

Progress Toward GEOS-MLT

Ricardo Todling

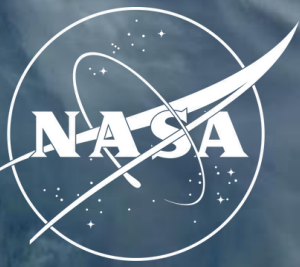
NASA/Global Modeling and Assimilation Office

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Boulder, September 10-11

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OUTLINE



- Motivation

- Status & Plans
 - GEOS-MLT GCM

 - Observing Systems

 - DA Strategy

- Preliminary Results

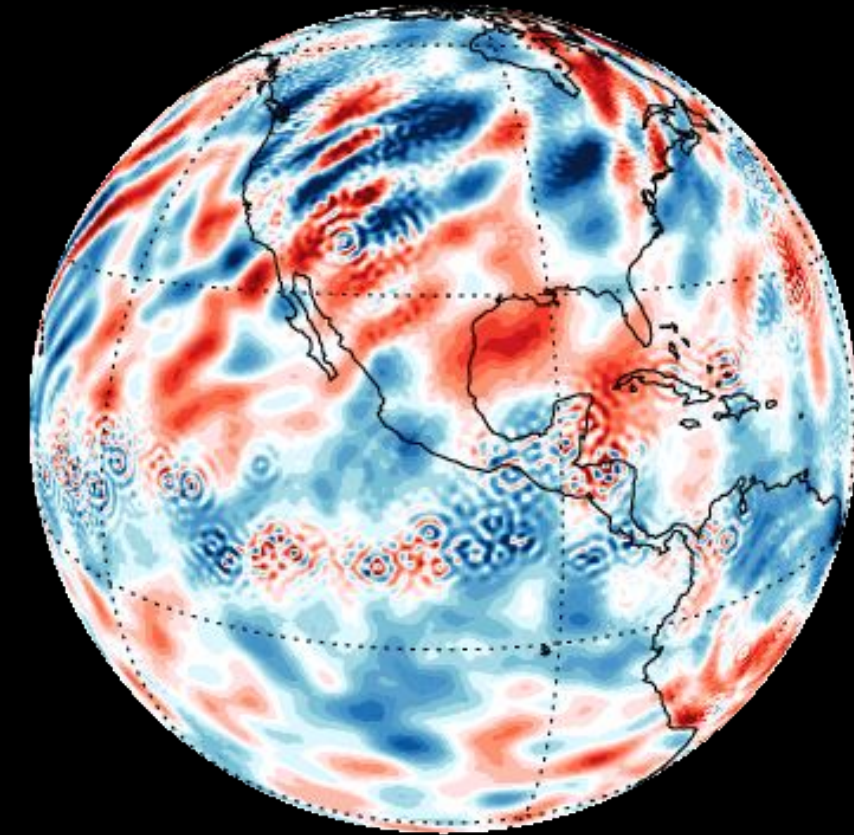
- Closing Remarks

Motivation

GEOS-MLT is a NASA internally funded project with the goals to:

- ❑ Develop an atmospheric system valid up to about 150 (200) km.
- ❑ Produce **retrospective analysis** from the ground to the lower thermosphere.

GEOS-MLT aim is also maintaining the reliability and quality of the current GEOS in the existing troposphere and stratosphere.



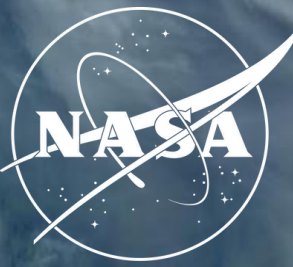
This diagram shows large wave perturbations in atmospheric vertical wind at ~60 km altitude in GEOS-FP product. These waves are associated with hurricane Patricia in 2015, revealing the interaction of with lower atmospheric weather with the upper stratosphere.

G. Liu et al 2024: [Journal of Geophysical Research, 130, e2024JA033528](#)

The success of the project will strengthen both Heliophysics and Earth Sciences domains, adding much needed capabilities to both:

- ❑ Long-term reanalysis that **inform AI** models
- ❑ Planning, design & launch of Earth **observing platforms**
- ❑ **Monitoring** of spacecraft orbits

Status & Plans: GEOS-MLT GCM



0.5-degree resolution model with a lid at 150 km: Target is 0.25-degree resolution with a lid at 200 km.

Lindzen scheme is wrong in the thermosphere: Using the “WACCMX kludge”.

Molecular viscosity: Explicit (horizontal) / implicit (vertical) implementation in FV3. Leans on MSIS for composition.

Thermal conduction: Leverages relationship between viscosity and conductivity via the Prandtl number.

Radiative transfer: Up to about 70 km RRTMG remains; above, blended with short-, long-wave & Joule heating parameterized via an ML formulation trained on WACCMX output.

FY25

FY26

FY27

Extend GEOS to 150 km
Parameterize MLT physics
Generate realistic backgrounds

Complete DA
Nature simulations
Initial documentation model capabilities

Retrospective simulations
Final documentation model capabilities

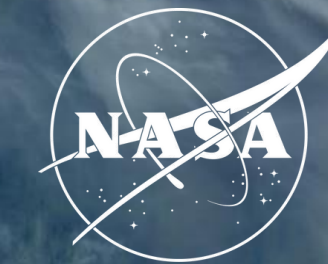
● Completed

● Ongoing

● Planned

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Status & Plans: Observing Systems under Consideration



Basic Target

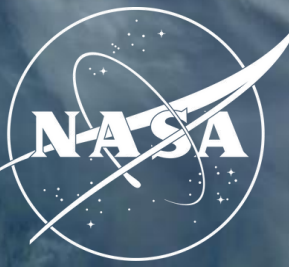
Collab with
CU-SWORD

Nice-to-have

Future

Observation System	Field	Altitude Range	Vertical Resolution	Cadence	Time Interval
SABER	Temp	40-120 km	2 km	Twice daily	2002-present
AIM SOFIE	Temp	10-100 km	1.2 km	Sunset/Sunrise, 65°-85° S/N	2008-2023
DMSP/SSMIS	Temp	20-80 km	--	Twice daily	Varies
Meteor radar	Wind	80-100 km	2 km	hourly	>20 y
TIDI	Wind	90-110 km	2.5 km	Twice daily	2002-present
SuperDARN	Wind	95 km	--	hourly	>20 y
AWE	Temp	~90 km	--	⁵ Once daily (n)	>2024
ICON	Wind	90-110 km	3 km	Twice daily (d/n)	2019-2022
	Wind	110-180 km	3 km	Once daily (d)	
	Wind	200-300 km	10 km	Twice daily (d/n)	
	Temp	90-105 km	3 km	Twice daily (d/n)	
GOLD	Temp	~150 km	--	Hourly	2018-present

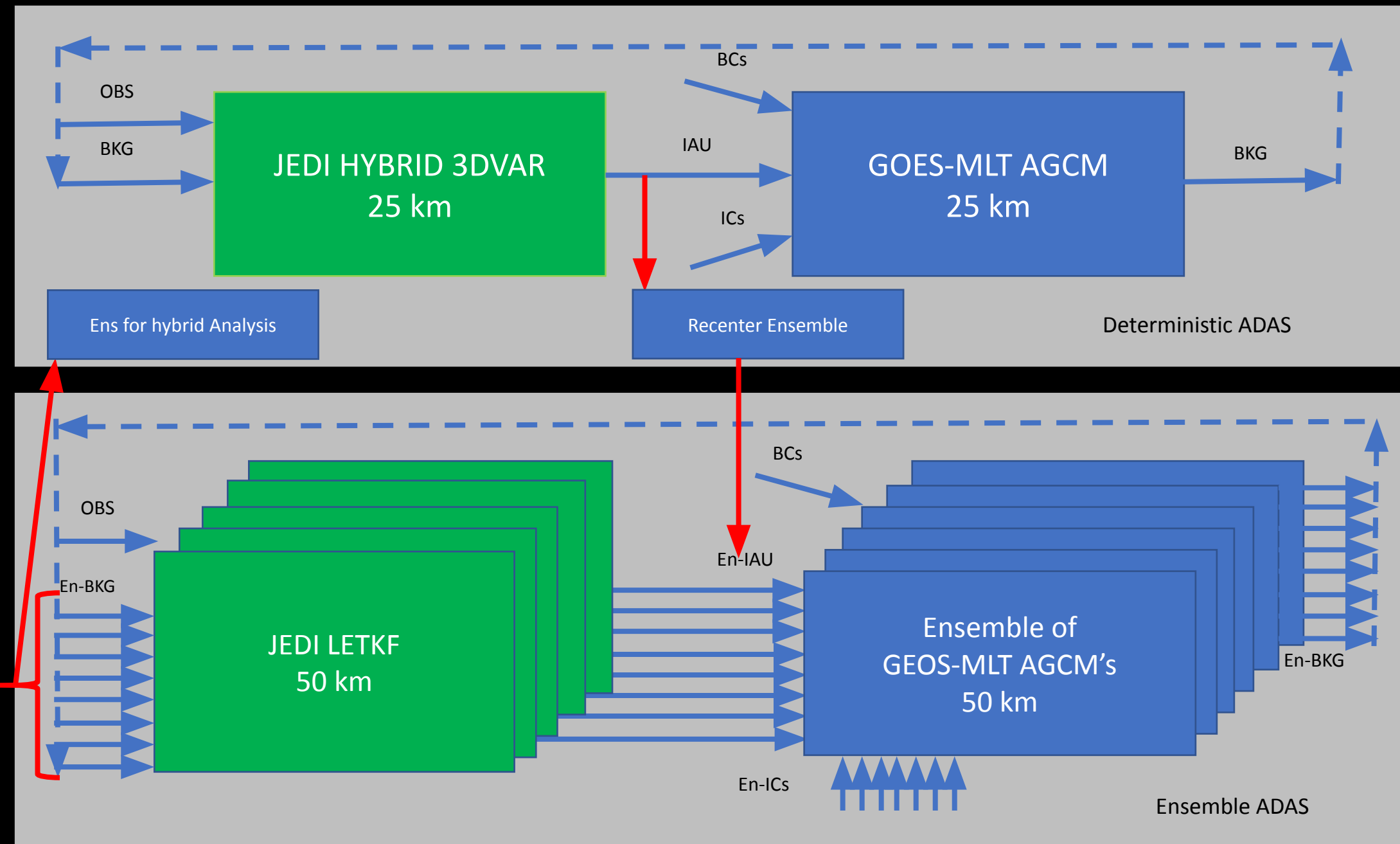
Status & Plans: Data Assimilation Strategy



The GEOS-MLT DA strategy is envisioned to be similar to how MERRA-21C is configured, with the following main differences:

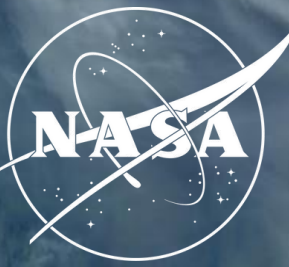
- ❑ A lid placed at around 200 km (M21 at 80 km).
- ❑ 190 vertical levels (M21C uses 72 levls).
- ❑ Fully JEDI-based in both its Deterministic & Ensemble components (M21 is fully GSI-based).
- ❑ 100% reliance on the ensemble above 1 hPa in the background error formulation (M21C is fully climatological above 1 hPa).
- ❑ The challenge with the above will be to keep the stratospheric behavior close to that of M21C.

Schematic of Envisioned GEOS-MLT DA System



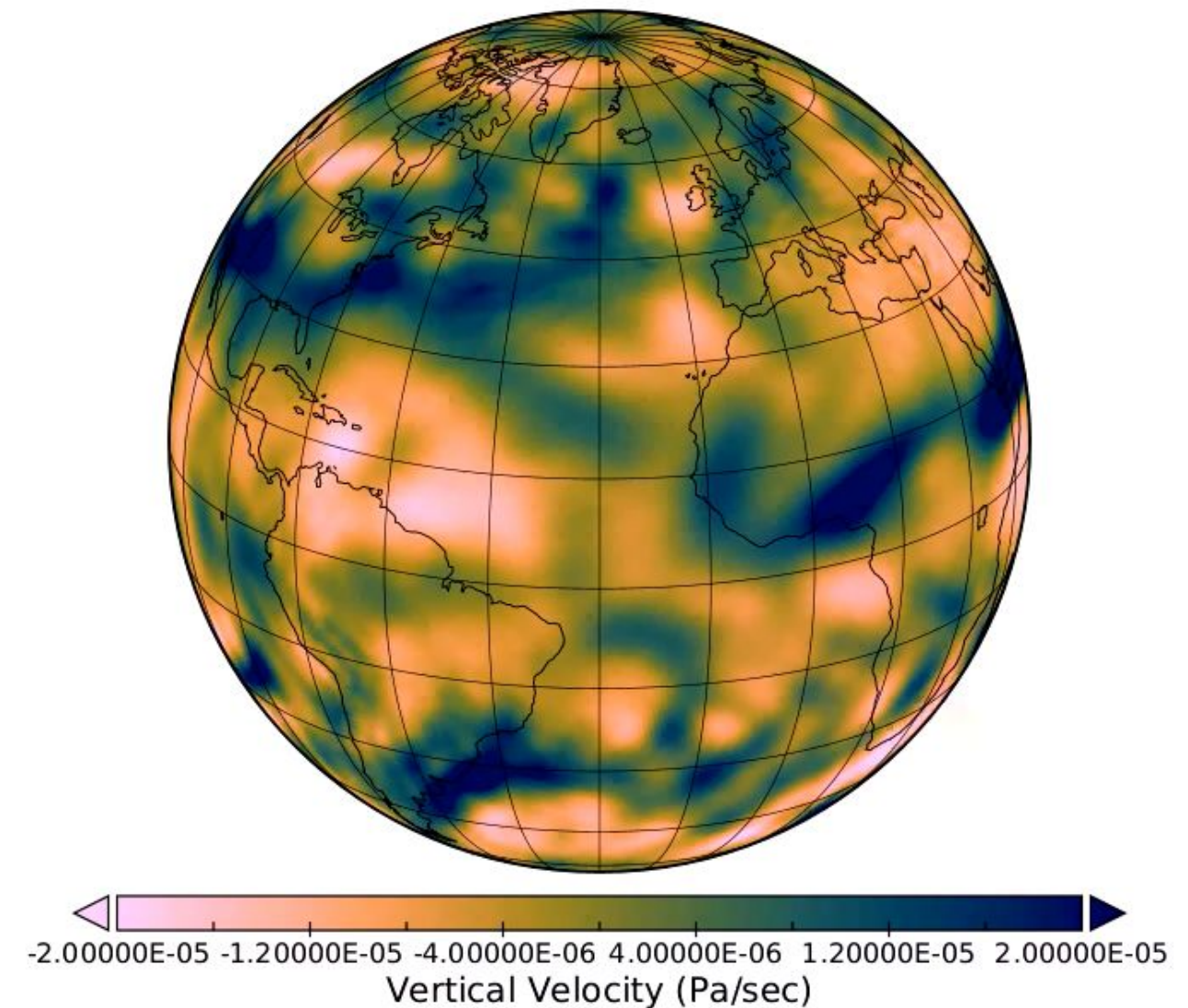
Preliminary Results

GEOS-MLT: Current adjustment to GEOS GCM



Enabling GEOS-MLT has so far amounted to making the following changes to GEOS:

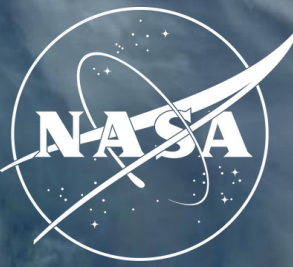
- ❑ Starting point: ~80 km GEOS 181 levels (current GEOS-FP uses still 72 levels only)
- ❑ Lifting the lid from ~80 km to ~150 km.
- ❑ Increasing the number of levels from 181 to 186.
- ❑ Removing GWD above original ~ 80 km limit.
- ❑ Adding molecular diffusion in FV3 dynamical core.



The inserted movie provides an illustration of the evaluation of vertical velocity around 110 km in the vertical. We see the propagation of gravity waves: one of the important features we aim at predicting.

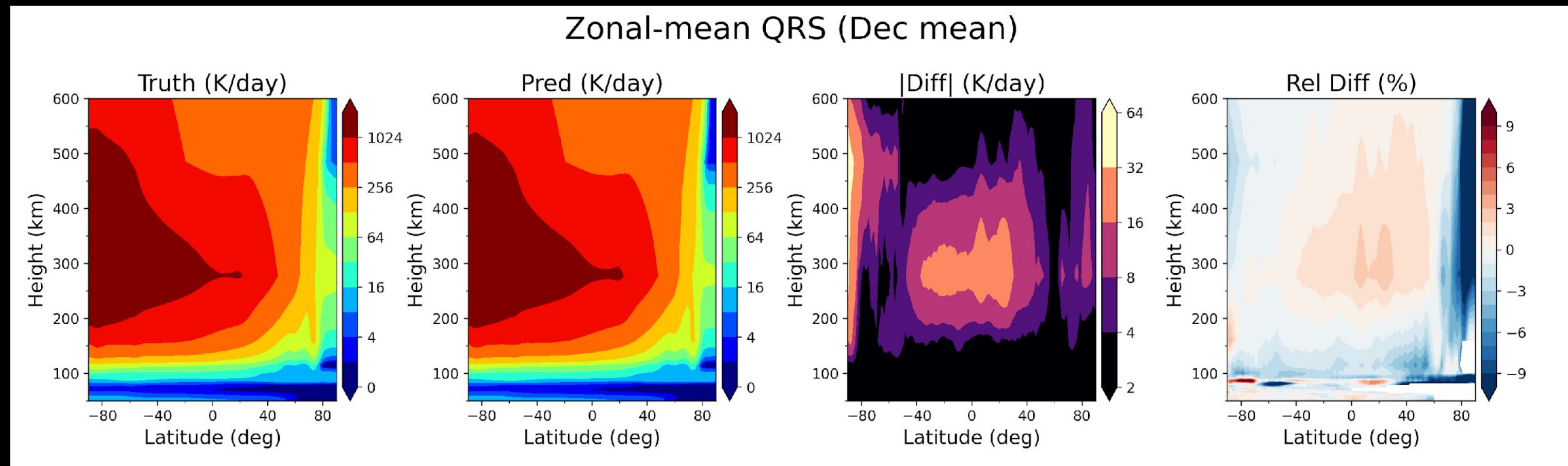
J. Pettit

GEOS-MLT: Current adjustment to GEOS GCM



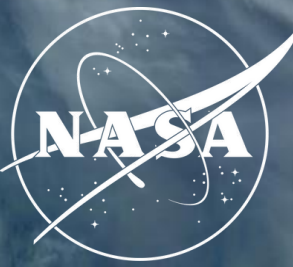
The ongoing adjustment and ML-based parameterization of the heating rate:

- ❑ Built ML model (UNet3D) to predict shortwave/longwave radiative heating (QRS/QRL) and Joule heating (QJOULE) on the GEOS grid using WACCM-X output.
- ❑ Data: 365-day (2000-01-01 to 2000-12-31) Training: 80%, Validation: 20%.
- ❑ **Input to ML:** DOY, F10.7, F10.7a, kp, UT, lev, lat, lon, Temperature (lev, lat, lon).
- ❑ **Output:** shortwave / longwave heating on GEOS grid.



A. Lee

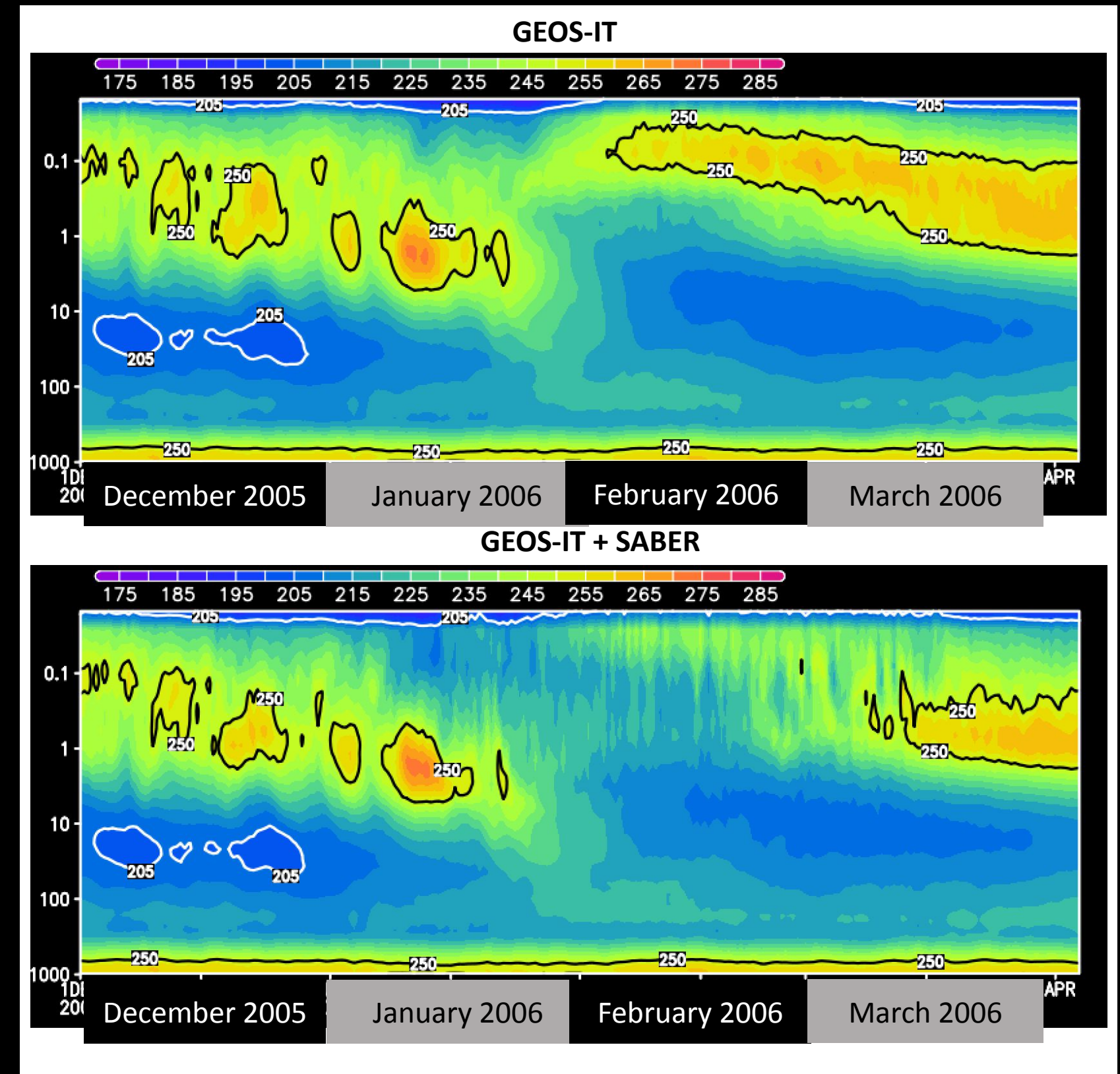
Early Demonstration: Correcting GEOS Upper Atmosphere with SABER Temperatures



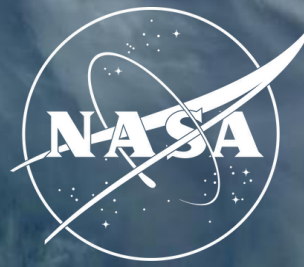
The assimilation of **MLS-Temperature** retrievals in MERRA-2 have been shown to provide an improved representation of events such as **sudden stratospheric warming (SSW)**; see Gelaro et al. 2017). It is expected that assimilation of **SABER Temperatures** would provide a similarly improved representation of such event over not observing the high altitudes in GEOS.

Through the support of NASA's Internal Research and Development program, the GMAO **GEOS-IT system** was used a couple of years ago by some of us to demonstrate the benefits of assimilating SABER. GEOS-IT provides support for NASA's Instrument Teams, and removes from our DA suites a number of instruments associated with the IT's; MLS is one of the instruments not assimilated in GEOS-IT, making it a good testbed for SABER.

The figure shows **zonally averaged temperature at 70° N**. The top panel is from GEOS-IT, which does not capture the SSW soon enough; the bottom is when SABER is assimilated, capturing the SSW just as when MLS is assimilated in MERRA-2.

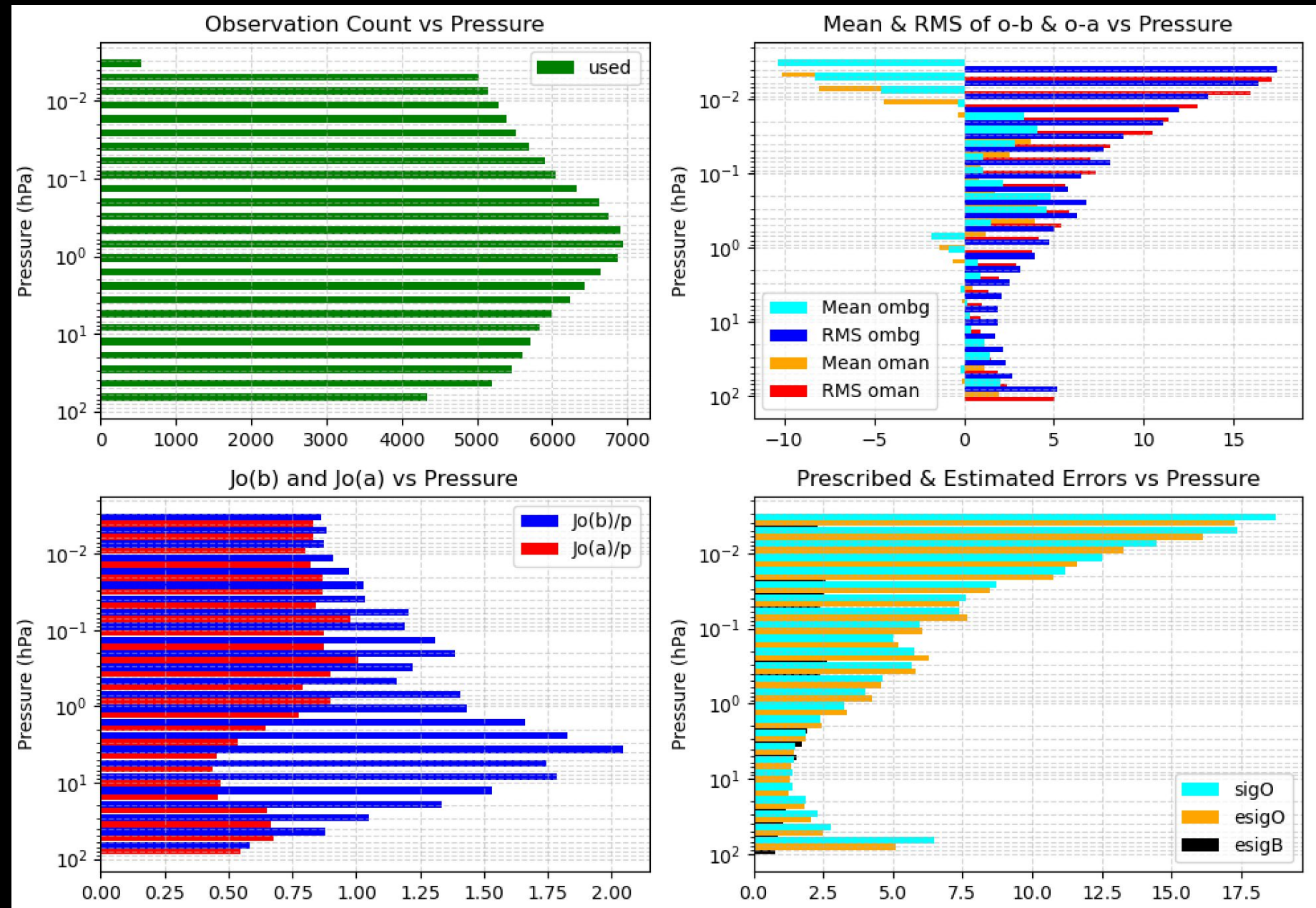


Enabling GEOS-MLT Data Assimilation: Bringing SABER to JEDI

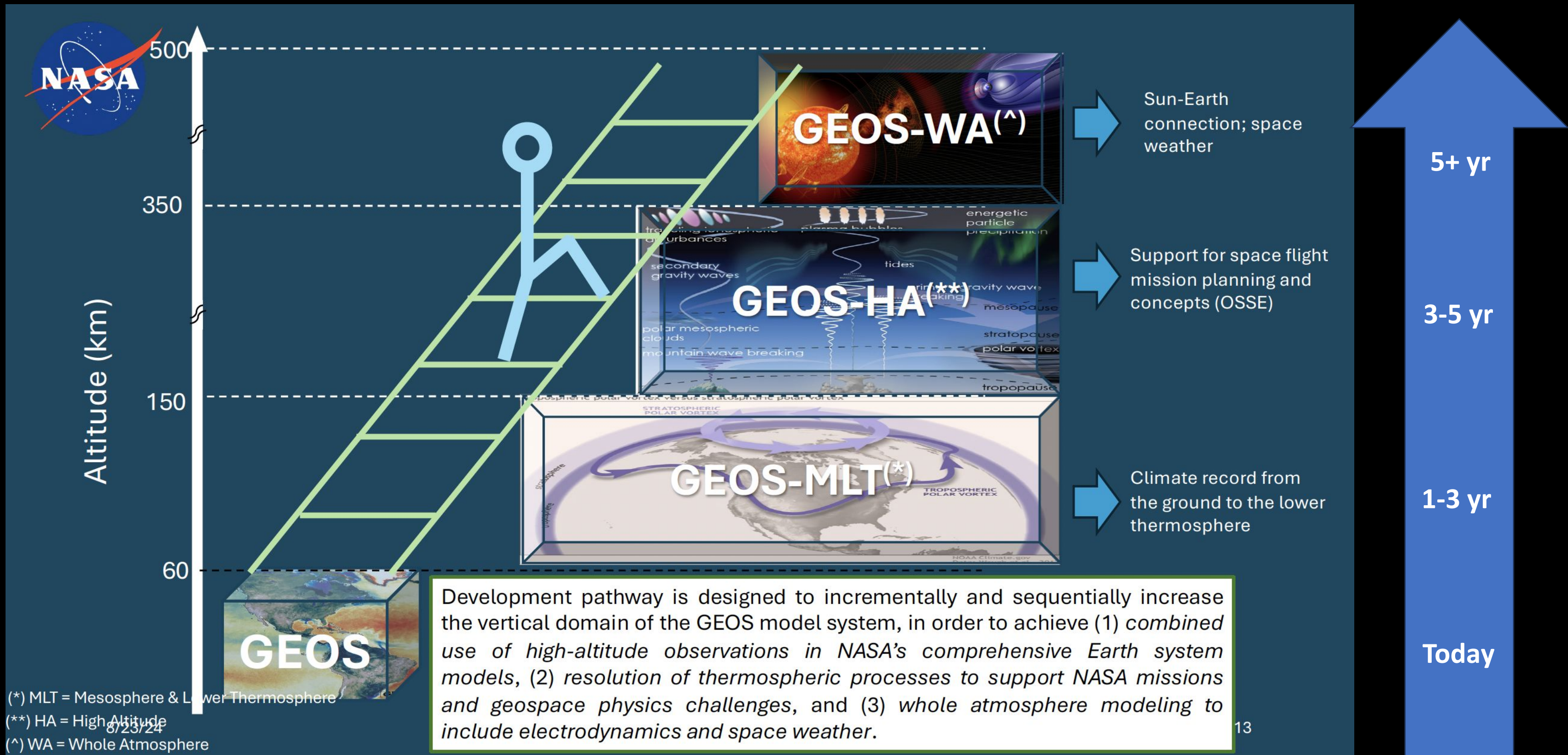
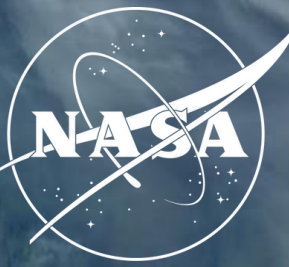


Beyond GSI and above 80 km: SABER for GEOS-MLT.

- ❑ A SABER IODA converter is now available in JEDI.
- ❑ Some very preliminary test has now been carried out combining SABER with the GEOS-MLT model, extended to roughly 150 km.
- ❑ The initial test is a proof-of-concept exercise using a simple 3DVAR JEDI application with an extrapolated version of the Background Error Covariance (BEC) typically used in the 80 km GEOS applications, such as GEOS-IT.
- ❑ A 1 K error is originally assigned to the temperature data when converting SABER to IODA.
- ❑ **Fig:** The Desroziers method is employed to tune the errors more meaningfully.

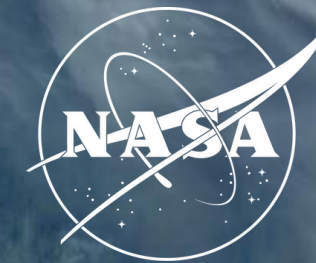


Extending GEOS: Long-Term Plans



(*) MLT = Mesosphere & Lower Thermosphere
 (**) HA = High Altitude
 (^) WA = Whole Atmosphere

Closing Remarks



- ❑ The last few months have seen considerable progress building a dynamically stable extension of GEOS with a lid set at 150 km (now being extended up to 200 km).
- ❑ We have also seen progress building an ML infrastructure to provide adequate mechanism to specifying the needed heating rates about ~80 km is nearly ready for integration in GEOS.
- ❑ A converter to SABER Temperature observations can now generate IODA for JEDI.
- ❑ Preliminary use of SATER-T in a mock 3DVAR shows meaningful results.
- ❑ Work is being done to create a IODA converter for Meteor Radar Winds (join with N. Peterson, D. Janches & T. Berger; also NRL). Similar mock 3DVAR will be conducted shortly.
- ❑ GEOS-JEDI is in final stages of testing. Integration of GEOS-MLT-JEDI will readily follow.