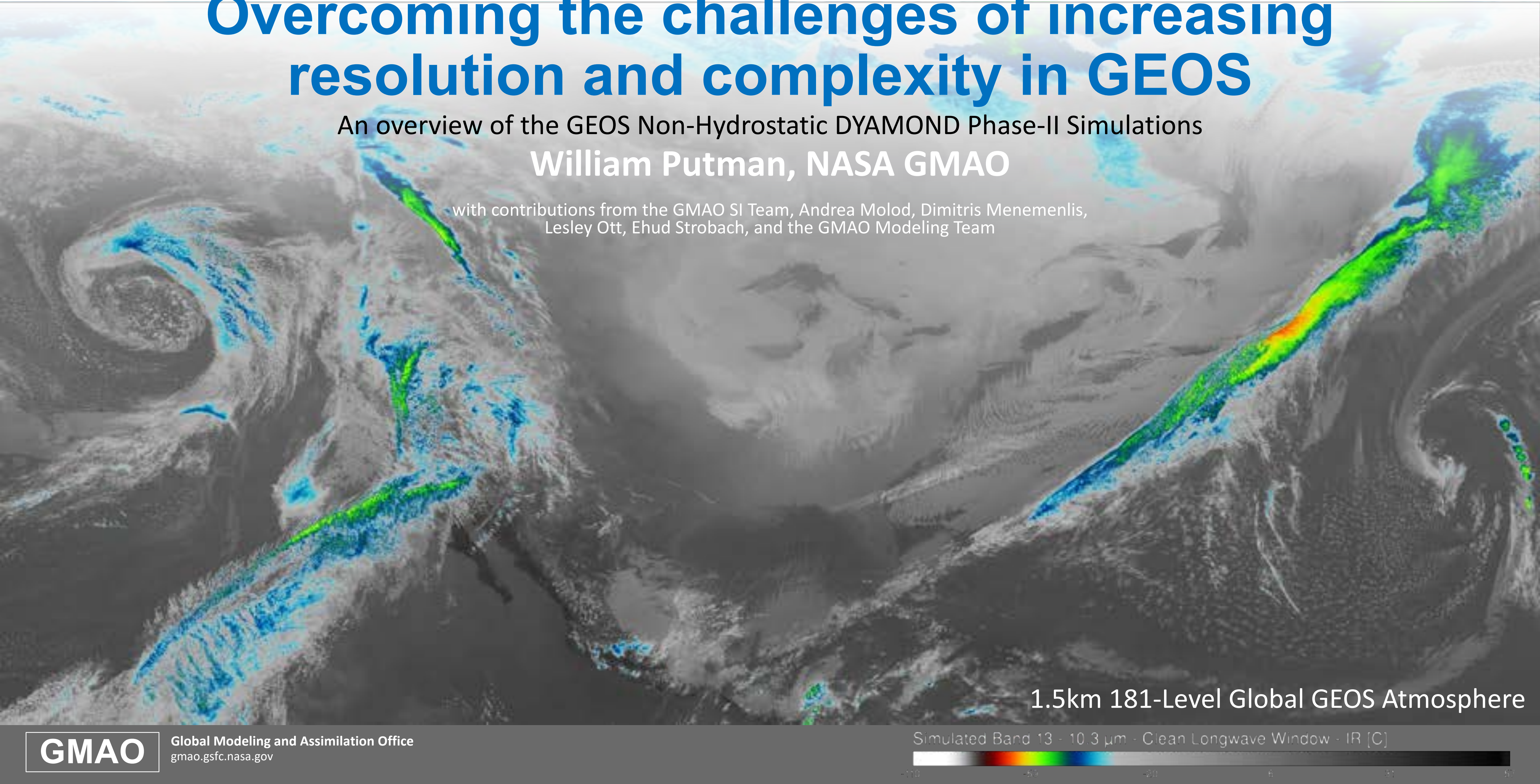
Overcoming the challenges of increasing resolution and complexity in GEOS

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



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GEOS DYAMOND Phase-II 40-day Simulations

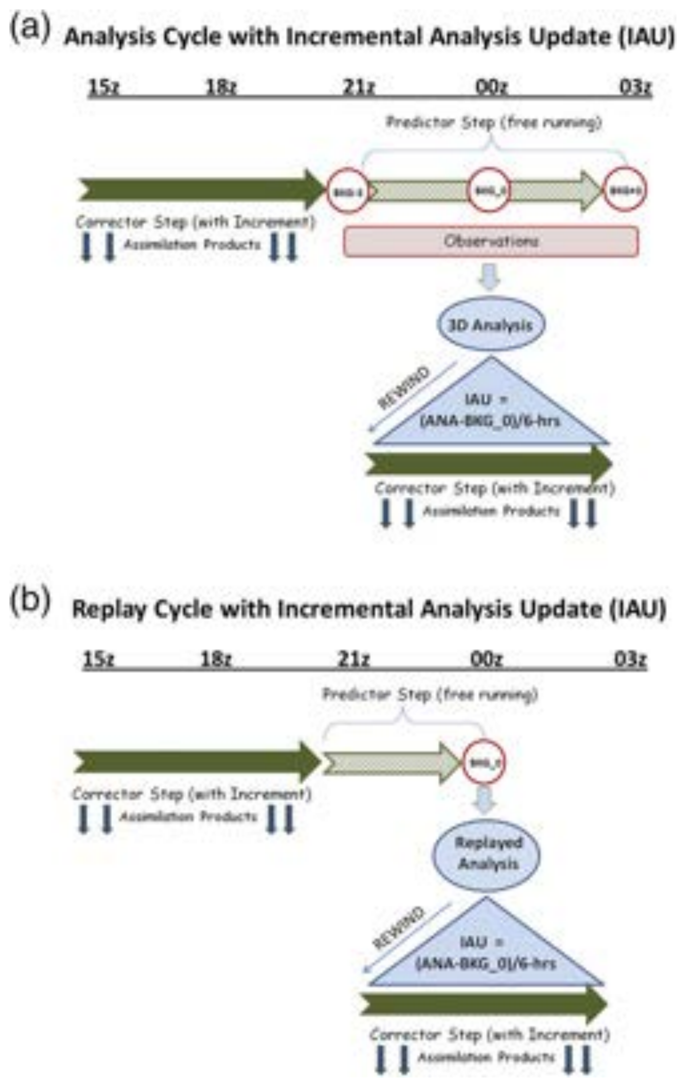
Configuration	Total Cores - "System"	Throughput	Data Volume
Coupled Atm-Ocn 6km 72-Level Atm 4km 90-Level Ocn	**8,160 Intel Xeon Haswell** processor cores "Pleiades" NASA-NAS	**3 Simulated Days /** Wallclock Day	**0.3 Petabytes**
Atmosphere+Carbon 3km 181-Level Atm	**39,360 Intel Xeon Skylake** processor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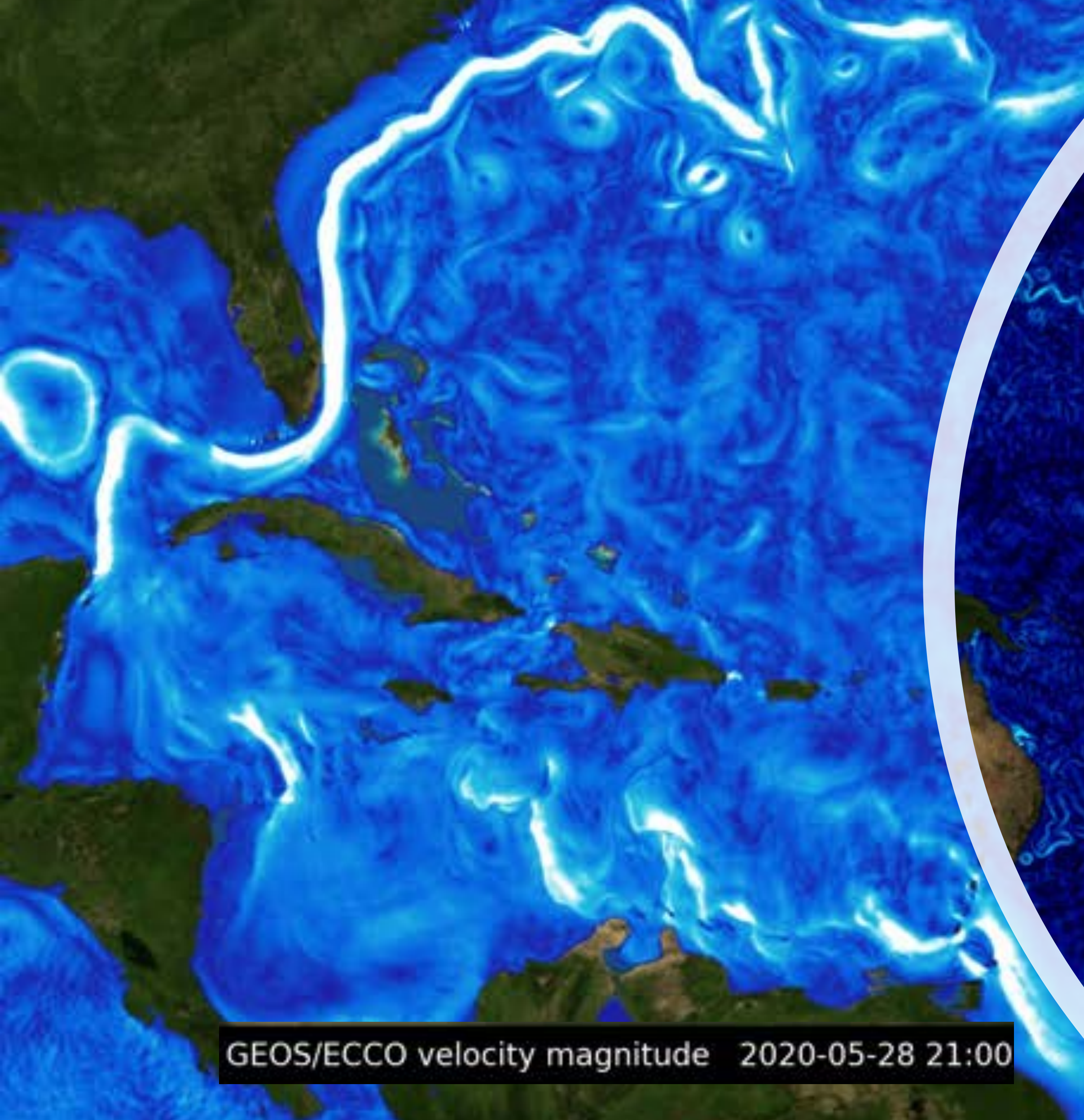


Coupled – 40-day DYAMOND Phase II

Extended for 1.5 Years

4km 90-level MITgcm Ocean

lat-lon-cap-2160 MITgcm (ECCO)

6km 72-level GEOS Atmosphere

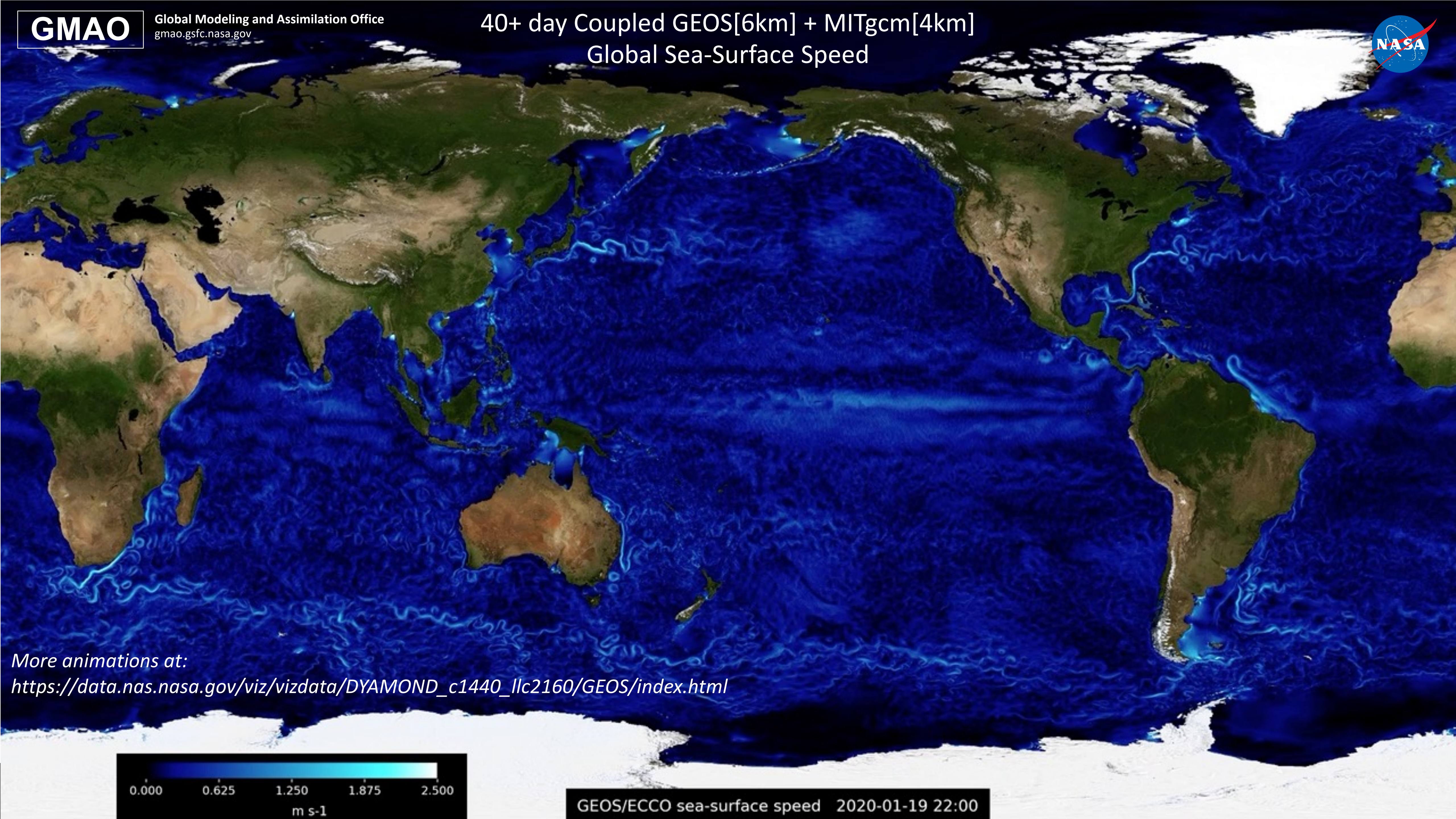
FV3 Dynamical Core

2-moment Morrison-Gettelman Cloud-aerosol microphysics

3D Output Frequency	3600s
2D Output Frequency	900s
Ocean DT	45s
Radiation DT	900s
Physics DT	45s
Acoustic DT	5s

Ocean DT, Radiation DT, Physics DT: Aggressive to avoid imposing time-scale constraints on the Atm-Ocn interface

Will study time scales of air/sea interaction in context with coarser resolutions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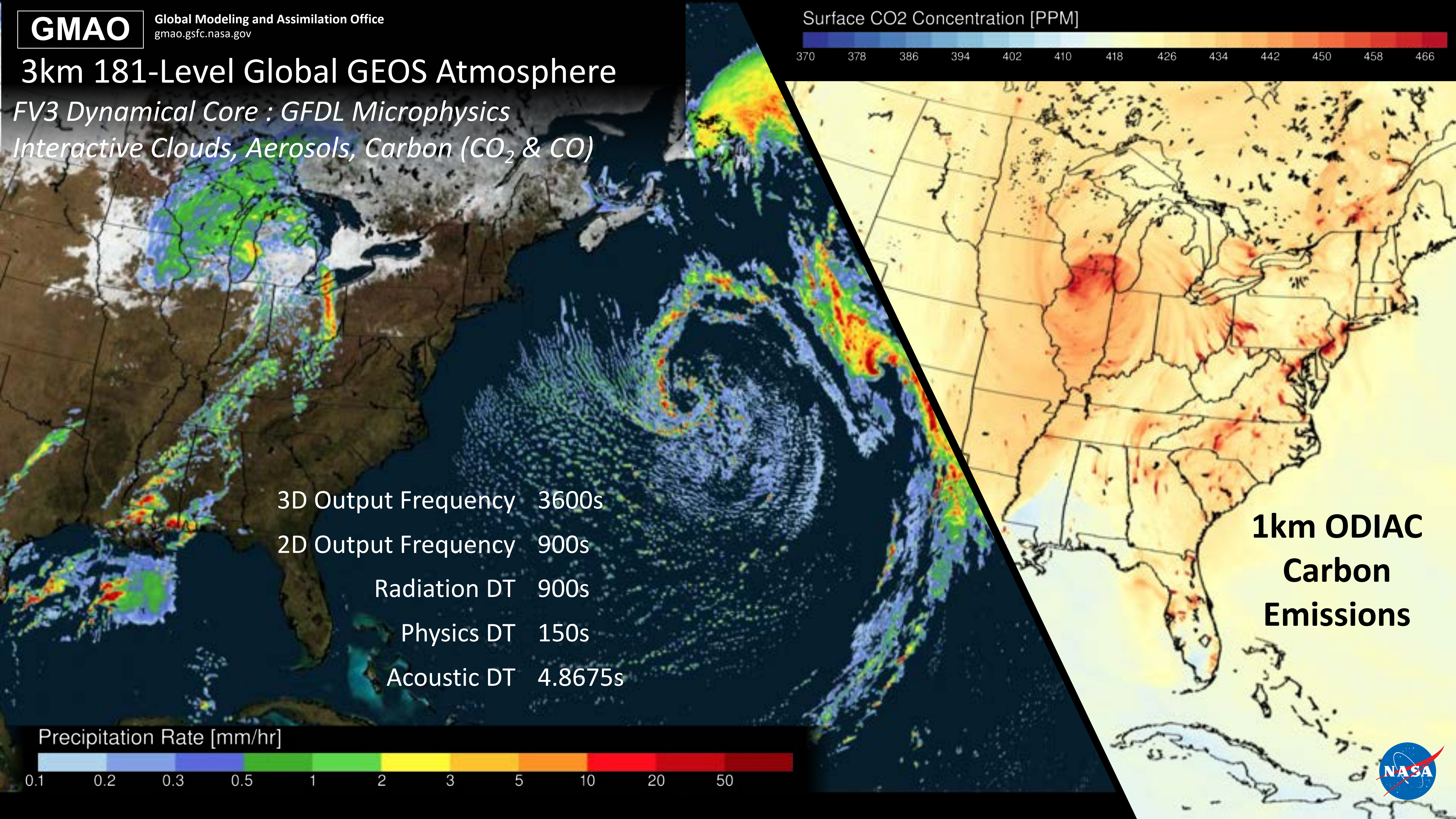
40+ day Coupled GEOS[6km] + MITgcm[4km]
Global Sea-Surface Speed
More animations at:
https://data.nas.nasa.gov/viz/vizdata/DYAMOND_c1440_llc2160/GEOS/index.html
0.000
0.625
1.250
1.875
2.500
m s-1
GEOS/ECCO sea-surface speed 2020-01-19 22:00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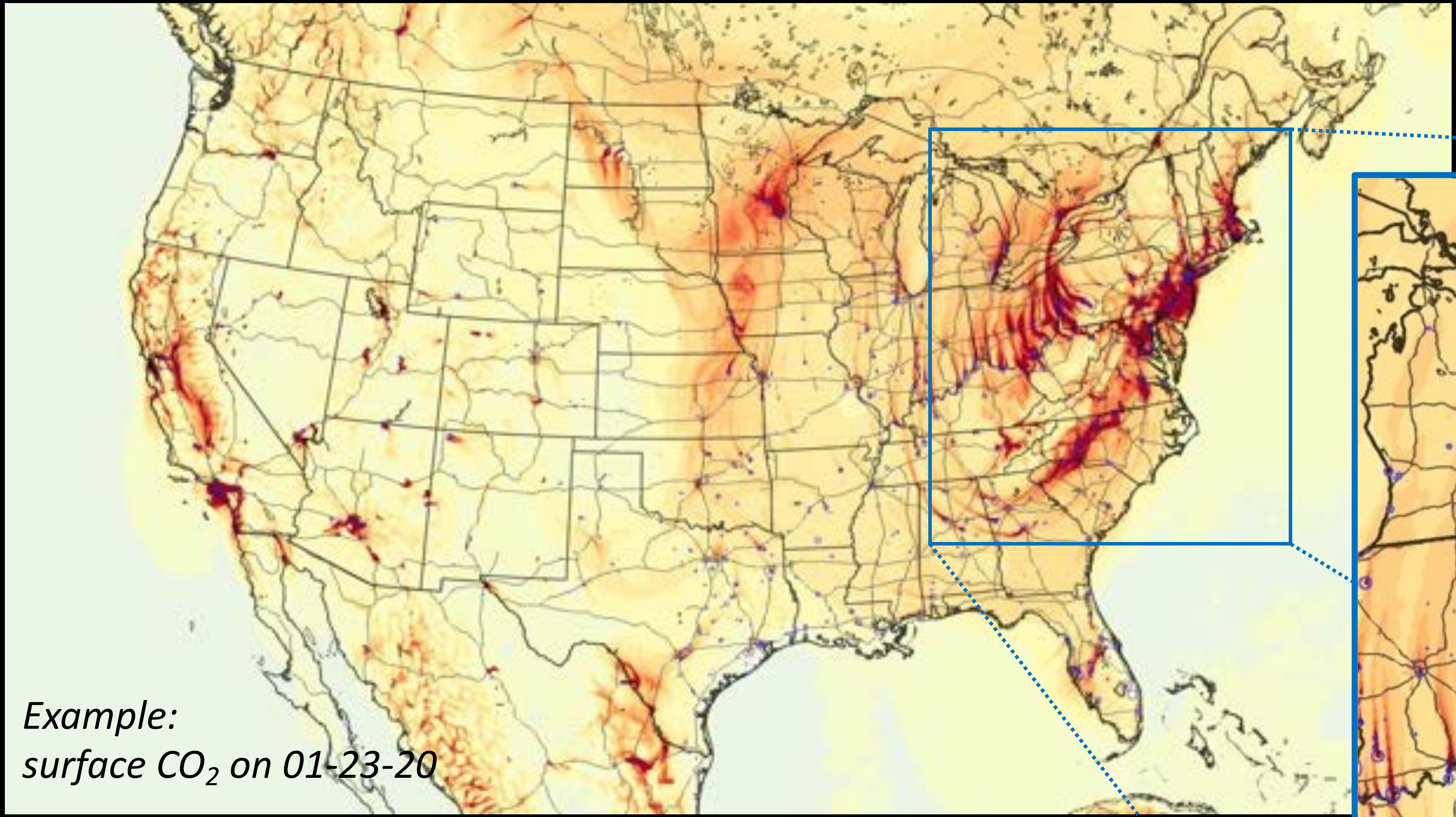
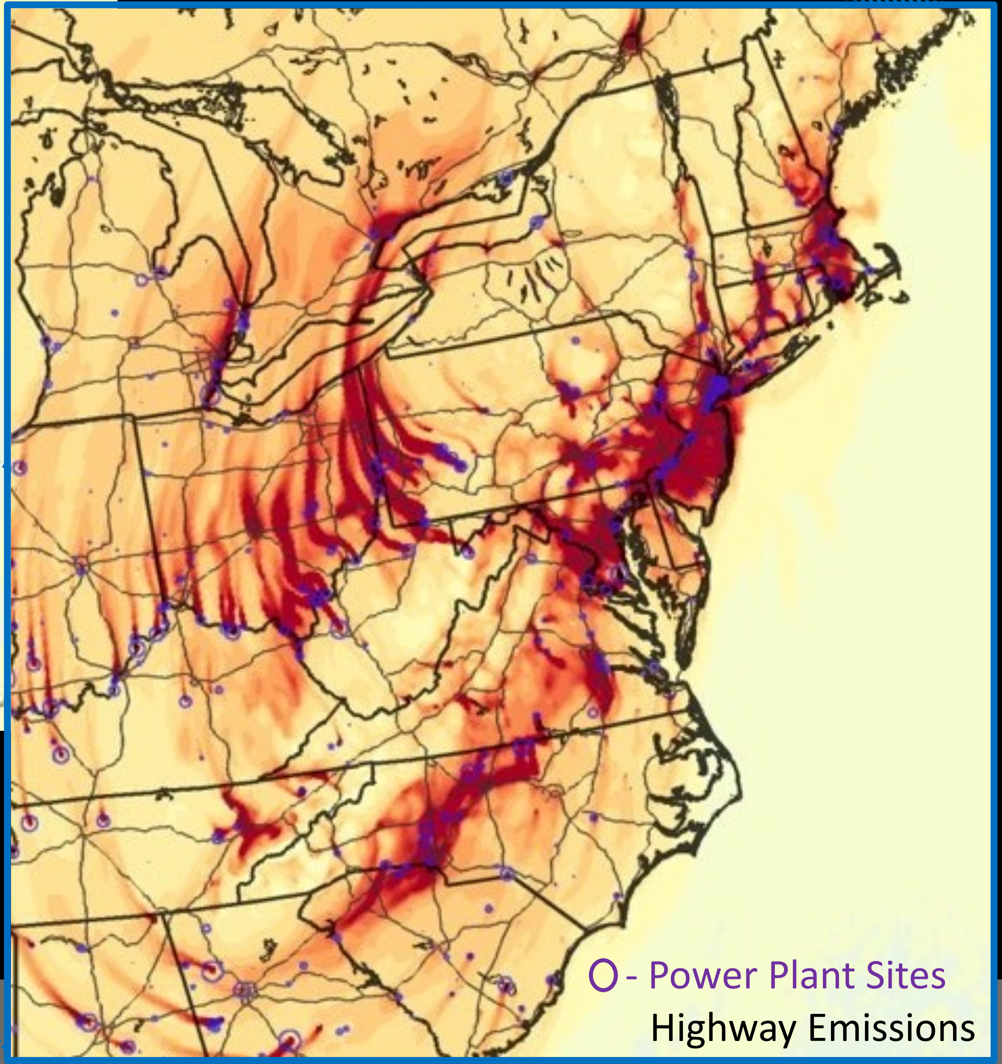
3km 181-Level Global GEOS Atmosphere
FV3 Dynamical Core : GFDL Microphysics
Interactive Clouds, Aerosols, Carbon (CO_2 & CO)
3D Output Frequency 3600s
2D Output Frequency 900s
Radiation DT 900s
Physics DT 150s
Acoustic DT 4.8675s
Precipitation Rate [mm/hr]
0.1 0.2 0.3 0.5 1 2 3 5 10 20 50
Surface CO2 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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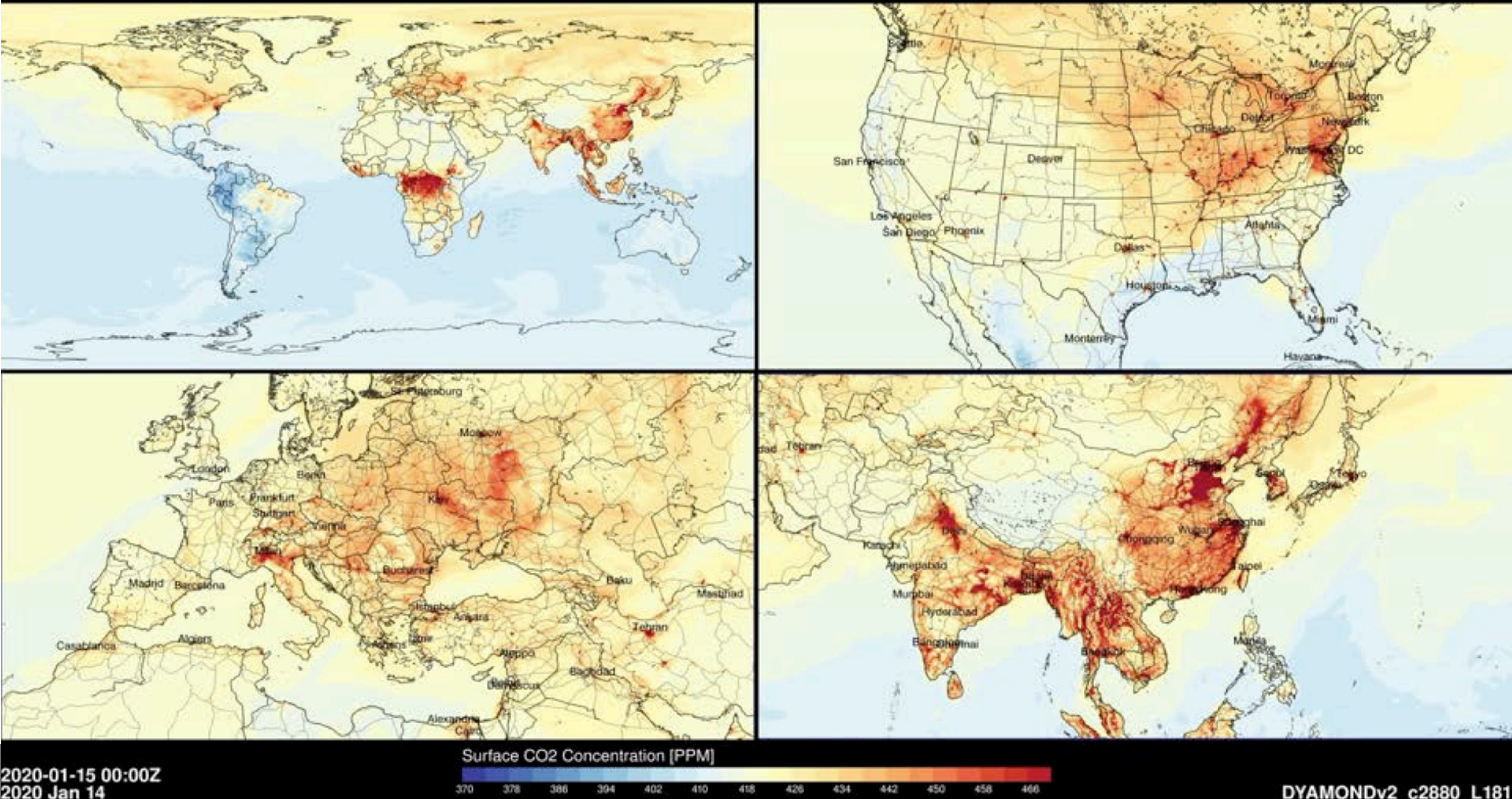

2020-01-15 00:00Z
2020 Jan 14

DYAMONDv2_c2880_L181

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3km 181-Level Global GEOS Atmosphere

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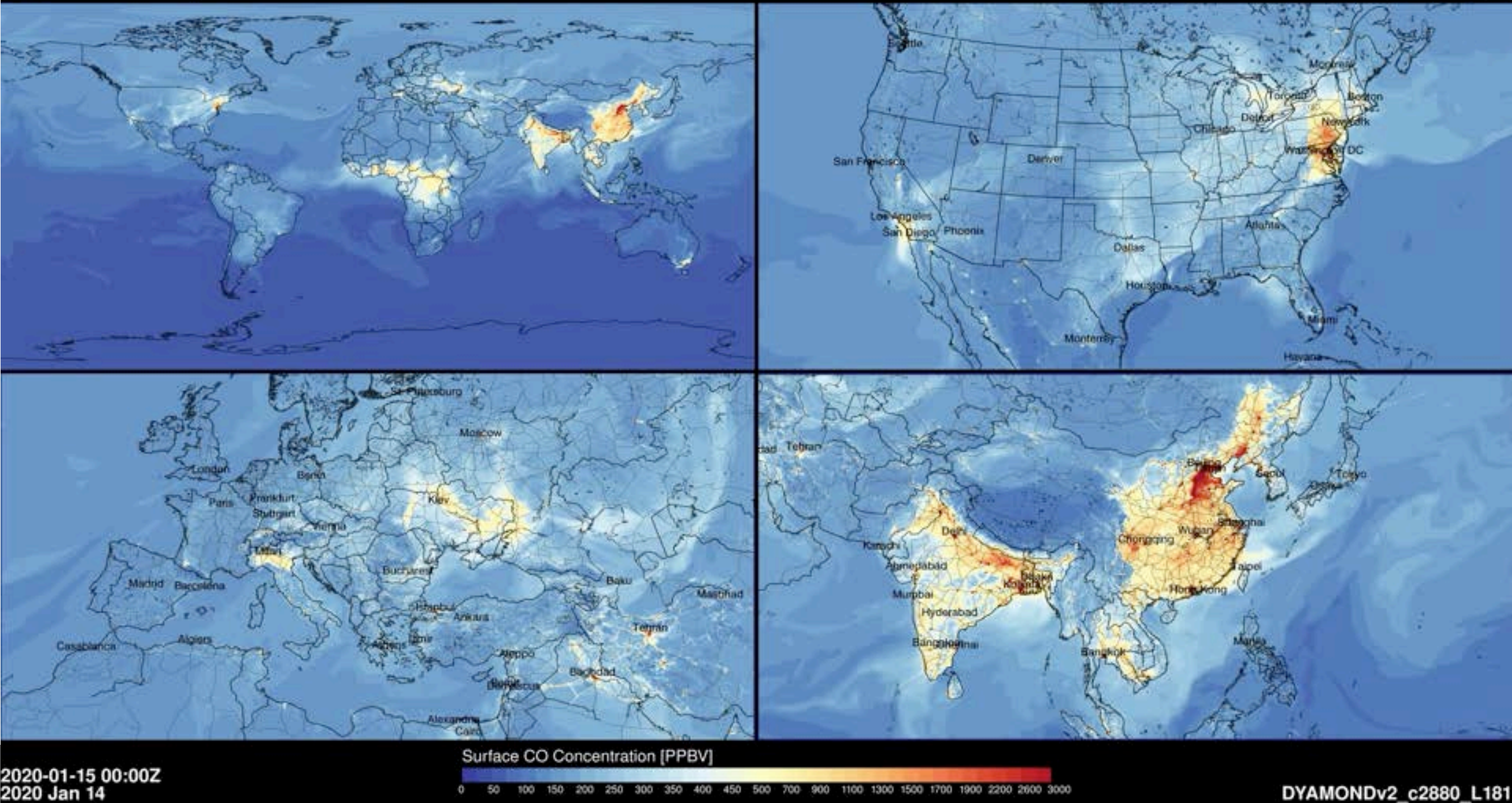

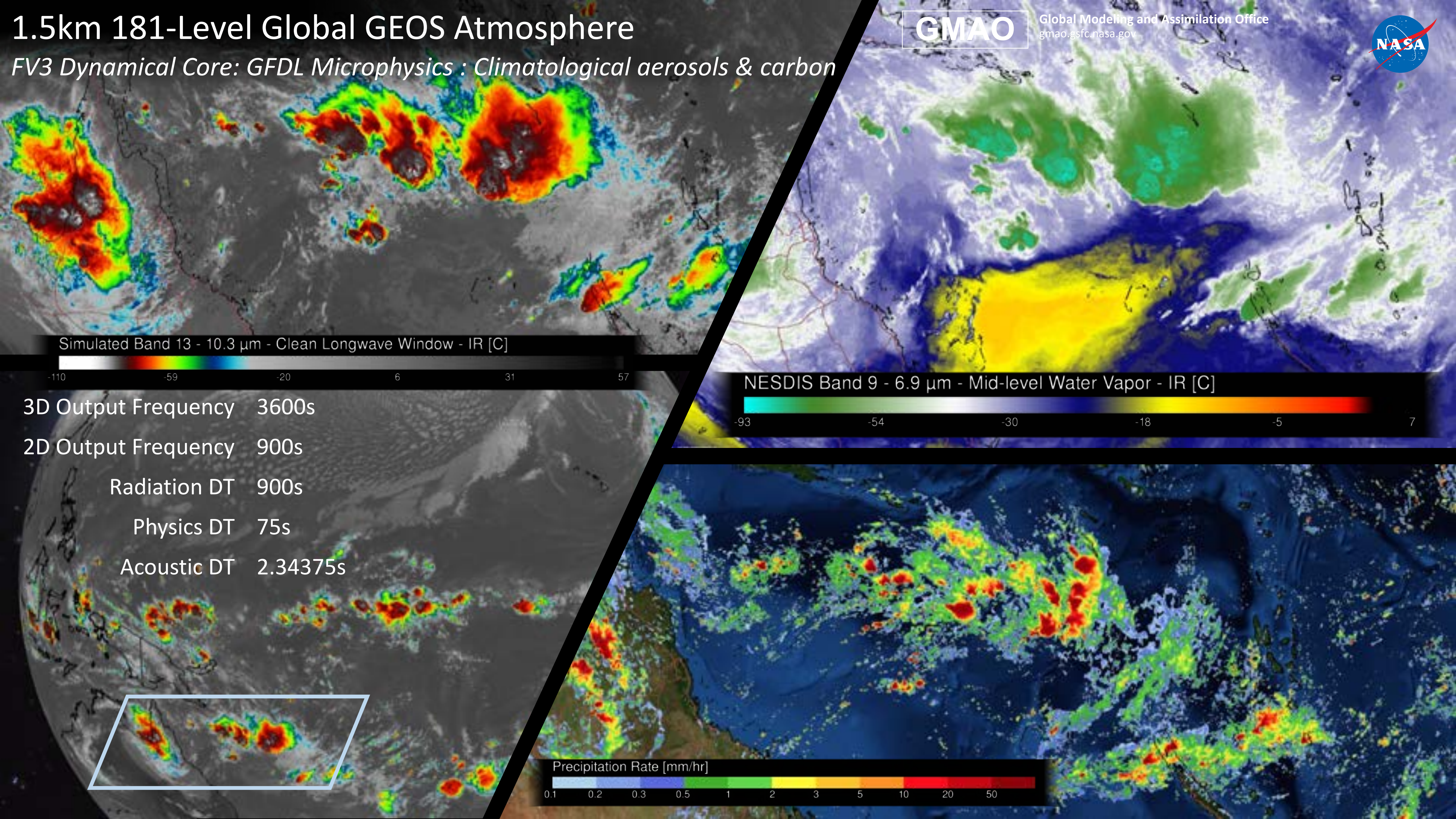
1.5km 181-Level Global GEOS Atmosphere
FV3 Dynamical Core: GFDL Microphysics : Climatological aerosols & carbon
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Simulated Band 13 - 10.3 µm - Clean Longwave Window - IR [C]
-110 -59 -20 6 31 57
3D Output Frequency 3600s
2D Output Frequency 900s
Radiation DT 900s
Physics DT 75s
Acoustic DT 2.34375s
NESDIS Band 9 - 6.9 µm - Mid-level Water Vapor - IR [C]
-93 -54 -30 -18 -5 7
Precipitation Rate [mm/hr]
0.1 0.2 0.3 0.5 1 2 3 5 10 20 50

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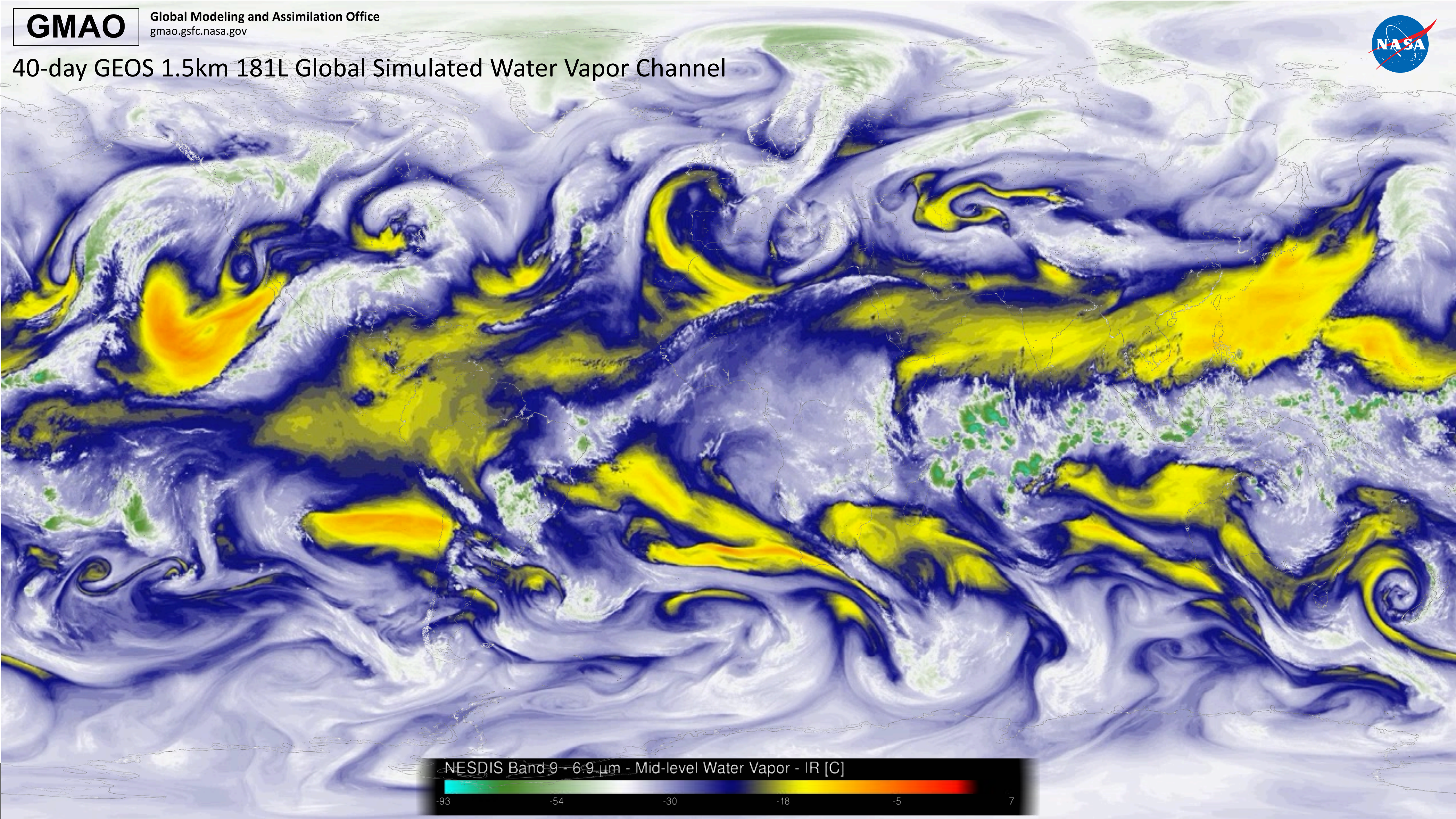
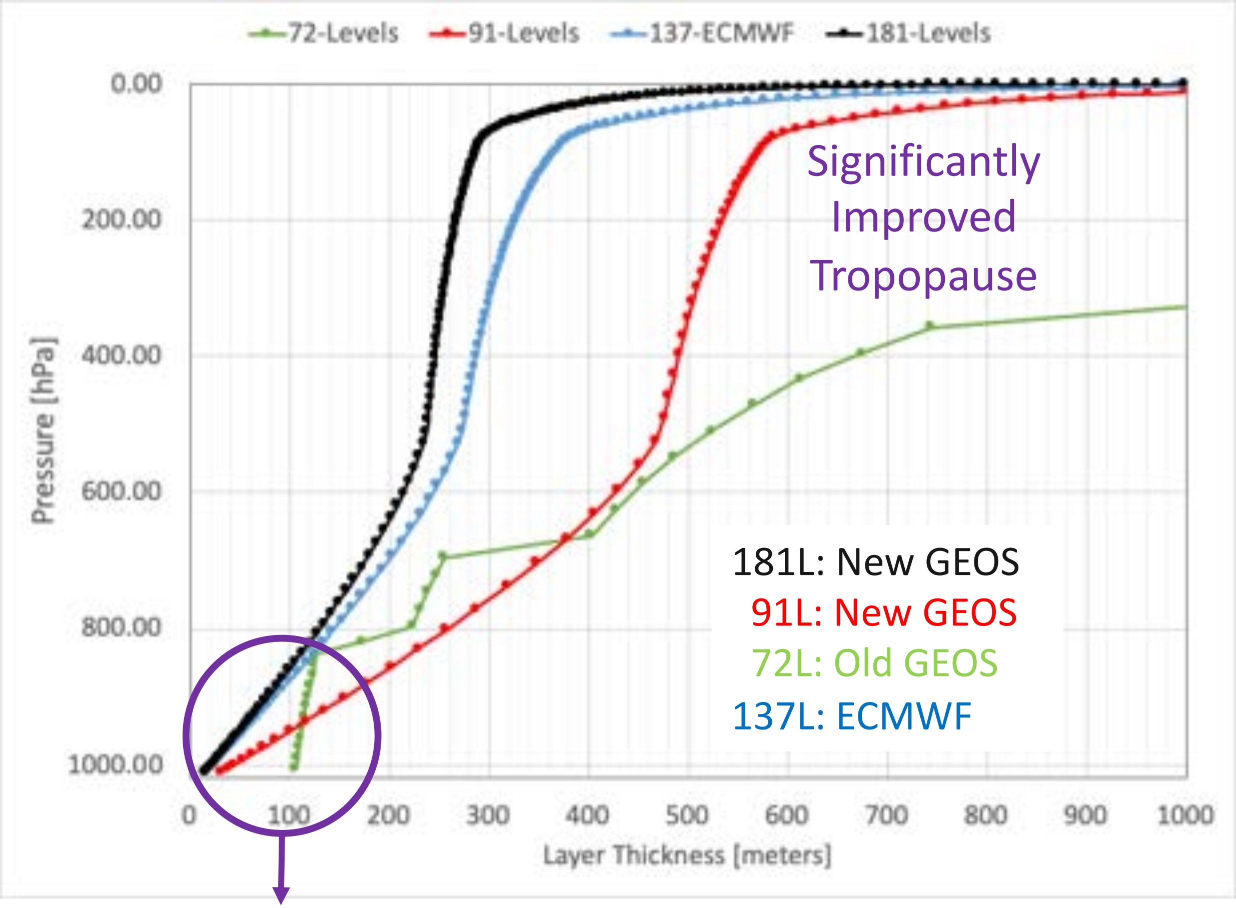
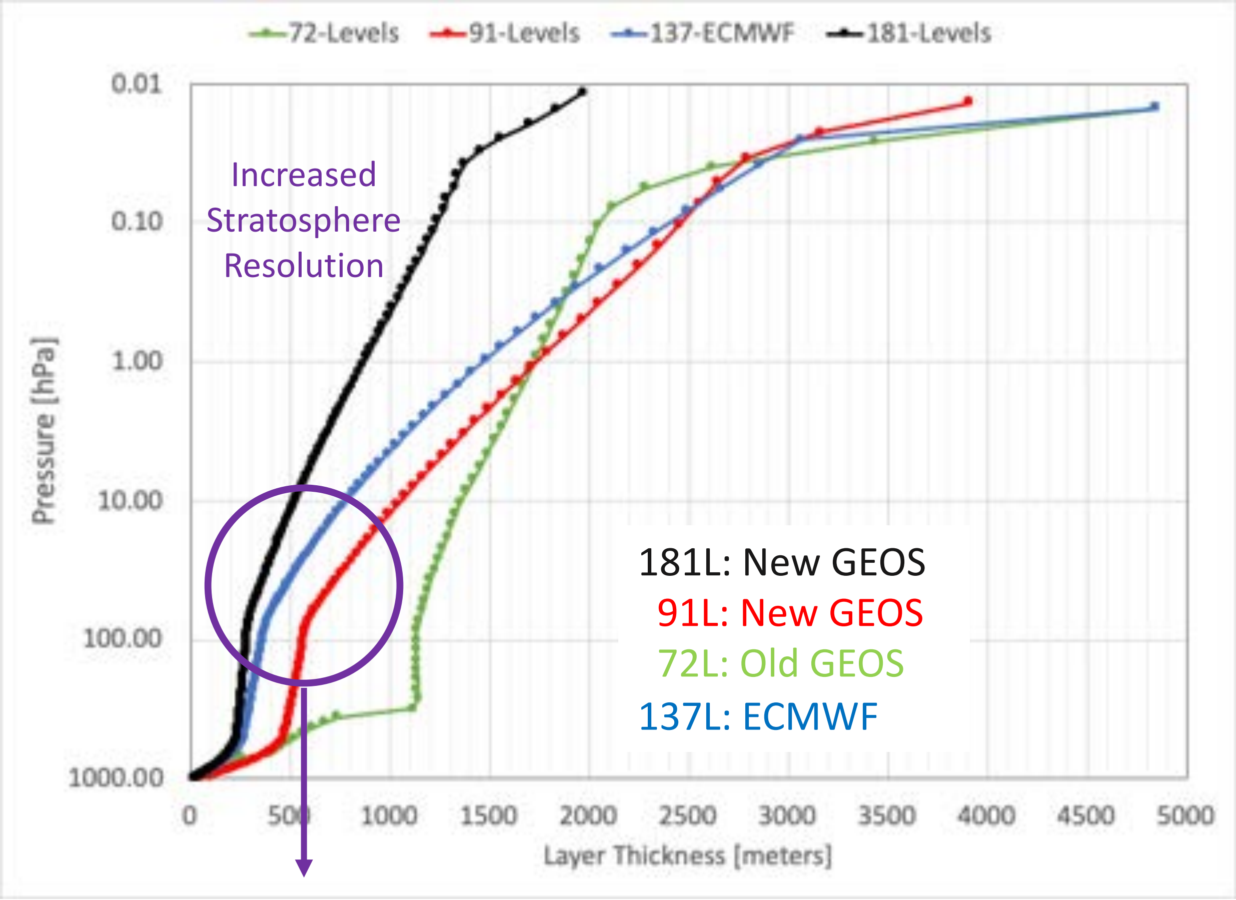
40-day GEOS 1.5km 181L Global Simulated Water Vapor Channel



GEOS 181 Vertical Levels

Smoother Delta-P and Delta-Z Profiles





Enhanced BL Resolution

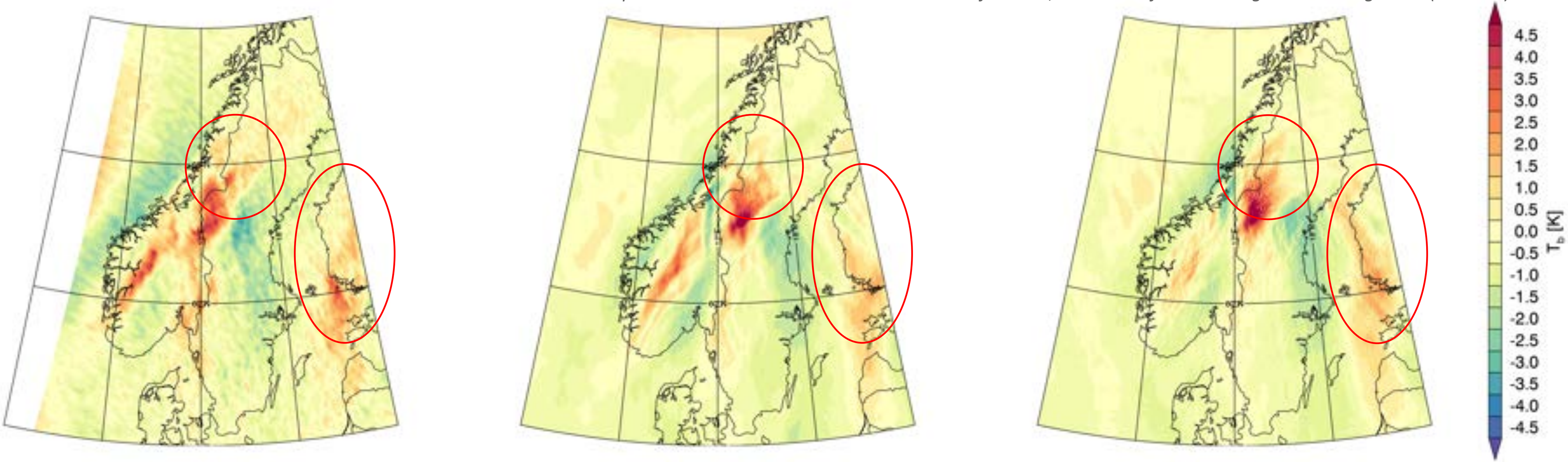
Delta-Z < 500m up to 10hPa:
Improved Downward Propagation of QBO

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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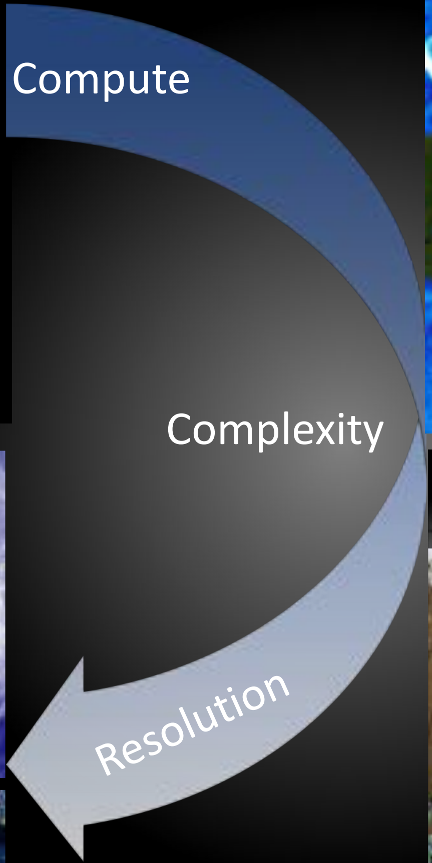

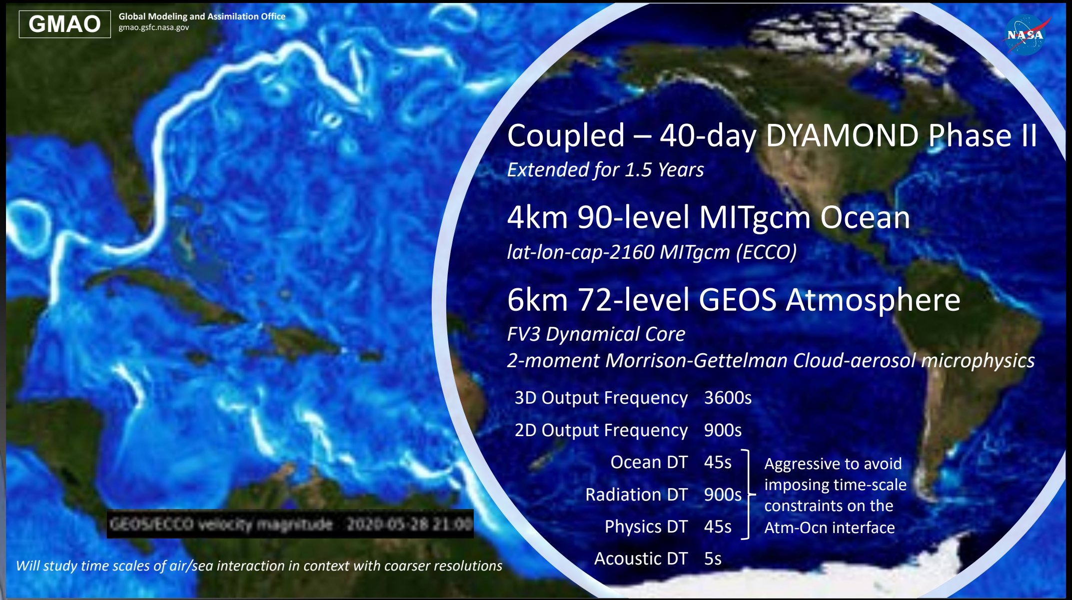

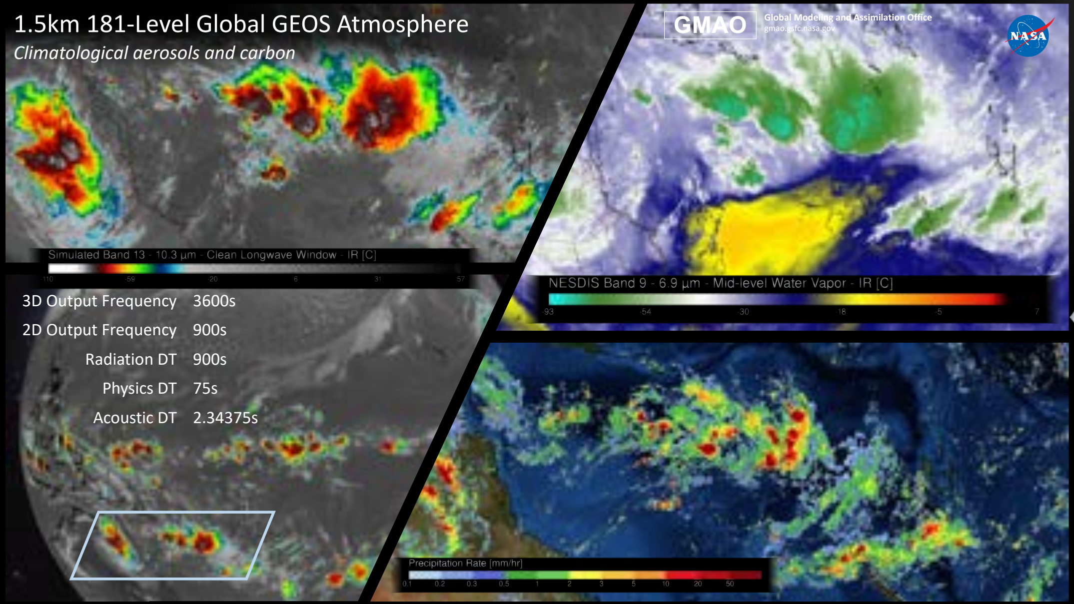

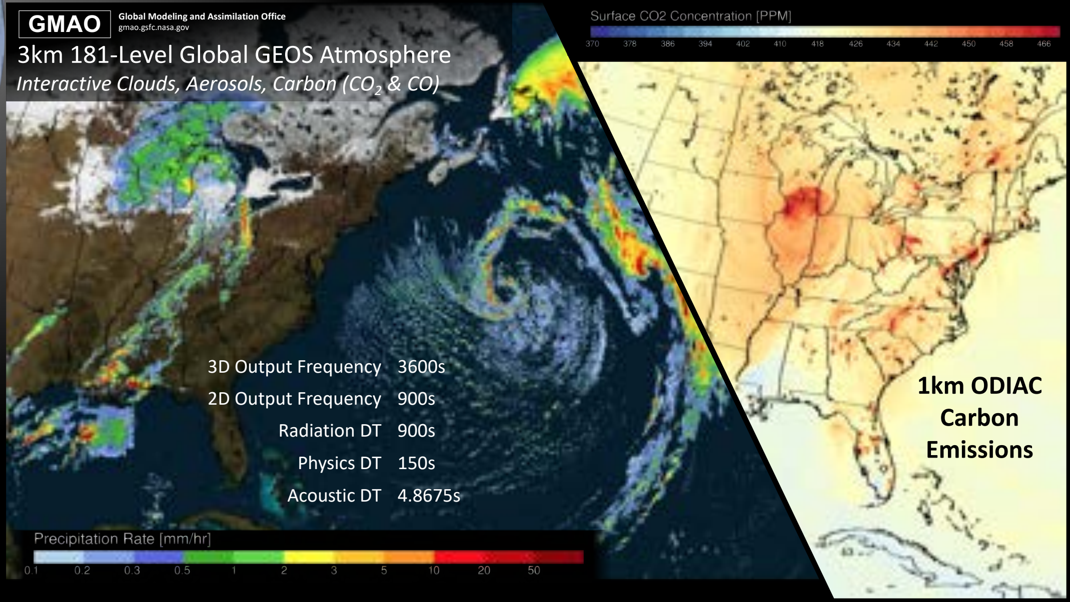

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