Mountain Micrometeorology Modeling with WRF

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Motivation

- Air quality forecast
- Wind farm siting
- Weather prediction e.g. cold pools

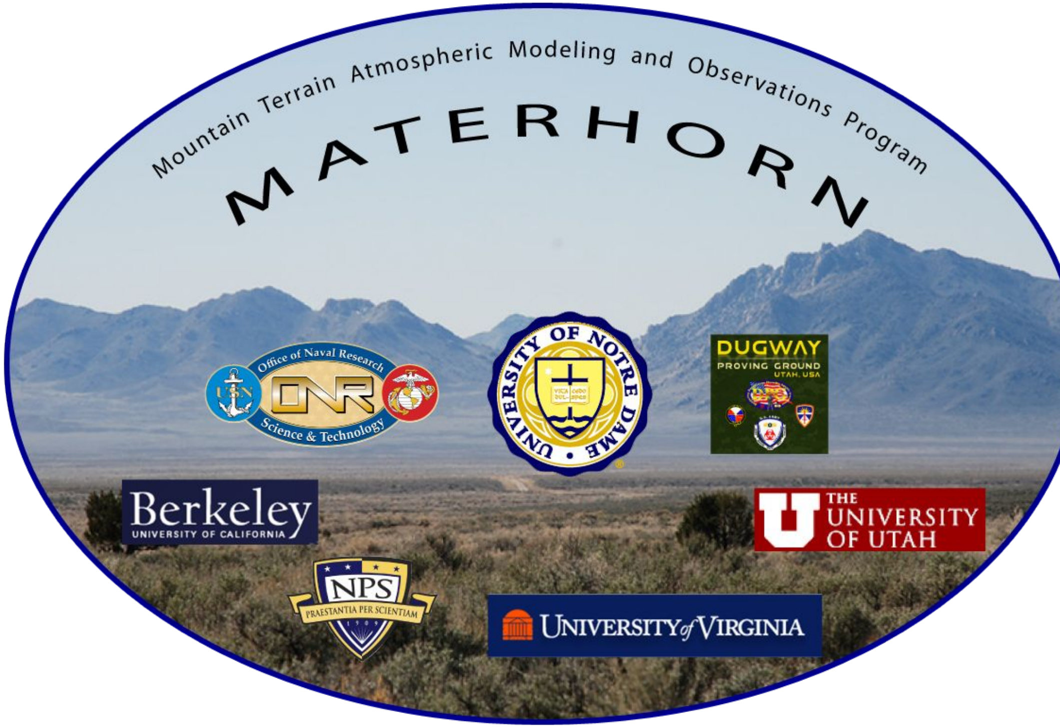
Photo Credit: Spencer Garn, ksl.com

Modeling goals

- perform large-eddy permitting simulations over Granite Peak
    - stable flows
    - mesoscale/microscale interactions
- investigate limitations of WRF
    - 10 m resolution? 100 m?
    - 30 deg slope? 45 deg?
- improve fidelity of LES over complex terrain

Overview

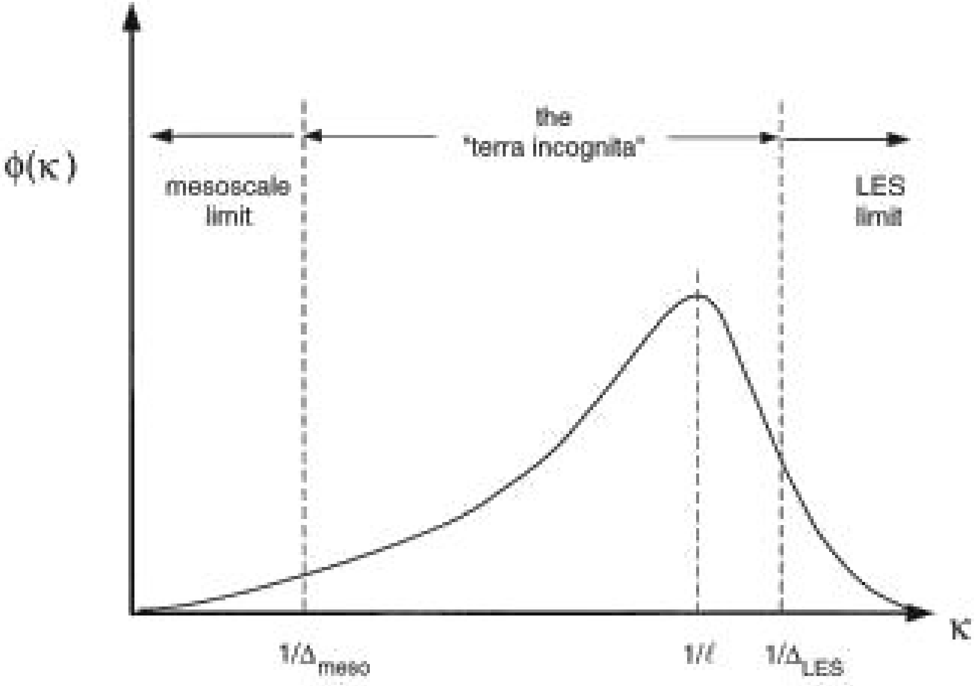
- Modeling challenges
  - *Terra incognita*
  - High resolution inputs
  - Slope aspect ratio
- Comparisons to observations
- Future work



Grid nesting across the gray zone

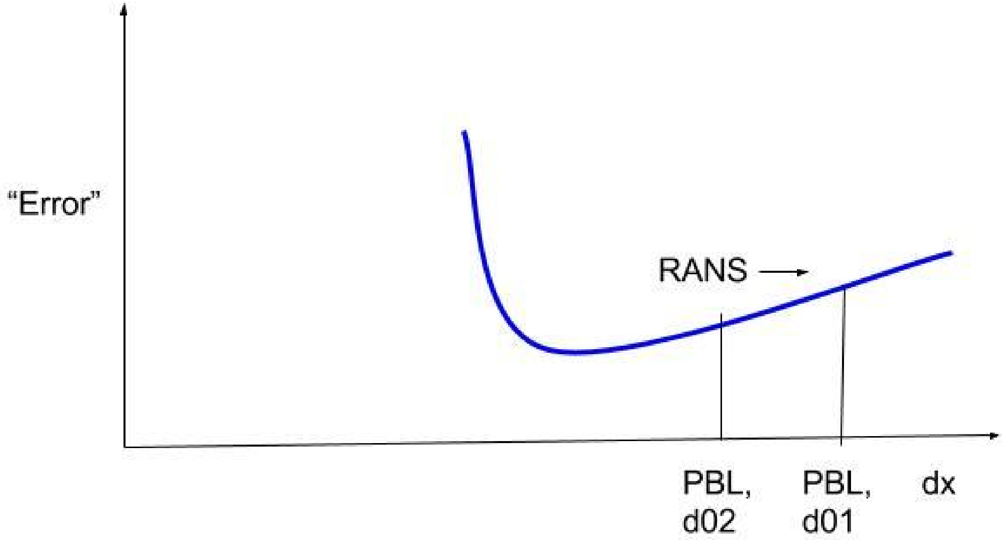
- Nesting past *terra incognita*

- 9 km -> 3 km -> 1 km -> 333 m -> 111 m ….



from Wyngaard (2004)

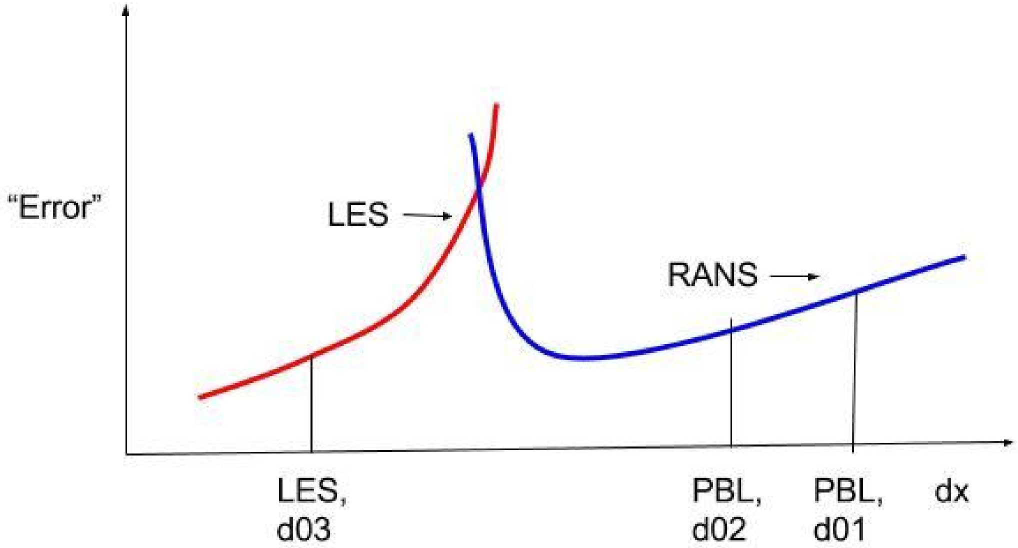
Nest past gray zone



Goal:

on mesoscale domains, d01 and d02, parameterize all turbulence

Nest past gray zone



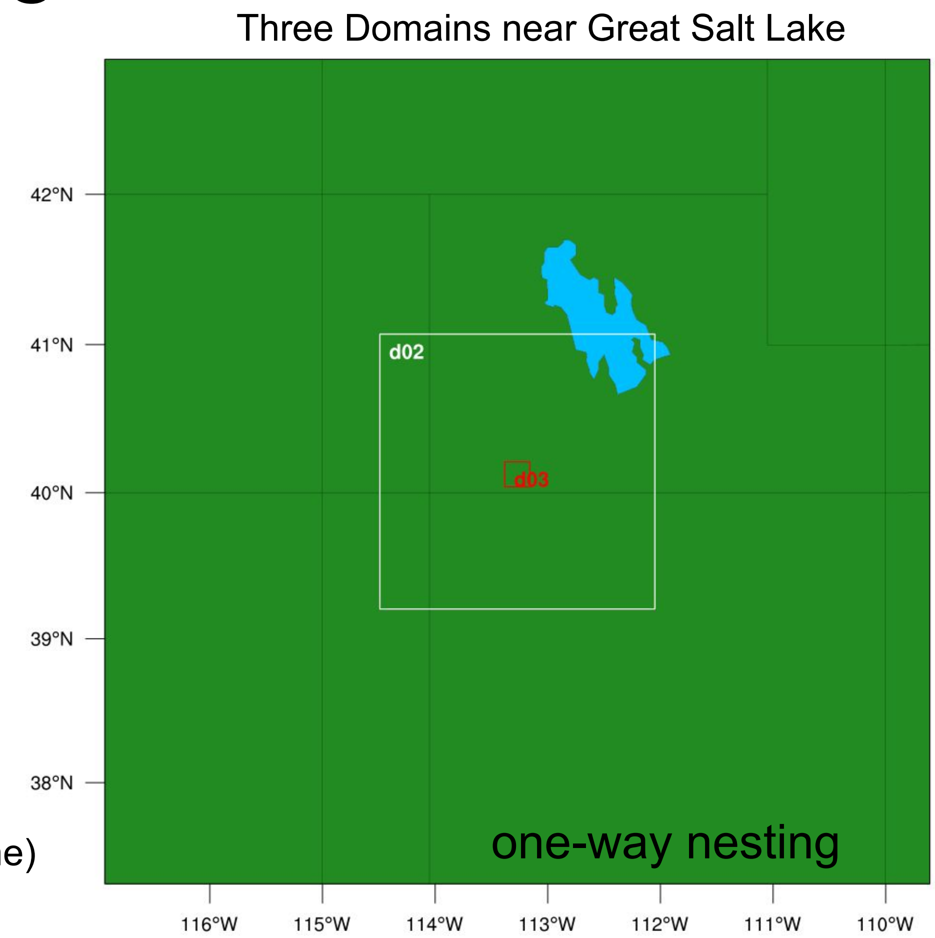
Goal:

on LES domain, d03, resolve most turbulence

Nest past gray zone

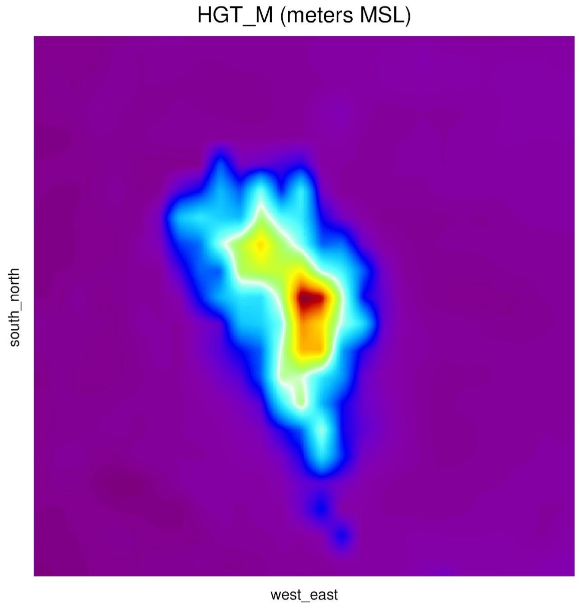
	d01 (6.3 km)	d02 (2.1 m)	d03 (100 m)
dx, dy	6.3 km	2.1 km	100 m
nx, ny	100 pts	100 pts	190 pts
dz (121 lvls)	~55 m to ~175 m		
dt	30 s	10 s	0.2 s
grid nest ratio	1	3	21
time step ratio	1	3	50

Large nest ratios bypass the *terra incognita* (gray zone)

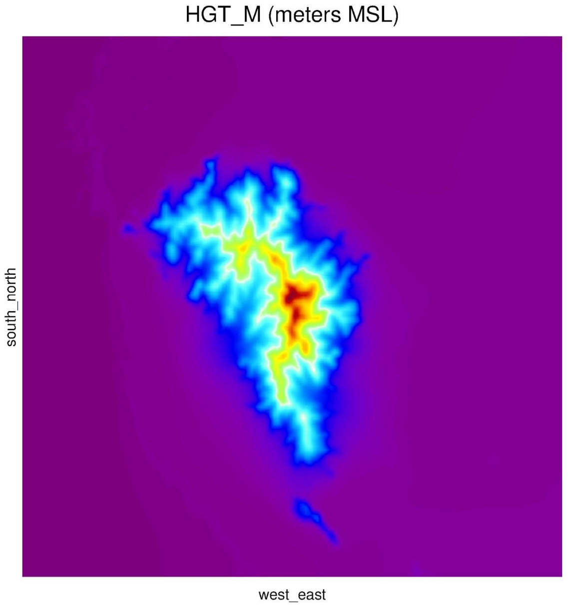


High res inputs: Topography

wrf out-of-the-box: 30s



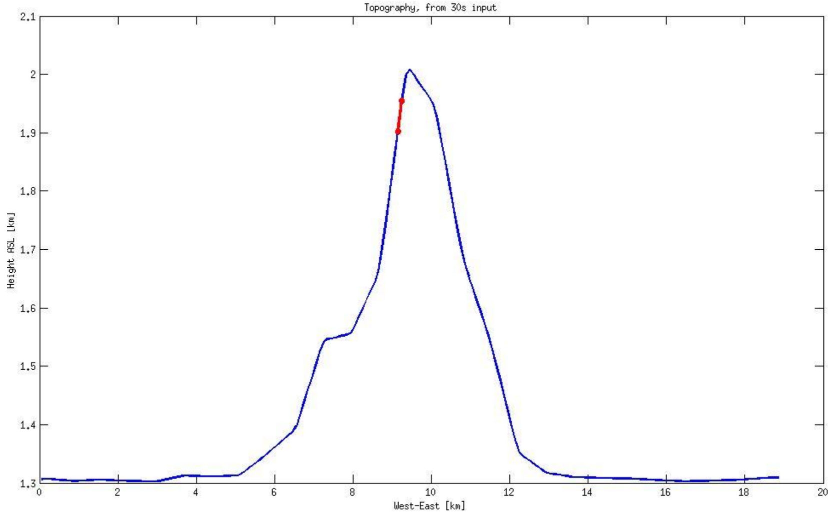
⅓ arcsecond topography from National Elevation Dataset



High res inputs: Topography

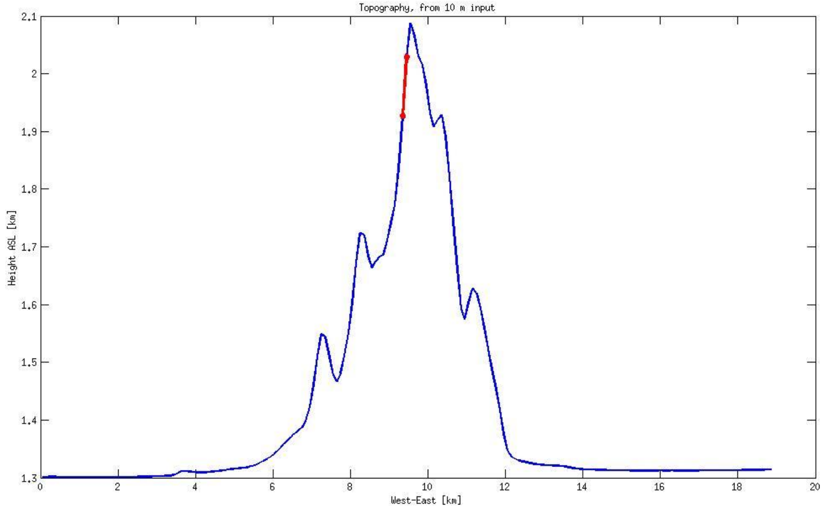
wrf out-of-the-box: 30s

max slope: 30 deg



⅓ arcsecond topography from National Elevation Dataset

max slope: 45 deg

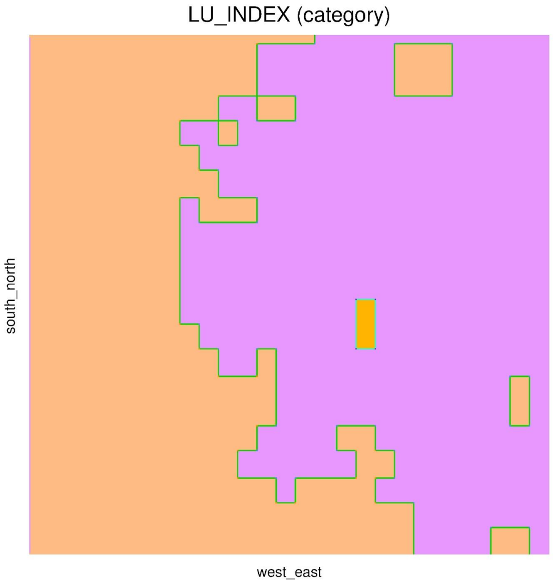


High res topographic input recreates complex terrain and leads to greater slopes

High res inputs: Land cover

wrf out-of-the-box:

30s NLCD Landuse

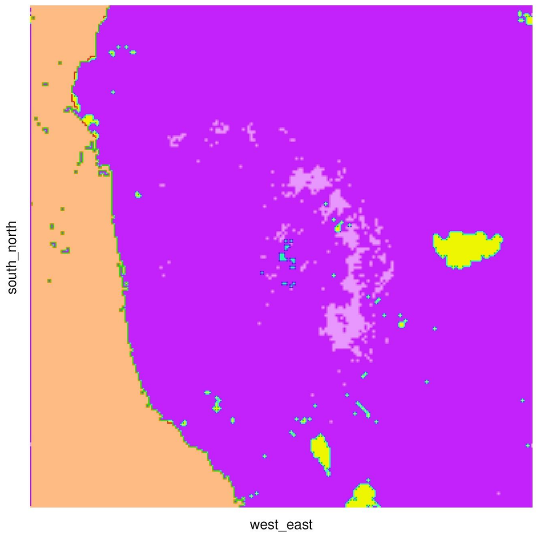


1s land use from NLCD

Additional land use categories:

Lava, Playa & White Sand

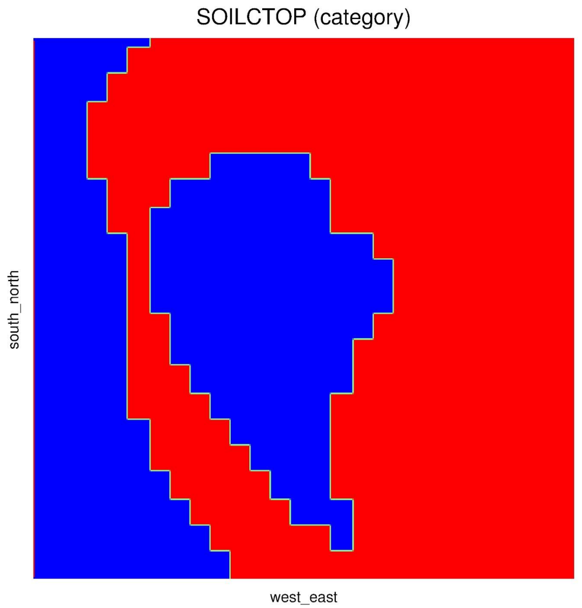
(as in Massey et al. 2014)



High res inputs: Soil type

Input	d01 (6.3 km)	d02 (2.1 km)	d03 (100 m)
Topo	30 s (~1 km)	3 s (~100 m)	⅓ s (~10 m)
Land Cover	30 s (~1 km)	1 s (~30 m)	1 s (30 m)
Soil type	30 s (~1 km)	30 s (~1 km)	30 s (~1 km)

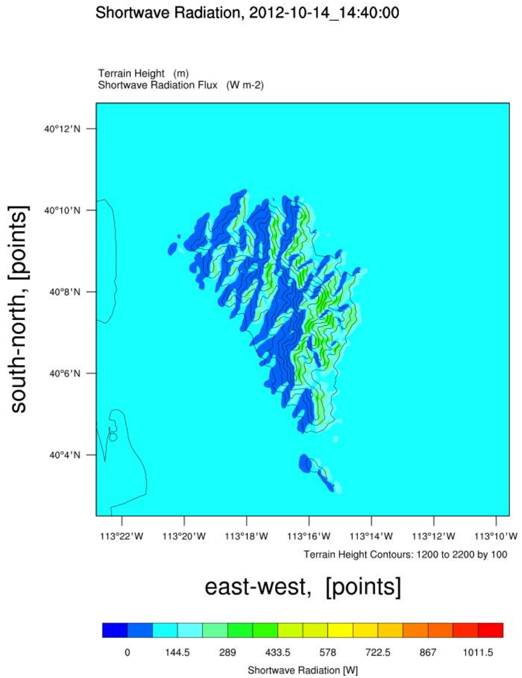
soil type resolution is not increased, lava and white sand have been added



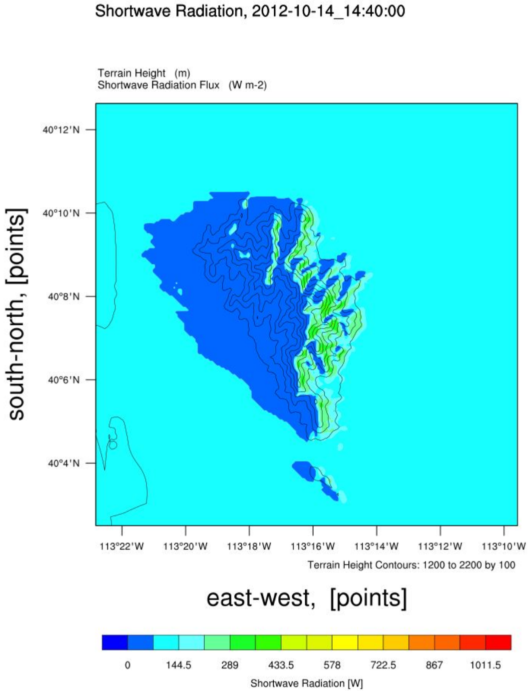
Example Soil type level

High res configurations

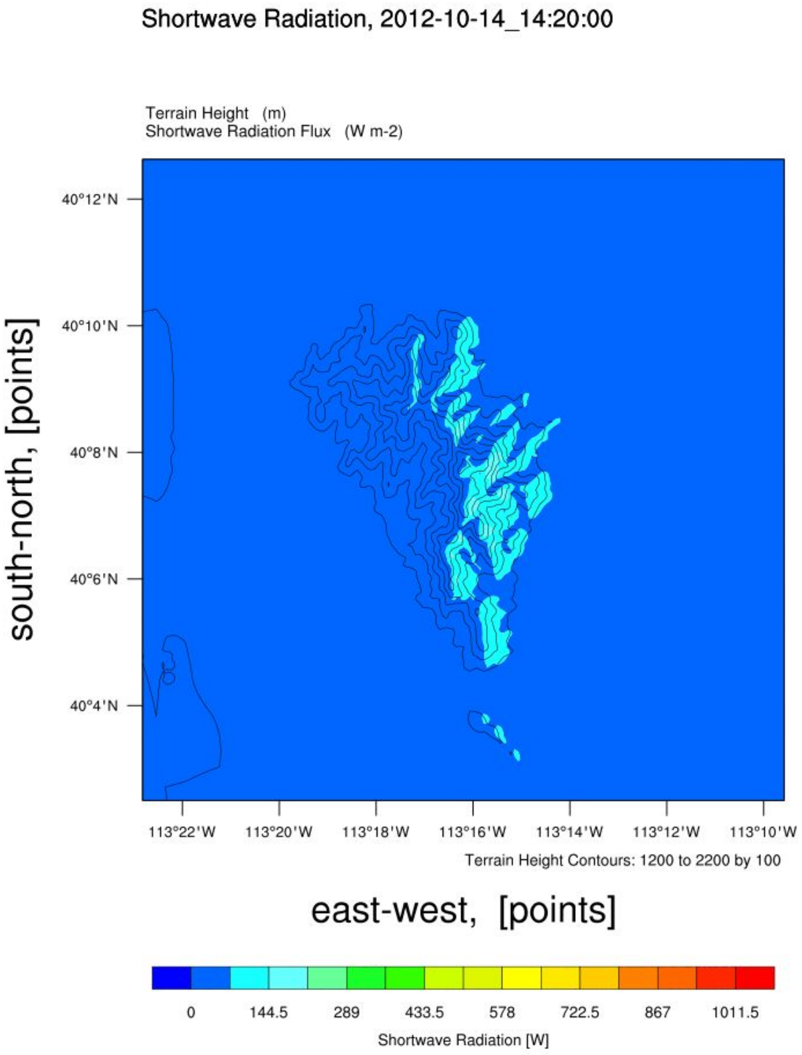
no topographic shading



SW with topographic shading



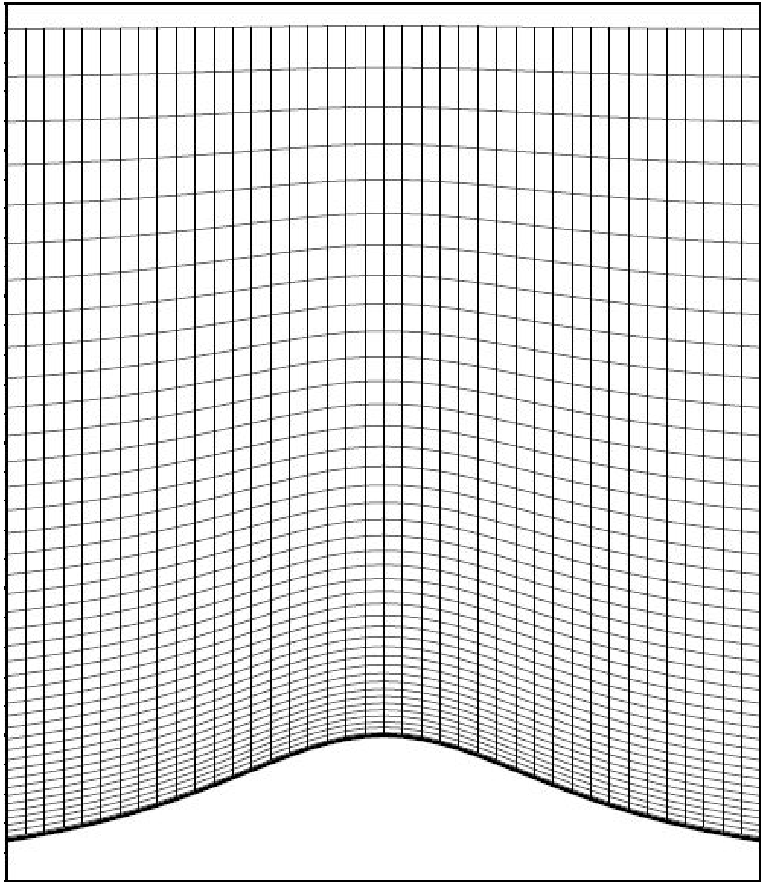
WRF can include effects of shadows, important in complex terrain



XY contour of SW rad

during IOP 6, 02 MDT 10/14/'12 -
02 MDT 10/15/'12

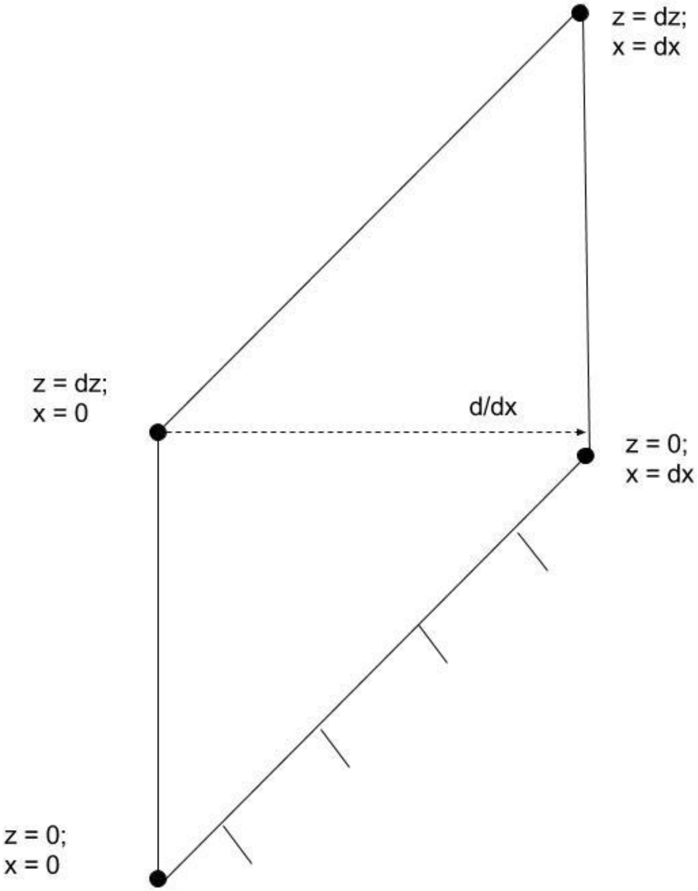
Terrain following coordinates



pressure based vertical coordinates

non-orthogonal grids lines

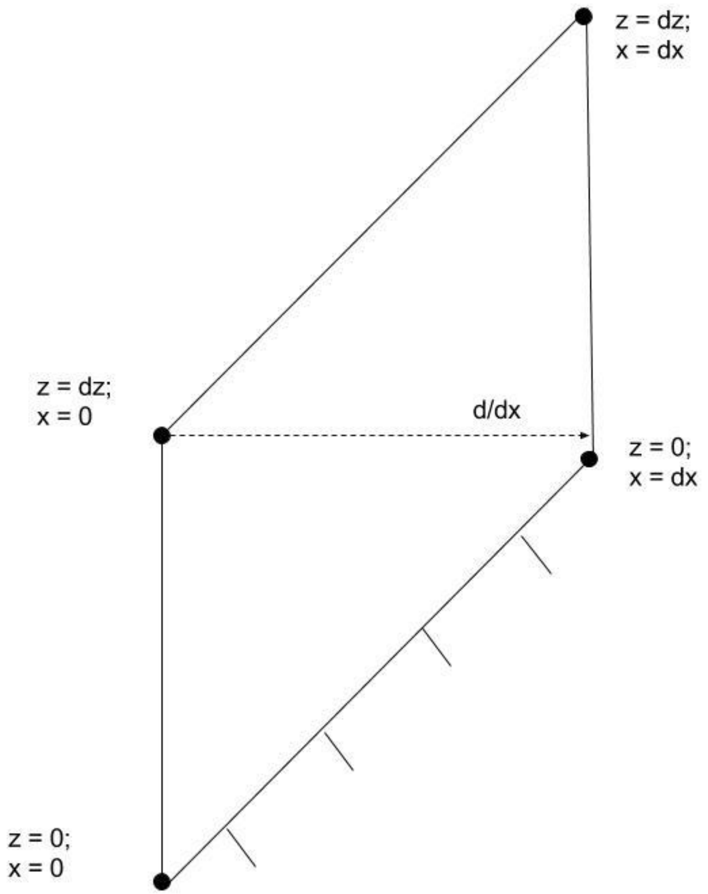
Slope aspect ratio

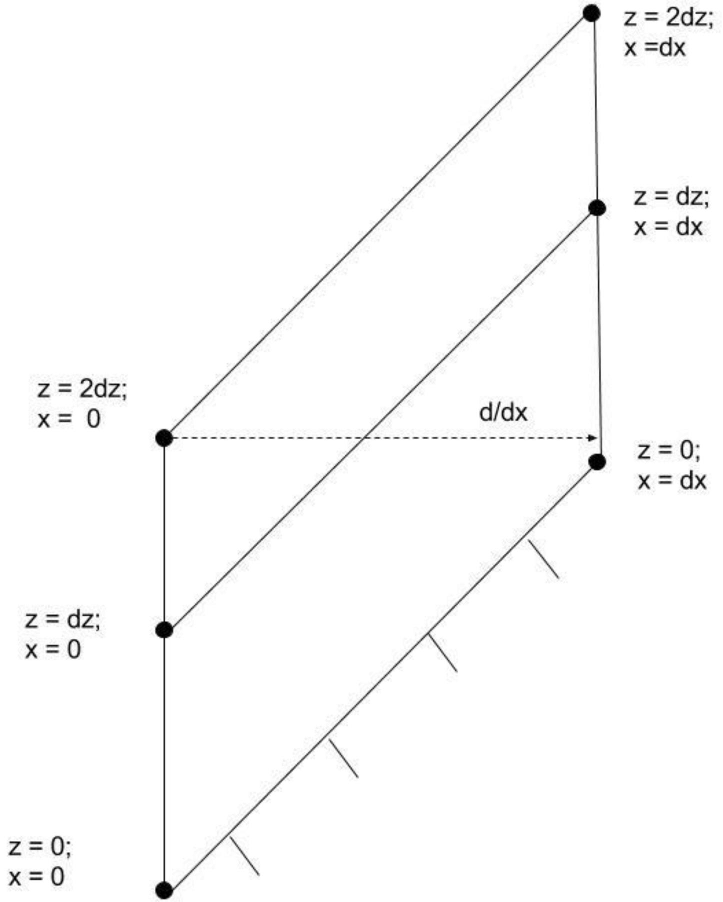


true derivative, d/dx, is bounded by single cell

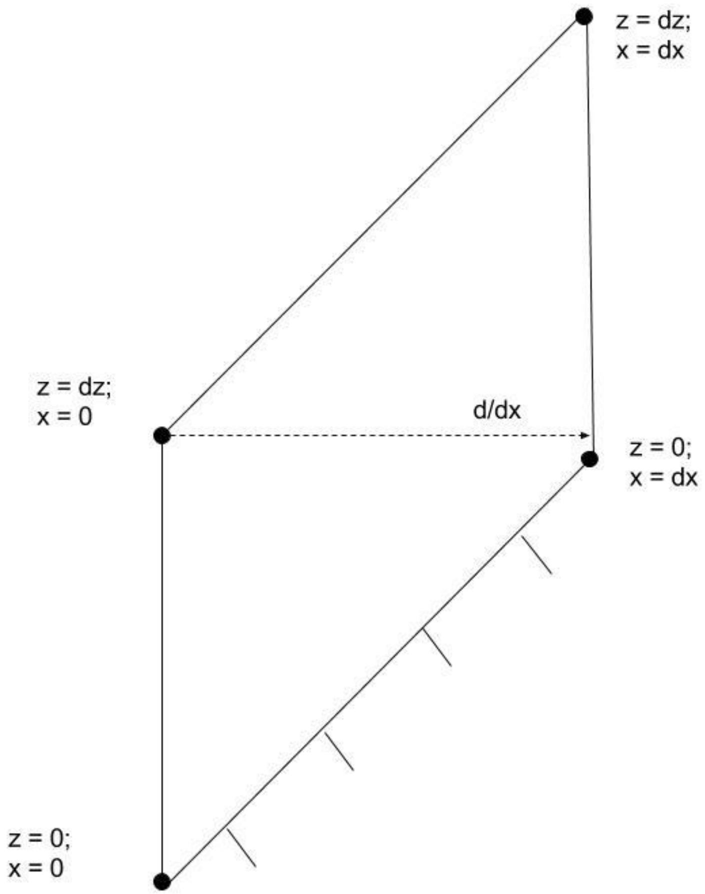
metric term errors arise, but will stay bounded

Slope aspect ratio





Slope aspect ratio

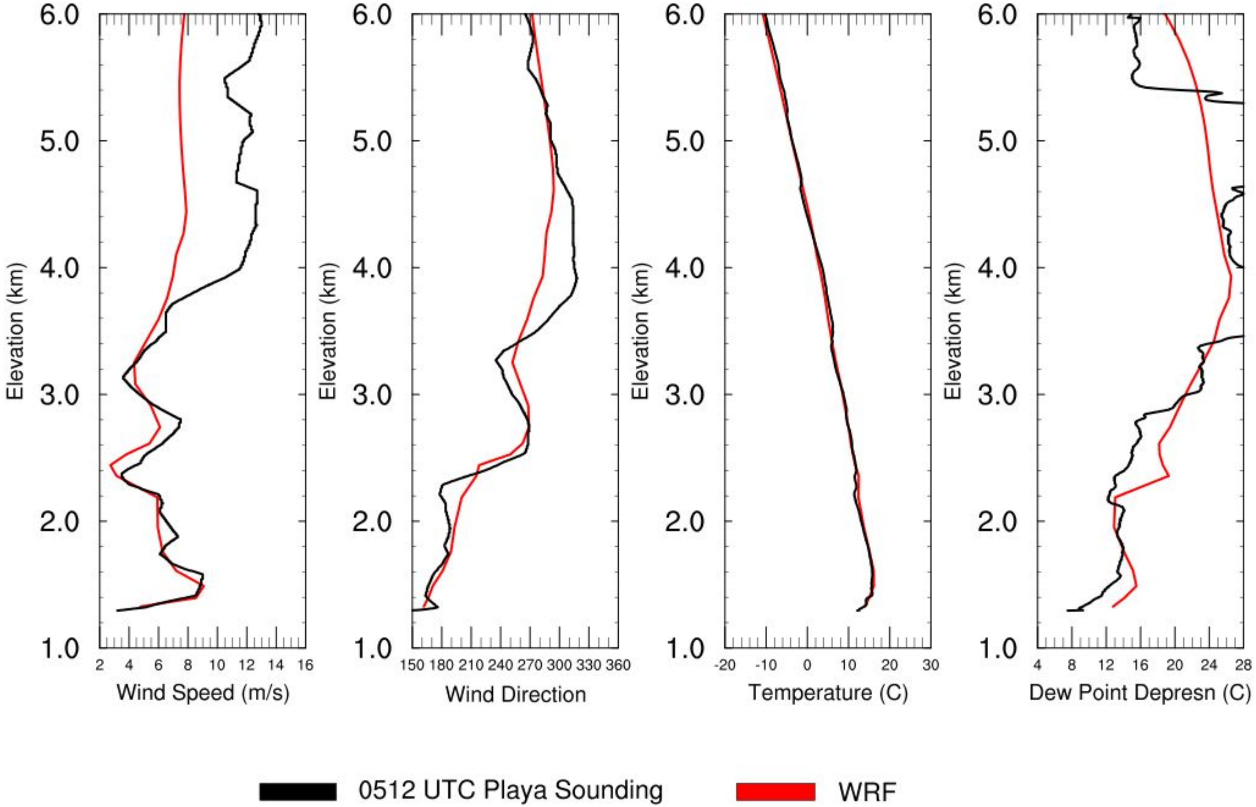


slope < arctan(b * dz/dx)

b ~ 1 to 5

Mahrer 1984

Comparison with observations

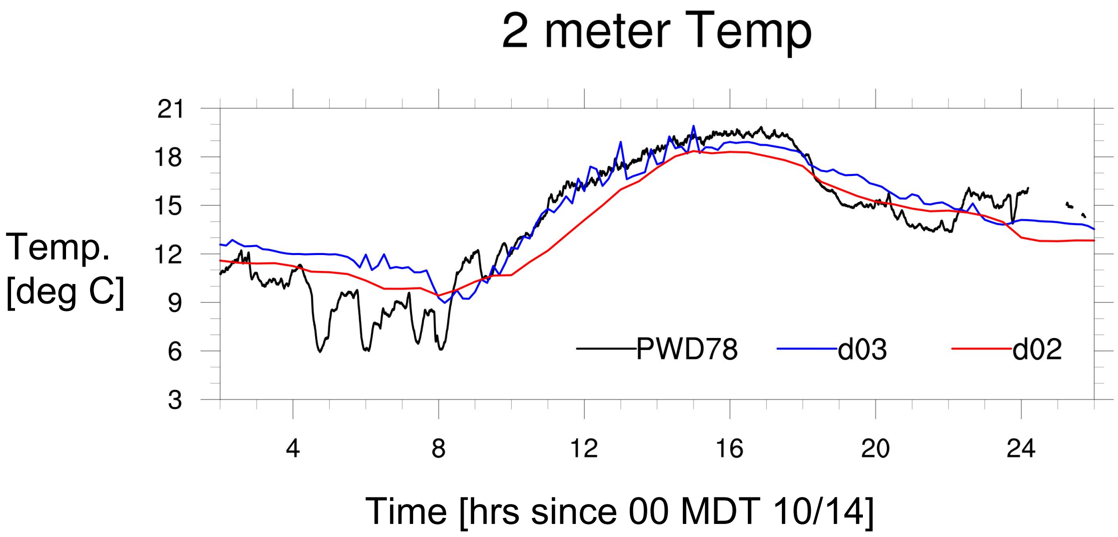


Surface time series - east slope

PWD78 on East Slope

not resolving dips in T2 during cold pool sloshing

not resolving quick drop in temperature as shadow front passes at ~1800 to 1900 MDT



Surface time series - valley

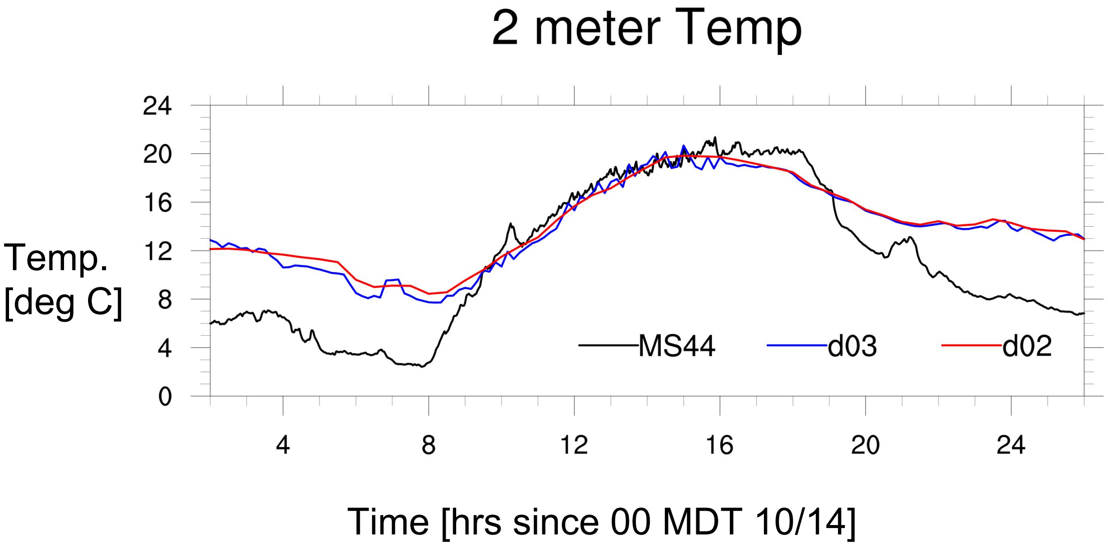
MS44 in valley to the east

no cold pool leads to large magnitudes of error

Problem: Mesoscale solution is recreated on LES domain

Possible Solutions:

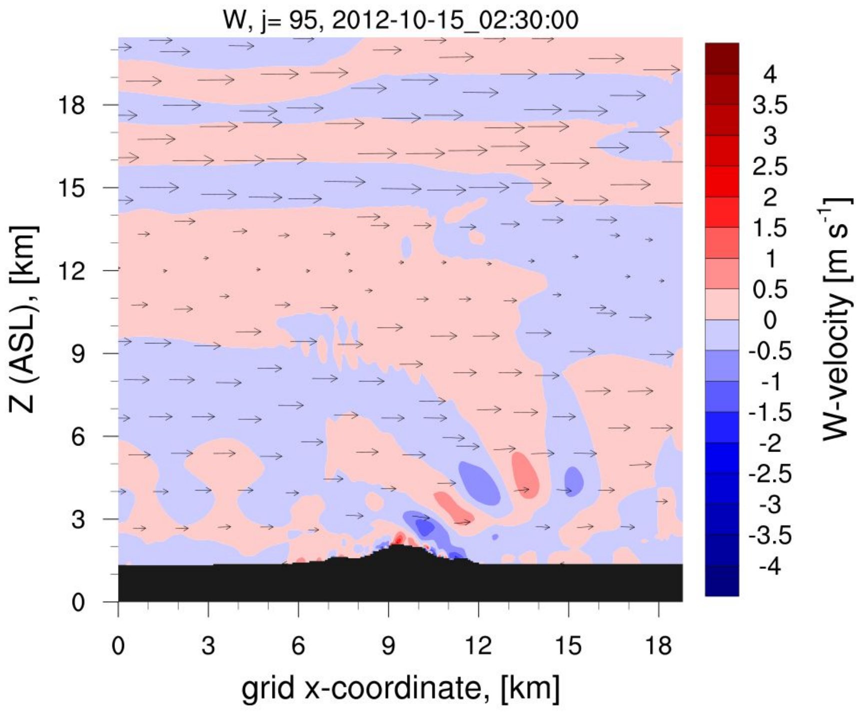
- larger LES domain
- finer vertical resolution
- lateral boundary perturbations



Small scale features

Are we resolving small scale motion on the LES domain?

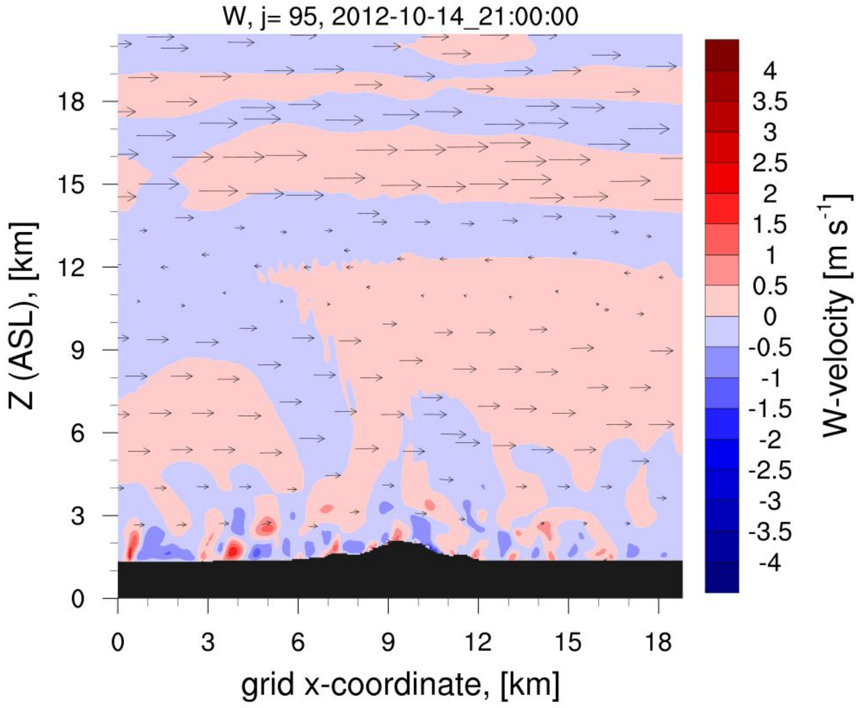
At night time, lee waves are resolved

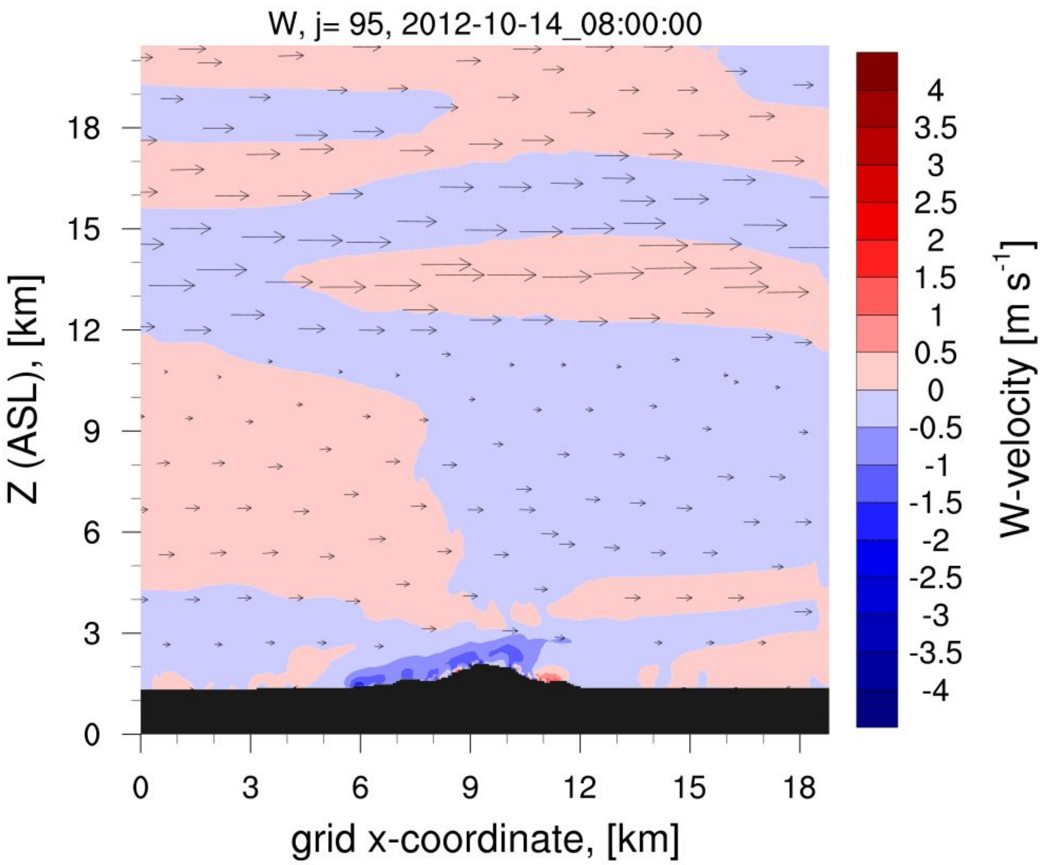


Small scale features

Are we resolving small scale motion on
 the LES domain?

During day time, thermal cells resolved



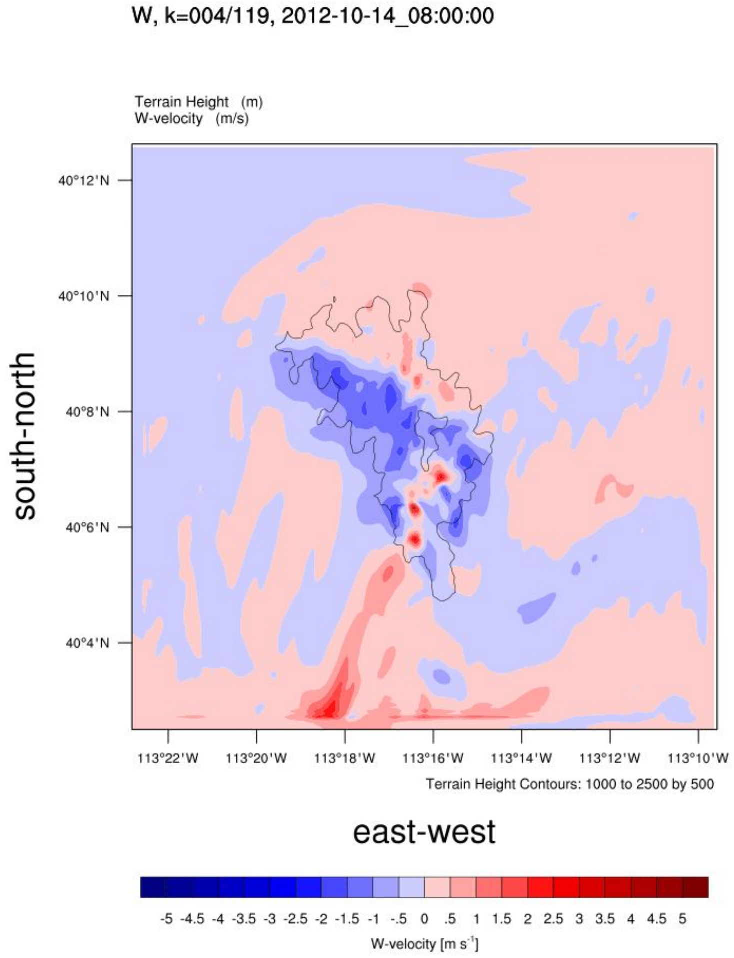


XZ contour of vertical velocity

during IOP 6:
02 MDT 10/14/'12 -
02 MDT 10/15/'12

Day: thermal plumes resolved

Night: lee waves resolved



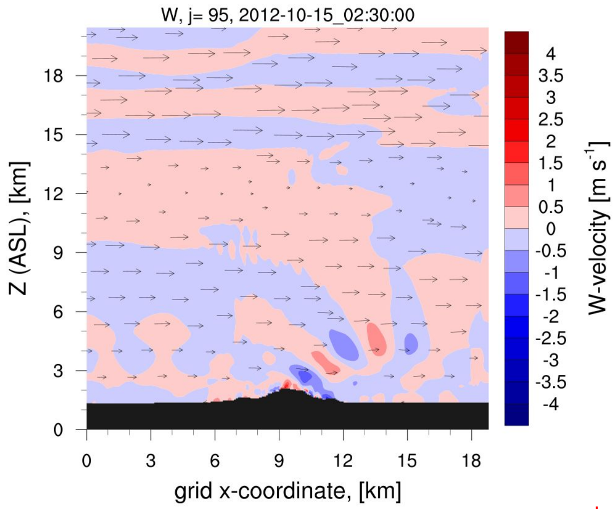
XY contour of vertical velocity

during IOP 6:
02 MDT 10/14/'12 -
02 MDT 10/15/'12

Day: thermal plumes resolved

Night: lee waves resolved

Conclusions



Successes:

WRF can run at 100 meters resolution over steep terrain,

~45 deg max slope, without blowing up if

i) vertical resolutions are sufficiently coarse and

ii) time steps are sufficiently small

Grey zone issues can be avoided through a nested approach

Take Home Message:

WRF-LES can resolve the small scale features of mountain micrometeorology

Future work

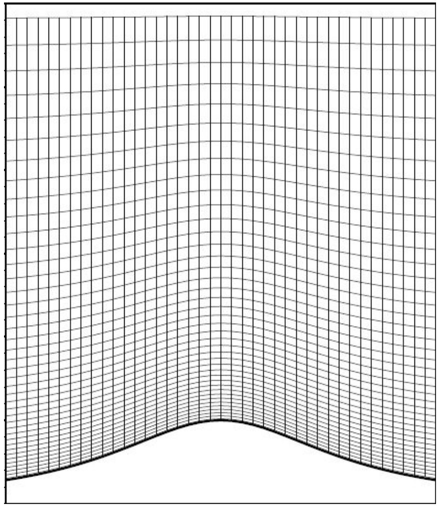
Ongoing challenge: better agreement with surface observations, sloshing, temperature biases.

May need to develop turbulence on LES domain with

- Larger domain
- Improved vertical resolution
- Lateral boundary perturbations

while considering

- Computational costs
- Slope aspect ratios



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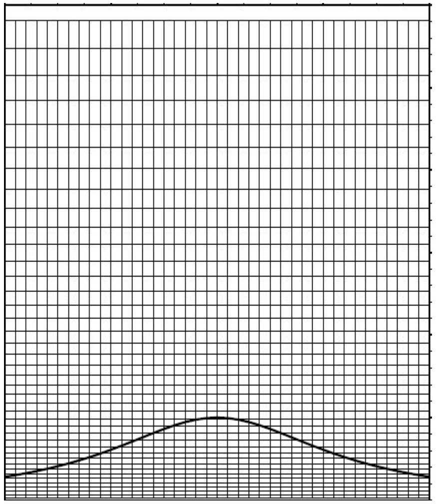


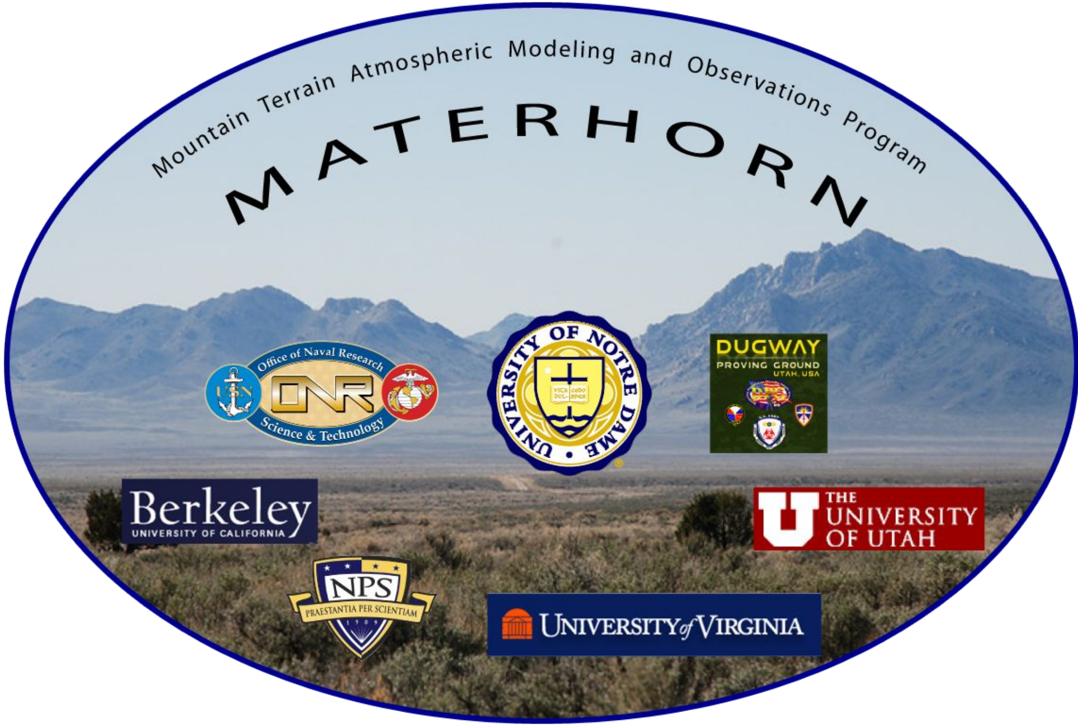
Take Home Message:

Difficulty resolving near surface variables, for a practical computational cost and without violating slope aspect stability limits, makes a good case for IBM-WRF.

Acknowledgments

ONR MURI
MATERHORN

Thanks to Massey et al. for land cover data!

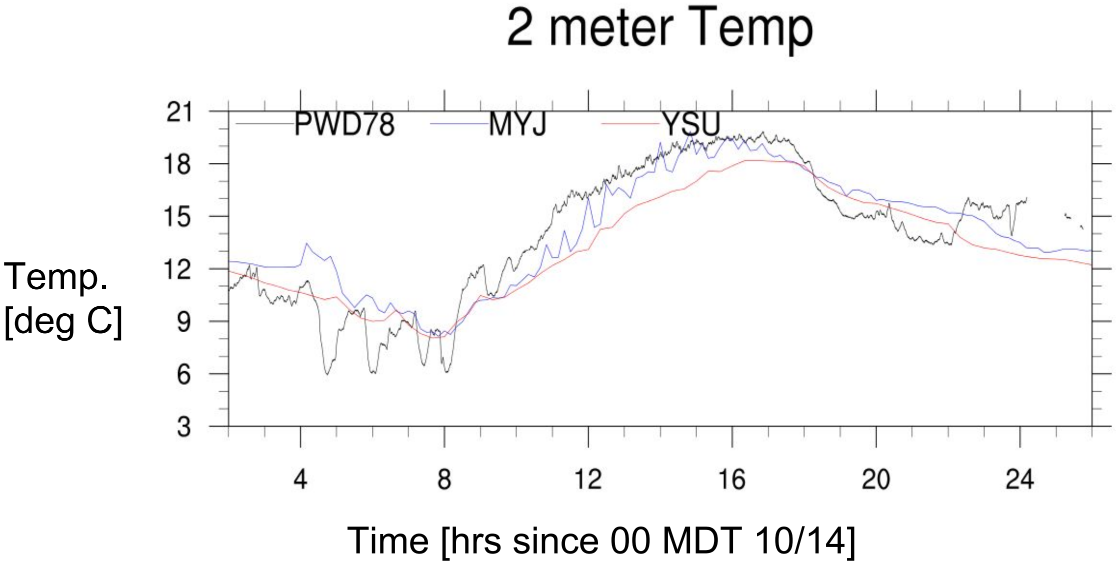


PBL closures

MYJ

vs

YSU



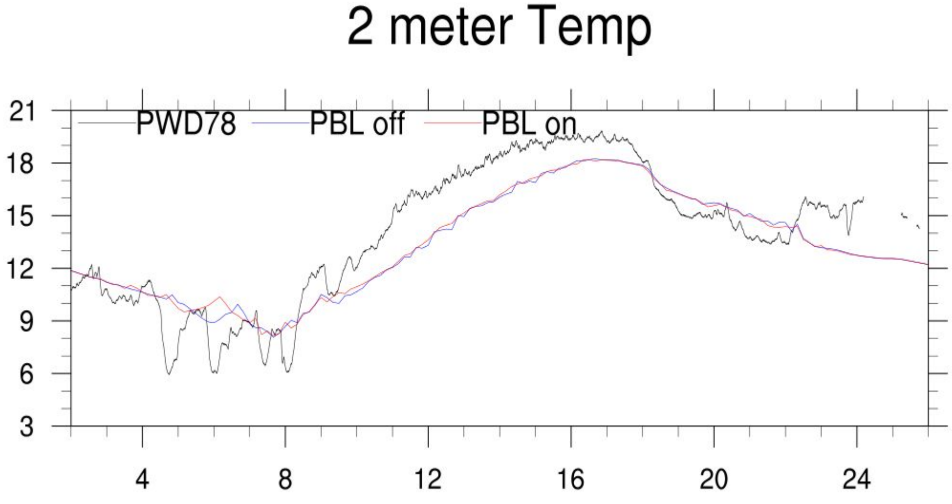
For complex terrain, MYJ (local scheme) outperforms YSU (non-local)

LES closures

TKE 1.5

vs

TKE 1.5
and MYJ



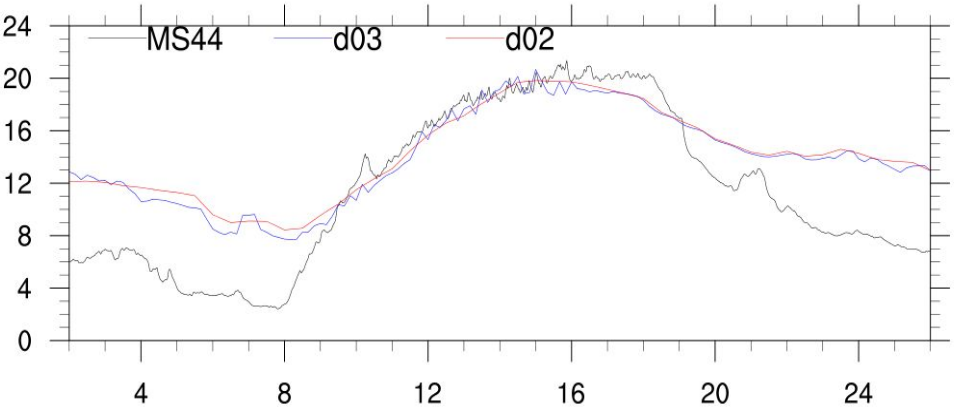
Temp.
[deg C]

Time [hrs since 00 MDT 10/14]

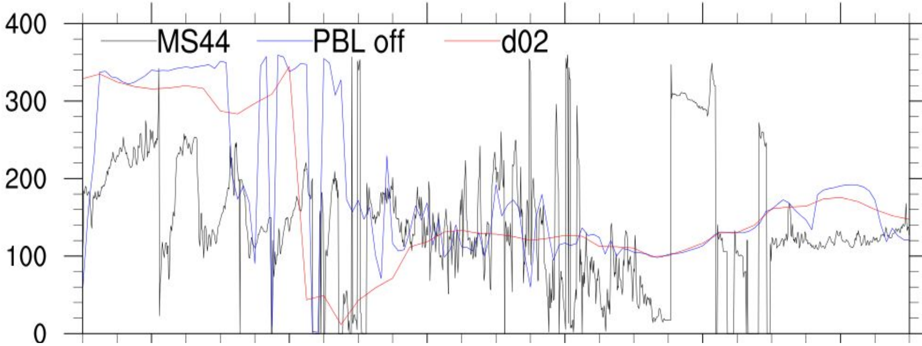
PBL vs LES

PBL domains' solutions for surface variables are recreated on LES domain

2 m Temp



Wind Direction



Wind Speed