Modeling of Clouds Precipitation in NWP : Overview 1: Cloud Modeling (issues affecting clouds in NWP models)

by

Brad Ferrier

NOAA/NWS/NCEP/EMC and SAIC/GSO

International Workshop on the Assimilation of Satellite Cloud and Precipitation Observations in NWP Models

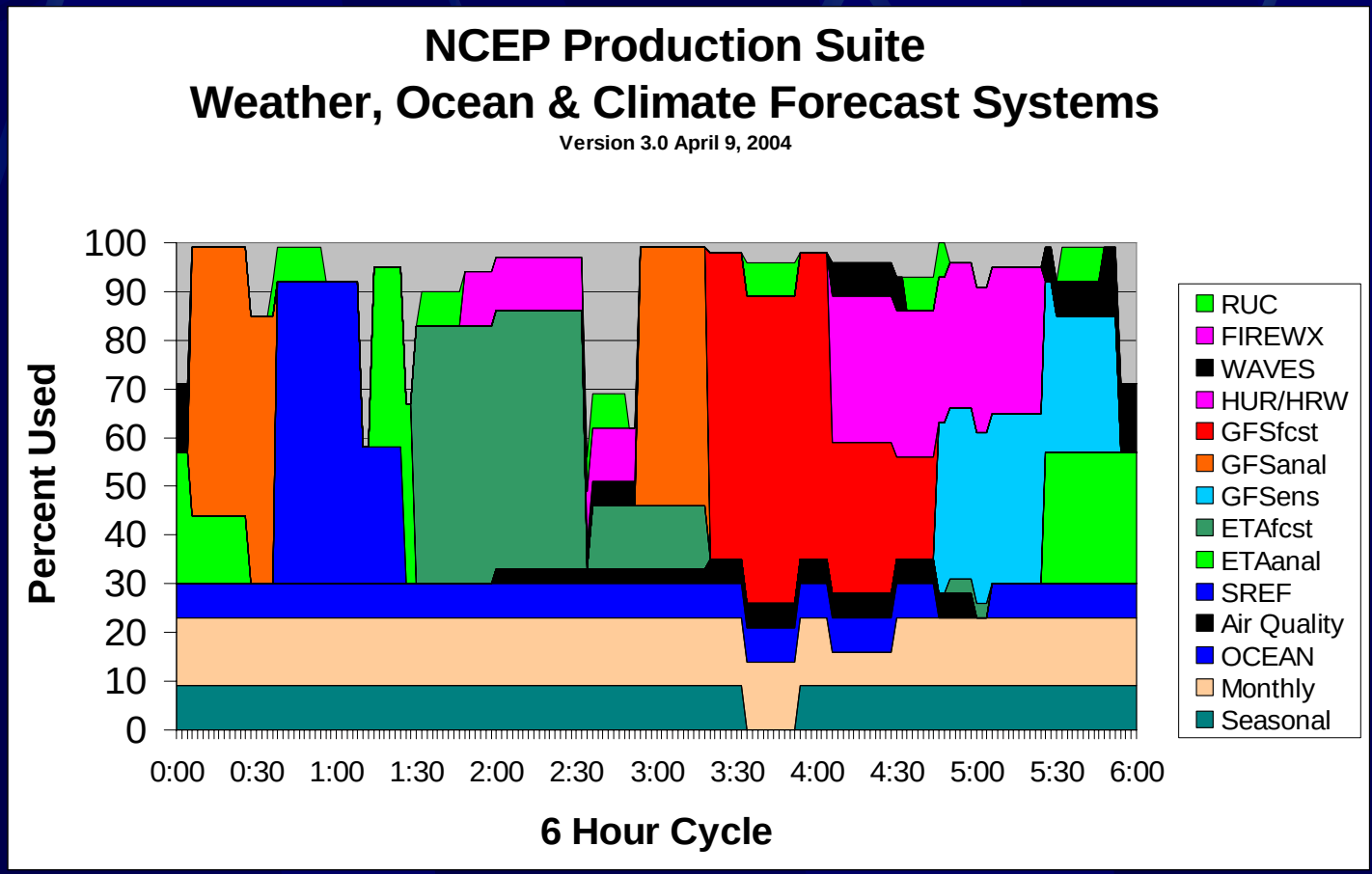
2-4 May 2005

OUTLINE

- Brief background of NCEP operational models
- Physical parameterizations affecting clouds
  - Overview of NCEP cloud schemes
    - Short review of "Eta/Ferrier" microphysics
  - Cloud-radiation issues
    - Cloud fraction schemes
    - Initial cloud verification efforts
  - Subgrid-scale cloud parameterizations
    - Shallow (nonprecipitating) convection
    - Deep (precipitating) convection
  - PBL (+ shallow convection) issues
- Summary remarks

(Old) NCEP Operational Model Suite

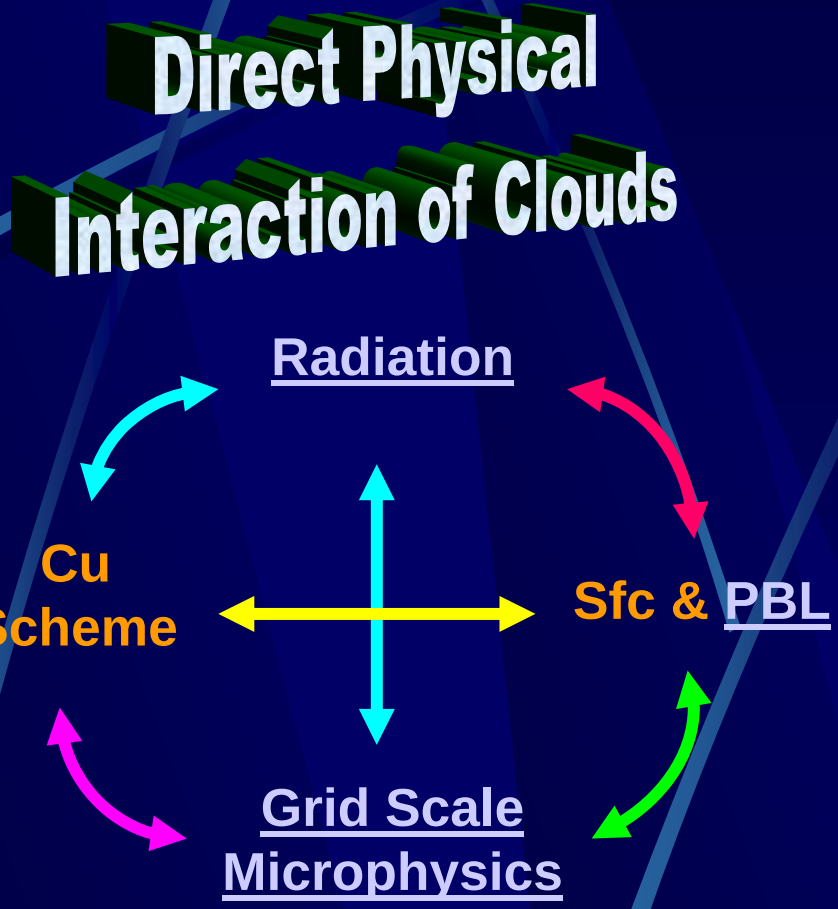
- "Jigsaw puzzle" from 2004 of NCO productions
- Lesson: Models must be efficient, try to KISS



Trying to Prevent Acronym Confusion …

- Current NCEP regional model (Eta) was renamed (Jan '05) the North American Mesoscale (NAM) model – represents the regional model guidance within NCEP's operational production suite
- NAMX (EtaX) was the parallel (test) version of the NAM (Eta) that became operational this week
- Next year the Weather Research and Forecasting (WRF) model will be the NAM model (replaces Eta)
- Two WRF dynamic cores WRF NMM (NCEP) and WRF ARW (formerly EM; NCAR)
- Global Forecast System (GFS) was formerly AVN / MRF

"THE PHYSICS WHEEL OF PAIN"



1. Hydrometeor phase, cloud optical properties, cloud overlap assumptions, & cloud fractions
2. Precipitation (incl. phase) and clouds
3. Subgrid transports, stabilization, detrainment
4. Sfc energy fluxes, LSM
5. Convection (deep & shallow), PBL evolution, precipitation

Model Verification Additional Links

Future Work

- Future cloud development will focus on:
  - Incorporate more partial cloudiness of "Sundqvist/Zhao" into current scheme
  - Different drop size spectra for rain formed from warm-rain coalescence vs. melting ice
  - Add more ice nucleation processes
- Continued physics development will focus on:
  - Improved interactions/connections between different physical processes
- Satellite clouds ⇒ model verification, precursor to assimilation of cloud information into models

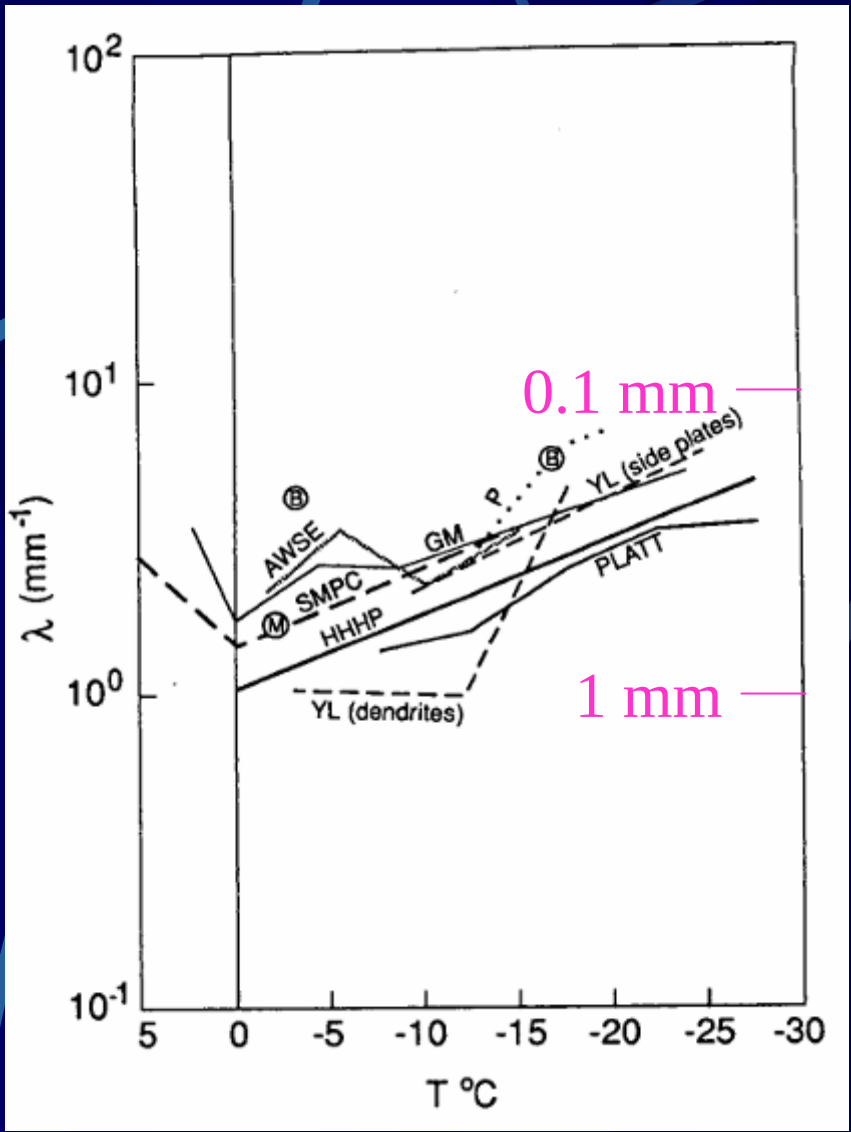
Challenges for Cloud & Precip Assimilation

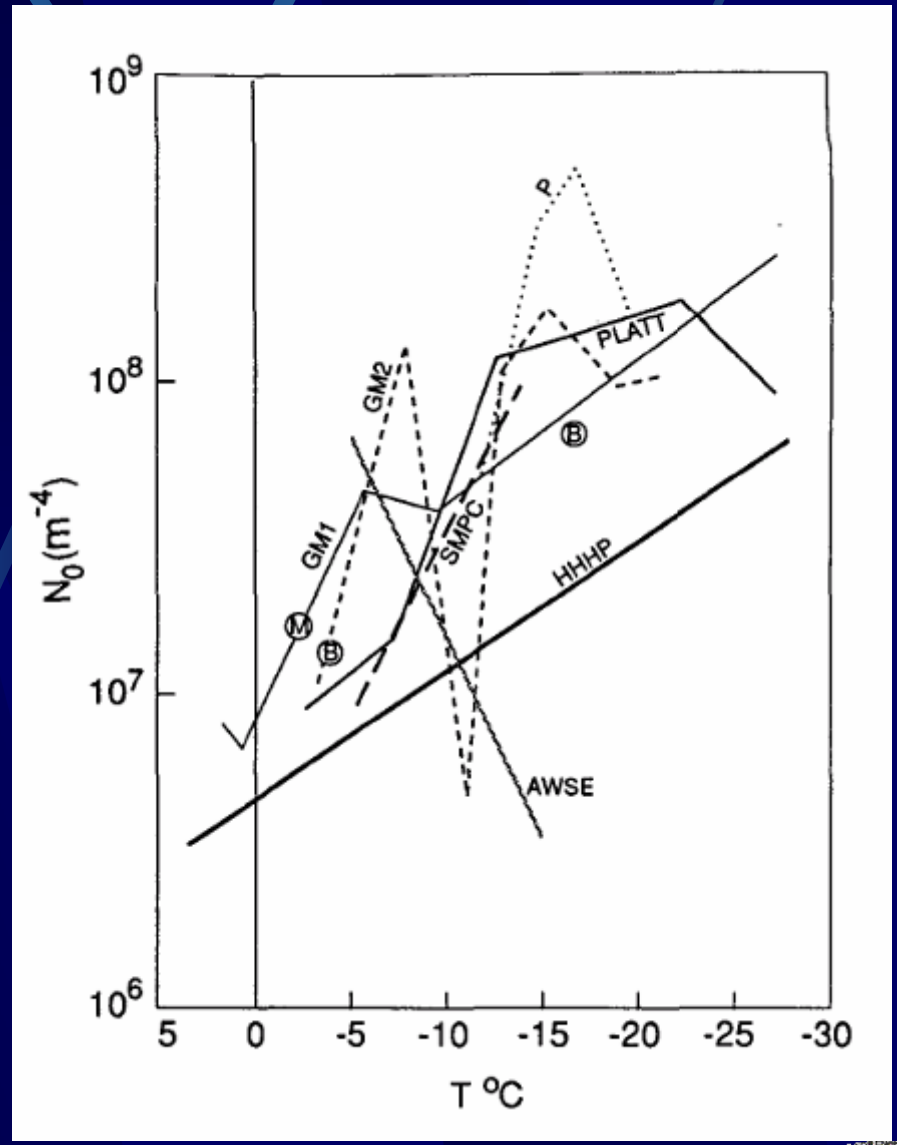
- **Recognize that**
  - Clouds are atmospheric canaries
  - Pathologies in physics can cause spurious vertical structures of T, Q (and thus RH) that affect clouds
  - Connections between physics is as important, if not more so, than the sophistication of the schemes
  - NWP is a gigantic systems integration challenge
- ***Robust*** **verification is extremely helpful in getting NWP clouds "in the same room" with observations**
  - "Skin" or "tops" of clouds, total cover
  - Total water and/or ice paths (NESDIS, CLAVRx)
  - ***Globally reliable observations w/ QC & bias corrections; smaller errors & uncertainties than in the models***

Comparing NCEP cloud microphysics schemes

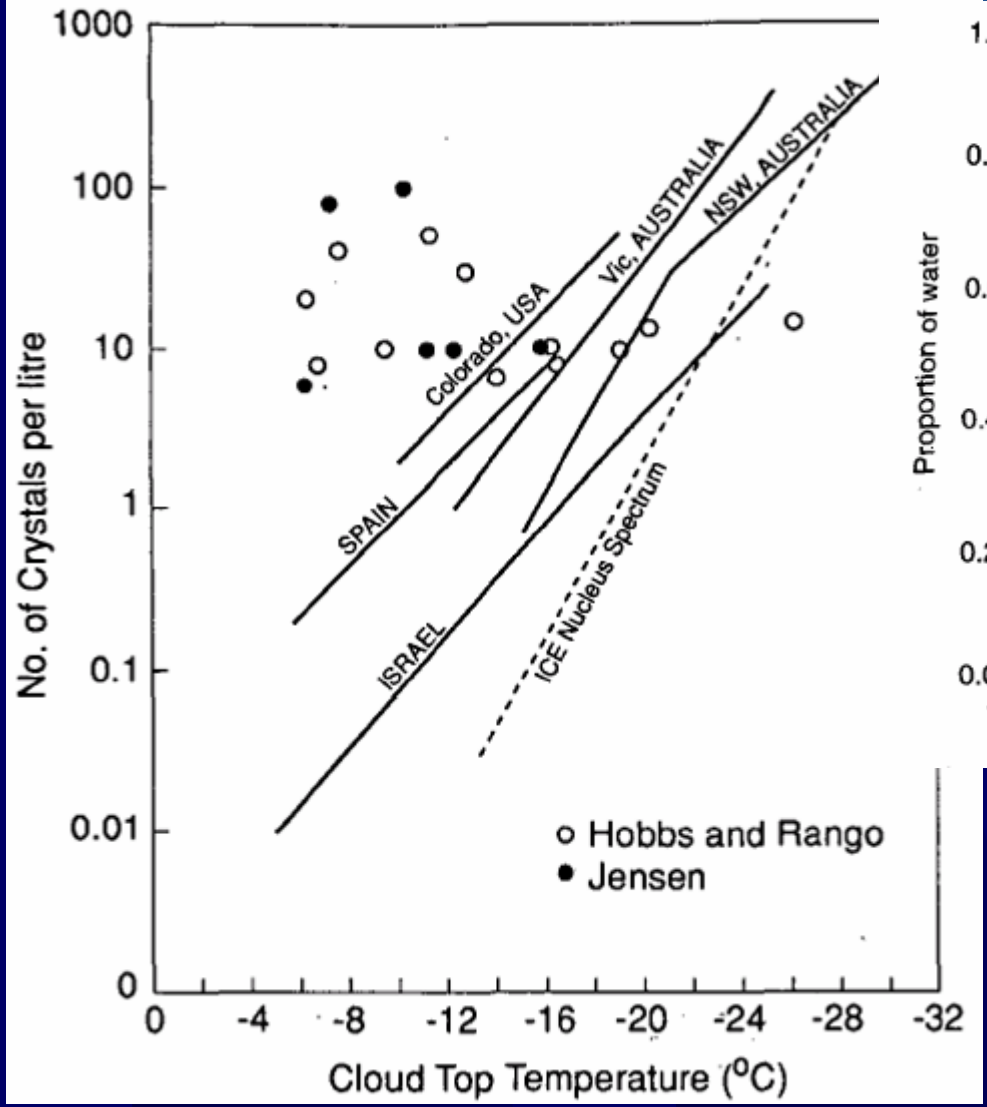
FEATURE	Zhao & Carr (1997) [Modified version in GFS]	Ferrier et al. (2002) [In NAM, WRF option]
Prognostic variables	Water vapor, cloud condensate (water or ice)	Water vapor, total condensate (cloud water, rain, cloud ice, snow/graupel/sleet)
Condensation algorithm	Sundqvist et al. (1989)	Asai (1965) [used in high res models]
Precip fluxes and storage	Top-down integration of precip, no storage, & instantaneous fallout.	Precip partitioned between storage in grid box & fall out through bottom of box
Precip type	Rain, freezing rain, snow	Rain, freezing rain, snow/graupel/sleet (variable rime density for precip ice)
Mixed-phase conditions	No coexistence of supercooled cloud water & ice, simple melting eqn.	Mixed-phase at >-10C (-30C in WRF), includes riming, more sophisticated melting/freezing

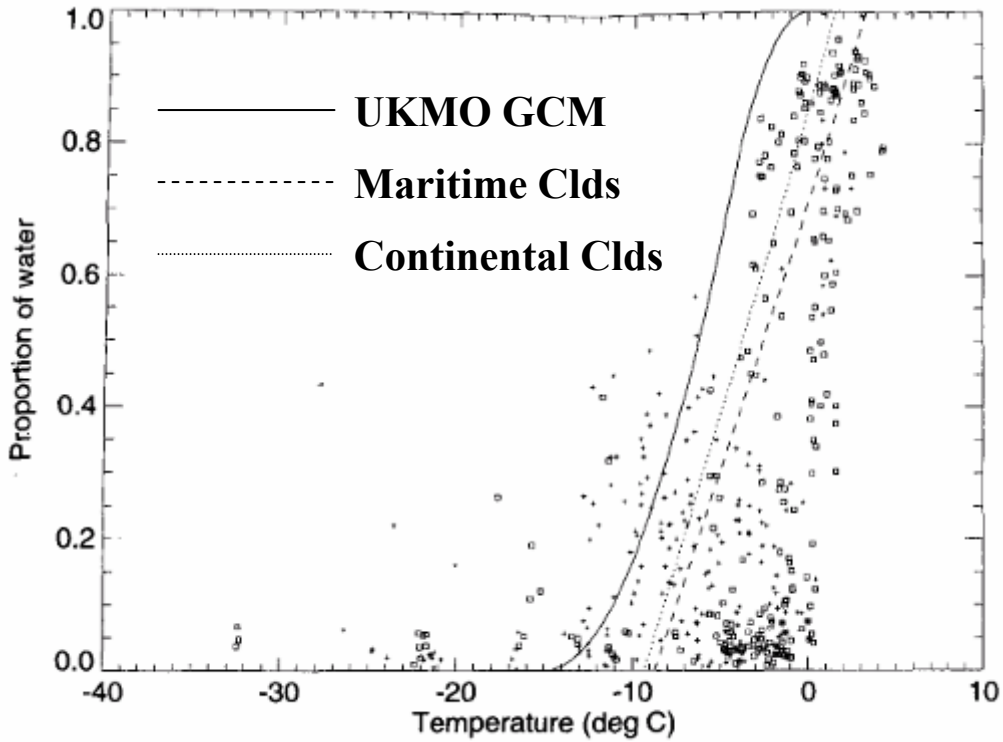
Global Ice Spectra (Ryan, BAMS, 1996)





Global Ice Properties (Ryan, BAMS, 1996)





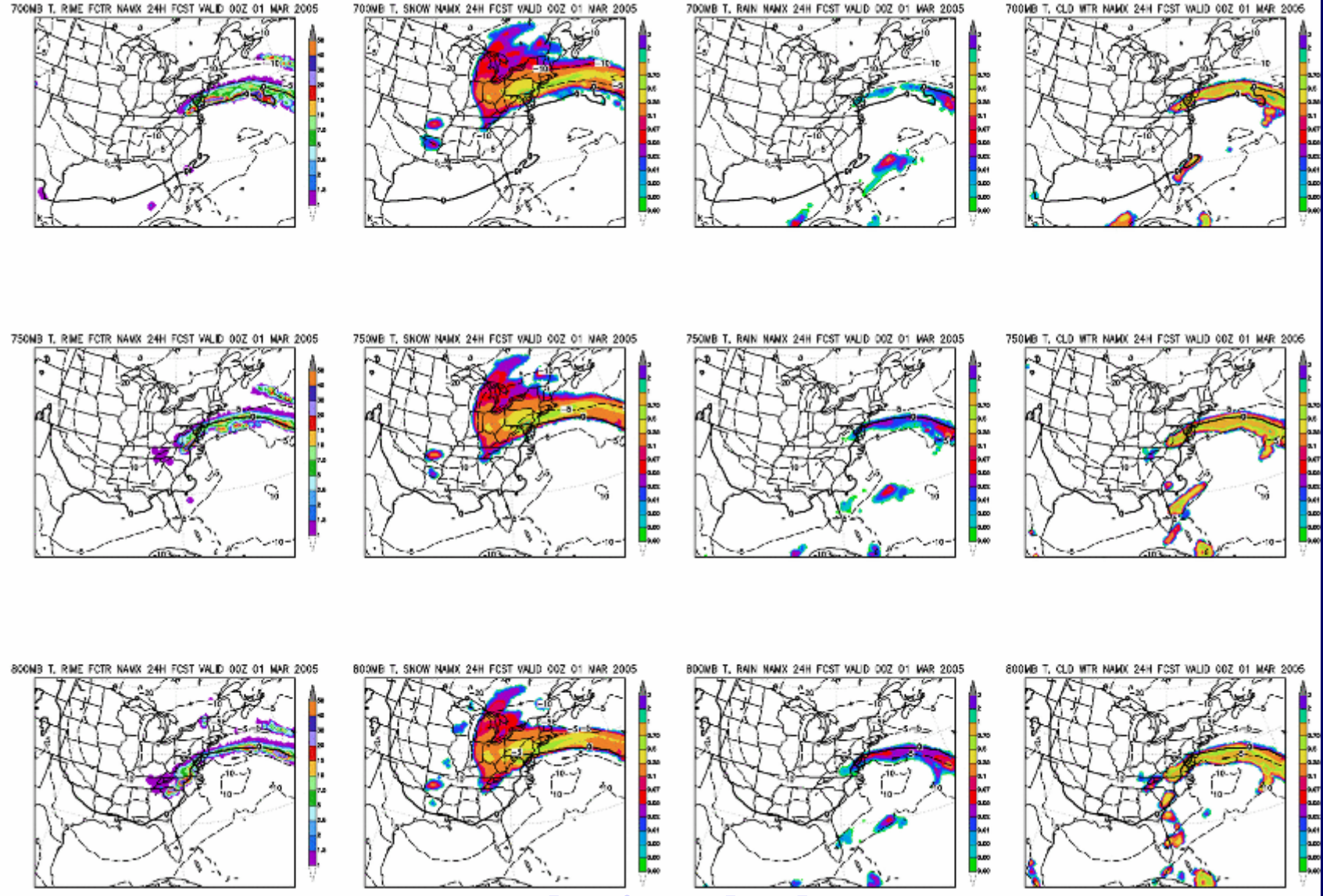
- N_{ice} weak function of T

Other Features of Ferrier Microphysics

- **Discrimination between cloud ice and "snow"**
  - Assume 50 μm size cloud ice, no fall speeds
  - No cloud ice if T>0°C (melting) ⇒ only "snow"
  - $N_s = 0.2 \cdot N_i$ (N_s=snow # conc, N_i=cloud ice # conc)
  - $N_s = 0.1 \cdot N_i$ if above ice saturation & -8°C < T < -3°C
- **Variable rime density ⇒ assumes accreted liquid water fills air holes of ice lattice w/o changing volume**
  - "Rime Factor" (3D array) ⇒ $RF = \frac{Total\ Growth}{Deposition\ al\ Growth}$
- **Efficient look-up tables store solutions for:**
  - Various particle moments (ventilation, accretion, mass, precipitation rate) at 1 μm resolution
  - Composite rain & ice (incl. rimed ice) fall speeds

(more on rime factor) (physics wheel)

24-h Fcst 3D Cloud Fields at 700, 750, 800 hPa



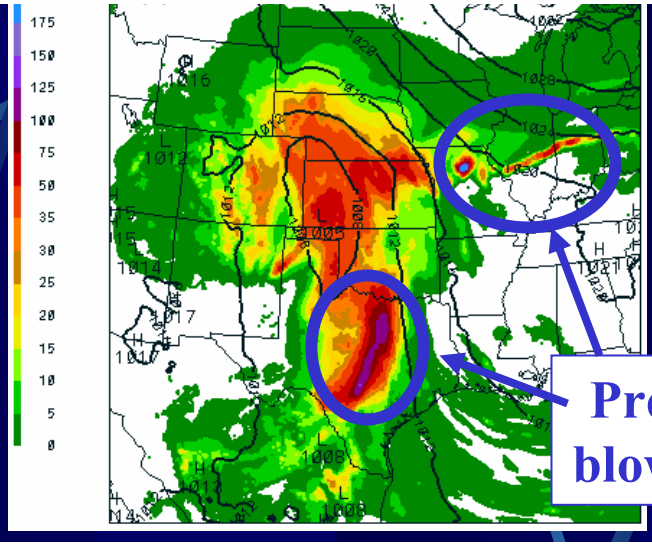
(physics wheel)

Reduction in spurious precipitation

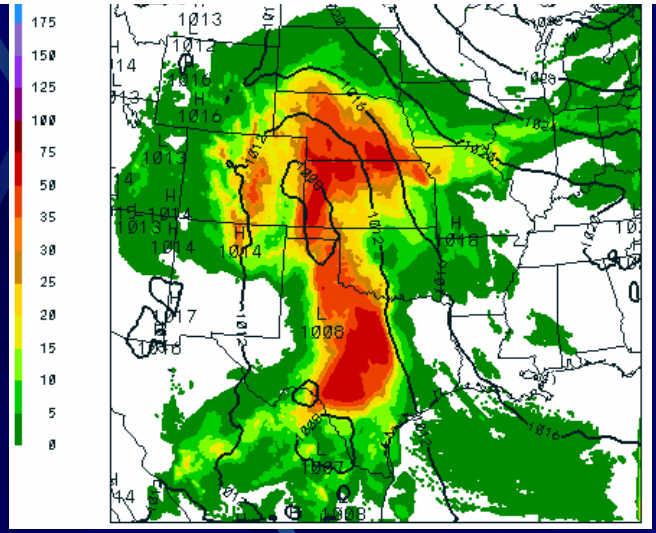
12Z 3 May '01 10-km Eta Central High Res Window Runs

(color fill – 24h precip in mm, contours of sfc pressure in mb)

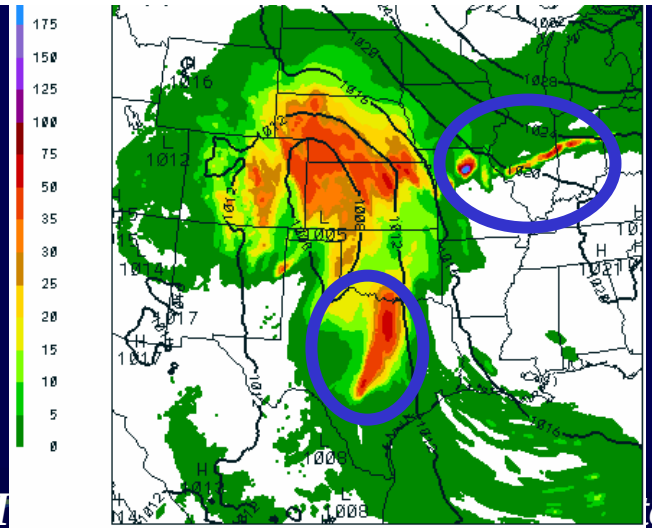
24-48h Total Precip 12Z 5/5/01 (Zhao)



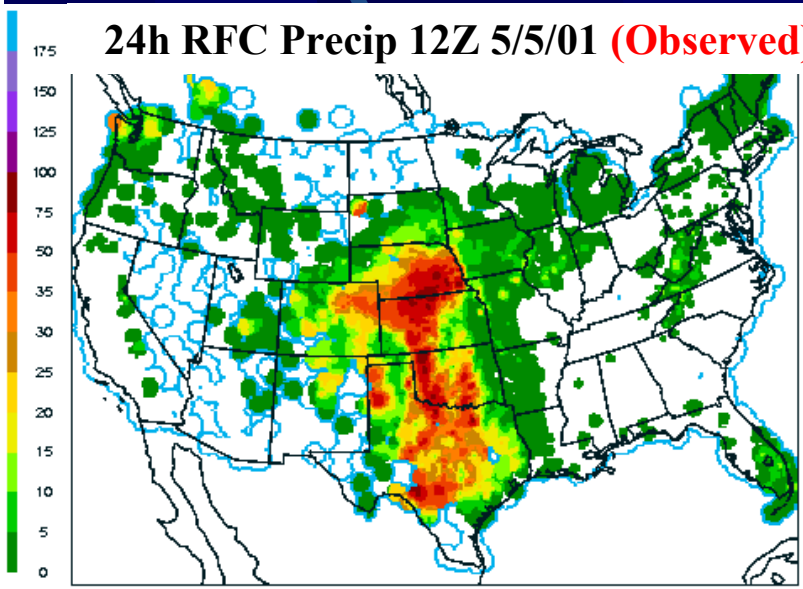
24-48h Total Precip 12Z 5/5/01 ("Ferrier")



24-48h Grid-scale Precip 12Z 5/5/01 (Zhao)



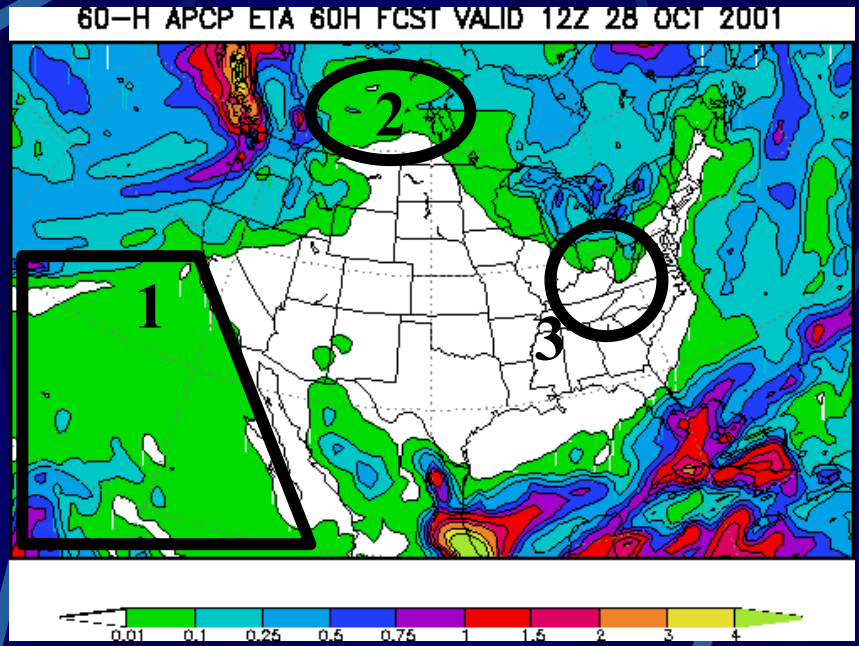
24h RFC Precip 12Z 5/5/01 (Observed)



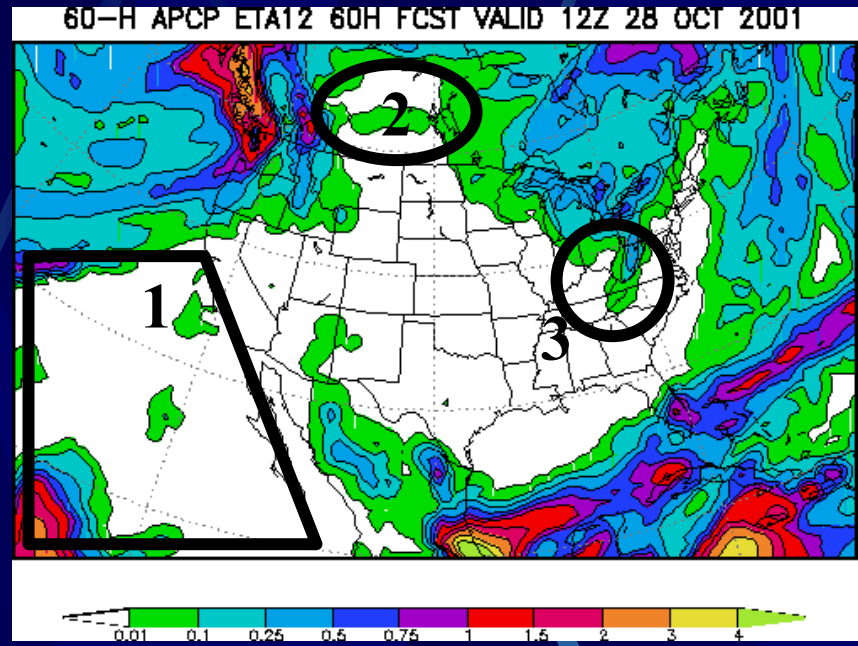
Environmental Modeling Center

Reduced high bias in light precipitation (areas 1, 2) & improved orographic precipitation (area 3)

(0-60 h forecasts of accumulated precipitation in inches valid 12Z 28 Oct 2001)



22-km Eta Zhao microphysics (OLD)



12-km Eta Ferrier microphysics (NEW)

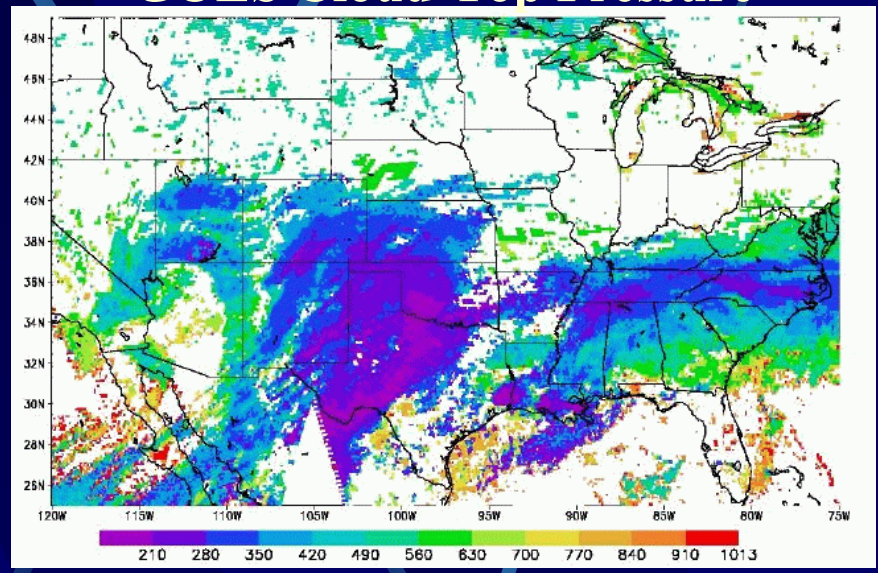
(physics wheel)

Reduced High Bias in Upper-Level Cloudiness

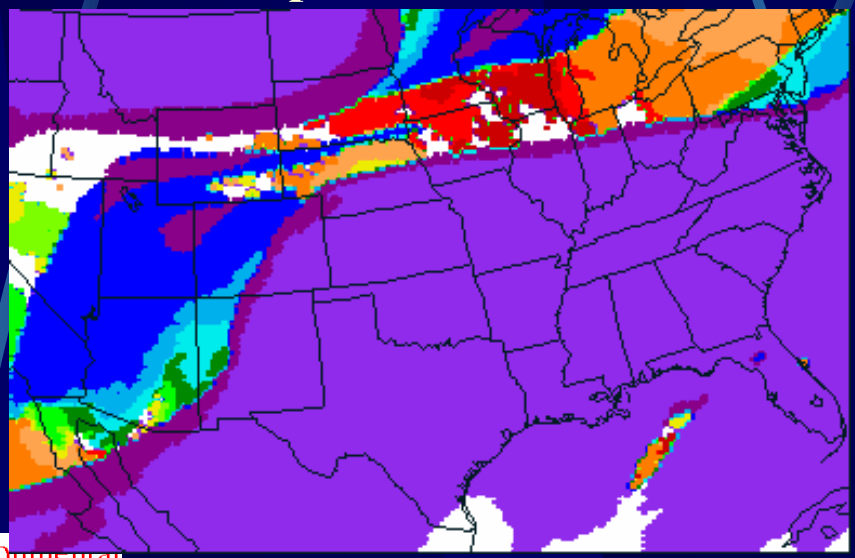
Observed (upper right) vs. forecast (bottom) cloud-top pressures (mb) for 12Z on 28 FEB 2001

(physics wheel)

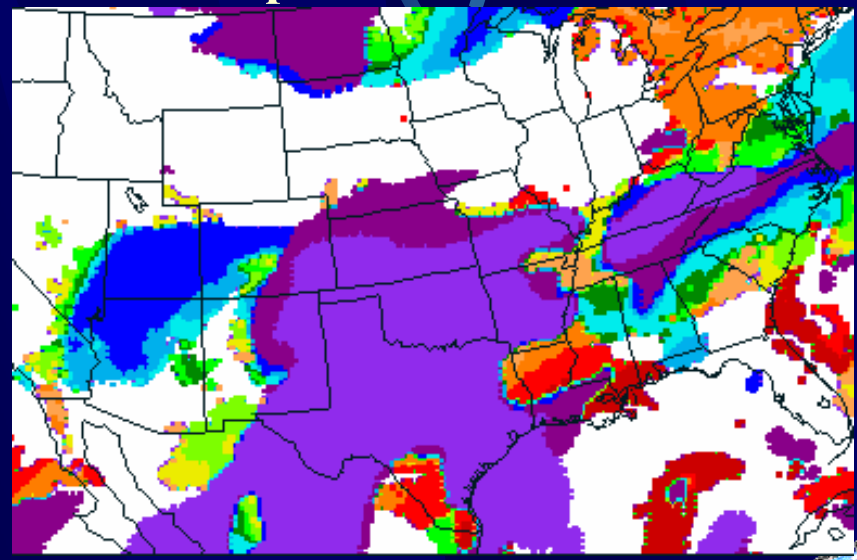
GOES Cloud-Top Pressure



Cloud-Top Pressure from Zhao



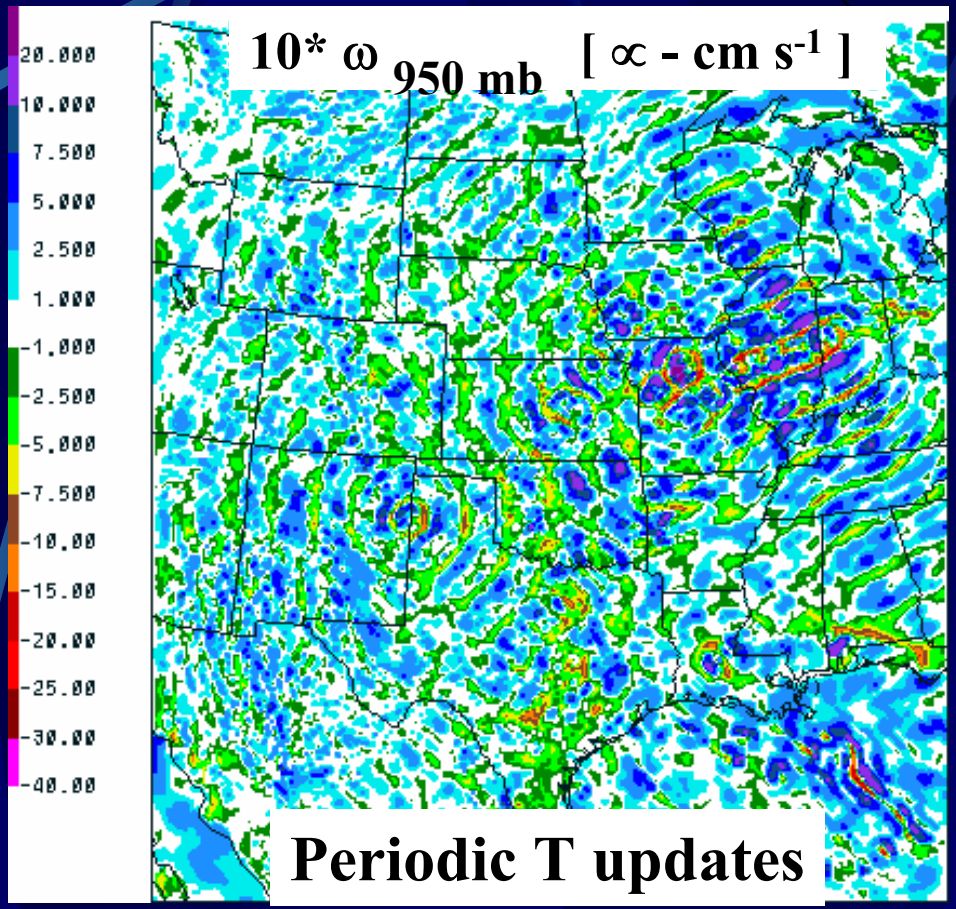
Cloud-Top Pressure from Ferrier

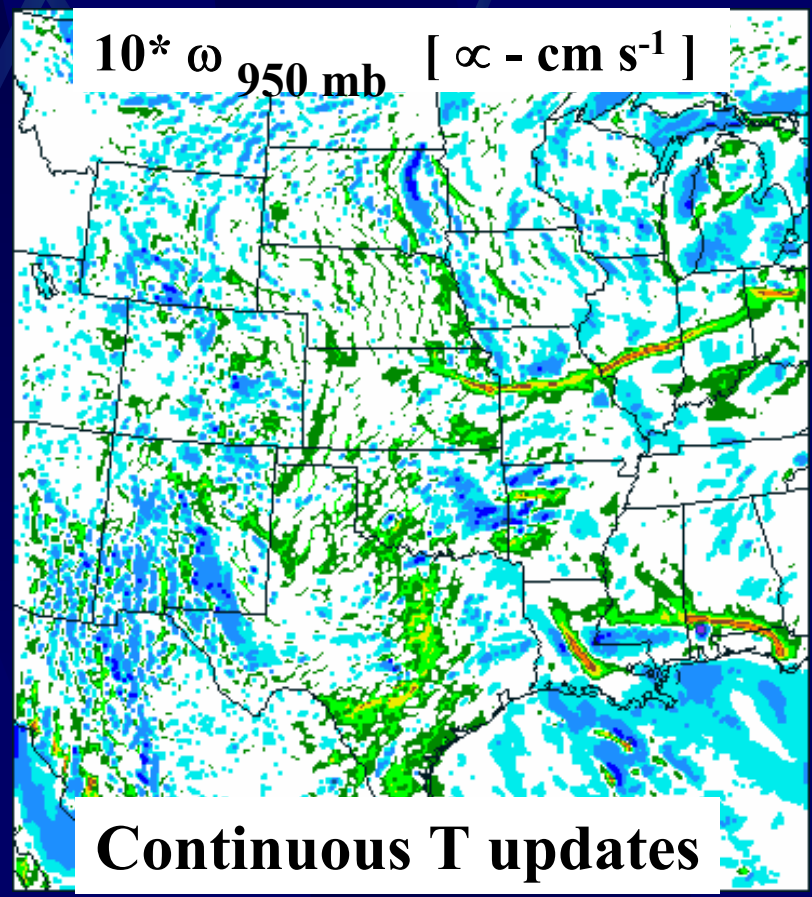


Removing spurious gravity wave excitation through continuous, incremental T changes by (Cu & grid-scale) cloud processes

Vertical motion valid at 00Z 5 May 2001 from 10-km Eta Central

(physics wheel)





Cloud-Radiation Challenges

- **Sensitivities to:**
  - Cloud optical properties (cloud fractions, cloud & ice water paths, effective radius of water & ice, single scattering albedos for water, overlap assumptions)
  - Cloud microphysics (glaciation temperature, ice nucleation rates, & autoconversion threshold of cloud to rain, etc.)
  - Aerosol effects, diurnal variation of albedos for direct (beam) component of radiation
  - Surface albedos (esp. diurnal effects of direct beam)
  - Treatment of parameterized convection
  - Top of model domain, capturing ozone layer

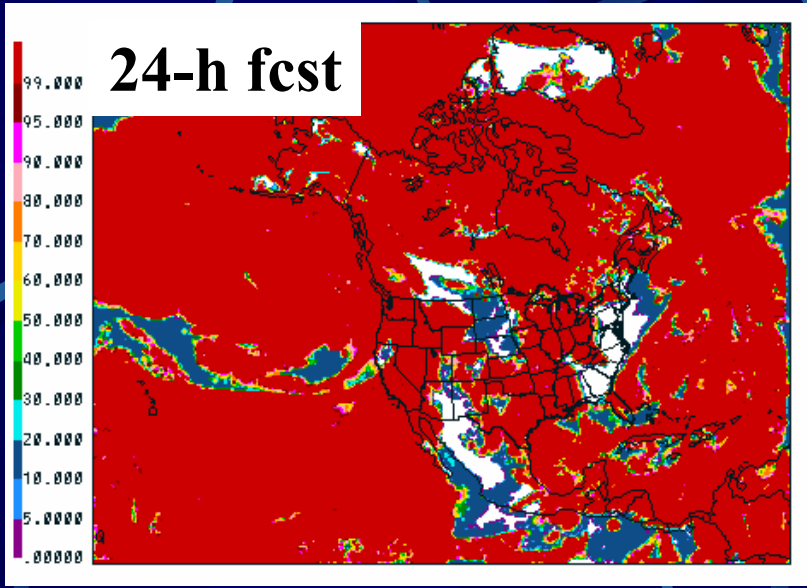
Summary of Cloud-Radiation Issues

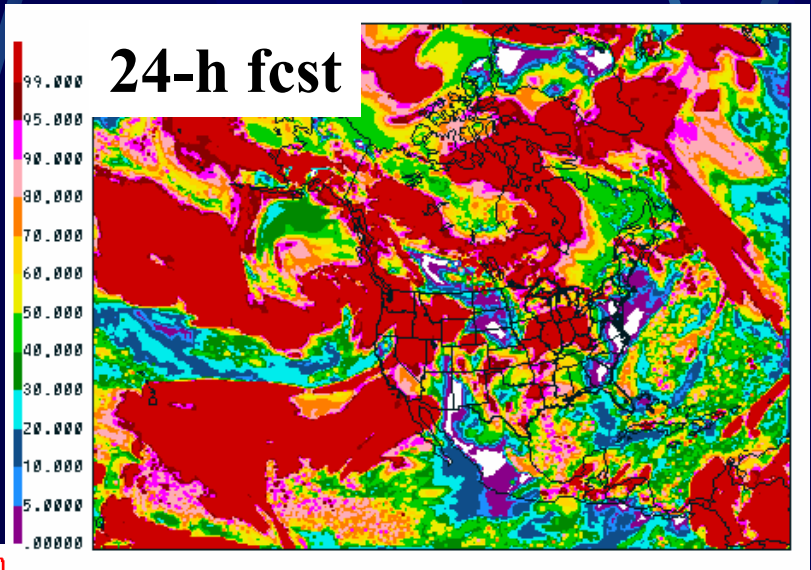
- **Arctic stratus – a challenge** (Curry *et al.*, 2000; Dong and Mace, 2003)
  - Shallow (tops often below 1 km), presence of supercooled liquid water (esp. near cloud top)
  - Little success with tuning cloud fractions alone
  - Incident radiation at low sun angles, underlying snow surfaces
    - ⇨ Direct (beam) sfc albedos too high at low sun angles
  - Greater *relative errors* in radiative forcing
  - Satellite verification desperately needed

(recent NAM changes) (physics wheel)

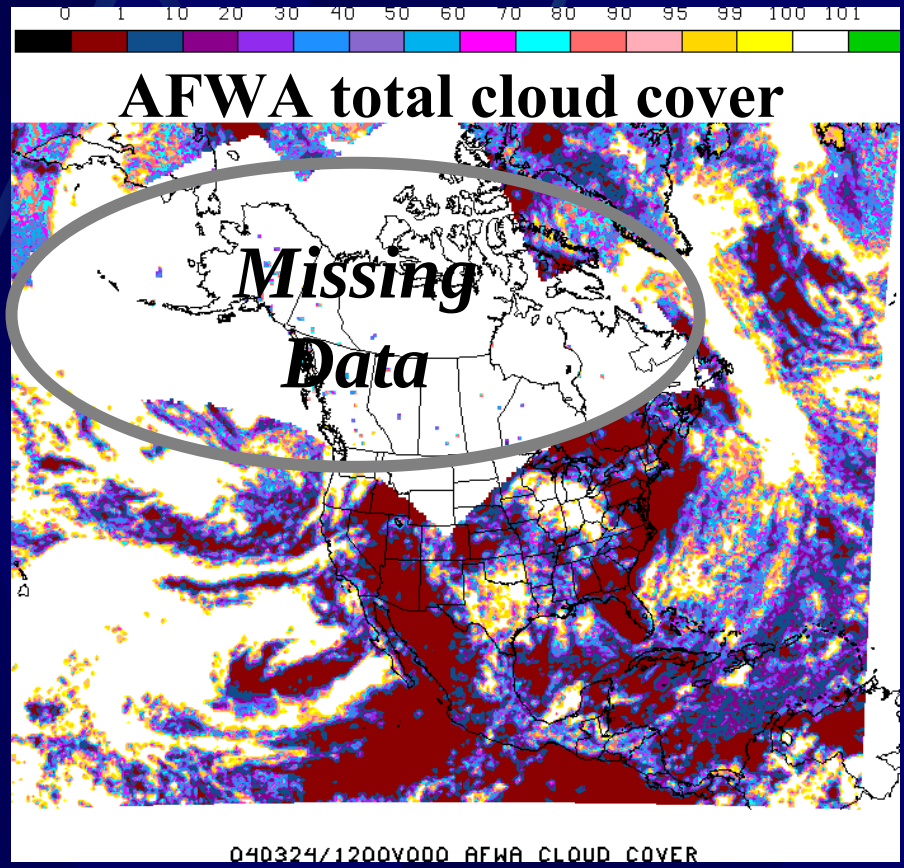
Total Cloud Cover

Experimental Operational

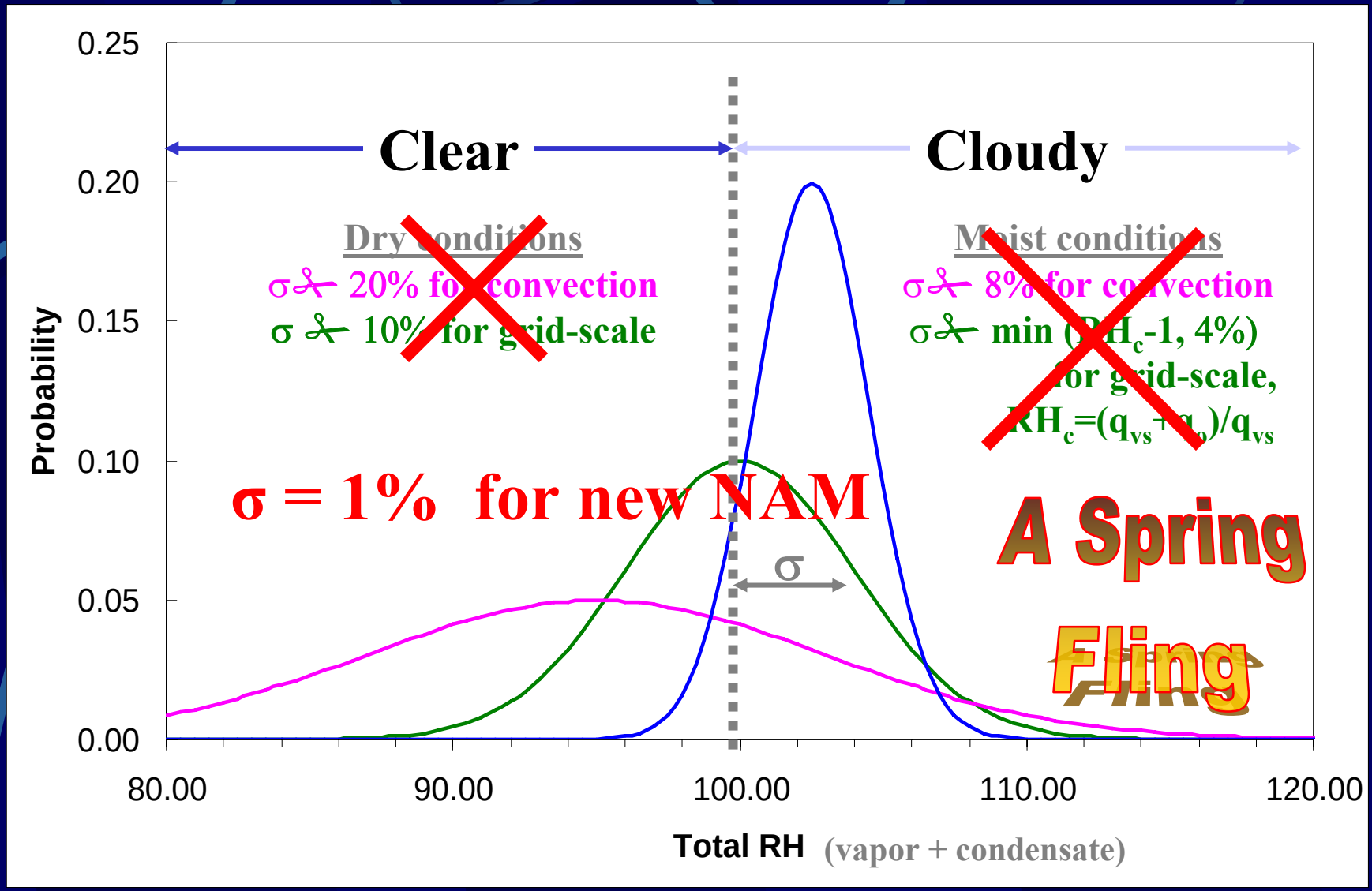




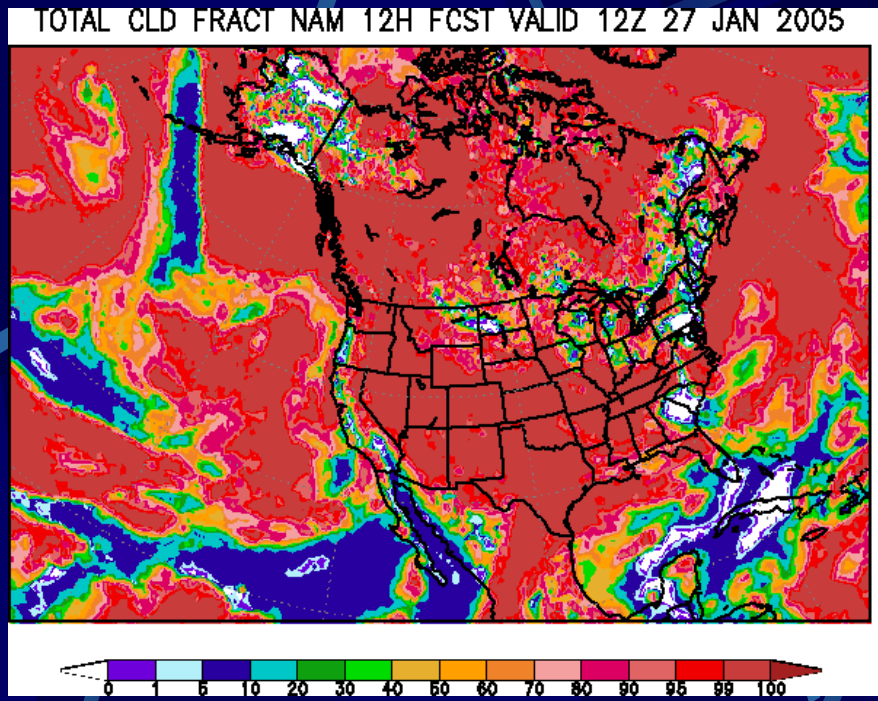
All valid at
12Z 24 Mar '04

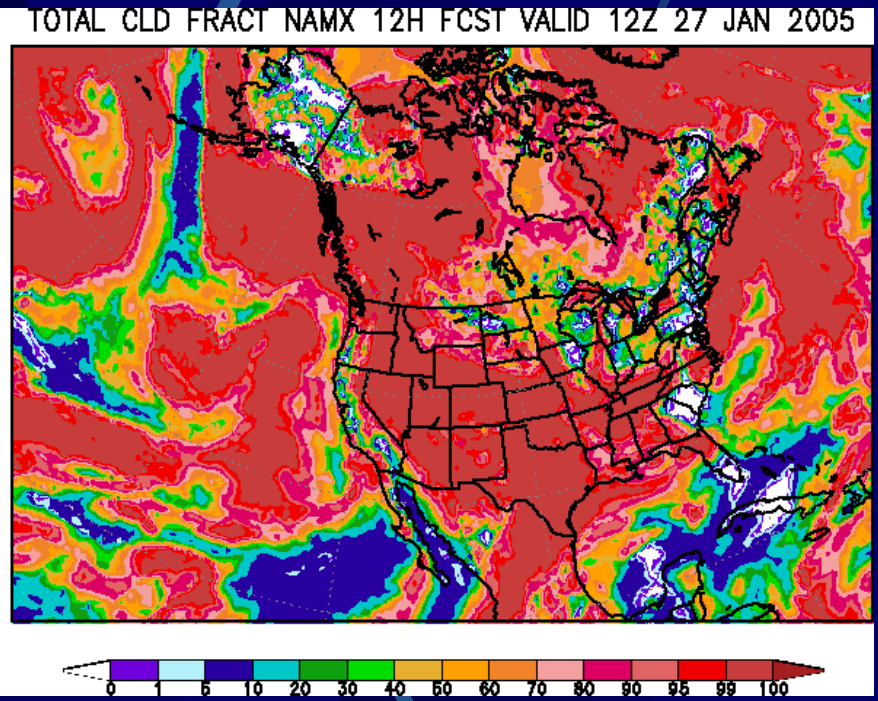


New Cloud Fraction Parameterization



NAM vs. NAMX total cloudiness





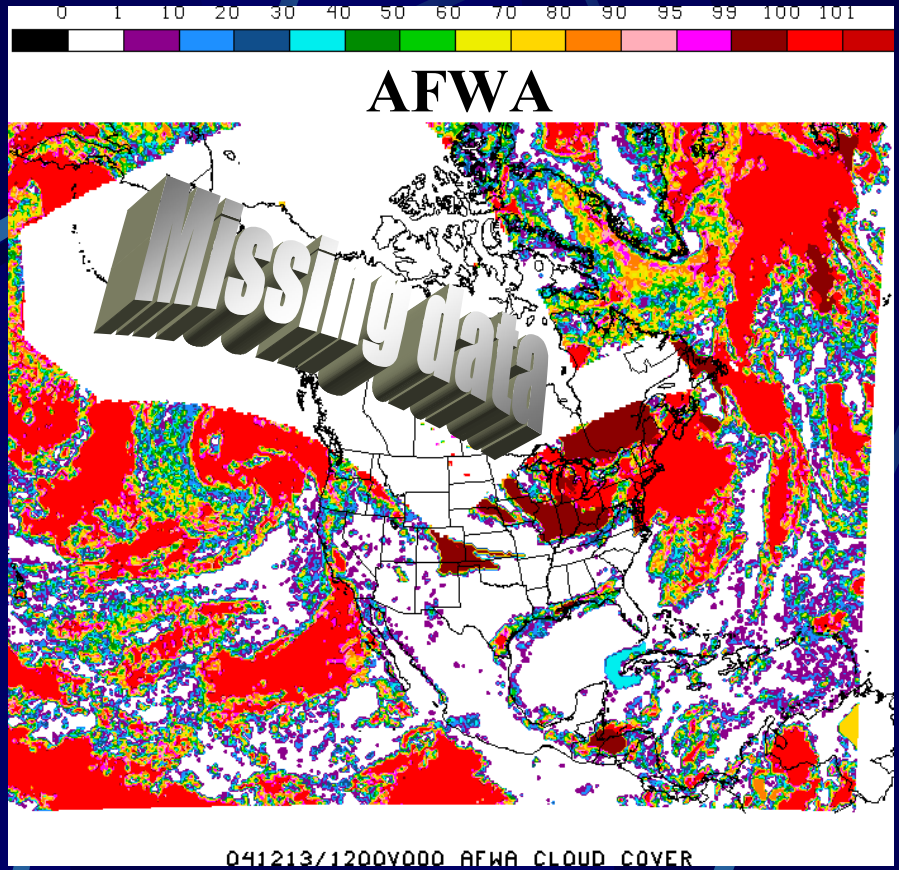
- **NAMX – slightly more partial cloudiness (replaces NAM as new operational model … May 3?)**

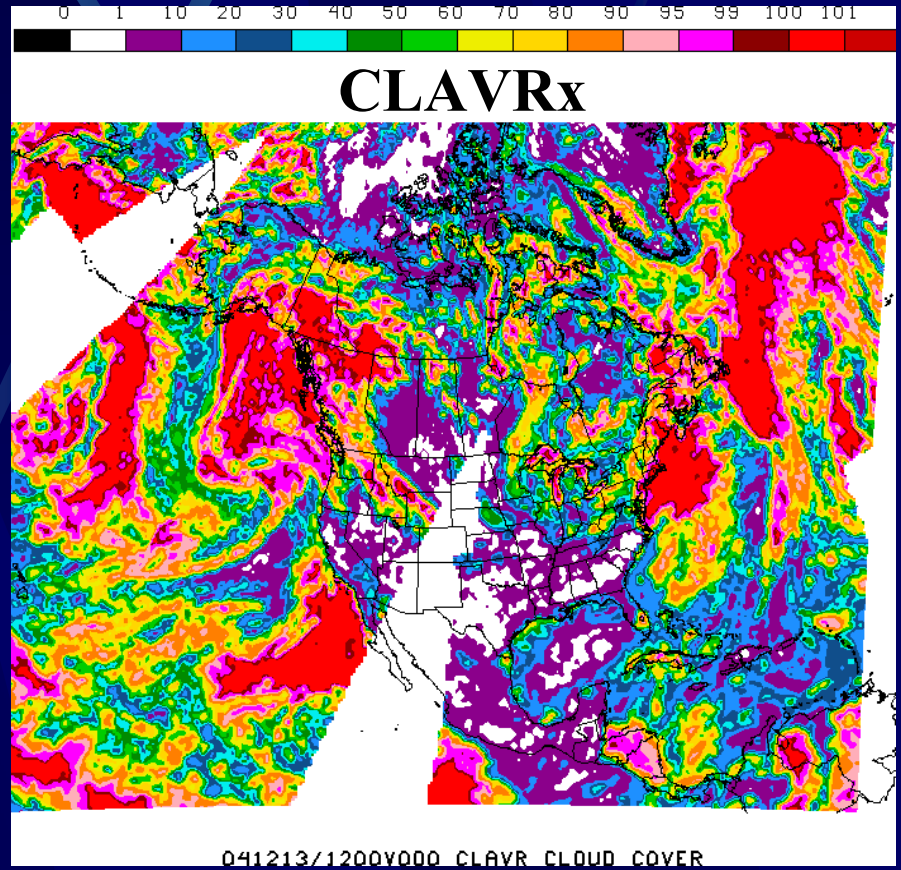
(physics wheel)

A few examples of NAM and GFS model comparisons against cloud analyses

AFWA, CLAVRX total cloudiness (%)

(12Z 13 December 2004)

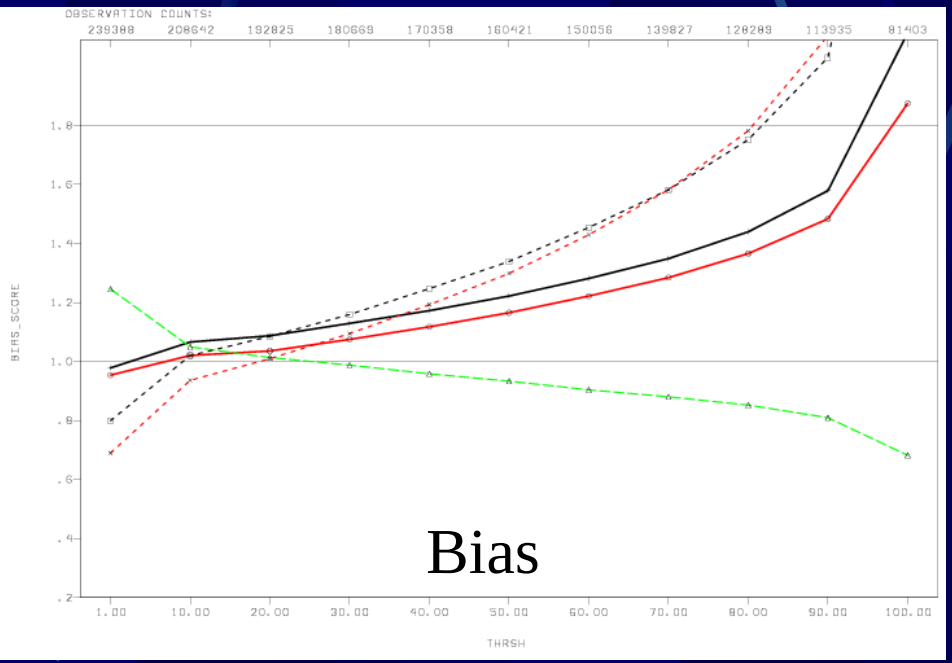




(Many thanks to Mary Hart)

Eta, EtaX scores from AFWA, CLAVRx (1 of 3)

00Z, 12Z analyses from 20041212 – 20050110
verified from 32-km Grid 221 over CONUS



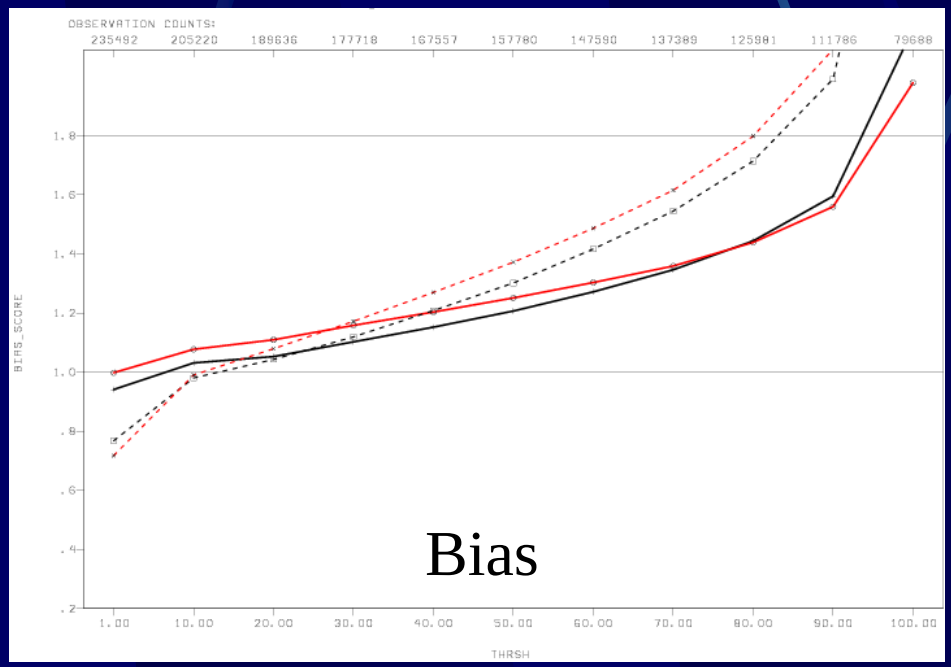
Bias

Heidke Skill Score

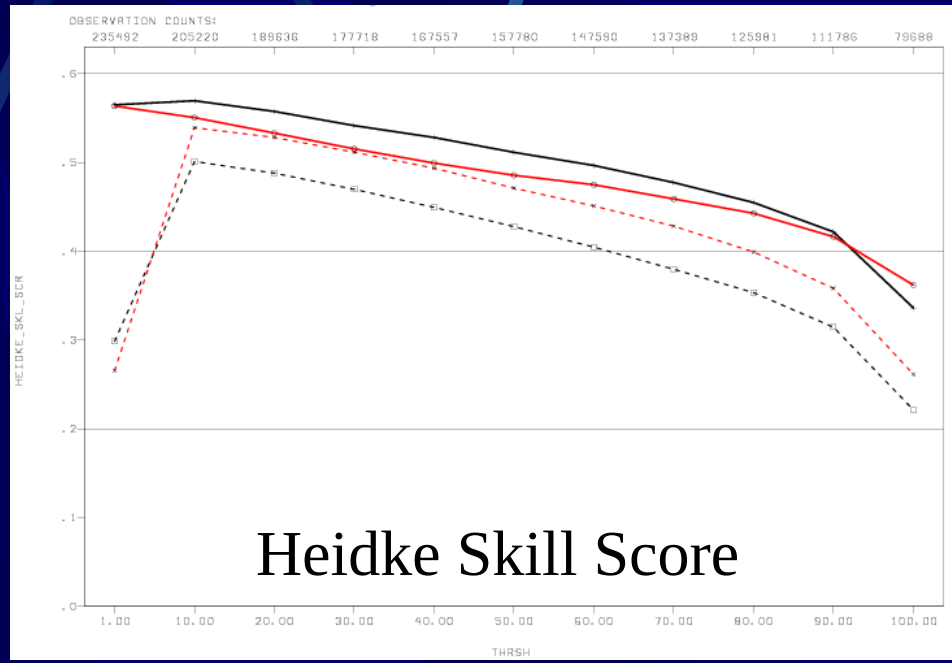
(physics wheel)

Eta, EtaX scores from AFWA, CLAVRx

00Z, 12Z 12-h fcsts from 20041212 – 20050110
verified from 32-km Grid 221 over CONUS



Bias

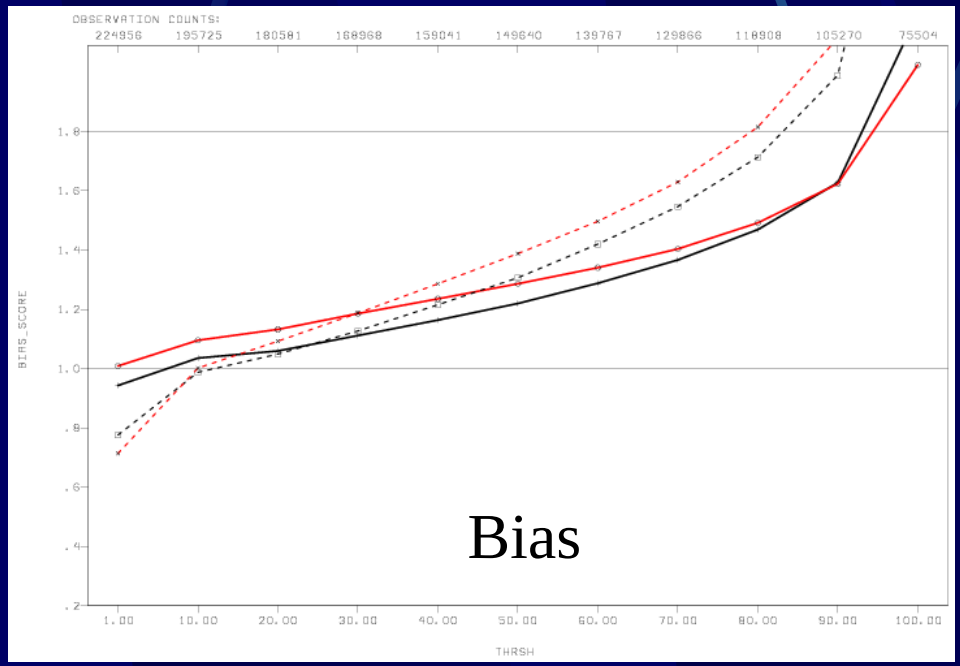


Heidke Skill Score

(physics wheel)

Eta, EtaX scores from AFWA, CLAVRx

00Z, 12Z 48-h fcsts from 20041212 – 20050110
verified from 32-km Grid 221 over CONUS



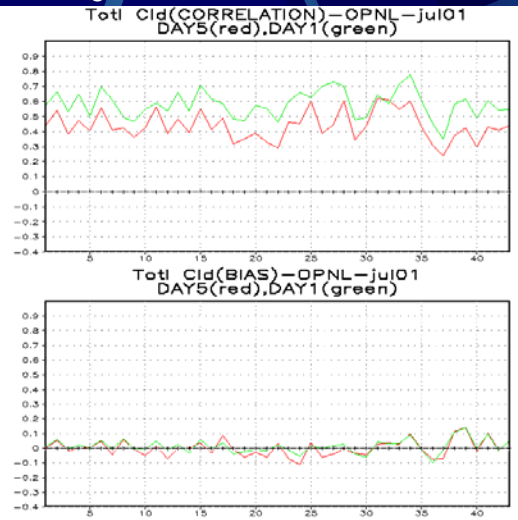
Bias

Heidke Skill Score

(physics wheel)

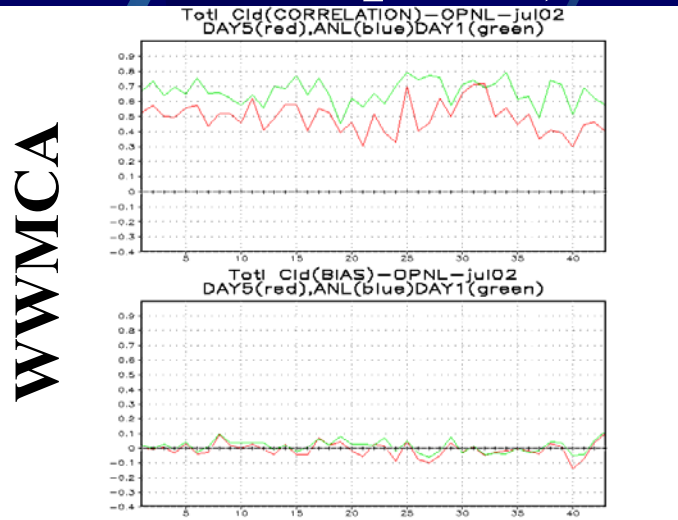
GFS Total Cloudiness vs. RTNEPH / WWMCA
(July '01-'04; *many thanks to Ken Campana!)*

RTNEPH



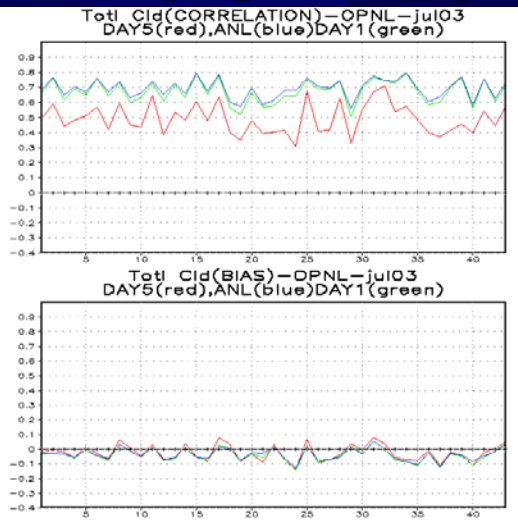
43 Geographical Regions

WWMCA



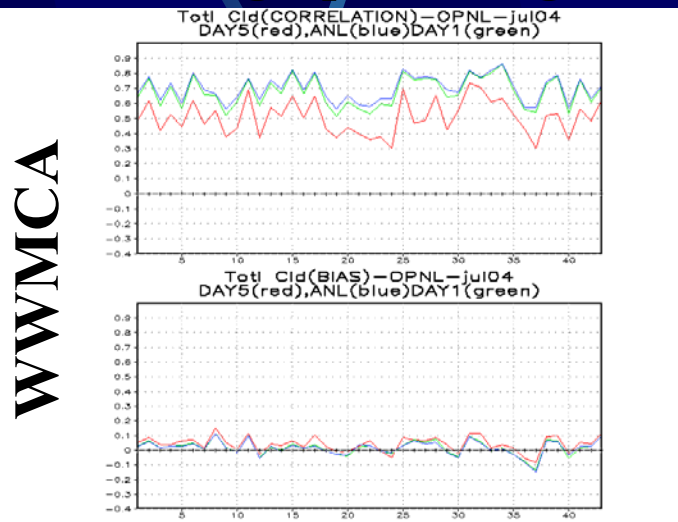
43 Geographical Regions

WWMCA



43 Geographical Regions

WWMCA

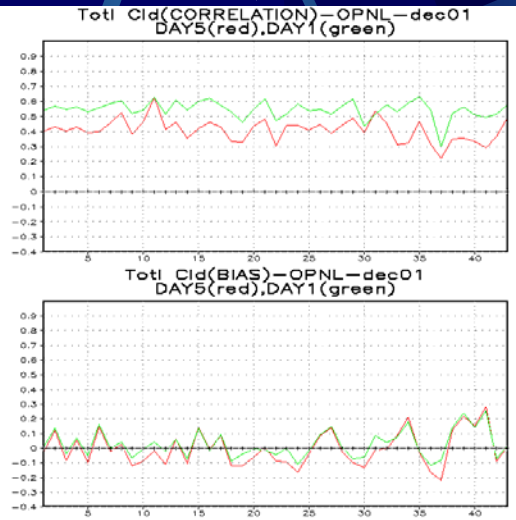


43 Geographical Regions

(physics wheel)

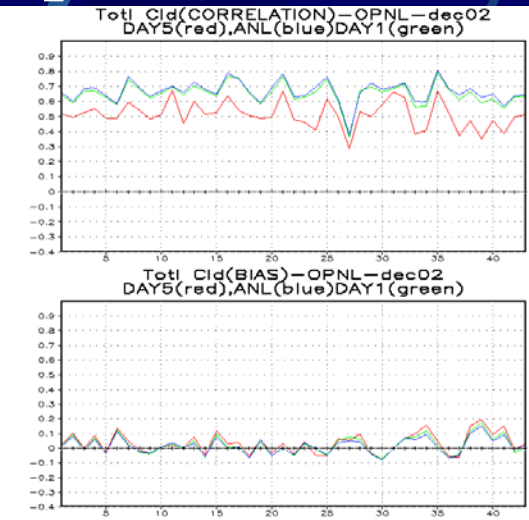
GFS Total Cloudiness vs. RTNEPH / WWMCA (Dec '01-'04 – K. Campana)

RTNEPH



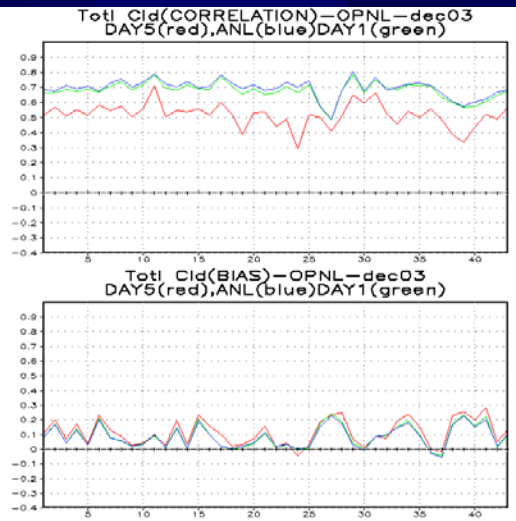
43 Geographical Regions

WWMCA



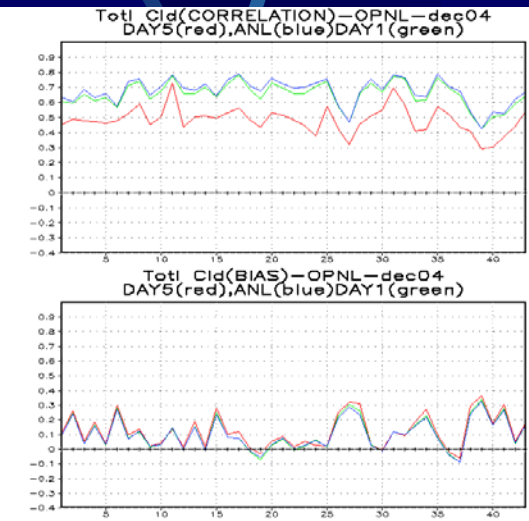
43 Geographical Regions

WWMCA



43 Geographical Regions

WWMCA



43 Geographical Regions

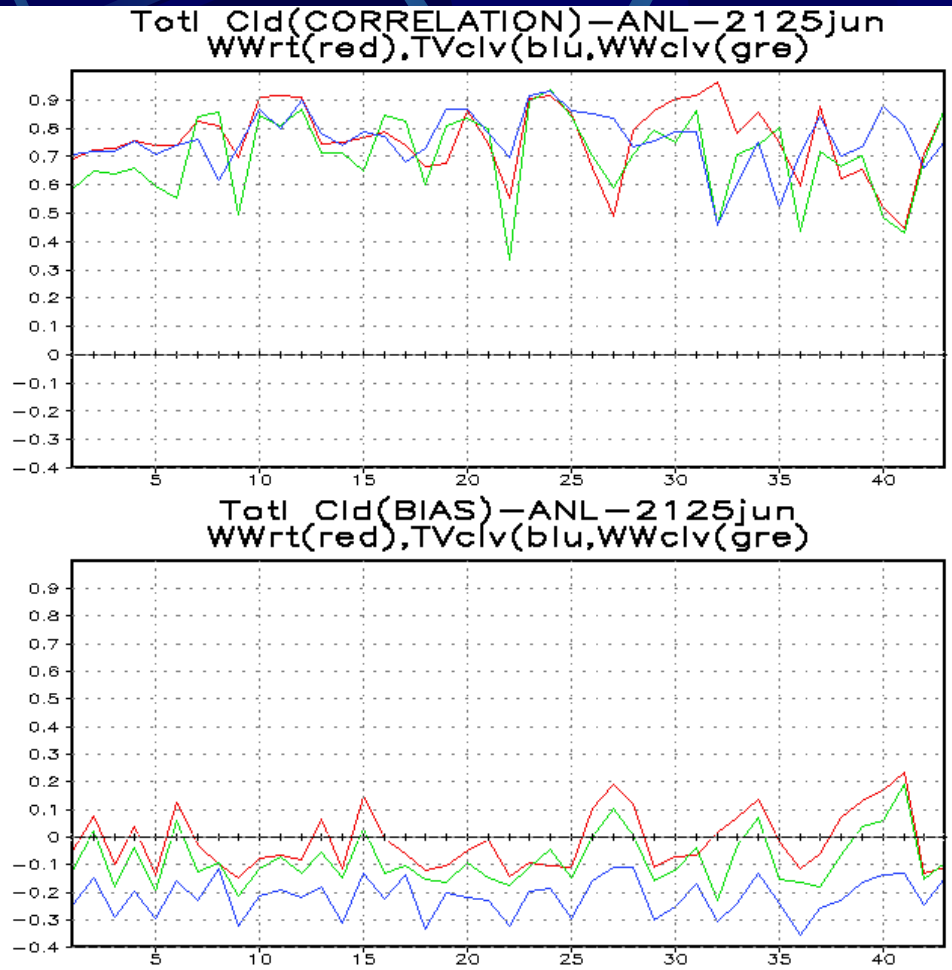
(physics wheel)

Comparisons Between Analyses (21-25 June 2005 – K. Campana)

WWrt - WWMCA v. RTNEPH

WWclv - WWMCA v. CLAVR

TVclv - TOVS v. CLAVR



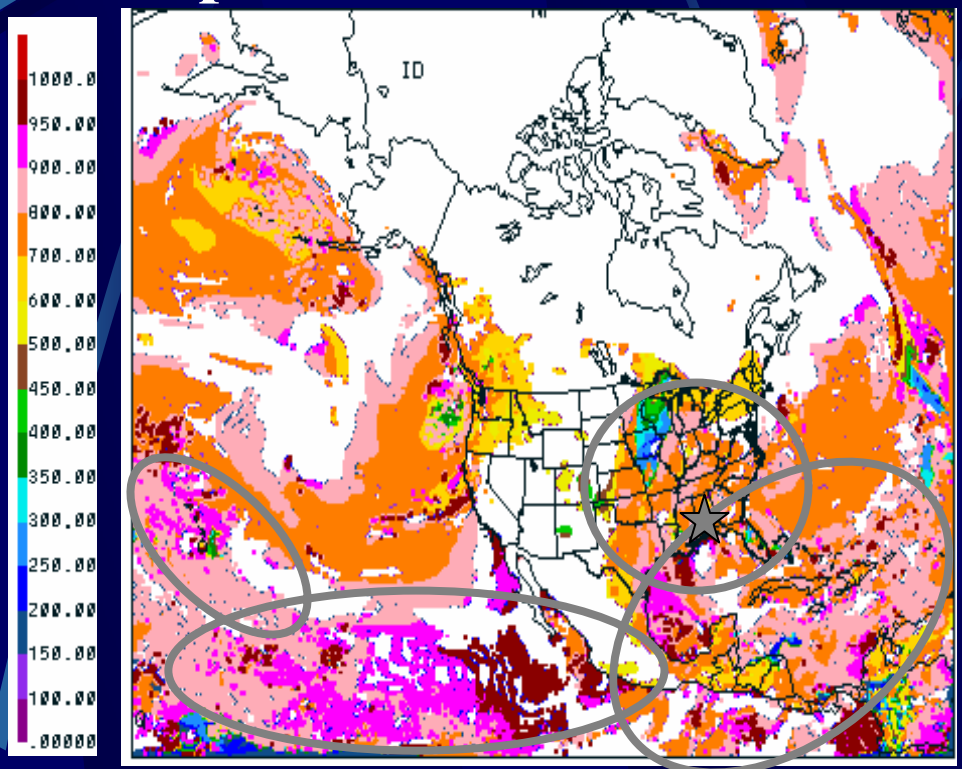
43 Geographical Regions

(physics wheel)

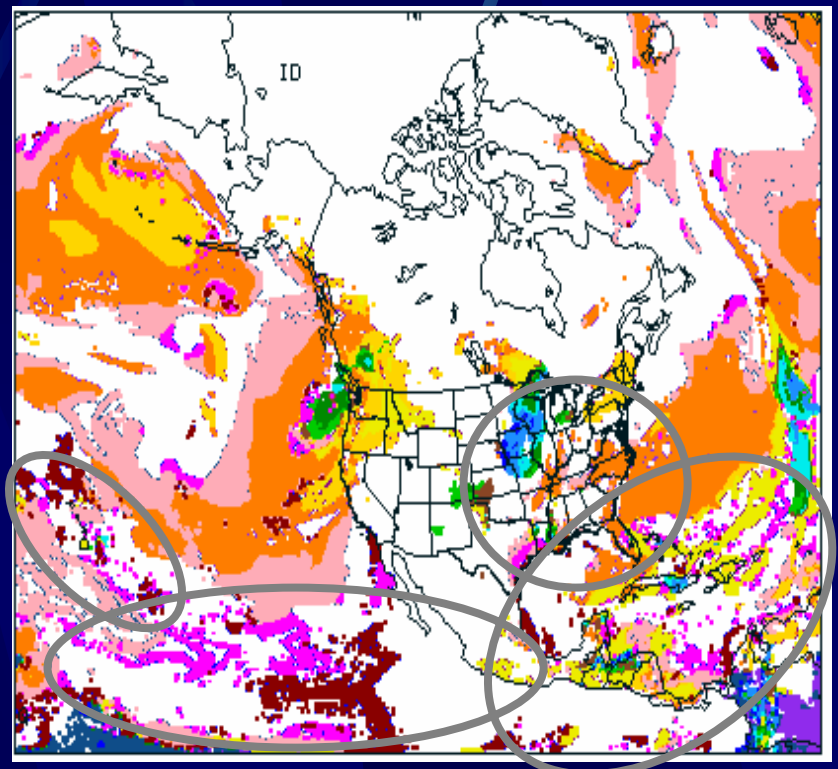
Shallow Convection

60-h fcsts of convective cloud-top pressure (hPa) valid at 00Z 26 March 2004 (exp "EtaW" not implemented)

Ops shallow Cu scheme

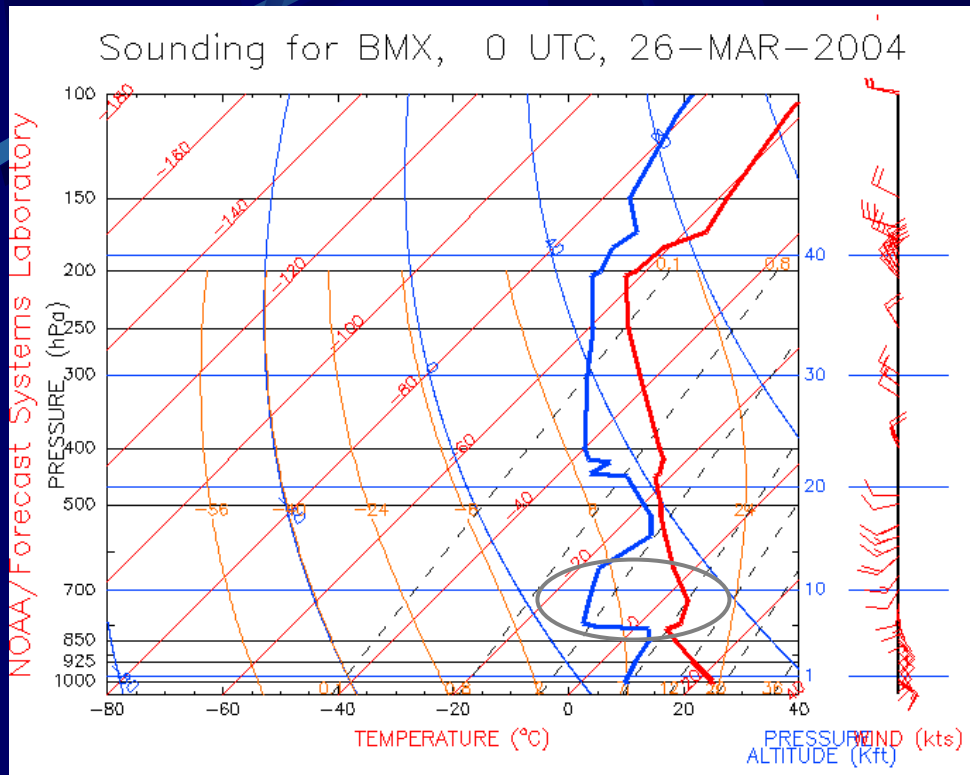


Exp shallow Cu (EtaW)

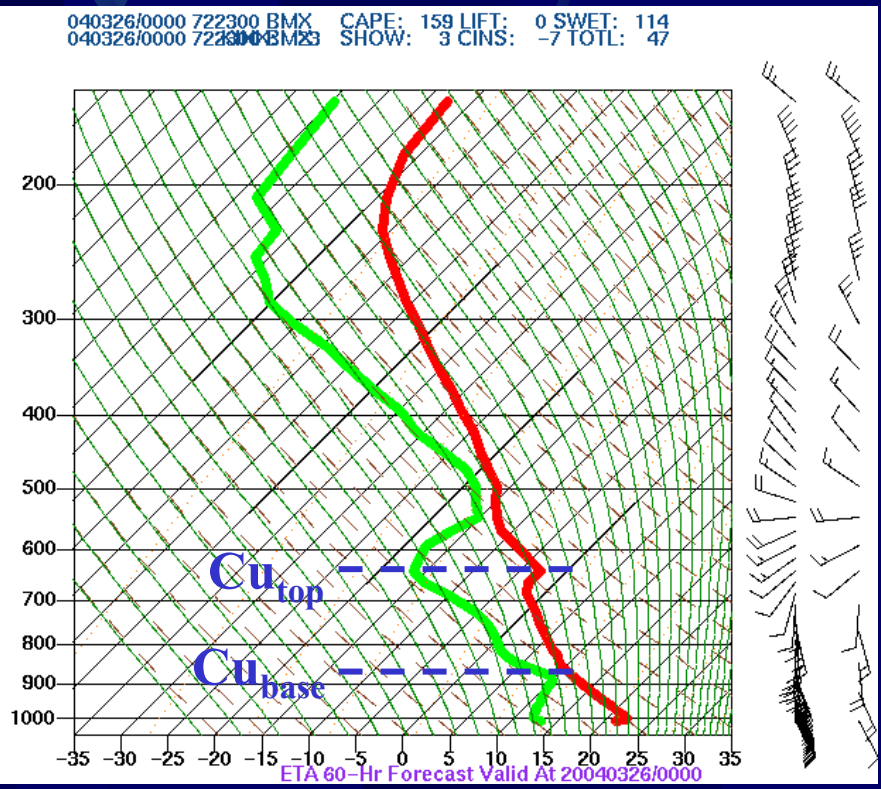


Impact of Eta Shallow Convection on Forecast Soundings

Observed (FSL)



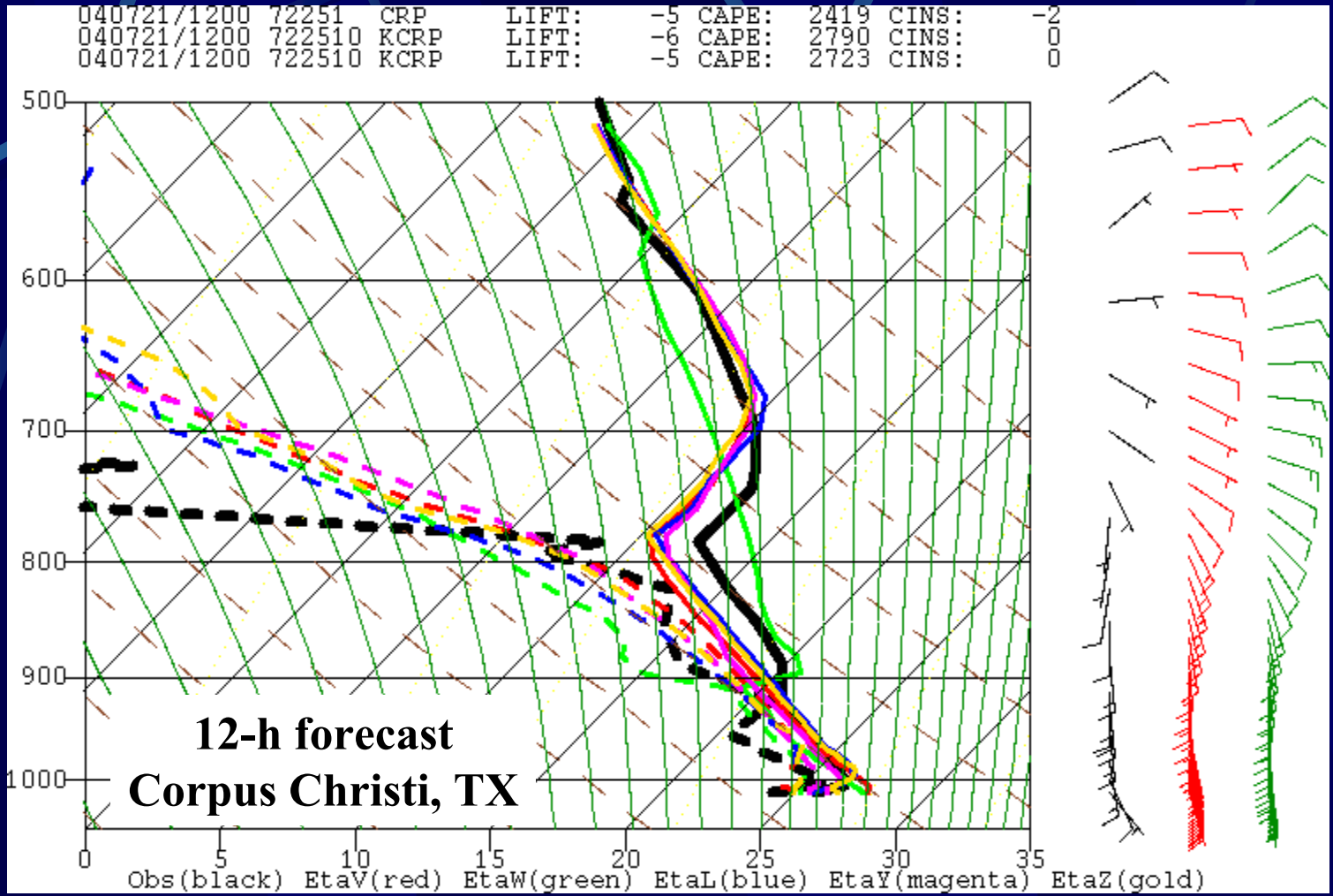
60-h fcst 12-km Eta



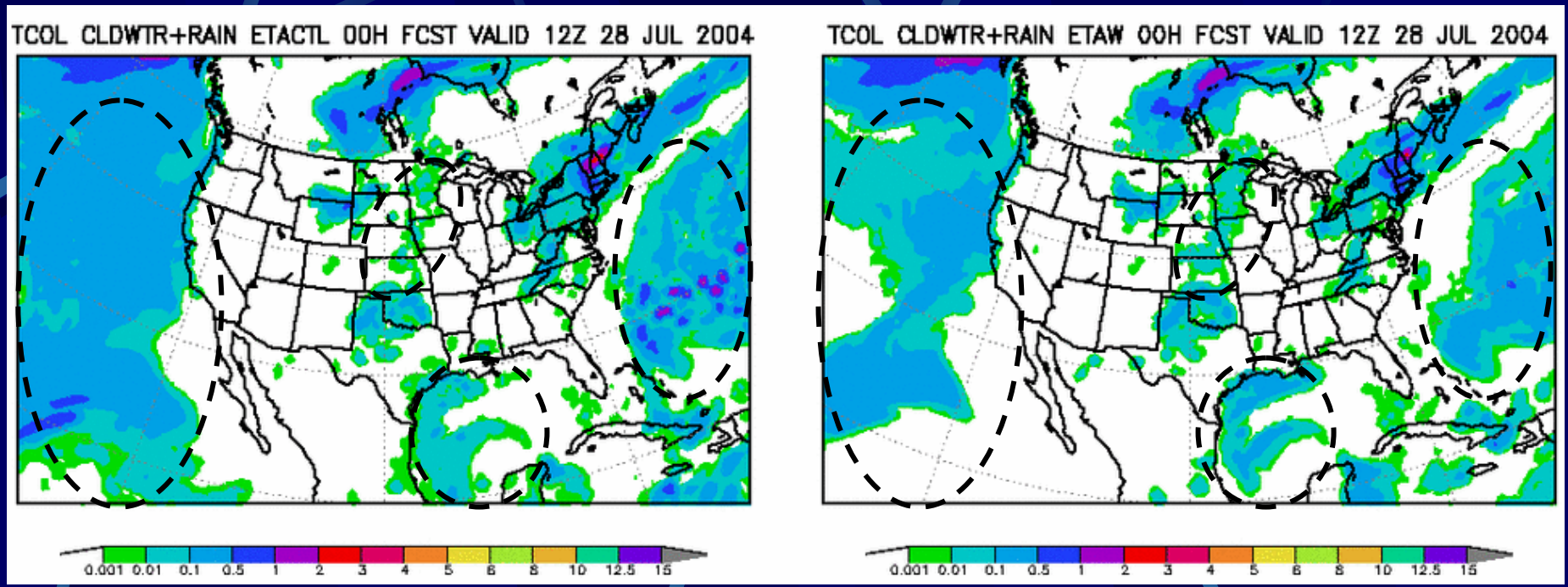
Birmingham, AL (Shelby airport)

(physics wheel)

EtaW => Shallow Convection Tests + Observed vs. Forecast Soundings



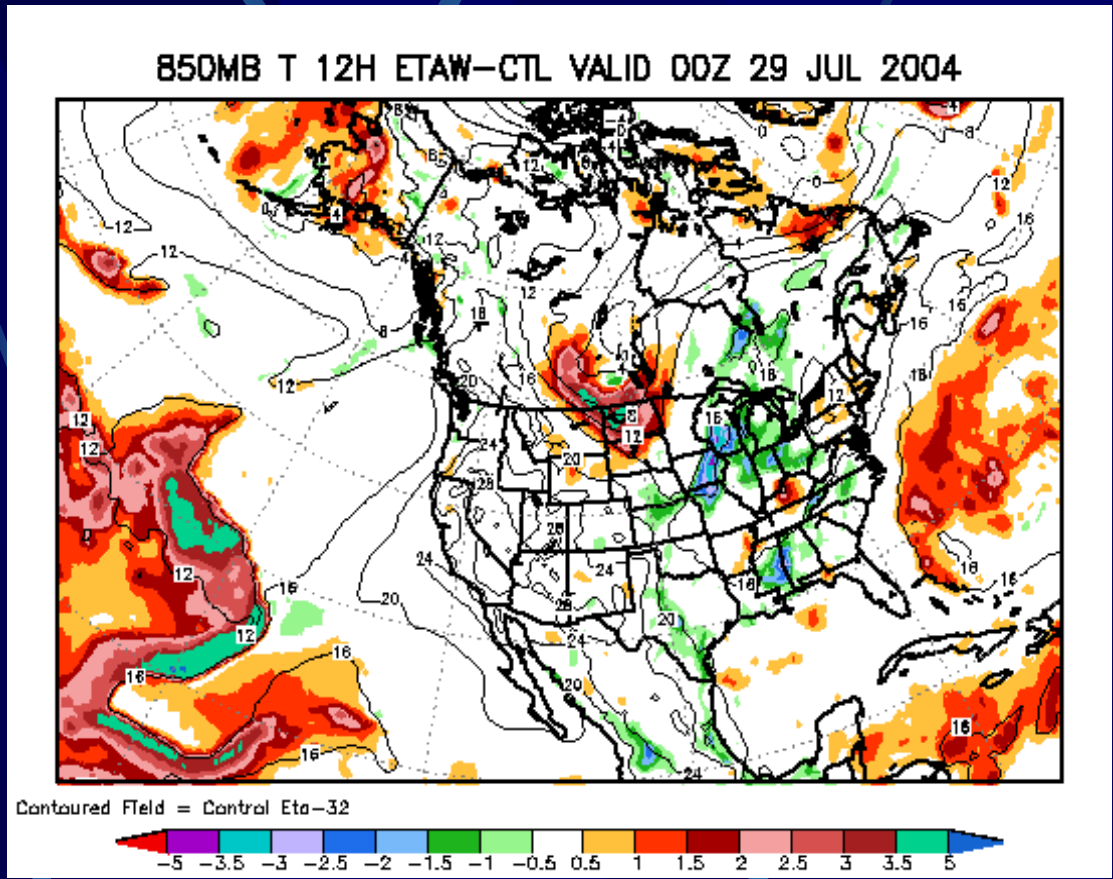
Total Column Liquid Water Control (left), EtaW (right)



- Low-level clouds & their content strongly impacted by shallow Cu & stable PBL changes

850 hPa Temperatures

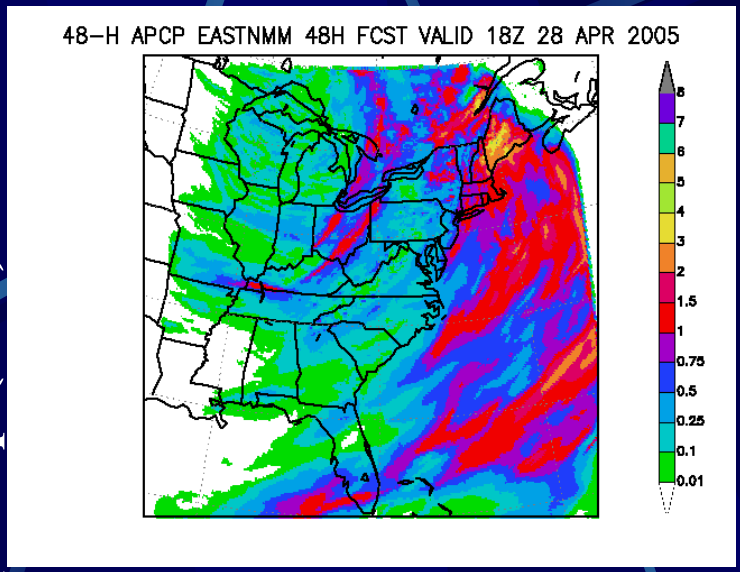
- Warmer in EtaW over subtropical oceans
- Larger PW in EtaW along Gulf coast (not shown)

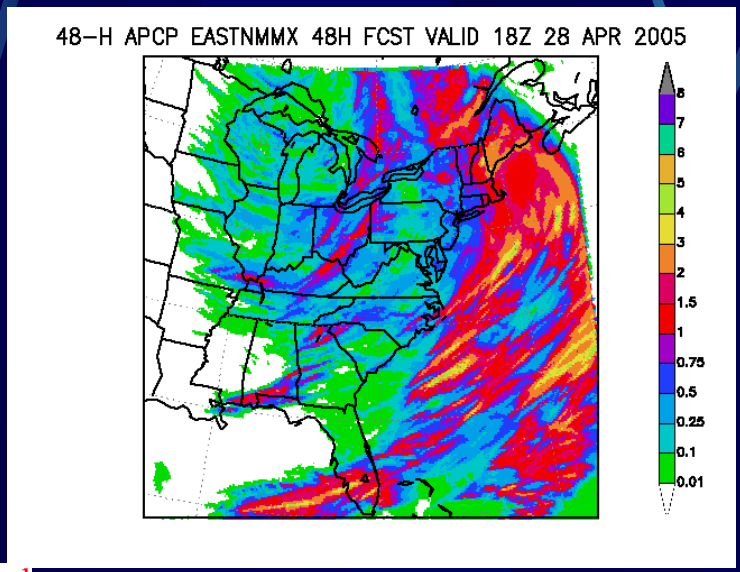


⇒ EtaW never implemented because of degraded QPF (physics wheel)

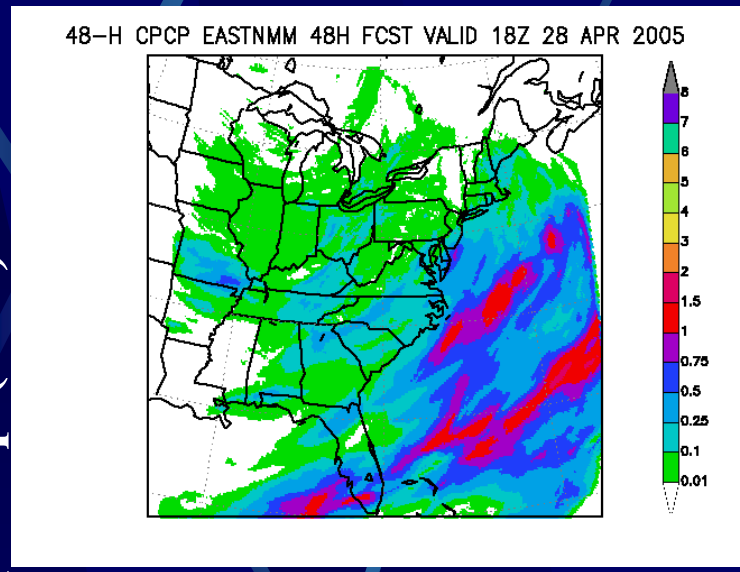
Deep Convection (1 of 5)

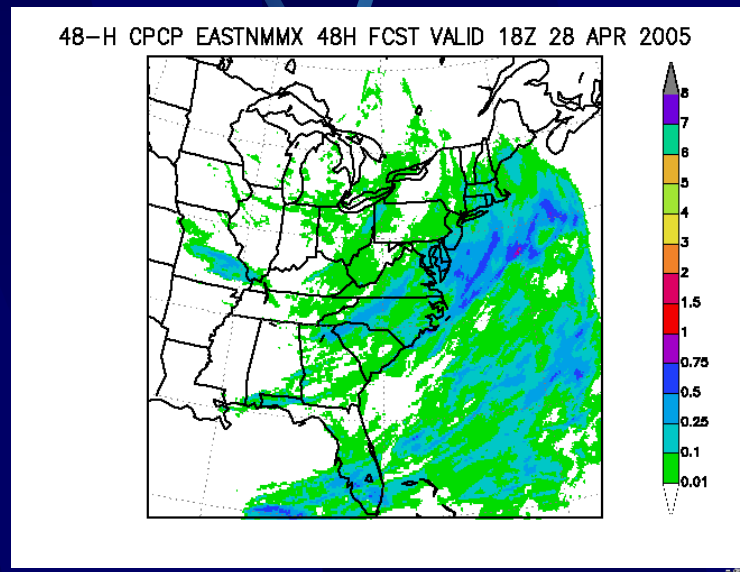
0-48 h total precip (mm)





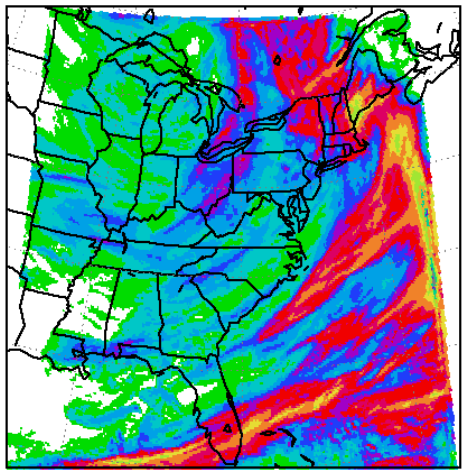
0-48 h conv precip (mm)

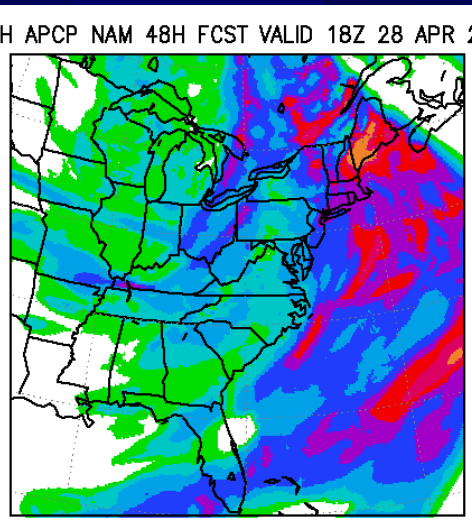




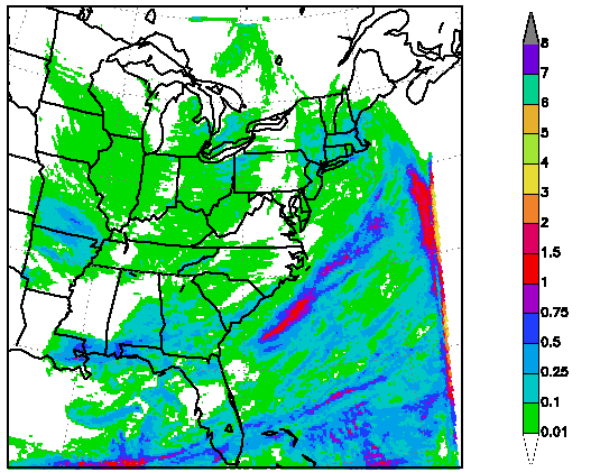
Deep Convection (2 of 5)

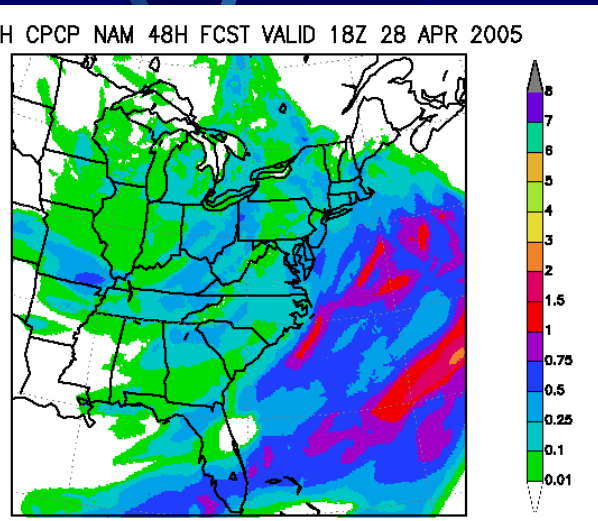
0-48 h total precip (mm)





0-48 h conv precip (mm)

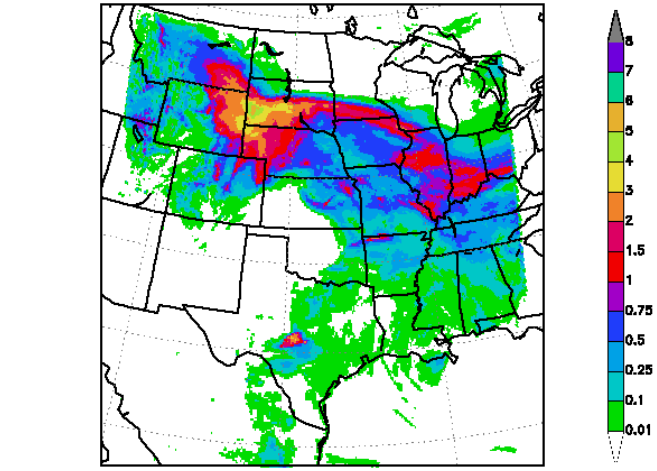


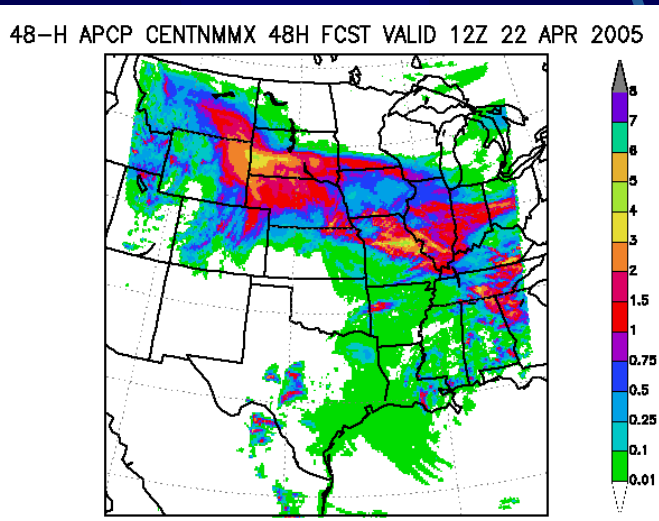


(physics wheel)

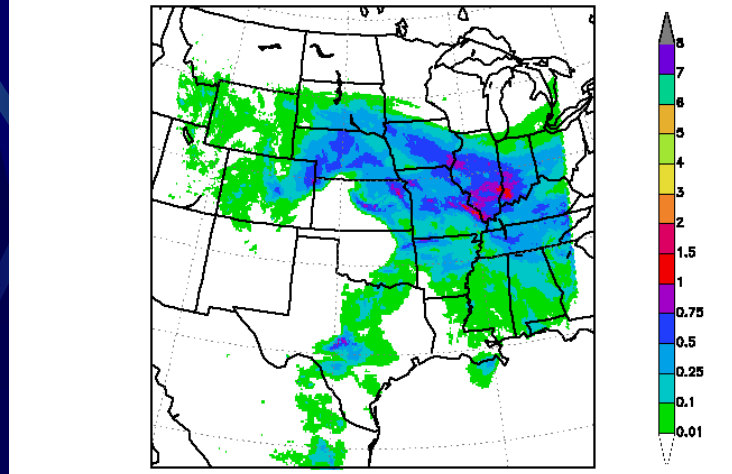
Deep Convection (3 of 5)

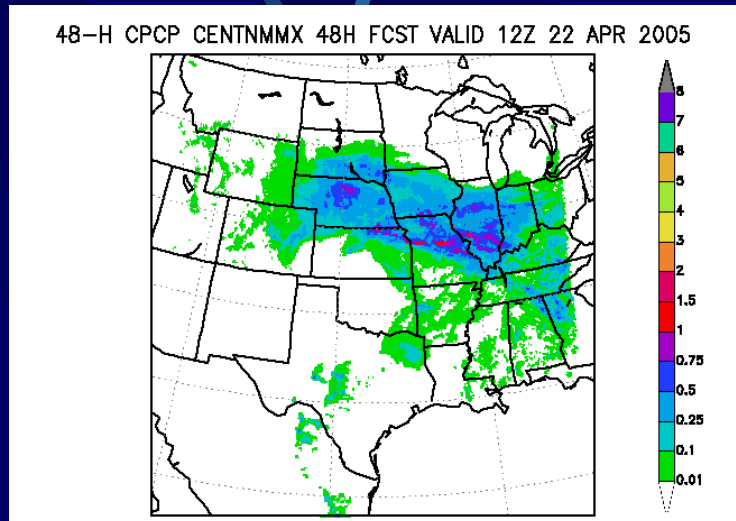
0-48 h total precip (mm)





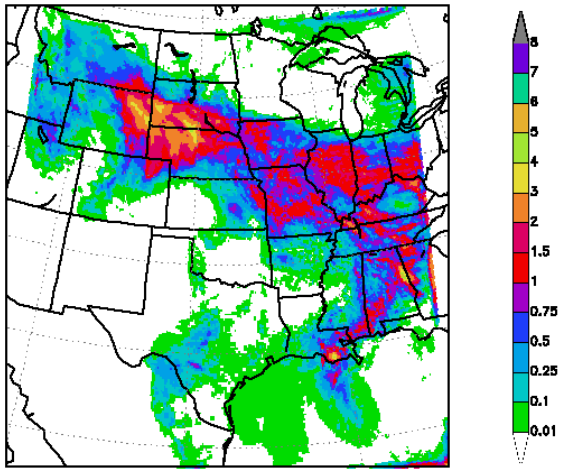
0-48 h conv precip (mm)

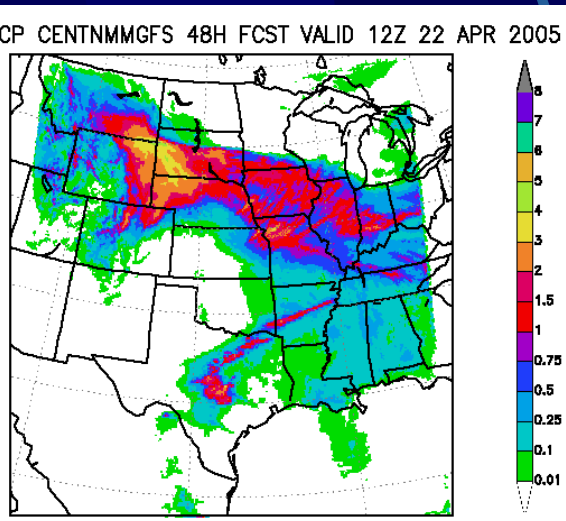




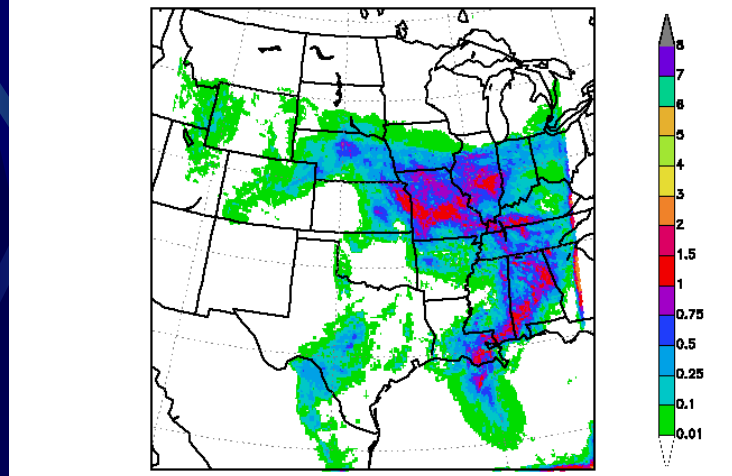
Deep Convection (4 of 5)

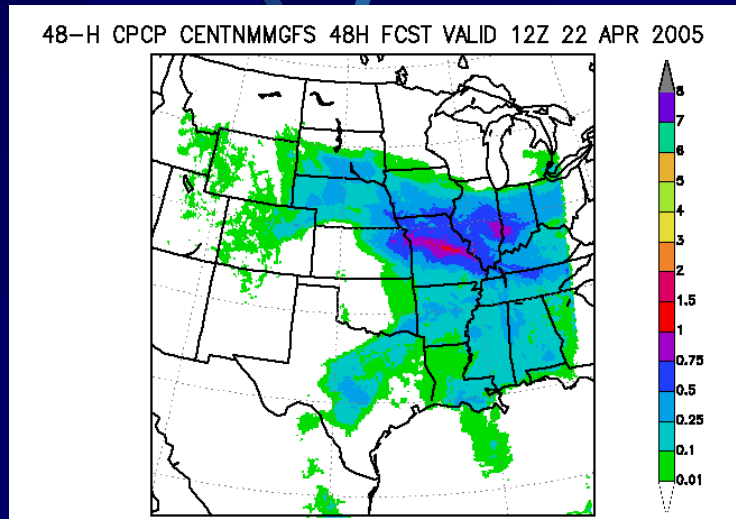
0-48 h total precip (mm)





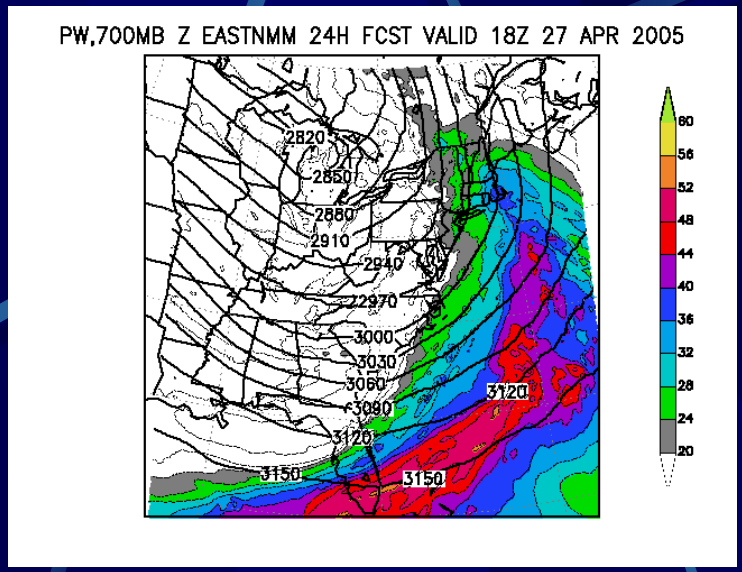
0-48 h conv precip (mm)

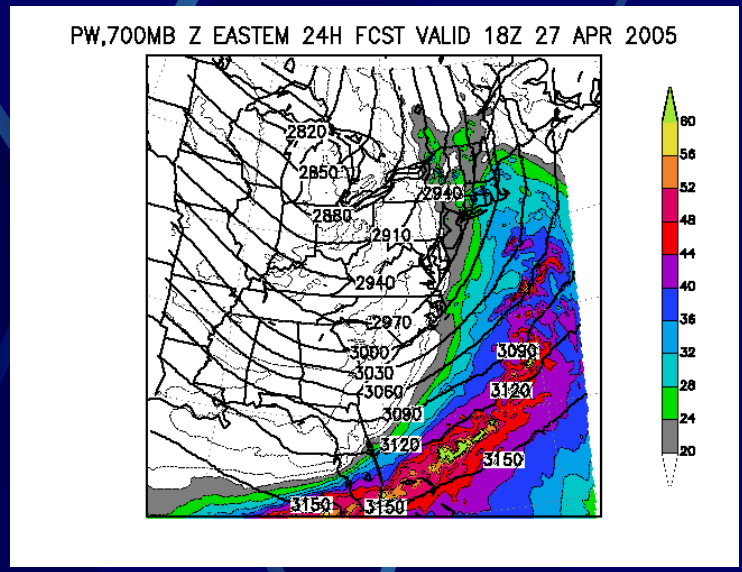


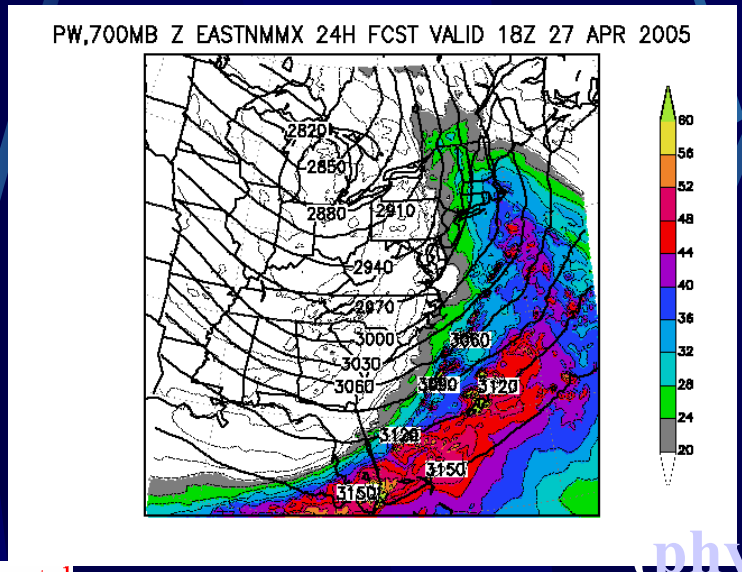


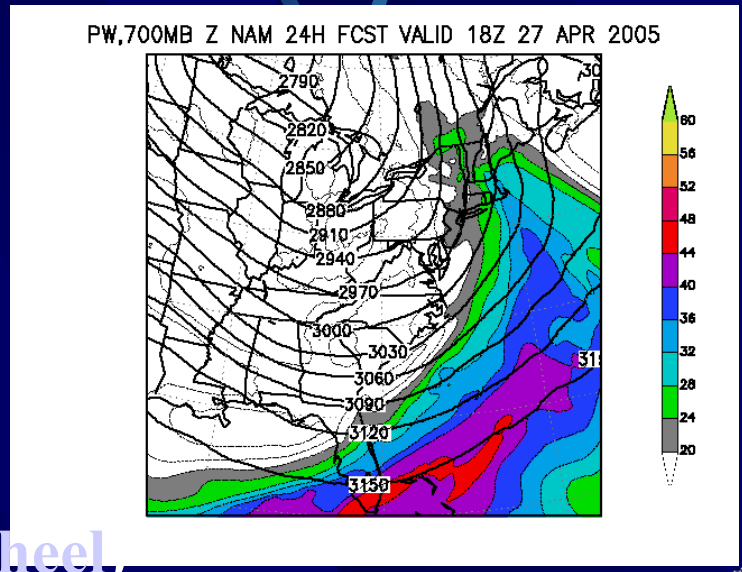
(physics wheel)

Deep Convection (5 of 5)



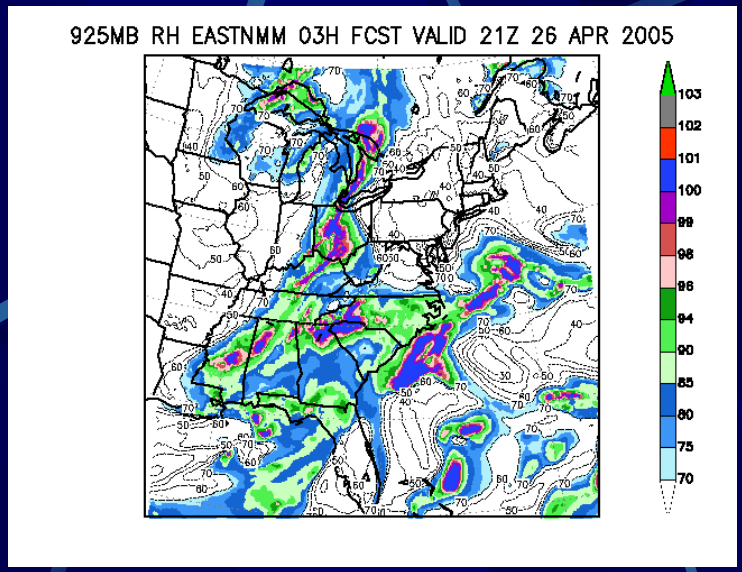


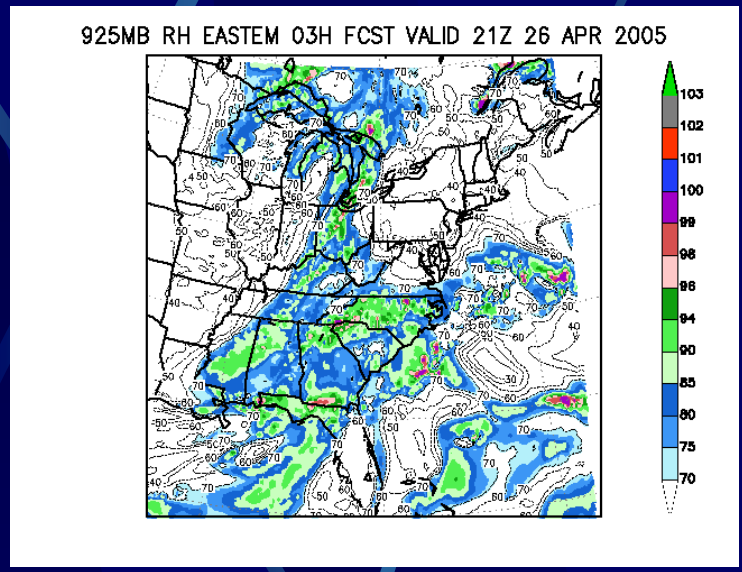


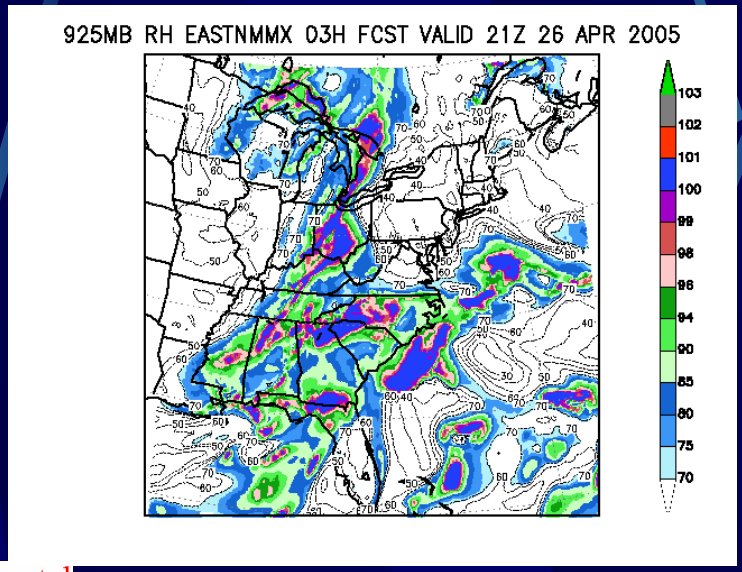


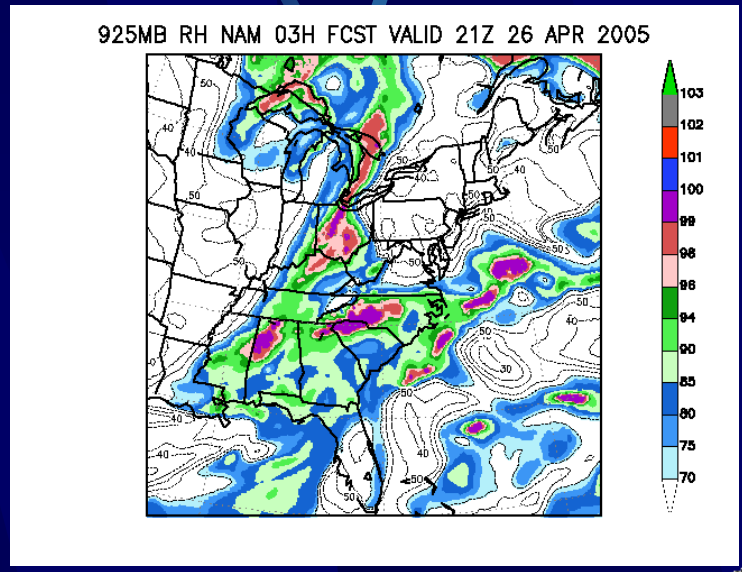
(physics wheel)

PBL + Shallow Convection (925 mb RH at 3 h)



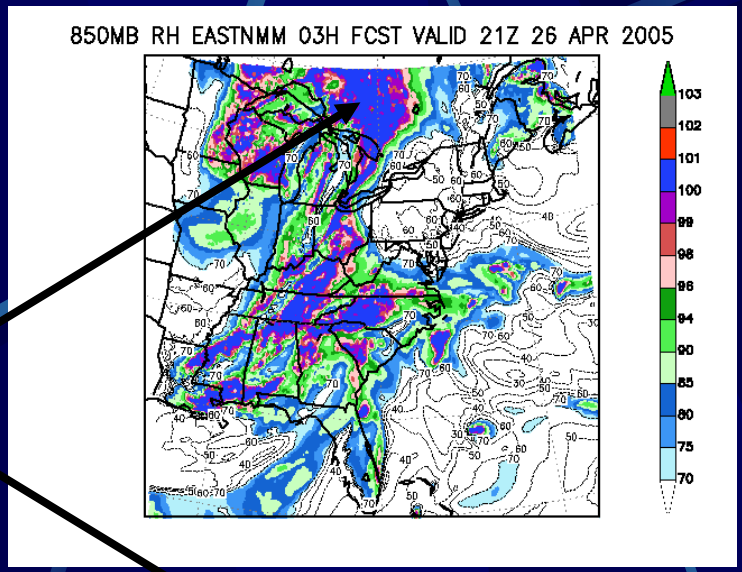


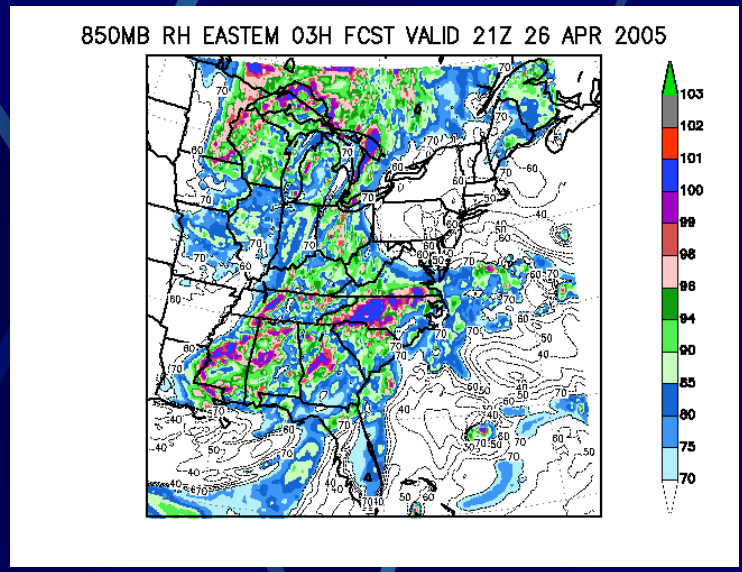


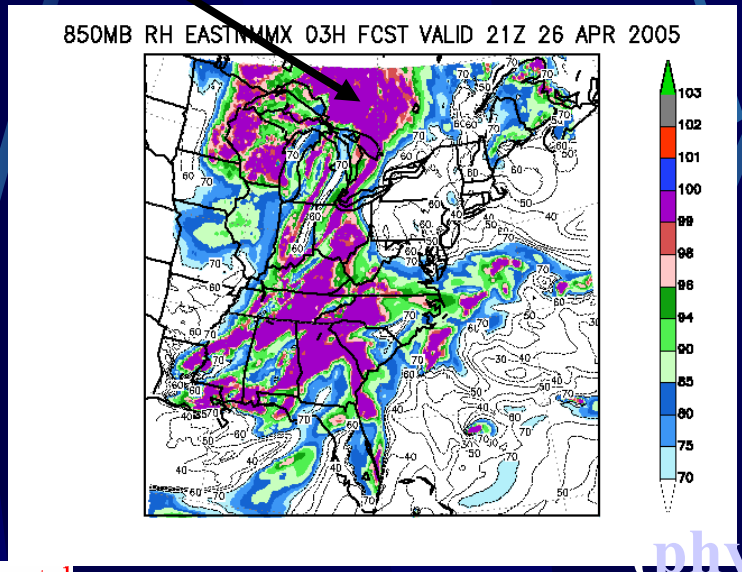


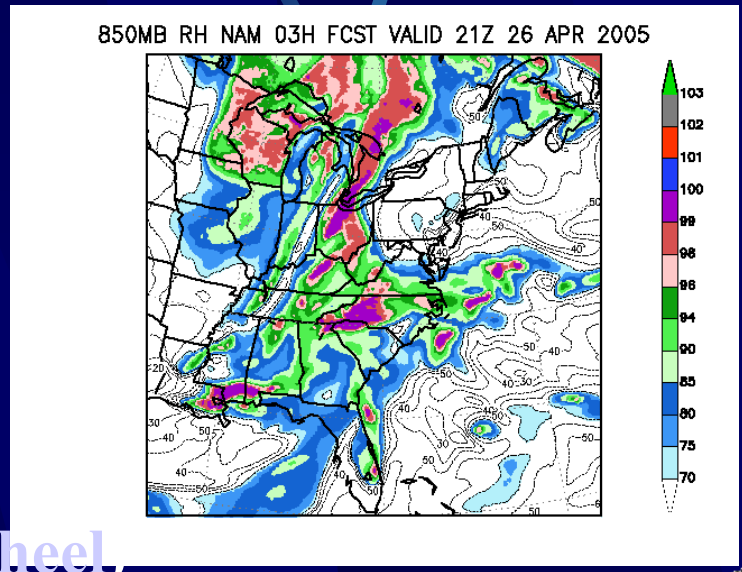
PBL + Shallow Convection (850 mb RH at 3h)

(inadequate GRIB precision)



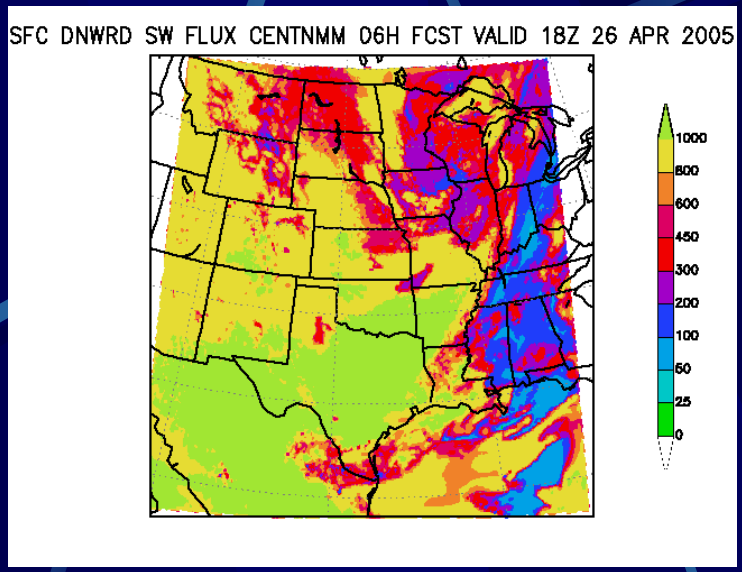


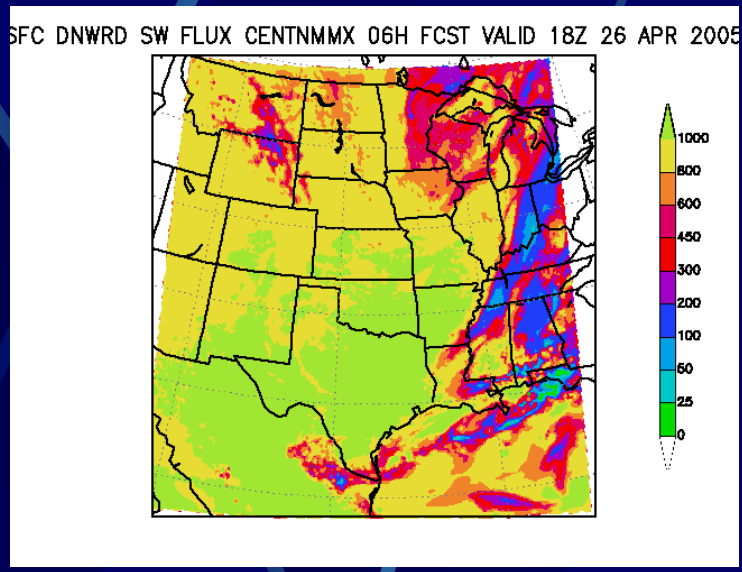


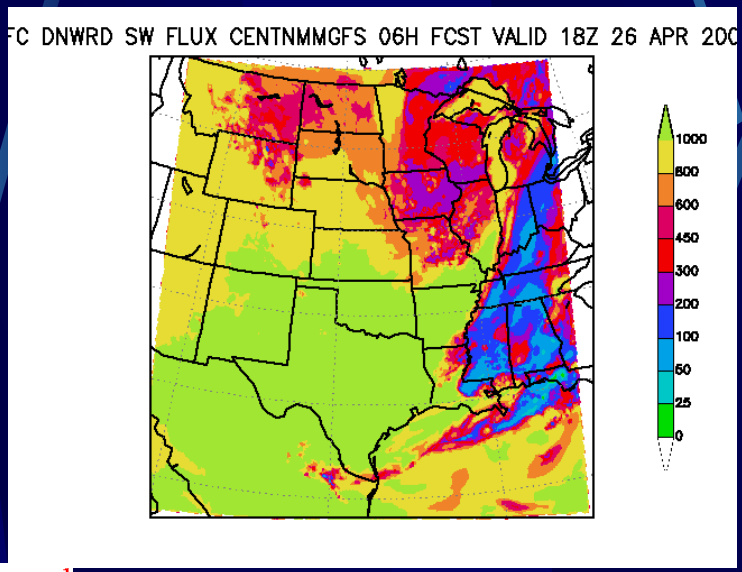


(physics wheel)

Incident Solar for Verification (1 of 2)?

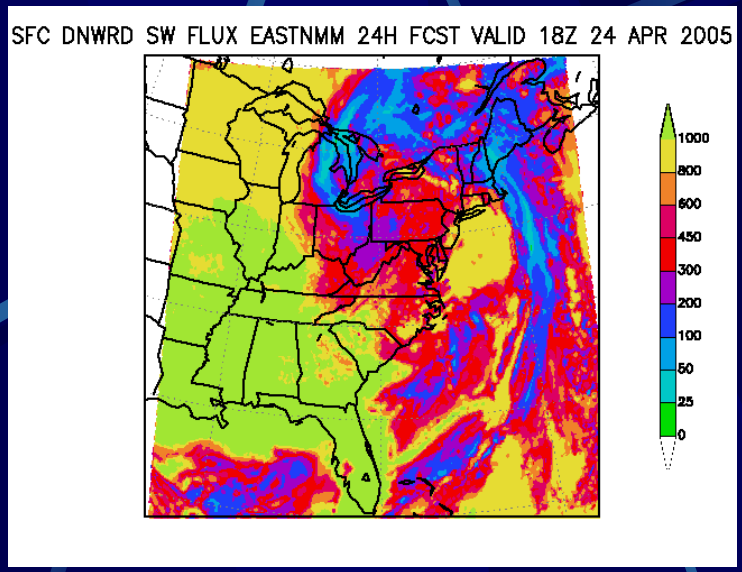


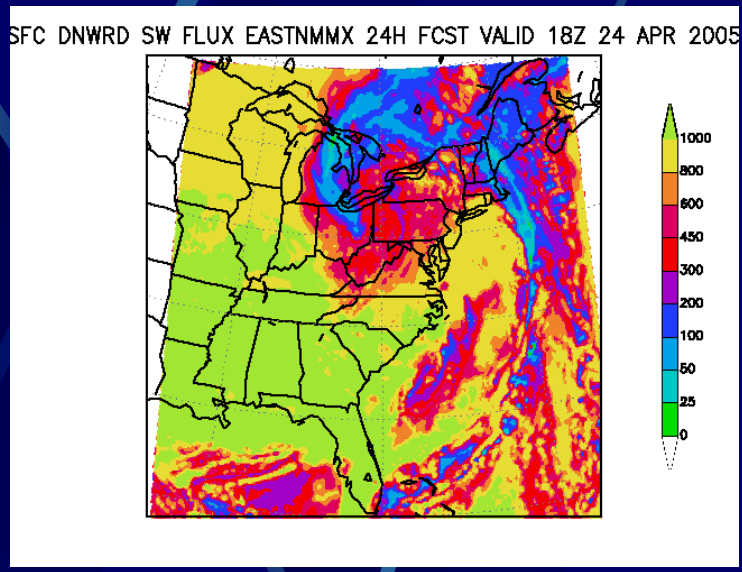


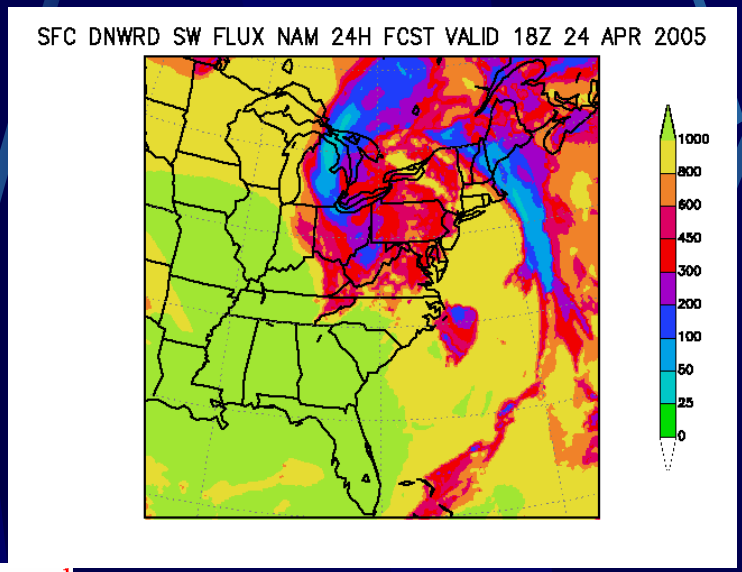


- 6-h forecasts (WRF EM not available)
- Over ocean evaluation using NESDIS retrievals, CLAVRx, etc?

Incident Solar for Verification (2 of 2)?







- 24-h forecasts (WRF EM not available)
- Large differences over ocean culmination of many spokes in "physics wheel"

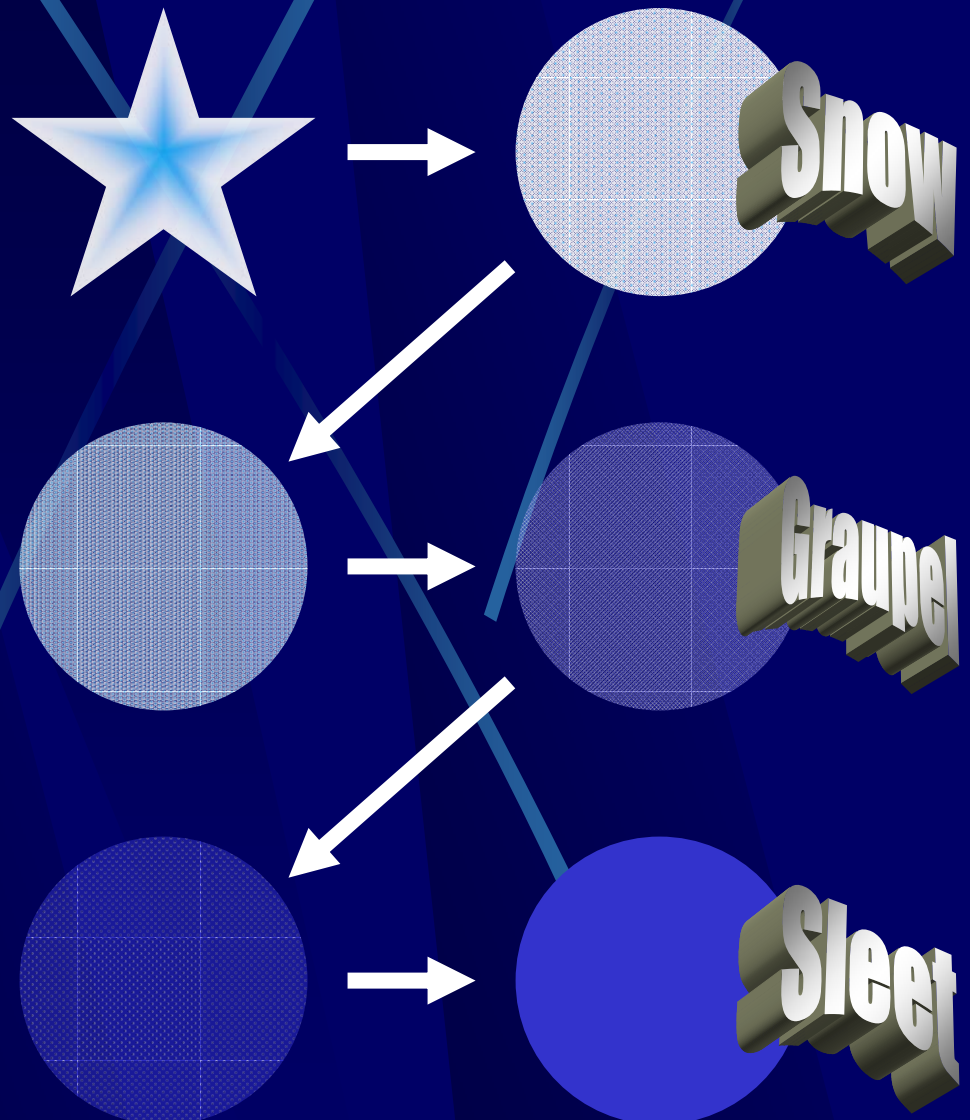
(physics wheel) (final remarks)

What Happens in Areas of Strong Ascent?

- Sequence of more heavily rimed precip ice
  1.0 (unrimed snow) ≤ RF ≤ ~46.4 (sleet at 0°C)

- When $N_s=(N_s)_{max}$ & $[D]=[D]_{max}$, then increase RF to accommodate large ice mixing ratios

- $(N_s)_{max}=20\ L^{-1}$, $[D]_{max}=1$ mm at 0°C
  - ✡ $(\rho q_s)=1.2\ g\ m^{-3}$ is max for unrimed snow

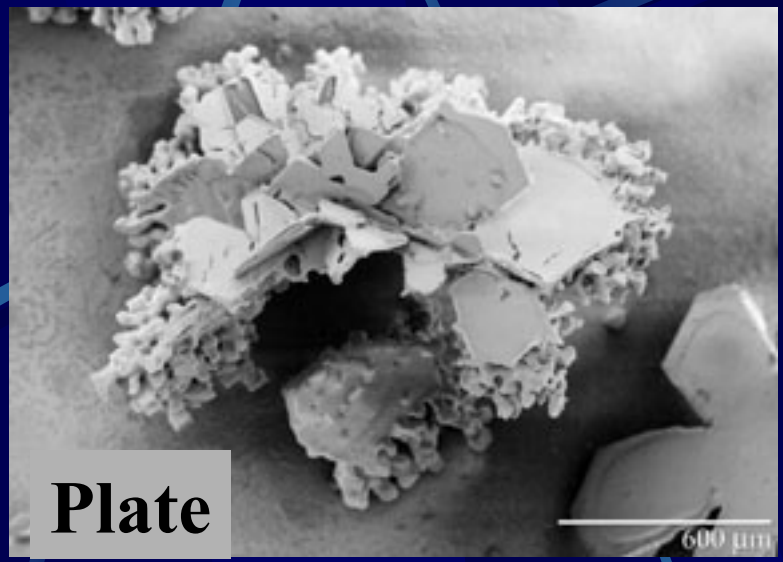


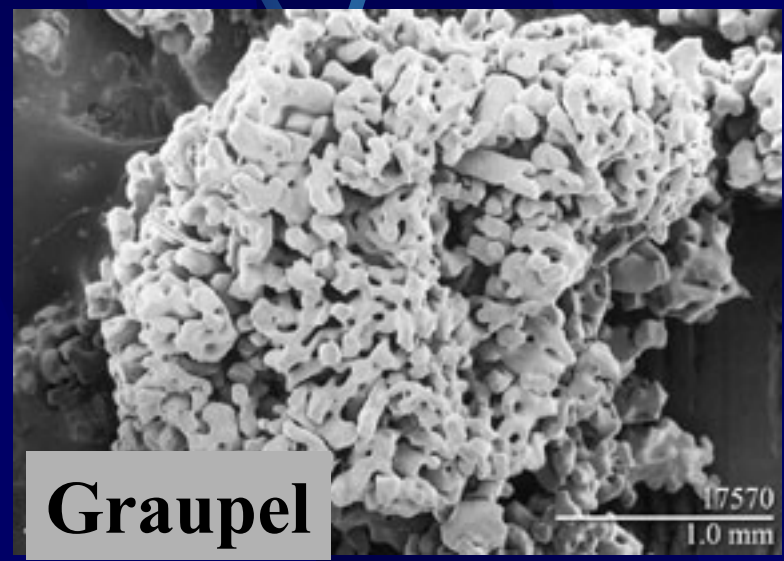
Cool Images of Rimed Snow & Graupel

(Electron Microscopy Unit at the Beltsville Agricultural Center)

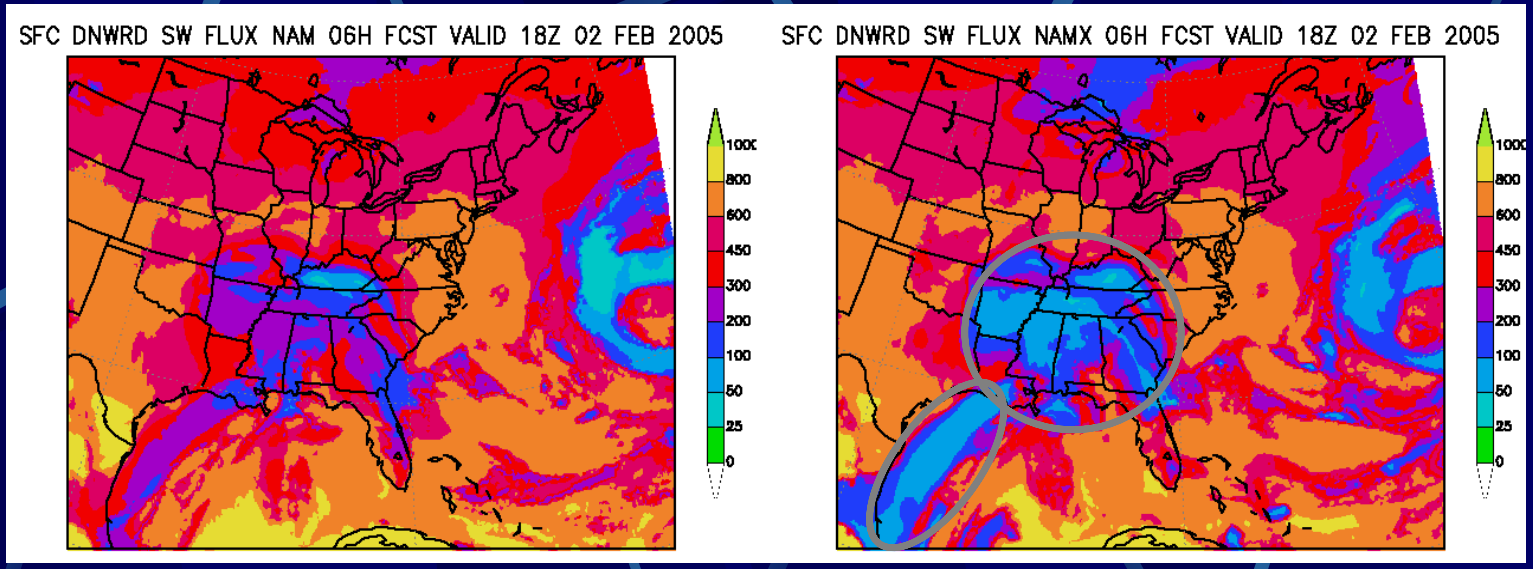
(microphysics)

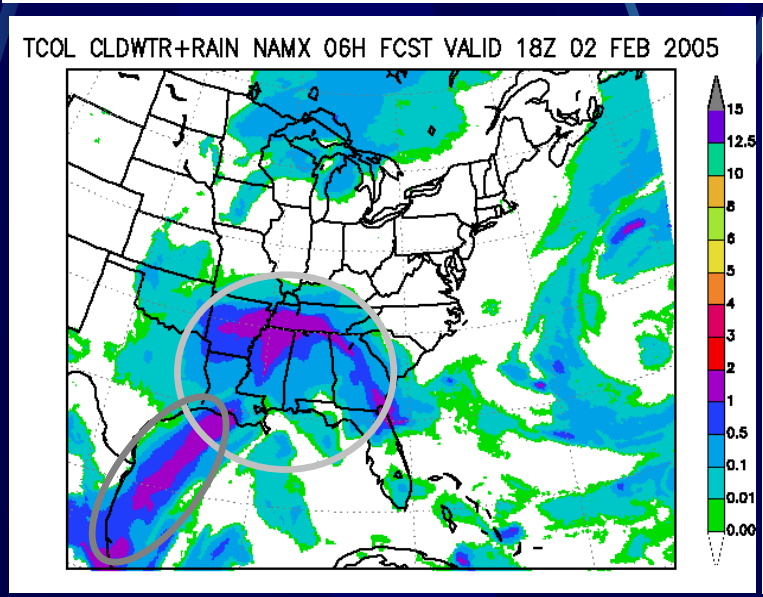
(physics wheel)

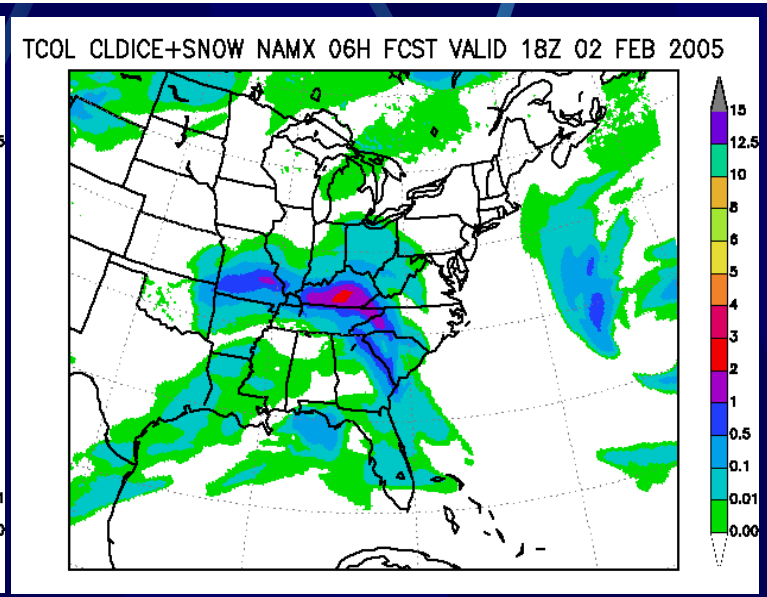




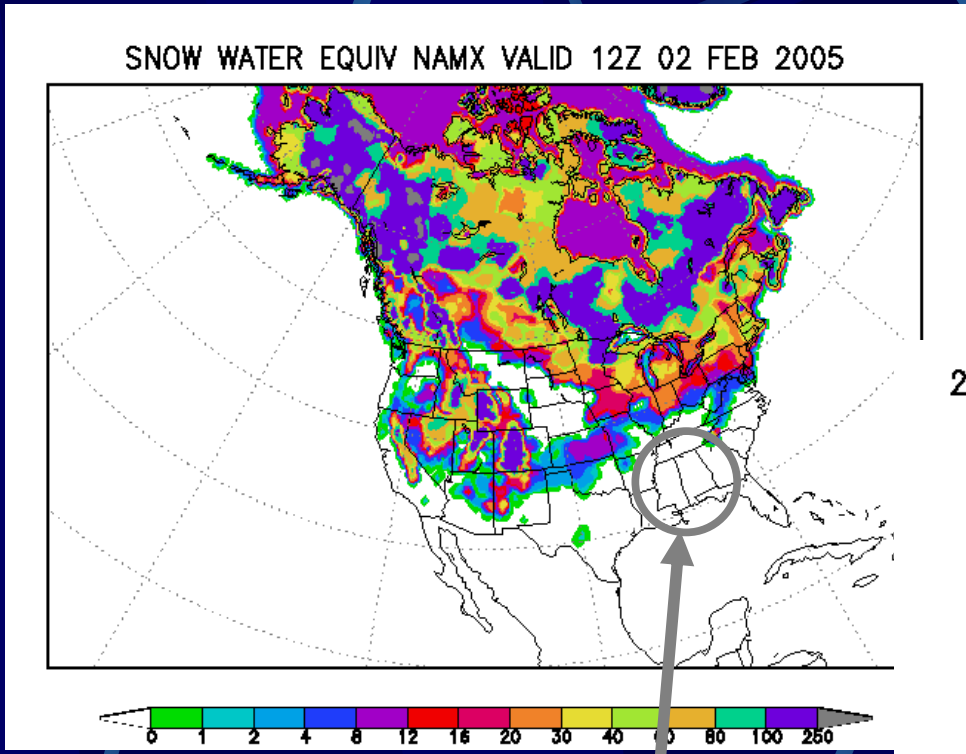
Shortwave NAM vs. NAMX

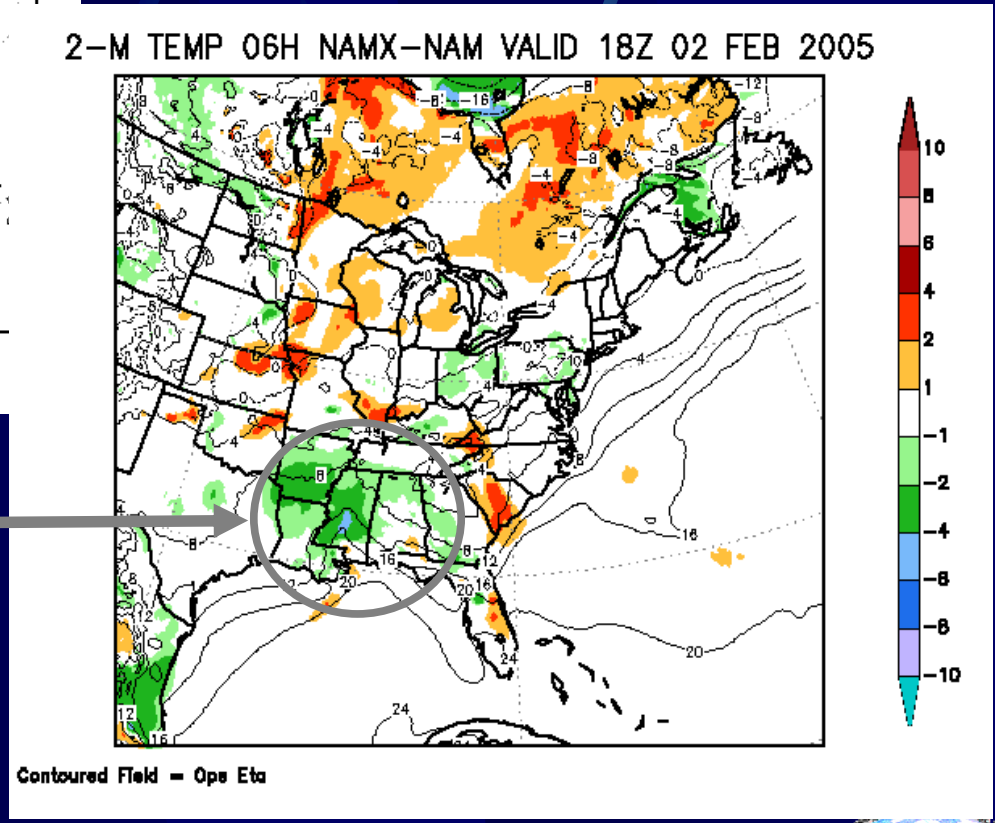






NAMX snow cover, 2-m T diffs



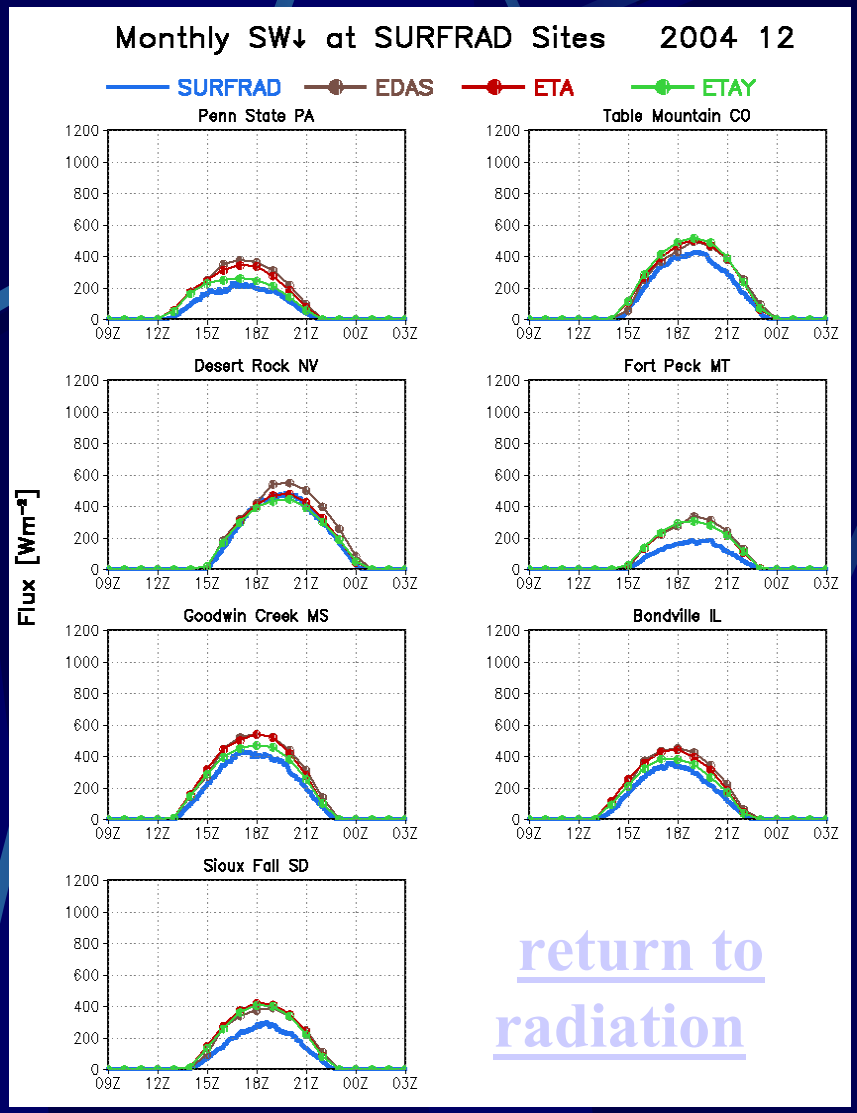


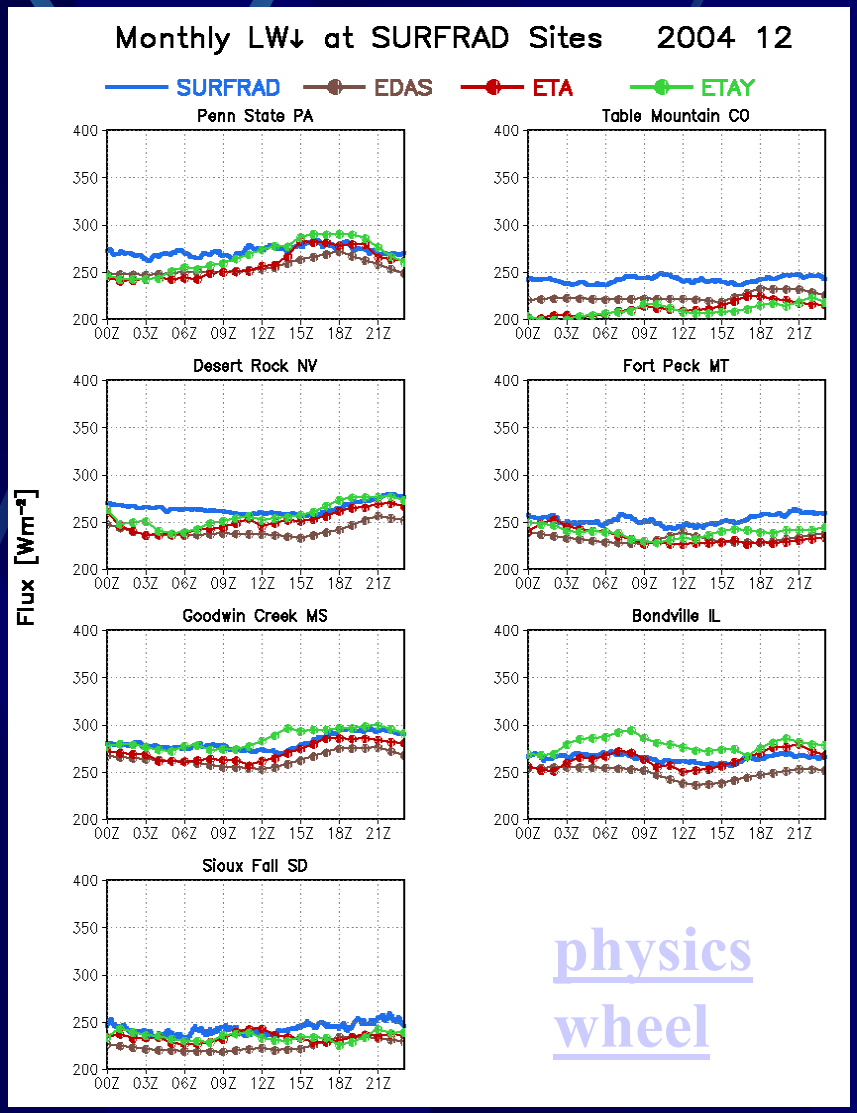
Snow-free area

(return to radiation)

(physics wheel)

Jesse Meng's SURFRAD verification
(ETAY is 32-km version of ETAX)





return to radiation

physics wheel

Additional Links & Resources

- **Russ Treadon's SSI notes:**
  http://www.emc.ncep.noaa.gov/gmb/gdas/research/info.html
  Talk at 2002 ECMWF/GEWEX humidity analysis workshop:
  http://www.emc.ncep.noaa.gov/gmb/gdas/research/treadon/ecmwf_humidity_talk/index.htm
  Workshop summary:
  http://www.emc.ncep.noaa.gov/gmb/gdas/research/treadon/ecmwf_humidity_talk/index.htm
- **RUC cloud analysis:**
  http://maps.fsl.noaa.gov/ppt_pres/RUC20-summary_files/v3_document.htm
- **Ying Lin's GOES cloud-top assimilation in the NAM (Eta):**
  http://wwwt.emc.ncep.noaa.gov/mmb/ylin/cloudtop/
- **Kozo Okamoto's presentation on assimilation of SSM/I radiances in the NCEP GDAS:**
  http://www.emc.ncep.noaa.gov/seminars/presentations/2005/Okamoto.EMCseminar_SSMI.ppt
- **Ken Campana's cloud verification:**
  http://wwwt.emc.ncep.noaa.gov/gmb/KENS_PLACE/

(physics wheel)