NASA's Emerging Vision for the ACCP Mission

Dave Winker / Jens Redemann / Philip Stier

and the ACCP Science Leadership Team:

Arlindo DaSilva, Scott Braun (GSFC)
Dave Winker, Rich Ferrare (LaRC)
Graeme Stephens, Duane Waliser (JPL)
Meloë Kacenelenbogen (NASA Ames), Walt Peterson (MSFC)

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Thriving on Our Changing Planet

A Decadal Strategy for Earth Observation from Space

A report of the Decadal Survey for Earth Science and Applications from Space
Released: 5 January 2018
Report available at: **http://www.nas.edu/esas2017**

Motivating science priorities from the DS:

"Most Important" Topics	"Most Important" DS Science Questions Relevant to ACCP
Extending and Improving **Weather** and **Air Quality Forecasts**	**W-4)** Why do convective *storms*, heavy *precipitation*, and *clouds* occur where and when they do?
	W-5) What processes determine the spatio-temporal structure of important *air pollutants*?
Reducing **Climate Uncertainty**	**C-2)** How can we reduce the uncertainty in the amount of future warming of the Earth, *improve predictions of local and regional climate response* and the uncertainty in global *climate sensitivity*?

National Academy recommendations to NASA:

	Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
A:	Aerosols	**Aerosol properties, aerosol vertical profiles, and cloud properties** to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
CCP:	Clouds, Convection, and Precipitation	**Coupled cloud-precipitation state and dynamics** for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
	Mass Change	**Large-scale Earth dynamics** measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
	Surface Biology and Geology	**Earth surface geology and biology,** ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
	Surface Deformation and Change	**Earth surface dynamics** from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

ACCP Aerosols, Clouds, Convection, and Precipitation Study

- A study now underway to identify options for an ACCP mission
  - Initiated October 2018
  - Recommendations to NASA HQ due in fall 2021
  - Launch anticipated in late 2020's
- Joint science/engineering study team formed:
  - Goddard, Langley, JPL, Ames, Marshall
  - External "science team" from academia
  - Now soliciting participation from international agencies (CNES, JAXA, CSA)
  - Welcome feedback from US & international science community
- Rather than single solution to address science objectives …
- *The study will identify multiple options at different levels of capability and different price points*

Status

- Have created a detailed (but preliminary) Science Traceability Matrix (STM)
  - Defines specific science objectives to meet high level goals
  - Identifies geophysical variables necessary to address science objectives
  - Attempts to define requirements on geophysical retrievals, instruments, and instrument capabilities
- Are now refining the STM
  - Engaging with international community: will ACCP meet future needs?
  - Bringing desires in line with resources ($)

Message from NASA HQ yesterday:
"Tell community to engage with us"

Science and Applications Traceability Matrix

Public Release E

16 September 2019

Note to Reviewers: Please use this on-line form to provide your comments: https://goo.gl/forms/RbSbNez4lNjjEjun2

ACCP Aerosols and Clouds, Convection, and Precipitation Study

A+CCP	A	CCP	2017 DS Most Important Very Important	Goals
			W-1a W-2a C-2a C-2g	**Goal 1** Cloud Feedbacks Reduce the uncertainty in low- and high-cloud climate feedbacks by advancing our ability to predict the properties of low and high clouds.
			W-1a W-2a W-4a C-2g H-1b C-5c	**Goal 2** Storm Dynamics Improve our physical understanding and model representations of cloud, precipitation *and dynamical* processes within deep convective storms.
			H-1b W-1a S-4a W-3a	**Goal 3** Cold Cloud and Precipitation Improve understanding of cold (supercooled liquid, ice, and mixed phase) cloud processes and associated precipitation and their coupling to the surface at mid to high latitudes and to the cryosphere.
			W-1a W-5a C-5a	**Goal 4** ***Aerosol Processes*** Reduce uncertainty in key processes that link aerosols to weather, climate and air quality related impacts.
	D I		C-2a C-2h C-5c	**Goal 5** ***Aerosol Impacts on Radiation*** Reduce the uncertainty in Direct (D) and Indirect (I) aerosol-related radiative forcing of the climate system.

Goal only fully realizable via combined mission.

A or CCP alone makes meaningful contribution to goal

ACCP Science Objectives

1. Low Cloud Feedback
2. High Cloud Feedback
3. Convective Storm Systems
4. Cold Cloud & Precipitation
5. Aerosol Attribution and Air Quality
6. Aerosol Processing, Removal and Redistribution
7. Aerosol Direct Effect and Absorption
8. Aerosol Indirect Effect

ACCP Aerosols and Clouds, Convection, and Precipitation Study

A+CCP	A	CCP	Objectives
			O7 Aerosol Direct Effects and Absorption **Minimum**: Reduce uncertainties in estimates of: 1) global mean clear and all-sky shortwave direct radiative effects (DRE) to ±1.2 W/m2 at TOA, surface and regional DRE, and the anthropogenic fraction, 2) Quantify the impacts of absorbing aerosol on atmospheric stability. **Enhanced**: Quantify the impact of absorbing aerosols on vertically resolved aerosol radiative heating rates and the aerosol radiative effect commensurate with the uncertainties in global mean DRE at TOA and surface.

A	CCP	ODO	POR	Utility Score	Geophysical Variables		Qualifiers
					Minimum	Enhanced	
√				3.8	Aerosol Extinction Profile (Total & Non-Spherical)		VIS & NIR, Profile
√		S	(√)	5.0	Aerosol Optical Depth		VIS to NIR Column, PBL
√			(√)	5.0	Aerosol Absorption Optical Depth		UV-VIS Column, PBL
√			(√)	4.5	Aerosol Fine Mode Optical Depth		Column, PBL
√			(√)	4.0	Aerosol Real Index of Refraction		Column, PBL
√				4.3	Aerosol Asymmetry Parameter		Colum, PBL
√				4.8	Aerosol Non-Spherical AOD Fraction		Column, PBL
√				3.5	Aerosol Extinction to Backscatter Ratio (Column)		VIS, NIR
√				5.0	Aerosol-Cloud Feature Mask		Profile
			√	N/A	Environmental Temperature		Profile
			√	N/A	Environmental Humidity		Profile
			√	N/A	Surface Albedo		
√	√			3.3	Cloud Optical Depth		
√	√		(√)	2.5	Cloud Droplet Effective Radius		
x	√			4.8	Areal Cloud Fraction		
√	√		√	N/A	Radiative fluxes (derived)		LW, SW Surface, TOA
√				5.0		Aerosol Effective Radius	Profile
√				5.0		Aerosol Absorption	UV-VIS Profile
√				4.5		Aerosol Fine Mode Extinction	Profile

Approach

General approach

a) Compute TOA SW aerosol direct radiative effect from observed aerosol and cloud properties (*e.g.,* Oikawa et al 2018; Thorsen et al 2019)
b) Estimate anthropogenic fraction of DRE using aerosol speciation approaches as in O5 and O6.
c) Estimate atmospheric heating due to aerosol absorption.
d) Characterize changes in atmospheric stability due to aerosol absorption

Role of models - used to estimate impacts of aerosol absorption on atmospheric heating and aerosol-cloud radiative interactions.

Role of Sub-orbital – validation of satellite retrievals, aerosol optical models.

New and Improved - Significant improvements in key aerosol variables (extinction profiles, absorption, size), especially over land.

Goal 4. Aerosol Processes and Air Quality

- **Objective 5** Aerosol Attribution and Air Quality
  - Quantify optical and microphysical aerosol properties - PBL and free troposphere
  - Improve understanding of sources, transport, species
  - Characterize near-surface particulate concentrations and improve AQ forecast skill

- **Objective 6** Aerosol Processing, Removal and Redistribution
  - Characterize the processing, redistribution and removal of aerosols by clouds & precip

Goal 5. Aerosol Impacts on Radiation

- **O7** Aerosol Direct Effects and Absorption
  - Reduce uncertainties in estimates of global mean clear and all-sky SW DRE
  - Provide observation-based estimates of anthropogenic fraction
  - Quantify the contribution of absorbing aerosol to atmospheric heating and semi-direct effect

- **O8** Aerosol Indirect Effect
  - Provide new and improved observations to constrain process level understanding of aerosol-cloud interactions and indirect effects:
    - *aerosol-warm cloud*
    - *cold and mixed-phase clouds*

Key message:

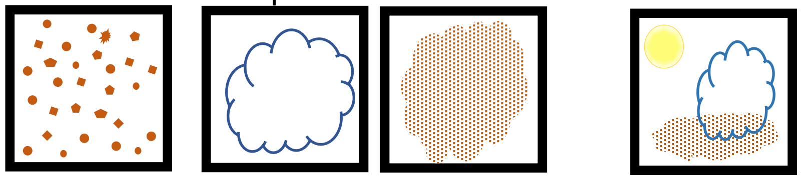
- ACCP will fly within the context of the future satellite PoR
  - GEO sensors such as AHI, ABI, SENTINEL
  - Polar sensors such as VIIRS
- ACCP makes use of and augments PoR with new capabilities

Aerosols

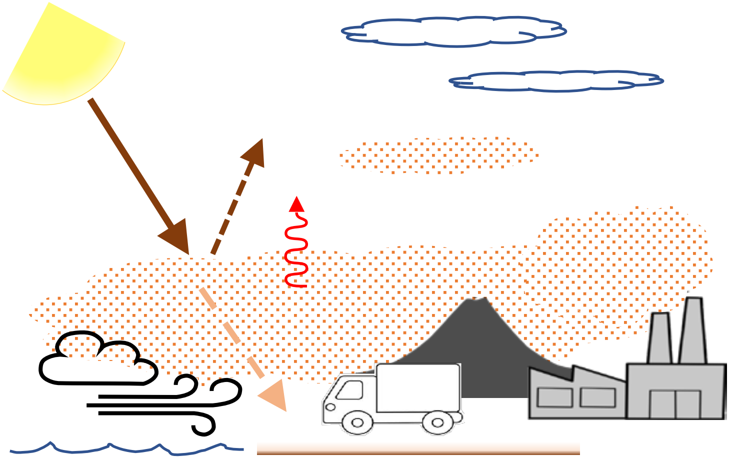
Program of Record (PoR)

Aerosol DO

Aerosol DIstribution | Aerosol Properties | Trace Gases | Vertical Profiles Enhanced properties



e.g. ABI,AHI VIIRS | e.g. 3MI PACE | e.g. Trop-OMI TEMPO | **Lidar Polarimeter**



ACCP will augment the future Program of Record (PoR)

1. 4D AEROSOL SAMPLING & LIFE CYCLE

Previous PoR measurements have not provided collocated temporal and vertical measurements of aerosol distribution and properties; key to understanding:

- **Aerosol Sources and Transport**
- **Aerosol Processing**
- **Aerosol Removal and Redistribution**
- **Modeling and Forecast Skill**

New Science Enabling Observations

2. AEROSOL AMOUNT

Improved measurements of AOD, AAOD, and aerosol extinction profiles to advance understanding of:

- **Aerosol Direct Radiative Effects at TOA & Surface**
- **Air Quality**
- **Aerosol Atmospheric Heating & Hydrologic Sensitivity**

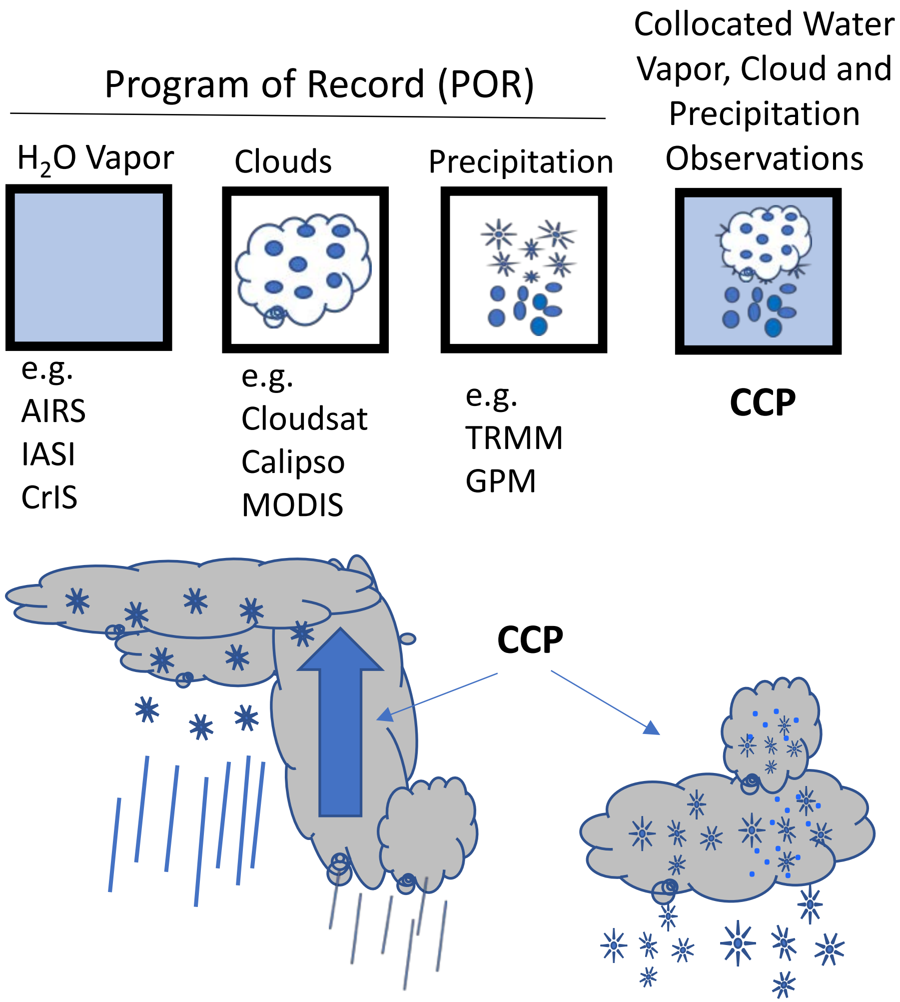
3. AEROSOL PROPERTIES

New and improved measurements of aerosol single scatter albedo and size to:

- **Discriminate Anthropogenic and Natural Aerosols**
- **Improve Understanding of Aerosol Sources**
- **Evaluate Modeling and Air Quality**

Clouds, Convection and Precipitation

Three New Science Enabling Observations



1. WATER VAPOR + CLOUDS + PRECIPITATION

Previous / POR measurements have not provided collocated measurements of water vapor, clouds and precipitation; these are key to understanding:

- **Low Cloud Climate Feedback**
- **High Cloud Climate Feedback**
- **Cloud and Precipitation Development**
- **Atmospheric Water Cycle**

2. VERTICAL MOTION IN EXTREME STORMS

There are no global measurements of vertical motion inside extreme storms; these are key to understanding:

- **Storm Development & Life Cycle**
- **Hydration of the Upper Troposphere**
- **Precipitation Extremes**

3. COLD CLOUDS AND SNOWFALL

Previous / POR measurements provided insufficient information to constrain snowfall estimates.

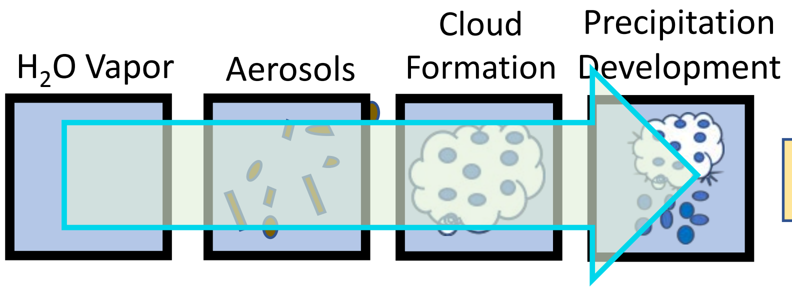
- **Polar Hydrometeorology**
- **Sea Ice and Ice Sheet Surface Mass Balance**

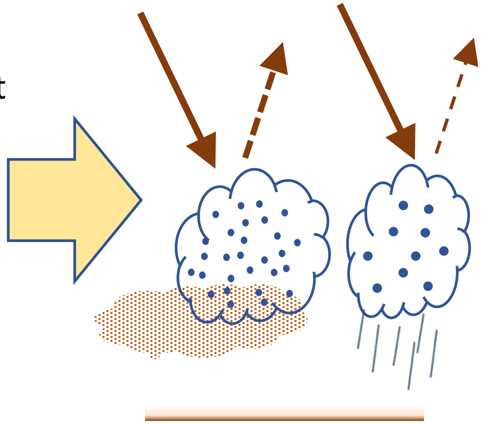
Links between 'A' & 'CCP'

I. Aerosol Effects on Cloud Microphysics and Precip

II. Aerosol Indirect Radiative Effects

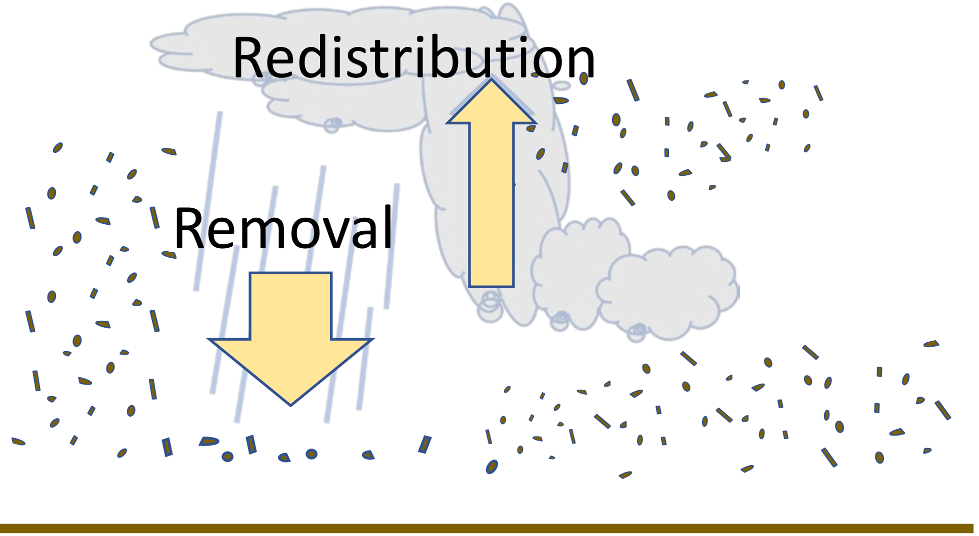
III. Aerosol Processing, Removal and Redistribution by Cloud





Aerosols are fundamental to the formation of clouds and precipitation, and thus relevant to all CCP objectives.

These aerosol impacts on clouds and precip lead to impacts on radiation, thus further linking Aerosol and CCP objectives.



Precipitation removes aerosols, convection and storms loft and redistribute aerosols

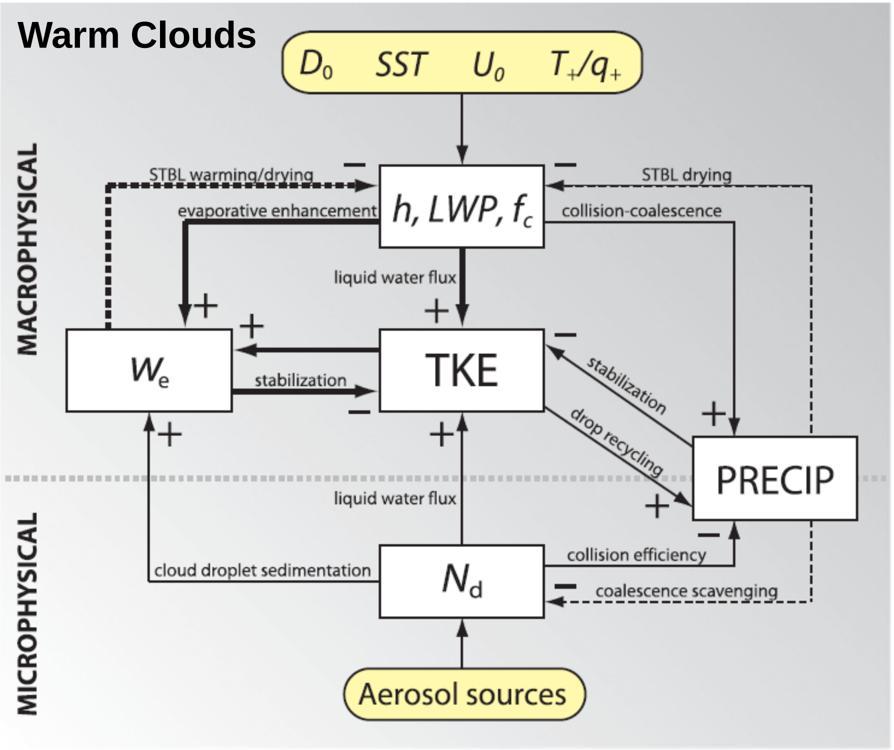
Chemical processing of aerosol occurs within cloud droplets

Aerosol variables vs capabilities of different instrument suites

Geophysical Variable	Backscatter Lidar	HSRL		Polarimeter	Polarimeter & BSL	Polarimeter & $2\beta + 1\alpha$	Polarimeter & $3\beta + 2\alpha$
		$2\beta + 1\alpha$	$3\beta + 2\alpha$				
Aerosol extinction profile	–	√	+		√ (TBD)	+	++
Near-surface aerosol extinction profile	–	√	+		–	√	++
Aerosol column absorption				√ (TBD)	√	+	++
Aerosol absorption profile					?	√	√
Aerosol size distribution parameters profile		–	√		?	?	?
Aerosol (column non-sphericity) non-spherical AOD	√ (TBD)	√	√	√ (TBD)	√	√	√
Aerosol (non-sphericity profile) non-spherical extinction profile	√ (TBD)	√	√		√	√	+
Aerosol column complex refractive index				–	√	+	++

– Less capability than ACCP Minimum requirement
√ Meets or somewhat exceeds Minimum (advances on A-train/PoR)
+ Significantly exceeds Minimum

What can ACCP do for the aerosol indirect effect?

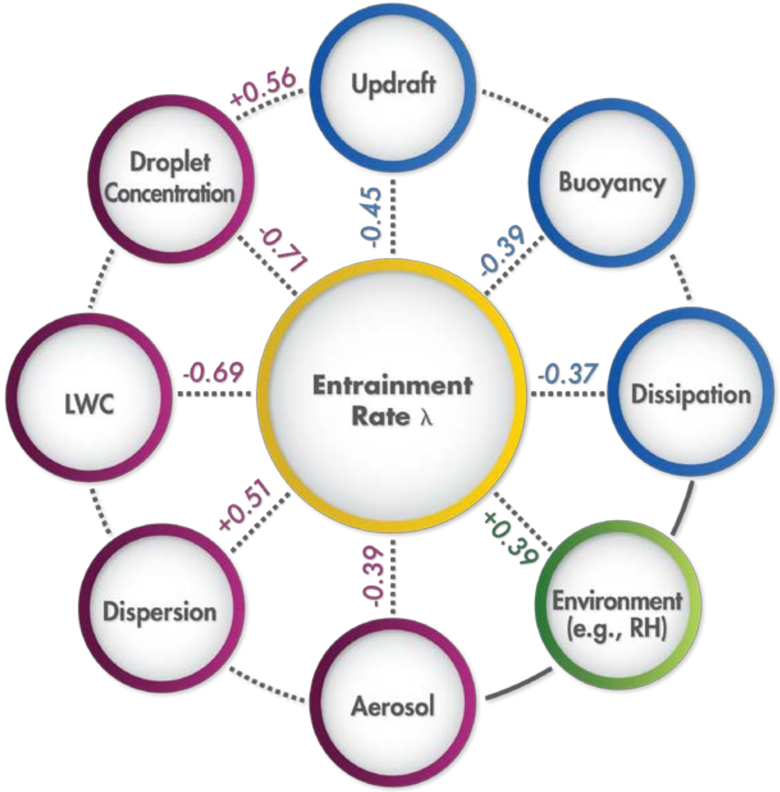


(Wood, MWR, 2012)

Aerosol indirect effects are the result of multiple coupled processes, weakly correlated to a number of variables

We envision an observational strategy focused on joint pdfs to characterize physical processes and higher level relationships

Correlation of processes to shallow cloud entrainment rate



(Courtesy Yangang Liu and Allison McComiskey)

Anticipate advances for Indirect Effects from new and improved retrievals

- Aerosols:
  - Polarimeter: improved aerosol size and Å
    - Fine- and coarse-mode R_{eff} and eff. variance?
  - Improved lidar sensitivity (at minimum)
  - Improved PBL aerosol extinction if HSRL
- Clouds:
  - Polarimeter: cloud-top droplet size and variance
  - Lidar: cloud-top extinction
  - Nakajima-King retrievals with improved spatial resolution

  (Polarimeter and Lidar together →) cloud-top CDNC
- Precipitation:
  - Possibly improved near-surface W-band radar

From DS report:

Designated Observable	DS Candidate Approach
Aerosols	Backscatter lidar & multi-angle polarimeter
Clouds, Convection, and Precipitation	Doppler radar & passive microwave

- DS felt HSRL was too expensive (but could be proven wrong)
- DS recommendations neglected traditional passive VIS-IR radiometers
  - Necessary for aerosol forcing, cloud feedbacks
- Use Program of Record? Add to ACCP payload?
  - UV-VIS-SWIR radiometer
  - Thermal to Far IR radiometer
  - Broad-band flux radiometer (CERES, EV-C)

Summary

- Significant science advances from the A-train
- EarthCARE (coming soon) will provide some new capabilities
- ACCP intended to continue advancement beyond A-train and EarthCARE
- ACCP may be our best chance to advance aerosol science in the 2030's
- Send us your thoughts!

Discussion topics (from Phil)

- Desires for continuity with current measurements vs new instruments?
    - Benefits of long-term records vs. insights from new, more advanced observations

- What variables would people prioritize for ERFari vs ERFaci?

- What would be the most useful data for data assimilation?
    - Speciation?

A+CCP	A	CCP	Objectives
			O5 Aerosol Attribution and Air Quality **Minimum:** Quantify optical and microphysical aerosol properties in the PBL and free troposphere to improve process understanding, estimates of speciation, aerosol emissions and predictions of near-surface particulate concentrations. **Enhanced:** Characterize changes in vertical profiles of optical and microphysical properties over space and time in terms of 3D transport, spatially resolved emission sources and residual production and loss terms.

Approach (1 of 2)

General Approach

a) Use ACCP measurements to estimate aerosol speciation using the following approaches:
   1) Optimal estimation algorithm using as prior aerosol state from an assimilation system that incorporates the aerosol PoR
   2) Empirical aerosol typing based on clustering of aerosol optical properties

b) Inverse calculations used to assess impact on emissions, and through revised emissions impact on forecasts of near-surface particulate concentrations

c) Model sensitivity studies, validated by ACCP data, used to gain insight into process parameterizations.

d) Complement and where possible expand on existing climate data records. Examine inter-annual variability of aerosol emissions, optical properties and impact on global AQ.

Role of Models – primary tool to integrate observations, test understanding & examine impacts and feedbacks.

A	CCP	ODO	POR	Utility Score	Geophysical Variables (1 of 2) Minimum	Enhanced	Qualifiers
√				4.2	Aerosol Extinction (Total & Non-Spherical)		VIS & NIR Profile
√		S	(√)	5.0	Aerosol Optical Depth		UV to SWIR Column, PBL
√				4.4	Aerosol Absorption Optical Depth		UV & VIS Column, PBL
√				4.4	Aerosol Fine Mode Optical Depth		Column, PBL
√			(√)	3.6	Aerosol Real Index of Refraction		Column, PBL
√				4.8	Aerosol Non-Spherical AOD Fraction		Column, PBL
√				4.2	Aerosol Extinction to Backscatter Ratio		VIS & NIR Column, PBL
√				4.8	Aerosol-Cloud Feature Mask		
√			(√)	N/A	Planetary Boundary Layer Height		
			√	N/A	Environmental Temperature		Profile
			√	N/A	Environmental Humidity		Profile

Approach (2 of 2)

Role of Sub-orbital – cal/val variable retrievals, validate process interpretation, advance process understanding with enhanced property measurement. Linking of optical to chemical aerosol properties.

New and Improved

a) Significant improvements of key aerosol variables (vertically/spectrally resolved aerosol absorption and extinction, fine mode fraction over land, etc.)

b) Improved global emissions and near surface aerosol characterization, with benefits for AQ analysis and forecasts.

ACCP Aerosols and Clouds, Convection, and Precipitation Study

A+CCP	A	CCP	Objectives
			O6 Aerosol Processing, Removal and Redistribution **Minimum:** Characterize the processing and removal of aerosols by clouds and light precipitation (<2 mm/hr). **Enhanced:** Characterize the processing, removal and redistribution of aerosols by clouds and heavy precipitation (> 2 mm/hr).

A	CCP	ODO	POR	Utility Score	Geophysical Variables (1 of 2) Minimum	Enhanced	Qualifiers
	√		(√)	4.5	Total Liquid Water Path		
√	√	S	(√)	4.0	Cloud Optical Depth		
√	√	S	(√)	5.0	Cloud Droplet Effective Radius		
	√		(√)	4.5	Precipitation rate		< 2mm/hr 2D @ surface
	√		(√)	4.0	Precipitation Phase		Profile, Near-surface included
	√		(√)	4.8	Precipitation Rate		Profile, Near-surface included
			√	N/A	Environmental Temperature		Profile
			√	N/A	Environmental Humidity		Profile
			√	N/A	Environmental Horizontal Wind		Profile
			√	N/A	Environmental Vertical Wind		Profile
√			(√)	N/A	Planetary Boundary Layer Height		

Approach – 1 of 2

General Approach

a) Use ACCP observations to estimate aerosol amount, size and optical properties using following approaches:
   1) Optimal estimation algorithm using as prior aerosol state from an assimilation system that incorporates the aerosol PoR
   2) Self-contained aerosol retrievals obtained with ACCP active and passive measurements and PoR if co-located.

b) Approach for Processing and Removal rely on geostationary passive aerosol data to characterize aerosol removal processes before and after clouds/precipitation events.

c) Changes in aerosol properties (size, absorption, etc.) will be used to characterize processing. Reduction in aerosol amount will be used to characterize removal, alongside concurrent cloud and precipitation properties.

d) Complement and where possible expand on existing climate data records. Examine inter-annual variability of aerosol processing and removal.

Role of Models – primary tool to integrate observations, test understanding & examine impacts and feedbacks.

Approach – 2 of 2

Role of Sub-orbital – cal/val variable retrievals, validate process interpretation, enhance process understanding with enhanced property measurement. Unless space component include multiple ACCP satellites on a train, a comprehensive campaign is necessary to address aerosol redistribution.

New and Improved

a) Significant improvements of key aerosol variables (vertically resolved aerosol absorption and extinction, fine mode fraction over land, etc.)

b) By means of the concurrent A and CCP measurements we will achieve significantly improved global analysis, model representation of key aerosol processes, and contextual PoR capabilities.

ACCP Aerosols and Clouds, Convection, and Precipitation Study

A+CCP	A	CCP	Objectives
			O8 Aerosol Indirect Effect **Minimum**: Provide high quality measurements to constrain process level understanding of *aerosol-warm cloud* interactions as a means to improve estimates of aerosol indirect radiative forcings. **Enhanced:** Provide high quality measurements to constrain process level understanding of interactions of aerosol with *cold and mixed-phase clouds* as a means to improve estimates of aerosol indirect radiative forcing.

Approach

General Approach - Measure a suite of cloud and aerosol variables to improve estimates of aerosol indirect radiative forcing via process-level understanding. The observational strategy focuses on joint statistics to characterize physical processes and higher level relationships between cloud, aerosol, precipitation, and radiation and comparisons with model simulations. (Chen et al 2016; Mulmenstad and Feingold 2018)

Role of Models - LES simulations will be used to test and understand process couplings (Feingold et al. 2016)

Role of Sub-orbital - More extensive validation of key satellite retrievals is needed, long-term surface observations combined with modeling will enhance process understanding (Sena et al 2016)

New and Improved - Significant improvements of key aerosol and cloud variables (aerosol amount and size, cloud LWP and microphysics including profiling, droplet concentrations, precipitation quantification)

A	CCP	ODO	POR	Utility Score	Geophysical Variables (1 of 2) Minimum / Enhanced	Qualifiers
√		S	(√)	4.6	Aerosol Optical Depth	UV to NIR Column, PBL
√				4.4	Aerosol Fine Mode Optical Depth	Column, PBL
√				4.6	Aerosol Extinction (Total & Non-Spherical)	VIS & NIR Profile
√				5.0	Aerosol-Cloud Feature Mask	
√	√		(√)	5.0	Cloud Liquid Water Path	
√			(√)	4.8	Cloud Optical Depth	
√			(√)	5.0	Cloud Droplet Effective Radius	
√	√			4.8	Cloud Droplet Concentration	Layer
√				4.2	Cloud Top Phase	
√			√	N/A	Areal Cloud Fraction	
√				5.0	Cloud Albedo	
	√		(√)	4.2	Precipitation Rate	<2 mm/hr; profile, Near surface desired
√			√	N/A	Planetary Boundary Layer height	Lidar and reanalysis
			√	N/A	Environmental Horizontal Wind	Profile
			√	N/A	Environmental Vertical Wind	Profile
				N/A	Environmental Humidity	Profile
				N/A	Environmental Temperature	Profile