ATMOSPHERE
Observing System

National Aeronautics and Space Administration

EARTH SYSTEM OBSERVATORY

NASA’s Earth System Observatory: Architecture and Status of the Atmosphere Observing System (AOS)

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International Cooperative for Aerosol Prediction (ICAP) Meeting, 20 October 2022, Monterey, CA

Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

Origin of AOS: Decadal Survey

- **AOS science directly flows from Decadal Survey "Most Important" Aerosol (A) and Clouds, Convection, and Precipitation (CCP) science priorities and measurement recommendations (below)**
- **A 2+ year multi-institutional study was performed to:**
  1. **Develop a project architecture by optimizing science return from mature instruments available at NASA centers or in industry**
  2. **Quantitatively assess architectures using simulated data and retrieval algorithms**

National Academies of Sciences, Engineering, and Medicine 2018

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach
Aerosols	*Aerosol properties, aerosol vertical profiles, and cloud properties* to understand their effects on climate and air quality	Backscatter lidar and multichannel/multiangle/polarization imaging radiometer flown together on the same platform
Clouds, Convection, and Precipitation	*Coupled cloud-precipitation state and dynamics* for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Dual-frequency radar, with multifrequency passive microwave and sub-mm radiometer

From the NASA 2017 Earth Science Decadal Survey, National Academies of Sciences, Engineering, and Medicine 2018

https://nap.nationalacademies.org/catalog/24938/thriving-on-our-changing-planet-a-decadal-strategy-for-earth

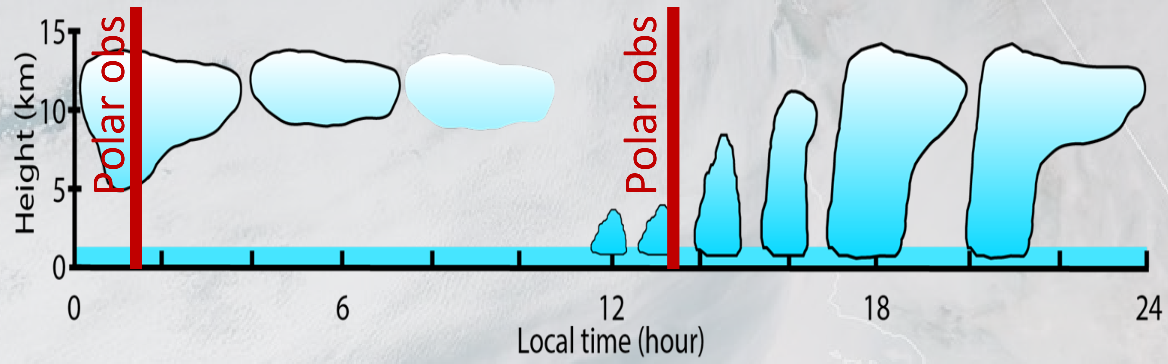
AOS Science Goals & Objectives

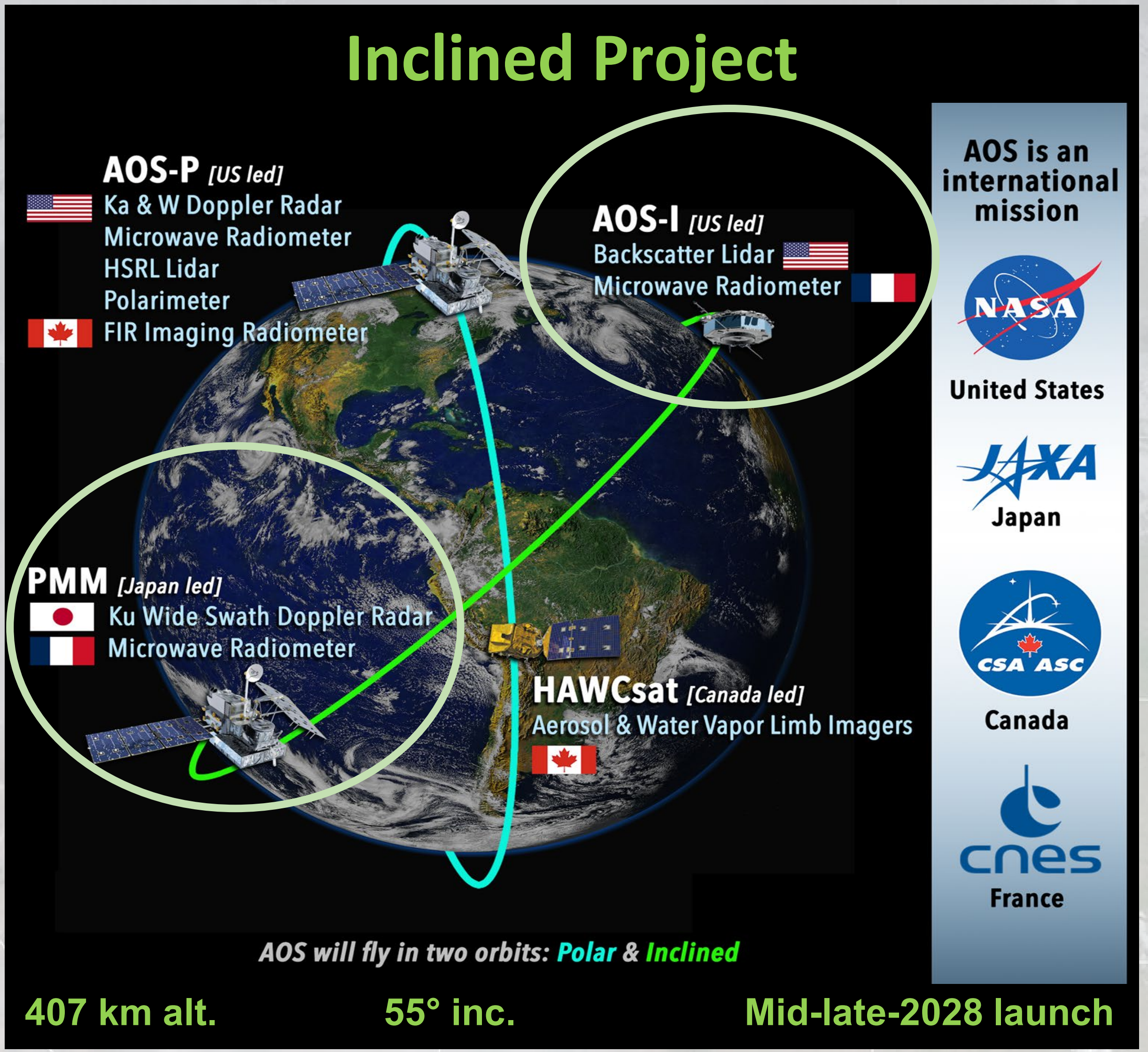
DS Questions: Climate | Convection | Aerosols

Goal	Science Objectives		Key Science Focuses	Inclined	Polar	Sub-orbital
G1	**O1**	**Low Clouds**	Sensitivity of low clouds to environmental factors (thermodynamics/dynamics); solar radiative climate feedbacks		√	√
G1	**O2**	**High Clouds**	Relationship of high cloud formation/properties to deep convection, large-scale environment; infrared radiative climate feedbacks	√	√	√
G2	**O3**	**Convective Storms**	Relationship between storm vertical motions and microphysics	√	√	√
G3	**O4**	**Cold Clouds and Precipitation**	Processes that govern phase partitioning and precipitation formation in cold clouds; key drivers of climate feedbacks at high latitudes		√	√
G4	**O5**	**Air Quality and Aerosol Attribution**	Identifying major sources of aerosols and their type/species; factors that relate aerosol microphysical/optical properties to near-surface air quality	√	√	√
G4	**O6**	**Aerosol Redistribution and Processing**	Wet removal and processing of aerosol by clouds and precipitation; impacts of vertical and long-range transport of aerosol	√	√	√
G5	**O7**	**Aerosol Direct Effects**	Role of aerosols in the Earth's energy budget; impact of absorbing aerosols on climate		√	√
G5	**O8**	**Aerosol Indirect Effects**	Aerosol impacts on clouds and precipitation systems; modulation of climate forcing due to changes in cloud radiative properties		√	√

The AOS Architecture (Pending HQ Reviews, Decisions)

- Inclined orbit required for developing understanding of **diurnal variability of deep convection, high clouds**
- Adds time-varying aerosol, PBL profiles, follow-on to CATS
- First ever time-difference microwave TBs for inferring dynamics, microphysics





Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

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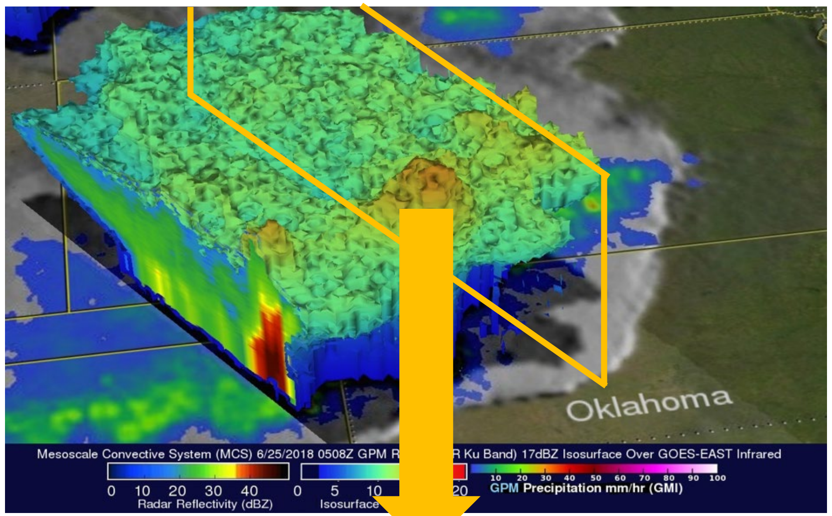
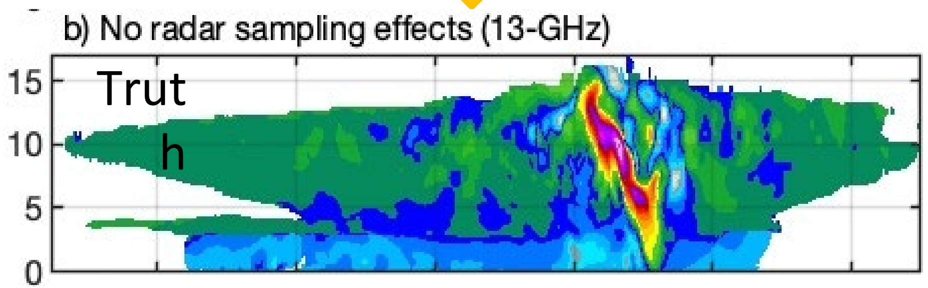
A Visual View of AOS-Inclined

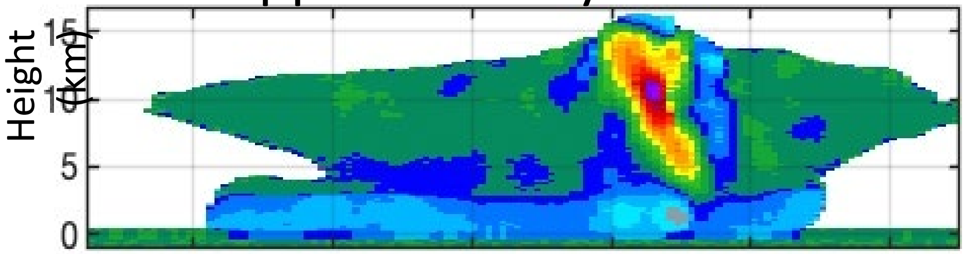
Launch NET July 2028

JAXA Wide Swath Ku Doppler Radar

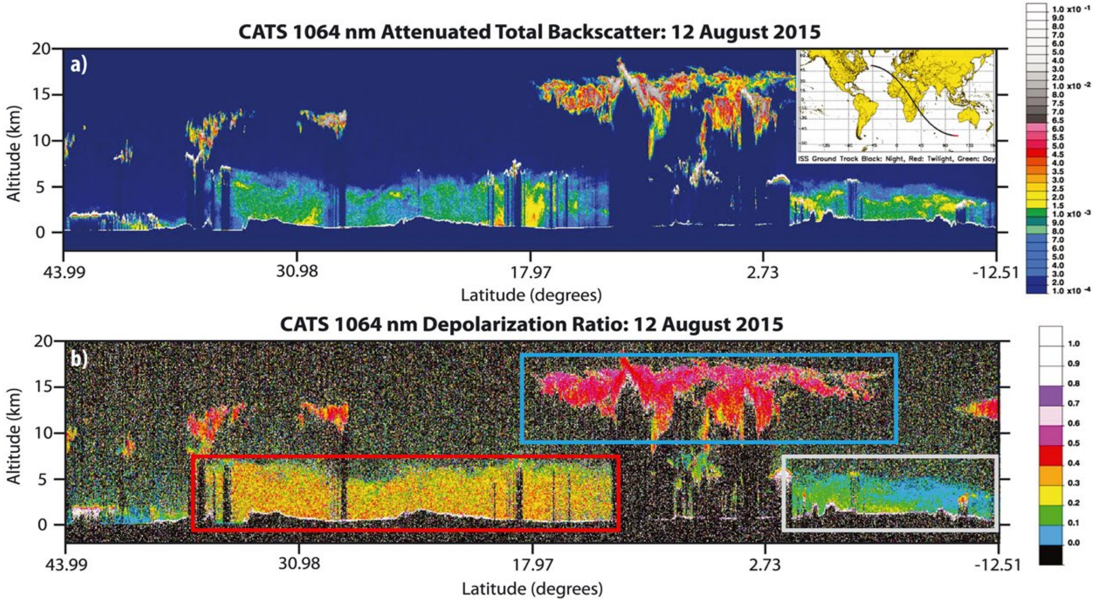




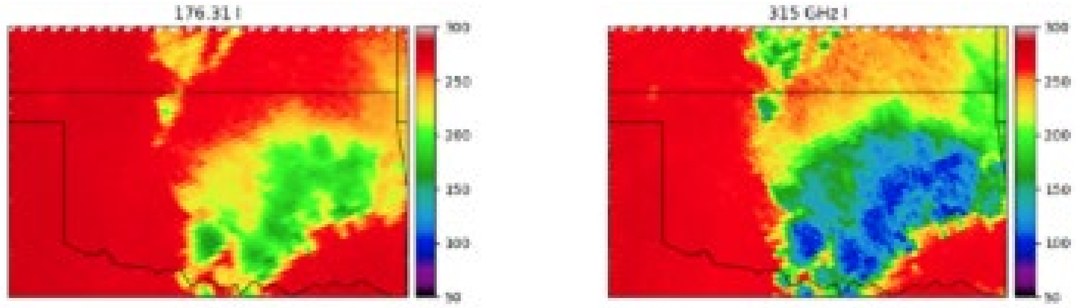
Ku Doppler Velocity



ALICAT: 532 & 1064 nm Backscatter Lidar



CNES Microwave Radiometers (89, 183, 325 GHz)



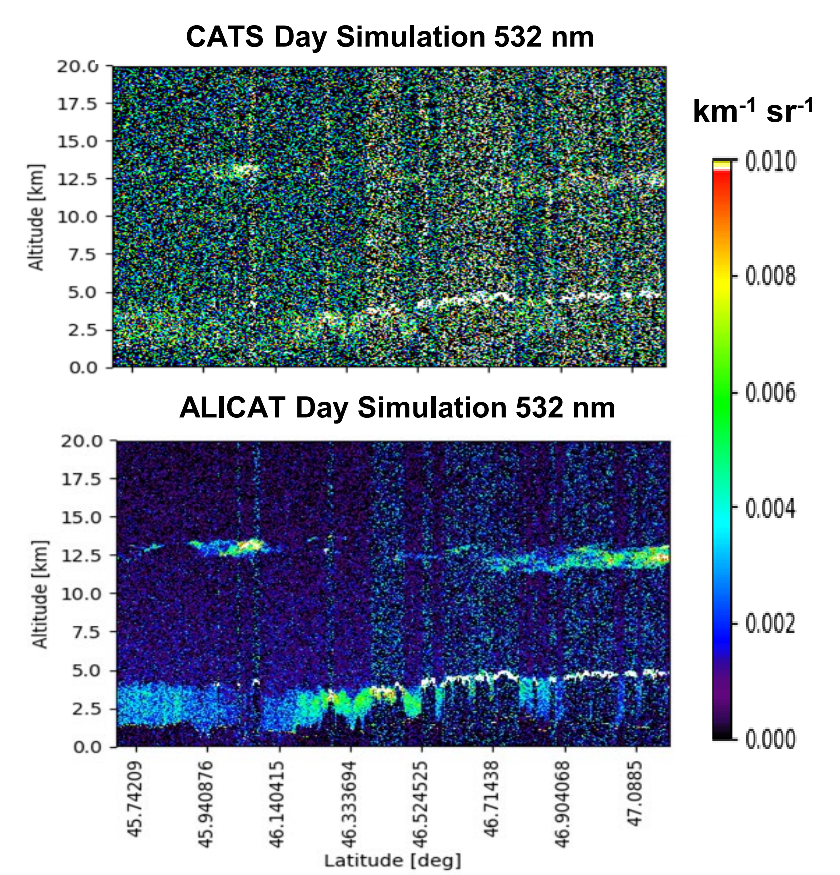
55° Inclination: Compromise between NASA, JAXA, CNES

Atmospheric Lidar Instrument for Clouds and Aerosol Transport (ALICAT)

- **Provides time-varying vertical profiles of total and perpendicular attenuated backscatter at 532 and 1064 nm**
- **New for ALICAT compared to CATS & CALIPSO:**
  - **Better daytime SNR than both (right)**
  - **More information content than CATS**
  - **Better data latency (<6 hours) and inclined orbit compared to CALIPSO**

ALICAT has hardware and algorithm heritage from CATS that operated on the ISS for 33 months

Lidar Instrument	ALICAT	CALIPSO	CATS
Operational Period	2028-2030+	2006-2023	2015-2017
532 nm Total Backscatter	●	●	
1064 nm Total Backscatter	●	●	●
532 nm Depolarization	●	●	
1064 nm Depolarization	●		●
Inclined Orbit	●		●
< 6 Hr Data Latency	●		●

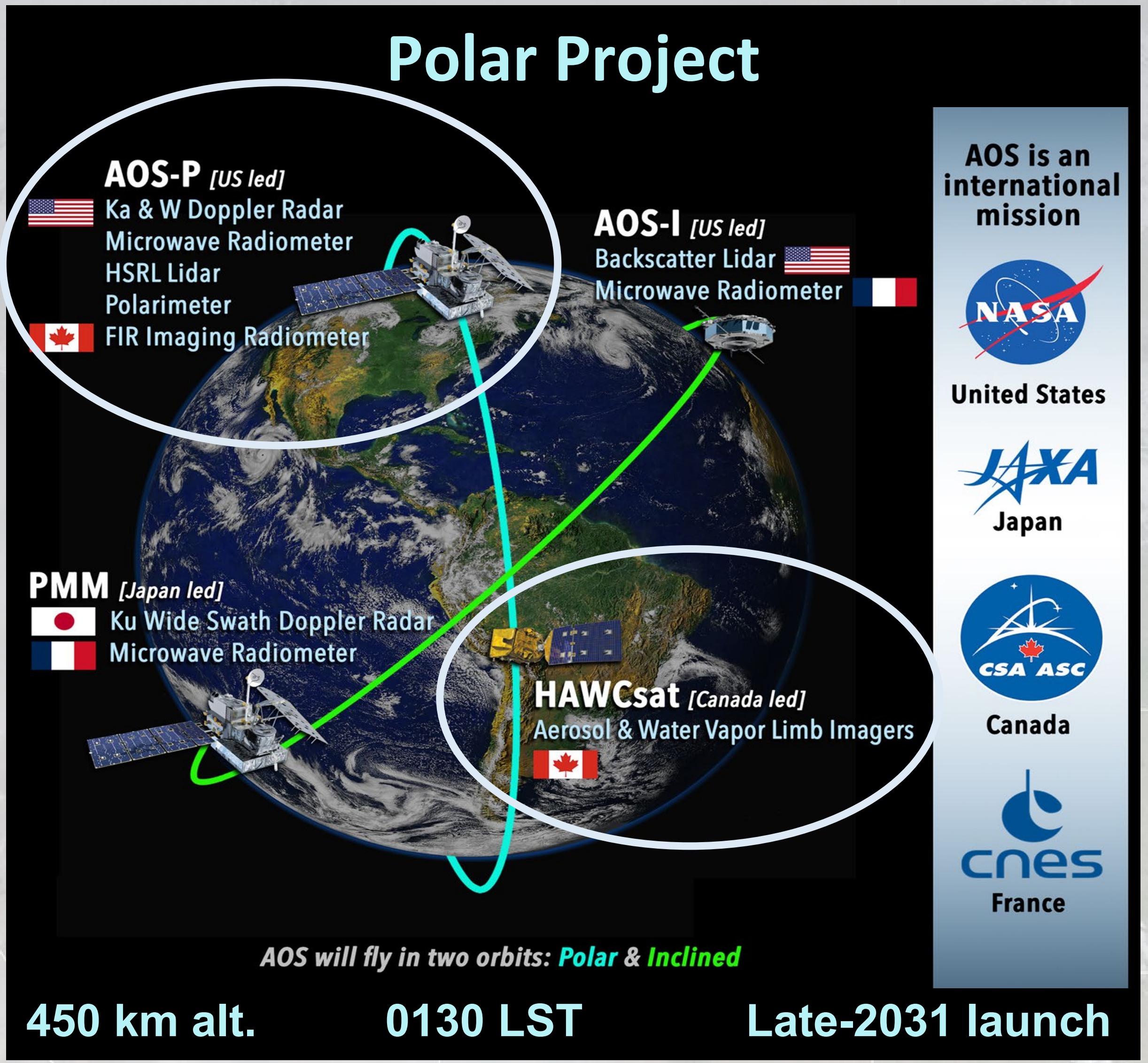


Courtesy of Ed Nowottnick and Patrick Selmer (NASA GSFC)

Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

The AOS Architecture (Pending HQ Reviews, Decisions)

- Global perspective required for developing understanding of **climate sensitivity, feedbacks, and aerosol forcing of the climate**
    - **Low latitude** clouds and interaction with aerosol are fundamental to climate feedbacks
    - **Midlatitude** cloud-precipitation processes are important to water resources and energy transport
    - **Polar regions** are important for capturing aerosol transport, critical to Earth's energy budget, and highly sensitive to climate change
- Global observations key to understanding linkages between energy and water cycles of the Earth system
- **AOS-P builds on the heritage of the A-Train**



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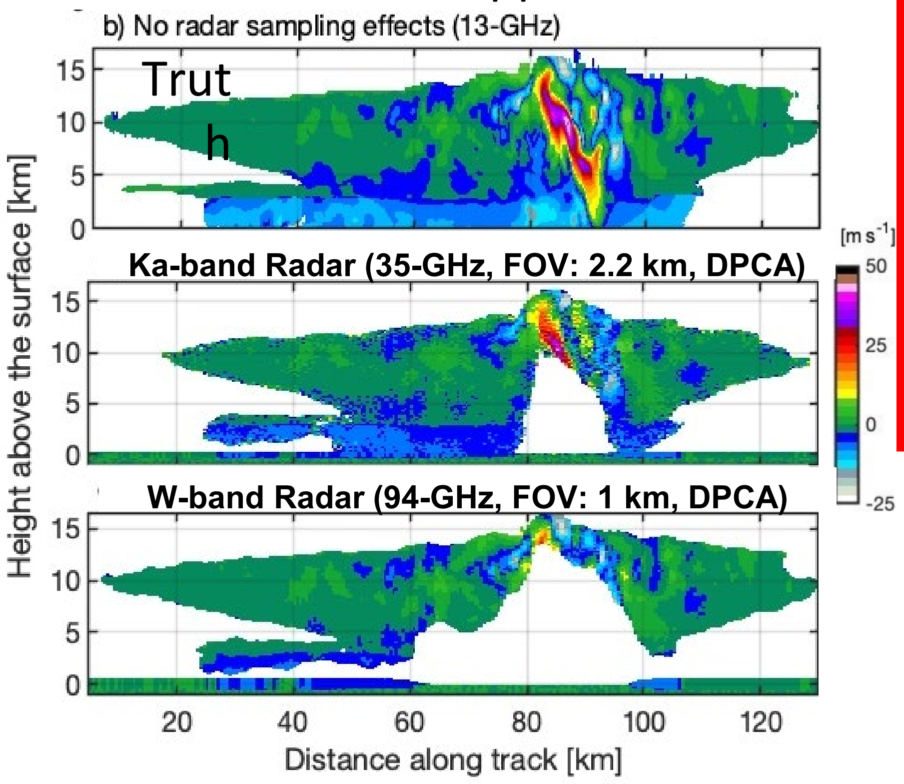
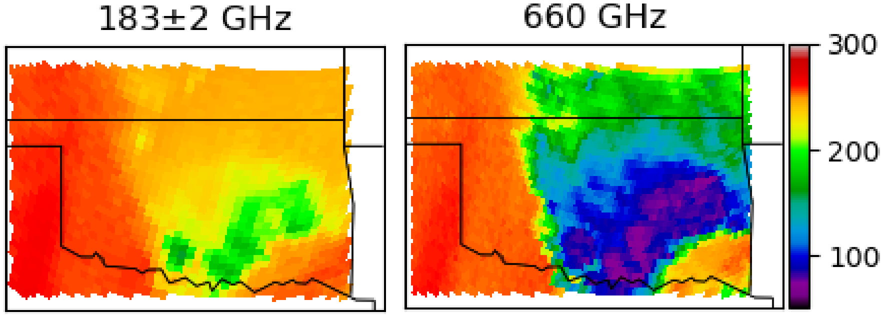
A Visual View of AOS-Polar

Launch NET December 2030

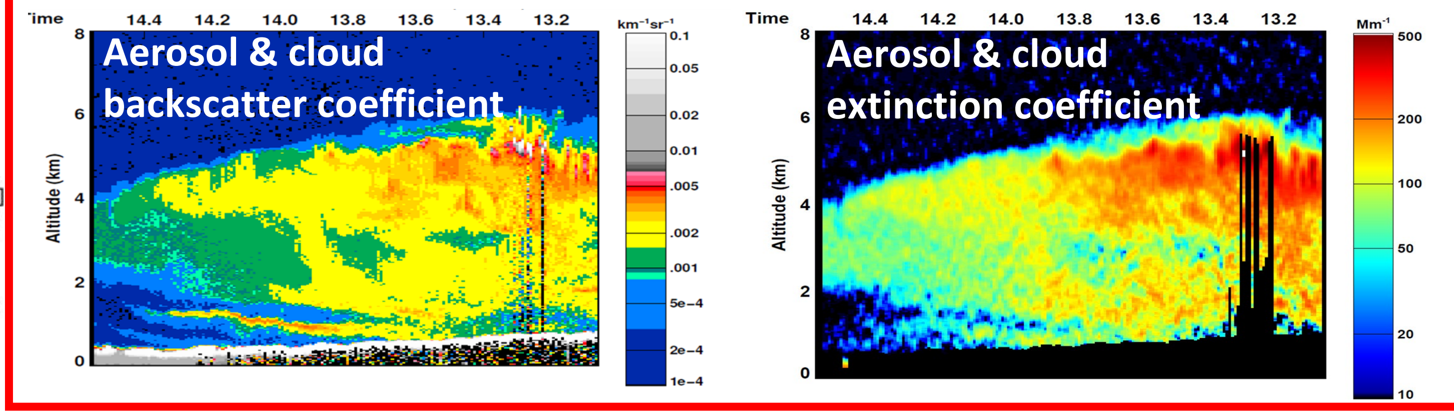
W-, Ka-band Doppler Radars



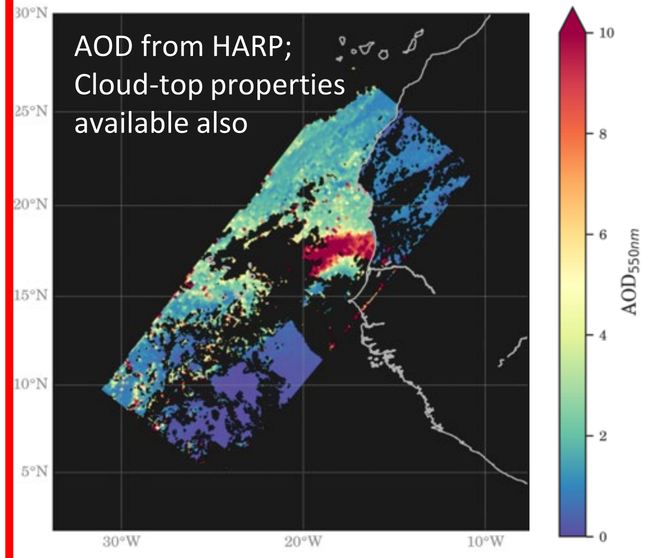
Microwave Radiometer: 89-700 GHz



Clio: 532 nm HSRL, 1064 Backscatter Lidar

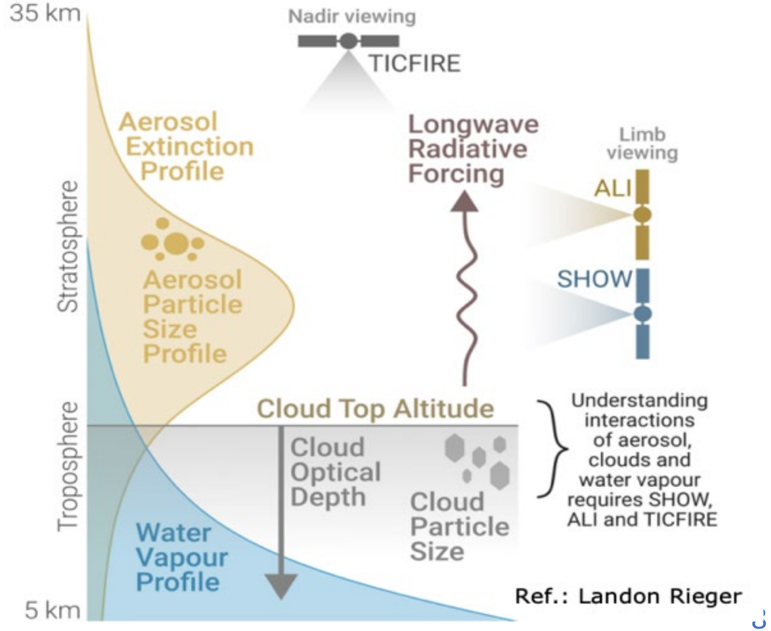


UV-VIS-NIR-SWIR Multi-angle Polarimeter



Courtesy of V. Martins

CSA LWIR-FIR Radiometer (4-73 μm), Aerosol/Moisture Limb Sounding



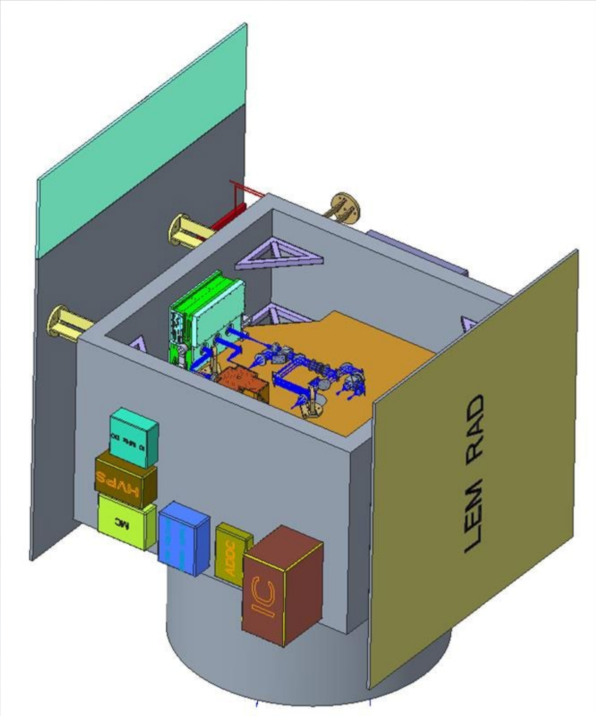
Clio HSRL

The Clio HSRL Instrument

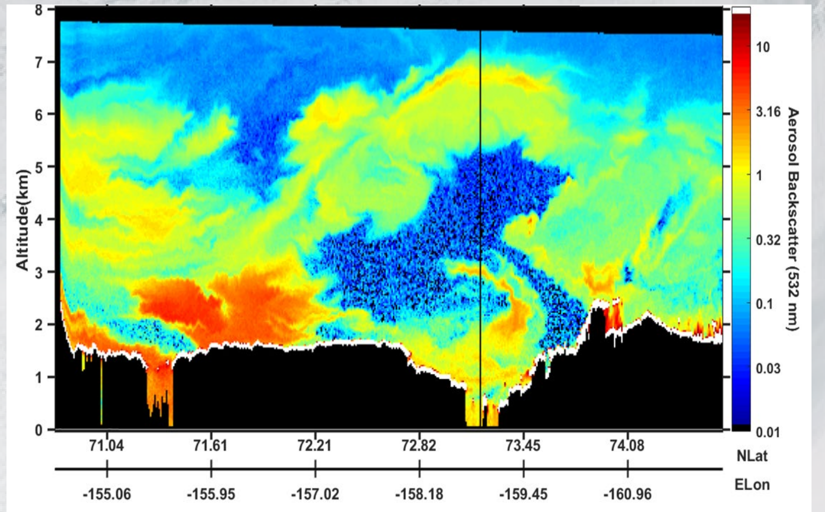
- Provides the accuracy, sensitivity, information content, and model compatibility to enable *transformative science* in the AOS Polar orbit
- Draws significant design heritage from CALIOP, GEDI, ATLAS, GLAS, as well as the airborne HSRL-2

Clio provides vertically-resolved profiles (especially in the PBL and below optically thin clouds) of:

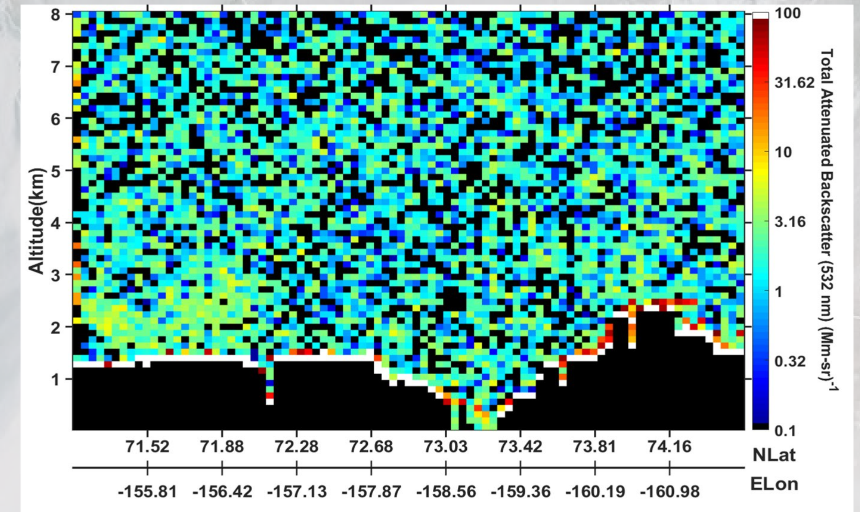
- **Aerosol extinction**
- **Aerosol backscatter**
- **Aerosol depolarization**
- **Aerosol type (e.g., dust vs. pollution vs. seasalt, etc.)**



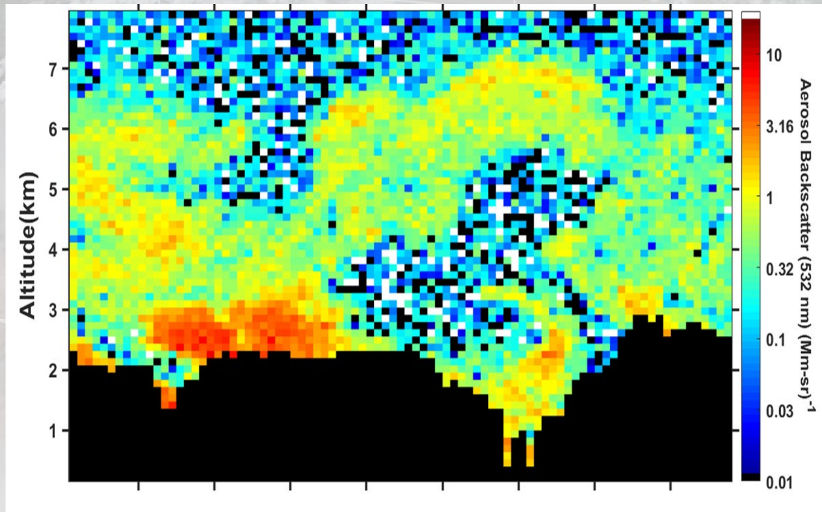
Airborne HSRL Aerosol Backscatter



CALIOP Attenuated Backscatter



Clio Aerosol Backscatter (simulated)



Pre-Decisional – AOS is in Pre-Phase A and NASA makes no commitments on the final design of the mission or instruments

AOS-P Polarimeter

The polarimeter is being competed and the exact instrument specs/performance are TBD.

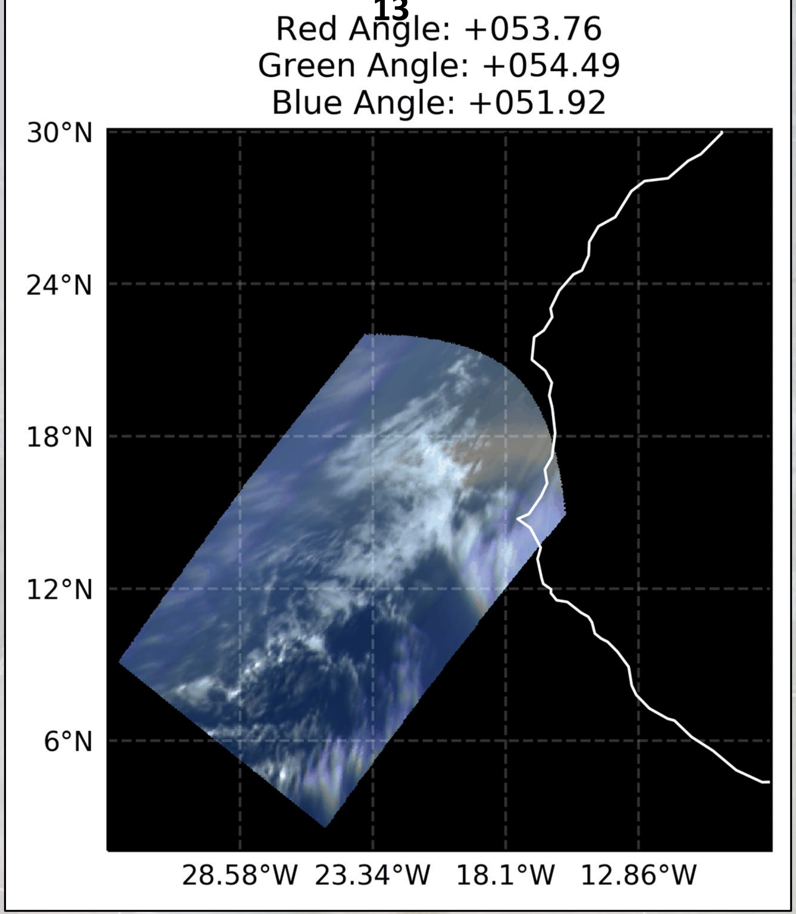
Instrument requirements summary:
Spatial resolution of 500m [1km], cross track swath of 300 [100] km
Total uncertainty: radiometric < 3%, DoLP < 0.005 [threshold: systematic uncertainty only]

Science driver	Wavelength range	# of bands	# of viewing angles per pixel
Aerosols	UV: 360 – 390 nm[1]	1	10 [5]
Aerosol, bi-spectral clouds	VIS-NIR: 410 – 870 nm	3	10 [5]
Cloudbow cloud retrievals	Hyperangle: 670 – 870 nm	1	60 [40][2]
Aerosols, bi-spectral clouds	SWIR:1000 – 2260 [1600] nm	3 [2]	10 [5]

[1]UV band is not included in threshold requirements
[2] < 2° [< 4°] angular resolution for scattering angles between 135° – 165° to use cloud bow observations for determination of cloud droplet size distribution.

[bracket indicates threshold]

HARP Cubesat RGB imagery, West Africa with Saharan dust, glint, clouds 2020 / 06 / 13



Not shown are hyperangle and polarimetric data. The AOS polarimeter would have UV, SWIR and better spatial resolution. From: https://esi.umbc.edu/hyper-angular-rainbow-polarimeter/

Compared to POLDER/PARASOL heritage

Better **cloud** measurements with SWIR channels and polarimetric rainbow approach.
At least an order of magnitude improvement in accuracy for **aerosol** properties.
More angles for parallax-based feature height detection.

Airborne Campaign Concepts

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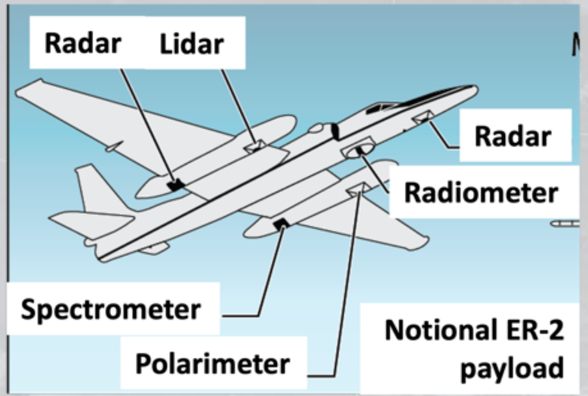
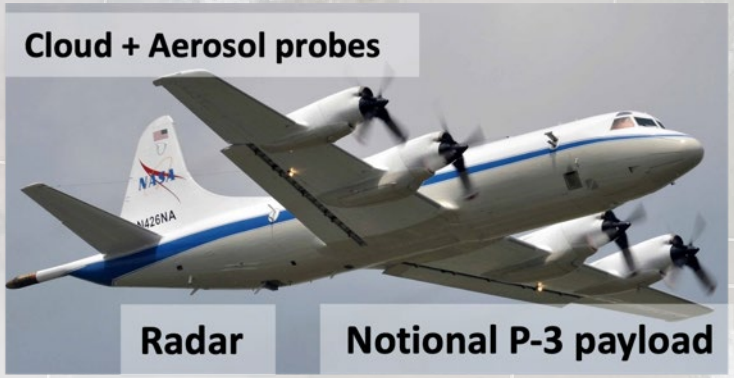
Low Clouds: *Microphysics, precipitation initiation*

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

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

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





Large airborne campaigns

- **Mid-latitude continental, spring-early summer 2029**
- **Oceanic, early summer 2031, 2032**

Campaigns after launch to enable cal-val

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AOS Applications

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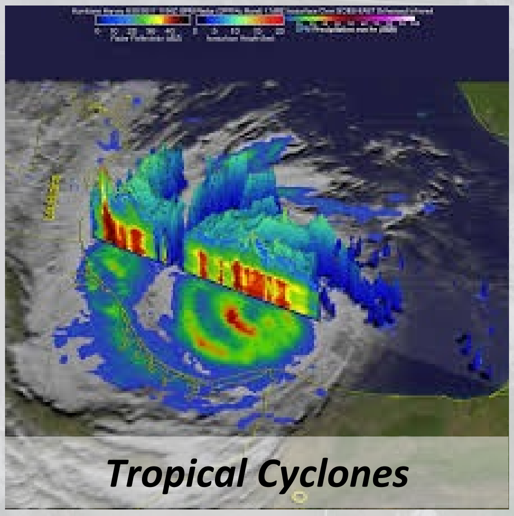
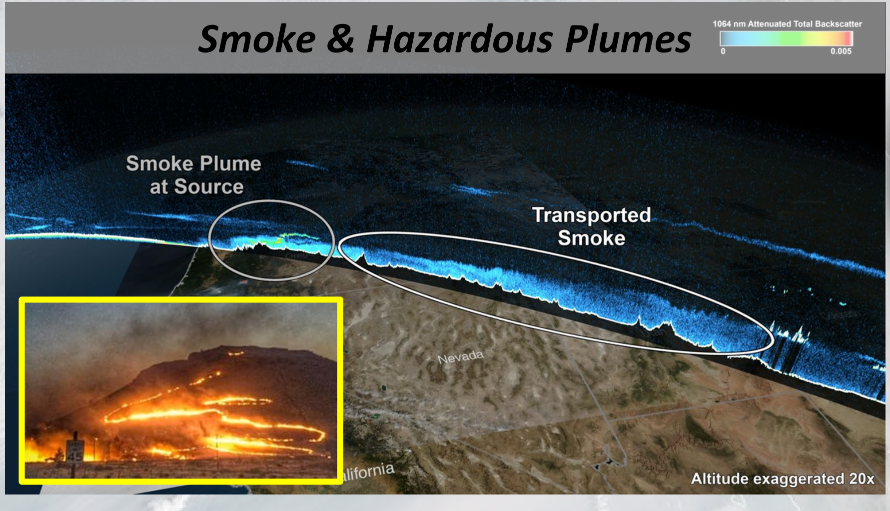
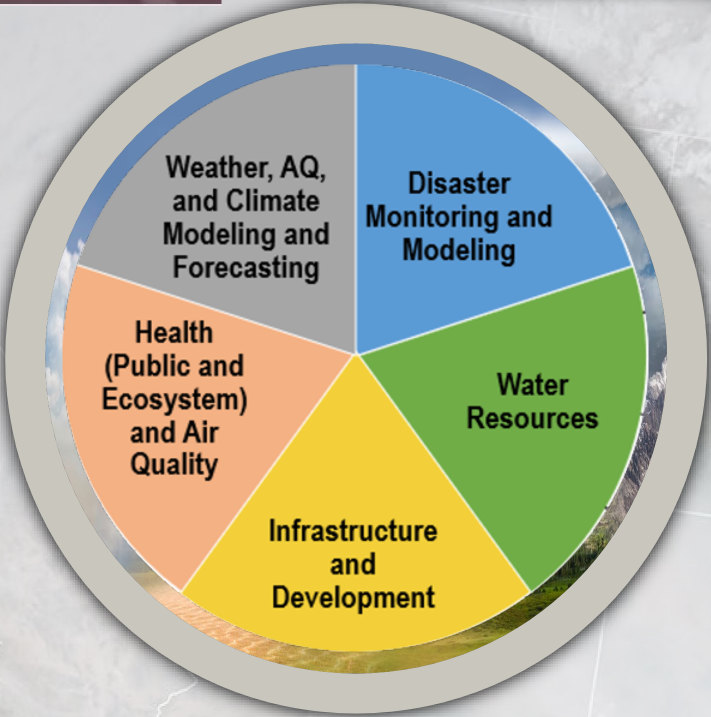
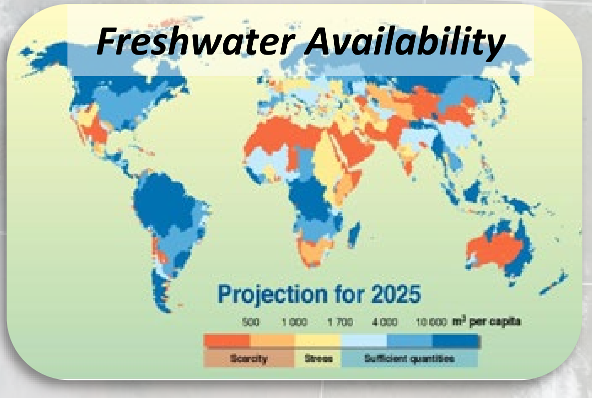
AOS will provide key information to support decision making at timescales from hours to decades, enabling improved weather and air quality forecasting today, seasonal to sub-seasonal changes in the near future, and societal challenges resulting from climate change in the decades to come.









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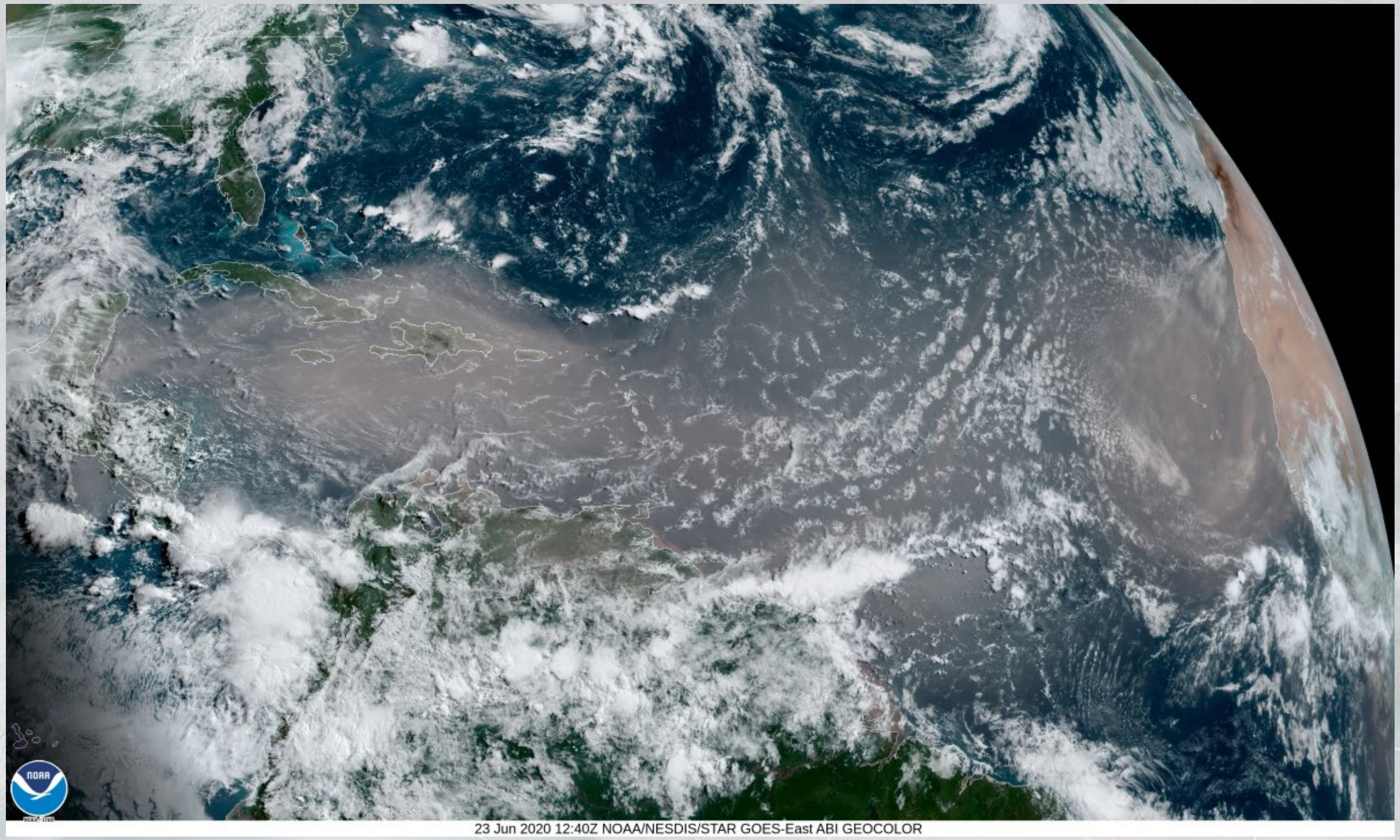
AOS Aerosol Measurements



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Aerosol Detection and Characterization

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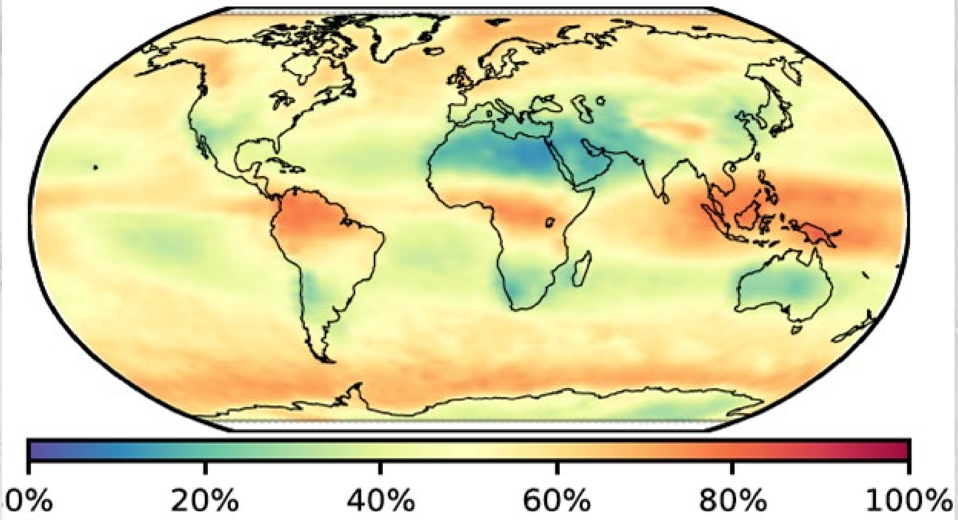
- **Key motivation of AOS: Significantly advance the measurement of aerosol properties beyond CALIPSO capabilities**
- Improve aerosol detection/sensitivity (CALIPSO non-detection in ~36% of opportunities to observe, particularly under thin clouds)
- Improve aerosol extinction & backscatter estimates and associated joint lidar-polarimeter retrievals of aerosol optics and microphysics



*Regional frequency of **thin cloud** from CALIPSO*

Courtesy of T. Thorsen

Key measurement goals:
- Reduce random error (increase SNR)
- Reduce systematic error (improve calibration and/or use HSRL)

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ALICAT Measurements: Sensitivity

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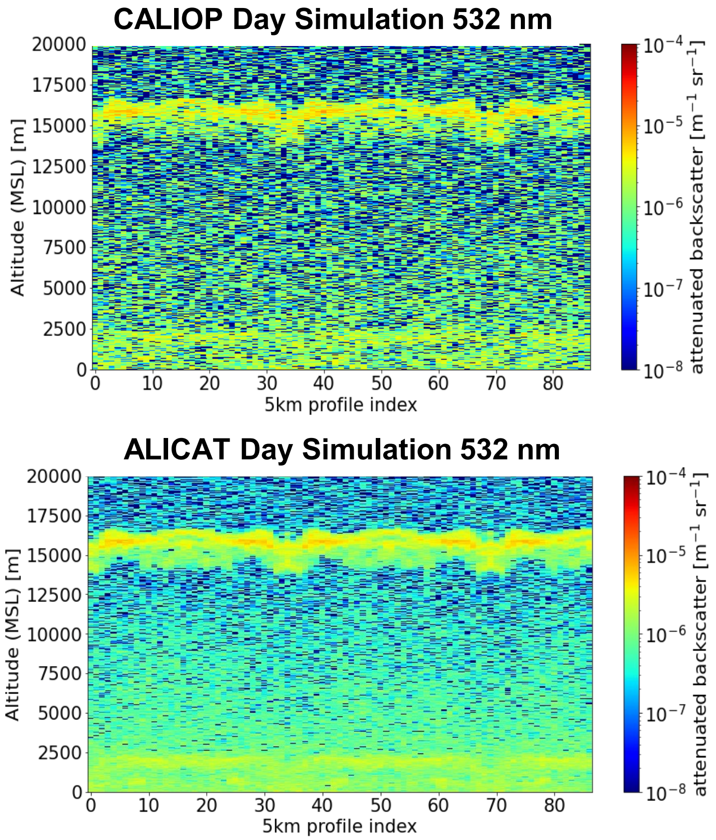
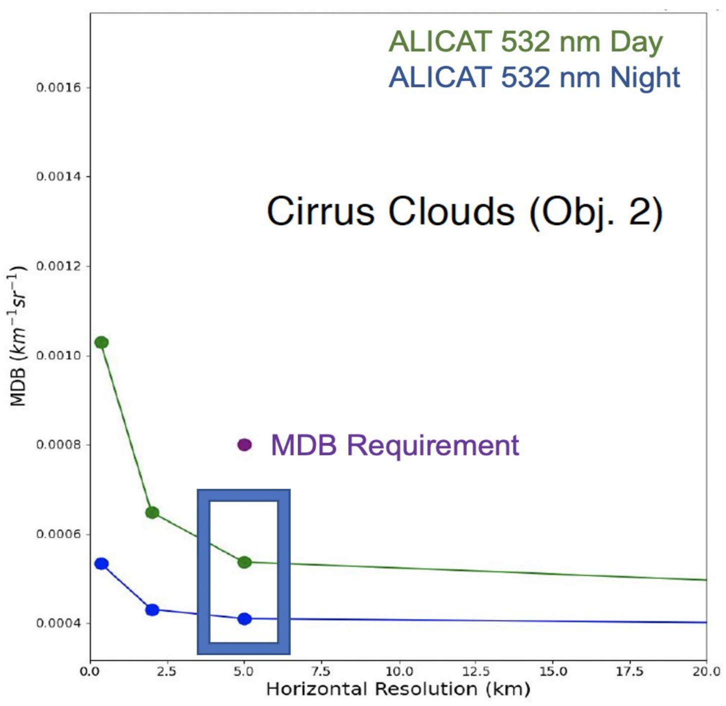
ALICAT's strengths are detection and quantification of optically thin high clouds and dust/smoke aerosols, all features with diurnal variability (enabled by improved SNR)

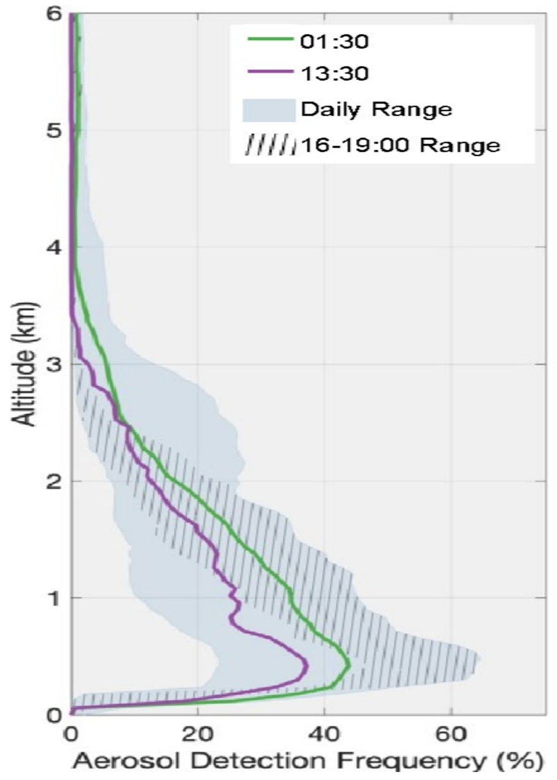


Courtesy of Willem Marais and Bob Holz (Univ. of Wisconsin)

Minimum Detectable Backscatter (MDB)



Diurnal Variability of Smoke Aerosols Observed by CATS over Borneo



Clio HSRL Measurements: Sensitivity

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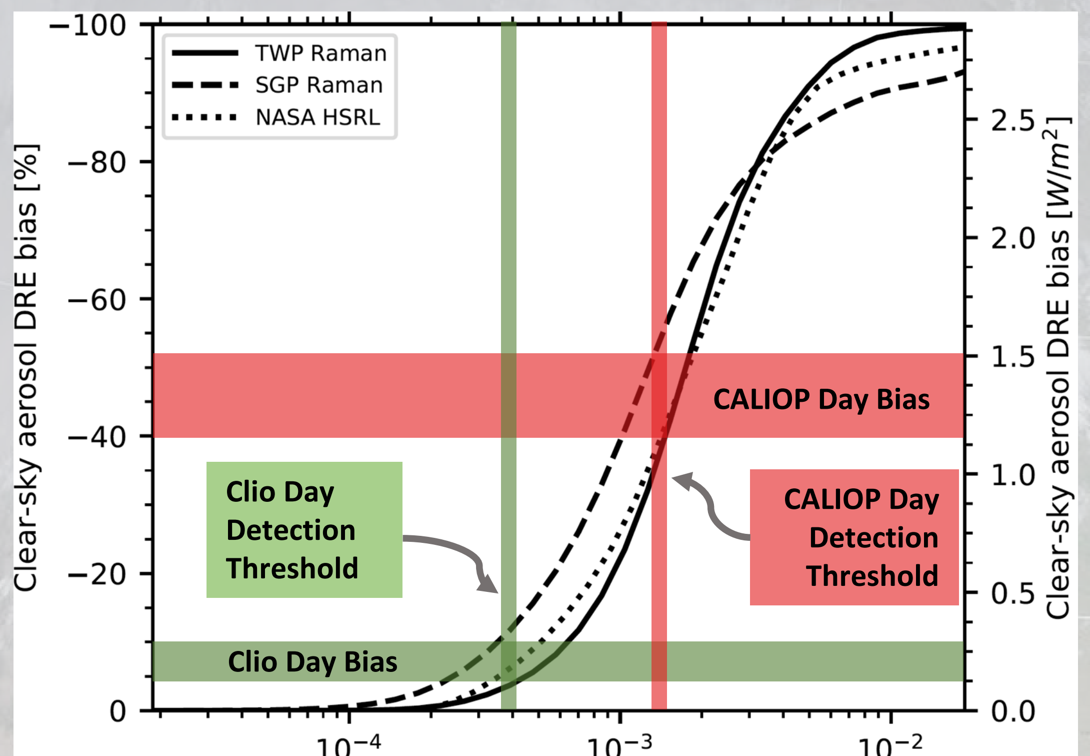
- CALIOP measurements lack sensitivity to detect a significant fraction of aerosols
  - Results in up to ~50% bias in clear-sky aerosol direct radiative effect
  - Partly due to SNR
  - Partly due to inability to quantify aerosols below clouds and near the surface
- Clio HSRL will provide the SNR and accuracy required to detect ~90% of aerosols and reduce biases in aerosol radiative forcing
  - Critical to AOS Objectives
    - O7: Aerosol Direct Effect and Absorption
    - O8: Aerosol Indirect Effect)
  - Greater accuracy is as important as higher SNR

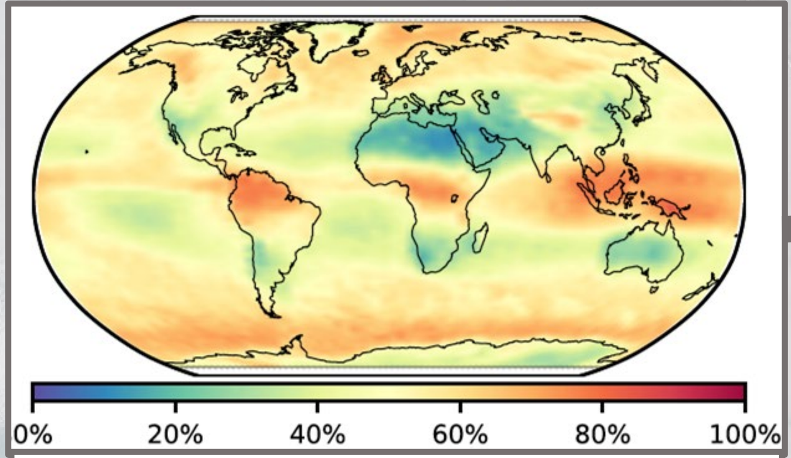


(adapted from Thorsen et al. 2017)

Impact of backscatter detection threshold on the aerosol direct radiative effect (DRE) bias

Clio HSRL Measurements: Accuracy

- Clio reduces systematic error (bias): i.e., increases accuracy
- Accurate measurements of particulate backscatter and extinction profiles
- Calibrated profiles to the surface including in multi-layer scenes and below thin clouds



*Regional frequency of **thin cloud** from CALIPSO*

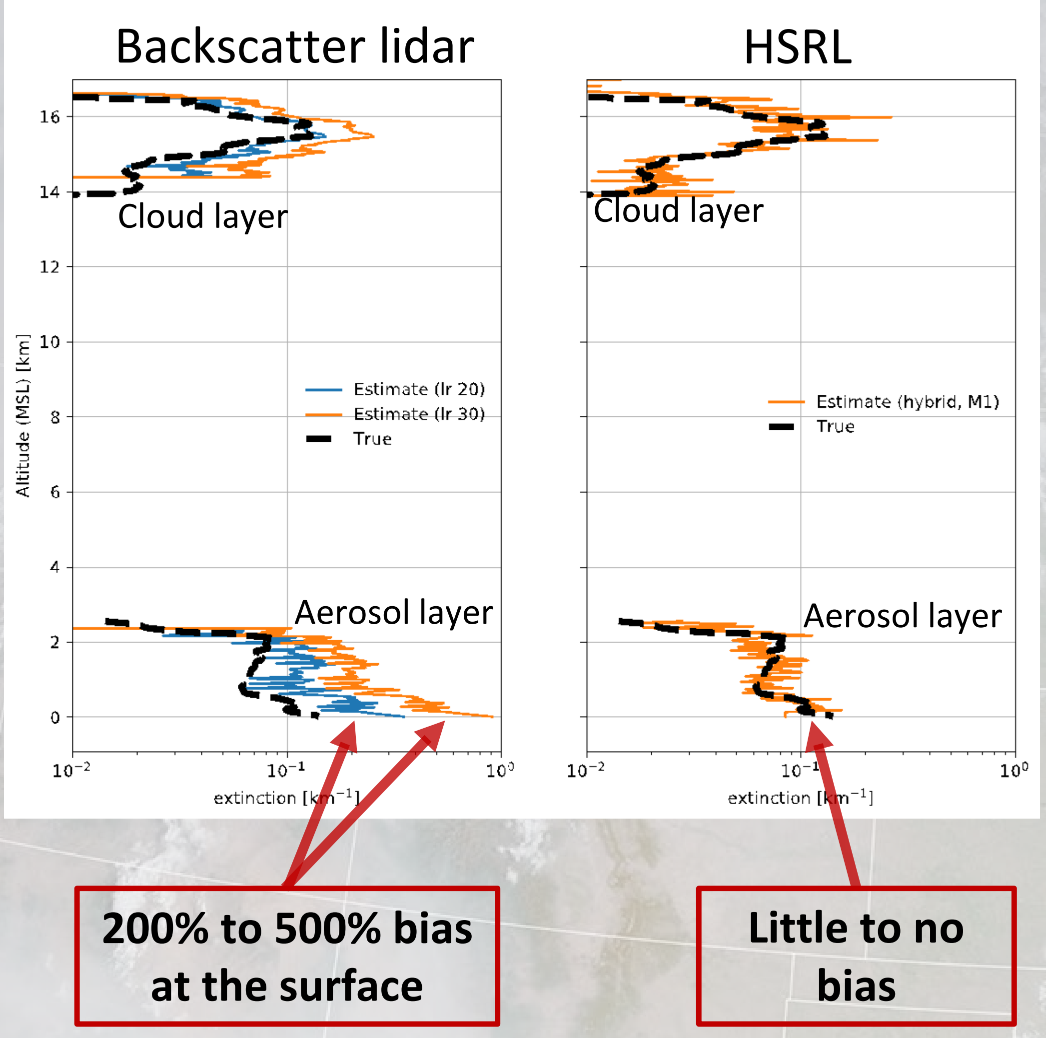


Figure from R. Holz, W. Marais

AOS-P Polarimeter: Aerosols

multiangle, polarimetric UV-VIS-NIR observations

↓

Aerosol optical depth

Aerosol absorption optical depth

Aerosol fine mode effective radius

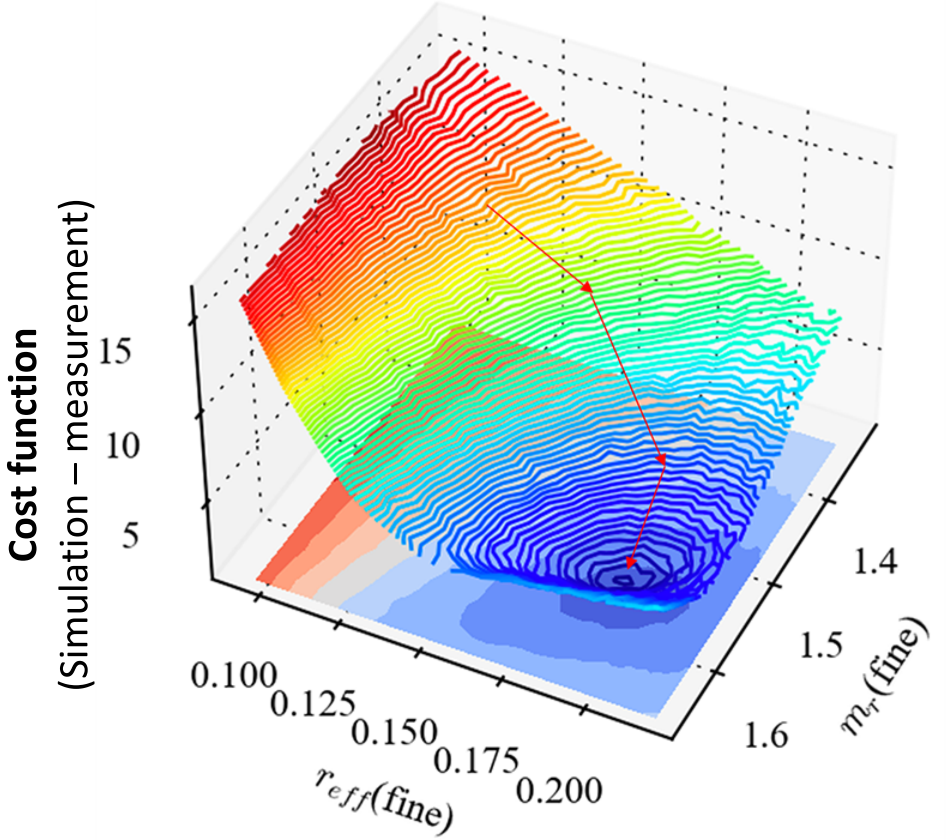
+other aerosol microphysical properties

Optimization-based retrieval approach

Radiative transfer simulations are iteratively adjusted until the simulation – measurement 'cost function' is minimized

Example Algorithms:

GRASP: 10.5194/essd-12-3573-2020
MAPP: 10.1364/AO.57.002394
RemoTAP: 10.5194/amt-2019-287
fastMAPOL: 10.5194/amt-2020-507



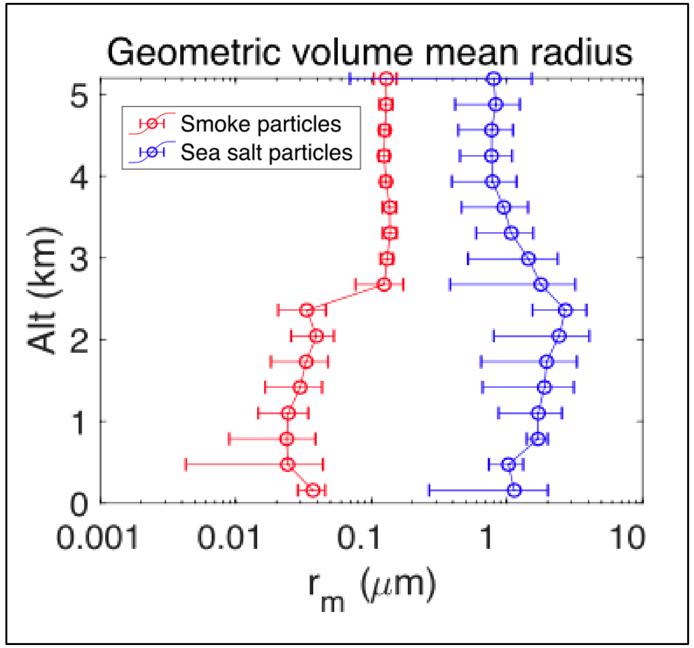
AOS-P Synergistic Lidar + Polarimeter Retrievals

multiangle, polarimetric UV-VIS-NIR observations

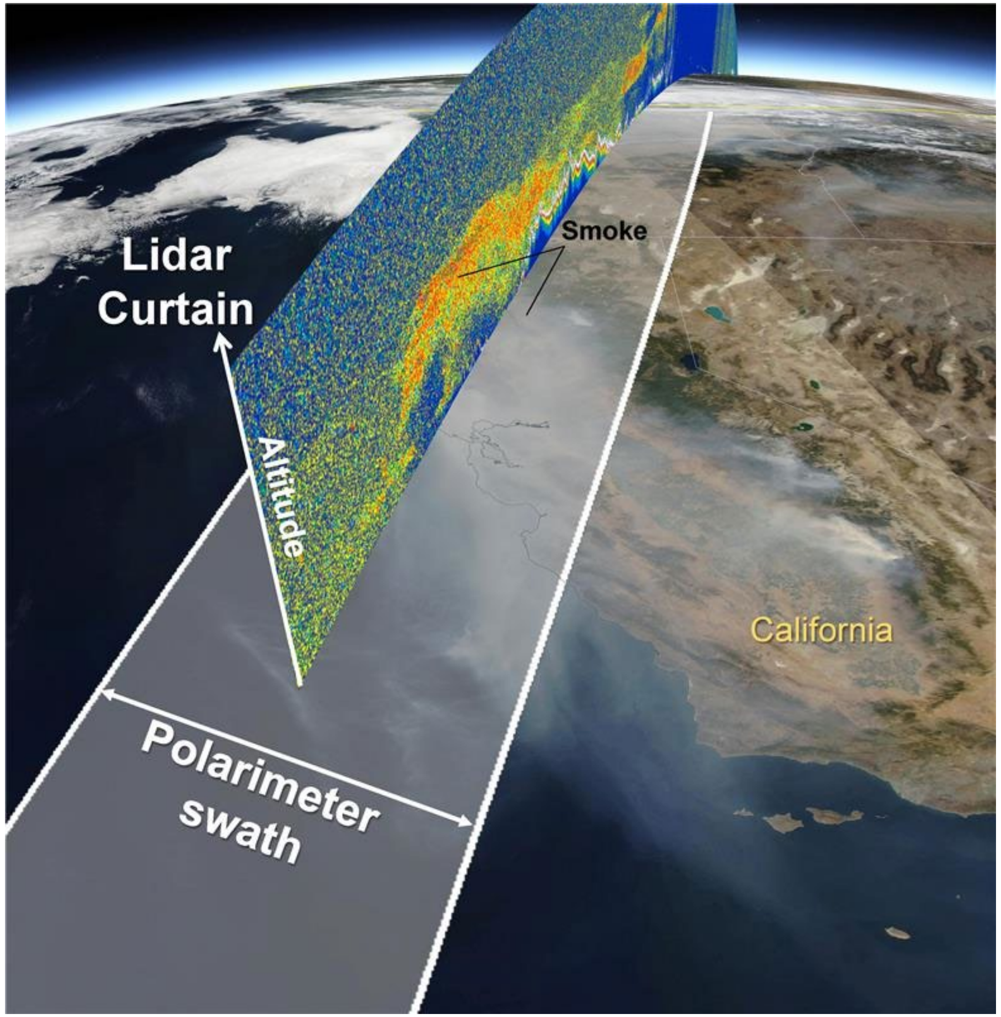
+

Lidar VIS-NIR Vertical Profiles

Synergistic vertically resolved microphysical properties & additional information content



Example of one of several retrieved parameters in F. Xu et al. doi: 10.3389/frsen.2021.620871



Note: We are exploring AOS-I synergy between the lidar and GEO data

AOS Timeline

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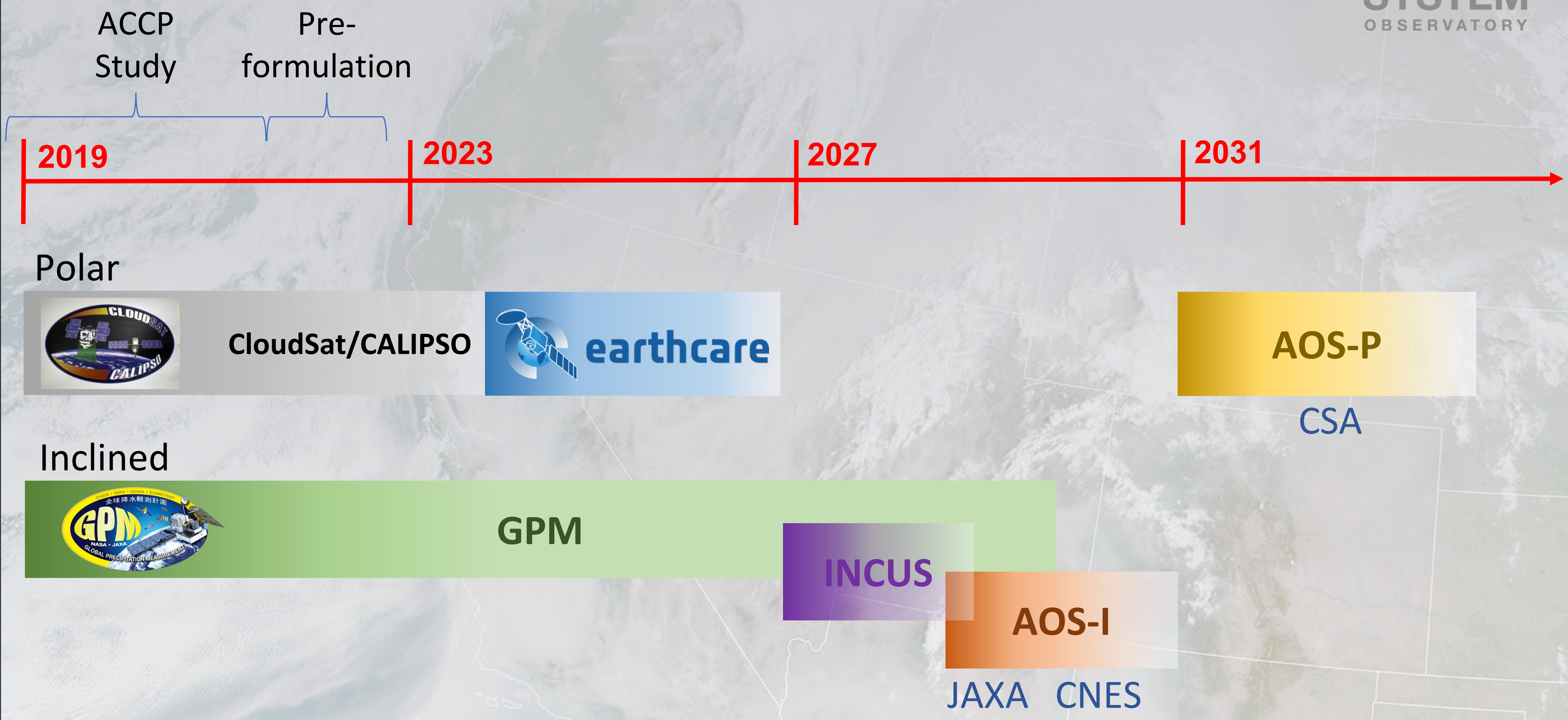

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Summary and Notes

- AOS science flows directly from NASA Decadal Survey
- AOS Mission Concept calls for a dual-orbit constellation
  - AOS-I lidar measurements provide aerosol profiles similar to CALIOP but time-varying with better daytime SNR
  - AOS-P will provide global polarimeter and HSRL aerosol measurements with more accuracy than any previous NASA mission
- Architecture contingent on HQ's reviews, decisions, and funding
  - ***Should*** be finalized by the end of 2022

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Email: john.e.yorks@nasa.gov

Thank you!

Questions?