

The Atmosphere Observing System (AOS): Future Space-Based and Suborbital Observations for the Study of Coupled Aerosol-Cloud-Precipitation Interactions

Scott Braun, NASA GSFC, AOS Project Scientist (PS)

Goddard Retiree Alumni Association
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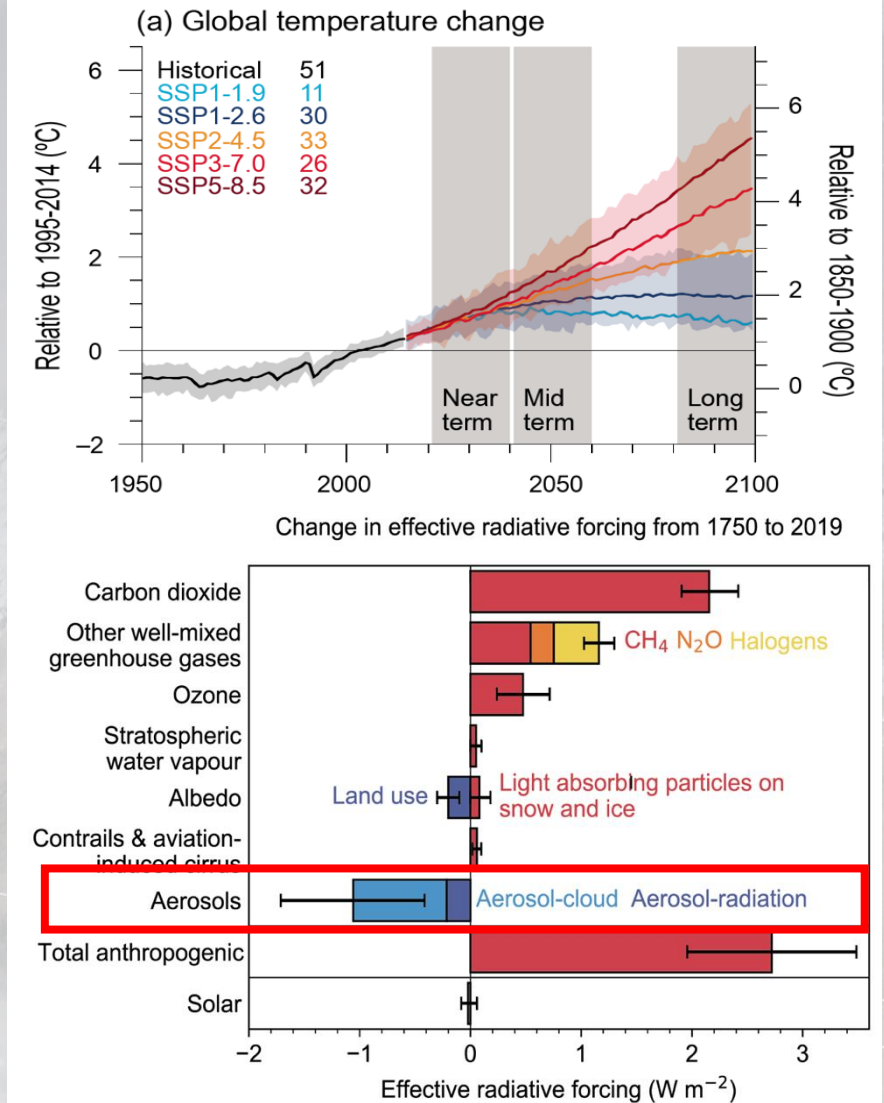
What Is AOS?

- AOS is a Decadal Survey mission that will deliver transformative space-based, airborne, and ground-based observations fundamental to understanding coupled aerosol-cloud-precipitation processes that profoundly impact weather, air quality and climate and play a critical role in feedbacks to the global water and energy cycles



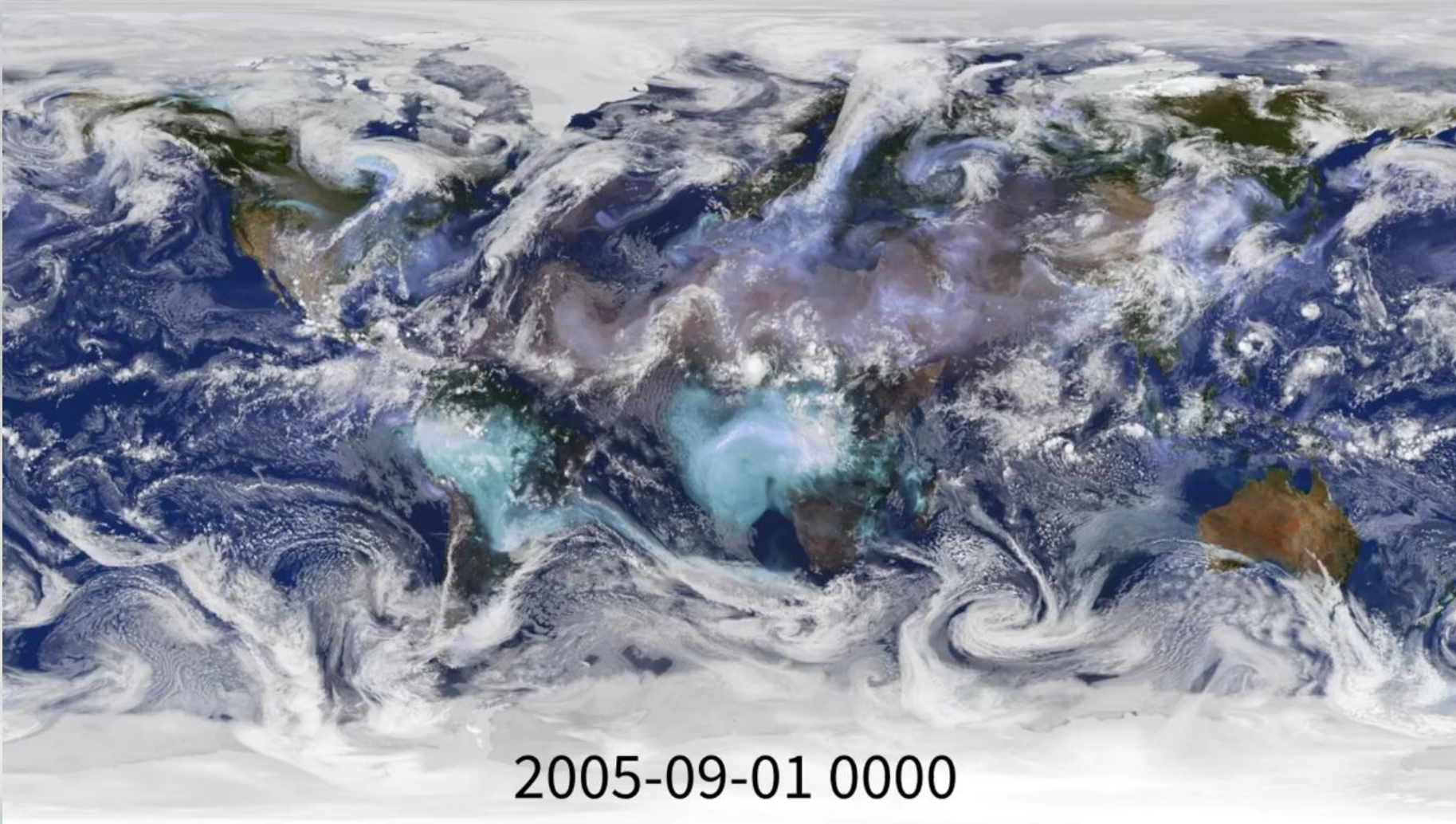
Why AOS Is Critical

- We are feeling the **impacts from climate change now**. Extreme weather events are increasing significantly and in 2022 alone, there were 18 weather/climate disaster events exceeding \$1 billion in the United States.
- The planet may reach **1.5°C warming in a decade**. The Earth system has moved from an era of linear to exponential change, driving a new era of surprises in how the Earth System responds to these changes.
- Interactions between aerosols, clouds and precipitation are the **largest source of uncertainty in climate models** and impact our ability to attribute past changes and make skillful projections.

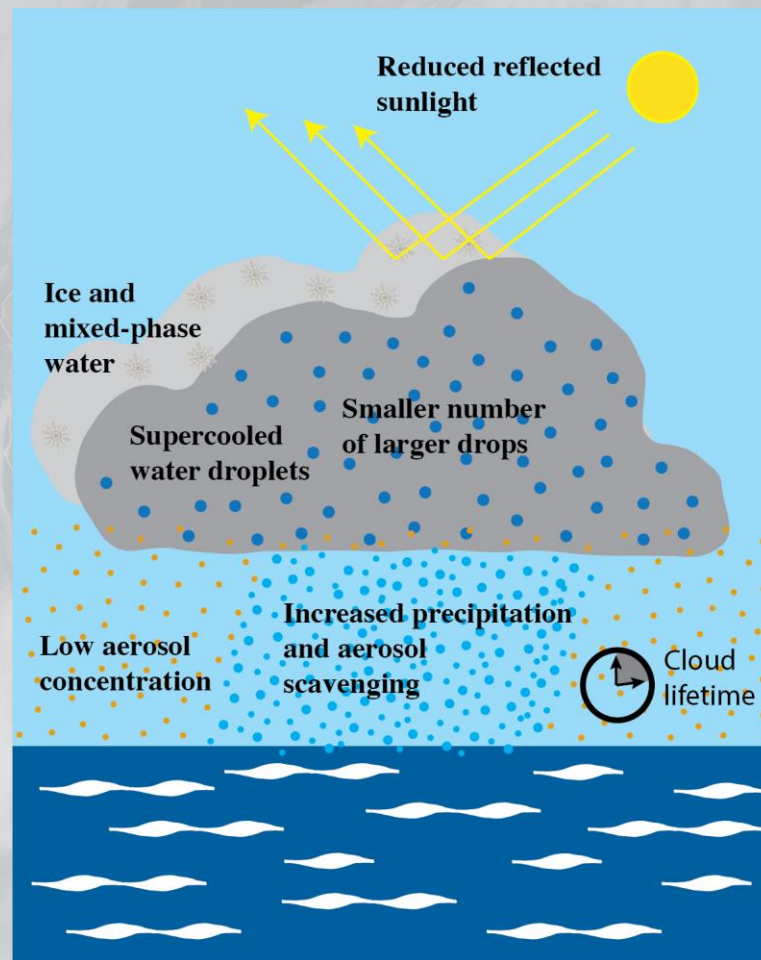
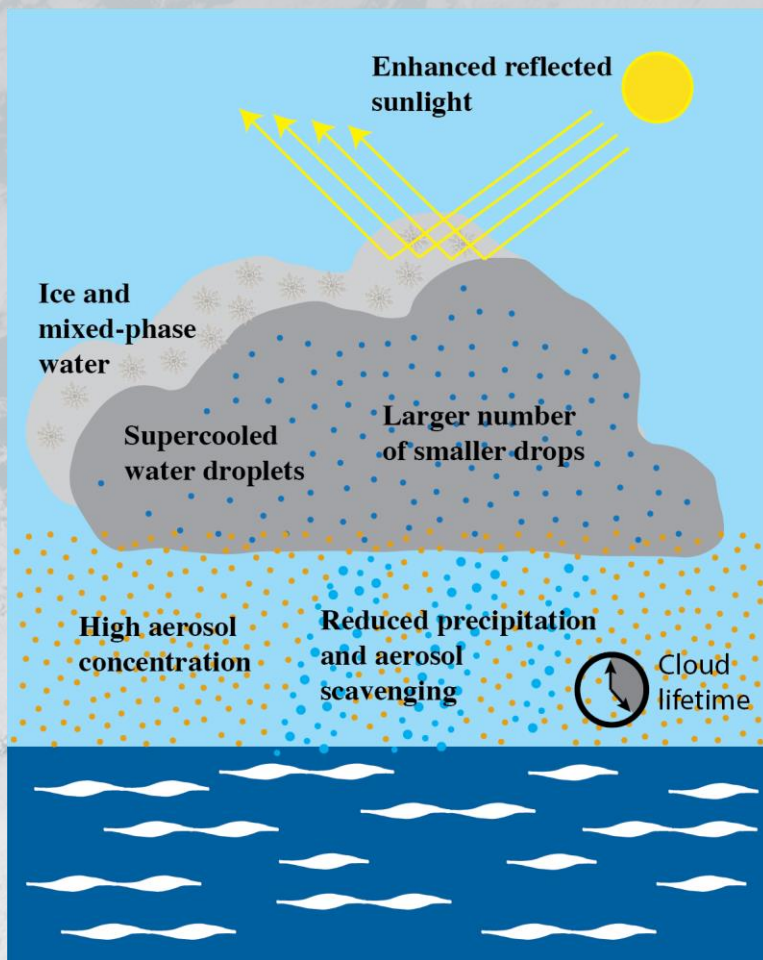


IPCC AR6 Report (Forster et al. 2021)

Aerosols and Clouds Coexist



Aerosol-Cloud-Precipitation Interactions



- Aerosols are critical to the formation and properties of clouds
 - Seeds of cloud formation
 - Impact precipitation development and cloud lifetime
 - Can change how clouds reflect or scatter radiation
- Interactions are key driver of uncertainty in radiative forcing of climate
- While still uncertain, aerosols may modify convection

Adapted from Stephens (2021) and Mülmenstädt et al. (2021)

The 2017 Decadal Survey Identified Aerosol-Cloud-Precipitation Interactions as Top Priority

AOS addresses priority science called out by *multiple* Earth Science Decadal Survey panels and related to *two* designated observables

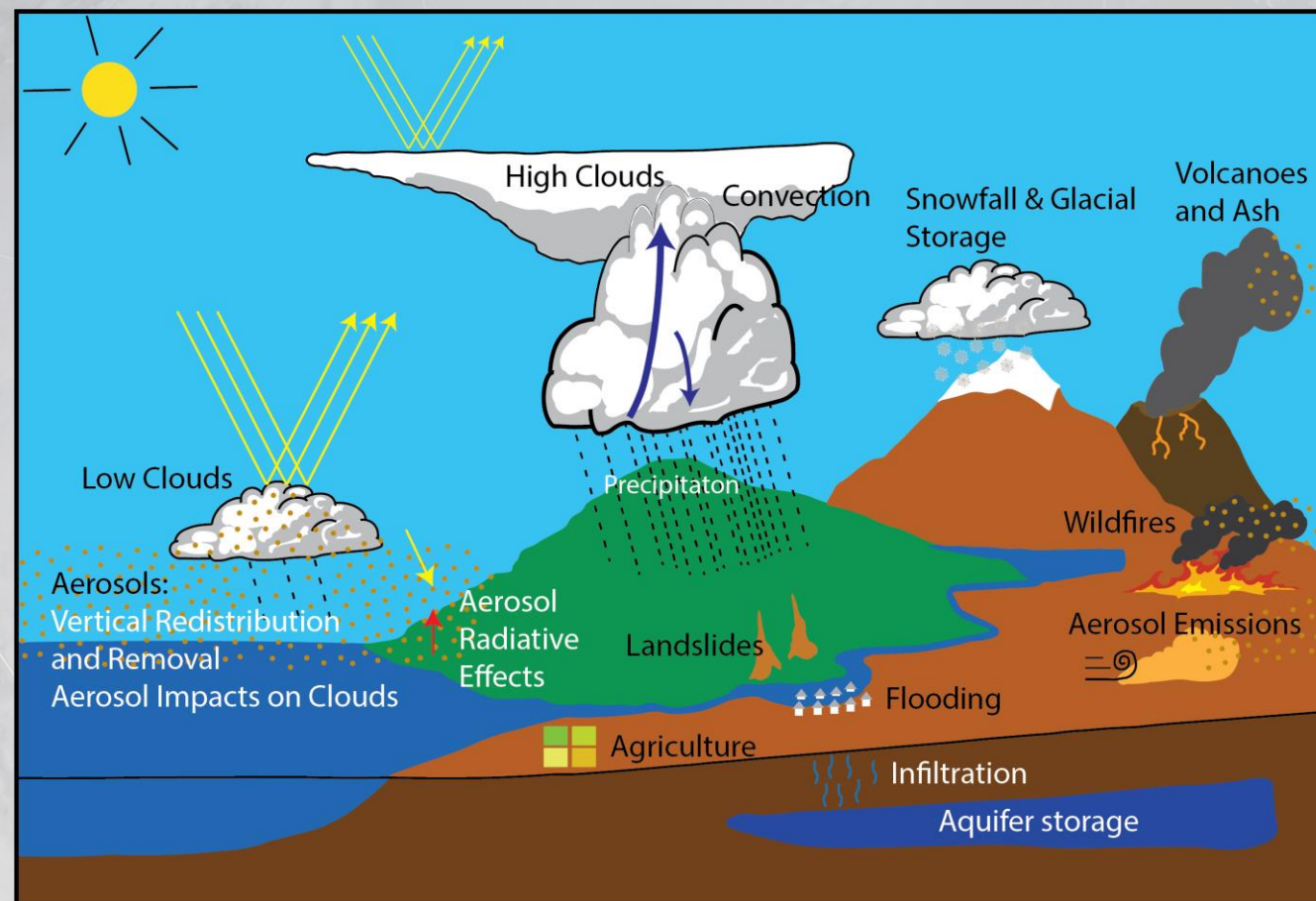
- Aerosols (A)
- Clouds, Convection, & Precipitation (CCP)

AOS focuses on three themes:

Climate sensitivity and feedback

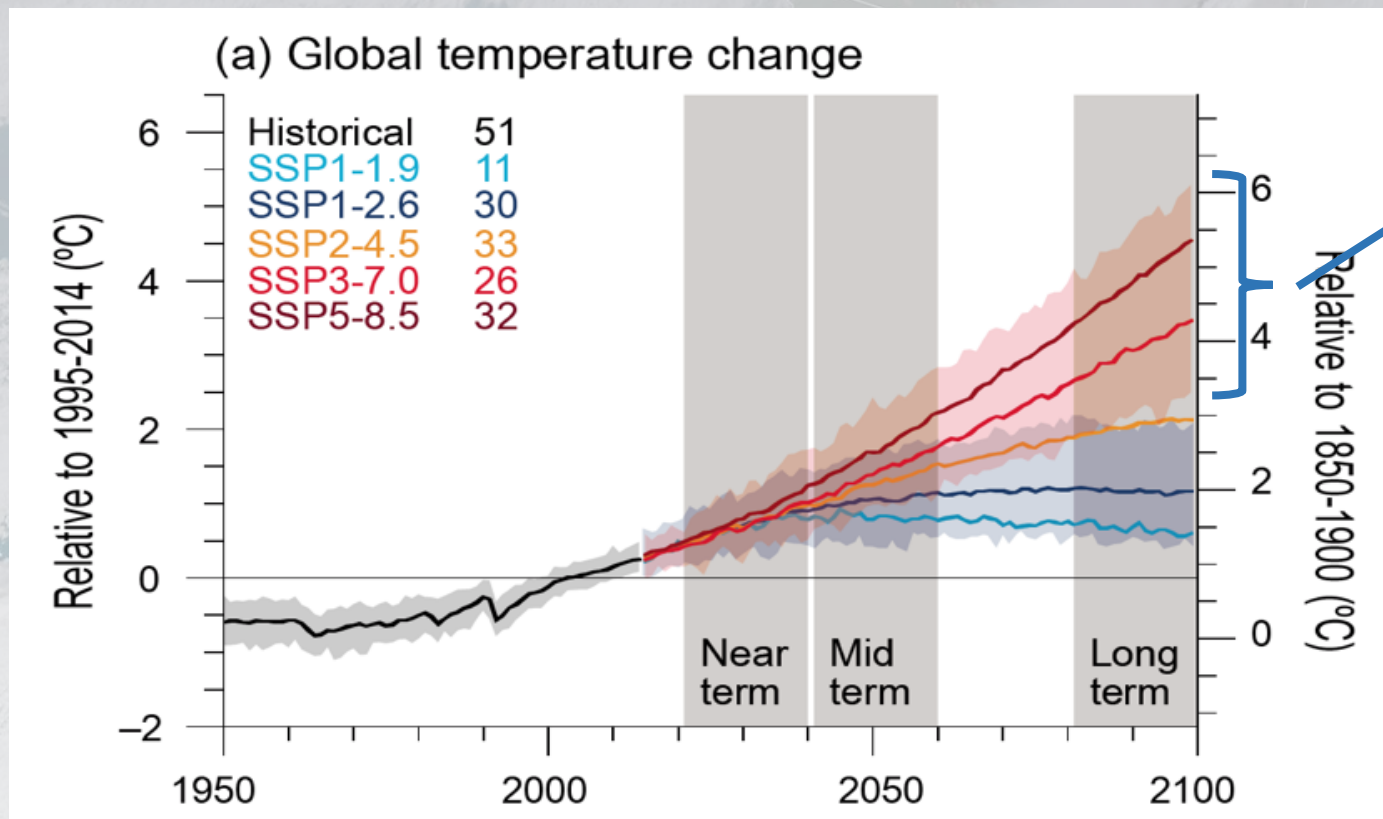
Convective storm formation processes

Aerosol distributions and processes



Theme 1: Climate Sensitivity and Feedbacks

1. CLIMATE: How can we improve our ability to predict local and regional climate response to natural and anthropogenic forcings and reduce the uncertainty in global climate sensitivity?



Projected future warming is highly uncertain. The two largest sources of uncertainty are

- the radiative forcing by aerosol that force the response and
- cloud feedbacks that define the response.

A seven-fold range in 'aerosol indirect radiative effects' results merely by changing how a model makes light rain (Jing and Suzuki, 2019)

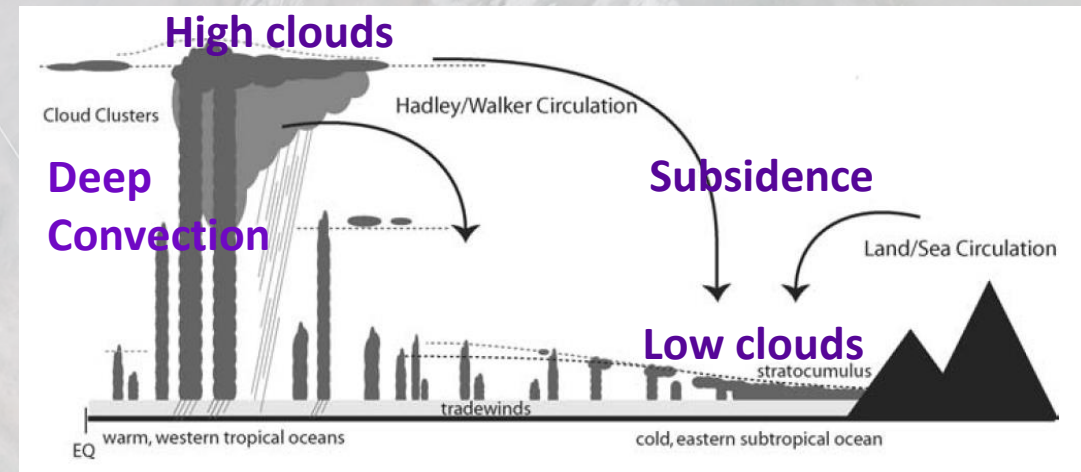
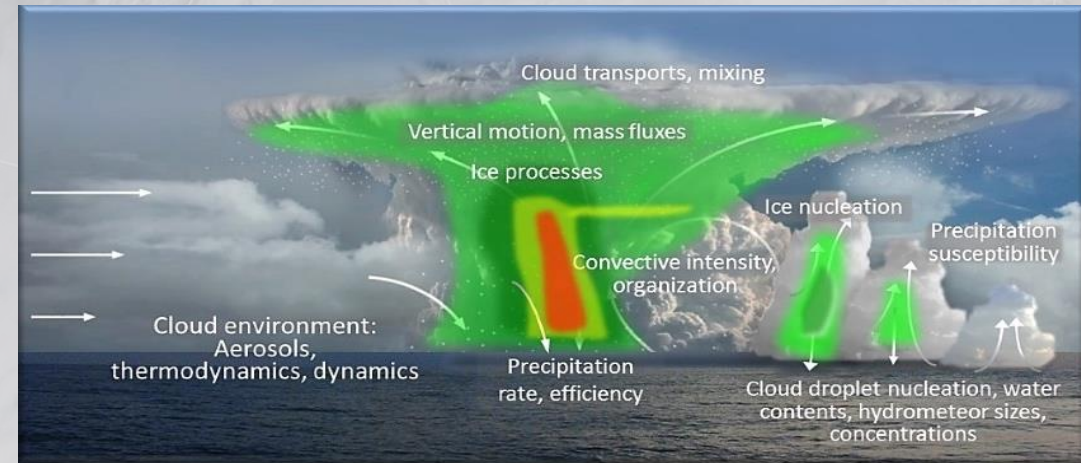
Theme 2: Convection Storm Formation Processes

2. CONVECTION: Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do? How do microphysical properties relate to storm dynamics?

The World Economic Forum (WEF, 2020) assessment of risks identified the change in extreme weather as both the most likely and most impactful on the future economies of the world.



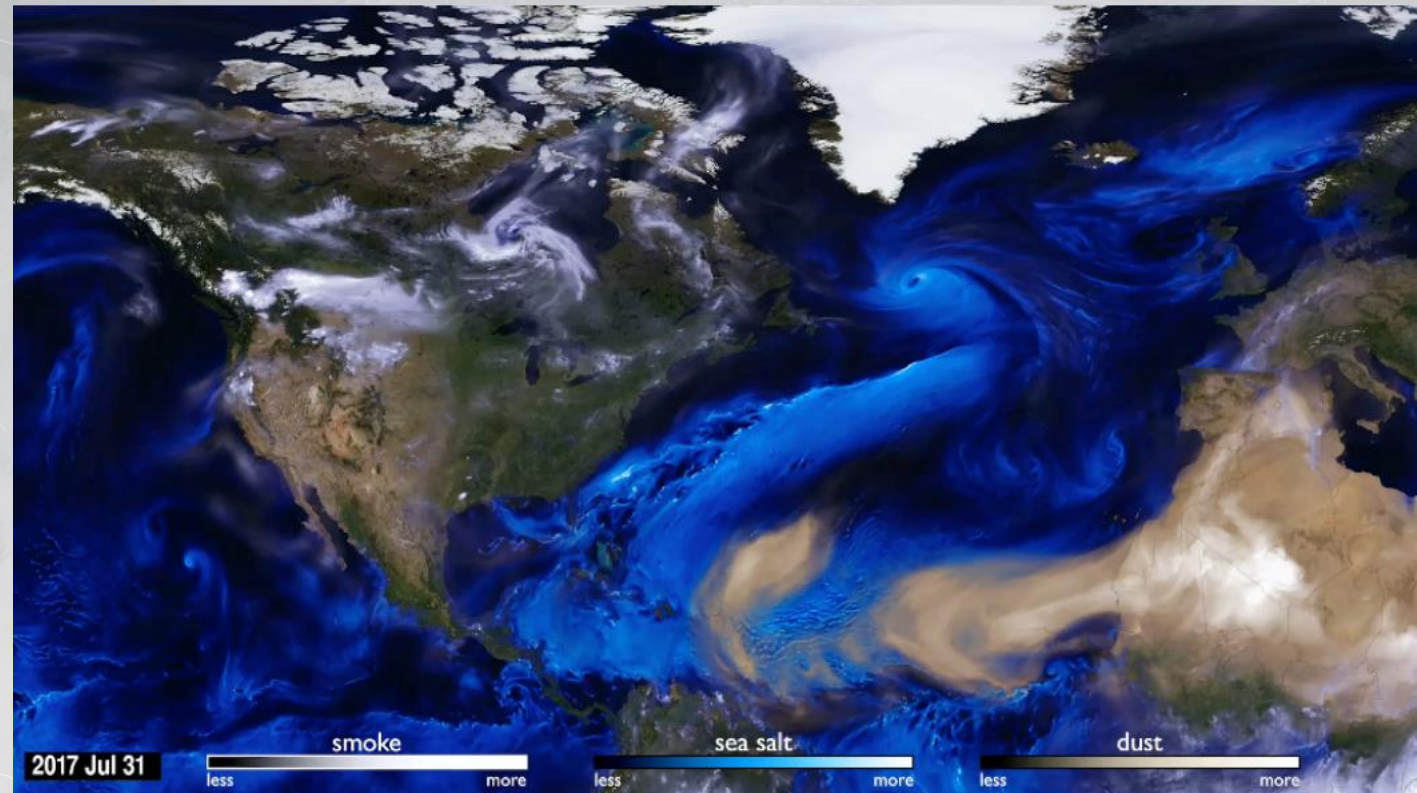
Convective storms deliver the majority of the fresh water for society in the form of rain and snow and are a principal source of life-threatening severe weather.



Theme 3: Aerosol Distributions and Processes

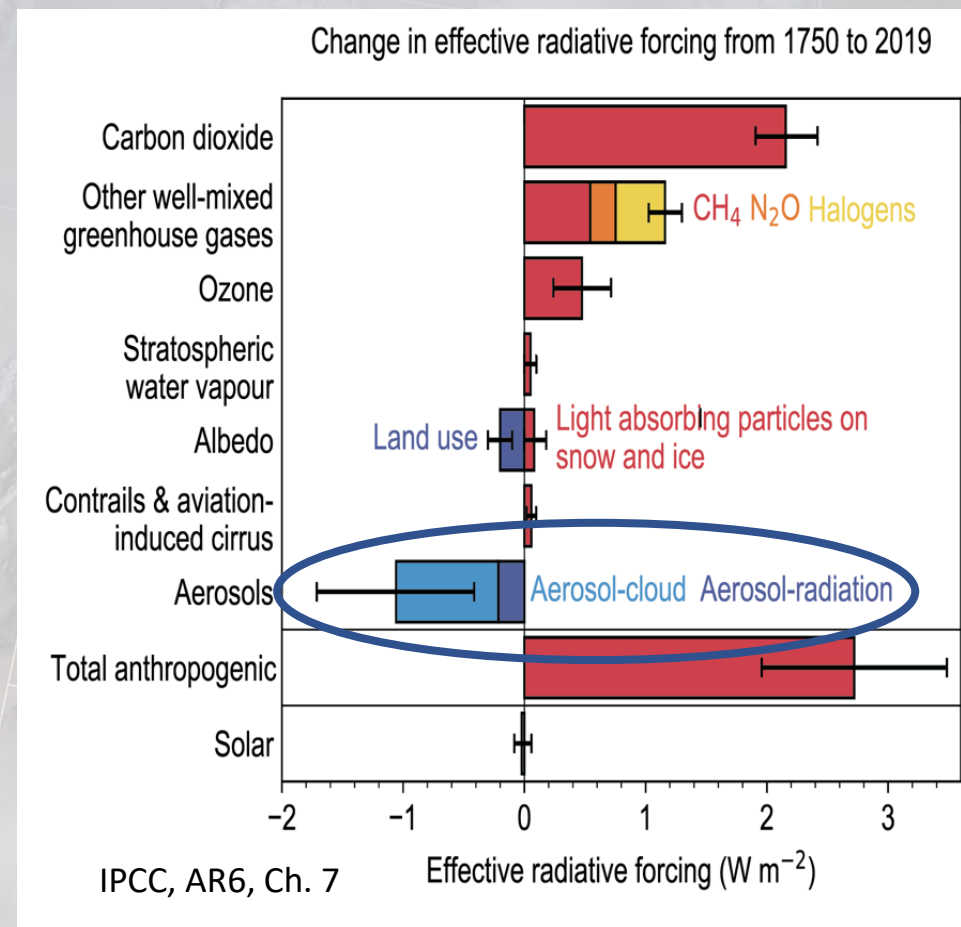
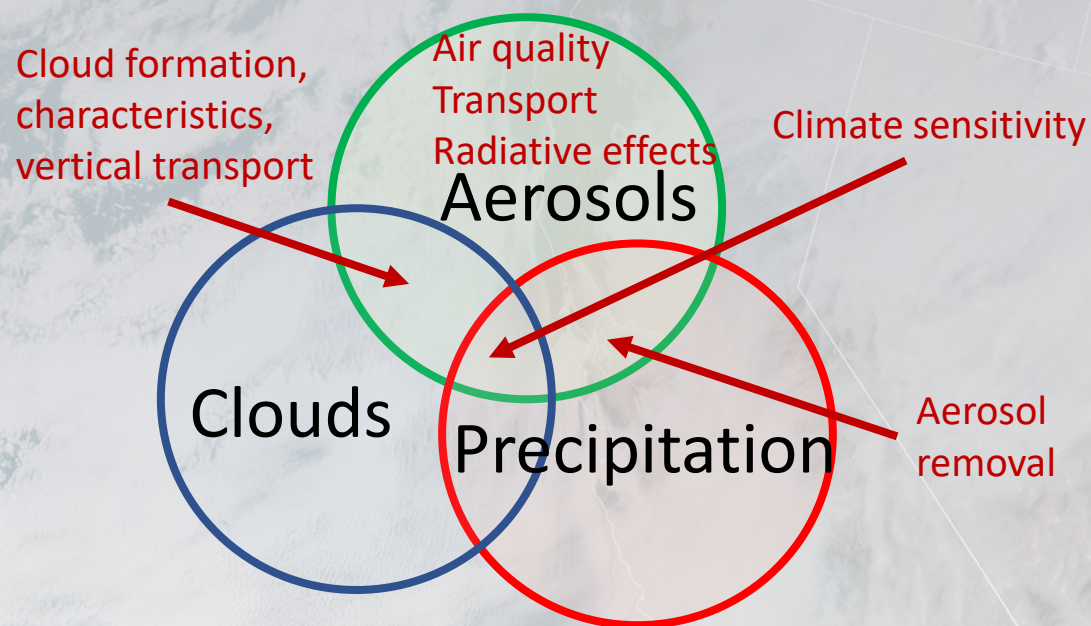
3. AEROSOLS: What processes determine the spatio-temporal structure of important air pollutants and their adverse impacts on human health, agriculture, and ecosystems?

- Aerosol profile and amount
- Aerosol type, particle size
- Emission, transport and removal
- Radiative effects of aerosols
- Diurnal component to dust and smoke emissions



The Need for AOS Synergy

While aerosols, clouds, and precipitation all have important science objectives on their own, it is their interactions that are most in need



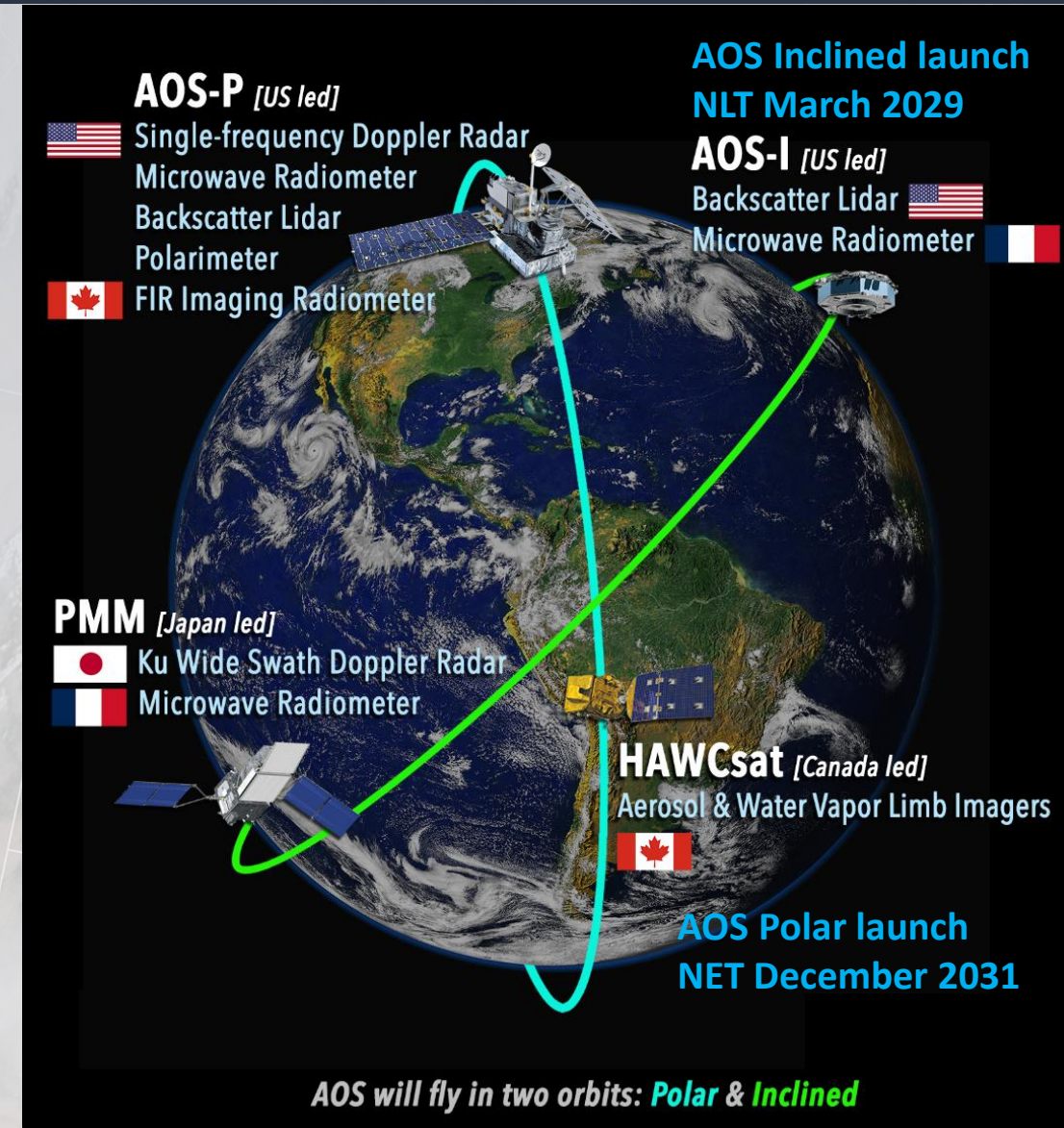
Why AOS Is Needed Now

- Key elements of the Earth-observing system of satellites related to atmospheric measurements are **coming to an end in the very near future**.
 - CloudSat, CALIPSO, Aqua, Terra ending soon; GPM will end before AOS
- **Major gaps in observing aerosol-cloud-precipitation interactions are imminent**, threatening our ability to detect important trends in climate forcings and feedbacks during this period of exponential change in our climate
- Precipitation measurements that have **become critical to the applications community** over the potentially 30 years of TRMM and GPM will come to an end should the inclined orbit element of AOS not launch by 2029

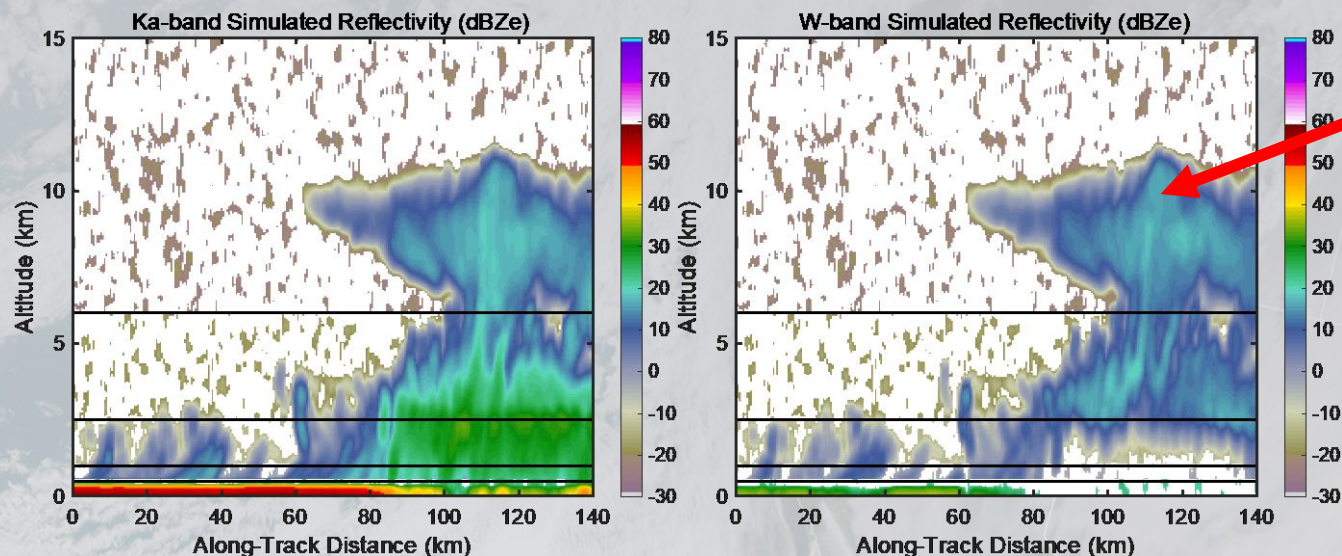
Building An Observing System



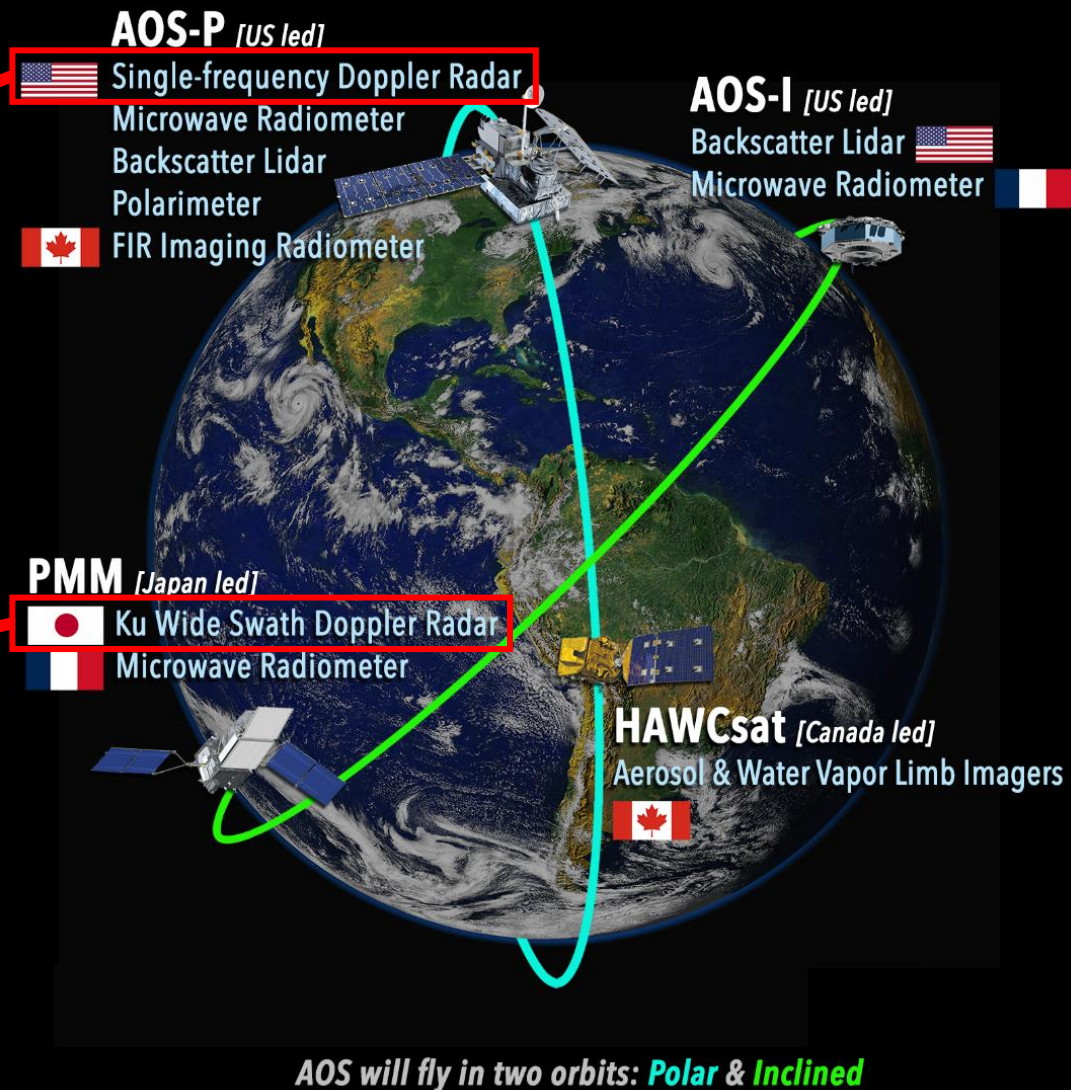
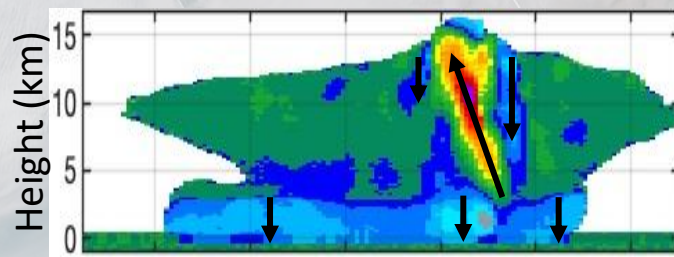
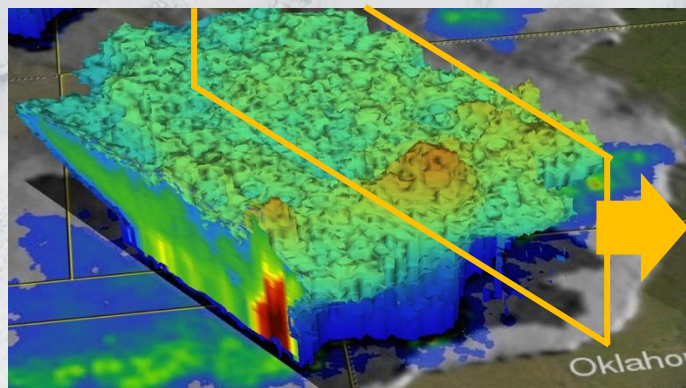
- Factors shaping architecture construction and concept development
 - **Cost-capped** mission that utilizes relatively **mature** measurement capabilities
 - Microphysical understanding requires **synergistic** multi-instrument approaches
 - **International** partnerships
 - **Continuity** desired (but not required) to the extent practical
 - **Applications** considered from early stages
- Completed Mission Concept Review, May 2022
- Independent Review Board (IRB) study August-September 2022
- Key Decision Point A review, January 13, 2023



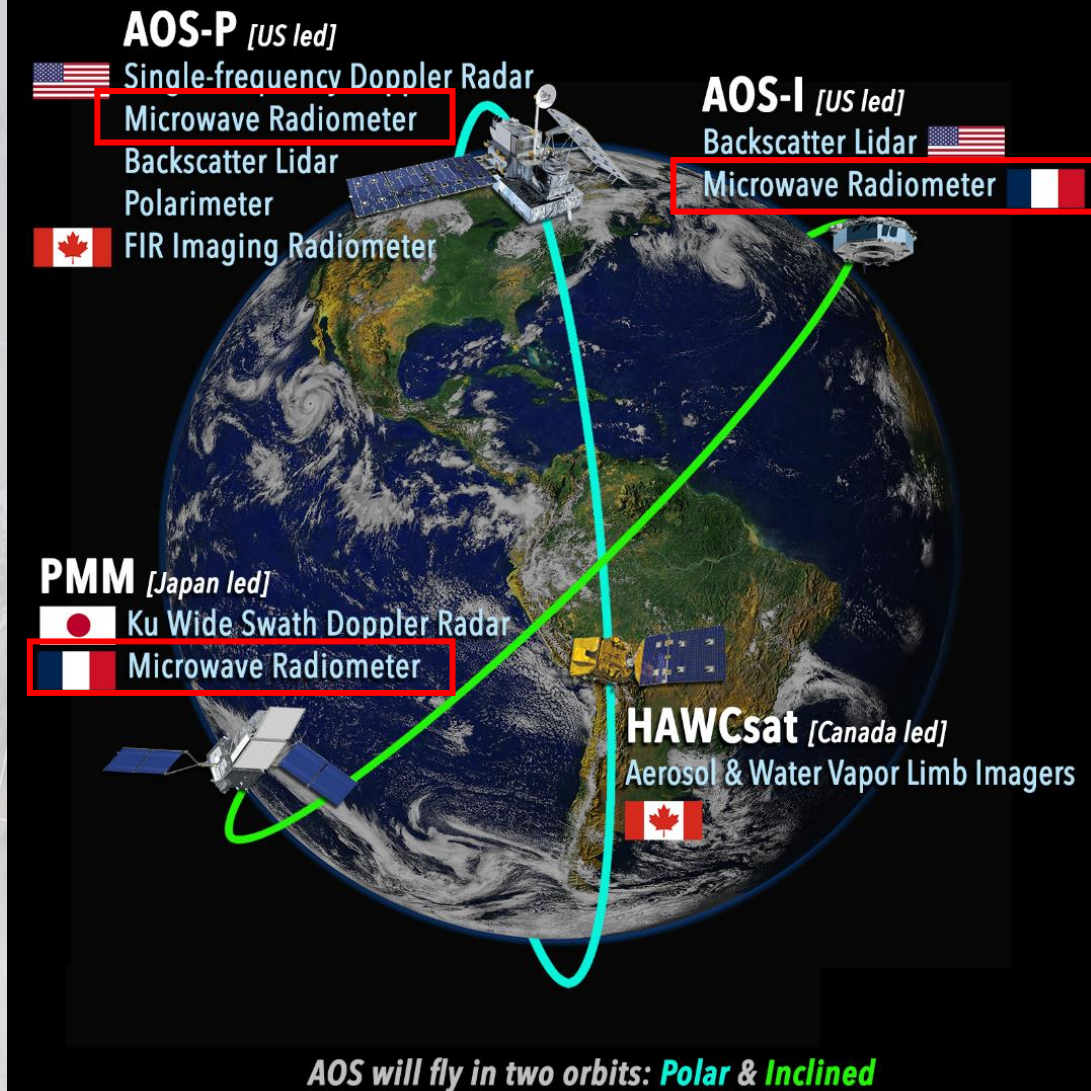
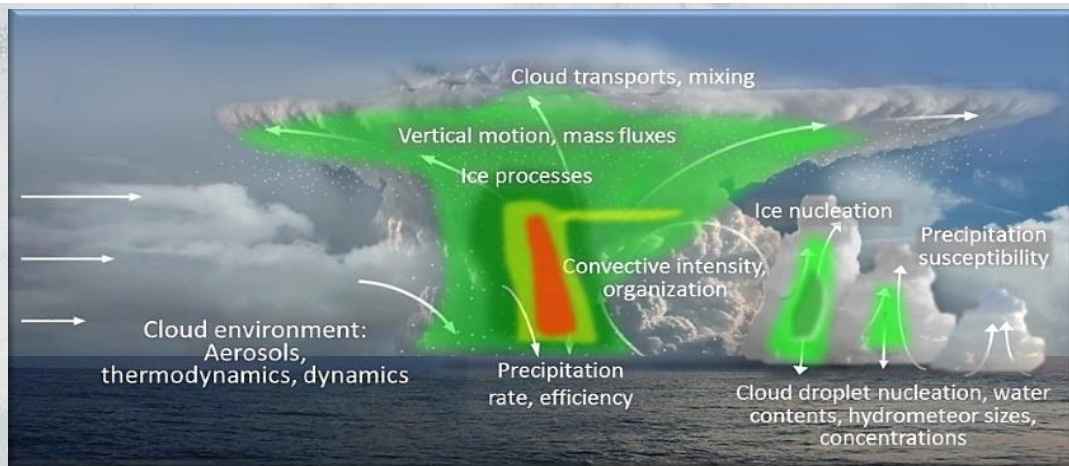
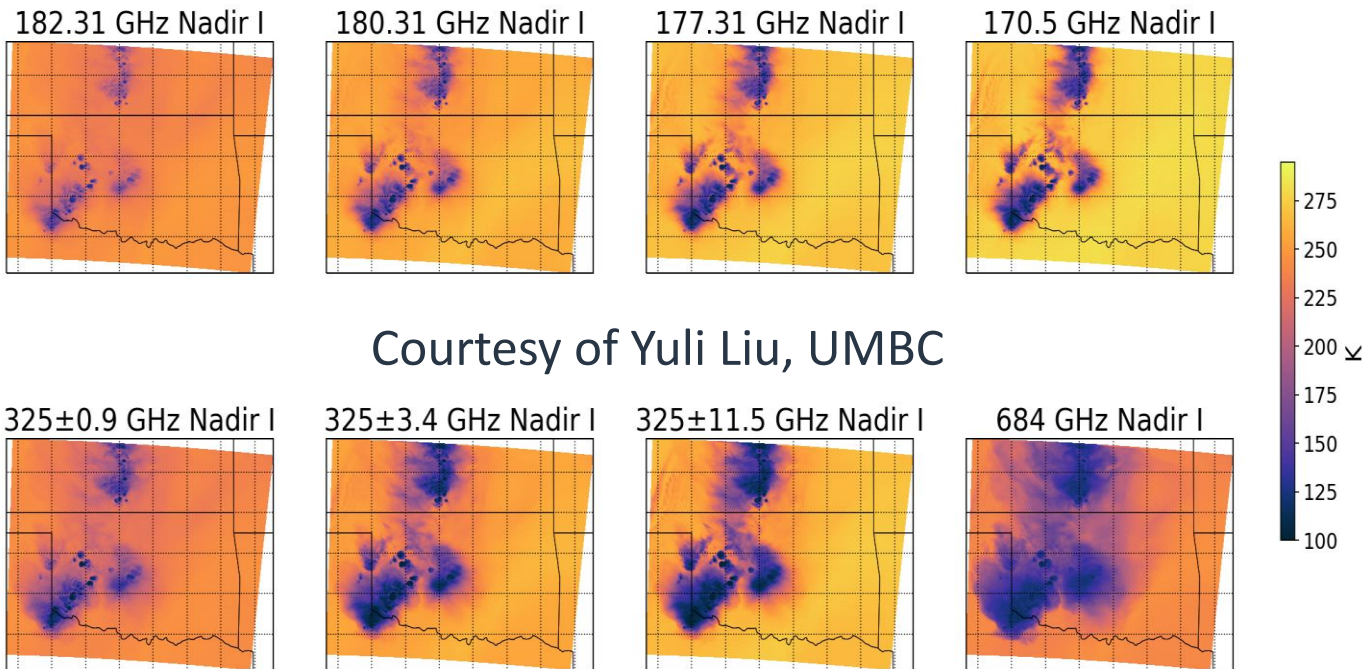
AOS Architecture Overview



JAXA Wide Swath Ku Doppler Radar



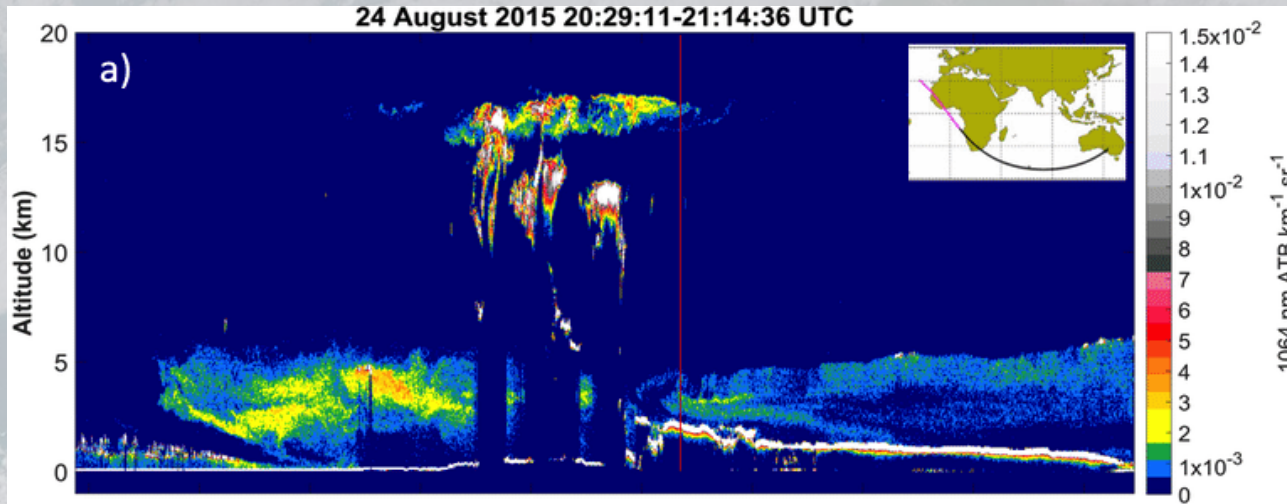
AOS Architecture Overview



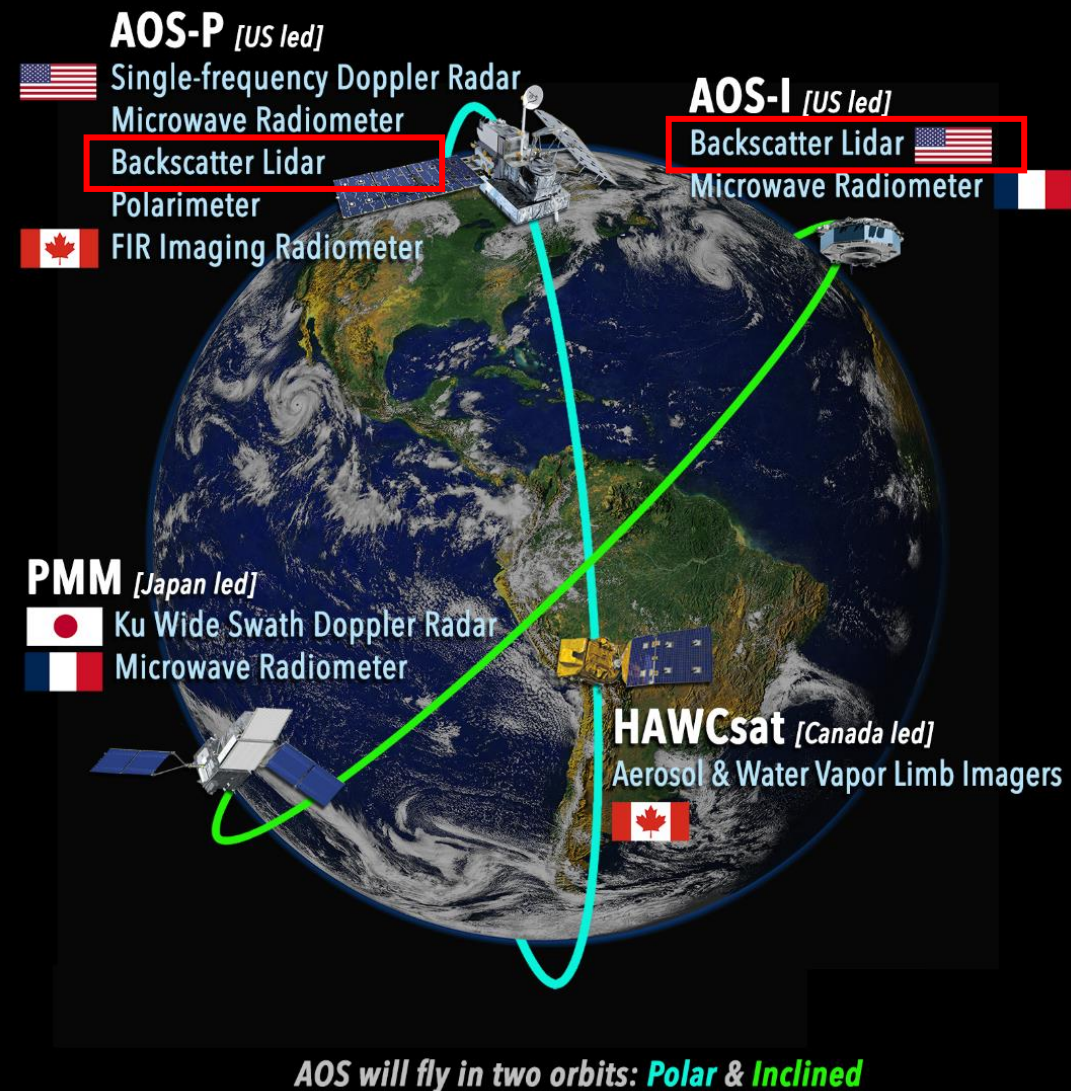
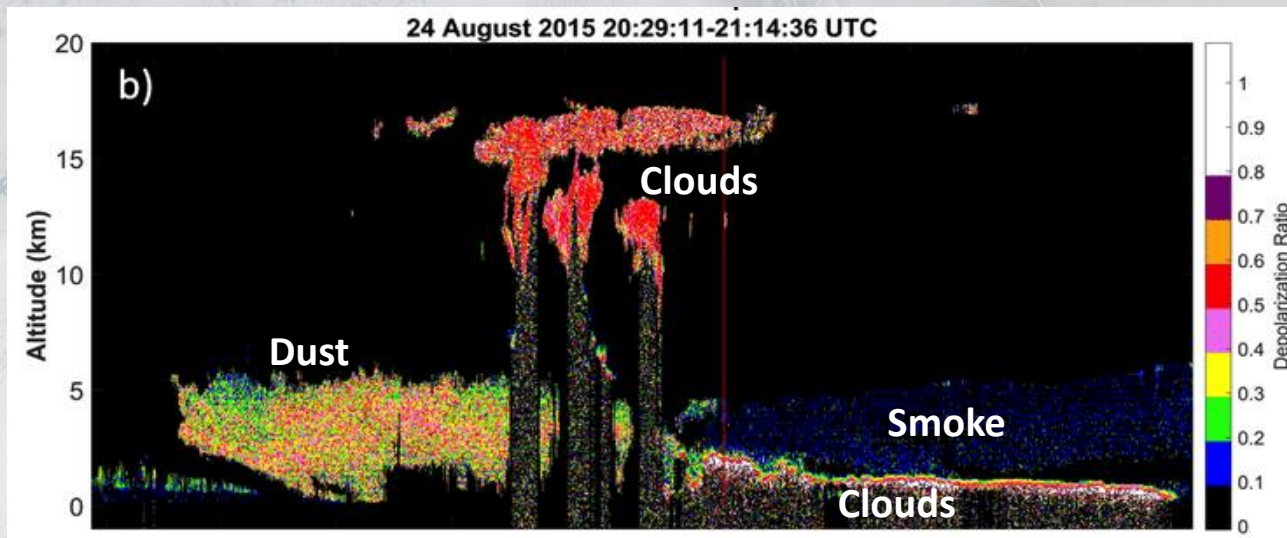
AOS Architecture Overview

532 nm, 1064 Backscatter Lidar

24 August 2015 20:29:11-21:14:36 UTC



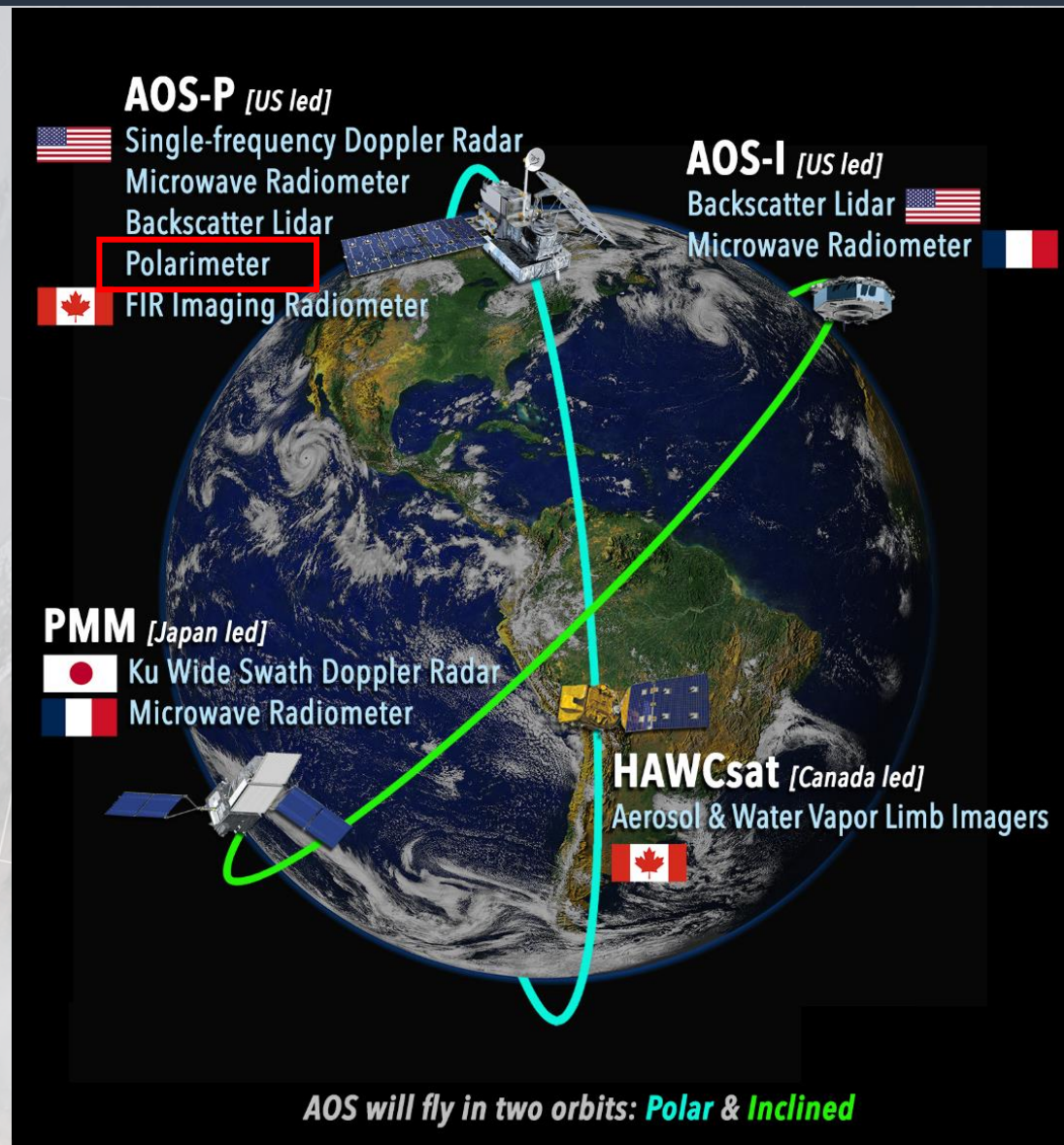
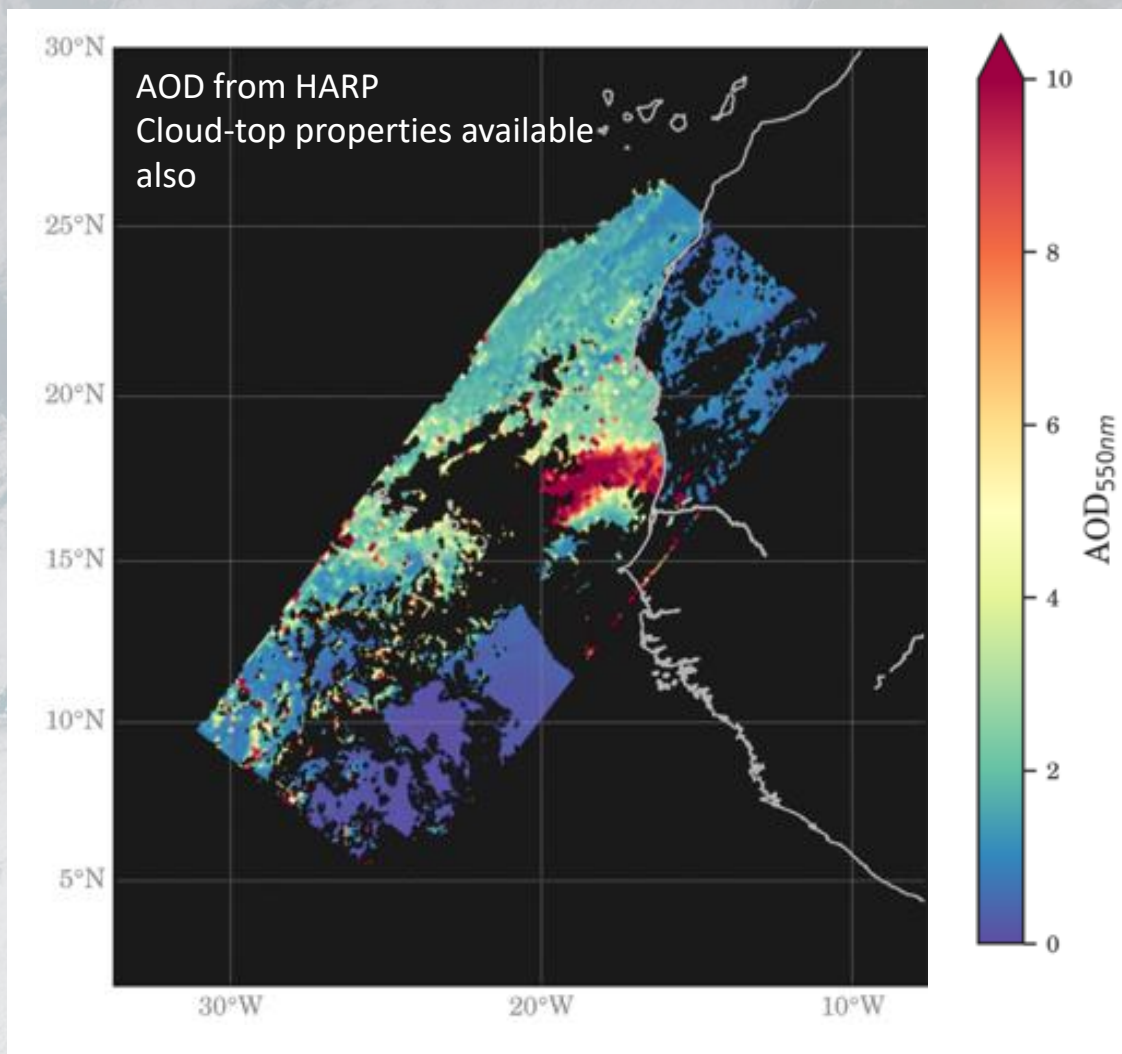
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AOS Architecture Overview

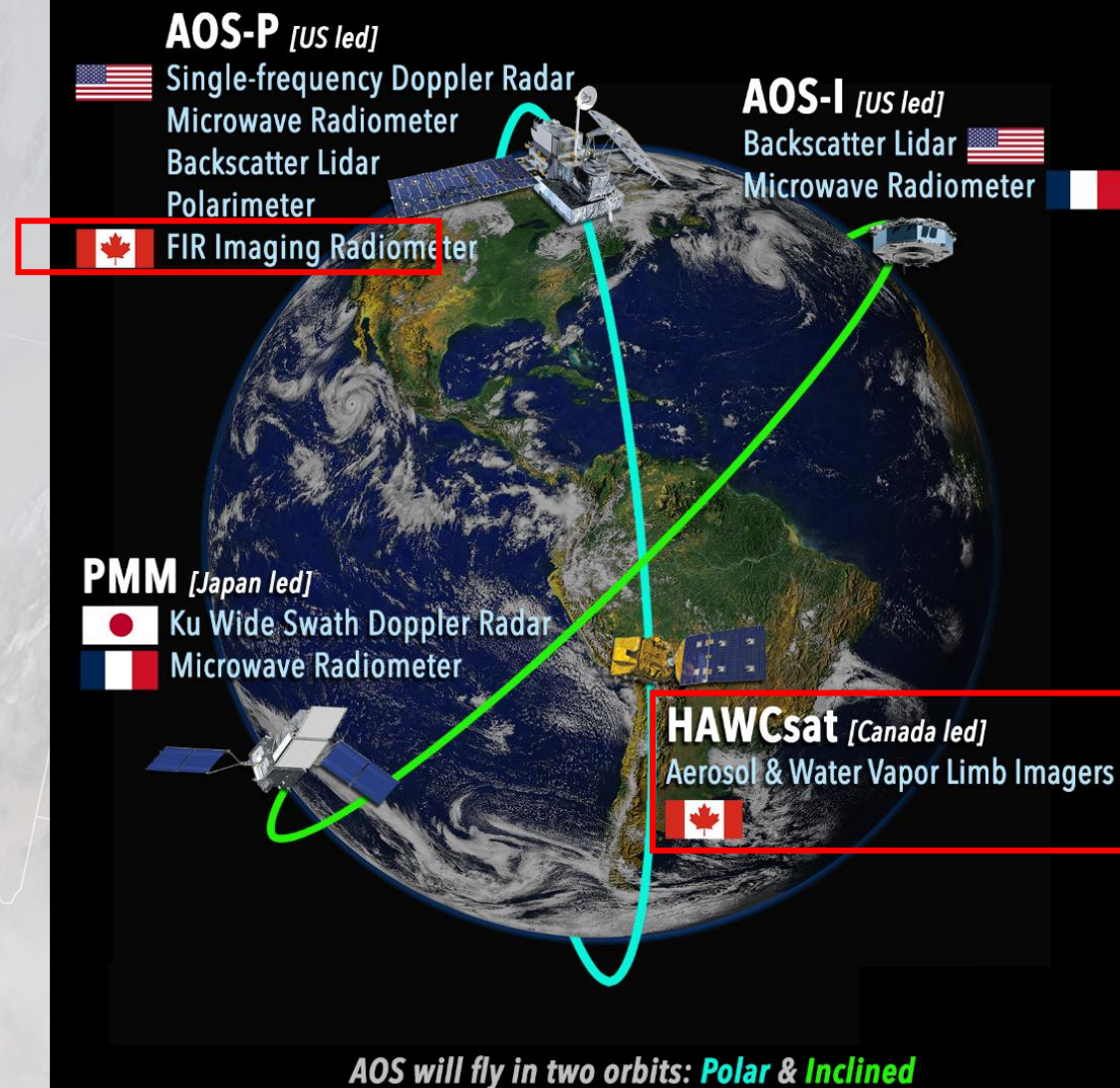
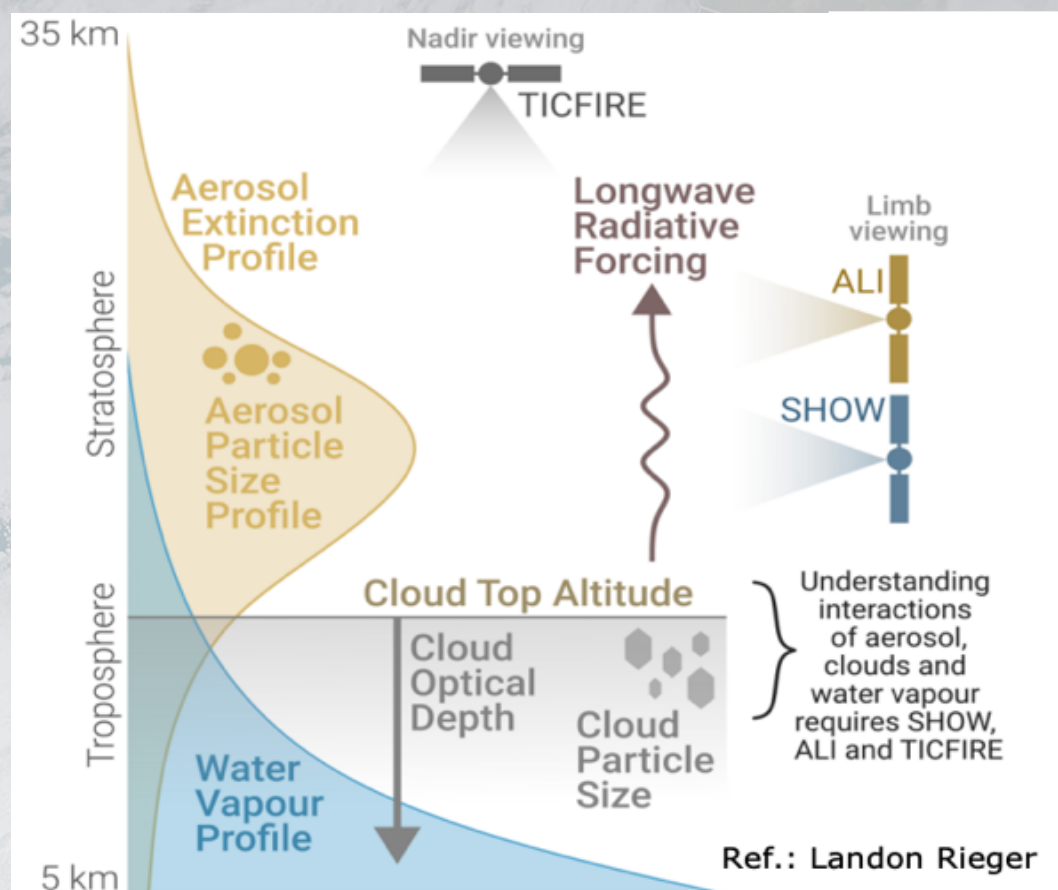


UV-VIS-NIR-SWIR Multi-angle Polarimeter



AOS Architecture Overview

Canadian Space Agency Longwave-Far Infrared
Imaging Radiometer (4-73 μm),
Aerosol/Moisture Limb Sounding



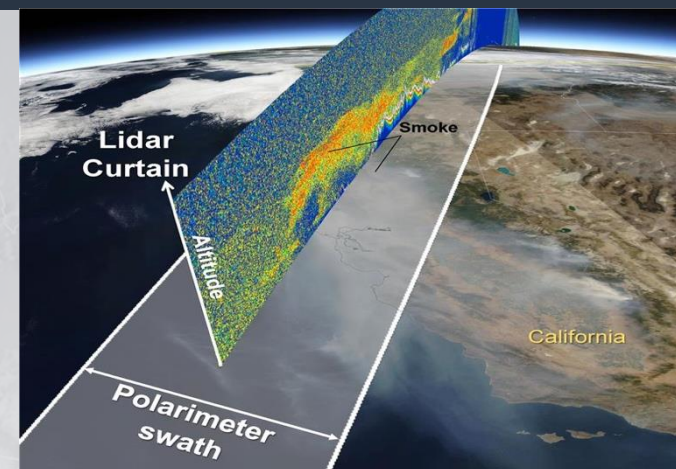
New Science and Key Synergies

- New Science

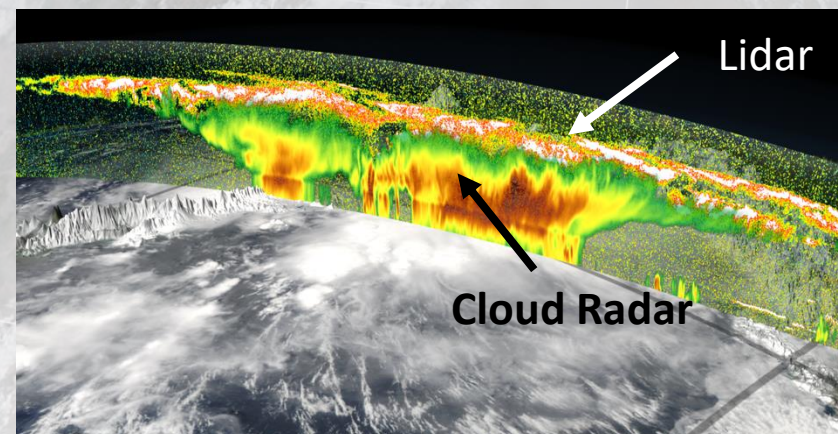
- Globally distributed and diurnally varying vertical air motions in convection
- Coupled dynamics and aerosol, cloud, and precipitation measurements, longwave radiation
- Short time-interval evolution of convective clouds
- Diurnal variability of coincident precipitation, cloud, and aerosol profiles

- Measurement Synergies

- Lidar, polarimeter, and CSA ALI provide enhanced information on aerosol properties
- Lidar, radar, and passive sensors provide comprehensive properties of clouds



Lidar+polarimeter synergy for aerosols: provides significant retrieval advances over lidar alone



Doppler radar+lidar+passive sensor synergy: adds dynamical information to cloud/precipitation profiling and passive properties

AOS Suborbital Element: Airborne Campaign Concepts



Low Clouds: *Microphysics, precipitation initiation*

Convection/High Clouds: *Microphysics and dynamics, anvil cirrus lifecycle.*

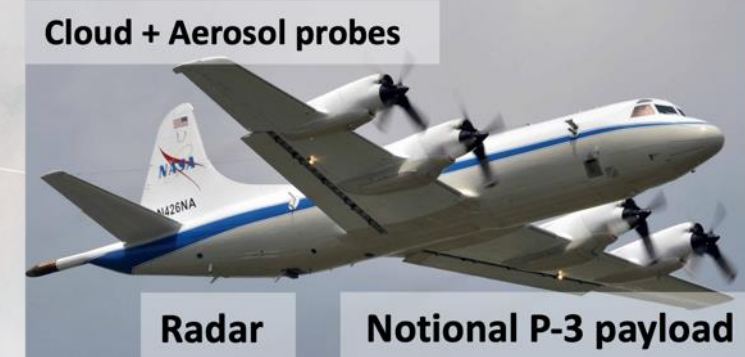
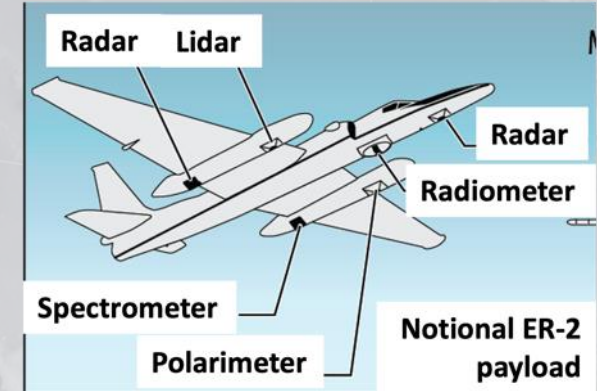
Aerosol-Cloud-Radiation Interactions:
Vertically resolved aerosol-cloud-radiation interaction processes and lifecycle.

Large airborne campaigns

- Mid-latitude continental, 2029 or 2030
- Oceanic, 2032-2033

Campaigns after launch to enable cal-val

Payloads depicted are notional... instruments to be prioritized / deconflicted for each campaign



- AOS is designed to take synergistic measurements related to
 - Climate sensitivity and feedbacks
 - Convective storm formation processes
 - Aerosol distributions and processes
- AOS is urgently needed as current observing systems are ending at a time when climate is rapidly changing
- Large, complex mission with multiple international partners needed to address the different measurement needs for characterizing aerosols, clouds and precipitation
- Inclined-orbit observatory launch no later than mid 2029
- Polar-orbit observatory launch no earlier than late 2031