NATIONAL WEATHER SERVICE

Updates on UFS-based coupled GEFS

Bing Fu

Coupled Modeling Division, NOAA/NWS/NCEP/EMC

Weeks 3-4/S2S webinar series, June 3, 2024

Acknowledgements to the Global UFS Community Developers

Atmospheric Physics

NCEP/EMC: Jongil Han, Michael Barlage, Anning Cheng, Bing Fu, Hong Guan, Zhichang Guo, Sanath Kumar, Xu Li, Wei Li, Qingfu Liu, Eric Sinsky, Ruiyu Sun, Kevin Viner, Helin Wei, Bo Yang, Fanglin Yang, Rongqian Yang, Weizhong Zheng, Xiaqiong Zhou
ESRL/GSL: Ben Green, Joseph Olson, Tanya Smirnova, Shan Sun, Xia Sun, Michael Toy
JCSDA/UCAR: Dom Heinzeller,
ESRL/PSL: Lisa Bengtsson, Jian-Wen Bao, Clara Draper, Grant Firl, Songyou Hong, Philip Pegion, Dustin Swales
DTC: Ligia Bernardet, Weiwei Li, Man Zhang

Data Assimilation

NCEP/EMC: Catherine Thomas, Guillaume Vernieres, Daryl Kleist, Cory Martin, Andrew Collard, Jiarui Dong, Andy Eichmann, Travis Elless, Nick Esposito, Iliana Genkova, Azadeh Gholoubi, Tseganeh Gichamo, Brett Hoover, Xin Jin, Emily Liu, Haixia Liu, Hyun-Chul Lee, Xuanli Li, Ron McLaren, Dagmar Merkova, Sudhir Nadiga, Shastri Paturi, Ashley Stanfield, Steve Stegall, Andy Tangborn, Russ Treadon, Yaping Wang, Youlong Xia
CIRES/GSL: Bo Huang, Mariusz Pagowski
PSL: Clara Draper, Jeff Whitaker
JCSDA/UCAR: Kriti Bhargava, Travis Sluka

Coupled Model Component Development

NCEP/EMC: Jessica Meixner, Jiande Wang, Lydia Stefanova, Jun Wang, Yuejian Zhu, Neil Barton, Saeideh Banihashemi, Arun Chawla, Bing Fu, George Gayno, Robert Grumbine, Walter Kolczynski, Matthew Masarik, Avichal Mehra, Ali Salimi-Tarazouj, Denise Worthen
ESRL/GSL: Ben Green, Shan Sun
ESRL/PSL: Lisa Bengtsson, Phillip Pegion
GFDL: Alistair Adcroft, Rusty Benson, Stephen Griffies, Robert Halberg, Matthew Harrison, Brandon Reichl, Marshall Ward
NCAR: Alper Altuntas, Gokhan Danabasoglu, Keith Lindsay, Gustavo Marques
NRL/ESMF: Gerhard Theurich
GMU: Ben Cash, Jim Kinter, Lawrence Marx, Cristiana Stan
FSU: Alexandra Bozec, Eric Chassignet, Alan Wallcraft
NASA: Akella Santha
Univ. Alaska: Katherine Hedstrom
U. Mich.: Christiane Jablonowski
Univ. Victoria: Andrew Shao

Field Evaluation

NCEP/EMC: Alicia Bentley, Mallory Row, Shannon Shields
NWS Regional SSDs
NCEP Centers

Products

NCEP/EMC: Hui-Ya Chuang, Wen Meng, Andrew Benjamin, L. Gwen Chen, Yali Mao, Bo Cui

Atmospheric Composition

NCEP/EMC: Partha Bhattacharjee, Jeff McQueen, Raffaele Montuoro, Li Pan, Ivanka Stajner
ARL: Barry Baker, Patrick Campbell, Rick Saylor
ESRL/GSL: Georg Grell, Shan Sun, Li (Kate) Zhang
CSL: Gregory Frost, Jian He, Stuart McKeen, Siyuan Wang
NESDIS/STAR: Ethan Hughes, Shobha Kondragunta, Xiaoyang Zhang

Infrastructure

NCEP/EMC: Rahul Mahajan, Jun Wang, Kate Friedman, Lin Gan, George Gayno, Ed Hartnett, Dusan Jovic, Walter Kolczynski, Hang Lei, Terry McGuinness, Alex Reichert, Mallory Row, Edward Stafford, Henry Winterbottom, Jack Wollen, Denise Worthen
Redline Performance: David Huber

Coupled Model Evaluation

NCEP/EMC: Lydia Stefanova, Jiande Wang, Michael Barlage, Neil Barton, Partha Bhattacharjee, Zhichang Guo, Robert Grumbine, Wei Li, Avichal Mehra, Ghazal Mohammadpour, Jiayi Peng, Sulagna Ray, Huug van den Dool, Helin Wei, Youlong Xia, Weizhong Zheng
CPC: Laura Ciasto, Yanyun Liu, Wanqiu Wang, Jieshun Zhu
ESRL/PSL: Chris Cox, Maria Gehne, Juliana Dias, Zachary Lawrence, Amy Solomon
GMU: V. Krishnamurthy, Eunkyo Seo, Cristiana Stan

Outline

- A brief introduction of GEFSv13
- UFS global coupled model Ensemble Prototypes (EPs)
  - UFS coupled model prototypes and ensemble prototypes
  - Some results from EP1, EP2 and EP3
  - **EP4 and EP5 (miniset)**: experiments with aerosol coupling
- GEFSv13 status and what's next

Transitioning to a fully coupled model

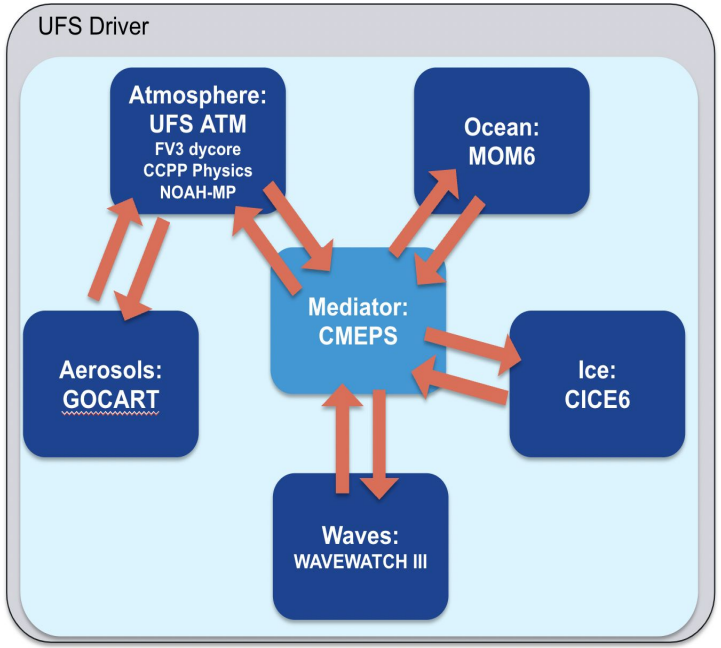
NOAA's next global model updates

GFSv17

GEFSv13

SFSv1

UFS fully coupled model



GEFSv13 Configurations (planned)

Components		V12 (Sep 23. 2020)	V13 (targeting FY26)
Atmos	Dynamics	**FV3 (Finite-Vol Cubed-Sphere) GFSv15**	FV3 (Finite-Vol Cubed-Sphere) GFSv17
	Physics	**saSAS, GFDL-MP, K-EDMF, oroGWD**	**saSAS, Thompson-MP, sa-TKE-EDMF, uGWD**
	Initial perturbation	**EnKF f06 (previous cycle)**	EnKF f00 (early cycle)
	Model uncertainty	**5-scale SPPT and SKEB**	5-scale SPPT, SKEB, **SPP, CA**
	Boundary (ocean surface)	**NSST + 2-tiered SST**	NSST
	Resolutions	**C384L64 (25km)**	**C384L127 (25km)**
Land	Model	**NOAH-LSM**	**NOAH-MP**
	Initial perturbation	**N/A**	Soil moisture
Ocean	Model	**N/A**	**MOM6 (0.25°L75)**
	Initial perturbation		**SOCA-Ens**
	Model uncertainty		**5-scale oSPPT and ePBL**
Ice	Model		**CICE6 (0.25°)**
	Initial perturbation		**SOCA-Ens**
Wave	Model	**WW3 (1-way) (0.5°)**	**WW3 (2-way) (0.25° lat/lon grid)**
Aerosol	Model	**GOCART (1-way)**	**GOCART (2-way)**

Timeline of the UFS coupled model prototypes

Coupled model prototype	Timestamp of the model tag
P5 ~~~~~~> (**EP1**)	09/16/2020
P6 ~~~~~~> (N/A)	02/19/2021
P7 ~~~~~~> (**EP2**)	08/23/2021
P8 ~~~~~~> (**EP3**)	05/31/2022
HR1~~~~~~> (**EP4**)	01/30/2023
HR2 ~~~~~~> (N/A)	07/24/2023
HR3~~~~~~> (**EP5**)	01/11/2024

6 months

8 months

9 months

8 months

6 months

4 months

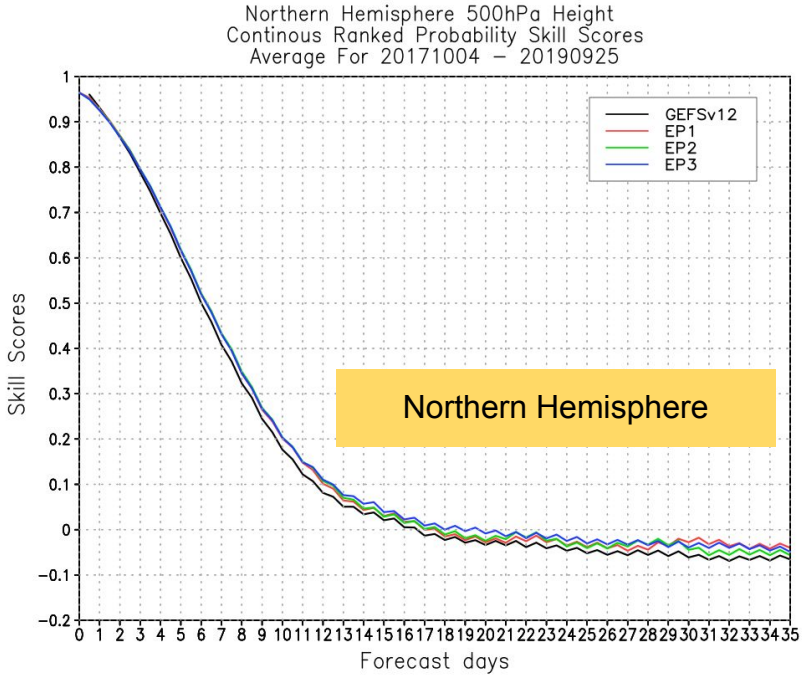
It usually takes **8 - 11** months to complete one ensemble prototype

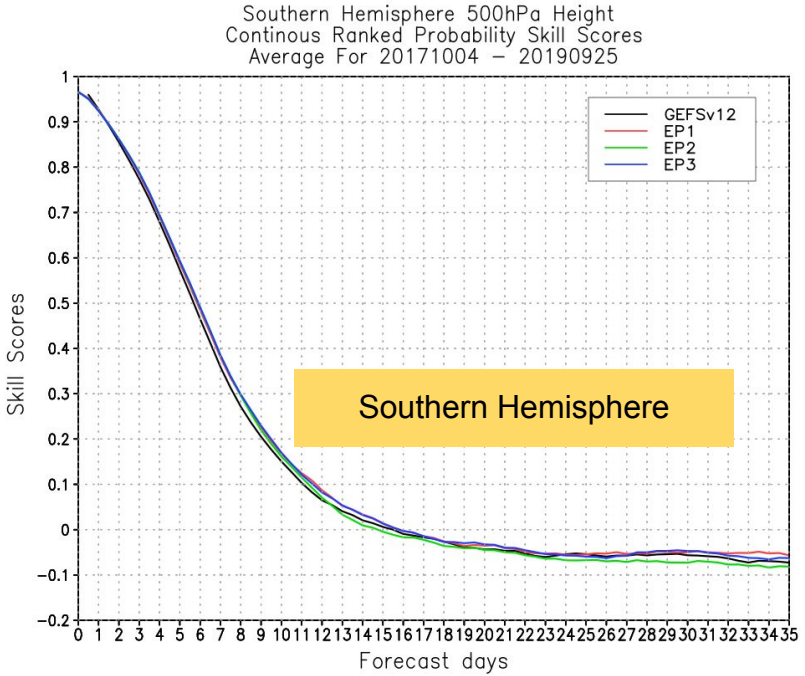
Experiment design of the ensemble prototypes

- Reference:
  - GEFSv12 (reforecast), 10 perturbed members + 1 control member
- Ensemble prototype:
  - 10 perturbed members + 1 control member (not 31 members due to resources)
- Run period:
  - Full set: Oct 2017 - Sep 2019 (one more year (Oct 2020 - Sep 2021) for EP4 and EP5)
  - Miniset: 8 winter cases and 8 summer cases in 2018
- Initial conditions:
  - Analysis :
    - ATM: GFS v15/v16 analysis
    - OCN: CFSR T&S (EP1), ORAS5 (EP2 - EP5)
    - ICE: CPC ice analysis
    - WAV: GFSv15 wind/ice forcing (EP1 - EP3), GEFSv12 reanalysis (EP4-EP5)
  - Initial perturbations:
    - ATM: GFS v15/v16 EnKF f06
    - OCN: generated from 3 ocean analysis (EP3-EP5)
    - WAV: GEFS v12 reforecast (EP4-EP5)
  - GEFSv13 replay ICs (only for EP5 experiments)

GEFS ensemble prototypes and experiments

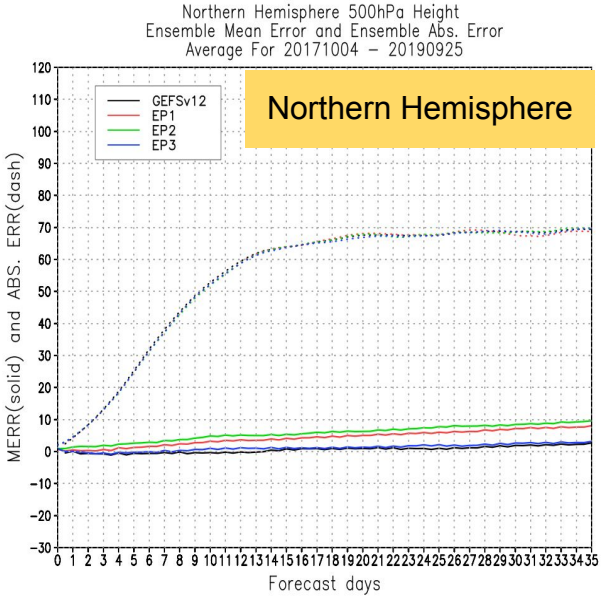
Skills of 500hPa geopotential height

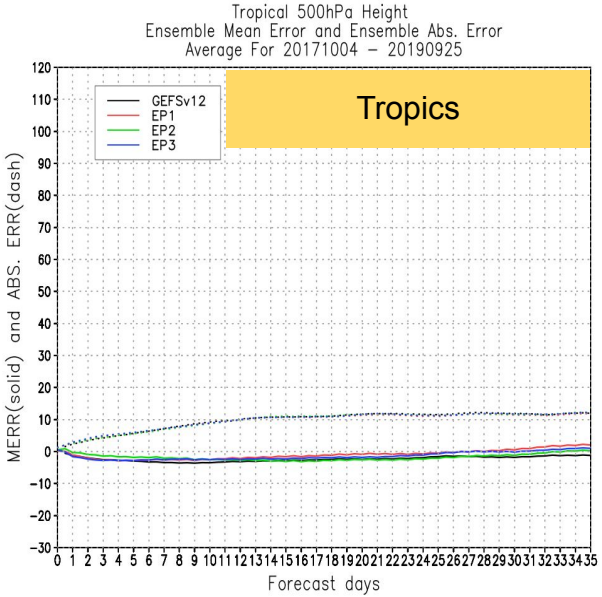


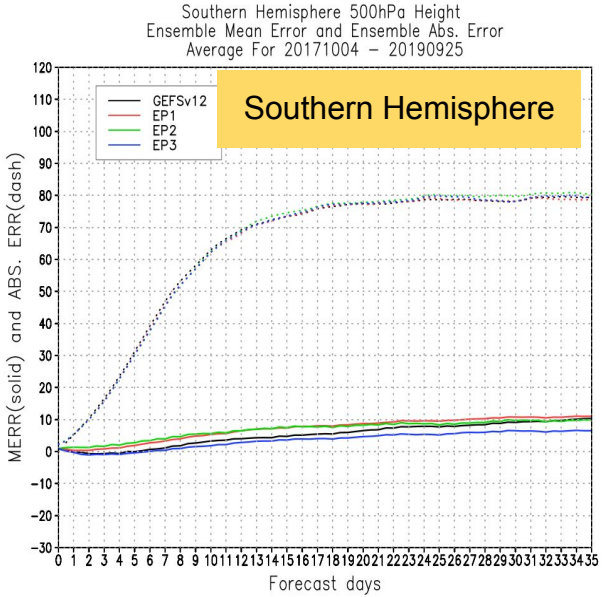


- For short lead-time: all three experiments are very similar and better than GEFSv12 up to week 2.
- For week-3 and beyond: EP3 is best in the NH, mixed in the SH.

Bias of 500hPa geopotential height

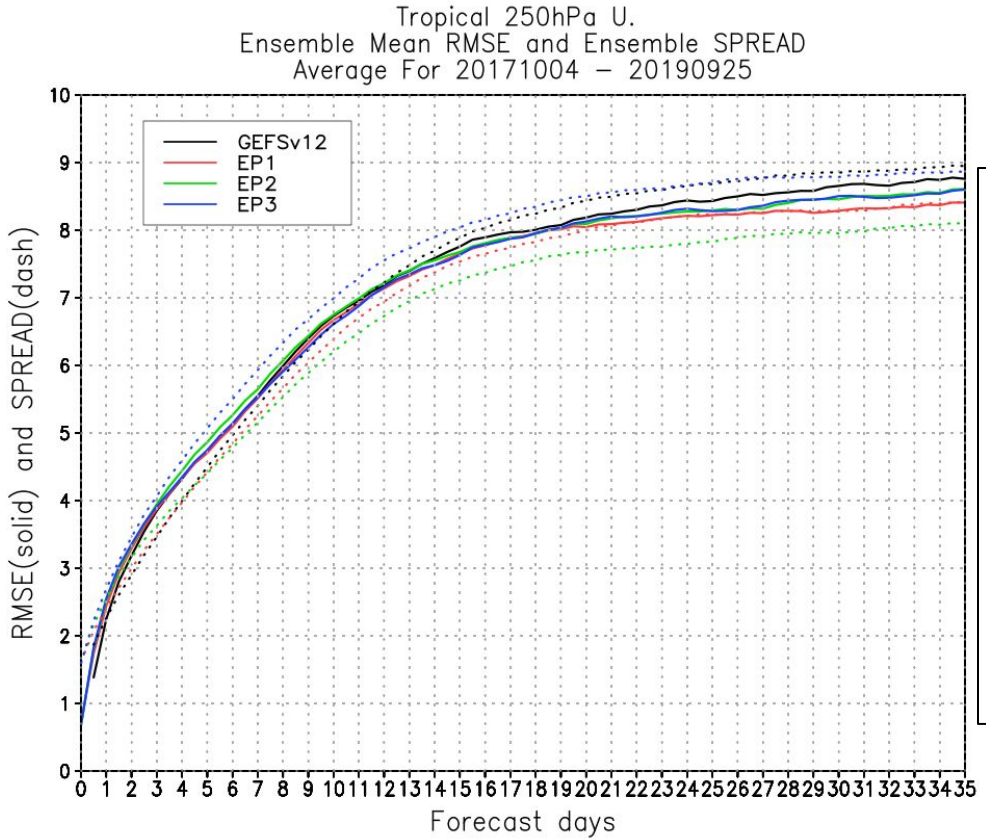






- Overall - EP3 shows **the best bias** for three domains
- EP1/EP2 introduces warm bias for all three domains

RMSE/SPRD for U250 tropical zonal winds



- Ensemble spread changes following the updates of ensemble prototype.
- An indication of the changes of the physical tendency

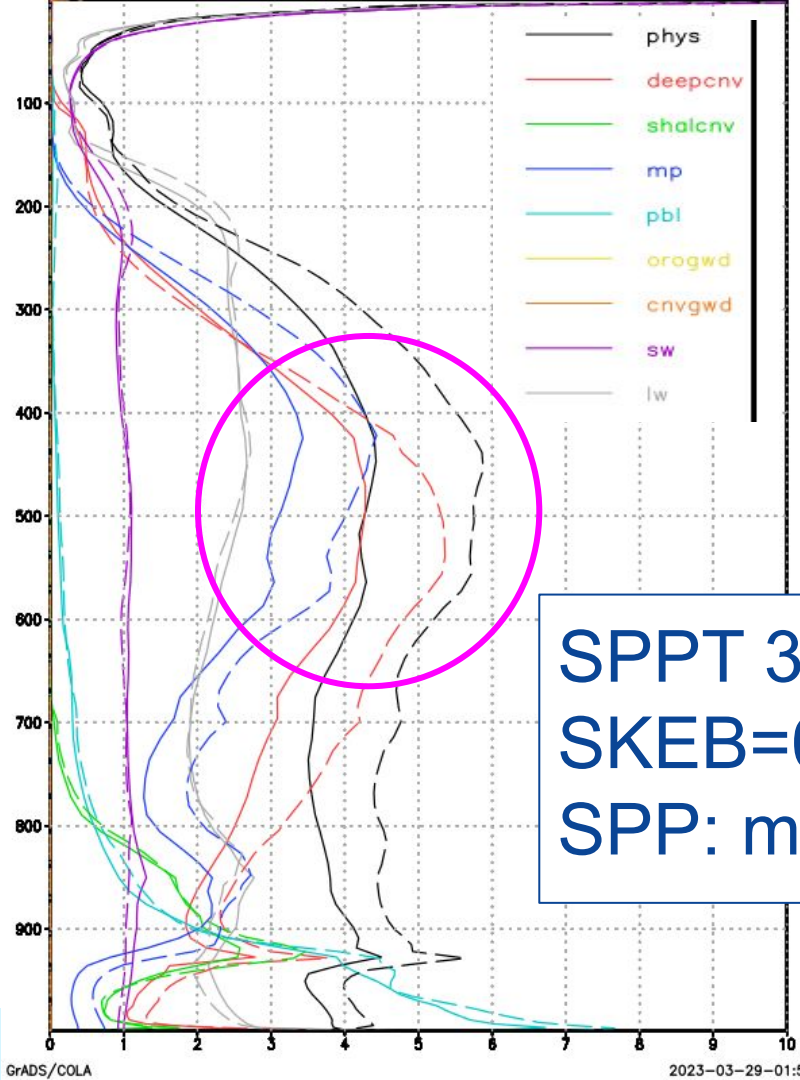
EP4 results

Physical tendency comparison:
EP3 (solid) vs EP4 (dash)

(p02: 20171004 00Z 252h forecast)

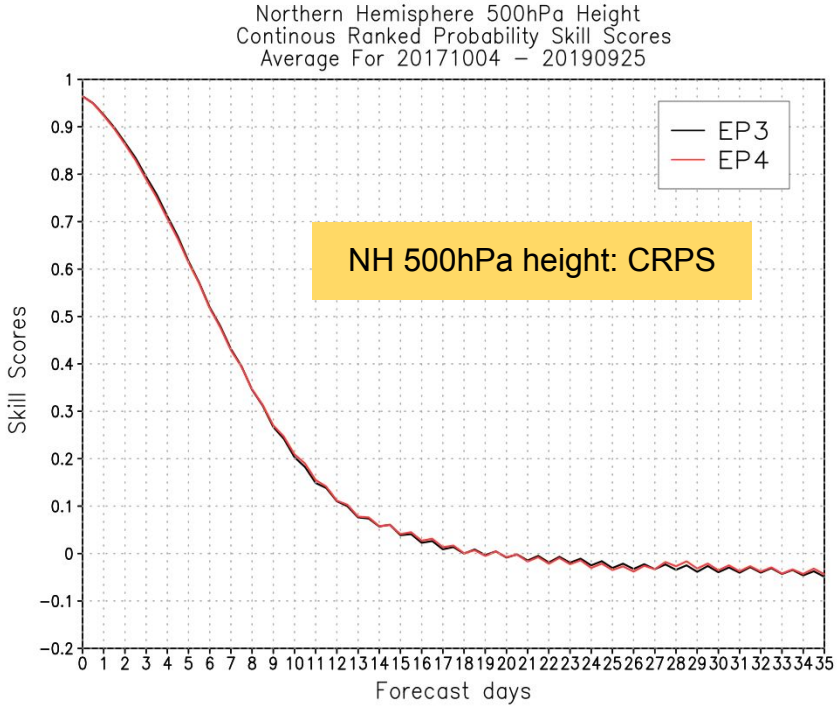
Averaged absolute DT/Dt (1e-5)
Over (40E-150W,20S-20N)

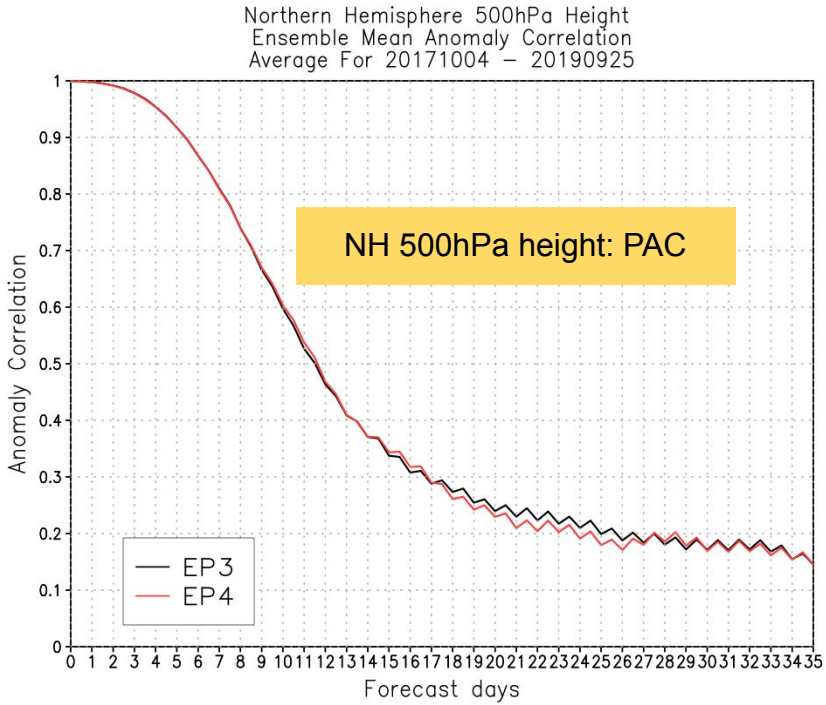
- Large difference of total physical tendency caused by mp and deep convection
- PBL is the major contributor for total tendency at lower level.
- PBL taper added from EP4



SPPT 30% off
SKEB=0.8
SPP: mp_cld

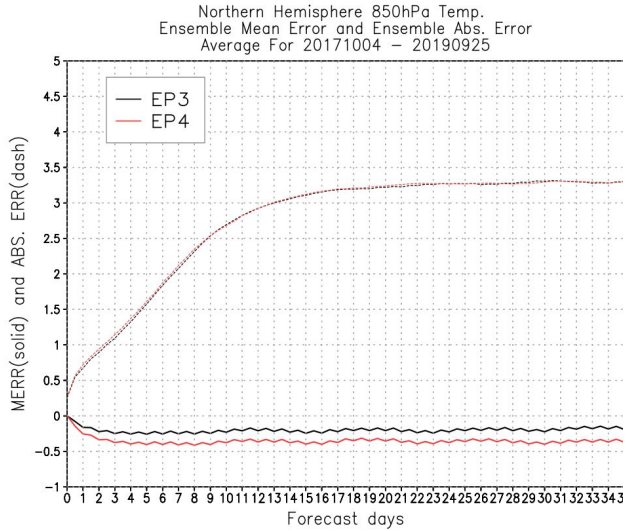
Skills of 500hPa geopotential height (NH: CRPS and AC)

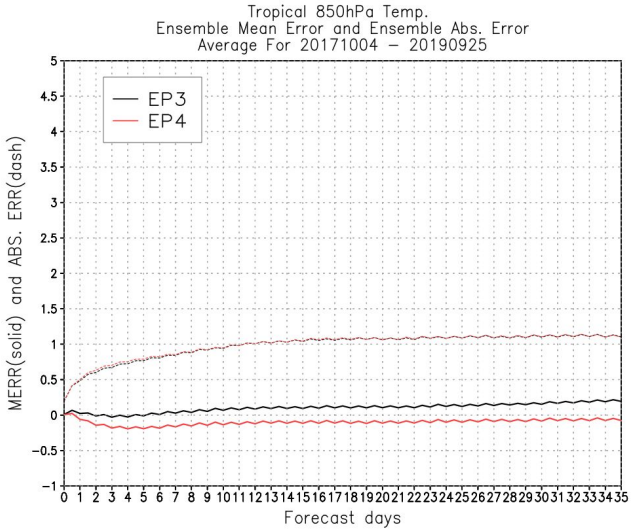


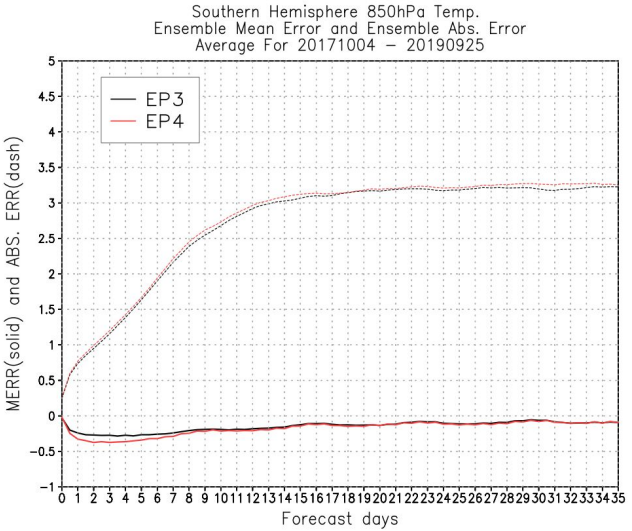


- For short lead-time: EP4 is similar to slightly worse (CRPS) better (AC) than EP3
- For week-2 and beyond: EP3 and EP4 are very similar, especially for CRPS, EP4 is slightly degraded from EP3 for ACC

Skills of 850hPa temperature (bias)

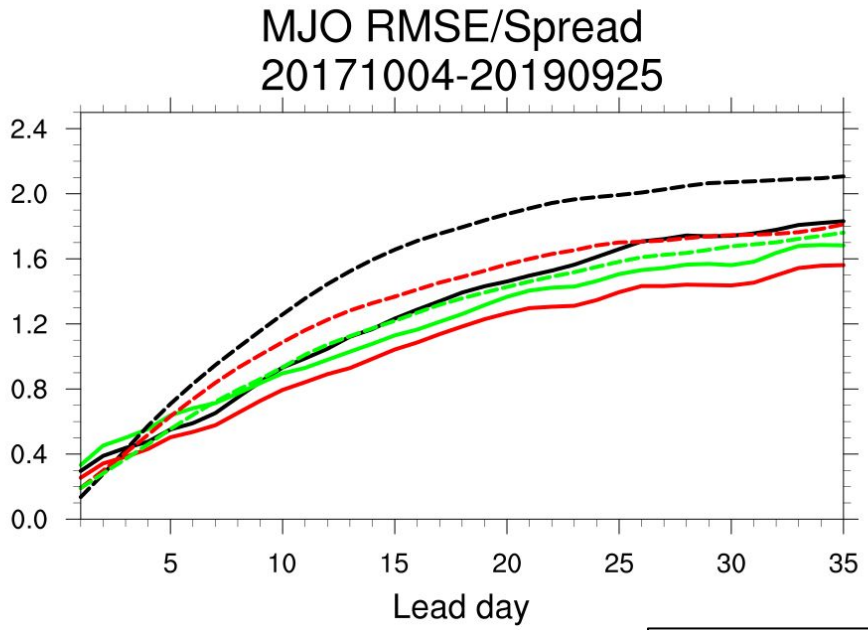


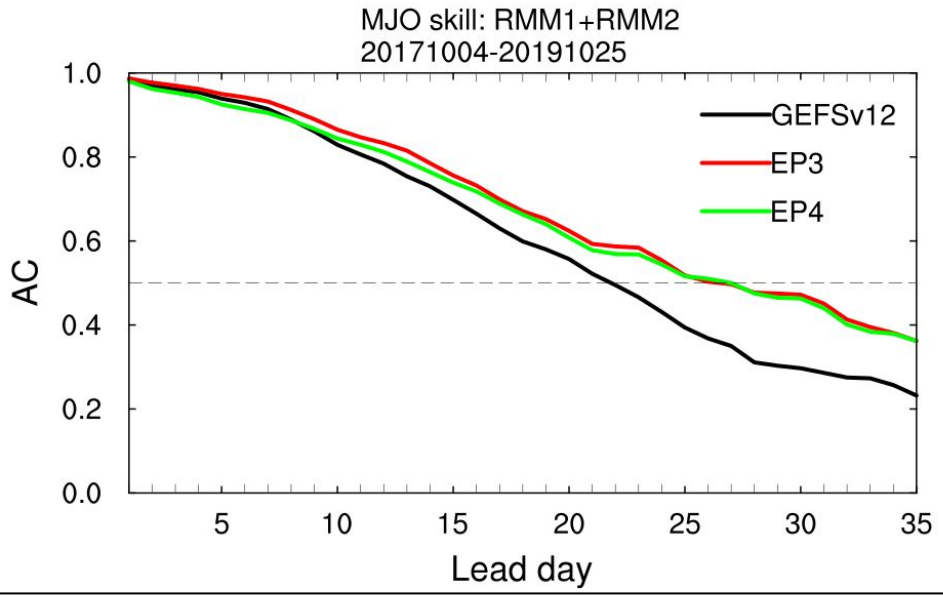


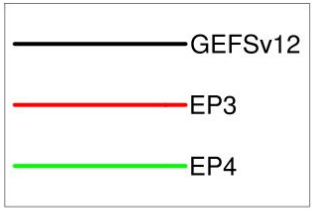


- It is similar to 500hPa height, EP4 shows colder bias from NH to tropical, less difference for SH

Latest Experiments - EP4 (2 years)



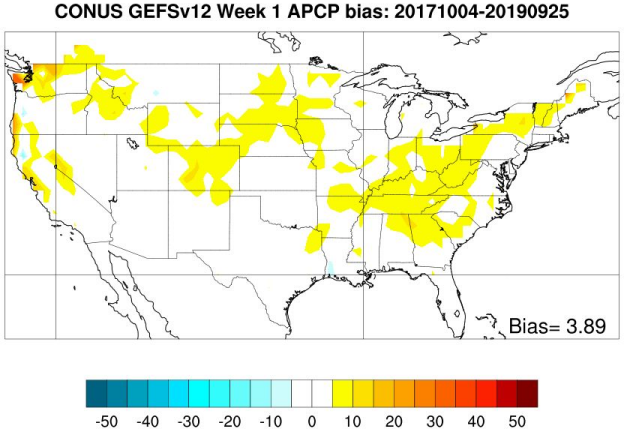


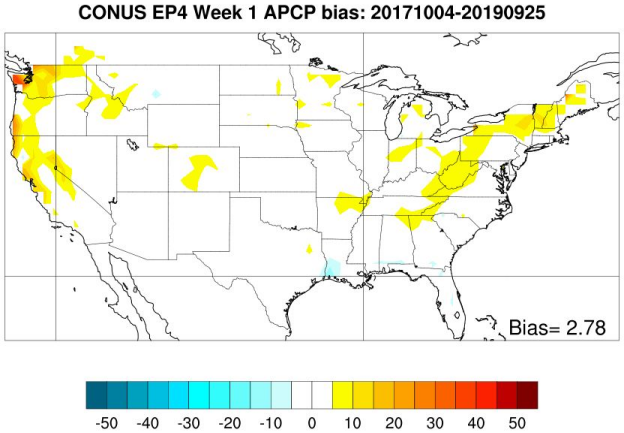


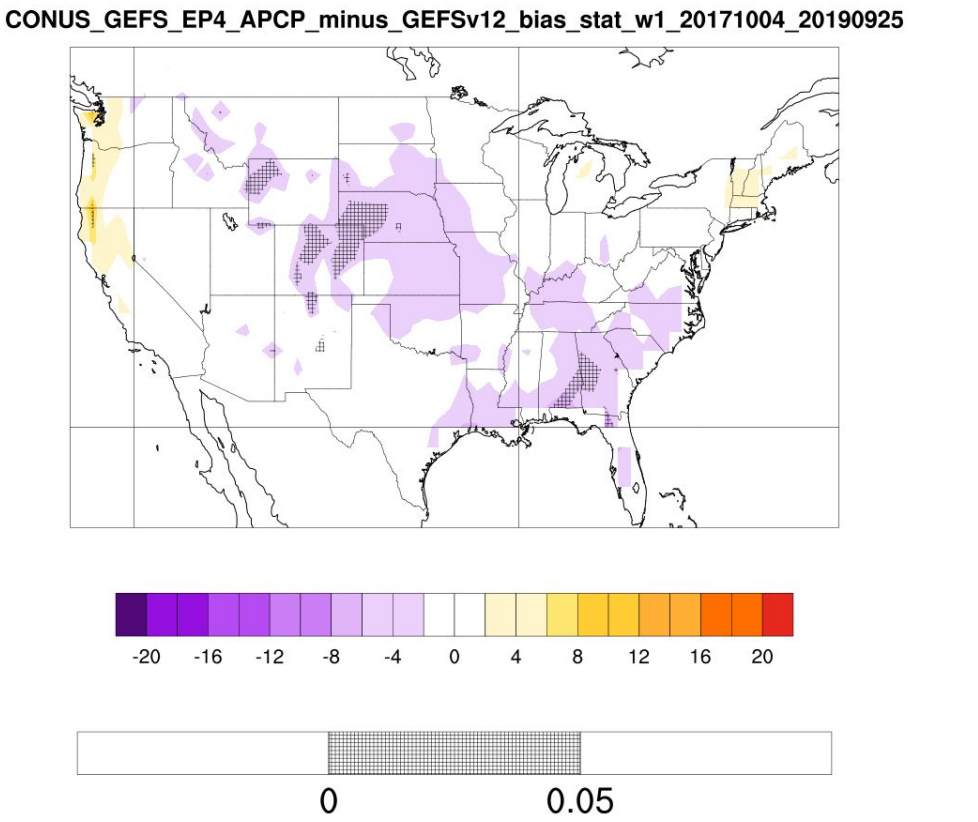
- EP4 experiments demonstrated reduced MJO spread, but increased RMS error from EP3.
- EP4 experiments have similar MJO skill (RMM1+RMM2) for longer lead-time, but it is degraded for short lead time.

Courtesy: Eric Sinsky

CONUS Precipitation Bias for Week-1 average (2 years)



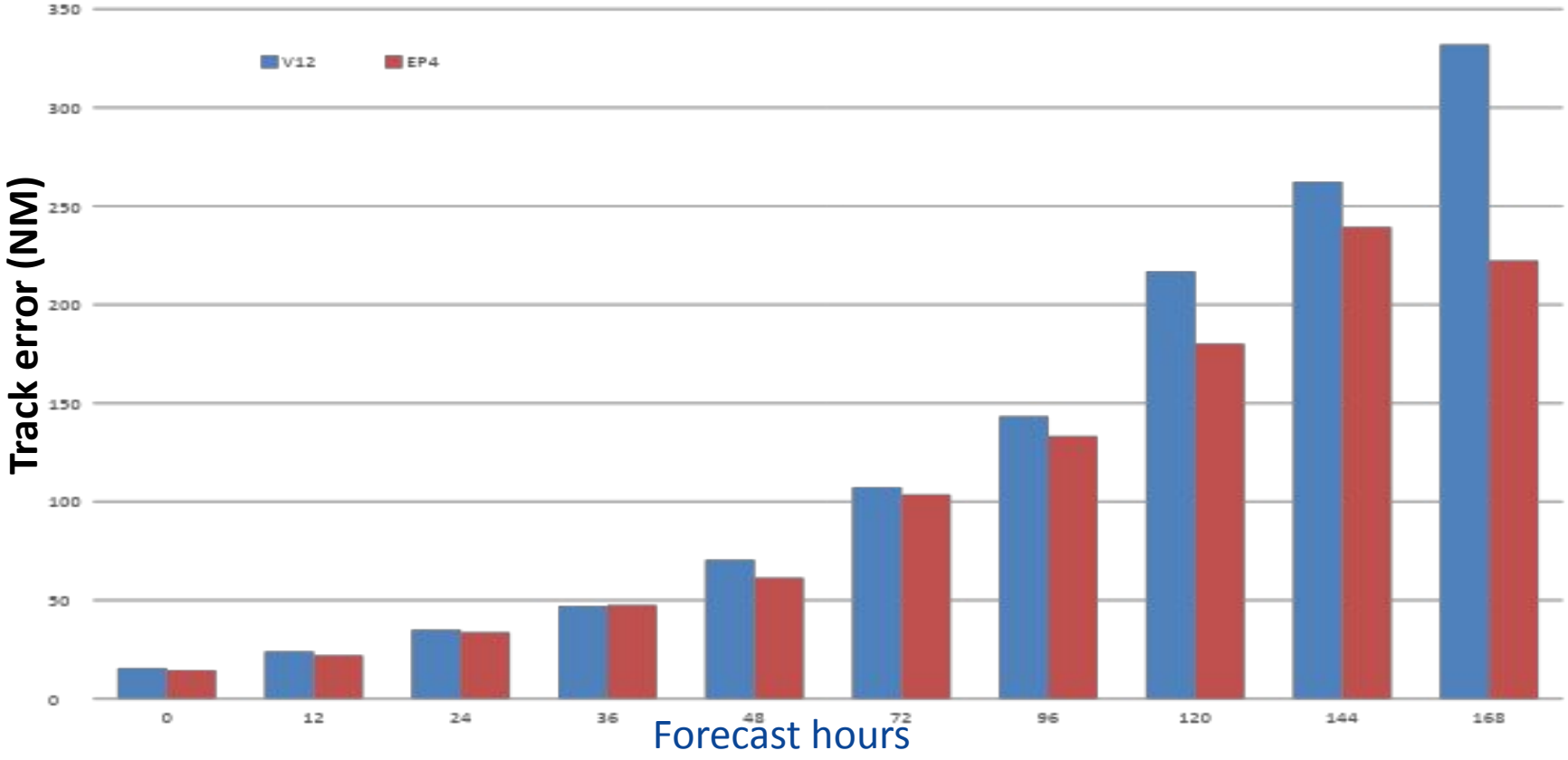




- APCP bias reduced in EP4 compared to GEFSv12

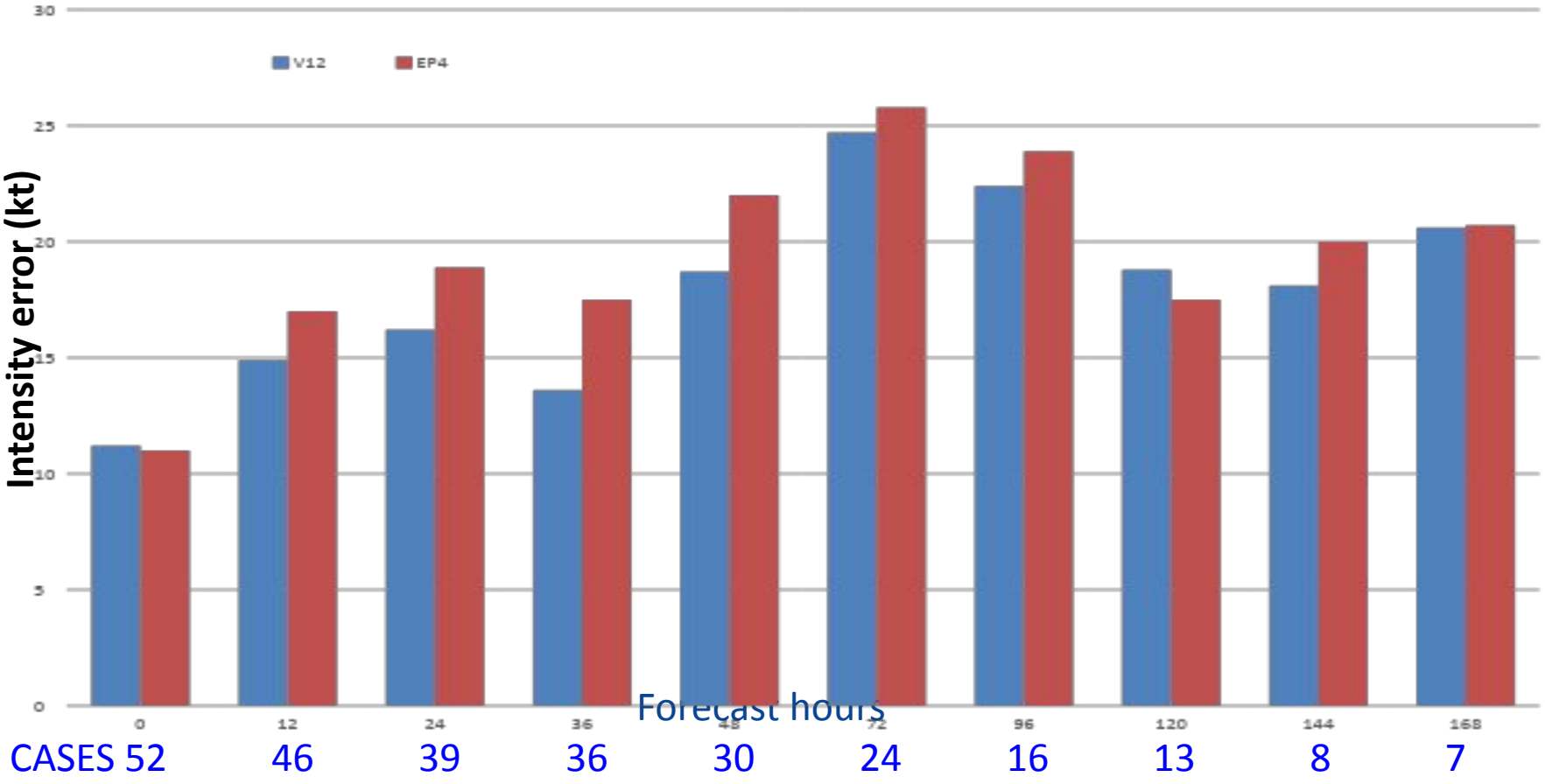
Courtesy: Eric Sinsky

Track error, 2020-2021, AL/EP/WP(Atlantic, East/West Pacific)



CASES	52	46	39	36	30	24	16	13	8	7

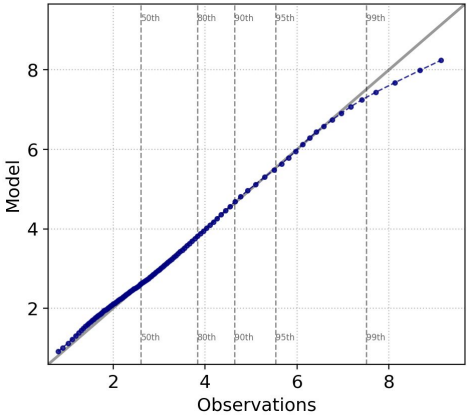
Intensity error, 2020-2021, AL/EP/WP(Atlantic, East/West Pacific)



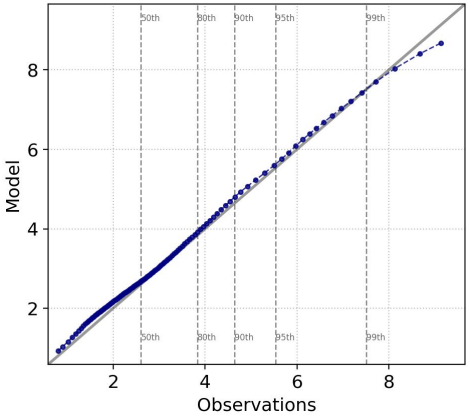
CASES	52	46	39	36	30	24	16	13	8	7

Courtesy: Jiayi Peng

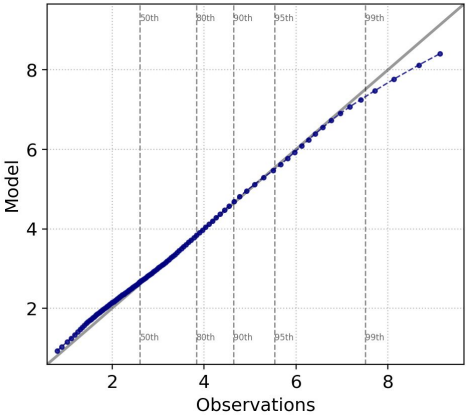
QQ plots, Hs(m) -Week 2, (8 winter cases)



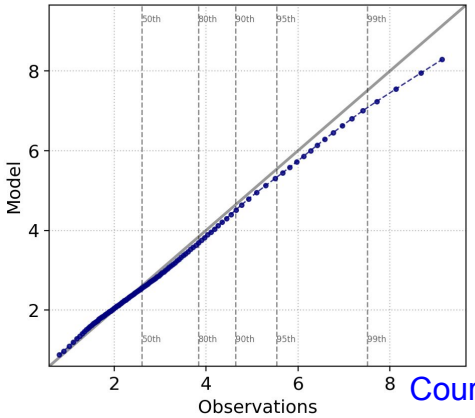
NOCUR



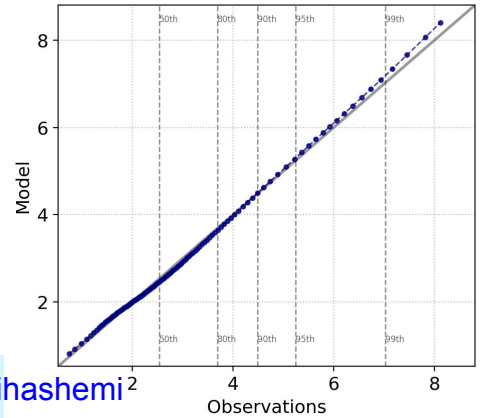
BMax_1.5



BMax_1.45



EP4



GEFSv12

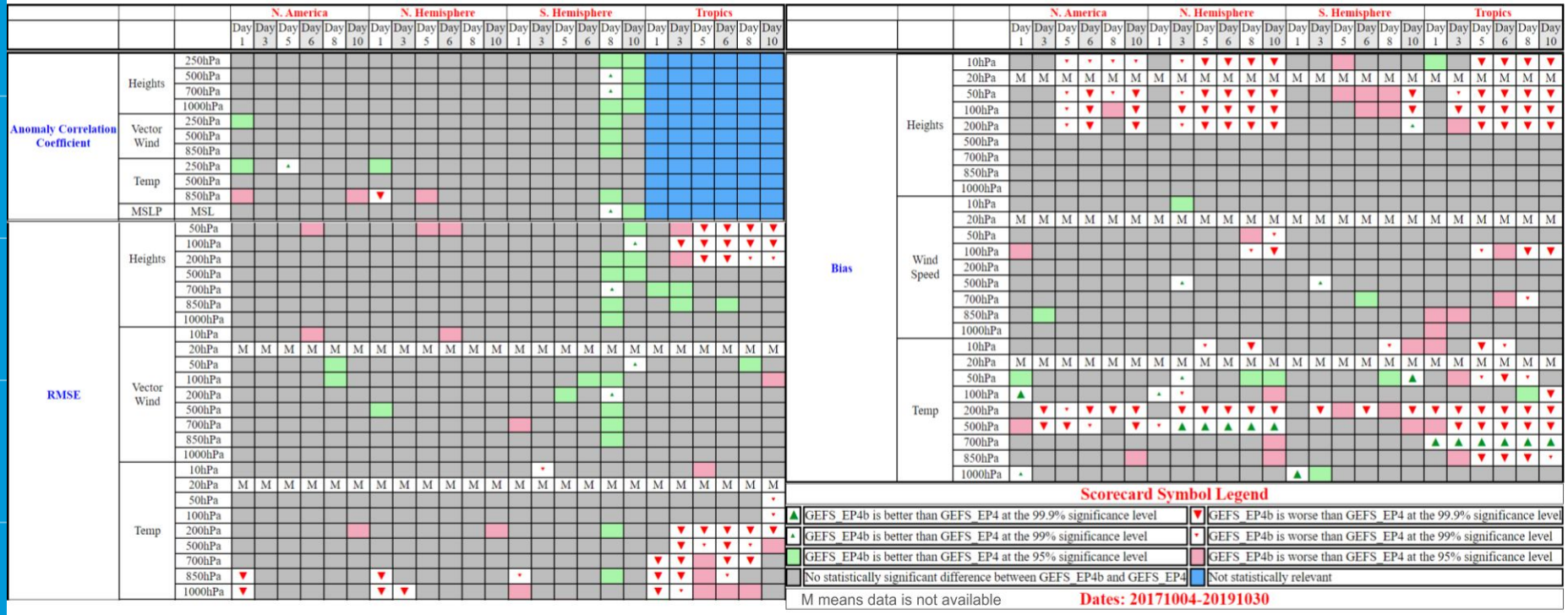
Courtesy: Saeideh Banihashemi

Experiments with aerosol from EP4 and EP5

- **EP4 (HR1 based):**
  - EP4: (aerosol: climatology): 2-year full set
  - EP4b: (aerosol: prognostic, observed emission): 2-year full set
- **EP5 (HR3 based): only miniset completed**
  - EP5d: (aerosol: prognostic, blending emission):
  - EP5r2: (aerosol: prognostic, blending emission):
    - replay ICs (UFS coupled model replay ERA5/ORAS5)

Ensemble mean of EP4b compared with EP4

Scorecard



Weekly averaged AC of GEFSv12/EP4/EP4b

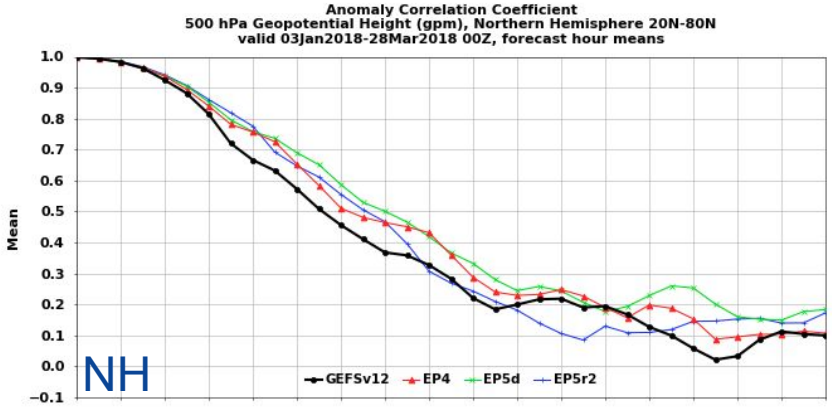
Z500: NH	GEFSv12	EP4	EP4b
Week 1	0.965	0.967	0.967
Week 2	0.629	**0.656**	**0.648**
Week 3-4	0.356	0.378	0.386

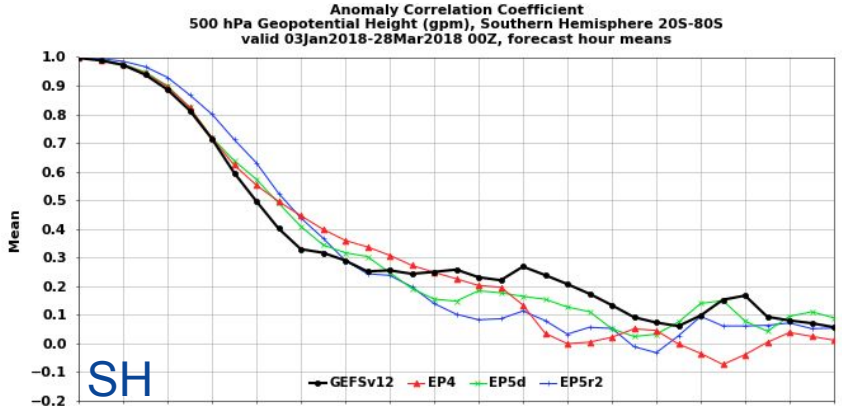
Z500: SH	GEFSv12	EP4	EP4b
Week 1	0.958	**0.961**	**0.962**
Week 2	0.586	0.584	0.604
Week 3-4	0.291	0.278	**0.243**

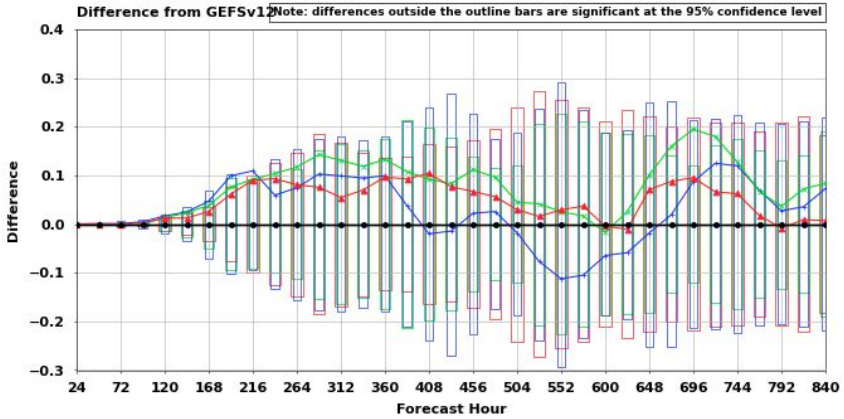
- Blue text: higher AC than GEFSv12 (bolded text: significant improvement from GEFSv12 at a 95% confidence interval)
- Red text: lower AC than GEFSv12 (bolded text: significant degradation from GEFSv12 at a 95% confidence interval)

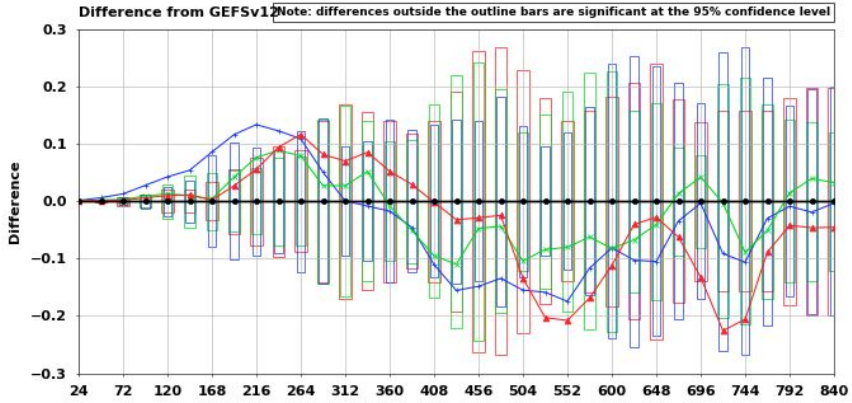
EP5 miniset results

Z500 ACC: Winter







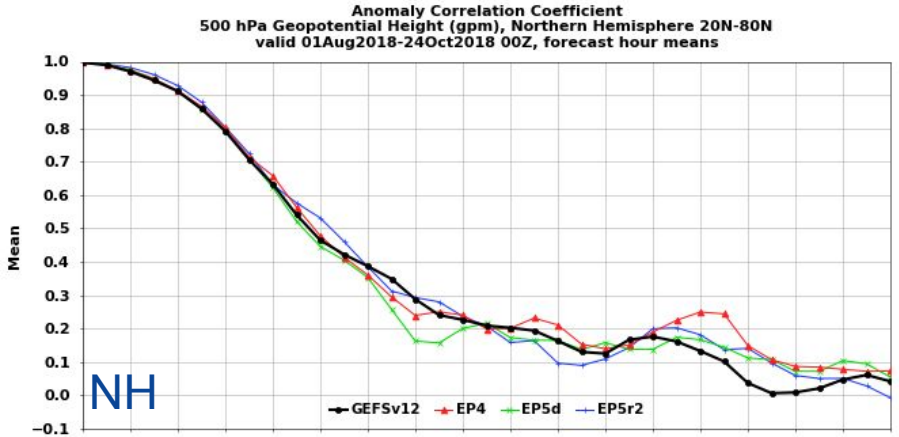


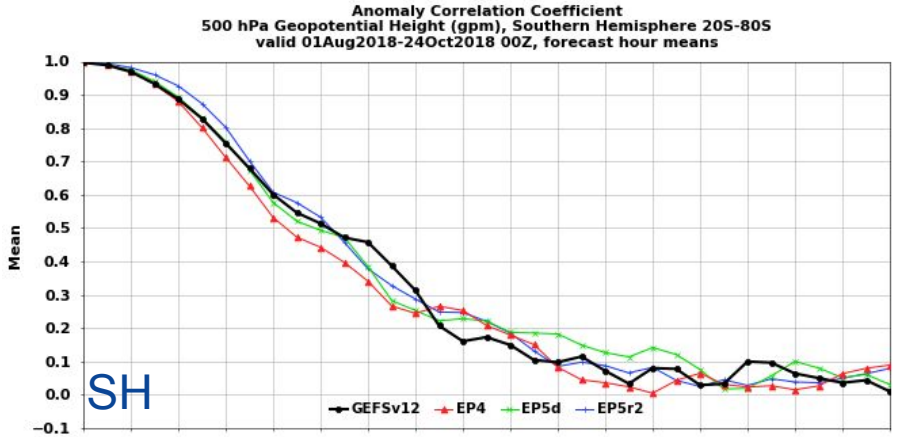
For NH, EP5r2 is comparable to other EPs, and all EPs perform better than GEFSv12

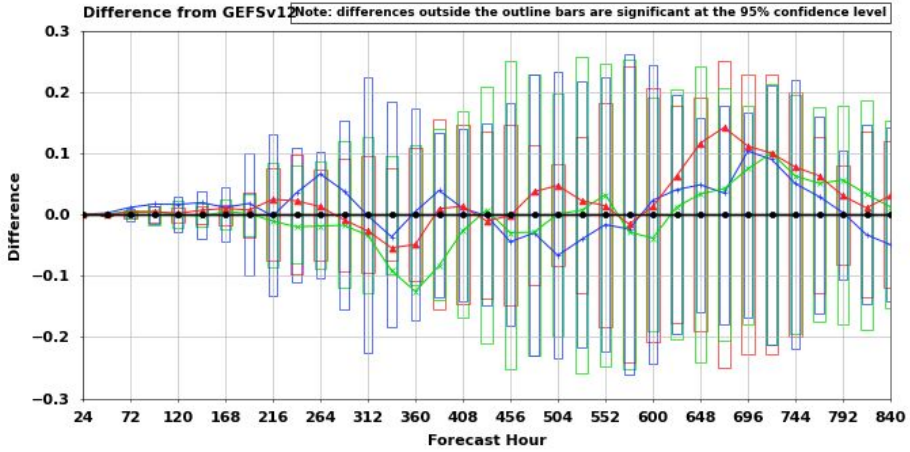
For SH, EP5r2 performs significantly better than other EPs and GEFSv12 for first 10 days

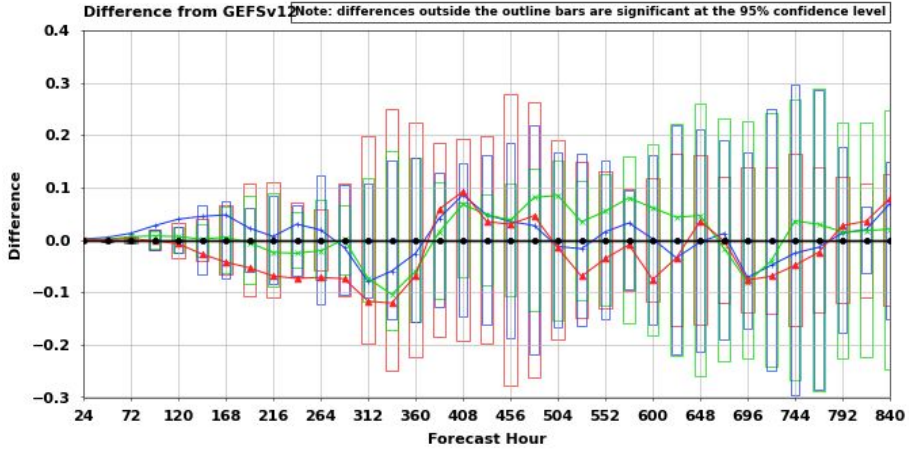
Courtesy: Eric Sinsky

Z500 ACC: Summer



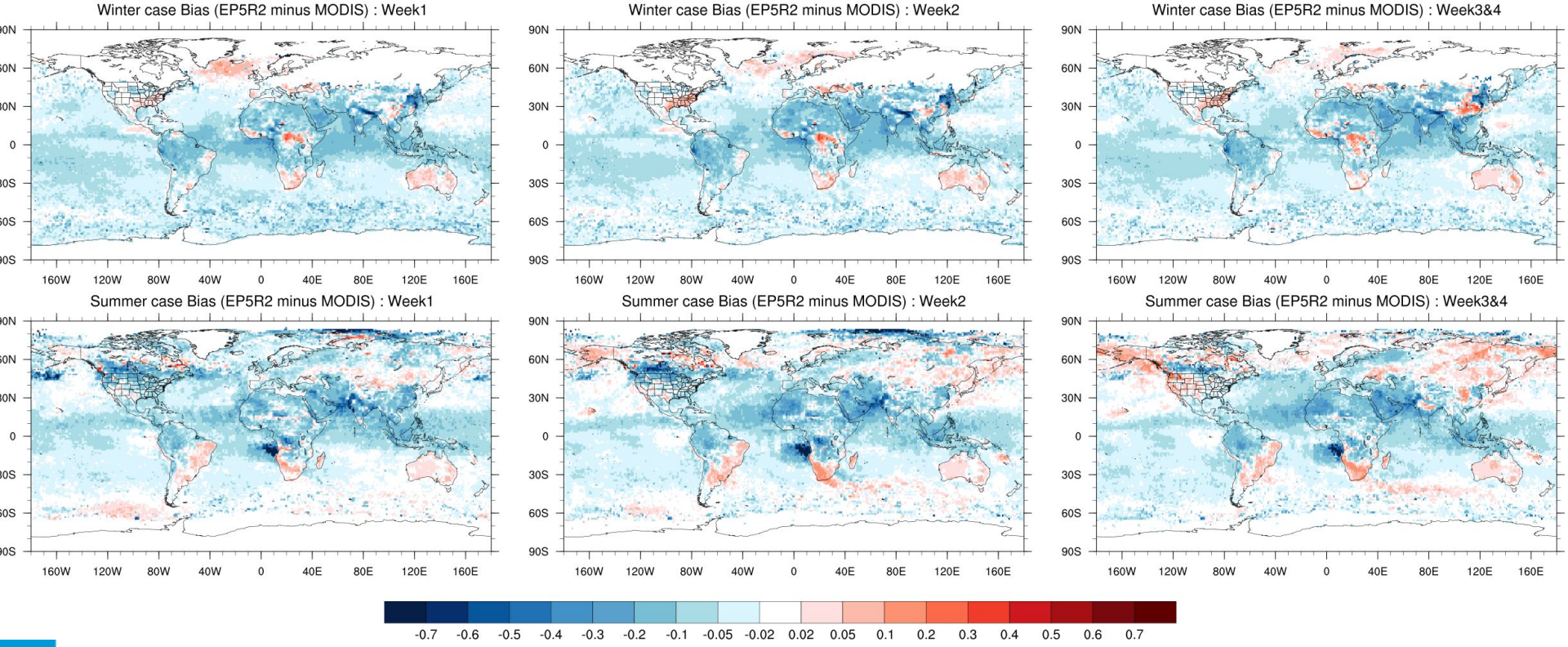






AOD bias in EP5r2 for winter (top) and summer (bottom)

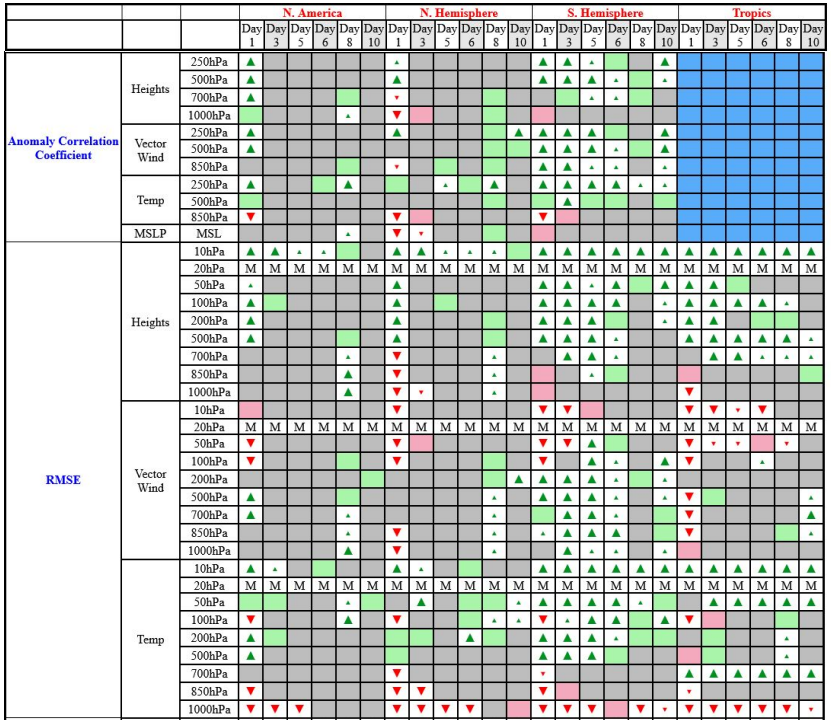
8 winter cases and 8 summer cases in 2018



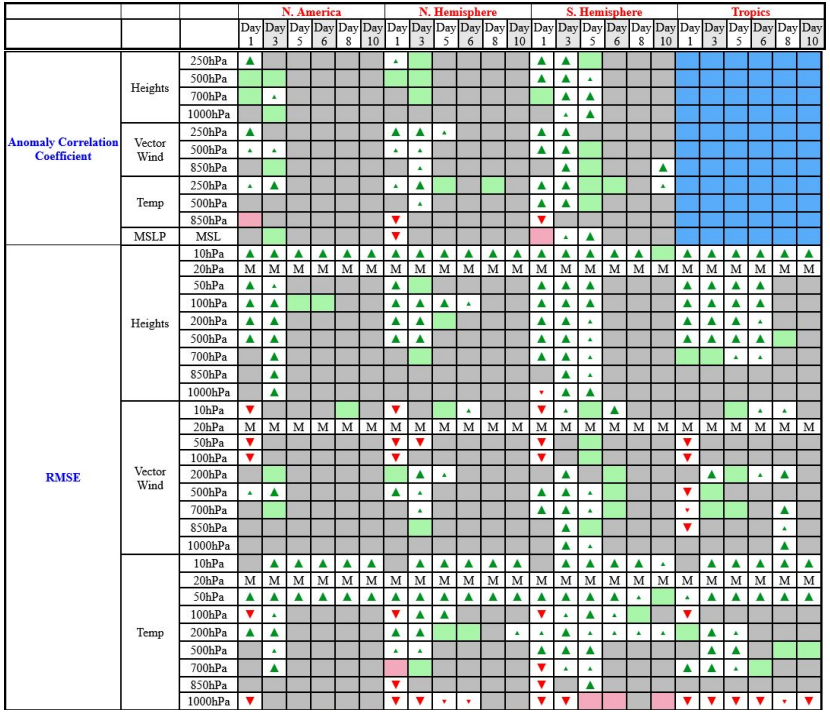
Green: EP5r2 significantly improved from GEFSv12
Red: EP5r2 significantly degraded from GEFSv12

EP5r2 vs. GEFSv12 AC/RMSE: Days 1-10

Winter



Summer

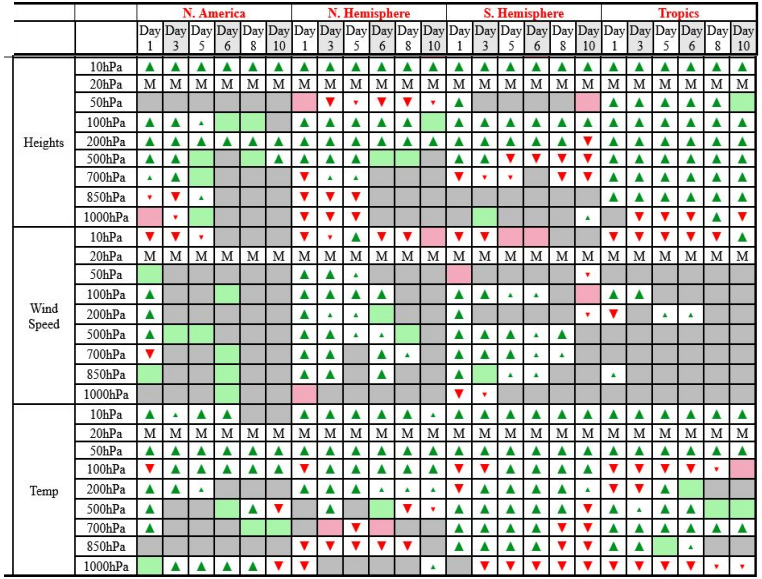


- ACC/RMSE differences are overall favorable (especially over SH) except for 1000 hPa temperature RMSE

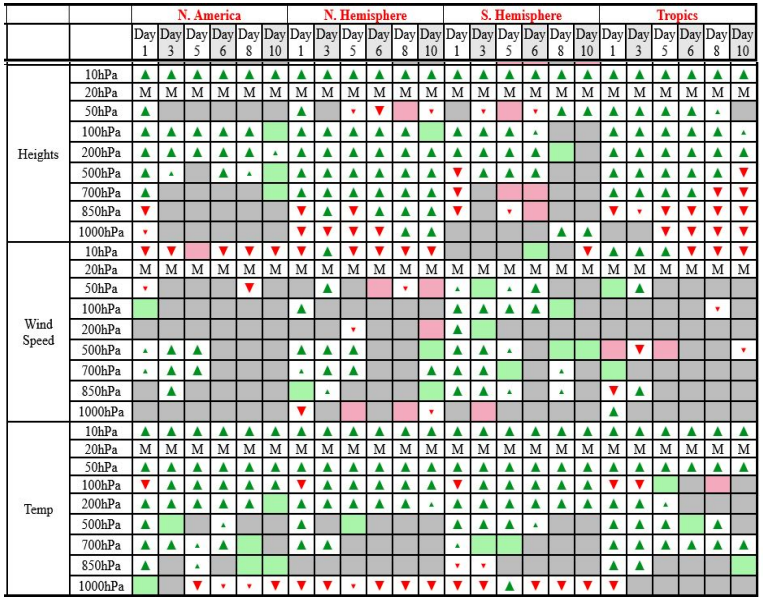
Green: EP5r2 significantly improved from GEFSv12
Red: EP5r2 significantly degraded from GEFSv12

EP5r2 vs. GEFSv12 Bias: Days 1-10

Winter



Summer



- Bias differences are generally favorable for both winter and summer

Summary

- Five ensemble prototypes (EP1 - EP5) have been developed following the development of UFS coupled model
- Overall the coupled ensemble model outperformed the current operational GEFSv12
- The latest EP (EP5r2) is running for the full set. We only have some results from the miniset, waiting for the evaluation for the full set (expected to be finished by early July)

Future plan

- Finish the EP5r2 full set run by July 1.
- Evaluation of EP5r2 full set run from July 1 - 31.
- Launch the GEFSv13 reforecast in August
  - If global-workflow for ensemble is ready
  - If the results from EP5r2 is satisfactory