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

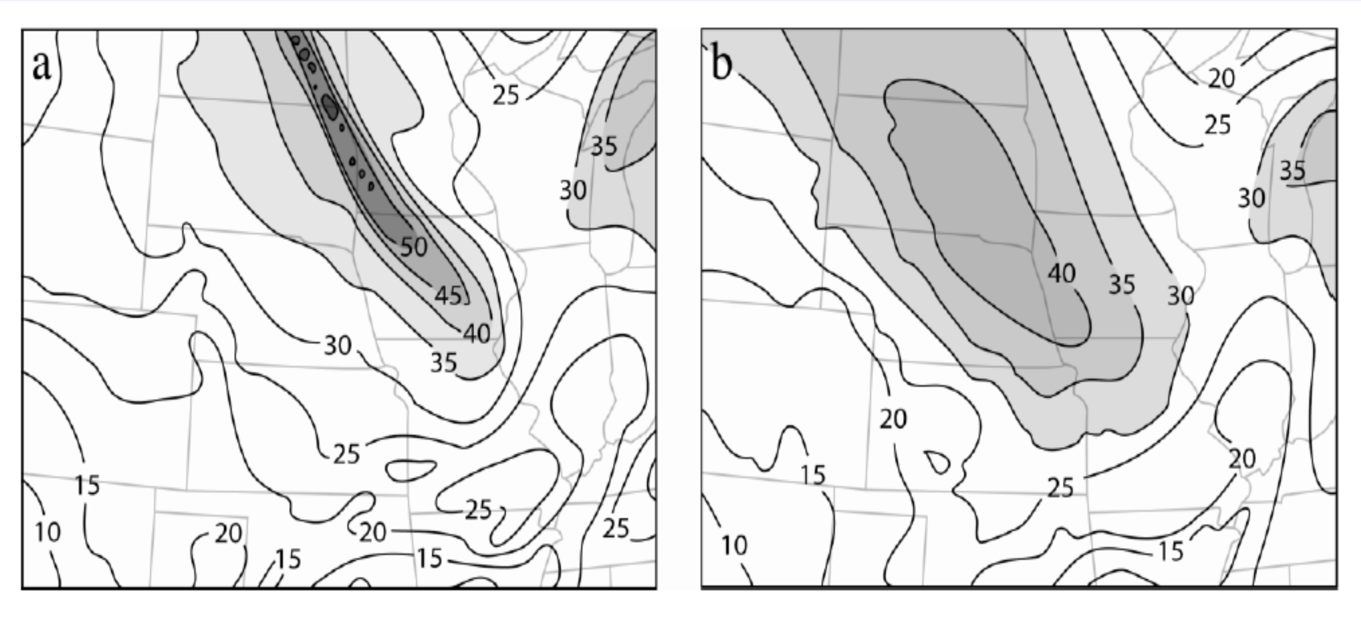
Best Practices of WRF

- 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

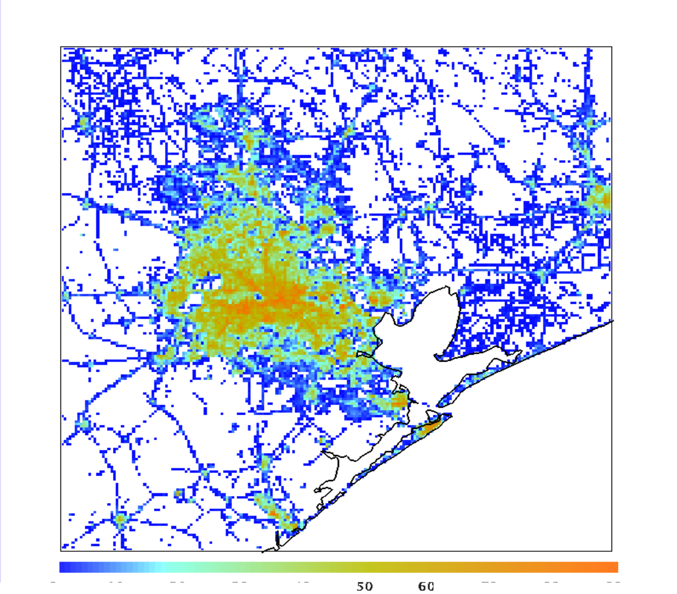


12-hour simulations of 250-hPa winds (m s-1) from the 40-km grid increment Eta Model initialized at 1200 UTC 3 August 1992, based on experiments that used a large (a) and a small (b) computational domain. (Warner, 2011)

Initialization and Spin-up Issues

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

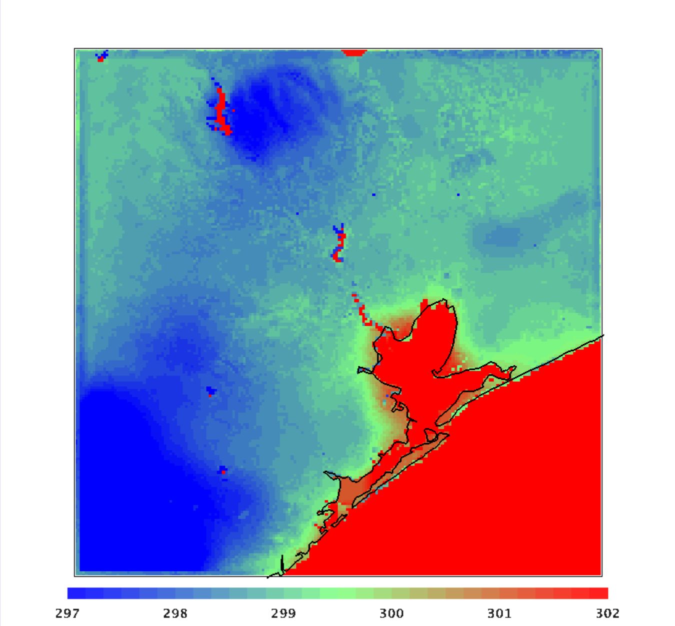
      e.g. landuse: *does it represent my area well?*
    - Know about the data: how good are the data?
      - Forecast data
      - Reanalysis data
      - Climate model data
- In the first few hours, expect noise in pressure fields
  - Mostly sound waves adjusting winds to terrain. No harmful lasting effects

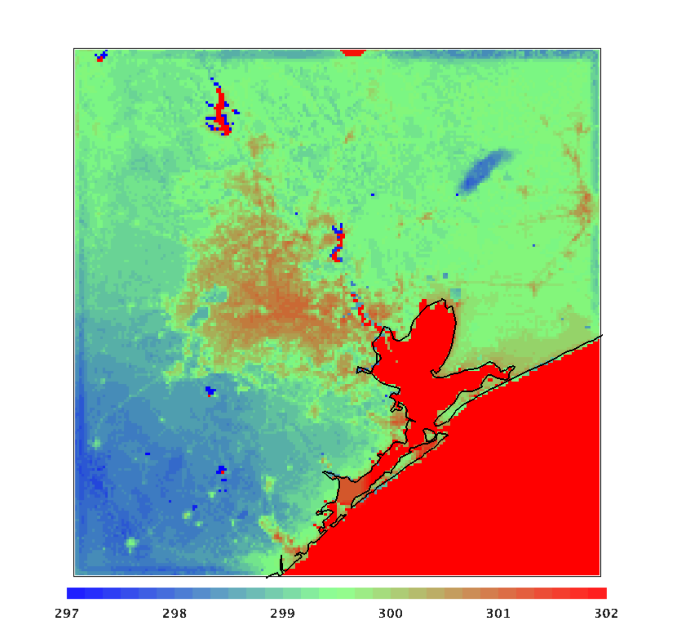


Impervious fraction (%)

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

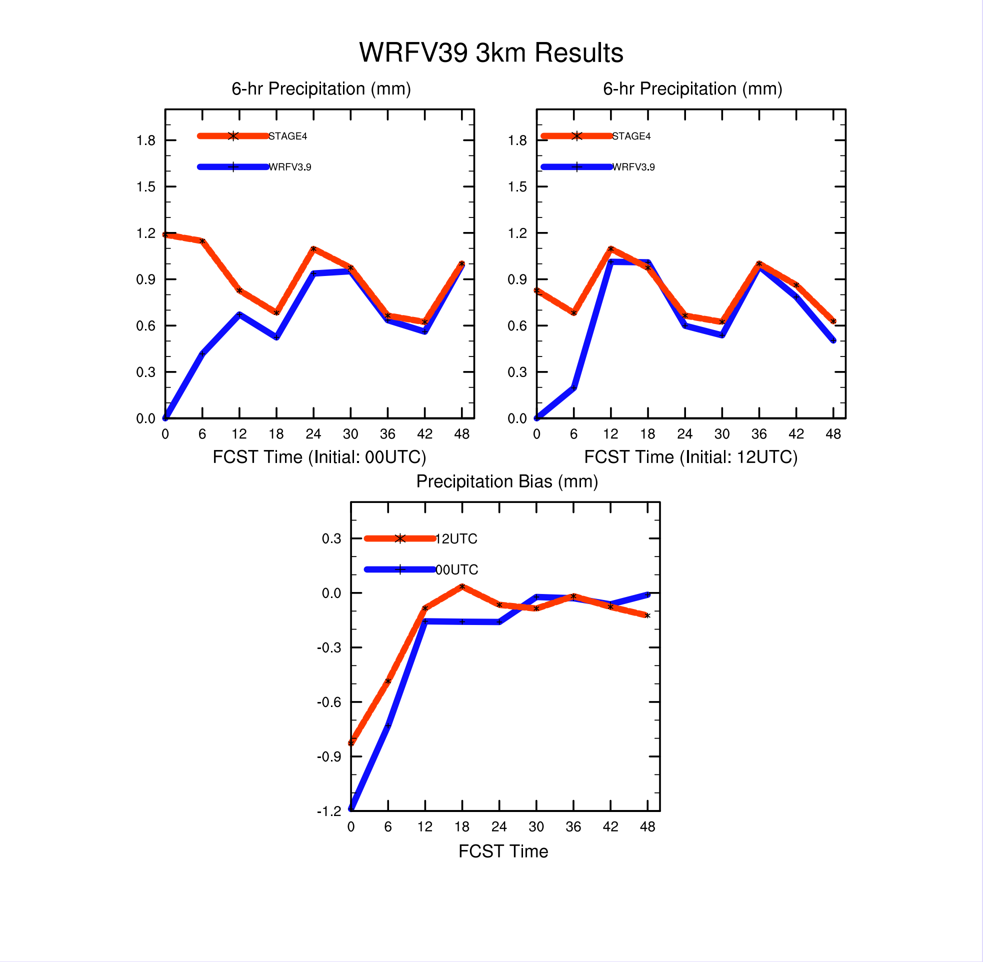
Pleim et al., 2012





Initialization and Spin-Up

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

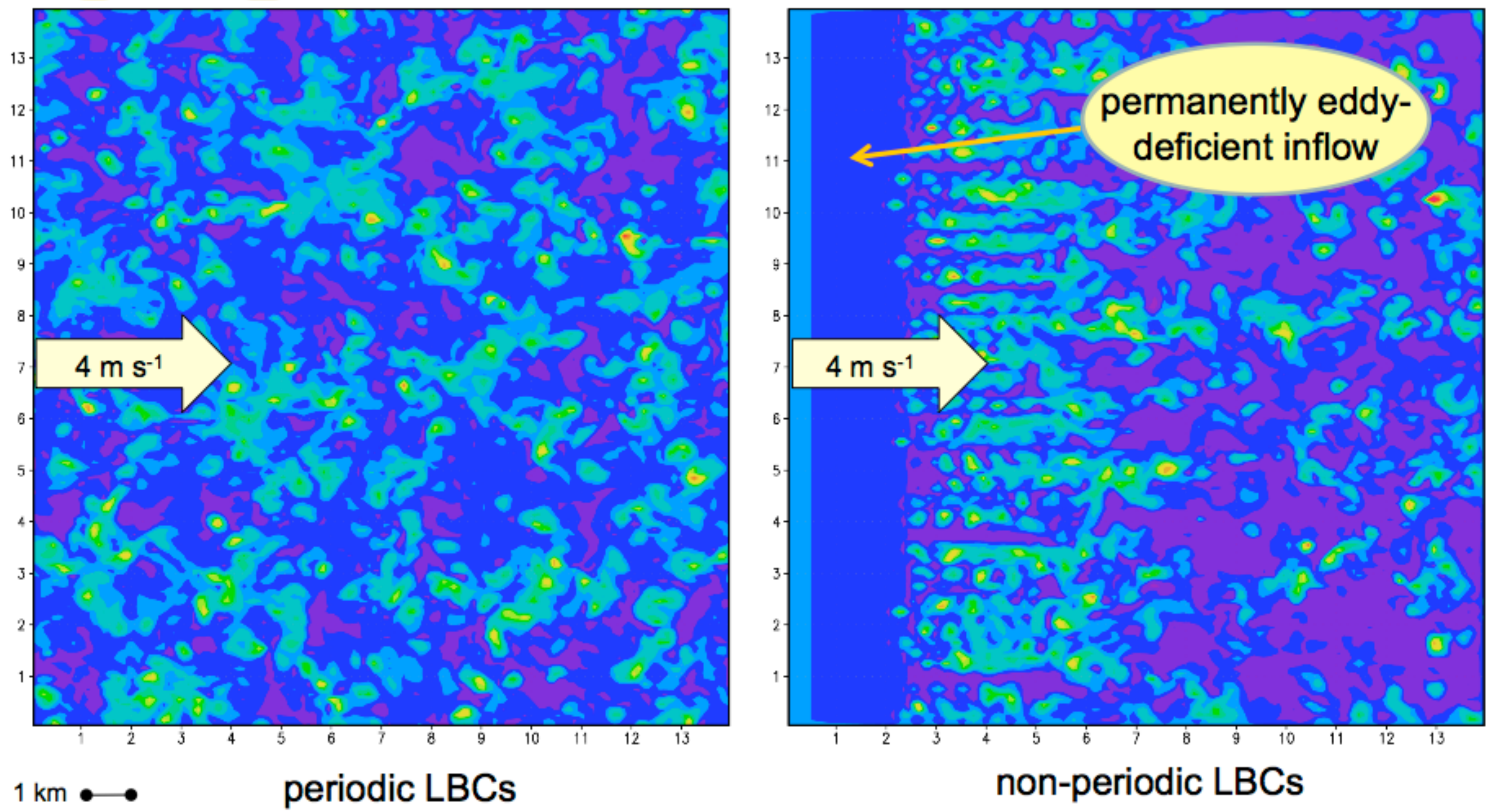


Red: StageIV

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



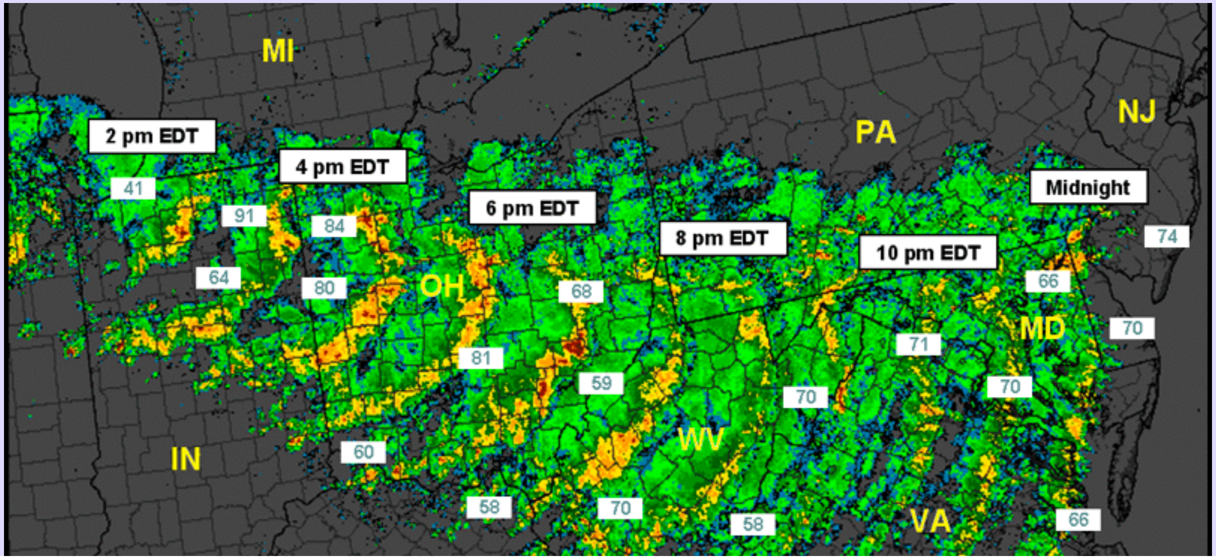
Gaudet et al. (2012)

Grid Size and Impact

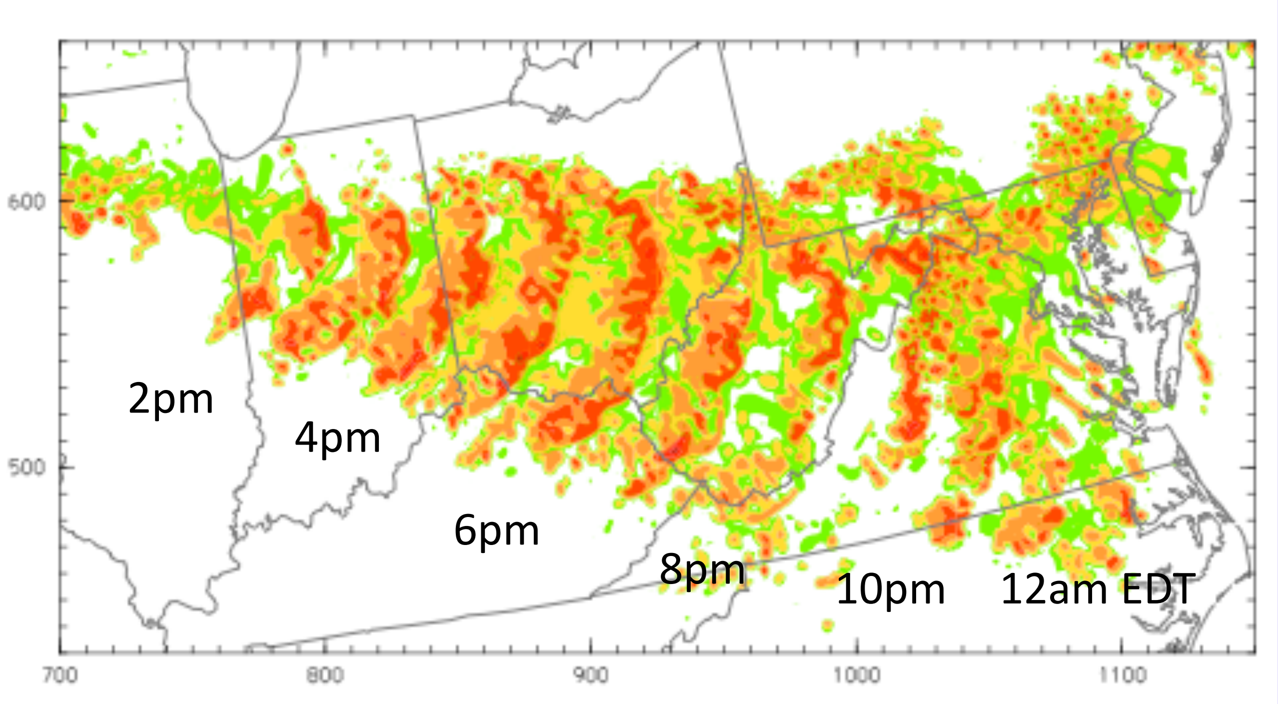
- $\Delta \approx 3$ km: Traditional cloud-permitting resolution
    - No need for deep-convective parameterization
- $\Delta \approx 30$ m: Traditional large-eddy simulation (LES) resolution
    - No need for a planetary boundary layer (PBL) parameterization
    - Turbulent eddies (i.e., thermals, rolls, etc.) are handled by the model's governing equations [plus surface-layer and subgrid turbulence schemes]
- $100 \text{ m} < \Delta < 1 \text{ km}$
    - A PBL scheme will still be needed for most cases
    - Shallow cumulus probably can be turned off (still on for $\Delta > 500$ m)
    - Advection Scheme: better use a monotonic/non-osciallaory option (adv_opt ≥ 2)

(Bryan, 2014)

Case Study: The Derecho of 29-30 June 2012

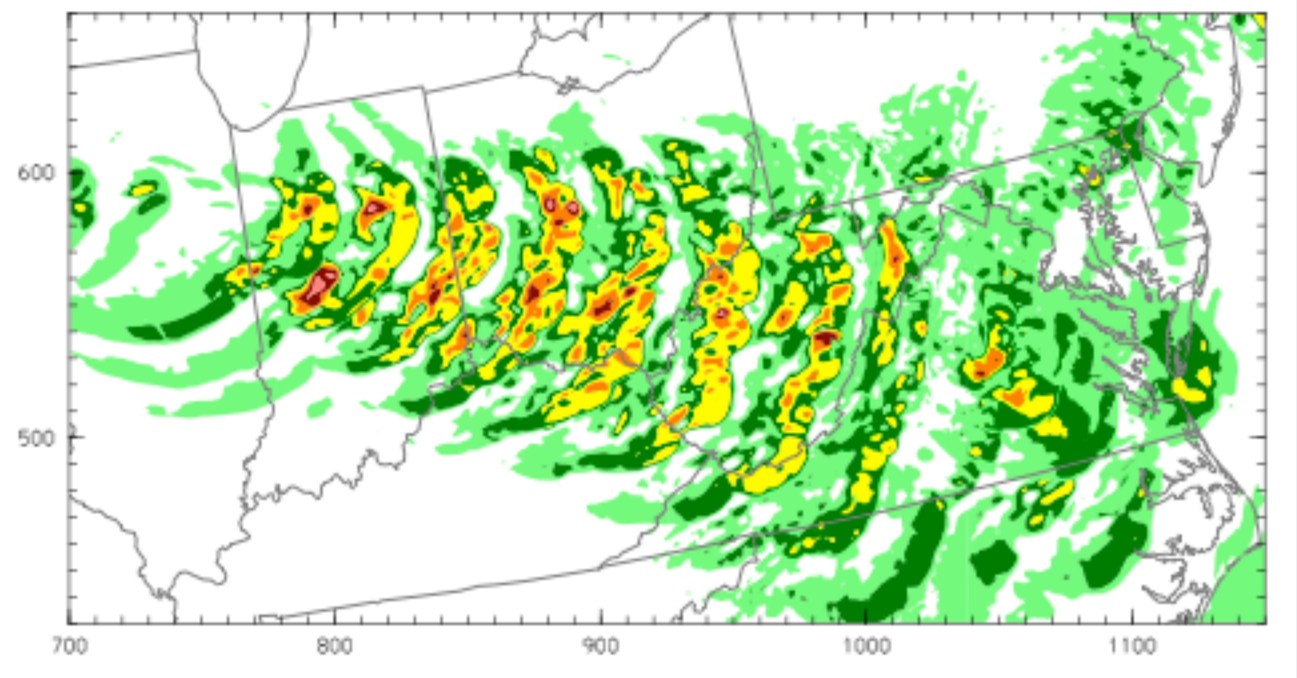


Radar composite reflectivity (provided by NOAA)



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

Simulated maximum wind



3-km run

15-km run

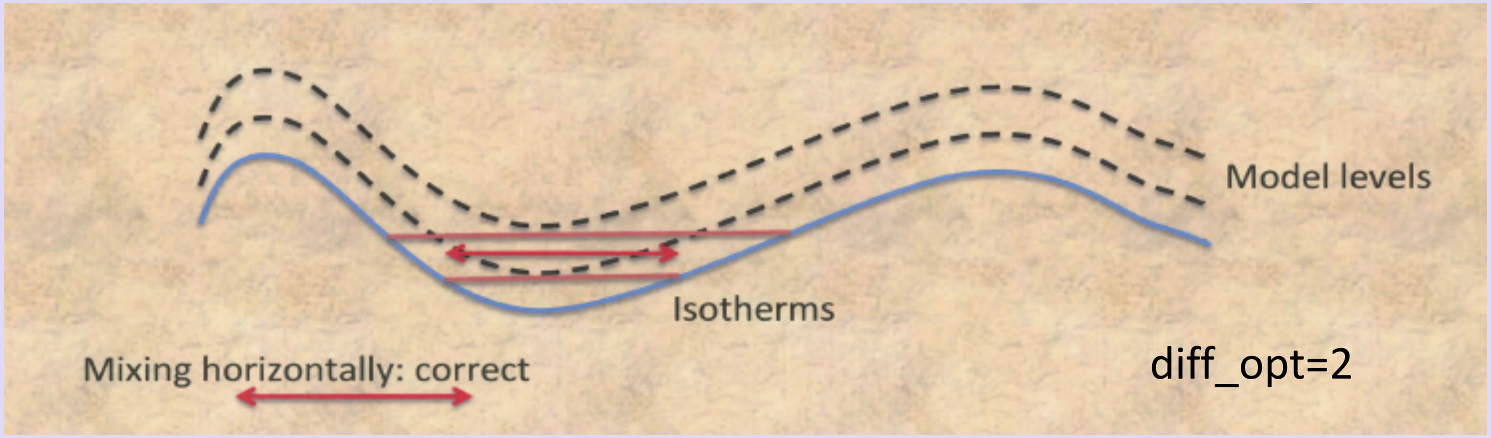
Model Levels and High Tops

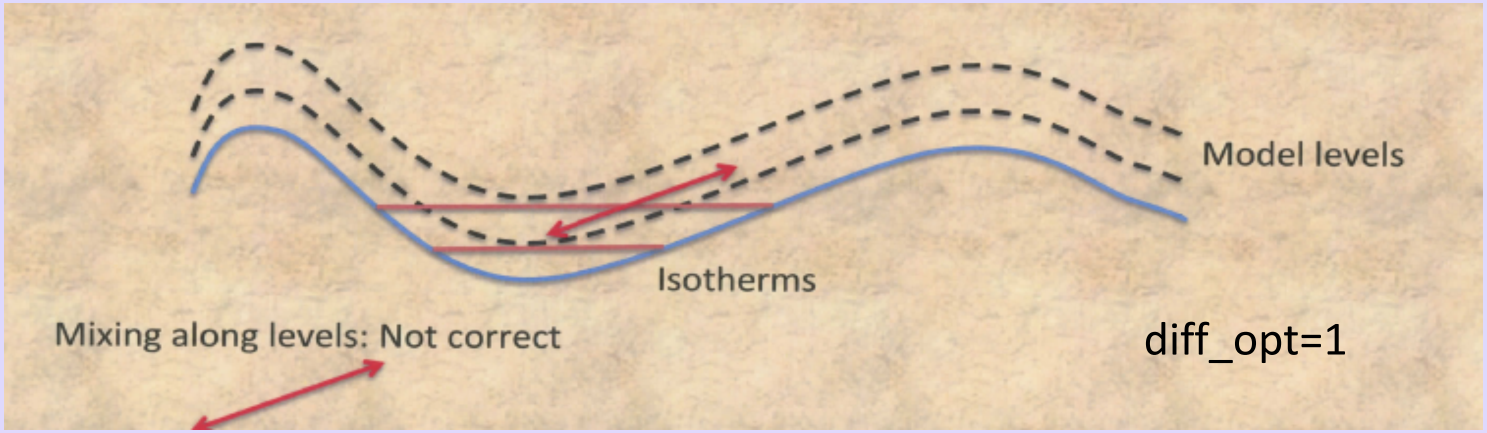
- At least 30 or more levels for a model top at 50 mb
- For tops near 1 hPa (45-50km), 60 or more levels are required.
- Ozone climatology becomes important above 30 hPa, where some or all of the ozone layer are included
  - Use RRTMG and CAM
- For high tops < 50 hPa
  - vertical grid distance should 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

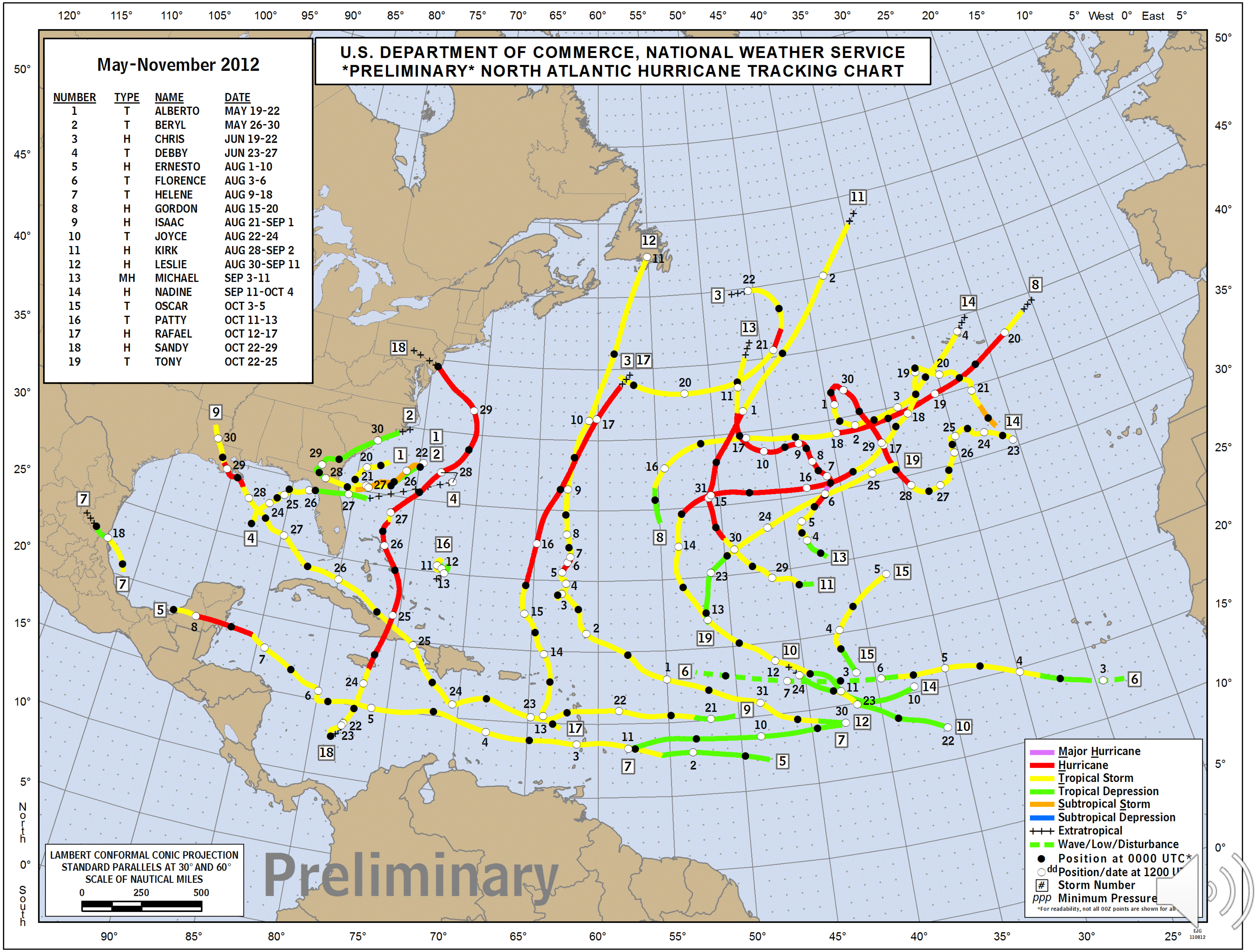
- Many options = more works
  - http://www2.mmm.ucar.edu/wrf/users/phys_references.html
  - http://www2.mmm.ucar.edu/wrf/users/docs/wrf-phy.html
- Testing of multiple options for a particular application
  - A given set of physics will perform differently depending on domain size, location, initialization 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.



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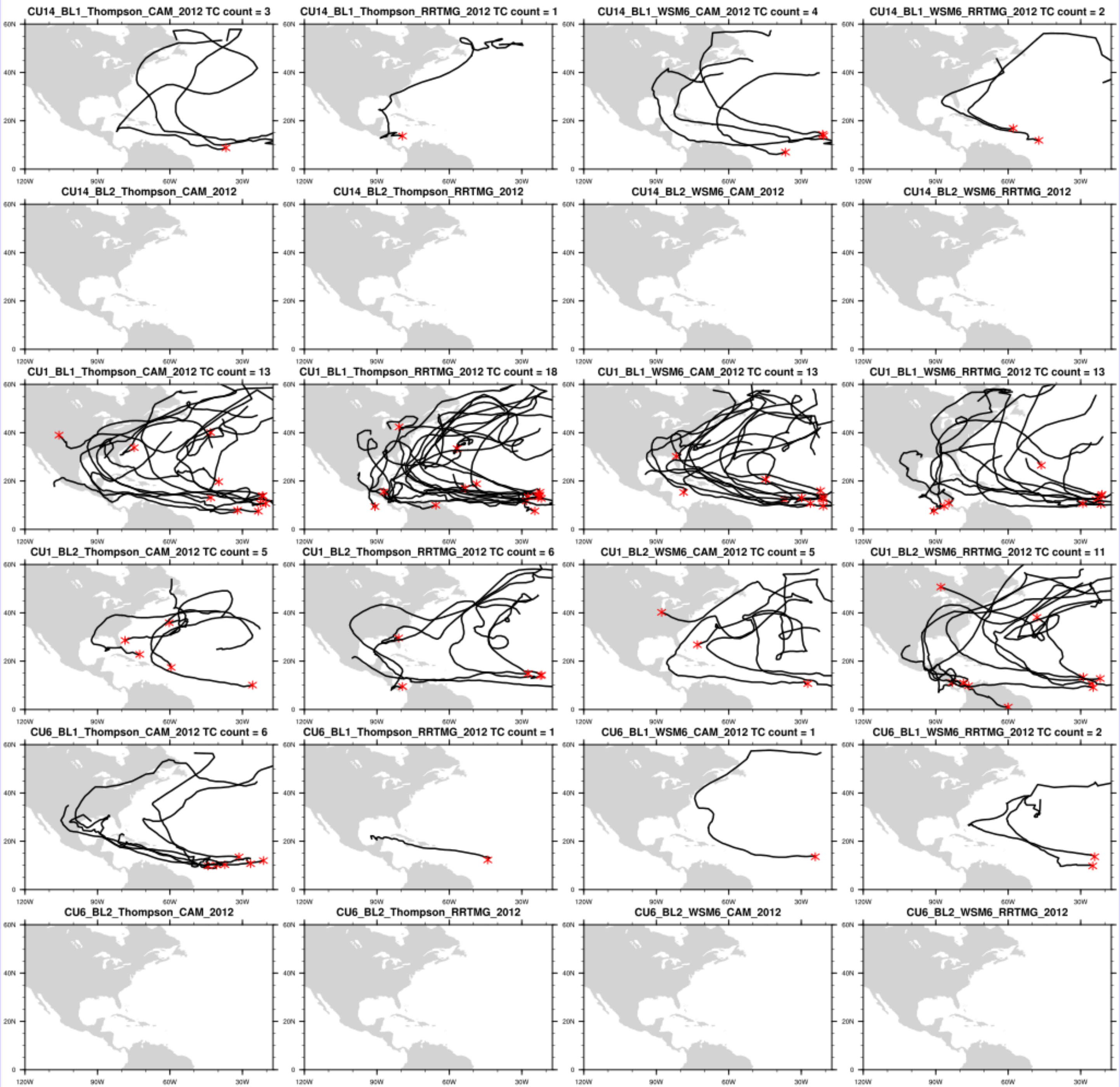
1	T	ALBERTO	MAY 19-22
2	T	BERYL	MAY 26-30
3	H	CHRIS	JUN 19-22
4	T	DEBBY	JUN 23-27
5	H	ERNESTO	AUG 1-10
6	T	FLORENCE	AUG 3-6
7	T	HELENE	AUG 9-18
8	H	GORDON	AUG 15-20
9	H	ISAAC	AUG 21-SEP 1
10	T	JOYCE	AUG 22-24
11	H	KIRK	AUG 28-SEP 2
12	H	LESLIE	AUG 30-SEP 11
13	MH	MICHAEL	SEP 3-11
14	H	NADINE	SEP 11-OCT 4
15	T	OSCAR	OCT 3-5
16	T	PATTY	OCT 11-13
17	H	RAFAEL	OCT 12-17
18	H	SANDY	OCT 22-29
19	T	TONY	OCT 22-25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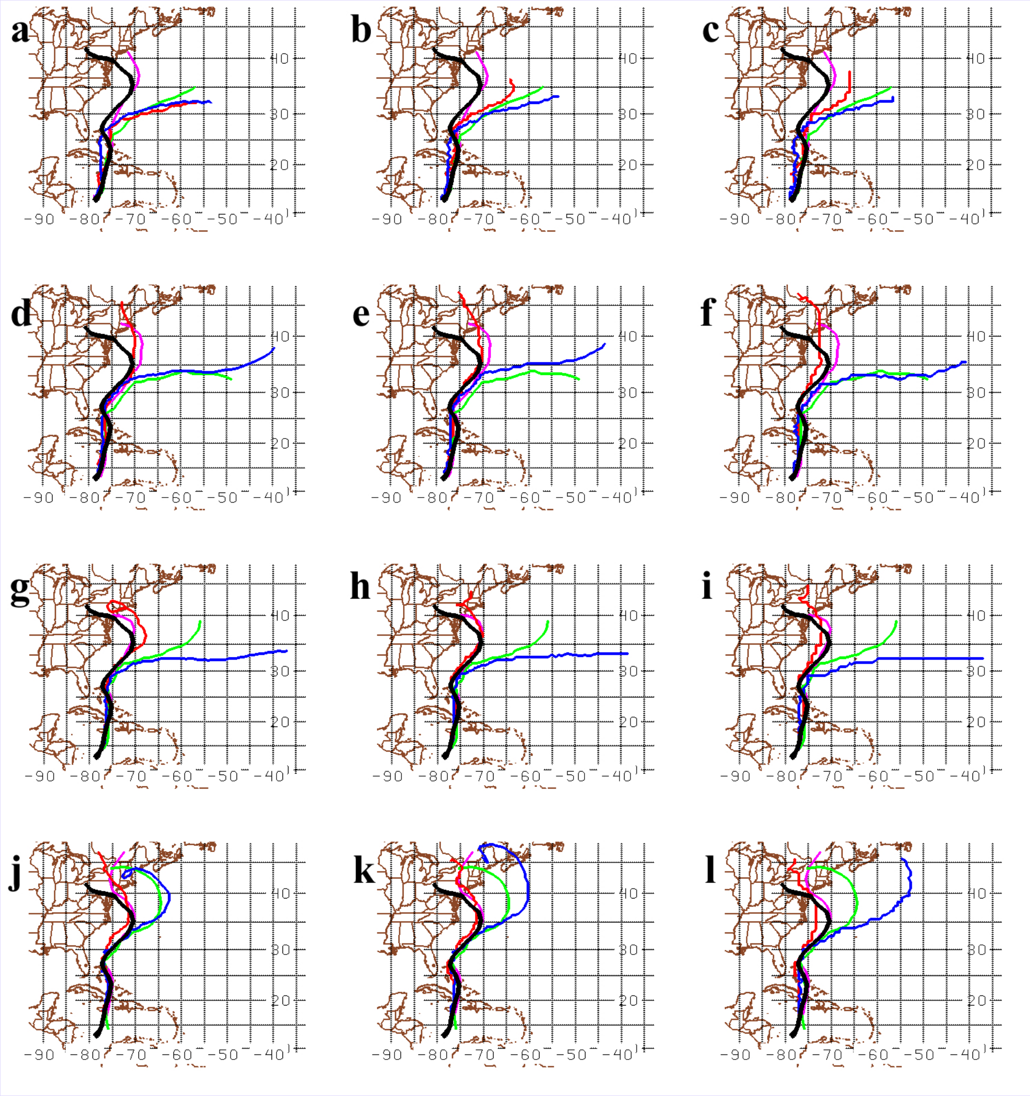

- ECMWF(pink)
- GFS(green)
- TWRF(red, Tiedtke)
- SWRF(blue, SAS)

(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

Other Options That May Be Considered

Example:

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

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 processes well, etc.
  - Limitation of the lateral boundaries
- Knowing where model is biased can be very useful