The NCEP Global Ensemble Forecast System

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Present for Ensemble Project

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EMC/NCEP/NWS/NOAA

Acknowledgement:

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8th NCEP Ensemble User Workshop

August 27-29 2019

College Park, MD 20740

Evolution of NCEP GEFS configuration

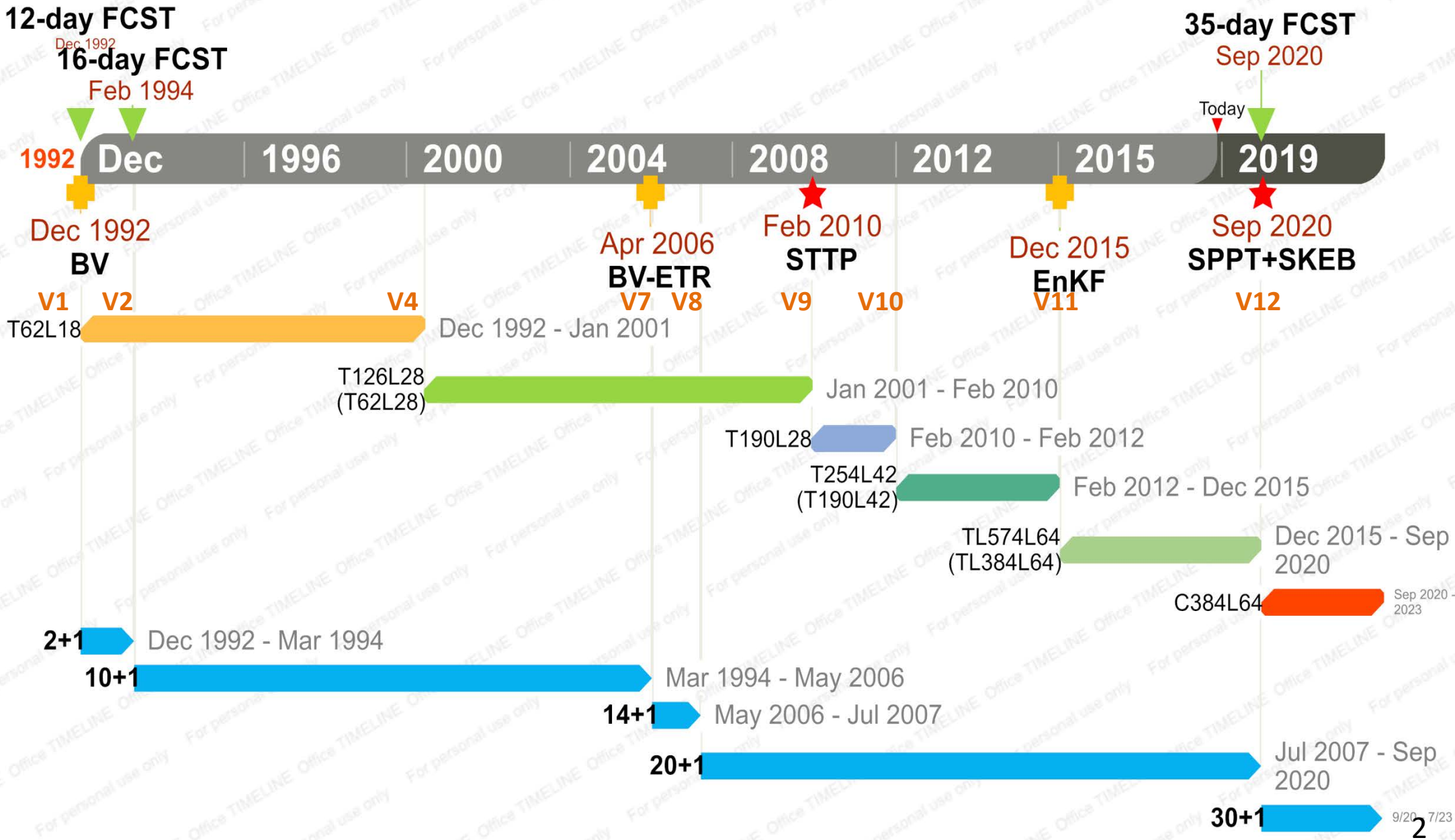
FCST Length

Uncertainty

Version #

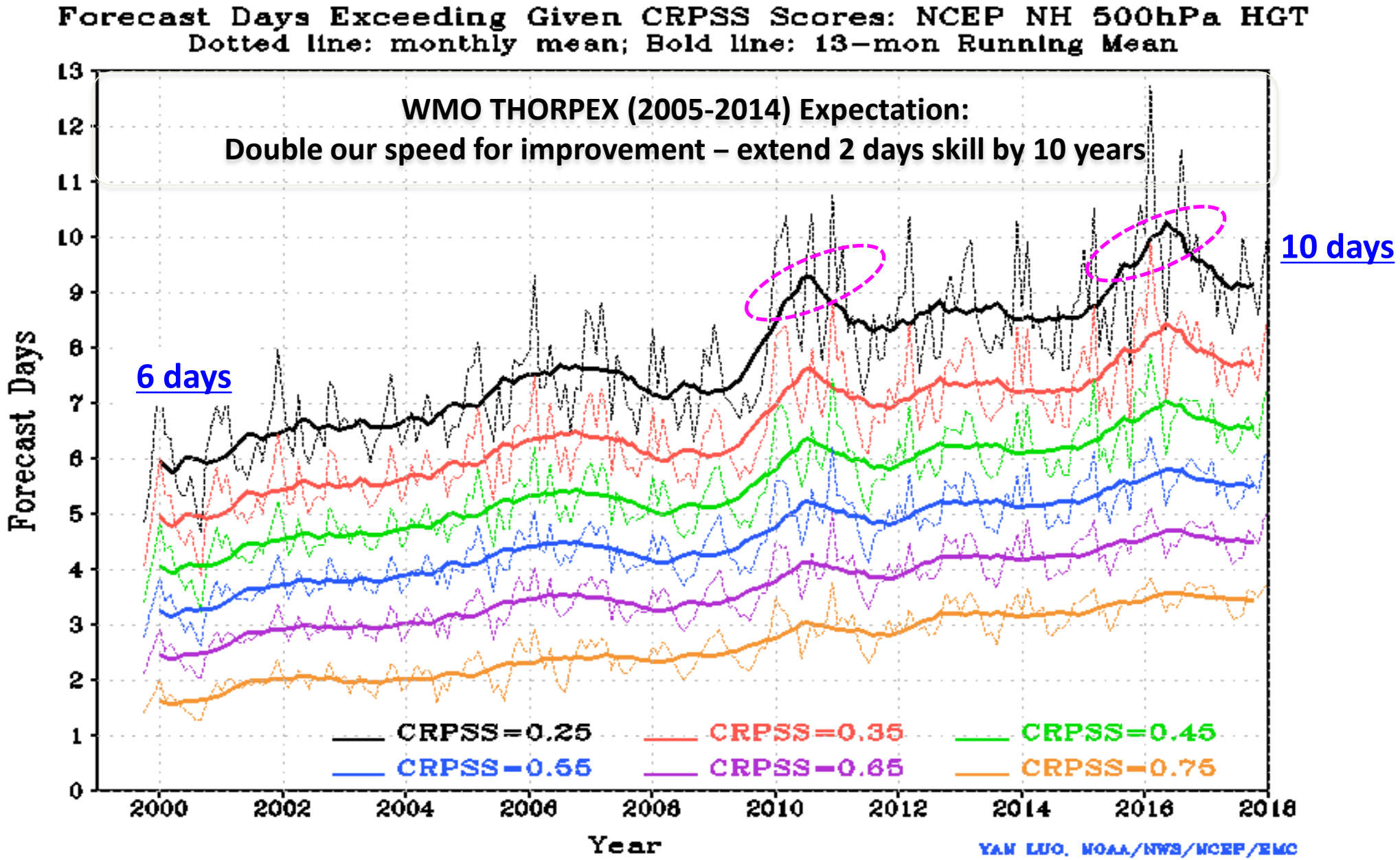
Resolution

Ensemble size



CRPSS for NH 500hPa geopotential height (2000-2018)

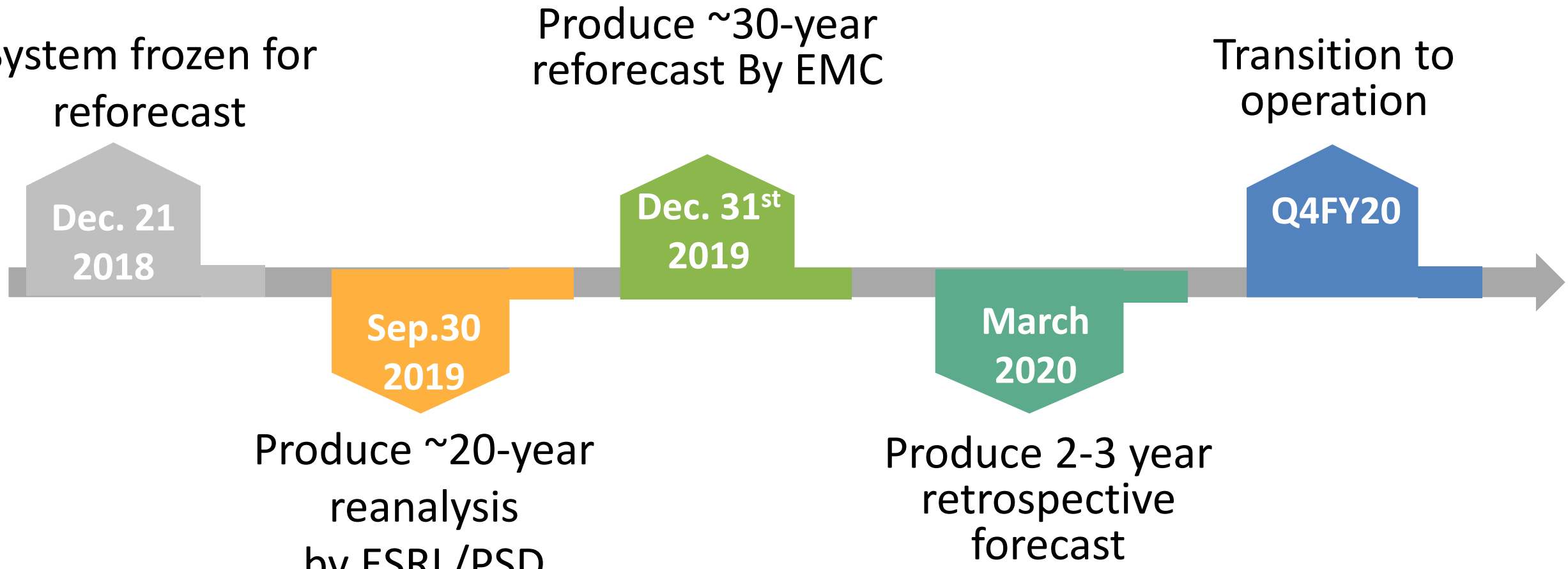
Note:
CRPSS=0.25 is equivalent to ACC=60



Known issues in GEFS production

- (Our collections through annual NPSR, user workshop and etc…)
- Strong warm/dry bias for most CONUS in summer time
- Tropical cyclone forecast
  - Weak TC storm intensity
  - Degradation of track forecast over ATL, EP in longer lead times
  - Under dispersion of TC track
- Under-dispersion of surface variables

Major milestones for FV3GEFS (v12)



PROD-GEFS (v11) .vs. FV3-GEFS (v12)

	PROD-GEFS	FV3-GEFS
Model	**GSM (hydro)**	**FV3 (non-hydro)**
Micro-phy	ZHAO-CARR MP	GFDL MP
IC uncertainty	EnKF TC perturbed after relocation	EnKF No relocation
Model uncertainty	STTP	Stochastic physics (SPPT + SKEB)
Resolution	TL574L64 (~33km), 0-8 days TL382L64 (~50km), 8-16 days	C384L64 (~25km)
Forecast days	16 days	16 days (06Z, 12Z and 18Z) 35 days (00Z)
Ensemble size	21 members	31 members
Ocean forcing	Persistent + relaxation SST	NSST and 2-tiered SST

Major model physics upgrades since last implementation

Physics updates in GSM (GFS v13 & v14)

- Corrected the **land** surface characteristics for grassland and cropland categories to reduce summertime warm and dry biases over Great Plains
- Upgraded **convective gravity wave drag**
- Updated **the convection schemes** with scale- and aerosol-aware features along with convective cloudiness enhancement
- Upgraded **surface layer parameterization** scheme to prevent the land-atmosphere system from decoupling.
- **NSST**

Physics update in FV3GEFS

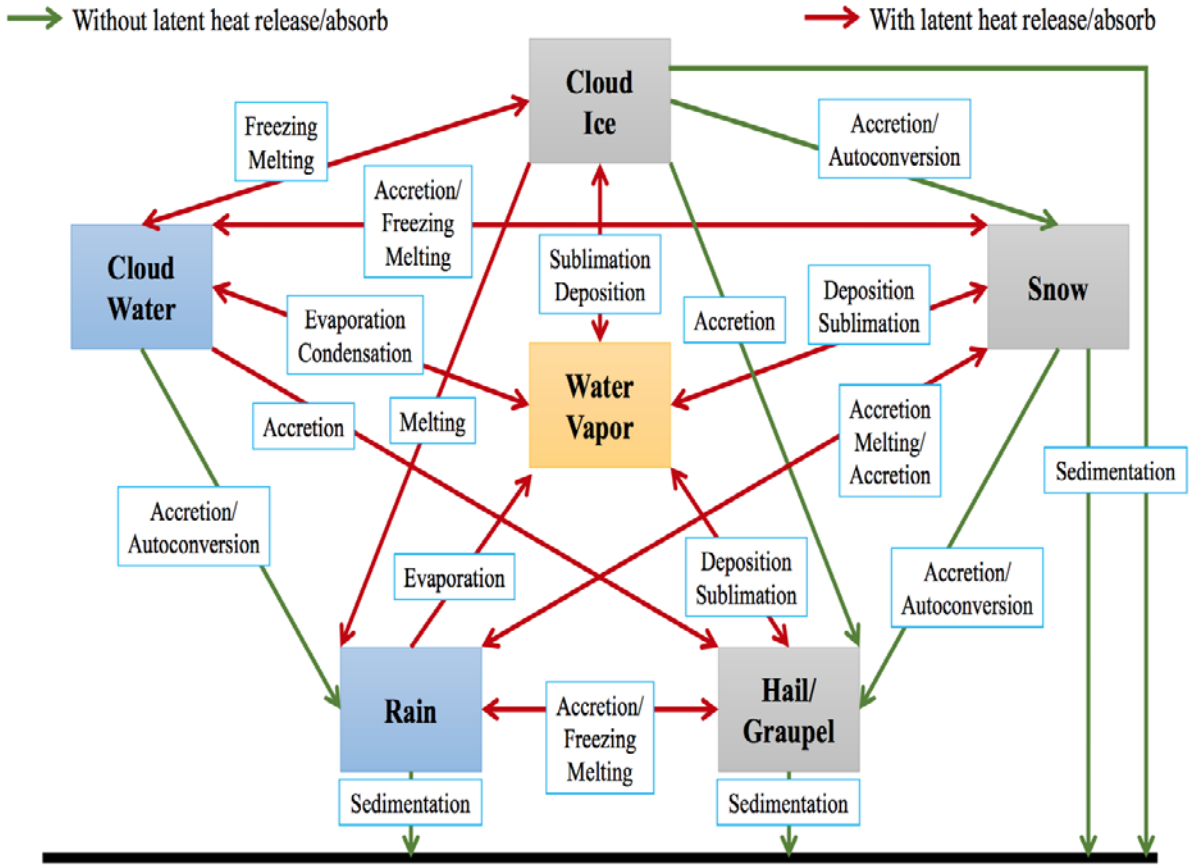
- **Fixed ground flux calculation under snow cover**

Physics updates in FV3GFS (GFS v15)

- **Replaced Zhao-Carr microphysics with the more advanced GFDL microphysics**
- **New parameterization of middle atmospheric water vapor photochemistry**
- **A revised bare soil evaporation scheme to reduce summer warm/dry bias over the Great Plains**
- **Updated parameterization of ozone photochemistry with additional production and loss terms**
- **Modify convection schemes to reduce excessive cloud top cooling**

Microphysics Scheme

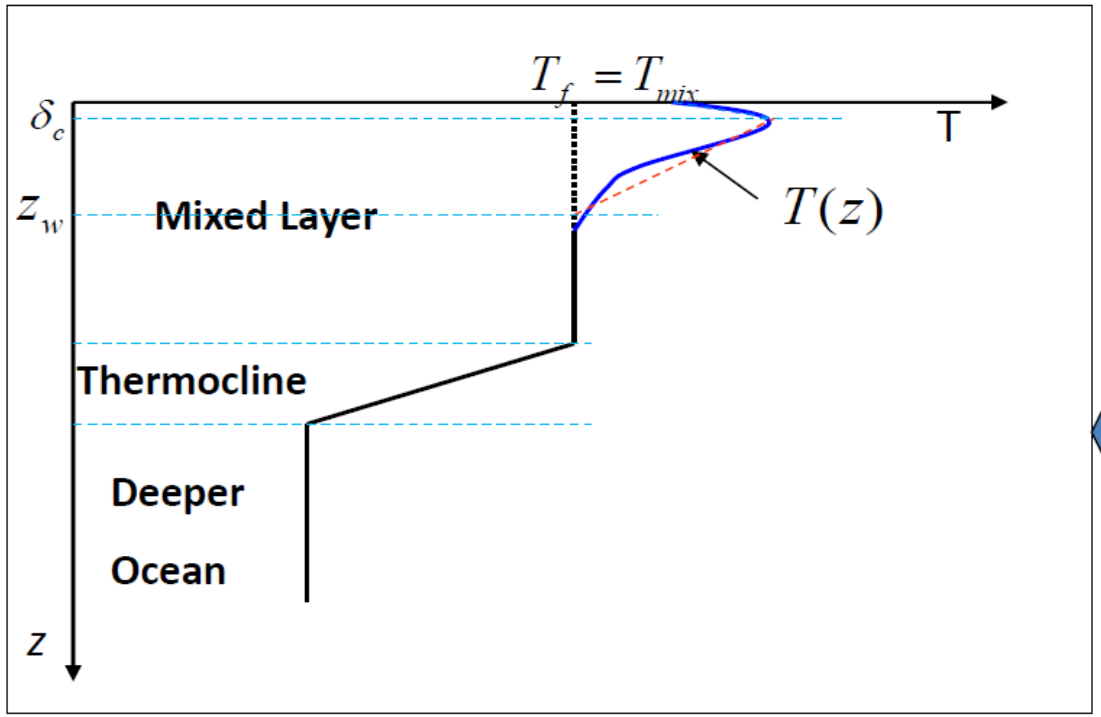
- **Zhao-Carr MP**
  - only one prognostic cloud species: total cloud water
- **GFDL MP**
  - Five prognostics cloud species: Liquid, ice, snow, graupel, rain more sophisticated cloud processes



From Fanglin Yang

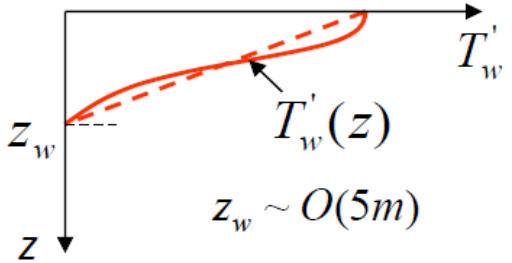
Near Surface Sea Temperature Scheme (NSST)

NSST is a **T-Profile** just below the sea surface.
Here, only the vertical thermal structure due to **diurnal thermocline layer warming** and **thermal skin layer cooling** is resolved



Diurnal Warming Profile

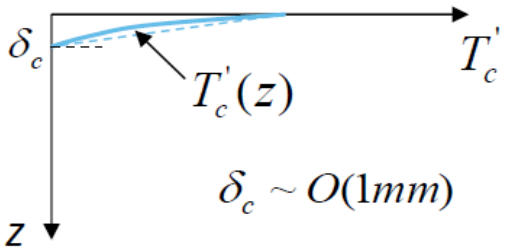
$$T_w'(z) = (1 - z / z_w) T_w'(0)$$



$z_w \sim O(5m)$

Skin Layer Cooling Profile

$$T_c'(z) = (1 - z / \delta_c) T_c'(0)$$



$\delta_c \sim O(1mm)$

$$T(z,t) = T_f(z_w,t) + T_w'(z,t) - T_c'(z,t) \quad z \in [0, z_w]$$

Courtesy of Dr. Xu Li

SST forcing in the GEFS operation and FV3GEFS

- **Operational:** Persistent + relaxation

$$SST_f^t = \underbrace{\left[SST_a^{t0} - SST_c^{t0}\right] e^{-(t-t0)/90}}_{\text{analysis - climatology at } t0} + \underbrace{SST_c^t}_{\text{Climatology at } t}$$

- **FV3GEFS:** Two-tiered SST

$$SST_f^t = (1-w) * \underbrace{\left[SST_a^{t0} - SST_{cfsrc}^{t0} + SST_{cfsrc}^t\right]}_{\text{Analysis + Climatological tendency}} + w * \underbrace{\left[SST_{cfs}^t - (SST_{cfs\_c}^t - SST_{cfsrc}^t)\right]}_{\text{Bias-corrected CFSv2 forecasts}}$$

$$w(t) = \frac{(t - t_0)}{35}$$

Initial perturbations in FV3 GEFS

- IC perturbations generated from EnKF 6h forecasts as the production
- Both high-resolution FV3GFS analysis and low-resolution EnKF forecasts are interpolated from Gaussian grid to FV3 native grid and then re-center ensemble member to analysis
- No TC relocation process to perturb tropical cyclone and environment separately, which simplifies the initialization process
- Include non-hydrostatic variables and 7 tracers in Ics
- Cold start the model

Stochastic physics schemes

- **Dynamics uncertainty**: Stochastic Energy Backscatter (SKEB)

  Energy at non-resolved scales cannot cascade to larger scales due to the model's finite resolution

  •Approach: Estimate energy lost each time step, and then transfer back to resolved scales

  •Stream function is randomly perturbed to represent upscale kinetic energy transfer

- **Physics uncertainty**: Stochastically perturbed physics tendencies (SPPT) [ECWMF tech memo #598]

  •Represents uncertainties in physical parameterizations

  •Multiplicative noise modifies total parameterized tendency

- *Above schemes (+ Shum) has been implemented to NCEP EnKF/hybrid DA in 2015*

SPs for FV3GEFS

- Tested/tuned all three schemes and different combination

- **No SPs under dividing streamline over mountain area**
  - Increase model stability but reduce spread for lower levels

- **Reduced SKEB's contribution**
  - Amplitude is reduced from 1.0 to 0.6 when we selected a less diffusive advection scheme (Hord=5)

- **5-scale SPPT** (next slide)

- **No SHUM**
  - To reduce tropical wind spread of lower levels

Examples of stochastic patterns for SPPT

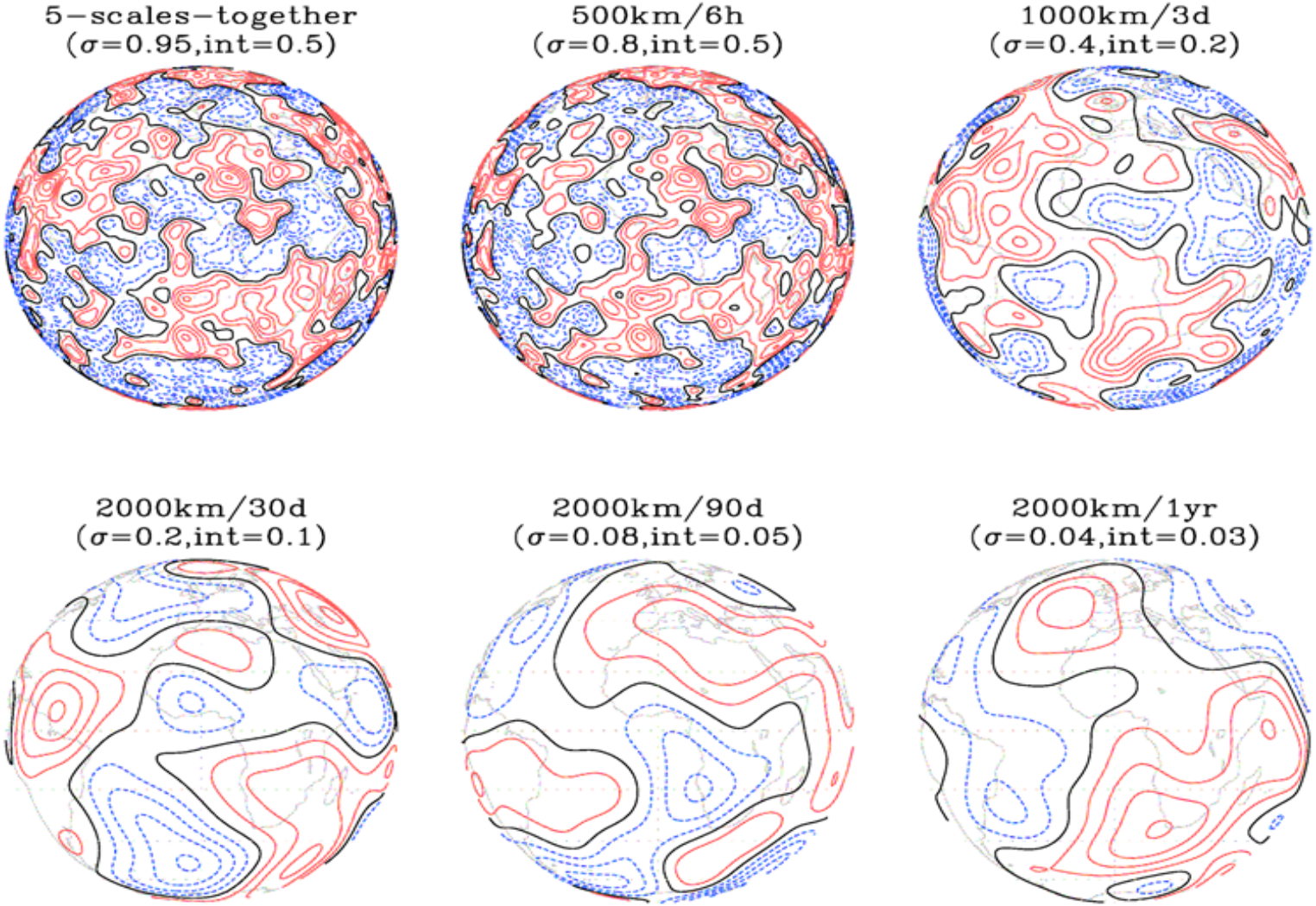
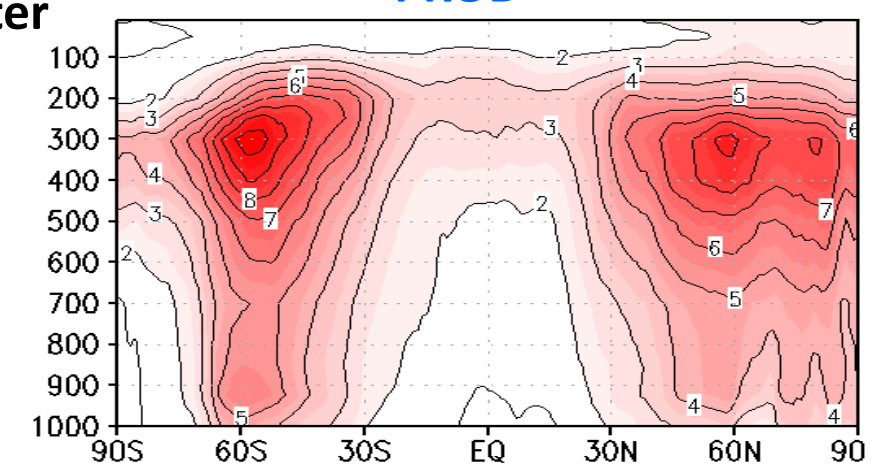


Fig. 2: 5-scale random patterns used in Stochastic Perturbed Physics Tendencies (SPPT). On the top of each plot, the numbers (except for upper left) represent the scales of spatial and temporal perturbations with the maximum amplitude and contour intervals in the bracket. ***Zhu et al, 2018: JGR***

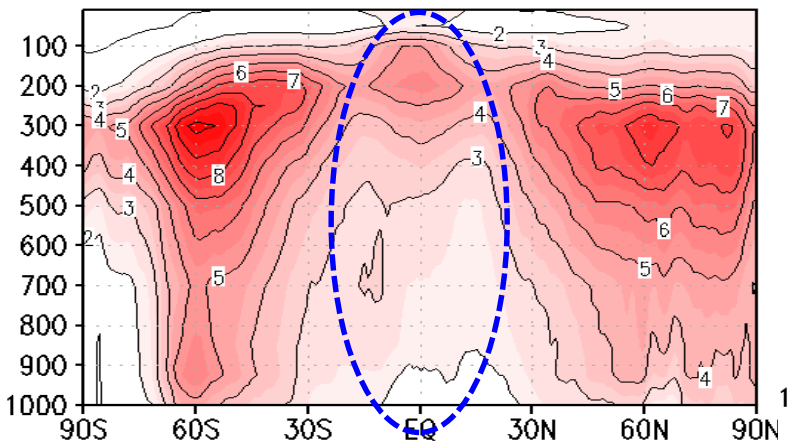
STTP vs SPs (fcst=120hr)

Winter

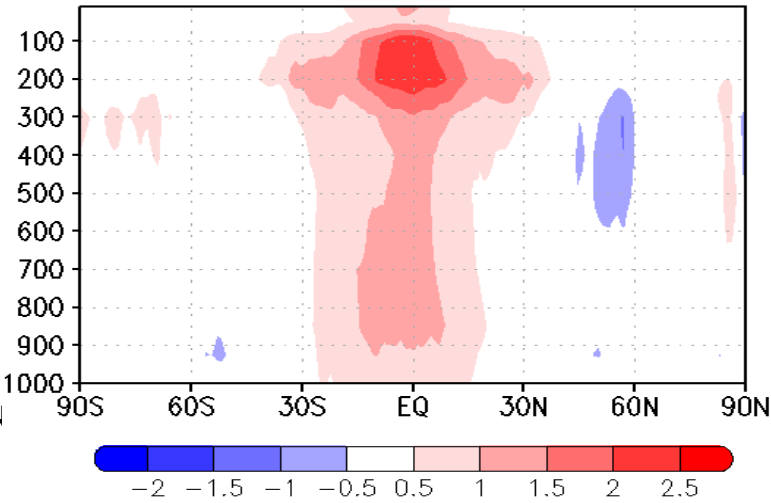
PROD



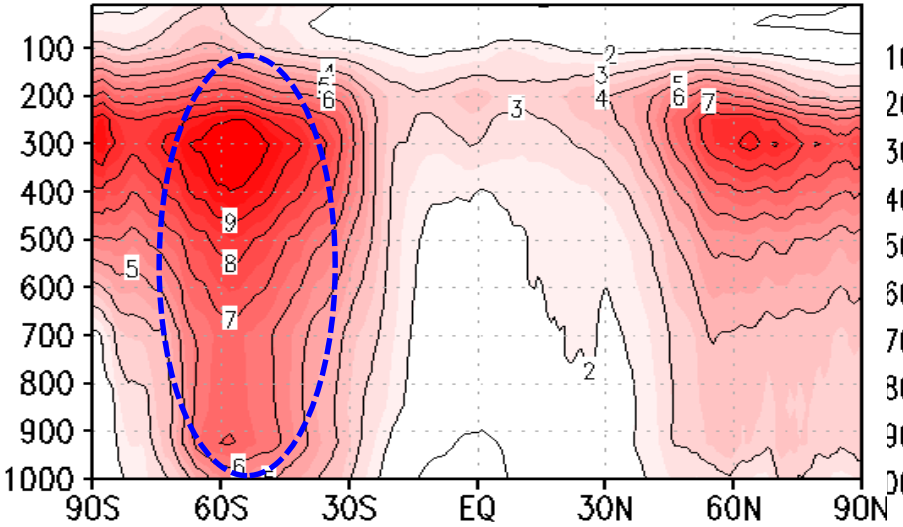
FV3GEFS

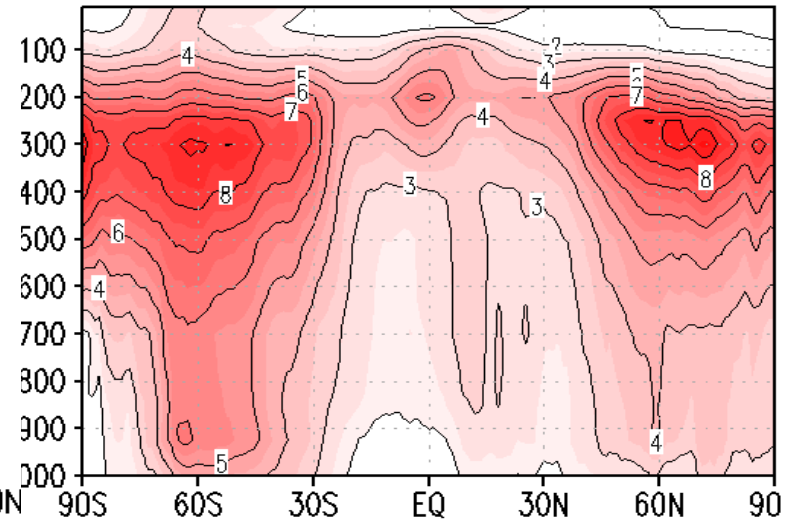


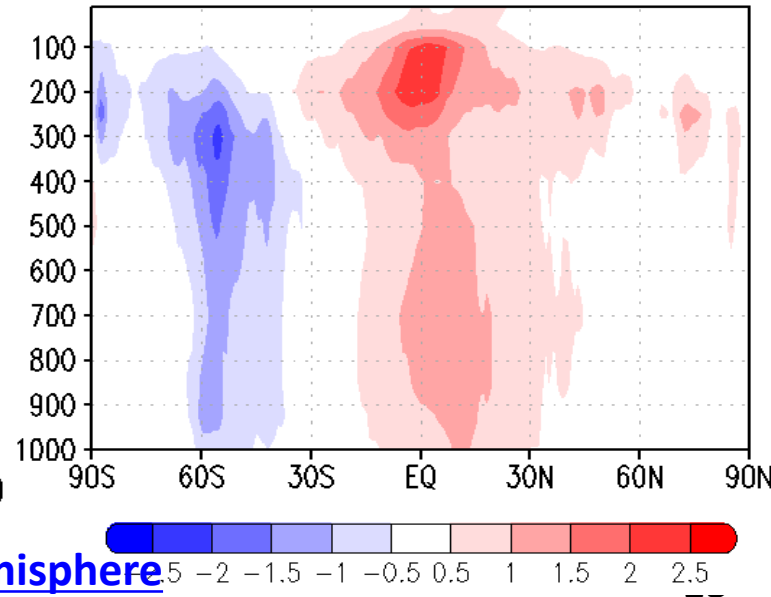
FV3GEFS-PROD



Summer







STTP has minor contribution to tropical

STTP overdispersion in winter hemisphere

FV3 GEFS real-time products

3 hourly out to 10 days at 0.25 degree resolution

6 hourly beyond 10 days at 0.5 degree resolution (out to 35 days)

- (GEFS v 11) 3 hourly out to 8 days then 6 hourly at 0.5 degree

New products--BUFR sounding

- All ensemble forecasts will insert to global sounding locations
- Include individual member, and ensemble mean

- **Produce 76 more variables**
  - ✓ **Surface variables (3)**
    - ❑ HGT On Cloud Ceiling
    - ❑ SNOHF and SNOWC
  - ✓ **PV on isentropic levels (2)**
    - ❑ 310 and 350K levels
  - ✓ **Vertical velocity on pressure levels (5)**
    - ❑ 10, 20, 30, 50 and 70 hPa levels
  - ✓ **More isentropic levels (4x3=12)**
    - ❑ 450, 550 and 650 K levels
    - ❑ U, V, T, PV
  - ✓ **More Pressure levels (6x5=30)**
    - ❑ 1, 2, 3, 5, 7 hPa levels
    - ❑ H, T, U, V, q, w
  - ✓ **Sigma levels (6x4=24)**
    - ❑ Lowest 4 sigma levels
    - ❑ H, T, P, U, V, RH

Retrospective runs

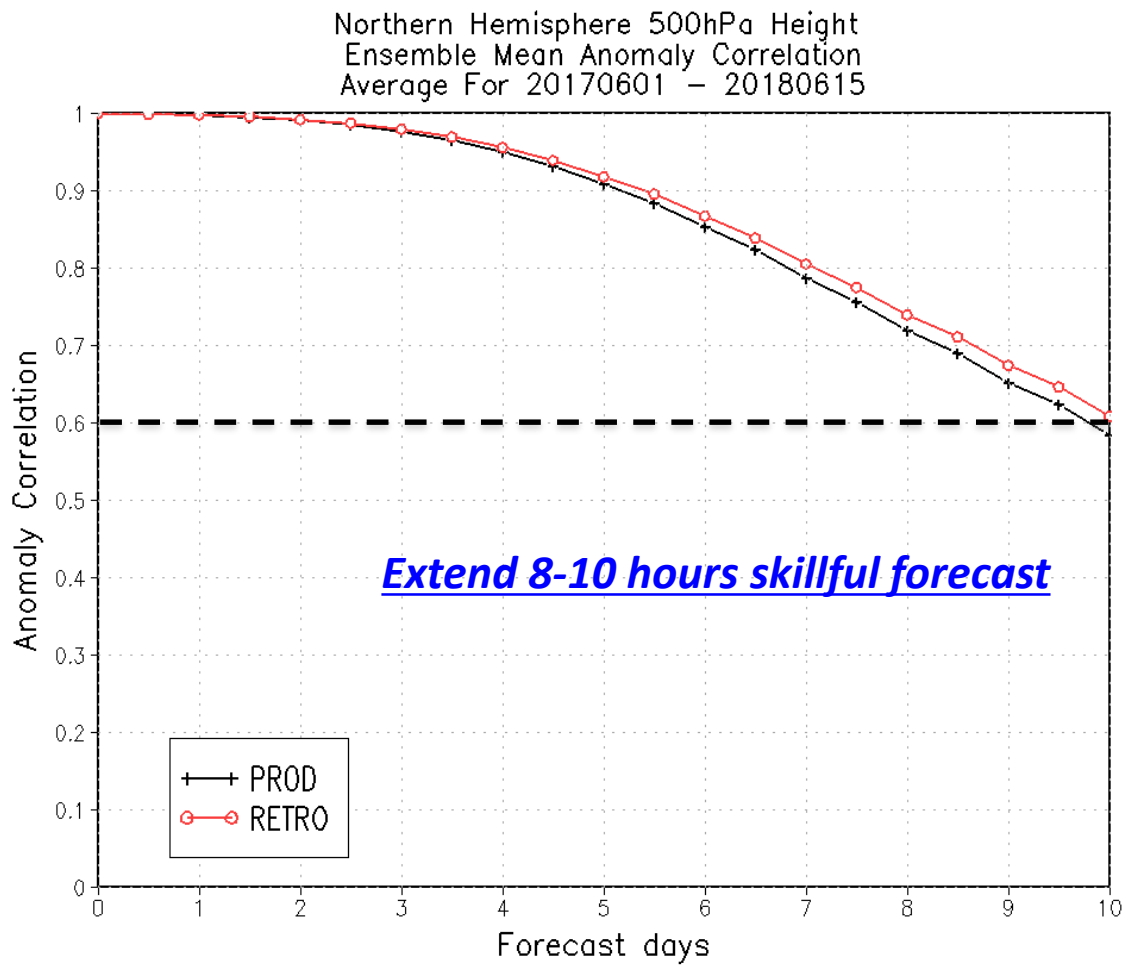
- **Out to 10 days**
  - Jun. 2017 – Nov 2018 , 00UTC (1.5 years) (Done)

    Three hurricane seasons
  - Summer 2017 (July – October), 12UTC (In Progressing)
  - Summer 2018 (July – October), 12UTC (In Progressing)
  - Summer 2019 (July – October); 12UTC

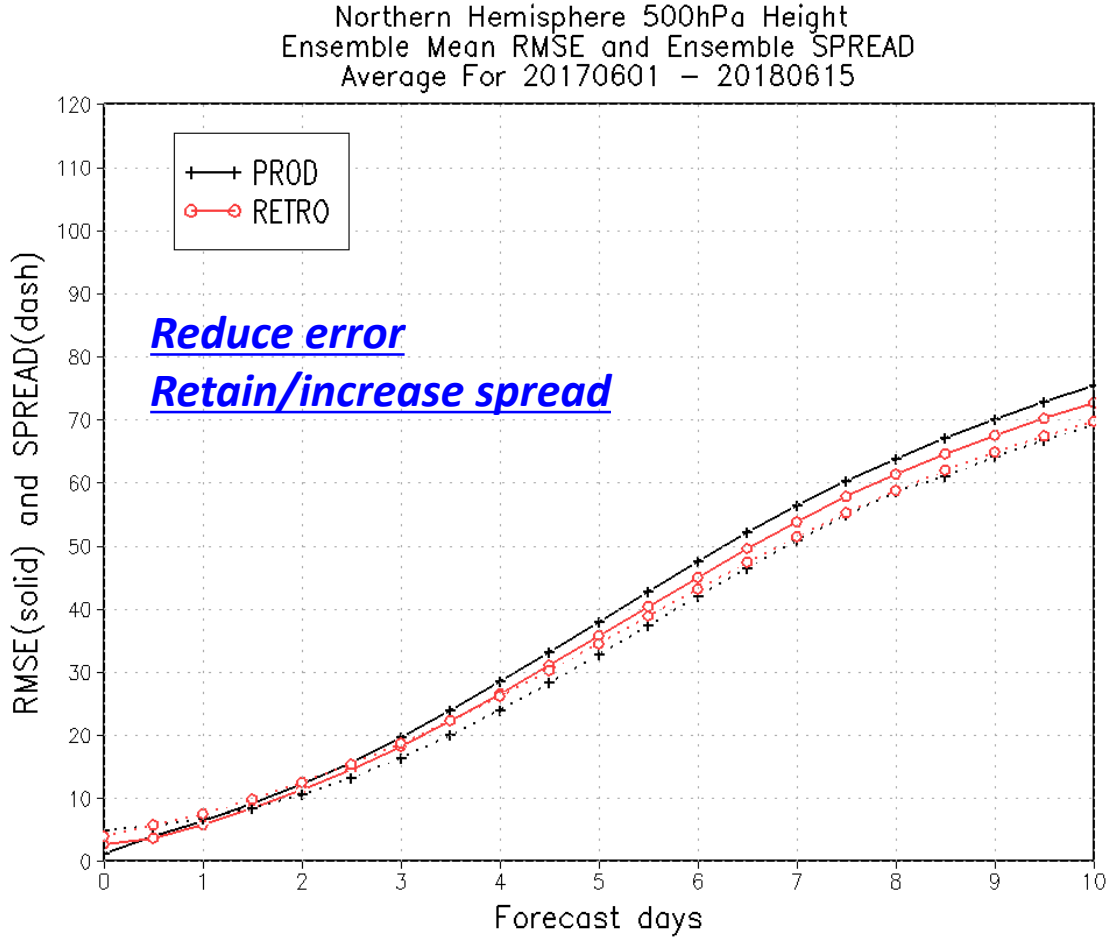
- **Out to 16 days** (coupling to wave ensemble)
  - Dec. 2018 – Nov.2019, 00UTC (one year)

Verification (based on 1-year retrospective)

NH Z500 PAC

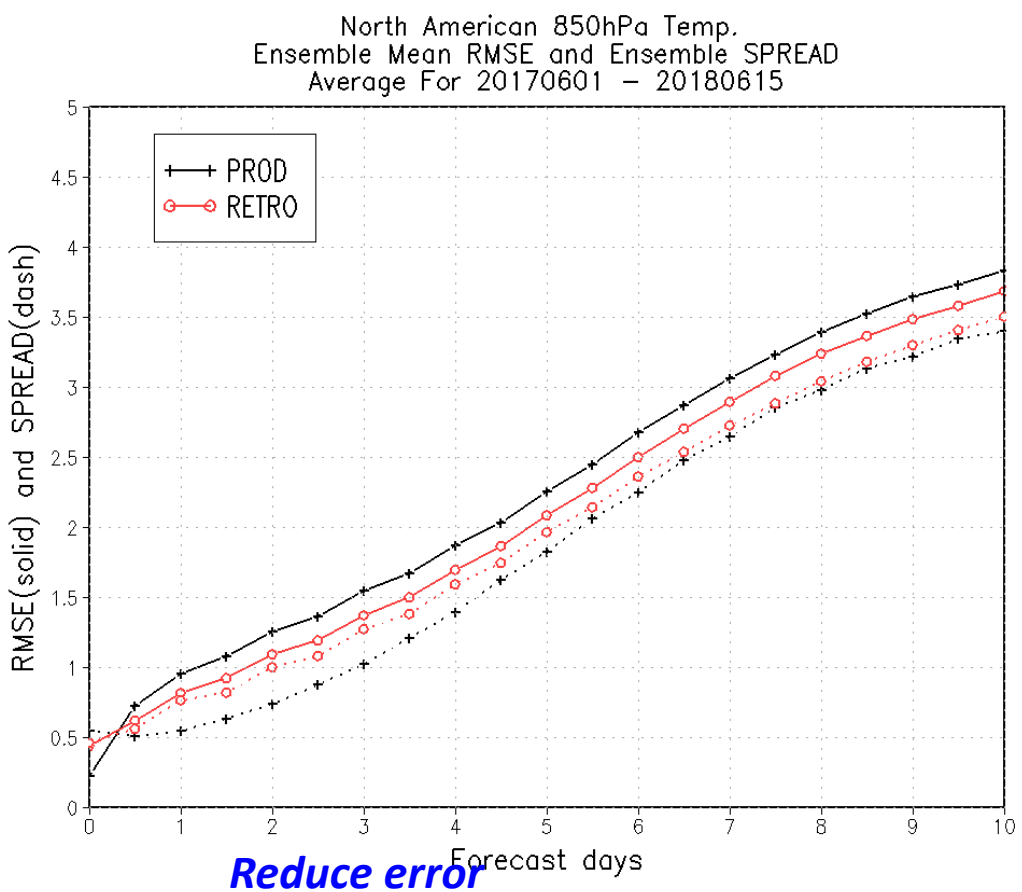


NH Z500 RMSE (solid) and Spread (Dash)



Verification (based on 1-year retrospective)

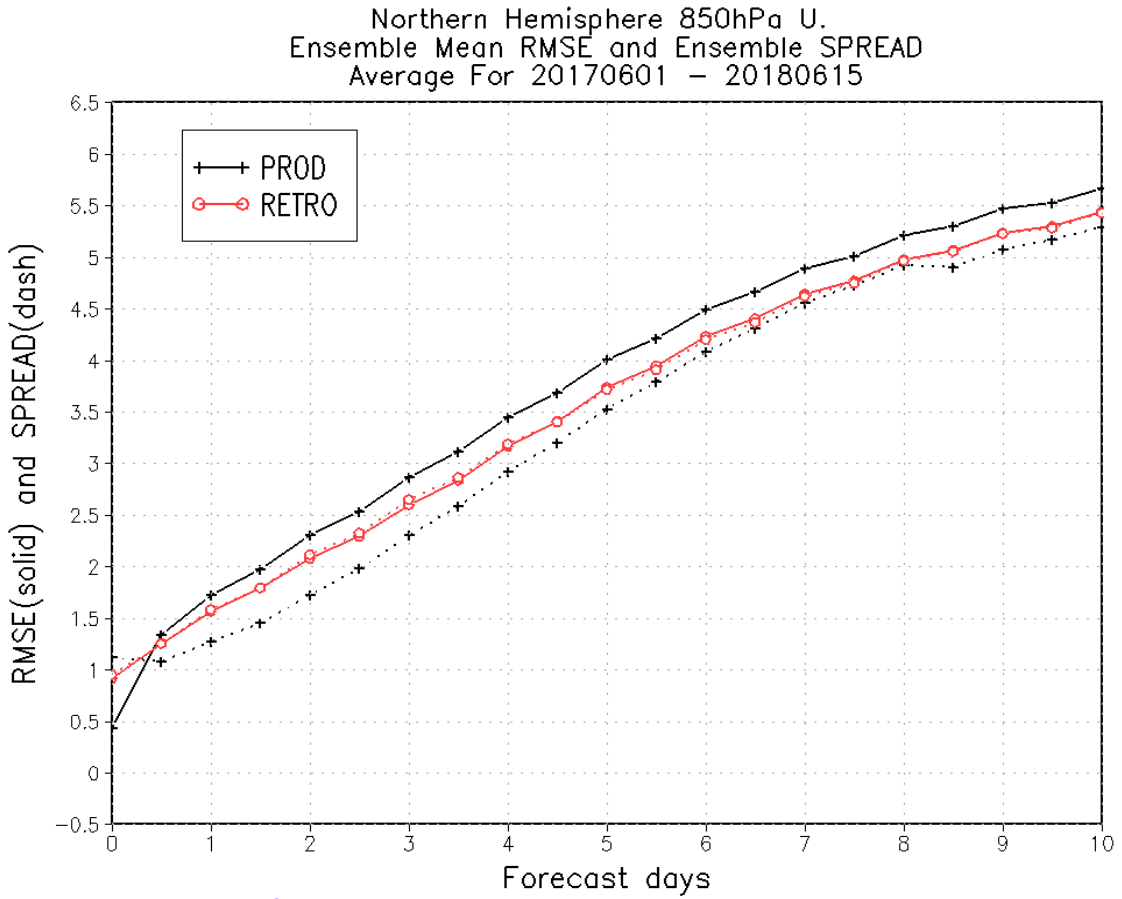
NH T850 RMSE and Spread



Reduce error

Increase spread

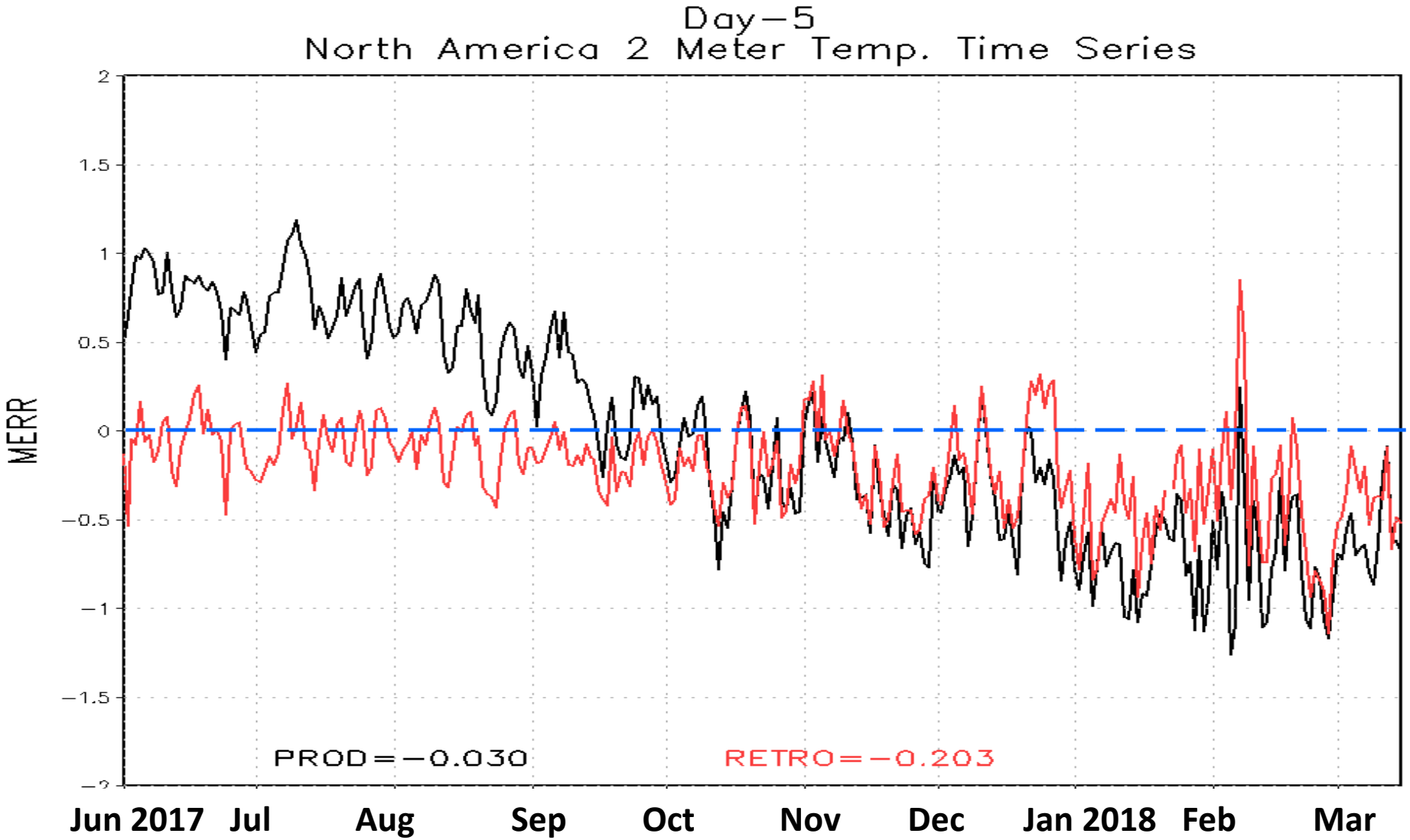
NH U850 RMSE and Spread



Reduce error

Increase spread

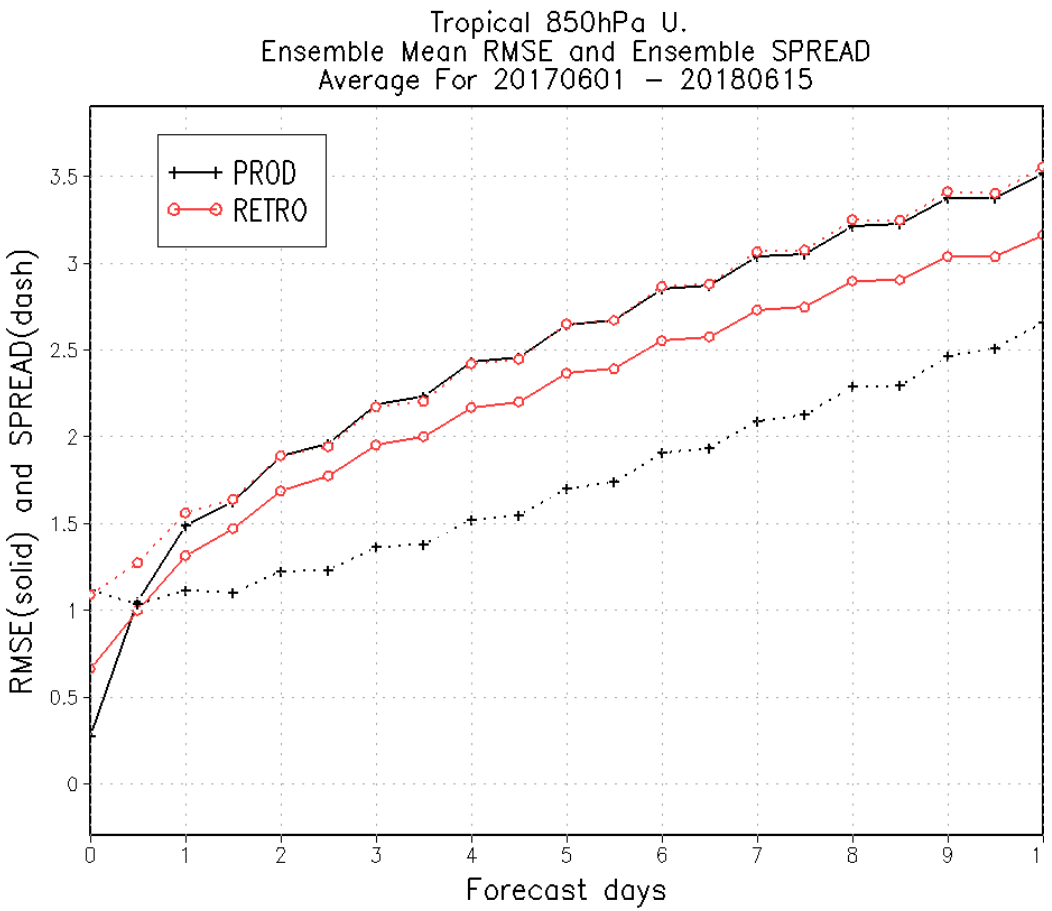
NA 2-m Temperature Bias



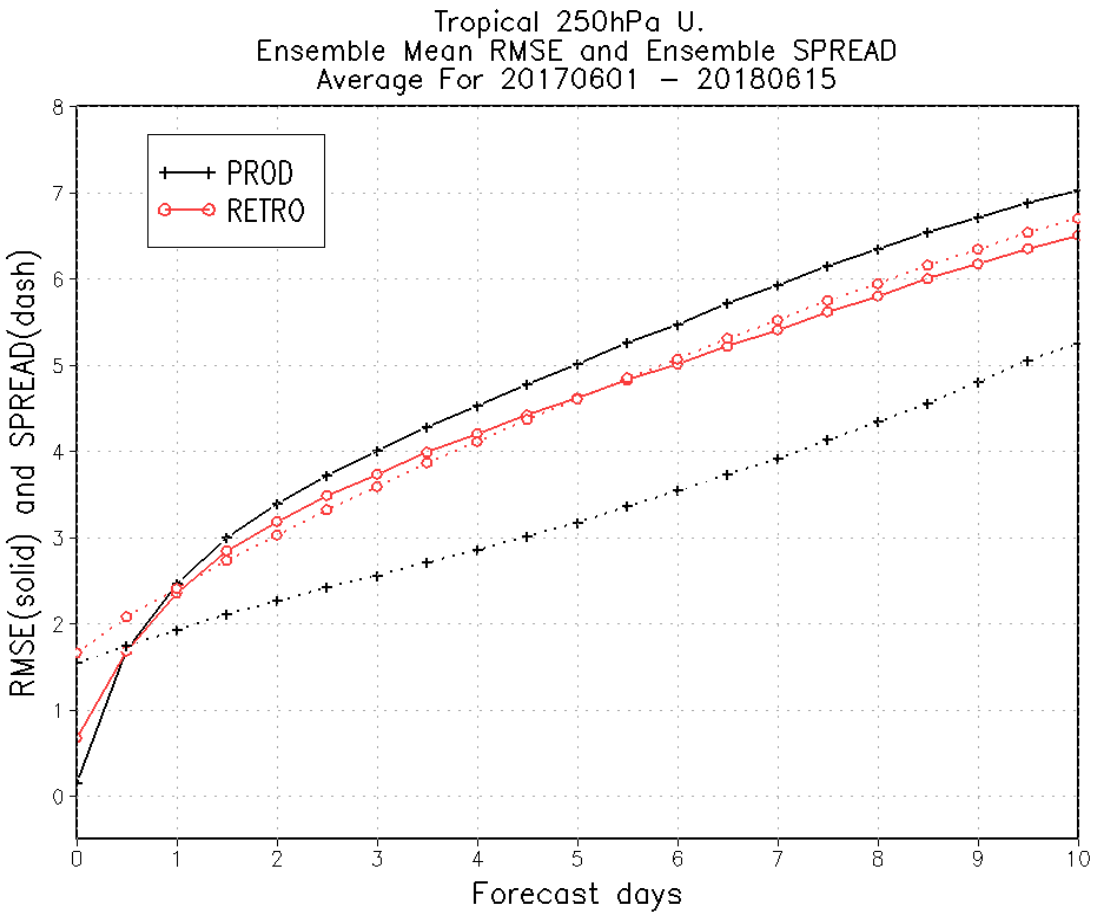
- **Smaller summer warm bias, slightly smaller winter cold bias**

Verification (based on 1-year retrospective)

TR U850 RMSE and Spread



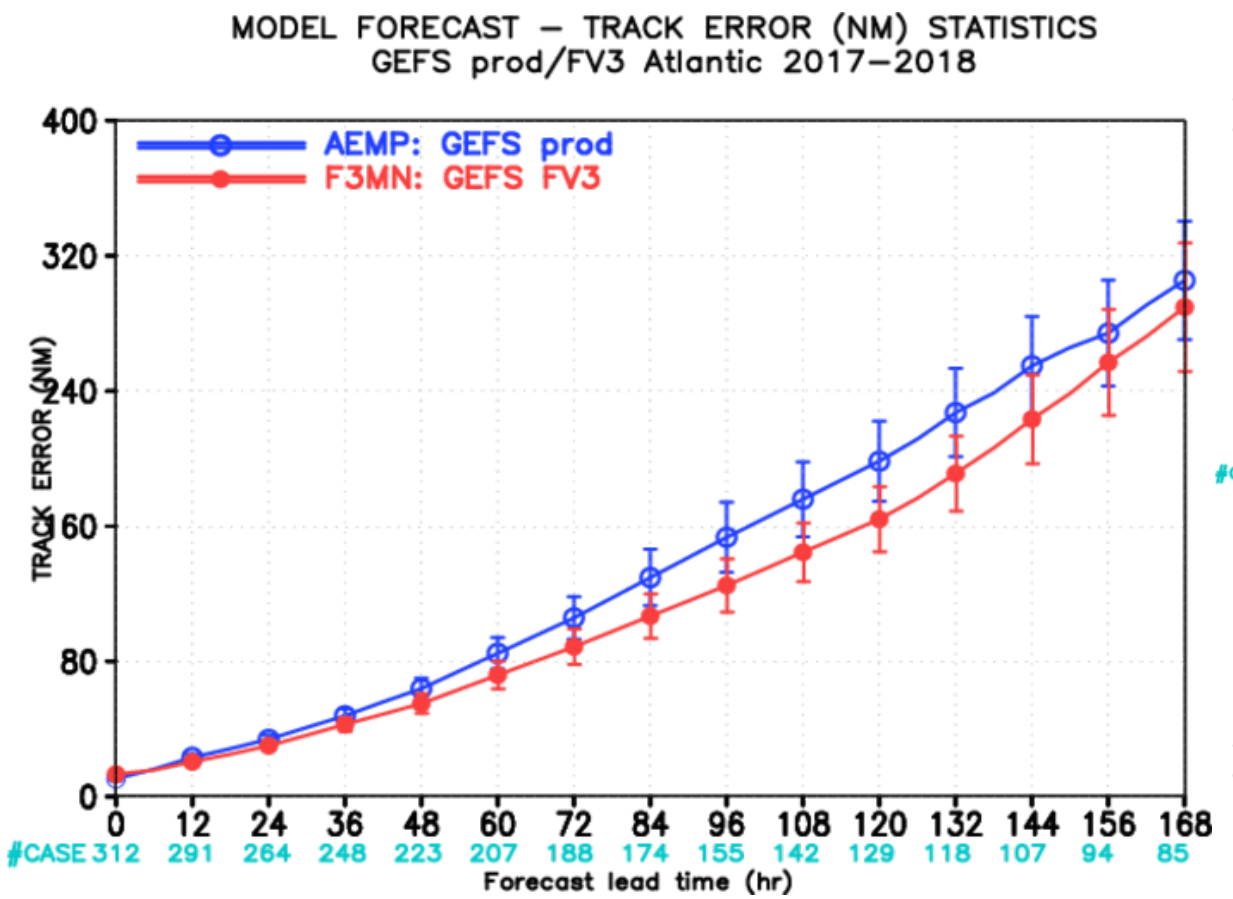
TR U250 RMSE and Spread

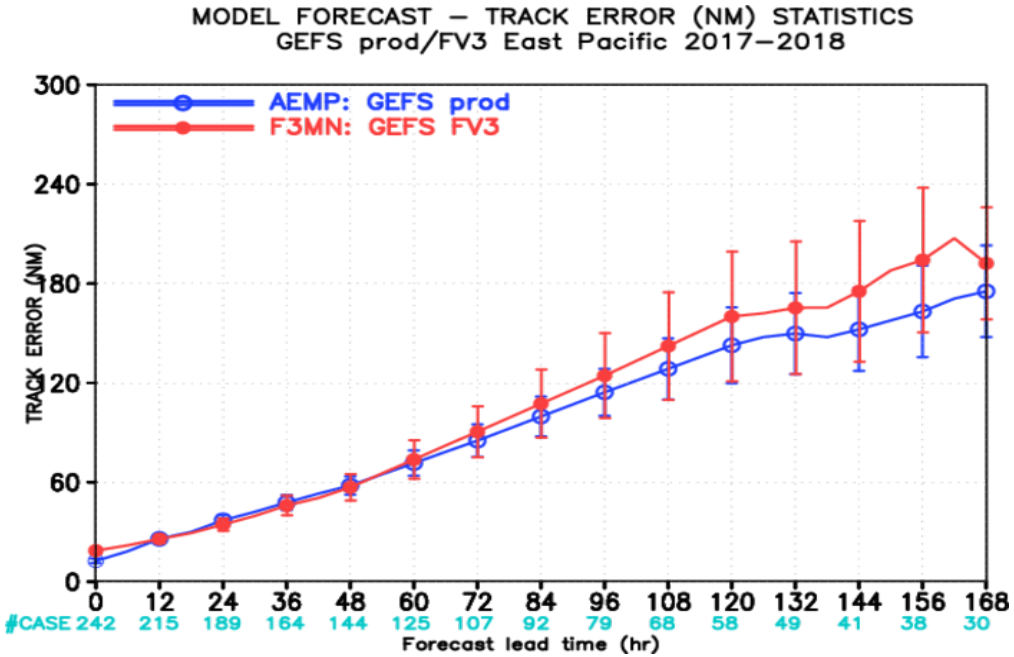


- Overspread at low levels over tropics

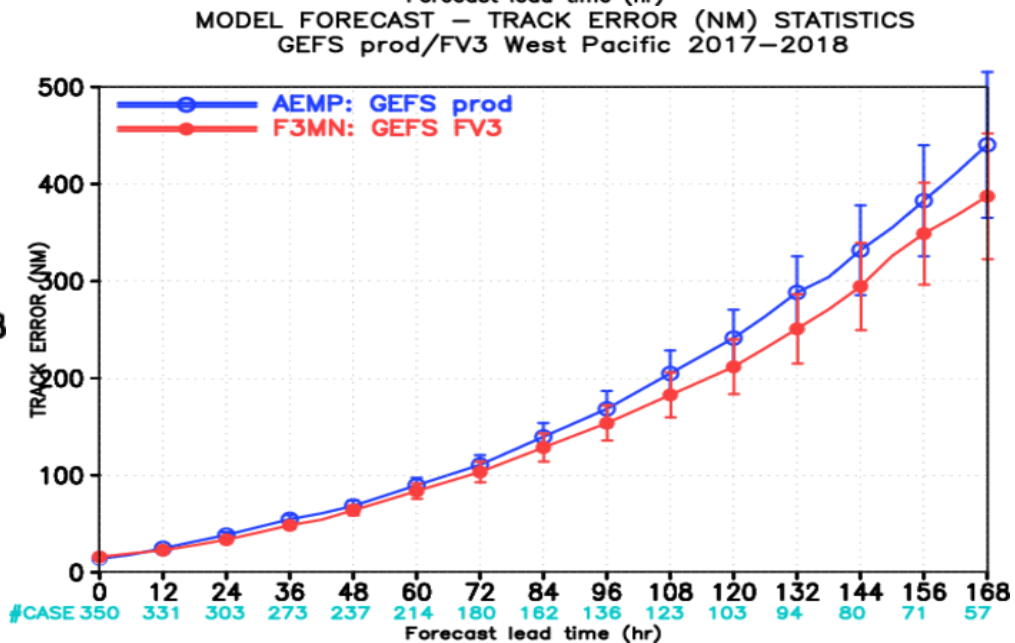
Tropical cyclone track forecast（2017 and 2018)

Atlantic





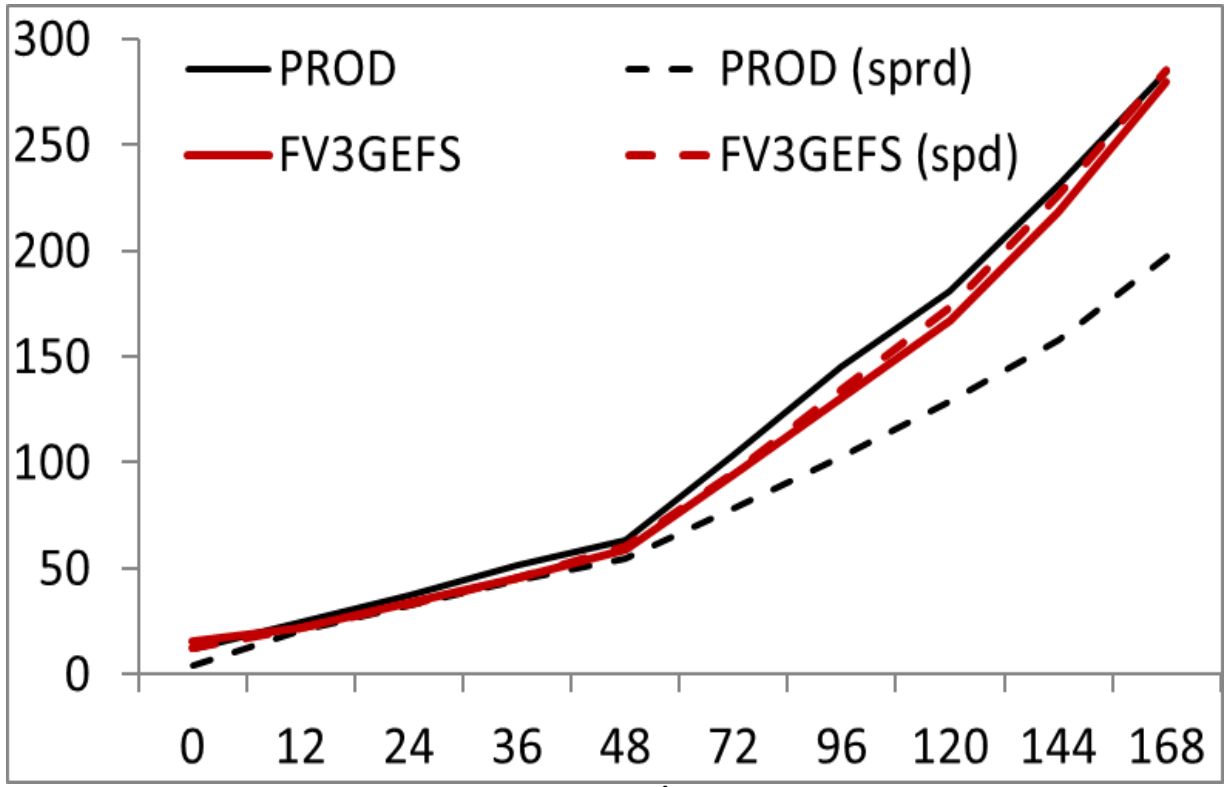
EP



WNP

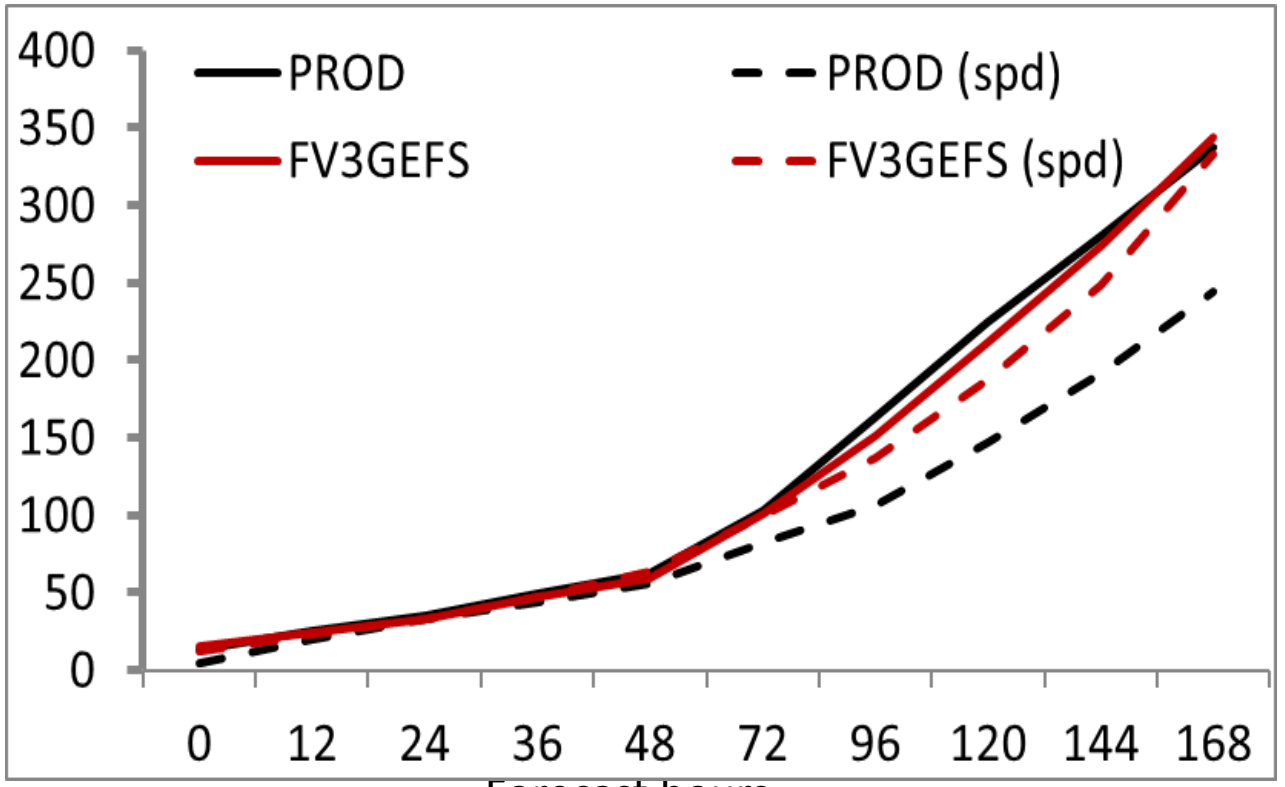
Track forecast error and spread (WNP/EP/ATL)

2017



CASES 297 268 241 210 184 141 106 82 66 53

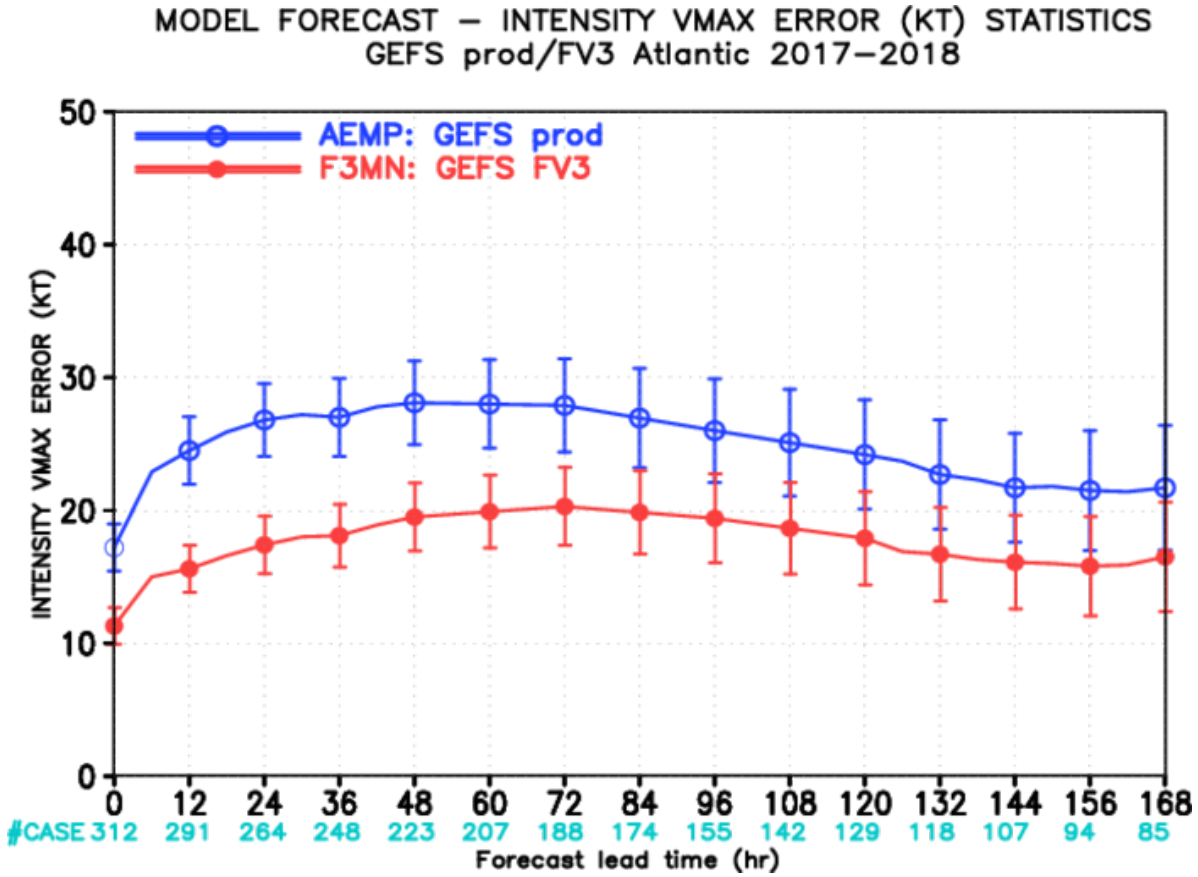
2018



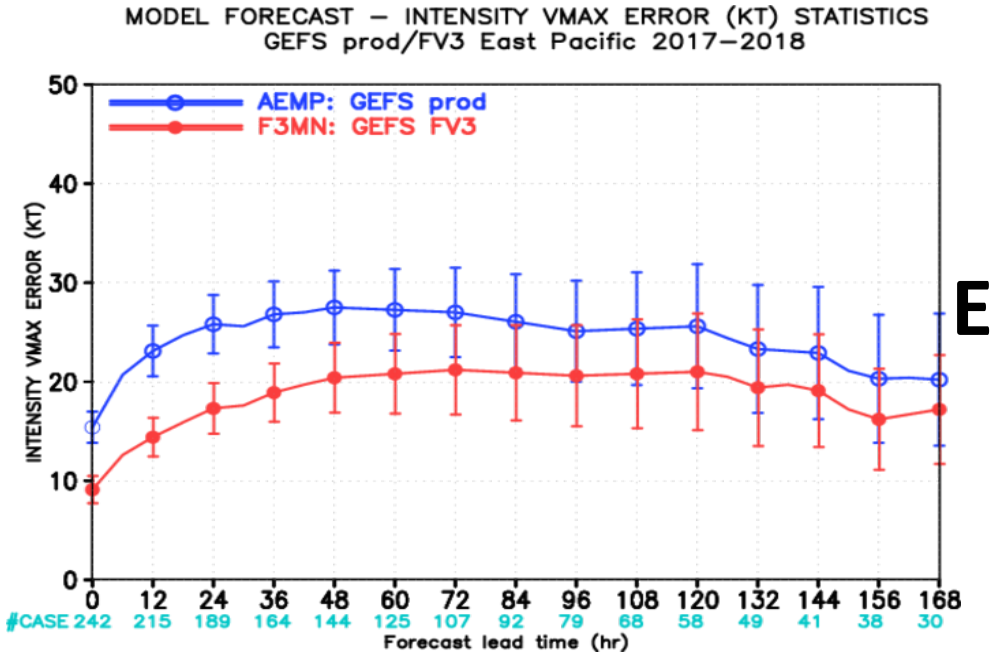
CASES 328 301 268 238 209 157 117 89 66 51

Tropical cyclone intensity forecast（2017 and 2018)

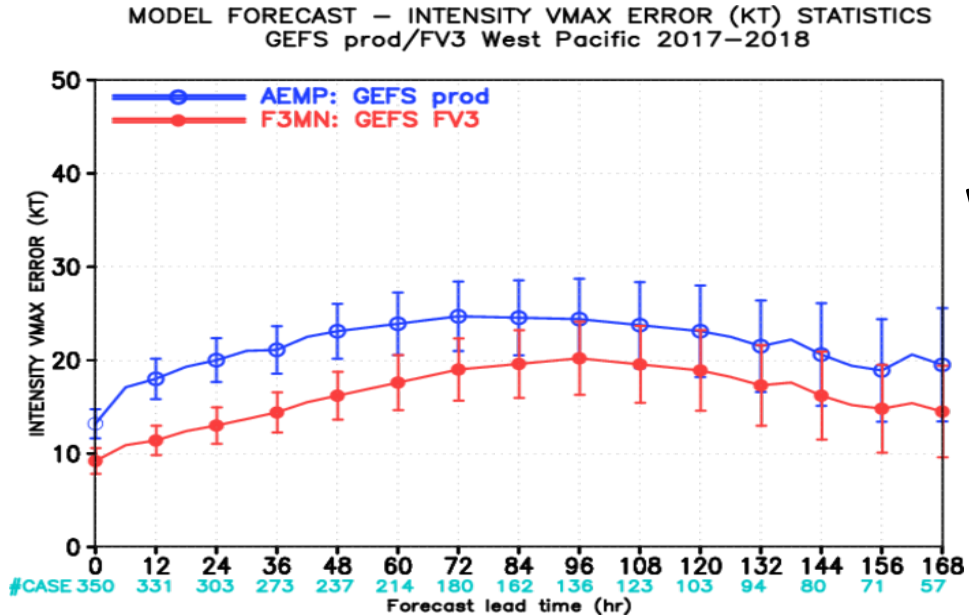
Atlantic



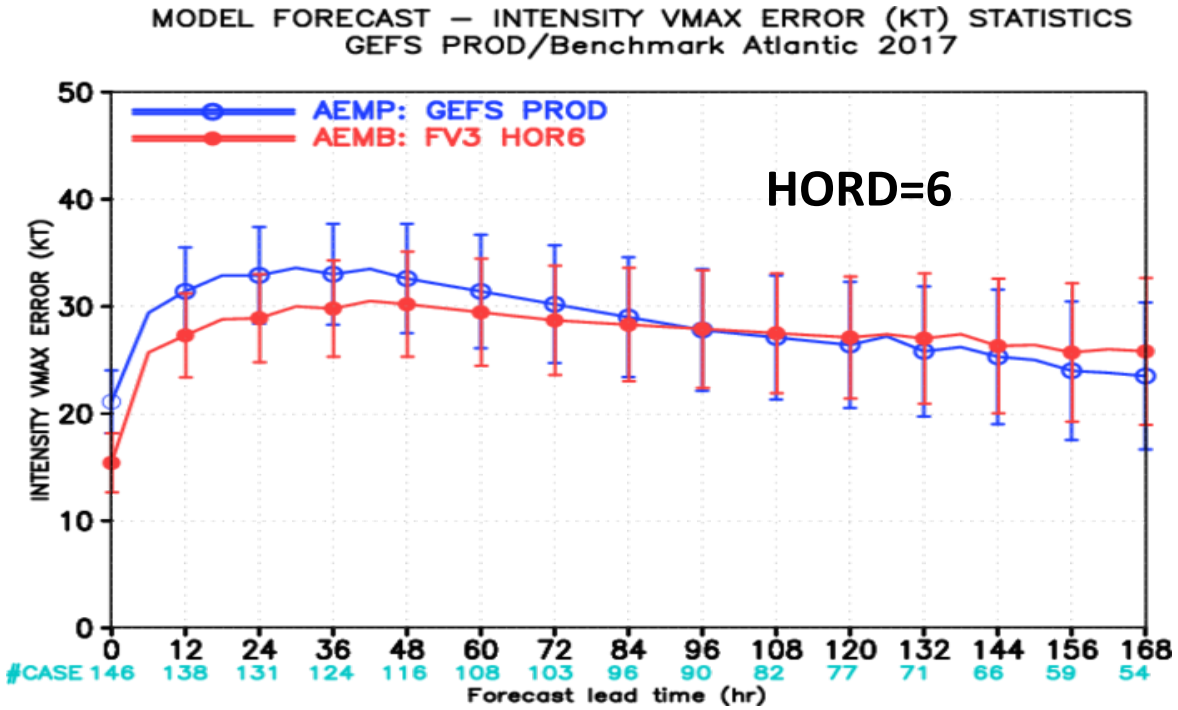
EP

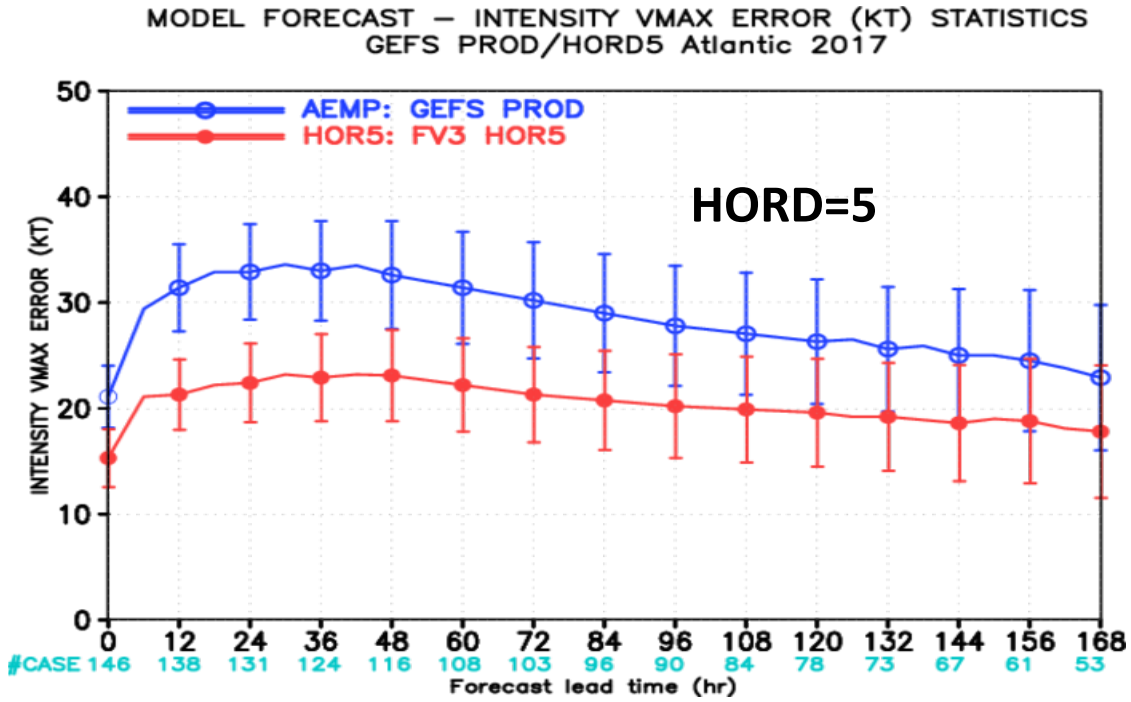


WNP



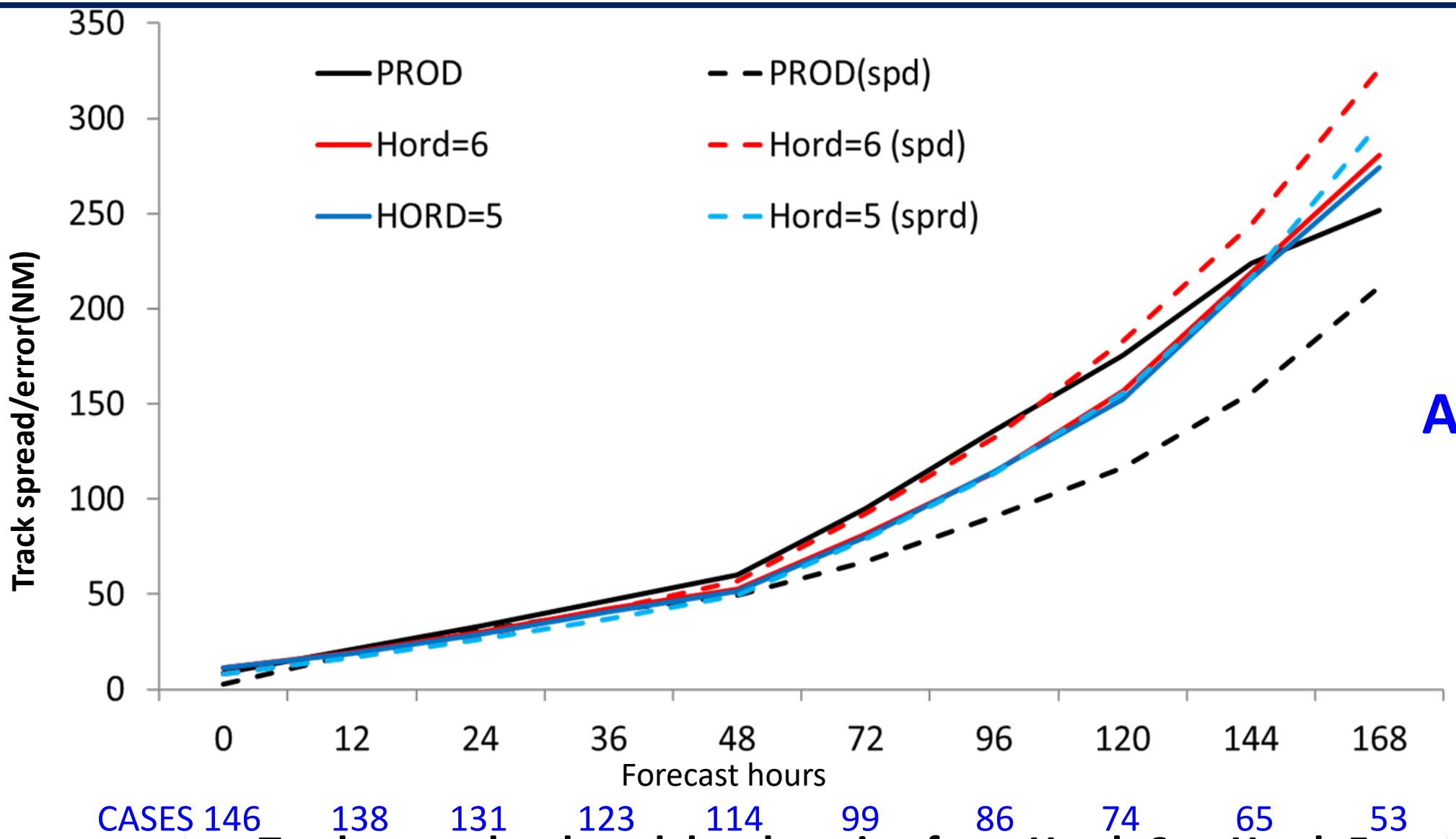
Influence of the advection scheme on TC intensity





- **Intensity forecast is improved significantly with less diffusive advection scheme (Hord=5)**
  - Hord=5 or 6: the advection schemes, both use PPM with same accuracy order except Hord=5 has a weaker $2\Delta x$ filter and less diffusive
  - Amplitude of SKEB is tuned with Hord=5

Influence of the advection scheme on TC track spread

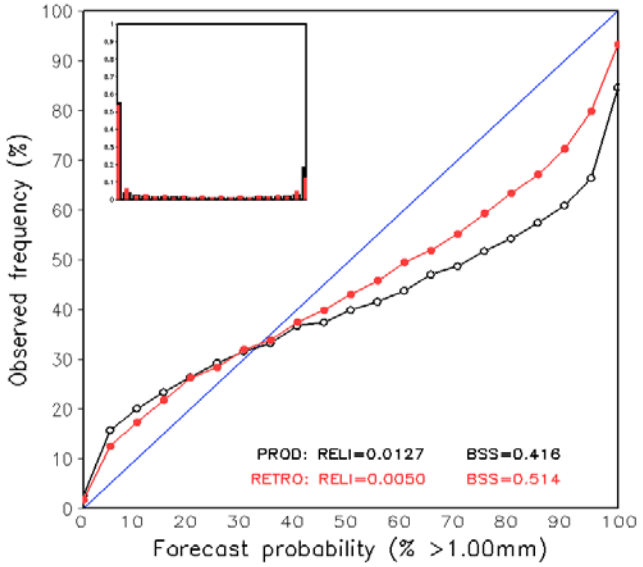


Atlantic 2017

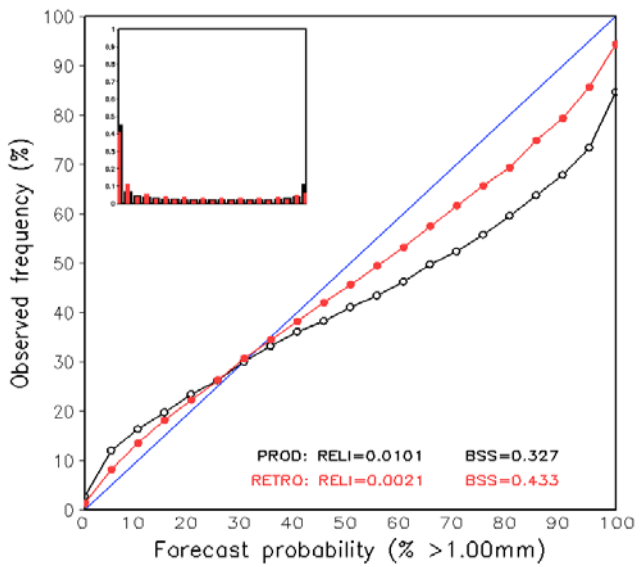
- **Track spread reduced by changing from Hord=6 to Hord=5**

Precipitation-Reliability Diagram (20170601-20180531)

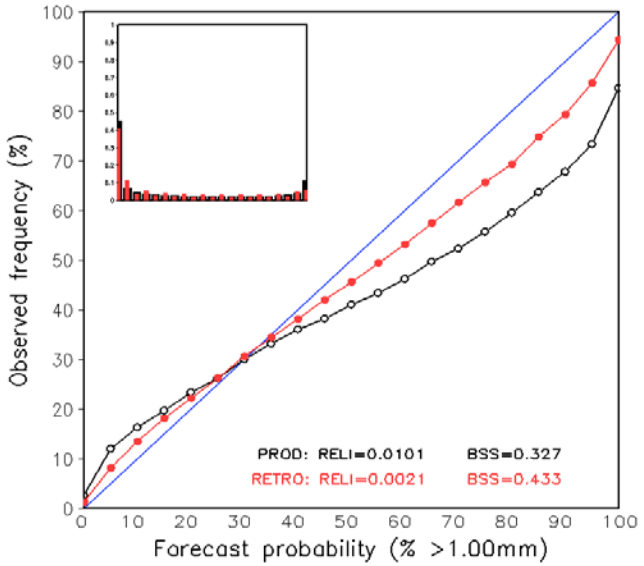
>1 mm; 12-36 hrs



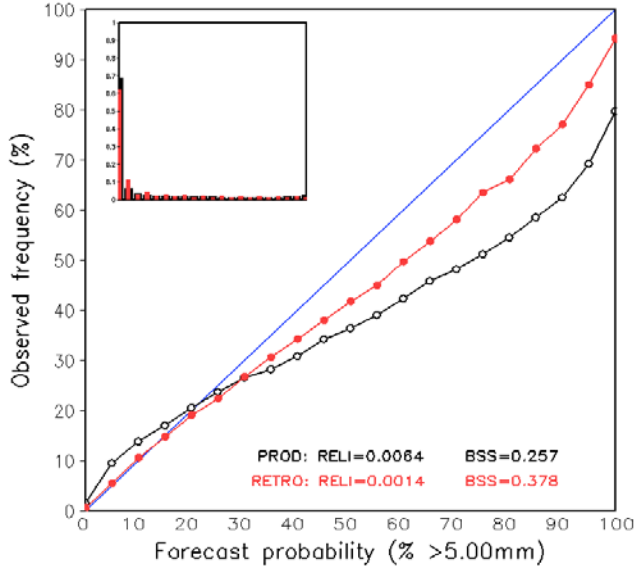
>1 mm; 60-84 hrs



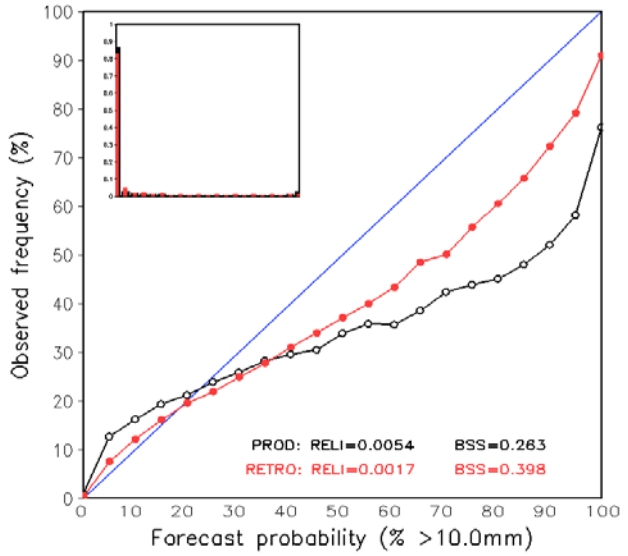
>1 mm; 108-132 hrs



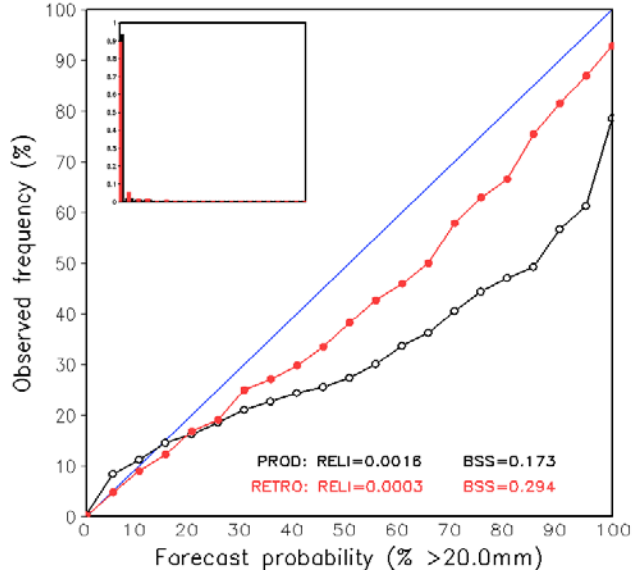
>5 mm; 60-84 hrs



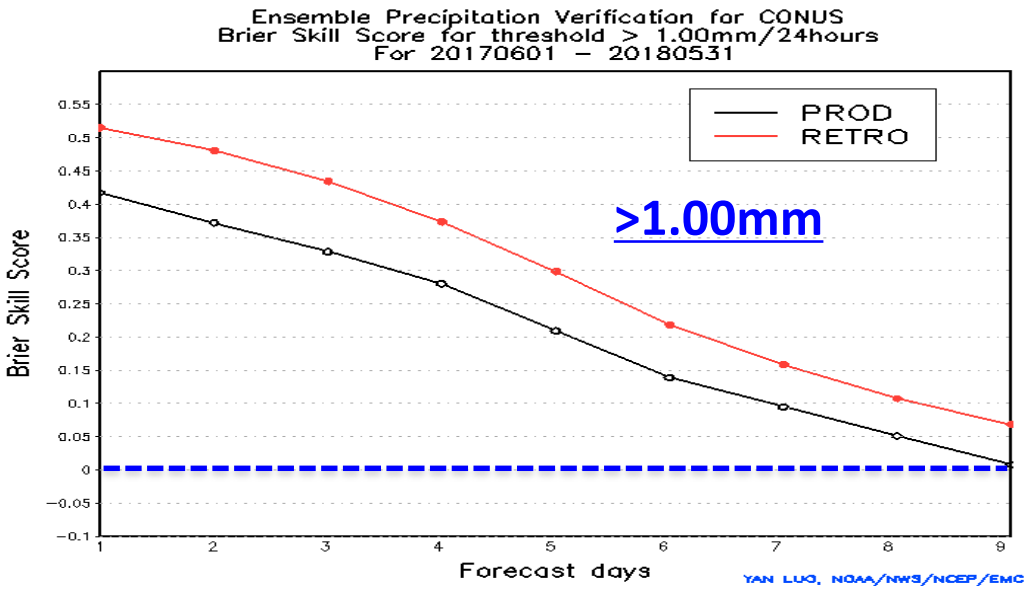
>10 mm; 12-36 hrs

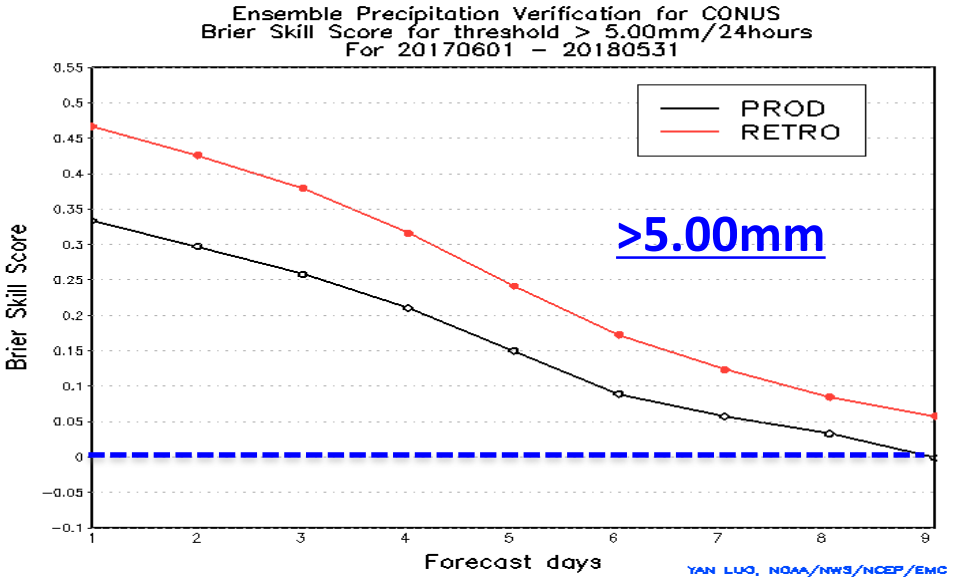


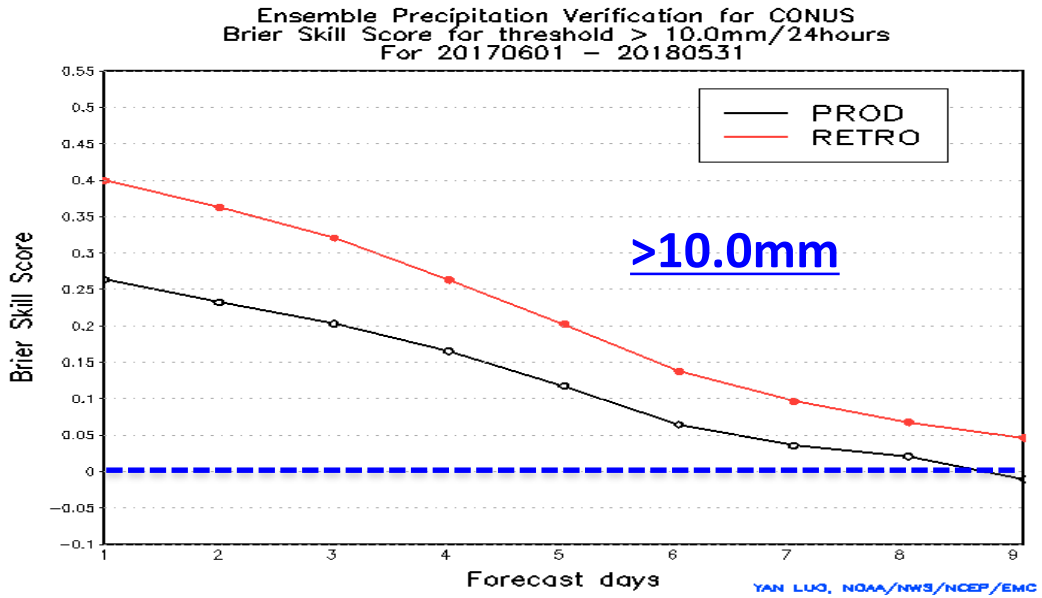
>20 mm; 36-60 hrs

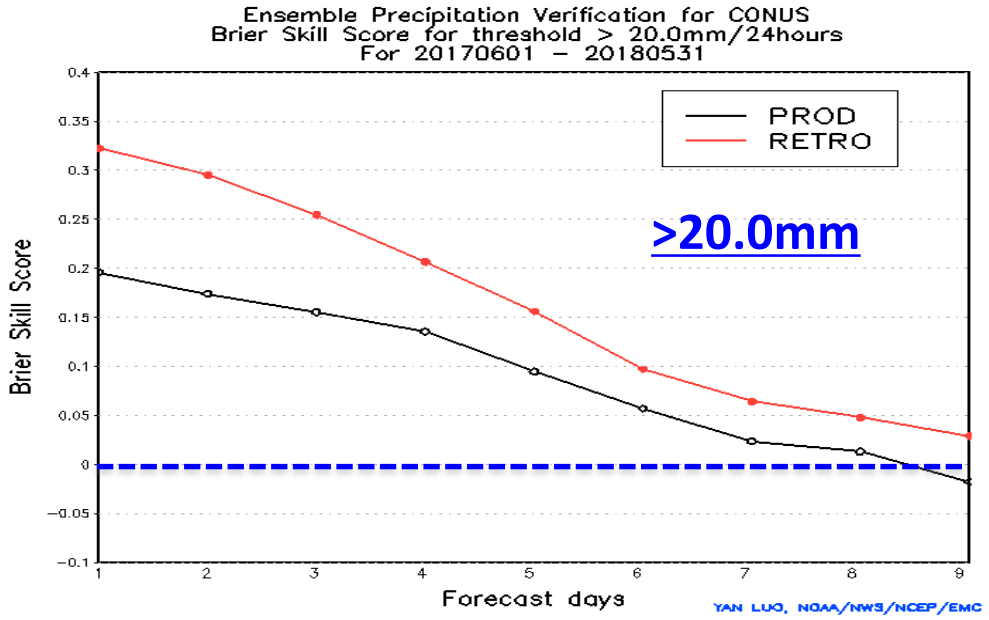


Precipitation Brier Skill Score for CONUS

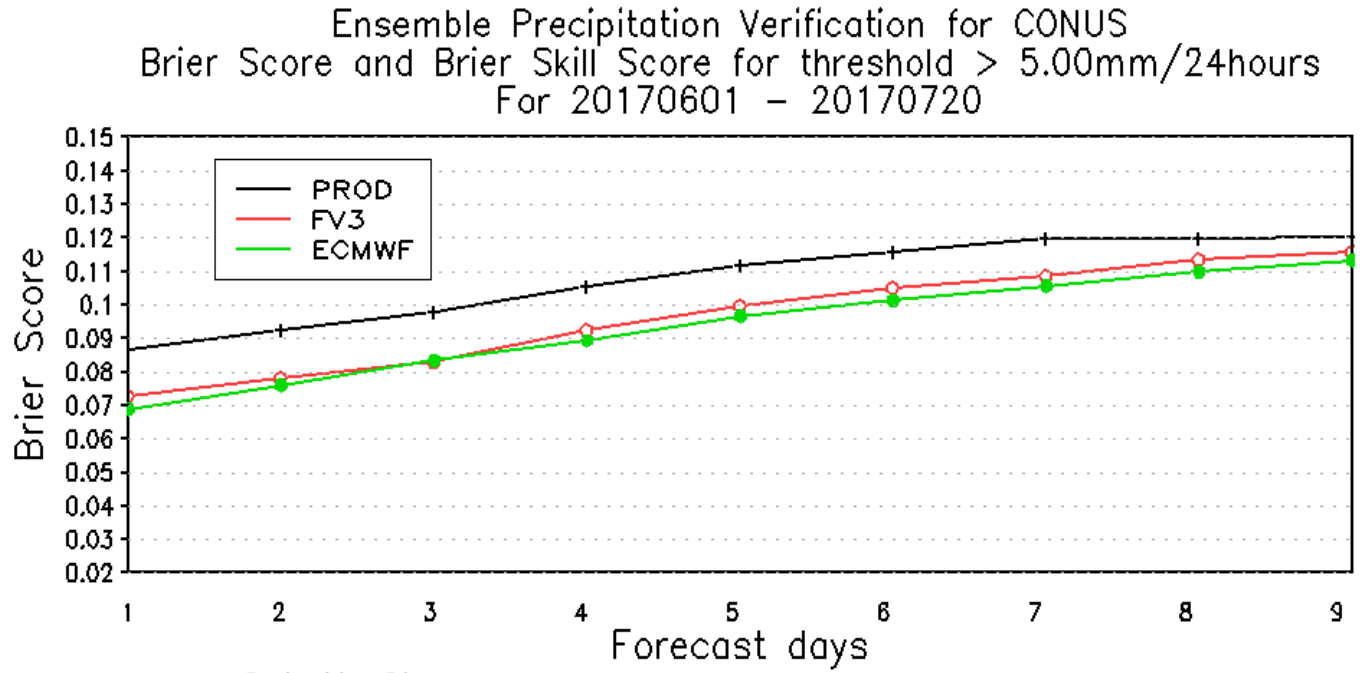


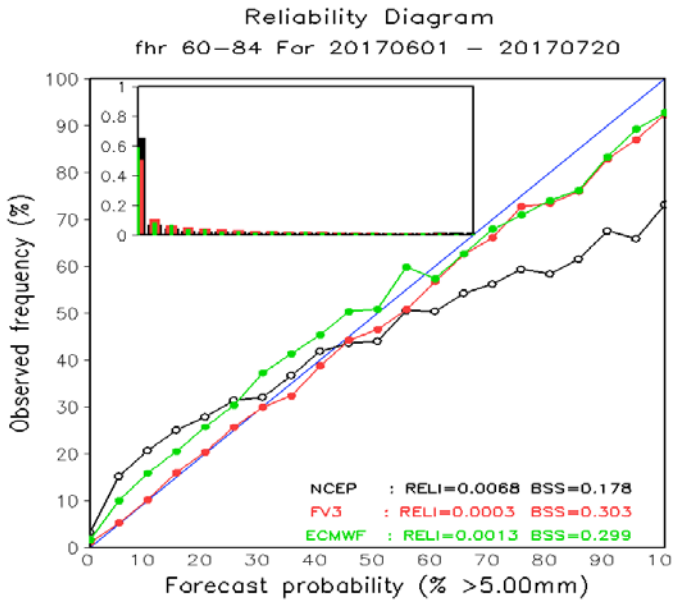


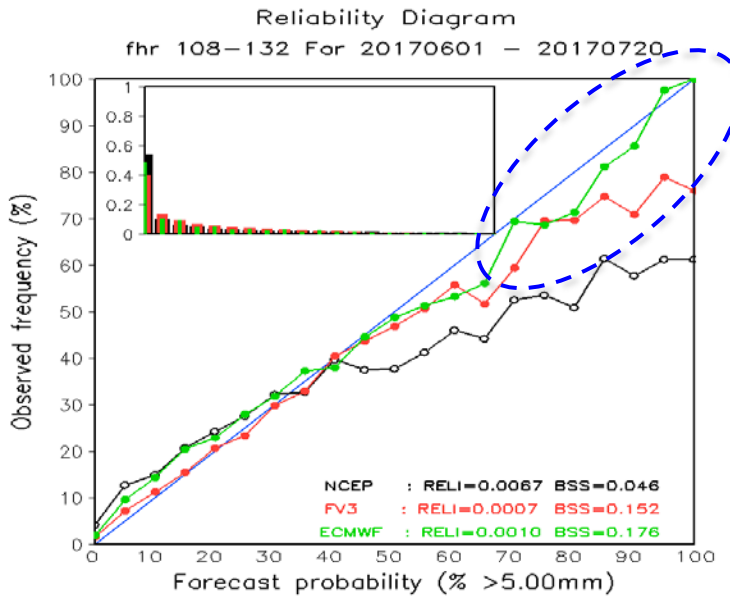




Probabilistic Quantitative Precipitation Forecast







Compare to ECMWF

Prod – operation GEFS

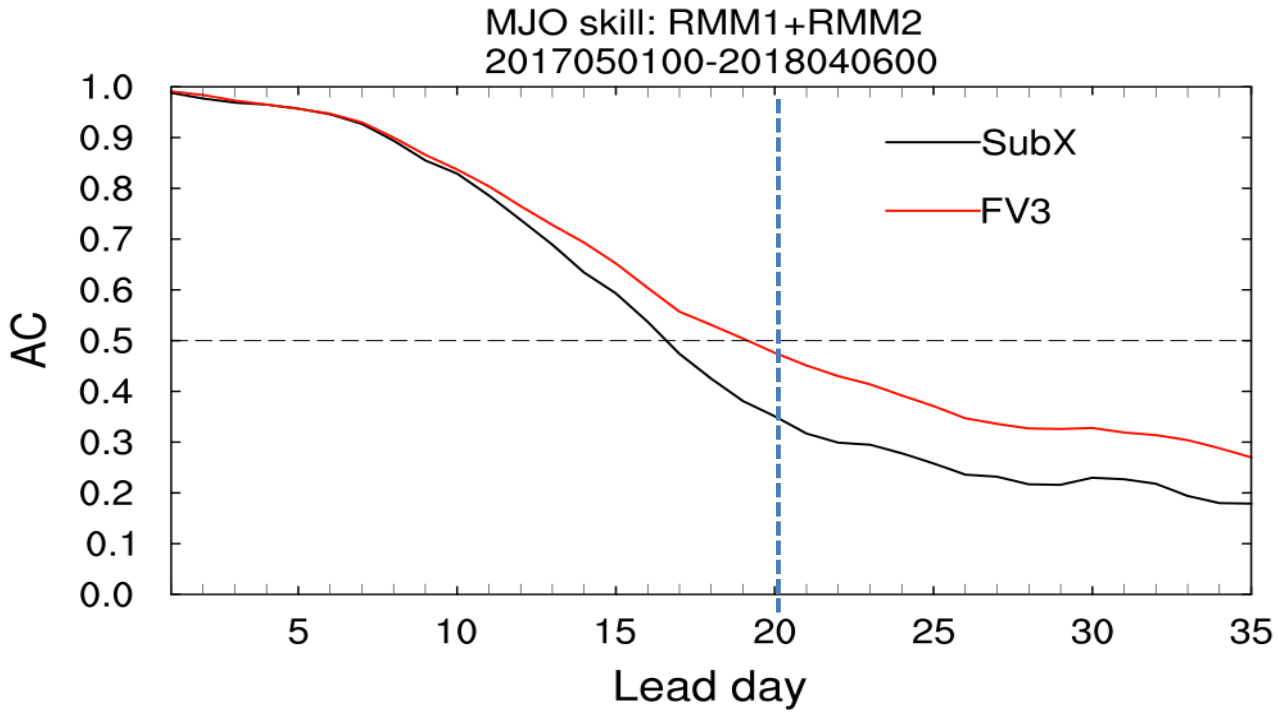
FV3 – FV3 GEFS

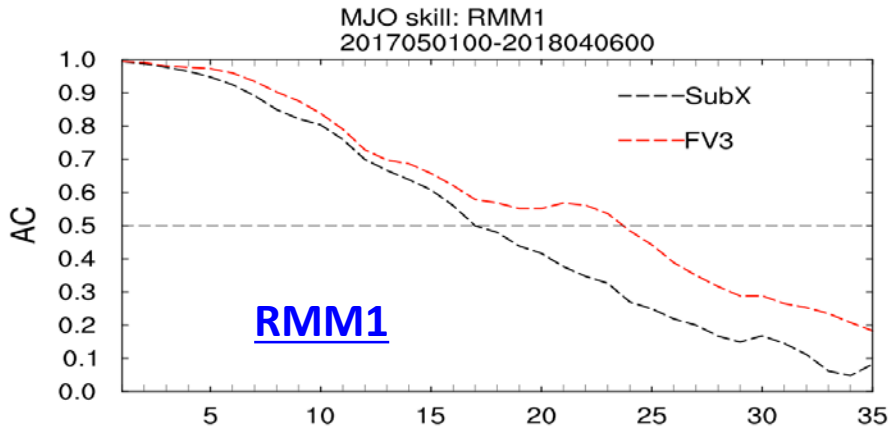
ECMWF – ECMWF ensemble

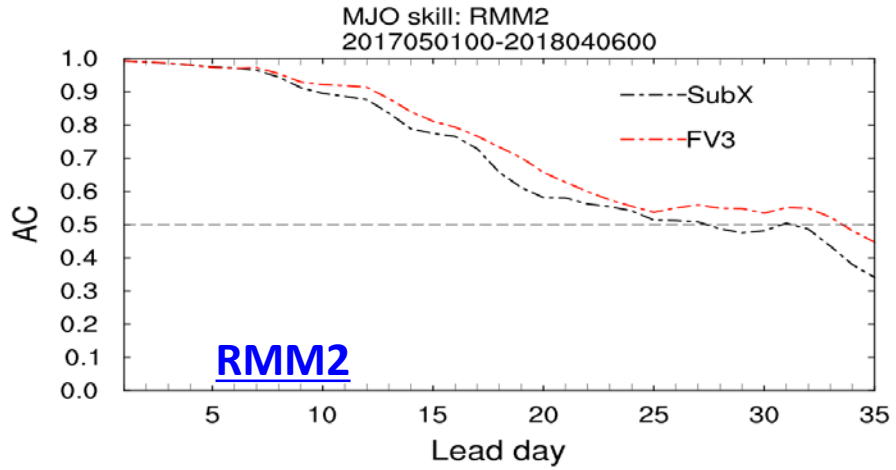
Possible reasons:

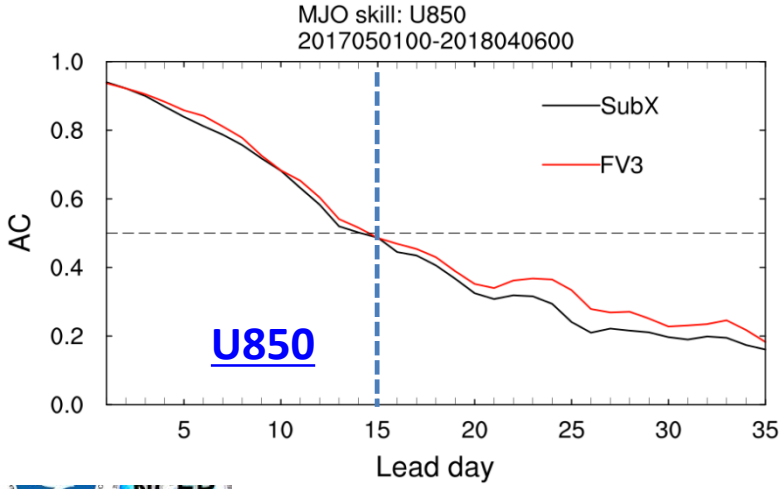
- FV3 – dynamics
- GFDL microphysics
- New stochastic (SPPT)
- Others
  - Better initial analysis
  - Better initial perturbation
  - Higher model resolution

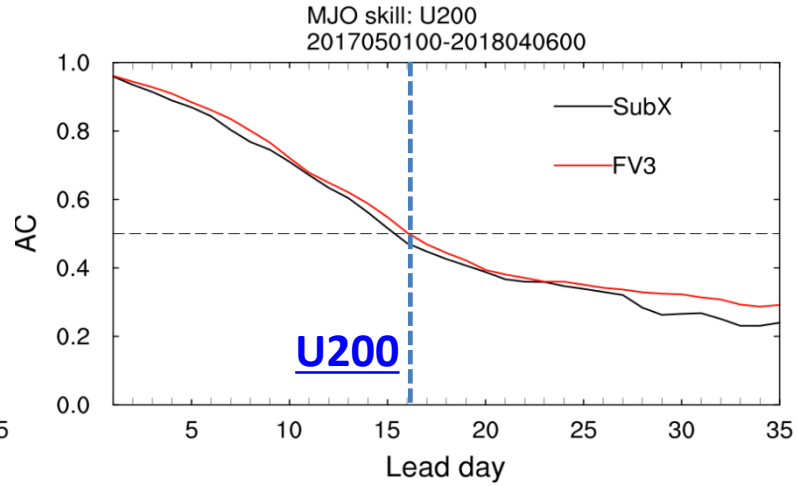
MJO Prediction Skills

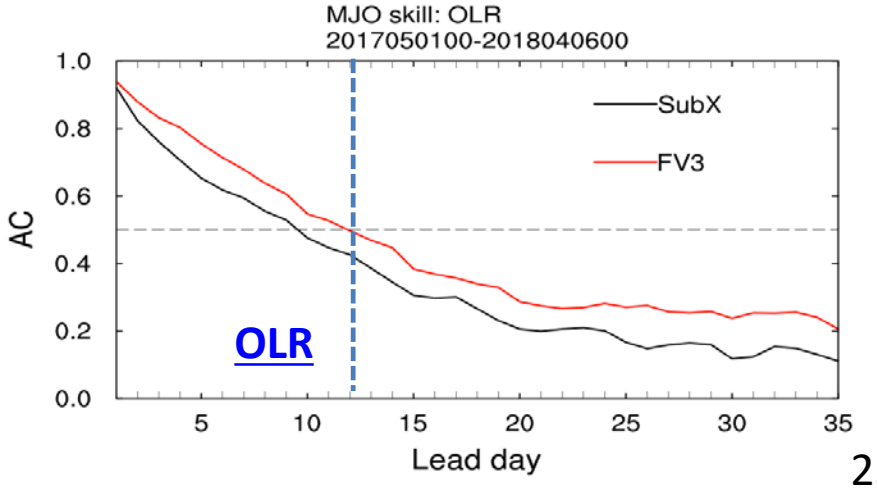












FV3GEFS performance summary

- Significantly improved large-scale forecast and extended skillful forecast about 8-10 hours
- Greatly improved PQPF, much more reliable precipitation forecast
- More intense TCs with smaller intensity forecast error
- Reduced hurricane track forecast error (based on incomplete retrospective runs), larger track spread
- Reduced summer warm bias, but no significant improvement in winter cold bias
- Over dispersion at tropical lower levels

When/What will FV3-GEFS deliver to public?

Fall 2020

25 km resolution
31 members
4 times per day
Out to 35 days (once per day)

PLUS

30 years GEFS reforecast
Once per day at 00UTC
5 members out to 16 days
11 members out to 35 days (every Wednesday)

Future GEFS (v13)

- **Unified Forecast System (UFS)**
  - Improved FV3 and advanced physics
- **Full coupling**
  - Atmosphere-Land-Ocean-Sea/Ice-Wave-Aerosol
- **Model uncertainties**
  - Introduce physical process based stochastic parameterization
- **Reanalysis**
  - Coupled DA
- **Reforecast**
  - 30+ years
- **Increase vertical resolution**
  - Take advantage for stratosphere prediction
- **Extended to 45-day forecast**
- **Expect in operation - 2023**

More Evaluations

- The evaluation of surface temperature (T2m)
  - Dr. Hong Guan will review it on Thursday through reforecast, include week-2; weeks 3&4

- The evaluation of tropical predictions (MJO and others)
  - Dr. Wei Li will review it on Thursday through reforecast

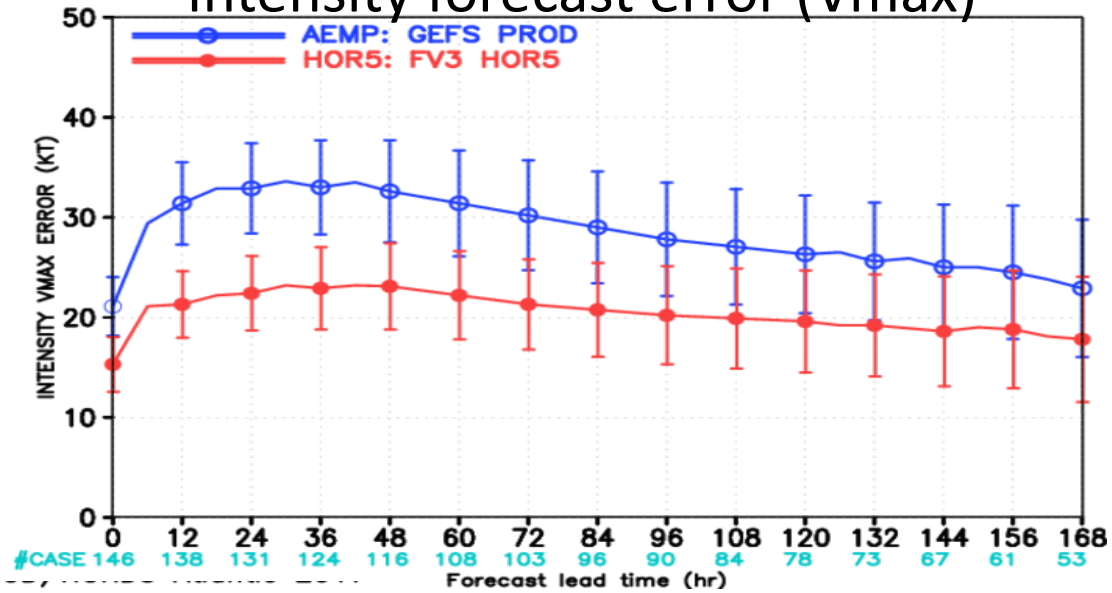
Thanks!!!

Evolution of NCEP GEFS configuration

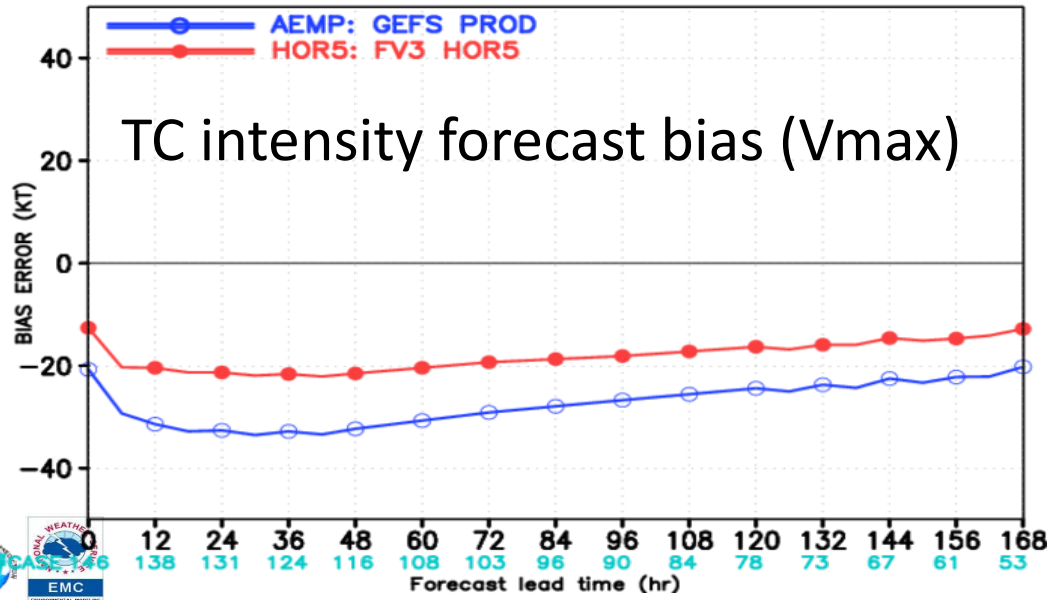
Version	Implementation	Initial uncertainty	TS relocation	Model uncertainty	Resolution	FCST length	Ens Size members	Daily frequency
V1.0	1992.12	BV	None	None	T62L18	12	2+1	00UTC
V2.0	1994.3				T62L18	16	10+1 (00UTC) 4+1 12UTC)	00,12UTC
V3.0	2000.6							
V4.0	2001.1				T126L28(0-2.5) T62L28(2.5-16)		10+1	
V5.0	2004.3				T126(0-3.5) T62L28(3.5-16)			
V6.0	2005.8				T126L28(0-7.5) T62L28(7.5-16)			00,06,12, 18UTC
V7.0	2006.5	BV- ETR	TSR		T126L28		14+1	
V8.0	2007.3						20+1	
V9.0	2010.2			STTP	T190L28			
V10.0	2012.2				T254L42 (0-8) T190L42 (8-16)			
V11.0	2015.12	EnKF (f06)			TL574L64 (0-8) TL382L64 (8-16)			
V12.0	Q4FY20		None	SPPT + SKEB	C384L64 (0-35)	35	30+1	

Hurricane intensity forecast (2017 Summer)

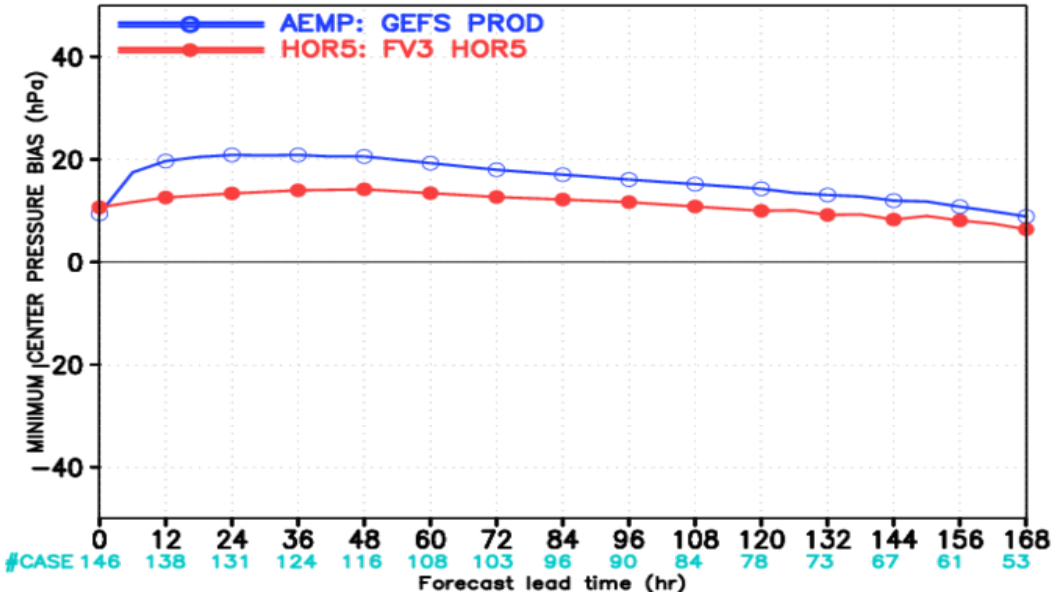
Intensity forecast error (Vmax)



Vmax bias



Pmin bias



SST Schemes (operation) and 2-tier SST approach

- Assimilate coupling

- **Operational:** Climatology relaxation

$$SST_f^t = \left[SST_a^{t0} - SST_c^{t0}\right] e^{-(t-t_0)/90} + SST_c^t$$

- **FV3GEFS:**

$$SST_f^t = (1-w) * \left[SST_a^{t0} - SST_{cfsrc}^{t0} + SST_{cfsrc}^t\right] + w * [SST_{cfs}^t - (SST_{cfs\_c}^t - SST_{cfsrc}^t)]$$

$SST_a^{t_0}$ -- SST analysis at initial time (RTG)

SST_c^t -- Climatological daily SST from RTG analysis for forecast lead-time t

SST_{cfs}^t -- CFS predictive SST (24hr mean) for forecast lead-time t

$SST_{cfs\_c}^t$ -- CFS model climatology (predictive SST) for forecast lead-time t

SST_{cfsrc}^t -- CFS reanalysis daily climatology for forecast lead-time t

$$w(t) = \frac{(t-t_0)}{35}$$

What's "Finite-Volume" about FV3?

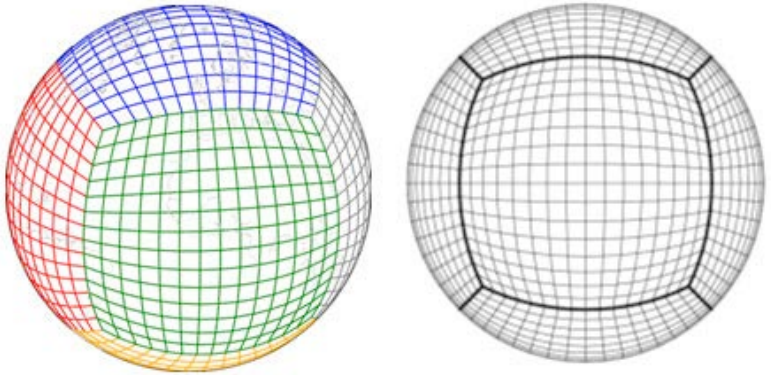
1. Vertically Lagrangian control-volume discretization based on 1st principles (Lin 2004)
   - Conservation laws solved for the control-volume bounded by two Lagrangian surfaces

2. Physically based forward-in-time "horizontal" transport (between two Lagrangian surfaces)
   - Conservative analog to the highly efficient trajectory based two-time-level semi-Lagrangian schemes in IFS; locally conservative and (optionally) monotonic via constraints on sub-grid distributions (Lin & Rood 1996; Putman & Lin 2007) – good for aerosols and cloud MP
   - Space-time discretization is non-separable -- hallmark of a physically based FV algorithm

3. Combined use of C & D staggering with optimal FV representation of Potential Vorticity and Helicity
   → important from synoptic-scale down to storm-scale

4. Finite-volume integration of pressure forces (Lin 1997)
   - Analogous to the forces acting upon an aircraft wing (lift & drag forces)
   - Horizontal and vertical influences are non-separable (Arakawa-type linear analyses are not applicable to FV's Lagrangian discretization)

5. For non-hydrostatic extension, the vertically Lagrangian discretization reduces the sound-wave solver into a 1-D problem (solved by either a Riemann solver or a semi-implicit solver with conservative cubic-spline)



FV3 on Cubed-Sphere Grid

Courtesy of Dr. S. J. Lin

Updated Ozone Physics in FV3GFS

Funded by NOAA Climate Program Office

Naval Research Laboratory CHEM2D Ozone Photochemistry Parameterization (CHEM2D-OPP, *McCormack et al.* (2006))

$$\frac{\partial \chi}{\partial t}(P-L) = (P-L)_0 + \left.\frac{\partial (P-L)}{\partial \chi_{O3}}\right|_0 \left(\chi_{O3} - \overline{\chi}_{O3}\right) + \left.\frac{\partial (P-L)}{\partial T}\right|_0 \left(T - \overline{T}\right) + \left.\frac{\partial (P-L)}{\partial c_{O3}}\right|_0 \left(c_{O3} - \overline{c}_{O3}\right)$$

NEMS GSM
Includes reference tendency and dependence on O3 mixing ratio

FV3GFS
Additional dependences on temperature and column total ozone

Reference tendency $(P\text{-}L)_0$ and all partial derivatives are computed from odd oxygen ($Ox \equiv O_3+O$) reaction rates in the CHEM2D photochemical transport model.
CHEM2D is a global model extending from the surface to ~120 km that solves 280 chemical reactions for 100 different species within a transformed Eulerian mean framework with fully interactive radiative heating and dynamics.

χ_{O3} prognostic Ozone mixing ratio
T Temperature
c_{O3} column ozone above

From: Shrivinas Moorthi