



Observing System Simulations for the AOS Mission

Arlindo da Silva*

Global Modeling and Assimilation Office

NASA/Goddard Space Flight Center

() with contributions from many at the AOS Team and GMAO*

2nd EarthCARE Modeling Workshop

Shizuoka, Japan – March 27-29, 2023



Outline

1. Brief Overview of AOS
2. AOS Modeling & Data Assimilation priorities
3. Observing System Simulations in AOS
 - The ACCP Study: Value Framework
 - Detailed and Fast simulators: framework
 - Toward Global Storm Resolving Nature Runs
4. Summary



EARTH SYSTEM OBSERVATORY

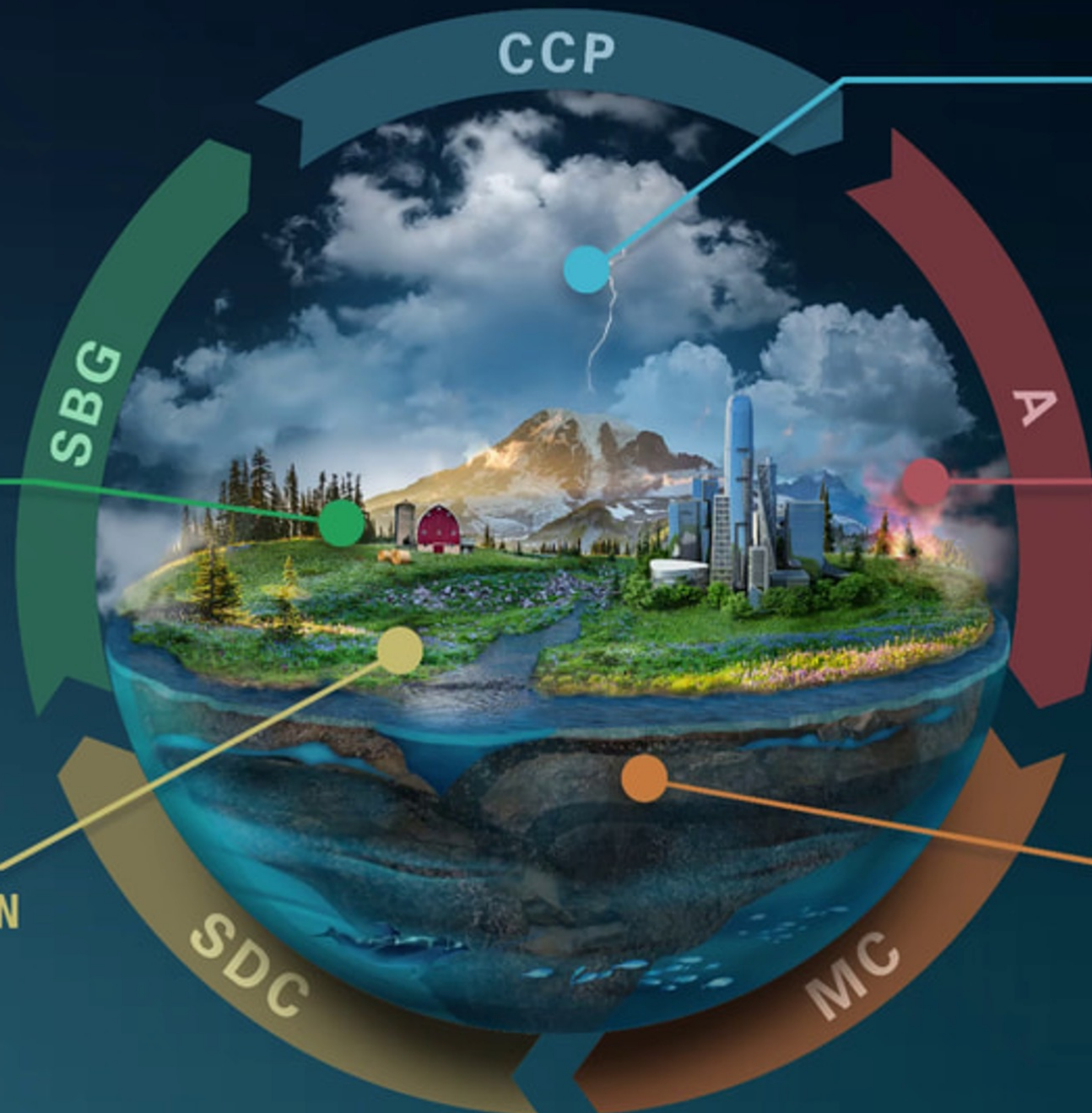
INTERCONNECTED
CORE MISSIONS

SURFACE BIOLOGY AND GEOLOGY

Earth Surface and
Ecosystems

SURFACE DEFORMATION AND CHANGE

Earth Surface Dynamics



CLOUDS, CONVECTION AND PRECIPITATION

Water and Energy in
the Atmosphere

AEROSOLS

Particles in the
Atmosphere

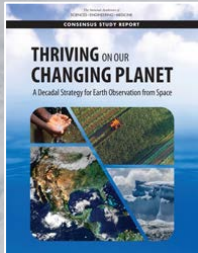
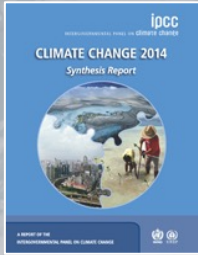
MASS CHANGE

Large-scale Mass
Redistribution

Atmosphere (AOS)

Decadal Survey Recommendations

**EARTH
SYSTEM
OBSERVATORY**



- ❖ The 2017 Decadal Survey recommended a new program element called *Designated Observables* with cost-capped missions to provide measurements essential to a comprehensive collection of Earth Science questions.
- ❖ AOS combines 2 Designated Observables

Aerosols

Aerosol properties, aerosol vertical profiles, and cloud properties to understand their effects on climate and air quality

Backscatter lidar and multi-channel, multi-angle imaging polarimeter

Clouds, Convection, and Precipitation

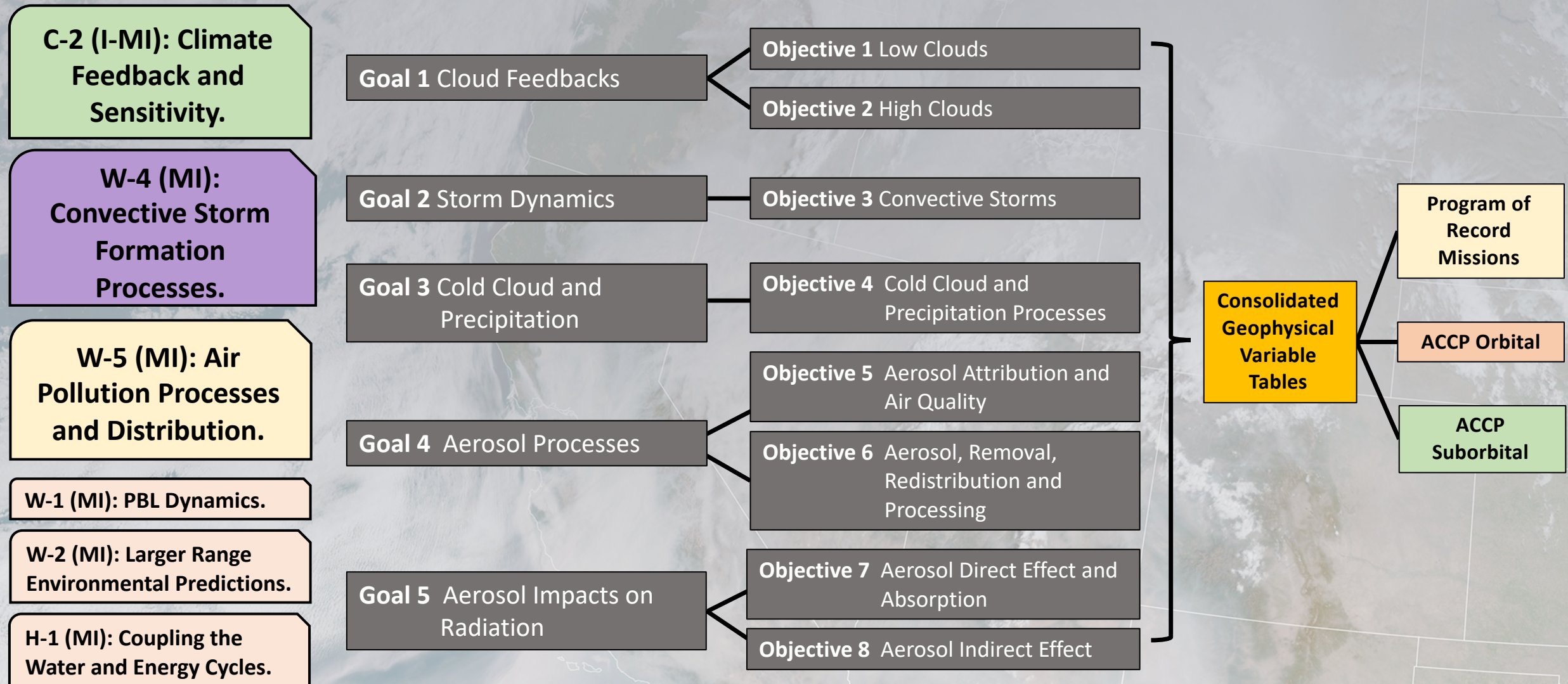
Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback

Radar(s), with Doppler, with multi-frequency passive microwave and sub-mm radiometer

Observable Priorities

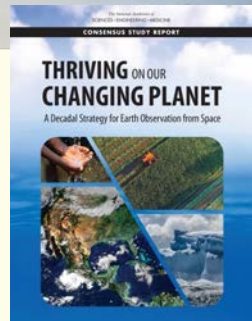
Desired Observables

AOS Science and Applications Traceability Flow



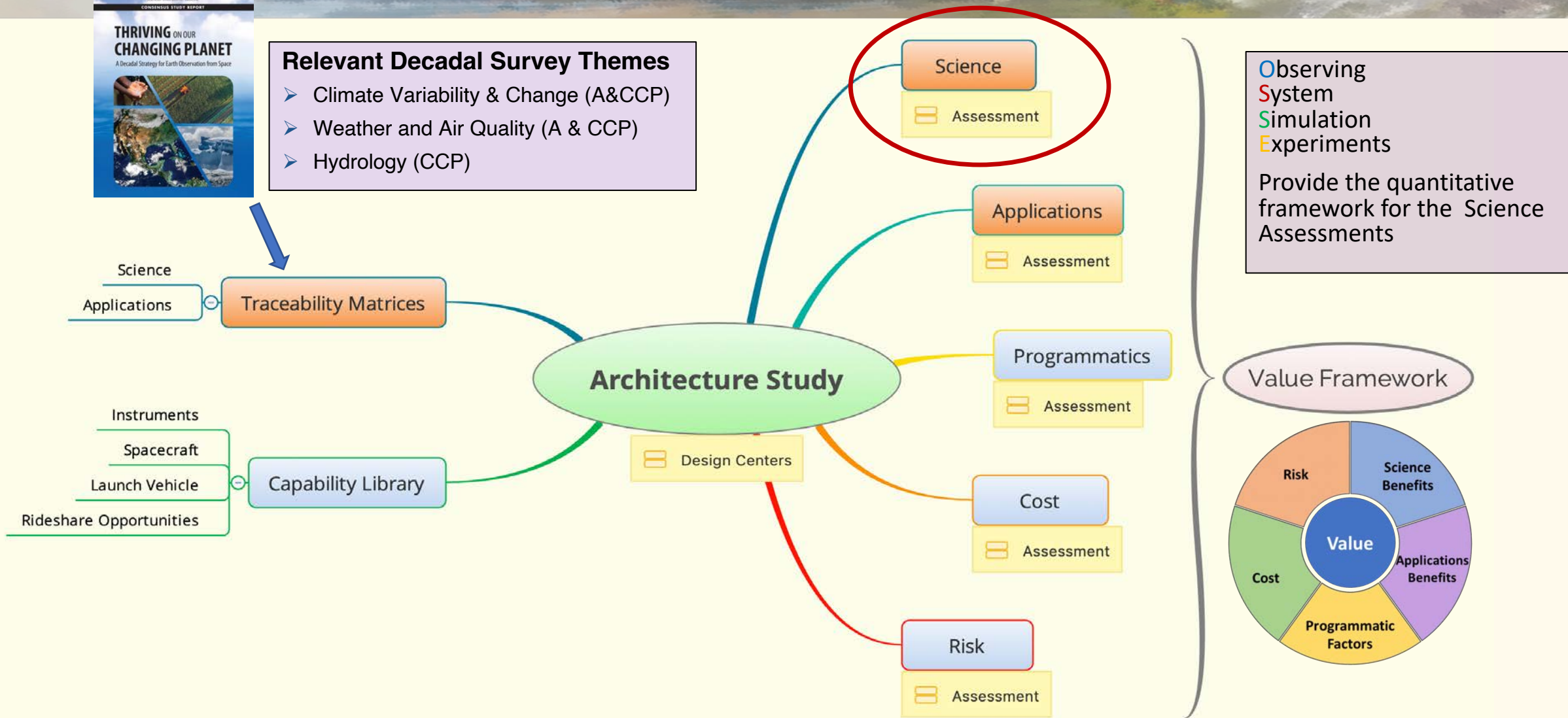


ACCP Study: Value Framework



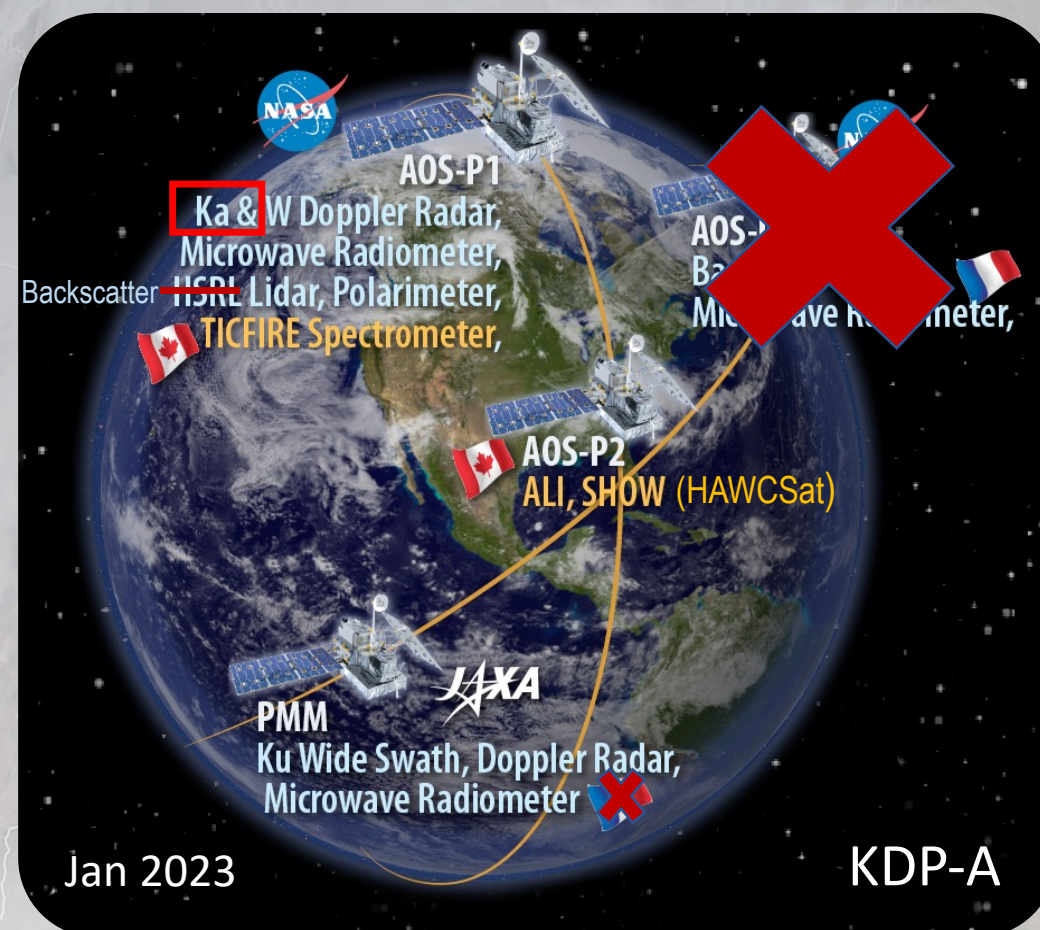
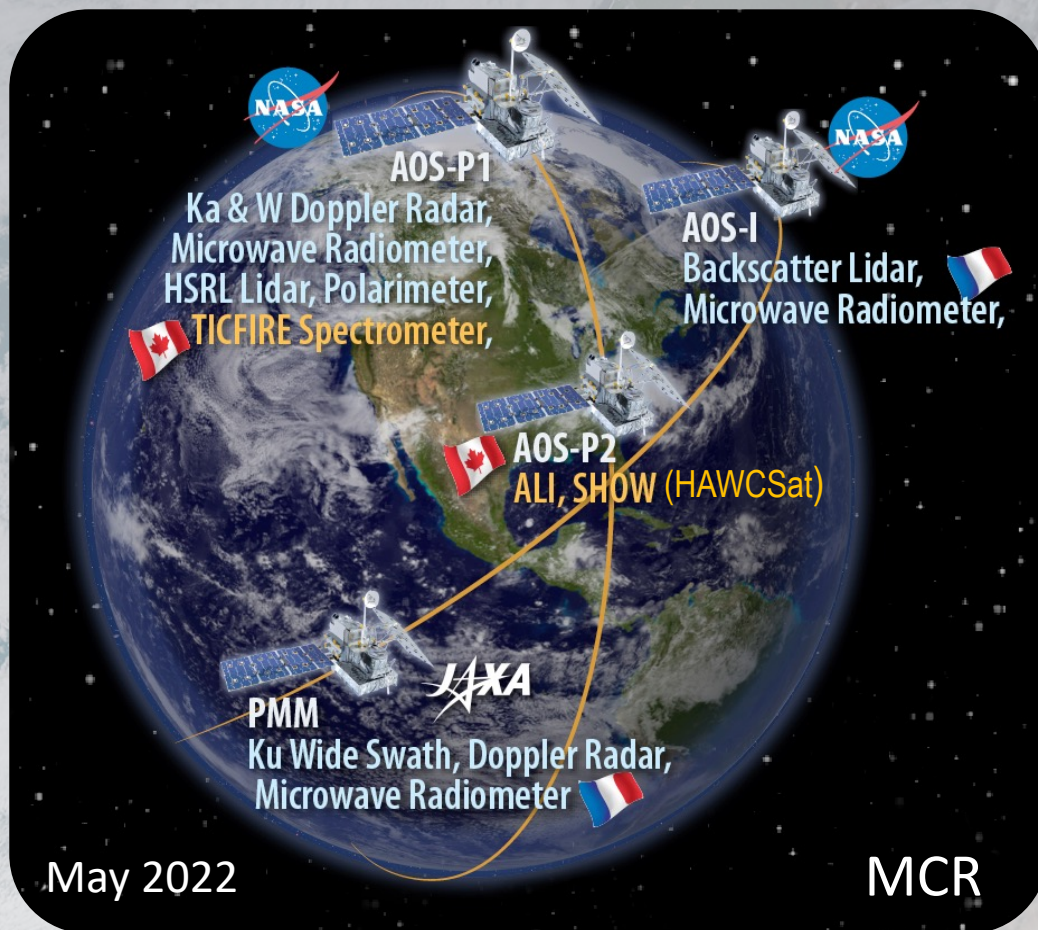
Relevant Decadal Survey Themes

- Climate Variability & Change (A&CCP)
- Weather and Air Quality (A & CCP)
- Hydrology (CCP)



AOS Architectures

**EARTH
SYSTEM**
OBSERVATORY



Launch: **Inclined** 12/2029 **Polar**: 12/2031

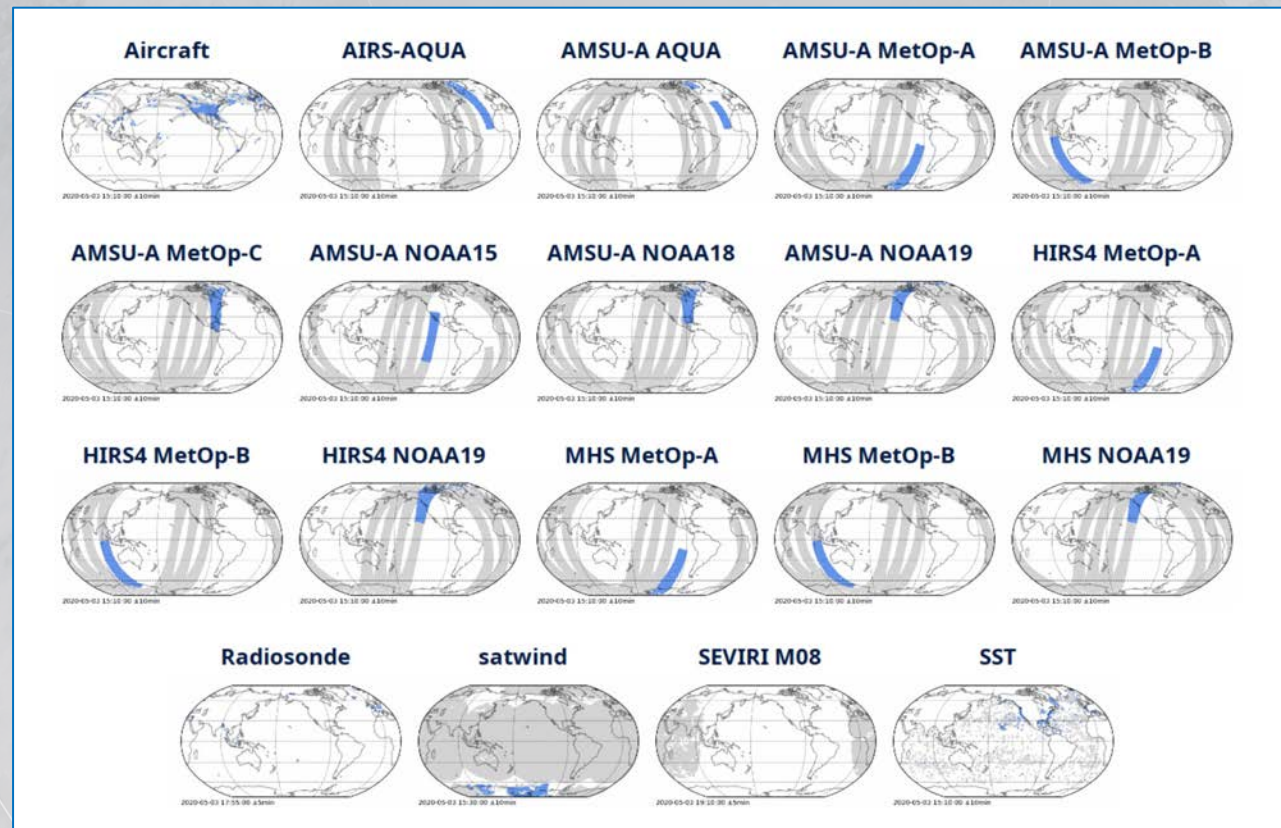


AOS Modeling & DA Priorities

- **Support and accelerate critical development activities**
 - Nature Runs and generation of instrument observables for algorithm development and evaluation
 - Suborbital campaign planning
- **Develop Modeling & DA capabilities for AOS**
 - Enable infrastructure for assimilation AOS data in NWP and atmospheric composition models (via the JEDI, CRTM)
 - Plan and Develop key **Level 4** products for AOS
 - **Develop COSP-like simulators for instrumenting climate models**

Data Assimilation of AOS Measurements

- Enable assimilation of key AOS **passive** measurements
 - Passive microwave (**all sky**)
 - Polarimeter (clear & above cloud aerosols)
 - Develop appropriate infrastructure in the **JCSDA JEDI Framework** for the benefit of multiple NWP forecasting centers.
- Explore assimilation of AOS **active** measurements
 - Radar and lidar assimilation are currently active topics of research
 - Expect assimilation of radar and lidar to be mature by the end of the decade



All operational NWP instruments used at NOAA/NWS/EMC for global GFS forecasts have been implemented in JEDI's Unified Forward Operator (UFO) component.

<https://www.jcsda.org/jcsda-project-jedi>

Fast Simulators: A Framework

• Goals

- Develop fast observation simulators to instrument climate/NWP models
 - Similar to COSP.
- Provide traceability to AOS Level 2 algorithms
 - Every time a L2 algorithm is updated, a consistent *fast simulator* is also released.

• Approaches

- Simplified analytical approximations, OR
- ✓ Machine Learning model trained on *detailed simulator of operational retrievals*
 - Enables traceability to operational retrievals as they evolve

• Detailed Retrieval Simulators

- Sample GSR Nature Run on instrument footprint
- Simulate observables
- Run operational retrieval code on these synthetic measurements



MODIS Cloud & Aerosol Retrieval Simulator

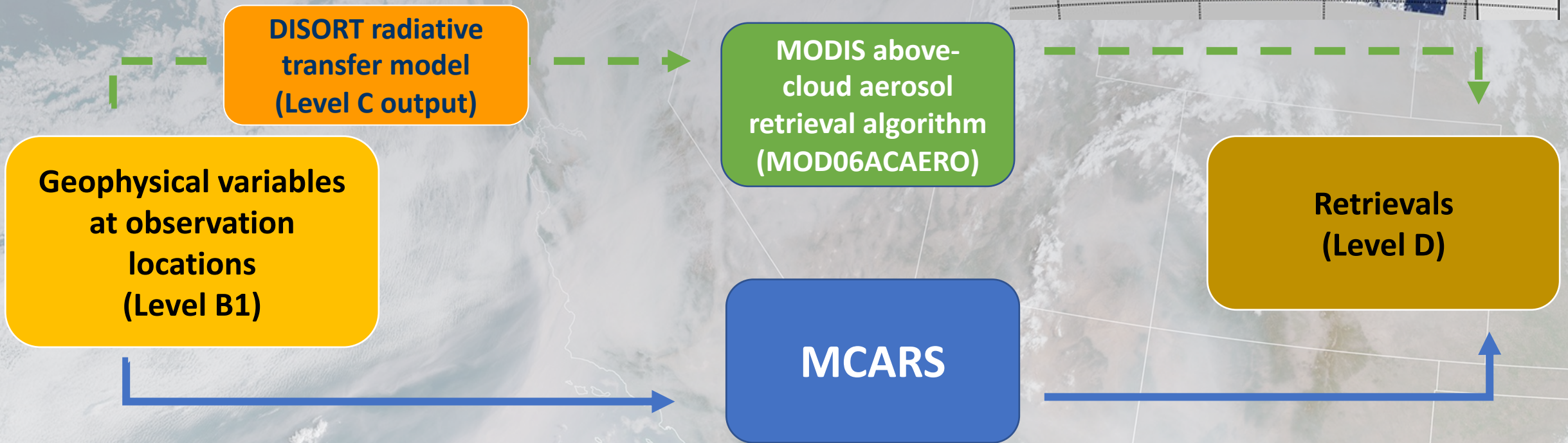
**EARTH
SYSTEM**
OBSERVATORY

- Algorithm proofing sandbox
- 1km MODIS sensor geometry + 7km GEOS-5 Nature Run + Total Water PDF sampling to go from 7km to 1km
- 25 MODIS channels (410nm – 14.2 μ m)
- Correlated-k atmospheric transmittance model
- DISORT-5 radiative transfer core
- Output to standard 1-km MODIS radiance file using [pdf-based downscaling](#)
- Runs on [operational](#) MODIS algorithms
- Any data product code runs as if presented with real data, no awareness of radiance source
- Can examine retrieval code in fine detail
- HPC application (400 processors, 8.5 hours wall-clock-time, 32 streams per granule)

Wind et al. 2013, 2016, 2022.

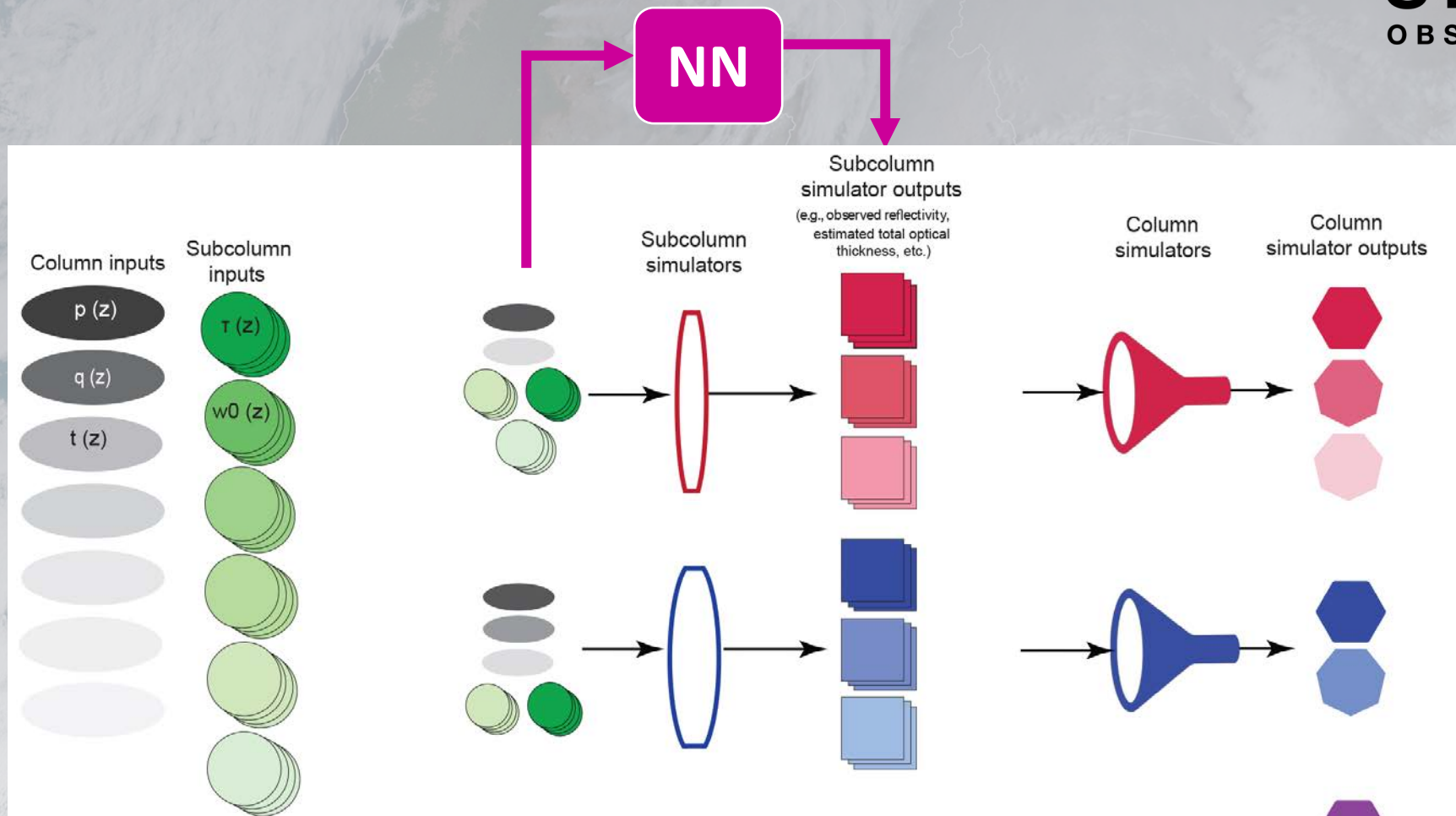


Proof of Concept: NN Surrogate for MCARS



AOS Retrieval Emulators in COSP v2

**EARTH
SYSTEM
OBSERVATORY**



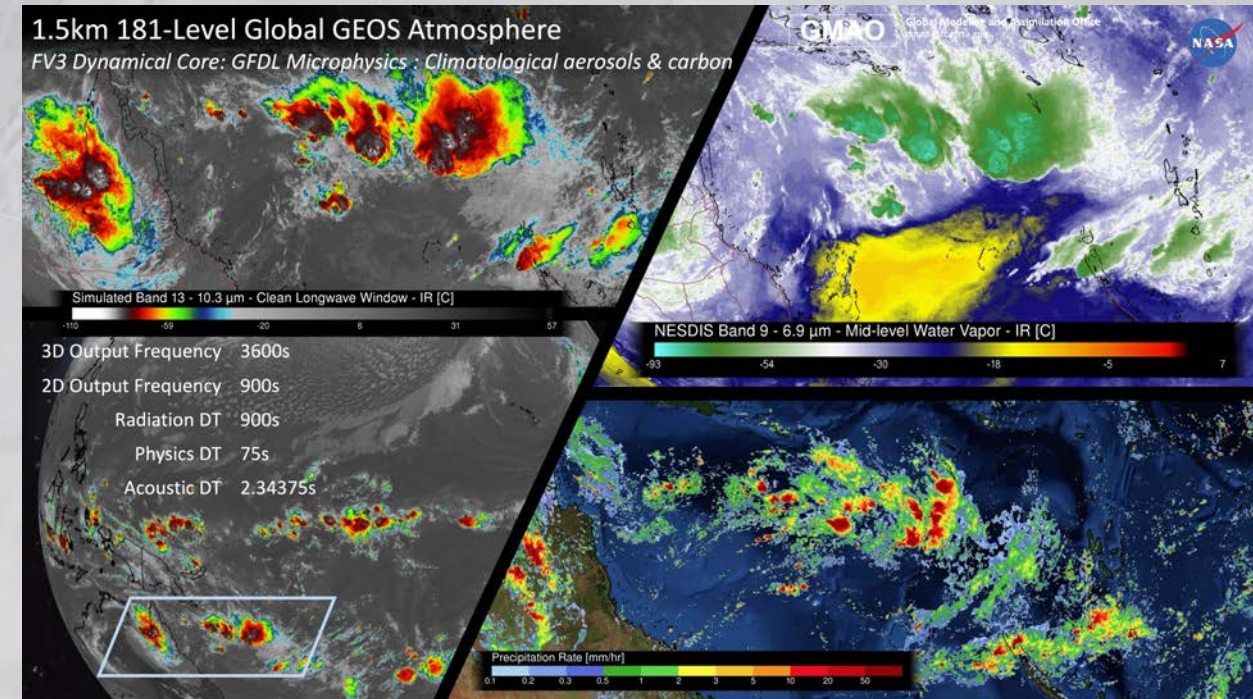
Goals

- Enable global storm resolving Observing System Simulation Experiments (OSSEs)
- Enable simulation of past, present and future observing systems from global storm resolving Nature Runs.
- Address computational challenges that prevent existing technologies from scaling to spatial resolutions that will be needed by end of the decade.

Applications

- Leverage and engage the [Joint Effort for Data Assimilation Integration \(JEDI\)](#) community by providing simulation of NWP observing system including all-sky radiances, accounting for the effect of aerosols
- Engage the [Earth System Observatory](#) (DSO) missions in development (AOS, SBG) by providing atmospheric Nature Runs for realistic observing system simulations enabling algorithm development, science and application demonstrations well before launch.

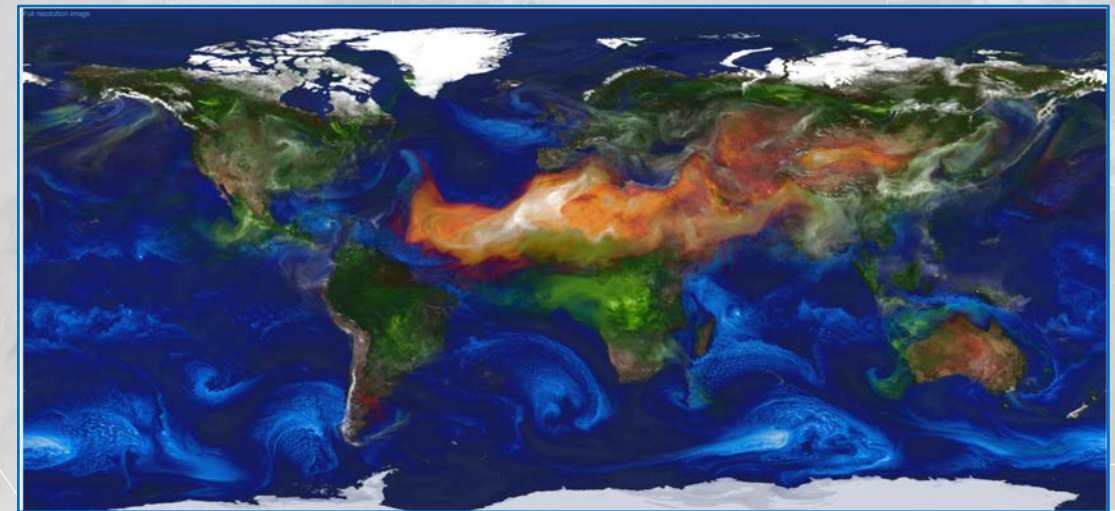
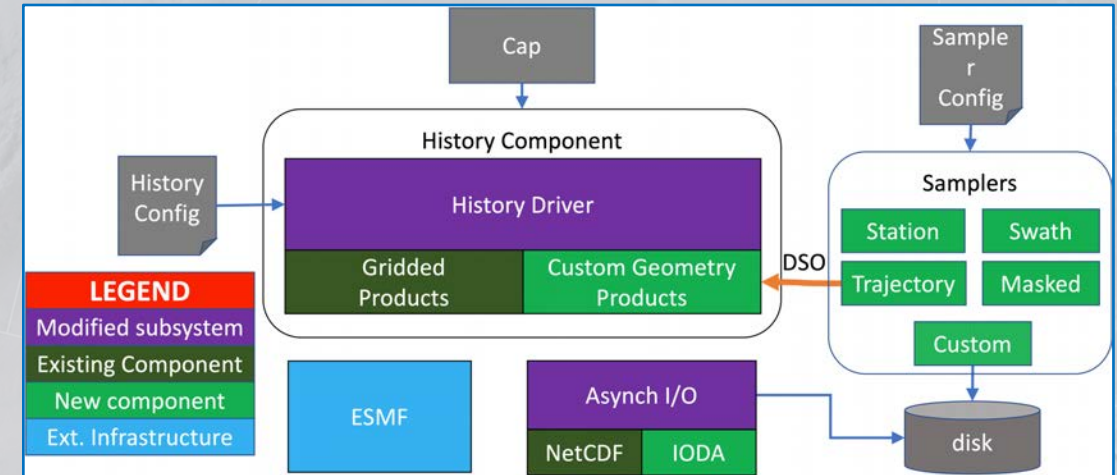
GEOS Non-Hydrostatic DYAMOND Phase-II Simulation



- **Traditional I/O based approaches for Nature Run generation are not practical.**
- **The increased spatial and temporal resolution of GSR simulations require exabytes of storage for 1 year simulation.**

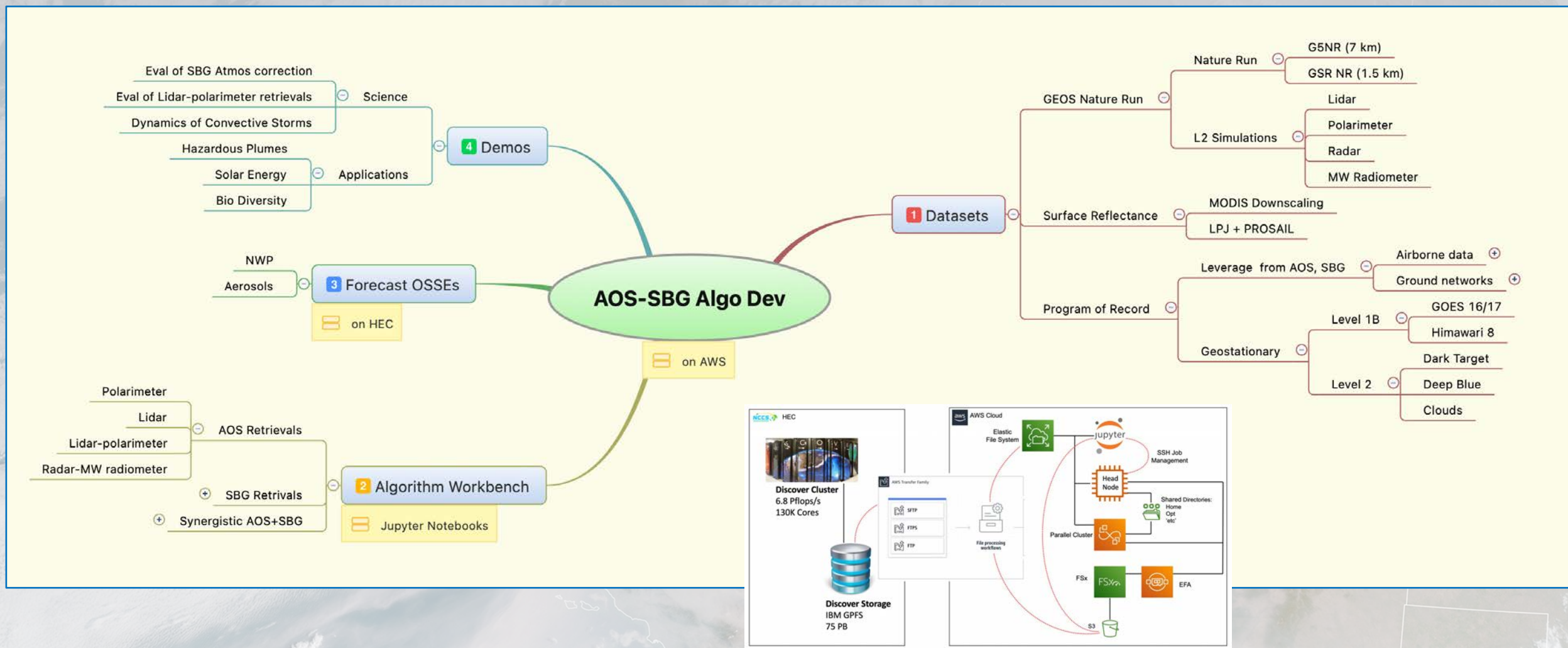
Two-phase Approach for GSR Nature Runs

- Extend parallel I/O capabilities of the GEOS model by including on-line sampling of *Geophysical Variables* at observation locations
 - ground stations, aircraft trajectories, satellite swaths
- Two-phase workflow for generating Nature Runs
 - 1) Model is spun up in a run with limited output except for frequent checkpoints and browse products
 - 2) Model is run from spun up checkpoints with output sampled at user specified observation locations
- Definition of a flexible API for custom geo-location samplers, allowing maximum flexibility



Machine Learning approaches being explored as an efficient device for “time interpolation”

AOS & SBG Analytic Collaborative on AWS





Summary

- In the next decade EarthCARE, INCUS and AOS will provide unprecedented measurements of aerosols, clouds convection and precipitation
- Following on the footsteps of EarthCARE, AOS will provide pre-launch a series of detailed and fast instrument simulators with traceability to algorithm versions.
- AOS is building DA capabilities for its instruments under the [JCDA JEDI Framework](#) for the benefit of many
- An [Analytic Collaborative Environment](#) is being established on AWS for algorithm development and early exploration of basic and applied science opportunities.



