ACCP Aerosols, Clouds, Convection, and Precipitation Study

Architecture Recommendation Review (ARR)

ACCP Team Strategy

- Initiate an Integrated Global Constellation for the future
  - The domestic and international interest in ACCP is extremely high
  - There are exciting opportunities to explore in adding to ACCP
  - "Build it and they will come…"
- Maintain NASA leadership in the development and implementation of the radar and lidar measurements to do novel and transformative Science
  - NASA Backscatter Lidar flown in space as well as High Spectral Resolution Lidar (HSRL) and multi-frequency Doppler Radars flown on many successful, airborne missions define present capability and inform development plan for ACCP space flight
- Work collaboratively with other agencies as the leader of the US science investigations and applications to make exciting advancements for Applications
  - Build on relationships established during previous spaceflight and airborne campaigns and from ACCP community applications needs assessments (conducted in concert with the RTI Innovation Advisors)

ACCP Study

After having…

- *looked at over 100 Architectures using our Extensive Instrument Library of Instruments*
- *had the world's experts perform simulations to quantitatively score Science Benefit*
- *completed rigorous designs for spacecraft to accommodate payload suite building blocks*
- *completed rigorous cost exercises including NICM, CEMA Parametric Analyses and had them independently assessed via Peer Review and Aerospace*
- *stood up Independent Technology Readiness Assessment (TRA) Boards to assess the Risks associated with our instruments*

89 Instruments
- *37 Radars*
- *10 Lidars*
- *15 Radiometers*
- *13 Polarimeters*
- *6 Spectrometers*
- *8 Other (e.g. Cameras)*

- all while maintaining our Value Framework principles
- and continuously engaging with the independent Science Community Committee and incorporating their feedback...
- the science and applications teams were able to develop a priority scheme
- the management team could use to optimize the Architectures within cost constraints and identify descopes and opportunities

ACCP Study

- *We are very excited to show you the Top 3 Architectures*
- *We are very pleased to report that the Science Team, Independent Science Community Committee, the Study Management Team and NASA Center Partner Management Board (PMB) leadership all agree on a singe recommendation to HQ…*
- *The recommended architectures provide multiple breakthrough technologies that will answer fundamental questions about how microscopic particles interact in the atmosphere to fuel severe storms, impact air quality, and influence our changing climate*
- *In this era of increasing weather and air quality extremes, the recommended architectures provide unique observations to reveal complex global processes*
- *ACCP will enable decision making that impacts people around the world, from short-term crises to long-term plans. It will advance:*
    - *Weather Forecasting, Climate Modeling, Air Quality Prediction, Disaster Monitoring*

SATM 3 Key Science Questions/5 Goals/8 Objectives

Science Implementation Strategies

Top Candidates for Final 3 Architectures—Programmatic Factors Cost, De-Scopes & Risk

Early Science Option
1st Launch As Early as 2027-2028
Lowest Risk

Why? Polar Orbit covers the poles for global scale measurement of integrated ACCP longer time scale processes tied to radiation and climate. Lower inclination orbit provides diurnal sampling critical for convection, precipitation and delta t measurements for shorter time scale processes.

First Mission: $579M
Second Mission: $1006M

All-In International
Only 1 Launch 2031
Highest Risk

Why? Polar Orbit covers the poles for global scale measurement of integrated ACCP longer time scale processes tied to radiation and climate. Instruments in polar provide increased Information with 3 frequency radar and 3 wavelength lidar vs. 2 for each in D1A and a wide swath precipitation radar beneficial for context and applications.

Single Mission: $1.584B
Note: If prohibited from International LV then this option exceeds cap

US Alternative To JAXA Radar
Only 1 Launch 2031

Why? Polar Orbit covers the poles for global scale measurement of integrated ACCP longer time scale processes tied to radiation and climate. Instruments in polar provide increased Information with 3 frequency radar and 3 wavelength lidar vs. 2 for each in D1A without wide swath precipitation radar beneficial for context and applications to reduce cost.

Single Mission: $1.419B

Architecture D1A stands above the rest offering the benefits of Constellation science, opportunities for Earlier Science at lower initial cost, and potential opportunities for additional International Collaboration

Instrument Nomenclature Key

Active Sensors

ACCP Identifier		Spectrum	Architecture		
			D1A	P1	P2
Doppler Radars	Radar_13E	KaD, WD	✓	✓	
	Radar_13E+1	KuD, KaD, WD			✓
	Radar_18	KuD, W	✓		
	Radar_17DN	KuD		✓	
Lidars	Lidar_05	532 nm HSRL 1064 nm	✓		
	Lidar_06	355 nm HSRL 532 nm HSRL 1064 nm		✓	✓
	Lidar_09er	532 nm 1064 nm	✓		

Passive Sensors

ACCP Identifier		Spectrum	Architecture		
			D1A	P1	P2
Spectro-meters	Spec_03	LWIR, FIR	✓	✓	✓
	Spec_04	UV,VIS,NIR,SWIR	✓	✓	✓
Radio-meters	Radio_07	118/183/240/310/380/ 660/880 GHz	✓	✓	✓
	Radio_09x	89/183/325 GHz	Possible substitute for Radio_07	Possible substitute for Radio_07	Possible substitute for Radio_07
Polari-meters	Polar_04b	UV/VIS, VNIR/SWIR	✓		
	Polar_07	UV/VIS, VNIR/SWIR	✓	✓	✓
Other	ALI	VNIR, SWIR		✓	✓
	SHOW	NIR		✓	✓
	Camera	VIS	✓	✓	✓

Study Plan & Process for Selecting Observing System Architectures

RFI #1 – General call for Instrument Capabilities

Filters: Qualitative Science Benefit Scoring and Initial Cost Estimates

~100 Potential Options

- Large number of constellations with Large to Small Sats required to accommodate Instruments
- Perform building-block level design center sessions (JPL, LaRC, MSFC, GSFC)
- Identify primary drivers and iterate against SATM

Filters: Science Value vetted with community team; and Risk and Cost Assessments

~12 Feasible Options

- Refine Science Scoring with OSSEs
- Refine Cost with parametric- and analogy-based models
- Instrument Technical Readiness Reviews
- Quantified Risk
- Programmatic Factors

3 Recommended Options To HQ

- Highest Science Value Within Cost
- Quantified Risk
- Programmatic Factors

We are here

Completed 8 Months Early: *Ready To Recommend 1 Architecture and To Move To Pre-Phase A*

1 Recommended Option to HQ

RFI #2 – Specific call for instrument technical information

June 2019

Sept 2020

Jan 2021

Original Plan: Summer 2021

FY22: Start Pre-Phase A

Study Team Dynamics

JPL Team-X Design Session
Summer 2019

SATM Review Feb. 2019
GSFC

Meeting with French Team
Feb. 2020
Washington, D.C

Major Community Engagement Events

April 2019 Full Community Workshop Pasadena, CA

Applications Workshops July 2019

Sub-Orbital Workshop March 2020

Modeling Workshop November 2020

Applications Transportation Workshop November 2020

Multiple Community Forums via Web-Ex

The 5 First Evers of ACCP

Greg Carmichael and Sue van den Heever

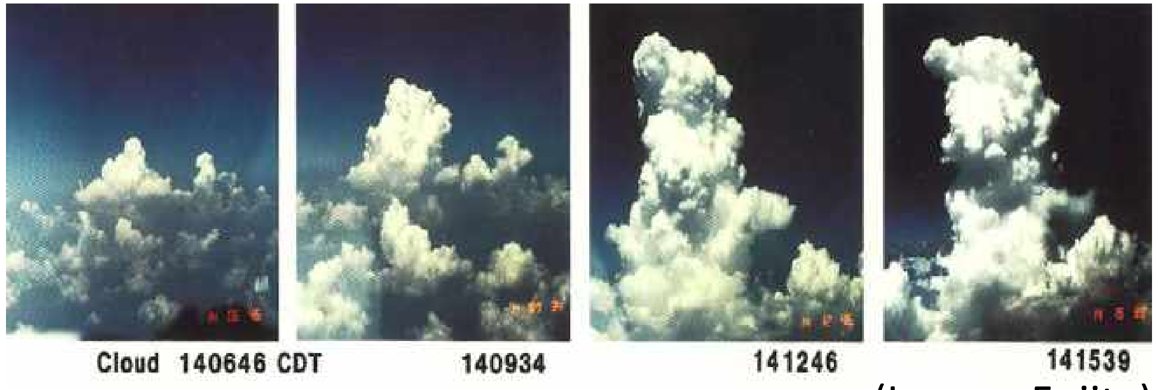
SCC Co-Chairs

The 5 First-Evers of ACCP

1. Global Observations of Vertical Motion
2. Global Profiles of Aerosol Properties
3. Co-Located Dynamics, Microphysics and Aerosol Characteristics
4. Evolution of Cloud and Aerosol Processes
5. Diurnal Cycle of Clouds and Aerosols

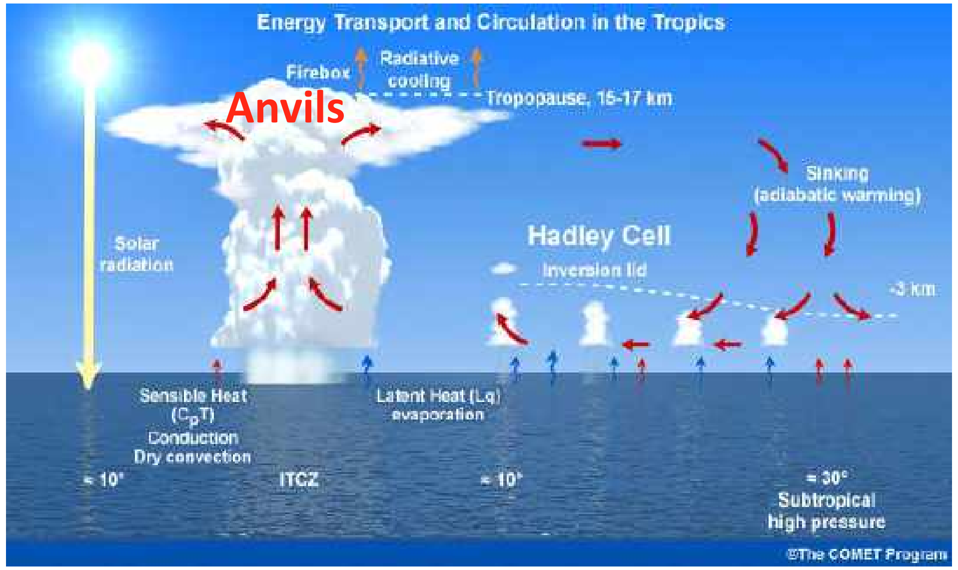
1. Vertical Motion – What We Know

1. Vertical Transport and Fresh Water

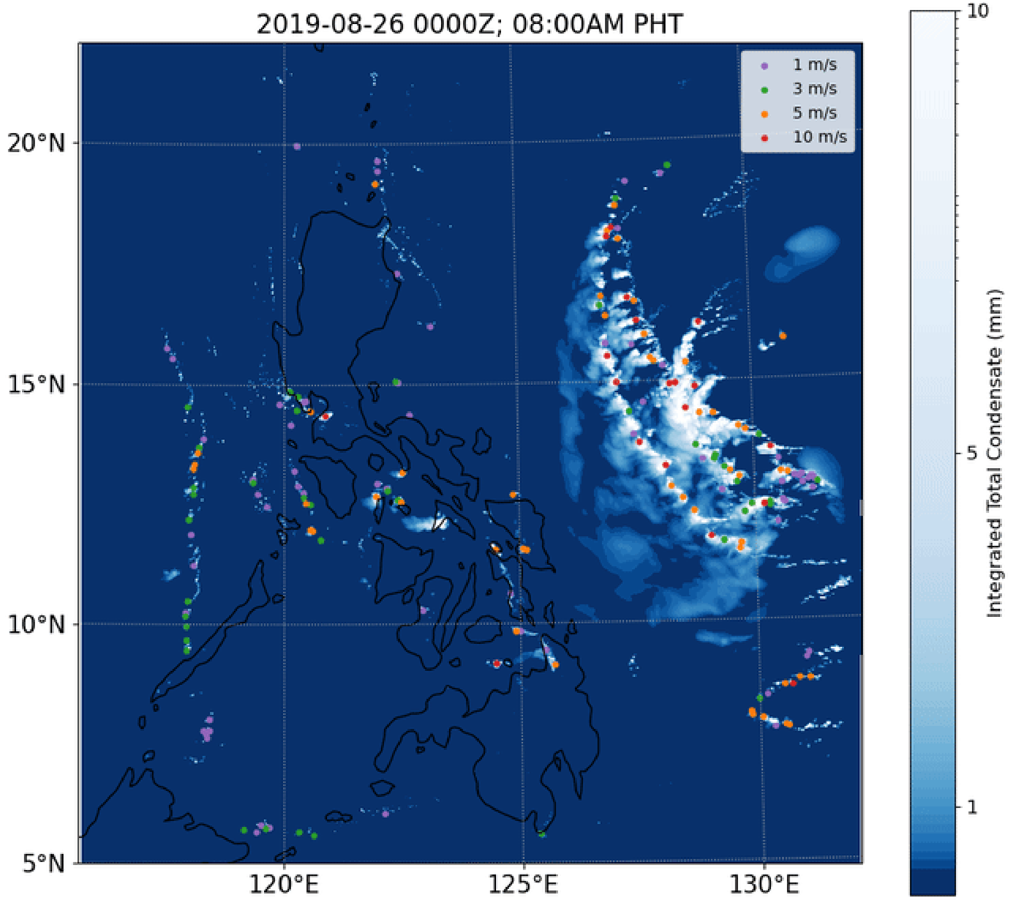


(Image: Fujita)

2. High Clouds and Large Scale Circulation



3. Storm Organization, Structure, and Longevity



The colored dots represent the location and intensity of vertical motions or updrafts in these systems (after Freeman and van den Heever 2020)

4. Severe Weather

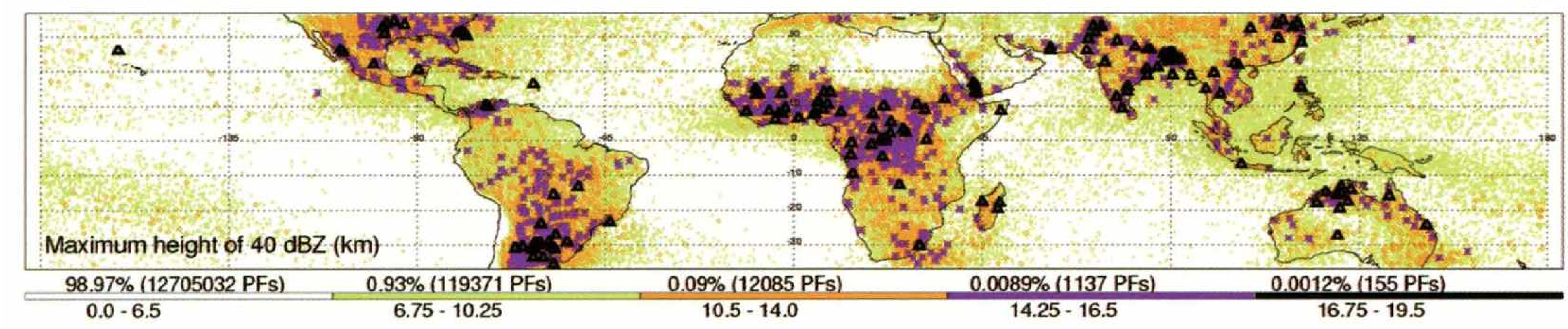
Tornadoes

Large hail

Heavy Rainfall and Lightning

1. Vertical Motion – What We Don't Know

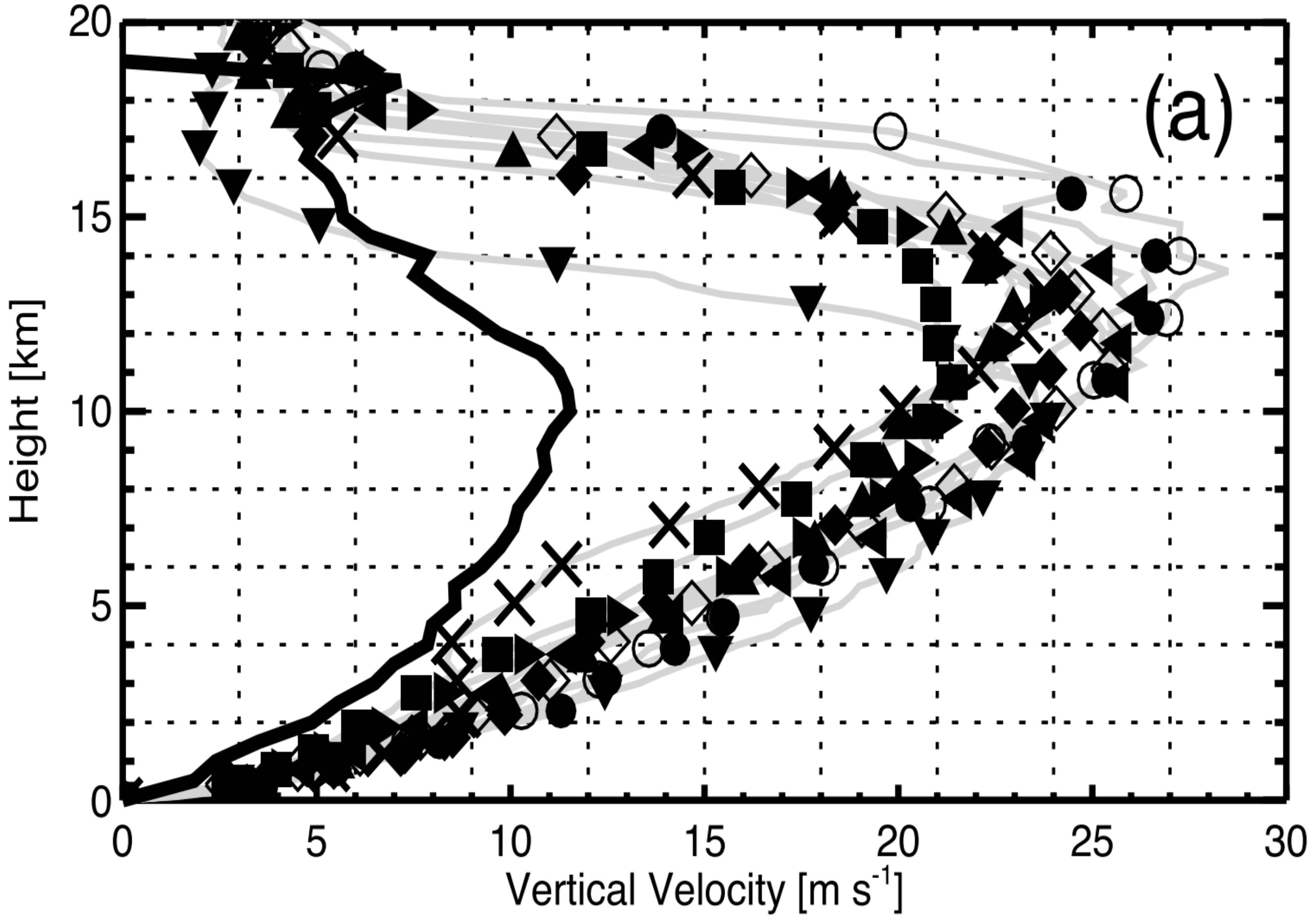
Distribution of the maximum height of 40 dBZ (km) (after Zipser et al. 2006).



- Why do storms over equatorial Africa produce less rainfall than those over equatorial America even though they have higher cloud tops, more lightning and are more intense?
- Why are storms so severe over Argentina but not over southern Africa or Australia?

1. Vertical Motion – What Do We Need?

- Our high-resolution cloud-resolving numerical models have been found at times to overpredict vertical motions
- Implications for our global climate model parameterizations
- **Global measurements of vertical motions in clouds**
- Address W-4 in the DS: "Why convective storms, heavy precipitation, and clouds occur when and where they do?"
- Evaluate our numerical models thereby improving prediction

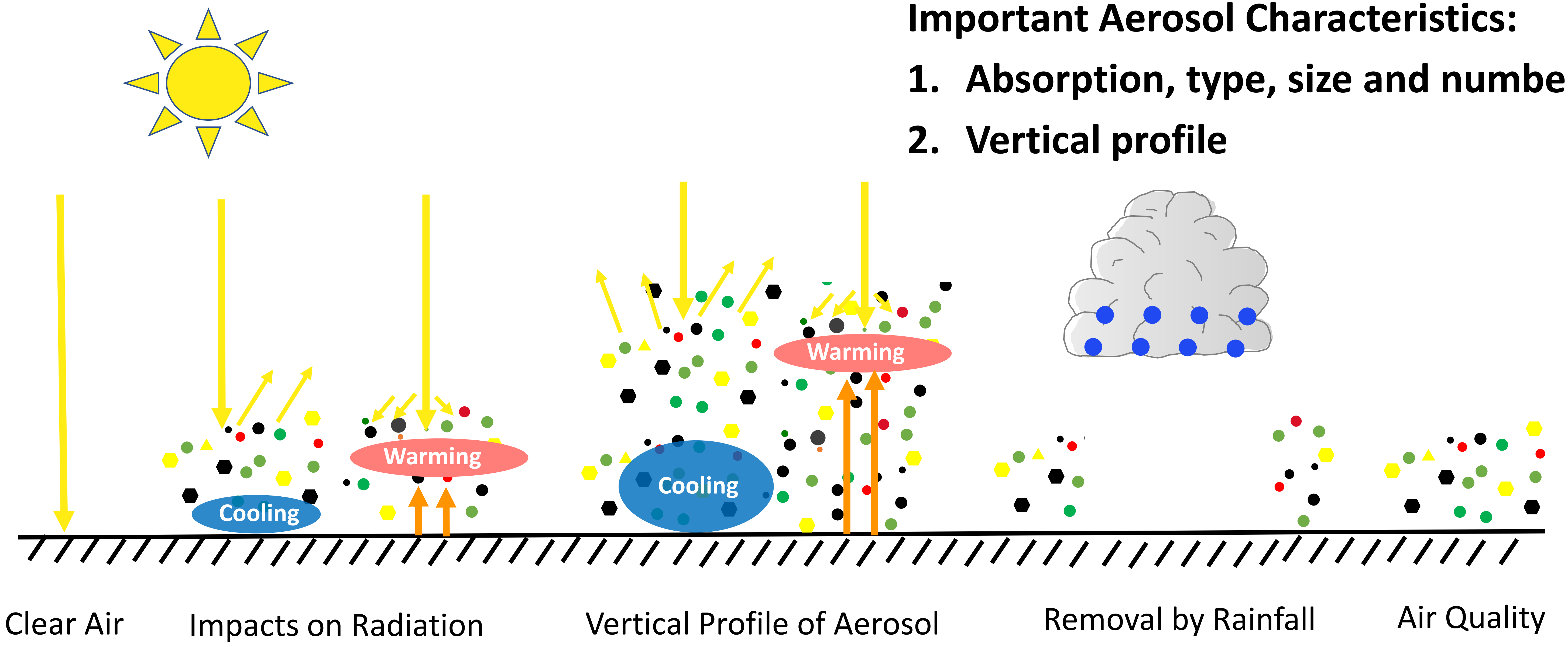


Simulated vertical velocity (symbols / dots) compared with Doppler-derived vertical velocity (solid curve) for the same case study (Varble et al 2014)

2. Profiles of Aerosol Properties

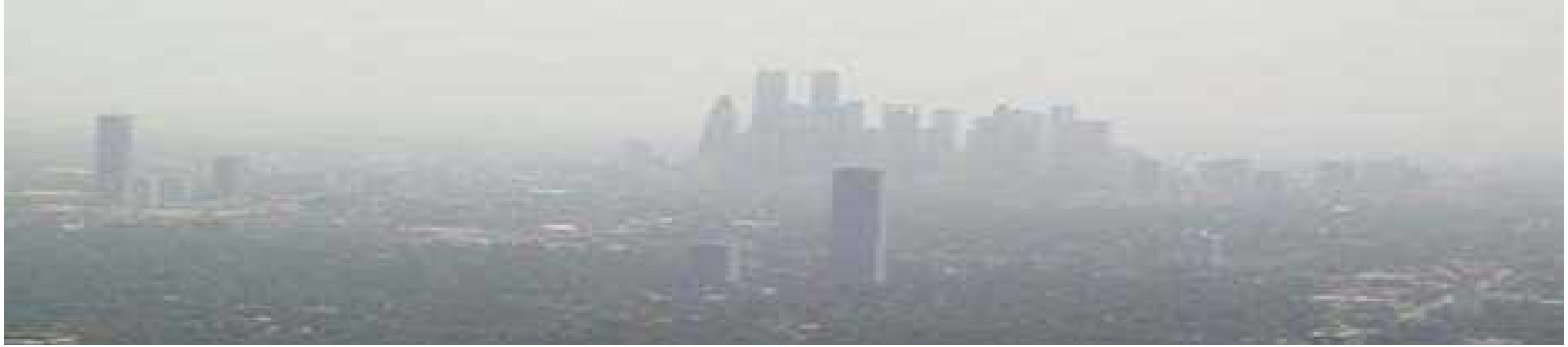
Important Aerosol Characteristics:

1. **Absorption, type, size and number**
2. **Vertical profile**

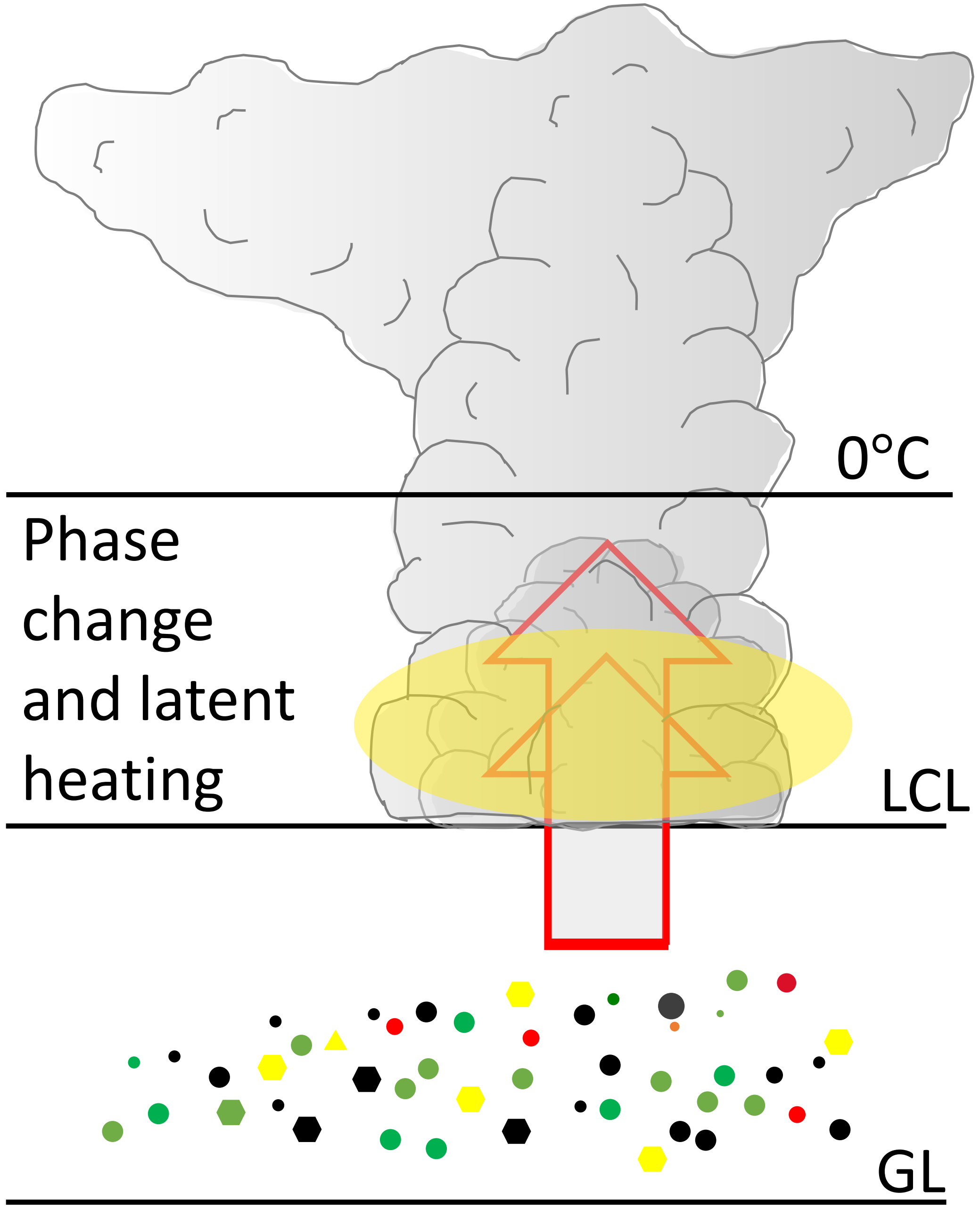


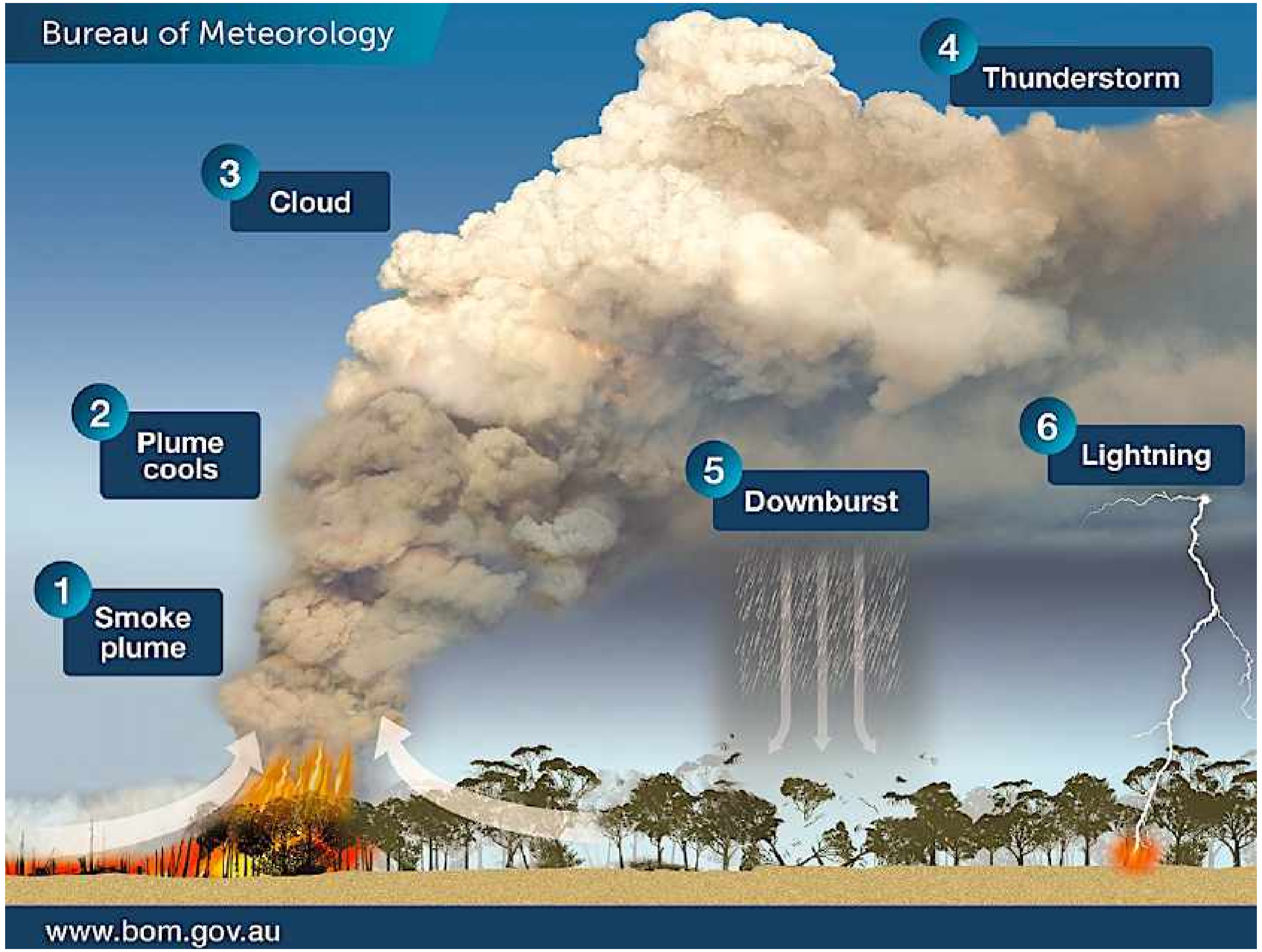
2. Vertical Profiles of Aerosol Properties – What Do We Need?

- **High-resolution profiles of aerosol properties**, including absorption and types → better quantify warming and anthropogenic contributions to forcing
- **Aerosol observations in the boundary layer** → advance our capabilities of identifying anthropogenic aerosols and links to human health
- **Simultaneous measurements of aerosol and precipitation processes** → better understanding of removal and redistribution processes



3. CO-LOCATED Dynamics, Microphysics and Aerosol Characteristics

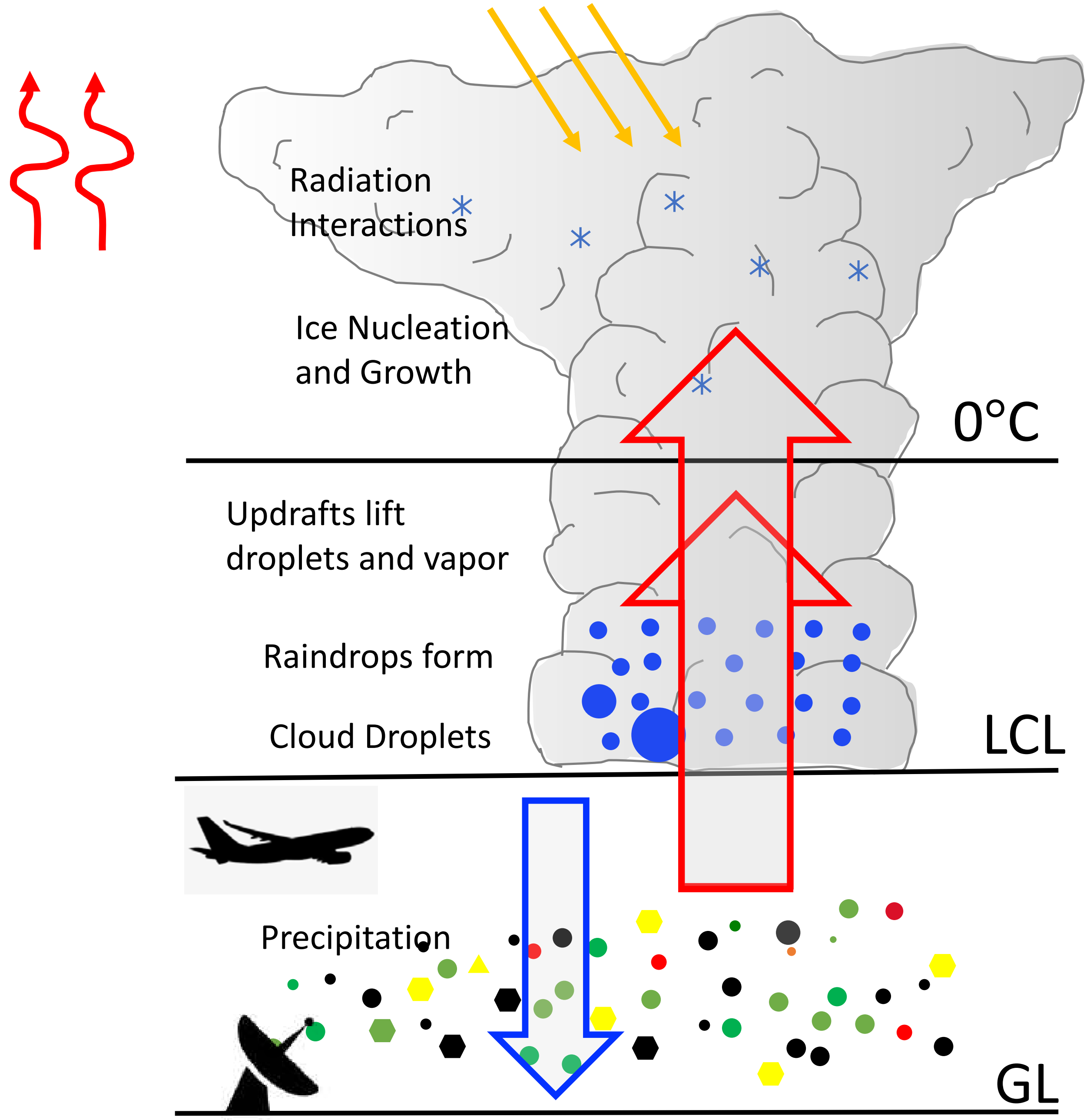




The storms developing in association with recent fires demonstrate links between vertical motion, aerosols, cloud and precipitation processes

3. CO-LOCATED Dynamics, Microphysics and Aerosol Characteristics – What Do We Need?

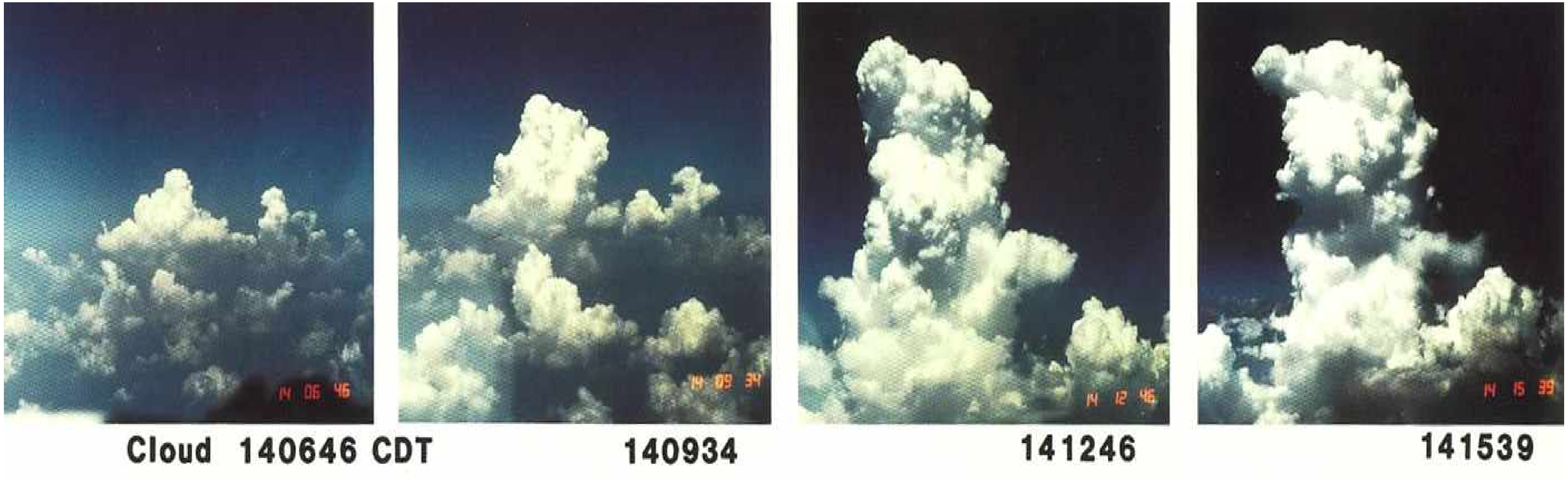
- Aerosols, cloud particles, vertical motion and radiation are integrally linked
- Global, CO-LOCATED simultaneous measurements of aerosols, cloud particles, vertical motion and radiation → significantly enhance our understanding and prediction of CLOUD PROCESSES
- Obtain critical complementary observations of vertical motion and aerosol and cloud processes below cloud and in the BL



4. Cloud and Aerosol PROCESSES

$$PROCESS = \frac{\partial X}{\partial t}$$

Image: Ted Fujita

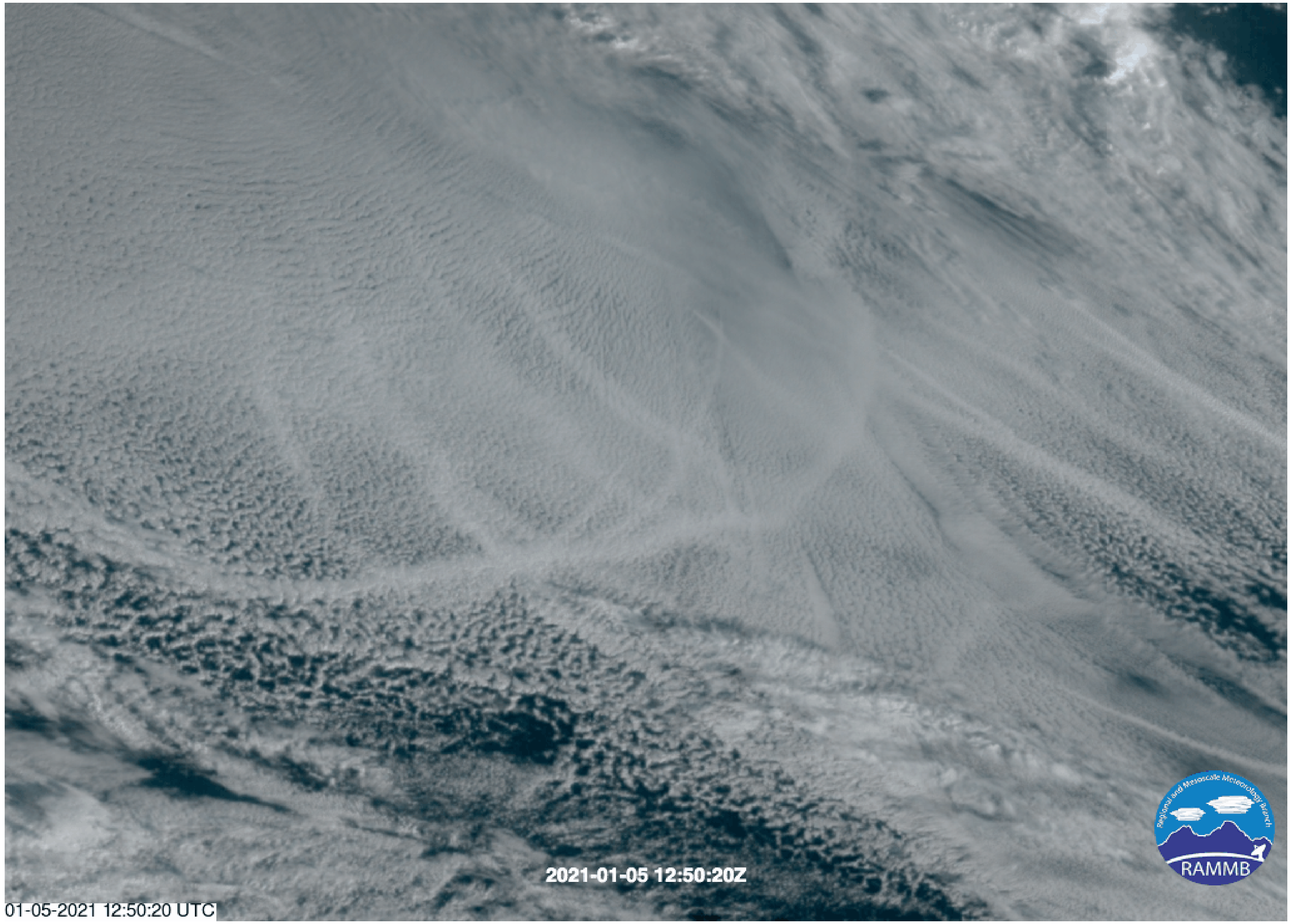


$\Delta t = 3\ minutes$ $\Delta t = 3\ minutes$ $\Delta t = 3\ minutes$

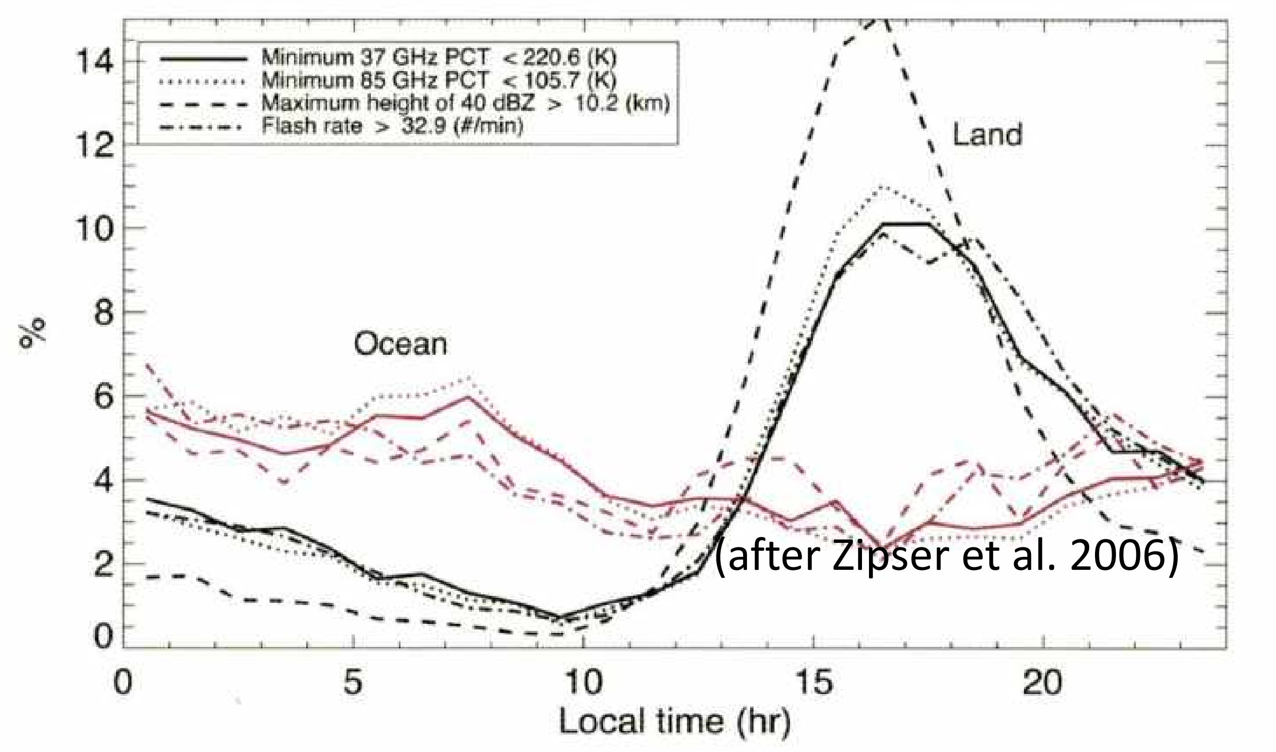
4. Cloud and Aerosol PROCESSES – What Do We Need?

- Evolution of stratocumulus clouds between open and closed cells, and the impact of ship tracks on the cloud system
- To understand the vertical motions within these shallow cloud systems, as well as how the aerosol plumes and cloud structures rapidly evolve and interact over short timescales **we need to make observations on short time intervals**

Evolving Stratocumulus and Ship Tracks



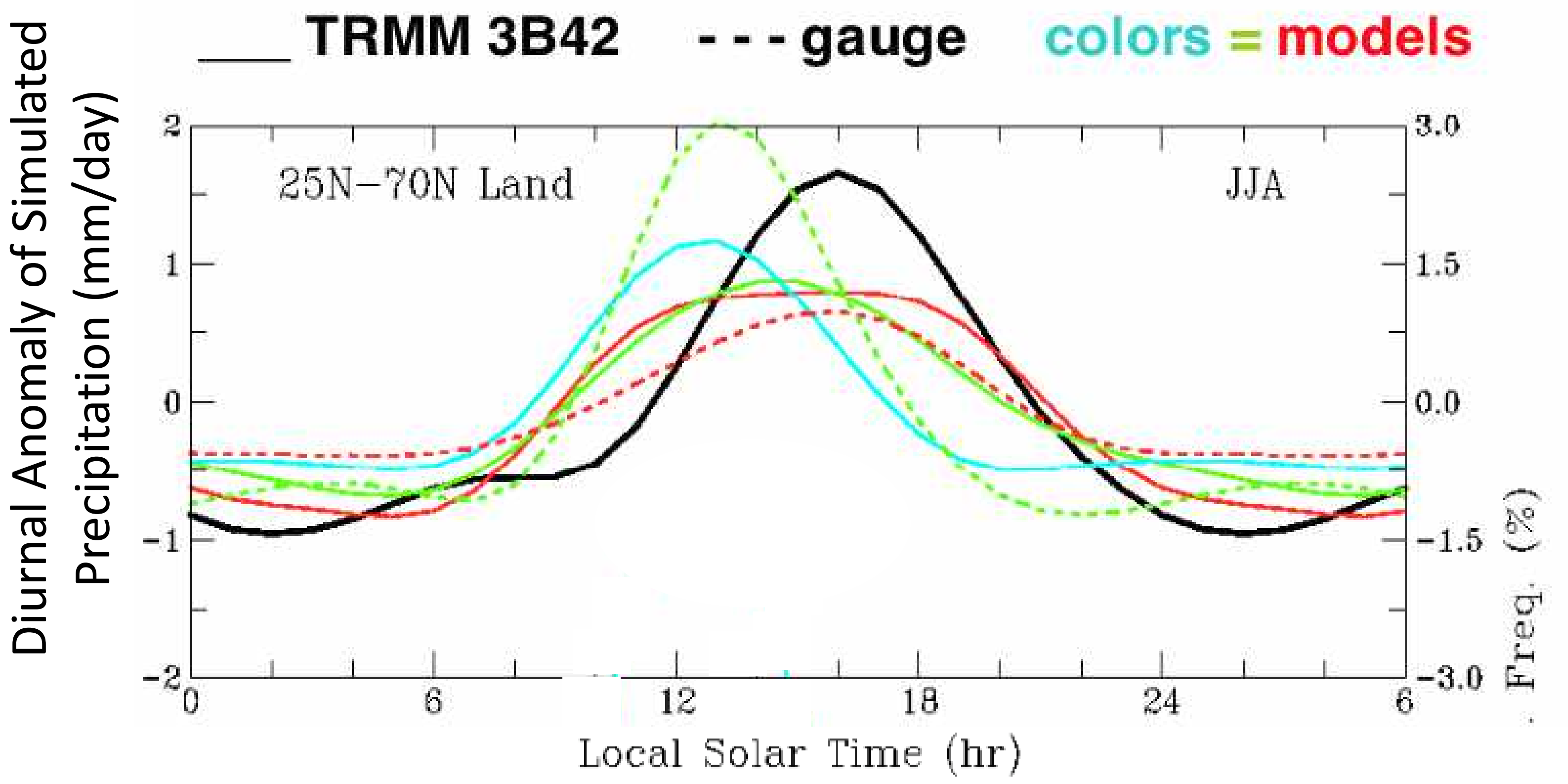
5. Diurnal Cycle – What Do We Need?



(after Zipser et al. 2006)

- Continental clouds and rain rates peak in mid-late afternoon or evening whereas maritime rainfall rates peak in the early morning
- Why do maritime clouds reach their maximum in the early morning hours?

IPCC AR4 Models (after Dai, 2006)



- In all AR4 GCMs rain occurs near local noon
- The diurnal evolution of cloud systems is also challenging in high-resolution NWP models

We need simultaneous co-located observations of the vertical motions, cloud, aerosols and radiation, throughout the diurnal cycle.

The 5 First-Evers of ACCP

1. Global Observations of Vertical Motion
2. Global Profiles of Aerosol Properties
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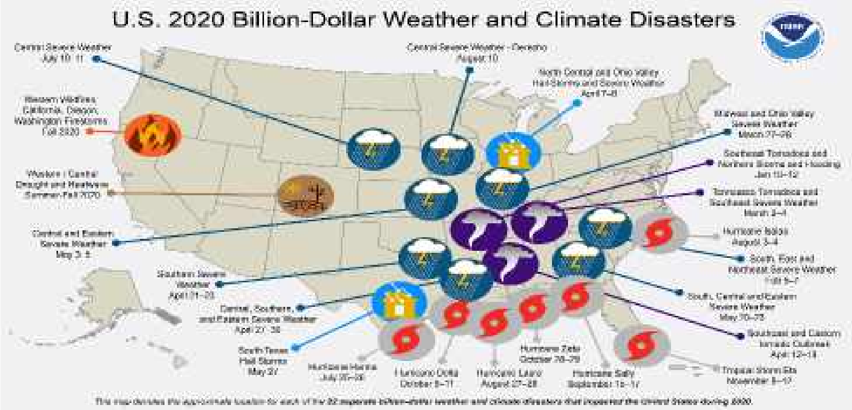
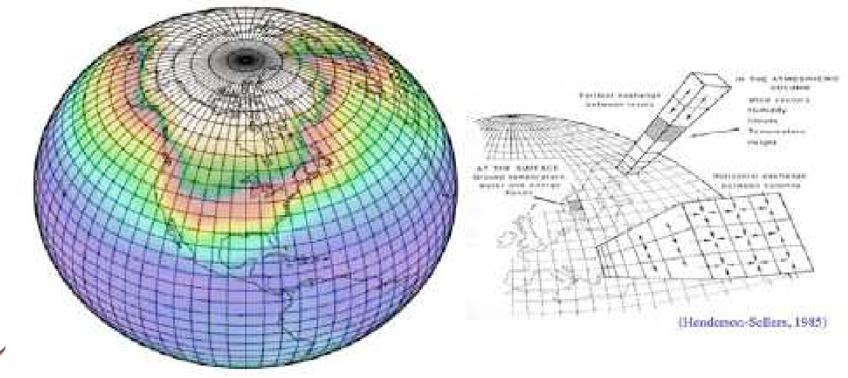
High Level ACCP Science and Applications

Scott Braun

Why ACCP Matters





ACCP Public Benefits for Storms:

First ever global view of thunderstorm vertical air motions and precipitation properties in severe storms, enabling operational weather communities to better understand and predict storms

ACCP Public Benefits for Air Quality

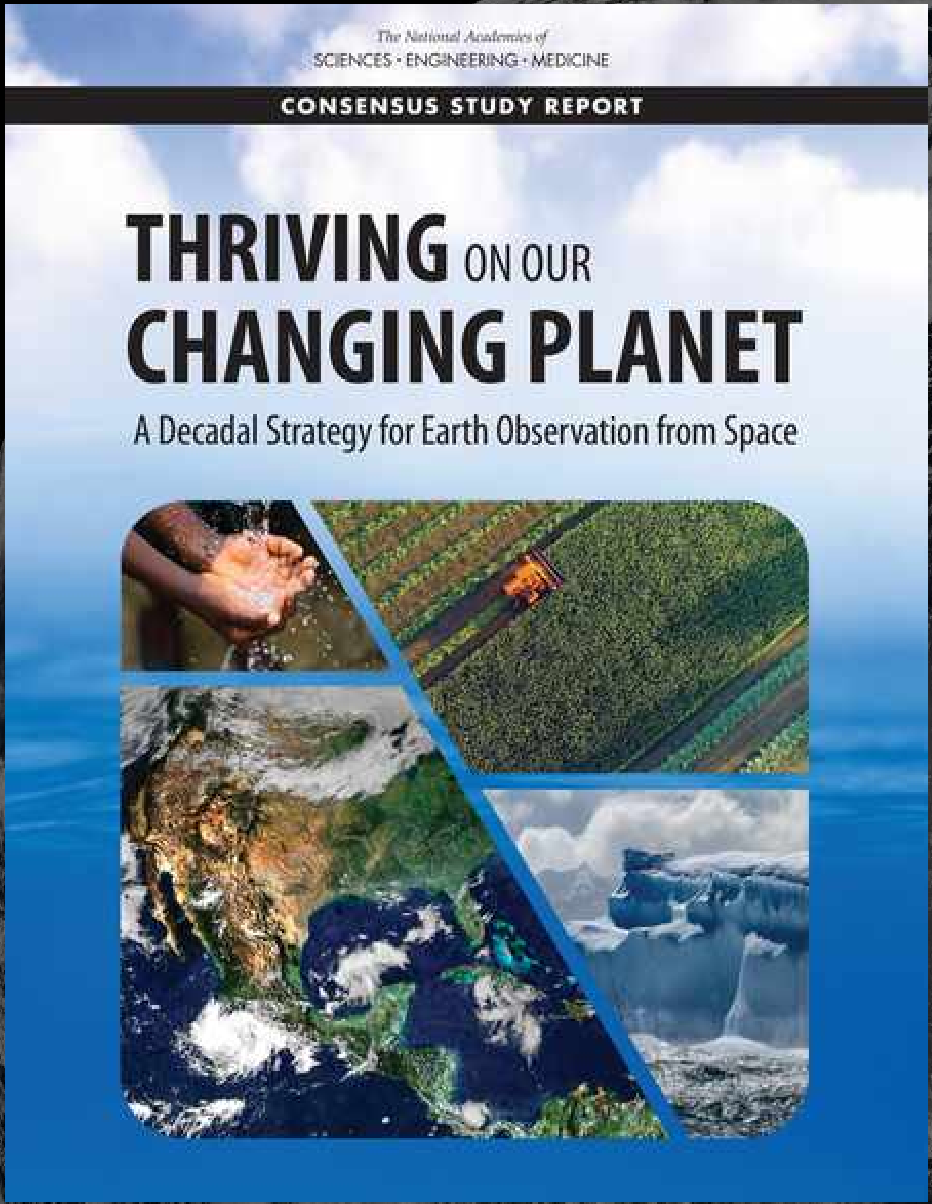
Unprecedent information on aerosols, enabling better understanding and prediction of the types and properties of aerosols that can be detrimental to people's health

ACCP Public benefits for Climate

Novel estimates of coupled vertical air motion, clouds and aerosol properties that will support sub-seasonal to seasonal (S2S) and climate modeling communities to better assess future hydrometeorological extremes

ACCP and the IPCC Assessment Report

AR6 WG1 report topic areas
Climate system observations, processes and interactions
Natural and anthropogenic drivers of climate change
Climate modelling, predictions, detection and attribution
Feedbacks and dynamical responses
Climate variability and implications for regional climate



Earth Science

NASA Earth Science unlocks the mysteries of our planet, exploring, discovering, and responding to the need to understand our planet's interconnected systems, from a global scale to minute processes. This knowledge and understanding serves the fundamental need to improve our lives on Earth, advancing this frontier for all humanity. NASA pursues both curiosity-driven and practically focused Earth science because our ability to thrive on our home planet is undeniably tied to our scientific understanding and predictive capability of its dynamics and phenomena.

Photo Credit: *NASA's Goddard Space Flight Center*
NASA's Global Modeling and Assimilation Office used Earth science data gathered from multiple missions to visualize several high impact events across the globe between August 2019 and January 2020, including Hurricane Dorian (August to September 2019), major fire events in South America and Indonesia (August to September 2019), and extreme wildfires in Australia (December 2019 to January 2020). The model helps demonstrate how different events interact and the environmental impacts they can have around the globe.

NASA Earth Science explores our rapidly changing world, where natural and human factors interact, following an interdisciplinary, Earth systems approach that examines the interplay among the atmospheric, ocean, land, and ice systems. Using the recommendations of the 2017 NASA Earth Science Decadal Survey, *Thriving on Our Changing Planet a Decadal Strategy for Earth Observation from Space*, as a compass, NASA Earth Science is developing the observing systems that will answer the most important science and application questions of the next decade across the following focus areas:

- Coupling of the water and energy cycles – ✓
- Ecosystem change
- Extending and improving weather and air quality forecasts – ✓
- Reducing climate uncertainty and informing societal response – ✓
- Sea-level rise
- Surface dynamics, geological hazards and disasters

Decadal Survey Science Questions Related to ACCP

Weather & Air Quality Panel

W-1 (MI): Planetary Boundary Layer Dynamics.

W-2 (MI): Larger Range Environmental Predictions.

W-4 (MI): Convective Storm Formation Processes.

W-5 (MI): Air Pollution Processes and Distribution.

W-6 (I): Air Pollution Processes and Trends.

W-9 (I): Role of Cloud Microphysical Processes.

W-10 (I): Clouds and Radiative Forcing.

Climate Variability and Change Panel

C-2 (MI): Climate Feedback and Sensitivity.

C-5 (I-VI): Aerosols and Aerosol Cloud Interactions.

Hydrological Cycle Panel

H-1 (MI): Coupling the Water and Energy Cycles.

C-8 (I): Causes and Effects of Polar Amplification.

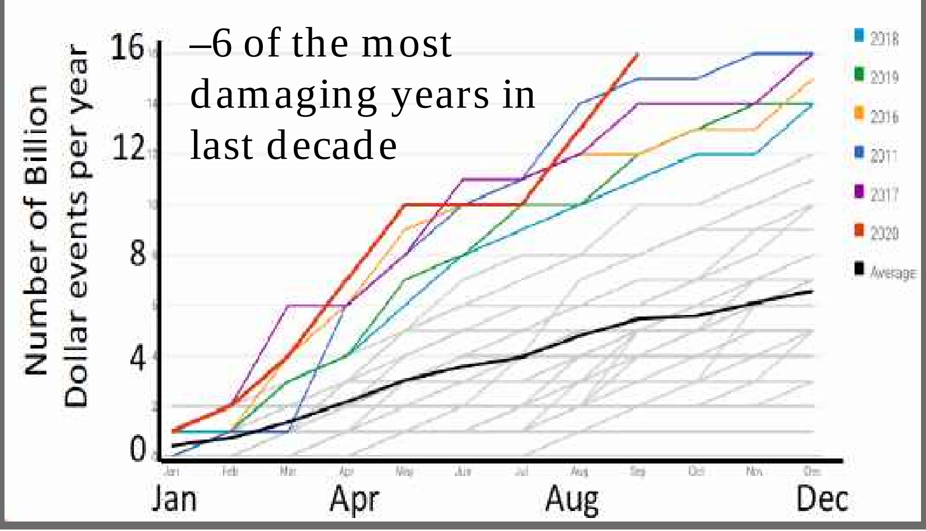
Most Important

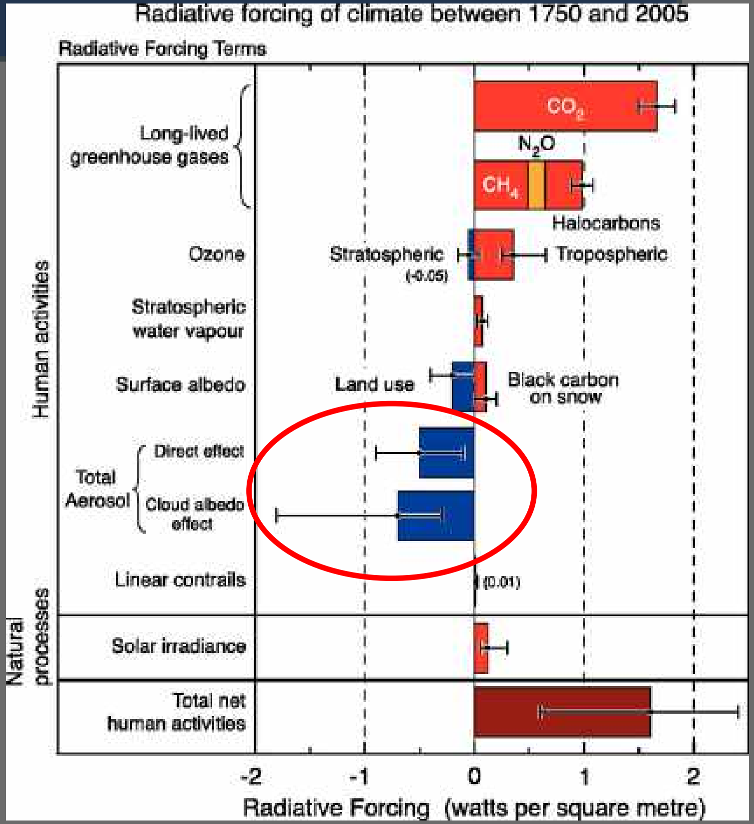
Very Important

Important

Decadal Survey Science Questions Related to ACCP

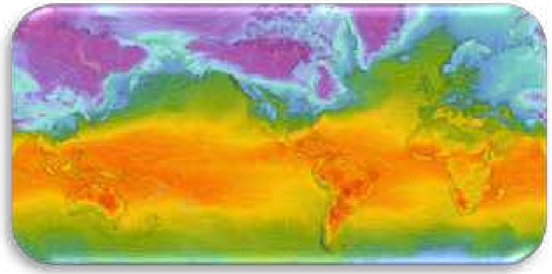
Weather & Air Quality Panel	Climate Variability and Change Panel	Hydrological Cycle Panel
W-1 (MI): Planetary Boundary Layer Dynamics.	**C-2 (MI): Climate Feedback and Sensitivity.**	**H-1 (MI): Coupling the Water and Energy Cycles.**
W-2 (MI): Larger Range Environmental Predictions.	**C-5 (I-VI): Aerosols and Aerosol Cloud Interactions.**	**C-8 (I): Causes and Effects of**
W-4 (MI): Convective Storm Formation Processes.		
W-5 (MI): Air Pollution Processes and Distribution.		





ACCP at a Glance

–Overarching Goal: Characterize the Role of Aerosols, Clouds, & Precipitation in Weather, Climate, and Air Quality Prediction



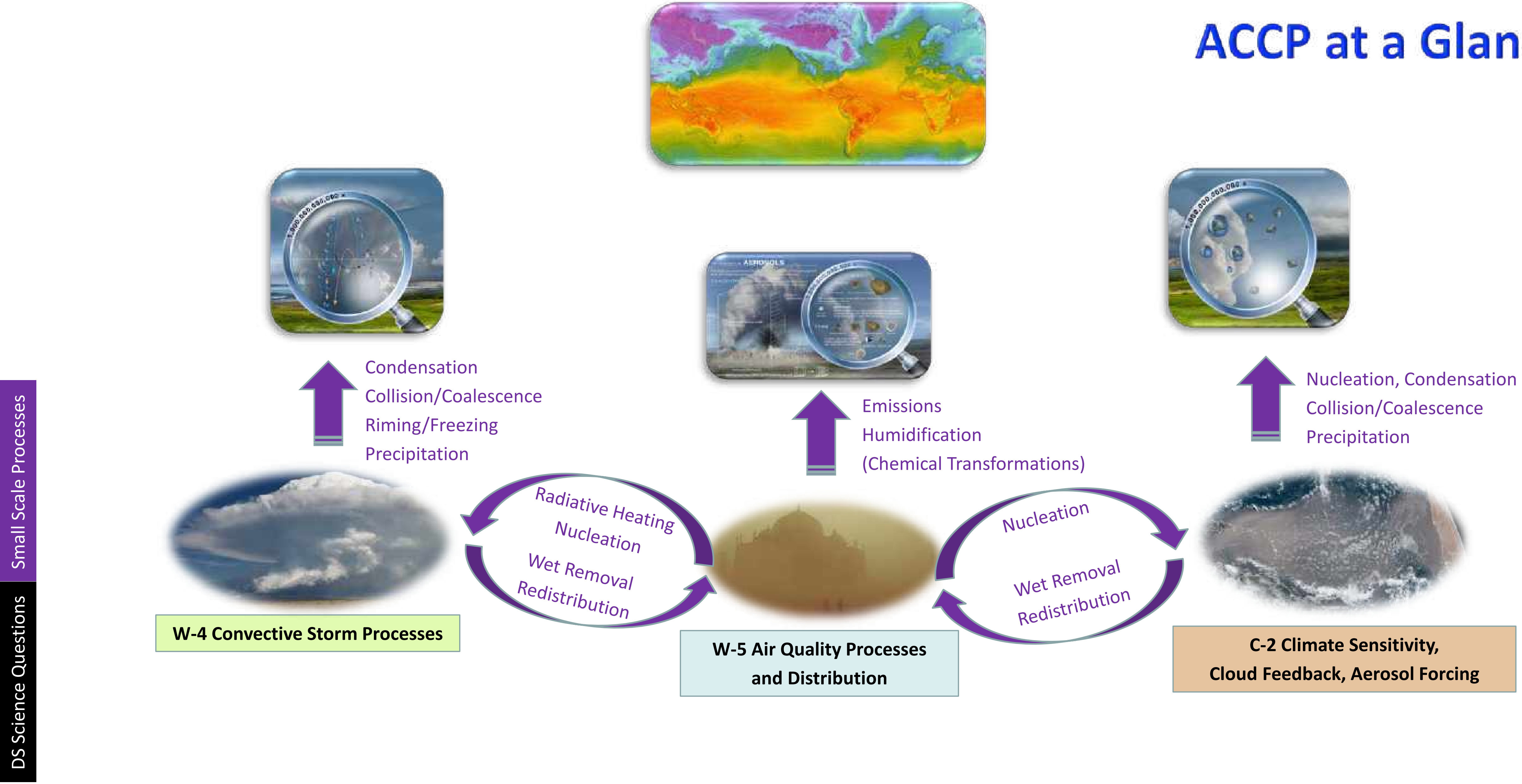
W-4 Convective Storm Processes

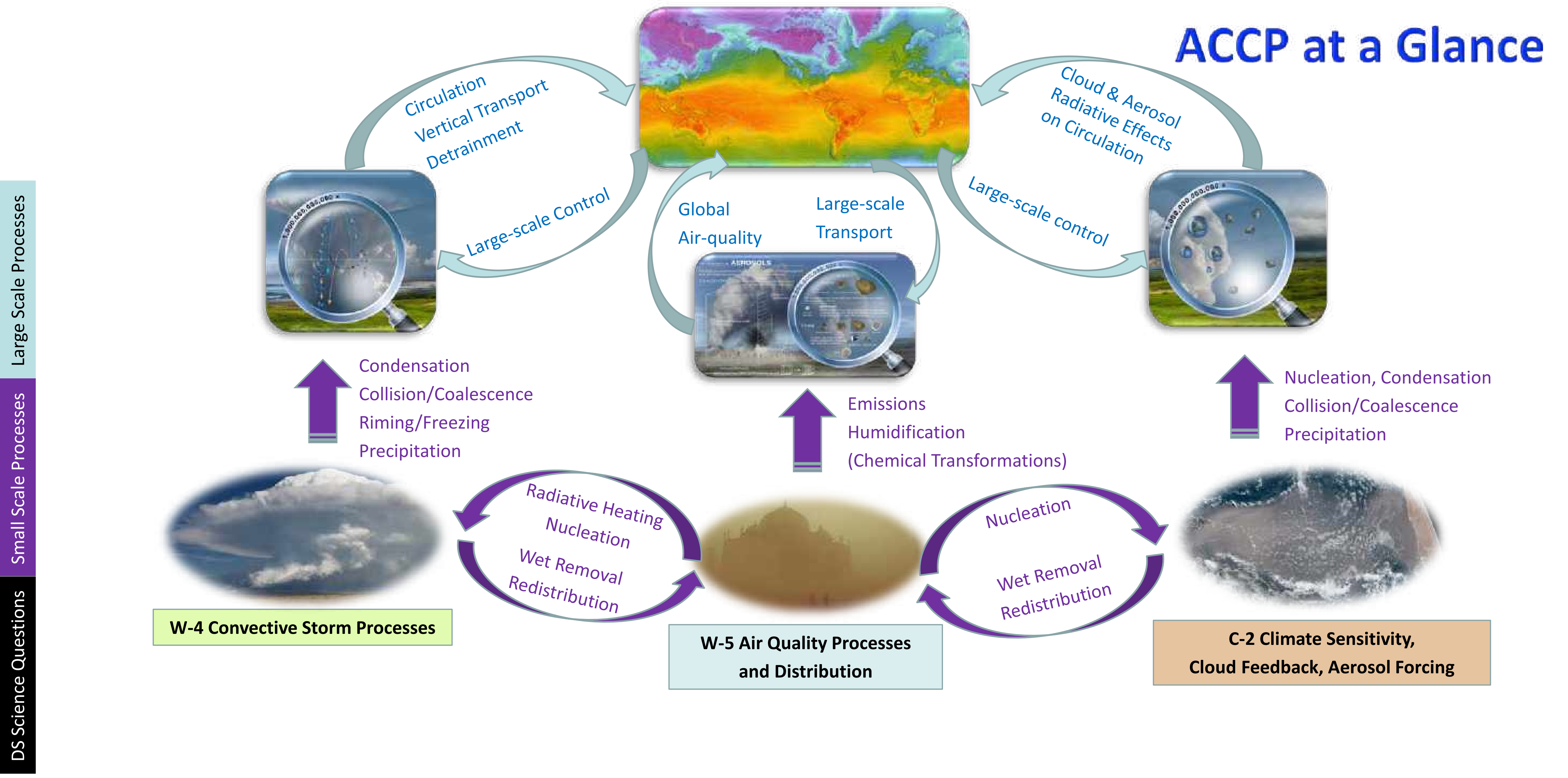
W-5 Air Quality Processes and Distribution

C-2 Climate Sensitivity, Cloud Feedback, Aerosol Forcing

DS Science Questions

ACCP at a Glance




ACCP at a Glance
Circulation
Vertical Transport
Detrainment
Large-scale Control
Cloud & Aerosol
Radiative Effects
on Circulation
Large-scale control
Global
Air-quality
Large-scale
Transport
Condensation
Collision/Coalescence
Riming/Freezing
Precipitation
Emissions
Humidification
(Chemical Transformations)
Nucleation, Condensation
Collision/Coalescence
Precipitation
Radiative Heating
Nucleation
Wet Removal
Redistribution
Nucleation
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Redistribution
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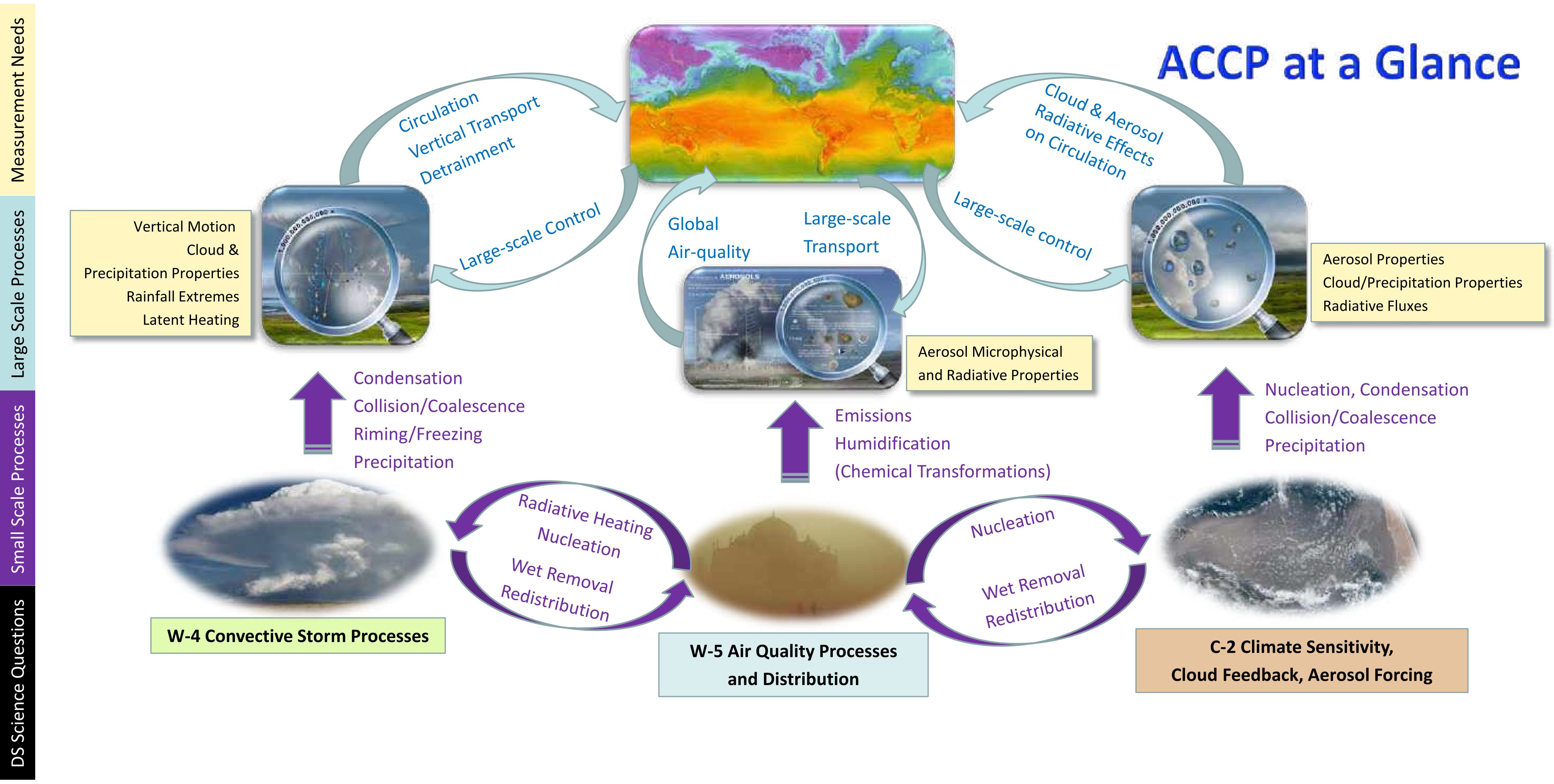
Small Scale Processes
DS Science Questions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Vertical Motion
Cloud &
Precipitation Properties
Rainfall Extremes
Latent Heating
Aerosol Properties
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Aerosol Microphysical
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Emissions
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Precipitation
Radiative Heating
Nucleation
Wet Removal
Redistribution
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W-5 Air Quality Processes
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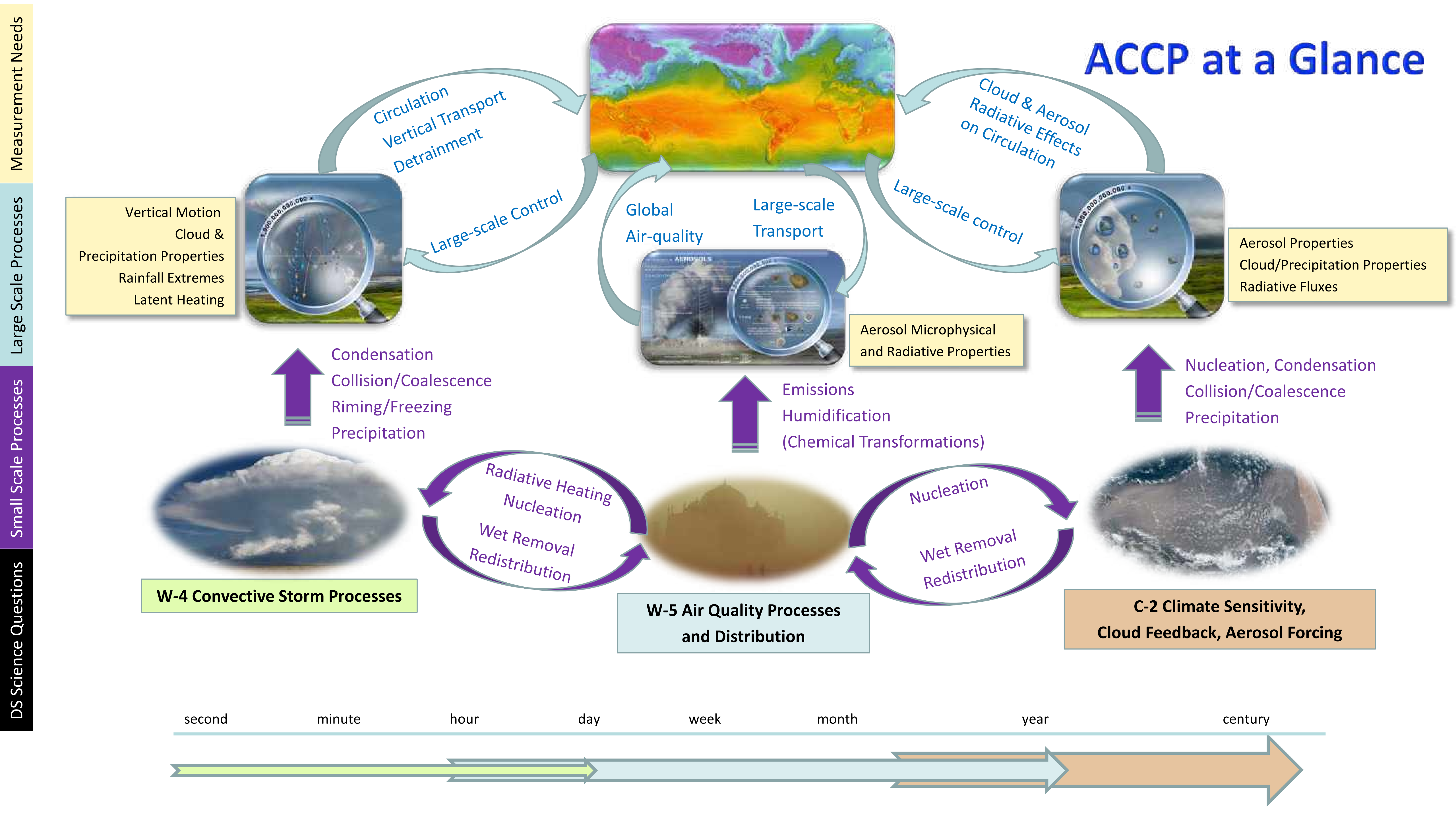
C-2 Climate Sensitivity,
Cloud Feedback, Aerosol Forcing



ACCP at a Glance
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Wet Removal
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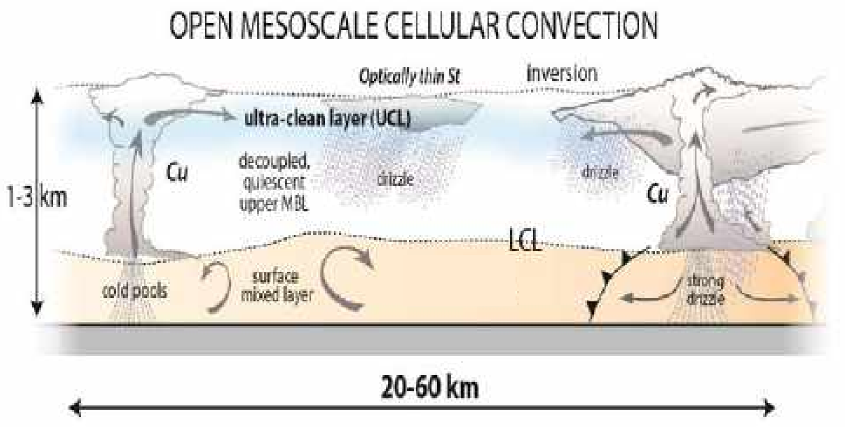
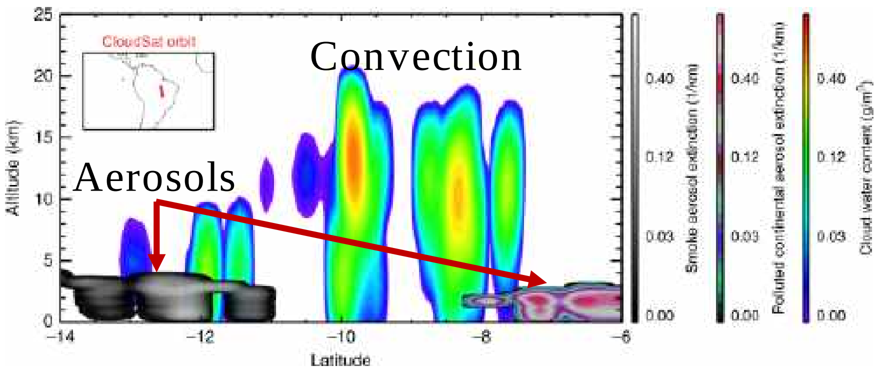
W-5 Air Quality Processes
and Distribution
C-2 Climate Sensitivity,
Cloud Feedback, Aerosol Forcing
second
minute
hour
day
week
month
year
century

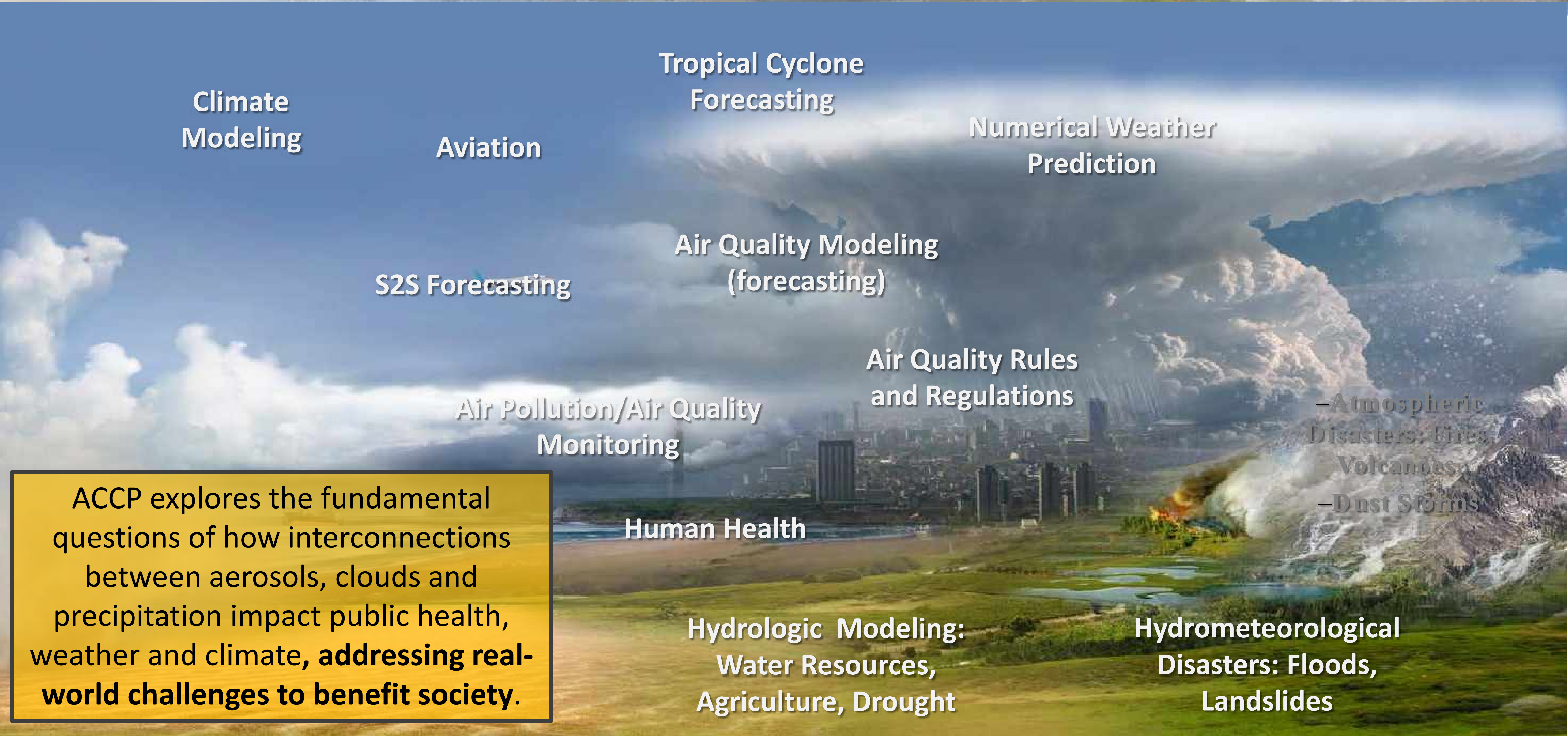
ACCP As A Central Part of the PoR

ACCP science requires active profiling measurements that likely will be absent from the PoR





ACCP Applications for Societal Benefit



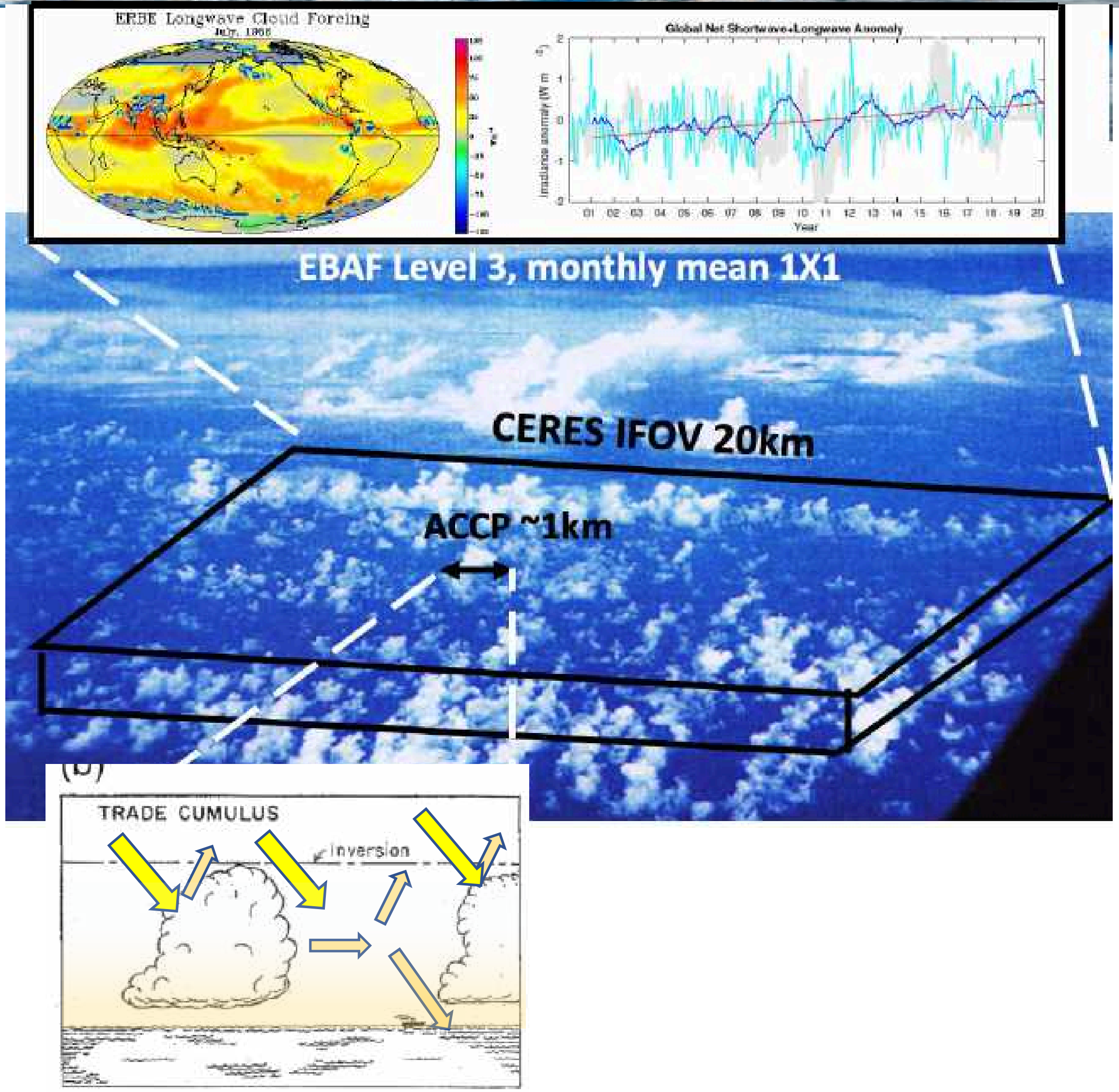
ACCP explores the fundamental questions of how interconnections between aerosols, clouds and precipitation impact public health, weather and climate**, addressing real-world challenges to benefit society**.

Addressing the radiation requirements for ACCP

- ACCP and the PoR (CERES, Libera)
- The transformative nature of the ACCP approach
- Heritage, Maturity & opportunities

Required Features	ACCP	PoR
Broadband fluxes	✔☐	✔☐
‘cloud’ scale rad fluxes	✔☐	✕
Property dependences (‘kernels’)	✔☐	(✕)

The ACCP approach to measure cloud & aerosol radiative effects



- Distinguish radiative effects of clouds and aerosol separately.
- Requires fluxes identified on the scale of clouds and spaces between them (order 1km)
- The PoR cannot resolve these effects on this scale but offers a large-scale constraint
- Quantifying the influences of clouds and aerosol on climate forcings and feedbacks requires quantification of changes in 'radiation' due to changes in 'cloud' and 'aerosol' distributions and properties – these sensitivities are expressed as 'kernels'

Spectral measurements offer a transformative and tightly constrained way of quantifying these Kernels from obs

Heritage, maturity & opportunities

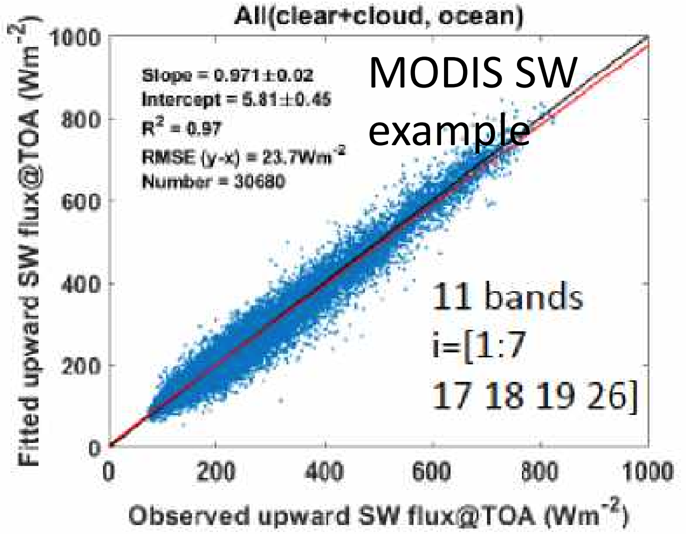
The ACCP approach to derive LW fluxes will draw directly from PREFIRE which in turn has significant heritage from applications of sounders (see AIRS example).

The ACCP approach to derive SW fluxes at the cloud scale draws directly from the EarthCARE approach. Spectral measurements are an essential constraint and CLARREO PF provides an ideal opportunity to develop & mature it.

Spectral observations to quantify ‘kernels’ draws in part from the significant heritage in cloud and aerosol property retrievals of MODIS and other spectral measurements.

Required Features	ACCP	PoR
Broadband fluxes	✔☐	✔☐
‘cloud’ scale rad fluxes	✔☐	✕
Property dependences (‘kernels’)	✔☐	(✕)

Broad band reconstruction examples from spectral



CERES SSF

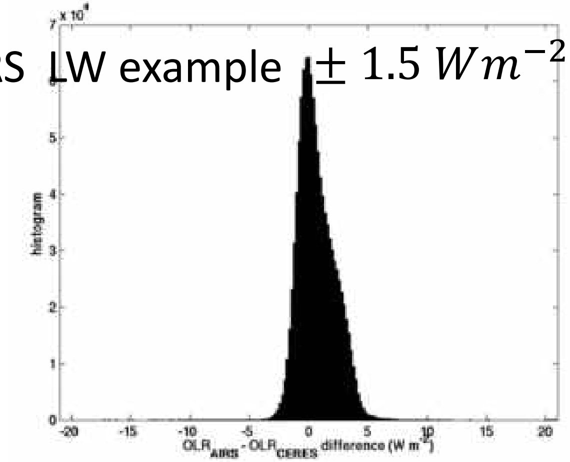
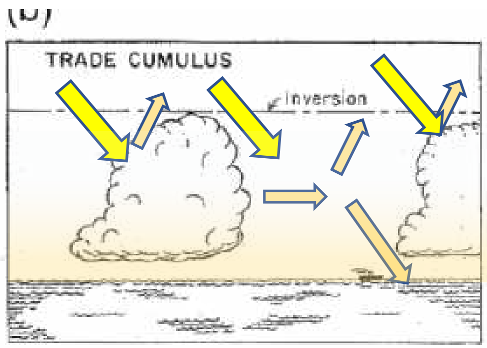


Figure 7. Histogram of differences between AIRS-derived OLR and CERES OLR for all individually collocated AIRS and CERES clear-sky footprints over the tropical oceans in 2004. In total 1.076 million collocated footprints are identified. The mean is 0.67 Wm^{-2} and the standard deviation is 1.52 Wm^{-2}.

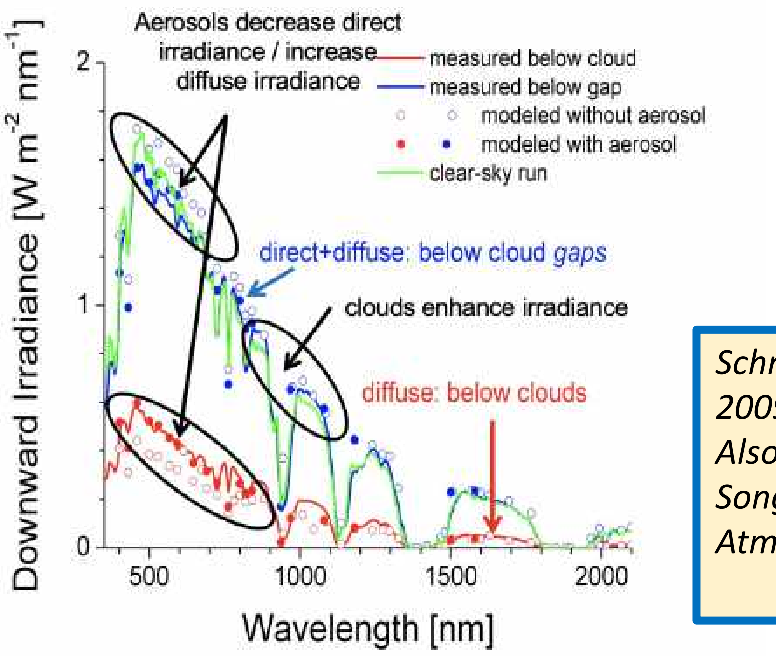
The next slide adds further support for the approach

The importance of spectrally resolved measurements

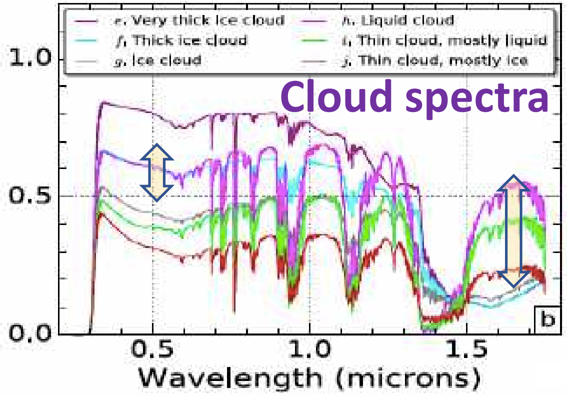


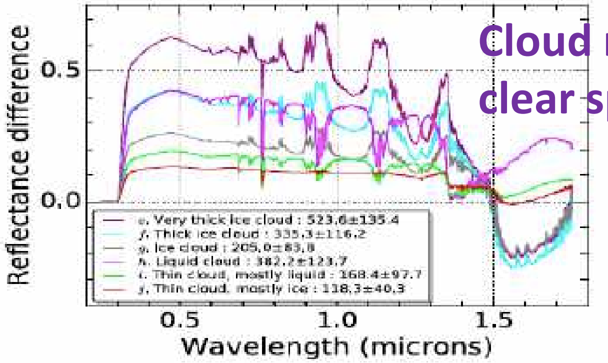
Spectral measurements differentiate aerosol from cloud effects

Example of Measurements

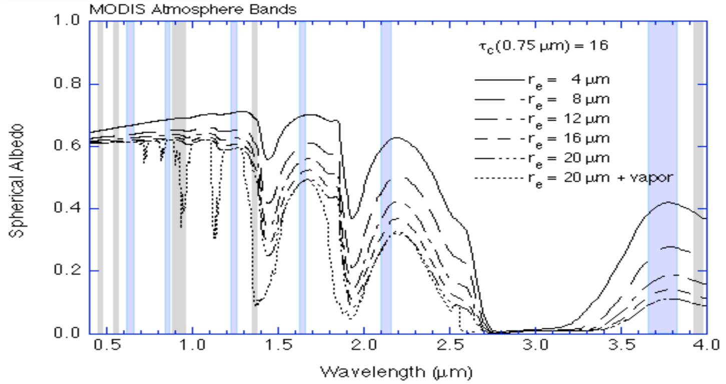


Schmidt et al., 2009, GRL
Also
Song et al., 2016 Atmos.Chem Phys





Cloud minus clear spectra



Spectra dramatically reveal separate dependencies on properties typically hidden in broadband

$$\frac{\partial R}{\partial x}$$

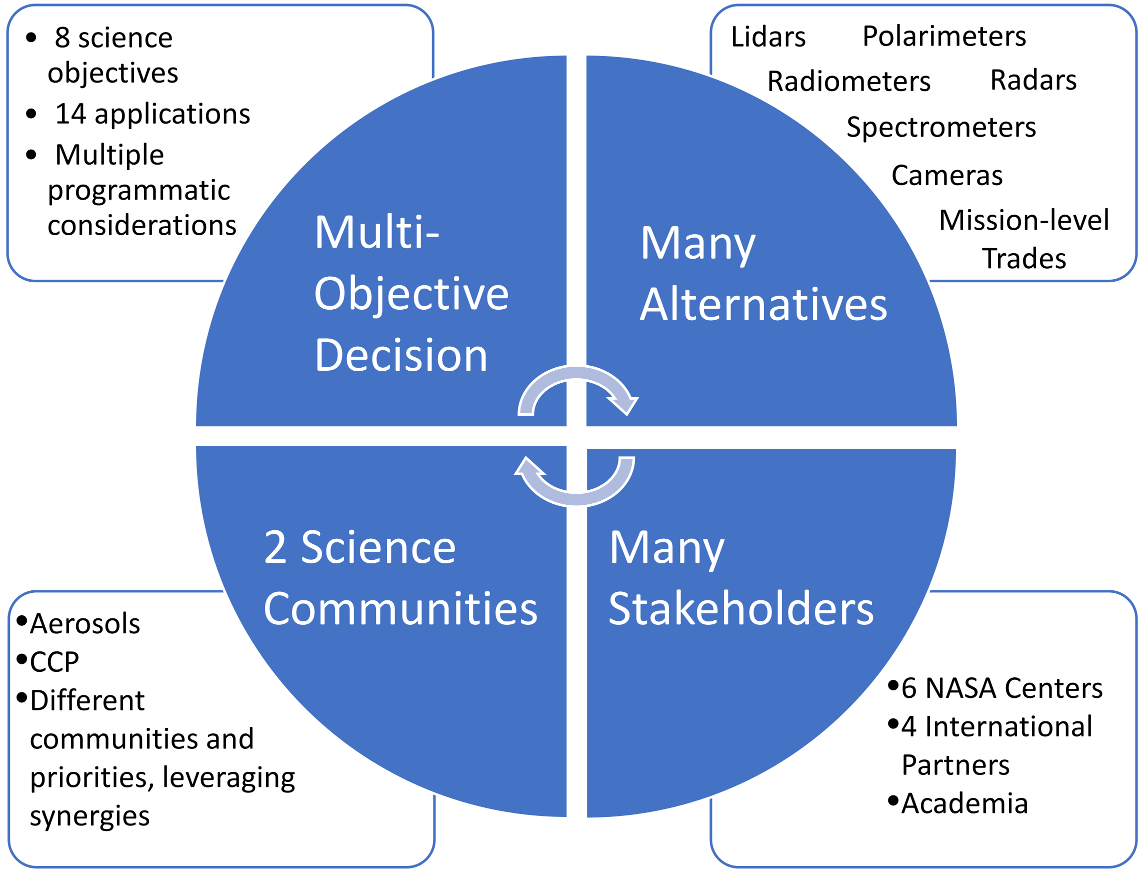
- x=optical depth & cloud amount
- x=liquid or ice water path
- x=particle size & profile
- x=cloud top height
- x=phase

Stephens et al., 2021; ACCP special issues Frontiers Remote Sens

A Value Framework for the ACCP Study

- The ACCP Value Framework enables scientists and engineers across multiple NASA centers, academia, and international partners to collaborate in defining and evaluating candidate observing system concepts

- A **structured**, **traceable**, and **transparent** approach to be responsive to a **complex** decision landscape:



- A **holistic** approach that **informs** the decision-making process:

  - Comprehensive examination of all elements of the decision space to **enable trade-offs** (science, applications, programmatic factors, cost, and risk)
  - **Common terminology** to enable productive conversations across a large, diverse group
  - **Data-driven**, consistent evaluations augmented by structured **expert judgement**
  - **Independent** team firewalled from LaRC that facilitates but does not provide input into the assessment

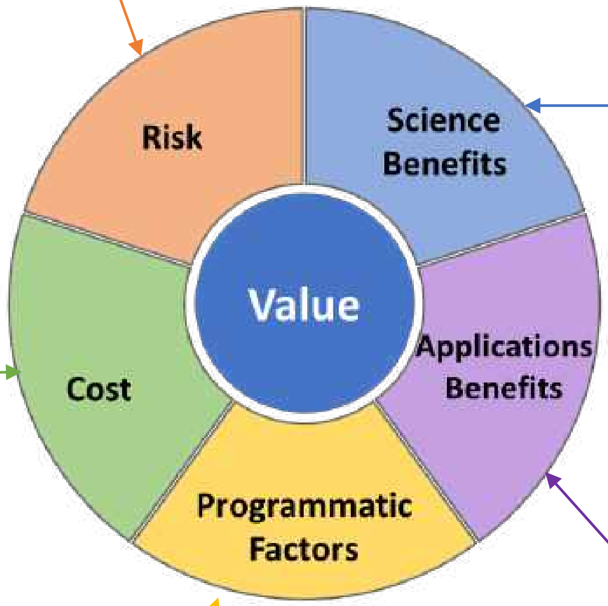
Strategic Assessment of the Architectures

Systems Engineering Team

- **Risk Review Board**
- **Technology Readiness Assessments**

CEMA
Aerospace Corp.

- **Cost estimates**



Management Team

- **7 Programmatic Factors**

Science Leadership Team
Science Impact Teams
Science Community Committee

- **Utility** quantifies how important a Geophysical Variable is to addressing a Science Objective
- **Quality** quantifies how often an architecture meets the SATM uncertainty targets
- **Science Benefit Score** combines Utility and Quality scores while accounting for **Sampling**

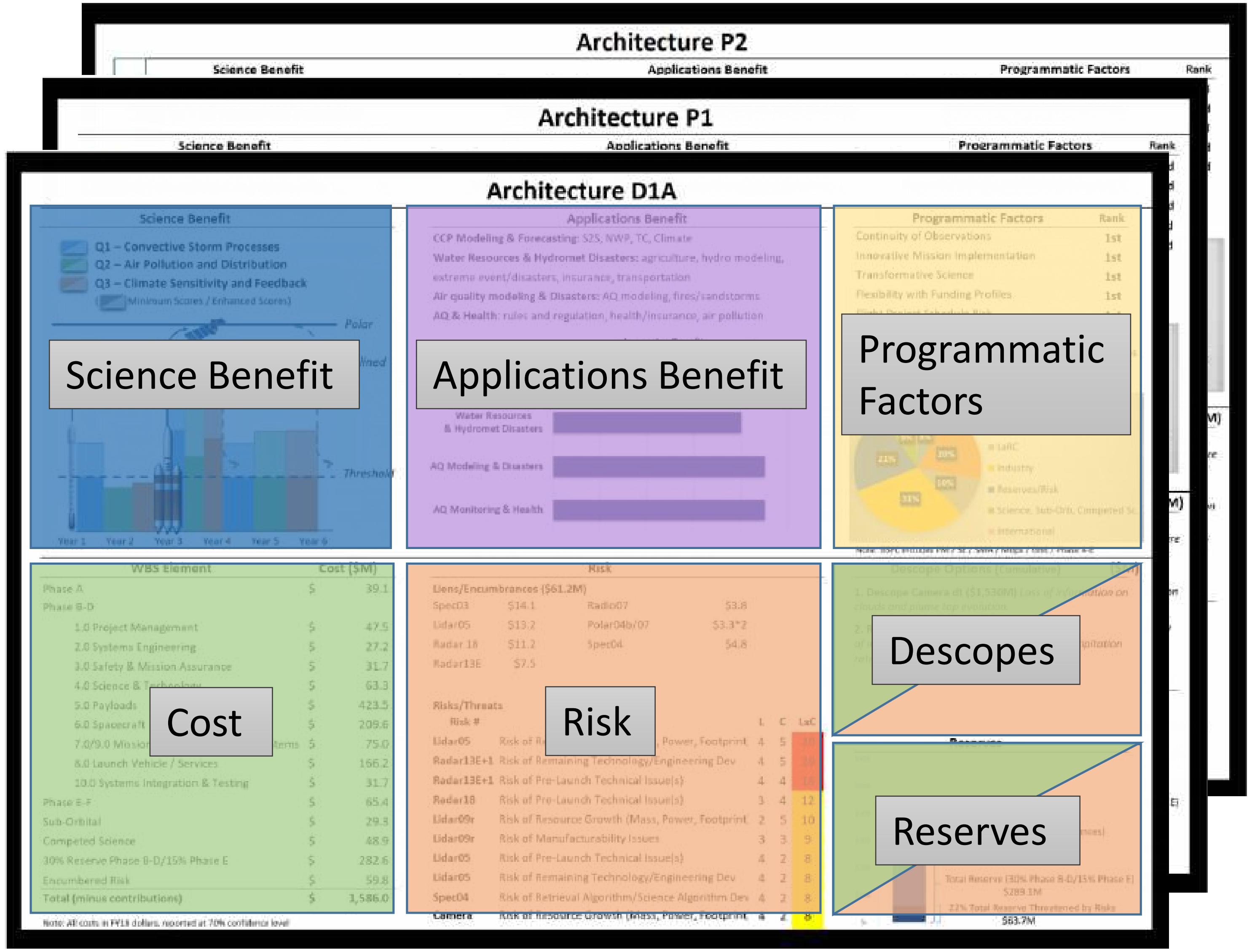
Applications Team

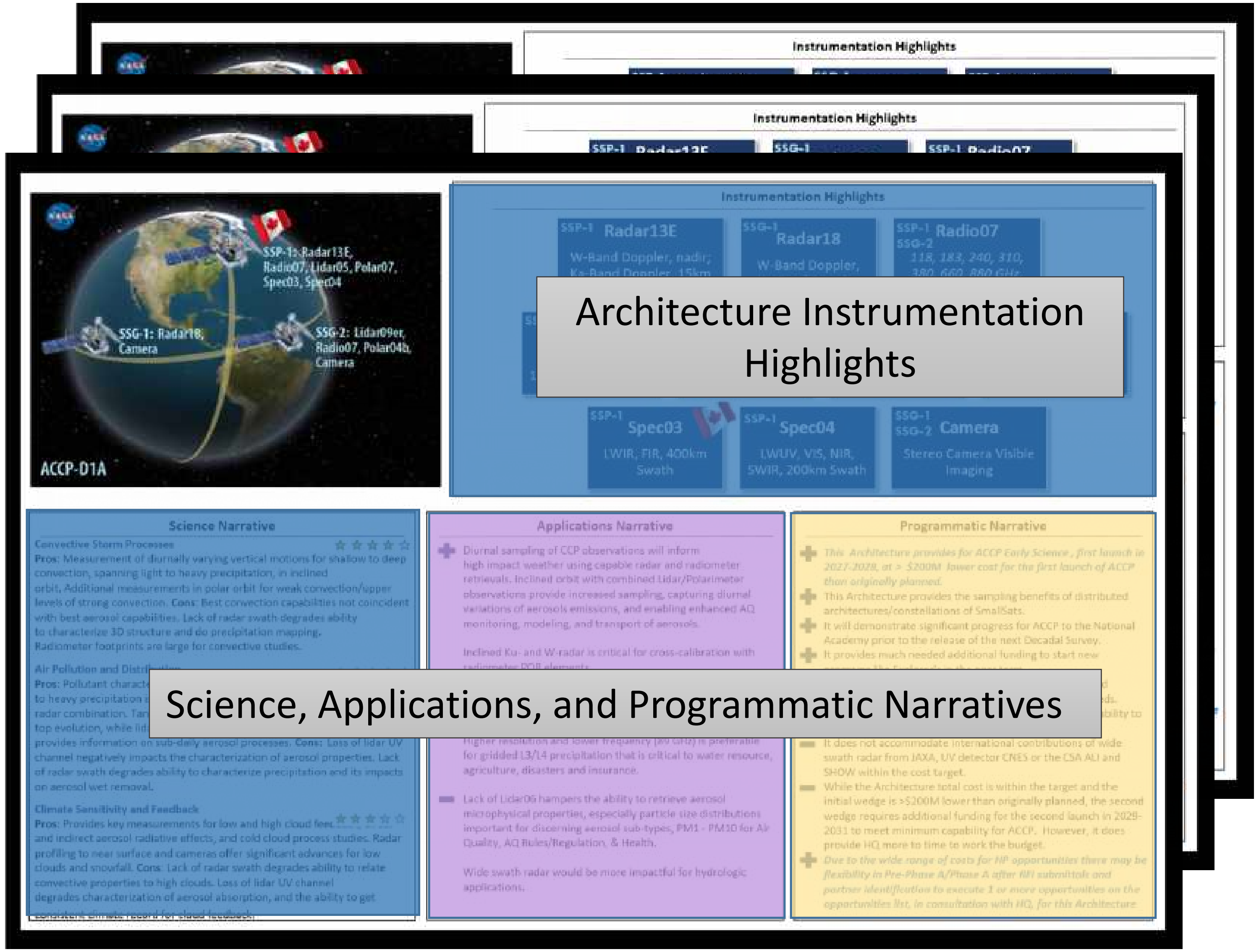
- **5 differentiable attributes**
- **75 applications in 4 thematic areas**

For each architecture under consideration:

- The assessment is performed consistently
- Objective assessments are prioritized
- Checks and balances are implemented
- All data sources are archived and linked to summary products

Analysis Summary Product: Baseball Cards

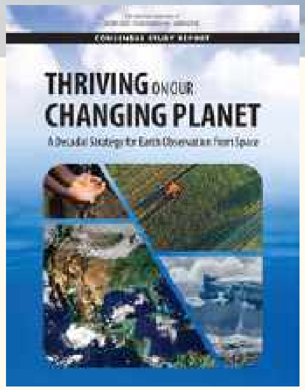




Science Benefit Scoring

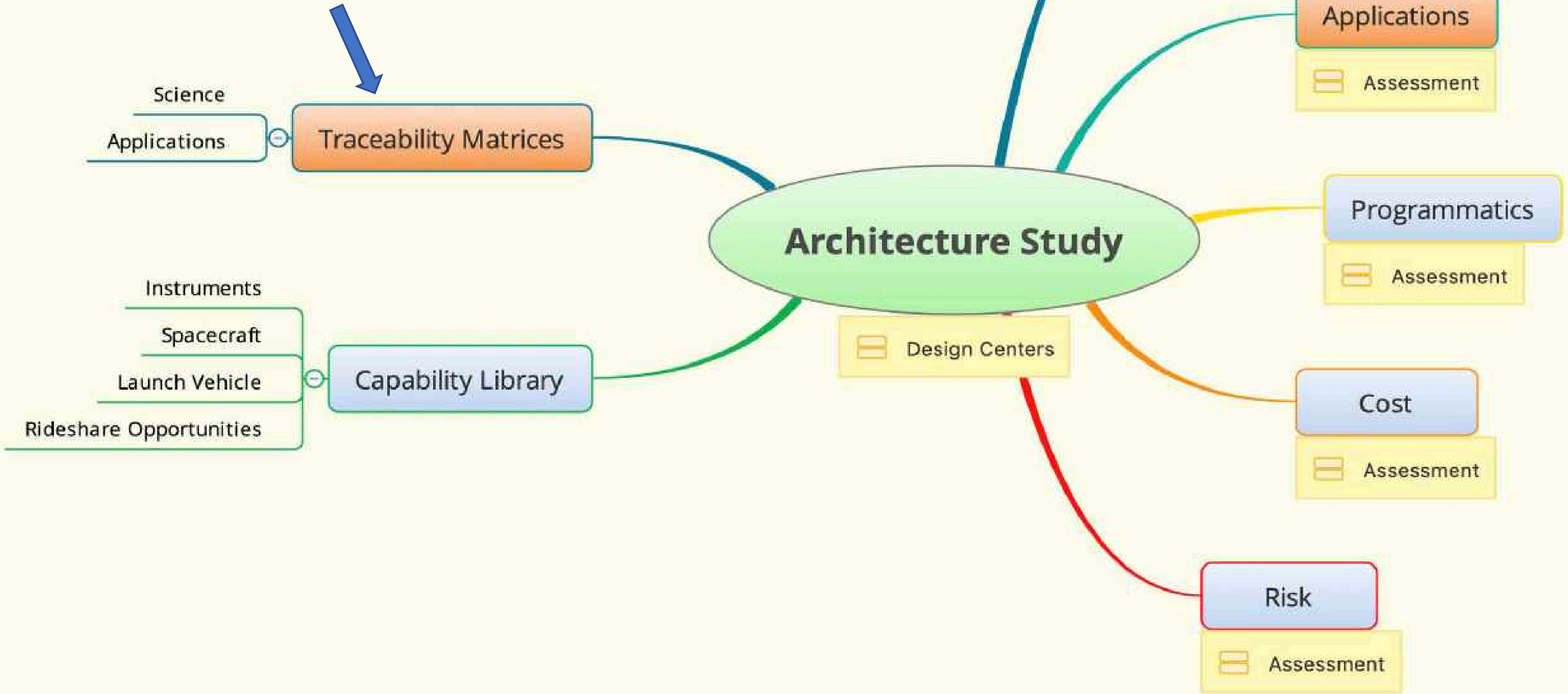
Arlindo da Silva

ACCP Study: Approach



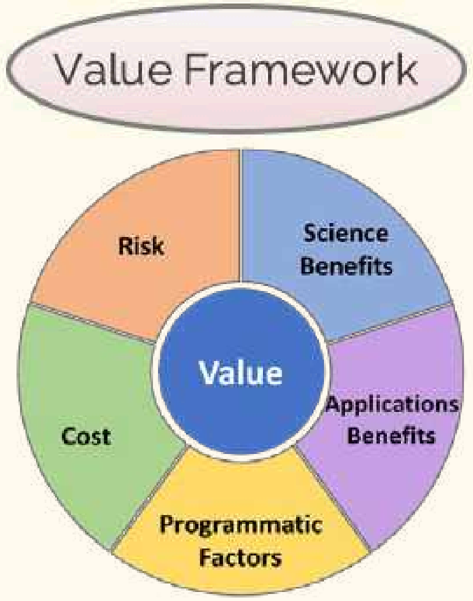
Relevant Decadal Survey Themes

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



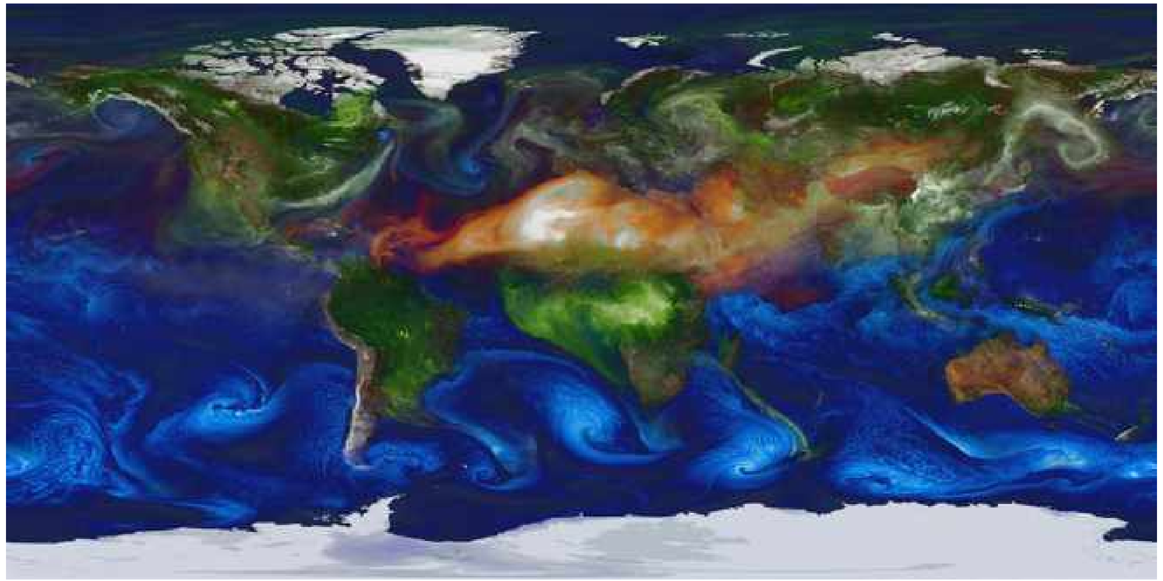
Observing
System
Simulation
Experiments

Provide the quantitative framework for the Science Assessments



OSSEs in ACPP

- **Traditionally**: OSSEs evaluate potential impact of new observations on a weather forecast (Hoffman and Atlas, 2016; BAMS)
- **Fundamentally**: OSSEs quantify information in a future observing system
- ACCP considers a **Spectrum of OSSEs:**
  - ✓ Retrieval OSSE
  - ✓ Sampling OSSE
  - o Forecast/reanalysis OSSE
  - o Process OSSE



Basic Science Benefit Scores

Utility: degree to which Geophysical Variable (GV) addresses the objective if it were measured perfectly.

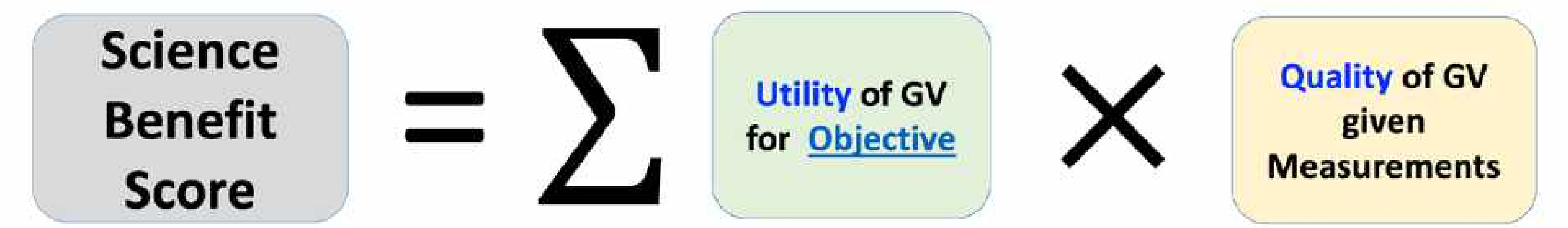
Science Benefit Score (for each Objective/ Science Questions) = $\sum_{\text{GVs}}$ **Utility of GV for Objective** (SALT) × **Quality of GV given Measurements** (SIT)

Quality: degree to which measurements provide the desired geophysical variable. OSSEs inform the quality assessment.

Similar to approach outlined on *Continuity of NASA Earth Observations from Space* report (NAS 2015)

Quality as Operational Efficiency

- As implemented in ACCP, the **Quality Score** is a measure of *Operational Efficiency.*
  - given opportunities to observe on a given orbit, the **Q-score** of a GV is the percent of retrievals that satisfy the uncertainty requirements called for in the SATM.
- The basic *Science Benefit Score* is average *Operational Efficiency*



Accounting for Sampling

- Being a process-oriented mission, it is important that the scoring process captures whether the phenomena of interest are appropriately sampled
- ACCP Sampling Scores builds on the basic Science Benefit scores of the previous slide:

Sampling Score = **Adequate Sampling of Natural Variability** + **Sufficiency of Quality Samples on given orbits**

(Orbits,Payload) (Can Orbit capture Natural Variability?) (Function of Utility x Quality)

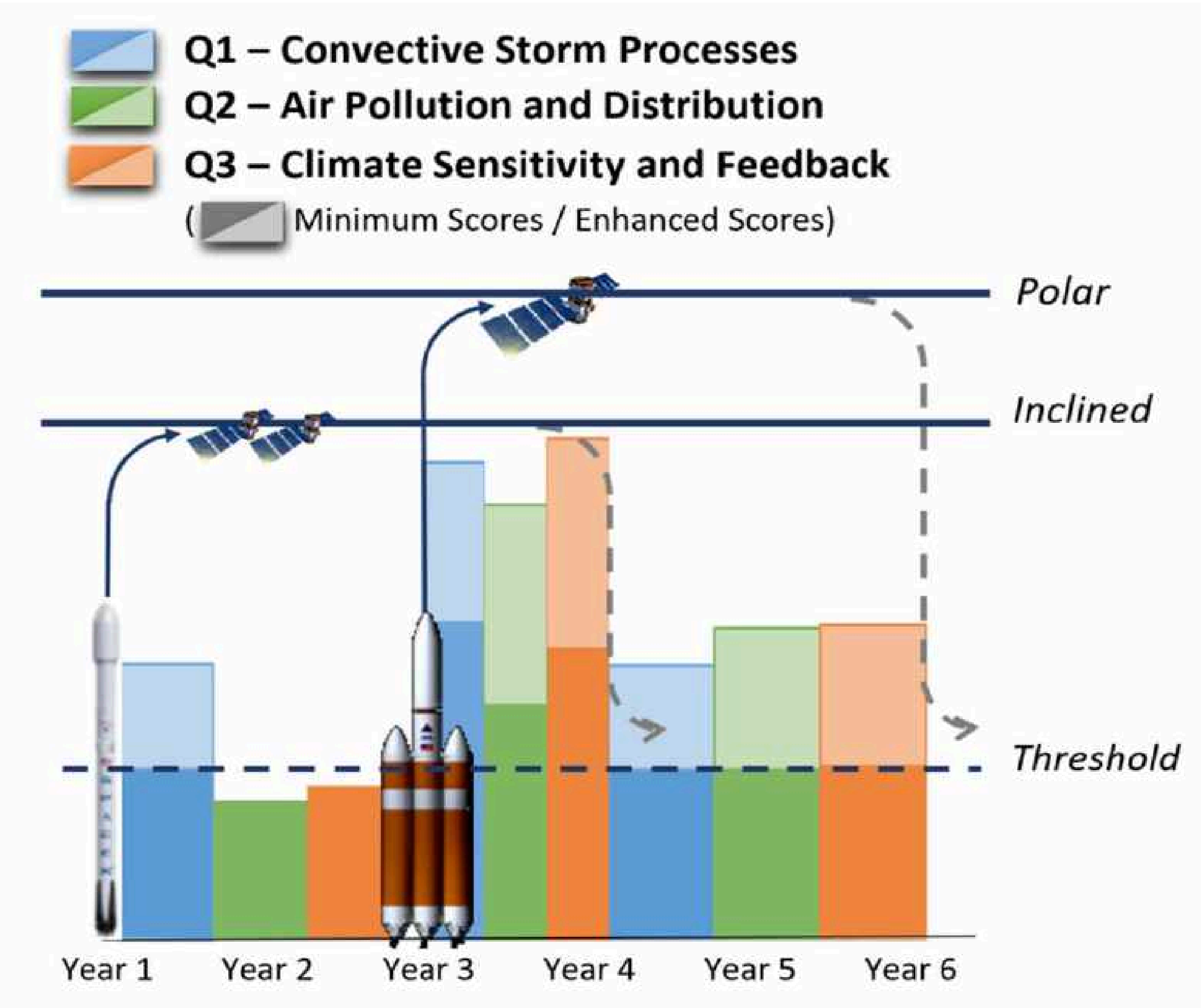
Example Scores

ACCP Science and Application Traceability Matrix (SATM) defines:

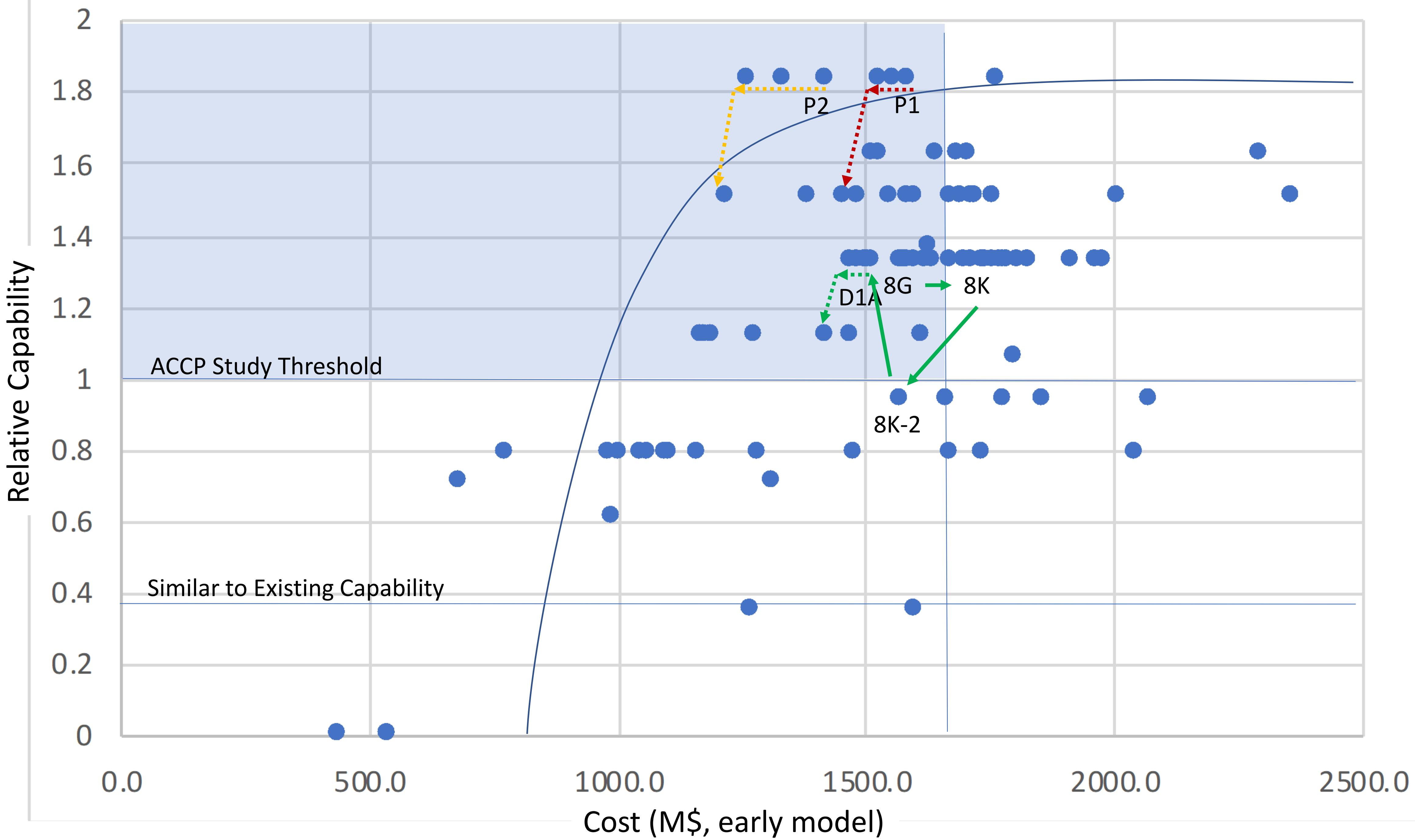
Minimum Science = **Threshold** Science

Enhanced Science = **Baseline** Science

A+C CP	A	CCP	Objectives
			O1 Low Clouds **Minimum**: Determine the sensitivity of boundary layer *bulk* cloud physical and radiative properties to large-scale and local environmental factors including thermodynamic and dynamic properties. **Enhanced**: Adds to Minimum cloud *microphysical* properties and enhanced bulk cloud properties.



ACCP Vertical Profiling Capability vs. Cost Reveals Viable Trade Space



ACCP Aerosols, Clouds, Convection, and Precipitation Study

ACCP Science Impact Team – Aerosols (SIT-A) Summary of Activities for HQ review

February 5, 2021

POC: Vickie Moran

Contents

- The Charter of the SIT-A… as it has evolved
- SIT-A Team Members and Tasking
- Active & Passive Aerosol Remote Sensing; Complexities Addressed
- SIT-A Architecture Evaluation Approach: Workflow and Methodologies
- Complementarity with Lidar Working Group Activities
- Quality Scores and Additional Outcomes
- SIT-A major findings

The Charter of the SIT-A has evolved!

- "… to quantitatively evaluate retrieval uncertainties for aerosol Geophysical Variables, to compare them to SATM requirements, and to translate them into Quality Scores that can be used in the Value Framework, highlighting relative performance differences between instrument combinations".
- Final approach also included expert elicitation.

Quality ≡ Fraction of retrievals that provide uncertainties or errors within SATM requirement

Quality of GV given Measurements

(SIT)

First Name	Last Name	Institution
Susanne	Bauer	GISS
Sharon	**Burton**	**LaRC**
Brian	**Cairns**	**GISS**
Patricia	Castellanos	GSFC
Eduard	Chemyakin	LaRC
Pete	Colarco	GSFC
Arlindo	da Silva	GSFC
Reed	**Espinosa**	**GSFC**
Richard	Ferrare	LaRC
Connor	**Flynn**	**U. Okla.**
Lan	Gao	U. Okla.
Michael	Garay	JPL
Robert	**Holz**	**U. Wisc.**
Meloe	Kacenelenbogen	ARC
Olga	Kalashnikova	JPL
Seiji	Kato	LaRC
Osku	Kemppinen	GSFC
Rob	Levy	GSFC
Xu	Liu	LaRC
Marcela	Loria	U. Okla.
Richard	Moore	LaRC
Ed	**Nowottnick**	**GSFC**
David	Painemal	LaRC
Kathleen	**Powell**	**LaRC**
Jens	**Redemann**	**U. Okla.**
Snorre	**Stamnes**	**LaRC**
Tyler	**Thorsen**	**LaRC**
Travis	Toth	LaRC
Mark	**Vaughan**	**LaRC**
Dave	Winker	LaRC
Feng	**Xu**	**U. Okla.**
John	**Yorks**	**GSFC**

SIT-A Team members represent most NASA centers and Universities involved in ACCP, plus various international institutions!

Names in bold: Team leads at their institutions and/or Study Team (expert assessment team) members

← US participants

↓ International participants

First Name	Last Name	Affiliation
Adam	Bourassa	Univ. of Saskatchewan
Marjolaine	Chiriaco	IPSL
Flavien	Cornut	CNRM, Aerosols
Juan	**Cuesta**	**LISA/Univ. of UPEC, French coPI for ACCP-Aerosols**
Oleg	**Dubovik**	**LOA/CNRS, Aerosols/Lidar**
Laaziz	El Amraoui	CNRM, Aerosols
Anton	Lopatin	LOA/CNRS, Aerosols/Lidar
Tomoaki	Nishizawa	NIES-Japan
Roseline	Schmisser	CNES, lidar
Solene	Turquety	LMD

SIT-A: People and Tasking

- For each instrument type/combination, various groups pursue independent approaches
- Differences in methodologies & algorithms are an advantage to the evaluation process

Approach	Groups @
DRS: Direct Retrieval Simulation	LaRC+GISS, GSFC, OU, LISA+CNES+Lille
RDA: Real data analysis	LaRC+GISS, GSFC, OU, **Lidar Working Group (UWisc+LaRC+GSFC)**
ICA: Information content analysis	LaRC+GISS, OU
SPA: Statistical performance analysis	LaRC, GSFC

Retrievals

Lidars

Retrievals

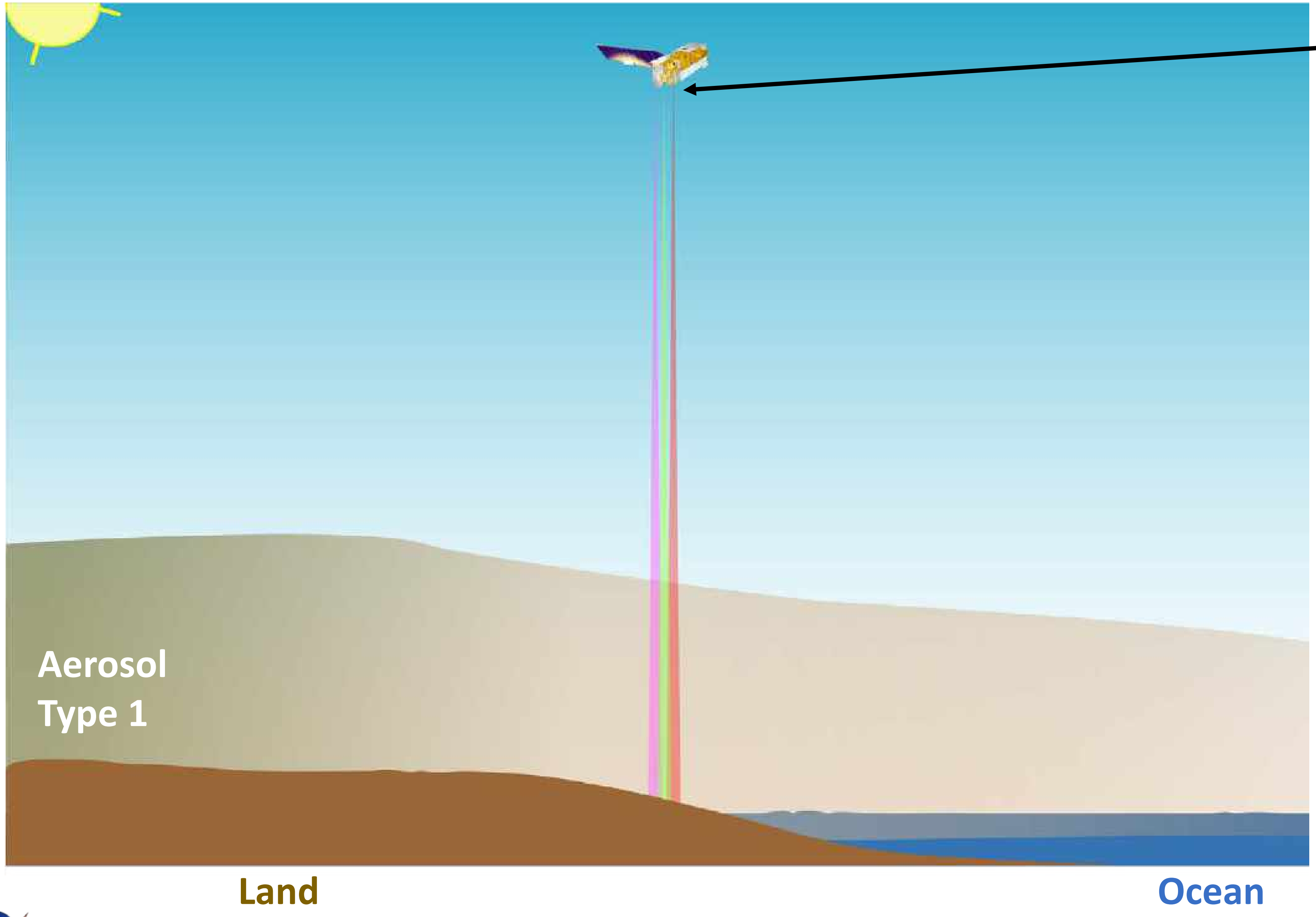
Polarimeters

Joint Retrievals

Lidar+Polarimeter Combinations

Success of ACCP depends on unprecedented information in joint retrievals

Active & Passive Aerosol Remote Sensing



Lidar:

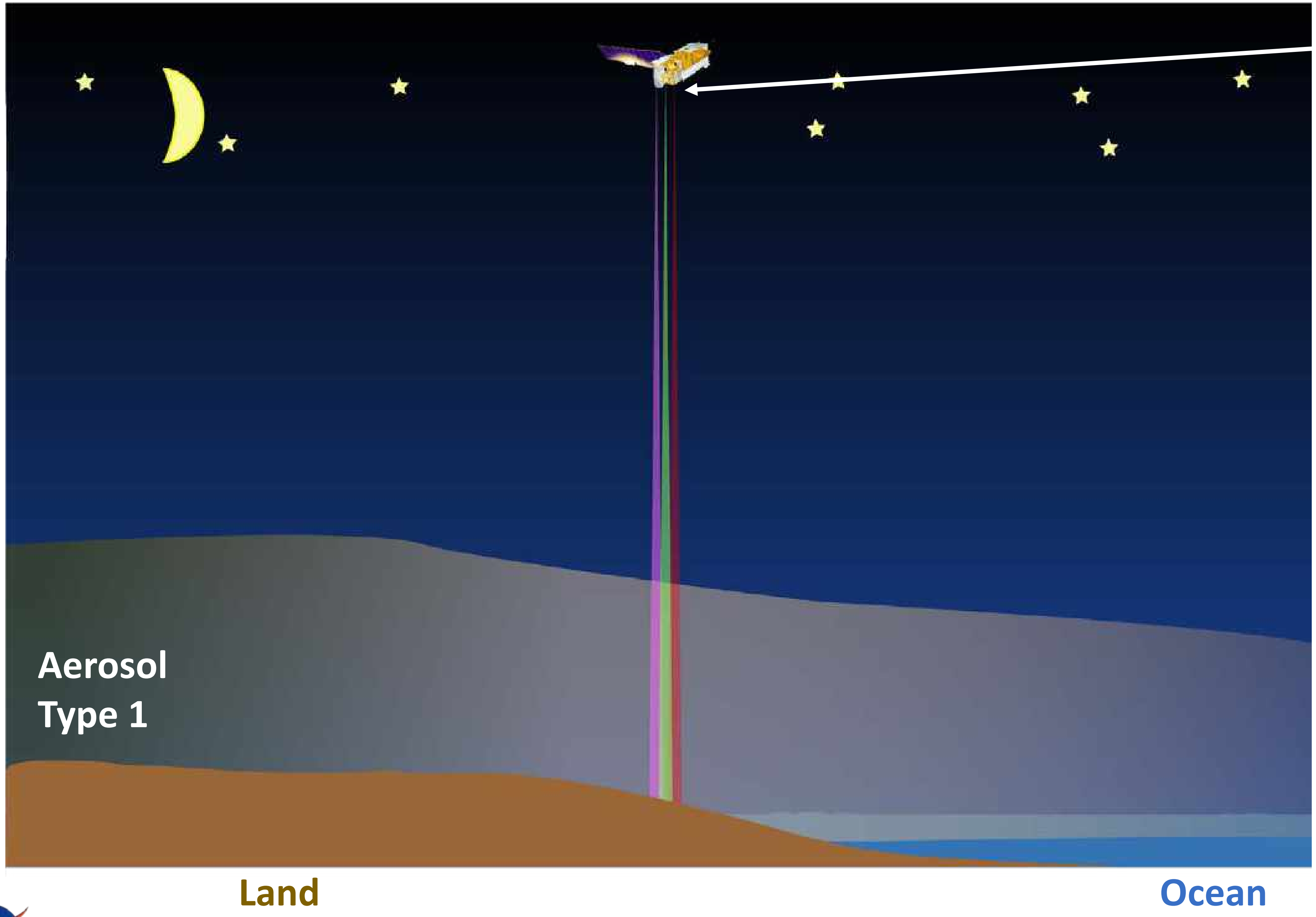
Backscatter lidar (lidar 9) measures attenuated aerosol backscatter

HSRL (lidar 5/6) measures true aerosol backscatter and extinction.

→ aerosol backscattering and extinction contain information on aerosol concentration, size and composition

→ Both backscatter and HSRL lidars measure depolarization (related to particle shape /type).

Active & Passive Aerosol Remote Sensing



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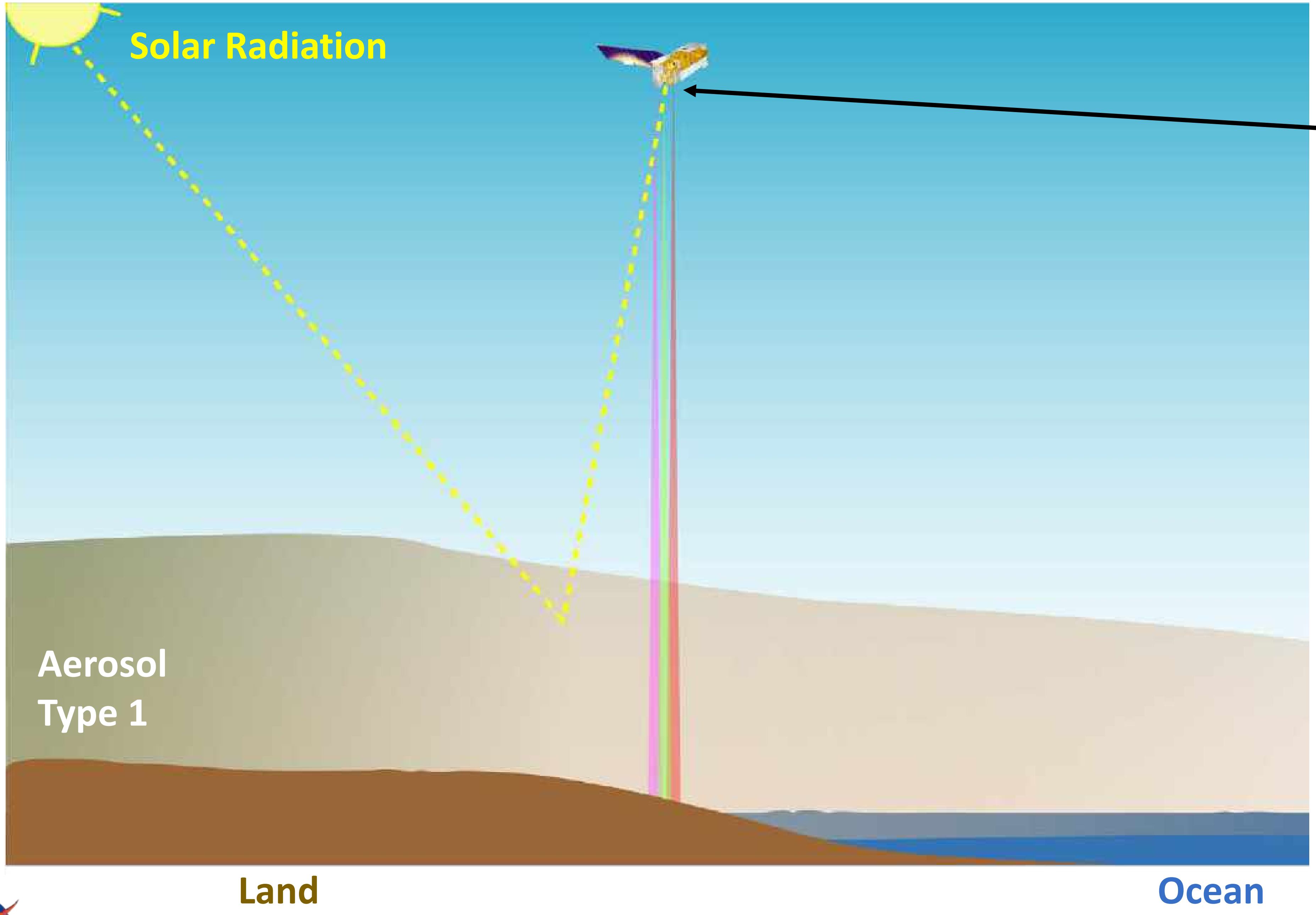
Active & Passive Aerosol Remote Sensing

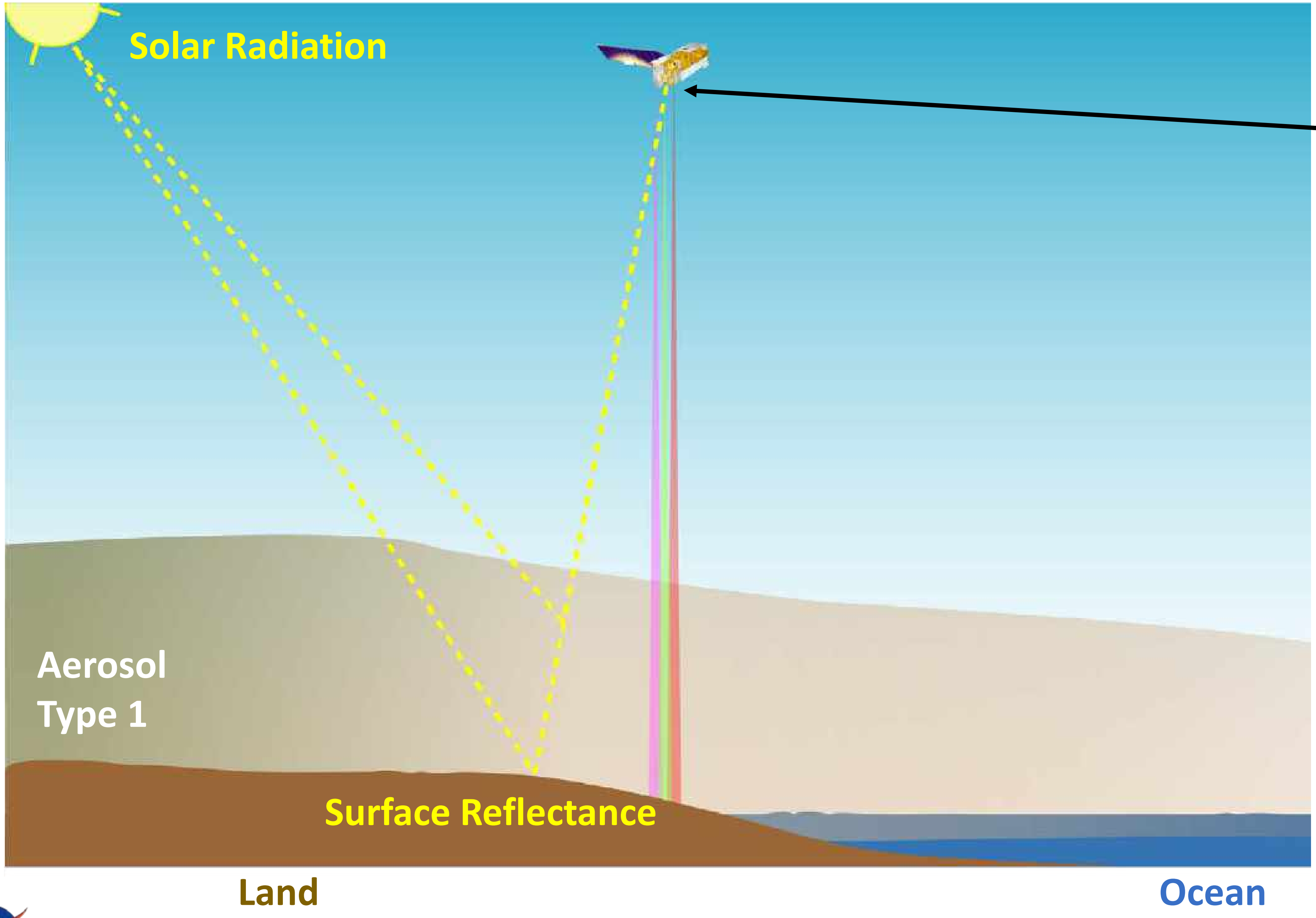


Polarimeter:

Spectral polarimeters measure total and polarized reflectances

→ total and polarized aerosol scattering

Active & Passive Aerosol Remote Sensing



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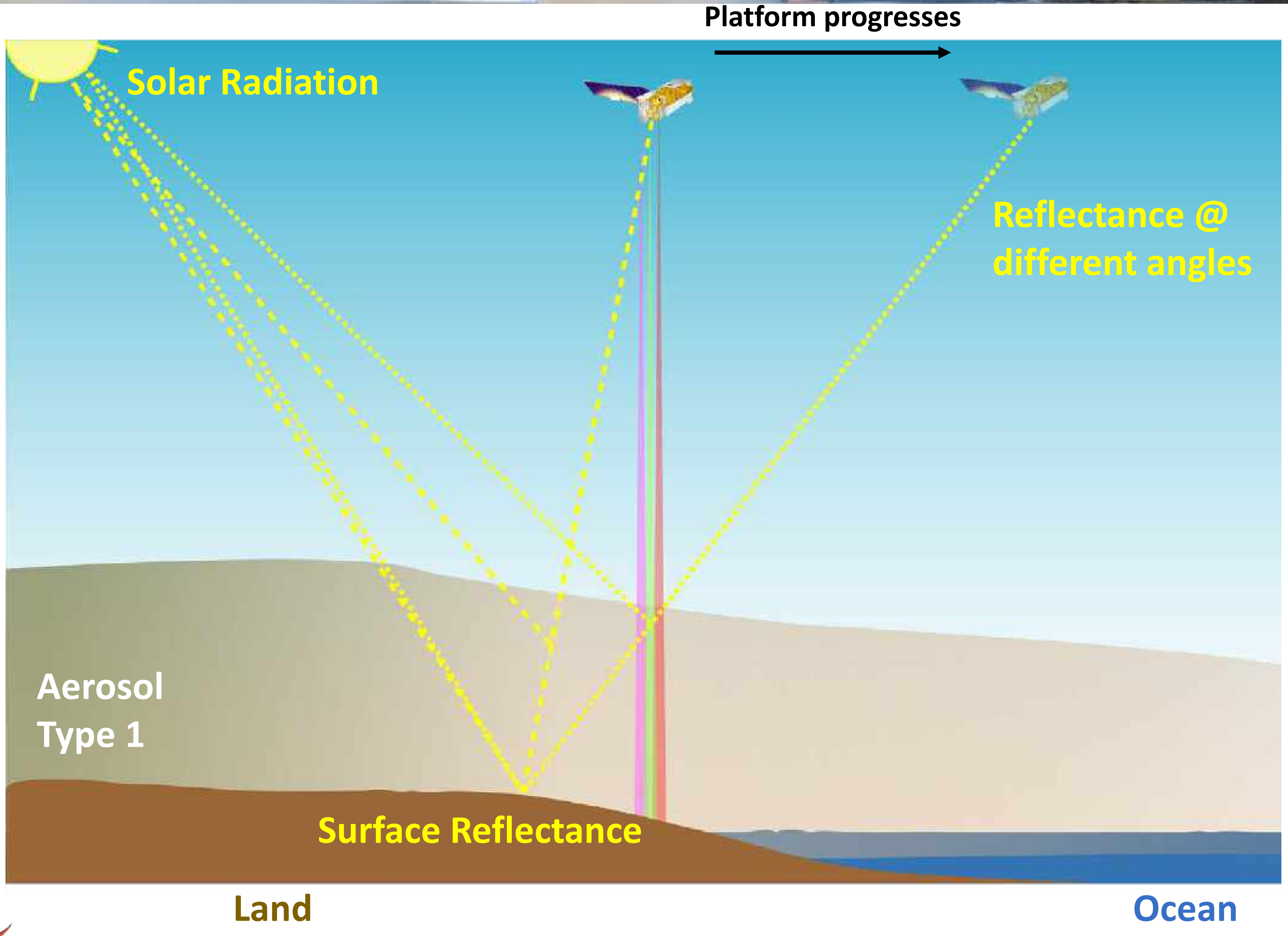
Active & Passive Aerosol Remote Sensing



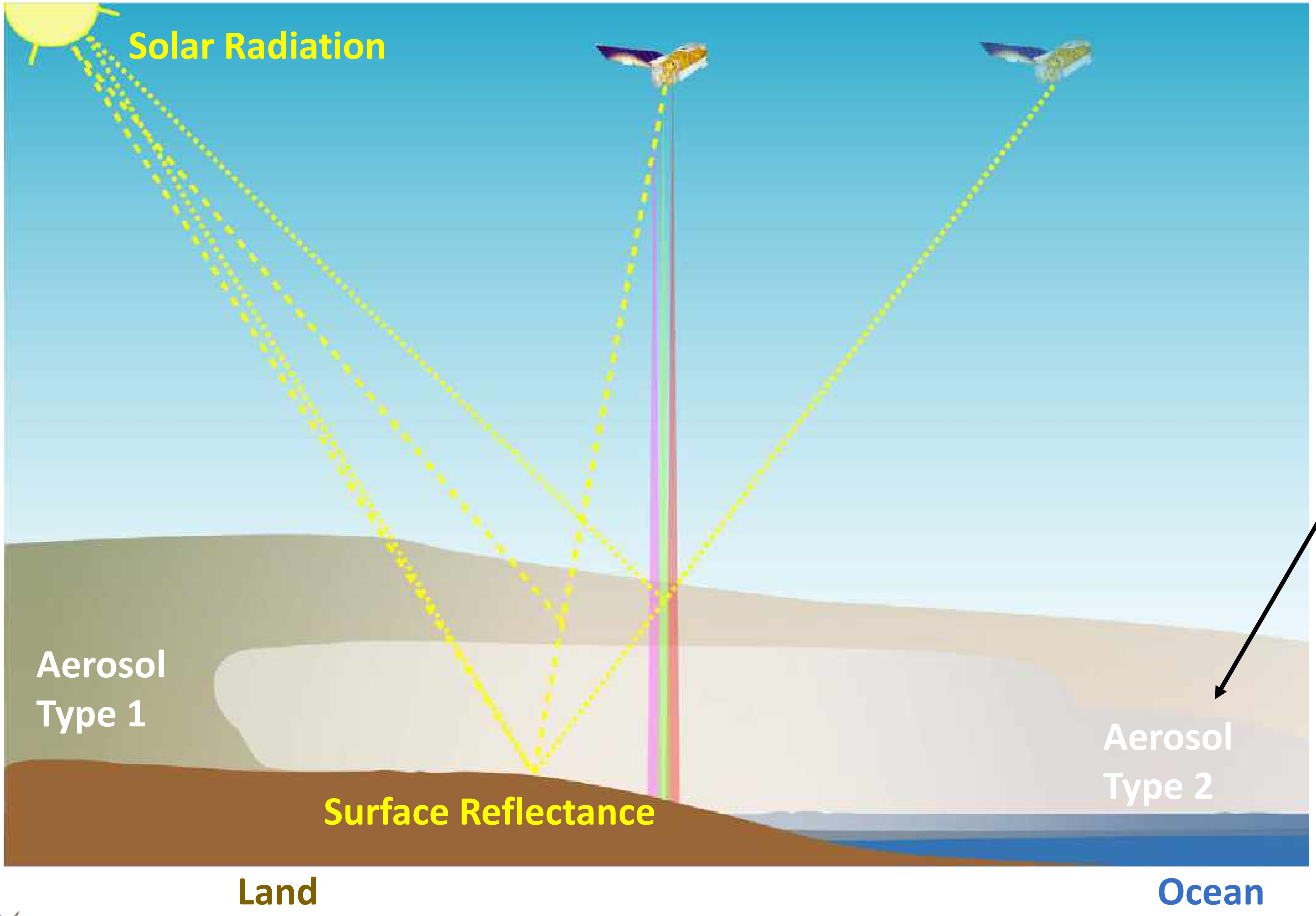
Polarimeter:

Spectral polarimeters measure total and polarized reflectances

→ total and polarized aerosol scattering

→ containing information on aerosol concentration, size and composition

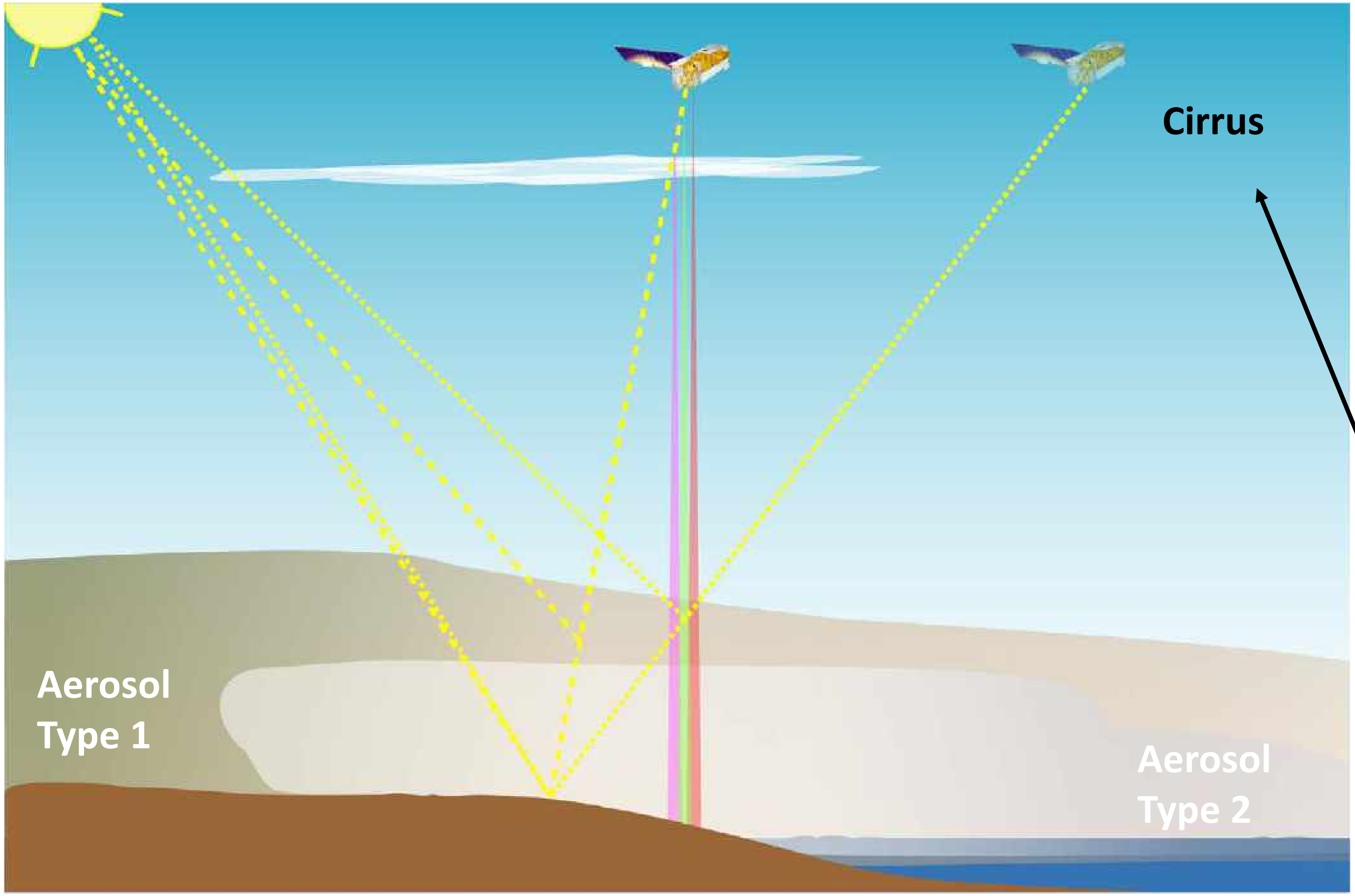
Active & Passive Aerosol Remote Sensing



Some challenges to aerosol remote sensing (RS):

- Surface reflectance
- Aerosol vertical distributions
- Lidar signals provide independent constraints on vertical distributions
- Atmospheric aerosol types are often mixed in type, and vary rapidly ~10km

Active & Passive Aerosol Remote Sensing



Land

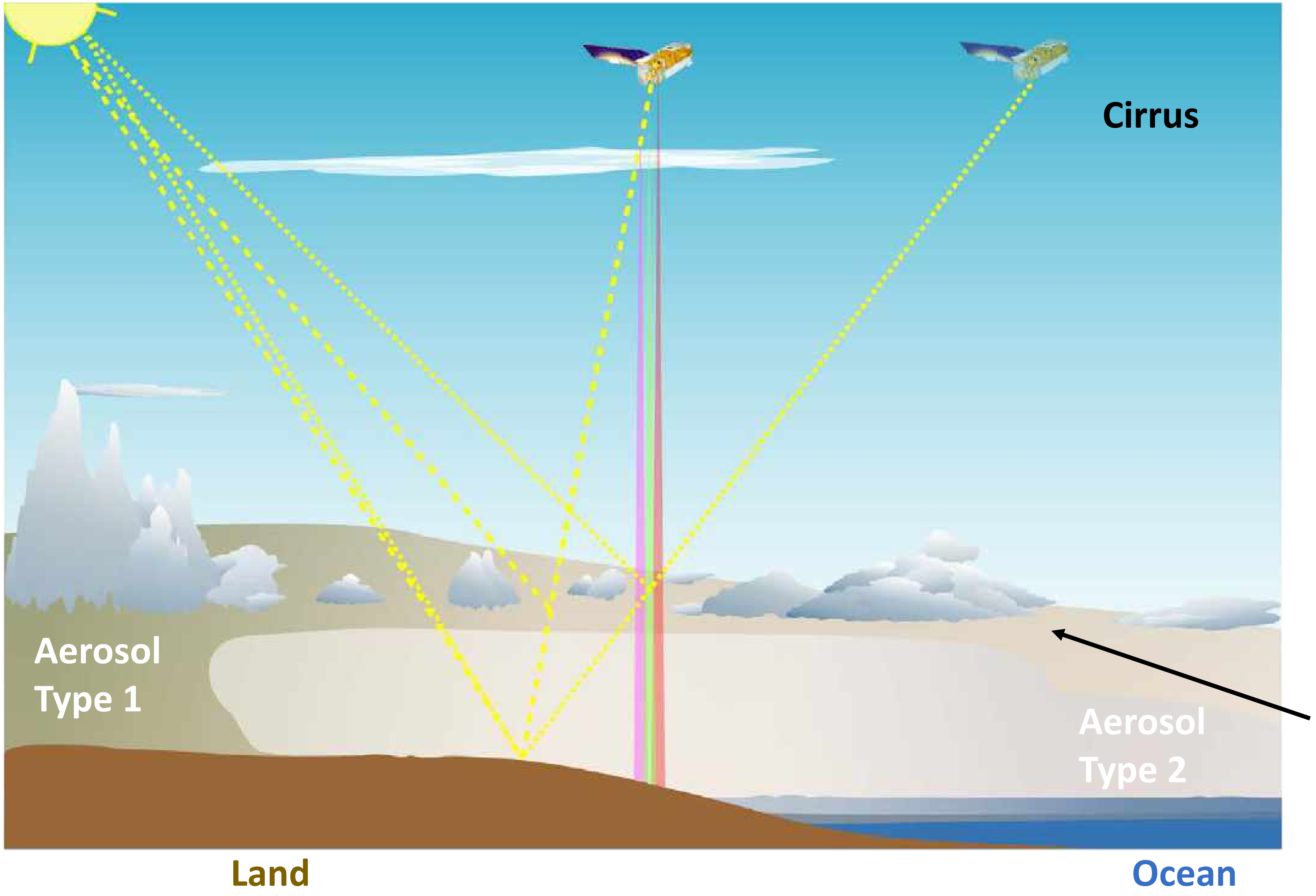
Ocean

Some challenges to aerosol remote sensing (RS):

- Surface reflectance
- Aerosol vertical distributions
- Lidar signals provide independent constraints on vertical distributions
- Atmospheric aerosol types are often mixed in type, and vary rapidly ~10km
- Cirrus clouds
  - major challenge for passive aerosol RS
  - challenge for active RS

"But nature did not deem it her business to make the discovery of her laws easy for us.“, Einstein 1911

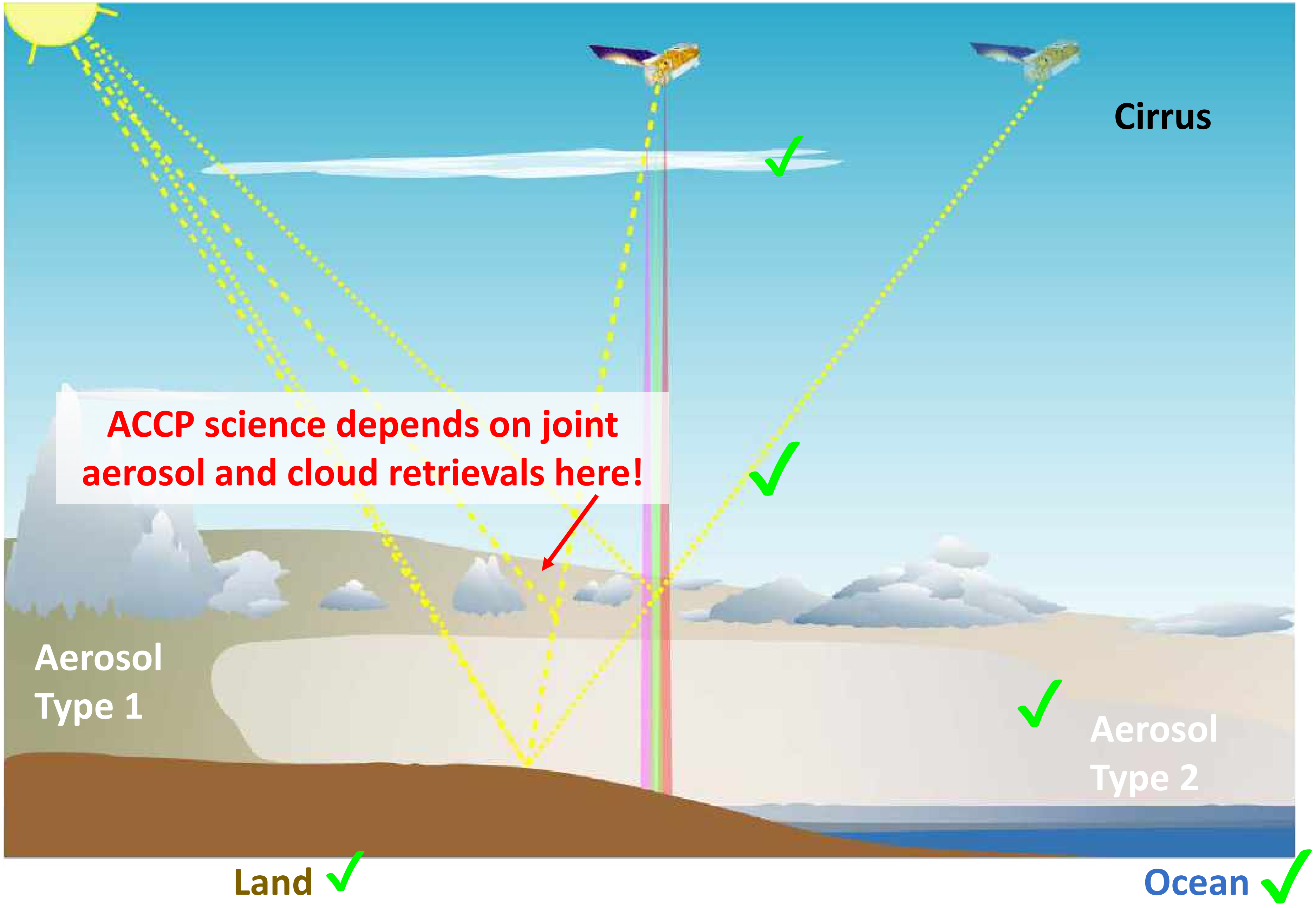
Active & Passive Aerosol Remote Sensing



Some challenges to aerosol remote sensing (RS):

- Surface reflectance
- Aerosol vertical distributions
- Lidar signals provide independent constraints on vertical distributions
- Atmospheric aerosol types are often mixed in type, and vary rapidly ~10km
- Cirrus clouds
  - major challenge for passive aerosol RS
  - challenge for active RS
- Low clouds
  - challenge for passive aerosol RS
  - challenge for active RS

Complexities Addressed in Retrieval Simulations



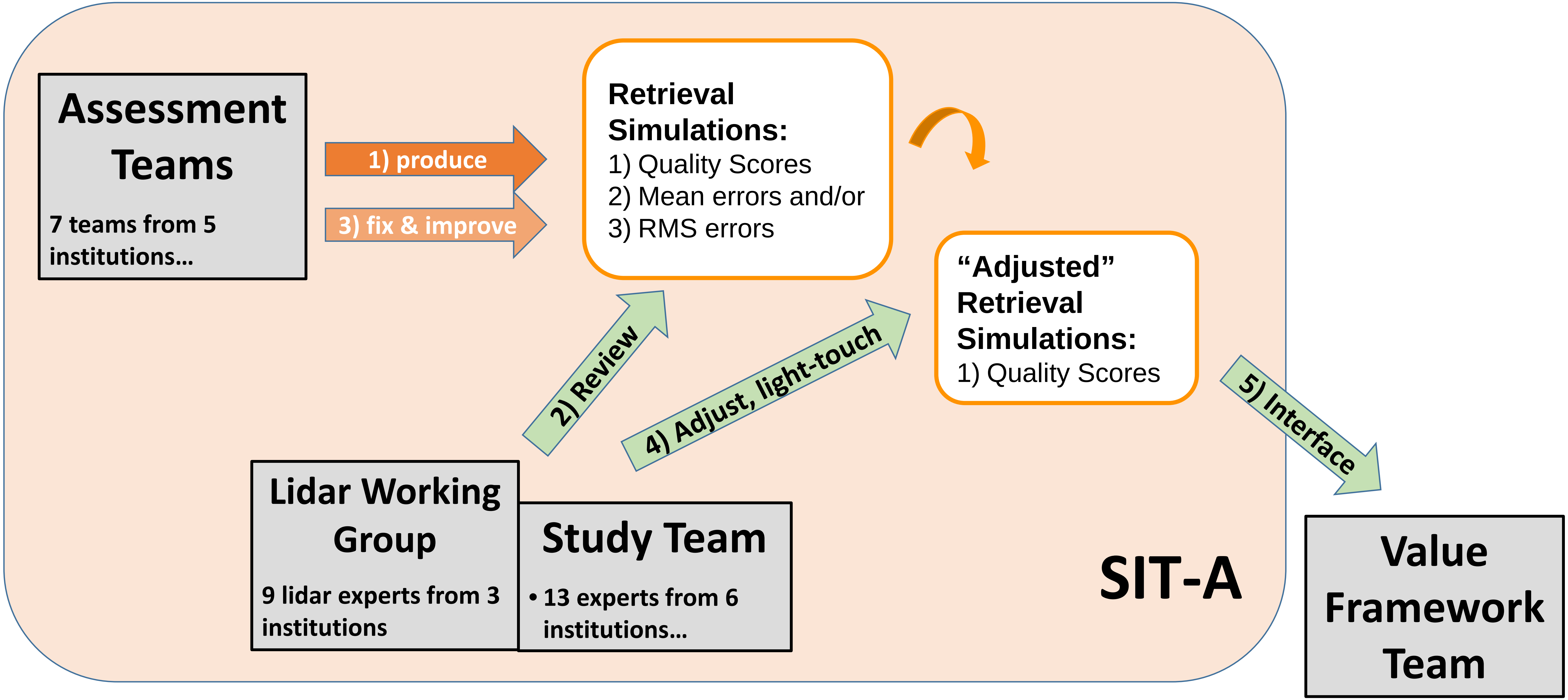
SIT-A ✓

- **Focused on L2 retrievals**
- Primarily used synthetic data, capturing various aerosol types and vertical distributions
- Approach captures forward model errors & “defines” truth
- Land and ocean surfaces & Daytime/Nighttime
- CALIPSO indicates that 51% of aerosol retrieval opportunities contain additional uncertainty from thin clouds. (Thorsen et al.)

LWG (Lidar Working Group, Eloranta et al.)

- **Focused on lidar performance and design requirements**
- Primarily used real data to assess retrieval capabilities
- Four actual combined aerosol/cloud scenes
- Led to lidar design improvements

The SIT-A Architecture Evaluation Approach: Workflow



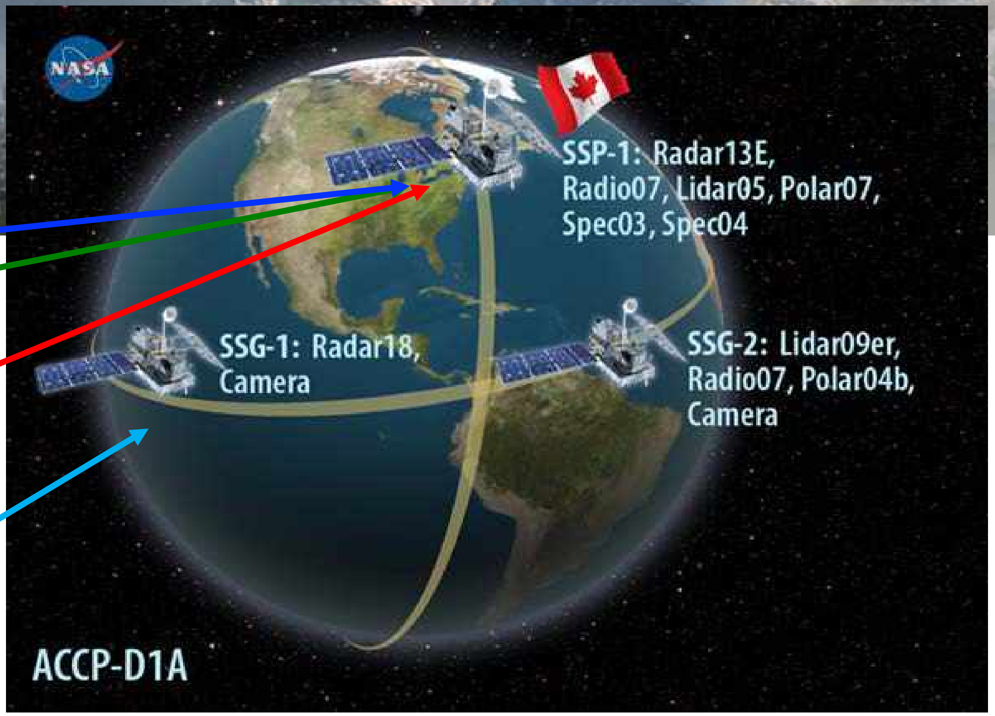
SIT-A Quality Scores

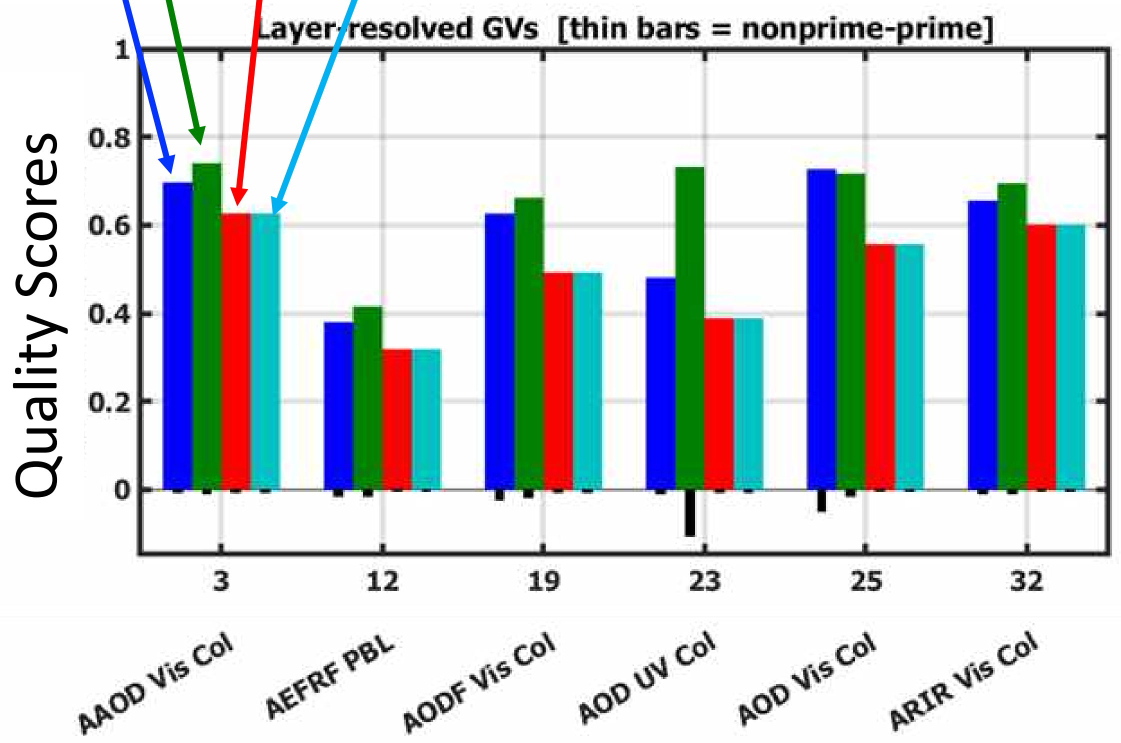
Polar Platform: Lidar 5 (HSRL-1), Polarimeter

Polar Platform: Lidar 6 (HSRL-2), Polarimeter

Polar Platform SSP2: Lidar 9 (backsc. lidar), Polarimeter

Inclined Platform: Lidar 9 (backsc. lidar), Polarimeter





Selection of most important Aerosol Geophysical Variables →

Quality Scores provide a measure of how well/often the instruments can retrieve the GVs relative to SATM uncertainties!

Permutations result in 1-2 Million Quality Scores.

Additional Outcomes - 1

Lidar Instrument Design changes

Advanced Retrieval Algorithm Development

Forward signal simulators

A retrieval community
(joint lidar+polarimeter)

- inclusive & respectful
- coalesced around learning & results
- collaborative in spirit & action

Additional Outcomes - 2

frontiers
in Remote Sensing | Satellite Missions

Research Topic

Remote Sensing of Cloud, Aerosols, and Radiation from Satellites

A Combined Lidar-Polarimeter Inversion Approach for Aerosol Remote Sensing over Ocean

Feng Xu[1*], Lan Gao[1], Jens Redemann[1], Flynn Connor[1], William R. Espinosa[2], Arlindo Da Silva[2], Snorre Stamnes[3], Sharon P. Burton[3], Xu Liu[3], Richard Ferrare[3], Brian Cairns[4], Oleg Dubovik[5]

[1]School of Meteorology, College of Atmospheric and Geographic Sciences, University of Oklahoma, United States, [2]Goddard Space Flight Center, National Aeronautics and Space Administration, United States, [3]Langley Research Center, National Aeronautics and Space Administration (NASA), United States, [4]Goddard Institute for Space Studies (NASA), United States, [5]UMR8518 Laboratoire d'optique atmosphèrique (LOA), France

Special Section in Frontiers of Remote Sensing has received 26 papers, mostly from the ACCP community!

Major Findings - 1

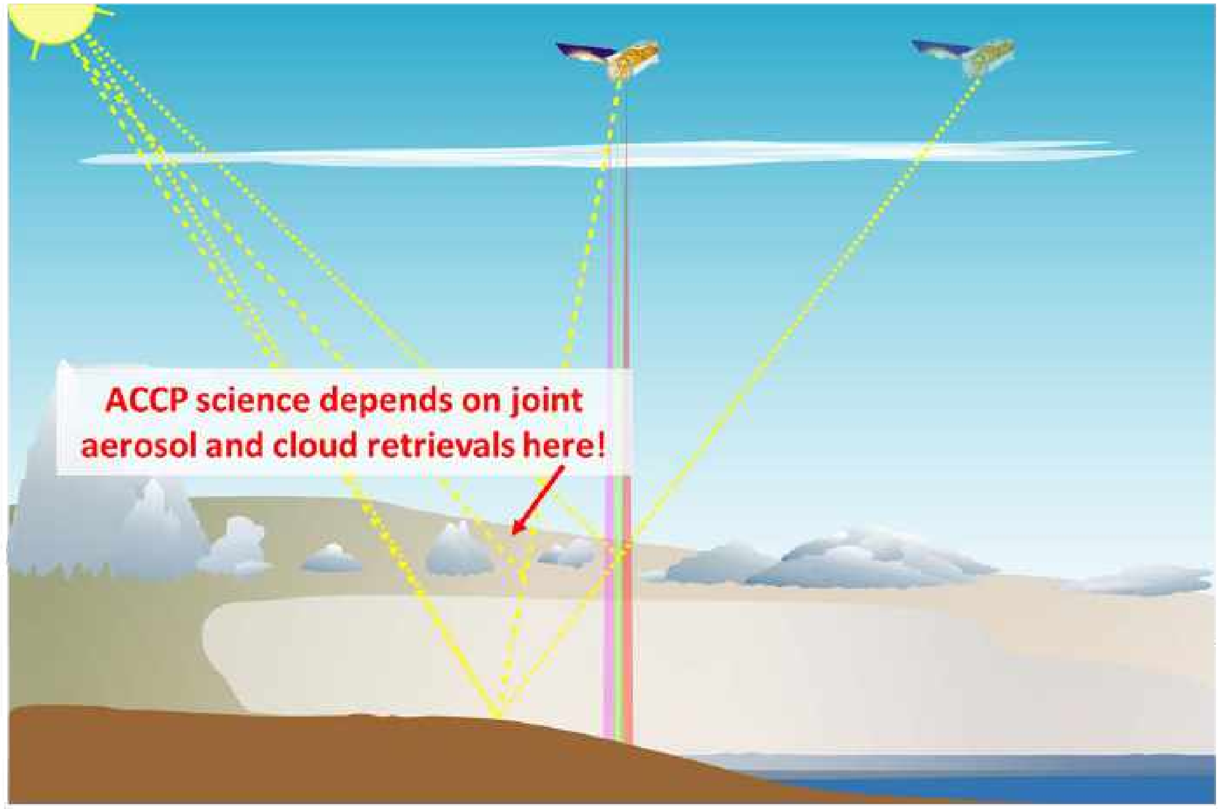
- Multiple complementary approaches are important (also LWG and SIT-A)
- Joint (lidar+polarimeter) retrieval simulations reduce retrieval errors
- SIT-A Quality Scores (QS) reflect physically plausible and significant differences:

Quality Scores **Polarimeter + HSRL-2**	**>** **Δ = 0.06-0.14**	**Quality Scores** **Polarimeter + HSRL-1**	**>** **Δ = 0.17-0.25**	**Quality Scores** **Polarimeter + Backscatter lidar**

- These observational capability differences can mean the difference between meeting and not meeting threshold science requirements!

Major Findings – Additional Outcomes

- LWG confirmed feasibility of spaceborne HSRL observations
- Significantly improved algorithms (far beyond previously published skill)
- French partners demonstrated notable differences in particle typing capabilities among lidars
- Algorithms are key to the synergistic observations of ACCP
- Collaborative, inclusive retrieval community, coalesced around results
- Need to expand and enhance joint retrievals



ACCP Science Impact Team – Clouds Convection Precipitation (SIT-CCP) Summary of Activities for HQ review

February 4, 2021

The SIT-CCP Study Team Leads

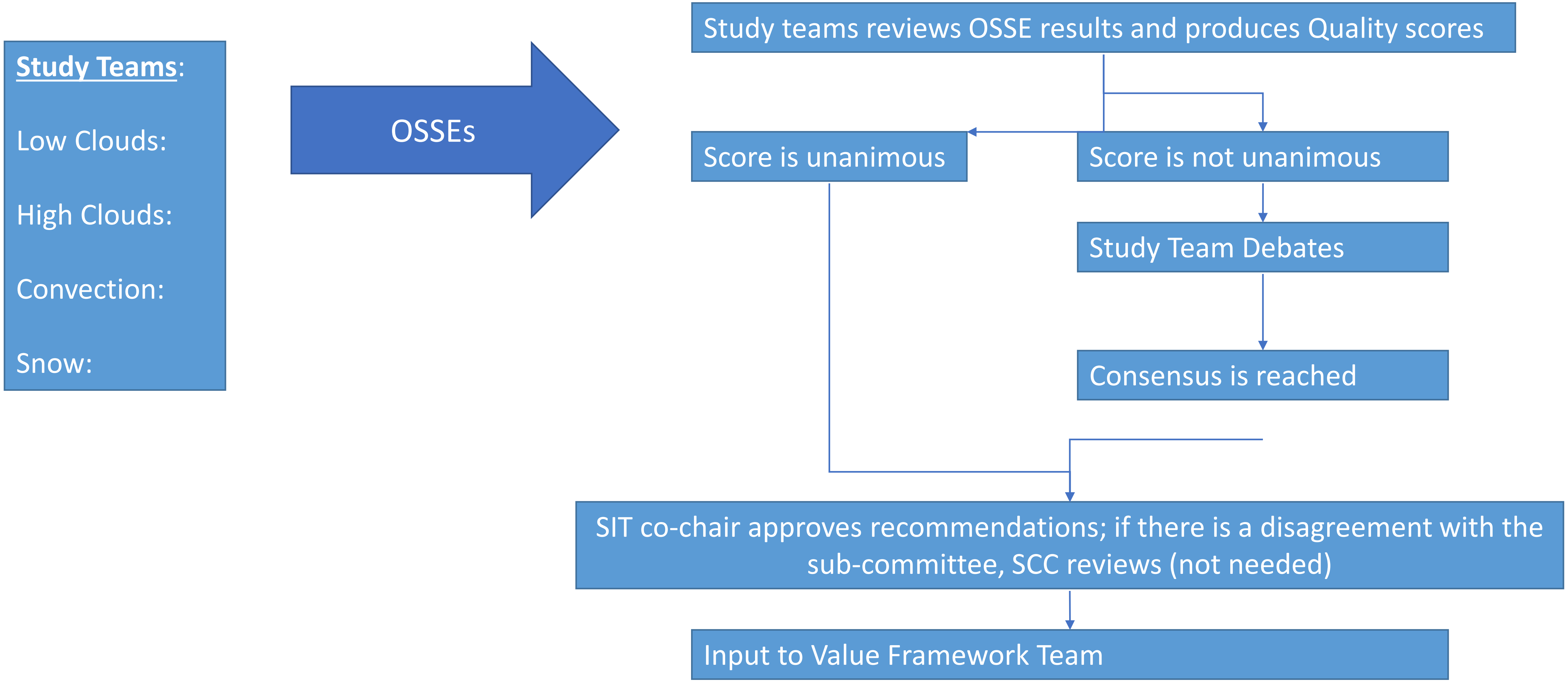
Derek Posselt, Ian Adams, Timothy Lang, Pavlos Kollias

The Charter of the SIT-CCP

- **SIT-CCP Charter:** … to critically evaluate retrieval uncertainties given measurement architectures for individual cloud and precipitation Geophysical Variables comparing them to SATM requirements.

Quality ≡ Fraction of simulated retrievals that provide uncertainties within SATM requirements

SIT-CCP Implementation



What We Accomplished for ACCP

- Accomplished the first-order objective of our charter.
  - Began 18 months ago with lessons learned from Aerosol Clouds Ecosystems (ACE).
  - Goal: Relative to science needs, formalize a methodology to objectively evaluate remote sensing architectures
  - After 6 Architecture Evaluation Workshops over 14 months, we are now quite nimble with a set of tools and a general methodology to critically evaluate subtle nuances to complicated remote sensing architectures and problems.

- **Stood up a team of young innovative scientists who now have a cutting edge war chest of methodologies that can be adapted to meet the scientific and algorithmic challenges of the ACCP Era.**

- Realization that to meet the process-oriented science objectives of ACCP, measurement **Synergies are fundamental. The level 2 algorithm suite will naturally evolve to exploit these synergies among radar, lidar, radiometer, polarimeter.** This is a significant advance over A-Train.

How SIT-CCP's Task Differed from SIT-A

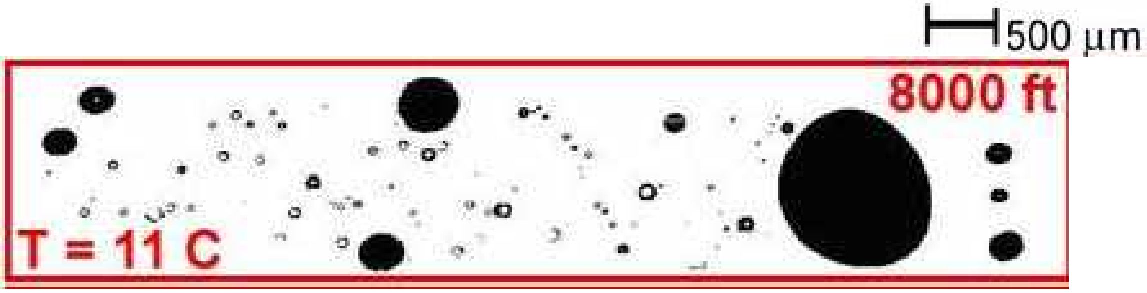
Climate Emphasis

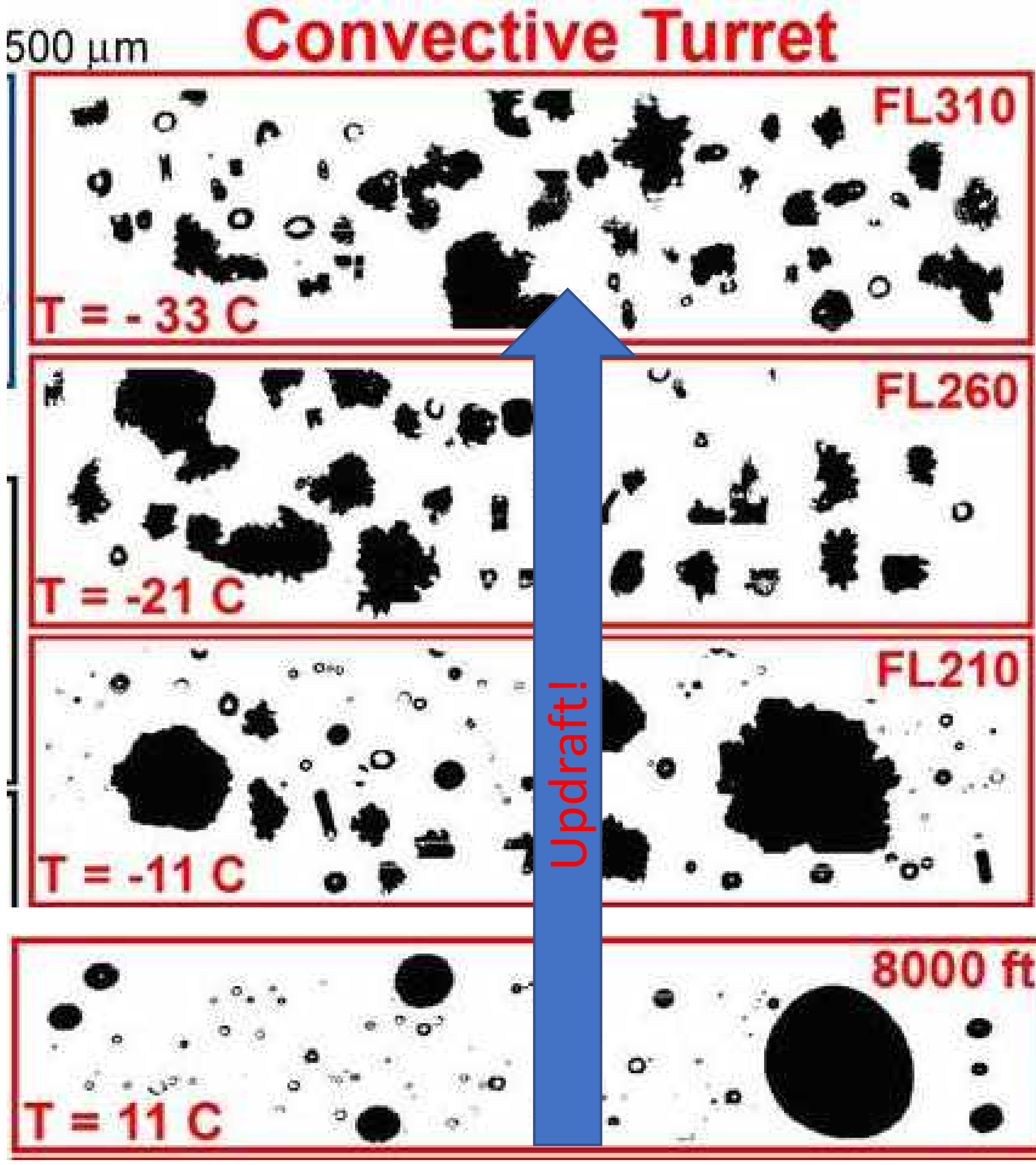
Low Clouds

High Clouds

- **Water clouds based in the boundary layer with ice or liquid phase precipitation**

- **Ice Clouds in the upper troposphere related to both convection and large-scale dynamics**





Convection Emphasis

Microphysics courtesy Dave Mitchell

Climate Emphasis – Low Clouds (O1, O8)

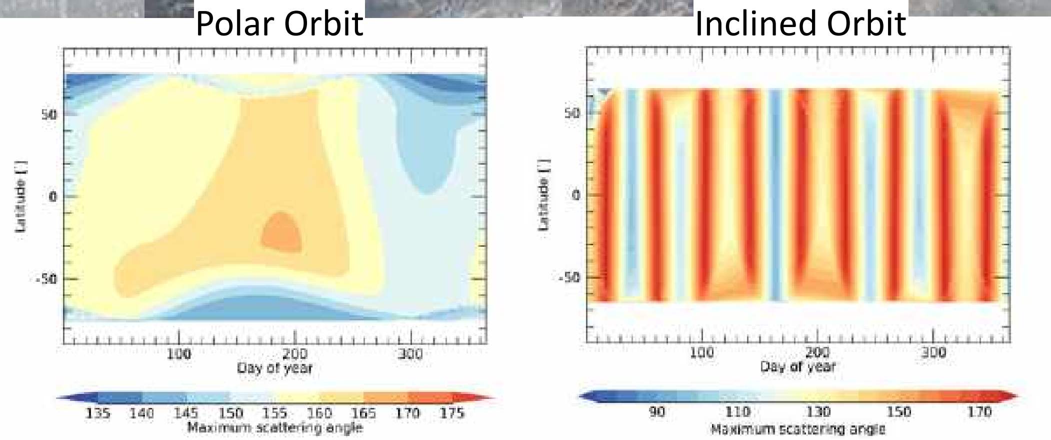
Study Team Lead: Derek Posselt
Study Team Members: Matt Lebsock, Rick Schulte, Yuli Liu, Jay Mace, Bastiaan Van Diedenhoven

Low Cloud Scoring Methods:

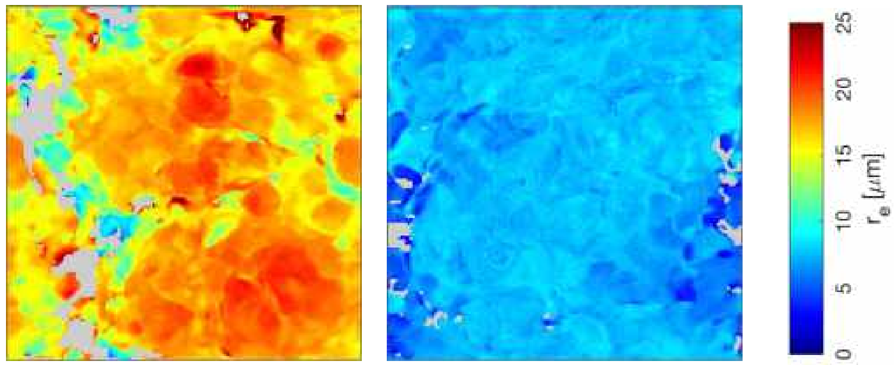
Tools: existing observations + sampling studies + high resolution models + Bayesian retrieval algorithms (Optimal Estimation and Markov Chain Monte Carlo)

- Existing observations:
  - spectrometer, multi-angle imager, polarimeter (aircraft and space)
  - microphysics from aircraft measurements (IPHEX, RICO, OLYMPEX)
  - disdrometer obs mapped to Z(z), Tb, and PIA
- Model output – subpixel variability
  - LES and CRM for Sc and Cu
  - ECCC (50 meter long-domain) - Spectrum of low cloud types
- Bayesian Retrievals – quantify uncertainty
  - Optimal Estimation
  - Markov chain Monte Carlo

Polarimeter Max Scatter Angle

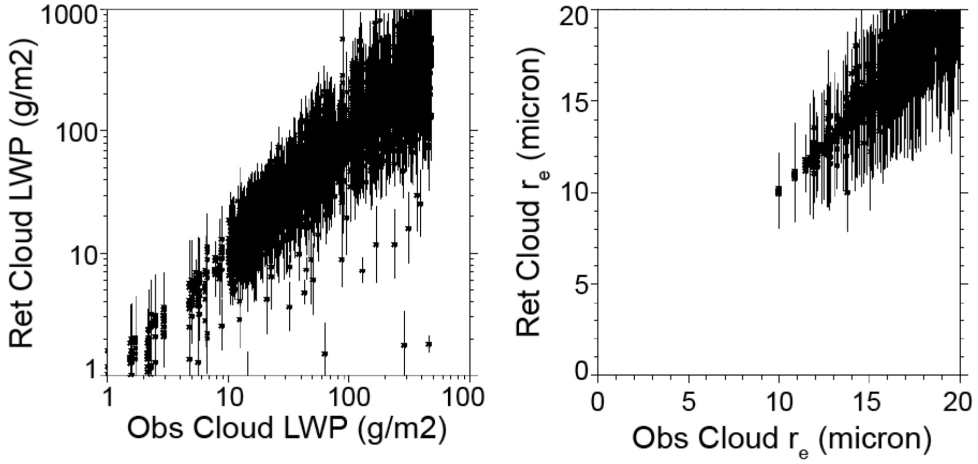


DHARMA LES dx=50m



r_{eff} Clean r_{eff} Polluted

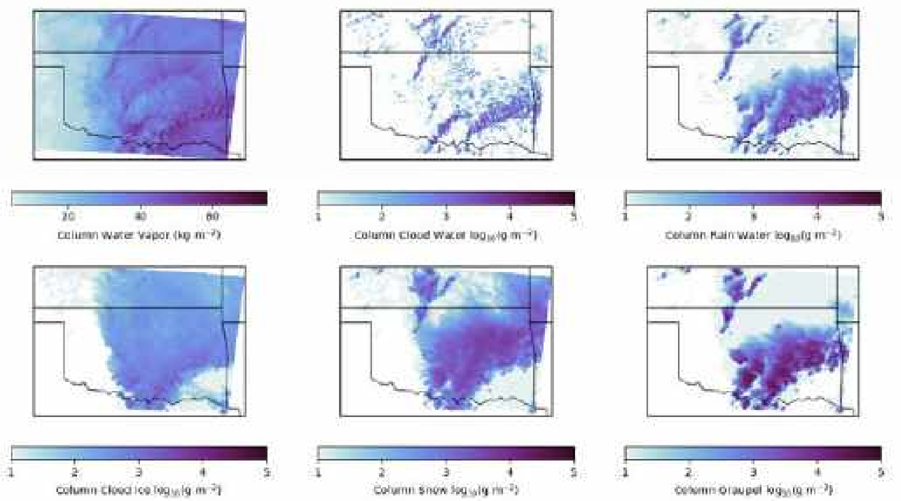
MCMC Results, Low Cloud Simulations



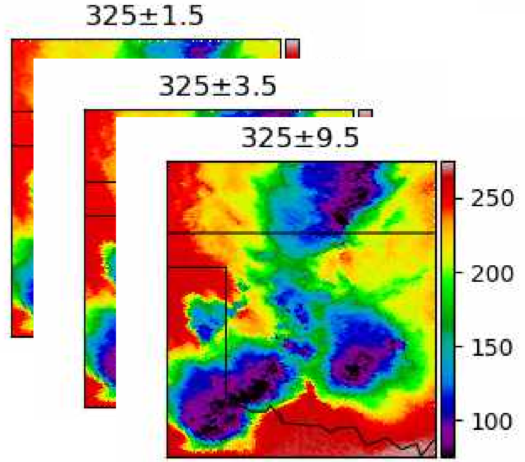
Climate Emphasis – High Clouds (O2)

Study Team Lead: Ian Adams
Study Team Members: Min Deng, Joe Munchak, Yuli Liu, Bastiaan Van Diedenhoven

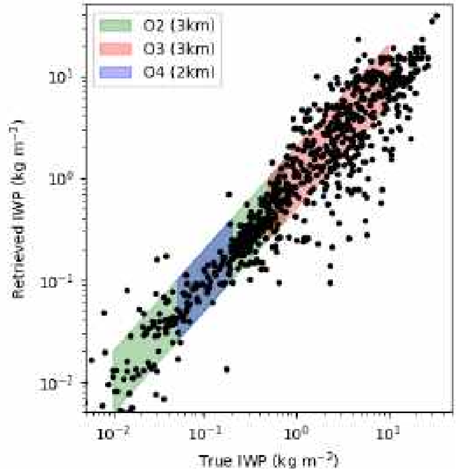
MC3E NU-WRF Simulation



Forward Model



Bayesian Inversion



Cloud-resolving models (ECCC, NU-WRF)

- Full atmospheric column
- Moderate horizontal resolution (down to 1 km)

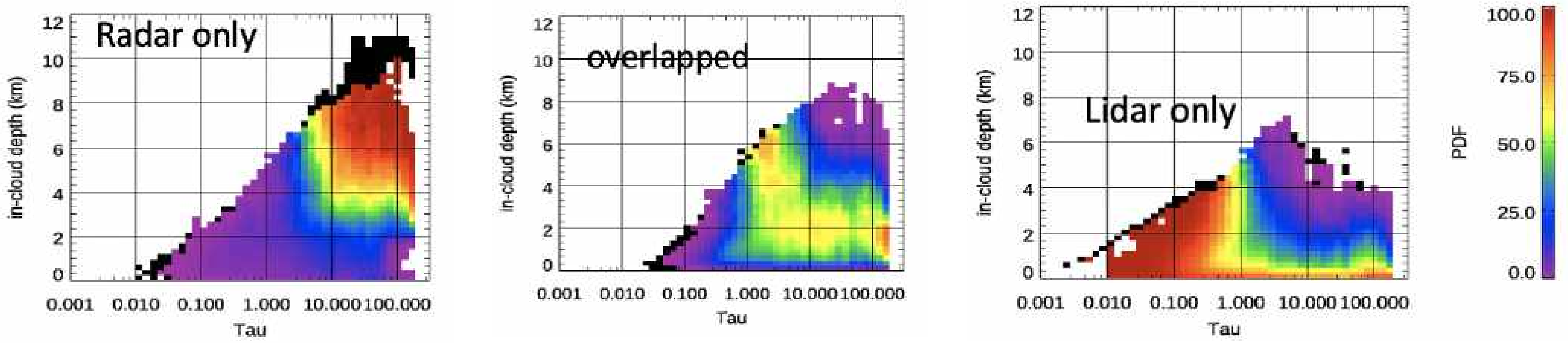
Synthetic & observational retrievals

- Monte Carlo Integration
- Optimal Estimation
- Synergistic lidar/radar & radar/radiometer
- Doppler-based vertical motion

Sampling studies

- Polarimeter rainbow sampling (polar vs inclined)
- Radar/lidar overlap
- Ku vs Ka band
- Radiometer resolution impacts

Radar/Lidar Cloud Sampling Analysis Based on 2C-ICE Product

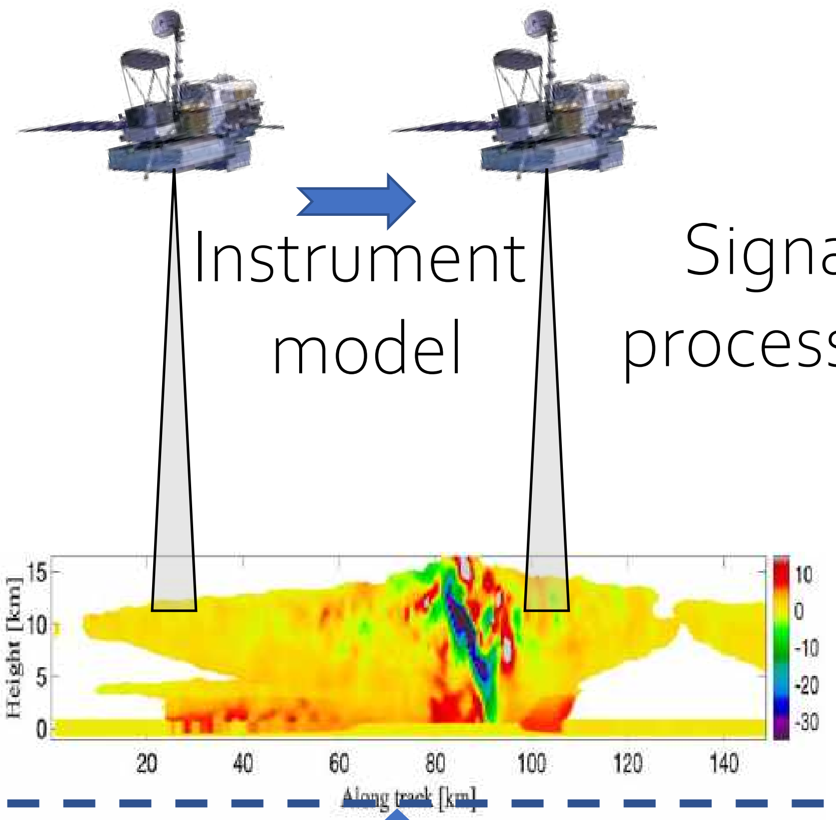


Radar Forward Modeling

Pavlos Kollias

Spaceborne Radar simulator

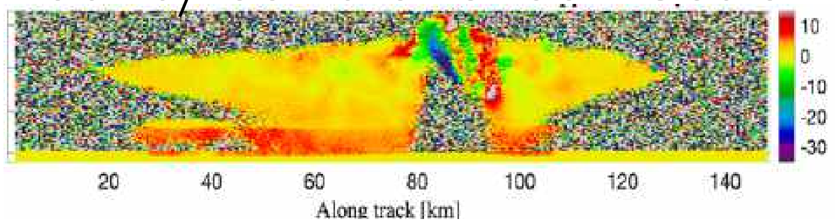
Forward model



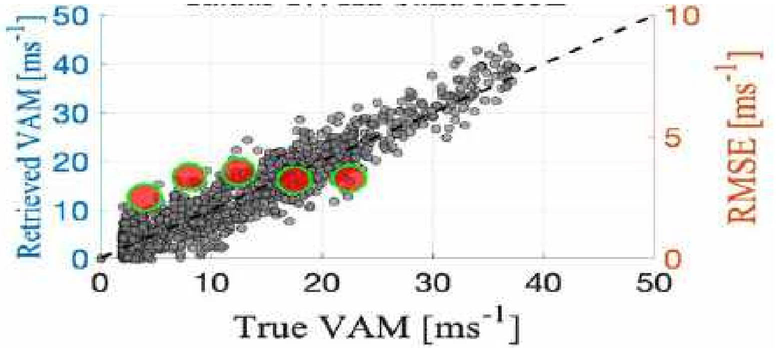
E/M modeling

L1B/L2A processing

Quality control & corrections



Vertical air motion retrieval



GV scoring procedure

High resolution numerical models

Variety of cloud and precipitation systems - Large library of deep convective clouds

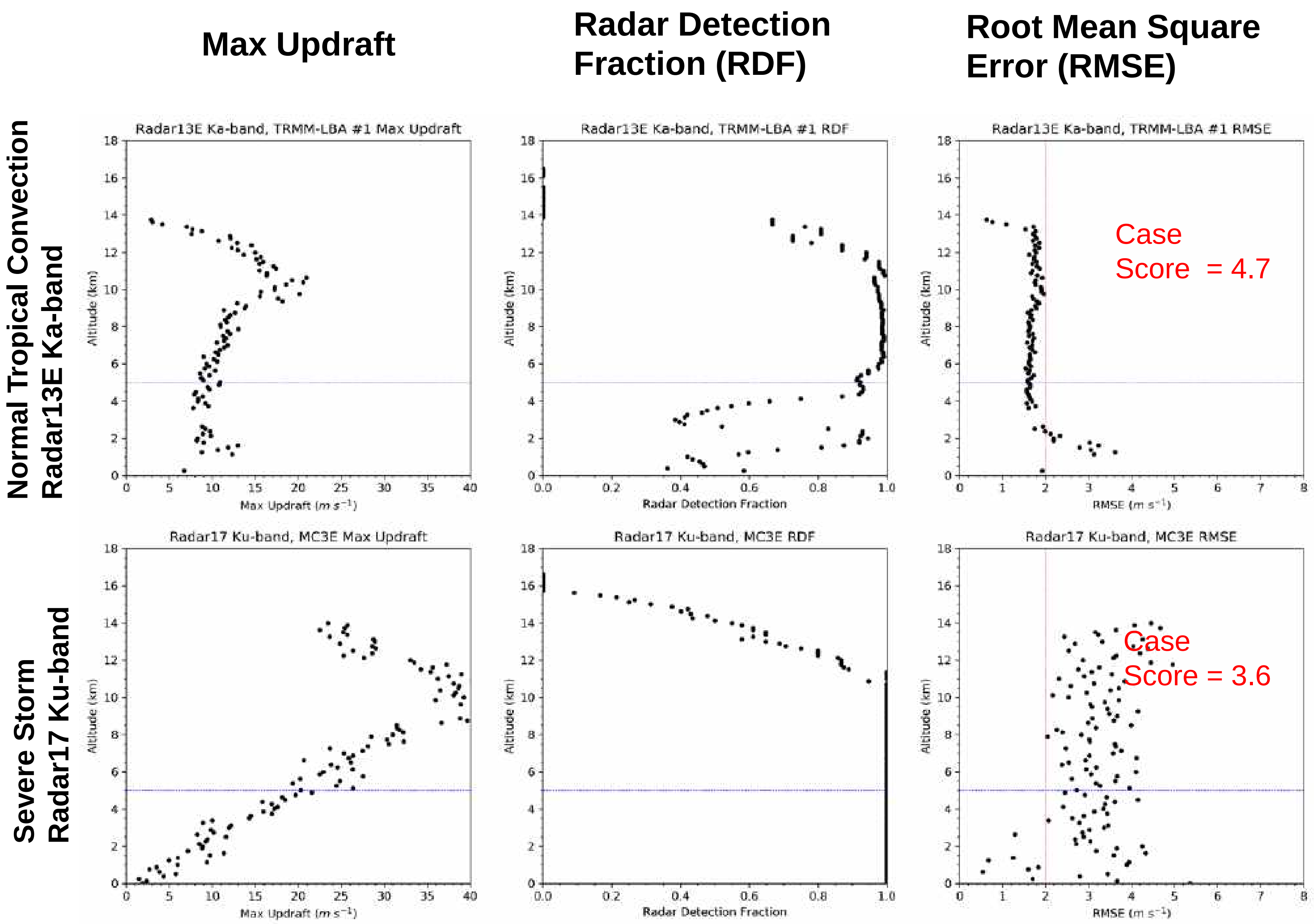
Convection (O3)

Study Team Lead: Tim Lang

Study Team Members: Pavlos Kollias, Mircea Grecu, Dan Cecil, Joe Munchank, Rachel Storer, Ziad Haddad, Patrick Gatlin

Example Scoring Procedure (O3):
In-Cloud Vertical Air Velocity (IVAV.z)

- Evaluate output from radar simulator
- Each level is weighted evenly between echo-top height and lowest level considered (0 or 5 km)
- Case Score = Sum(RDF * 5.0 / Weight) over all levels with RMSE <= limit, plus Sum(0.0 / Weight) for RMSE > limit (or no detection)
- RMSE limit is larger of 2 m s^{-1} or 30% of max updraft; Maximum score = 5.0
- Final score is average of all seven O3-relevant cases (range from shallow convection to severe storm)



Summary

- **Realization that Emerged from CCP-SIT Effort:**

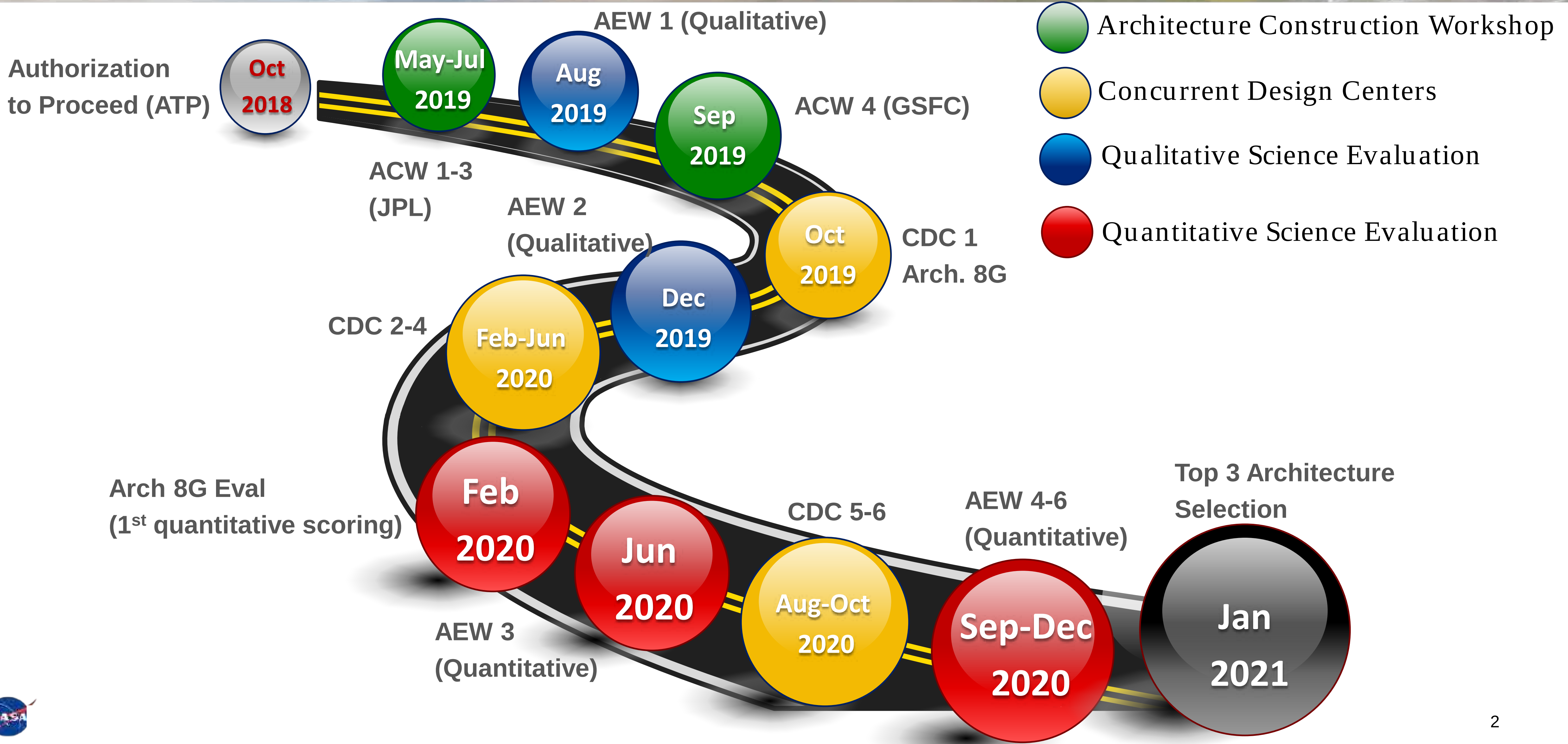
  - **Measurement synergies are fundamental to ACCP Success**
    - **CCP-science relies on full suite of A and CCP instrumentation.**
      - **ACCP is an integrate observing system**

  - **To meet CCP Science needs, the level 2 algorithm suite that is evolving for ACCP must exploit synergies among *radar, lidar, radiometers and polarimeters*.**

How Science Benefit Scoring Informed A Priority MindMap That Led to the Top 3 Candidate Architectures

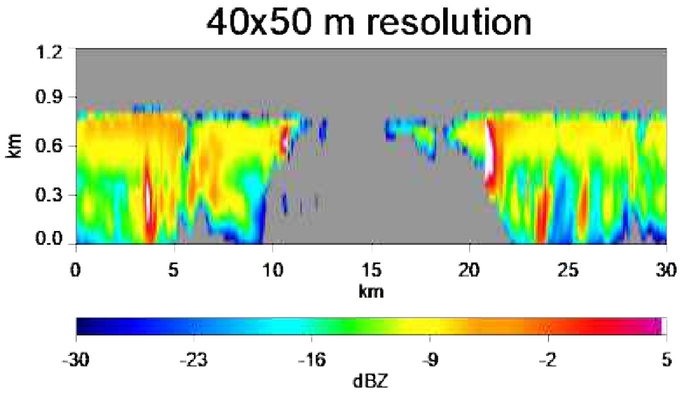
Scott Braun and Arlindo da Silva

Science Evaluation Road Map

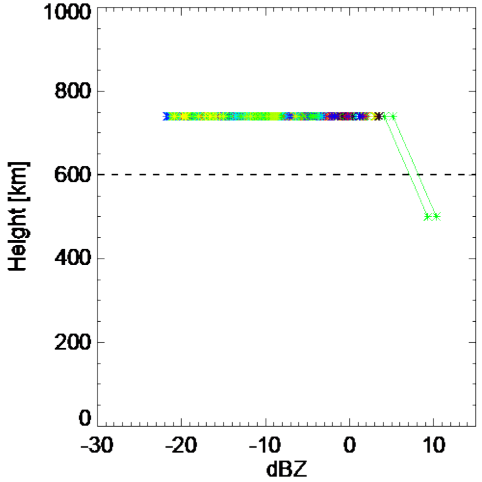


Lessons Learned—Radar

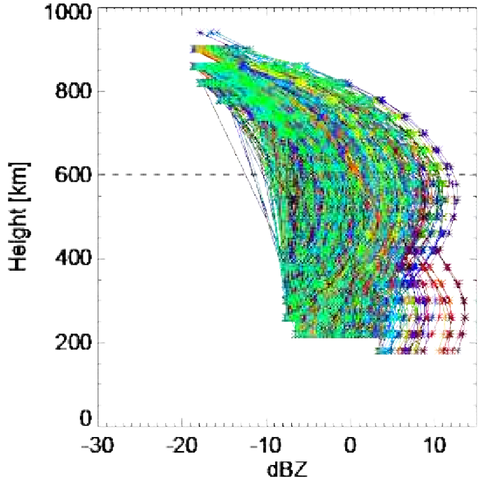
Profiling Closer To Surface



CloudSat

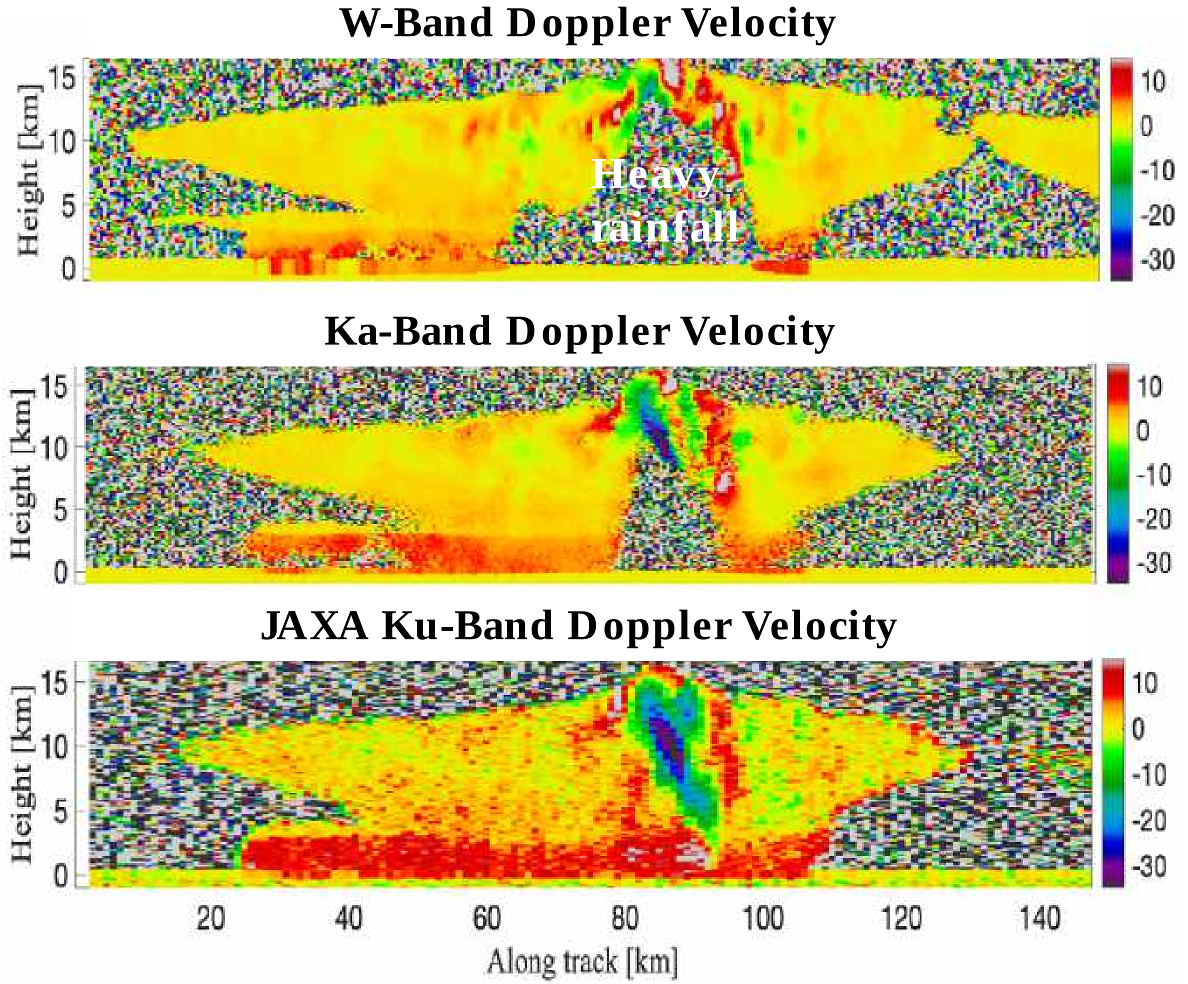


ACCP W-, Ka-band radar



Courtesy of Matt Lebsock (JPL)

Penetrating Convection And Doppler

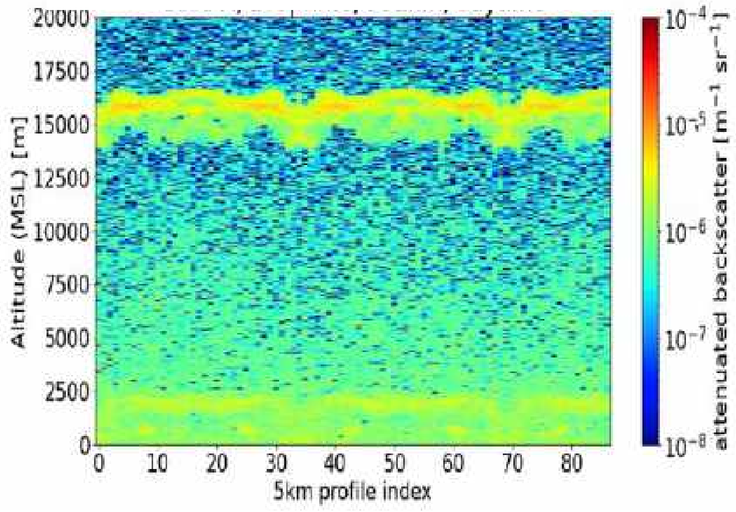


Simulations above produced by Pavlos Kollias (SUNY Stony Brook)

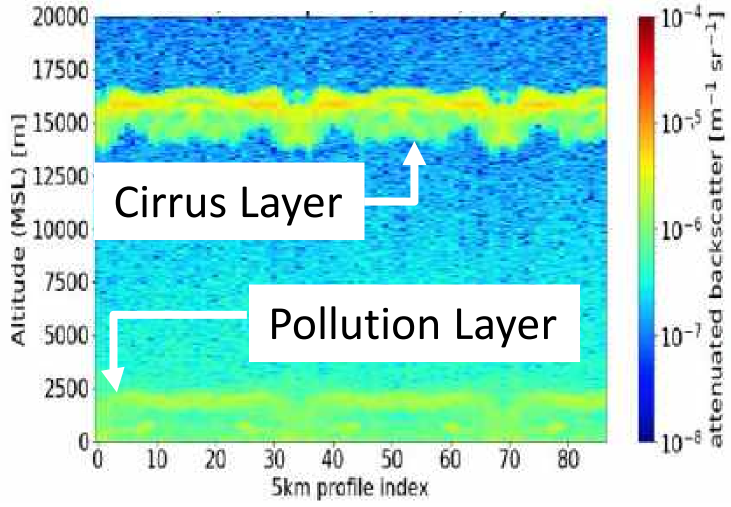
Lessons Learned—Lidar

- All lidars provide improved signal to noise (SNR) compared to CALIPSO
- HSRL provides direct measurement of particulate backscatter
- HSRL(+UV) > HSRL > Backscatter

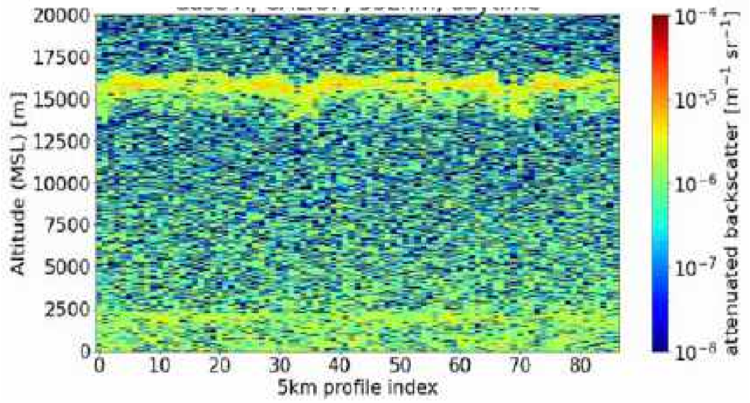
Backscatter Lidar (Lidar9er)

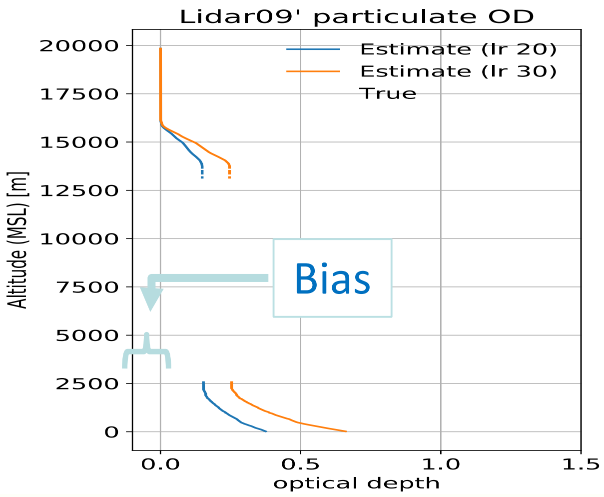


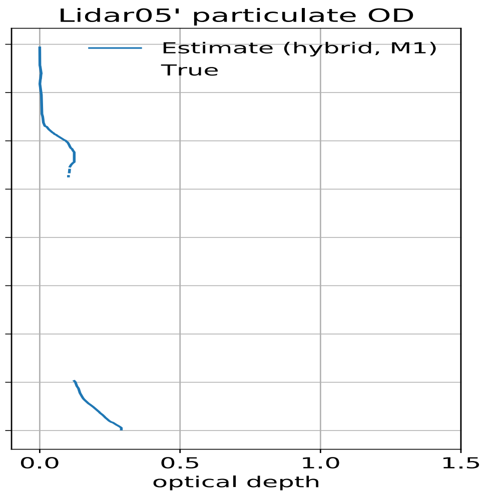
HSRL (Lidar05)



CALIPSO Reference Simulation





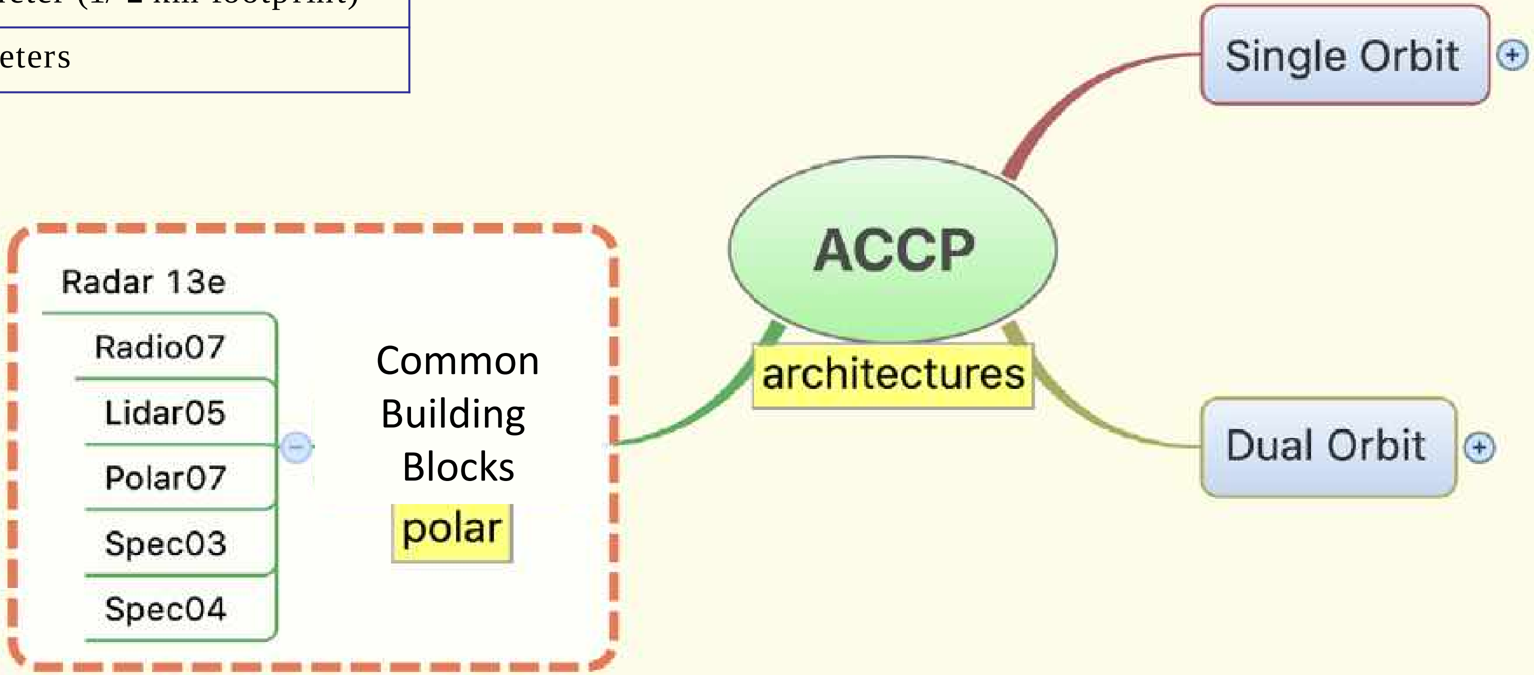


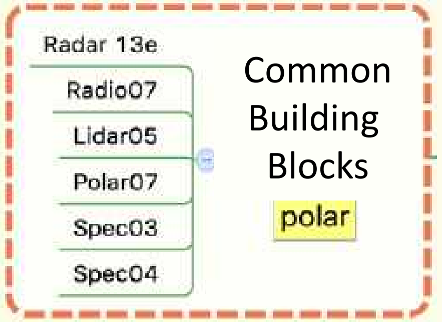
Simulations produced ACCP Lidar Working Group

Lessons Learned—Passive Instruments

- Passive microwave essential for context and precipitation constraints, cloud ice properties
  - Convection-resolving resolution
  - Applications desire for 89 GHz
  - Time-differenced measurements likely useful, but retrievals not sufficiently mature
- Polarimeters provide essential constraint for aerosol retrievals
  - Higher spatial resolution generally preferred over wider swath
- Spectrometers essential for radiation measurements collocated with clouds and aerosols
- Stereo cameras provide innovative measurements of cloud and aerosol plume dynamics
  - Identified as the highest priority among the different types of time-differenced measurements
  - Reasonably mature concept and deliverables
- ALI and SHOW provide valuable information on upper troposphere/lower stratosphere aerosols and moisture

Instrument Legend	
Radar13E	W Doppler, Ka Doppler
Radio07	118-880 GHz cubesat
Lidar05	VIS HSRL, NIR Backscatter
Polar07	UV-SWIR Polarimeter (1/ 2 km footprint)
Spec03/04	UV-FIR Spectrometers





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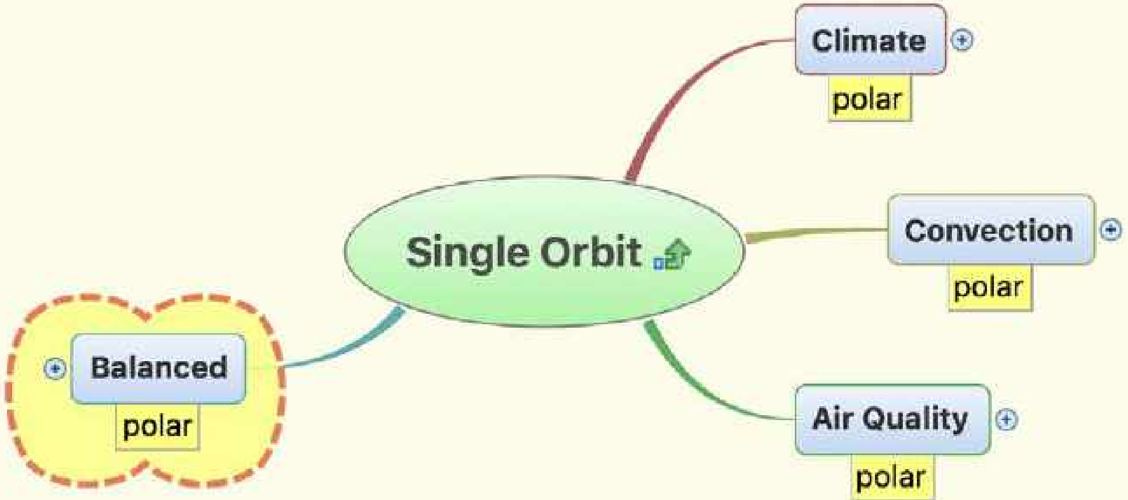

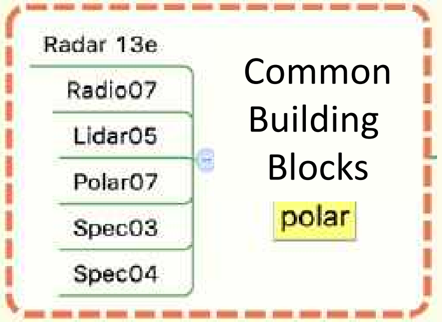

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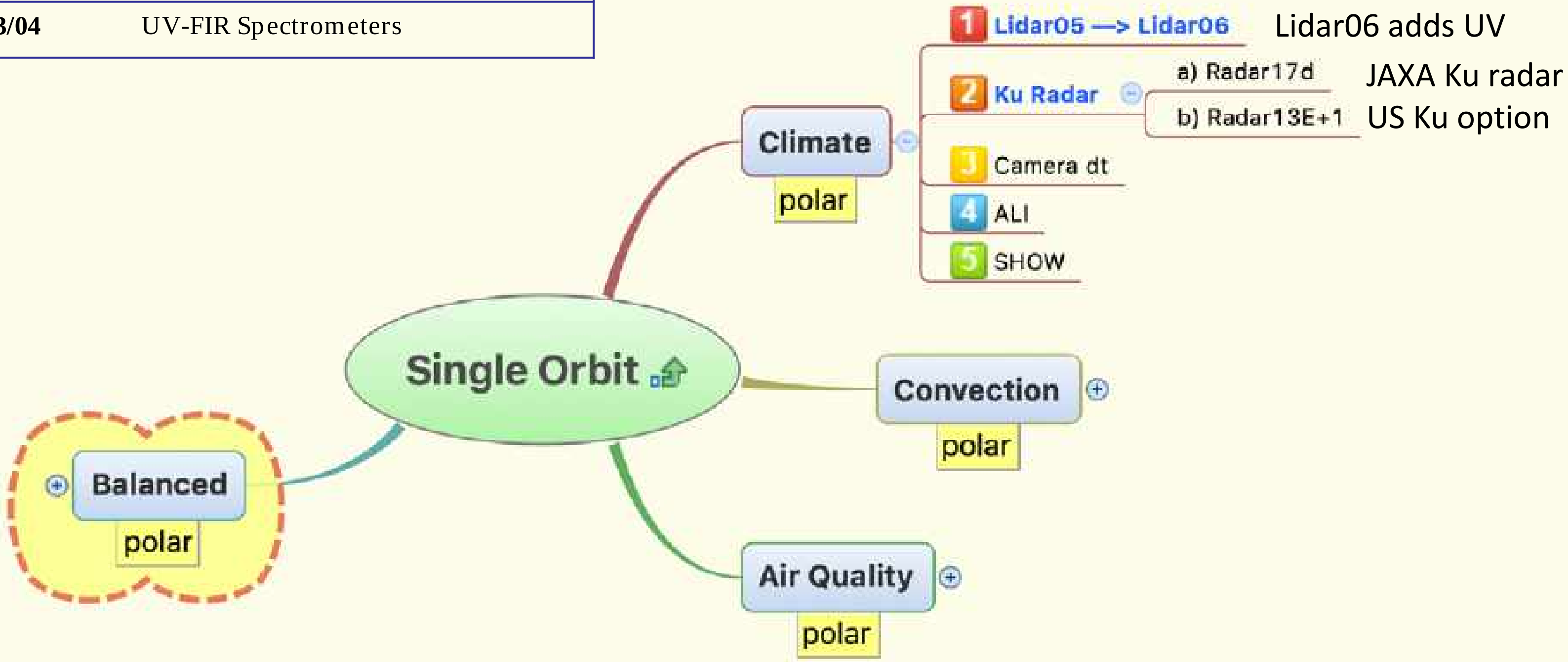

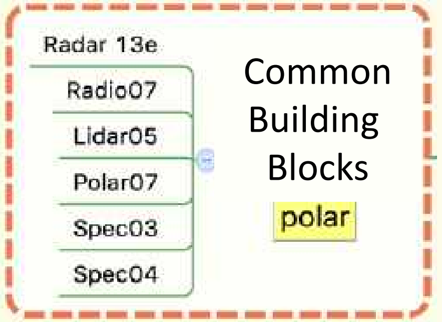

Instrument Legend	
Radar13E	W Doppler, Ka Doppler
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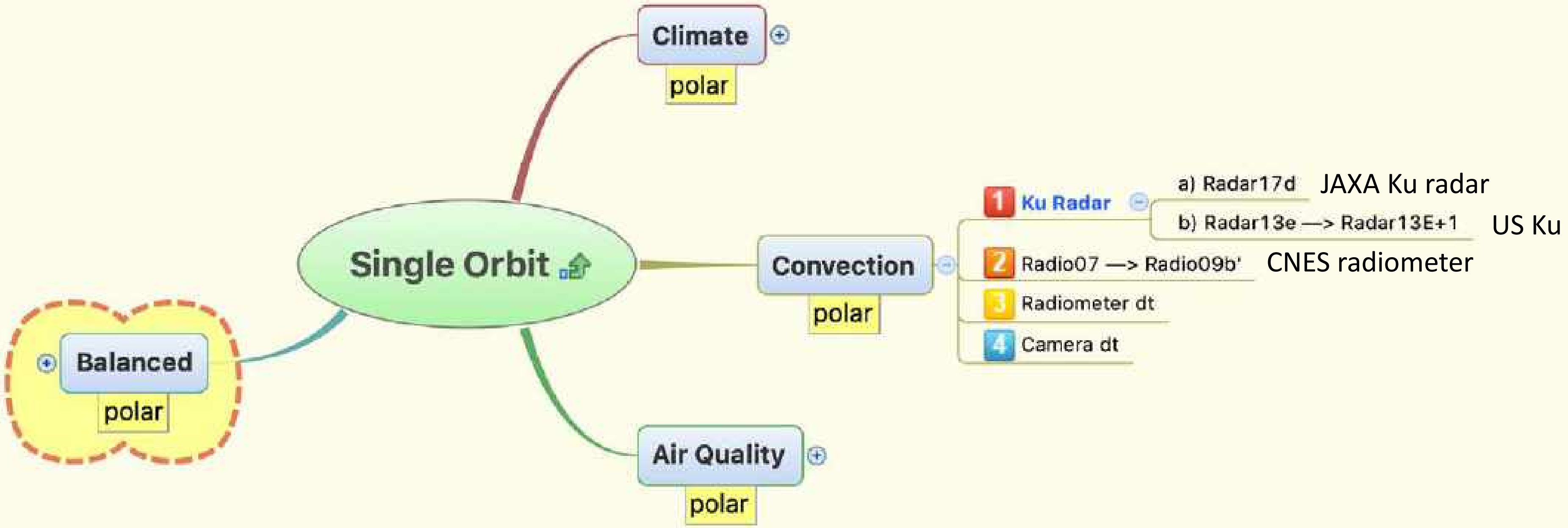

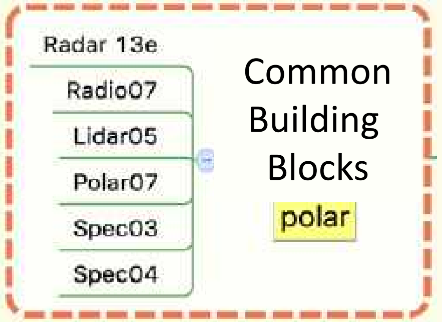

Instrument Legend	
Radar13E	W Doppler, Ka Doppler
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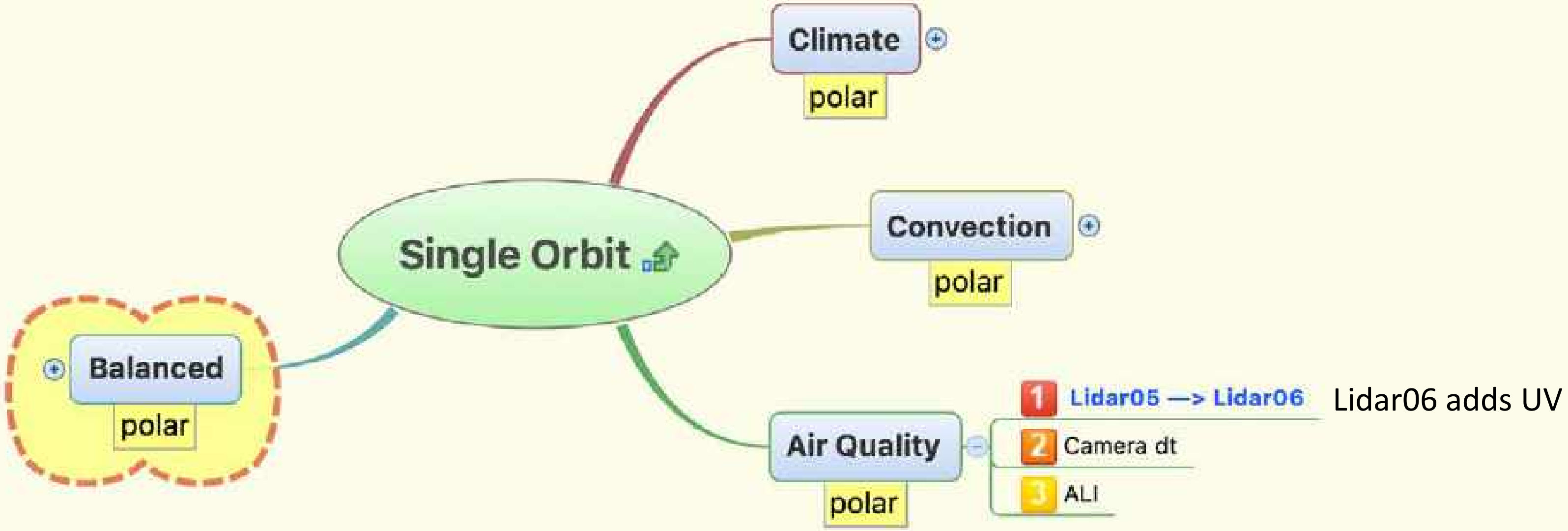

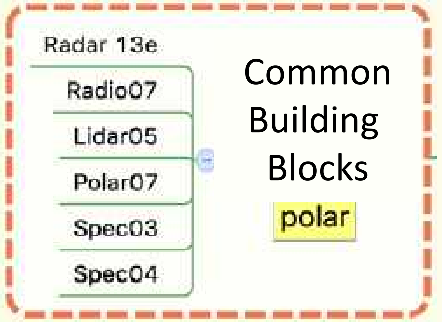

Instrument Legend	
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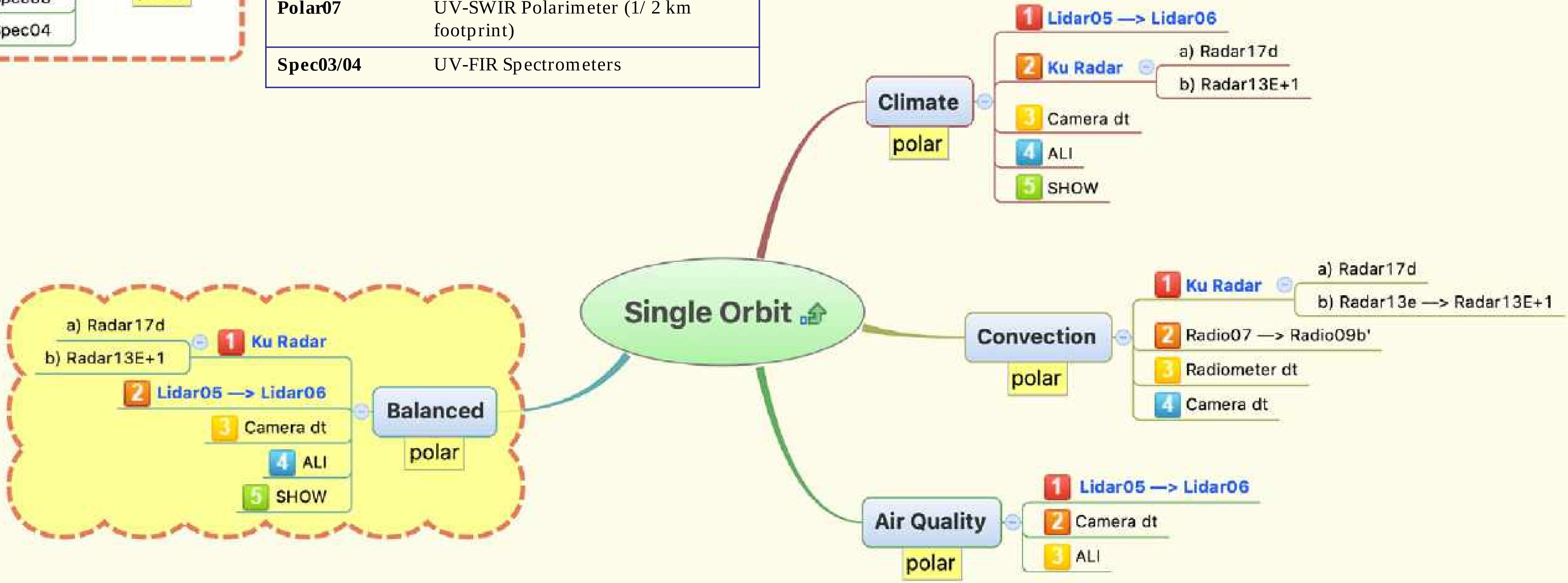
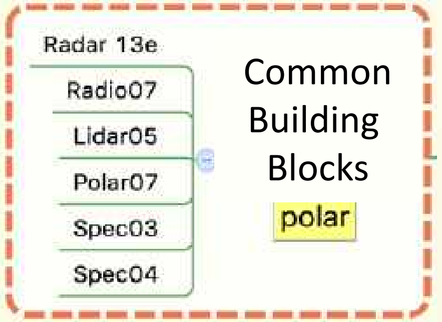
Spec03/04	UV-FIR Spectrometers

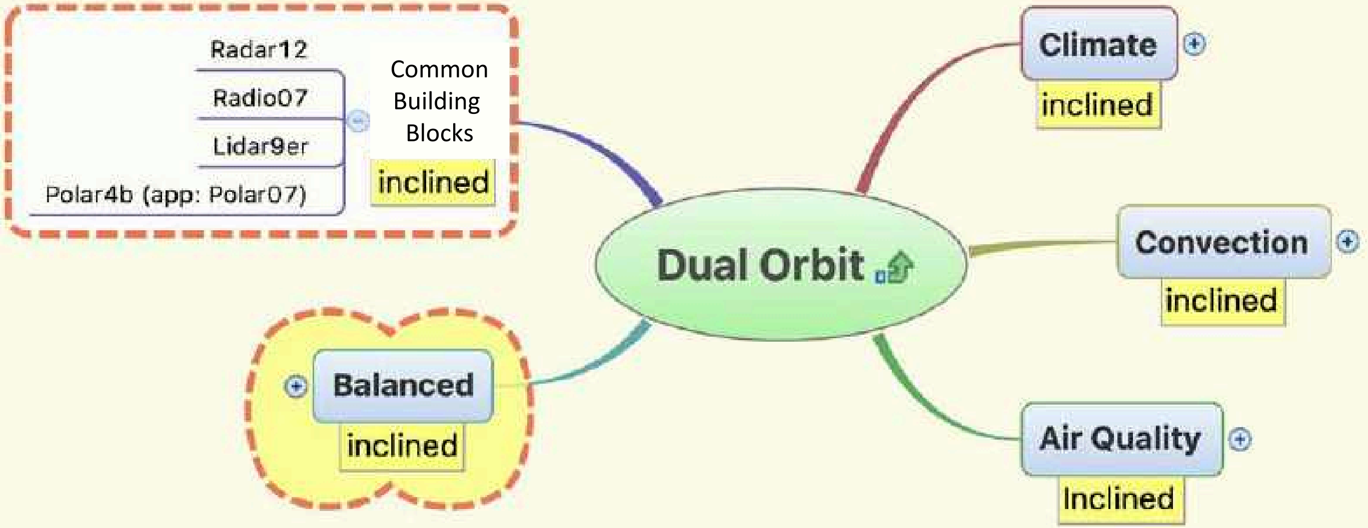


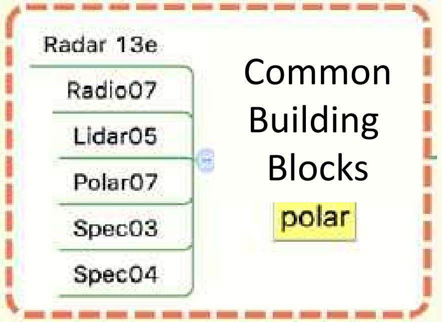
Architectures **P1**, **P2** emerged from the Single Orbit Balanced Prioritization



Instrument Legend	
Radar13E	W Doppler, Ka Doppler
Radio07	118-880 GHz cubesat
Lidar05	VIS HSRL, NIR Backscatter
Polar07	UV-SWIR Polarimeter (1/ 2 km footprint)
Spec03/04	UV-FIR Spectrometers

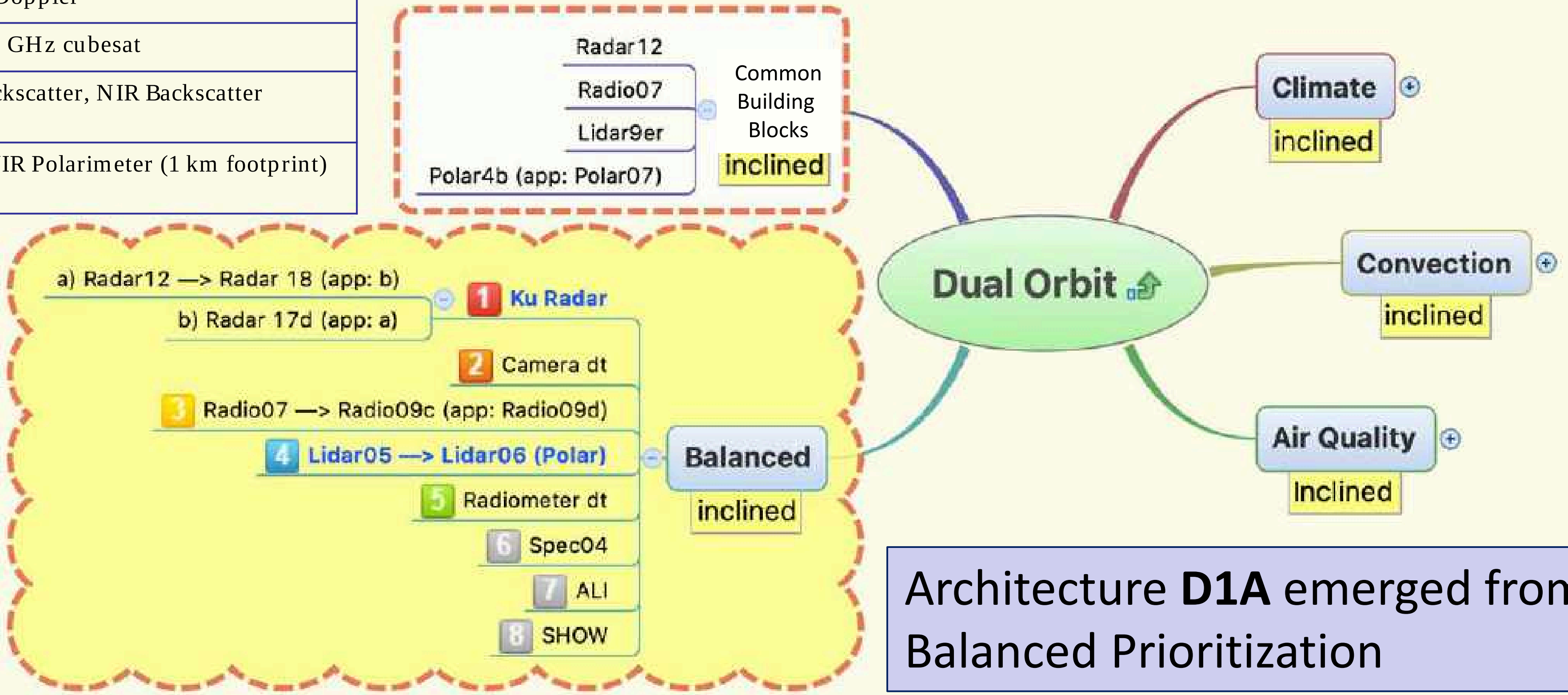
Inclined Instrument Legend	
Radar12	W, Ka Doppler
Radio07	118-880 GHz cubesat
Lidar9er	VIS Backscatter, NIR Backscatter
Polar04b	UV-SWIR Polarimeter (1 km footprint)





Instrument Legend	
Radar13E	W Doppler, Ka Doppler
Radio07	118-880 GHz cubesat
Lidar05	VIS HSRL, NIR Backscatter
Polar07	UV-SWIR Polarimeter (1/ 2 km footprint)
Spec03/04	UV-FIR Spectrometers

Inclined Instrument Legend	
Radar12	W, Ka Doppler
Radio07	118-880 GHz cubesat
Lidar9er	VIS Backscatter, NIR Backscatter
Polar04b	UV-SWIR Polarimeter (1 km footprint)



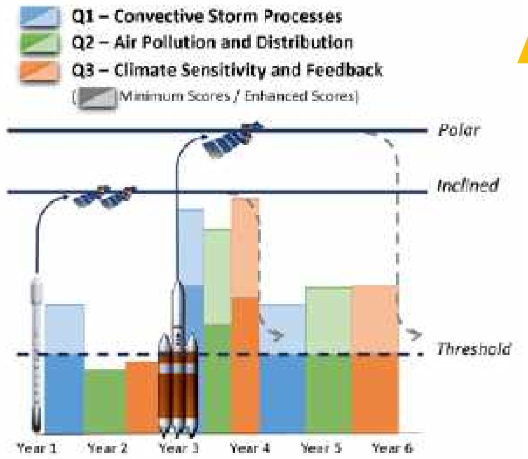
–Science question priorities not expanded

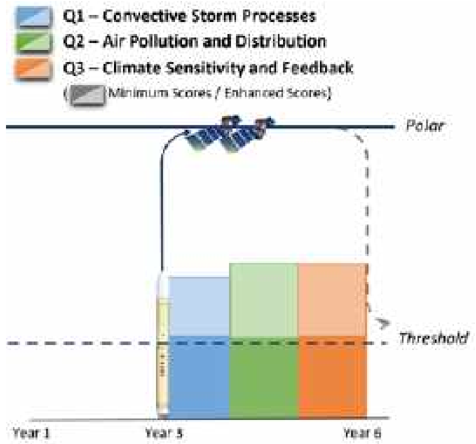
Architecture **D1A** emerged from the Dual Orbit Balanced Prioritization

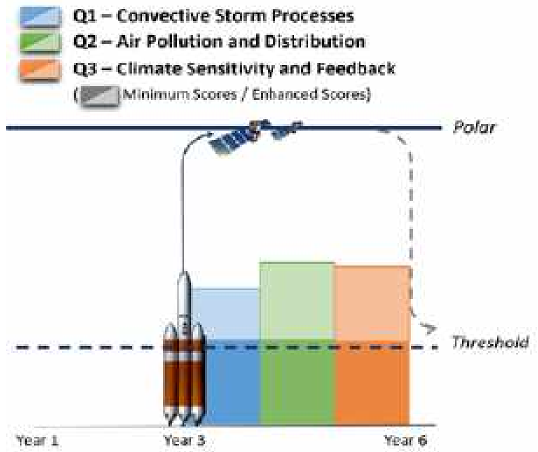
ACCP Aerosols, Clouds, Convection, and Precipitation Study

Science Considerations Across Architectures

ACCP Science Considerations Across Architectures







Overall Architecture Rank Closely Mimics Science Benefit Rank

D1A > P1 ≳ P2

W-4 Convective Storm Processes	W-5 Air Quality Processes and Distribution	C-2 Climate Sensitivity, Cloud Feedback, Aerosol Forcing

The following slides highlight the relative science value of the 3 ACCP Architectures considering the 3 primary DS Questions and other science-related merit

ACCP Science Across Architectures

Convective Storm Processes

Pros: Provides capabilities for measuring vertical motions from shallow to deep convection. Measurements span light to heavy precipitation with GPM-like swath for 3D structure and precipitation mapping. **Cons**: Radiometer footprints are large for convective studies. No information on critical sub-daily varying processes.

Air Pollution and Distribution

Pros: Lidar, polarimeter, radar combination

characterization of aerosol size, concentration. **Cons:** Lack of inclined orbit is detrimental to characterization of sub-daily aerosol processes.

Climate Sensitivity and Feedback

Provides key measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud processes. Radar profiling to near surface and tandem stereo cameras offer significant advances for low clouds and snowfall. ALI and SHOW provide information for the important upper-troposphere/lower-stratosphere (UTLS) region. Lidar UV channel aids the characterization of aerosol absorption.

Convective Storm Processes

Pros: Provides capabilities for measuring vertical motions from shallow to deep convection. Measurements span light to heavy precipitation. **Cons**: Lack of radar swath degrades ability to characterize 3D structure and do precipitation mapping. Radiometer footprints are large for convective studies. No information on critical sub-daily varying processes.

Air Pollution and Distribution

Pros: Lidar, polarimeter, radar combination provides unprecedented

ability to characterize precipitation and its impacts on aerosol wet removal**.** Lack of inclined orbit is detrimental to characterization of sub-daily aerosol processes.

Climate Sensitivity and Feedback

Pros: Provides key measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud processes. Radar profiling to near surface and cameras offer significant advances for low clouds and snowfall. ALI and SHOW provide information for the important upper troposphere/lower stratosphere (UTLS) region. Lidar UV channel aids the characterization of aerosol absorption. **Cons**: Lack of radar swath degrades ability to relate convective properties to high clouds.

Convective Storm Processes

Pros: Measurement of diurnally varying vertical motions for shallow to deep convection, spanning light to heavy precipitation, in inclined orbit. Additional measurements in polar orbit for weak convection/upper levels of strong convection. **Cons**: Best convection capabilities not coincident with best aerosol capabilities. Lack of radar swath degrades ability to characterize 3D structure and do precipitation mapping. Radiometer footprints are large for convective studies.

Air Pollution and Distribution

channel negatively impacts the characterization of aerosol properties. Lack of radar swath degrades ability to characterize precipitation and its impacts on aerosol wet removal**.**

Climate Sensitivity and Feedback

Pros: Provides key measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud process studies. Radar profiling to near surface and cameras offer significant advances for low clouds and snowfall. **Cons**: Lack of radar swath degrades ability to relate convective properties to high clouds. Loss of lidar UV channel degrades characterization of aerosol absorption, and the ability to get consistent climate record for cloud feedback.

Let’s Breakdown the Baseball Card Text into Simple Tables and Highlights

W-4 Convective Storm Processes

Most Relevant Instruments & Features for W-4

Radar13E: Ka-D, W-D
Radar18: Ku-D, W
Radio07
Camera Δt
&
<u>**Inclined Orbit**</u>

Radar13E: Ka-D, W-D
Radar17: Ku-D (<u>**wide swath**</u>)
Radio07
Camera Δt

Radar13E+1: Ku-D, Ka-D, W-D
Radio07
Camera Δt

Attribute	P1	P2	D1A
Shallow-to-Deep	Yes	Yes	Yes
Light to Heavy	Yes	Yes	Yes
Convective Scale Radiometer Footprints	No	No	No
Diurnal Variations (Inclined)	No	No	Yes
Tropics, Tropical Mid-Lat Weather Forcing & S2S Enriched (Inclined)	No	No	Yes
Radar w/ Wide Swath	Yes	No	No

Major distinguishing features

- D1A has <u>**inclined orbit**</u>, enables richer examination of long-standing science challenges: diurnal, S2S, and tropical-extratropical teleconnections
- P1 has a <u>**wide swath**</u> radar, enables richer synoptic context and process examination

W-5 Air Quality Processes and Distribution

Most Relevant Instruments & Features for W-5

Lidar06: HSRL w/ UV
Polar07:
Radar13E: Ka-D, W-D
Radar17: Ku-D (**wide swath**)
Camera Δt
ALI

Lidar05: HSRL
Polar07:
Radar13E: Ka-D, W-D
Radar18: Ku-D, W
Camera Δt
&
Inclined Orbit

Lidar06: HSRL w/ UV
Polar07:
Radar13E+1: Ku-D, Ka-D, W-D
Camera Δt
ALI

Attribute	P1	P2	D1A
Aerosol Size, Type & Concentration Characterization (HSRL+UV)	Excellent w/ Boost from UV	Excellent w/ Boost from UV	Excellent
Aerosol Removal/Redistribution (Lidar+Polar+Radar Config)	Very Good w/ Boost from Wide Swath Radar	Very Good	Very Good
Smoke/Volcano Plume Top Evolution (Camera Δt)	Yes	Yes	Yes
Extreme Smoke/Volcano Events and Relation to Convection (ALI)	Very Good w/ Boost from ALI	Very Good w/ Boost from ALI	Very Good
Subdaily Aerosol Processes (Inclined)	No	No	Yes

Key distinguishing features

- All have **HSRL**, enables unprecedented aerosol characterization, P1 and P2 have added boost from UV channel.
- D1A has **inclined orbit**, enables examination of diurnal aerosol/AQ variations

Other distinguishing features

- P1 and P2 have **ALI limb spectrometer**, provides a boost to extreme plume event examination
- P1 has a **wide swath** radar, provides a boost to aerosol removal/redistribution studies

C-2 Climate Sensitivity, Cloud Feedback, Aerosol Forcing

Most Relevant Instruments & Features for C-2

Lidar06: HSRL w/ UV
Polar07:
Radar13E: Ka-D, W-D
Radar17: Ku-D (**wide swath**)
Camera Δt
ALI

Lidar06: HSRL w/ UV
Polar07:
Radar13E+1: Ku-D, Ka-D, W-D
Camera Δt
ALI

Lidar05: HSRL
Polar07:
Radar13E: Ka-D, W-D
Radar18: Ku-D, W
Camera Δt
&
Inclined Orbit

Attribute	P1	P2	D1A
Low and High Cloud Feedback	Yes	Yes	Yes
Direct & Indirect Aerosol Radiative Effects	Yes	Yes	Yes
Cold Cloud Feedback Processes	Yes	Yes	Yes
Radiation Absorption By Aerosol Boost	Yes w/ Boost from UV lidar	Yes w/ Boost from UV lidar	Yes
Low cloud & Snowfall Boost (Radar profiling to surface and camera Δt)	Yes	Yes	Yes
Upper Troposphere/Lower Stratosphere Climate Feedback Processes (ALI, SHOW)	Yes w/ Boost from ALI, SHOW	Yes w/ Boost from ALI, SHOW	Yes
Relate properties of convection to high cloud feedback	Very Good w/ Boost from Wide Swath Radar	Very Good	Very Good

Distinguishing features

- P1 & P2 have **HSRL with UV channel**, provides boost to examinations of 1) radiation absorption by aerosols and 2) cloud-climate continuity (e.g. w/ Earthcare).
- P1 and P2 have **ALI, SHOW limb spectrometers**, provides boost to upper troposphere/lower stratosphere cloud feedback studies.
- P1 has a wide **swath** radar, provides better sampling for studying connections between convection and high cloud feedback .

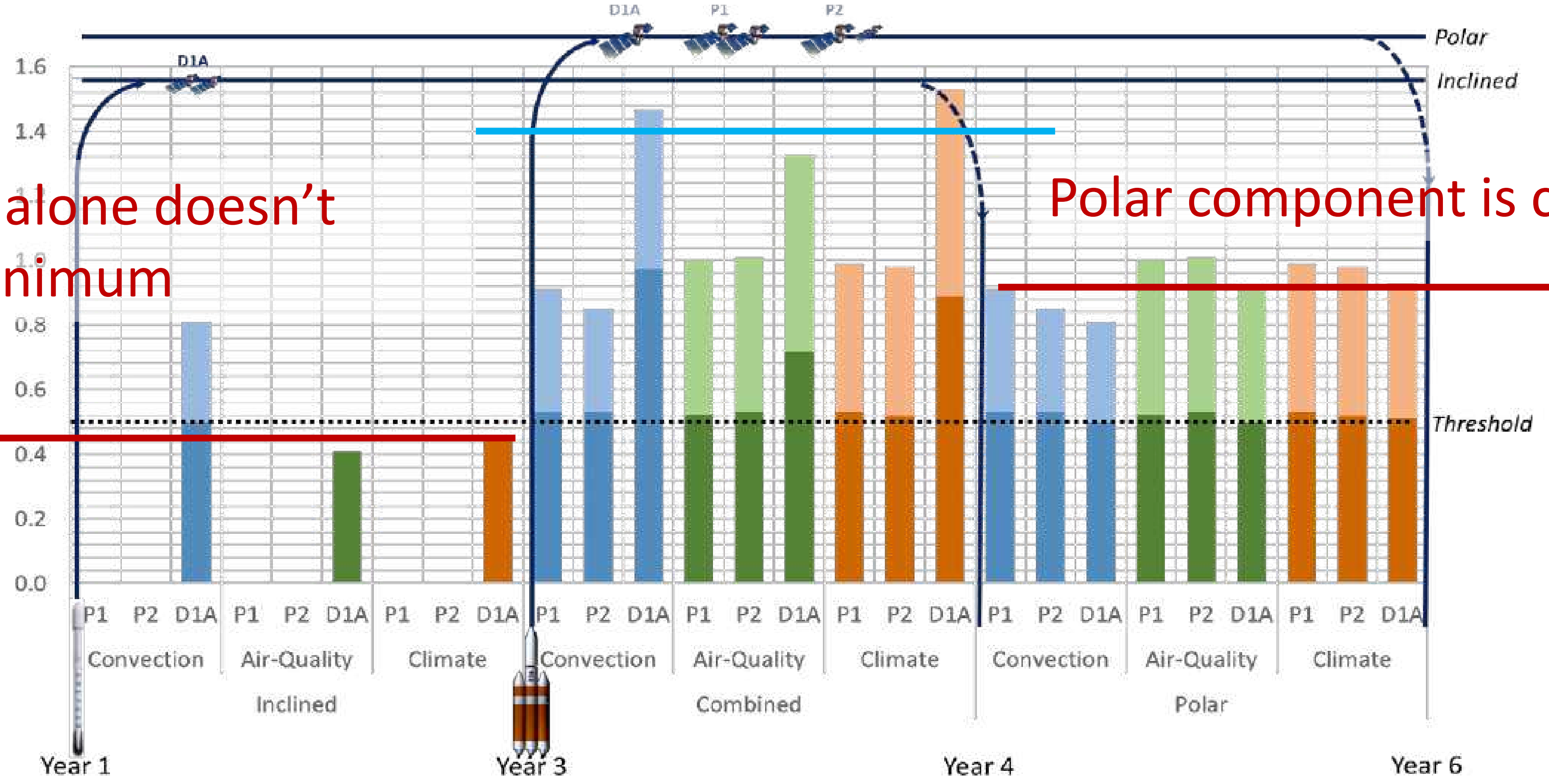
ACCP Science Considerations Across Architectures

Polar core is crucial to meet minimum ACCP Science.

Polar+Inclined - considerable increase for science benefits

Inclined alone doesn't meet minimum

Polar component is crucial



ACCP Science Considerations Across Architectures

Overall Architecture Rank Closely Mimics Science Benefit Rank	D1A > P1 $\gtrsim$ P2

W-4 Convective Storm Processes	W-5 Air Quality Processes and Distribution	C-2 Climate Sensitivity, Cloud Feedback, Aerosol Forcing

Summary Comments

- The polar platform is 'core' and essential to meeting Minimum science.
- Despite a number of science benefits of P1 and P2, the greater ranking of D1A is strongly tied to its early launch and science return, and its inclined orbit, which enables diurnal sampling of ACCP quantities and processes – particularly convection, and it enables an added emphasis on tropical convection and tropical-extratropical connections important to weather and subseasonal to seasonal (S2S) forecasting.

Synergies with other DO Missions

	SBG	MC	SDC
Basic Synergies with ACCP	• Enabled Joint Science Objectives e.g. Energy and Water Fluxes • Joint Retrieval Algorithms e.g. especially SBG spectrometers and ACCP lidar and polarimeters • Joint Validation Assets, Activities and Campaigns • Combined observation constraints on atmosphere and ecosystem models	Notably through ACCP precipitation measurements, including improved high latitude snowfall measurements over the POR.	Mostly anticipated in the intersection of applied science, with ACCP providing valuable information on precipitation/flood, wildfire and volcano plume/intensity information, etc all aiding Hazards theme for SDC.
P1	Basic Synergies	Swath for Radar provides improved precipitation time/space sampling.	Swath for Radar provides improved precipitation time/space sampling.
P2	Basic Synergies	Basic Synergies	Basic Synergies
D1A	Depending on SBG start, an early start for ACCP Inclined Orbit could provide more SBG overlap.	Depending on MC start, an early start for ACCP Inclined Orbit would provide more MC overlap.	Anticipated later start for SDC limits synergy; early prototyping of synergies can be explored with NISAR.

Greatest Synergies

Applications Impact Team (AIT) ACCP HQ Review

Team Members

Dalia Kirschbaum (GSFC), Ali Omar (LaRC)
Emily Berndt (MSFC)

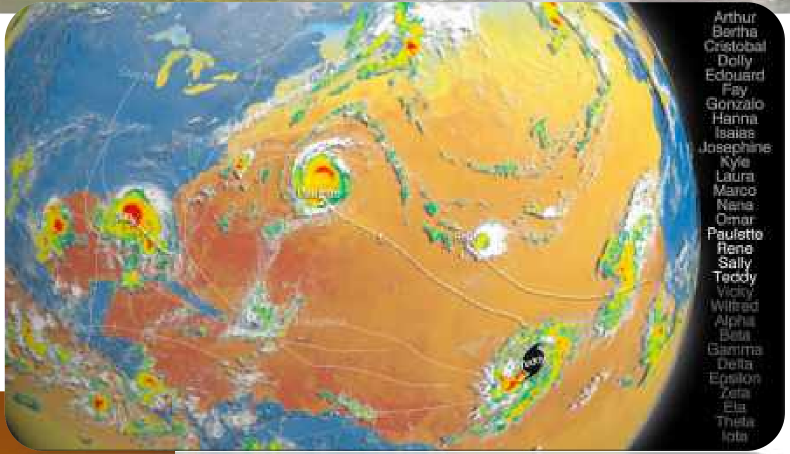
Bryan Duncan (GSFC), Melanie Follette-Cook (GSFC), Amber Soja (LaRC), Svetla Hristova-Veleva (JPL), Aaron Naeger (MSFC), Anita LeRoy (MSFC), Patrick Gatlin (MSFC)

Innovations in Science for Societal Benefit

ACCP explores the fundamental questions of how interconnections between aerosols, clouds and precipitation impact our weather and climate, **addressing real-world challenges to benefit society.**

The ACCP Applications Impact Team (AIT) is charged with **ensuring that applications are considered to the greatest extent possible in mission design.**

22 billion-dollar weather and climate disasters in 2020



38 million people in the Western US were exposed to unhealthy levels of air pollution from wildfires in 2020

Climate change is exacerbating hydrologic extremes and stressing water resources

ACCP Team Expertise

AIT Mission & Program Expertise

Early Adopter & Applied Science Programs

Communities of Practice & Potential

Community Assessment Report (Pre-Phase A Requirement) to **characterize communities of practice and potential** who could benefit from ACCP in the future.

	Agriculture	Food & Beverage	Logistics	Transportation	Energy	Health
	Precision Agriculture Agriculture Institutes	Vertically integrated food companies Companies operating in tropical climates	Major carriers Logistics arms of major brands	Commercial airlines Aircraft engine manufacturers	Alternative energy companies	Medical device companies Companies with pollution restrictions Exposure and Hazards Groups
A	✓	✓		✓	✓	✓
CCP	✓	✓	✓	✓	✓	✓

ACCP Community & Stakeholder Feedback

- Over 110 workshop attendees and surveys solicited
- Over 60 independent interviews
- Engagement with National/International agencies and the private sector

ACCP Stakeholder Workshops

- Weather and Air Quality Modeling (7/2019)
- Transportation and Logistics (11/2020)
- Air Quality (3/2021)

Science Conference Engagements

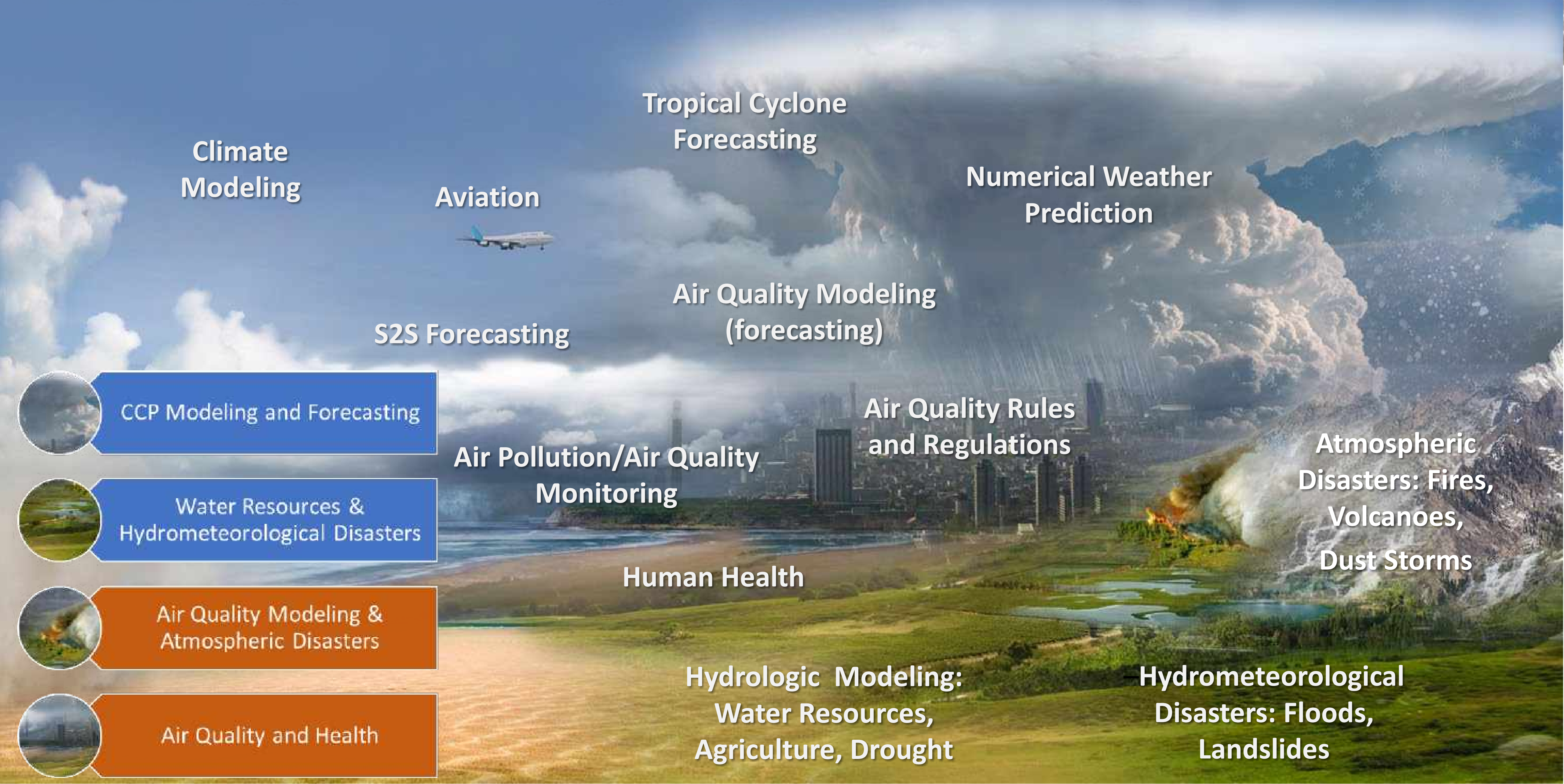
AGU, AMS, Community Forums, HAQAST Workshops, GPM Science Team, International Association of Wildland Fire, CALIPSO Science Team

Interviews with Communities of Practice and Potential

Surveys and Trainings

- Weather and AQ modeling community
- ARSET GPM training

ACCP Applications: High Impact Enabled Application Areas



Community Characterization of Attributes

Attributes for prioritizing architectures

Instrument characteristics
- Channels/Bands/Products
- Swath width
- Spatial resolution

Architecture characteristics
- Geographic coverage, frequency of overpass, time of day
- Preferred orbit
- Delta-t

Measurement characteristics
- Latency
- Continuity
- Novelty

Assign Scores (1-5) for each Application

Included in scoring

- Instrument capabilities
- Architecture characteristics
- Continuity and novelty
- Potential L2/L3/L4 product
- Synergies/gaps with the program of record

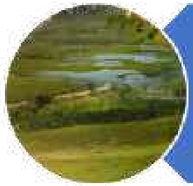
Not considered at this time

- Latency
- Data accessibility/formats
- Specific GV's linked to architectures with defined accuracy
- Cost
- Programmatic risk

Assigning Applications Benefit Scores

Average Scores by Thematic Areas

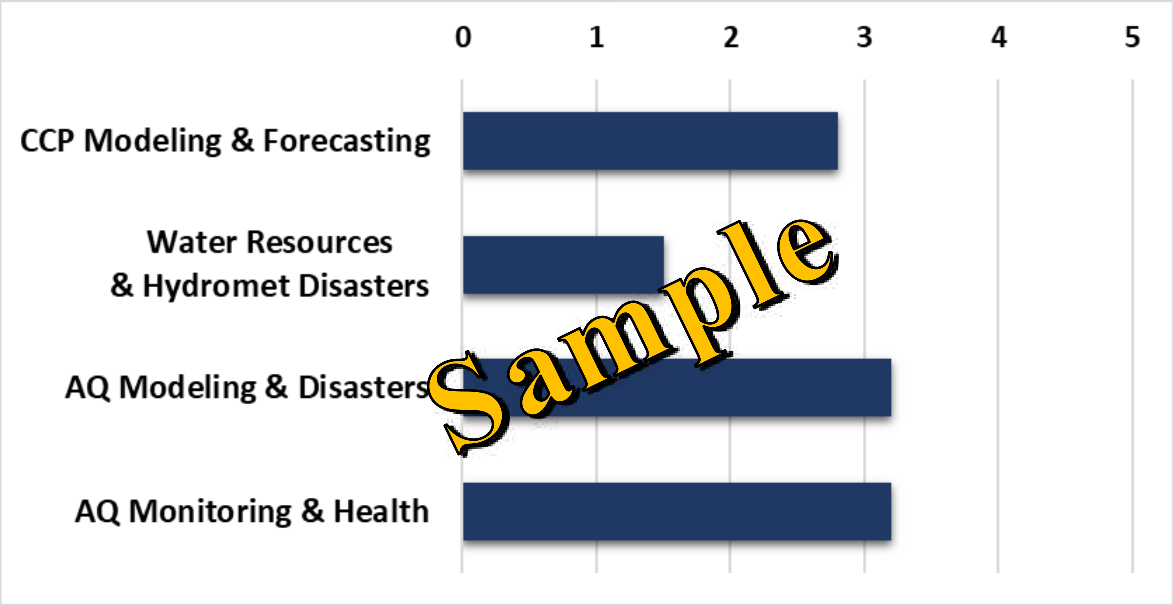

CCP Modeling and Forecasting


Water Resources & Hydrometeorological Disasters


Air Quality Modeling & Atmospheric Disasters


Air Quality and Health

Summary Charts and Narratives



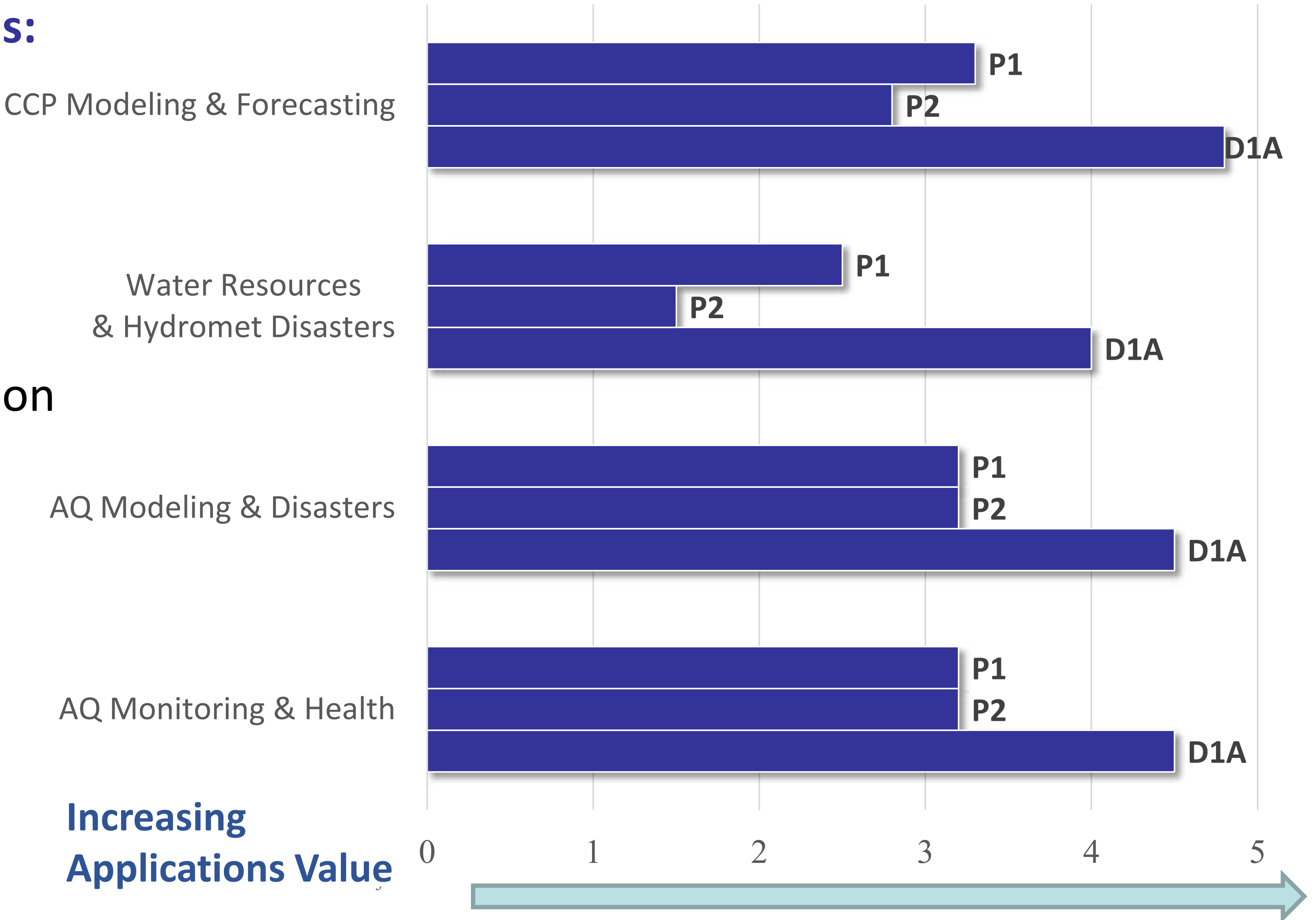
ACCP Architecture Comparisons

Factors that enhance applications:

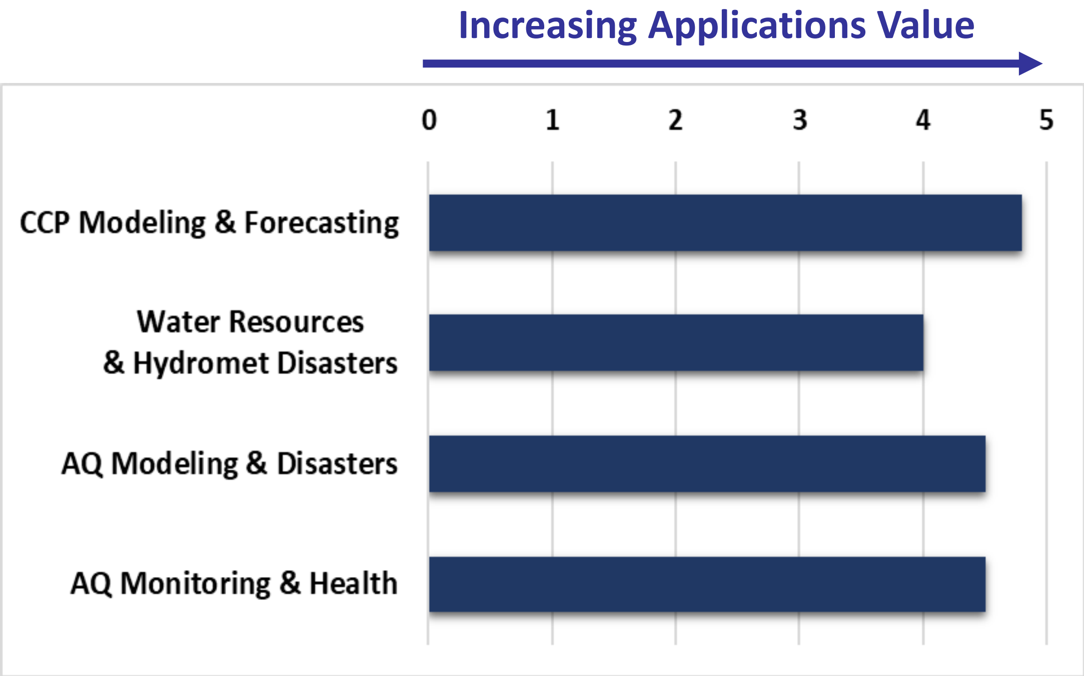
- Diurnal sampling
  - Precipitation
  - Aerosols
- Advanced precipitation and convection observations
- Aerosol type and size information

Opportunities to further enable applications:

- Low Latency
- Low frequency radiometer channels
- UV Lidar Channel



Architecture D1A – Ranked 1st



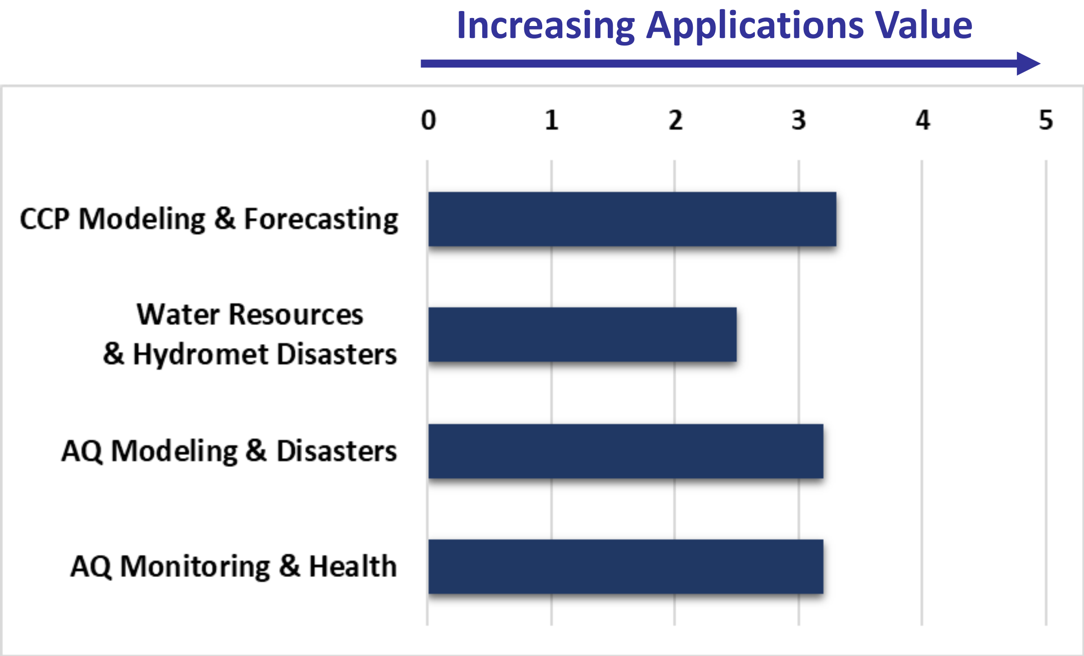
Factors that Enhance Applications	Benefits	Opportunities to Further Enable Applications	Benefits
Combined Lidar/Polarimeter	Polar & inclined orbit supports AQ modeling & monitoring centers' need for increased sampling and diurnal aerosol observations	**Adding a UV wavelength**	Enables estimates of PM1 and PM2.5, and more accurate aerosol types (e.g., dust, smoke)
Radar/Radiometer observations	Allows for cross-calibration with the POR to derive L3/L4 products	**Lower frequency radiometer channels**	Improves characterization of precipitation extremes over land
Ku/W-band Doppler Radar	Captures diurnal precipi tation and convection to improve modeling	**Wider swath radar**	Better supports weather and climate modeling applications

Radiometer data assimilation advances NWP skill for high impact weather event

L3/L4 precipitation informs crop yield modeling and water resource allocation

Diurnal observations of wildfire smoke improves air quality modeling

Architecture P1 – Ranked 2nd



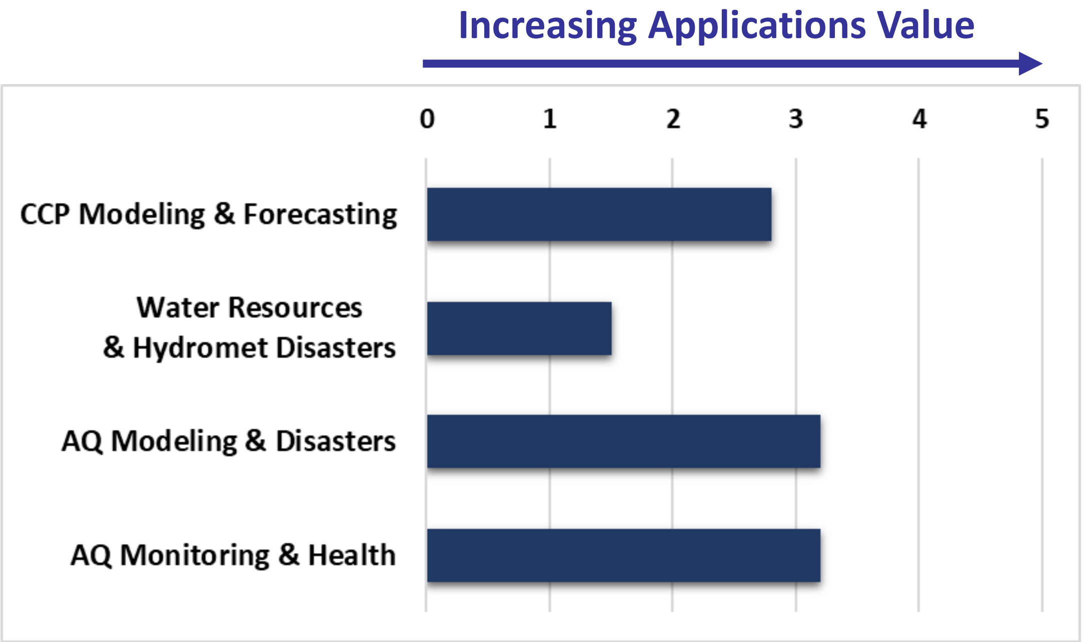
Factors that Enhance Applications	Benefits	Opportunities to Further Enable Applications	Benefits
Lidar retrievals of particle micro-physical properties and types	Supports health studies & air quality models. Enables estimates of space-based PM1 & PM2.5 and more accurate aerosol subtypes	**Inclined orbit for sampling & diurnal changes**	Resolves daily evolution of convection, aerosol distributions and precipitation for high impact weather events
Wide swath radar	Supports L3/L4 products for hydrologic applications and CCP model improvement	**Inclined radiometer**	Cross-calibration with POR important for L3/L4 gridded products
Ku radar observations of deltaT	Leads to improvement in NWP, S2S and climate models	**High resolution and lower freq-uency radiometer**	Improves gridded precipitation products

Observations of volcanic plumes support aviation safety and navigation decisions

Discerning aerosol types informs air quality monitoring and health studies for identifying hazardous levels of PM

Vertical profiles of precipitation enable situational awareness of tropical cyclones

Architecture P2 – Ranked 3rd



Factors that Enhance Applications	Benefits	Opportunities to Further Enable Applications	Benefits
Lidar retrievals of particle micro-physical properties and types	Supports health studies & air quality models. Enables estimates of space-based PM1 & PM2.5 and more accurate aerosol subtypes	**Inclined orbit for sampling & diurnal changes**	Resolves daily evolution of convection, aerosol distributions and precipitation for high impact weather events
Stereo cameras	Helps identify smoke and volcanic plume heights, critical for accurate monitoring and forecasting	**Inclined radiometer**	Provides cross-calibration with POR important for L3/L4 gridded products
3-frequency Ku/Ka/W Doppler radar	Enhances CCP model development with vertical velocity and hydrometeor details	**Wider swath radar**	Improves weather and climate modeling by resolving precipitation extremes over land

Vertical information on precipitation and clouds support climate model development and verification.

ECMWF

Resolving vertical extent of critical aerosol types will advance air quality smoke forecasts

Better knowledge of global vertical distributions of aerosols helps health professionals assess the global impact of air pollution.

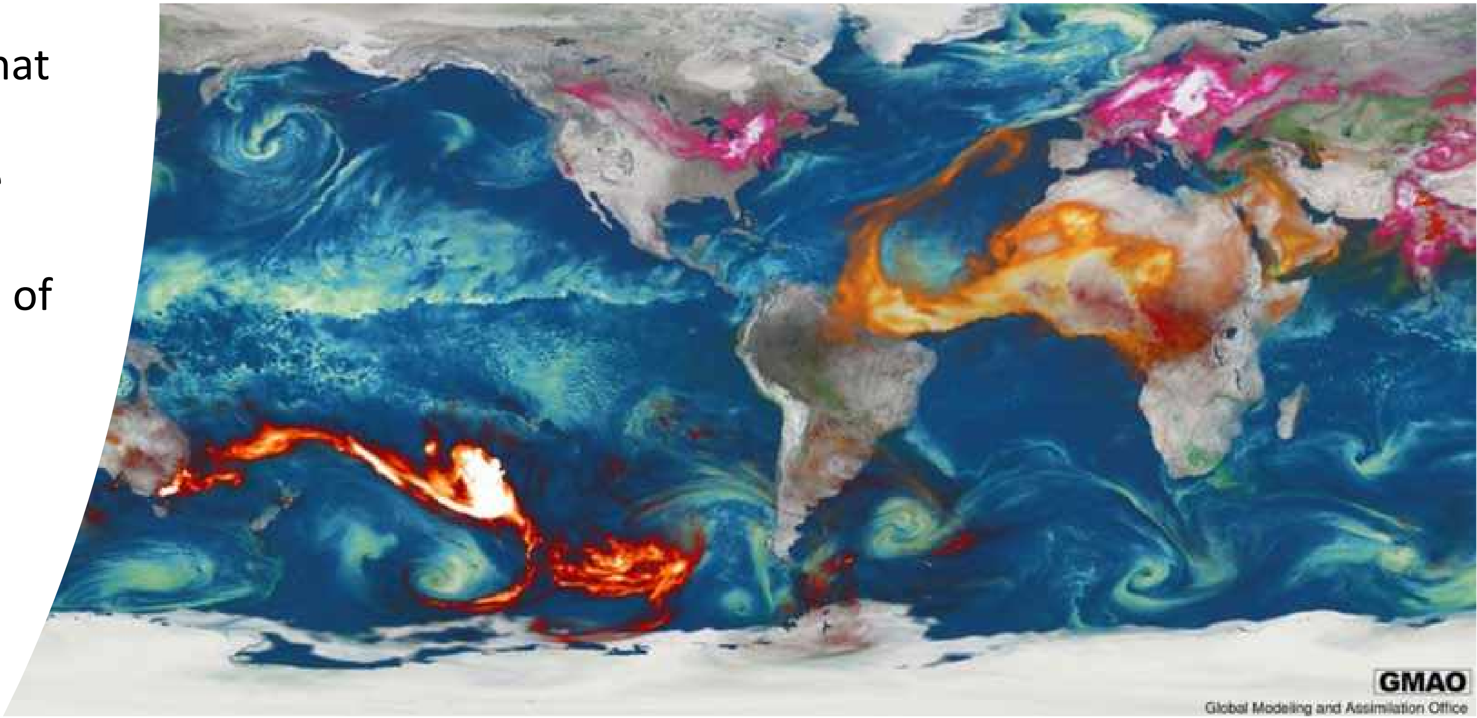
Benefits of Latency

	Weather Forecasting	Disaster Modeling/Monitoring	Health & Air Quality
Long-term Decisions	**> 6 hour Latency** • Applied research studies • Improve algorithms • Model verification	**> 6 hour Latency** • Disaster relief & preparedness • Community planning • Developing models and studying past events	**> 6 hour Latency** • Exceptional event demonstrations and aerosol transport • Health studies/trends
Short-term Decisions	**3-6 hour Latency** • Operational hurricane forecasting • Operational weather forecasting • Operational model data assimilation	**3-6 hour Latency** • Volcanic disasters/warnings for aviation • Smoke/dust and air quality warnings for human health	**3-6 hour Latency** • Air quality model data assimilation • Air quality forecasting • Smoke modeling
Time-critical Decisions	**1 hour Latency** • Weather nowcasting/warnings • Fire weather/smoke forecasts • Dust storm warnings • Ingest in rapid update models	**1 hour Latency** • Disaster warning, evacuation, response, mobilization • Short-term flooding/landslide risk assessment	**1 hour Latency** • Air quality forecasting • Public health warnings (plume or catastrophic releases) • Chemical weather forecasting

Innovations in Science for Societal Benefit

ACCP will enable decision making that impacts people around the world, from short-term crises to long-term plans. It will advance:

- **Weather Forecasting** by observing vertical air motions in storms along with atmospheric parameters to improve our understanding of severe storm events
- **Climate Modeling** by providing measurements that reveal the inner workings of aerosol, cloud and precipitation processes resulting in more reliable climate predictions
- **Air Quality** through more precise measurements of aerosols in the horizontal and vertical to better forecast impacts on human health
- **Disaster monitoring** by rapidly conveying observations and predictions of volcanic plumes, wildfire smoke, and extreme precipitation

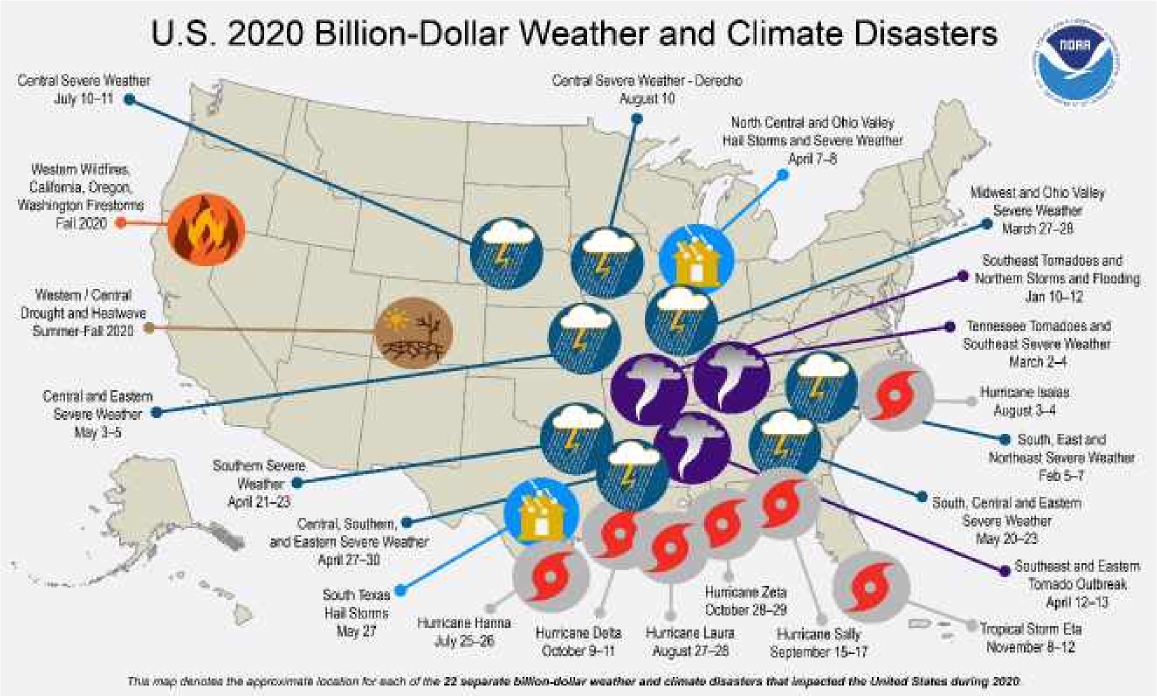


Agenda

Section	Time	Time Allocation	Topic	Presenter
	11:00	5	Introductory Remarks	
1	11:05	5	Study Overview	V. Moran
2	11:10	25	High Level ACCP Science & Applications	S. Van den Heever; S. Braun
3	11:35	10	ACCP Radiation Measurement	G. Stephens
4	11:45	5	Decision Process/Value Framework Overview	M. Ivanco
5	11:50	5	Science Scoring Process Overview	A. DaSilva
6	11:55	5	Candidate Architectures Identification & Groupings	J. Piepmeier
7	12:00	15	SIT-A: Quality Simulations, Scoring Methodology, & Lessons Learned	J. Redemann
8	12:15	15	SIT-CCP: Quality Simulations, Scoring Methodology, & Lessons Learned	J. Mace
9	12:30	15	How Science Benefit Scoring of Architecture Elements Informed	S. Braun
	12:45	10	Break	
			Top 3 Architectures	
10	12:55	20	a. Description of Science & Synergy with other DO/Tos	D. Waliser
11	1:15	15	b. Enabled Applications	D. Kirschbaum/A. Omar
12	1:30	20	c. Instrumentation and Technology Readiness Assessment	S. Bidwell
13	1:50	20	d. Programmatics	V. Moran
14	2:10	10	Sub-Orbital Vision & Status	W. Petersen
15	2:20	5	Comparison of 3 Architectures and Recommendation of One	C. Trepte
	2:25	5	Remarks from Center Partner Management Board	Irons/Friedl/Dyal
16	2:30	5	Community Assessment	S. Van den Heever
			Next Steps—	
17	2:35	20	Plan for Pre-Phase A	V. Moran
	2:55	5	Closing Remarks	D. Vane
	3:00	4.0		

Extra Slides

Innovations in Science for Societal Benefit: Severe Storms



January 8th, 2021, *www.climate.gov*

2020 had 22 separate billion-dollar weather and climate disasters across the United States, shattering the previous annual record of 16 events and causing **$95 billion** in damages.

2017 Decadal Survey Questions

W-4 (MI): Convective Storm Formation Processes.
Why do convective storms, heavy precipitation, and clouds occur exactly when and where they do?

ACCP will accelerate public benefits of science:

By providing the first ever global view of convection and precipitation motion in severe storms, enabling operational weather communities to better understand the timing, intensity and severity of storms that lead to improved forecasting skill over high-risk areas.

D1A Advantages

Diurnal sampling of convection and extreme precipitation for NWP and tropical cyclone monitoring and modeling

Innovations in Science for Societal Benefit: Air Quality

San Francisco Skyline on Sept 9th, 2020

AP Photo/ Eric Riseberg

Wildfires have accounted for up to 25% of $PM_{2.5}$ in recent years across the United States and up to 50% in the Western U.S. (Burke et al. 2021, PNAS). **200,000 Americans die every year from air pollution related illnesses** and in 2020, an estimated 38 million people in the Western U.S. were exposed to unhealthy levels of wildfire smoke for at least five days.

2017 Decadal Survey Questions

W-5 (MI): Air Pollution Processes and Distribution. What processes determine the spatio-temporal structure of important air pollutants and their concomitant adverse impact on human health, agriculture, and ecosystems?

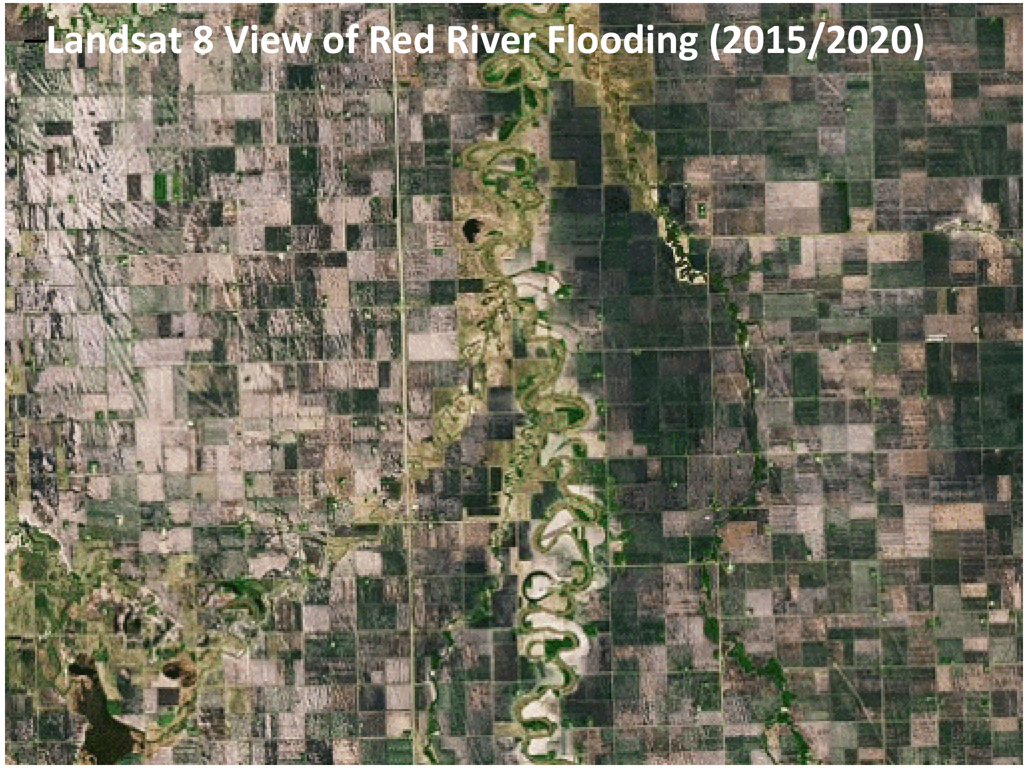
ACCP will accelerate public benefits of science

Through enhanced observations of aerosol types and sizes, ACCP will provide unprecedented data to more accurately model population exposure to both total and speciated PM around the globe, which can provide insight into how to most effectively reduce the human health risk of particulate air pollution.

D1A Advantages

Frequent sampling of aerosols emissions from inclined and polar orbits will improve air quality monitoring and resolution of aerosol transport in high-risk areas.

Innovations in Science for Societal Benefit: Climate Modeling



Hydrologic extremes of drought and flooding stress water resources and damage communities in the Red River basin in the south-central U.S. with an expected increase in the frequency of extreme events (droughts and floods) by the end of the century (Bertrand et al. 2018, JAMC)

2017 Decadal Survey Questions

C-2 (I-MI): Climate Feedback and Sensitivity. How can we reduce the uncertainty in the amount of future warming of Earth, improve our ability to predict local and regional climate response to natural and anthropogenic forcings, and reduce the uncertainty in global climate sensitivity?

ACCP will accelerate public benefits of science

Novel estimates of vertical motion, aerosols, and microphysical properties of precipitation and clouds will support seasonal to seasonal (S2S) and climate modeling, leading to improvements in model parameterization and verification to better assess hydrometeorological extremes within vulnerable communities.

D1A Advantages

Diurnal sampling of precipitation, clouds and convection will advance climate modeling through model verification and parameterizations.

Informing Architectures: Polar

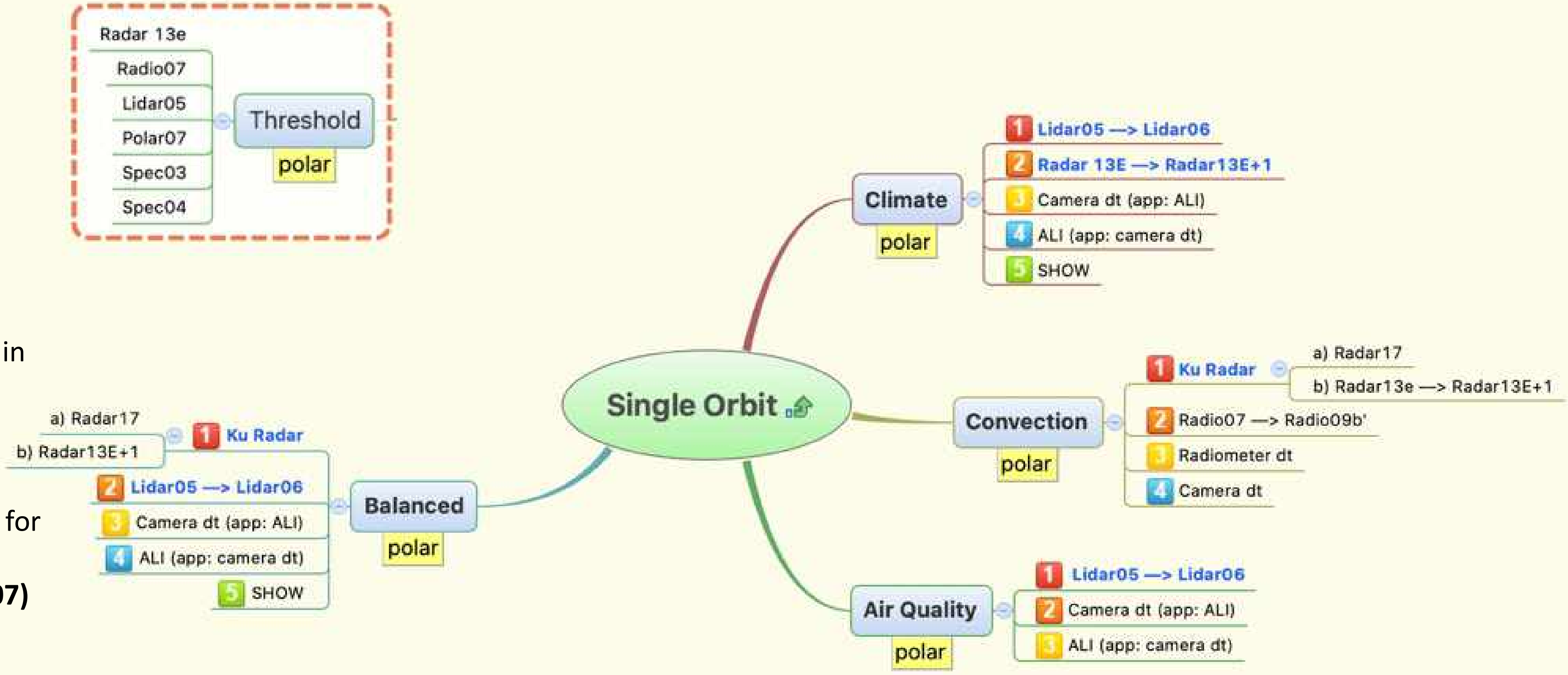
Priorities for Polar

CCP

- **Wide Swath Ku radar –** severe storms
- **Capable radiometer –** TC forecasting, NWP, S2S, Hydro/Disasters community
- **Nadir-pointing Ku-Radar** - Model parameterization and verification in modeling

Aerosols

- **Lidar06** – Microphysical retrievals for AQ monitoring
- **High resolution Polarimeter (Pol07)** Spatially extend AQ assessment
- **Camera dt -** High-altitude plumes
- **Spec04** – AOD, SSA, absorption for AQ modeling
- **ALI** – Detecting high-altitude smoke and volcanic plumes



–**Applications priorities indicated by "app"

Informing Architectures: Inclined

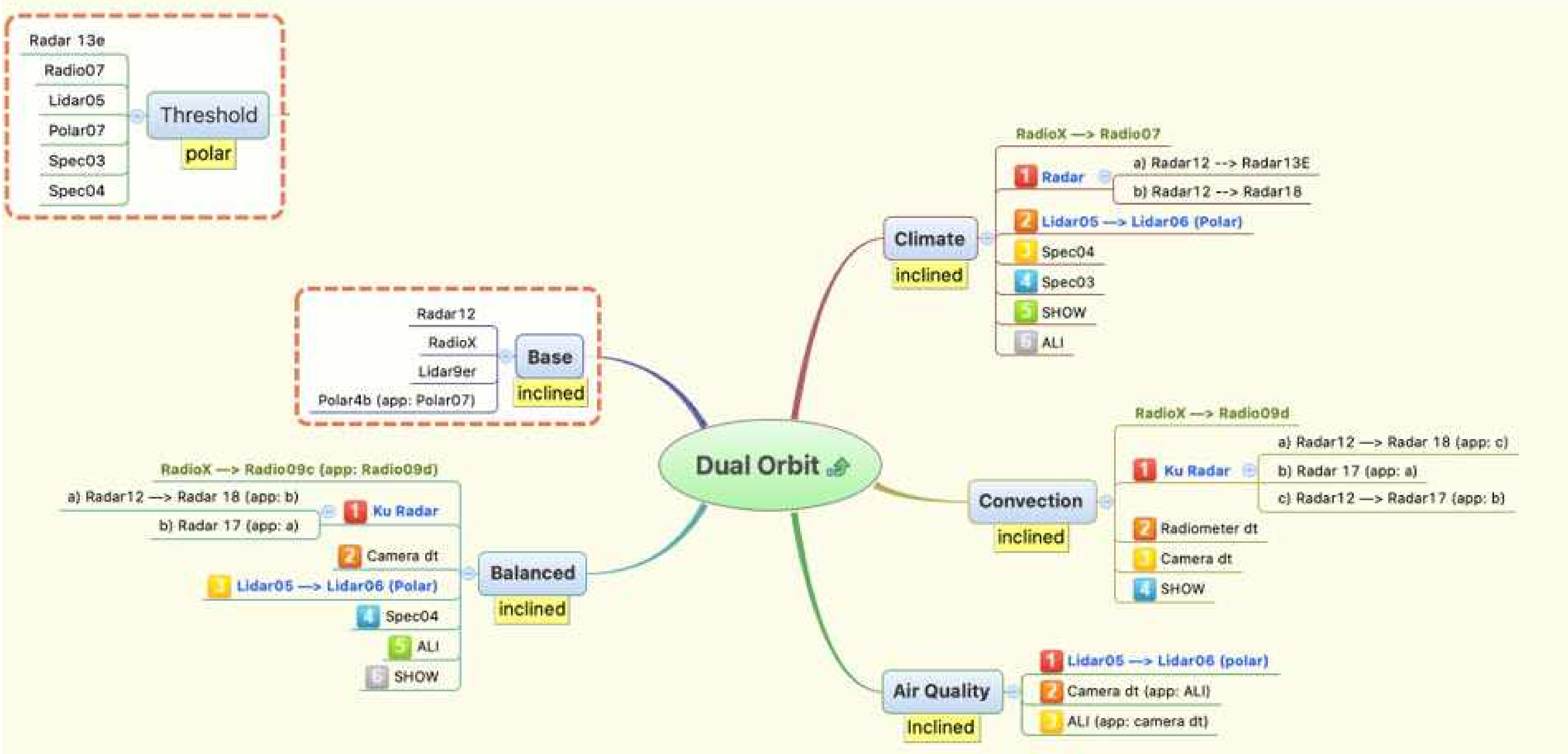
Priorities for Inclined

CCP

- **Radiometer (89 GHz, High res):** TC forecasting, NWP, S2S, Hydro/Disasters community (L3/L4)
- **Ku Radar** (Radar 18) – Climate modeling, NWP, S2S communities
- **Radar and radiometer dt** – Model verification in climate, S2S, NWP

Aerosols

- **ALI** – High-altitude plumes and aiding calibration for extinction and typing
- **Camera dt** - Plume top heights
- **Spec04** - Cloud information/clearing, multi-wavelength AOD, SSA, absorption



**Applications priorities indicated by "app"

Sub-Orbital Working Group Vision and Status

Walt Petersen[1], Jay Mace[2], Felix Seidel[3], Jens Redemann[4]

[1]NASA Marshall Space Flight Center; [2]University of Utah; [3]NASA Jet Propulsion Laboratory/Cal Tech.; [4]University of Oklahoma

And the SOWG Committee

Jennifer Comstock, Andrew Dessler, Silke Gross, Andrew Heymsfield, Jose Jimenez, Pedro Campuzano Jost, Ralph Kahn, Pierre Kirstetter Mark Kulie, Zen Mariani, James Mather, Allison McComiskey, Greg McFarquhar, Richard Moore, Joe Munchak, Steve Nesbitt, Sebastian Schmidt, Martin Wirth, Mengistu Wolde, Rob Wood

Framework

Goal: Provide **Sub-Orbital observations (surface-airborne)** as an integral element of the ACCP observing system

Why Sub-Orbital: Aspects of ACCP science will be **challenging, if not impossible to fully achieve from orbit alone (**e.g., in situ, spatial/time access and resolution, process evolution, accuracy); **Cal/Val** of products; **Select targeting of science- early, and in synergy with phasing of orbital components.**

Objectives: **Maximize ACCP's total science return** (science / cost)

- **Sub-Orbital framework** in-sync with ACCP orbital architecture and SATM
  - Set of sub-orbital **science foci**
  - **In situ data** needed for satellite retrievals
  - **Calibration / Validation** needs and approach(es)
  - Opportunities/partnerships to **bridge** gaps wrt POR and/or launch schedule

Identifying Science Foci

<u>Community Workshop March 2020</u>

Science targets including:

a. High level strategies
b. Data useful to algorithms
c. Cal/val synergies

Community enthusiasm produces copious science input for all SATM objectives

Small set of prioritized science modules

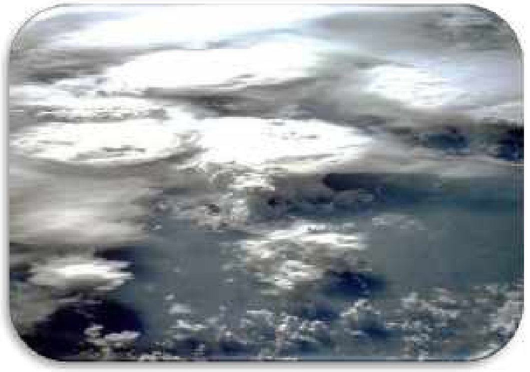
Science Themes and Modules

- Three science themes with *__highly__ synergistic process* modules and a *Systematic aerosol sampling* module
- *Space-time resolved and in situ measurements*, airborne and/or surface-based platform accessible

Low Cloud/ACI

- Precipitation initiation in shallow Cumulus
- Open/Close cell transitions in marine stratocumulus
- Ice precipitation process in cold marine PBL clouds

Convection and High Cloud



- Convective core processes and environment controls
- Convective detrainment
- Anvil cirrus lifecycle

Aerosol ACI/API

- Vertically-resolved aerosol effects on cloud formation
- Impact of convection on aerosol redistribution and removal
- Influence of PBL on aerosol attribution and vertical redistribution

\+

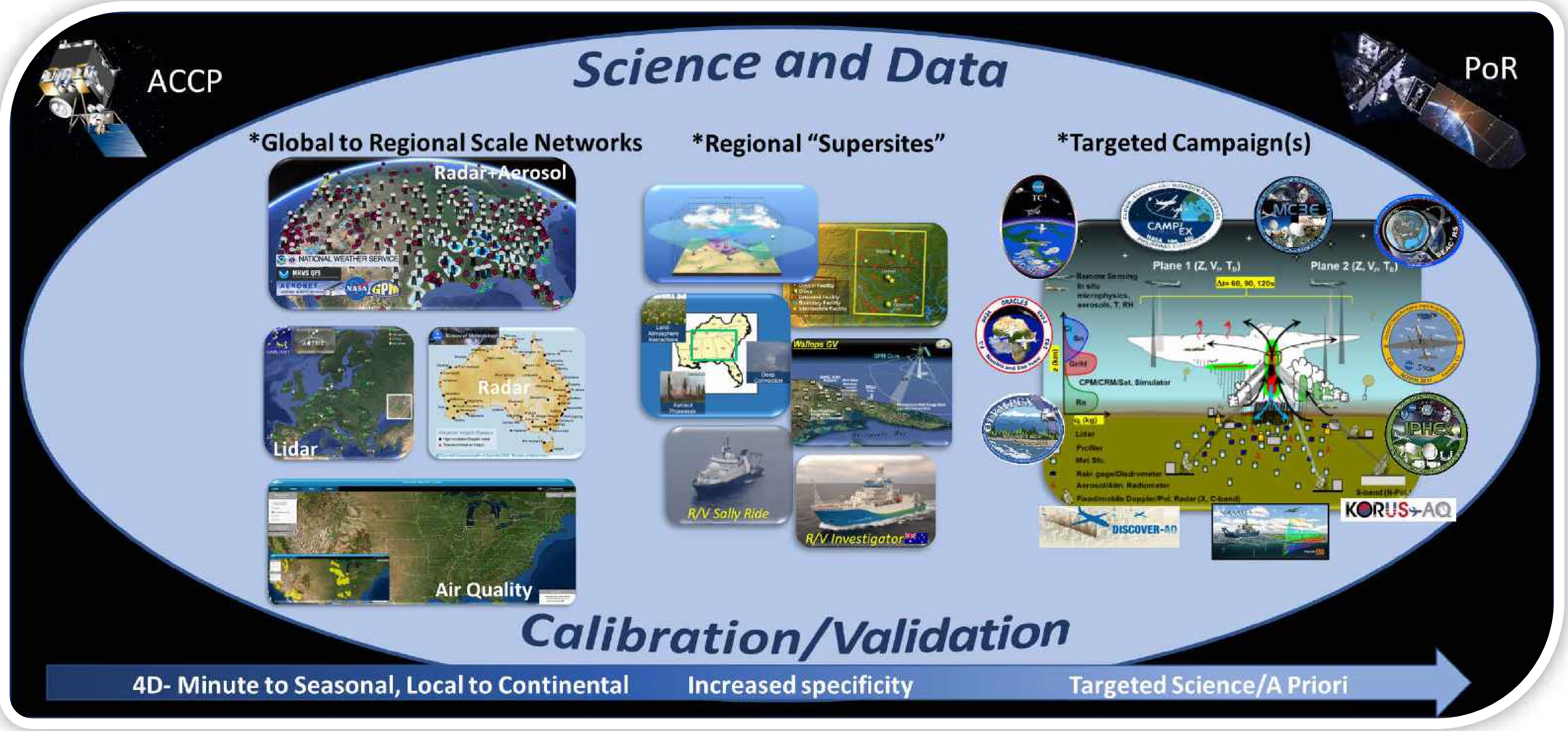
Systematic Aerosol

- In situ aerosol profile
- Intensive properties
- Speciation
- Radiative properties

Workshop 2

- Prior Field Data
- Long Term Ground Based in situ and Remote Sensing
- Multi or focused single Aircraft Campaign
- Systematic Aircraft Measurement
- Ship-Based Remote Sensing
- Non-traditional (UAS, Balloon…)

Draft Implementation "Vision"



Summary

- **Sub Orbital is integral to ACCP science** - traceable to SATM focusing on augmenting and supplementing

- Diversity of ACCP science: **a spectrum of implementation strategies** from ground-based to multi-aircraft.
  - Emphasis is on strong intra agency, inter agency, and international partnerships

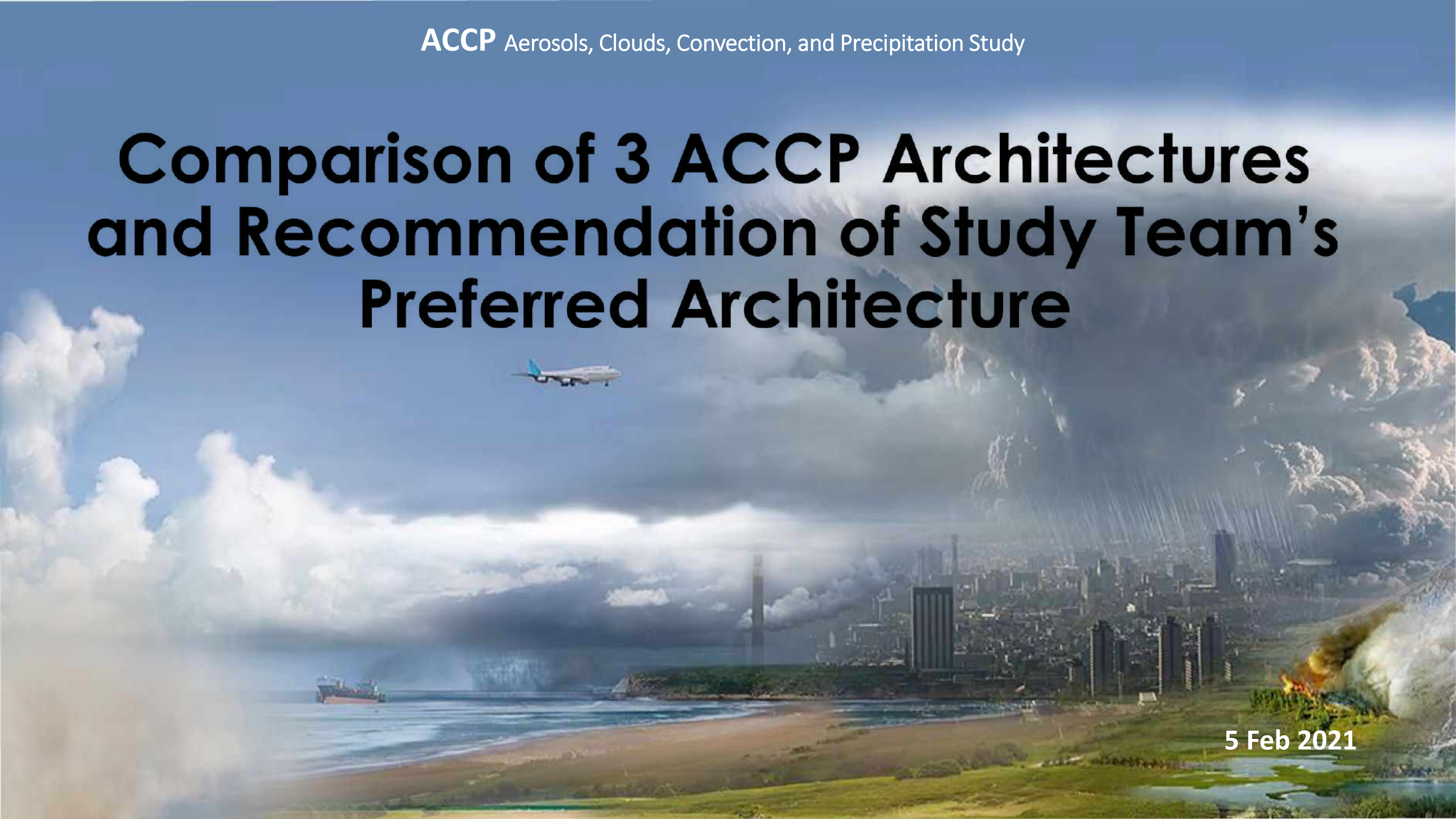
- **Science and Implementation strategies modularized** so that ACCP SubOrbital can
  1. Respond quickly
  2. Develop long-term planning for implementation in Phase A

Moving Forward

#	ACCP Suborbital Tasks	Who	End Date
1	Complete ACCP Sub-Orbital framework based on Workshop 1	SOWG	July 2020
2	Define ACCP Sub-Orbital science foci to achieve most optimal ACCP observing system	SOWG Chairs	Nov. 2020
3	**Refine ACCP Sub-Orbital science foci with SOWG**	SOWG	Jan. 2021
4	Consult with ACCP Leadership/Stakeholder groups (SMT/SALT/SCC/Modeling WG etc.)	SOWG	On going
5	**Draft ACCP Sub-Orbital/Cal-Val implementation & preparation for workshop #2**	SOWG	March 2021
6	Hold workshop #2 to further develop/refine implementation with community	SOWG & Community	Mar 29-Apr 16, 2021
7	Coalesce workshop inputs, refine, and map implementation approaches to science modules and cal/val; Draft implementation plan	SOWG	August 2021
8	Debrief and iterate with Leadership/Stakeholders; Apply adjustments	SOWG Chairs	Sept/Oct 2021
9	Complete Sub-orbital implementation framework/plan	SOWG Chairs	November 2021
10	Initiate implementation phases/components and logistics	Team	NET Phase A

ACCP Aerosols, Clouds, Convection, and Precipitation Study

Comparison of 3 ACCP Architectures and Recommendation of Study Team's Preferred Architecture



5 Feb 2021

Science Value Benefit Comparison

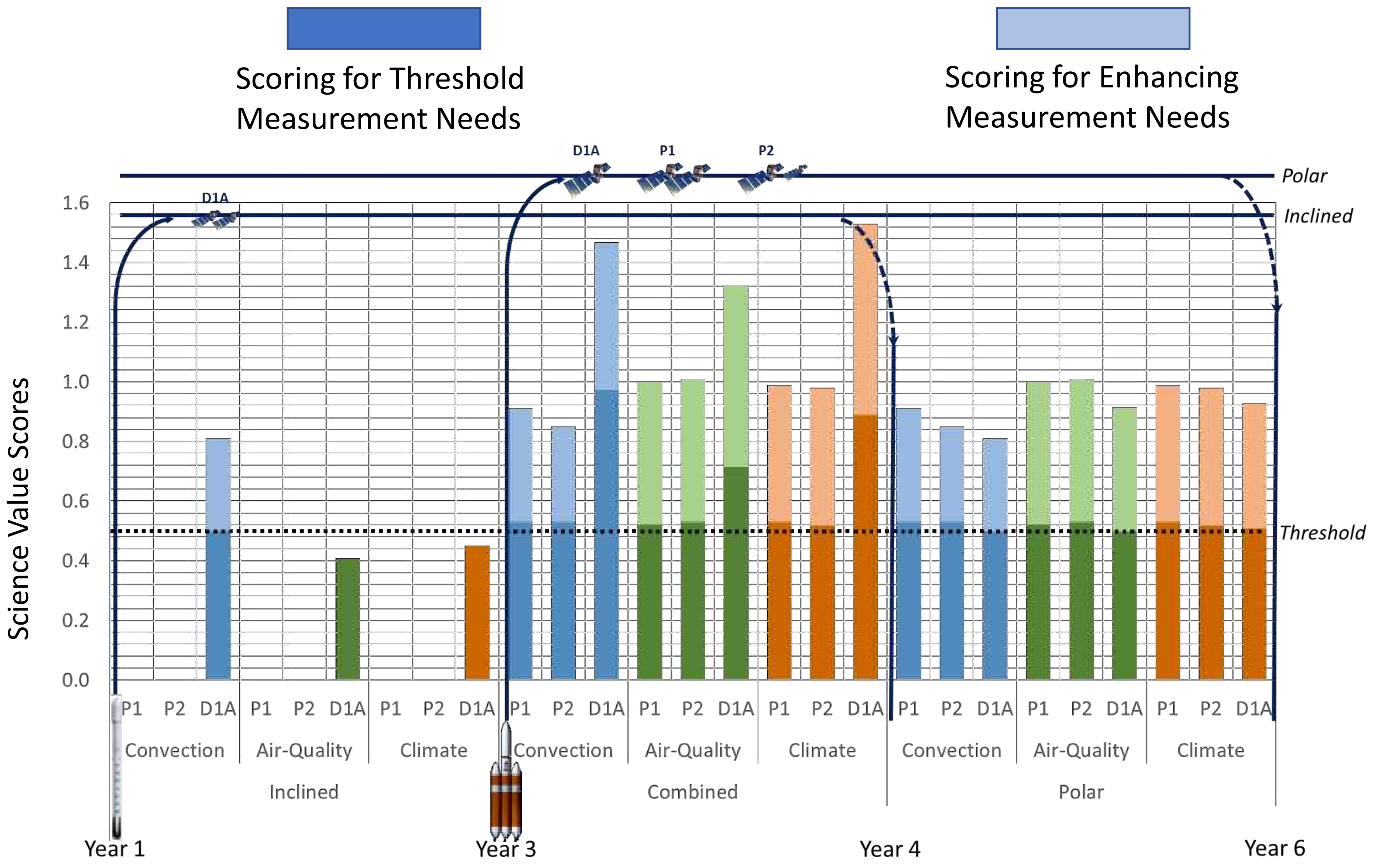
P1, P2, and D1A will make substantive advancements towards ACCP science goals

P1 & P2 offer the most capable instrument suites

D1A offers most balanced approached

- Early Science Opportunity (CY 27/28)
- Adds diurnal sampling
- Superior value with combined platforms; however, inclined segment by itself fails to satisfy threshold science

D1A ranks highest for Science Value



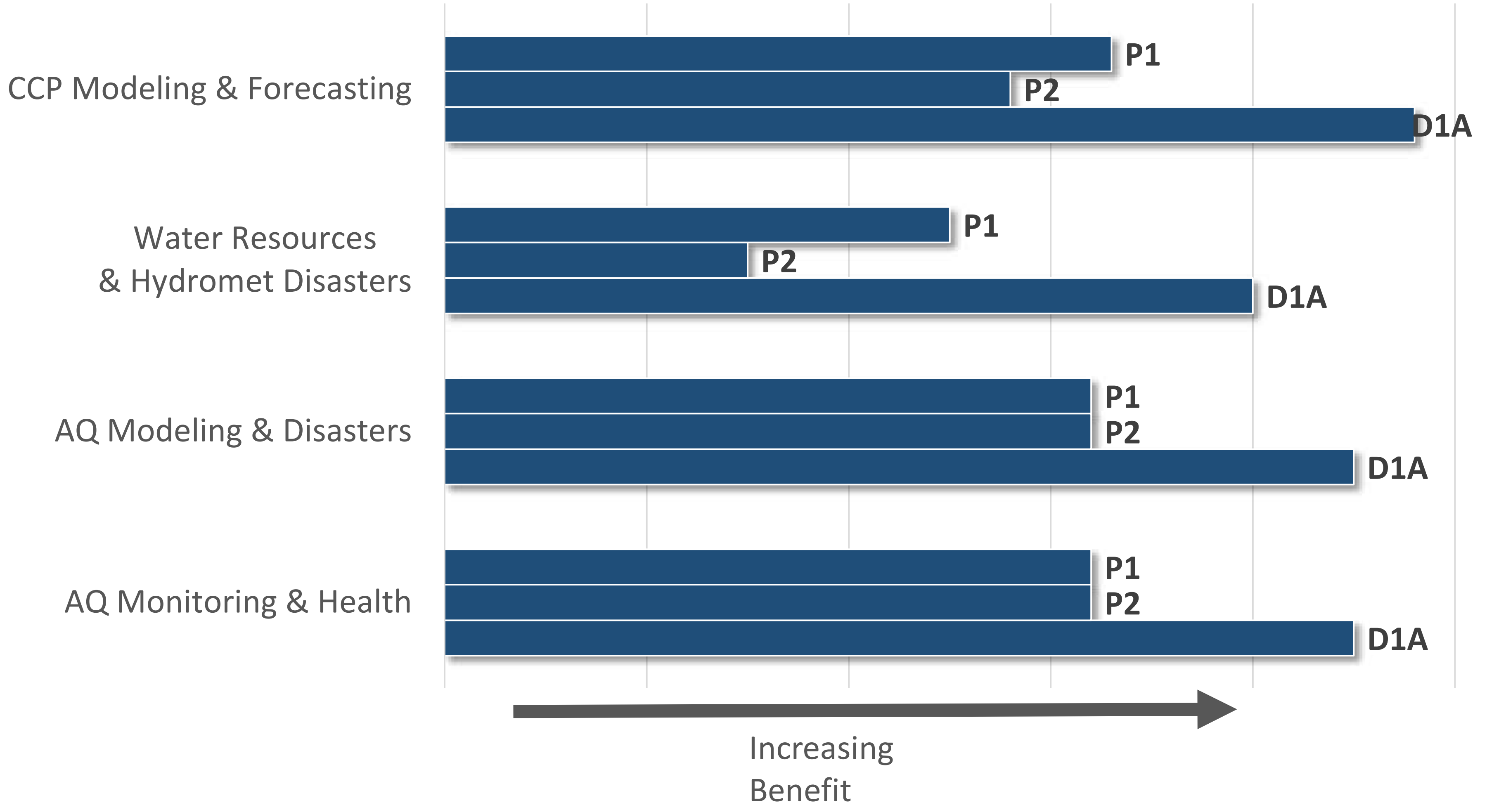
ACCP Applications Value Benefit Comparison

All architectures provide measurements that greatly enhance the PoR

P1 provides more benefit than P2 for weather/hydrology focus areas

P1 and P2 provide the same value for Health and Air Quality needs

D1A ranks highest because the diurnal sampling adds considerable value to A and CCP applications: (D1A > P1 > P2)



D1A realizes highest scoring with diurnal sampling

Programmatic Factors Comparison

D1A Ranks Highest with each Programmatic Factor

	P1	P2	D1A
Continuity of Observations	2nd	2nd	1st
Innovative Mission Implementation	2nd	2nd	1st
Transformative Science	2nd	3rd	1st
Flight Project Schedule Risk (1=Least Risk)	3rd	2nd	1st
Number of International Partners	3	2	1
Cross-benefit with Other Disciplines	Hydrology Oceans	Hydrology Oceans	Hydrology Oceans
Possible Launch Timeframe	2031	2031	1st 2027/28 2nd 2028/29

ACCP Preferred Recommendation

Based on the rankings of science, applications and programmatic factors, **D1A is identified as the preferred architecture for ACCP**

Consensus opinion with SALT, SIT and AIT

- > 90% of U.S. responders favor D1A
- Opinion drops slightly to 80% when international participants are included

The Study Management Team agrees with this recommendation

- Conversations with CNES, CSA, and JAXA will continue to explore contributions that might be feasible within cost cap

Community Assessment of the Architectures

Greg Carmichael and Sue van den Heever

SCC Co-Chairs

SCC Assessment of the Proposed Architectures

Science Community Committee

- **Independent committee**
- Comprised of university faculty and non-NASA lab scientists
- Mid-career experts in aerosols, convection, clouds and precipitation
- Represent the broader science community and end users of the data
- **First and foremost interested in the science that can be achieved using ACCP data**

SCC Co-Chairs			
Greg Carmichael	Univ. of Iowa	Sue van den Heever	Colorado State Univ.
US SCC Members			
Ana Barros	Duke Univ.	Andy Dessler	Texas A&M
Graham Feingold	NOAA CSL	Mike Fromm	NRL
Andrew Gettelman	NCAR	Colette Heald	MIT
Steve Klein	LLNL	Mark Kulie	NOAA/NESDIS/STAR
Tristan L'Ecuyer	Univ. Wisconsin	Ruby Leung	PNNL
Yang Liu	Emory Univ.	Johnny Luo	CCNY
Allison McComiskey	BNL	James Nelson	NOAA/NWS/NCEP
Steve Nesbitt	Univ. Illinois	Jeff Reid	NRL
Lynn Russell	Scripps	Courtney Schumacher	Texas A&M
Armin Sorooshian	Univ. Arizona	Rob Wood	Univ. Washington

SCC Contributions to the ACCP Study Framework

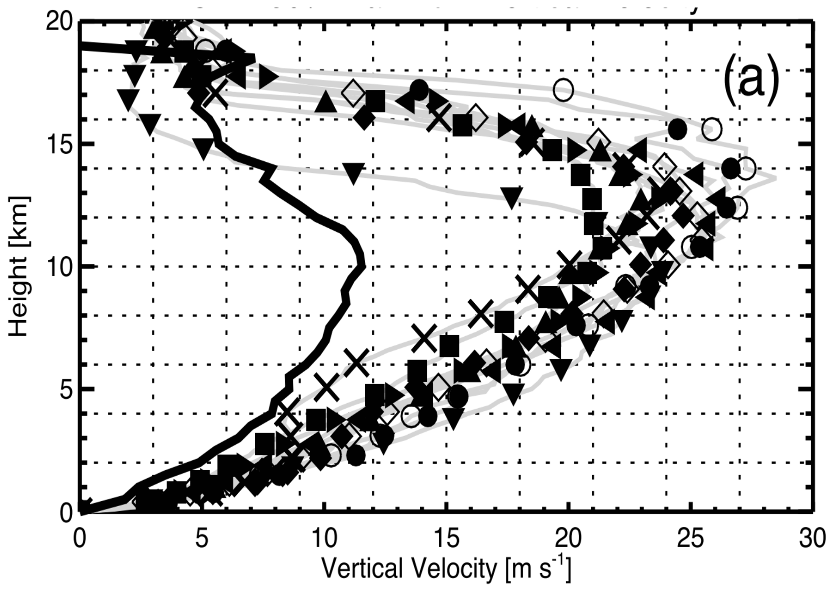
- **Assist and Assess**
- Involved from the start
- Actively evaluated and provided feedback on:
  - Science objectives and overarching statements
  - Proposed instruments and architectures
  - Proposed methodology and approaches
  - Narrative
- Actively involved
  - Modeling workshop(s)
  - Suborbital working group

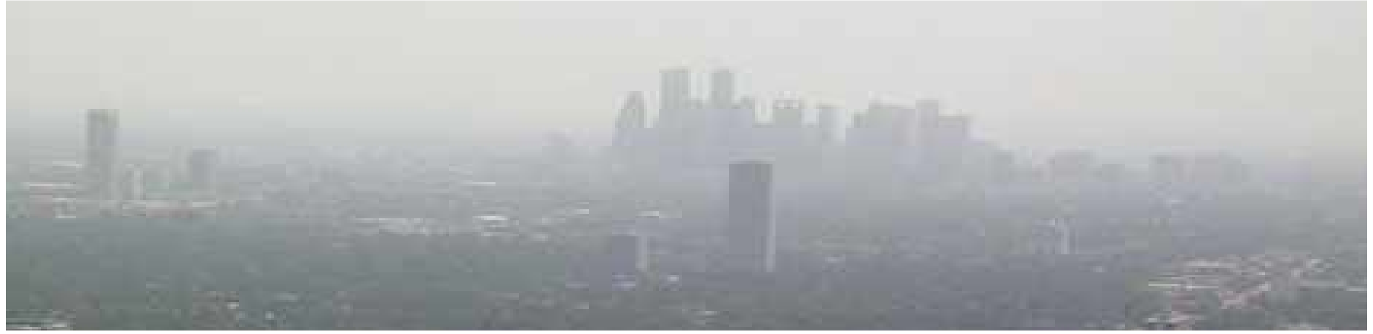
The 5 First-Evers of ACCP

1. Global Observations of Vertical Motion
2. Global Profiles of Aerosol Properties
3. Co-Located Dynamics, Microphysics and Aerosol Characteristics
4. Evolution of Cloud and Aerosol Processes
5. Diurnal Cycle of Clouds and Aerosols

The 5 First-Evers of ACCP

1. **Global Observations of Vertical Motion**
   - ACCP: first global measurements of the vertical motions through multi-frequency Doppler radars
2. **Global Profiles of Aerosol Properties**
   - ACCP: vertical profiles of aerosol properties throughout the depth of the troposphere through hyper spectral resolution lidar
   - Simultaneous measurements of aerosol and precipitation processes by locating lidar and radars on the same platform.

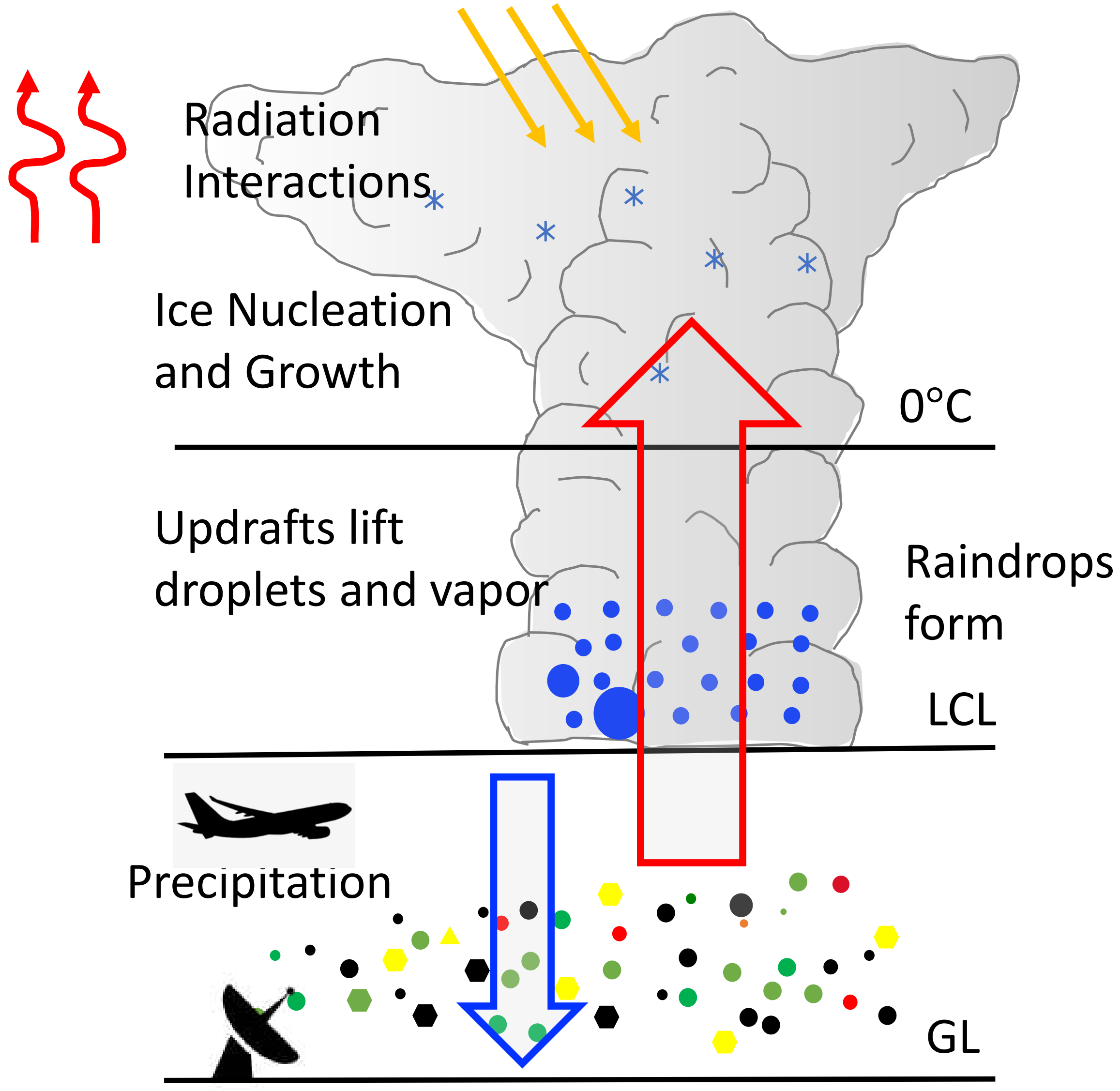




The 5 First-Evers of ACCP

3. Co-Located Dynamics, Microphysics and Aerosol Characteristics

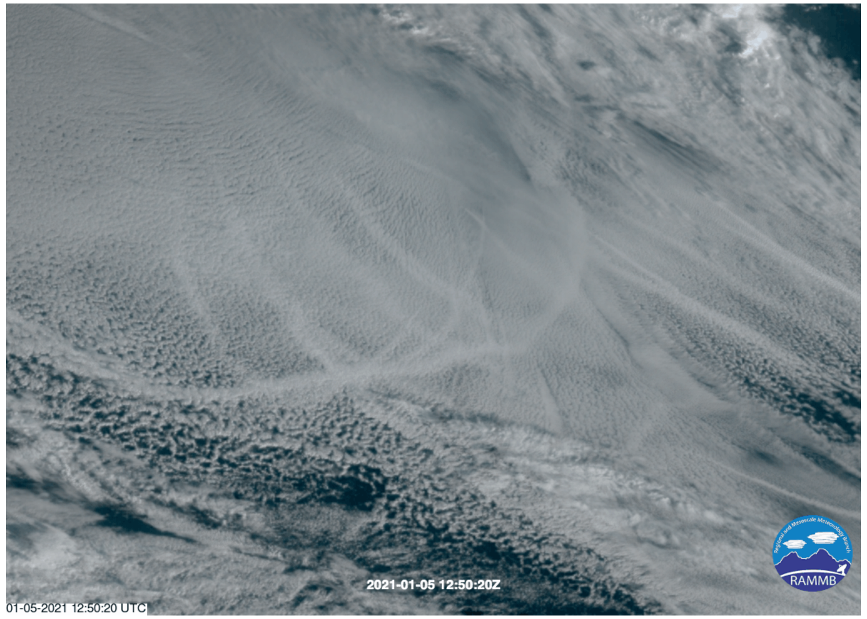
- **ACCP: first co-located simultaneous measurements of aerosol, cloud, vertical motion, precipitation and radiation processes through the use of radars, lidars, radiometers, polarimeters and spectrometers on the SAME PLATFORM.**
- **The Suborbital component is critical in obtaining complementary BL and below cloud observations.**



The 5 First-Evers of ACCP

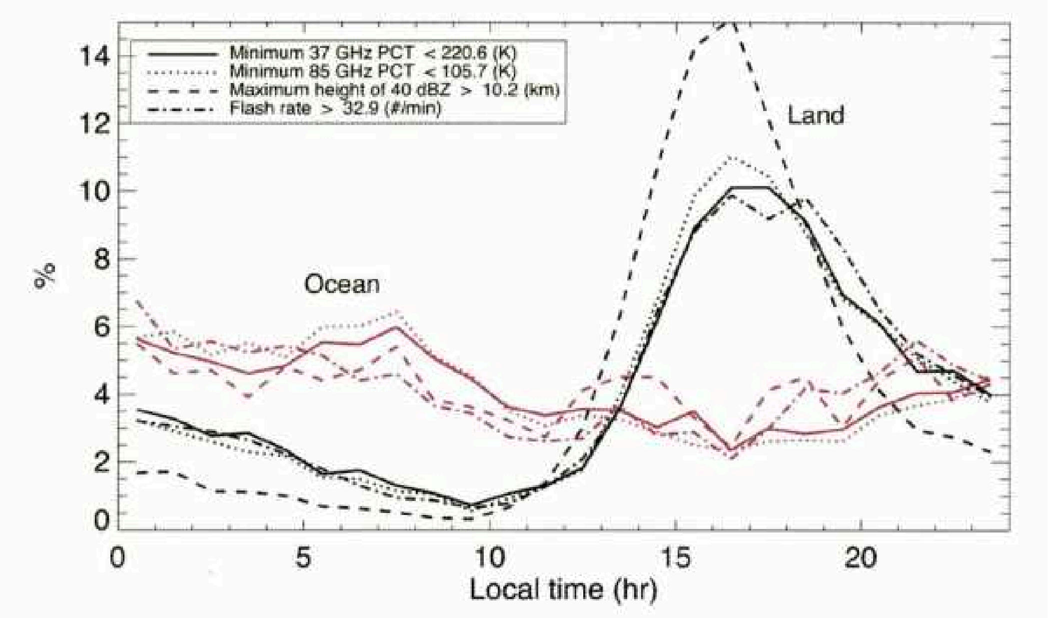
4. Evolution of Cloud and Aerosol Processes

- **The delta-t cameras are truly novel → important advances in our understanding of the vertical motions of shallow BL clouds, as well as plume heights.**



5. Diurnal Cycle

- **A-CCP: simultaneous co-located sampling of vertical motions, clouds, aerosols and radiation through the use of the Doppler radars, lidars, radiometers and polarimeters on the INCLINED orbit.**



SCC Assessment of the Architectures

- 2 (~10%) of the SCC identified P1 as their top priority

- 2 (~10%) of the SCC identified P2 as their top priority

- **15 (~80%) of the SCC identified D1A as their top priority**

- Independent SCC poll
- The findings of the SCC are in strong support the SALT, SIT and SMT recommendations
- The majority of the SCC believe that D1A will be successful in delivering the 5 FIRST-EVERS

A-CCP's novel, transformative measurements will significantly enhance our understanding of the earth's weather and climate system and will also allow us to better predict aerosol, cloud, convection and precipitation processes on weather through S2S through climate scales.

Instrumentation Highlights

Radar13E
W-Band Doppler, Nadir; Ka-Band Doppler, 15km Swath

Radar17
Ku-Band Doppler, 255km Swath

Radio07
118, 183, 240, 310, 380, 660, 880 GHz, 750km Swath

Lidar06
355nm & 532nm HSRL, 1064nm Backscatter

Polar07
Multi-angle, UV-SWIR, 550km Swath, 0.5km FOV

Spec03
LWIR, FIR, 400km Swath

Spec04
UV, VIS, NIR, SWIR, 200km Swath

Camera
Tandem Stereo Camera Visible Imaging

ALI
Aerosol Limb Sounder

SHOW
Water Vapor Limb Sounder

Polar = Polarimeter Radio = Radiometer Spec = Spectrometer

Science Narrative

Convective Storm Processes

Pros: Transformative capabilities for measuring vertical motions in shallow to deep convection. Measurements span light to heavy precipitation with 3 coincident frequencies, GPM-like swath for 3D structure and precipitation feature context. **Cons:** Radiometer footprints are large for convective studies. Lack of inclined orbit is detrimental to characterization of sub-daily convective processes.

Air Pollution and Distribution

Pros: Lidar, polarimeter, radar combination provides unprecedented particulate characterization and information on aerosol removal/redistribution in light to heavy precipitation. Tandem stereo cameras add information on plume top evolution, while ALI provides information on extreme volcanic/smoke events and their relation to vertical transport by convection. Lidar UV channel enables better characterization of aerosol type, size, absorption, concentration. **Cons:** Lack of inclined orbit is detrimental to characterization of sub-daily aerosol processes.

Climate Sensitivity and Feedback

Provides broad diversity of measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud processes. Radar profiling to near surface offer significant advances for low clouds and snowfall; tandem stereo cameras advance low cloud science. ALI and SHOW provide information for the important upper-troposphere/lower-stratosphere (UTLS) region. Lidar UV channel aids the characterization of aerosol absorption and discrimination of anthropogenic aerosols.

Applications Narrative

Factors that Enhance Applications

The 3-wavelength lidar will provide estimates of aerosol size (e.g., PM1, PM2.5) and type (e.g., dust, smoke). Health studies and AQ models would benefit from accurate measurements of extinction profiles, leading to improved aerosol sizes/types.

The wide swath radar is important for gridded precipitation to support Water Resources applications and NWP improvements to CCP Modeling & Forecasting.

Stereo cameras will provide information on smoke and volcanic plume heights, which are critical for accurate monitoring and forecasting.

Opportunities to Further Enable Applications

The addition of an inclined orbit would provide more sampling to:

- **Capture diurnal aerosol observations** that will improve the reliability of AQ monitoring & forecasting.
- **Resolve diurnal convective cycle** that will greatly expand the benefit to support Water Resources, Weather, and Climate applications.
- **Enable radiometer cross-calibration with the POR** to benefit Water Resources and CCP applications.

Higher spatial resolution (5-10 km) and lower frequency radiometer channels (89 GHz) would enhance gridded precipitation to support Water Resources applications and precipitation characterization for CCP applications.

Programmatic Narrative

Pros:

- **This architecture maximizes the extent to which international contributions are utilized and is truly a multi-national collaboration with proven and trusted partners.**
- The CSA instrument's smaller Size, Weight and Power are less costly to accommdate. The Aerosol Limb Sounder (ALI) and Water Vapor Sensor (SHOW) are de-scopable providing enhancing capability if there are development issues. The Spectrometer (Spec03) is not de-scopable, however, it is not high risk and saves the US cost by providing minimum capability it would otherwise bear full cost for.

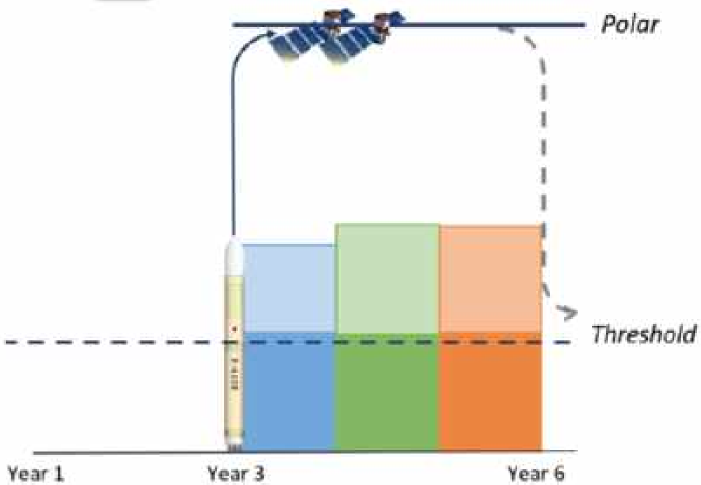
Cons:

- Lidar 06 (CNES): Accommodating the UV capability within the already complex US High Spectral Resolution Lidar (HSRL) adds cost and risk to the delivery of the most expensive and complex ACCP instrument for significantly enhancing capability. The UV capability is moderately de-scopable should issues arise.
- Radar 17 (JAXA): Accommodating the very large JAXA radar (~400kg/600W) which provides Ku Band Dopper with Wide Swath, even with a contributed LV, drives the SSP-2 Spacecraft to be large and expensive.
- **Lidar 06 and Radar 17 drive a single launch/single orbit plane to stay within the cost target increasing program complexity, decreasing flexibility and deferring ACCP Science until the full system can be developed and launched together (2031 dependent upon funding profile).**
- **There is some likelihood that de-scope option(s) may need to be executed in Pre-Phase A / Phase A to stay within cost target.**

Architecture P1

Science Benefit

- Q1 – Convective Storm Processes
- Q2 – Air Pollution and Distribution
- Q3 – Climate Sensitivity and Feedback
- (Baseline Science/ Enhanced Science)



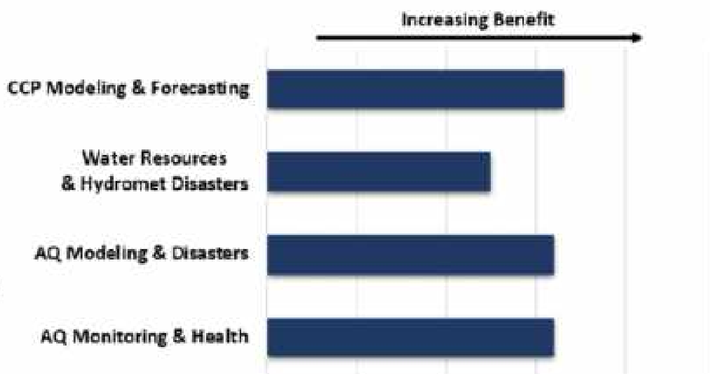
Applications Benefit

CCP Modeling & Forecasting: S2S, NWP, Climate, Tropical Cyclone Forecasts

Water Resources & Hydromet Disasters: Agriculture, Hydro-modeling, Extreme Events/Disasters, Insurance, Transportation

AQ & Disasters: AQ Modeling, Fires, Volcanoes, Dust Storms

AQ & Health: Rules and Regulation, Health/Insurance, Air Pollution



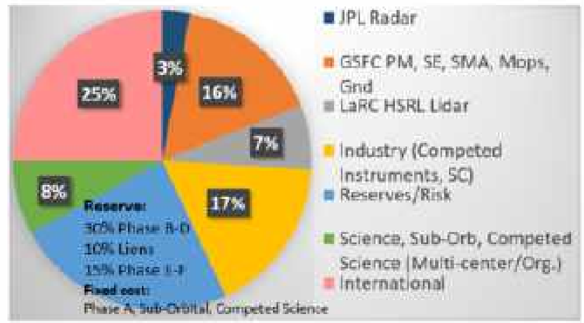
Programmatic Factors

Programmatic Factors	Rank
Continuity of Observations	2nd
Innovative Mission Implementation	2nd
Transformative Science	2nd
Flexibility with Funding Profiles	3rd
Flight Project Schedule Risk	3rd

Number of International Partners: 3

Cross-benefit with Other Disciplines: Oceans

Distribution of Work



WBS Element

WBS Element		Cost ($M)
Phase A	$	39.1
Phase B-D		
1.0 Project Management	$	77.6
2.0 Systems Engineering	$	44.5
3.0 Safety & Mission Assurance	$	51.7
4.0 Science & Technology	$	103.5
5.0 Payloads	$	749.1
6.0 Spacecraft	$	285.4
7.0/9.0 Mission Operations/Ground Systems	$	82.5
8.0 Launch Vehicle / Services	$	-
10.0 Systems Integration & Testing	$	51.7
Phase E-F	$	81.0
Sub-Orbital	$	29.3
Competed Science	$	48.9
30% Reserve Phase B-D/15% Phase E	$	446.8
Encumbered Risk	$	100.3
Total (minus contributions)	**$**	**1,598**

Note: All costs in FY18 dollars, reported at ~50% confidence level

Risk

Liens/Encumbrances FY18 ($100.3M)

Lidar06	$37.9	Radio07	$3.7	SHOW	$1.7
Radar17	$26.1	Polar04b/07	$3.2		
Spec03	$13.8	Spec04	$4.7		
Radar13E	$7.3	ALI	$1.8		

Top 10 Risks/Threats

Risk #	Type	Risk Title	Likelihood	Consequence	LxC
Lidar06	P	Risk of Growth (Mass, Power, Footprint)	4	5	20
Radar13E	P	Risk of Remaining Technology Dev.	4	5	20
Lidar06	T	UV Transmitter On-Orbit Degradation	3	5	15
Arch-1	T	Risk of Single Launch	2	5	10
Radar13E	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Lidar06	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8
Camera	P	Risk of Science Algorithm Dev.	4	2	8
ALI/SHOW	P	Risk of Science Algorithm Dev.	4	2	8

P–Programmatic w/Cost Consequence (2–2-5%; 3–5-7%; 4–7-10%; 5–>10%); T–Technical

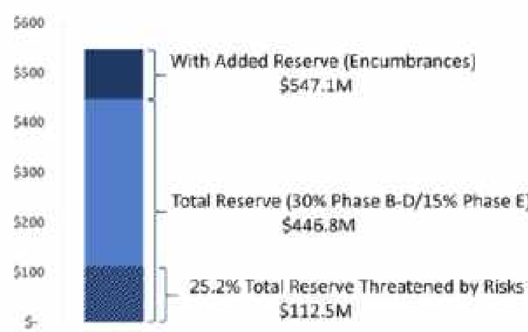
Descope Options (Cumulative) ($M)

1. **Descope ALI/SHOW ($1,556M)** *Loss of information for the important upper-troposphere/lower-stratosphere (UTLS) region and extreme volcanic/smoke events and their relation to vertical transport by convection.*

2. **Descope Camera Δt ($1,529M)** *Loss of information on clouds and plume top evolution.*

3. **Lidar05 in lieu of Lidar06 ($1,456M)** *Loss of lidar UV channel degrades the characterization of aerosol properties, including absorption.*

Reserves



Instrumentation Highlights

Radar13E+1
W-Band Doppler, Nadir; Ka-Band Doppler; Ku-Band Doppler; 15km Swath

Radio07
118, 183, 240, 310, 380, 660, 880 GHz, 750km Swath

Lidar06
355nm & 532nm HSRL, 1064nm Backscatter

Polar07
Multi-angle, UV-SWIR, 550km Swath, 0.5km FOV

Spec03
LWIR, FIR, 400km Swath

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Camera
Tandem Stereo Camera Visible Imaging

ALI
Aerosol Limb Sounder

SHOW
Water Vapor Limb Sounder

Polar = Polarimeter Radio = Radiometer Spec = Spectrometer

Science Narrative

Convective Storm Processes

Pros: Transformative capabilities for measuring vertical motions in shallow to deep convection. Measurements span light to heavy precipitation with 3 coincident frequencies. Cons: Lack of Ku radar swath degrades ability to characterize 3D structure and provide feature context. Radiometer footprints are large for convective studies. Lack of inclined orbit is detrimental to characterization of sub-daily convective processes.

Air Pollution and Distribution

Pros: Lidar, polarimeter, radar combination provides unprecedented particulate characterization and information on aerosol removal/redistribution in light to heavy precipitation. Tandem stereo cameras add information on plume top evolution, while ALI provides information on extreme volcanic/smoke events and their relation to vertical transport by convection. Lidar UV channel enables better characterization of aerosol type, size, absorption, concentration. Cons: Lack of radar swath degrades ability to characterize precipitation and its impacts on aerosol wet removal. Lack of inclined orbit is detrimental to characterization of sub-daily aerosol processes.

Climate Sensitivity and Feedback

Pros: Provides broad diversity of measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud processes. Radar profiling to near surface and cameras offer significant advances for low clouds and snowfall. ALI and SHOW provide information for the important upper troposphere/lower stratosphere (UTLS) region. Lidar UV channel aids the characterization of aerosol absorption and discrimination of anthropogenic aerosols. Cons: Lack of radar swath degrades ability to relate convective properties to high clouds.

Applications Narrative

Factors that Enhance Applications

The 3-wavelength lidar will provide estimates of aerosol size (e.g., PM1, PM2.5) and type (e.g., dust, smoke). Health studies and AQ models would benefit from accurate measurements of extinction profiles, leading to improved aerosol sizes/types.

Coincident 3-frequency Ku/Ka/W Doppler radar observations are very desirable for CCP model development, providing vertical velocity and hydrometeor details.

Stereo cameras will provide information on smoke and volcanic plume heights, which are critical for accurate monitoring and forecasting.

Opportunities to Further Enable Applications

The addition of an inclined orbit would provide more sampling to:

- **Capture diurnal aerosol observations** that will improve the reliability of AQ monitoring & forecasting.
- **Resolve diurnal convective cycle** that will greatly expand the benefit to support Water Resources, Weather, and Climate applications.
- **Enable radiometer cross-calibration with the POR** to benefit Water Resources and CCP applications.

Inclusion of a wider swath radar and higher spatial resolution (5-10 km) and lower frequency radiometer channels (89 GHz) will improve gridded precipitation for Water Resources applications and precipitation characterization for CCP Modeling & Forecasting.

Programmatic Narrative

Pros:

- **This architecture utilizes a single Radar for Ku, Ka and W Band Doppler, giving up Ku band Swath, to reduce overall Size, Weight and Power to reduce the cost of P1.**
- **This architecture has the lowest overall cost. Because this architecture has the lowest overall cost, there is less likelihood that de-scope option(s) may need to be executed in Pre-Phase A / Phase A to stay within cost target.**
- The CSA instruments' smaller Size, Weight and Power are less costly to accommodate. The Aerosol Limb Sounder (ALI) and Water Vapor Sensor (SHOW) are de-scopable providing enhancing capability if there are development issues. The Spectrometer (Spec03) is not de-scopable, however, it is not high risk and saves the US cost by providing minimum capability it would otherwise bear full cost for.

Cons:

- Lidar 06 (CNES): Accommodating the UV capability within the already complex US High Spectral Resolution Lidar (HSRL) adds cost and risk to the delivery of the most expensive and complex ACCP instrument for significantly enhancing capability. The UV capability is moderately de-scopable should issues arise.
- **Lidar 06 and Radar 13E+1 cost drive a single launch/single orbit plane to stay within the cost target deferring ACCP Science until the full system can be developed and launched together (2031 dependent upon funding profile).**

Architecture P2

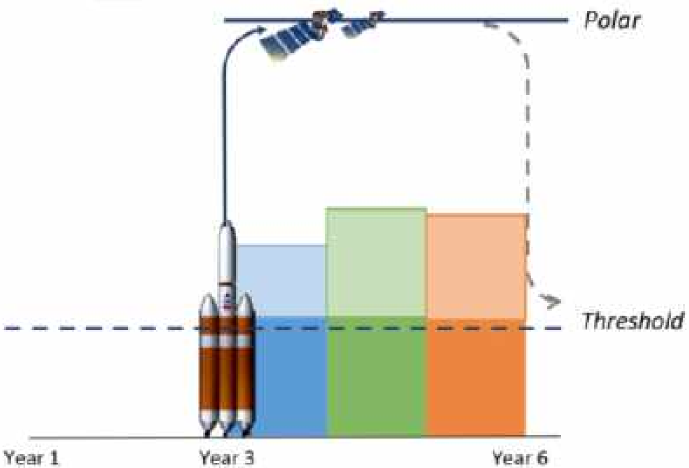
Science Benefit

Q1 – Convective Storm Processes

Q2 – Air Pollution and Distribution

Q3 – Climate Sensitivity and Feedback

(Baseline Science/ Enhanced Science)



Applications Benefit

CCP Modeling & Forecasting: S2S, NWP, Climate, Tropical Cyclone Forecasts

Water Resources & Hydromet Disasters: Agriculture, Hydro-modeling, Extreme Events/Disasters, Insurance, Transportation

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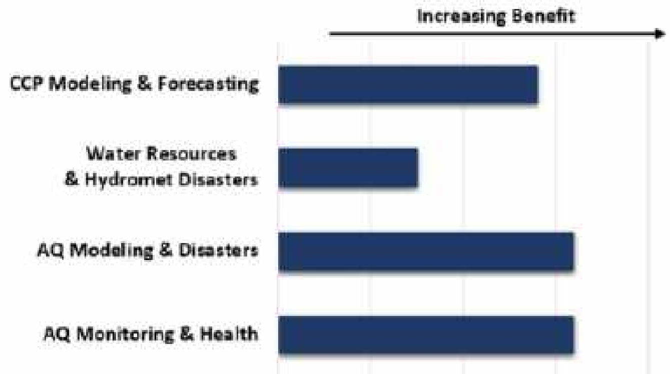
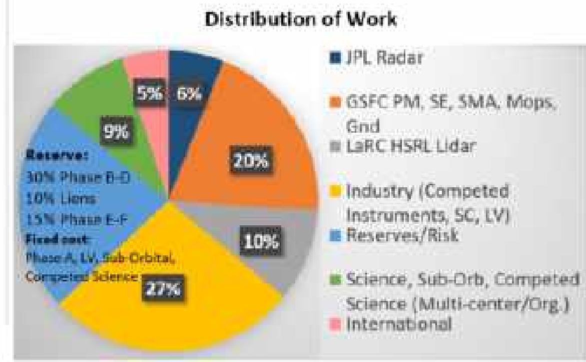


Programmatic Factors

Programmatic Factors	Rank
Continuity of Observations	3rd
Innovative Mission Implementation	2nd
Transformative Science	3rd
Flexibility with Funding Profiles	2nd
Flight Project Schedule Risk	2nd

Number of International Partners: 2

Cross-benefit with Other Disciplines: Oceans



WBS Element

WBS Element		Cost ($M)
Phase A	$	39.1
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1.0 Project Management	$	44.9
2.0 Systems Engineering	$	25.7
3.0 Safety & Mission Assurance	$	29.9
4.0 Science & Technology	$	59.8
5.0 Payloads	$	386.4
6.0 Spacecraft	$	211.8
7.0/9.0 Mission Operations/Ground Systems	$	82.5
8.0 Launch Vehicle / Services	$	107.5
10.0 Systems Integration & Testing	$	29.9
Phase E-F	$	81.0
Sub-Orbital	$	29.3
Competed Science	$	48.9
30% Reserve Phase B-D/15% Phase E	$	273.4
Encumbered Risk	$	76.3
Total (minus contributions)	**$**	**1,432.0**

Note: All costs in FY18 dollars, reported at ~50% confidence level

Risk

Liens/Encumbrances FY18 ($76.3M)

Lidar06	$37.9	Polar04b/07	$3.2
Spec03	$13.8	Spec04	$4.7
Radar13E+1	$9.5	ALI	$1.8
Radio07	$3.7	SHOW	$1.7

Top 10 Risks/Threats

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Radar13E+1	P	Risk of Remaining Technology Dev.	4	5	20
Radar13E+1	P	Risk of Pre-Launch Technical Issue(s)	4	4	16
Lidar06	T	UV Transmitter On-Orbit Degradation	3	5	15
Arch-1	T	Risk of Single Launch	2	5	10
Lidar06	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8
Camera	P	Risk of Science Algorithm Dev.	4	2	8
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P=Programmatic w/Cost Consequence (2=2-5%; 3=5-7%; 4=7-10%; 5=>10%); T=Technical

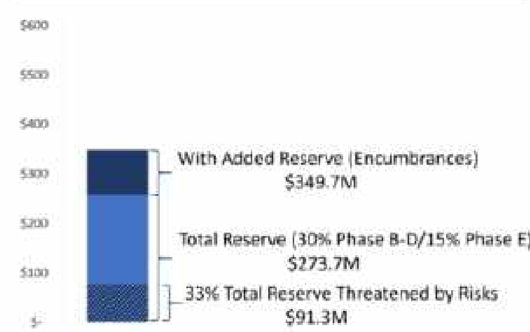
Descope Options (Cumulative) ($M)

1. **Descope ALI/SHOW ($1,334M)** *Loss of information for the important upper-troposphere/lower-stratosphere (UTLS) region and extreme volcanic/smoke events and their relation to vertical transport by convection.*

2. **Descope Camera Δt ($1,262M)** *Loss of information on clouds and plume top evolution.*

3. **Lidar05 in lieu of Lidar06 ($1,217M)** *Loss of lidar UV channel degrades the characterization of aerosol properties, including absorption.*

Reserves



Instrumentation Highlights

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W-Band Doppler, Nadir; Ka-Band Doppler; 15km Swath

Radar18
W-Band Doppler, Ku-Band Doppler

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118, 183, 240, 310, 380, 660, 880 GHz, 750km Swath

Lidar05
532nm HSRL, 1064nm Backscatter

Lidar09er
532nm, 1064nm Backscatter

Polar07
Multi-angle, UV-SWIR, 550km Swath, 0.5km FOV

Polar04b
Multi-angle, UV-SWIR, 1130km Swath, 1 km FOV

Spec03
LWIR, FIR, 400km Swath

Spec04
UV, VIS, NIR, SWIR, 200km Swath

Camera
Tandem Stereo Camera Visible Imaging

Polar = Polarimeter Radio = Radiometer Spec = Spectrometer

Science Narrative

Convective Storm Processes

Pros: Transformative measurement of diurnally varying vertical motions in shallow to deep convection, spanning light to heavy precipitation, in inclined orbit. Additional measurements in polar orbit for weak convection/upper levels of strong convection.
Cons: Narrow Ku radar swath degrades ability to provide feature context. Radiometer footprints are large for convective studies.

Air Pollution and Distribution

Pros: Particulate characterization and aerosol removal/redistribution in light to heavy precipitation is well served by the lidar, polarimeter and radar combination. HSRL Lidar in polar orbit provides unprecedented characterization of near-surface pollutants. Tandem stereo cameras add information on plume top evolution, while lidar/polarimeter measurements in inclined orbit provides information on sub-daily aerosol processes. Cons: Loss of lidar UV channel negatively impacts the characterization of aerosol properties. Lack of radar swath degrades ability to characterize precipitation and its impacts on aerosol wet removal.

Climate Sensitivity and Feedback

Pros: Provides key measurements for low and high cloud feedback, direct and indirect aerosol radiative effects, and cold cloud process studies. Radar profiling to near surface and cameras offer significant advances for low clouds and snowfall. Cons: Lack of radar swath degrades ability to relate convective properties to high clouds. Loss of lidar UV channel degrades characterization of aerosol absorption, and the ability to get consistent climate record for cloud feedback.

Applications Narrative

Factors that Enhance Applications

Inclined orbit enhances coverage and sampling opportunities, affecting the observations of high impact A and CCP phenomena.

Combined Lidar/Polarimeter in both polar and inclined orbit supports AQ modeling/monitoring centers need for increased sampling and diurnal aerosol observations to improve the reliability of AQ monitoring and forecasting.

Combined Radar/Radiometer observations in the inclined orbit allow for cross-calibration with the POR to derive gridded precipitation products to support Water Resources and CCP applications.

Ku/W-band Doppler Radar observations capture diurnal precipitation rates and convection to support NWP, aviation, and tropical cyclone centers to improve modeling and forecasting.

Stereo cameras will provide information on smoke and volcanic plume heights, which are critical for accurate monitoring and forecasting.

Opportunities to Further Enable Applications

The addition of a UV wavelength (355 nm) to the lidar will enable estimates of PM1 and PM2.5, and more accurate aerosol types (e.g., dust, smoke) for Health and AQ applications.

Inclusion of a wider swath radar and higher spatial resolution (5-10 km) and lower frequency radiometer channels (89 GHz) will improve gridded precipitation for Water Resources applications and precipitation characterization for CCP Modeling & Forecasting.

Programmatic Narrative

Pros:

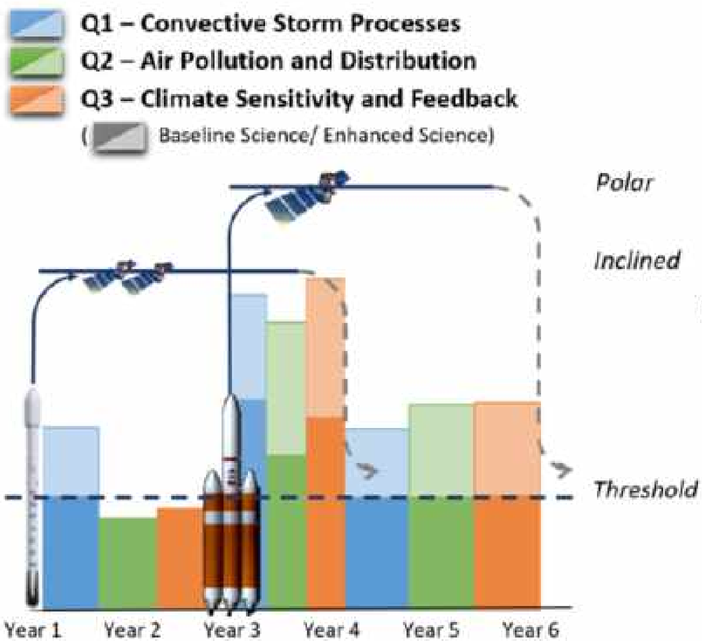
- **Path for Early Science, first launch in 2027-2028 leading to a significant response to the 2017 Decadal Survey report.**
- **Highest ranked for transformative science and application opportunities.**
- **Enhanced sampling benefits enabled from distributed constellation of SmallSats.**
- **Significant Industry-Hosted Payload capability to reduce cost and enable first launch segment.**
- **Large opportunity for industry involvement; NASA multi-center participation consistent with Tier/Core Competency priorities.**
- Due to the wide range of costs for Hosted-Payload opportunities there may be flexibility in Pre-Phase A/Phase A after RFI submittals and partner identification to execute 1 or more opportunities on the opportunities list, in consultation with HQ, for this Architecture.

Cons:

- **Minimal International participation; it does not accommodate contributions of a wide swath doppler radar from JAXA, UV lidar detector from CNES, or the ALI and SHOW limb instruments from CSA within the cost target.**
- Funding profile within total cost guidance, with the initial funding wedge >$200M lower than originally planned, but with second wedge requiring additional funds for the second launch in 2029-2031 to meet Threshold Science needs for ACCP.

Architecture D1A

Science Benefit



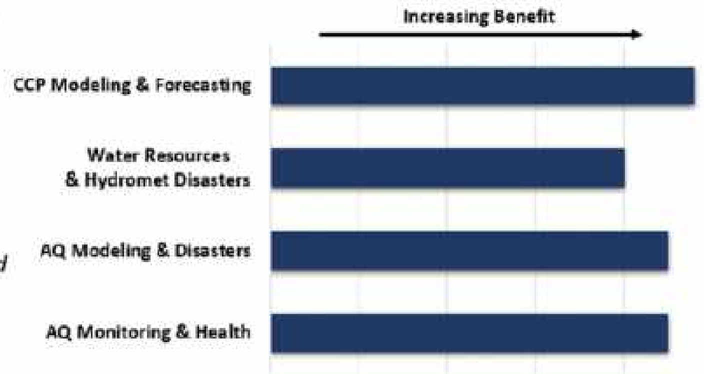
Applications Benefit

CCP Modeling & Forecasting: S2S, NWP, Climate, Tropical Cyclone Forecasts

Water Resources & Hydromet Disasters: Agriculture, Hydro-modeling, Extreme Events/Disasters, Insurance, Transportation

AQ & Disasters: AQ Modeling, Fires, Volcanoes, Dust Storms

AQ & Health: Rules and Regulation, Health/Insurance, Air Pollution



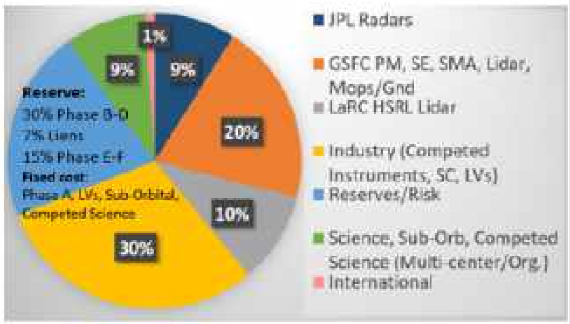
Programmatic Factors

Programmatic Factors	Rank
Continuity of Observations	1st
Innovative Mission Implementation	1st
Transformative Science	1st
Flexibility with Funding Profiles	1st
Flight Project Schedule Risk	1st

Number of International Partners: 1

Cross-benefit with Other Disciplines: Hydroglogy, Oceans

Distribution of Work



WBS Element

WBS Element	Cost ($M)	
Phase A	$	39.1
Phase B-D		
1.0 Project Management	$	47.5
2.0 Systems Engineering	$	27.2
3.0 Safety & Mission Assurance	$	31.7
4.0 Science & Technology	$	63.3
5.0 Payloads	$	423.5
6.0 Spacecraft	$	209.6
7.0/9.0 Mission Operations/Ground Systems	$	75.0
8.0 Launch Vehicle / Services	$	166.2
10.0 Systems Integration & Testing	$	31.7
Phase E-F	$	65.4
Sub-Orbital	$	29.3
Competed Science	$	48.9
30% Reserve Phase B-D/15% Phase E	$	282.6
Encumbered Risk	$	59.8
Total (minus contributions)	**$**	**1,586.0**

Note: All costs in FY18 dollars, reported at ~50% confidence level

Risk

Liens/Encumbrances FY18 ($59.8M)

Spec03	$13.8	Radio07	$3.7
Lidar05	$12.9	Polar04b/07	$6.5
Radar 18	$10.9	Spec04	$4.7
Radar13E	$7.3		

Top 10 Risks/Threats

Risk #	Type	Risk Title	Likelihood	Consequence	LxC
Lidar05	P	Risk of Growth (Mass, Power, Footprint)	4	5	20
Radar13E	P	Risk of Remaining Technology Dev.	4	5	20
Lidar09r	P	Risk of Growth (Mass, Power, Footprint)	2	5	10
Radar18	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Radar13E	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Lidar09r	P	Risk of Manufacturability Issues	3	3	9
Lidar05	P	Risk of Remaining Technology/Engineering Dev.	4	2	8
Lidar05	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8

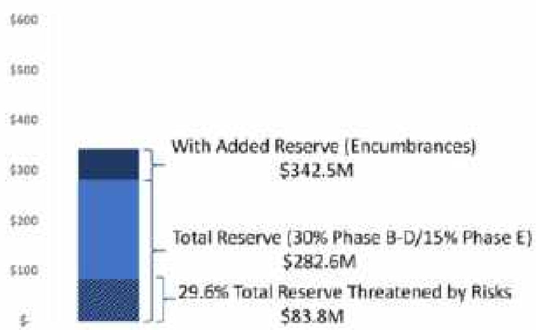
P=Programmatic w/Cost Consequence (2=2-5%; 3=5-7%; 4=7-10%; 5=>10%); T=Technical

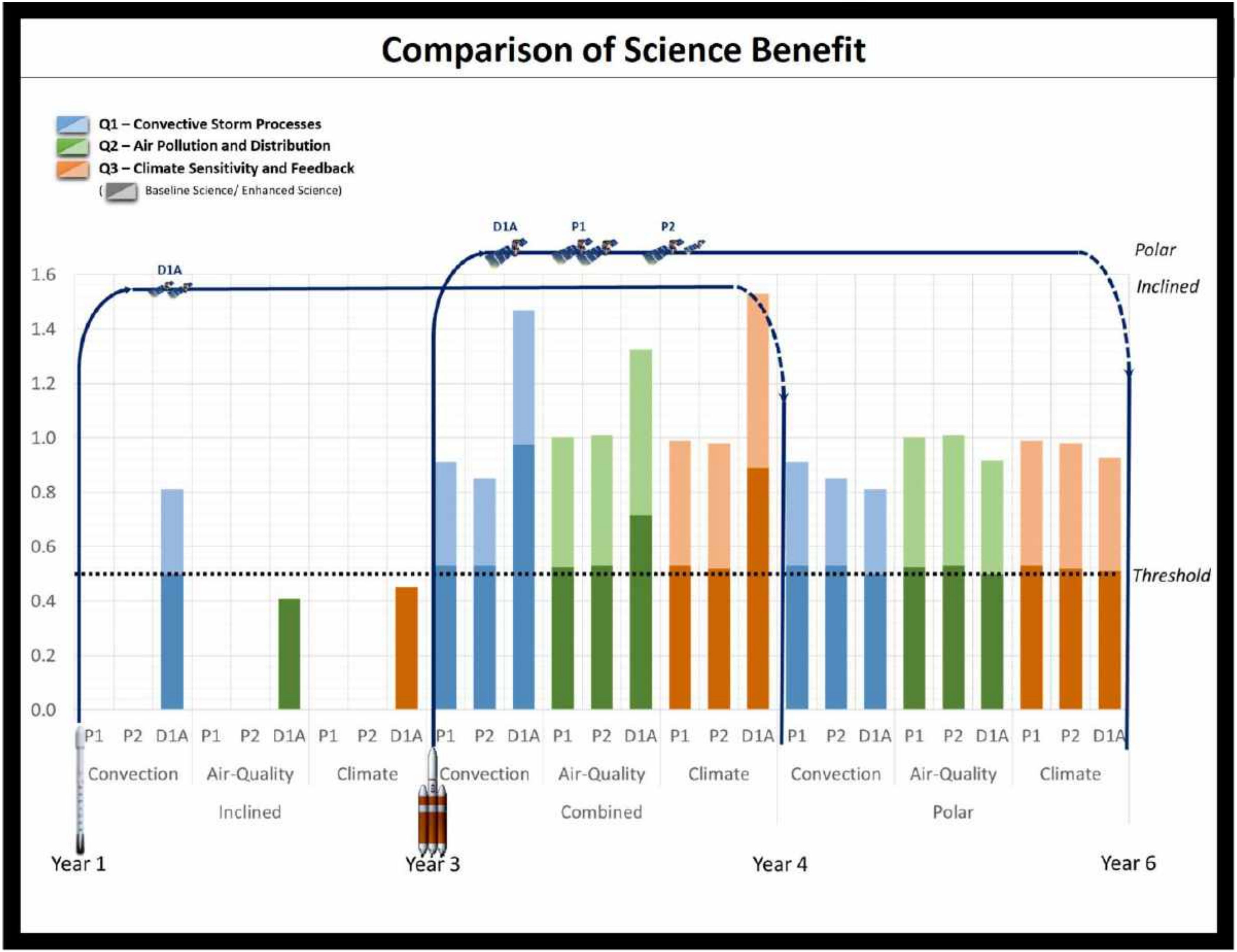
Descope Options (Cumulative) ($M)

1. Descope Camera Δt ($1,530M) *Loss of information on clouds and plume top evolution.*

2. Radar12 in lieu of Radar18 ($1,497M) *Loss of information about vertical motions and precipitation rates in heavy rainfall events.*

Reserves



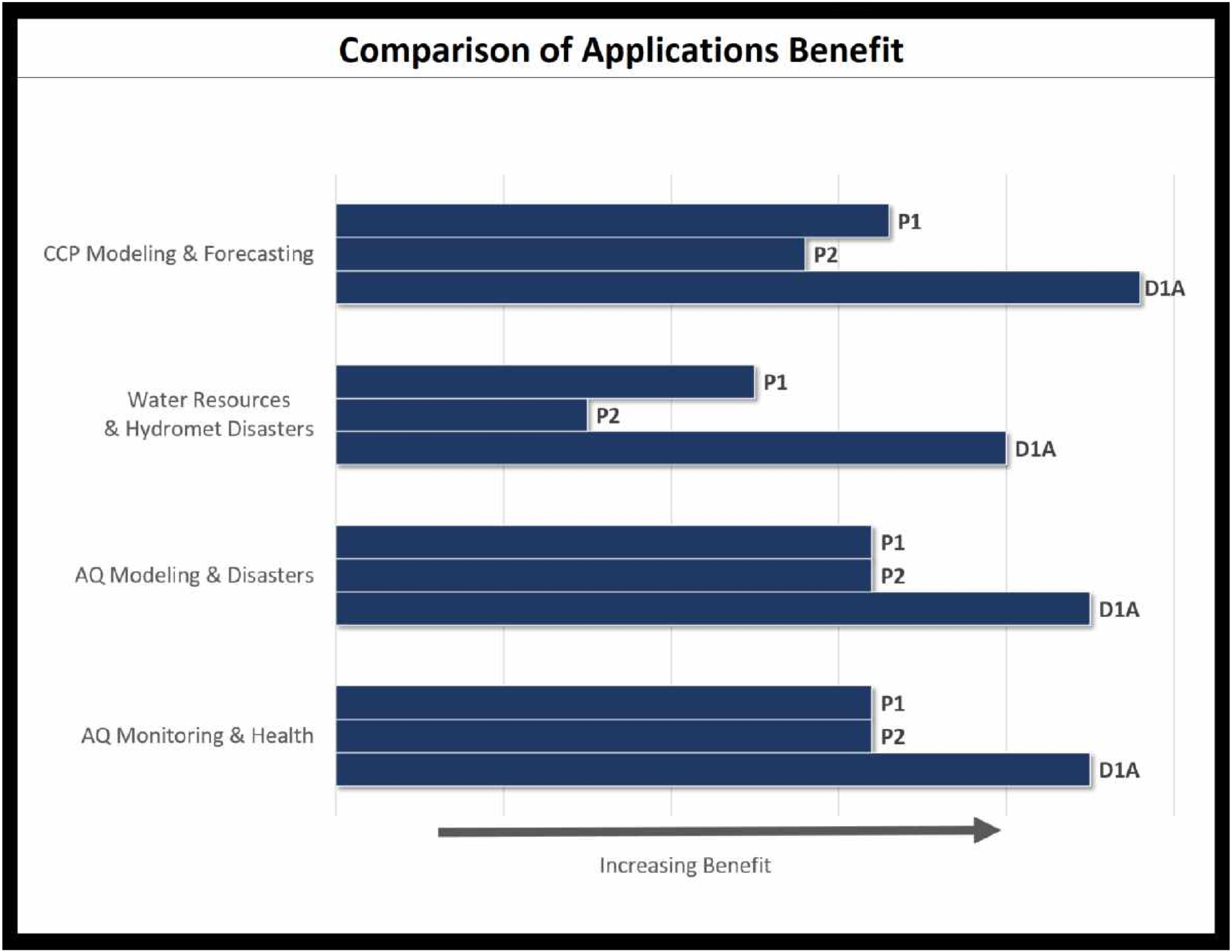

Comparison of Science Benefit
Q1 – Convective Storm Processes
Q2 – Air Pollution and Distribution
Q3 – Climate Sensitivity and Feedback
(Baseline Science/ Enhanced Science)
D1A
P1
P2
Polar
Inclined
Threshold
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A P1 P2 D1A
Convection Air-Quality Climate Convection Air-Quality Climate Convection Air-Quality Climate
Inclined
Combined
Polar
Year 1
Year 3
Year 4
Year 6

Comparison of Science Benefit

Active and passive measurements in all 3 architectures provide measurements of air motions within clouds, with vertical profiling of aerosol, cloud and precipitation properties that make substantive advancements toward ACCP science goals.

While the single orbit architectures **P1** and **P2** deliver the most capable instrumentation in a single package, these architectures do not sample the sub-daily variability of key processes. Compared to **P1**,the lack of radar swath in architecture **P2** degrades its ability to characterize 3D structure and do precipitation feature context with adverse impacts on the characterization of aerosol wet removal.

Architecture **D1A** provides a balanced solution in which diurnal measurements are now included with an additional inclined orbit, at the expense of some reduction in the polar orbit measurement capabilities. Most notably, the loss of lidar UV channel in **D1A** negatively impacts the characterization of aerosol properties. Much like **P2**, lack of radar swath in **D1A** degrades ability to characterize precipitation and its impacts on aerosol wet removal. However, during the inclined segment (years 1-2), architecture **D1A** provides early information on sub-daily processes. During the overlap segment (year 3), the additional sampling from the dual orbits allows D1A to sample diurnal processes, while providing cross-calibration of the diurnal lidar and improved characterization of aerosol, cloud and precipitation properties from polar orbit. While architecture **D1A** meets threshold science for convection, the polar segment is required for it to meet threshold for aerosol and climate feedback science.



Comparison of Applications Benefit
CCP Modeling & Forecasting
Water Resources
& Hydromet Disasters
AQ Modeling & Disasters
AQ Monitoring & Health
P1
P2
D1A
P1
P2
D1A
P1
P2
D1A
P1
P2
D1A
Increasing Benefit

Comparison of Applications Benefit

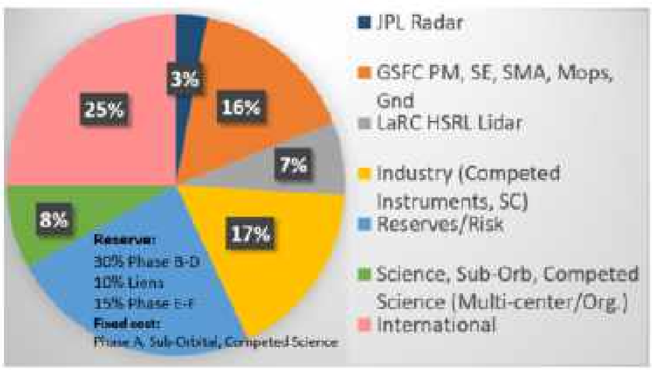
D1A provides the most opportunity for enhancing and extending applications for both A and CCP. The diurnal observations made possible by the inclined orbit are fundamental for precipitation and convection applications, and also provides increased sampling and critical information on the diurnal distribution of aerosols. Integrated, diurnal ACCP observations from **D1A** will advance models and forecasting 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.

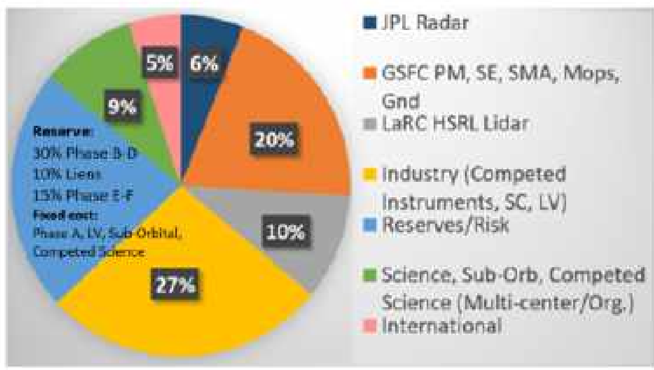
For aerosol applications, communities request increased sampling and greater accuracy in aerosol typing available from **D1A,** raising the bar beyond the POR and increasing synergy with ground-based networks. The two lidars on **D1A** (backscatter on the inclined and two-channel high-spectral resolution lidar, HSRL, in polar orbit) will provide vertical information on aerosol distributions, important for AQ forecasting and Disasters (e.g., fires, volcanoes, dust). The two-channel HSRL lidar will provide accurate aerosol types, while the lidar/polarimeter combination in the inclined will improve aerosol typing from the backscatter lidar. The three-channel HSRL (**P1 and P2**) will yield better characterization of aerosol size (e.g., PM1, PM2.5), an important parameter for the health and AQ communities, but lack the increased sampling and diurnal observations from **D1A**.

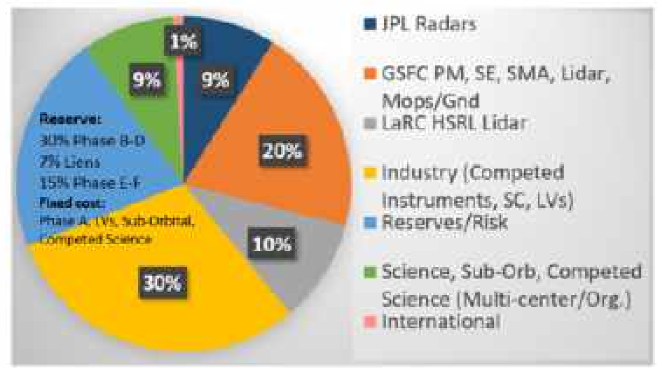
For Hydrologic and CCP applications, communities request increased sampling to capture the diurnal cycle of convection and high impact phenomena available only in **D1A**. Only the **D1A** inclined orbit radiometer observations provide an opportunity for cross-calibration with the PoR to extend precipitation measurements. **D1A** provides coincident Ka/W Doppler observations in polar orbit, with coincident Ku/W Doppler observations in an inclined orbit, presenting a valuable set that allows capturing the spectrum of CCP variables to benefit applications. **Novel estimates of vertical velocity, provided by all three architectures,** enable first ever global view of convective motion and precipitation in severe storms, enabling modeling and forecasting communities to better improve forecast skill of high impact events. Coincident Ku/Ka/W Doppler radar **(P2)** and wide-swath Ku-band **(P1)** are desirable for weather and climate model development, however the benefit of the **D1A** inclined orbit is more desirable. **An important desire for all architectures** is addressing the outstanding need for higher resolution (<5-10km) and lower frequency radiometer channels (e.g. 89GHz) to improve precipitation characterization.

Comparison of Programmatic Factors

	P1	P2	D1A
Continuity of Observations	2nd	3rd	1st
Innovative Mission Implementation	2nd	2nd	1st
New Science	2nd	3rd	1st
Flexibility with Funding Profiles	3rd	2nd	1st
Flight Project Schedule Risk	3rd	2nd	1st
Number of International Partners	3	2	1
Cross-benefit with Other Disciplines	Oceans	Oceans	Hydrology, Oceans







P1
All-In International
Only 1 Launch 2031
Highest Risk — Indicated by Liens

P2
US Alternative To JAXA Radar
Only 1 Launch 2031
Lower Risk—Indicated by Liens

D1A
Early Science Option
1st Launch As Early as 2027-2028
Lowest Risk—Indicated by Liens

Comparison of Cost

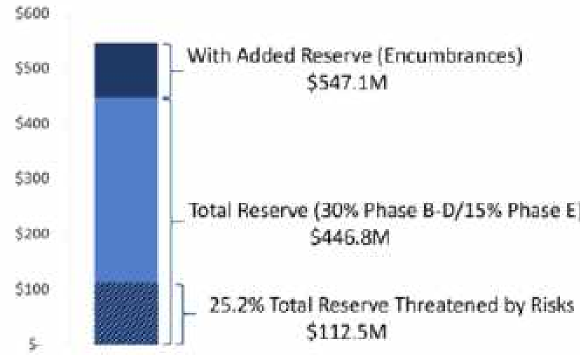
WBS Element	P1 Cost ($M)		P2 Cost ($M)		D1A Cost ($M)	
Phase A	$	39.1	$	39.1	$	39.1
Phase B-D						
1.0 Project Management	$	77.6	$	44.9	$	47.5
2.0 Systems Engineering	$	44.5	$	25.7	$	27.2
3.0 Safety & Mission Assurance	$	51.7	$	29.9	$	31.7
4.0 Science & Technology	$	103.5	$	59.8	$	63.3
5.0 Payloads	$	749.1	$	386.4	$	423.5
6.0 Spacecraft	$	285.4	$	211.8	$	209.6
7.0/9.0 Mission Ops/Ground Systems	$	82.5	$	82.5	$	75.0
8.0 Launch Vehicle / Services	$	-	$	107.5	$	166.2
10.0 Systems Integration & Testing	$	51.7	$	29.9	$	31.7
Phase E-F	$	81.0	$	81.0	$	65.4
Sub-Orbital	$	29.3	$	29.3	$	29.3
Competed Science	$	48.9	$	48.9	$	48.9
30% Reserve Phase B-D/15% Phase E	$	446.8	$	273.4	$	282.6
Encumbered Risk	$	100.3	$	76.3	$	59.8
Total (minus contributions)	**$**	**1,598**	**$**	**1,432**	**$**	**1,586**

Note: All costs in FY18 dollars, reported at ~50% confidence level

Comparison of Risk

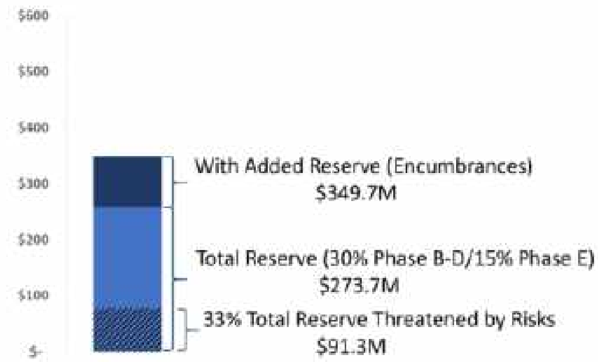
P1

Risk #	Type	Risk Title			
Lidar06	P	Risk of Growth (Mass, Power, Footprint)	4	5	20
Radar13E	P	Risk of Remaining Technology Dev.	4	5	20
Lidar06	T	UV Transmitter On-Orbit Degradation	3	5	15
Arch-1	T	Risk of Single Launch	2	5	10
Radar13E	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Lidar06	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8
Camera	P	Risk of Science Algorithm Dev.	4	2	8
ALI/SHOW	P	Risk of Science Algorithm Dev.	4	2	8



P2

Risk #	Type	Risk Title			
Lidar06	P	Risk of Growth (Mass, Power, Footprint)	4	5	20
Radar13E+1	P	Risk of Remaining Technology Dev.	4	5	20
Radar13E+1	P	Risk of Pre-Launch Technical Issue(s)	4	4	16
Lidar06	T	UV Transmitter On-Orbit Degradation	3	5	15
Arch-1	T	Risk of Single Launch	2	5	10
Lidar06	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8
Camera	P	Risk of Science Algorithm Dev.	4	2	8
ALI/SHOW	P	Risk of Science Algorithm Dev.	4	2	8



D1A

Risk #	Type	Risk Title			
Lidar05	P	Risk of Growth (Mass, Power, Footprint)	4	5	20
Radar13E	P	Risk of Remaining Technology Dev.	4	5	20
Lidar09r	P	Risk of Growth (Mass, Power, Footprint)	2	5	10
Radar18	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Radar13E	P	Risk of Pre-Launch Technical Issue(s)	3	3	9
Lidar09r	P	Risk of Manufacturability Issues	3	3	9
Lidar05	P	Risk of Remaining Technology/Engineering Dev.	4	2	8
Lidar05	P	Risk of Pre-Launch Technical Issue(s)	4	2	8
Spec04	P	Risk of Science Algorithm Dev.	4	2	8
Camera	P	Risk of Growth (Mass, Power, Footprint)	4	2	8