Use of a UAS for Investigations of Aerosol, Cloud, and Radiation Interactions

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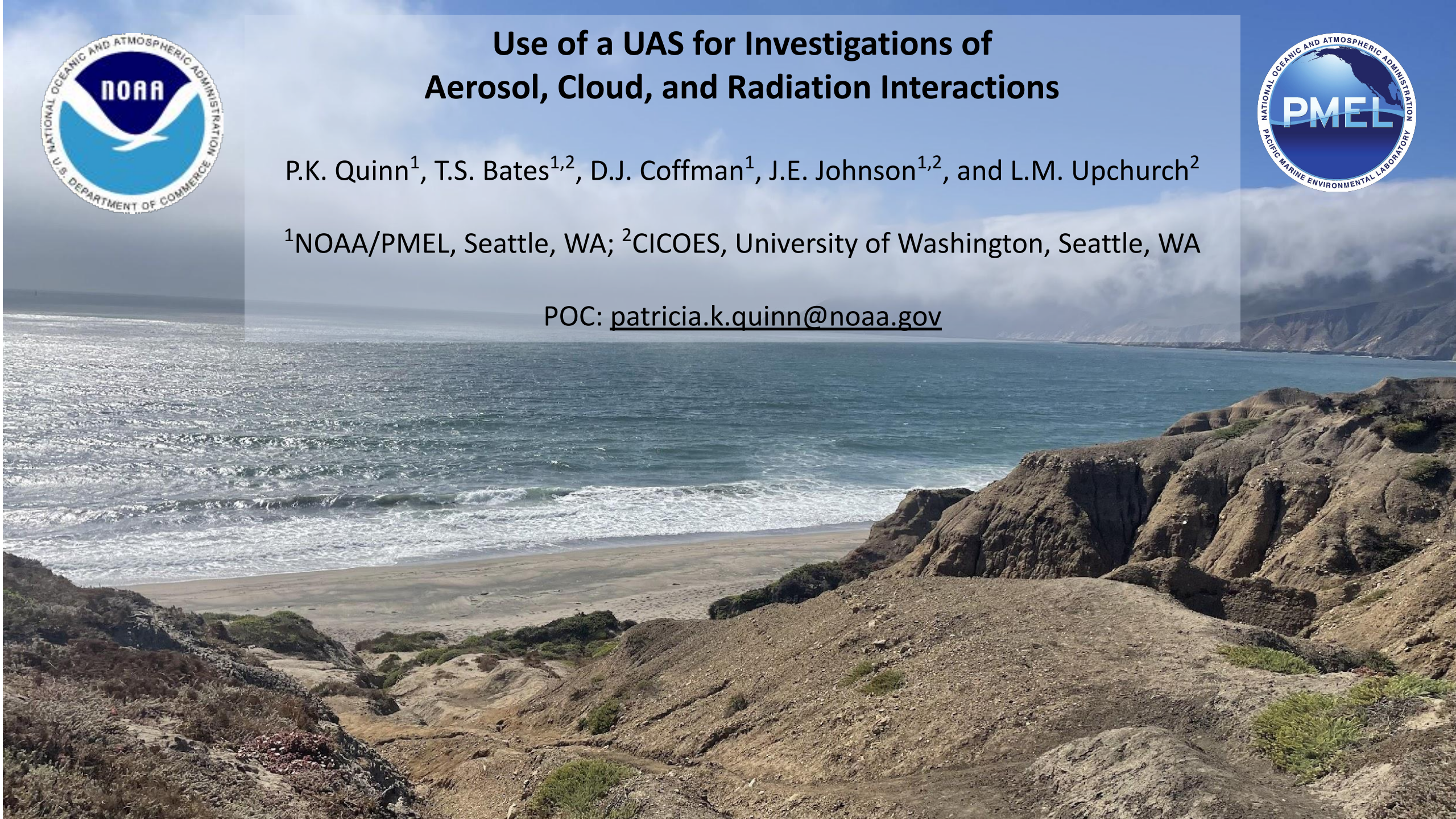
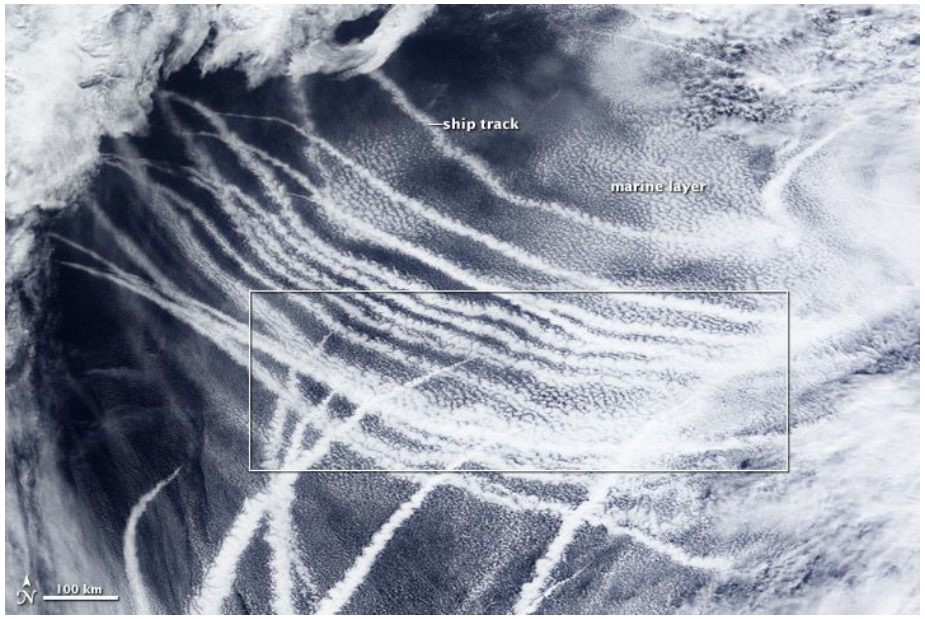


Impetus

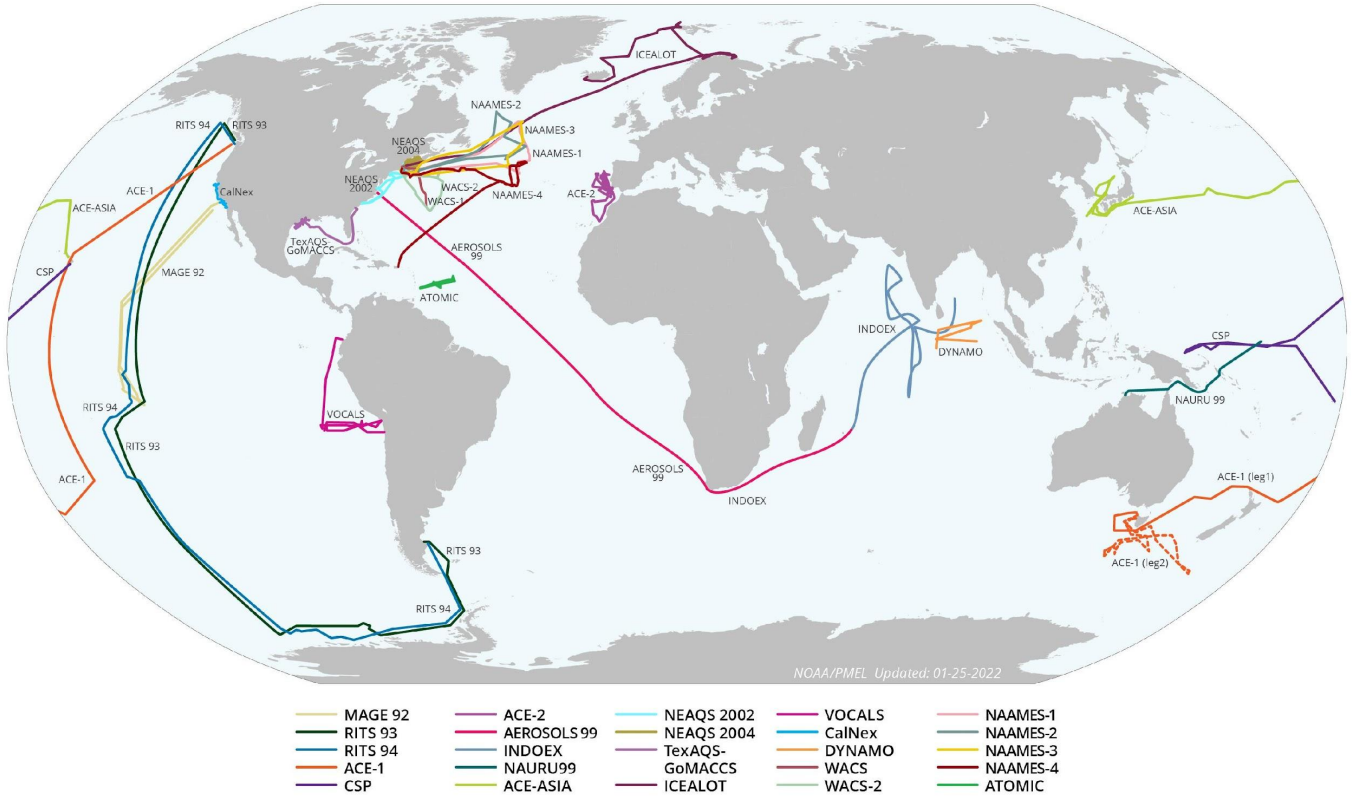
- Atmospheric aerosol particles have large local impacts on climate yet, according to the IPCC, contribute the largest uncertainty to radiative climate forcing estimates.



Satellite image of ship tracks in marine stratus clouds off the U.S. West Coast (NASA GSFC)

- The response of clouds to changes in aerosol properties is particularly sensitive in marine regions due to low particle number concentrations.
- Vertical profiles of aerosol and cloud properties in marine regions are required to improve climate models and decrease uncertainties in forcing estimates through validation and verification.
- Shipboard launch and recovery of aerosol and cloud payloads will expand NOAA's shipboard surface measurements to include vertical profiles and aid in increased accuracy of climate models.

NOAA PMEL Atmospheric Chemistry Group
Global Dataset of Shipboard Measurements of Aerosol Properties (1992 – 2020)



- Largest existing dataset of marine aerosol chemical, microphysical, optical, and cloud-nucleating properties.
- Several cruises have been conducted in conjunction with crewed aircraft measuring aerosol vertical profiles (ACE-1, ACE-2, ACE-Asia, NEAQS, TexAQS, VOCALS, CalNex, NAAMES, ATOMIC).
- Routine UAS shipboard flights would allow for more frequent and less expensive measurements of upper atmosphere aerosol properties.

2016 NOAA SBIR UAS Requirements:

- Altitude ceiling of 10,000 ft
- Endurance of 3 hrs (~150 miles) or more
- Able to carry a 12 lb payload
- Launch and recovery from a confined space (ship deck)
- Pusher engine to avoid contamination for air sampling
- Modular nose cone payload configuration for easy swapping of payloads between flights
- Total weight of UAS, fuel, and payload not to exceed 55 lb for FAA part 107 compliance
- L3Harris (then Latitude Engineering) awarded Phase I (2016) and Phase II (2018) SBIRs for the development of the FVR-55, a hybrid vertical-take-off-and-landing – fixed wing UAS.

PMEL Payloads

Swapping of payloads in between shipboard flights

- 30 to 45 minutes for swap and refueling

PMEL has developed two payloads for assessing aerosol radiative effects:

- **Clear Sky Payload** for looking at direct radiative effects, i.e., aerosol scattering and absorption of incoming solar radiation
- **Cloudy Sky Payload** for looking at impacts of aerosol particles on cloud properties
- These payloads will be discussed in more detail later in talk

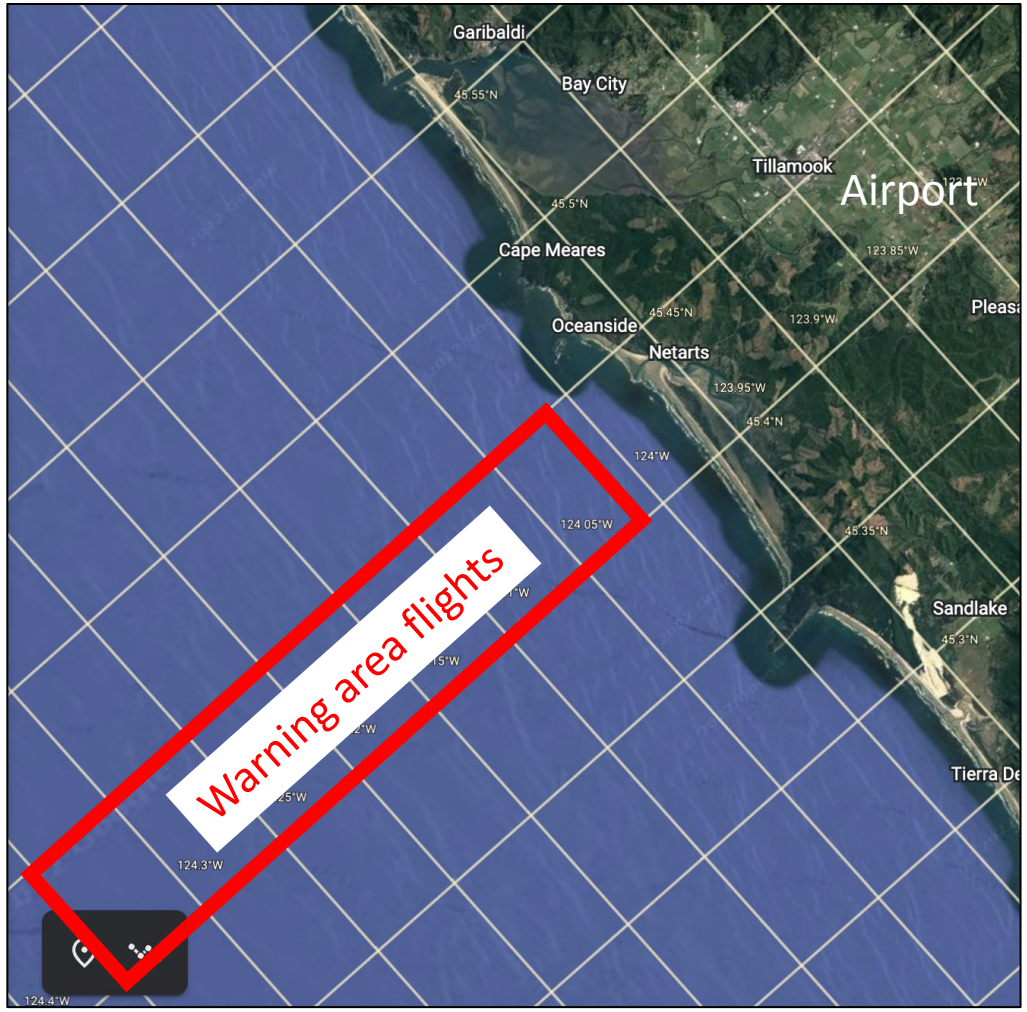
Timeline of Flights
Proof of concept

- **First shipboard flights with payloads onboard the FVR-55** took place offshore of Key West in March 2022
- Marine-grade VTOL motors to overcome turbulence from the ship's superstructure
- dGPS for accuracy of landing on the ship deck without interference from the ship's magnetometer
- Demonstrated ability to autonomously land on the ship deck with an accuracy of 0.2 to 2.8'
- 8 total flights, 4 Clear Sky and 4 Cloudy Sky

L3Harris FVR-55 with
Clear Sky Payload onboard

TowBoatU.S. Richard L. Becker
with landing platform

Timeline of Flights
First science flights with the FVR-55
Tillamook Oregon UAS Test Range (August 2022)



- **First high altitude, over ocean science flights in clear sky and in marine stratocumulus clouds with payloads onboard the FVR-55** took place from the Tillamook UAS Test Range (Tillamook, Oregon) in August 2022

- COA allowed for flights up to 10,000’ over the airport and in offshore warning areas

- Chase plane required for access to warning areas

- A total of 14 flights (38.5 hrs) were completed, 9 with the Cloudy Sky and 5 with the Clear Sky Payoad. Flight times ranged from 2 to 4.5 hrs with altitudes up to 10,000’ and distances up to 20 NM from the coast.

Atmos. Meas. Tech., 17, 3157–3170, 2024

Transition from the FVR-55 to the larger FVR-90

- Reducing the weight of the L3Harris FVR-55 + fuel + payloads below 55 lbs for FAA Part 107 compliance was deemed to be unlikely in the near term

- Switching to the FVR-90 would allow for:

  - increased payload weight (from 13 to 22 lbs) meaning more instrumentation

  - longer endurance (up to 6 hours depending on fuel burn)

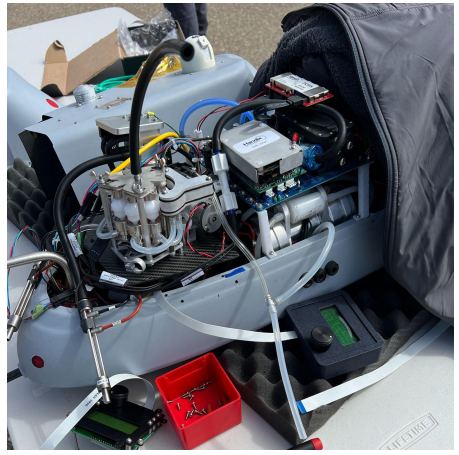
L3Harris FVR-55

Overwatch Aero FVR-90

Transition from the FVR-55 to the larger FVR-90

With the additional payload weight:

- Particle sizing instrumentation was added to both payloads to extend the particle diameter range from 0.14 to 3 µm which allows for the assessment of aerosol impacts on light scattering and cloud properties
- Downward and upward looking broadband radiometers were added to allow for a direct connection between measured aerosol, cloud, and radiative properties.
- GPS was added to both payloads to reduce reliance on UAS telemetry data.



Clear Sky payload

Cloudy Sky payload

Cloudy Sky Payload Instruments
Parameters and sensors in red indicate those added when the payload was integrated into the FRV-90 nose cone

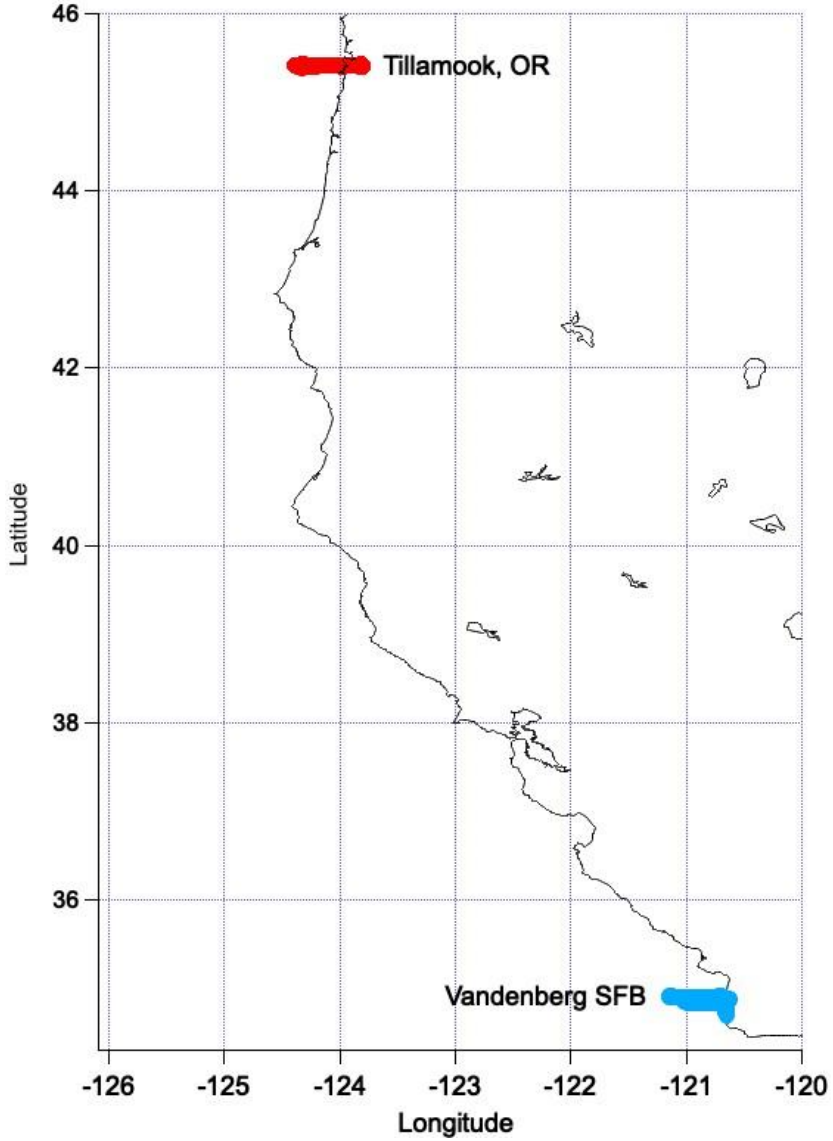
Measured Parameter	Sensor
Particle Number Size Distribution, 0.01 to 0.37 um	Brechtel Miniature Scanning Electrical Mobility Sizer (mSEMS)
Particle Number Size Distribution, 0.14 to 3 um	Handix Portable Optical Particle Spectrometer (POPS)
Total Particle Number Concentration, > 0.005 um	Handix MAGIC 250 CPC
Cloud droplet number size distribution	DMT Cloud Droplet Probe (CDP-2)
Solar Radiation (Upward and Downward)	SP Lite2 Pyranometer
Atmospheric Temperature	Rotronic HC2-S3 InterMet HYT271 InterMet NTC Thermistor
Atmospheric Relative Humidity	Rotronic HC2-S3 InterMet HYT271
GPS	InterMet

Clear Sky Payload Instruments

Parameters and sensors in red indicate those added when the payload was integrated into the FRV-90 nose cone

Measured Parameter	Sensor
Particle Number Size Distribution, 0.01 to 0.37 um	Brechtel Miniature Scanning Electrical Mobility Sizer (mSEMS)
Particle Number Size Distribution, 0.14 to 3 um	Handix Portable Optical Particle Spectrometer (POPS)
Total Particle Number Concentration, > 0.005 um	Handix MAGIC 250 CPC
Aerosol Light Absorption Coefficient, 450, 525, 624 nm	Brechtel Miniature Particle Soot Absorption Photometer (STAP)
Solar Radiation (Upward and Downward)	SP Lite2 Pyranometer
Sun and sky radiance, 460.3, 550.4. 671.2, and 860.7 nm	Mini Scanning Aerosol Sun Photometer (mini-SASP)
Chemical composition, inorganic ions	Brechtel Multi-Channel Chemical Sampler
Atmospheric Temperature	Rotronic HC2-S3 InterMet HYT271 InterMet NTC Thermistor
Atmospheric Relative Humidity	Rotronic HC2-S3 InterMet HYT271
GPS	InterMet

Timeline of Flights
First science flights with the FVR-90 and upgraded payloads
Vandenberg Space Force Base (July - August 2023)



UxS Operations Center
Office of Marine and Aviation Operations

Mission planning and command

PMEL

CICOES

Science

OVERWATCH AERO, LLC

FVR-90 pilots and engineers

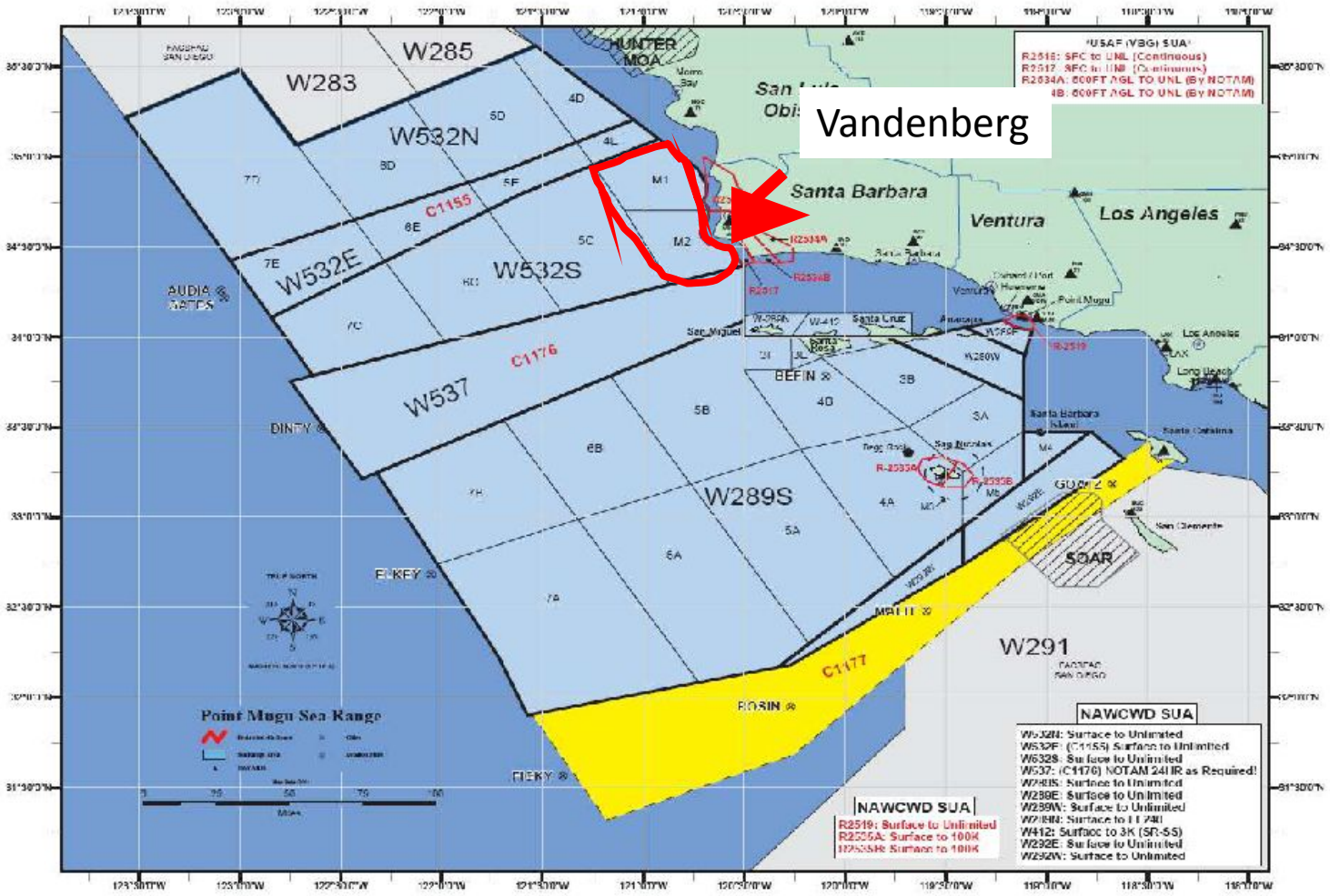
30th SPACE WING

30

Airspace control

Vandenberg Space Force Base

SEA RANGE AREAS



- BVLOS Operations over water
- Operations only in daylight hours
- Maximum altitude of 16,000’

FVR90 Launch with Cloudy Sky Payload -- July 31, 2023 Vandenberg Space Force Base

Lessons learned – Vandenberg 2023

- Fifteen flights were flown, 8 with Cloudy Sky and 7 with Clear Sky for a total of 46 hrs.
- Altitudes up to 10,000’ were reached with flight durations up to 6 hrs.
- Higher liquid water content clouds offshore from Vandenberg compared to Tillamook affected the UAS pitot tube (UAS stalled)
- Sampling plan was adjusted to limit time in cloud and to allow time for pitot tube to dry out (1 min in cloud, 10 min above cloud)
- These mitigation measures prevented further incidents but did not allow for sustained flights in cloud

Cloud liquid water content

Next steps

- Work with Overwatch Aero to integrate a drained and heated pitot tube along with the Cloudy Sky payload into the FVR-90
- Flights at Vandenberg to test the drained and heated pitot tube for deeper penetration into clouds (Spring 2026) (Funding dependent)
- First NOAA shipboard flights of the FVR-90 with PMEL's payloads during TEPEX-E (Fall 2026) (Funding dependent)

Acknowledgments

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