Review of GFS Forecast Skills in 2017

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Change History of GFS Configurations

Mon/Year	Lev	Truncations	Z-cor/dyncore	Major components upgrade
Aug 1980	12	R30 (375km)	Sigma Eulerian	first global spectral model, rhomboidal
Oct 1983	12	R40 (300km)	Sigma Eulerian	
Apr 1985	18	R40 (300km)	Sigma Eulerian	GFDL Physics
Aug 1987	18	T80 (150km)	Sigma Eulerian	First triangular truncation; diurnal cycle
Mar 1991	18	T126 (105km)	Sigma Eulerian	
Aug 1993	28	T126 (105km)	Sigma Eulerian	Arakawa-Schubert convection
Jun 1998	42	T170 (80km)	Sigma Eulerian	Prognostic ozone; SW from GFDL to NASA
Oct 1998	28	T170 (80km)	Sigma Eulerian	the restoration
Jan 2000	42	T170 (80km)	Sigma Eulerian	first on IBM
Oct 2002	64	T254 (55km)	Sigma Eulerian	RRTM LW;
May 2005	64	T382 (35km)	Sigma Eulerian	2L OSU to 4L NOAH LSM; high-res to 180hr
May 2007	64	T382 (35km)	Hybrid Eulerian	SSI to GSI
Jul 2010	64	T574 (23km)	Hybrid Eulerian	RRTM SW; New shallow cnvtion; TVD tracer
Jan 2015	64	T1534 (13km)	Hybrid Semi-Lag	SLG; Hybrid EDMF; McICA etc
May2016	64	T1534 (13km)	Hybrid Semi-Lag	4-D Hybrid En-Var DA
Jun2017	64	T1534 (13km)	Hybrid Semi-Lag	NEMS GSM, advanced physics
Jan 2019	64	FV3 (13km)	Finite-Volume	NGGPS FV3 dycore

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

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)

- **07-08/2013**

  - 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.

- **01/14/2015**

- **Upgrade to T1534 Semi-Lagrangian (~13km)** : Use Lagrangian instead Hermite vertical interpolation; Use high resolution daily RGT SST and daily sea ice analysis; Extend high resolution forecast from 8 days to 10 days; Use McICA radiation approximation; Reduced drag coefficient at high wind speeds; Hybrid EDMF PBL scheme and TKE dissipative heating; Retuned ice and water cloud conversion rates, background diffusion of momentum and heat, orographic gravity-wave forcing and mountain block; Updated physics restart and sigio library; Consistent diagnosis of snow accumulation in post and model; Compute and output frozen precipitation fraction; Divergence damping in the stratosphere to reduce noise; Added a tracer fixer for maintaining global column ozone mass; Stationary convective gravity wave drag; New blended snow analysis to reduce reliance on AFWA snow; Changes to treatment of lake ice to remove unfrozen lake in winter; Modified initialization to reduce a sharp decrease in cloud water in the first model time step; Replace Bucket soil moisture climatology with CFS/GLDAS; Add vegetation dependence to the ratio of the thermal and momentum roughness.

- **GSI Changes**: increase horizontal resolution of ensemble from T254 to T574; reduce number of second outer loop iterations from 150 to 100; upgrade to CRTM v2.1.3 ; move to enhanced radiance bias correction scheme; correct bug in AMSU-A cloud liquid water bias correction term; assimilate new radiances: F17 an F18 SSMIS, MetOp-B IASI ; increase ATMS observation errors; turn on cloud detection channels for monitored instruments: NOAA-17, -19 HIRS, GOES-13 and -14 sounders; changes in assimilation of atmospheric motion vectors (AMV): assimilate NESDIS GOES hourly AMVs, improve AMV quality control ; improve GPS RO quality control .

Major GFS Changes (cont'd)

- 05/11/2016

- **Data Assimilation Upgrade**

  * Upgrade the 3D Hybrid Ensemble-Variational to **4D Hybrid Ensemble-Variational Data Assimilation.**
  * **Multivariate Ozone update**
  * Assimilate **all-sky** (clear and cloudy) **radiances**
  * Bias correct aircraft data
  * Modify relocation and storm tracking to allow hourly tropical cyclone relocation
  * other upgrades (e.g. CRTM, Data selection/thinning, AMV winds, etc.)

-Model Upgrade

  * Corrections to land surface to reduce summertime warm, dry bias over Great Plains
  * Hourly output fields through 120-hr forecasts
  * add five more levels from 10 hPa to 1 hPa in post-processed pgb files

- **07/19/2017**

-Model Upgrade

  * Implement GSM source code in NOAA Environmental Modeling System (**NEMS**) framework
  * Replace spectral history file output (sigma files) with new **nemsio** binary files on model native grid.
  * Implement Near Surface Sea Temperature (**NSST**) to replace Real-Time Global SST (RTGSST) to provide more realistic ocean boundary conditions.
  * Upgrade deep & shallow convection schemes with **scale- and aerosol-aware** features along with convective cloudiness enhancement
  * Upgrade the land surface model to increase ground heat flux under deep snow; and unify snow cover fraction and snow albedo. Use new **high-resolution MODIS-based snow-free albedo, maximum snow albedo, soil type and vegetation type.**
  * Upgrade surface layer parameterization scheme to modify the roughness-length formulation and introduce a stability parameter constraint in the Monin-Obukov similarity theory to prevent the land-atmosphere system from decoupling.

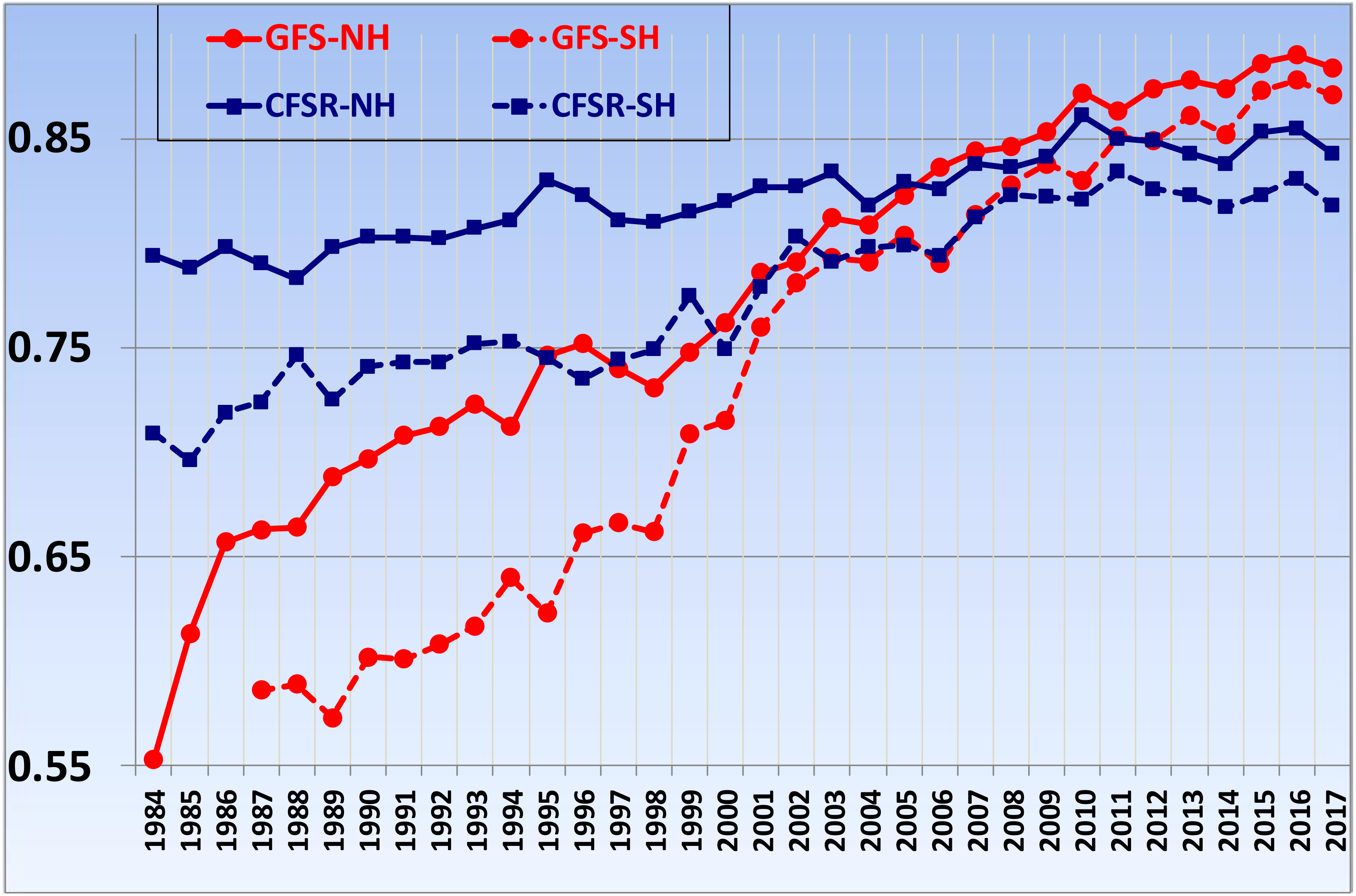
Major GFS Changes (cont'd)

07/19/2017

-**Data assimilation**

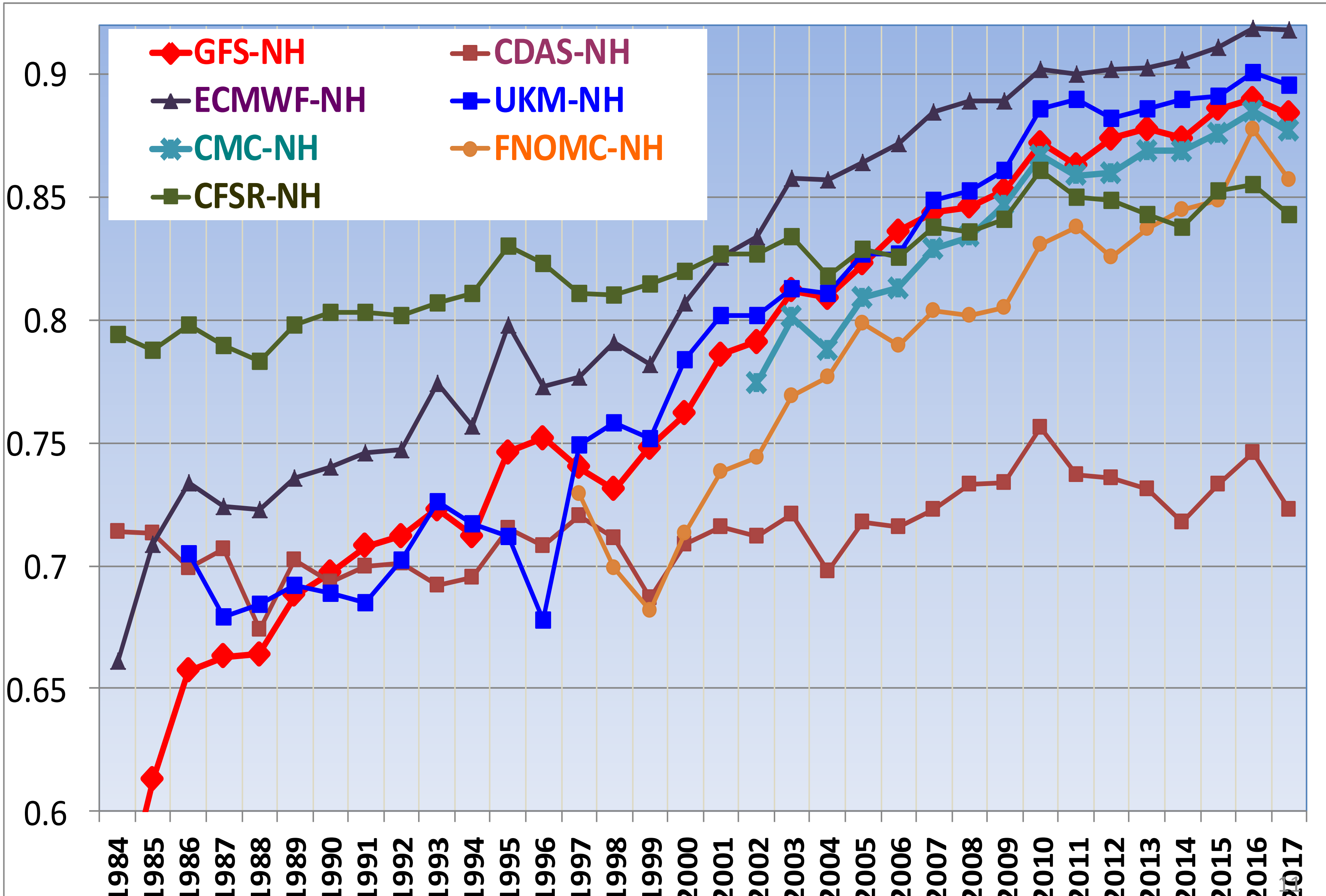
* Implement Near Sea-Surface Temperature (**NSST**) Analysis
* Implement CrIS full resolution data assimilation capability
* Implement readiness for new Geostationary Operational Environmental Satellite (GOES-16), Joint Polar Satellite System (JPSS-2) and COSMIC-2 (Constellation Observing System for Meteorology, Ionosphere and Climate) data assimilation capability
* Extend Regional Advanced Television Infrared Observation Satellite (TIROS) Operational Vertical Sounder (ATOVS) Retransmission Services (RARS) and Direct Broadcast Network (DBNet) capability
* Implement bug fix to cloud water increment in Gridpoint Statistical Interpolation (GSI)
* Upgrade land surface type specification in Community Radiative Transfer Model (CRTM)
* Assimilate Visible Infrared Imaging Radiometer Suite (**VIIRS**) Atmospheric Motion Vectors (AMVs) and implement log-normal wind quality control for AMVs
* Assimilate Geostationary Operational Environmental Satellite system (GOES) clear-air water vapor winds
* Assimilate additional global navigation satellite system (GNSS) –Radio Occultation (RO) observations.
* Modify pressure and hybrid coordinates transformation during the storm relocation. Change relocation of the vorticity and divergence fields to the relocation of u,v wind components
* Remove bogus Tropical Storm/Hurricane data for use in Data Assimilation.
* Assimilate Global Hawk dropsonde data when available

Annual Mean 500-hPa HGT Day-5 Anomaly Correlation

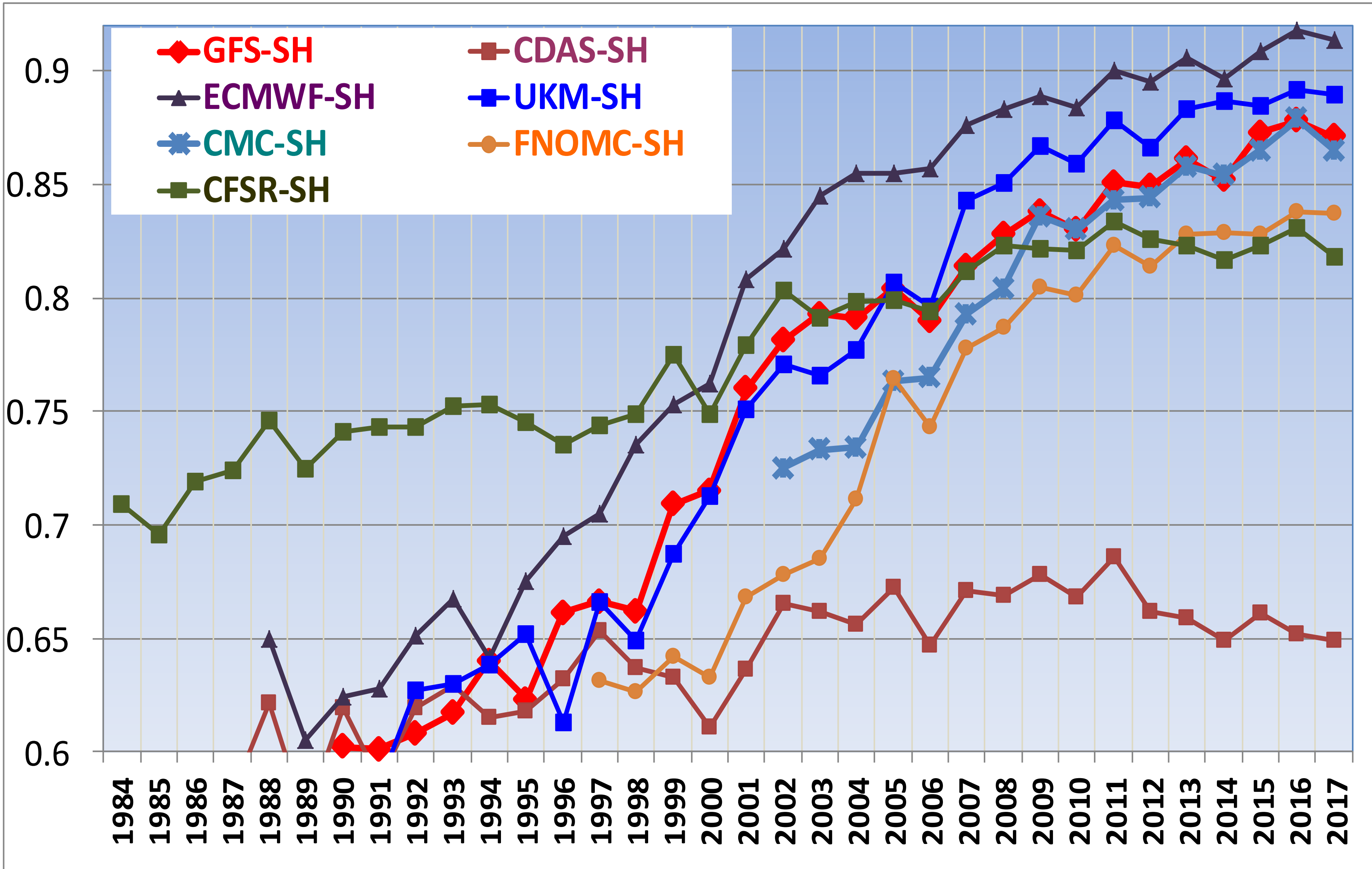


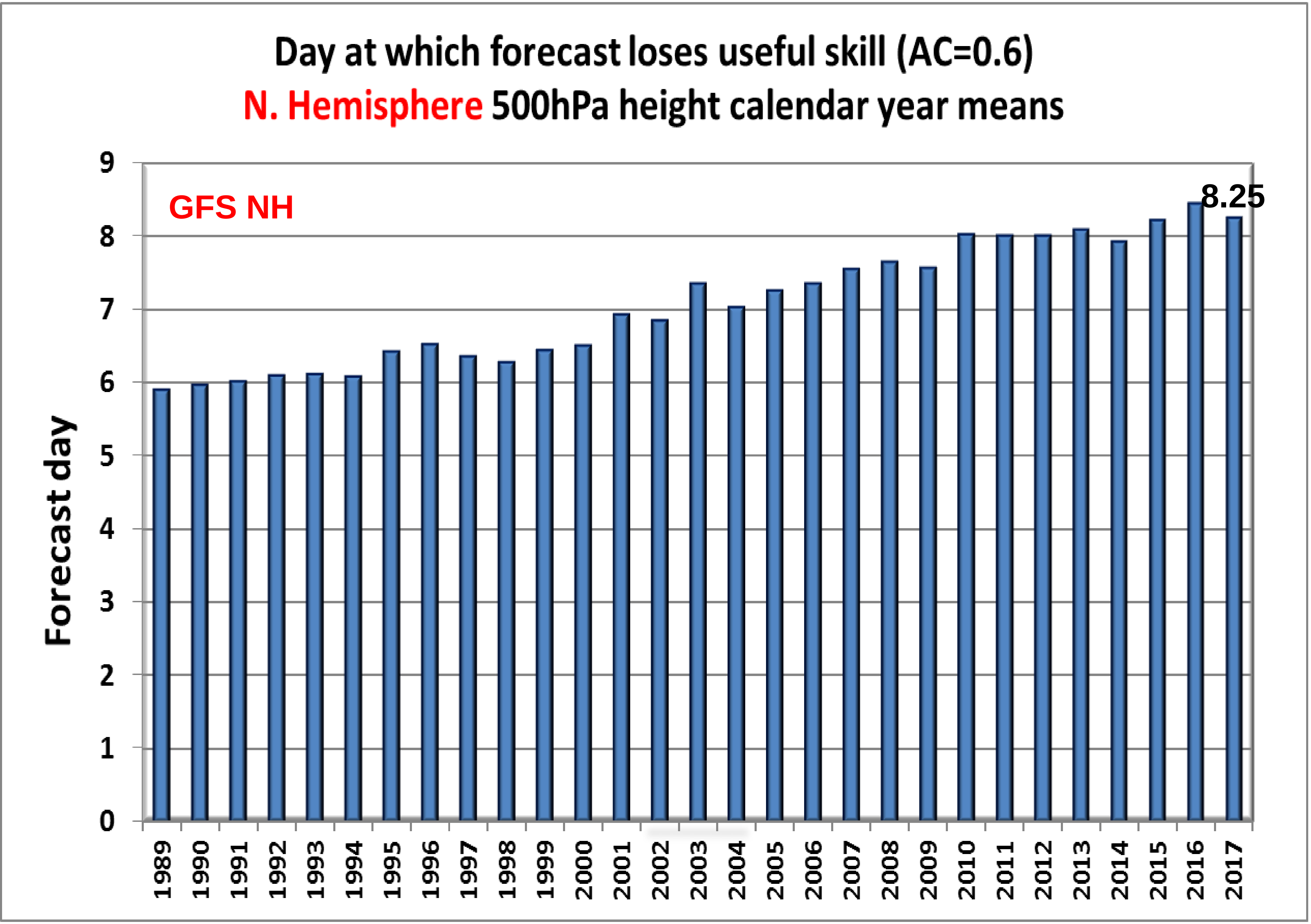
Increase by 0.1 per decade

Annual Mean NH 500hPa HGT Day-5 AC



Annual Mean SH 500hPa HGT Day-5 AC





Day at which forecast loses useful skill (AC=0.6)
N. Hemisphere 500hPa height calendar year means
GFS NH
8.25
Forecast day
0
1
2
3
4
5
6
7
8
9
1989
1990
1991
1992
1993
1994
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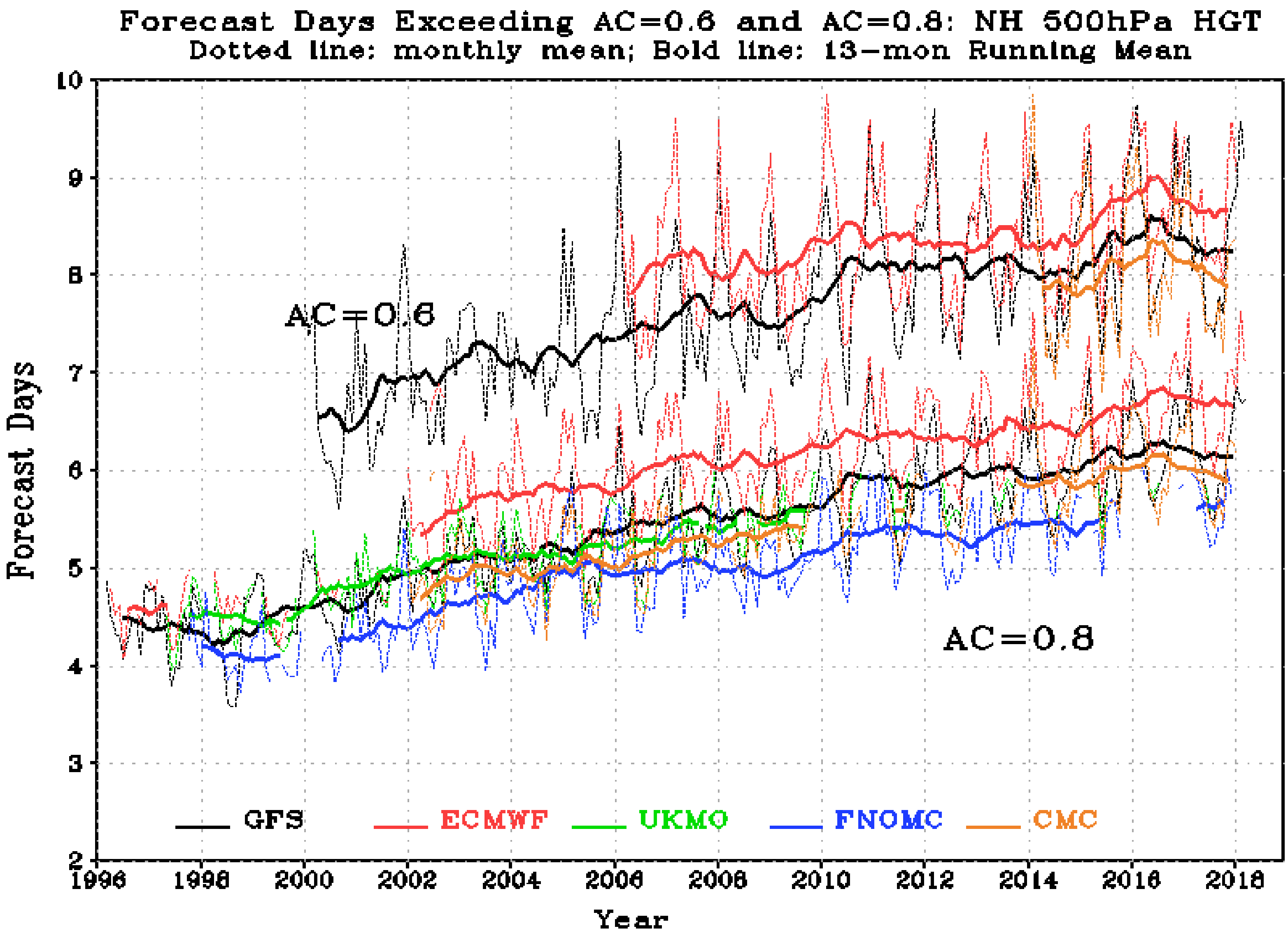
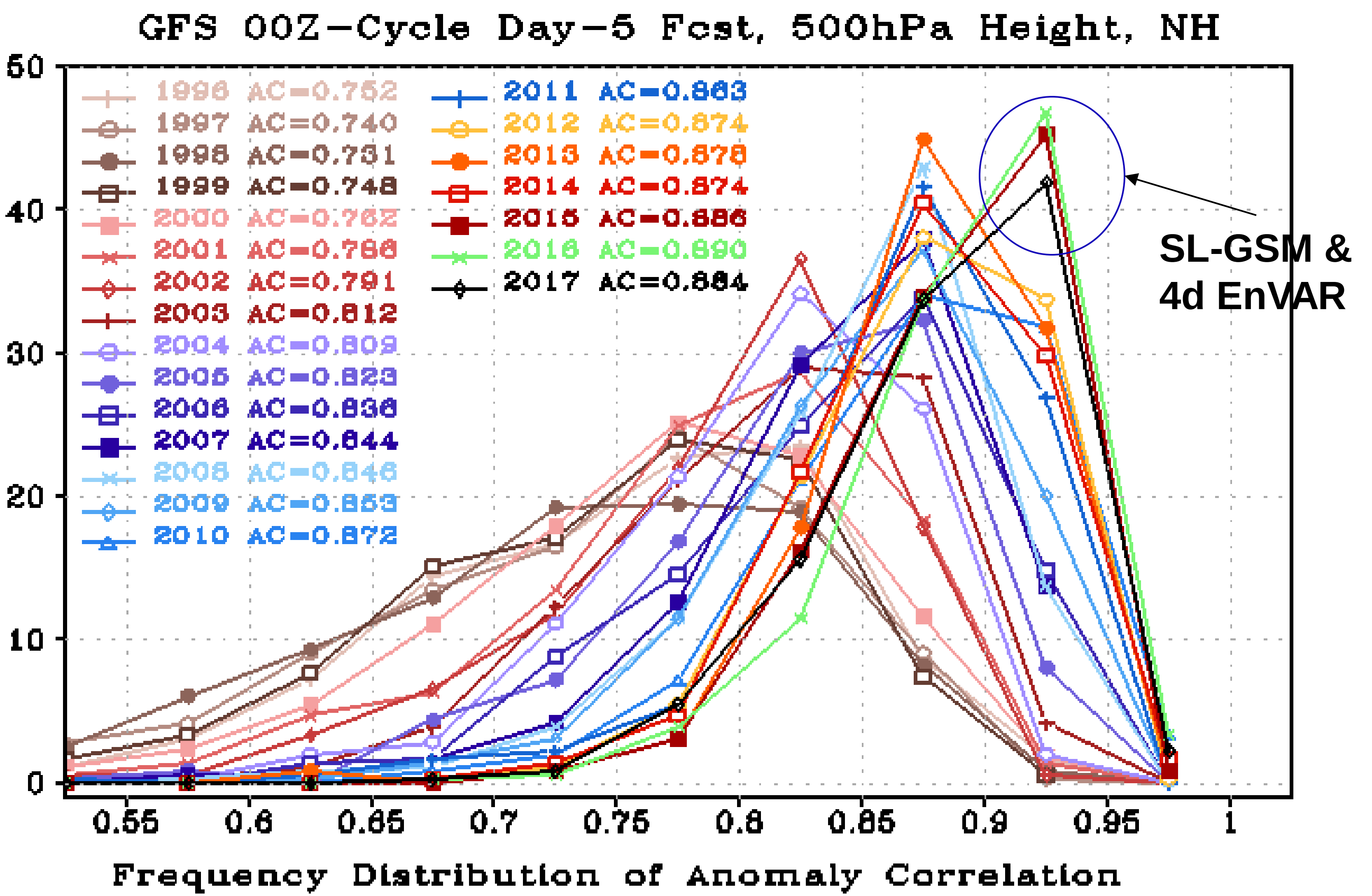
2017

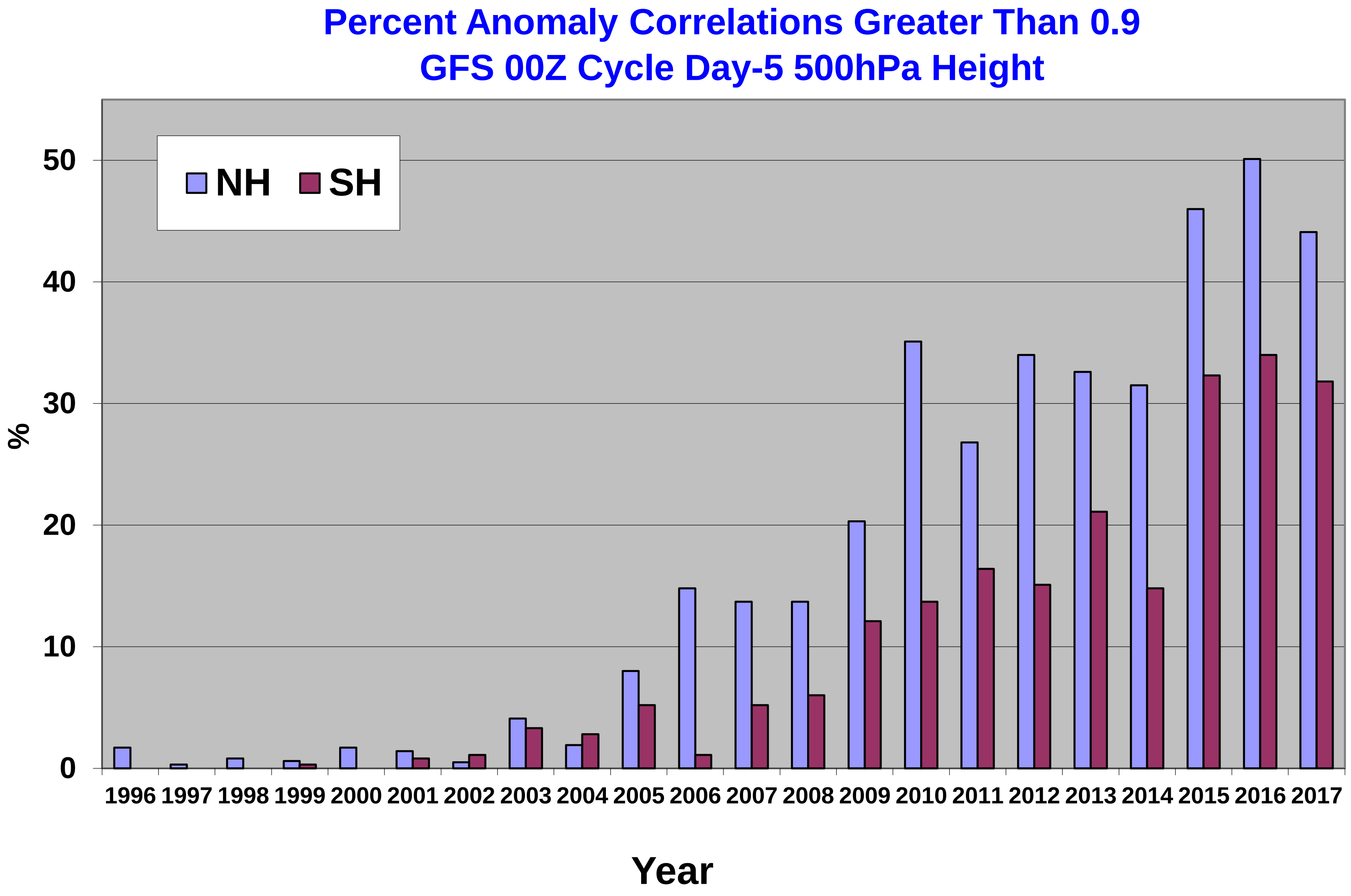
Useful Forecast Days for Major NWP Models, NH



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

Frequency Distribution





Percent Anomaly Correlations Greater Than 0.9
GFS 00Z Cycle Day-5 500hPa Height
NH
SH
%
0
10
20
30
40
50
1996
1997
1998
1999
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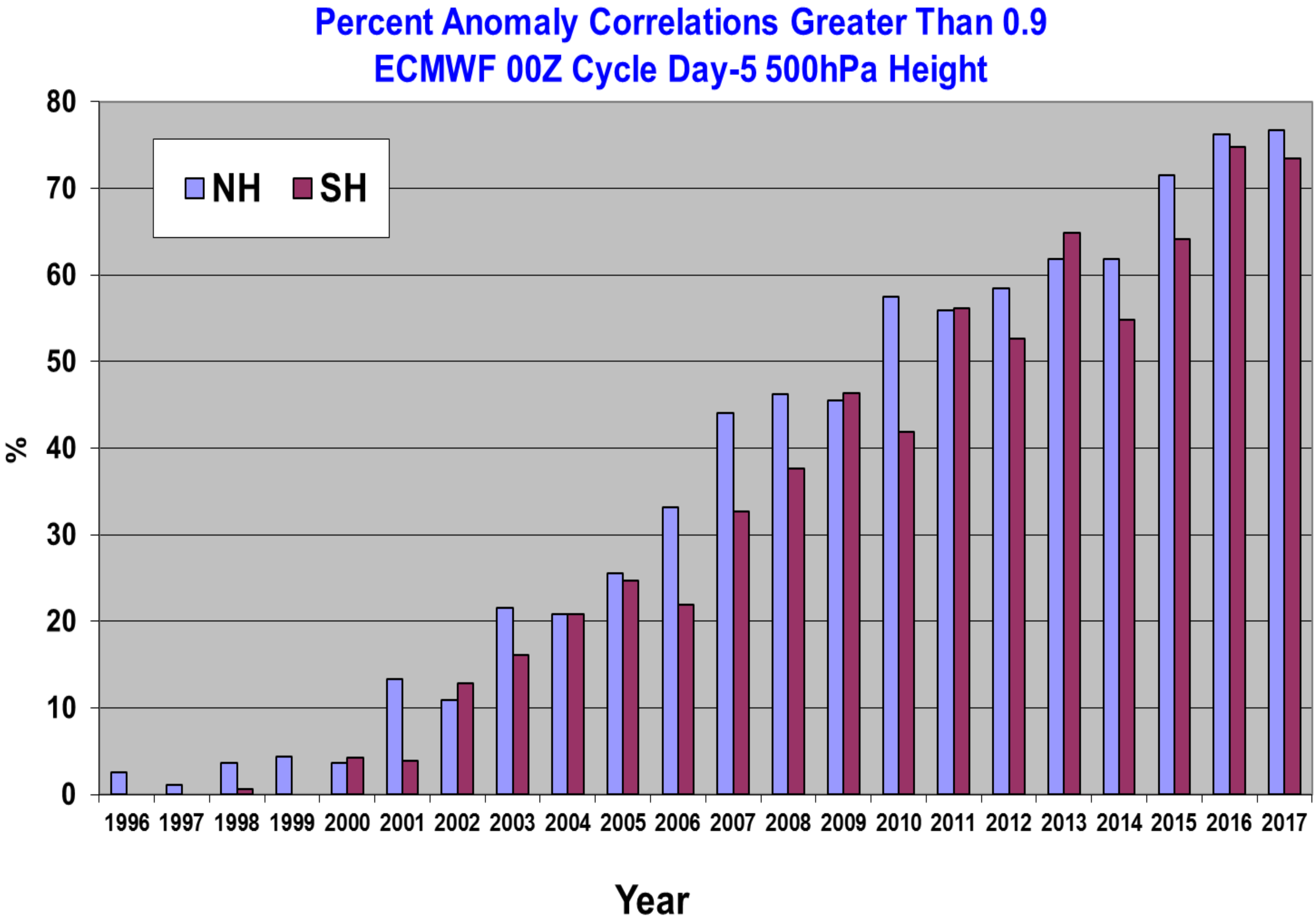
2015
2016
2017
Year



Percent Anomaly Correlations Greater Than 0.9
ECMWF 00Z Cycle Day-5 500hPa Height
NH
SH
%
0
10
20
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70
80
1996
1997
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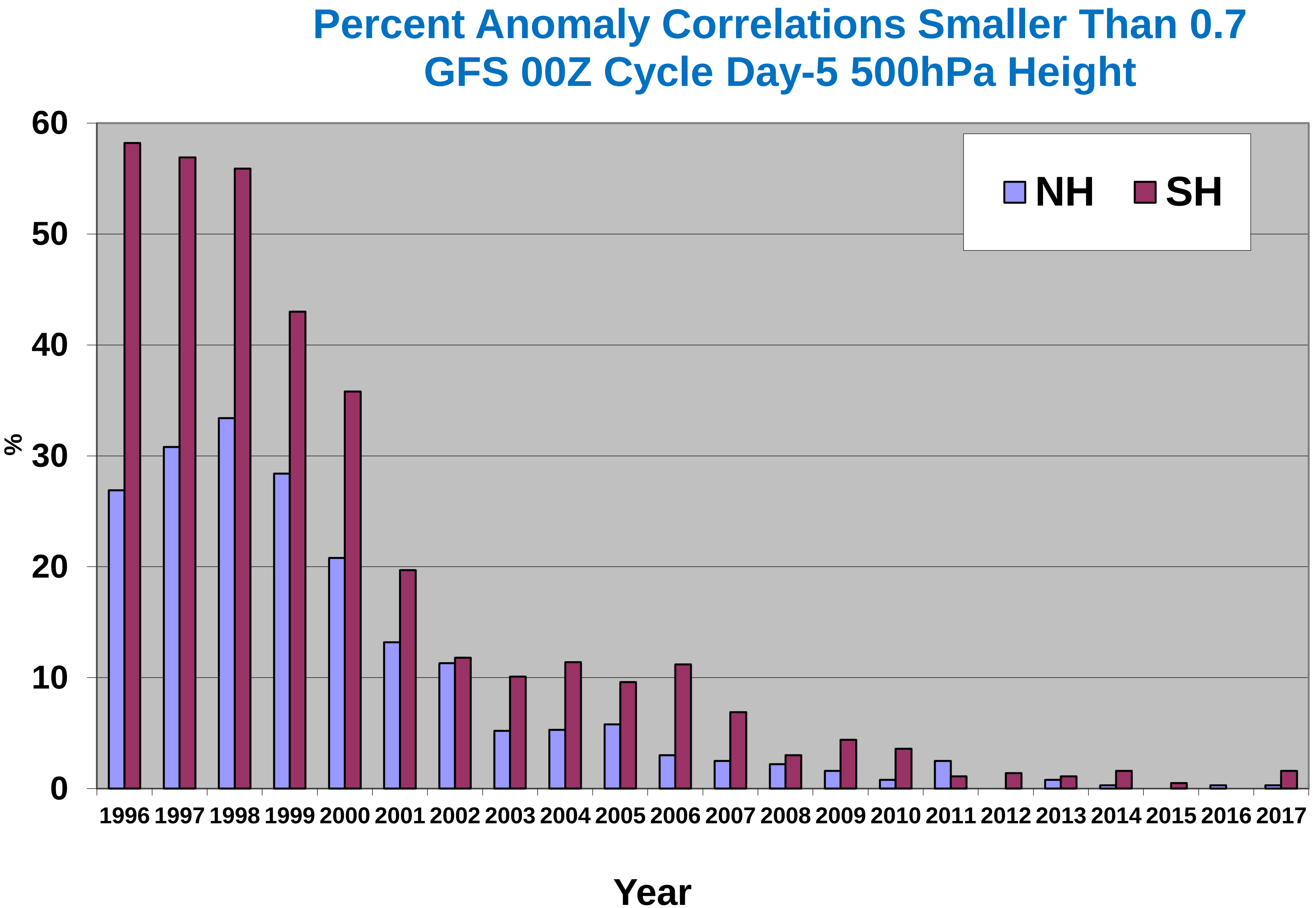
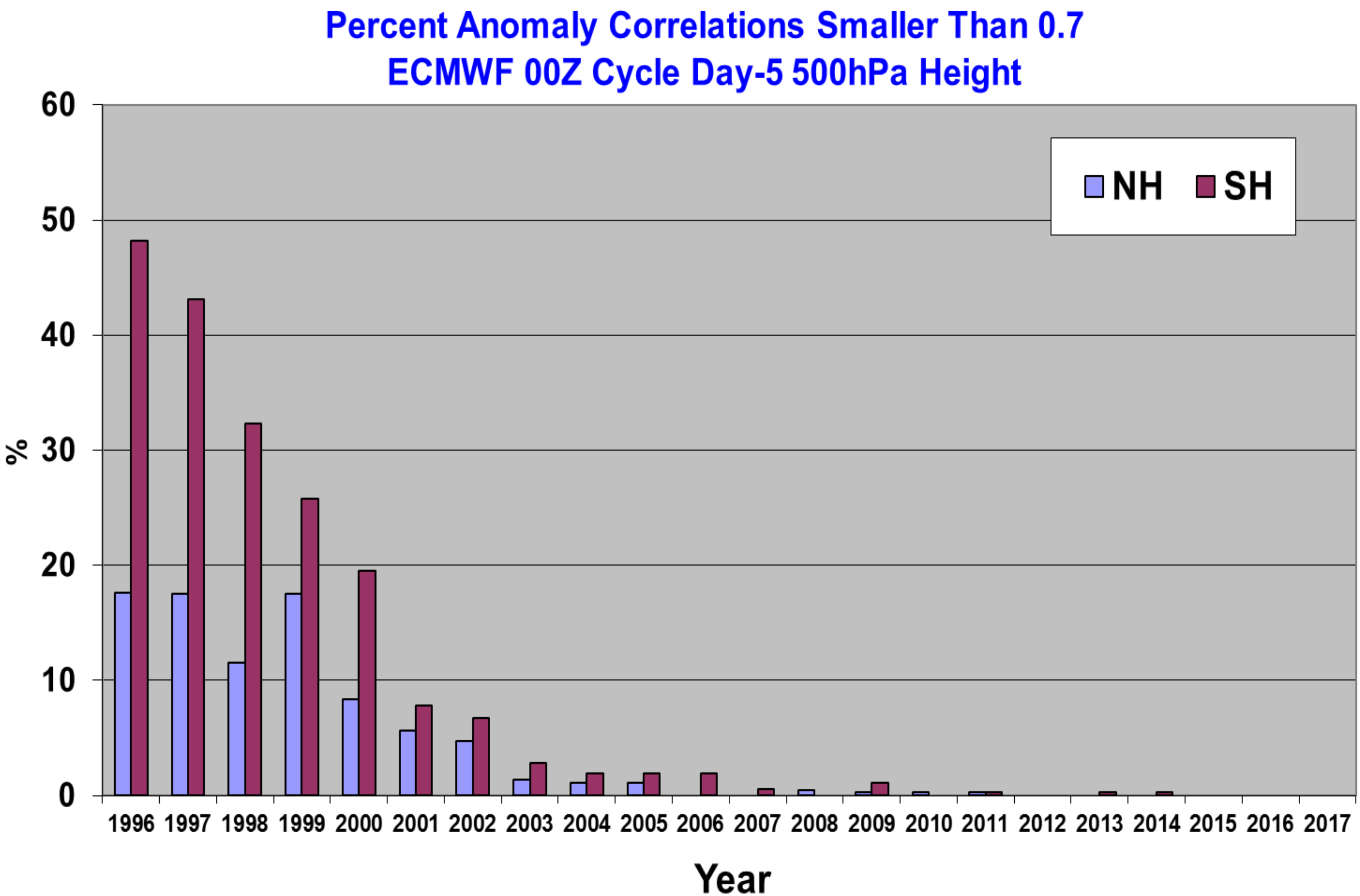


Percent Anomaly Correlations Smaller Than 0.7
GFS 00Z Cycle Day-5 500hPa Height
NH
SH
%
0
10
20
30
40
50
60
1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017
Year



Percent Anomaly Correlations Smaller Than 0.7
ECMWF 00Z Cycle Day-5 500hPa Height
NH
SH
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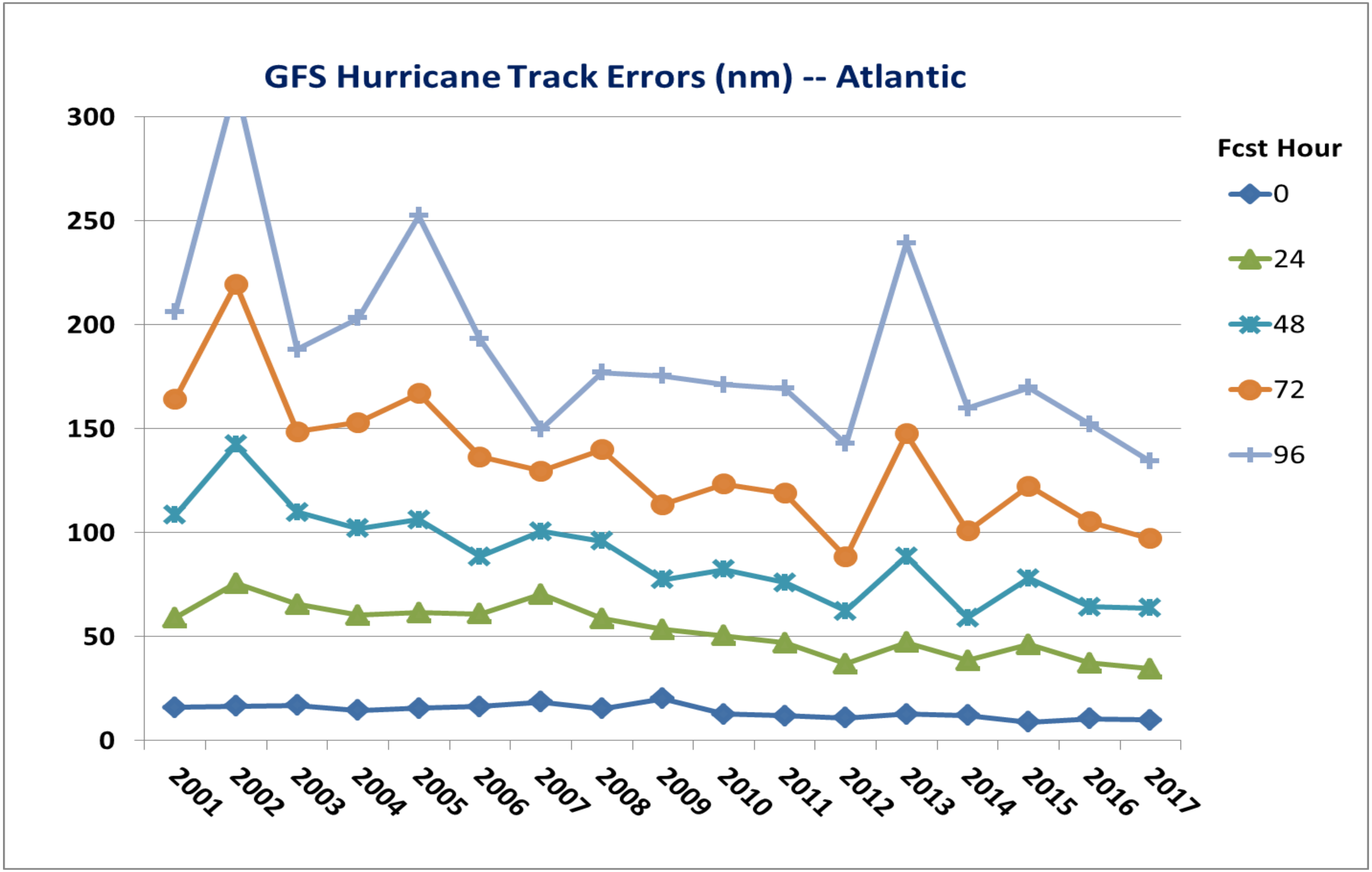
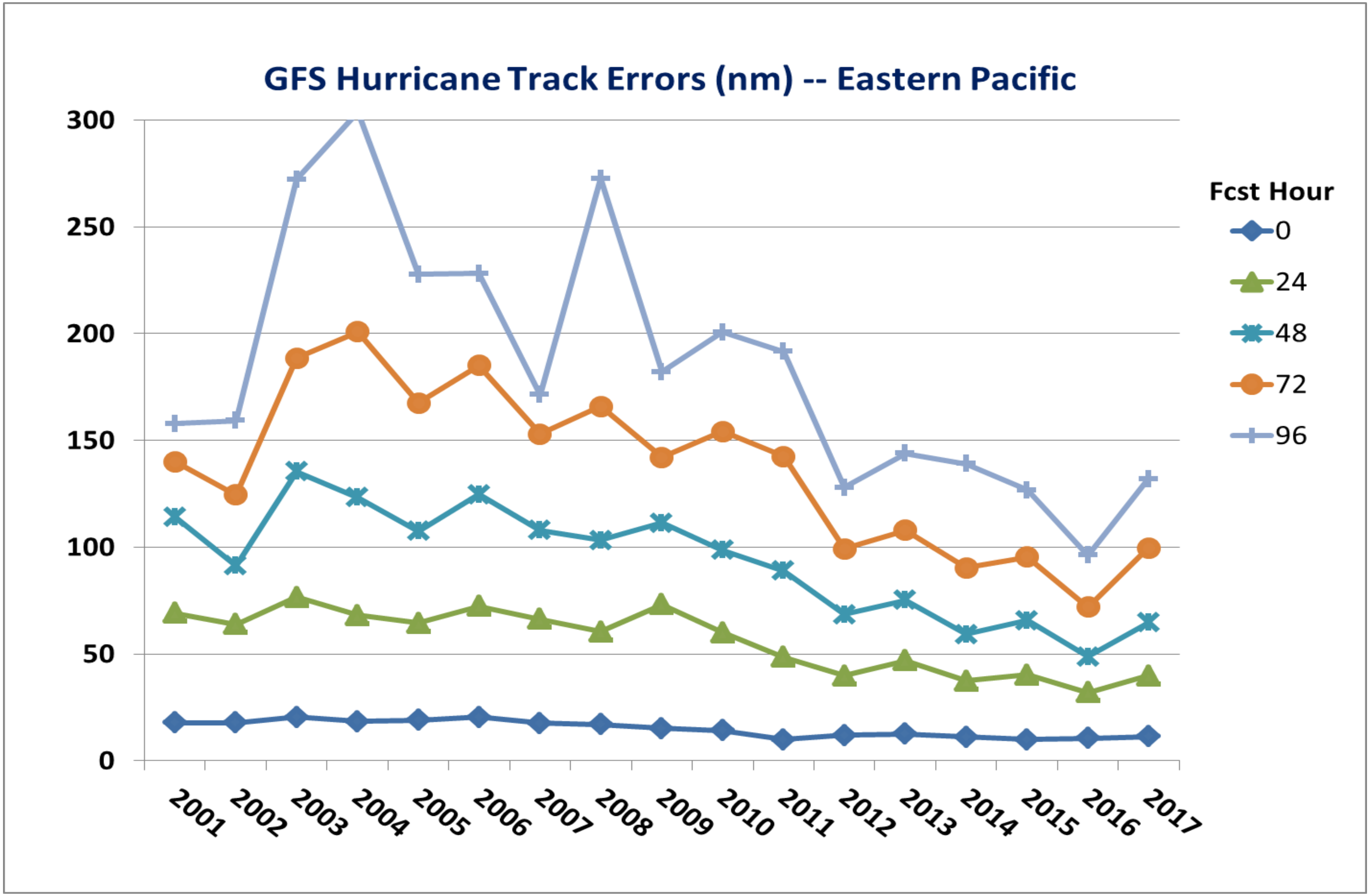
2017
Year

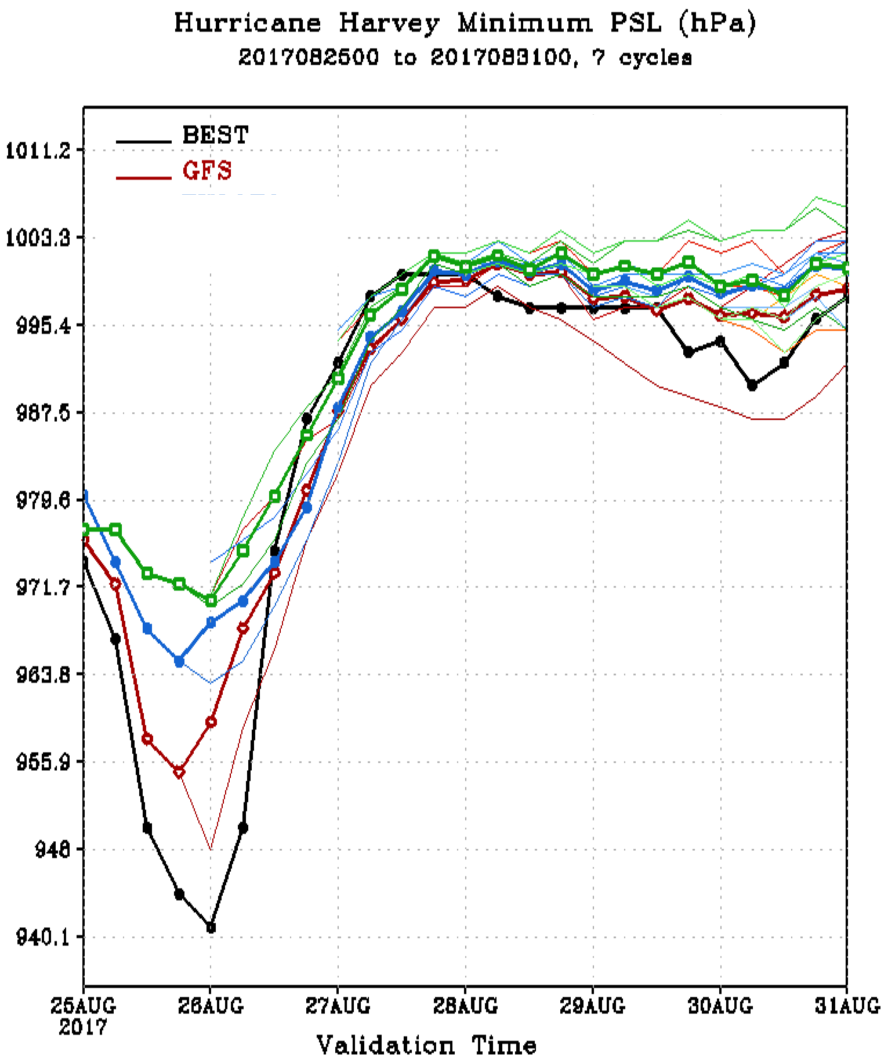
Hurricane Track

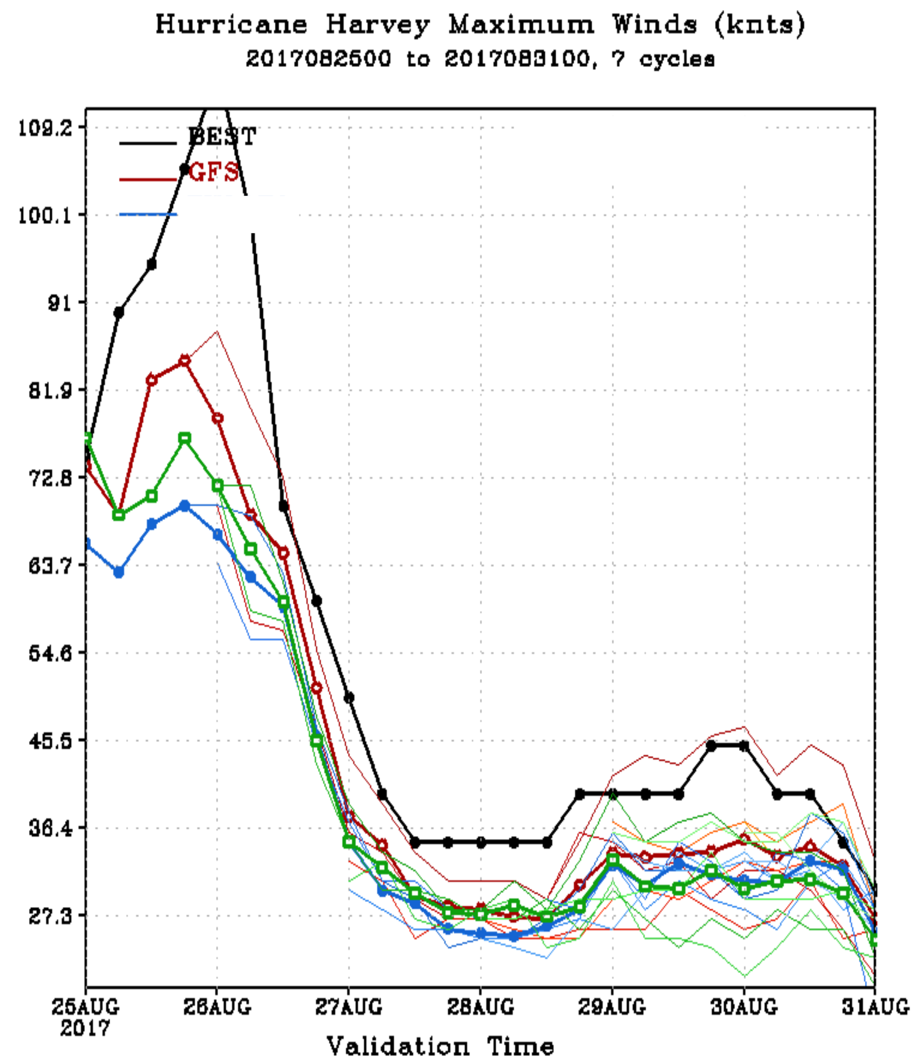


Hurricane Track



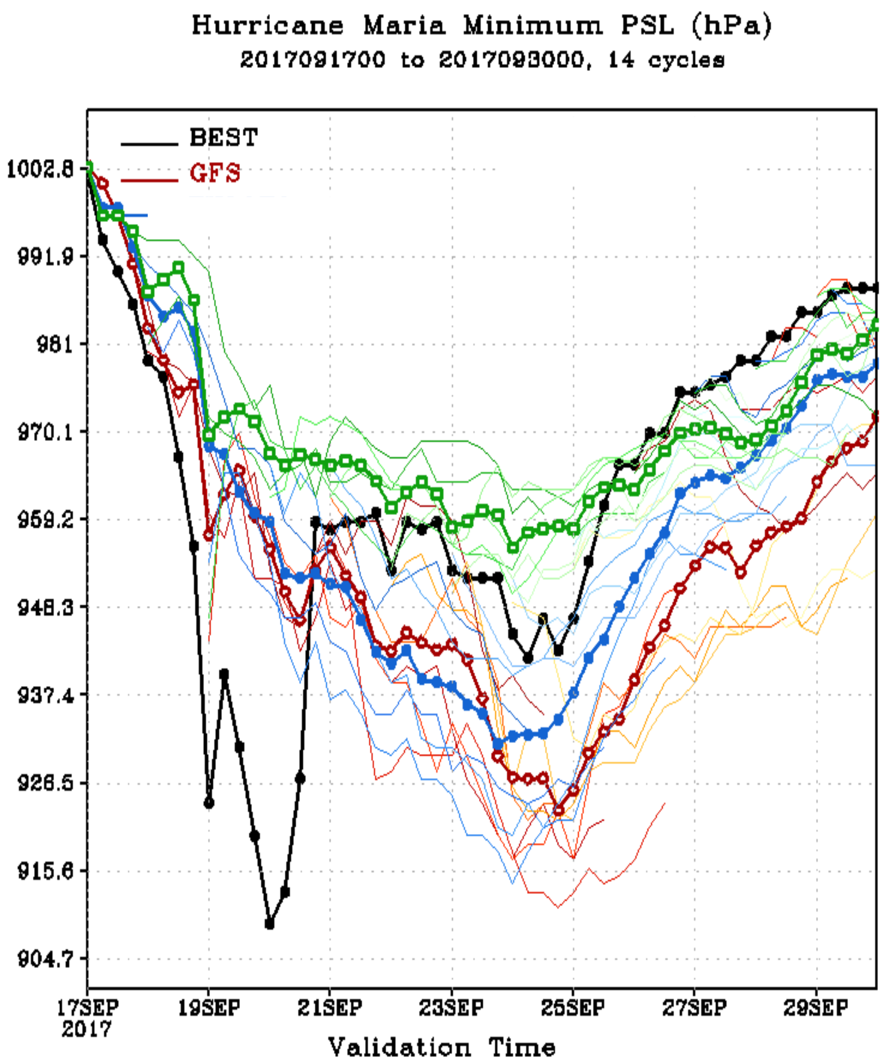
Hurricane Harvey

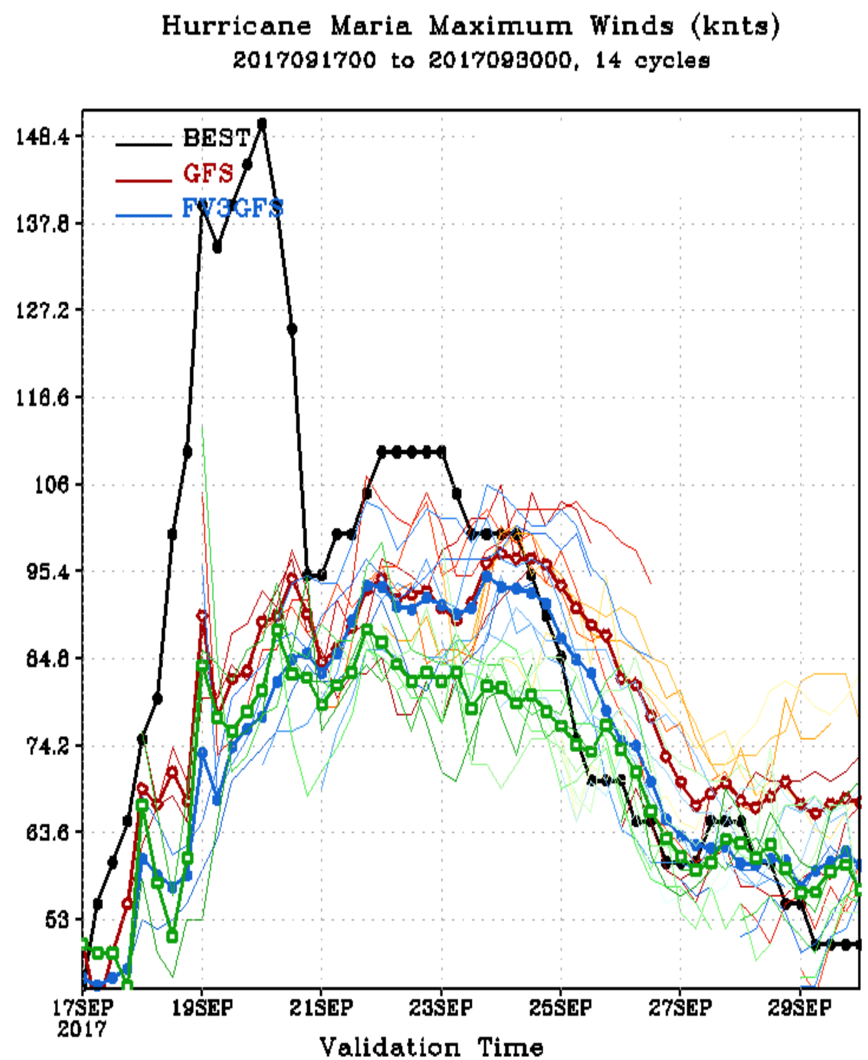




GFS failed to capture the rapid intensification and strong winds

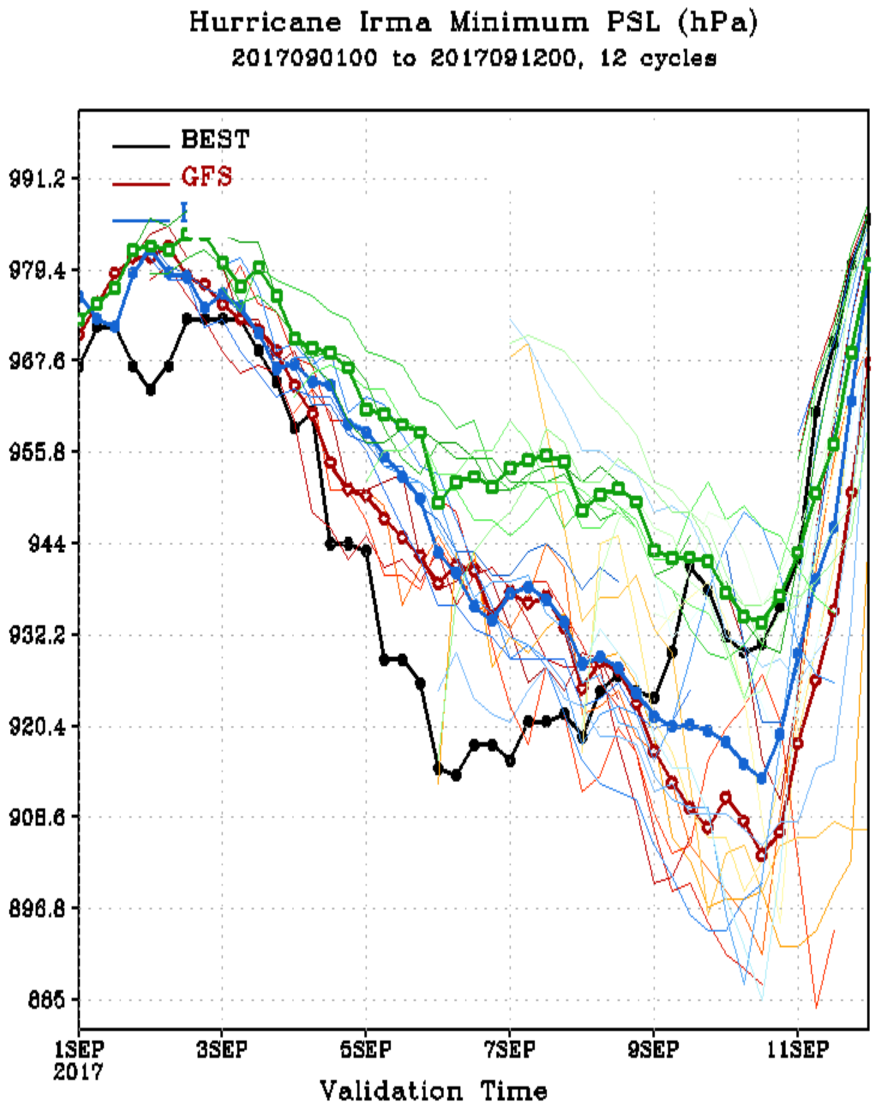
Hurricane Maria

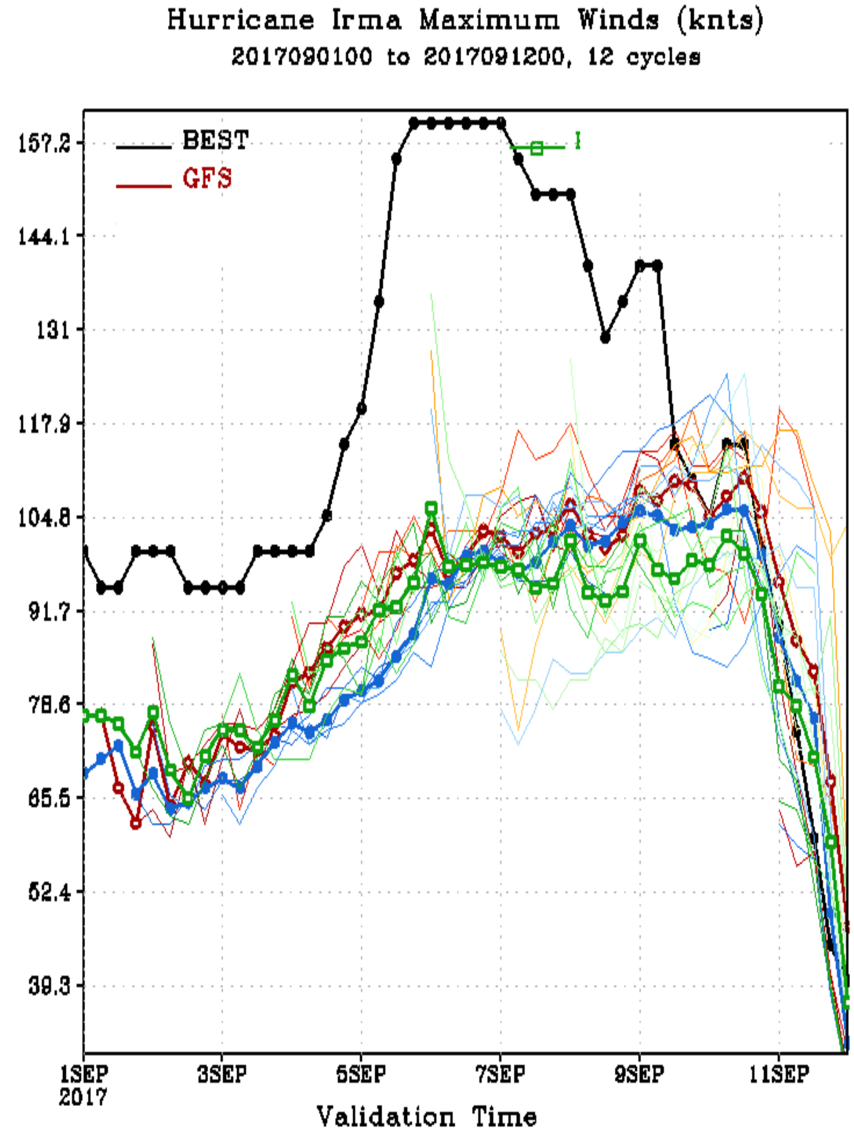




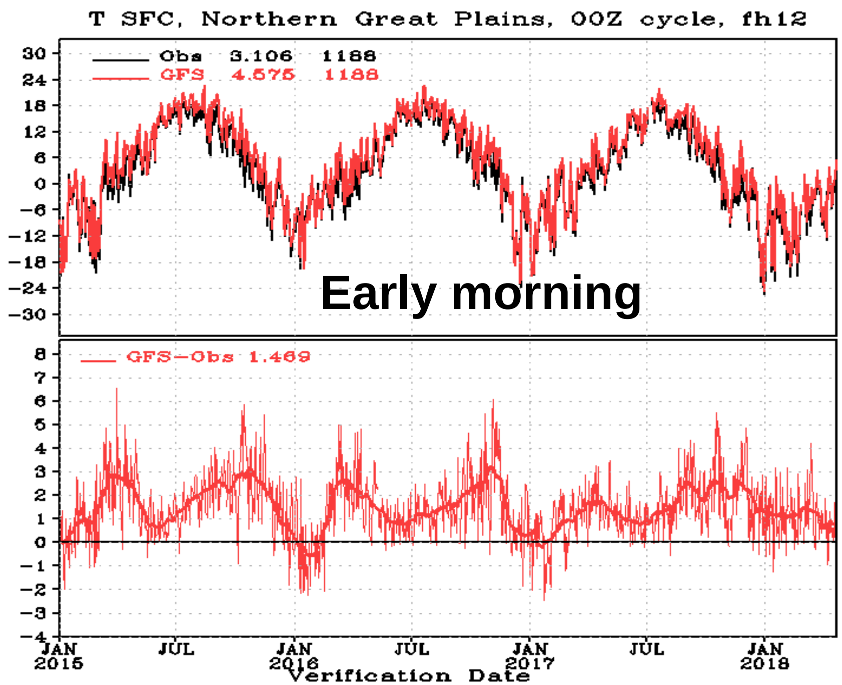
GFS failed to capture the rapid intensification and strong winds

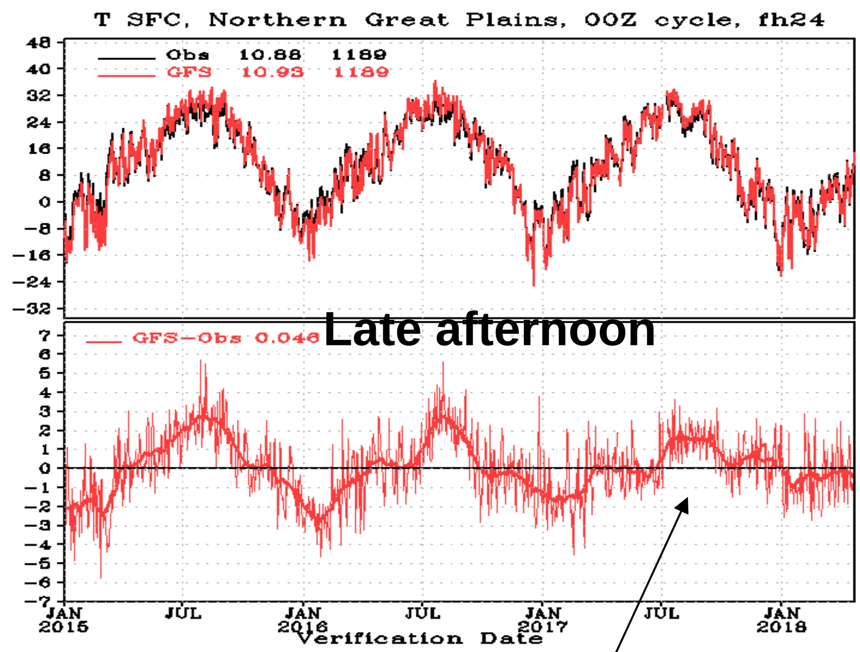
Hurricane Irma





T2m verified against station observations
Northern Great Plain Jan2015 ~ Apr2018



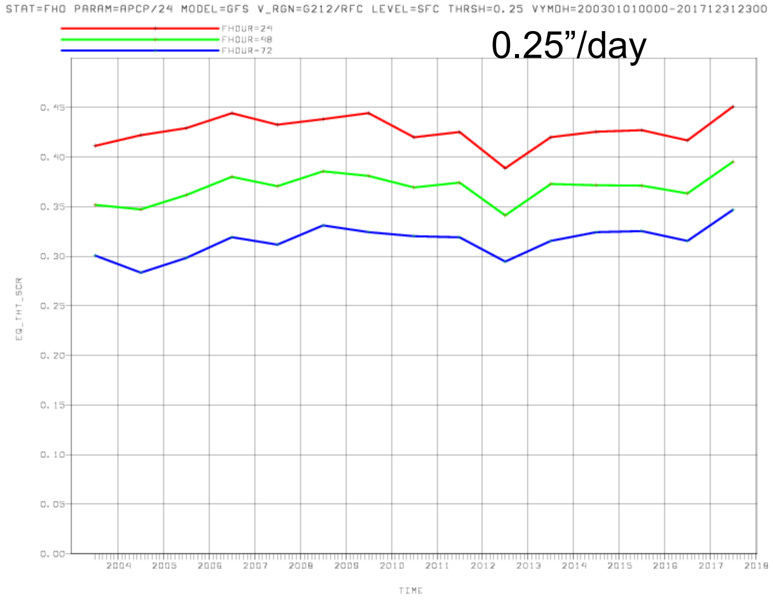


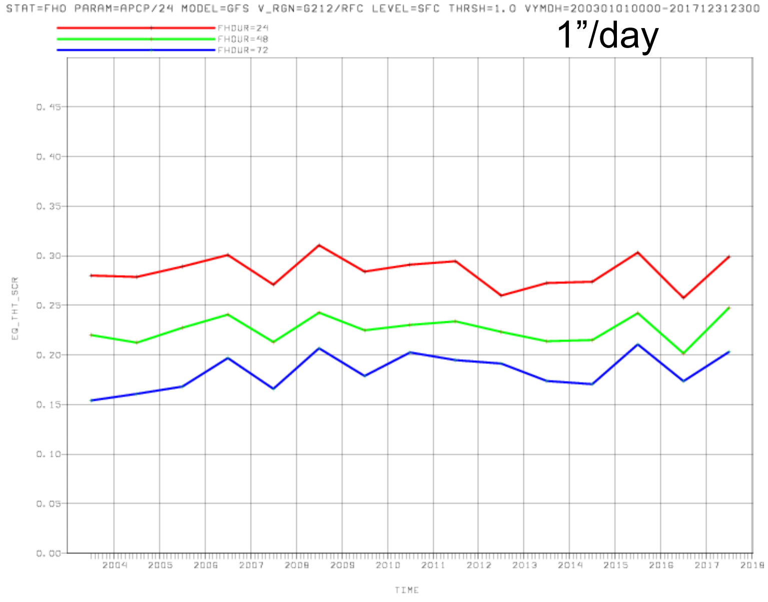
Warm bias exists in all seasons; slightly reduced in 2017 in comparison with 2015 and 2016.

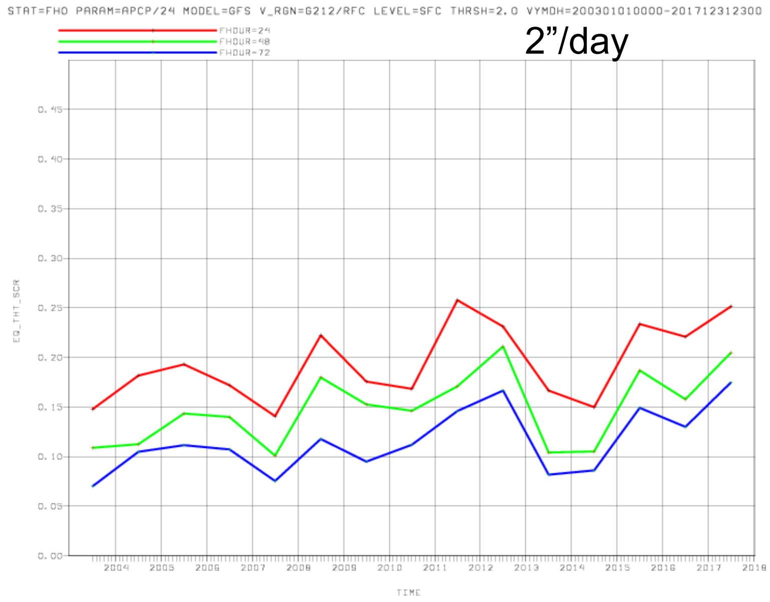
Both summer warm bias and winter cold bias has been reduced in 2007 and early 2018 compared to previous years

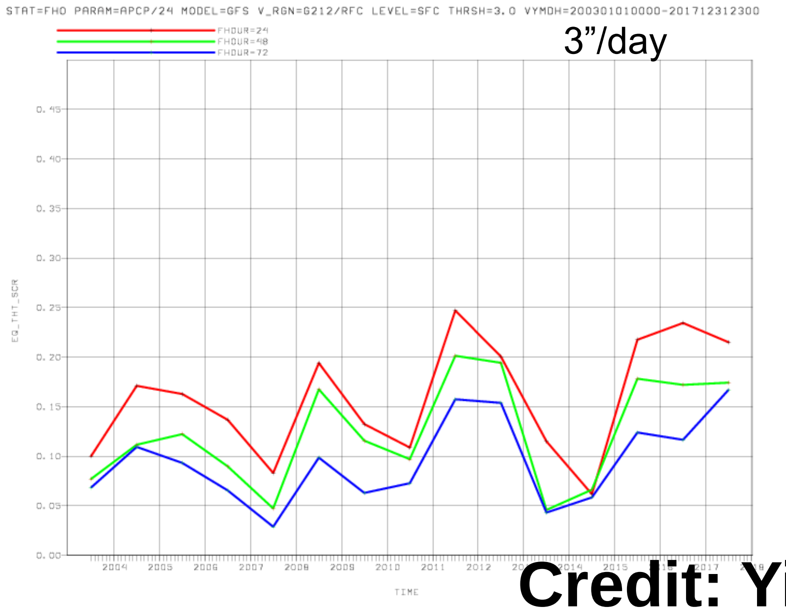
http://www.emc.ncep.noaa.gov/gmb/STATS_vsdb/annual/g2o/g2o_00Z/

GFS 24/48/72h annual ETS, 2003-2017, 40km CONUS





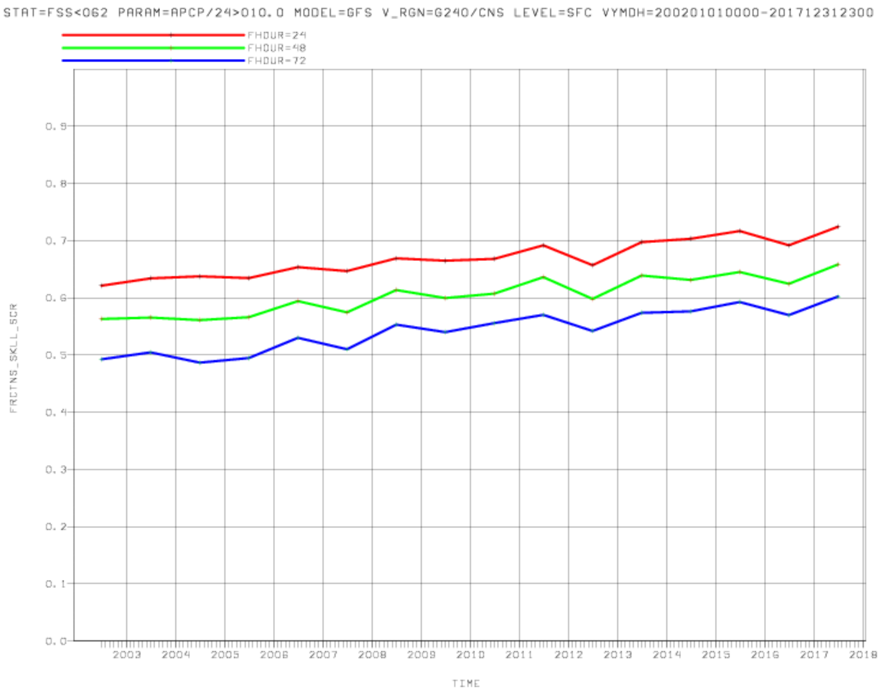




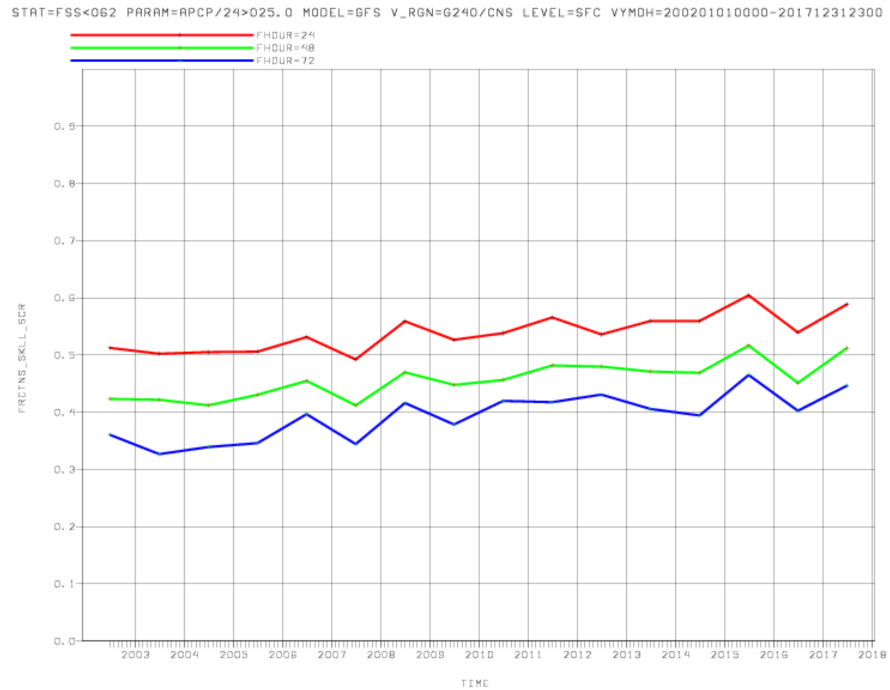
Credit: Ying Lin

GFS 24/48/72h annual FSS, 2003-2017 at 62km spatial scale, CONUS

10mm/day



25mm/day



Credit: Ying Lin

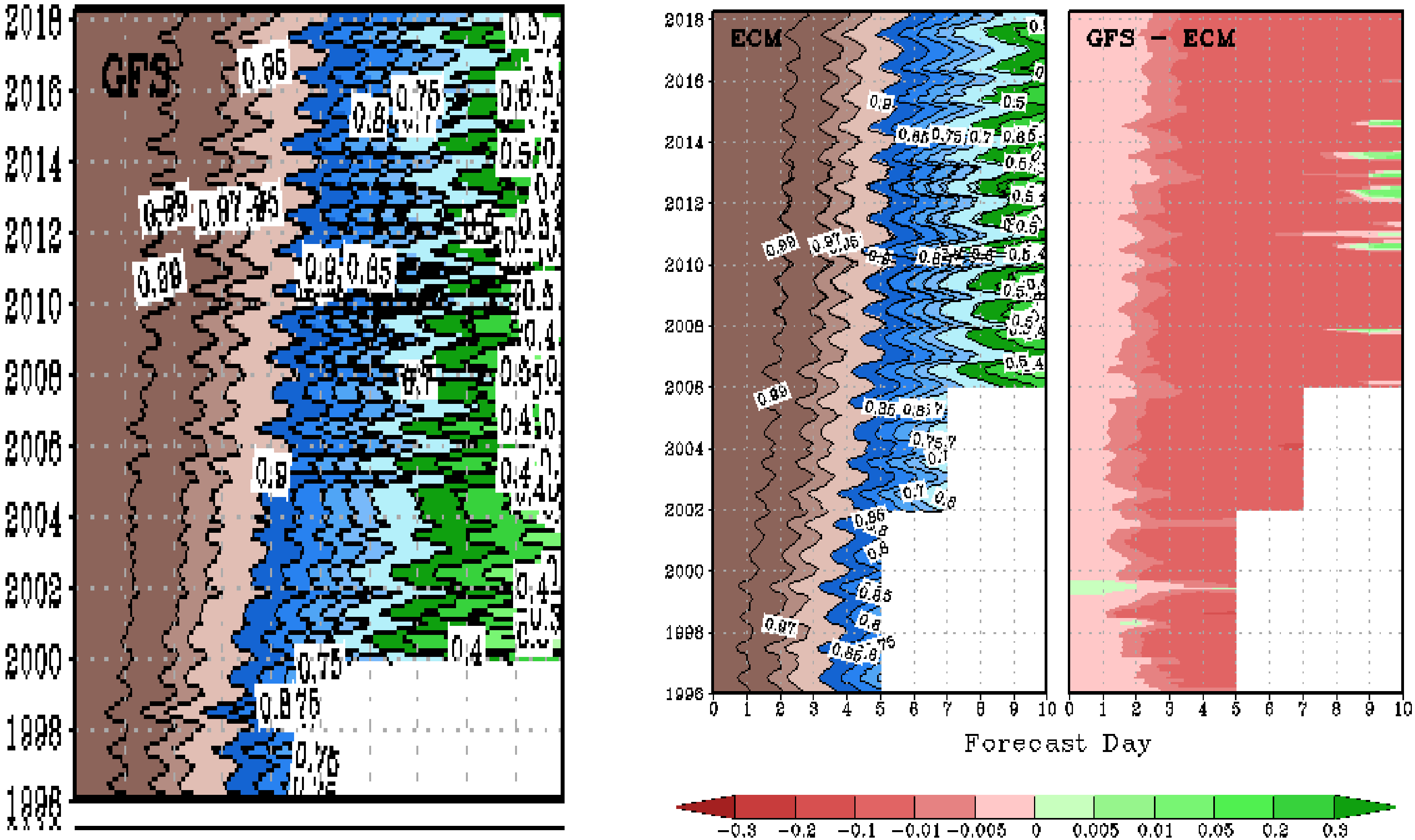
A Controversial Topic

- GFS forecast skill has been improved over the years, but is always behind the ECMWF model.

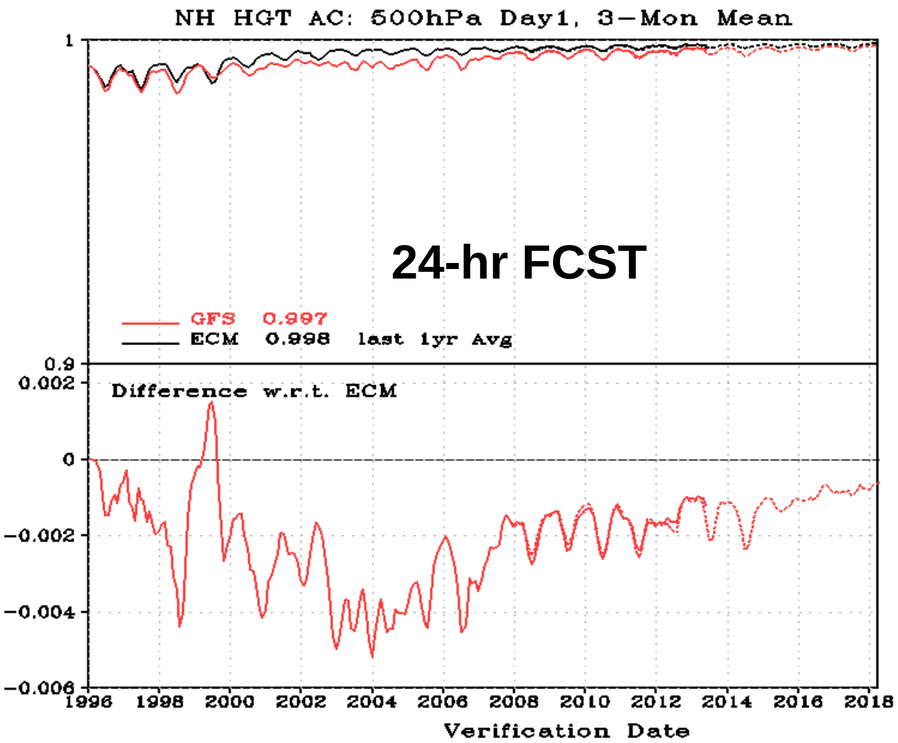
- The goodness of a forecast system is determined by the quality of both the forecast model and data assimilation technique.

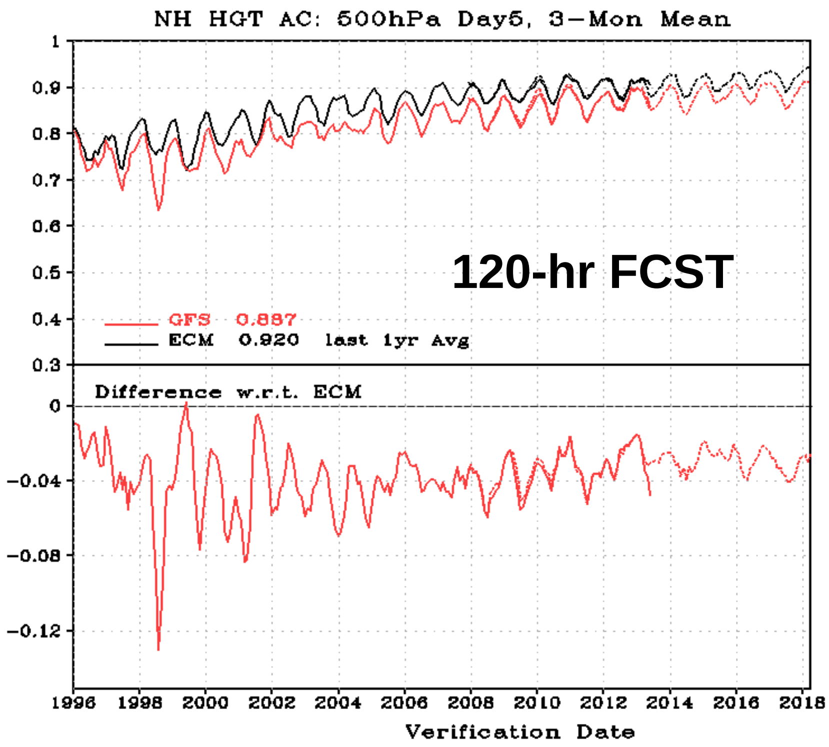
- **For the GFS, which of the two has been better improved over the years?   Or, which needs to be better improved to shorten the gap of forecast skills between GFS and ECMWF ?**

NH 500-hPa HGT ACC



NH 500-hPa HGT ACC



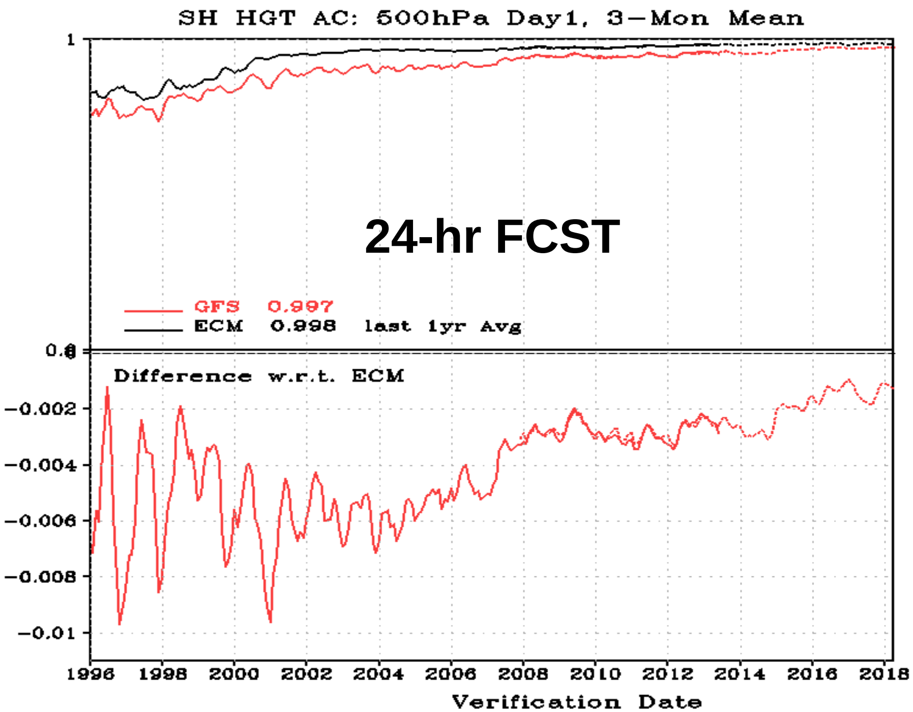


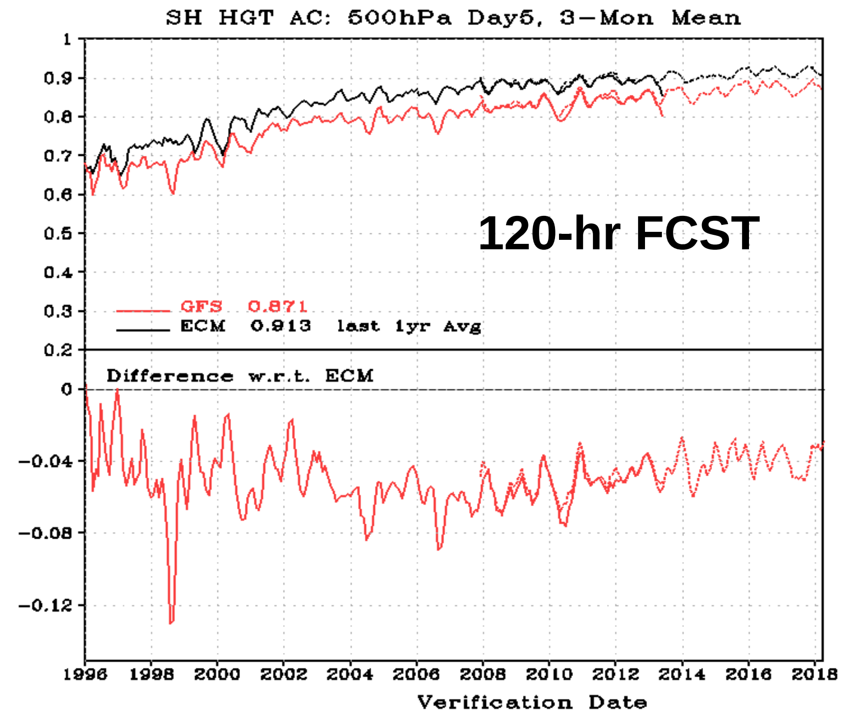
The gap increased from 1996 to 2004, and since has been gradually reduced in the past 15 years

The gap remains unchanged in the past two decades

Is the improvement in DA greater than the improvement in GFS forecast model ?

SH 500-hPa HGT ACC





Is the improvement in DA greater than the improvement in GFS forecast model ?

A BAMS article , still in preparation

The Contribution of NCEP's Global Forecast System to the Revolution in Weather Forecasting

Development Division /Environmental Modeling Center
National Meteorological Center /National Centers for Environmental Prediction
DOC/NOAA/NWS

Sela photo
Oliphant Louis cartoon

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Glenn White is leading the effort of writing this article