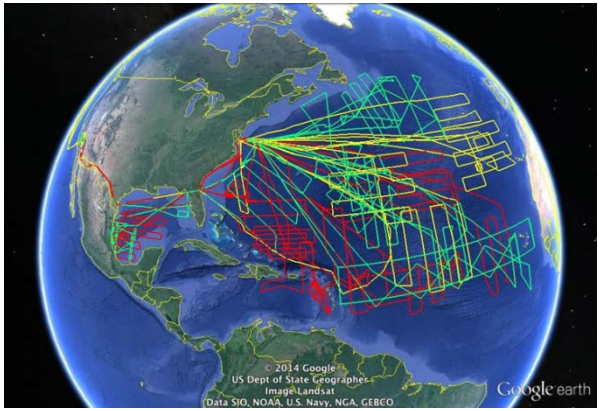
NOAA UAS Program Office Capabilities and GOES-R Support

NOAA UAS Program

April 2015

NOAA UAS Program Vision and Key Roles

- ***Vision***
  - **UAS observations will become an essential component of the NOAA observing system**
- ***Key Roles***
  - **Serve as the NOAA subject matter experts for UAS technology and observations**
  - **Assist with the research, development, demonstration and transition to application of select UAS observing strategies**
- ***Science Focus Areas***
  - **High Impact Weather Observations**
  - **Polar Observations**
  - **Marine Observations**



Fixed-Wing UAS Capabilities

High Altitude Long Endurance (HALE)

- Maximum Altitude 65,000 ft
- Maximum Endurance 25 hrs
- Maximum Payload Weight 1200 lbs

Medium Altitude Long Endurance (MALE)

- Maximum Altitude 40000 ft
- Maximum Endurance 24 hrs
- Maximum Payload Weight 400 lbs int, 2000 lbs ext

Low Altitude Long Endurance (LALE)

- Maximum Altitude 19,500 ft
- Maximum Endurance 24 hrs
- Maximum Payload Weight 13.5 lbs

Low Altitude Short Endurance (LASE)

- Maximum Altitude 1000 ft (operating altitude, higher capable)
- Maximum Endurance 2 hrs
- Maximum Payload Weight approx 2 lbs

Other Unmanned Capabilities

Vertical Takeoff and Landing (VTOL)

- Maximum Altitude 3280 ft
- Maximum Endurance 1.4 hr
- Maximum Payload Weight 1.7 lb

Aircraft-launched UAS (ACL)

- Maximum Altitude 20,000 ft
- Maximum Endurance 1.5 lbs
- Maximum Payload Weight 0.9 lbs

Balloon-launched UAS (BL)

- Maximum Altitude 100,000 ft
- Maximum Endurance N/A
- Maximum Payload Weight 3 lbs

Surface Unmanned Vehicles (SUV)

- Maximum Altitude Sea Level
- Maximum Endurance 8.6 hr
- Maximum Payload Weight 15 lb

Tethered Balloons (TB)

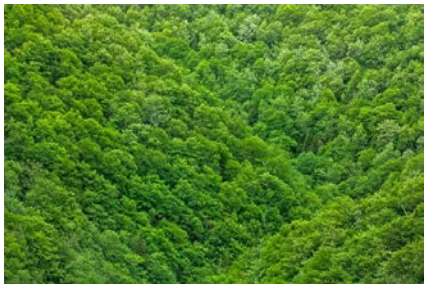
- Maximum Altitude 25,000 ft
- Maximum Endurance N/A
- Maximum Payload Weight 2,200 lbs

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

GOES-R ABI Cal/Val Mission Needs:

- **Operations over three types of environments:**
  - **1) Ocean (100 km offshore)**
  - **2) Land – Vegetated**
  - **3) Land – Barren Desert**

- **Sensor packages to obtain radiation data…**
  - **- UV-Vis-NIR Spectrum Radiation (0.2 – 1.1um)**
  - **- LWIR Spectrum (~10.0 – 12.5um)**
  - **- SWIR Spectrum (1.6 – 2.25um) [Potential]**



- **Coordinate UAS missions with simultaneous ER-2 flyover observations and geostationary satellite-based observations**

- **Nadir and Off-nadir autonomous observations, depending upon sub-mission requirements**

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

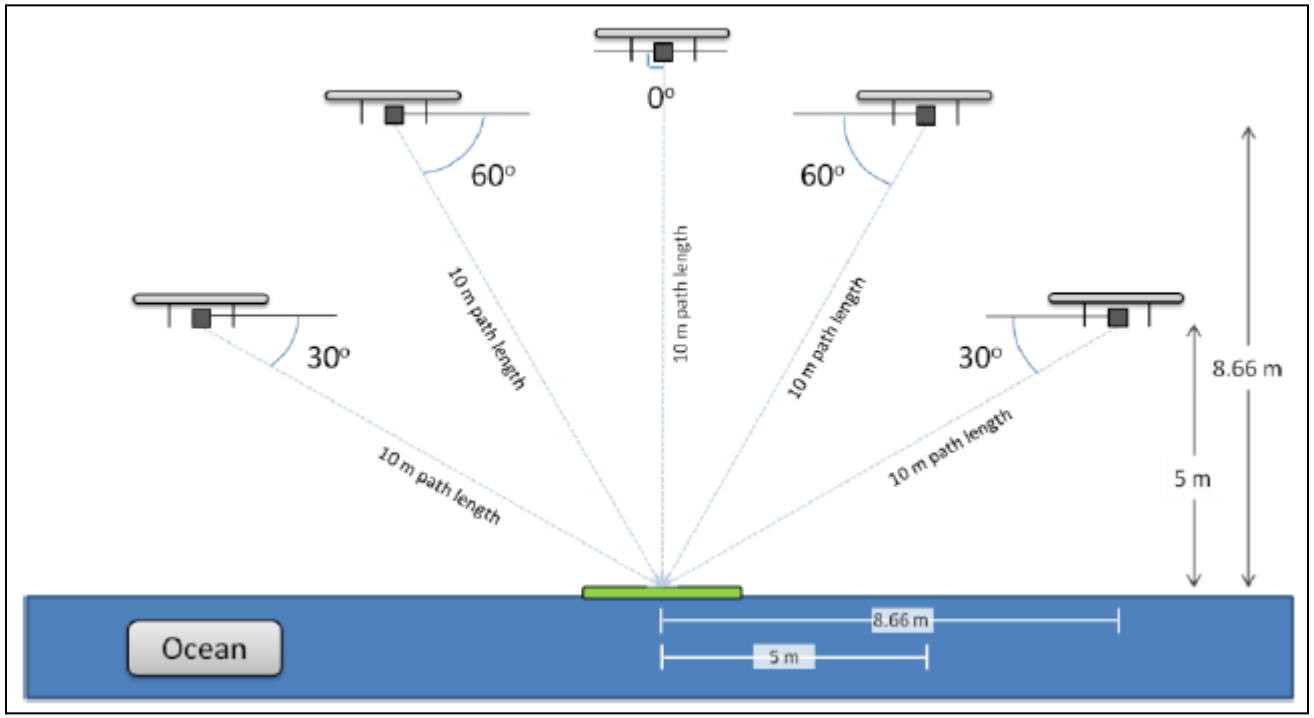
Requirements Review: Oceanic Cal/Val Component

- **Request for VTOL (i.e. “rotary wing”) UAS platform operations**
- **Autonomously control the view geometry of the sensor payloads for oblique angle data collection of a fixed earth target**
- **View geometry:**
  - Nadir to ≥70 degrees off-nadir (ideally approaching 90 degrees)
  - Maintain a 10 m (no more than 15 m) distance from target
- **Payload Types/Data:**
  1) Spectrometer (UV-VIS-NIR spectral range)
  2) Radiometer (LWIR spectral range)
- **Metadata will be collected and stored:**
  - Image acquisition times, sensor geometry angles, GPS location

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Oceanic Cal/Val Component

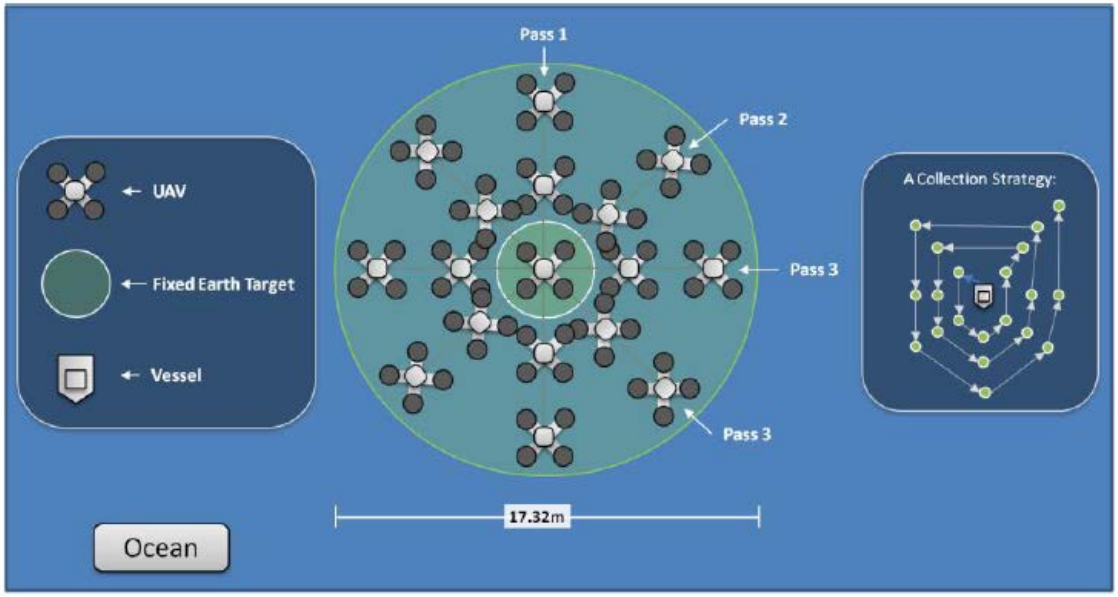
- **Definition: Single Pass from One Target Collection**
  - Maintain a fixed radius of 10 meters, ideally (no more than 15 meters)
  - Start at a large off-nadir angle (70 to 90 degrees), then fly VTOL UAS on an arc up and over a fixed ocean target, ending the pass at the same off-nadir angle on the other side
  - Sensors remain fixed on the target during the entire overpass.



NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Oceanic Cal/Val Component

- **Definition: Complete Collection for One Target**
  - Repeat for a total of four passes, rotating azimuthally around a target, essentially piecing together a collection of target observations from as many different observation angles within the skyward hemisphere as possible.

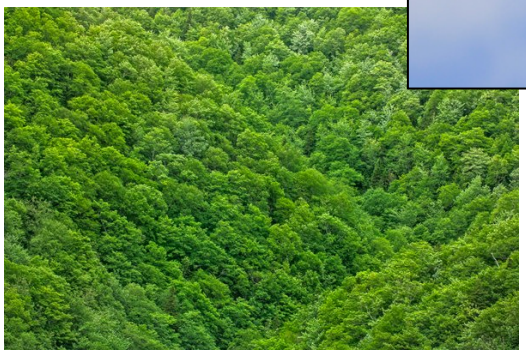


- **Definition: Full Mission Collection**
  - Repeat target observation collections for multiple targets, radiating outward from a central location (likely a ship) until a sizeable enough footprint of the ocean surface has been sampled (initially proposed to be ~1 to 5 km out in all directions.)

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Requirements Review: Land Cal/Val Component

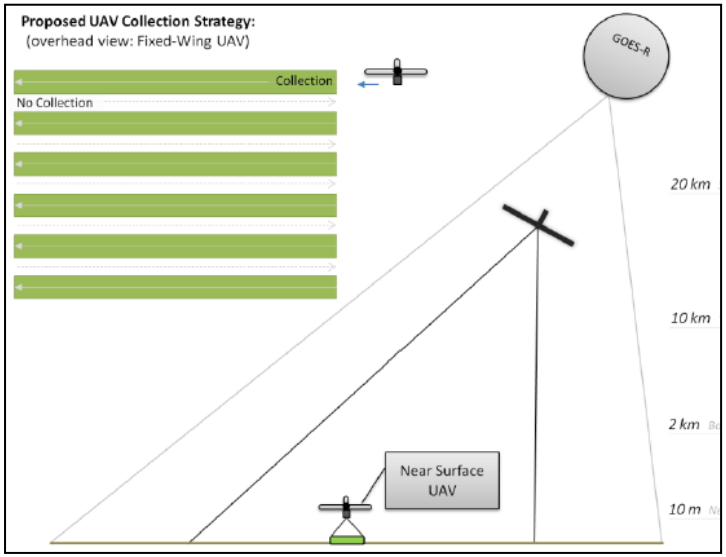
- **Request for small fixed wing UAS platform operations**
- **View geometry:**
  - Nadir view
  - Maintain a 10 m (no more than 20 m) distance from surface
- **Payload Types/Data:**
  - Radiometer (LWIR spectral range)



NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Land Cal/Val Component

- Obtain surface brightness temperature data of vegetated and barren desert land surfaces
- Use fixed wing UAS platform with nadir-looking sensors to cover a broad geographic region (~5 to 20 km)
- Autonomous flight through pre-flight programming of waypoints
- “Lawn-mower Pattern” flight paths used to fully canvas the footprint within the GOES-R satellite ABI infrared band pixels
- Metadata will be collected and stored:
  - Image acquisition times, sensor geometry angles, GPS location



NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Sensor Payload Recommendations and Synopsis:

- *LWIR Sensor: "Apogee / SI-series"*

  The Apogee S1-series of sensors provides the highest amount of accuracy (least error), which is balanced against a reasonable response time. It also provides for one of the smaller and lighter payload solutions. Furthermore, this line of instruments has a history of use aboard UAS platforms for crop monitoring missions and has also been mounted to the front of ships for sea surface temperature measurements.

- *UV-VIS-NIR Sensor: "StellarNet / BLK-C-SR" (with PDA detector option)*

  The StellarNet Black Comet Super Resolution (BLK-C-SR) sensor with the Toshiba TCD1201D photodiode array detector configuration boasts the highest signal-to-noise ratio while maintaining an optical resolution that is right on par with other comparable sensors. At a weight of 0.40 kg, which puts it in the middle of the pack with respect to this specification, the benefits appear to far outweigh this minor drawback.

- *NIR-SWIR Sensor: "Ocean Optics / NIRQuest512-2.5"*

  The Ocean Optics NIRQuest512-2.5 possesses the largest amount of weight in this class of researched sensors; however, this instrument provides a relatively high optical resolution while yielding a signal-to-noise ratio that is a full one to two orders of magnitude greater than other comparable sensors.

Backup Slides

Long-wave IR (LWIR) / 8.0-14.0 µm Range Spectral Sensor Specifications

Manufacturer	Heitronics	Heitronics	Apogee	Micro-Epsilon	Omega
Sensor Model	"KT15.85 IIP"*	"KT15.82 IIP"	"SI" Series	"ThermoMETER CS"	"OS301-LT"
Spectral Range (um)	9.6 – 11.5	8.0 – 14.0	8.0 – 14.0	8.0 – 14.0	8.0 – 14.0
Calibrated Targeted Temperature Range	-25 – 200 C	-30 – 1,000 C	-30 – 65 C	-40 – 400 C	-20 – 100 C
Temperature Accuracy	0.5 C, Plus 0.7% diff b/w target and housing temp	0.5 C, Plus 0.7% diff b/w target and housing temp	0.2 C	1.5 C, Or +/- 1.5 %	1.0 C, Or +/- 1.0 %
Temperature Resolution	0.40 C**	0.05 C**	Dependent upon data logger ***	0.10 C ****	Dependent upon data logger ***
Response Time	1.00 s	1.00 s	0.60 s (95% response)	0.03 s (90% response)	0.24 s (90% response)
Sensor Weight	1.300 kg	1.300 kg	0.190 kg	0.058 kg	0.095 kg
Payload Dimensions (cm)	L x W x H: 16.1 x 5.1 x 5.1	L x W x H: 16.1 x 5.1 x 5.1	Diameter x L: 2.3 x 6.0	Diameter x L: 1.4 x 8.7	Diameter x L: 1.8 x 10.3
Operational Environment Temperatures	-20 – 60 C	-20 – 60 C	-55 – 80 C	-20 – 80 C	0 – 70 C
Operational Environment Humidity	*(Not Provided)*	*(Not Provided)*	0 to 100%, Non-condensing	10 to 95%, Non-condensing	0 to 95%, Non-condensing
Power	Direct: 22.0 – 30.0 V Alternating: ~24.0 V	Direct: 22.0 – 30.0 V Alternating: ~24.0 V	2.5 V	Direct: 5.0 – 30.0 V	Direct: 24.0 – 28.0 V

* Advertised for "meteorological" remote sensing applications

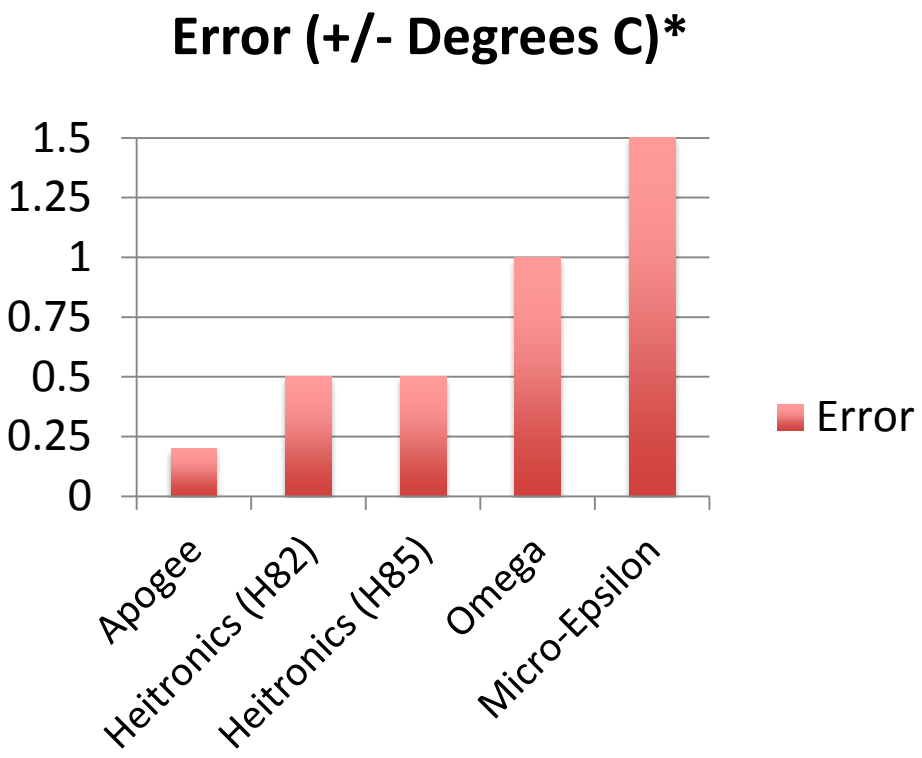
** Dependent on target temperature and response time / Shown, with Detector Type "A" @ 20C Target Temp

*** Potentially 0.05 C sensitivity with data logger resolution of 3 uV.

**** Target temp <100°C and time constant >0.2s.

Long-wave Spectral Sensors: Temperature Accuracy Comparison

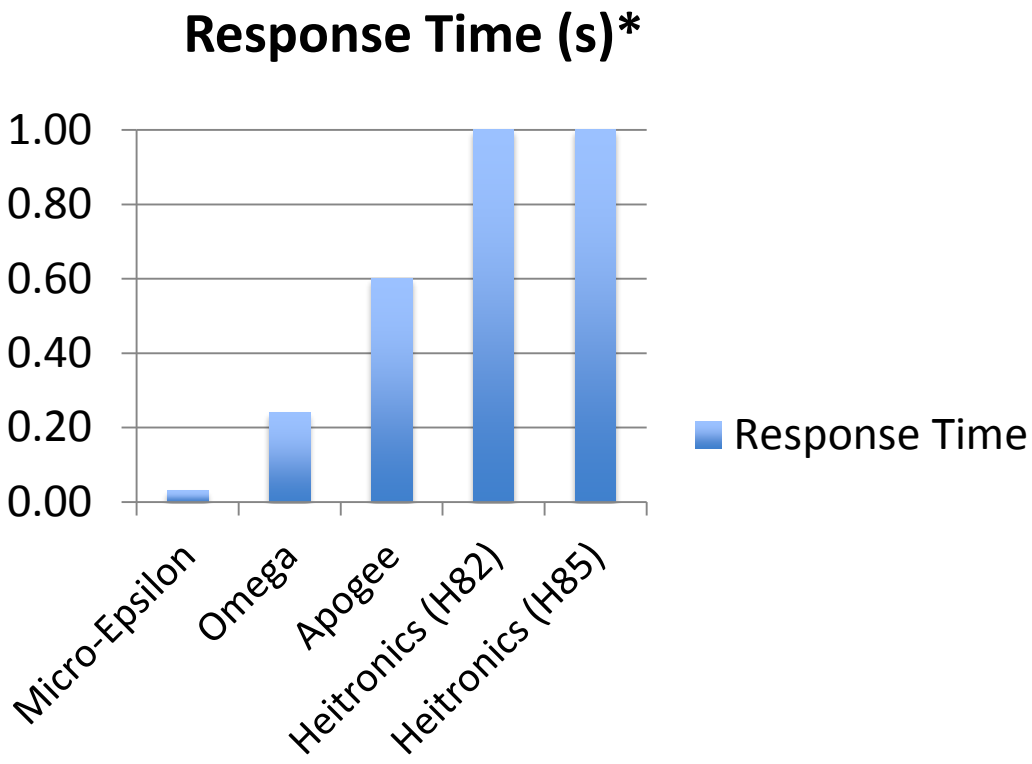
Rank	Sensor	Error (+/-)
1	Apogee "SI" Series	0.2 C
2a	Heitronics "KT15.82" (H82)	0.5 C
2b	Heitronics "KT15.85" (H85)	0.5 C
3	Omega "OS301-LT"	1.0 C
4	Micro-Epsilon "ThermoMETER CS"	1.5 C



**Lower values indicate improved performance attributes*

Long-wave Spectral Sensors: Response Time Comparison

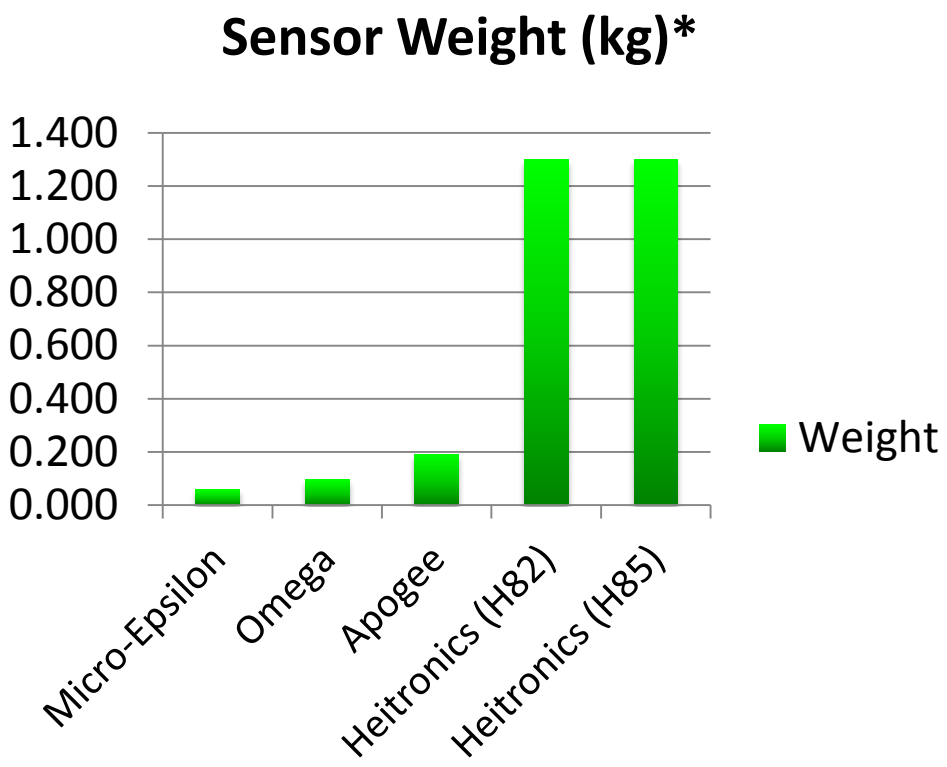
Rank	Sensor	Response Time
1	Micro-Epsilon “ThermoMETER CS”	0.03 s
2	Omega “OS301-LT”	0.24 s
3	Apogee “SI” Series	0.60 s
4a	Heitronics “KT15.82” (H82)	1.00
4b	Heitronics “KT15.85” (H85)	1.00



**Lower values indicate improved performance attributes*

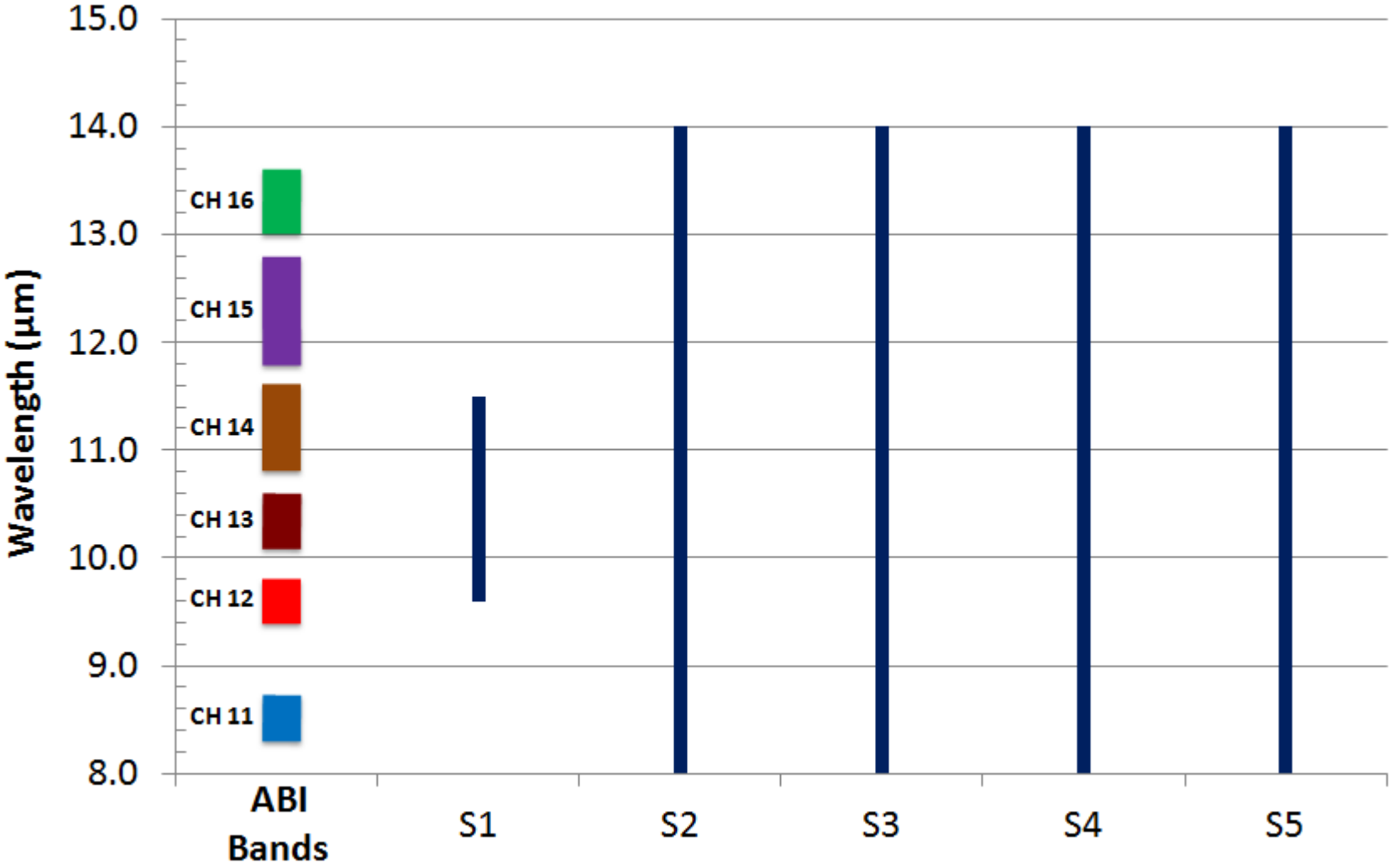
Long-wave Spectral Sensors: Sensor Weight Comparison

Rank	Sensor	Sensor Weight
1	Micro-Epsilon “ThermoMETER CS”	0.058 kg
2	Omega “OS301-LT”	0.095 kg
3	Apogee “SI” Series	0.190 kg
4a	Heitronics “KT15.82” (H82)	1.300 kg
4b	Heitronics “KT15.85” (H85)	1.300 kg



**Lower values indicate more desirable attributes*

Sensor Example Spectral Ranges and ABI Channels 11-16 Coverage



S1: Heitronics / KT15.85 IIP	**S4: Micro-Epsilon / ThermoMETER CS**
S2: Heitronics / KT15.82 IIP	**S5: Omega / OS301-LT**
S3: Apogee / "SI" Series	

UV-VIS-NIR / 0.2-1.2 µm Range
Spectral Sensor Specifications

Manufacturer	Ocean Optics	StellarNet	Avantes
Sensor Model	"USB2000+"	"BLK-C-SR"	"AvaSpec-ULS2048XL"
Spectral Range (um)	0.20 – 1.10	0.20 – 1.08	0.20 – 1.16
Dynamic Range	1,300:1 (for a single acquisition)	2,000:1 (w/ 6 decades)	3,800:1
Detector/ Type	Sony ILX511B/ CCD	Sony ILX511/ CCD (Toshiba TCD1201D PDA, optional)	Hamamatsu S11155-2048-01/ Back-thinned CCD
Pixel Count/ Size	2048 / 14x200um	2048 / 14x200um	2048 / 14x500um
Signal to Noise Ratio	250:1	CCD= 1,000:1 PDA= 2,000:1	450:1
Optical Resolution	1.5 nm	~ 1.5 nm	0.09 – 20 nm***
Integration Time	0.001 – 65 s	0.001 – 65 s	0.000002 – 20 s
Sensor Weight	0.190 kg*	~0.400 kg**	0.855 kg
Payload Dimensions (cm)	L x W x H: 8.9 x 6.3 x 3.4	L x W x H: 15.0 x 10.0 x 6.9	L x W x H: 17.5 x 11.0 x 4.4
Operational Environment Temperatures	-30 to 70 C	*(Not Provided)*	0 to 55 C
Operational Environment Humidity	0 to 90%, Non-condensing	*(Not Provided)*	10 to 90%, Non-condensing
Power	250 mA @ 5 VDC	100 mA @ 5 VDC	Default USB power, 450 mA … or… With SPU2 external 12VDC, 200 mA

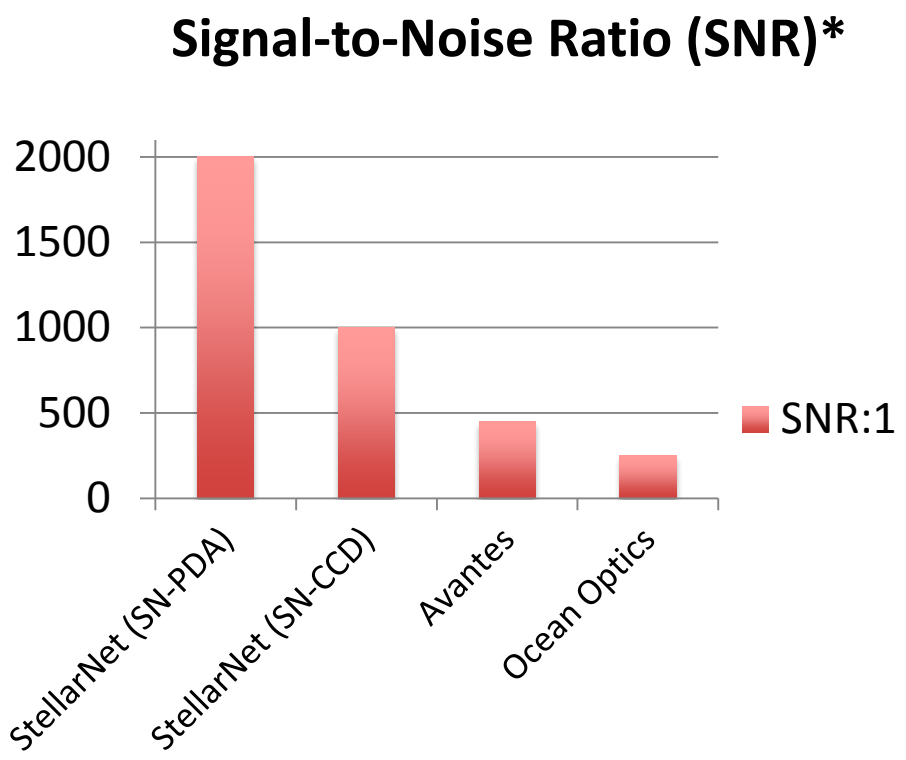
* Includes full battery kit, Raspberry Pi processer, and cables

** Estimated from similar sensors from this manufacturer with specs quoted at "14 ounces"

*** Resolution depends on grating configuration. Example: **1.5 nm** @ 25um slit size w/ 300 lines/mm grating

UV-VIS-NIR Spectral Sensors: Signal-to-Noise Ratio Comparison

Rank	Sensor	SNR
1	StellarNet "BLK-C-SR" (SN-PDA)**	2,000:1
2	StellarNet "BLK-C-SR" (SN-CCD)**	1,000:1
3	Avantes "AvaSpec-ULS2048XL"	450:1
4	Ocean Optics "USB2000+"	250:1



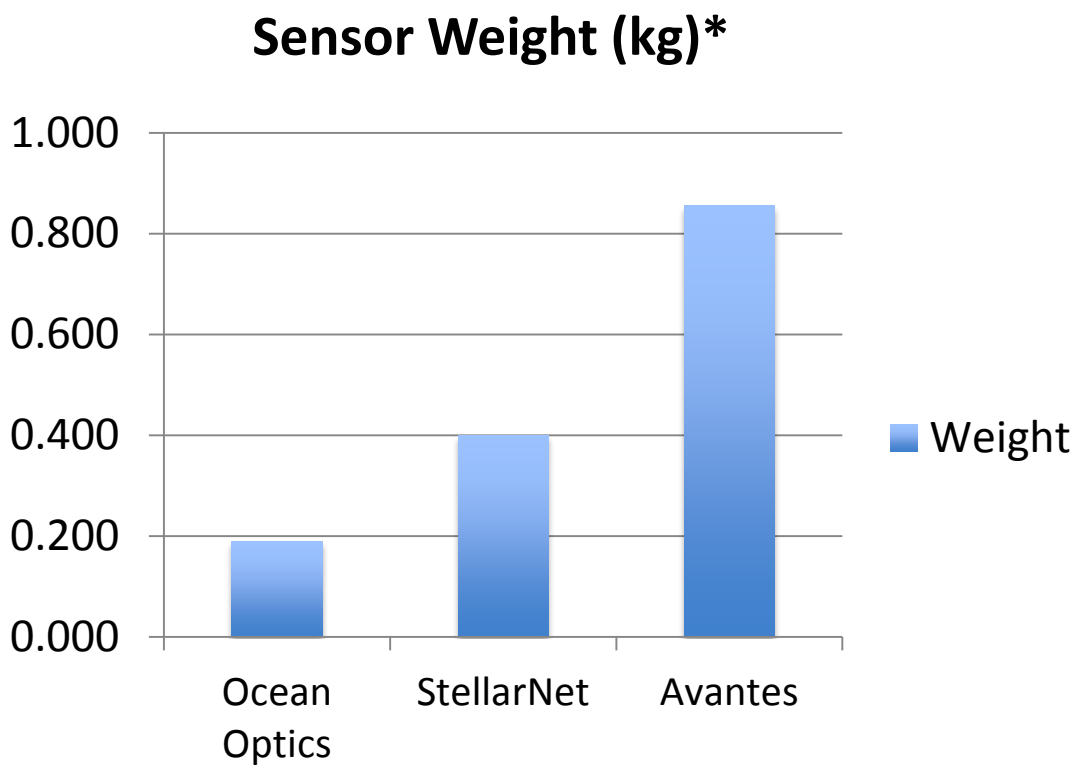
** *"Photodiode Array" (PDA) detector configuration*

"Charge Coupled Device" (CCD) detector configuration

**Higher ratios indicate improved performance attributes*

Long-wave Spectral Sensors: Sensor Weight Comparison

Rank	Sensor	Sensor Weight
1	Ocean Optics "USB2000+"	0.190 kg
2	StellarNet "BLK-C-SR"	0.400 kg
3	Avantes "AvaSpec-ULS2048XL"	0.855 kg



**Lower values indicate more desirable attributes*

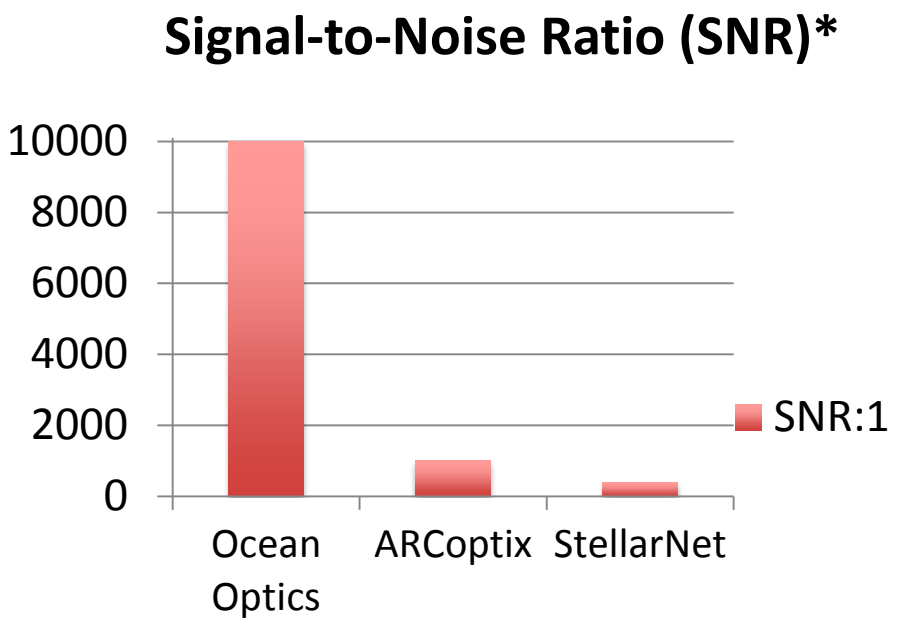
Near- to Short-wave IR (NIR/SWIR) / 0.9-2.6 µm Range Spectral Sensor Specifications

Manufacturer	Ocean Optics	StellarNet	ARCoptix
Sensor Model	"NIRQuest512-2.5"	"RED-Wave-NIRX-SR"*	"FT-NIR Rocket"
Spectral Range (um)	0.9 – 2.50 (w/ Grating NIR1)	0.90 – 2.30	0.9 – 2.60
Dynamic Range	7,500:1	4,000:1 (w/ 5 decades)	3,000:1
Detector/ Type	Hamamatsu G9208-512W InGaAs/ Linear PDA	Sensors Unlimited, Inc. LD InGaAs / Cooled Linear PDA	Extended type InGaAs/ Single Photodiode
Pixel Count/ Size	512 / 25x250um	512** / 25x250um	Single photodiode / *Not Provided*
Signal to Noise Ratio	10,000:1	400:1 (w/ 2x TEC cooling)	> 1,000:1 (single measurement) > 5,000:1 (25 avg measurements)
Optical Resolution	~6.3 nm	~26 nm**	0.8 nm @ 1.0um 2.0 nm @ 1.7 um 5.0 nm @ 2.6 nm
Integration Time	0.001 – 0.20 s	0.001 – 0.25 s	*(Not Provided)*
Sensor Weight	1.18 kg (w/out power supply)	~0.400 kg***	0.850 kg
Payload Dimensions (cm)	L x W x H: 18.2 x 11.0 x 4.7	L x W x H: 15.0 x 10.0 x 6.9	L x W x H: 18.0 x 16.0 x 8.0
Operational Environment Temperatures	10 to 35 C	*(Not Provided)*	10 to 30 C
Operational Environment Humidity	0 to 90%, Non-condensing	*(Not Provided)*	*(Not Provided)*
Power	3,000 mA MAX @ 5 VDC	100 mA @ 5 VDC	5 V (USB Powered)

* 'Can be coupled with StellarNet's BLACK-Comet (BLK-C) unit to cover the entire 0.20-2.30 um range.'
** Optional detector configuration with 1024 pixel count; Yields increased optical resolution of ~14 nm
*** Estimated from similar sensors from this manufacturer with specs quoted at "14 ounces"

NIR-SWIR Spectral Sensors:
Signal-to-Noise Ratio Comparison

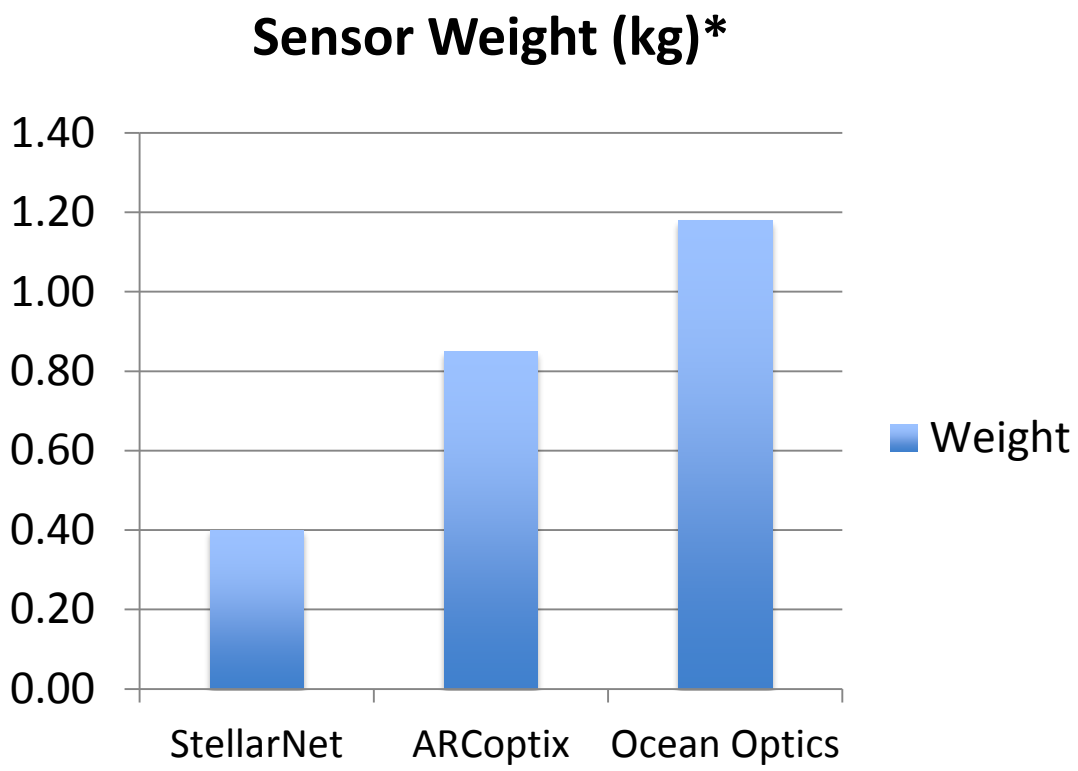
Rank	Sensor	SNR
1	Ocean Optics “NIRQuest512-2.5”	10,000:1
2	ARCoptix “FT-NIR Rocket”	1,000:1
3	StellarNet “RED-Wave-NIRX-SR”	400:1



**Higher ratios indicate improved performance attributes*

NIR-SWIR Spectral Sensors:
Sensor Weight Comparison

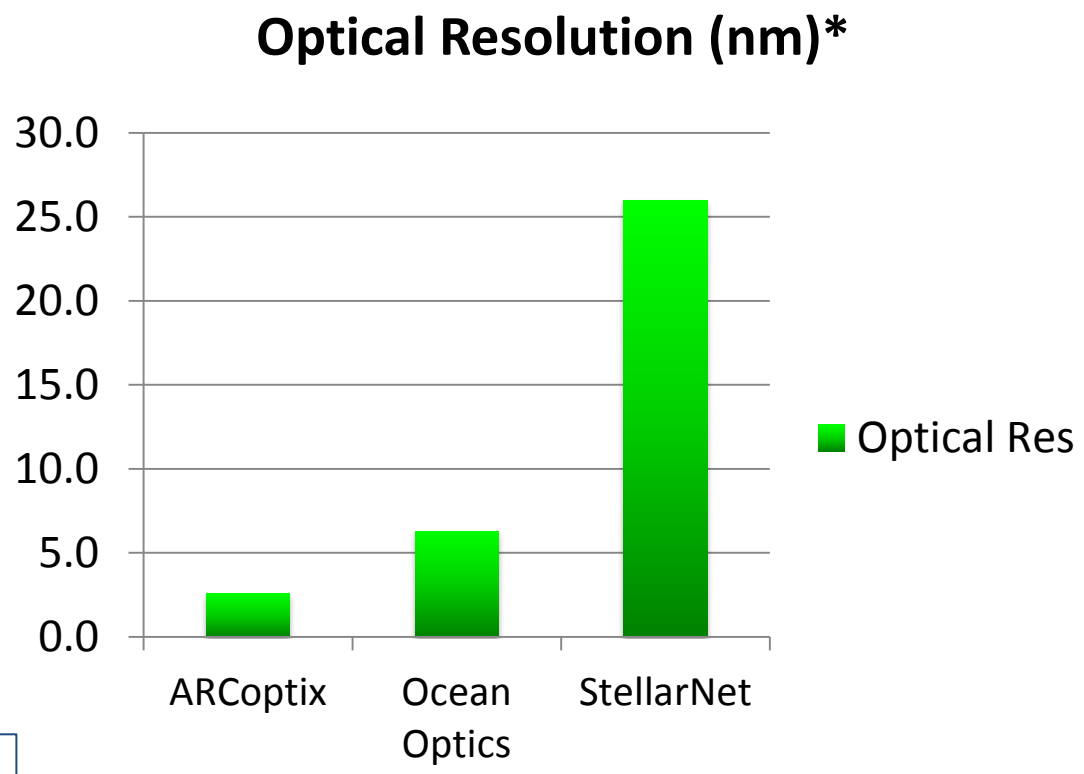
Rank	Sensor	Sensor Weight
1	StellarNet “RED-Wave-NIRX-SR”	0.40 kg
2	ARCoptix “FT-NIR Rocket”	0.85 kg
3	Ocean Optics “NIRQuest512-2.5”	1.18 kg



**Lower values indicate more desirable attributes*

NIR-SWIR Spectral Sensors:
Optical Resolution (aka: "Spectral Resolution") Comparison

Rank	Sensor	Optical/Spectral Resolution
1	ARCoptix "FT-NIR Rocket"	2.6 nm**
2	Ocean Optics "NIRQuest512-2.5"	6.3 nm
3	StellarNet "RED-Wave-NIRX-SR"	26.0 nm



*** Averaged across spectrum with* Extended Type InGaAs, single photodiode detector.
Advertised specs for three spectral points:

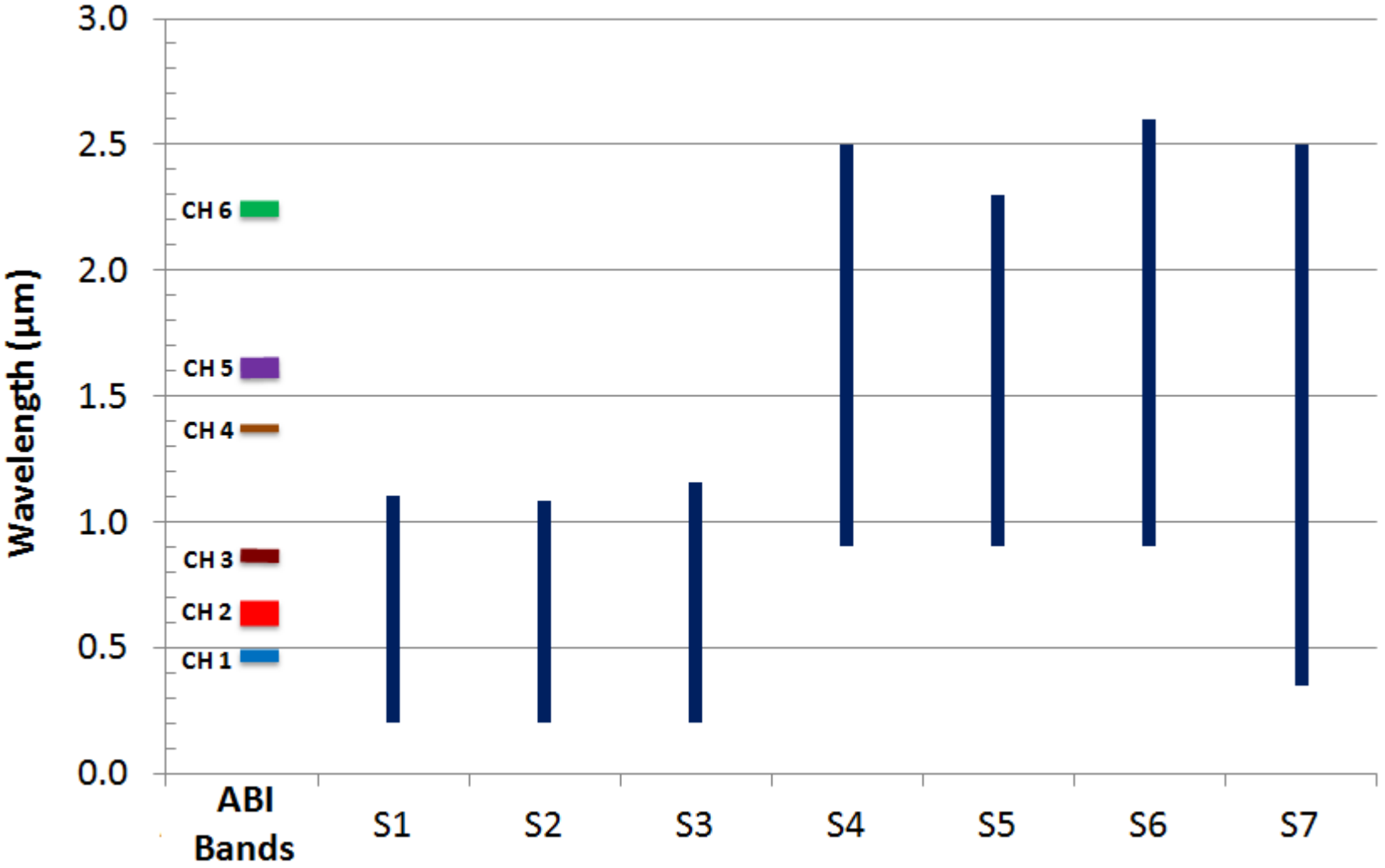
Opt Res= 0.8 nm @ 1.0um wavelength
Opt Res= 2.0 nm @ 1.7 um wavelength
Opt Res= 5.0 nm @ 2.6 nm wavelength

**Lower values indicate improved performance attributes*

VIS to SWIR Integrated Option / 0.35-2.50 µm Range Spectral Sensor Specifications

Manufacturer	ASD Inc. (PANalytical)
Sensor Model	"FieldSpec 4 Hi-Res"
Spectral Range (um)	0.35 – 2.50
Dynamic Range	N/A for this type of sensor
Detector/ Type	VIS -VNIR (0.35-1.0 um): 512 element silicon PDA SWIR 1 and SWIR2 (1.0-1.8 um and 1.8-2.5um): Graded Index InGaAs PDA, TE Cooled (single diode)
Pixel Count/ Size	VNIR: 512 / 50x2,500um SWIR1 and SWIR2: Single photodiode, each / 1,000x1,000um
Signal to Noise Ratio	SNR is N/A for this type of sensor. However, the Noise Equivalent Delta Radiance (NEDL) is as follows: VNIR 1.0 $X10^{-9}$ $W/cm^2/nm/sr$ @ 700 nm SWIR 1 1.4 $X10^{-9}$ $W/cm^2/nm/sr$ @ 1400 nm SWIR 2 2.2 $X10^{-9}$ $W/cm^2/nm/sr$ @ 2100 nm
Optical Resolution	3 nm @ VIS 8 nm @ SWIR
Integration Time	For VNIR: 0.009 – 0.136 s
Sensor Weight	5.44 kg
Payload Dimensions (cm)	L x W x H: 36.8 x 29.2 x 12.7
Operational Environment Temperatures	0 to 40 C
Operational Environment Humidity	0 to 100%, Non-condensing
Power	12 VDC / 60 Watts

Sensor Example Spectral Ranges and ABI Channels 1-6 Coverage



S1: Ocean Optics / USB2000+	**S4: Ocean Optics / NIRQuest512-2.5**	**S7: ASD Inc. / FieldSpec 4 Hi-Res**
S2: StellarNet / BLK-C-SR	**S5: StellarNet / RED-Wave-NIRX-SR**	
S3: Avantes / AvaSpec-ULS2048XL	**S6: ARCoptix / FT-NIR Rocket**	

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Oceanic Cal/Val Component

- **Definition: Single Pass from One Target Collection**
  - Maintain a fixed radius of 10 meters, ideally (no more than 15 meters)
  - Start at a large off-nadir angle (70 to 90 degrees), then fly VTOL UAS on an arc up and over a fixed ocean target, ending the pass at the same off-nadir angle on the other side
  - Sensors remain fixed on the target during the entire overpass.

- **Definition: Complete Collection for One Target**
  - Repeat for a total of four passes, rotating azimuthally around a target, essentially piecing together a collection of target observations from as many different observation angles within the skyward hemisphere as possible.

- **Definition: Full Mission Collection**
  - Repeat target observation collections for multiple targets, radiating outward from a central location (likely a ship) until a sizeable enough footprint of the ocean surface has been sampled (initially proposed to be ~1 to 5 km out in all directions.)

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Oceanic Cal/Val Component

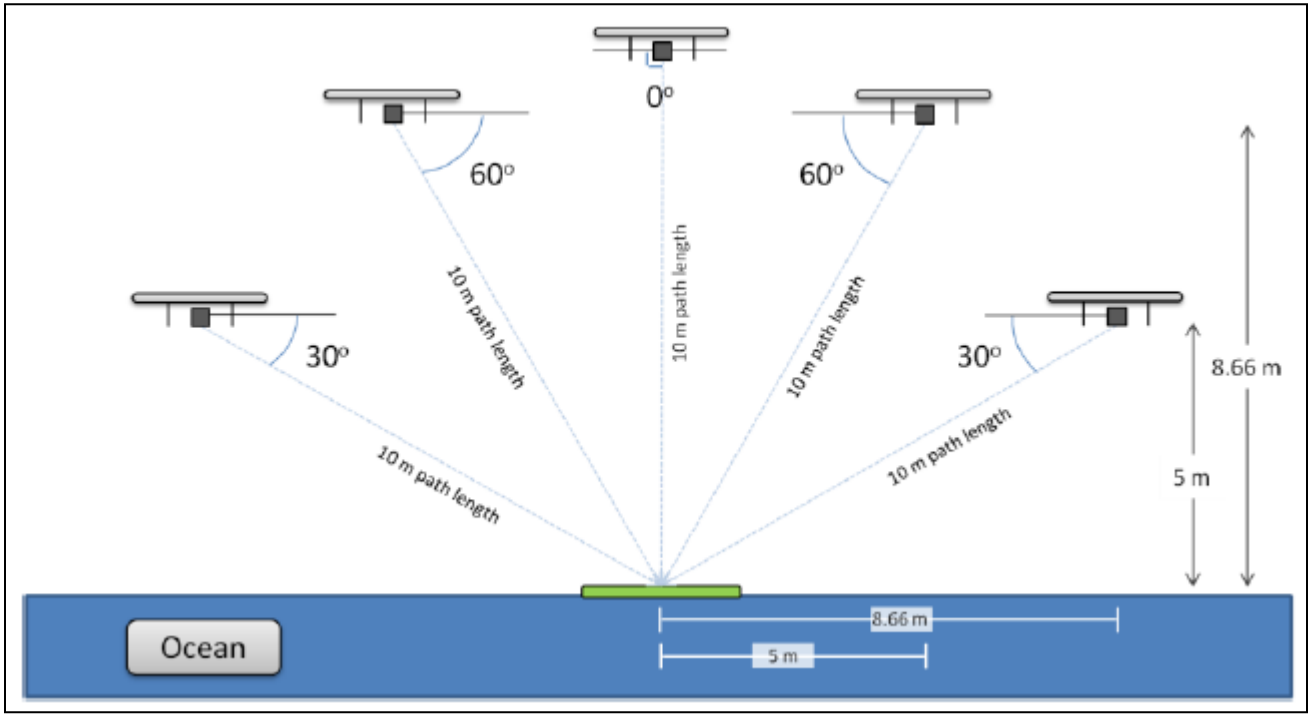


Figure 1: Schematic of proposed goniometric measurements, illustrating a single pass-over of a fixed ocean target by a VTOL UAS platform
(Provided from original GOES-R Cal/Val team UAS requirements draft)

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Oceanic Cal/Val Component

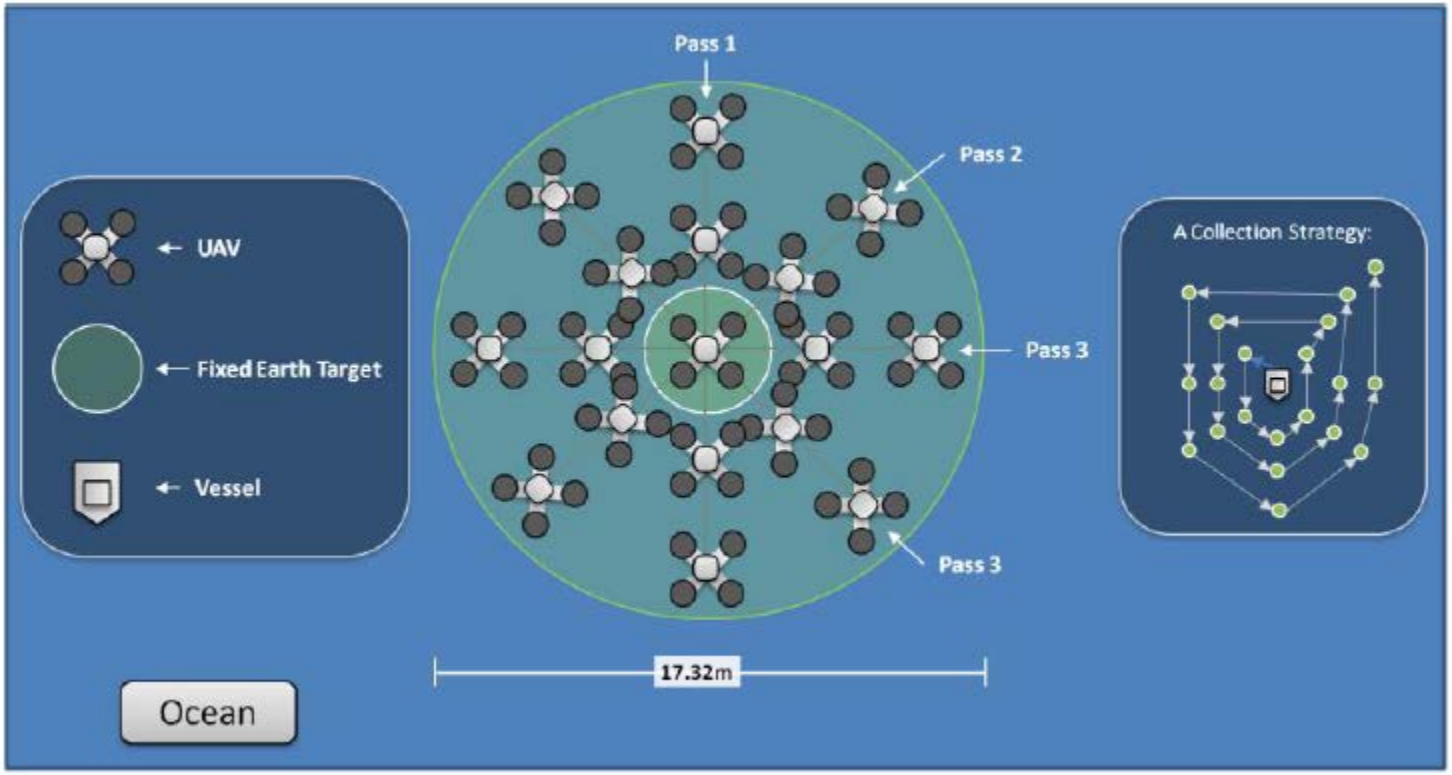


Figure 2: Schematic of a complete observation collection as proposed for a single target. A full collection consists of four single passes over the target… see Figure 1. (Provided from original GOES-R Cal/Val team UAS requirements draft)

NOAA GOES-R Advanced Baseline Imager Calibration and Validation UAS Mission Overview

Proposed CONOPS Review: Land Cal/Val Component

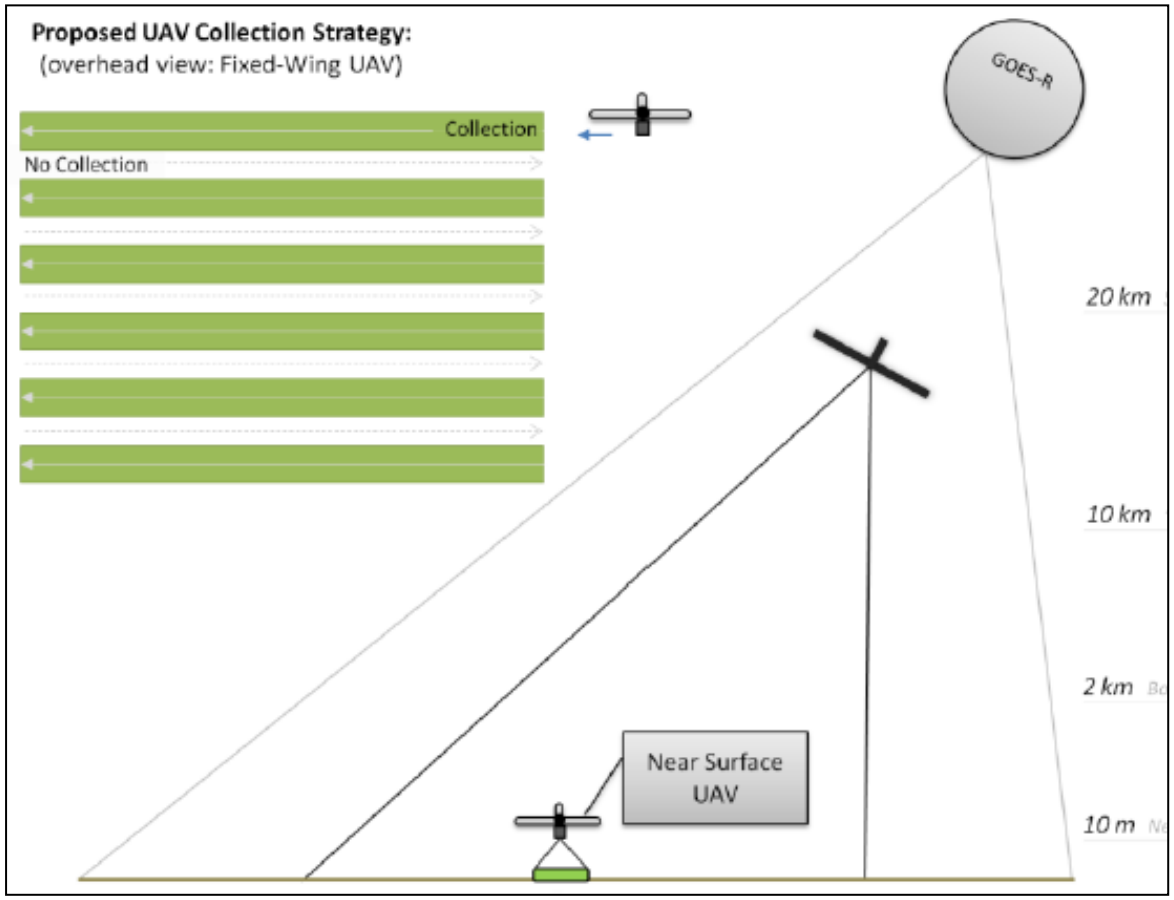


Figure 3: Schematic of the fixed wing UAS observation collection strategy. The GOES-R Cal/Val team has noted that the collection does not require continuous coverage. (Provided from original GOES-R Cal/Val team UAS requirements draft)

Observing Strategies by Fixed Wing UAS Capabilities and Science Focus Area

UAS Platform	High Impact Weather	Marine	Polar
HALE 	**RESEARCH** Oceanic storm vertical meteorological profiles Ocean storm surface winds / rain High altitude air quality		**DEVELOPMENT** Arctic weather vertical meteorological profiles Arctic high altitude air quality **RESEARCH** Sea Ice surveys
MALE 	**DEMONSTRATION** Flood aerial surveys **RESEARCH** Continental storm damage assessment -	**DEMONSTRATION** Maritime enforcement surveys Wildlife surveys **RESEARCH** Coastal gravity observations	**RESEARCH** Flood aerial surveys
LALE 	**RESEARCH** Continental storm in situ observations Continental storm damage assessment	**RESEARCH** Wildlife assessments	**DEMONSTRATION** Sea ice surveys Arctic weather in situ observations Arctic in situ air quality **DEVELOPMENT** Arctic icing weather observations Wildlife assessments
LASE 	**DEMONSTRATION** Flood aerial surveys **DEVELOPMENT** Flood digital elevation mapping Continental storm in situ observations **RESEARCH** Continental storm damage assessment	**DEMONSTRATION** Maritime enforcement surveys Maritime oil spill aerial surveys Maritime oil spill response imagery Marine debris response imagery Wildlife aerial surveys **RESEARCH** Coastal digital elevation mapping	**DEMONSTRATION** Sea ice aerial surveys for ships Arctic oil spill aerial surveys

Observing Strategies by Other Unmanned Capabilities and Science Focus Area

UAS Platform	High Impact Weather	Marine	Polar
VTOL 	RESEARCH Continental storms in situ meteorological observations Air quality in situ observations	DEMONSTRATION Maritime oil spill response imagery Wildlife assessments	DEMONSTRATION Wildlife assessments
ACL 	DEMONSTRATION Oceanic storm low altitude in situ meteorological observations		
BL 	DEMONSTRATION Air quality vertical profiles		RESEARCH Arctic air quality vertical profiles
SMUV 	DEMONSTRATION Oceanic storm low altitude in situ meteorological observations	DEVELOPMENT Maritime assessments Wildlife assessments Coastal assessments	
TB 		RESEARCH Maritime assessments	RESEARCH Arctic maritime assessments