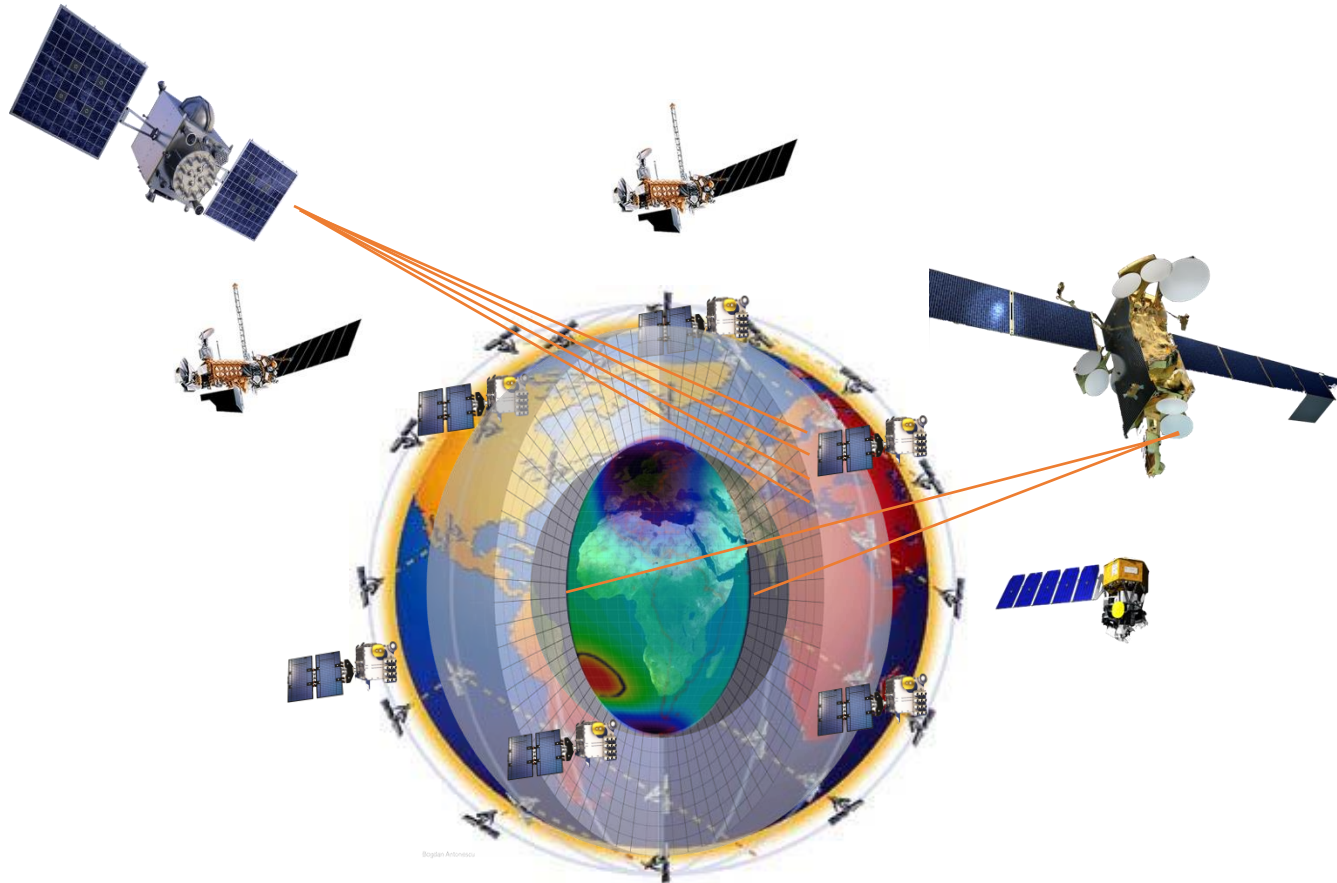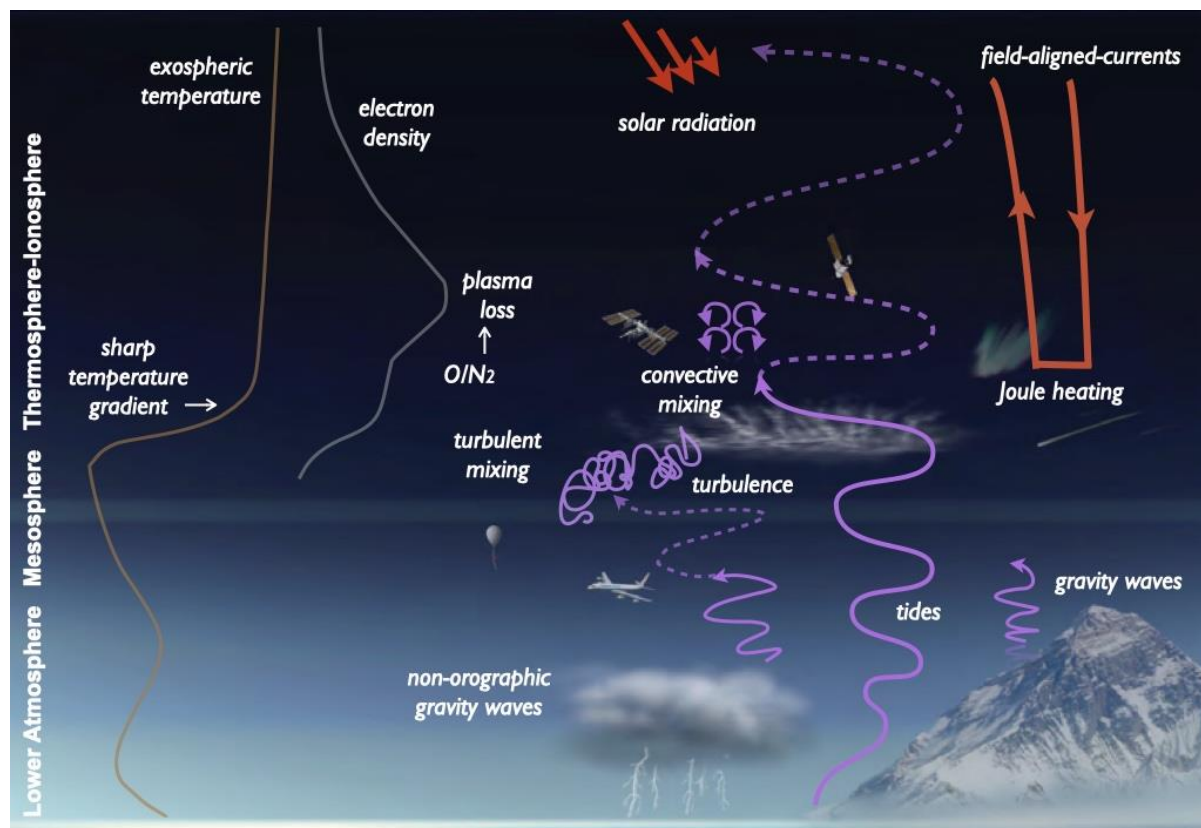# Towards Whole Atmosphere Satellite Data Assimilation

Tomoko Matsuo, Brandon DiLorenzo, Clayton Cantrall (JHUAPL), and Stryder Demarois in collaboration with C.-T. Hsu (NCAR), A. Kubaryk (SWPC/CIRES), T. W. Fang (SWPC), T. Fuller-Rowell (SWPC/CIRES), N. Maruyama (CU), and H. Shao (JCSDA)

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Why Whole Atmosphere DA?

The ionosphere-thermosphere system's **global structure and dynamical evolution** is influenced by vertical coupling of atmospheric layers.
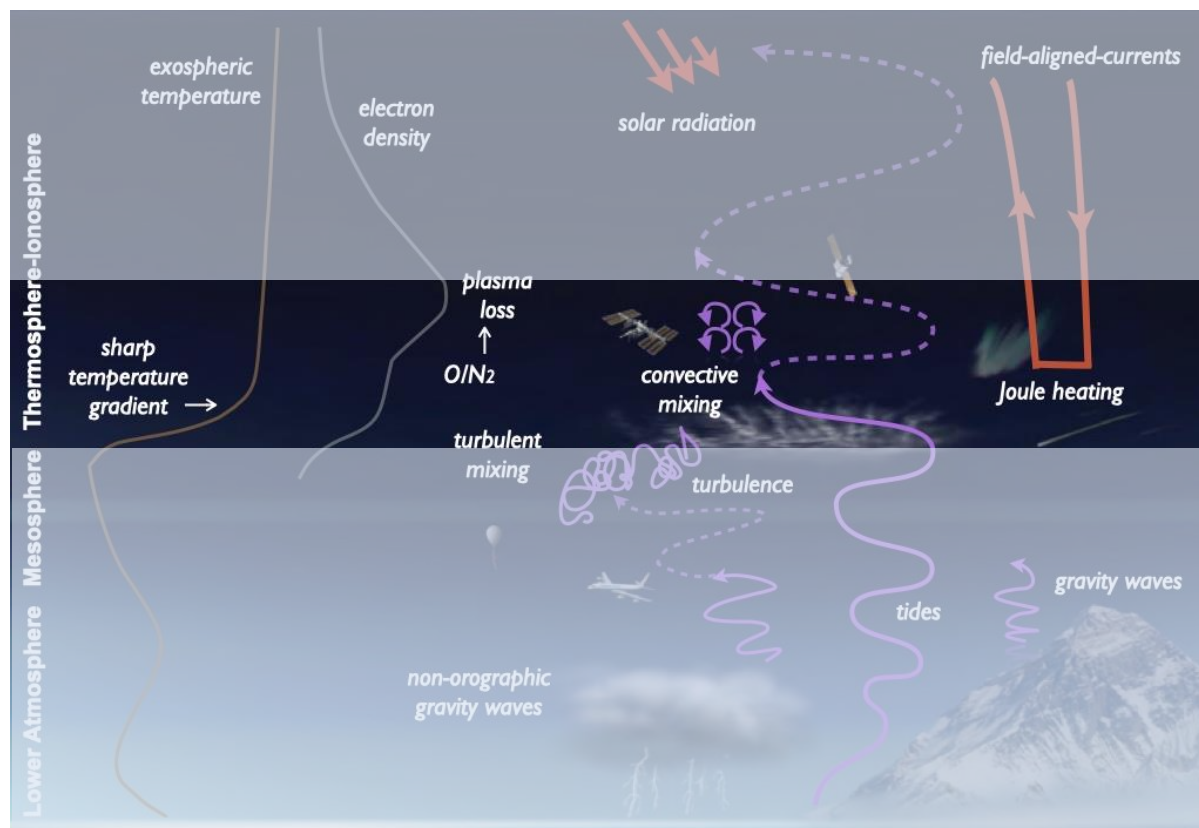

Project Goals

- Leverage the global-scale view of the lower thermosphere provided by the GOLD and ICON missions.

- Capitalize on NOAA NWS whole atmosphere data assimilation and ensemble forecast system (that runs 24/7 since Feb 2022)

- Demonstrate the utility of GOLD disk radiance measurements for potential benefits to SWPC's space weather services

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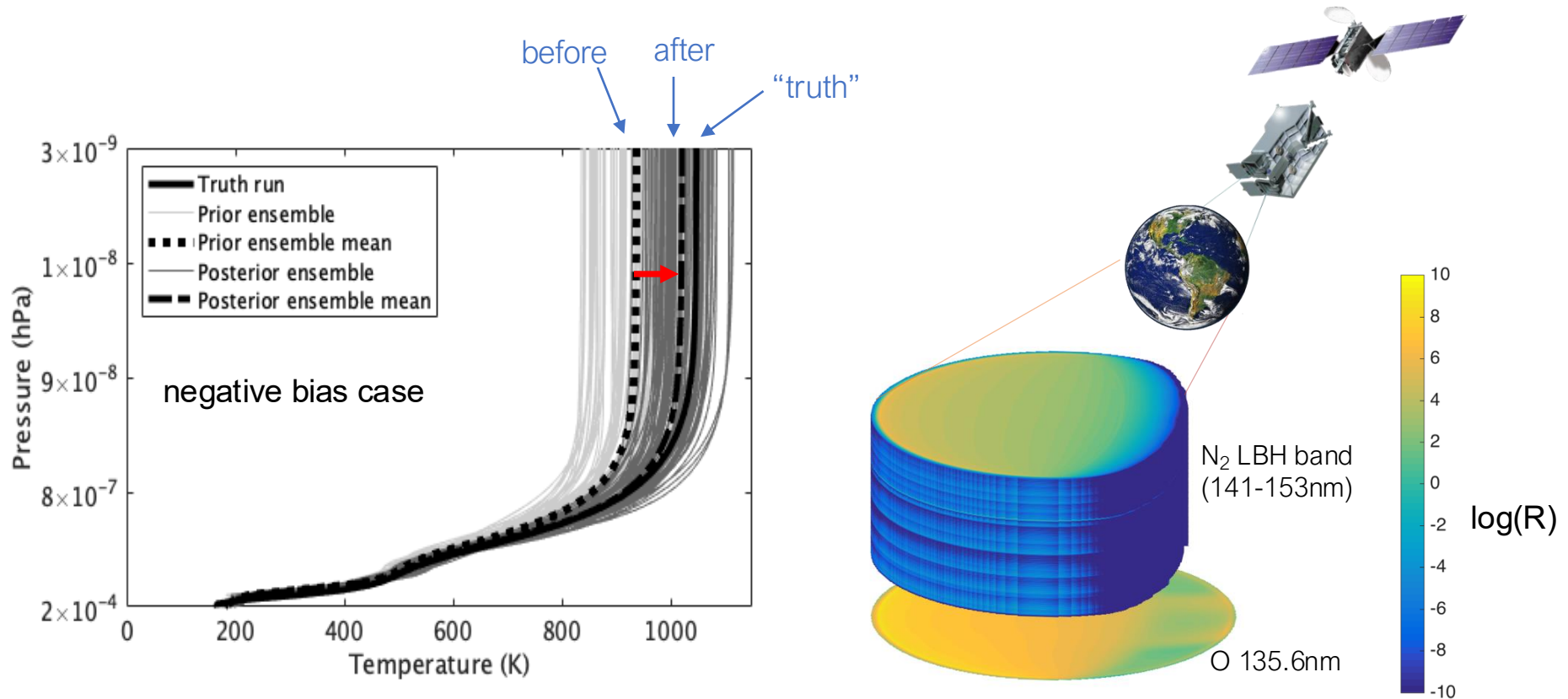

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Demonstrated Impact of GOLD FUV Radiance Assimilation Through OSSEs with NOAA WAM

- *Reduction of model biases and uncertainty due to GOLD data*

before   after   "truth"

Truth run
Prior ensemble
Prior ensemble mean
Posterior ensemble
Posterior ensemble mean

negative bias case

Pressure (hPa)

Temperature (K)

N_2 LBH band (141-153nm)

log(R)

O 135.6nm

OSSE: EnSRF with 100 members

[Cantrall, Matsuo & Solomon, JGR, 2019]

Benefits of Assimilating from GOLD Level 1C Radiance Data

- **Minimize representativeness error** $\quad \mathbf{y} = \mathcal{H}(\mathbf{x}) + \boldsymbol{\epsilon}$

- **Make uncertainty quantification more tractable**
  Absolute radiometrically-calibrated FUV intensities are **not required**

PCA of simulated TOA LBH emissions

FUV "temperature proxy"

$$\sum_{\lambda\,=\,138.58}^{139.2} I_\lambda \,/\, \sum_{\lambda\,=\,138.0}^{138.58} I_\lambda$$
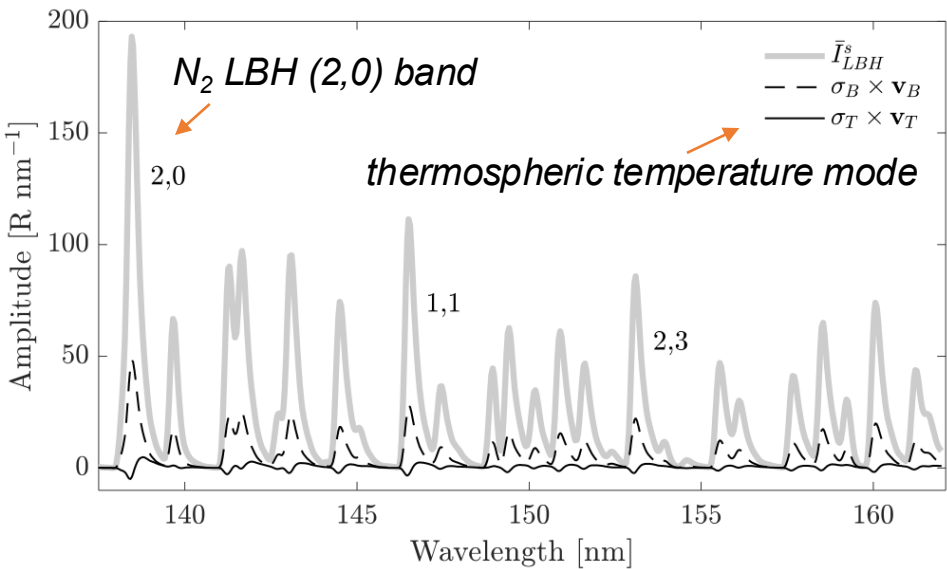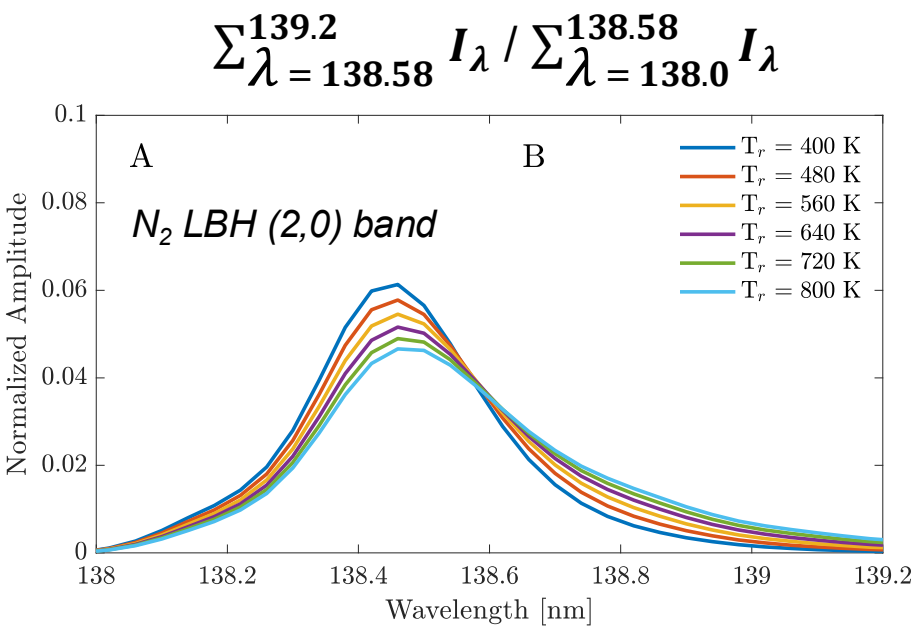
[Cantrall and Matsuo, AMT, 2021]

FUV Temperature Proxy Computation from GOLD Level 1C Data Incorporated into GSI Observer Routines
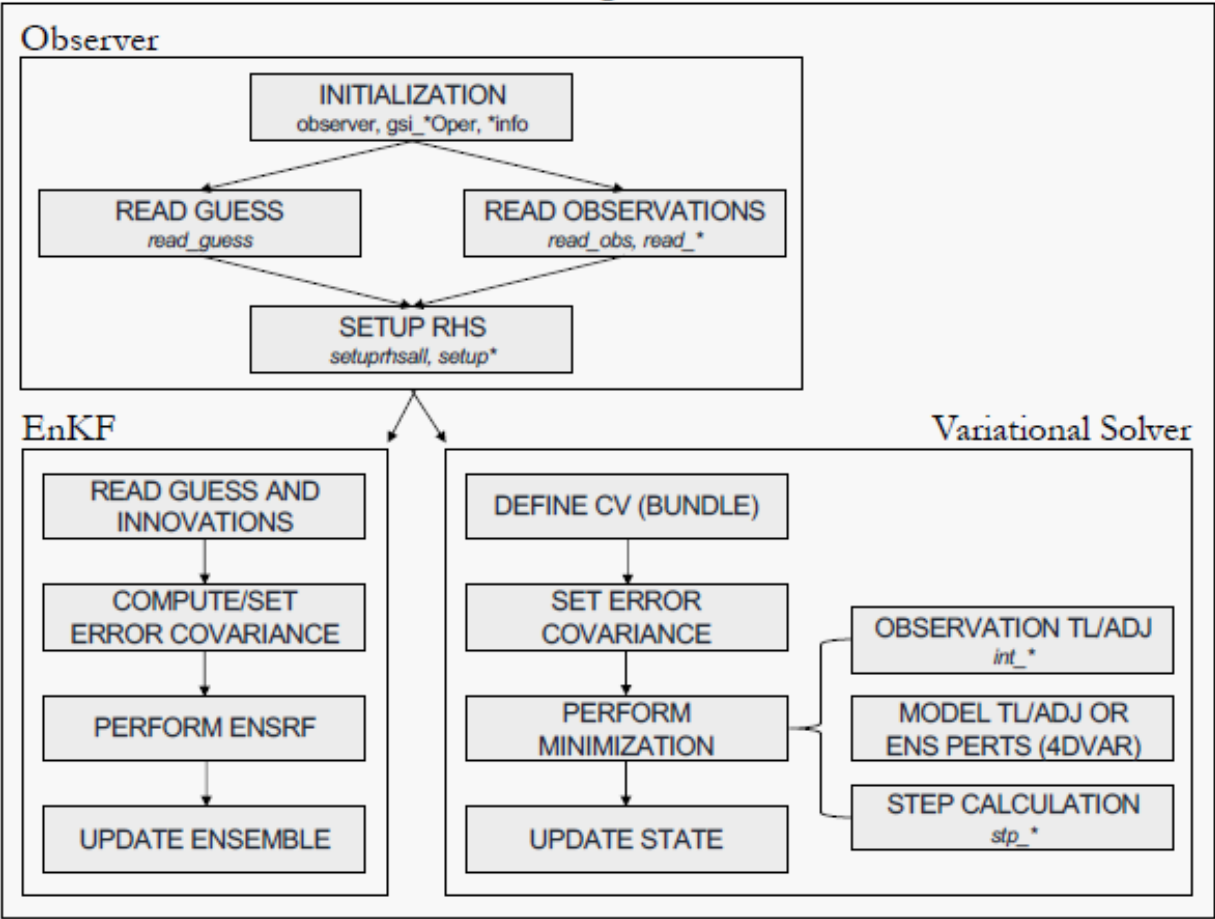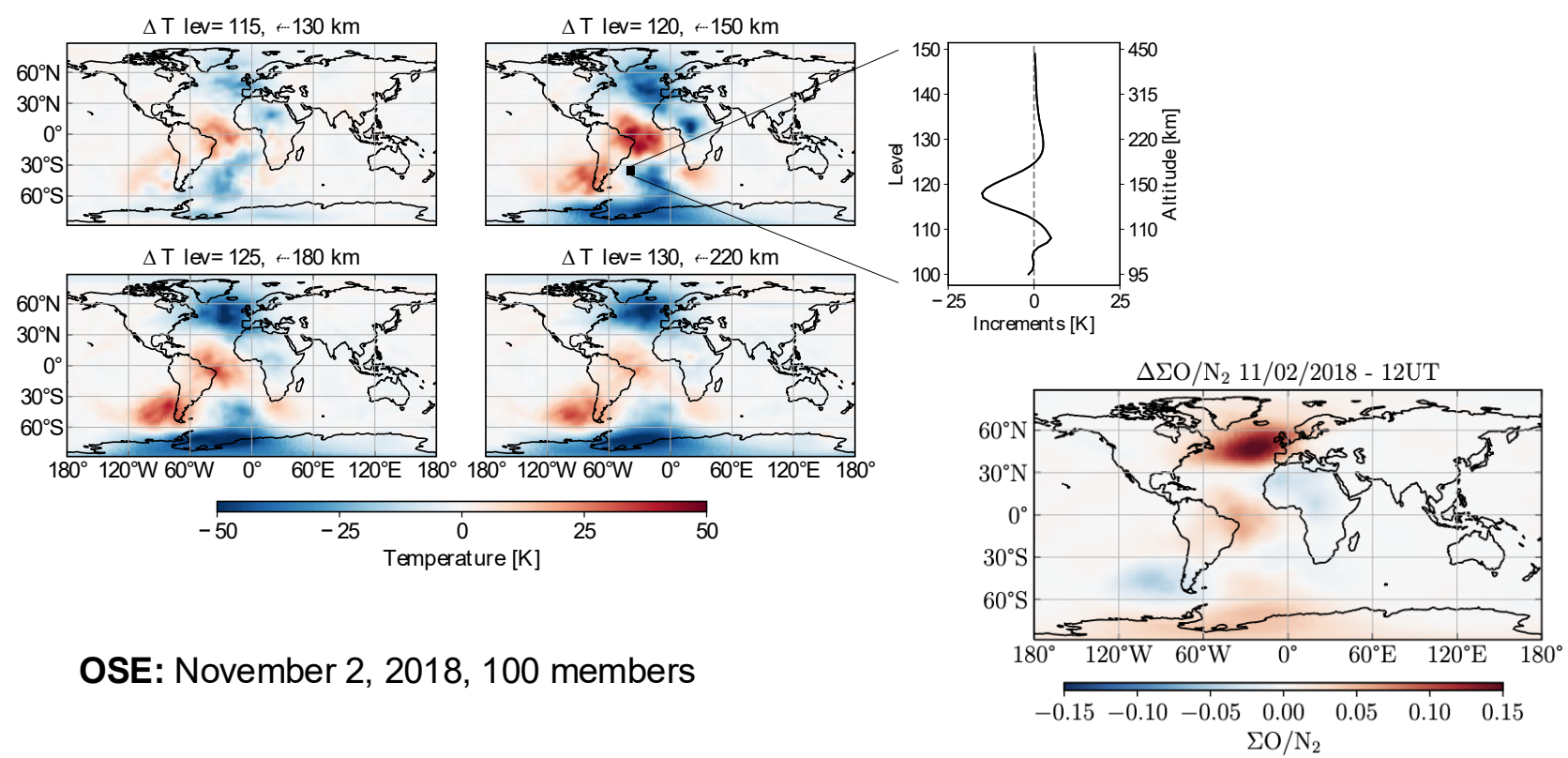

[Cantrall, PhD thesis, 2022]

Assimilation of GOLD FUV L1C Radiance Data into NOAA WAM

- *Changes in temperature & composition due to GOLD radiance data assimilation*
- *Reduction of model uncertainty (ensemble spread) – now shown*

**OSE:** November 2, 2018, 100 members

[Cantrall, PhD thesis, 2022]

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Cycling Experiment with NOAA GSI EnSRF – Nov 2-7, 2018

Ensemble Initialization

- One-month WAM forecast launched on Oct 1 through Nov 2

- 80-member ensemble

- Perturbed drivers: F10.7, Kp, hemispheric power, solar wind flow speed, proton density, and B_z
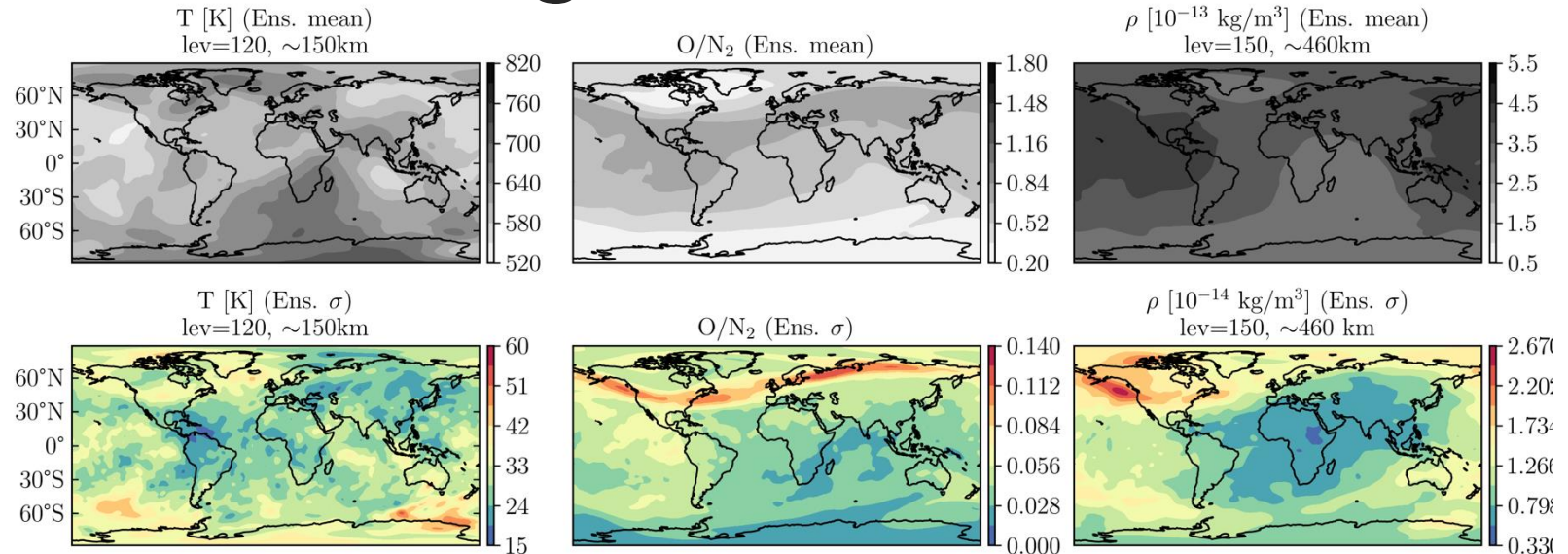
Cycling Experiment Set-up

- Starting 12 UT on Nov 2

- Ending 18 UT on Nov 7

- 6-hour measurement updates

    - GOLD Disk Observations only available at **12UT** and **18UT**

- Updating temperature and major thermosphere species (e.g., O, N_2, O_2)
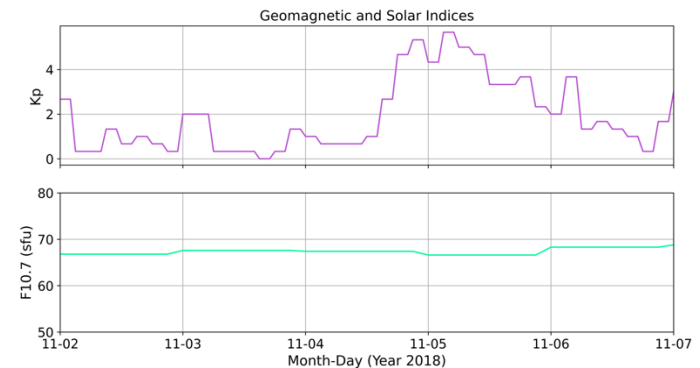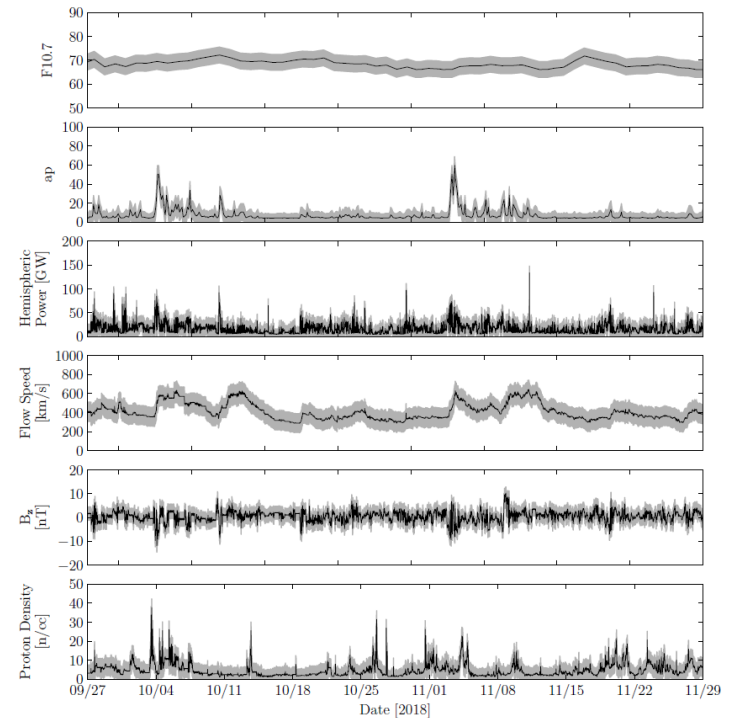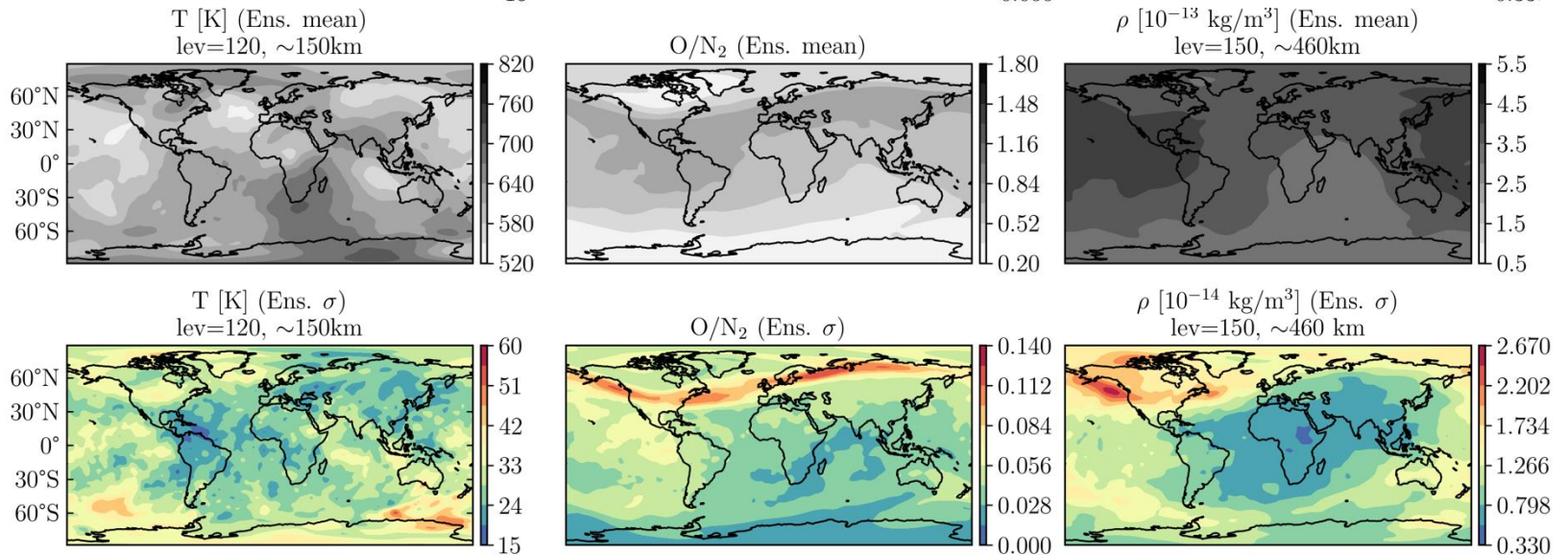
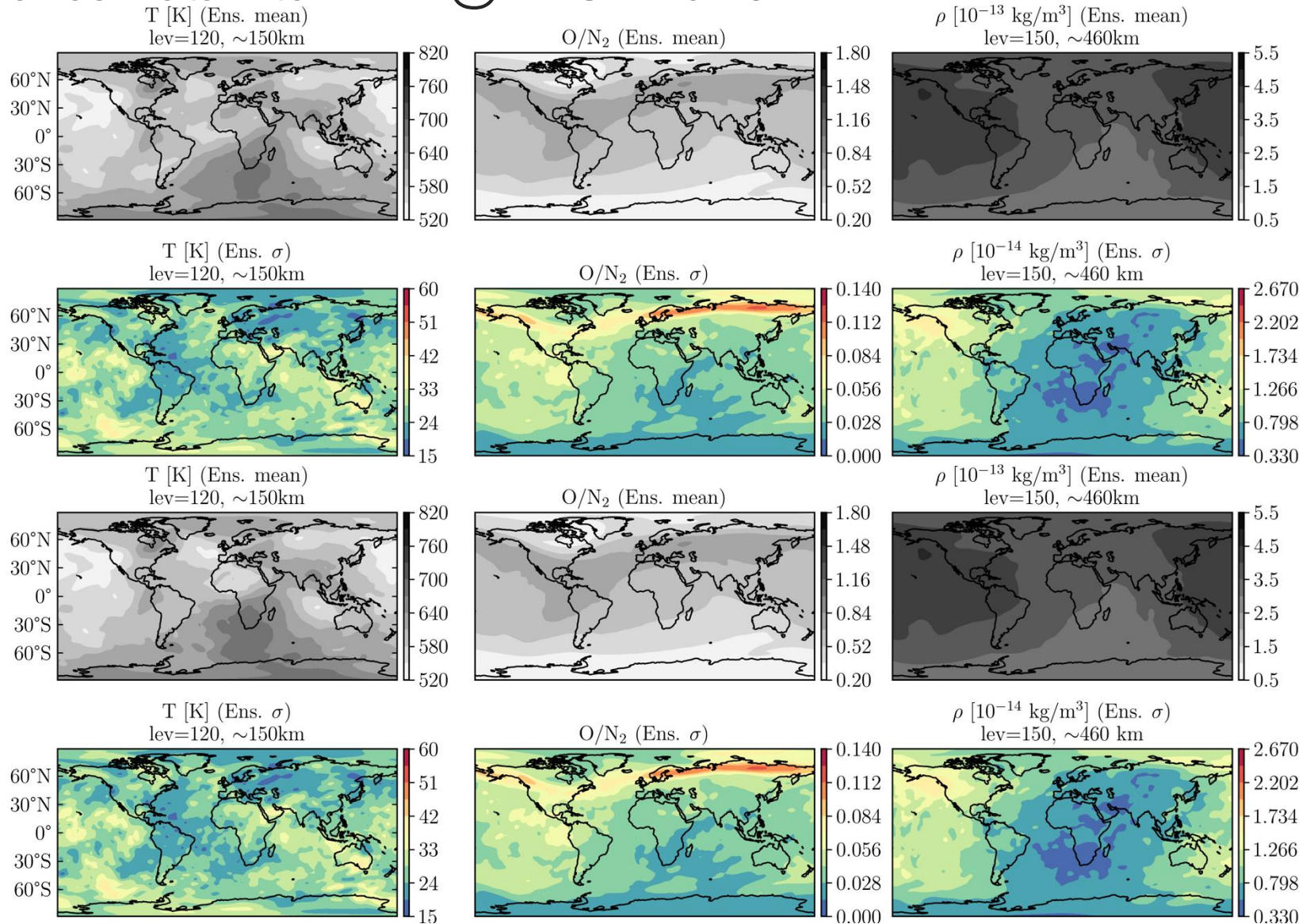# Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 2
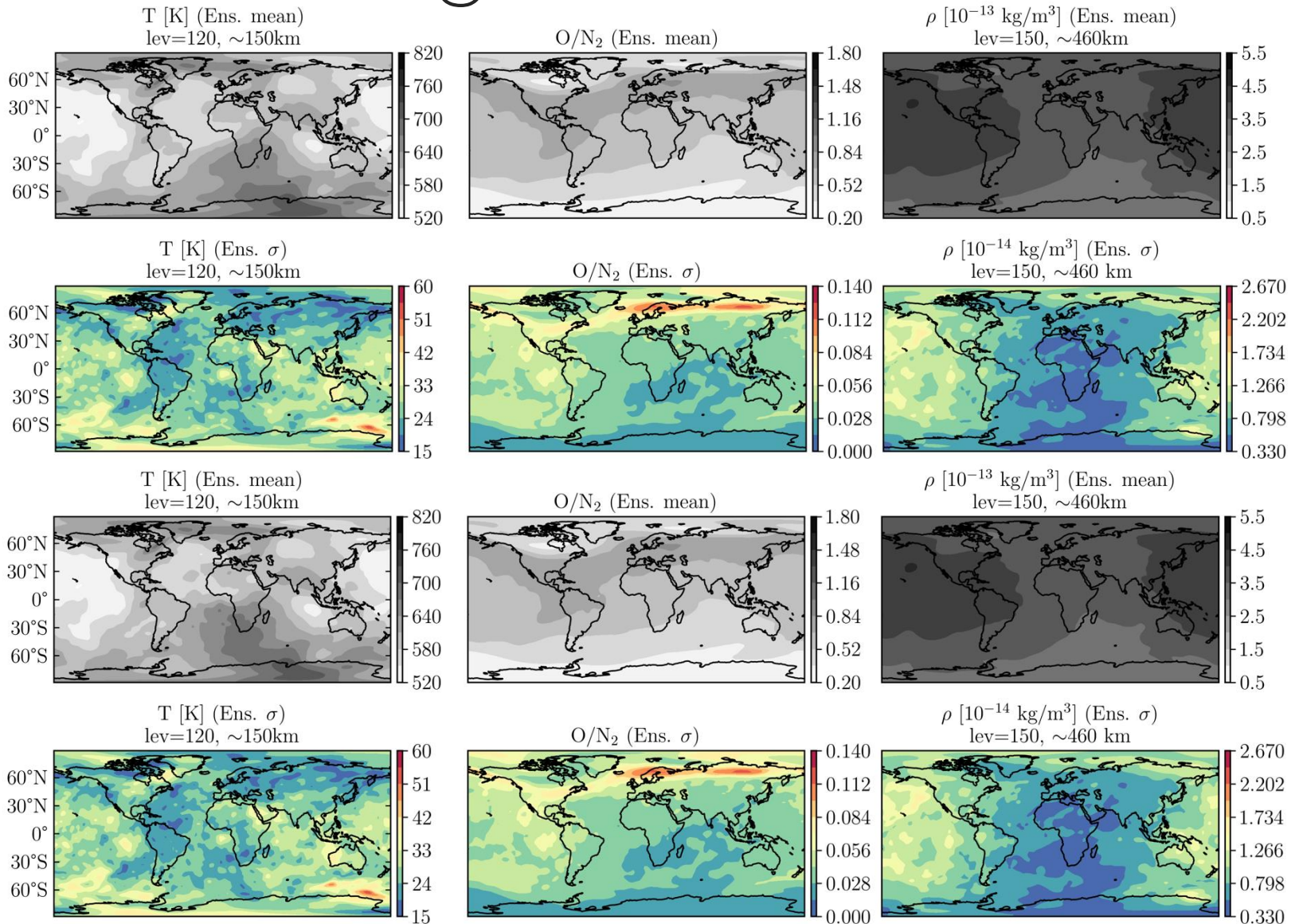

Forecast

DA Analysis

Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 3

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Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 4
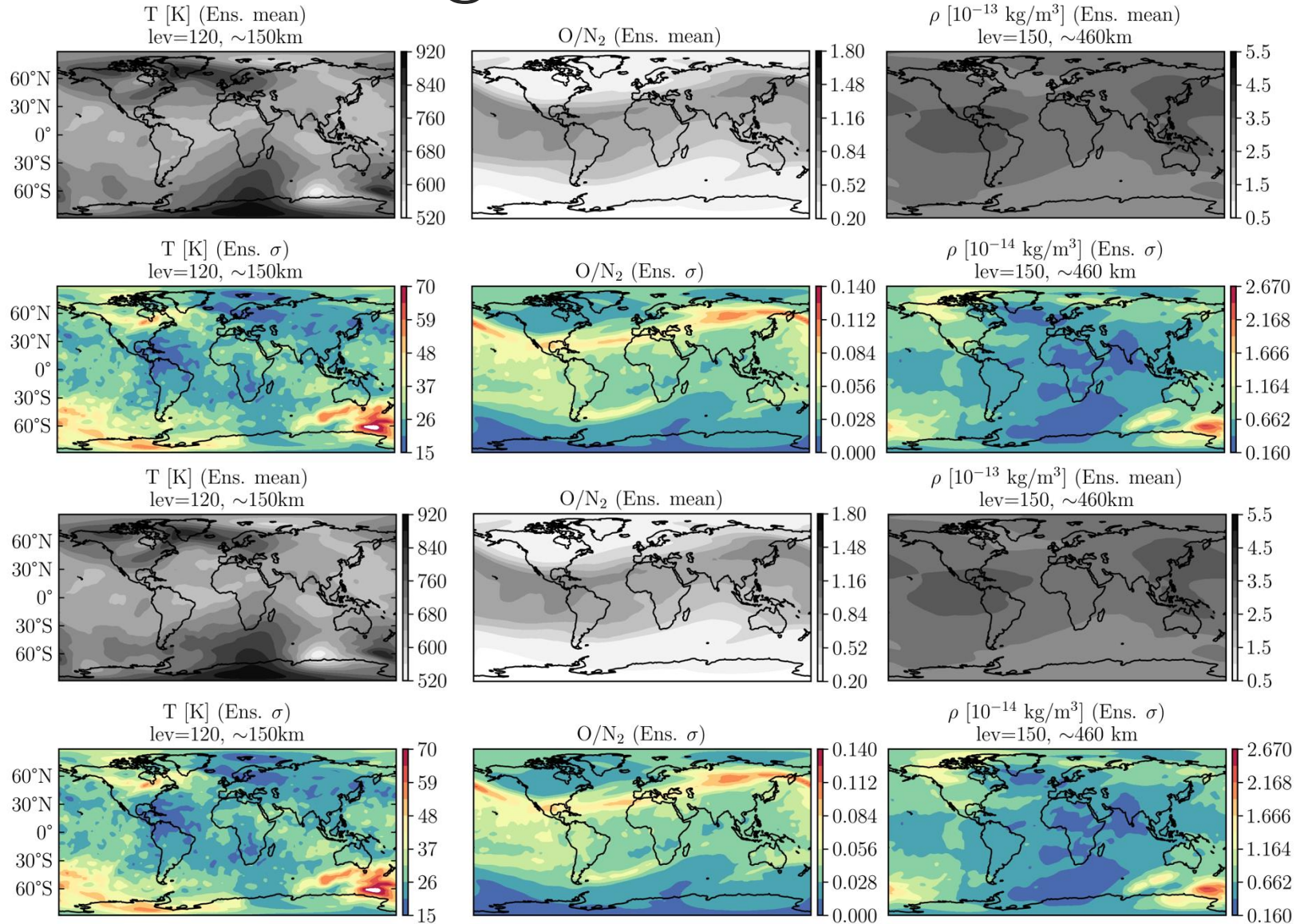

Forecast

DA Analysis

Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 5
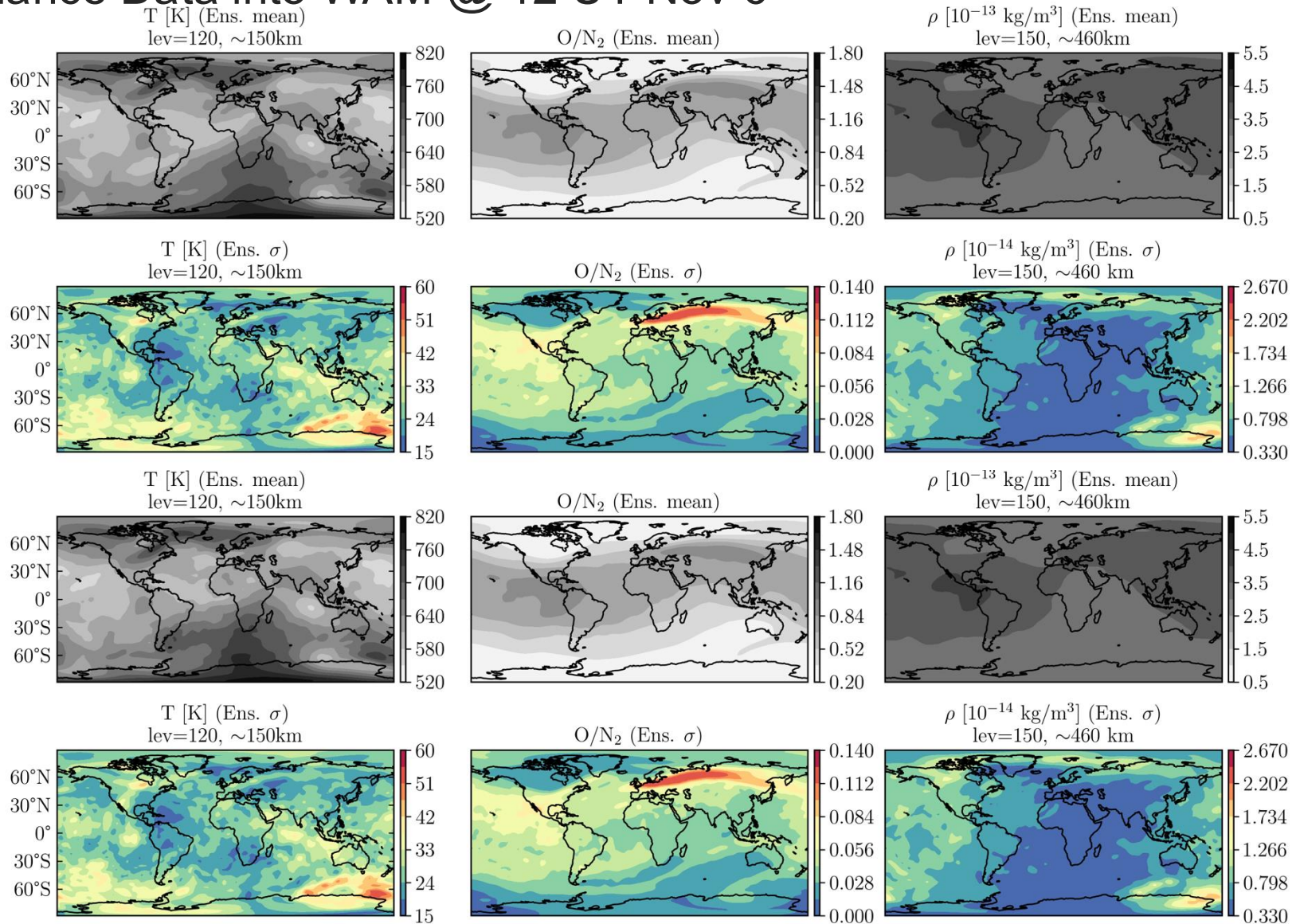
Forecast

DA Analysis

Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 6
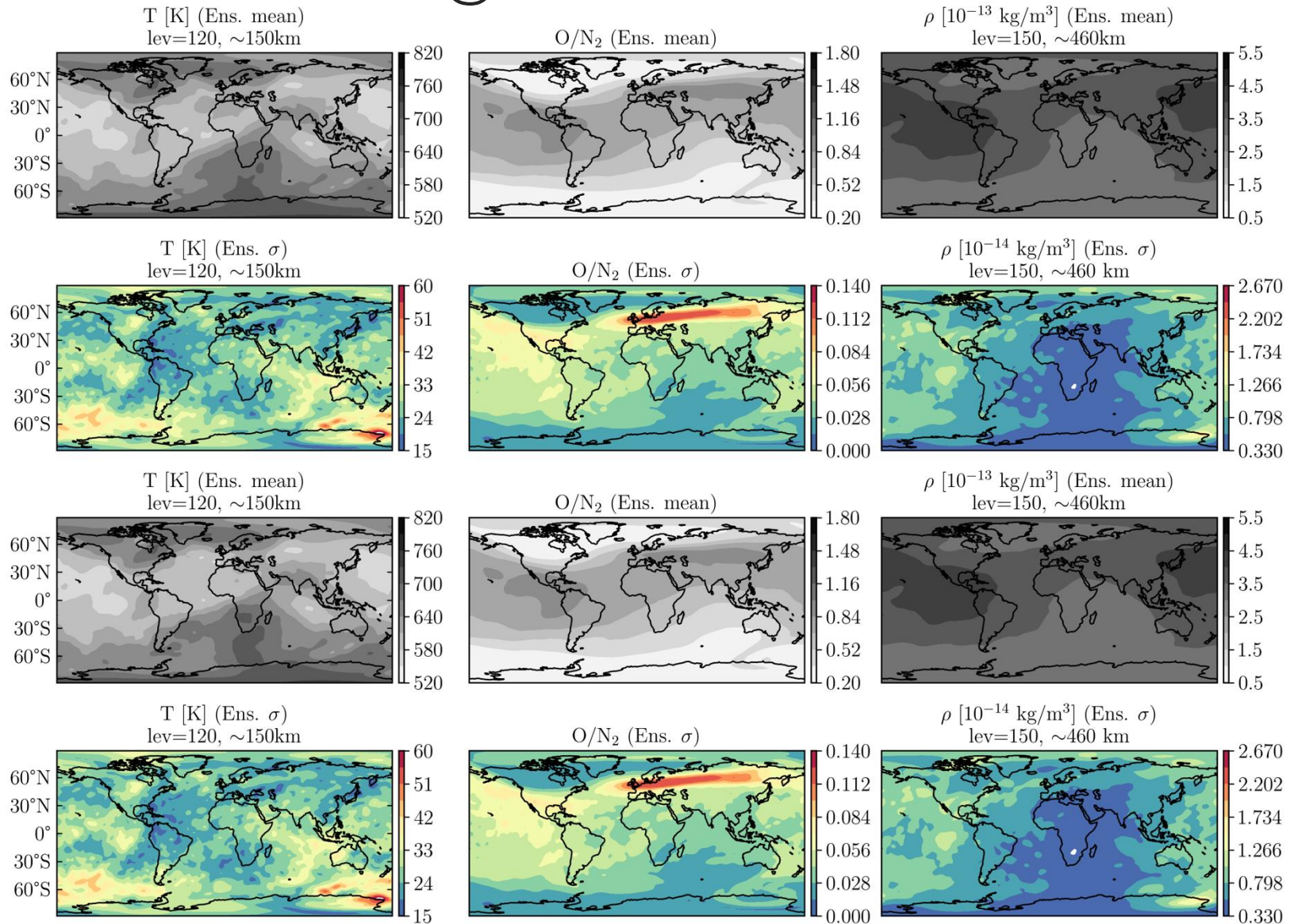

Forecast

DA Analysis

Mass Density Changes at ~460 km by Assimilation of GOLD Radiance Data into WAM @ 12 UT Nov 7

Ann and H.J. Smead
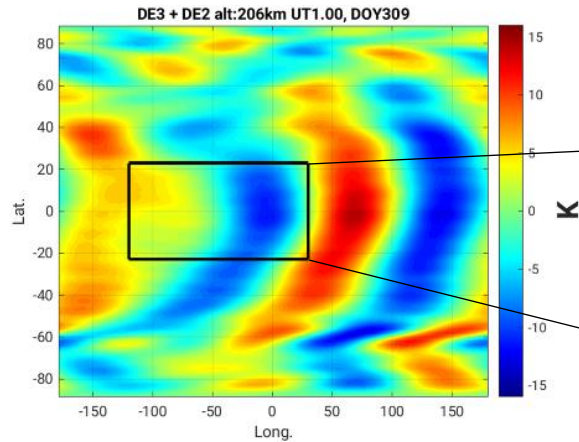Department of Aerospace Engineering Sciences
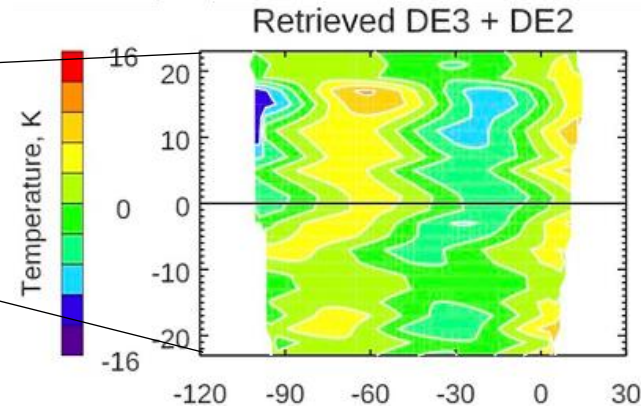UNIVERSITY OF COLORADO BOULDER

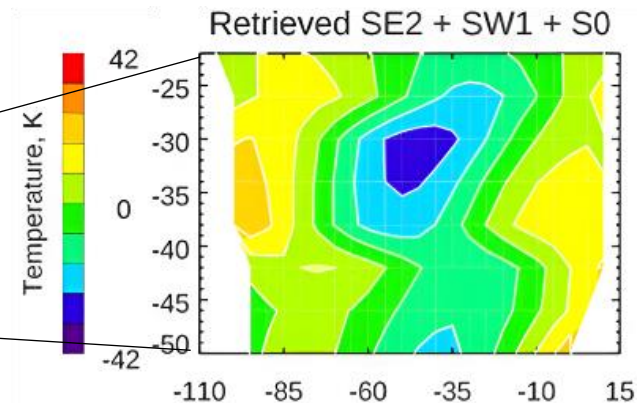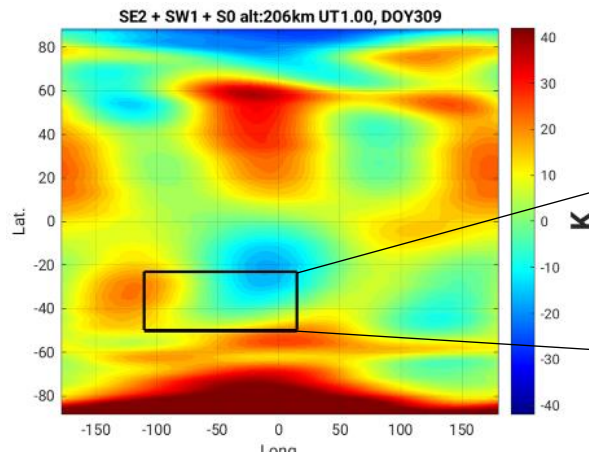# Tidal Diagnostics of Analysis Fields From GOLD Radiance Data Assimilation Into WAM

Analysis from GOLD radiance assimilation

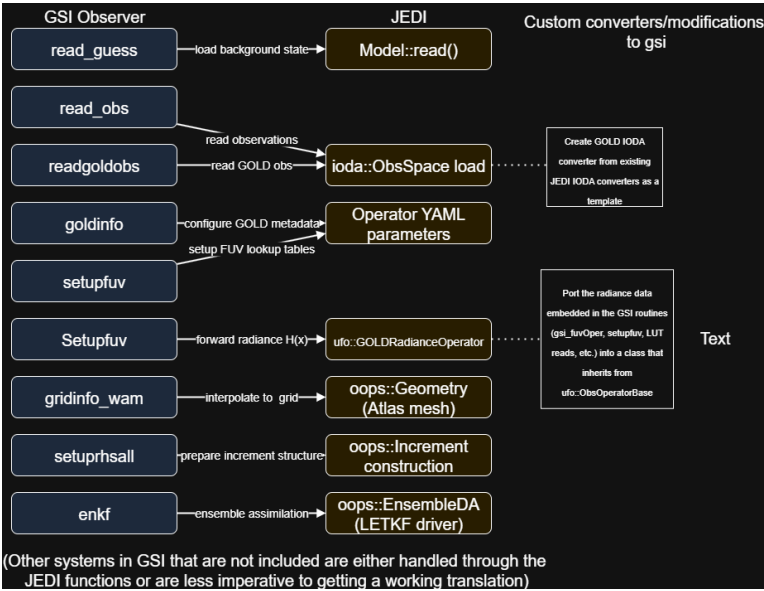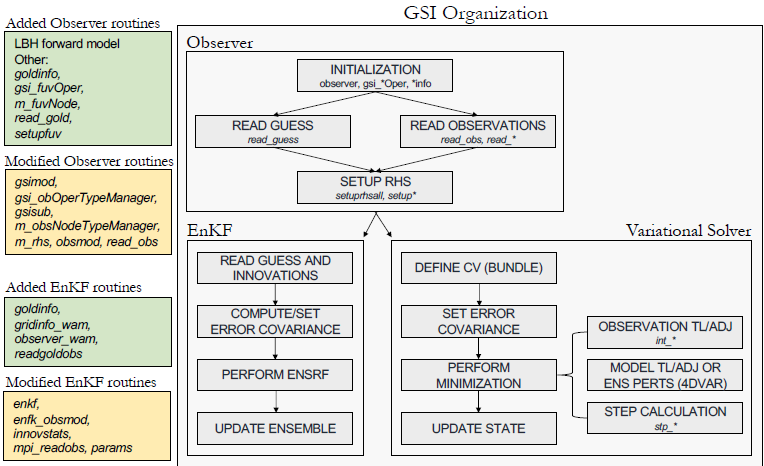Estimated from simultaneous GOLD observations of temperature and O/N^2

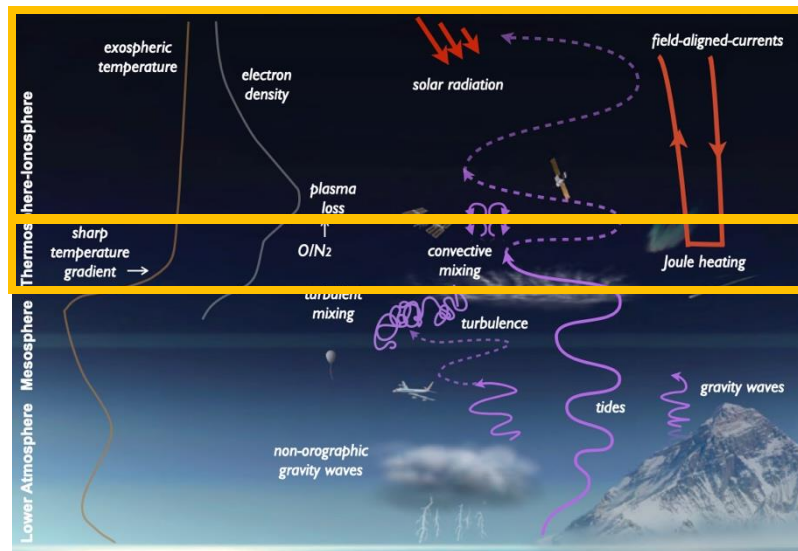[Krier et al., 2021]

[Krier and England, 2024]

Work-in-progress:
Towards transitioning current GSI capabilities to JEDI

- JEDI IODA provides a unified observation format, replacing GSI's Observer-specific file structures

- IODA supports multiple observation types and sensors (including GOLD radiances), streamlining integration into different DA systems

- Using IODA aligns GOLD with modern DA frameworks, enabling consistency across models

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Towards Whole Atmosphere Satellite Data Assimilation

GOLD and ICON data

Better understand coupling of the upper and lower thermosphere regions

Summary

- Demonstrated a capability to assimilate GOLD radiance data into NOAA WAM-IPE using GSI

- Conducted a cycling experiment with GSI EnSRF

Nest Steps

- Adjust localization parameters

- Validate analysis fields with independent neutral mass density data sets

- Compare to ICON-TIEGCM HME data products

- Compare to GOLD tidal diagnostic analysis [e.g., Krier & England, 2024]

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