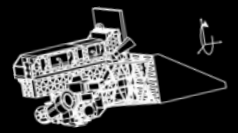
EarthCARE validation with the PACE Postlaunch Airborne eXperiment (PACE-PAX)

Kirk Knobelspiesse, NASA GSFC Ocean Ecology Laboratory

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:

- 676.5 km, polar, ascending orbit, 98°
- Sun synchronous, 13:00 Equatorial crossing
- Global (land and ocean) data
- Data to OB.DAAC (oceancolor.gsfc.nasa.gov)


PACE launch:
8 February 2024
(665 days ago)
Same launch vehicle as EarthCARE!

Mission status

Phase E (prime mission ops) through mid-Apr 2027

- PACE will be considered for mission extension (TBC)
- Fuel for ~10 years

All instruments and the spacecraft are operating nominally

- processes to address, quickly recover from, or permanently mitigate all anomalies have been established/executed

All required (heritage) products available; advanced emerging

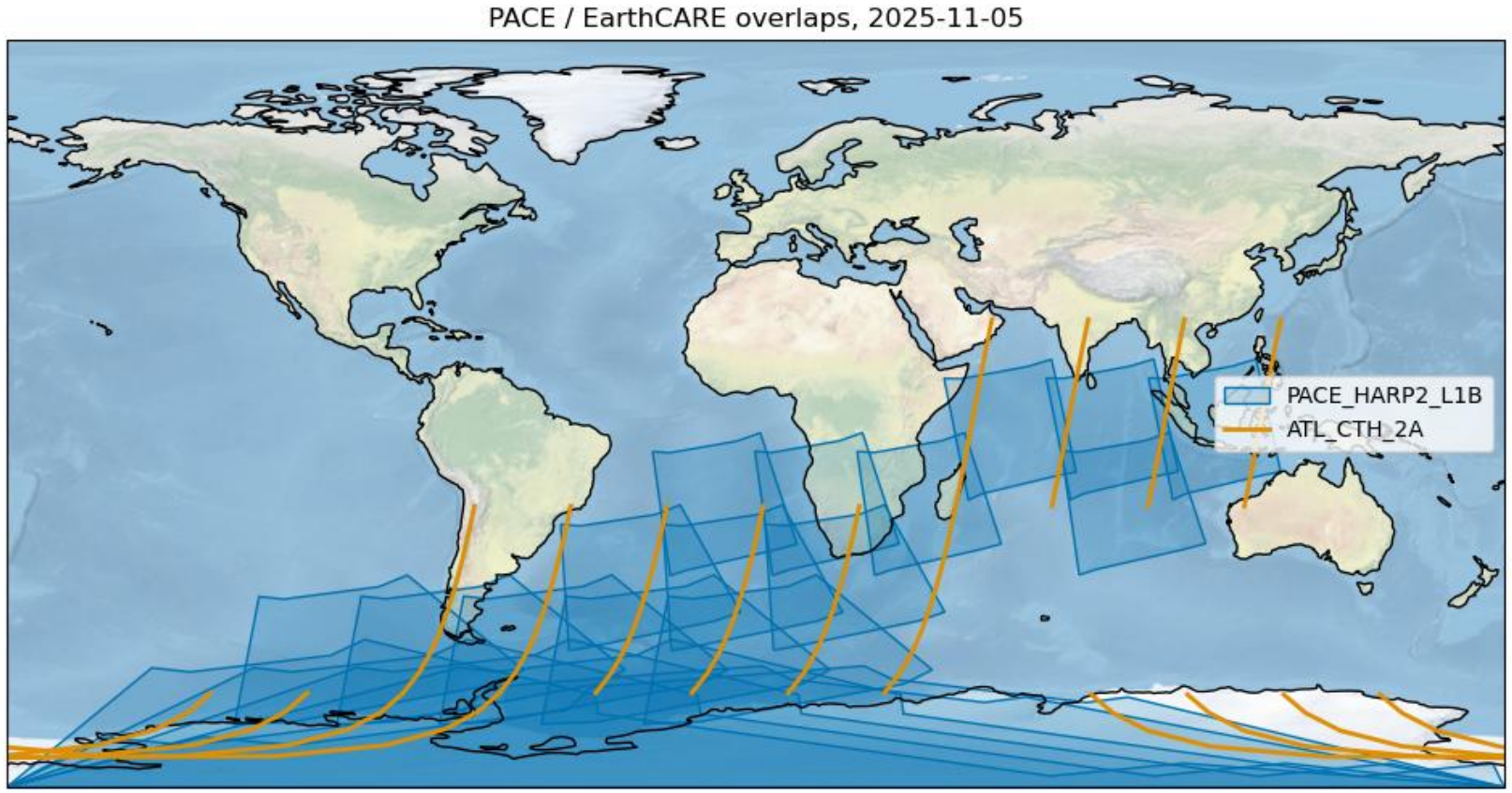
pace.gsfc.nasa.gov

Learn more about PACE and access data
News and updates mailing list:
pace-community-join@lists.nasa.gov

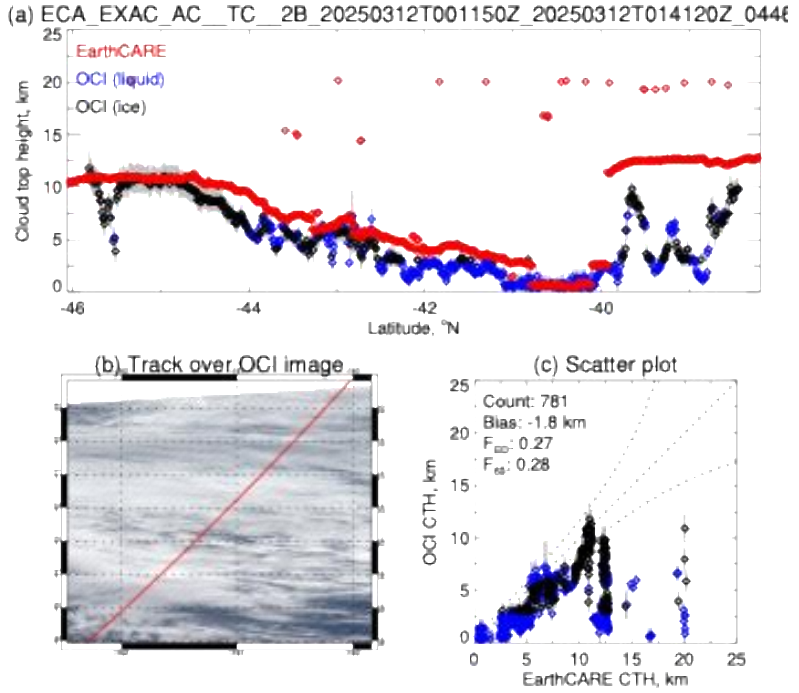
Note all data are accessible through NASA MAAP

PACE-PAX

PACE (day-side ascending) and EarthCARE (day-side descending) have different but sometimes overlapping orbits



EarthCARE/ATLID (orange) and PACE/HARP2 (blue) granule overlaps for one day. Note center-swath overlaps typically are at 40˚-50˚S (from Sean Foley)



PACE/OCI cloud top height product validation using EarthCARE/ATLID (from Andy Sayer)

See: Monday's poster by Sean Foley "Validation of 3D Cloud Reconstruction / Tomography from HARP2 (PACE) with ATLID and CPR'

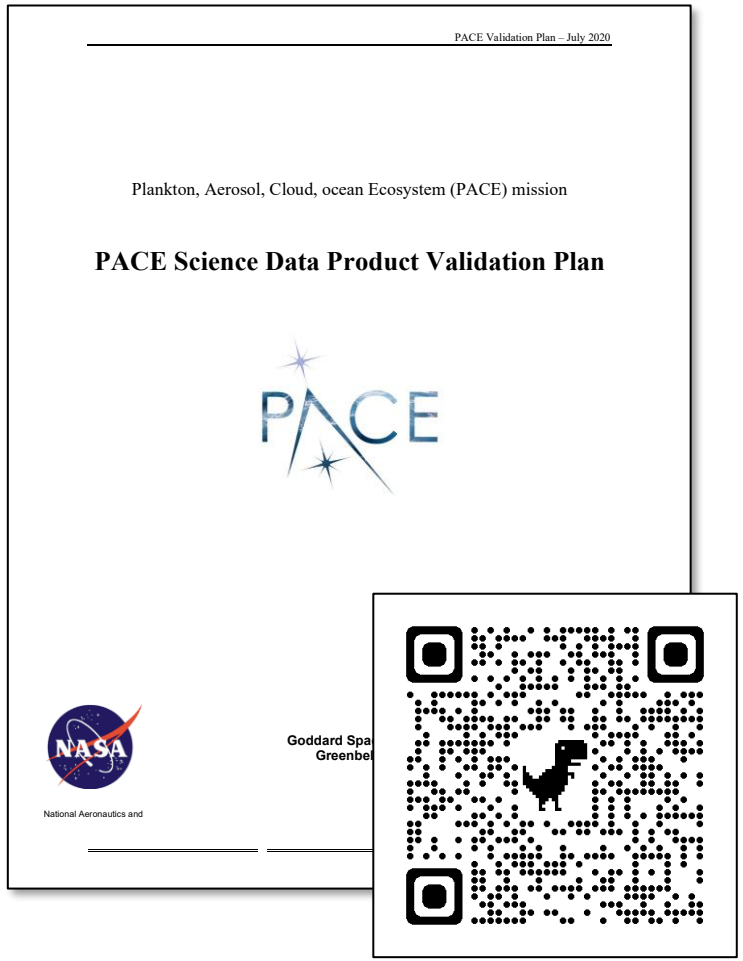
Data product status

Algorithm suite [name]	Instrument	Products	Version	L2/L3 status
Apparent Optical Properties [OC_AOP]	OCI	Spectral remote sensing reflectances (and standard uncertainties), apparent visible wavelength, fluorescence line height	3.1	Provisional (L2 and L3)
Biogeochemical properties [OC_BGC]	OCI	Chlorophyll-a (uncertainty), phytoplankton carbon, particulate organic carbon	3.1	Provisional (L2 and L3)
Cloud mask [CLDMASK]	OCI	Cloud mask	3.1	Provisional (L2)
Cyanobacteria Index (CI)	OCI	CI for inland waters	3.1	In implementation
Inherent Optical Properties [OC_IOP]	OCI	Spectral absorption and backscattering coefficients and their components (and standard uncertainties), spectral diffuse attenuation coefficients	3.1	Provisional (L2 and L3)
Land vegetation indices [LANDVI]	OCI	NDVI, EVI, CCI, NDSI, PRI, CIRE, MARI, CAR, NDWI, NDII	3.1	Provisional (L2 and L3)
MOANA	OCI	Distribution of three phytoplankton populations in the Atlantic Ocean (cells mL-1 of Prochlorococcus, Synechococcus, and autotrophic picoeukaryotes)	3.1	Provisional (L3)
Multiangle Implementation of Atmospheric Correction [MAIAC]	OCI	Aerosol and surface properties, exact list TBC		In implementation
OCI Clouds [CLD]	OCI	Cloud mask, optical thickness, effective radius, liquid water path, top height, top temperature, top pressure [multiple permutations]	3.1	Provisional (L2 and L3)
Photosynthetically Available Radiation [PAR]	OCI	Daily mean and instantaneous photosynthetically available radiation, above and below surface, scalar and planar	3.1	Provisional (L2 and L3)
Surface reflectance [SFREFL]	OCI	Spectral surface reflectance @122 wavelengths	3.1	Provisional (L2 and L3)
Trace gases	OCI	NO2, O3		Provisional (L2, L3)
Unified aerosol algorithm [AER_UAA; UVAI_UAA]	OCI	Spectral aerosol optical depth, fine mode fraction (ocean only), near-UV single scattering albedo (for high AOD), UV aerosol index	3.1	Provisional (L2, L3)
Aquaverse	OCI	Water quality parameters for inland waters	3.1	In implementation
Greenland Cryo (CRYOIS)	OCI (HARP future)			In development
Aerosol FastMAPOL [MAPOL_OCEAN]	HARP2	Aerosol and ocean properties	3	Provisional (L2, L3)
Aerosol GRASP	HARP2	Aerosol, ocean and land properties		In implementation
Aerosol/Ocean FastMAPOL coastal [MAPOL_COASTAL] (tbd)	HARP2	Aerosol and ocean properties with component based approach		In development
AtmoNR	HARP2	Volumetric 3D cloud reconstruction		In development
Ocean Surface	HARP2	Ocean surface refractive index, NIR AOD		Development paused
Polarimetric cloud [CLOUD_GPC]	HARP2	Cloud liquid index, liquid cloud droplet effective radius and variance	3	Provisional (L2 and L3)
Aerosol Microphysical Aerosol Properties from Polarimeters (MAPP)	OCI + HARP2 + SPEXone	Aerosol and ocean properties, aerosol and land		In implementation
Aerosol FastMAPOL [MAPOL_OCEAN]	SPEXone	Aerosol and ocean properties	3	Provisional (L2, L3)
Aerosol RemoTAP [RTAP_OC; RTAP_LD]	SPEXone	Aerosol, ocean and land properties. Separate processing stream for products over ocean (OC) and land (LD)	3	Provisional (L2),L3

Validation is required to ‘graduate’ to standard product status

https://pace.oceansciences.org/data_table.htm

PACE validation activities



pace.oceansciences.org/documents.htm

1. NASA Ocean Ecology Lab field support group
2. PACE Validation Science Team (PVST)
3. Existing community activities
   - Instrument networks e.g. AERONET, ARM, Cloudnet
   - Ongoing field activities
4. SeaBASS archive and analysis system: seabass.gsfc.nasa.gov
5. PACE Postlaunch Airborne eXperiment

PACE Postlaunch Airborne eXperiment (PACE-PAX)

validation that can only be done with an aircraft+ship, multi-sensor field campaign

PACE-PAX

PACE Postlaunch Airborne eXperiment (PACE-PAX)

Central-Southern California, September 2024

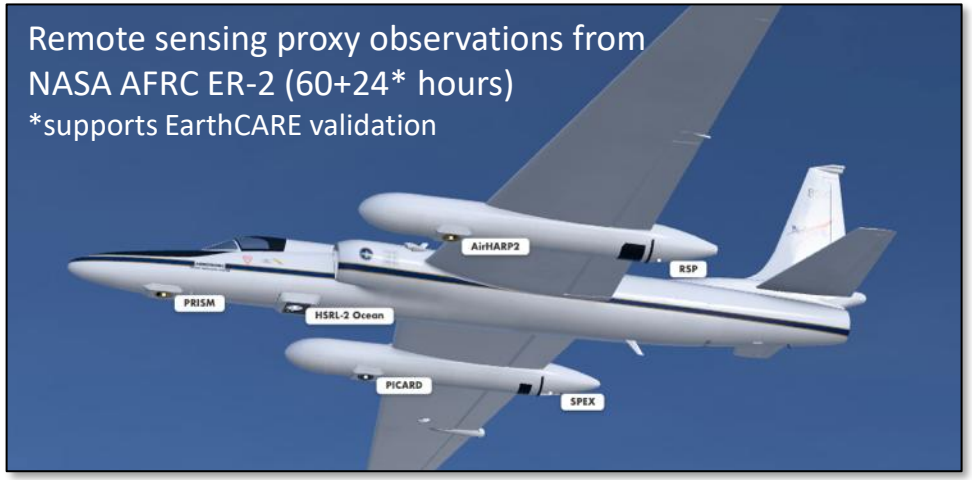
Objective: validate new ocean, atmosphere and land surface products from NASA's PACE observatory

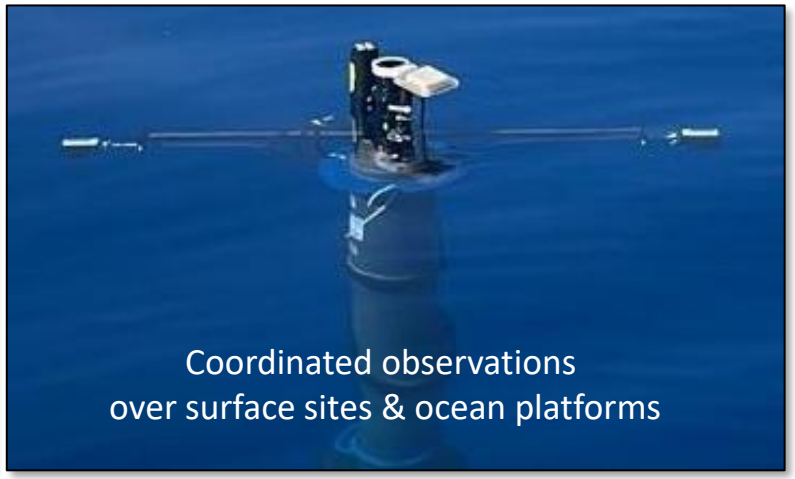
60 Twin Otter flight hours

60 ER+2 flight hours +24 for EarthCARE validation

More details at pace.oceansciences.org/pace-pax.htm

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





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 reference	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*	R/V Shearwater	Day cruises, ocean and atm. obs.	Mike Ondrusek	NOAA
HyperNAV*	Ocean floats	Radiometric calibration ocean floats	Andrew Barnard	OSU
AERONET, AERONET-OC*	Surface	Aerosol prop., water leaving radiance	E. Lind / P. Gupta	NASA GSFC

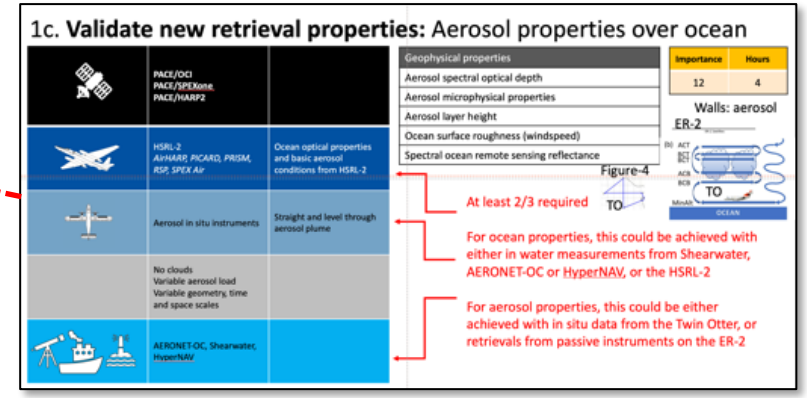
*externally supported activities

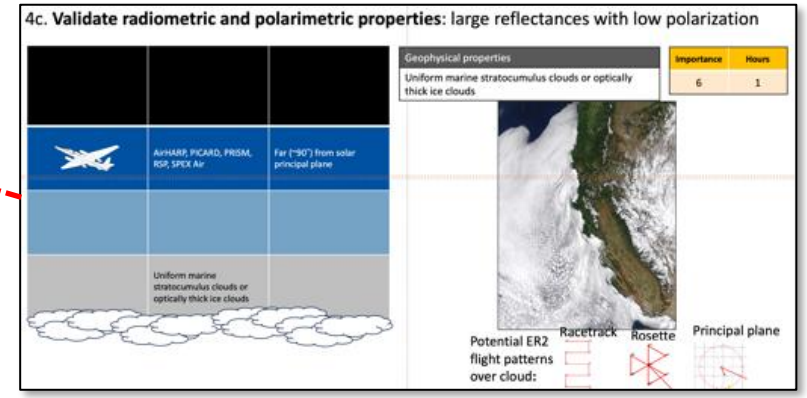
How we organized: the validation traceability matrix

Validation objectives	ID	Measurement objectives	Importance, w	Required time (hours)	Total observed (hours)	Objective success	Remaining score
1. Validate new retrieval properties	a	Land surface parameters	8	2.0	3.0	0.994	0.1
	b	Ocean radiometric parameters	10	8.0	18.0	0.999	0.0
	c	Aerosol parameters over the ocean	12	8.0	20.5	0.998	0.0
	d	Aerosol parameters over land	12	8.0	22.0	1.000	0.0
	e	Cloud parameters	12	8.0	7.8	0.930	0.8
	f	Ocean surface parameters	1	8.0	1.5	0.354	0.6
3. Validate in a narrow swath	a	Aerosol parameters over the ocean (PACE)	10	8.0	3.0	0.556	4.4
	b	Aerosol parameters over land (PACE)	10	8.0	7.0	0.751	2.5
	c	Cloud parameters (PACE)	5	2.0	2.5	0.918	0.4
	d	Aerosol parameters (EarthCARE)	8	4.0	5.5	0.956	0.4
	e	Cloud parameters (EarthCARE)	8	4.0	2.5	0.632	2.9
4. Validate radiometric and polarimetric properties	a	Validate large reflectances	6	2.0	1.0	0.972	0.2
	b	Validate large reflectances with high polarization	6	2.0	1.5	0.826	1.0
	c	Validate large reflectances with low polarization	6	2.0	2.5	0.982	0.1
	d	Overfly vicarious calibration sites	6	4.0	0.0	0.268	4.4
6. Focus on specific processes or phenomena	a	High aerosol loads over land	4	2.0	0.5	1.000	0.0
	b	High aerosol loads over ocean	4	2.0	0.0	0.393	2.4
	c	Multiple aerosol layers	1	2.0	0.0	1.000	0.0
	d	Aerosol under thin cirrus	2	2.0	3.5	0.826	0.3
	e	Aerosol above liquid phase cloud	4	2.0	0.0	0.826	0.7
	f	Broken clouds with complex structure	4	2.0	3.0	0.895	0.4
	g	Dust aerosols over ocean	4	2.0	0.0	0.430	2.3
	h	Aerosol and ocean parameters over turbid waters	2	2.0	2.3	0.932	0.1
	i	Aerosol and ocean parameters over biologically productive waters	4	2.0	5.3	0.994	0.0
	k	Smoke aerosols over ocean	1	2.0	0.0	0.713	0.3
		total:	**150**	**98**	**112.8**	**0.835**	

PACE-PAX overall objectives satisfied: **0.835**

Each objective had a ranked importance, a requirement on amount of observation, and a specific measurement configuration

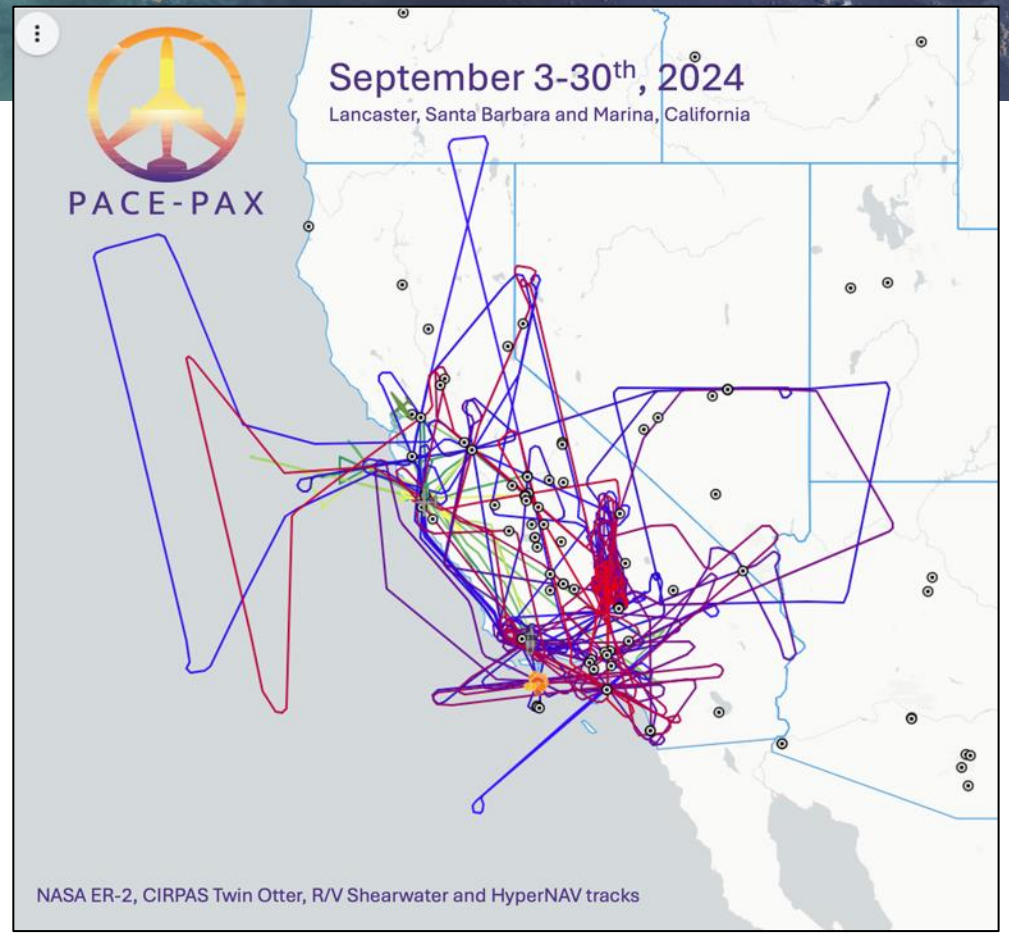




Approach in Knobelspiesse et al, 2025 in review

PACE-PAX accomplishments

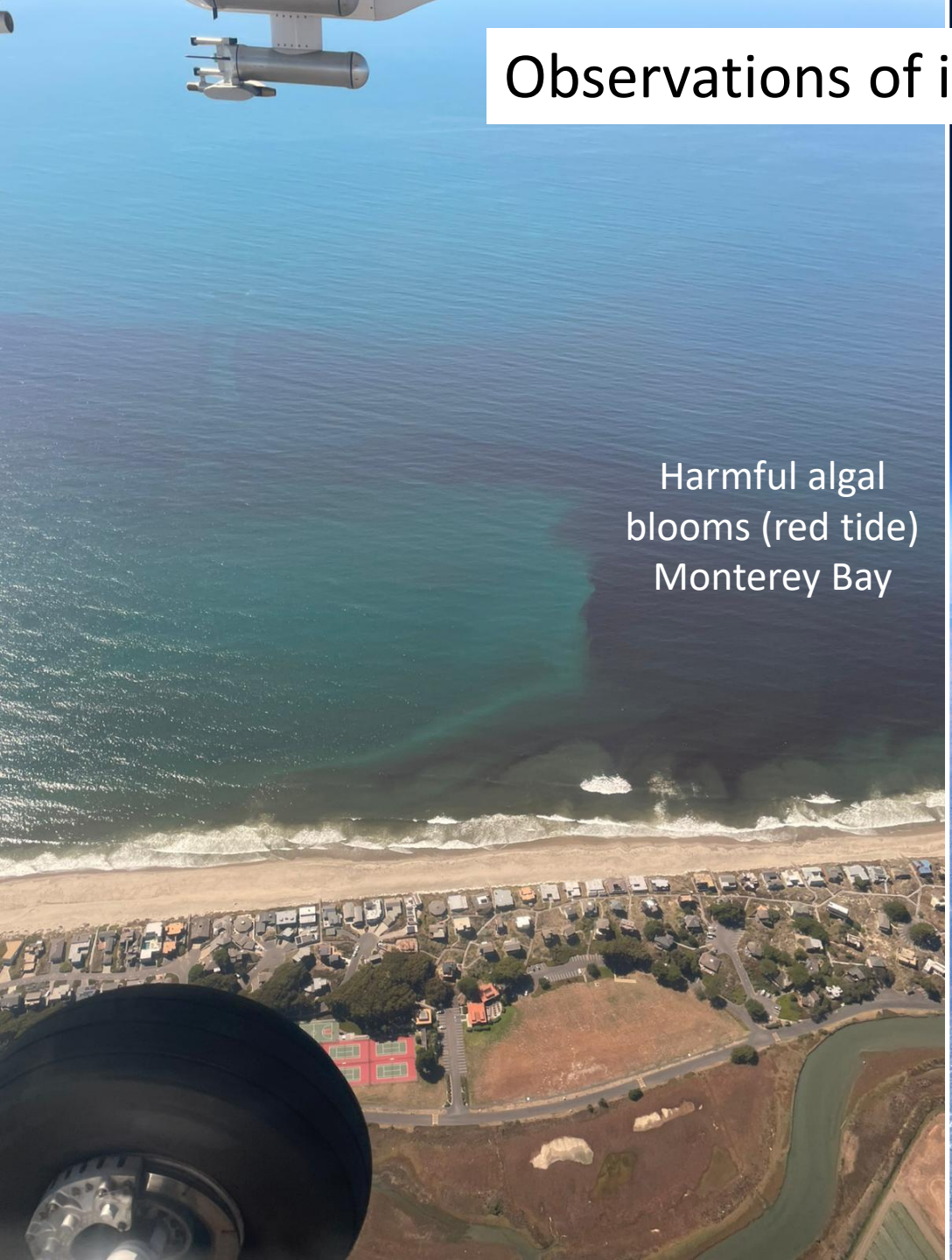
- 13 NASA ER-2 science flights 80.9 flight hours
- 17 CIRPAS Twin Otter science flights 60 flight hours
- 15 day trips of the R/V Shearwater
- 9 day trips of the R/V Blissfully
- 16 days of observations during a PACE overpass
- 6 days of observations during an EarthCARE overpass
- Ground vicarious calibration at Ivanpah Playa
- Cooperation with PACE Validation Science Team (PVST) efforts
- Many overflights of AERONET ground sites
- Wildfires in Southern California, Red tides, and other events

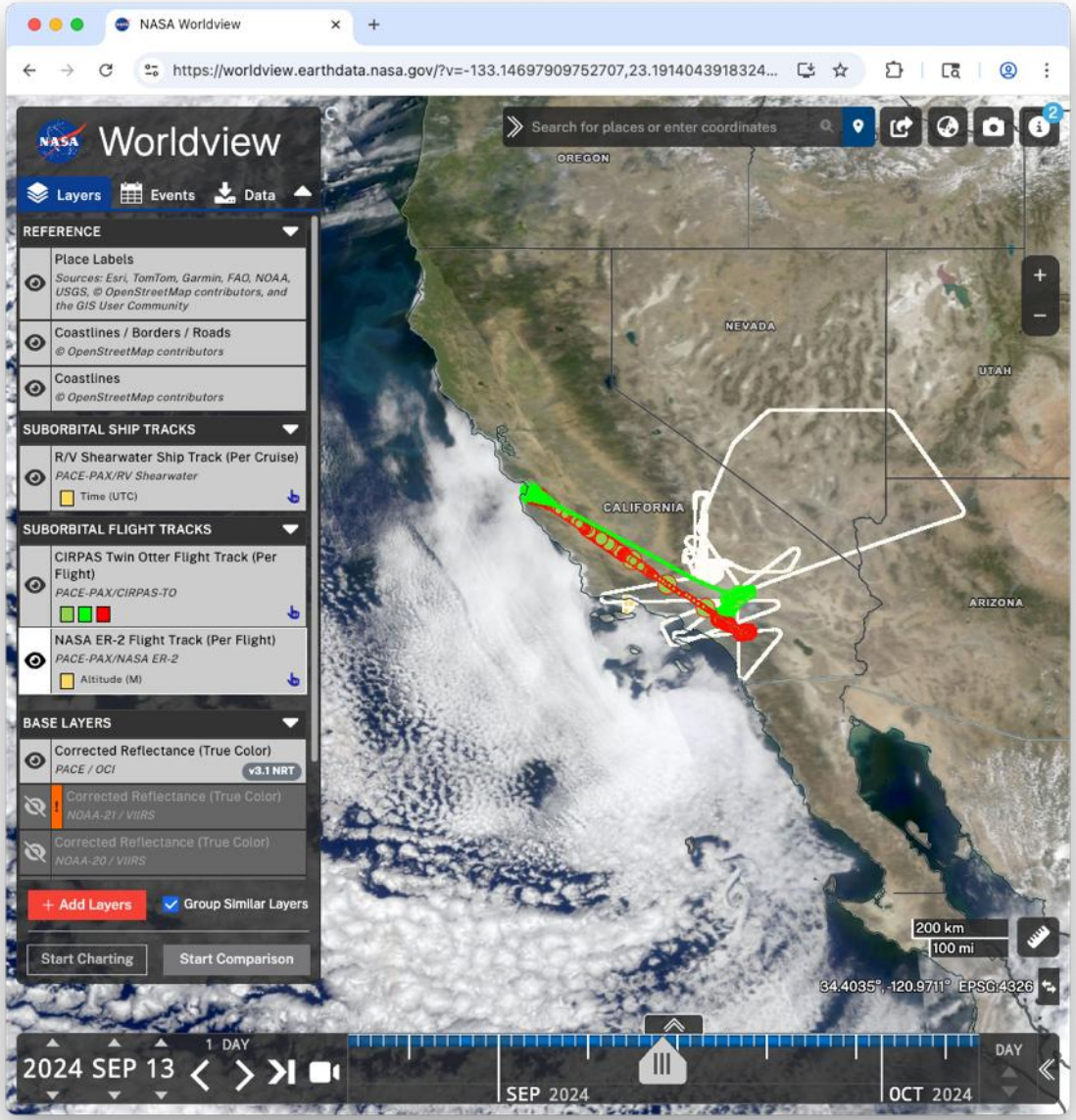


EarthCARE validation assessment

Operations ID	Date	ER-2 flight segment	Twin Otter flight segments	PACE overpass time	EarthCARE overpass time	EarthCARE orbit number	Coordinated observation location	Coordination observation conditions	Comments
RF0908	9/8/24	22:18 – 22:40	22:06-22:23 (up) 22:23-22:43 (down)		22:39	1602	ER-2: Monterey Bay, Northern California and Central Valley; Twin Otter: CEOBS site	Marine stratocumulus clouds over bay, low AOD over land. CEOBS site cloud free	CEOBS is Navy Postgraduate School site with scanning radar, lidar, microwave radiometer, AERONET and more.
RF0917	9/17/24	21:41 – 21:58 22:12 – 22:33		20:14	22:47	1742	Out and back along line from coastal central California over Central Valley to Modesto	Moderate aerosol loads (most likely smoke) under intermittent cirrus clouds	Out and back along EarthCARE track, end of line 15 min prior to EarthCARE overpass.
RF0919	9/19/24		21:50-22:00 (over cloud) 22:10-22:30 (no cloud)	19:45, 21:23	22:15	1773	Twin Otter spirals near Camarillo, CA	Partly cloudy; first spiral down to cloud top, then repositioned for second spiral in cloud free conditions	Planned ER-2 flight scrubbed due to aircraft problem. Note Twin Otter spiral times TBC
RF0923	9/23/24	21:34 – 22:05	-	20:25	21:53	1853	Arizona, including Grand Canyon	Some clouds in northern portion, otherwise no cloud with low aerosol load	
RF0926	9/26/24	22:09 – 22:40	-	20:31	22:22	1882	California Central Valley and Sierra Nevada mountains, Nevada near Reno	Cloud free, low aerosol load	Note additional ground instrumentation in Reno at the Desert Research Institute
RF0930	9/30/24	21:48– 22:20		21:09	22:02	1944	South-East California from Mexico border to west of Las Vegas	Elevated aerosols identified as ‘dusty mix’	

Observations of interest beyond validation





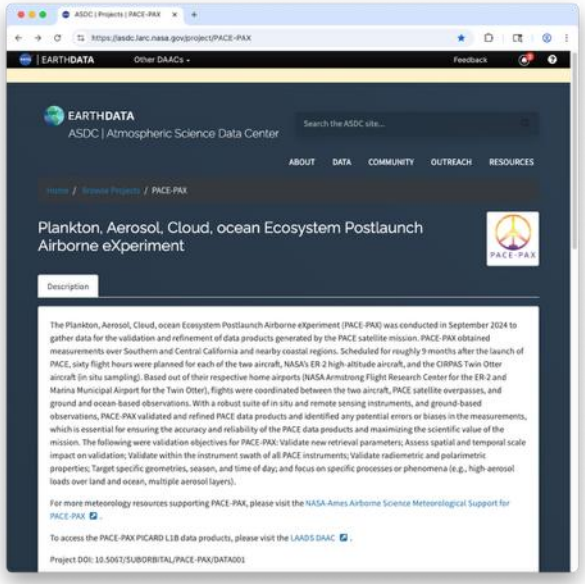
Data are discoverable with NASA Earthdata Search, https://search.earthdata.nasa.gov/

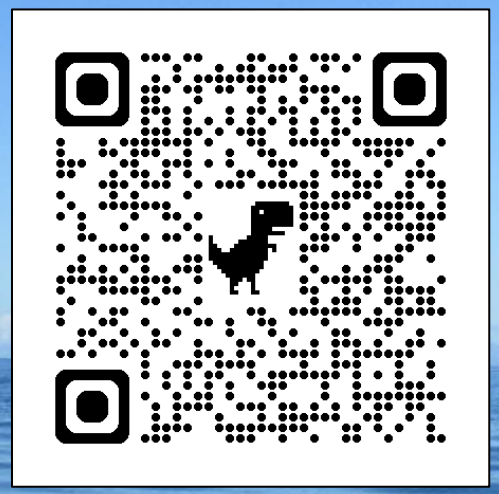
Data are finalized and free and open to the public

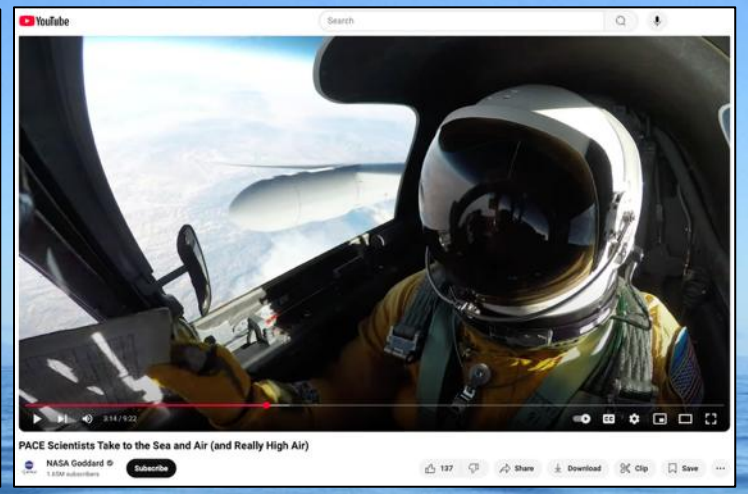
Main data archive:
DOI: 10.5067/SUBORBITAL/PACE-PAX/DATA001

Ocean data archive:
DOI: 10.5067/SeaBASS/PACE-PAX/DATA001

Flight reports, news, updates at PACE-PAX website:
https://pace.oceansciences.org/pace-pax.htm







A video about PACE-PAX: https://youtu.be/cCsuck3dJU4?feature=shared

Thank you!

Kirk Knobelspiesse, PACE-PAX Mission Scientist, Kirk.Knobelspiesse@nasa.gov
Brian Cairns, PACE-PAX Deputy Mission Scientist, Brian.Cairns@nasa.gov
Ivona Cetinić, PACE-PAX Deputy Mission Scientist, Ivona.cetinic@nasa.gov

PACE-PAX

Interested in learning more about PACE? See our Community of Practice in the Applications section here: pace.gsfc.nasa.gov

Backup slides

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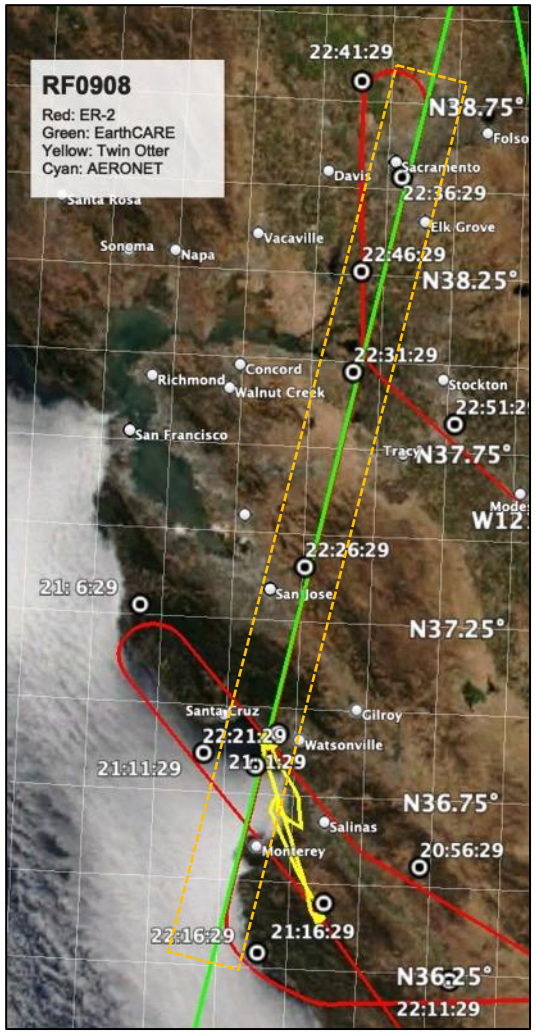
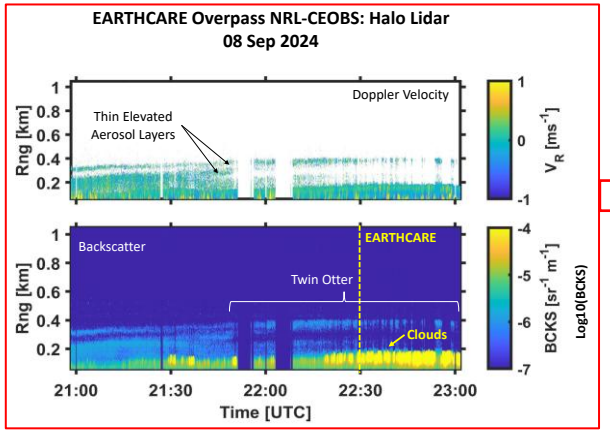
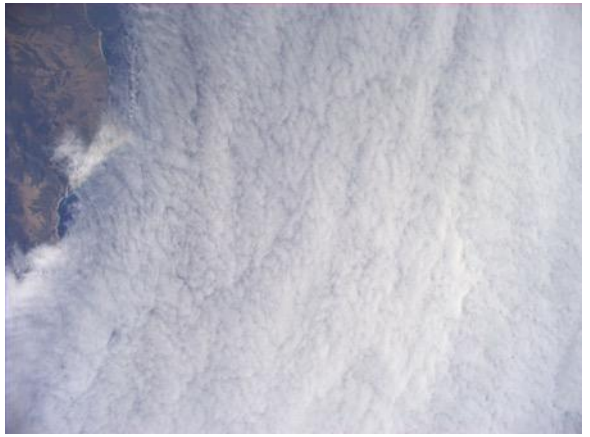
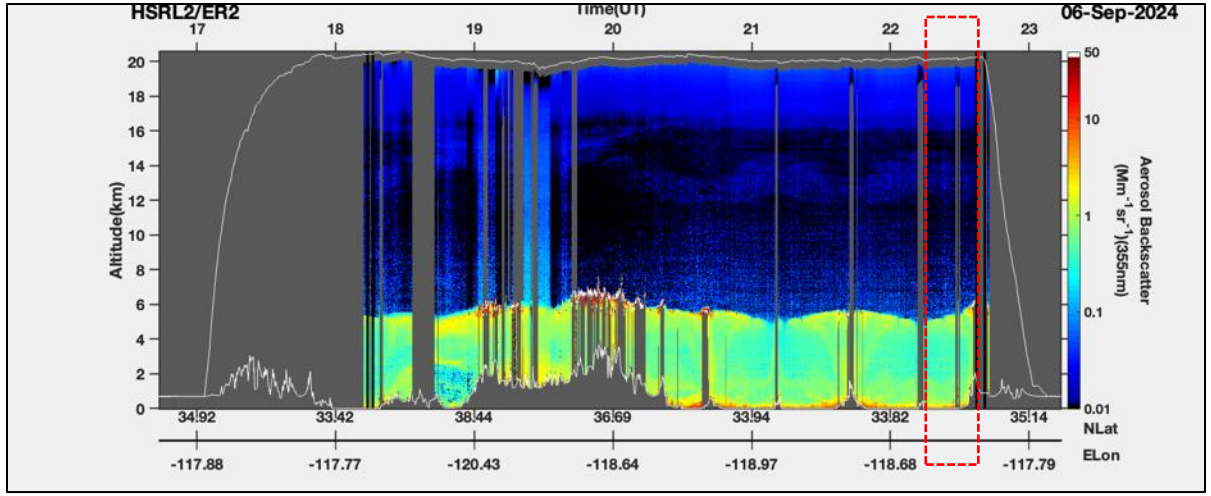




MVIS: 22:22 over CEOBS site

MVIS: 22:17 cloudy start of EarthCARE line





MVIS: 22:36 end of EarthCARE line at Sacramento

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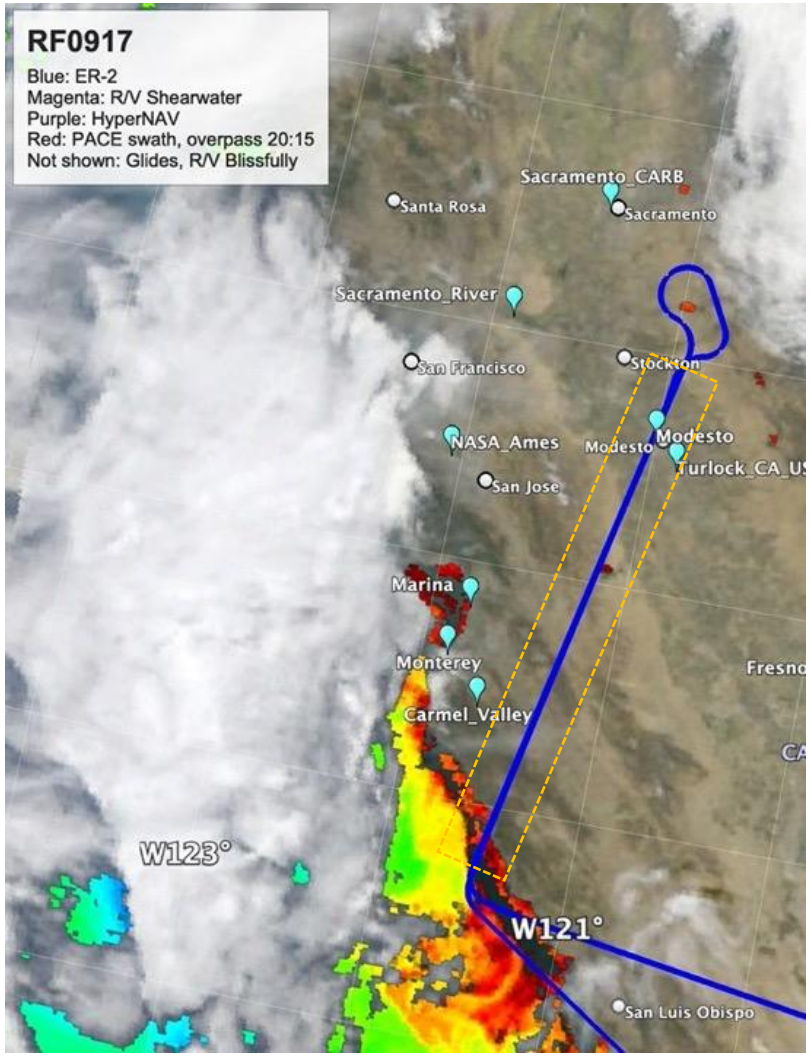
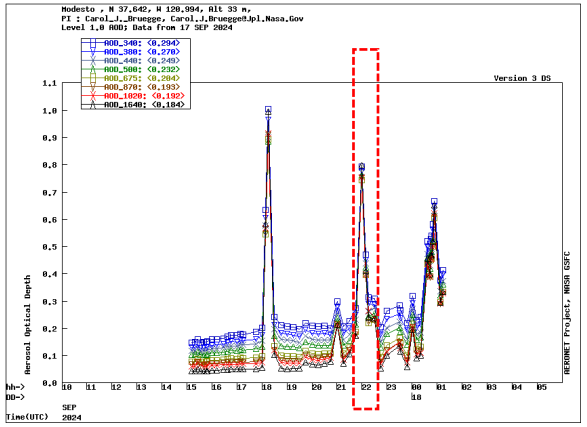
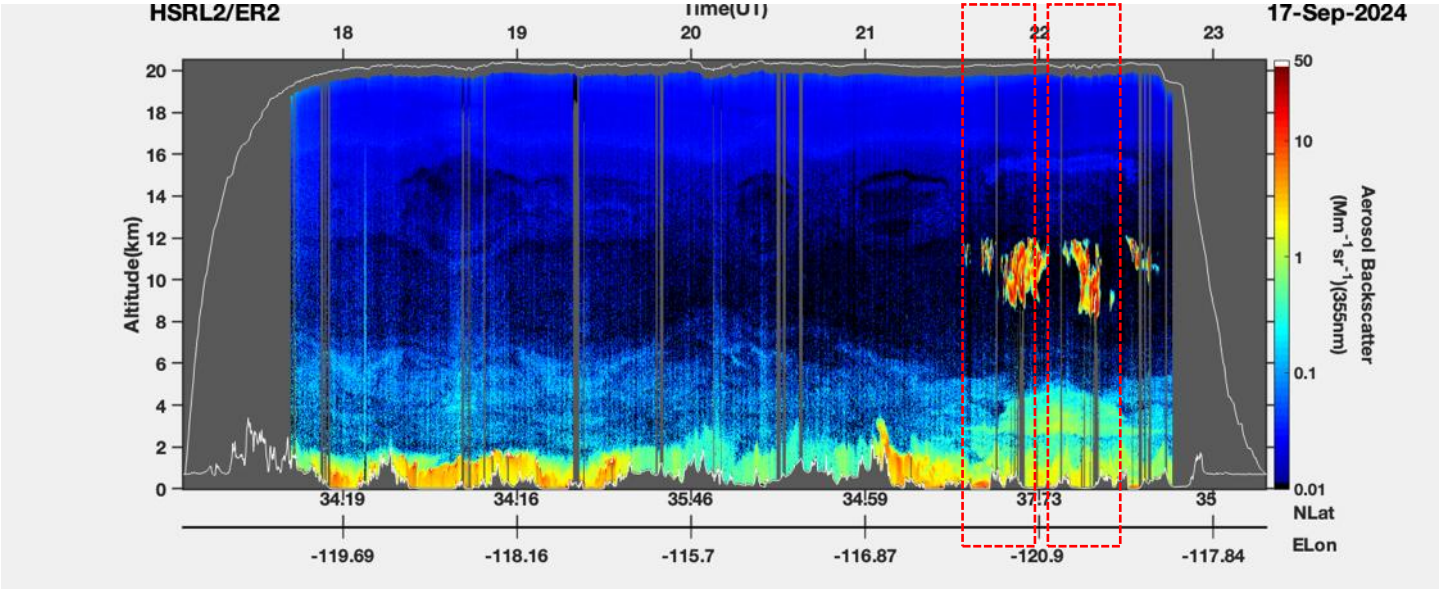


Modesto AERONET, no cloud screening



MVIS: 22:13:30 Modesto

MVIS: 22:30 EarthCARE line end at Big Sur



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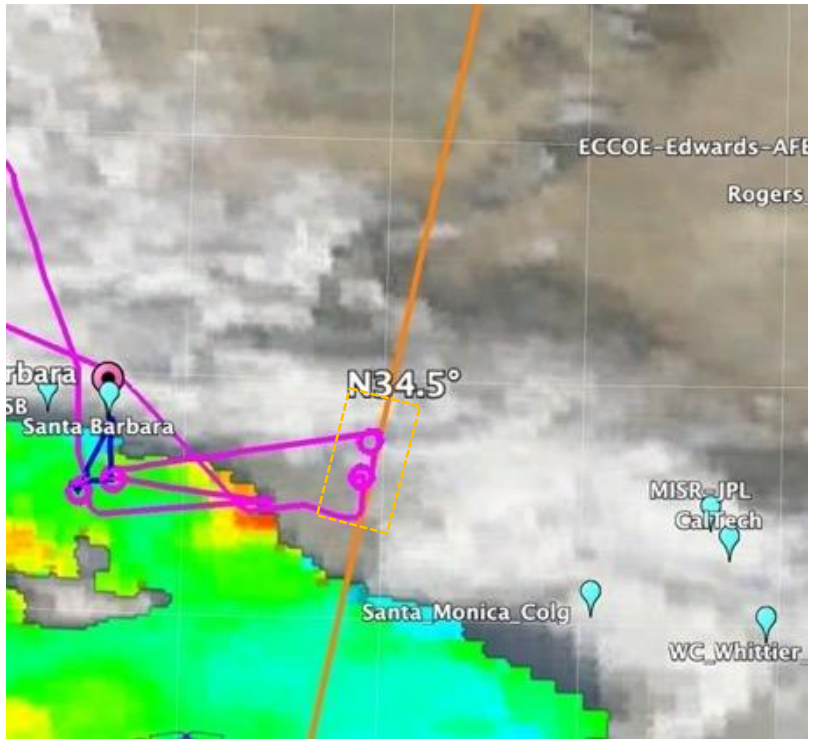
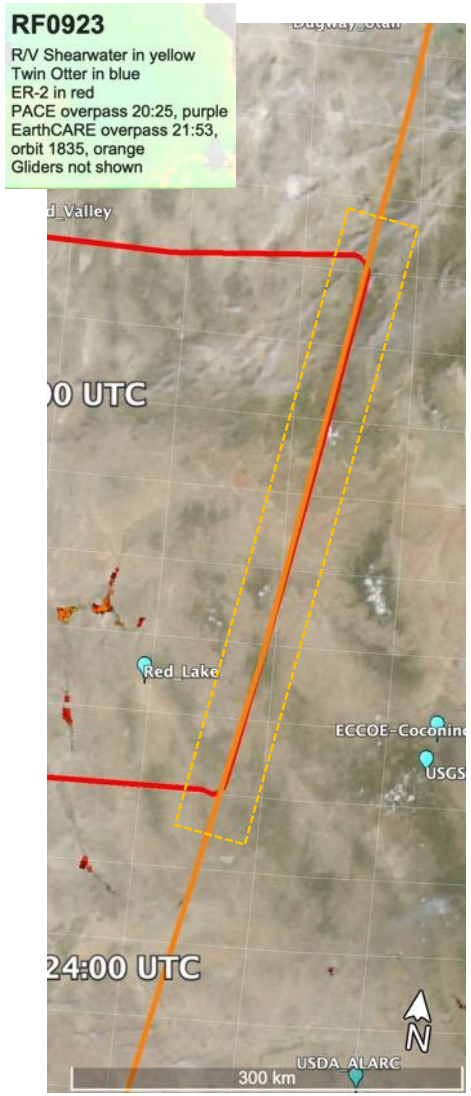
RF0919
R/V Shearwater in blue
R/V Blissfully as pirate ship
Twin Otter in Magenta
ER-2 flight scrubbed
PACE overpass 19:45, 21:23
ER-2 orbit 1773 at 22:15 in orange
HyperNAV in purple
Gliders not shown



From Twin Otter flight report (PACE-PAX_RF0919_TO_Report)

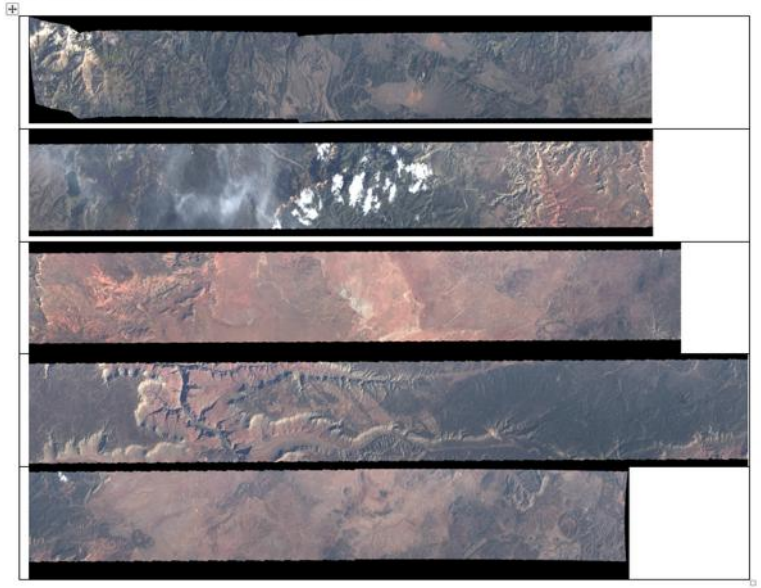
"…we headed towards the EART4, climbing rapidly to get over the clouds on the shore. We reached 6.2 kft trying to hit the upper layer of aerosol on the way to the EART4 overpass location. We had broken clouds underneath us at 21:54 UTC, and overcast cloud cover at 21:56 UTC. We descended to the cloud top at 22:00 UTC before spiraling up, with the aerosol layer thinning at 7.5 kft to having scattering coefficients of ~ 2.5 Mm^{-1}. We could not go into the clouds without IFR. After spiraling up, we transitioned to coordinates provided by Sam Leblanc via the chat for clearer skies to spiral down to 2.0 kft. We landed at 22:43:17 UTC at Camarillo, CA"

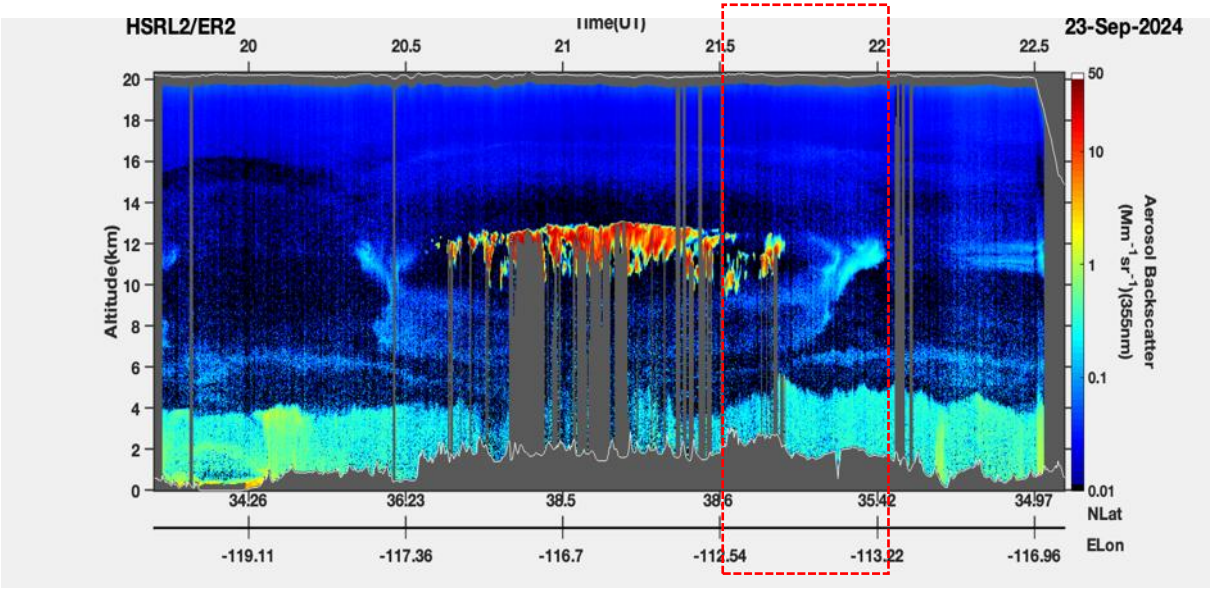
Operations ID	Date	ER-2 flight segment	Twin Otter flight segments	PACE overpass time	EarthCARE overpass time	EarthCARE orbit number	Coordinated observation location	Coordination observation conditions	Comments
RF0923	9/23/24	21:34 – 22:05	(not in EarthCARE track)	20:25	21:53	1853	Arizona, including Grand Canyon	Some clouds in northern portion, otherwise no cloud with low aerosol load	



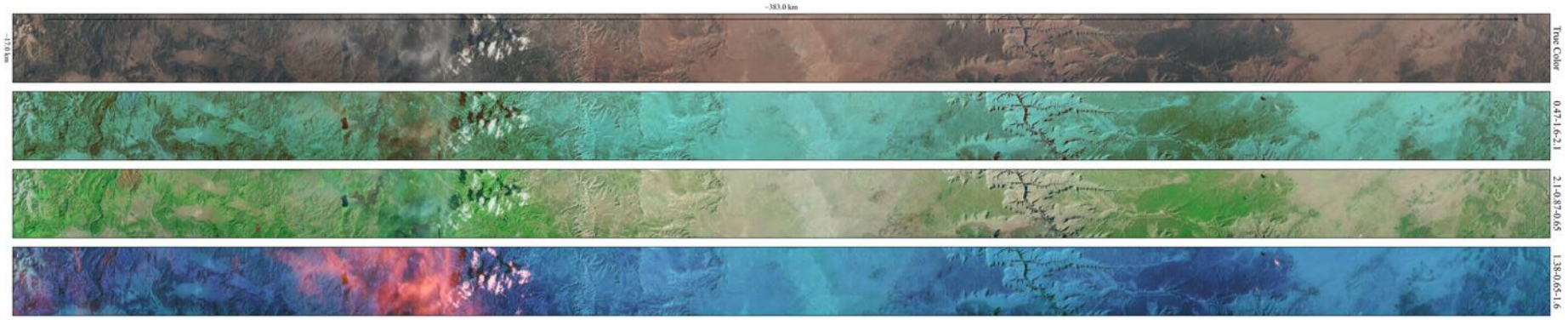
PRISM quicklooks

EarthCARE track, starting from north to south

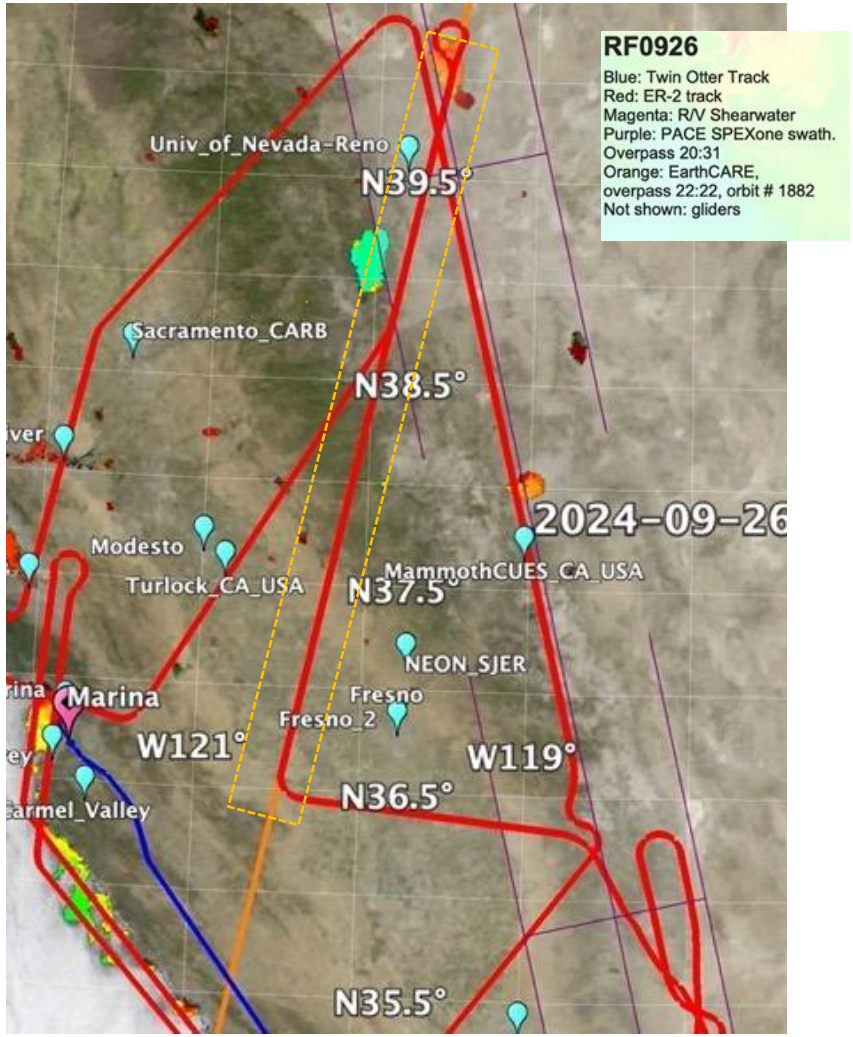




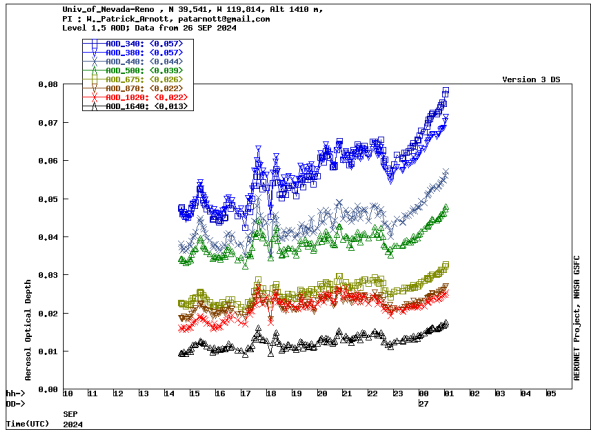
PICARD quicklook



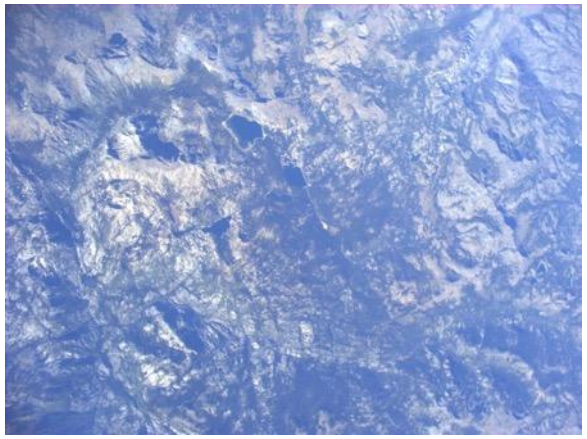
Operations ID	Date	ER-2 flight segment	Twin Otter flight segments	PACE overpass time	EarthCARE overpass time	EarthCARE orbit number	Coordinated observation location	Coordination observation conditions	Comments
RF0926	9/26/24	22:09 – 22:40	-	20:31	22:22	1882	California Central Valley and Sierra Nevada mountains, Nevada near Reno	Cloud free, low aerosol load	Note additional ground instrumentation in Reno at the Desert Research Institute

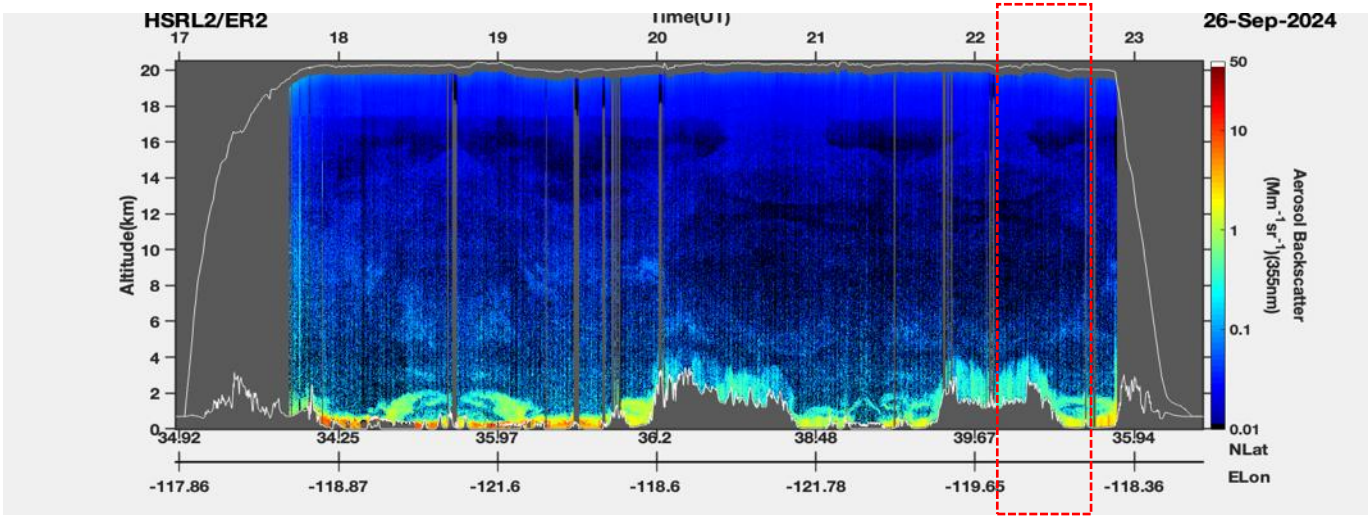


AERONET: Univ_of_Nevada-Reno



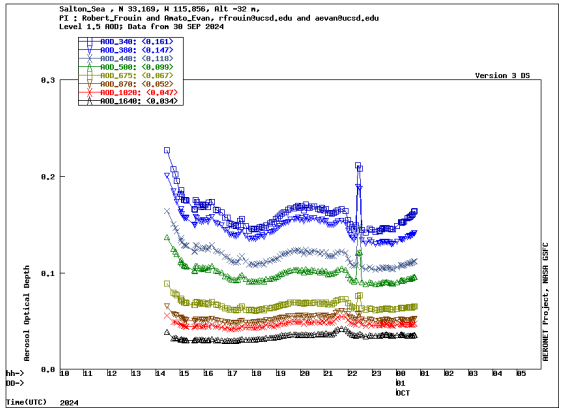
MVIS: 22:22 Sierra Nevada mountains



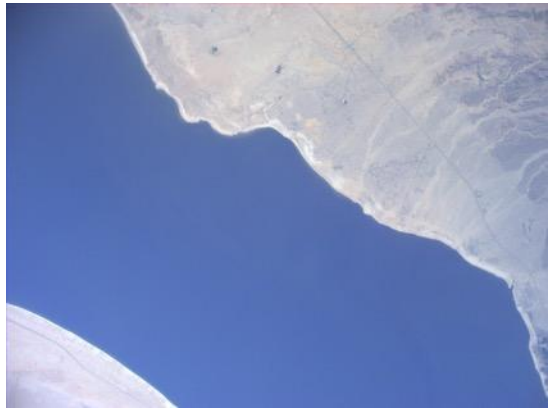


Operations ID	Date	ER-2 flight segment	Twin Otter flight segments	PACE overpass time	EarthCARE overpass time	EarthCARE orbit number	Coordinated observation location	Coordination observation conditions	Comments
RF0930	9/30/24	21:48– 22:20		21:09	22:02	1944	South-East California from Mexico border to west of Las Vegas	Elevated aerosols identified as 'dusty mix'	

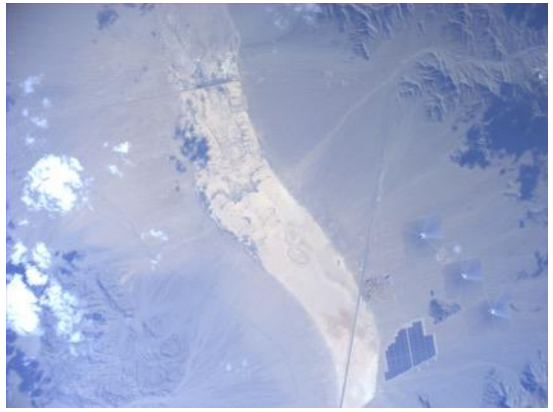
AERONET: Salton_Sea

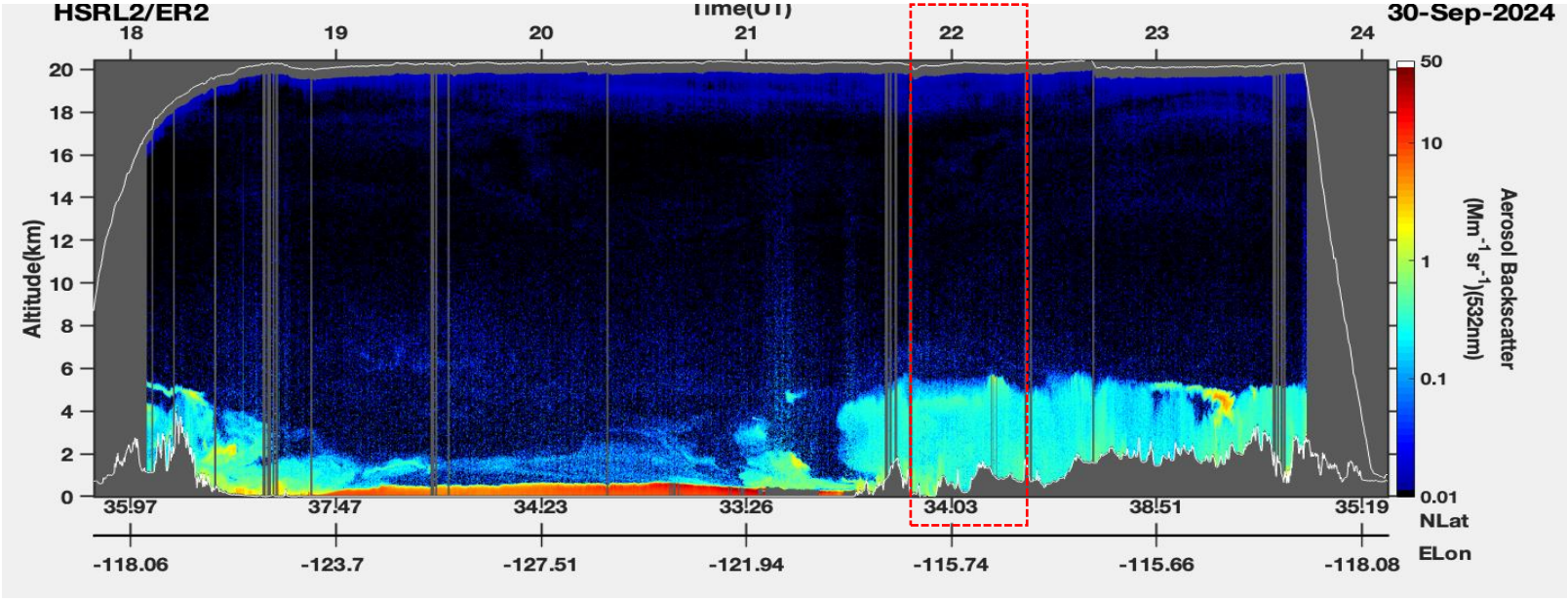


MVIS: 21:53:30 Salton Sea

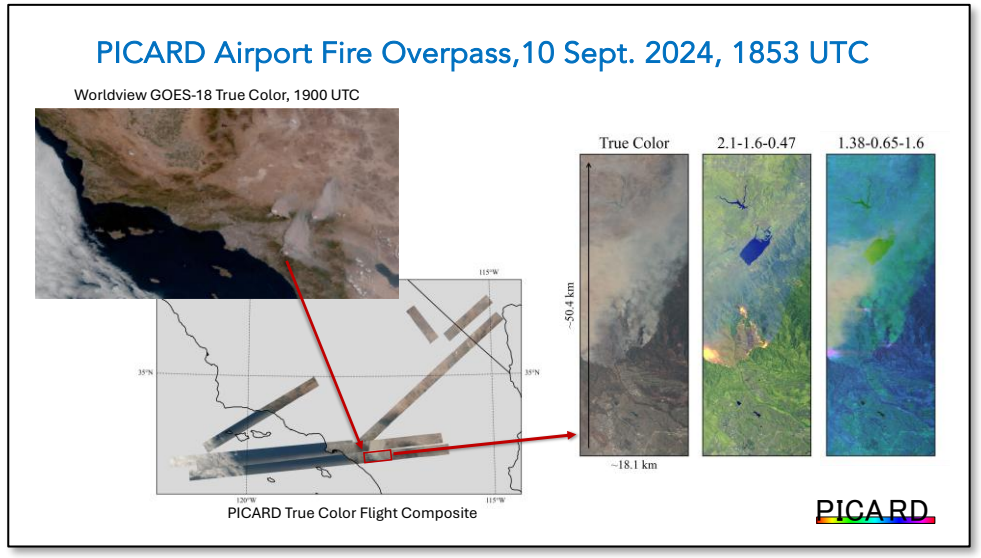


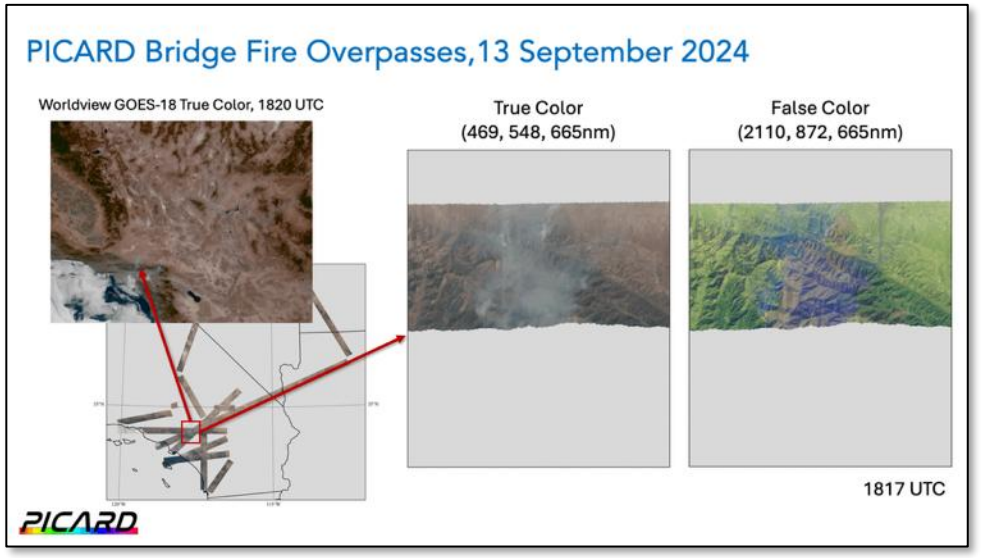
MVIS: 22:13:30 Ivanpah Playa

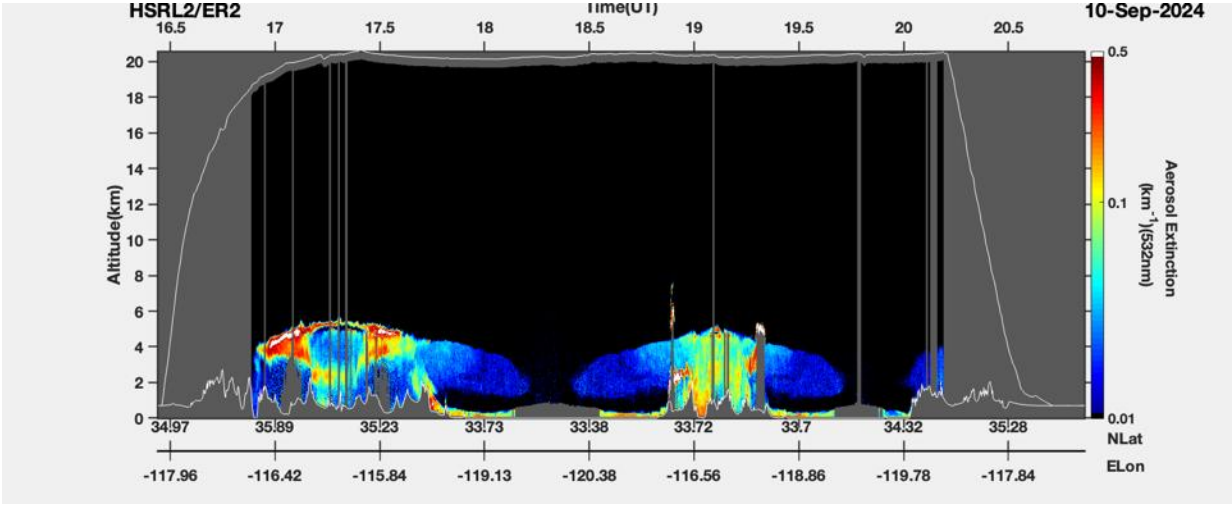


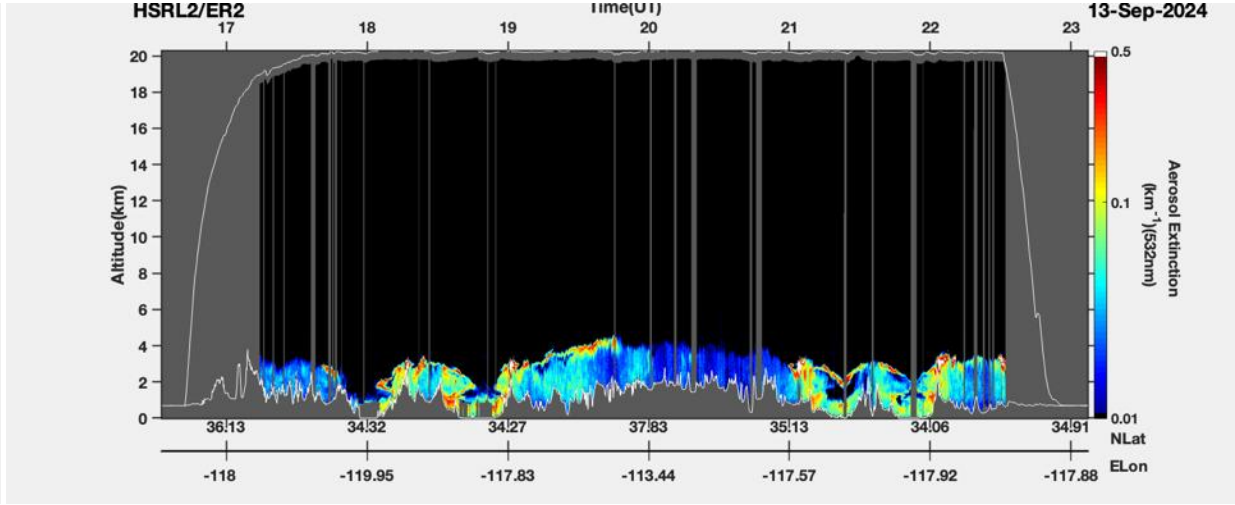


Los Angeles area fires, as observed by PICARD and HSRL-2





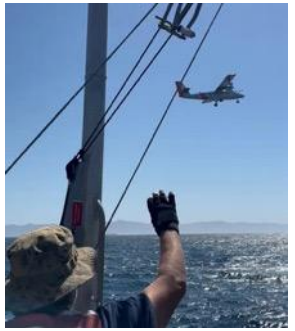




Media and blogs

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

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



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

https://blogs.nasa.gov/pace/2024/08/27/stephen-broccardo-a-star-in-pace-data-collection/

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