Theme 2: Modeling, Data Assimilation, and Advanced Computing

Stan Benjamin

Introduction, Global Modeling Development

From NOAA Research 5-Year Plan

- From “overarching research questions”
  - “4. **What improvements to *observing systems, analysis approaches, and models* will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes? “**

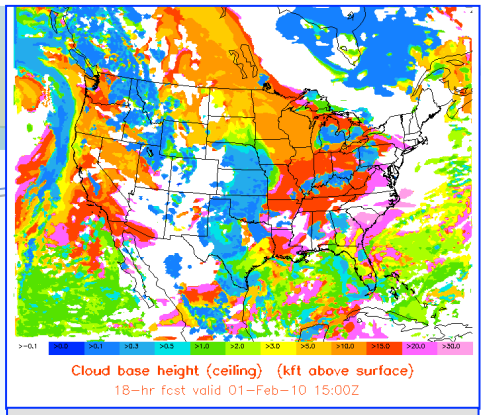
From NOAA Research 5-Year Plan

- From "overarching research questions"
  - "4. **What improvements to *observing systems, analysis approaches, and models* will allow us to better analyze and predict the atmosphere, ocean, and hydrological land processes? "**

ESRL role:

- **Develop new or improved models and assimilation techniques**
  - **improve prediction and understanding of phenomena**
  - **support operational forecasting and research**
- **Apply those "sharpened tools" to --**
  - **aviation, severe weather, hydrology, energy, other**

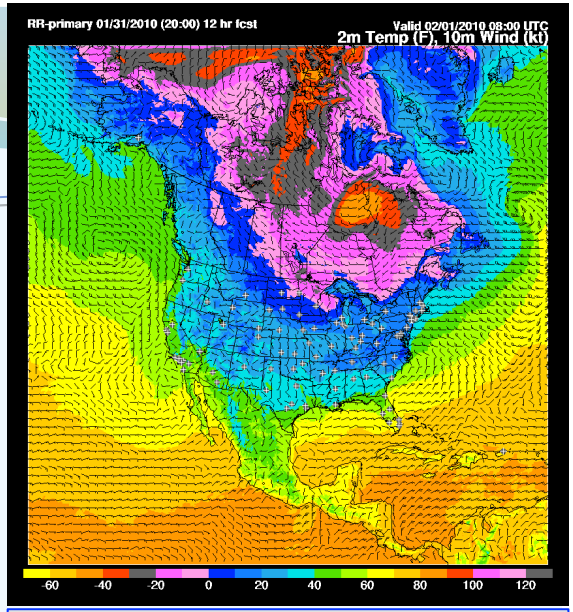
Themes on ESRL Efforts in Modeling/Assimilation



18h Ceiling fcst – RUC
Valid 15z 1 Feb 2010

- ESRL activities have been *diverse*
  - from 1 to 12-h-forecast to interseasonal NWP applications
  - strongly focused around interaction with NCEP but with other applications
- ESRL's modeling/assimilation activities toward operations
  - ***primarily regional*** **(RUC, WRF, LAPS)** but with…
  - **rapidly increasing *global component*** in last three years (FIM/NIM, EnKF assimilation)
- ESRL's advanced computing facility and related software development have been essential for Theme 2 achievements.

Themes on ESRL efforts in modeling/assimilation



Rapid Refresh 12-h fcst
– 2m temp - Using WRF, GSI

- ***Collaboration* with partner labs** in development of modeling, data assimilation, post-processing, advanced computing
  - already generally strong (NCEP, NCAR, NASA, OAR (NSSL, GFDL, AOML, ARL), universities), poised to grow stronger
- A strong growth toward development of **coupled models**
  - WRF-chem, related FIM-chem
  - FIM-atmosphere-ocean coupled model on common icosahedral grid (extendable to nonhydrostatic NIM also)
  - Improvements in land-surface (soil, snow, vegetation) models

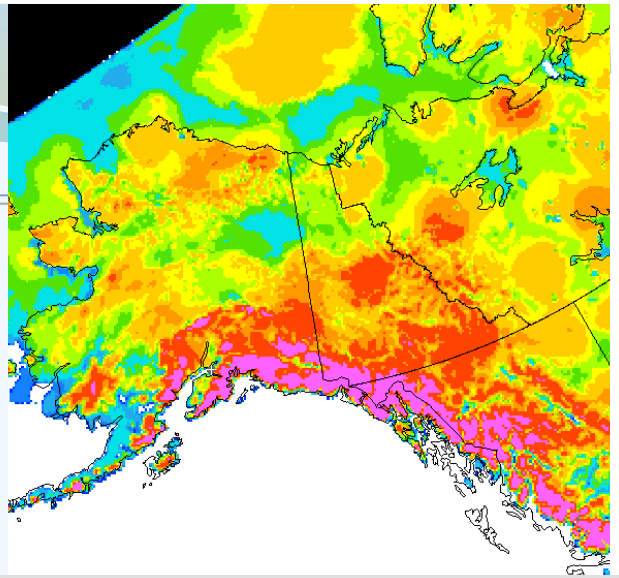
Successes at ESRL

- **Operational impacts**
  - RUC since 1994, hourly updating niche in NCEP's suite
    - First effective hourly assimilation to reduce forecast errors
    - First radar reflectivity assimilation at NCEP, implemented November 2008
  - Rapid Refresh – RUC replacement in 2010,

    3-km HRRR nest, both using ESRL-enhanced WRF
  - LAPS – data assimilation component of AWIPS
    - Commonly used in NWS Forecast Offices, supports local modeling
  - FIM global model development (upcoming)
  - Ensemble Kalman Filter assimilation (upcoming)

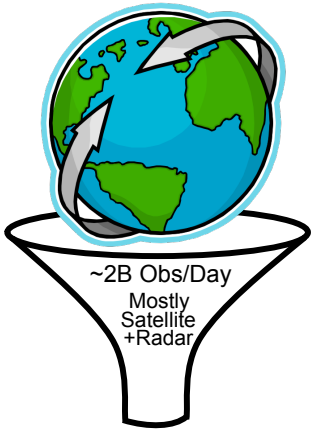
Successes at ESRL

- **Contributions to community**
  - Key role in development of WRF
    - Parameterizations – convection, land-surface model, cloud physics, WRF-chem. PBL schemes
    - Digital filter initialization (key for 1-h cycle)
  - Development of GSI for cloud assimilation, application to WRF-ARW
  - Demonstration of uncertainty forecasts, especially for QPF via NOAA Hydrometeorology Testbed (HMT)



Snow water equiv – 1Feb10
RR-WRF cycled using RUC LSM

NOAA's NWS Model Production Suite



Global Data Assimilation

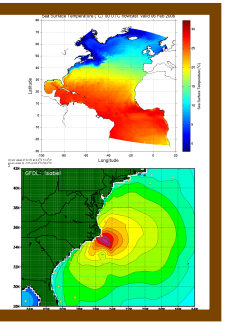
Global Forecast System

Climate CFS
MOM3

Hurricane
GFDL
HWRF

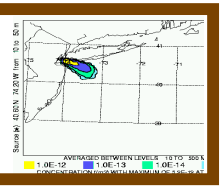
Coupled

Oceans
HYCOM
WaveWatch III

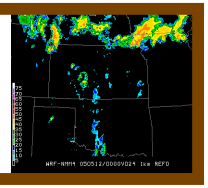


North American Mesoscale
WRF NMM

Dispersion
ARL's HYSPLIT



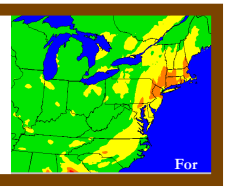
Severe Weather
WRF NMM
WRF ARW



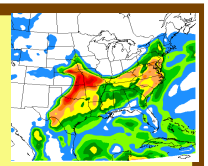
North American Ensemble Forecast System
GFS, Canadian Global Model

Short-Range Ensemble Forecast
WRF: NMM+ARW
ETA, RSM

Air Quality
NAM+CMAQ

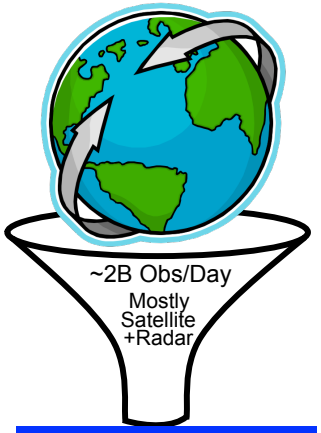


Rapid Update for Aviation, Severe Weather, Energy



NCEP overview

Contributions from ESRL toward NOAA's Future Model Production Suite



EnKF, hybrid DA

FIM, NIM

High-perfomance computing

CFS
MOM3

Hurricane
FIM

Coupled

Oceans
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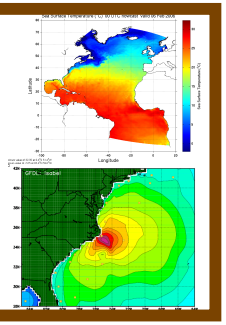
WaveWatch III



North American Mesoscale
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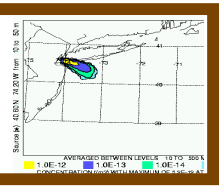
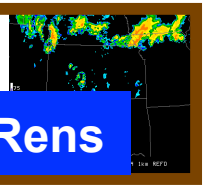


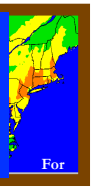
Severe Weather
HRRR, HRRRens



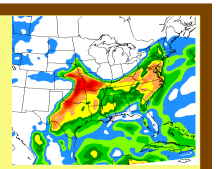
Forecast Uncertainty

Short-Range Ensemble Forecast
WRF: NMM+ARW
ETA, RSM

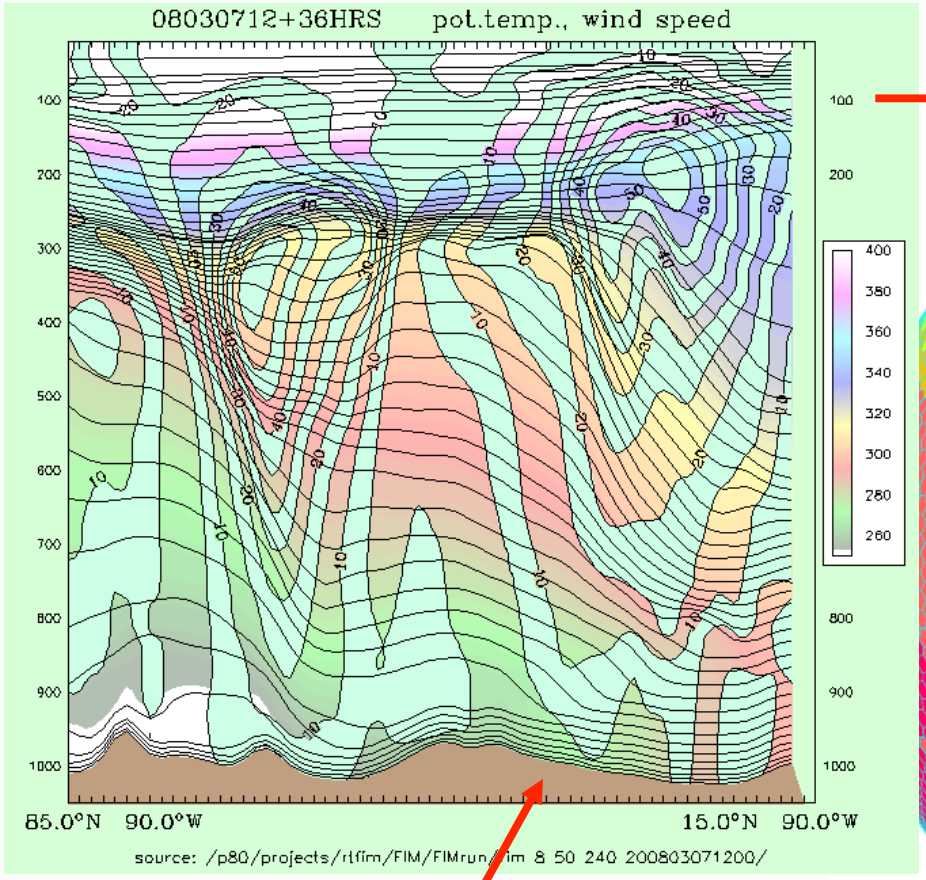
Inline chemistry

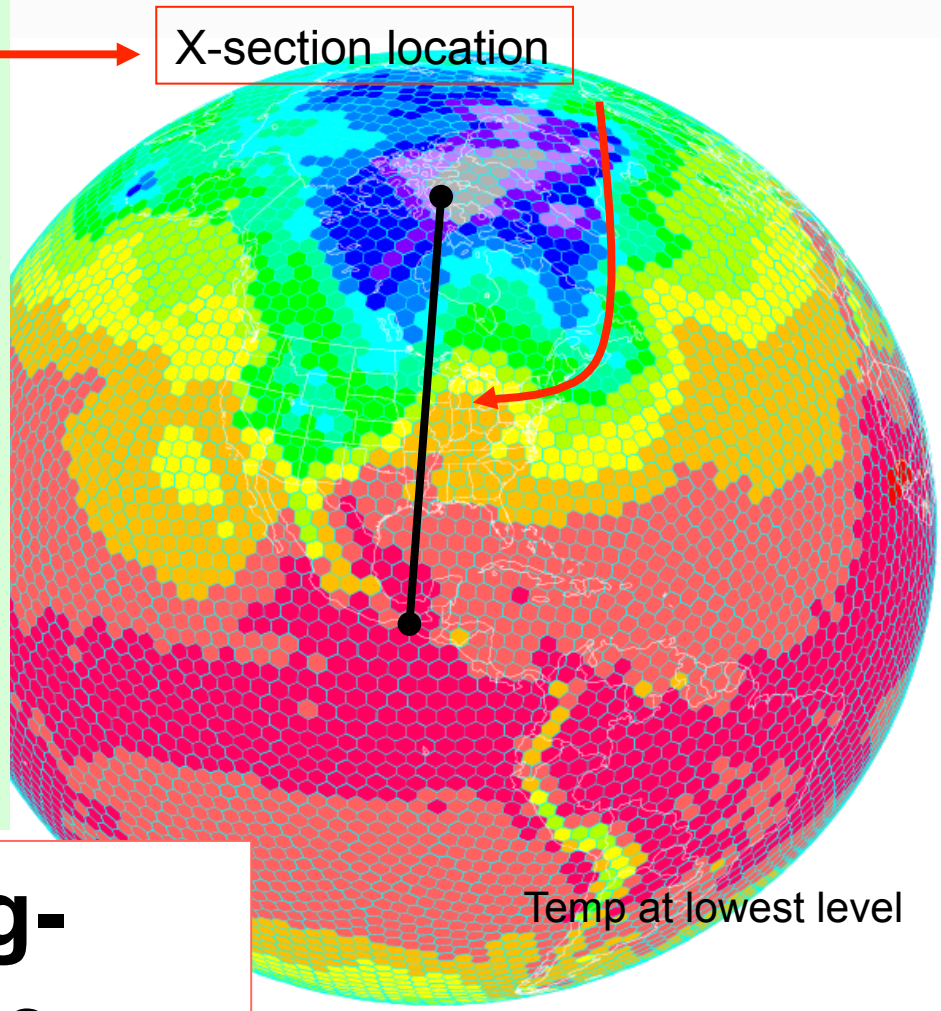


RR/HRRR
for Aviation, Severe Weather, Energy



End of Theme 2 Introduction
….. And now on to **Global Modeling**

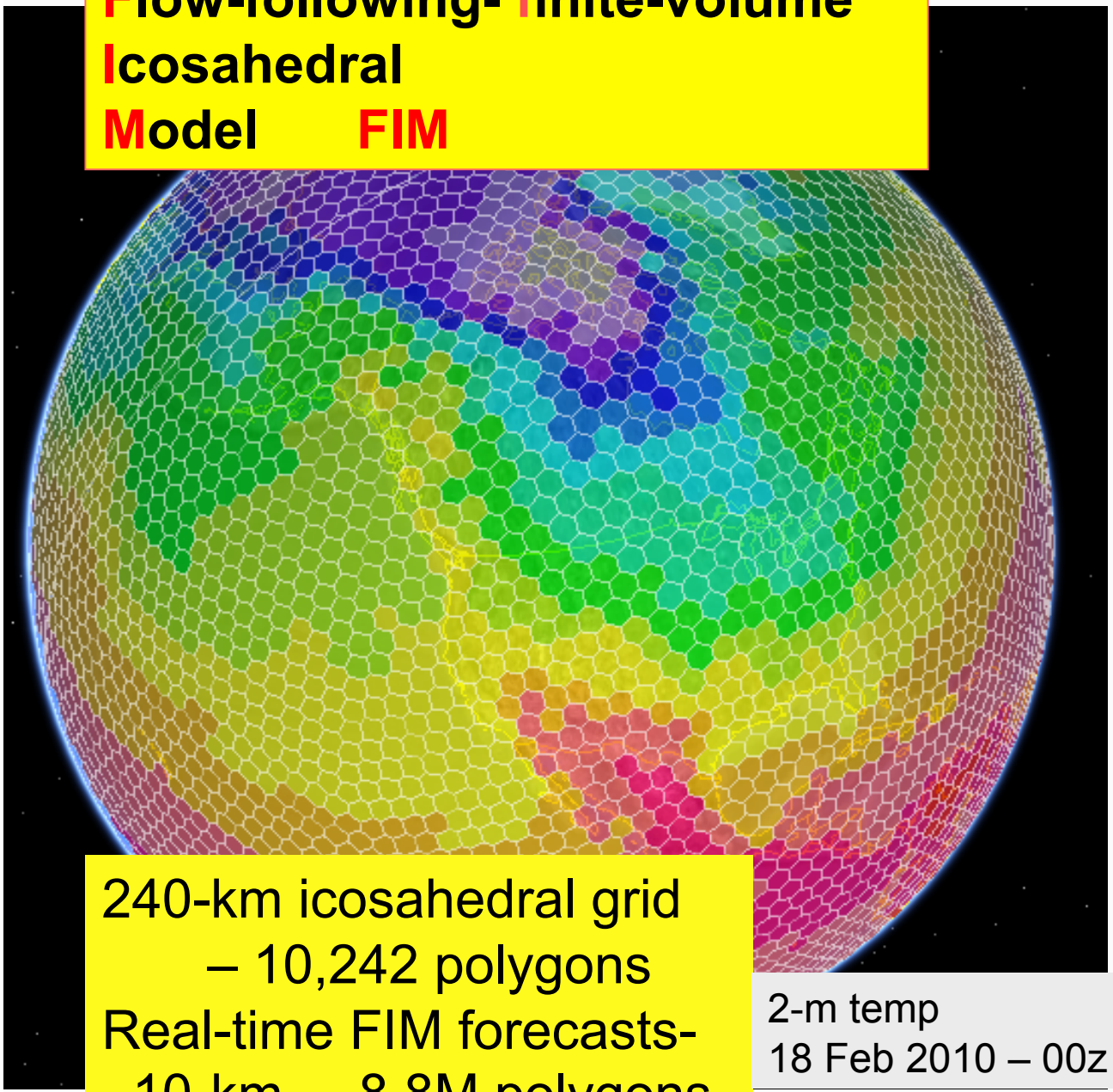




Flow-following-finite-volume Icosahedral Model FIM

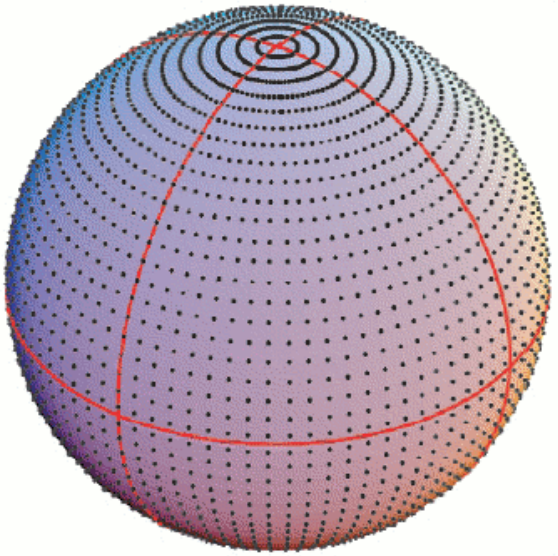
NOAA/ESRL

Flow-following- finite-volume Icosahedral Model FIM



240-km icosahedral grid
– 10,242 polygons
Real-time FIM forecasts-
10-km – 8.8M polygons

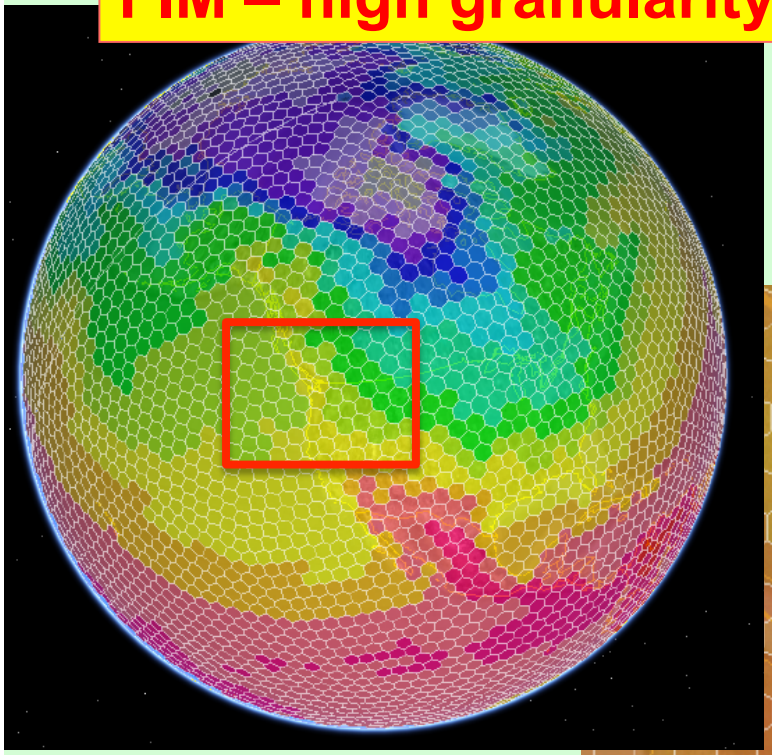
2-m temp
18 Feb 2010 – 00z

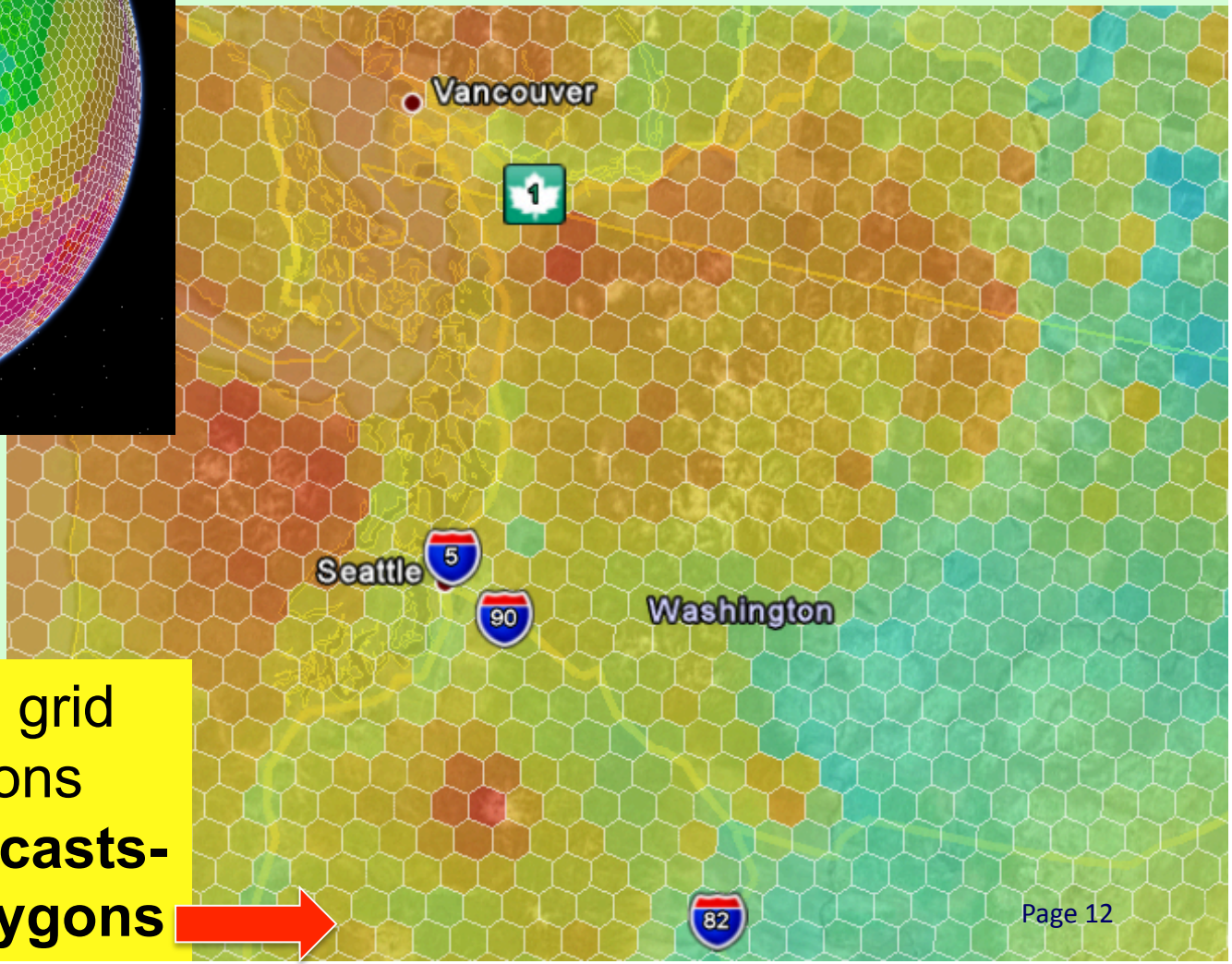


Lat-lon grid

NOAA/ESRL

FIM – high granularity with resolution

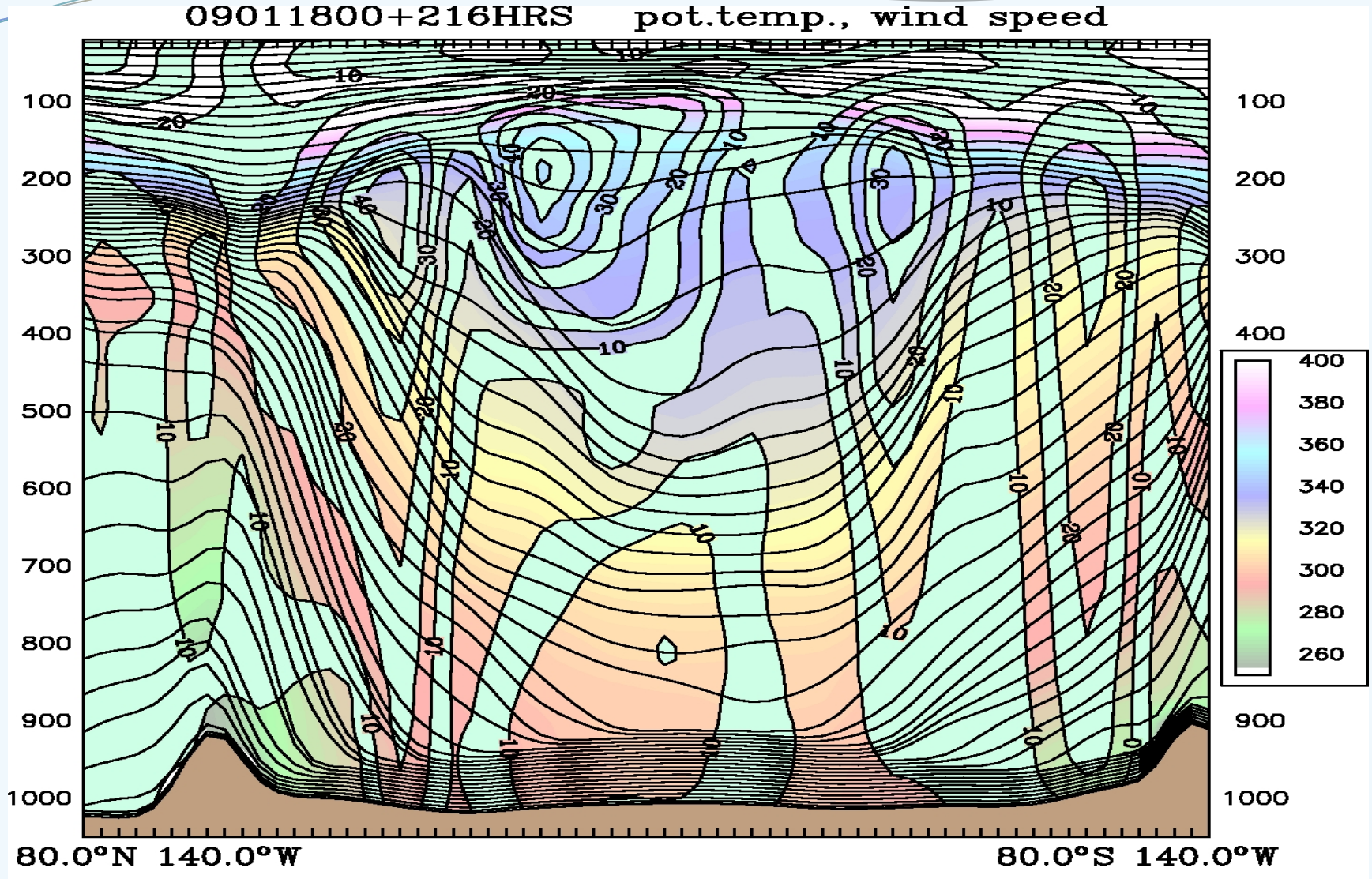




240-km icosahedral grid – 10,242 polygons

Real-time FIM forecasts- 15-km – ~4M polygons

FIM hybrid-isentropic vertical coordinate



FIM Configurations

Resolution

- Real-time testing at 30-km, 15-km, and 10-km resolution
- 64 vertical levels – hybrid θ-σ
- Ptop = 0.5 hPa, θ-top = 2200K, ~60 km

Physics

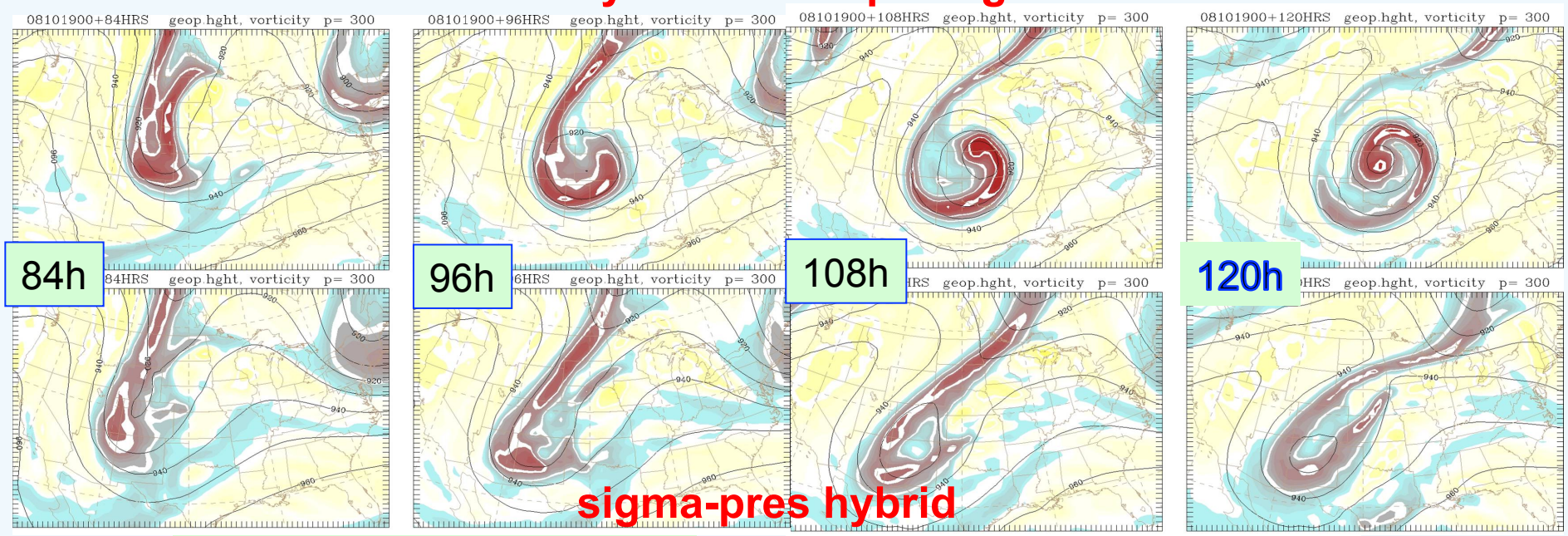
- Current real-time FIM uses GFS physics suite
- Testing with WRF physics options, WRF-chem

Initial conditions for real-time runs

1. Interpolation from GFS spectral data to FIM icosahedral hybrid θ-σ vertical coordinate
2. Ensemble Kalman using GFS T190 – FIMY parallel

FIM simulations on 60-km mesh using 2 vertical coordinate options

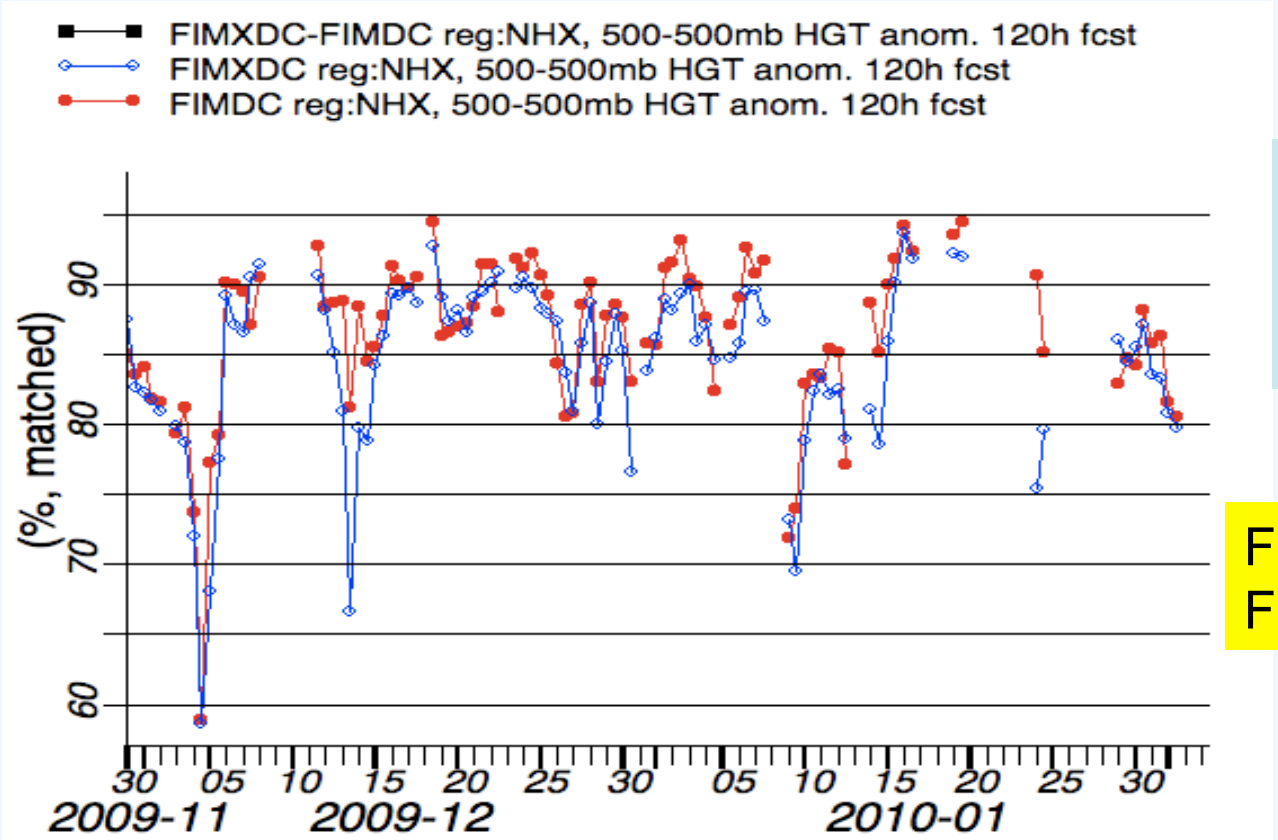
Hybrid isentropic-sigma



300-hPa height / rel vorticity

Hybrid isentropic coordinate (including PV conservation) provides sharper vortex roll-up than sigma coordinate.

Vertical coordinate comparison - parallel - FIM-hybrid θ-σ (FIM) vs. FIM-σ (FIMX)

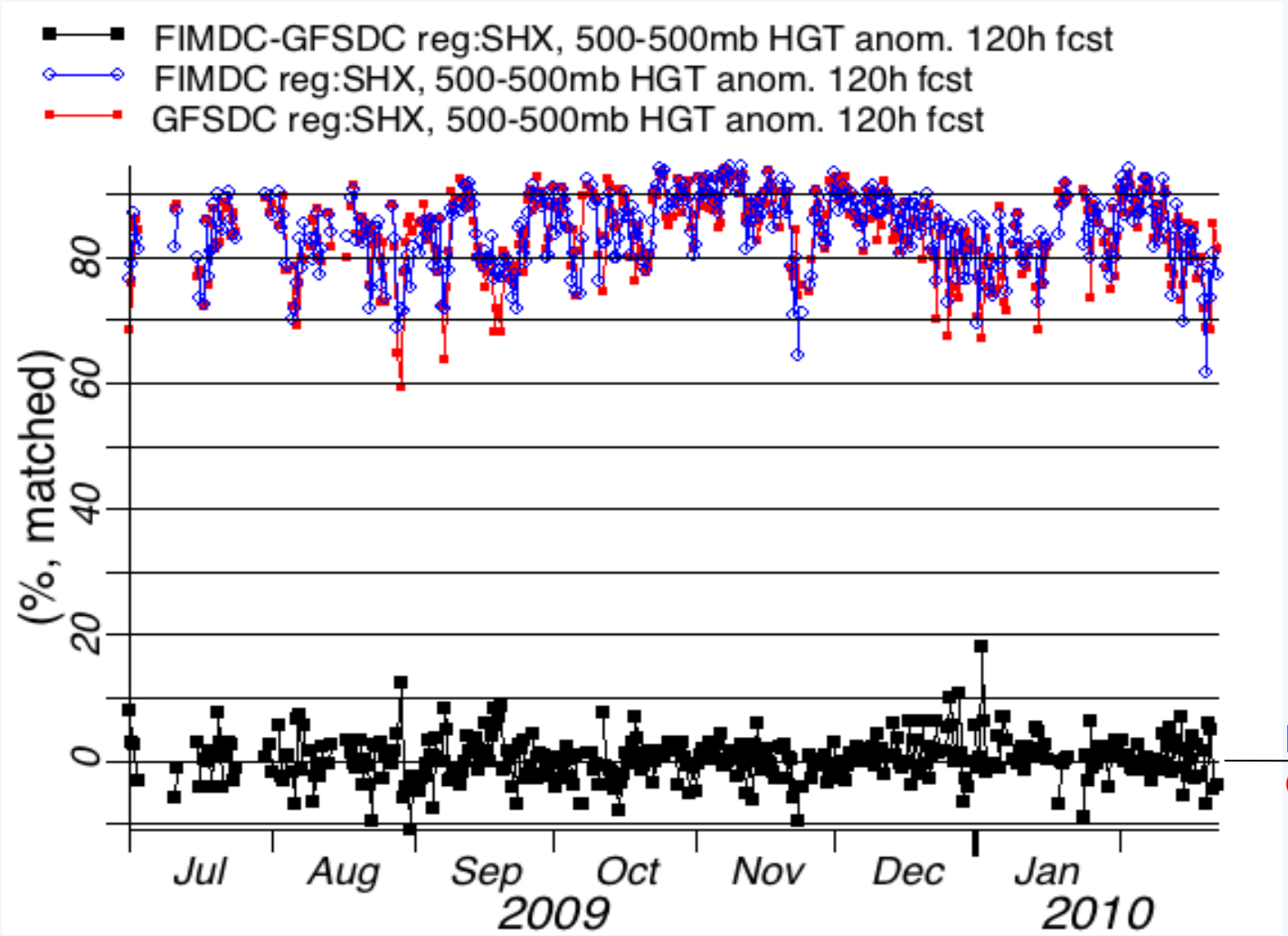


500 hPa ACC
N. Hemisphere
5-day forecasts
- vs. GFS analysis

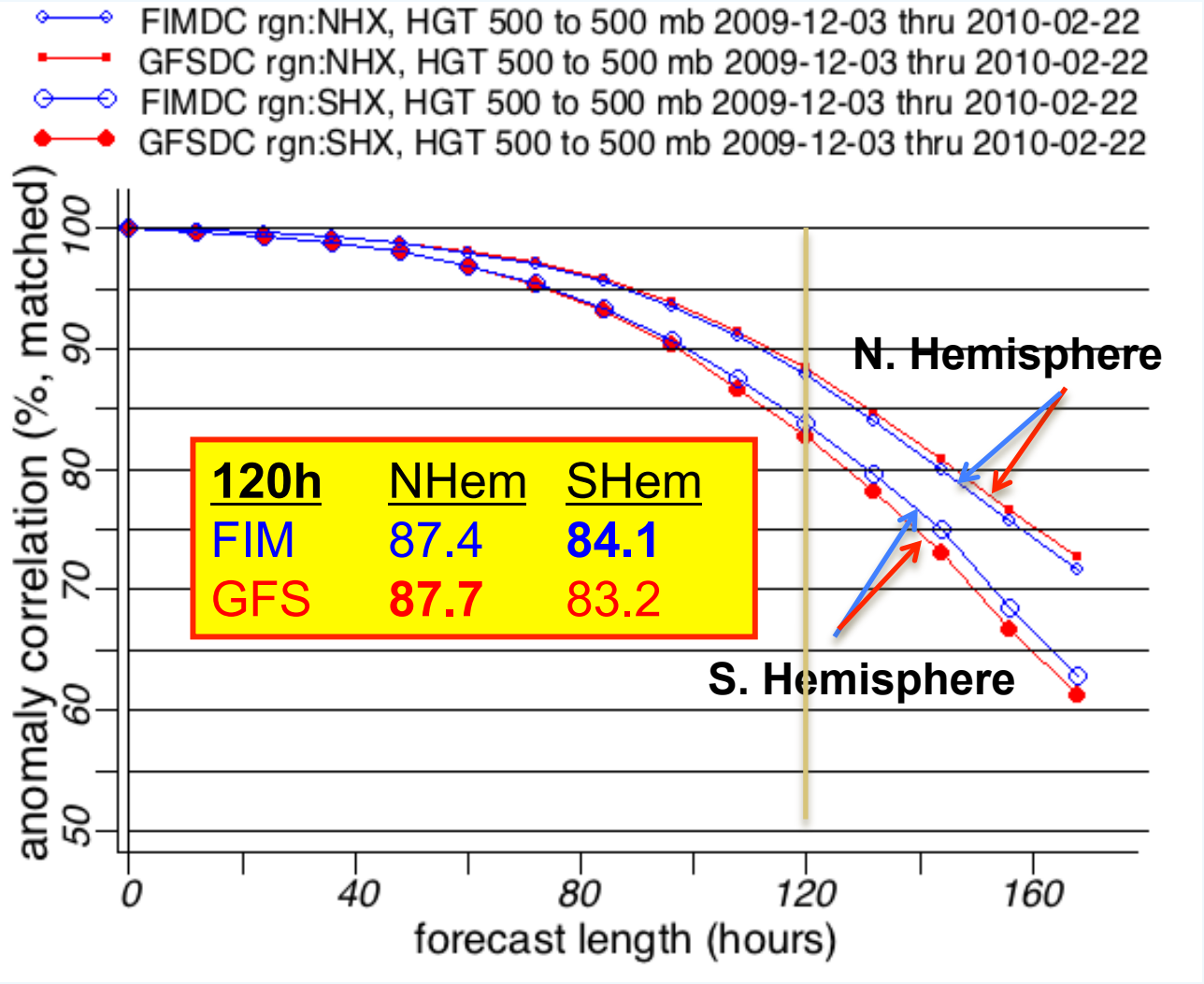
FIM (θ-σ) – **86.5**
FIM-σ – 84.6

Hybrid θ-σ coordinate provides improvement over σ (hybrid σ–p)

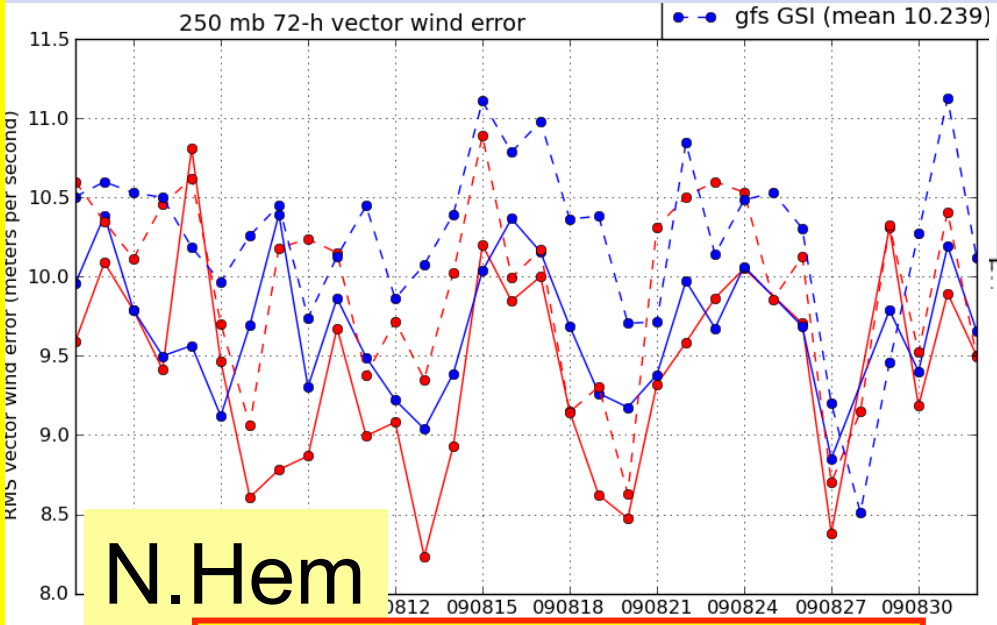
FIM vs. GFS, 500-hPa anom corr – 120h
S. Hemisphere – (GSI initial conditions for both)

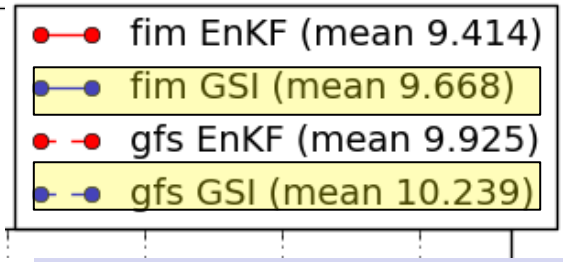


FIM vs. GFS, 500-hPa anomaly correlation (GSI initial conditions for both)



72-h **250-hPa** Wind RMS vector error (vs. analyses) ***smaller is better*** **Aug 09**



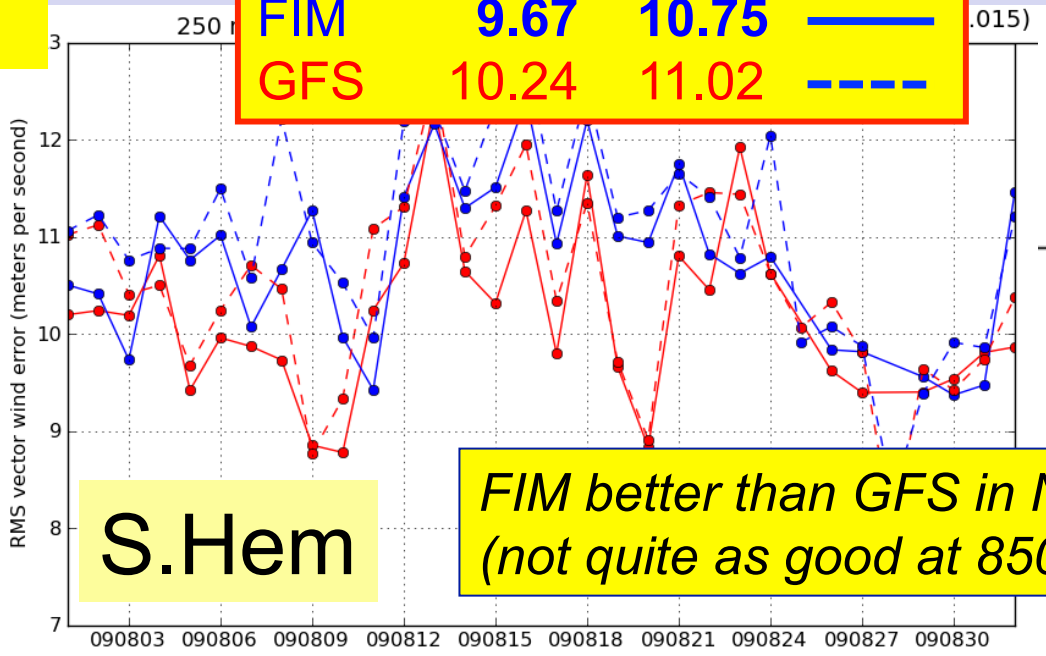


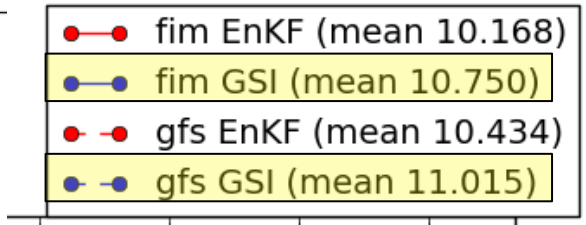
N.Hem

FIM – ——————

GFS - - - - - - - - - -

	NH	SH - (m/s)	
FIM	**9.67**	**10.75**	———
GFS	10.24	11.02	- - - -

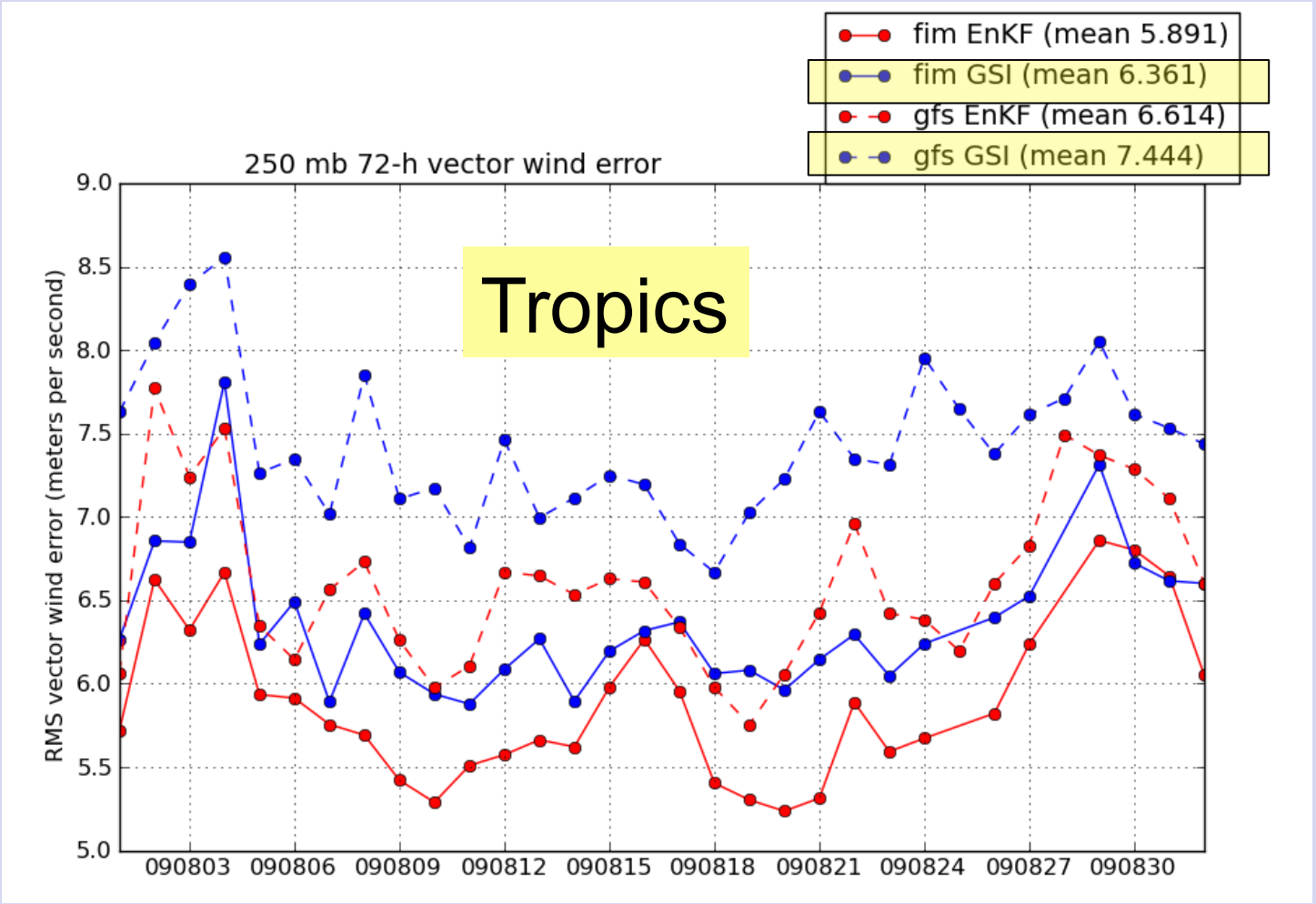




S.Hem

FIM better than GFS in NH/SH at 250 hPa, (not quite as good at 850 hPa)

72-h **250-hPa** Wind RMS vector error (vs. analyses) **smaller is better Aug 09**



FIM – ——————

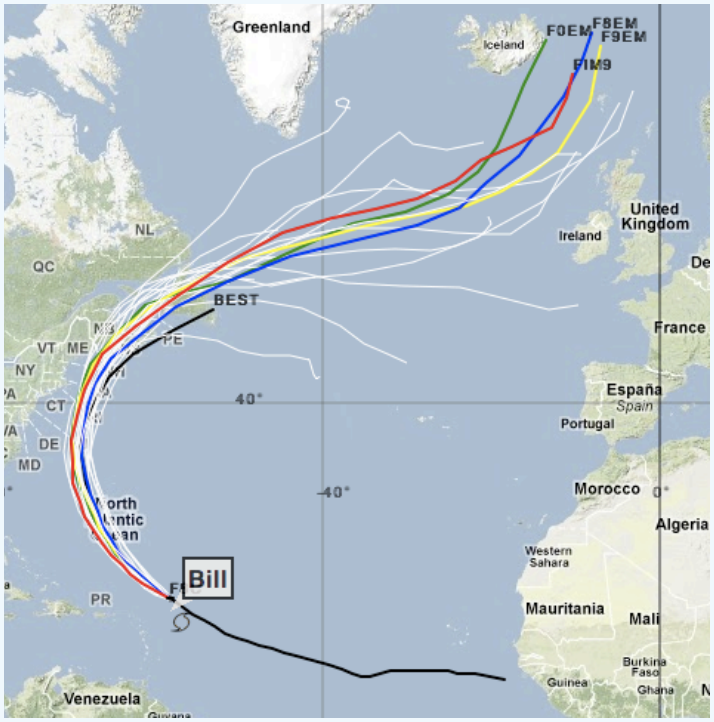
GFS - ----------

	Tropics- m/s
FIM	**6.36** ——
GFS	7.44 ----

FIM much better than GFS, EnKF IC adds further accuracy

NOAA Hurricane Forecast Improvement Project (HFIP)

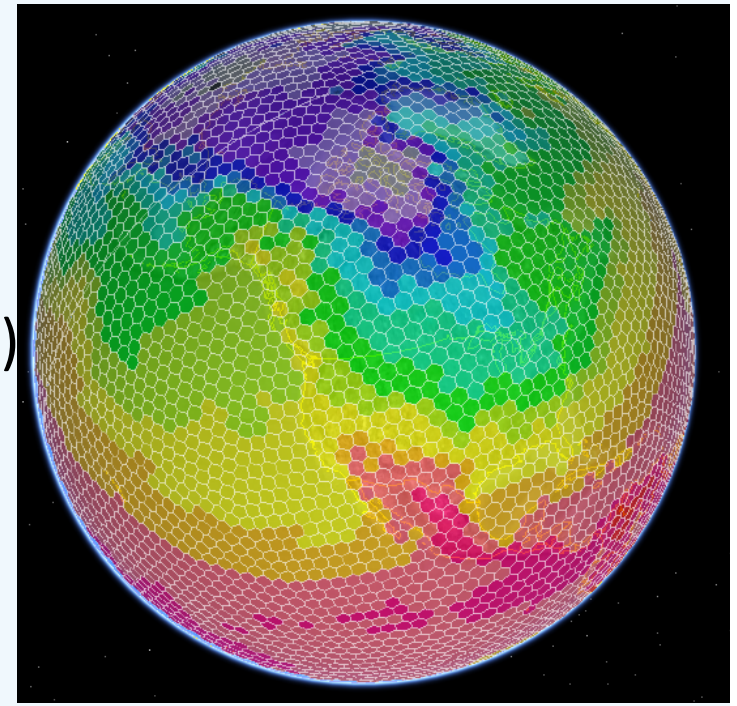
- Goal – improve track and intensity forecasts
- NOAA, universities, Navy, NCAR, etc.
- Global component (primarily FIM, some GFS)
  - NSF-funded TACC supercomputer
  - FIM-15km, FIM-10km, FIM-ensemble-30km
  - Ensemble Kalman Filter data assimilation
  - Experiments for resolution and initial condition sensitivity



Improved intensity with 30km➔15km➔10km resolution, better track forecast with EnKF initial conditions (than 3Dvar)

FIM/NIM Commonality

- Built on same software structure to allow following common features (some in development):
  - icosahedral horizontal structure
  - I/O, ESMF structure
  - Grid structure, code design for parallel performance (multi-CPU and GPU)
  - physical parameterization options
  - ocean component
- Common regression testing environment – more failsafe development

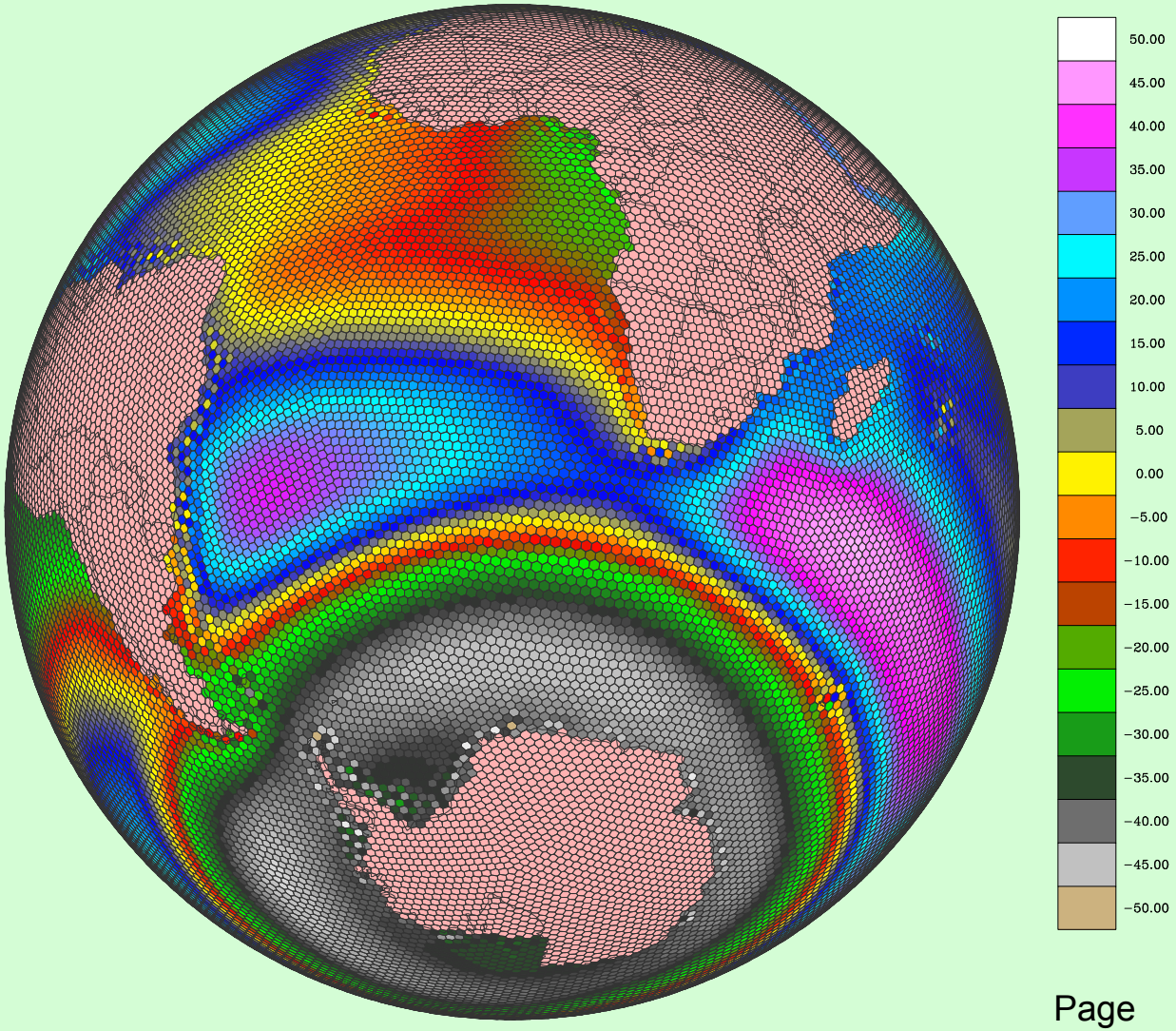


- Initial discussions with NCAR on using similar framework for MPAS (NCAR's new global icosahedral model)

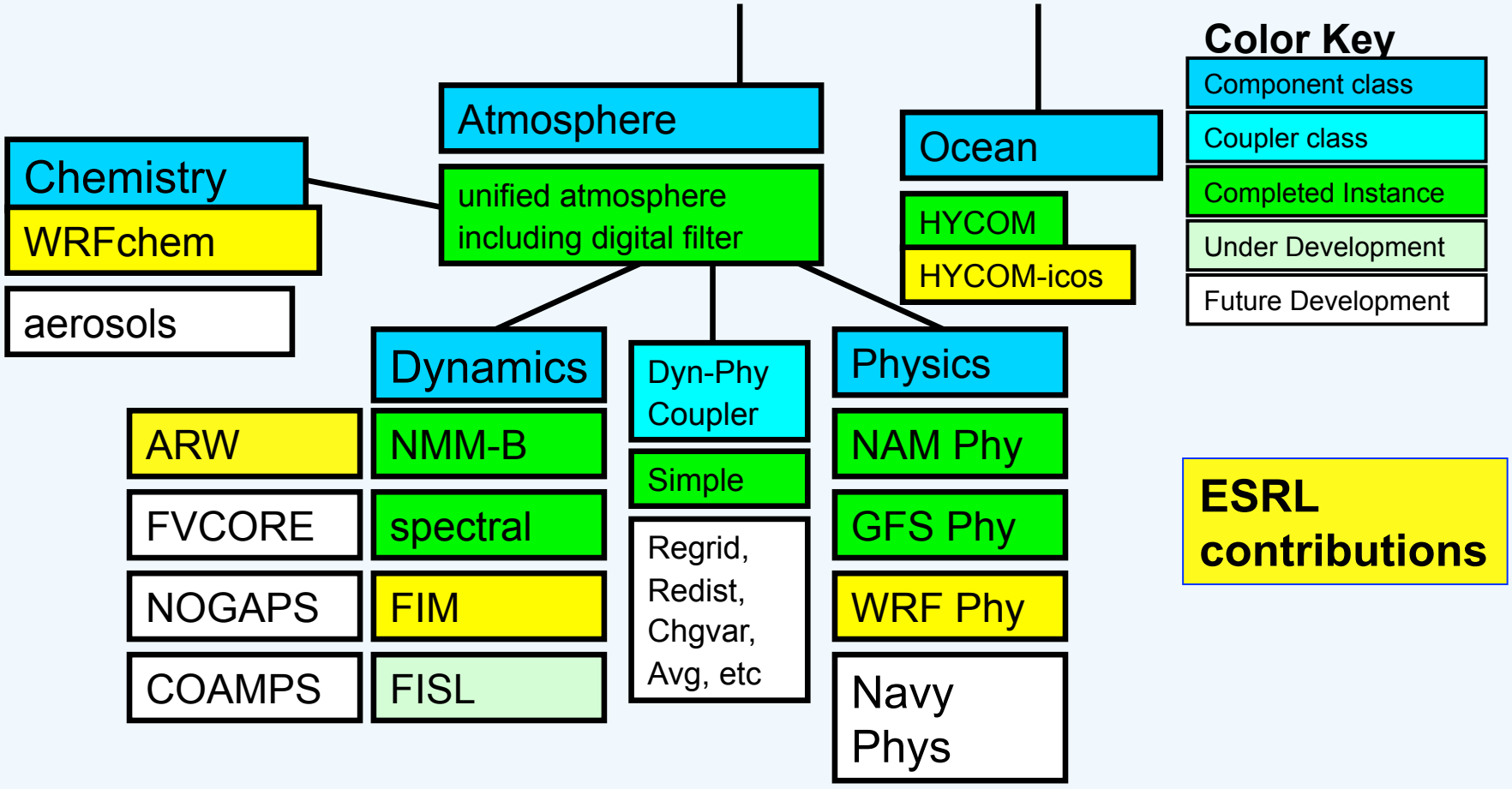
Recent ESRL effort: Develop mirror FIM-HYCOM Atmosphere-Ocean on same icosahedral grid

Initial atmos/ocean coupled FIM:
Sea surface height

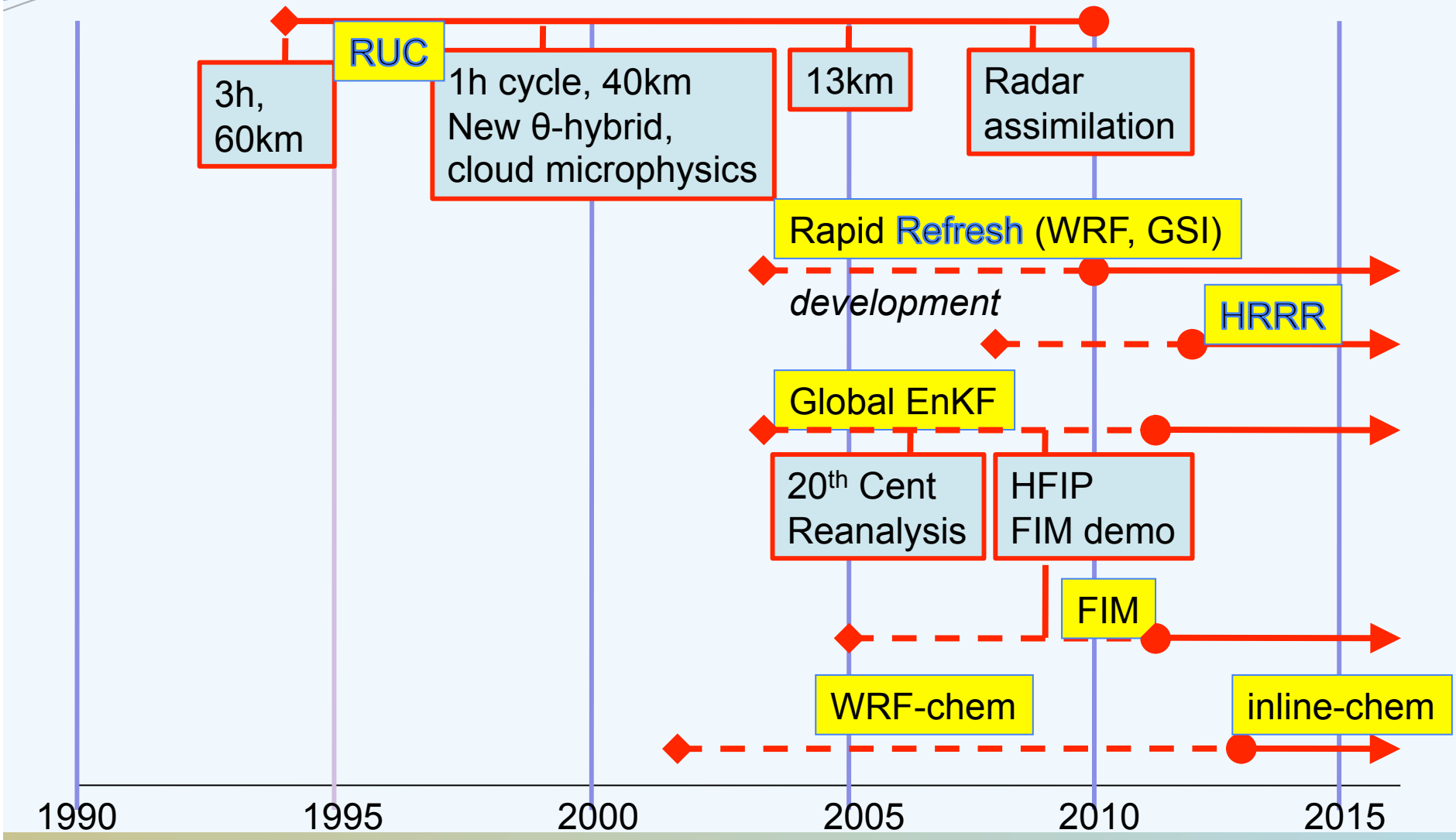
- *After 5-yr spinup of a 4-layer isopycnic ocean forced by time-invariant zonally averaged zonal wind stress extracted from FIM initial conditions.*
- *Horizontal resolution ~120 km (G6)*



NCEP Architecture using ESMF/NEMS



ESRL models/assimilation transfers to operations at NCEP (past and likely in future)



From NOAA Research 5-Year Plan

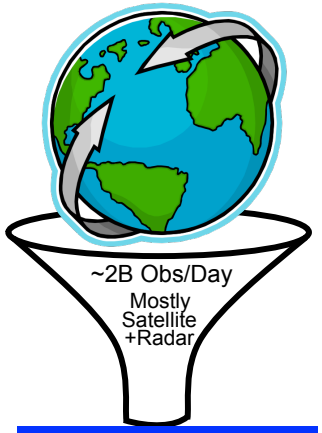
- From the "Commerce and Transportation mission goal"
  - "Provide accurate, timely, and integrated weather information to meet air and surface transportation needs"

    RUC, Rapid Refresh, HRRR, assimilation of radar, clouds

- From "Framing NOAA's Future Research"
  - "NOAA will foster a research organization with an appropriate rate of radical innovation that can transform our science, emphasizing areas of greatest scientific and technological opportunities and potential benefits to the nation."

    • *Increasing integration within ESRL of modeling/assimilation efforts (Theme 2)* ***with other Themes (physics, weather/climate applications)***
    • *Increasing integration* ***with ESRL chemical science efforts***

Contributions from ESRL toward NOAA's Future Model Production Suite



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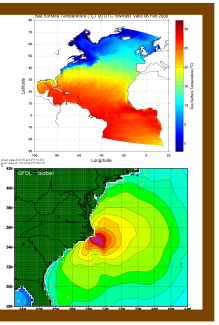

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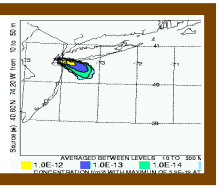
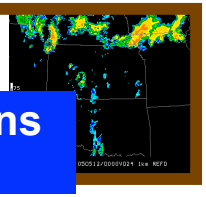
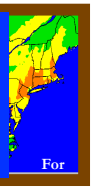


Severe Weather
HRRR, HRRRens



Inline chemistry



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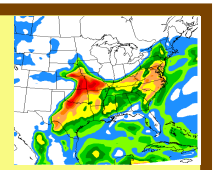
for Aviation, Severe Weather, Energy



Additional oral presentations on ESRL efforts in modeling, assimilation, advanced computing

- **Data assimilation, rapid cycling NWP** — Steve Weygandt
- **Inline chemistry – model, assimilation** — Georg Grell
- **Forecast uncertainty** — Paul Schultz
- **Advanced computing** — Mark Govett
- **The path forward** — Zoltan Toth