An Overview of current and potential uses of UASs for Aerosol Research

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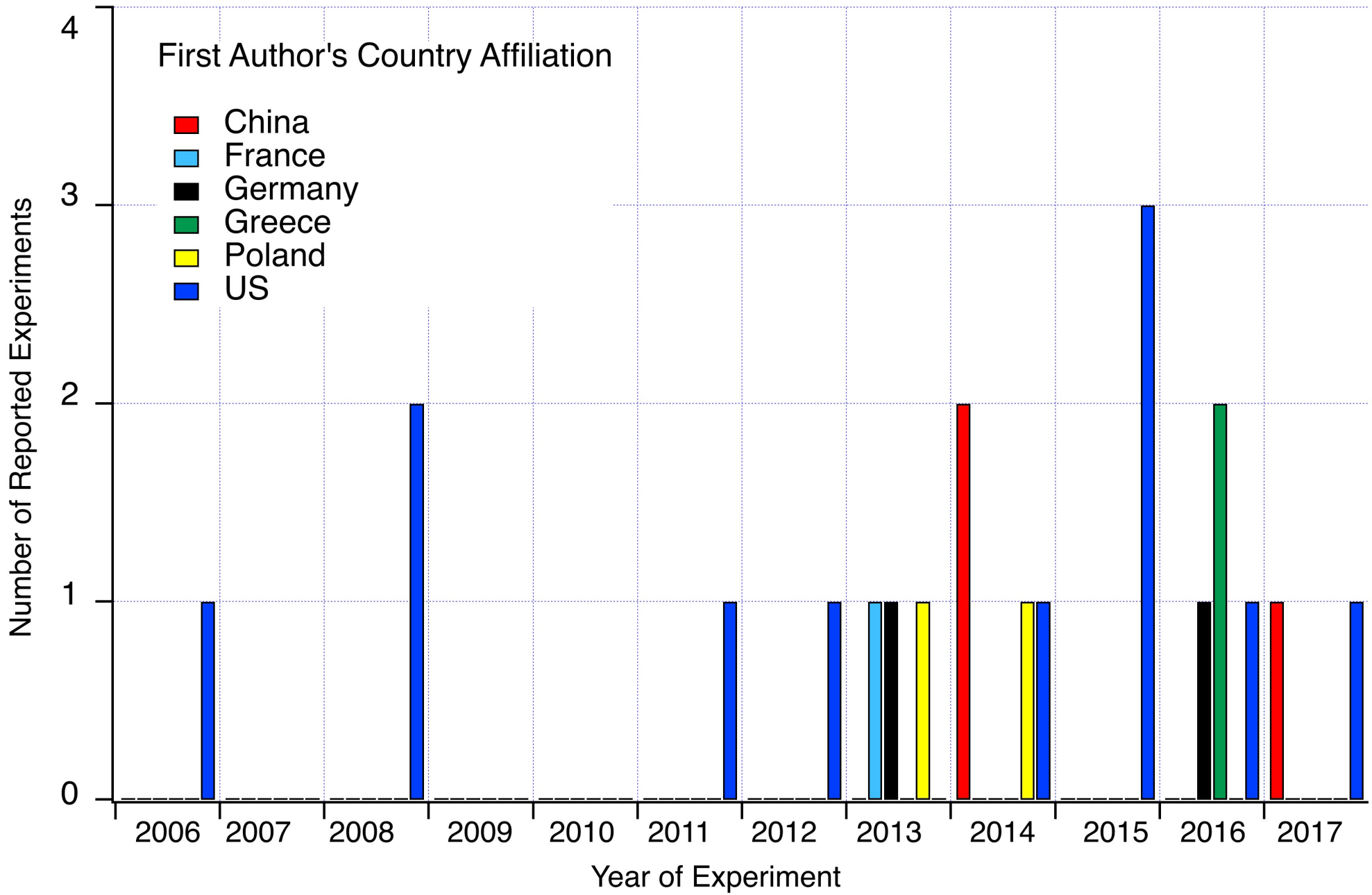
Published UAS studies for aerosol research



Locations of reported UAS experiments using aerosol sensors
(Color indicates first author country affiliation)

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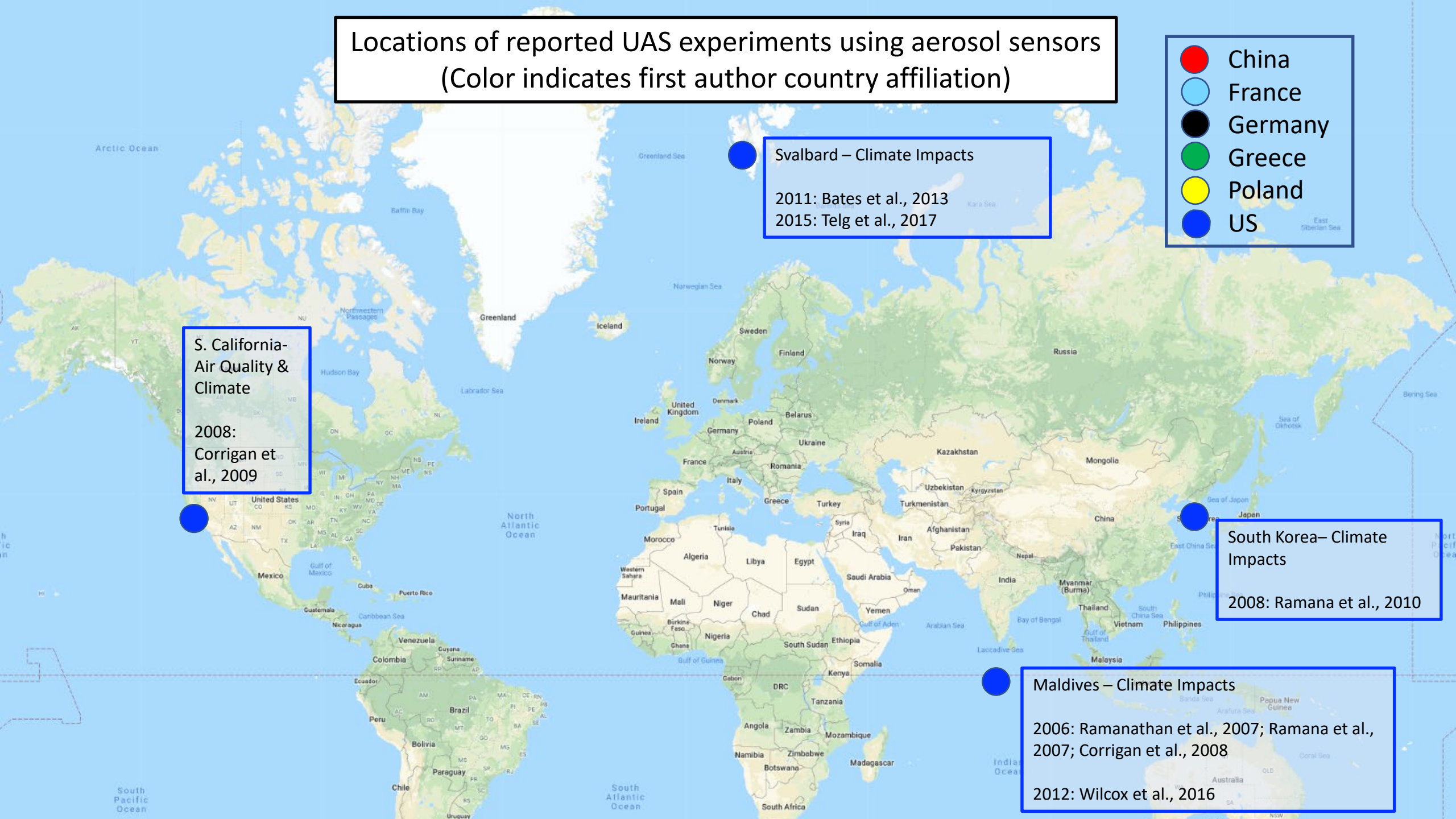

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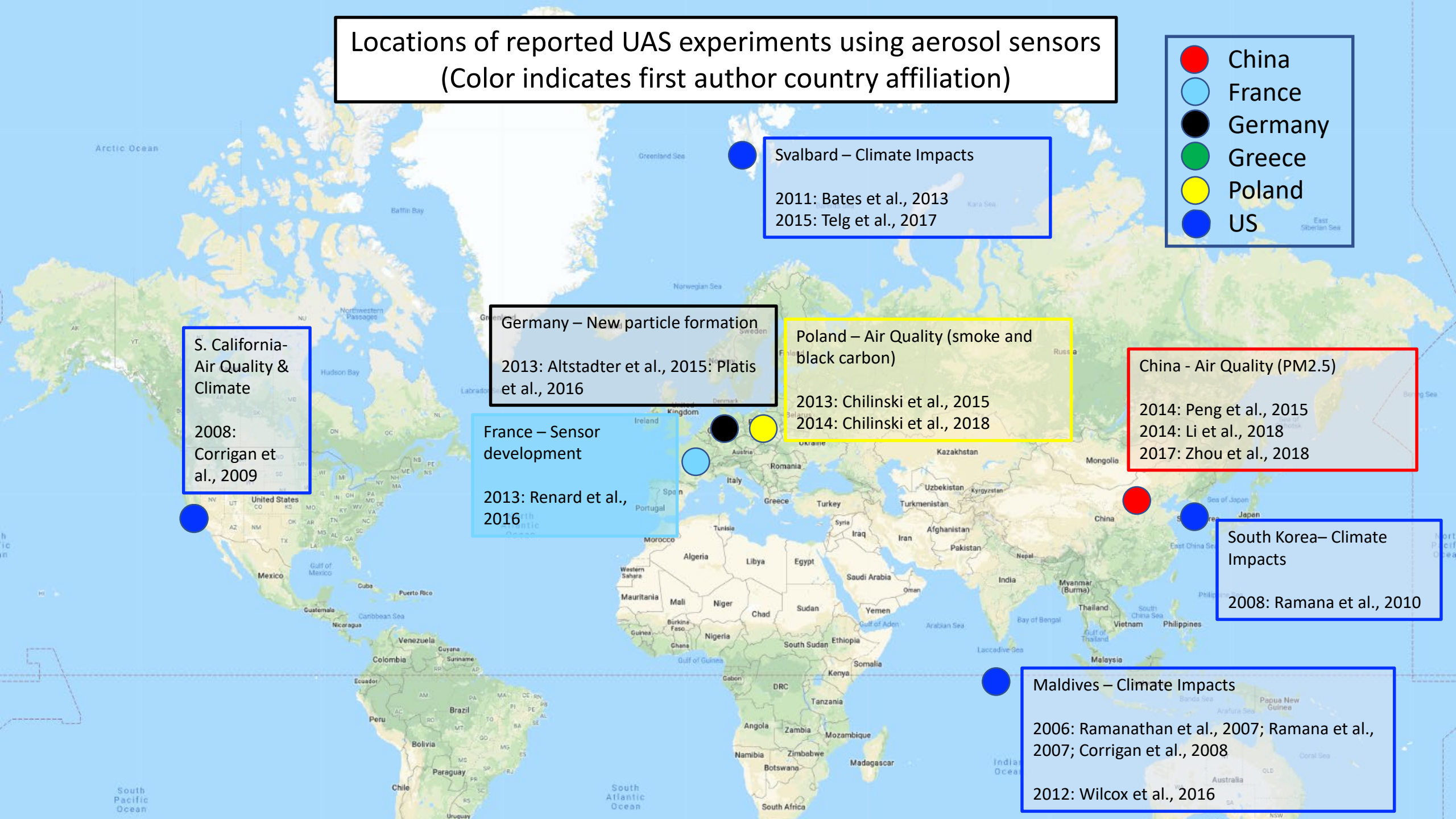

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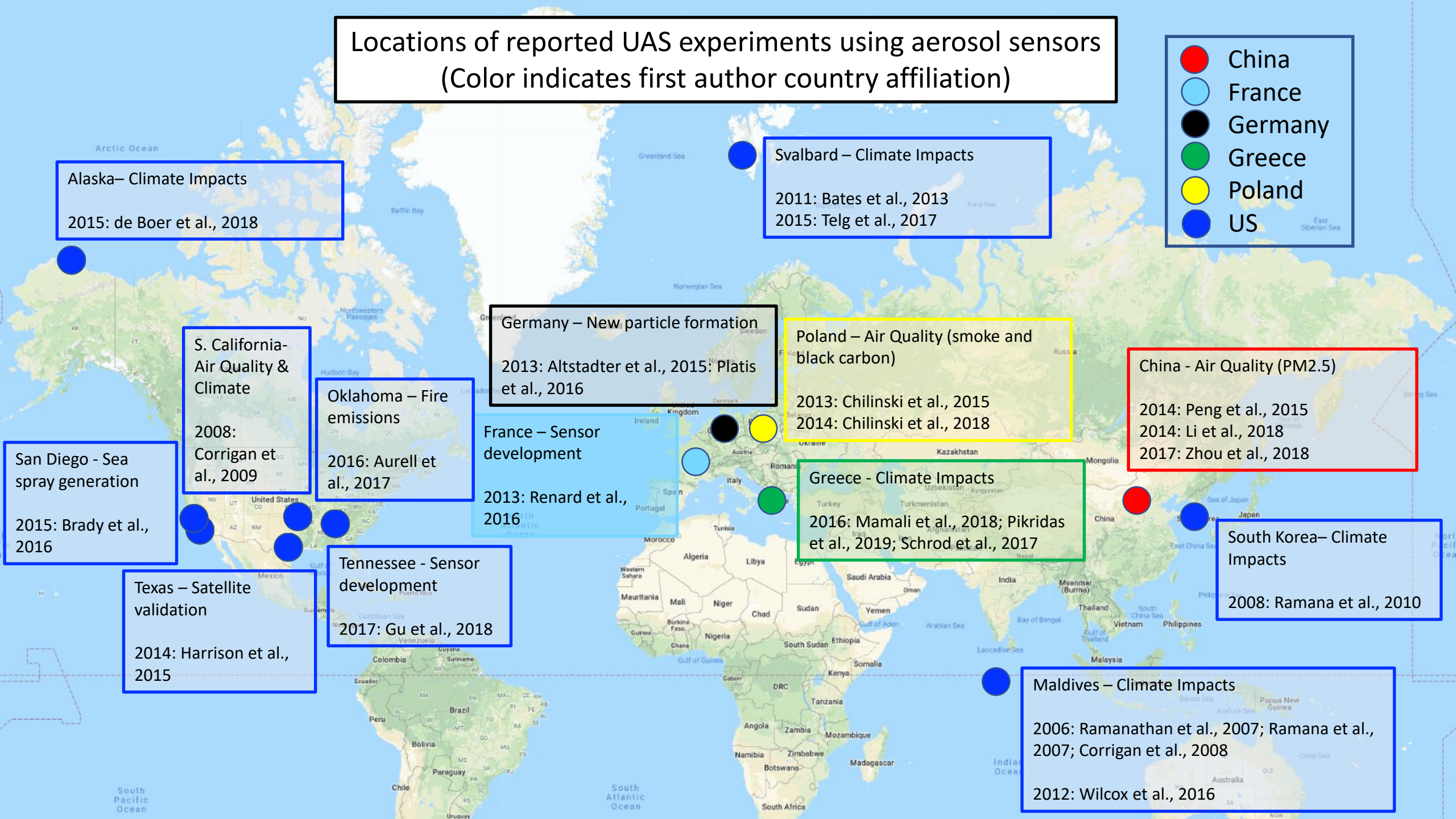


Published Results from UAS Aerosol Research
Most results came out of first deployments /sensor validation studies

Application	Measurement	Published Result
Aerosol radiative forcing	Black carbon	- Layers aloft due to long range transport or atmospheric dynamics are not detected at the surface - Warming trends in Asia amplified by brown cloud solar absorption - Warming over Asia influenced by the source of black carbon - Absorption of sunlight by black carbon suppresses atmospheric turbulence
Particle formation	Ultra-fine particles	Particle formation during boundary layer development in the morning
Air pollution monitoring	Light scattering at two angles PM2.5	A mix of carbonaceous and dust particles occurs in rural-urban transition zones Dispersion mechanisms of local pollutants between the boundary layer and aloft Amounts and concentrations of boundary layer pollutants vary seasonally with long-range transport pathways
Sea spray emissions	Number size distribution	Constraint of sea spray aerosol emission rates from coastal wave breaking
Ice nucleating particles	INPs	Ice nucleating particles occur over the Mediterranean due to dust transport from the Sahara
Fire emissions	Filter sample and laboratory analysis Number concentration and black carbon	Emission factors from open burning of military ordnance California wildfires lead to a warming of the atmosphere due to absorption by black carbon, a cooling at the surface, and a corresponding reduction in convection.

Sensors for Total Particle Number Concentration

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
Miniaturized CPC (handheld TSI 2007)	1.3 s response time D_p > 6 nm and D_p > 18 nm	0.87	2.3	- Modified commercial product - Lower threshold diameters adjustable with temperature - Butanol based	$3,000	Corrigan et al., 2008; Altstadter et al., 2015
Brechtel advanced mixing CPC (aMCPC)	180 ms response time Accuracy +/- 8% D_p > 7 nm	2.7	50	- Modified commercial product - Butanol based	$23,000	Bates et al., 2013

Sensors for Particle Number Size Distribution

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
Miniaturized optical particle counter (OPC) (MetOne 9722, MetOne 80080, MetOne 212-2, MetOne GT-526, Alphasense N2)	0.3 to 3 um with 2 to 8 size channels	0.58	5.4	- Modified commercial product - Limited size resolution - Misses accumulation mode (CCN)	$450 - 3000 off the shelf	Corrigan et al., 2008; Brady et al., 2016; Altstadter et al., 2015; Mamali et al., 2018; Bezantakos et al., 2018
Brechtel mini OPC	0.195 to 3 um	0.5	20	- Misses part of the accumulation mode (CCN)	$20,000	Brechtel.com
Light Optical Aerosol Counter (LOAC)	0.2 to 100 um	0.3		- 2 scattering angles allows for determination of size and type of particle - Misses the accumulation mode (CCN)	Not commercially available	Renard et al., 2016
Printed Optical Particle Spectrometer	0.13 to 3 um	0.6	5	- Misses part of the accumulation mode (CCN)	$10,000	Gao et al., 2016
Brechtel miniSEMS (Scanning Electrical Mobility Sizer)	Sec to min response time 0.005 to 0.3 um	2.2	60 with aMCPC	- Captures accumulation mode - Requires the aMCPC for counting particles	$45,000	Brechtel.com
Polyurethane Differential Mobility Analyzer (PU DMA)		0.15		- Polymer coated with a conductive film - Material costs ~ $100 - Lab tested but not yet flown	Not commercially available	Barmpounis et al., 2015
High-Pass Electrical Mobility Filter (HP-EMF)	Sub-10 nm			- “Inexpensive” - “Lightweight”	Not commercially available	Surawski et al., 2017

Sensors for Aerosol Light Absorption Coefficient

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
Miniaturized Aethalometer (AethLabs AE-31, AE-33, AE-51)	+/- 0.2 ug BC m^{-3}	0.28	Internal battery	- Modified commercial product - Single wavelength only provides information about BC		Corrigan et al., 2008; Chillinski et al., 2018
microAeth AE51	1 - 300 sec time response +/- 0.1 ug BC m^{-3}	0.28	Internal battery	- Single wavelength only provides information about BC	$6,500	Aethlabs.com
Brechtel Single Channel Tricolor Absorption Photometer (STAP)	+/- 0.2 Mm^{-1} (0.02 ug BC m^{-3})	0.66	10	- Three wavelengths provides information about BC and dust	$14,000	Bates et al., 2013

Filter Collection for Aerosol Chemical Composition

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
SKC PM sampler	D_p < 2.5 or 10 um		Internal battery	- Modified commercial product - One 37 mm filter - Laboratory chemical analysis	$750	Aurell et al., 2017
Brechtel Filter Sampler		0.7 kg	10	- Eight 13 mm diameter filters - Laboratory chemical analysis - Sampling controlled by remote user command	$13,500	Bates et al., 2013

Sensor for Aerosol Optical Depth

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
Miniature Scanning Aerosol Sun Photometer (mini SASP)	- Detection limit better than 0.01	0.4	5	- Designed to keep mass, power consumption, and cost low	Not commercially available	Murphy et al., 2016

Sensor for Cloud Droplet and Ice Nuclei Number Concentration

Sensor	Performance	Weight (kg)	Power (W)	Comments	Cost	Reference
Cloud Droplet Probe (DMT)	- 2 to 50 um size range	0.84	22 to 39		$58,000	
Electrostatic Precipitator with laboratory analysis		0.6		- 7 substrates		Schrod et al., 2017

Range of UASs used for aerosol research

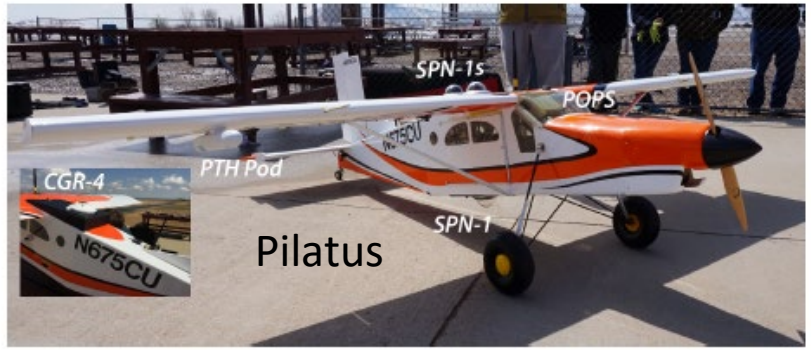
Copters
~ 8 to 30 min
Up o 6 kg payloads

3D Robotics Iris quadcopter

Versa X6sci hexacopter

Electric engine
~ 15 to 60 min
Up to 6 kg payloads

Skywalker X8



Pilatus

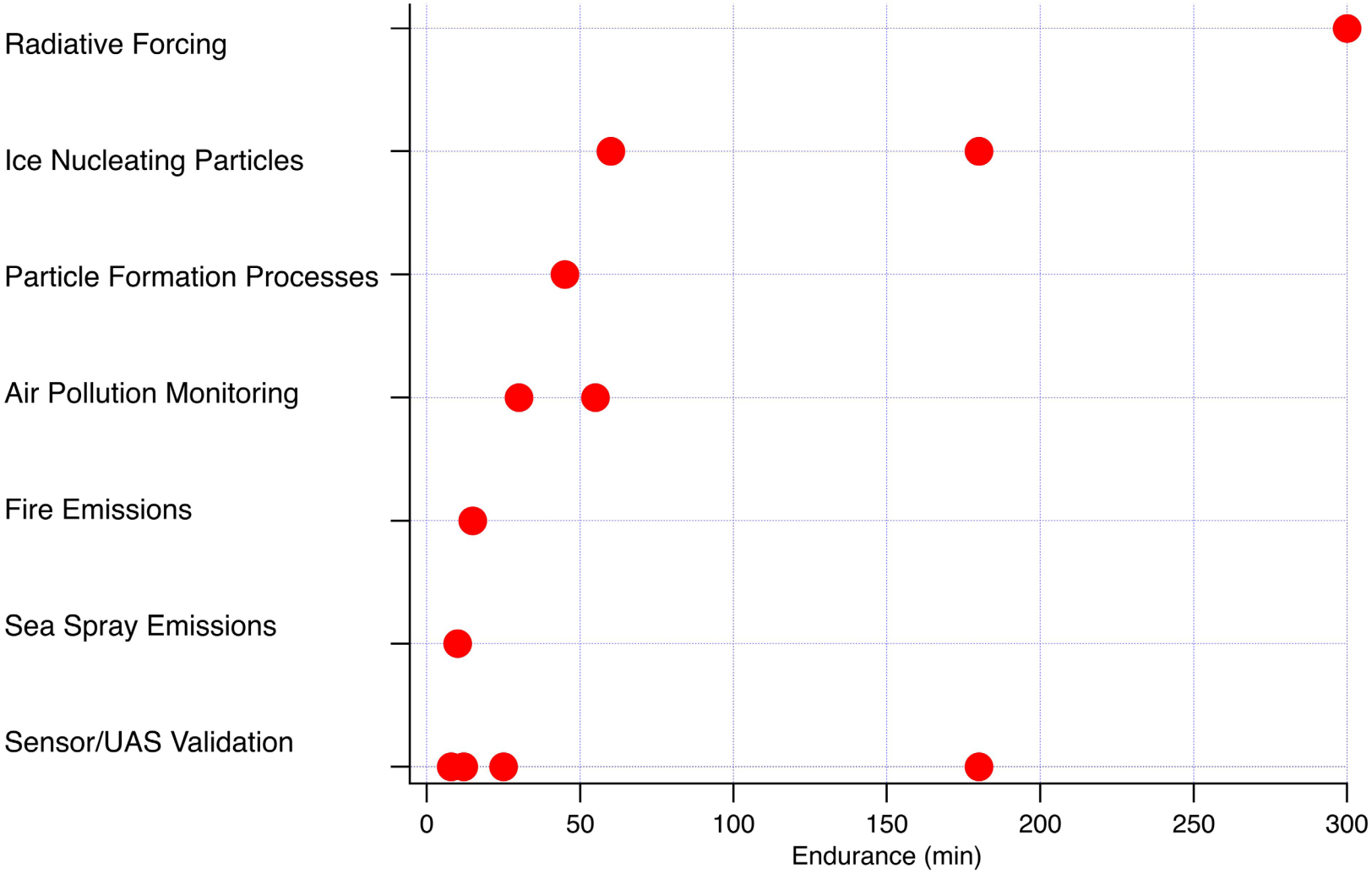
Carolo P360

Gas engine
~ 3 to 6 hr
Up to 12 kg payloads

Manta

Cruiser

Aircraft endurance (minutes) sorted by application



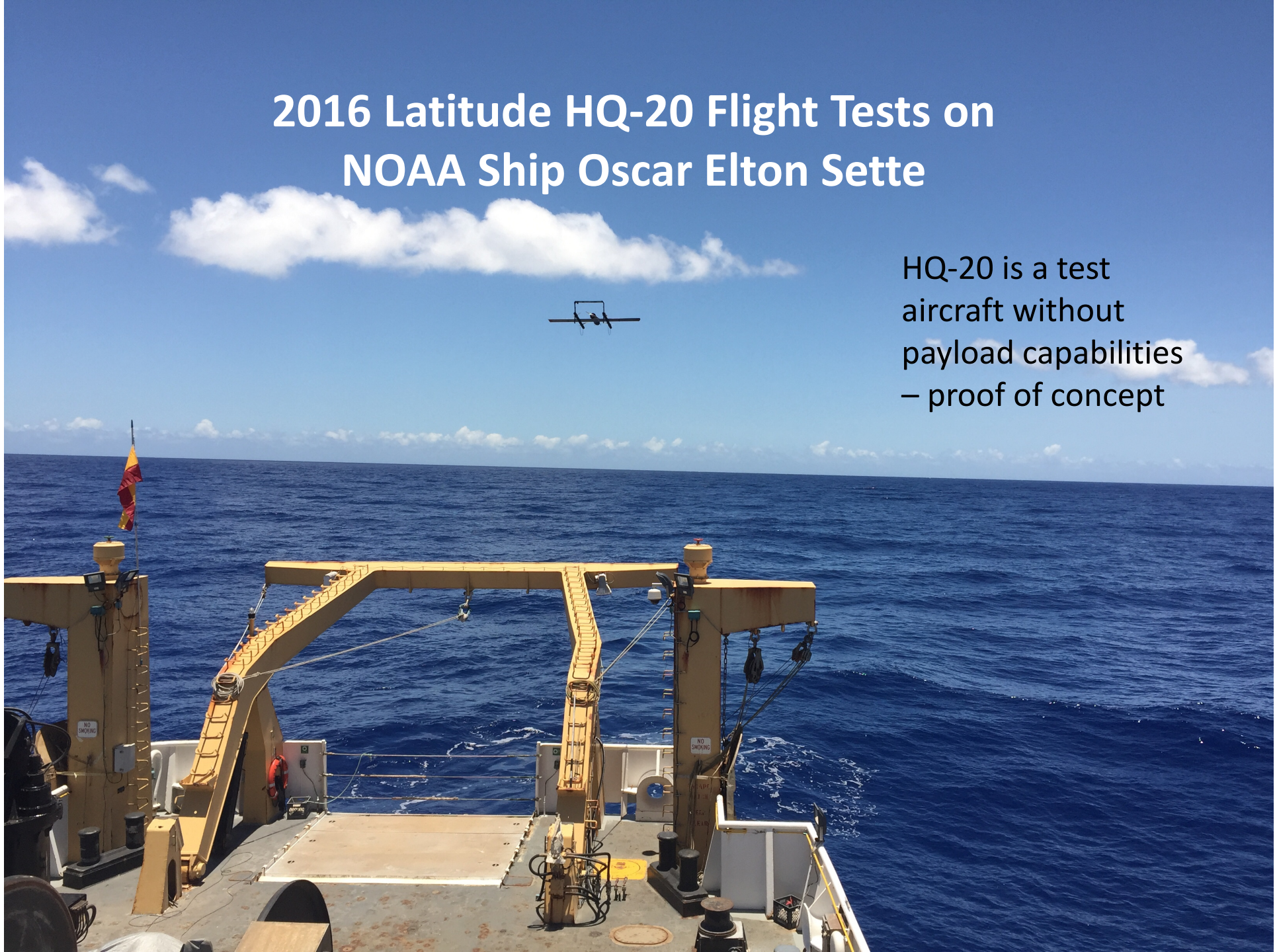
L3 Latitude HQ-55 developed through the NOAA SBIR Program with the intention of flying from a ship

Hybrid Quadrotor (HQ) Technology

Combines vertical takeoff and landing (VTOL) capabilities of a quadrotor with the speed and range of a fixed-wing aircraft

- No launcher or runway needed
- Pusher engine – required for gas and aerosol measurements
- Nose cone payload
- Weighs less than 55 lb qualifying as a small UAS
- “Marine” grade VTOL motors
- Differential GPS for autonomous take off and landing
- Endurance of up to 10 hours
- Has been shown to fly to 13,350’ density altitude
- Speed of ~ 40 kts
- Wing span ~ 16’
- Payload capacity up to 6 kg

2016 Latitude HQ-20 Flight Tests on NOAA Ship Oscar Elton Sette

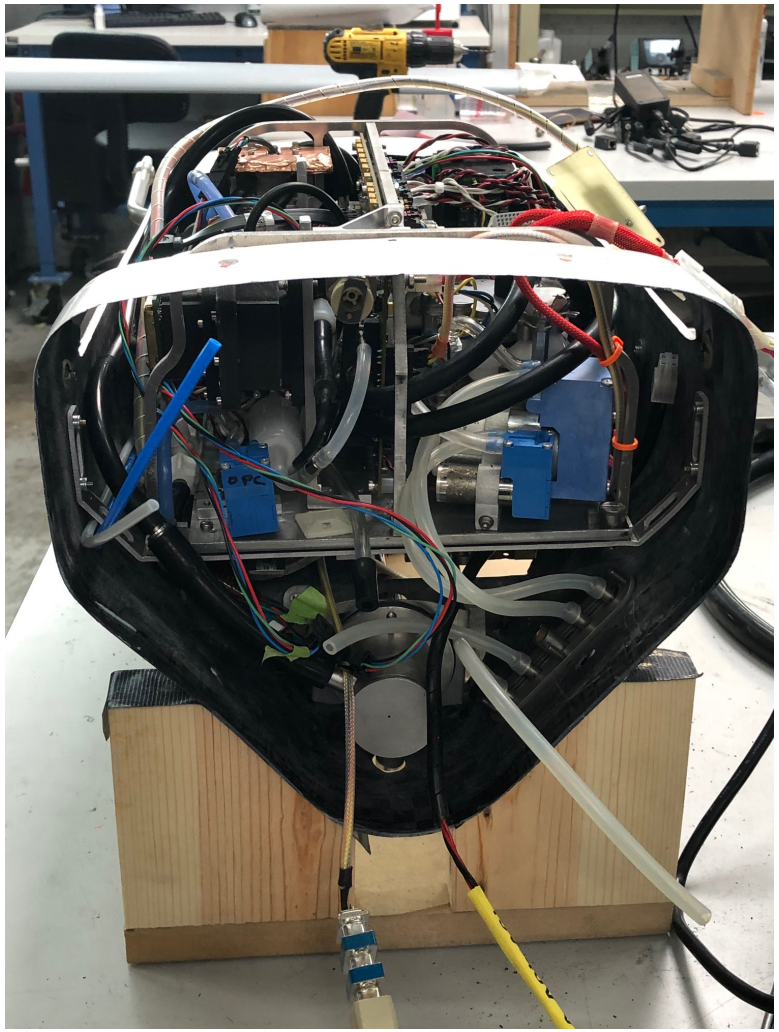


HQ-20 is a test aircraft without payload capabilities – proof of concept

UAS Measurements

Parameter	Method
Clear Sky Payload	
Number concentration	Brechtel Mixing CPC
Number size distribution	POPS, 140 to 3000 nm
Absorption coefficient	Brecthel mini-PSAP (450, 525, and 624 nm)
Aerosol Optical Depth	Mini SASP (460, 550, 670, and 860 nm)
Chemical composition	Filter, IC and thermal-optical analysis
Met variables	T, P, RH
Cloudy Sky Payload	
Cloud droplet number distribution	DMT CDP, 2 to 50 um
Number size distribution	Brechtel mini-SEMS and POPS, 5 to 3000 nm
Met variables	T, P, RH

Clear Sky Payload in HQ-55 nose cone



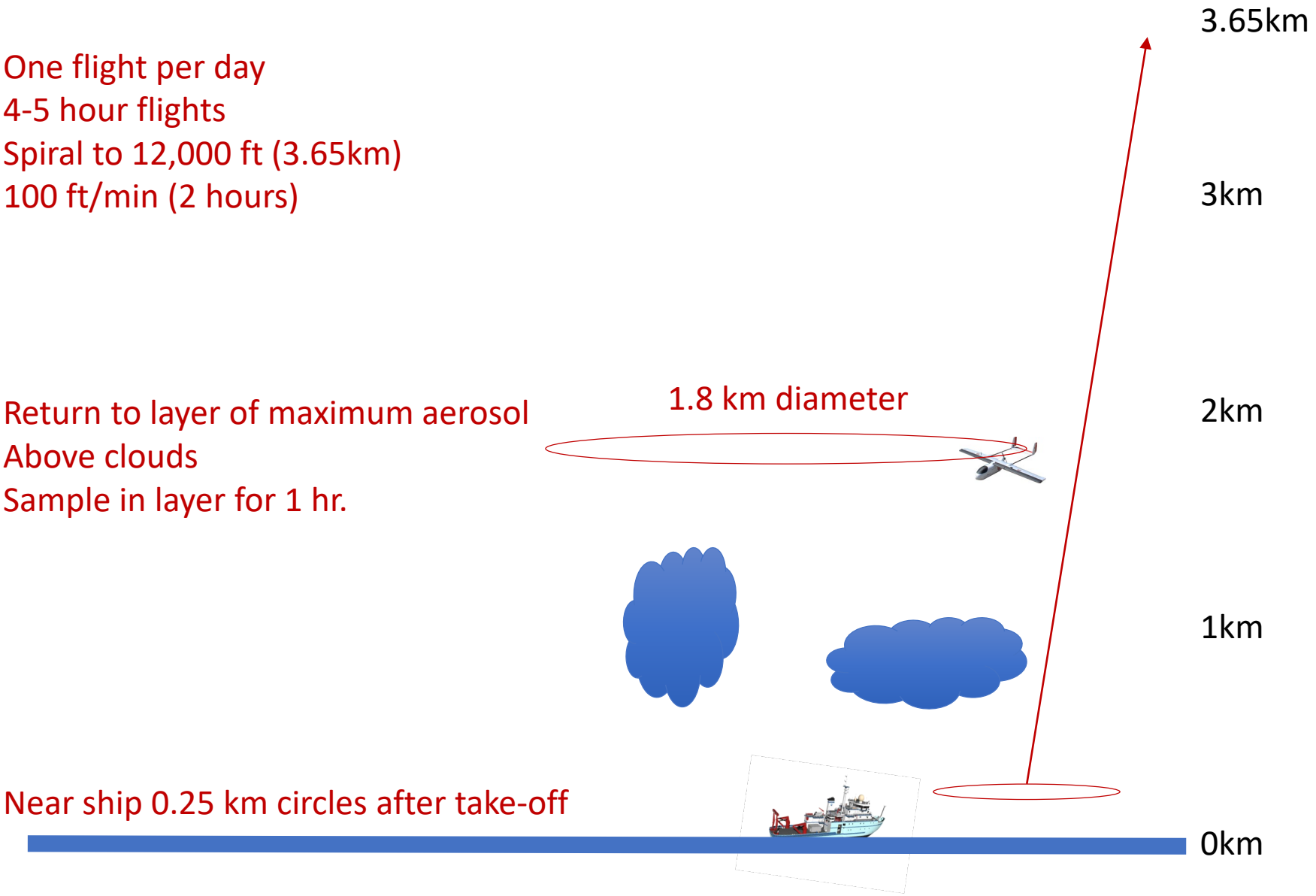
Nose cone mounted in HQ-55 with mini-SASP on top

HQ-55 UAS Clear Sky Payload Flight Plan

One flight per day
4-5 hour flights
Spiral to 12,000 ft (3.65km)
100 ft/min (2 hours)

Return to layer of maximum aerosol
Above clouds
Sample in layer for 1 hr.

Near ship 0.25 km circles after take-off



HQ-55 UAS Cloudy Sky Payload Flight Plan

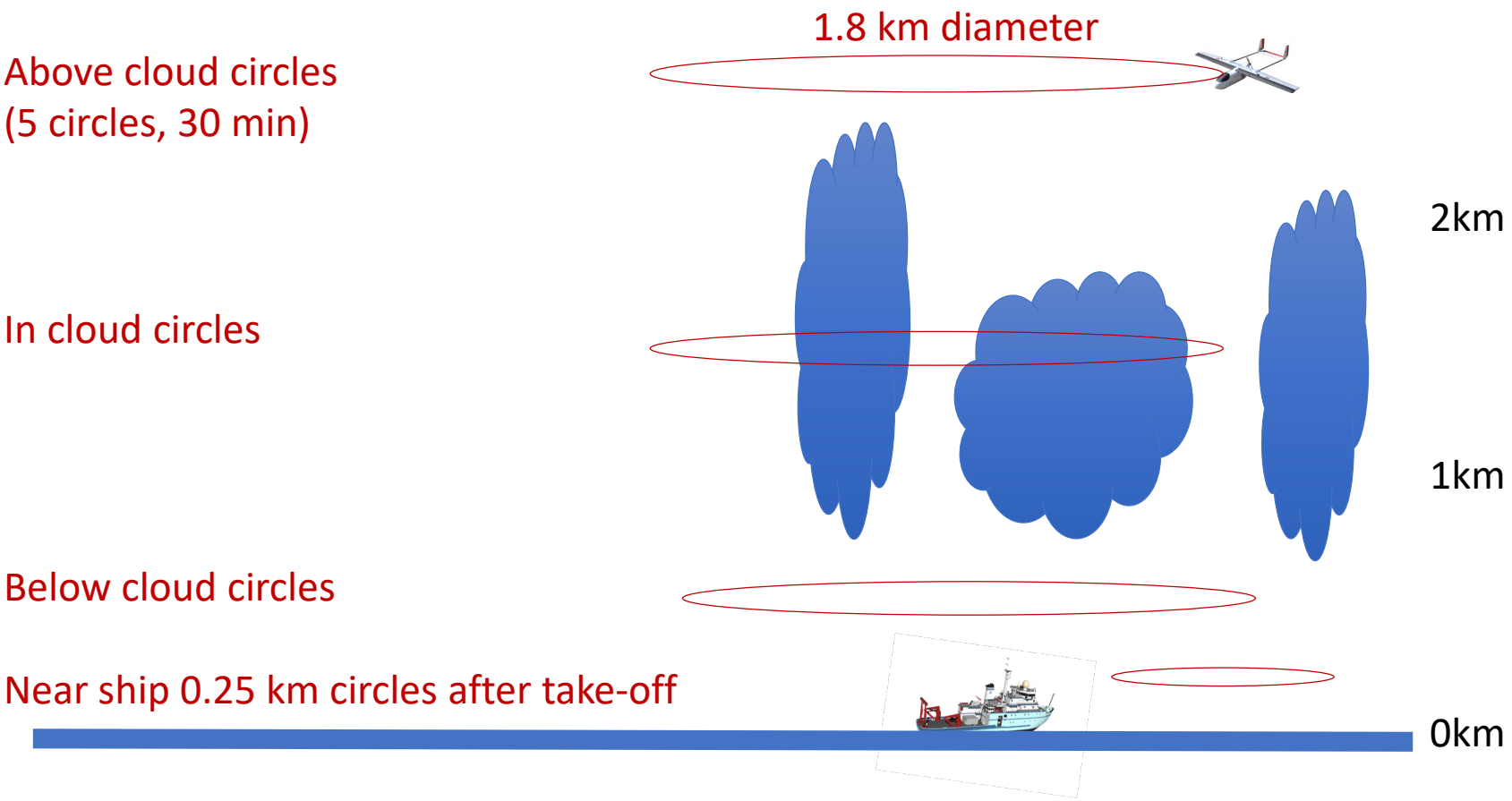
One flight per day
3-4 hour flights
Repeat below, in, and above
cloud circles 2 times

Above cloud circles
(5 circles, 30 min)

In cloud circles

Below cloud circles

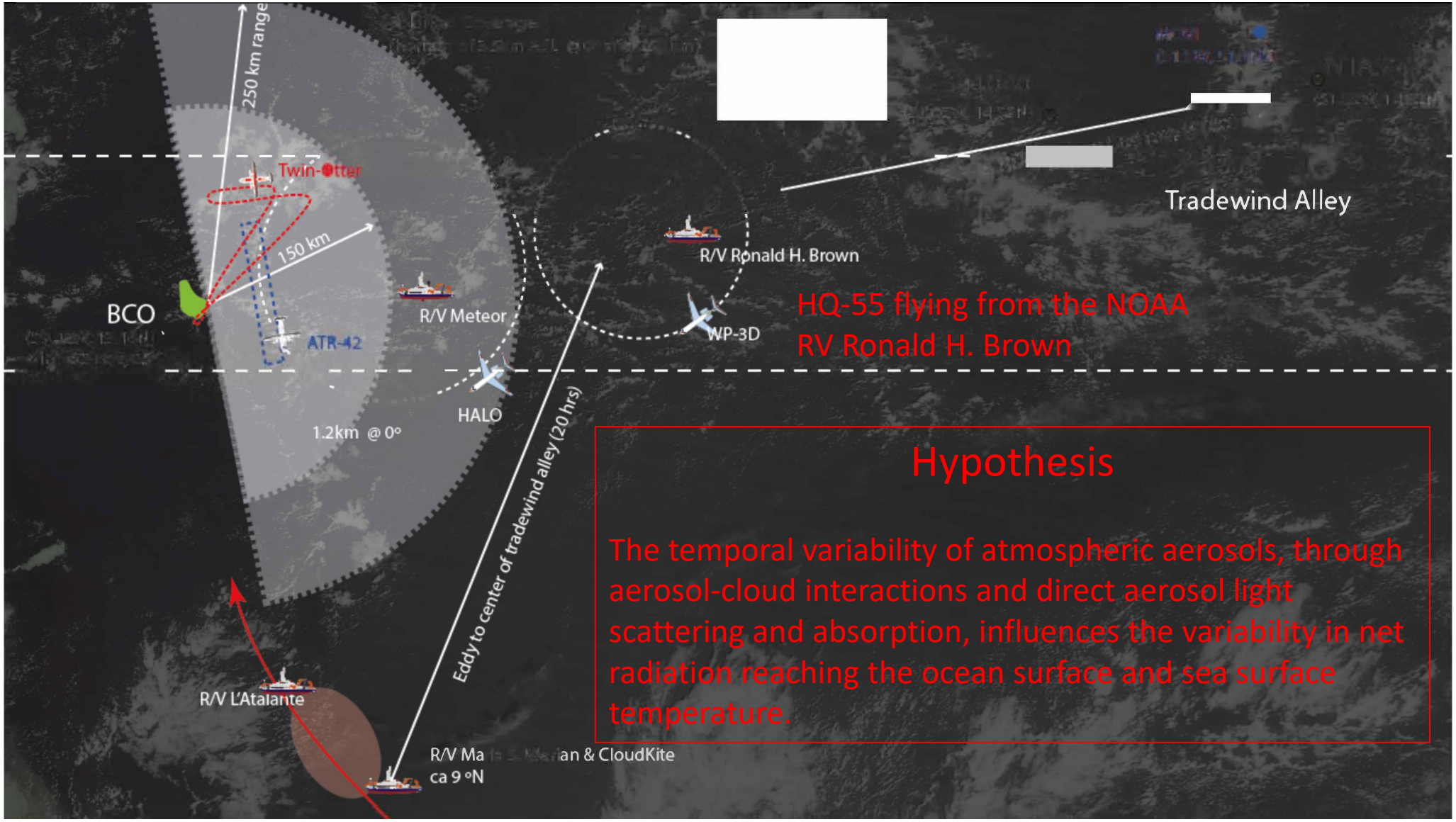
Near ship 0.25 km circles after take-off



ATOMIC

Atlantic Tradewind Ocean-Atmosphere Mesoscale Interaction Campaign

January – February 2020



Hypothesis

The temporal variability of atmospheric aerosols, through aerosol-cloud interactions and direct aerosol light scattering and absorption, influences the variability in net radiation reaching the ocean surface and sea surface temperature.

Impediments to the use of UASs for aerosol research

- Few impediments for low altitude routine monitoring applications with a limited number of required sensors (e.g., air pollution monitoring)

- A major impediment for higher altitude, longer endurance missions with multiple sensors is cost (e.g., climate studies)

  - High performance sensors (light, accurate, fast time response)
  - Long endurance aircraft with a heavy payload capacity
  - Pilots
  - Funding

- Emphasis on transition-to-operations over research and innovation