Roadmap of Deterministic to Probabilistic

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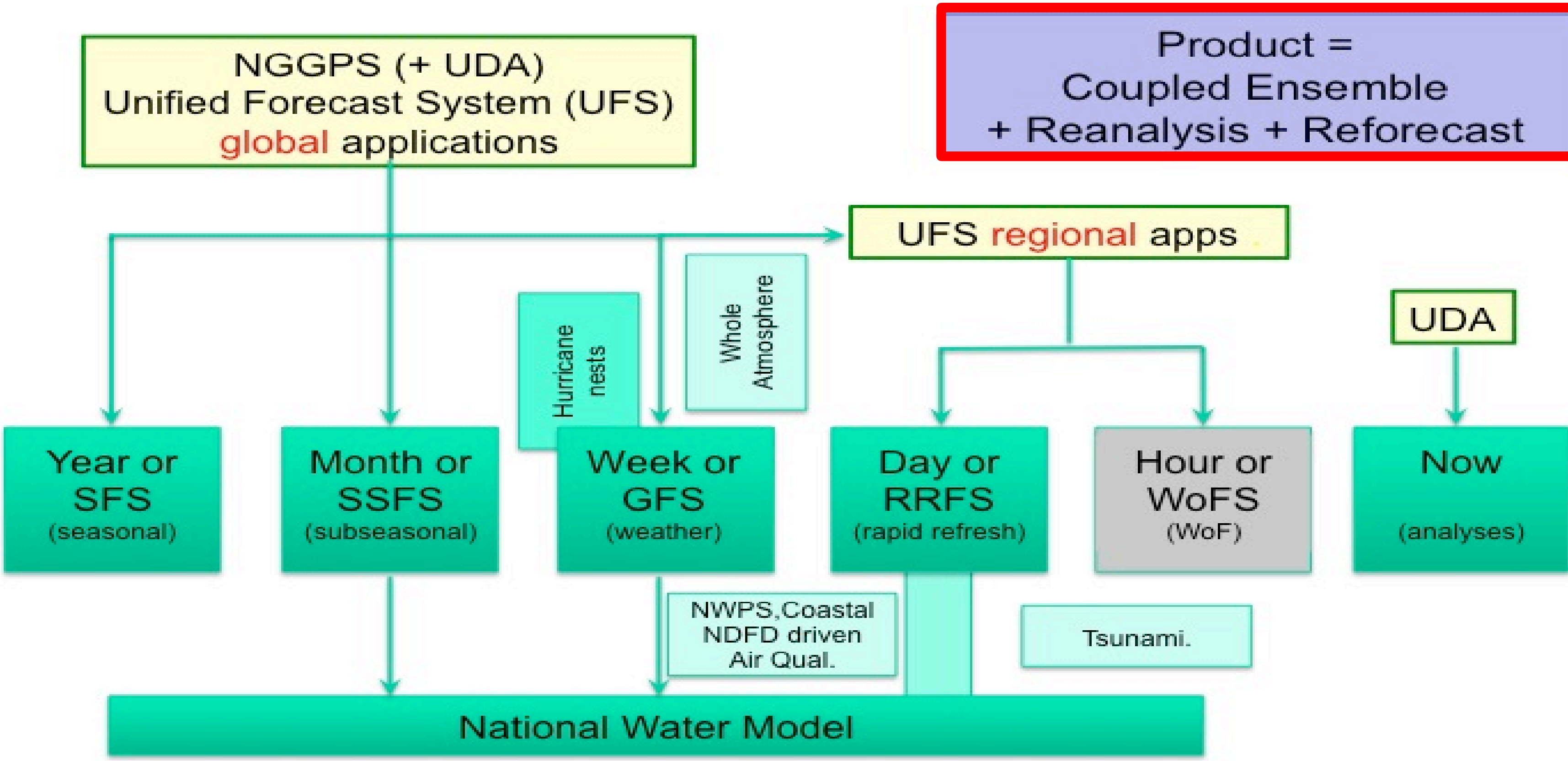
Background

- **Ensembles are designed to simulate the sources of forecast errors linked to initial condition and model uncertainties**
- **Initial condition uncertainties: Singular Vectors, Breeding Vectors, ensemble data assimilation**
- **Model uncertainties: stochastic schemes, perturbed parameters, multi-model ensemble**
- **Reforecasts are used to estimate the ensemble characteristics (reliability and accuracy, and model biases)**

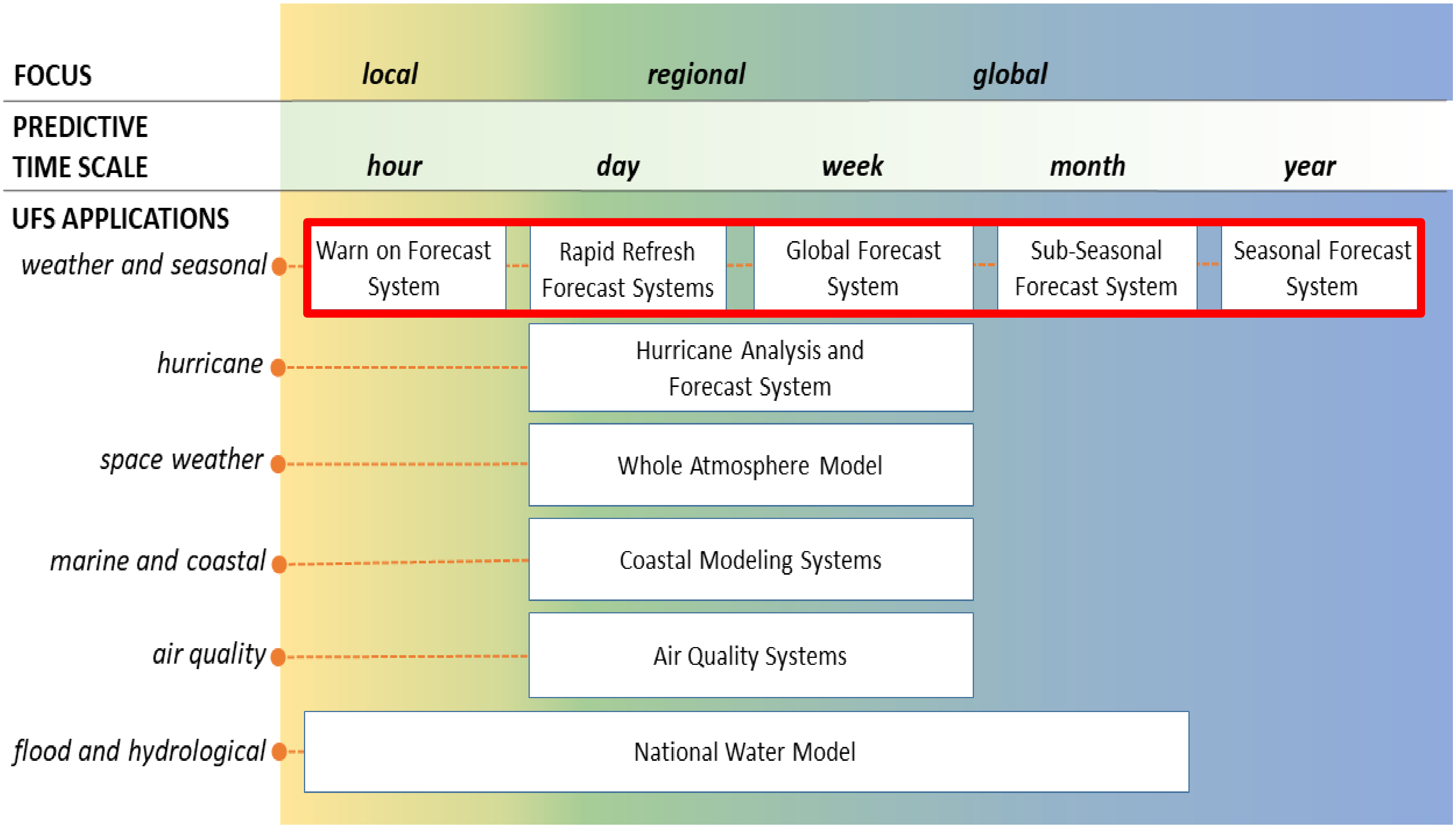
Unified Forecast System



UDA: Unified Data assimilation
SFS: Seasonal Forecast System
SSFS: Subseasonal Forecast System

GFS: Weather Forecast System
RRFS: Rapid Refresh Forecast System
WoFS; Warn on Forecast System

Scope of Unified Forecast System



Roadmap: 5 Year "End State"

Element	Cadence	Range	Resol.	Ens.	Update	RR
SFS	7 d	9-15 mo	50 km (g)	28	4 y	1979-present
SSFS	24 h	35-45 d	35 km (g)	31	2 y	20-25 y
GFS	6 h	7-10 d	13 km (g)	26	1 y	3 y
RRFS	1 h 6-12 h 6-12 h	18 h 30 h 60 h	3 km (r)	26	1 y	TBD
WoFS	5-15 min	2-4h	1 km (r)	26	1 y	TBD

(g) Global
(r) Regional

Resolutions are for atmosphere
Other component models may have different resolutions

SFS= Seasonal Forecast System
SSFS= Sub-Seasonal Forecast System
GFS= Global Forecast System
RRFS= Rapid Refresh Forecast System
WoFS = "Warn on Forecast" System

Changing use of WCOSS
Needing ~ 37 PFlop machine

Strategic Implementation Plan (SIP) FY20-22

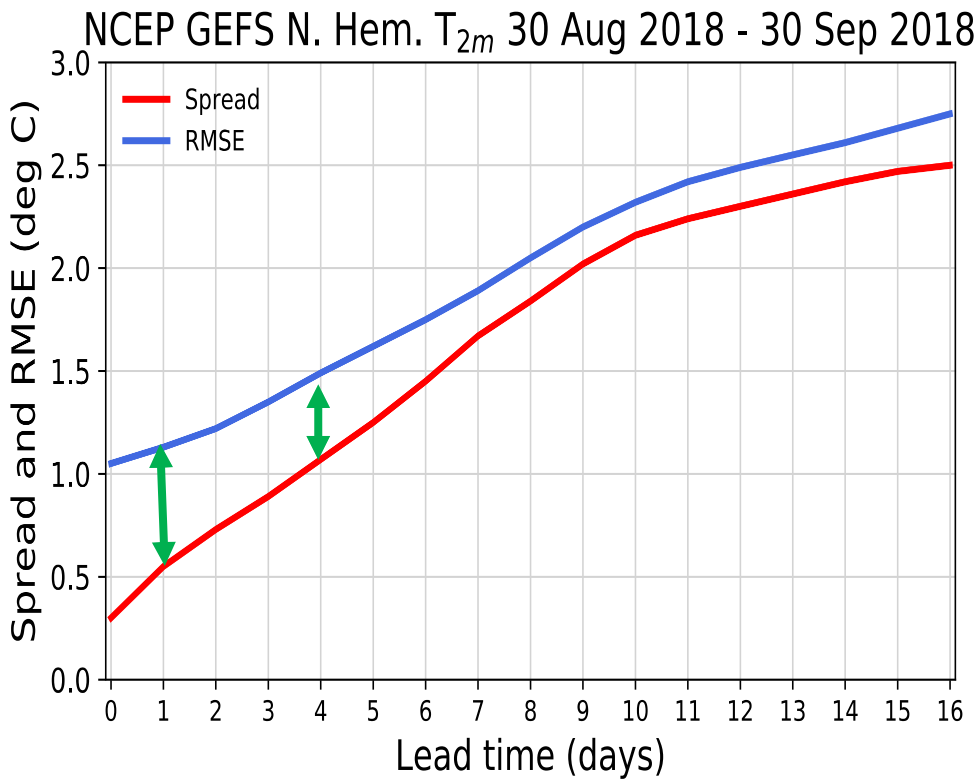
- **13 UFS Working Groups (WGs)**

- **2 Application Teams (ATs):**
  - **Mid-range weather to extended range (S2S) using coupled system**
  - **Convective Allowing Model**

- **ATs design focused tasks to address the requirements and forecast goals and model deficiencies**

- **WG on Ensemble Development:**
  Co-Chairs Tom Hamill; Yuejian Zhu; Ryan Torn

Spread vs. RMSE (Inconsistency)

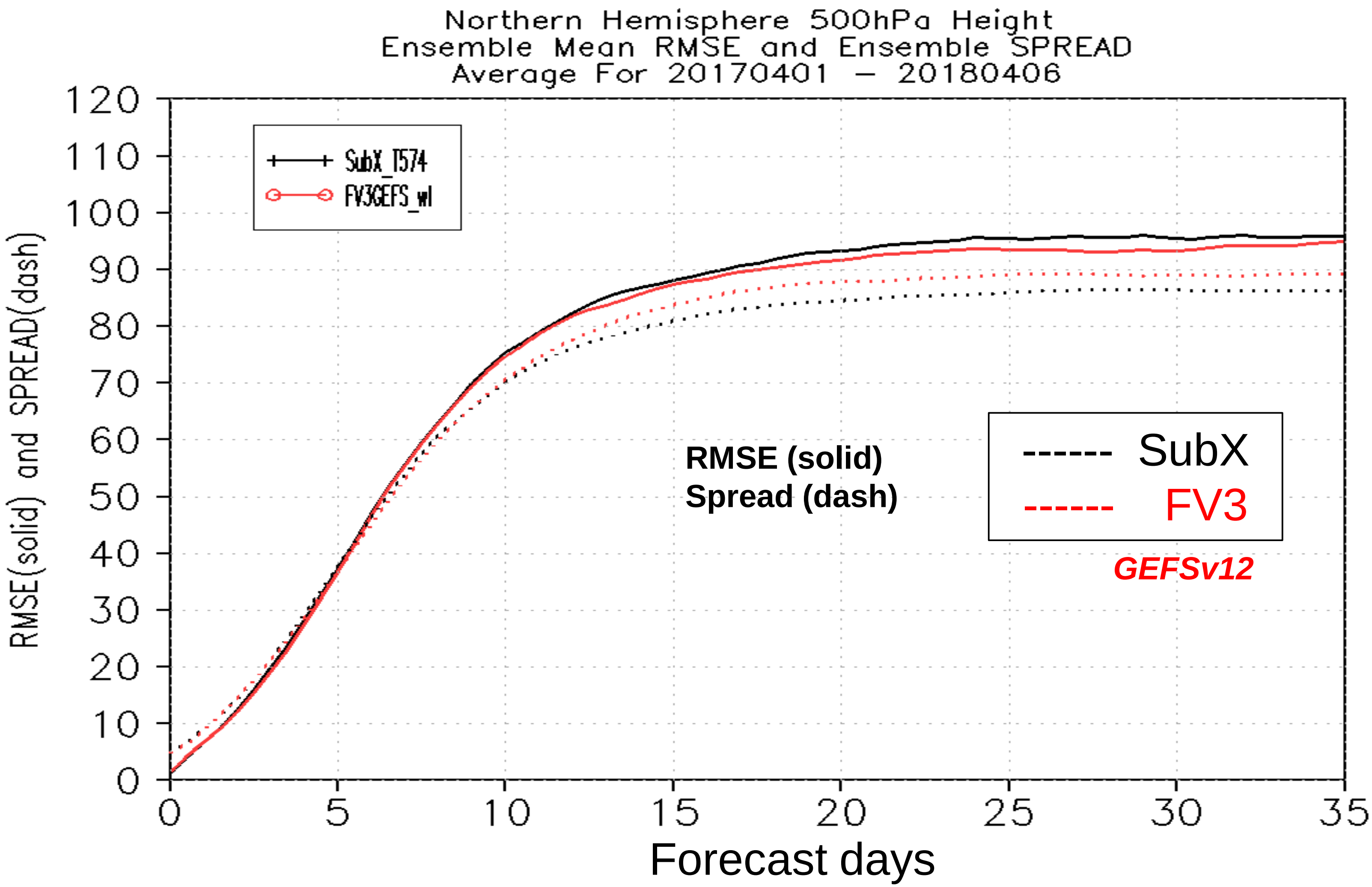


- The gap between spread and RMSE is a major issue in **Global Ensemble Forecast System (GEFSv11).**
- Is it due to overestimation of RMSE due to **uncertainties in T_{2m} analysis**?
- Is it due to too little spread in **initialization ensemble**?
- Is it due to the treatment of **model uncertainty**?

Ensemble Working Group

Co-Chairs: Tom Hamill; Yuejian Zhu; Ryan Torn

Spread vs. RMSE (Consistency Improved in H500)



Courtesy of *Yuejian Zhu*

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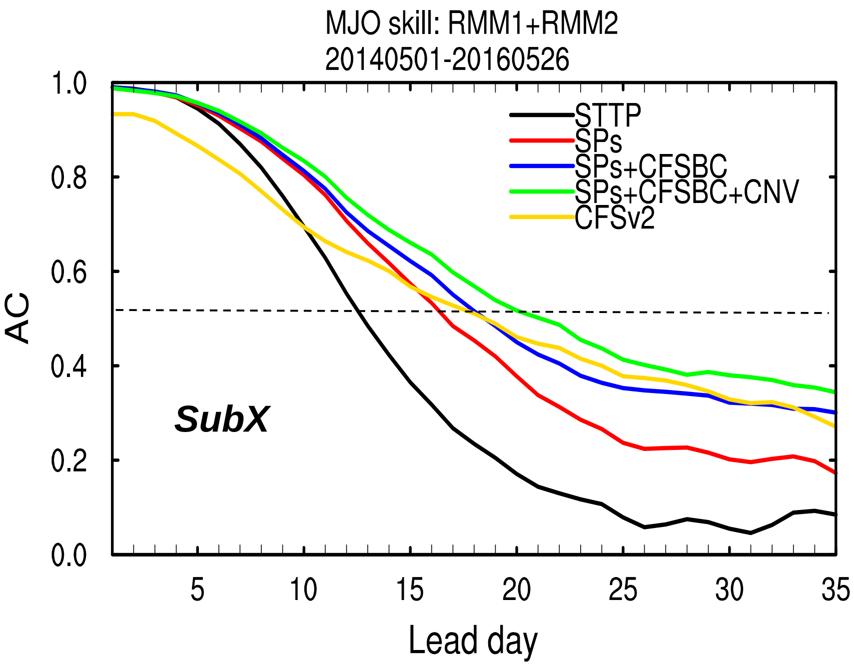
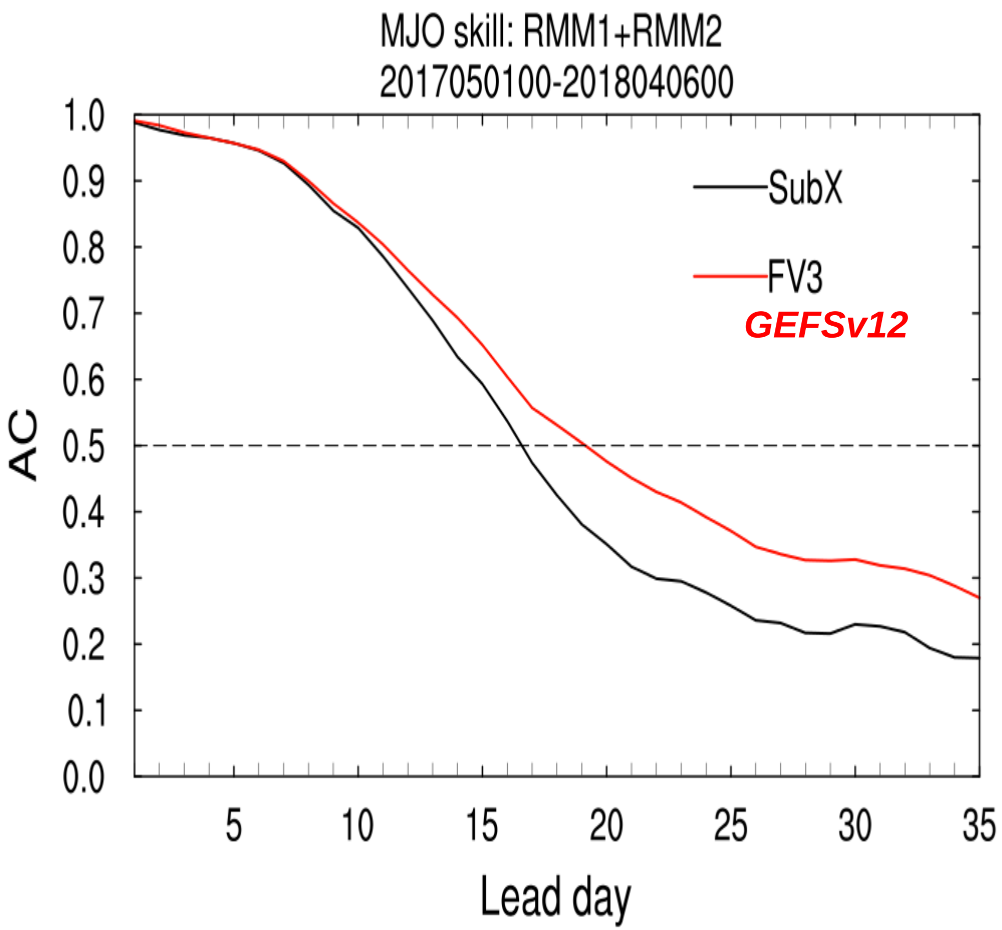
MJO Prediction Skill Improved

GEFSv11+ to support SubX
- **SPPT+SHUM+SKEB**
- **Bias corrected CFSv2 SST**
- **Scale aware convection scheme**





Courtesy of *Yuejian Zhu*

Multi Model Ensemble vs. Unified Model Approach

- **Multi Model Ensembles** (MMEs) have been used successfully in meteorology at many scales. Generally an MME is shown to be better that the individual models that make up an MME. This makes the MME a tool of choice for ensembles.

- … but …

- Many centers move to **Unified Modeling Approach** (UMA) (Single Model) to simplify operations, and to focus development resources. **A main goal of a UMA is to accelerate model improvement**.

Modeling Model Improvement

- Agreed-upon metrics m_t that improves with time from initial skill m_0 at an improvement rate α.

$$m(t) = m_t + (m_0 - m_t)e^{-\alpha t}$$

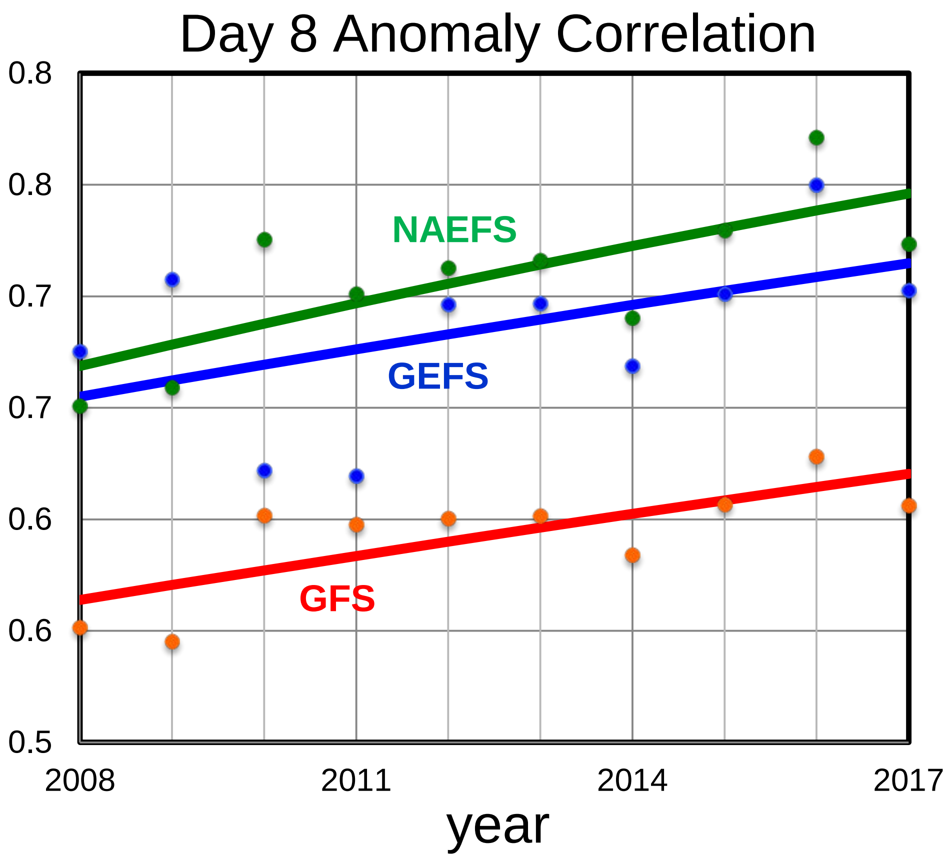
- Two models with initial skill $m_{0,1}$ and $m_{0,2}$ and with improvement rates α_1 and α_2

- A poor model that improves quicker will catch up with the better model at time t_c

$$t_c = \frac{\ln \beta}{\alpha_2 - \alpha_1} \qquad \beta = \frac{m_{0.2} - m_t}{m_{0.1} - m_t}$$

NCEP Global Models

- Models:
  - GFS (deterministic)
  - GEFS (UMA ensemble)
  - NAEFS (MME)
- Metric:
  - 500 hPa Anomaly Corr.
- Data source:
  - EMC
- Processing:
  - Annual improvement rate α fit to 10 year data.
  - Relative accuracy β fit to last 5 year data



NCEP Global Models

Annual improvement rate α in percent

forecast day	2	4	6	8	10	12	14
GFS	6.4%	4.3%	2.6%	1.5%	0.9%	0.4%	0.2%
GEFS	7.6%	5.1%	3.3%	2.1%	1.4%	0.9%	0.6%
NAEFS	9.2%	6.4%	4.3%	3.0%	2.2%	1.7%	1.2%

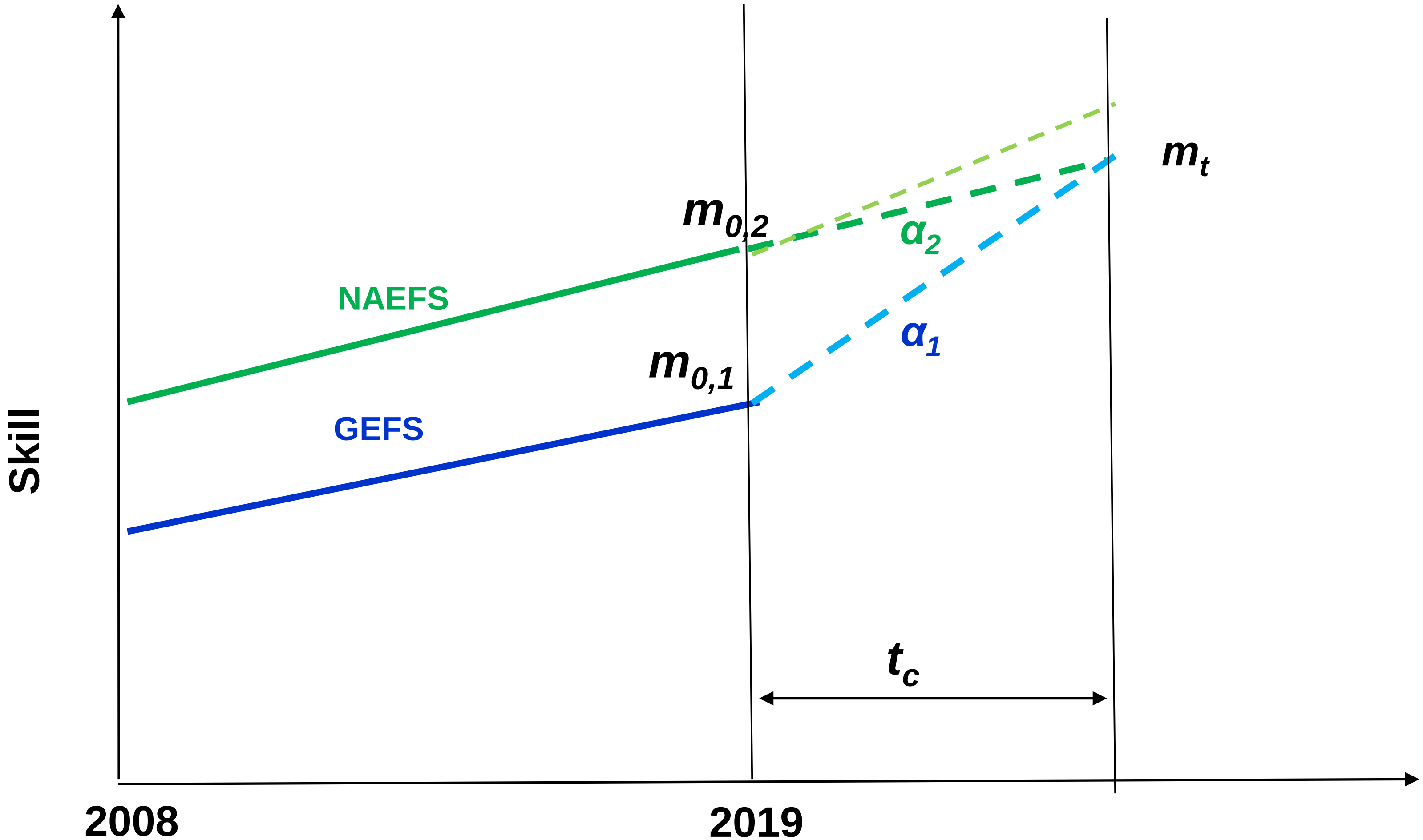
Improvement from deterministic to probabilistic forecasts

Relative accuracy in percent

forecast day	2	4	6	8	10	12	14
GFS → GEFS	-3.4%	13.3%	27.1%	34.0%	34.7%	32.6%	28.6%
GEFS → NAEFS	25.5%	14.8%	10.5%	8.2%	7.0%	6.6%	6.5%

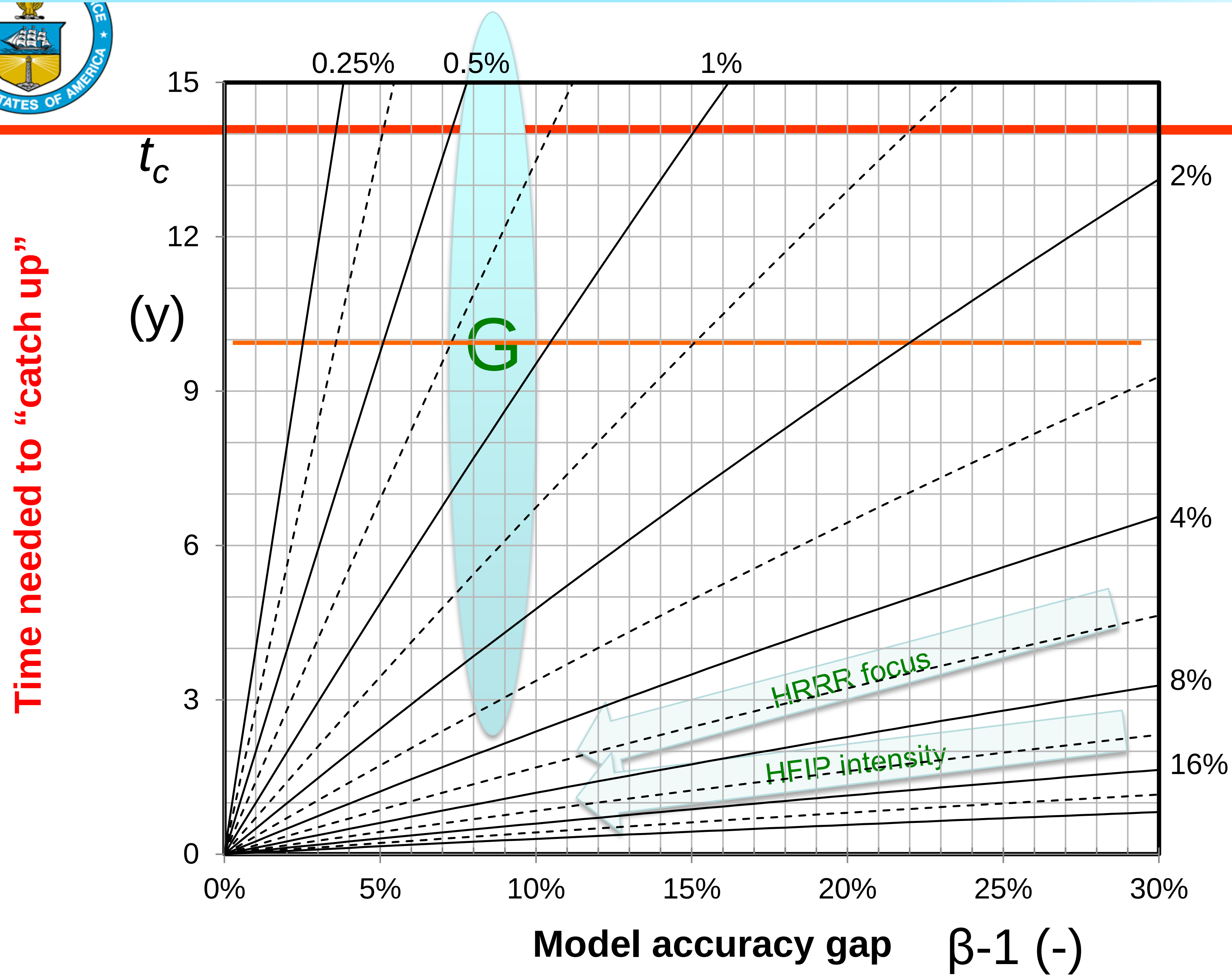
Improvement from UMA to MME

UMA vs. MME
Skill Improvement



- MME (NAFES) is better than UMA (GEFS) ensemble by 7-10% currently
- However, an accelerated improvement in GEFS will allow it to catch up with NAFES in a few years

Lines for constant α (y^{-1}) for given β and t_c



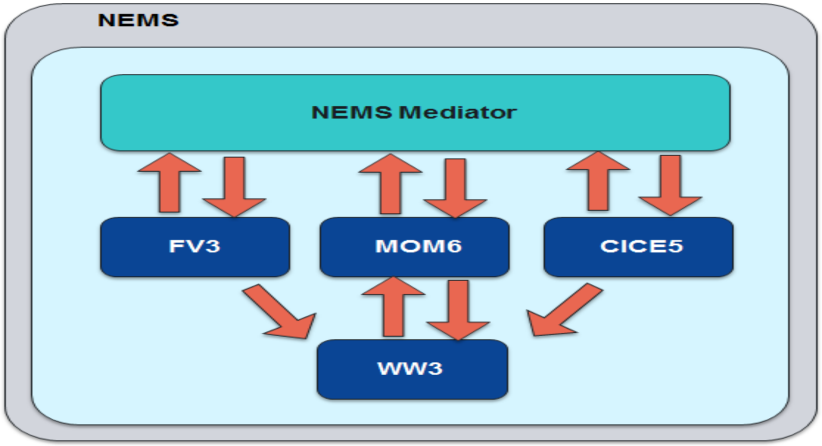
Subseasonal to Seasonal Forecast Systems

Sub-Seasonal Forecast System (GEFSv13)
(0 – 35/45 days)

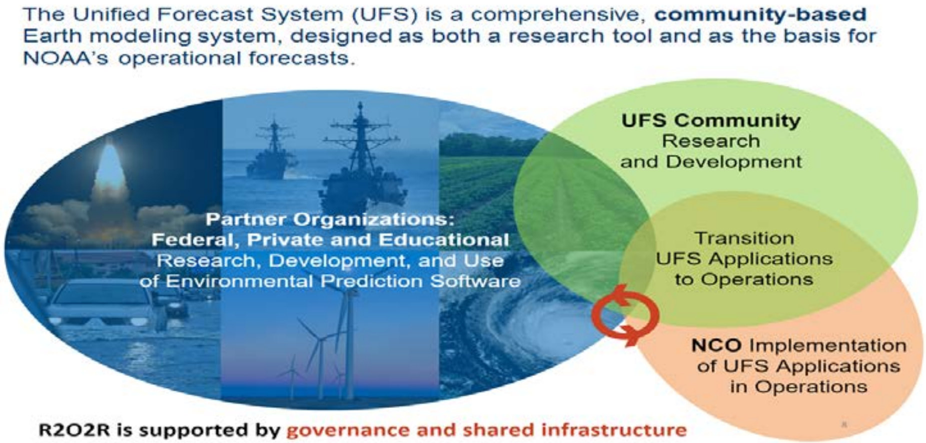
- **Coupled System (FV3+MOM6+CICE5+WWW3+GOCART)**
- **Weekly coupled DA**
- **Reanalysis and reforecast (1999-present)**
- **FY23: Implement GEFSv13**

Seasonal Forecast System (SFSv1)
(0 – 9/15 months)

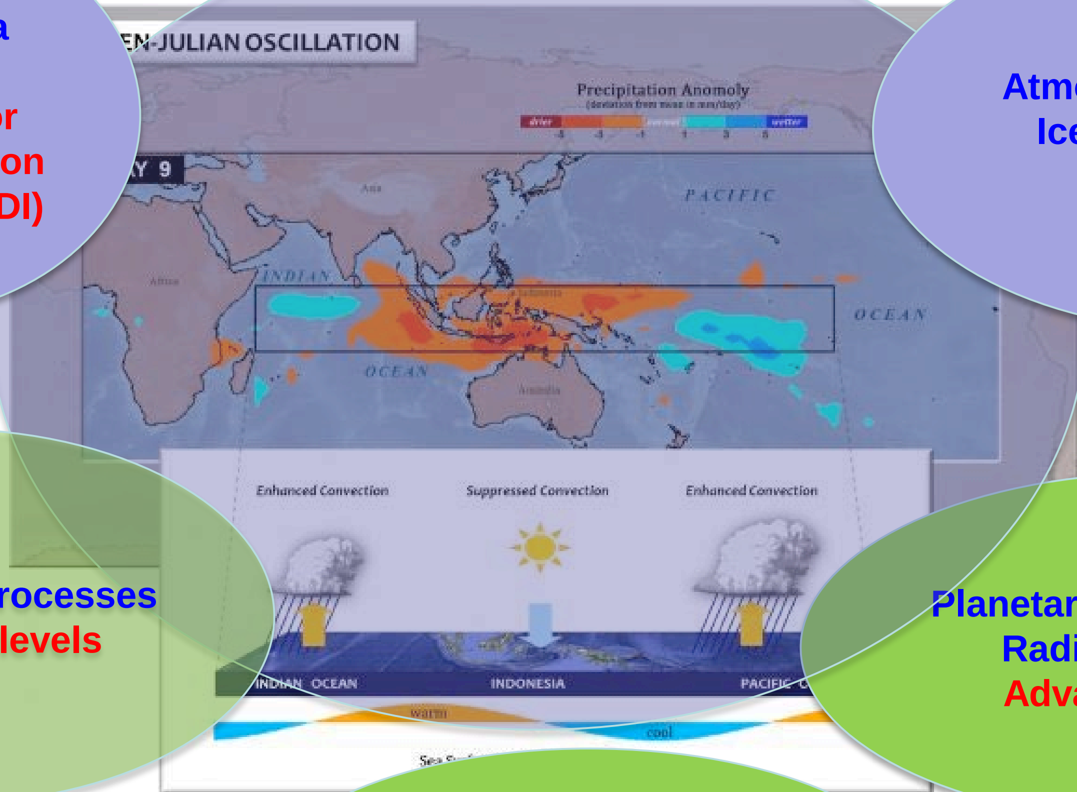
- **Fully coupled Unified Forecast System**
- **Fully coupled DA**
- **Reanalysis and reforecast (1979-present)**
- **FY24: Implement SFSv1**



Community-Based Model Development



Focused Areas in Development



Coupled Data Assimilation
Joint Effort for Data Assimilation Integration (JEDI)

Atmosphere-Ocean-Sea Ice-Land Interaction
Surface Fluxes

Stratosphere Processes
126 vertical levels

Planetary Boundary Layer; Radiation Package
Advanced Physics

Model Uncertainties
Stochastic Parameterizations

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Ensemble Strategies for S2S Forecast

- **Initialization of atmosphere, ocean, sea ice and land with "weakly or strongly coupled data assimilation"**
- **Coupled initial perturbations**
- **Stochastic parameterizations**
- **Forecast configurations (ensemble size, burst and lagged ensemble)**
- **Model biases, over-confident prediction, and initialization shocks**

Conclusions

- **Forecasts have become more accurate and reliable thanks to improvements in the initial conditions; in the quality of forecast models; and in ensemble configurations.**

- **The introduction of coupling to dynamic ocean and sea-ice models has led to improvements.**

- **The use of reforecasts has made it possible to extract more meaningful signals from the raw forecast data.**

- **Calibrated ensemble forecasts have been used in wide applications including energy, retail and agriculture, as well as disaster risk mitigation worldwide.**

Thanks!

Global Ensemble Forecast System (GEFSv12)

Model Configuration

- FV3 Dynamic Core, C384L64 (~25km)
- GFSv15 Physics + Stochastic Physics (SPPT+SKEB)
- Uncoupled (NSST + 2-Tier SST from CFSv2)
- One-way coupled to Global Wave Ensemble System (GWES)
- Control member coupled to Aerosols & Chemistry

Frequency

- 5-member, 4 cycles/day
- 20 members out to +16 day per day
- 11 members, every Wednesday, out to +35 day

Reanalysis and Reforecast

- GEFSv12 Reanalysis (20 yr): 1999-present
- GEFSv12 Reforecast (30 yr): 1990-present
  I.C.: 1990-1998 from CFSR; 1999-present from GEFS Reanalysis

Q1FY20: Start users evaluation

Q4FY20: Implement GEFSv12 into operations

GEFSv11 vs. GEFSv12

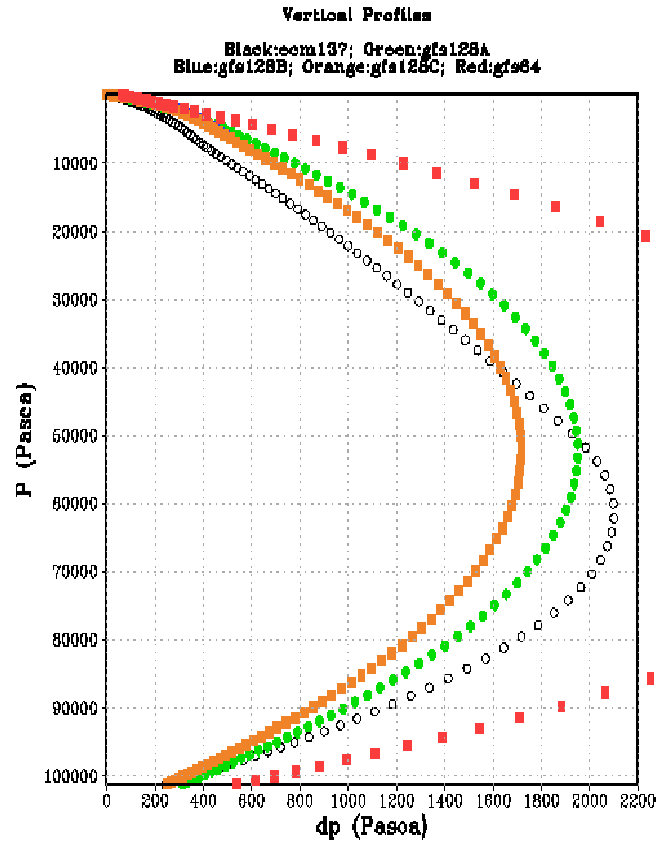
GEFSv11 (21 members)	GEFSv12 (31 members)
GSM	FV3
ZHAO-CARR MP	GFDL MP
TL574L64 (~33km) (d1-8)+TL382 (~50km) (d9-16)	C384L64 (~25km) (d1-16) (~25km) (d16-35)
Climatology relaxation	NSST +2-tiered SST
Stochastic STTP	Stochastic physics (SPPT + SKEB)
GSM-GFS EnKF 06 fcst	FV3-GFS EnKF 06h fcst

GFSv16

Q2FY21: Upgrade to Deterministic Global Model

- **Model resolution:**
  - Increased vertical resolution from 64 to 127 vertical levels
  - Raise model top from 54 km to 80 km
  - Increased horizontal resolution from 13 km to 10 km (proposed)
- **Dynamics:** New advection algorithms from GFDL
- **Advanced physics chosen from Physics Test Plan:**
  - PBL/turbulence: K-EDMF => sa-TKE-EDMF
  - Land surface: Noah => Noah-MP
  - Gravity Wave Drag: => unified gravity-wave-drag
  - Radiation: updates to cloud-overlap assumptions,
  - Microphysics: Improvements to GFDL MP
- **Two-way interactive coupling to WaveWatchIII**
- **Data Assimilation Upgrades:**
  - Local Ensemble Kalman Filter (LETKF)
  - 4-Dimensional Incremental Analysis Update (4DIAU)
  - SKEB based land surface perturbations
  - Land Data Assimilation
  - Shifting and Lagging Ensemble Members
  - Improved cloud analysis, NSST, stratospheric humidity

127 levels, 80km top



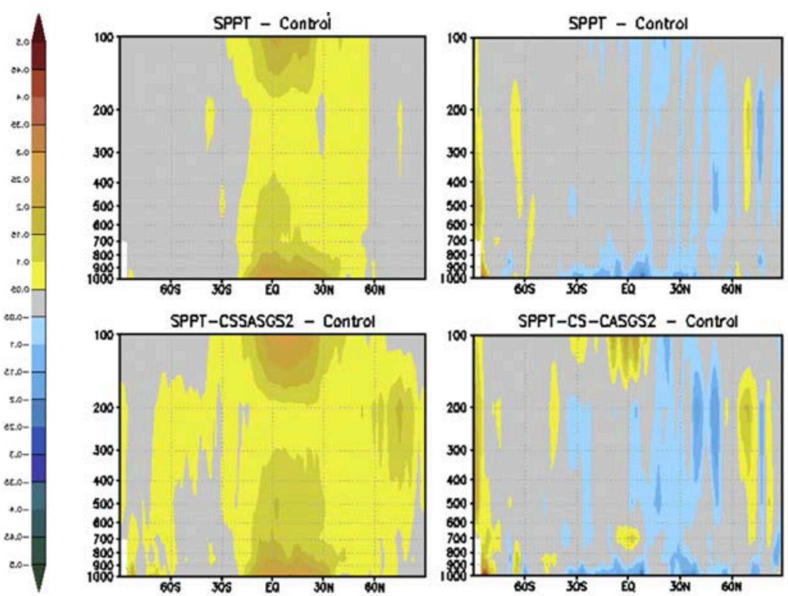
Stochastic Deep Convective Parameterization Development

Introducing uncertainty contributed by sub-grid scale processes into the deep convective parameterization

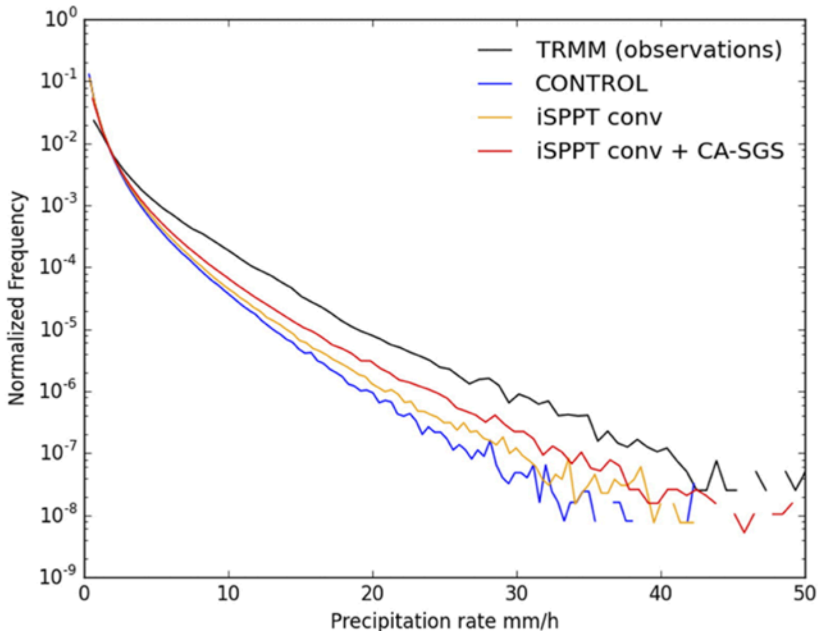
Cellular automata (CA) is used to trigger a different number of convective plumes in each grid cell.
c/o Lisa Bengtsson, Jian-Wen Bao, CIRES and ESRL/PSD.

Example : SPPT + CA perturbations compared with SSPT alone.

T spread difference +120H Error std difference



Example: frequency distribution of 6h precipitation showing that there are fewer drizzle events and more strong precipitation events with CA, which is more like observations.



Courtesy of *Tom Hamill*

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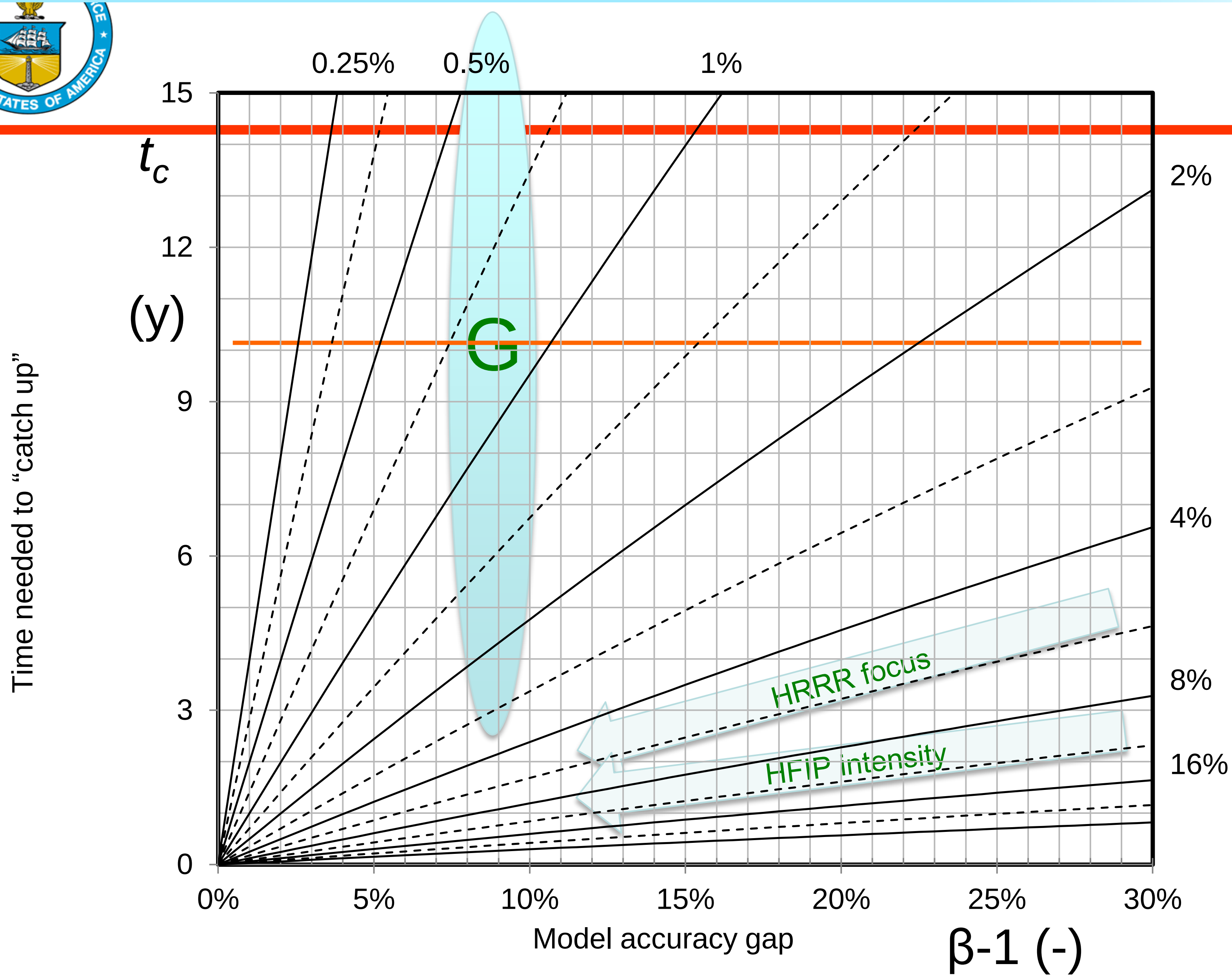
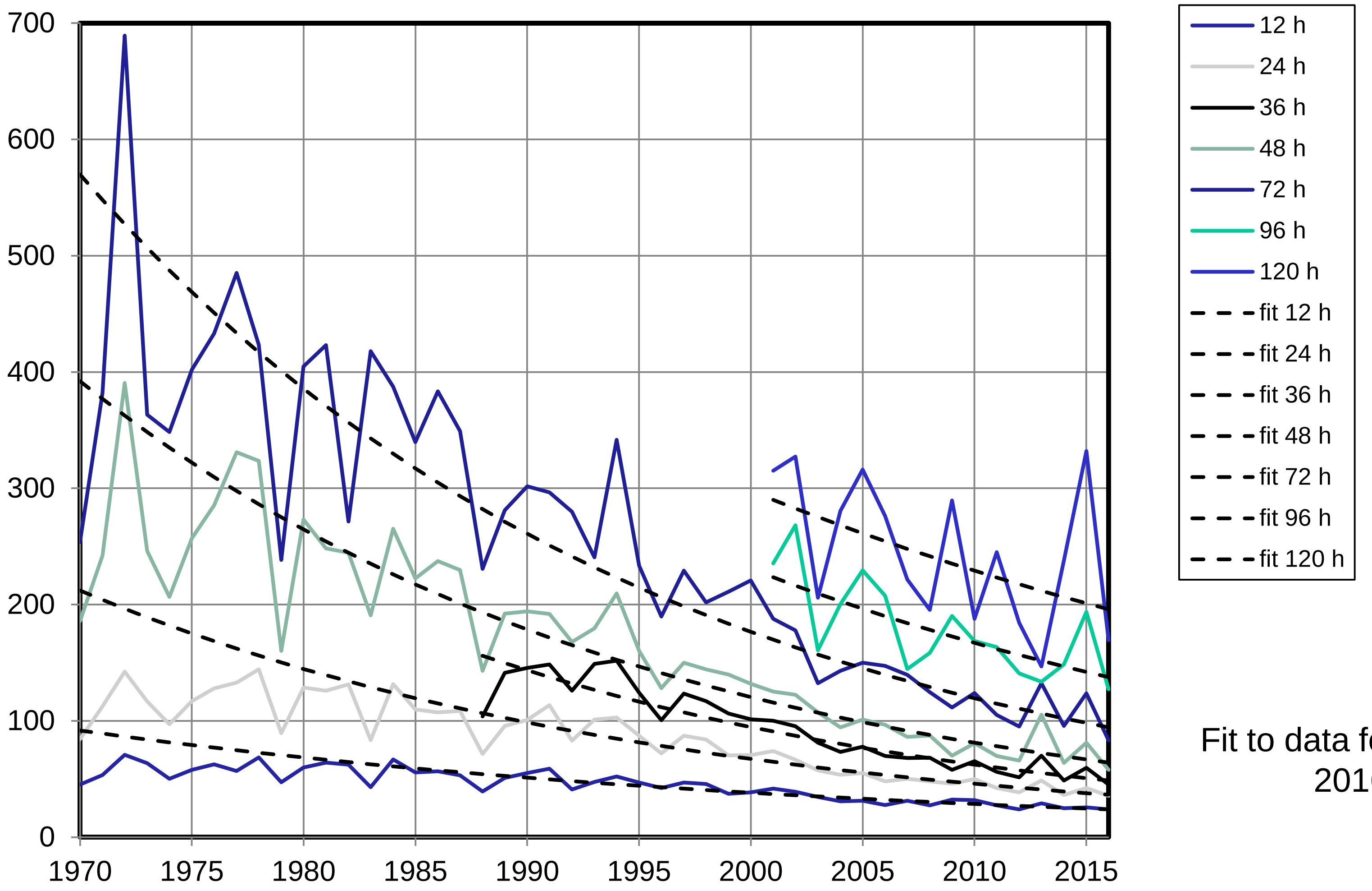


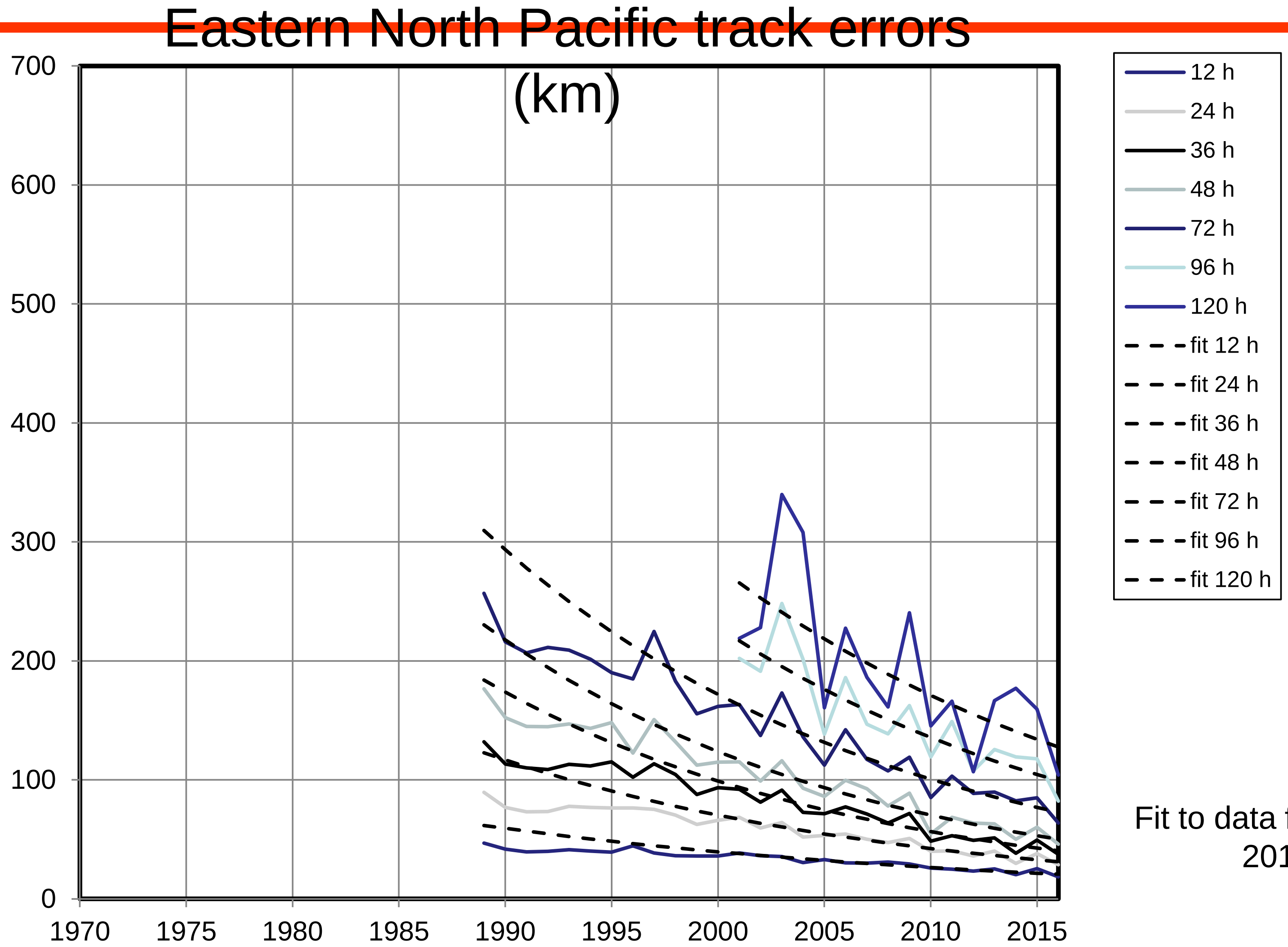
Hurricane Modeling

North Atlantic track errors (km)



Fit to data for 2001 - 2016

Hurricane Modeling



Fit to data for 2001 - 2016

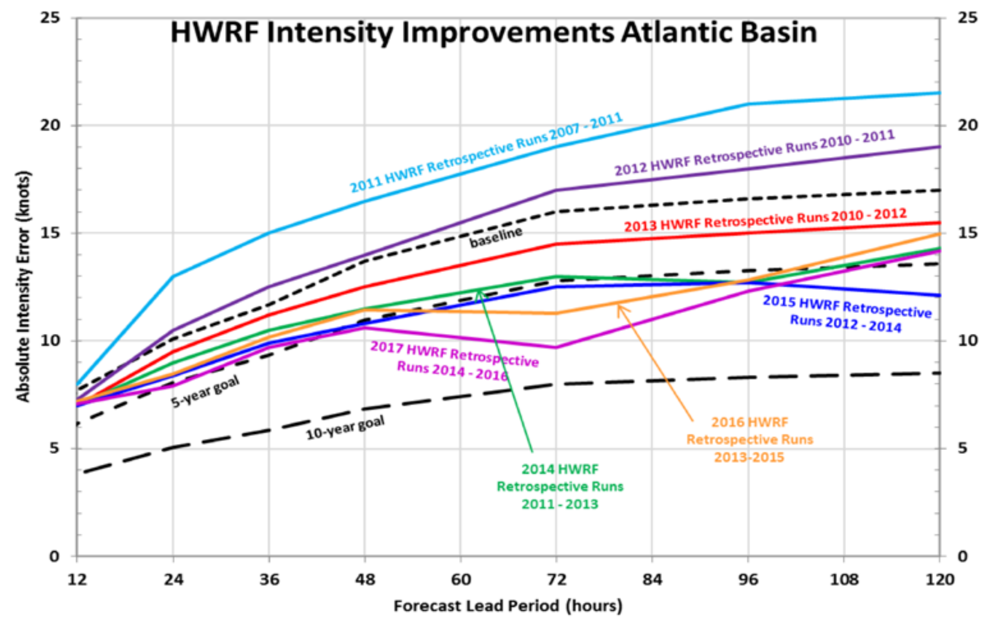
Hurricane Modeling

Annual improvement rate α in track error

forecast :	12 h	24 h	36 h	48 h	72h	96 h	120 h
NA 1970 - 2016 :	2.1%	2.7%		3.3%	3.4%		
ENP 1989 - 2016 :	2.7%	3.6%	4.2%	4.4%	4.4%		
NA 2001 - 2016 :	2.9%	3.8%	4.2%	3.9%	3.9%	3.2%	2.6%
ENP 2001 - 2016 :	4.0%	5.1%	5.6%	5.6%	5.4%	5.2%	4.9%

- Intensity errors:
  - HFIP project

  Goal to improve by 10% annually for 5 years



RAP / HRRR

- High Resolution Rapid Refresh, data provided by Curtis Alexander, using 5 years of data.
  - Temperature, humidity and wind (profiles) improve 5% per year
  - Precipitation skill improved 10% per year
  - Precipitation bias improved by 12% per year
  - HRRR focus on severe weather and precip: HRRR focal areas improve by 5-7% faster than background model improvements