Microphysics: EMC Status

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The Parameterization of Moist Processes for Next-Generation Weather Prediction Models

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Overview

- Overview of microphysics schemes in global and regional EMC models
- Brief review of regional EMC models
- Strengths and weaknesses from a short-range (<3.5 day) forecast perspective
- Assessing model performance
- Microphysics requirements for the next-generation prediction system: A shorter-range forecast view
- Near-term (1-2 year) opportunities at EMC

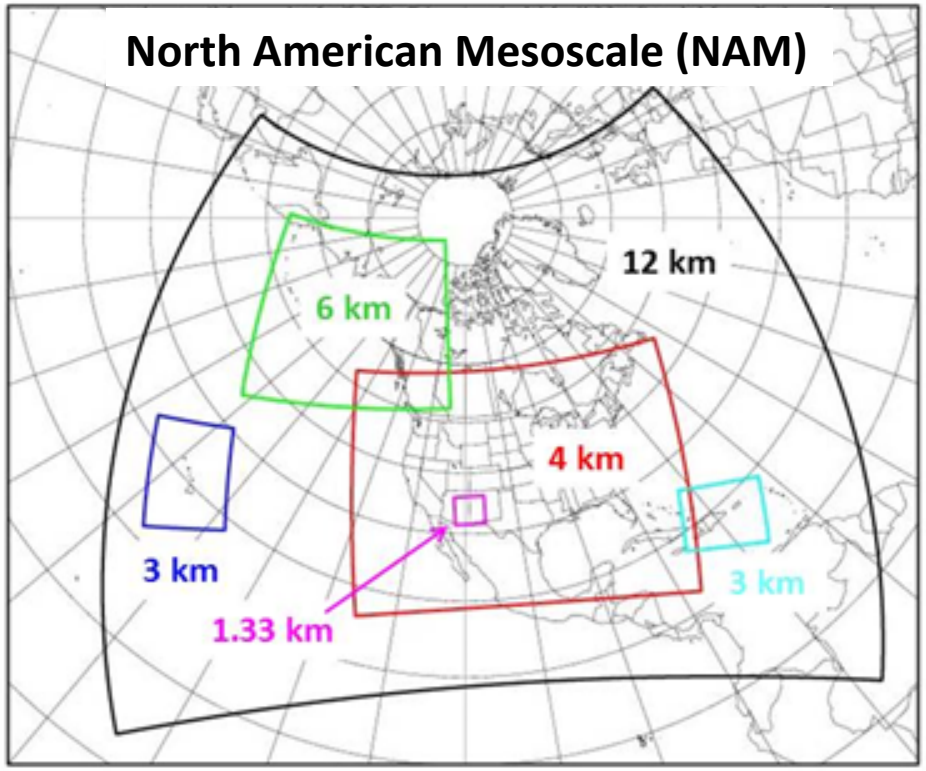
Microphysics Schemes in EMC Models

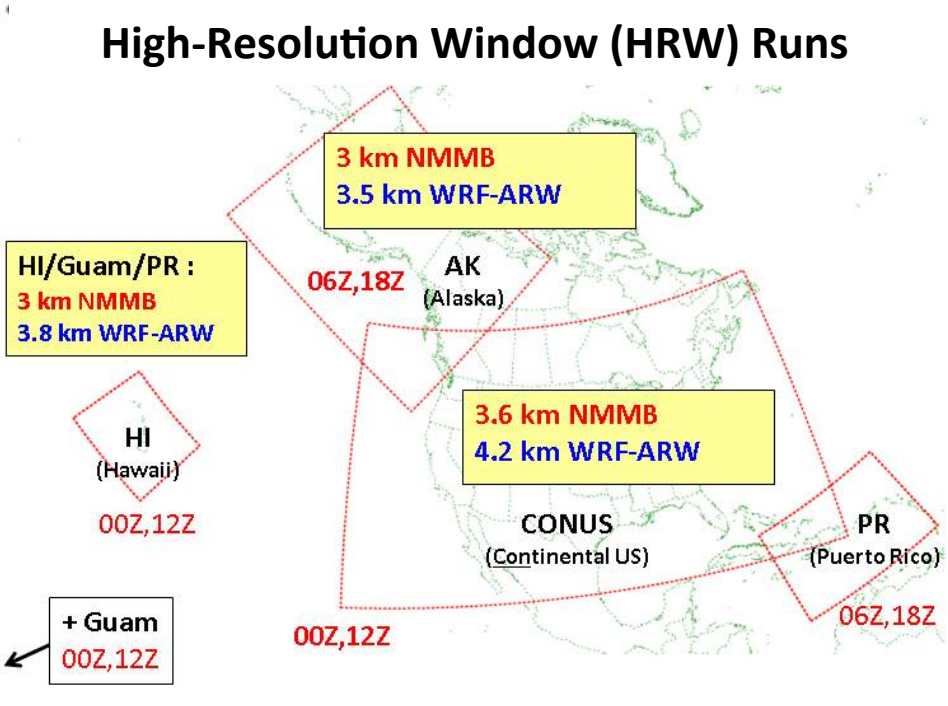
- GFS & GEFS: Zhao & Carr (1997) + Moorthi *et al.*
  - Qv, cloud condensate (Qcw+Qci) + ice/water flag
  - Treats partial cloudiness, earlier onset of condensation
- NAM: Ferrier-Aligo (F-A; Aligo *et al*., 2014)
  - Inside microphysics: Qcw, Qci, Qr, Qs, Rime Factor (RF)
    - RF ⇔ ice density for snow/graupel/sleet/hail
  - Advection of Qt in 12-km parent (F_ice, F_rain, F_RimeF storage arrays)
  - Advection of Qcw, Qr, Qci+Qs, mass-weighted RF in nests
- Hurricane WRF (HWRF): old version of Ferrier
  - Advection of Qt in 12-km parent, smaller size rain drops

Microphysics Schemes in EMC Models

- High-Resolution Window (HRW): Early version of F-A in NMMB, WSM6 in WRF ARW
  - WSM6 – Qv, Qcw, Qci, Qr, Qs, Qg
- Rapid Refresh (RAP) & High-Resolution Rapid Refresh (HRRR): Thompson microphysics
  - Thompson: Qv, Qcw, Qci, Qr, Qs, Qg, Nci, Nr
- Ops Short-Range Ensemble Forecast (SREF)
  - NMMB: Ferrier, GFS, & WSM6
  - WRF NMM, ARW: Ferrier (mp_phys=5)
- Parallel SREF (currently being tested):
  - Mix of F-A (NMMB)/Ferrier (ARW), WSM6, and Thompson in NMMB & ARW members (removed WRF NMM)

Regional Systems (4/day)



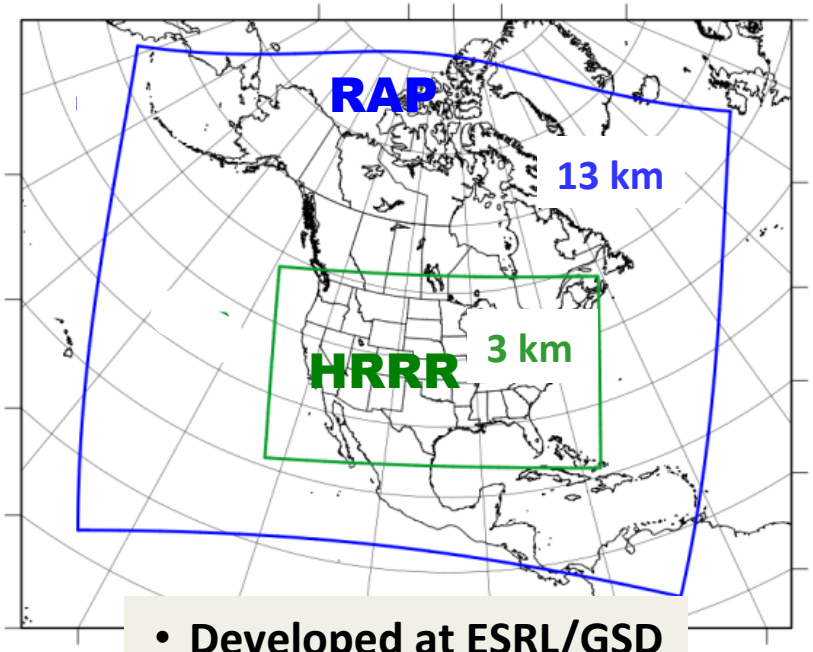


- 12 km/60L to 84 h (SREF, 16 km/35-40L)
- Nests (60L) to 60 h, except 1.33 km fire weather to 36 h (relocatable)
- 1-way nesting, runs @ 00Z, 06Z, 12Z, 18Z
- Ferrier-Aligo microphysics

- NMMB & WRF ARW (40L) to 48 h
- 00Z, 12Z cycles - CONUS, Hawaii, Guam
- 06Z, 18Z cycles – AK, PR
- Initialized from Rapid Refresh (RAP)
- Early F-A in NMMB, WSM6 in WRF-ARW

Rapid Refresh Systems (24/day)

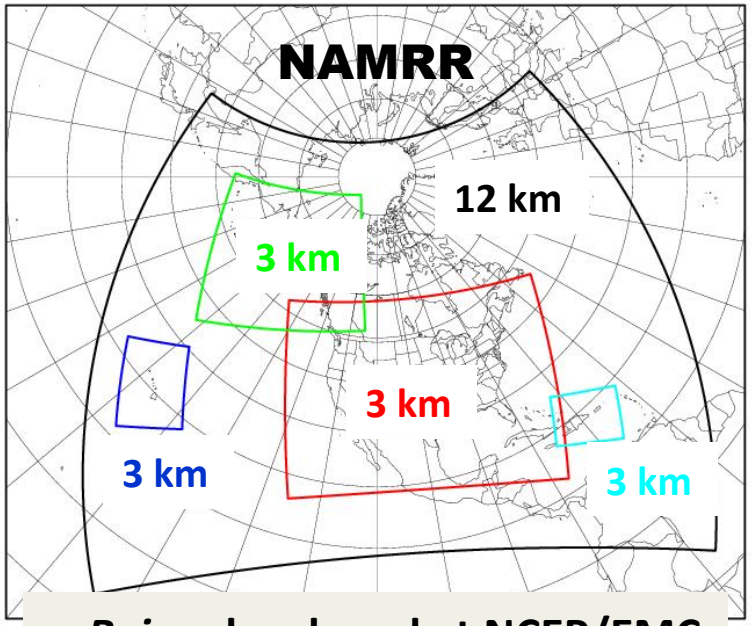
RAP = Rapid Refresh
HRRR = High-Resolution Rapid Refresh



- Developed at ESRL/GSD
- WRF ARW model

- RAP - 13 km/50L hourly to 18 h
- HRRR – 3 km/50L hourly to 15 h
- Updated Thompson microphysics (both)
- Grell 3D ensemble Cu (RAP)

NAMRR = NAM Rapid Refresh
(to be implemented in Q1FY16)



- *Being* developed at NCEP/EMC
- NEMS/NMMB model

- Similar to NAM at 00, 06, 12, 18Z
- Other hours, hourly runs to 18 h
- Updated Ferrier-Aligo microphysics
- BMJ convection in 12 km parent

Microphysics Summary

Scheme / Feature	Zhao-Carr-Moorthi (GFS)	Ferrier-Aligo (NAM)
Prognostic variables	Water vapor, cloud condensate (water or ice)	Water vapor, total condensate/ cld water, rain, cld ice+"snow", mass-weighted rime factor
Condensation algorithm	Sundqvist *et al.* (RH_c~95%, partial clouds)	Lin *et al*., Rutl-Hobbs (target RH=98%)
Precip fluxes & storage	Top-down integration of precip, no storage, instantaneous fallout.	Precip partitioned between storage in grid box & fall out through bottom of box
Precipitation type	Rain, freezing rain, snow	Rain, freezing rain, snow/graupel/sleet (RF)
Mixed-phase conditions	Liquid or ice (supercooled water & ice do not coexist), simple melting	Mixed-phase as cold as -40°C, more complex melting & freezing processes

Strengths & Weaknesses – GFS microphysics

- Strengths
  - Partial cloudiness for $\Delta x,y > O(10\ km)$
  - Runs fast, tuned well in many global runs
- Weaknesses
  - Formulations of some processes are simple
  - Partial cloudiness becomes more binary (clear, not clear) at higher resolutions
  - No suspended precipitation (rain, snow, etc)
  - Graupel (rimed snow, frozen rain) becomes important at $\Delta x,y < O(4\ km)$
  - Fewer post processing applications (simulated radar reflectivities & passive microwave radiances; refined snowfall accumulations; low bias in C&V)

Strengths & Weaknesses – F-A microphysics

- Strengths vs other microphysics
  - Runs almost as fast as GFS microphysics
  - Has suspended precipitation (rain, snow, etc) including variable-density graupel (rime factor, RF)
- Weaknesses vs GFS microphysics
  - F-A, WSM6, and Thompson lack partial cloudiness, may not perform as well at >O(10 km)
- Strengths vs WSM6, Thompson microphysics
  - Variable density for snow/graupel/sleet (similar to Morrison)
  - NLImax differs for stratiform (RF<10) vs convection (RF>10)
- Weaknesses vs WSM6, Thompson microphysics
  - Combines cloud ice, snow, graupel into total ice that gets advected in the model (similar to Morrison)
  - Two sets of microphysics arrays, has led to confusion, errors
  - GFS, F-A, & WSM6 do not have Ni, Nr as in Thompson

Assessing Model Performance

- Objective verification statistics are necessary but not sufficient for determining whether forecast guidance has improved
- Need to understand how guidance is used by forecasters
- Some guidance critical to forecasters may not be well represented or captured from objective verification statistics
  - More important for high-impact weather events

Collaboration with NCEP Service Centers

- Regular meetings with:
  - Storm Prediction Center (SPC) – severe local convective storms (mode, evolution)
  - Weather Prediction Center (WPC) – precipitation, winter storms, flash floods
  - Aviation Weather Center (AWC) – ceiling & visibility near airports, radar echo tops in transit
- Participate in NCEP experimental testbeds
- Will gradually incorporate NWS regions too
- Improving post processing of model output is also important in improving quality of forecast guidance

Next 2 slides show forecast applications of improved microphysics for:

1) Severe local weather storms;
2) Aviation and winter weather.

(Courtesy of Eric Aligo)

Improved Simulated Radar Reflectivity Structures of Severe Local Storms (NAM nests)

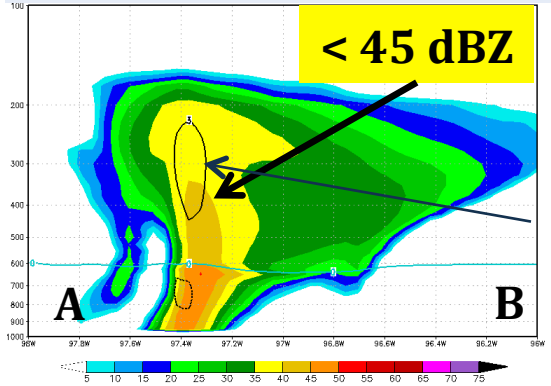
22 h Forecasts at 20 May 2013 - Moore, OK Tornado Outbreak

Old NAM Microphysics

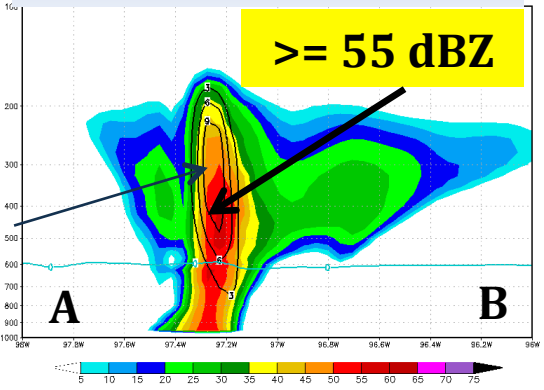
New Ferrier-Aligo Microphysics

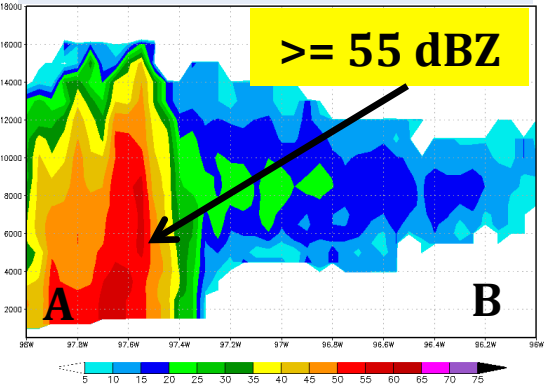
Observed Reflectivity

Vertical "Slices"



"W"

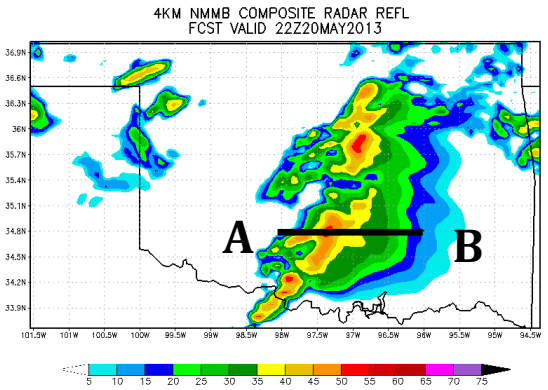


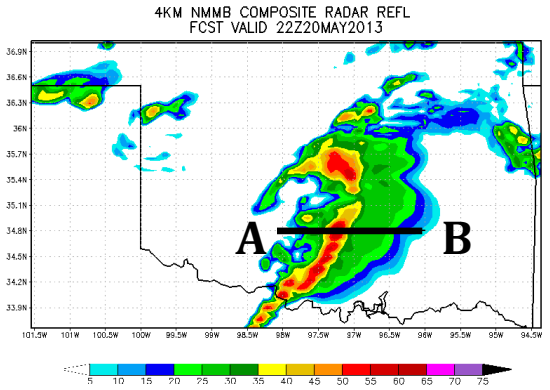


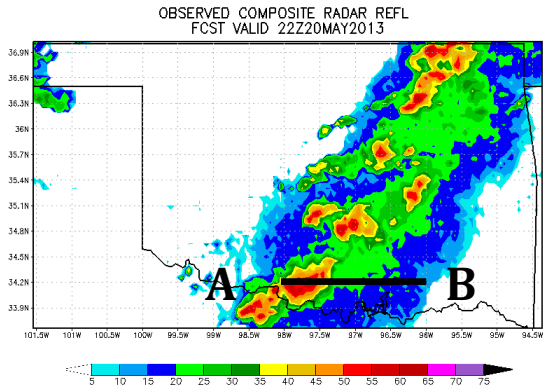
Weaker Storm

Stronger Storm (Improved)

Horizontal Maps

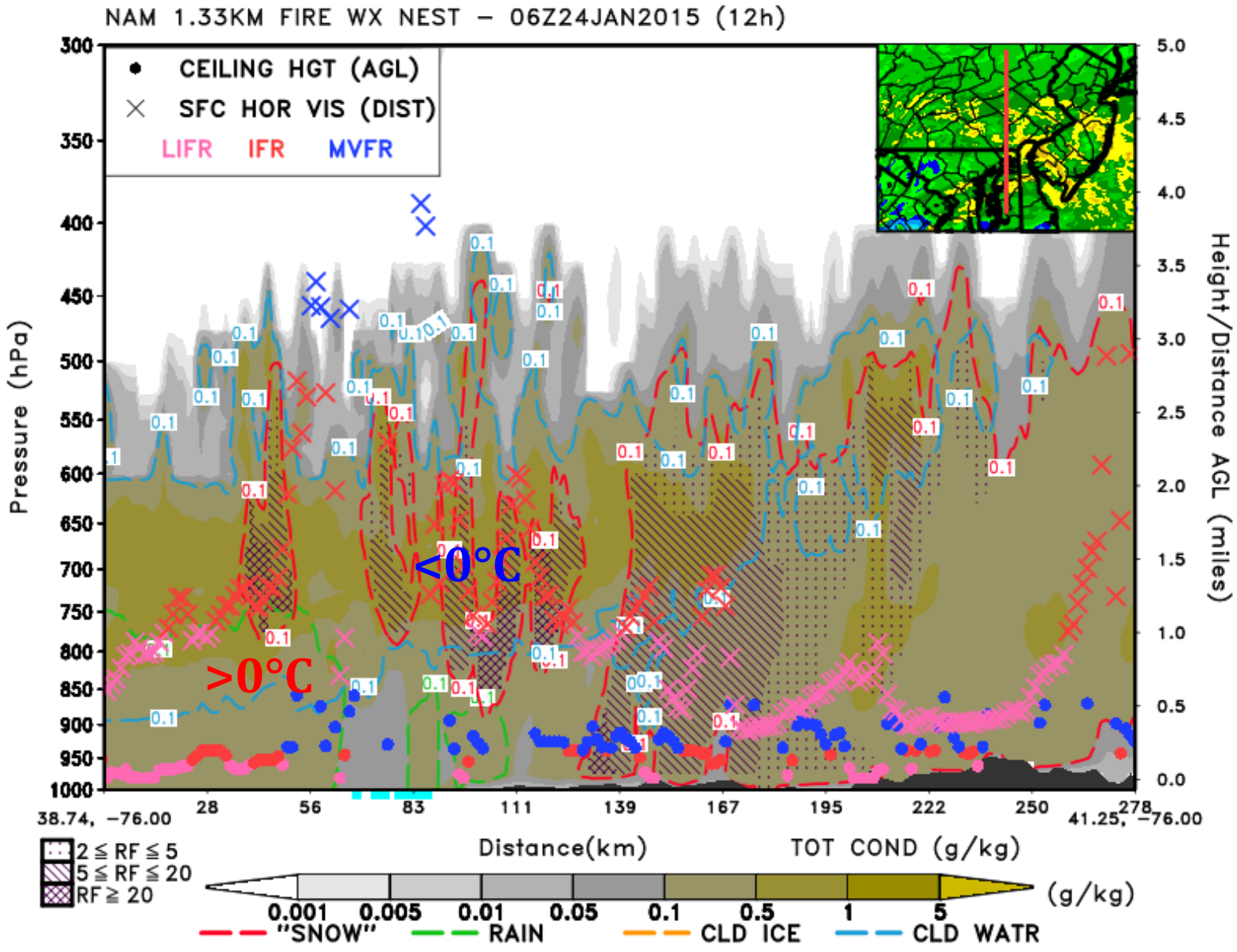






4-km NMMB Forecasts

Cross Section from 1.33-km Fire WX Nest

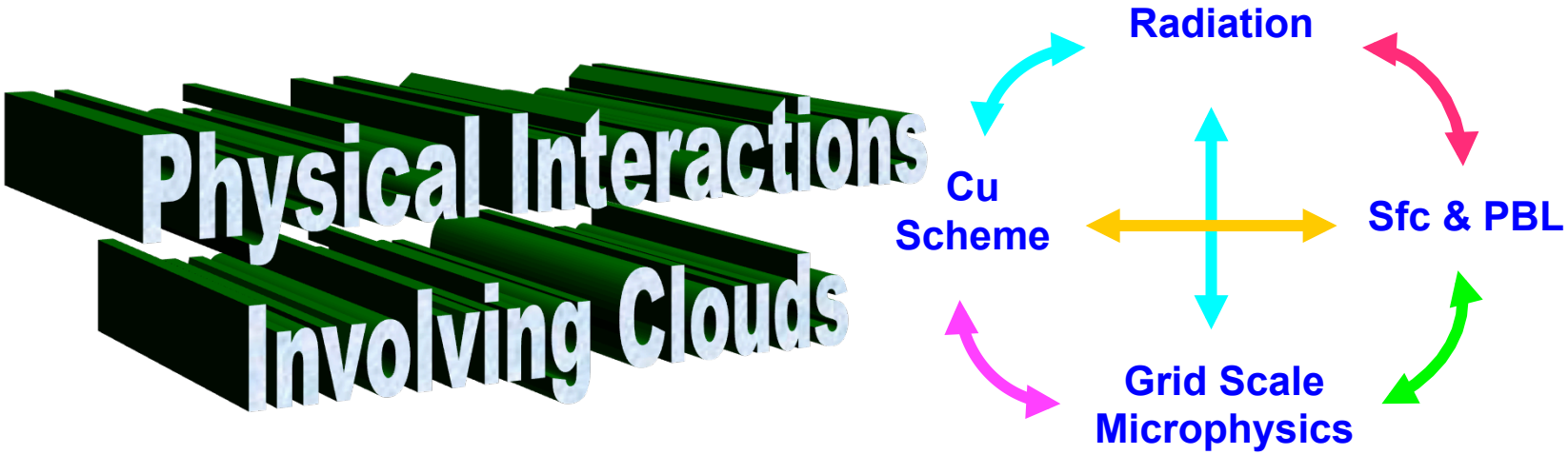


Microphysics Requirements for Next-Generation Global Prediction System: A shorter-range view

- Account for partial cloudiness?
- Account for aerosol-CCN interactions?
- Predict suspended precipitation? Include graupel? Frozen drops? Hail?
- Provide different precipitation types at the surface? Provide different ice densities/habits that impact snow-to-liquid ratios for improved surface snowfall forecasts?
- Double-moment (Qx, Nx)? For all species? For simulated radar calculations?
- Improved computational efficiency (no question).

⇨ If "yes" to all, will the requirements be the same as for higher-resolution regional systems?

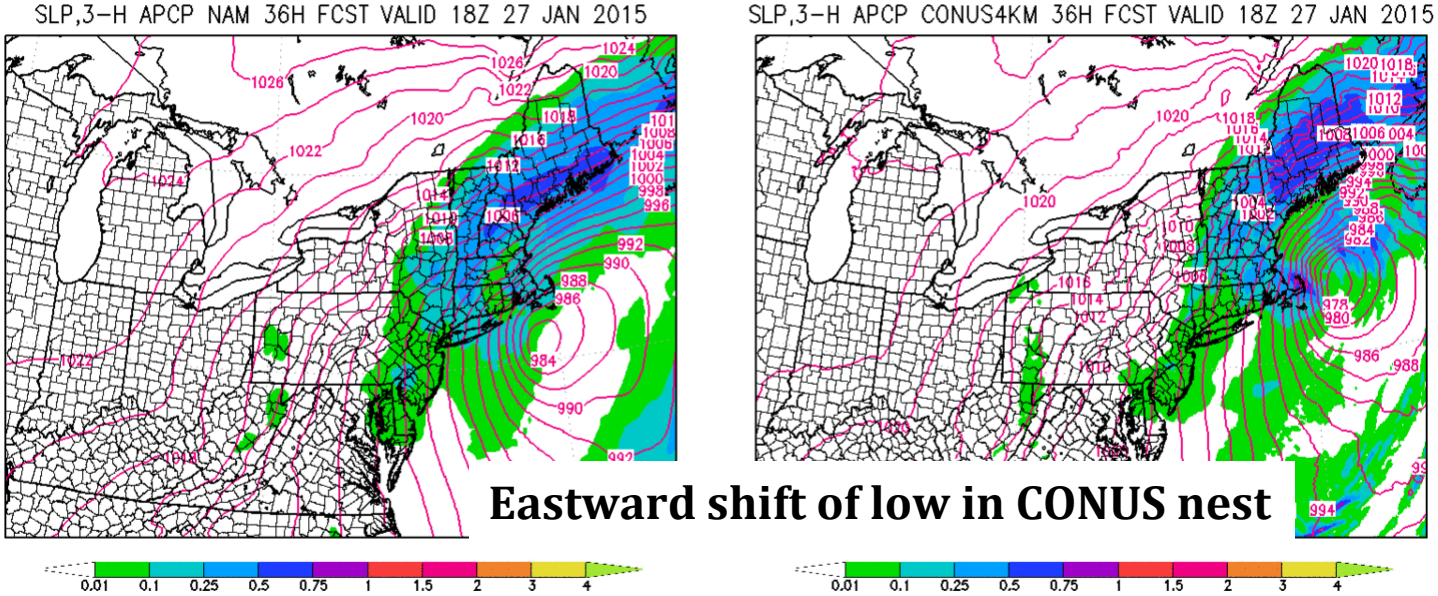
"THE PHYSICS WHEEL OF PAIN"



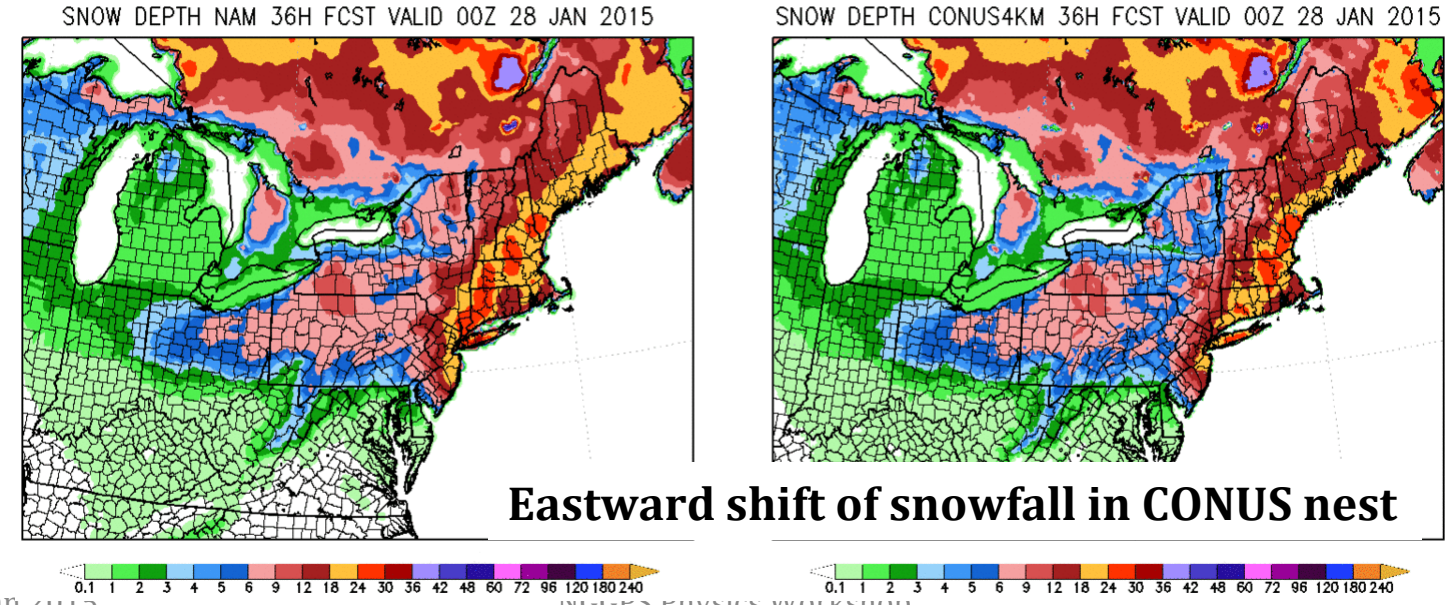
Complex interactions between different physical processes makes it difficult to:

- **Identify errors in forecast timing and placement due solely to the microphysics;**
- **Determine what is working well, what isn't, and what improvements need to be made.**

12-km NAM (L) vs 4-km CONUS nest (R)



Eastward shift of low in CONUS nest



Eastward shift of snowfall in CONUS nest

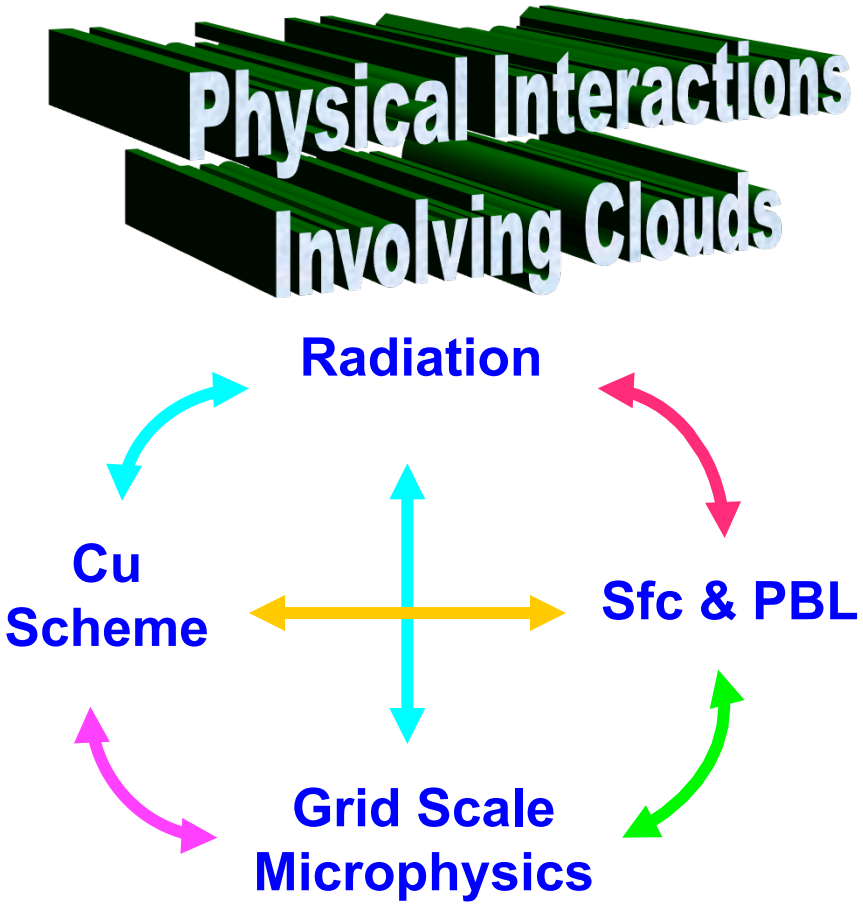
(Courtesy of Eric Rogers)

Near-Term Opportunities for EMC

- If the GFS microphysics continues to be run in the GFS in the next 1-2 years, some customer requests could be met by:
  - Write to output 3D fields of either:
    - Vertical fluxes of rain and precipitating ice (snow), or
    - Mixing ratios from the precipitation fluxes using assumed rain and snow fall speed relationships.
  - Estimate "rime factor" from growth of snow from liquid accretion vs other processes?
  - Calculate estimated radar reflectivity

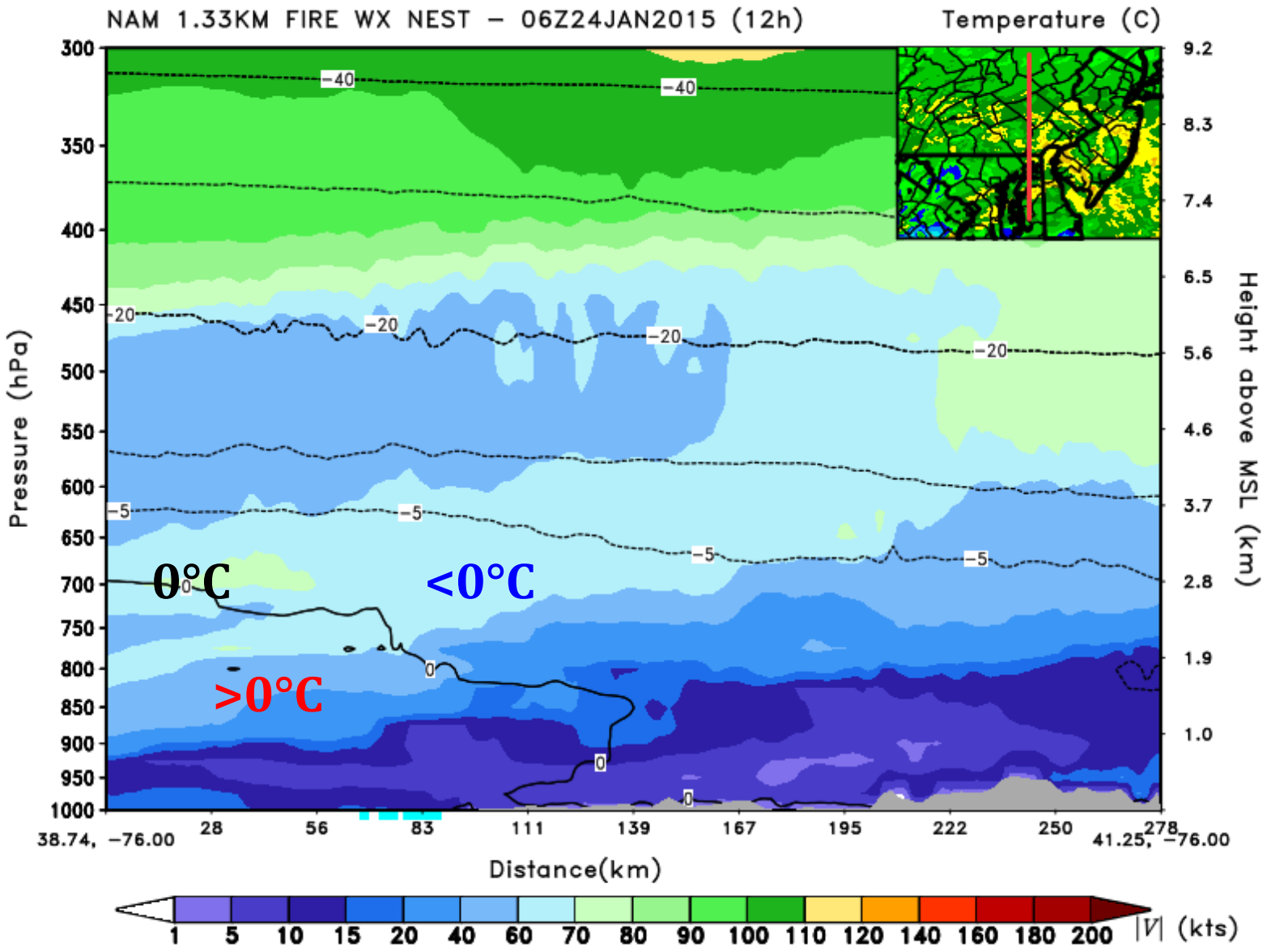
Extra Slides

"THE PHYSICS WHEEL OF PAIN"



1. Phase & optical properties (r_{eff}), overlap assumptions, horizontal fractions
2. Precipitation (+ phase) and clouds
3. Subgrid transports, detrainment
4. Energy exchanges with land & ocean surfaces
5. Convection (deep & shallow), PBL evolution

Cross Section from 1.33-km Fire WX Nest



(Courtesy Eric Aligo)