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The NASA Plankton, Aerosol, Cloud, ocean Ecosystem mission Postlaunch Airborne eXperiment (PACE-PAX)

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Abstract. The PACE Postlaunch Airborne eXperiment (PACE-PAX) was a field campaign conducted in September 2024 in California to collect validation data for the NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) and JAXA/ESA Earth, Cloud, Aerosol and Radiation Explorer (EarthCARE) missions. PACE-PAX utilized coordinated observations from two research aircraft, several research vessels, and additional ocean and ground-based assets to collect comprehensive measurements of atmospheric aerosols, clouds, ocean color properties, and land surface characteristics. The NASA ER-2 high-altitude aircraft flew 13 research flights with 80.9 flight hours total, carrying remote sensing instruments serving as a proxy for those on PACE, plus a High Spectral Resolution Lidar. The Navy Postgraduate School CIRPAS Twin Otter flew 17 research flights totaling 60 flight hours at low altitude, equipped with in-situ aerosol and cloud microphysics instrumentation. The NOAA R/V Shearwater conducted 15 day trips collecting ocean color radiometry, bio-optical properties, and water samples in the Santa Barbara Channel. The R/V Blissfully, a 30-foot sailboat, conducted 9 sampling days in the San Pedro Channel collecting ocean color radiometry profiles with a HyperPro instrument and discrete water samples for phytoplankton pigment and absorption measurements. A Slocum glider occupied a 10 km transect in the Santa Barbara Channel for 24 days with in-situ CTD, ocean color radiometry, optical backscatter, and broadband acoustic measurements. Data were also collected as part of the PACE Validation Science Team (PVST) or other externally funded efforts. Operations were coordinated using a Validation Traceability Matrix (VTM) decision support algorithm to maximize validation opportunities while targeting diverse geophysical conditions. This included varying atmospheric, land and ocean properties throughout California and nearby regions, as well as observations of a major biomass burning event in the Los Angeles region and harmful algal blooms (HABs) in the Monterey Bay. PACE-PAX airborne data are archived at the NASA Atmospheric Science Data Center with standardized formatting at https://doi.org/10.5067/SUBORBITAL/PACE-PAX/DATA001 (Knobelspiesse et al., 2025a). Ocean data are archived at the SeaWiFS Bio-optical Archive and Storage System (SeaBASS), at https://doi.org/10.5067/SeaBASS/PACE-PAX/DATA001 (Knobelspiesse et al., 2025b). This comprehensive dataset provides critical early-mission validation data for novel PACE and EarthCARE remote sensing capabilities and is also a rich dataset for other purposes.

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1 Introduction

Satellite remote sensing provides critical observations of Earth's atmosphere, oceans, ice and land surface, which must be validated so that their uncertainties are understood. This is particularly important for satellite missions that introduce new measurement capabilities or retrieve geophysical parameters in a manner not attempted before. Validation is also part of the process of ensuring a satellite mission meets its design requirements, and often such missions incorporate the gathering of field validation data into post-launch activities. The PACE-PAX campaign was created for this purpose to support the NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission. During planning phases, PACE-PAX was augmented to also support the joint ESA and JAXA Earth, Cloud, Aerosol and Radiation Explorer (EarthCARE) mission, whose scientific goals overlap with that of PACE.

This manuscript summarizes the activities of PACE-PAX, and the utility of gathered data for PACE and EarthCARE validation or scientific investigation. This is a condensed version of a much longer post-campaign NASA Technical Memorandum (Knobelspiesse et al., 2025c), which contains detailed measurement description tables, flight reports, and other material. A pre-campaign NASA Technical Memorandum (Knobelspiesse et al., 2023) is also available and describes the campaign prior to its implementation, but the abovementioned post-campaign Technical Memorandum and this manuscript are the authoritative references for PACE-PAX. Additionally, a description of the Validation Traceability Matrix (VTM) decision support algorithm that was used to plan and implement PACE-PAX is documented in Knobelspiesse et al., 2026.

The NASA Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission was launched on February 8th, 2024, representing a significant advancement in Earth observation capabilities (Werdell et al., 2019, 2024). PACE carries three instruments designed to provide observations of ocean ecosystems, atmospheric aerosols, land surfaces, and clouds. The Ocean Color Instrument (OCI, Meister et al, 2024) is a wide-swath (2660 km) hyperspectral scanning radiometer measuring from the ultraviolet (UV) to shortwave infrared (SWIR) (340–2260 nm) with continuous 5 nm spectral resolution in the visible (VIS) and near-infrared (NIR), and selected channels in the SWIR. OCI provides heritage ocean color, aerosol, and cloud products as well as advanced products that exploit its hyperspectral and ultraviolet sensitivity. PACE also includes two contributed multi-angle polarimeters (MAPs). The Hyper-Angular Rainbow Polarimeter-2 (HARP2, McBride et al., 2024, Martins et al., 2024), developed at the University of Maryland Baltimore County (UMBC), observes linear polarization at four wavelengths (440, 550, 670, and 870 nm) with up to 60 viewing angles in one channel, with an image swath nearly as wide as OCI. The Spectro-Polarimeter for Exploration-one (SPEXone, Fu et al., 2025, Rietjens et al., 2021, Hasekamp et al., 2019), developed by a Dutch consortium including Airbus and the Space Research Organization Netherlands (SRON), provides highly accurate spectropolarimetric measurements in variable spectral resolution through the 385–770 nm range in each of five viewing angles in a narrower 100km swath. The combination of hyperspectral ocean color observations and multi-angle polarimetry enables novel retrievals of aerosol properties, cloud characteristics, and ocean ecosystem parameters that were not possible with

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previous satellite missions, and capabilities that were not originally in the mission design, such as land surface characteristics (e.g. Caplan et al., 2025, Huemmerich et al., 2025).

The ESA/JAXA Earth, Cloud, Aerosol and Radiation Explorer (EarthCARE) mission, launched on May 28th, 2024, makes complementary active and passive observations of clouds, aerosols, and radiation (Wehr et al., 2023; Eisinger et al., 2024). EarthCARE carries four instruments: the ATMospheric LIDar (ATLID), a high spectral resolution lidar operating at 355 nm, the Cloud Profiling Radar (CPR), a 94 GHz Doppler radar, the Multi-Spectral Imager (MSI), a passive instrument measuring at seven wavelengths (0.67, 0.865, 1.65, 2.21, 8.8, 10.8, and 12.0 µm), and the Broad-Band Radiometer (BBR), measuring reflected solar and emitted thermal radiation. The active instruments (ATLID and CPR) provide vertical profiles with narrow swaths, while MSI has a 150 km swath and BBR an approximately 17-28km swath. EarthCARE's synergistic observations enable retrieval of vertical profiles of clouds and aerosols, a capability that complements PACE's wide-swath passive and polarization sensitive measurements.

Both missions require comprehensive validation to assess data quality and support algorithm development. The PACE Program Level Requirements Agreement (PLRA, Cetinić et al, 2025) and Mission Requirements Document (MRD, Cetinić et al, 2023) specify that post-launch validation work must evaluate PACE mission required science data products (typically 'heritage' products collected by prior missions, see PLRA) within 12 months of commissioning, while new products must be validated to acquire 'standard' product status for the purposes of archival and distribution, as described in the PACE Science Data Product Validation Plan (PVP). Similarly, EarthCARE has an extensive calibration and validation plan supported by dedicated funding from ESA and JAXA (Koopman, 2024). While surface-based observations from ships or land sites are a cornerstone for the collection of validation data, several challenges mean that they must be augmented by field campaigns including airborne observation. For example, many PACE and EarthCARE products represent new measurements that require validation data not routinely collected by existing networks. Furthermore, multi-parameter algorithms require simultaneous observations of multiple geophysical properties to confidently validate results. Finally, narrow swath instruments (PACE/SPEXone, EarthCARE) have infrequent coincident overpasses of fixed ground sites, which limits surface-based validation opportunities.

Airborne field campaigns address these challenges by providing flexible, comprehensive observations that can be coordinated with satellite overpasses. Aircraft can swiftly reposition within satellite swaths, measure multiple parameters simultaneously, carry airborne analogs of satellite instruments for direct comparison, and target specific geophysical conditions or processes. PACE-PAX was designed to leverage these advantages to support early-mission validation of both PACE and EarthCARE.

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Figure 1 PACE-PAX photo montage. Clockwise from top left: (a) Mike Ondrusek (NOAA), mission scientist onboard the R/V Shearwater, waves to the Navy Postgraduate School (NPS) Twin Otter as it samples at low altitude. (b) The Bridge fire, photographed by NASA ER-2 pilot Kirt Stalling on September 10, 2024, with overlay of the PACE-PAX logo and mission details. (c) Carl Goodwin (NASA JPL/Caltech) performs calibration reference measurements at Ivanpah Playa, California. (d) Scott Freeman (NASA GSFC) and Harrison Smith (NASA GSFC) deploy instrumentation from the R/V Shearwater in the Santa Barbara Channel. (e) Instrument integration on the NASA ER-2 in preparation for PACE-PAX. (f) San Francisco observed by the NPS Twin Otter during low altitude sampling over the San Francisco Bay. (g) The R/V Shearwater seen from the NPS Twin Otter, corresponding to image (a).

PACE-PAX was conducted in September 2024 in California, utilizing coordinated observations from two research aircraft, multiple ocean-going vessels and autonomous platforms, and ground-based assets. The NASA ER-2 high-altitude aircraft carried airborne analogs of PACE instruments including multi-angle polarimeters and imaging spectrometers, while the Navy Postgraduate School (NPS) Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter flew at low altitude with in-situ instrumentation to characterize aerosols and clouds. The NOAA R/V Shearwater and privately operated R/V Blissfully collected ocean color radiometry and bio-optical measurements. Additional measurements were collected from partner platforms, some of which part of the PACE calibration and validation teams. These platforms performed coordinated observation with PACE, EarthCARE, other observation sites in the region, and each other, as highlighted in Figure 1. Operations were guided by a Validation Traceability Matrix (VTM) approach (Knobelspiesse et al., 2026) that systematically linked validation objectives to required measurements, platforms, and success criteria.

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This paper describes the PACE-PAX dataset and its availability for satellite validation and scientific research. Sect. 2 provides an overview of campaign design and objectives. Sect. 3 describes the measurement platforms, instrumentation, and data products. Sect. 4 presents an overall assessment of the campaign and examples of ongoing projects using PACE-PAX data. Appendix A contains a summary of major achievements for each campaign day. The complete technical documentation of campaign operations, instrument specifications, and daily reports is available in the PACE-PAX post-campaign technical memorandum (Knobelspiesse et al., 2025c). Note all listed dates in this publication without a year refer to 2024 unless noted otherwise, the active deployment year for PACE-PAX, and all times are indicated in UTC.

2. Campaign overview and design

PACE-PAX was conducted in September 2024 and based in Southern and Central California. The four top-level validation objectives were:

Objective 1: Validate new retrieval parameters. The primary focus of PACE-PAX was the validation of new 'advanced' data products, that is, those not included in the list of 'required' products in the PACE PLRA. In the terminology of NASA, these are 'Level 2' products representing geophysical parameters (NASA, 2020). Many of these advanced products are produced by algorithms that simultaneously determine multiple parameters and must be validated by simultaneous observation of all parameters. Additionally, this objective prioritizes validation measurements that are not already acquired by other means. We utilized two validation pathways. The first is a direct comparison between PACE-PAX observations and satellite data products. The second is to gather airborne data at 'Level 1' (calibrated and georeferenced radiances or reflectances that are inputs to data product algorithms), and compare products derived from the airborne Level 1 data to direct (in situ) PACE-PAX observations. In this manner, the algorithms producing Level 2 products are validated. For this purpose, we created an airborne proxy of the PACE instrument suite on the high-altitude aircraft.

Objective 2: Validate within the instrument swath of all PACE and EarthCARE instruments. While OCI and HARP2 have wide swaths enabling 1-to-2-day global coverage, SPEXone's narrow swath results in approximately 30-day global coverage, meaning comparisons to fixed ground sites are less frequent. EarthCARE's active instruments (ATLID lidar and CPR radar) have extremely narrow, single-pixel-wide swaths. Airborne platforms were positioned within these narrow swaths during satellite overpasses to maximize validation opportunities. In practice, this objective is like that of Objective 1, but it ensures that direct validation for narrow swath instruments occurs.

Objective 3: Validate radiometric and polarimetric parameters prior to their use for retrieval of geophysical parameters with instrument proxies. This objective supports PACE in-flight calibration activities through direct validation of Level 1 (radiance and polarization) observations. PACE-PAX included overflights of established calibration sites including

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Railroad Valley, Nevada and Ivanpah Playa, California, as well as the oceangoing PACE vicarious calibration system HyperNav (Barnard et al., 2024a, 2024b). These observations characterize Level 1 uncertainties before retrieval algorithms are applied.

Objective 4: Focus on specific processes or phenomena. PACE-PAX targeted diverse geophysical conditions to test algorithm robustness, including high aerosol loads over land and ocean, multiple aerosol layers, aerosol above clouds, broken clouds with complex structure, dust and smoke aerosols, and ocean properties over turbid and biologically productive waters. Dedicated sampling of these conditions ensures retrieval algorithms function correctly across the range of natural variability.

Each of these top-level objectives flow to more narrowly focused sub-objectives and the requirements for their successful observation. This is the structure of the VTM and it was used to create decision support algorithms to implement these objectives systematically (Knobelspiesse et al., 2026). The VTM approach, based on the Science Traceability Matrix concept (Weiss et al., 2005), traces top-level validation objectives through required measurements, platform capabilities, and success criteria. The VTM parameterizes each measurement objective with importance (w) and required observation time in flight hours (h). The capability of the campaign instruments and deployment conditions define completeness (c, values from 0 to 1), and probability of success (p, values from 0 to 1). These parameters are used to design the campaign and later serve as a guide for measurement prioritization in the field. The Time Fulfillment Function (f, values from 0 to 1) at the end of the campaign indicates the success observing that objective. The Time Fulfillment Function incorporates required and actual hours. As described in Knobelspiesse et al., 2026, values greater than 0.63 indicate threshold (minimum) requirements are met, those greater than 0.87 mean that baseline (goal) requirements have been met, while a value of 1 is the theoretical limit given infinite observation. Table 1 presents a summary of the PACE-PAX VTM with the four main objective categories and their sub-objectives. A summary of activities organized by VTM objective is provided in Knobelspiesse et al., 2025c.

Table 1 PACE-PAX Validation Traceability Matrix (VTM) summary. Modified from Knobelspiesse et al, 2026. For the full VTM, see https://pace.oceansciences.org/pace-pax.htm and Knobelspiesse et al., 2025c. Numerical parameters indicate importance (w), required observation time in flight hours (h), completeness (c, values from 0 to 1), and long-term probability of success (p, values from 0 to 1). These parameters, along with completed and remaining flight hours and near-term probability of success, were used to plan the campaign before arriving in the field, and for each day's operations while in the field. The final column contains the value of the Time Fulfillment Function (f, values from 0 to 1), at the end of the campaign, expressing the overall success of this objective. Italicized objectives have met the threshold (minimum), while boldfaced objectives have met baseline (goal) requirements.

ID	Measurement objective	*w*	*h*	*c*	*p*	*f*
1a	New products: land surface properties	8	2.0	1.0	0.50	**0.99**
1b	New products: ocean radiometric properties	10	8.0	1.0	0.50	**0.99**
1c	New products: aerosol properties over the ocean	12	8.0	1.0	0.50	**0.99**
1d	New products: aerosol properties over land	12	8.0	1.0	0.75	**0.99**
1e	New products: cloud properties	12	8.0	1.0	0.50	**0.92**
1f	New products: ocean surface properties	1	8.0	0.5	0.25	0.35

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2a	Simultaneous PACE observations: aerosol properties over the ocean	10	8.0	1.0	0.50	0.56
2b	Simultaneous PACE observations: aerosol properties over land	10	8.0	1.0	0.50	*0.75*
2c	Simultaneous PACE observations: cloud properties	5	2.0	1.0	0.50	**0.92**
2d	Simultaneous EarthCARE observations: aerosol properties	8	4.0	1.0	0.25	**0.94**
2e	Simultaneous EarthCARE observations: cloud properties	8	4.0	1.0	0.25	0.46
3a	Radiometric and polarimetric properties: large reflectances	6	2.0	1.0	0.50	**0.98**
3b	Radiometric and polarimetric properties: large reflectance high polarization	6	2.0	1.0	0.75	**0.89**
3c	Radiometric and polarimetric properties: large reflectance low polarization	6	2.0	1.0	0.75	**0.98**
3d	Radiometric and polarimetric properties: vicarious calibration sites	6	4.0	1.0	0.25	0.50
4a	Specific phenomena: High aerosol loading over land	4	2.0	1.0	0.50	**0.99**
4b	Specific phenomena: High aerosol loading over ocean	4	2.0	1.0	0.50	0.39
4c	Specific phenomena: Multiple aerosol layers	1	2.0	1.0	0.50	**0.99**
4d	Specific phenomena: Aerosols under thin cirrus clouds	2	2.0	1.0	0.50	*0.83*
4e	Specific phenomena: Aerosols above liquid cloud	4	2.0	1.0	0.25	*0.86*
4f	Specific phenomena: Broken clouds with complex structure	4	2.0	1.0	0.75	**0.89**
4g	Specific phenomena: Dust aerosols over ocean	4	2.0	1.0	0.25	0.43
4h	Specific phenomena: Aerosol, ocean properties, turbid water	2	2.0	1.0	0.50	**0.97**
4i	Specific phenomena: Aerosol, ocean properties, biologically productive water	4	2.0	1.0	0.25	**0.99**
4j	Specific phenomena: Smoke aerosols over ocean	1	2.0	1.0	0.25	*0.71*

Using the VTM as a guide, trade studies were performed to establish the major components of the mission. The Aerosol Characterization from Polarimeter and Lidar (ACEPOL, Knobelspiesse et al, 2020) was the starting point, with elements added or removed to maximize a VTM-based overall 'potential success' score with minimal cost. We arrived at a campaign that had four core platforms: the NASA ER-2 high-altitude aircraft for remote sensing observations, the NPS CIRPAS Twin Otter low-altitude aircraft for in-situ sampling of aerosols and clouds, and the NOAA R/V Shearwater coastal research vessel, and the R/V Blissfully sailboat for ship-based ocean and atmospheric measurements. Costs were reduced by operating these platforms out of their home institutions: the NASA Armstrong Flight Research Center (AFRC) in Lancaster, California for the ER-2; Marina, California for the Twin Otter; Santa Barbara, California for the R/V Shearwater. The R/V Blissfully sailed from its home in San Diego, California to operate day cruises, mostly under sail, out of Long Beach, California for PACE-PAX.

2.1 Area of operations and timeline

PACE-PAX was conducted in coastal California from Monterey Bay southward to the Los Angeles basin, extending westward over the Pacific Ocean and eastward to Nevada and Arizona. In addition to the ease and lower cost of operating out of home institutions/ports, this region has well instrumented ground-based observational sites, diverse geophysical conditions including coastal ocean ecosystems, marine stratocumulus clouds, desert surfaces, and both clean and polluted atmospheres. September was chosen based on climatological data indicating a likelihood of higher aerosol loads than the annual average, and somewhat

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reduced cloud cover over the ocean. Coordinated observations were planned such that the aircraft flew to the locations of the research vessels, ground validation sites, and each other. Figure 2 shows the spatial coverage of PACE-PAX operations.

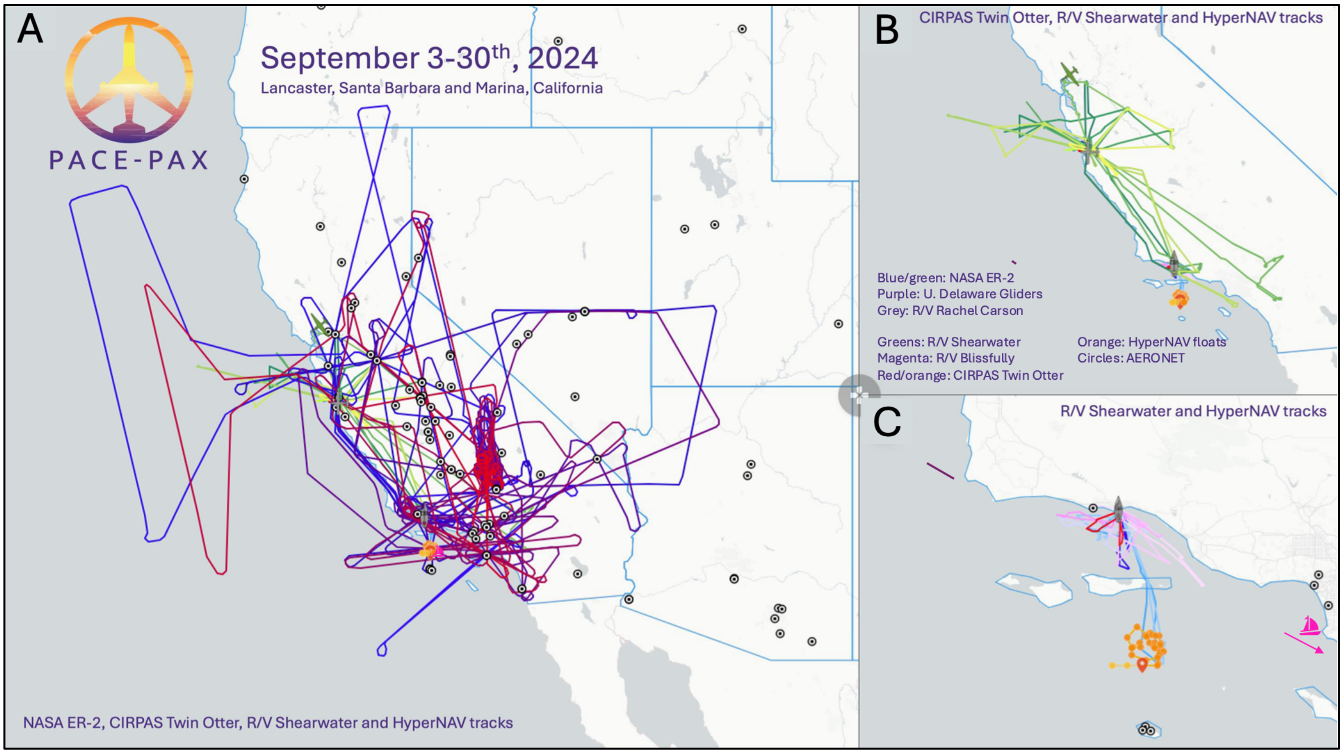

Figure 2 PACE-PAX flight tracks. Panel A shows the tracks of the NASA ER-2 (red-blue), NPS Twin Otter (green-yellow) and R/V Shearwater (pink-purple-blue). Individual colors indicate different observation days. Black circles show ground observation sites, primarily AERONET or NEON sites (see Sect. 3.6). Panel B has the NPS Twin Otter and R/V Shearwater tracks (only), while Panel C indicates surface based assets only. R/V Shearwater tracks as before are in pink-purple-blue, HyperNAV vicarious calibration locations are in orange, and the R/V Blissfully was deployed outside the plot to the south-east (indicated by the magenta-pink arrow). Map visualization was performed within the NASA Mission Tools Suite (MTS, see Sect. 2.3).

The campaign achieved 22 coordinated observations with the PACE satellite, and 6 with EarthCARE. Overall conditions were somewhat typical for California in September, with extensive offshore marine stratocumulus cloud cover and relatively cloud-free conditions with variable aerosol loads over land. Several extreme wildfires in the Los Angeles region were observed, as well as red tide events in Monterey Bay. A summary of the PACE-PAX timeline is presented in Table 2.

Table 2 PACE-PAX field campaign timeline, with field operations highlighted.

PACE-PAX timeline	
2014-2016	PACE Science and Applications Team, initial concept discussions

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July 2021	PACE-PAX white paper and VTM designed, guiding initial studies on implementation
January 2023	PACE-PAX team selections finalized
Sept. 11-15 2023	First virtual field campaign dry run
February 8 2024	PACE launch
February 2024	EarthCARE validation added to PACE-PAX objectives
March 4-8 2024	First PACE-PAX science team meeting and second field campaign dry run
May 28 2024	EarthCARE launch
Aug. 28-29 2024	ER-2 and Twin Otter aircraft check flights
Sept. 3 2024	First Twin Otter science flight
Sept. 4 2024	First ER-2 science flight, first PACE underflight
Sept. 6 2024	First R/V Shearwater cruise, R/V Blissfully cruise
Sept. 8 2024	First EarthCARE underflight
Sept. 19 2024	Last R/V Blissfully cruise
Sept. 26 2024	Last R/V Shearwater cruise
Sept. 27 2024	Last Twin Otter science flight
Sept. 30, 2024	Last ER-2 flight
Dec. 31 2024	Preliminary data due to ingest archive
Feb. 18-21 2025	Second PACE-PAX science team meeting
March 31 2025	Final data due to archive. Data become publicly available at ingest archive
Summer 2025	Data migrate to final archive at ASDC and SeaBASS

2.2 Components and sampling strategy

PACE-PAX employed a multi-platform approach designed to provide simultaneous observations of multiple physical or biogeochemical properties. The campaign was built around four core platforms with complementary measurement capabilities. The NASA ER-2 high-altitude aircraft carried remote sensing instruments, analogous to PACE and EarthCARE sensors including multi-angle polarimeters, hyperspectral imagers, and a high spectral resolution lidar. The NPS CIRPAS Twin Otter low-altitude aircraft was outfitted with in-situ aerosol and cloud microphysics instrumentation. The NOAA R/V Shearwater collected observations of ocean color radiometry, inherent optical properties, and water constituents, while the R/V Blissfully deployed a smaller set of instruments to characterize the atmosphere and ocean. This vertical sampling strategy enabled validation at multiple levels, as the ER-2 provided satellite-equivalent remote sensing observations for radiometric comparison and algorithm testing, the Twin Otter observed aerosol and cloud properties directly, and the R/V Shearwater and R/V Blissfully collected data for validation of ocean color atmospheric correction and ocean color products.

Additional platforms expanded capability and extended the spatial and temporal coverage. University of Delaware underwater glider sampled subsurface ocean properties, while the NASA HyperNAV vicarious calibration system (Barnard et al. 2024a, 2024b) was deployed for coordinated overflights. Ocean radiometric and biogeochemical observations were conducted by team from University of California, Santa Barbara (in the Santa Barbara channel), and team from University of California, San

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Diego (in Monterey Bay). Ground-based measurements were collected at established calibration sites (Ivanpah Playa, California, Railroad Valley, Nevada) and validation networks such as AERONET (Holben et al, 1998). Detailed platform and instrumentation descriptions are provided in the next section.

2.3 Modeling and forecasting support

Effective daily operations required accurate forecasts of meteorological conditions, cloud cover, and aerosol loading across the PACE-PAX domain. Three sources of forecasting support were provided. The primary campaign forecasting team was from the NASA Ames Research Center (ARC) meteorological forecasting group, which provided daily meteorological, marine, and aerosol forecasts throughout the deployment. The ARC team hosted forecast products on a publicly accessible server (https://bocachica.arc.nasa.gov/PACE-PAX/) that included customized maps of cloud fraction and aerosol optical depth derived from model output, as well as satellite imagery products including cloud top height and base. Daily weather briefings were performed at AFRC in coordination with the NASA AFRC operational weather forecasting team, whose primary focus was ensuring the safety of ER-2 operations, including surface wind speeds and directions at AFRC (which constrained ER-2 takeoff and landing), extreme surface temperatures (which limited crew exposure on the runway), and pilot safety considerations including high-altitude radiation and bail-out contingency weather. Aerosol and atmospheric composition forecast support was additionally provided by the NASA Global Modeling and Assimilation Office (GMAO) using the Goddard Earth Observing System Forward Processing (GEOS FP) global prediction model, which generates 10-day forecasts updated four times daily. GMAO provided customized cross-sections of carbon, sulfates, dust, and sea salt along planned aircraft and vessel flight routes via the Framework for Live User-Invoked Data (FLUID) system, which was integrated with the NASA Mission Tools Suite (MTS) for real-time monitoring during operations. The forecasting and flight planning workflow was tested during dry run exercises in September 2023 and March 2024 before the campaign. Archived forecast products are available at the URLs above and described further in the PACE-PAX technical memorandum (Knobelspiesse et al., 2025c).

3 Measurement platforms and payload

This section describes the measurement platforms and instrumentation, with a focus on the types of measurements collected and data products generated rather than detailed instrument specifications. Complete technical details are in Knobelspiesse et al., 2025c and references therein. Table 3 summarizes instrument platforms and their primary measurement capabilities.

Table 3 Observation platforms, including aircraft and research vessels, deployed or utilized during PACE-PAX.

Platform and Operator	Deployment dates	Altitude / location	Instrumentation	Key measurements
NASA ER-2	September 4-30, 13 flights, 80.9 flight hours	High altitude, regional spatial extent	Remote sensing, including proxies of EarthCARE / ATLID	Multi-angle polarimetric radiance (385-2250 nm), Hyperspectral

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			and all three PACE instruments	radiance (380-2400 nm), Aerosol/cloud/ocean lidar profiles
NPS CIRPAS Twin Otter	September 3-27, 17 flights, 60 flight hours	Low altitude, local spatial extent	Aerosol and cloud in situ sampling	Aerosol/cloud size distributions, Scattering/absorption coefficients, Hygroscopic growth, Single scattering albedo, aerosol asymmetry and scattering phase function
NOAA R/V Shearwater	September 6-26 15 day cruises, 40 stations	Ocean surface, Santa Barbara Channel	Surface and in-water optical sensors; water sampling	Ocean color radiometry profiles and above water radiometry and polarimetry, Inherent Optical Properties (IOPs) (absorption, attenuation, backscatter), Ocean pigments (HPLC), Particulate organic carbon, Phytoplankton Community Structure, and additional hydrographic properties
R/V Blissfully*	September 6-19, 9 day cruises	Ocean surface, San Pedro Channel	Surface and in-water optical sensors; water sampling	Ocean color radiometry profiles, Ocean pigments (HPLC)
HyperNAV*	August 31 – September 22, 19 profiles	Autonomous ocean float, south of Santa Barbara Channel	Autonomous profiling radiometer	Vicarious calibration reference quality hyperspectral upwelling and water leaving radiance
U. Delaware Glider*	September 7 – October 1, continuous operation	Autonomous ocean glider, Santa Barbara Channel	Autonomous underwater radiometer and other sensors	Subsurface acoustic backscatter, ocean color radiometry, temperature, salinity, depth, optical backscatter, and chlorophyll fluorescence
R/V Rachel Carson*	September 25-27, (3 day cruises)	Ocean Surface, Monterey Bay	Surface and in-water optical sensors; water sampling	Ocean color radiometry, transect sampling of ocean biogeochemical properties
UCSB small boats*	September 9, 20 (2 day cruises)	Ocean surface, Santa Barbara Channel	Surface and in-water optical sensors; water sampling	Ocean color radiometry profiles, Ocean pigments (HPLC)
AERONET sites*	Continuous during campaign	Multiple sites on land and coastal platforms	Sun photometers, above water radiometers for AERONET-OC sites	Aerosol optical depth (340-1640 nm), aerosol microphysical properties, ocean surface reflectance (AERONET-OC)
NEON sites*	Continuous during campaign	San Joaquin Experimental Range and Teakettle Experimental Forest	Co-located with AERONET sites with extensive additional measurements	Ecological and meteorologically relevant measurements
NRL-CEOBS site*	Continuous during campaign	Watsonville, California	Ka-band radar, Doppler lidar, Ceilometer, Microwave radiometer, Flux tower	Surface based cloud/aerosol profiles, atmospheric state, boundary layer structure, aerosol optical depth
Railroad Valley*	Continuous, overflights on: September 13, 22, 23, and 30	Tonopah Basin, Nevada	Ground surface reflectance reference measurements	Surface reflectance characterization, aerosol optical depth
Ivanpah Playa*	Coordinated air-surface deployment on September 17	Mojave Desert, California	Ground surface reflectance reference measurements	Surface reflectance characterization, aerosol optical depth
Marina Tower	Continuous during campaign	Marina Airport air traffic control tower	Aerosol and cloud in situ sampling	Similar instruments to Twin Otter for inlet characterization via Twin Otter low altitude flyby

* volunteer or externally funded effort or existing validation resource

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The observations described in Table 3 were deployed at different times and locations throughout the campaign. Coordination of all these elements to achieve the validation objectives was one of the primary challenges of PACE-PAX. The VTM described in Sect. 2 and Table 1 was a planning tool for this purpose, and each VTM objective had a corresponding diagram of the required elements. Many objectives could be satisfied in two ways: either through direct underflight of the PACE or EarthCARE spacecraft, or underflight of the ER-2 containing an airborne proxy to PACE or EarthCARE. Coordination with the satellite is ideal, but less common as there is only one (or in some cases two) overpass per day, and overpasses in the PACE-PAX region were not always possible. Thus, the PACE and EarthCARE proxies on the ER-2 were important to gather data that can be used to validate the algorithms used to generate a geophysical product.

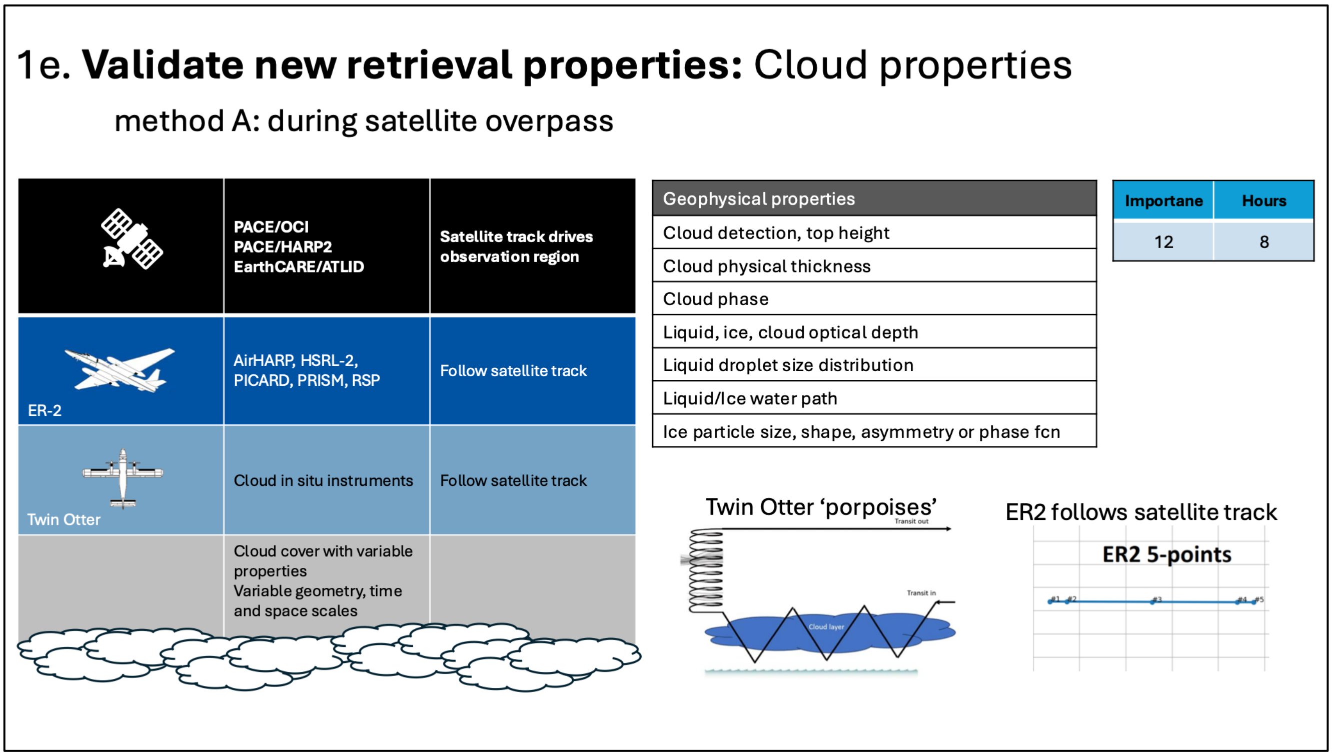

Figure 3 VTM operational diagram for objective 1e 'Validate new retrieval properties; clouds'. This diagram illustrates all the required observations and the conditions under which they are to be made and was a guide for mission planners during PACE-PAX. This example illustrates validation during a satellite overpass.

Figure 3 and Figure 4 are examples of VTM objective diagrams used to aid missing planning. The complete set is in the PACE-PAX Technical Memorandum (Knobelspiesse et al, 2025c). Figure 3 illustrates the components necessary to satisfy validation objective 1e, new cloud property retrieval algorithms (such the PACE/HARP2 GISS Polarimetric Cloud algorithm CLOUD_GPC, doi:10.5067/PACE/HARP2/L2/CLOUD_GPC/4.0). This diagram indicates that the ER-2 and Twin Otter

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should follow the satellite track during an overpass, with the Twin Otter performing an above cloud spiral down to cloud top altitude, then ‘porpoise’ up and down within the cloud along the satellite track. The ER-2, meanwhile, simply follows the satellite track. Alternatively, the validation objective can be satisfied when a satellite is not present as indicated in Figure 4. In this case, an area is selected that is expected to be cloudy and is within range of the Twin Otter. Like before, the Twin Otter ‘porpoises’ within the cloud, while meanwhile the ER-2 overflies the scene at a heading chosen to be within 20˚ of the solar principal plane to optimize remote sensing geometry. In this case, the remote sensing measurements from the ER-2 are processed with PACE algorithms and validated against Twin Otter observations, thus validating the algorithmic approach.

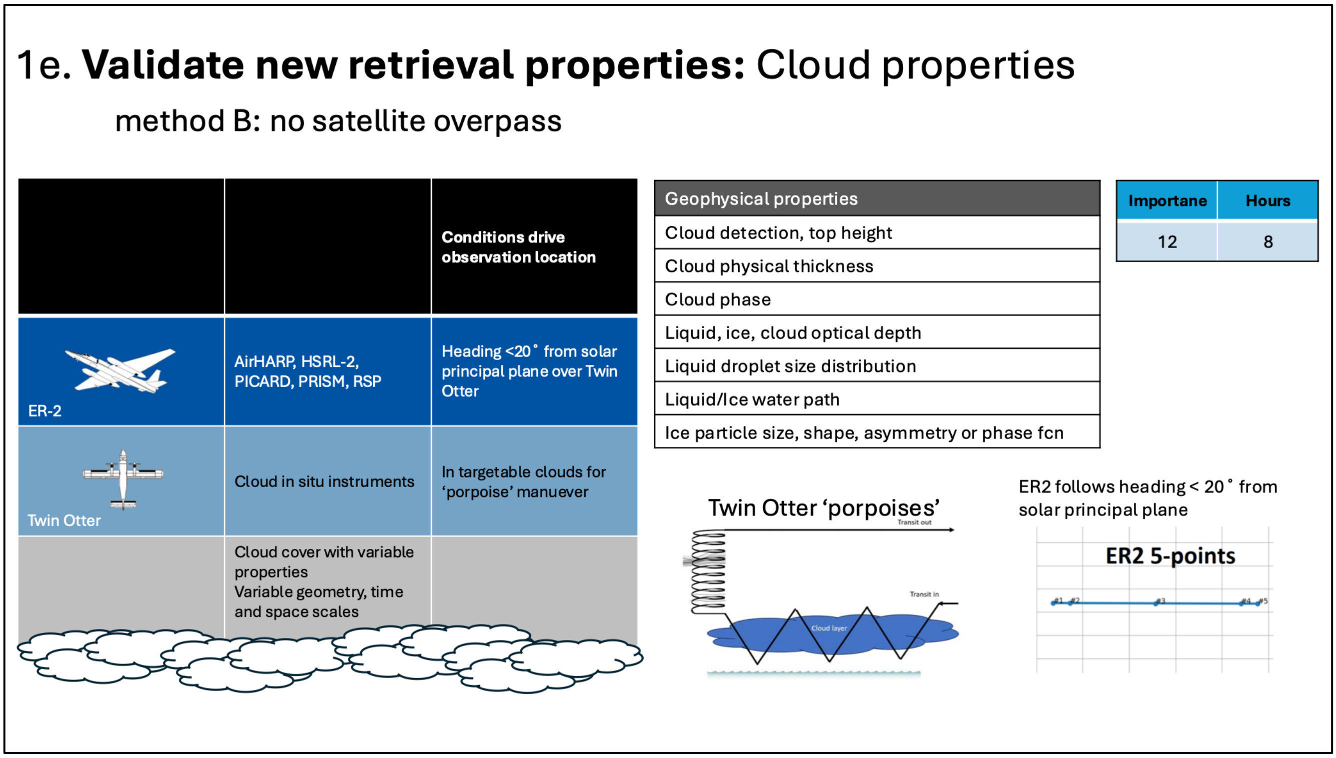

Figure 4 Like Figure 3, this is the VTM operational diagram for objective 1e ‘Validate new retrieval properties; clouds’. This method, however, is for times when a satellite overpass is not possible.

3.1 NASA ER-2 high altitude aircraft

The NASA ER-2 (https://airbornescience.nasa.gov/aircraft/ER-2_-_AFRC) is a high-altitude research aircraft operated by the NASA Armstrong Flight Research Center (AFRC) in Lancaster, California and based at that location during PACE-PAX. The ER-2 is a modified version of the Lockheed U-2, capable of flying above 60,000 feet (18.3 km), with a listed range and duration of 3,000 nautical miles (5,556 km) and 8 hours. During PACE-PAX, operational constraints limited individual flight durations

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to 6.7 hours or less, but this was more than sufficient to broadly cover the investigation area and overfly the other assets. Two instruments (PRISM and HSRL-2) were installed in the nose and fuselage, respectively, while the remaining four were installed in the wing superpods**.**

Table 4 NASA ER-2 instrument payload for PACE-PAX. "Satellite analog" indicates the PACE or EarthCARE instrument most closely replicated by the airborne instrument.

Instrument	Measurements	Satellite analog	Key literature references
Airborne Hyper-Angular Rainbow Polarimeter (AirHARP)	Multi-angle polarimetric imager at 440, 550, 670, 870 nm. 60 viewing angles for 670nm, 10 for all others. Native pixel spatial resolution ~20m, 250m as archived.	PACE/HARP2	McBride et al. (2020, 2024a, 2024b), Sienkiewicz et al. (2025), Martins et al. (2024)
Spectropolarimeter for Planetary Exploration, Airborne (SPEX Airborne)	Multi-angle spectropolarimetric imager 385–770 nm, 3 nm spectral resolution for radiance, 7-30nm for polarimetry. 9 viewing angles, 500–1000m spatial resolution.	PACE/SPEXone	Rietjens et al. (2010, 2021, 2022), van Amerongen et al. (2019), Fu et al. (2020, 2025)
Research Scanning Polarimeter (RSP)	Multi-angle polarimetric scanner at 410, 469, 555, 670, 864, 962, 1589, 1885, 2264 nm (9 bands). Up to 152 viewing angles per band. Nadir spatial resolution 280 m, sampling 185 m.	PACE/HARP2, PACE/SPEXone	Cairns et al. (1999), Chowdhary et al. (2001), Knobelspiesse et al. (2011)
Portable Remote Imaging Spectrometer (PRISM)	Hyperspectral imager 350–1050 nm, 3.5 nm spectral resolution. Nadir pixel 19 m.	PACE/OCI (with PICARD)	Chapman et al. (2019)
Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD)	Hyperspectral imager 370–2400 nm, 204 bands, 10 nm resolution. Nadir spatial resolution 42 m.	PACE/OCI (with PRISM)	Guerin et al. (2011), Hoffmann et al. (2026)
High Spectral Resolution Lidar-2 (HSRL-2)	Lidar providing vertical profiles of aerosol backscatter (355, 532, 1064 nm), extinction (355, 532 nm), and depolarization (355, 532, 1064 nm). Ocean surface wind speed and in water backscattering and attenuation. Along-track resolution 100 m, vertical resolution 30 m (backscatter) to 300 m (extinction).	EarthCARE/ATLID	Hair et al. (2008), Burton et al. (2012, 2018), Rogers et al. (2009), Dmitrovic et al., (2023), Collister et al., (2024)

The ER-2's high-altitude vantage point is typically above all aerosols and clouds, providing observations similar to those collected from orbit, but with more temporal and spatial control. ER-2 flight lines were frequently oriented along or near PACE and EarthCARE ground tracks, with flight planning coordinated in advance based on satellite orbit predictions. In addition to satellite underflights, the ER-2 made targeted overflights of the Twin Otter and surface and ocean assets including the R/V Shearwater, R/V Blissfully, and others listed in Table 3.

The six ER-2 instruments are summarized in Table 4. They provide airborne proxies for all three PACE instruments (OCI, HARP2, SPEXone) as well as the EarthCARE ATLID lidar, enabling comparisons with satellite observations at Level 1 (calibrated optical properties such as radiance, degree of linear polarization (DoLP), extinction and backscatter). The Airborne Hyper-angular Rainbow Polarimeter (AirHARP, McBride et al. (2020, 2024a, 2024b), Sienkiewicz et al. (2025), Martins et al. (2024)) and Spectro-Polarimeter for Exploration (SPEX Airborne, Rietjens et al. (2010, 2021, 2022), van Amerongen et al. (2019), Fu et al. (2020, 2025)) are airborne prototypes with nearly identical properties to PACE/HARP2 and PACE/SPEXone

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(with finer spatial resolution). While it is not an imager like the other polarimeters, the Research Scanning Polarimeter (RSP, Cairns et al. (1999), Chowdhary et al. (2001), Knobelspiesse et al. (2011)) exceeds their capabilities in terms of spectral range and number of viewing angles. It is capable of acting as a proxy for either PACE/HARP2 or PACE/SPEXone. The Portable Remote Imaging Spectrometer (PRISM, Chapman et al. (2019)) and Pushbroom Imager for Cloud and Aerosol Research and Development (PICARD, Hoffmann et al. (2026)) are UV-NIR imaging spectrometers. Generally, PRISM is designed for lower reflectance Ocean Color remote sensing, while PICARD has VNIR to SWIR channels with dynamic range appropriate for cloud remote sensing. Together, their capabilities match that of PACE/OCI, for which a specifically designed airborne proxy does not exist. A dataset merging PICARD and PRISM was created for PACE-PAX. This incorporated spatial co-registration of PRISM data to the coarser PICARD footprint, and mapping both datasets to the spectral sensitivity of PACE/OCI, as illustrated in Figure 5. The sixth instrument on the ER-2 was the High Spectral Resolution Lidar-2 (HSRL-2, Hair et al. (2008), Burton et al. (2012, 2018), Rogers et al. (2009)), a 3β+2α+3δ lidar, meaning that it has sensitivity to aerosol backscatter and depolarization at three channels, and extinction in two. This exceeds the capability of EarthCARE/ATLID, which has sensitivity to backscatter, extinction and depolarization at 355nm alone. Additionally, it is sensitive to ocean surface wind speed, particulate backscatter, and extinction (Dmitrovic et al., (2023), Collister et al., (2024)).

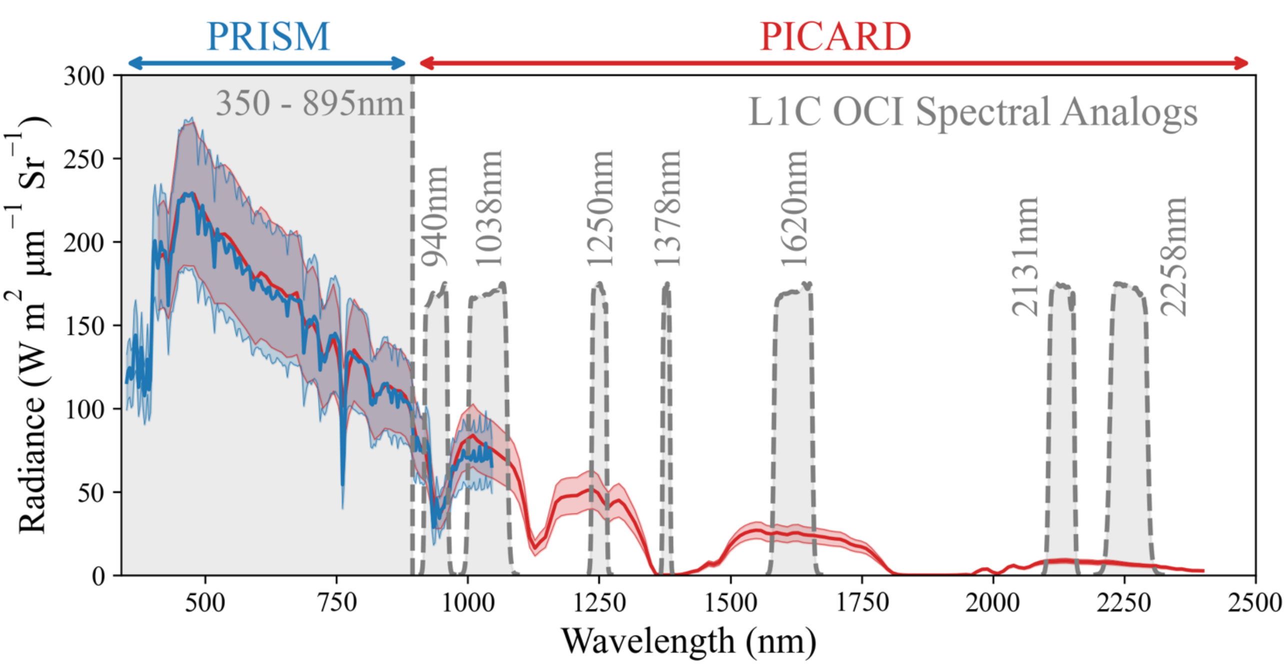

Figure 5 Mapping of PRISM (blue) and PICARD (red) data to PACE/OCI spectral sensitivity (grey). PRISM provides contiguous data in the UV/NIR (350-895) corresponding to that of OCI, while PICARD data are spectrally averaged into OCI NIR/SWIR discrete NIR/SWIR channels.

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By the completion of the campaign, the ER-2 flew for a total of 80.9 flight hours. Most of the flight time was either over California or the Pacific Ocean. Some flight segments covered neighboring states of Oregon, Nevada, Utah and Arizona, including over desert playas used for vicarious calibration (Railroad Valley, NV and Ivanpah Playa, CA).

3.2 NPS CIRPAS Twin Otter low altitude aircraft

The Naval Postgraduate School (NPS) Center for Interdisciplinary Remotely Piloted Aircraft Studies (CIRPAS) Twin Otter (DH-6) (https://airbornescience.nasa.gov/aircraft/Twin_Otter_-_CIRPAS_-_NPS) is a low-altitude research aircraft that supports atmospheric and oceanographic research. The aircraft is instrumented to measure meteorological state variables, aerosol microphysical and optical properties, and cloud and precipitation drop concentration and size distributions. During PACE-PAX, the Twin Otter was based at Marina Municipal Airport (OAR) in Marina, California, its home base near the Monterey Bay and Pacific Ocean. The aircraft conducted 17 research flights between September 3rd and 27th, accumulating 60 total flight hours. Most operations were concentrated in the Monterey Bay area, Central California, the Santa Barbara Channel, and the Los Angeles basin, with several dedicated flights to sample wildfire smoke from the Bridge, Line, and Boon fires. Several flights were flown as double sorties, with a fueling stop at intermediate airports (Camarillo, CA and Chino, CA) to extend the operational range into Southern California and overfly the RV Shearwater and R/V Blissfully.

The Twin Otter flew at altitudes from near-surface to approximately 10,000 feet (~3 km), providing in-situ sampling throughout the lower atmospheric column. Several types of flight patterns were used. Spiral profiles, in which the aircraft ascended or descended in a tight circle over a fixed geographic location, were used to characterize the vertical structure of aerosols and clouds. 'Porpoise' maneuvers, in which the aircraft repeatedly ascended and descended through cloud layers at a fixed altitude range, were used to build statistical characterization of cloud microphysical properties. Level runs were used to transit to other regions and to sample horizontal variability at a defined altitude, often chosen in flight at a level that maximized aerosol load. Low approaches at Marina Airport were also conducted at the beginning and/or end of flights to assist in characterizing the aerosol inlet size cut by comparison with air traffic control tower based instrumentation which was installed as part of PACE-PAX.

The instruments deployed on the Twin Otter are listed in Table 5. In addition to the NPS/CIRPAS facility instrumentation, the NASA Langley Aerosol Research Group Experiment (LARGE) suite was added for further capability to observe aerosol and cloud properties. The NOAA Laser Imaging Nephelometer (LINeph, Ahern et al, 200) was also added to characterize the aerosol polarimetric scattering phase function.

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370 **Table 5 Instruments deployed on the CIRPAS Twin Otter. Those indicated with * were installed in the Marina air traffic control tower but not the aircraft.**

Instrument	Group (Manufacturer)	Description	Key literature references
Passive Cavity Aerosol Spectrometer Probe (**PCASP**) - SPP200	Facility, wing mounted (PMS, Inc.)	Particle Size Distribution, 0.1 - 3.4 µm	Cai et al., (2013)
Cloud Droplet Probe (**CDP**)	Facility, wing mounted (DMT, Inc.)	Cloud Droplet Size Distribution. 2.0 - 47.0 µm	
Cloud Imaging Probe (**CIP**)	Facility, wing mounted (DMT, Inc.)	Cloud Drop Size Distribution. 15.45µm-1.55mm @25µm resolution	Baumgardner and Korolev (1997), Korolev et al, (1998)
Cloud and Aerosol Spectrometer (**CAS**)	Facility, wing mounted (DMT, Inc.)	Cloud and aerosol particle size distribution. 0.5µm-80µm	Brenguier et al. (1994), Paluch and Baumgardner (1989), Baumgardner et al. (1996, 2001)
HotWire (**HW**) Liquid Water Content	Facility, wing mounted (DMT, Inc.)	Liquid Water Content of clouds. 0.01 – 3 g/m3	
Ultrafine Condensation Particle Counter (**TSI-3025**)	Facility (TSI, Inc.)	Particle concentration. Dp > 0.003 µm	
Temperature	Facility (Rosemount)	Total Temperature	
Dew Point Temperature	Facility (EdgeTech)	Chilled Mirror device	
Gerber Particulate Volume Monitor (**PVM-100A**)	Facility, wing mounted	Cloud Liquid Water Content, PSA (particle surface area), LWC (liquid water content), Re (effective radius). 0.002-10 g/m^3, 5-20,000 cm^2/m^{3,} 3-50 µm.	Gerber (1991), Gerber et al. (1994)
Barometric, Dynamic, and Radome-Angle Pressures	Facility (Setra)	Barometric and differential transducers. 600-1100 mb +/- 75 mb	
Wind	Facility	Mean Wind, Slip- and Attack angles. m/s	
TANS Vector platform attitude	Facility (Trimble, Inc)	GPS, Pitch, Roll, Heading	
NovAtel GPS PROPAC	Facility (NovAtel, Inc)	GPS, Lat, Long, Alt, ground speed and track	
C-MIGITS-III, GPS/INS	Facility (Systron, Inc.)	Lat, Long, Alt, ground speed and track, pitch, roll, heading,	
Heitronics KT 19.85 Pyrometer (downlooking/nadir)	Facility (Heiman)	Sea surface temperature. -5 to 45˚ C adjustable.	
SPN-1 Sunshine Pyranometer	Facility (Delta-T Devices)	Global (Total) and Diffuse solar irradiance (W/m^2). 0.4-2.7 µm	
Cockpit and wing cameras	Facility	Forward and down view of environmental and surface conditions	
TSI-3563 Integrating Nephelometer	LARGE (TSI, Inc.)	Total aerosol scattering coefficient at 450, 550, 700 nm; passively dried to <50% RH; f(RH) via tandem humidified system	Anderson and Ogren (1998)
Brechtel Tricolor Absorption Photometer (**TAP**)	LARGE (Brechtel)	Total aerosol absorption coefficient at 465, 520, 640 nm, actively dried to 35°C	Brechtel Manufacturing Inc. (2022)
Ultra High Sensitivity Aerosol Spectrometer (**UHSAS**)	LARGE (DMT)	Dry aerosol size distribution; 59.2–1054.4 nm diameter, passively dried to <50% RH	
TSI-3321 Aerodynamic Particle Sizer (**APS**)	LARGE (TSI, Inc.)	Dry aerosol size distribution; 528-5661 nm diameter, passively dried to <50% RH	Anderson and Ogren (1998)
Printed Optical Particle Spectrometer (**POPS**)	LARGE (Handix Scientific Inc.)	Aerosol size distribution 254–3084 nm diameter, not for ambient size distribution	
Spectral Aerosol Light Absorption Detector (**SALAD**)*	LARGE	Hyperspectral aerosol absorption coefficient 300–800 nm at 0.8 nm resolution, ambient conditions, particles <10 µm	

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Spectral aerosol Extinction instrument (**SpEx**)*	LARGE	Hyperspectral aerosol extinction coefficient 300–800 nm, particles <10 µm	
Laser Imaging Nephelometer (**LiNeph**)	NOAA	Aerosol scattering phase function (P_{11}) and degree of linear polarization at 405 and 660 nm, dry particles <1.5 µm	Ahern et al. (2022, 2025)

The facility cloud probes (CDP, CIP, CAS, hot-wire) were mounted on external wing pylons to sample ambient air without modification, providing in-cloud measurements of droplet size distributions and liquid water content. The LARGE instruments sampled through the CIRPAS community aerosol inlet, which removes large particles and conditions the aerosol sample for optical measurements. The combined LARGE suite provides aerosol scattering and absorption coefficients at multiple wavelengths and relative humidities, enabling derivation of aerosol single scattering albedo (SSA), scattering Ångström exponent, hygroscopic growth factors, and ambient optical properties. The NOAA Chemical Sciences Laboratory's (CSL) LiNeph uniquely provides the full scattering phase function for intensity and the degree of linear polarization for aerosols sampled with the community aerosol inlet. This makes it directly relevant to satellite algorithm validation in that it observes the single scattering properties at the core of those methods. Figure 6 shows the flight tracks with the Twin Otter during PACE-PAX, with color highlighting when ambient relative humidity was less than 40%, in which LiNeph results can be directly compared to remote sensing retrievals.

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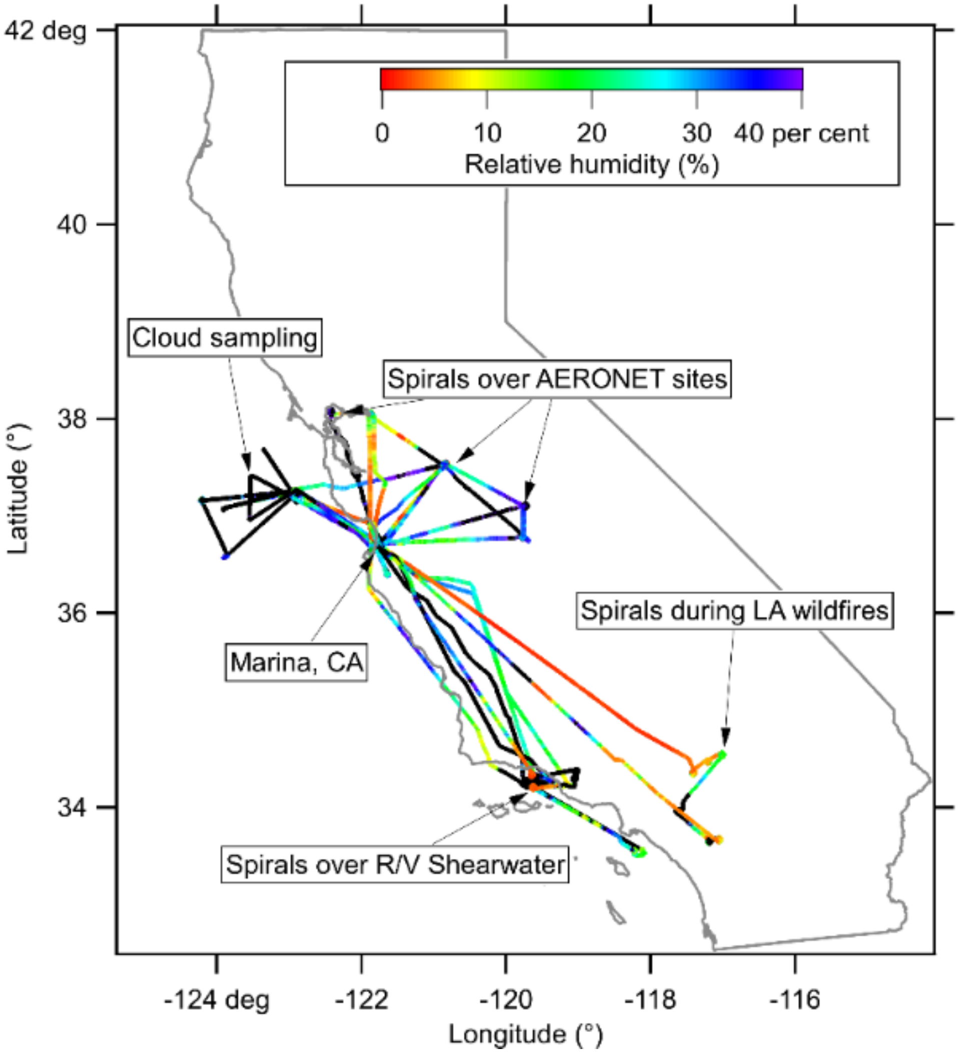

Figure 6 Flight tracks of the CIRPAS Twin Otter during PACE-PAX. Colored points indicate when ambient relative humidity was <40% and aerosol measurements from the LiNeph can be directly compared to retrieval algorithms.

To aid validation efforts, the In-Situ Aerosol Retrieval Algorithm (ISARA) was used to process Twin Otter observations into aerosol optical properties appropriate for validation of remote sensing algorithm products. ISARA has two main steps. First, the complex refractive index is estimated by calculating theoretical scattering and absorption coefficients from the measured dry size distributions across a range of real and imaginary refractive indices (RRI and IRI). The RRI and IRI combination that simultaneously matches the measured dry scattering coefficients at 450, 550, and 700 nm (within 20%) and measured absorption coefficients at 470, 532, and 660 nm (within 1 Mm^{-1}) is selected as the best estimate. Next, optical properties are corrected for water hygroscopic growth. The physical hygroscopicity parameter (κ, Petters and Kreidenweis, 2007) is estimated to account for the growth of dry aerosol particles as they absorb water vapor at ambient relative humidity. This allows the dry in-situ measurements to be scaled to ambient conditions. ISARA produces estimates of ambient aerosol:

- number concentration, surface area, and volume size distributions,
- scattering, absorption, and extinction coefficients,
- complex refractive index, and
- single scattering albedo (SSA).

In addition to the airborne payload, the NASA LARGE team operated a suite of instruments continuously throughout the campaign from the decommissioned air traffic control tower at Marina Municipal Airport. The tower installation served three objectives: (1) providing continuous aerosol context for Twin Otter flight activities; (2) assessing the sampling efficiency of the Twin Otter CIRPAS community aerosol inlet; and (3) testing developmental hyperspectral optical instrumentation. Sample flow was provided by an omnidirectional inlet mounted on the roof of the tower approximately 18m above ground level (60 m above mean sea level), with instruments operating in an enclosed control room one floor below. All transport tubing was conductive silicone with intentionally gradual bends to minimize particle losses. The instrument suite mirrored that of the Twin Otter LARGE payload and included a TSI-3563 integrating nephelometer (scattering coefficient at 450, 550, 700 nm; ambient RH), a Brechtel TAP absorption photometer (absorption at 465, 520, 640 nm; actively dried), a DMT UHSAS (size distribution 84.3–1054 nm; passively dried), a TSI-3321 APS (size distribution 597–11028 nm; ambient RH), and the developmental SALAD and SpEx hyperspectral instruments.

The primary value of the tower dataset lies in its combined use with Twin Otter low approach maneuvers for the purpose of airborne instrument validation. On 15 occasions during the campaign, the Twin Otter flew a low approach directly over the runway at the same height as the control tower (~18 m above ground), allowing direct comparison of airborne and tower-based aerosol measurements under nearly identical sampling conditions. These paired measurements characterize the large particle size cut of the CIRPAS community aerosol inlet, a source of uncertainty in the airborne dataset. Users of the Twin Otter LARGE data should note that inlet particle loss corrections have not been applied to the archived data, and the ongoing inlet characterization analysis may result in updated data products.

3.3 NOAA R/V Shearwater

The NOAA Channel Islands National Marine Sanctuary R/V Shearwater is a 62-foot high-speed catamaran operating out of Santa Barbara, California (https://channelislands.noaa.gov/research/vessels.html). The vessel was chartered for 15 days during PACE-PAX, conducting day trips between September 6 and 28th, 2024, primarily in the Santa Barbara Channel (stations illustrated in Figure 7). Station timing and location was coordinated with PACE satellite overpasses and ER-2 or Twin Otter flight lines when feasible. The R/V Shearwater hosted scientists from NOAA, NASA Goddard Space Flight Center (GSFC),

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Columbia University's Lamont-Doherty Earth Observatory (LDEO), the City College of New York (CCNY), and the Naval Research Laboratory (NRL), whose combined instrumentation provided a comprehensive suite of ocean optical, biogeochemical, and atmospheric measurements, as summarized inTable 6.

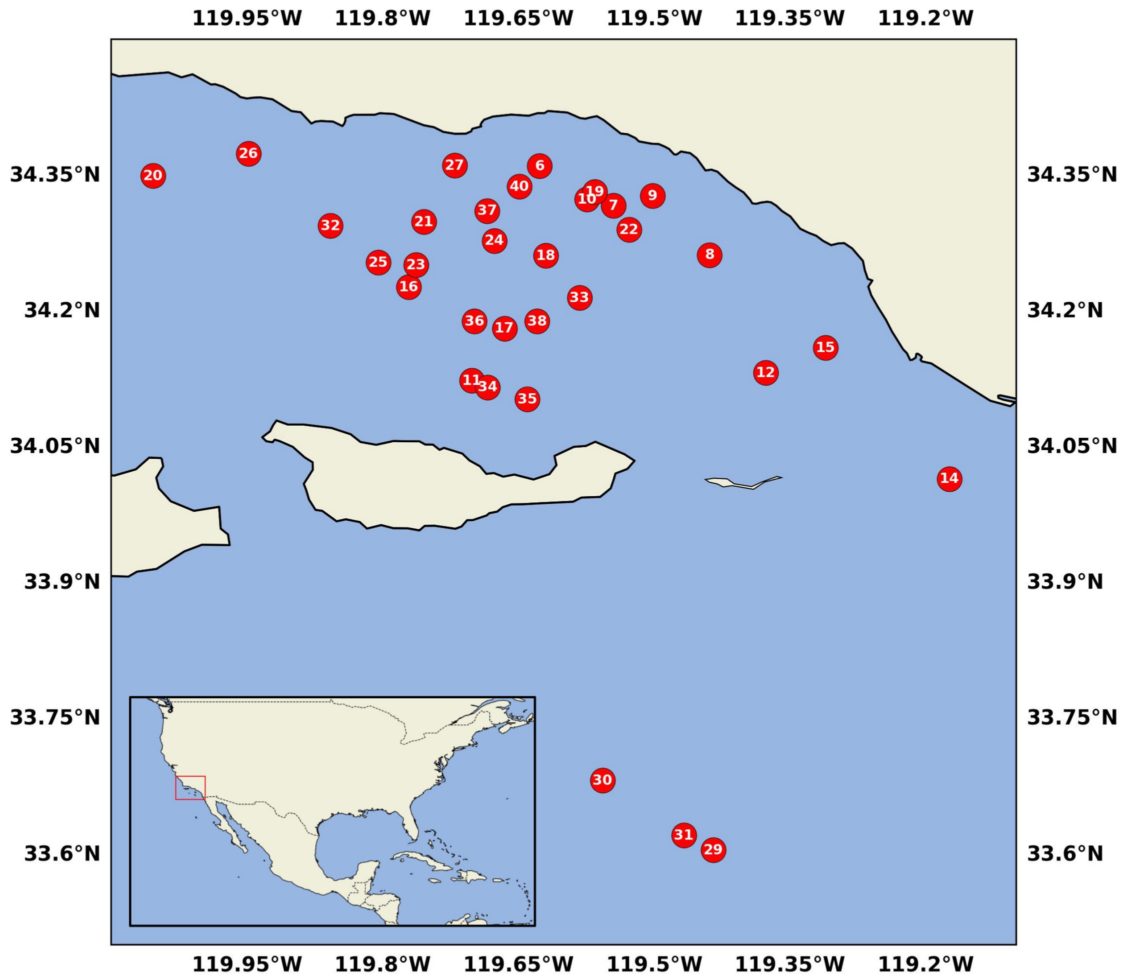

Figure 7 stations sampled by the R/V Shearwater during PACE-PAX.

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440 **Table 6 Summary of instrumentation and measurements deployed on the R/V Shearwater. *Denotes laboratory measurements performed on samples collected and preserved at sea. + Denotes data/samples collected but not yet available on SeaBASS or any other databases.**

Instrument	Institution	Measurements	Sample Type
HyperPro II	NOAA	In-water upwelling radiance Lu(λ), downwelling irradiance Ed(λ), surface irradiance Es(λ); derived Rrs(λ) and Kd(λ) – 350–805 nm (137 channels)	Vertical profile
High-performance liquid chromatography (HPLC)*	NASA	Phytoplankton pigments, community composition	Discrete surface at station
PySAS above water radiometer	NASA GSFC	Water-leaving radiance (L_t), sky radiance (L_i), solar irradiance (E_d) – 350-750 nm	continuous (hourly)
Inherent Optical Property (IOP) Underway (TSG, Hyper-bb, Hyper-a, ac-s)	NASA GSFC	Temperature, salinity, backscattering (b_b), absorption (a), and attenuation (c)	continuous (hourly)
IOP-Profiler (hyper-a, ac-s, 3x SC-6 bb, CTD; LISST-VSF)	NASA GSFC	Temperature, salinity, depth, absorption (a), attenuation (c), and backscatter coefficients (b_b), and volume scattering function	vertical profile
Particle Absorption*	NASA GSFC	Total particle (a_p), detritus/non algal (a_d), and phytoplankton (a_{ph}) absorption – 290-850 nm	Discrete surface at station
Colored Dissolved Organic Matter (CDOM) Absorption*	NASA GSFC	Spectral absorption of colored dissolved organic matter (a_g) – 250-700 nm	Discrete surface at station
Particulate Organic Carbon (POC)*	NASA GSFC	particulate organic carbon	Discrete surface at station
Particulate Inorganic Carbon (PIC)*+	NASA GSFC	particulate inorganic carbon	Discrete surface at station
Dissolved organic Carbon (DOC)*	NASA GSFC	dissolved organic carbon	Discrete surface at station
Total Suspended Matter (TSM)*+	NASA GSFC	total suspended matter	Discrete surface at station
S3e Flow Cytometry*	NASA GSFC	community composition	Discrete surface at station
FlowCam*+	Columbia	community composition	Discrete surface at station
IFCB	NASA GSFC	community composition	continuous
LIFT-FRRF	NASA GSFC	phytoplankton physiological parameters	continuous
FIRe	Columbia	phytoplankton physiological parameters	continuous
Hyperspectral polarimetric imager	NRL/CCNY	Sky and water Stokes parameters (I, Q, U); 402–902 nm (126 bands); 7 viewing angles (25°–55°); above water at ~5 m height	Discrete surface at station
Multispectral polarimetric camera	NRL/CCNY	Sky and water Stokes parameters (I, Q, U); 442, 494, 550, 655 nm; 7 viewing angles (25°–55°); 100-frame video average; above water at ~5 m height	Discrete surface at station

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Spectropolarimeter	NRL/CCNY	Sky and water polarized radiance (I, Q, U); 300–1100 nm; <0.7 nm spectral resolution; HARP2-matched bands at 440, 550, 650, 685, 710, 873 nm	Discrete surface at station
ASD FieldSpec HandHeld 2	NRL/CCNY	Upwelling radiance L_u, downwelling irradiance E_d, remote sensing reflectance Rrs; 350–800 nm, 1 nm spectral resolution	Discrete surface at station
Microtops sun photometer	NRL/CCNY	Aerosol optical depth at 440, 675, 870, 936, 1020 nm	Discrete surface
LISST-100x (flow-through)	NRL/CCNY	Particle size distributions (PSD); 1.09–184 µm	Continuous
CLASS (Zinger Enterprises)	NRL/CCNY	Chlorophyll concentration, chlorophyll fluorescence, normalized fluorescence line height	Continuous
Cimel sun photometer[+]	NASA GSFC	(Experimental) spectral aerosol optical depth	Continuous
Pandora spectrometer	NASA GSFC	Columnar trace gas amounts (O_3, NO_2, and CH_2O)	Continuous. Note data archived at ASDC

By the completion of the campaign, the R/V Shearwater occupied 40 stations in the Santa Barbara Channel, collecting in-water optical profiles and discrete water samples under a range of atmospheric and ocean conditions. The Santa Barbara Channel is a region of diverse biological productivity, with upwelling-driven high chlorophyll waters near the coast transitioning to oligotrophic conditions offshore. This biogeochemical diversity provides a valuable range of ocean optical conditions for PACE validation, including both open ocean and coastal waters. All ocean optical and biogeochemical data from the R/V Shearwater are archived at the NASA SeaBASS archive, with the exception of the Microtops sun photometer data stored at AERONET and PANDORA spectrophotometer data stored at the PACE-PAX archive.

3.4 R/V Blissfully

The R/V Blissfully is a privately owned 30-foot sailboat that supported PACE-PAX from 6 to 19 September 2024 (9 sampling days). The vessel operated in the San Pedro Channel off Southern California, sampling 19 stations near the University of Southern California (USC) SeaPRISM AERONET-OC validation site on an offshore oil rig. The R/V Blissfully operated with a minimal but targeted instrument package focused on ocean color radiometry and supporting water sample collection. The instrument suite is summarized in Table 7. At each station, the standard protocol consisted of three sets of five HyperPro profiles to 20 m depth and a single deep cast to 60 m, providing statistically robust profiles of in-water optical properties. Discrete water samples were collected in triplicate at each station for shore-based laboratory analysis.

Table 7 Summary of instrumentation and measurements deployed on the R/V Blissfully. *Denotes laboratory measurements performed on samples collected and preserved at sea. + Denotes data/samples collected but not yet available on SeaBASS or any other databases.

Instrument	Measurements	Sample Type
HyperPro II	In-water upwelling radiance Lu(λ), downwelling irradiance Ed(λ), surface irradiance Es(λ); derived Rrs(λ) and Kd(λ) – 350–805 nm (137 channels)	Vertical profile

High-performance liquid chromatography (HPLC)*	Phytoplankton pigments, community composition	Discrete surface at station
Particle absorption*	Total particle (ap), detritus/non-algal (ad), and phytoplankton (aph) absorption	Discrete surface at station
Flow cytometry vial*	Bacterial community composition	Discrete surface at station
Lugol's preserved whole water*+	Plankton community composition via FlowCam/IFCB	Discrete surface at station
Microtops sun photometer	Aerosol optical depth at 440, 675, 870, 936, 1020 nm	Discrete at station

The primary value of the R/V Blissfully dataset lies in its geographic complementarity to the R/V Shearwater operations and its focus on validation. While the Shearwater primarily sampled in the biologically productive Santa Barbara Channel, the Blissfully sampled the San Pedro Channel, where the established USC SeaPRISM AERONET-OC site provides long-term aerosol and ocean color reference data. The proximity to the SeaPRISM site enables quality assessment of the HyperPro radiometry by comparison with the automated above-water CIMEL photometer, providing an additional layer of data quality control. Furthermore, on several days (notably 8 and 13 September) the R/V Blissfully operated simultaneously with the ER-2 and PACE overpass, providing in-water observations through smoke-laden atmospheres from the Southern California wildfires, a particularly valuable dataset for assessing the accuracy of smoke aerosol atmospheric correction in ocean color retrievals. Additionally, this data collection is part of the growing ocean going movement to collect data from non-traditional research vessels, while minimizing environmental noise, and reliance of fossil fuels do facilitate scientific discovery (e.g., TARA oceans, Sunagawa et al, 2020).

3.5 Additional ocean assets

Several additional ocean-based assets supplemented the core R/V Shearwater and R/V Blissfully operations, extending spatial and temporal coverage and providing specialized measurements for vicarious calibration and biological oceanography. These assets are described briefly below and summarized in Table 8.

The HyperNAV autonomous profiling float (Barnard et al., 2024a, 2024b) provides hyperspectral measurements of upwelling radiance for PACE OCI vicarious calibration (Werdell et al, 2024). The system measures upwelling radiance $L_u(\lambda)$ from 350–900, along with vertical profiles of temperature, salinity, and pressure from a depth of roughly 500 m to the ocean surface. The float is programmed to surface within ±1 hour of the PACE overpass, providing near-coincident measurements for vicarious calibration. During PACE-PAX, the HyperNAV system was deployed in the basin south of the Santa Barbara Channel from August 31st through September 22nd and made 19 daily profiles. Unfortunately, most observations were under overcast skies and insufficient for the stringent vicarious calibration matchup requirements. The sole clear-sky day was at the PACE-OCI swath edge, but the dataset as a whole is useful for comparisons to ER-2 remote sensing observations.

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The University of Delaware contributed a Teledyne-Marine Generation 3 Slocum glider named "Orris," carrying both optical and acoustic sensors. The glider was deployed along a 10 km transect line from September 7th through October 1st (25 days), was overflown by the ER-2 many times, and was overflown by PACE in biologically productive water conditions. The glider measured at 1 Hz and provided continuous subsurface characterization of physical and bio-optical ocean properties throughout the campaign.

The R/V Rachel Carson conducted three consecutive day cruises (25–27 September 2024) from Moss Landing Harbor in Monterey Bay, California, as part of PACE Validation Science Team (PVST) activities. The cruises sampled along a southeast-to-northwest transect in Monterey Bay. A NASA-supported HyperPro/HyperOCR profiling system collected in-water upwelling radiance $L_u(\lambda)$, downwelling irradiance $E_d(\lambda)$, and surface irradiance $E_s(\lambda)$ at three stations. The PVST team also collected a large suite of biological and optical measurements in coordination with MBARI and SIO collaborators. On September 27th, the R/V Rachel Carson was overflown by both the ER-2 (at ~19:36 UTC) and the Twin Otter (spiral during PACE overpass at ~20:39-21:09 UTC), making this the only occasion when the Rachel Carson was part of a full multi-platform coordinated observation. PACE overflew the area at 21:04 UTC. All data are archived in SeaBASS.

The University of California, Santa Barbara (UCSB) contributed two small-boat cruises in the Santa Barbara Channel on the 5th and 20th of September as part of PVST Santa Barbara Channel Rapid Response activities. Each cruise occupied two stations, for a total of four stations. Two radiometric systems were deployed: a Compact Optical Profiling System (C-OPS, BioSpherical Instruments) measuring in-water upwelling radiance and downwelling irradiance at 18 wavelengths (320–780 nm), plus ancillary sensors for temperature, chlorophyll fluorescence, PAR, pressure, and tilt, and a HyperPro II profiling system (Sea-Bird Scientific) measuring hyperspectral $L_u(\lambda)$, $E_d(\lambda)$, and $E_s(\lambda)$ from 350–805 nm. Discrete water samples for HPLC pigment analysis were collected at each station. Derived products include remote sensing reflectance Rrs(λ) and diffuse attenuation coefficient $K_d(\lambda)$. All data are archived at NASA SeaBASS. The UCSB group also provided laboratory space and access to a pure water system to the R/V Shearwater throughout the campaign.

Table 8 Summary of other ocean surface instrumentation and measurements.

Platform	Investigator/Institution	Deployment dates	Location	Key measurements
HyperNAV float	A. Barnard / Oregon State University	August 31st – September 19th, 19 profiles	South of Santa Barbara Channel	Hyperspectral upwelling radiance $L_u(\lambda)$ 350–900nm, temperature, salinity, pressure (surface to ~500 m)
Slocum glider “Orris”	M. Oliver / University of Delaware	September 7th – October 1st, continuous	10 km transect in Santa Barbara Channel	E_d (380, 470, 532 nm, PAR), L_u (380, 470, 532, 664 nm), optical backscatter (532, 700 nm), chlorophyll fluorescence, CTD, acoustic backscatter (200, 333 kHz)

R/V Rachel Carson	C. Anderson / Scripps Institution of Oceanography, UCSD	September 25-27, 3 day cruises	Monterey Bay	In-water $L_u(\lambda)$, $E_d(\lambda)$, $E_s(\lambda)$, derived $Rrs(\lambda)$, $K_d(\lambda)$, biological and optical suite
UCSB small vessels	S. Maritorena / UCSB	September 5th, 20th, 2 day cruises	Santa Barbara Channel	C-OPS in-water radiance/irradiance at 18 wavelengths (320–780 nm), HyperPro II $L_u(\lambda)$, $E_d(\lambda)$, $E_s(\lambda)$ 350–805 nm, HPLC pigments

3.6 Additional land assets

PACE-PAX operations were coordinated with established ground-based measurement networks and dedicated surface observation sites throughout California and adjacent regions. These assets provided continuous or targeted observations of surface and atmospheric properties that complement other PACE-PAX measurements. Most of these assets operated continuously throughout the campaign period without requiring dedicated campaign logistics, serving as persistent reference measurements for satellite and airborne validation.

The Aerosol Robotic Network (AERONET, Holben et al., 1998) is a global federation of ground-based sun photometers (Holben et al., 1998). The network provides standardized, quality-controlled measurements of spectral aerosol optical depth (AOD), aerosol size distribution, single scattering albedo (SSA), complex refractive index, and other inversion products. The AERONET-OC (Ocean Color) program extends the standard AERONET capability to offshore platforms (e.g lighthouses, oceanographic towers, oil platforms) where CIMEL photometers measure both AOD and normalized water-leaving radiance (Rrs), enabling direct validation of satellite ocean color products. The Maritime Aerosol Network (MAN) component of AERONET provides ship-borne AOD measurements using hand-held Microtops II sun photometers, which were deployed on the R/V Shearwater and R/V Blissfully. The AERONET program specifically supported PACE-PAX by maximizing the operational availability of sites in the campaign region, with particular emphasis on AERONET-OC and instruments with UV spectral capability relevant to PACE OCI's UV channels. Many ER-2 and Twin Otter flight lines were designed to overfly AERONET sites, providing column-integrated aerosol optical depth as a reference for in-situ vertical profiles and remote sensing retrievals.

Two National Ecological Observatory Network (NEON) field sites in California were overflown during PACE-PAX, providing additional reference measurements of atmospheric and surface properties. The San Joaquin Experimental Range (SJER) and Lower Teakettle Experimental Forest (TEAK) are sites with meteorological, ecological, soil, remote sensing (including AERONET sun photometers) and other instrumentation.

The Naval Research Laboratory Coastal Environmental Observation Station (CEOBS) is a permanent research site located on the immediate coastline of Monterey Bay near Watsonville, California. The site provides continuous measurements of the

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coastal boundary layer and cloud systems and is near the Twin Otter base at Marina Airport. Active profiles are made with a Ka-band scanning Doppler radar, a Doppler lidar, a DIAL lidar, a ceilometer and a rain radar. Passive observations are made with a microwave radiometer, a visibility sensor, an all-sky camera, an AERONET sun photometer and several other radiometers and flux meters. In situ aerosol and cloud measurements are taken from the surface and a flux tower. The CEOBS site was overflown by either or both the ER-2 and the Twin Otter on six days, including profiling spirals by the latter. On September 8th, the EarthCARE ground track passed over the CEOBS site while coordinated measurements were made by the ER-2 and the Twin Otter.

Railroad Valley is a well-characterized bright desert playa located in the Tonopah Basin of Nevada (38.5°N, 115.7°W) that has been used extensively as a vicarious calibration reference for satellite sensors. The site is characterized by high, spatially uniform surface reflectance, low and stable aerosol loading, and minimal cloud cover, making it well-suited for radiometric calibration of satellite and airborne sensors. The Radiometric Calibration Test Site (RadCaTS, Czapla-Myers et al, 2008), including an AERONET sun photometer, is situated in Railroad Valley, and used for radiometric calibration of Earth Observing satellites (e.g. Czapla-Myers et al, 2017). The ER-2 made four targeted overflights of Railroad Valley during PACE-PAX, on September 13th, 22nd (twice) and 23rd. These overflights of the spatially uniform site support radiometric validation of PACE and ER-2 passive remote sensing observations (VTM Objective 3).

Like Railroad Valley, Ivanpah Playa is a bright desert dry lake that can serve as a radiometric calibration reference. Ivanpah Playa is located in the Mojave Desert in California (35.6°N, 115.4°W) and has a somewhat higher surface reflectance than Railroad Valley. Unlike Railroad Valley, Ivanpah Playa does not have a permanent radiometric calibration site. However, a ground team from JPL traveled to Ivanpah Playa on September 17th and made surface characterization measurements with an ASD FieldSpec spectroradiometer and aerosol measurements with a handheld Microtops II sun photometer during an ER-2 and PACE overpass.

4. Overall campaign assessment and example observations

Of the 25 PACE-PAX measurement objectives, fifteen were observed such that they exceeded baseline (goal) requirements, and another four exceeded threshold (minimum) requirements. When factoring in the relative importance of each objective, the overall PACE-PAX Achievement Function (A) value is 0.838, above the threshold and just below baseline (Figure 8). Seventeen flights were performed by the Twin Otter and thirteen by the ER-2. These flights were throughout California and offshore, and in nearby areas of Nevada, Arizona, Utah and Oregon the case of the ER-2. The R/V Shearwater made fifteen day trips, while the R/V Blissfully made nine. 22 coordinated observations were made during a PACE overpass, and six with EarthCARE. Over land, coordinated observations were made over AERONET, NEON and CEOBS sites, as well as the Railroad Valley and Ivanpah Playa bright reference areas. Conditions were somewhat typical for California in September, with

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extensive offshore marine stratocumulus cloud cover and relatively cloud-free conditions with variable aerosol loads over land. Several extreme wildfires in the Los Angeles region were observed, as well as red tide events in Monterey Bay and other blooms in the Santa Barbara channel. Table contains a day-by-day summary of flights and major events. The post-campaign Technical Memorandum (Knobelspiesse et al, 2025c) has extensive tables and more description, sorted by measurement objective, specific measurement platform combinations, and so forth.

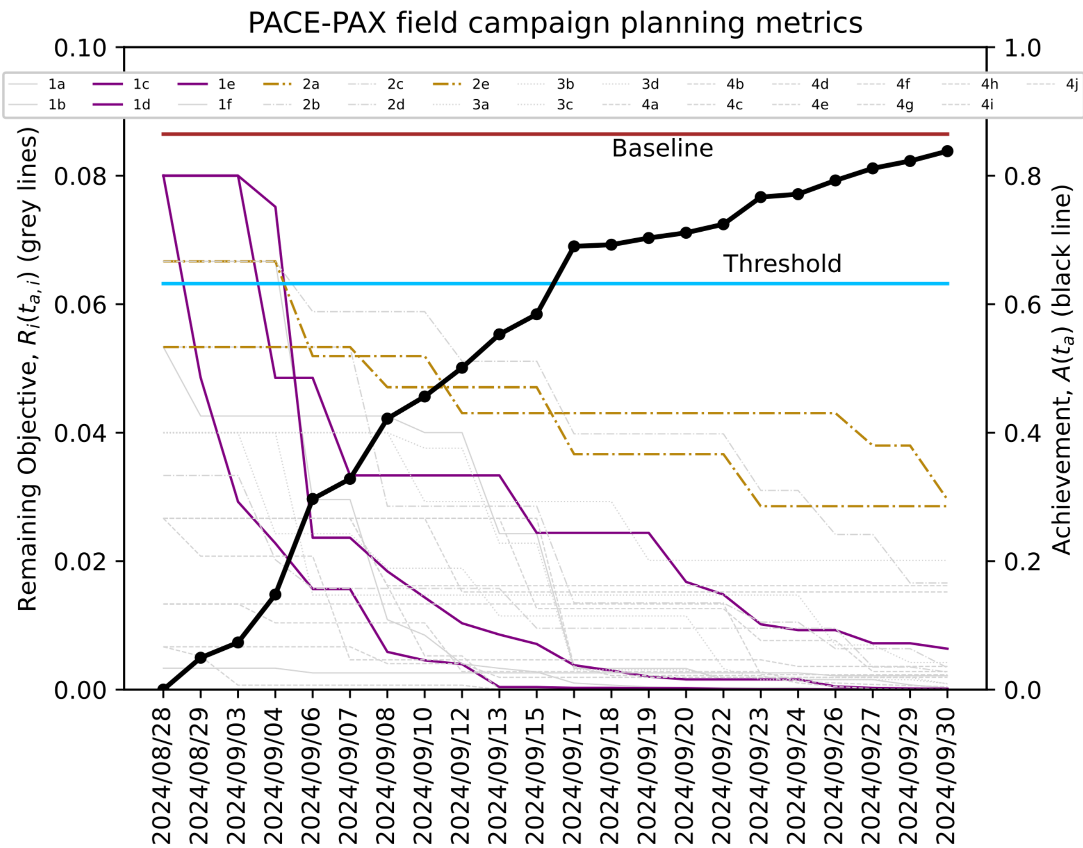

Figure 8 Modified from Knobelspiesse et al., 2026, showing components of the Underway Decision Support Algorithm (U-DSA) which was used to guide decisions in the field. The abscissa labels are dates of operation, note August dates were aircraft check flights prior to campaign science operations. The Achievement function, A(t_a), is shown in the solid black line and is referenced to the right ordinate axis. In the U-DSA, "Threshold" indicates the minimum required to declare a mission a success, while "Baseline" is the goal. Each VTM objective (see Table 1) has its own Threshold and Baseline, so the Achievement function is an overall metric that combines each VTM objective's success with each objective's relative importance. The plots in purple, yellow and light grey reference the Remaining Objective function, $R_i(t_{a,i})$, which indicates how much remains to be observed for each objective, weighted by the relative importance of that objective and the amount of time needed to satisfy Threshold and Baseline. Objectives highlighted in purple (1c, 1d, 1e) were the highest at the start of the campaign, while those with the highest at the end of the campaign are highlighted in yellow (2a and 2e). The remaining objective functions were consulted throughout the campaign to guide planning.

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Several measurement objectives were not sampled sufficiently to meet threshold. In some cases, this was due to metrological conditions, specifically a lack of large aerosol loads over ocean. The ocean within range of PACE-PAX aircraft and ships was frequently covered by (marine stratocumulus) clouds, and in situations where they were not the aerosol amount was typically low. This affected the ability to make simultaneous observations with PACE over the ocean in cloud-free conditions (objective 2a) and more generally meet specific phenomena objectives like 4b (High aerosol loading over ocean) and 4g (Dust aerosols over ocean). Ocean cloudiness also affected the ability to overfly the HyperNAV vicarious calibration site (3d) which for operational necessity was positioned in an eddy south of the Santa Barbara Channel. This eddy was within an aviation Special Use Airspace (SUA), limiting ER-2 and Twin Otter access. On days when that access was granted, it was often cloudy. Validation by flying in the EarthCARE ground track was also challenged by meteorological conditions, namely windspeed at the ground. EarthCARE's overpass time at this latitude is after PACE, at roughly 15:00 – 16:00 local time (later to the west over the ocean). During PACE-PAX, windspeed increased in the afternoon at AFRC, which was risky for safe landing of the ER-2. For this reason, several flight segments planned for the ER-2 coordination with EarthCARE were cancelled or shortened.

This remainder of this section illustrates the potential for validation and scientific analysis with PACE-PAX data: multi-platform column closure observations, aerosol remote sensing comparisons, cloud microphysical property retrievals, and observations of Southern California wildfire smoke. These examples are not intended as comprehensive analyses, but rather as demonstrations of the unique capabilities and scientific value of the PACE-PAX dataset. In each case, the simultaneous availability of multiple measurement types, such as remote sensing from orbit, remote sensing from high-altitude aircraft, in-situ atmospheric profiling, and ocean surface measurements, creates opportunities for rigorous validation and closure studies that are not possible with any single platform or instrument type.

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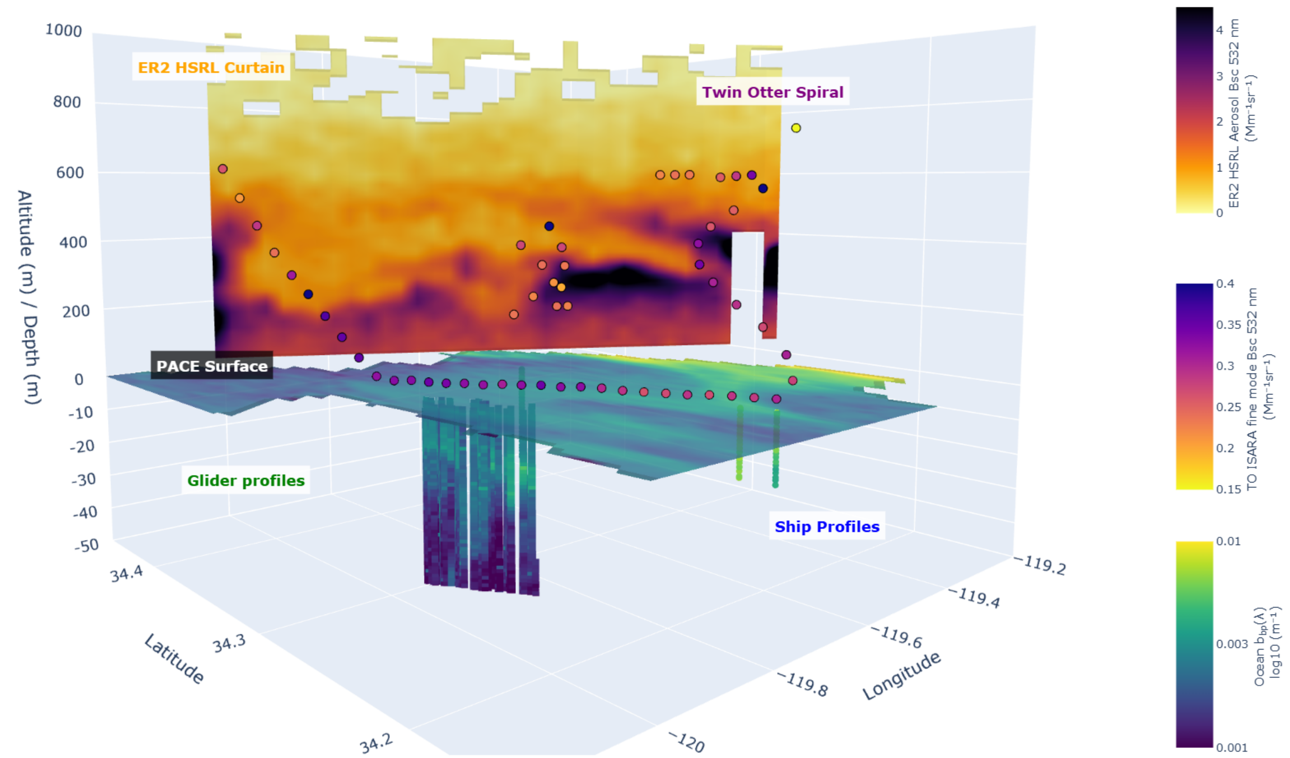

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Figure 9 View of Santa Barbara channel area from five different platforms on September 26, 2024. Ocean surface backscattering (442 nm), derived from PACE OCI measurements, is horizontally superimposed on glider based (backscattering at 532 nm) and R/V Shearwater based (backscattering at 440 nm) profiles collected that day. The CIRPAS Twin Otter flew several spirals over the R/V Shearwater stations (dots indicating ISARA fine mode fraction backscattering at 532 nm), and through ER-2 HSRL curtain indicating vertical distribution of the aerosol backscattering (532 nm).

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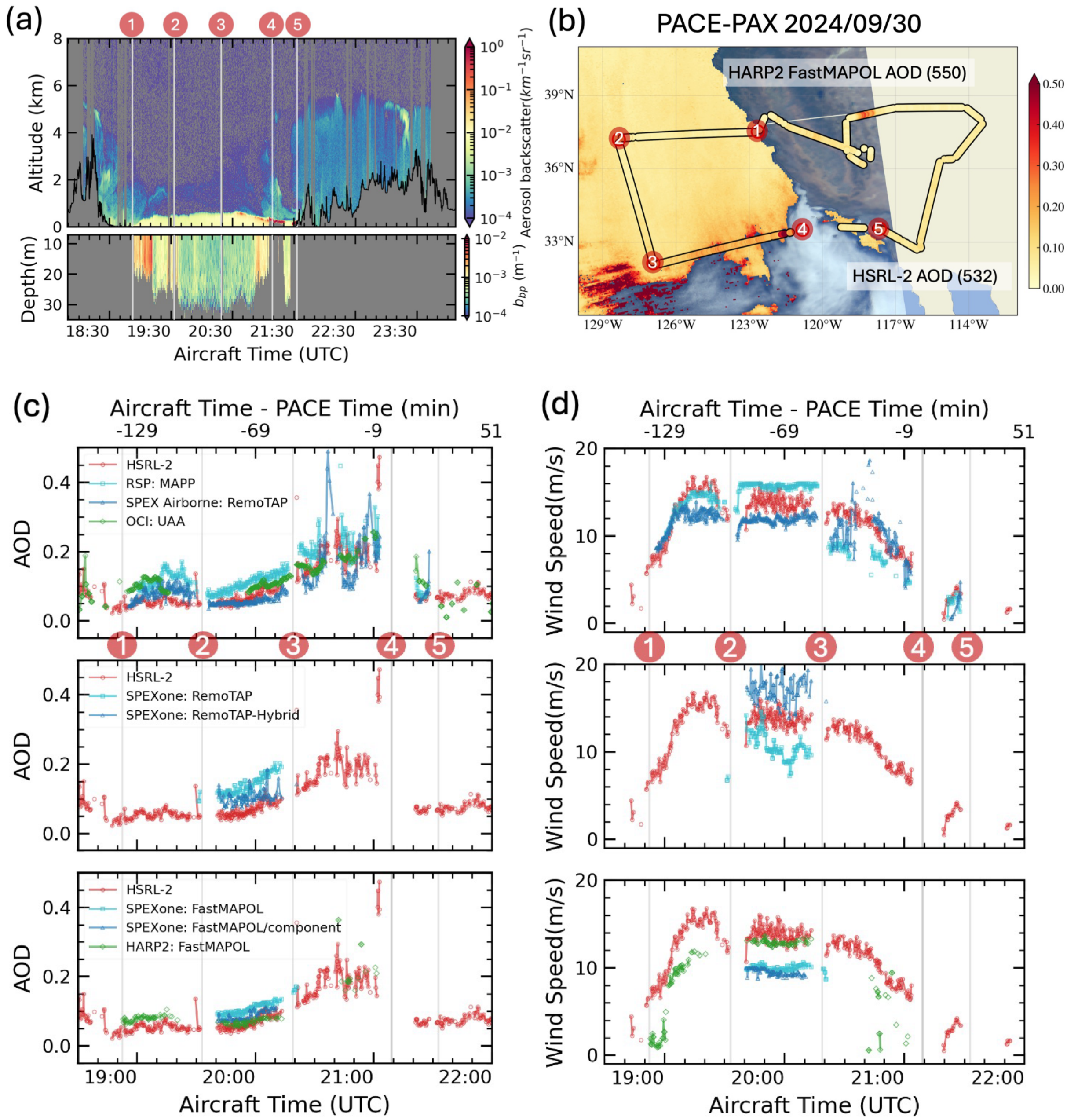

Figure 10 Aerosol and wind speed comparisons from the PACE-PAX field campaign on September 30, 2024 (a) HSRL-2 aerosol backscatter and ocean particulate backscattering coefficient (b_{bp}) profiles (b). Note the phytoplankton bloom between points (1) and (2) as indicated in the HSRL-2 b_{bp} profiles. HSRL-2 AOD at 532 nm along the flight track compared with PACE HARP2 AOD at 550 nm from the FastMAPOL product. (c, d) Cross-comparisons of retrieved AOD (550 nm) and wind speed with HSRL-2 products. Upper panels: the MAPP product from RSP measurements, the RemoTAP product from SPEX Airborne, and the UAA product from PACE OCI measurements. Middle panels: RemoTAP and RemoTAP-Hybrid products from PACE SPEXone. Lower panels:

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FastMAPOL products from SPEXone and HARP2, FastMAPOL/component products from SPEXone. Red dots labeled 1–5 indicate the flight direction, with the PACE overpass occurring near point 4 at 21:09 UTC.

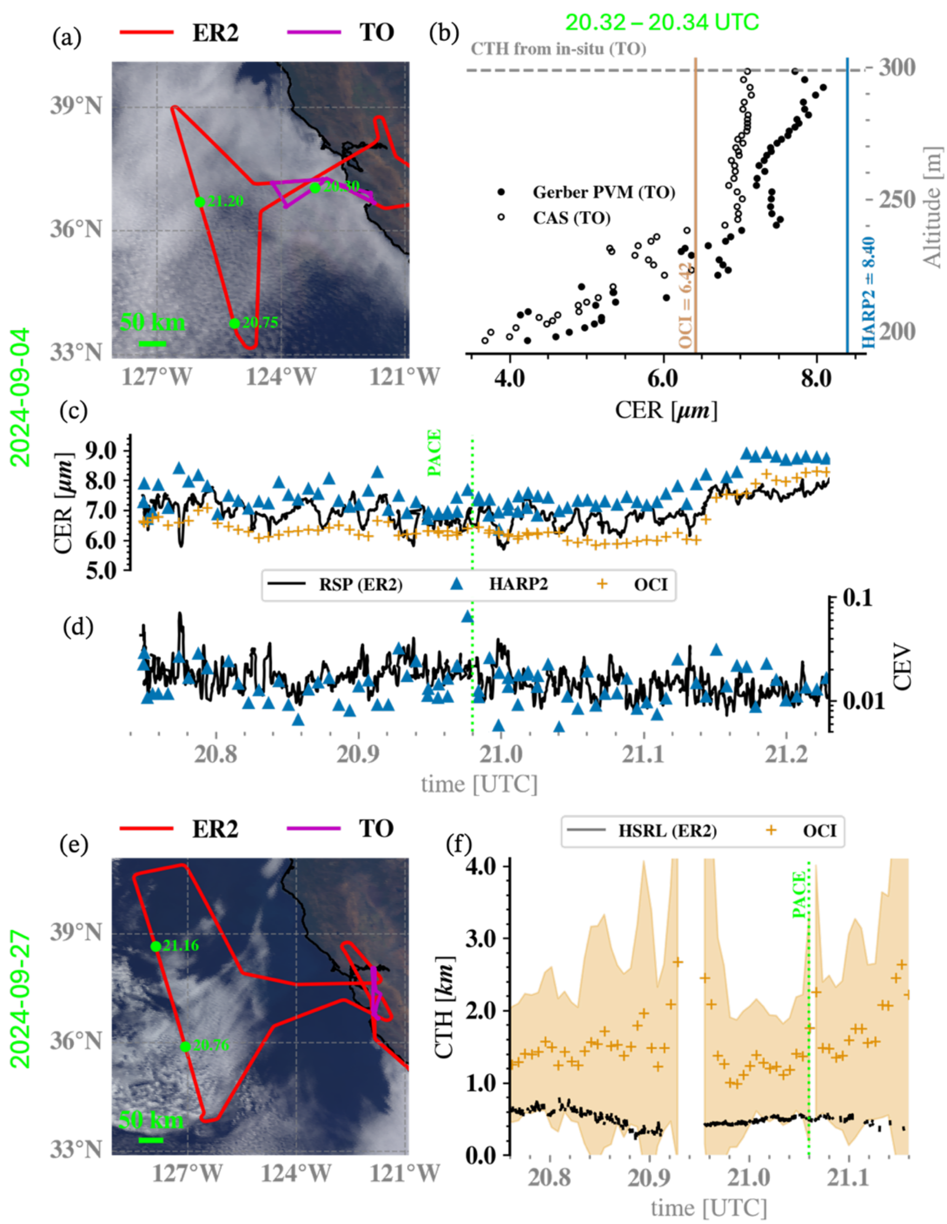

Figure 11 Flight tracks of the ER-2 (red) and TO (magenta) aircraft overlaid on PACE OCI true-color images for (a) September 4, 2024, and (e) September 27, 2024. (b) In-situ cloud effective radius (CER) profiles measured by the Gerber Particulate Volume Monitor (PVM; filled black circles) and Cloud and Aerosol Spectrometer (CAS; open black circles) probes between 20.14 and 20.18 UTC on September 4. The horizontal grey dashed line indicates the in-situ cloud top height (CTH). Vertical solid lines represent the corresponding retrieved CER values from OCI (brown) and HARP2 (blue). (c, d) Time series on September 4 of (c) CER and (d) cloud effective variance (CEV), comparing ER-2 RSP retrievals (solid line) with PACE HARP2 (triangles) and OCI (crosses)

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products. (f) Time series of CTH on September 27, comparing ER-2 HSRL-2 (solid line) and OCI (crosses) retrievals. The shaded area indicates estimated OCI CTH uncertainties (1σ). In panels (c), (d), and (f), the vertical dotted lines indicate the time of the PACE satellite overpasses.

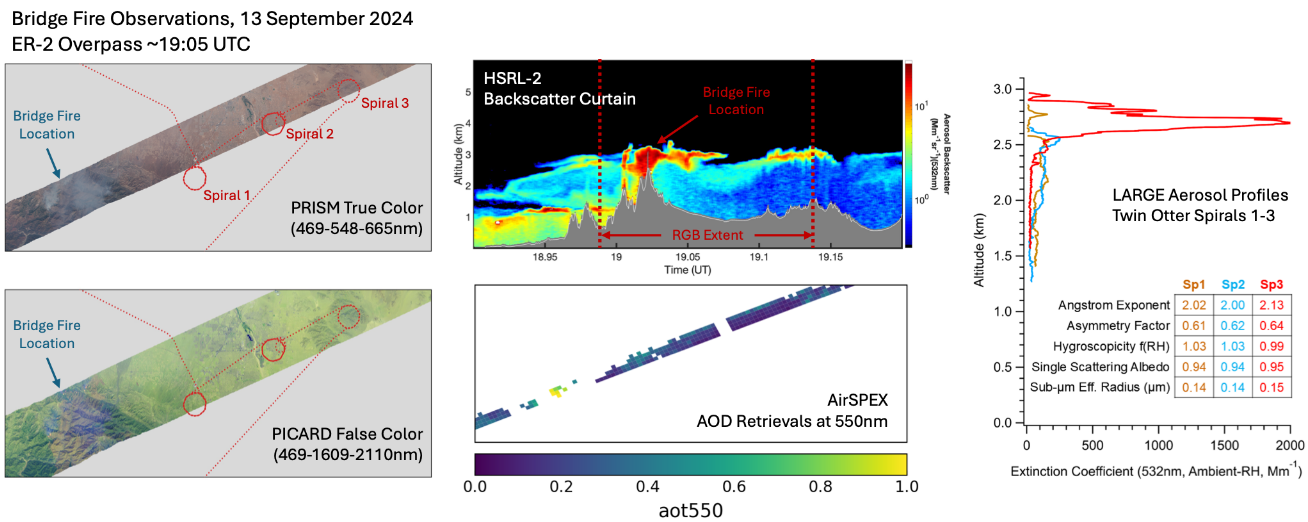

Figure 12 PACE-PAX observations of the Bridge Fire near Big Pines, California, obtained on 13 September 2024. Three ER-2 overpasses occurred (at roughly 19:05 UTC shown here) along with three Twin Otter spirals in the region downwind of the fire. A true color image from PRISM (upper left) shows the extent of the smoke, the Twin Otter flight track is overlayed on the image with red dashed lines. A false color RGB from PICARD (lower left) using shortwave infrared (SWIR) wavelengths where smoke is transparent shows the extent of the burn region and location of the active fire. A backscatter curtain from HSRL-2 (upper middle) shows the smoke plume and other aerosols vertically, while AOD retrievals from AirSPEX (bottom middle) correspond well with the smoke observed in the PRISM RGB. Vertical profiles of aerosol extinction from the LARGE instrumentation on the Twin Otter are shown at right for the three spirals, along with profile mean properties (inset table).

5. Conclusions

The PACE Postlaunch Airborne eXperiment (PACE-PAX) was conducted in September 2024 in California to support post-launch validation of the NASA PACE and JAXA/ESA EarthCARE satellite missions. The campaign successfully coordinated observations from two research aircraft, multiple ocean vessels, and a network of ground and ocean assets during 22 PACE and 6 EarthCARE satellite overpasses, exceeding threshold (minimum) and nearly meeting baseline (goal) requirements established in our VTM and planning algorithms. The resulting dataset spans the full measurement chain from in-water ocean optical properties through the atmospheric column to top-of-atmosphere radiances, providing the simultaneous multi-parameter observations required for validation of novel satellite products that depend on coupled atmosphere-ocean or atmosphere-land retrieval algorithms.

The dataset is distinguished by several characteristics that make it particularly valuable for satellite validation and algorithm development. First, the ER-2 payload provides airborne analogs for all three PACE instruments and for the EarthCARE ATLID

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lidar, enabling comparison at the radiance and polarization level before retrieval algorithms are applied. Second, the geographic diversity of the observations, ranging from biologically productive coastal ocean environments to desert calibration sites, wildfire smoke plumes, and marine stratocumulus cloud decks, ensures that algorithms are tested across a wide range of geophysical conditions. Third, the standardized data formats used throughout the campaign (PACE L1C for airborne remote sensing data, ICARTT for in-situ data, and SeaBASS for ocean optical data) facilitate direct comparison with satellite observations and promote data reuse by the broader scientific community.

All PACE-PAX data are publicly available through the NASA Atmospheric Science Data Center and NASA SeaBASS. Dataset DOI's are provided in the Code and Data Availability section. Users are encouraged to consult the PACE-PAX post-campaign technical memorandum (Knobelspiesse et al., 2025c) for detailed instrument specifications, daily flight reports, and additional technical documentation. The PACE-PAX website (https://pace.oceansciences.org/pace-pax.htm) provides additional resources including an operations summary table, and links to the data archive.

6. Acronyms and units

AC-S	Absorption and attenuation meter
AERONET	AErosol RObotic NETwork
AERONET-OC	AERONET Ocean Color
AFRC	Armstrong Flight Research Center
AirHARP2	Airborne Hyper-Angular Rainbow Polarimeter 2
AoLP	Angle of Linear Polarization
AOD	Aerosol Optical Depth (synonymous with AOT)
AOT	Aerosol Optical Thickness (synonymous with AOD)
APS	Aerodynamic Particle Sizer
ARC	NASA Ames Research Center
ARTDECO	Automated Radiative Transfer Data for Earth and Climate Observations
ASDC	Atmospheric Science Data Center
ATBD	Algorithm Theoretical Basis Document
ATLID	ATMospheric LIDar (EarthCARE instrument)
BAERI	Bay Area Environmental Research Institute
BBR	Broad-Band Radiometer (EarthCARE instrument)
CAPS-PMSSA	Cavity Attenuated Phase Shift Particle Matter Single Scattering Albedo
CCNY	City College of New York
CEOBS	Coastal Environmental OBserving Station
Chl	Chlorophyll
CIRPAS	Center for Interdisciplinary Remotely-Piloted Aircraft Studies
C-OPS	Compact Optical Profiling System
CPR	Cloud Profiling Radar (EarthCARE instrument)
CTD	Conductivity Temperature Depth
$E_d(\lambda)$	Downwelling irradiance [W m^{-2} nm^{-1}]
ESPO	Earth Science Project Office
EarthCARE	Earth, Cloud, Aerosol and Radiation Explorer
ER-2	Earth Resources 2

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$E_s(\lambda)$	Spectral downwelling surface (above-water) solar irradiance [W m^{-2} nm^{-1}]
ESDS	Earth Science Data Systems
E_u	Upwelling irradiance [W m^{-2}]
F_0	Extraterrestrial solar irradiance [W m^{-2}]
FLUID	Framework for Live User-Invoked Data
GEOS-FP	Goddard Earth Observing System Forward Processing
GISS	NASA Goddard Institute for Space Studies
GMAO	Global Modeling and Assimilation Office
GSFC	NASA Goddard Space Flight Center
HARP2	Hyper-Angular Rainbow Polarimeter 2 (PACE instrument)
HPLC	High Performance Liquid Chromatography
HSRL2	High Spectral Resolution Lidar-2
IFCB	Imaging FlowCytobot
IOP	Inherent Optical Properties
IRI	Imaginary Refractive Index
ISARA	In-situ and Satellite-based Aerosol Research Algorithms
JPL	Jet Propulsion Laboratory
κ	Physical hygroscopicity parameter
LaRC	NASA Langley Research Center
LARGE	Langley Aerosol Research Group Experiment
LDEO	Lamont-Doherty Earth Observatory
LiNeph	Laser imaging Nephelometer
L_u	Upwelling radiance [W m^{-2} sr^{-1}]
L_w	Water-leaving radiance [W m^{-2} sr^{-1}]
L_{wn}	Normalized water-leaving radiance [W m^{-2} sr^{-1}]
MAN	Maritime Aerosol Network
MBARI	Monterey Bay Aquarium Research Institute
MSI	Multi-Spectral Imager (instrument on EarthCARE)
MTS	Mission Tools Suite
NEON	National Ecological Observatory Network
NOAA	National Oceanographic and Atmospheric Administration
NPS	Naval Postgraduate School
NRL	Naval Research Laboratory
NSF NCAR	National Science Foundation National Center for Atmospheric Research
OCI	Ocean Color Instrument (PACE instrument)
PACE	Plankton, Aerosol, Cloud, ocean Ecosystem
PACE-PAX	PACE Postlaunch Airborne eXperiment
PAR	Photosynthetically Available Radiation [E m-2 d -1]
PICARD	Portable Imaging CAmeRA for Detector characterization
POPS	Printed Optical Particle Spectrometer
PRISM	Portable Remote Imaging SpectroMeter
PVST	PACE Validation Science Team
PVST-SBCR	PACE Validation Science Team - Santa Barbara Channel Rapid Response
RH	Relative Humidity
RadCaTS	Radiometric Calibration Test Site
RRI	Real Refractive Index
Rrs	Remote sensing reflectance [sr^{-1}]
RSP	Research Scanning Polarimeter
SC-6	Scattering sensor
SeaBASS	SeaWiFS Bio-optical Archive and Storage System

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SIO	Scripps Institution of Oceanography
SJER	San Joaquin Experimental Range (NEON site)
SPEXone	Spectropolarimeter for Planetary Exploration - one
SRON	Space Research Organisation Netherlands
SSAI	Science Systems and Applications Inc.
SSA	Single Scattering Albedo
SUA	Special Use Airspace
SZA	Solar Zenith Angle
TAP	Tricolor Absorption Photometer
TEAK	Lower Teakettle Experimental Forest (NEON site)
TSG	ThermoSalinoGraph
TSI	Total Sky Imager
U-DSA	Underway Decision Support Algorithm
UCSB	University of California Santa Barbara
UCSD	University of California San Diego
UMBC	University of Maryland Baltimore County
USC	University of Southern California
UTC	Coordinated Universal Time
UV	Ultraviolet
VTM	Validation Traceability Matrix

Appendix A. Day by day summary

Table A1. PACE-PAX field campaign significant events such as satellite overpasses. More detailed tables, including all instances VTM objective observation, are in Knobelspiesse et al., 2025c, as well as flight reports. Aerosol amount is specified by the mid-visible wavelength Aerosol Optical Depth (AOD), where high > 0.2, medium 0.1-0.2, low < 0.1. Mentions of R/V Shearwater include co-located Slocum glider observations. All times in UTC.

Date	ID	Location	Conditions	Description
28 Aug	**CF0828**	ER-2 check flight, aborted due to instrument issue.		
29 Aug	**CF0829**	ER-2 and Twin Otter check flights, some observations of aerosols over land by both.		
3 Sept.	**RF0903**	Twin Otter only flight in California central valley with PACE overpass.		
PACE overpass 20:27 OCI + HARP2		Sierra Nevada foothills	Low aerosol load, multiple layers	Twin Otter spiral over NEON SJER site during PACE overpass
4 Sept.	**RF0904**	Coordinated Twin Otter and ER-2 flights, including an underpass of PACE along its surface track, over a marine stratocumulus covered ocean, followed by coordination with the Twin Otter offshore. Some overflights of AERONET in California Central Valley with ER-2.		
PACE overpass 20:59 all instruments		Offshore Northern California	Marine stratocumulus cloud	Long ER-2 flight along PACE ground track; some instruments inoperable. Twin Otter performing cloud samples nearer to shore

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<table>
<tr><td>6 Sept.</td><td>RF0906</td><td colspan="4">Coordinated Twin Otter, ER-2, R/V Shearwater, and R/V Blissfully operations with PACE overpass. Twin Otter performed a double sortie to observe over R/V Shearwater and R/V Blissfully. ER-2 overflies all in mostly cloud-free conditions, including operations further north near a fire.</td></tr>
<tr><td colspan="3">PACE overpass 20:30
all instruments</td><td>Ground track over Sierra Nevada mountains plus Los Angeles and offshore segment</td><td>Occasional broken cloud over mountains, high AOD over Los Angeles, medium offshore.</td><td>Long ER-2 line along PACE ground track including offshore over R/V Blissfully. Meanwhile Twin Otter overflies R/V Shearwater and gliders in biologically active Santa Barbara channel. ER-2 later overflies both.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>7 Sept.</td><td>RF0907</td><td colspan="4">Twin Otter flight over ocean to sample forecasted (smoke) aerosols above marine stratocumulus clouds west of the Monterey Bay during the PACE overpass (within OCI and HARP2 but not SPEXone swath)</td></tr>
<tr><td colspan="3">PACE overpass 21:04
OCI + HARP2</td><td>Offshore northern California</td><td>Marine stratocumulus cloud, low AOD above cloud</td><td>Twin Otter performing cloud and aerosol samples</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>8 Sept.</td><td>RF0908</td><td colspan="4">Coordinated Twin Otter, ER-2, R/V Shearwater, and R/V Blissfully operations with EarthCARE overpass</td></tr>
<tr><td colspan="3">EarthCARE overpass 22:39
orbit #1602</td><td>California Central Valley to Monterey Bay</td><td>Low AOD over land, marine stratocumulus clouds offshore</td><td>Twin Otter spirals over CEOBS site while ER-2 follows EarthCARE track, overflying CEOBS during EarthCARE overpass.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>10 Sept.</td><td>RF0910</td><td colspan="4">Short ER2 flight in Southern California focusing on extremely active Line, Airport and Bridge fires, with overpass of R/V Blissfully and HyperNAV offshore. Intense smoke from fires in eastern LA basin and downwind to the east and north, with imagery indicating creation of pyrocumulus.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>12 Sept.</td><td>RF0912</td><td colspan="4">Twin Otter, R/V Shearwater, and R/V Blissfully activities coordinated with PACE overpass, in most cases within the SPEXone swath. The Twin Otter performed spirals over AERONET sites in the California, while research vessels gathered data offshore.</td></tr>
<tr><td colspan="3">PACE overpass 20:39
all instruments</td><td>California Central Valley to western Santa Barbara channel</td><td>Low aerosol AOD over land, possibly with dust. Biologically productive ocean.</td><td>Twin Otter spirals over turbid water AERONET-OC site in Sacramento River delta. R/V Shearwater in OCI and HARP2 swath in moderately productive water.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>13 Sept.</td><td>RF0913</td><td colspan="4">Focus on large Southern California fires (Bridge, Line and Airport). Twin Otter double sortie to the Los Angeles Basin. R/V Shearwater, R/V Blissfully and Gliders all collect data offshore, with clouds clearing as the day progresses. ER-2 samples above all these assets. PACE overpass(19:36; 21:14) are far from the observation region, but data are collected during overpass for PACE/OCI validation. Additionally, Railroad Valley calibration overflight by the ER-2.</td></tr>
<tr><td colspan="3">PACE overpass 19:36
OCI swath edge</td><td>Los Angeles and offshore</td><td>Extremely high AOD due to Los Angeles region fires</td><td>ER-2 overflies R/V Blissfully then onshore to Twin Otter doing aerosol sampling spiral east of Bridge fire. ER-2 is east of LA during overpass.</td></tr>
<tr><td colspan="3">Railroad Valley 20:18</td><td>Railroad Valley, NV</td><td>Low AOD, no clouds</td><td>ER-2 overflies Railroad Valley calibration site.</td></tr>
<tr><td colspan="3">PACE overpass 21:14
OCI swath edge</td><td>Los Angeles and offshore</td><td>Extremely high aerosol AOD due to Los Angeles region fires</td><td>ER-2 overflies Twin Otter doing aerosol sampling spiral east of Airport fire, then offshore over R/V Blissfully. R/V Shearwater samples in cloud-free conditions.</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td>15 Sept.</td><td>RF0915</td><td colspan="4">ER2 samples SoCal smoke on line with marine stratus near coast, on to overpasses of blissfully, shearwater, HyperNAV but unfortunately clouds. Then up north for PACE track over clouds and return to</td></tr>
</table>

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<table>
<tr><td></td><td></td><td colspan="3">HyperNAV location for time of PACE overpass, but possible cloud contamination.</td></tr>
<tr><td colspan="2">20:44 PACE overpass
all instruments</td><td>Offshore central California</td><td>Partly cloudy marine stratocumulus, possibly mid-level clouds</td><td>ER-2 samples along PACE track prior to overpass, then down to Santa Barbara channel near HyperNAV, R/V Shearwater and R/V Blissfully. Possible cloud cover for all surface platforms.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>17 Sept.</td><td>RF0917</td><td colspan="3">Successful ER-2, R/V Shearwater, R/V Blissfully operations during PACE and EarthCARE overpasses. Additionally, the ER-2 overflew Ivanpah Playa while a ground team characterizes surface conditions.</td></tr>
<tr><td colspan="2">PACE overpass 20:14
All instruments (ER-2)
OCI+HARP2 for R/V's</td><td>ER-2 over Mojave desert in all instrument swaths, R/V Shearwater and R/V Blissfully offshore in OCI and HARP2 swath</td><td>Low AOD, cloud free.</td><td>ER-2 follows PACE ground track over Mojave Desert in California, Nevada and Arizona, near Ivanpah Playa. Meanwhile, the R/V Shearwater (Santa Barbara Channel) and R/V Blissfully (San Pedro Channel) sample in cloud-free conditions</td></tr>
<tr><td colspan="2">Ivanpah Playa 20:02, 20:40</td><td>ER-2 over Ivanpah Playa calibration site</td><td>Very low AOD, cloud free</td><td>Two passes over Ivanpah Playa by the ER-2 while a ground team characterizes surface conditions. Aircraft headings are oriented 90˚ from each other.</td></tr>
<tr><td colspan="2">EarthCARE overpass 22:27
orbit #1742</td><td>California Central Valley to central California coast</td><td>Moderate smoke AOD, some thin cirrus with aerosols underneath</td><td>Very long ER-2 out and back along EarthCARE ground track</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>18 Sept.</td><td>RF0918</td><td colspan="3">Ocean only operations with R/V Shearwater, R/V Blissfully and gliders in generally cloud-free conditions during PACE overpass.</td></tr>
<tr><td colspan="2">PACE overpass 20:49
OCI+HARP2</td><td>Santa Barbara Channel (R/V Shearwater), San Pedro Channel (R/V Blissfully)</td><td>Cloud free</td><td>Research vessels sample in cloud-free conditions during PACE overpass, within OCI and HARP2 swath.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>19 Sept.</td><td>RF0919</td><td colspan="3">Twin Otter double sortie to Southern California for observation during EarthCARE overpass and R/V Shearwater observation. Also, PACE overpasses at edge of OCI swath.</td></tr>
<tr><td colspan="2">PACE overpass 19:45
OCI swath edge</td><td>Los Angeles and nearby offshore areas</td><td>Cloud free, low AOD</td><td>Twin Otter spiral down over R/V Shearwater in PACE/OCI swath. R/V Blissfully on station.</td></tr>
<tr><td colspan="2">PACE overpass 21:23
OCI swath edge</td><td>Los Angeles and nearby offshore areas</td><td>Cloud free, low AOD</td><td>Twin Otter spiral down over R/V Shearwater in PACE/OCI swath. R/V Blissfully on station.</td></tr>
<tr><td colspan="2">EarthCARE overpass 22:17
orbit #1773</td><td>Los Angeles and nearby offshore areas</td><td>Partially cloudy for Twin Otter</td><td>Twin Otter spiral in EarthCARE ground track over Los Angeles, spiral interrupted by clouds.</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>20 Sept.</td><td>RF0920</td><td colspan="3">Short Twin Otter flight over ocean with marine stratocumulus clouds during PACE overpass</td></tr>
<tr><td colspan="2">PACE overpass 20:20
OCI+HARP2</td><td>Offshore west of Monterey and San Francisco</td><td>Marine stratocumulus clouds, aerosols above clouds</td><td>Twin otter porpoising through cloud top at time of PACE overpass</td></tr>
<tr><td colspan="5"></td></tr>
<tr><td>22 Sept.</td><td>RF0922</td><td colspan="3">ER-2 makes coordinated measurements with Twin Otter in California Central Valley and later overflies R/V Shearwater near the HyperNAV south of the Santa Barbara Channel during a PACE overpass. ER-2 also overflies Railroad Valley calibration site.</td></tr>
<tr><td colspan="2">Railroad Valley 17:25, 17:45</td><td>Railroad Valley, NV</td><td>Low AOD, no clouds</td><td>ER-2 overflies Railroad Valley calibration site.</td></tr>
</table>

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PACE overpass 19:50 OCI swath edge	South of the Santa Barbara Channel	Cloudy	Attempt at ER-2, R/V Shearwater, HyperNAV coordination stymied by clouds
23 Sept. **RF0923**	Coordinated observations with ER-2 and Twin Otter with clouds and aerosols over land, then PACE and EarthCARE underpasses over land.		
20:25 PACE overpass all instruments	Mojave Desert California and Nevada	Mostly cloud free, some cirrus	ER-2 along PACE ground track
EarthCARE overpass 21:53 orbit #1853	Utah and Arizona, including Grand Canyon	Mix of cloud free, cirrus and mid-level clouds. Low AOD.	ER-2 along EarthCARE ground track
24 Sept. **RF0924**	Twin Otter observations of clouds during PACE overpass. Attempted EarthCARE observations but conditions precluded successful sampling.		
20:59 PACE overpass OCI+HARP2	Offshore Northern California	Marine stratocumulus clouds	Twin Otter spiral down above and into cloud during PACE overpass.
25 Sept. **RF0925**	R/V Shearwater observations during PACE overpass.		
PACE overpass 19:55 OCI swath edge	Santa Barbara Channel	Clear skies, biologically active water	R/V Shearwater on station during PACE overpass
PACE overpass 21:33 OCI swath edge	Santa Barbara Channel	Clear skies, biologically active water	R/V Shearwater on station during PACE overpass
26 Sept. **RF0926**	Last full coordination between ER-2, Twin Otter, Shearwater with PACE and EarthCARE overpasses. Generally cloud free with low aerosol optical depths. Twin Otter spirals above Shearwater and a phytoplankton bloom during PACE overpass.		
PACE overpass 20:31 All instruments (ER-2) OCI+HARP2 for Twin Otter and R/V Shearwater	Inland California, Sierra Nevada Mountains to Nevada near Reno	Cloud free, low AOD	ER-2 along PACE ground track, meanwhile Twin Otter spirals over R/V Shearwater
EarthCARE overpass 22:22 orbit #1882	Nevada near Reno, Sierra Nevada Mountains to Central Valley	Cloud free, low AOD	ER-2 along EarthCARE ground track
27 Sept. **RF0927**	Last coordination between ER-2 and Twin Otter. ER-2 on PACE track. Both ER-2 and Twin Otter coordinate over R/V Rachel Carson in the Monterey Bay. Twin Otter spiral over CEOBS.		
PACE overpass 21:04 All instruments (ER-2) OCI+HARP2 for Twin Otter and R/V Rachel Carson	Offshore Northern California, Monterey Bay	ER-2: partly to fully cloudy with low clouds. Montery Bay is clear with multiple aerosol layers	ER-2 offshore in PACE track. Twin Otter spirals over R/V Rachel Carson in Monterey Bay
29 Sept. **RF0929**	ER-2 flight with a long PACE track overflight along the Sierra Nevada Mountains and California Central Valley. Generally cloud free, low aerosol loading over land and marine stratocumulus clouds over ocean. Good coordination with glider		
PACE overpass 20:35 All instruments	Oregon / California border along Sierra Nevada Mountains to Southern California and offshore	Cloud free, low to moderate AOD	Very long ER-2 line transversing California along PACE ground track, overflying several AERONET sites.

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30 Sept.	**RF0930**	Successful ER-2 flight with under flights by of PACE (offshore) and EarthCARE (California/Arizona border). Generally cloud free. Observations of smoke from "Happy" fire and Railroad Valley calibration reference	
PACE overpass 21:09 All instruments	Offshore Central California	Cloud free, moderate AOD, high surface windspeed, gradient of ocean Chl-a concentration	Long offshore cloud free ER-2 line along PACE track
EarthCARE overpass 22:02 orbit #1944	Starting in Southern California near Salton Sea, north to Las Vegas	Cloud free, moderate AOD, dusty aerosol mix	ER-2 along EarthCARE ground track
Railroad Valley 22:59	Railroad Valley, NV	Low AOD, no clouds	ER-2 overflies Railroad Valley calibration site.

Code and data availability

PACE-PAX data are publicly available for use by all. There are two primary repositories. Data collected on aircraft and associated surface-based comparison data (such as the Marina Tower site and Ivanpah Playa characterization) are stored in the Airborne Science Data Center (ASDC) as part of the NASA Earth Science Data Systems (ESDS) Program. Ocean data collected on the R/V Shearwater, R/V Blissfully and other assets are archived at the SeaWiFS Bio-optical Archive and Storage System (SeaBASS). Externally funded observation networks, such as AERONET and NEON host their own archives. URLs and DOI's for all these networks are listed in Table . Additionally, a campaign website (https://pace.oceansciences.org/pace-pax.htm) is hosted as part of the overall PACE mission website. This contains links to datasets, flight reports and other documentation, and Google Earth Keyhole Markup Language (KML) files with flight tracks, satellite data and other information to aid data exploration. The Knobelspiesse et al., 2025c NASA Technical Memorandum contains complete documentation on PACE-PAX, including tabulated observation characteristics, flight reports, and more details on measurement platforms. The PACE-PAX design and implementation approach is documented in Knobelspiesse et al., 2026, with code available as noted in Table 9.

Table 9 PACE-PAX reference information and datasets

Dataset	DOI	URL
PACE-PAX airborne data at ESDS ASDC	10.5067/SUBORBITAL/PACE-PAX/DATA001	https://asdc.larc.nasa.gov/project/PACE-PAX
a, K., Cairns, B., Cetinic, I., Ahern, A., Bennett, J. R., Bucholtz, A., Hair, J., Jordan, C., Martins, V., Meyer, K., Schlosser, J., Thompson, D., van Diedenhoven, B., & Ziemba, L. (2025). Plankton, Aerosol, Cloud, ocean Ecosystem - Postlaunch Airborne eXperiment Campaign Data [Dataset]. NASA Langley Atmospheric Science Data Center Distributed Active Archive Center. https://doi.org/10.5067/SUBORBITAL/PACE-PAX/DATA001		
PACE-PAX ocean data at SeaBASS	10.5067/SeaBASS/PACE-PAX/DATA001	https://seabass.gsfc.nasa.gov/experiment/PACE-PAX
Knobelspiesse, K., Cairns, B., Cetinic, I., Aurin, D., El-Habashi, A., Foster, R., Gilerson, A., Goes, J., Mannino, A., Maritorena, S., Ondrusek, M. Seegers, B. (2025b). Plankton, Aerosol, Cloud, ocean Ecosystem - Postlaunch Airborne eXperiment Campaign Data		

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[Dataset]. NASA SeaWiFS Bio-optical Archive and Storage System (SeaBASS). https://doi.org/10.5067/SeaBASS/PACE-PAX/DATA001	
Websites and external data sources	
PACE-PAX (primary) website	https://pace.oceansciences.org/pace-pax.htm
PACE-PAX logistics website at the NASA Earth Science Project Office (ESPO)	https://espo.nasa.gov/pace-pax
AERONET	https://aeronet.gsfc.nasa.gov; https://aeronet.gsfc.nasa.gov/new_web/PACE-PAX.html
U. Delaware gliders	https://gliders.ioos.us/erddap/tabledap/ud_orris-20240907T1638.html
HyperNAV floats	https://misclab.umeoce.maine.edu/HyperNAV
Railroad Valley Radiometric Calibration Site	https://calval.cr.usgs.gov/apps/railroad-valley
NEON sites	https://www.neonscience.org/data
NASA Ames Meteorological Support	https://bocachica.arc.nasa.gov/PACE-PAX/
Publications	
Knobelspiesse, K., Cairns, B., Cetinic, I., and LeBlanc, S.: The PACE Postlaunch Airborne eXperiment (PACE-PAX): post campaign report, National Aeronautics and Space Administration, 2025c.	https://ntrs.nasa.gov/citations/20250011273
Knobelspiesse, K. D., Cairns, B., Cetinić, I., Craig, S., Franz, B. A., Gao, M., Ibrahim, A., Mannino, A., Sayer, A. M., and Werdell, P. J.: The PACE Postlaunch Airborne eXperiment (PACE-PAX), National Aeronautics and Space Administration, [pre campaign plan], 2023.	https://ntrs.nasa.gov/citations/20230008223
Knobelspiesse, K. D., Alfter, J., Cairns, B., Cetinić, I., LeBlanc, S., Nicholas, S., and Ueyama, R.: Field campaign design and implementation with traceability matrix decision support, Journal of Atmospheric and Oceanic Technology, e250079, https://doi.org/10.1175/JTECH-D-25-0079.1, 2026.	https://github.com/knobelsp/TM-DSA

Please note that PACE-PAX data, gathered by Government of the United States of America, is public domain and bears a Creative Commons Zero (CC0) license.

Video supplement

The NASA Goddard Space Flight Center produced a feature video about the PACE-PAX field campaign: https://youtu.be/cCsuck3dJU4?feature=shared or https://svs.gsfc.nasa.gov/14723

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KDK, BC and IC conceptualized the campaign, provided supervision, and carried out the investigation. SN and JA provided project administration. PACE-PAX team member P. Jeremy Werdell provided supervision and funding acquisition. KDK wrote the original manuscript draft, which was reviewed and edited by IC followed by the full author list (including the PACE-PAX team). Visualization for figures in Sect. 4 was created by IC, BC and PACE-PAX team members Adam Ahern, James

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Competing interests

Authors declare that they have no conflict of interest.

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The review statement will be added by Copernicus Publications listing the handling editor as well as all contributing referees according to their status anonymous or identified.

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