Application of WRF

How to get better performance

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Best Practices of WRF

- WRF is well-tested and documented. It can be used by people who have no experiences or formal training.
- However, in spite of advanced parameterization schemes in WRF and high-resolutions permitted by faster computers, correct choice of options is still a prerequisite for successful application of WRF

Best Practices of WRF

- A Thorough Analysis of the Research Topic
  - Conclusions and approaches in previous studies? Questions not answered? Incomplete knowledge? Important processes (convection, radiation, surface forcing, etc.?)
  - extensive literature review
- Your Scientific or Practical Objectives?
  - Scientific questions you want to answer
  - What can you do with WRF? Where and how WRF simulations may be helpful

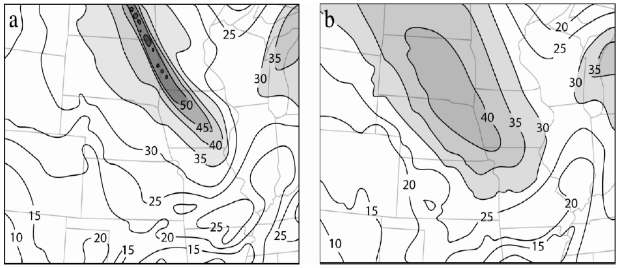
Best Practices of WRF

- The Model Configuration
  - Domain – often have profound influences
  - Resolution (horizontal and vertical)
  - Time and method of initialization
    - Cold start?
    - Variational data assimilation?
    - Spinup time?
  - Lateral Boundary Locations
  - Physics/dynamics options

How to determine the model domain

- How large do they need to be?
  - Should not be too small, otherwise solution will be determined by forcing data
  - No less than 100x100 (at least 10 grid points are in the boundary zone)
- Where to place my lateral boundaries?
  - Avoid steep topography
  - Away from the area of interest

Importance of domain

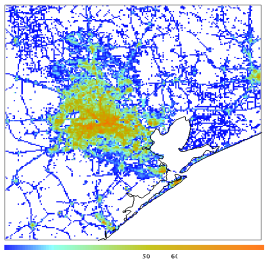


12-hour simulations of 250-hPa winds (m s-1) from the 40-km grid increment Eta Model initialized at 1200 UTC 3 August 1992, based on experiments that used a large (a) and a small (b) computational domain. (Warner, 2011)

Initialization and Spin-up Issues

- Model problems often arise from poor initial condition
  - Appropriate initial time
  - Quality of initial condition
    - Check land data:

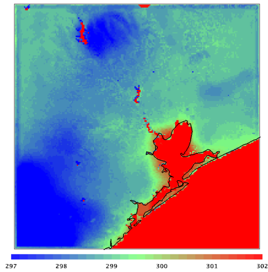
      e.g. landuse: *does it represent my area well?*
    - Know about the data: how good are the data?
      - Forecast data
      - Reanalysis data
      - Climate model data
- In the first few hours, expect noise in pressure fields
  - Mostly sound waves adjusting winds to terrain. No harmful lasting effects

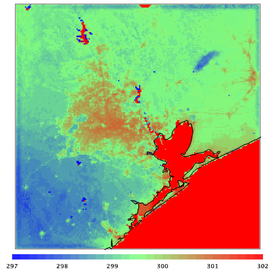


Impervious fraction (%)

Skintemp simulated with and without Impervious (Aug 26, 2006, 10Z)

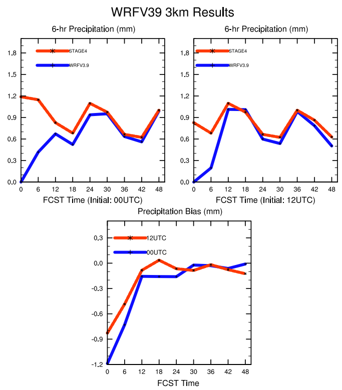
Pleim et al., 2012





Initialization and Spin-Up

Convective Spin-Up: An example of NCAR's 3-km convective runs

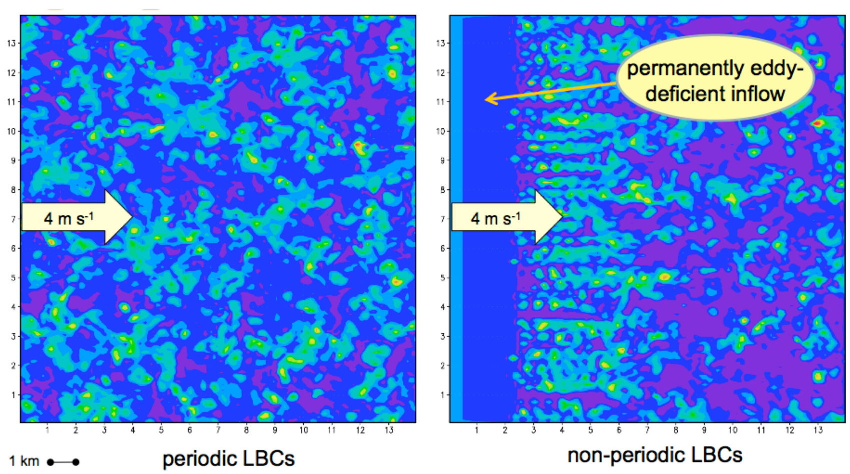


Red: StageIV

Blue: WRFV3.9

Lateral Boundary Condition

- A basic and potentially serious limitation to regional model simulation, including WRF
- Possible negative effects of LBC
- How to minimize the negative LBC impact on forecast quality: guidelines and cautions
  - Strong forcing should be avoided at lateral boundaries
  - Resolution-consistent input data should be used
  - More frequent is better
  - Interactive boundaries should be employed when possible



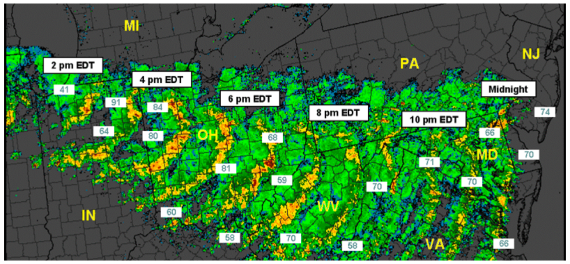
Gaudet et al. (2012)

Grid Size and Impact

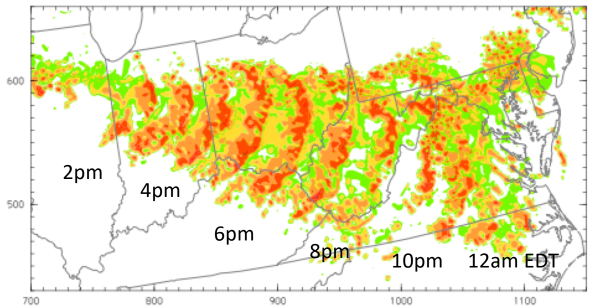
- $\Delta \approx 3$ km: Traditional cloud-permitting resolution
  - No need for deep-convective parameterization
- $\Delta \approx 30$ m: Traditional large-eddy simulation (LES) resolution
  - No need for a planetary boundary layer (PBL) parameterization
  - Turbulent eddies (i.e., thermals, rolls, etc.) are handled by the model's governing equations [plus surface-layer and subgrid turbulence schemes]
- 100 m < Δ < 1 km
  - A PBL scheme will still be needed for most cases
  - Shallow cumulus probably can be turned off (not for Δ > 500 m)
  - Advection Scheme: better use a monotonic/non-osciallaory option (adv_opt ≥ 2)

(Bryan, 2014)

Case Study: The Derecho of 29-30 June 2012

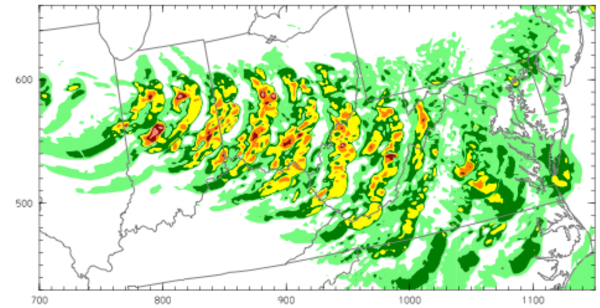


Radar composite reflectivity

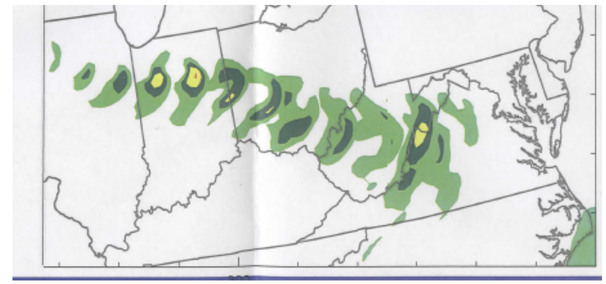


WRF simulation of maximum reflectivity, DX=3km, initialized at 1200 UTC 29 June

Simulated maximum wind



3-km run



15-km run

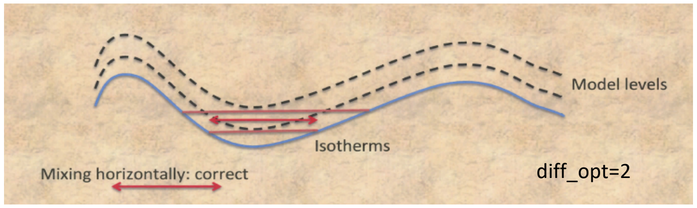
Model Levels and High Tops

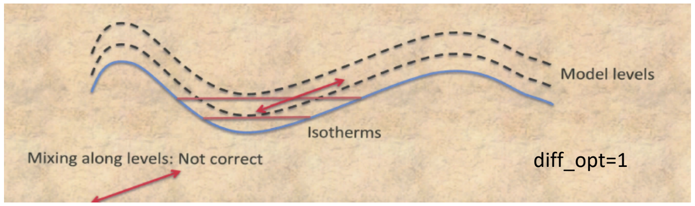
- At least 30 or more levels for a model top at 50 mb
  - For high tops < 50 hPa
    - Stratosphere option for base state: Iso_temp=200 K. This prevents base state from becoming unrealistically cold.
    - Since V3.6.1, a positive lapse rate is allowed in stratosphere
  - For tops near 1 hPa (45-50km), 60 or more levels are required.
  - Ozone climatology becomes important above 30 hPa, where some or all of the ozone layer are included
    - Use RRTMG since CAM monthly ozone is available in RRTMG
- Vertical grid distance should not be larger than 1000 m (Radiation, microphysics, less accurate lateral BC)
- If finer horizontal grid size is used, more levels will be needed in the vertical
- Make sure dz < dx

Complex Terrain

- Steep terrain (> 45 degrees) may cause numerical stability problems.
  - Increasing epssm (0.1->0.5 or even larger)
    - This is a sound wave damper that can stabilize slope treatment by dynamics
  - For large slopes, set diff_opt=2
    - diff_opt=1 is less realistic than diff_opt=2, and diff_opt=2 used to be less stable but becomes more stable in recent versions
  - For V3.6 and later version, diff_opt=2 and km_opt=4 can be used together to improve stability

Diffusion





Dudhia (2014)

Selecting Model Physics

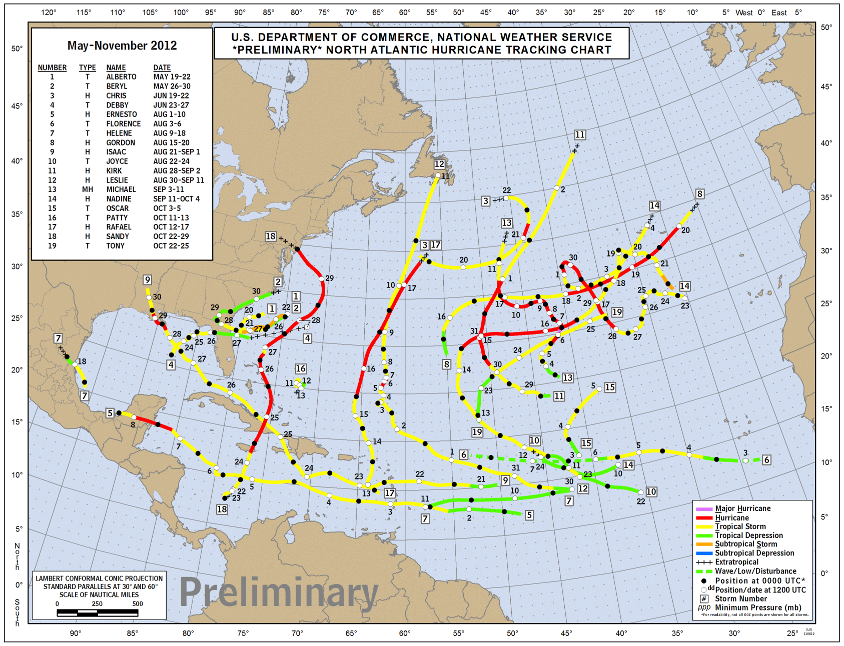
- Many options = more works
  - http://www2.mmm.ucar.edu/wrf/users/phys_references.html
  - http://www2.mmm.ucar.edu/wrf/users/docs/wrf-phy.html
- Testing of multiple options for a particular application
  - A given set of physics will perform differently depending on domain size, location, initialization and phenomenon of interest
  - Certain combinations better tested than others, but still no guarantee for better performance

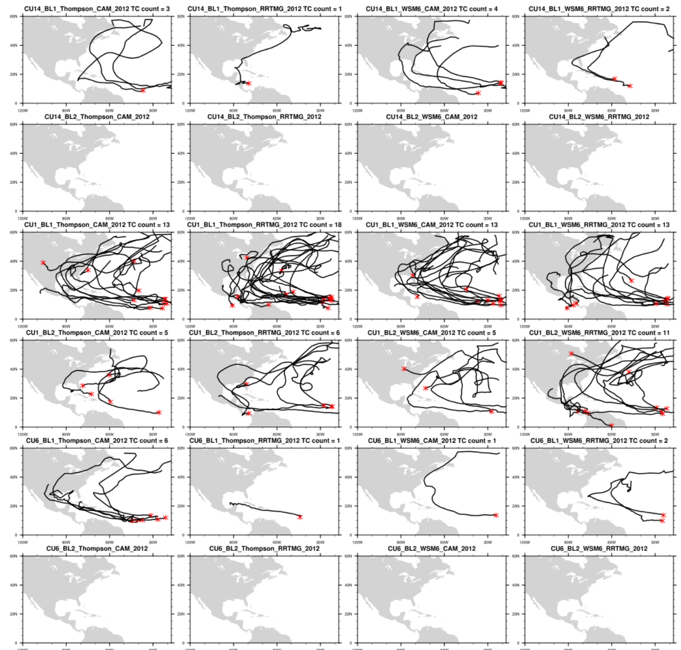
Physics in multi-scale model

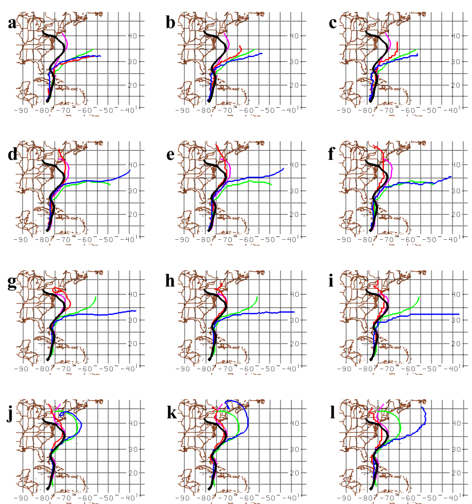
- Grid size and cumulus
  - DX > 10km, yes
  - DX < 4km, probably not
  - Grey Zone: 5-10km, no consensus, may try to use scale-aware cumulus scheme, such as GF, MSKF.
- Grid size and microphysics
  - For DX > 10km, no complex scheme is necessary
  - For DX <4km (convection-resolving), need at least graupel

Physics in Multi-scale Model

- Grid Size and PBL
  - PBL assumes all eddies are unresolved
    - DX > 500 m, PBL should be activated
  - LES assumes eddies are well resolved
    - DX < 100 m, LES should be applied
  - For DX 100-500 m, either may work to some extent
  - Terra incognita: resolved CISCs, violation of PBL assumption, and unresolved interaction between CISC and smaller scale turbulence.







- ECMWF(pink)
- GFS(green)
- TWRF(red, Tiedtke)
- SWRF(blue, SAS)

(Grid interval from left to right: 30, 60, 90-km;
Top two: initialized at 0000 and 1200 UTC 23 Oct.;
Bottom two: initialize at 0000 and 1200 UTC 24 Oct.)

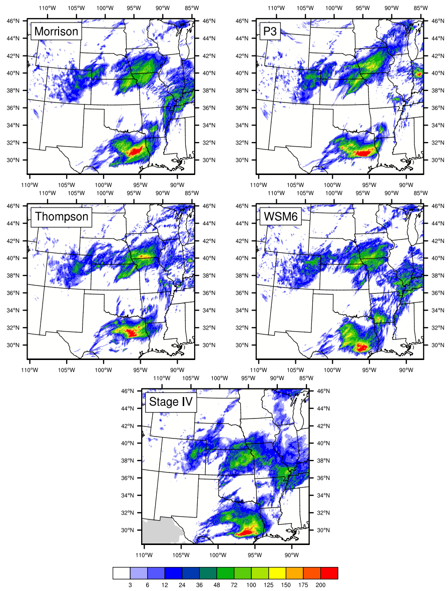
Simulation of Hurricane Sandy: why such a large difference?

Bassill (2014)

Test of Sandy Simulation

- *For this case*, cumulus parameterization is the dominant driver of forecast track accuracy
- Poor track forecasts by the GFS/GEFS are not due to ‘inappropriate’ initial conditions, nor are they consequences of the differences in model resolution
- These types of examples serve to emphasize the importance of parameterization development as a necessary condition for forecast improvement

12-36hr FCST of Rain

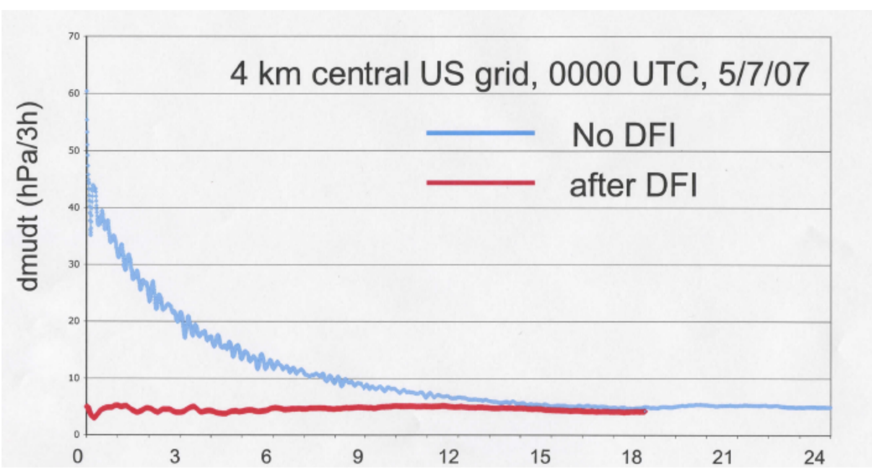


Other Options That May Be Considered

Example:

- Upper level damping over topography
- Gravity-wave drag if resolution is coarse
- Digital Filter Initialization
- Horizontal Diffusion
- Spectral Nudging

Domain average 3-hourly dry-hydrostatic column pressure tendency

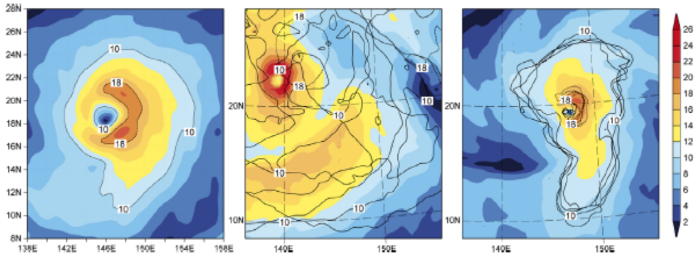


Forecast Hours

Spectral Nudging

- It is useful for controlling longer wave phases. Compensates for errors due to low-frequency narrow lateral boundaries
- The "spectral nudging" method imposes time-variable large-scale atmospheric states on a regional atmospheric model
- Spectral nudging may be seen as a suboptimal and indirect data assimilation technique.
  - Wave number is selected so that domain size/wavenumber =~1000km in X and Y direction
  - Nudge U, V, THETA, Geopotential (not QV, since it has no wave pattern)
  - Can nudge in all levels or use ramp above a specified model level (if_zfac_ph, k_zfac_ph, etc.)

- However, strong nudging may reduce or filter out extreme events since nudging pushes the model toward a relatively smooth, large-scale state.



Horizontal 10 m wind speed fields (m s−1) for typhoon Songda (200418), on 1 September 2004, 0:00.
From left: CFSR reanalysis, CCLM-NN, CCLM-SN.

(Frauke Feser1 and Monika Barcikowska, Environmental Research Letters, 2012)

Keep in mind

- Model results can be affected by many choices:
    - Domain configuration, both horizontal and vertical;
    - Input data;
    - Initial and lateral boundary conditions.
- Model has limitations:
    - Physics: biases, may not represent certain process well, etc.
    - Limitation of the lateral boundaries
- Knowing where model is biased can be very useful