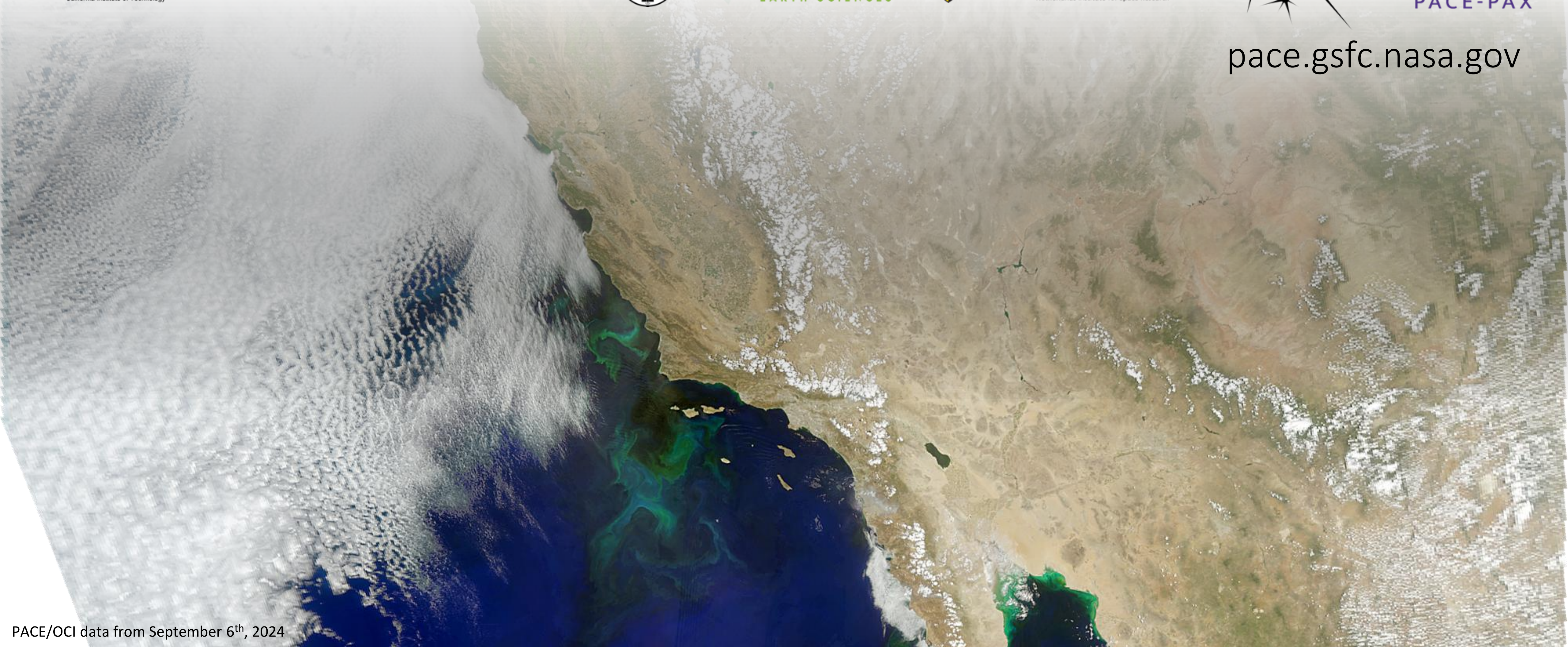
Multi-faceted PACE validation with the PACE-PAX field campaign

Kirk Knobelspiesse*

*prepared on personal time

pace.gsfc.nasa.gov



PACE/OCI data from September 6th, 2024

Multi-faceted PACE validation with the PACE-PAX field campaign

Kirk Knobelspiesse*
*prepared on personal time

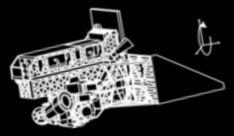
JPL Jet Propulsion Laboratory California Institute of Technology | NOAA | UMBC | NASA Langley Research Center | GODDARD EARTH SCIENCES | NPS | SRON Netherlands Institute for Space Research

PACE PACE-PAX

pace.gsfc.nasa.gov

PACE/OCI data from September 6th, 2024

OCI

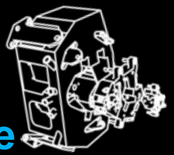


340-890 nm in 2.5 nm steps
7 discrete SWIR, 940-2260 nm
1-2 day coverage ±20° tilt, 1km

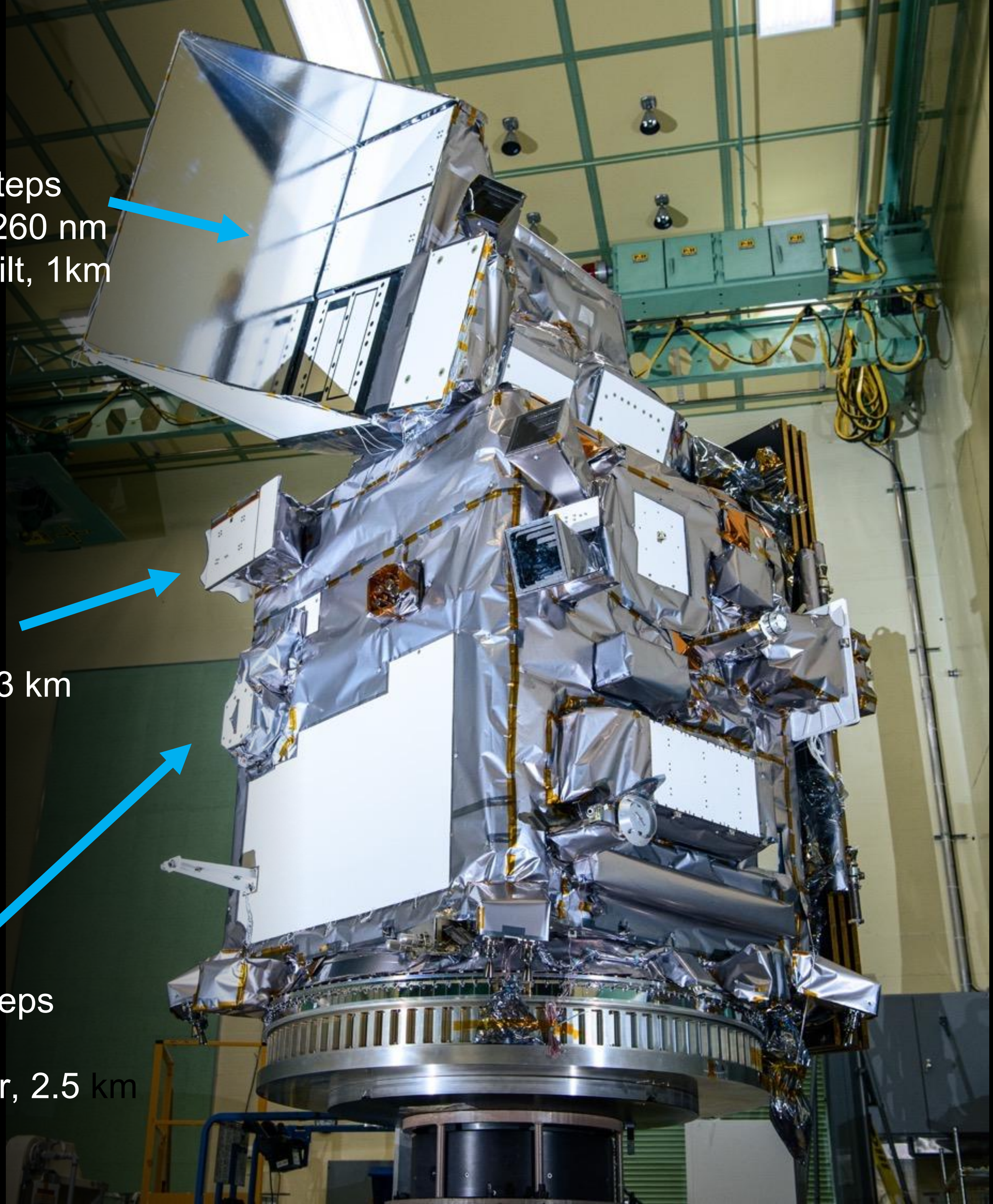
HARP2

440, 550, 670, 870 nm
10-60 viewing angles
wide swath polarimeter, 3 km

SPEXone



380-770 nm in 2-4 nm steps
5 viewing angles
narrow swath polarimeter, 2.5 km

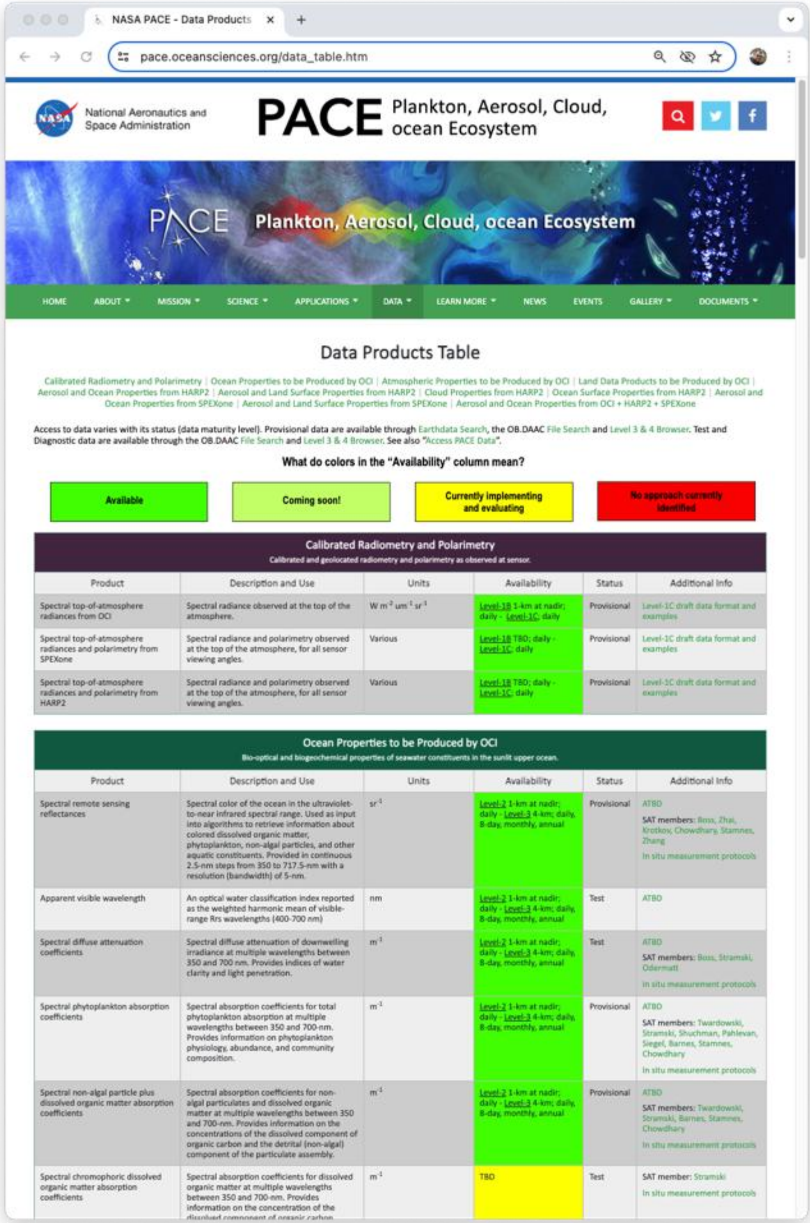


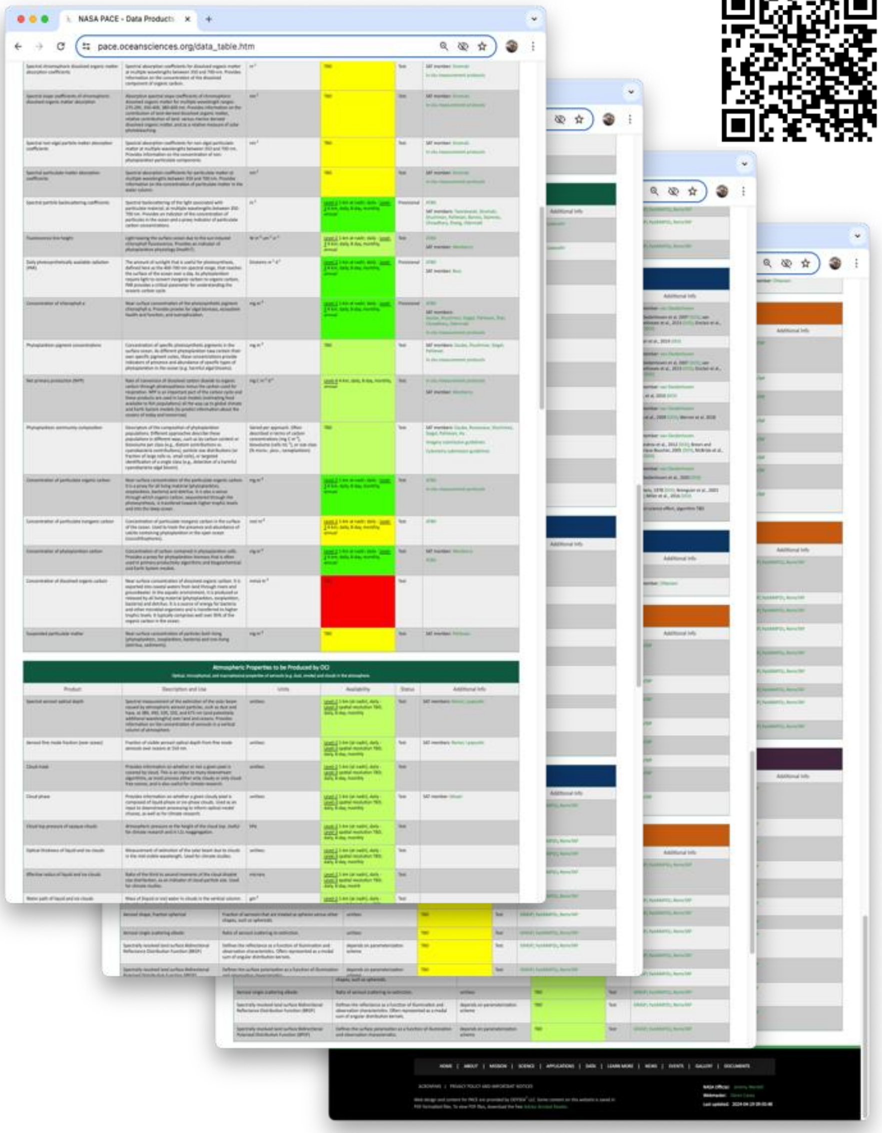
NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

PACE will extend key systematic ocean color, aerosol, & cloud climate data records, reveal the diversity of organisms fueling marine food webs, and introduce new methods to observe aerosols and clouds, the largest source of climate uncertainty.

Characteristics:

- February 8^{th} launch, April 11th data release
- 676.5 km, polar, ascending orbit, 98^{o}
- Sun synchronous, 13:00 Equatorial crossing
- Global (land and ocean) data
- Data to OB.DAAC (oceancolor.gsfc.nasa.gov)



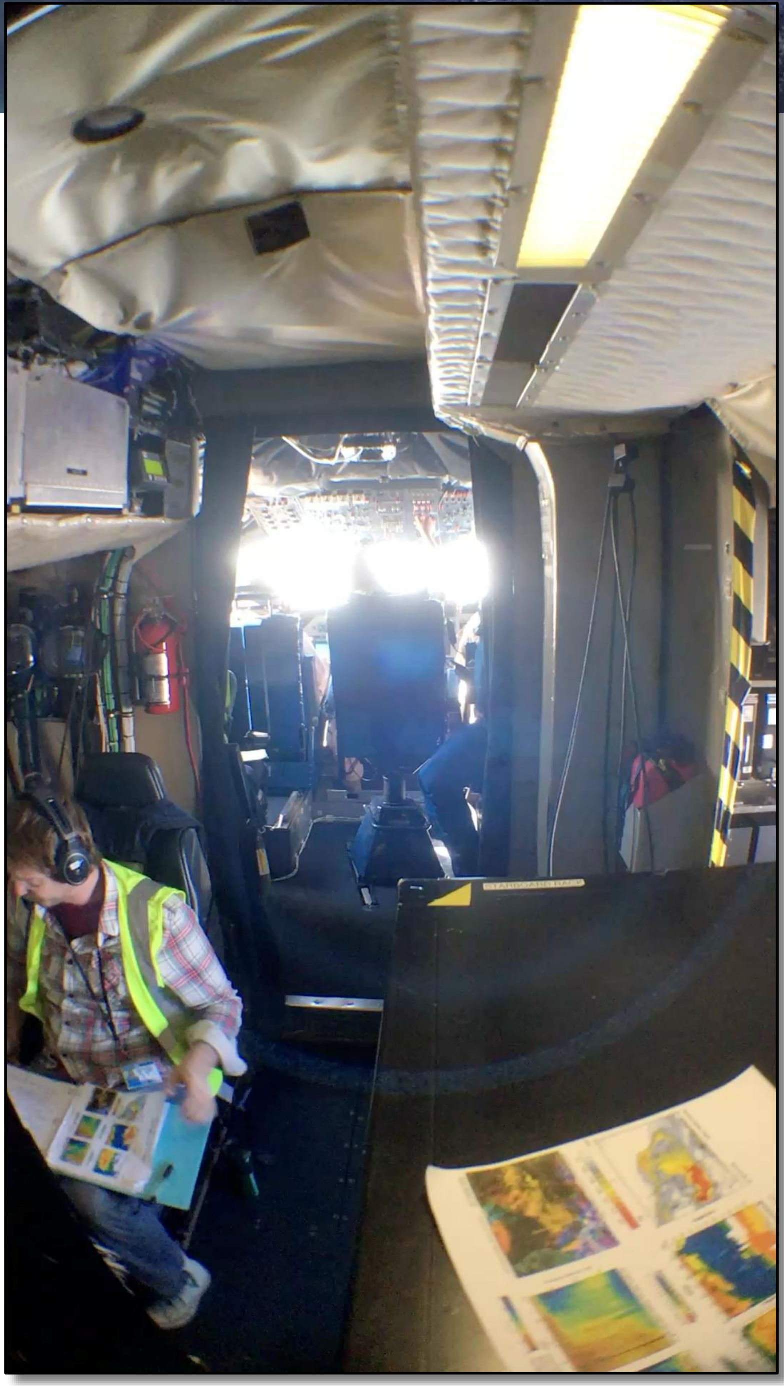


PACE has many data products

… some are currently available, others coming soon, being tested, or potential future development

Validation happens in many ways

Inside NASA P-3 during the ORACLES field campaign, SE Atlantic Ocean off São Tomé



AERONET Cimel Sun Photometer at NASA Ames Research Center, California

PACE data product development

Algorithm contributors
- PACE Project Science team
- PACE Science team members
- PACE instrument team members
- International science and user community

Implementation
- PACE Science Data Segment (SDS)
- Science Operations Team (SOT)
- Science Operations Board (SOB)

Test product
- Products that have been implemented as production-capable science code
- Feasibility and resource requirement assessment

Provisional product
- Not fully validated, quality may be sub-optimal
- Used for performance and science assessment

Standard product
- Permanent archive and distribution
- Fully validated and documented


Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission

PACE Science Data Product Validation Plan

[Jul-20] PACE Science Data Product Validation Plan PDF (973 KB) »

pace.oceansciences.org/documents.htm

Validation
- Demonstrate data products meet defined (accuracy, coverage, etc.) requirements
- Typically uses comprehensive and statistically robust comparison to field observations or other remote sensing data

Documentation
- Algorithm Theoretical Basis Document
- Validation, uncertainty assessment

PACE validation activities

- NASA Ocean Ecology Lab field support group
- PACE Validation Science Team (PVST)
- Existing community activities
  - Instrument networks e.g. AERONET, ARM, Cloudnet
  - Ongoing field activities
- SeaBASS archive and analysis system
- PACE Postlaunch Airborne eXperiment

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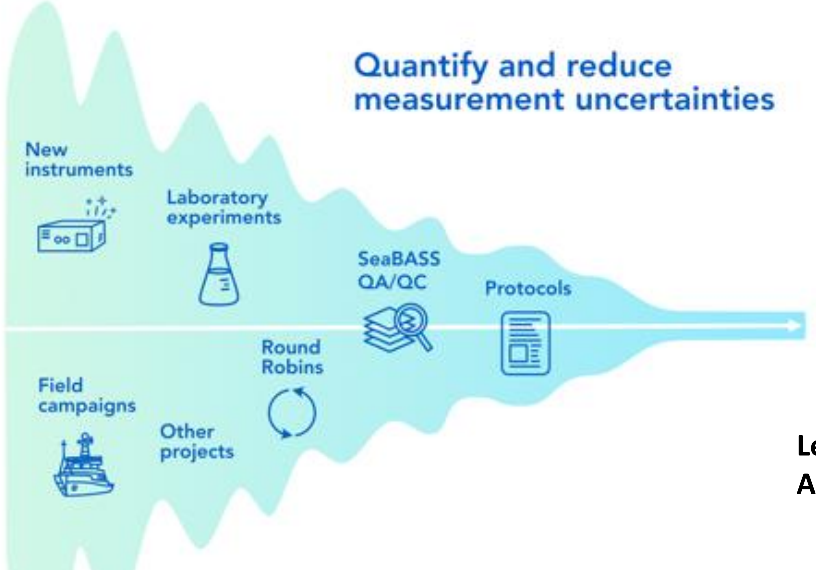
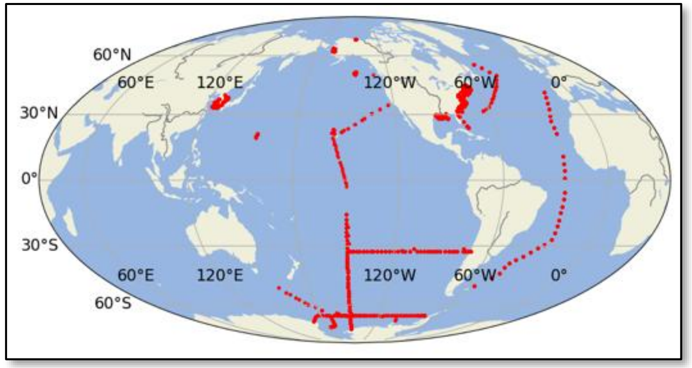
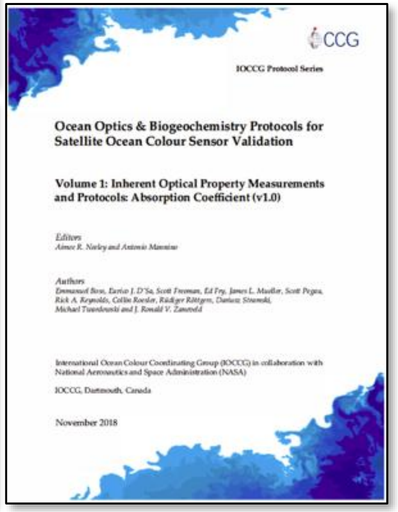


Lead: Antonio Mannino
Antonio.Mannino-1@nasa.gov





IOCCG Protocol Series

Ocean Optics & Biogeochemistry Protocols for Satellite Ocean Colour Sensor Validation

Volume 1: Inherent Optical Property Measurements and Protocols: Absorption Coefficient (v1.0)

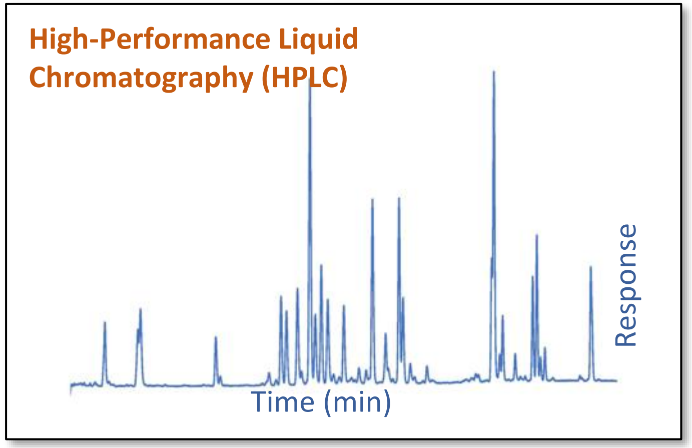
Editors
Aimee R. Neeley and Antonio Mannino

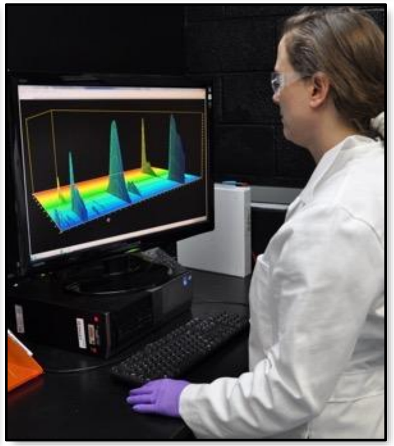
Authors
Emmanuel Boss, Eurico J. D'Sa, Scott Freeman, Ed Fry, James L. Mueller, Scott Pegau, Rick A. Reynolds, Collin Roesler, Rüdiger Röttgers, Dariusz Stramski, Michael Twardowski and J. Ronald V. Zaneveld

International Ocean Colour Coordinating Group (IOCCG) in collaboration with National Aeronautics and Space Administration (NASA)

IOCCG, Dartmouth, Canada

November 2018





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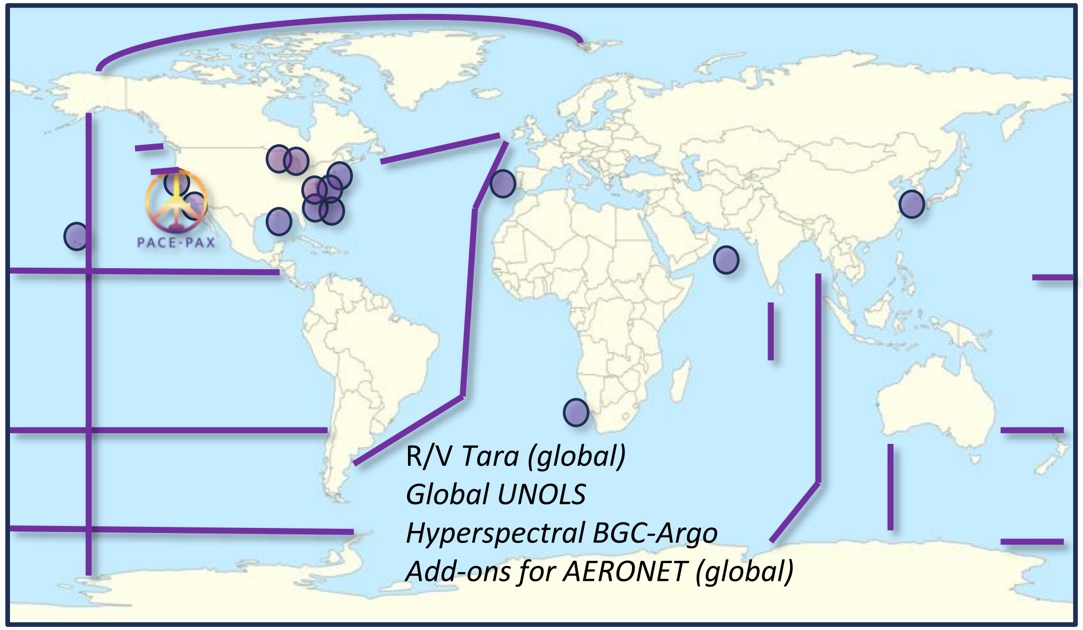

Ocean inherent optical properties	a_p	a_{ph}	a_{nap}	a_{cdom}	$a_{cdom+nap}$	b_{bp}	VSF		
Ocean apparent optical properties	PAR	K_d	K_{Lu}	L_u	L_w	L_{sky}	E_d	R_{rs}	nLw
Ocean Biogeochemistry	Chl (fluoro metric)	HPLC	UHPLC	PCC	NPP (and associated metrics)	PSD	TSM (TBD)	Carbon (PIC, POC DOC, Cphyto)	
Aerosols & clouds	AOD	Aerosol microphysical properties		COD	Cloud droplet size distribution, ice properties				

- Competitively selected teams funded by NASA
- 24 selections, 3-4 year projects
- Subelement 1: validate core radiometric ocean color and heritage atmospheric retrievals from OCI
- Subelement 2: validate advanced (new) products making use of hyperspectral (OCI) and polarimetric (HARP2, SPEXone) PACE capabilities

Full list of selected projects

Lead: Ivona Cetinić
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PACE validation activities

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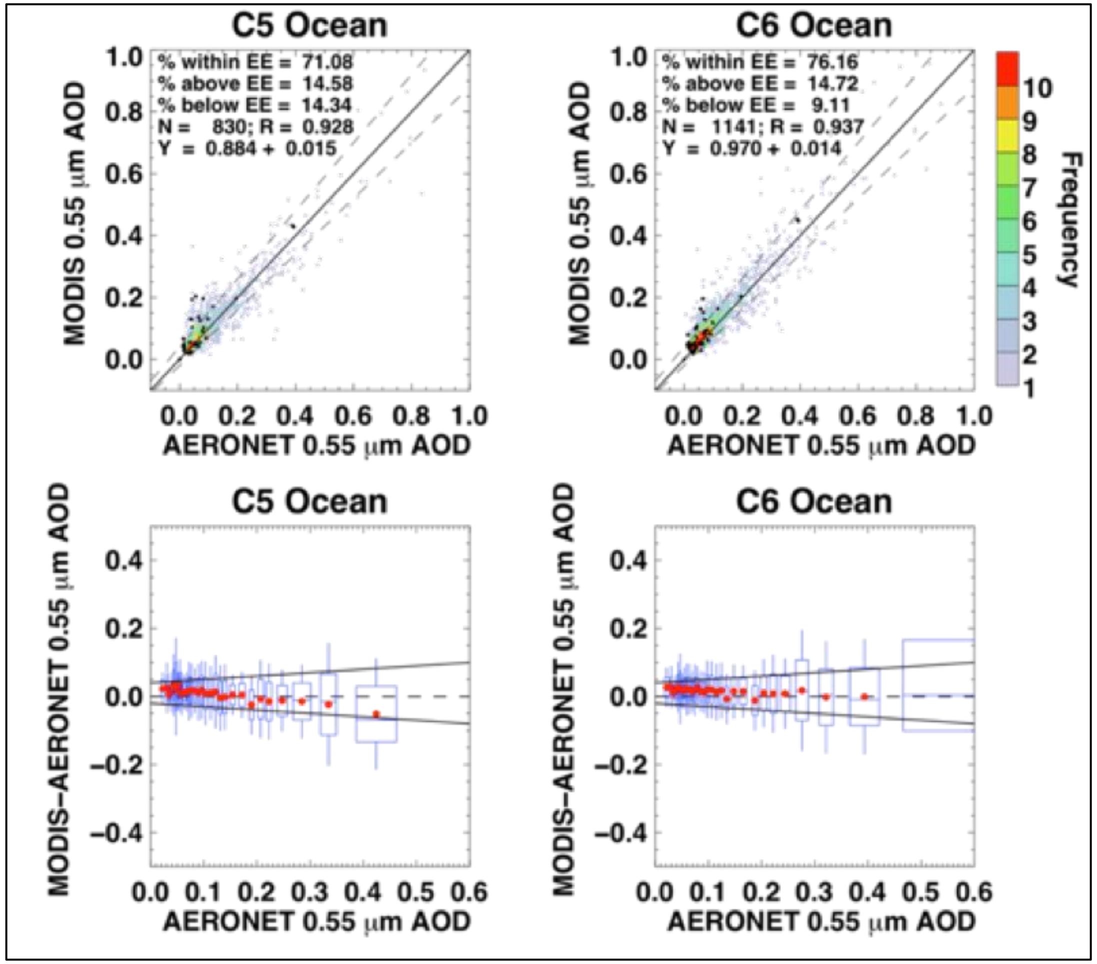

From MODIS Dark Target aerosol algorithm theoretical basis document (ATBD)
https://darktarget.gsfc.nasa.gov/atbd-product-evaluation

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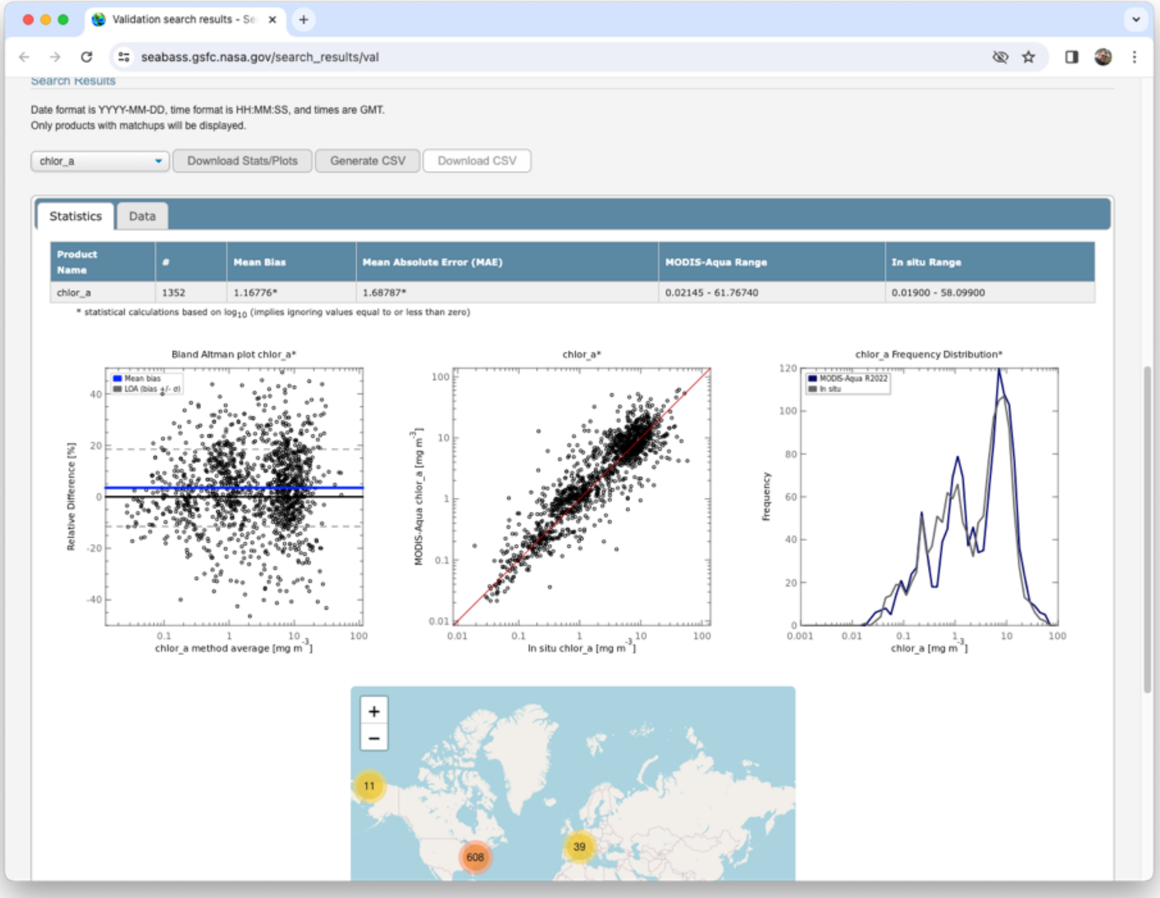

PACE matchups

Leads:

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Inia Soto Ramos
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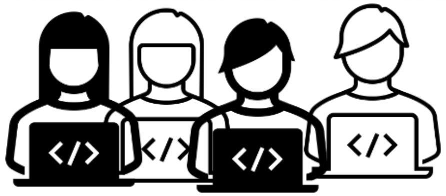

pace.oceansciences.org/pace_aop.htm

seabass.gsfc.nasa.gov

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NASA
PACE SCIENTISTS TAKE
TO THE SEA AND AIR
(AND REALLY HIGH AIR)

https://www.youtube.com/watch?v=cCsuck3dJU4

PACE-PAX overall objectives

- Validate new, multi-parameter, algorithms
- Coordinated observations under PACE & EarthCARE
- Validate PACE radiometry & polarimetry
- Validate ability to observe specific processes

PACE-PAX detailed objectives

ID	Measurement objective
1a	New products: land surface properties
1b	New products: ocean radiometric properties
1c	New products: aerosol properties over the ocean
1d	New products: aerosol properties over land
1e	New products: cloud properties
1f	New products: ocean surface properties
2a	Simultaneous PACE observations: aerosol properties over the ocean
2b	Simultaneous PACE observations: aerosol properties over land
2c	Simultaneous PACE observations: cloud properties
2d	Simultaneous EarthCARE observations: aerosol properties
2e	Simultaneous EarthCARE observations: cloud properties
3a	Radiometric and polarimetric properties: large reflectances
3b	Radiometric and polarimetric properties: large reflectance high polarization
3c	Radiometric and polarimetric properties: large reflectance low polarization
3d	Radiometric and polarimetric properties: vicarious calibration sites
4a	Specific phenomena: High aerosol loading over land
4b	Specific phenomena: High aerosol loading over ocean
4c	Specific phenomena: Multiple aerosol layers
4d	Specific phenomena: Aerosols under thin cirrus clouds
4e	Specific phenomena: Aerosols above liquid cloud
4f	Specific phenomena: Broken clouds with complex structure
4g	Specific phenomena: Dust aerosols over ocean
4h	Specific phenomena: Aerosol, ocean properties, turbid water
4i	Specific phenomena: Aerosol, ocean properties, biologically productive water
4j	Specific phenomena: Smoke aerosols over ocean

…determined by extensive and thoughtful discussion among PACE project scientists, funded collaborators, etc

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1c. **Validate new retrieval properties:** Aerosol properties over ocean

	PACE/OCI **PACE/SPEXone** **PACE/HARP2**	
	HSRL-2 *AirHARP, PICARD, PRISM, RSP, SPEX Air*	Ocean optical properties and basic aerosol conditions from HSRL-2
	Aerosol in situ instruments	Straight and level through aerosol plume
	No clouds Variable aerosol load Variable geometry, time and space scales	
	AERONET-OC, Shearwater, HyperNAV	

Geophysical properties
Aerosol spectral optical depth
Aerosol microphysical properties
Aerosol layer height
Ocean surface roughness (windspeed)
Spectral ocean remote sensing reflectance

Importance	Hours
12	4

Walls: aerosol

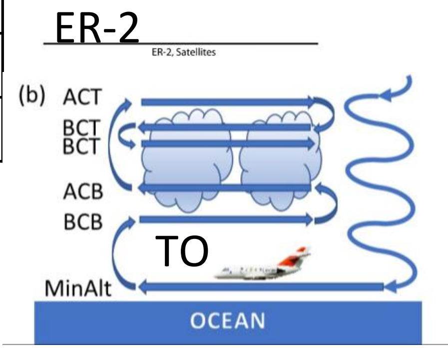

Figure-4

At least 2/3 required

For ocean properties, this could be achieved with either in water measurements from Shearwater, AERONET-OC or HyperNAV, or the HSRL-2

For aerosol properties, this could be either achieved with in situ data from the Twin Otter, or retrievals from passive instruments on the ER-2

PACE-PAX detailed objectives

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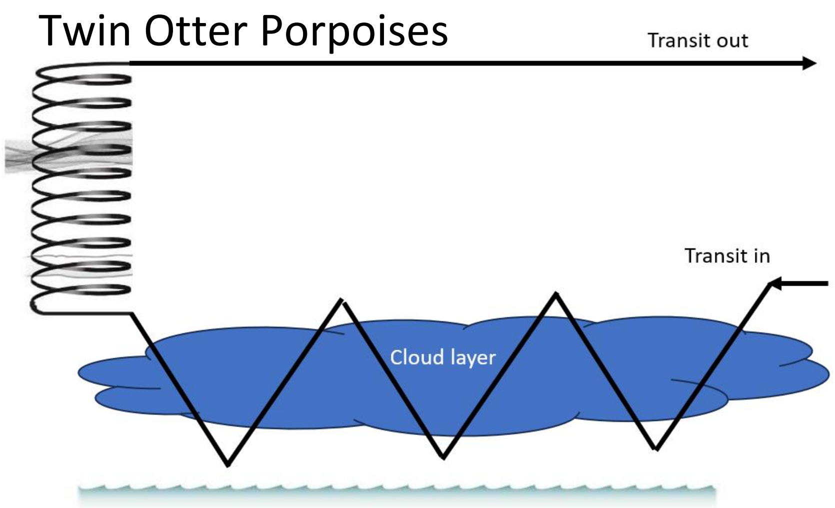
1e. **Validate new retrieval properties:** Cloud properties

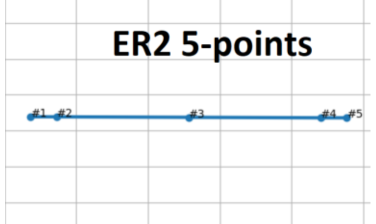
	PACE/OCI **PACE/HARP2**	
	AirHARP, HSRL-2, *PICARD*, *PRISM*, *RSP*	
	Cloud in situ instruments	TBD flight plan
	Cloud cover with variable properties Variable geometry, time and space scales	

Geophysical properties
Cloud detection, top height
Cloud physical thickness
Cloud phase
Liquid, ice, cloud optical depth
Liquid droplet size distribution
Liquid/Ice water path
Ice particle size, shape, asymmetry or phase fcn

Importance	Hours
12	4



ER2 straight Line (setup, start, center, end, exit)



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4j	Specific phenomena: Smoke aerosols over ocean

This is complicated!
How do we manage and plan for a field campaign like this?

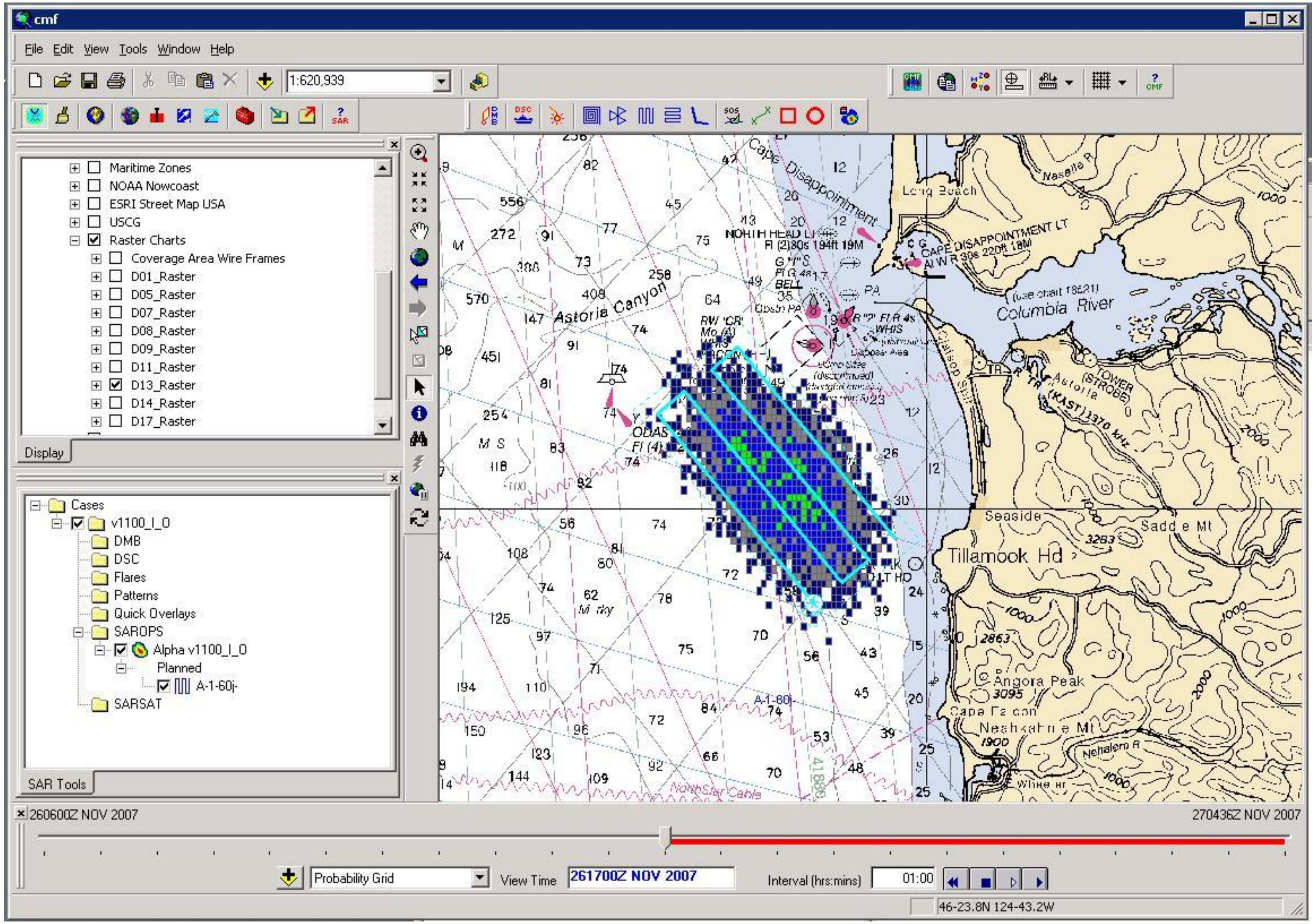
Adding numerical quantifiers helps planning

w - weighting (importance)
h - hours needed for minimum observation
c - completeness of given measurement
p - probability of complete measurement

ID	Measurement objective	*w*	*h*	*c*	*p*
1a	New products: land surface properties	8	2.0	1.0	0.50
1b	New products: ocean radiometric properties	10	8.0	1.0	0.50
1c	New products: aerosol properties over the ocean	12	8.0	1.0	0.50
1d	New products: aerosol properties over land	12	8.0	1.0	0.75
1e	New products: cloud properties	12	8.0	1.0	0.50
1f	[illegible]	1	8.0	0.5	0.25
[illegible]	...rties over the	10	8.0	1.0	0.50
[illegible]	...rties over land	10	8.0	1.0	0.50
[illegible]	...ies	5	2.0	1.0	0.50
[illegible]	... properties	8	4.0	1.0	0.25
[illegible]	...roperties	8	4.0	1.0	0.25
[illegible]	...eflectances	6	2.0	1.0	0.50
[illegible]	...eflectance high	6	2.0	1.0	0.75
[illegible]	...eflectance low	6	2.0	1.0	0.75
[illegible]	...us calibration sites	6	4.0	1.0	0.25
[illegible]	...land	4	2.0	1.0	0.50
[illegible]	...ocean	4	2.0	1.0	0.50
[illegible]	[illegible]	1	2.0	1.0	0.50
[illegible]	...clouds	2	2.0	1.0	0.50
[illegible]	...d	4	2.0	1.0	0.25
4f	Specific phenomena: Broken clouds with complex structure	4	2.0	1.0	0.75
4g	Specific phenomena: Dust aerosols over ocean	4	2.0	1.0	0.25
4h	Specific phenomena: Aerosol, ocean properties, turbid water	2	2.0	1.0	0.50
4i	Specific phenomena: Aerosol, ocean properties, biologically productive water	4	2.0	1.0	0.25
4j	Specific phenomena: Smoke aerosols over ocean	1	2.0	1.0	0.25

We then adapted concepts of Search and Rescue theory

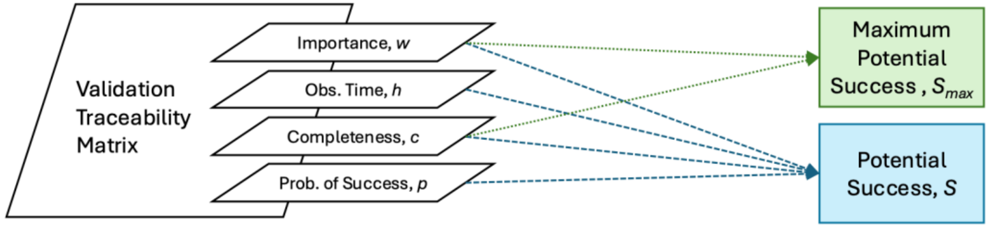
…but instead of finding the best way to search a grid of locations, we are finding the best way to ‘search’ measurement objectives

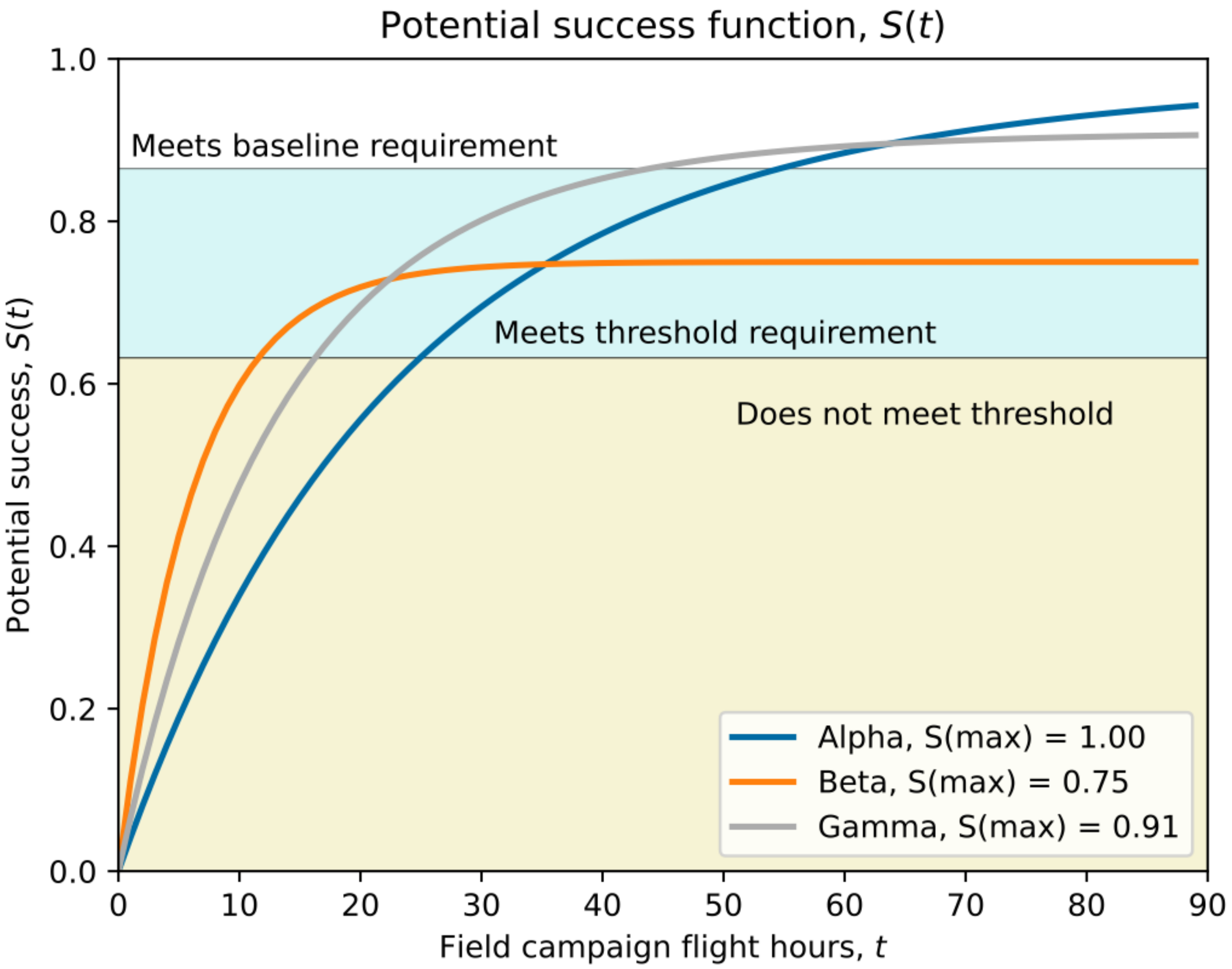


U.S. Coast Guard - http://www.uscg.mil/hq/c2cen/img/CMF_SearchPlan_on_Chart.JPG

Before the campaign, these numbers help us do trade studies

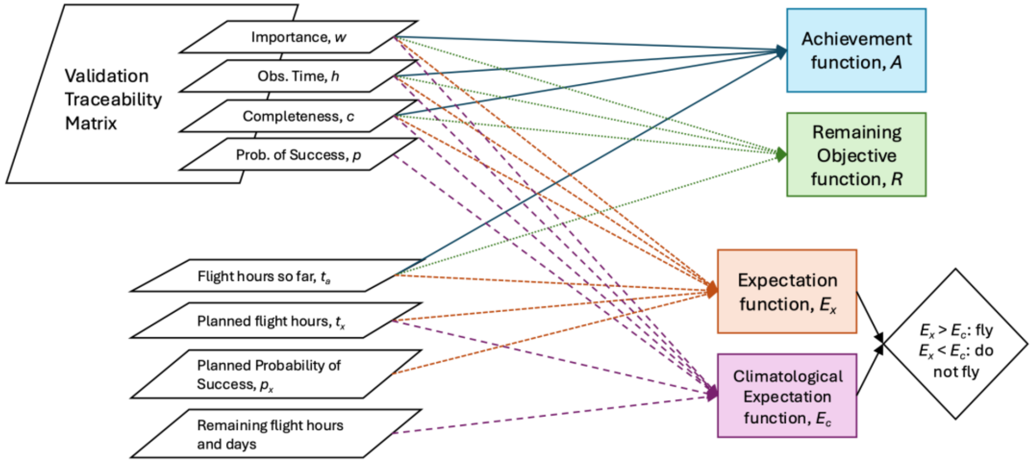
Pre-campaign Decision Support Algorithm (PC-DSA) components

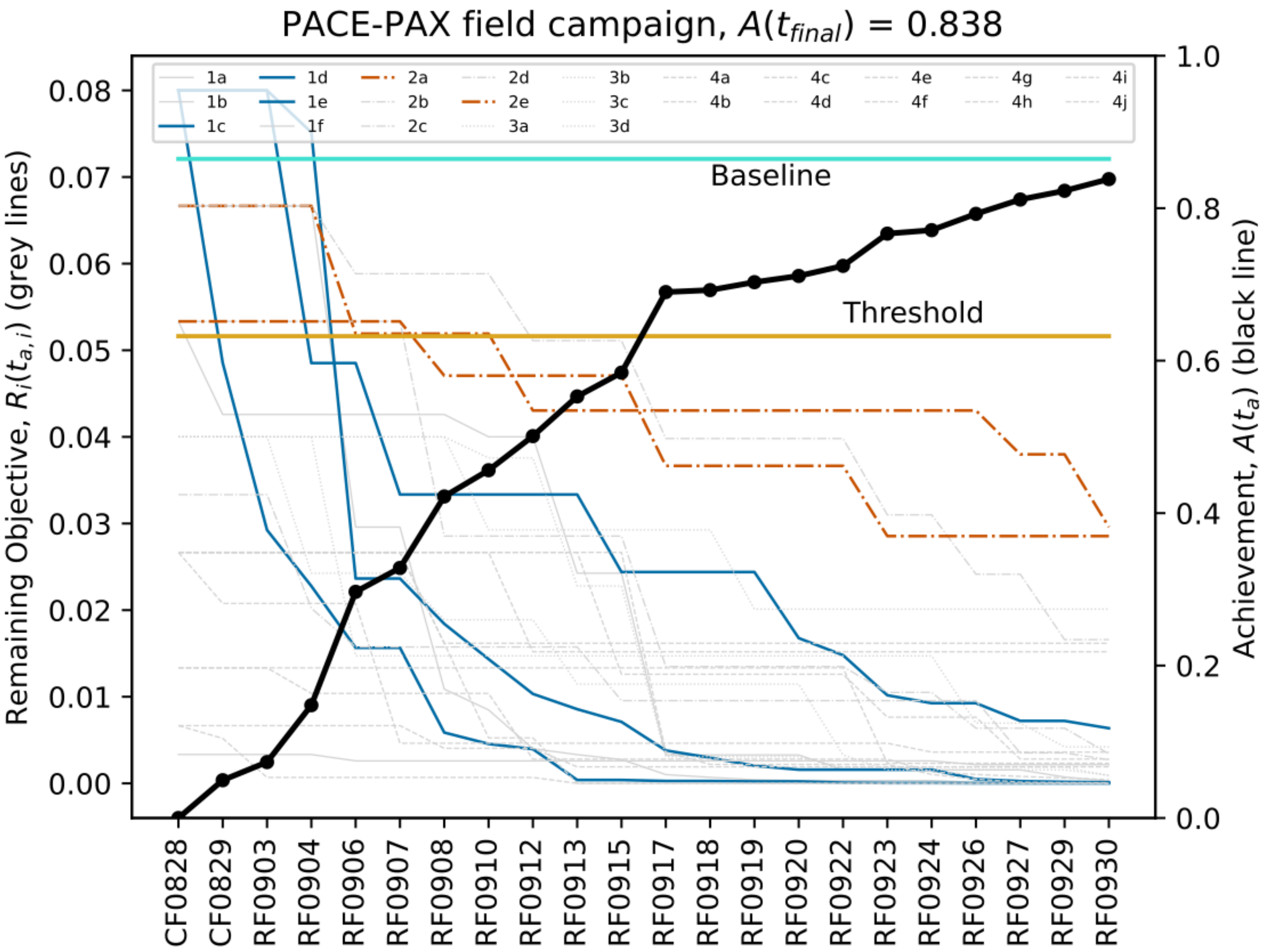




During the campaign, we use this approach to track progress and plan subsequent flights

Underway Decision Support Algorithm (U-DSA) components





Recently submitted paper to J. Atmospheric and Oceanic Technology

Github: https://github.com/knobelsp/TM-DSA

Field campaign design and implementation with traceability matrix decision support

Kirk D. Knobelspiesse,[a] Brian Cairns,[b] Ivona Cetinić,[a,c] Samuel LeBlanc,[d,e] Sommer Nicholas,[d] and Rei Ueyama[d]

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[b] *NASA Goddard Institute for Space Studies, New York, NY*

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Corresponding author: Kirk D. Knobelspiesse, Kirk.Knobelspiesse@nasa.gov

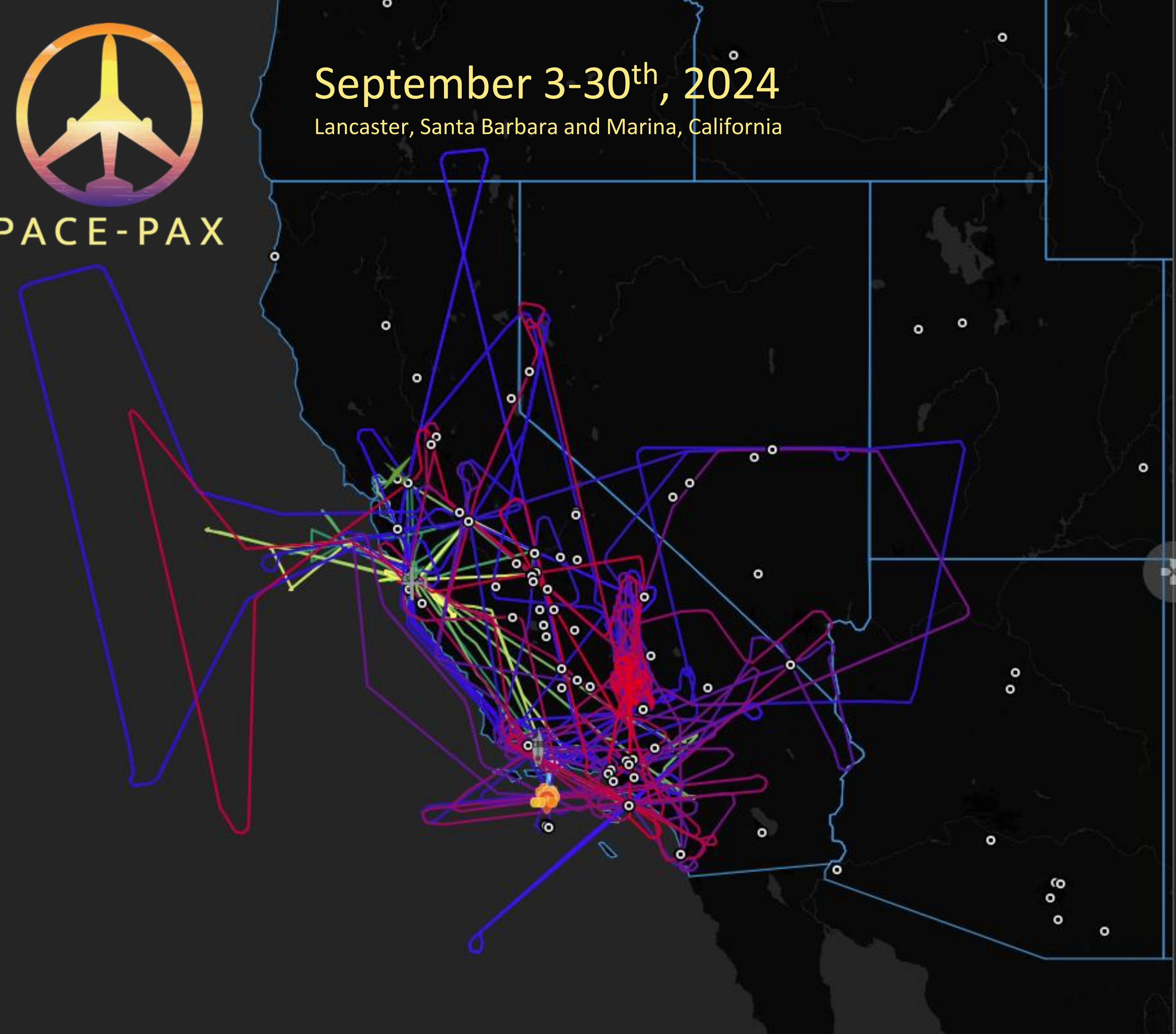
ABSTRACT

Intensive field data collection efforts (i.e., field campaigns) can be complex undertakings. Field campaign teams must balance multi-faceted and competing objectives, known and unknown constraints, and must be adaptable to changing conditions. We developed several tools to manage these challenges for a recent field campaign, the Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) Postlaunch Airborne eXperiment (PACE-PAX). PACE is a recently launched multidisciplinary satellite mission, and PACE-PAX was part of the data validation efforts for PACE. Two aircraft, two research ships, and various other surface-based measurements were coordinated to provide a validation dataset useful for many of PACE's data products. Two specific tools were utilized for this purpose. First, we developed a Validation Traceability Matrix (VTM) which connects validation objectives to measurement design and implementation. Crucially, measurement objectives in the VTM are numerically weighted to express differences in importance. They are further assessed in terms of the quantity of measurements needed to satisfy that objective and the likelihood of successful observation. The VTM is coupled with a decision algorithm, which provides a scoring mechanism. This score can be used prior to the campaign to compare mission design options with trade studies. During the campaign, it is used to assess the value of completed observations and guide planning for future observations. In this paper, we demonstrate how our traceability matrix decision support tools were used successfully with the PACE-PAX field campaign and provide guidelines and implementation tools for their use in future field campaigns.

PACE-PAX

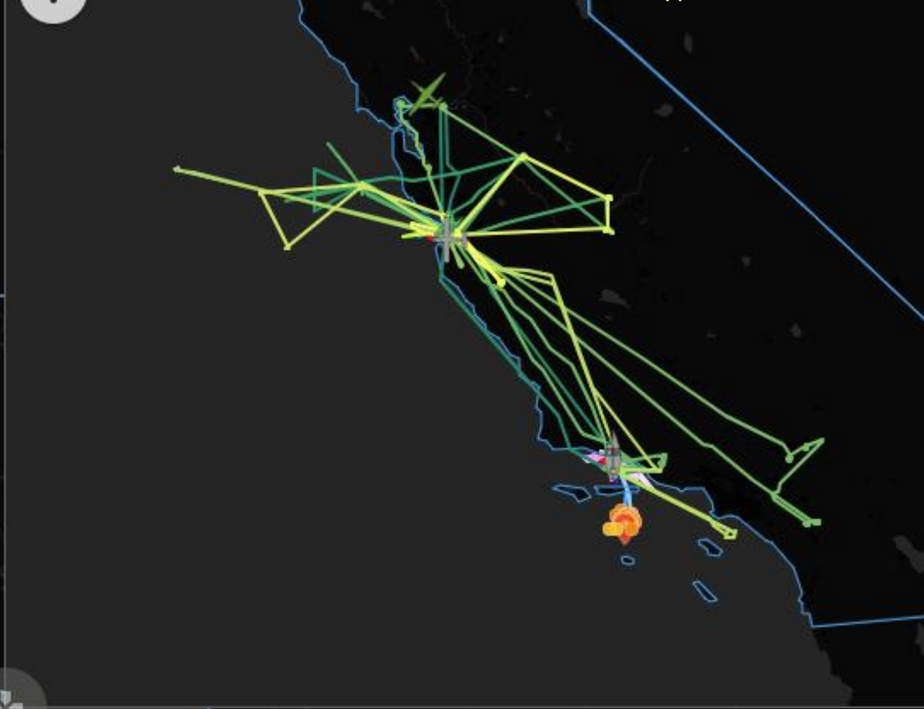
September 3-30th, 2024

Lancaster, Santa Barbara and Marina, California

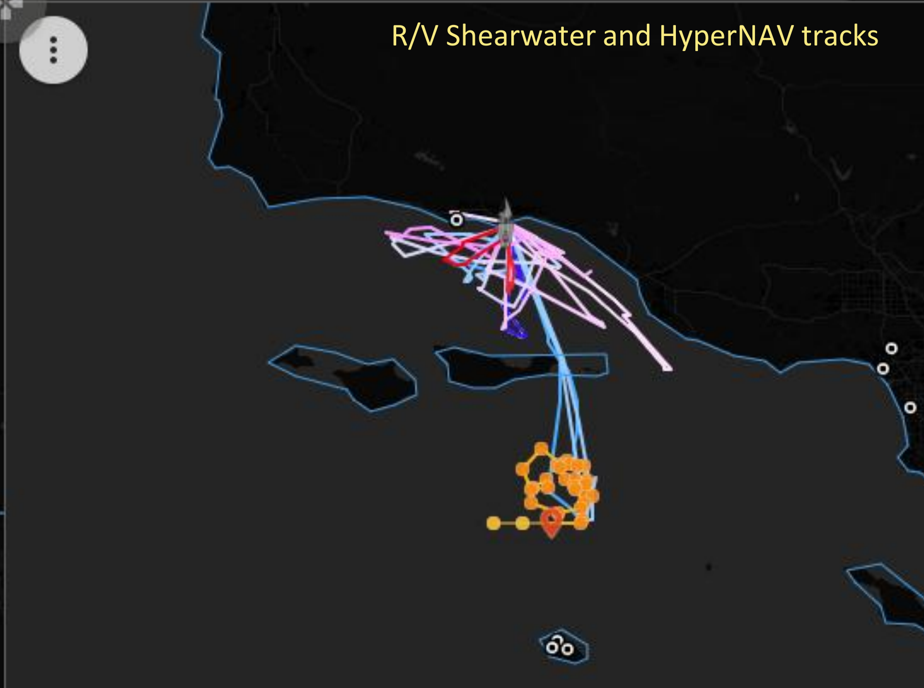


NASA ER-2, CIRPAS Twin Otter, R/V Shearwater and HyperNAV tracks

CIRPAS Twin Otter, R/V Shearwater and HyperNAV tracks



R/V Shearwater and HyperNAV tracks

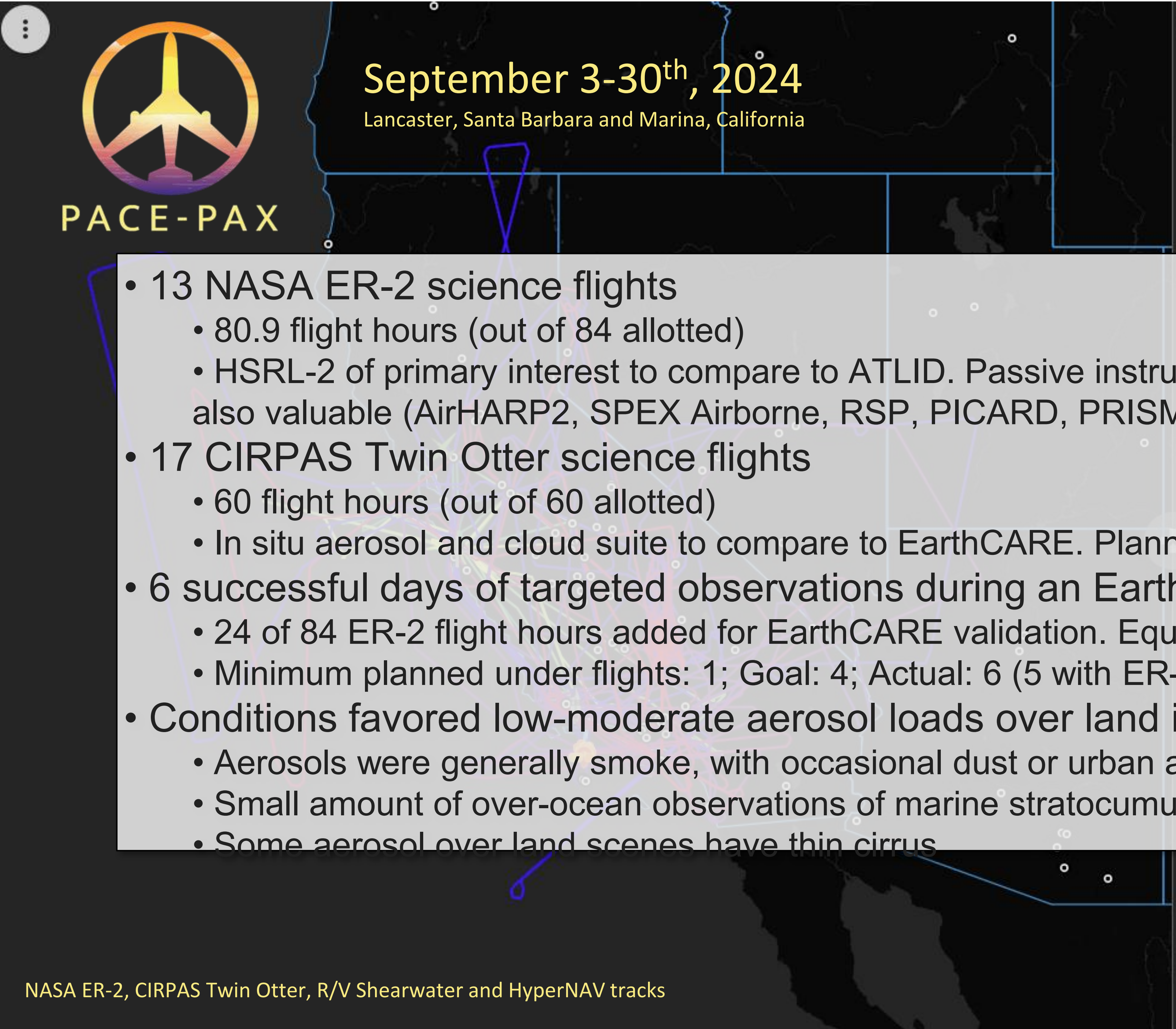


PACE-PAX

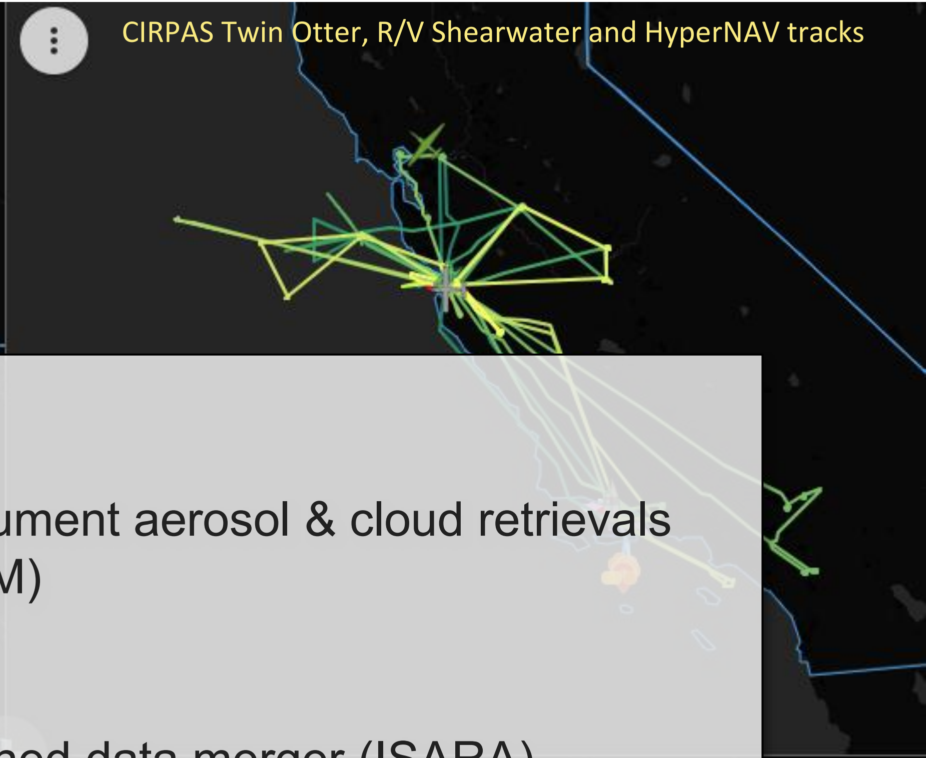
September 3-30th, 2024

Lancaster, Santa Barbara and Marina, California

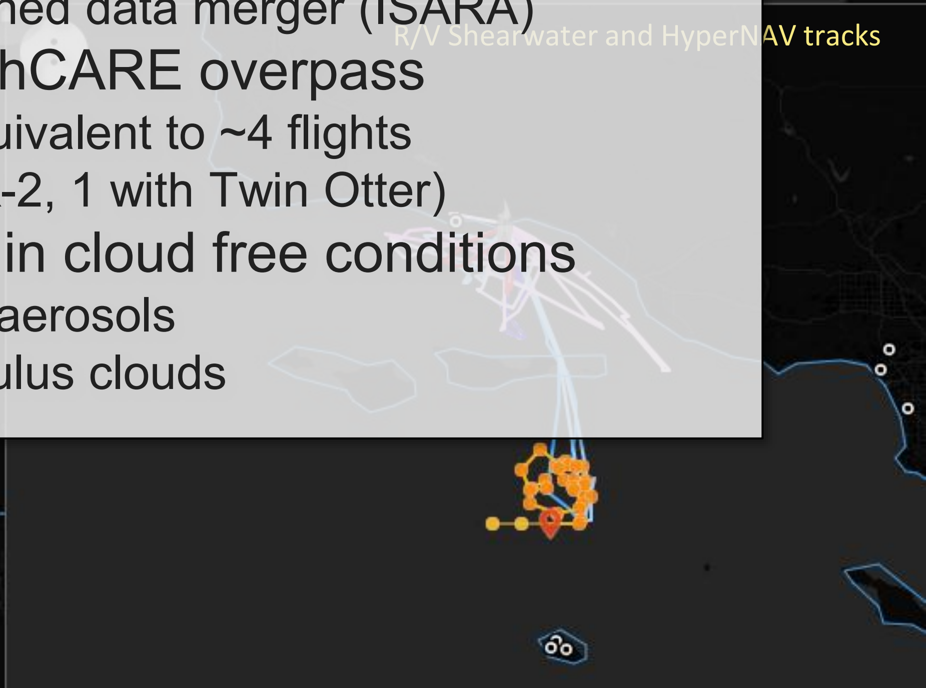
- 13 NASA ER-2 science flights
  - 80.9 flight hours (out of 84 allotted)
  - HSRL-2 of primary interest to compare to ATLID. Passive instrument aerosol & cloud retrievals also valuable (AirHARP2, SPEX Airborne, RSP, PICARD, PRISM)
- 17 CIRPAS Twin Otter science flights
  - 60 flight hours (out of 60 allotted)
  - In situ aerosol and cloud suite to compare to EarthCARE. Planned data merger (ISARA)
- 6 successful days of targeted observations during an EarthCARE overpass
  - 24 of 84 ER-2 flight hours added for EarthCARE validation. Equivalent to ~4 flights
  - Minimum planned under flights: 1; Goal: 4; Actual: 6 (5 with ER-2, 1 with Twin Otter)
- Conditions favored low-moderate aerosol loads over land in cloud free conditions
  - Aerosols were generally smoke, with occasional dust or urban aerosols
  - Small amount of over-ocean observations of marine stratocumulus clouds
  - Some aerosol over land scenes have thin cirrus



NASA ER-2, CIRPAS Twin Otter, R/V Shearwater and HyperNAV tracks



CIRPAS Twin Otter, R/V Shearwater and HyperNAV tracks



R/V Shearwater and HyperNAV tracks

PACE-PAX instrumentation

Instrument	Platform	Role	Lead PI	Institution
AirHARP	ER-2	PACE/HARP2 polarimetry proxy	J. Vanderlei Martins	UMBC
PICARD	ER-2	PACE/OCI spectrometer proxy	J. Jacobson / K. Meyer	NASA ARC/GSFC
PRISM	ER-2	PACE/OCI spectrometer proxy	David R. Thompson	JPL
SPEX Airborne	ER-2	PACE/SPEXone polarimetry proxy	B. van Diedenhoven	SRON
HSRL-2	ER-2	Aerosol/cloud/ocean Lidar	T. Shingler / J. Hair	NASA LaRC
RSP	ER-2	Multi-angle polarimeter ref.	B. Cairns / K. Sinclair	NASA GISS
Facility instruments	Twin Otter	Aerosol/cloud in situ instruments	Anthony Bucholtz	NPS
LARGE	Twin Otter	Aerosol/cloud in situ instruments	Luke Ziemba	NASA LaRC
LI-Nephelometer	Twin Otter	Aerosol phase functions	Adam Ahern	NOAA
ISARA	Twin Otter	In situ data synergy activity	Snorre Stamnes	NASA LaRC
Ocean instruments*	RV Shearwater	Day cruises, instrumentation TBD	Mike Ondrusek	NOAA
HyperNAV*	Ocean floats	Radiometric calibration ocean floats	Andrew Barnard	OSU
AERONET, AERONET-OC*	Surface	Aerosol prop., water leaving radiance	P. Gupta / E. Lind	NASA GSFC

*externally supported activities

PACE-PAX instrumentation

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LARGE	[illegible]	[illegible]	[illegible]	[illegible]
LI-Nephe[illegible]	[illegible]	[illegible] phase functions	Adam Ahern	NOAA
ISARA	[illegible]	[illegible]	[illegible] Stamnes	NASA LaRC
Ocean instruments*	RV Shearwater	Day cruises, instrumentation TBD	Mike Ondrusek	NOAA
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AERONET, AERONET-OC*	Surface	Aerosol prop., water leaving radiance	P. Gupta / E. Lind	NASA GSFC

*externally supported activities

PACE 'Proxy' instruments

- These make the same measurements as PACE, so PACE algorithms can be tested even if the satellite is not overhead
- Data submitted in a compatible for format (Level 1C) to that of PACE

PACE-PAX instrumentation

Instrument	Platform	Role	Lead PI	Institution
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PRISM	ER-2	PACE/OCI spectrometer proxy	David R. Thompson	JPL
SPEX Airborne	ER-2	PACE/SPEXone polarimetry proxy	B. van Diedenhoven	SRON
HSRL-2	ER-2	Aerosol/cloud/ocean Lidar	T. Shingler / J. Hair	NASA LaRC
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LARGE	Twin Otter	Aerosol/cloud in situ instruments	Luke Ziemba	NASA LaRC
[illegible]	[illegible]	[illegible]	Adam Ahern	NOAA
ISARA	Twin Otter	In situ data synergy activity	Snorre Stamnes	NASA LaRC
Ocean instruments*	RV Shearwater	Day cruises, instrumentation TBD	Mike Ondrusek	NOAA
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AERONET, AERONET-OC*	Surface	Aerosol prop., water leaving radiance	P. Gupta / E. Lind	NASA GSFC

Remote sensing reference instruments

- HSRL-2: Lidar that can validate aerosol, cloud and ocean products
- RSP: multi-angle polarimeter whose capabilities exceed those of PACE polarimeters

*externally supported activities

PACE-PAX instrumentation

Aerosol and cloud in situ instruments

- Point samples, to help relate atmospheric column retrievals to accurate and detailed understanding of aerosols or clouds in a parcel of air

Instrument	Platform	Role	Lead PI	Institution
AirHARP	ER-2	PACE/HARP2 polarimetry proxy	J. Vanderlei Martins	UMBC
PICARD	ER-2	PACE/OCI spectrometer proxy	J. Jacobson / K. Meyer	NASA ARC/GSFC
PRISM	ER-2	PACE/OCI spectrometer proxy	David R. Thompson	JPL
SPEX Airborne	ER-2	PACE/SPEXone polarimetry proxy	[illegible]	[illegible]
HSRL-2	ER-2	[illegible]	T. Shingler / J. Hair	NASA LaRC
RSP	ER-2	Multi-angle polarimeter ref.	B. Cairns / K. Sinclair	NASA GISS
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*externally supported activities

PACE-PAX instrumentation

Surface based measurements

- Over land validation focussed on overflights of ground stations, esp. AERONET
- Over ocean validation involved coordinated in-water + above water + aircraft + satellite observations

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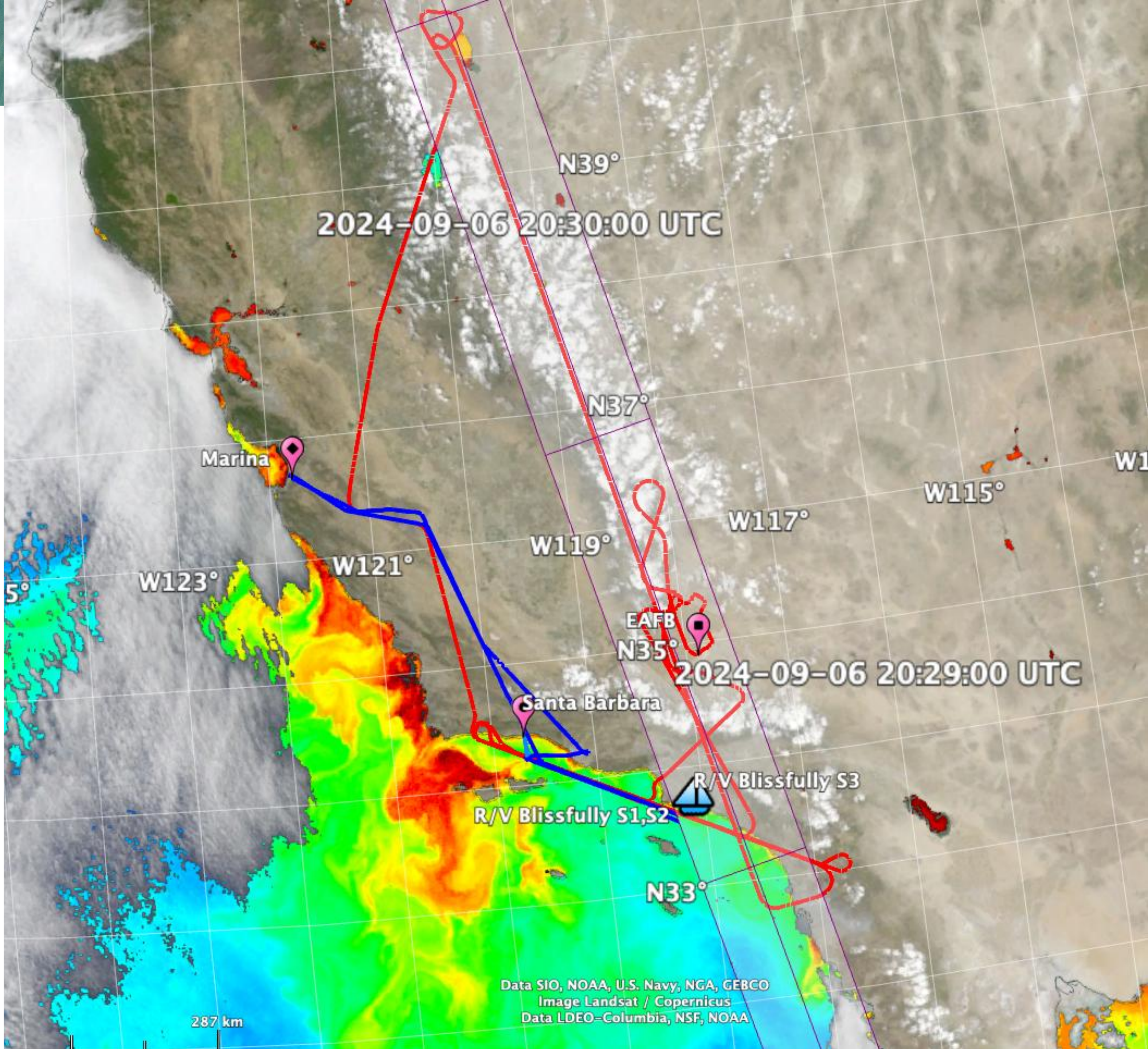
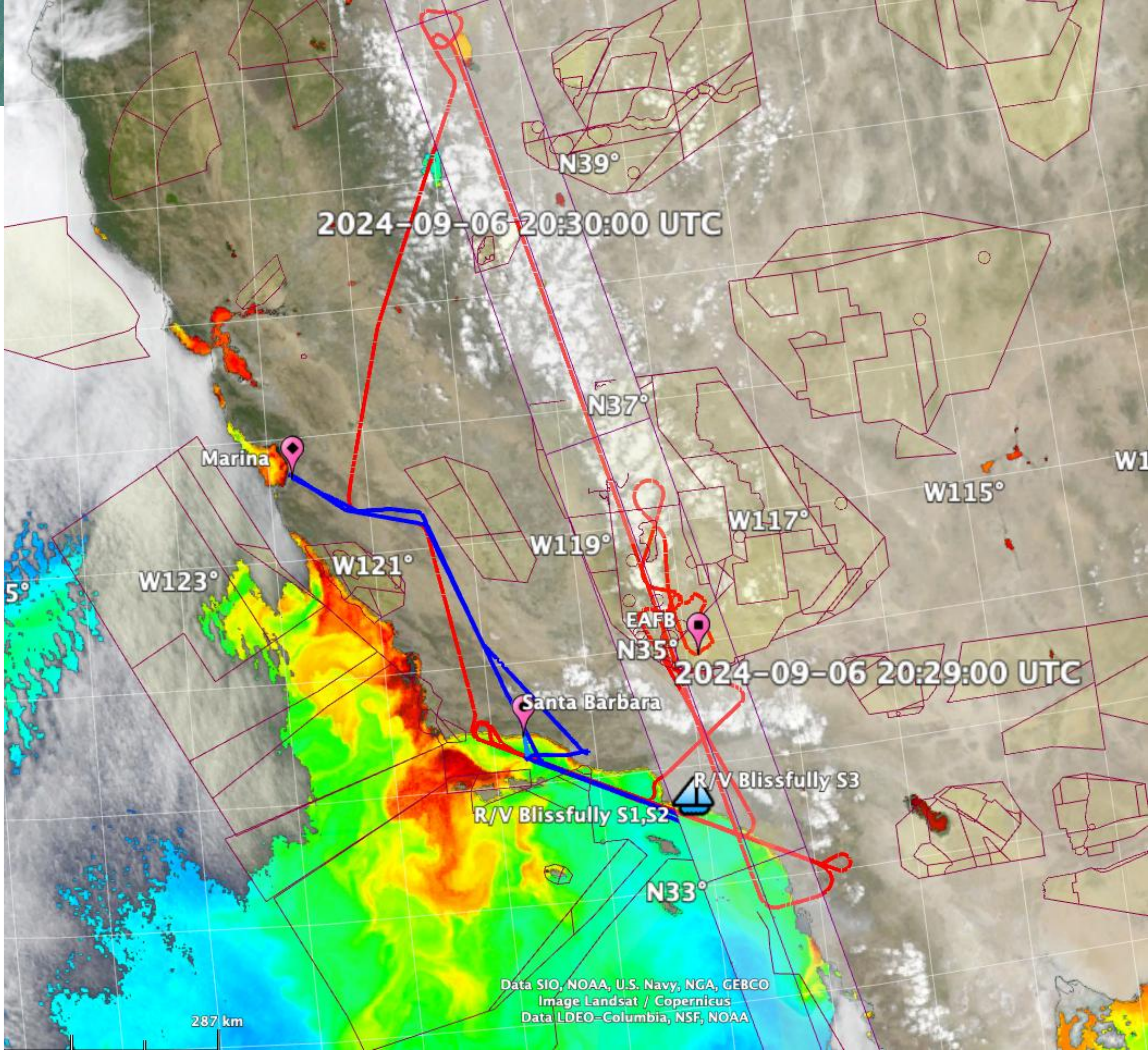
IOPs	a_p	a_{ph}	a_{nap}	a_{cdom}	$a_{cdom+nap}$	b_{bp}	VSF		
AOPs	PAR	K_d	K_{Lu}	L_u	L_w	L_{sky}	E_d	R_{rs}	*nLw*
Biogeochemistry	Chl (fluorometric)	HPLC	UHPLC	PCC	PSD	TSM	Carbon (POC DOC, Cphyto)		
Atmospheric	AOD	Angstrom	And many, many more…						

PACE-PAX ocean measurements

Example from September 6th (RF0906)

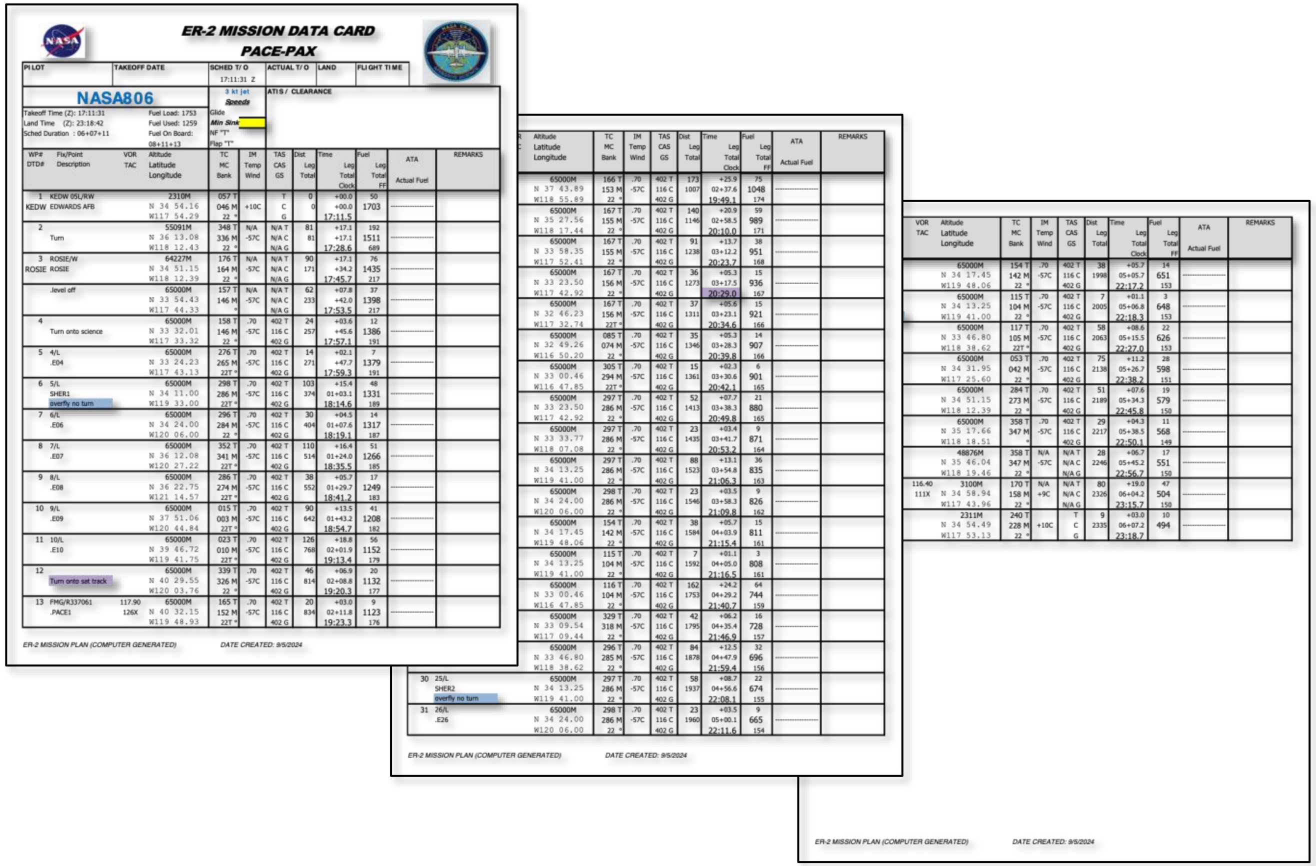


Example from September 6th
(RF0906)



Restricted flight areas boxed in red

What an actual flight plan looks like (for the ER-2)



ER-2 MISSION DATA CARD
PACE-PAX

PILOT	TAKEOFF DATE	SCHED T/O	ACTUAL T/O	LAND	FLIGHT TIME
NASA806		17:11:31 Z			

3 kt jet — Speeds: Glide; Min Sink; NF "T"; Flap "T" — ATIS / CLEARANCE

Takeoff Time (Z): 17:11:31 — Fuel Load: 1753
Land Time (Z): 23:18:42 — Fuel Used: 1259
Sched Duration: 06+07+11 — Fuel On Board: 08+11+13

WP# DTD#	Fix/Point Description	VOR TAC	Altitude Latitude Longitude	TC MC Bank	IM Temp Wind	TAS CAS GS	Dist Leg Total	Time Leg Total Clock	Fuel Leg Total FF	ATA Actual Fuel	REMARKS
1 KEDW	KEDW 05L/RW EDWARDS AFB		2310M N 34 54.16 W117 54.29	057 T 046 M 22 °	 +10C	T C G	0 0	+00.0 +00.0 17:11.5	50 1703	----------	
2	Turn		55091M N 36 13.08 W118 12.43	348 T 336 M 22 °	N/A -57C	N/A T N/A C N/A G	81 81	+17.1 +17.1 17:28.6	192 1511 689	----------	
3 ROSIE	ROSIE/W ROSIE		64227M N 34 51.15 W118 12.39	176 T 164 M 22 °	N/A -57C	N/A T N/A C N/A G	90 171	+17.1 +34.2 17:45.7	76 1435 217	----------	
	.level off		65000M N 33 54.43 W117 44.33	157 T 146 M °	N/A -57C	N/A T N/A C N/A G	62 233	+07.8 +42.0 17:53.5	37 1398 217	----------	
4	Turn onto science		65000M N 33 32.01 W117 33.32	158 T 146 M 22 °	.70 -57C	402 T 116 C 402 G	24 257	+03.6 +45.6 17:57.1	12 1386 191	----------	
5	4/L .E04		65000M N 33 24.23 W117 43.13	276 T 265 M 22T °	.70 -57C	402 T 116 C 402 G	14 271	+02.1 +47.7 17:59.3	7 1379 191	----------	
6	5/L SHER1 overfly no turn		65000M N 34 11.00 W119 33.00	298 T 286 M 22T °	.70 -57C	402 T 116 C 402 G	103 374	+15.4 01+03.1 18:14.6	48 1331 189	----------	
7	6/L .E06		65000M N 34 24.00 W120 06.00	296 T 284 M 22 °	.70 -57C	402 T 116 C 402 G	30 404	+04.5 01+07.6 18:19.1	14 1317 187	----------	
8	7/L .E07		65000M N 36 12.08 W120 27.22	352 T 341 M 22T °	.70 -57C	402 T 116 C 402 G	110 514	+16.4 01+24.0 18:35.5	51 1266 185	----------	
9	8/L .E08		65000M N 36 22.75 W121 14.57	286 T 274 M 22T °	.70 -57C	402 T 116 C 402 G	38 552	+05.7 01+29.7 18:41.2	17 1249 183	----------	
10	9/L .E09		65000M N 37 51.06 W120 44.84	015 T 003 M 22T °	.70 -57C	402 T 116 C 402 G	90 642	+13.5 01+43.2 18:54.7	41 1208 182	----------	
11	10/L .E10		65000M N 39 46.72 W119 41.75	023 T 010 M 22T °	.70 -57C	402 T 116 C 402 G	126 768	+18.8 02+01.9 19:13.4	56 1152 179	----------	
12	Turn onto sat track		65000M N 40 29.55 W120 03.76	339 T 326 M 22 °	.70 -57C	402 T 116 C 402 G	46 814	+06.9 02+08.8 19:20.3	20 1132 177	----------	
13	FMG/R337061 .PACE1	117.90 126X	65000M N 40 32.15 W119 48.93	165 T 152 M 22T °	.70 -57C	402 T 116 C 402 G	20 834	+03.0 02+11.8 19:23.3	9 1123 176	----------	

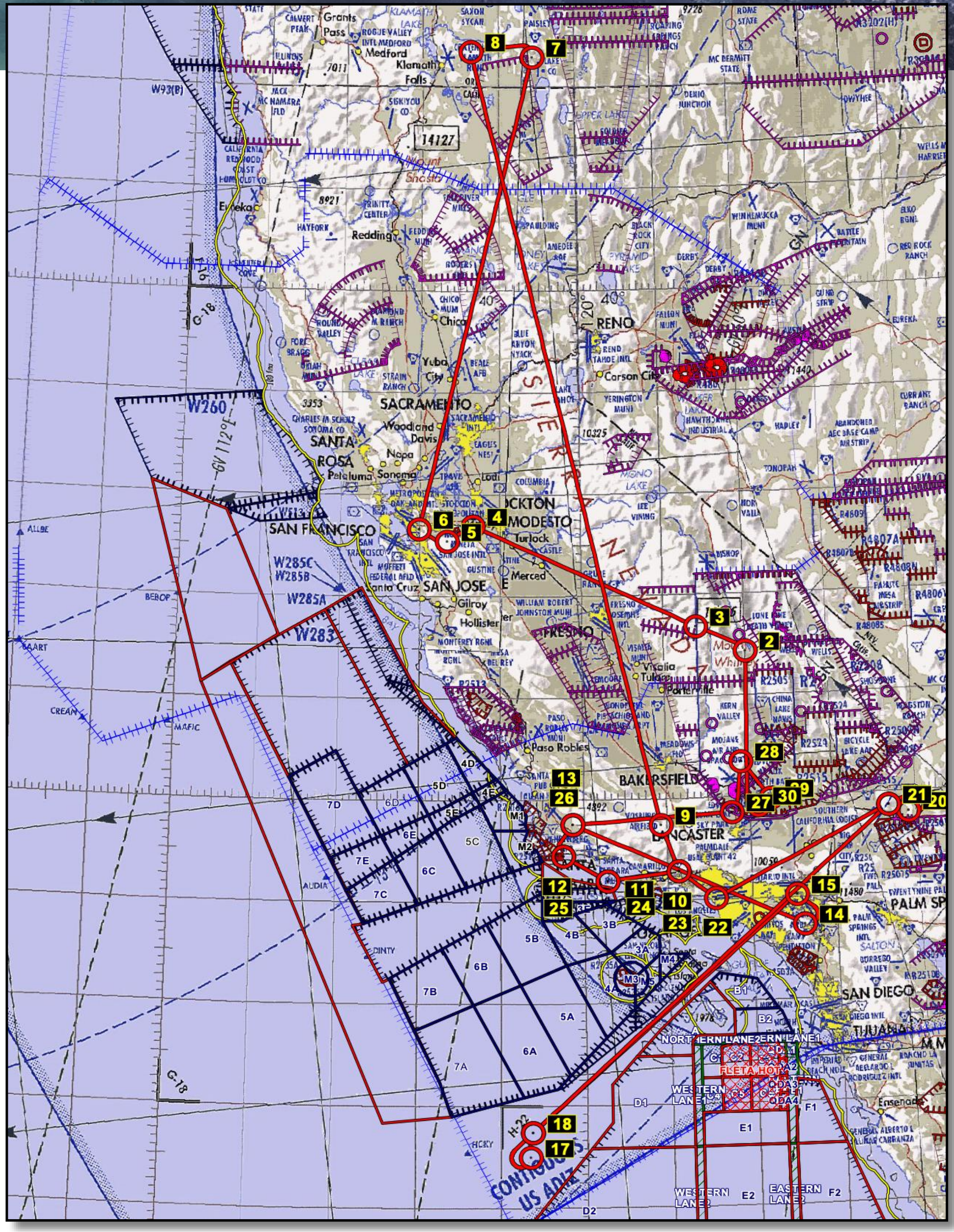
ER-2 MISSION PLAN (COMPUTER GENERATED) — DATE CREATED: 9/5/2024

WP#	Fix/Point Description	Altitude Latitude Longitude	TC MC Bank	IM Temp Wind	TAS CAS GS	Dist Leg Total	Time Leg Total Clock	Fuel Leg Total FF	ATA Actual Fuel	REMARKS
		65000M N 37 43.89 W118 55.89	166 T 153 M 22 °	.70 -57C	402 T 116 C 402 G	173 1007	+25.9 02+37.6 19:49.1	75 1048 174	----------	
		65000M N 35 27.56 W118 17.44	167 T 155 M 22 °	.70 -57C	402 T 116 C 402 G	140 1146	+20.9 02+58.5 20:10.0	59 989 171	----------	
		65000M N 33 58.35 W117 52.41	167 T 155 M 22 °	.70 -57C	402 T 116 C 402 G	91 1238	+13.7 03+12.2 20:23.7	38 951 168	----------	
		65000M N 33 23.50 W117 42.92	167 T 156 M 22 °	.70 -57C	402 T 116 C 402 G	36 1273	+05.3 03+17.5 20:29.0	15 936 167	----------	
		65000M N 32 46.23 W117 32.74	167 T 156 M 22T °	.70 -57C	402 T 116 C 402 G	37 1311	+05.6 03+23.1 20:34.6	15 921 166	----------	
		65000M N 32 49.26 W116 50.20	085 T 074 M 22 °	.70 -57C	402 T 116 C 402 G	35 1346	+05.3 03+28.3 20:39.8	14 907 166	----------	
		65000M N 33 00.46 W116 47.85	305 T 294 M 22T °	.70 -57C	402 T 116 C 402 G	15 1361	+02.3 03+30.6 20:42.1	6 901 165	----------	
		65000M N 33 23.50 W117 42.92	297 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	52 1413	+07.7 03+38.3 20:49.8	21 880 165	----------	
		65000M N 33 33.77 W118 07.08	297 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	23 1435	+03.4 03+41.7 20:53.2	9 871 164	----------	
		65000M N 34 13.25 W119 41.00	297 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	88 1523	+13.1 03+54.8 21:06.3	36 835 163	----------	
		65000M N 34 24.00 W120 06.00	298 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	23 1546	+03.5 03+58.3 21:09.8	9 826 162	----------	
		65000M N 34 17.45 W119 48.06	154 T 142 M 22 °	.70 -57C	402 T 116 C 402 G	38 1584	+05.7 04+03.9 21:15.4	15 811 161	----------	
		65000M N 34 13.25 W119 41.00	115 T 104 M 22 °	.70 -57C	402 T 116 C 402 G	7 1592	+01.1 04+05.0 21:16.5	3 808 161	----------	
		65000M N 33 00.46 W116 47.85	116 T 104 M 22 °	.70 -57C	402 T 116 C 402 G	162 1753	+24.2 04+29.2 21:40.7	64 744 159	----------	
		65000M N 33 09.54 W117 09.44	329 T 318 M 22 °	.70 -57C	402 T 116 C 402 G	42 1795	+06.2 04+35.4 21:46.9	16 728 157	----------	
		65000M N 33 46.80 W118 38.62	296 T 285 M 22 °	.70 -57C	402 T 116 C 402 G	84 1878	+12.5 04+47.9 21:59.4	32 696 156	----------	
30	25/L SHER2 overfly no turn	65000M N 34 13.25 W119 41.00	297 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	58 1937	+08.7 04+56.6 22:08.1	22 674 155	----------	
31	26/L .E26	65000M N 34 24.00 W120 06.00	298 T 286 M 22 °	.70 -57C	402 T 116 C 402 G	23 1960	+03.5 05+00.1 22:11.6	9 665 154	----------	

ER-2 MISSION PLAN (COMPUTER GENERATED) — DATE CREATED: 9/5/2024

VOR TAC	Altitude Latitude Longitude	TC MC Bank	IM Temp Wind	TAS CAS GS	Dist Leg Total	Time Leg Total Clock	Fuel Leg Total FF	ATA Actual Fuel	REMARKS
	65000M N 34 17.45 W119 48.06	154 T 142 M 22 °	.70 -57C	402 T 116 C 402 G	38 1998	+05.7 05+05.7 22:17.2	14 651 153	----------	
	65000M N 34 13.25 W119 41.00	115 T 104 M 22 °	.70 -57C	402 T 116 C 402 G	7 2005	+01.1 05+06.8 22:18.3	3 648 153	----------	
	65000M N 33 46.80 W118 38.62	117 T 105 M 22T °	.70 -57C	402 T 116 C 402 G	58 2063	+08.6 05+15.5 22:27.0	22 626 153	----------	
	65000M N 34 31.95 W117 25.60	053 T 042 M 22 °	.70 -57C	402 T 116 C 402 G	75 2138	+11.2 05+26.7 22:38.2	28 598 151	----------	
	65000M N 34 51.15 W118 12.39	284 T 273 M 22 °	.70 -57C	402 T 116 C 402 G	51 2189	+07.6 05+34.3 22:45.8	19 579 150	----------	
	65000M N 35 17.66 W118 18.51	358 T 347 M °	.70 -57C	402 T 116 C 402 G	29 2217	+04.3 05+38.5 22:50.1	11 568 149	----------	
	48876M N 35 46.04 W118 19.46	358 T 347 M 22 °	N/A -57C	N/A T N/A C N/A G	28 2246	+06.7 05+45.2 22:56.7	17 551 150	----------	
116.40 111X	3100M N 34 58.94 W117 43.96	170 T 158 M 22 °	N/A +9C	N/A T N/A C N/A G	80 2326	+19.0 06+04.2 23:15.7	47 504 150	----------	
	2311M N 34 54.49 W117 53.13	240 T 228 M 22 °	 +10C	T C G	9 2335	+03.0 06+07.2 23:18.7	10 494	----------	

ER-2 MISSION PLAN (COMPUTER GENERATED) — DATE CREATED: 9/5/2024

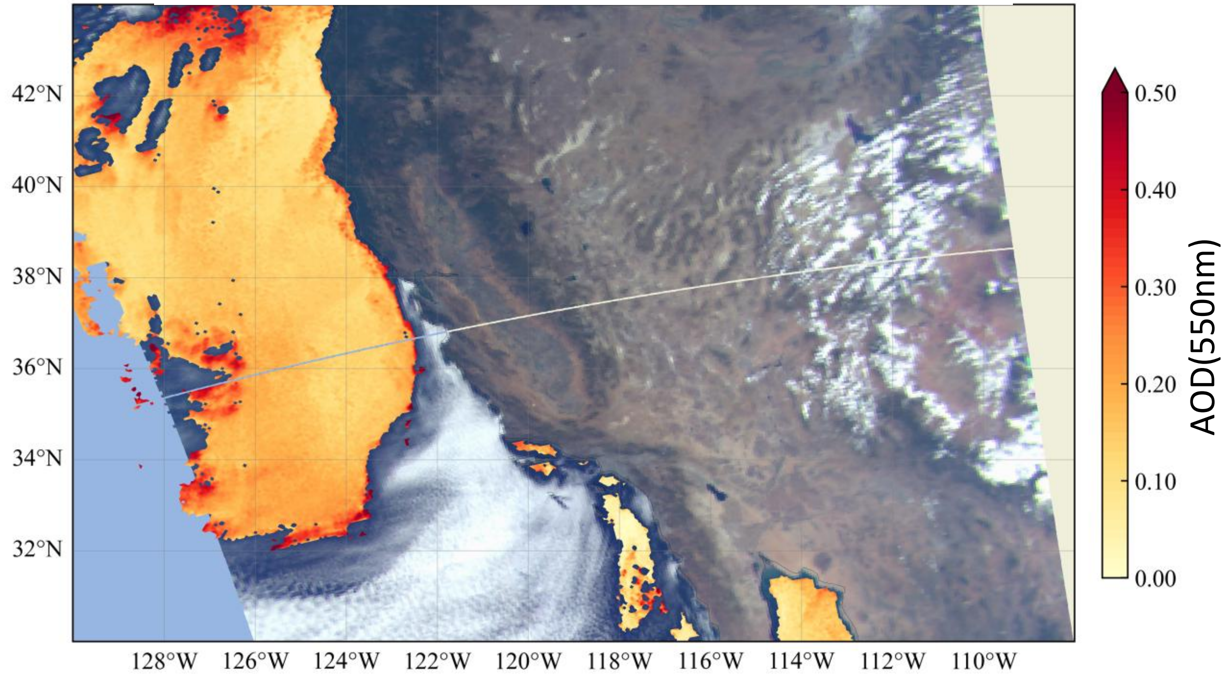


Example validation with field campaign data

FastMAPOL - PACE/HARP2 multi-angle polarimeter algorithm for retrieval of aerosol microphysical properties and ocean color

Slides from Meng Gao, NASA GSFC

PACE/HARP2 FastMAPOL AOD, 2024/09/29



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https://doi.org/10.5194/amt-14-4083-2021

Atmospheric Measurement Techniques
Open Access
EGU

Efficient multi-angle polarimetric inversion of aerosols and ocean color powered by a deep neural network forward model

Meng Gao[1,2], Bryan A. Franz[1], Kirk Knobelspiesse[1], Peng-Wang Zhai[3], Vanderlei Martins[3], Sharon Burton[4], Brian Cairns[5], Richard Ferrare[4], Joel Gales[1,6], Otto Hasekamp[7], Yongxiang Hu[4], Amir Ibrahim[1,2], Brent McBride[3,2], Anin Puthukkudy[3], P. Jeremy Werdell[1], and Xiaoguang Xu[3]

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[4]MS 475, NASA Langley Research Center, Hampton, VA 23681-2199, USA
[5]NASA Goddard Institute for Space Studies, New York, NY 10025, USA
[6]Science Applications International Corp., Greenbelt, MD, USA
[7]Netherlands Institute for Space Research (SRON, NWO-I), Utrecht, the Netherlands

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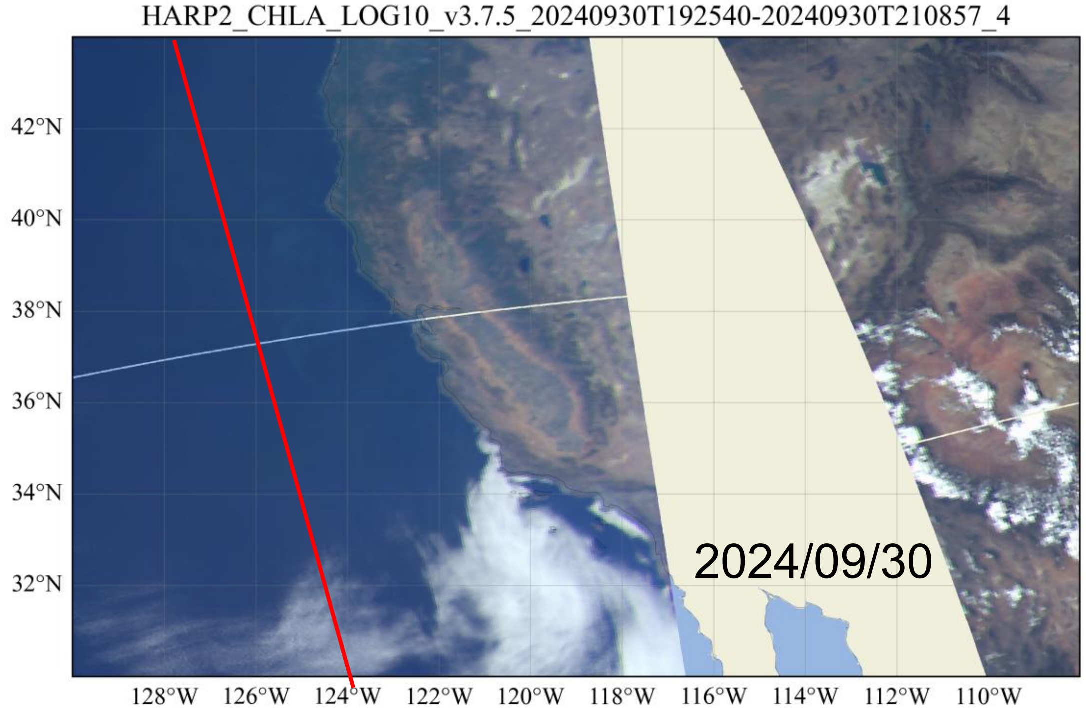
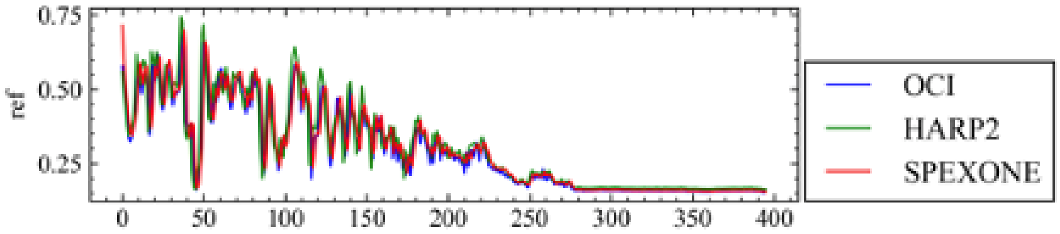
Current validation effort and plan

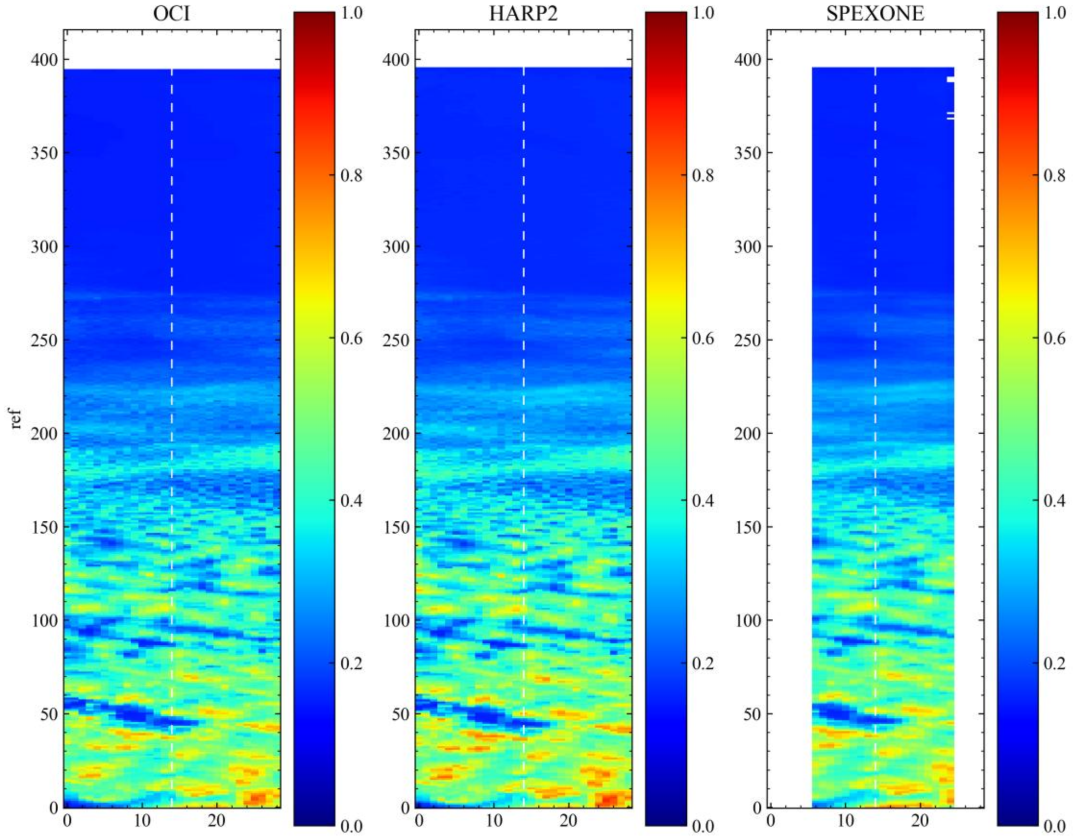
- L1 :
  - Compare between PACE instruments
  - Compare with RT model
  - Compare with airborne instruments
- L2 :
  - Compare AOD
    - vs airborne observations (HSRL, AirHARP, etc)
    - vs ground networks (AERONET)
  - Compare aerosol properties (absorption, size, height)
    - vs airborne observations (HSRL, AirHARP, etc)
    - vs ground networks (AERONET)
  - Compare to ocean or land surface measurements
  - Compare between instruments, and algorithms
- L3 :
  - Check basic pattern, and overall magnitude, scale dependence
  - Compare with OCI (same L3 grids)
  - Compare with other satellite missions

L1C cross comparisons

- **OCI & HARP2 & SPEX:**
  - Common L1C grids
  - Good agreement on reflectance (<1%),
  - Relatively larger difference on polarization mostly on 440nm.
  - Comparison with airborne instruments next





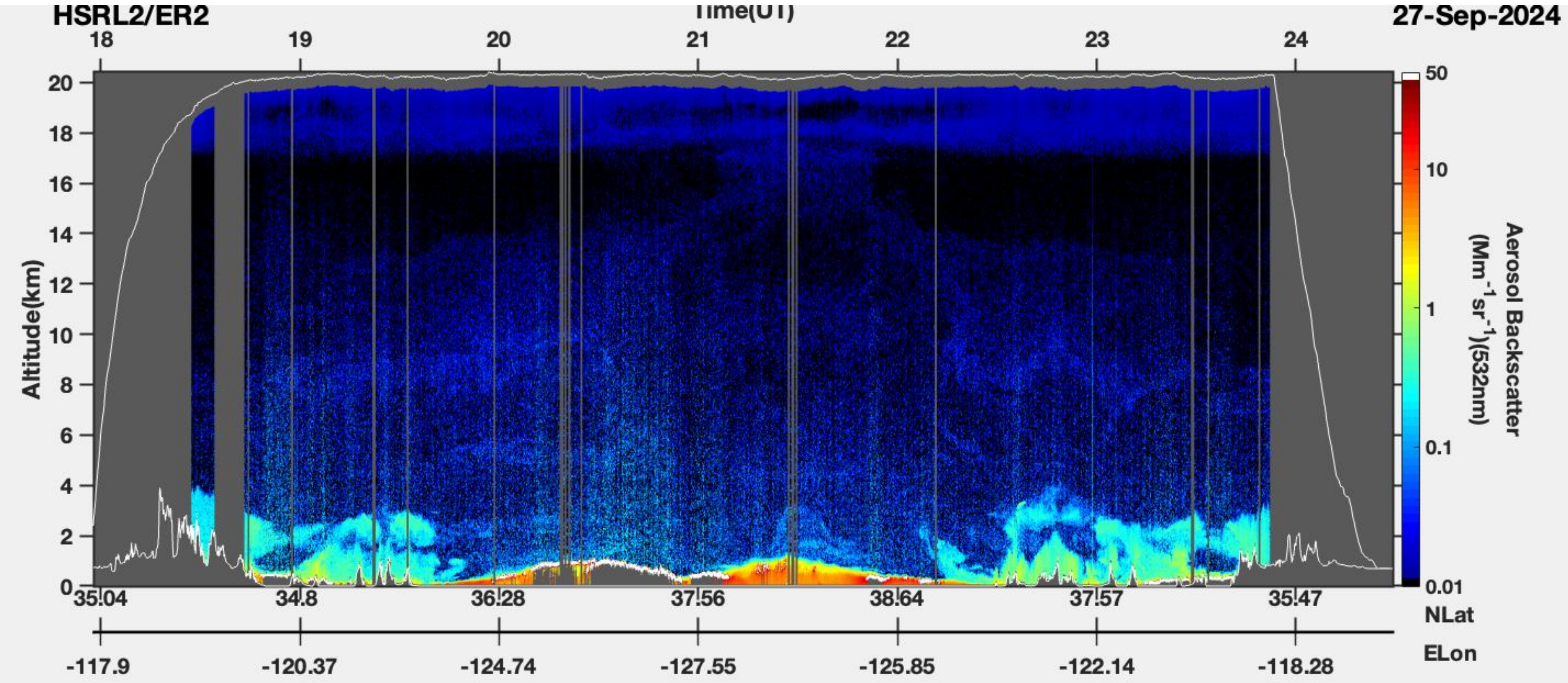


Reflectance at 440 (20 degree)

L2 AOD validations with HSRL (total 9 days)

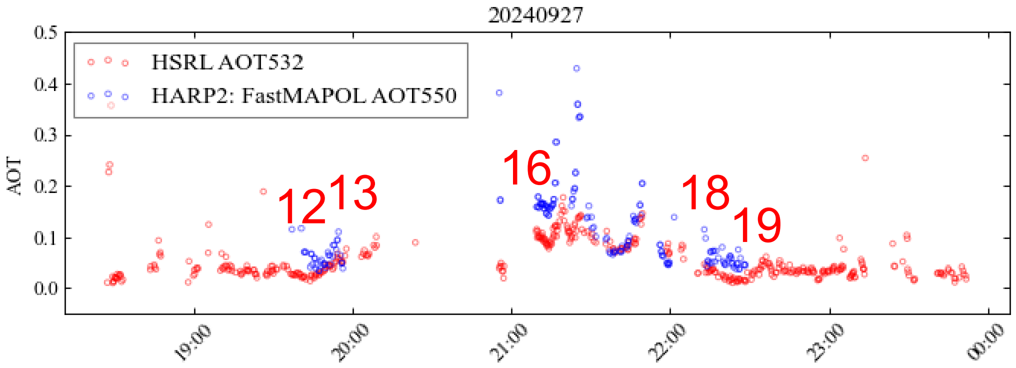
High Spectral Resolution Lidar (HSRL-2): vertical profile of aerosol extinction and backscatter

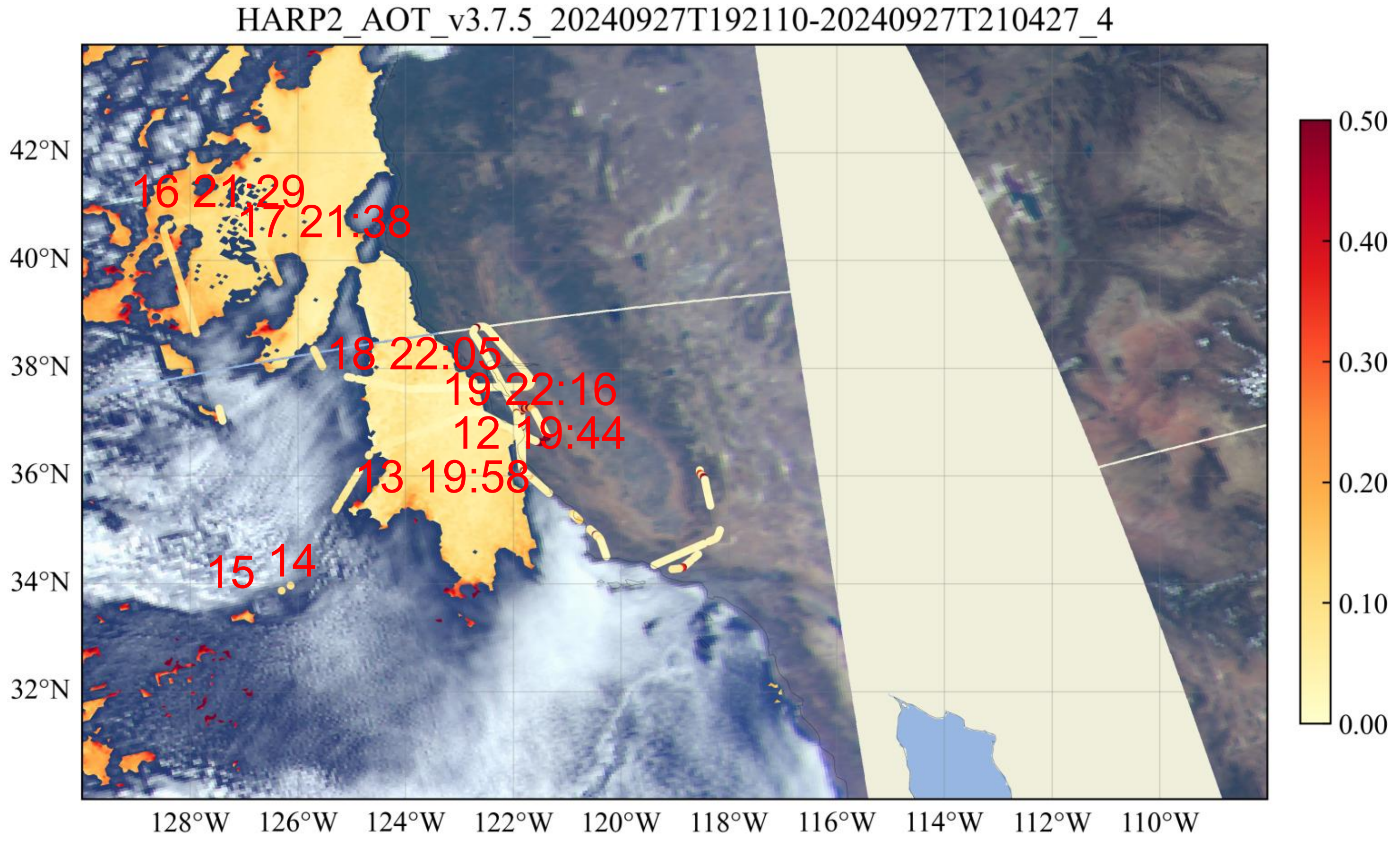
- This can be integrated to calculate Aerosol Optical Depth (AOD) and compared to that FastMAPOL product
- Benefits: alternative means of deriving AOD, frequency of measurements



L2 AOD validations with HSRL (2024/09/27)

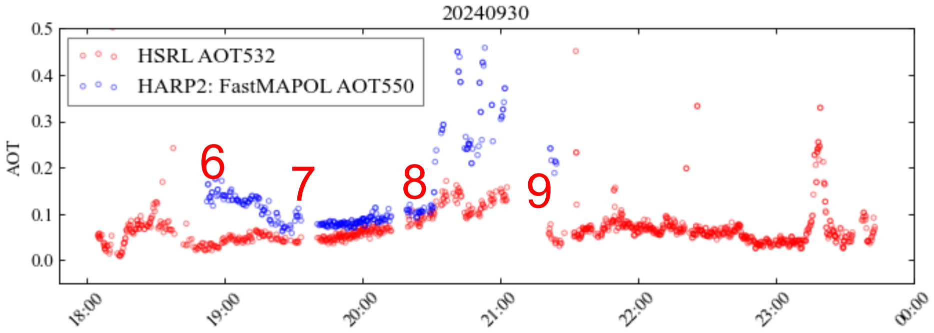
- Provide large number of collocated pixels.
- General agree with expectation.
- Impacts by time difference and distance to cloud.

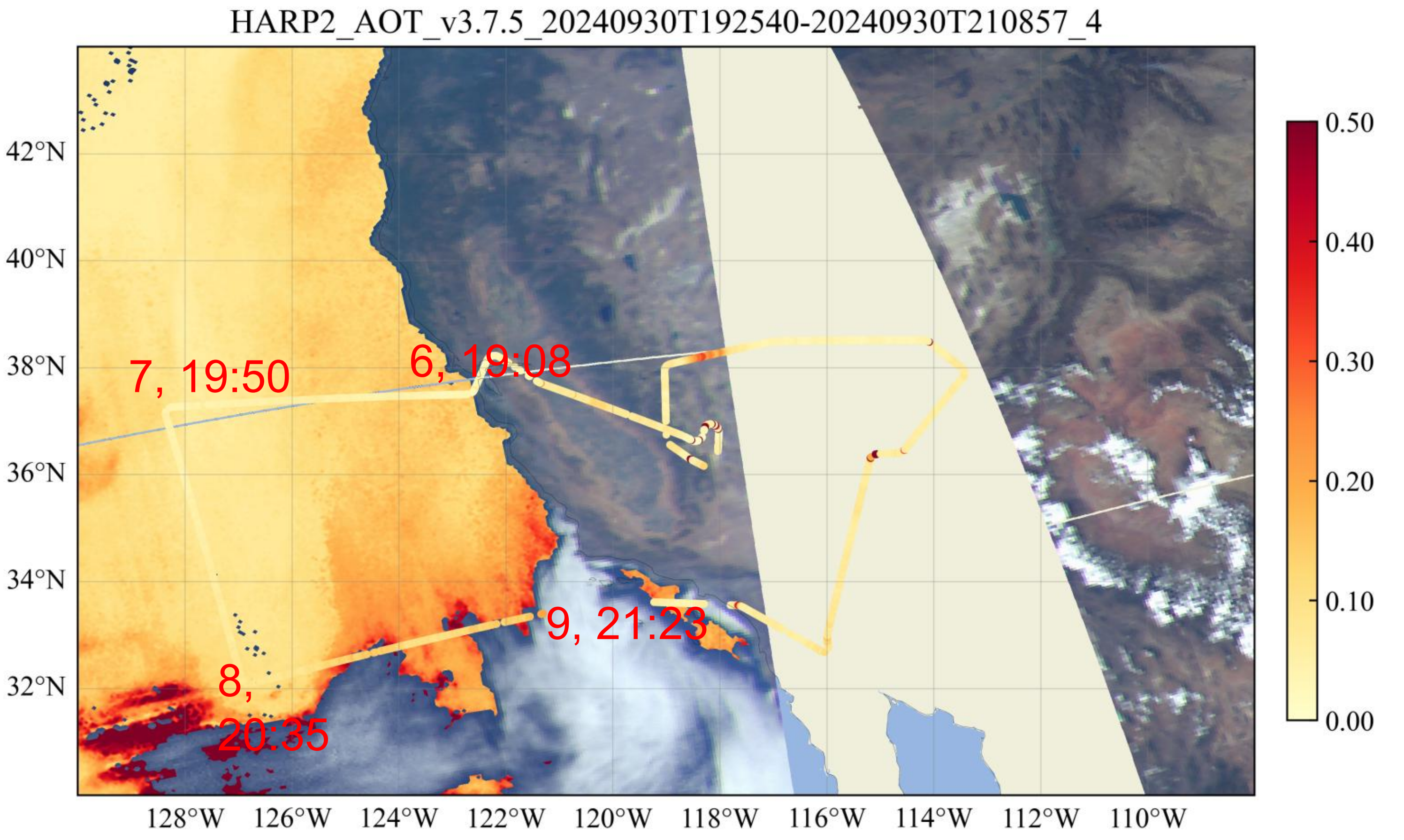




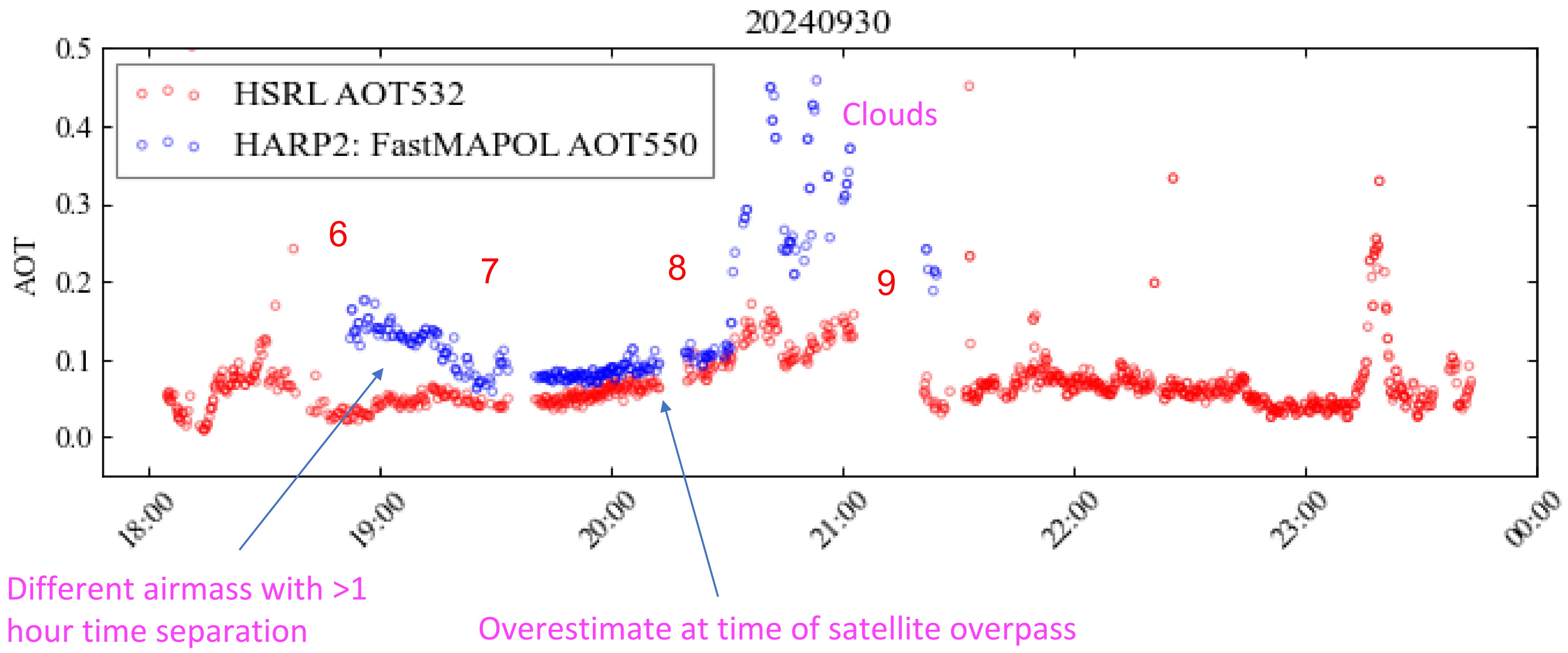
L2 AOD validations with HSRL (2024/09/30)

- Provide large number of collocated pixels.
- General agree with expectation.
- Impacts by time difference and distance to cloud.





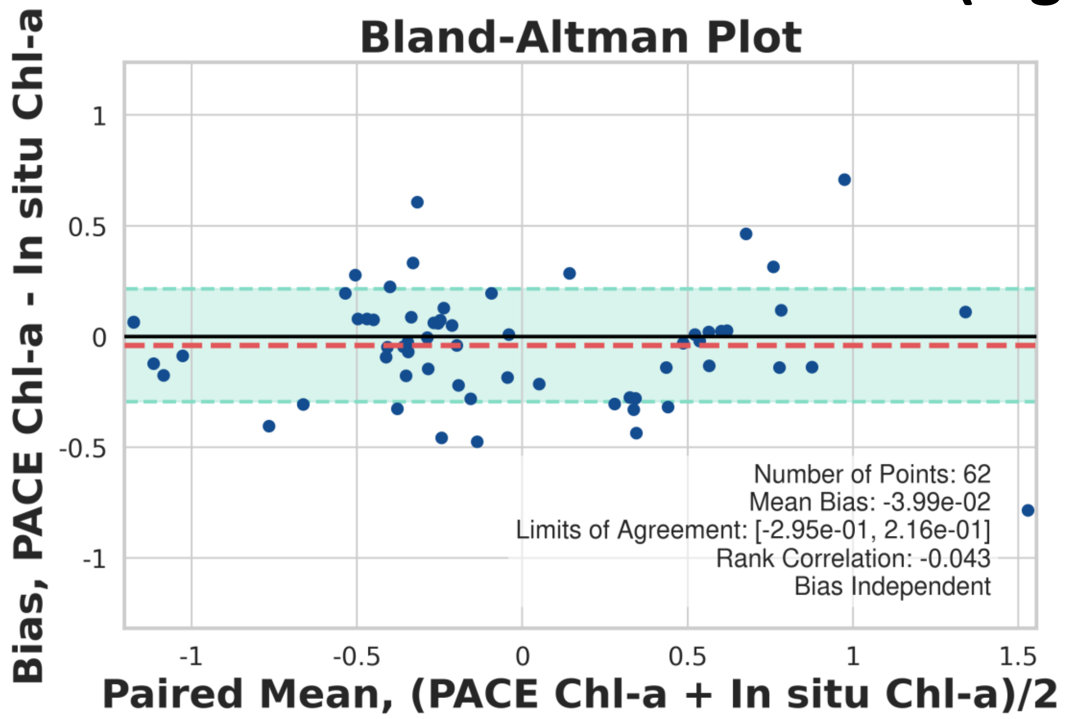
L2 AOD validations with HSRL (2024/09/30)



PACE-PAX also contributed to overall statistical assessment

PACE matchups page
pace.oceansciences.org/pace_data_matchups.htm

Chl-a (log mg m-3)



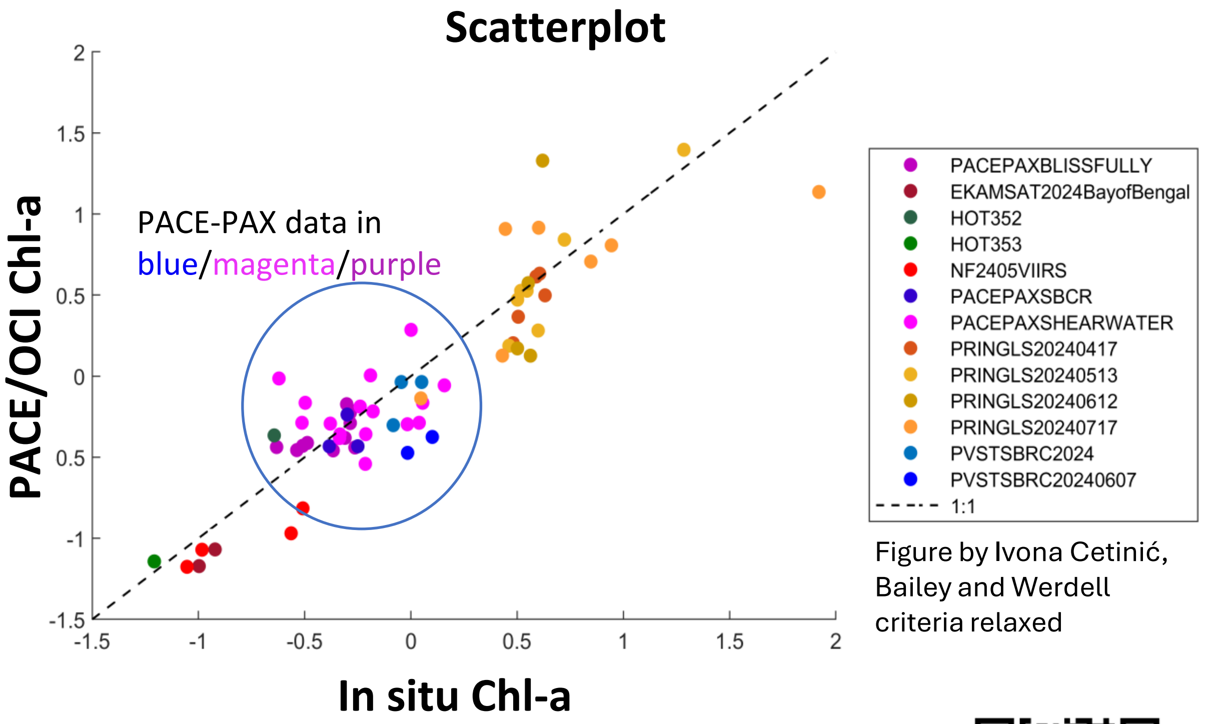


Figure by Ivona Cetinić, Bailey and Werdell
criteria relaxed

Curious about Bland-Altman analysis? More details are at my soapbox: github.com/knobelsp/BlandAltman

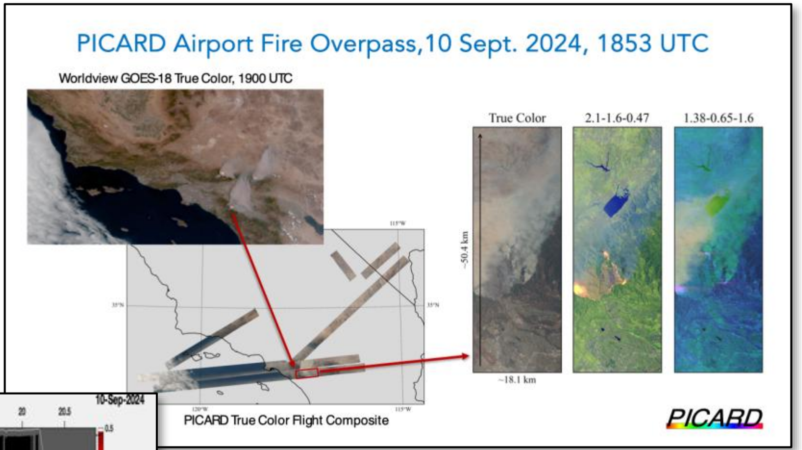
In addition to validation, we collected data useful for algorithm development and scientific analysis, e.g. biomass burning events

Major, simultaneous S. California Wildfires

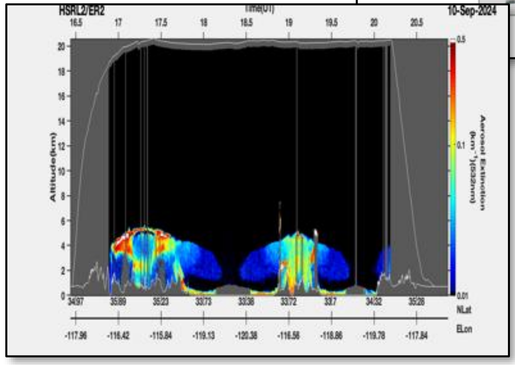
- Bridge fire: 54,878 acres burned
- Line fire: 43,978 acres burned
- Airport fire: 23,526 acres burned

Fires began 5-9th Sept, observed on the 8th, 10th, 13th, 15th, and more

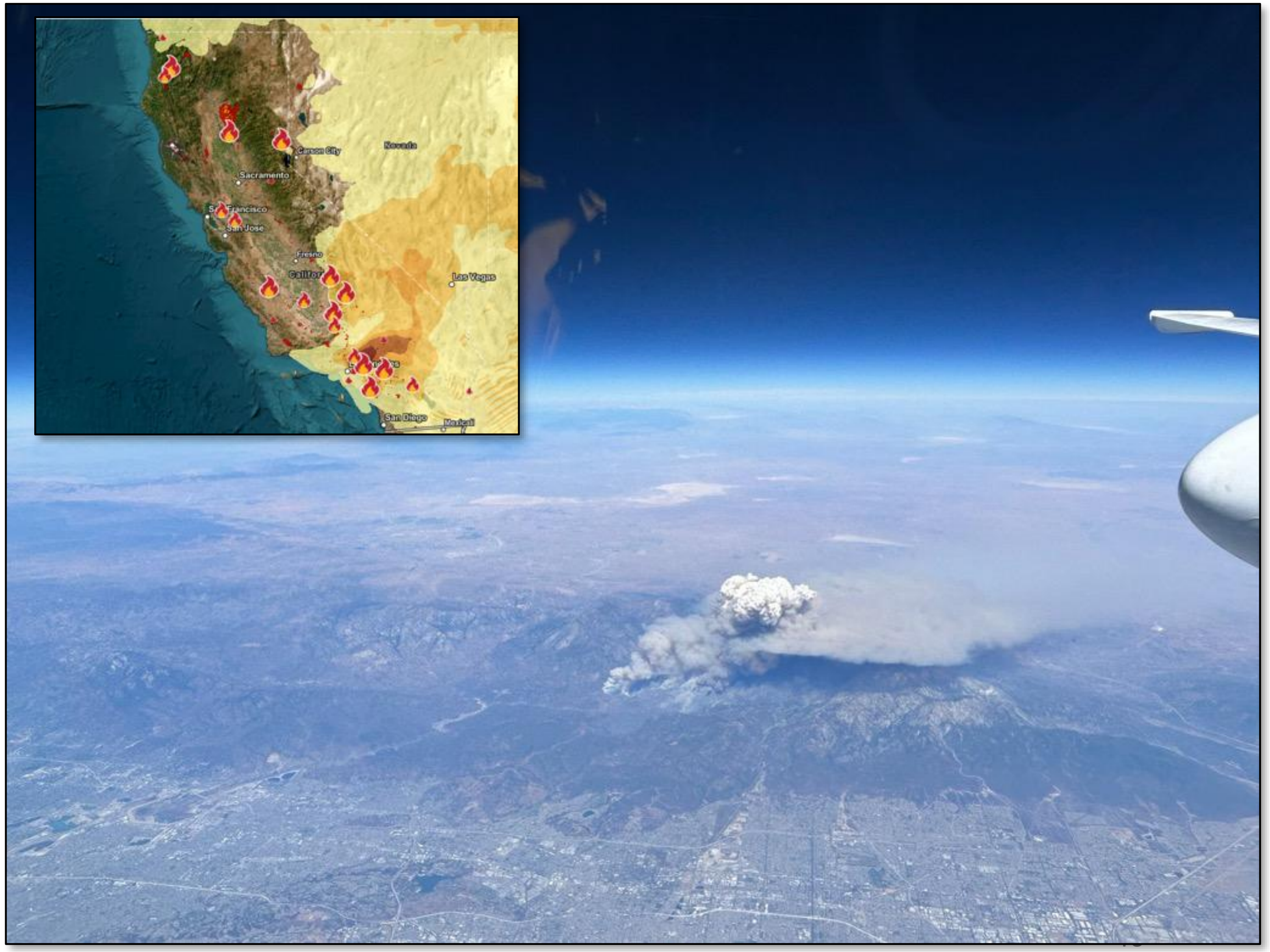
PICARD →



HSRL2 ↓



Note: data are preliminary and not for scientific use



Next steps: archive & documentation

Ocean data SeaBASS archive seabass.gsfc.nasa.gov

All other data

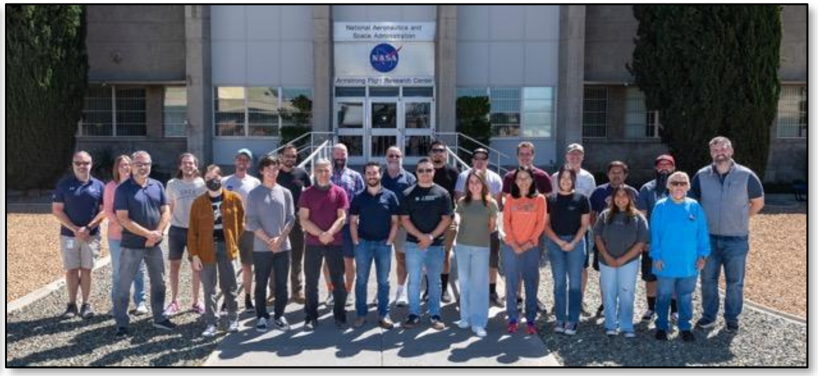
- Temporary ingest archive: www-air.larc.nasa.gov
- (Future) Permanent archive: Atmospheric Science Data Center asdc.larc.nasa.gov

Data are free for use by all

Documentation and websites

- PACE-PAX white paper currently available
- Flight/ship reports to a NASA Technical Report
- Peer-reviewed manuscript in BAMS or ESSD
- Dedicated portion of PACE website

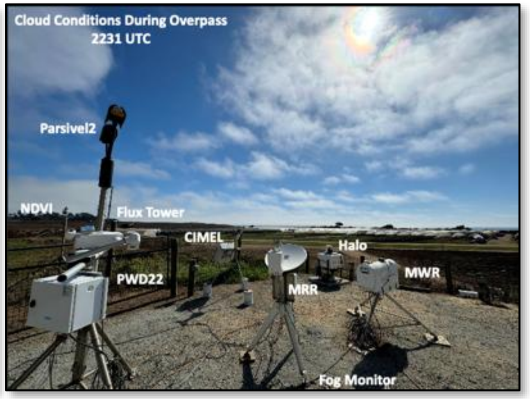
pace.oceansciences.org/pace-pax.htm



Thank you!

GODDARD EARTH SCIENCES · NPS · SRON Netherlands Institute for Space Research

JPL Jet Propulsion Laboratory California Institute of Technology · NOAA · UMBC · NASA Langley Research Center



Backup slides

NASA PACE-PAX

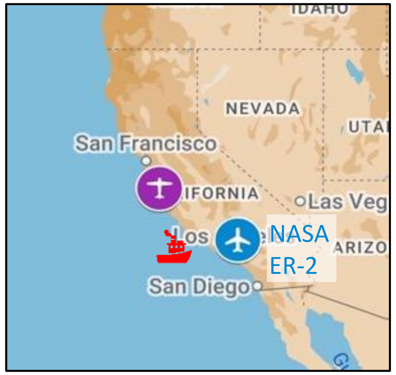
https://earthobservatory.nasa.gov/blogs/fromthefield/2024/09/13/sailing-away-for-pace/

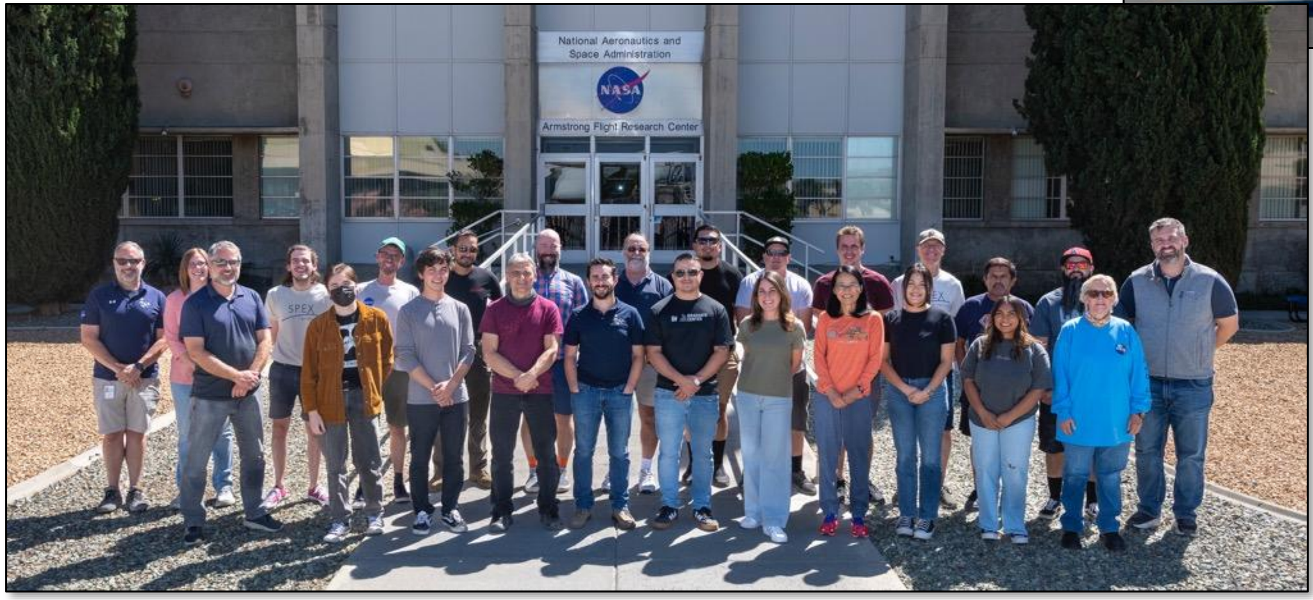
R/V Blissfully

https://earthobservatory.nasa.gov/blogs/fromthefield/2024/09/24/twenty-one-hours-a-day-on-30-foot-floating-science-lab/

NASA PACE-PAX

NASA ER-2



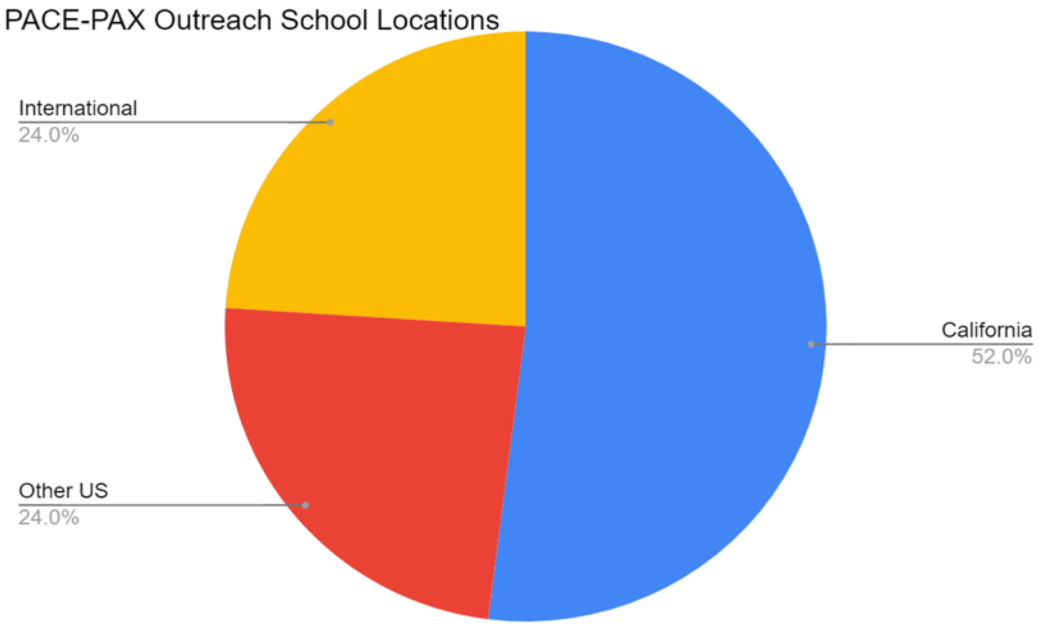


https://blogs.nasa.gov/pace/2024/09/24/nasa-pilots-use-specialty-suits-to-validate-data/

NPS/ CIRPAS Twin Otter

https://earthobservatory.nasa.gov/blogs/fromthefield/2024/09/18/day-in-the-life-of-a-pace-pax-mission-flight/

- 62 presentations to 24 K-12 schools in three countries (USA, Philippines, South Africa and 6 US states. **Over 2,425 students reached!**
- Reaching 50 at risk and 41 special education students at Flour Bluff ISD in Texas
- 30 presentations were for GLOBE schools
- Setting up multiple virtual tours of R/V *Blissfully* with the help of Dr. Bridget Seegers
- Receiving handmade cards from TK students in California

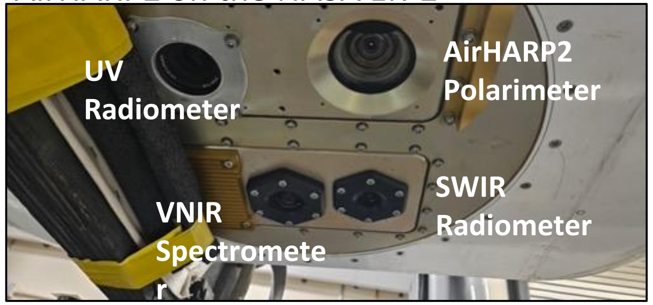


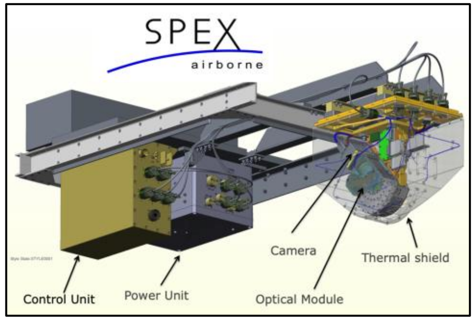
+ NASA Earth field blogs + participation in Girls in Aviation + Girls in Ocean Sciences

ER-2 instrumentation

Instrument	Platform	Role	Lead PI	Institution
AirHARP	ER-2	PACE/HARP2 polarimetry proxy	J. Vanderlei Martins	UMBC
PICARD	ER-2	PACE/OCI spectrometer proxy	J. Jacobson / K. Meyer	NASA ARC/GSFC
PRISM	ER-2	PACE/OCI spectrometer proxy	David R. Thompson	JPL
SPEX Airborne	ER-2	PACE/SPEXone polarimetry proxy	B. van Diedenhoven	SRON

AirHARP2 on the NASA ER-2

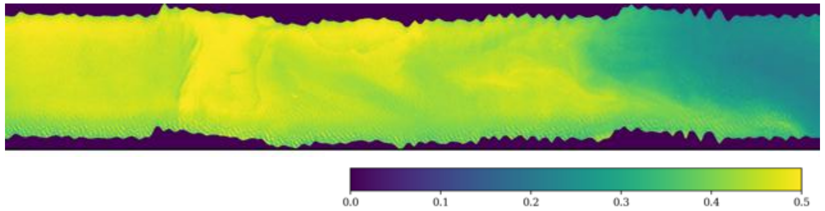




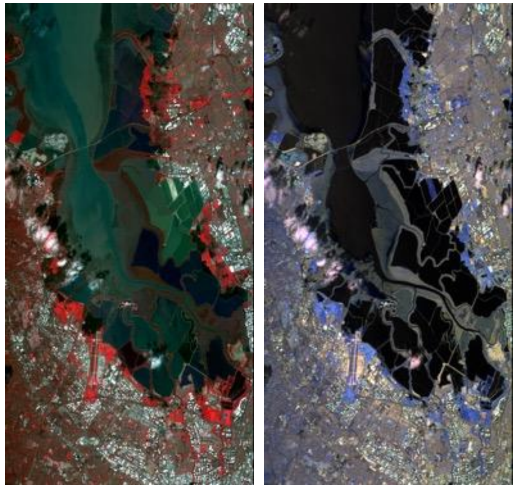
"Proxy" instruments are airborne analogs to PACE sensors

AirHARP ← → PACE/HARP2
SPEX Airborne ← → PACE/SPEXone
PICARD + PRISM ← → PACE/OCI

PRISM OC3M Chl-a (mg/m^3)



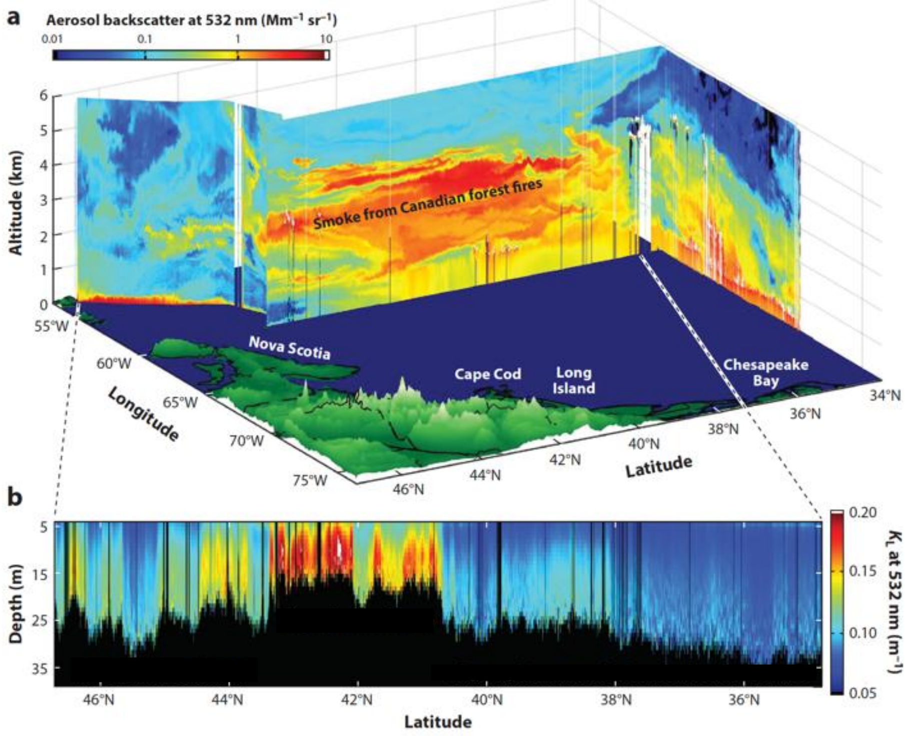
PICARD Imagery, 12 Apr 2023
Left: VNIR (RGB 0.75 µm – 0.65 µm – 0.55 µm)
Right: SWIR (RGB 2.15 µm – 1.55 µm – 1.15 µm)



ER-2 instrumentation

Instrument	Platform	Role	Lead PI	Institution
HSRL-2	ER-2	Aerosol/cloud/ocean Lidar	T. Shingler / J. Hair	NASA LaRC
RSP	ER-2	Multi-angle polarimeter ref.	B. Cairns / K. Sinclair	NASA GISS

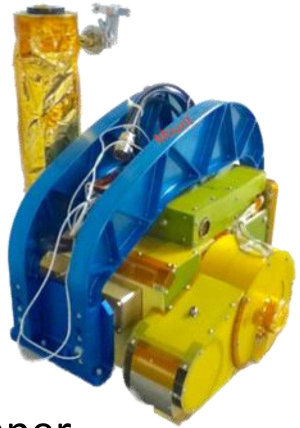
HSRL provides vertical profiles



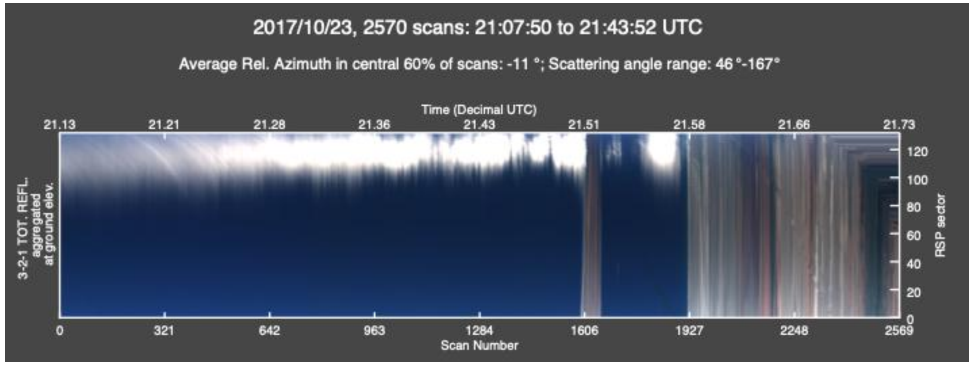
Other remote sensing instruments provide additional validation data

2 → High Spectral Resolution Lidar

→ Research Scanning Polarimeter



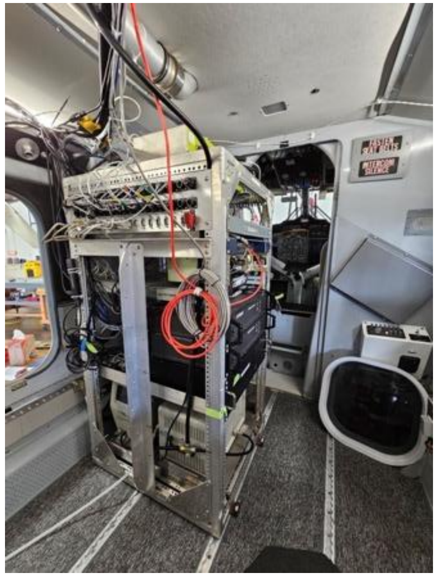
RSP is an along track scanner



Twin Otter instrumentation

Instrument	Platform	Role	Lead PI	Institution
Facility instruments	Twin Otter	Aerosol/cloud in situ instruments	Anthony Bucholtz	NPS
LARGE	Twin Otter	Aerosol/cloud in situ instruments	Luke Ziemba	NASA LaRC
LI-Nephelometer	Twin Otter	Aerosol phase functions	Adam Ahern	NOAA
ISARA	Twin Otter	In situ data synergy activity	Snorre Stamnes	NASA LaRC

Twin Otter has a complement of aerosol and cloud in situ probes

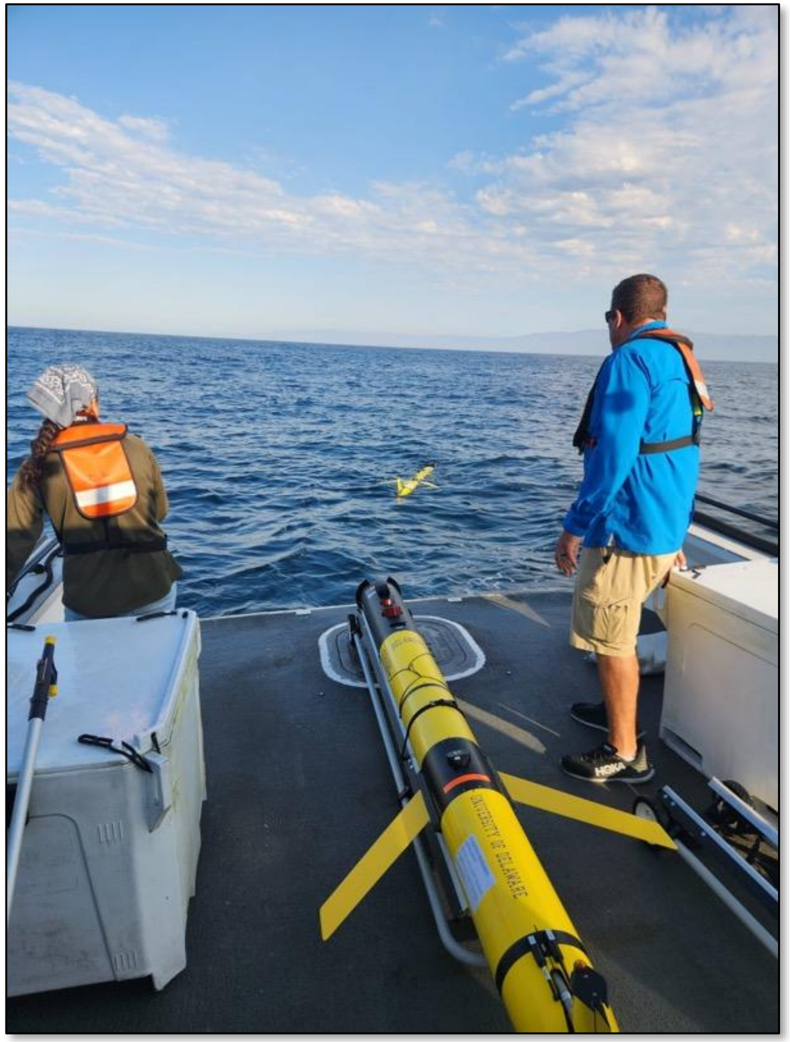


PACE-PAX Twin Otter
Instrumentation

CIRPAS Facility Instrumentation:

- **Navigation, meteorology, winds**
- **PCASP**: Passive Cavity Aerosol Spectrometer Probe 0.1 – 3.0µm
- **CAPS**: Cloud, Aerosol and Precipitation Spectrometer
    - **CIP**: Cloud Imaging Probe, 12.5µm-1.55mm @25µm resolution
    - **CAS**: Cloud Aerosol Spectrometer, 0.6µm-50µm
    - **LWC**: Liquid Water Content, 0.01 – 3 g/m3
- **CDP:** Cloud Droplet Probe, 2-47 µm
- **TSI WCPC 3789**: Water-based Condensation Particle Counter 2nm-1.0µm
- **TSI UCPC 3025A**: Ultrafine Condensation Particle Counter Dp>3nm
- **Magic CPC 210**: Condensation Particle Counter 5nm-2.5µm
- **KT-19 Downlooking**: Surface, SST, cloud top temperatures
- **SPN-1:** Solar Pyranometer (up-looking), total/direct/diffuse solar radiative fluxes
- **Video Cameras**: Cockpit-forward view; Wing-fuselage/down view
- **SATCOM Downlink**: Allows researchers on the ground to view subset of the aircraft data in real-time

U. Del. Gliders, HyperNAV, AERONET, CEOBS, R/V Rachel Carson



University of Delaware

NPS PRAESTANTIA PER SCIENTIAM

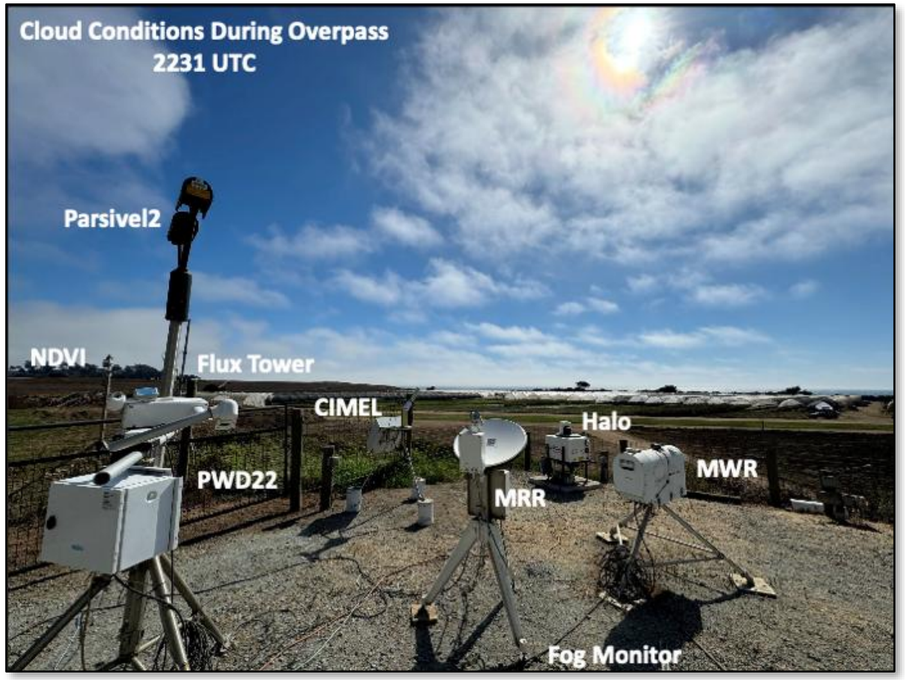
Scripps Institution of Oceanography

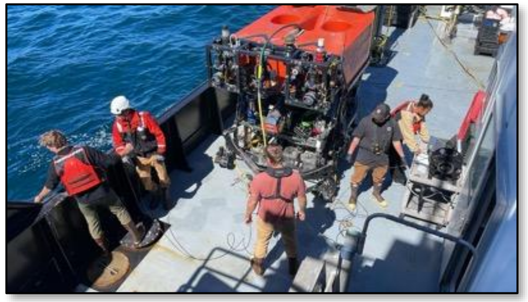
UC San Diego

AERONET AEROSOL ROBOTIC NETWORK

Oregon State University

UC SANTA BARBARA

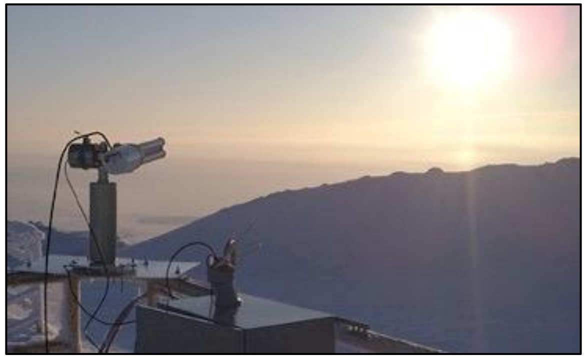


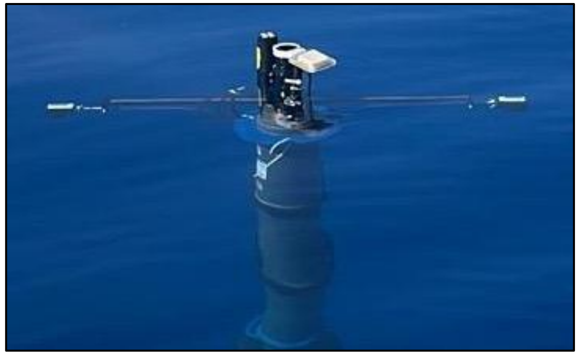


Surface instrumentation

Instrument	Platform	Role	Lead PI	Institution
Ocean instruments*	RV Shearwater	Day cruises, instrumentation TBD	Mike Ondrusek	NOAA
HyperNAV*	Ocean floats	Radiometric calibration ocean floats	Andrew Barnard	OSU
AERONET, AERONET-OC*	Surface	Aerosol prop., water leaving radiance	P. Gupta / E. Lind	NASA GSFC

- NOAA
- NASA Field support group
- PACE Validation Science team members (somewhat TBD)
  - S. Broccardo "C-STAR" aerosol radiometer/sun photometer
  - R. Foster above water polarimeter
- New ship-worthy AERONET aerosol radiometer/sun photometer
- PANDORA





*externally supported activities