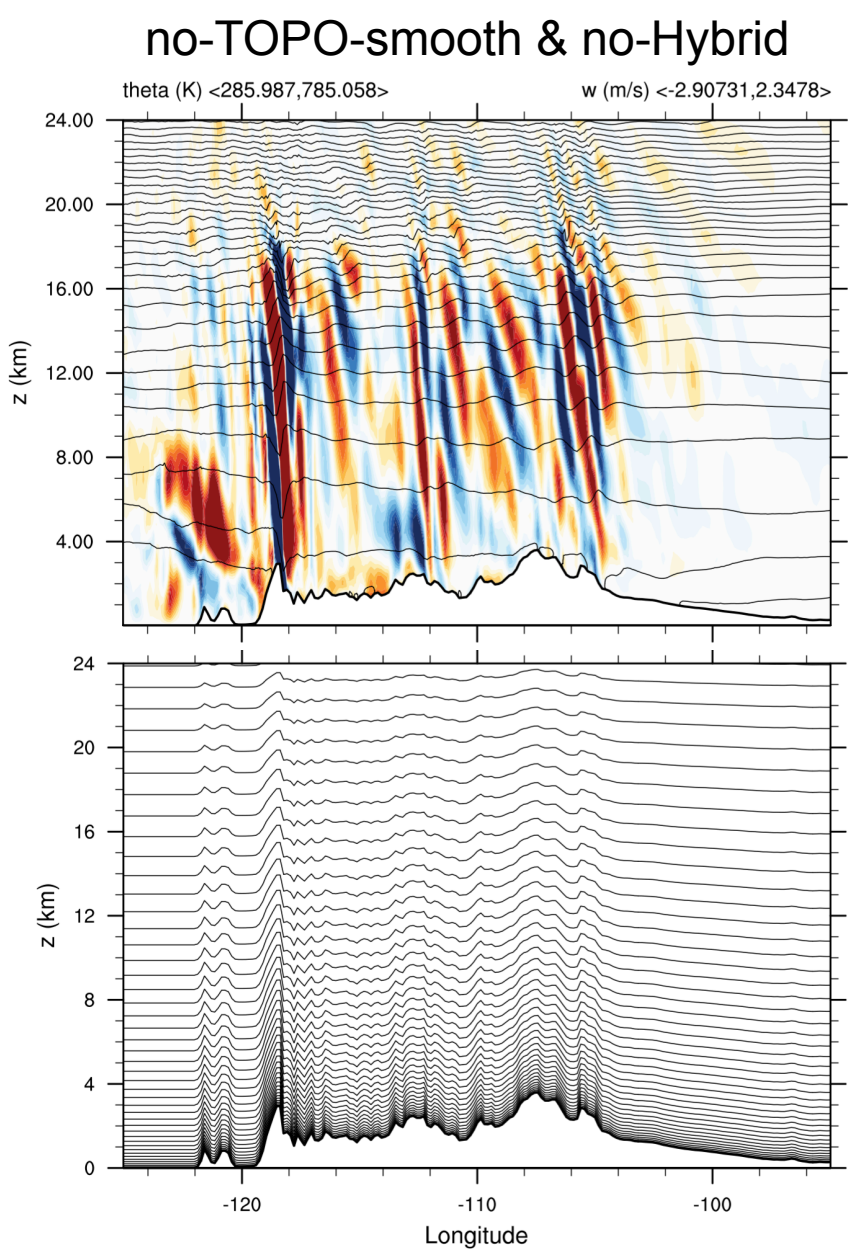
– a mesh for simulations

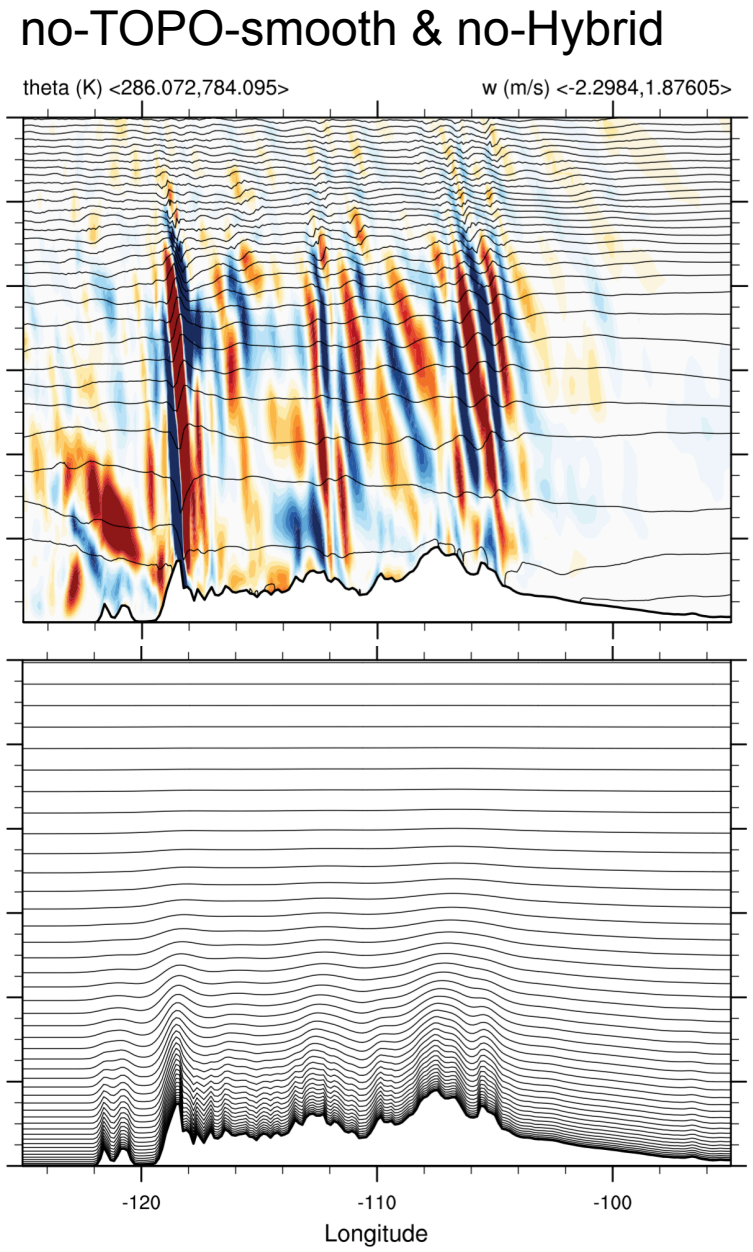
variable resolution ($15 \sim 60km$)



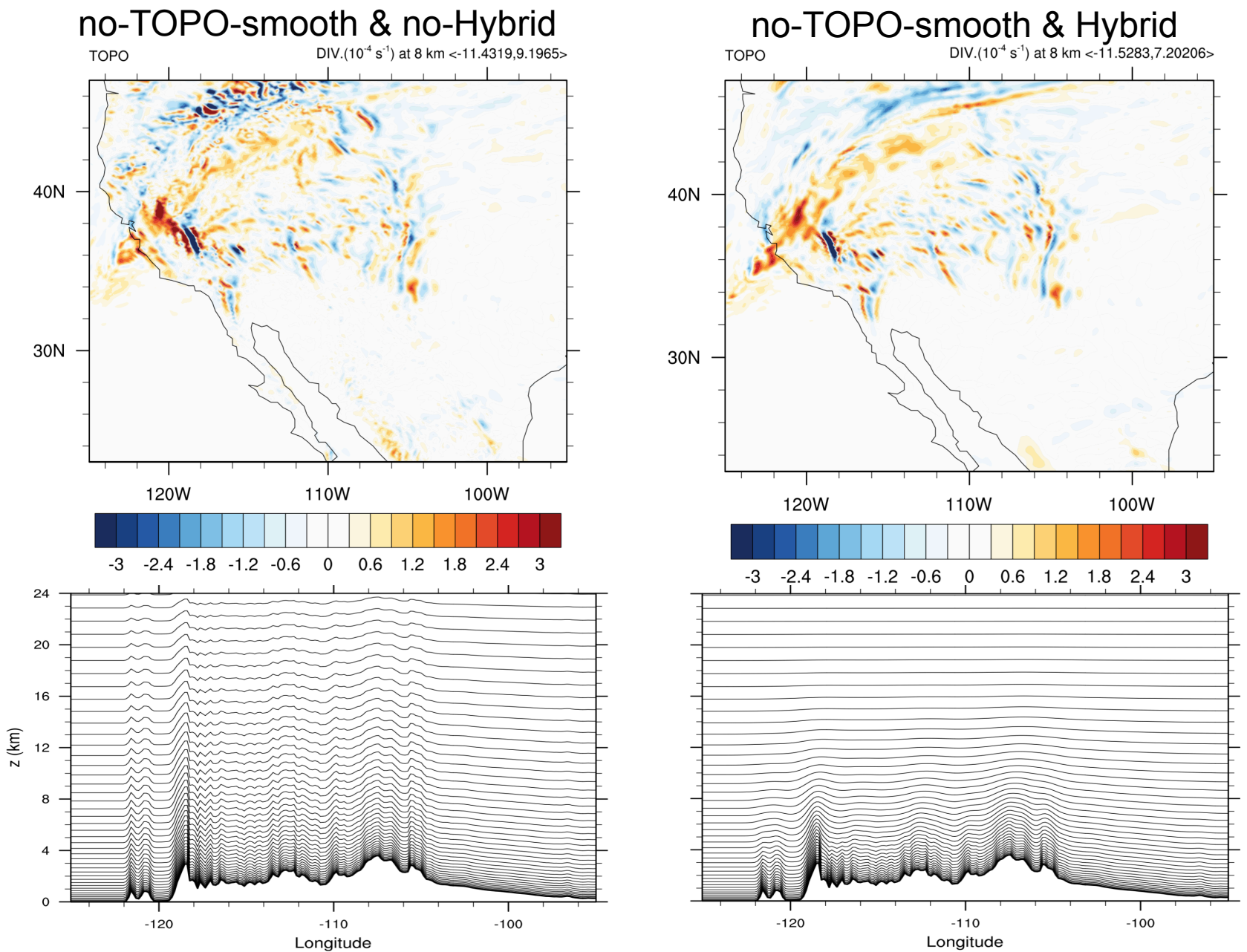
	WRF	MPAS
Initial Data	GFS .5deg F00 Analysis	
Model Top	10 hPa (50 lev.)	30km (50 lev.)
Mesh Size	759 × 568	535554 Cells (GLOBAL)
dt (dyn.)	60s	90s
CPS	GF	TIEDTKE
PBL	MYNN 2.5-lev.	YSU
MP	THOMPSON	WSM6
RA_LW	RRTMG	
RA_SW	RRTMG	
SFC	RUC	NOAH

Sensitivity of Air Turbulences (w) - MPAS





Sensitivity of Hybrid Coordinate - MPAS



Summary and Plans

- False Alarm of mountain waves is well reproduced in WRF-ARW simulations when $2\triangle$ mode of terrain data (small scales) is not filtered well.
- Regardless of interpolation method or sources of topography, this smoothed topography is important to avoid *false alarm* of air turbulence diagnosis.
- Lack of vertical resolutions is not a source of strong mountain waves.
- In MPAS, hybrid vertical coordinate is helpful to reduce overestimation of mountain waves, but careful comparison is required (i.e. using hybrid coordinate option in new WRF)
- Overall study should be considered together with lower level results.
- We will extend our research for high-resolution simulations.

Energy Spectra for Simulation