WRF Advanced Usage and Best Practices

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Motivation

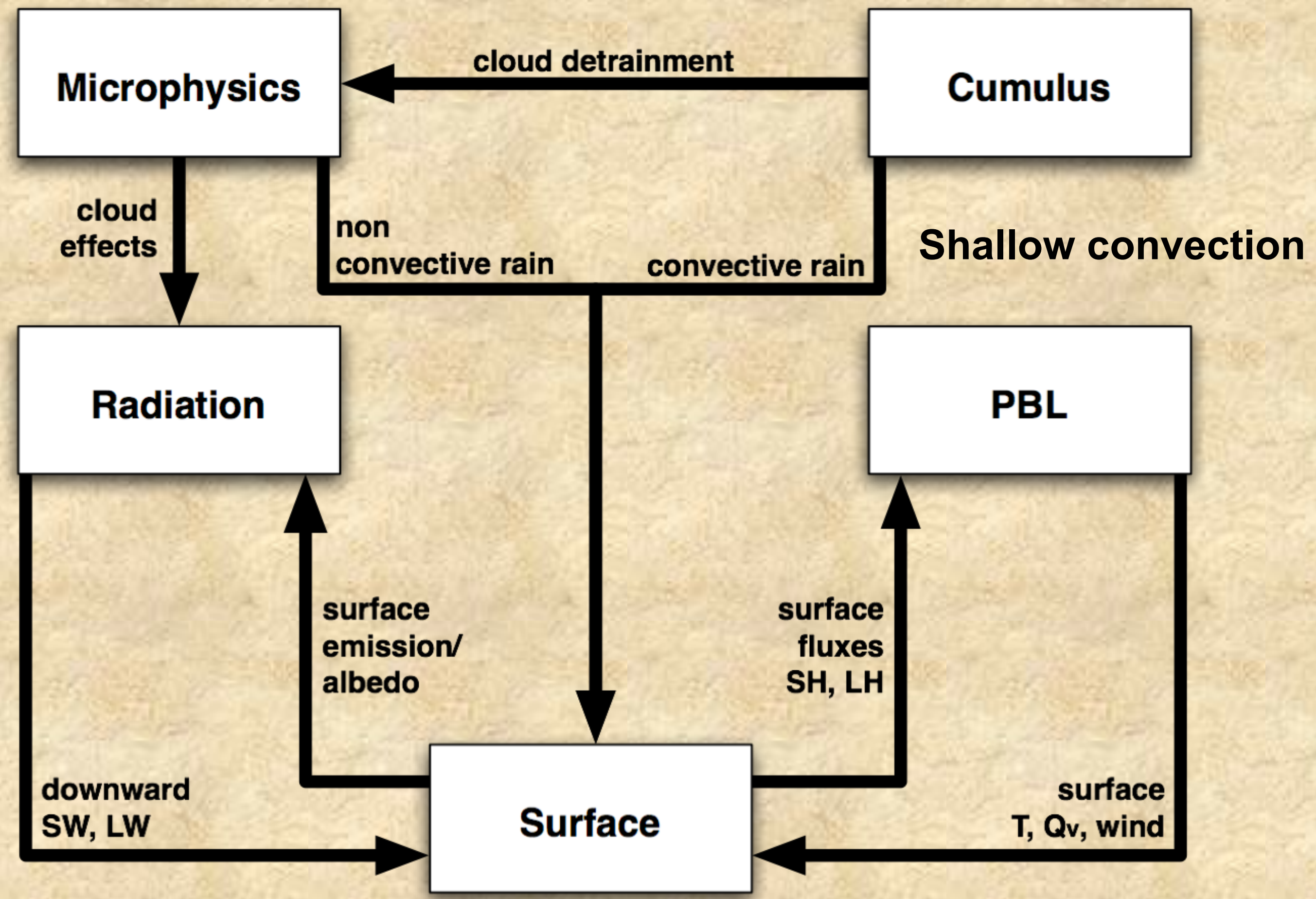
- This talk is motivated by our user support questions
  - We often find problems are due to wrong usages of the model
  - Many questions on how to do various advanced applications
  - We hope to address some here
  - Can’t be comprehensive (questions can be asked later)

Topics

- Physics: So many options to choose from
- Complex terrain
- Nesting, resolution and domain sizes
- Model levels and high tops
- Nudging options: use or not
- Initialization and spin-up issues
- Damping and advection options

Physics

Direct Interactions of Parameterizations



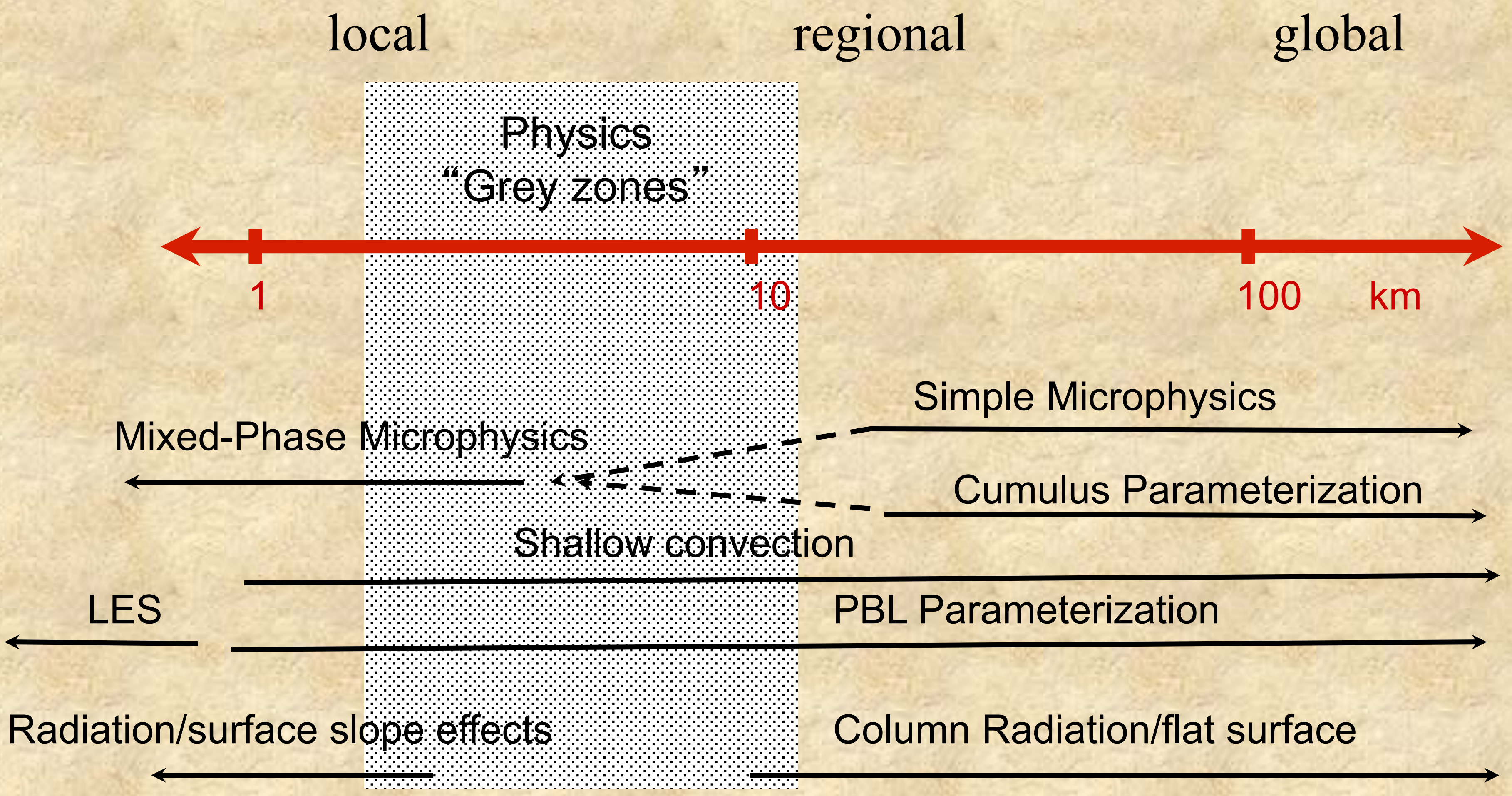
Physics

- All WRF options enable the basic interactions outlined in previous figure (no “wrong” combination in that sense)

However

- Consider tried and trusted schemes first
  - see papers on similar uses of WRF
  - See example in Users’ Guide
- Consider what remains unresolved or unrepresented – WRF may have options to help
  - Subgrid cloud effects, aerosol effects on clouds/ radiation, radiation-microphysics coupling

Physics in Multiscale Model

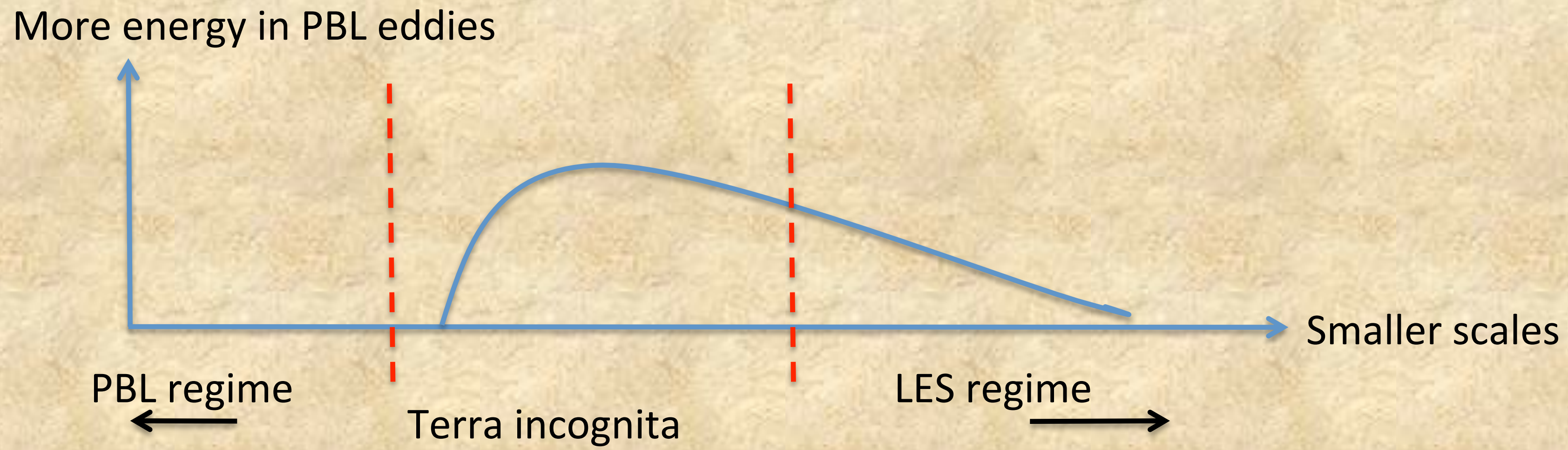


Physics

- Consider grid size when choosing sophistication of microphysics
  - Don’t need complex scheme for 10 km grid
  - Do need at least graupel for convection-resolving grids
- When to use cumulus parameterization
  - Grid size > 10 km - yes
  - Grid size < 4 km - probably not
  - Perhaps best to avoid grid sizes 5-10 km for convective cases

LES Modeling

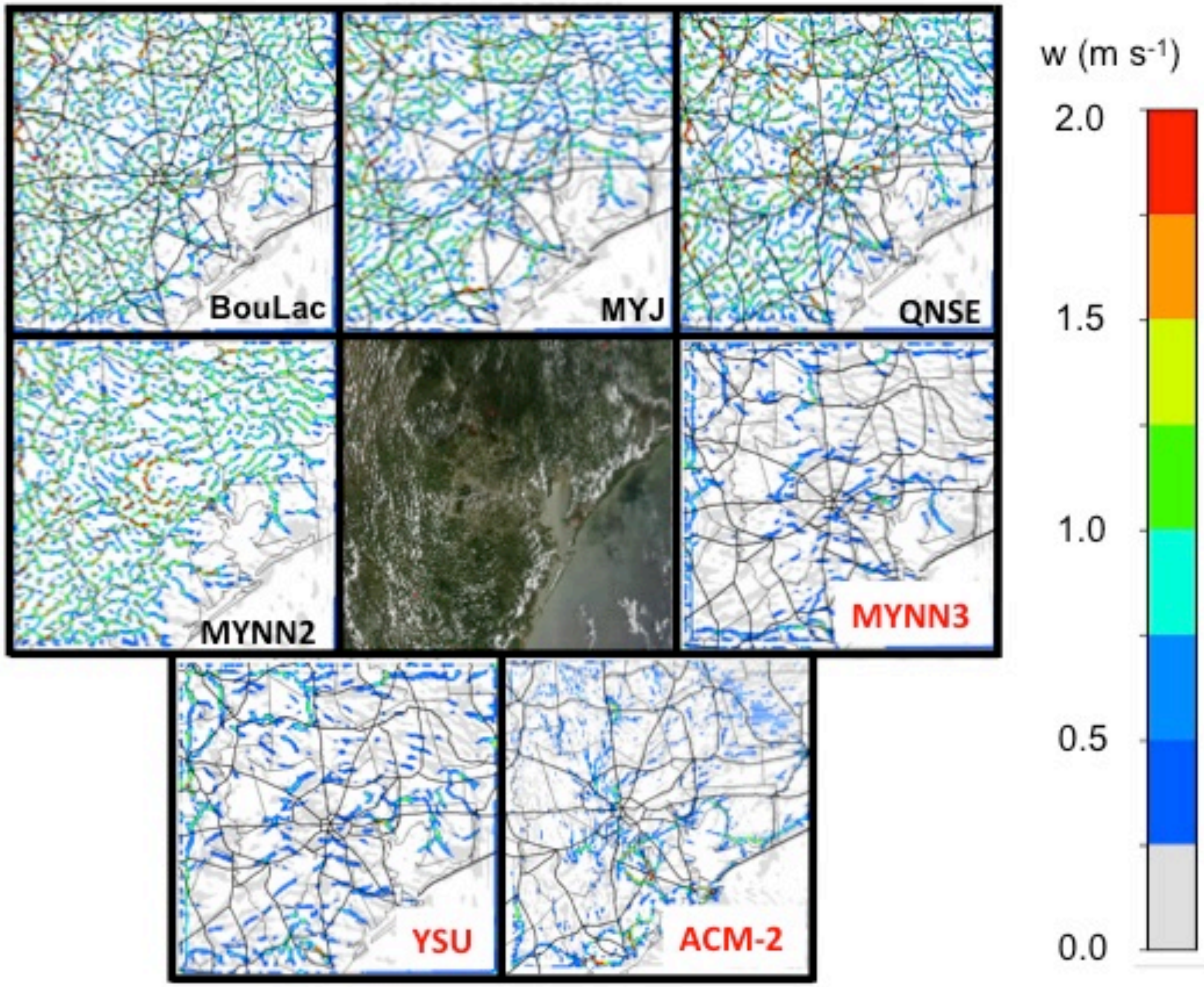
- "Terra Incognita" range of grid sizes where main PBL eddies are partially resolved
  - PBL assumes all eddies are unresolved
  - LES assumes eddies are well resolved



Boundary-Layer Rolls

Mesoscale simulations are sensitive to choice of PBL parameterization options

Ching et al. 2014



WRF simulations of vertical velocity in the PBL (125-m, Level 10) for 20 UTC August 4, 2006 over Houston-Galveston Texas area

Satellite image is from Terra 17:20 UTC, 500-m pixels:

PBL schemes 1: Vertical fluxes are proportional to local vertical gradients:
- BouLac
- MYJ
- QNSE
- MYNN2

PBL schemes 2: Vertical fluxes using non-local closure schemes:
- MYNN3
- YSU
- ACM-2

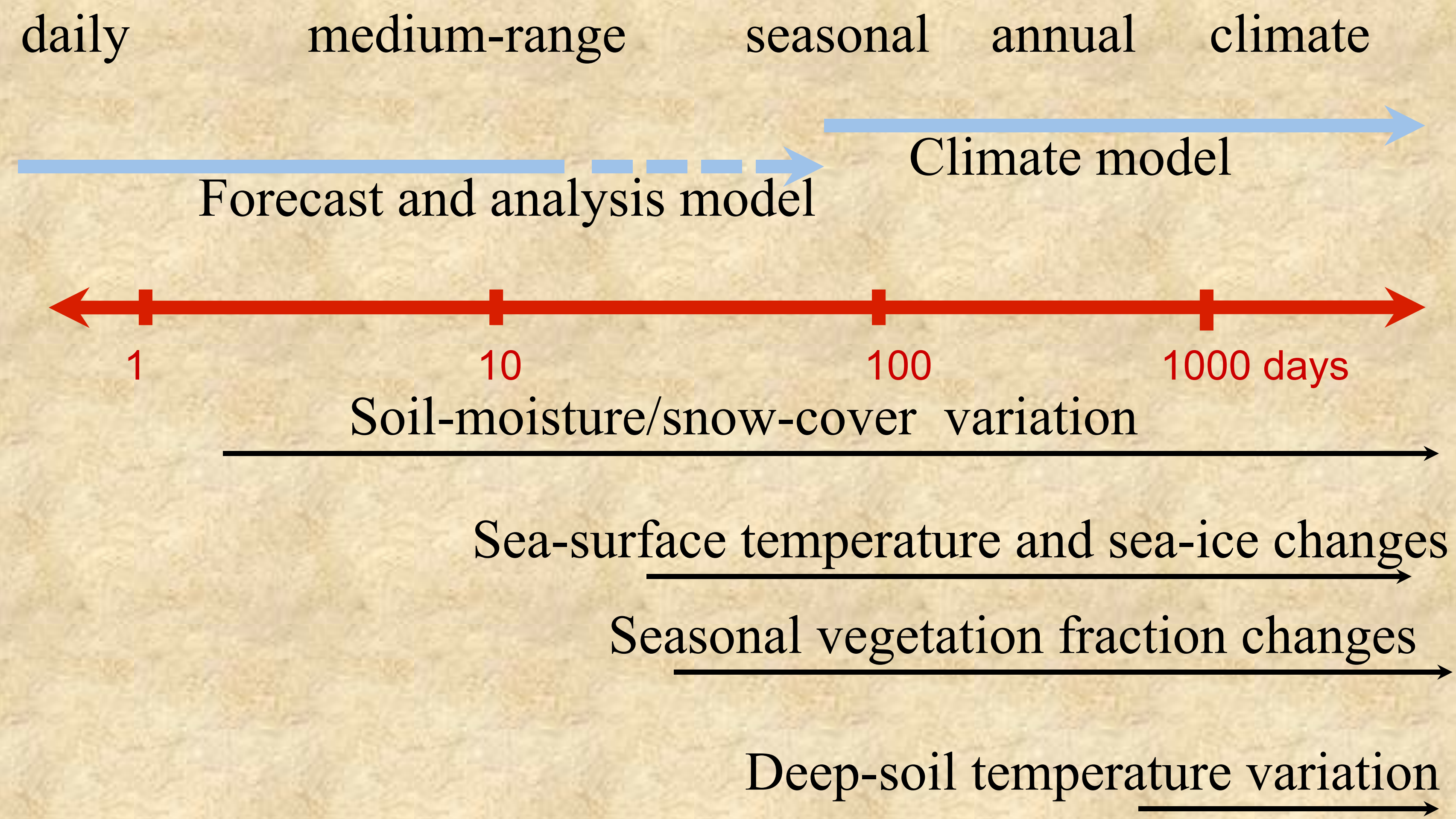
Physics

- When to use LES
  - Grid size > 500 m – use PBL
  - Grid size < 100 m – use LES
  - Grid size 100-500 m – either may work to some extent
- Important note: keep dz < dx
  - Particularly applies to LES with real data where model levels stretch with height
  - Can lead to significant noise at top if not done
- When to use slope radiation effects
  - When slope is resolved and significant (dx < 2 km probably)

Climate runs

- WRF physics is suitable for climate runs
- Extra diagnostic packages are provided for max/min daily temp, etc.
- Select physics appropriately

Weather to Climate Modeling

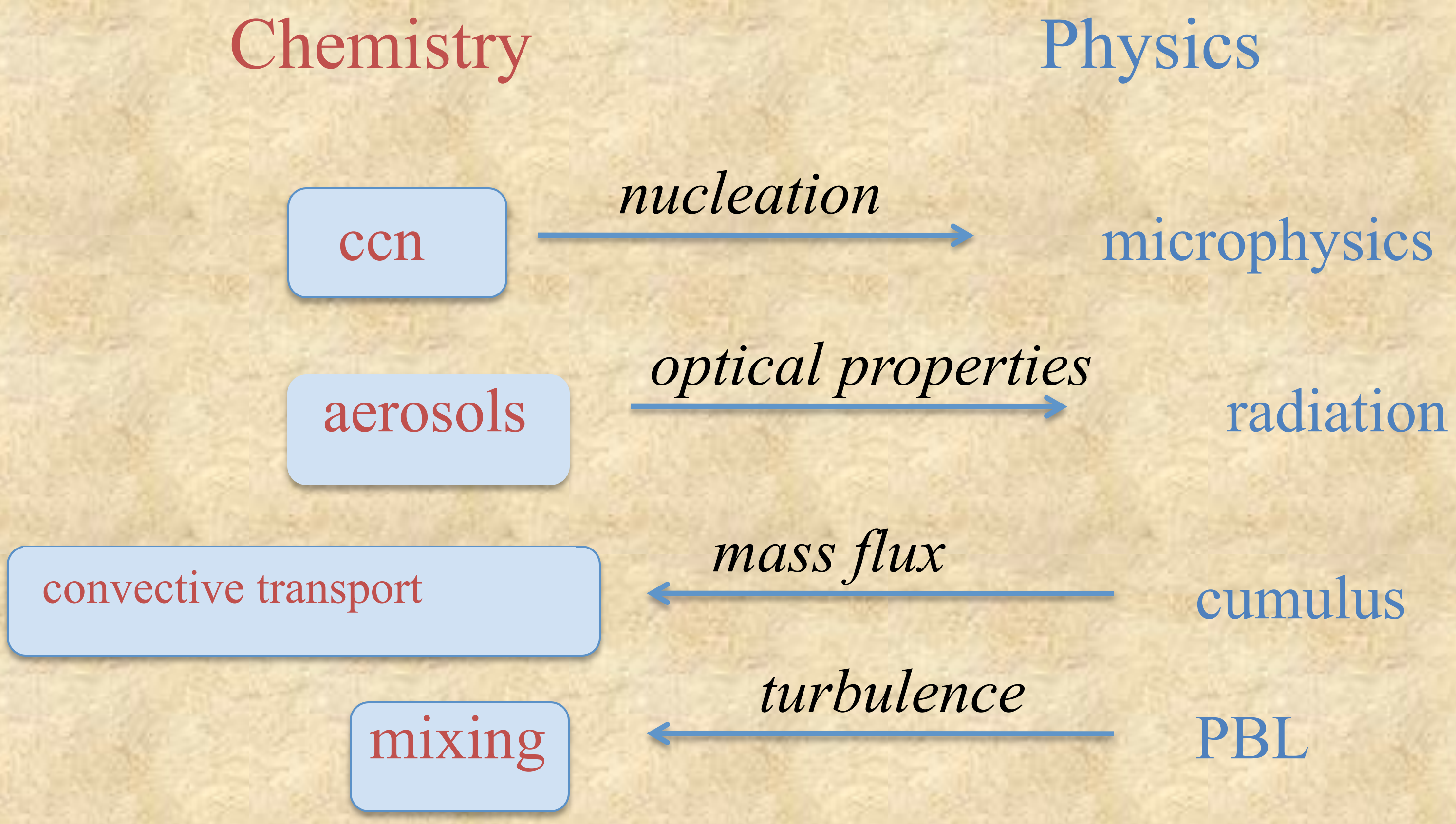


Physics

- Regional climate physics
  - Use land model with soil moisture and evolving snow
  - Use sst_update for evolving vegetation fraction and seasonal cycle too (albedo, roughness length)
  - Longer simulations may need
    - deep soil temperature update option
    - Greenhouse gas update option

Physics/Chemistry Coupling in WRF

This limits some physics choices a lot

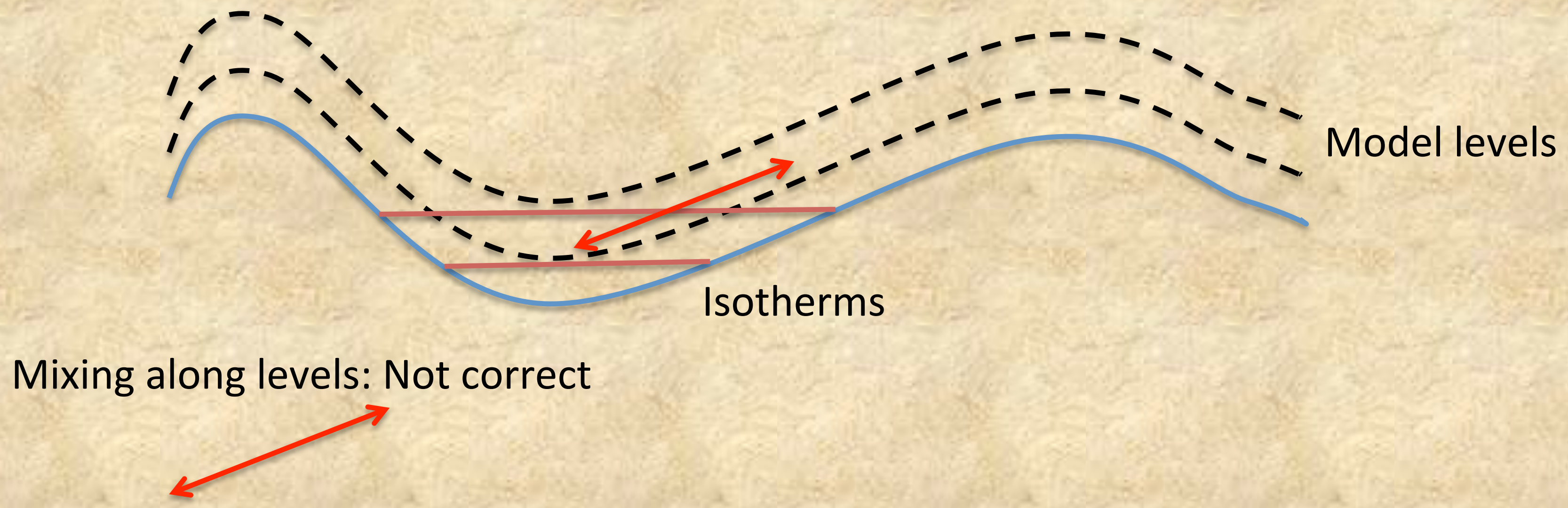


Complex Terrain

- Steep terrain (> 45 degrees) may cause numerical stability problems – some things to try
- For immediate blow-ups try increasing *epssm* from default 0.1 to 0.5 or even 1.0
  - This is a sound-wave damper that can stabilize slope treatment by dynamics (little other effect)
- For significant slopes, *diff_opt=1* is less realistic than *diff_opt=2*, but *diff_opt=2* was often unstable
  - V3.6 now has a *diff_opt=2, km_opt=4* option with improved numerical stability

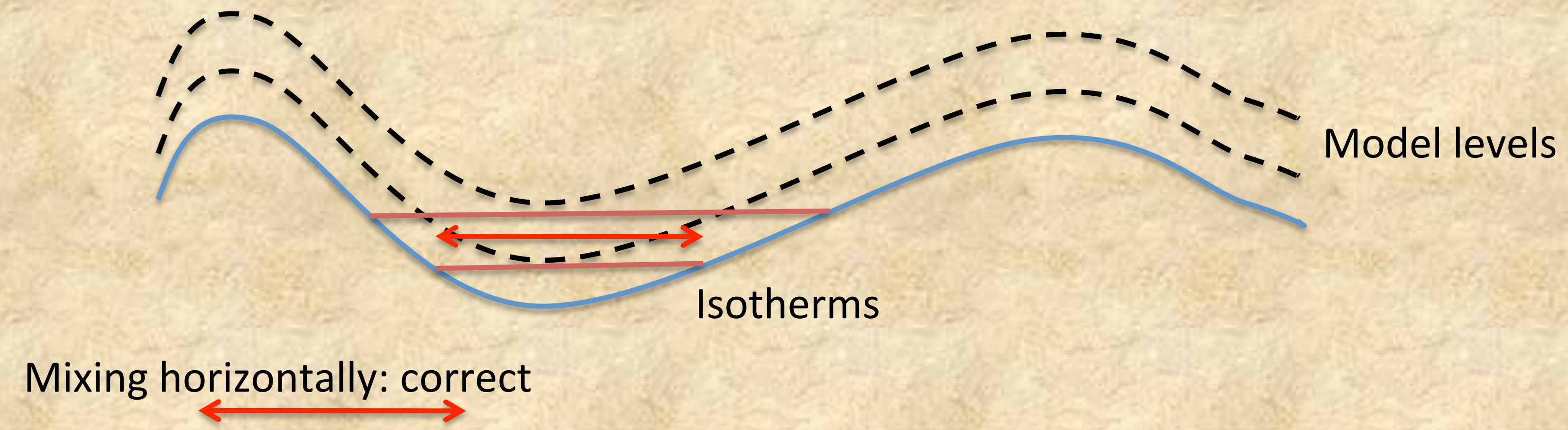
Diffusion

- *diff_opt=1*



Diffusion

- *diff_opt=2*



Complex Terrain

- LES in complex terrain remains challenging
- Can now nest down to LES (e.g., 1 km PBL, 333 m LES) with V3.6 since *diff_opt, km_opt* are now domain dependent
  - Inflow boundary may need to develop rolls
- TKE option (*km_opt=2*) appears more stable than 3d Smagorinsky (*km_opt=3*)
- *eppsm* > 0.1 may be needed

Nesting, Resolution and Domain Size

- Nesting is probably needed if your target resolution is much less than your analysis resolution
- Use outer domain(s) to keep low-resolution analysis well upstream of domain of interest
- Usually makes no sense to use less than 100x100 points in a domain on computers these days
- Outer domain grid size could be about 1/3 analysis (or boundary-data) resolution
- Keep interior nest boundaries away from each other
- Recommend 3:1 nest ratio
- 5:1 also appears acceptable but be cautious of keeping boundary far from area of interest to allow hi-res adjustment
- Use two nest levels rather than large dx jump with a single nest

Nesting, Resolution and Domain Size

- Try to keep all physics options constant across nest boundaries
  - Cumulus schemes on/off differences can lead to spurious rainfall gradient at nest boundary (rain outside, clear inside)
    - Solved by using 1-way nesting or no feedback or same cu_physics on both domains
  - Another common exception is PBL/LES where you can change to LES at hi-res but may see gradients
    - Should use large enough nest area to keep boundary gradients away from region of interest

Model Levels and High Tops

- Not setting *eta_levels* gives default stretching near ground and uniform Δz higher up
  - Be aware that matching of level thicknesses may be discontinuous, so you may want to use this as a starting point and edit your own levels in the namelist.
  - If you choose too few levels for model top pressure, real.exe will stop because its default dz is not allowed to exceed 1 km (a good rule to follow to prevent noise)
- Choosing base state appropriate to domain surface temperatures (*base_temp=270,280,290*) may help reduce pressure-gradient force error (keeps p’ smaller)

Model Levels and High Tops

- For high tops < 50 hPa use the (default) stratosphere option for the base state (e.g. iso_temp=200 K)
  - This prevents base state from becoming unrealistically cold at high levels
  - In V3.6.1 we will allow a stratospheric positive lapse rate
- For tops near 1 hPa (45-50 km), may need 60 or more levels
- Some studies (Evan) show 500 m vertical resolution is needed if studying gravity waves in stratosphere
- RRTM and RRTMG radiation include code to prevent cold bias at model top (Cavallo) by estimating downward radiation above model top with extra layers
- Ozone climatology becomes important for tops above about 30 hPa that include some or all of the ozone layer
  - CAM monthly ozone is now available for RRTMG

Nudging Options: Use or not

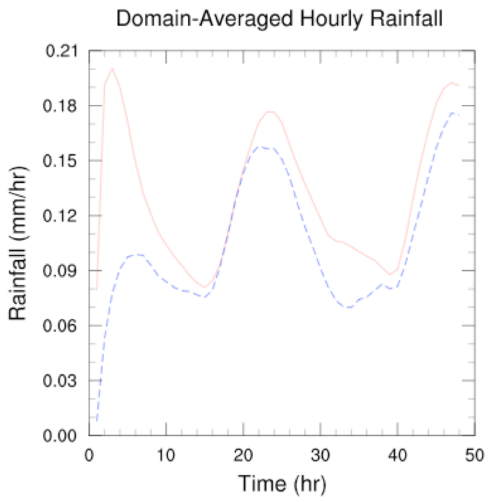
- Four-Dimensional Data Assimilation (Nudging) has specific purposes
  - Adding data during a model run (dynamic analysis)
  - Helping with dynamic initialization (nudged pre-forecast)
  - Keeping an outer domain on track (BCs)
- Nudging introduces fake terms so not recommended for case studies of dynamics and physics effects in events
- Spectral Nudging only affects larger scales (>500-1000 km typically) and may be useful in very large domains if timing of weather systems needs to be accurate in areas far from boundaries (e.g. reanalysis)
  - Can be seen as an interior correction for lateral-boundary distortion of long waves especially by linear interpolation in time

Initialization and Spin-Up Issues

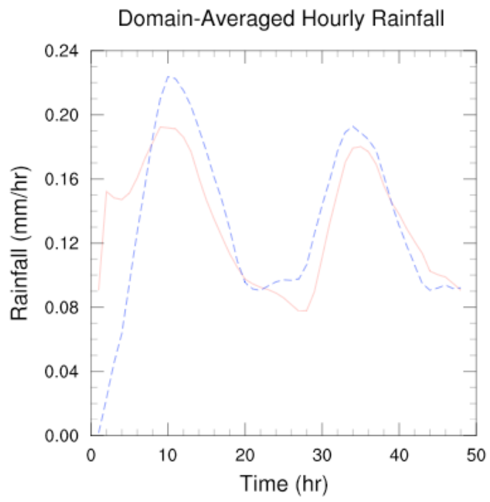
- Model problems often caused by poor initial condition
  - Poor soil temperature or moisture
  - Inappropriate water temperatures or missing masking at coastlines when creating SST in pre-processors
  - Check inputs carefully including soil temperatures, sea-surface temperature
- In first few hours, expect noise in pressure fields
  - Mostly sound waves adjusting winds to terrain
  - This disappears in about the time-scale for sound waves to leave the domain area and has no harmful lasting effects
  - For large domains this is longer (~1 hour per 1000 km)
  - If interested in the first hour or two (e.g. short-period cycling) consider Digital Filter Initialization that effectively filters high-frequencies out from the beginning

Initialization and Spin-Up Issues

- Convection Spin-Up
  - Model will take time to develop deep convection (e.g. 00Z initialization in central US)
  - This delay may be followed by a high bias when convection finally spins up
  - Example of NCAR's 3km convective runs from 2009



00Z



12Z

RUC initialized (red), GFS (blue)

Initialization and Spin-Up Issues

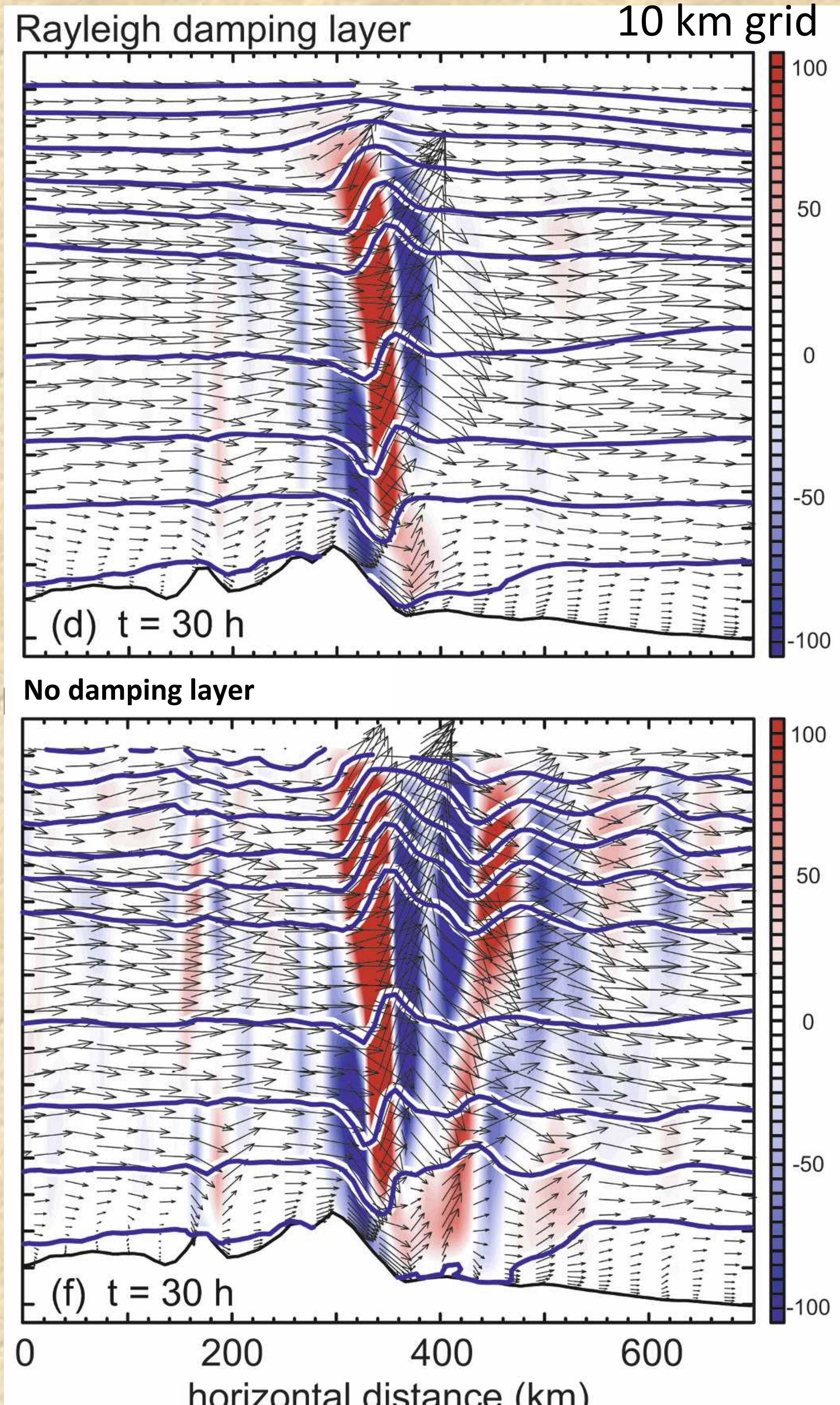
- Land Model
  - Soil moisture and temperature analysis come from generally much coarser offline analyses
  - Soil-data resolution and terrain don't match WRF
    - We handle elevation adjustment for soil temperature using SOILHGT data from source model
    - Cannot handle landuse/soil differences in hi-res domain which means adjustments may occur in soil moisture
    - This adjustment is slow and only way to prevent it is an offline land analysis on the same grid (HRLDAS for Noah)

Damping Options

- Convective instabilities (CFL)
  - *w_damping* is an artificial negative buoyancy added to updrafts if they approach the CFL stability limit
    - Only recommended for those doing long runs or mass-production/operational runs where they don't want to individually handle blow-ups with re-runs using a short time-step
    - Generally has no effect other than inside strong updrafts
  - Alternative is adaptive time-step option that automatically adjusts time step based on CFL criteria

Damping Options

- Model-top reflection of mountain waves is best solved with *damp_opt=3* (Rayleigh damping of w) for real-data cases
  - This very effective at producing proper wave tilts consistent with no reflection

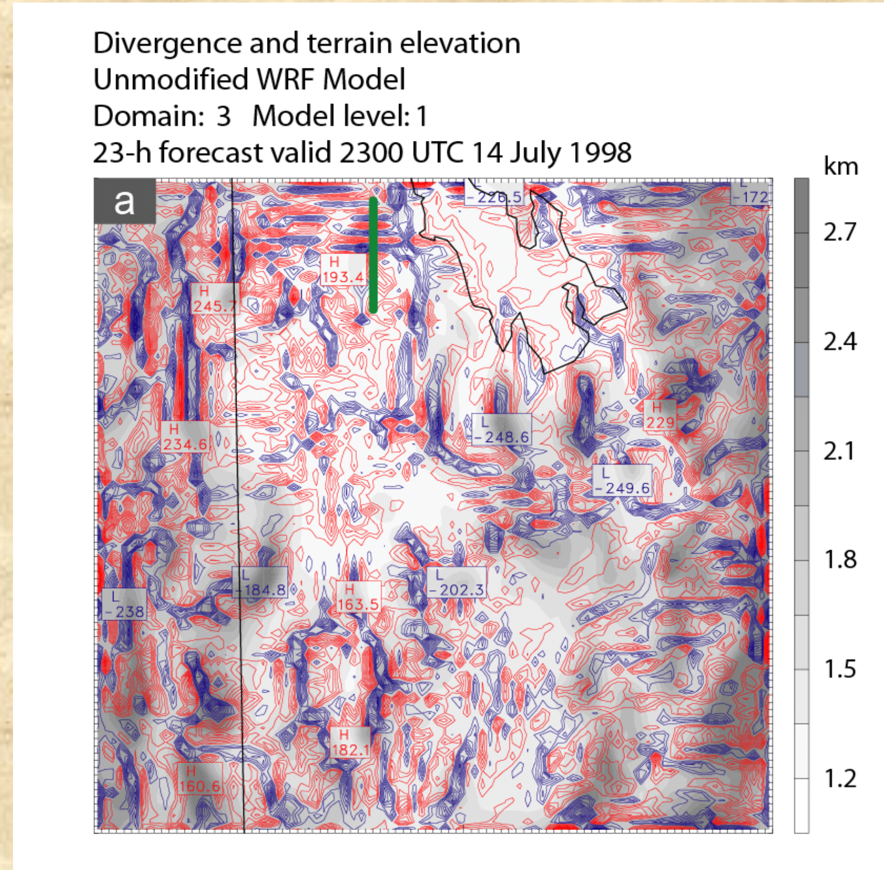


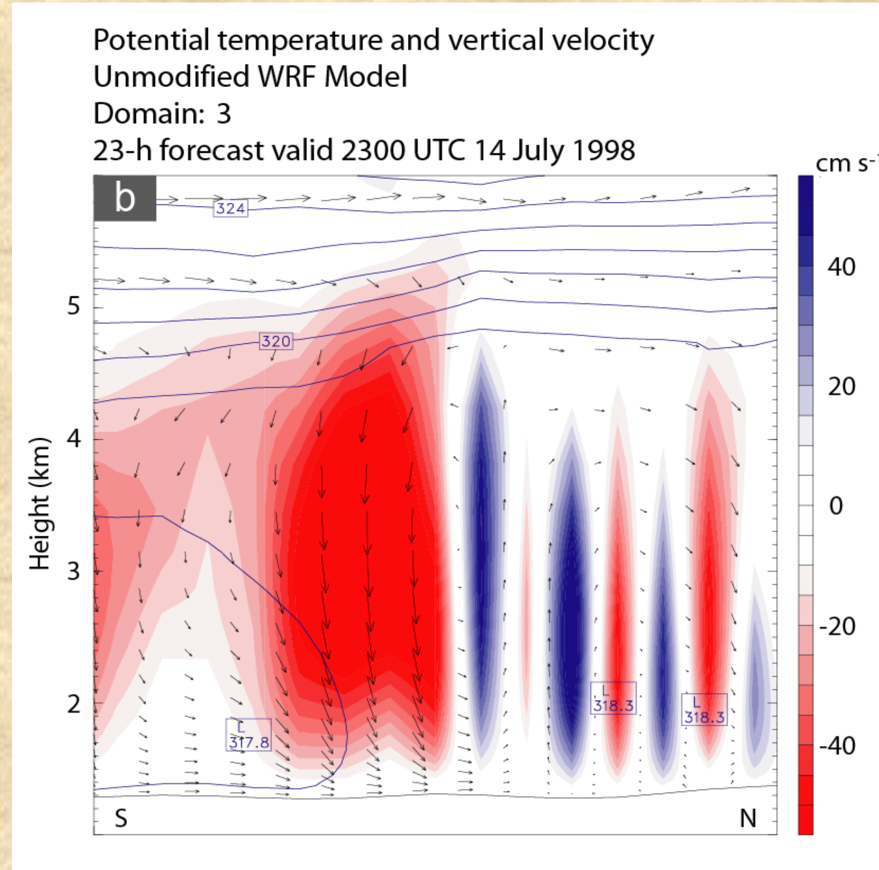
Klemp et al., (2008 MWR)

Damping Options

- *diff_6th_opt*
  - Selective filter to remove poorly resolved structures (off by default)
  - Most common example is 2Δx waves in boundary layer with weak wind and grid sizes in the 1-4 km range
    - Note that in weak winds odd-order advection damping is less able to smooth the result, so problem appears less with strong enough wind
  - *diff_6th_opt=2* (positive definite option) should be used
    - Acts on all advected fields including moisture and option 1 creates negative water that, when zeroed out, becomes a significant non-conserving source

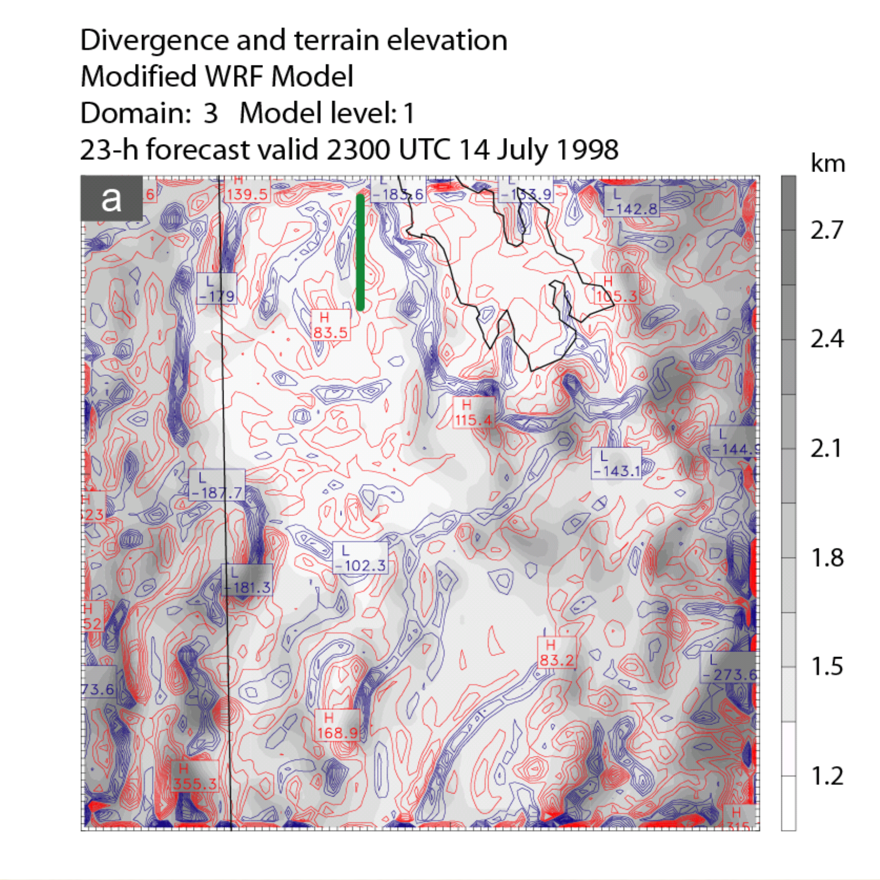
Example of case study: noisy boundary layer

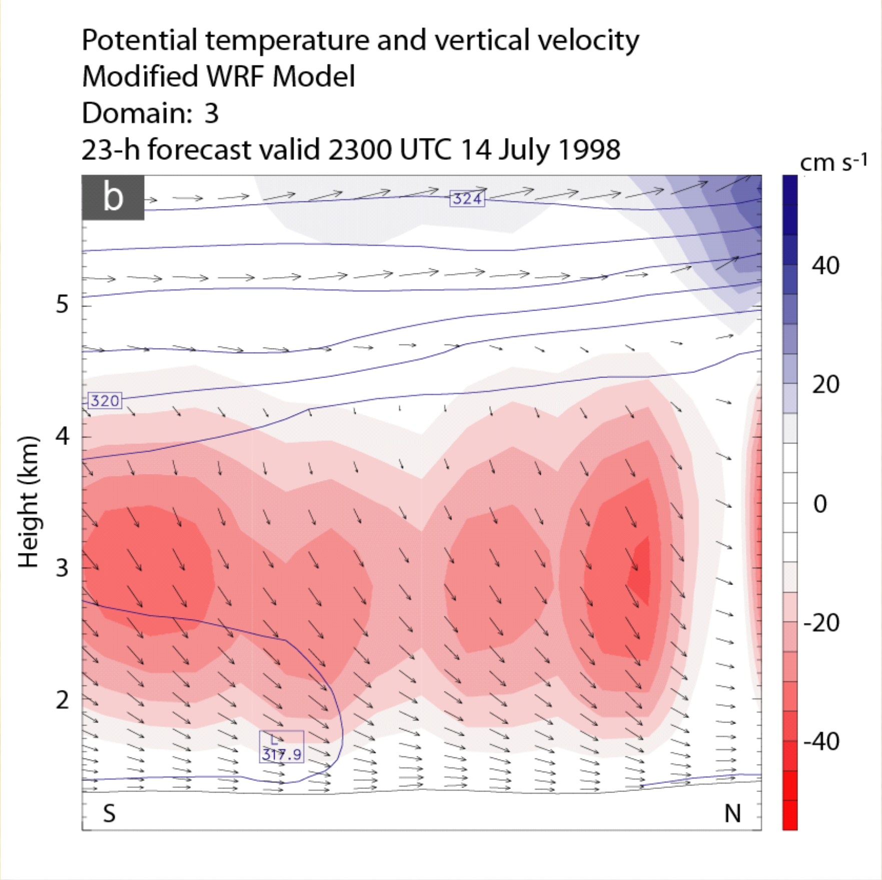




- Reduced diffusion in weak wind allows grid-scale noise to grow in daytime boundary layers

Example of case study: noisy boundary layer





- Adding 6th-order, monotonic, numerical diffusion removes most of the grid-scale noise

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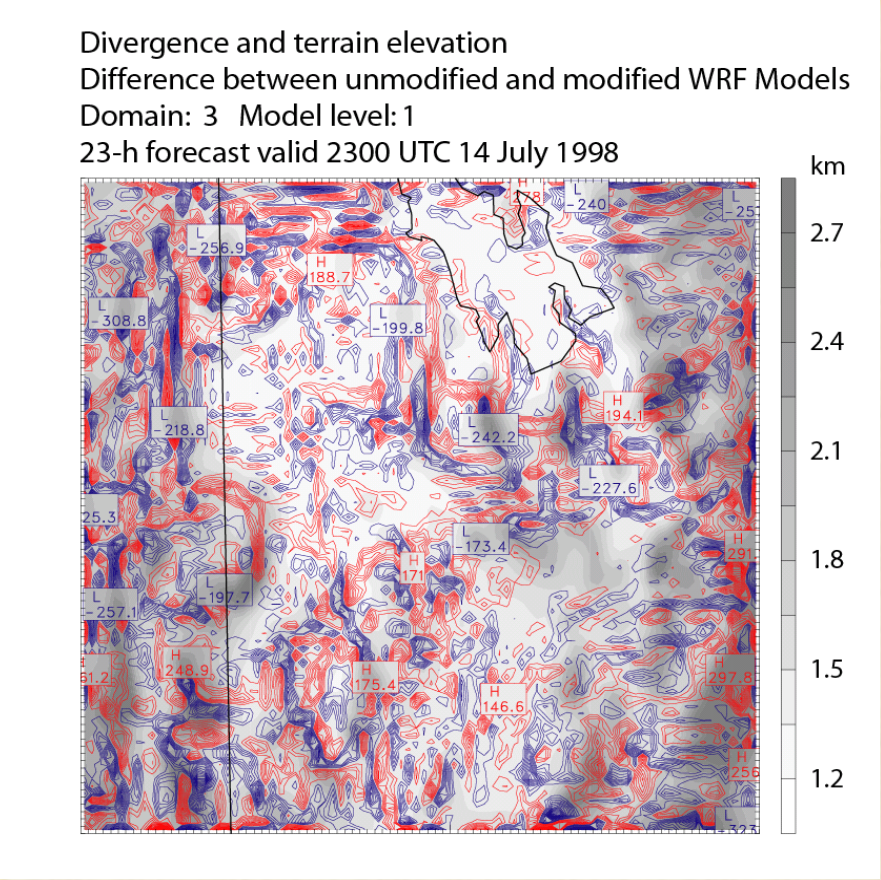

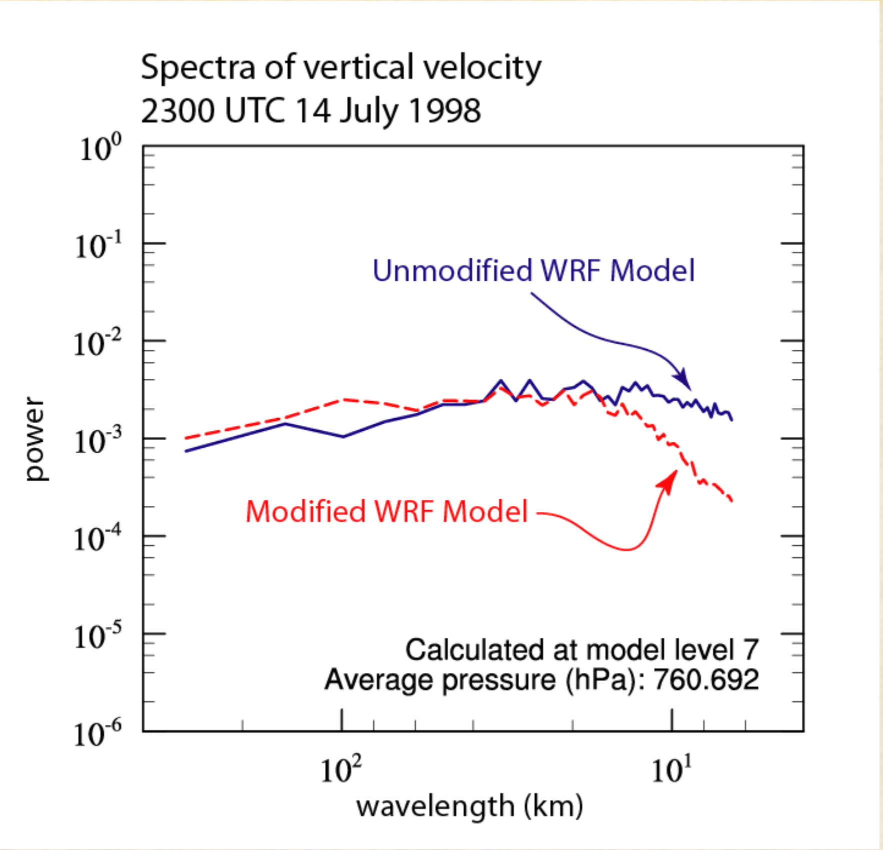

- Added diffusion acts mainly on wavelengths less than 6 times grid interval

Advection Options

- 5th order horizontal, 3rd order vertical by default
  - cleaner than even-ordered schemes
  - If using even-ordered maybe diff_6th_opt is helpful
- Positive definite is the default (required for water conservation)
- Monotonic is available (reduces overshoot in maxima), perhaps good for chemistry
- WENO is designed to reduce oscillations at cloud edges

Further Best Practices Reading

- Chris Davis' best practices talk: http://www2.mmm.ucar.edu/wrf/users/workshops/WS2012/ppts/discussion1.pdf
- Wei's tutorial best practices talk: http://www2.mmm.ucar.edu/wrf/users/tutorial/201401/best-practices_wang.pdf

***Reference**:*

Warner, T., 2011. Quality assurance in atmospheric modeling. *Bull. Amer. Met. Soc. Dec. issue, p1601 – 1611.*

Summary

- Physics: So many options to choose from
- Complex terrain
- Nesting, resolution and domain sizes
- Model levels and high tops
- Nudging options: use or not
- Initialization and spin-up issues
- Damping and advection options

Questions?