The Development and Success of NCEP's Global Forecast System

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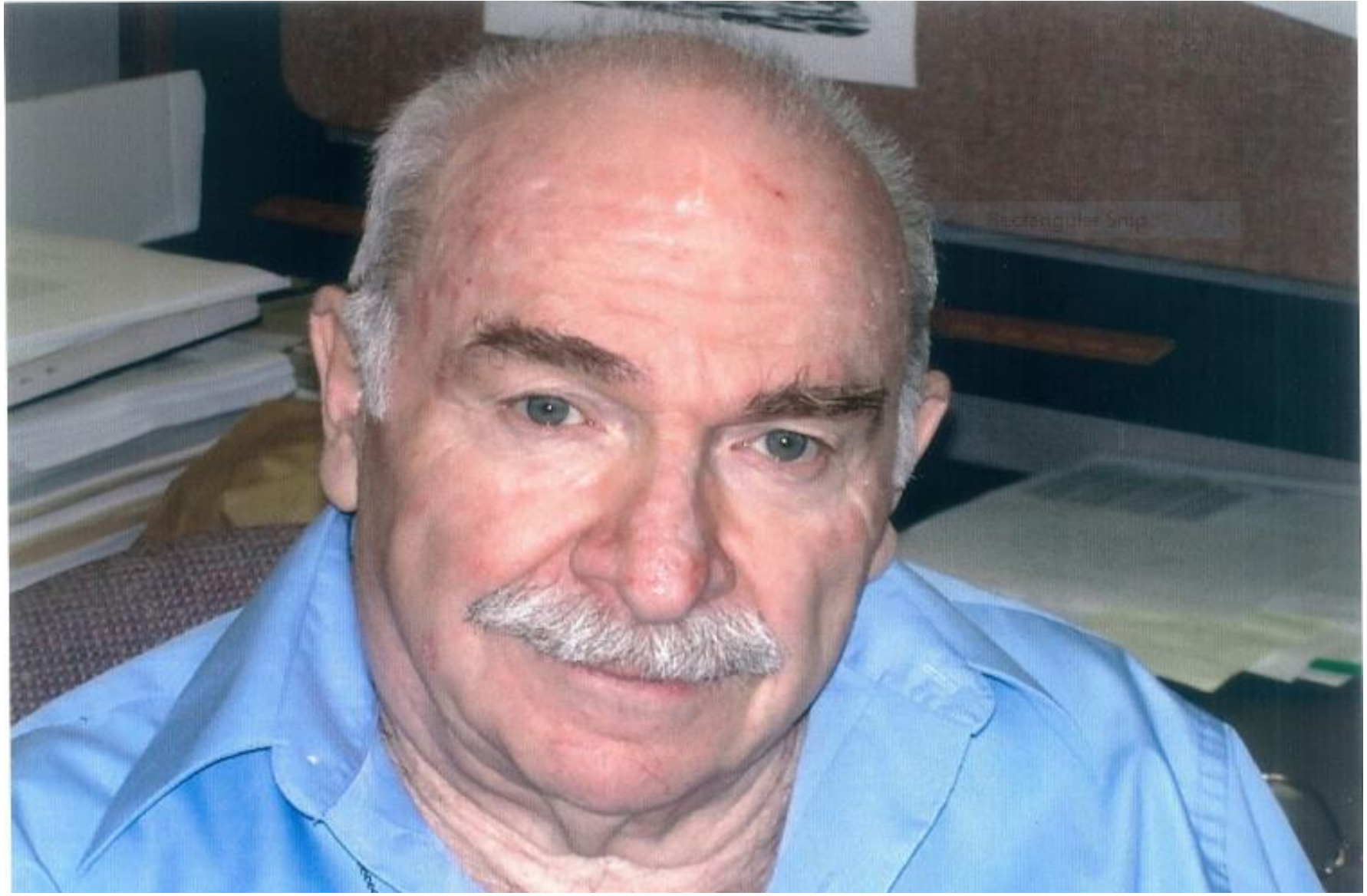
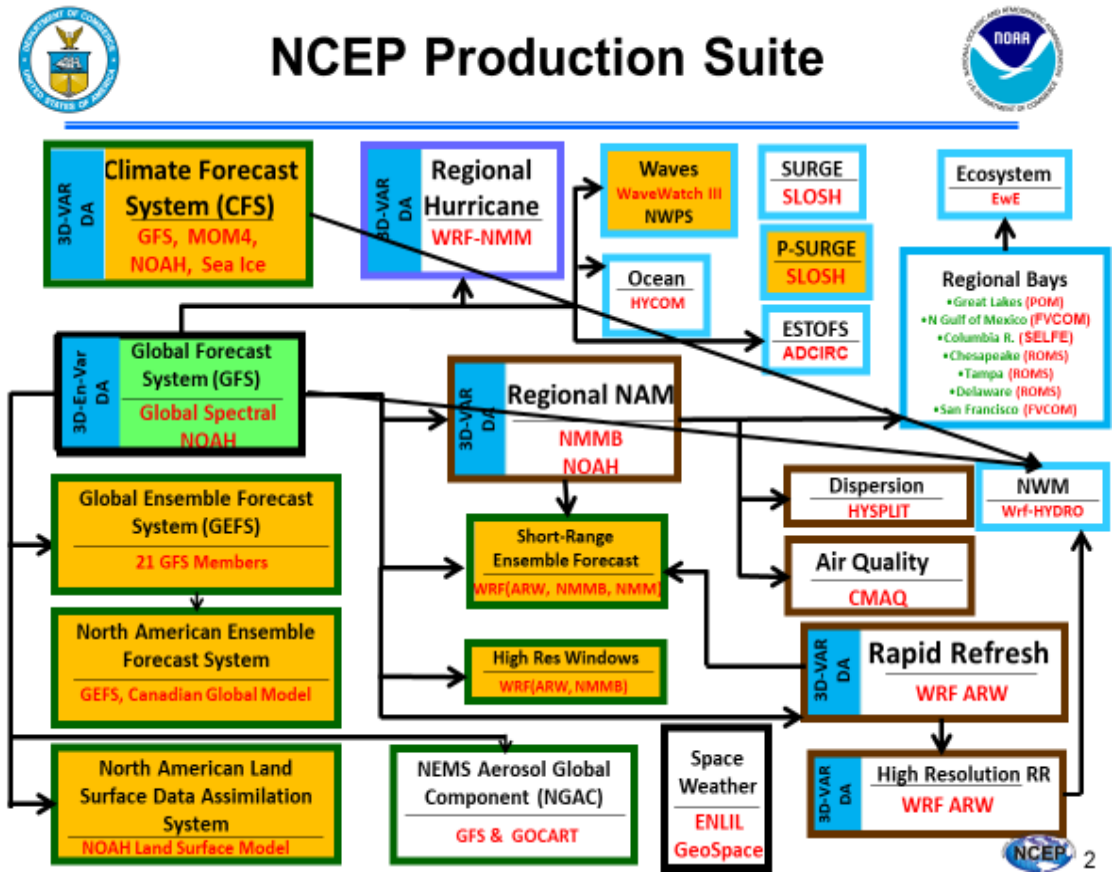
Some of the authors

(top) The Development Division in the early 1990's at the World Weather Building.
(bottom) EMC in the NCWCP Auditorium in 2017. Bottom picture by Michiko Masutani.



Dr. Joseph Sela created the spectral GFS and developed it from 1975 until his death in 2010 as the GFS was accurately forecasting Snowmageddon (Feb 5-6 2010) 6 days in advance.
This paper is dedicated to him.

Over last 70 years numerical weather prediction has become the core element of weather forecasts



The GFS is the center of the NCEP Production Suite.

1952	IBM 701	1 kiloflop
1957	IBM 704	8 kiloflops
1960	IBM 7090	67 kiloflops
1963	IBM 7094	100 kiloflops
1966	CDC 6600	3 megaflops
1971	IBM 360-195	6 megaflops
1972	3 IBM 360-195s	18 megaflops
1981	CDC Cyber 205	400 megaflops
1987	2 CDC Cyber 205s	800 megaflops
1990	Cray Y-MP	2.6 gigaflops
1994	Cray C9016	15.3 gigaflops
1999	IBM SP2	700 gigaflops
2003	IBM SP2 upgrade	2.5 teraflops
2005	IBM P5	7 teraflops
2007	IBM P6	17 teraflops
2012	IBM X86	1.48 petaflops
2015	IBM Cray	4.09 (5.57) petaflops
2018	IBM Dell	2.84 (8.41) petaflops

NMC/NCEP computers

1950—first weather forecasts on computer

Sept. 1954—Sweden first operational NWP forecast-barotropic model

May 6,1955—first operational US NWP forecast-barotropic model

Sept. 18, 1974-NMC's first global system

- *Hough analysis*
- *2.5º, 9-layer sigma coordinate primitive equation model*
- *Initially to provide initial conditions for expanded Northern Hemisphere model and to use satellite profiles*
- *Later 5 and 10 day forecasts*

Sept. 22, 1978—optimal interpolation analysis to handle heterogeneous FGGE data base

May 27, 1980—Spectral, R(rhomboidal truncation)30 waves (375 km)
12 layers, limited physics—global data assimilation system

Aug. 1980—Spectral aviation, medium-range global forecasts

Spectral more computationally efficient

April 17, 1985—R40, 18 layers, GFDL E-2 physics,
enhanced silhouette mountains

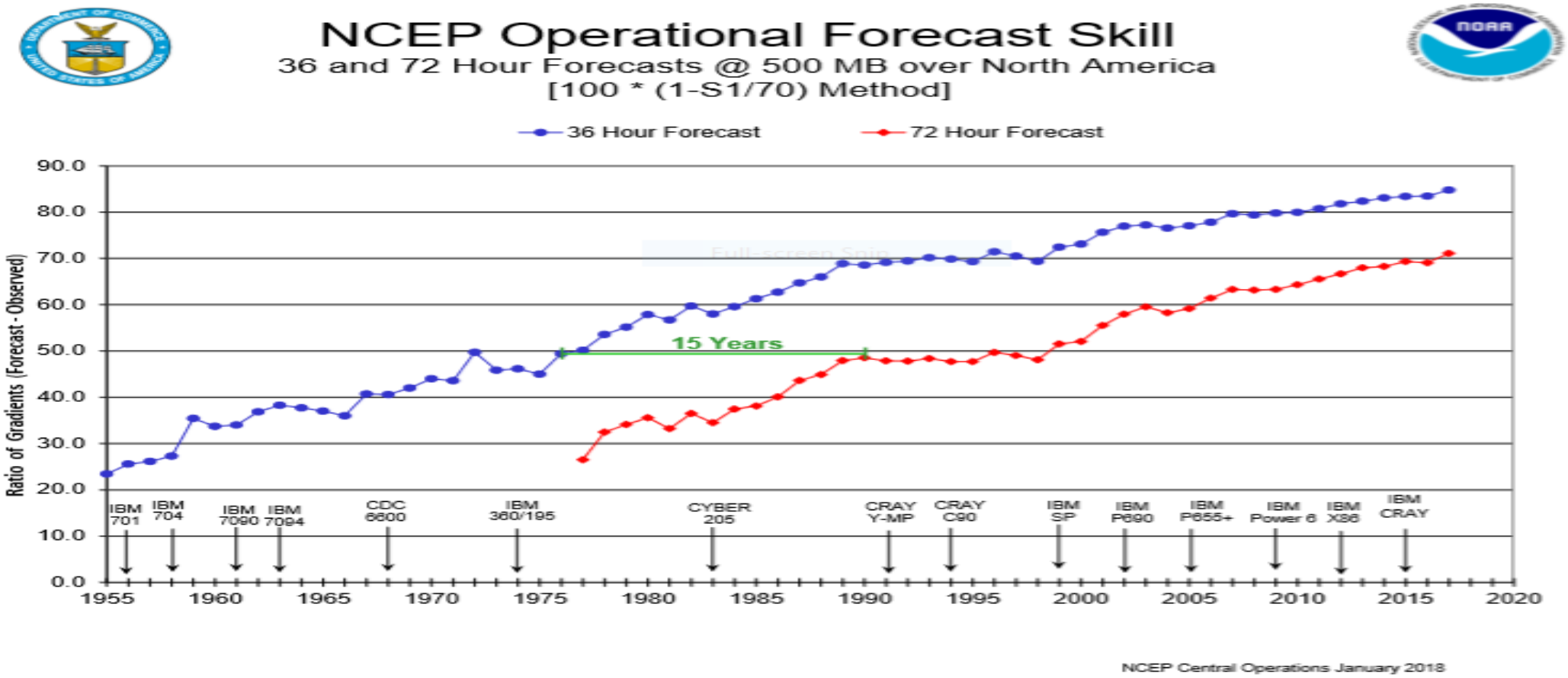
Extended useful forecasts (.6 anomaly correlation for 500 NH height)
from 4 days in winter to 5 days in winter

Now useful forecasts extend to 9 days in winter

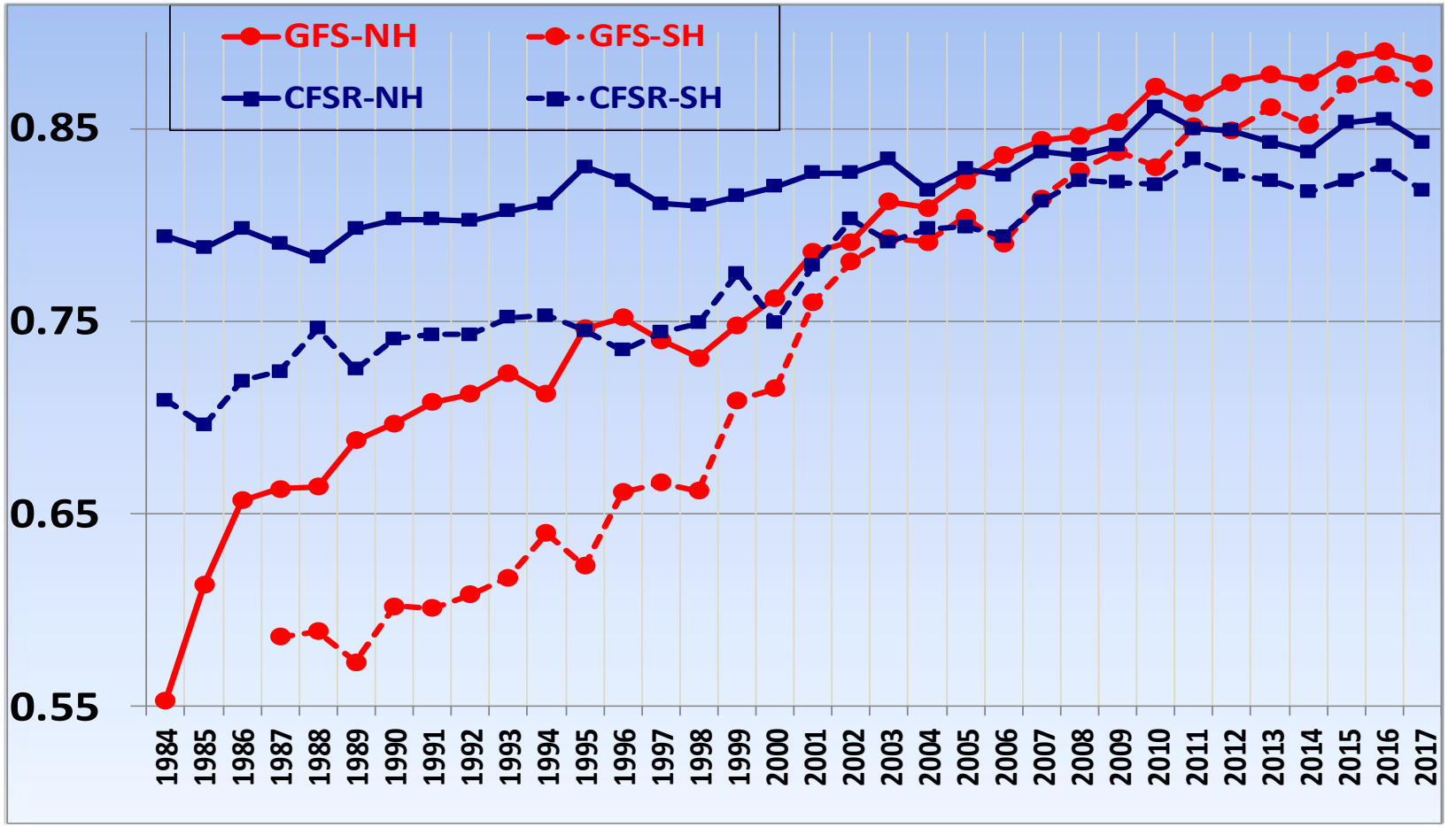
	Levels	Truncation		
Aug. 1980	12	R30(375 km)	Sigma Eulerian	First global spectral model
Oct. 1983		R40 (300 km)		
Apr. 1985	18			GFDL Physics, silhouette mts
Aug. 1987		T80 (150 km)		Diurnal cycle
Mar. 1991		T126 (105 km)		Mean mts, Spectral Statistical Interpolation analysis (SSI) (June 1991)
Aug. 1993	28			Simplified Arakawa-Schubert(SAS) convection
Jun 1998	42	T170 (80 km)		Prognostic ozone, NASA shortwave
Oct. 1998	28	T126 (105 km)		
Jan. 2000	42	T170 (80 km)		
Oct. 2002	64	T254 (55 km)		RRTM long wave
May 2005		T382 (35 km)		NOAH land surface model

	Levels	Truncation		
May 2007			Hybrid Eulerian	Gridpoint Statistical Interpolation (GSI) data assimilation
Jul. 2010		T574 (23 km)		RRTM shortwave; new shallow convection
Jun. 2015		T1534 (13 km)	Hybrid Semi-Lagrangian	Hybrid EDMF; McICA
May 2016				4-D Hybrid En-Var data assimilation
Jun. 2017				NEMS Global spectral model; improved physics
Jan. 2019		FV3 (13km)	Finite-Volume	NGGPS FV3 dynamic core

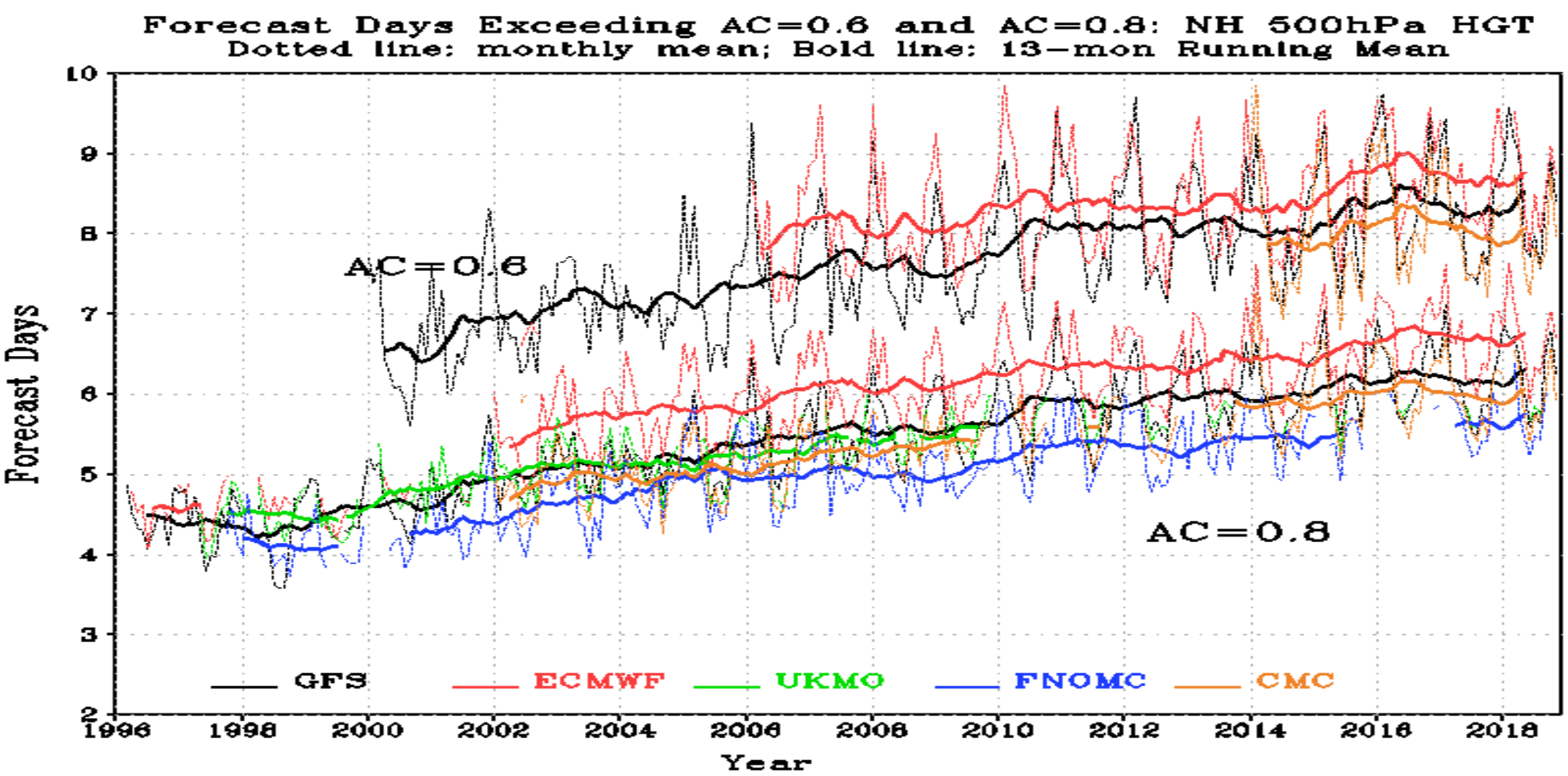
- *Changes often developed with outside collaborators, often in response to GFS problems discovered by users*
- *Major changes tested over years of forecasts in parallel tests alongside operational system*
- *Evaluated statistically against analyses and against observations*
- *Evaluated synoptically with input from operational forecasters*
- *Interaction with operational forecasters and users greatly expanded in recent years: Model Evaluation Group*
- *Open evaluation process*
- *Testing often revealed problems in new system, often quickly addressed by EMC*



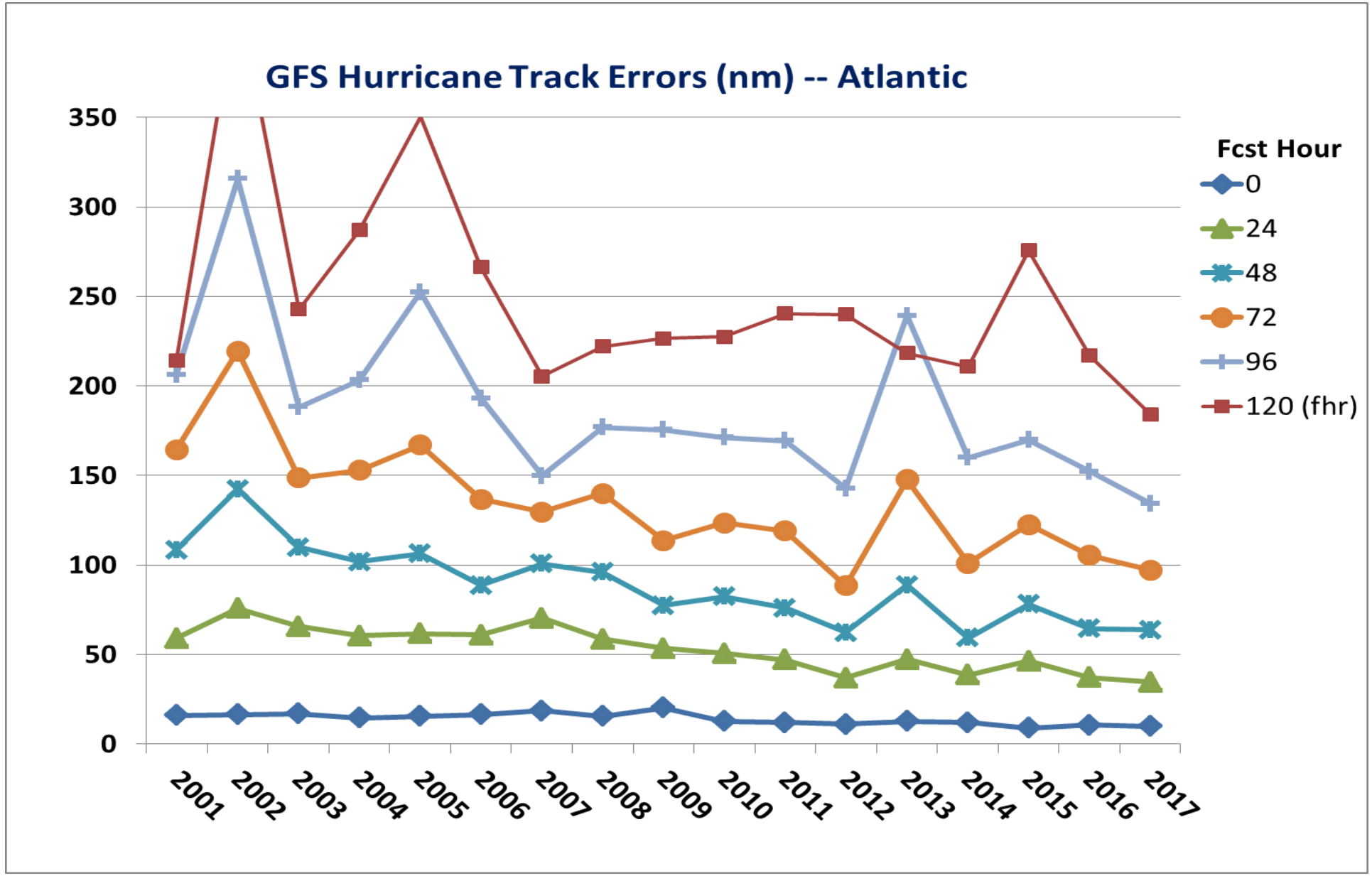
Annual mean S1 skill score (Twerles and Wobus, 1954; Hirano, 1992) from 1955-2017, measuring the relative error in the pressure gradient of 500 hPa height over North America. The skill of GFS forecasts is shown since 1980; the skill of manual and earlier models' forecasts is shown before. An S1 score of 0 was considered useless; a score of 71 was deemed equivalent to the difference in hand analyses over North America drawn by different skilled synoptic meteorologists and considered a perfect forecast.



Annual mean 500 hPa height anomaly correlations for 5 day forecasts in the NH and SH by the operational GFS and by the CFSR, a frozen version of the operational GFS of 2010 (Saha *et al*., 2010). The CFSR shows the effects of improvement in observations; the GFS shows the effect of all improvements to the GFS since 1984.



The 13-month running mean length of forecast in days it takes for 500 hPa height forecasts anomaly correlations to reach .8 (the limit of good forecasts) and .6 (the limit of useful forecasts) for global forecasts by the GFS, ECMWF, United Kingdom Meteorological Office (UKMO), CMC and the U. S. Navy's Fleet Numerical Meteorology and Oceanography Center (FNOMC)'s global deterministic forecasts for NH. Thinner lines represent monthly mean values through Nov. 2018. UKMO forecasts extend only to 6 days; currently they are somewhat better than the GFS out to 6 days.


GFS Hurricane Track Errors (nm) -- Atlantic
350
300
250
200
150
100
50
0
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
Fcst Hour
0
24
48
72
96
120 (fhr)

- *Cliff Mass: Numerical weather prediction one of modern wonders of the world, truly international endeavor*
- *GFS spectacular steady progress over the decades*
  - *But still not as good as it could be*
- *GFS software, output freely available, used around the world*
  - *Complaints from Russia, Argentina about problems in 2 meter temperatures*
  - *GFS fields initialize, provide boundary conditions for regional forecast systems in Israel, South America, elsewhere*

GFS system also used for

- *Reanalyses*
- *Seasonal forecast systems*
- *Global ensemble*

- *Spectral dynamic core to be replaced by GFDL's finite volume FV3*
  - *Tested thoroughly, approved, results of evaluation can be seen at*

https://www.emc.ncep.noaa.gov/users/Alicia.Bentley/fv3gfs/

Detailed history of the GFS can be obtained from qw15911@gmail.com