Microphysics Schemes in EMC's Operational Hurricane Models

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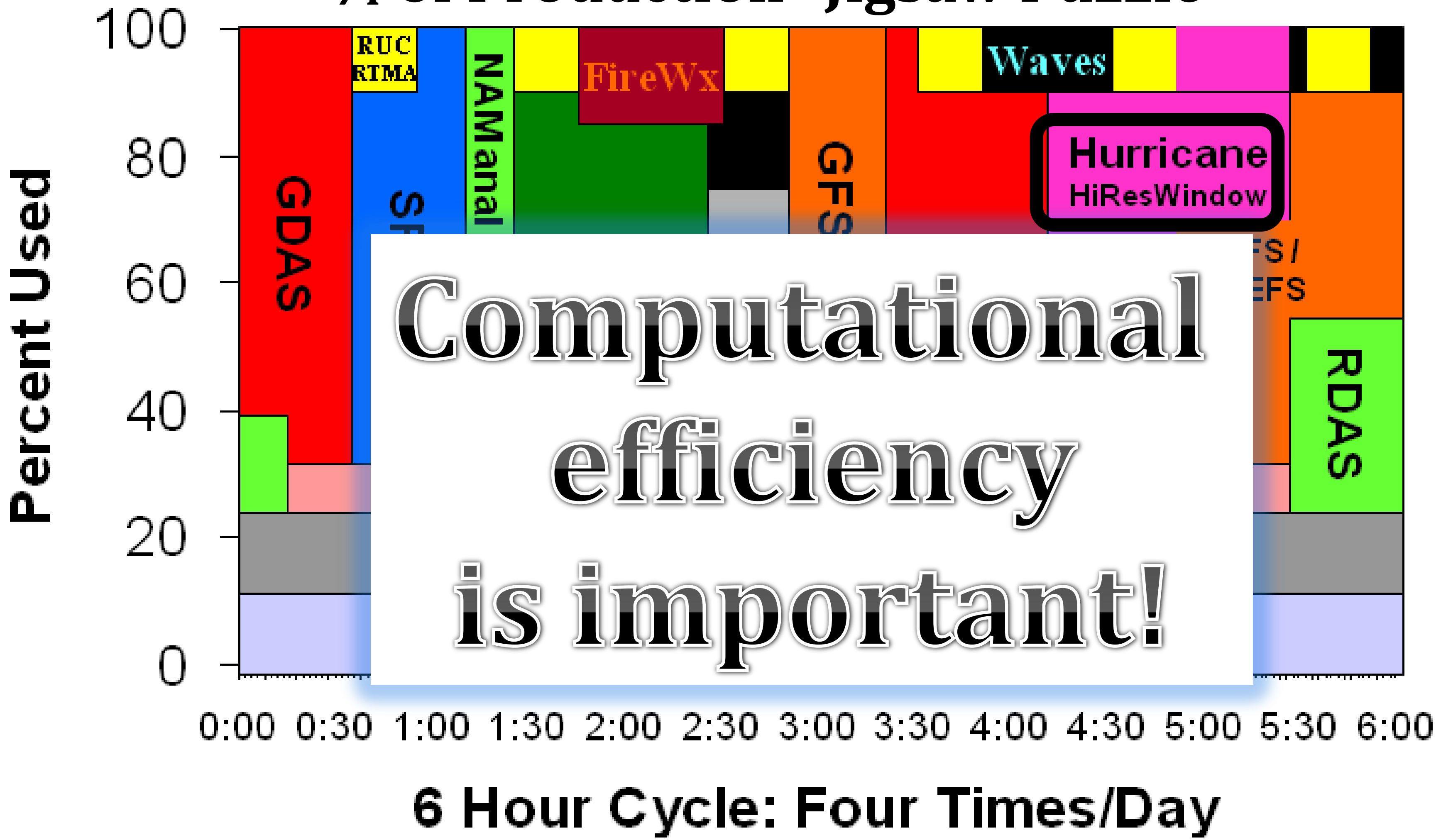
HFIP Physics Workshop

9 – 11 August 2011

Complex Production Suite (~2009)

¼ of Production "Jigsaw Puzzle"



Computational efficiency is important!

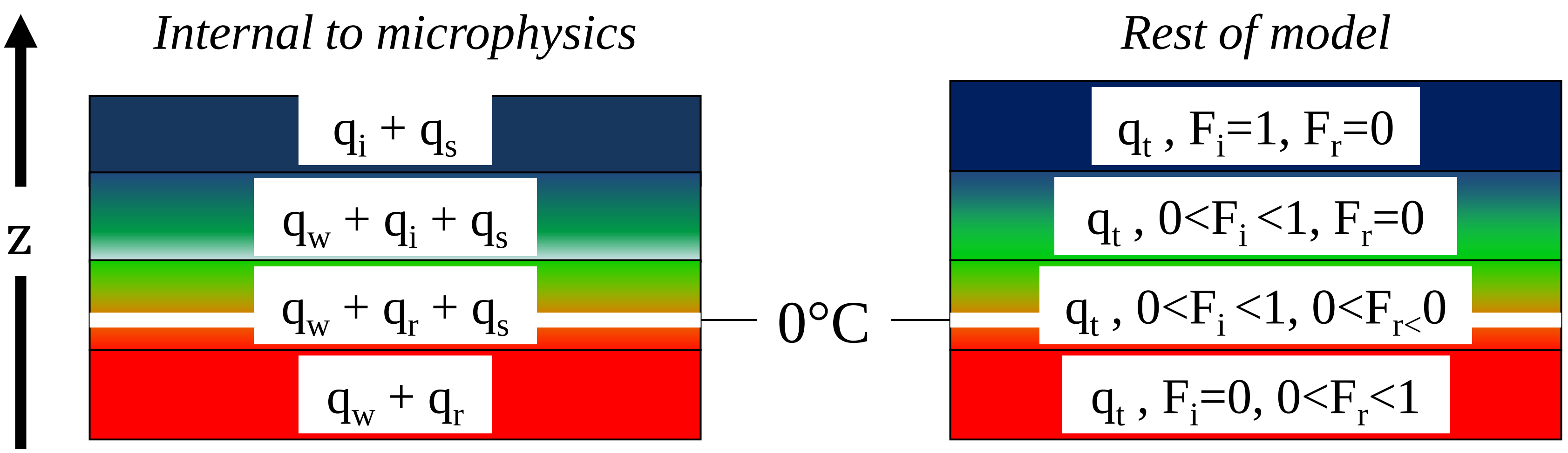
Microphysics Summary

Scheme / Feature	Zhao-Moorthi (GFS)	Ferrier *et al*. (2002) (GFDL, HWRF, NAM)
Prognostic variables	Water vapor, cloud condensate (water or ice)	Water vapor, total condensate (cld water, rain, cld ice, “snow”)
Condensation algorithm	Sundqvist *et al.* (RH_c~95%, partial clouds)	Lin *et al*., Rutl-Hobbs (target RH ~100%)
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
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

Advecting Total Condensate ("Ferr")

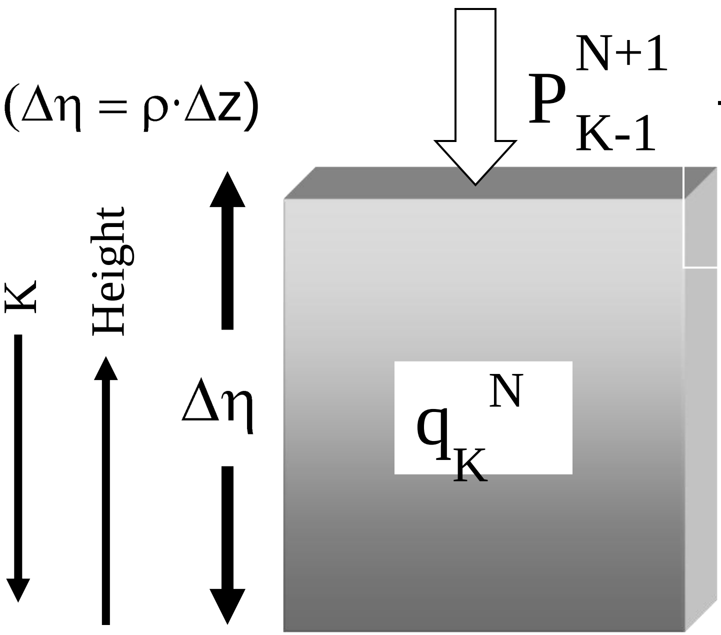
- Water vapor (q_v), total condensate (q_t) advected in model (efficient)
- Cloud water (q_w), rain (q_r), cloud ice (q_i), precip ice (q_s) in microphysics
- Arrays store fraction of condensate in form of ice (F_i), fraction of liquid in form of rain (F_r; $0 \le F_i$, $F_r \le 1$), fixed between microphysics calls.

$$q_t = q_w + q_r + q_i + q_s \,,\ q_{ice} = q_i + q_s \ \Rightarrow\ F_i = q_{ice}/q_t \,,\ F_r = q_r/(q_w + q_r)$$



Precipitation Sedimentation (1 of 3)

(a)

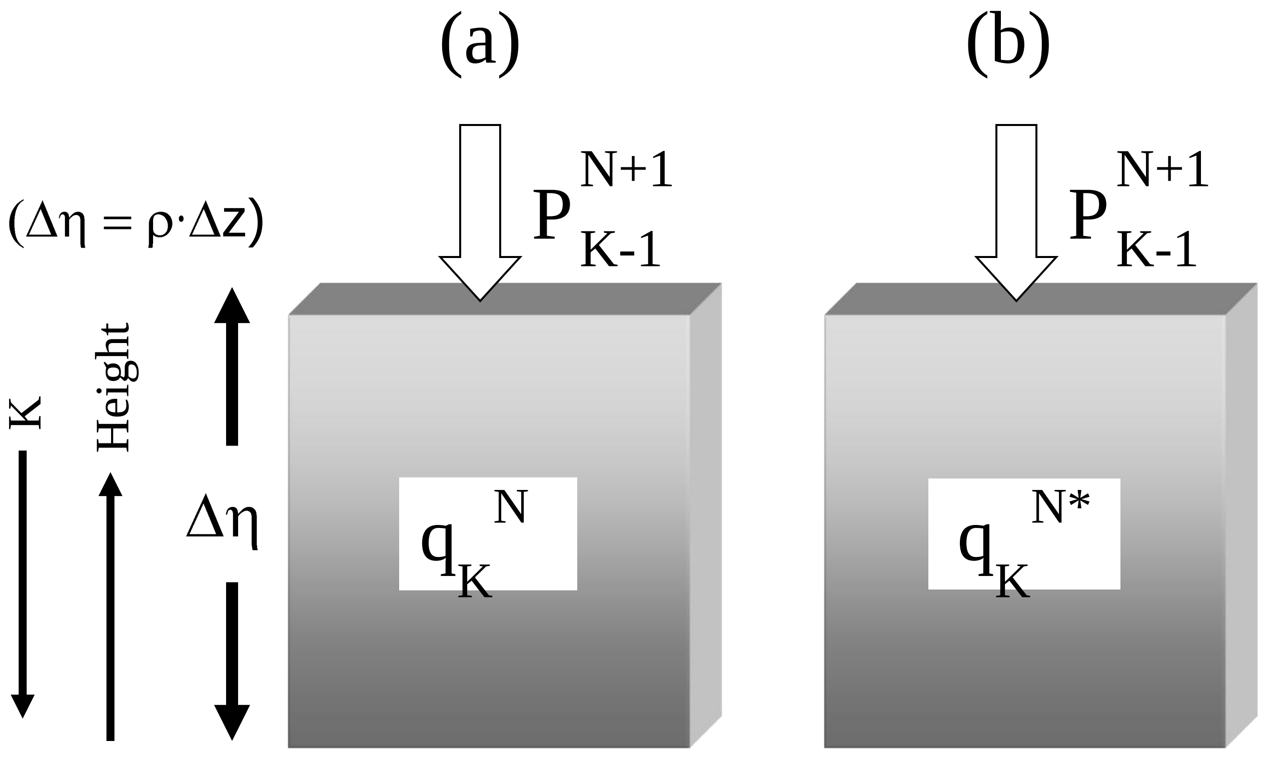


- Time-accumulated fall of precipitation into grid box from above at time N+1 $(P_{rate} \cdot \Delta T_{phy})$

- Existing precipitation mixing ratio in the grid box at time N

(a) Fall of precipitation into grid from above + already existing precipitation

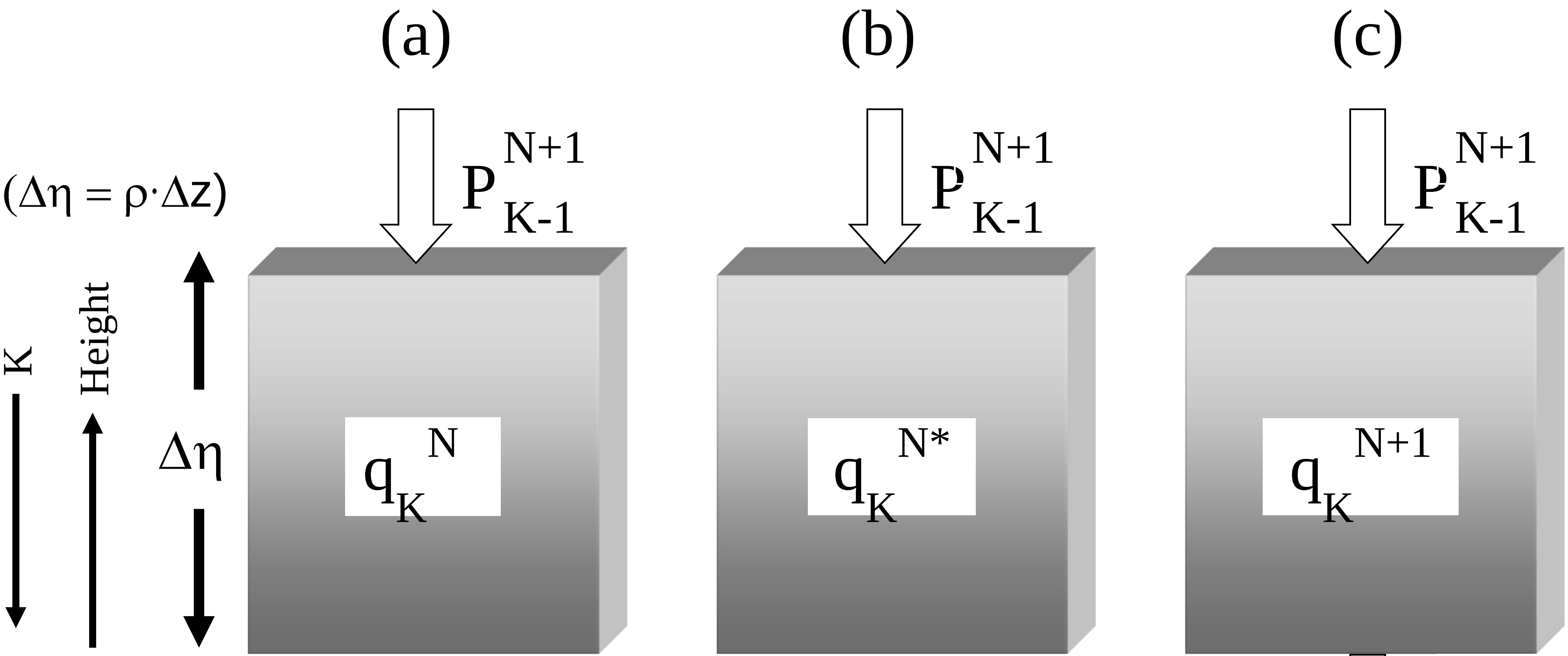
Precipitation Sedimentation (2 of 3)

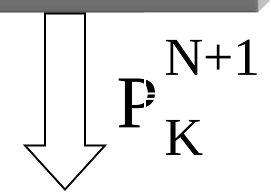


(a) Fall of precipitation into grid from above + pre-existing precipitation

(b) Calculate microphysical sources/sinks based on estimate of time-averaged precipitation mixing ratio, q_K^{N*}

Precipitation Sedimentation (3 of 3)





(a) Fall of precip into grid from above + pre-existing precip

(b) Calculate microphysical sources/sinks based on time-averaged estimate of mixing ratio, q_K^{N*}

(c) Partition storage (q_k^{N+1}) and precipitation through bottom of box (P_k^{N+1}) based on thickness of model layer ($\Delta\eta$) & estimated fall distance ($\Delta t\cdot V_k$)

Other Assumptions

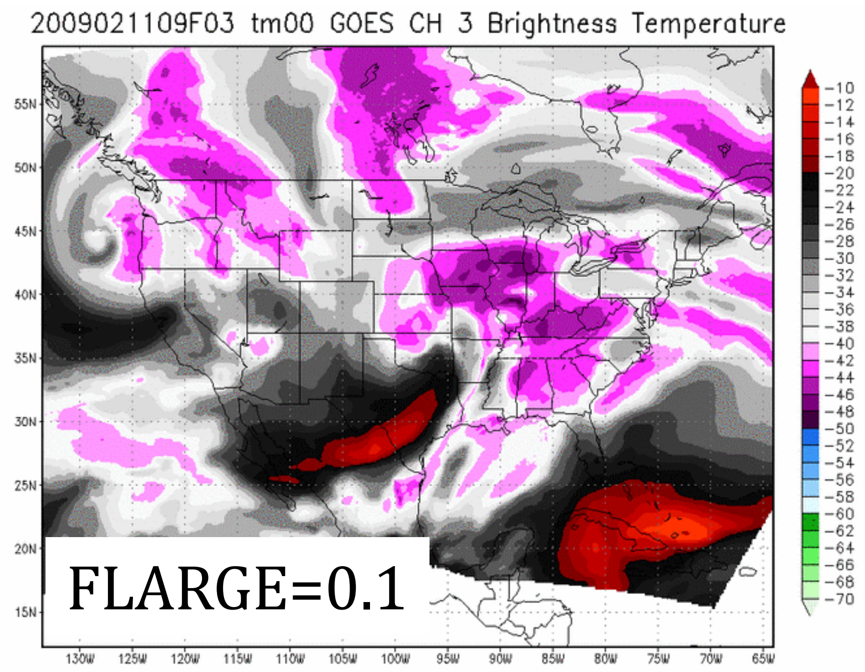
- Small cloud ice and large precipitation ice
  - $N_{SI} \sim 10 * N_{LI}$
  - FLARGE=large/(small + large) => 0.1 (Hurr), 0.03 (NAM)
- Variable density for "snow" (similar to Morrison)
  - 3D rime factor (RF) array for snow/graupel/sleet

$$RF = \frac{Deposition + Accretion}{Deposition}$$

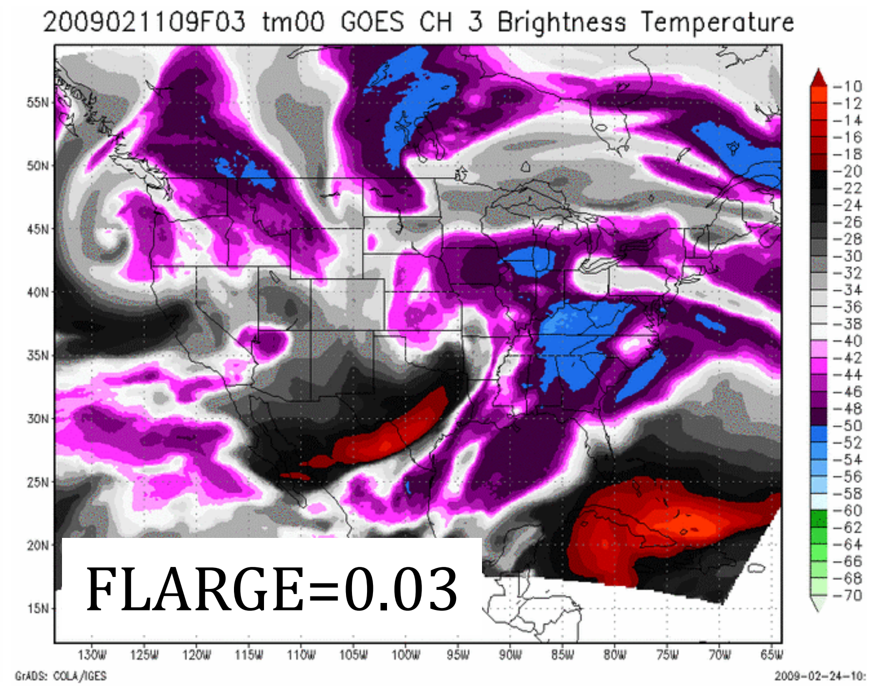
- 1-μm tables for ventilation, accretion, mass, & precipitation rates for liquid drops & ice (fast)

Forecast satellite products (TOA radiances)

3-h NAM forecast water vapor channel 3 (6.5 μm)

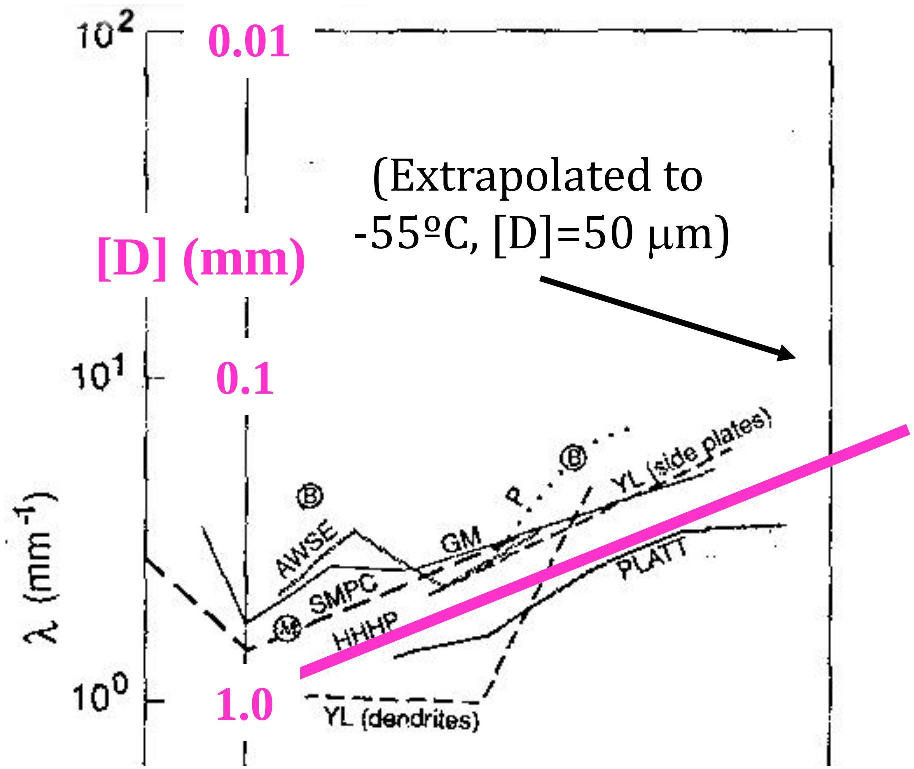


Less small ice particles, warmer T_b's (flagged by SPC)



More small ice particles, cooler T_b's (better)

First-guess "snow" size (1 of 2)



Assumes (M-P) exponential spectra:

$N(D)=N_o\exp(-\lambda\cdot D)$, $[D] = \lambda^{-1}$,

N_o - intercept, λ - slope, [D] – mean D.
1st guess is

$[D]=D_o\exp(-0.0536*T_c)$,

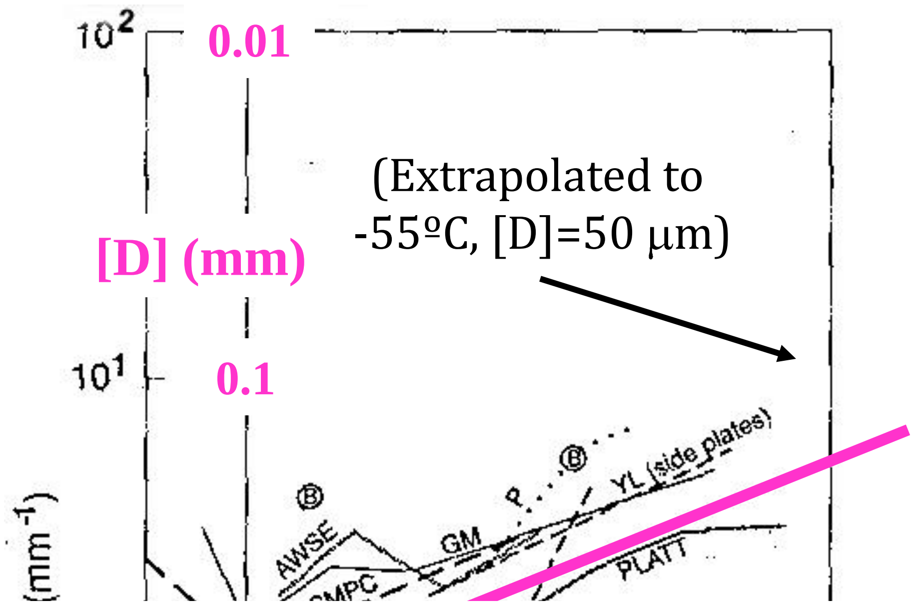
T_c in °C, D_o=1 mm. Adjust [D] so

$N_{LImin} \leq N_{LI} \leq N_{LImax}$

HHHP (Washington state)
SMPC (California)

Based on extratropical stratiform layer clouds

First-guess "snow" size (2 of 2)



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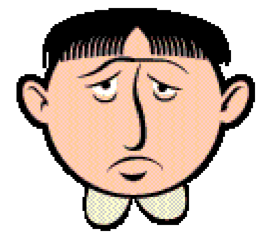
Should new parameters be tested for tropical systems?

My Apologies

Much of what follows is from NMMB model development



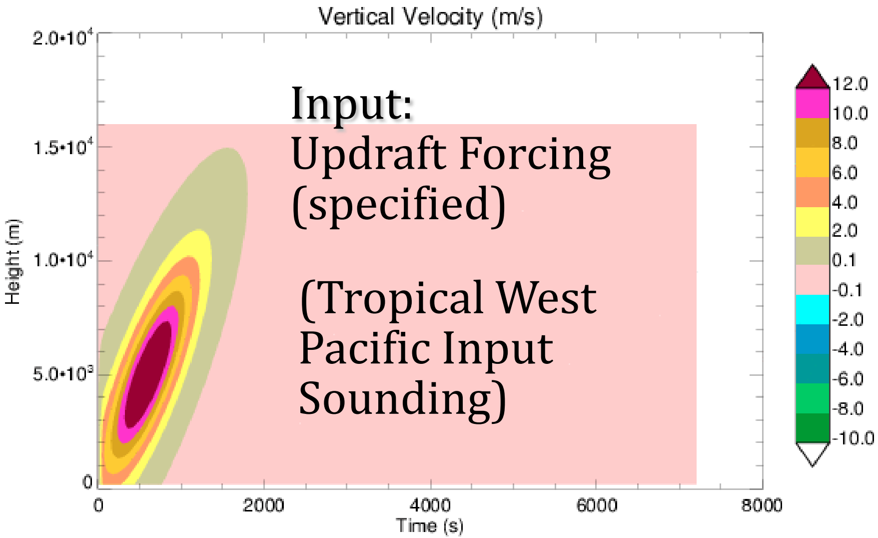
It is not in the GFDL Hurricane Model, in the HWRF model, nor in WRF

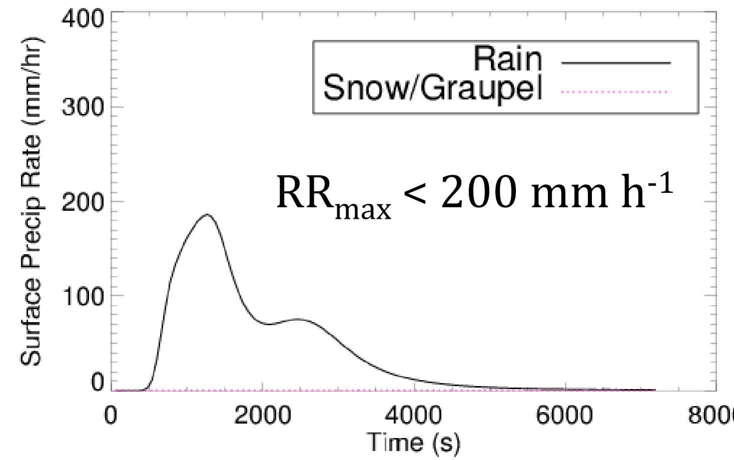
Recent Activities (NEMS/NMMB)

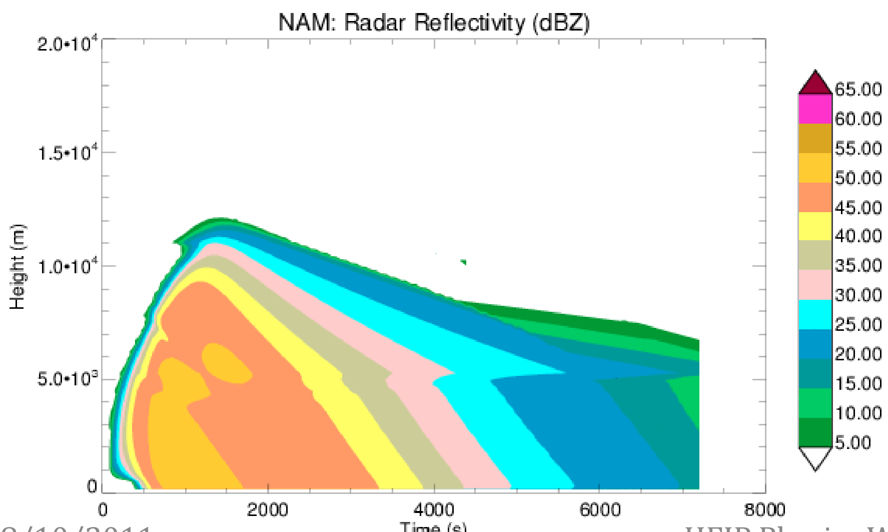
- Changes in "new" NMMB version of Fer
  - Larger rain drops (expanded rain tables)
  - Allow cloud ice (50 μm crystals) to fall slowly
  - New cloud water to rain autoconversion (Liu & Daum)
  - Faster falling rimed ice ($\sim V_{RF}^2$ for $V_{RF}>1$)
- Flag to control hydrometeor advection
  - Advect q_w, q_r, q_i or "CWM" only (F_i, F_r)
  - Applies to all schemes in NMMB (e.g., WSM6, etc)
- Incorporate aspects of GFS/Zhao into Fer?
  - Cloud "macrophysics" for >O(10 km) grids

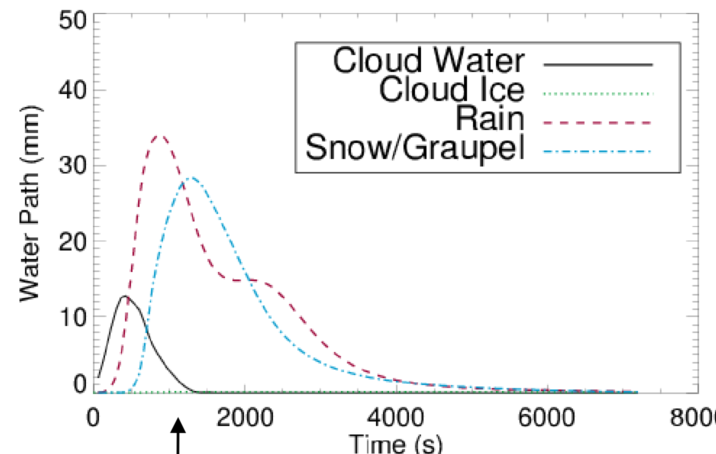
1D Column Tests (1 of 3)

Sample 1D input/output (thanks to B. Shipway, UKMO)







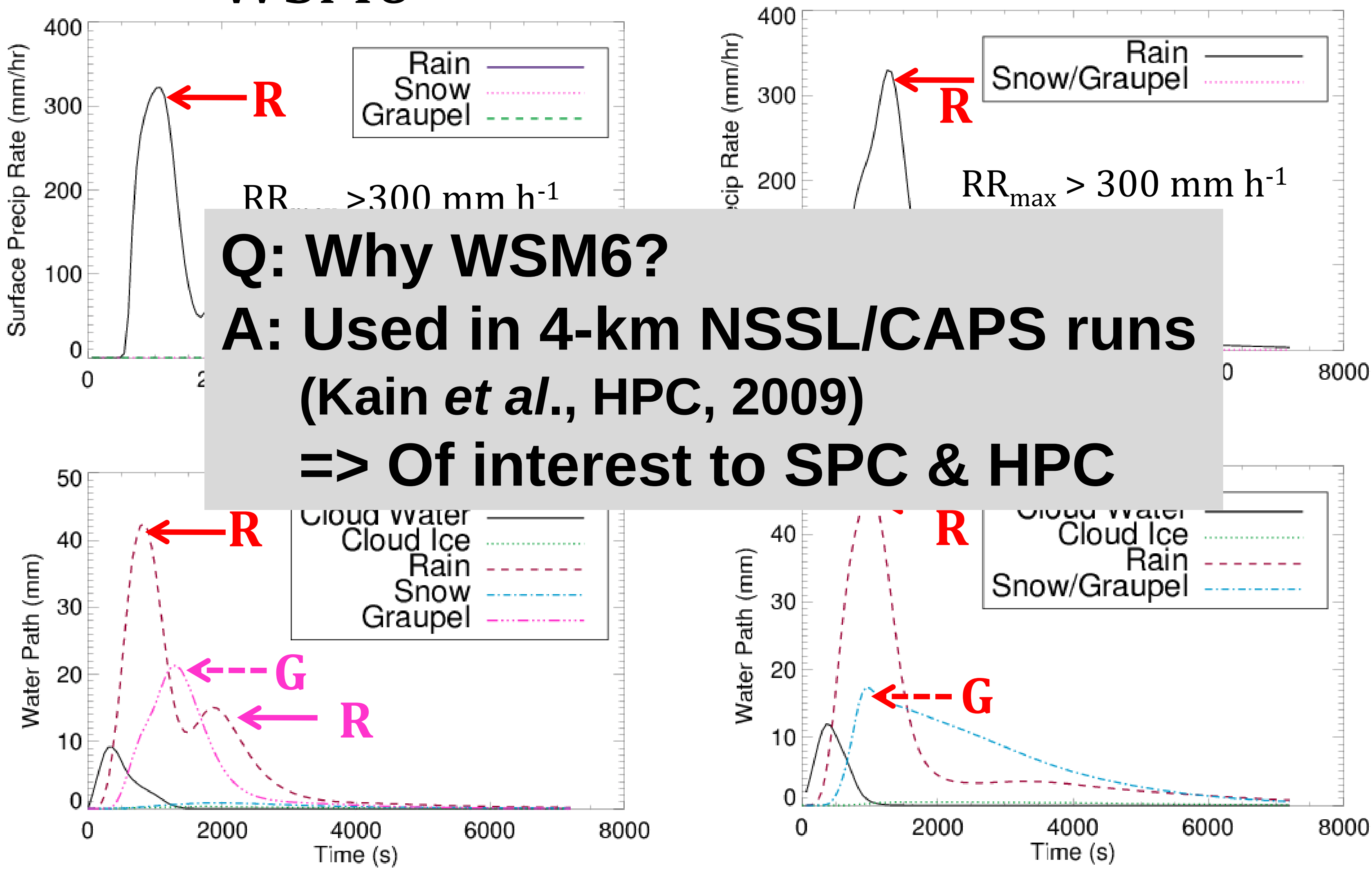


↑

← “Old” NAM Fer

1D Column Tests (2 of 3)

WSM6 | "New" NMMB fer



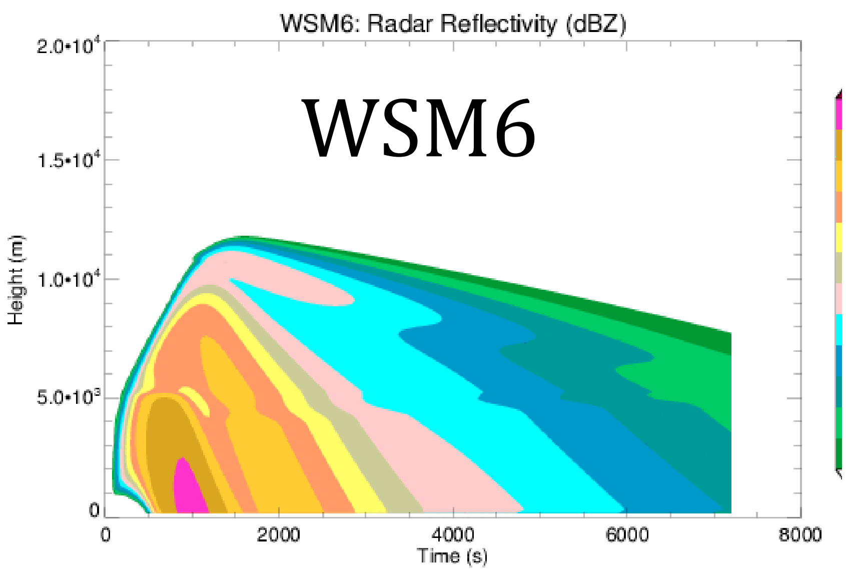
Q: Why WSM6?

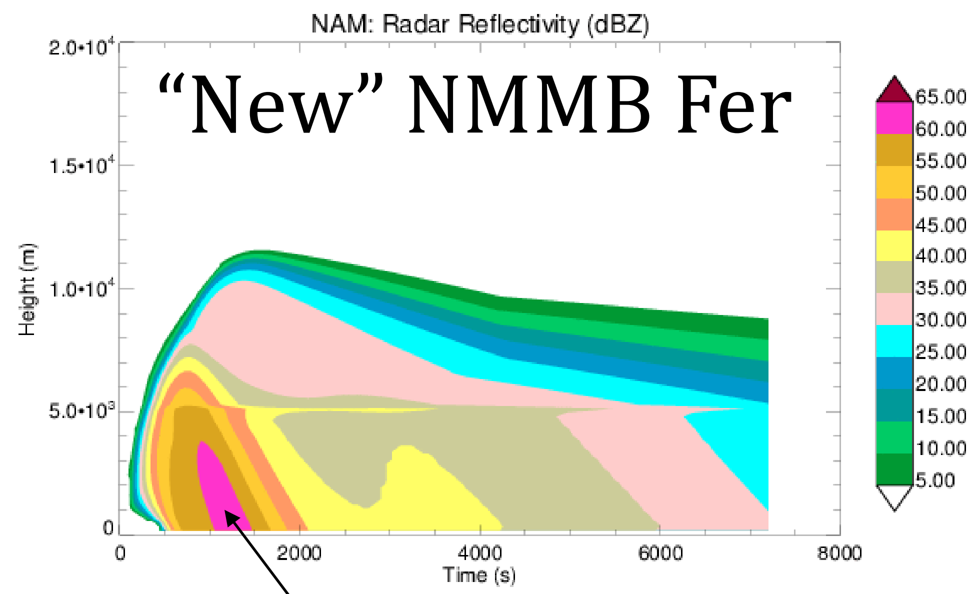
A: Used in 4-km NSSL/CAPS runs

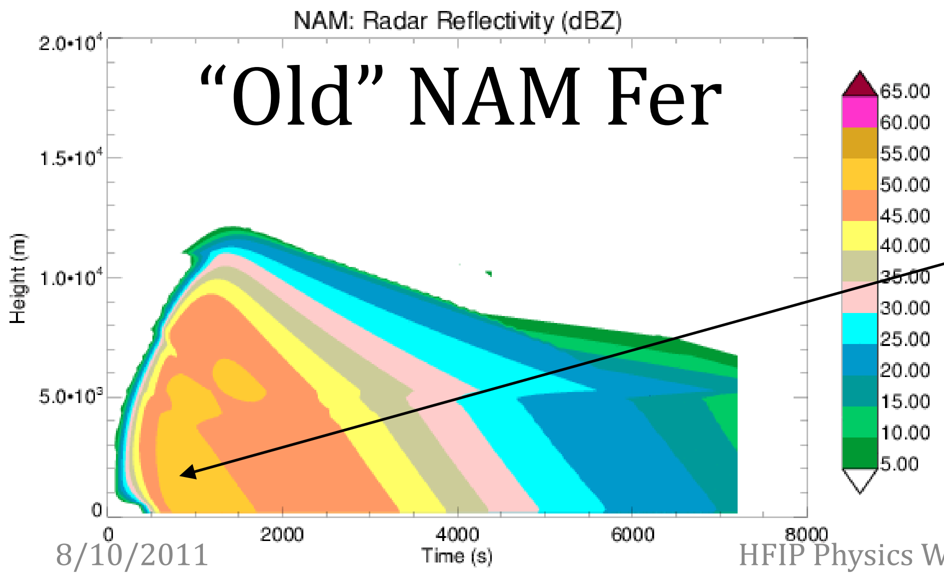
(Kain *et al*., HPC, 2009)

=> Of interest to SPC & HPC

1D Column Tests (3 of 3)



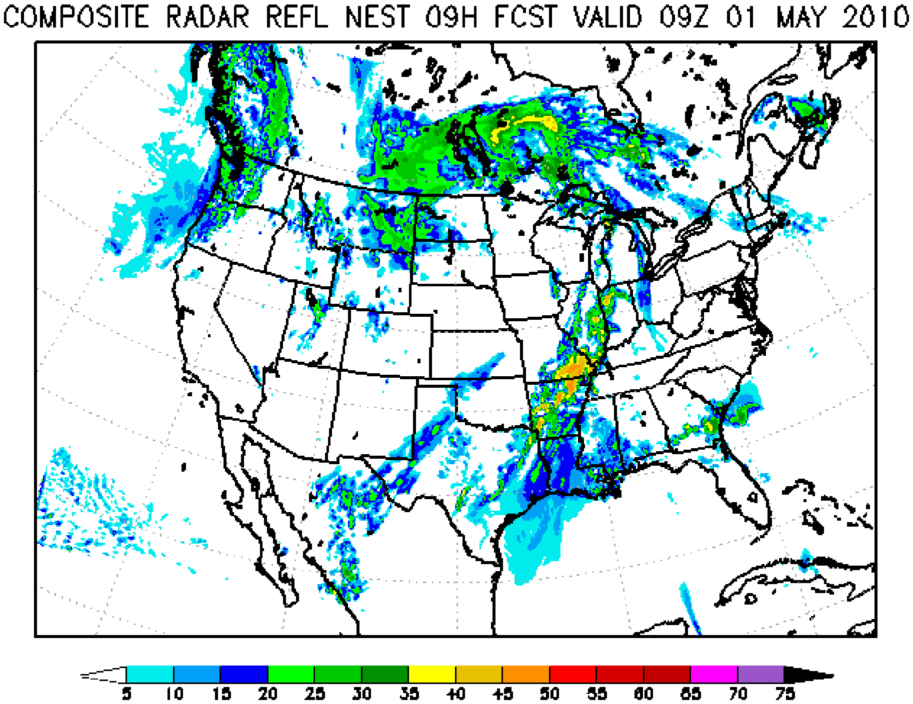




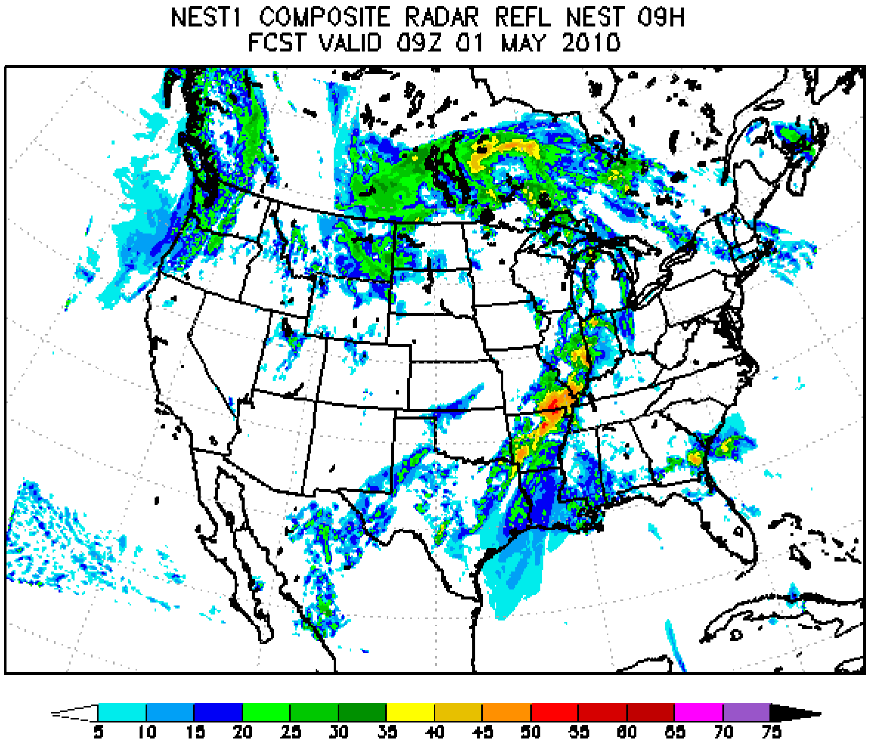
Much higher dBZ & peak rain rates in “New” vs. “Old” Fer

Impact of microphysics change

“Old” NAM Fer



“New” NMMB Fer



- **4-km CONUS nest runs using NMMB**
- **Higher composite dBZ in revised version (right)**

Scientific Challenges (1 of 2)

- Higher resolution models (inner nests)
  - Depends more on cloud physics details
    - Riming, accretion becomes important (graupel, hail)
    - Different ice habits – m(D), V(D), "shape effects"
    - Number concentrations, size spectra of hydrometeors
  - Fundamental aspects of ice still not well known
    - First initiation of ice, ice nucleation at cold temps, ice enhancement/multiplication (esp. tropical Cu!)
    - Collection efficiencies between colliding ice species
  - Huge range in costs & complexities of approaches
  - Forecasts often limited by other error sources

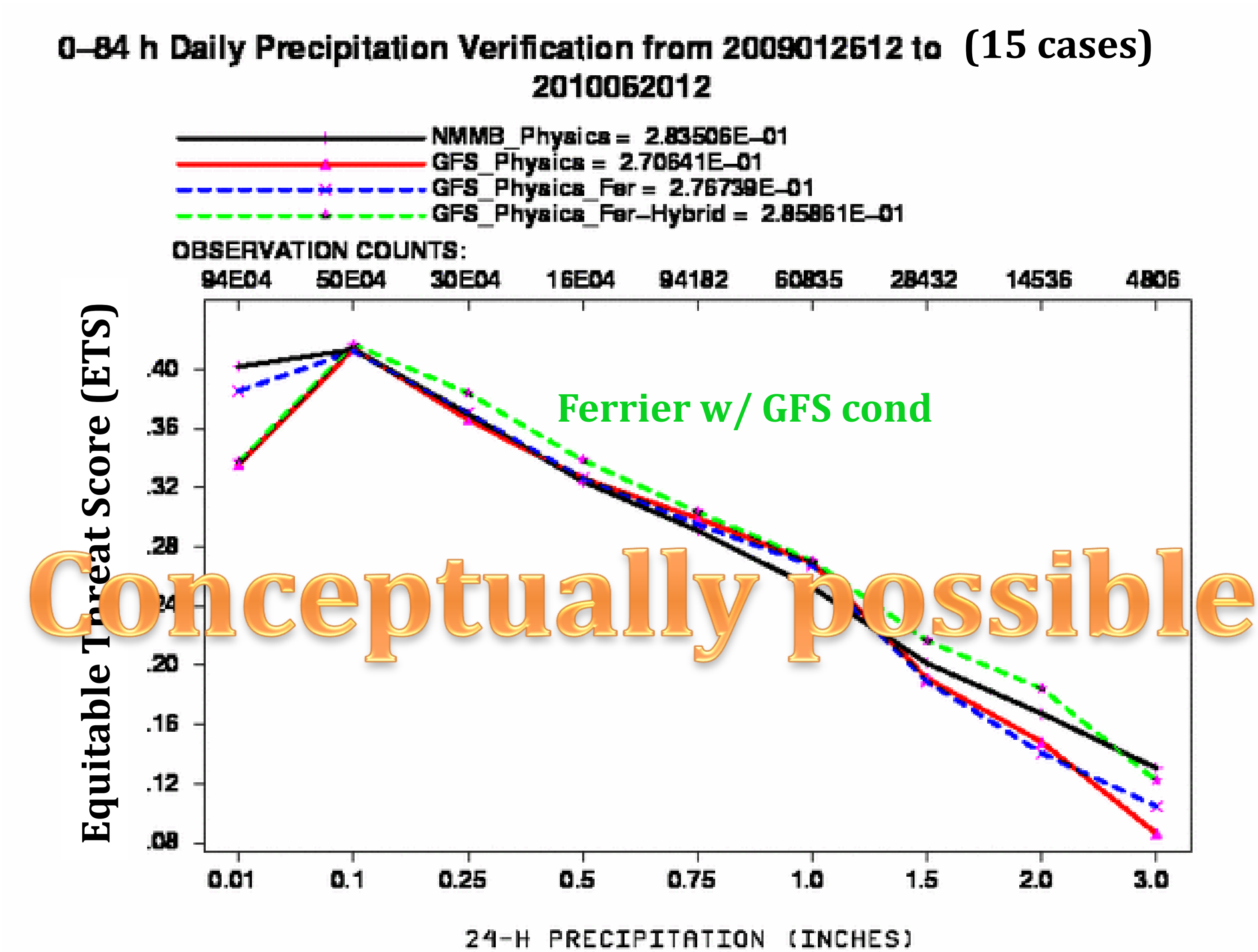
Scientific Challenges (2 of 2)

- Coarser grids (outer domain) & subgrid-scale cloud processes
  - Shallow & deep convection
    - Contrasting approaches between modeling groups
    - More interactions w/microphysics for mass flux schemes (e.g., ncloud=1 in SAS)
  - Partial cloudiness, cloud macrophysics
    - GFS/Zhao-Moorthi – uses Sundqvist condensation
    - Validity of collection kernels questionable because of subgrid-scale variability

Combine NAM & GFS Micro?

- Why?
  - Some NMMB forecasts improved using GFS micro with GFS PBL + SAS
  - Desire for physics unification (S. Lord)
  - Useful for HWRF's outer 27-km domain
  - Sundqvist condensation "responds" to moisture convergence (dT/dt, dQ/dt)
    - dP/dt=0, RH_c=95% rather than 100%
    - Used Sundqvist-based condensation and accretion processes in Ferrier scheme
- Sensitive to proper treatment of detrained condensate from SAS convection (ncloud=1)

Preliminary QPF Results (12-km NMMB)



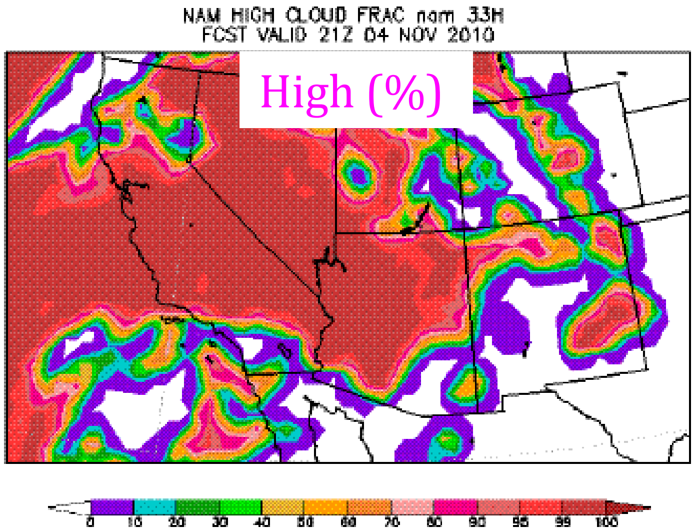
Radiation, cloud fractions

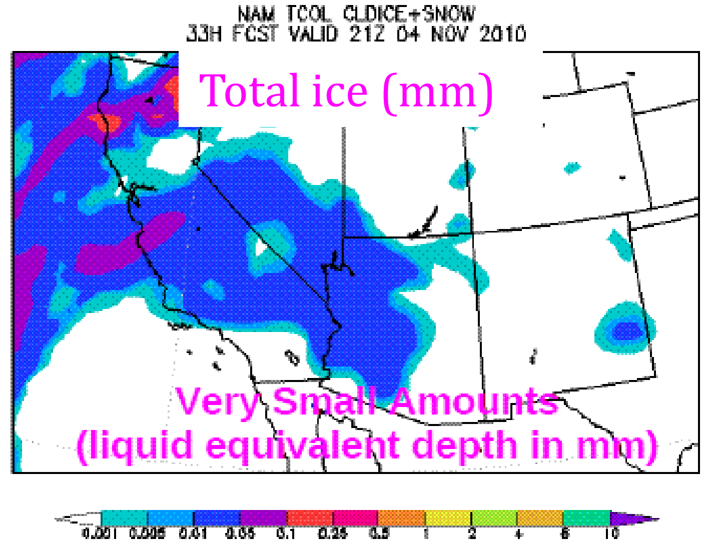
- Subtle differences between NAM & HWRF versions of GFDL SW, LW radiation
  - Xu-Randall/Zhao cloud fraction (HWRF) vs PDF-based method (NAM) vs simple method (NMM B)
  - Cloud absorption coefficients (old GFDL radiation units)

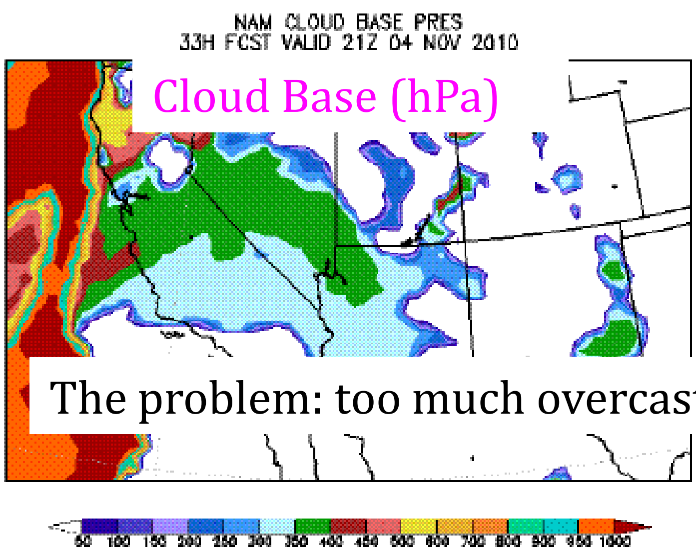
	HWRF, NAM	Ops NAM	NMMB
Cloud Water	800	1600	800
Ice	500	1000	500

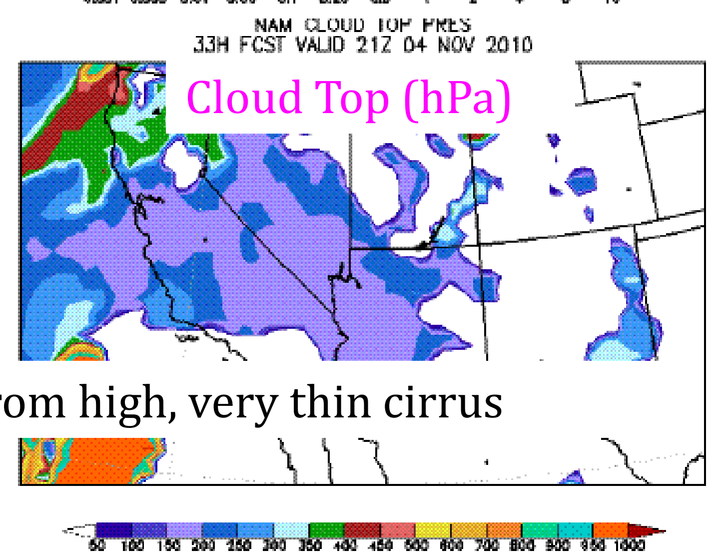
  - Larger cloud emissivities in NAM, NMMB
  - In WRF/NAM code, LW fluxes are avg of T_{skin} + T_{low}, ; also avg'ed LW cooling rates in lowest 2 layers
    - Removed in the operational NAM (March 2008)

Cloud Fraction Changes (1 of 4)





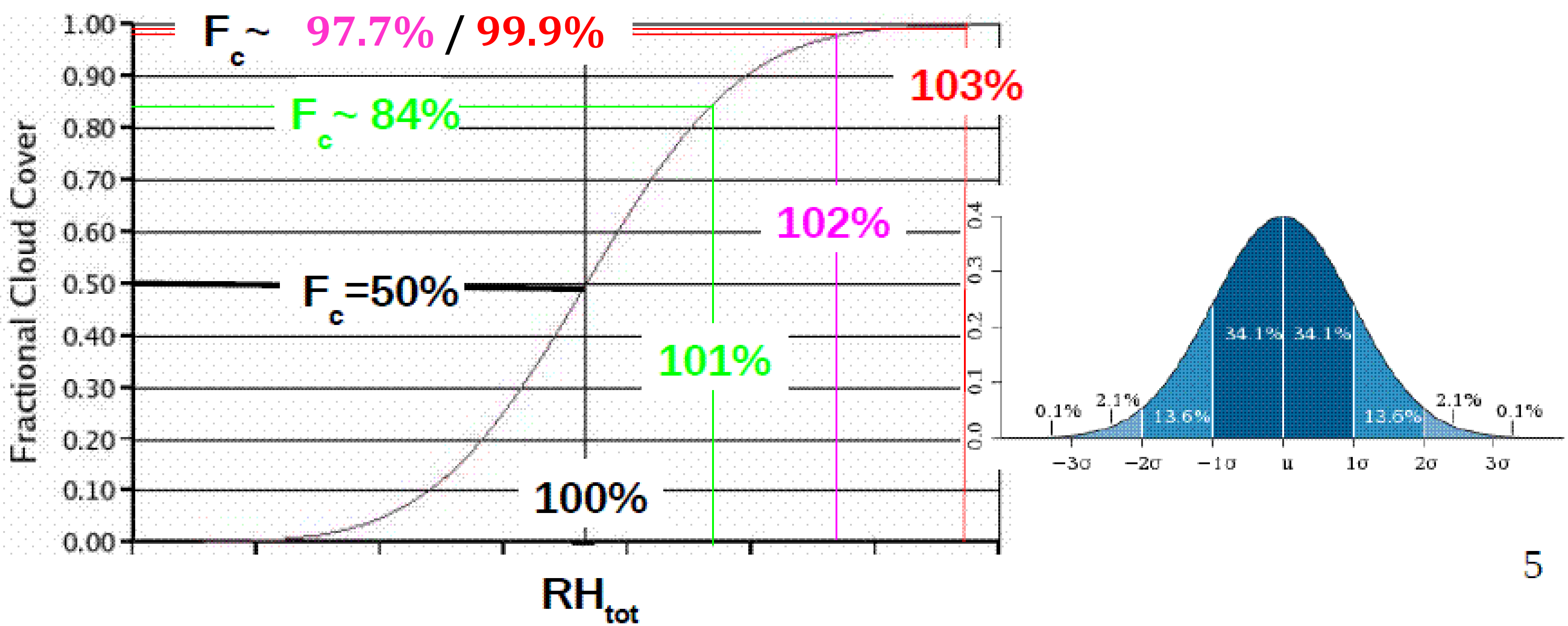




The problem: too much overcast from high, very thin cirrus

Cloud Fraction Changes (2 of 4)

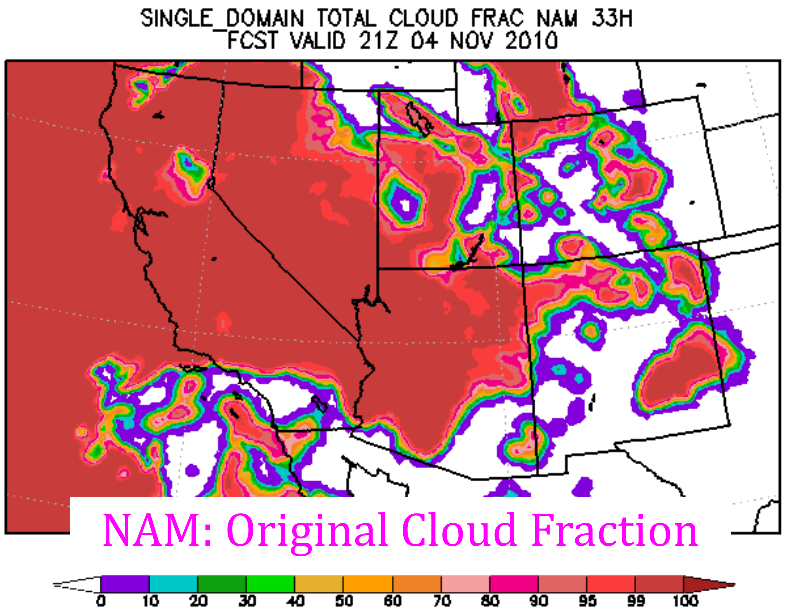
- Total relative humidity, $RH_{tot}=(Q_v+Q_{cld})/Q_{sat}$
- Cloud fraction (F_c) a function of RH_{tot}, assumed to be Gaussian with σ=1%

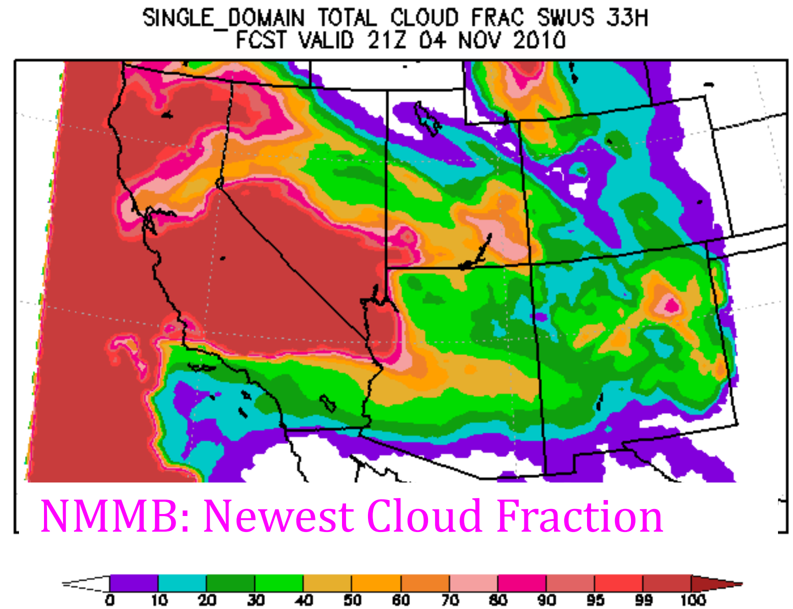


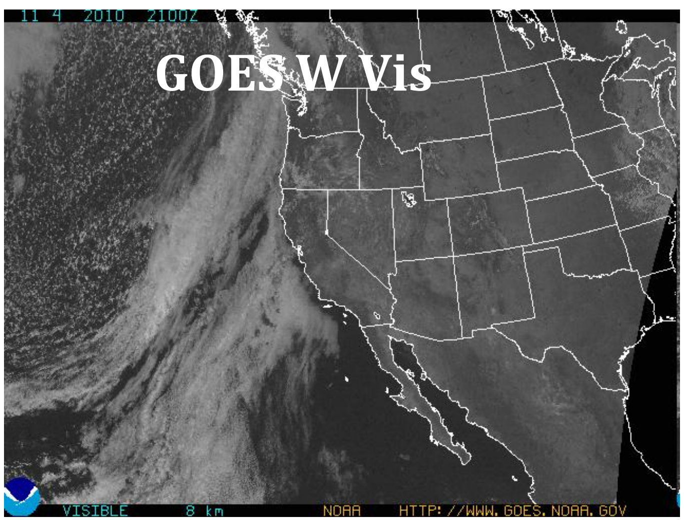
Cloud Fraction Changes (3 of 4)

- Cloud water condensation
  - Many CCN, droplet # conc O(10^2 – 10^3 cm^{-3})
  - Water supersaturations rarely exceed 1%
- Vapor deposition onto ice
  - Far fewer IN, crystal # conc O(1 – 10^3 L^{-1})
  - Much higher SS_{ice} at water saturation
    ~10% (-10°C), ~21.5% (-20°C), ~34% (-30°C), ~48% (-40°C)
- Ice saturation used for Q_{sat} in F_c at T<0°C
- RH_{tot}»100% & $F_c \rightarrow 1$ even when $Q_{cld} \rightarrow 0$

Cloud Fraction Changes (4 of 4)







Less upper-level cirrus (right)

Simple fix for cloud fraction (Fc):
$$F_c=\min[1, SQRT(10^5*Q_{cld})]$$

Better objective verification vs. CLAVRx & surface obs (not shown)

Community Challenges

- Managing multiple modeling systems (versionitis)
  - HWRF, WRF, & NEMS community codes are complex
  - Connections between physics ("wheel of pain")
    - e.g. , $SW\downarrow_{sfc}$ important for ocean & land models
- Do HWRF movable nest(s) complicate things?
  - Thompson, WSM6 used to work in single domain runs in WRF V2.2
  - Do they work in HWRF V3.3 (e.g. Sam T's tests)?
- NCEP operations: optimizing costs & benefits
  - Desire for more complex physics - vs - limited computing & human resources