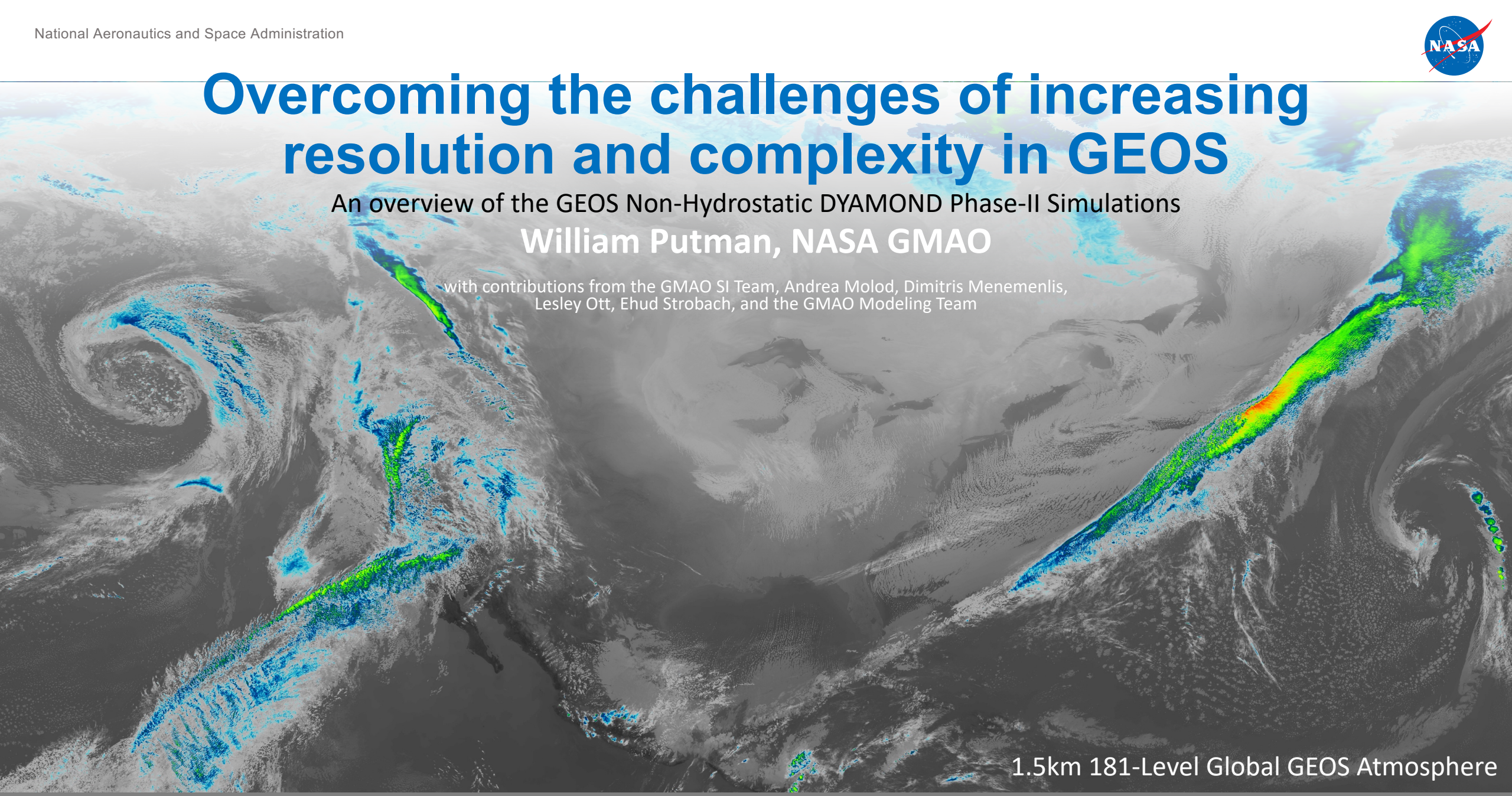
Overcoming the challenges of increasing resolution and complexity in GEOS

An overview of the GEOS Non-Hydrostatic DYAMOND Phase-II Simulations

William Putman, NASA GMAO

with contributions from the GMAO SI Team, Andrea Molod, Dimitris Menemenlis, Lesley Ott, Ehud Strobach, and the GMAO Modeling Team



National Aeronautics and Space Administration

GEOS DYAMOND Phase-II 40-day Simulations

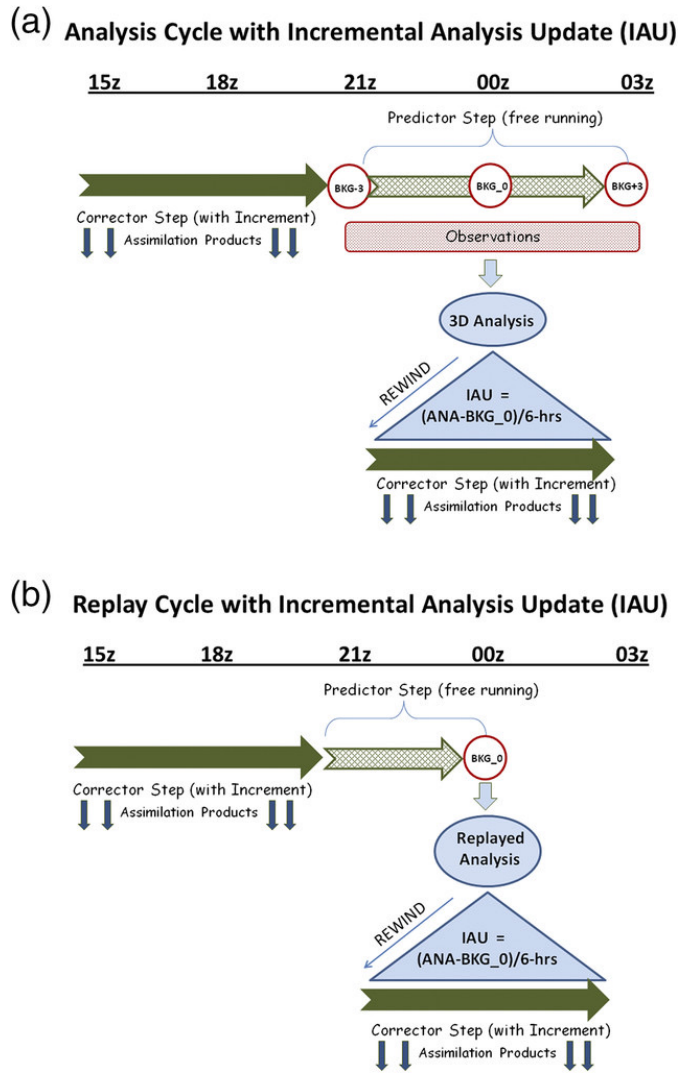
Configuration	Total Cores - "System"	Throughput	Data Volume
Coupled Atm-Ocn 6km 72-Level Atm 4km 90-Level Ocn	**8,160 Intel Xeon Haswell** processor cores "Pleiades" NASA-NAS	**3 Simulated Days /** Wallclock Day	**0.3 Petabytes**
Atmosphere+Carbon 3km 181-Level Atm	**39,360 Intel Xeon Skylake** processor cores "Discover" NASA-NCCS	**7 Simulated Days /** Wallclock Day	**2.0 Petabytes**
Atmosphere 1.5km 181-Level Atm	**39,440 Intel Xeon Skylake** processor cores "Discover" NASA-NCCS	**1.5 Simulated Days /** Wallclock Day	**1.3 Petabytes**

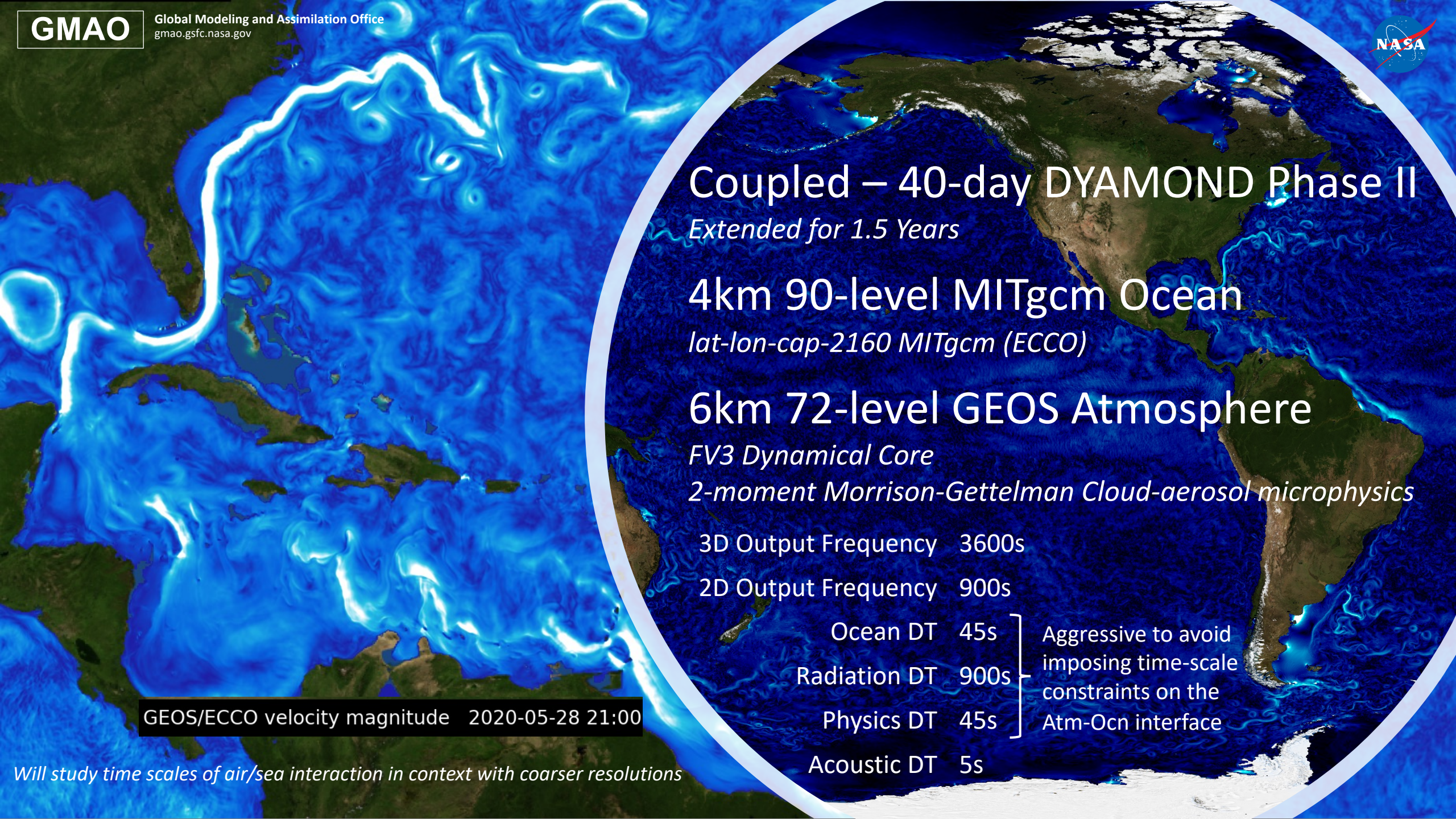
Significant Technical Challenges

- Memory per node
  - Requires the use of shared memory and OpenMP
  - Removal of all global arrays
  - Memory scaling of communication buffers for MPI
- Managing data for input/output
  - 1km global emission data – requires shared memory buffers on node
  - Global scatter/gather operations performed at the node level with SHMEM
  - Asynchronous I/O
  - Inline vs Offline data compression
    - 3km output was compressed as a post-processing step (to improve model throughput)
    - 1.5km output compressed inline by output server (conserve disk utilization)
    - 1.5km 181L 3-dimensional output split into 2 files per variable due to memory issues

Initialization Approach

- Initialization of aerosols, carbon and cloud/precip condensates
  - Use of GEOS Replay approach
    - Takacs, L. L., M. J. Suarez, and R. Todling, 2018. **The Stability of Incremental Analysis Update**. *Monthly Weather Review*, **146**, 3259-3275. DOI: 10.1175/MWR-D-18-0117.1
  - Leverages the GEOS Incremental Analysis Update
  - Replay to the ERA5 3d 137-Level state every 6-hours.
  - 5-day spin-up period 15-Jan-2020 to 20-Jan-2020
- Ocean initial conditions were obtained from an MITgcm ocean-only simulation at 2km global resolution.

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NASA
Coupled – 40-day DYAMOND Phase II
Extended for 1.5 Years
4km 90-level MITgcm Ocean
lat-lon-cap-2160 MITgcm (ECCO)
6km 72-level GEOS Atmosphere
FV3 Dynamical Core
2-moment Morrison-Gettelman Cloud-aerosol microphysics
3D Output Frequency 3600s
2D Output Frequency 900s
Ocean DT 45s
Radiation DT 900s
Physics DT 45s
Aggressive to avoid imposing time-scale constraints on the Atm-Ocn interface
Acoustic DT 5s
GEOS/ECCO velocity magnitude 2020-05-28 21:00
Will study time scales of air/sea interaction in context with coarser resolutions

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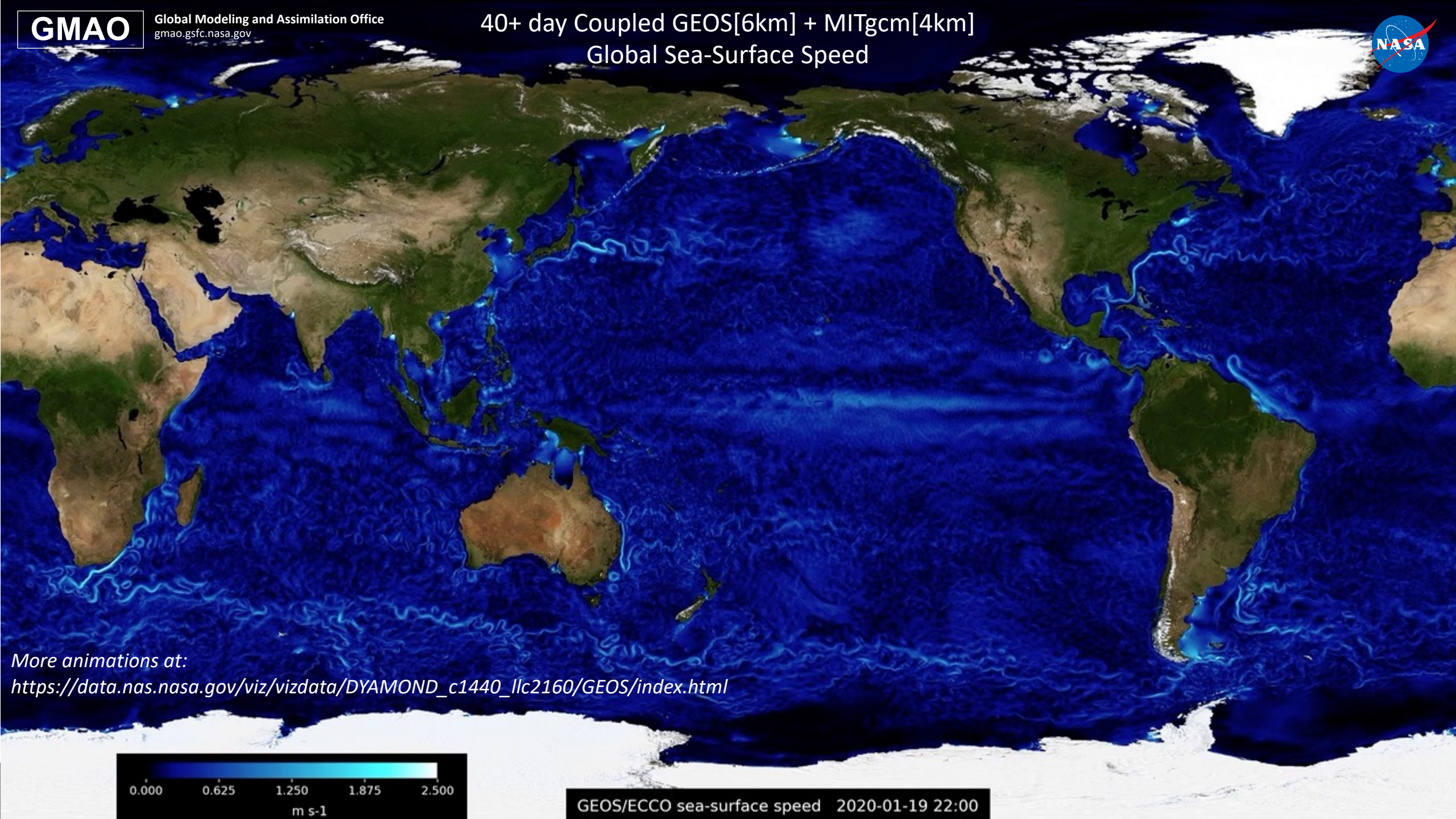
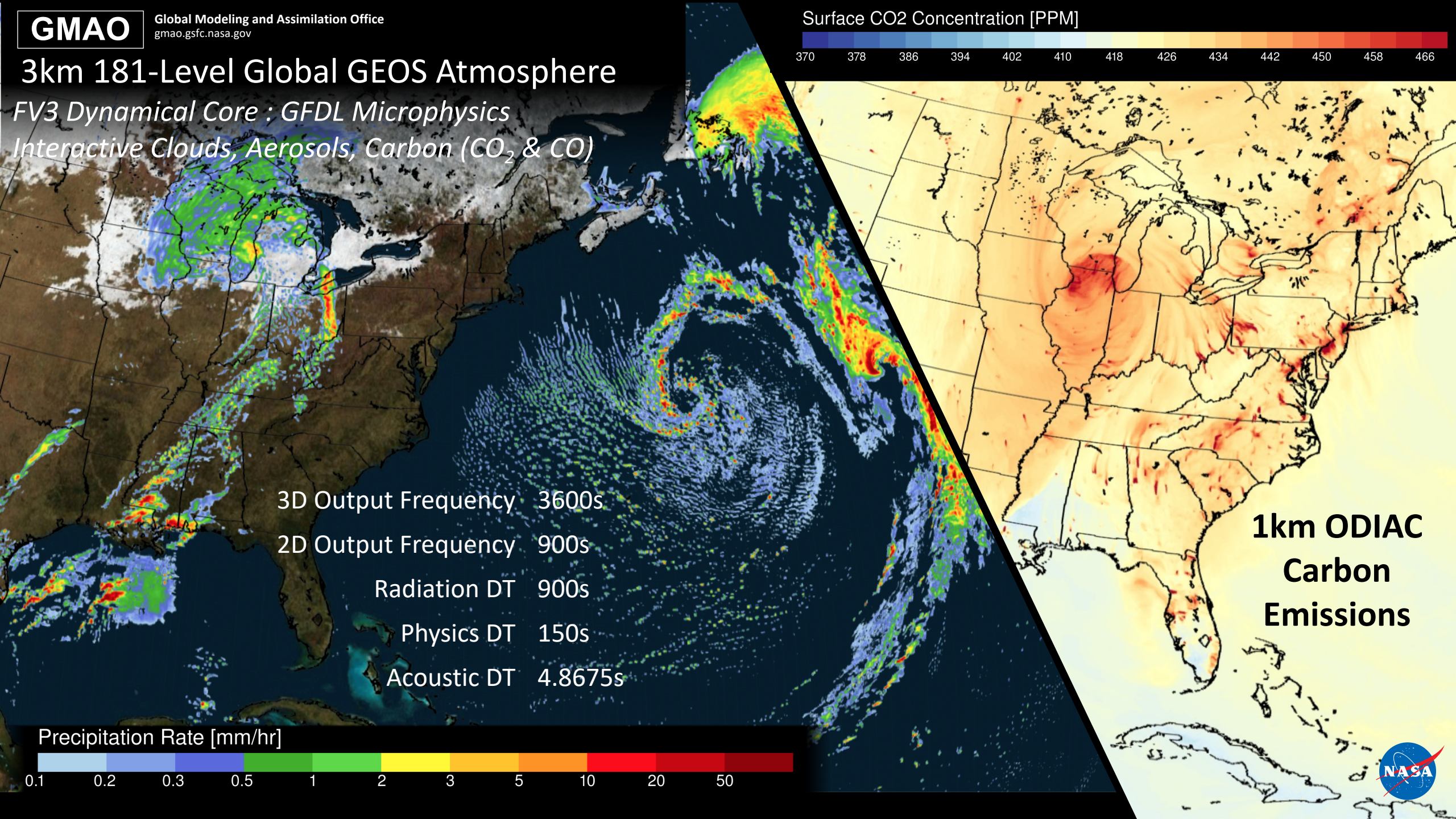
40+ day Coupled GEOS[6km] + MITgcm[4km]
Global Sea-Surface Speed



More animations at:
https://data.nas.nasa.gov/viz/vizdata/DYAMOND_c1440_llc2160/GEOS/index.html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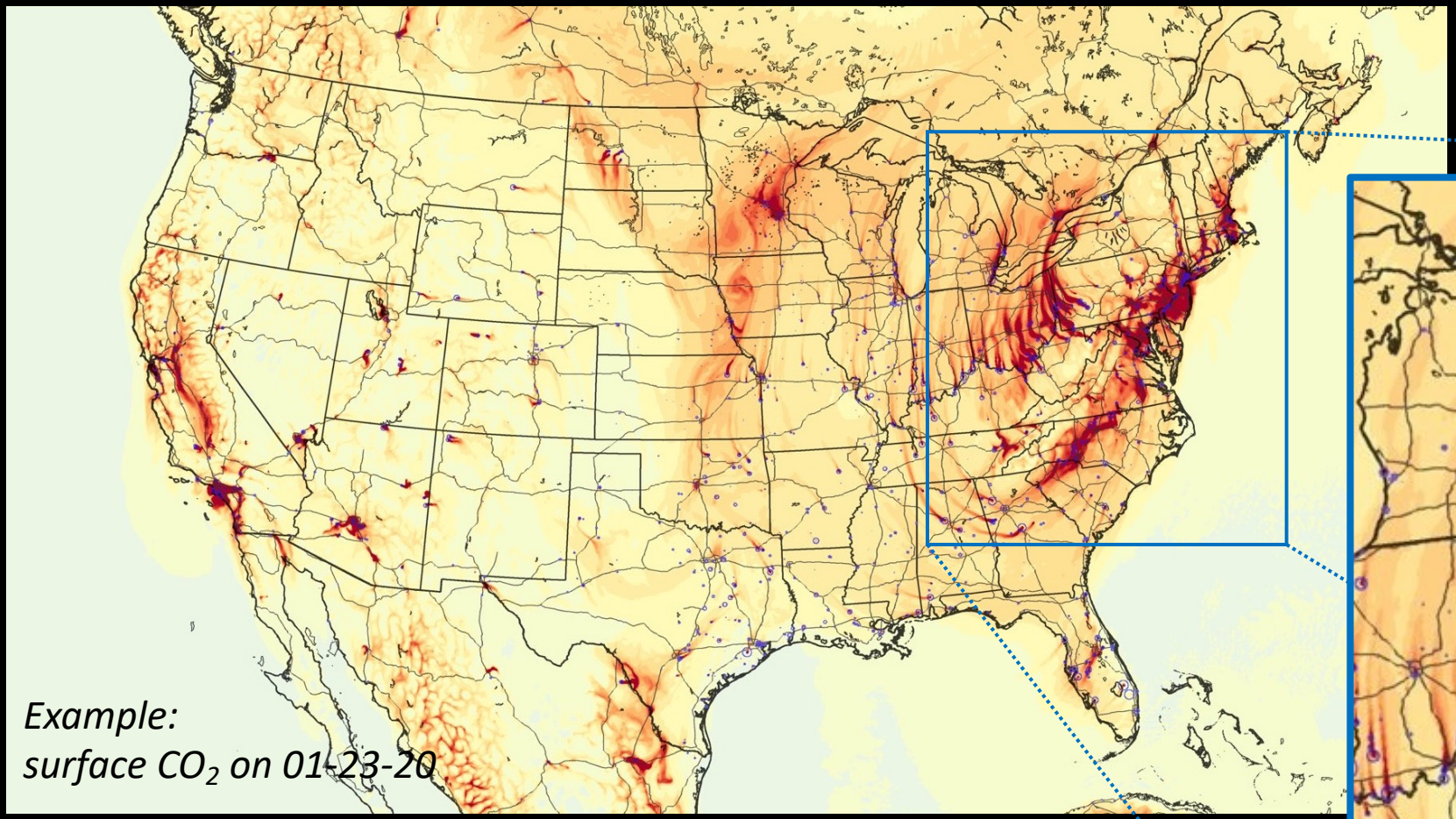
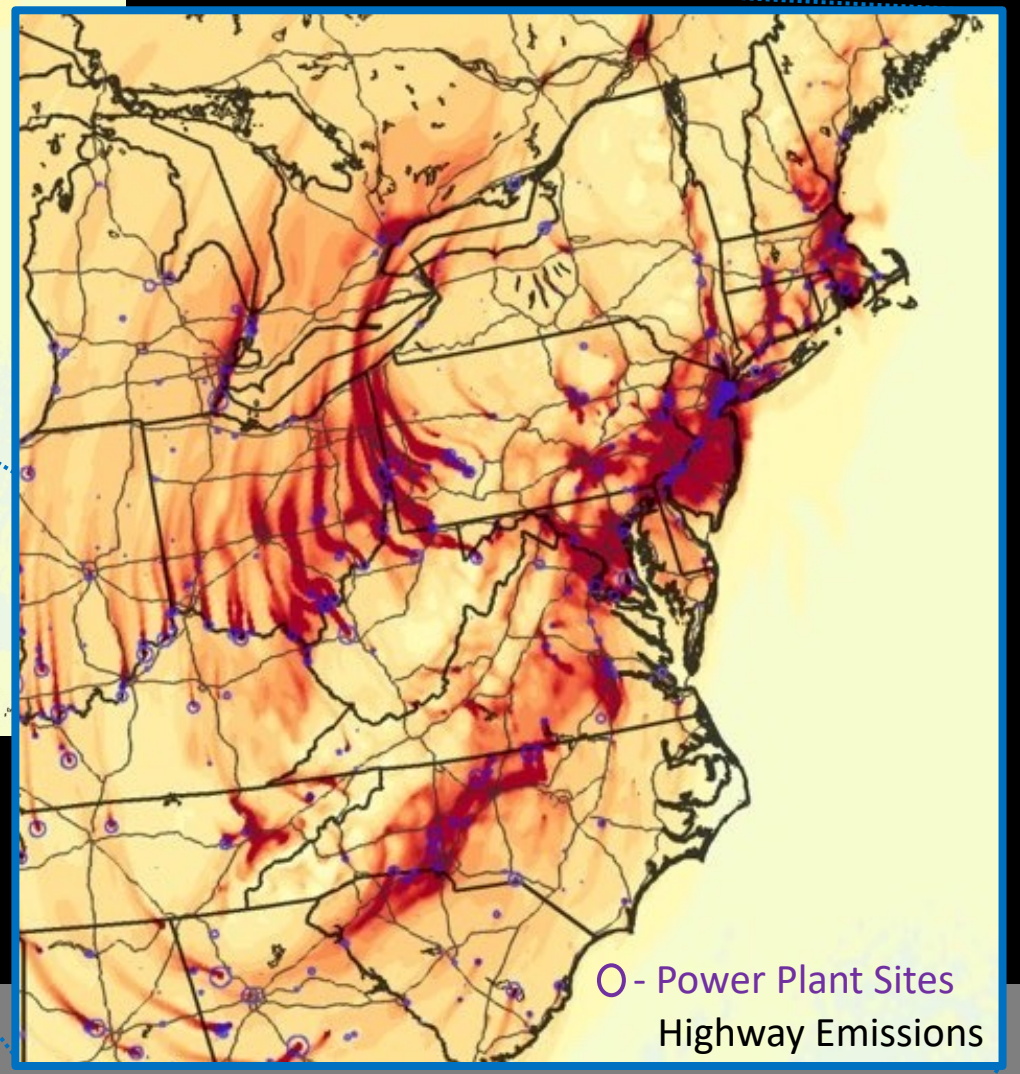
3km 181-Level Global GEOS Atmosphere
FV3 Dynamical Core : GFDL Microphysics
Interactive Clouds, Aerosols, Carbon (CO_2 & CO)
3D Output Frequency 3600s
2D Output Frequency 900s
Radiation DT 900s
Physics DT 150s
Acoustic DT 4.8675s
Precipitation Rate [mm/hr]
0.1 0.2 0.3 0.5 1 2 3 5 10 20 50
Surface CO2 Concentration [PPM]
370 378 386 394 402 410 418 426 434 442 450 458 466
1km ODIAC Carbon Emissions
NASA

3-km 181L Global GEOS CO_2 simulation





- One of the highest resolution global CO_2 simulations to date
- Includes 1-km ODIAC emissions
- Planned work: examination of plume statistics, automated plume detection methods, and correlations between CO, CO_2, and aerosols

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3km 181-Level Global GEOS Atmosphere

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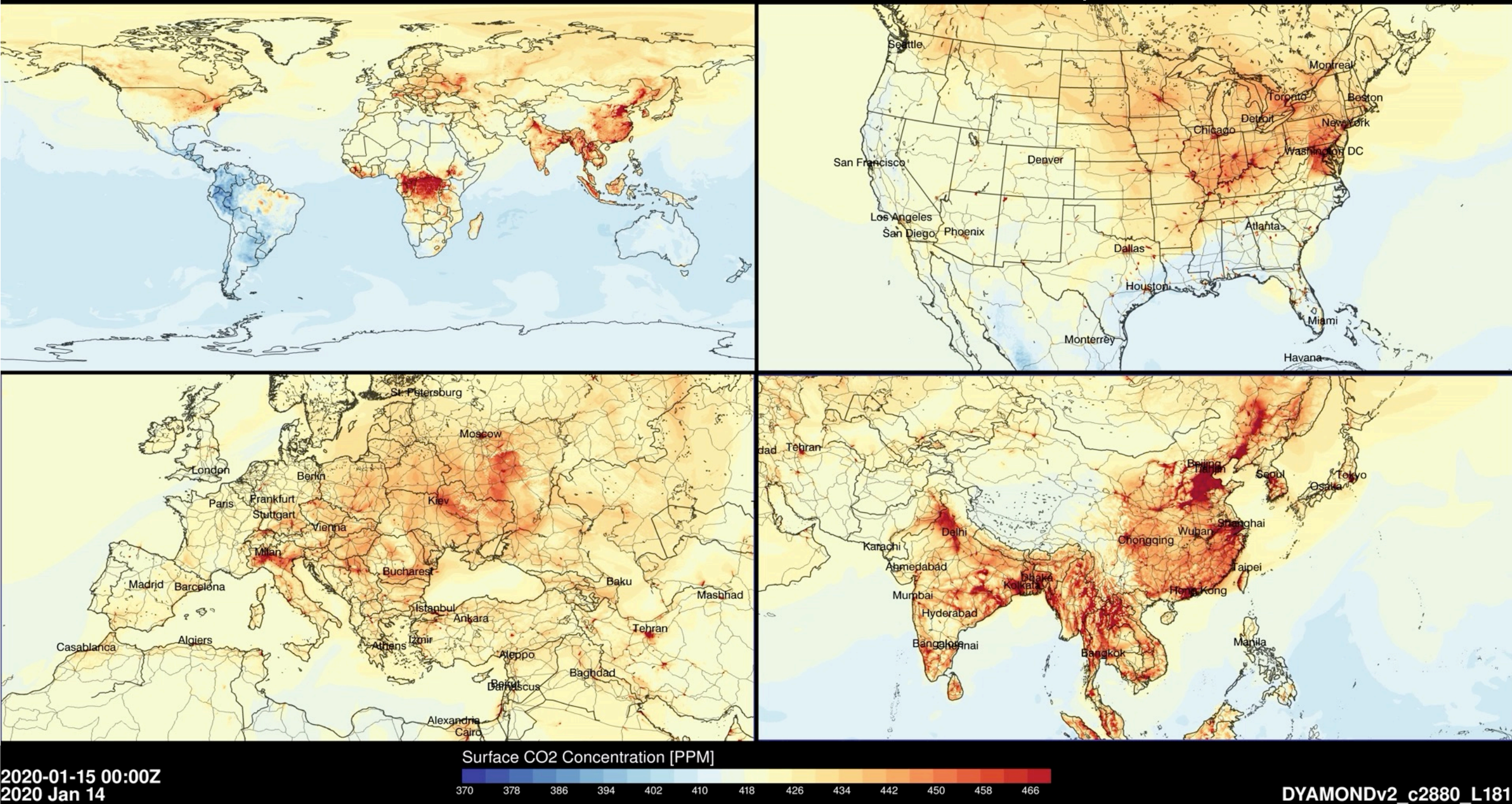

Surface CO2 Concentration [PPM]

370 378 386 394 402 410 418 426 434 442 450 458 466

2020-01-15 00:00Z
2020 Jan 14

DYAMONDv2_c2880_L181

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3km 181-Level Global GEOS Atmosphere

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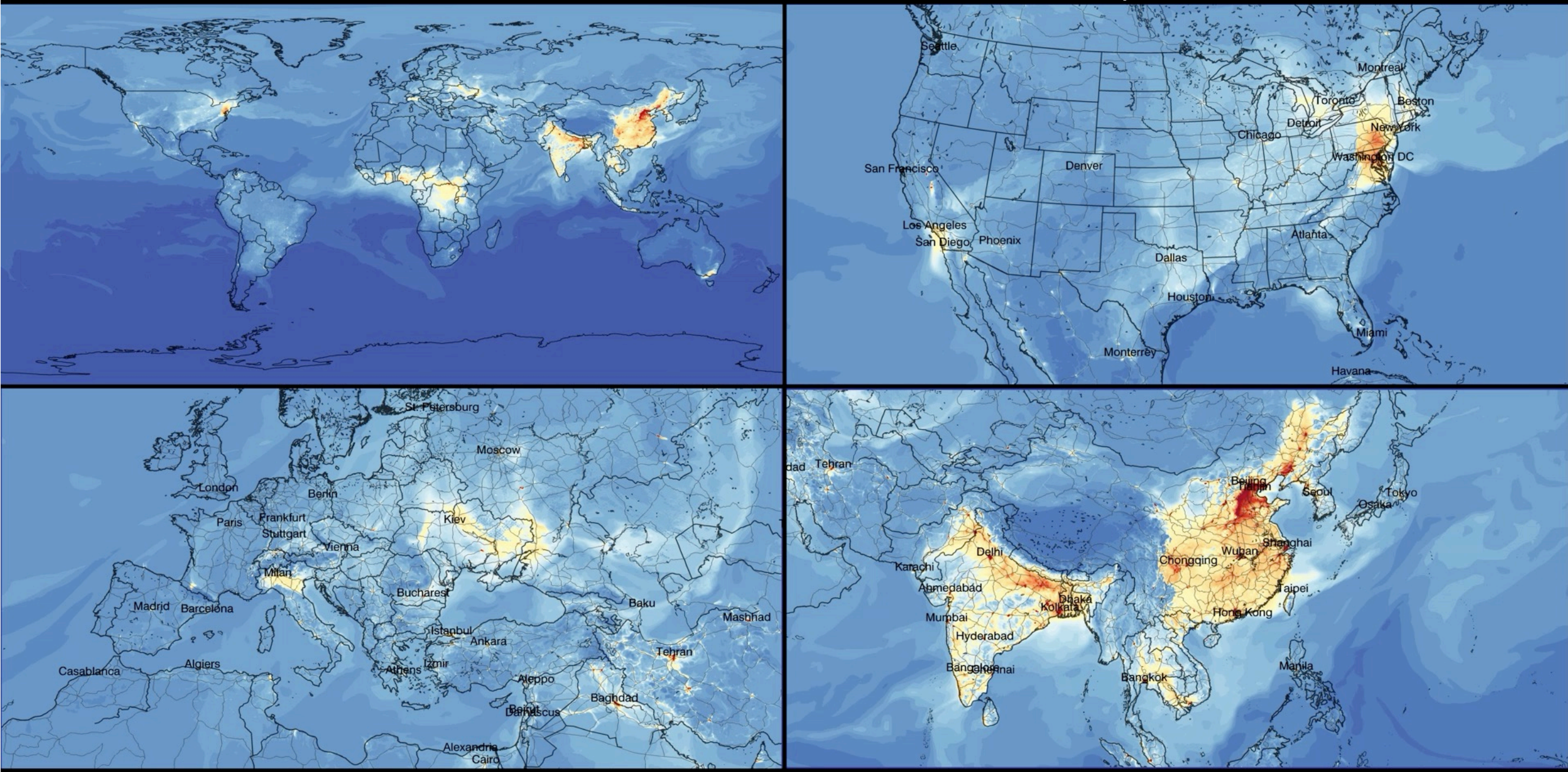

Surface CO Concentration [PPBV]

0 50 100 150 200 250 300 350 400 450 500 700 900 1100 1300 1500 1700 1900 2200 2600 3000

2020-01-15 00:00Z
2020 Jan 14

DYAMONDv2_c2880_L181

1.5km 181-Level Global GEOS Atmosphere

FV3 Dynamical Core: GFDL Microphysics : Climatological aerosols & carbon

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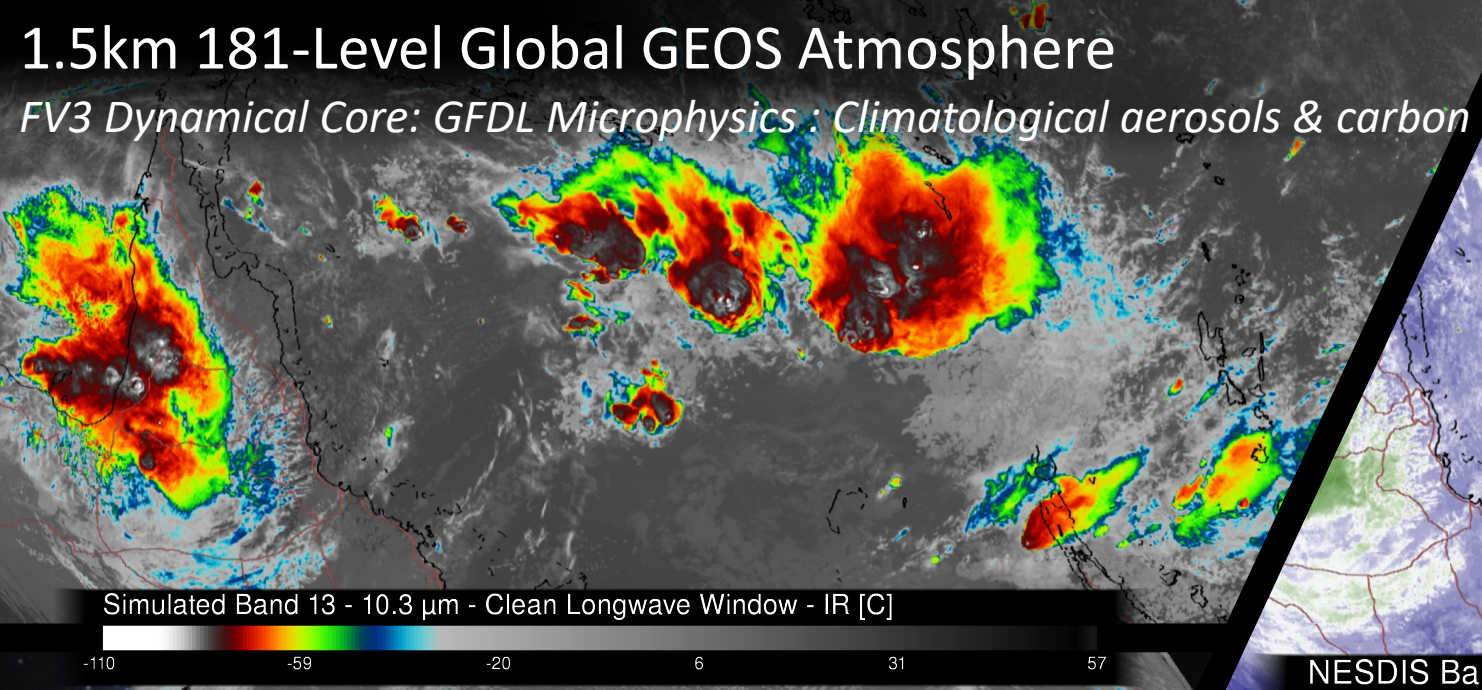
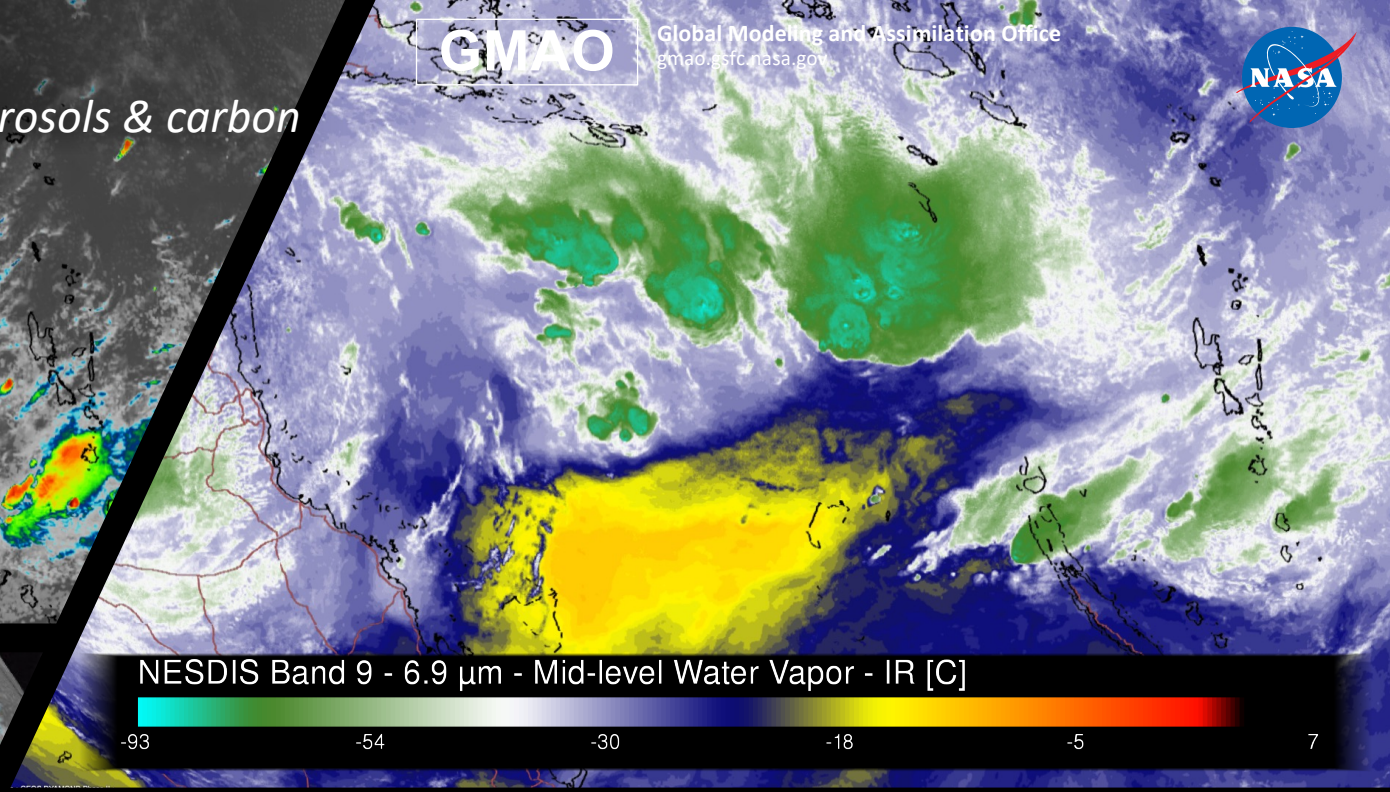
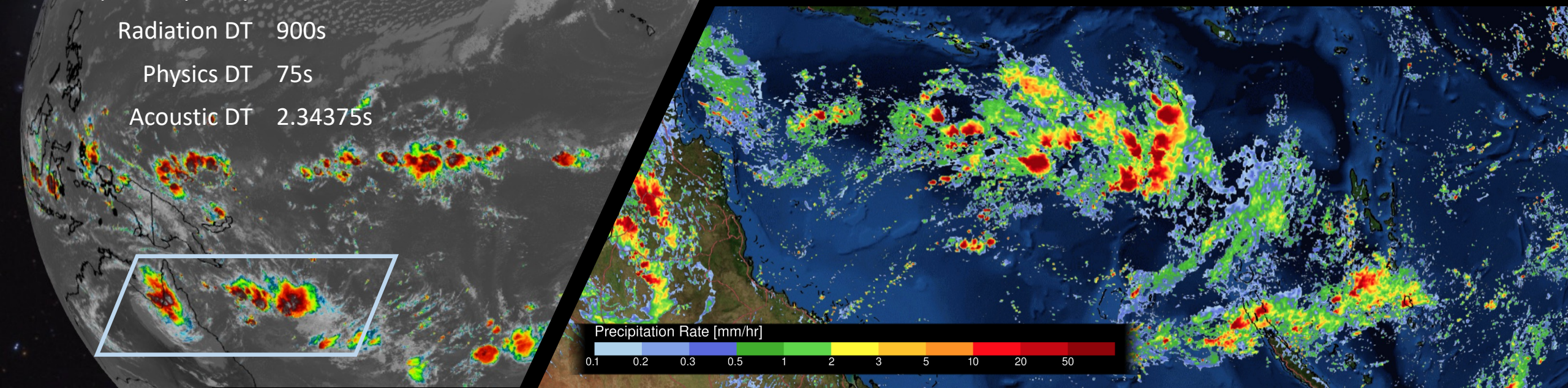




3D Output Frequency	3600s
2D Output Frequency	900s
Radiation DT	900s
Physics DT	75s
Acoustic DT	2.34375s



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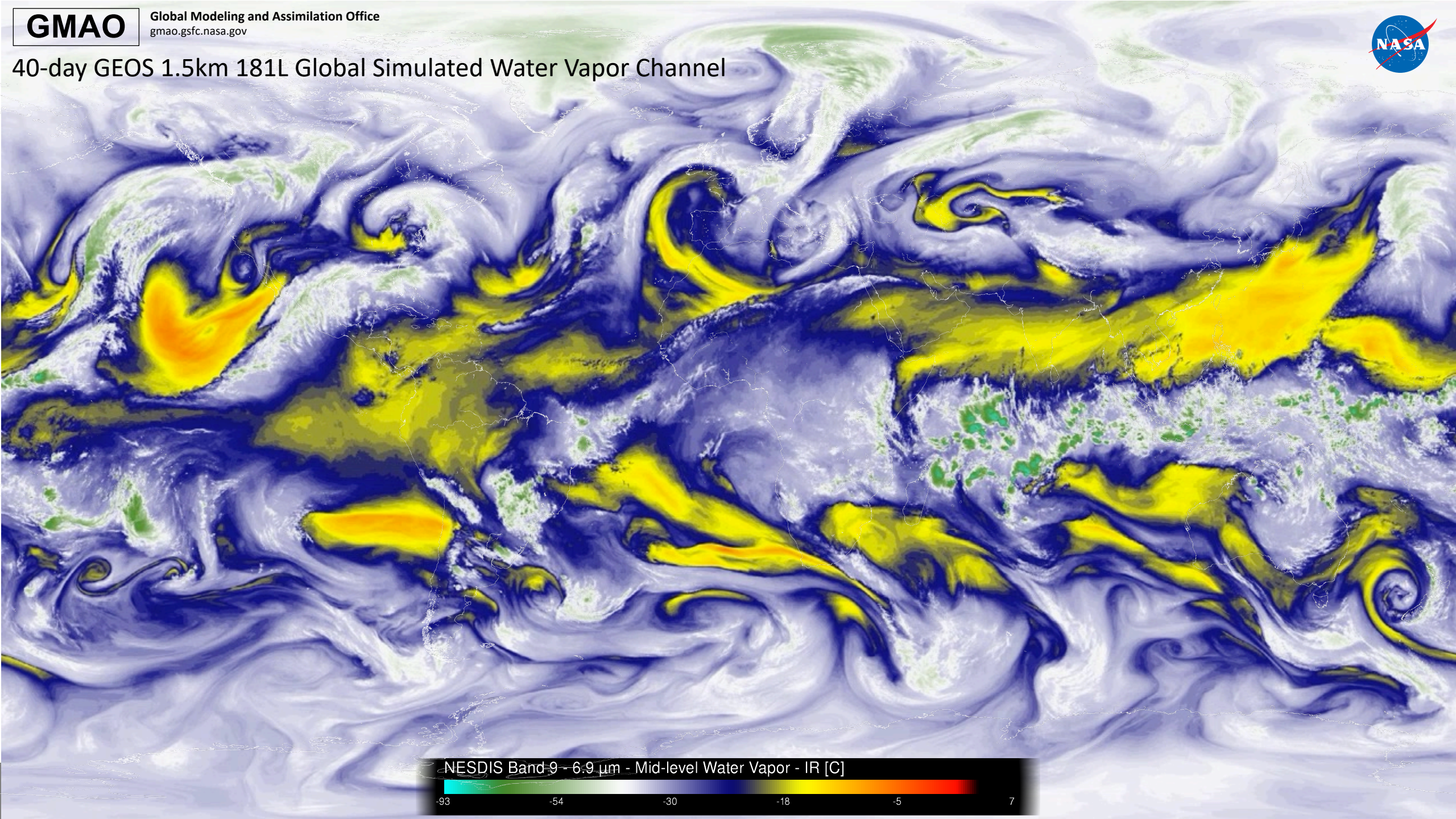
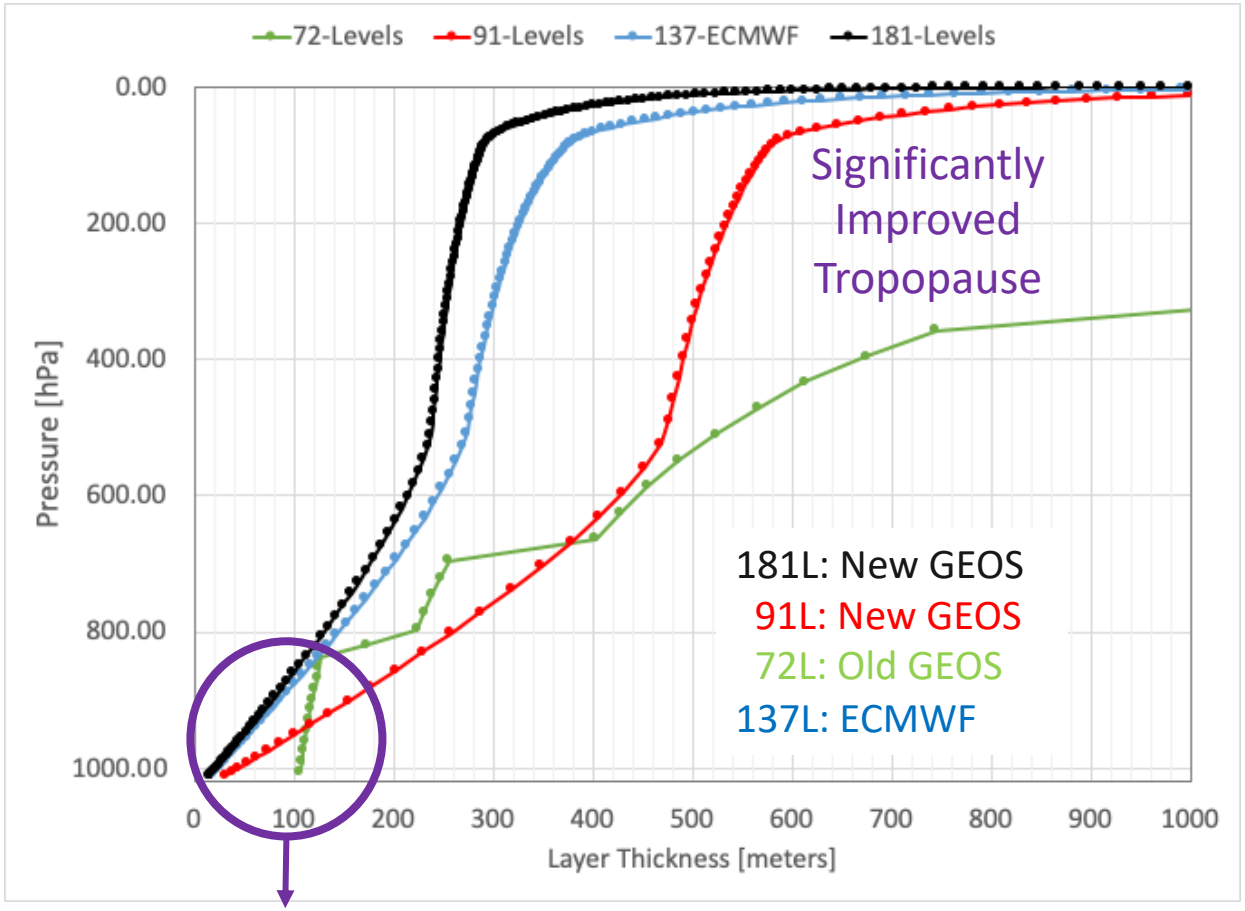
40-day GEOS 1.5km 181L Global Simulated Water Vapor Channel

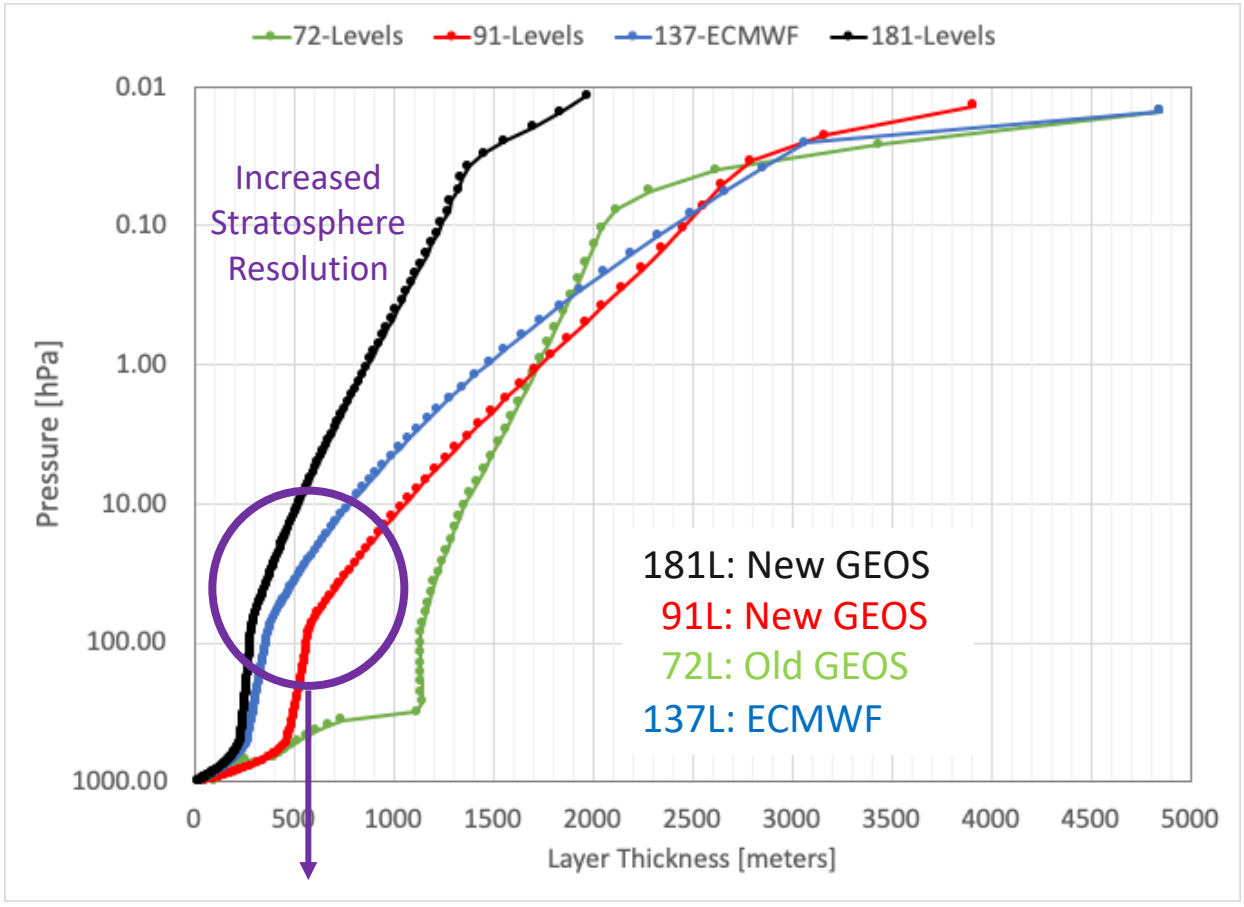


GEOS 181 Vertical Levels

Smoother Delta-P and Delta-Z Profiles



Enhanced BL Resolution



Delta-Z < 500m up to 10hPa:
Improved Downward Propagation of QBO

Orographic Gravity Waves

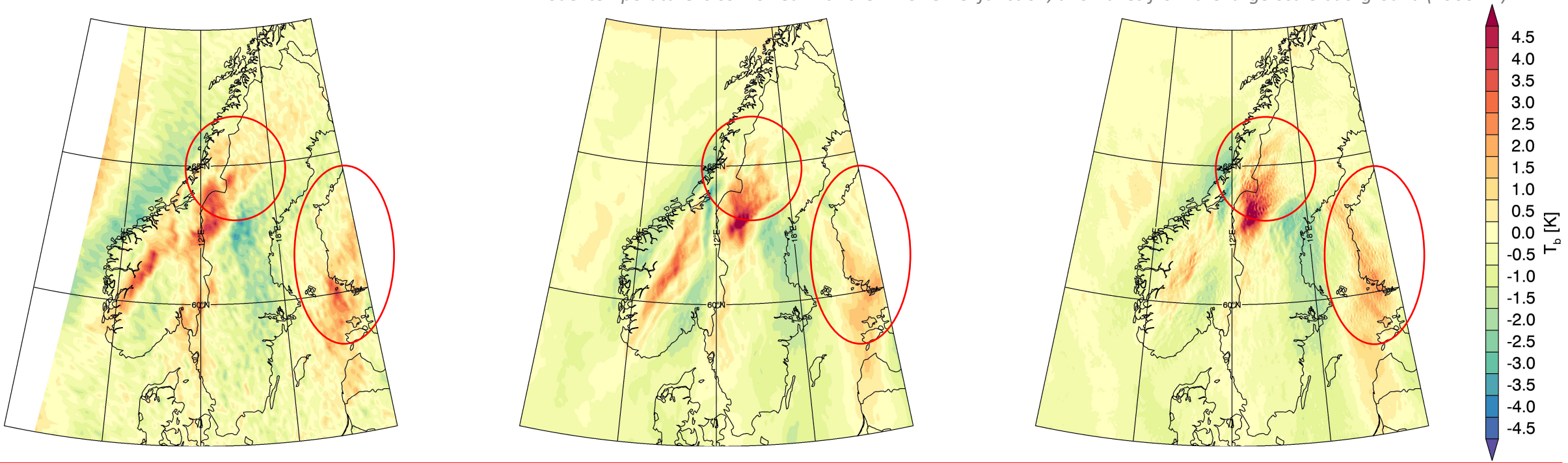
22-January-2020 01:30 Local Time

AIRS (brightness T anomalies)

GEOS 3km 181L

GEOS 1.5km 181L

model temperature is convolved with the AIRS kernel function, anomalies from the large-scale background (>500km)



Enhanced fidelity of orographic gravity waves with increased vertical and horizontal resolution

AIRS brightness temperature anomalies are derived from radiance measurements in the 15 micron CO_2 fundamental band with the large-scale background (>500km) removed. The kernel function peaks near 40 km, so the majority of the gravity wave signal is coming from the mid to upper stratosphere

Images & analysis courtesy of Laura Holt, NWRA

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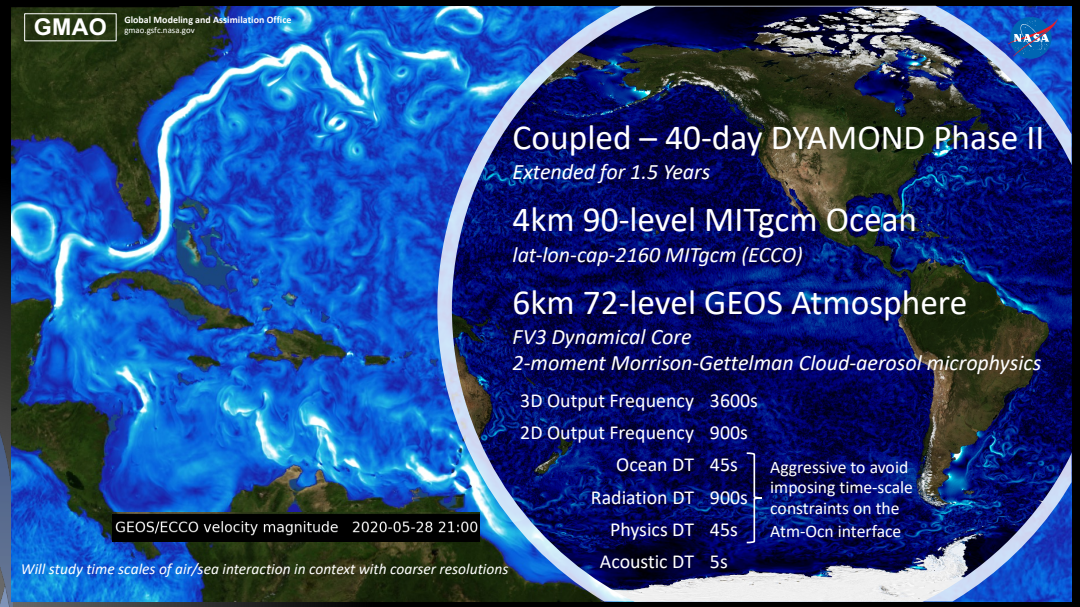
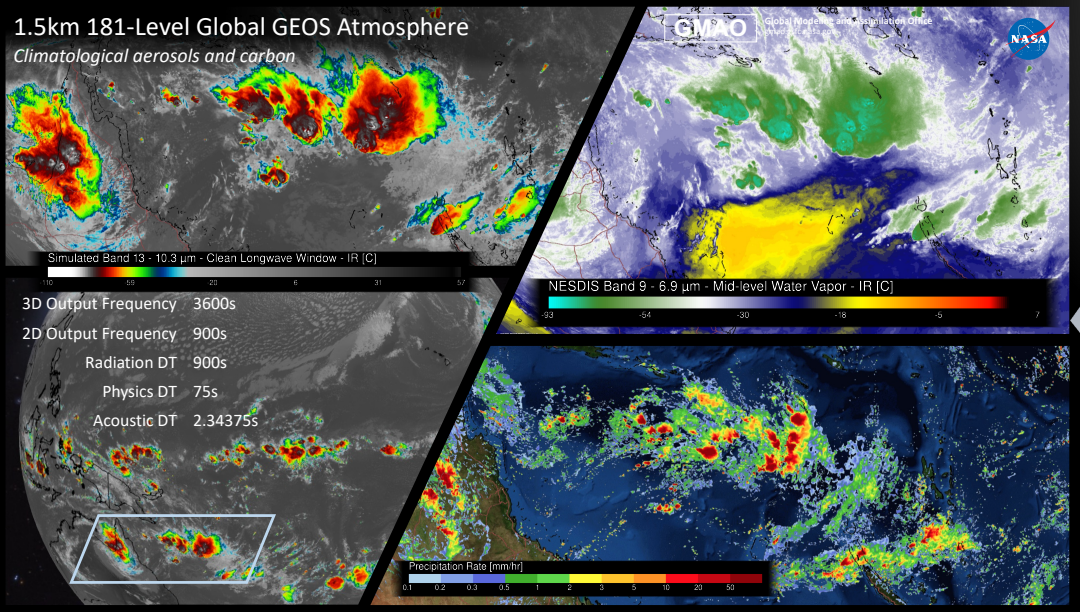
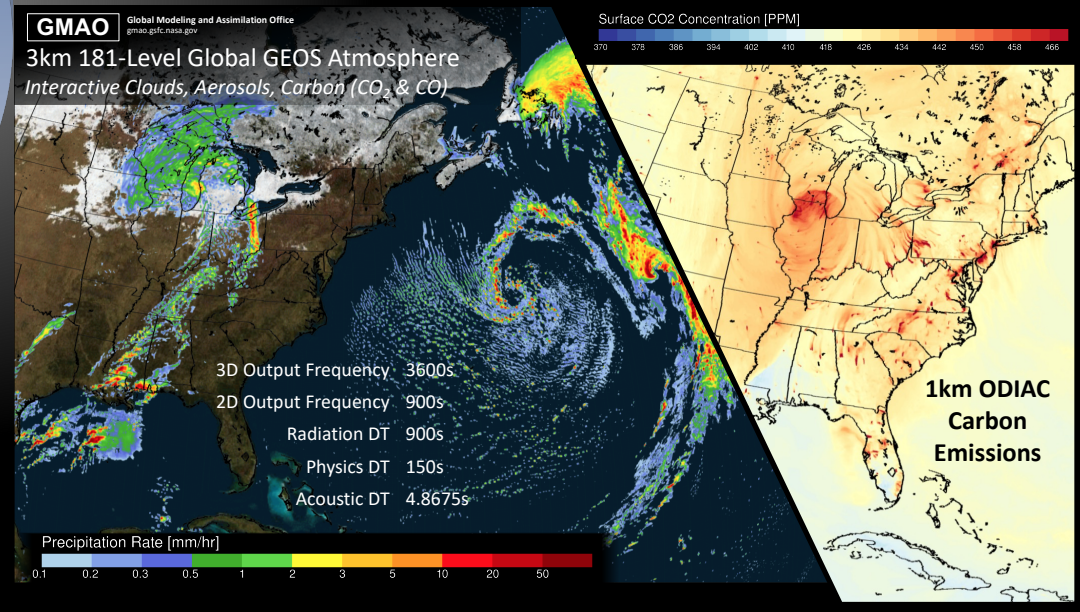
Compute

Complexity

Resolution







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