MATERHORN LES Updates

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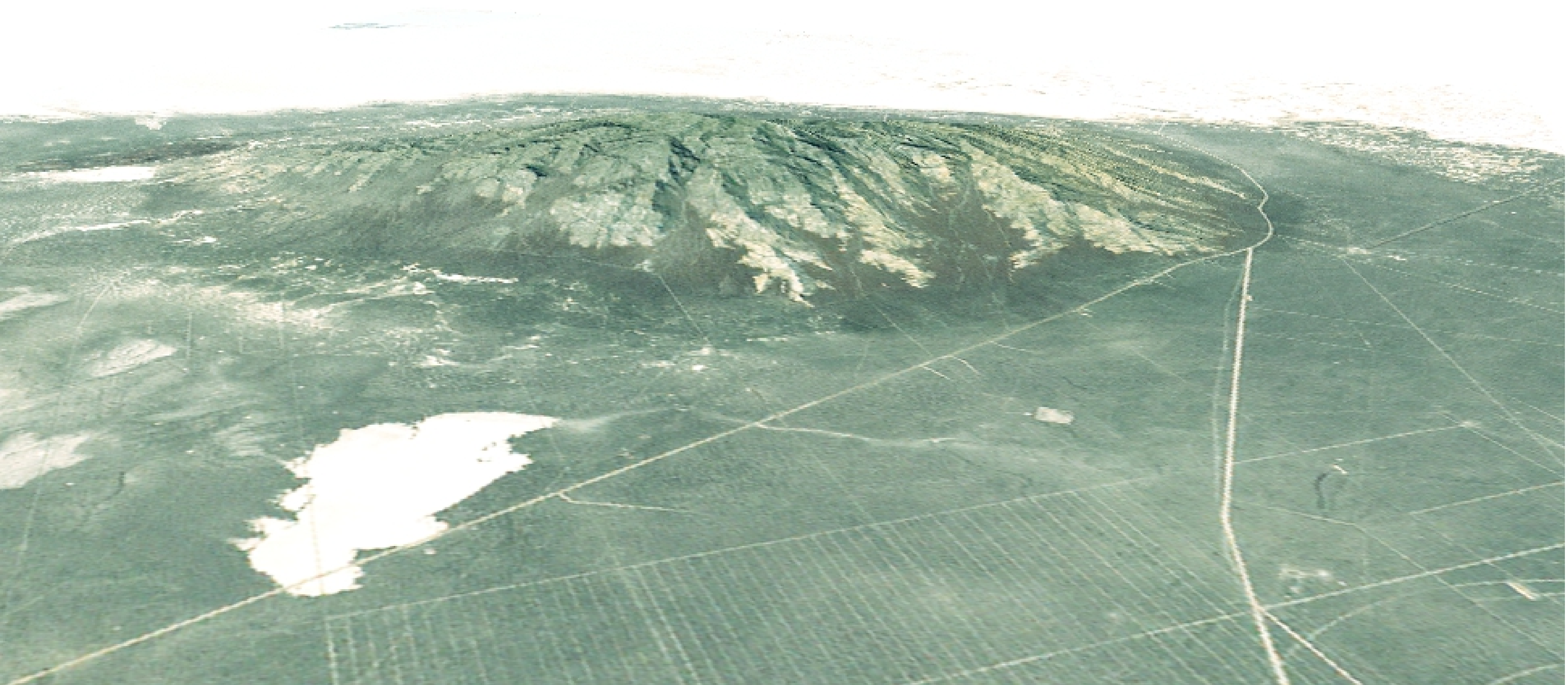
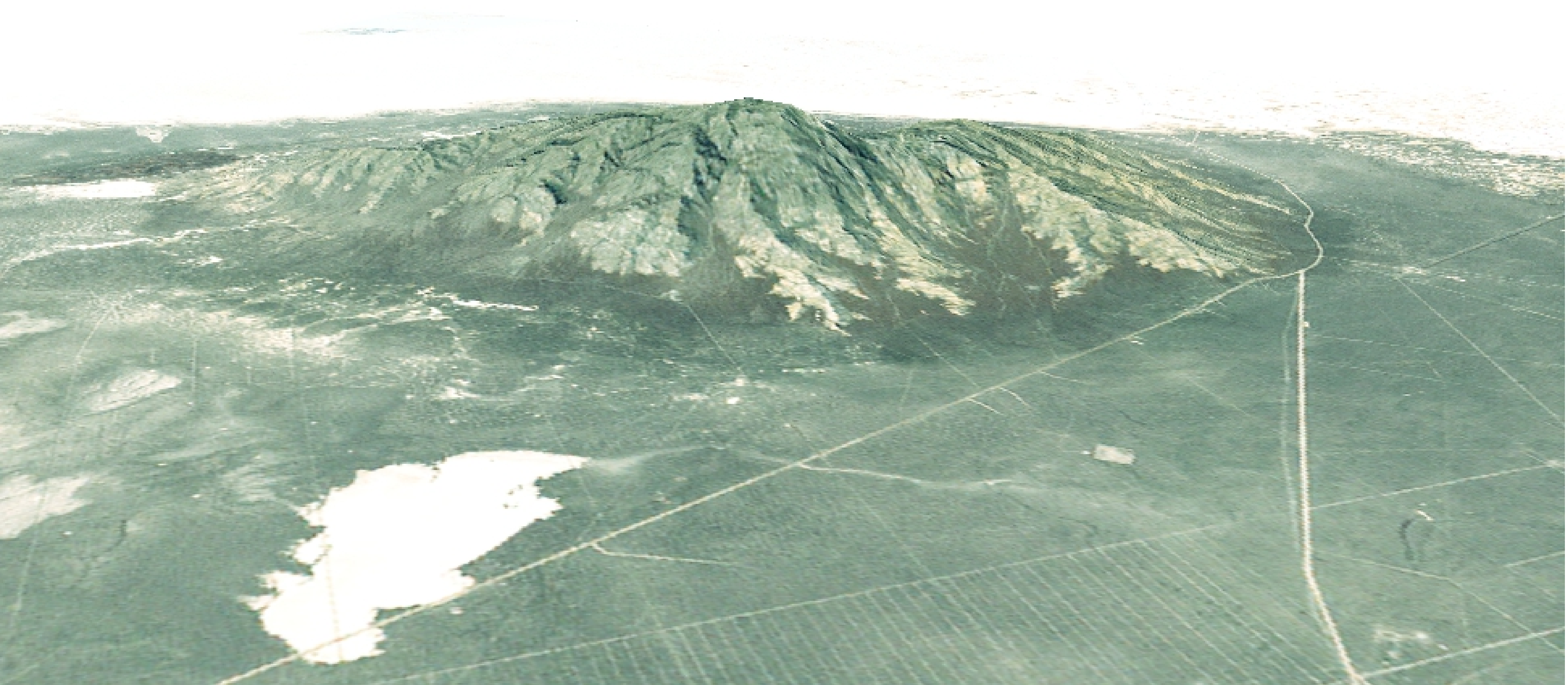
Motivation

- Different models for different scales
  - Mesoscale codes: mesoscale
  - LES codes: microscale
- Want a single model for all scales
  - Nest from mesoscale to microscale
  - Handle complex terrain (GMAST)

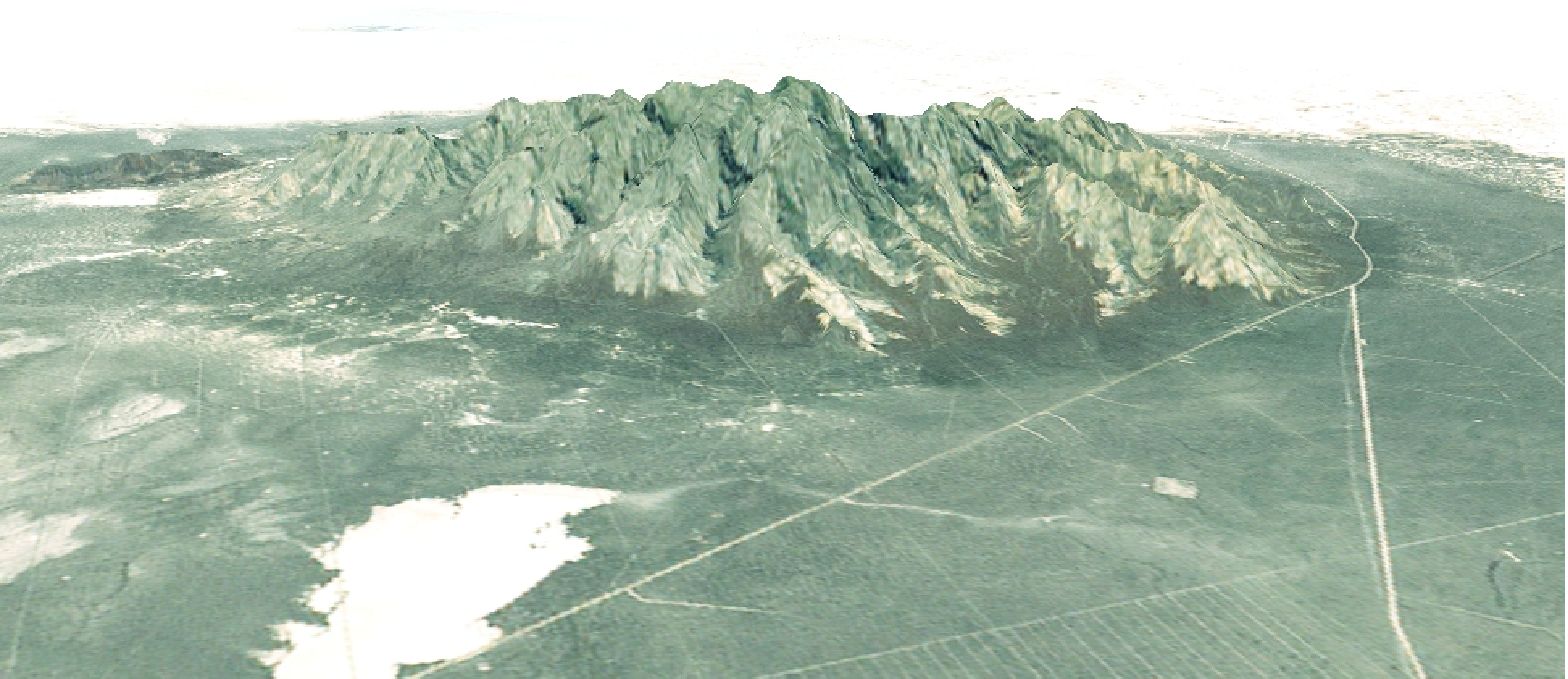
dx = 1000m
max slope = 13°
z-axis scaled by 2



dx = 500m
max slope = 20°
z-axis scaled by 2

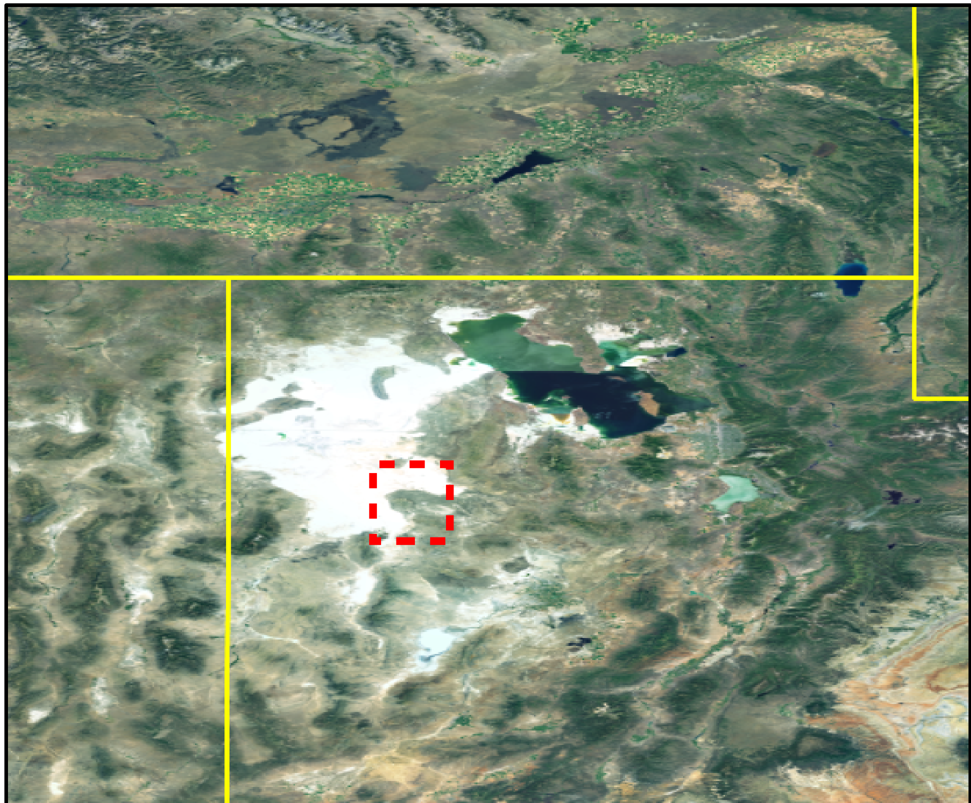


dx = 50m
max slope = 86°
z-axis scaled by 2



Mesoscale Models

- Atmospheric physics
- Terrain-following coordinates
  - Coarse only
- Sophisticated lateral boundaries
- Limited by resolution (computationally)

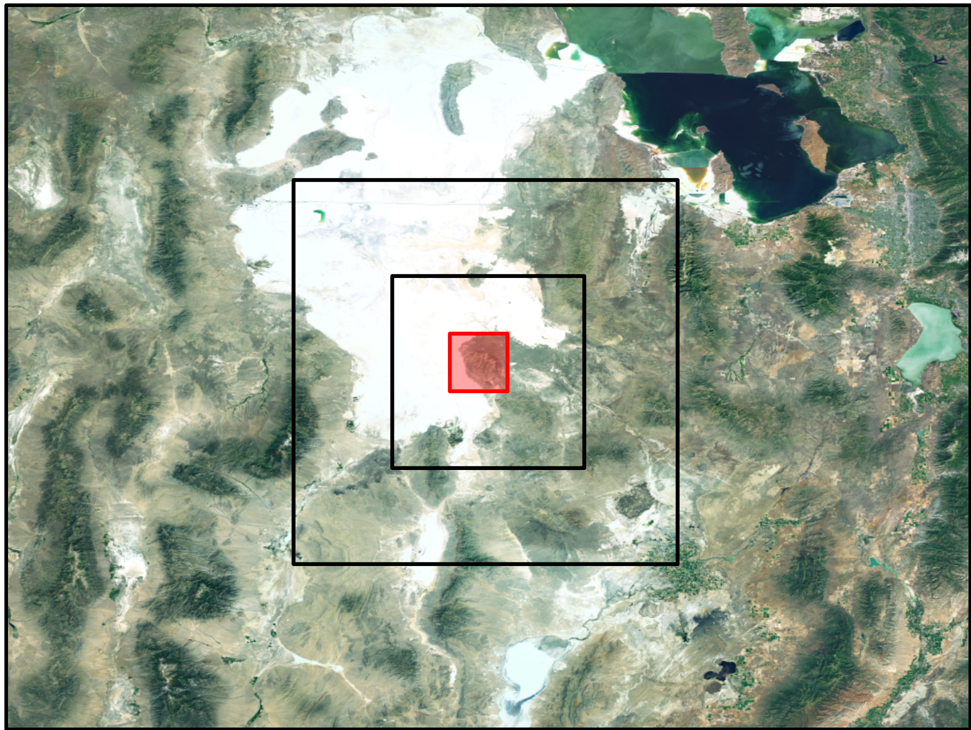


Microscale Models

- Large-eddy simulation (LES)
- Limited atmospheric physics
- Sophisticated bottom boundary
  - High resolution, complex terrain
- Simple lateral boundaries
- Limited by domain size (computationally)

Single Model

- Push these two model-types together
  - Mesoscale models -> finer resolution
    - Terrain-following coordinates an issue
  - LES models -> larger domains

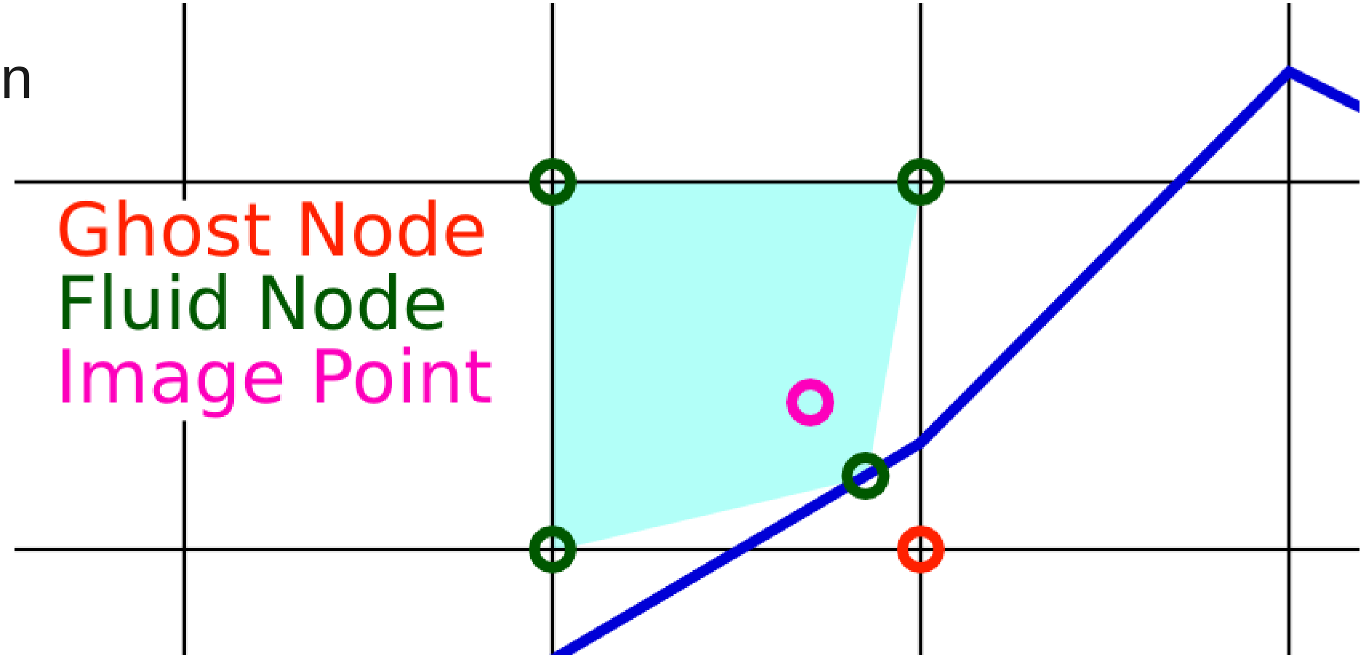


WRF/IBM-WRF Framework

- WRF: Weather Research and Forecasting model
  - Capable as mesoscale *or* LES code
- IBM-WRF (Lundquist et al. 2010, 2012)
  - WRF + immersed boundary method (IBM)
  - Same model; just a switch
    - Nesting possible
- Excellent candidate for single model

IBM (as seen in WRF)

- Nodes just below surface are ghost nodes
- Ghost nodes reflected across the boundary (image point)
- Image point value found
  - Interpolated from nearest fluid nodes
  - Two interpolation options (bi/trilinear, inverse distance weighted)
- Ghost node value found
  - Linear interpolation between image, boundary and ghost node

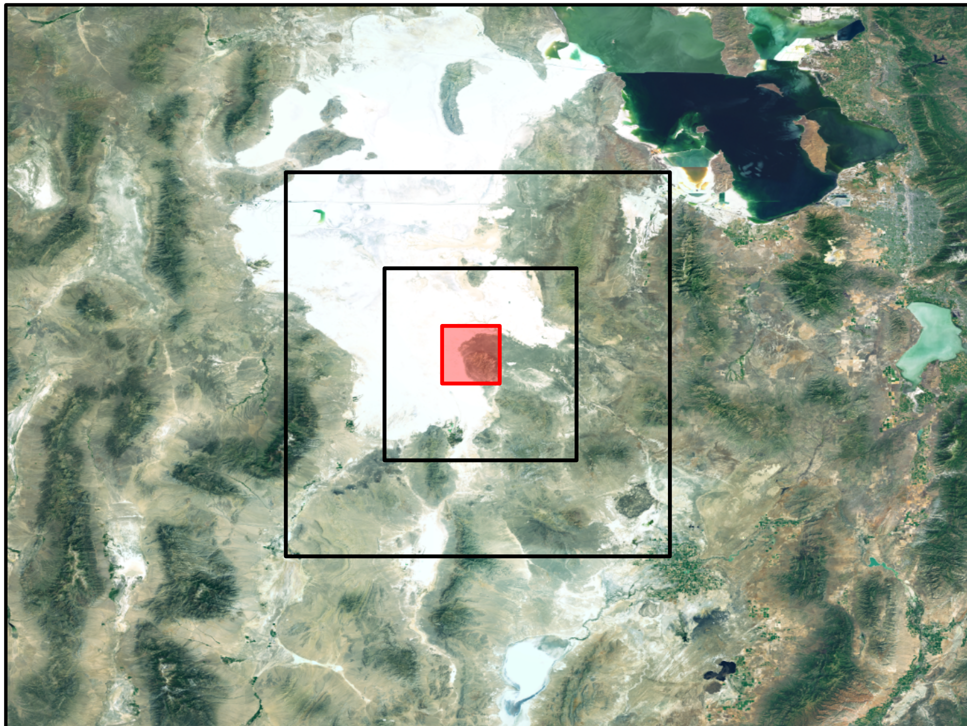


Questions for WRF/IBM-WRF

- Where should switch occur?
  - Quality vs. performance tradeoff
- Quantify impact of terrain on WRF
  - GMAST for now
  - Generalizable in the future

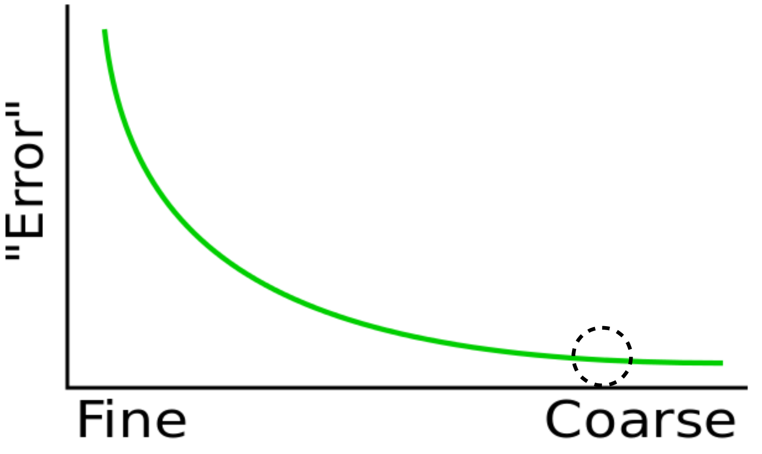
The Handoff

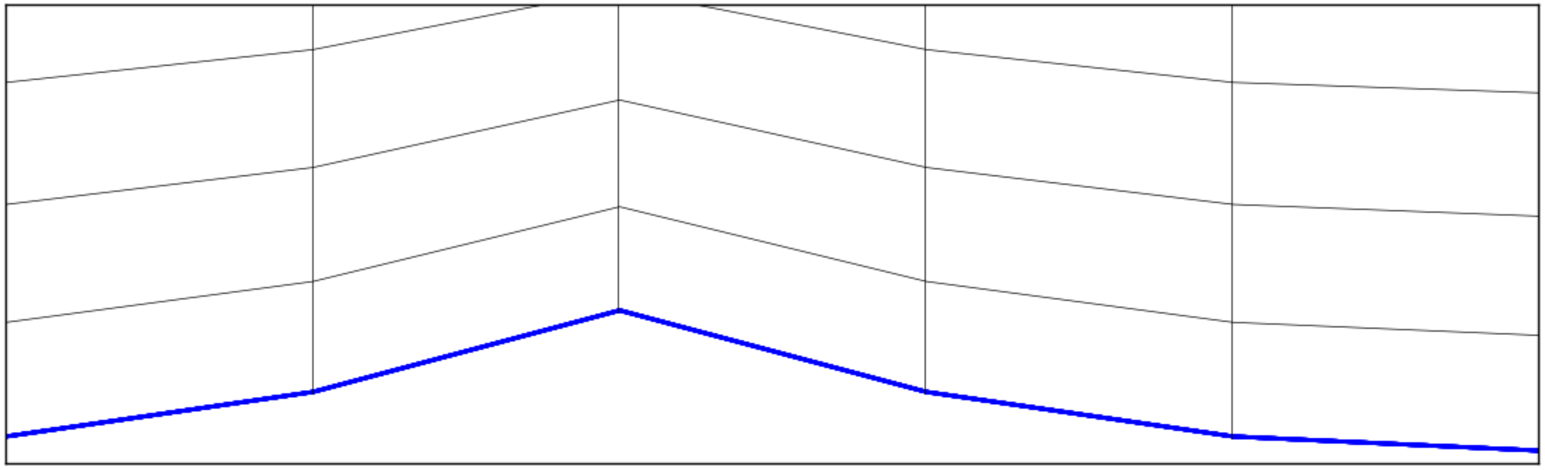
- Must switch from WRF to IBM-WRF eventually
- When to switch? Complex question
  - Resolution, steepness, aspect ratio, turbulence closure
  - Want to answer *generally*
    - Not only for GMAST



WRF Alone

- Coarse resolution
  - smooth terrain
  - low error
- Fine resolution
  - steep terrain
  - high error





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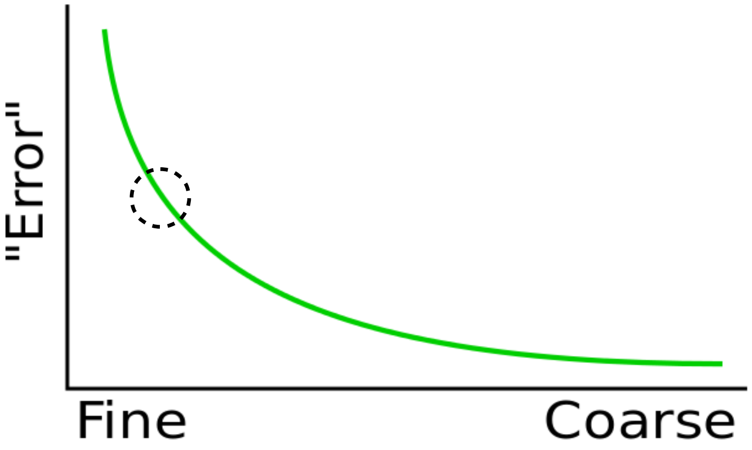
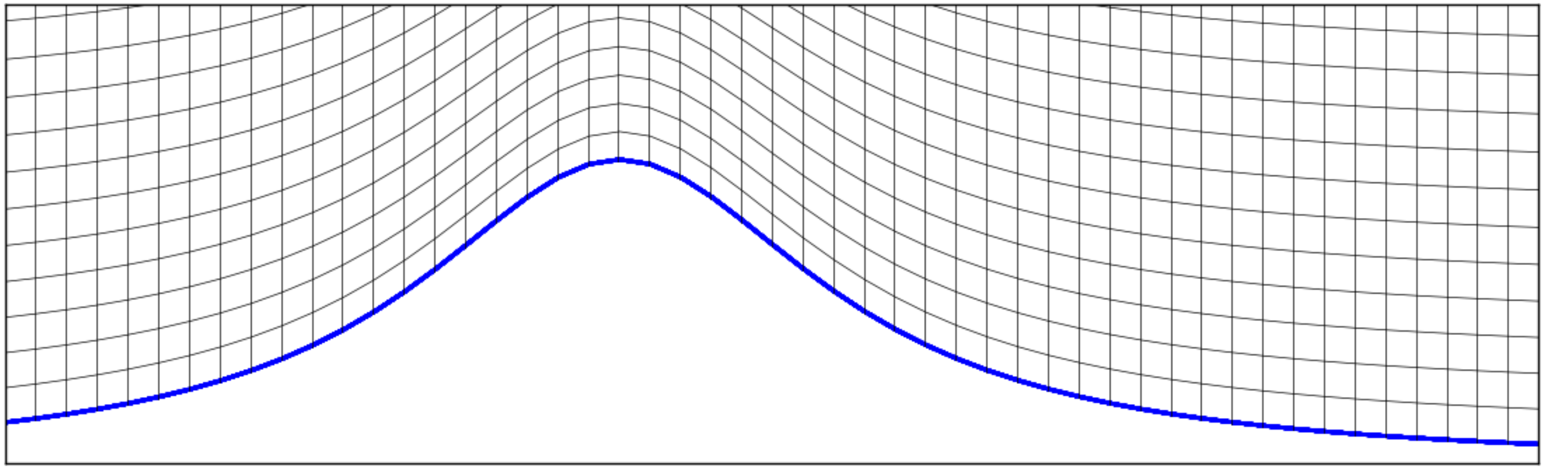
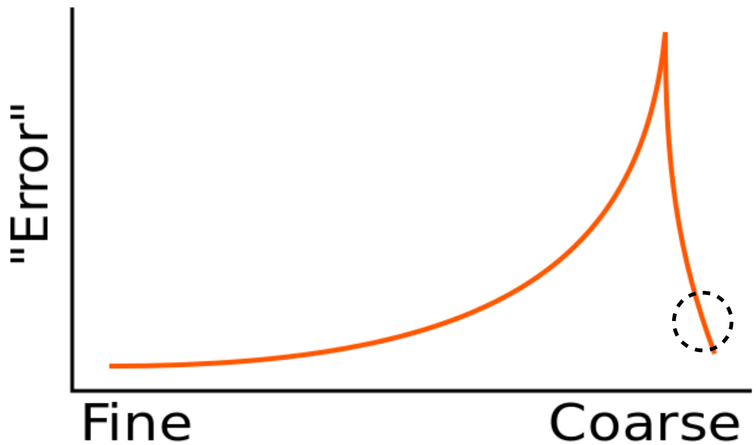
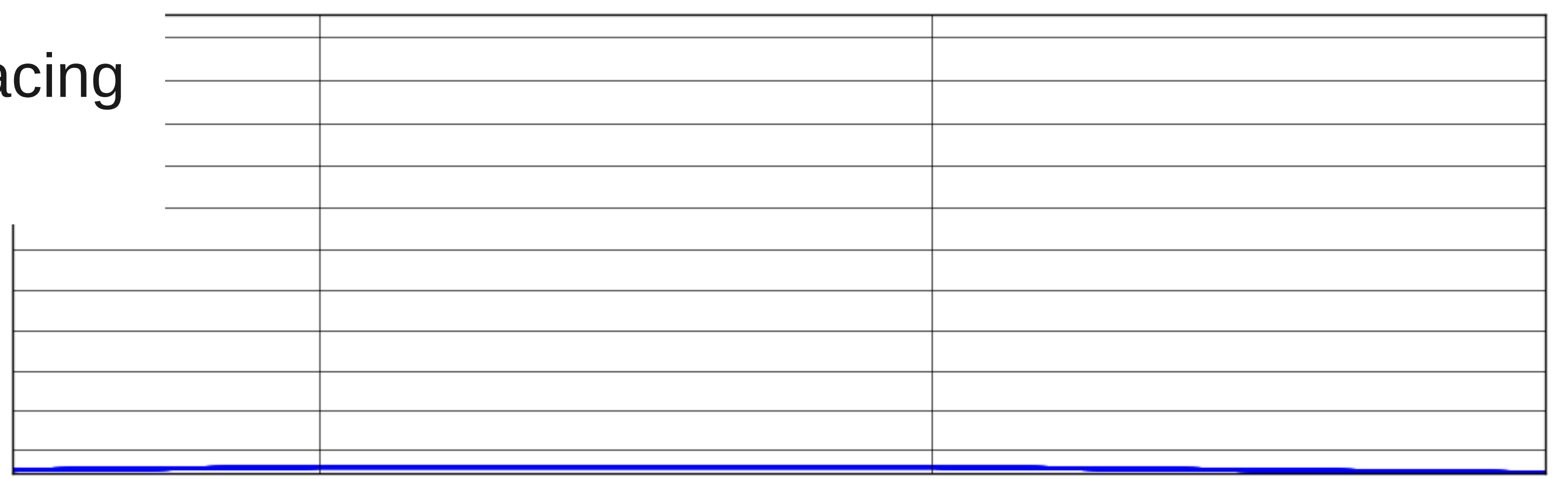




IBM-WRF Alone

- Very coarse resolution
  - grid-scale > mountain-scale (flat plate)
  - low error
- Coarse resolution
  - large spacing
  - high error (interpolation)
- Fine resolution
  - small spacing
  - low error





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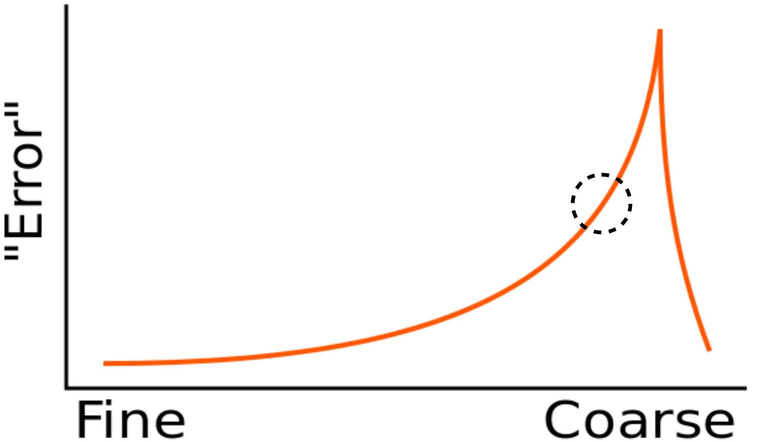

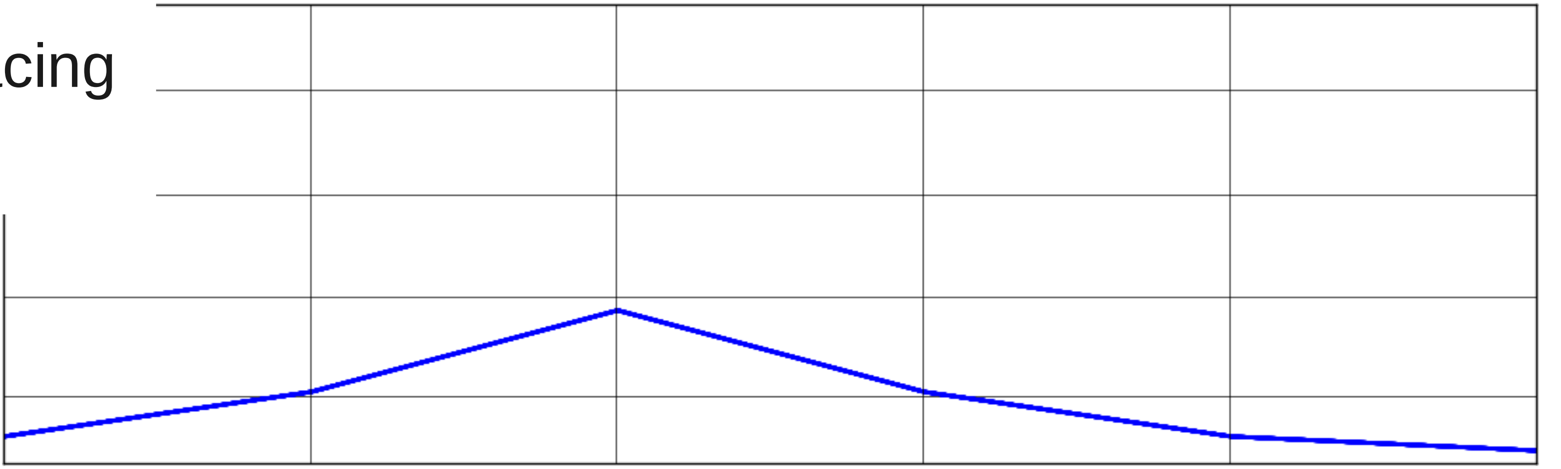

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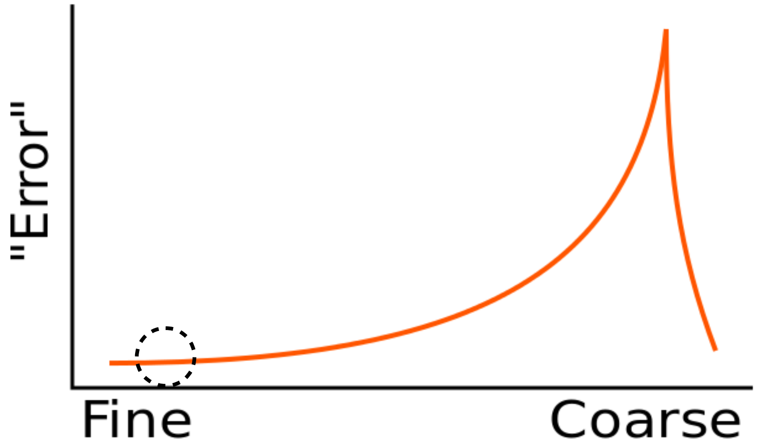
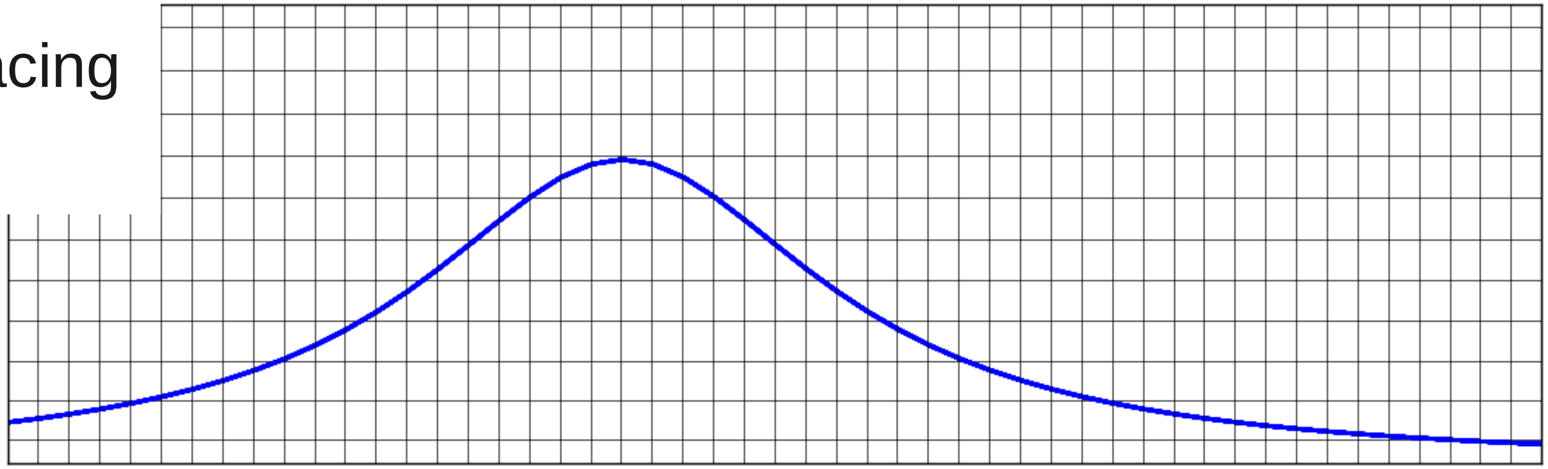
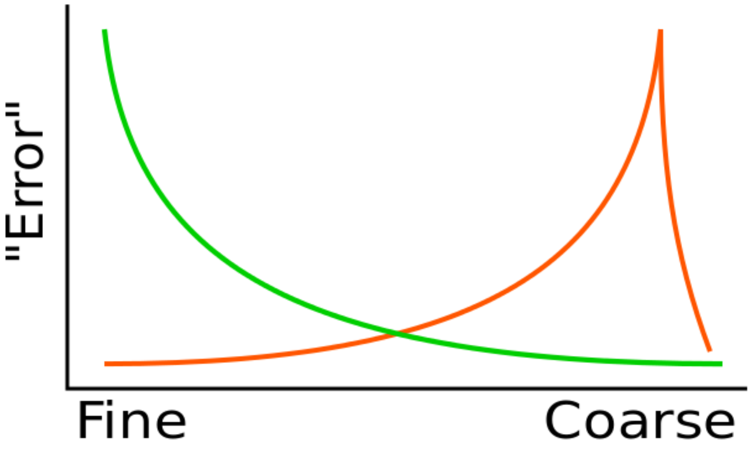




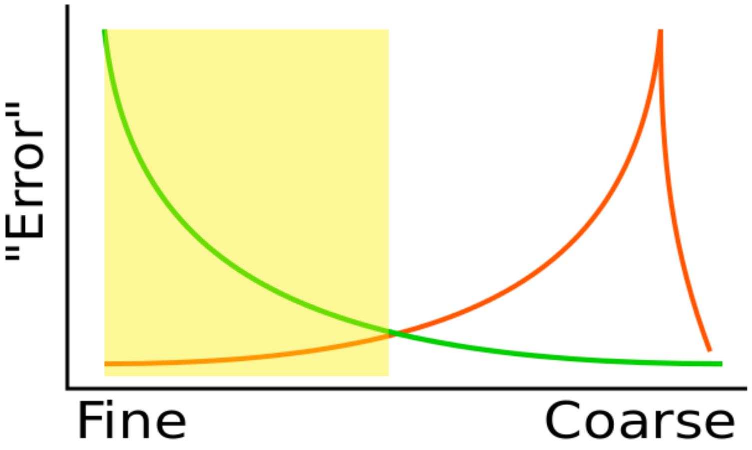
Together

- Switch at intersection for best results
- Want to develop general guidelines for this curve
  - WRF starts blowing up near 300m resolution on 2D GMAST
    - We're just getting started!



Still want slope relationship

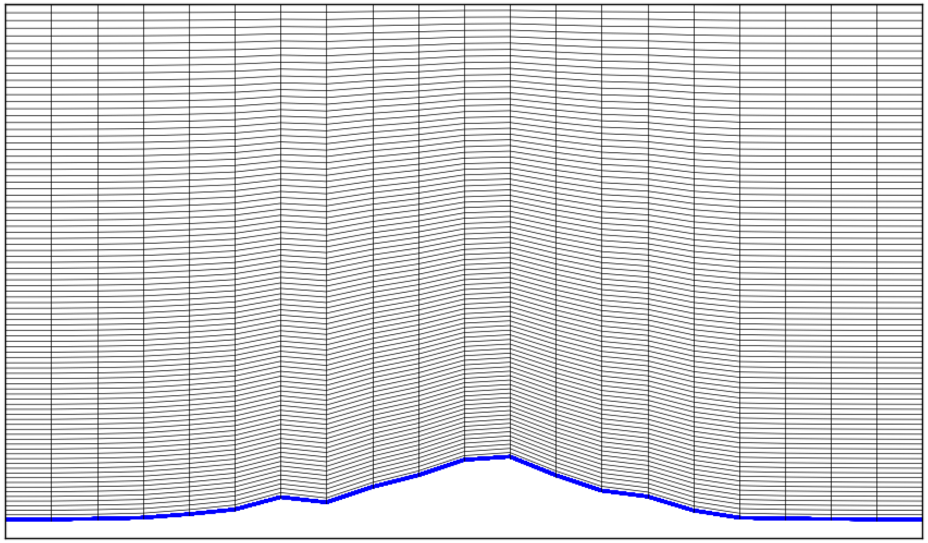
- Focus on steepness
  - Fixed resolution
  - Large, constant eddy viscosities (5 values used)
  - Scale GMAST (steepness knob)
- Find (illustrative) curve for yellow box

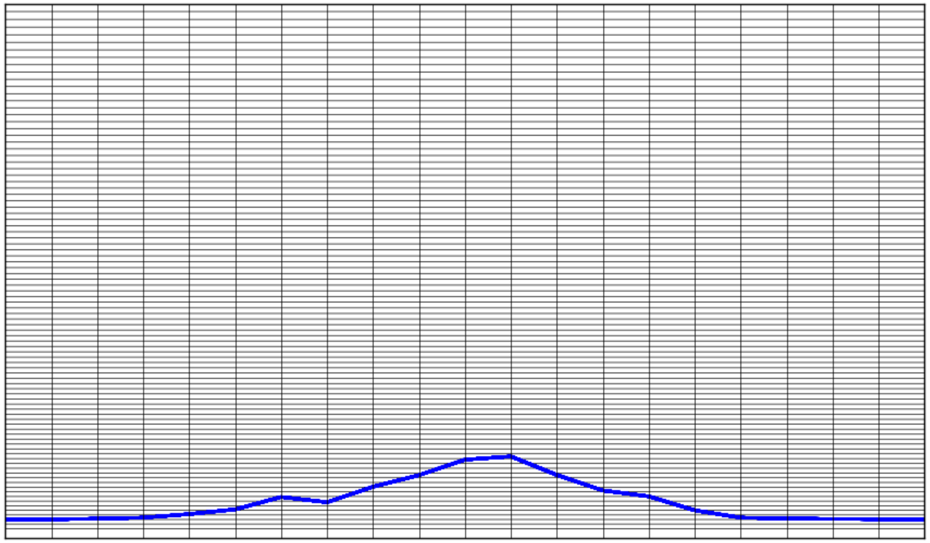


Setup

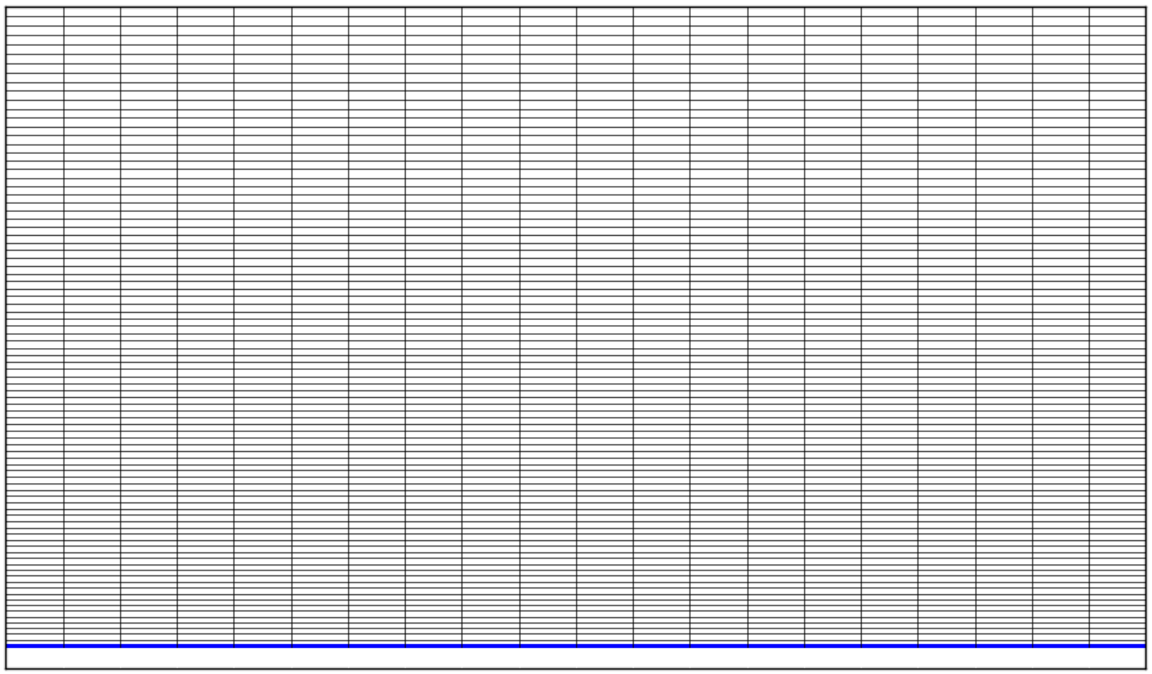
to scale

- 2D domain
- 6 hours
- dx = 500m
- nx = 100
- dt = 0.25s
- z_{top} = 7000m
- z_{floor} = 1315m
- dz = 50m - 85m
- $u_g = u_0$ = 5m/s
- $K_h = K_v$ = 20, 30, 40, 50, 100m^2/s
- no physics
- neutral temperature profile
- BCs
  - lateral: periodic
  - top: 2km Rayleigh layer (coef=0.003)
  - bottom: no-slip



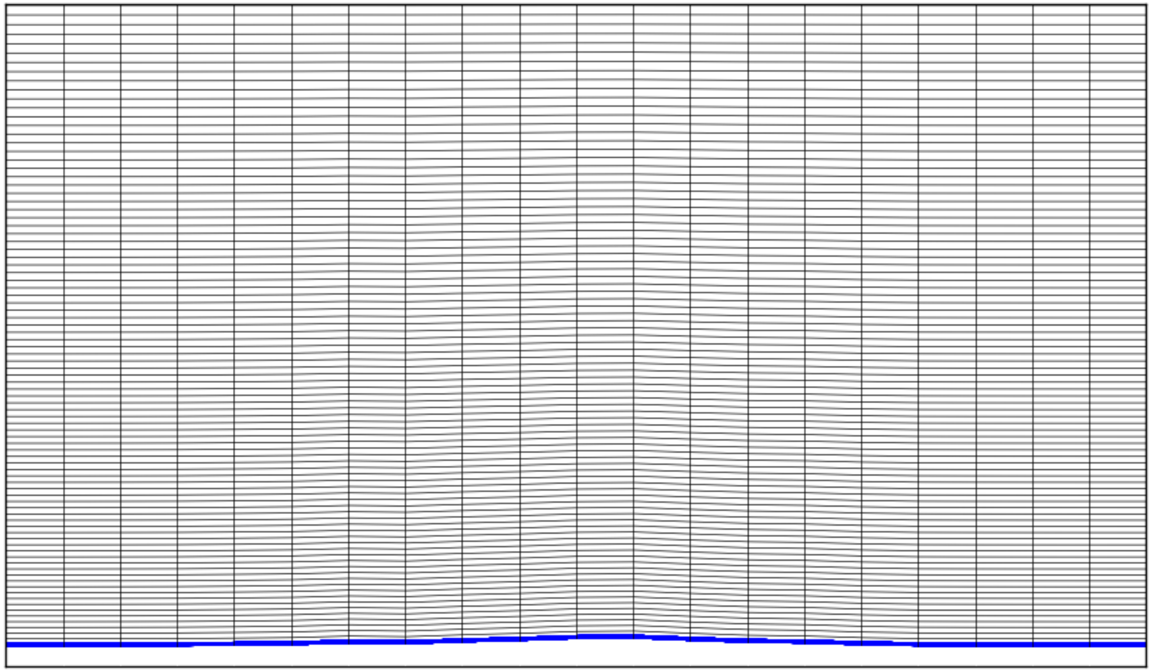


to scale



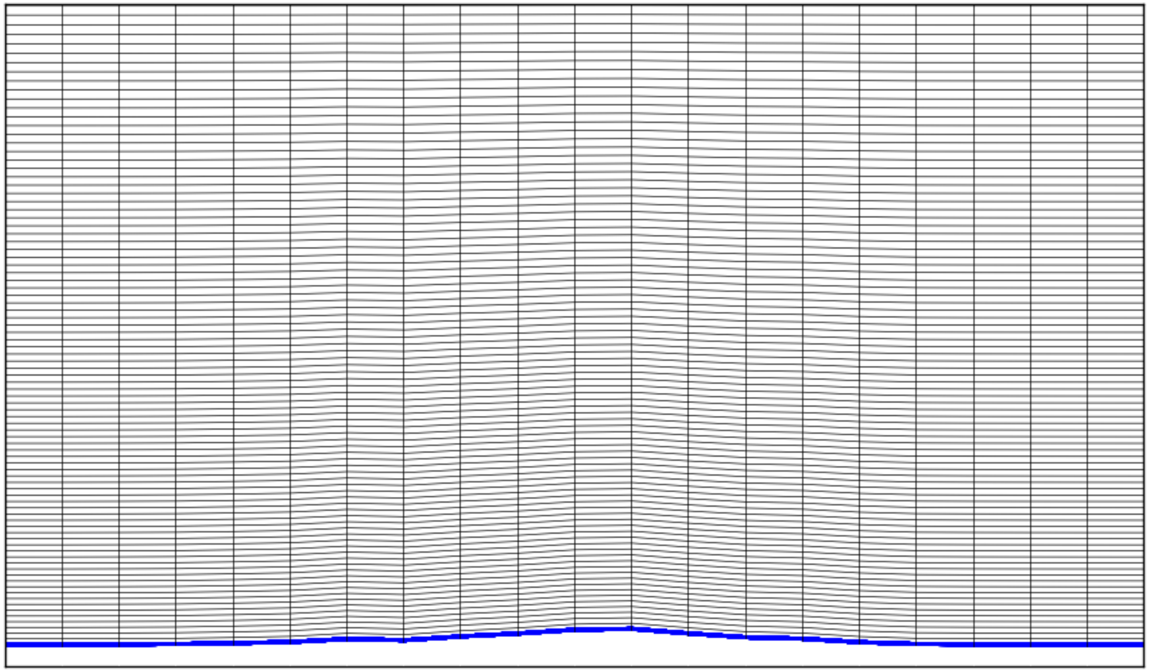
scale = 0.0
slope = 0.0

to scale



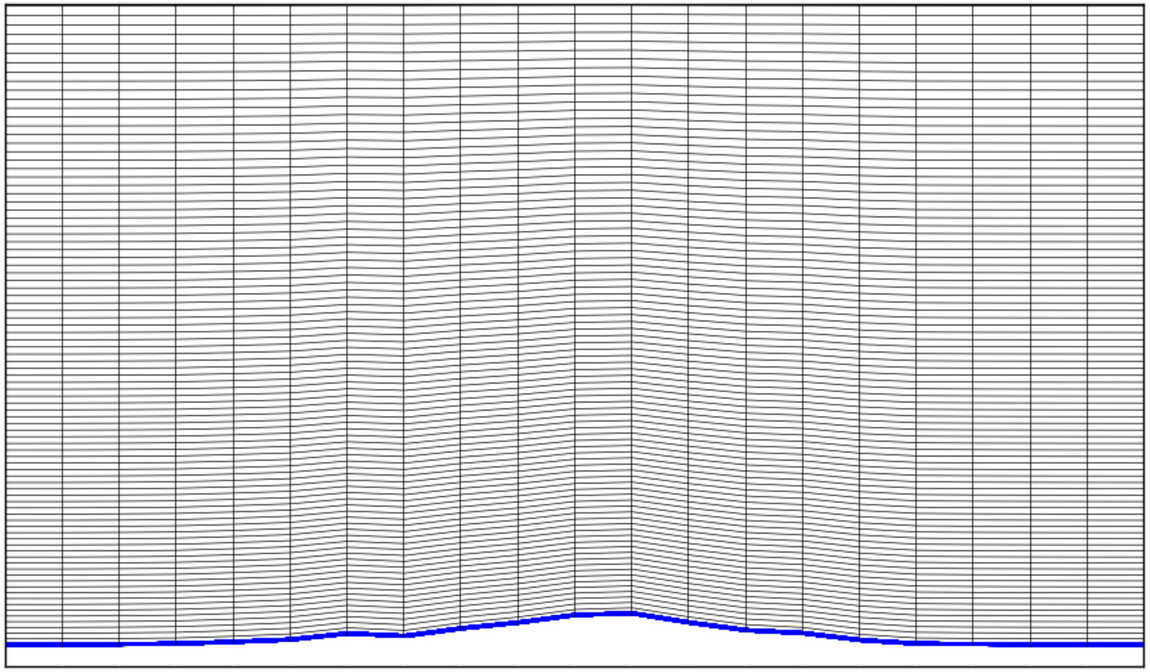
scale = 0.1
slope = 2.3°

to scale



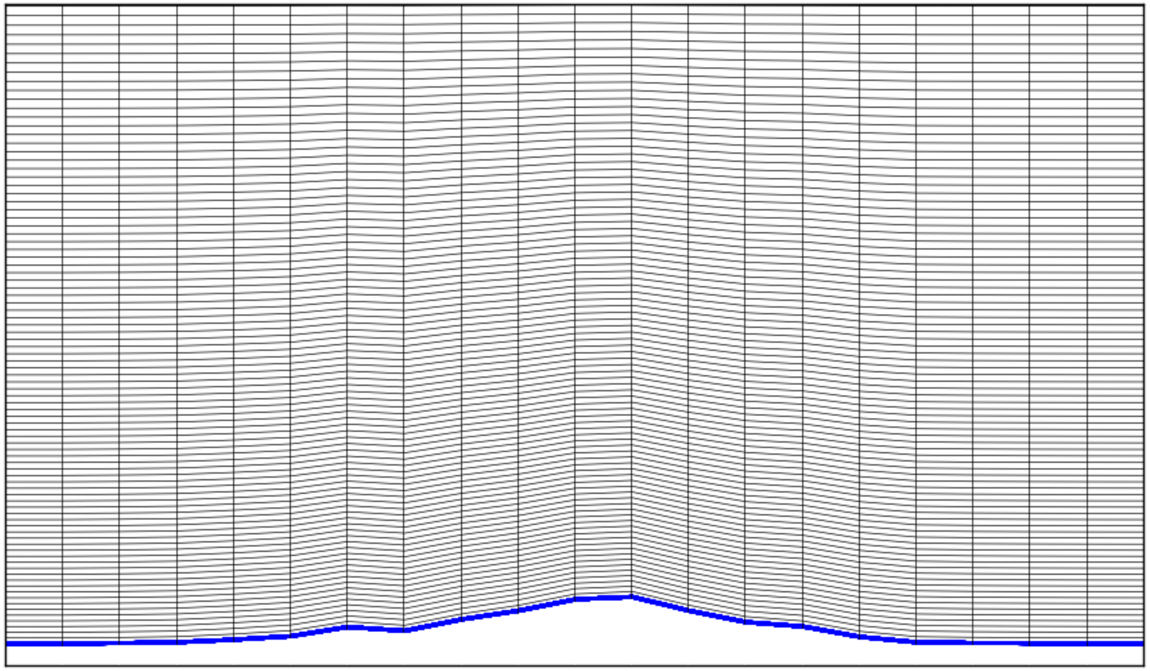
scale = 0.2
slope = 4.6°

to scale



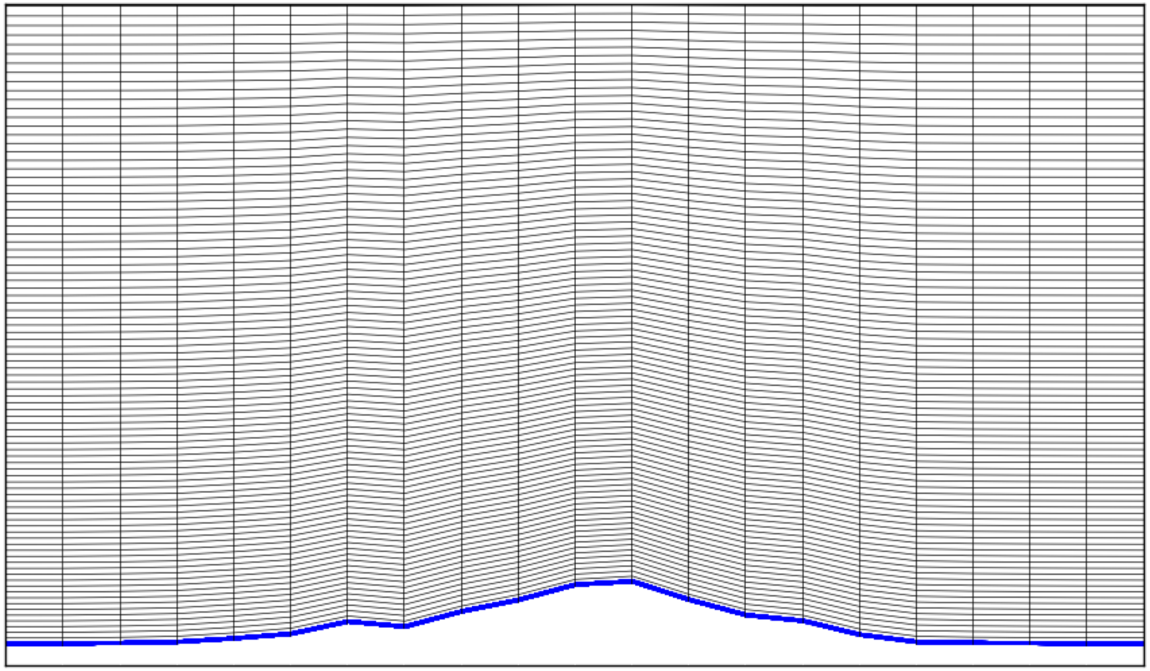
scale = 0.4
slope = 9.2°

to scale



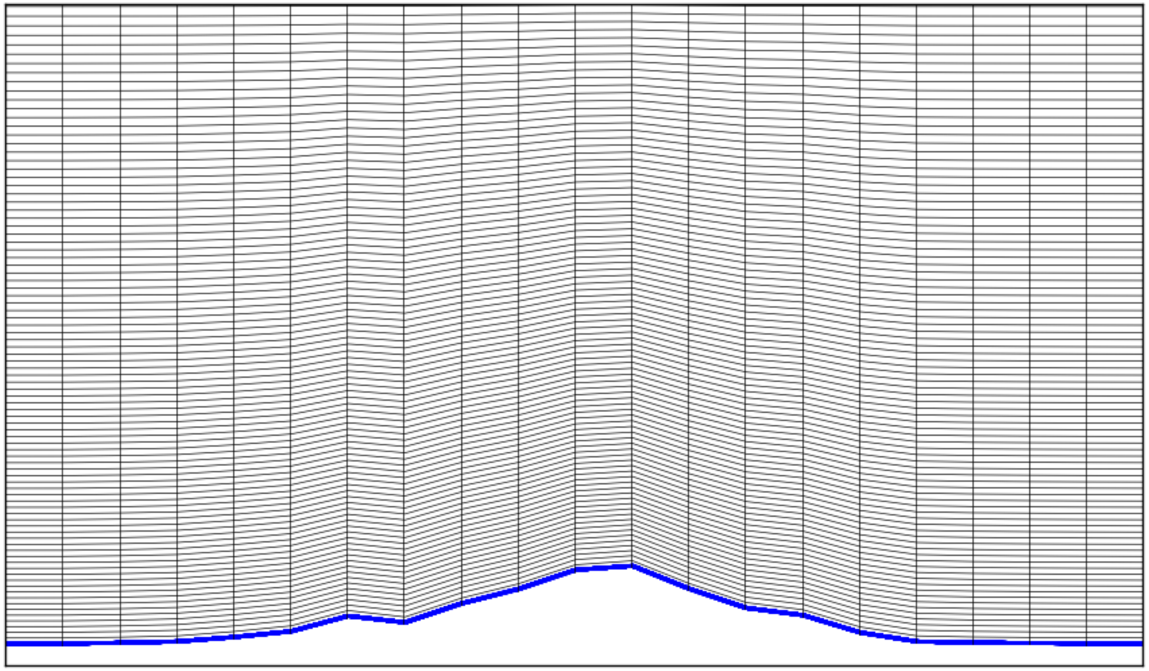
scale = 0.6
slope = 14°

to scale

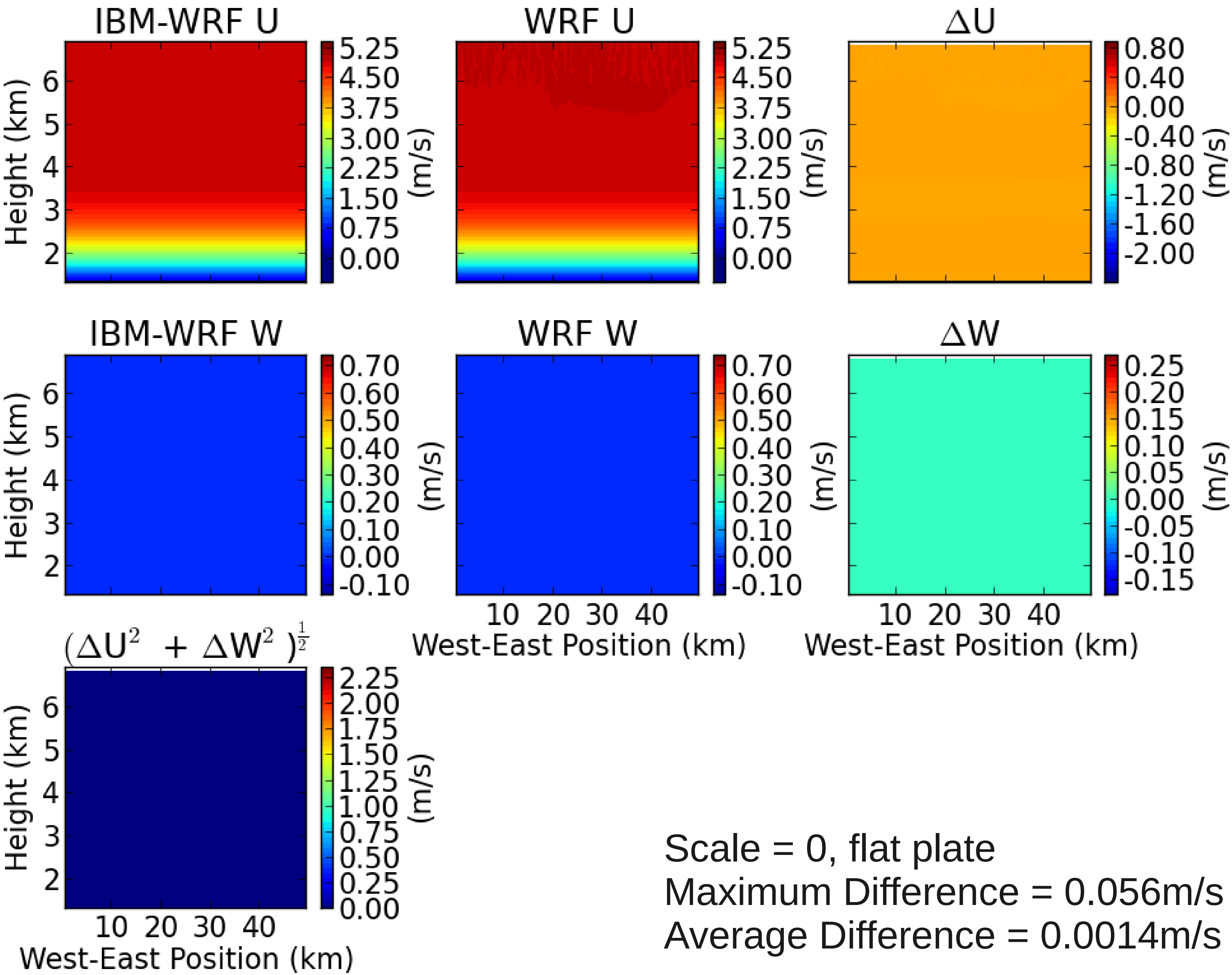


scale = 0.8
slope = 18°

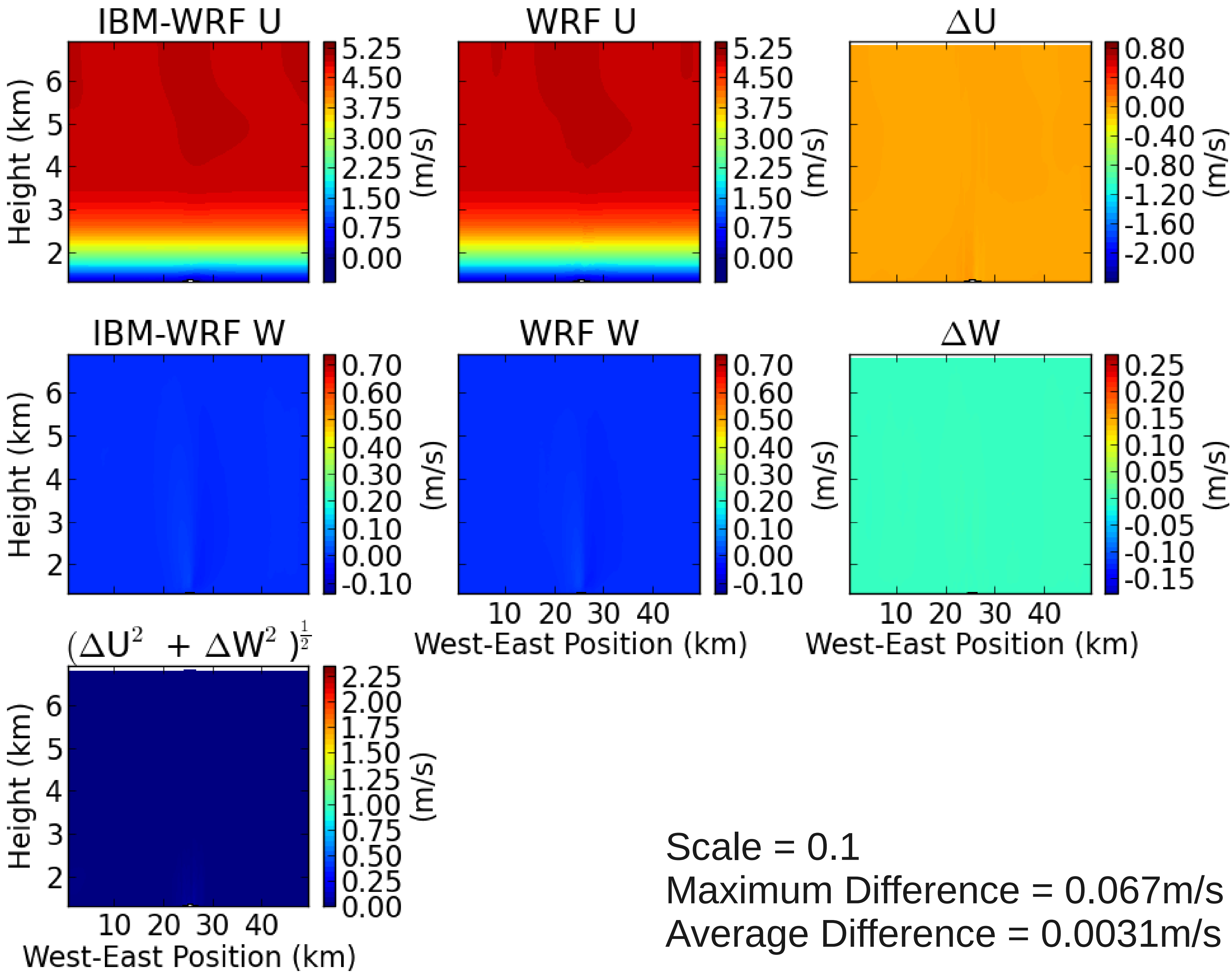
to scale



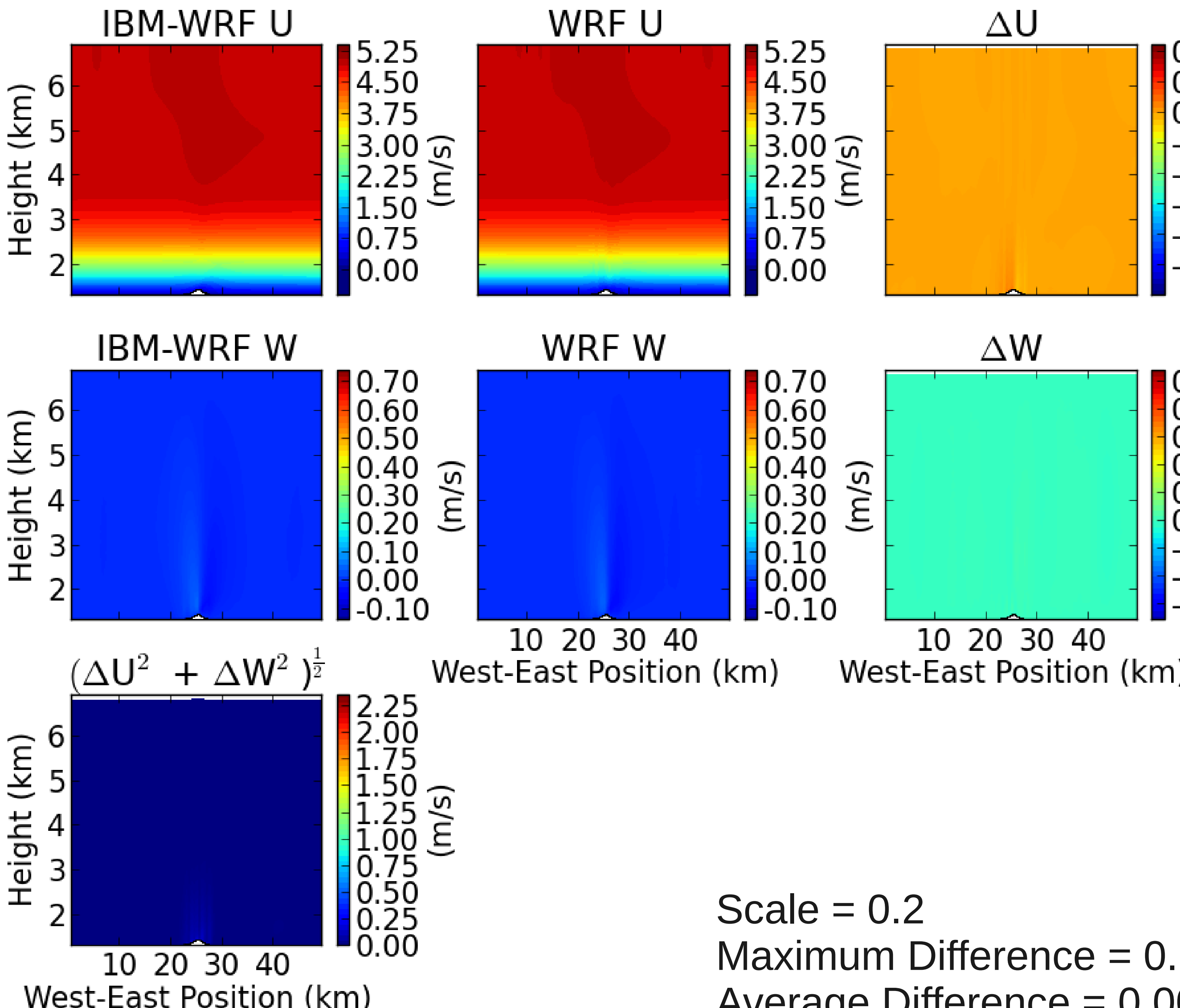
scale = 1.0
slope = 22°



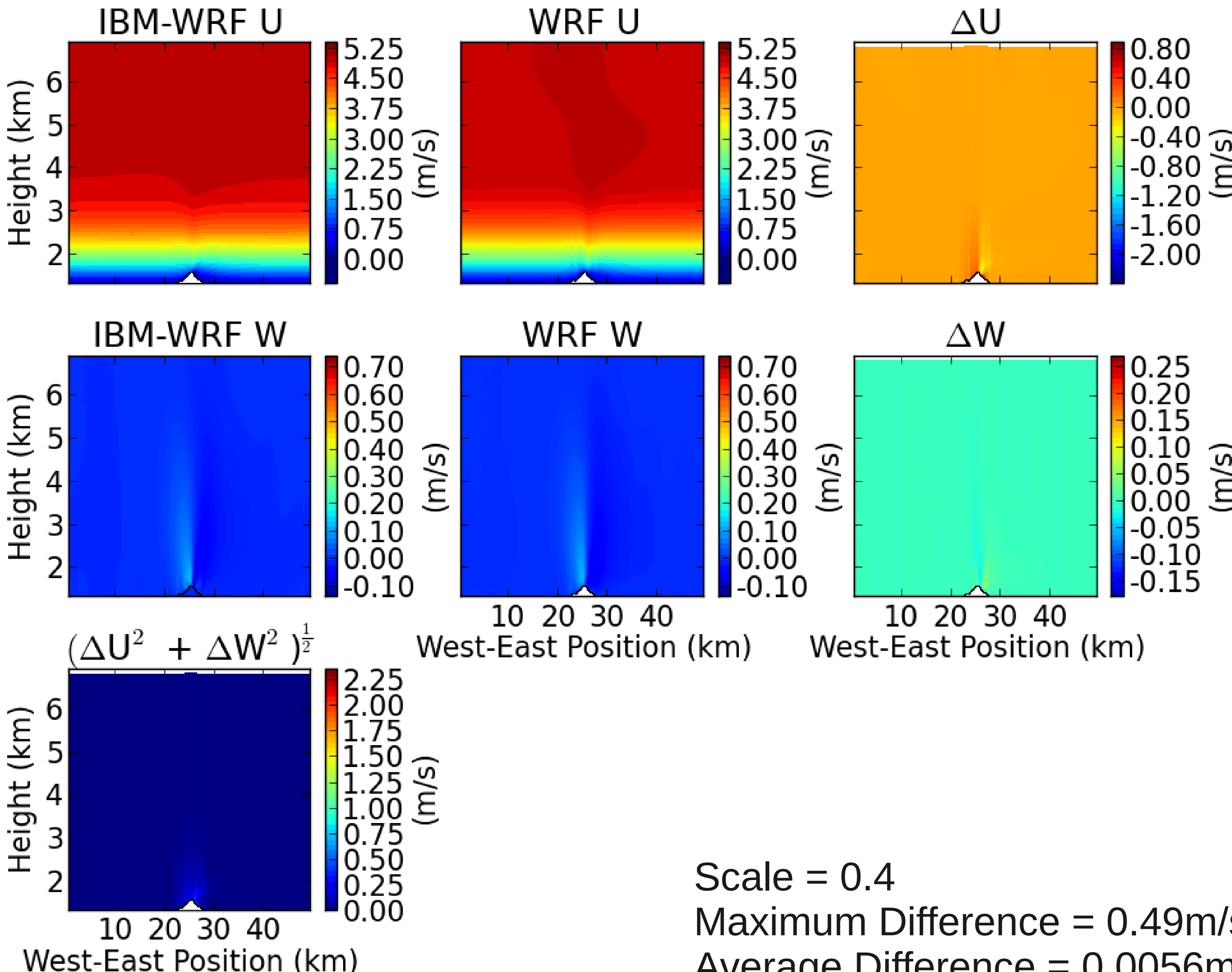
Scale = 0, flat plate
Maximum Difference = 0.056m/s
Average Difference = 0.0014m/s



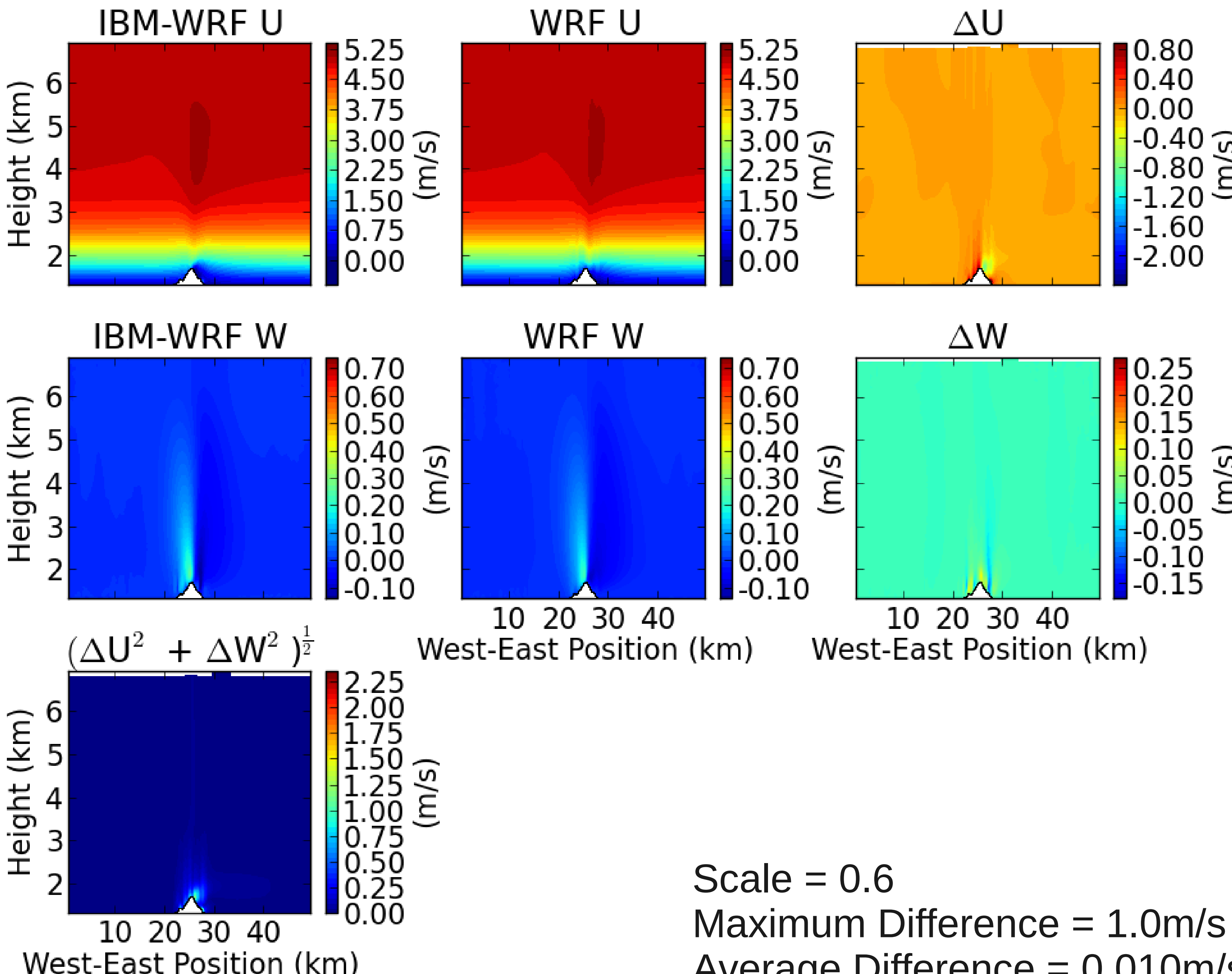
Scale = 0.1
Maximum Difference = 0.067m/s
Average Difference = 0.0031m/s



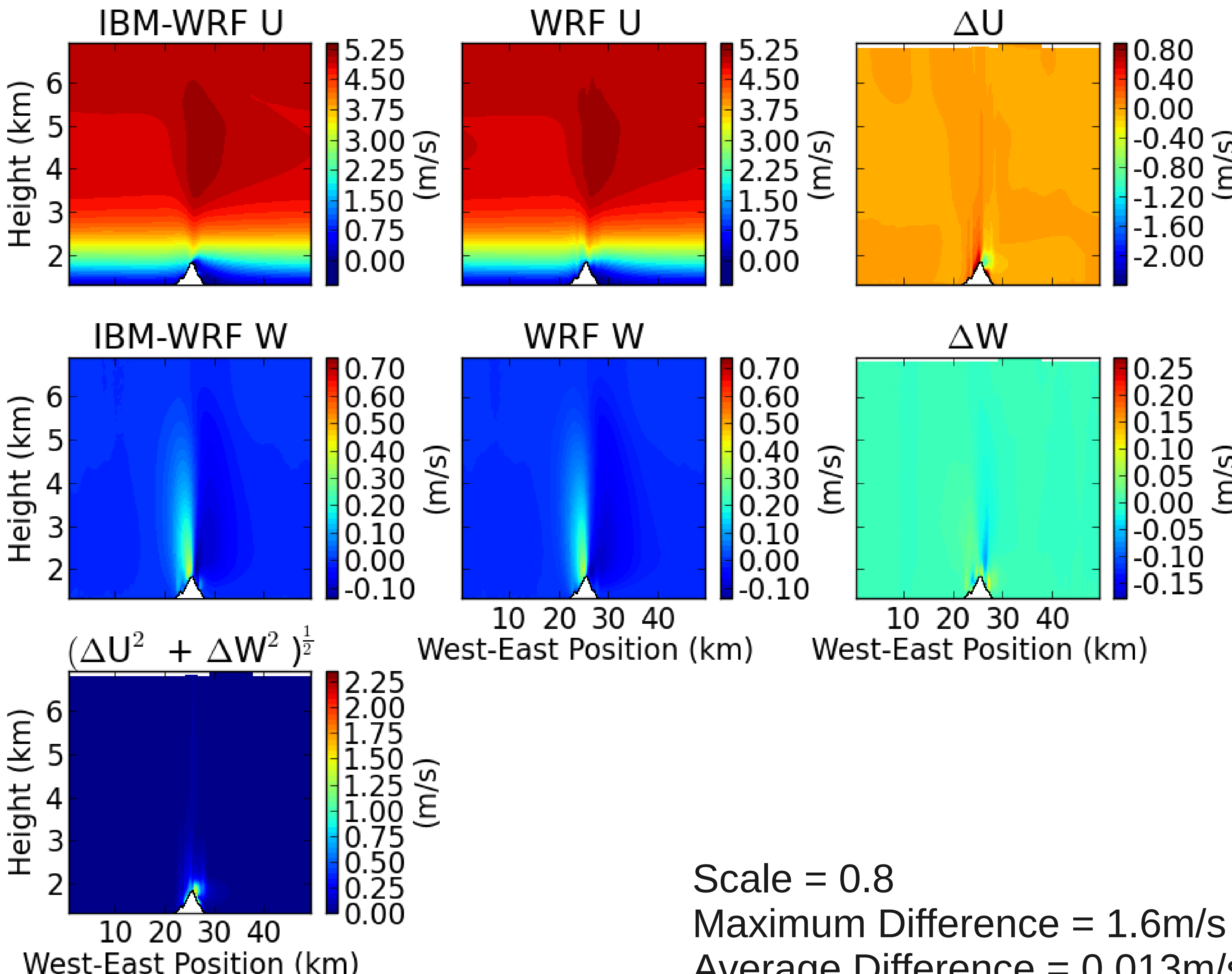
Scale = 0.2
Maximum Difference = 0.14m/s
Average Difference = 0.0032m/s



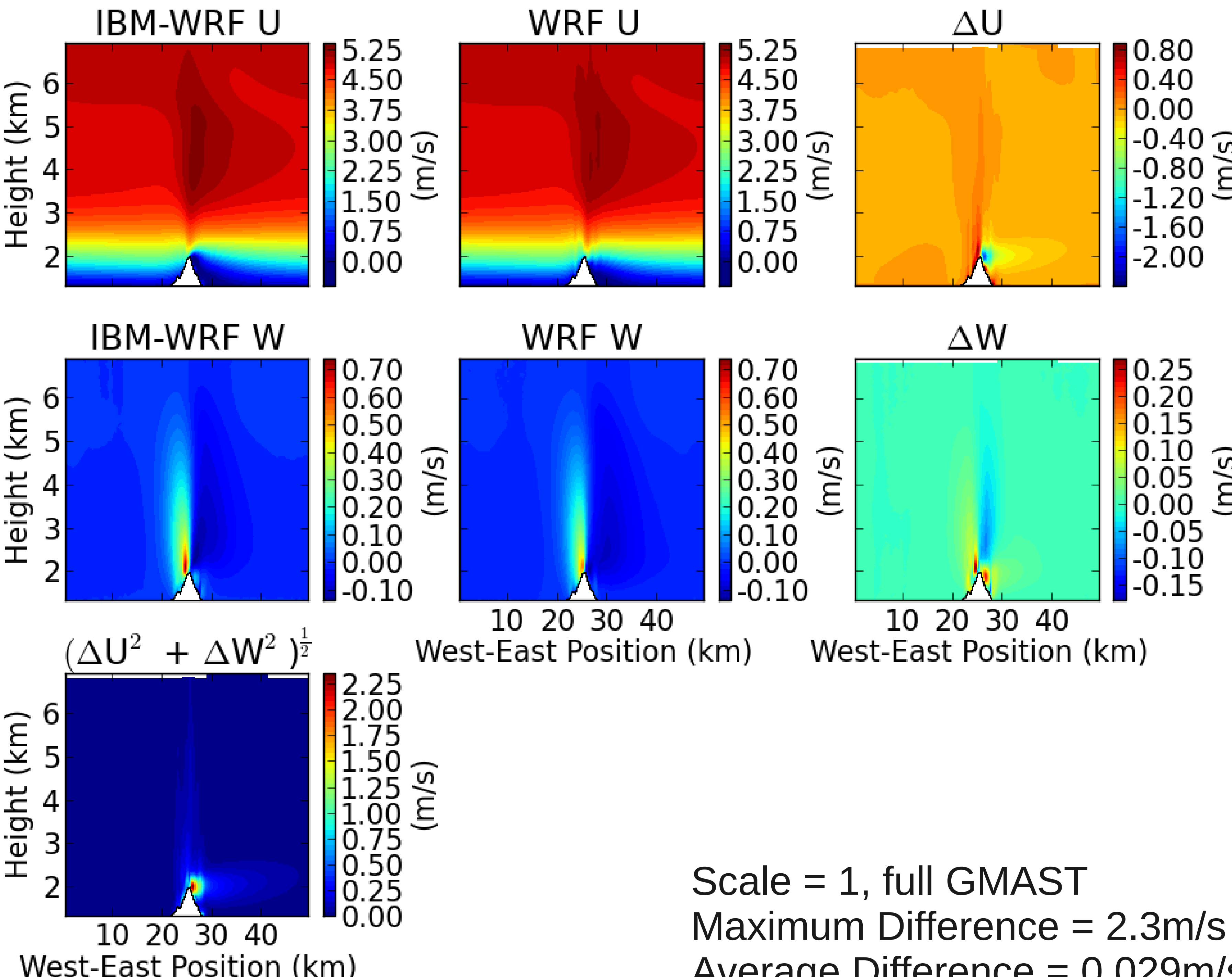
Scale = 0.4
Maximum Difference = 0.49m/s
Average Difference = 0.0056m/s



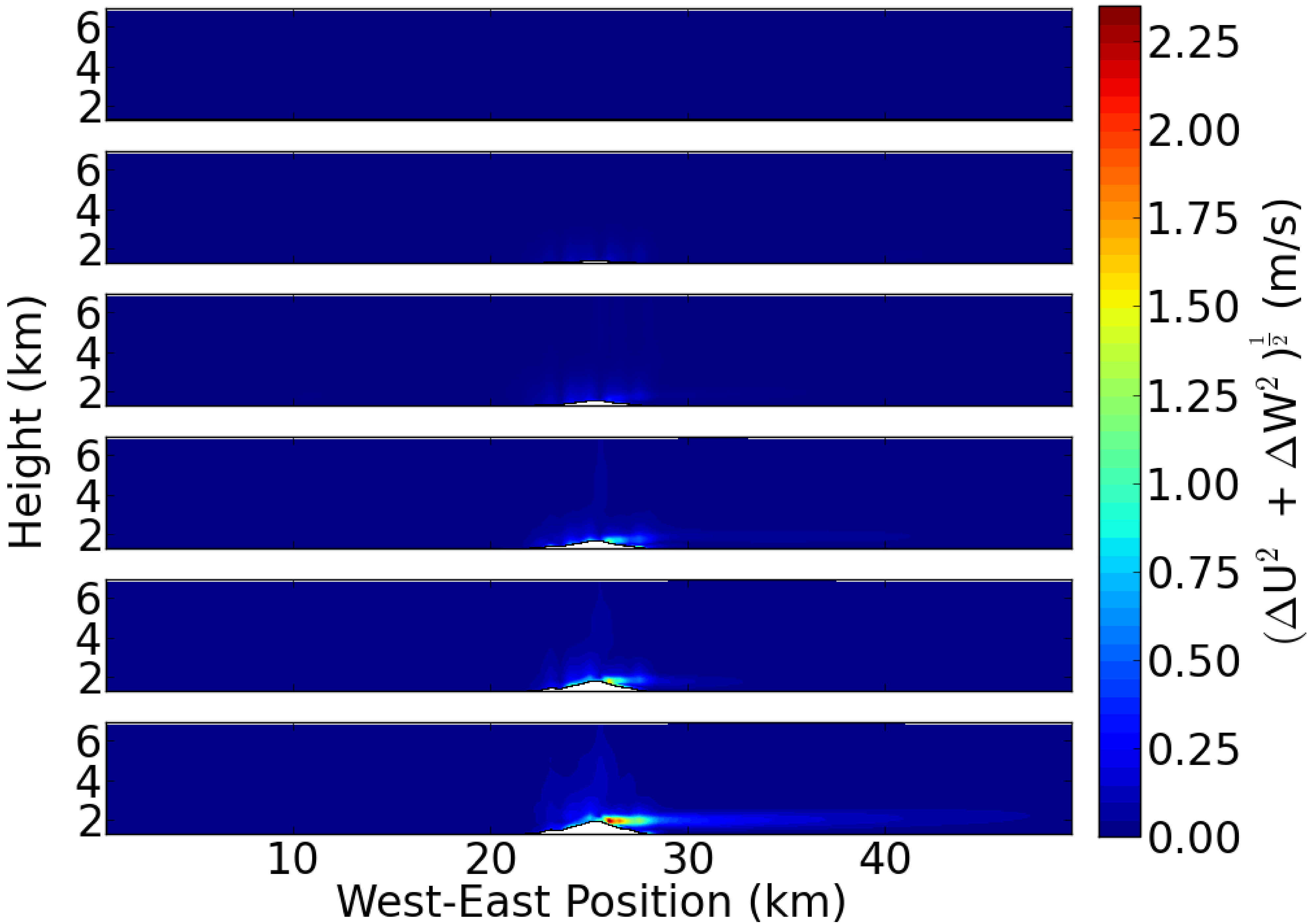
Scale = 0.6
Maximum Difference = 1.0m/s
Average Difference = 0.010m/s



Scale = 0.8
Maximum Difference = 1.6m/s
Average Difference = 0.013m/s



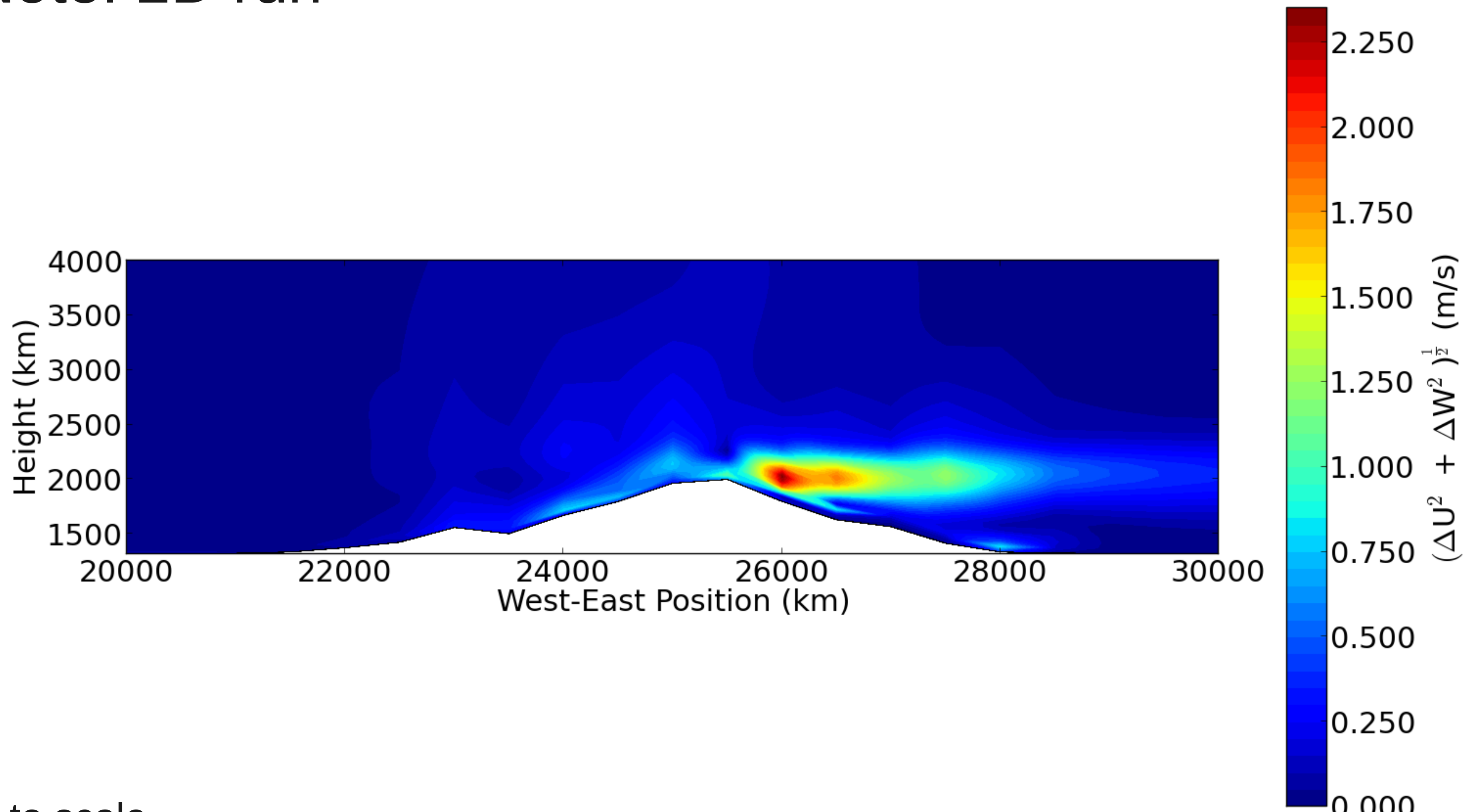
Scale = 1, full GMAST
Maximum Difference = 2.3m/s
Average Difference = 0.029m/s



Height (km)
6
4
2
10
20
30
40
West-East Position (km)
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
$(\Delta U^2 + \Delta W^2)^{\frac{1}{2}}$ (m/s)

Terrain-Following Coordinates

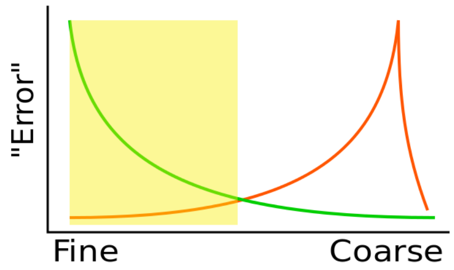
- Heavy impact on lee-side of GMAST
  - Note: 2D run

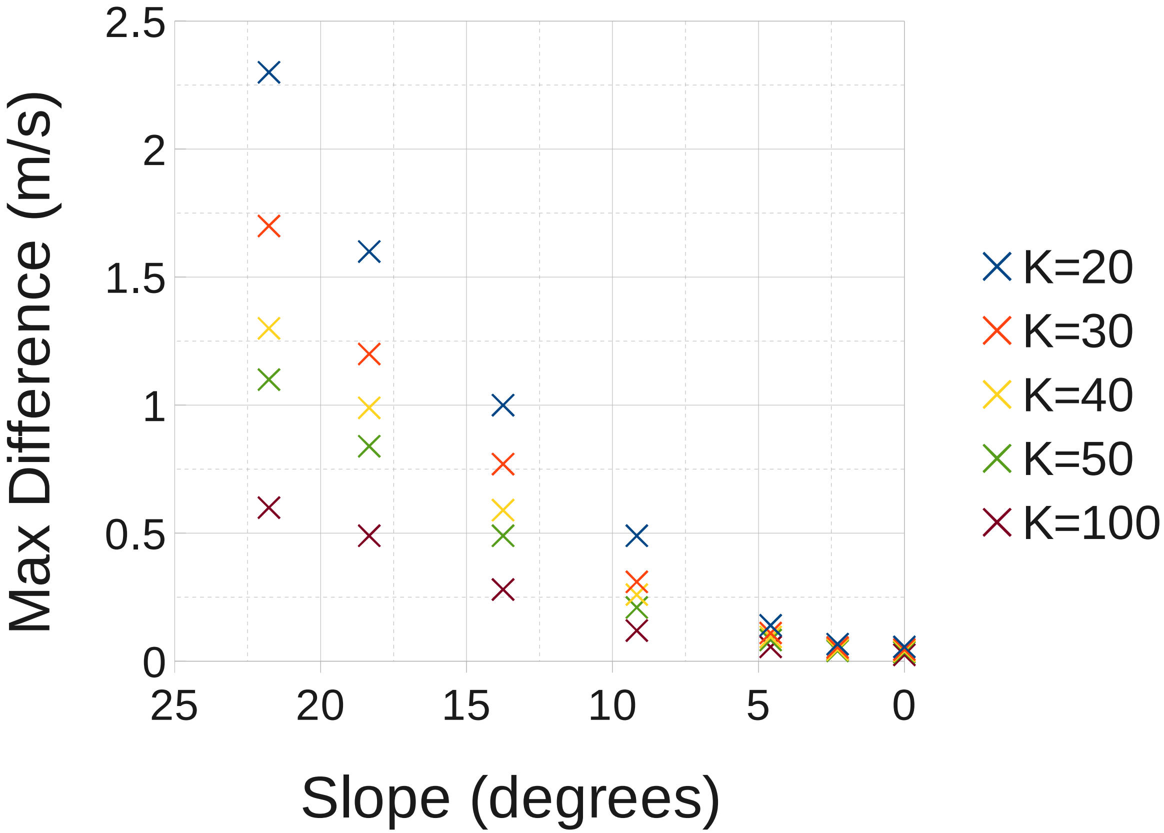


to scale

Slope vs. Difference

- Very strong correlation
  - Increasing K reduces difference (as expected)





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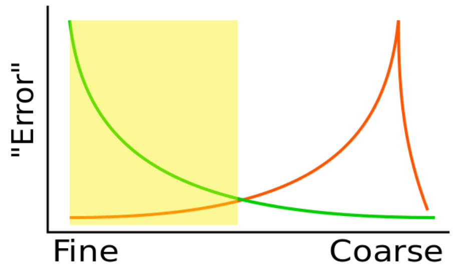
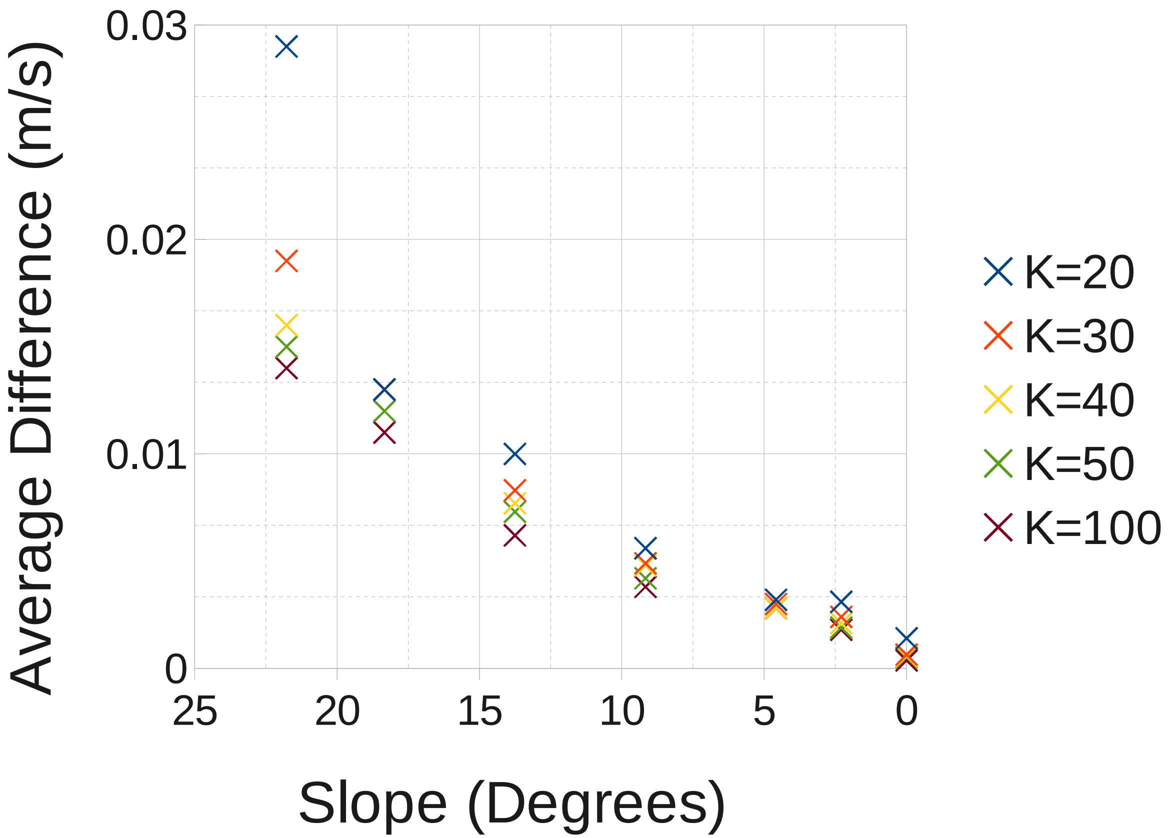
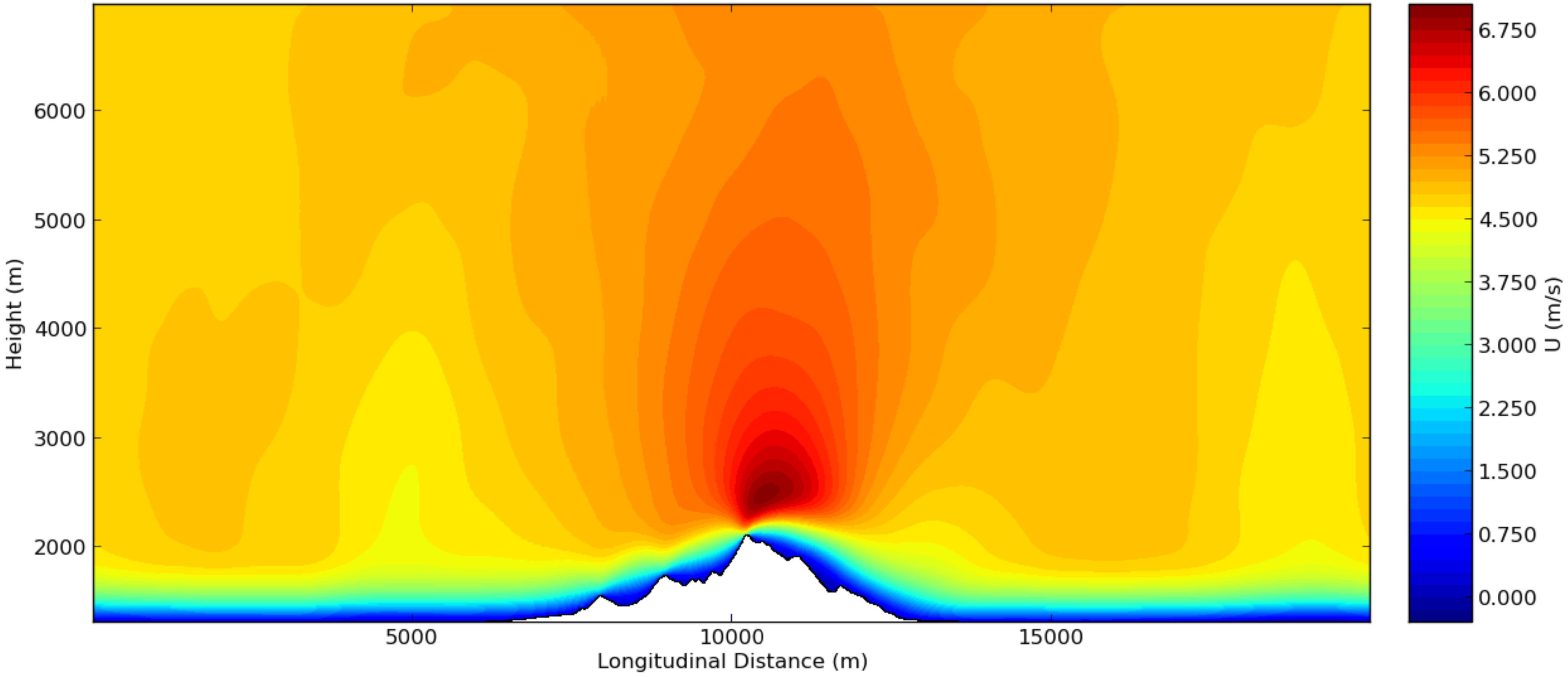




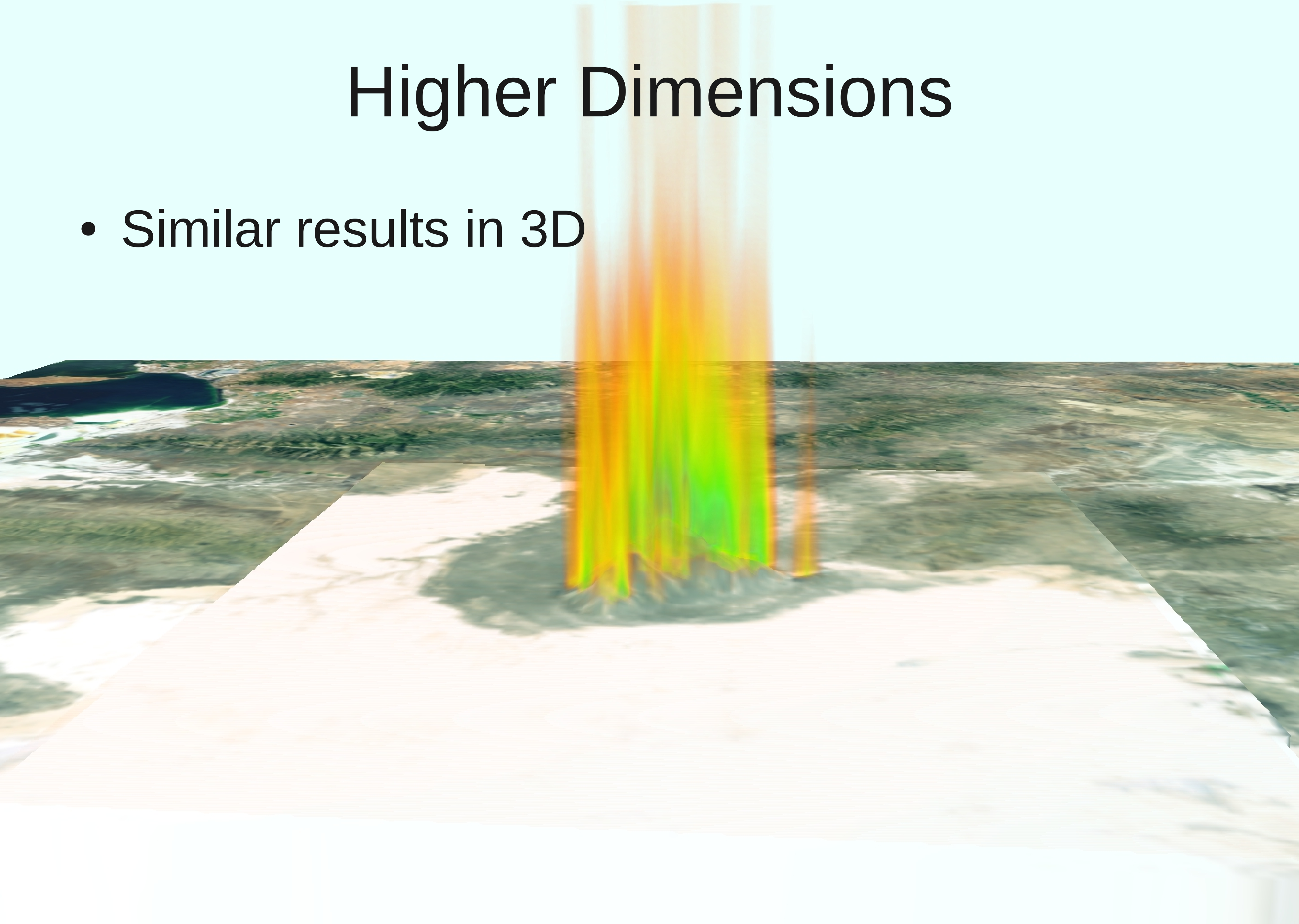
Higher Resolutions

- 500m chosen for WRF's sake
  - Much higher resolutions possible on GMAST with IBM-WRF
  - 10m shown below



Higher Dimensions

- Similar results in 3D



Summary

- Meso-to-micro scale code feasible
  - Many questions still outstanding
- WRF and IBM-WRF agree well for small slopes
- Terrain-following coordaintes feel GMAST aloft
  - GMAST steep enough to warrant IBM-WRF

Ongoing Work

- Further characterization
- Idealized nesting from WRF to IBM-WRF
- Add log-law bottom boundary
- IBM-WRF performance optimization

Future Work

- Real nesting from WRF to IBM-WRF
- High resolution slope flows
- Methods in the “*terra incognita*”