The NASA GMAO retrospective analysis for the early 21st Century GEOS-R21C

From MERRA-2 to GEOS-R21C and MERRA-3

Amal EL Akkraoui[a,b]

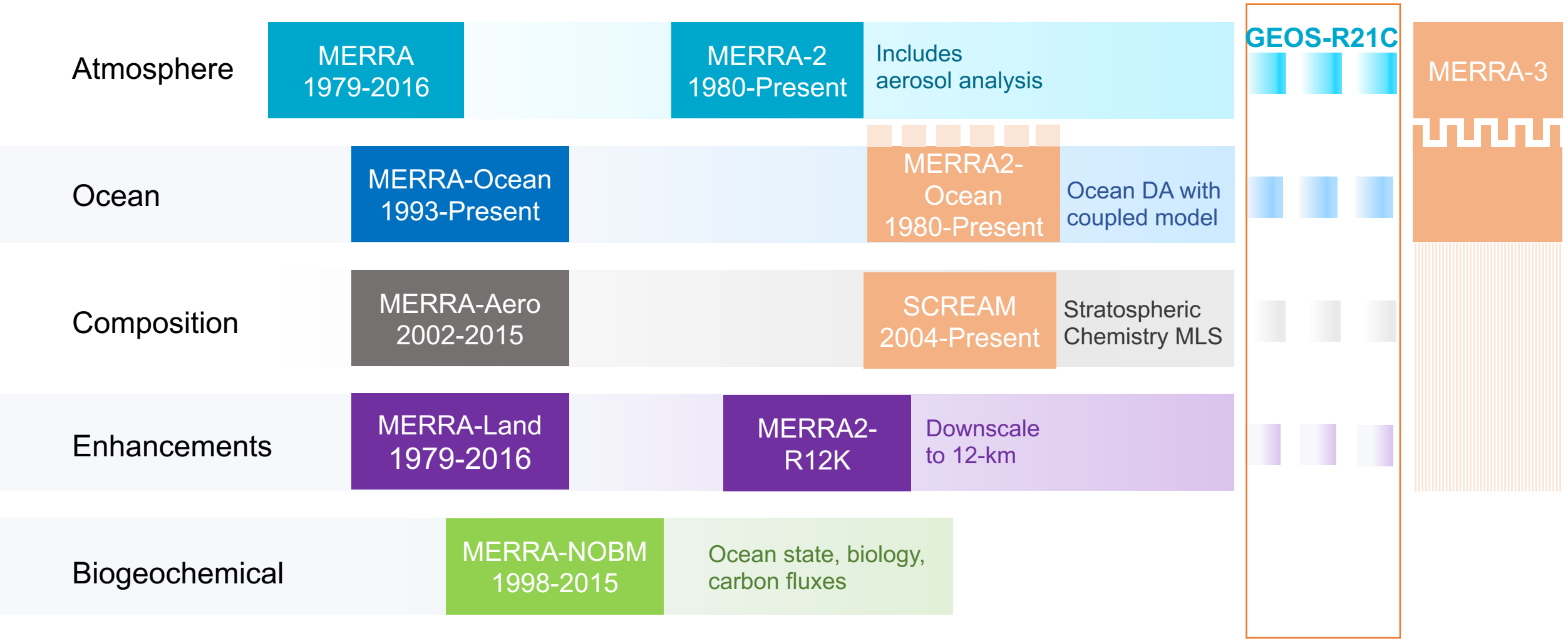
Contributors: Larry Takacs[a,b], Krzysztof Wargan[a,b], Meta Sienkiewicz[a,b], Mohar Chattopadhyay[a,b], Jianjun Jin[a,b], Christine Bloecker[a,b], Will McCarty[a], *Rob Lucchesi*[a,b], Ron Gelaro[a], and Steven Pawson[a]

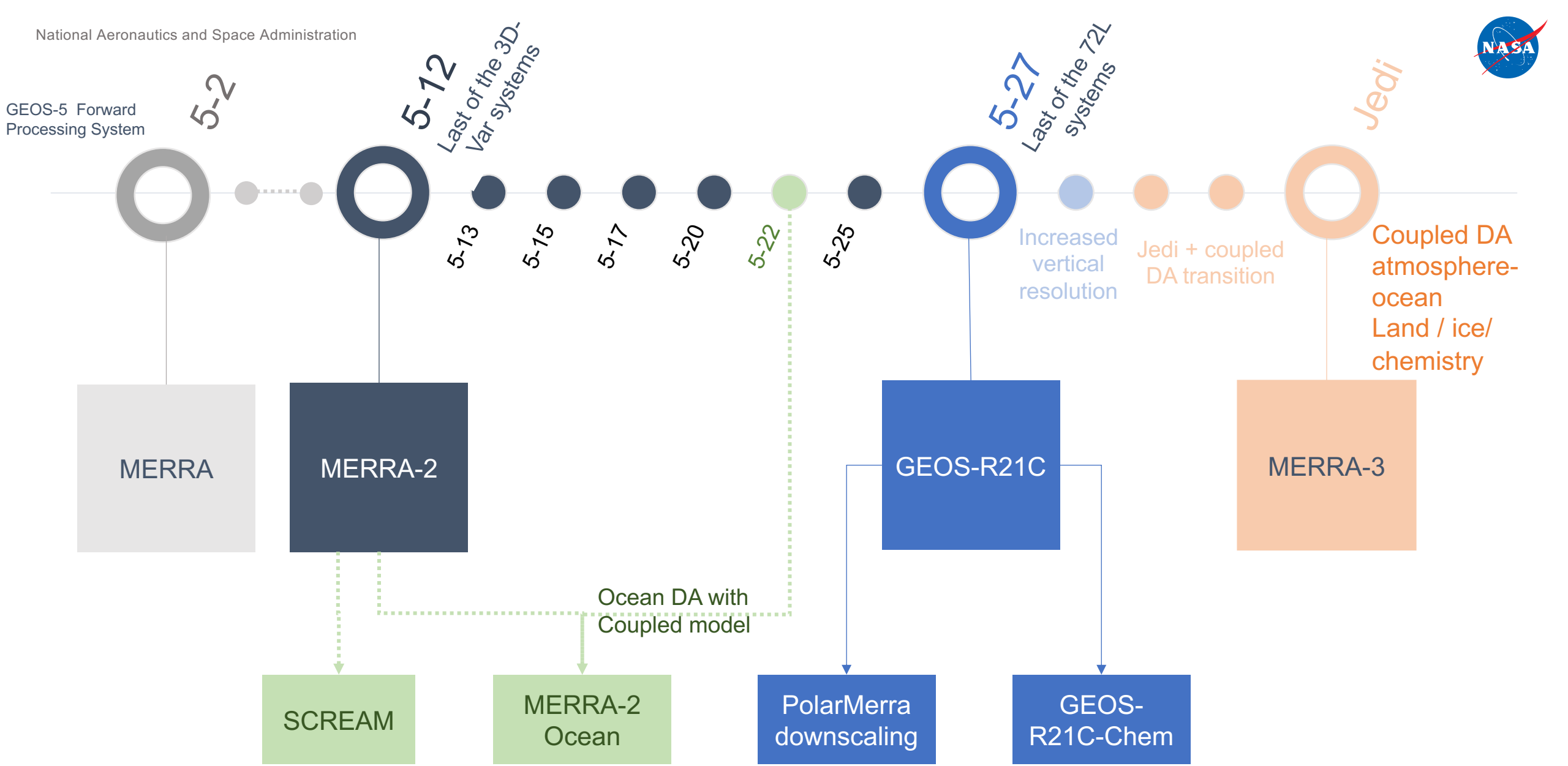
[a]GMAO, Earth Sciences Division, Sciences and Exploration Directorate, NASA GSFC.

[b]Science Systems and Applications, Inc. (SSAI)

Joint WCRP-WWRP Symposium on Data Assimilation and Reanalysis, Sep 12-18, 2021

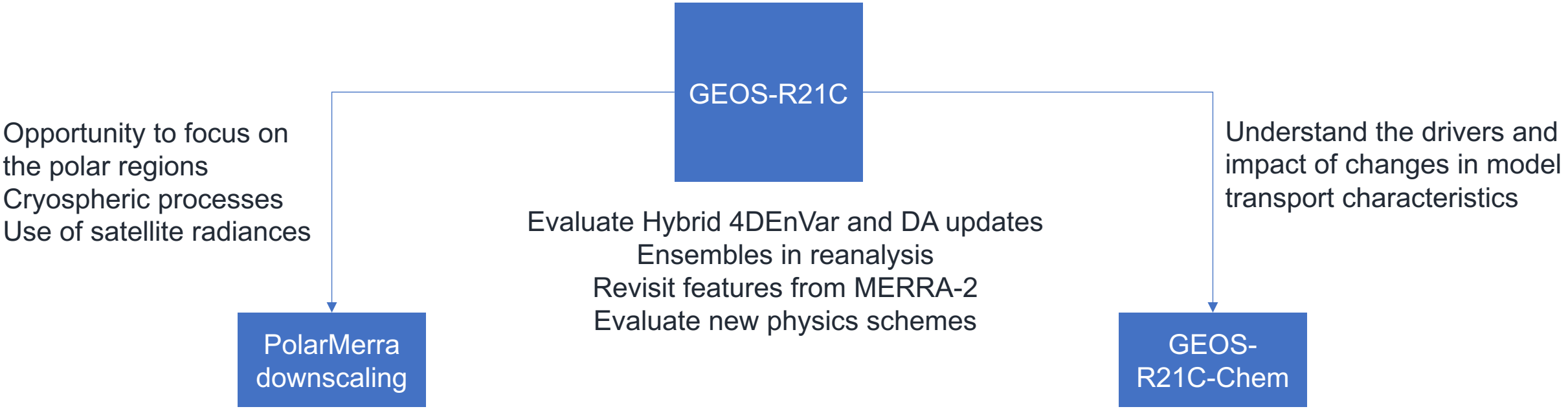
GMAO reanalyses and derivative products




GEOS-5 Forward Processing System
5-2
5-12
Last of the 3D-Var systems
5-13
5-15
5-17
5-20
5-22
5-25
5-27
Last of the 72L systems
Increased vertical resolution
Jedi + coupled DA transition
Jedi
Coupled DA atmosphere-ocean Land / ice/ chemistry
MERRA
MERRA-2
GEOS-R21C
MERRA-3
Ocean DA with Coupled model
SCREAM
MERRA-2 Ocean
PolarMerra downscaling
GEOS-R21C-Chem

GEOS-R21C: An Enhanced Atmospheric Reanalysis

GEOS-R21C is not a replacement to MERRA-2, but rather a stepping-stone towards MERRA-3, providing a baseline for its atmospheric component and the opportunity to explore aspects of Earth System coupling with other offline components.



GEOS-R21C: An Enhanced Atmospheric Reanalysis

Build on the advances introduced into GEOS-FP after MERRA-2 to produce an enhanced atmospheric reanalysis 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.

25-km resolution system that uses **hybrid 4D-EnVar all-sky** DA and covers the period **2000-onwards**.

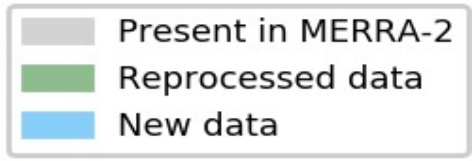
Continue focus on atmospheric composition, via a proposed offline "derivative" reanalysis for atmospheric constituents **GEOS-R21C-Chem** using CoDAS and GEOS-Chem.

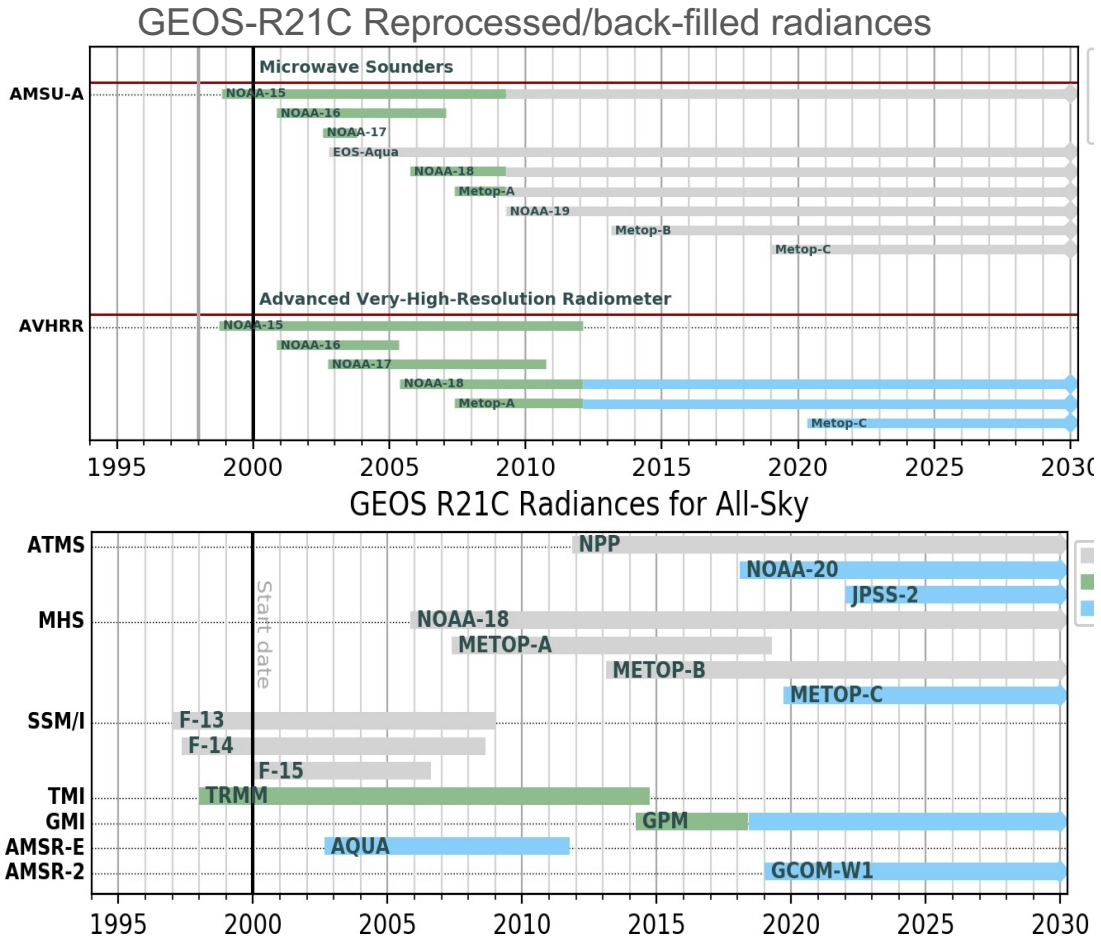
Enhance focus on Cryospheric processes, via a proposed additional activity, **Polar MERRA** downscaling.

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

Observing system for GEOS-R21C

- **Reprocessed** versions of **older** operational observations. (AMSU-A, AVHRR, AMV, SBUV-2, MLS, COSMIC, radiosondes).
- **New** data (OMPS-NP, OMPS-NM, COSMIC2, Metop-C, JPSS…, and possibly loon balloons)
- **Improved** use of observations: All-sky (GMI, TMI, MHS, AMSR-2, AMSR-E, and ATMS).



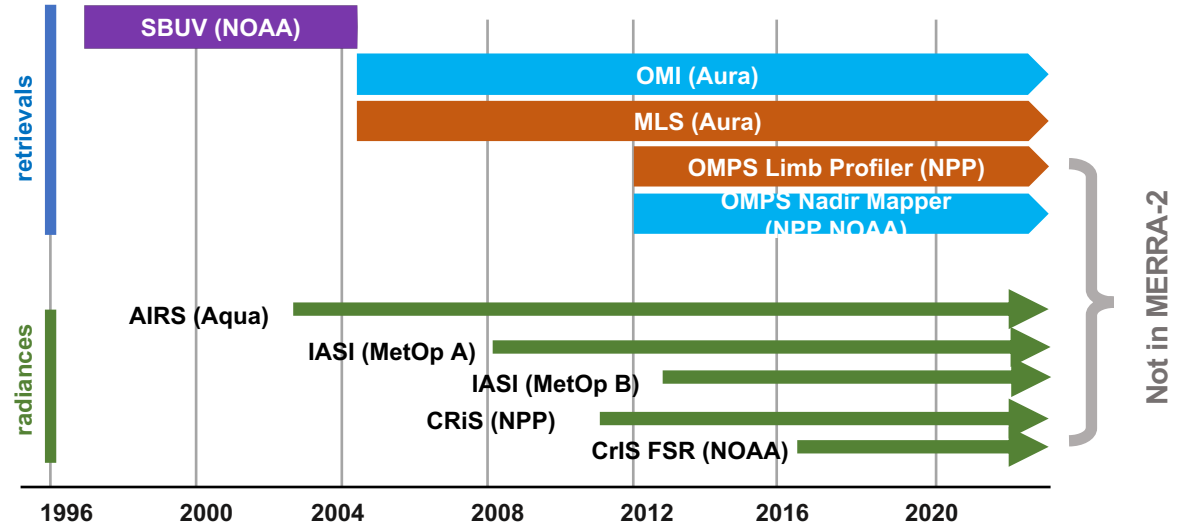


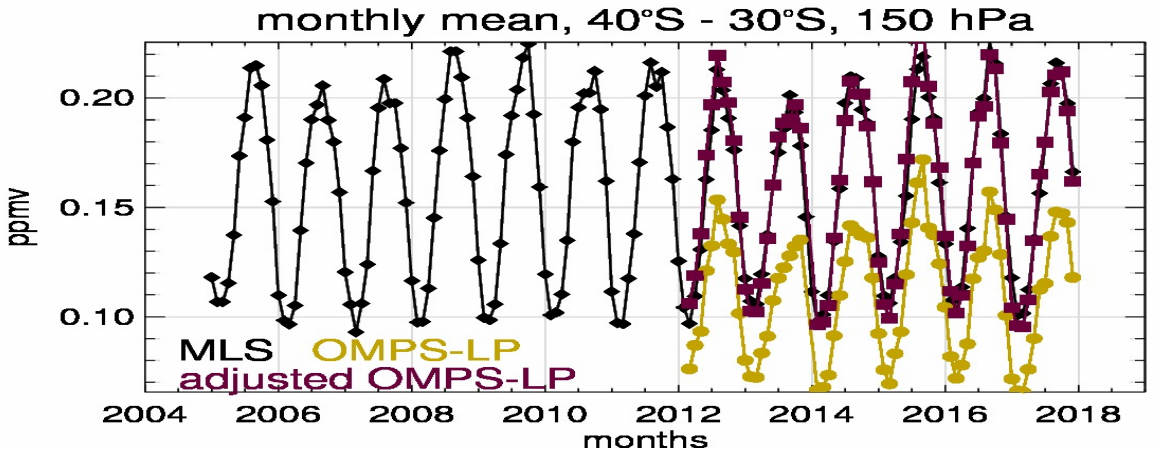
Ozone data for GEOS-R21C

- Many new data types compared to MERRA-2; new versions of old data.
- Assimilation of ozone-sensitive radiances in 9.6μm for the first time in a GMAO reanalysis.

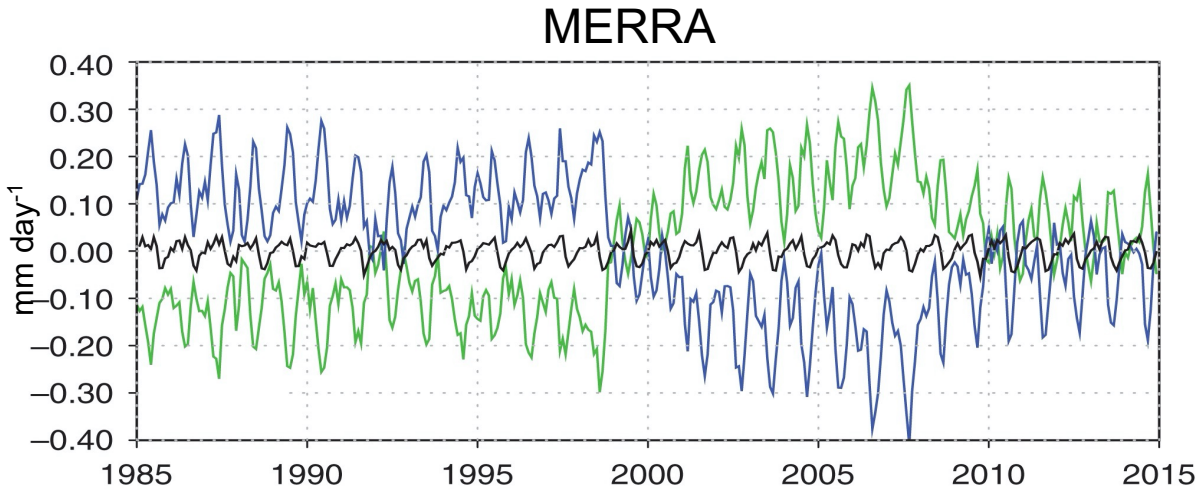
- Ozone observing system changes in MERRA-2: 2004 (SBUV→Aura transition) and 2015-2016 (a change of MLS data versions).

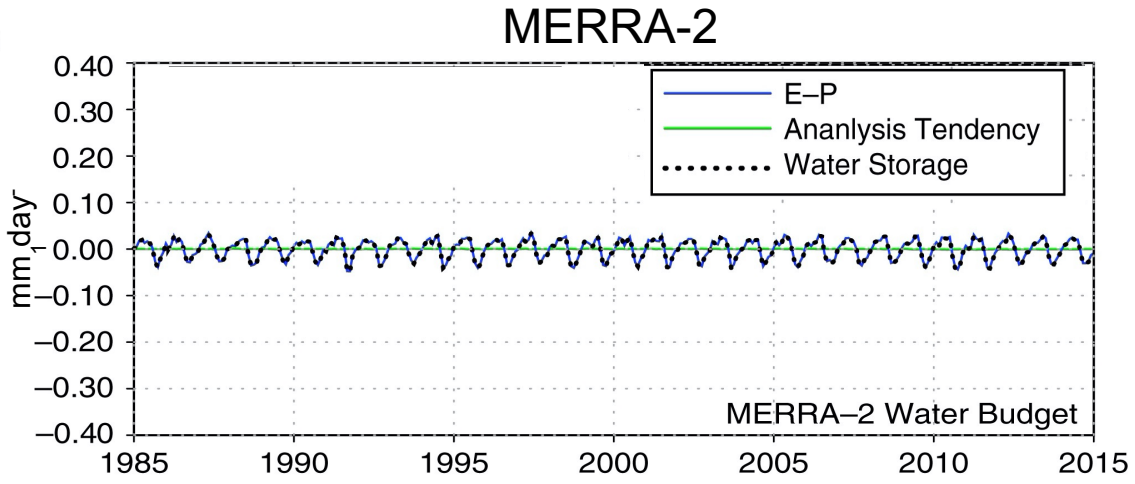
Homogenization is applied to ensure continuity in Total column ozone (OMI and OMPS-NM) and ozone profiles (MLS and OMPS-LP).

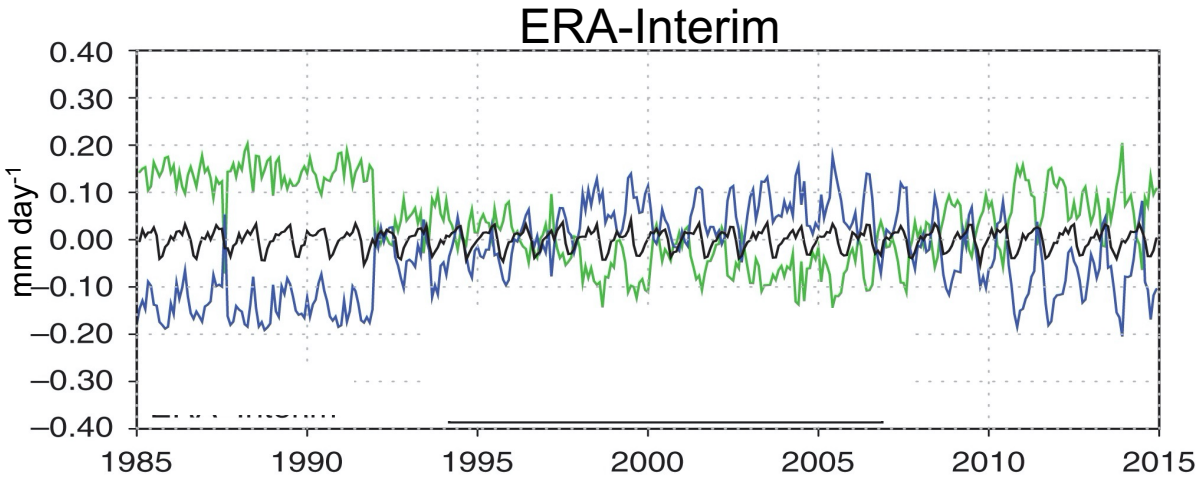




A Re-Examination of Global Constraints in MERRA-2 Dry Mass Conservation





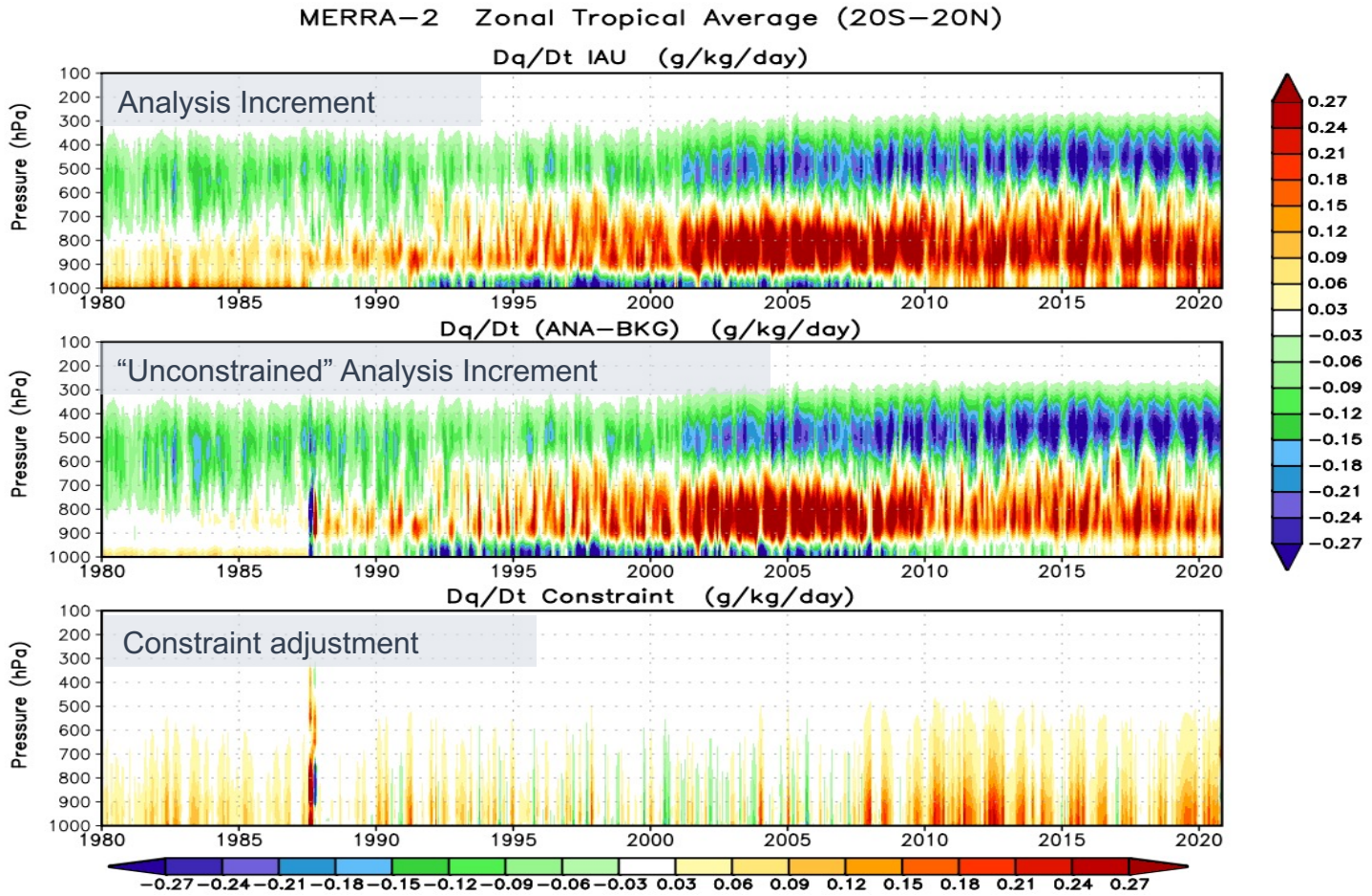


- Constraint applied in MERRA-2 conserves dry-mass and provides E-P balance;
- Reduces spurious jumps in precipitation due to observing system changes.

A Re-Examination of Global Constraints in MERRA-2 Dry Mass Conservation

- Undesirable effects of analysis increment.
- Reformulations of this constraint were tested for GEOS-R21C but may require a re-tuning of the model physics.

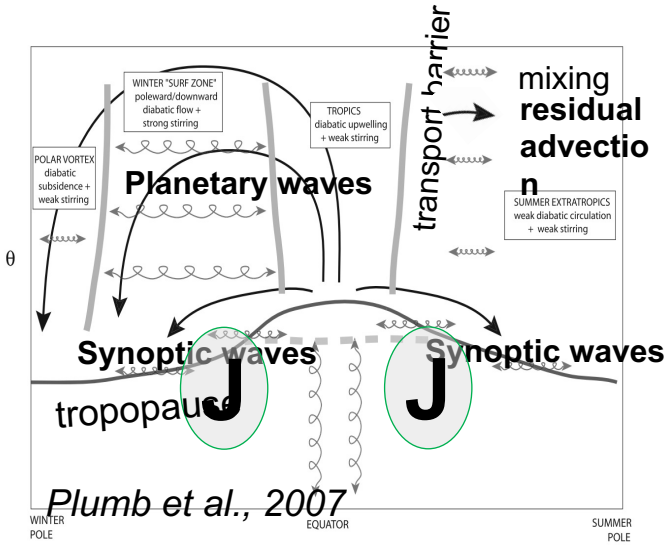
Globally Integrated Constraint adjustment



GEOS-R21C → GEOS-R21C-Chem

Model Transport

Objective: Evaluation of the dynamical/convective/diffusive transport characteristics of the candidate systems for GEOS-R21C.



Plumb et al., 2007

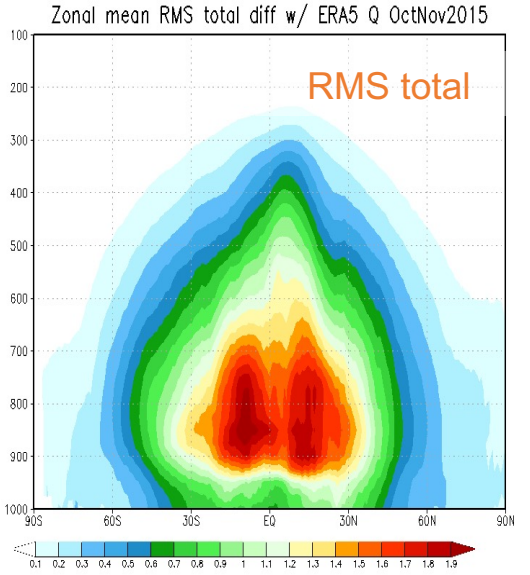
What we know so far:

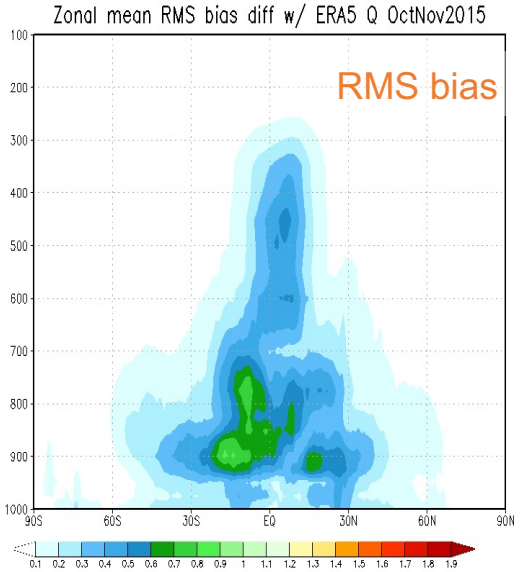
- The Brewer-Dobson Circulation (BDC) has been getting stronger in more recent model versions (e.g., stratospheric age-of-air (AOA), chemical constituents (CH4, N2O)).
- A faster BDC appears to be related to changes in wave convergence in the lower stratosphere associated with changes in (zonal wind) critical lines.
- Replay can do a good job of reproducing DAS lower stratospheric transport characteristics. But the fidelity of transport in replay simulations ultimately rests on the fidelity of the DAS.

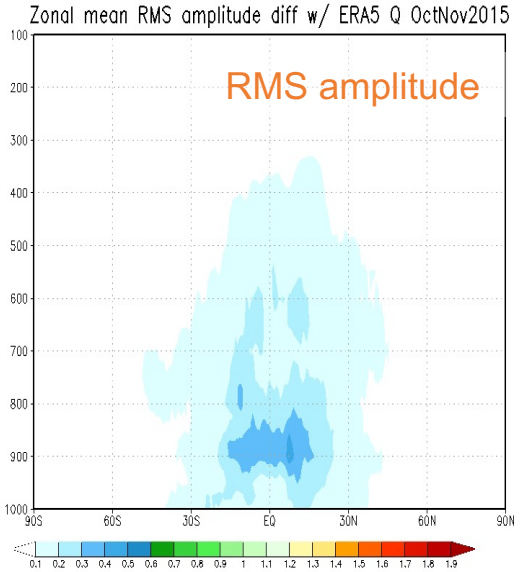
Clara Orbe, Larry Takacs, Kris Wargan, Andrea Molod and Amal El Akkraoui

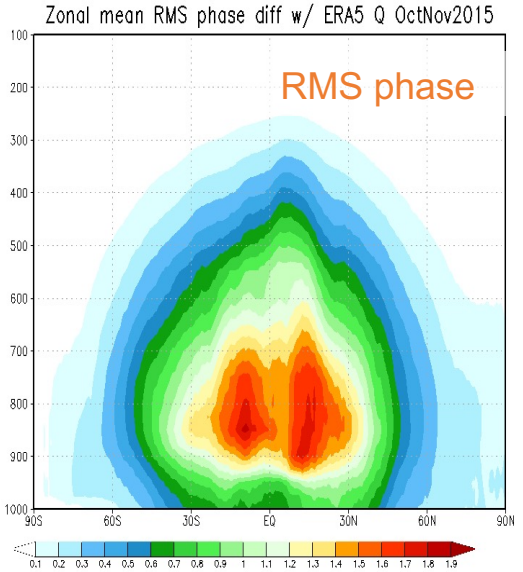
RMS Difference with ERA5 – Specific Humidity

MERRA-2









$$\mathrm{MSE}_{\mathrm{TOT}} = \mathrm{MSE}_{\mathrm{BIAS}} + \mathrm{MSEAMPL} + \mathrm{MSEPHAZ}$$

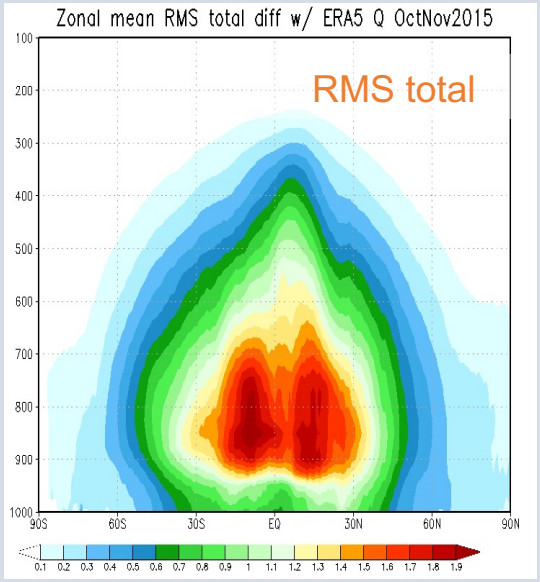
$$\mathrm{MSE}_{\mathrm{BIAS}} = (\bar{X} - \bar{Y})^2$$

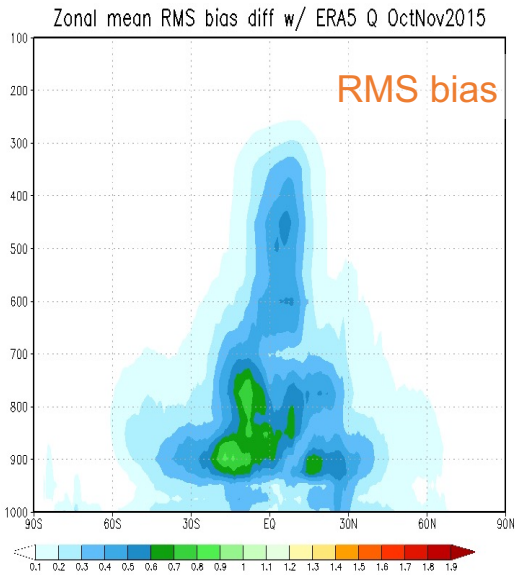
$$\mathrm{MSE}_{\mathrm{AMPL}} = \left(\sigma(X) - \sigma(Y)\right)^2$$

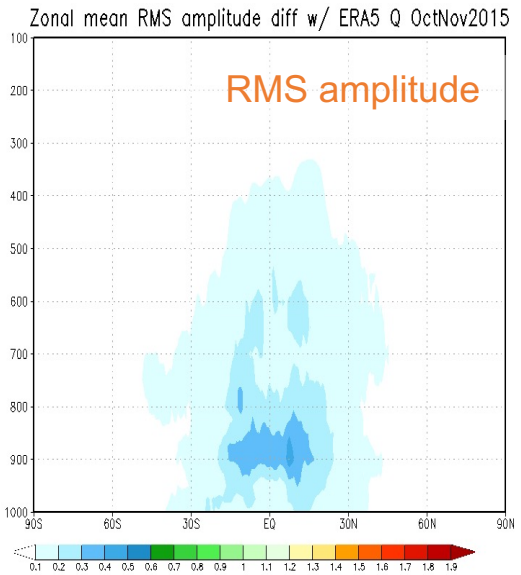
$$\mathrm{MSE}_{\mathrm{PHAZ}} = 2\,(1-\rho)\,\sigma(X)\sigma(Y)$$

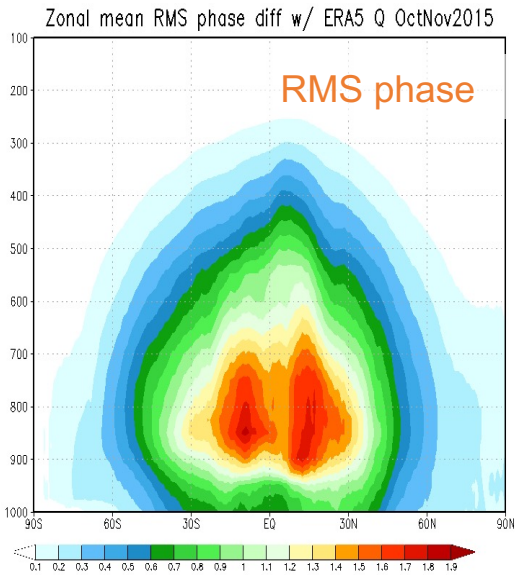
RMS Difference with ERA5 – Specific Humidity

MERRA-2

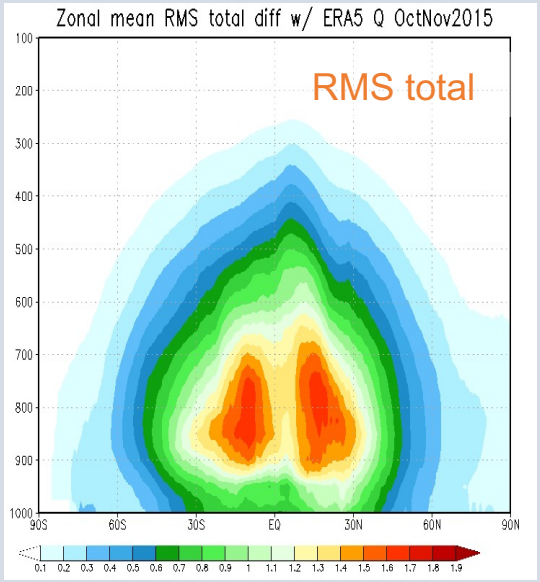


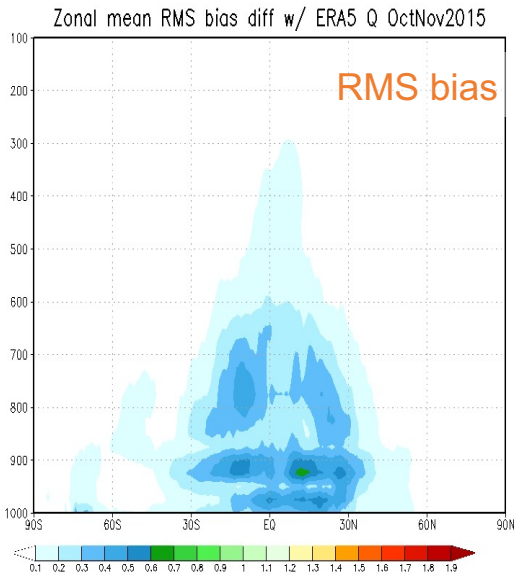


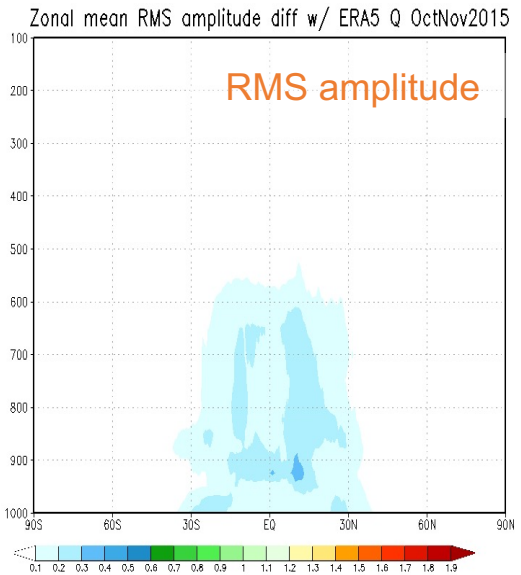


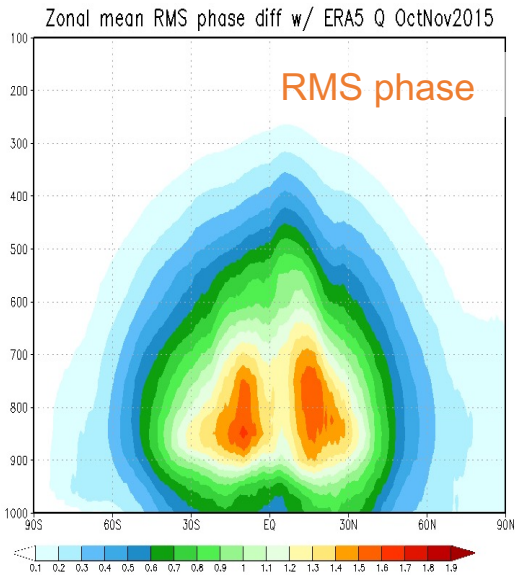


Prototype-R21C









Summary

- GMAO continues its incremental progress towards an Integrated Earth System Reanalysis through a combination of systems with increased levels of complexity and coupling.
- A new 25+ year atmospheric retrospective analysis, GEOS-R21C, is planed as a modern baseline for the atmospheric component of the future Coupled Reanalysis MERRA-3.
- With two proposed off-line derivative products for the chemistry and the cryosphere, GEOS-R21C will be an opportunity to further understand the interactions between the atmosphere and other Earth System components.

- Preliminary test results with a prototype-R21C are encouraging. Production expected to start in winter 2022.
- On-going work: reformulation of dry-mass constraint, further assessment of model transport mechanisms, use of IMERG product for the observation-corrected model precipitations, updated aerosol module.