

Arctic System Modeling Efforts in the GMAO

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NASA Goddard Space Flight Center

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Original image: NASA SVS

Global Modeling & Assimilation Office

GMAO performs research, develops models and assimilation systems, and produces quasi-operational products in support of NASA's missions.

The "**Goddard Earth Observing System**" (GEOS) family of global models is used for applications across a range of themes: Weather Analysis and Prediction, Seasonal-Decadal Analysis and Prediction, Reanalysis, Global Mesoscale Modeling, and Observing System Science.

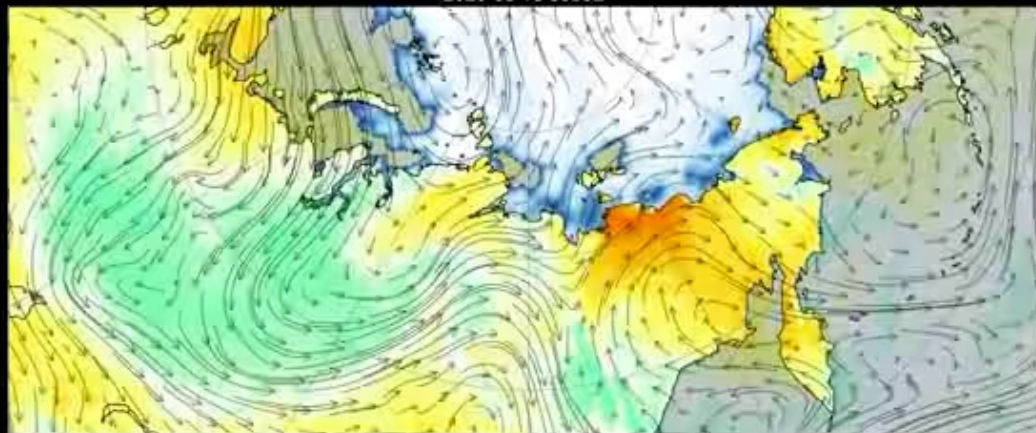
Our Arctic System modeling efforts are closely linked with GMAO's Earth system modeling and data assimilation priorities.

Predicting polar weather with GEOS-FP

2020 Eurasian Heatwave (Cullather & Partyka, 2020)

2-m Temp Anomaly, 250 hPa Wind, Sea Ice Cover, Organic Carbon Mass Density

2020-06-15 0030Z



20 m s⁻¹
→

2-m Temperature Anomaly [°C]



Sea Ice Cover

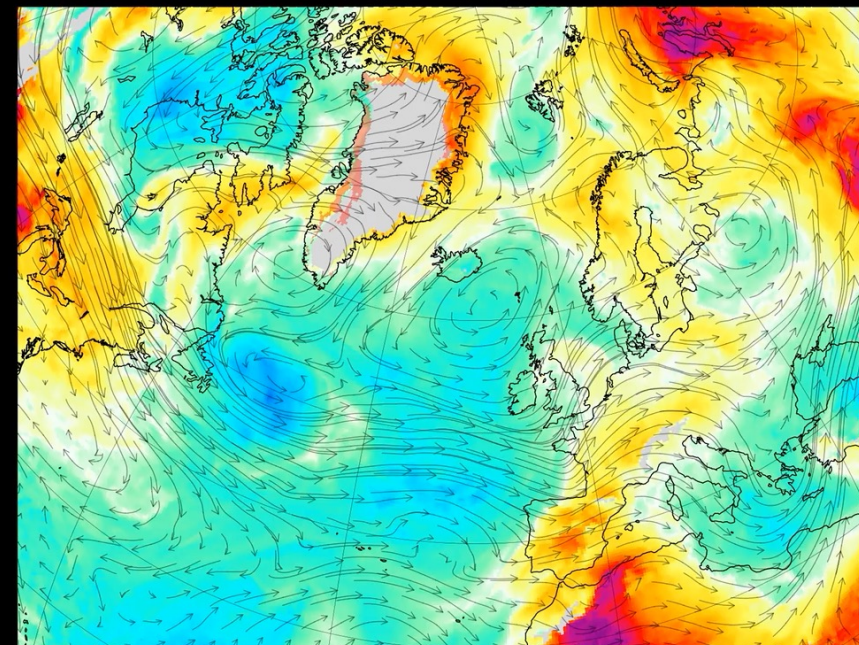


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2019 Greenland Melt Event (Cullather et al., 2020)

850 hPa Zonal Temp Anom, 250 hPa Wind, Surface Melt

2019-07-20 0030Z



20 m s⁻¹
→

850 hPa Temperature Difference from Zonal Mean [°C]



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Surface Melt

Subseasonal to seasonal prediction in the Arctic

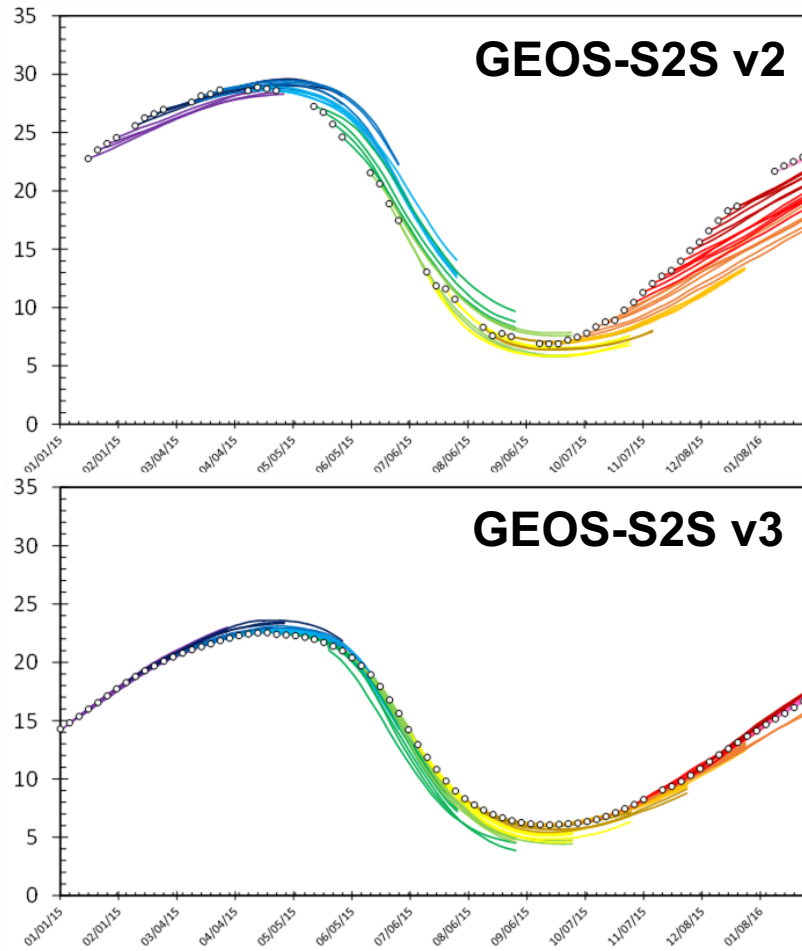
The upgrade from version 2 to version 3 of GEOS S2S system has multiple Arctic relevant changes

- MOM5 with increased vertical and horizontal resolution
- Improved atmosphere-ocean interface layer (diurnal warming and cooling)
- Improved ice sheet runoff routing
- Improved techniques for sea ice fraction during initialization period (SST & sea ice fraction nudging)
- Assimilation of SMAP and Aquarius SSS
- 40 ensemble members per forecast with new perturbation scheme
- Forecasts initialized with MERRA-2 Ocean: a weakly coupled atmosphere-land-ocean reanalysis will cover the period 1982-present and is due for public release late 2021/early 2022.

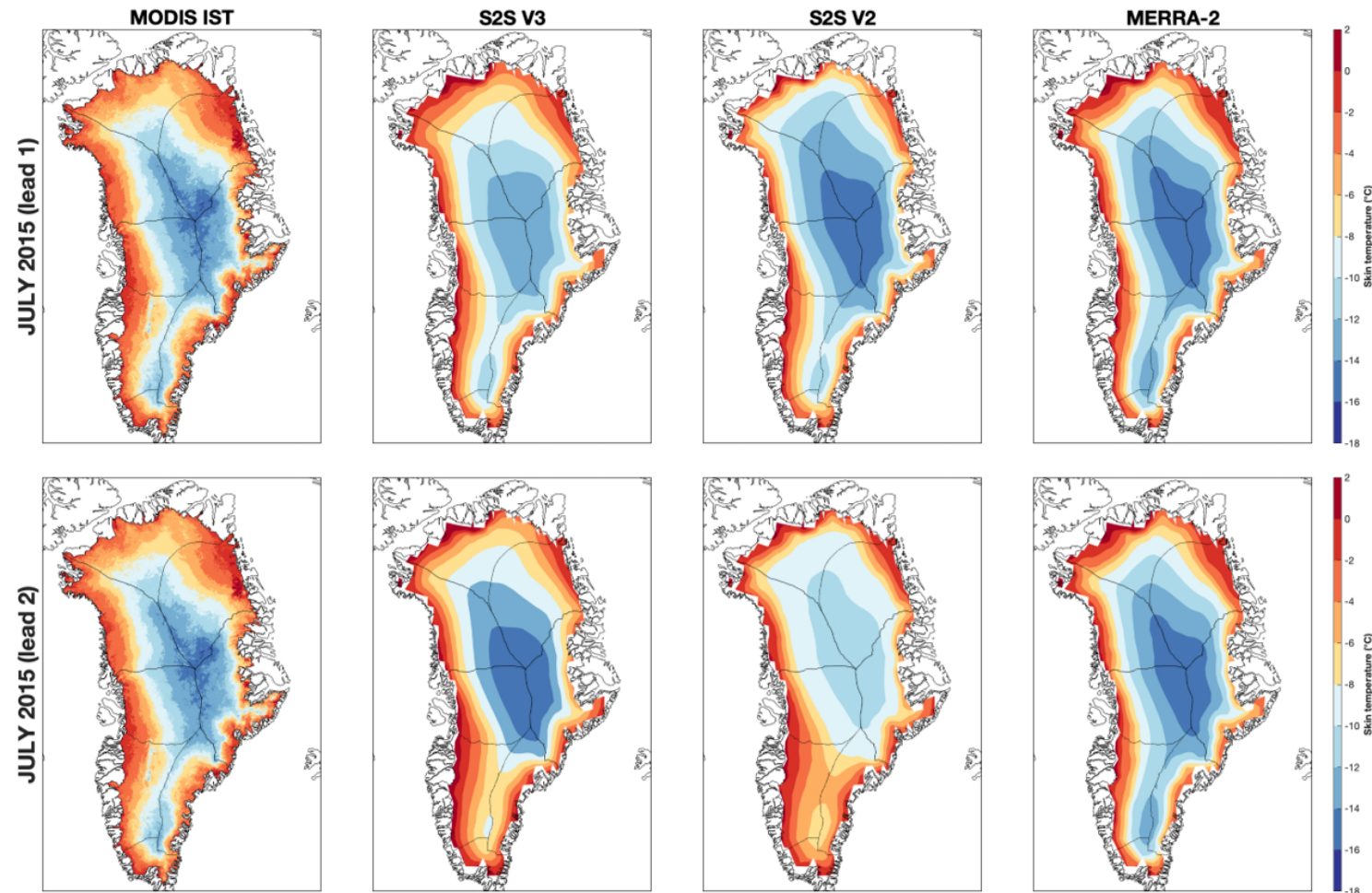


Subseasonal to seasonal prediction in the Arctic

3-month Arctic sea ice volume forecasts

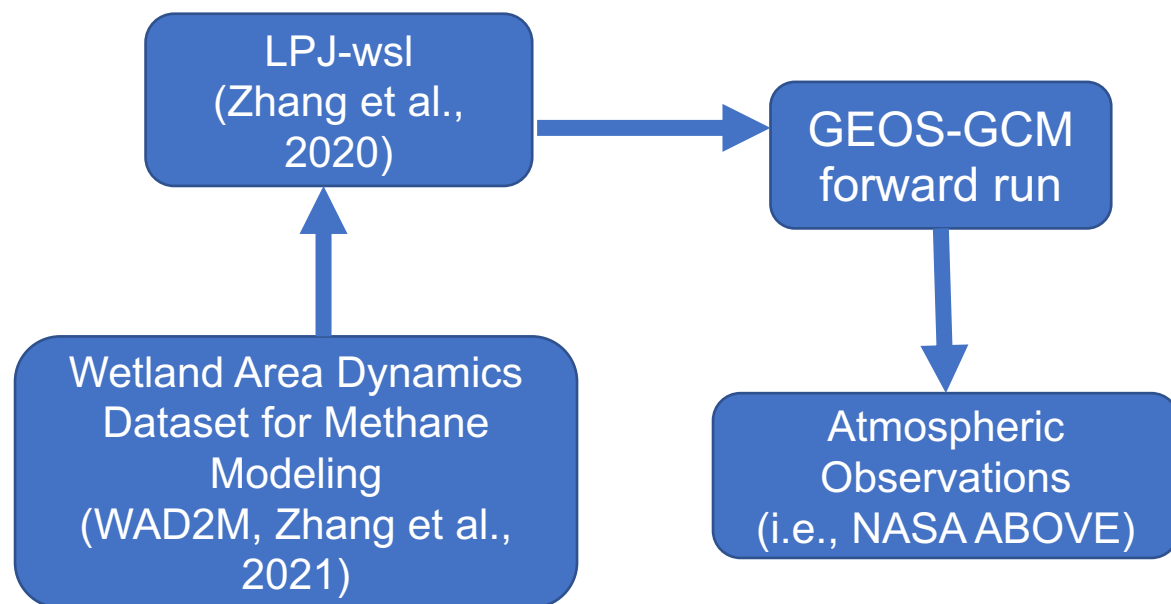


Ice sheet skin temperature forecasts



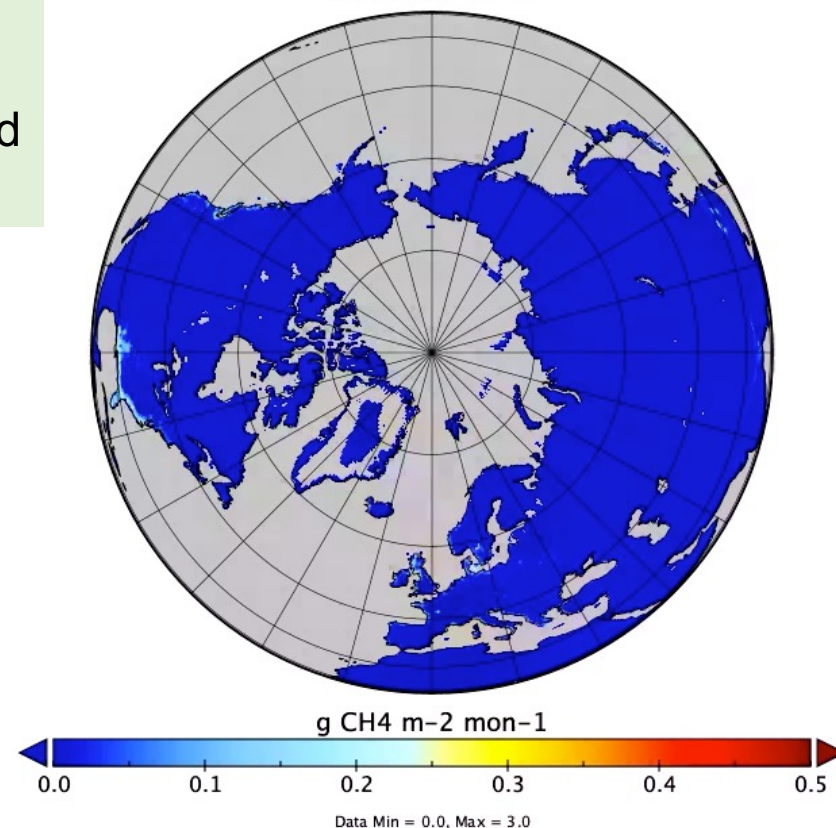
Modeling Arctic wetland and inland water methane emissions

GMAO, Biospheric Science Lab & collaborators are working on wetland methane emission model development and evaluation using remote sensing, process models, atmospheric circulation models, and aircraft surveys.



LPJ-wsl wetlad CH4 emissions

Time: 2020-01-01



Sweeney, C., Chatterjee, A., Wolter, S., McKain, K., Bogue, R., Newberger, T., Hu, L., Ott, L., Poulter, B., Schiferl, L., Weir, B., Zhang, Z., and Miller, C. E.: Atmospheric carbon cycle dynamics over the ABoVE domain: an integrated analysis using aircraft observations (Arctic-CAP) and model simulations (GEOS), Atmos. Chem. Phys. Discuss. [preprint], <https://doi.org/10.5194/acp-2020-609>, in review, 2020.

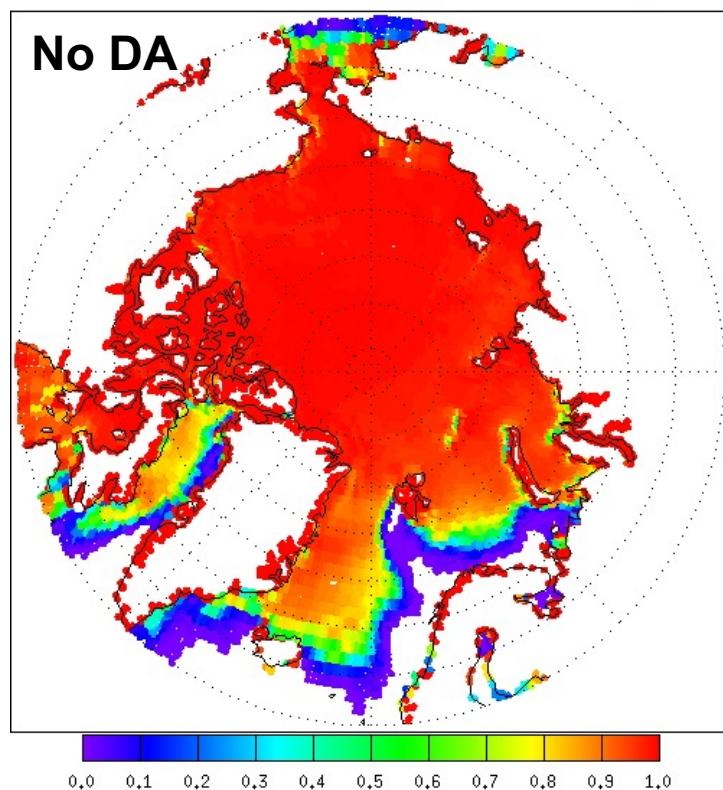
Zhang, Z., Zimmermann, N.E., Stenke, A., Li, X., Hodson, E.L., Zhu, G., Huang, C., Poulter, B.: Wetland methane emissions in future climate change. Proceedings of the National Academy of Sciences Sep 2017, 114 (36) 9647-9652; DOI: 10.1073/pnas.1618765114

Zhang, Z., Fluet-Chouinard, E., Jensen, K., McDonald, K., Hugelius, G., Gumbrecht, T., Carroll, M., Prigent, C., Bartsch, A., and Poulter, B.: Development of the global dataset of Wetland Area and Dynamics for Methane Modeling (WAD2M), Earth Syst. Sci. Data, 13, 2001–2023, <https://doi.org/10.5194/essd-13-2001-2021>, 2021.

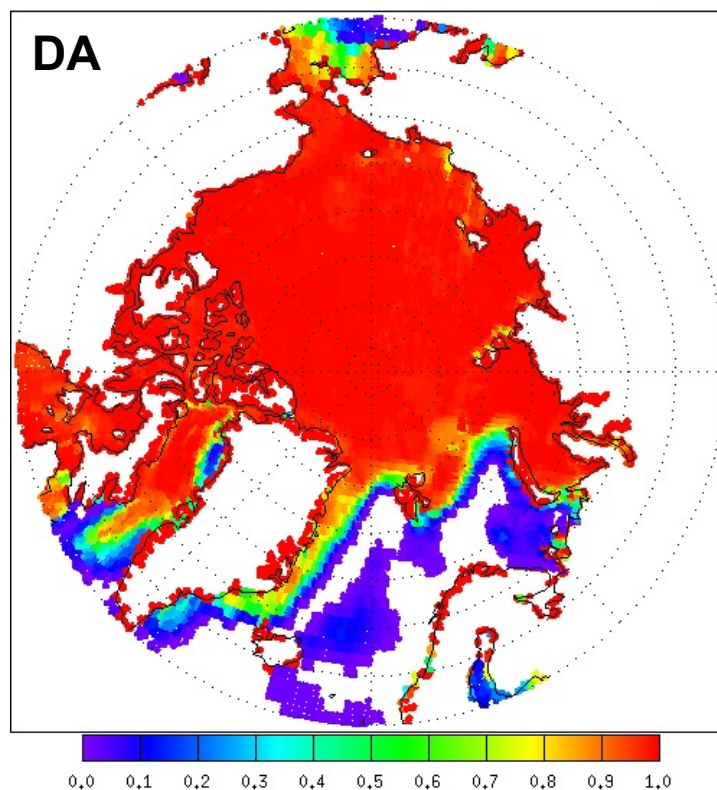
Assimilating sea ice observations using SOCA-GEOS

The effect of assimilating EMC sea ice fraction and CryoSat2 Freeboard
GEOS sea ice fraction comparison (April 2015)

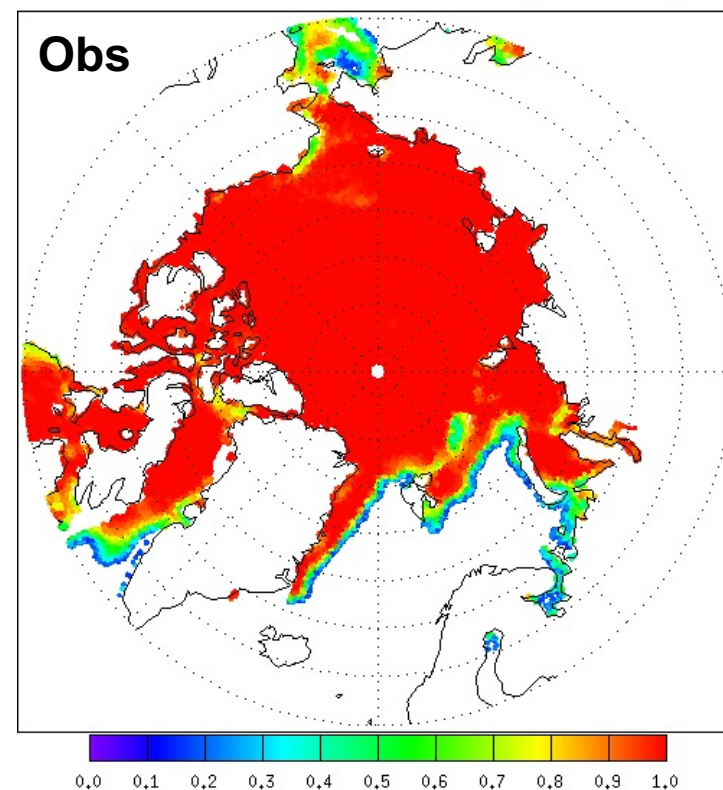
NoDA: Seaiice Fraction (20150407 12Z)



3DVAR: Seaiice Fraction (20150407 12Z)



Satellite Ice Concentration Data (20150407)



Improving polar processes and assessment with PolarMERRA

Stage 1. Comprehensive assessments and focused improvements in polar processes for the GEOS model and R21C, an atmospheric reanalysis for the 2000s (~2021-22).

Stage 2. Replay GEOS-R21C at high resolution over the poles, potentially using GEOS' new variable mesh (~2022-23; a *PolarMERRA specific product*).

Stage 3. Potential additional polar improvements and knowledge transfer to the MERRA-3 coupled reanalysis (2024-25).

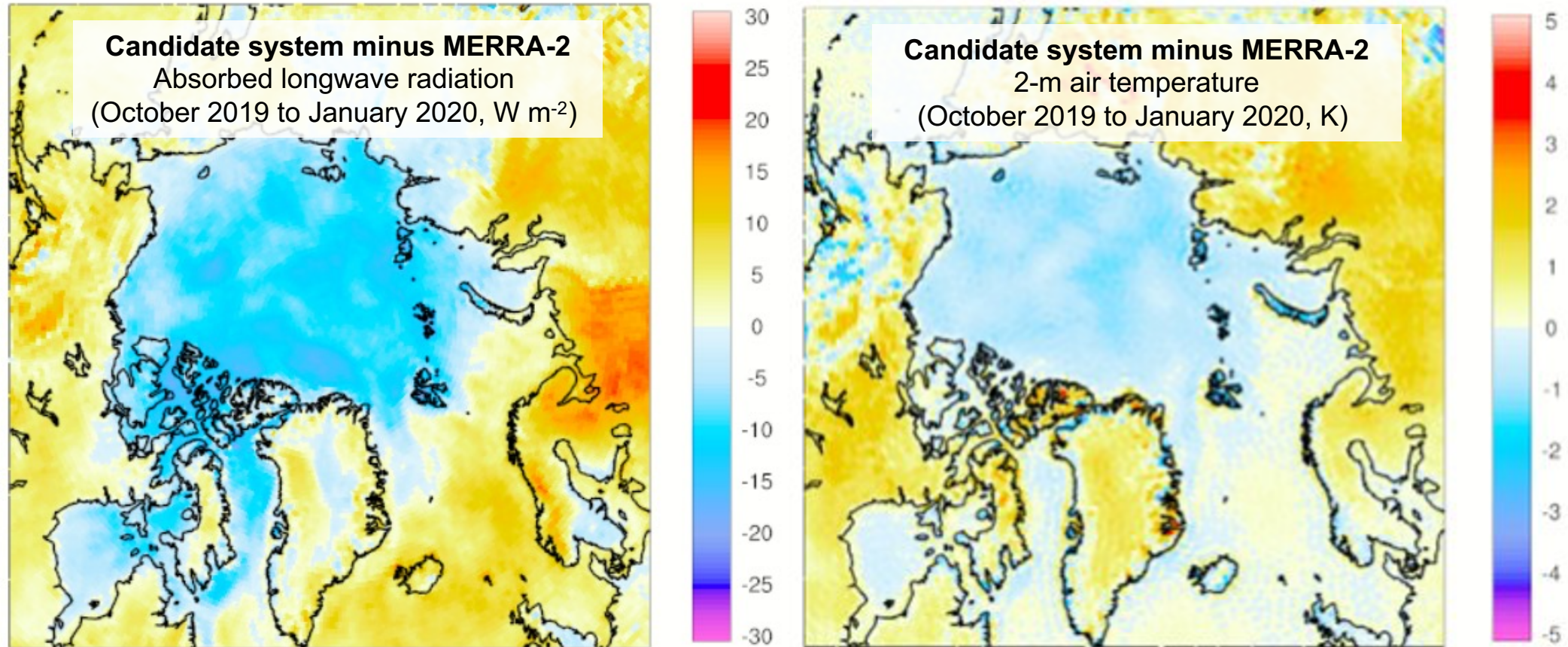
At each stage, detailed observational assessments will guide changes and improvements in the GEOS model.

Sample Scorecard

Greenland Ice Sheet monthly gridded comparisons (2011/10)					
Observation	Model	MERRA	MERRA-2	R21C	ERA5
Albedo (MODIS)	RMSE	0.65	2.23	0.48	
	COR	0.21	-0.12	0.45	
	SD	0.13	0.27	0.18	
IST (MODIS)	RMSE	2.87	2.65	0.68	
	COR	0.92	0.96	0.85	
	SD	2.73	1.98	1.28	
Water Vapor (MODIS)	RMSE	0.33	0.38	0.55	
	COR	0.14	0.12	0.77	
	SD	0.03	0.04	0.98	
SWTUP (CERES)	RMSE	9.66	9.64	1.4	
	COR	0.59	0.6	1	
	SD	16.36	16.63	1.95	
SWTUPCLR (CERES)	RMSE	4.03	3.48	1.95	
	COR	0.88	0.89	0.98	
	SD	3.57	3.42	3.77	
LWTUP (CERES)	RMSE	9.54	9.55	1.77	
	COR	0.68	0.69	0.95	
	SD	14.35	14.28	3.13	
LWTUPCLR(CERES)	RMSE	4.1	3.36	2.2	
	COR	0.92	0.94	0.93	
	SD	4.44	4.54	4.47	
SWCRF (CERES)	RMSE	2.5	2.51	1.94	
	COR	0.02	-0.08	0.5	
	SD	5.93	6.12	3.71	
LWCRF (CERES)	RMSE	1.76	1.99	2.02	
	COR	0.02	-0.08	0.62	
	SD	3.08	3.74	3.71	

Work by Erika Simon

Improving polar processes and assessment with PolarMERRA



The implementation of the rapid radiative transfer module (RRTMG) to better parameterize longwave radiation and improved cloud microphysics between MERRA-2 and the current candidate system result in a reduction in absorbed longwave radiation (left) and 2-m air temperatures (right).

Future directions and associated challenges (a glaciologist's perspective)

GMAO is working toward a fully coupled Earth System model for both reanalysis and forecasts.

Observational limitations

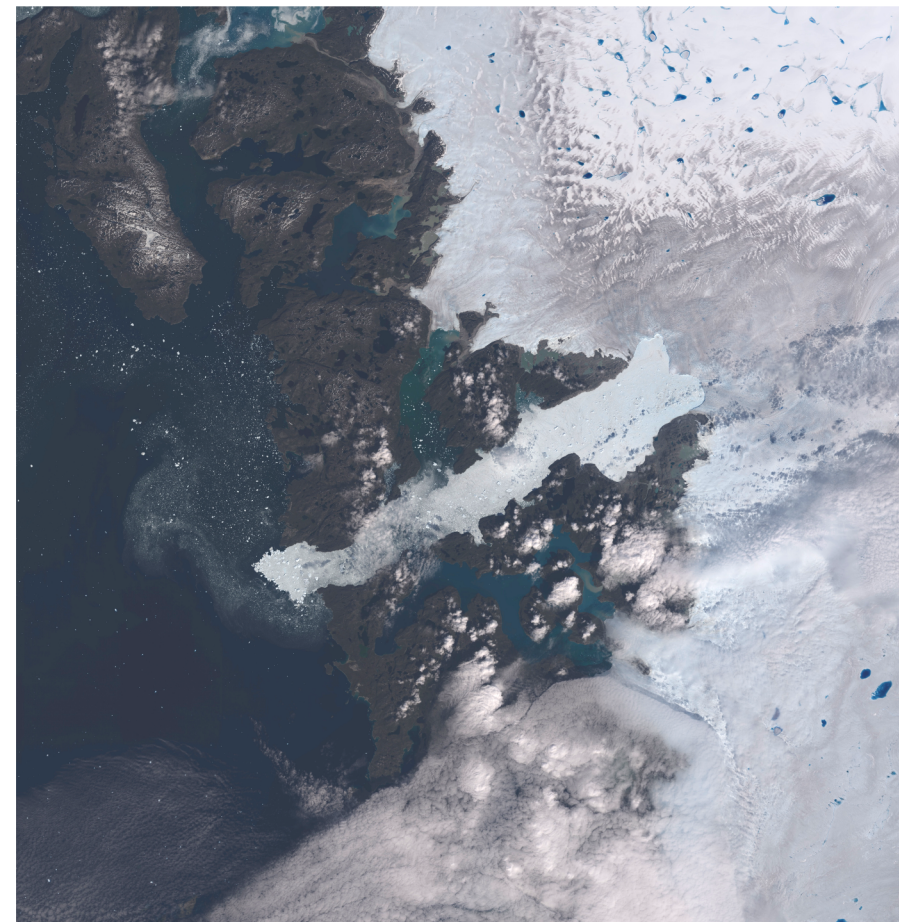
Effective integration of Arctic freshwater hydrology into fully coupled models.

Assessment and adaptation of polar processes for global models.

Predictability and prediction skill (Arctic-midlatitude connections)

Decadal scale prediction

Hazard prediction (permafrost thawing, wave erosion)



Collaborations: Increasing complexity and applications

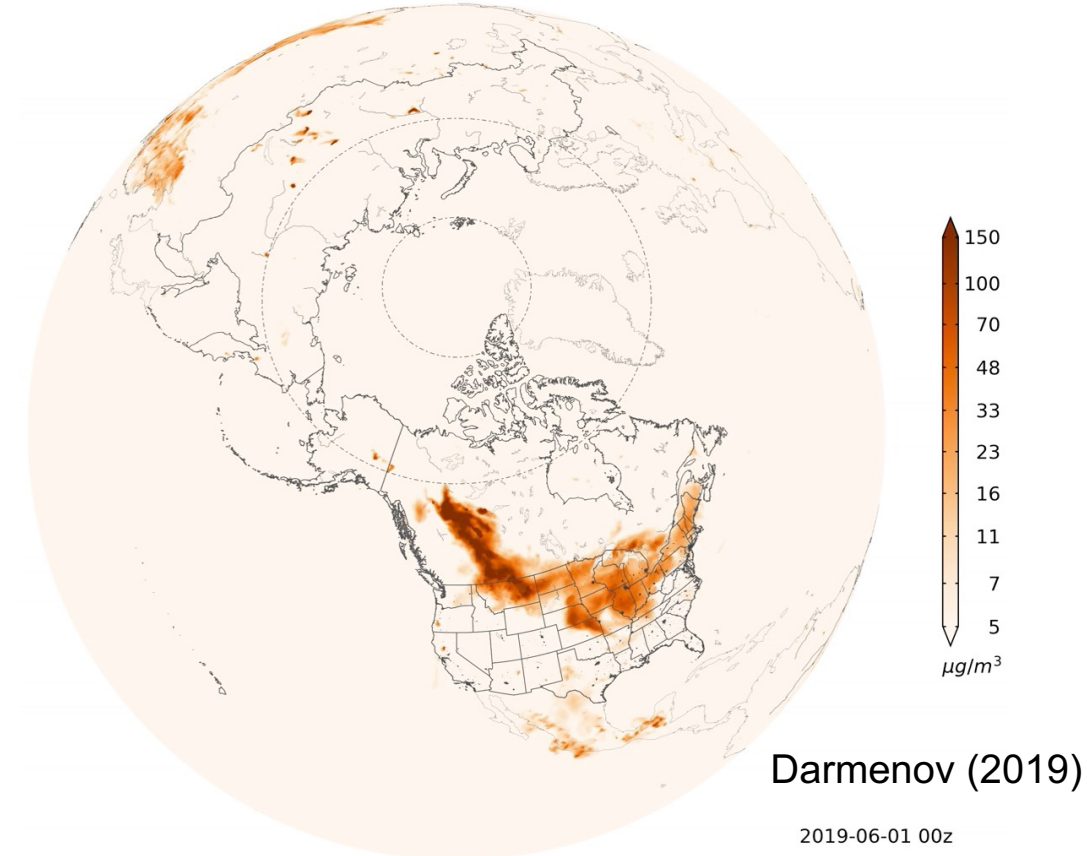
Fine particulate matter (PM_{2.5})

GMAO is a member of the Joint Center for Satellite Data Assimilation

Increasing GEOS complexity through coupling

- Currently use ocean, sea ice, atmospheric chemistry, and ocean biogeochemistry models.
- Directly relevant possibilities
 - Integration of a fire model
 - Improved coupling with dynamical ice sheet models
 - Both atmosphere and ocean coupling, including iceberg freshwater fluxes

Clear areas of collaboration in hazard assessment and prediction



Fine particulate matter at the surface (PM_{2.5}) from fires in North America and Eurasia. Plots are shown from June 1, 2019 to August 18, 2019, using analyses from the NASA/GMAO near real-time atmospheric assimilation system GEOS-FP.