SCRIPPS INSTITUTION OF OCEANOGRAPHY UC San Diego

Airborne Ocean Topography in support of SWOT

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OBJECTIVES AND SIGNIFICANCE

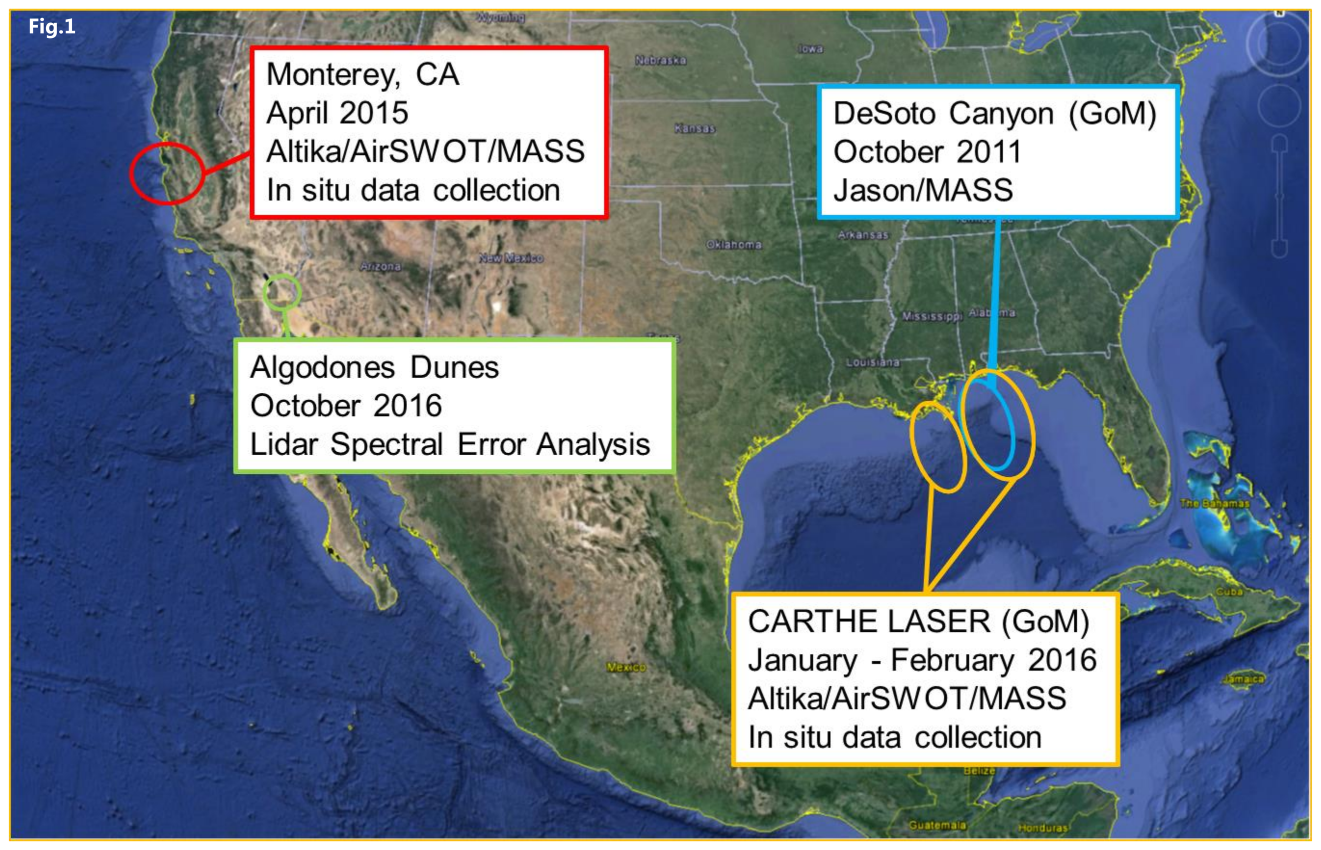
With the growing interest in understanding air-sea interaction, upper ocean dynamics and thermodynamics, increasing emphasis has been placed on submesoscale ocean processes. As we move to higher spatial resolution, for example, the 2-km requirement and 500-m goal of the Surface Water and Ocean Topography (SWOT) mission, the surface wave field will become of more significance for the dynamics since the wave field correlates with the submesoscale dynamics through wave-current interaction. Here we present some scientific examples of the use of airborne lidar for the measurement of ocean topography from mesoscales of O(100) km to surface gravity waves of wavelengths O(1) m. In the context of the SWOT program our expected contributions will be:

Mesoscale and Submesoscale Processes: Use our archived and future airborne measurements of sea surface topography, sea surface temperature (SST) and ocean surface current data to obtain SSHA spectra from wavelengths O(100) km down to O(1)m, to test spectral theories and models.

Tides and High-Frequency Motions: to provide high resolution ocean topography data to test barotropic tidal models and identify high frequency baroclinic tidal and related nonlinear internal wave SSH displacements.

Surface Wave Processes: Test models of "wave-driven" ocean circulation.

Calibration/Validation: The fundamental time-of-flight measurements of airborne scanning lidars along with high precision GPS/IMU data make such measurements a potentially important contributor to the Cal/Val stage of the SWOT mission.



Weight	120 kg total (including acquisition rack) / 79 kg without hyperspectral imager
Power requirements	600 W total, 400 W without hyperspectral imager

Instrumentation		Measurement
Scanning Waveform Lidar	Riegl Q680i	Surface waves, surface slope, directional wave spectra (vert. accuracy ~2-3cm per point)
Long-wave IR Camera (QWIP)	FLIR SC6000	Ocean surface processes, wave kinematics and breaking, frontal processes
High-Resolution Video	JaiPulnix AB-800CL	Ocean surface processes, wave kinematics and breaking, frontal processes
Hyperspectral Camera	EagleAISA	Ocean surface and biogeochemical processes
GPS/IMU	Novatel SPAN-LN200	Georeferencing, trajectory

Modular Aerial Sensing System (MASS)

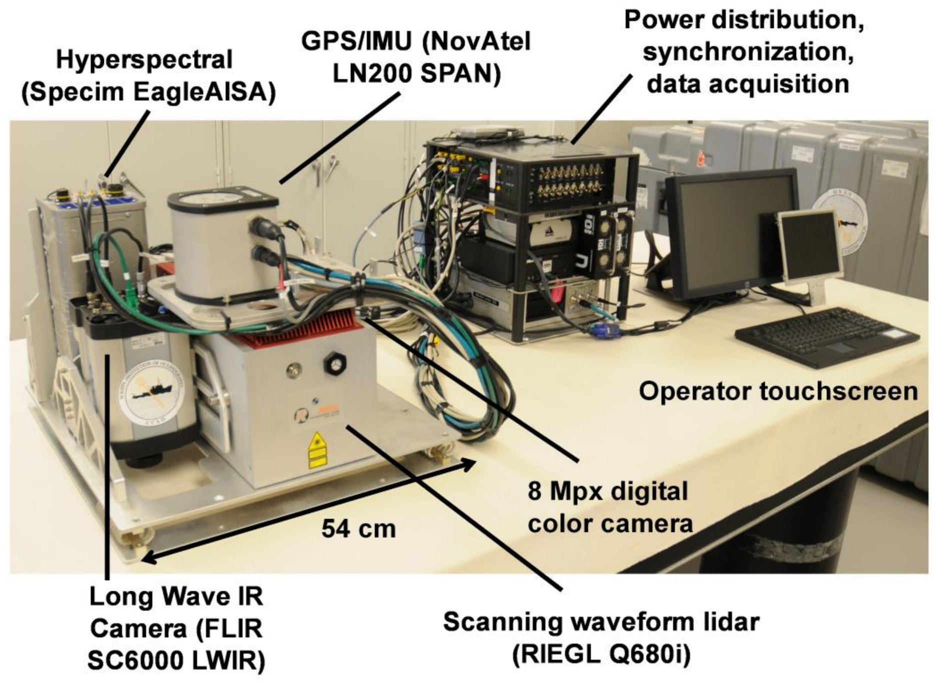
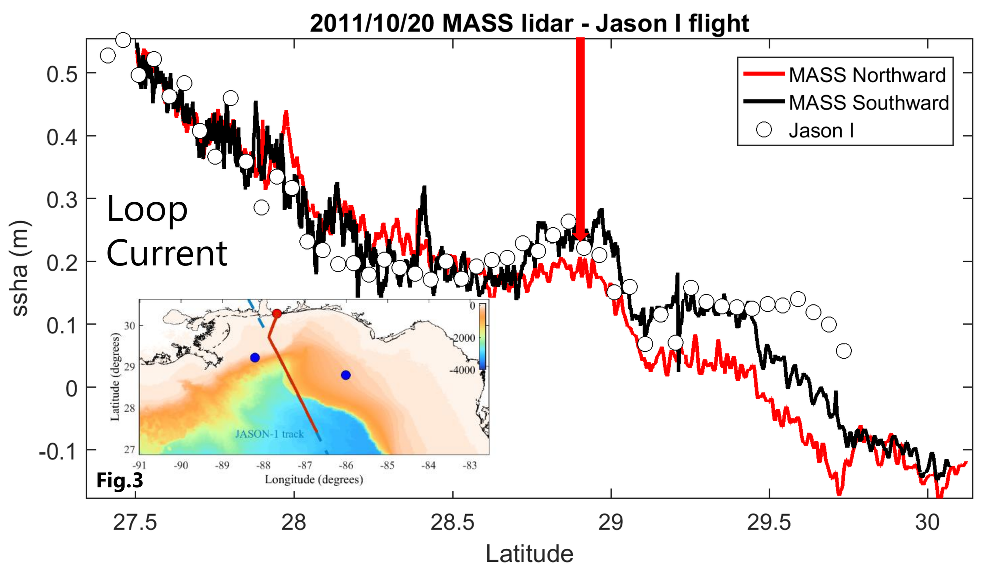


Fig. 2. Bottom panel: Modular Aerial Sensing System (MASS) at the Air-Sea Interaction Laboratory, Scripps Institution of Oceanography. The instrument package is typically installed on a Partenavia/Vulcanair P68 aircraft (top panel). The airborne system includes a scanning waveform Lidar, Long-Wave Infrared (LWIR) camera, SST sensor, visible high resolution camera, hyperspectral (VNIR) imager, and a GPS/IMU system.

SSHA from Airborne and Satellite Altimetry



Reciprocal passes across the Loop Current

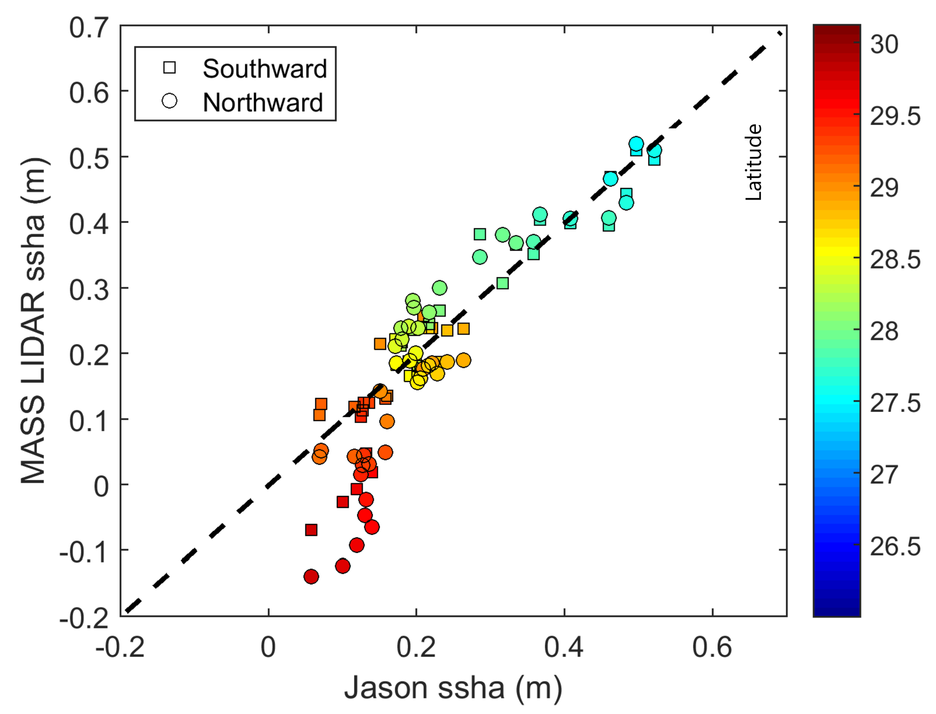


Fig. 4: Scatterplot of the SSHA measured by Jason-I and the MASS lidar averaged over the along-track spatial resolution of the satellite for the latter (color coded by latitude). Note the divergence for the northern part of the track, as we get close to the continental shelf.

Wave Directional Observations down to wavelengths of 0.8m

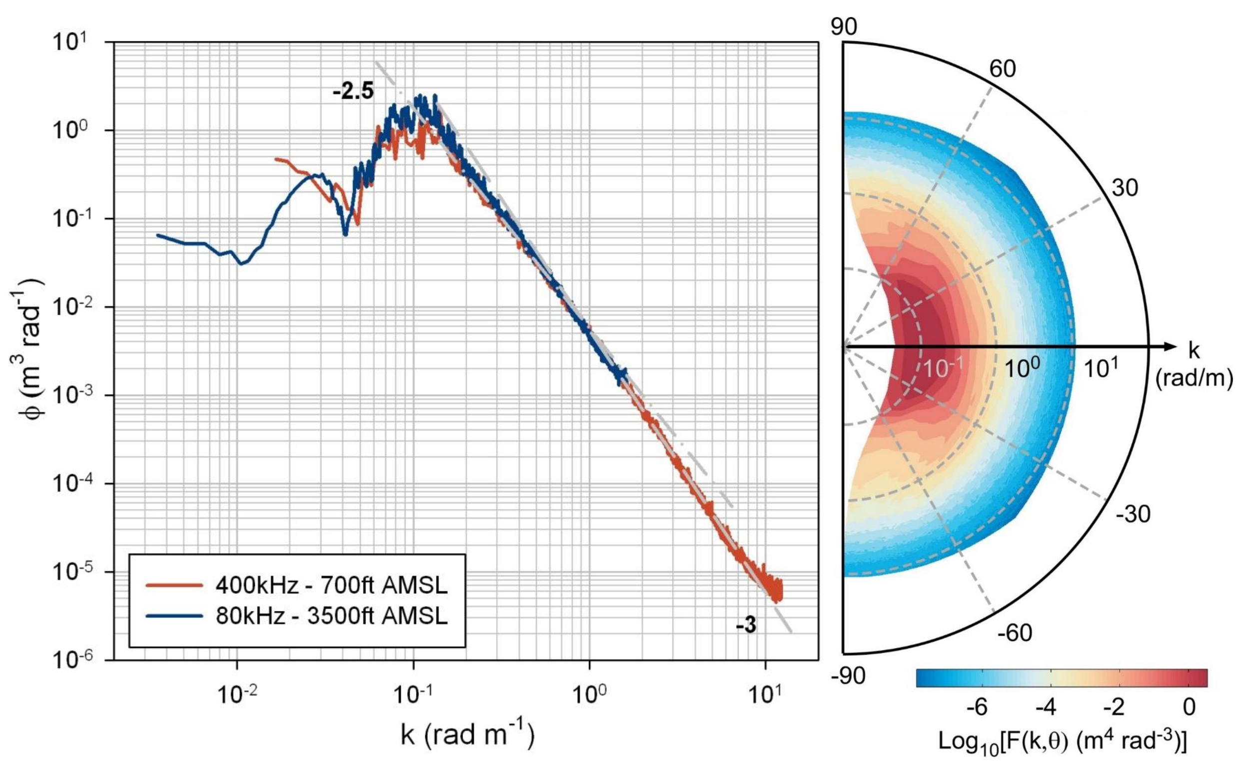
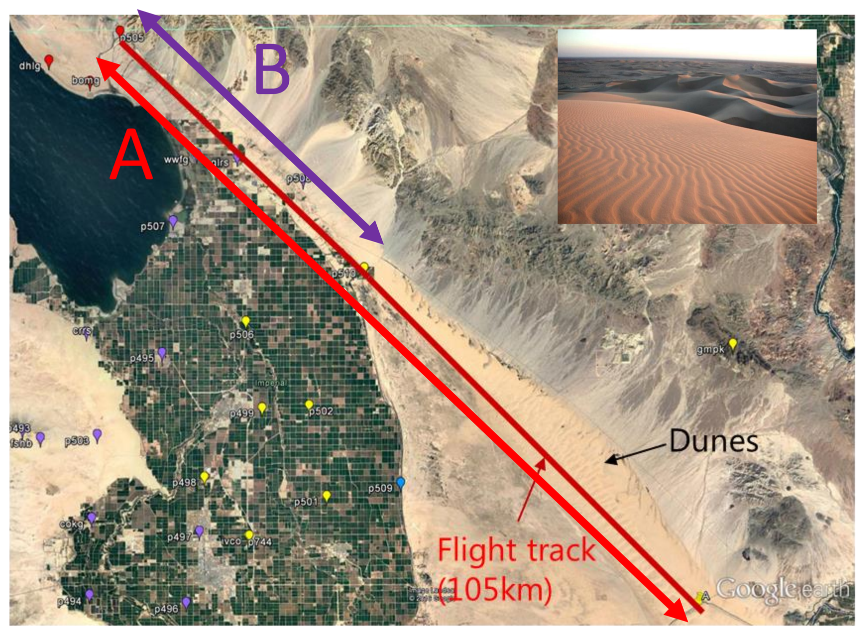


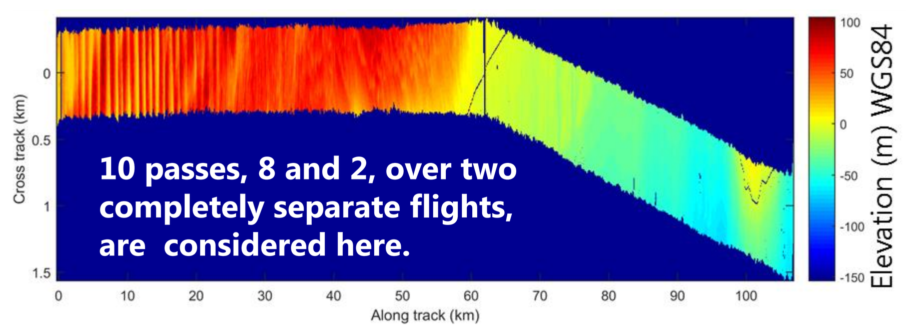
Fig. 5. (left) Omnidirectional wavenumber spectra for two passes flown at two different altitudes: 1100 m AMSL in blue, swath width 800 – 1000 m, spatial resolution of 1.2 m; 200 m AMSL in red 200 m swath, 12 – 25 cm spatial resolution from sea surface topography data recorded using the MASS on 4 Aug 2011 in the Santa Barbara Channel. These data give spectra down to wavelengths of 0.8 – 0.9 m, with directional resolution there of 0.2º, and 3.6º at the peak of the spectrum, λ = 64 m. Note -5/2 and -3 spectral slopes. (right) Directional spectrum from the sea surface topography recorded at 200 m AMSL.

References
Melville, W.K., Lenain, L., Cayan, D.R., Kahru, M., Kleissl, J.P., Linden, P.F. and Statom, N.M., 2016. *The Modular Aerial Sensing System.* Journal of Atmospheric and Oceanic Technology, 33(6), pp.1169-1184.

Spectral Error Validation Campaign

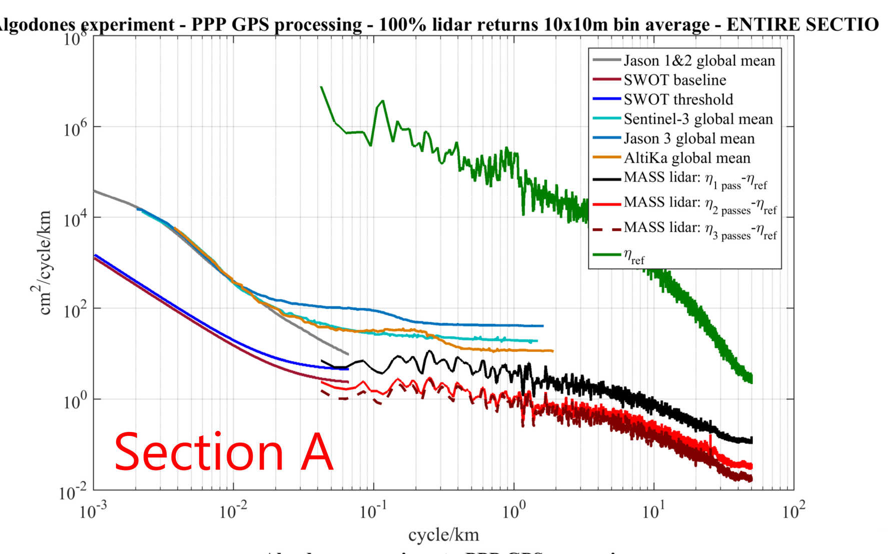
Algodones Dunes Campaign, October 17-19 2016

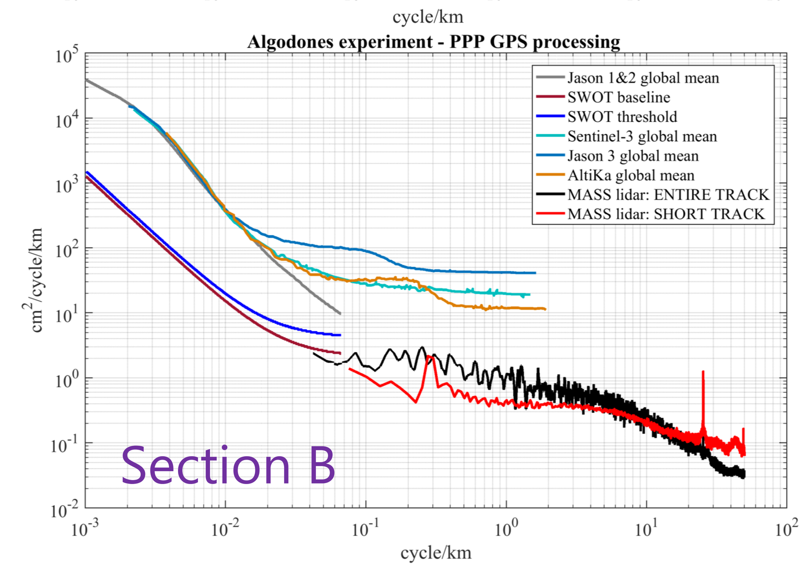




Procedure:
1 Compute residual from the 10-pass mean elevation profile (our reference) for n flight lines of resolution dx and dy.
2 Compute Residual spectrum for each pass and the n flight lines, then average them together.

Compliant with SWOT requirements for reciprocal airborne tracks



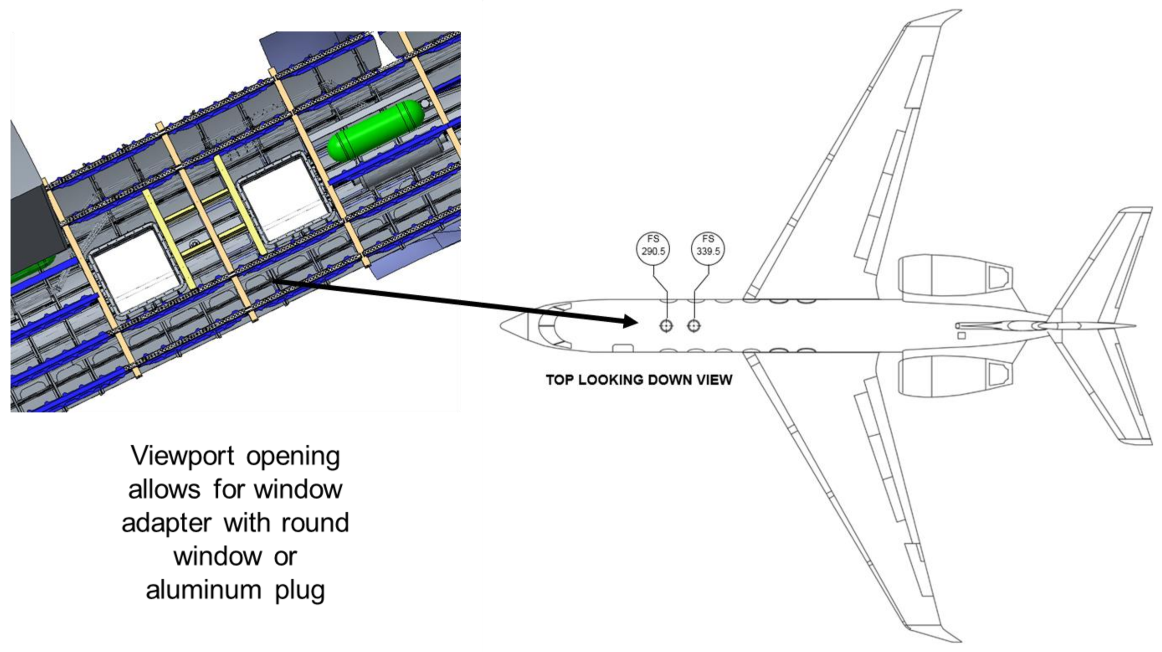


Transitioning to Longer Range Platforms For the CAL/VAL

NASA G-V (or equivalent)
Endurance: up to 15 hours
Useful Payload: 8,000 lbs
Gross Take-off Weight: 91,000 lbs
Max Altitude: 51,000 MSL
Air Speed: up to 500 knots
Range: 5,500 Nmi

MASS Integration in G-V (on-going, pilot experiment scheduled for Spring 2019)

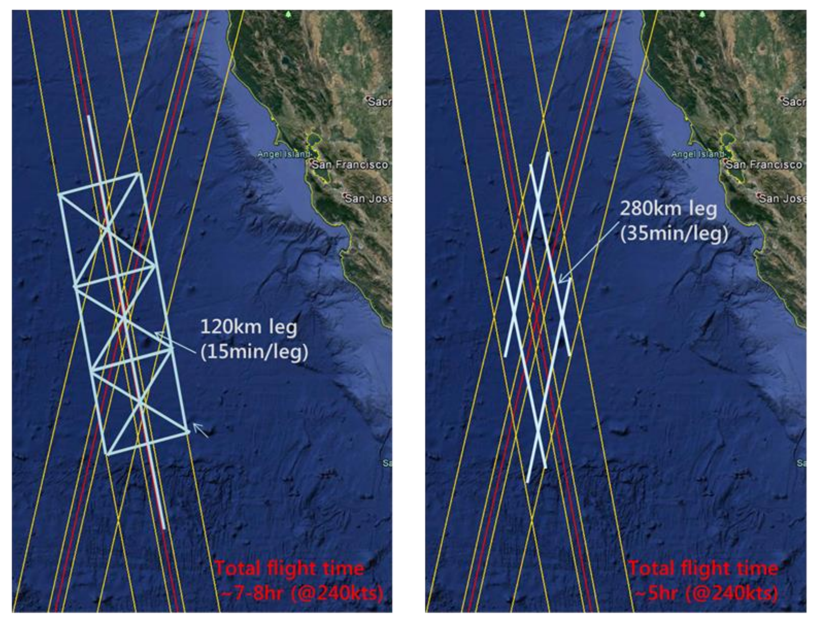
- Proposed concept validated by JSC, now proceeding with System Requirement Review (SRR)
- Using two 17.4" diameter optical viewports to be installed in Fall 2018



Viewport opening allows for window adapter with round window or aluminum plug

Site & Flight profiles

Flight profiles adjusted depending on objectives:
- Cross-track variability sampling and phase screen evaluation
- Spectral comparison with long, reciprocal, along track passes and few cross tracks
- Directional wave properties map (Hs directional spectra, steepness etc…)
- All cross tracks are reciprocal to reduce ssh errors and compute surface current from IR imagery (assuming there is enough temperature structure at the surface)



Summary: Airborne topographic lidar is an important tool for broadband micro- to meso-scale measurements of ocean surface processes. Airborne altimetry with an along-track resolution of O(1) m and a swath width comparable to the 250 m-resolution ocean data of SWOT will prove useful in better understanding surface signatures of ocean processes. The ability to measure surface-wave directional spectra when combined with SST data will contribute to upper ocean modeling (e.g. Langmuir turbulence). The correlation of sub-mesoscale current gradients (e.g. fronts) with ocean surface wave fields will prove important for the interpretation of SWOT data, not just for EM bias corrections.

Spectral studies of MASS noise levels have been made over the California desert showing compliance with SWOT requirements for reciprocal airborne tracks. An airborne lidar component for cal/val is proposed with associated airborne remote sensing and expendables (e.g. AXCTDs), and marine atmospheric boundary layer studies for winds and atmospheric stability.