NATIONAL WEATHER SERVICE

GEFS version 13 – Aerosols:

Increasing realism of NOAA's flagship Global Ensemble Forecast System

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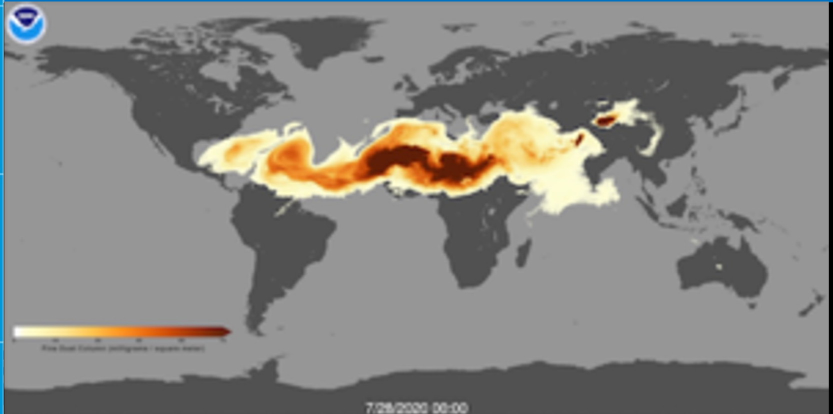
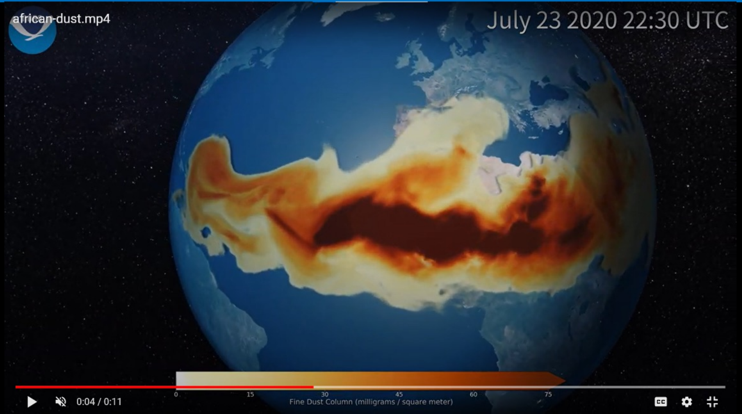
Barry Baker – OAR/ARL, Li (Kate) Zhang – OAR/GSL, Gregory Frost – OAR/CSL
The GFS development team & the PSL ensemble team, NASA/GMAO

Air Quality Forecasters Workshop, October 12-13, 2023





Courtesy:
Eric Hackathorn,
NOAA/GSL

Roadmap

Operational: GEFSv12-Aerosol

- One member of the Global Ensemble Forecast System (GEFS)
- One-way coupled Atmosphere-Aerosols-Waves system
- 5-day global aerosol predictions

Target: GEFSv13

- Two-way coupled, Atmosphere/Aerosols/Land/Ocean/Wave/Sea Ice
- Prognostic aerosols included in all GEFS members
- Aerosol-radiation feedback impacts meteorology
- 35-day global aerosol predictions

GEFS version 12

Base Model:	
GFS Model	FV3 (Finite-Vol Cubed-Sphere)
Resolution	C384 (25km) L64 (hybrid)
Physics	GFSv15 packages (GFDL MP)
Boundary forcing	NSST + 2-tiered SST
Non-Atmos Coupled Components	Waves (one-way) Aerosols (one-way), one member only
Ensemble Methods:	
Initial perturbations	EnKF -f06
Model uncertainty	5-scale SPPT and SKEB
Members	Control + 30 pert members
Forecast Details:	
Daily frequency	00, 06, 12 and 18UTC
Forecast length	16 days, 35 days (00UTC)
Other Details:	
Reforecast	30 years (1989-2018)
Implementation	September 2020 (5 years of V11)

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https://doi.org/10.5194/gmd-15-5337-2022

Geoscientific Model Development
Open Access
EGU

Development and evaluation of the Aerosol Forecast Member in the National Center for Environment Prediction (NCEP)'s Global Ensemble Forecast System (GEFS-Aerosols v1)

Li Zhang[1,2], Raffaele Montuoro[1,2,7], Stuart A. McKeen[1,3], Barry Baker[4,5], Partha S. Bhattacharjee[6], Georg A. Grell[2], Judy Henderson[2], Li Pan[6], Gregory J. Frost[3], Jeff McQueen[7], Rick Saylor[8], Haiqin Li[1,2], Ravan Ahmadov[1,2], Jun Wang[7], Ivanka Stajner[7], Shobha Kondragunta[9], Xiaoyang Zhang[10], and Fangjun Li[10]

- Single GOCART-based aerosol component
- Substantial improvement over former operational NGACv2 system in both composition and variability of aerosol distributions

Species	N	Obs. median ($mg\,m^{-2}$)	GEFS-Aerosols MMO	NGACv2 MMO	GEFS-Aerosols r coefficient	NGACv2 r coefficient
Sulfate	153	0.58	0.72	–	0.63	–
OC	146	0.55	1.03	–	0.80	–
BC	152	0.011	3.35	–	0.78	–
Dust (< 3 µm diam)	130	0.038	0.54	46.37	0.39	0.39

GEFS version 13

Target configuration

Base Model:	
GFS Model	UFS Coupled
Resolution	Atmos/Aerosol/Land: C384 (25km) L127, Ocean/Ice: 0.25° tripole, Wave 0.25° lat/lon
Atmos Physics	CCPP (saSAS, Thompson-MP, sa-TKE-EDMF, uGWD, NOAH-MP)
Boundary forcing	N/A
Ensemble Methods:	
Initial perturbations	EnKF f00 (early cycle)
Model uncertainty	Atmos: 5-scale SPPT, SKEB, SPP, CA; Ocean: 5-scale oSPPT and ePBL
Members	Control + 30 pert members
Forecast Details:	
Daily frequency	00, 06, 12 and 18UTC
Forecast length	16 days, 35/48 days (00UTC, Mon & Thu)
Other Details:	
Reforecast	30 years (1994-2023)
Implementation	Q1 FY2026

- Built on the Unified Forecast System (UFS)
- UFS-Aerosols component embeds NASA's 2nd-generation GOCART model
- Updated dust scheme (FENGSHA)
- Aerosol-radiation feedback enabled
- Prognostic aerosols included in all 31 members
- Global aerosol predictions up to 35 days
- First-ever aerosol data assimilation (GDAS-Aero v1)

Roadmap – Development

- Development performed through sequential Ensemble Prototypes (EP) consisting of 10 perturbed members + control
- EPs based on GFS prototypes
- Prognostic aerosols introduced in EP4 with aerosol-radiation feedback (EP4a)
- EP4a aerosol configuration based on early experiments for UFS coupled prototype 8 (P8)
- EP4b - updated aerosol component with dust bugfix and scaling of biomass burning

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Description and Results from UFS Coupled Prototypes for Future Global, Ensemble and Seasonal Forecasts at NCEP

Lydia Stefanova[1], Jessica Meixner[2], Jiande Wang[1], Sulagna Ray[3], Avichal Mehra[2], Michael Barlage[2], Lisa Bengtsson[4], Partha S. Bhattacharjee[1], Rainer Bleck[5], Arun Chawla[2], Benjamin W. Green[5,7], Jongil Han[2], Wei Li[1], Xu Li[1], Raffaele Montuoro[2], Shrinivas Moorthi[2], Cristiana Stan[6], Shan Sun[5], Denise Worthen[1], Fanglin Yang[2], Weizhong Zheng[1]

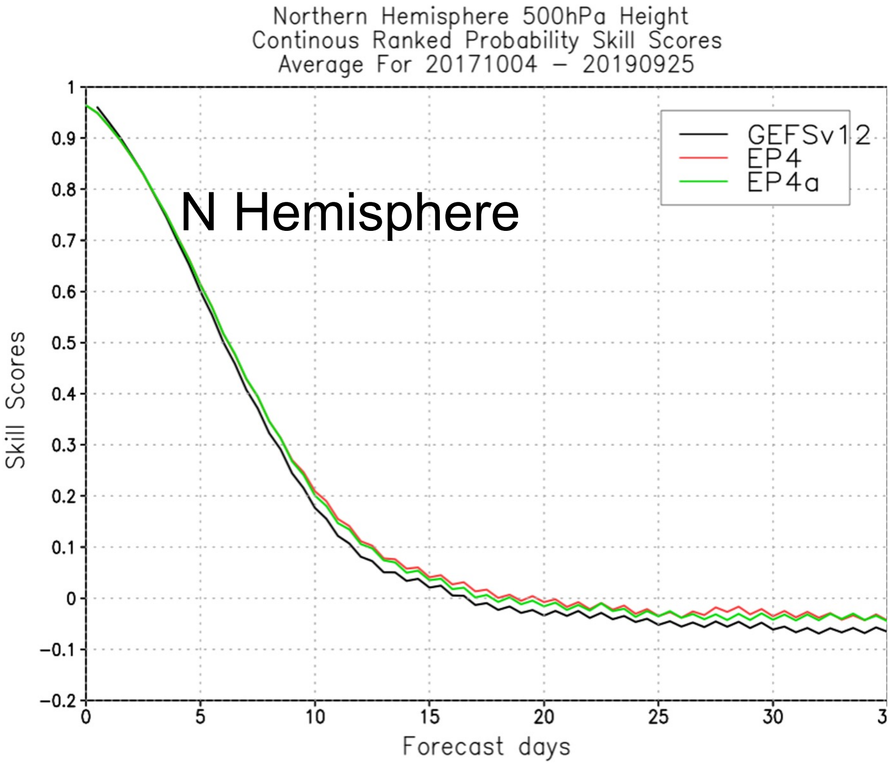
Roadmap – EP4a experiments

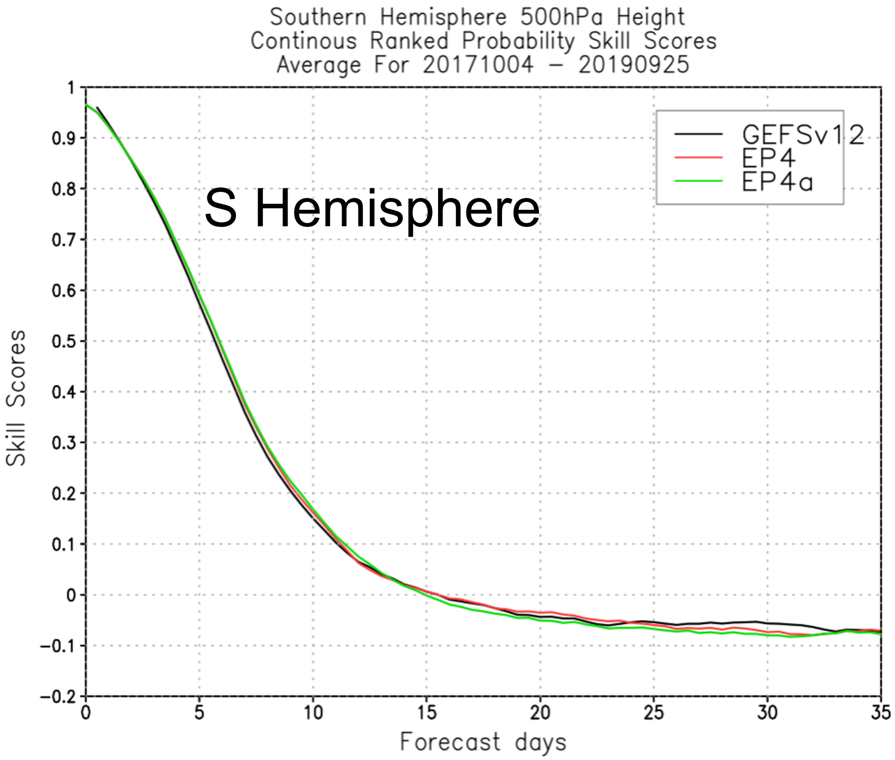
- 35-day, free forecasts
- **Mini-set**
  - 16 cases: 8 summer and 8 winter cases (2018)
    - Winter: 20180103, 20180110, 20180117, 20180124, 20180131, 20180207, 20180214, 20180221
    - Summer: 20180801, 20180808, 20180815, 20180822, 20180829, 20180905, 20180912, 20180919
- **Full set**
  - 104 cases: Oct. 2017–Sept. 2019, Oct. 2020–Sept. 2021
  - Once per week (Wednesday 00 UTC), 11 members, out to 35 days

Roadmap – EP4a evaluation

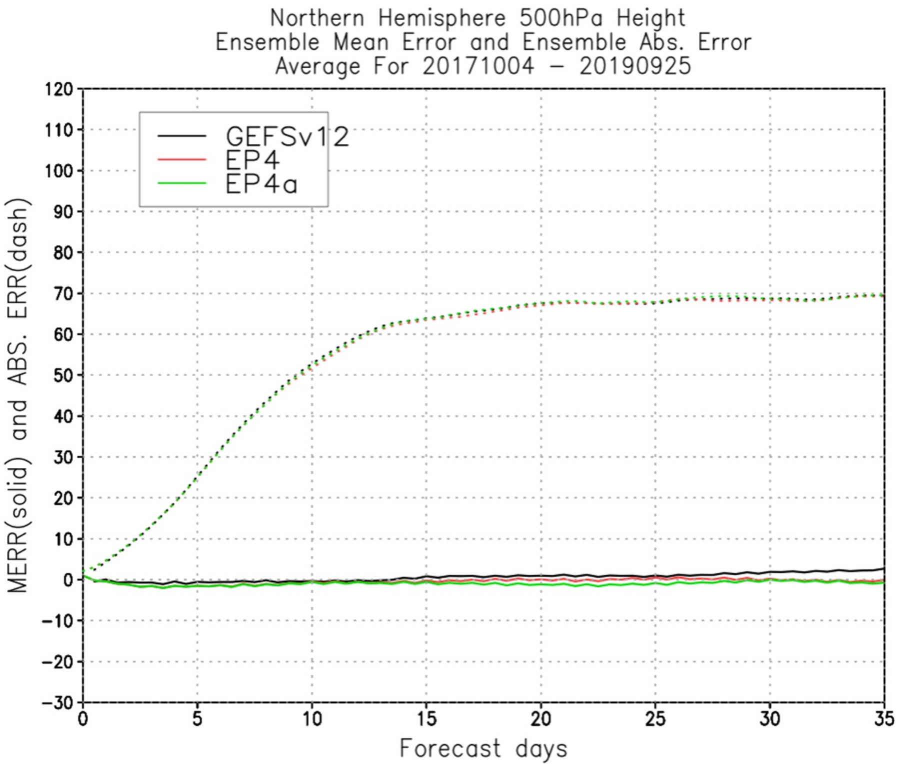
1. Analysis of aerosol optical depth (AOD) and distributions
    - Compare AODs against NASA (MERRA-2) and ECMWF (CAMS) global reanalysis datasets
    - Compare surface distributions to AERONET data
2. Evaluation of aerosol impact on meteorology
    - Use standard GEFS metrics to compare EP4a to EP4:
        - 500 hPa height – Anomaly Correlation (AC)
        - 500 hPa height – Continuous Ranked Probability Skill Scores (CRPSS)
        - 500 hPa height – bias
        - 850 hPa temperature – bias
        - 850 hPa zonal wind – RMSE
        - 250 hPa zonal wind – RMSE
        - MJO
        - Surface diagnosis

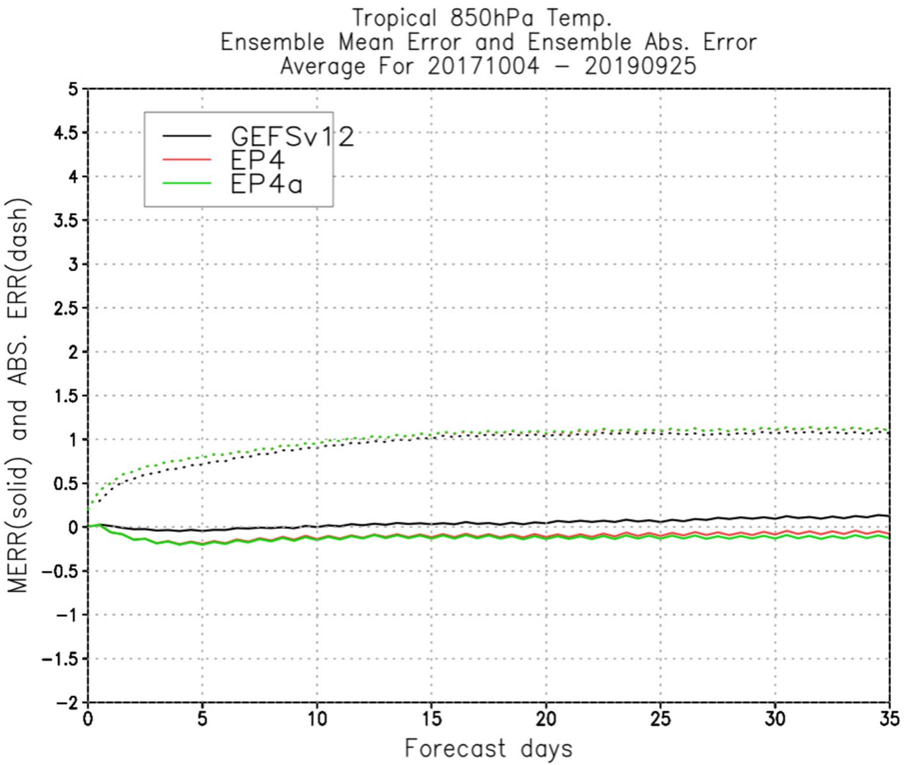
500 hPa Height – CRPSS



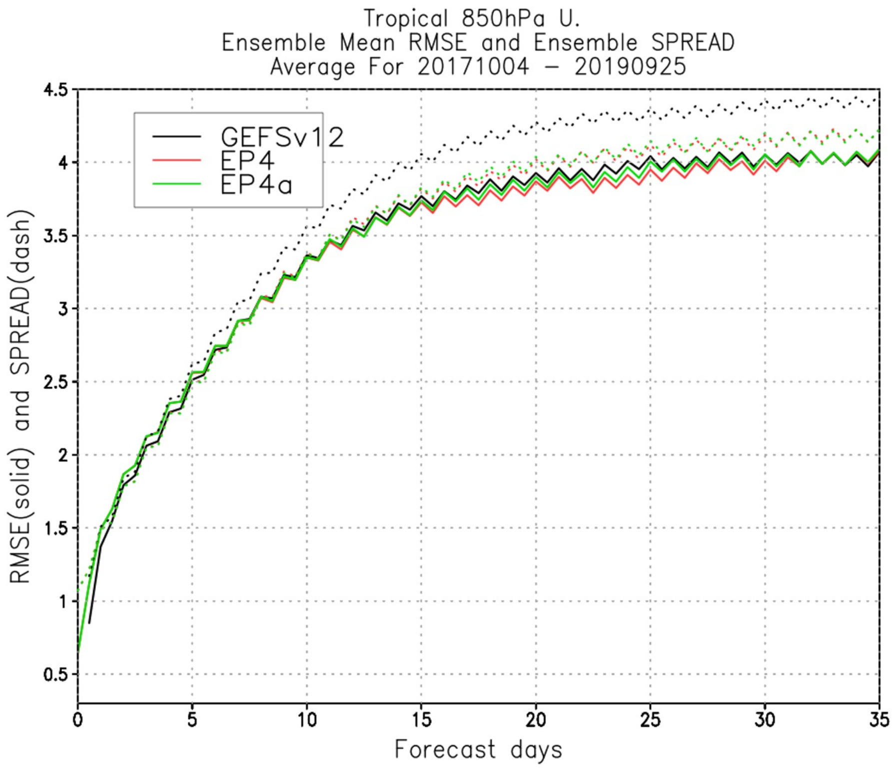


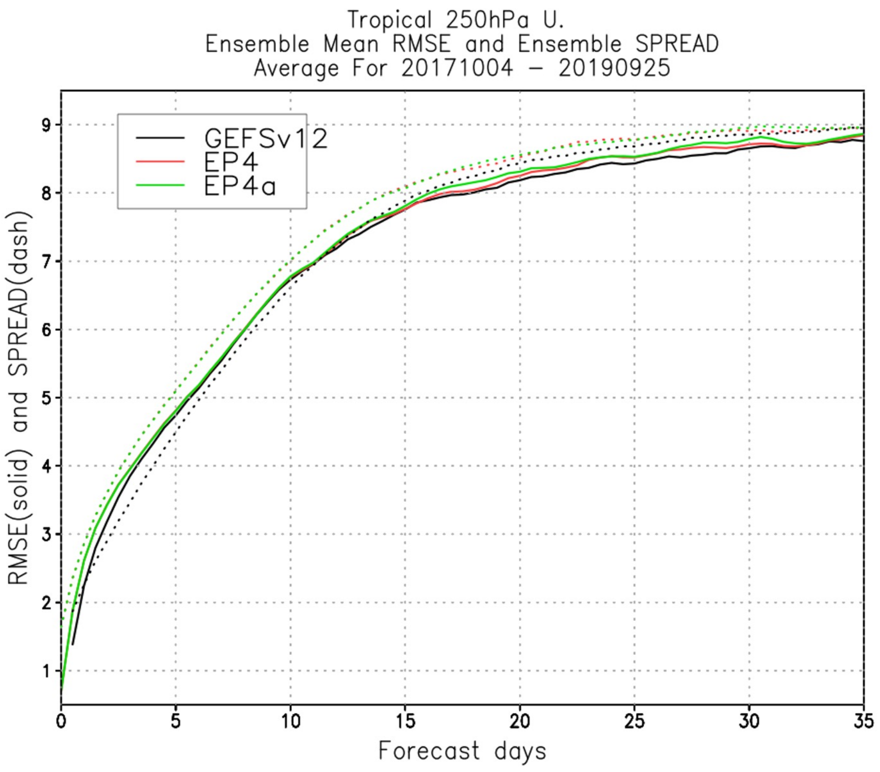
500 hPa Height & 850 hPa Temperature





Zonal wind – 250 hPa & 850 hPa



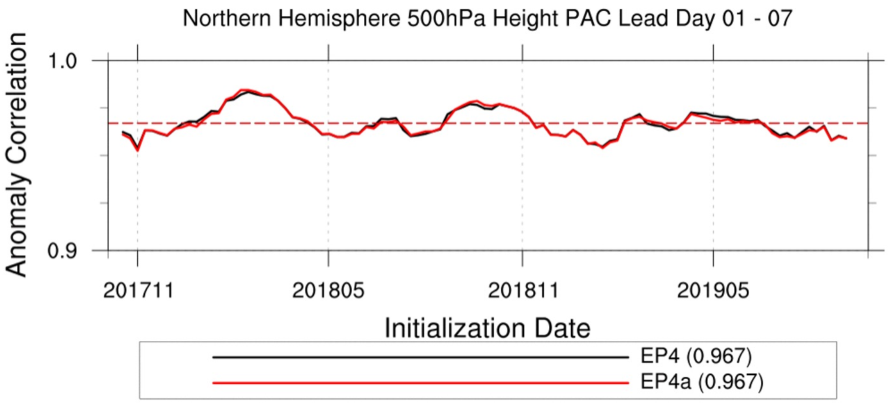


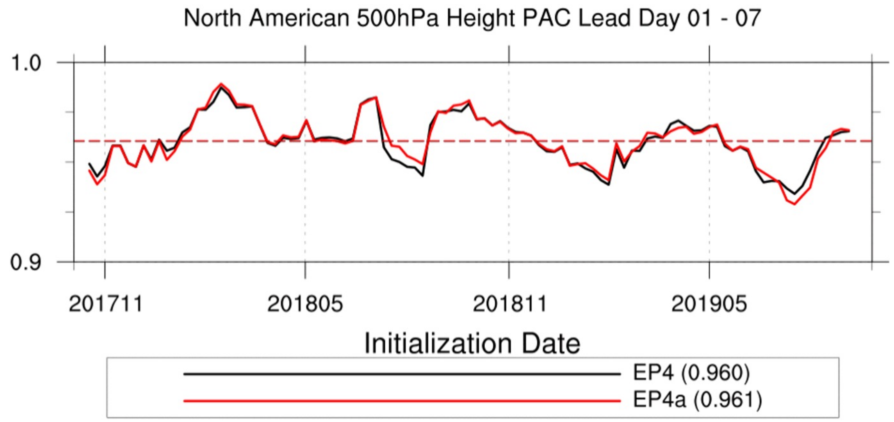
500 hPa Height

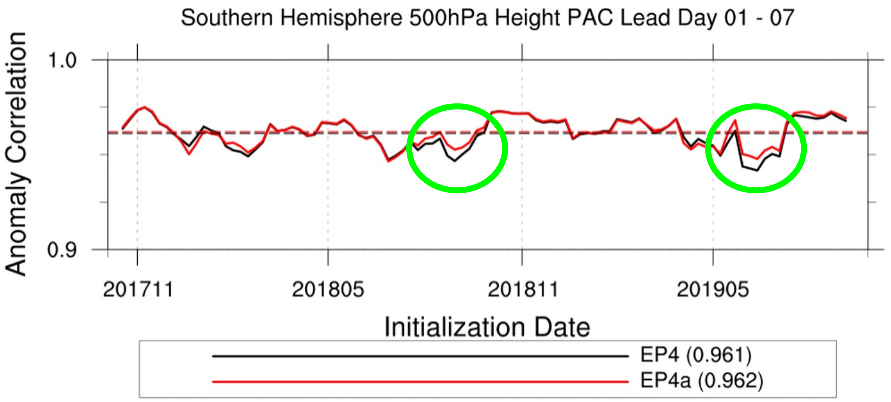
2017-2019 Average Anomaly Correlation

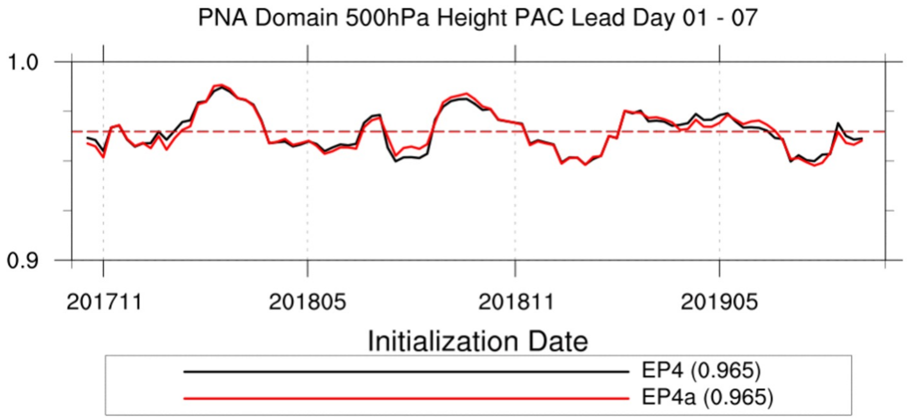
500 hPa Height Average AC	Free Forecast Period	EP4	EP4 + aerosols	Change
Northern Hemisphere	Week 1	0.967	0.967	—
	Week 2	0.656	0.646	–0.010 (-1.5%)
	Week 3-4	0.378	0.368	–0.010 (-2.6%)
Southern Hemisphere	Week 1	0.961	0.962	+0.001 (+0.1%)
	Week 2	0.584	0.601	+0.017 (+2.9%)
	Week 3-4	0.278	**0.225**	**–0.053 (-19.1%)**

500 hPa Height – Week 1

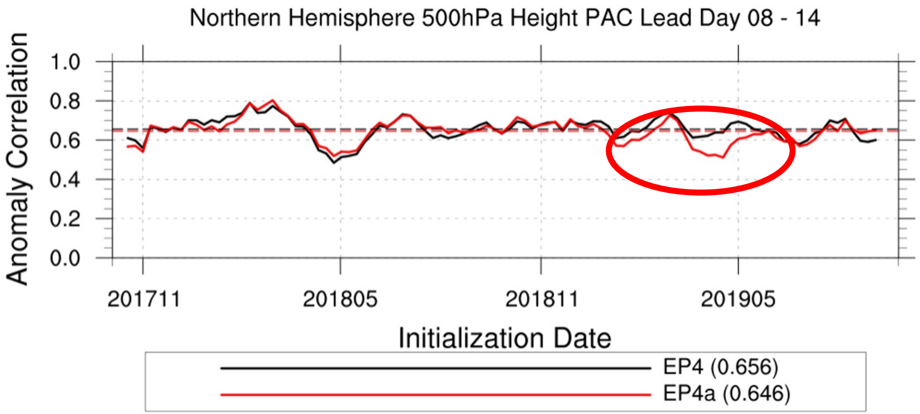


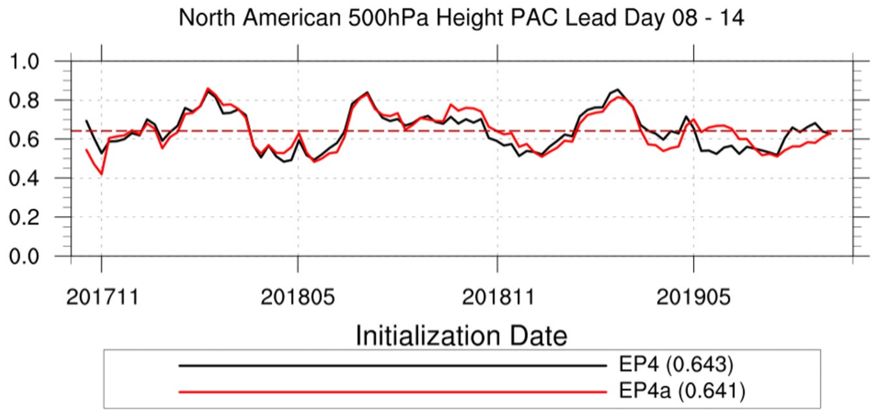


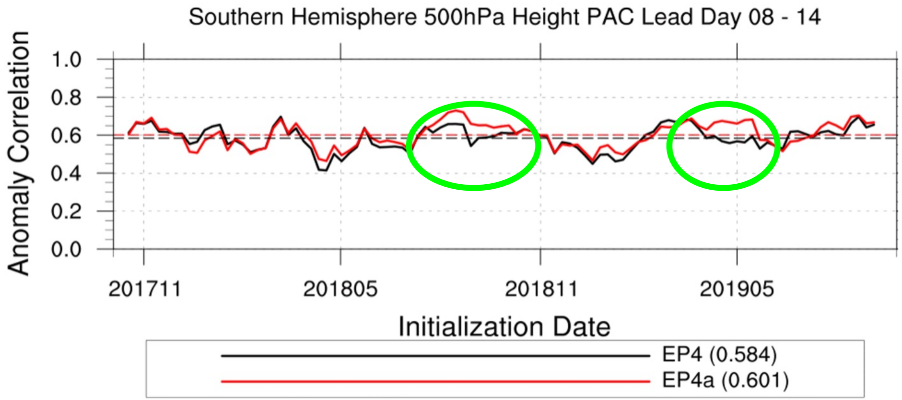


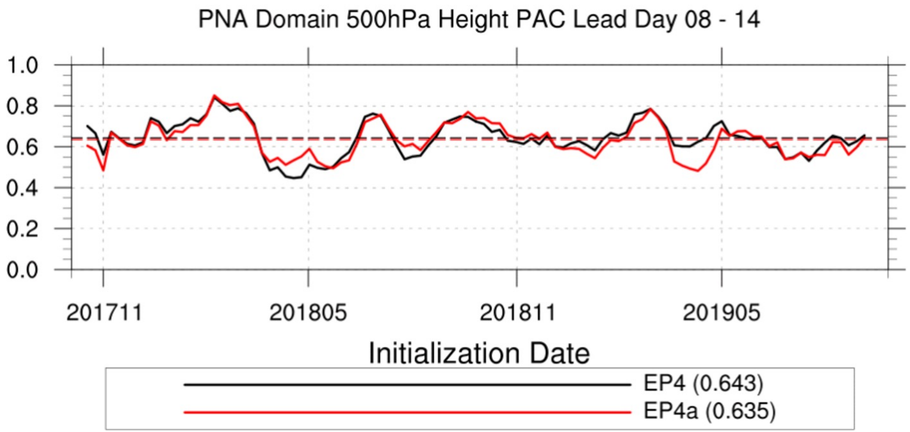


500 hPa Height – Week 2

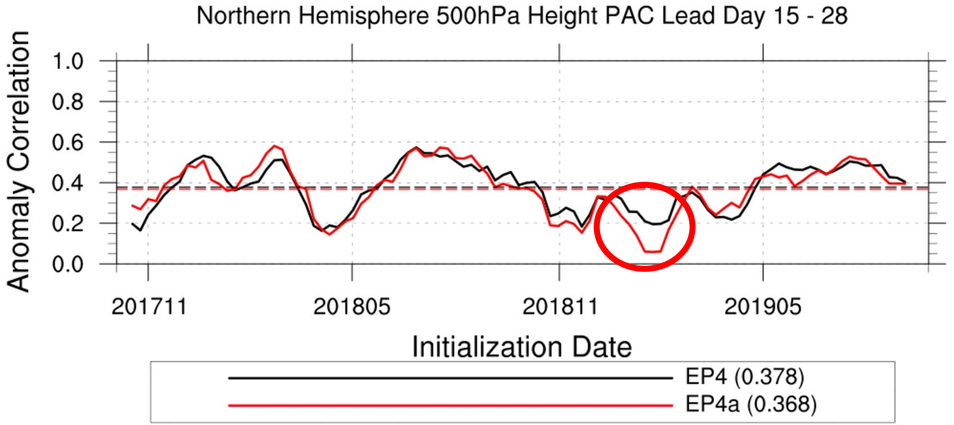


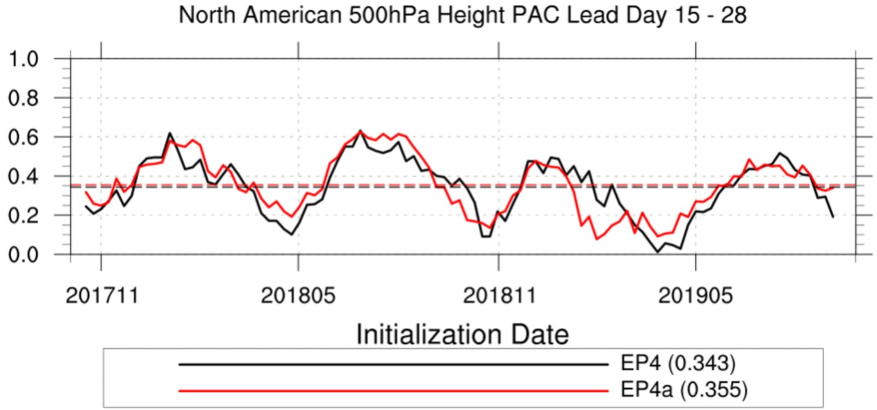


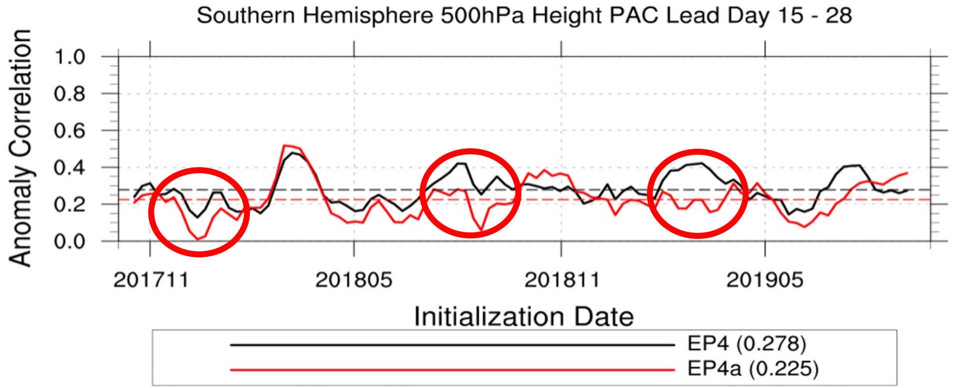


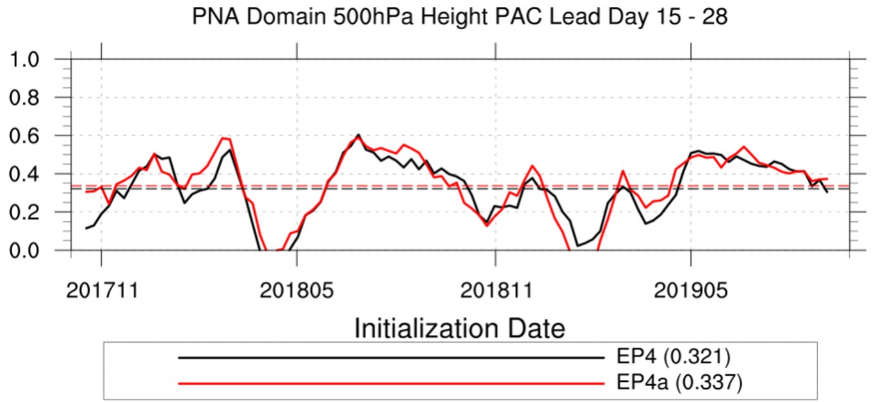


500 hPa Height – Week 3-4









EP4a evaluation summary

Aerosols

- Dust and biomass burning overprediction

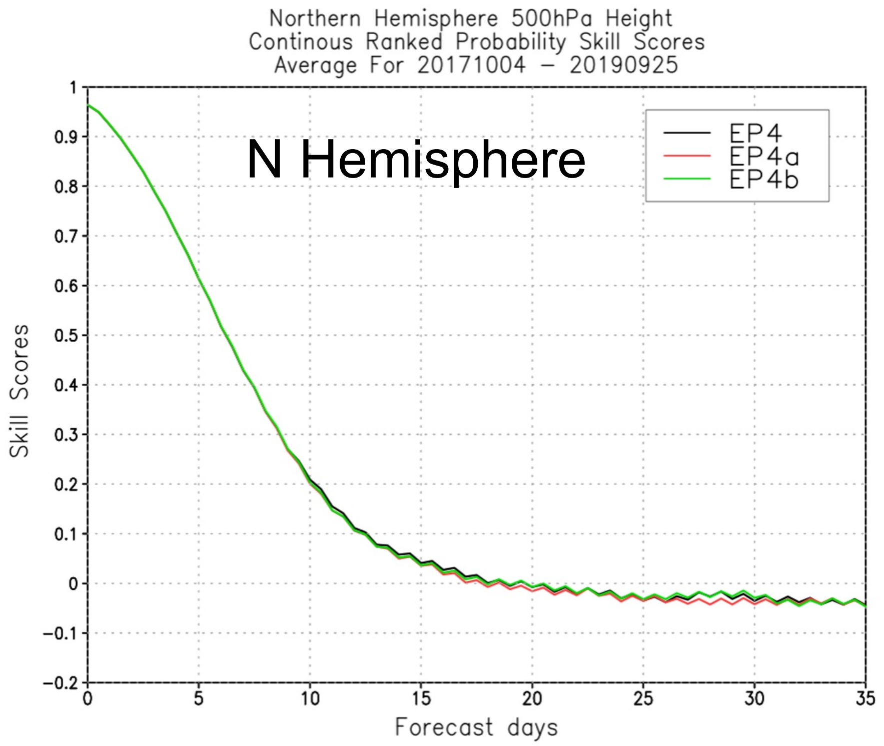
Atmosphere

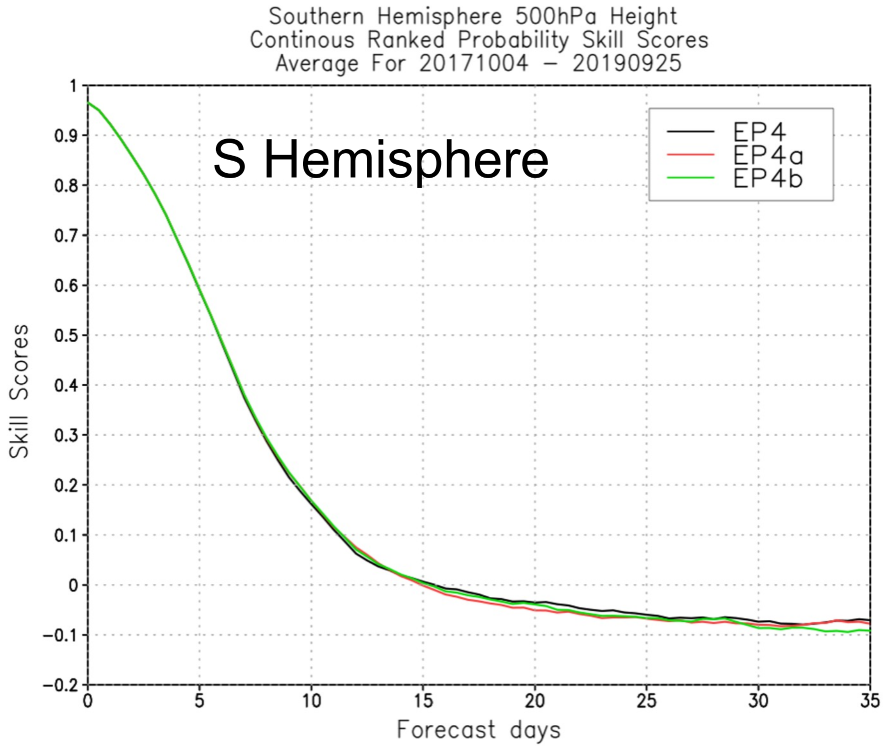
- Improvements over EP4 in Week 1
- Mixed results in Week 2 – improvement in SH, degradation in NH (500hPa height)
- Noticeable degradation in Week 3-4
- Slightly colder than EP4

EP4b – Aerosol updates

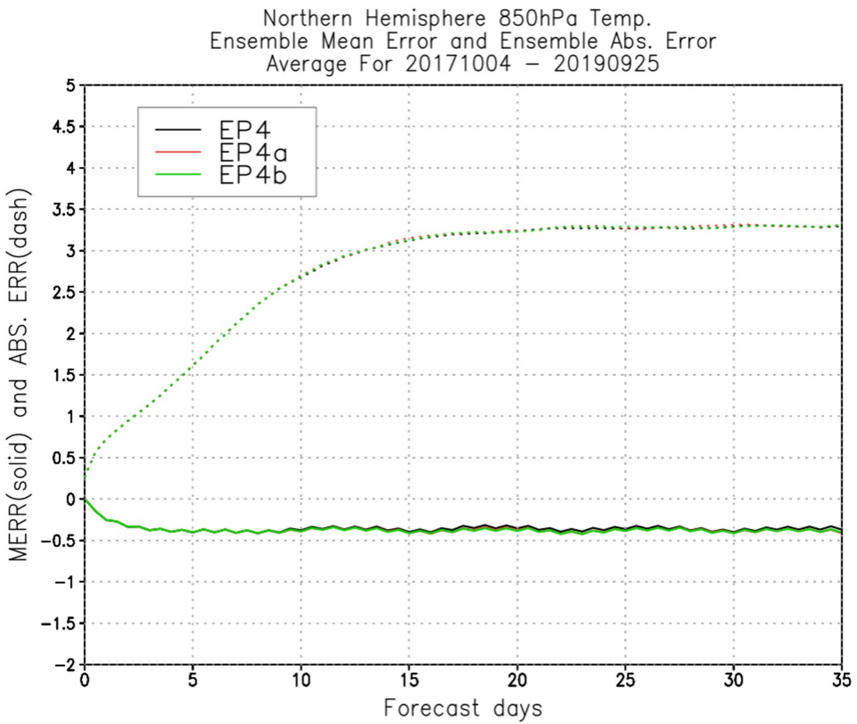
- **Dust scheme (FENGSHA)**
  - Corrected soil moisture (bugfix)
  - Improved surface inputs - fixes for high latitude and non-permeable surfaces
- **Biomass-burning emissions**
  - Scaled Quick Fire Emission Dataset (QFED) for consistency with 2nd-generation GOCART assumptions

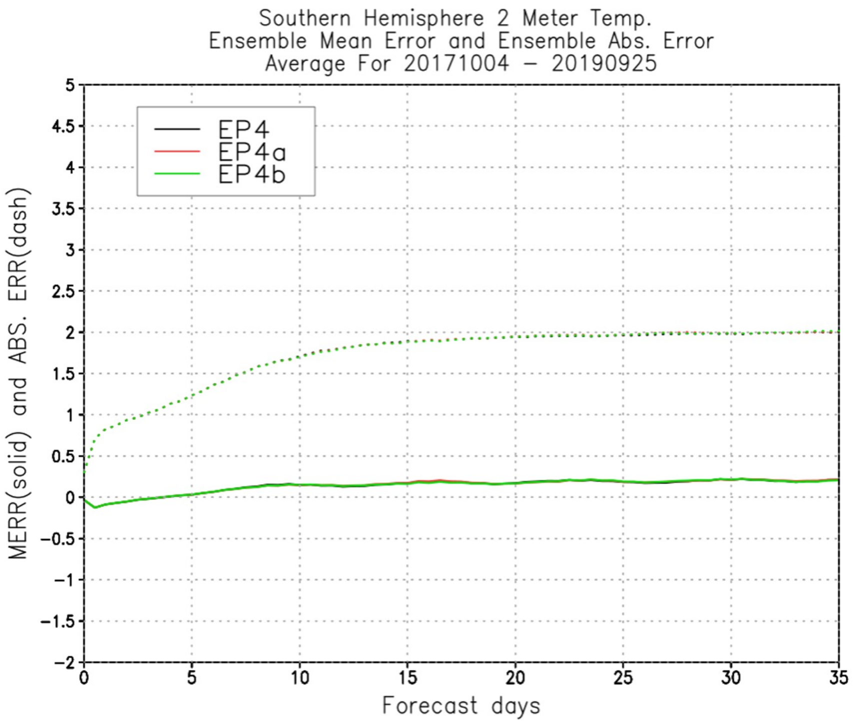
500 hPa Height – CRPSS



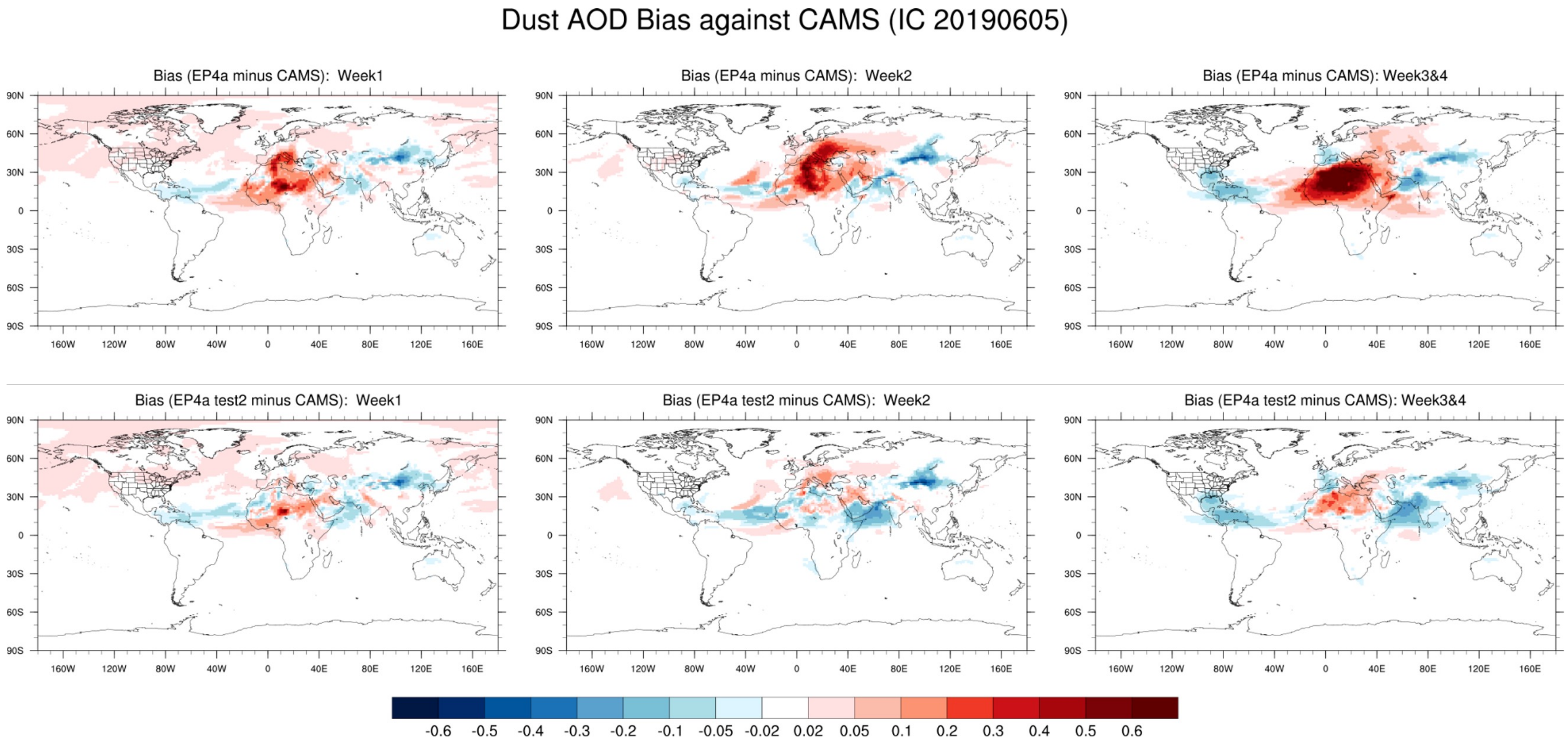


850 hPa Height & 2m Temperature

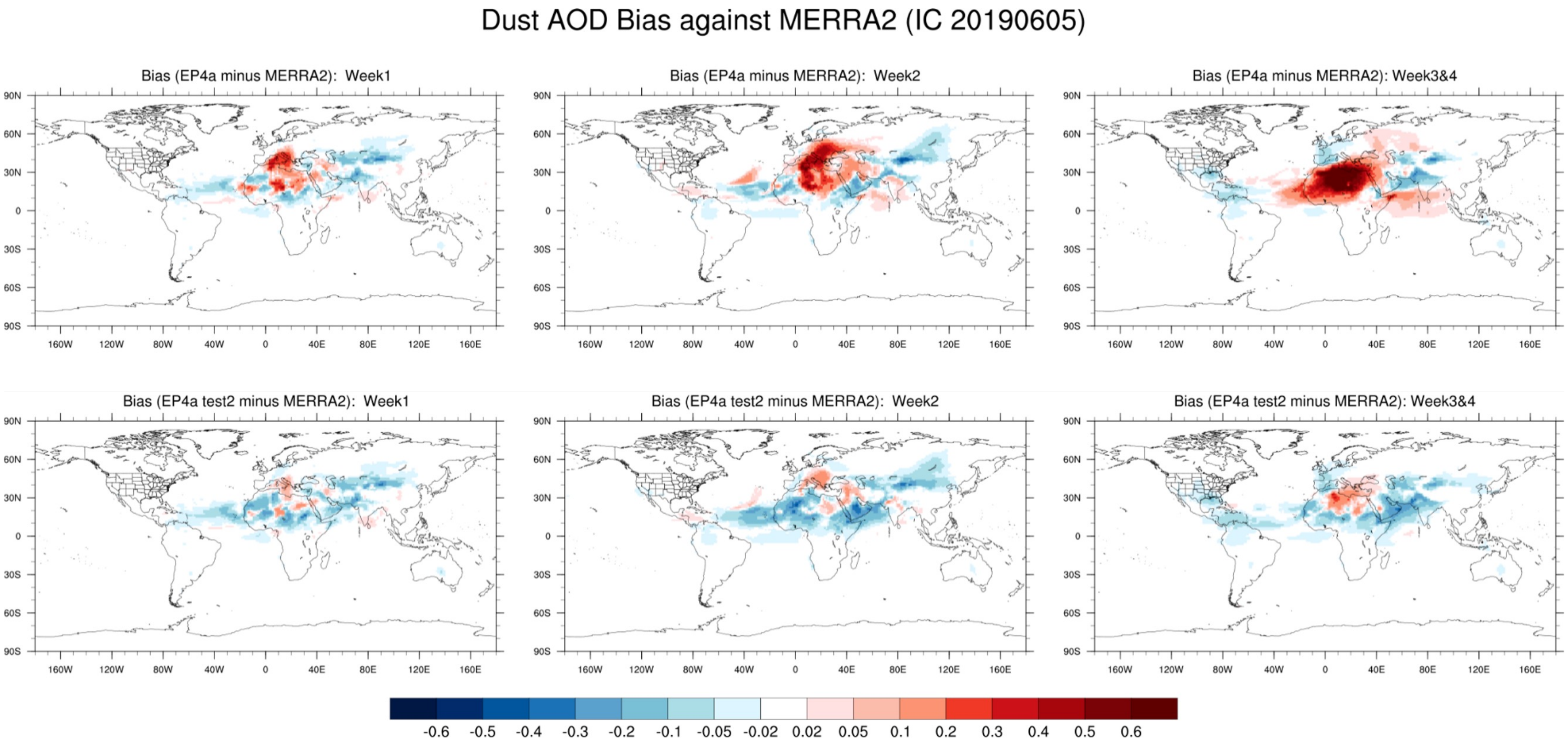




EP4b – Preliminary results (control)

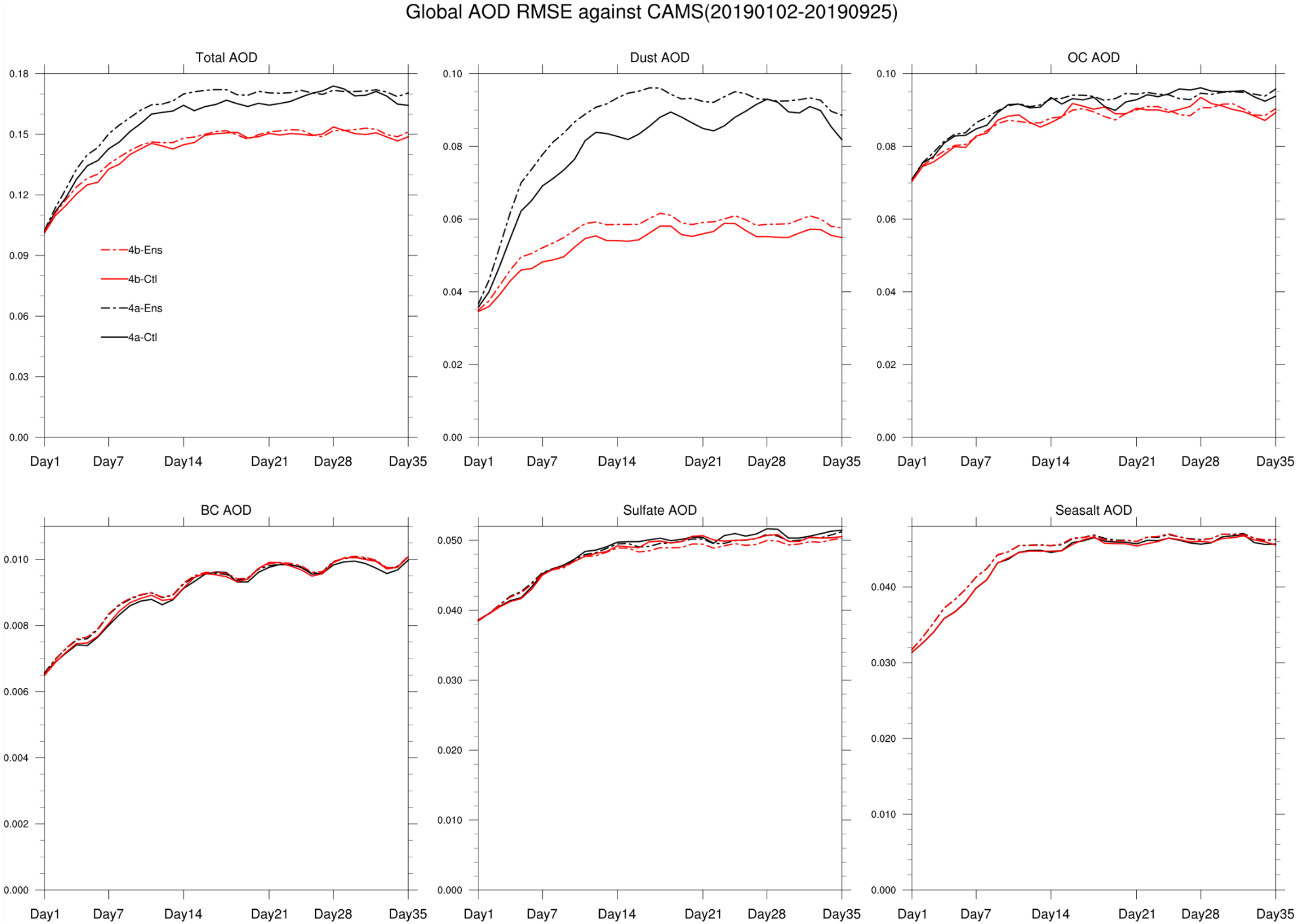


EP4b – Preliminary results (control)



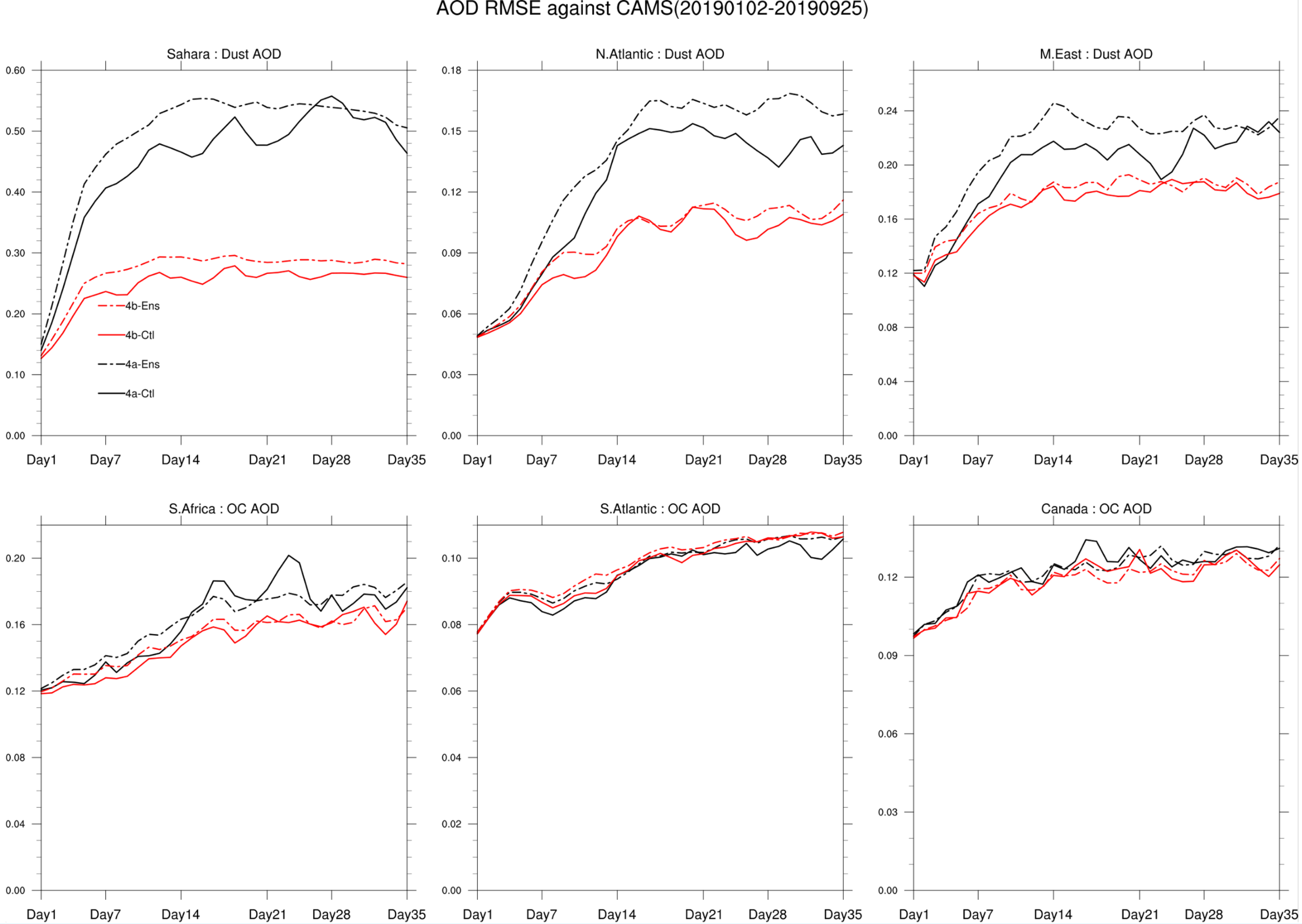
EP4b

Preliminary results from ensemble experiment



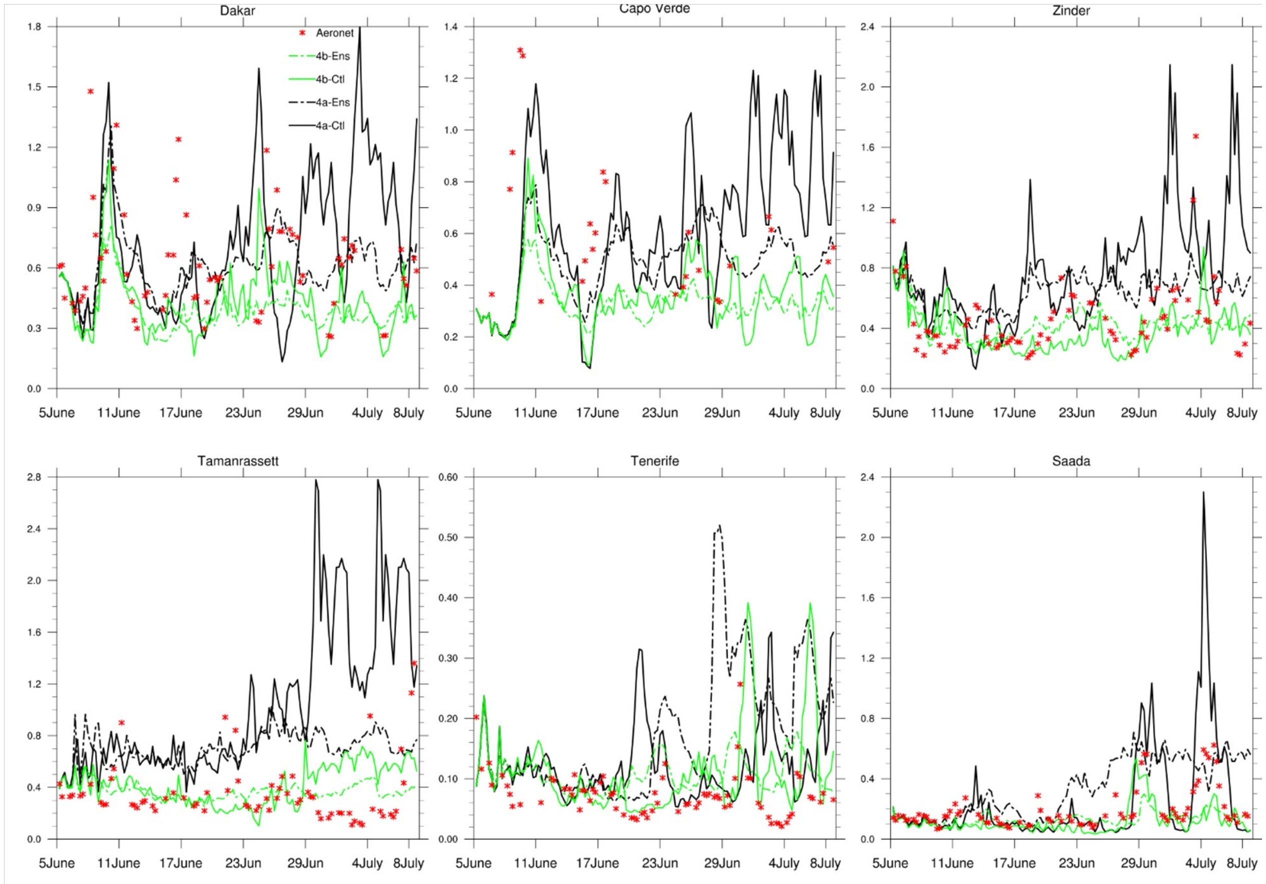
EP4b

Preliminary results from ensemble experiment



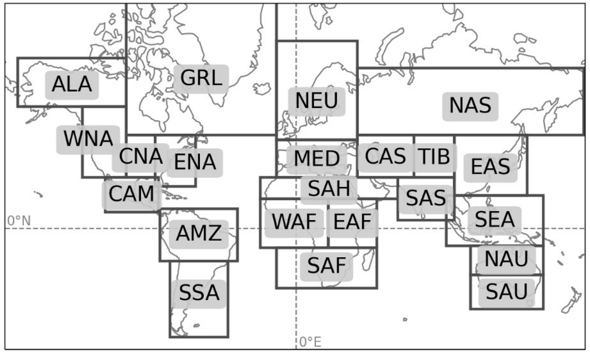
EP4b – Preliminary results (control)

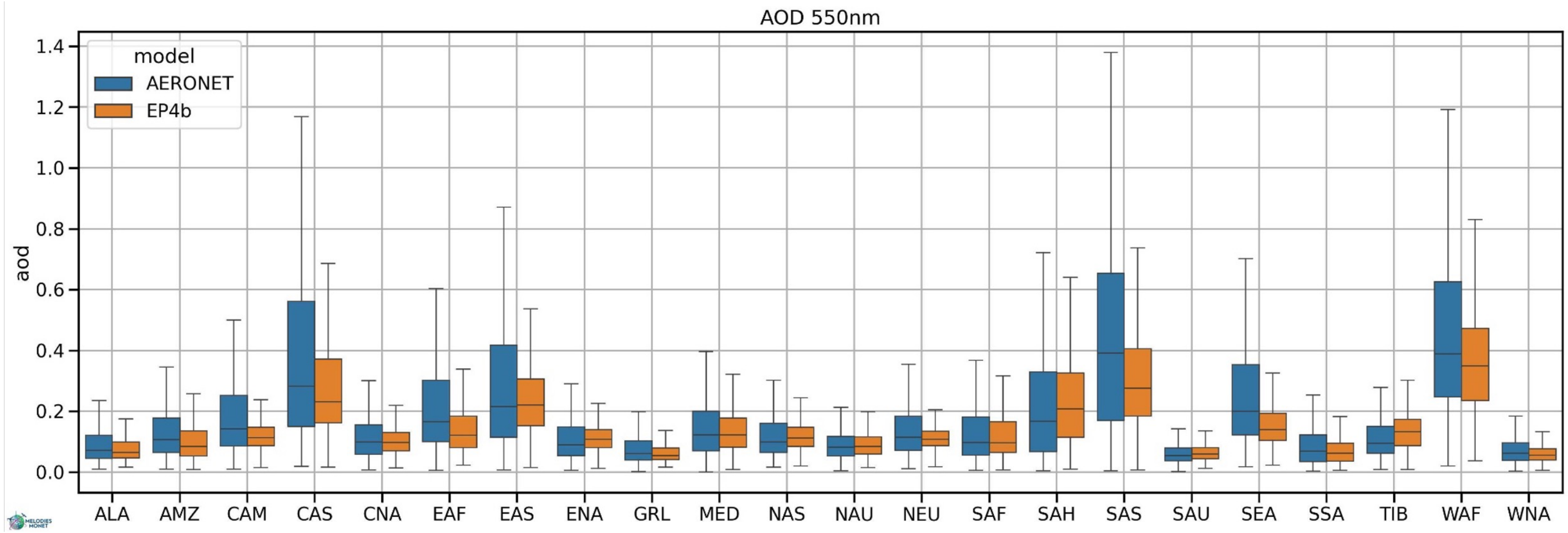
Example of Sahara stations



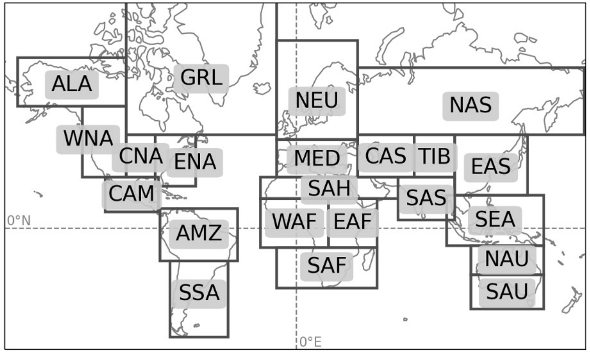
Comparisons to Aeronet

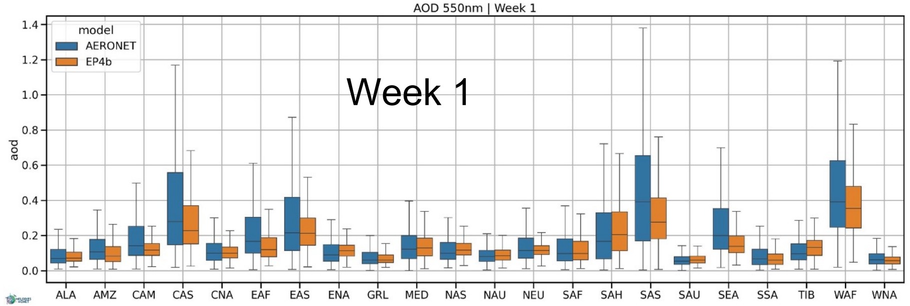
Overall comparisons to aeronet are good with the notable underprediction in the AOD mean in southern and central Asia

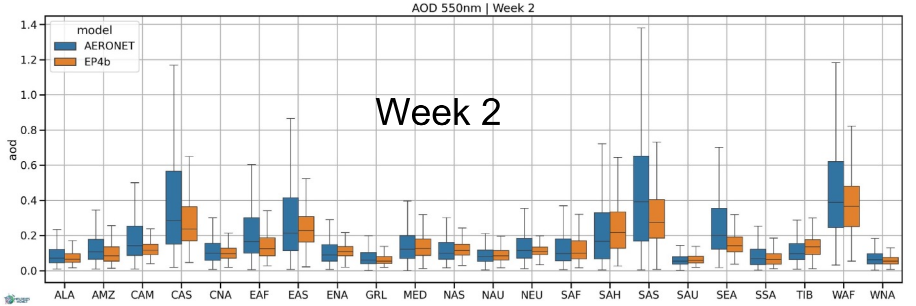


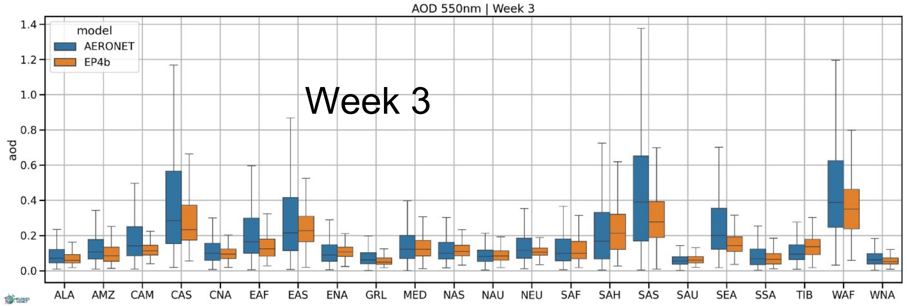


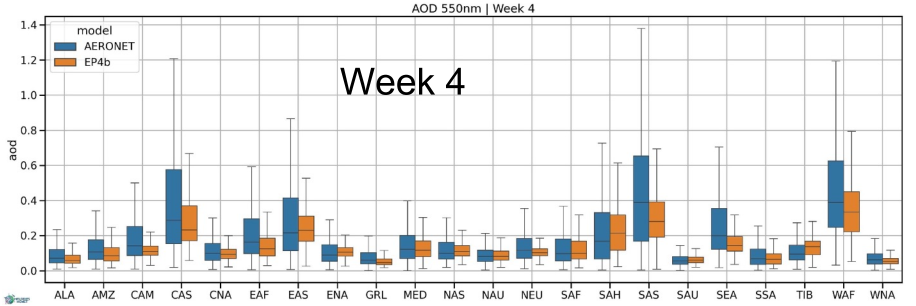
Comparison to Aeronet

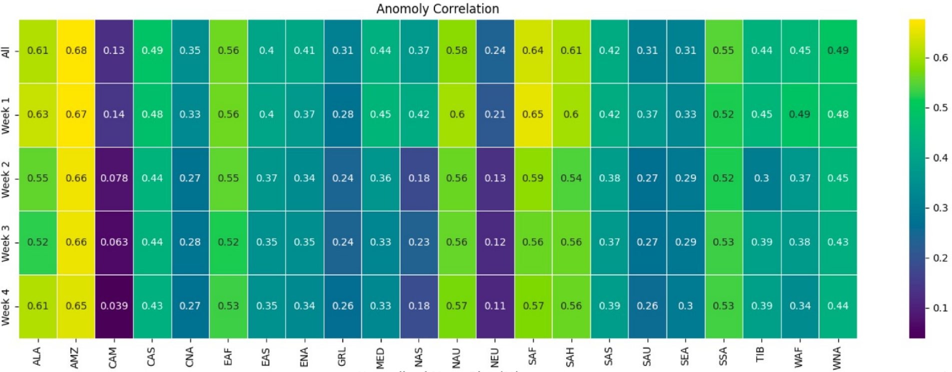




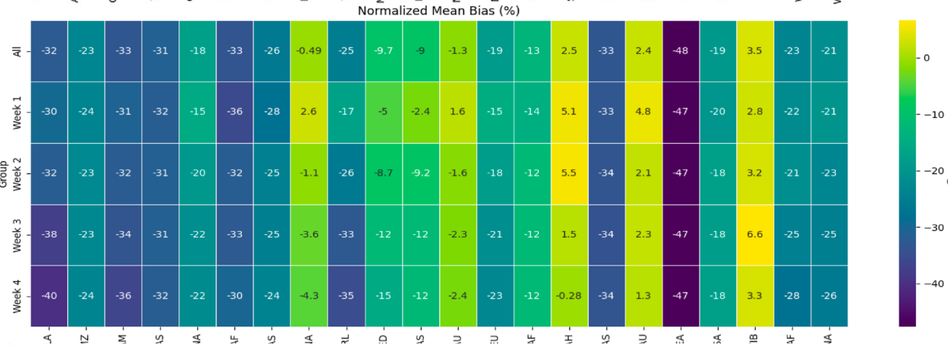


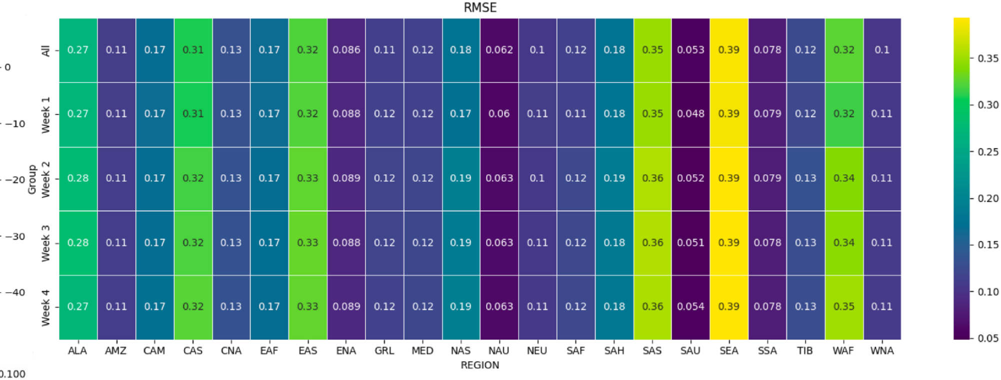


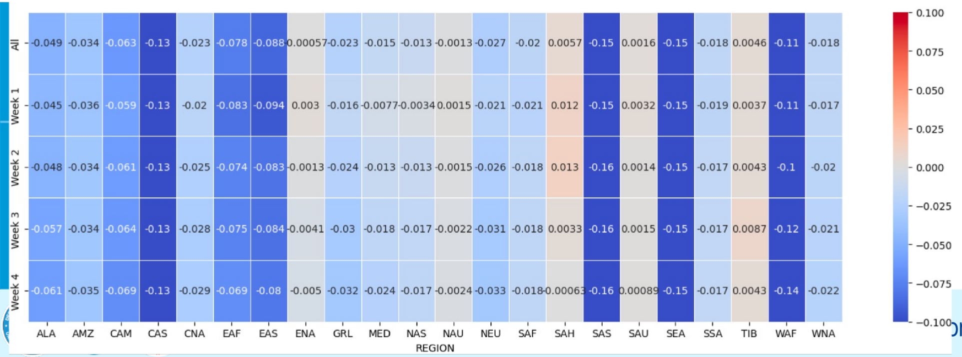


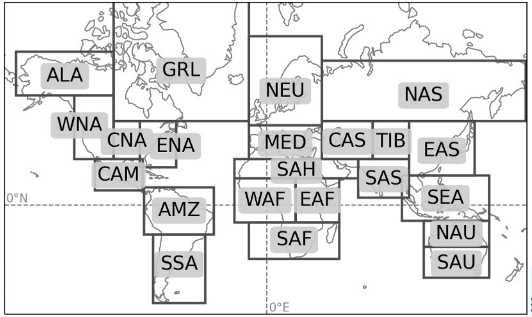

Anomoly Correlation
All 0.61 0.68 0.13 0.49 0.35 0.56 0.4 0.41 0.31 0.44 0.37 0.58 0.24 0.64 0.61 0.42 0.31 0.31 0.55 0.44 0.45 0.49
Week 1 0.63 0.67 0.14 0.48 0.33 0.56 0.4 0.37 0.28 0.45 0.42 0.6 0.21 0.65 0.6 0.42 0.37 0.33 0.52 0.45 0.49 0.48
Week 2 0.55 0.66 0.078 0.44 0.27 0.55 0.37 0.34 0.24 0.36 0.18 0.56 0.13 0.59 0.54 0.38 0.27 0.29 0.52 0.3 0.37 0.45
Week 3 0.52 0.66 0.063 0.44 0.28 0.52 0.35 0.35 0.24 0.33 0.23 0.56 0.12 0.56 0.56 0.37 0.27 0.29 0.53 0.39 0.38 0.43
Week 4 0.61 0.65 0.039 0.43 0.27 0.53 0.35 0.34 0.26 0.33 0.18 0.57 0.11 0.57 0.56 0.39 0.26 0.3 0.53 0.39 0.34 0.44
ALA AMZ CAM CAS CNA EAF EAS ENA GRL MED NAS NAU NEU SAF SAH SAS SAU SEA SSA TIB WAF WNA
0.6 0.5 0.4 0.3 0.2 0.1


Index of Agreement
Group
All 0.63 0.64 0.44 0.58 0.49 0.61 0.51 0.46 0.48 0.51 0.44 0.56 0.42 0.6 0.59 0.52 0.47 0.55 0.59 0.43 0.52 0.55
Week 1 0.62 0.64 0.44 0.57 0.48 0.61 0.51 0.44 0.46 0.51 0.43 0.56 0.4 0.61 0.59 0.52 0.48 0.56 0.58 0.42 0.54 0.55
Week 2 0.61 0.63 0.41 0.56 0.45 0.6 0.48 0.41 0.45 0.46 0.39 0.55 0.37 0.57 0.54 0.5 0.43 0.54 0.57 0.37 0.48 0.53
Week 3 0.61 0.63 0.42 0.56 0.46 0.59 0.47 0.41 0.46 0.45 0.39 0.54 0.37 0.56 0.55 0.5 0.42 0.54 0.58 0.4 0.49 0.53
Week 4 0.62 0.62 0.41 0.55 0.45 0.6 0.47 0.41 0.47 0.46 0.39 0.55 0.38 0.56 0.54 0.5 0.42 0.54 0.58 0.38 0.49 0.53
ALA AMZ CAM CAS CNA EAF EAS ENA GRL MED NAS NAU NEU SAF SAH SAS SAU SEA SSA TIB WAF WNA


Normalized Mean Bias (%)
Group
All -32 -23 -33 -31 -18 -33 -26 -0.49 -25 -9.7 -9 -1.3 -19 -13 2.5 -33 2.4 -48 -19 3.5 -23 -21
Week 1 -30 -24 -31 -32 -15 -36 -28 2.6 -17 -5 -2.4 1.6 -15 -14 5.1 -33 4.8 -47 -20 2.8 -22 -21
Week 2 -32 -23 -32 -31 -20 -32 -25 -1.1 -26 -8.7 -9.2 -1.6 -18 -12 5.5 -34 2.1 -47 -18 3.2 -21 -23
Week 3 -38 -23 -34 -31 -22 -33 -25 -3.6 -33 -12 -12 -2.3 -21 -12 1.5 -34 2.3 -47 -18 6.6 -25 -25
Week 4 -40 -24 -36 -32 -22 -30 -24 -4.3 -35 -15 -12 -2.4 -23 -12 -0.28 -34 1.3 -47 -18 3.3 -28 -26
0 −10 −20 −30 −40


RMSE
Group
All 0.27 0.11 0.17 0.31 0.13 0.17 0.32 0.086 0.11 0.12 0.18 0.062 0.1 0.12 0.18 0.35 0.053 0.39 0.078 0.12 0.32 0.1
Week 1 0.27 0.11 0.17 0.31 0.13 0.17 0.32 0.088 0.12 0.12 0.17 0.06 0.11 0.11 0.18 0.35 0.048 0.39 0.079 0.12 0.32 0.11
Week 2 0.28 0.11 0.17 0.32 0.13 0.17 0.33 0.089 0.12 0.12 0.19 0.063 0.1 0.12 0.19 0.36 0.052 0.39 0.079 0.13 0.34 0.11
Week 3 0.28 0.11 0.17 0.32 0.13 0.17 0.33 0.088 0.12 0.12 0.19 0.063 0.11 0.12 0.18 0.36 0.051 0.39 0.078 0.13 0.34 0.11
Week 4 0.27 0.11 0.17 0.32 0.13 0.17 0.33 0.089 0.12 0.12 0.19 0.063 0.11 0.12 0.18 0.36 0.054 0.39 0.078 0.13 0.35 0.11
ALA AMZ CAM CAS CNA EAF EAS ENA GRL MED NAS NAU NEU SAF SAH SAS SAU SEA SSA TIB WAF WNA
REGION
0.35 0.30 0.25 0.20 0.15 0.10 0.05

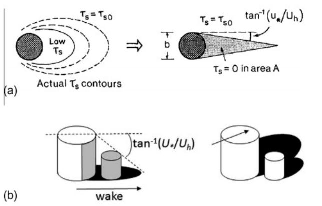

All -0.049 -0.034 -0.063 -0.13 -0.023 -0.078 -0.088 0.00057 -0.023 -0.015 -0.013 -0.0013 -0.027 -0.02 0.0057 -0.15 0.0016 -0.15 -0.018 0.0046 -0.11 -0.018
Week 1 -0.045 -0.036 -0.059 -0.13 -0.02 -0.083 -0.094 0.003 -0.016 -0.0077 -0.0034 0.0015 -0.021 -0.021 0.012 -0.15 0.0032 -0.15 -0.019 0.0037 -0.11 -0.017
Week 2 -0.048 -0.034 -0.061 -0.13 -0.025 -0.074 -0.083 -0.0013 -0.024 -0.013 -0.013 -0.0015 -0.026 -0.018 0.013 -0.16 0.0014 -0.15 -0.017 0.0043 -0.1 -0.02
Week 3 -0.057 -0.034 -0.064 -0.13 -0.028 -0.075 -0.084 -0.0041 -0.03 -0.018 -0.017 -0.0022 -0.031 -0.018 0.0033 -0.16 0.0015 -0.15 -0.017 0.0087 -0.12 -0.021
Week 4 -0.061 -0.035 -0.069 -0.13 -0.029 -0.069 -0.08 -0.005 -0.032 -0.024 -0.017 -0.0024 -0.033 -0.018 -0.00063 -0.16 0.00089 -0.15 -0.017 0.0043 -0.14 -0.022
ALA AMZ CAM CAS CNA EAF EAS ENA GRL MED NAS NAU NEU SAF SAH SAS SAU SEA SSA TIB WAF WNA
REGION
0.100 0.075 0.050 0.025 0.000 −0.025 −0.050 −0.075 −0.100


ALA
GRL
NEU
NAS
WNA
CNA
ENA
MED
CAS
TIB
EAS
CAM
SAH
SAS
0°N
WAF
EAF
SEA
AMZ
NAU
SAF
SSA
SAU
0°E

Summary

- GEFSv13 Development well underway.
- Early results show good agreement and on average no negative impacts on meteorology from inclusion of prognostic aerosols in weeks 1 -2
- Some negative impacts in weeks 3-4 but GEFSv13 prototype is better than the current operational GEFSv12

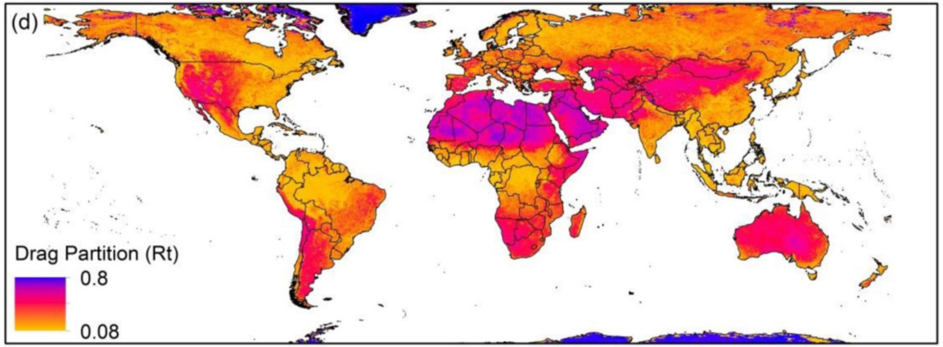
Fengsha - Updates (in a nutshell)



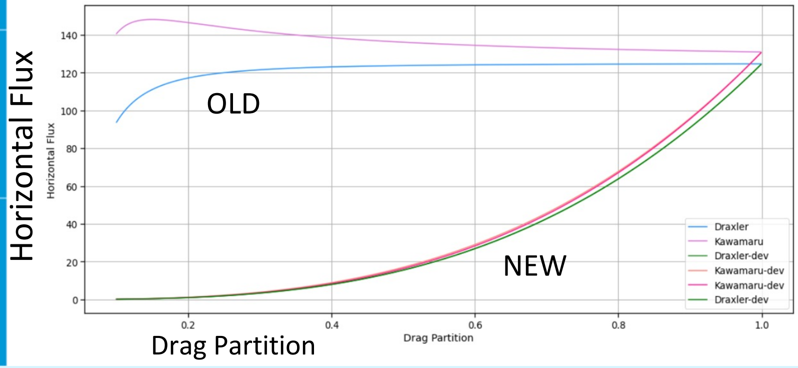
Update the drag partition to Chappel and Webb 2016

$$F = \alpha A \frac{\rho_a}{g} \left(R u_*^3 \right) \left(1 - \frac{u_{*t}^2}{u_*^2} \right) \left(1 + \frac{u_{*t}^2}{u_*^2} \right)$$

Area
Density
Friction Velocity
Threshold Velocity
Vertical To Horizontal Flux Ratio
Gravity
Drag Partition



[Webb et al. 2020]



Data driven dry threshold velocity