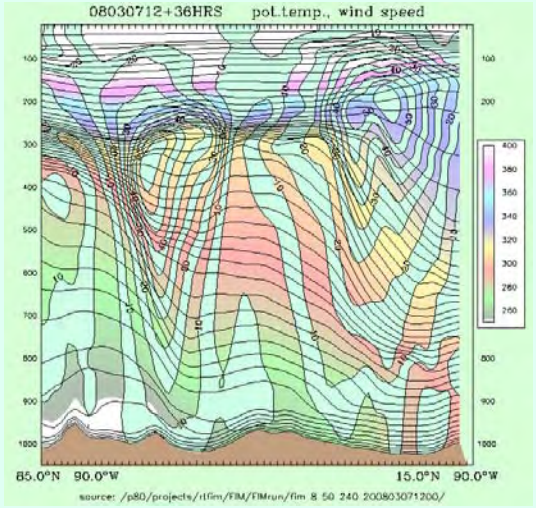
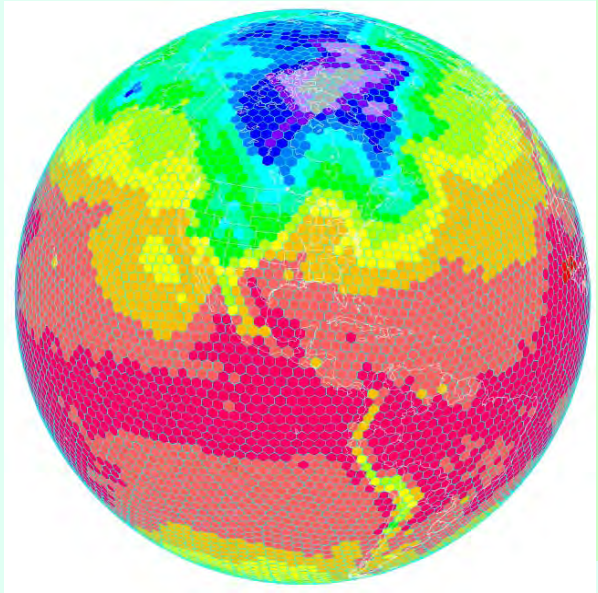


Performance comparison of hybrid isentropic-sigma vs. sigma configurations of the FIM global model

Stan Benjamin, Susan Sahm,
Rainer Bleck, John Brown, Bill Moninger
-NOAA Earth System Research Laboratory



- What is the FIM model
- Design of θ–σhybrid coordinate in FIM
- Retro experiment design
- Results - statistics and cases

RUC/Rapid Refresh Development and Testing

Major transitions:

- RUC13 change package –Spring 2008
  - – radar reflectivity assimilation
  - - TAMDAR
  - - Improved radiation, convection physics in RUC

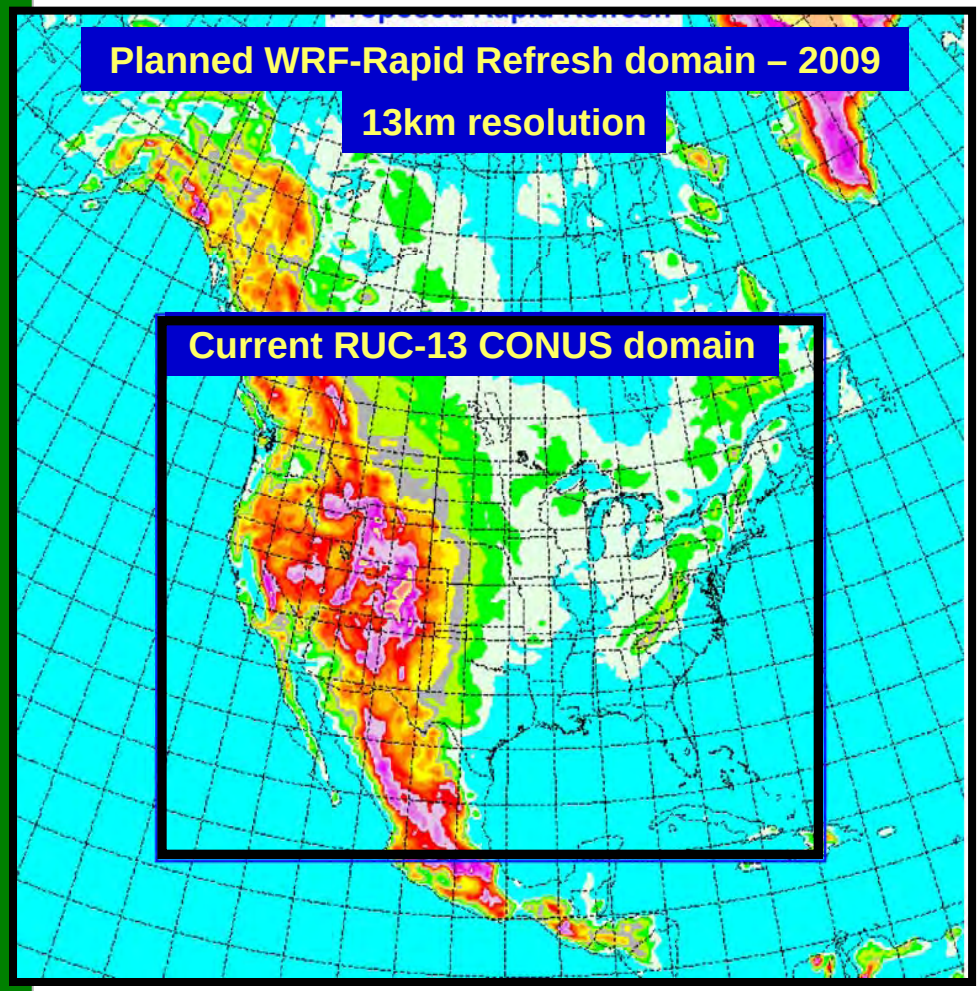
- Rapid Refresh JIFed for ops by 9/09
  - • WRF ARW, GSI, North America

- Ensemble Rapid Refresh
  - • proposed by 2012, to use ESMF framework

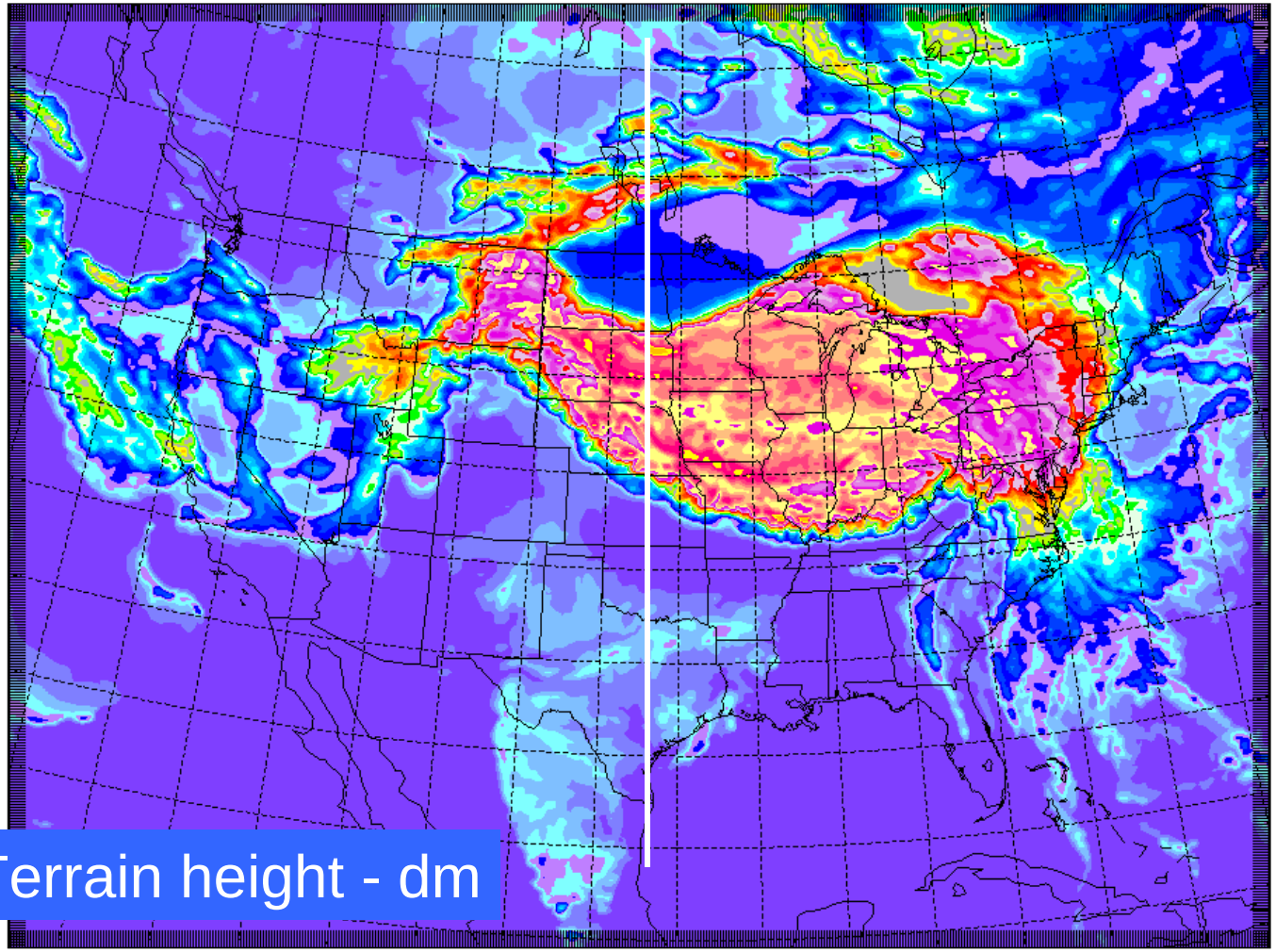
- High-Res Rapid Refresh (HRRR) – RR nest proposed to NCEP by 2012
  - • 3km hourly updated 12h forecast
  - • In testing at GSD
  - • NE Corridor → CONUS, AK

http://ruc.noaa.gov

http://rapidrefresh.noaa.gov/rr

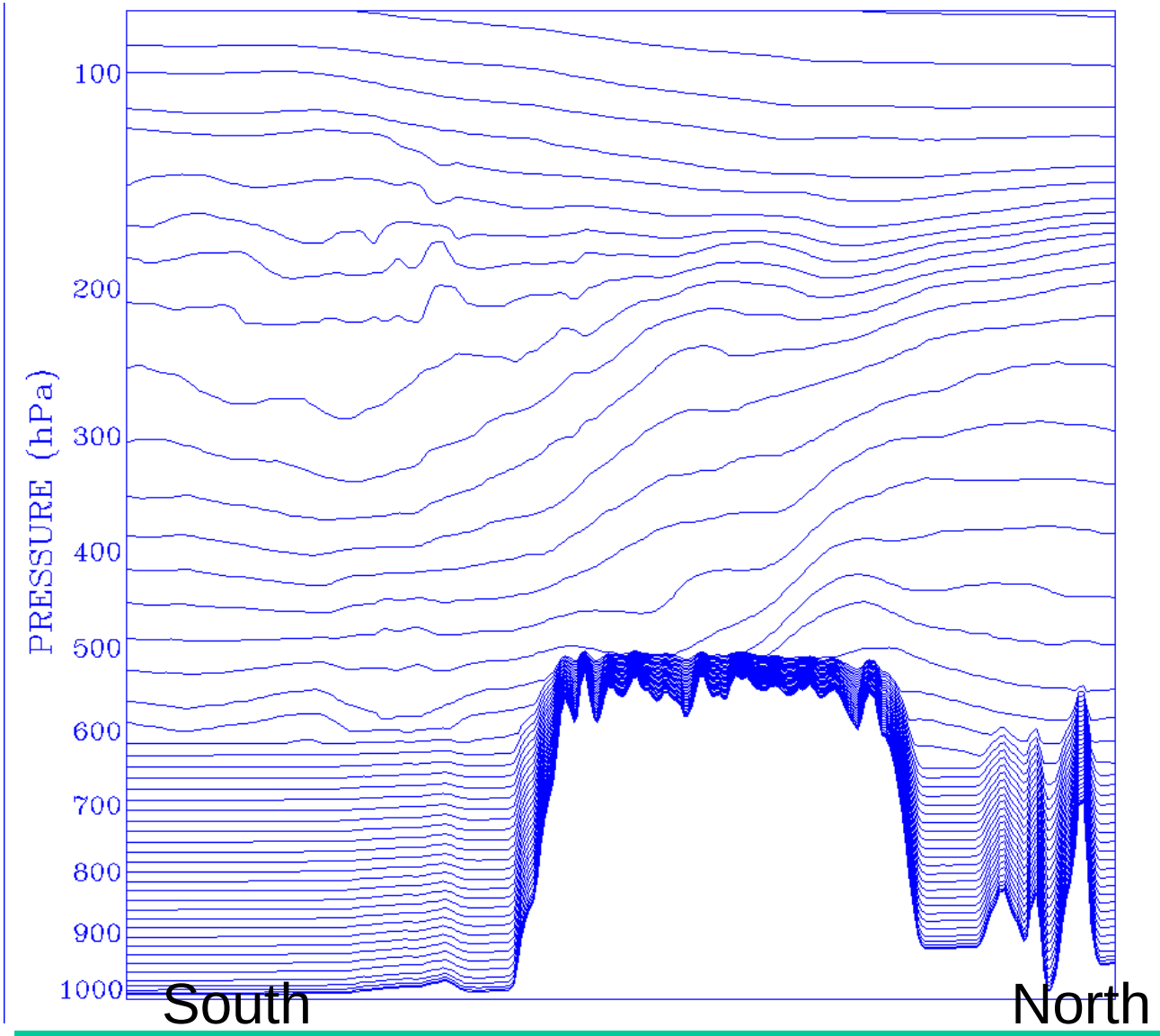


Test applicability of RUC-like hybrid θ-σ ALE coordinate to global domain



NAM data interpolated to current RUC coordinate using Asia terrain field -13km dx

Case – 12h NAM data valid 30 Aug 2005 00 UTC

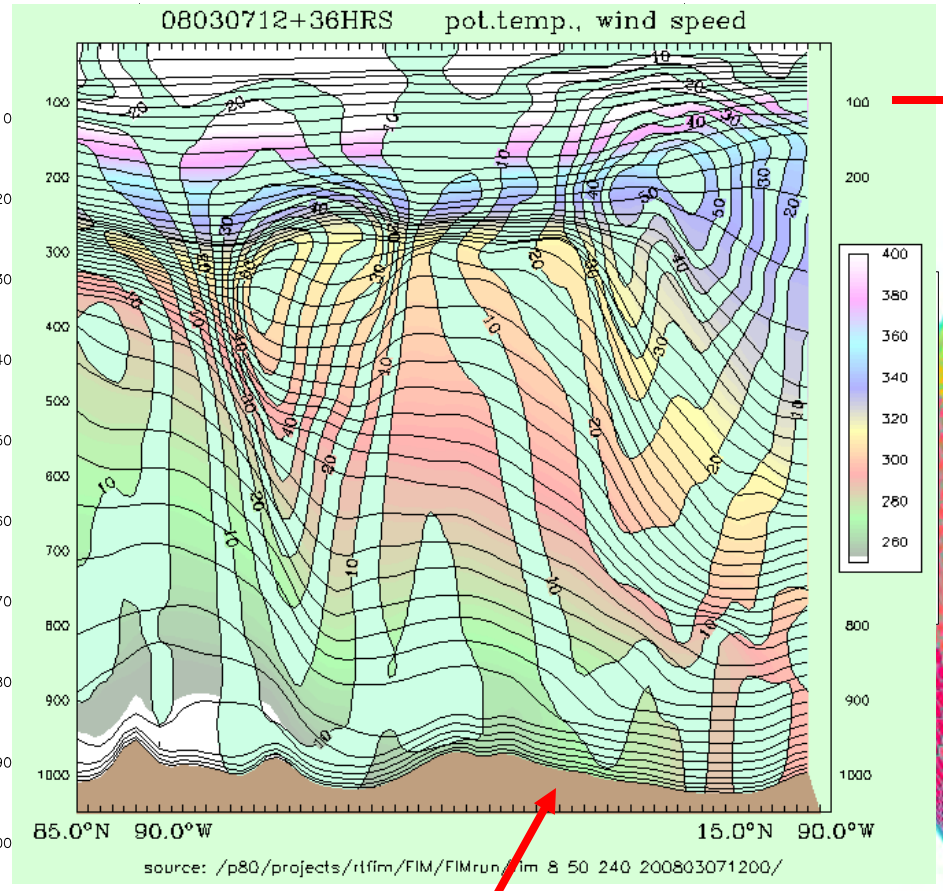


NAM data interpolated to current RUC coordinate using Asia terrain field -13km dx

Case –
12h NAM data valid 30 Aug 2005
00 UTC

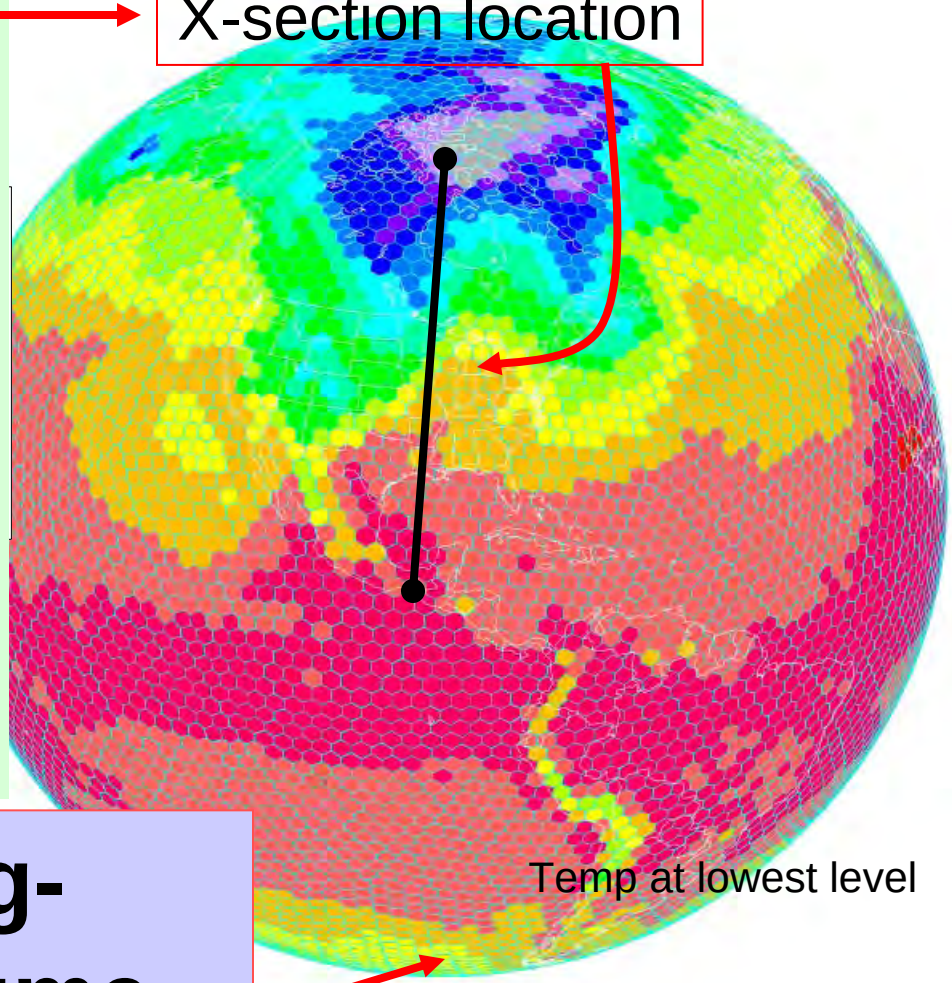
Adjustments planned

- Relaxed sigma layer compression up to 400 hPa
- Reference θ_v levels down to 200 K (currently 232K in RUC)



85.0°N 90.0°W 15.0°N 90.0°W

X-section location



Temp at lowest level

Flow-following-finite-volume Icosahedral Model FIM

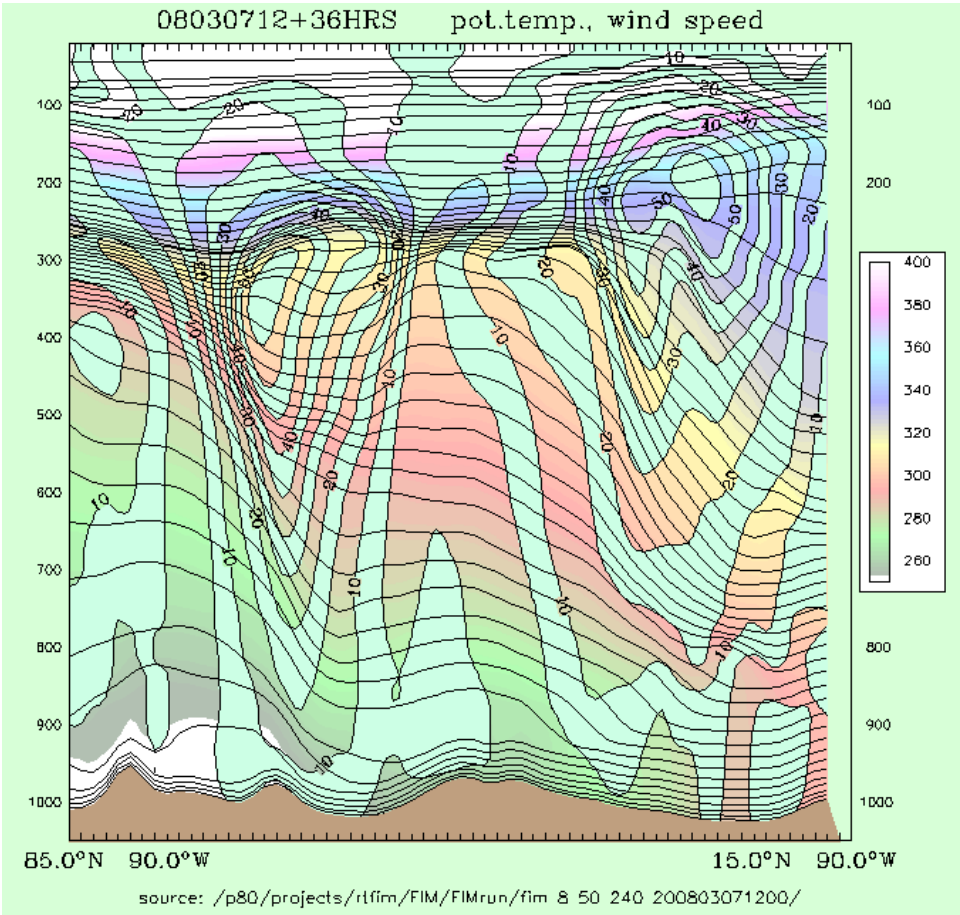
FIM design – vertical coordinate

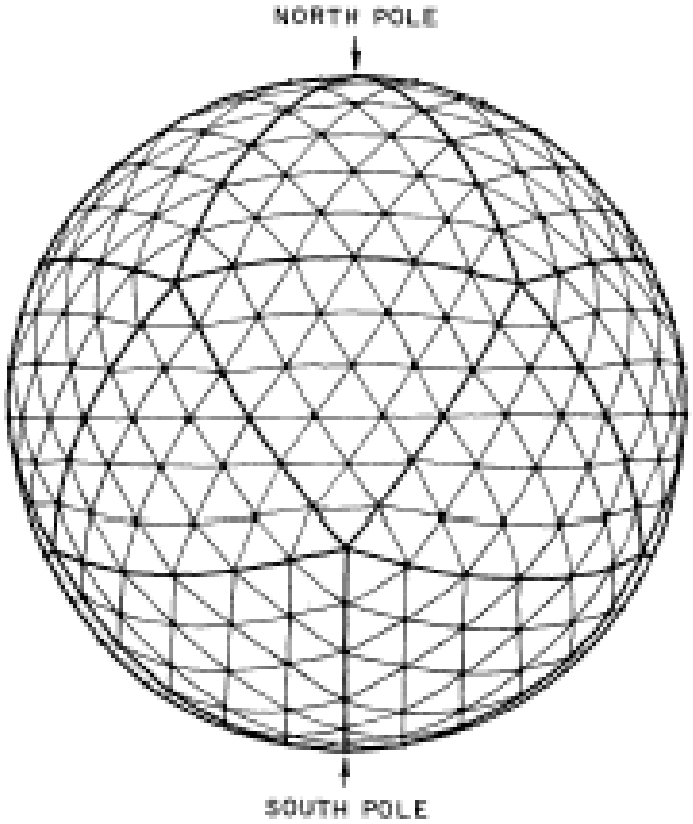
Hybrid (sigma/ isentropic) vertical coordinate

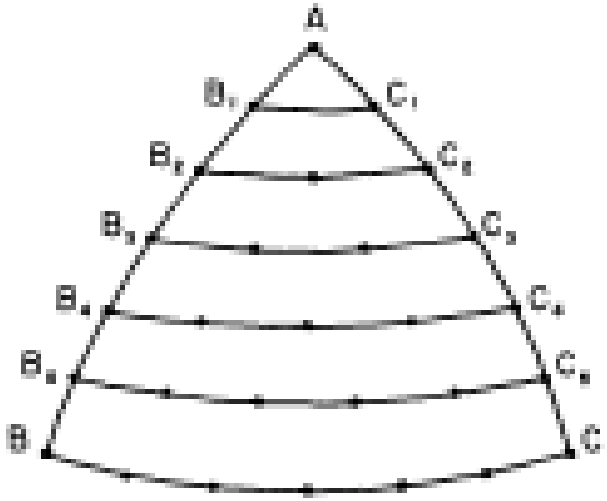
- Used in NCEP Rapid Update Cycle (RUC) model
- Used in HYCOM ocean model

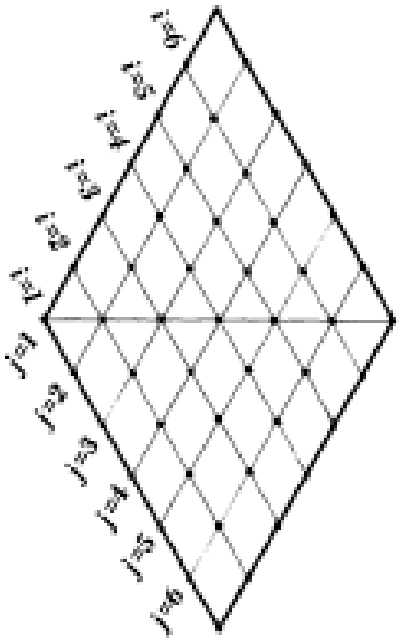
Builds on work by

- Rainer Bleck,
- RUC group (Benj et al. 2004-Mon.Wea.Rev.),
- Don Johnson et al. (U. Wisconsin),
- Akio Arakawa et al. (UCLA)
- Henry Juang (NCEP/EMC),
- Guenther Zangl (NCAR,DWD)









N=(m**2)*10 + 2
“m” is any integer ratio between arc(AB~8000 km) and target resolution.
e.g., for dx~20 km, then m=8000/20=400
→N=(400**2)*10+2~1.6 million points.

How to make an icosahedral grid ⇒ high granularity possible with icosa-hedral model

Sadourny, Arakawa, Mintz, MWR (1968)

240km icosahedral grid
Level-5 – 10242 polygons

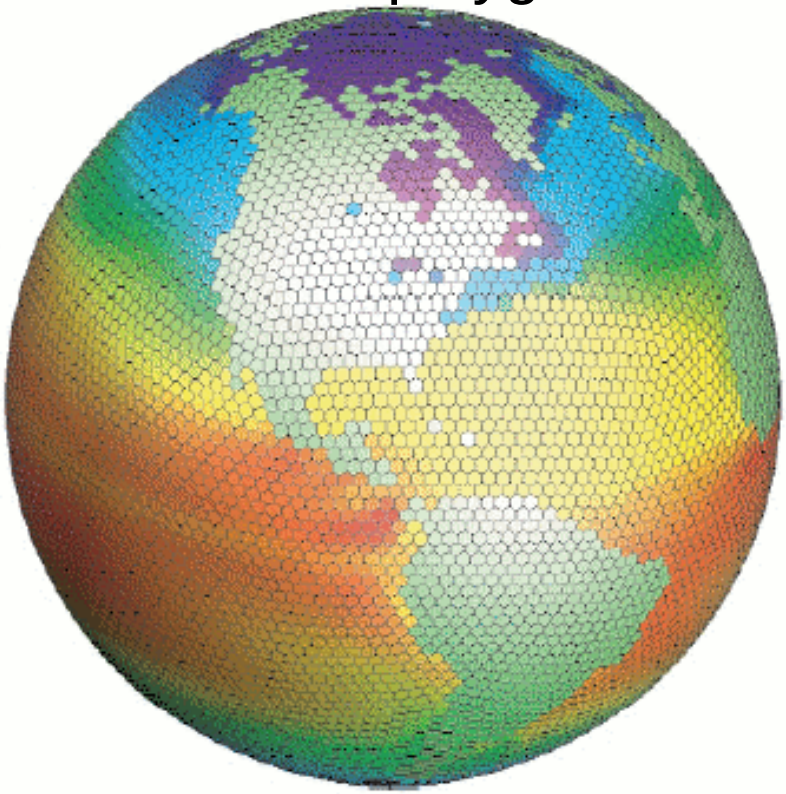


Figure 1. An example of a geodesic grid with a color-coded plot of the observed sea-surface temperature distribution. The continents are

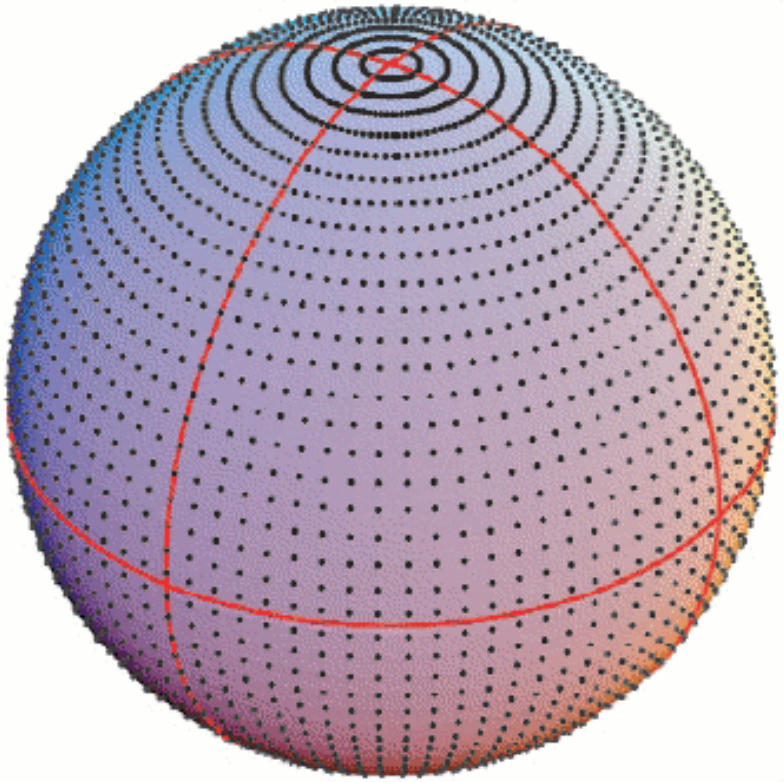


Figure 2. An example of a latitude–longitude grid. A pole is at the top. The black dots represent grid cell centers that are equally spaced in longitude

Diagrams - Randall et al. – Colorado State University
http://kiwi.atmos.colostate.edu/DOE_Cooperative_Agreement/pdf/CISE.pdf

Lagrangian vertical coordinate:
<u>Pros</u> and <u>Cons</u>
("Lagrangian" = isentropic in atmospheric applications)

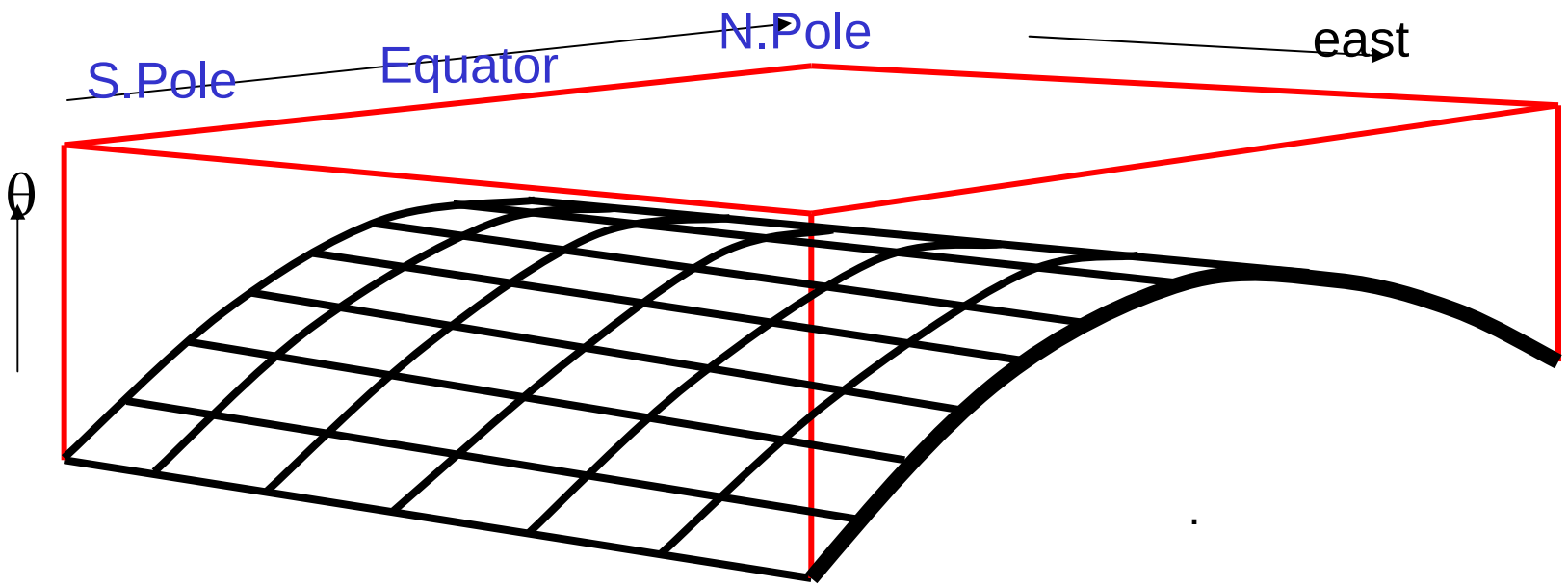
Major Pros:

- No uncontrolled diabatic **mixing** (in the vertical **and** horizontal)
- Numerical dispersion errors associated with vertical **transport** are minimized
- Optimal finite-difference representation of frontal zones & frontogenesis

Major Cons:

- Coordinate-ground intersections are inevitable (atmosphere doesn't fit snugly into x,y,q grid box)
- Poor vertical resolution in weakly stratified regions
- **Elaborate transport operators needed to achieve conservation**

The x,y,θ grid box

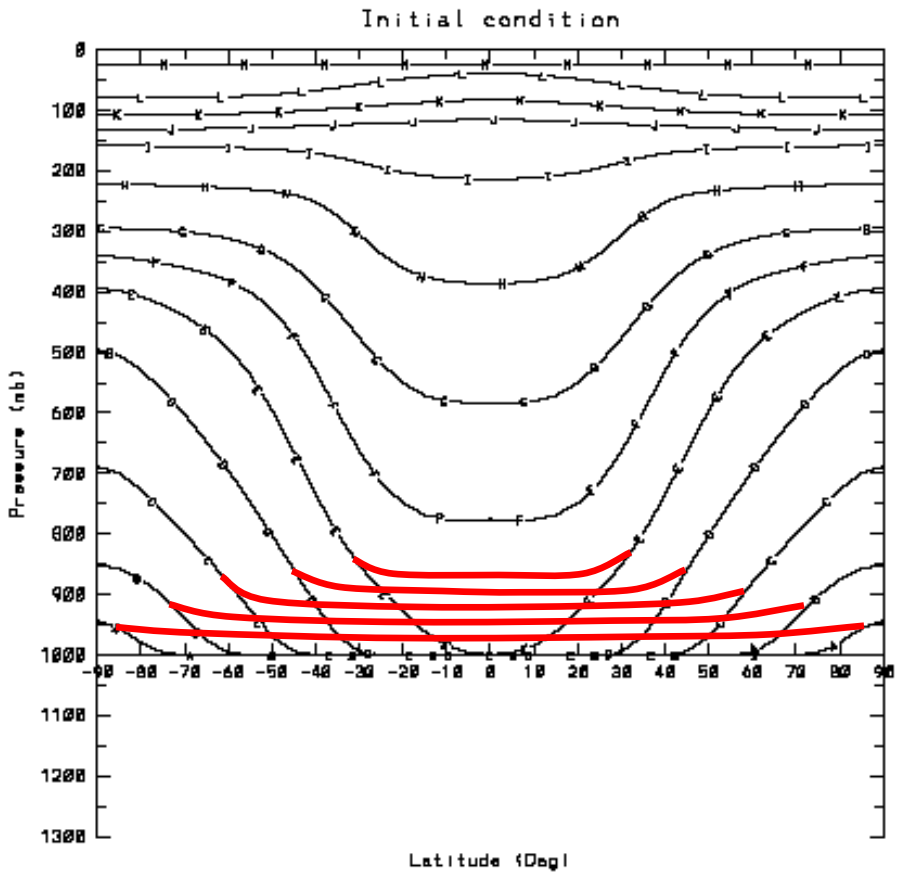


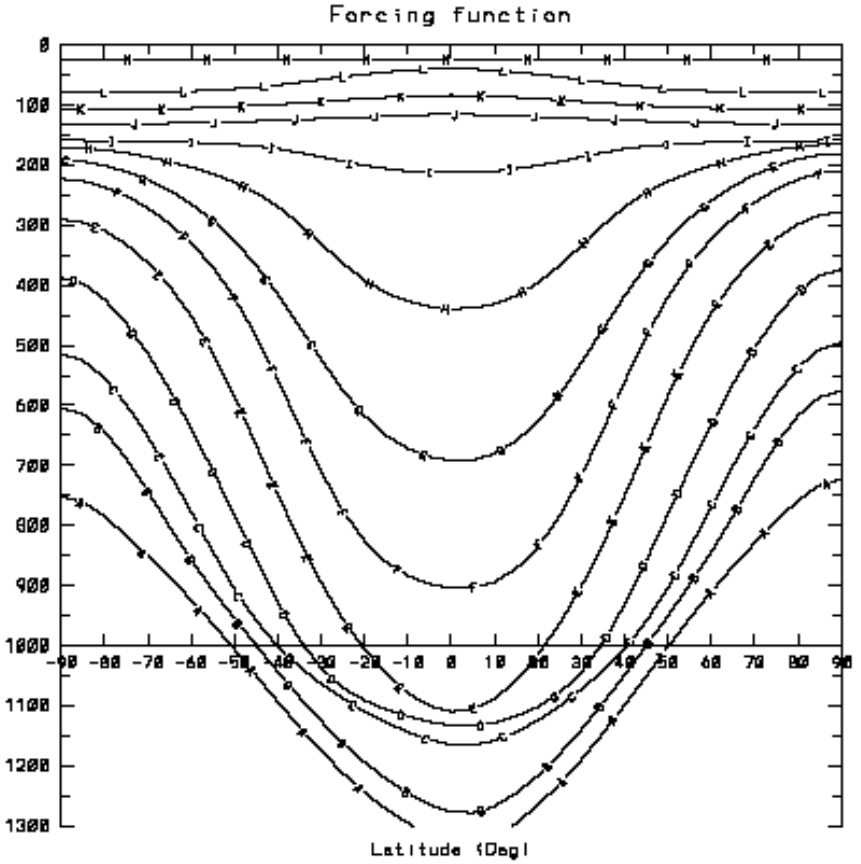
Major Cons:

- Coordinate-ground intersections are inevitable (atmosphere doesn't fit snugly into x,y,θ grid box)
- Poor vertical resolution in weakly stratified regions

Fixes:

- Reassign grid points from underground portion of x,y,θ grid box to above-ground "*s*" surfaces
- Low stratification => large portion of x,y,θ grid box is underground => no shortage of grid points available for re-deployment as *s* points


Initial condition
Pressure (mb)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
Latitude (Deg)


Forcing function
0
100
200
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600
700
800
900
1000
1100
1200
1300
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 30 40 50 60 70 80 90
Latitude (Deg)

"Hybrid" means different things to different people:

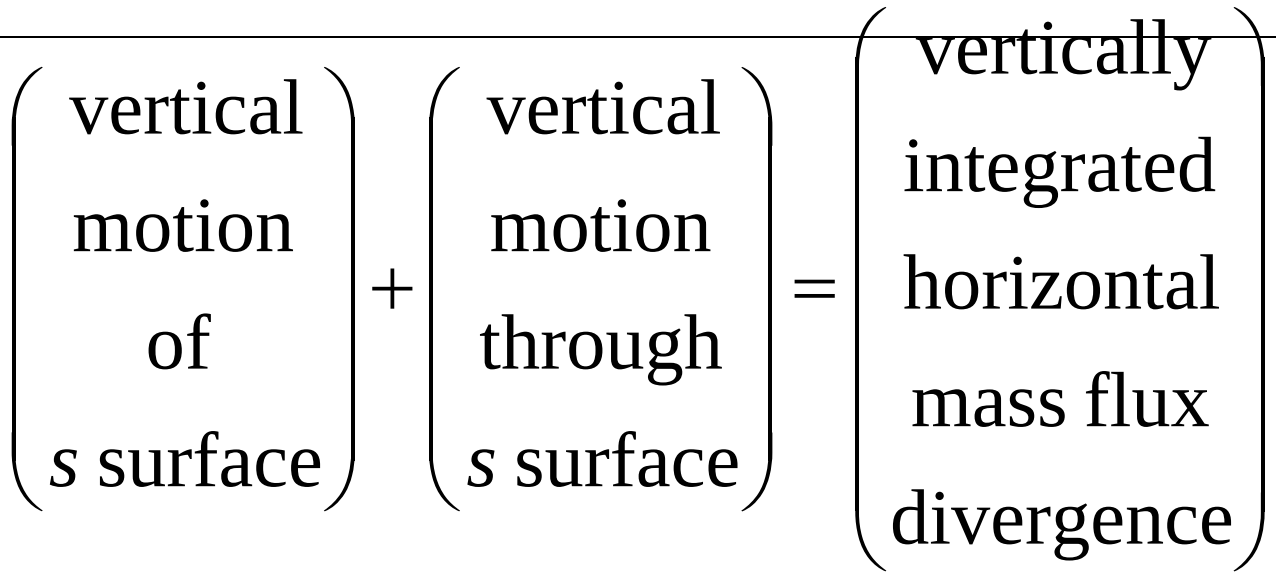
- linear combination of 2 or more conventional coordinates (examples: p+sigma, p+theta+sigma)
- ALE (Arbitrary Lagrangian-Eulerian) coordinate

ALE maximizes size of isentropic subdomain.

ALE: **“Arbitrary Lagrangian-Eulerian” coordinate**

- Original concept (Hirt et al., 1974): maintain Lagrangian character of coordinate but “re-grid” intermittently to keep grid points from fusing.
- In RUC, FIM, and HYCOM, we apply ALE in the vertical only and re-grid for 2 reasons:
  - (1) to maintain minimum layer thickness;
  - (2) to nudge an entropy-related thermodynamic variable toward a prescribed layer-specific “target” value by importing mass from above or below.
- Process (2) renders the grid **quasi-isentropic**

Continuity equation in generalized ("s") coordinates

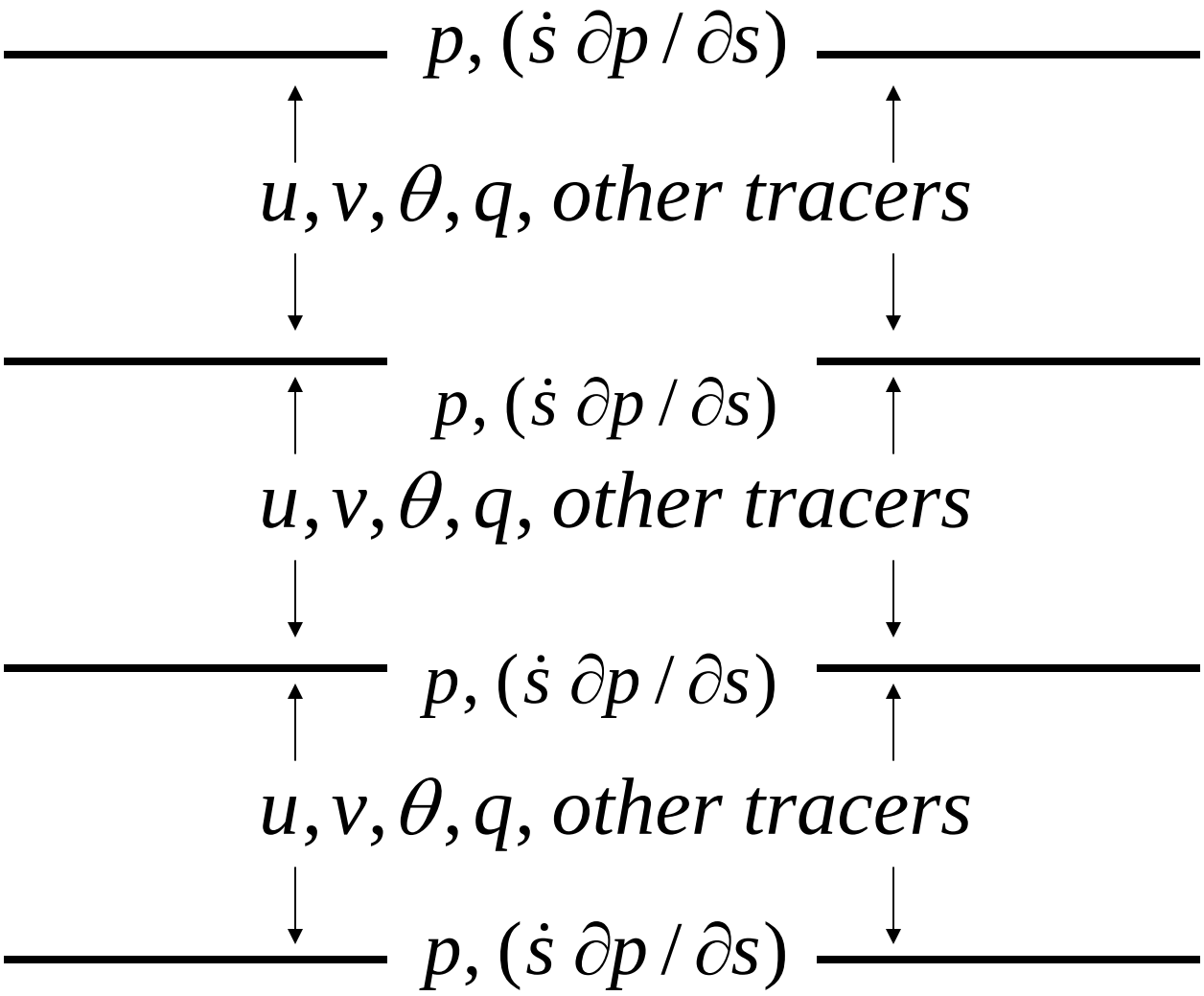


(zero in fixed grids)

(zero in material coord.)

(known)

Staggering of variables in layer or stacked shallow-water models: Used in FIM

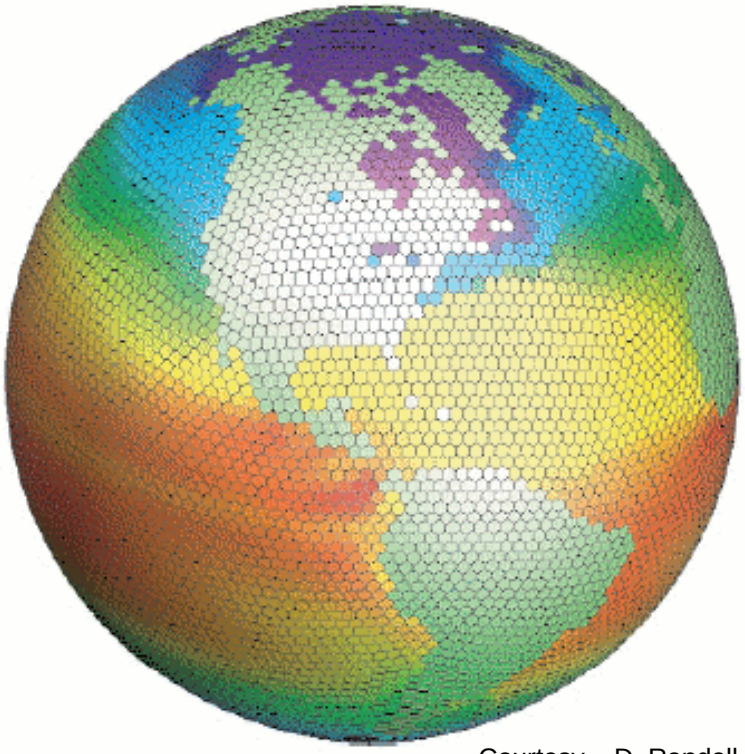


NOAA/ESRL

Status on Development of ***FIM***
Flow-following FV Icosahedral Model

Sandy MacDonald
Jin-luen Lee
Rainer Bleck
Stan Benjamin
John Brown

- presented by Stan Benjamin



Courtesy – D. Randall

FIM

- *Contribution toward future NOAA global modeling system*
- Developed at ESRL, collaboration so far with GFDL, EMC

NOAA modeling meeting - Jan 2006

Goals for NOAA future model development (per GSD)

- Design for *weather* (1h to 2 weeks) and *climate* applications
- Applicable at 1-4 km resolution
- Accurate for moisture, entropy, and tracer transport
- Quasi-Lagrangian vertical coordinate
  - Minimize cross-coordinate vertical transport
- Grid with nearly constant map scale without singularities
- Contribute diversity to NCEP global ensemble system

NOAA modeling meeting - Jan 2006

FIM development – Task Plan

NOAA modeling meeting - Jan 2006

FY2006 Goals

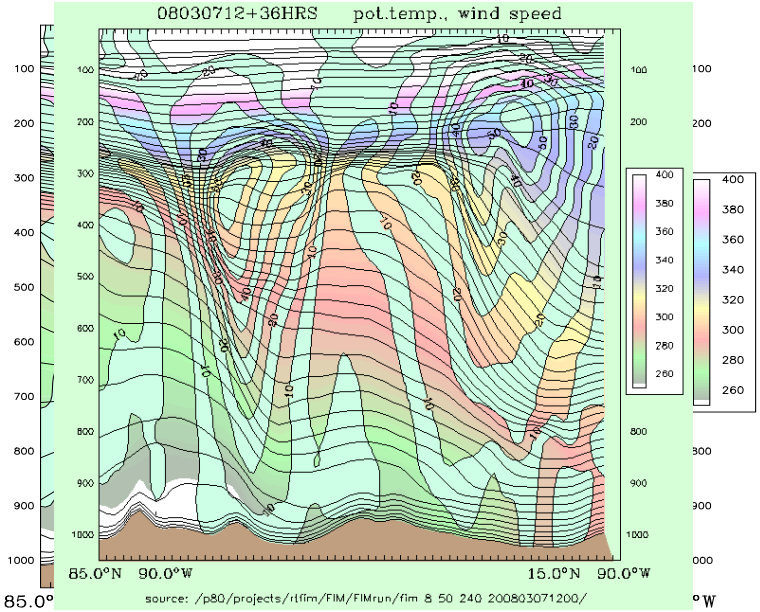
- Overall - Complete global circulation model (GCM) version
- Incorporate GFS physics package
- Perform idealized tests (e.g., Held-Suarez, transport of actual vs. proxy PV, θ_e)
- Design for optimal computational efficiency on non-structured (icosahedral) horizontal grid
- Design appropriate θ-σ ALE coordinate for global 1-20km application

FY2007 Goals

- Switch from idealized to observed initial conditions
- Work with EMC on incorporating FIM dynamic core into FY07 GFS version suitable for alternative dynamic cores
- Develop non-hydrostatic version of FIM
- Collaborate with other NOAA research partners to develop and test further refinements

FIM model/ system

-Contributors



FIM development

- 2006 - current

Jin Lee	
Sandy MacDonald	
Rainer Bleck	
Jian-Wen Bao	
John M. Brown	
Jacques Middlecoff	
Ning Wang	
Stan Benjamin	
Bill Moninger Susan Sahm Ed Szoke Brian Jamison	Verification, Web page, Evaluation
Tom Henderson	ESMF, Subversion
Chris Harrop	WorkFlow Manager, xml real-time scripts
Georg Grell	FIM- chemistry, aerosols

FIM configuration in hybrid vs. sigma tests

Resolution

- **G8 - 30km resolution (side of rhombus divided by 2**8)**
- **50 vertical levels - hybrid theta-sigma**
  - Reference θ_v for each level, min-Δp (2.5, 5, 10… hPa) near sfc
- **Ptop = 20 hPa**

Physics

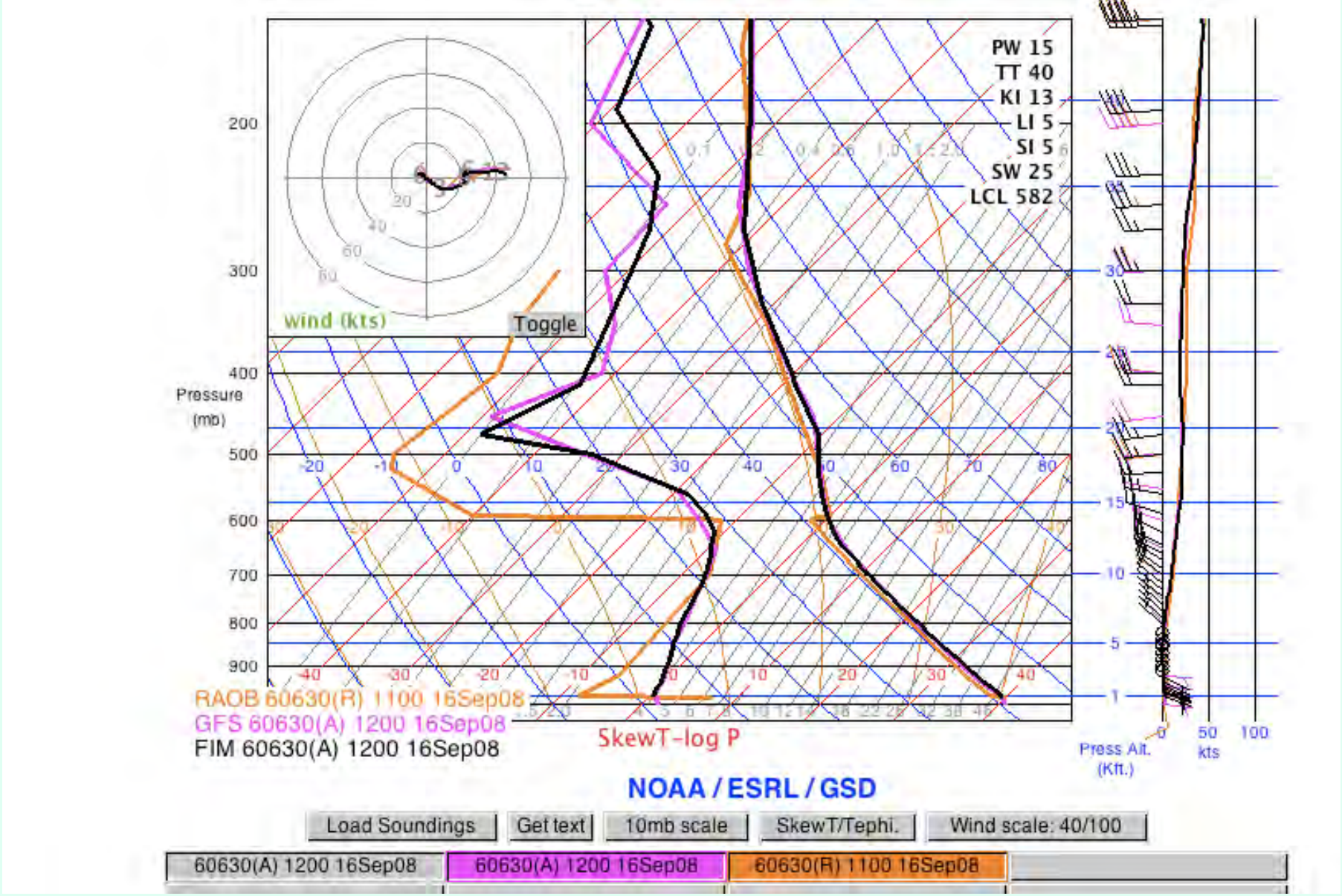
- **GFS physics**
- **(currently) called every dynamics time step (45 sec)**

Initial conditions

- **Interpolation from GFS spectral data to FIM icosahedral hybrid vertical coordinate**
- **Horizontal first, then vertical**

(Resolutions tested for other cases)

- G5 (240km) - G9 (15km)
- 50 hybrid levels (220-547K), 100 hybrid levels (220-547K)



Hybrid interp works - 0h GFS, FIM both fit temps about same - - example for raob site in southern Algeria - 12z - 16 Sept 08

http://fim.noaa.gov

U.S. Department of Commerce | National Oceanic & Atmospheric Administration | NOAA Research

Earth System Research Laboratory

Flow-following finite-volume Icosahedral Model (FIM)

Assimilation and Modeling Branch (AMB) Projects GSD Home ESRL Home

Current and Forecast Graphics

Global - CONUS
W. Atlantic - Africa
Arctic - W. Pacific
FIM GRIB viewer
Ice/snow - SST

Soundings

Interactive (Java)

Other NOAA Model Products

NCEP Model Products (GFS,etc.)

Organization

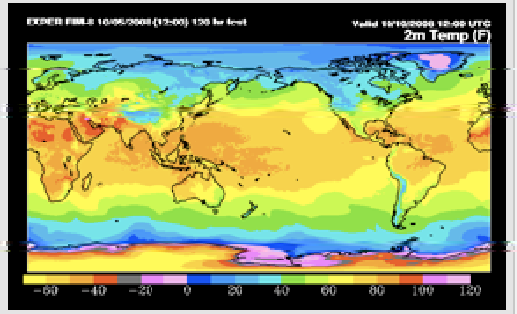
[redacted]
Rapid Refresh home
[redacted]
AMB/GSD Staff
ESRL/GSD

Description

Manuscript description of FIM model

The FIM Model

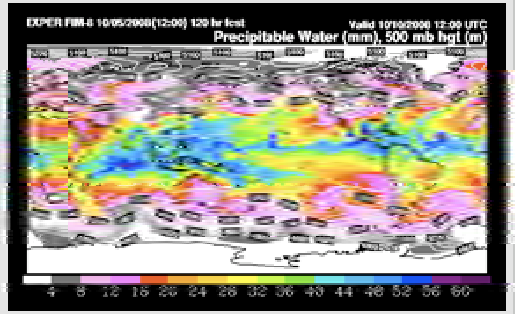
NOAA/ESRL scientists have developed an initial version of a new global model including use of the adaptive isentropic-sigma hybrid vertical coordinate successful with the RUC model, accurate finite-volume horizontal advection, and use of an icosahedral horizontal grid. ESRL is collaborating with NCEP/EMC on ESMF-compatibility of the FIM model, and was aided by GFDL on its initial design.



2-m Temperature - 5-day fcst

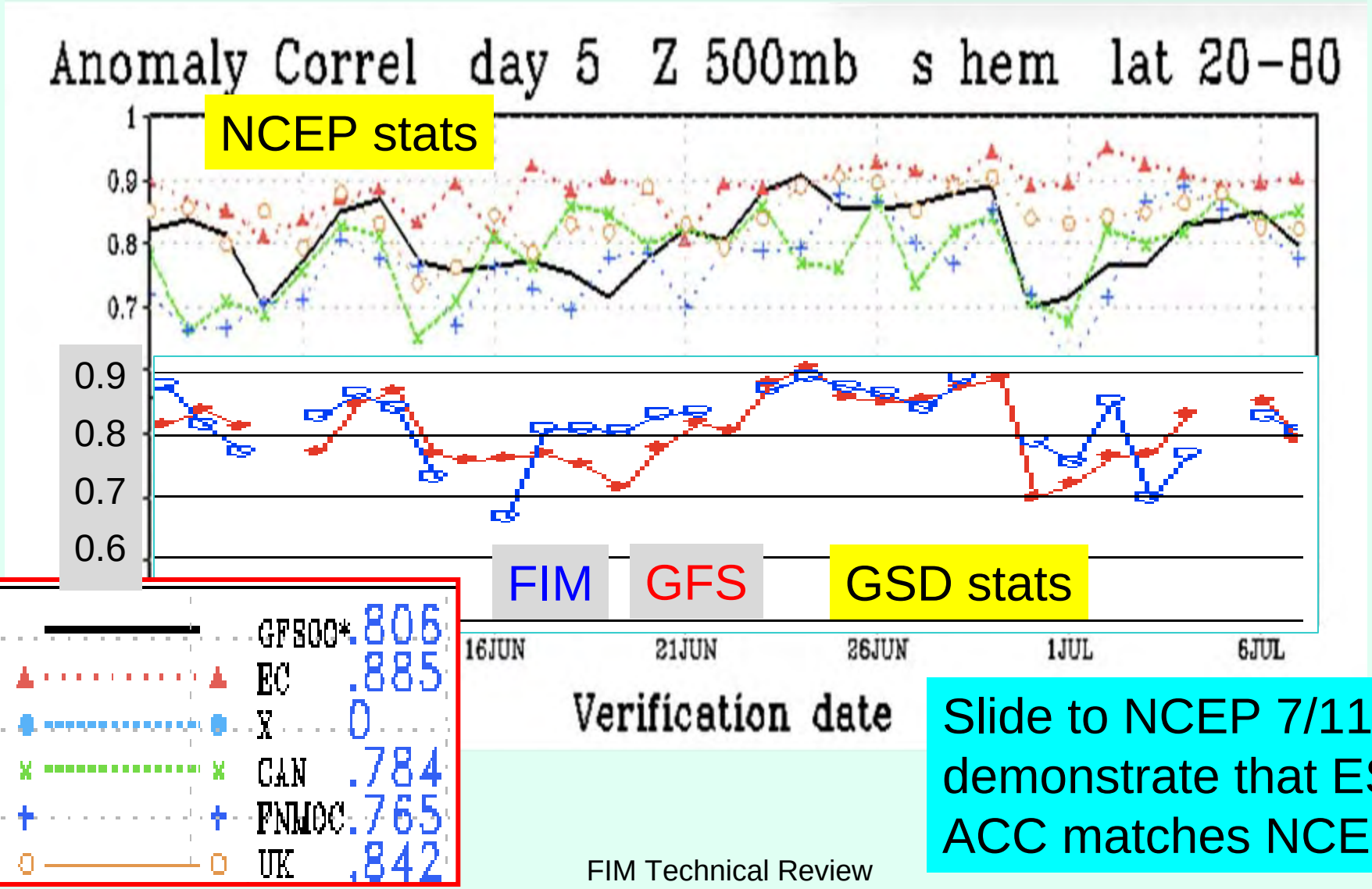
Three unique features of the FIM

- icosahedral horizontal grid, mostly hexagons except for 12 pentagons ("I" in FIM)
- isentropic-sigma hybrid vertical coordinate, adaptive, concentrates around frontal zones, tropopause, similar to RUC model ("**F**" for Flow-following in FIM)
- finite-volume horizontal transport (Also



Precipitable Water/500hPa Height - 5-day fcst

GFS vs. FIM, other global models (EC, UK, etc.)
(sanity check for our Anomaly processing)



Slide to NCEP 7/11 to demonstrate that ESRL ACC matches NCEP's

Some recent FIM model code changes (other than ESMF, efficiency, I/O, issues)

Spring 2008

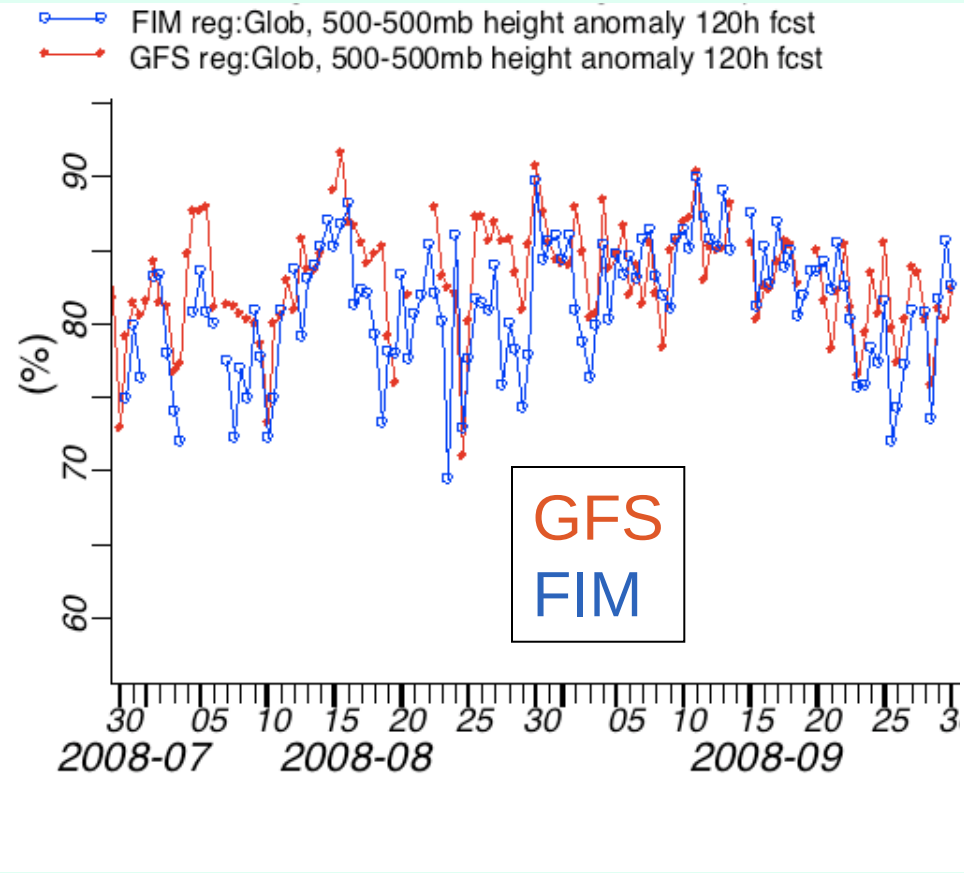
- **17 April - introduction of virtual potential temperature to FIM numerics**
- **3 June – Fix to land-surface "freckle" problem - land-use interpolation error**

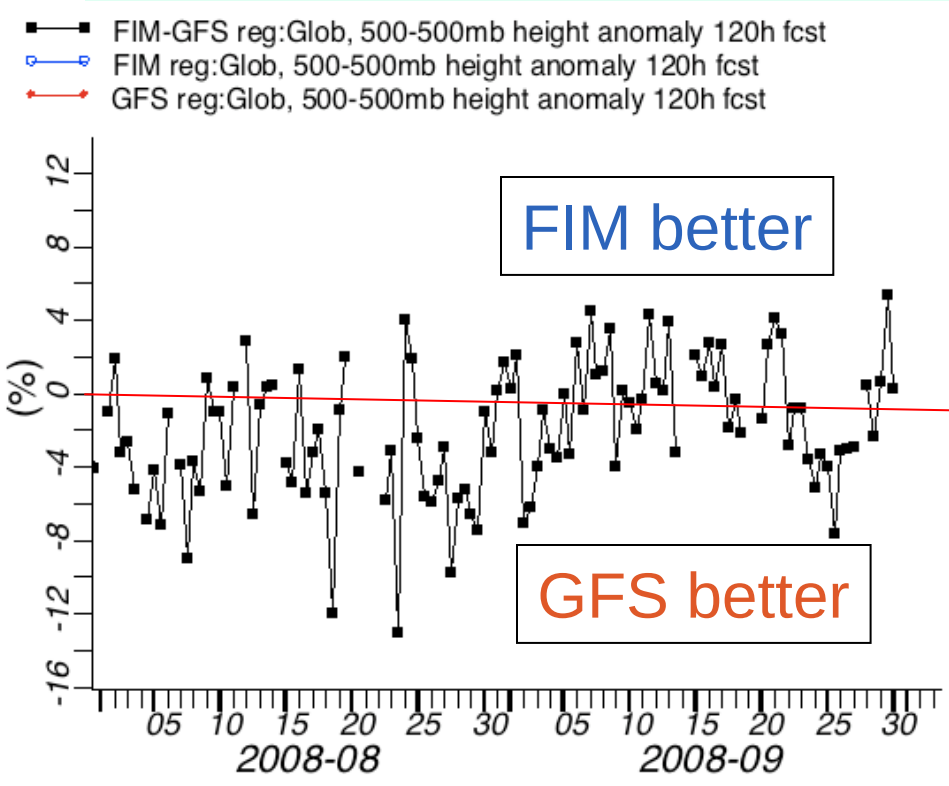
More recent

- **21 August - Solution to FIMprep problem - wrong assignment of GFS hybrid sigma-pressure levels**
- **28 August - Fix to assignment of soil moisture values to both liquid water and total values.**

Still a problem

- **Remaining issue for interpolation from GFS initial conditions to FIM (vertical interpolation)**



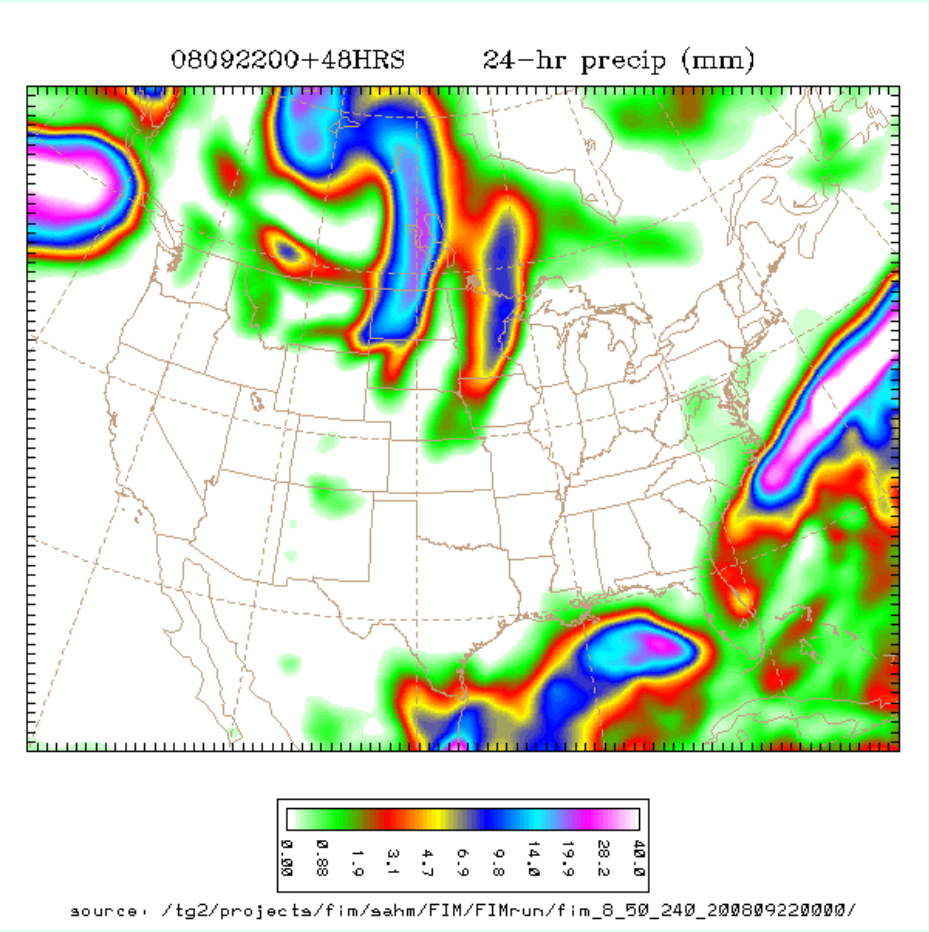


- FIM fixes in late August improved 5-day forecast skill relative to GFS in September
- Major variations in day-to-day skill between GFS and FIM

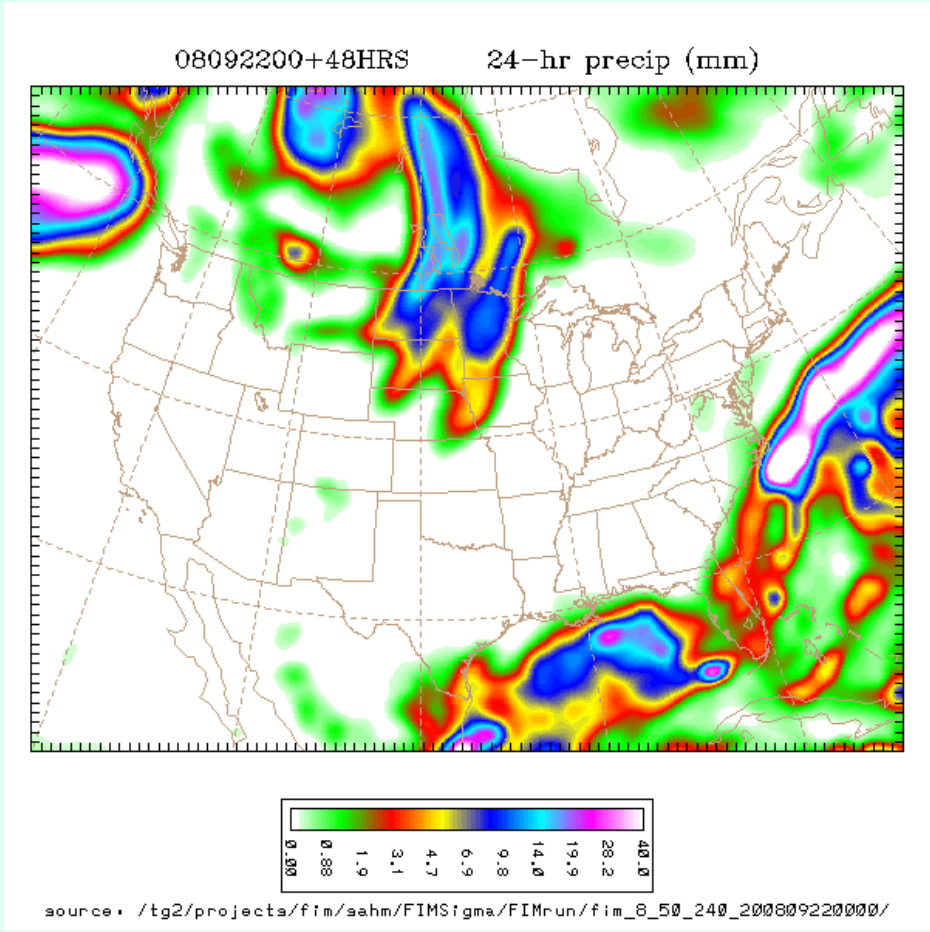
FIM vertical coordinate sensitivity experiment

- **Used two versions of FIM**
- **θ-σ (hybrid isentropic sigma) vs. σ (sigma) vertical coordinate**
- **Vertical coordinate isolated in single module in FIM model, allowing "relatively easy" modification**
- **3 seasons - 7-10 day comparisons**
  - Feb 08, June 08, Sept 08
- **00z initial times only**
- **Controlled experiments other than vertical coordinate**
  - Same GFS IC, use of same GFS physics in both, same FIM time step (45 s), etc.

FIM hybrid vs. FIM sigma - 48h fcst - runs init 00z 22 Sept 08

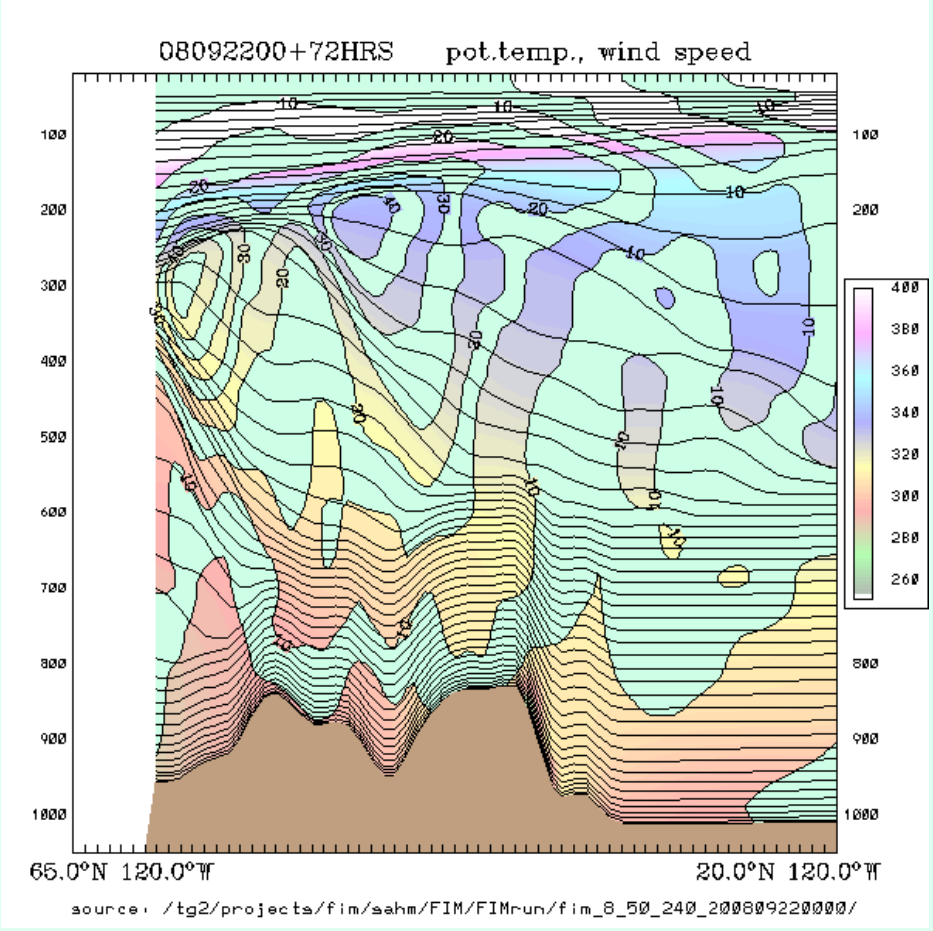


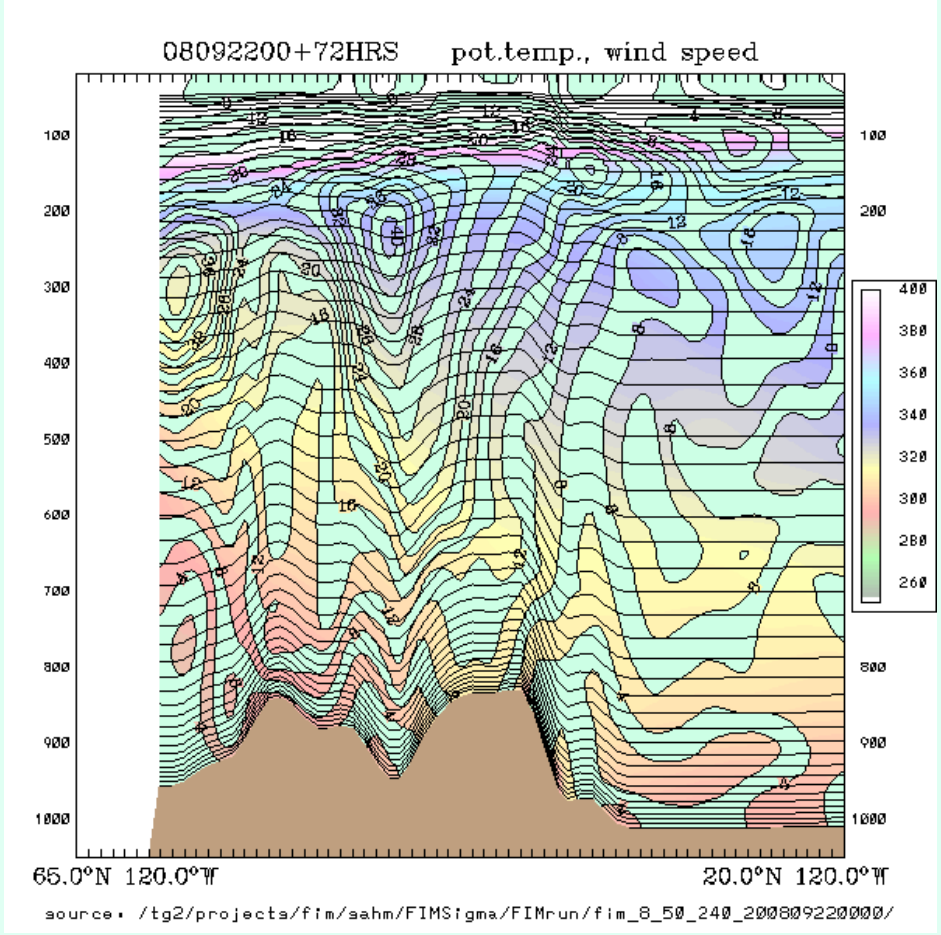
Hybrid-theta



Sigma

FIM hybrid vs. FIM sigma - 72h fcst - runs init 00z 22 Sept 08

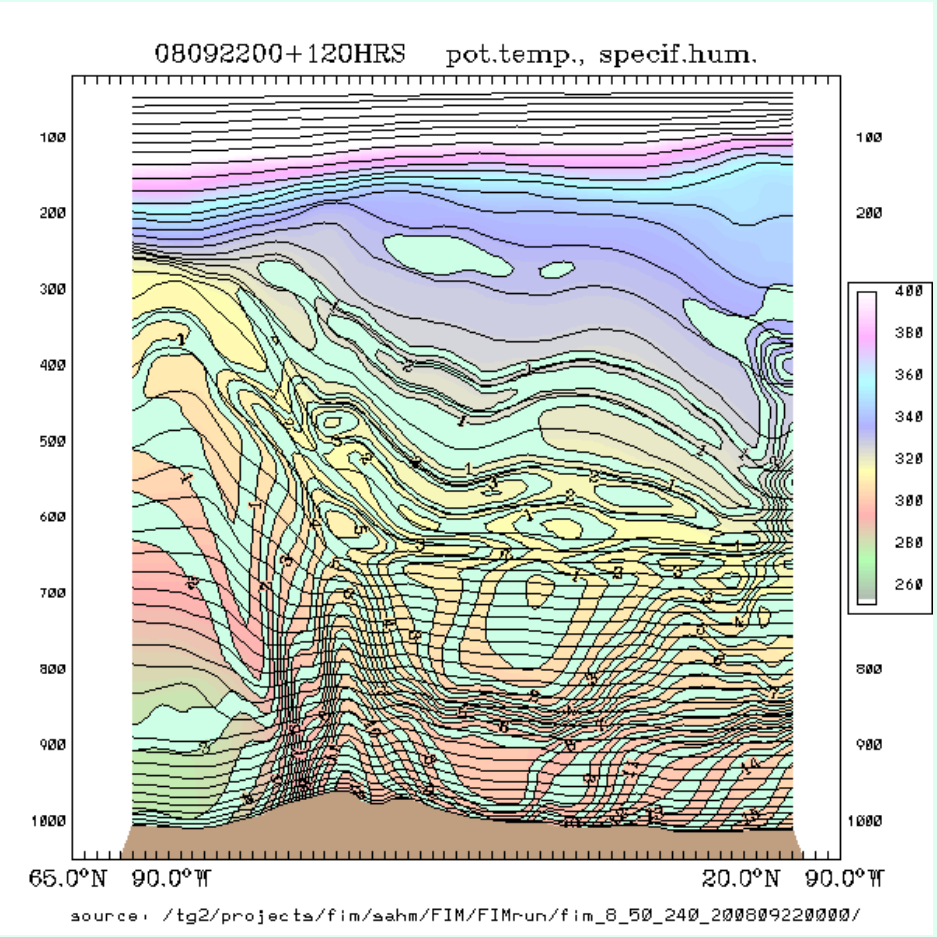




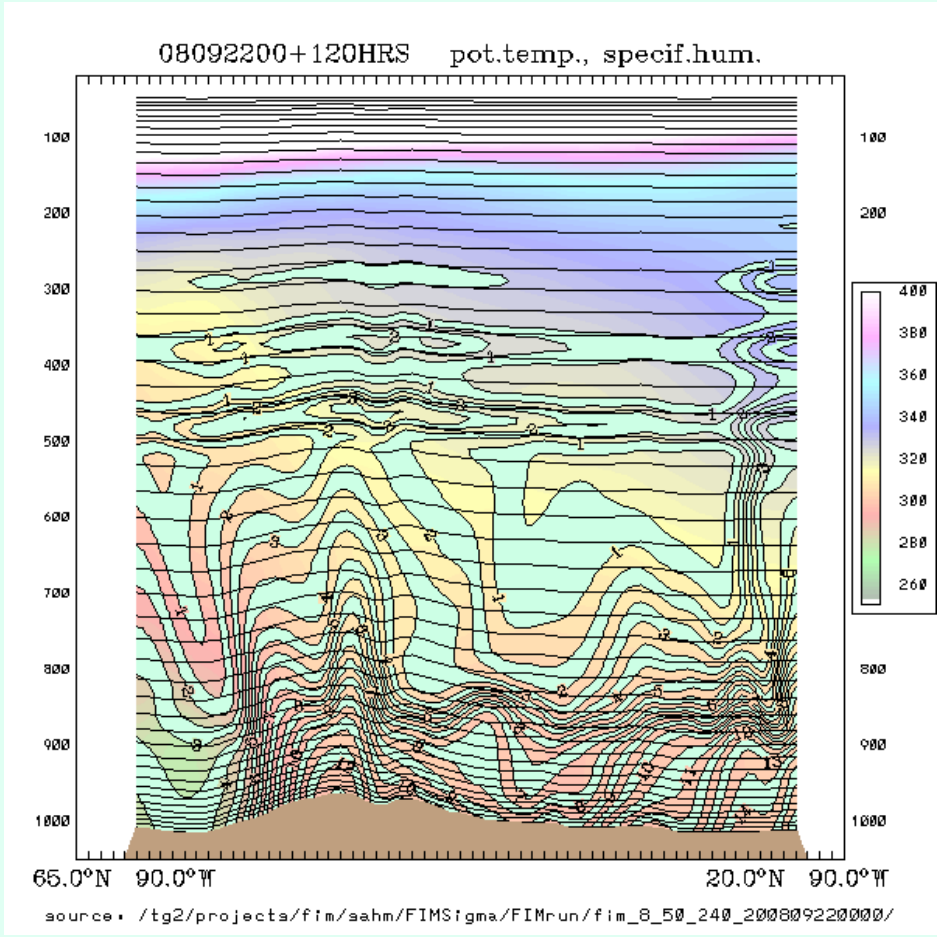
Hybrid-theta

Sigma

FIM hybrid vs. FIM sigma - 120h fcst - runs init 00z 22 Sept 08

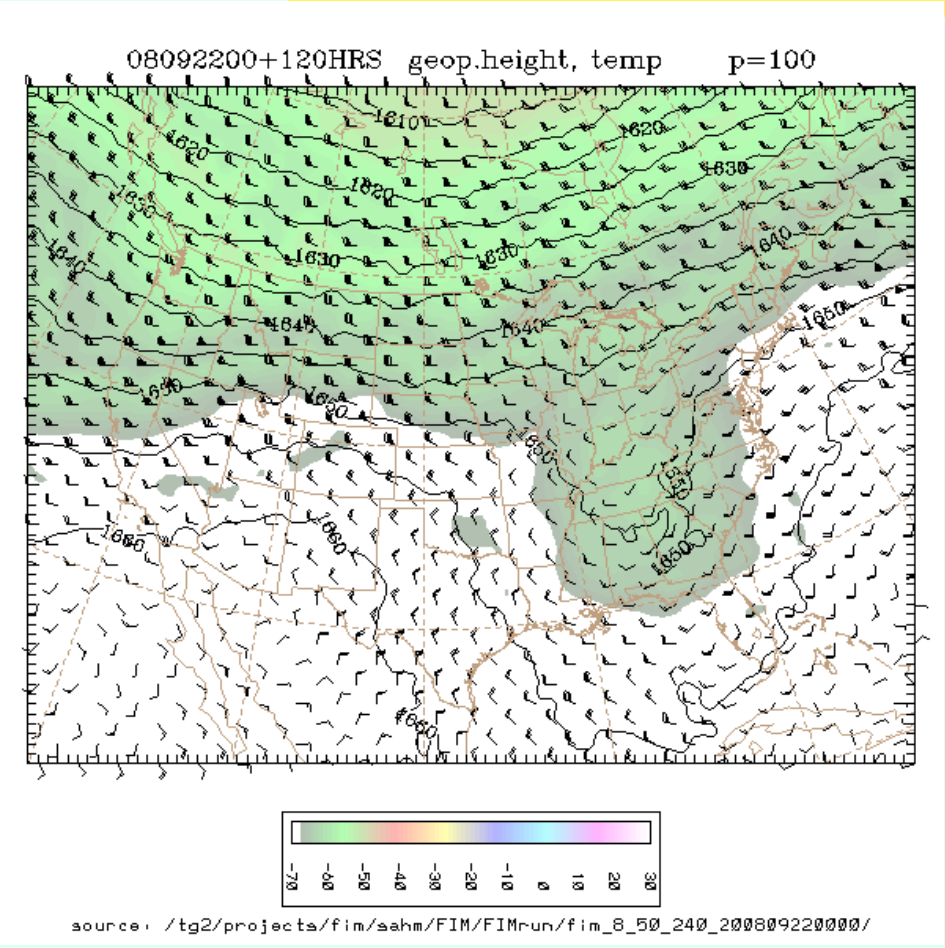


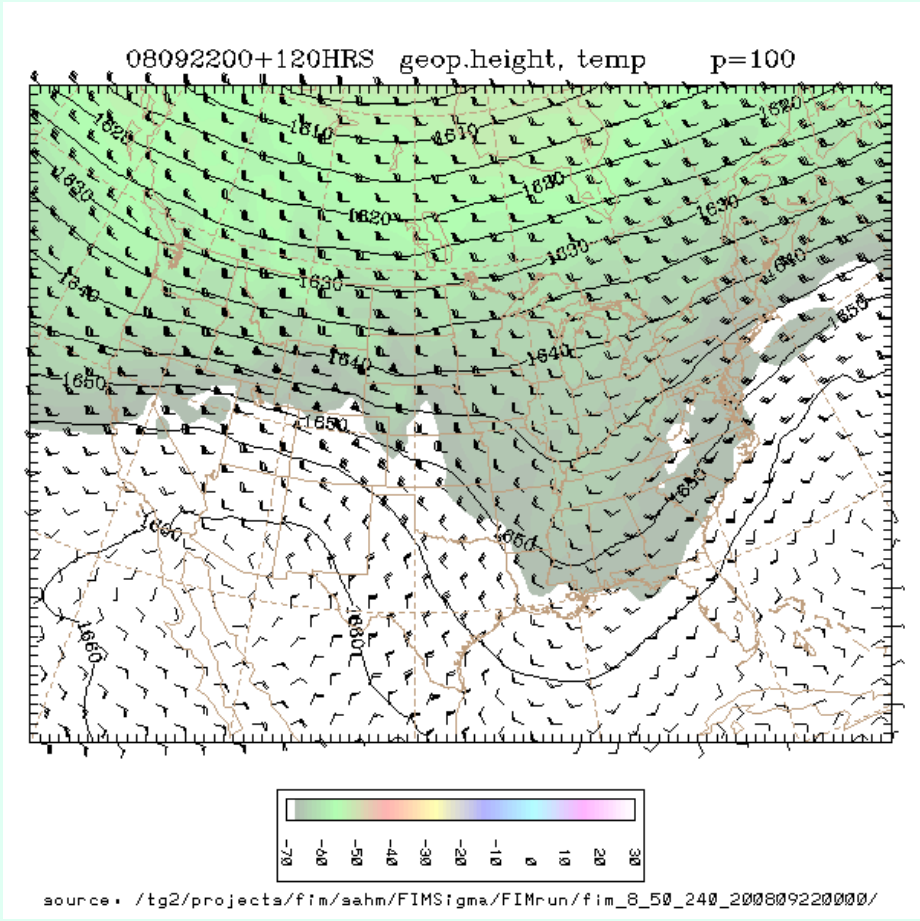
Hybrid-theta



Sigma

FIM hybrid vs. FIM sigma - 120h fcst - runs init 00z 22 Sept 08

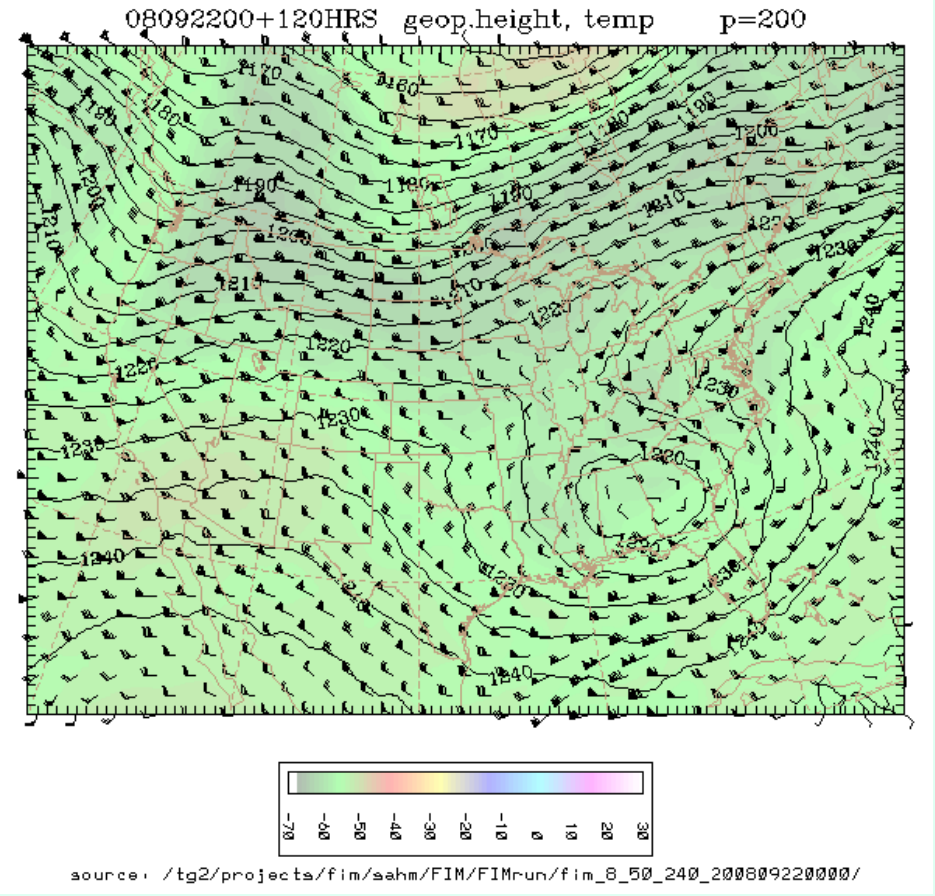


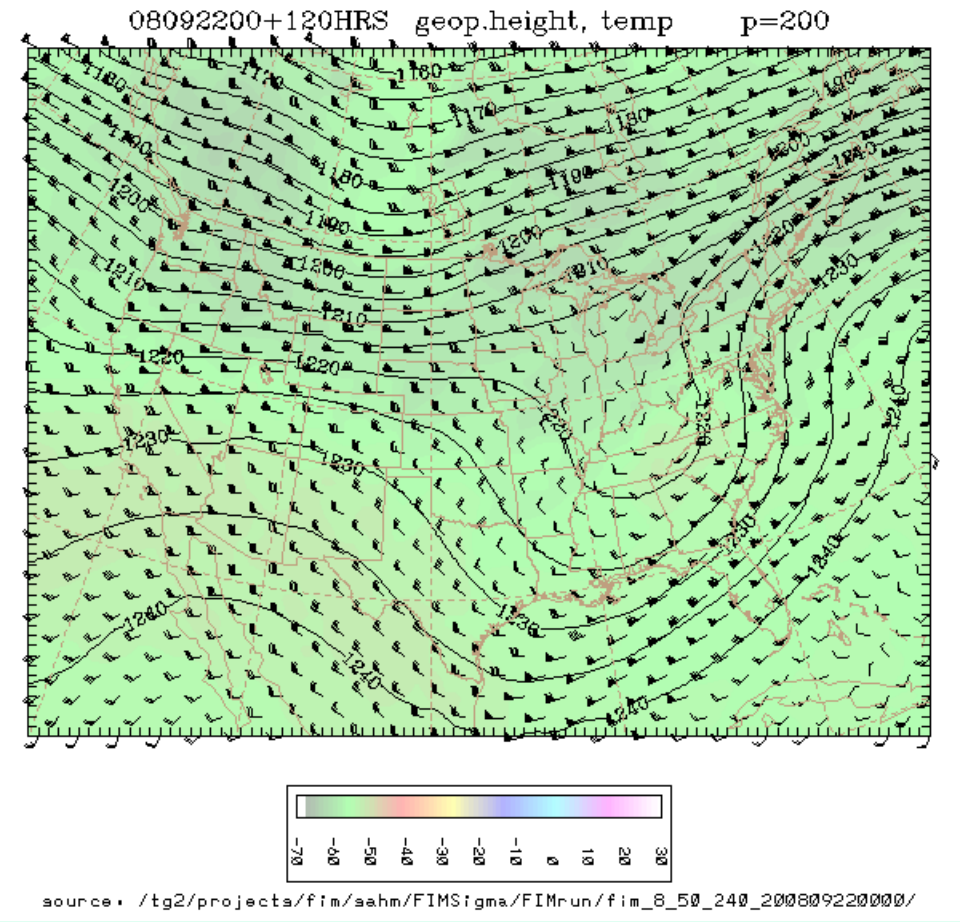


Hybrid-theta

Sigma

FIM hybrid vs. FIM sigma - 120h fcst - runs init 00z 22 Sept 08

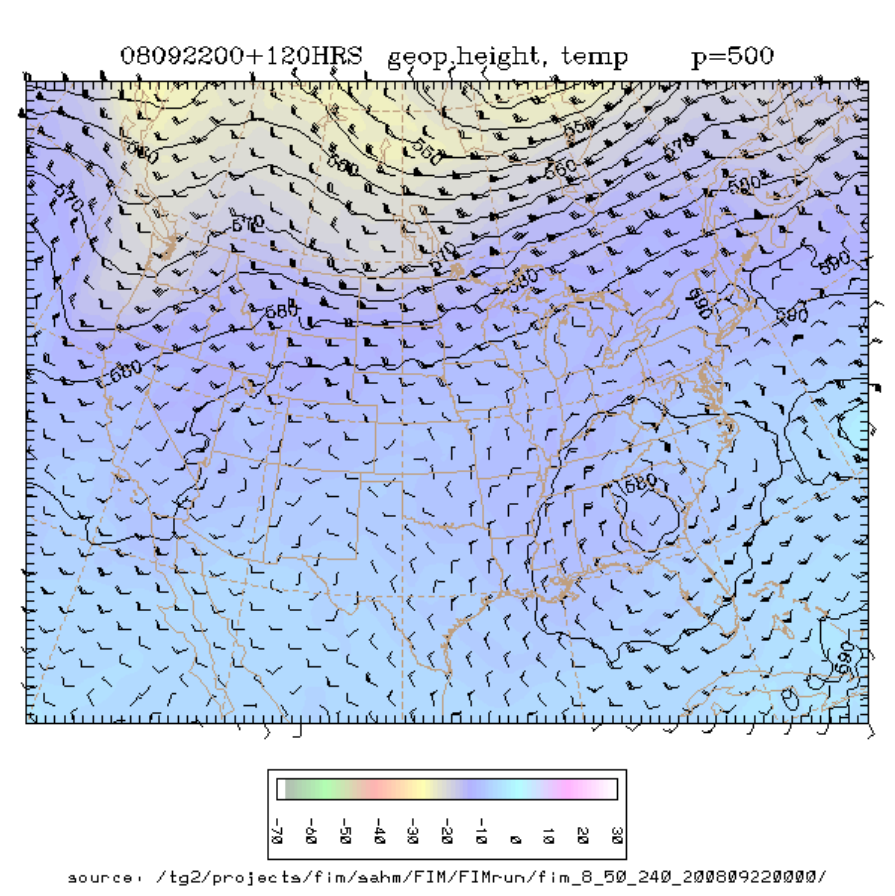


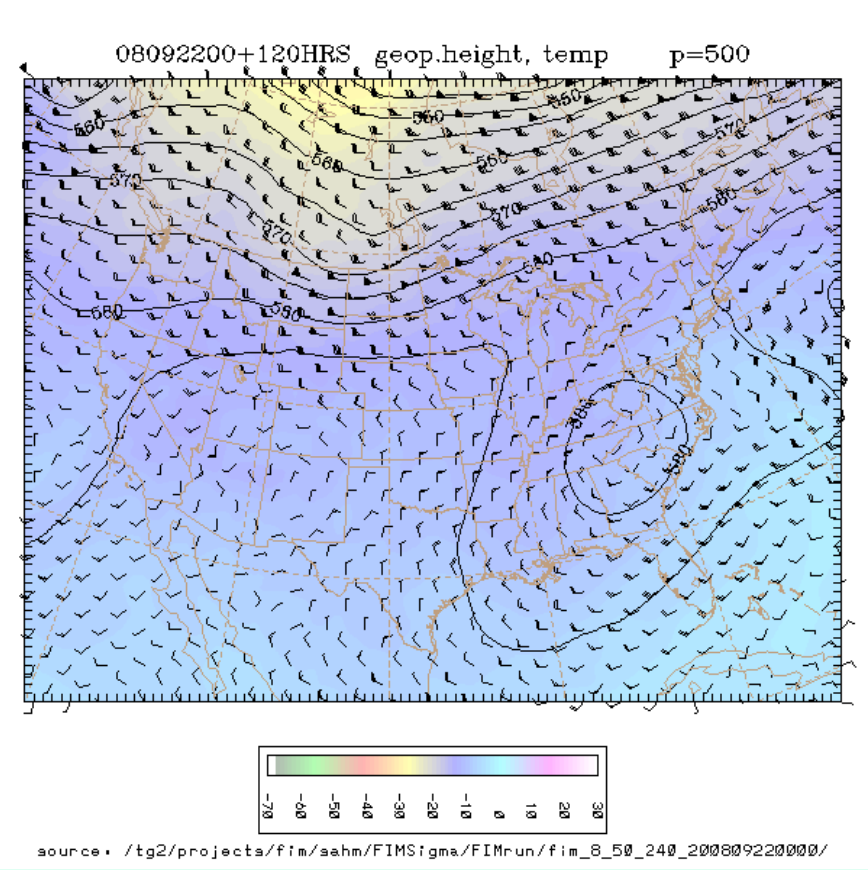


Hybrid-theta

Sigma

FIM hybrid vs. FIM sigma - 120h fcst - runs init 00z 22 Sept 08



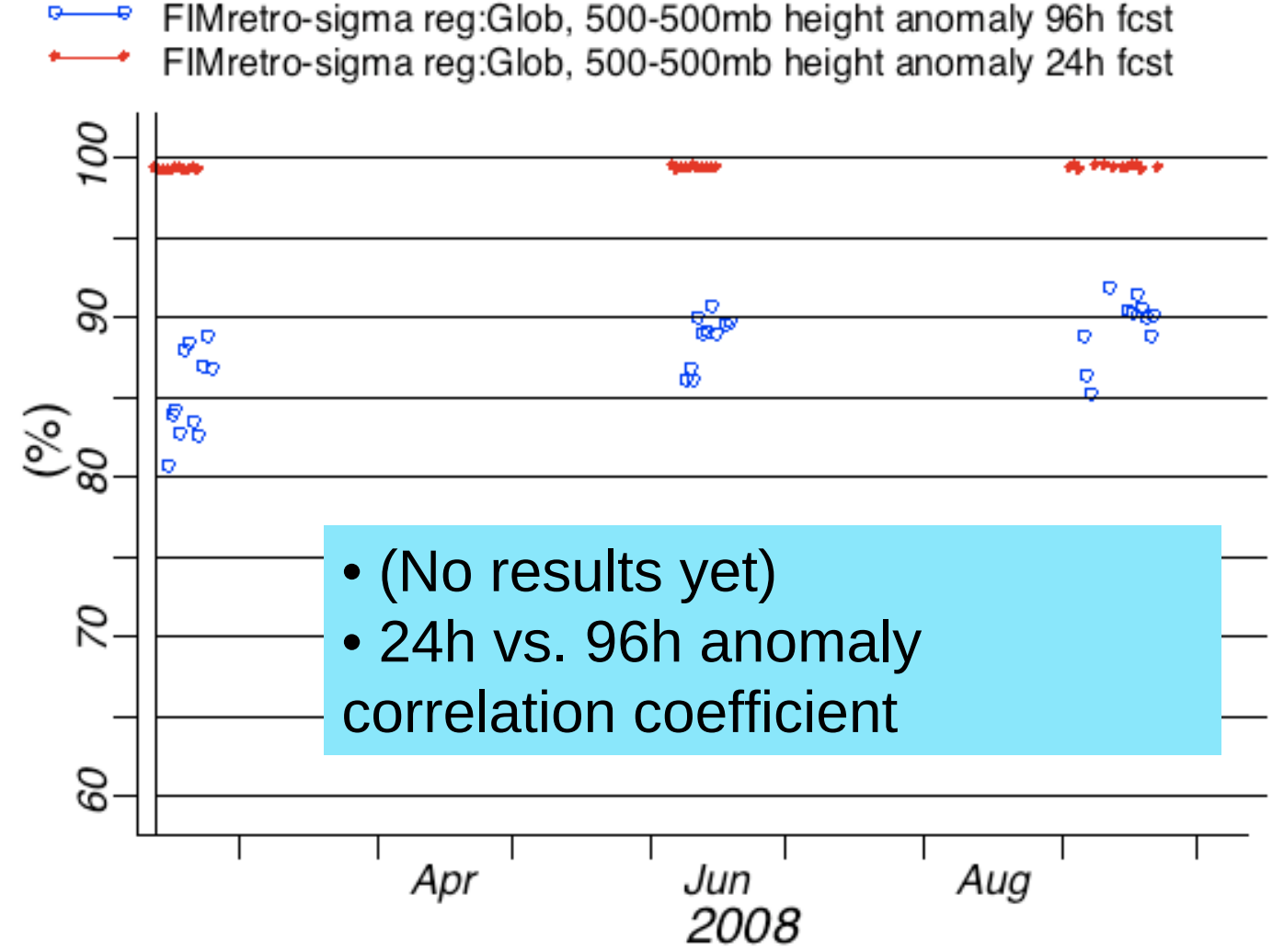


Hybrid-theta

Sigma

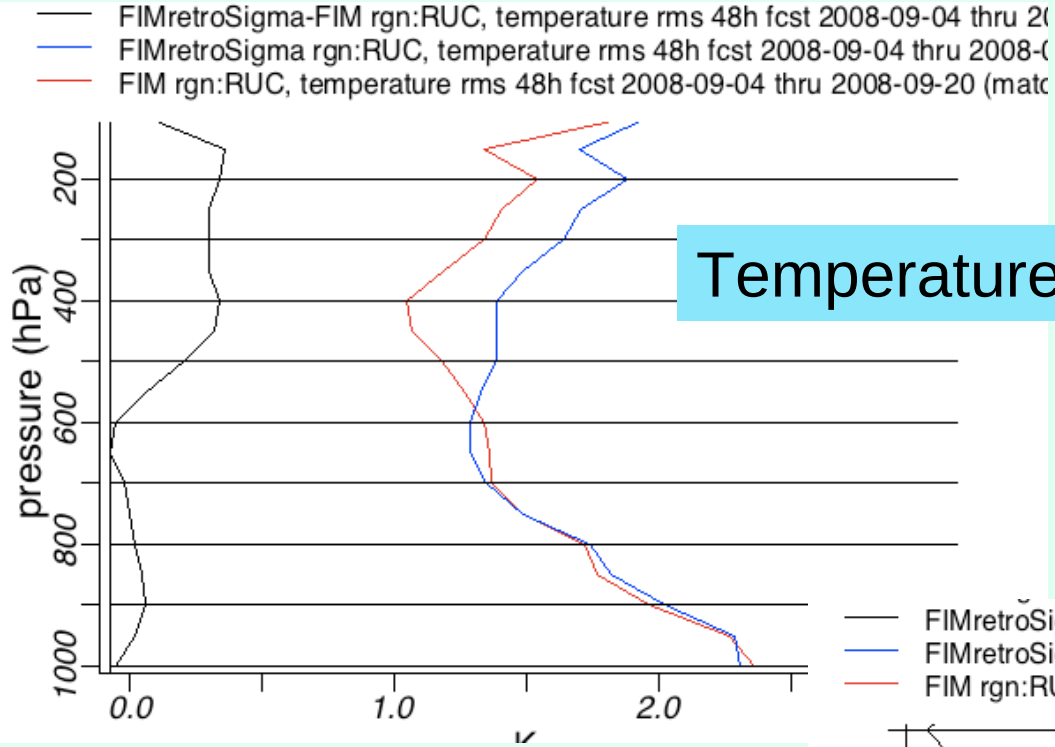
FIM vertical coordinate sensitivity experiment

- **3 seasons - 7-10 day comparisons**
  - Feb 08, June 08, Sept 08



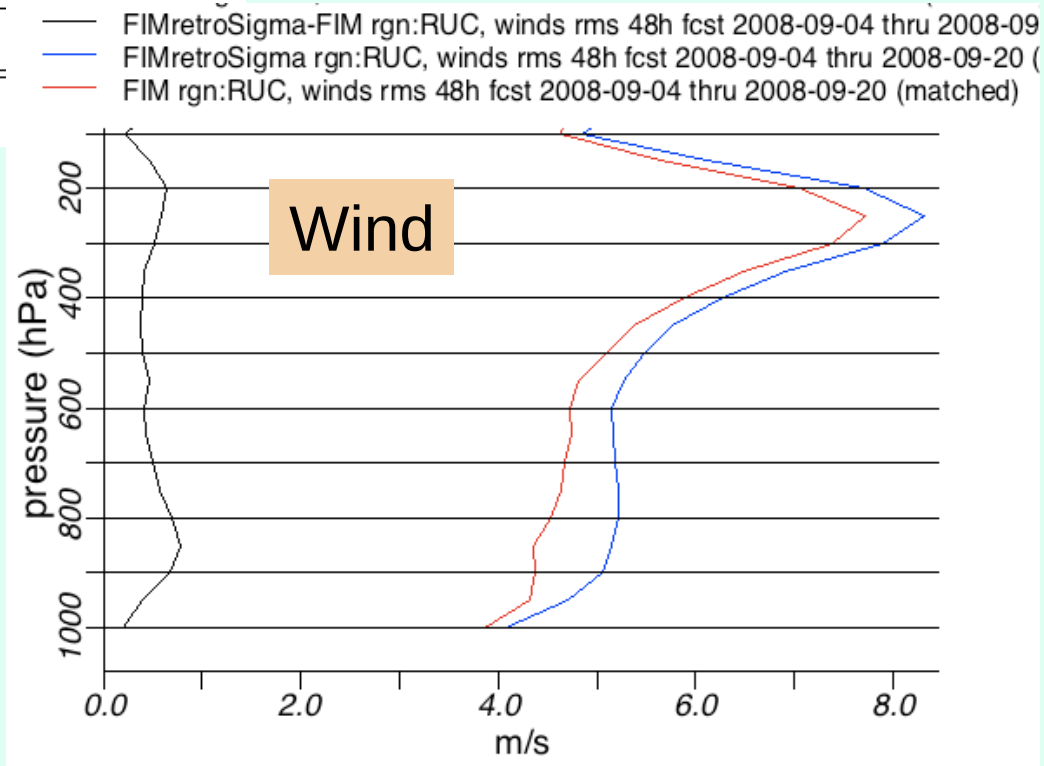
Sept 08 period
48 h forecasts
Raob verification
- Global

FIM-hybrid
FIM-sigma



Temperature

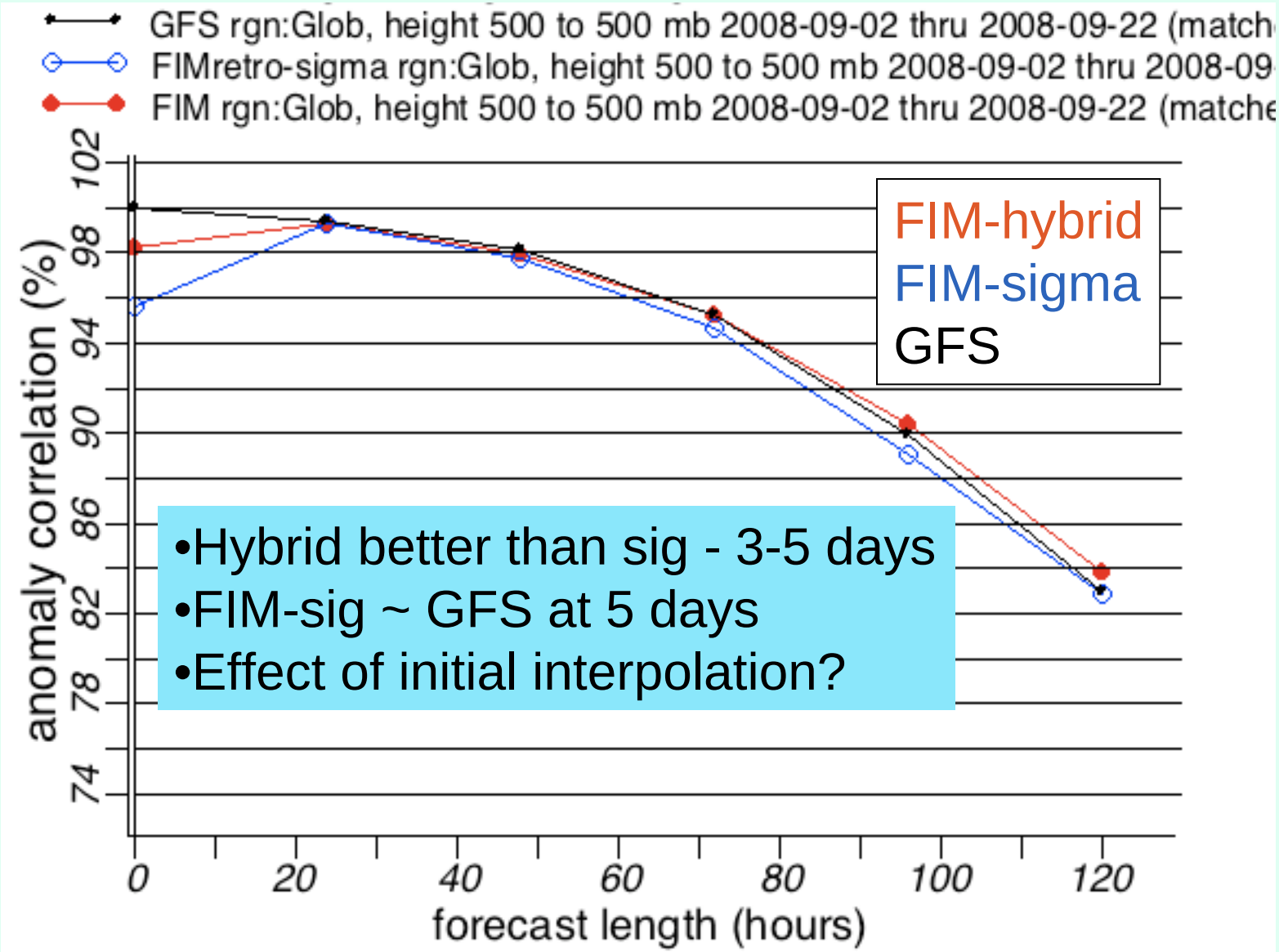
Temps - FIM-hybrid better than FIM-sigma in upper troposphere (roughly θ levels).



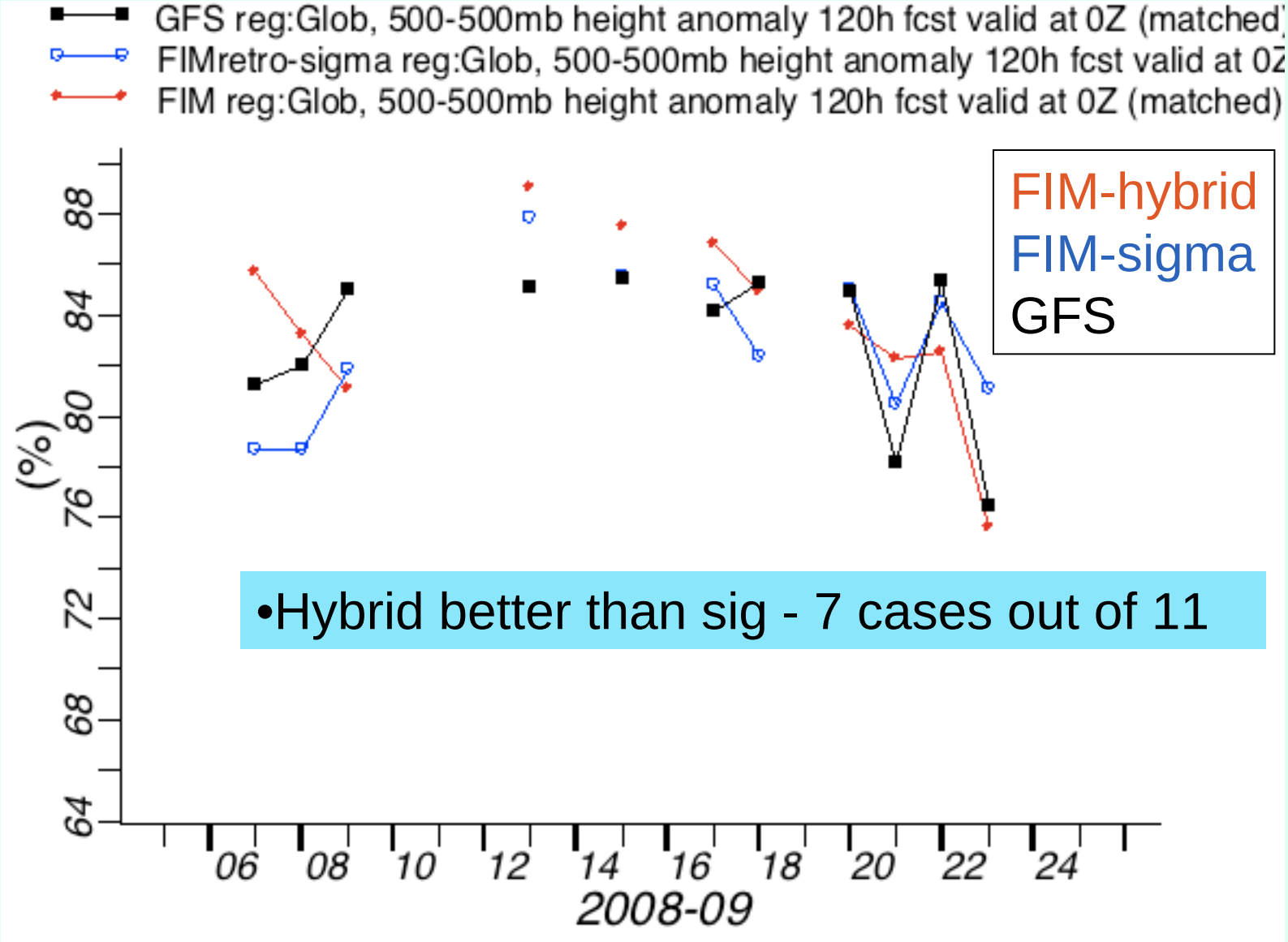
Wind

FIM-hybrid better than FIM-sigma for temps in upper troposphere.

500hPa height anomaly correlation coefficient - Sept 08

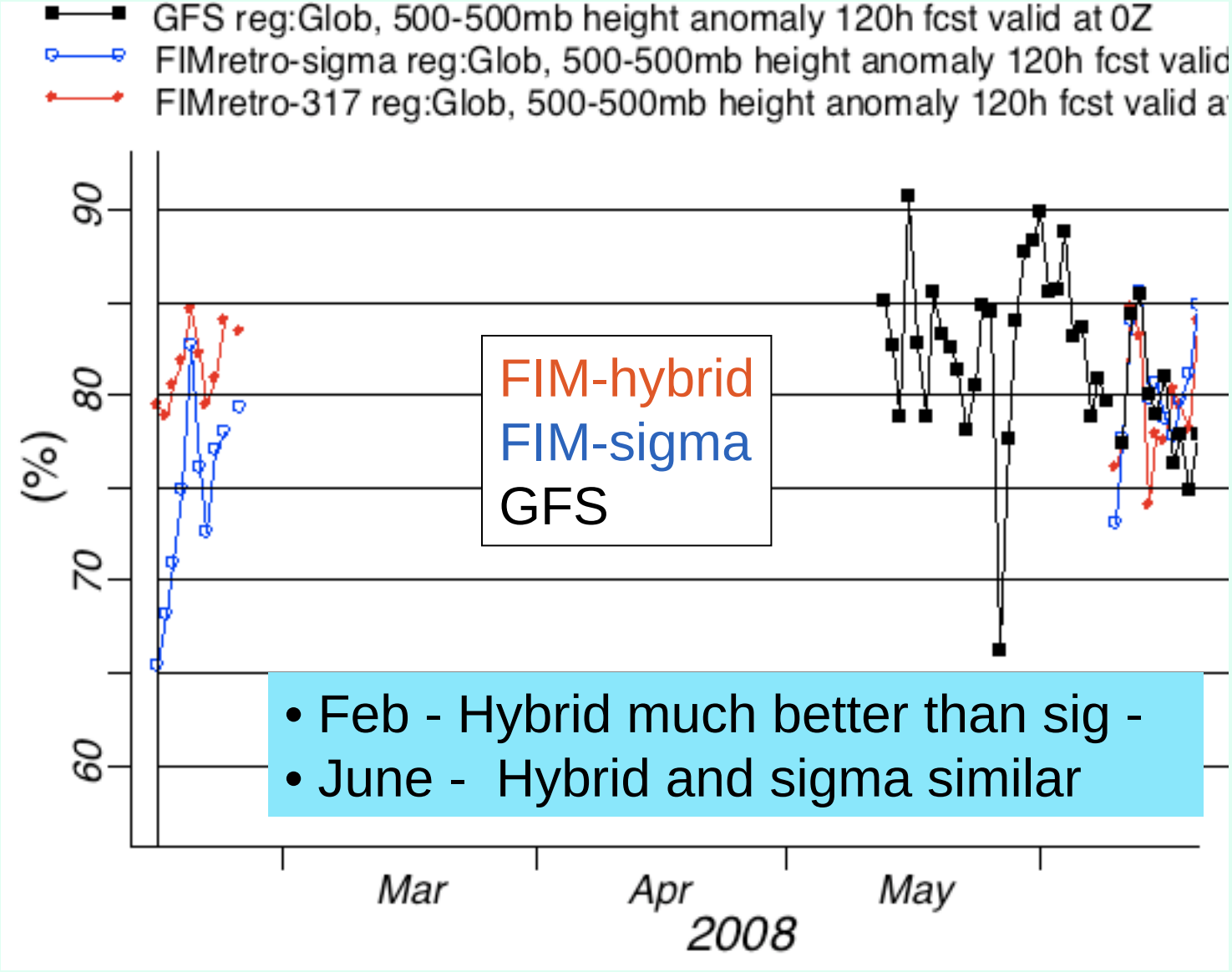


5-day 500hPa height anomaly correlation coefficient Sept 08



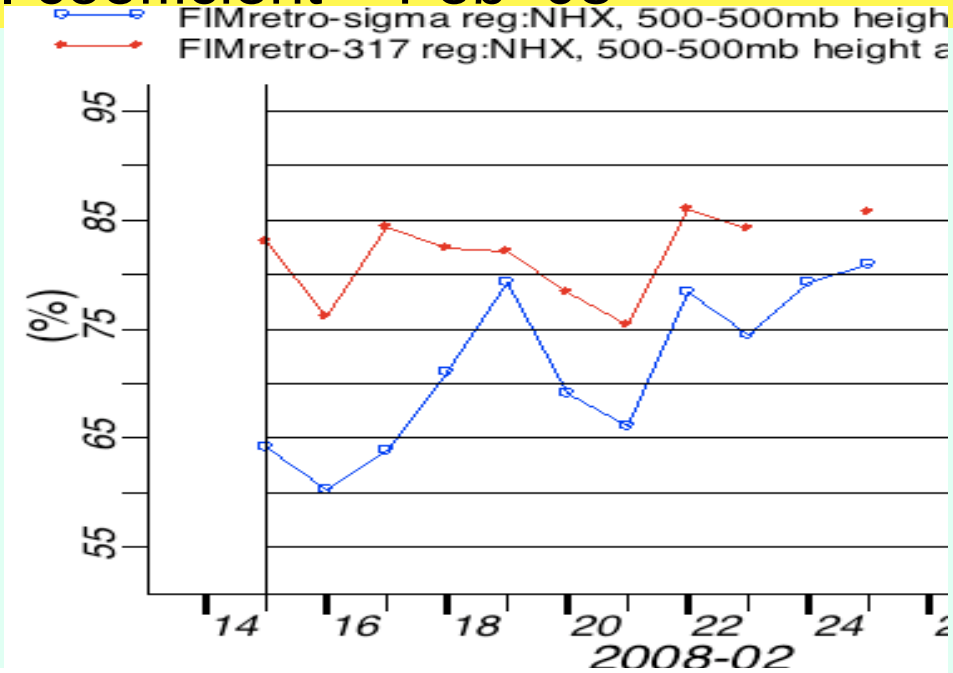
- Hybrid better than sig - 7 cases out of 11

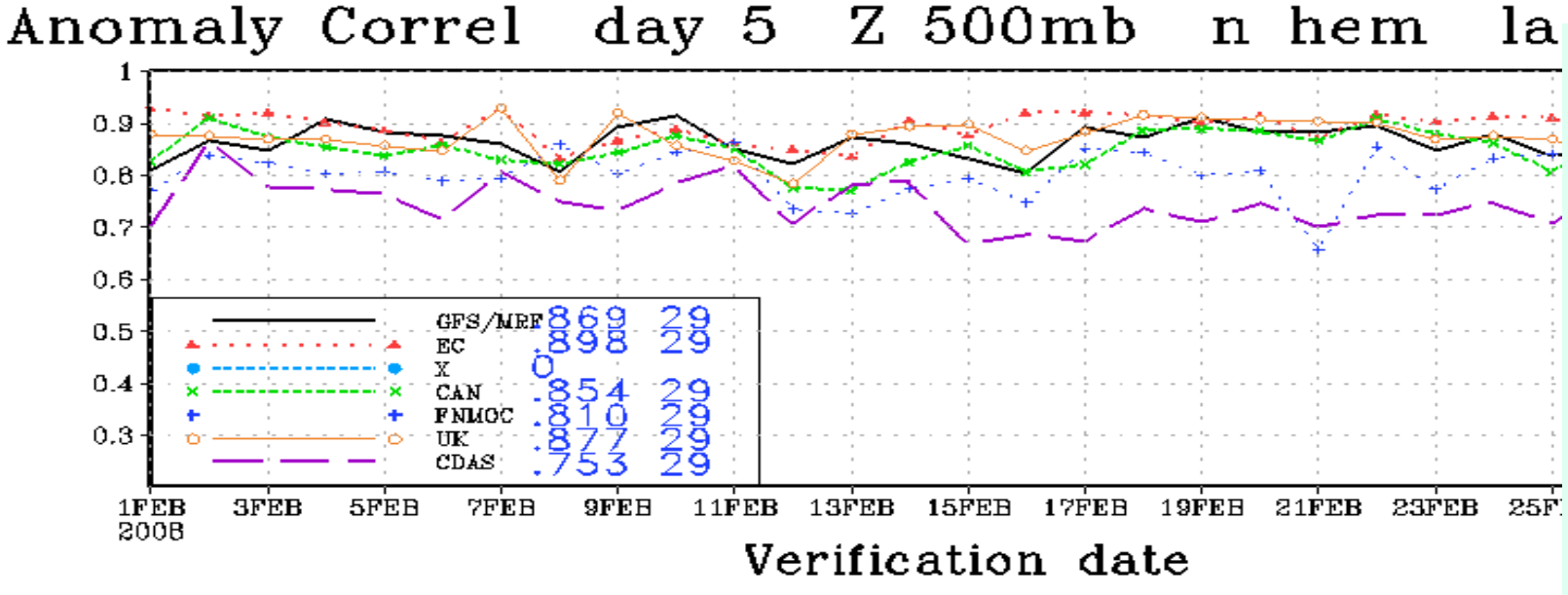
500hPa ht anomaly corr. coefficient - Feb, June 08



500hPa ht anomaly corr. coefficient - Feb 08

FIM-hybrid
FIM-sigma
GFS

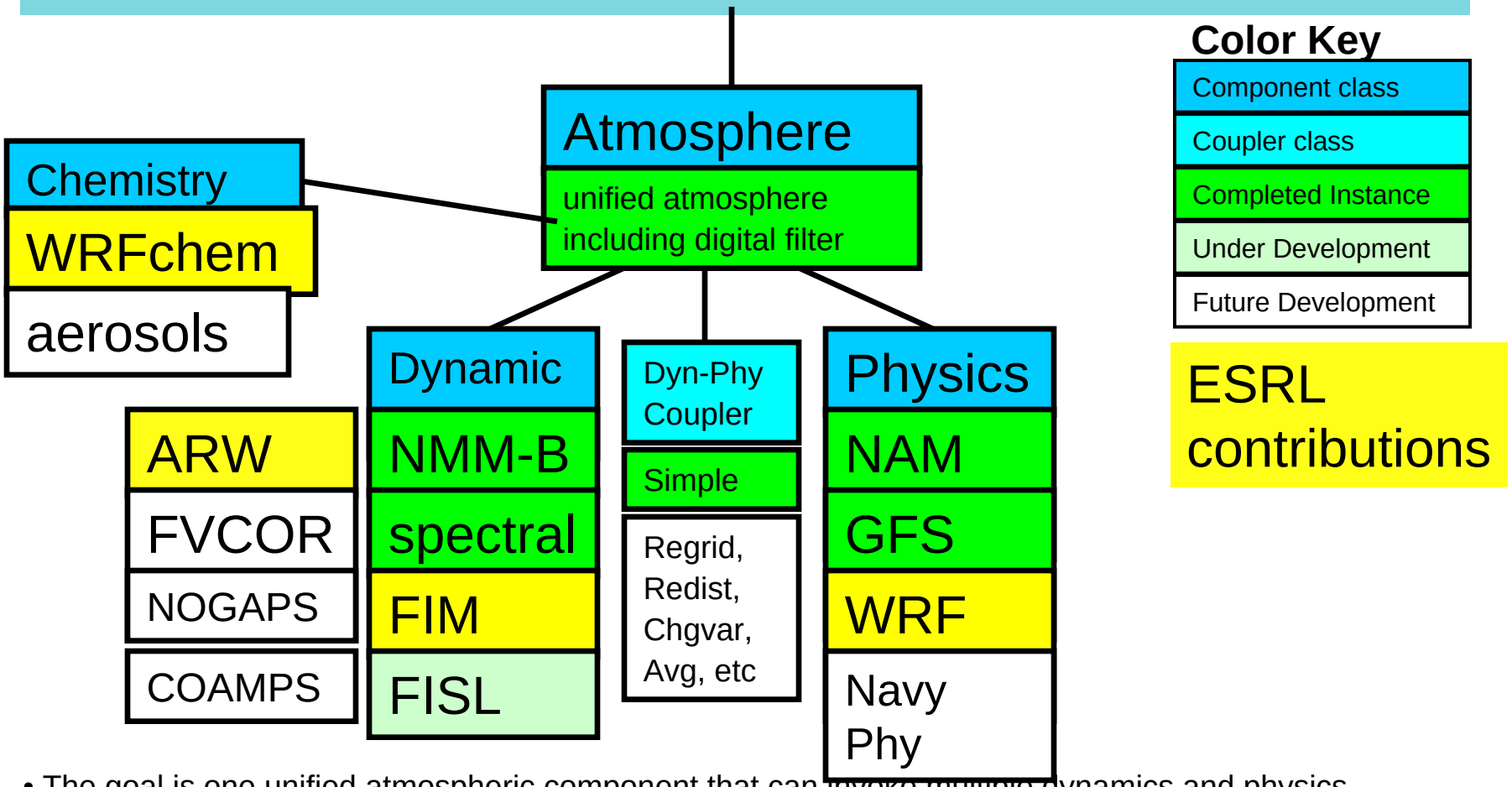




The bigger picture within NOAA for operational prediction with earth system models - ESMF

- **Earth System Modeling Framework**
  - Conventions for coupling between earth system model components
- Community effort, partially supported by NOAA (also NCAR, NASA, DoD, etc.)
- ESMF structure used for **NEMS**
  - **NOAA Environmental Modeling System**
  - Earth system coupling framework

NCEP Architecture using ESMF



- The goal is one unified atmospheric component that can invoke multiple dynamics and physics.
- At this time, dynamics and physics run on the same grid in the same decomposition, so the coupler literally is very simple.

Summary

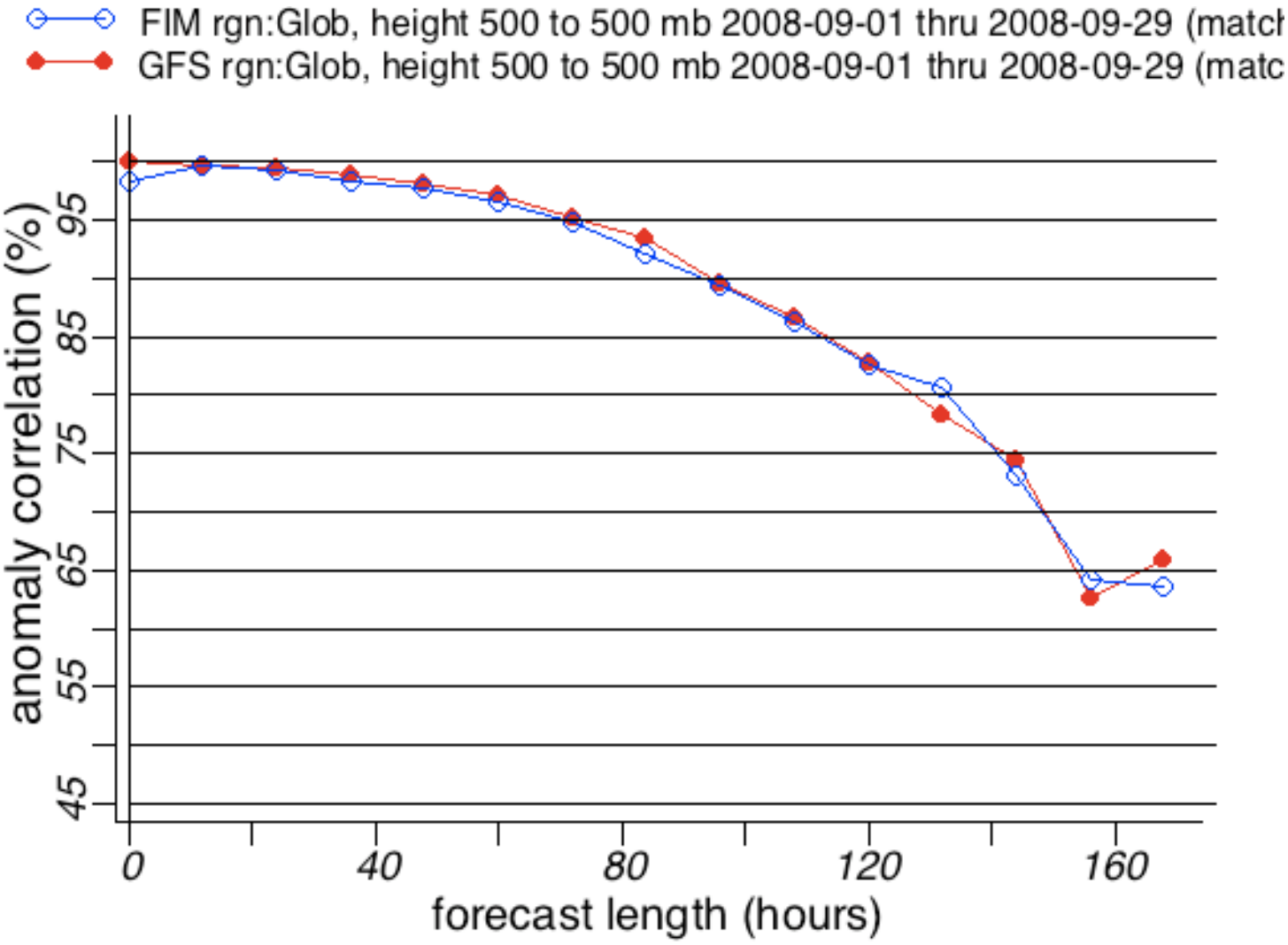
- **FIM - global model designed at NOAA/ESRL with hybrid isentropic-sigma (ALE) and icosahedral horizontal grid. Still in debugging/evaluation stage.**
- **Significant progress in FIM forecast skill from Aug08 changes, now comparable with GFS in 5-day 500hPa anomaly correlation correlation**
- **Retro testing over extended period starting for different components of FIM**
  - **hybrid-theta-sigma vs. sigma** (Feb, June, Sept 2008 10-days each)
    - Slightly improved 500hPa ACC, temp/wind
    - Noisier in FIM-hybrid -- upper BC?
    - Issue on interpolation to FIM init conds?
    - More tests to follow
  - resolution, physics frequency, etc.

- From Rainer Bleck HYCOM/ocean model talk

"Hybrid" means different things to different people:

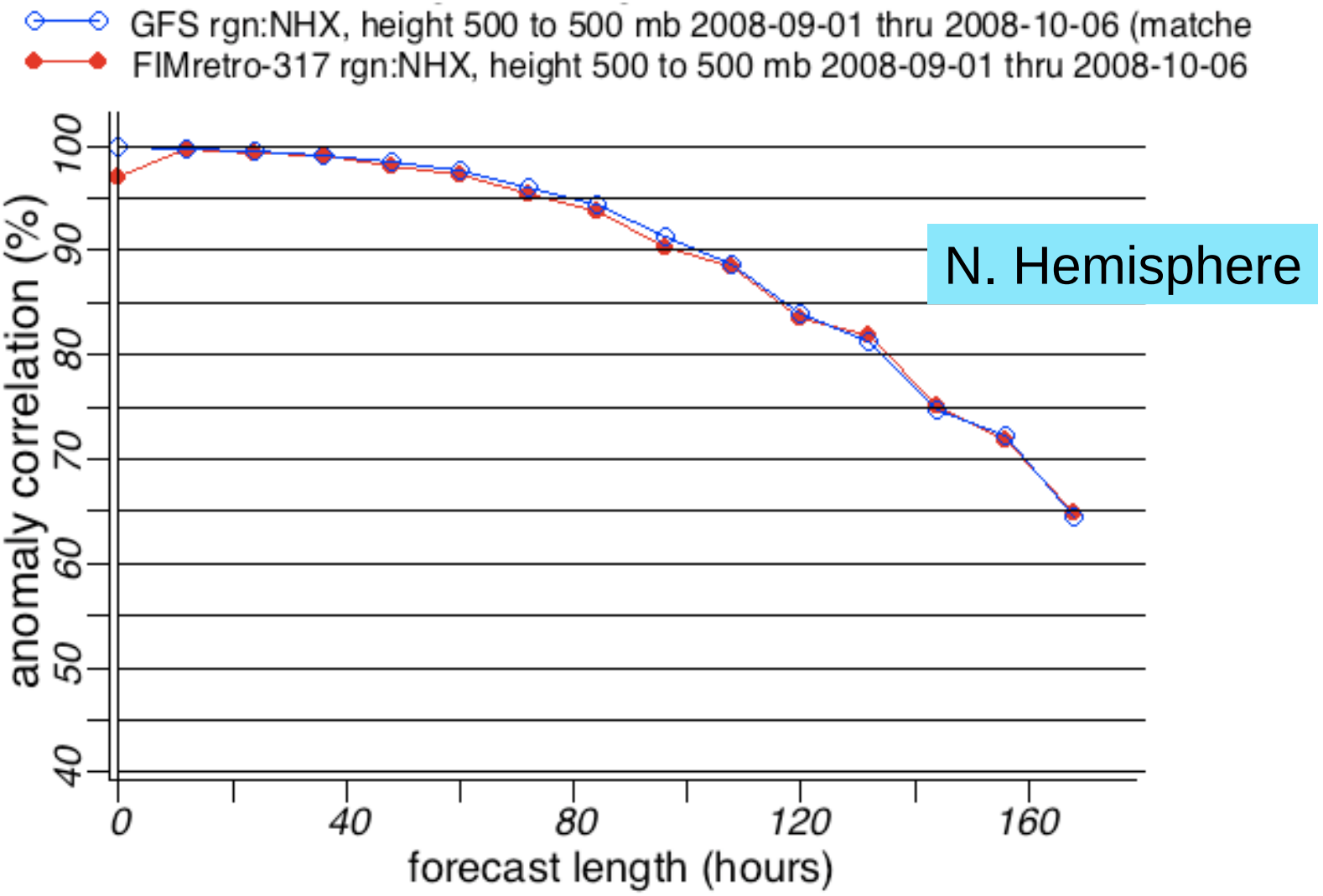
- linear combination of 2 or more conventional coordinates (examples: sigma, z+rho, z+rho+sigma)
- ALE (Arbitrary Lagrangian-Eulerian) coordinate

ALE maximizes size of isopycnic subdomain
(isentropic subdomain for atmospheric model)

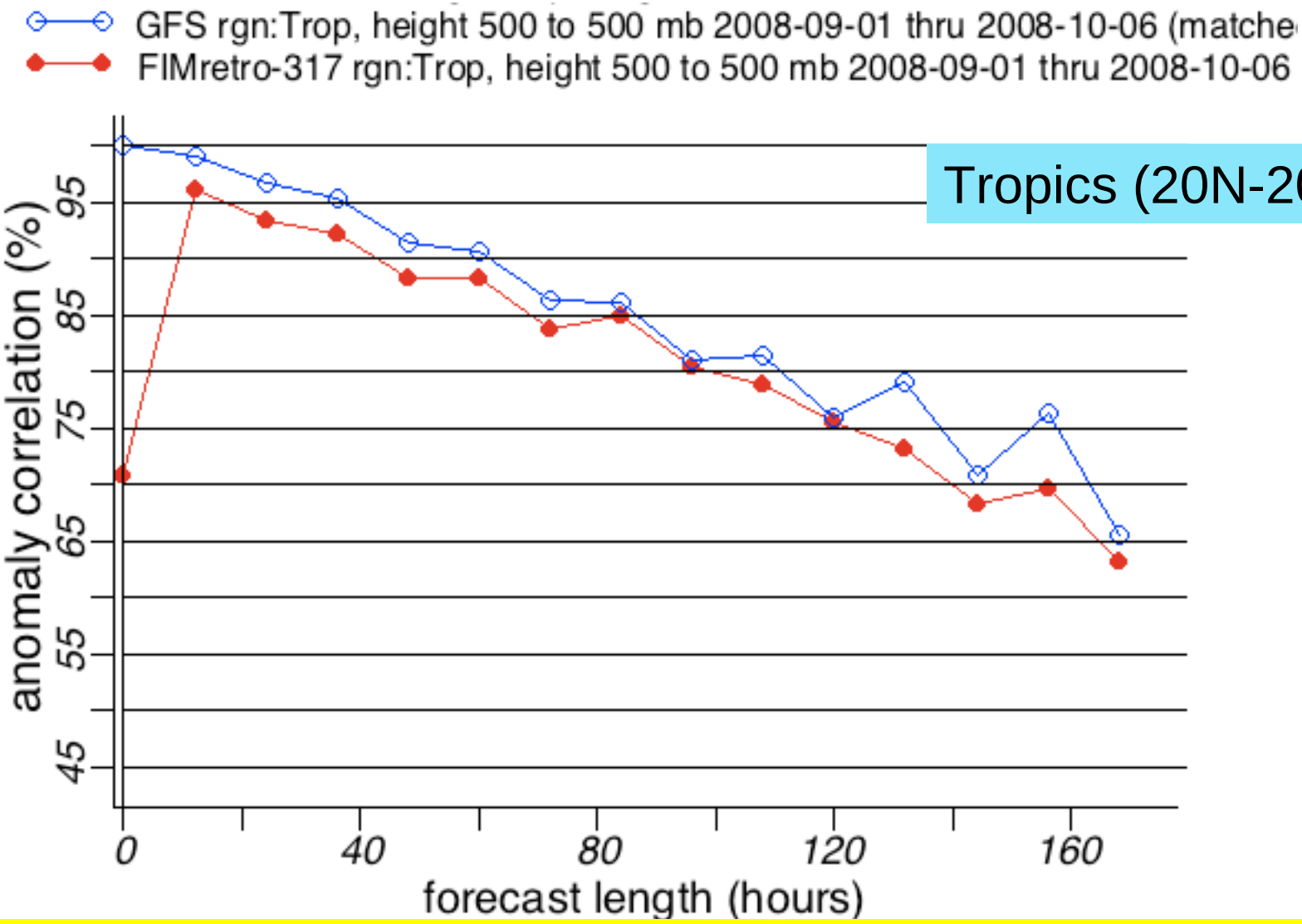


-Close performance for FIM and GFS out to 120h, GFS slightly better for 144, 168h

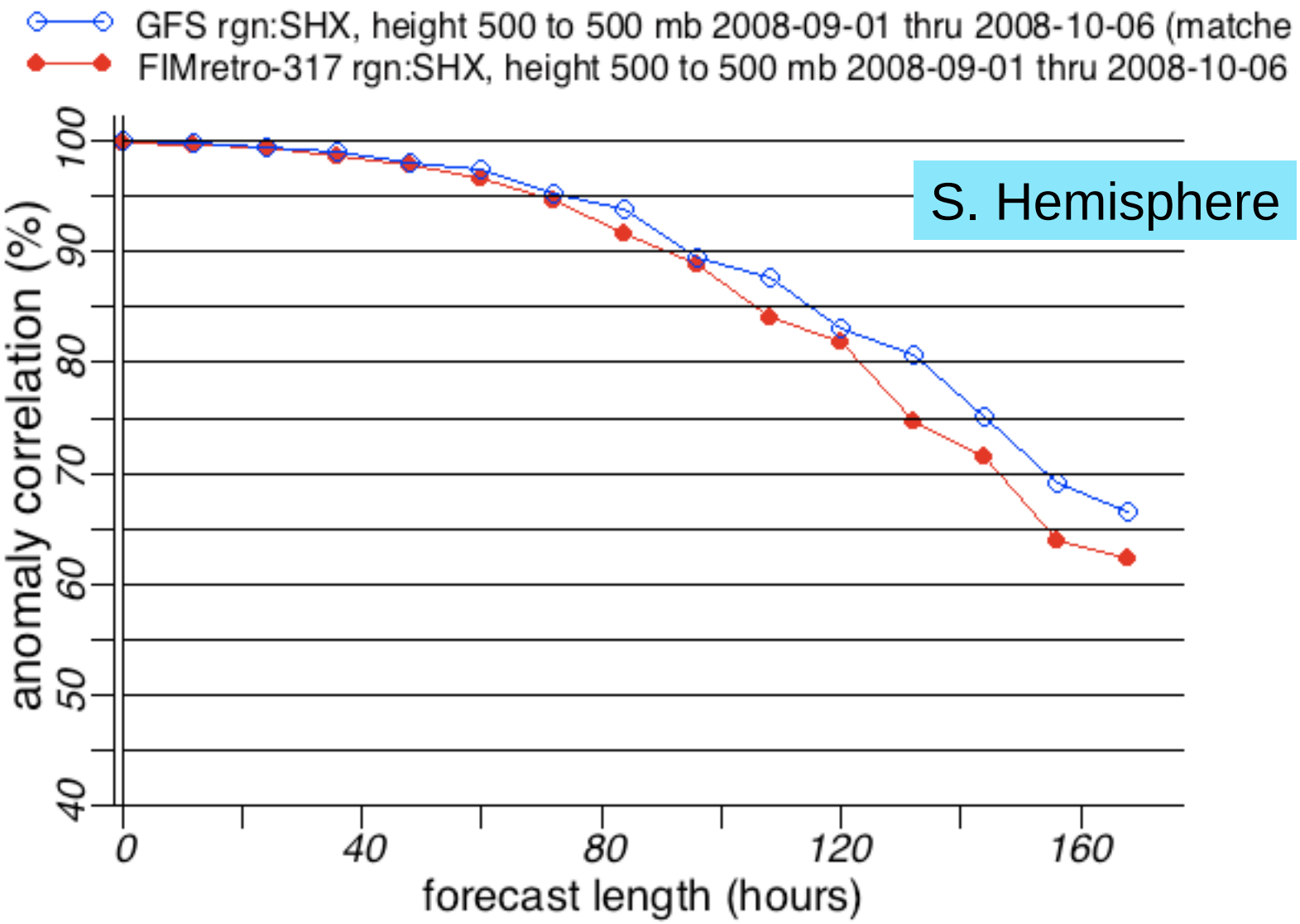
- More cases for times that are multiples of 24h



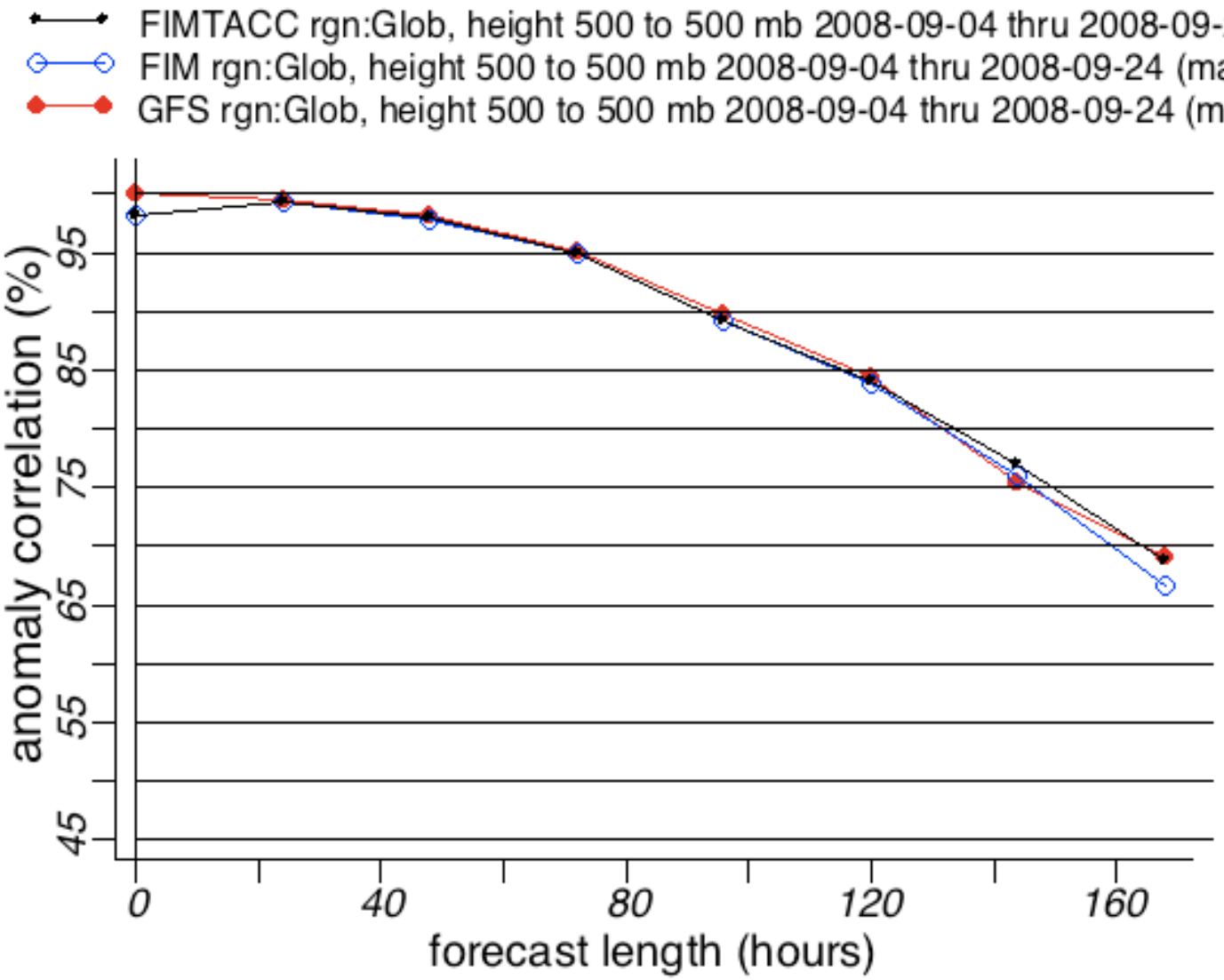
-Close performance for FIM and GFS



- GFS better than FIM
- Problem with heights in FIM initial conditions



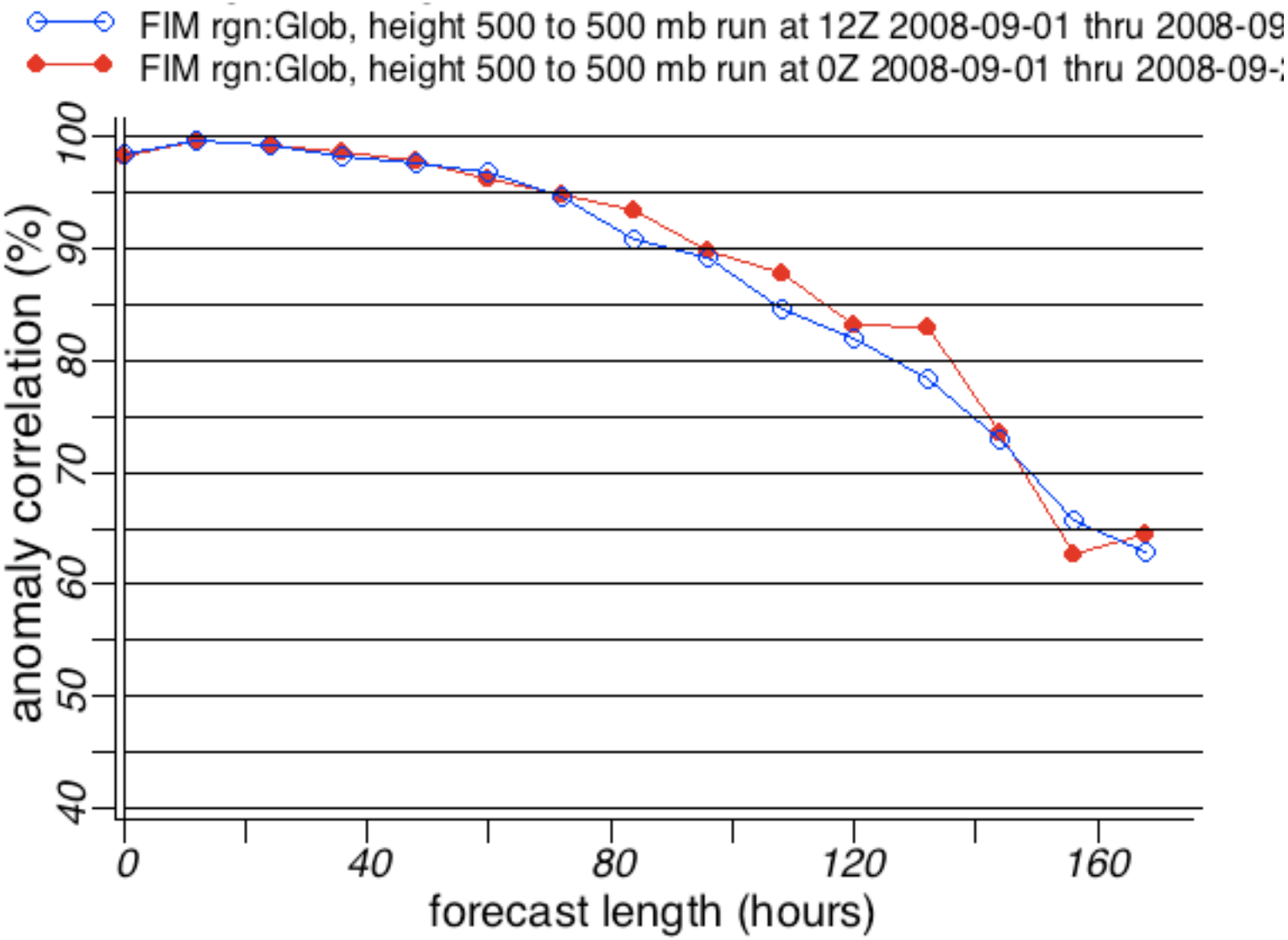
- GFS better than FIM



FIM9 (15km) slightly better than FIM8 (30km)
FIM 00h grids degraded compared to GFS IC

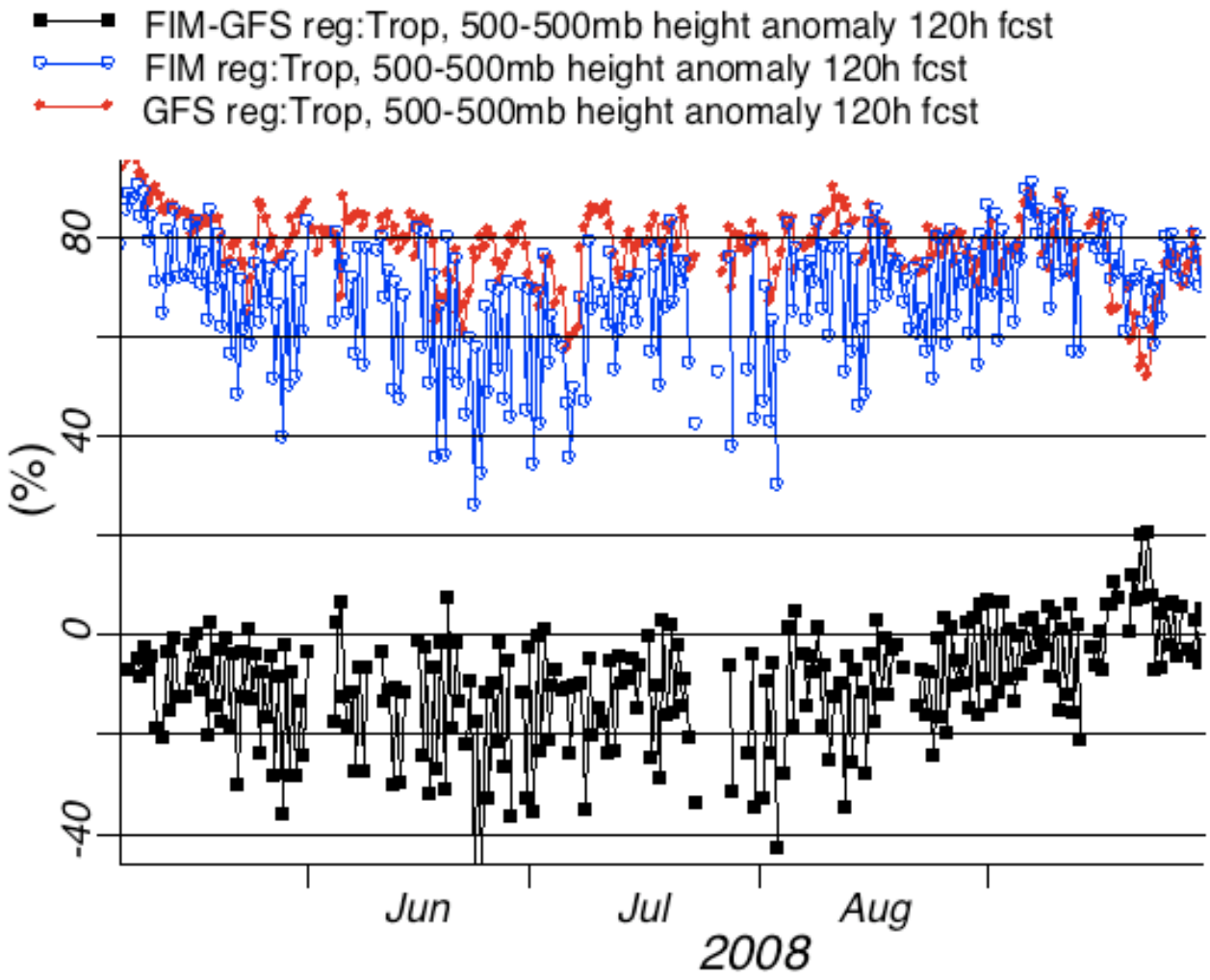
Current issue

- Problem with FIM initial height fields
- More prominent at 12z than 00z

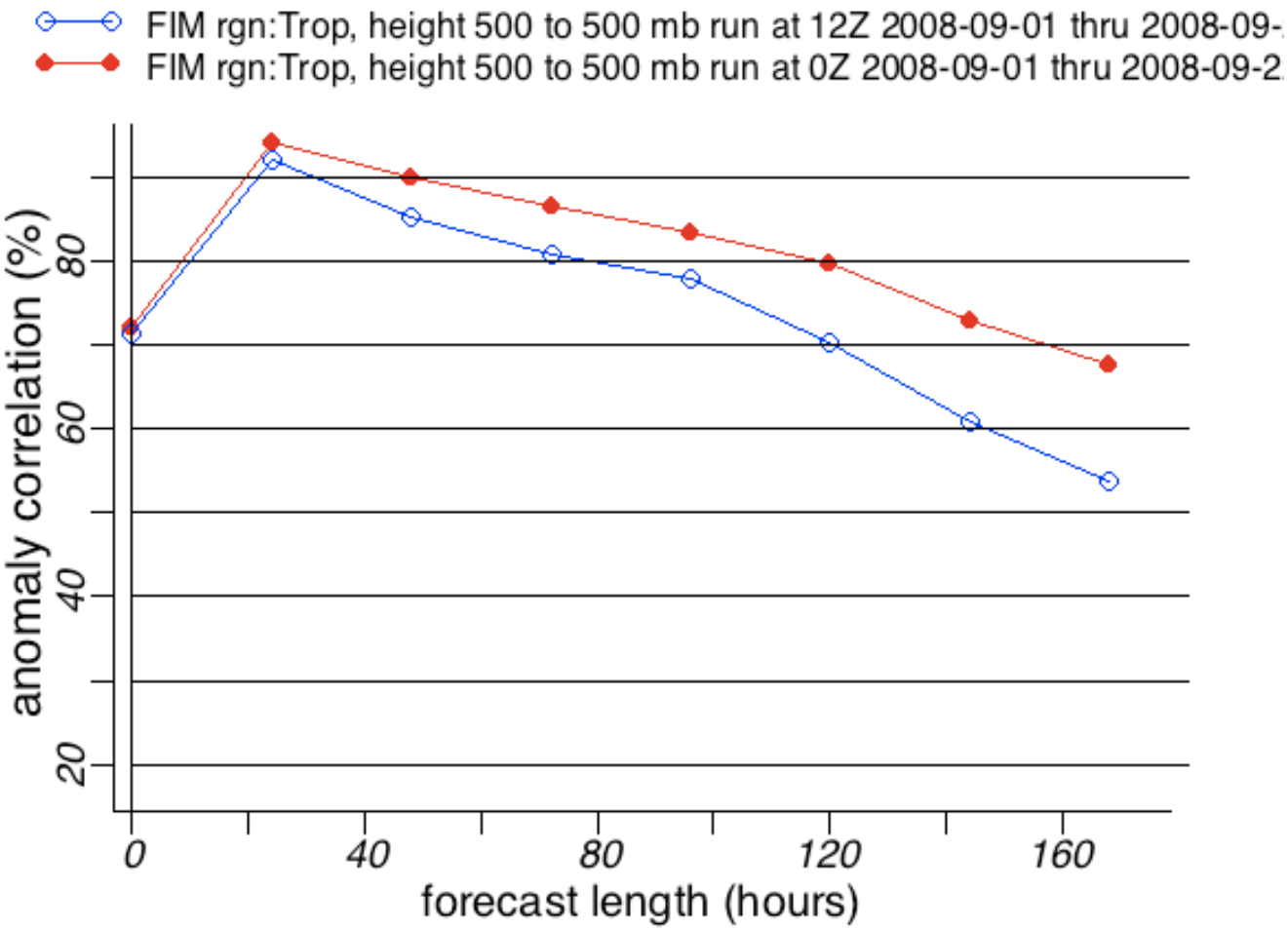


Generally better skill for FIM runs initialized at 00z than for those those initialized at 12z

[NOTE: Many fewer cases at verif times not divisible by 24]



- Tropics - FIM comparable to GFS in late September but not early Sept

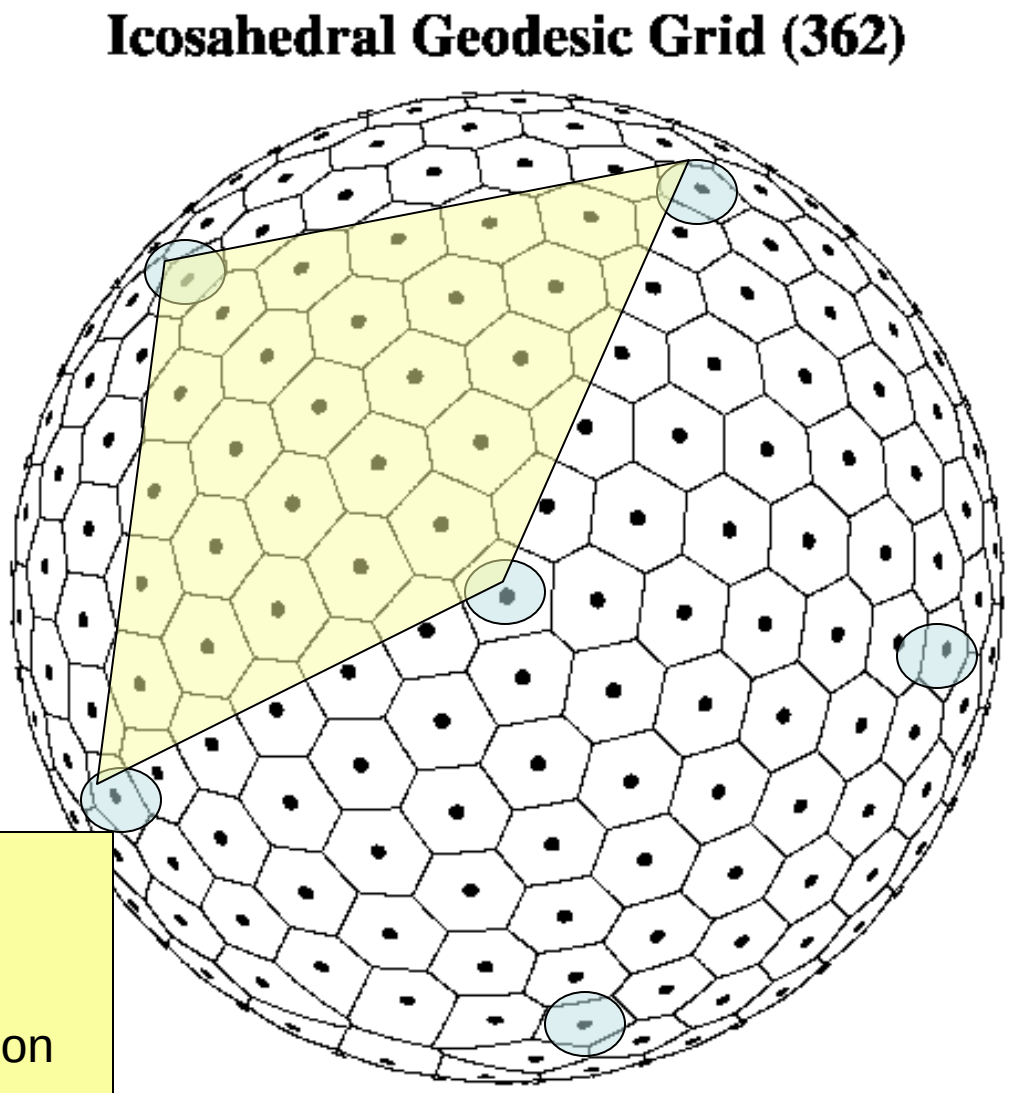


-Tropics - FIM 120h skill much poorer for 12z init than for 00z init

- FIM initial height problem also more prominent in tropics

Icosahedral grid

- 6 rhombi covering sphere
- All point volumes - *hexagons* (except 12 points at rhombi corners - pentagons)
- Map-scale factor variation – 0.95
- Grid resolution example - level-5 icosahedral grid – 240km resolution)



((2**n)**2)*10 + 2 = no. cells

5th level -
(32**2)*10 + 2 = 10242 ~240km resolution
6th level – 40962 cells ~120km resolution
7th level – 163842 cells ~60km resolution
8th level – 655,362 cells ~30km resolution
9th level – 2,621,442 cells ~15km resolution