HFIP Global modeling team

- ESRL
  - Stan Benjamin (+ Mike Fiorino, John Brown, JeffW, Bao…)
- NCEP/EMC
  - Steve Lord
- NRL
  - Melinda Peng, Carolyn Reynolds
- GFDL
  - Shian-Jiann Lin
- AOML
  - Kevin Yeh

Goal: Improve hurricane (tropical cyclone -TC) track (priority 1) and intensity (priority 2) forecasts using improvements to current operational and research global models.

Outline

- Global modeling team goals – Stream 1 and Stream 2
- Summary of development efforts by
  - ESRL (FIM)
  - EMC (GFS)
  - GFDL (Cubed Sphere Model – CSM)
  - NRL (NOGAPS)
- 2009 TC season HFIP demo for
  - configuration – deterministic, ensemble
  - results
- Key questions raised in 2009
- Plans for 2010

From HFIP global modeling plan – Dec 2008

Statement of the role of global models

TC track forecasts for duration of 2 days and longer
• especially dependent on global models, either directly or through critical lateral boundary conditions for regional models.

Thus, HFIP global model forecasts will be the distillation of combined efforts from the Global Modeling Team with those from:
• Physics Team
• Data Assimilation Team
• Ensemble Forecast Team

Global Model Team efforts will critically affect Regional Model forecasts for TCs.

From HFIP global modeling plan – Dec 2009

Overview

Incorporate improvements to global models from model dynamics, model physics (coordinated with Global Model Physics Team), increased resolution and system diversity and collaborate with other HFIP Teams to achieve HFIP goals

Key global modeling components

Numerics	✓
Horizontal resolution	✓
Horizontal grid structure	✓
Vertical grid structure	✓
Vertical resolution	✓
Physical parameterizations	✓
Initialization techniques	2010
Global model ensembles	✓

From HFIP global modeling plan – Dec 2009

Overview: Global Modeling Development Team toward improved TC forecasts

- Stream 1 – improve current operational models
  - EMC - development, testing of GFS
  - NRL – development, testing of NOGAPS
  - EMC, ESRL - NAEFS readiness for GFS, FIM
- Stream 2 – prepare next-gen global models anticipating substantial HPC augmentation
  - ESRL - development of FIM, demo of high-res FIM, EnKF init of FIM, FIM ensemble, (test new physics)
  - EMC – test higher-res GFS on TACC
  - GFDL – development/test Cubed Sphere Model
  - NRL – development/test advanced NOGAPS

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FIM-2009 model

ESRL

Resolution

- 3 resolutions: 30km, 15km, 10km
- 64 vertical levels - hybrid theta-sigma
- Ptop = 0.5 hPa, θ-top = 2000K

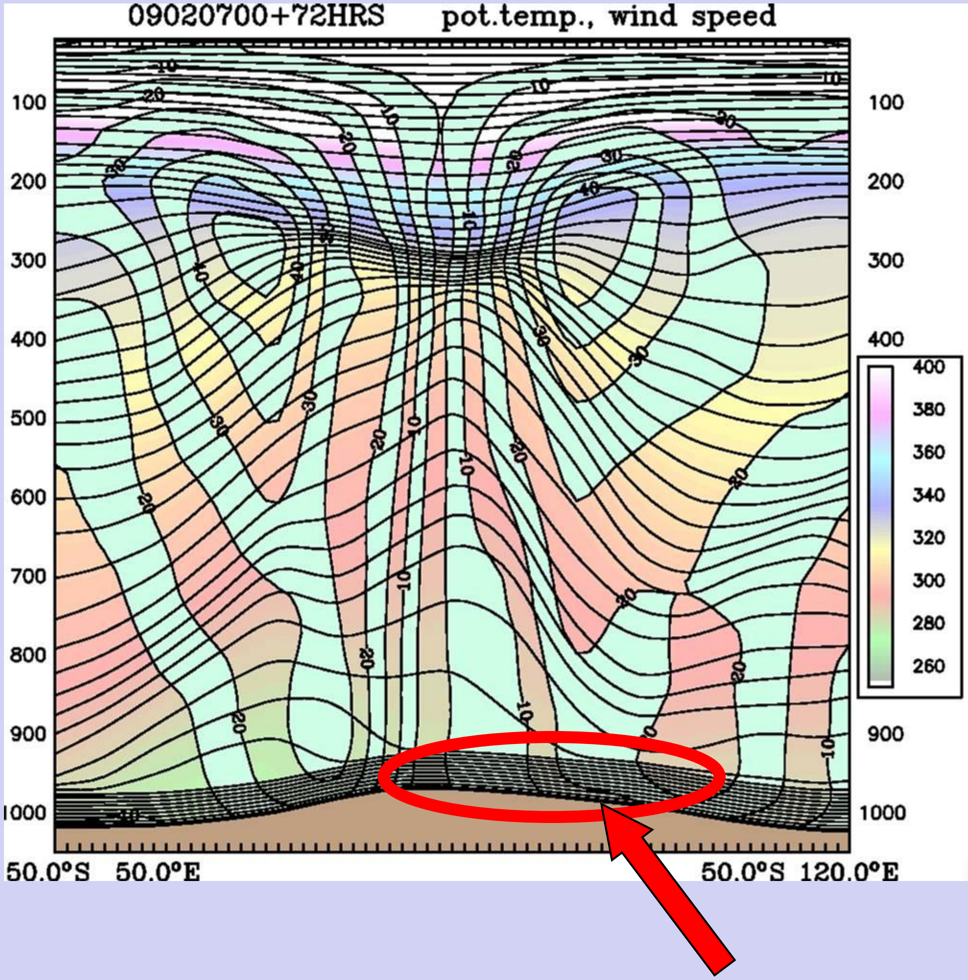
Physics

- GFS physics suite, many changes to FIM physics interfaces from Nov 2008 – May 2009

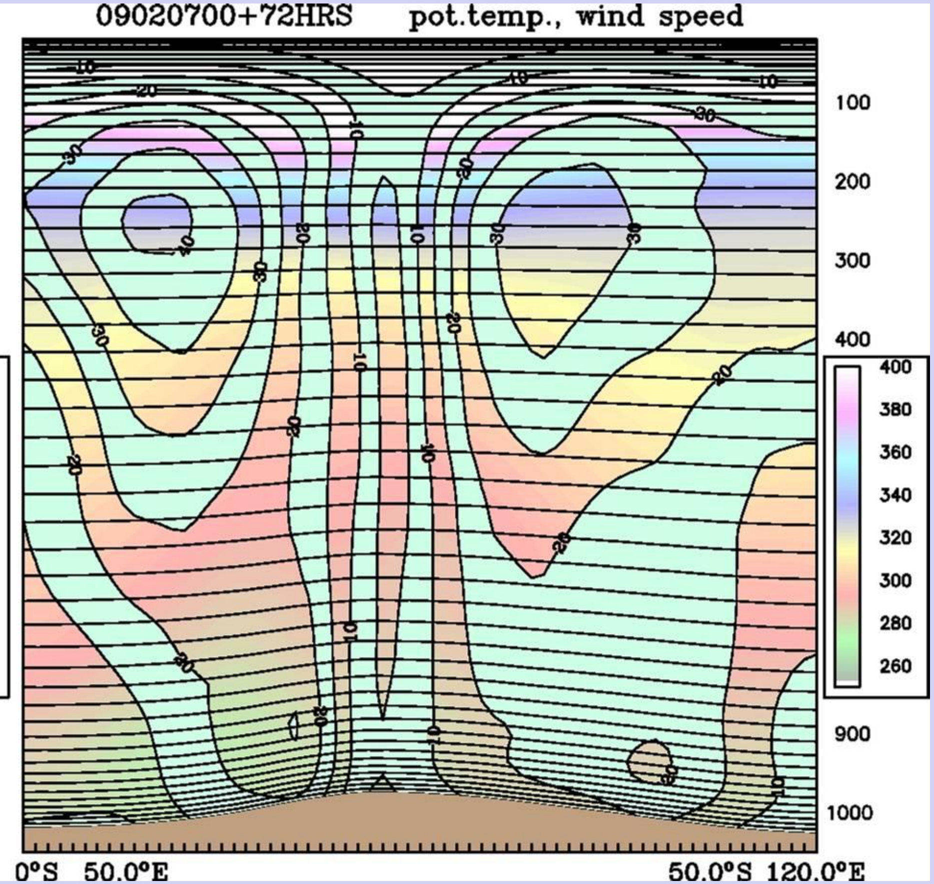
July upgrades to FIM model for TACC

- Random number generator for convection cloud top (currently in FIMX)
- Relaxed vertical regridding – much quieter forecasts
- Distributed output - allows 10km output, faster I/O overall
- Trisection added to icosahedral grid structure, allowing 10km resolution

Hybrid sigma-theta



pure sigma

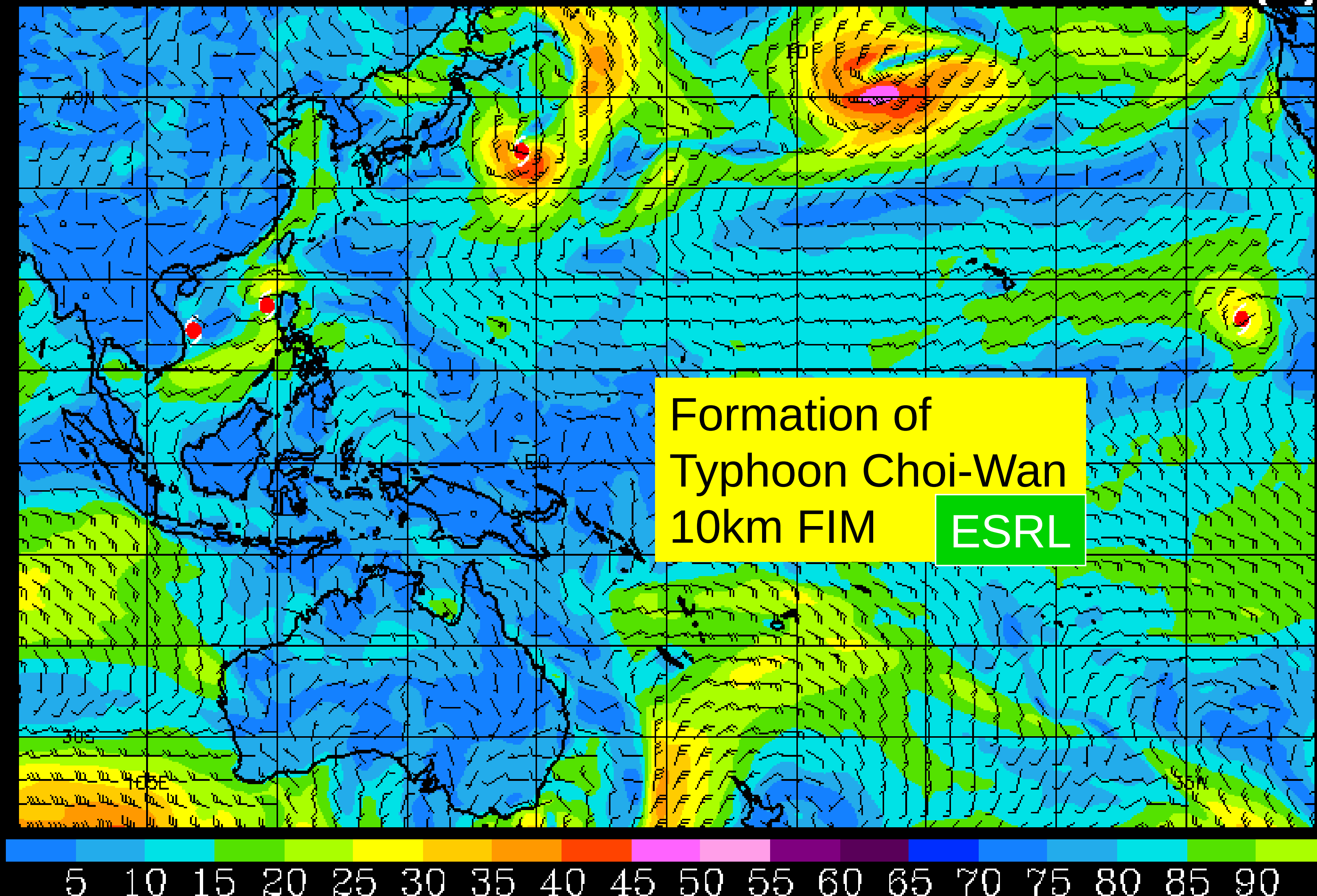


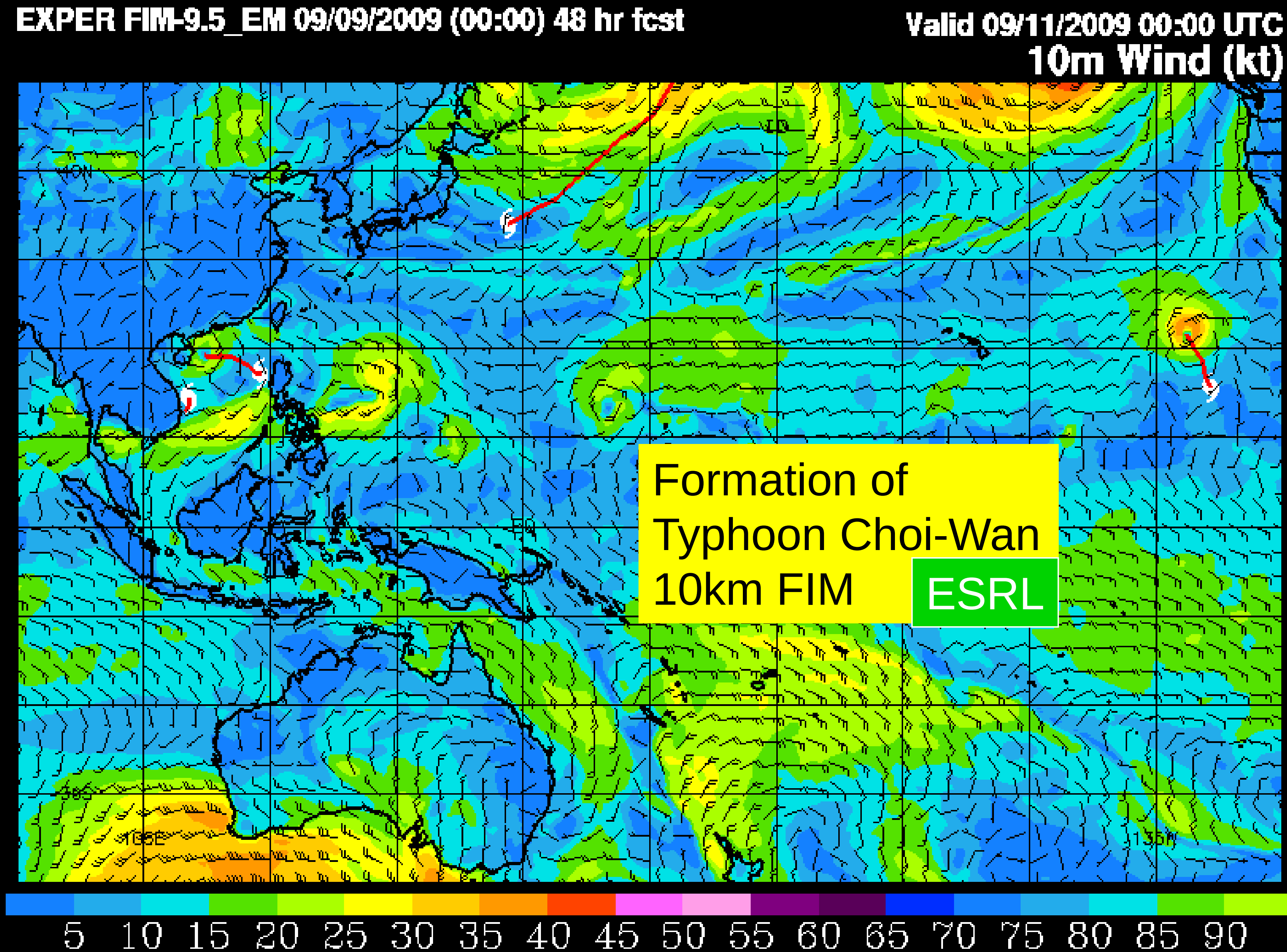
tighter-than-optimal packing of sigma layers

EXPER FIM-9.5_EM 09/09/2009 (00:00) 0 hr fcst

Valid 09/09/2009 00:00 UTC

10m Wind (kt)

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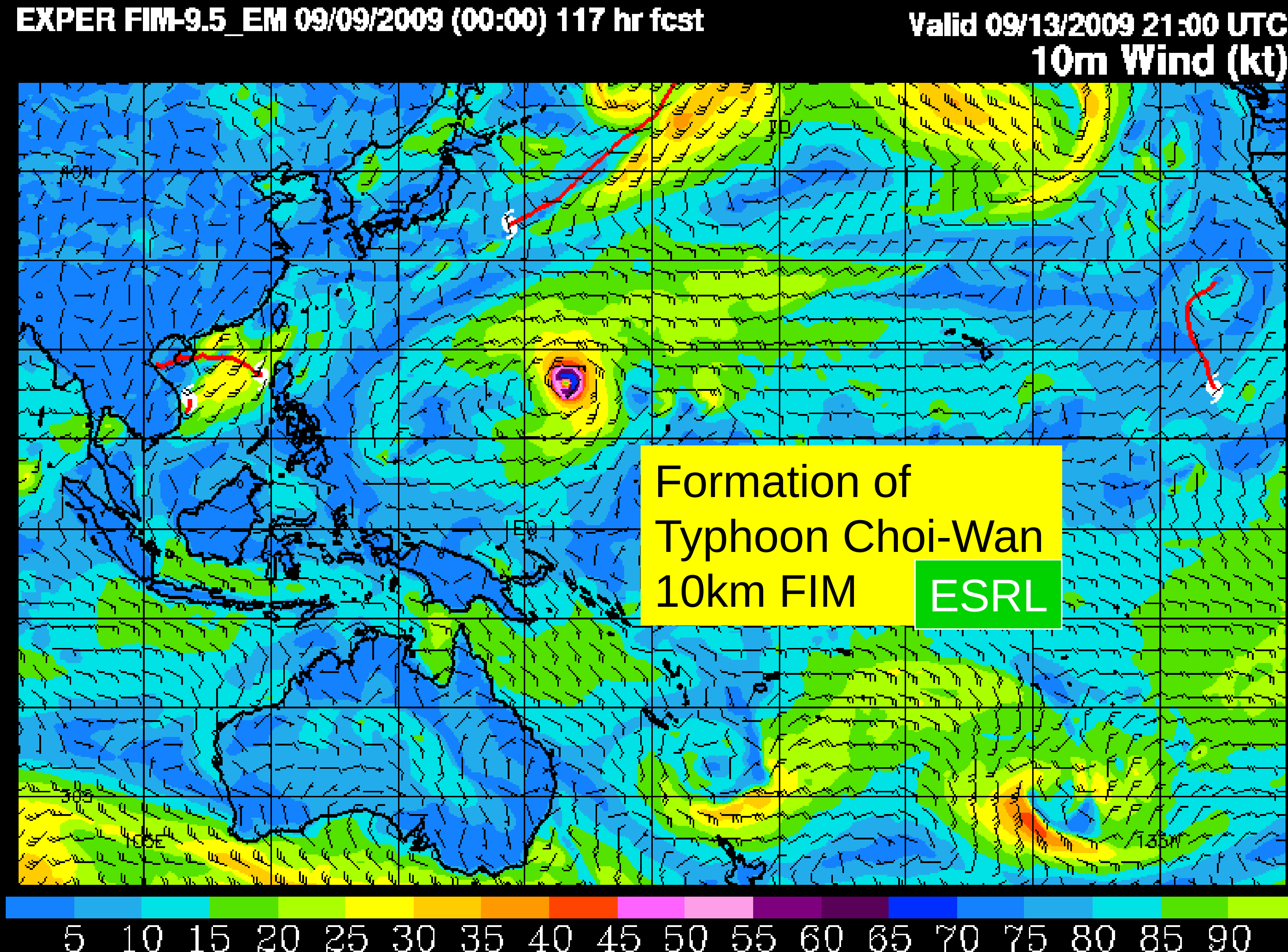
Valid 09/11/2009 00:00 UTC
10m Wind (kt)
Formation of
Typhoon Choi-Wan
10km FIM
ESRL
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90


EXPER FIM-9.5_EM 09/09/2009 (00:00) 117 hr fcst
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10m Wind (kt)
Formation of
Typhoon Choi-Wan
10km FIM
ESRL
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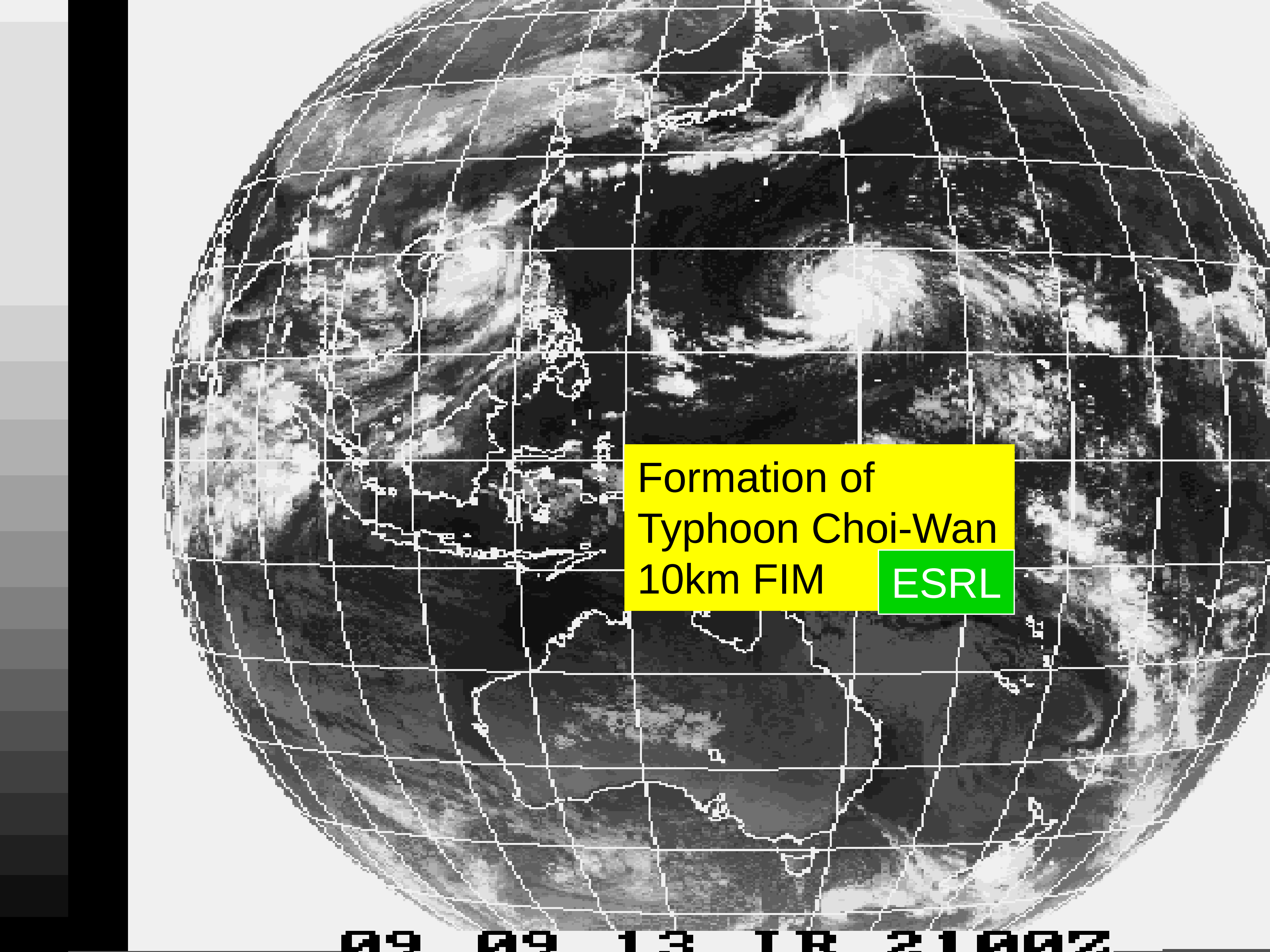

Formation of
Typhoon Choi-Wan
10km FIM
ESRL
09 09 13 IR 2100Z

ESRL

FIM Changes in July-Aug 2009

- **Version updates for GSD FIM:**
- 8/26/2009-00z - FIM revision 762 - Includes modified hybgen (vertical filter, minimum thickness near top, increased relaxation in coordinate movement toward target values). Setting of ptop to 50 Pa (instead of 10 Pa) and min thickness near top = 50 Pa. TACC FIM updated to r762 at same time.
- 7/26/2009-00z - FIM revision 671 - Includes xkt2 random number generator cloud top in convective parameterization, also fixes errors to properly set the initial liquid soil moisture (was being set as total soil moisture including frozen).
- 7/22/2009-00z - Revision to reference potential temperature table to spread out vertical levels near top, revision 661
- 3/20/2009-00z - FIM revision 577 - Correction of initialization and evolution of liquid soil moisture.

FY10 Implementation Plan

NCEP

- GSI/GFS Fall Bundle – December
  - Ingest new data types
  - GSI Code changes
  - GFS code restructuring
  - Consolidation of GDAS & GFS Posts
  - Benefits
    - Better tropical cyclone definition
    - Small incremental improvement in forecast skill
- GFS Shallow Convection – March
  - Shallow convection, Deep Convection, PBL
  - Benefits
    - Significant reduction in gridpoint storms
    - Small incremental improvement in forecast skill
- GFS Resolution Increase – May
  - T574L64
  - Benefits
    - Overall improvement in forecast skill

NCEP

GSI Changes – December 2009

- Adding new observation data sources.
  - **Tropical storm pseudo sea-level pressure obs**
  - NOAA19 hirs/4,AMSU-A, & MHS brightness temp obs
  - NOAA18 sbuv/2. Monitor N19 GOME, and OMI ozone (no assimilation)
  - RARS (currently only EARS) 1B data
  - EUMETSAT-9 atm motion vectors
- Implementing improved techniques in GSI analysis.
  - Use uniform thinning mesh for brightness temp data
  - Improvements to assimilation of GPS RO data (QC, retune ob errors, improved forward operator)
  - Add dry mass pressure constraint
  - Merge GMAO & EMC codes for 4d-var capability
  - Update background error covariance
  - Proper use of different spectral truncation between background and analysis

NCEP

Expected Benefits

- Data Assimilation
  - **Improve tropical storm track & intensity forecasts**
  - Slight incremental improvement in overall forecast accuracy
- Model
  - Facilitate testing and implementation of future upgrades
  - Reduce code maintenance
- **Improvements expected to be small and primarily due to the assimilation changes**

Details on assimilation effects on GFS TC forecasts from Steve Lord (assim) and Carolyn R. (ensemble)

Experiments for HFIP

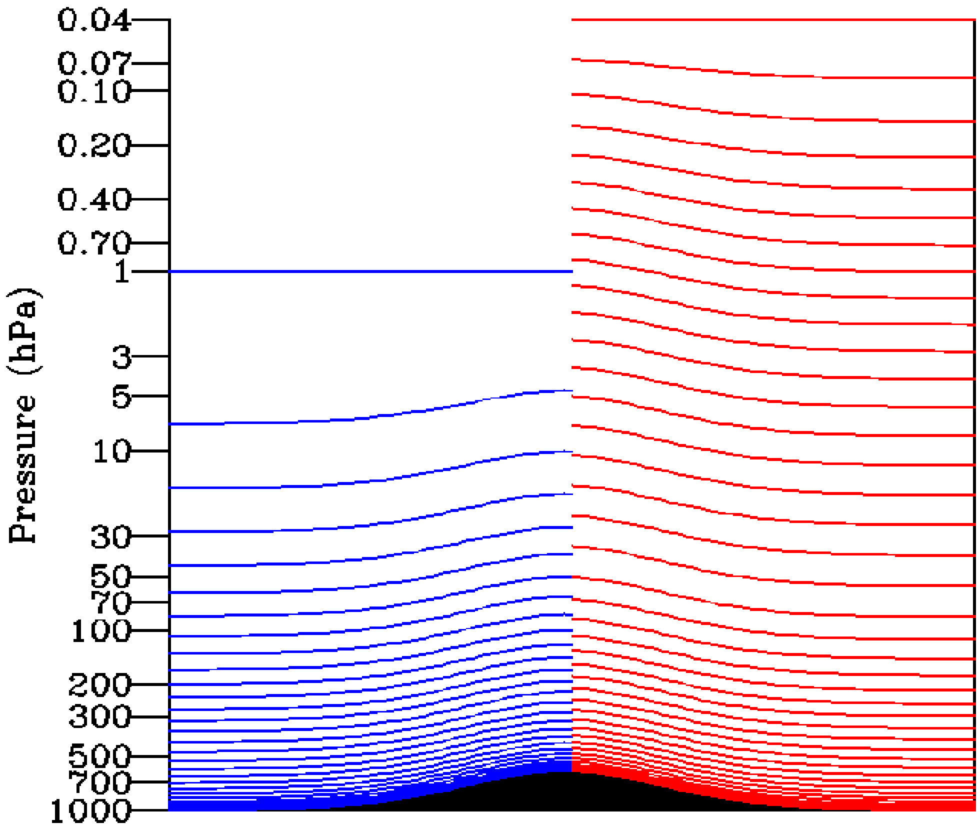
NCEP

- High resolution global ensembles (NCEP/GEFS)
  - T574L64 (~23km horizontal resolution)
  - Initial analysis
    - GSI T382L64 analysis
    - ETR (ensemble transform with rescaling)
      - Every 24 hours
      - Cycling at T382L64 resolution
      - NCEP/CCS
    - Upgrade to T574L64
  - Integrations
    - At Texas Advanced Computing Center (TACC)
    - Use GFS model at T574L64 resolution
    - 5 members (include control)
    - Out to 168 hours
  - Experiments
    - Once per day for period of Sept. 1st – 20th 2009
  - Output
    - Tracks for each members, ensemble mean

NRL Global Model Improvements

NRL Data Assimilation and Global Model Personnel

NRL



Global Forecasting System Major Upgrade September 2009.

From 30 levels (left) 3DVAR to 42 Levels and 4DVAR

NRL

NRL NOGAPS Recent Upgrades: Impact on TC track

- **New multi-level sea-ice temperature prediction,**
- **Change in lower level cumulus cloud prediction (fixed low cloud bias)**
- **Correct optical thickness calculation, which over-estimated mixed cloud thicknesses**
- **Increased lower perturbation temperature in the cumulus parameterization**

Results

- **Statistically significant improvement in SH AC**
- **Statistically significant improvement in TC tracks at 96 h**
- **Small but significant Arctic AC improvement in the winter season**
- **Reduced lower tropical temperature error**
- **No increase in run-time**

Ridout, Hogan, Peng

GFDL

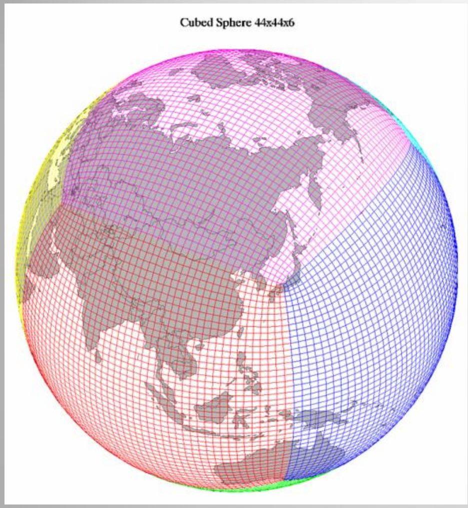
The GFDL High-Resolution Atmosphere Model is developed for 1-100 km resolution, sharing most of the codes with the GFDL AM2/AM3 for IPCC, except the following major modifications

- N*on-hydrostatic Cubed-sphere Finite-Volume dynamical core.*

- *6-category single-moment bulk cloud microphysics with* computational efficiency significantly improved with time implicit treatment of microphysics processes and vertically Lagrangian terminal fall of all condensates (rain, snow, ice, and graupel). Subgrid cloud formation is accounted for by using both vertical & horizontal subgrid distributions (with a PDF approach).

- The deep convective parameterization scheme is replaced by an essentially *non-precipitating* *shallow* convection scheme (Zhao *et al*. 2009)

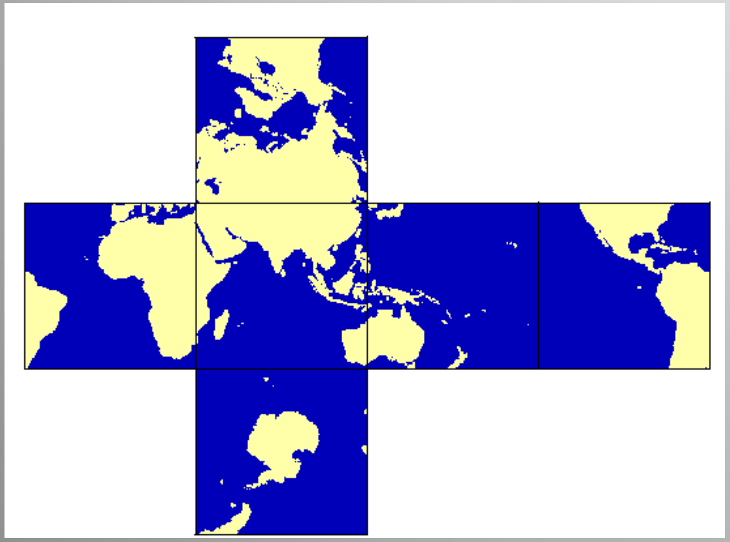
- *Surface fluxes modified for high-wind situation over ocean* (*Moon et al*. 2007)



Gnomonic Cubed Sphere grid

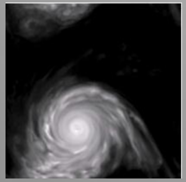
GFDL

- Defined by intersects of great circles with equal-distance along 12 edges
- Maximum local grid aspect ratio ~ 1.061
- Maximum global grid aspect ratio ~ 1.414



Resolutions:

1) TC climatology:	C180 ,	Δx ~ 50 km
2) HFIP 2009:	C360 ,	Δx ~ 25 km
3) HFIP 2010:	C720,	Δx ~ 12.5 km
4) “Cloud-resolving”	C2000,	Δx ~ 4.5 km



Hurricane in a doubly periodic box

Can also be used as a regional model

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NOAA global model experiments - TACC-Ranger– Austin, TX

• 62,976 processor machine using Linux

• **2009 - NOAA allocated 15 million hours from 1 July through 31 Dec 2009**

What actually happened

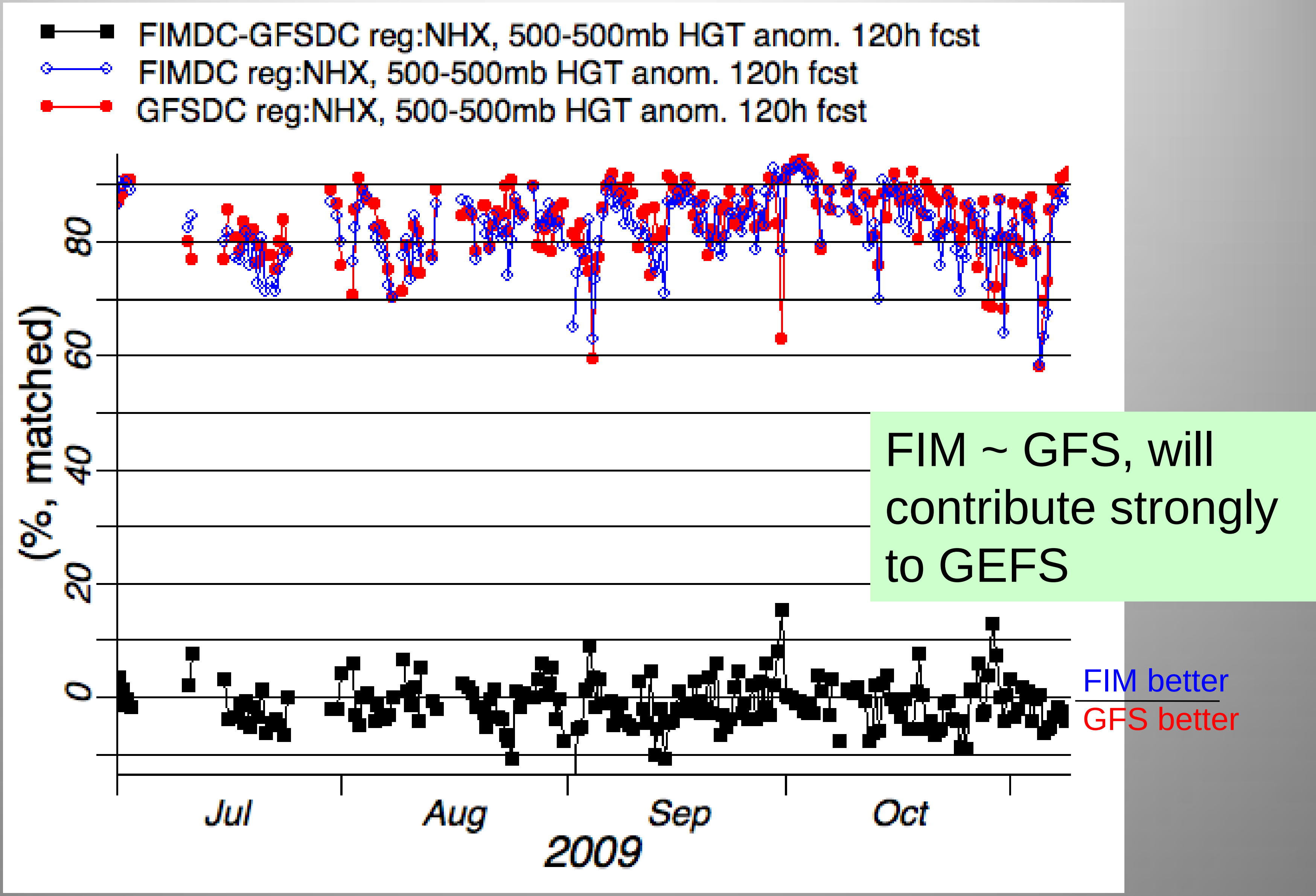
• **11 million hours used – 7/15/2009 – 10/2/2009**

- **40% - EnKF data assimilation – 6h update cycle -9h forecasts**
- **20% - 10km FIM – once daily**
- **20% - FIM30 20-member ensemble – once daily**
- **20% - FIM15 – 2 runs – EnKF, GSI initial conditions**
- **Limited runs of GFS ensemble – T574/64L – 5-member ensemble – 4 TCs**

• **4 Mh reserved for 2008 EnKF**

- **Work underway**
- **Queue now very slow compared to Real-time HFIP demo period**

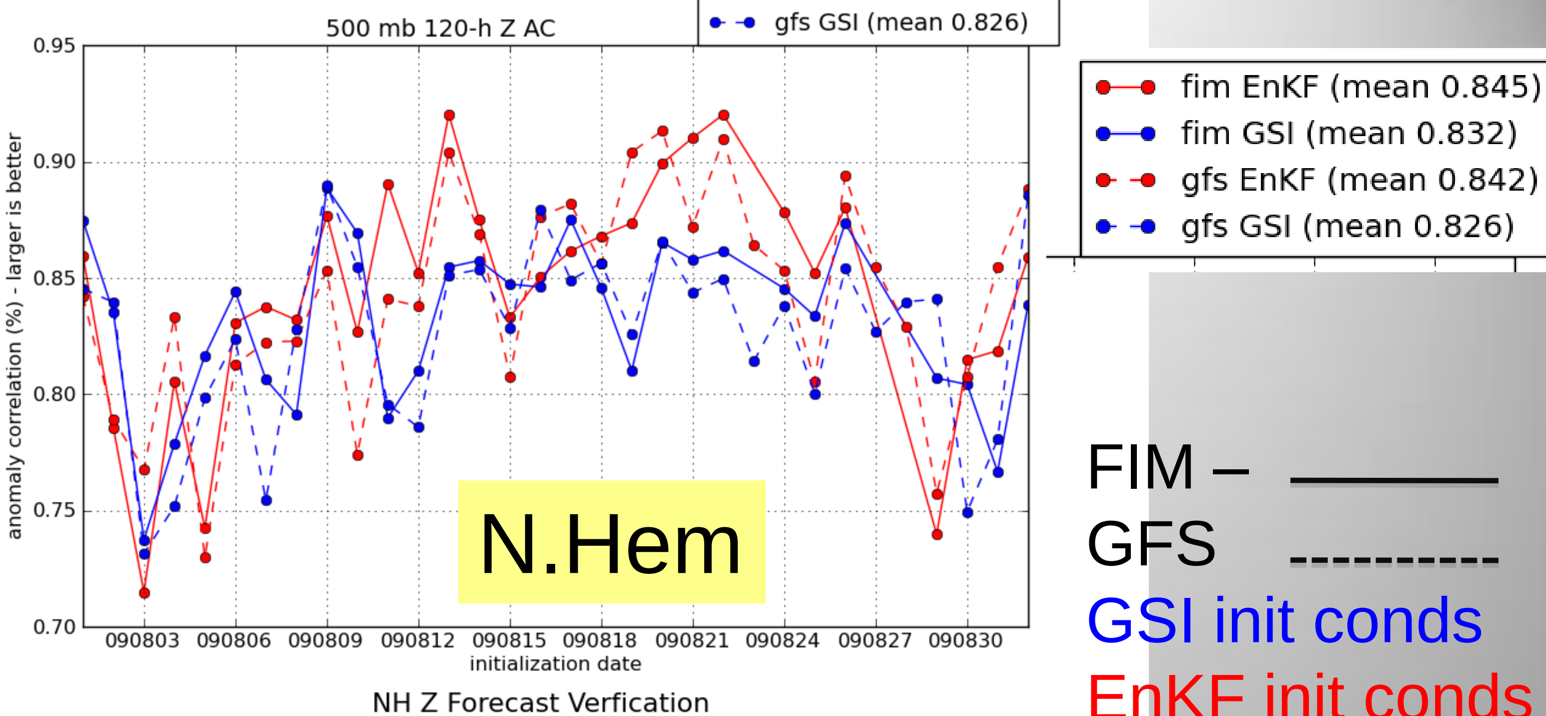
FIM, GFS, 500 hPa anom corr
N. Hemisphere – 120h

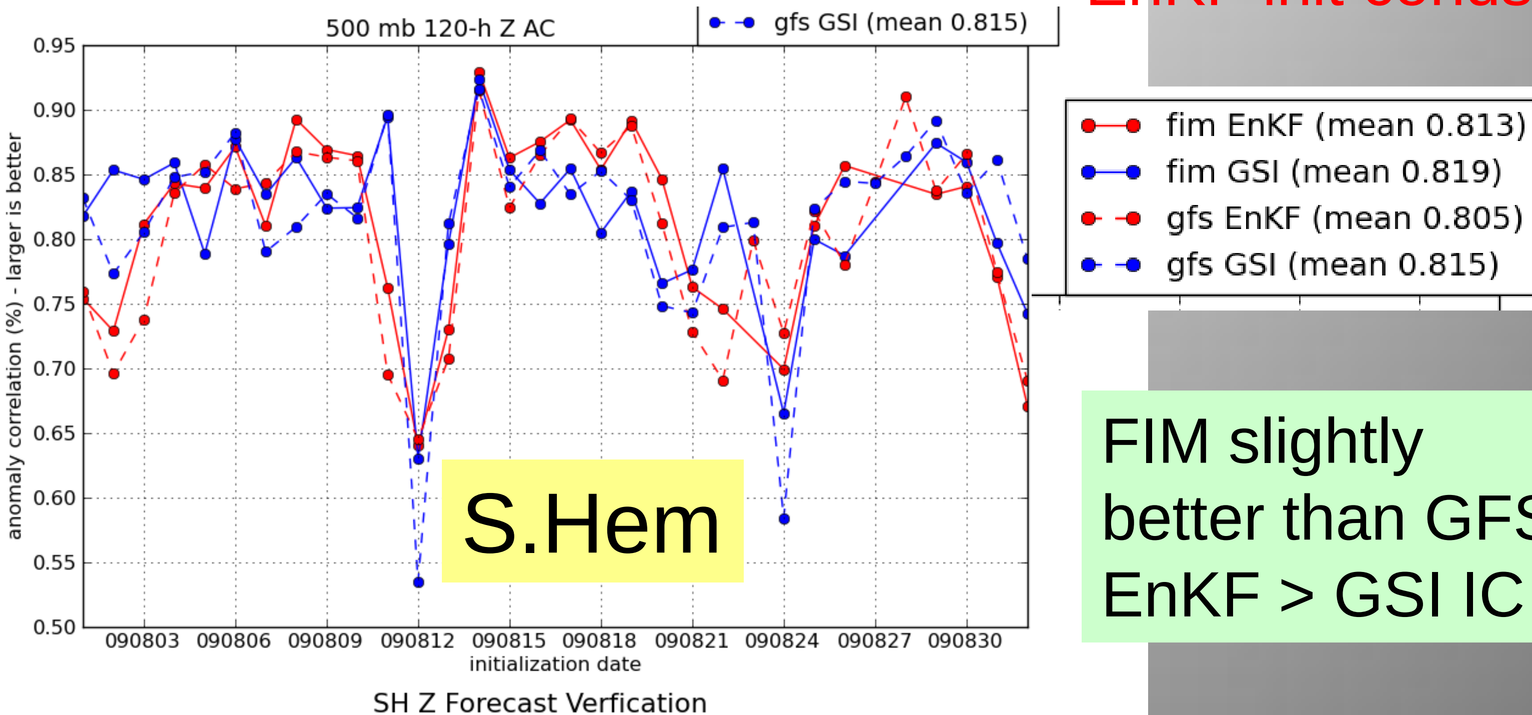


FIM ~ GFS, will contribute strongly to GEFS

120h 500hPa height Anom Corr Coef (ACC)

Aug09





FIM – ————

GFS ----------

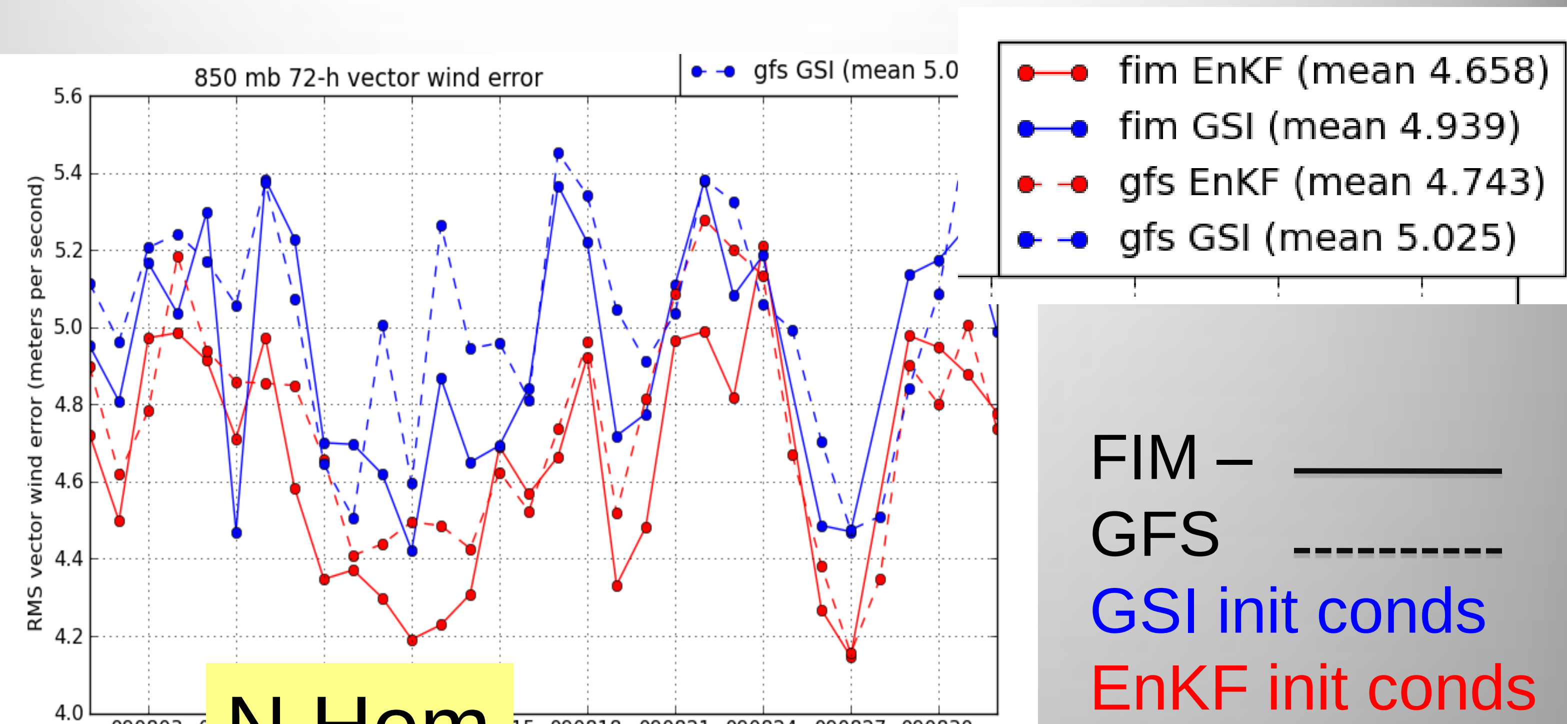
GSI init conds

EnKF init conds

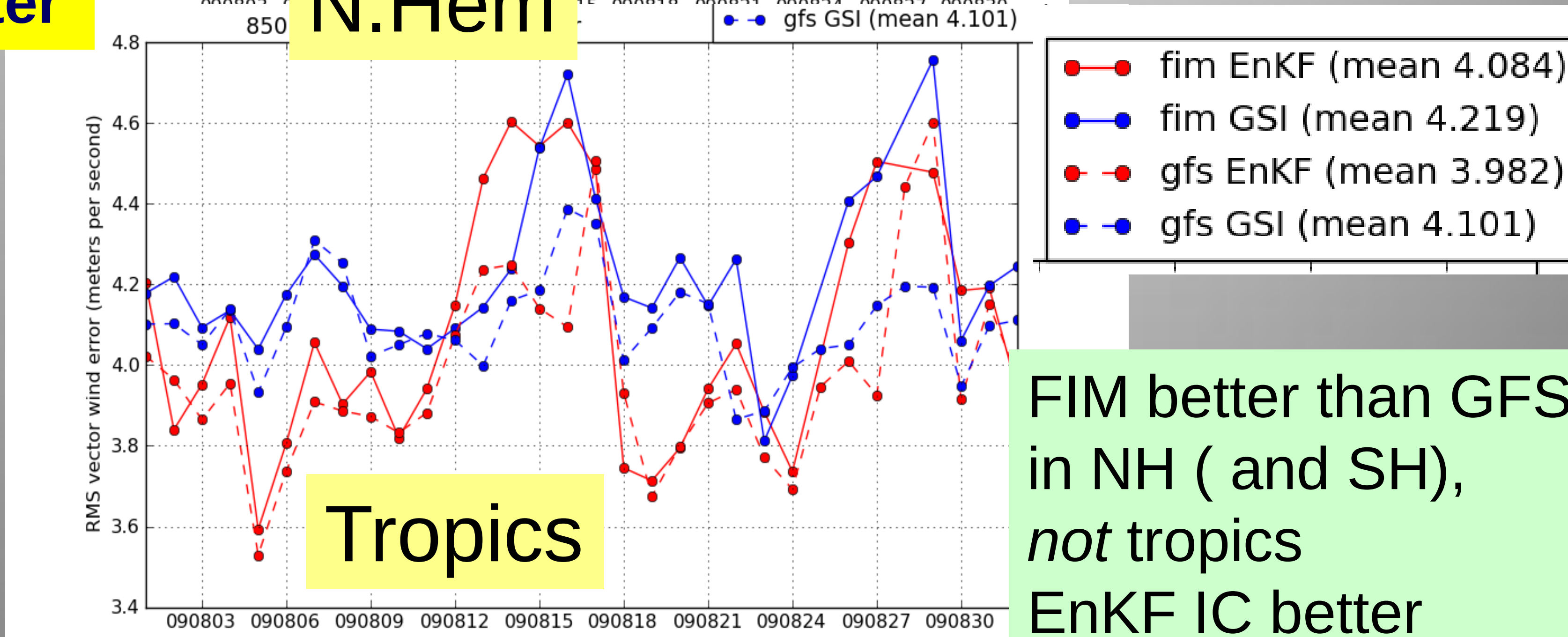
FIM slightly better than GFS

EnKF > GSI IC

72h 850hPa Wind RMS vector error (vs. analyses) **smaller is better**

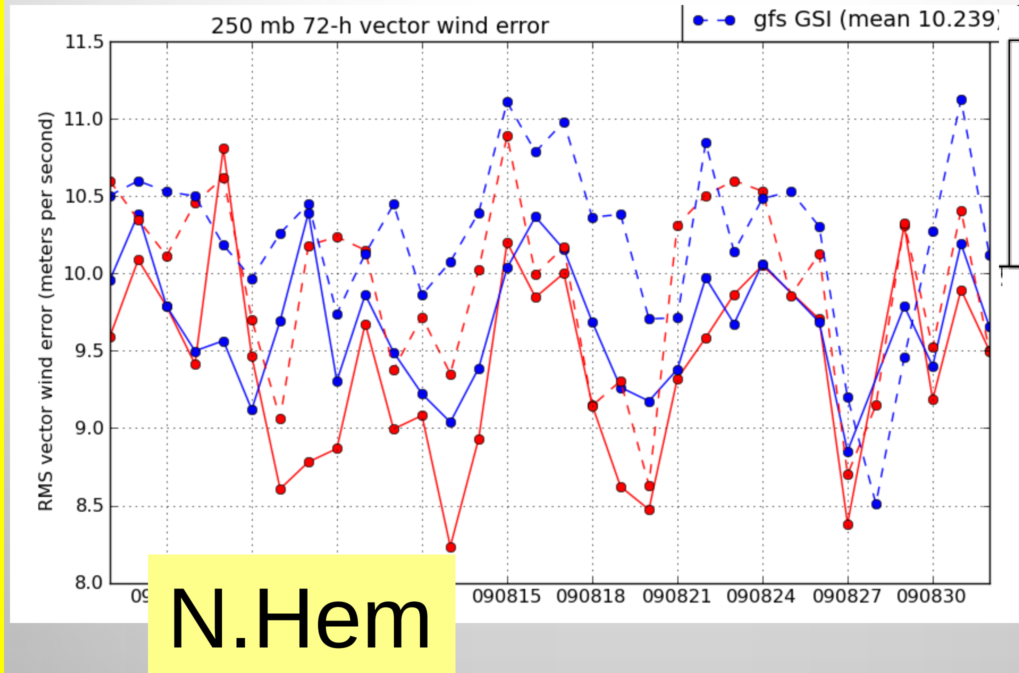


FIM – ________
GFS ----------
GSI init conds
EnKF init conds



FIM better than GFS in NH (and SH), *not* tropics
EnKF IC better

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

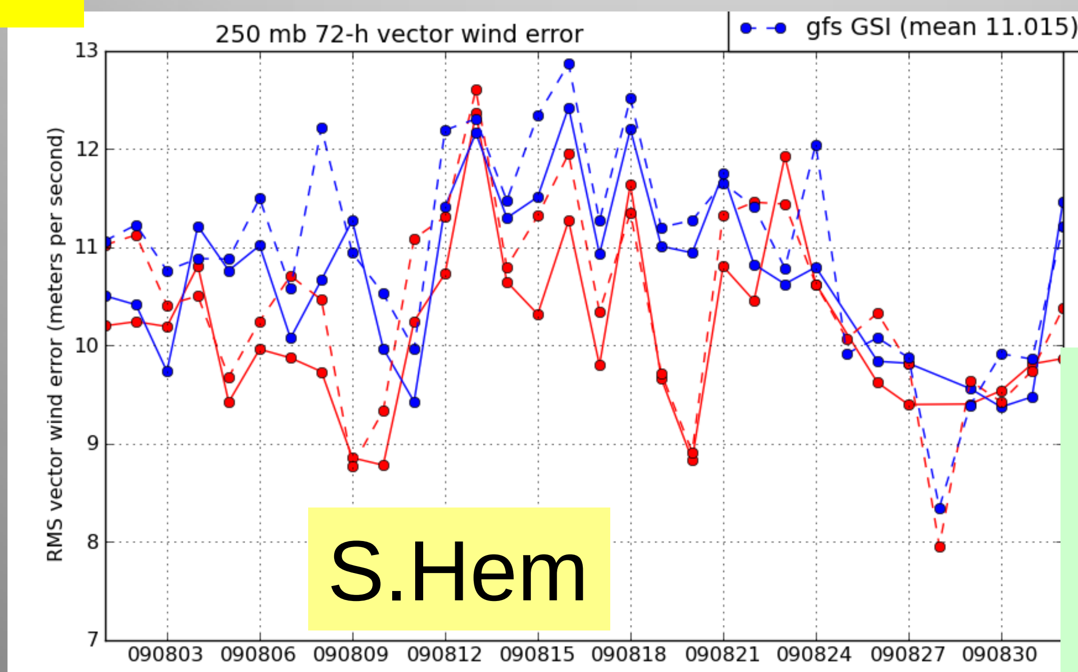


FIM – ________

GFS ----------

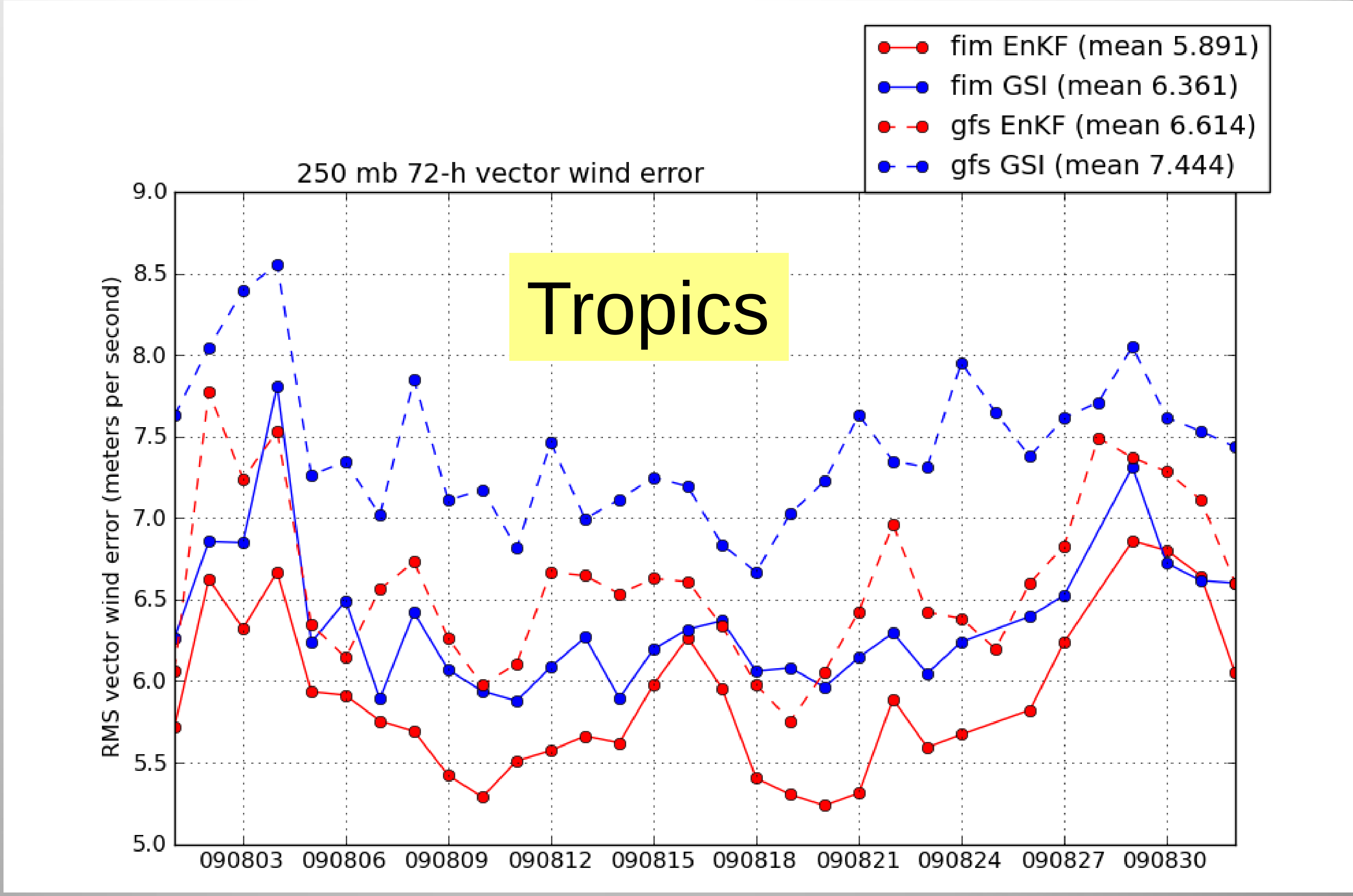
GSI init conds

EnKF init conds



FIM better than GFS in NH/SH, EnKF IC adds further accuracy

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



FIM – ______

GFS ----------

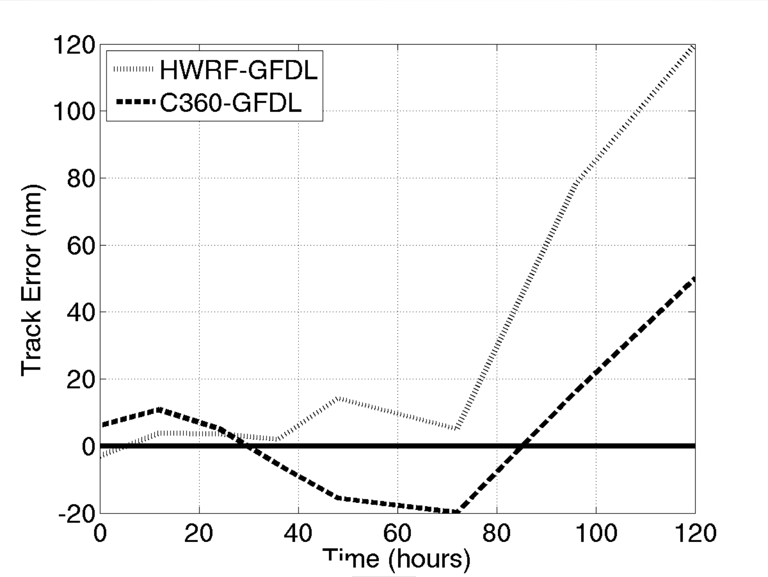
GSI init conds

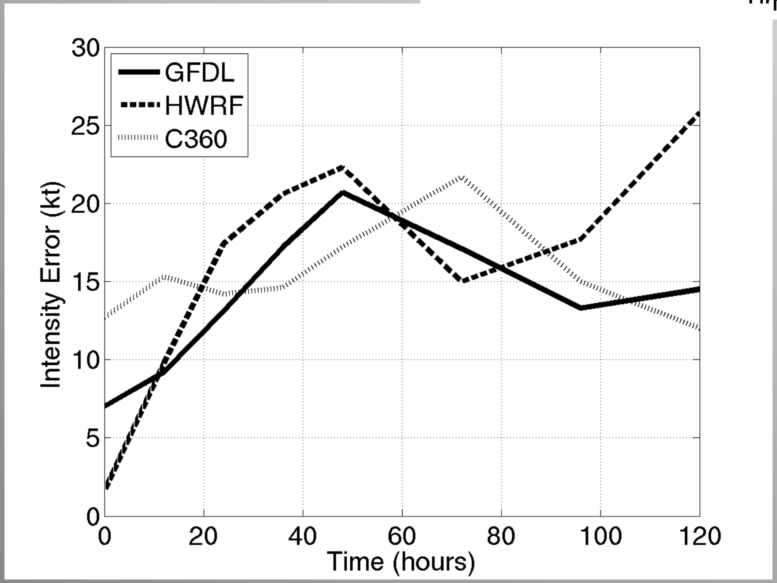
EnKF init conds

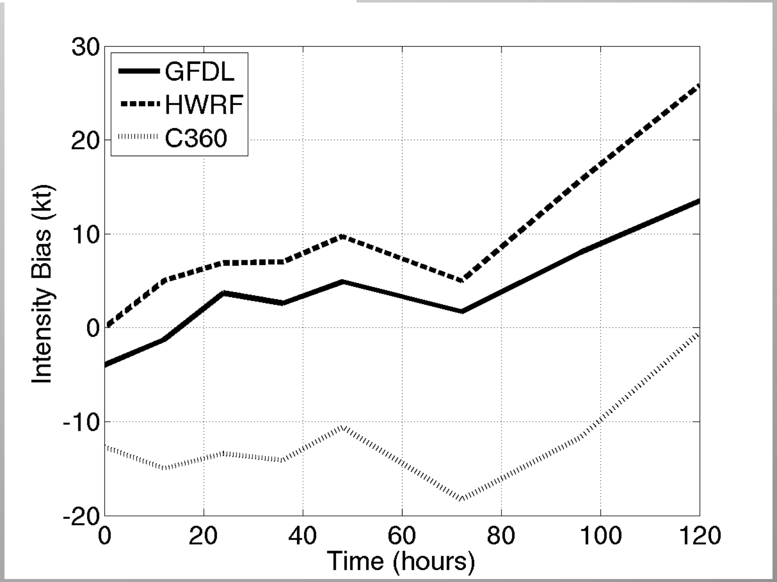
FIM better than GFS,
EnKF IC adds further accuracy

2009 Atlantic hurricanes (near real-time forecasts)

GFDL





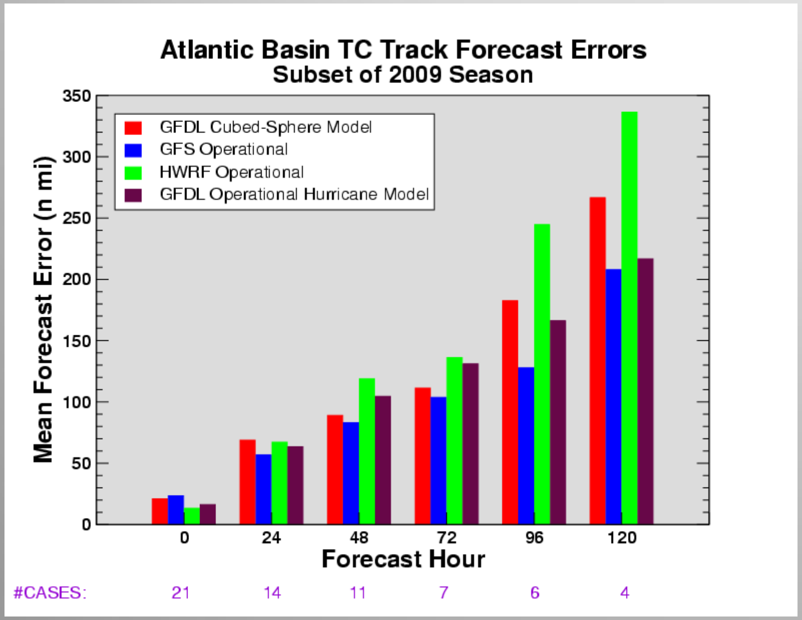


(forecasts by Jeff Gall)

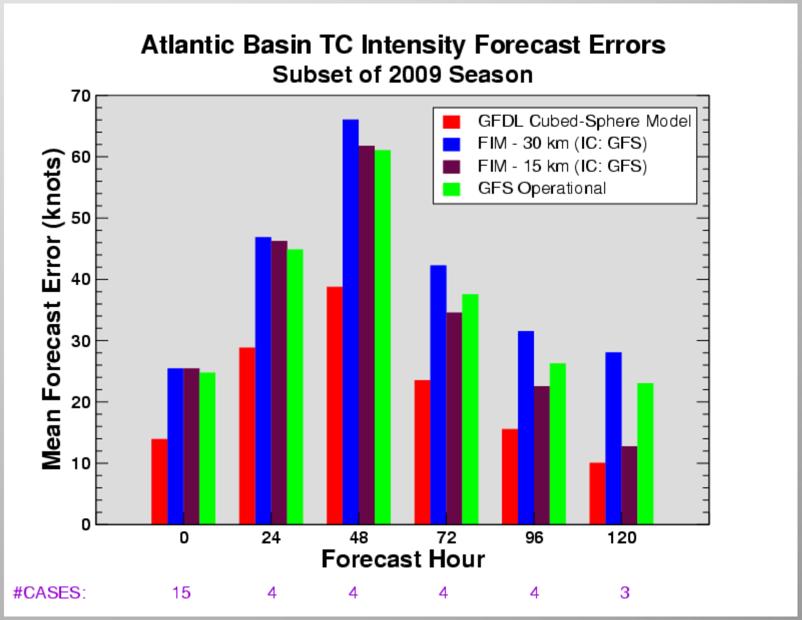
2009 near real-time forecasts

GFDL

Track errors



Intensity errors

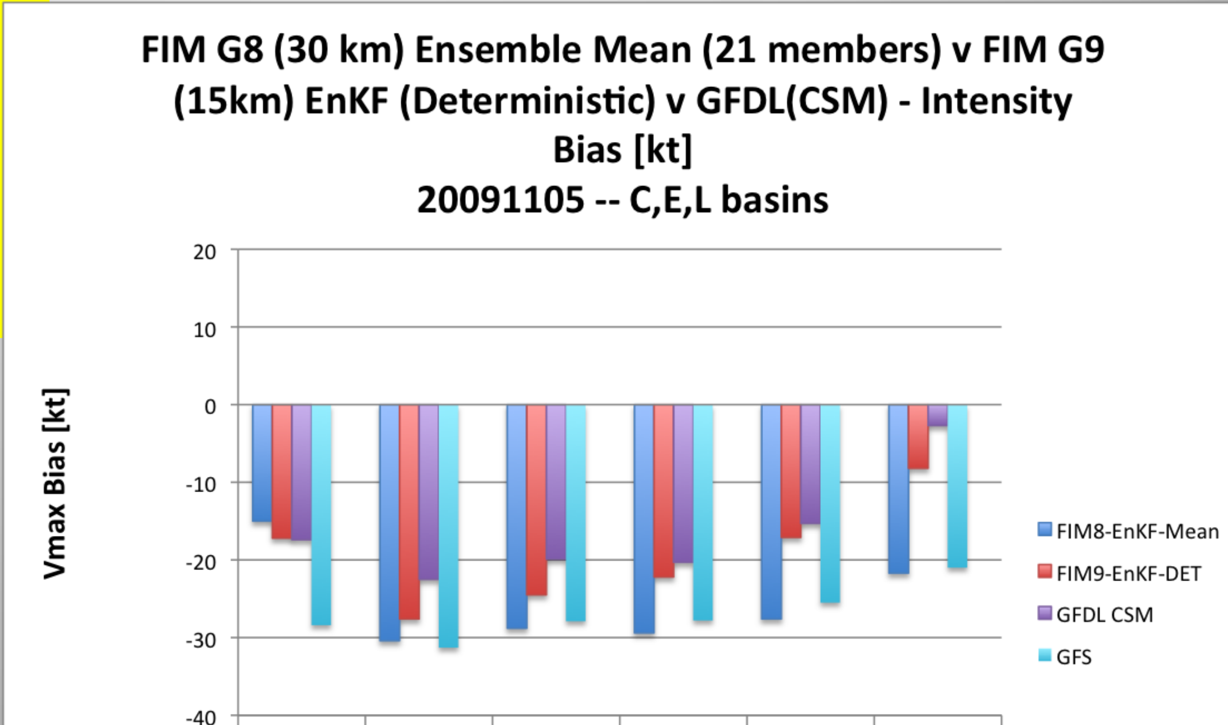


(forecasts by J. Gall, analysis by T. Marchuk)

TC intensity forecast error – all basins, 2009
- FIM-15km-det vs. FIM-15-ens-mean
- GFDL CSM added

ESRL

- FIM-15km-EnKF similar in intensity forecast to GFDL CSM
- FIM-15km-det-EnKF much better than FIM-30km-mean for intensity



	0	24	48	72	96	120
FIM8-EnKF-Mean	-15	-30.4	-28.8	-29.4	-27.6	-21.7
FIM9-EnKF-DET	-17.2	-27.6	-24.5	-22.2	-17.1	-8.2
GFDL CSM	-17.4	-22.5	-19.9	-20.3	-15.3	-2.7
GFS	-28.4	-31.3	-27.9	-27.8	-25.5	-21
N	39	31	27	18	11	7

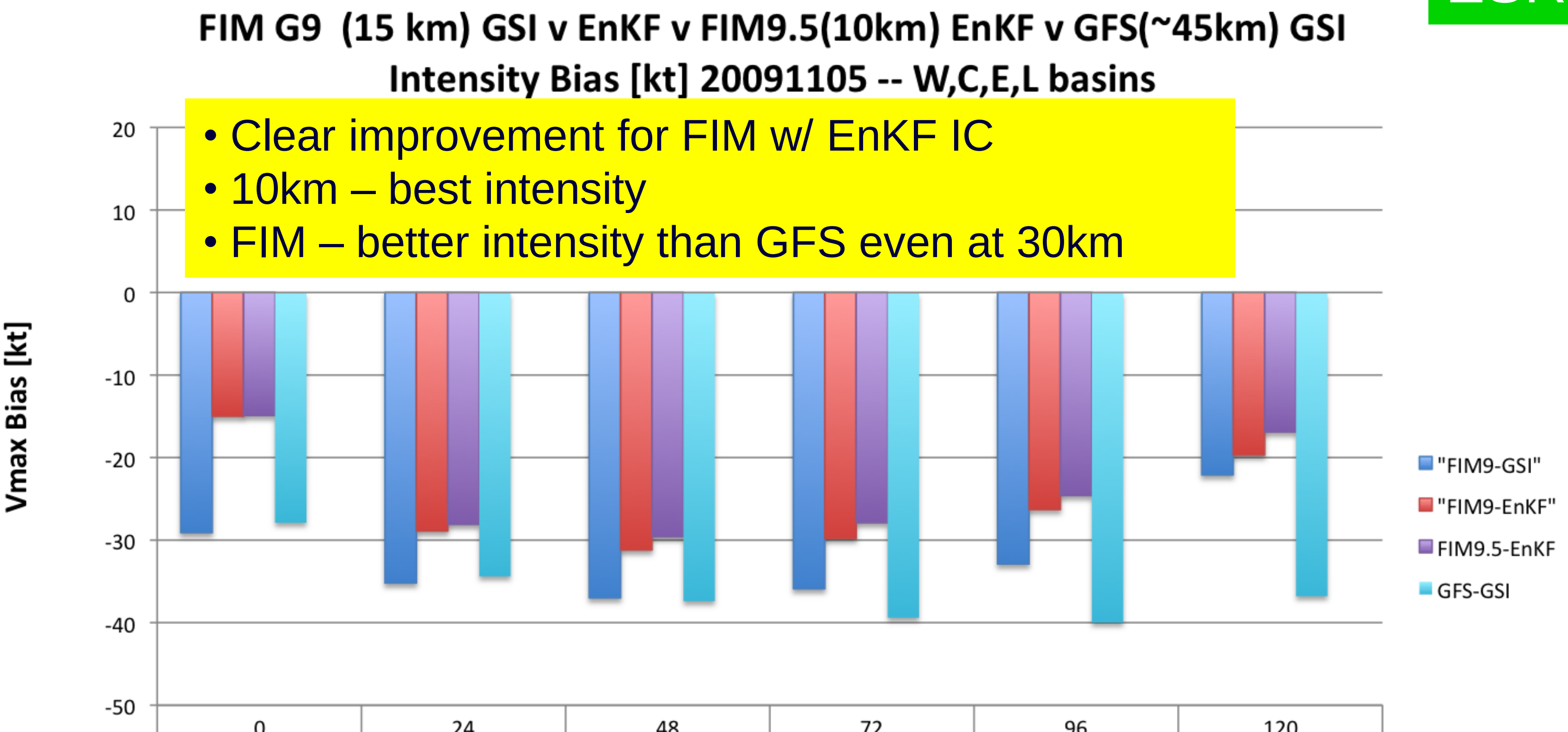
TC intensity forecast error – all basins, 2009

-2 versions of FIM-15km: **GSI init conds, EnKF init conds**

- **FIM 10km vs. 15km vs. 30km**

ESRL

- Clear improvement for FIM w/ EnKF IC
- 10km – best intensity
- FIM – better intensity than GFS even at 30km

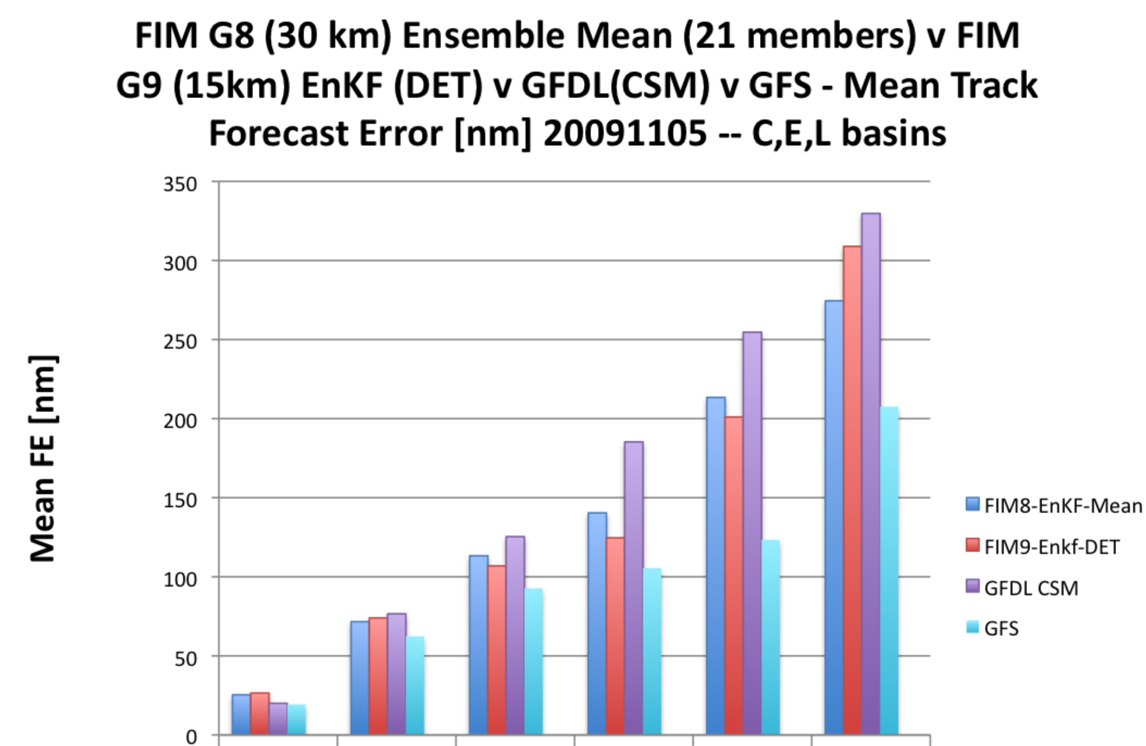


	0	24	48	72	96	120
"FIM9-GSI"	-29.1	-35.2	-37	-35.9	-32.9	-22.1
"FIM9-EnKF"	-15	-28.9	-31.2	-29.8	-26.3	-19.7
FIM9.5-EnKF	-14.9	-28.1	-29.6	-27.9	-24.6	-16.9
GFS-GSI	-27.9	-34.4	-37.4	-39.4	-40	-36.8
N	82	62	48	30	20	12

TC track forecast error – all basins, 2009
- FIM-15km-det vs. FIM-15-ens-mean
- GFDL CSM added

ESRL

•FIM-15km-det-EnKF slightly better than FIM-30km-mean for track for 48, 72, 96h, slightly worse for 120h
• FIM track forecasts better than CSM-C360 at all forecast times
• GFS has lowest track error for this limited number of cases

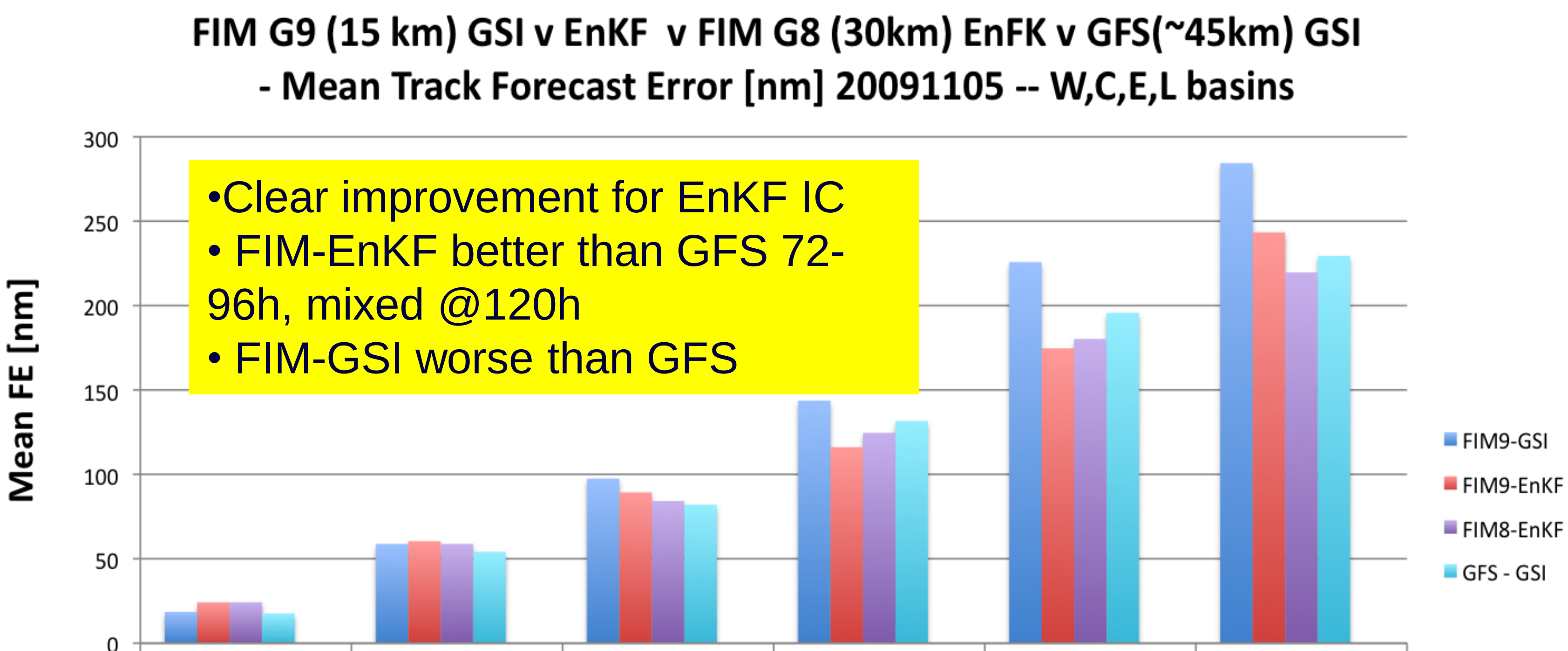


FIM8-EnKF-Mean	25.4	71.6	113.3	140.4	213.4	274.5
FIM9-Enkf-DET	26.5	74	106.9	124.6	201	308.9
GFDL CSM	20	76.6	125.4	185.3	254.7	329.7
GFS	19.3	62.4	92.7	105.5	123.4	207.6
N	38	30	26	17	10	6

TC track forecast error – all basins, 2009 -2 versions of FIM-15km:

- GSI init conds, EnKF init conds

ESRL



	0	24	48	72	96	120
FIM9-GSI	18.5	58.8	97.5	143.7	225.7	284.4
FIM9-EnKF	24.2	60.4	89.3	116.1	174.7	243.4
FIM8-EnKF	24.2	58.8	84.2	124.6	180.2	219.6
GFS - GSI	17.6	54.1	82	131.6	195.7	229.5
N	144	103	80	55	35	21

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Current & 2010-2011 plans:

GFDL

- C360 (~25 km) resolution for seasonal hurricane predictions
- C720 (~12 km) for near future (2010?) 5-10 day forecasts

- Coupled GFDL ocean and "Wave Watch III" model (to improve surface momentum & heat fluxes)
- Improve the 4D vortex initialization (and reducing the initial position & intensity errors!)

- Global ***"cloud-resolving"*** (~4.5 km with minimal convective parameterization) forecast experiments to be performed at DOE's Argonne National Laboratory. Platform: IBM Blue Gene (P/Q) scaling to 200,000 cores (or higher) required for real-time forecast to be meaningful.

NOGAPS Future Plans: FY10

- Semi-Lagrangian/Semi-implicit scheme (higher resolution)
- Improved Convective Momentum Transport
  - Above two topics in global physics summary
- New Fu-Liou radiation scheme
- Improved cloud prediction
- ESMF superstructure framework
- Upgrade of the EFS
- Convective and mid atmosphere GWD

FIM – next year

• Implementation at NCEP in 2010 as experimental component for global ensemble forecast system using ESMF (Henderson, HFIP engineer, EMC)

• Improved numerics – continuity eqn, vertical coordinate

• Further testing of

  • WRF physics options (Grell/Devenyi cumulus, Lin microphysics),

  • WRF/chem options: (Grell, Bao).

ESRL

• Additional work on OFIM - icosahedral matched HYCOM-isopycnal ocean component

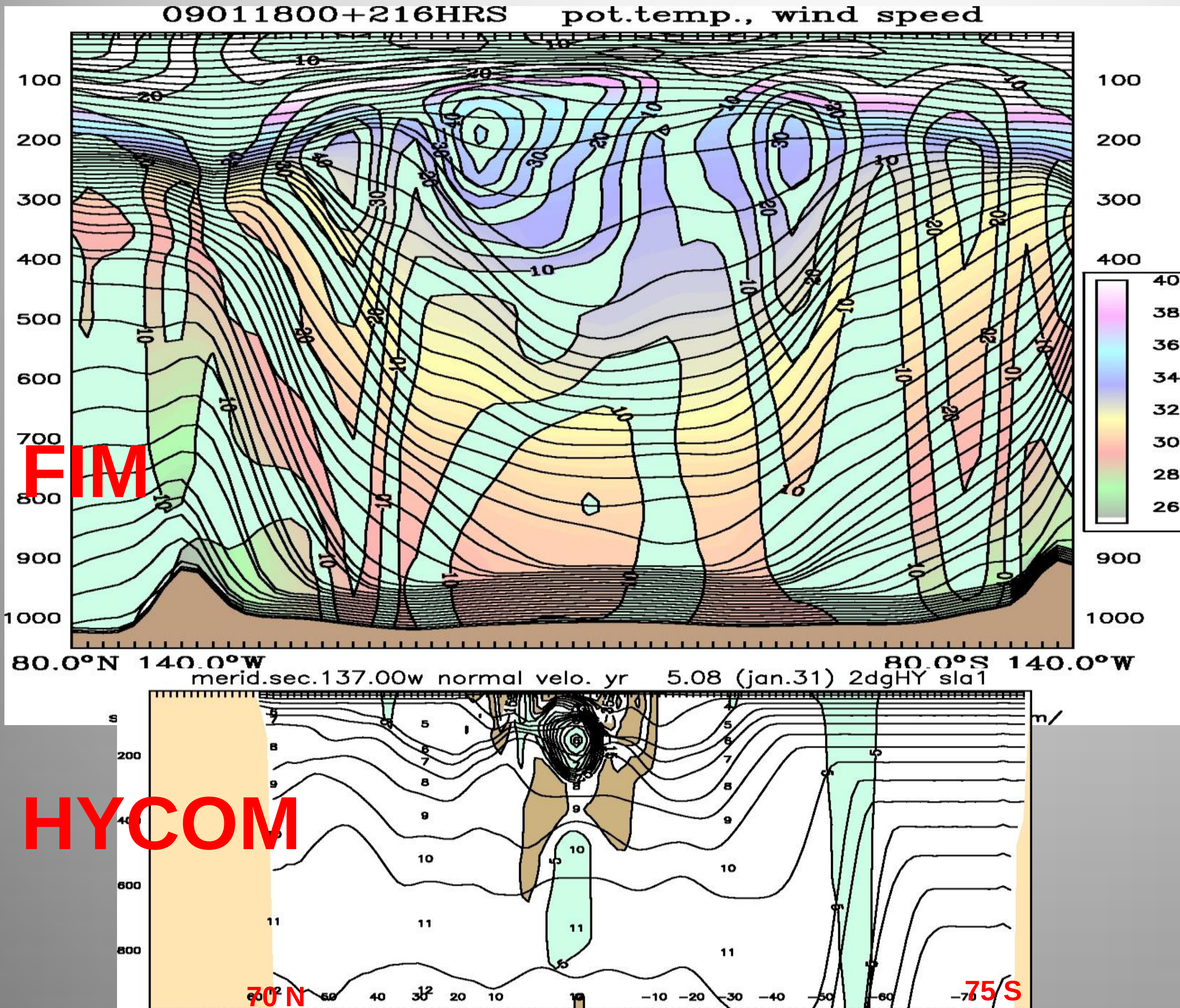
• Continue testing with GOCART aerosols, real-time fire data with global emissions inventories

• Initialize with improved initial conditions – EnKF with improved TC balance, EnKF with both GFS and FIM

• Continued development of 5km Nonhydrostatic Icosahedral Model (NIM) (Lee, MacDonald, others – ESRL)

Work underway: Develop mirror FIM-HYCOM Atmosphere-Ocean on same icosahedral grid - **OFIM➔CFIM**

ESRL



Advantages:

- avoid atmos/ocean coupling problems (1-1 pt correspondence)

Inherits:

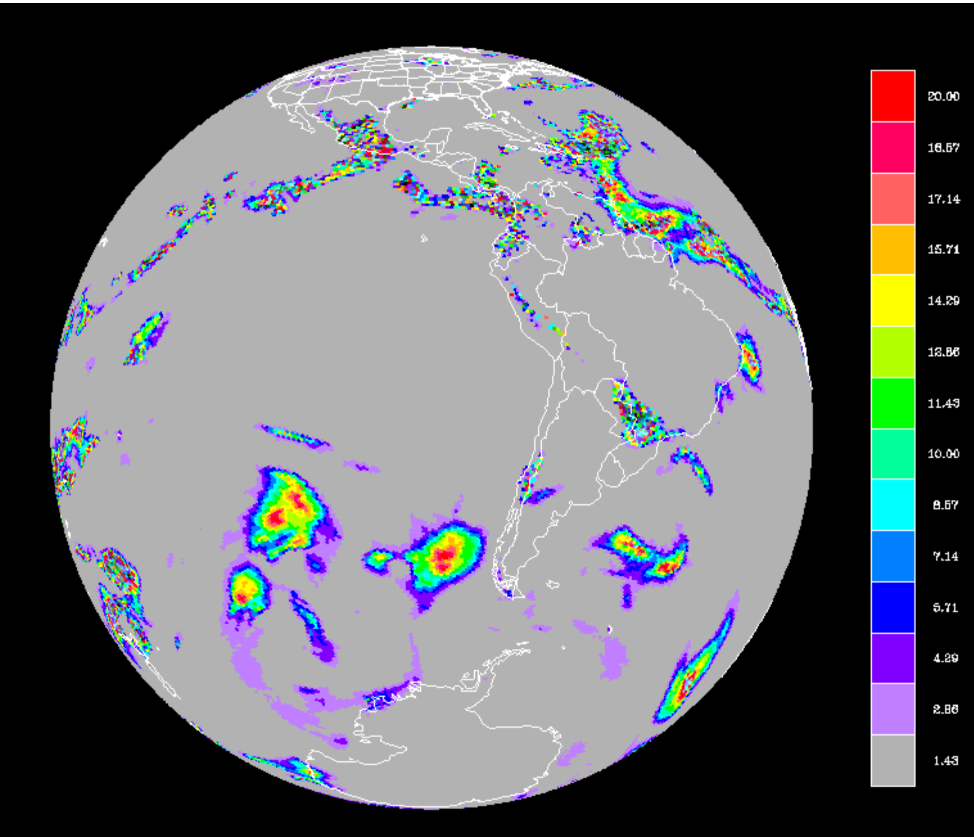
- icos numerical advantages
- FIM model framework (modules, MPI) augmented w/ HYCOM ocean prognostic eqns
- ESMF/NUOPC compliance

ESRL

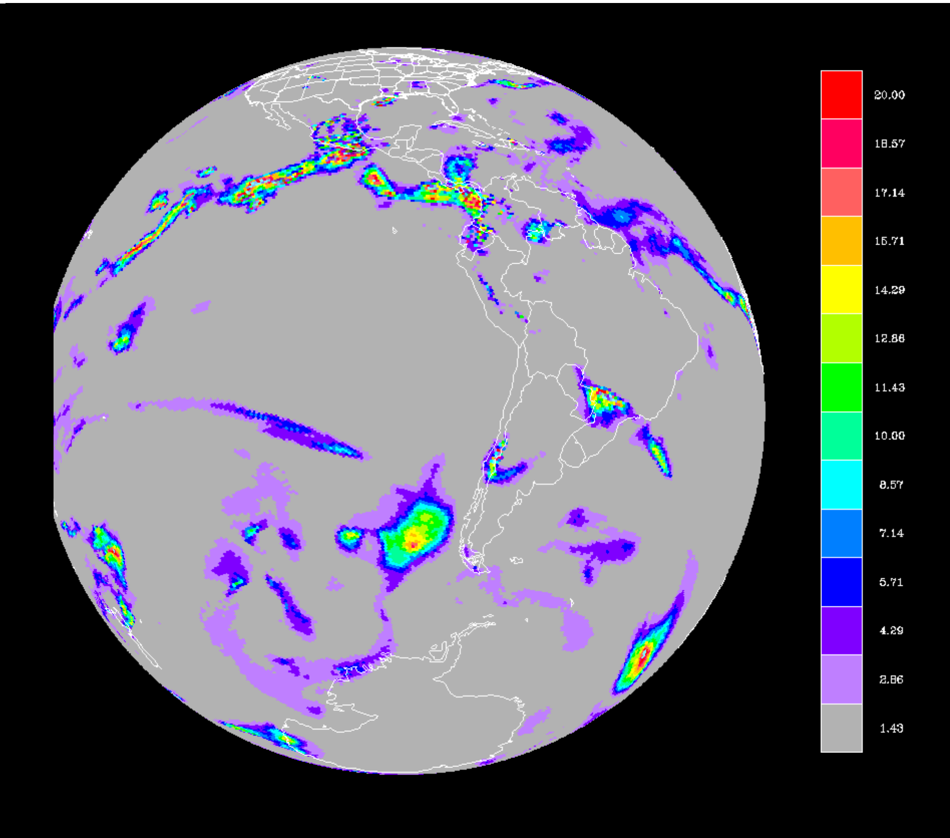
Initial FIM tests w/ WRF physics –
- Grell-Devenyi convection
- Lin microphysics

60km- 12hr **total** precipitation comparison

Grell-Devenyi conv schcheme



GFS Physics w/ Pan-Grell conv scheme

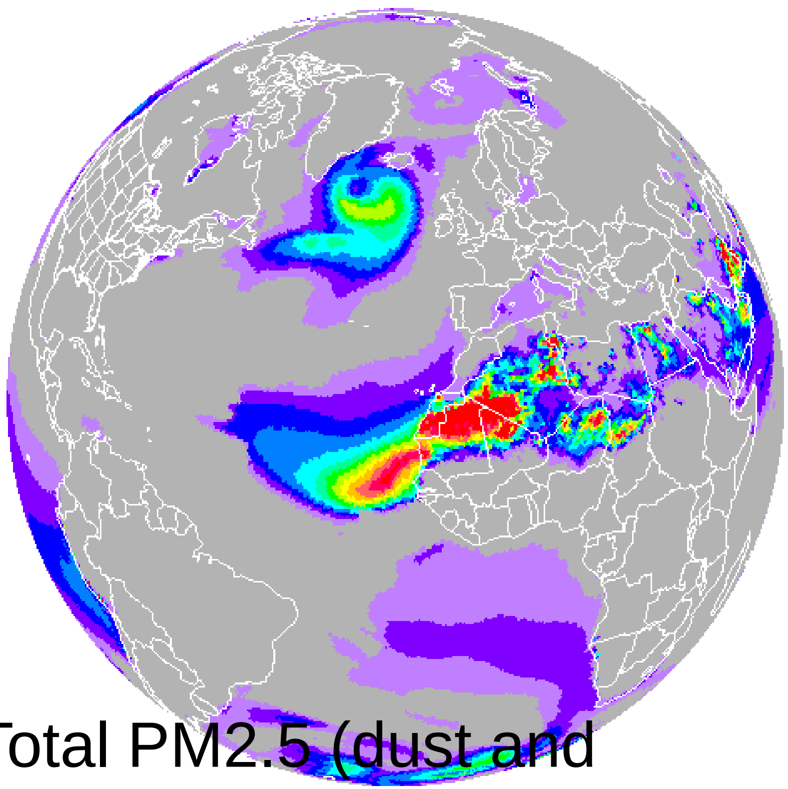


FIM- with GOCART parameterization (18 aerosols) + GFS physics

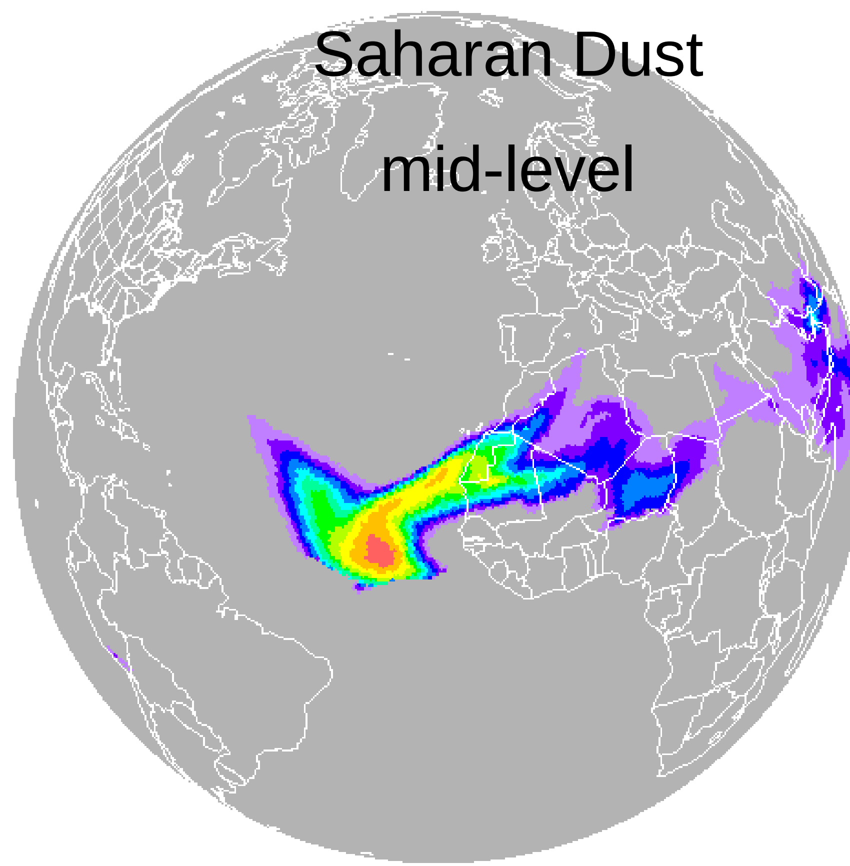
Dust and Sea-salt, 5-day forecast

G7-60km resolution tests here

ESRL



Total PM2.5 (dust and sea-salt, some sulfate) at surface



Global Model Team – HFIP – 2009 achievements

- High-resolution real-time demonstrations
  - GFS-T572 (23km), FIM-10km/15km, CSM-C360/720 (25km/12km)
  - High-res ensemble – FIM-30km / 20 member
  - Improved numerics in FIM – vertical regridding
  - Development toward NIM @ ESRL
  - NRL NOGAPS-SL testing
  - New physics / data-assimilation tested with experimental high-res global models

- Results @ global scale
  - Higher resolution ➔ more accurate intensity forecasts but not necessarily more accurate track (yet)
  - Demonstration of improved track forecasts from EnKF assimilation together with high-res global model (FIM, GFS)
  - TC demographics – not revealed by current track/intensity verification, but major emphasis in 2009 HFIP global model (and physics) teams
  - Exposure to year-round testing reveals unanticipated results
    - FIM polar-night jet @ stratopause – CFD instability (solved)
    - FIM-EnKF – exposure of surface pressure noise issue, now leading to improved FIM continuity equation solution

Primary global modeling issues

- Performance for TC track, intensity, demographics
- Maintain at least equal performance in extratropics and polar regions while improving tropical performance

- Numerics - understand effects on TC track, intensity, demographics
    - Horizontal and vertical coordinates
- Diffusion
- Resolution
    - Not yet fully addressed in 2009 – topography and land-surface not yet introduced at sub-45km resolution in FIM
- Coupled atmos-ocean model non-linearity
- Interdependencies between all issues above with physics and data assimilation

    ➔Interaction w/ Physics Team and Data Assimilation Team (much stronger in 2009 than in 2008)