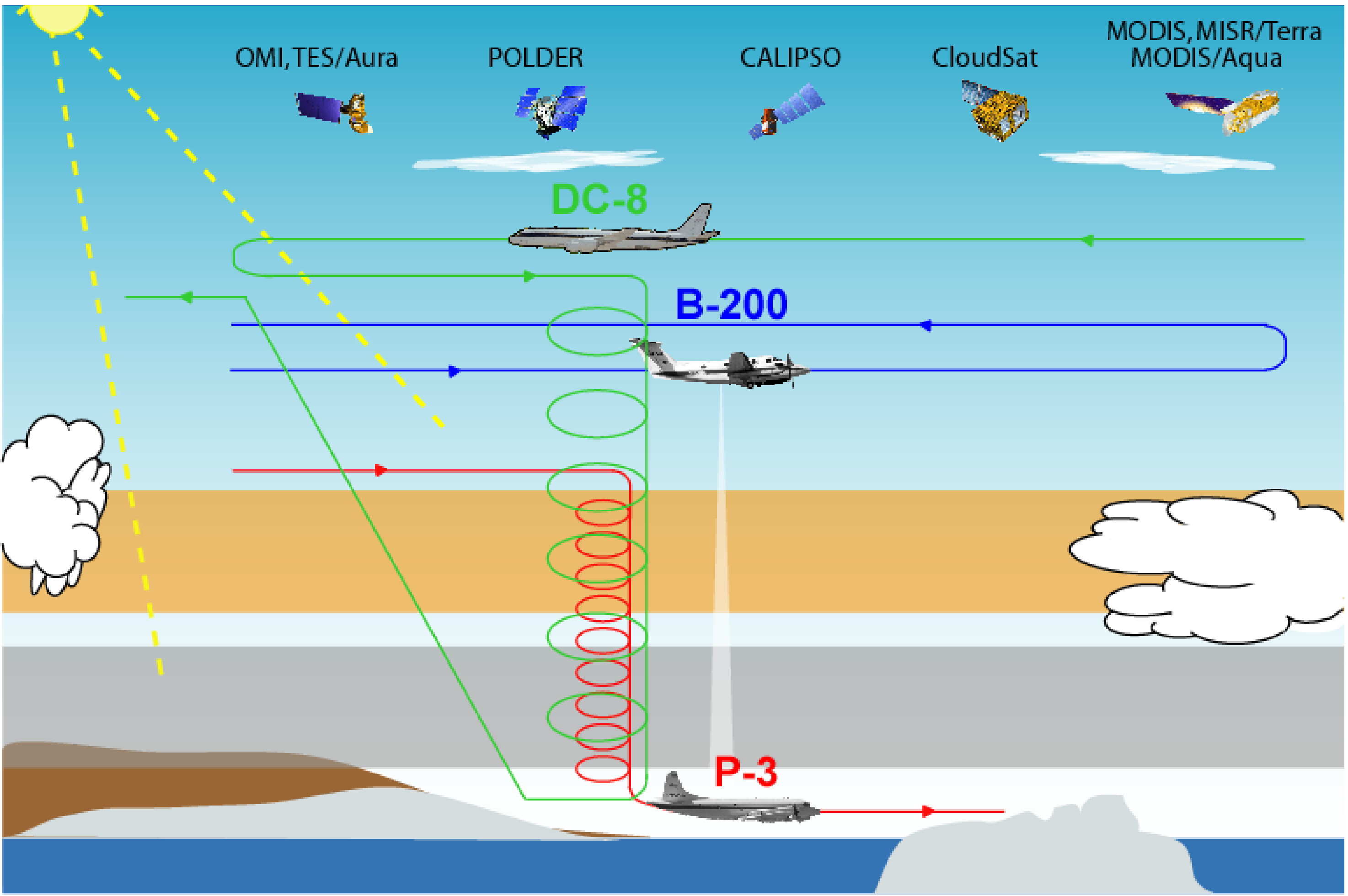
Aircraft Coordination for Interdisciplinary Science

Phil Russell

with key inputs from: Antony Clarke, Rich Ferrare, Jens Redemann, Jack Dibb



ARCTAS
Science Team Meeting
Lanham-Seabrook, MD
8-10 Jan 2008

Motivations for Coordinated Flight Plans

- Questions that ARCTAS and POLARCAT address involve measurements that are on different A/C.

- Some objectives require concurrent measurements with diverse platforms.

- Similar measurements on different platforms need intercomparisons to confirm a common data set.

- Scientific return and a broader spatial and temporal context are enhanced through coordinating A/C with satellite overpasses and/or surface sites.

Example Science Question

How does Arctic aerosol radiative forcing efficiency relate to aerosol particle size distribution, composition (including water content, ionic, organic), & mixing state (internal, external)?

Science Questions

How do Arctic aerosol, cloud, and surface properties important to radiation and remote sensing relate to aerosol physiochemical properties and history?

Properties important to radiation and remote sensing
- Aerosol radiative forcing efficiency
- Cloud albedo, optical depth and droplet size
- Surface reflectance and albedo
- Aerosol extinction-to-backscatter ratio
- Aerosol SSA(λ) & absorption Angstrom exponent

Related aerosol physiochemical properties and history
- particle size distribution
- composition (including water content, ionic, organic)
- mixing state (internal, external)
- sizes active as cloud condensation nuclei (CCN)
- particle shape
- Gas-phase tracers, precursors & trajectories (sources)

Science Question(s)

How do Arctic aerosol, cloud and surface properties important to radiation and remote sensing relate to aerosol physiochemical properties and history?

Examples of properties important to radiation and remote sensing

- Aerosol radiative forcing efficiency [P-3]
- Cloud albedo, optical depth and droplet size [P-3]
- Surface reflectance and albedo [P-3]
- Aerosol extinction-to-backscatter ratio [B-200]
- Aerosol SSA(λ) & absorption Angstrom exponent [P-3]

Examples of aerosol physiochemical properties and history

- Aerosol particle size distribution [P-3, DC-8, B-200]
- Aerosol composition (including water content) [P-3, DC-8]
- Aerosol particle shape [B-200, others?]
- Gas-phase tracers, precursors & trajectories (sources) [DC-8]

POLARCAT-ARCTAS objectives:

- Determine the vertical layering of Arctic pollution, associated optical properties and the related physiochemistry of Arctic aerosol.
- Characterize the direct radiative effects within pollution and smoke layers in the Arctic.
- Investigate the size resolved properties of cloud condensation nuclei (CCN) and interactions of aerosols with clouds and their impact on radiative forcing.
- Measure BRDF & albedo of snow, ice & other surfaces and compare those measurements to any available surface-based measurements of snow albedo/reflectance as affected by deposition of black carbon from anthropogenic and biomass burning sources.
- Study impact of boreal forest fire emissions on the composition of the troposphere and on concentrations of soot, organics and ionic species.
- Determine the lofting, transport and evolution of smoke aerosol physiochemistry and associated optical properties.
- Validate aerosol, trace gas, and cloud products of space observations from polar orbital satellites.

From the ARCTAS White Paper:

Strategy for enabling exploitation of NASA satellite data to improve understanding of arctic atmospheric composition and climate

Satellites: CALIPSO, CloudSat, OMI, TES, HIRDLS, MLS, ACE, MODIS, AIRS, MISR, MOPITT

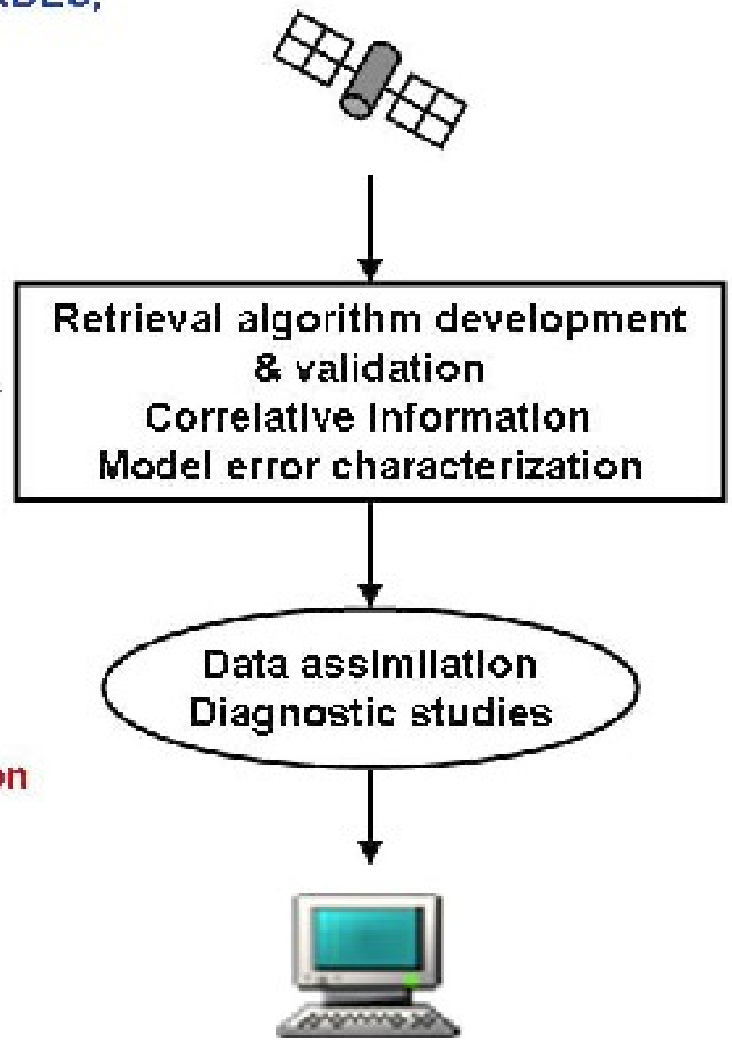
- Aerosol optical depth, properties **
- CO, ozone, BrO, NO_2, HCHO

Aircraft: DC-8 and smaller platforms

- Detailed in situ chemical and aerosol measurements
- Remote sensing of ozone, aerosol, surface properties **

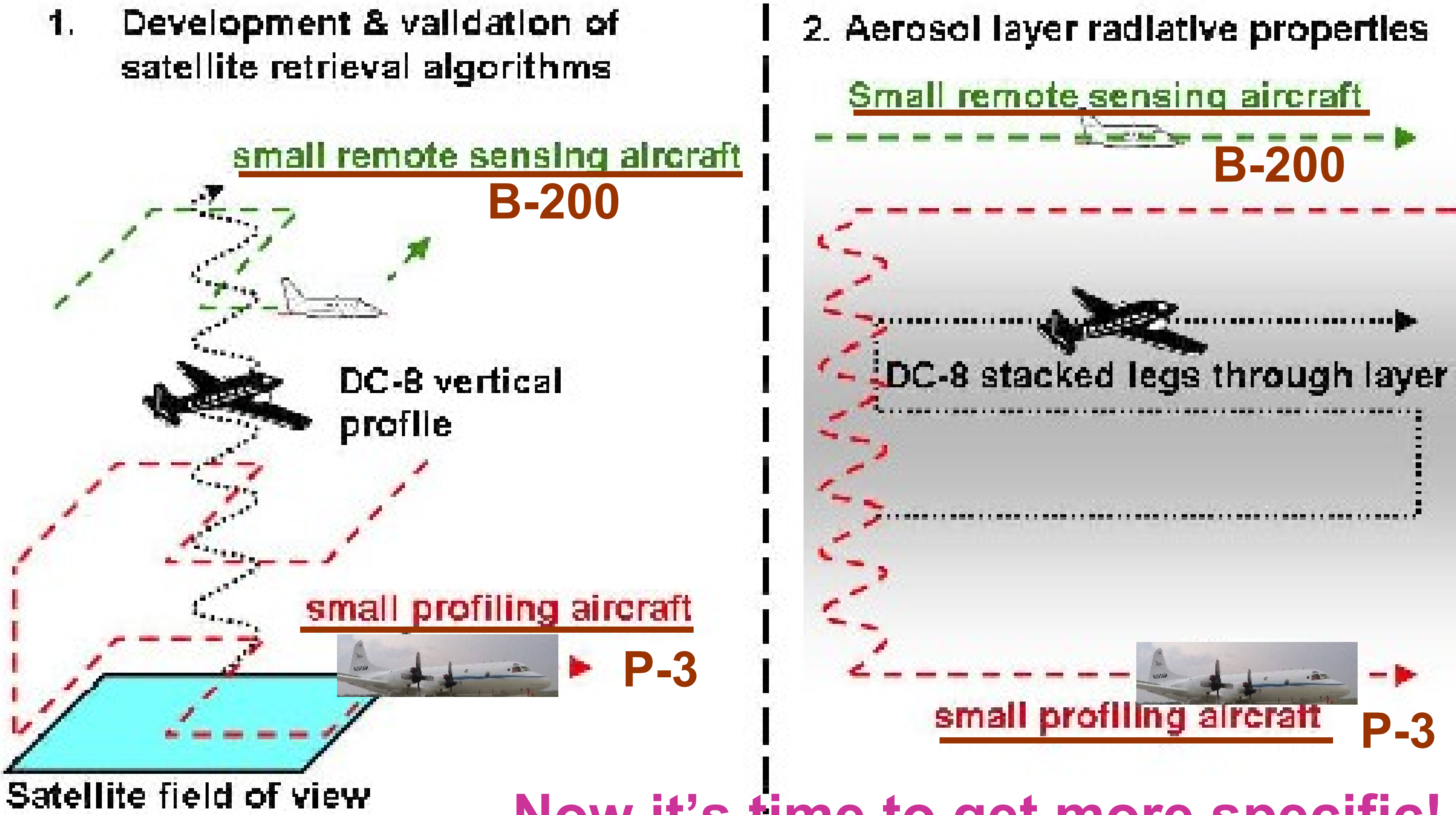
Models: CTMs, GCMs, ESMs

- Source-receptor relationships for Arctic pollution
- Effects of boreal forest fires
- Aerosol radiative forcing **
- Arctic chemistry



**+ clouds & radiation

Coordinated flights of DC-8 and smaller aircraft for investigating aerosol radiative effects

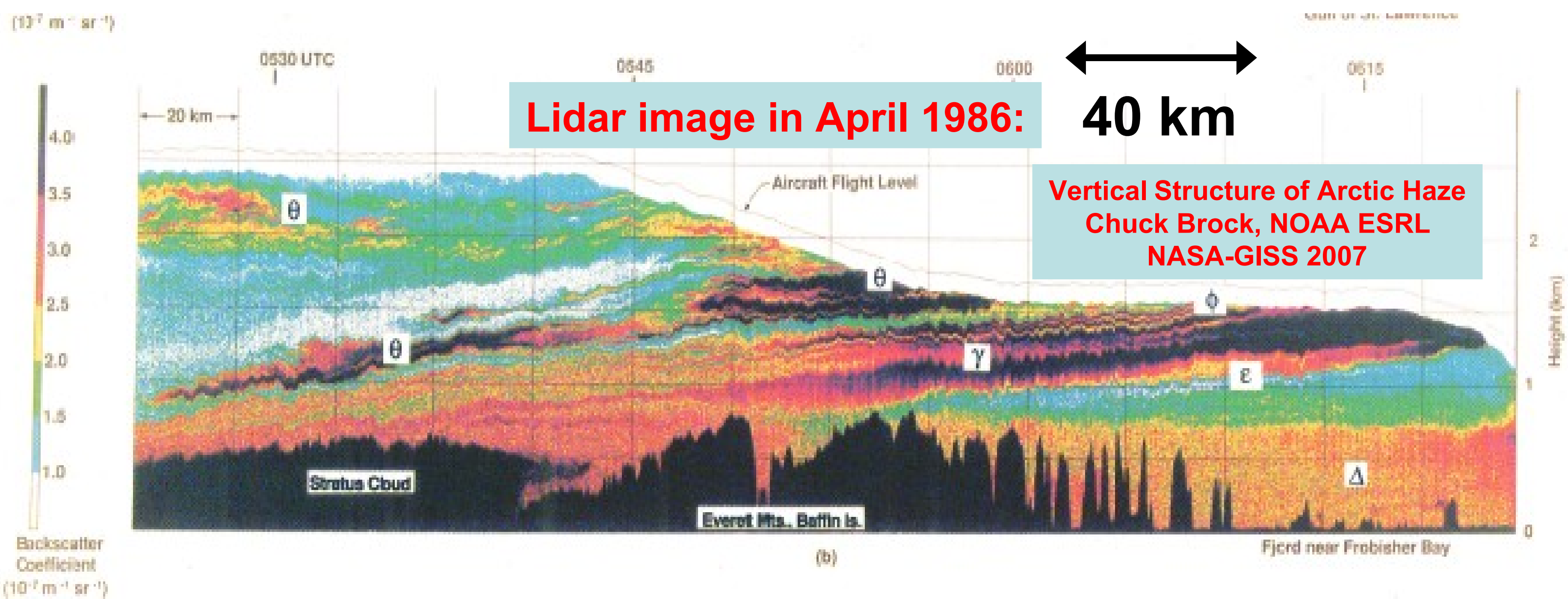


Now it's time to get more specific!

Lidar image in April 1986:

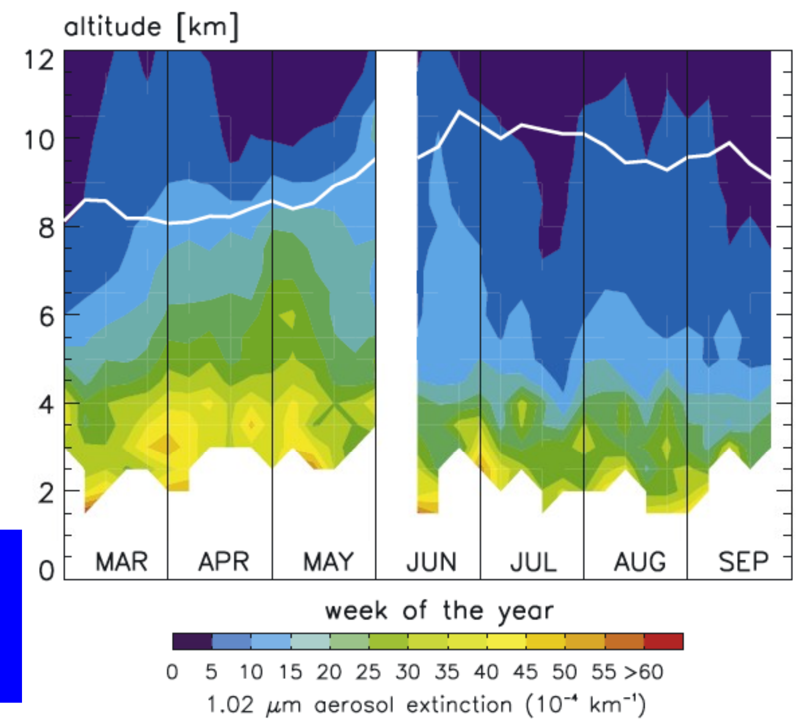
40 km

Vertical Structure of Arctic Haze
Chuck Brock, NOAA ESRL
NASA-GISS 2007



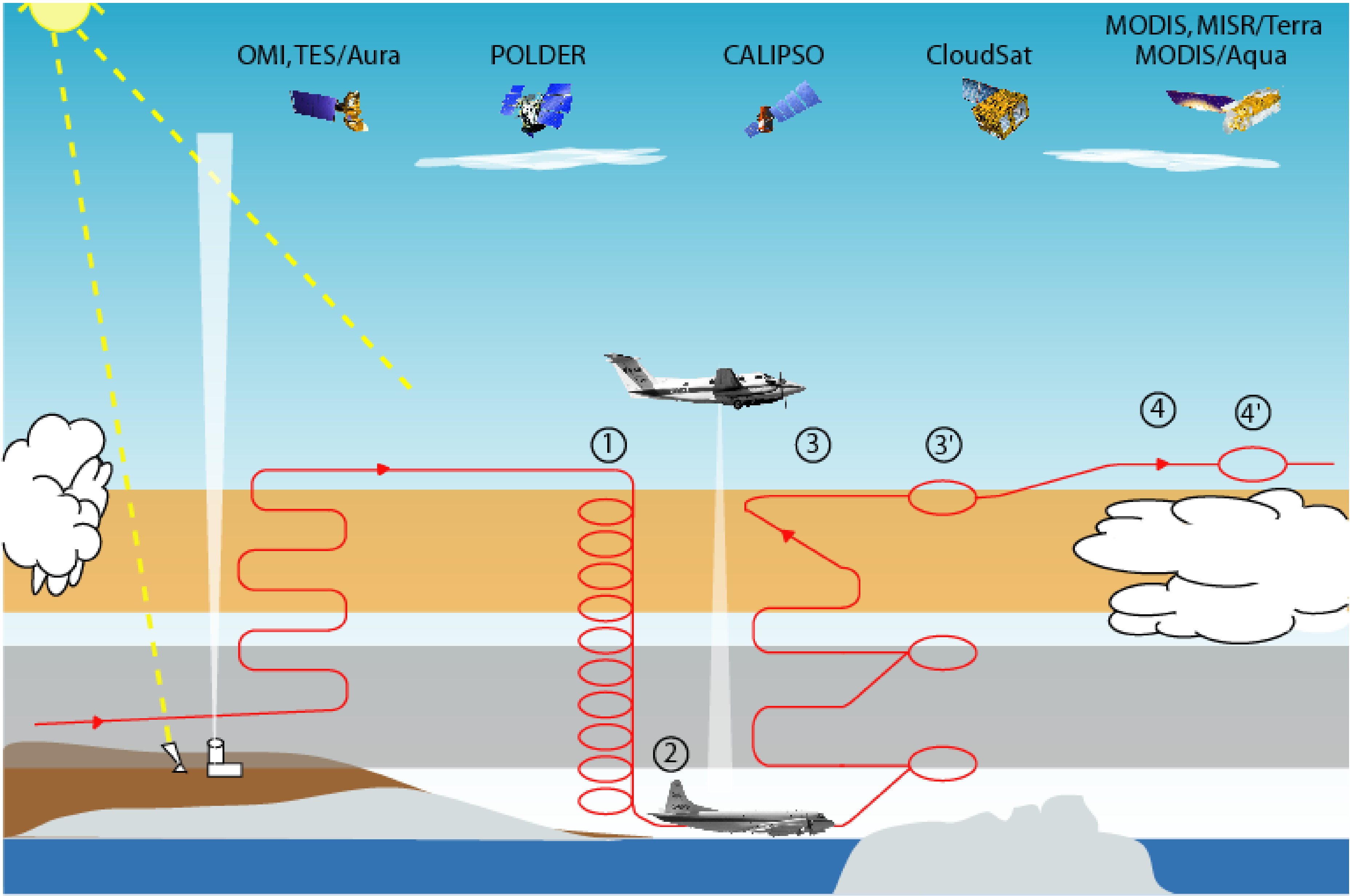
Extremely laminar transport

- Sloping thin layers
- Strong gradients vertically & horizontally
- Frequently decoupled surface layer (relevance of surface statistics?)
- Highest concentrations may be aloft
- Diamond dust and stratus near surface



Treffeisen et al.
SAGE II observations suggest maximum vertical extent in March-April.

Expected P-3 Flight Patterns for Aerosol-Cloud-Radiation Goals in ARCTAS



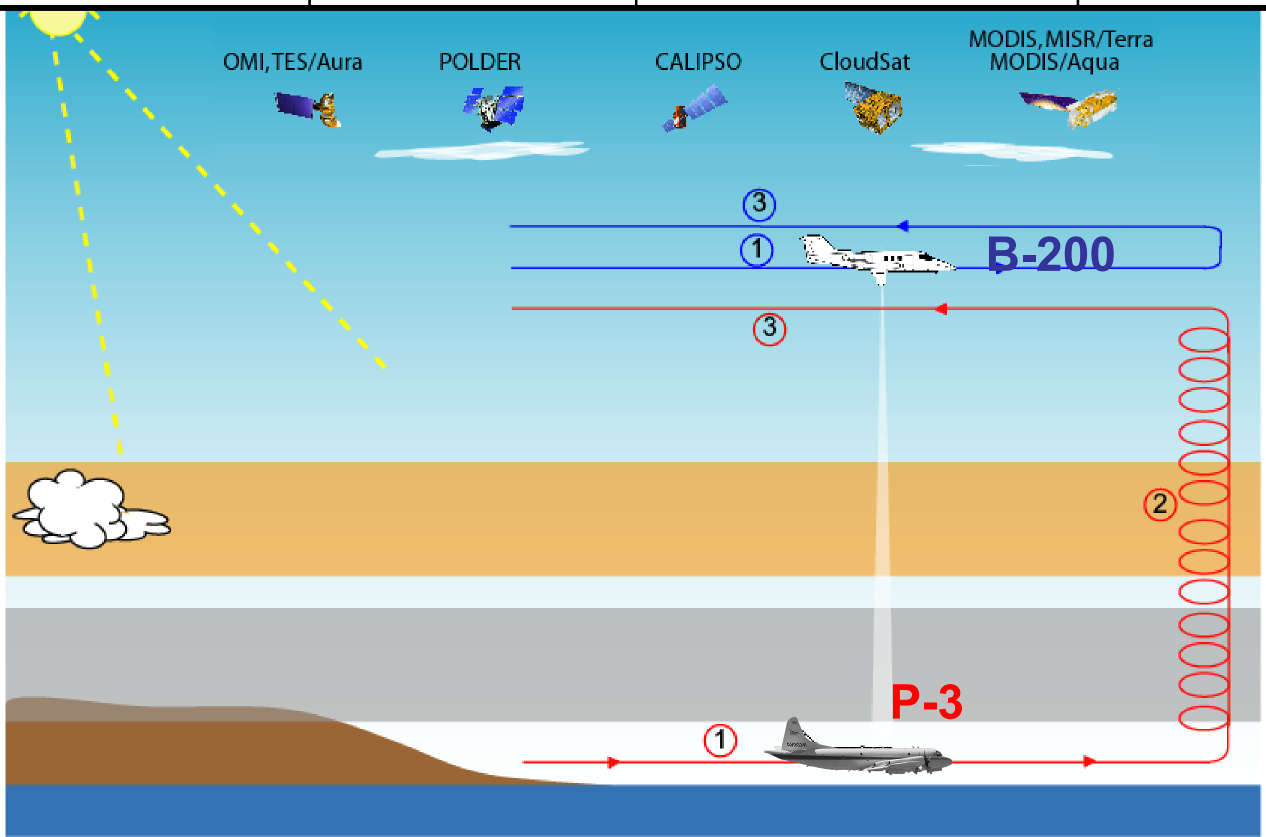
The following examples are in terms of Flight Modules

Because:

- **The P-3 & DC-8 have long flight durations**
- **Coordinated flight patterns will only be part of any given flight**
- **It's usually easier to coordinate early in a flight than later**

Clear sky, Module 1

Science objectives	**P-3 instruments involved**	**Coord instruments w/ other aircraft**	**Coordination with satellite-instruments**
-Find AOD+flux gradients -Compare HSRL, AATS, HiGEAR, AERO3X, CALIPSO ext. profiles -Compare RSP retrievals to AATS AOD & HiGEAR/AERO3X properties	AATS, SSFR, BBR, HiGEAR, AERO3X, CAR	B-200: HSRL+RSP	**CALIPSO**: CALIOP **Aqua**: MODIS **PARASOL**: POLDER **Aura**: OMI, TES **Terra**: MISR, MODIS



Coordinated B200/HSRL - Airborne in situ Measurements Ex. DOE CHAPS – June 2007

- Increases in total aerosol number measured by PCASP instrument on G-1 suggests penetration of plume from Oklahoma City
- However, coincident HSRL aerosol backscatter measurements show these aerosol number variations are due to G-1 flying in and out of PBL rather than Oklahoma City plume

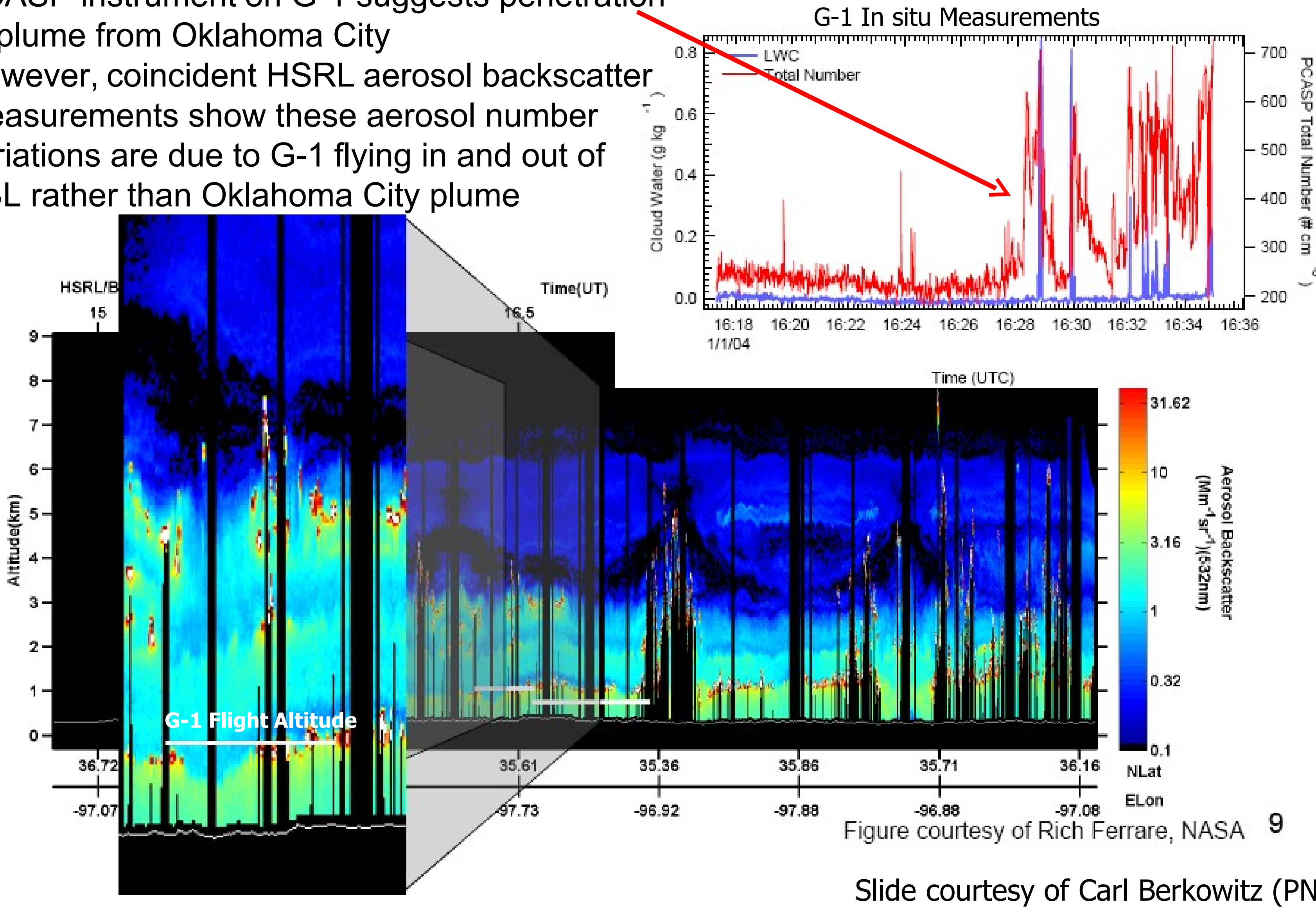
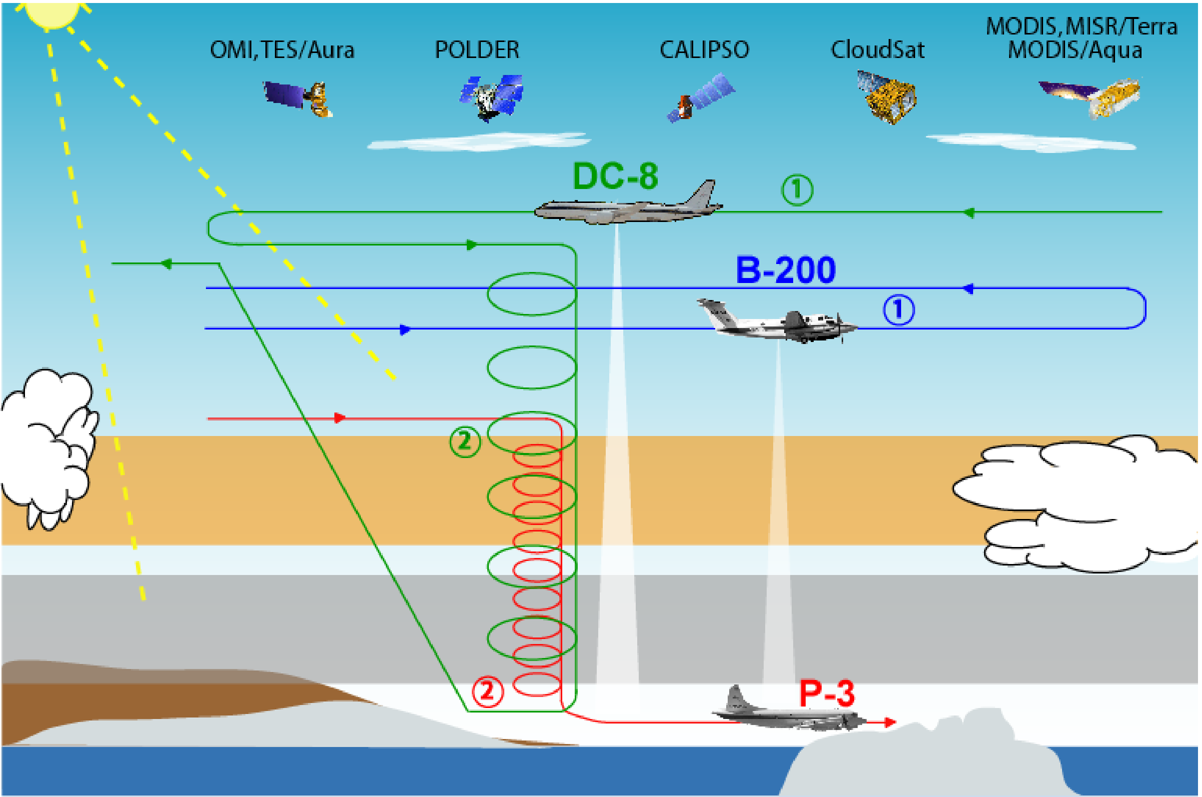


Figure courtesy of Rich Ferrare, NASA

Slide courtesy of Carl Berkowitz (PNNL)

Clear sky, Module 2

Science objectives	P-3 instruments Involved	Coord instruments w/ other aircraft	Coordination with satellite-instruments
-Find AOD+flux gradients -Compare HSRL, AATS, HiGEAR, AERO3X, CALIPSO ext. profiles -Compare DC-8 & B-200 backscat profiles -Compare DC-8 & P-3 in situ	AATS, SSFR, BBR, HiGEAR, AERO3X, CAR	**B-200**: HSRL+RSP **DC-8**: Lidar + in situ	**CALIPSO**: CALIOP **Aqua**: MODIS **PARASOL**: POLDER **Aura**: OMI, TES **Terra**: MISR, MODIS

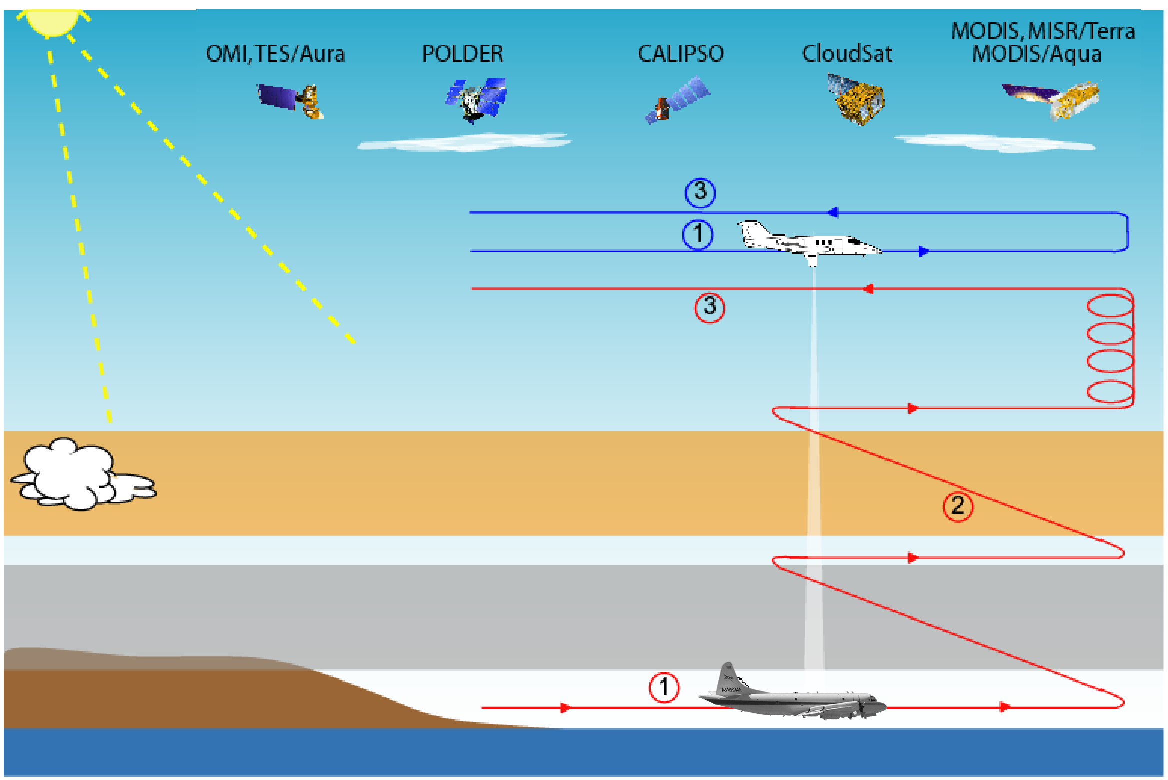


(1) Compare DC-8 & B-200 lidar profiles (+ CALIPSO if available)

(2) Nested spirals give comparisons of DC-8 in situ to
- P-3 in situ
- AATS & HSRL ext

Clear sky, Module 3

Science objectives	P-3 instruments involved	Coord with instruments on other aircraft	Coordination with satellite-instruments
-SSFR+AATS flux divergence for aerosol absorption compared to HiGEAR, AERO3X in situ	AATS, SSFR, BBR, HiGEAR, AERO3X, CAR	**B-200**: HSRL+RSP	**Aqua**: MODIS (possibly in-glint) **PARASOL**: POLDER **Aura**: OMI, TES



Background on Radiative Flux Divergence & Closure, Absorption Spectra, etc.

Downwelling Flux: $F\downarrow$

Upwelling Flux: $F\uparrow$

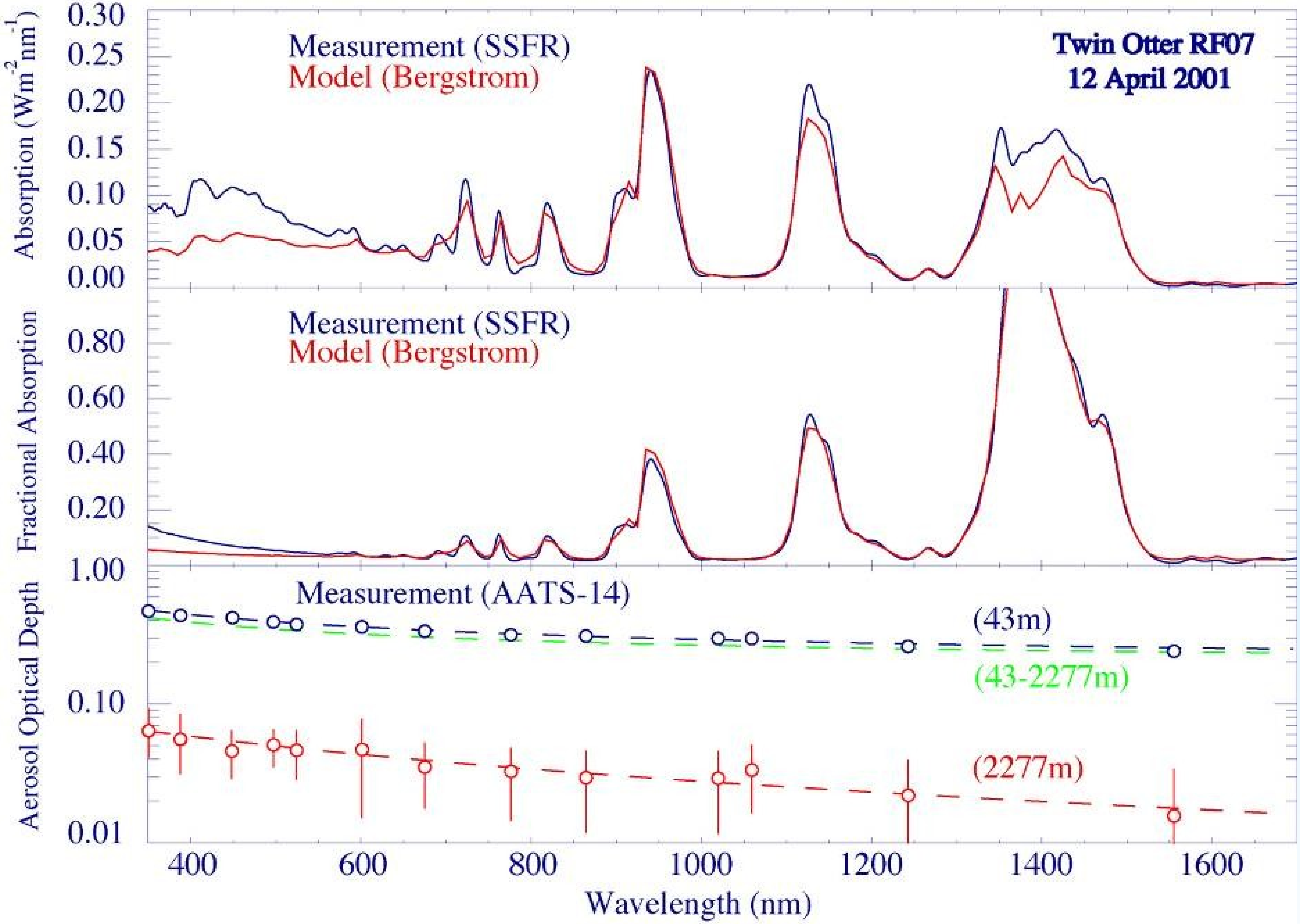
Net Flux: $F\downarrow - F\uparrow$

Flux Divergence (absorption):

$$(F\downarrow - F\uparrow)_{2000m} - (F\downarrow - F\uparrow)_{43m}$$

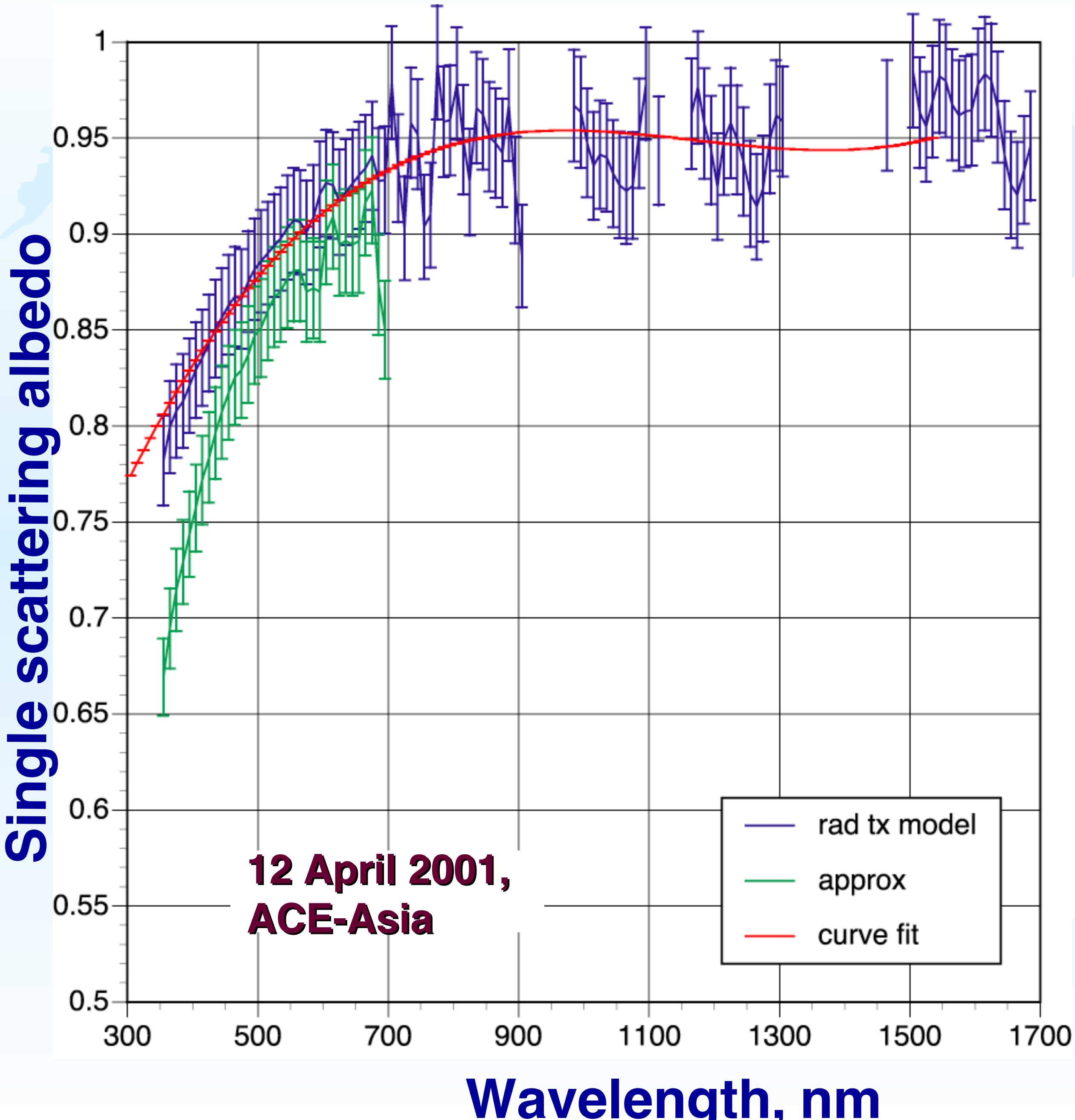
Fractional absorption:

$$[(F\downarrow - F\uparrow)_{2000m} - (F\downarrow - F\uparrow)_{43m}] / F\downarrow_{2000m}$$



Pilewskie, Bergstrom, Schmid et al.

Aerosol Single Scattering Albedo Spectrum



Derived from measured flux and AOD spectra.

<u>Desirable features</u>:

- **Describes aerosol in its ambient state (incl volatiles like water, organics, nitrates)**
- **Wide λ range: UV-Vis-SWIR**
- **Includes λ range of OMI-UV, OMI-MW, MISR, MODIS, CALIPSO, HSRL, Glory ASP, RSP, POLDER, …**
- **Coalbedo (1-SSA) varies by factor 4, λ = 350-900 nm**

[Bergstrom, Pilewskie, Schmid et al., *JGR* 2004]

P. Russell, Earth Science Seminar, NASA Ames, 19 July 2007

SSA Spectra from 4 Experiments

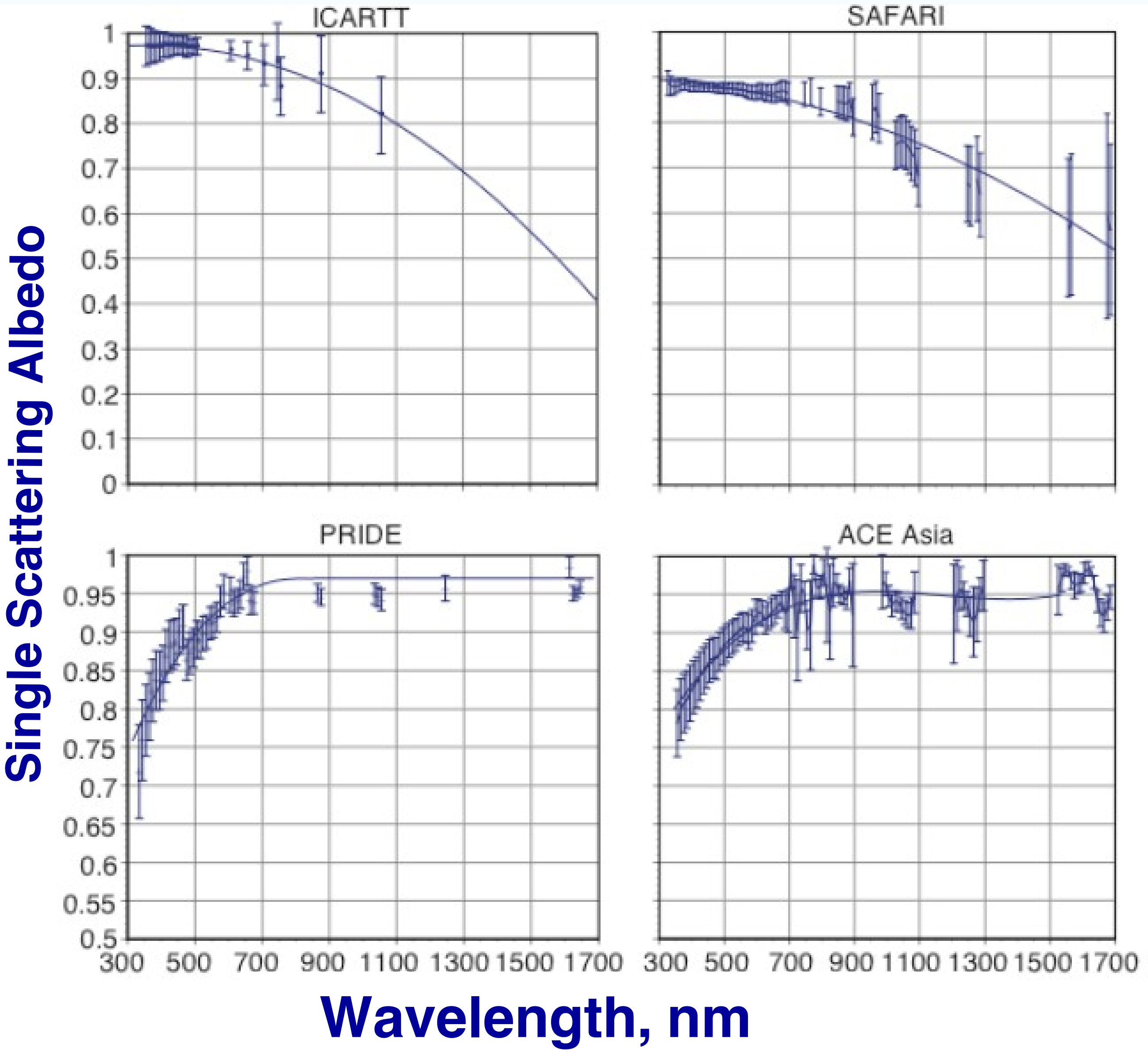
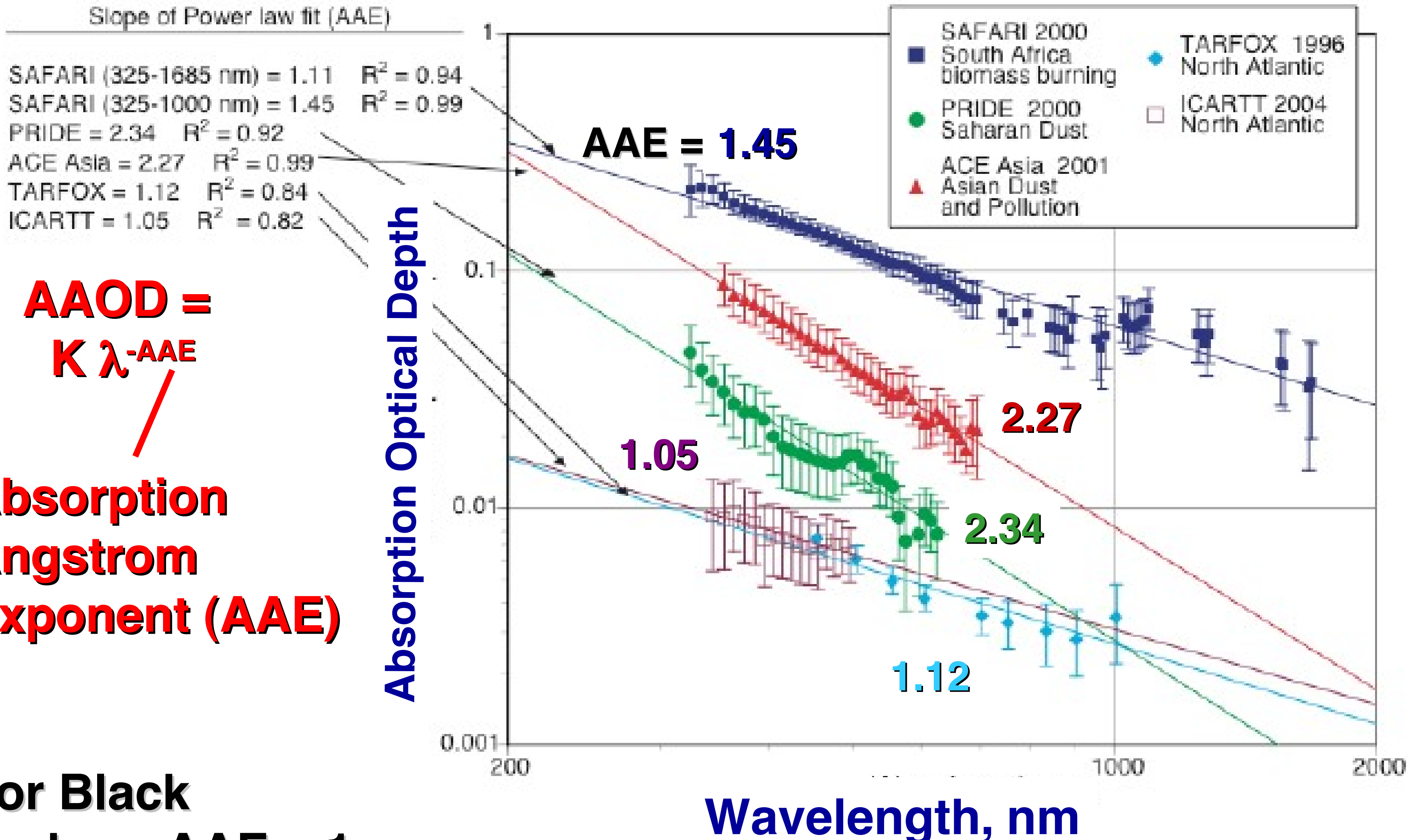


Figure 3. The single scattering albedo for the cases presented in Figu

Bergstrom et al., *ACP*, 2007

Aerosol Absorption Optical Depth (AAOD) Spectra from 5 Experiments



AAOD = K λ^{-AAE}

Absorption Angstrom Exponent (AAE)

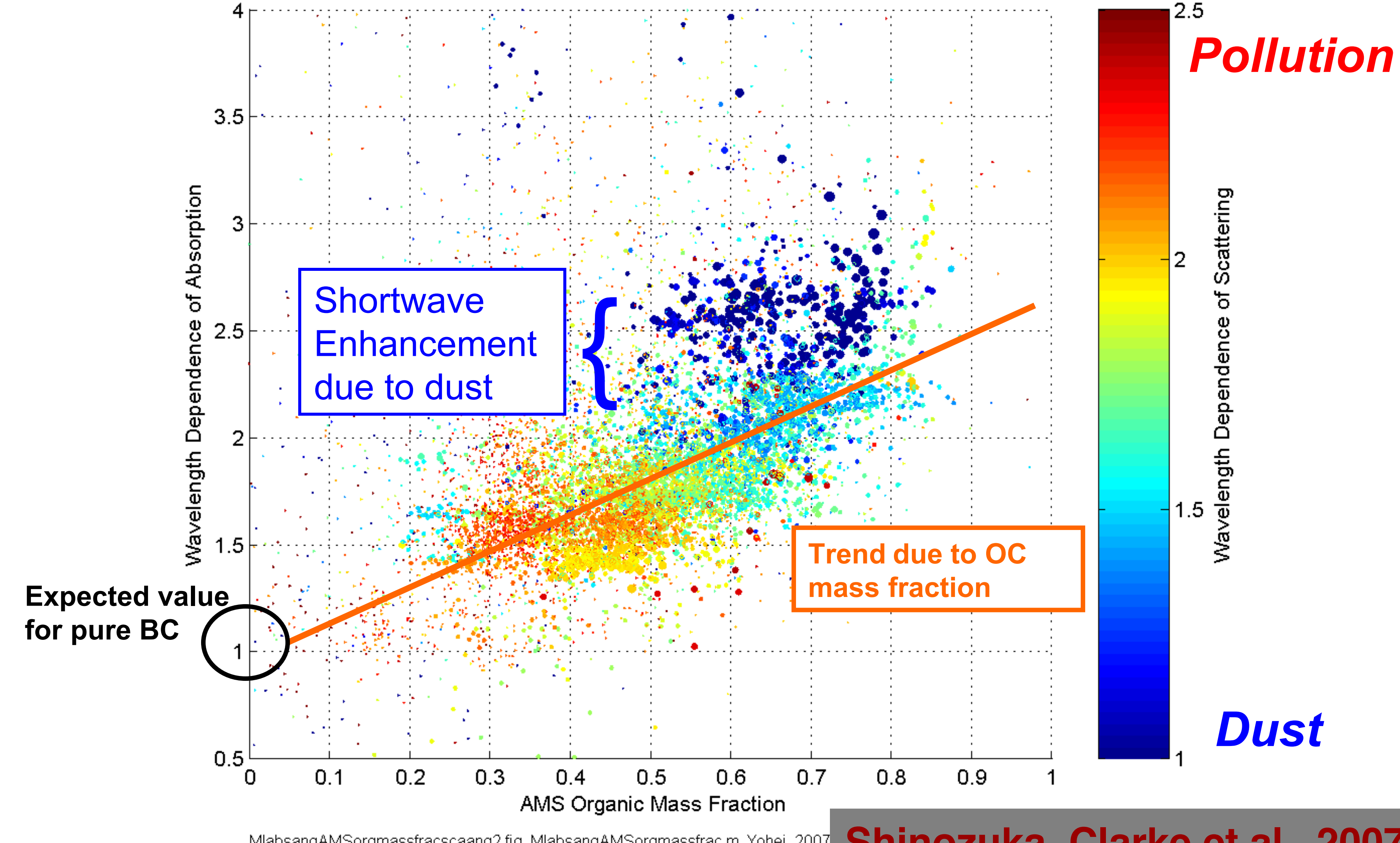
For Black Carbon, AAE = 1

Bergstrom et al., *ACP*, 2007

Wavelength dependence of absorption over Mexico is linked to both the organic carbon component (AMS - J, Jimenez, P.DeCarlo) and dust.

Model and remote sensing implications for SSA etc.

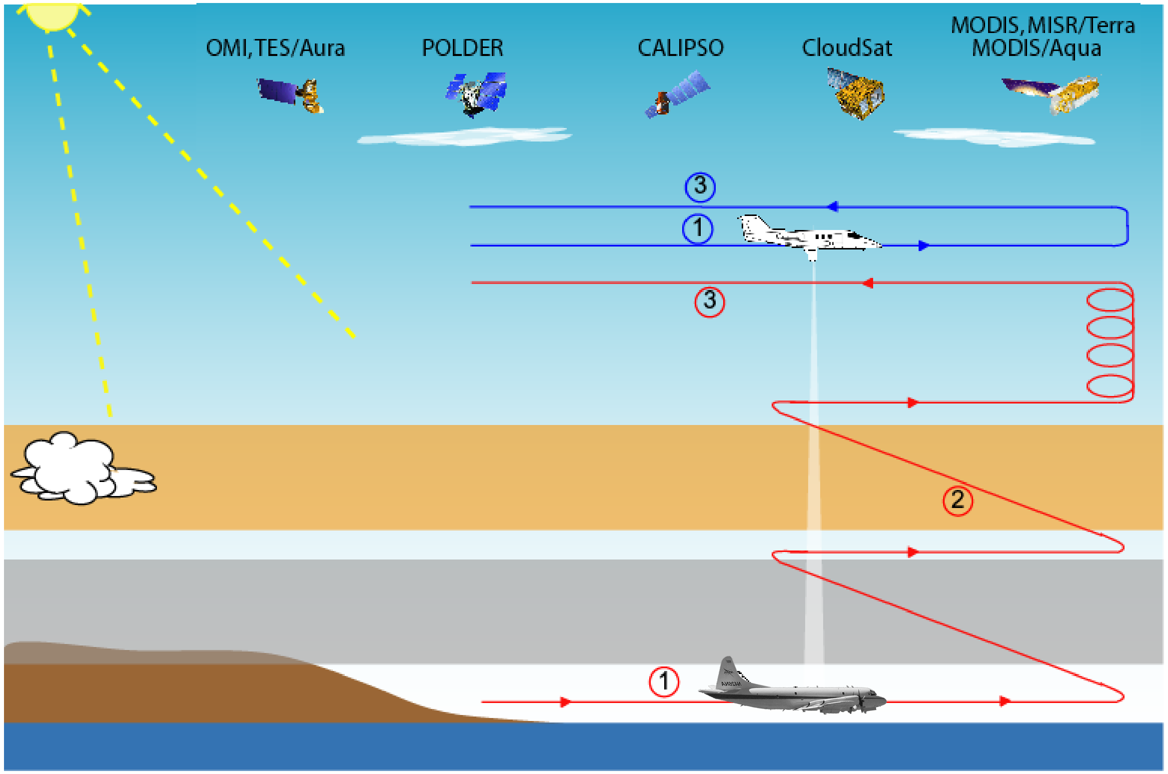
Aerosol Optics



Shinozuka, Clarke et al., 2007

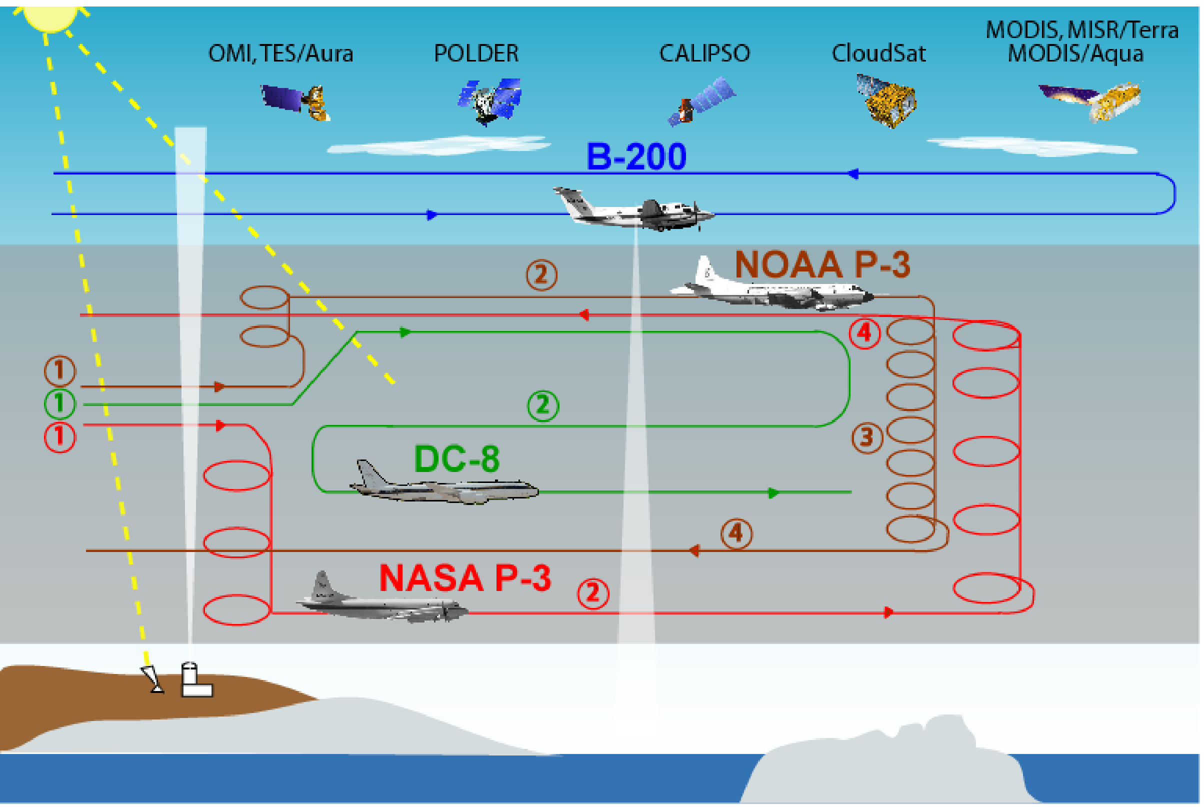
Clear sky, Module 3

Science objectives	**P-3 instruments involved**	**Coord instruments w/ other aircraft**	**Coordination with satellite-instruments**
-SSFR+AATS flux divergence for aerosol absorption compared to HiGEAR, AERO3X in situ	AATS, SSFR, BBR, HiGEAR, AERO3X, CAR	**B-200**: HSRL+RSP	**Aqua**: MODIS (possibly in-glint) **PARASOL**: POLDER **Aura**: OMI, TES



Radiative Flux Closure with In Situ

Science objectives	P-3 instruments involved	Coord with instruments on other aircraft	Coordination with satellite-instruments
-Radiative flux divergence for closure & aerosol absorption (compare abs to HiGEAR & AERO3X in situ, + DC-8 in situ)	AATS, SSFR, BBR, HiGEAR, AERO3X	**B-200**: HSRL + RSP **DC-8**: in situ + lidar **NOAA P-3**: SSFR + BBR +?	**Aura**: OMI, TES **Terra**: MISR **Aqua**: MODIS (possibly in glint) **PARASOL**: POLDER

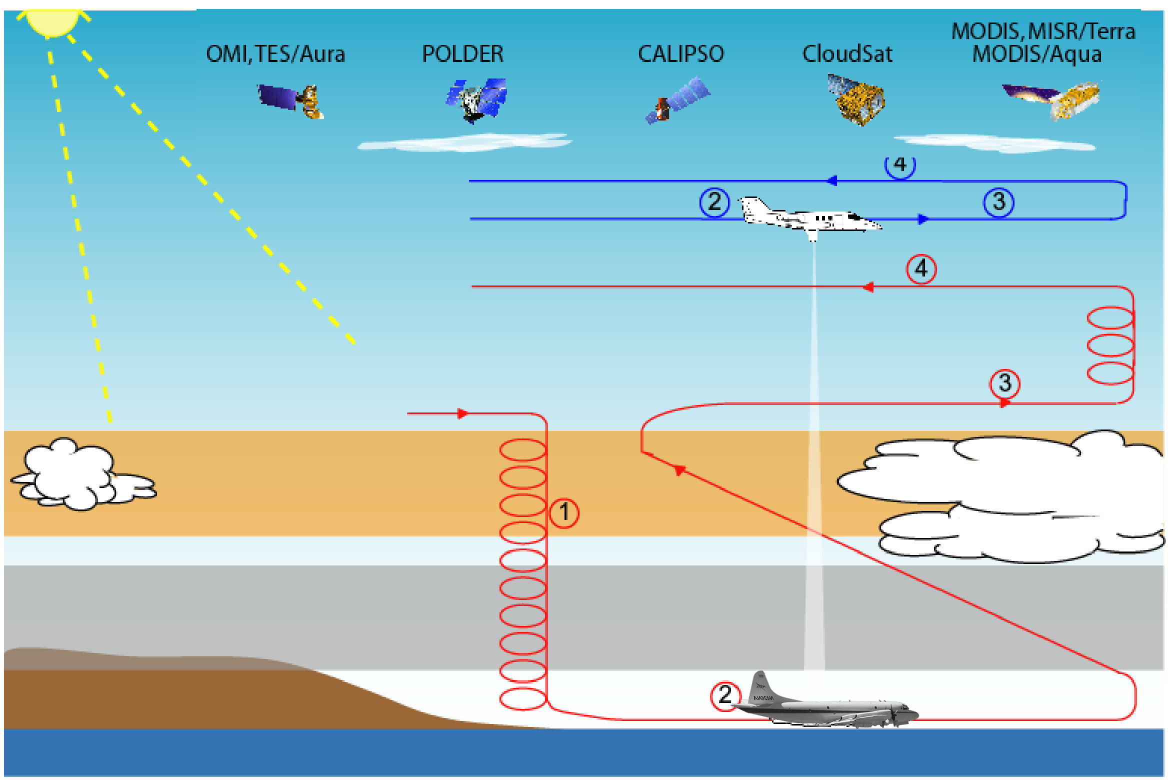


(1) Compare NASA & NOAA P-3 SSFRs & BBRs, NASA P-3 & DC-8 in situ
(2) Flux divergence by 2 P-3s while DC-8 samples within layer & B-200 profiles from above.
(3) P-3 spiral in HSRL curtain gives 4-way extinction comparison (HSRL, AATS, HiGEAR, AERO3X)
(4) Flux divergence with 2 P-3s in swapped positions

Caveat: Only Summer smoke may have large enough AOD

Partly cloudy, Module 1

Science objectives	P-3 instruments involved	Coord instruments w/ other aircraft	Coordination with satellite instruments
-Study AOD in vicinity of clouds (aerosol-cloud sep.) -Aerosol indirect effect -Compare RSP+SSFR cloud retrievals	AATS, SSFR, HiGEAR, AERO3X	**B-200**: HSRL+RSP	**CALIPSO**: CALIOP **Aqua**: MODIS **PARASOL**: POLDER **Aura**: OMI, TES



Partly cloudy, Module 1

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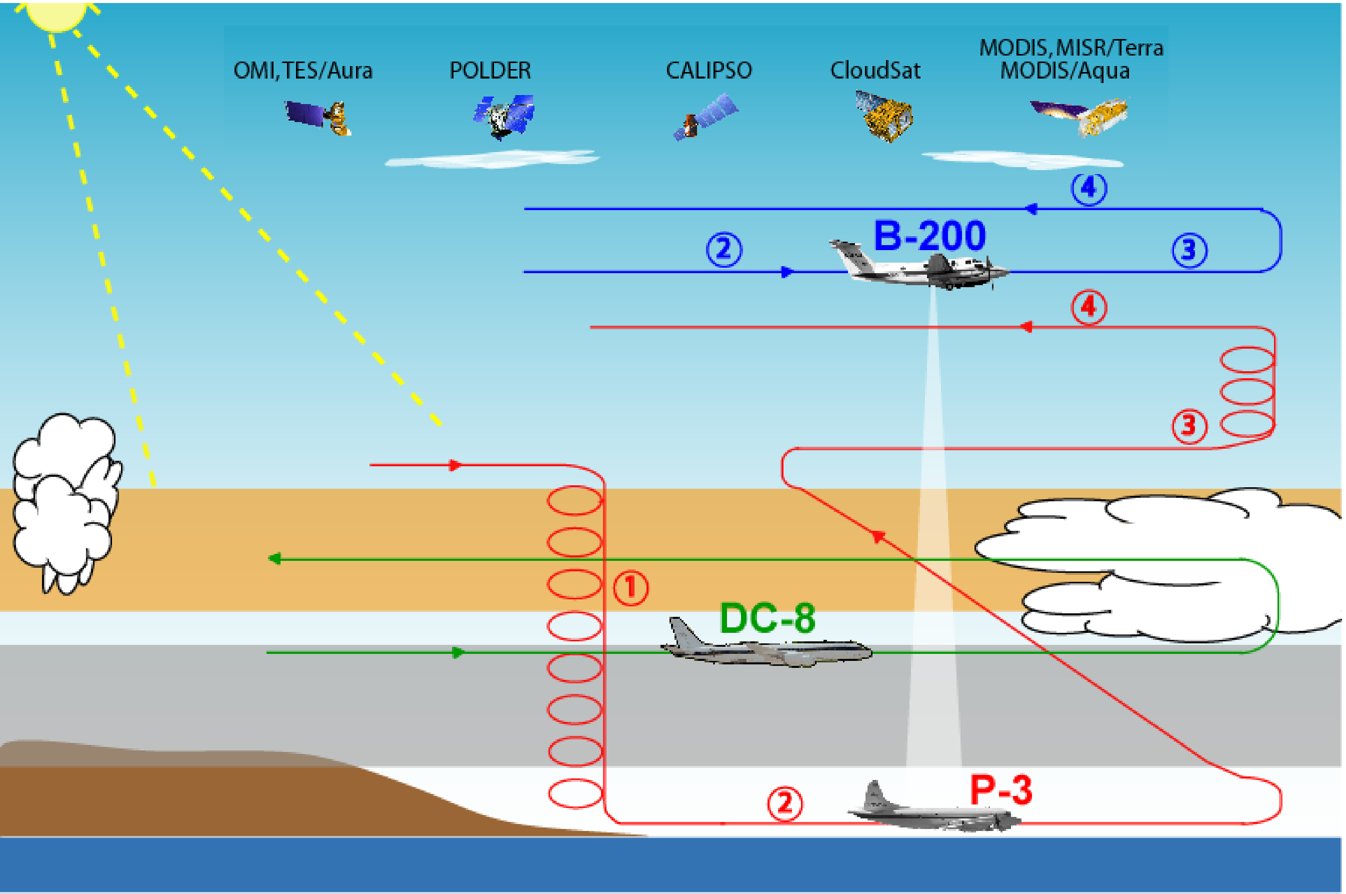
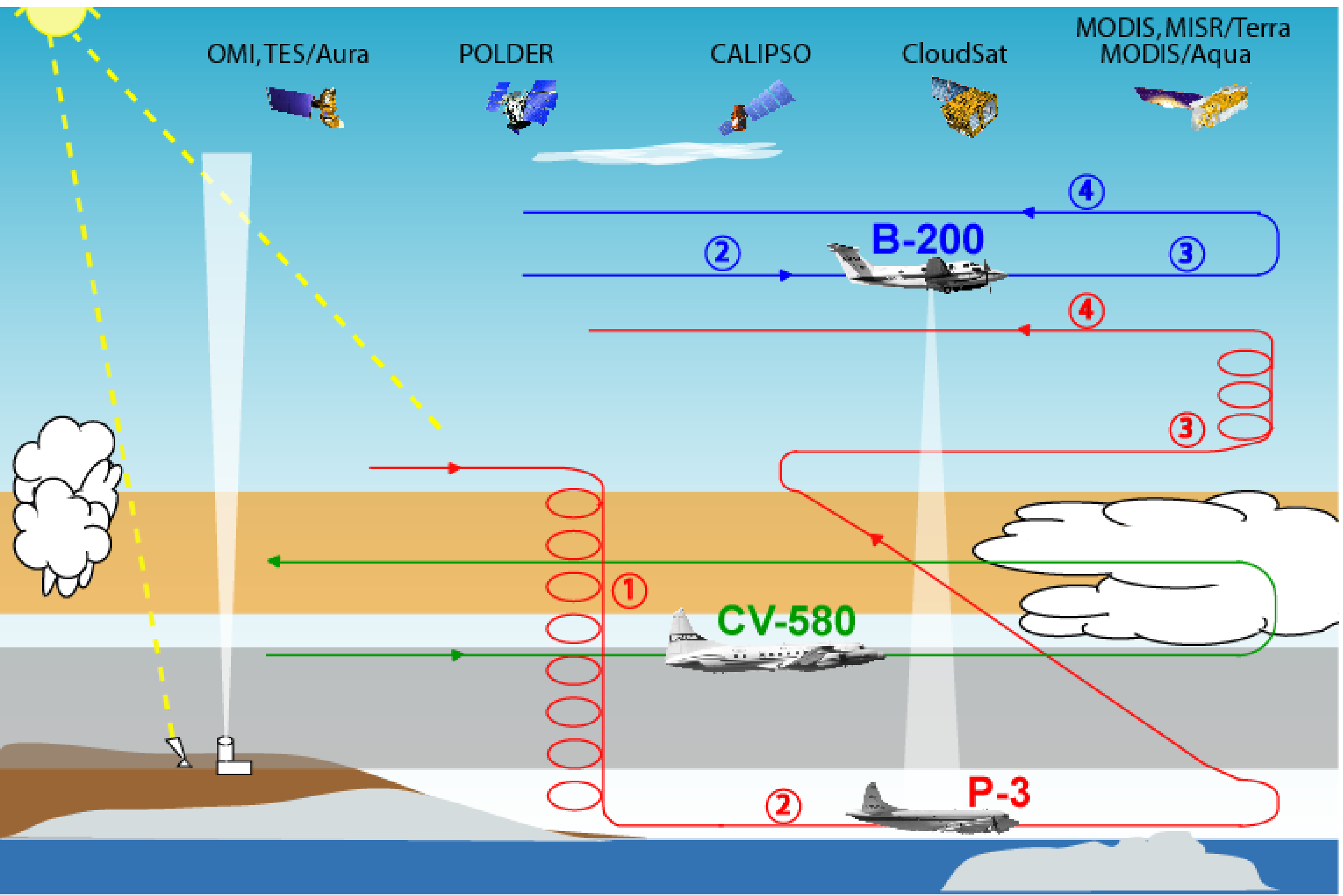


Add DC-8 for below-cloud aerosol & within-cloud measurements

Partly cloudy, Module 1

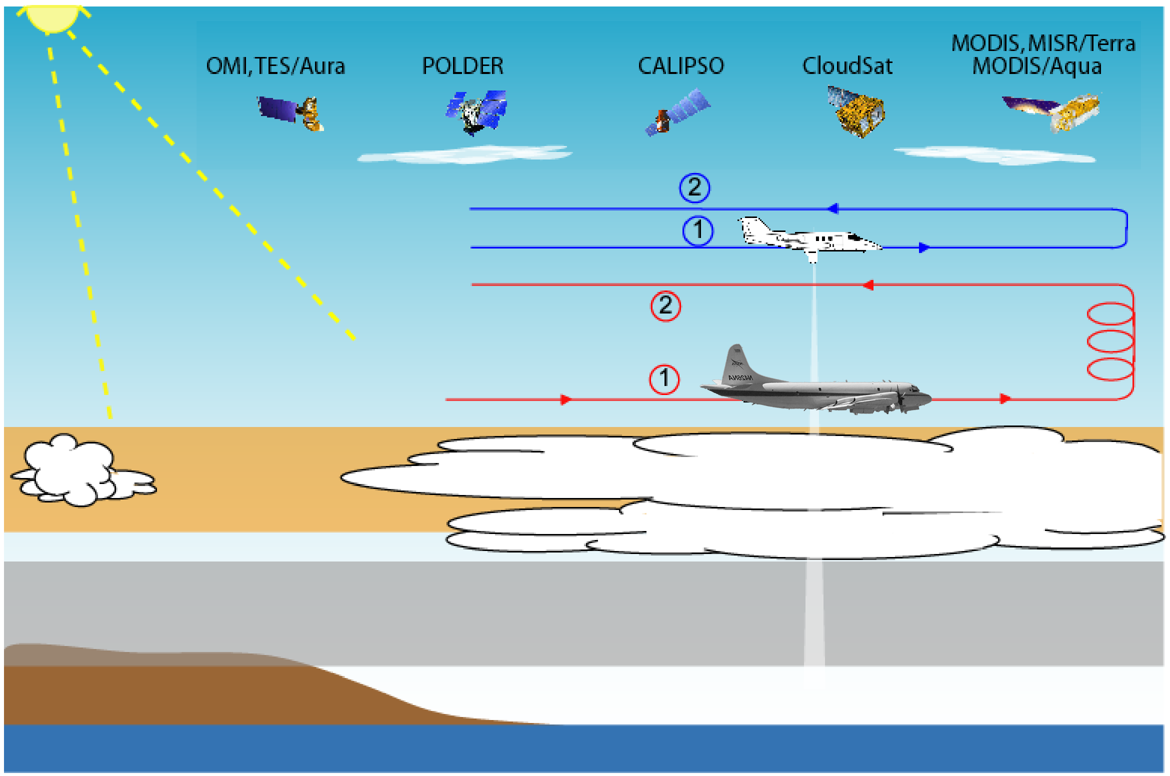
Science objectives	P-3 instruments involved	Coord with instruments on other aircraft	Coordination with satellite instruments
-Study AOD in vicinity of clouds (aerosol-cloud sep.) -Aerosol indirect effect -Compare RSP+SSFR cloud retrievals with in-cloud meas	AATS, SSFR, HiGEAR, AERO3X	**B-200**: HSRL+RSP **CV-580**: In situ	**CALIPSO**: CALIOP **Aqua**: MODIS **PARASOL**: POLDER **Aura**: OMI, TES



Add CV-580 for below-cloud aerosol & within-cloud measurements

Cloudy, Module 1

Science objectives	P-3 instruments involved	Coordination with instruments on other aircraft	Coordination with satellite-instruments
-Compare RSP+SSFR cloud retrievals -Aerosol above clouds	AATS, SSFR, BBR, HiGEAR, AERO3X, CAR	**B-200**: HSRL+RSP	**Aqua**: MODIS **PARASOL**: POLDER **Aura**: OMI, TES



Cloudy, Module 1

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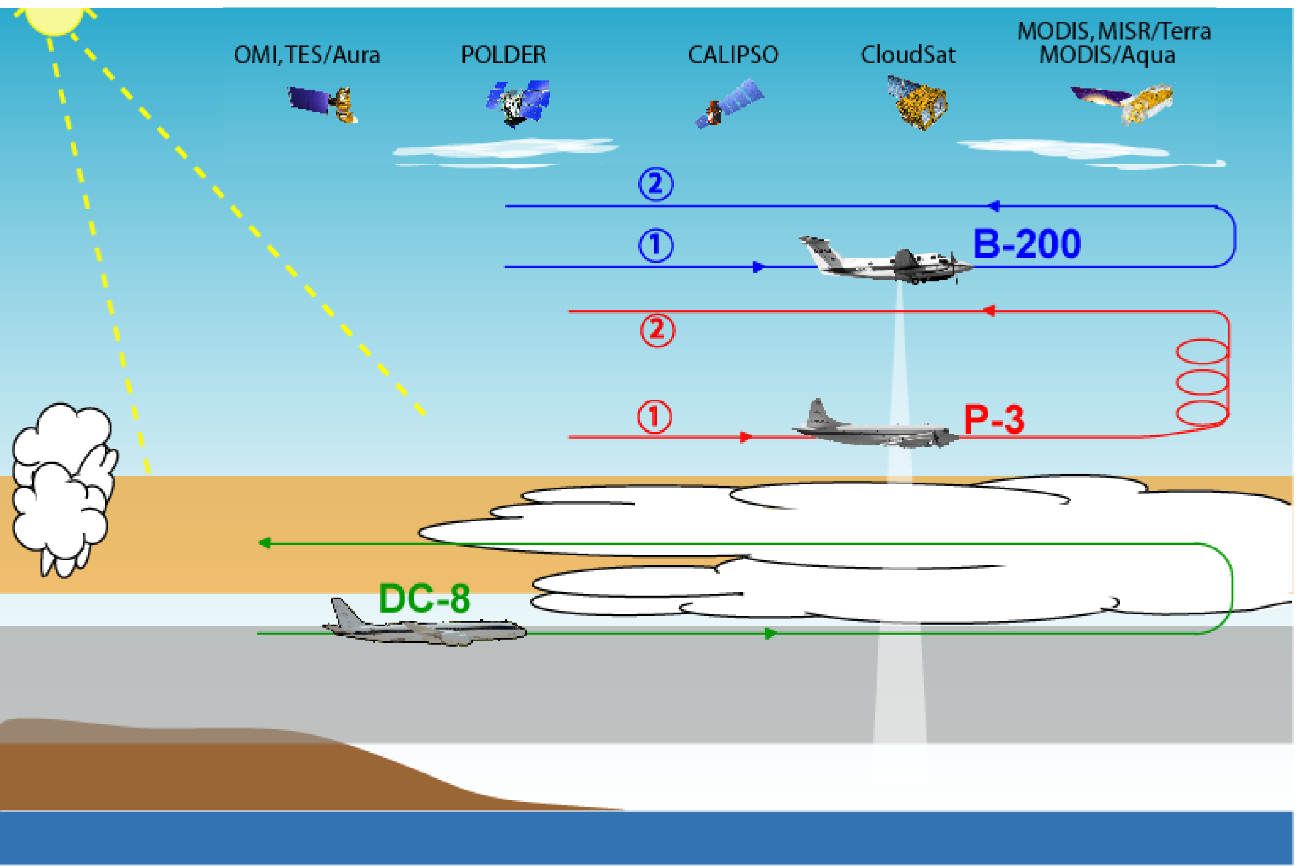

Add DC-8 for below-cloud aerosol & within-cloud measurements

Cloudy, Module 1

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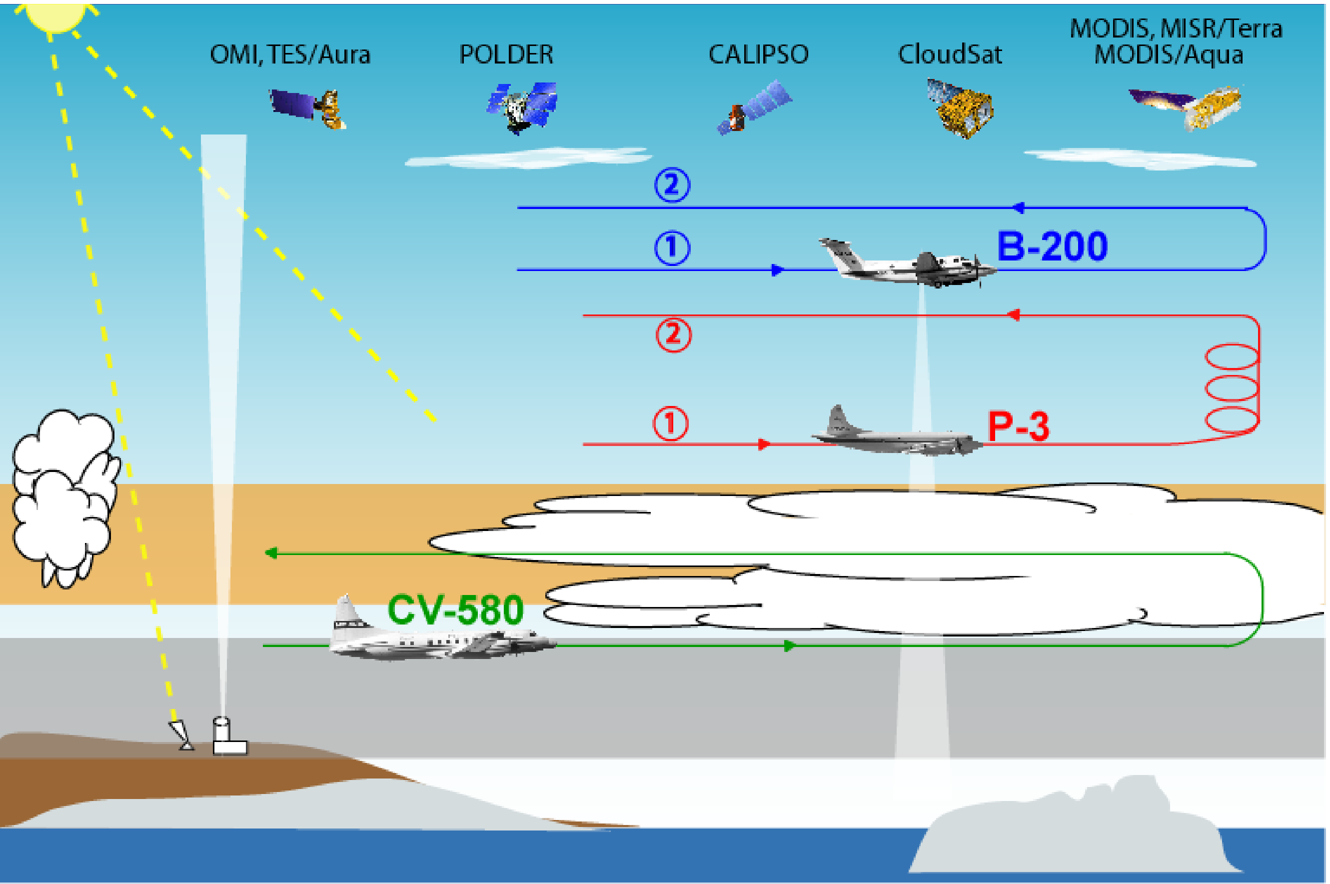


Add CV-580 for below-cloud aerosol & within-cloud measurements

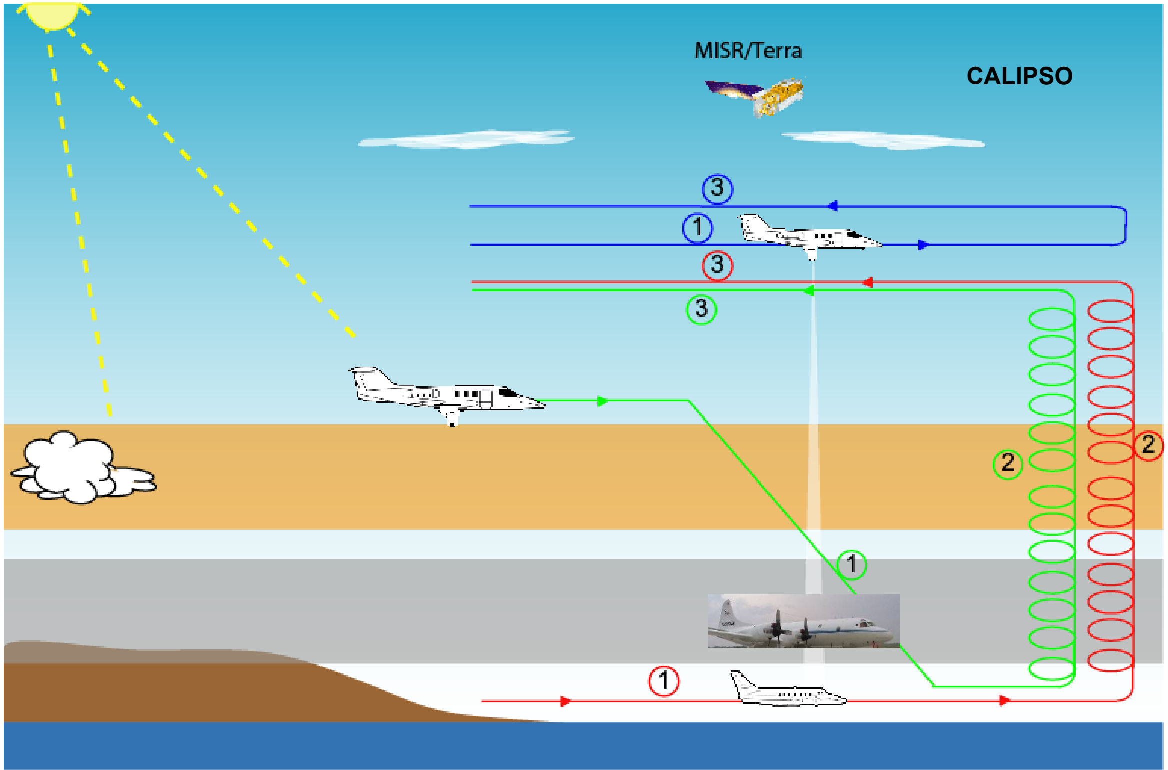
End of Presentation

Remaining slides are backup

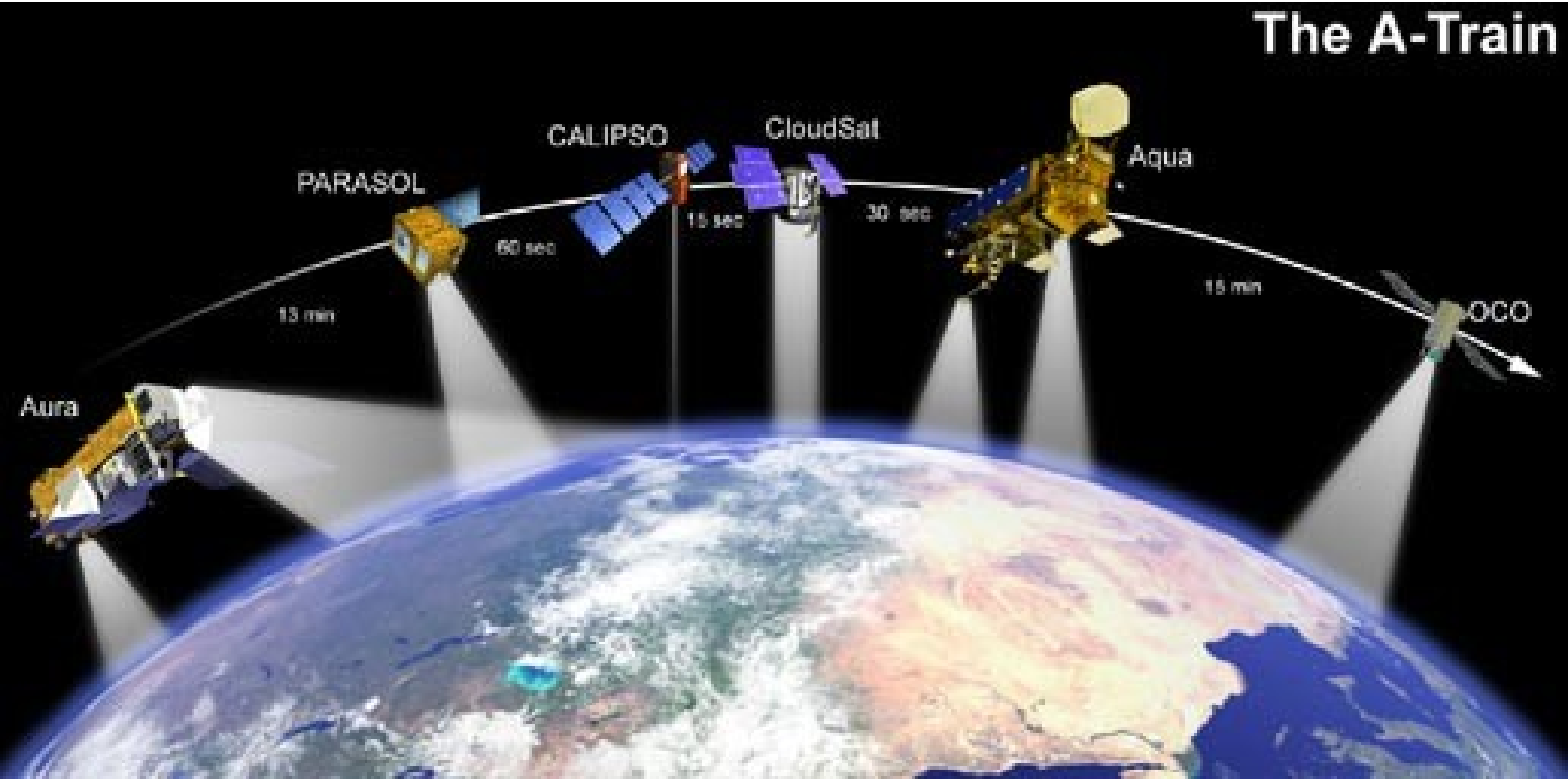
ICEALOT Cruise, 17 March-28 April 2008

Clear sky, Module 2

Science objectives	P-3 instruments involved	Coord with instruments on other aircraft	Coordination with satellite-instruments
-MISR local mode val. -Closure AATS+SSFR vs. DC-8 in situ -Compare HSRL+AATS+HiGEAR+AERO3X+CALIPSO ext.	AATS, SSFR, HiGEAR, AERO3X, CAR	**B-200**: HSRL+RSP **DC-8**: in situ + lidar	**Terra**: MISR, MODIS **CALIPSO** **A-Train**



The A-Train is a set of satellites that fly in sequence



Many P-3 flights will include legs or profiles under the A-Train or other satellites

Coordinated B200/HSRL - Airborne in situ Measurements
Ex. INTEX-B/MILAGRO/MAX-Mex – March 2006

West side of MC basin
- High depolarization, low aerosol/extinction ratio: dust

East side of MC basin
- Low depolarization, high extinction/backscatter ratio: urban pollution

- HSRL data provide vertical context for in situ data
- HSRL and G-1 measurements show changes associated with Mexico City pollution