Review of GFS Forecast Skills in 2013

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Acknowledgments : All NCEP EMC Global Climate and Weather Modeling Branch members are acknowledged for their contributions to the development and application of the Global Forecast Systems.

Disclaimer: The review does not cover all aspects of the complex system, and is biased towards personal experience. The review is focused more on problems and issues of the forecast system rather than on general performance skill scores.

Outline

1. **Major GFS changes in recent years**

2. **Forecast skill scores**
   - **AC and RMSE**
   - **Hurricane Track and Intensity**
   - **Precipitation**
   - **Surface 2-m temperature**
   - **Verification Against Rawinsonde Observations**

3. **Summary and Discussion**

Change History of GFS Configurations

Mon/Year	Levels	Truncations	Z-cor/dyncore	Major components upgrade
Aug 1980	12	R30	Sigma Eulerian	first global spectral model, rhomboidal
Oct 1983	12	R40	Sigma Eulerian	
Apr 1985	18	R40	Sigma Eulerian	GFDL Physics
Aug 1987	18	T80	Sigma Eulerian	First triangular truncation; diurnal cycle
Mar 1991	18	T126	Sigma Eulerian	
Aug 1993	28	T126	Sigma Eulerian	Arakawa-Schubert convection
Jun 1998	42	T170	Sigma Eulerian	Prognostic ozone; SW from GFDL to NASA
Oct 1998	28	T170	Sigma Eulerian	the restoration
Jan 2000	42	T170	Sigma Eulerian	first on IBM
Oct 2002	64	T254	Sigma Eulerian	RRTM LW;
May 2005	64	T382	Sigma Eulerian	2L OSU to 4L NOAH LSM; high-res to 180hr
May 2007	64	T382	Hybrid Eulerian	SSI to GSI
Jul 2010	64	T574	Hybrid Eulerian	RRTM SW; New shallow cnvtion; TVD tracer
?? 2014	64	T1534	Hybrid Semi-Lag	Hermite SLG; Hybrid EDMF; McICA etc

Vertical layers double every ~11 years; change of horizontal resolution is rapid; sigma-Eulerian was used for 27 years !

Source http://www.emc.ncep.noaa.gov/gmb/STATS/html/model_changes.html maintained by M. Iredell, P. Caplan, F. Yang

Major GFS Changes

- 3/1999
  - **AMSU-A** and HIRS-3 data
- 2/2000
  - **Resolution change: T126L28 → T170L42 (100 km → 70 km)**
  - Next changes
    - 7/2000 (hurricane relocation)
    - 8/2000 (data cutoff for 06 and 18 UTC)
    - 10/2000 – package of minor changes
    - 2/2001 – radiance and moisture analysis changes
- 5/2001
  - **Major physics upgrade (prognostic cloud water, cumulus momentum transport)**
  - Improved QC for AMSU radiances
  - Next changes
    - 6/2001 – vegetation fraction
    - 7/2001 – SST satellite data
    - 8/200 – sea ice mask, gravity wave drag adjustment, random cloud tops, land surface evaporation, cloud microphysics…)
    - 10/ 2001 – snow depth from model background
    - 1/2002 – Quikscat included

Logged by S. Lord and F. Yang

Major GFS Changes (cont'd)

- 11/2002
  - **Resolution change: T170L42 → T254L64 (70 km → 55 km)**
  - Recomputed background error
  - Divergence tendency constraint in tropics turned off
  - Next changes
    - 3/2003 – NOAA-17 radiances, NOAA-16 AMSU restored, Quikscat 0.5 degree data
    - 8/2003 – RRTM longwave and trace gases
    - 10/2003 – NOAA-17 AMSU-A turned off
    - 11/2003 – Minor analysis changes
    - 2/2004 – mountain blocking added
    - 5/2004 – NOAA-16 HIRS turned off
- 5/2005
  - **Resolution change: T254L64 → T382L64 (55 km → 38 km)**
  - **2-L OSU LSM → 4-L NOHA LSM**
  - Reduce background vertical diffusion
  - Retune mountain blocking
  - Next changes
    - 6/2005 – Increase vegetation canopy resistance
    - 7/2005 – Correct temperature error near top of model

Major GFS Changes (cont'd)

- 8/2006
  - Revised orography and land-sea mask
  - NRL ozone physics
  - Upgrade snow analysis
- 5/2007
  - **SSI (Spectral Statistical Interpolation) → GSI (Gridpoint Statistical Interpolation).**
  - **Vertical coordinate changed from sigma to hybrid sigma-pressure**
  - **New observations (COSMIC, full resolution AIRS, METOP HIRS, AMSU-A and MHS)**
- 12/2007
  - JMA high resolution winds and SBUV-8 ozone observations added
- 2/2009
  - **Flow-dependent weighting of background error variances**
  - **Variational Quality Control**
  - METOP IASI observations added
  - Updated Community Radiative Transfer Model coefficients
- 7/2010
  - **Resolution Change: T382L64 → T574L64 (38 km → 23 km)**
  - **Major radiation package upgrade (RRTM2 , aerosol, surface albedo etc)**
  - **New mass flux shallow convection scheme; revised deep convection and PBL scheme**
  - **Positive-definite tracer transport scheme to remove negative water vapor**

Major GFS Changes (cont'd)

- 05/09/2011
  - GSI: Improved OMI QC; Retune SBUV/2 ozone ob errors; Relax AMSU-A Channel 5 QC; New version of CRTM 2.0.2 ; Inclusion of GPS RO data from SAC-C, C/NOFS and TerraSAR-X satellites; Inclusion of uniform (higher resolution) thinning for satellite radiances ; Improved GSI code with optimization and additional options; Recomputed background errors; Inclusion of SBUV and MHS from NOAA-19 and removal of AMSU-A NOAA-15 .
  - GFS: New Thermal Roughness Length -- Reduced land surface skin temperature cold bias and low level summer warm bias over arid land areas; Reduce background diffusion in the Stratosphere .

- 5/22/2012
  - GSI Hybrid EnKF-3DVAR : A hybrid variational ensemble assimilation system is employed. The background error used to project the information in the observations into the analysis is created by a combination of a static background error (as in the prior system) and a new background error produced from a lower resolution (T254) Ensemble Kalman Filter.
  - Other GSI Changes: Use GPS RO bending angle rather than refractivity; Include compressibility factors for atmosphere ; Retune SBUV ob errors, fix bug at top ; Update radiance usage flags; Add NPP ATMS satellite data, GOES-13/15 radiance data, and SEVERI CSBT radiance product ; Include satellite monitoring statistics code in operations ; Add new satellite wind data and quality control.

- 09/05/2012
  - GFS : A look-up table used in the land surface scheme to control Minimum Canopy Resistance and Root Depth Number was updated to reduce excessive evaporation. This update was aimed to mitigate GFS cold and moist biases found in the late afternoon over the central United States when drought conditions existed in summer of 2012.

Major GFS Changes (cont'd)

- **2013**

  - GFS was moved from IBM CCS to WCOSS supercomputers. They two systems have different architectures.

  - GSI change on August 20: New satellite data, including METOP-B, SEVIRI data from Meteosat-10, and NPP CrIS data.

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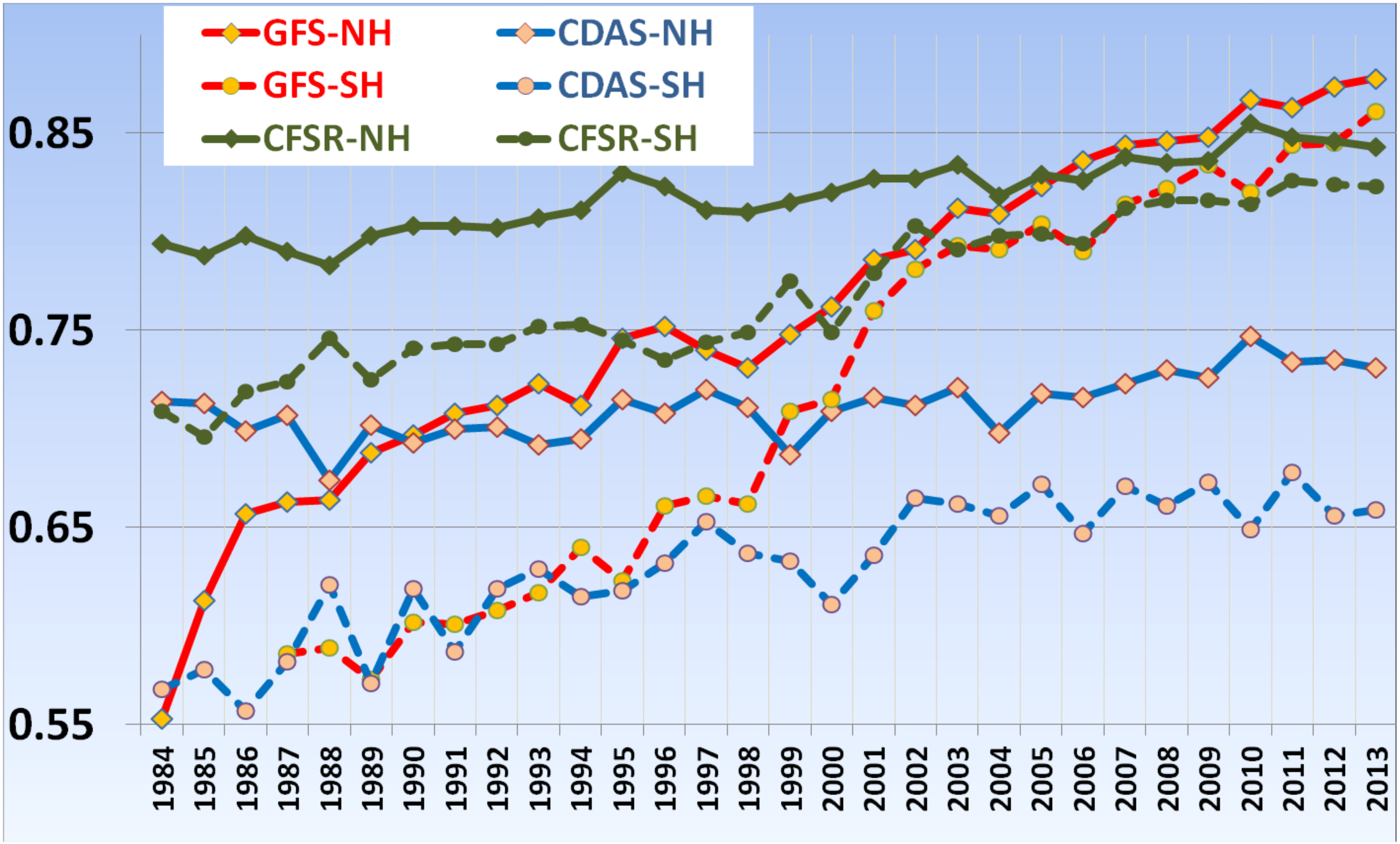
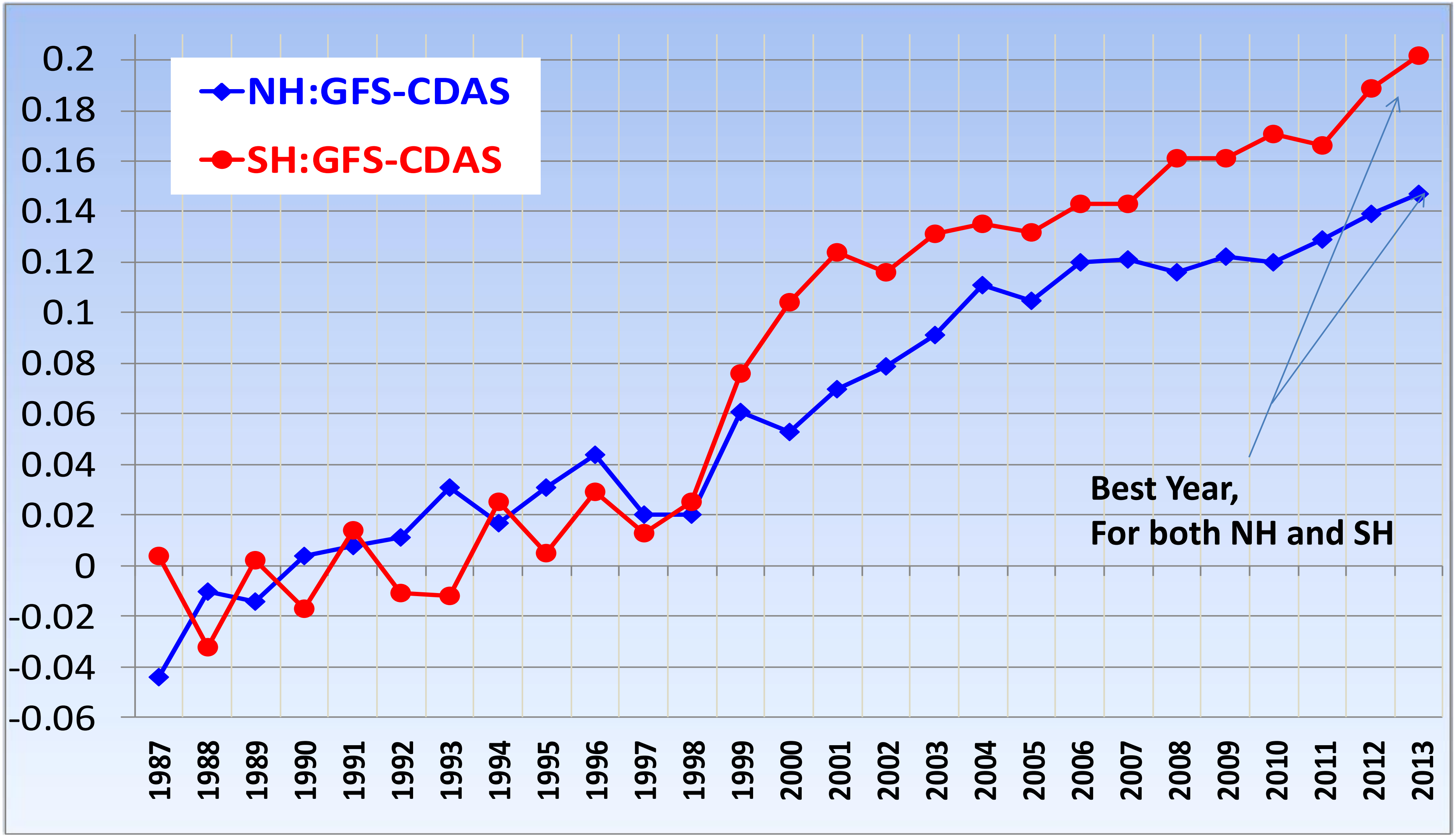
Annual Mean 500-hPa HGT Day-5 Anomaly Correlation



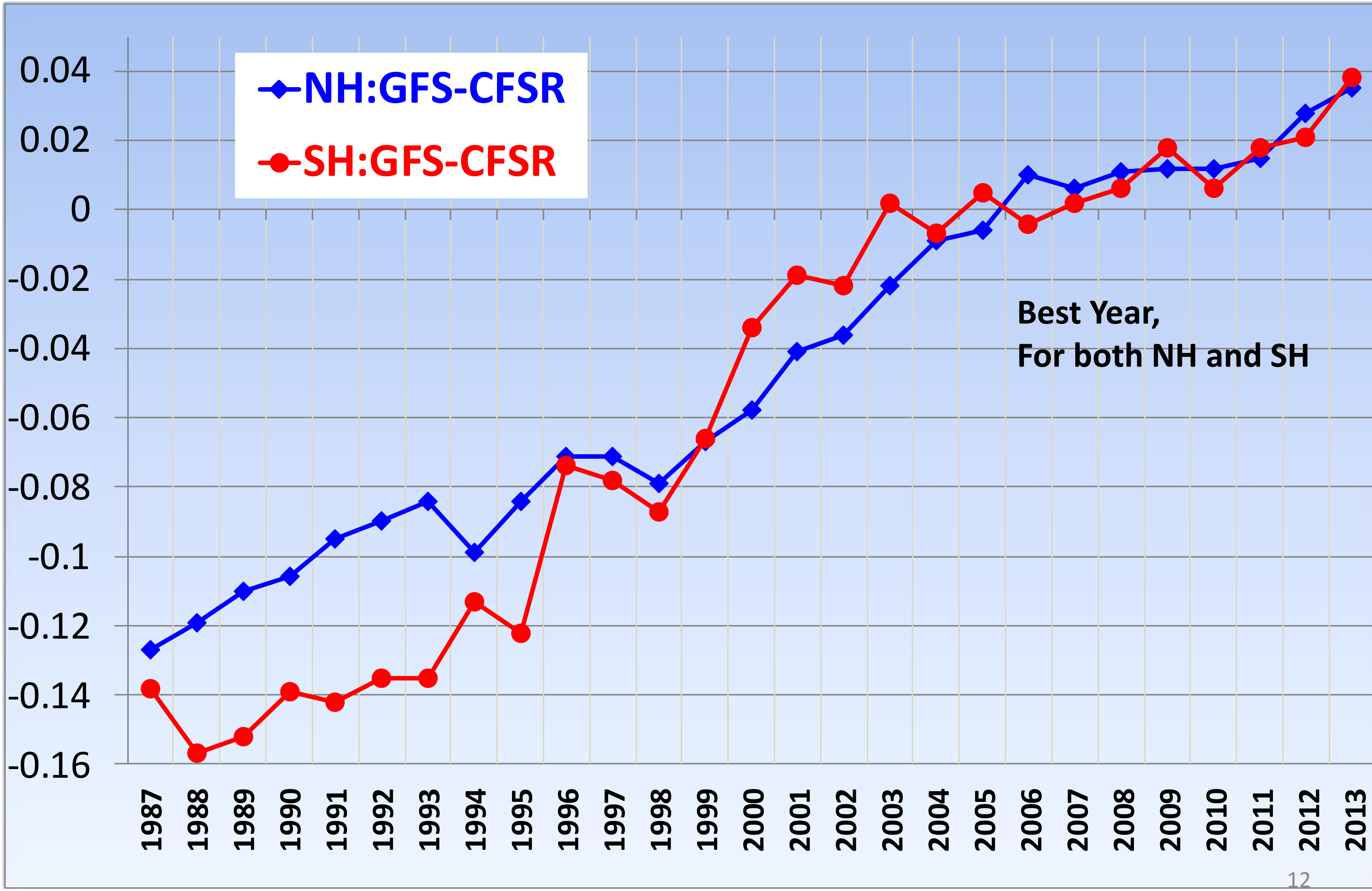
CDAS is a legacy GFS (T64) used for NCEP/NCAR Reanalysis circa 1995.
CFSR is the coupled GFS (T126) used for reanalysis circa 2006.
After 2010, CDAS and CFSR scores have been dropping – is the nature getting more difficult to predict?

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation
GFS minus CDAS

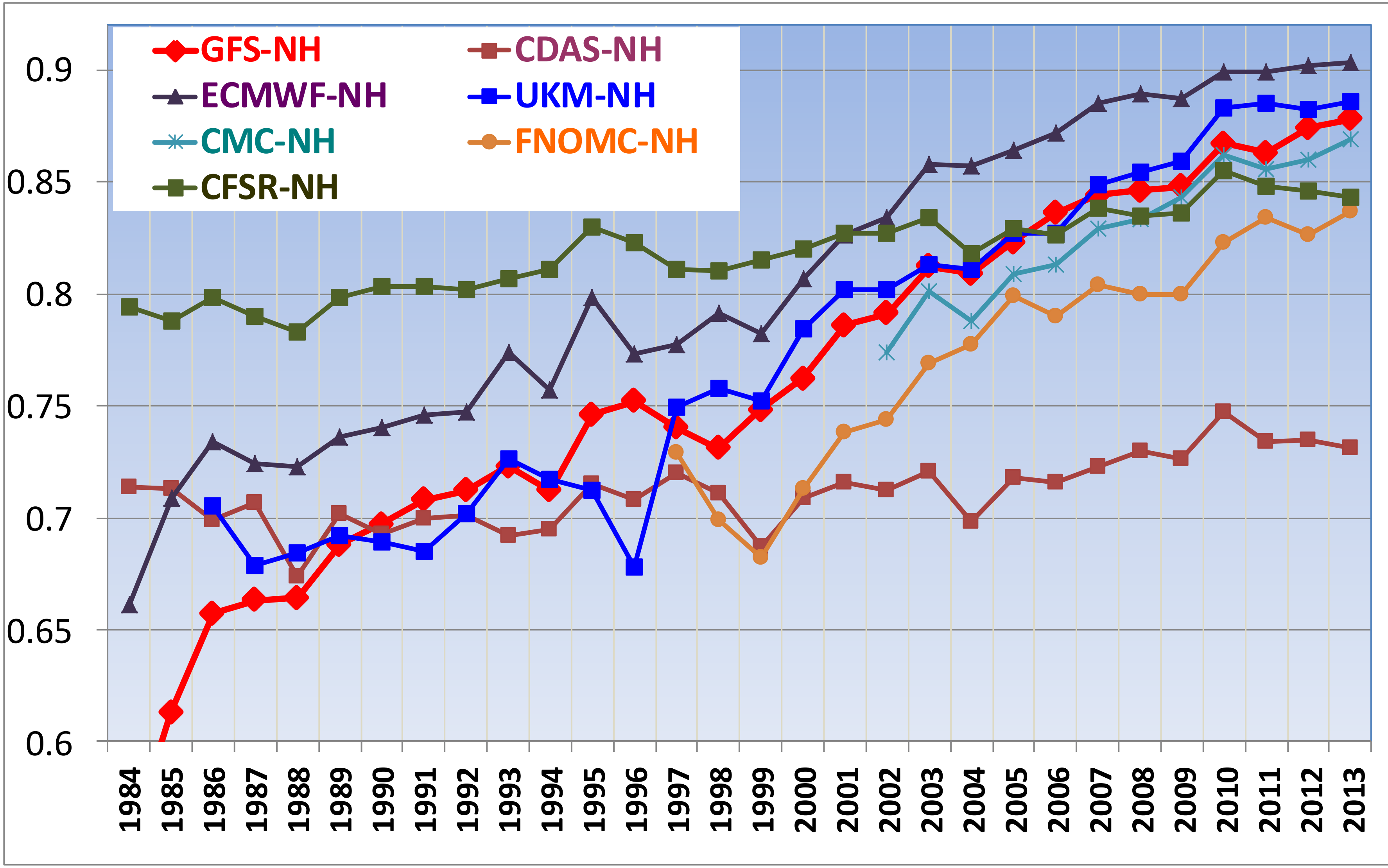


After 1999, the gain in SH is much faster than that in NH. Is it an indication of better use of satellite observations in DA?

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation
GFS minus CFSR

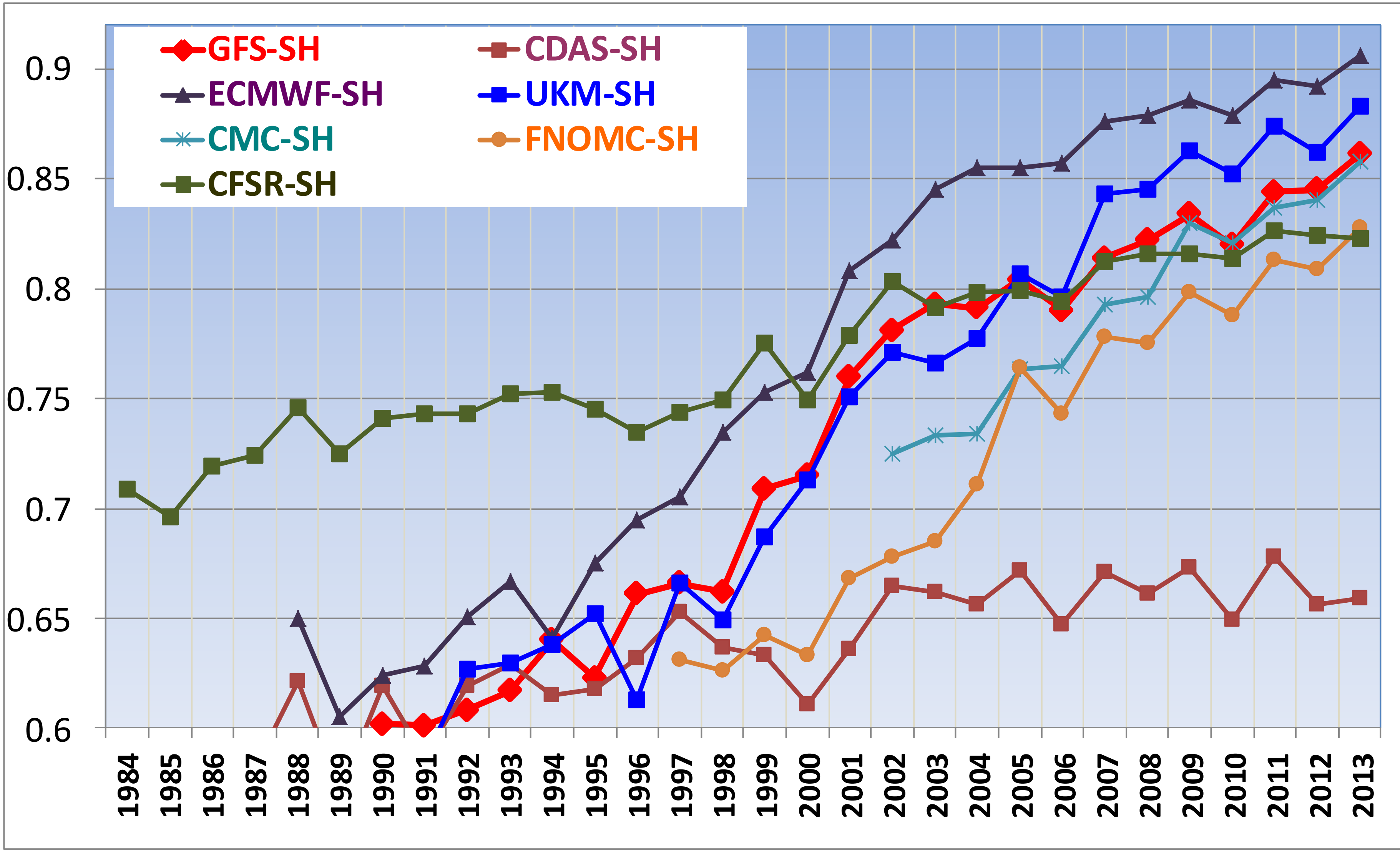


Annual Mean NH 500hPa HGT Day-5 AC



- **All models except CFSR and CDAS were better in 2013 than in 2012.**

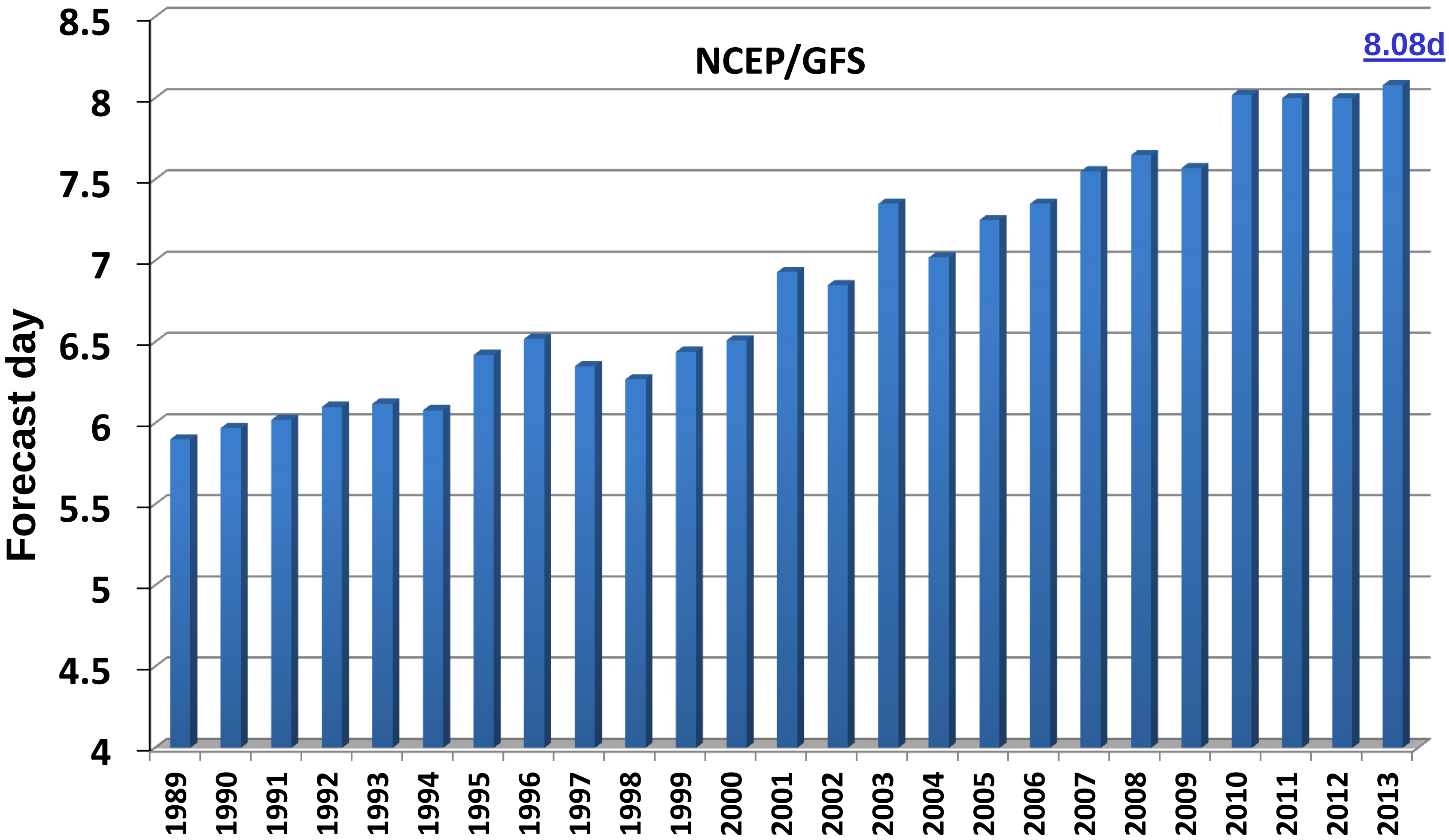
Annual Mean SH 500hPa HGT Day-5 AC



- **All models were better in 2013 than in 2012. CMC caught up with GFS.**

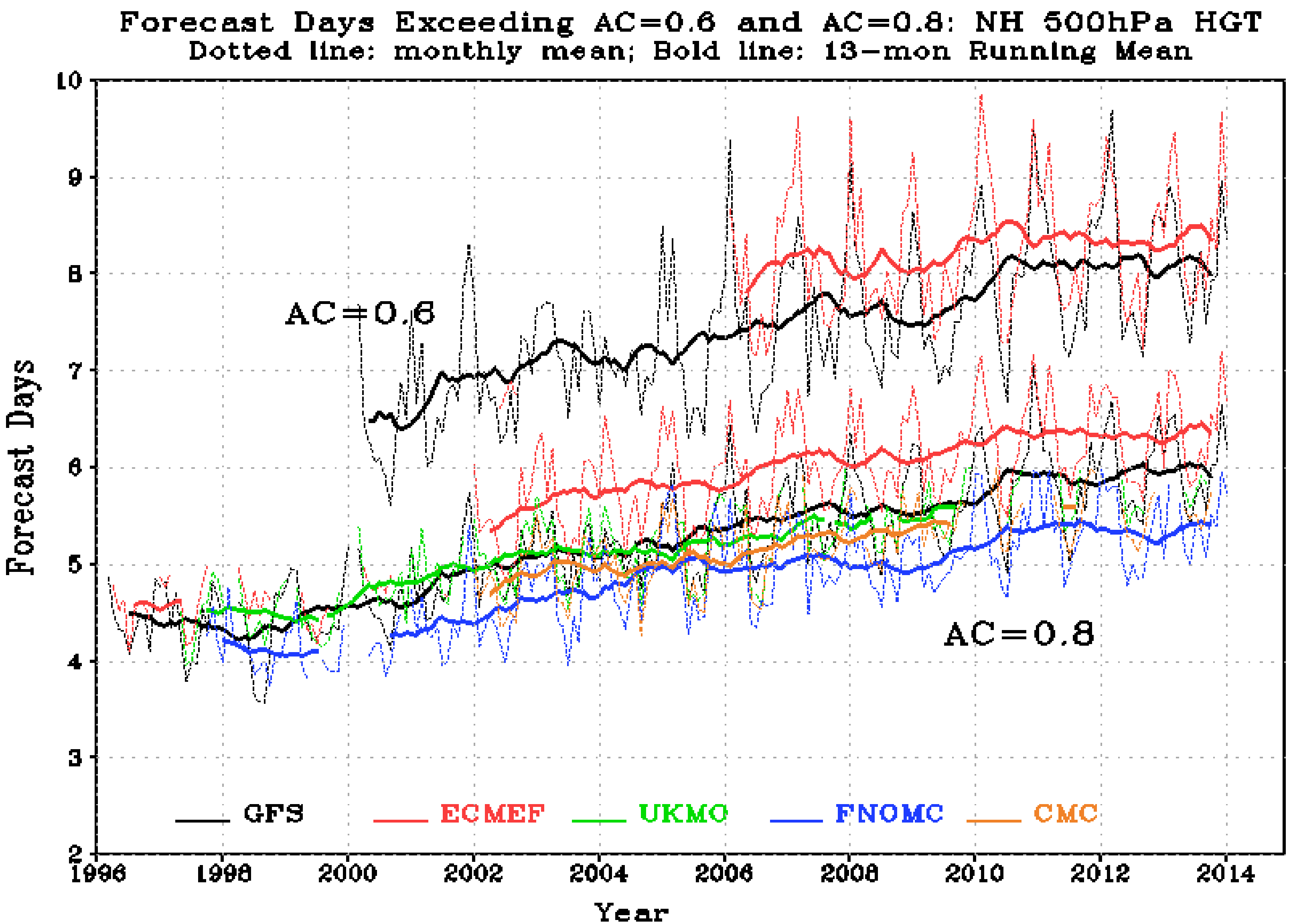
Reformatted Bob Kistler Diagram

Day at which forecast loses useful skill (AC=0.6)
N. Hemisphere 500hPa height calendar year means



Increase is about one day per decade

Useful Forecast Days for Major NWP Models, NH

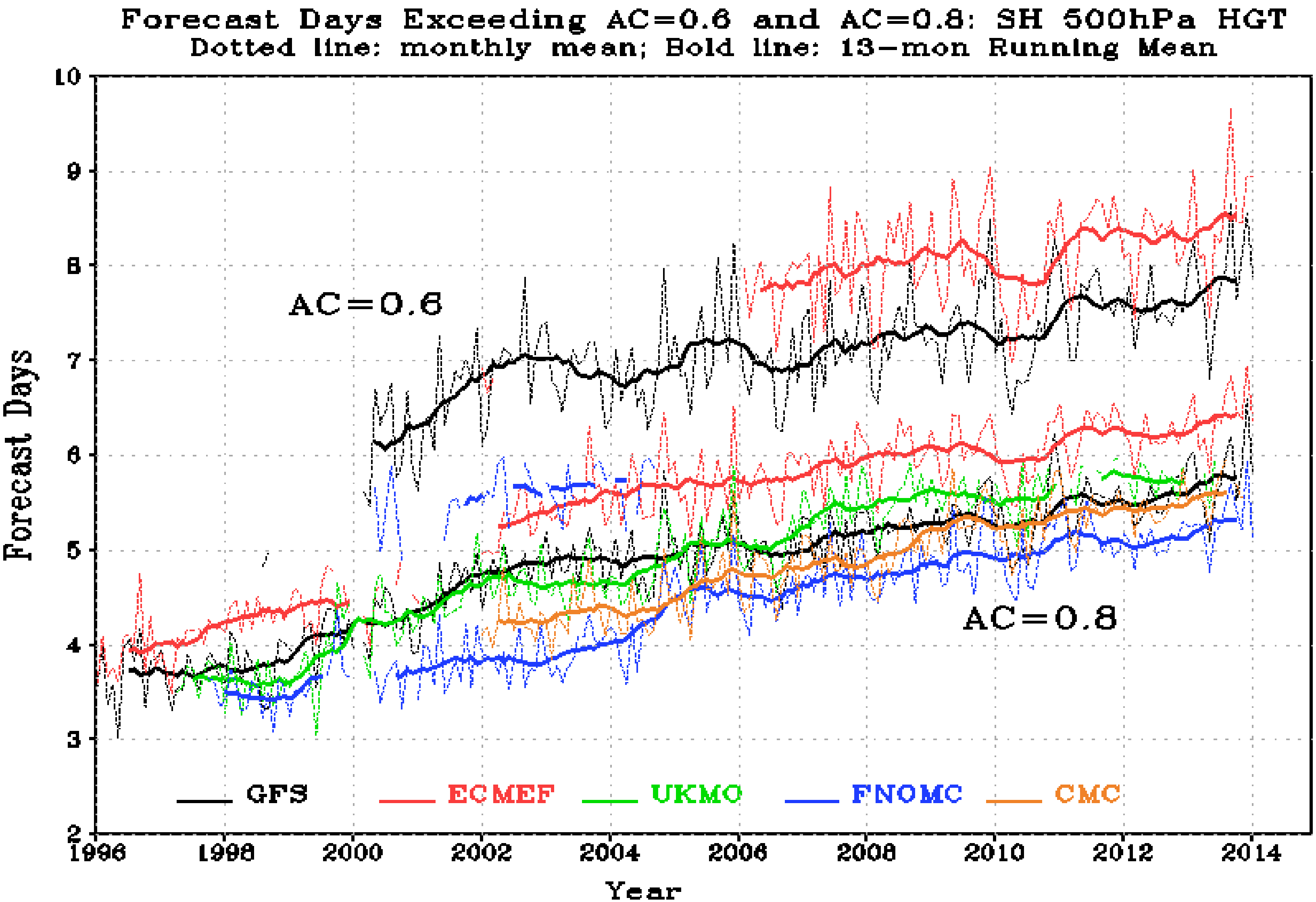


GFS lags ECM by ~0.3 day

GFS lags ECM by ~0.4 day

http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/longterm/ by F. Yang

Useful Forecast Days for Major NWP Models, SH

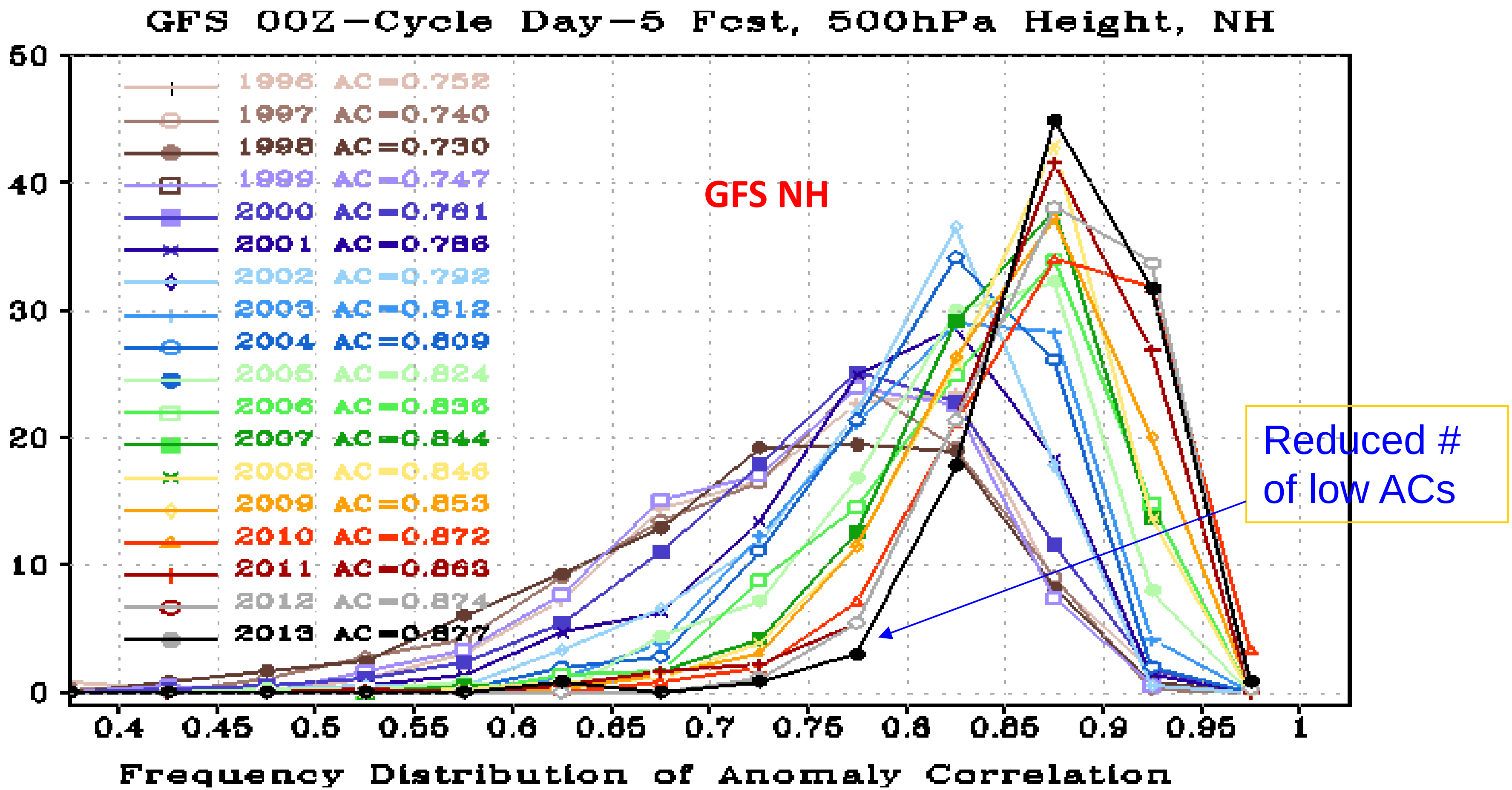


GFS lags ECM by ~0.7 day

GFS lags ECM by ~0.7 day

AC Frequency Distribution

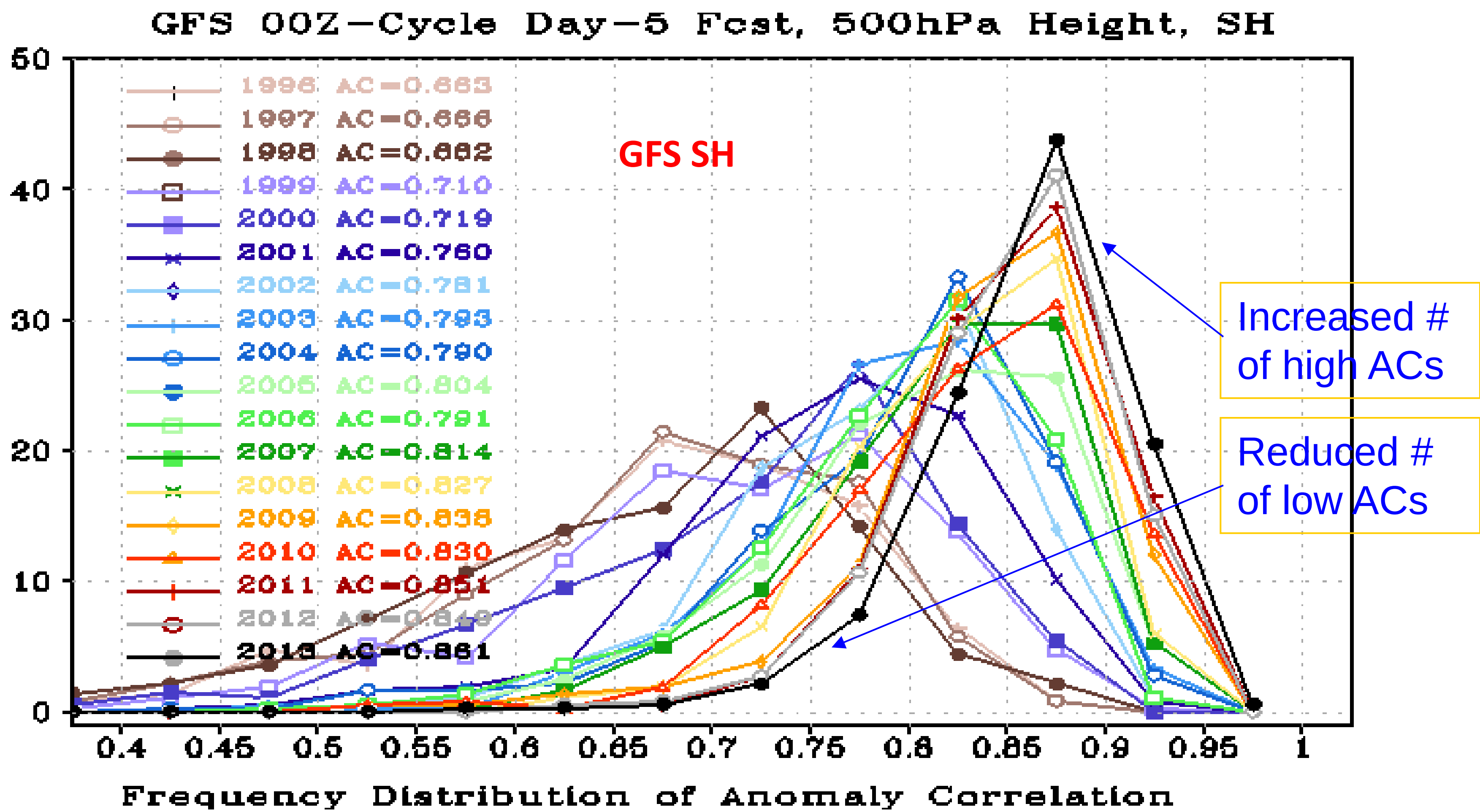
Twenty bins were used to count for the frequency distribution, with the 1st bin centered at 0.025 and the last been centered at 0.975. The width of each bin is 0.05.



- Jan 2000: T126L28 → T170L42
- May 2001: prognostic cloud
- Oct 2002: T170L42 → T254L64
- May 2005: T254L64 → T382L64;
  2-L OSU LSM →4-L NOHA LSM

- May 2007: SSI → GSI Analysis;
  Sigma → sigma-p hybrid coordinate
- July 2010: T382L64 → T574L64; Major Physics Upgrade
- May 2012: Hybrid-Ensemble 3D-VAR Data Assimilation

AC Frequency Distribution



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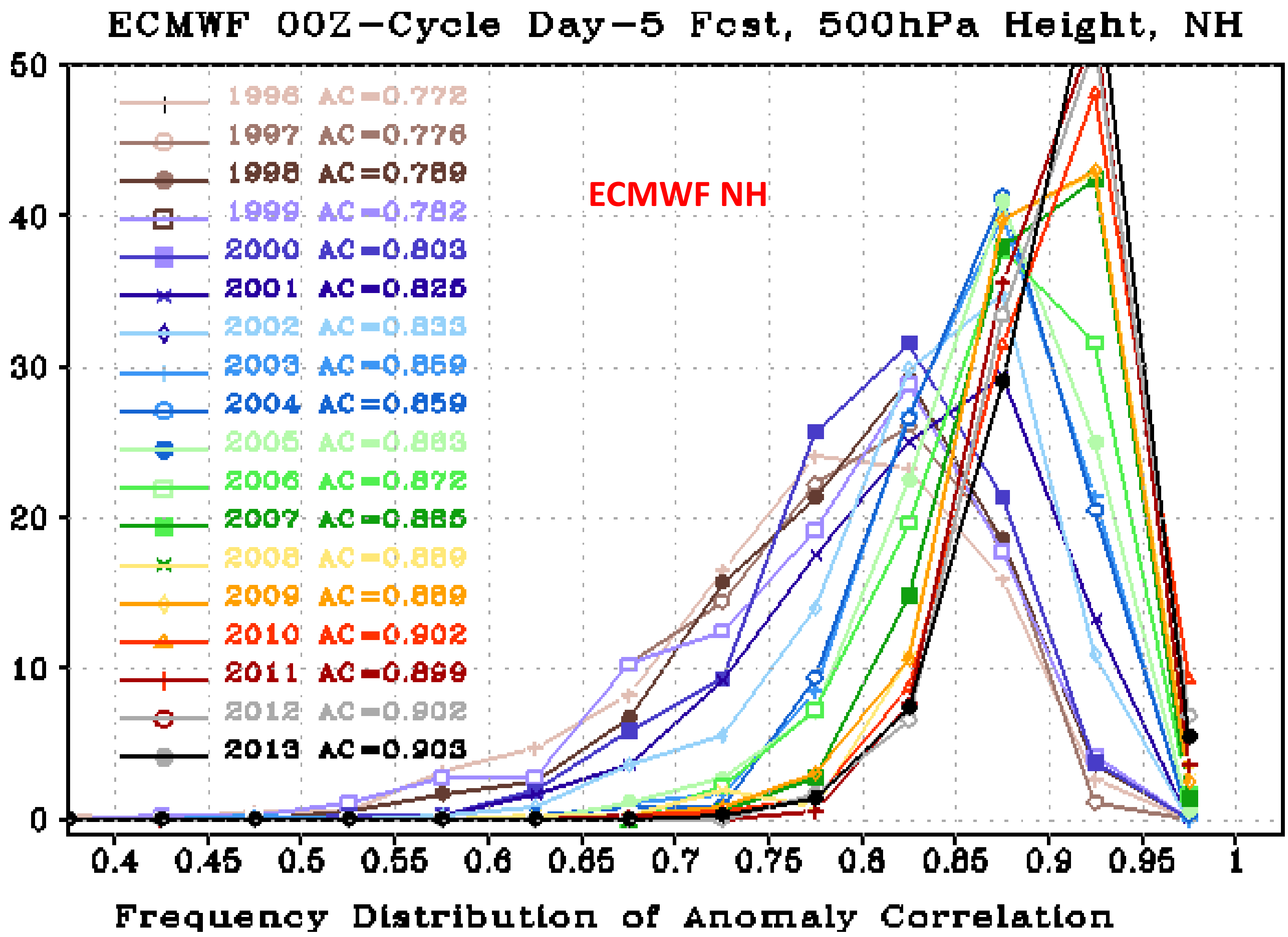

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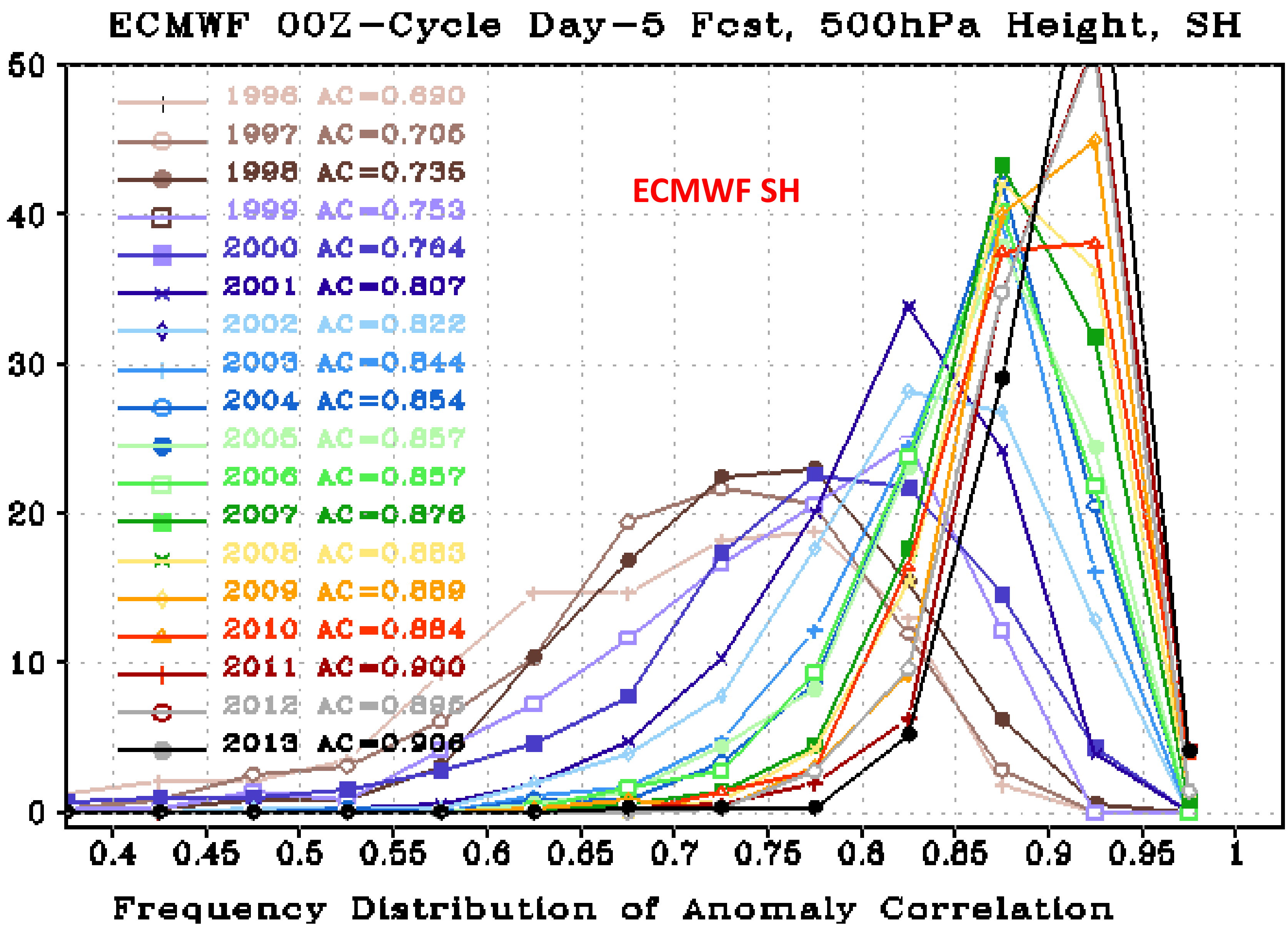
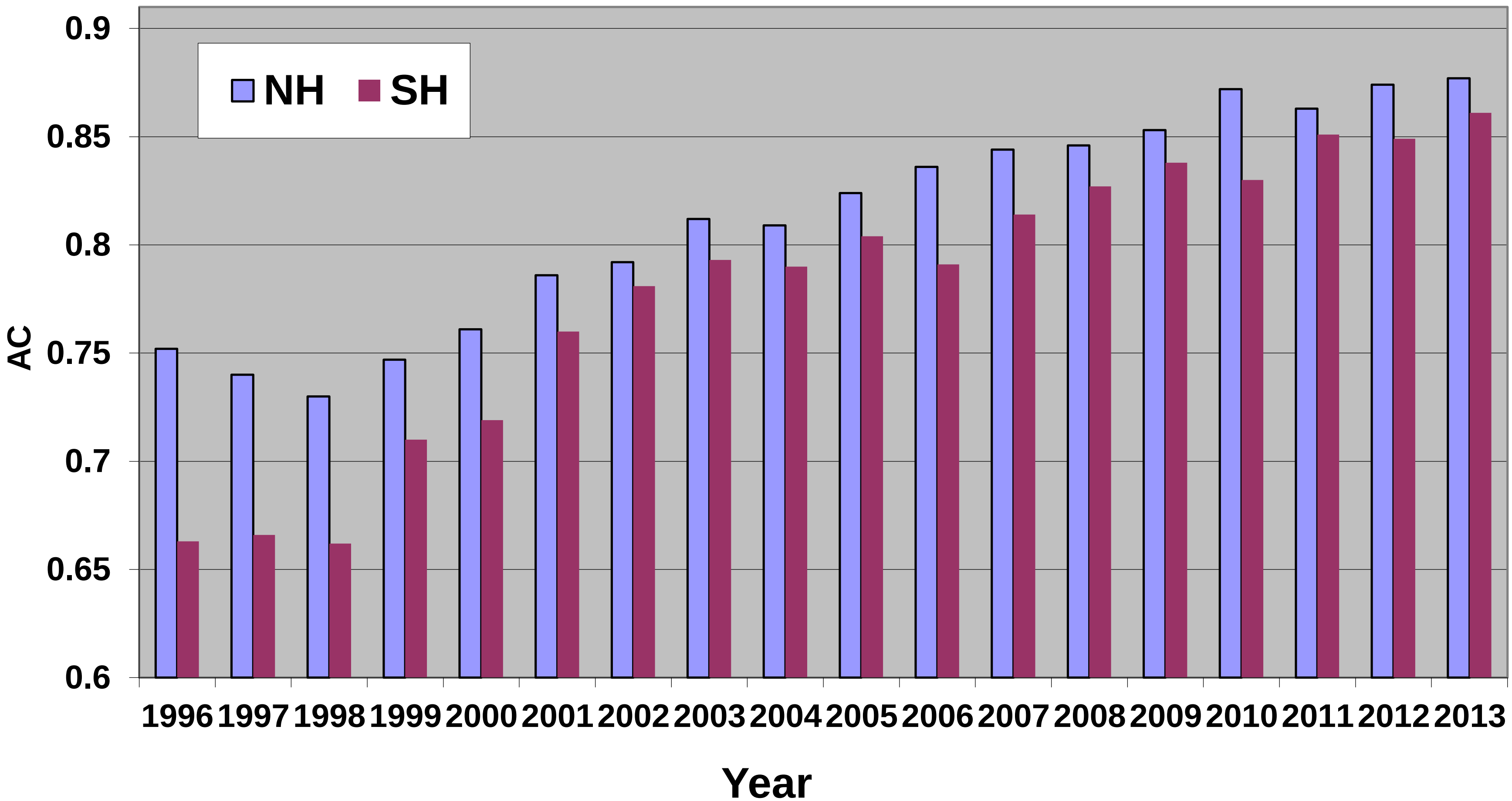


GFS 00Z Cycle Day-5 500hPa Height Anomaly Correlation



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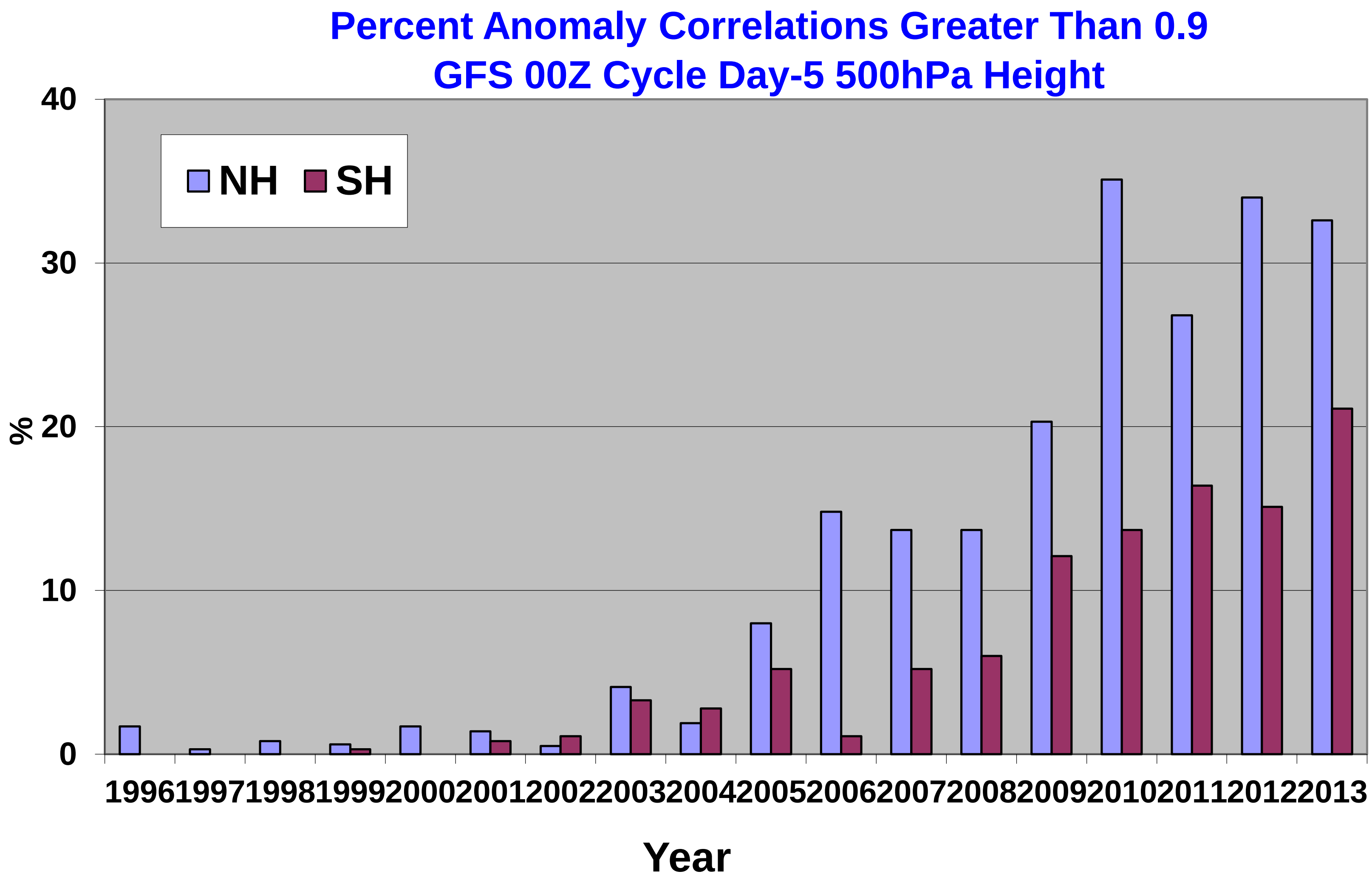

NH: slight decrease

SH: nice increase

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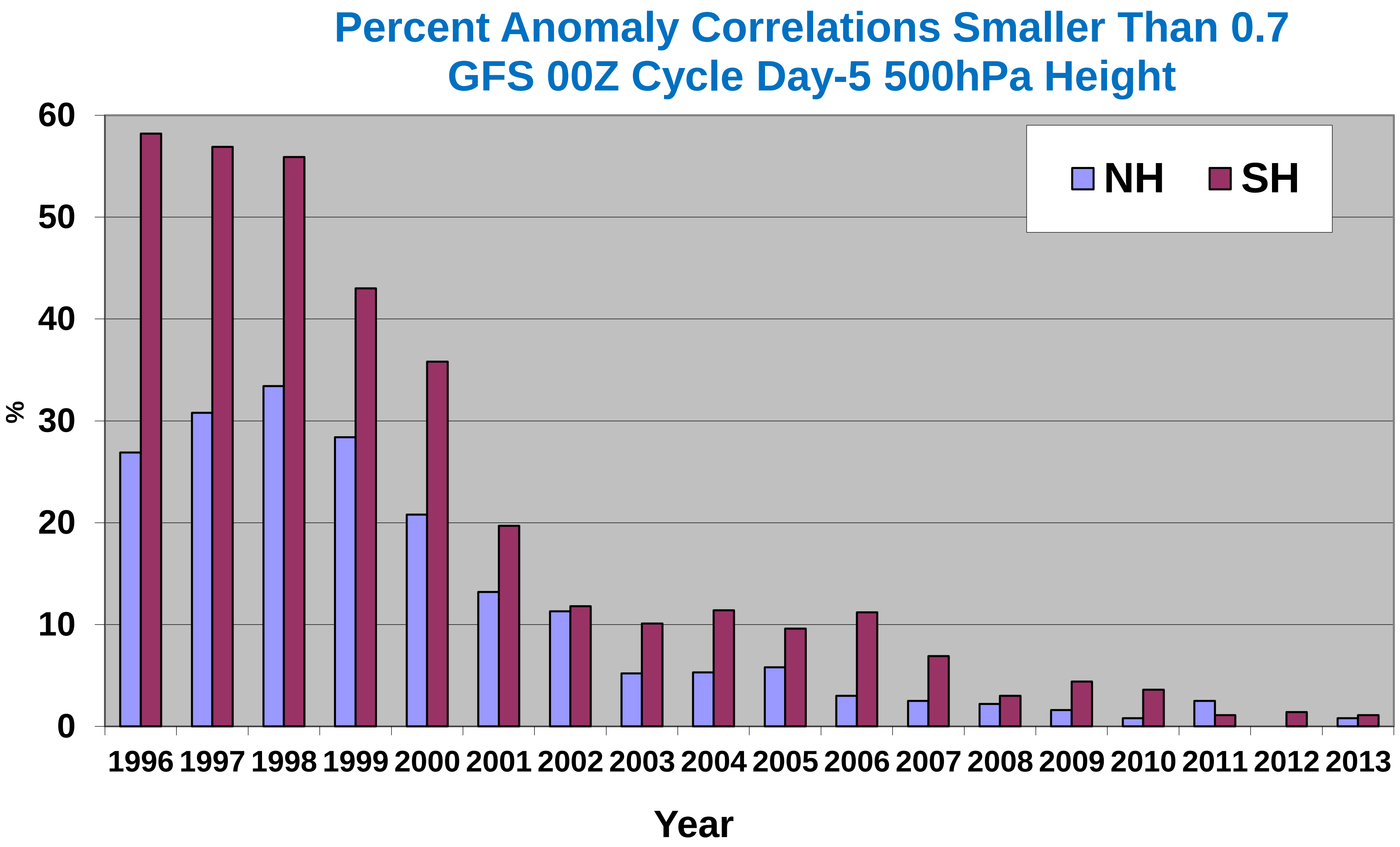

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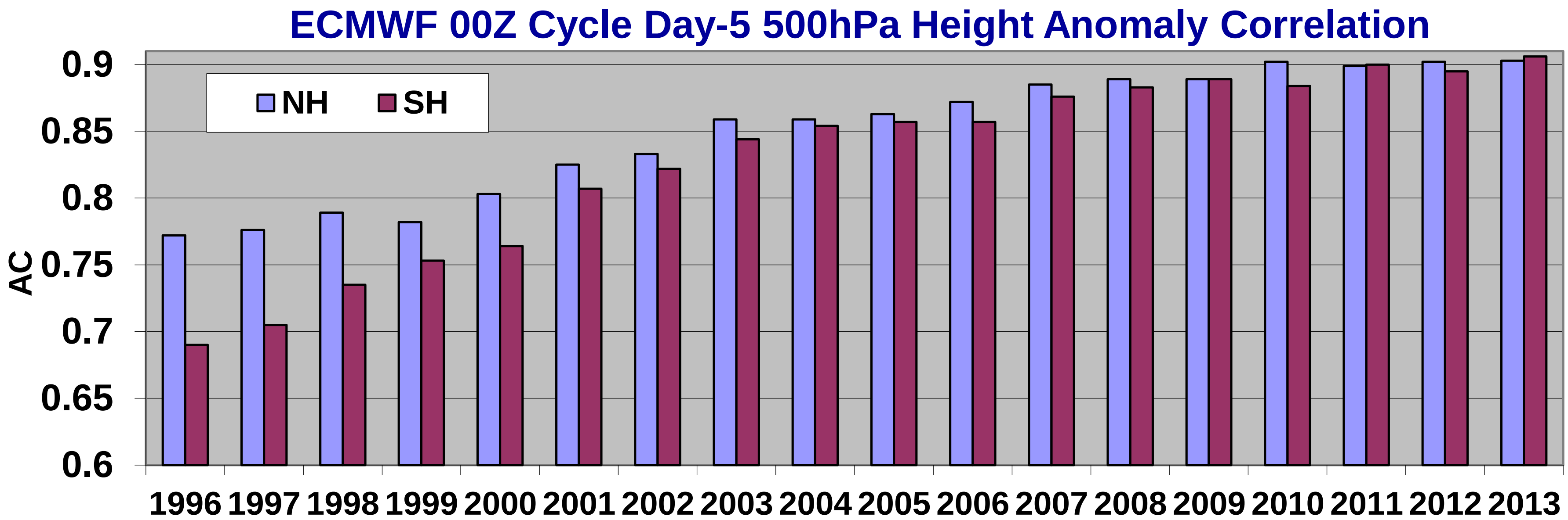
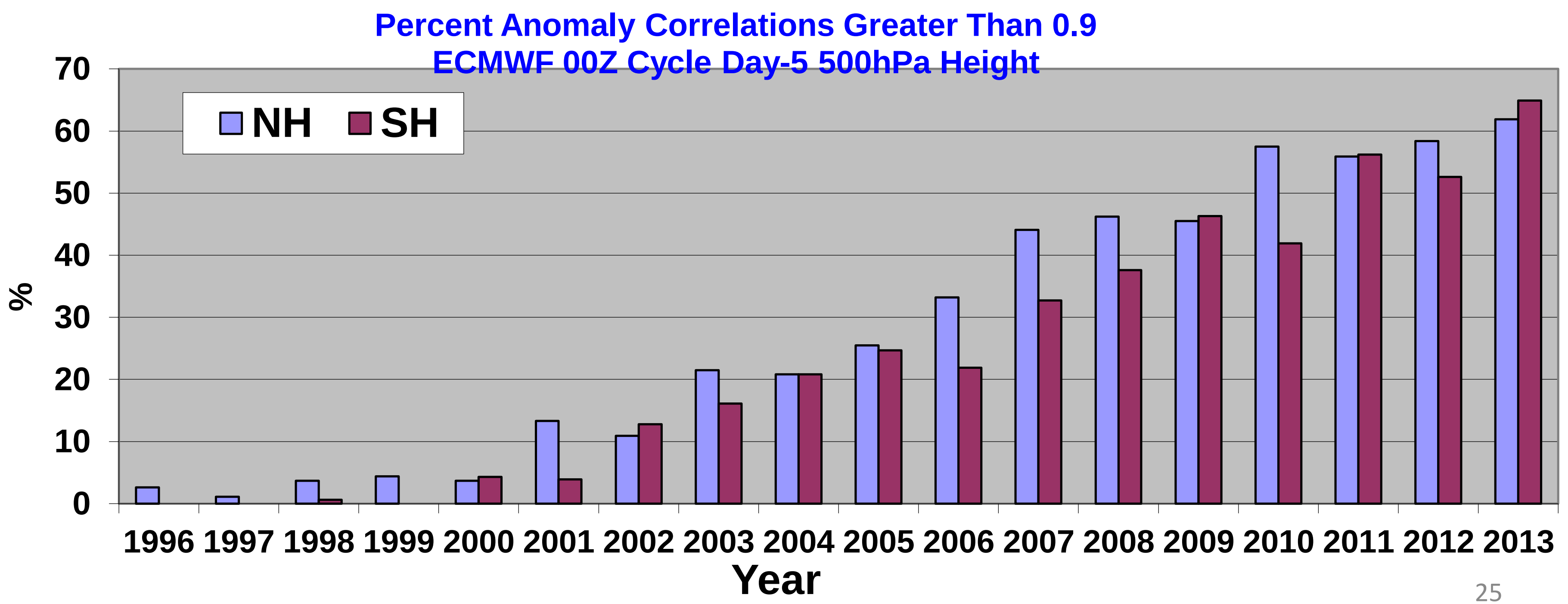
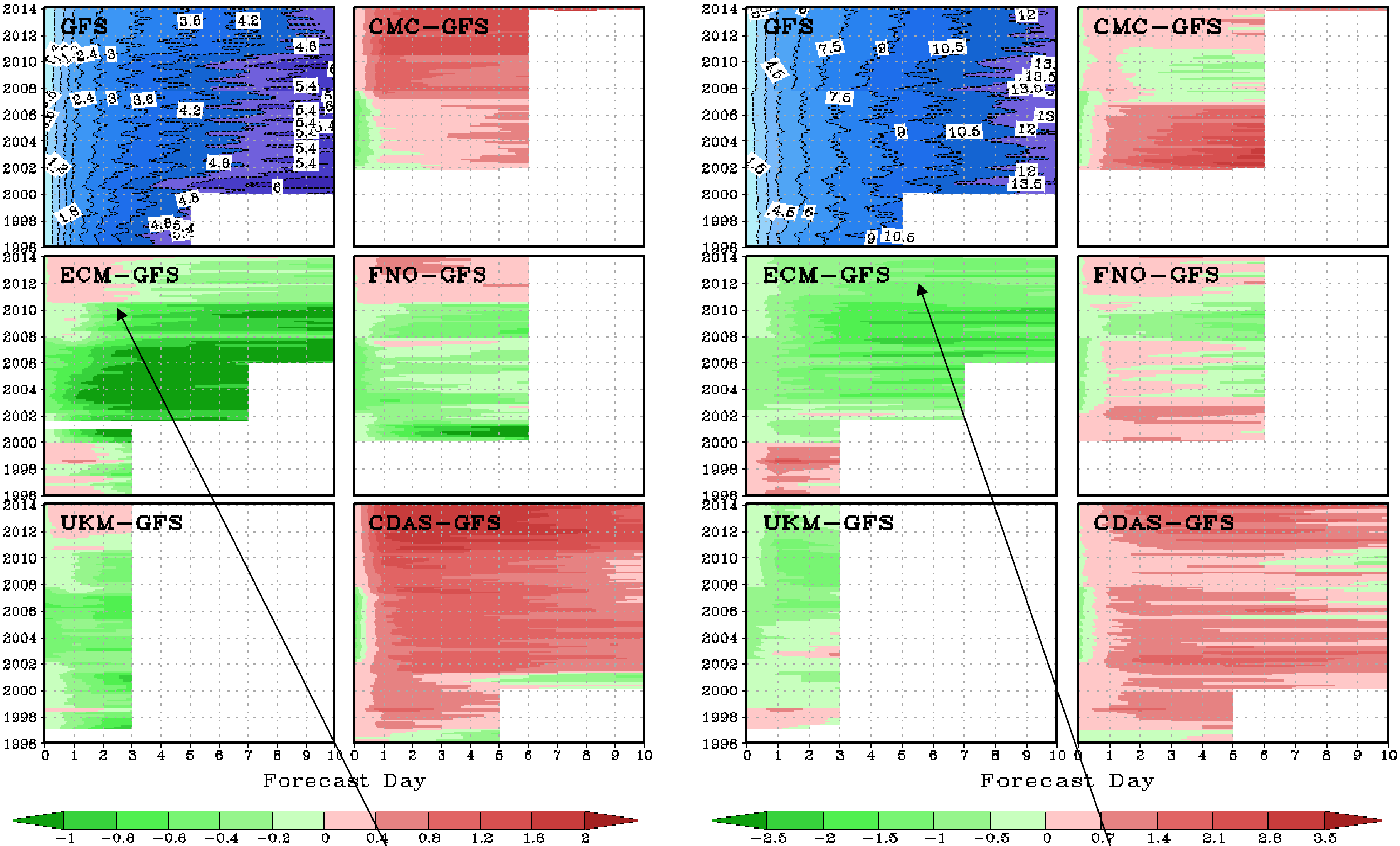

ECMWF 00Z Cycle Day-5 500hPa Height Anomaly Correlation
NH
SH
AC
0.9
0.85
0.8
0.75
0.7
0.65
0.6
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013


Percent Anomaly Correlations Greater Than 0.9
ECMWF 00Z Cycle Day-5 500hPa Height
NH
SH
%
70
60
50
40
30
20
10
0
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013
Year

Tropical Wind RMSE, 00Z Cycle, Multiple NWP Models

850 hPa

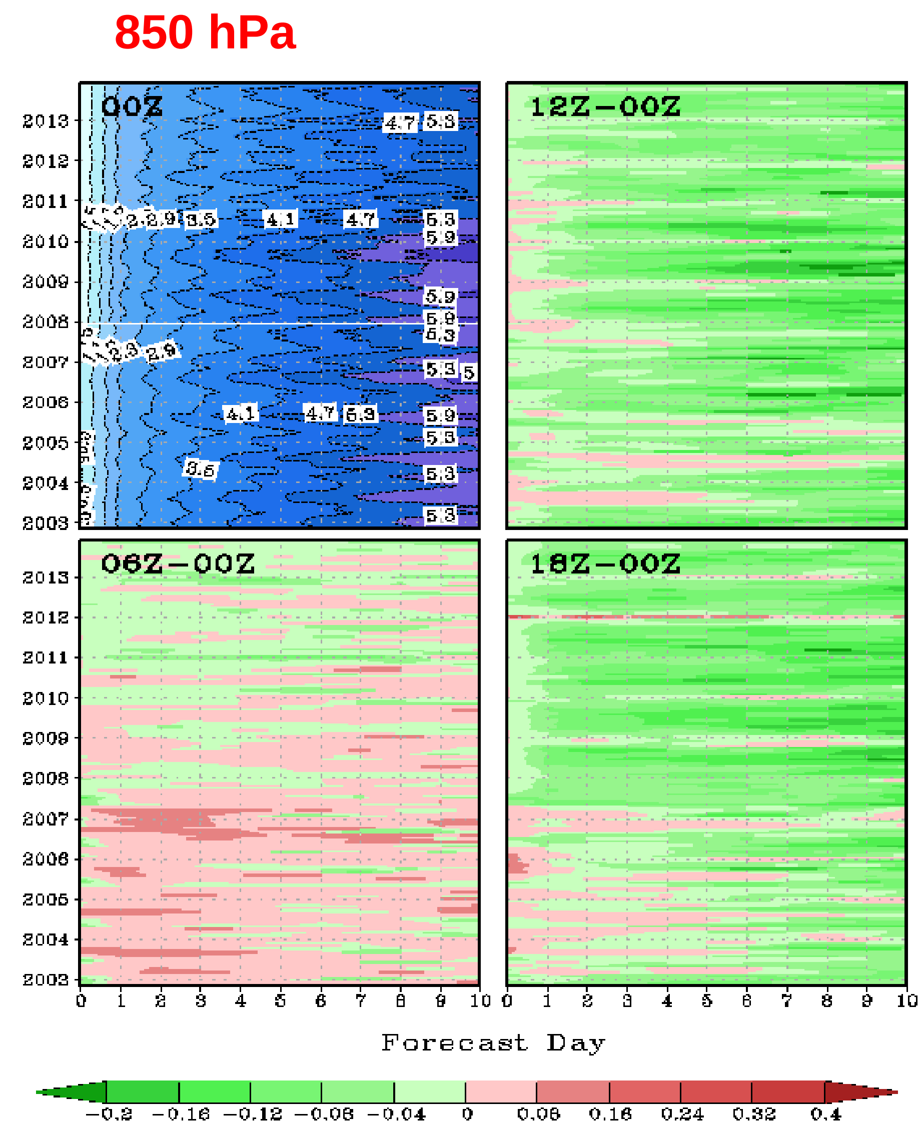
200 hPa

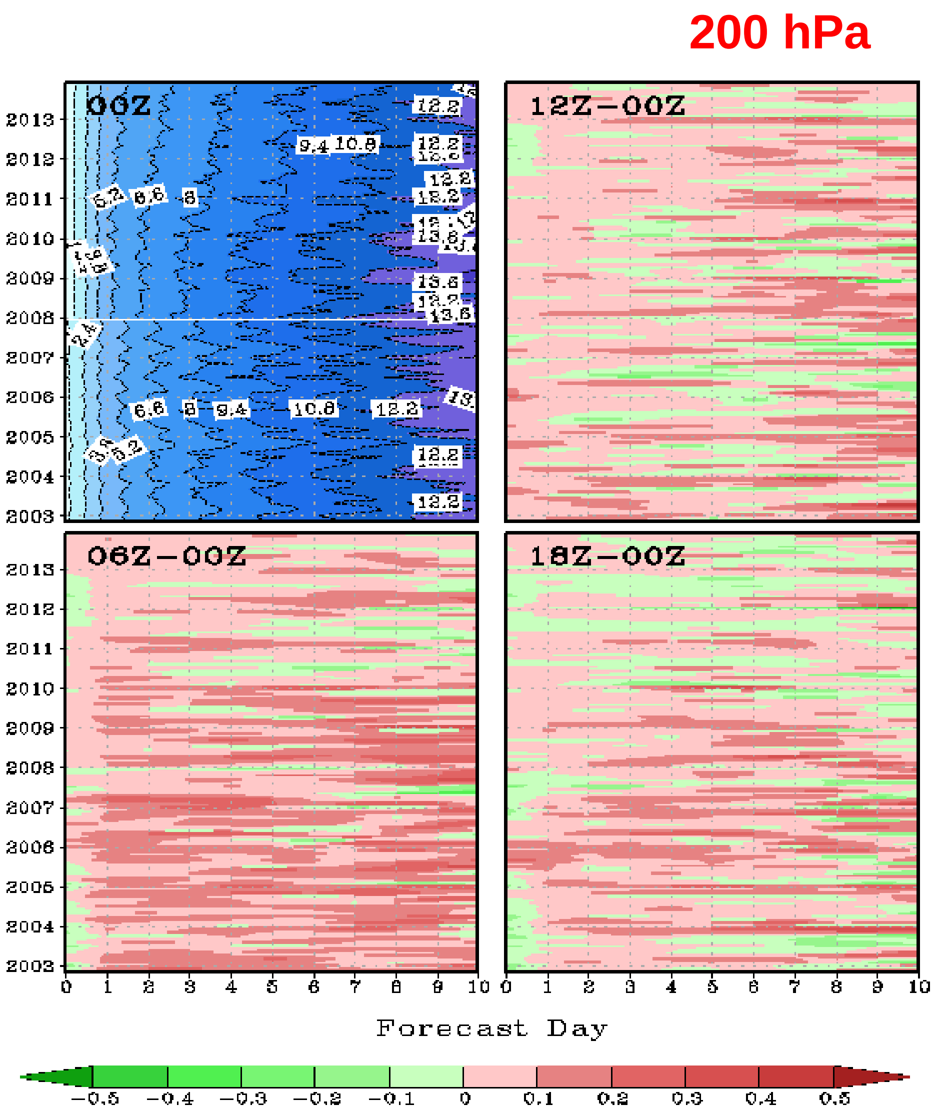


July2010 T574 GFS Implementation largely reduced GFS wind RMSE

Still worse than ECM and UKM at 200 hPA

Tropical Wind RMSE, GFS 4 Cycles

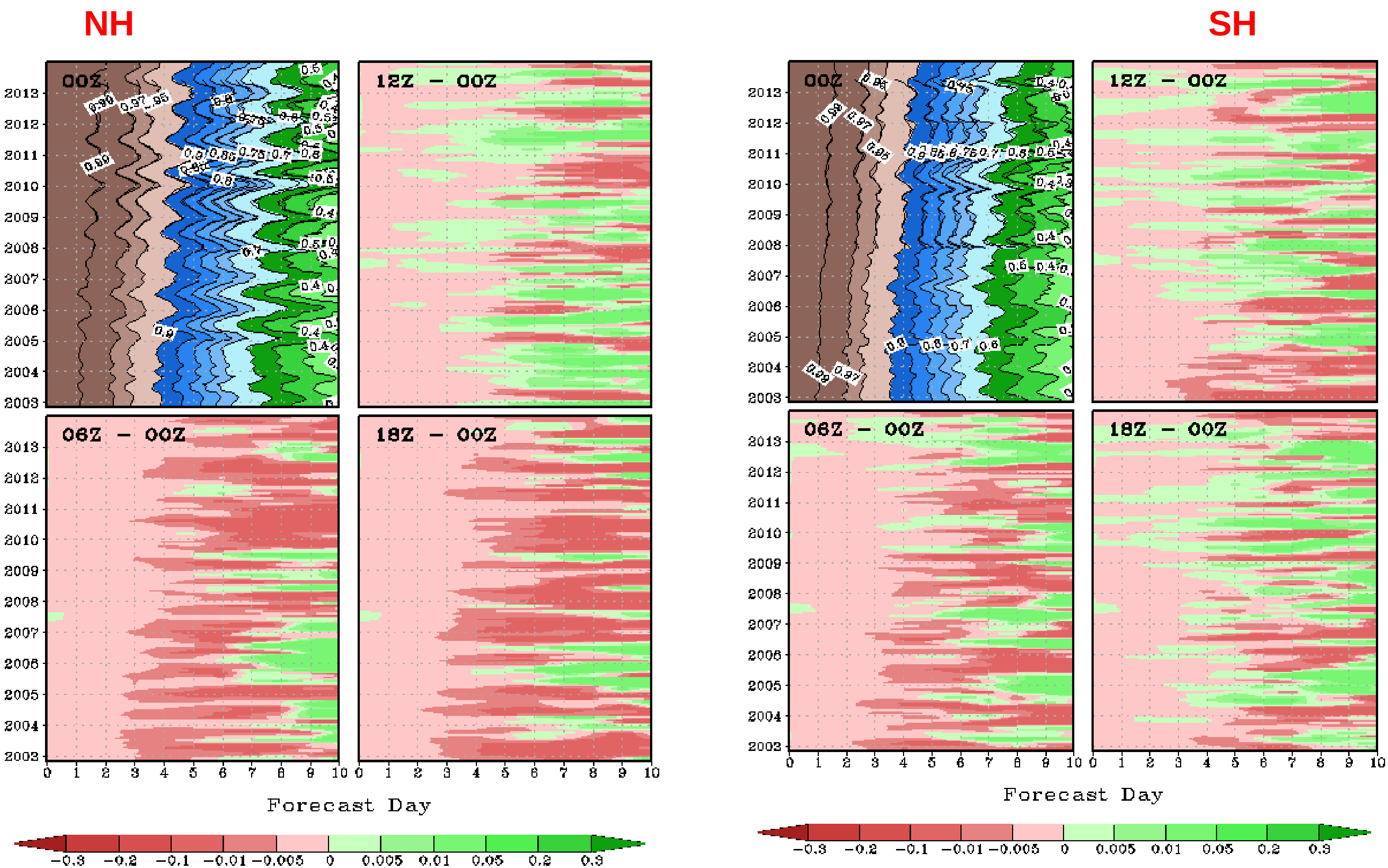




00Z: RMS reduction after 2010;
12Z and 18Z better than 00Z

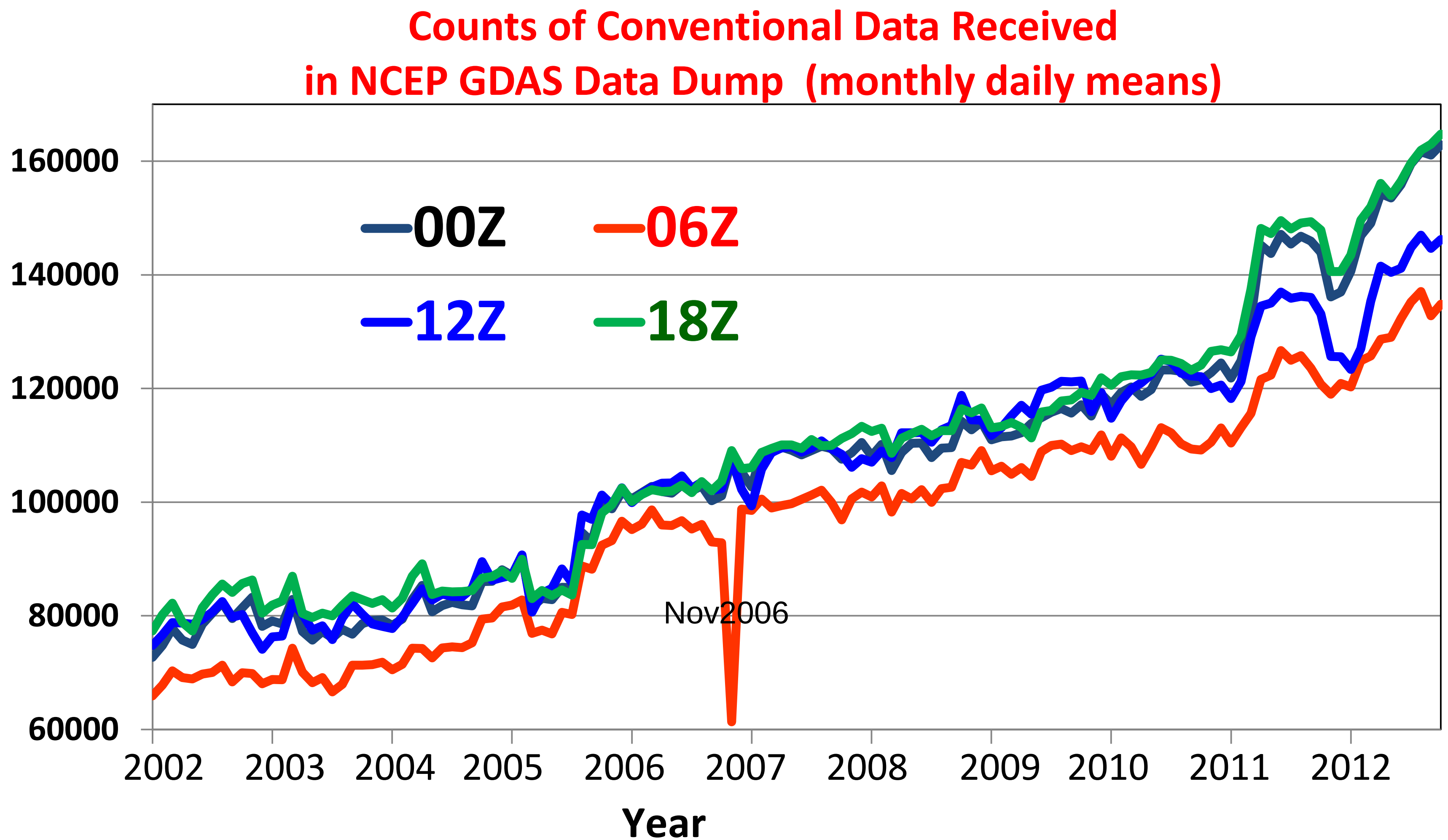
00Z the best

500hPa Height AC, GFS 4 Cycles



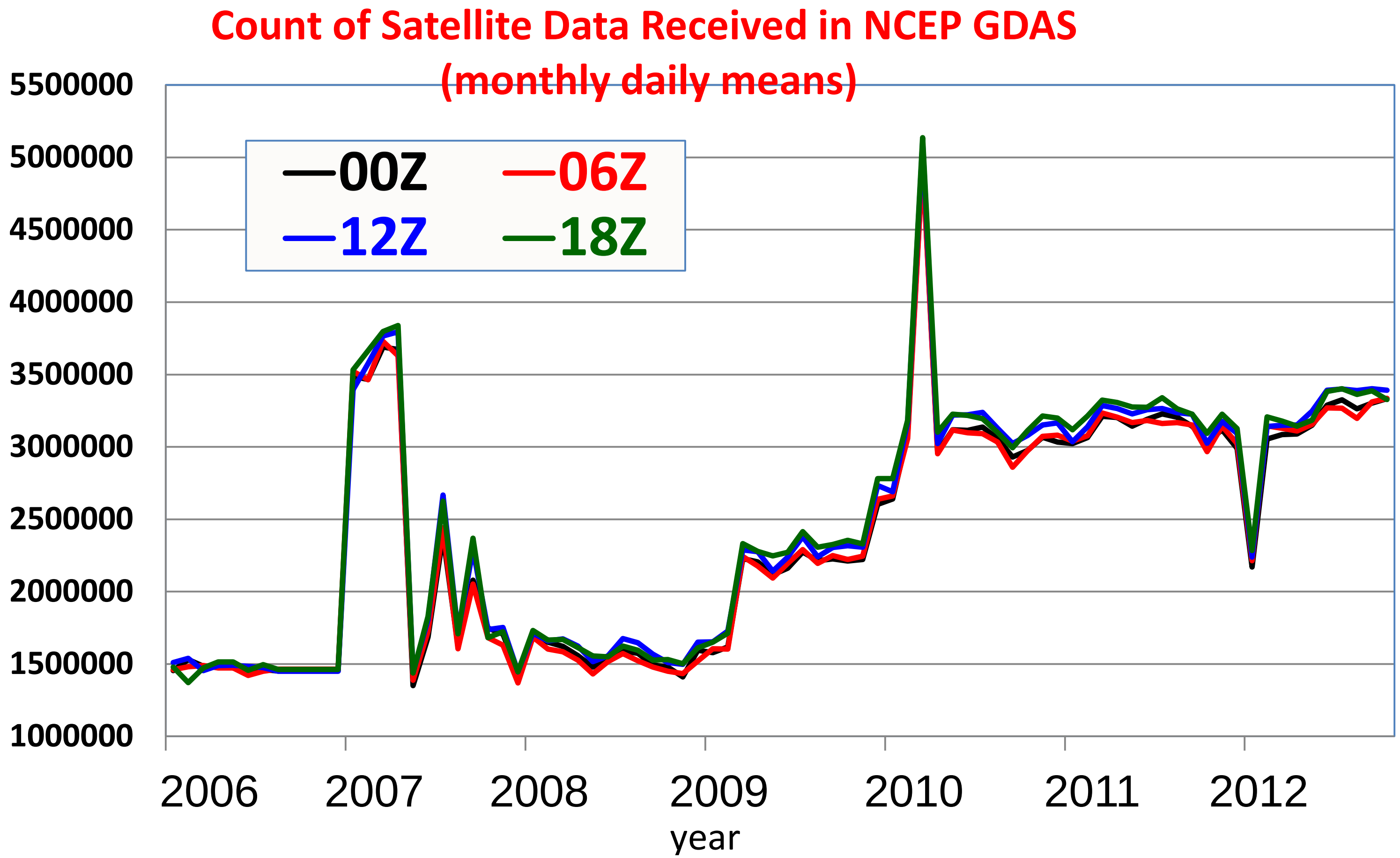
00Z cycle has the best score in both NH and SH; 06Z and 18Z the worst

Data Source: http://www.nco.ncep.noaa.gov/sib/counts/



- **06Z data count is always about 10% less (primarily ACARS) than other cycles**.
- The counts for 00Z , 12Z and 18Z are similar except that **after March 2011 the 12Z count started to deviate from the 00Z and 18Z cycles.**

Data Source: http://www.nco.ncep.noaa.gov/sib/counts/



- **No significant difference in the number of satellite data assimilated in the GFS forecast system among the four cycles.**
- **Not all differences in forecast skills among GFS 4 cycles can be explained by data counts.**

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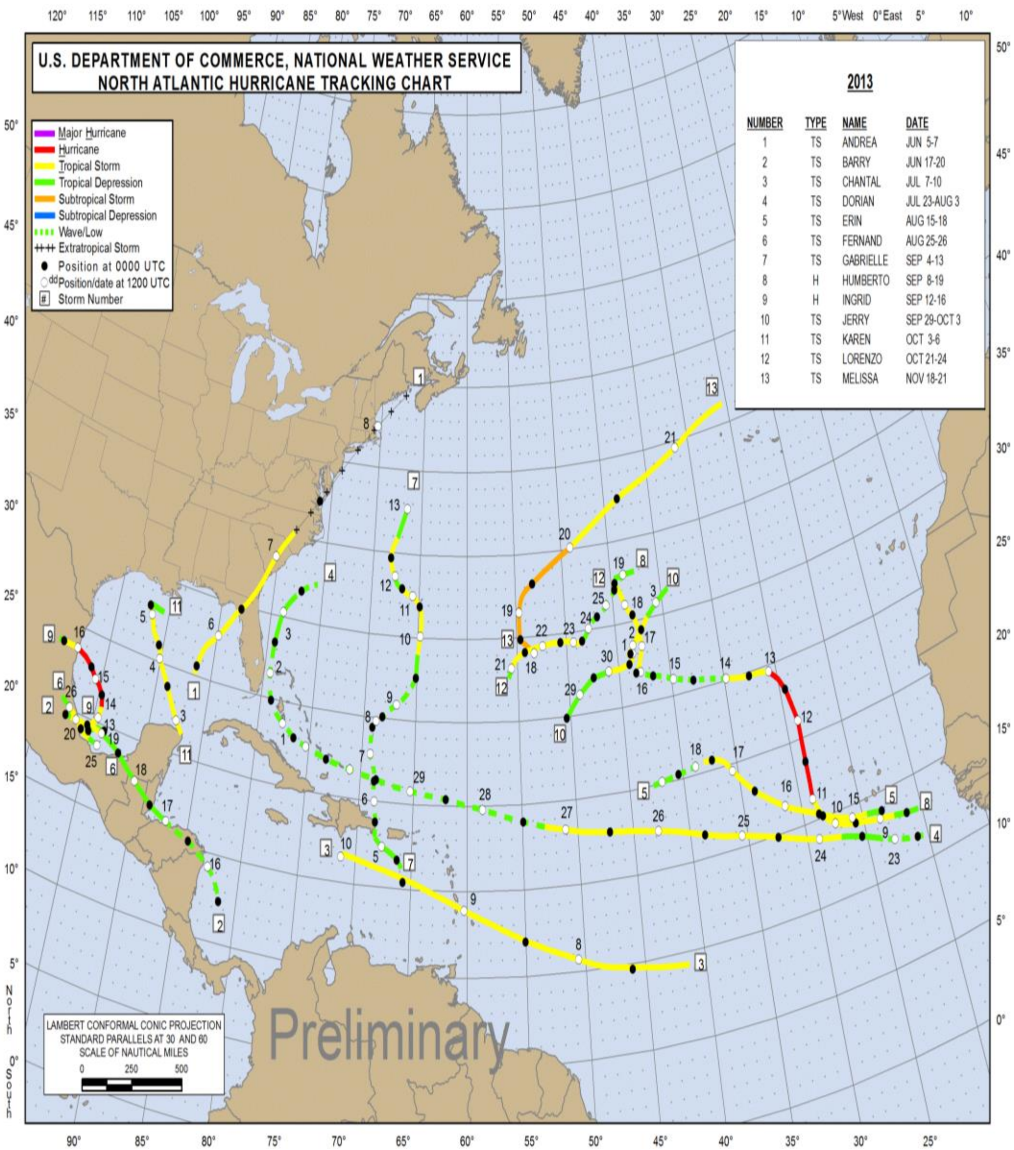
2013 Atlantic Hurricanes, one of the most quiet year



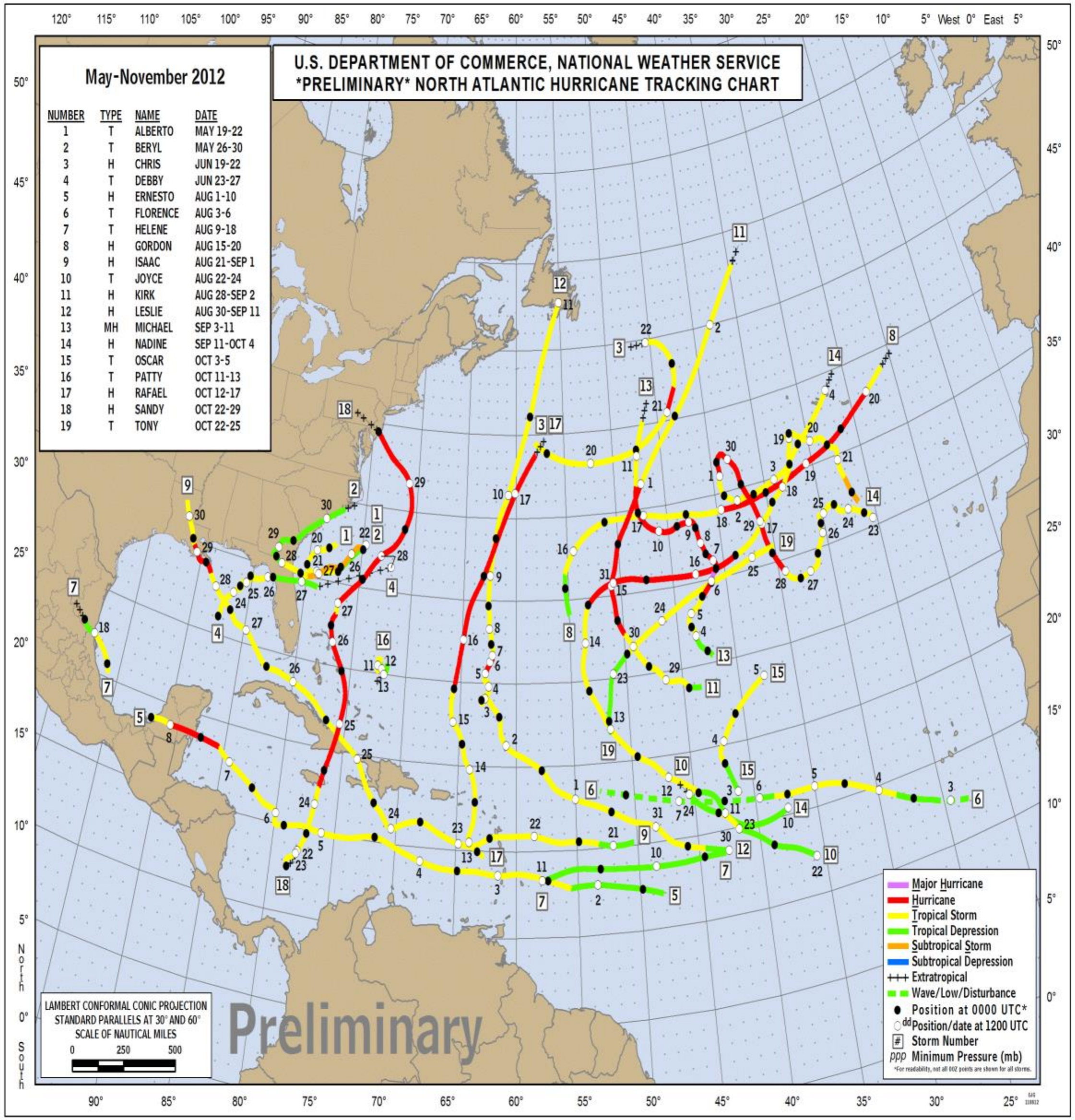
www.nhc.noaa.gov/

First system formed	**June 5, 2013**
Last system dissipated	**December 7, 2013**
Strongest storm	**Humberto – 979 hPa, 90 mph (150 km/h)**
Total depressions	**15**
Total storms	**14**
Hurricanes	**2**
Major hurricanes (Cat. 3+)	**0**
Total fatalities	**47 total**
Total damage	**~ $1.51 billion (USD)**

http://www.wikipedia.org

NOAA's Atlantic Hurricane Season Outlook : a 70 percent likelihood of 13 to 20 named storms, of which 7 to 11 could become hurricanes, **including 3 to 6 major hurricanes** (Category 3, 4 or 5).

2012 Atlantic Hurricanes

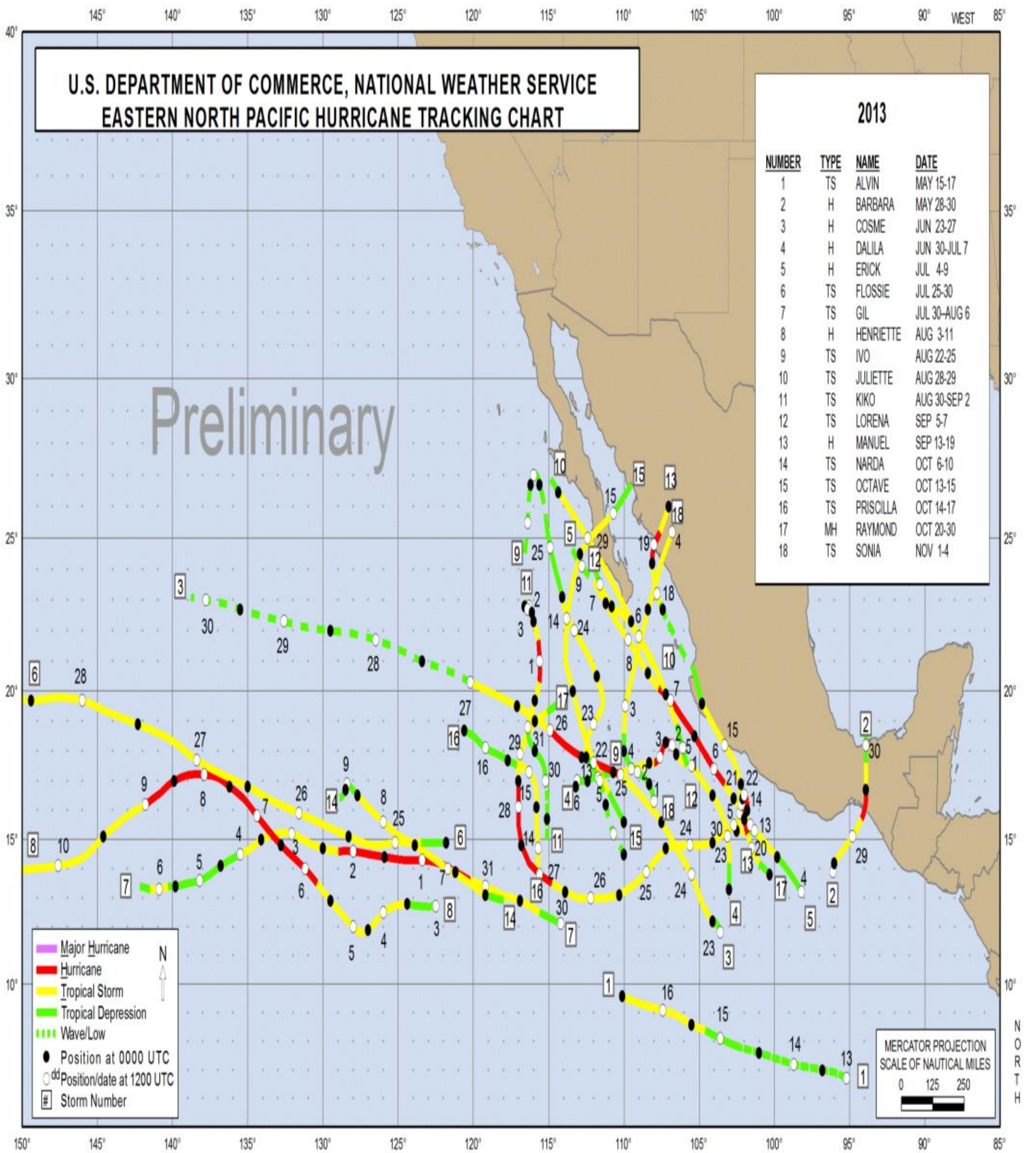


www.nhc.noaa.gov/

First storm formed	May 19, 2012
Last storm dissipated	October 29, 2012
Strongest storm	Sandy – 940 hPa, 110 mph
Total depressions	19
Total storms	19
Hurricanes	10
Major hurricanes (Cat. 3+)	1
Total fatalities	316 direct, 12 indirect
Total damage	~ $68 billion

http://www.wikipedia.org

2013 Eastern Pacific Hurricanes

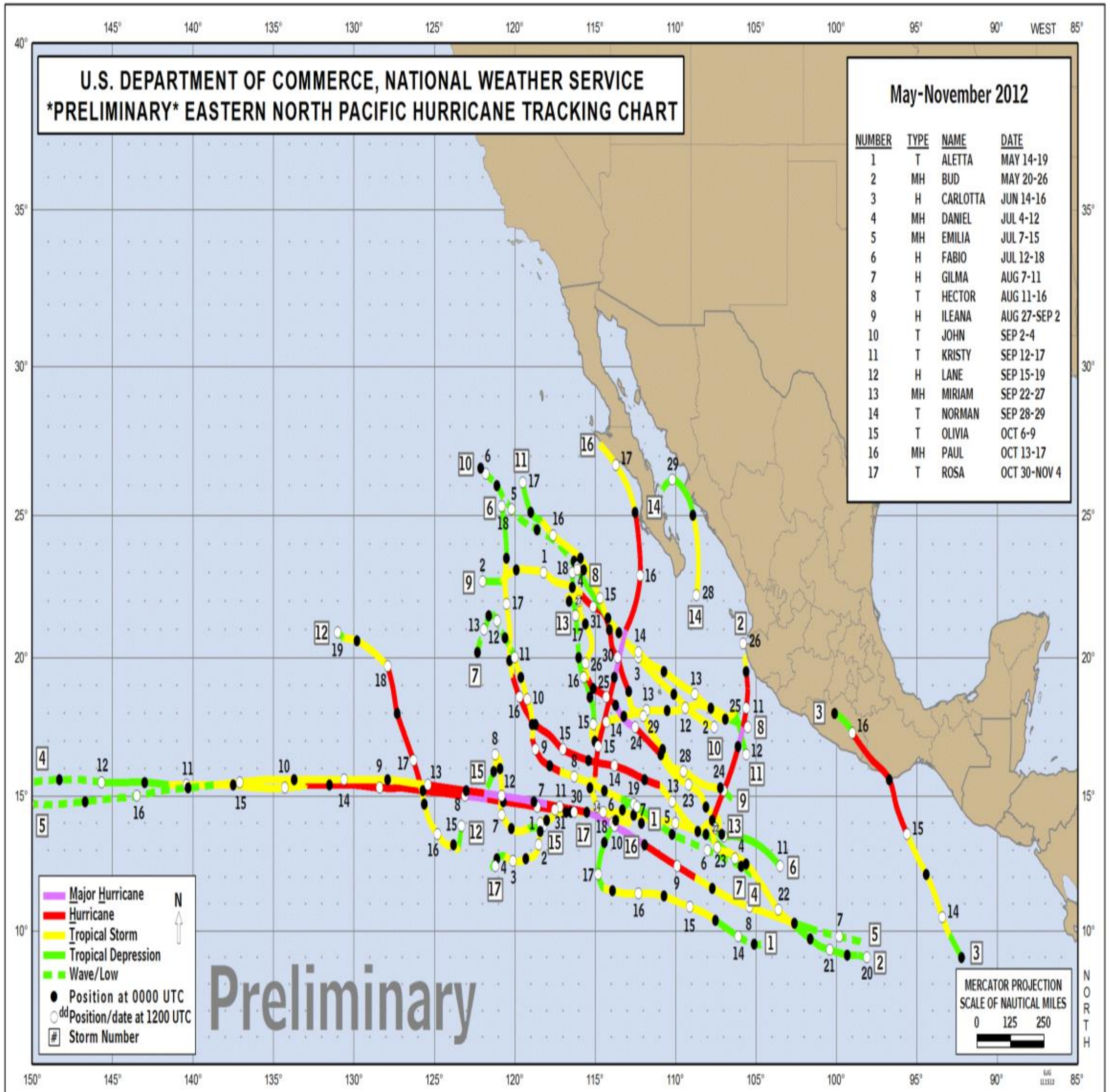


First system formed	May 15, 2013
Last system dissipated	November 4, 2013
Strongest storm	Raymond – 951 hPa, 125 mph
Total depressions	21
Total storms	20
Hurricanes	9
Major hurricanes (Cat. 3+)	1
Total fatalities	181 confirmed
Total damage	$4.2billion

www.nhc.noaa.gov/

http://www.wikipedia.org

2012 Eastern Pacific Hurricanes

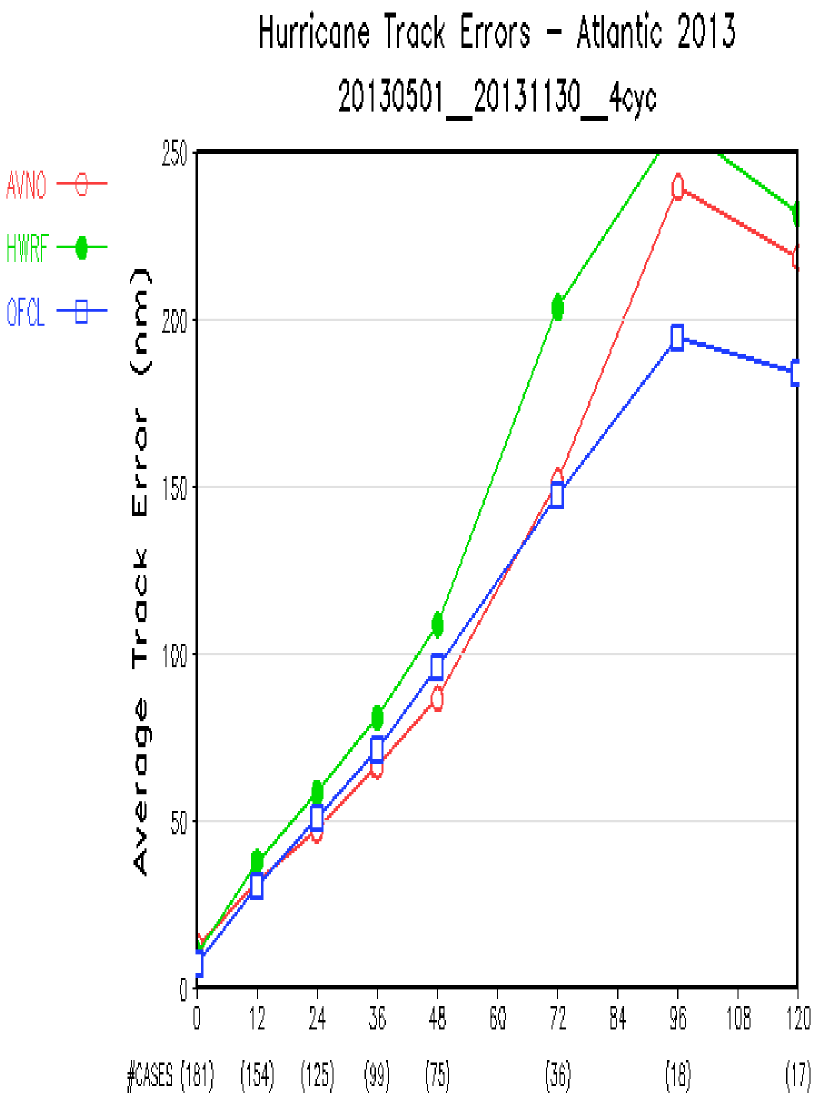


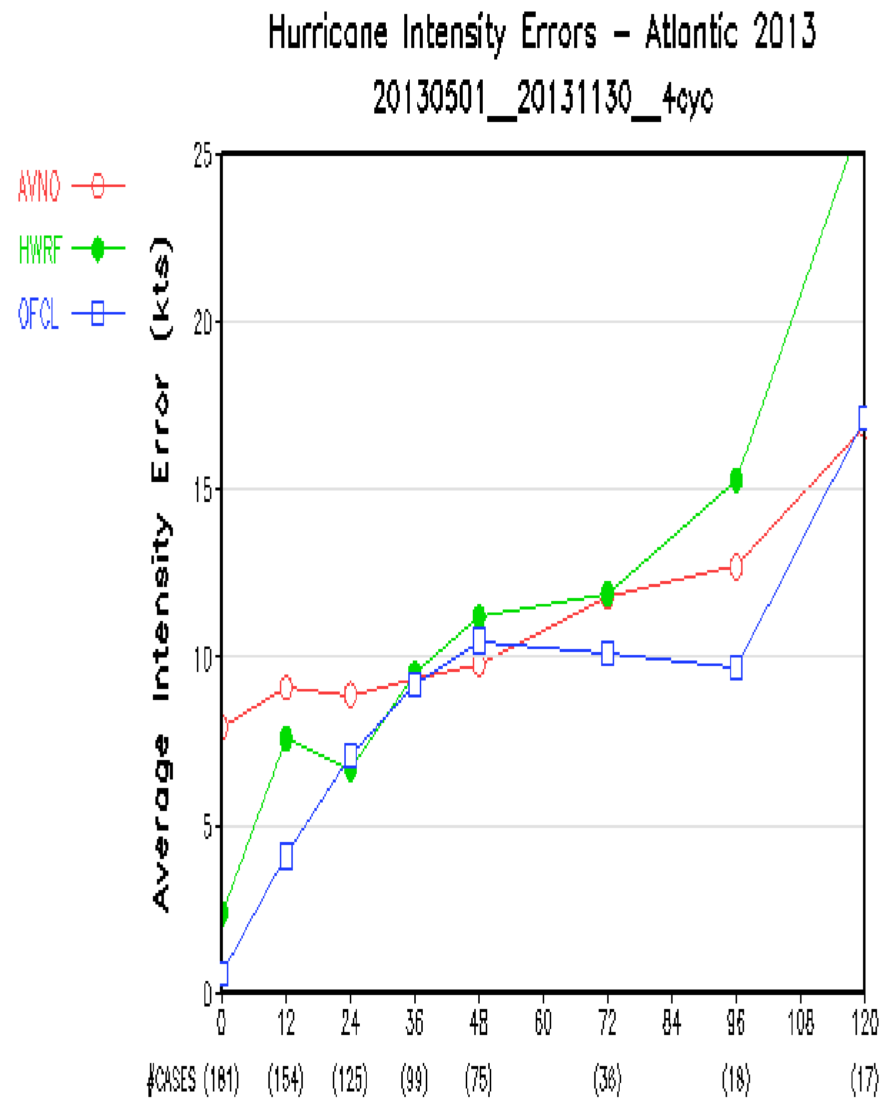
First storm formed	**May 14, 2012**
Last storm dissipated	**November 3, 2012**
Strongest storm	**Emilia – 945 hPa, 140 mph**
Total depressions	**17**
Total storms	**17**
Hurricanes	**10**
Major hurricanes (Cat. 3+)	**5**
Total fatalities	**8 total**
Total damage	**$123.2 million (2012 USD)**

www.nhc.noaa.gov/

http://www.wikipedia.org

2013 Atlantic Hurricane Track and Intensity Errors

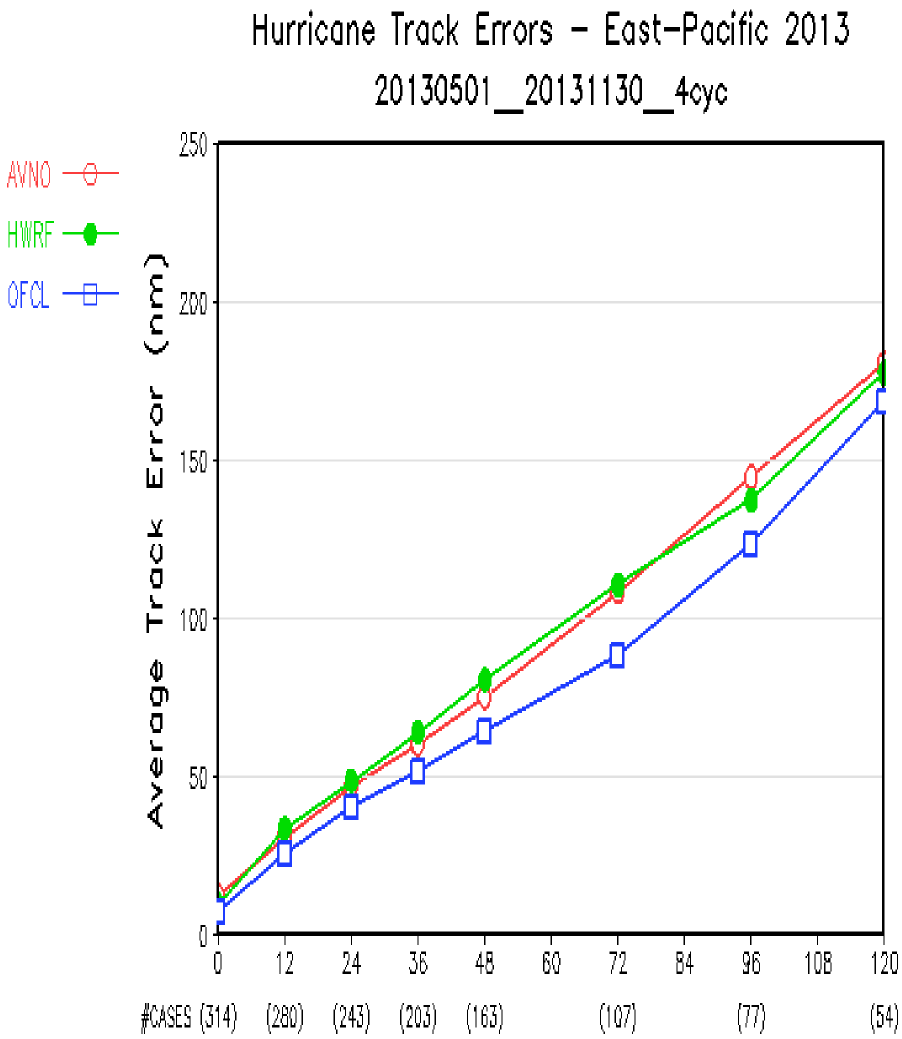


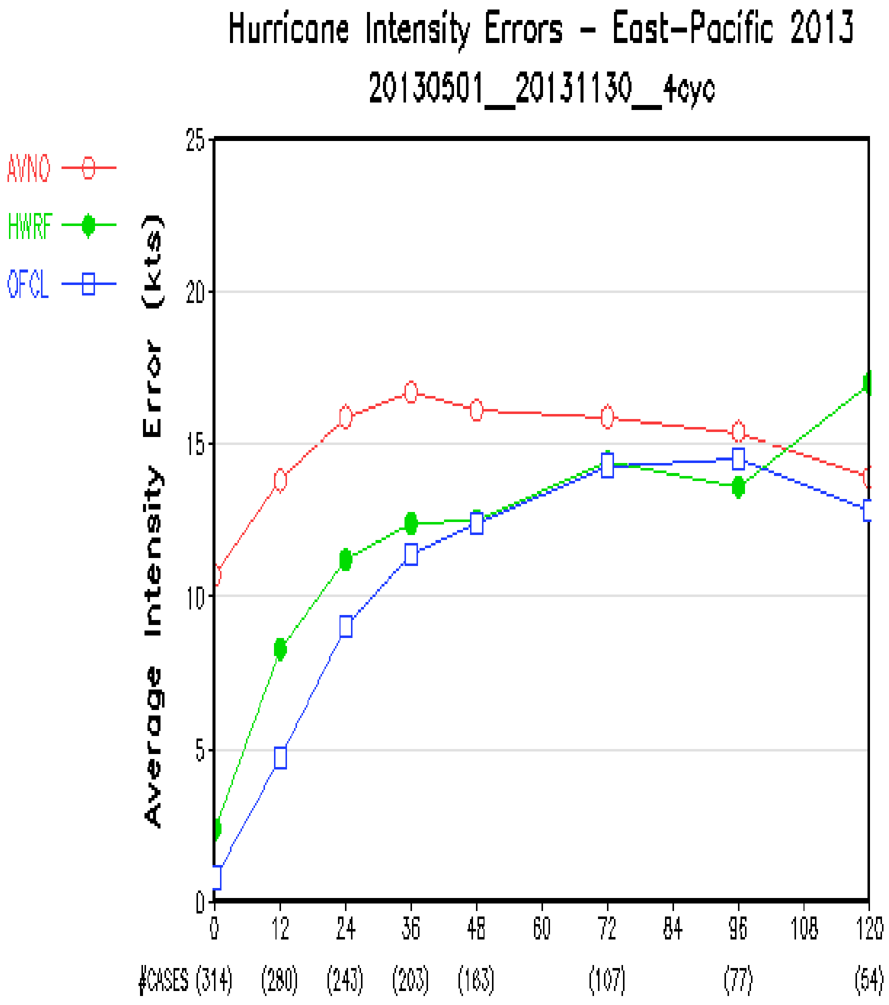


GFS track is as good as HWRF track, GFS intensity still falls behind HWRF

AVNO = GFS

2013 Eastern Pacific Hurricane Track and Intensity Errors





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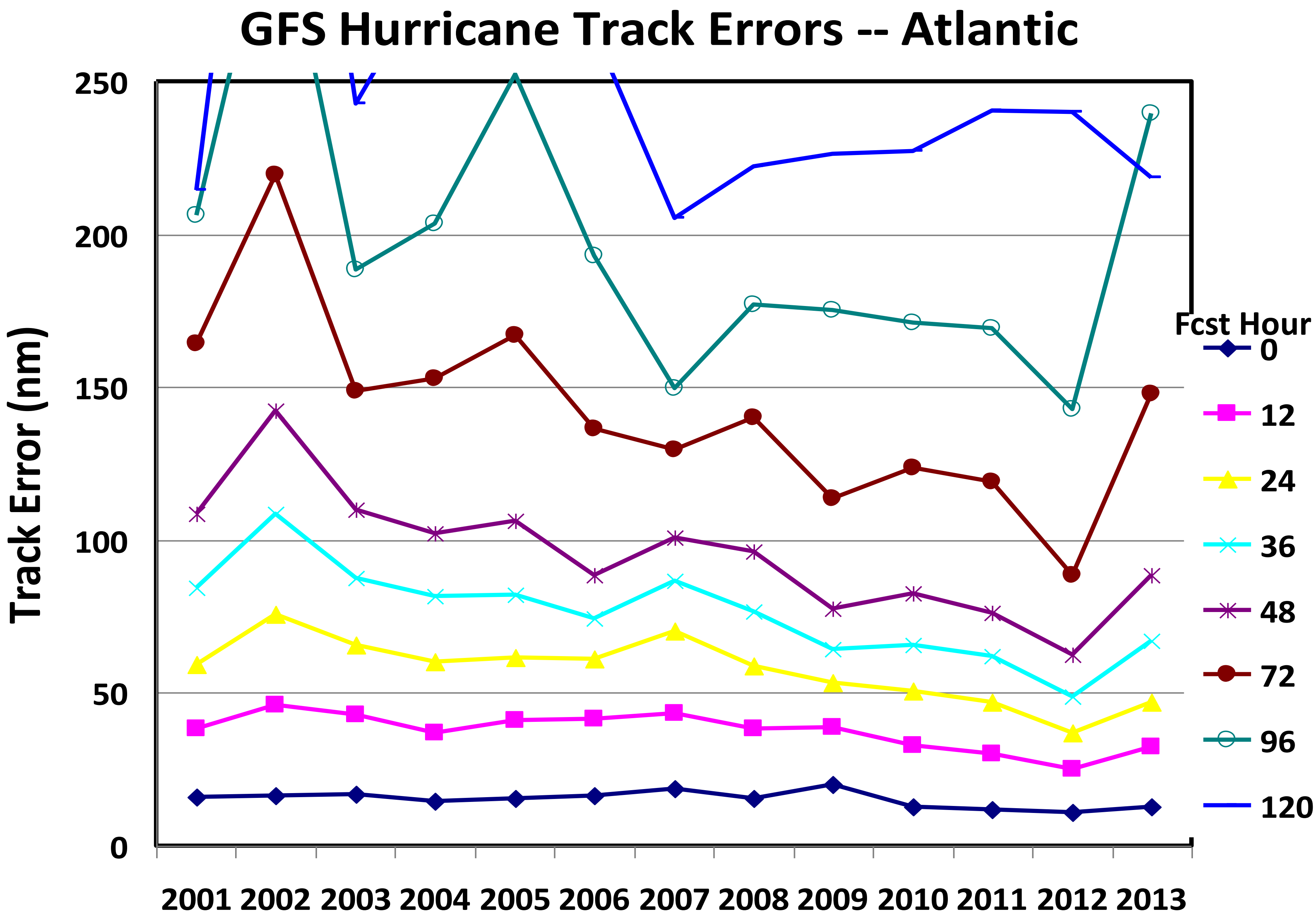
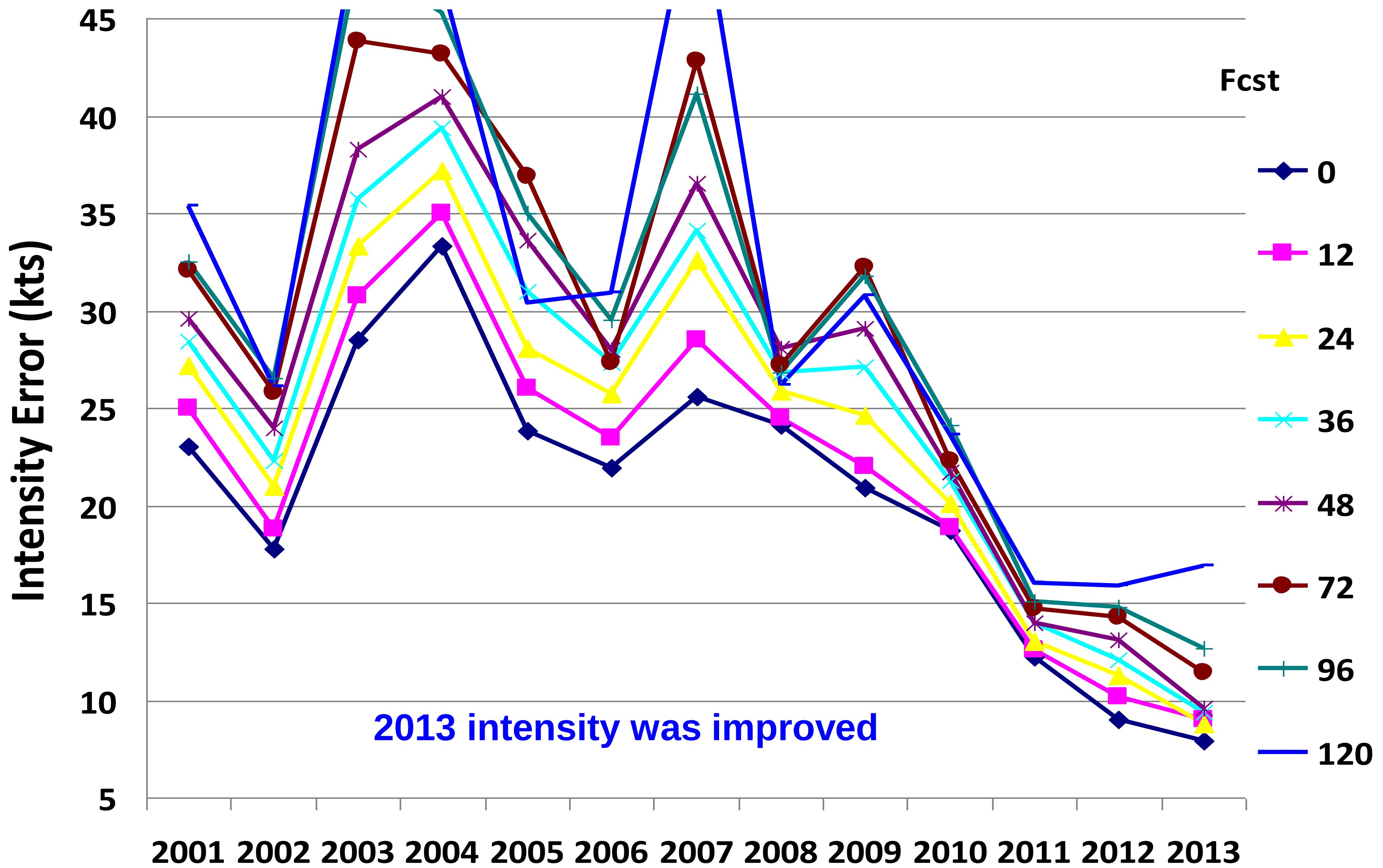
Hurricane Track and Intensity Forecast Errors NCEP GFS : 2001 ~ 2013



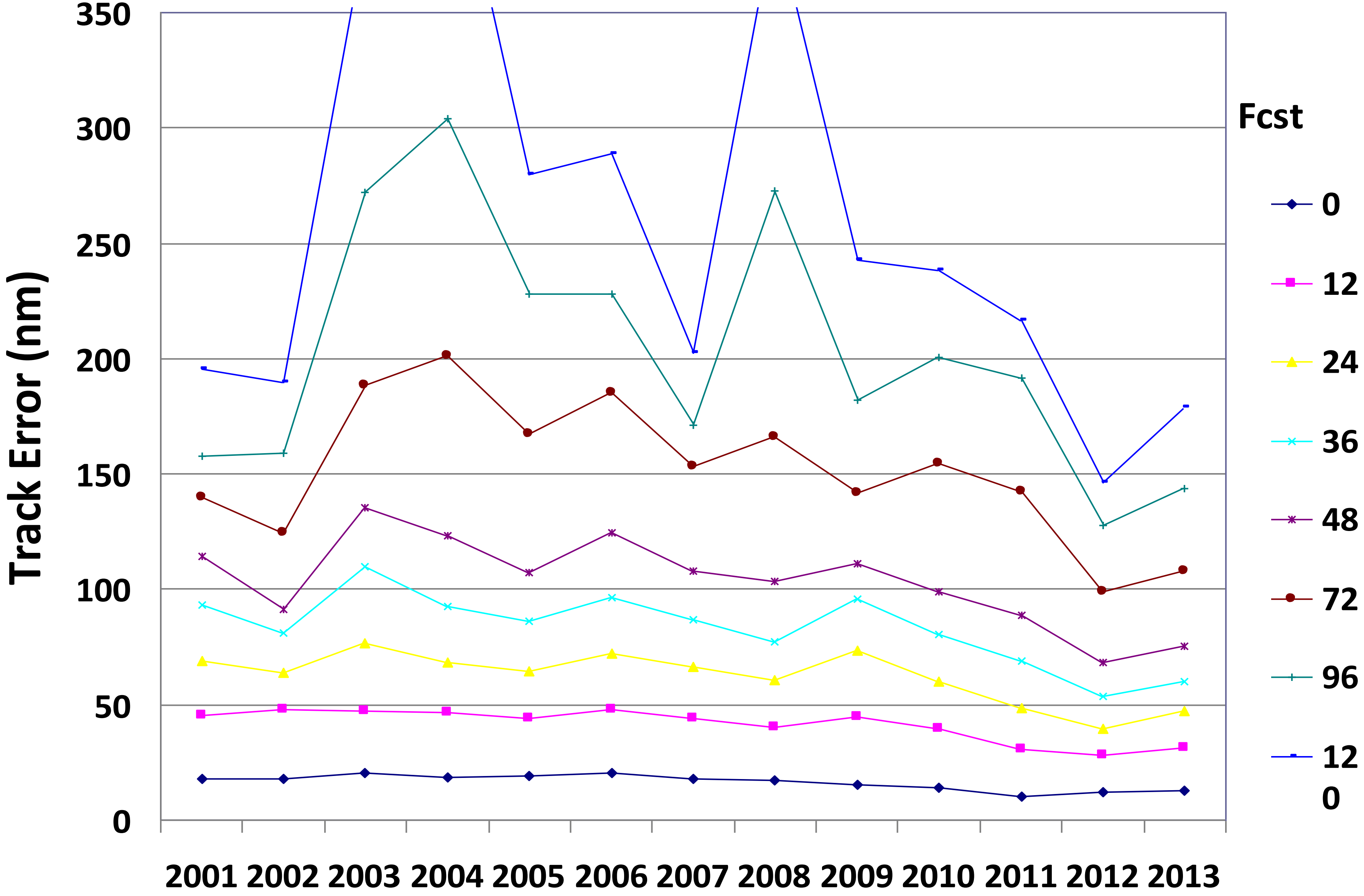
Has been always improving ……, but 2013 track is worse than 2012 !!!

GFS Hurricane Intensity Errors -- Atlantic



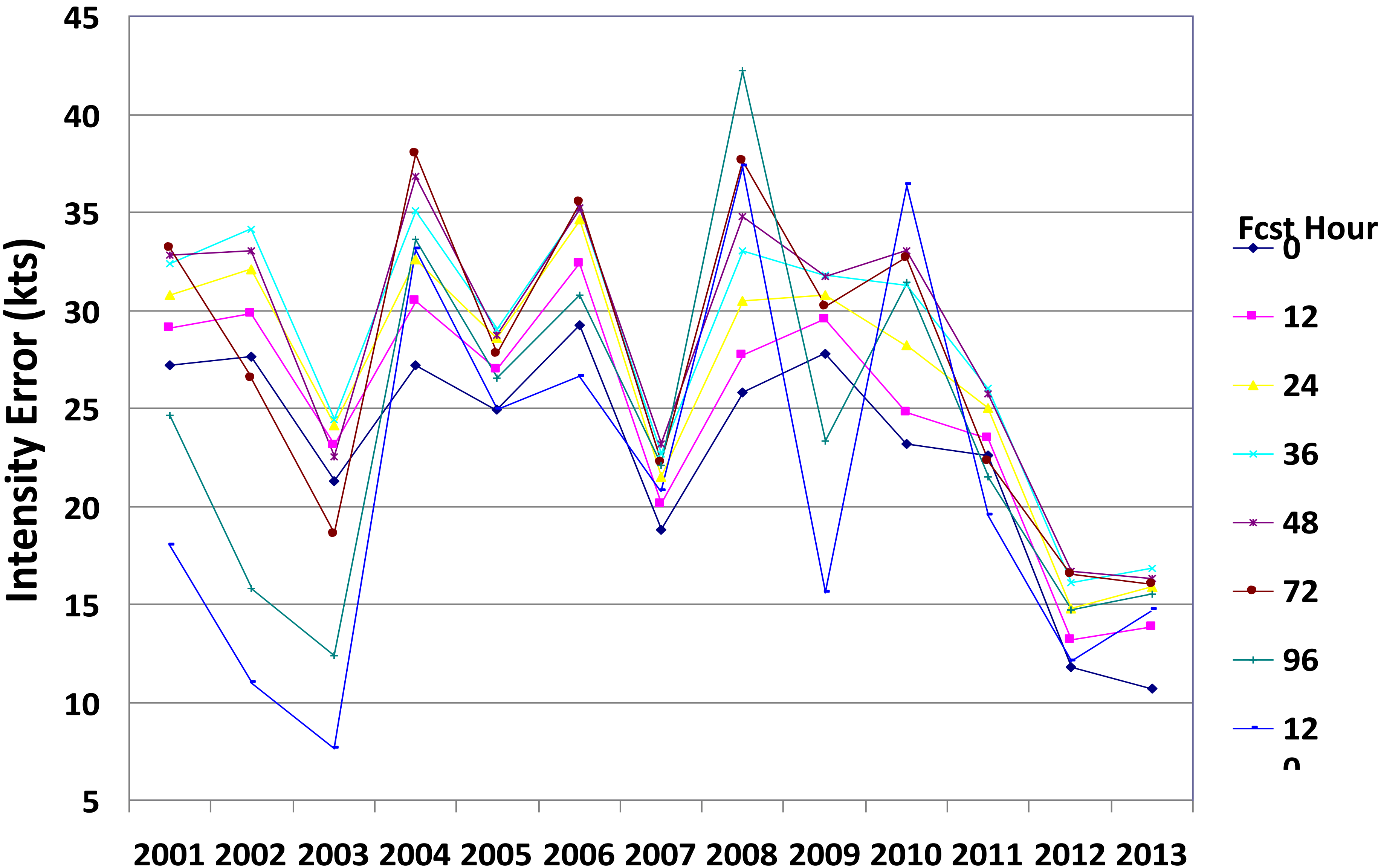
Intensity further improved in 2013, likely due to the hybrid ENKF-3DVAR GSI Implementation in May 2012

GFS Hurricane Track Errors – Eastern Pacific



2013 track is lightly worse than 2012 track !!!

GFS Hurricane Intensity Errors – Eastern Pacific



2013 intensity is slightly degraded

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   – Surface 2-m temperature
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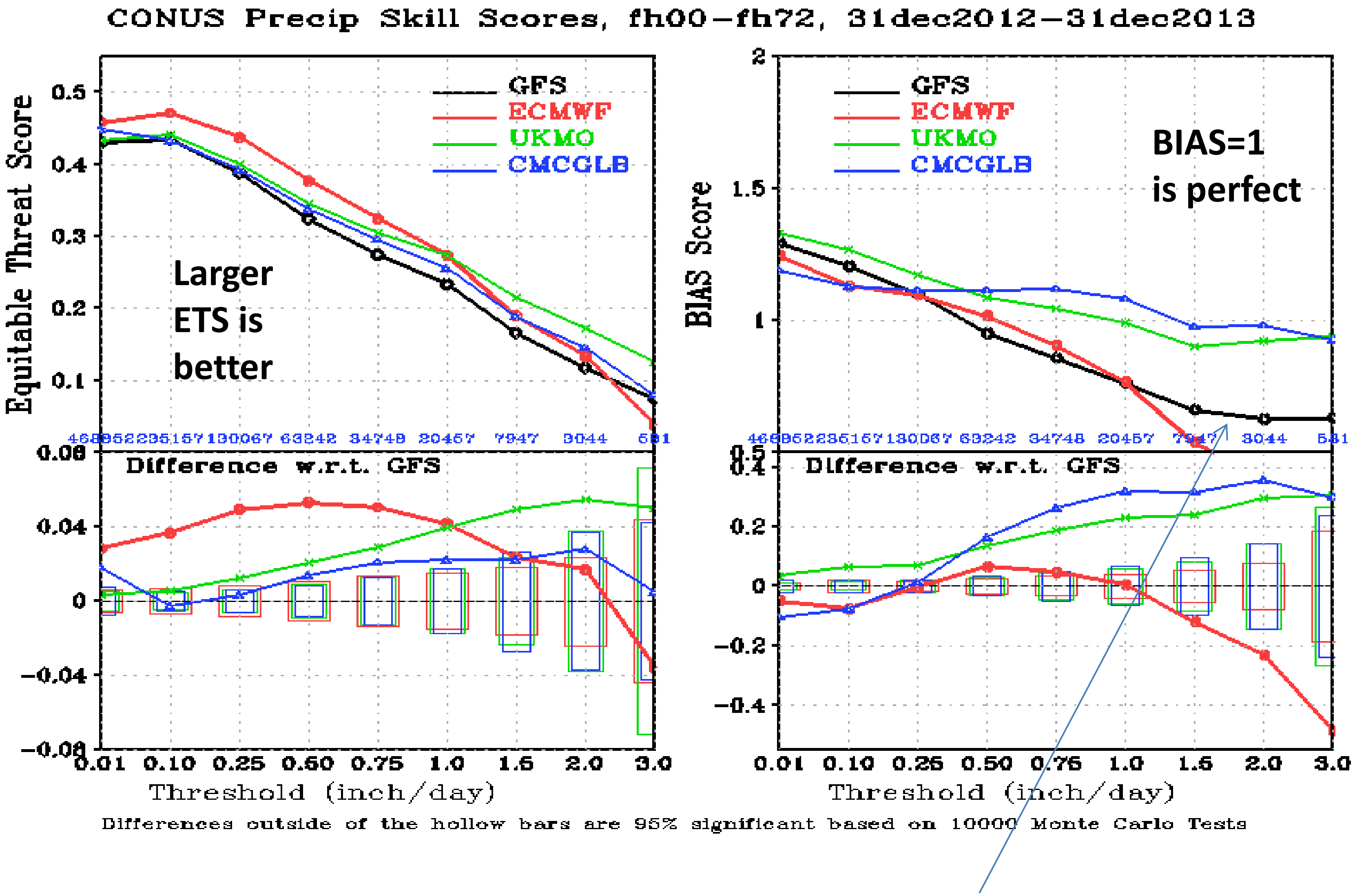
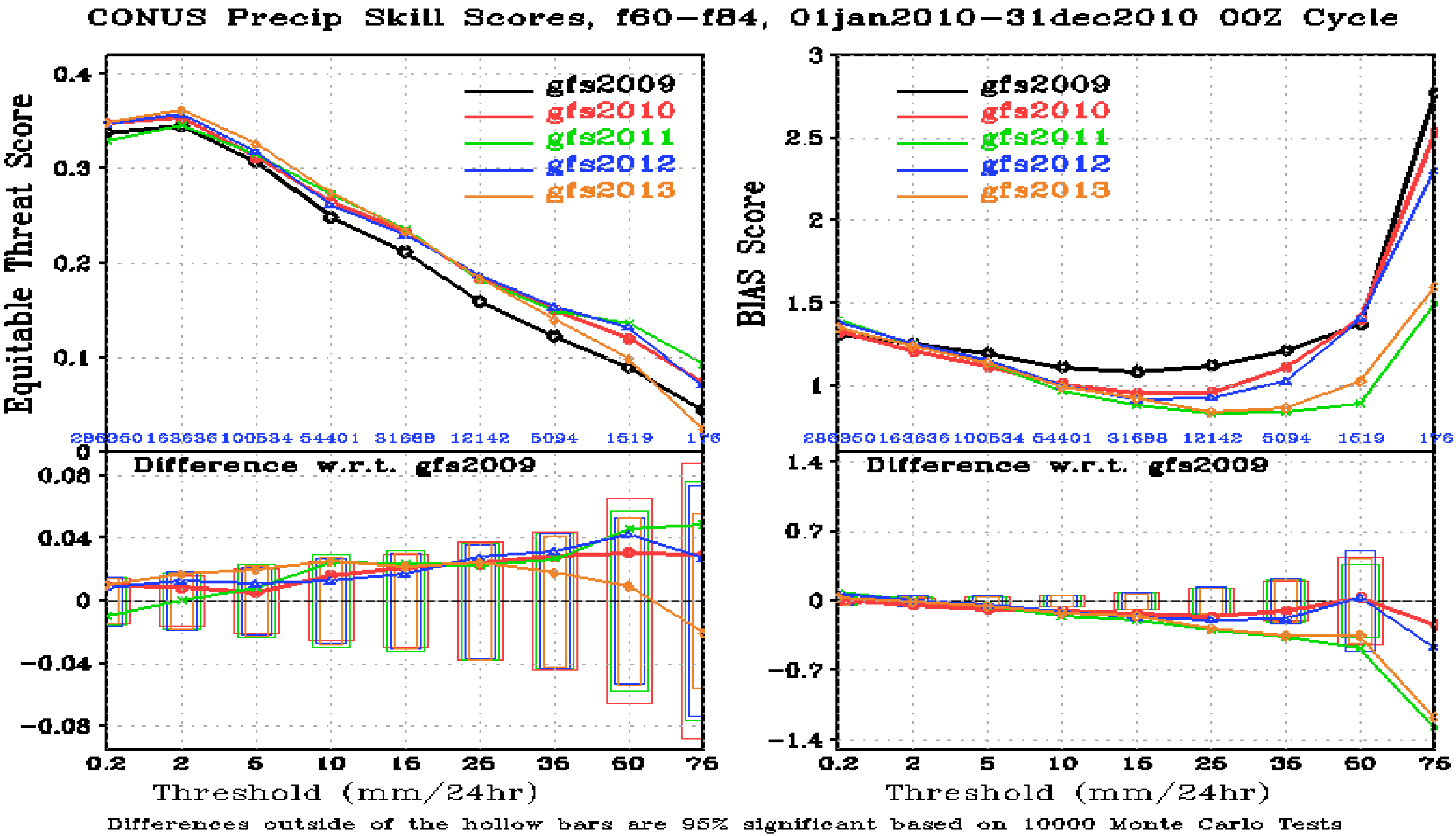
3. Summary and Discussion

2013 Annual Mean CONUS Precipitation Skill Scores, 0-72 hour Forecast



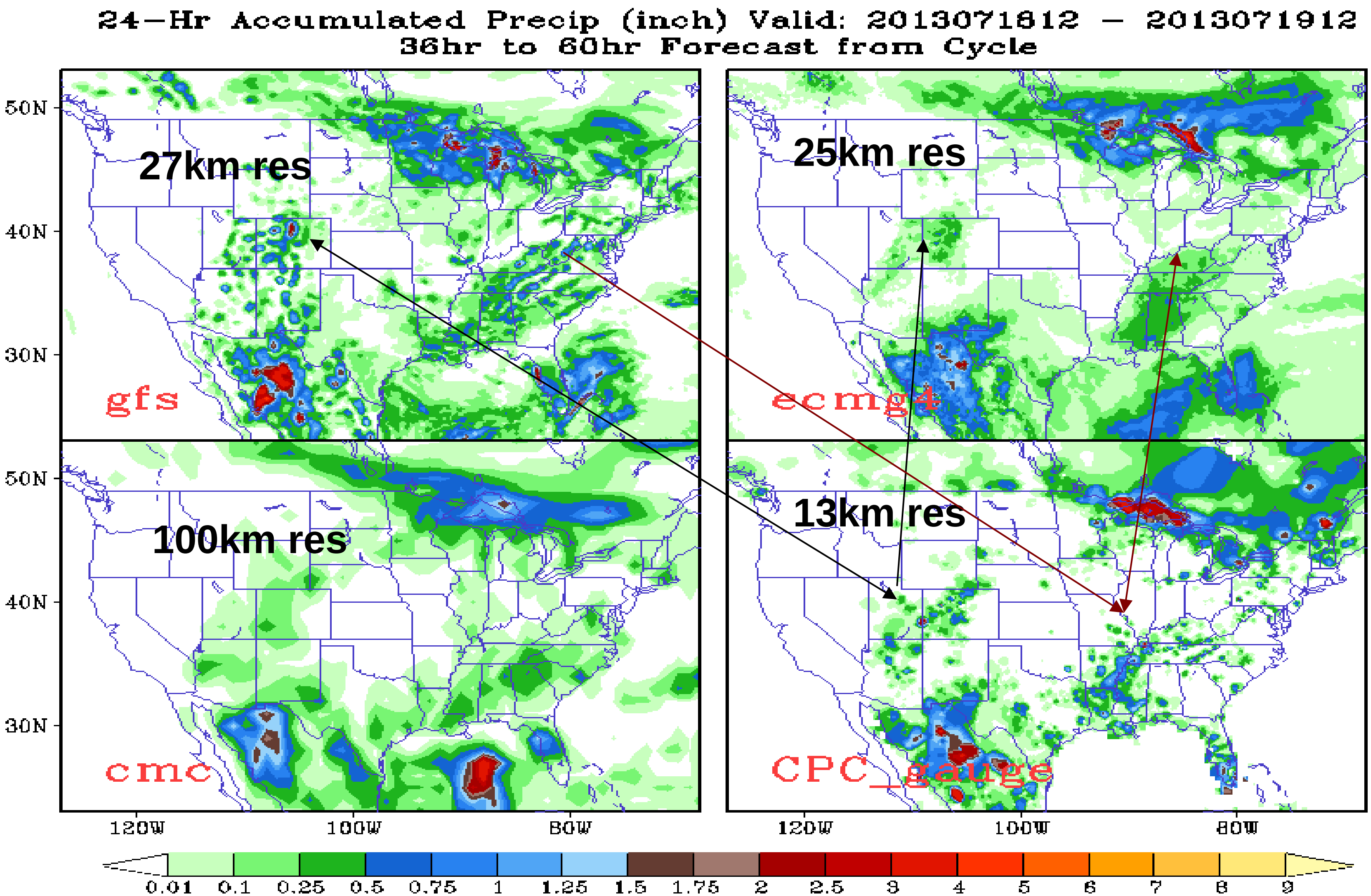
- ECMWF has the best ETS, but it tends to underestimate heavy rainfall events.
- GFS has the lowest ETS score; GFS underestimated heavy rainfall events

GFS CONUS Precipitation Skill Scores, Annual Mean, 2009 ~ 2013



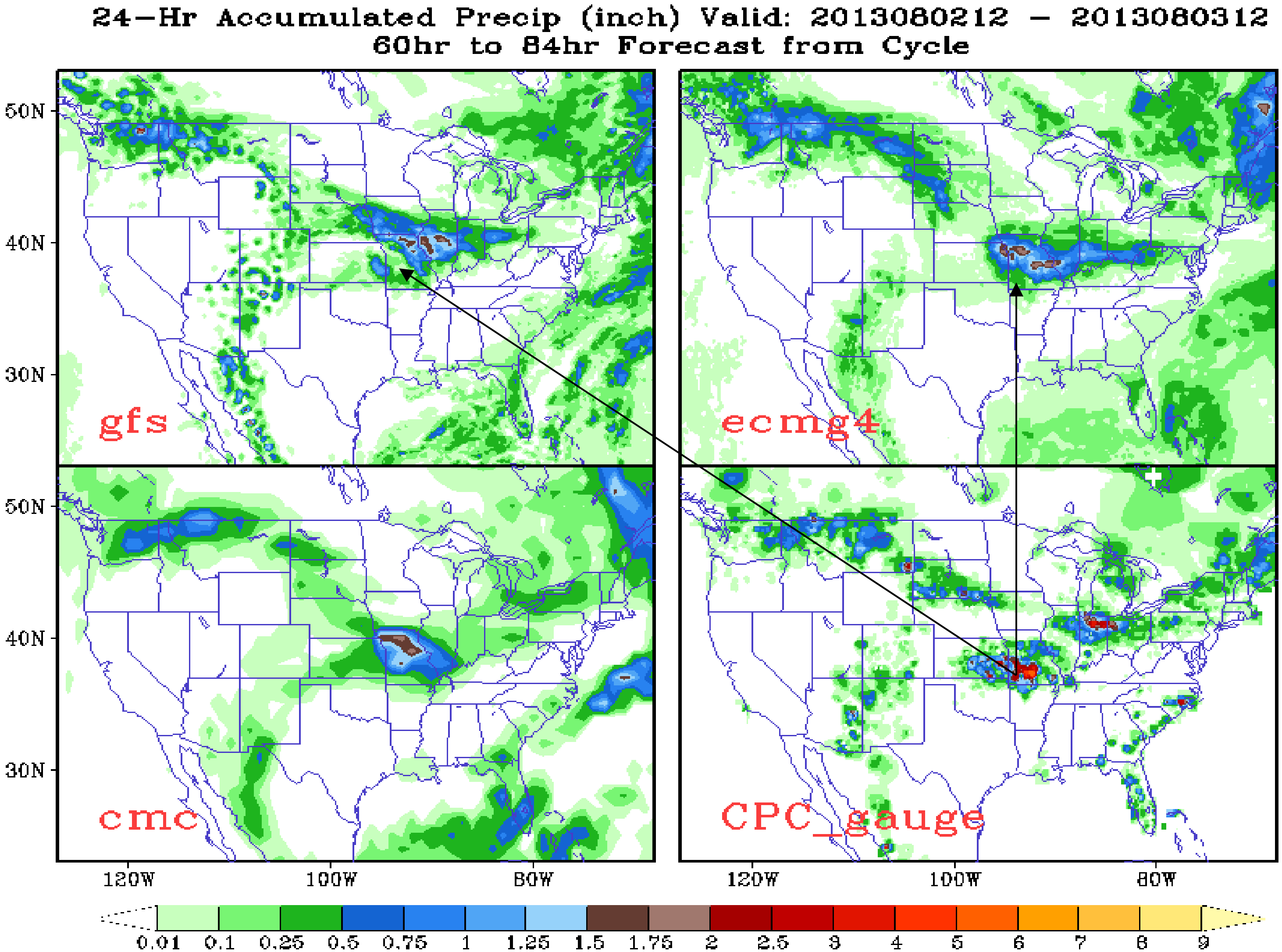
GFS ETS was significantly improved after the 2010 T574GFS implementation.
The score did not vary much in the past five years. 2013 is slightly better than 2012; however, BIAS was increased for moderate rainfall events.

GFS tends to produce more popcorn rainfall than does ECMWF, especially over high terrains.



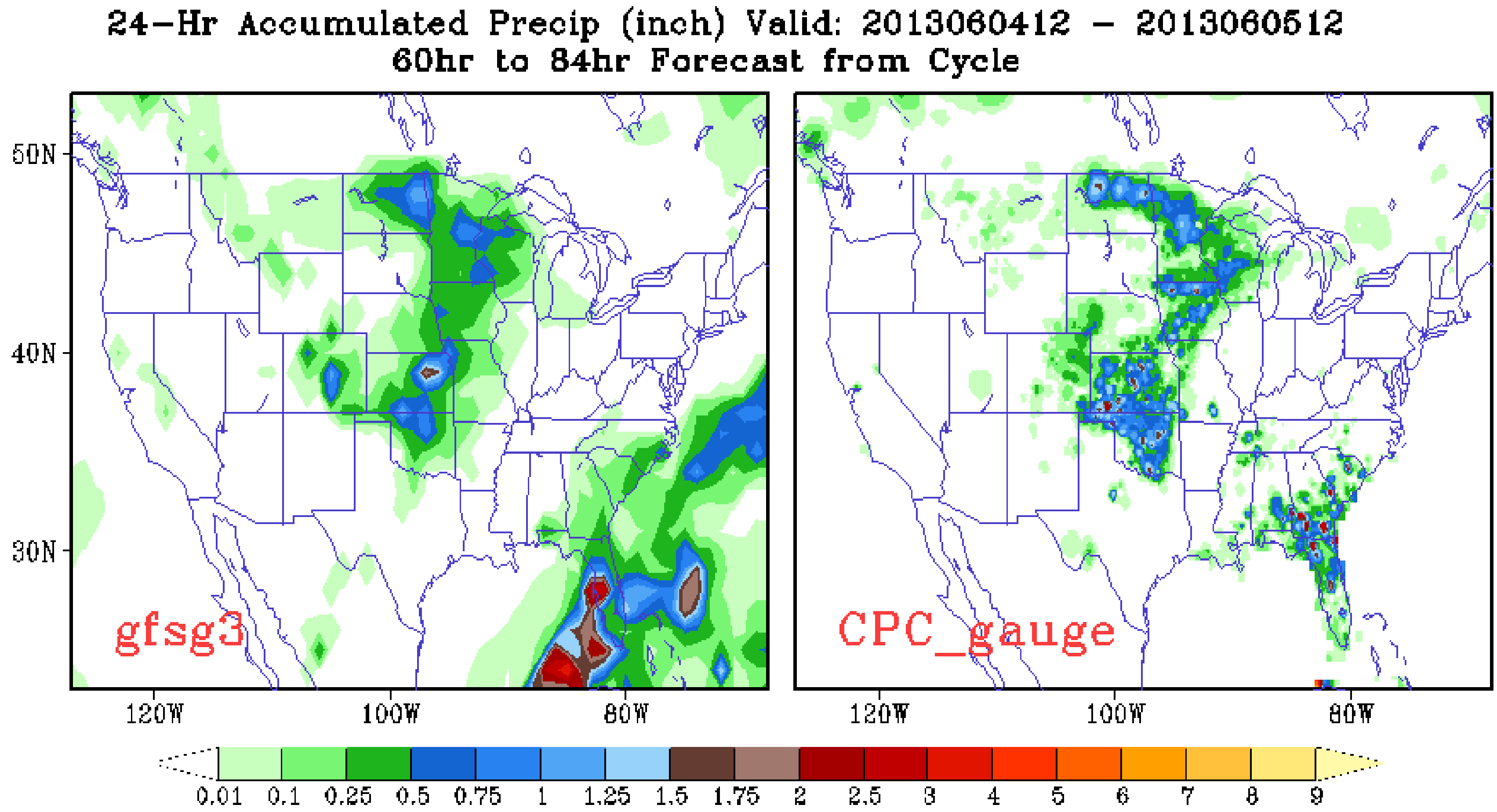
http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/

A Case of Central US Flood 08/03/2013: GFS underestimated the intensity and moved too fast away from Missouri to Illinois.



http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/

Animation of GFS 3-day Forecast and Gauge Observed 24h Accumulated Rainfall for June-July-August 2013



GFS is 60-84 hour forecast from the 00Z cycle. While CPC obs is at 0.125 deg resolution, GFS forecast data used here are only at 1-deg resolution. Therefore, pay more attention to the phase and occurrence and less attention to intensity.

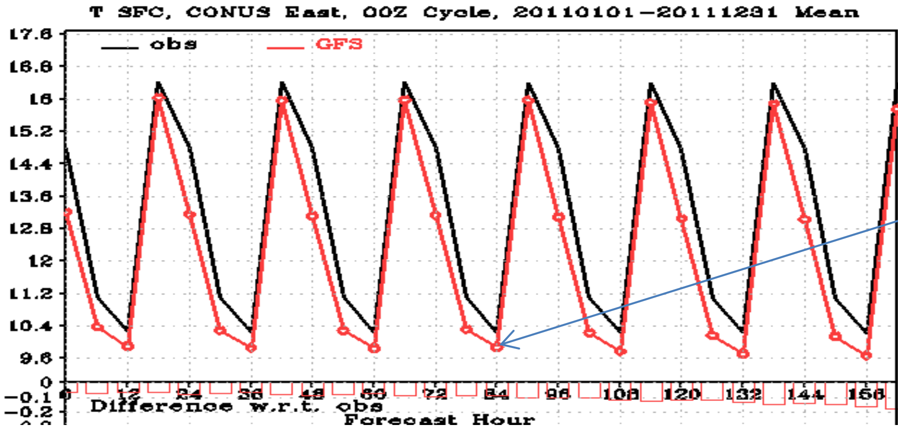
Outline

1. Major GFS changes in recent years

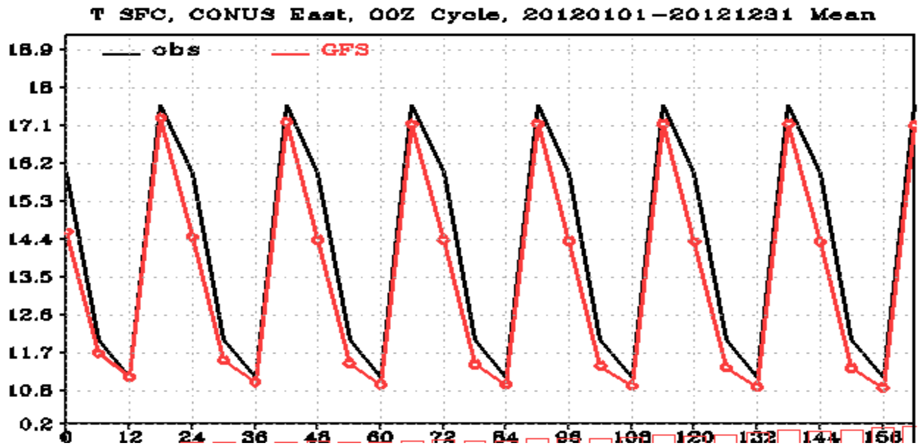
2. Forecast skill scores
   - AC and RMSE
   - Hurricane Track and Intensity
   - Precipitation
   - **Surface 2-m temperature**
   - Verification Against Rawinsonde Observations

3. Summary and Discussion

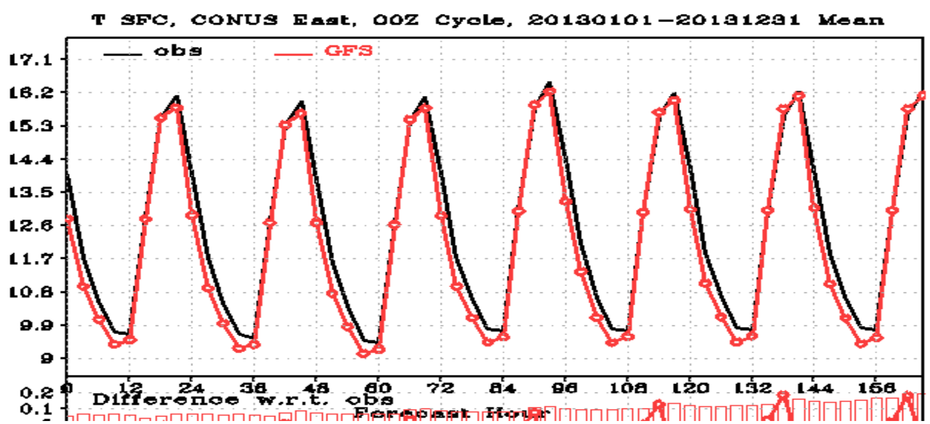
CONUS East T2m Verified against Surface Station Observations



2011
6-hrly

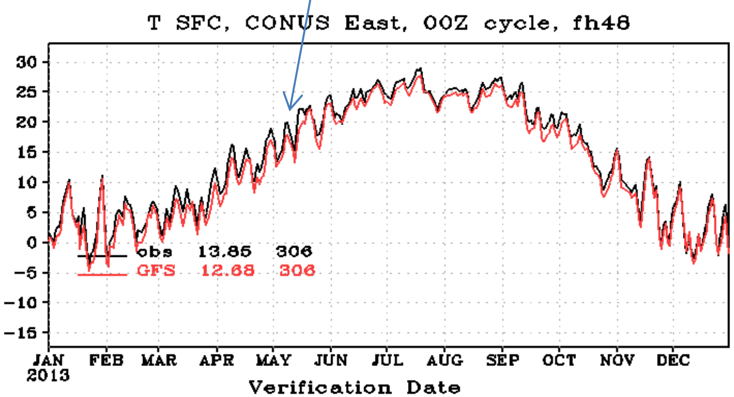


2012
6-hrly



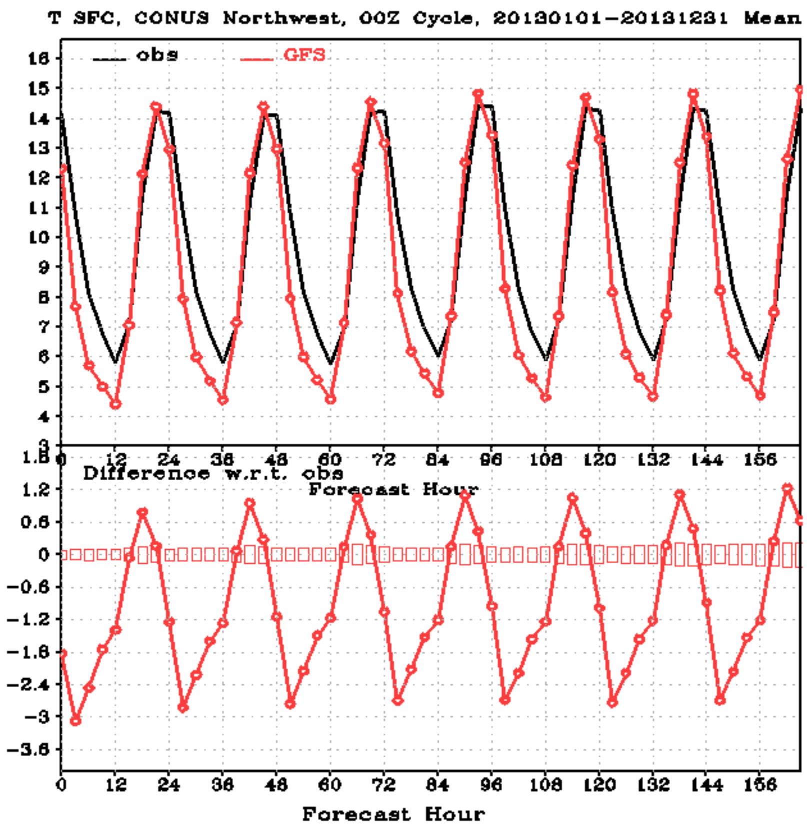
2013
3-hrly

- Nighttime cold bias had been persistent for all years, although in 2013 the cold bias was slightly reduced.
- The nighttime cold bias is found mostly in Spring and Fall seasons.

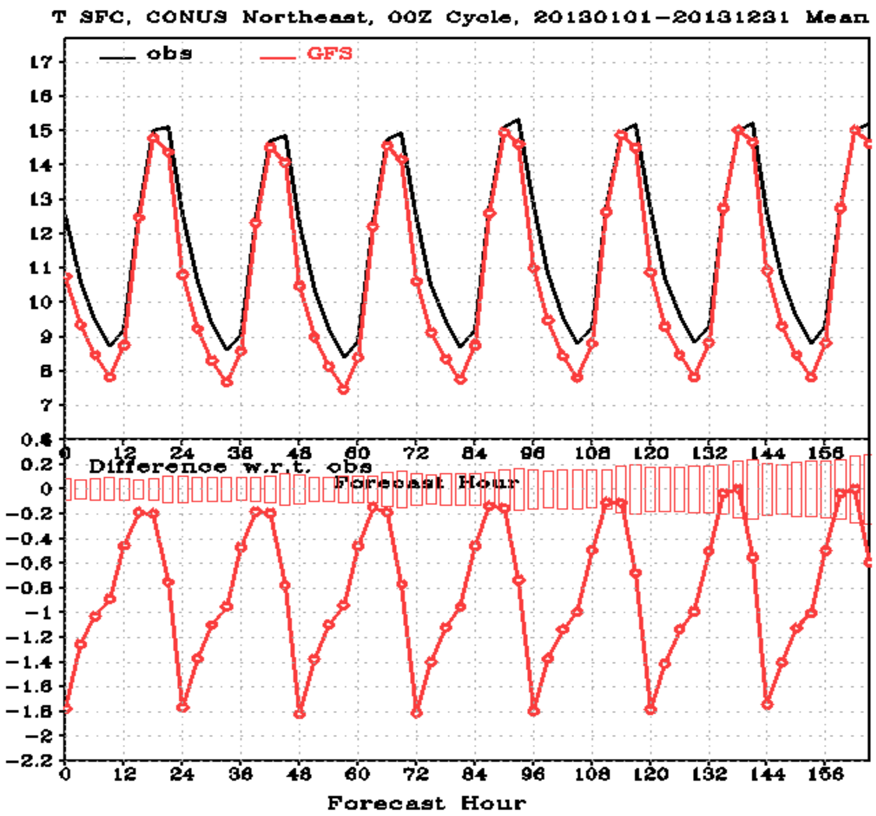


www.emc.ncep.noaa.gov/gmb/wx24fy/g2o/

Nighttime Cold Bias –cont'd



Northwest, 2013

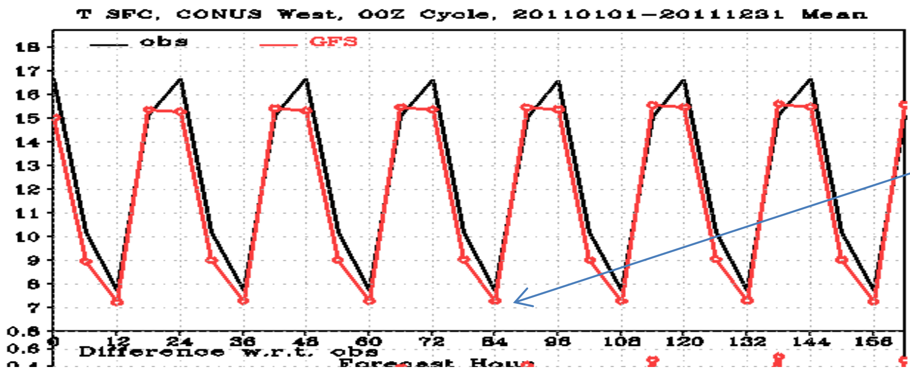


Northeast, 2013

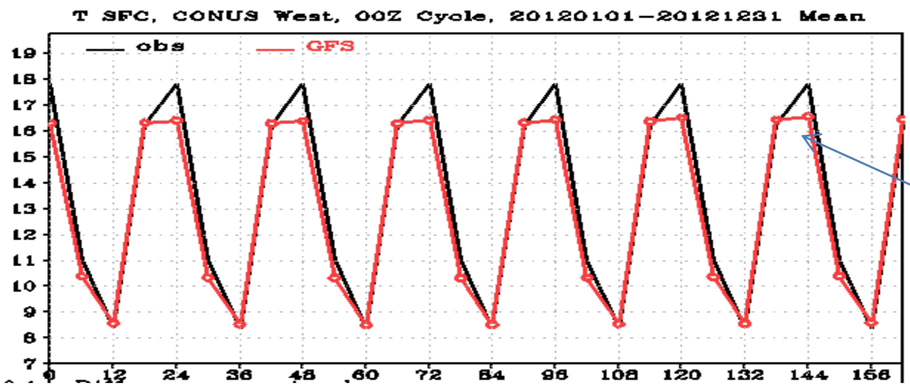
- The largest nighttime cold bias is found in CONUS northwest and northeast.
- Helin Wei commented that the bias is likely caused by **inaccurate snow-related physics** such as snow albedo, snow roughness, snow density and the lack of consideration of the shading effect of canopy when snow is under canopy, and **PBL problems under stable boundary layer conditions**.

www.emc.ncep.noaa.gov/gmb/wx24fy/g2o/

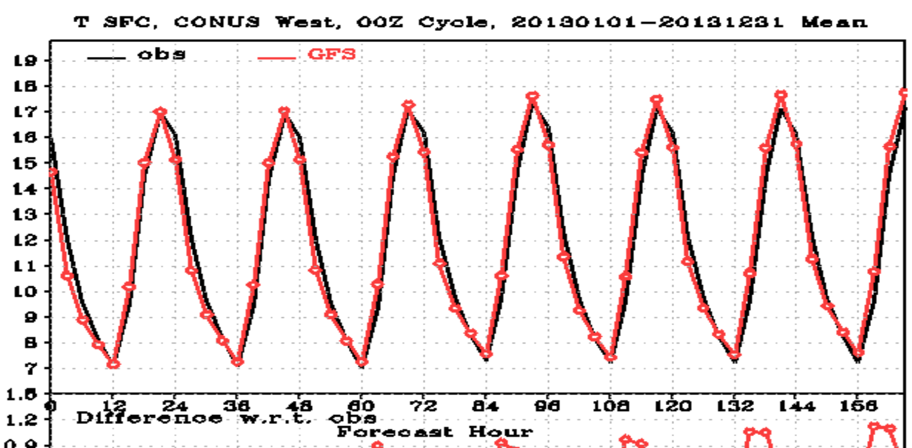
CONUS West T2m Verified against Surface Station Observations



2011
6-hrly



2012
6-hrly

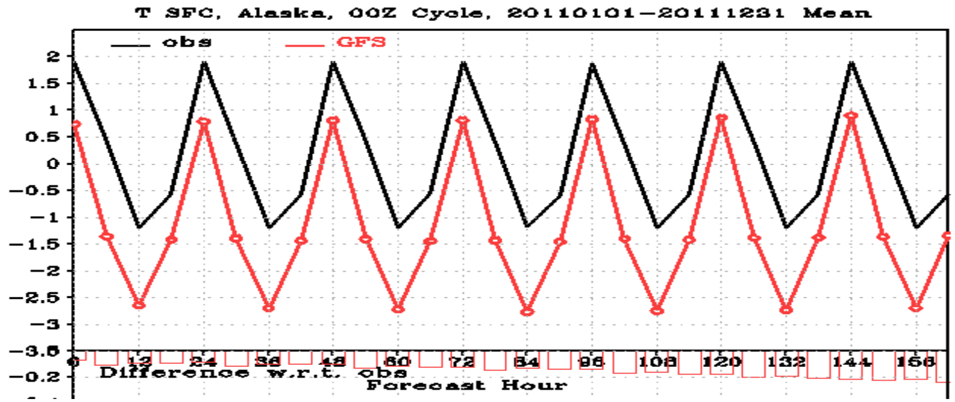


2013
3-hrly

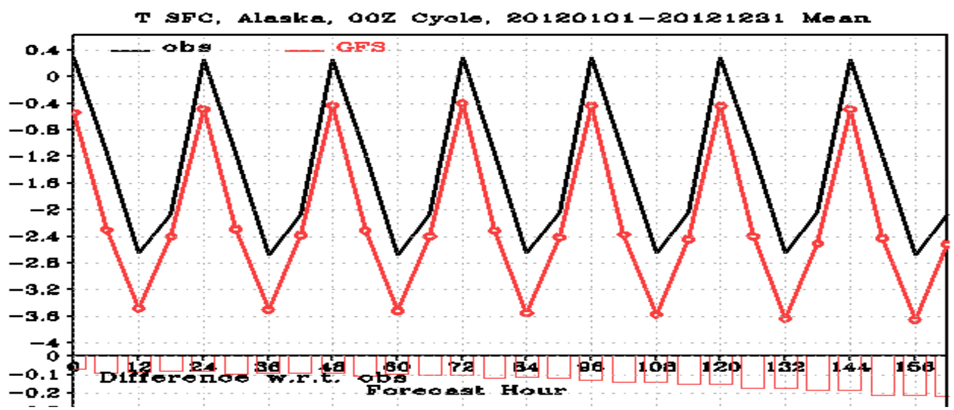
- **Nighttime cold bias found in 2011 was reduced in 2012 and 2013, due to cancellation of cold and warm biases in different regions.**
- **Increasing verification frequency from 6 hourly to 3 hourly in 2013 suggests that the daytime cold bias found in 2011 and 2012 was artificial. The GFS forecast of the daily maximum is rather accurately in 2013.**

www.emc.ncep.noaa.gov/gmb/wx24fy/g2o/

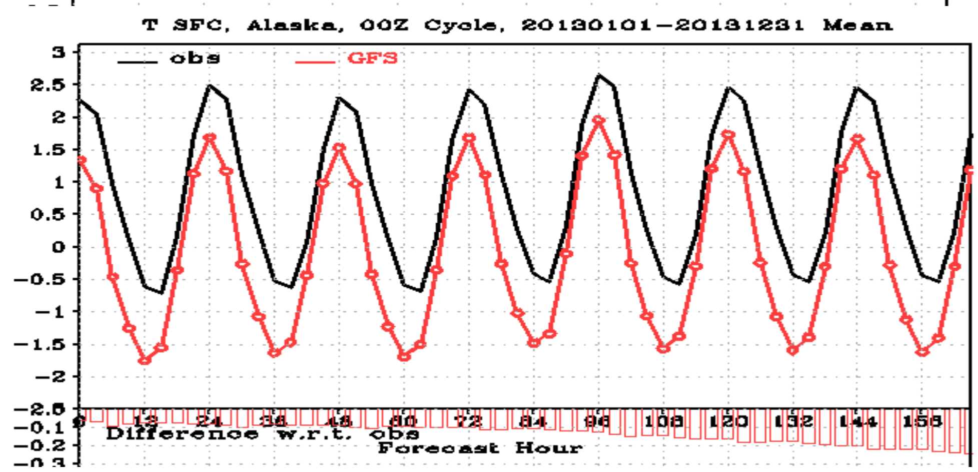
Alaska T2m Verified against Surface Station Observations



2011
6-hrly



2012
6-hrly



2013
3-hrly

- **T2m over Alaska is too cold during both day and night times for all years.**
- **The cold bias is largely reduced in the upcoming T1534 GFS .**

www.emc.ncep.noaa.gov/gmb/wx24fy/g2o/

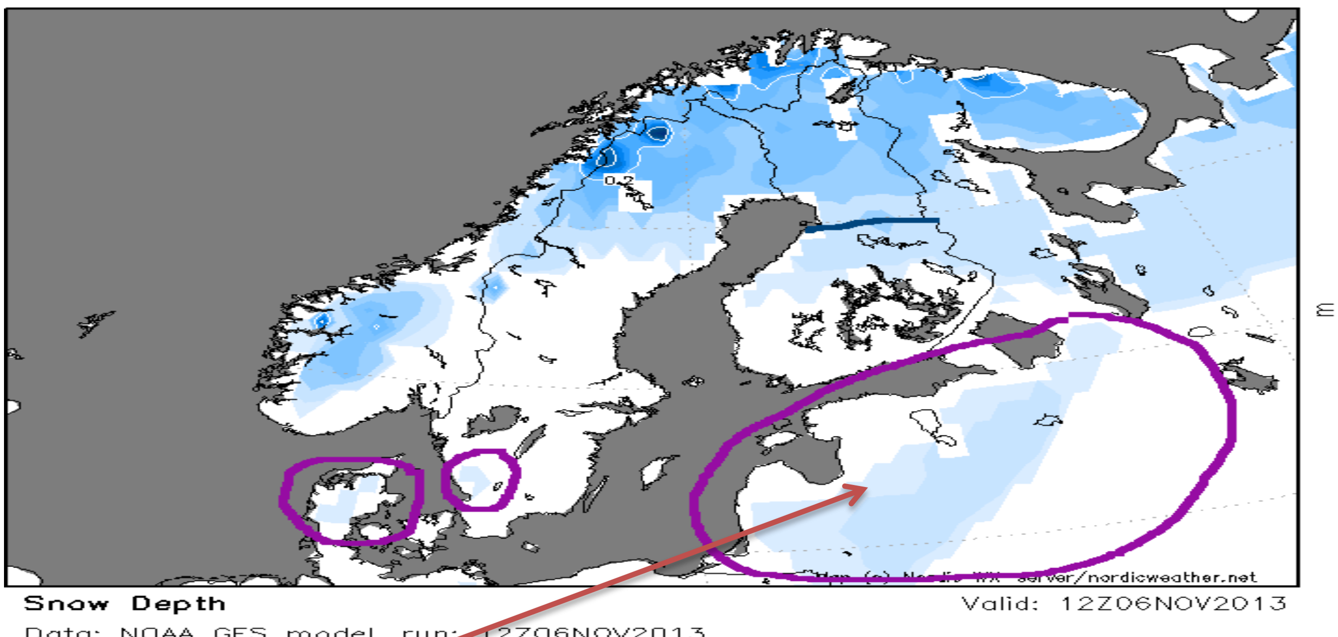
A case of false snowfall found in the operational GFS that led to excessively cold surface

Fanglin Yang and Hui-Ya Chuang

November 14, 2013

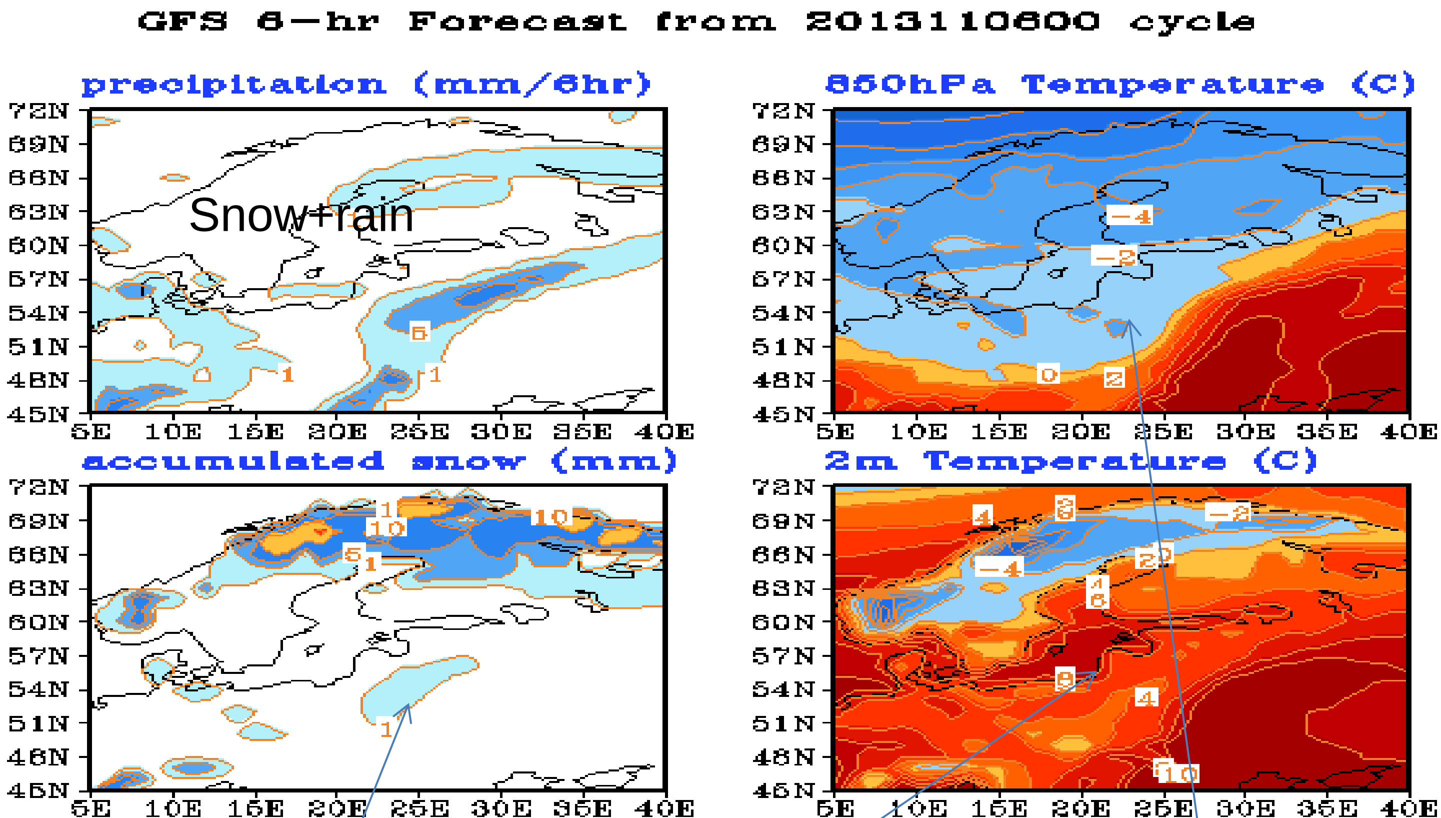
On 11/06/2013 Roblom Henrik from Finland reported that **in Finland/Nordics** the **GFS has by far too much snow in its forecasts**. In huge areas are snow in the forecast **even if it has been plus-degrees for weeks** and it has in reality been no snow so far this season. This again **cause many variables, like temperature, to be totally off, as most up to 5-C too cold !**.

GFS analysis (fh00 fcst) of snow depth from 2013110612 cycle
-- which is 6-hr fcst from the previous cycle.



Observation showed no snow here

Why does GFS forecast snow while observed sfc temperature is above freezing?

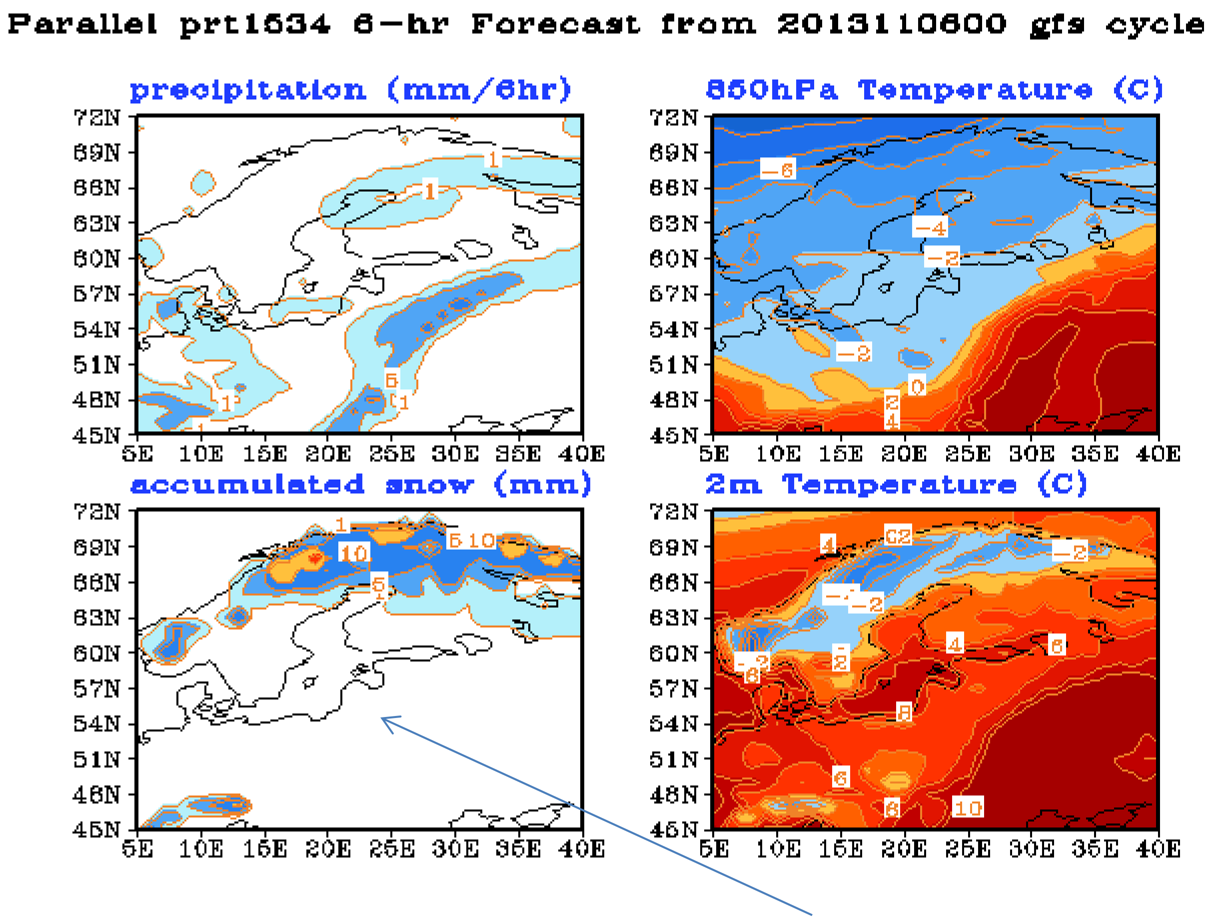


- **In the current GFS,** **total precipitation is partitioned into snow and rain based on 850-hPa temperature.**
- **For this case, temperature over the coast of the Baltic is below zero on 850 hPa but a few degrees above freezing near the surface.**
- **False snow is produced on the ground.**

Is there a solution to remove GFS false snow cover?

- A new “calprecip” program has been included in the GFS, and is under testing. It will be implemented along with the next GFS major upgrade and goes to operation in 2014.
- This program uses a more comprehensive approach to partition snow and rainfall. It produced more accurate snow accumulation.

GFS T1534 Parallel Result



00Z Cycle
Nov 06, 2013

The parallel running with the new "calprecip" did not produce false snowfall near the southeast coast of Baltic Sea.

Outline

1. Major GFS changes in recent years

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   - Precipitation
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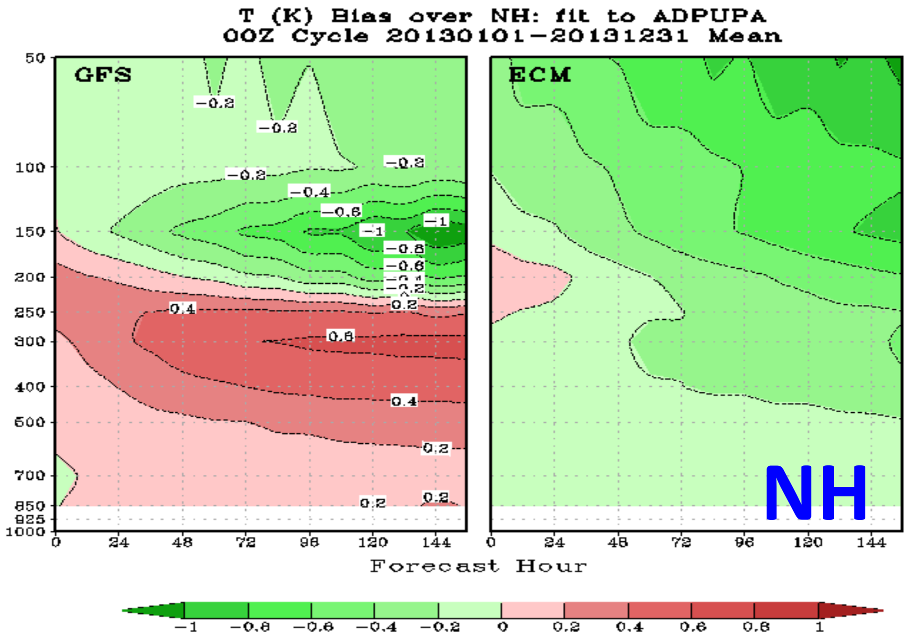
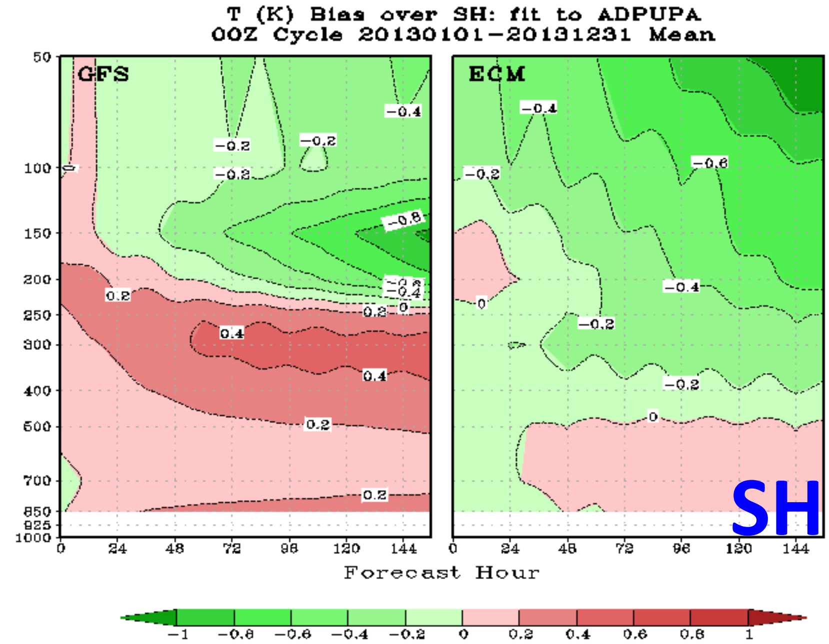
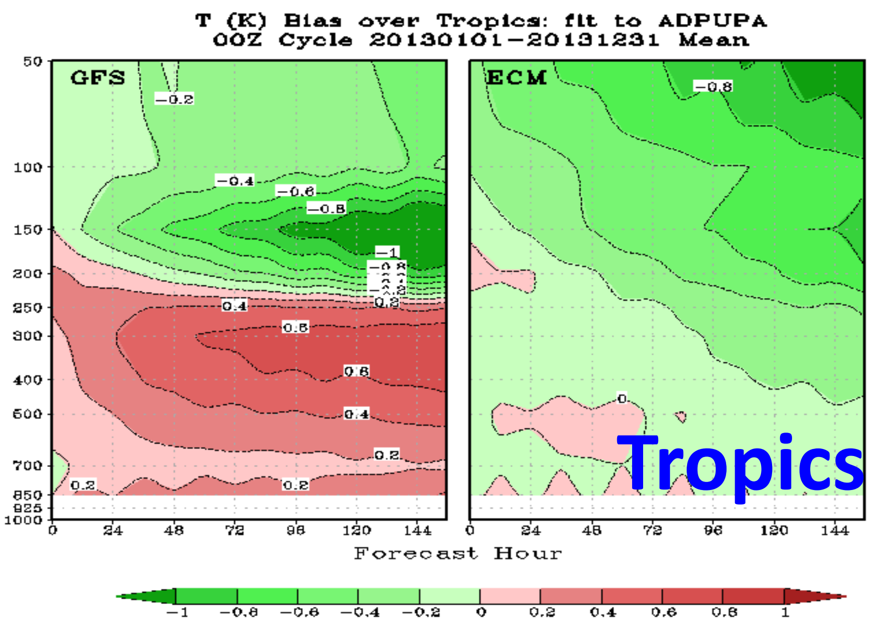
   - **Verification Against Rawinsonde Observations**

3. Summary and Discussion

Temperature Bias , Verified against Rawinsonde Observations, 2013 Annual Mean







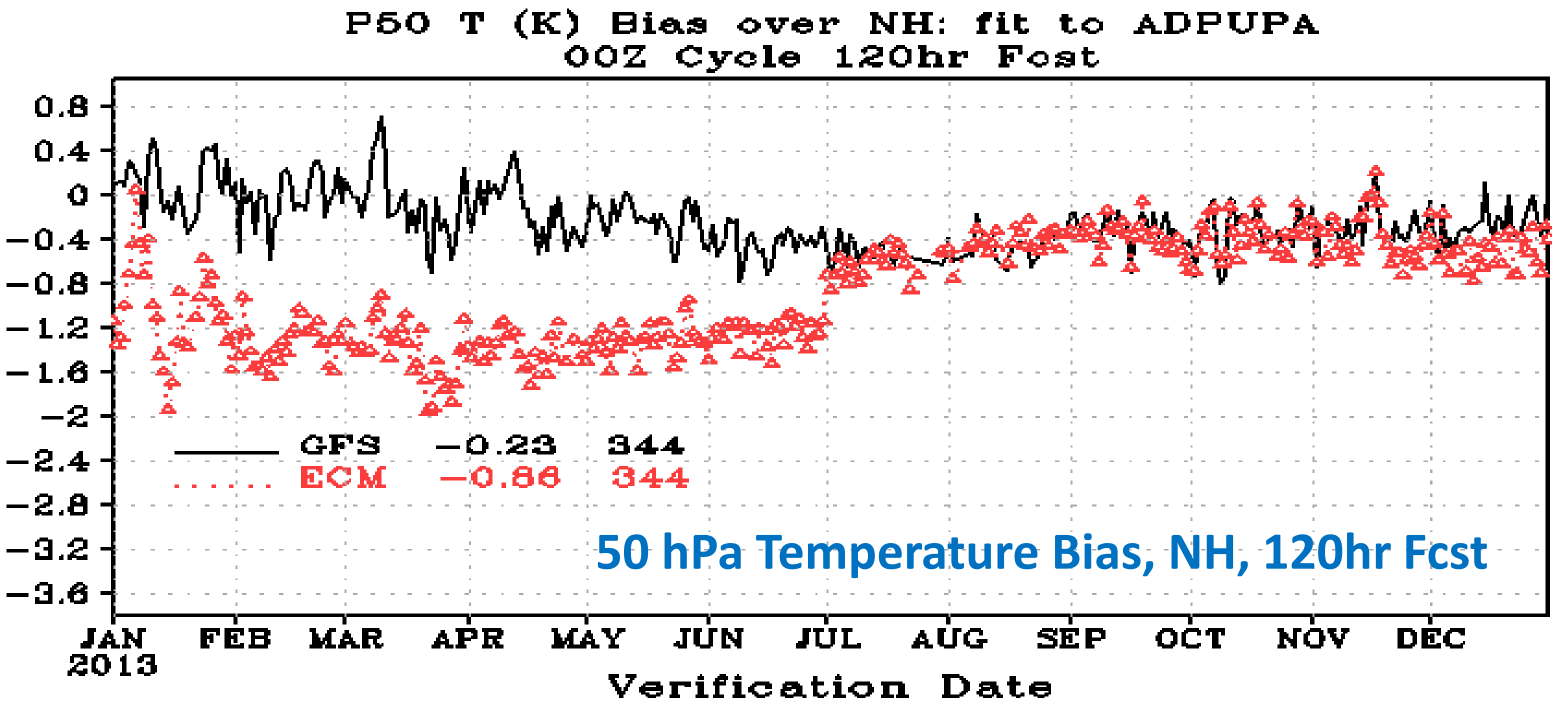
Compared to RAOBS

1. **GFS was too warm in the upper troposphere and too cold at the tropopause and lower stratosphere.**

2. **ECMF was too cold in the entire stratosphere.**

3. **ECMWF was better than the GFS in the troposphere but worse in the stratosphere.**

- **ECMWF significantly reduced its cold bias in the stratosphere after its July-2013 implementation, from which its model vertical resolution was increased from 91 layers to 137 layers. (see http://www.ecmwf.int/publications/library/do/references/show?id=90759).**
-
- **The improvement was attributed to higher vertical resolution, better non-stationary GWD parameterization, and better data assimilation etc.**



Thanks for Daryl Kleist for bringing my attention to ECMWF's model upgrade.

Sensitivity of T1534 SLG GFS Stratospheric Temperature to Model Vertical Resolution

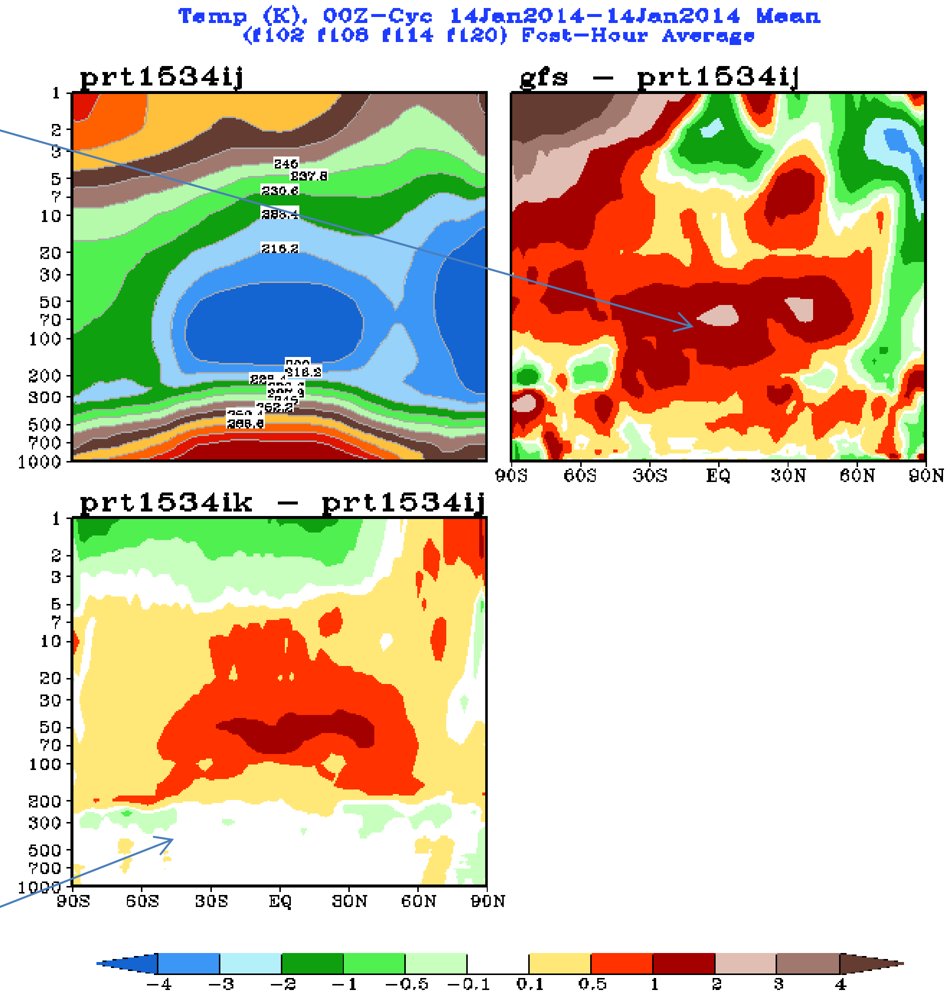
- The T1534 Semi-Lag GFS has large cold bias in the lower stratosphere, a symptom similar to the previous 91L ECMWF cold bias.

A Sensitivity Test:

- prt1534ij: control run, 64-L T1534 SLG-GFS, pure Hermite dynamical core.
- prt1534ik: the same as prt1534ij except with a vertical resolution of 92 layers. I doubled the layers between 300 hPa and 5 hPa.
- GFS: current operational T574 Eulerian model.

Outcome:

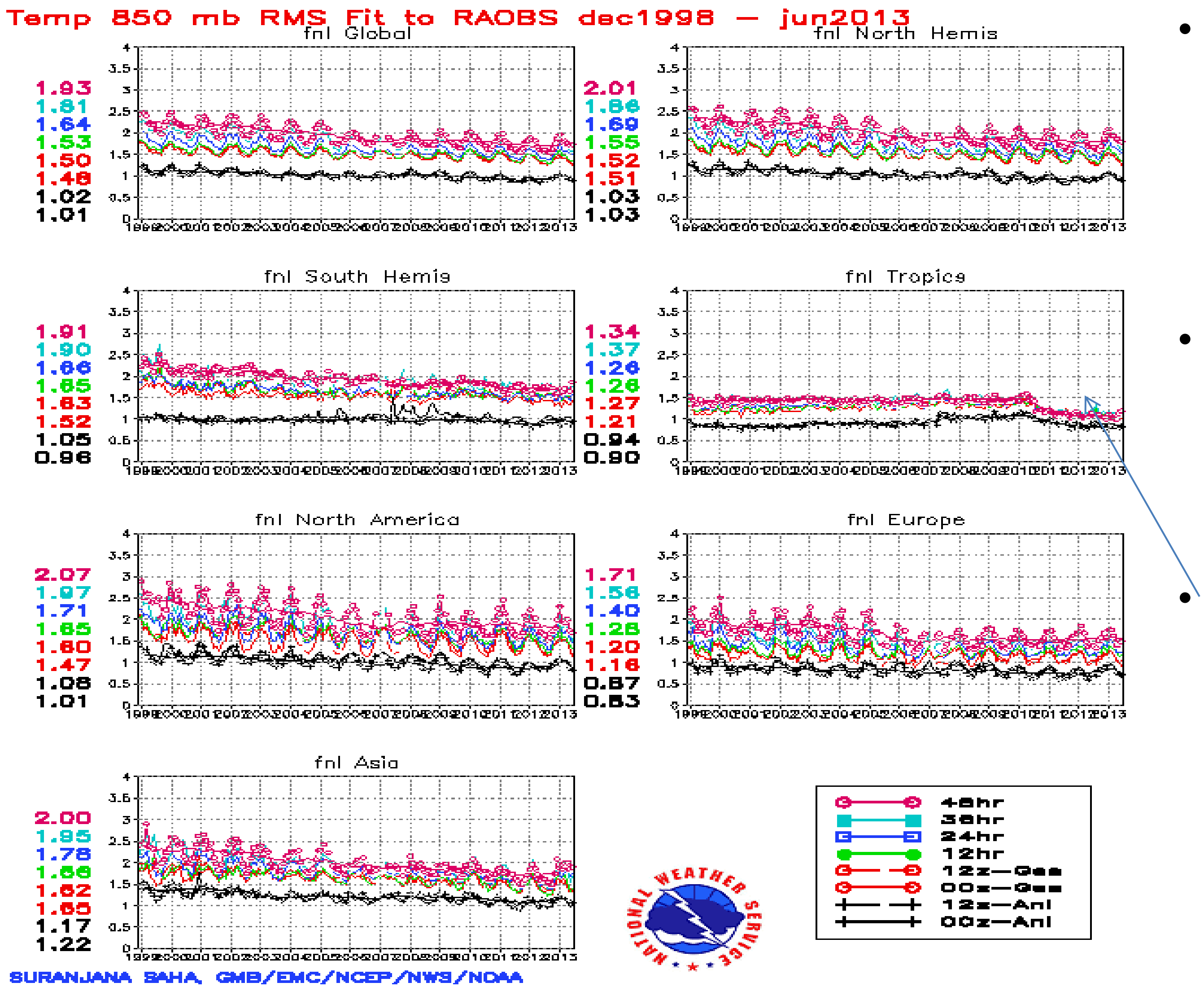
Increasing T1534 SLG GFS vertical resolution reduced the cold bias by 1 to 2 degree in a 5-day forecast.



Note: Shrivinas Moorthi added a divergence damping to the latest version of T1534 GFS. It reduced the cold bias down to about 1-2 degrees.

Long-Term Fit-to-Obs Stats

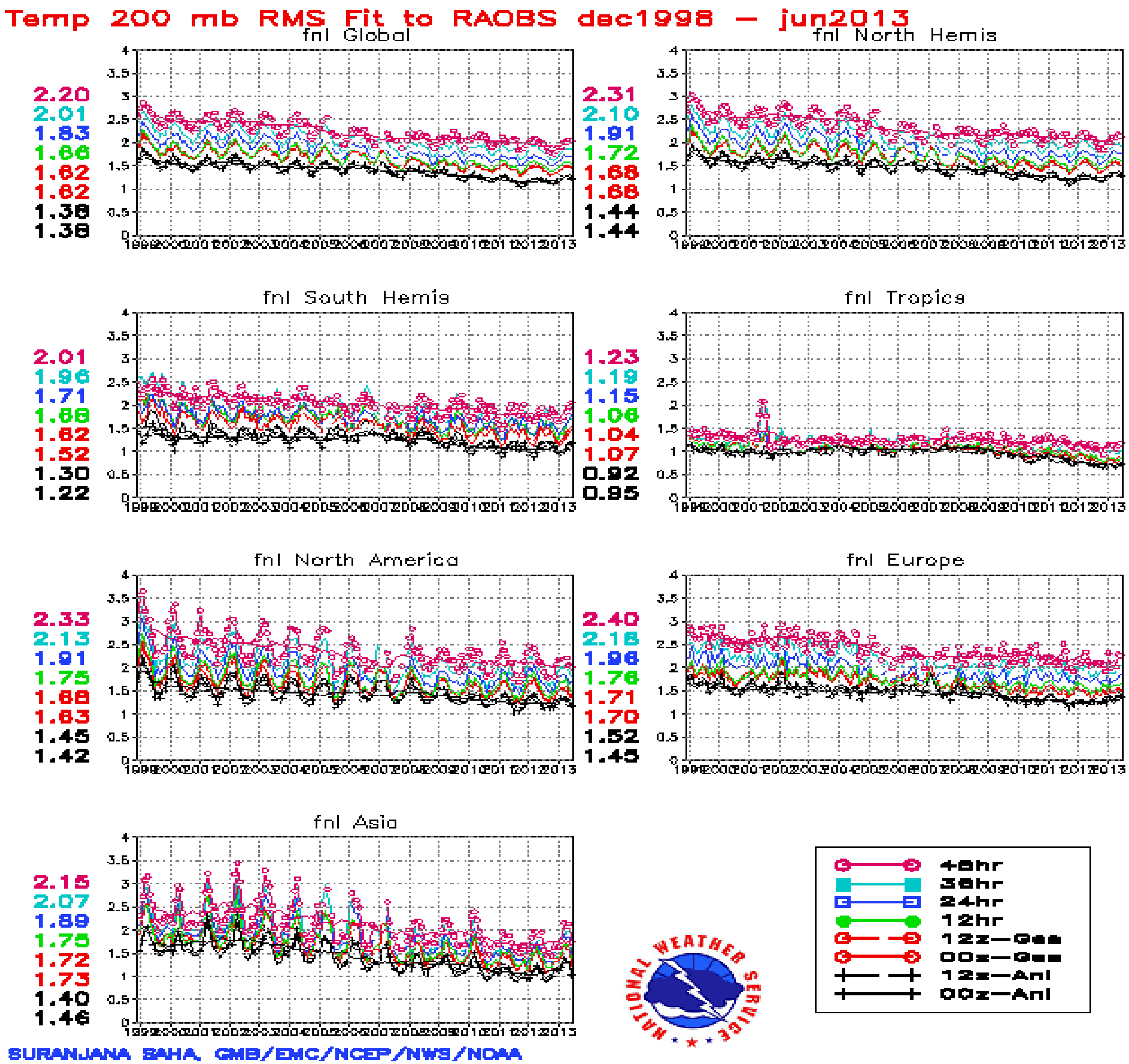
by Suru Saha and Jack Woollen , http://www.emc.ncep.noaa.gov/gmb/ssaha/



- Persistent reduction in model forecast biases in all regions except the tropics.
- Bias reduction from reanalysis is slower than does the forecast.
- Large reduction in the tropics in for both forecasts and analyses after 2010 T574 implementation.

Long-Term Fit-to-Obs Stats

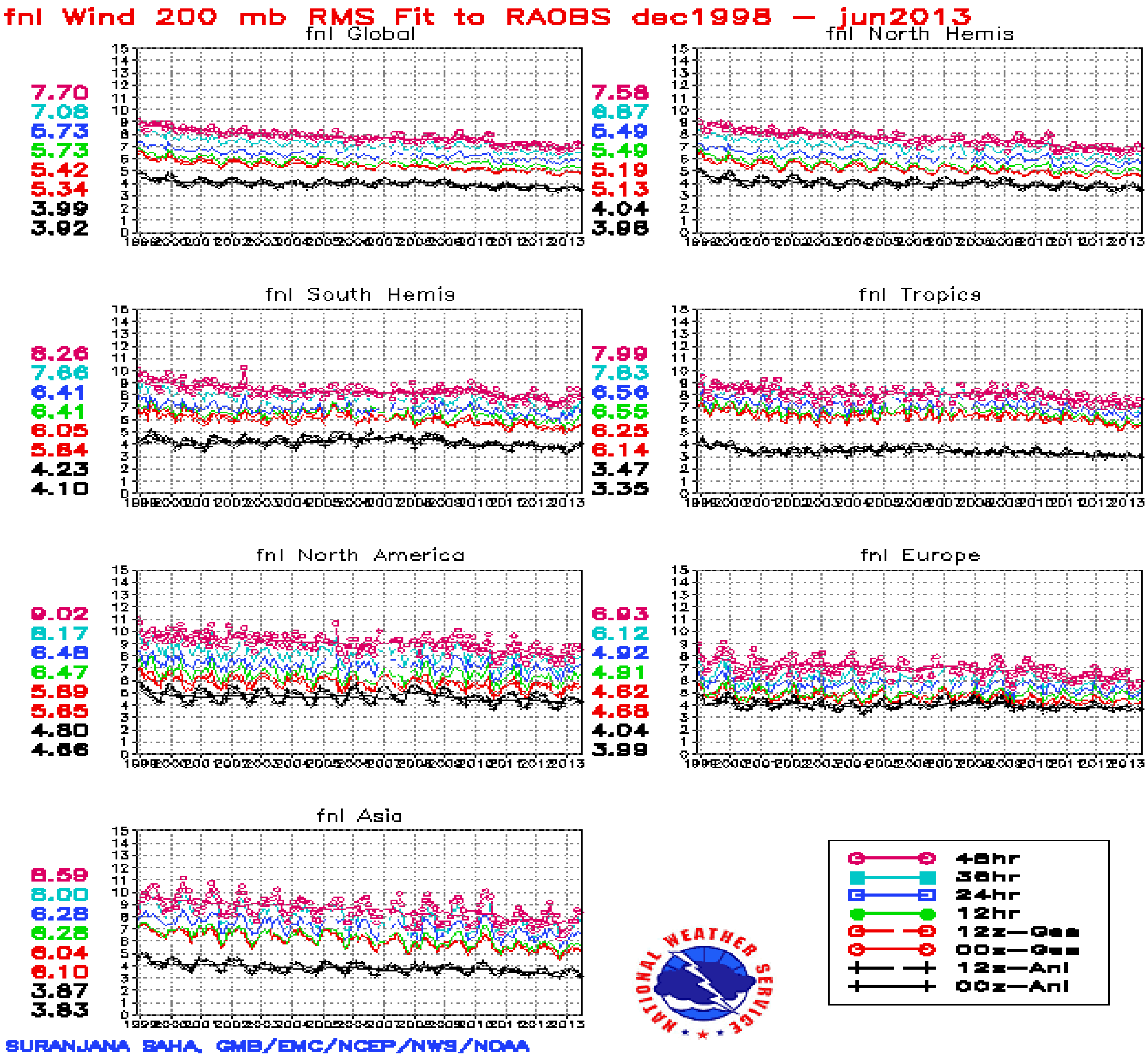
by Suru Saha and Jack Woollen , http://www.emc.ncep.noaa.gov/gmb/ssaha/



- The analysis showed a better improvement in temperature at 200hPa than at 850hPa.

Long-Term Fit-to-Obs Stats

by Suru Saha and Jack Woollen , http://www.emc.ncep.noaa.gov/gmb/ssaha/



- Reduction of forecast wind error at 200hPa is slow, except in the tropics after 2010.
- Analysis showed little improvement.

Outline

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3. **Summary and Discussion**

Summary and Discussion -1

- There was no GFS upgrades in 2013. Instead, the system was moved from CCS to WCOSS suptercomputers.

- In 2013, GFS continues to show forecast improvement of 500-hPa height AC.

- GFS remains trailing behind ECMWF by ~0.3 days in the NH and by 0.7 days in the SH for useful forecast days (AC>=0.6).

- Among the GFS daily four cycles, the 00Z cycle has the best forecast skill. It is not clear why the four cycles differ from each other. The difference cannot be solely explained by different observation data counts.

- In the past ten years, GFS hurricane track and intensity forecast had been greatly improved in both the Atlantic and Pacific basins. However, in 2013 GFS track forecasts were slightly degraded in both basins.

Summary and Discussion -2

- GFS CONUS precipitation forecast was improved after the 2010 T574 implementation, and did not vary much in the past 4 years. GFS's QPF scores fell behind leading NWP models. GFS tends to produce popcorn rainfalls over high terrains.

- GFS has large 2m temperature cold bias at nighttime over the CONUS northwest and northeast. The bias is likely caused by inaccurate snow-related physics and PBL issues under stable boundary layer conditions.

- Snow and rainfall on the ground in the current GFS is determined by 850hPa temperature. This may lead to false snow fall (or rainfall) on the ground, and lead to large surface temperature bias. An improved algorithm has been included the T1534 GFS.

- GFS was too warm in the upper troposphere and too cold at the tropopause and lower stratosphere. Nevertheless, fit-to-obs stats showed that biases of GFS temperature and wind have been gradually reduced over the past 15 years.

- ECMWF reduced its cold bias in the stratosphere after increasing model vertical layers from 91 to 137 in July 2013. Sensitivity test made with the T1534 GFS also showed that increasing vertical resolution can reduce the cold bias found in the 64-L SLG GFS.

Configuration of Major Global High-Res NWP Models (2013)

System	Analysis	Forecast Model	Forecast Length and Cycles	upcoming
NCEP GFS	**Hybrid 3DVAR** (T382) + **EnkF** (T254)	**Semi-implicit Spectral T574L64** (23km, 0.03 hPa)	4 cycles 16 days	**semi-lag T1534**
ECMWF IFS	**4DVAR** T1279L91 (T255 inner loops)	**Semi-Lag Spectral T1279L137** (16km, 0.01 hPa)	2 cycles 10 days	
UKMO Unified Model	**Hybrid 4DVAR** with MOGREPS Ensemble	**Gridded**, 70L (25km; 0.01 hPa)	4 cycles 6 days	
CMC GEM	**4DVAR**	**Semi-lag Gridded** (0.3x0.45 deg; 0.1 hPa)	2 cycles 10 days	Non-hydrostatic; 4DVAR
JMA GSM	**4DVAR**	**Semi-lag spectral T959 L60** (0.1875 deg; 0.1 hPa)	4 cycles 9 days (12Z)	
NAVY NOGAPS	**4DVAR Ens Hybrid**	**NAVGEM T359L42 semi-lag** (42km; 0.04hPa)	2 cycles 7.5 days	