GMAO's Plans to Upgrade Products over the Next Five Years

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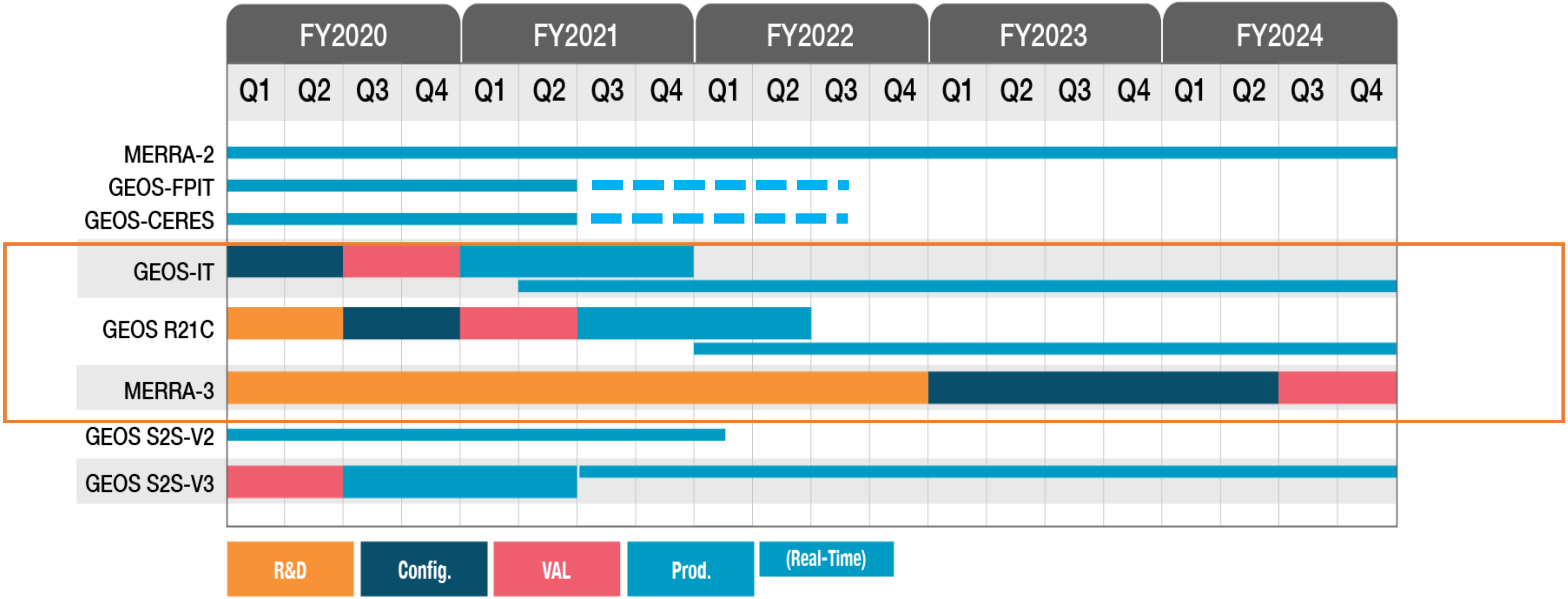
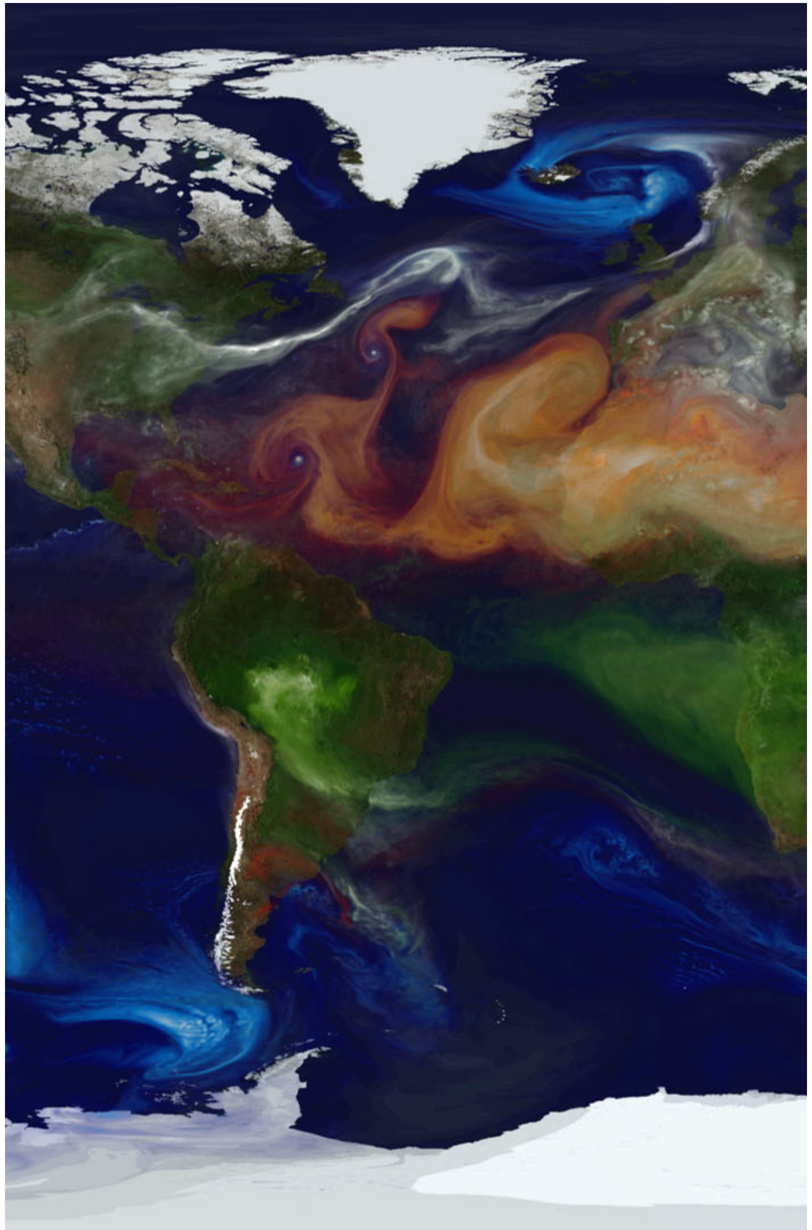
Presentation at the CERES Science Team Meeting, September 16, 2020

Timeline for GEOS Products





Plan of Presentation

Overview of GMAO’s main GEOS systems and upgrade strategies

GEOS-FP as a flagship system: impacts of NASA observations

Reanalyses: from MERRA-2 to MERRA-3, via GEOS-R21C

Instrument Team Support: GEOS-IT

Discussion

Summary of Major GMAO Products

GMAO's current products that are documented both technically and through robust file specifications, well validated, and released to the broad community for research and applications

System	Focus	Customers/Applications
GEOS-FP "weather prediction"	Impacts of NASA observations on NWP: forefront resolution and complexity	NASA Field Missions (weather, aerosols) Multiple Agencies: NOAA/FAA; NOAA field stations; NRL
GEOS-CF "air quality"	Pioneering global system for atmospheric composition using multiple NASA assets	Health/Air Quality studies (via NASA Applied Sciences) Multiple agencies: NIH, Army, NOAA
GEOS-S2S "seasonal prediction"	Ensembles of coupled Earth System predictions, emphasizing NASA observations	National ensembles (NMME, SubX), drought/sea-ice prediction Multiple Agencies and international linkages
MERRA-2 "reanalysis"	Stable product for climate studies, emphasizing NASA data	Only current national reanalysis: USGCRP/NCA applications Interagency use: DoE, DoT, NOAA, …
GEOS-FPIT "mission support"	Stable, well validated, low-latency product for use by NASA instrument teams	More than 20 NASA Instrument Teams
GEOS-Nature Run "mission planning"	Complex Earth System simulations at fine resolution with obs. simulators	Planning for new space-based missions NOAA and broad community; DoE/Smithsonian; NSF

~2015

GEOS-FP
Atmosphere
50km,L72
3D-Var
Near-real time NWP

MERRA-2
Atmosphere
50km,L72
3DVar
1980-onwards

GEOS-FPIT
Atmosphere
50km,L72
3DVar
EOS-period

~2020

GEOS-FP
Atmosphere
12.5km,L72
Hybrid 4DEnVar
Near-real time NWP

GEOS-IT
Atmosphere
50km,L72
3DVar
EOS to post-EOS period
Based on current GEOS-FP (5.25)

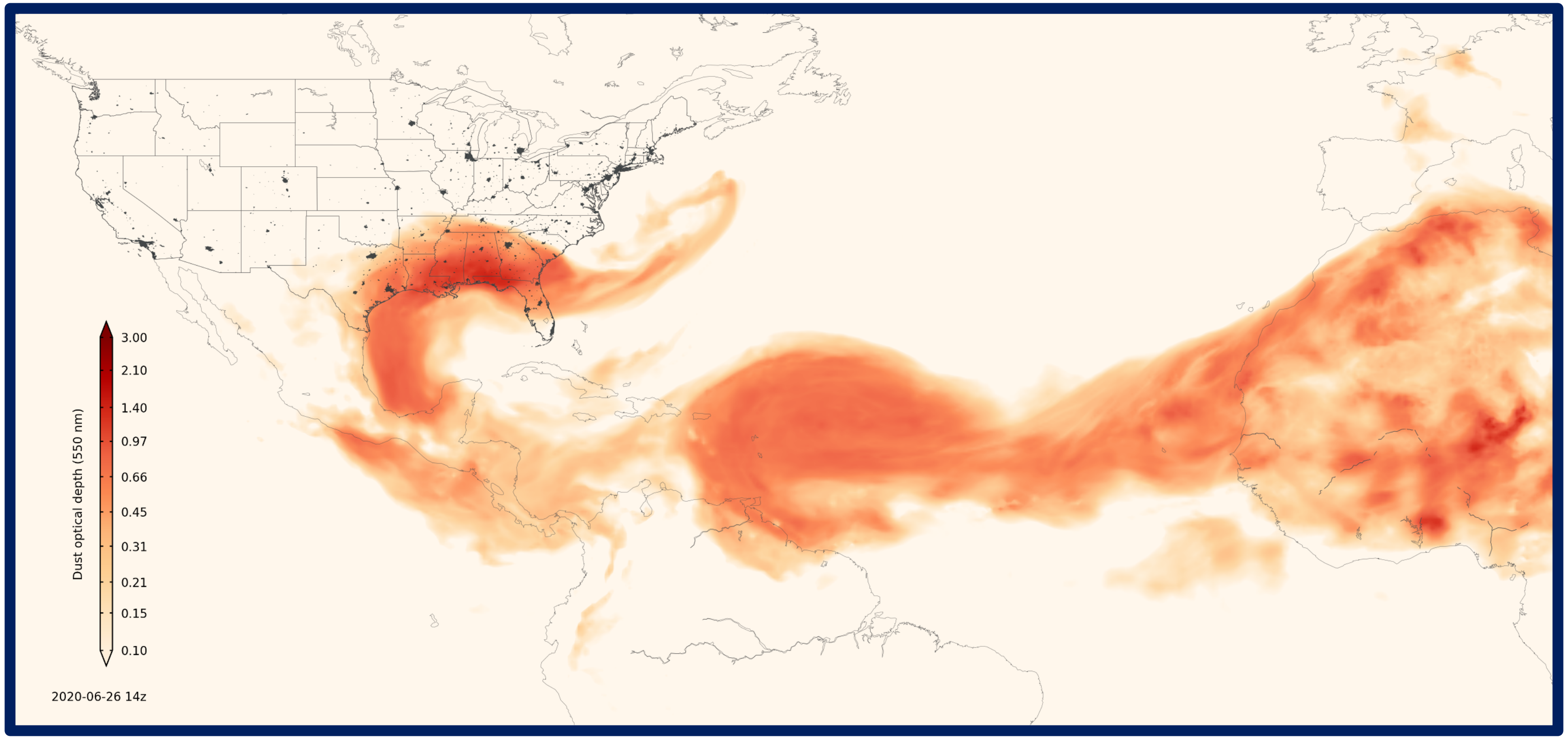
GEOS-R21C
Atmosphere
25km,L72
Hybrid 4DEnVar
EOS to post-EOS period
Based on future GEOS-5.26/27

~2025

GEOS-FP
Higher resolution and complexity with more links to SubX/S2S

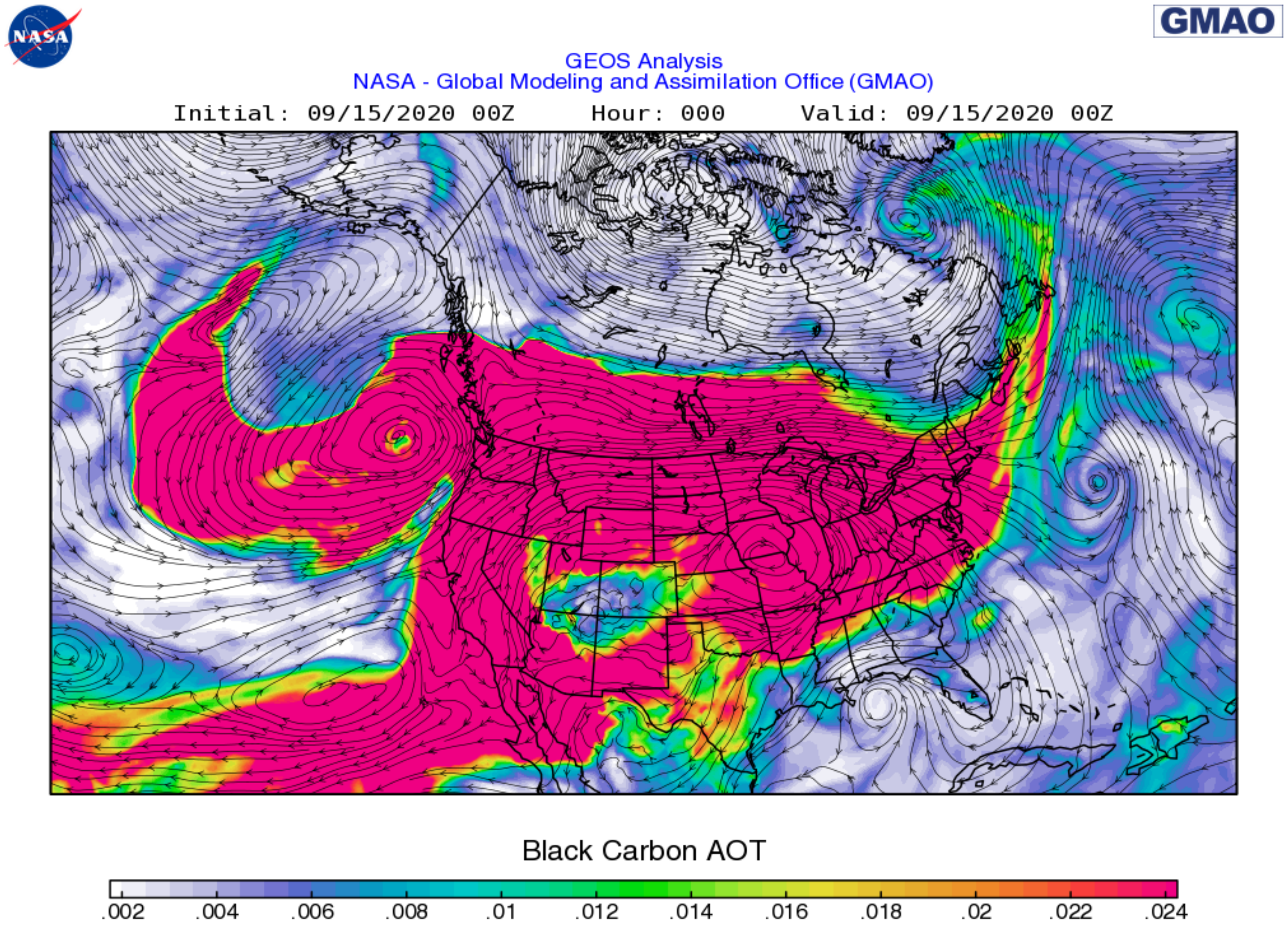
MERRA-3
Coupled Earth System
Higher vertical resolution
JEDI-based DA
Multi-decade

Atmospheric Dust Rivers: Saharan Dust Makes the Journey to the Americas



During June 2020, dust from the Sahara Desert was forecast and observed to cross the Atlantic Ocean, impacting the Caribbean, the US Gulf Coast states, and recirculated over parts of the mid-Atlantic region. This still image taken from the NASA GEOS model shows the Saharan dust on June 26, 2020 at 14z, carried west across the Atlantic by prevailing winds. Darker orange colors represent a higher concentration of dust particles in the atmosphere.

Transition from Dust to Biomass Burning

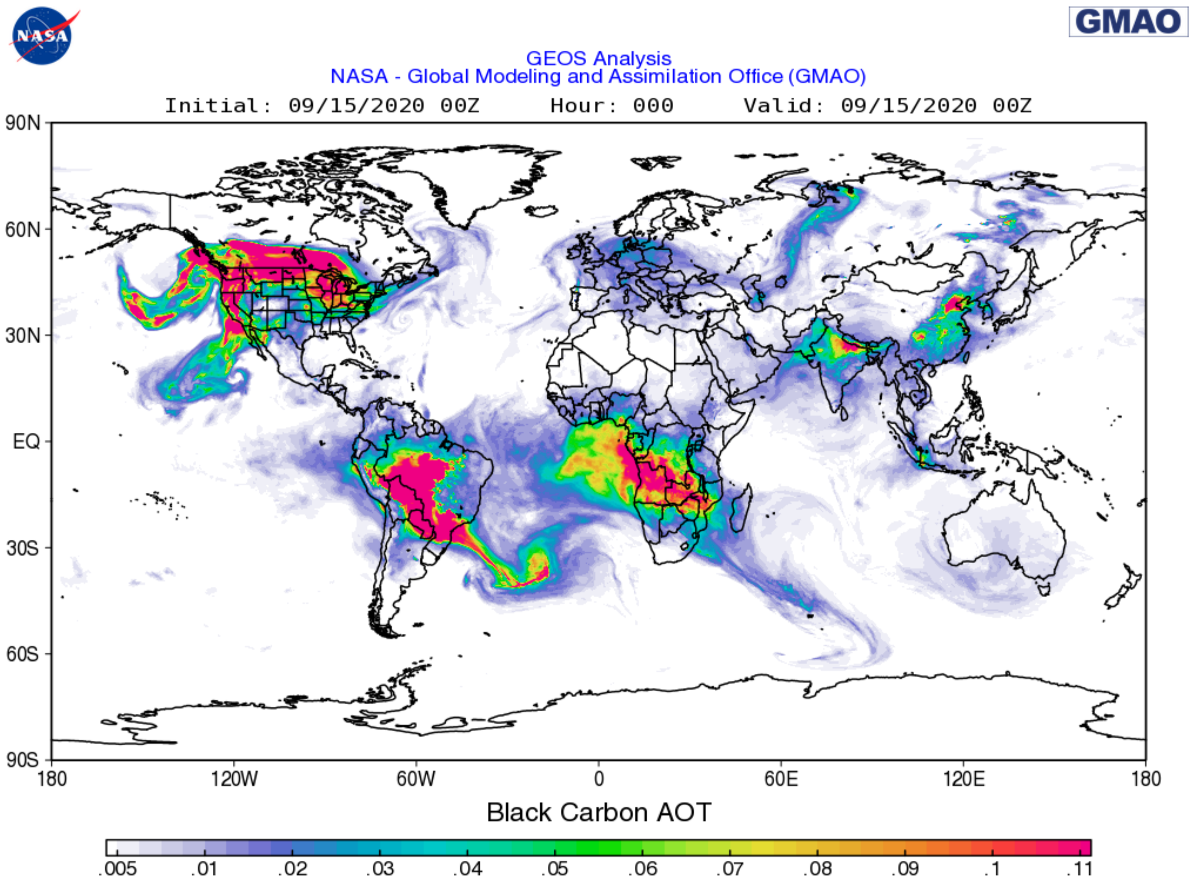


The top story has now changed somewhat: the West-Coast fires are having a massive impact on North American aerosols in September 2020.

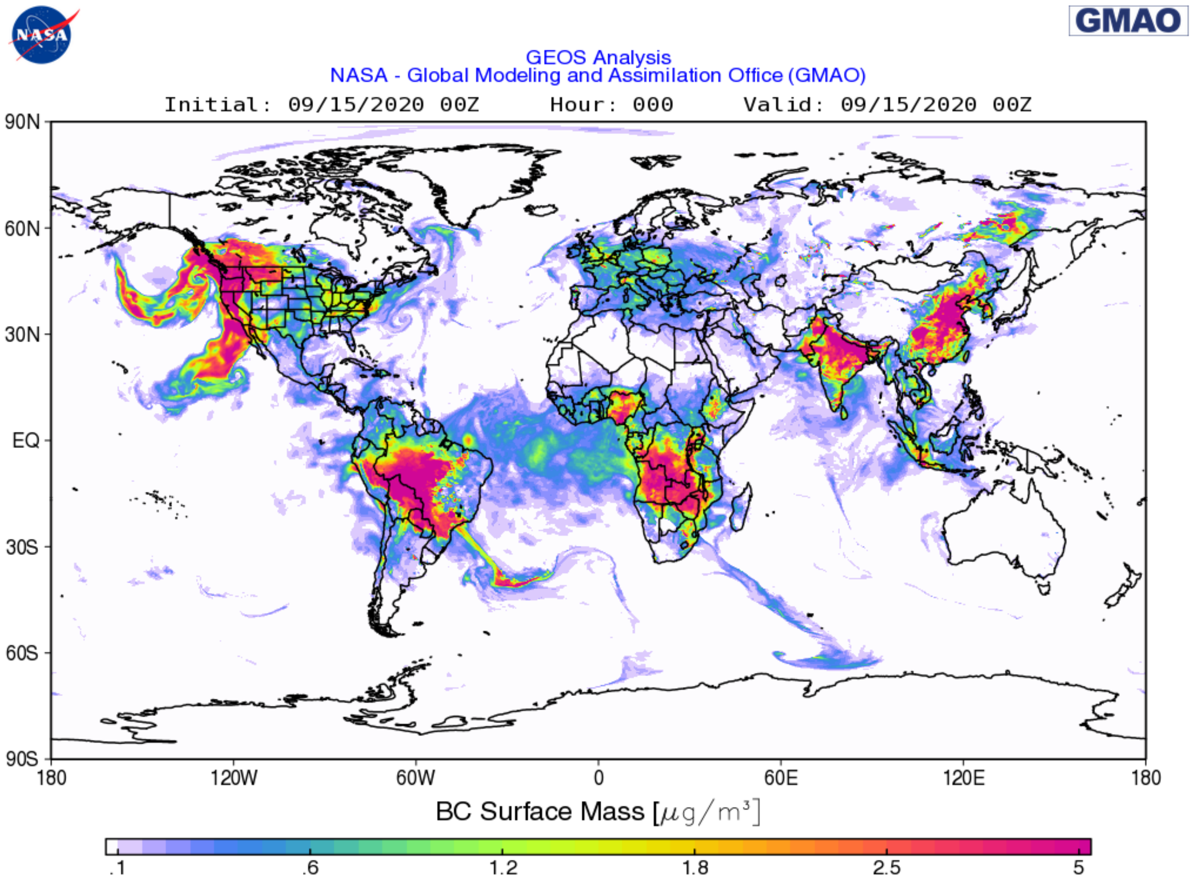
Black Carbon from biomass burning coeveed almost the entire USA and much of Canada on September 15, 2020. Our default contour scale saturates out – these pinkish values are typically reached in a few small regions.

Emissions are computed using fire-radiative power from MODIS observations and aerosol optical depth is assimilated.

Global Black Carbon Aerosol on September 15, 2020



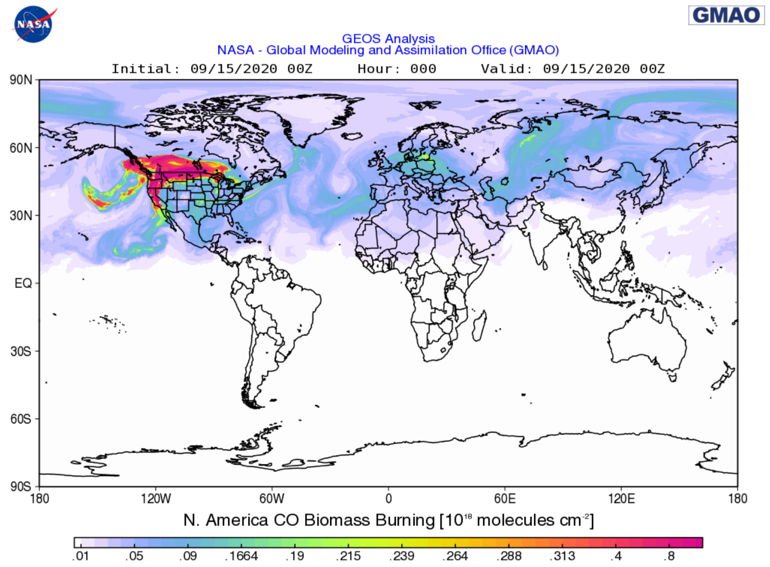
550nm Optical Depth



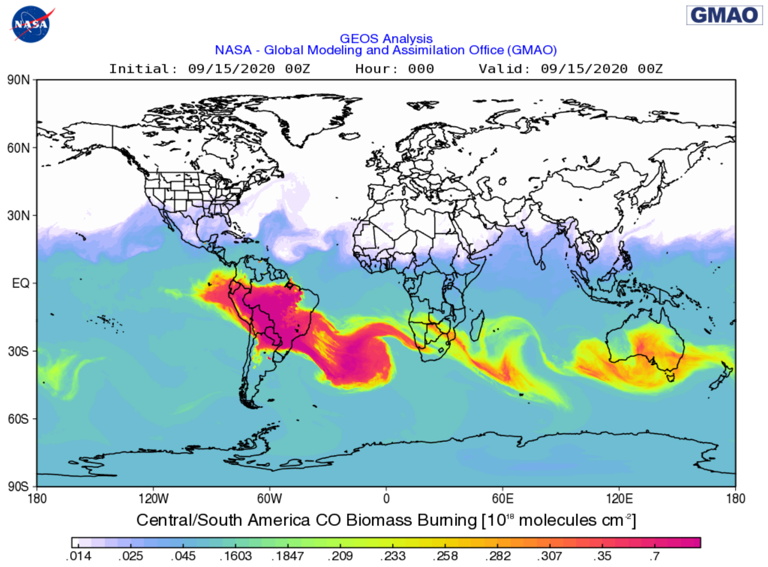
Surface Mass

Tagged CO from Biomass Burning on September 15, 2020

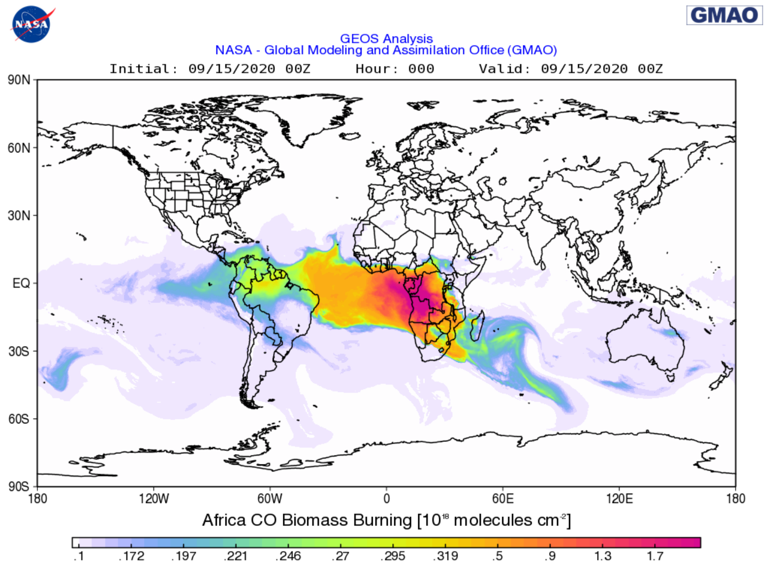
North America



South America



Africa



Focus here on the intercontental/hemispheric spread
(the color scales are different on each panel)

Changes in GEOS-FP

GEOS-FP is our forefront system for NWP, with high resolution and complexity

- Pioneer the use of NASA satellite observations for weather prediction
- Test advances in the model and assimilation techniques
- Adding complexity, such as interactive aerosols, land and cryospheric processes, etc.

Past five years:

- Overhauled model has led to more realistic moisture, temperature, land surface, … in the analyses
- new observations have been added, including all-sky microwave, ocean skin radiances, and hyperspectral IR
- opportunity to use reprocessed versions of older operational observations (e.g., AMSU)

Next five years:

- Increased model resolution (horizontal and vertical)
- Additional complexity (such as cloud microphysics-aerosol interactions) to be tested
- Overhaul of data assimilation infrastructure and methodology (potentially 4DVar)

FPIT (GEOS-5.12.4)

GEOS-5.13.0

GEOS-5.13.1

GEOS-5.16.5

GEOS-5.17.0

GEOS-5.21.0

GEOS-5.22.0

FP (GEOS-5.25.1)

Capability to process additional input observation types, such as METOP-B AMSUA, METOP-B IASI, METOP-B MHS, CRIS, SSMIS, and GOES sounder.

Hybrid 3D-Var data assimilation.

Enhancement to the forecast model **parameterization of surface drag**

Hybrid 4D-EnVar DA.

Increase spatial **resolution to 12.5km**.

Updated topography data set;

Retuning of the gravity-wave drag and turbulence parameterizations. Changes to the moist physics to improve the representation of intense precipitation events.

FPIT (GEOS-5.12.4)

GEOS-5.13.0

GEOS-5.13.1

GEOS-5.16.5

GEOS-5.17.0

GEOS-5.21.0

GEOS-5.22.0

FP (GEOS-5.25.1)

Change to model physics (RRTMG longwave radiation + improved representation of cloud ice and liquid effective radii). Dynamical core update. **All sky assimilation** of GPM GMI radiances. **Updated variational bias-correction scheme.** Update to 4DIAU.

Assimilation of radiances from **Cris and ATMS from NOAA-20**. Addition of **total column ozone measurements from the OMPS nadir mapper instrument**. NEXRAD velocity-azimuth display (VAD) winds disabled. Retuned Observation errors for all polar AMVs from MODIS and AVHRR. Update added to account for inter-channel correlations in the specification of the observation error matrix for AIRS and IASI hyper-spectral IR radiances.

FPIT (GEOS-5.12.4)

GEOS-5.13.0

GEOS-5.13.1

GEOS-5.16.5

GEOS-5.17.0

GEOS-5.21.0

GEOS-5.22.0

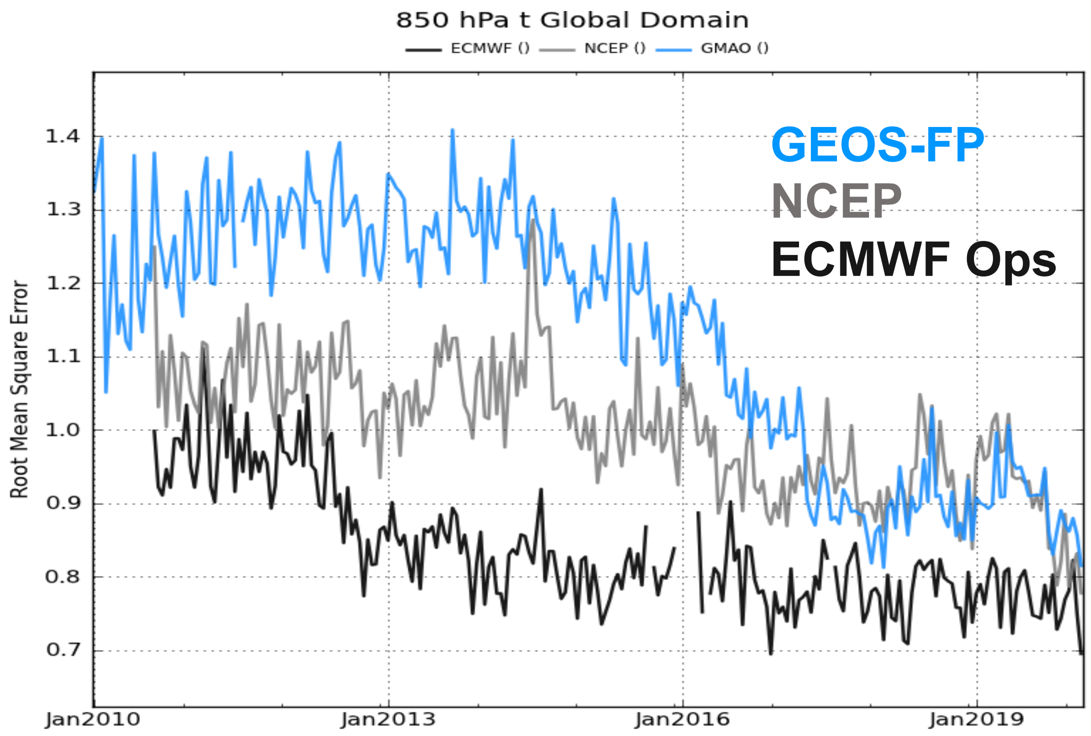
FP (GEOS-5.25.1)

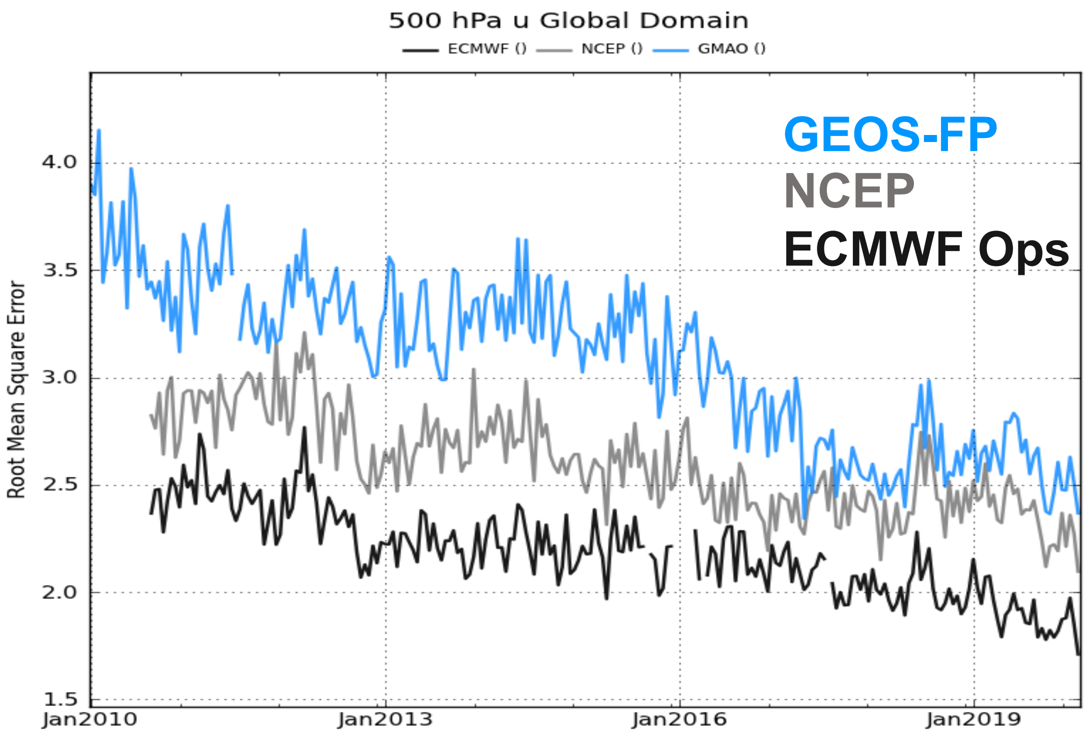
Deep convective parameterization (RAS) replaced with a combination of the **Grell-Freitas scale-aware deep and congestus parameterization** combined with the Park and Bretherton shallow convection scheme.

New **RRTMG shortwave radiation scheme**. Update to cloud liquid and ice radiative properties in the single-moment microphysics.

Catchment land model now includes **updated hydrology features** making GEOS systems consistent with operational GMAO production of SMAP Level 4 soil moisture products. This includes extensive updates of model BC (soil textures, vegetation phenology) and **improved physical treatments of soil moisture diffusion and surface thermodynamics**.

Long-Term Improvements of Forecast Skill





Time series of 48h forecast rms error for 850hPa temperature and 500hPa zonal wind

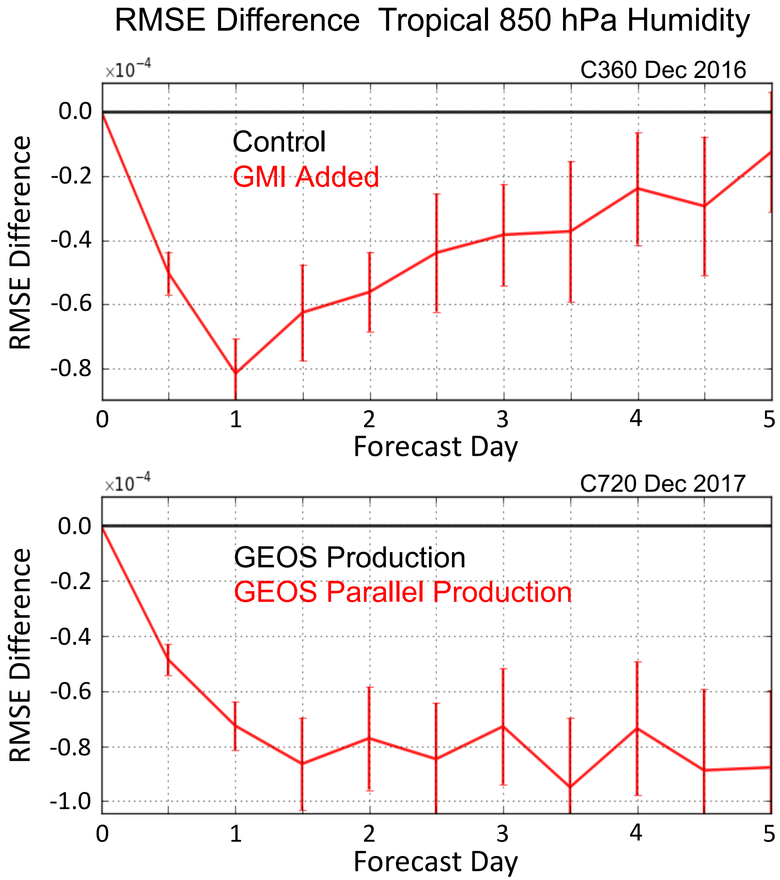
Impact of GMI All-Sky Radiances on Forecast Skill

Science testing

Adding GMI all-sky radiances improves the initial state and leads to reduced error, especially in the Tropics. Largest impact is at day-one, with diminishing impact thereafter.

Implementation in GEOS-FP

Combining GMI assimilation with improved model physics extends the beneficial impacts throughout the five-day forecast period.



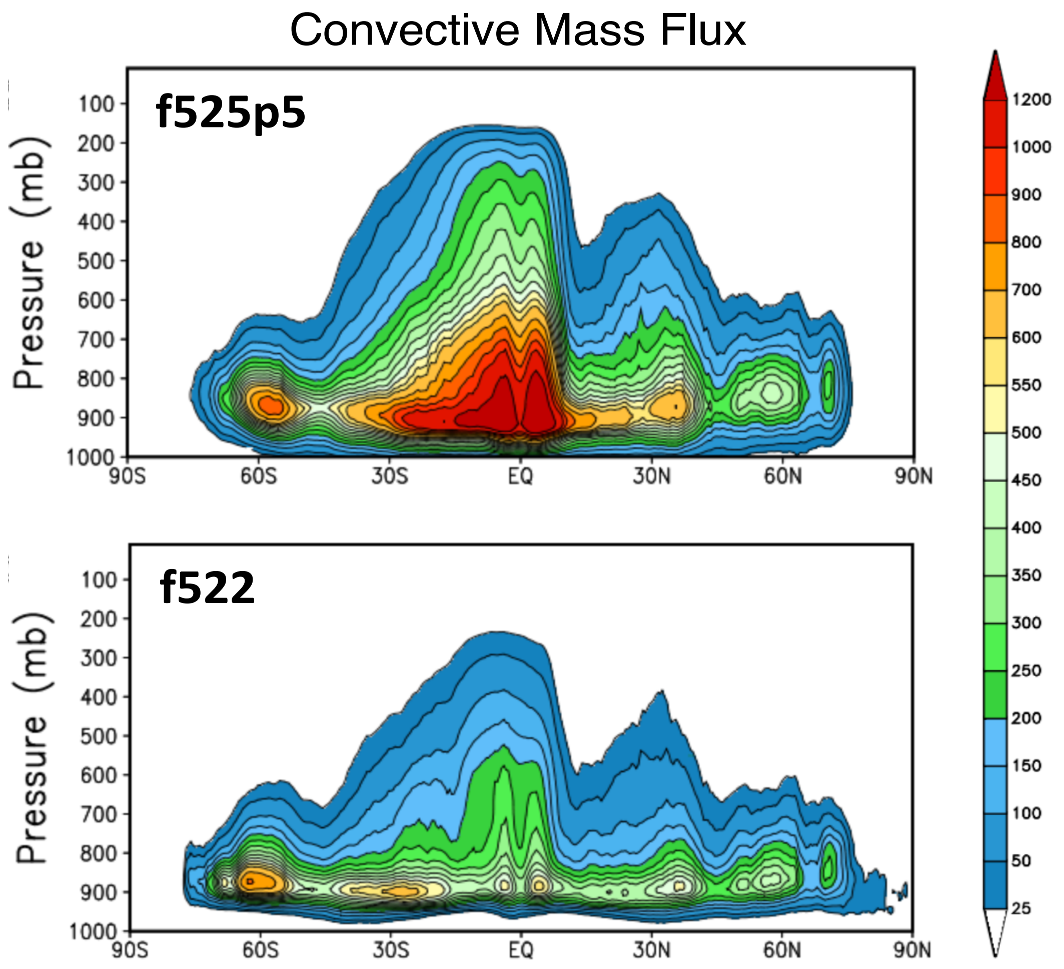
Changes in Cloud Mass Fluxes

The change from the older RAS convection code to the combination of Grell-Freitas and Park-Bretherton leads to a more vigorous in-cloud transport (enhanced mass fluxes) in most locations.

The current GEOS-FP system (GEOS-5.25p5, top) will transfer in to future reanalyses.

GEOS-5.22 uses RAS, as in MERRA-2.

Full implications of these changes are still under investigation.



GEOS-R21C: An Enhanced Atmospheric Reanalysis

Build on the advances introduced into GEOS-FP for a “post-MERRA” product for the early 21st Century

- Targeting clouds/precipitation and surface energy balance through enhanced use of observations
- Bridging the gap from NASA’s EOS observations to the post-EOS observations
- Opportunity to use reprocessed versions of older operational observations (e.g., AMSU series)

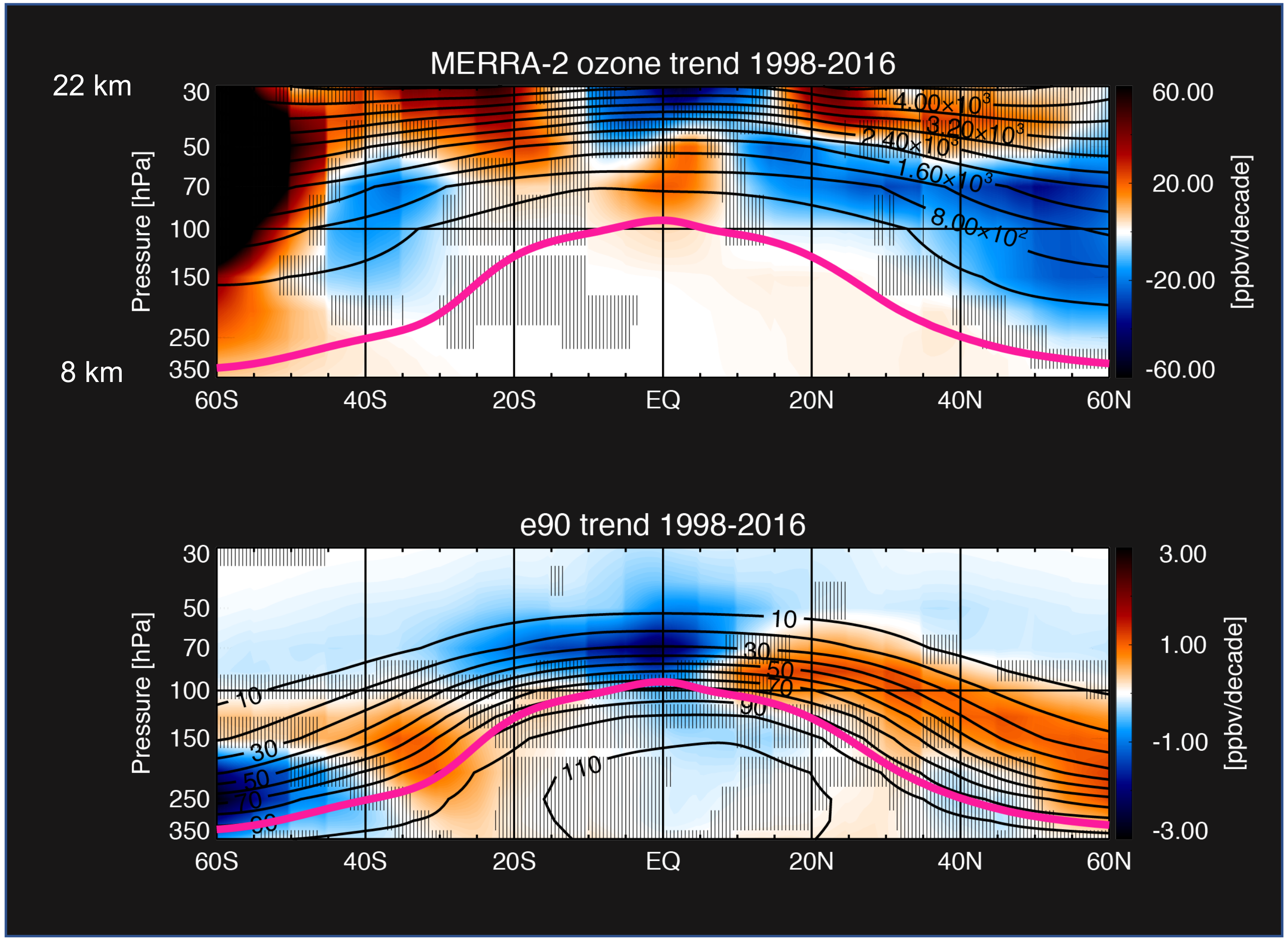
Targeting a 25-km resolution system that uses hybrid 4D-EnVar assimilation

Continue focus on atmospheric composition, via a proposed “derivative” aerosol/composition reanalysis

Enhance focus on cryospheric processes, via a proposed additional activity

A potential step towards a Level-4 product for NASA’s PMM Science Team

MERRA-2 Ozone: Trend-Quality Analysis Based on MLS

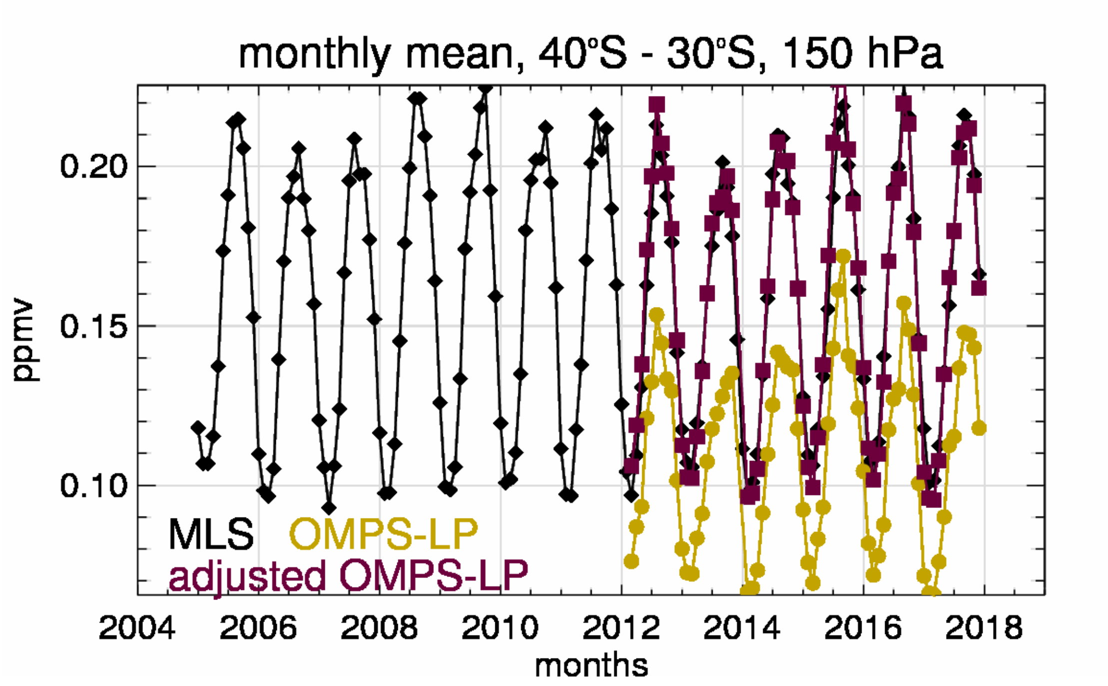


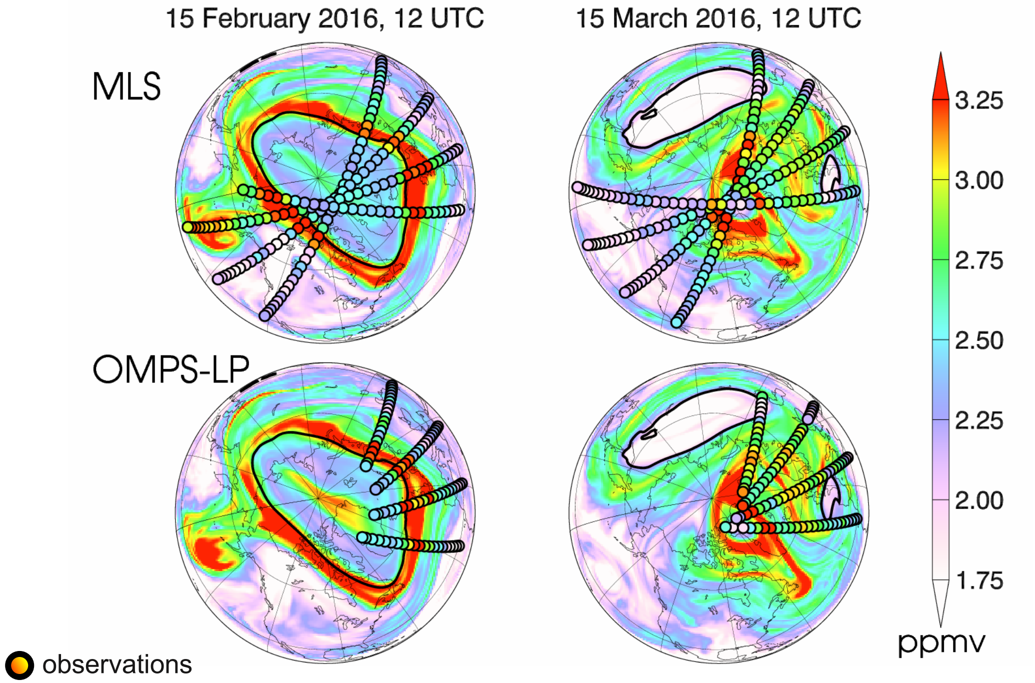
Atmospheric ozone concentrations are expected to increase after 1998 because of the Montreal Protocol. In MERRA-2, ozone just above the tropopause has continued to decline (blue shading in top panel). An idealized tracer reveals enhanced tropical-extratropical mixing between 1998 and 2016 (bottom panel).

This implies that transport changes between 1998 and 2016 most likely caused ozone in the extratropical lower stratosphere to decline. Either long-term variations or a systematic change in mixing are to blame.

Working to Combine MLS and OMPS-LP Data for the Future

Assimilation of high-resolution satellite observations can provide accurate representations of stratospheric ozone on time scales ranging from hours to decades.

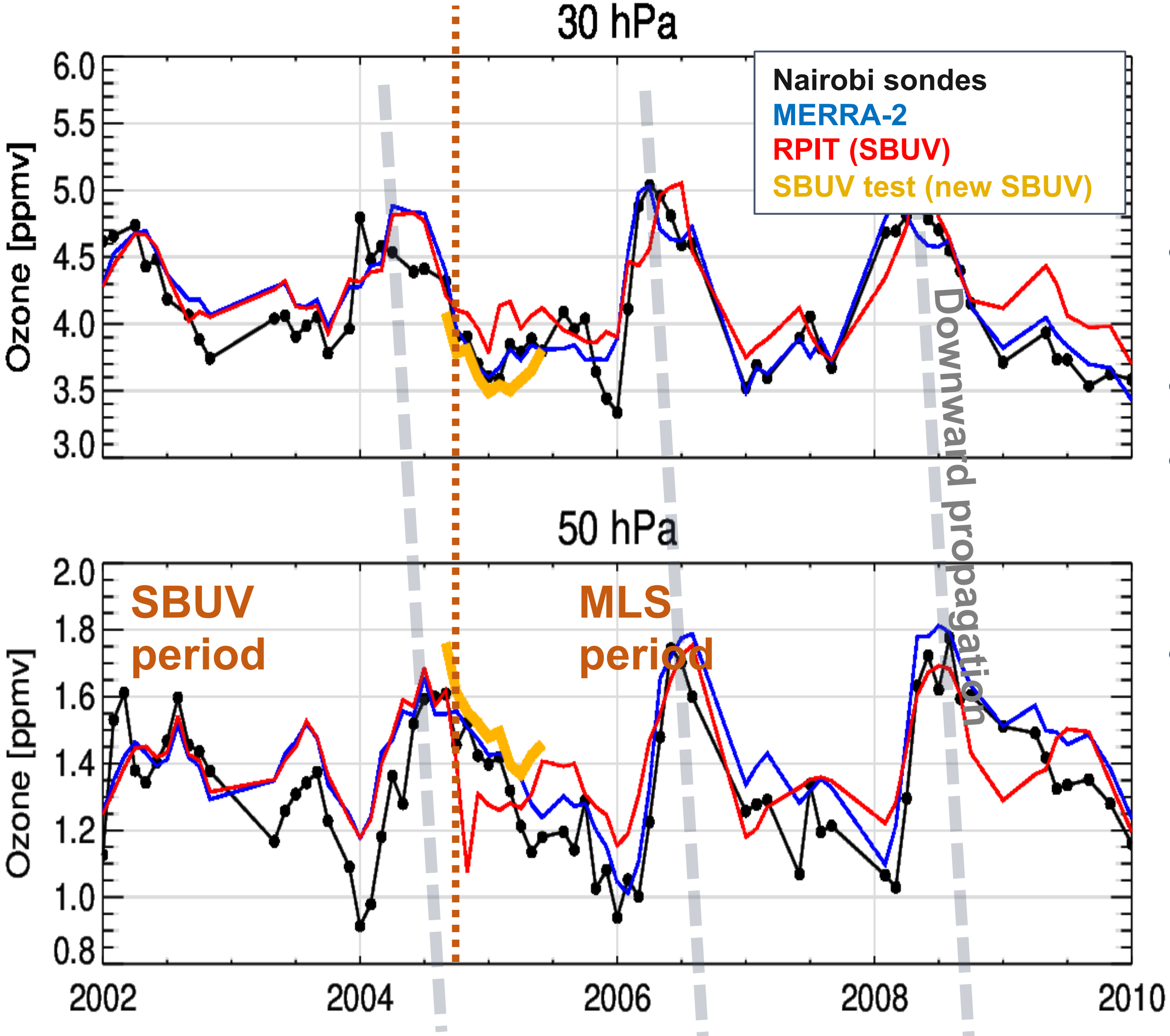




Observations: Systematic differences between MLS and OMPS-LP ozone can be corrected by applying a simple adjustment to the OMPS-LP data.

Assimilation: Maps of ozone concentrations at the 480-K potential temperature surface (approximately 19 km above the sea level) from assimilation of MLS and OMPS-LP observations during the 2016 winter and spring.

Reprocessed SBUV to be used in GEOS-R21C and GEOS-IT



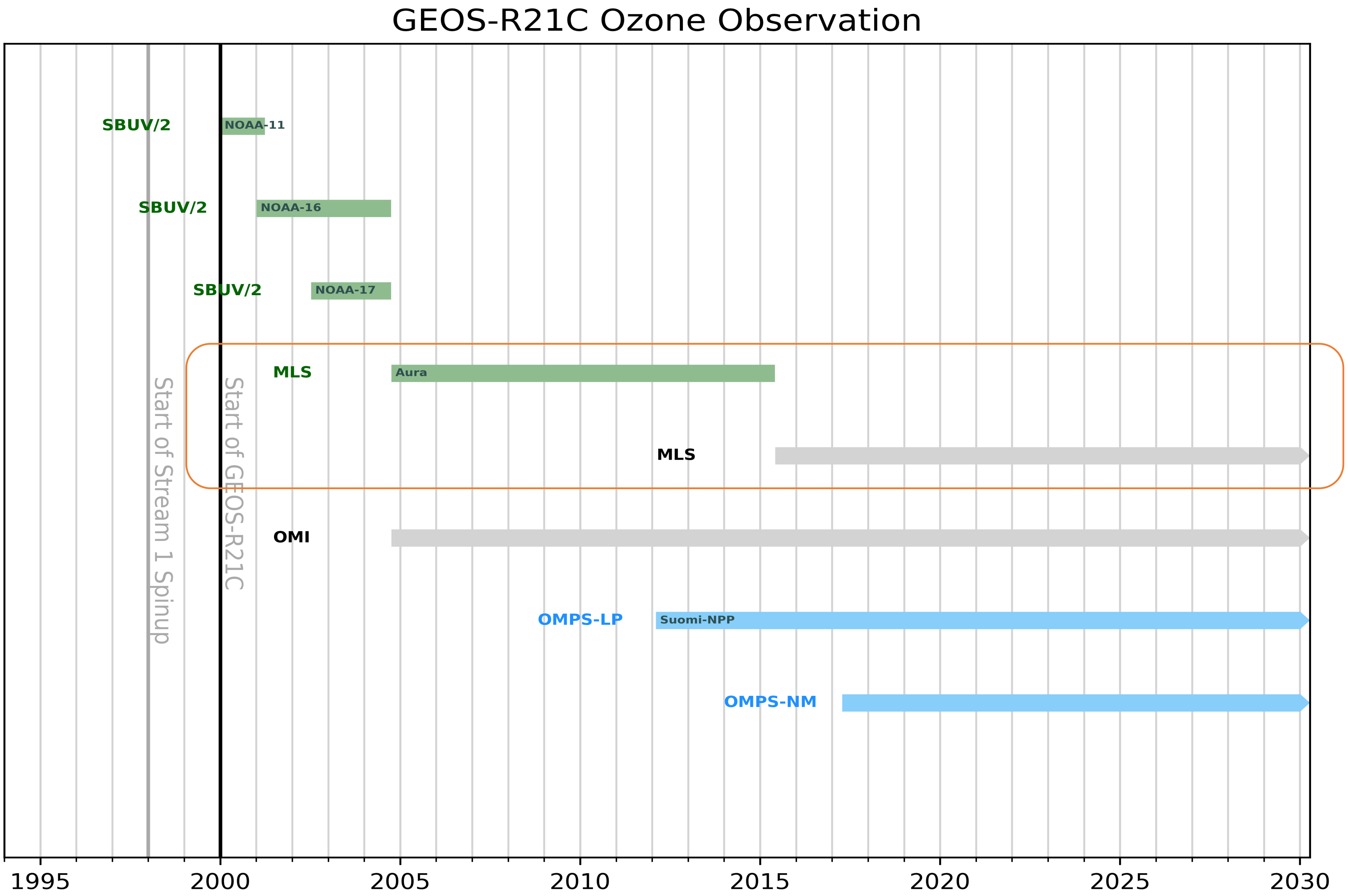
Monthly averaged data from ozonesondes and three analyses at Nairobi

- New version of SBUV ozone data: dynamical priors account for the QBO
- Observation errors retuned
- Test analysis in better agreement with ozonesondes and MERRA-2 than RPIT (“old” version of SBUV data)
- Improvements of SBUV analysis:

MERRA-2 → RPIT → new SBUV test

😔 😐 🙂

Ozone data

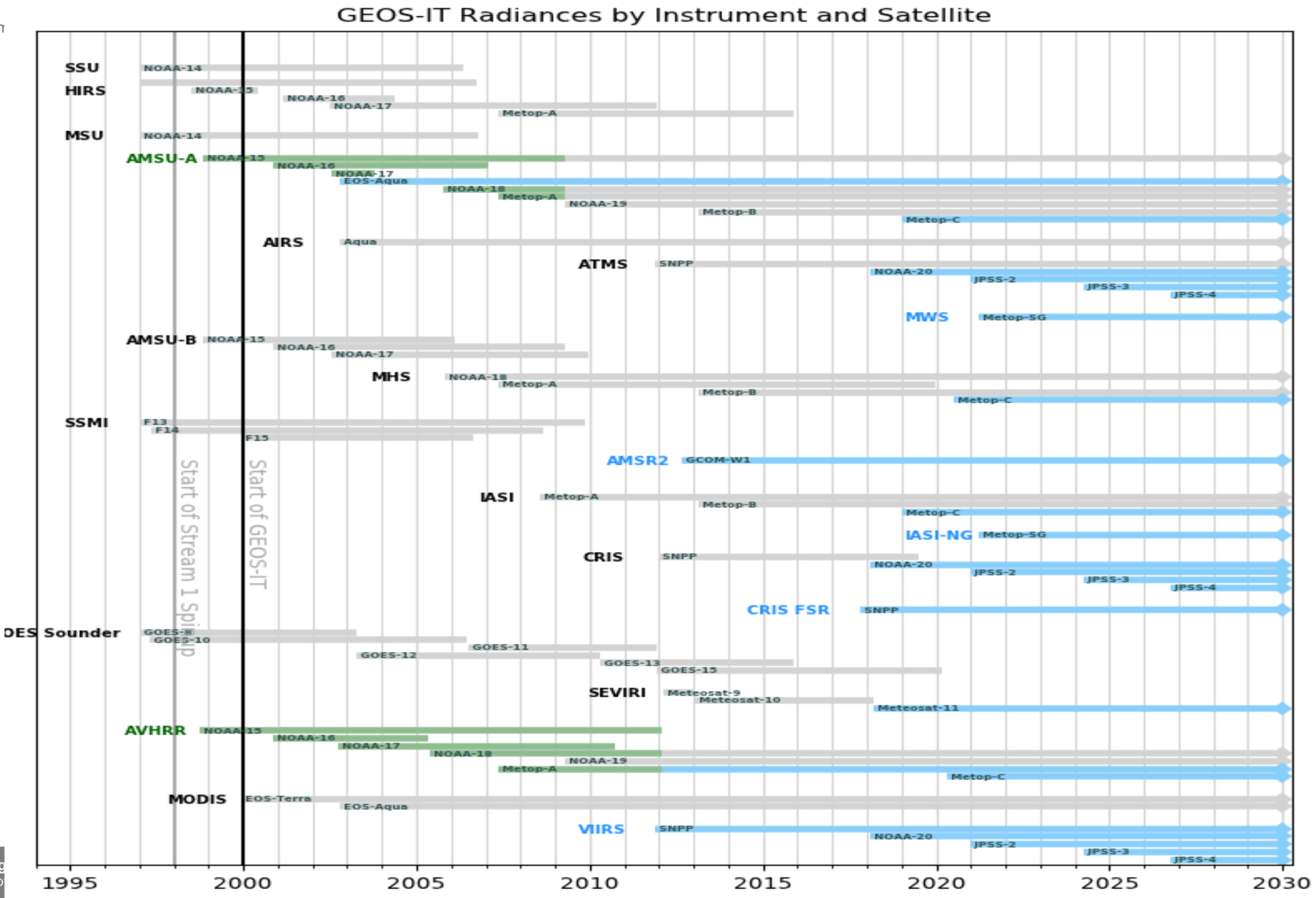

GEOS-R21C Ozone Observation
SBUV/2
NOAA-11
SBUV/2
NOAA-16
SBUV/2
NOAA-17
MLS
Aura
MLS
OMI
OMPS-LP
Suomi-NPP
OMPS-NM
Start of Stream 1 Spinup
Start of GEOS-R21C
1995
2000
2005
2010
2015
2020
2025
2030

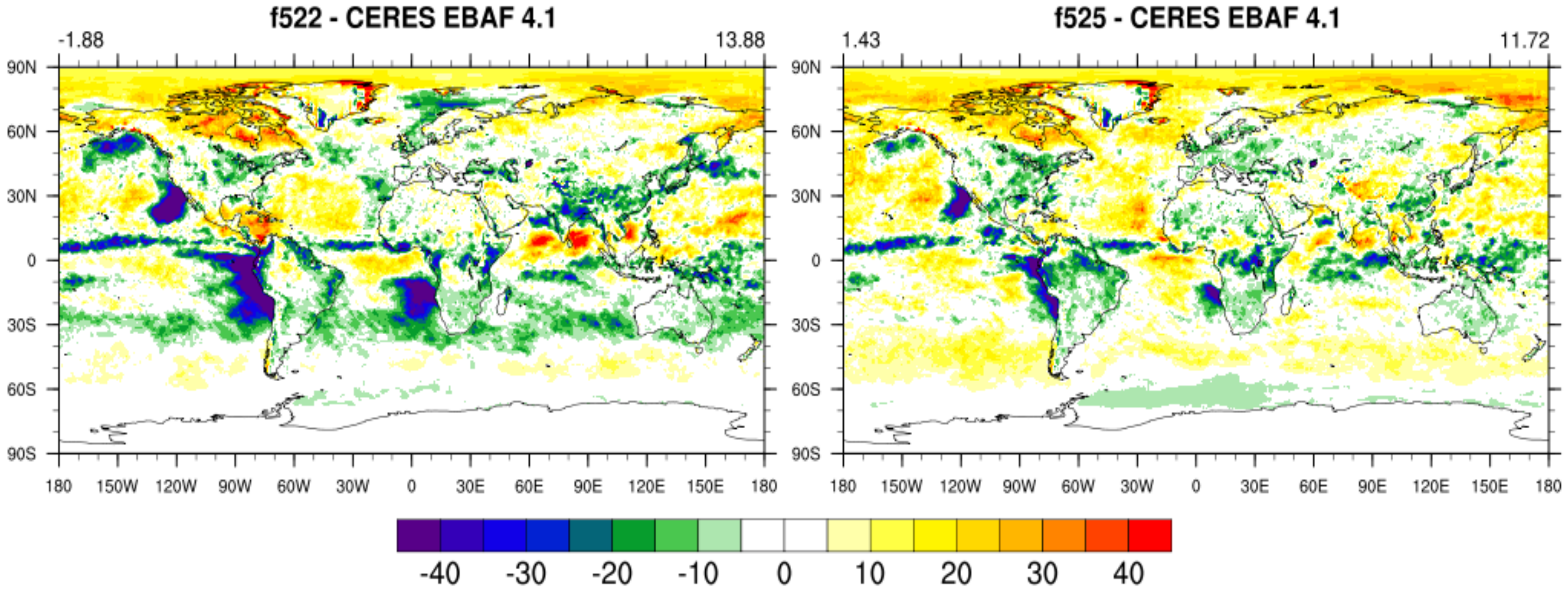
Observing system

Reprocessed

Used in FPIT

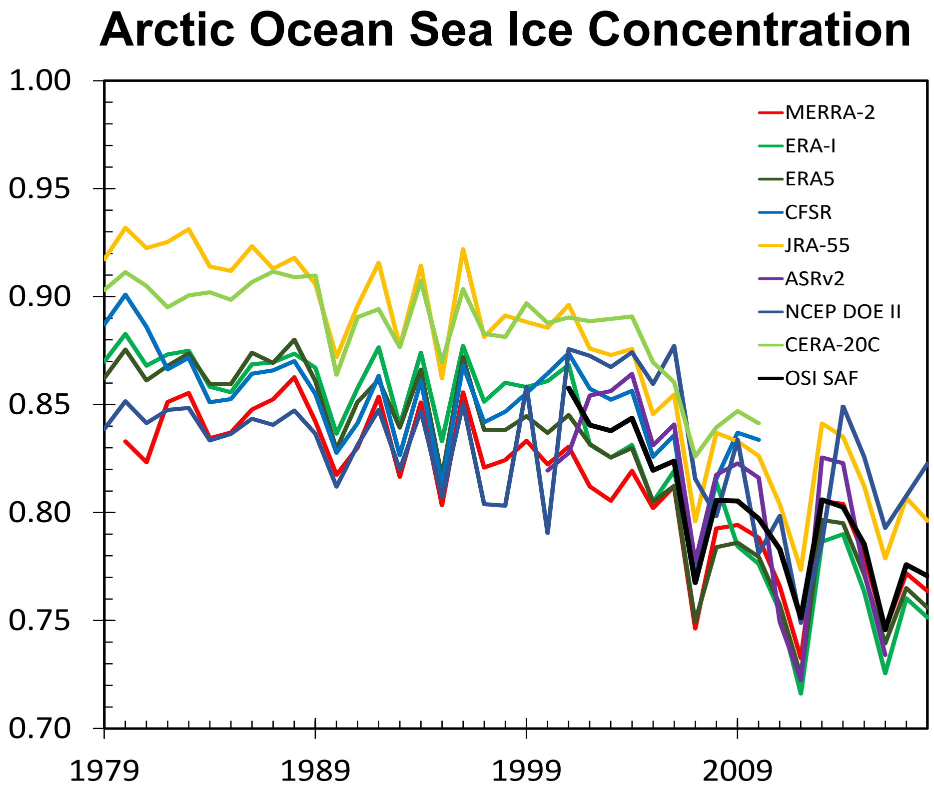
NEW




f522 - CERES EBAF 4.1
-1.88
13.88
f525 - CERES EBAF 4.1
1.43
11.72
90N
60N
30N
0
30S
60S
90S
180 150W 120W 90W 60W 30W 0 30E 60E 90E 120E 150E 180
-40 -30 -20 -10 0 10 20 30 40

Newer GEOS Systems: Improvements over MERRA-2 in the Arctic Region

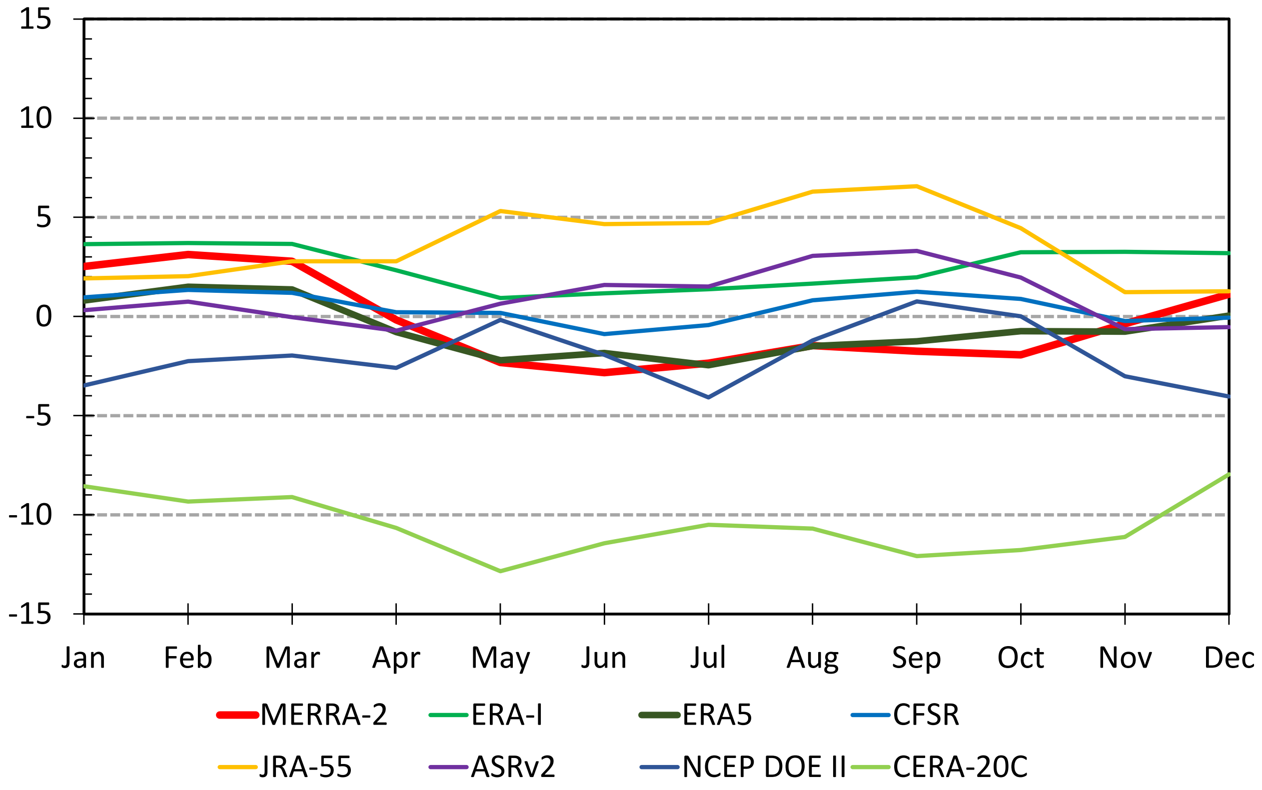
- Evaluation of nine reanalyses in comparison to CERES EBAF 4.1 to evaluate TOA flux response of changing Arctic sea ice.
- Reanalyses have significant TOA insolation differences. MERRA-2 (& other GEOS analyses) do not represent the Gregorian Calendar centennial drift (gradual shift in annual cycle). Other reanalyses have issues.
- Each reanalysis uses different sea ice cover. Differences can be large.



Averaging domain

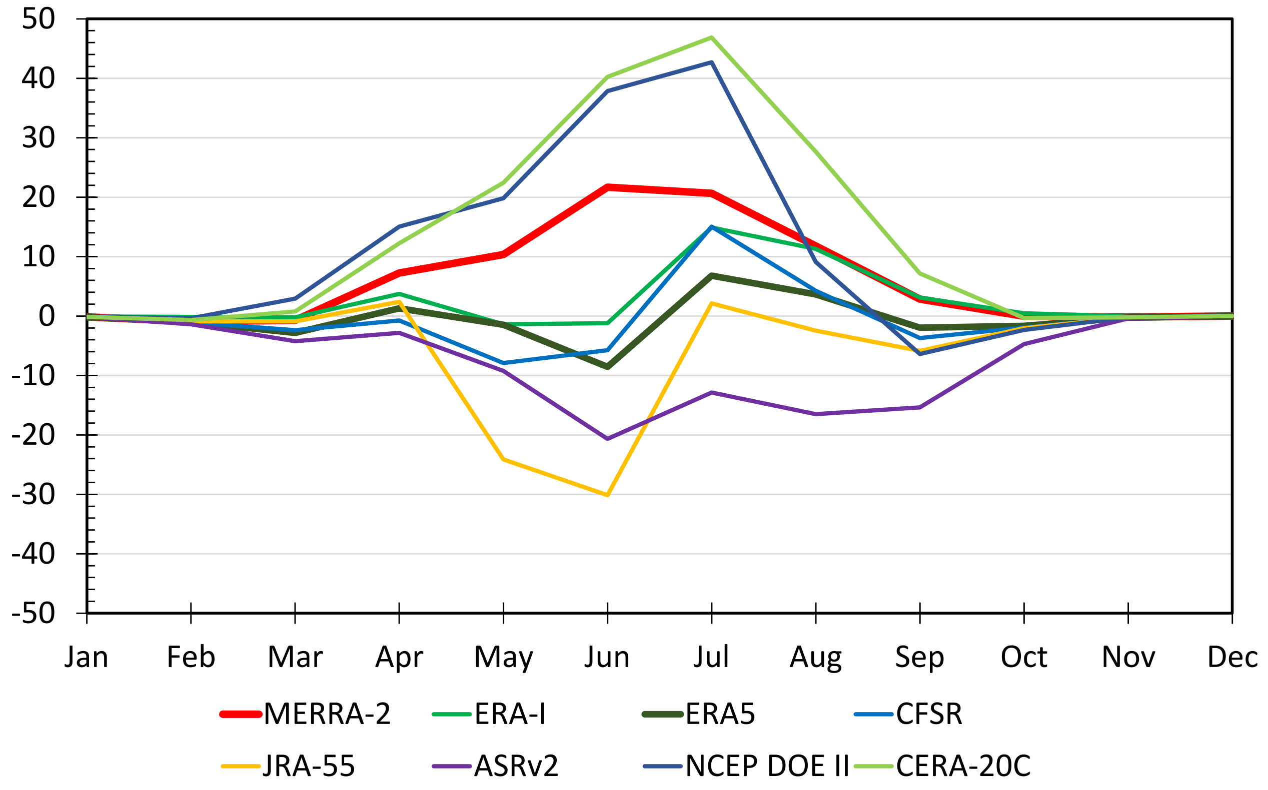
CERES-EBAF 4.1 TOA Flux Comparison: Nine Reanalyses Upwelling Fluxes

Upwelling Longwave Radiative Flux Minus CERES-EBAF, 2001-2010



MERRA-2 shows a seasonal biases in upwelling LW

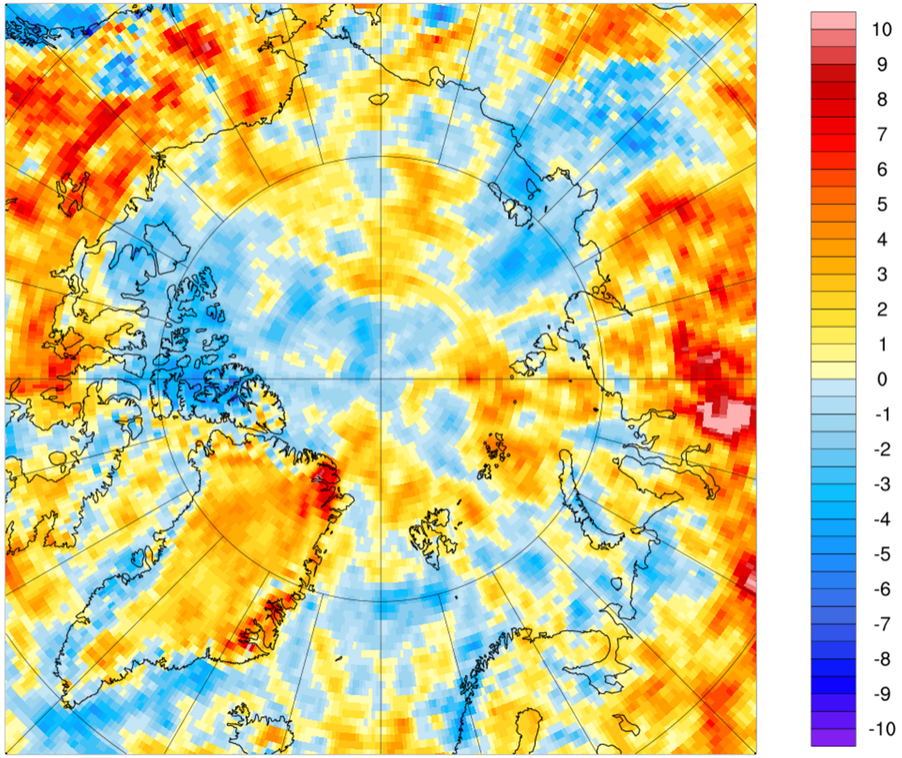
Upwelling Shortwave Radiative Flux Minus CERES-EBAF, 2001-2010



MERRA-2 overestimates upwelling SW in Summer

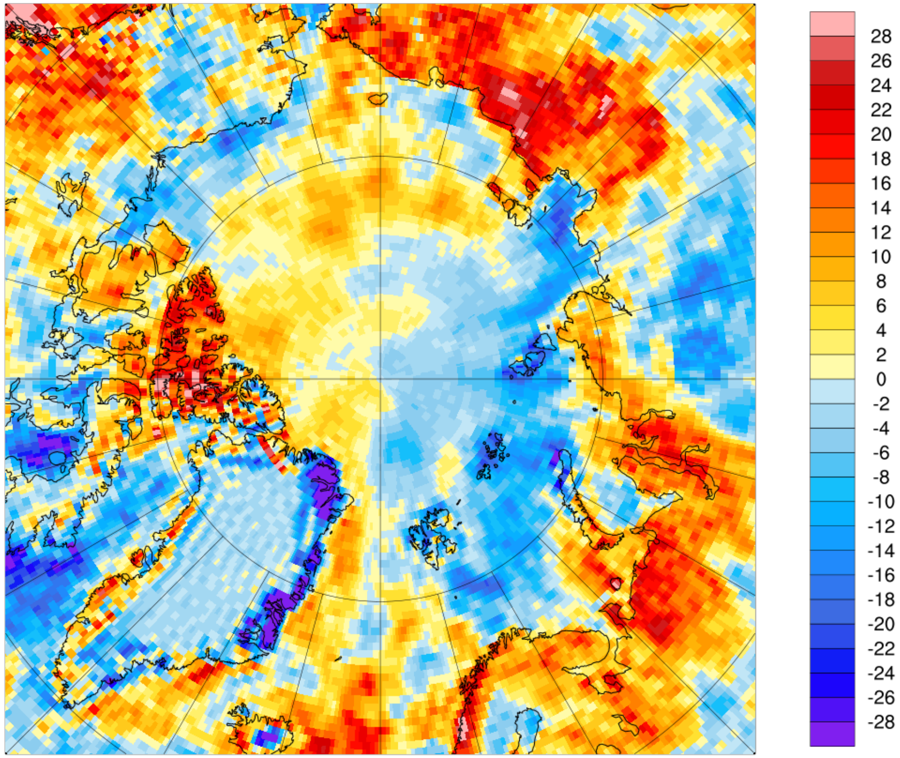
TOA Flux Changes in GEOS-FP from MERRA-2 (August 2020)

GEOS-5.25p7 – MERRA-2
TOA Upwelling Longwave, Aug 2020 [W m^{-2}]



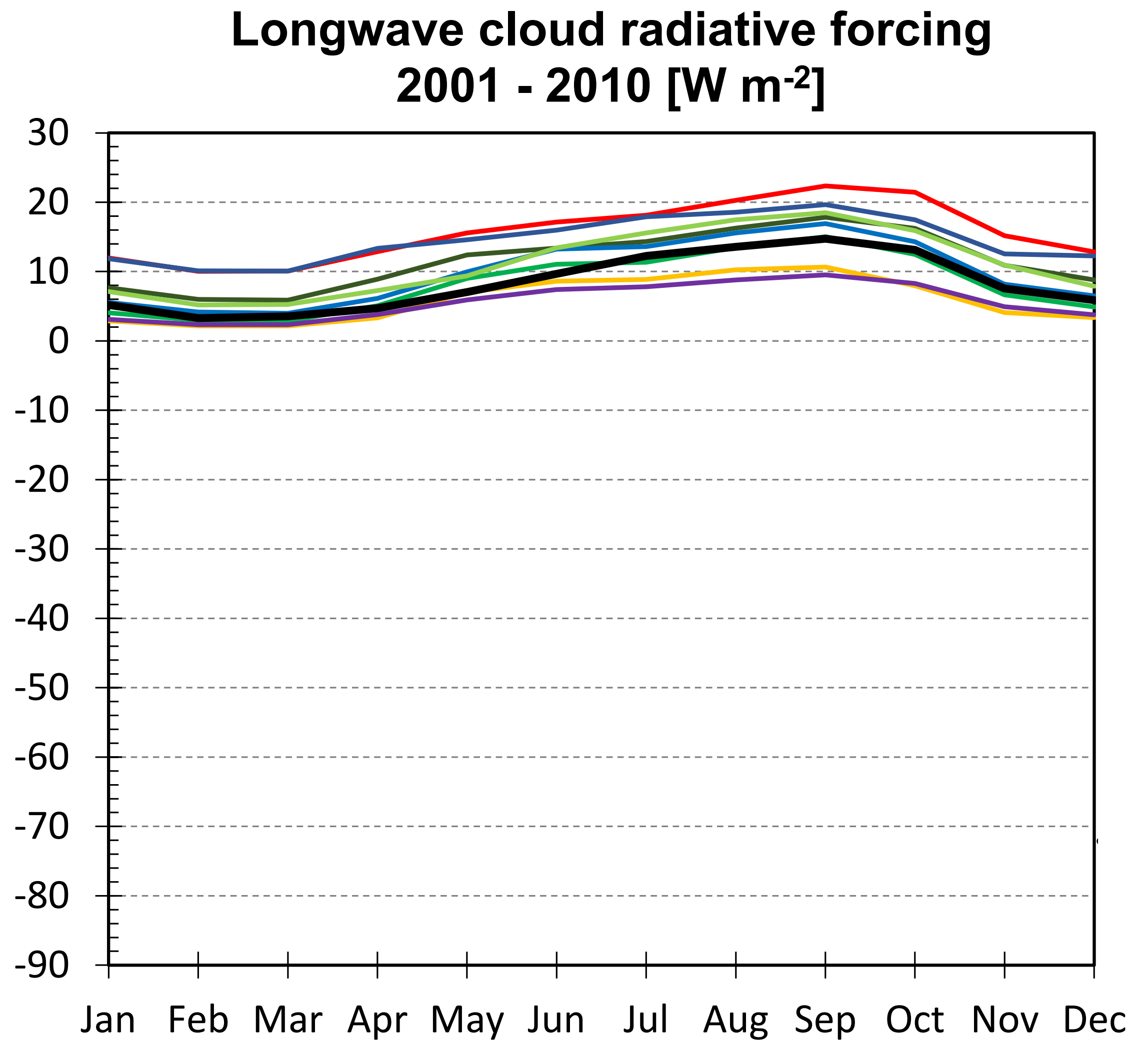
Large local changes – small overall change
NOT GETTING WORSE

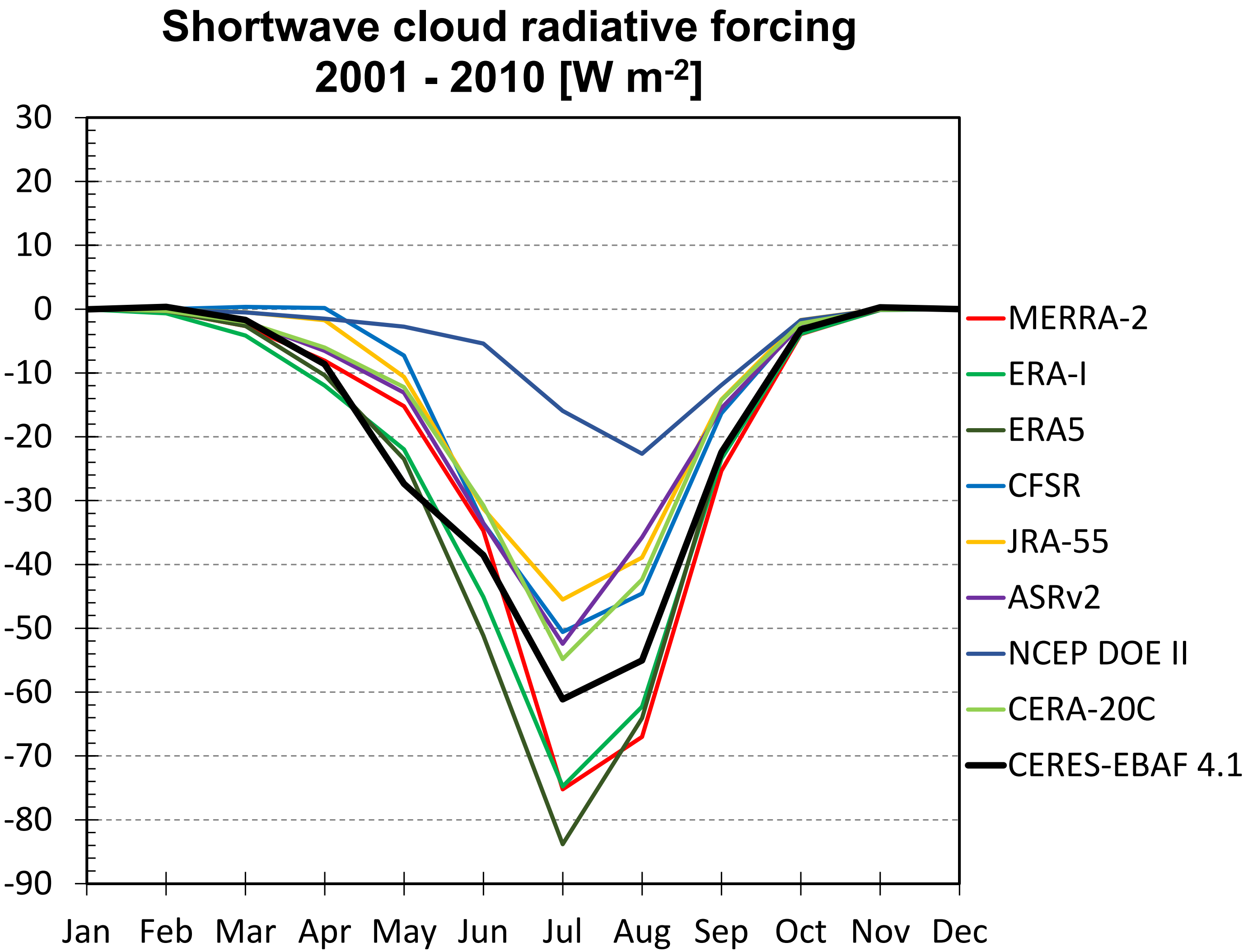
GEOS-5.25p7 – MERRA-2
TOA Upwelling Shortwave, Aug 2020 [W m^{-2}]



Substantial decrease over most of Arctic Ocean
GETTING SUBSTANTIALLY BETTER

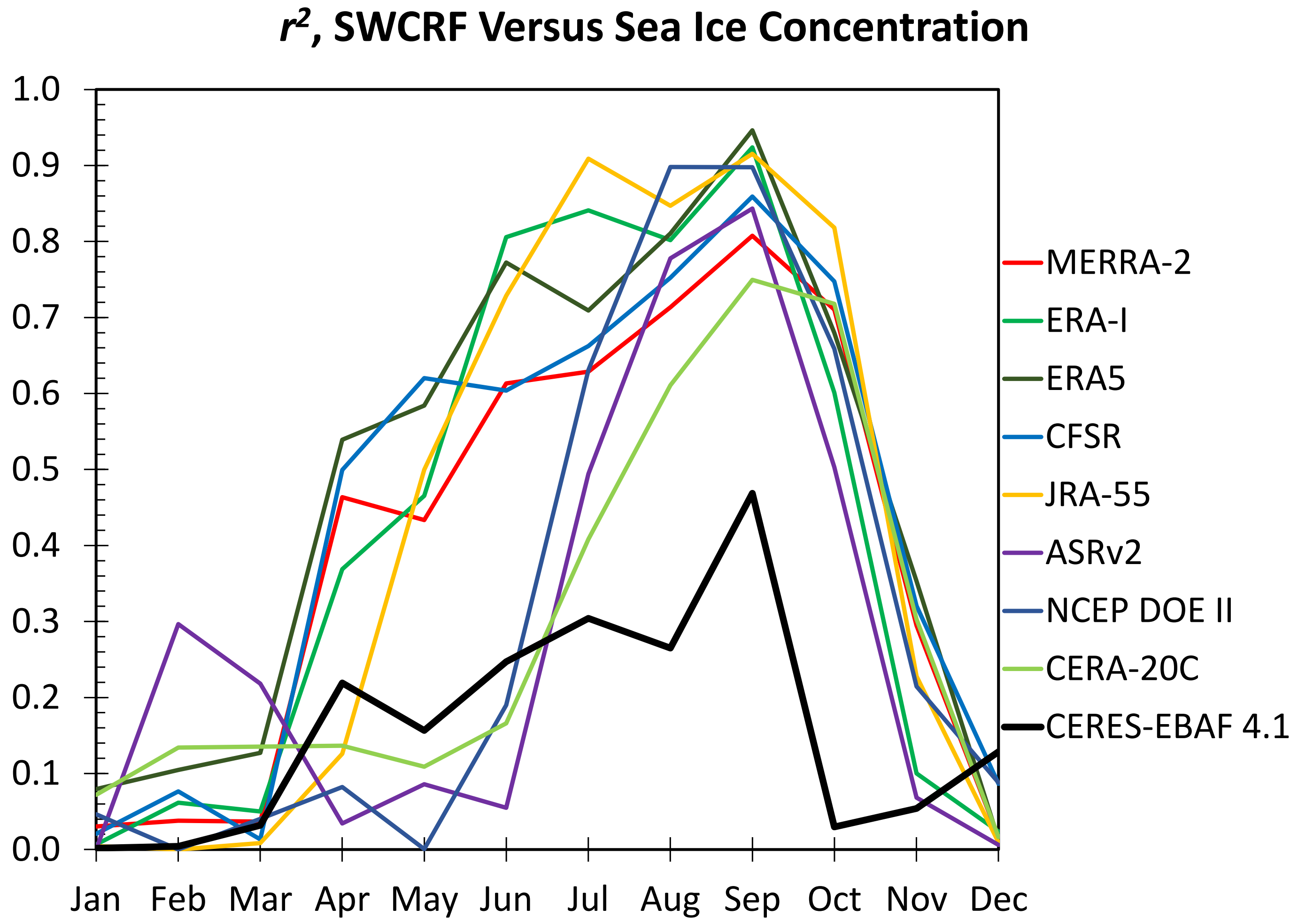
CERES-EBAF 4.1 TOA Flux Comparison in nine reanalyses
Cloud Radiative Forcing





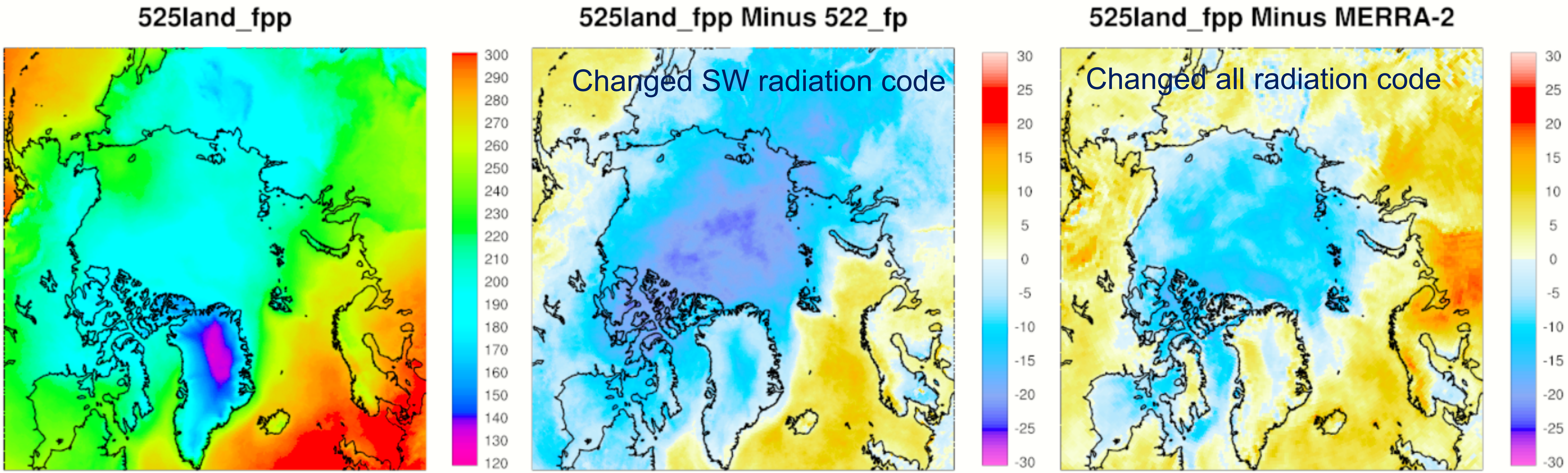
CERES-EBAF 4.1 TOA Flux Comparison
Arctic Ocean SW Cloud Forcing vs Sea Ice Concentration

- **All** reanalyses show a close agreement between TOA SW cloud forcing and sea ice cover, particularly in late summer.
- Observations (EBAF) do not show this relationship. CERES indicates the disconnect between Arctic surface and atmosphere (e.g., Kay and l'Ecuyer 2013).
- (Not enough years to evaluate in GEOS-FP)



Surface Flux Changes in GEOS Forward Processing

Surface Absorbed Longwave Radiation, Oct 2019 - Jan 2020 [W m^{-2}]

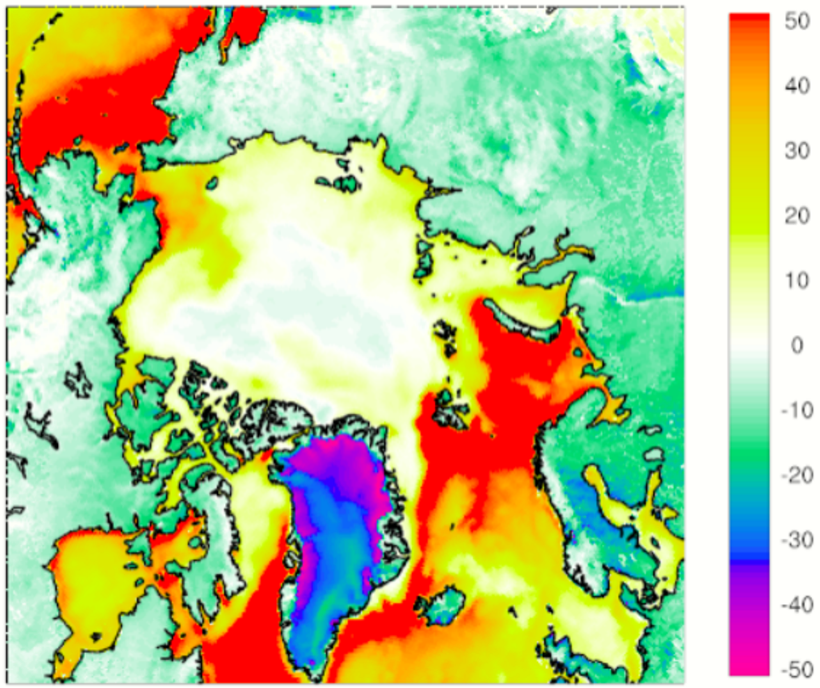


Recent work has focused on implementation of longwave and shortwave RRTMG.
Differences with forward-processing versions show a decrease in surface downwelling longwave in winter.

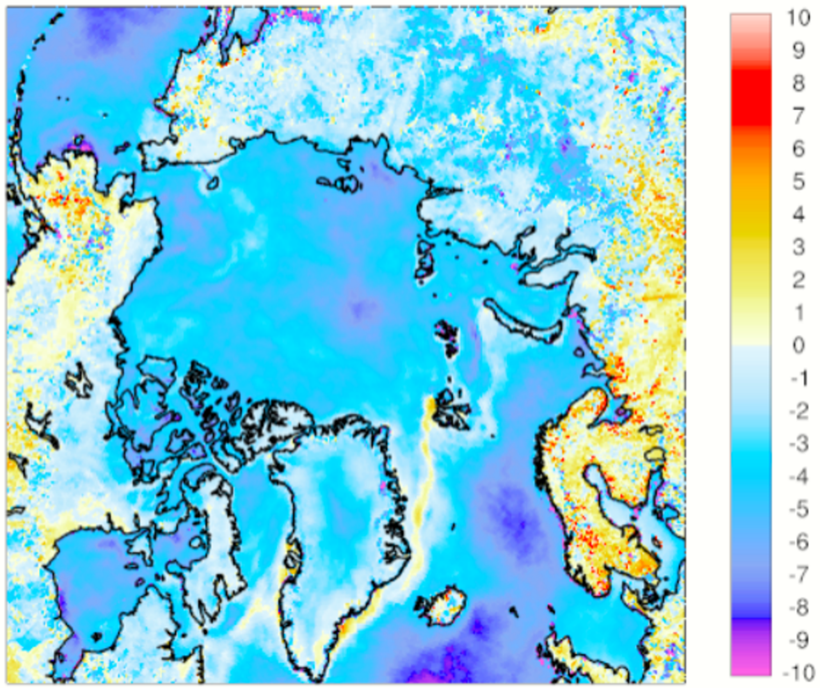
Surface Flux Changes in GEOS Forward Processing

Sensible Heat Flux, Oct 2019 - Jan 2020 [W m^{-2}]

525land_fpp

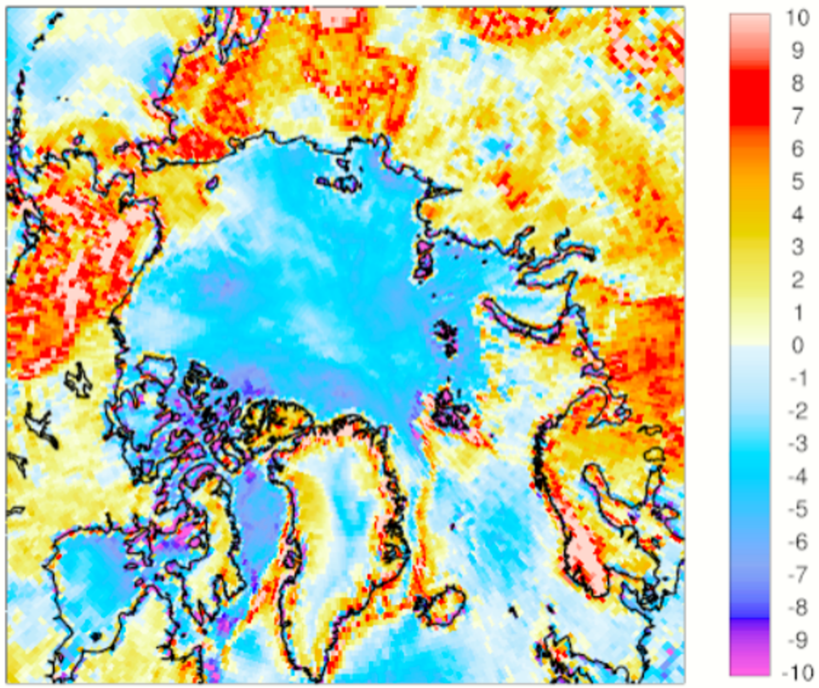


525land_fpp Minus 522_fp



Changed SW radiation code

525land_fpp Minus MERRA-2



Changed all radiation code

The new “physics” package implemented in GEOS-5 since MERRA-2 appears to be improving the energy balance in the Arctic in the GEOS-FP system in a way that will lead to GEOS-R21C (GEOS-5.26) being more realistic than MERRA-2 (GEOS-5.14)

More diagnosis is needed

Proposed Transition from GEOS-FPIT to GEOS-IT

Commitment to NASA's Earth Science Mission means GMAO wants to provide the best-possible products

GEOS-FPIT uses a ~2015-era version of the GEOS model and assimilation system

- model enhancements lead to more realistic moisture, temperature, land surface, … analyses
- older models become hard to maintain in modern computing environments
- new observations typically cannot be assimilated in older systems
- opportunity to use reprocessed versions of older operational observations (e.g., AMSU)

Planning to retain the 50-km resolution of GEOS-FPIT (time-to-completion and data volumes)

Continue use of the "3DVar" assimilation technique (HPC cost and data volumes)

Continue the "subscription only" access via the GES-DISC

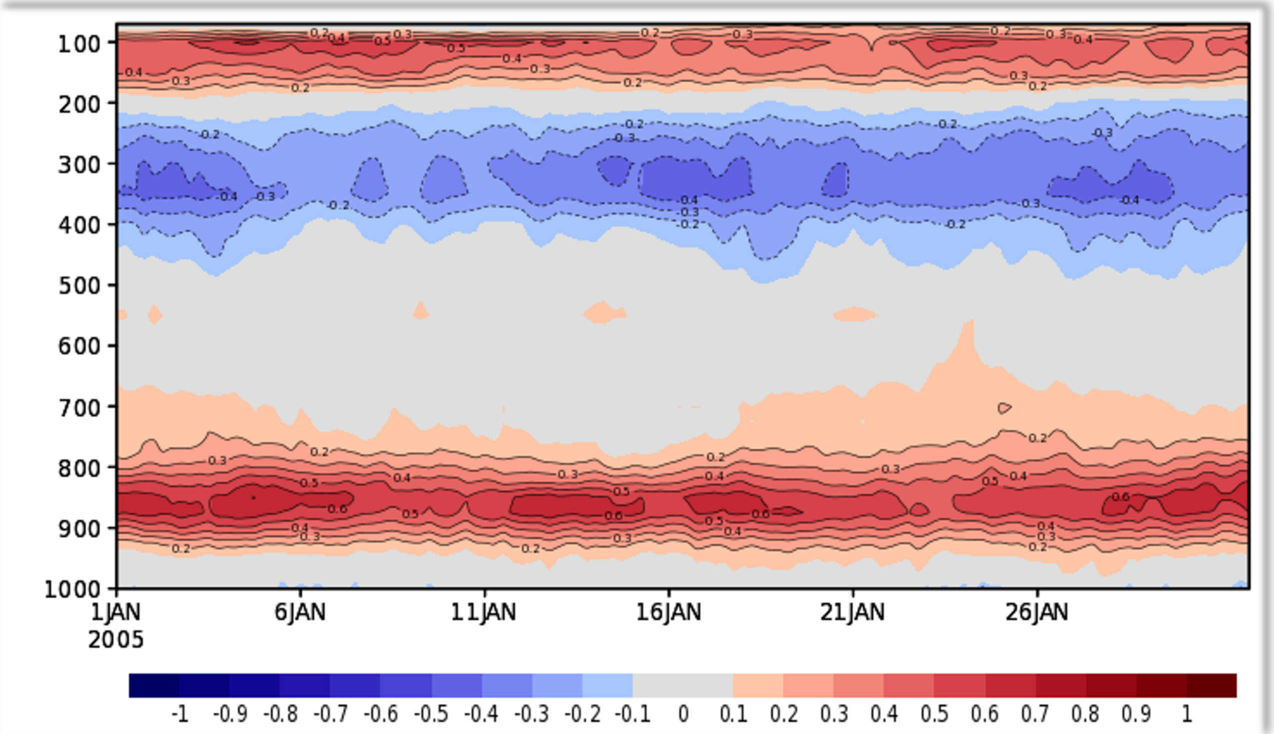
Preliminary evaluation of T and Q: "candidate" GEOS-IT system compared with current GEOS-FPIT system

Candidate system = 3dVar test with new SBUV/2 and no MLS

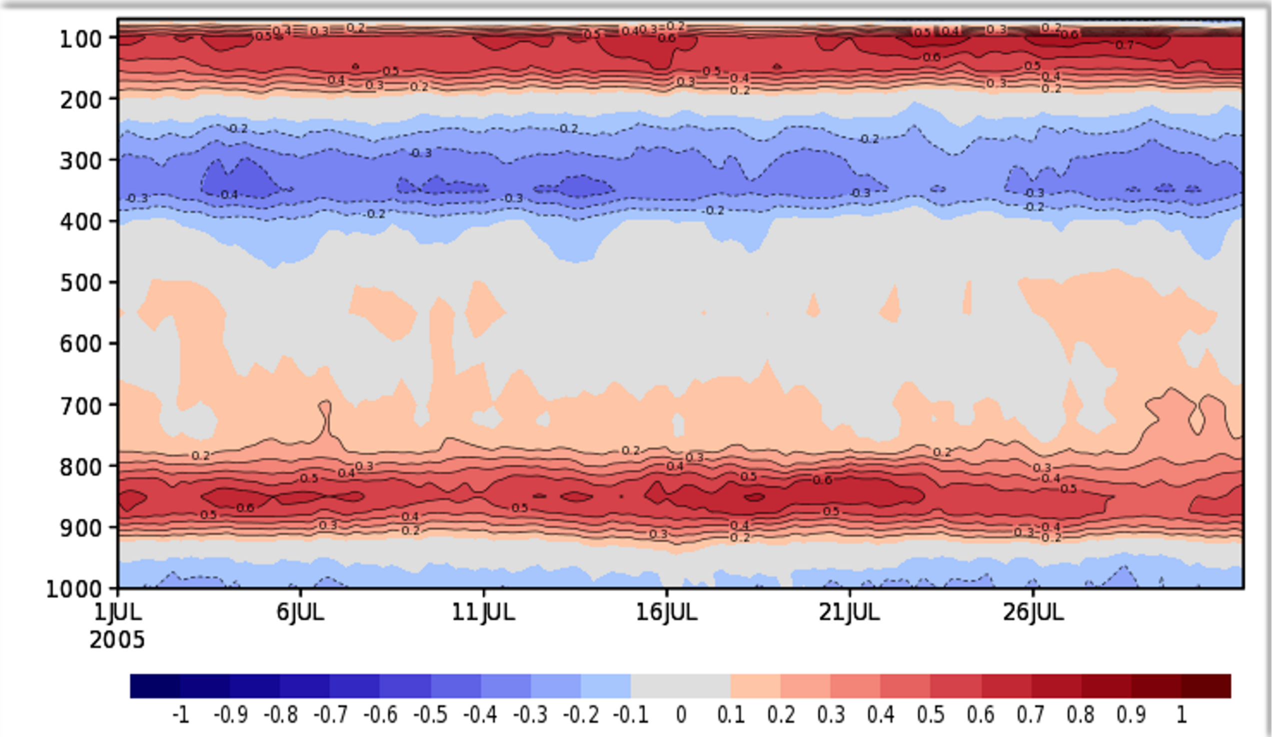
Current system = d5124_rpit_jan12 (GEOS-FPIT)

There are substantial differences in the global (60N,S) temperature between the candidate GEOS-IT and the current GEOS-FPIT systems

Candidate minus current FP-IT TEMP; January 2005

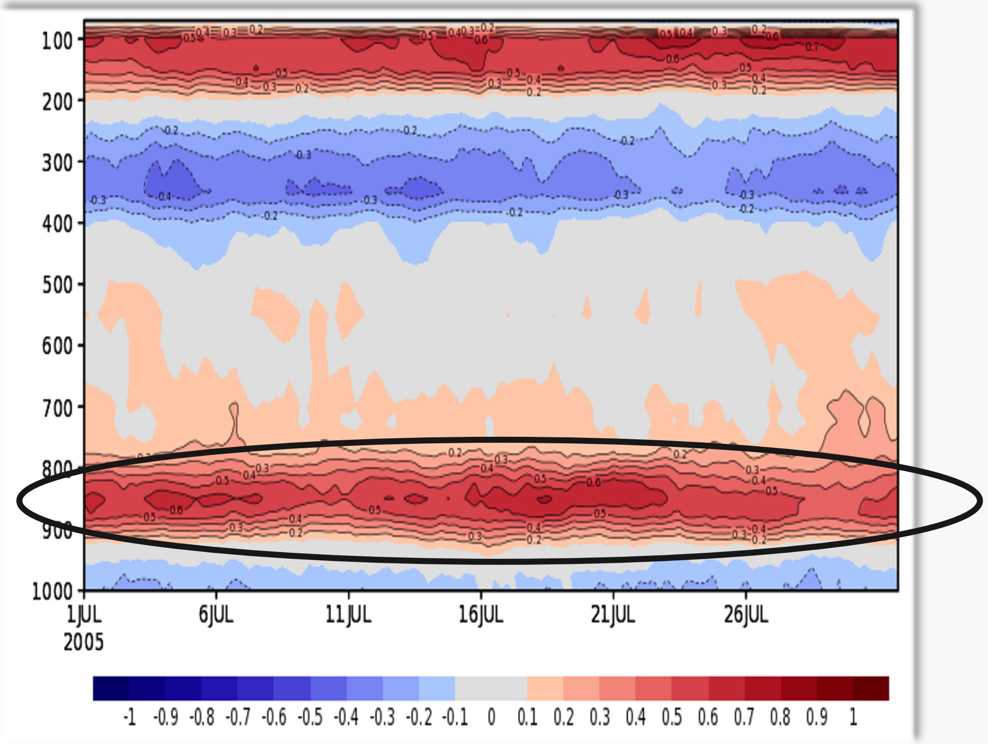


Candidate minus current FP-IT TEMP; July 2005

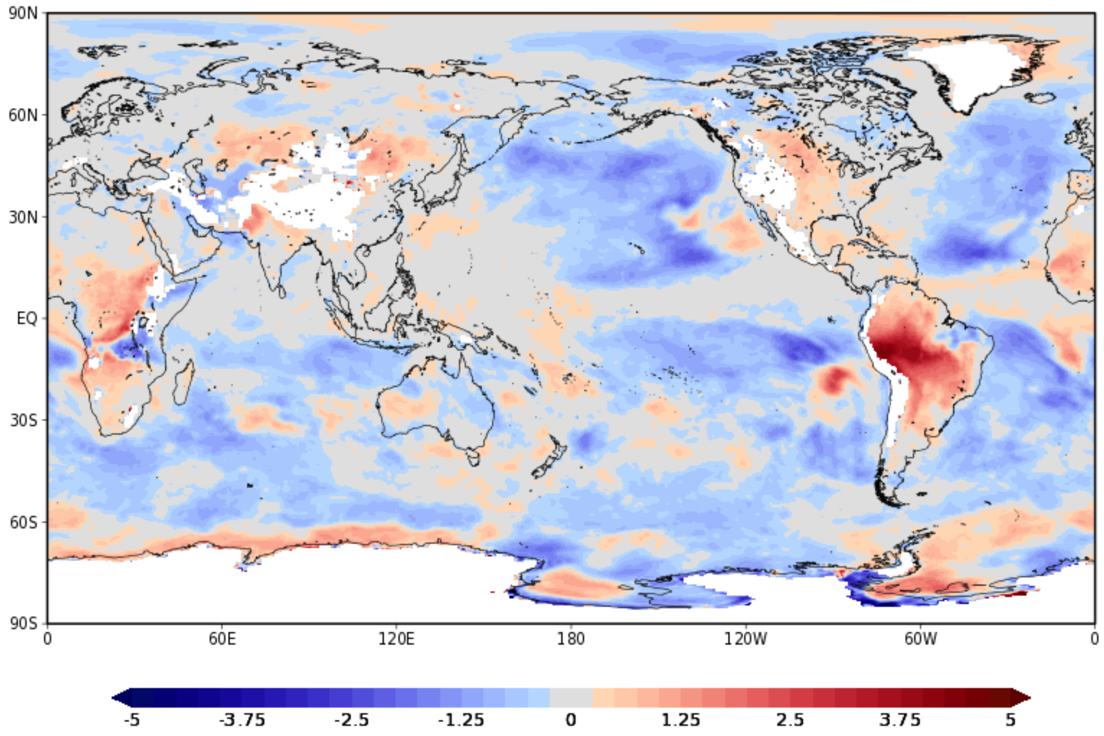


How do these differences compare with ERA-5 Reanalysis temperatures?

Test minus current FP-IT TEMP; July 2005

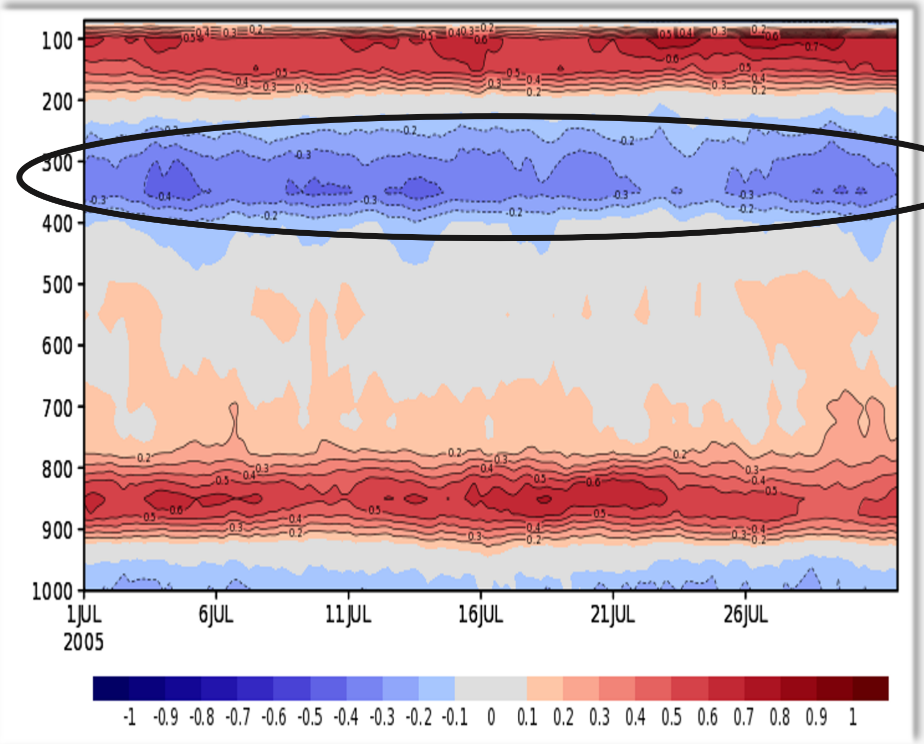


850T Closeness to ERA5
Blue = Candidate, Red = Current

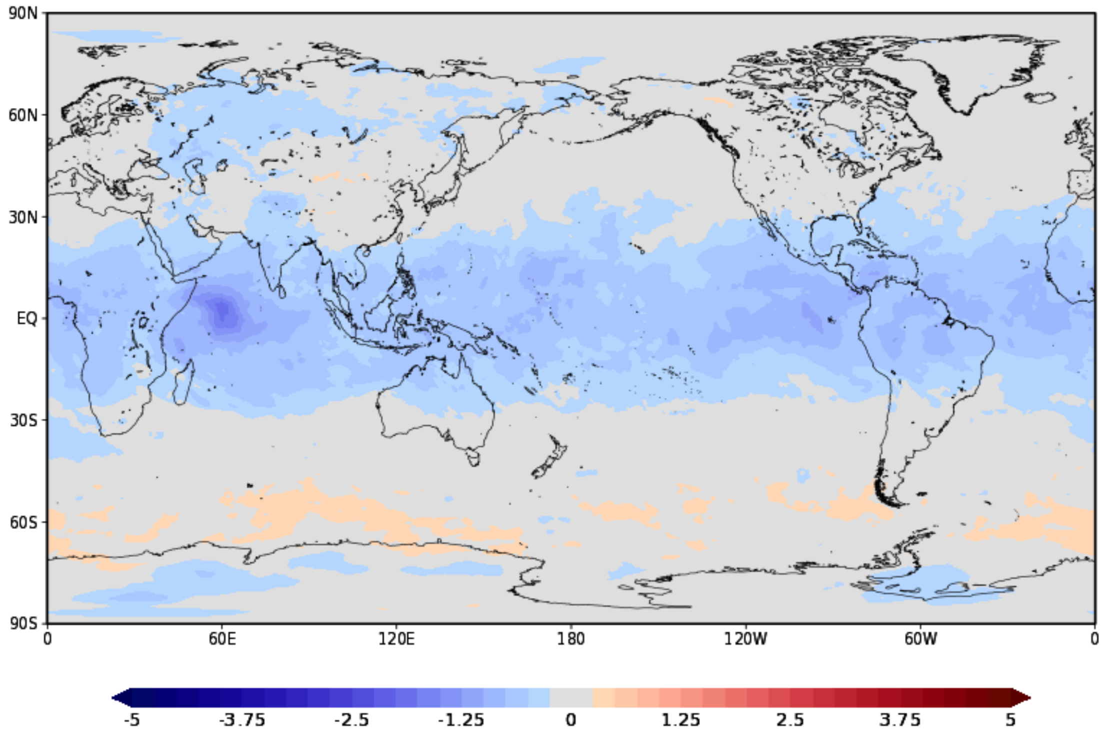


Substantial improvement over most ocean surface, and some degradation over land (especially over South America)

Test minus current FP-IT TEMP; July 2005

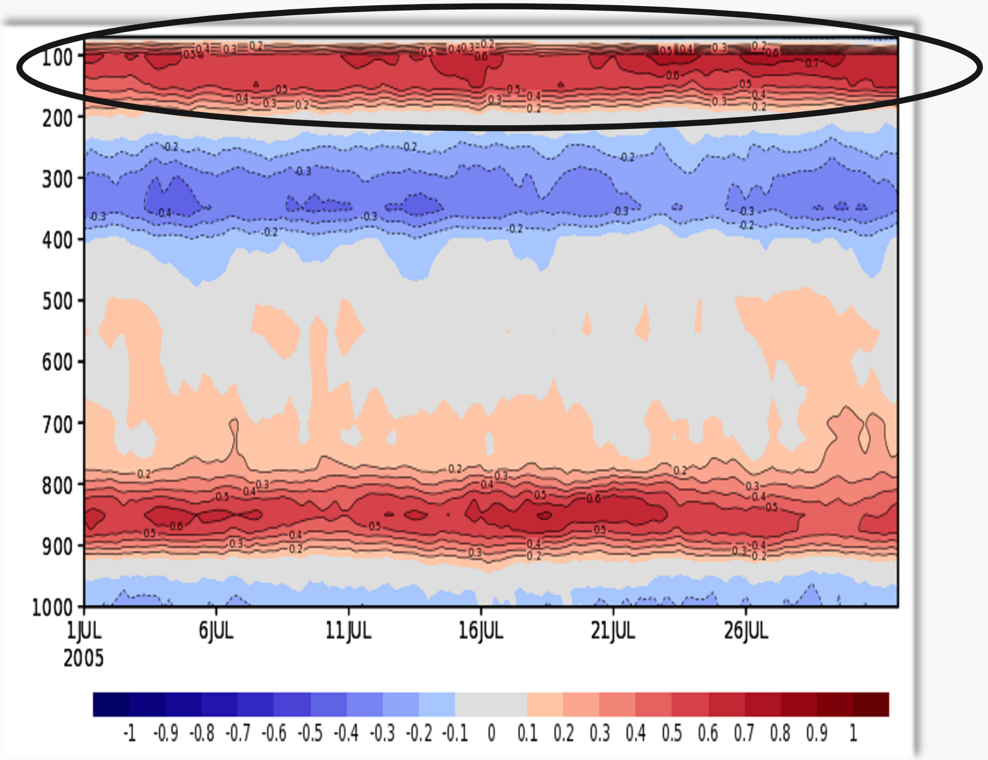


300T Closeness to ERA5
Blue = Candidate, Red = Current

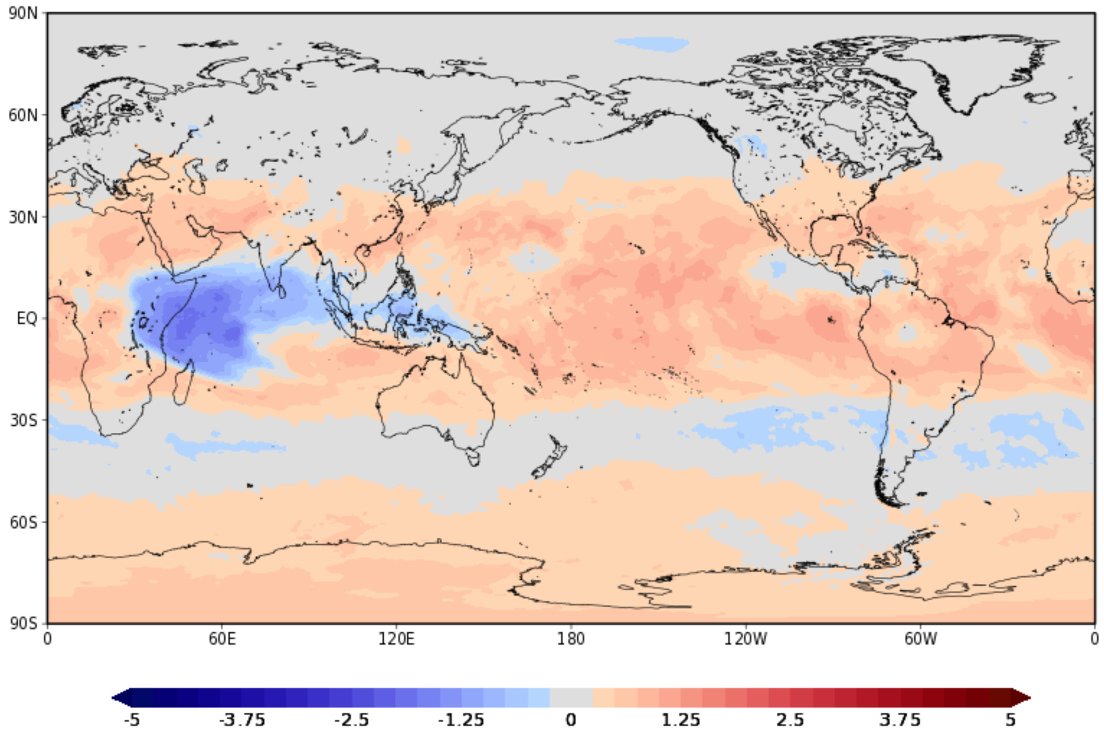


Near-universal substantial improvement (except for a sliver of degradation along 60S)

Test minus current FP-IT TEMP; July 2005



150T Closeness to ERA5
Blue = Candidate, Red = Current



Candidate system is warmer and further away from ERA-5. But compared with NCEP (not shown) the warmer 150mb temperatures in the candidate system are closer in candidate than in the current FP-IT

Summary

Investments in developing GEOS system:

- New suite of model parametrizations
- Advanced data assimilation enabling use of new observations
- Reprocessed historical observations

Specific diagnostics demonstrate improvements in:

- Thermal structure and moisture
- Energy balance over the Arctic

New reanalysis products will be available over the next two years

- GEOS-IT – specifically for instrument teams (~2021)
- GEOS-R21C – a “modern” atmospheric reanalysis for EOS and post-EOS era (~2022-23)

Discussion

How will these advances aid the CERES science team?

How about MERRA-3 in ~2024-2025 (a coupled analysis for ~1980-2030)

Longer term: a “Level-4 CERES Product”?

Timeline of GMAO Projects