Radar and Maritime Domain Awareness : current and future capabilities

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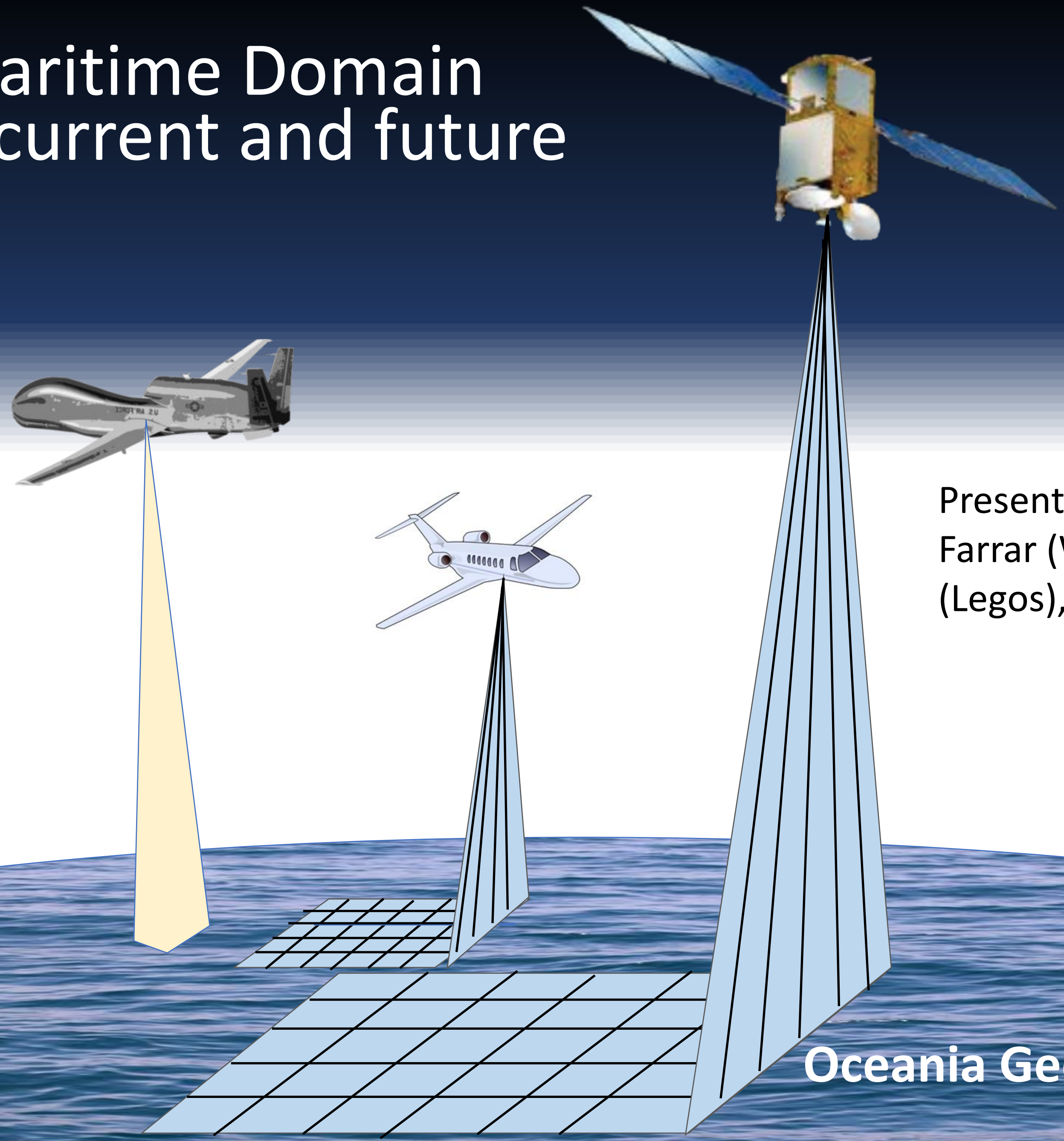


Presentation contributions from Tom Farrar (WHOI) & Rosemary Morrow (Legos), SWOT; Chris Ruf (UM), CYGNSS.

Oceania Geospatial Symposium 2022

Radar remote sensing for Maritime Domain Awareness

MDA includes:

- Environmental trends and impacts of climate change including coastal/shoreline preservation, fisheries and ecosystem health
- Pollutant spills, marine debris, inadvertent transport of invasive species
- (EEZ) regulation and security, search and rescue, economic development and planning

Today will focus on a few specific capabilities relevant to these:

- Ocean environmental sensing
  - Upcoming Surface Water Ocean Topography (***SWOT)*** mission (altimetry)
  - ***CYGNSS (GNSS-R for ocean-winds)***
- Coastal change mapping / monitoring & coastal inundation
  - ***CYGNSS & Rongowai (GNSS-R for inundation)***
  - ***NASA airborne demonstration for coastal topography and shoreline changes***
- Maritime security, debris and pollutant transport
  - CYGNSS debris example
  - Takahē (NZ/DLR mission concept collaboration for advanced small-object detection and tracking)

Where is global warming going?

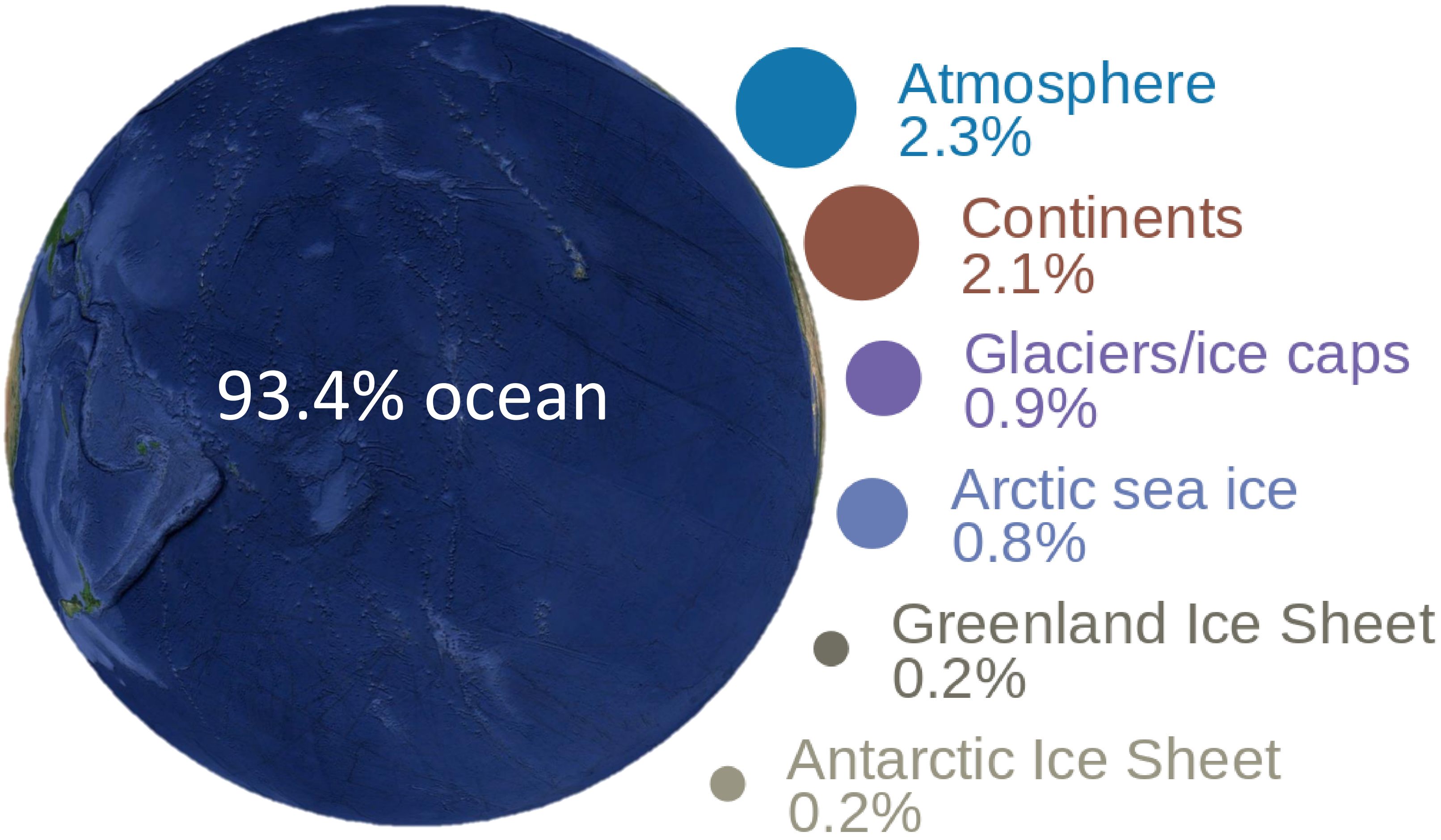
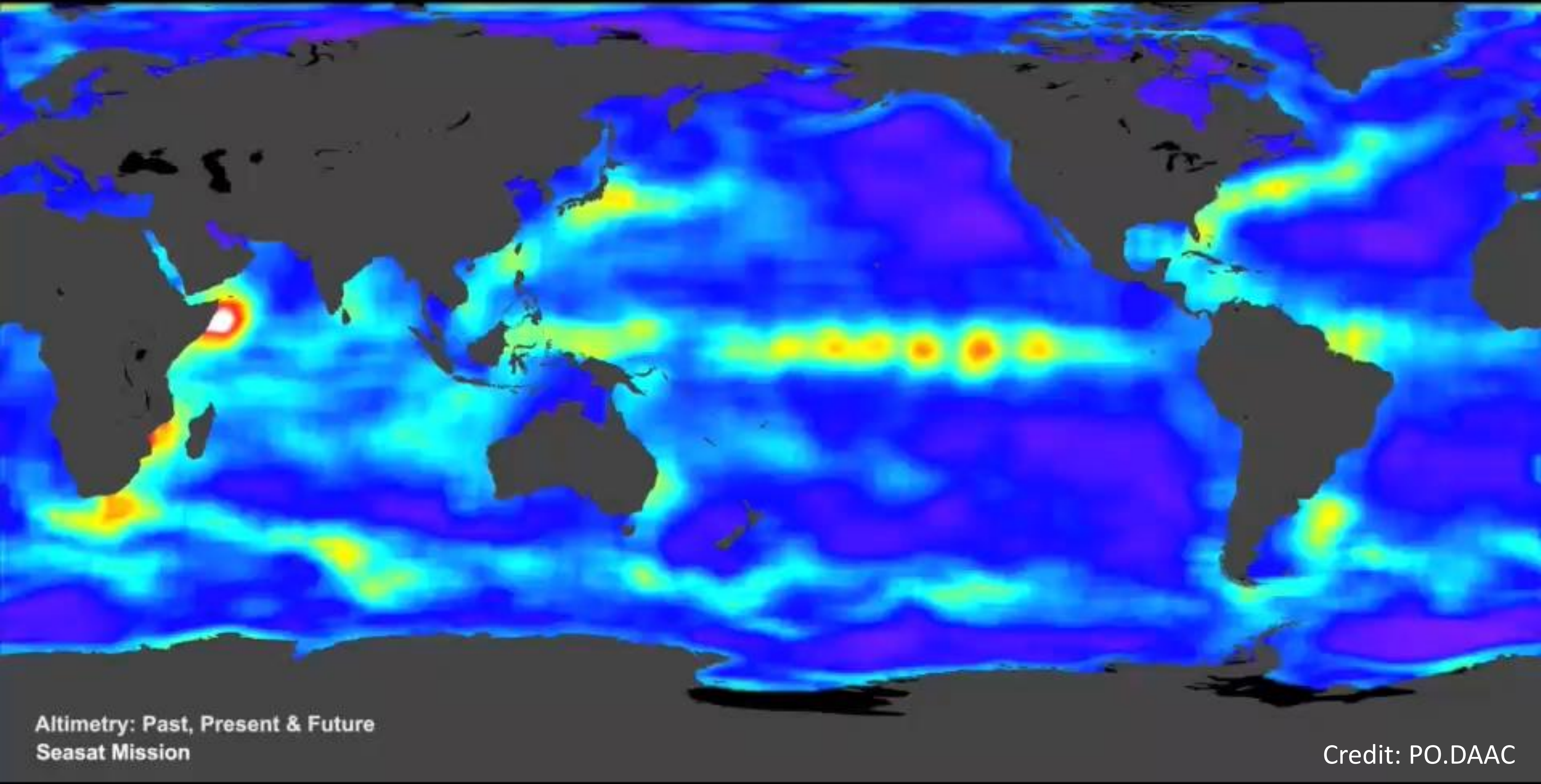


Image Credit: IPCC

This heat is redistributed in the oceans both horizontally & vertically



Credit: PO.DAAC

Ocean environmental sensing : SWOT

Mission Science

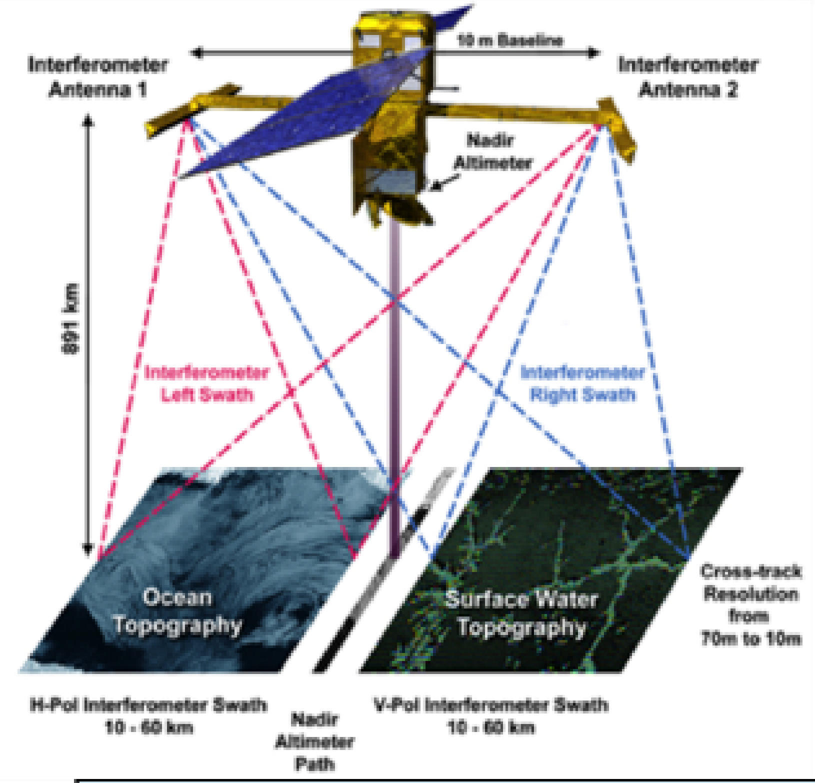
Oceanography: Characterize the ocean mesoscale and sub-mesoscale circulation at spatial resolutions of 15 km and greater.

Hydrology: To provide a global inventory of all terrestrial water bodies whose surface area exceeds $(250m)^2$ (lakes, reservoirs, wetlands) and rivers whose width exceeds 100 m (rivers).

- To measure the global storage change in fresh water bodies at sub-monthly, seasonal, and annual time scales.
- To estimate the global change in river discharge at sub-monthly, seasonal, and annual time scales.

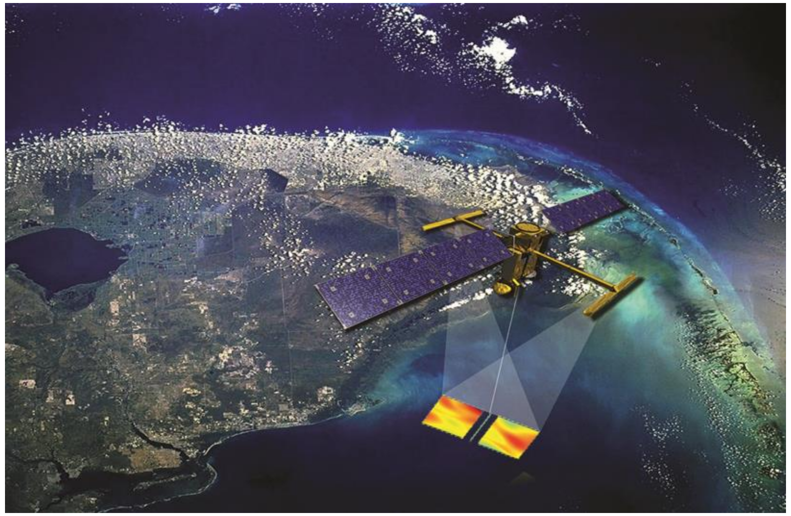
Mission Architecture

- Ka-band SAR interferometric (KaRIn) system with 2 swaths, 50 km each
- Produces heights and co-registered all-weather imagery
- Use conventional Jason-class altimeter for nadir coverage, radiometer for wet-tropospheric delay, and GPS/DORIS/LRA for POD.
- On-Board interferometric SAR processing over the ocean ($500m^2$ resolution) for data vol. reduction.



- Partnered mission : NASA/ JPL, CNES, UKSA & CSA
- Science mission duration of 3 years
- Calibration orbit: 857 km, 77.6° Incl., 1 day repeat
- Science orbit: 891 km, 77.6° Incl., 21 day repeat
- Flight System: ~2400kg, ~2100W
- Launch Vehicle: SpaceX Falcon 9
- Cat 2 Project, Risk Class: C
- Target Launch Readiness: 12 December 22

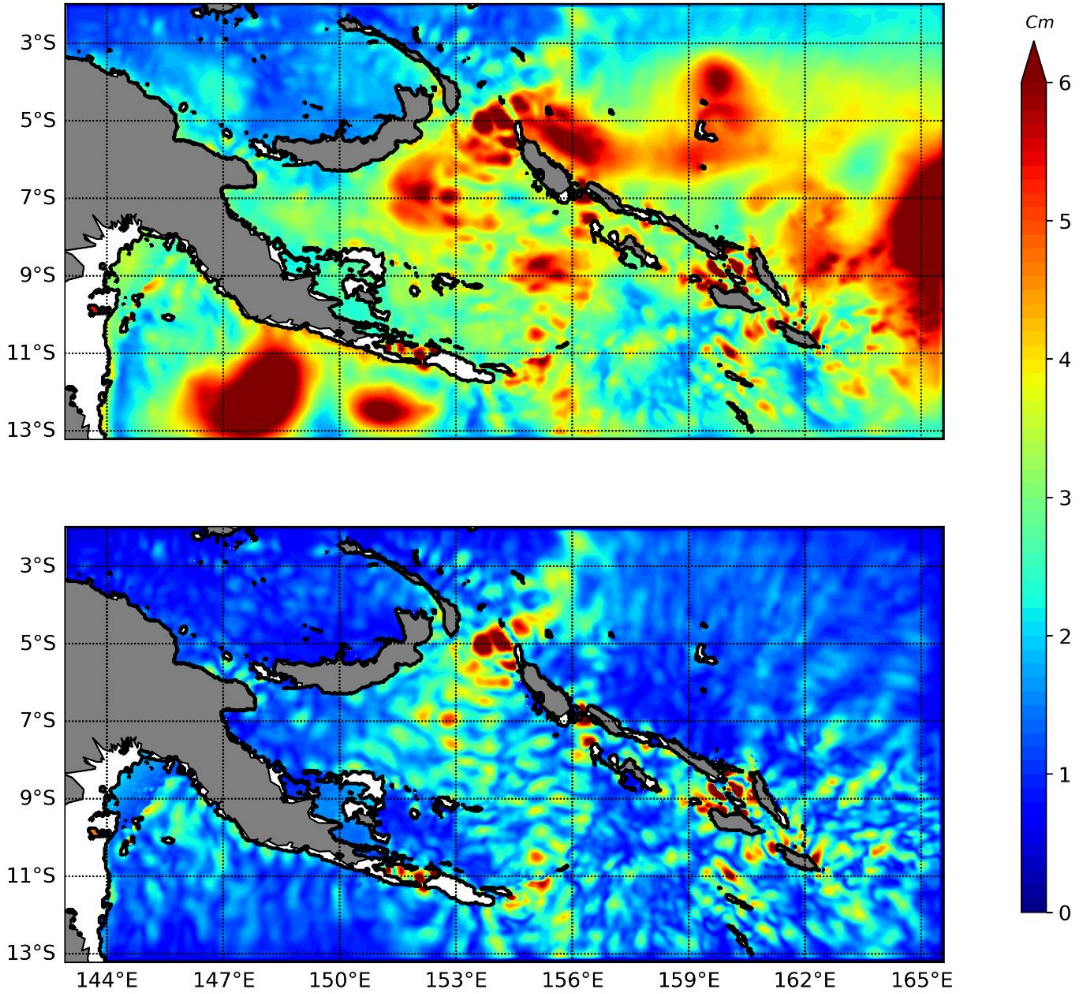
SWOT Ocean Objectives



SWOT SAR/Interferometry

- 2D observations 120 km wide

Example for Papua New Guinea/Solomon Islands



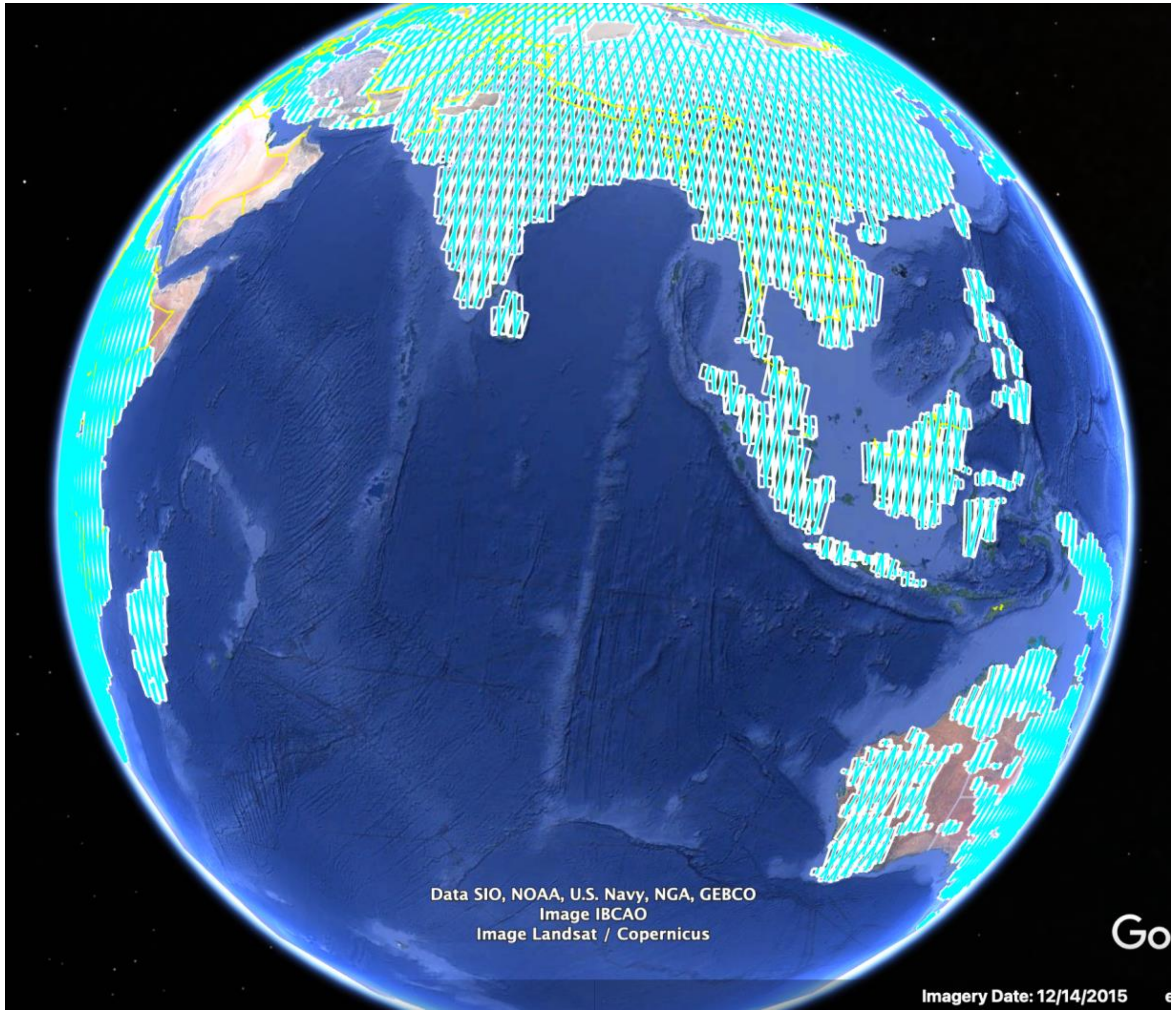
Ocean objectives:

- Observe small ocean eddies > 10 km diameter to enhance ocean currents & fill the gap 10-100 km.
- Measure ocean tides, and internal tides - > mixing and energy dissipation
- Global ocean observations of 250m x 250m (coastal) or 2x2 km (open ocean)

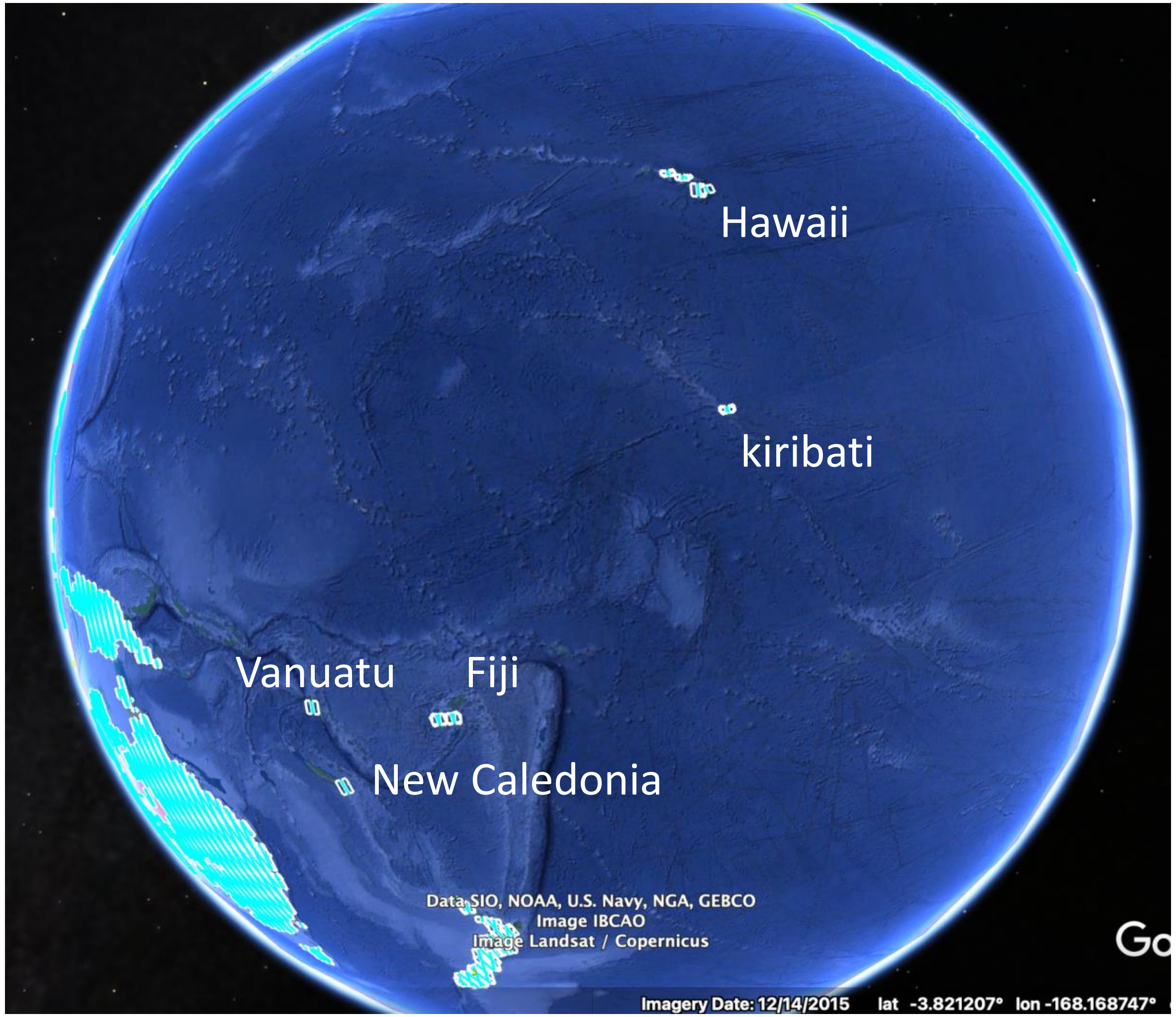
Launch Dec 12!

SWOT "High-rate" Data – Inland and Shores

- SWOT will collect high-resolution data for Water levels and extent in lakes, reservoirs and floodplains > 250 m^2
- River Levels, slopes and width > 100 m wide



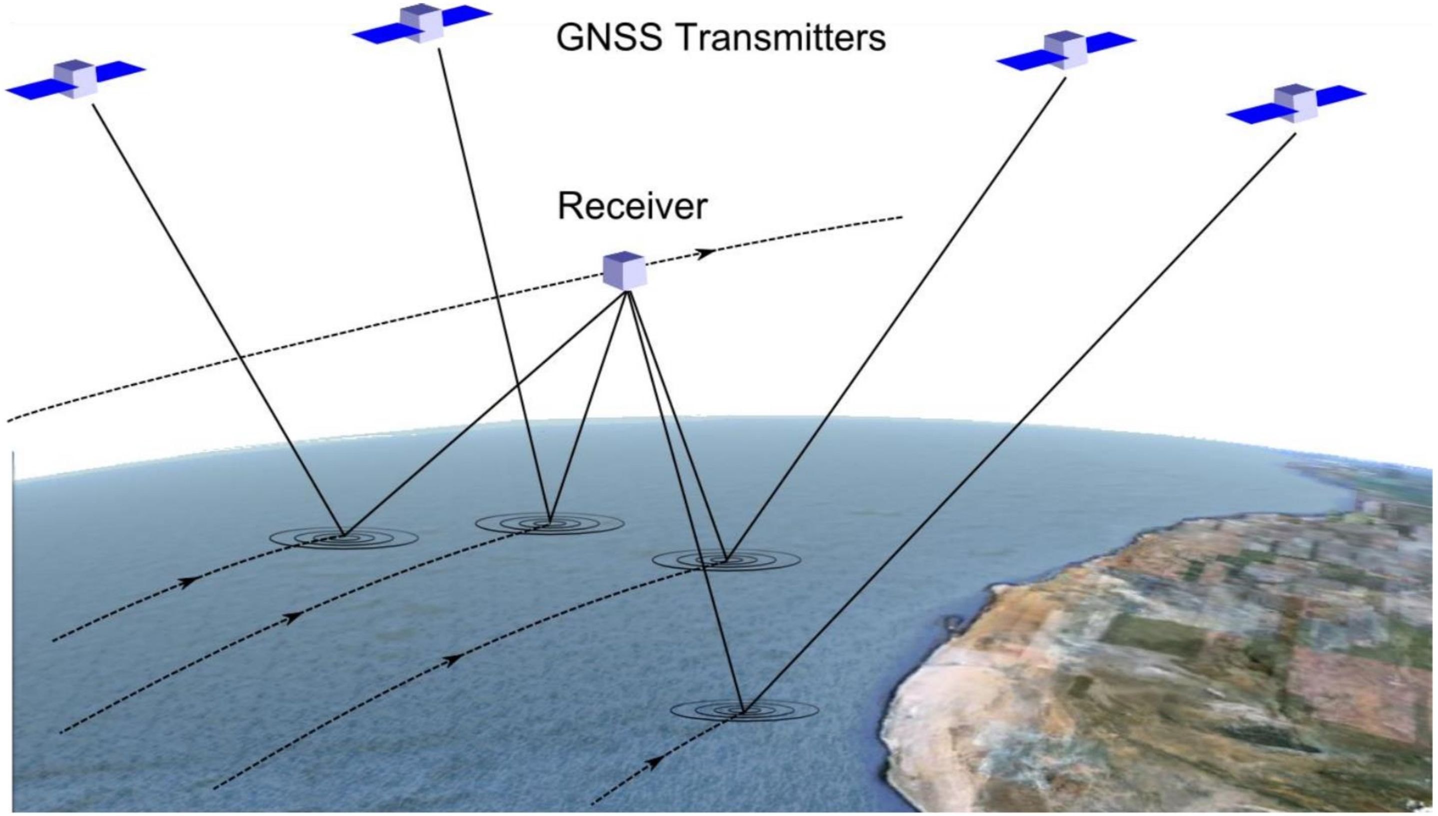
- Below are maps showing coverage for the Oceanic island nations planned for High-rate data collection. (21 day repeat)



Ocean environmental sensing:
Cyclone Global Navigation Satellite System (CYGNSS) Mission

NASA's CYGNSS mission has 8 microsats receiving GNSS signals for the first frequent space-based measurements of surface wind speeds in the inner core of tropical cyclones

- Launched 12/2016
- 35 degree inclination
  - Mean revisit 7 hours
  - Median 3 hours
- Now in extended mission life
- Commercial and governmental follow-on missions with advanced capabilities



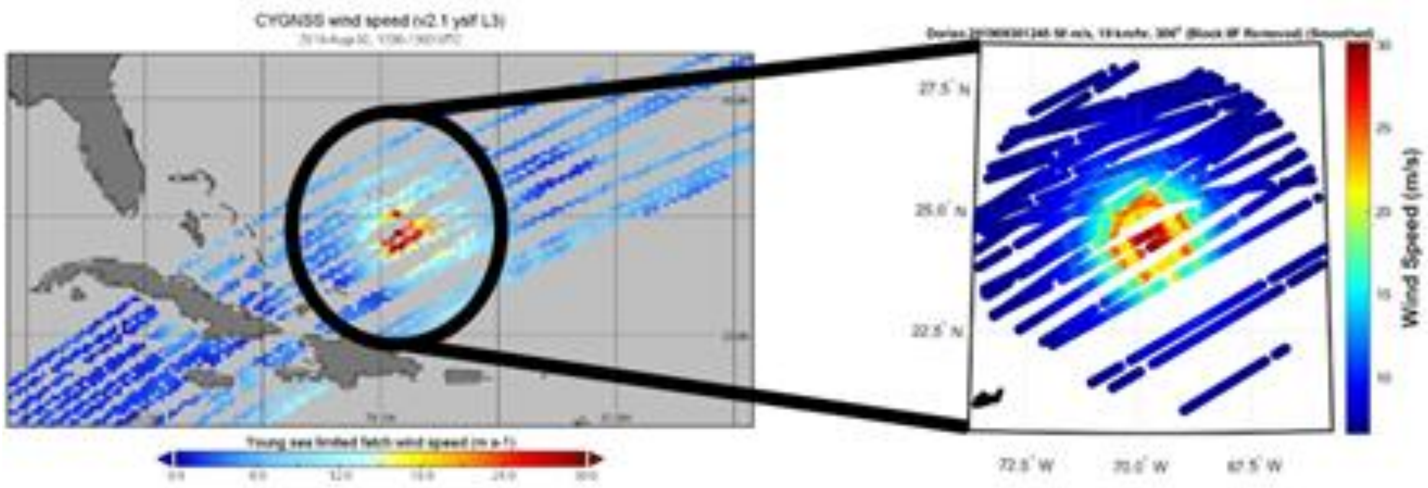
NASA CYGNSS (Cyclone GNSS) is a constellation of 8 microsatellites that receive GPS reflections off of the Earth's surface

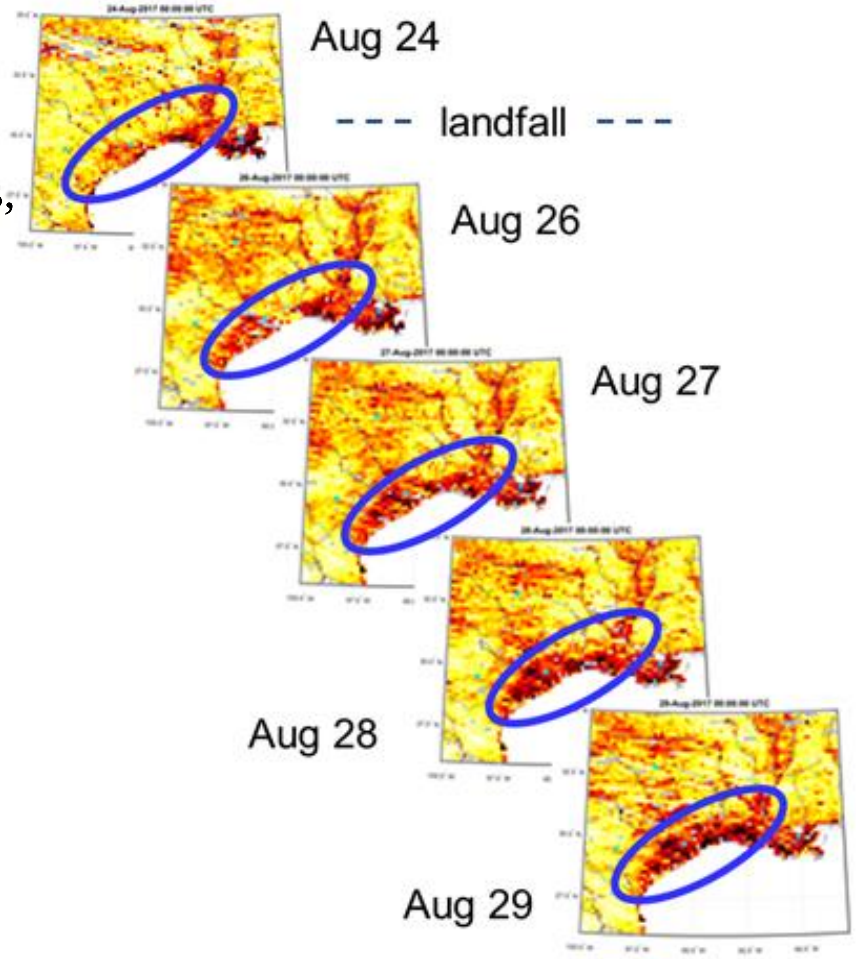
(PI Ruf – University of Michigan)

CYGNSS Global Wind Speed Product & Inland Inundation

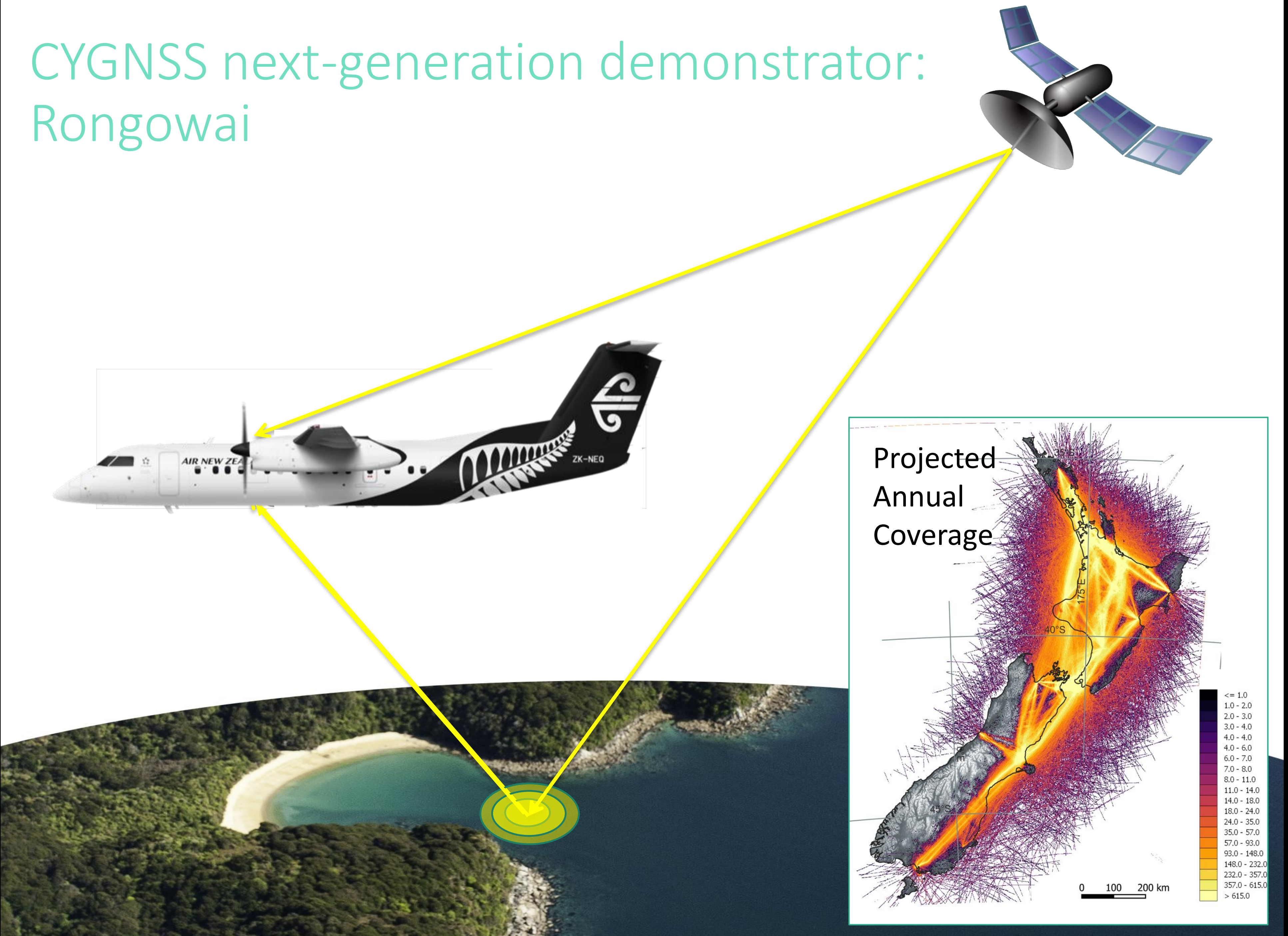
- **Measure winds in tropical cyclones**
  - Hurricane Dorian on 30 Aug 2019 at 02:45 UTC

- Map flood inundation after hurricane landfall
  - Aftermath of Hurricane Harvey landfall in SE Texas, Aug 2018





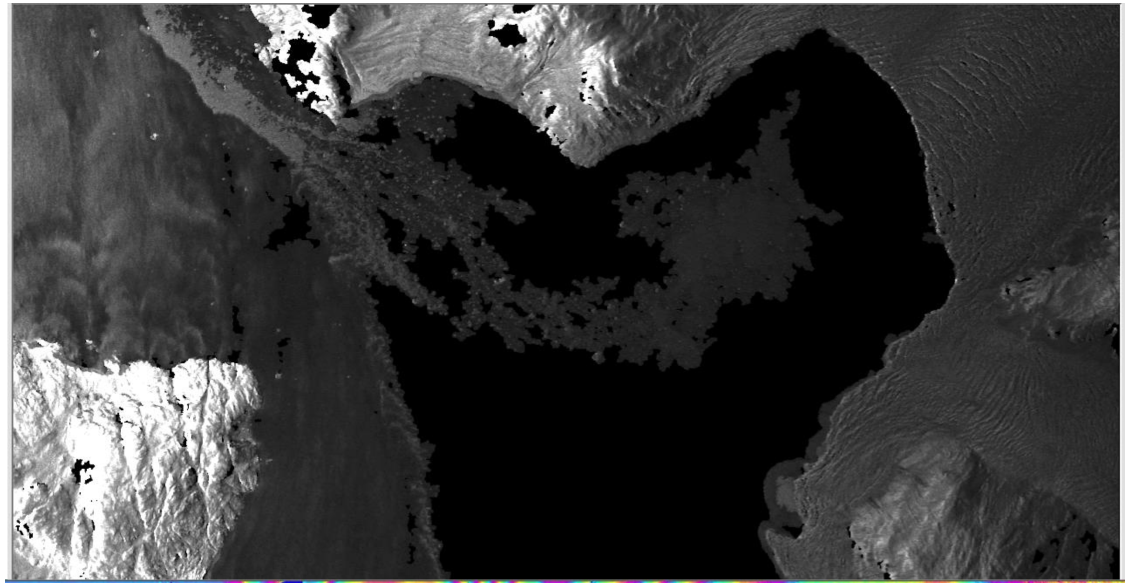
CYGNSS next-generation demonstrator: Rongowai

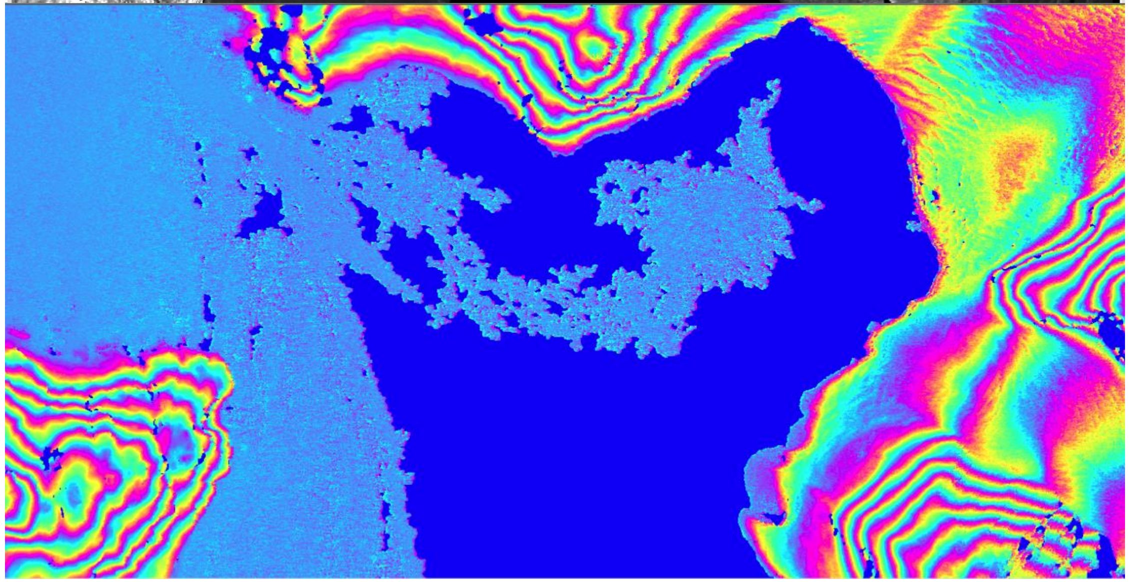


NZ international collaboration supporting NASA for its next generation mission

- Air New Zealand Q300 domestic platform
- World-first collaboration between NASA and a commercial passenger airline
- Next-generation receiver for advanced capabilities
- ***Extensive coastal coverage for changing inundation dynamics with sea-level rise***
- Science benefits for wetland and soil-moisture monitoring
- Long-term monitoring of local and regional climate change impacts

Shoreline and coastal change mapping: Airborne InSAR





- NOAA has a national shoreline mapping initiative supported primarily through airborne lidar surveys
- Dynamic coastal zones require repeat observations to assess impact from events such as storm-surge and flooding from hurricanes
- Low-lying Pacific Islands are vulnerable, including salt-water intrusion into fragile ecosystems and drinking water

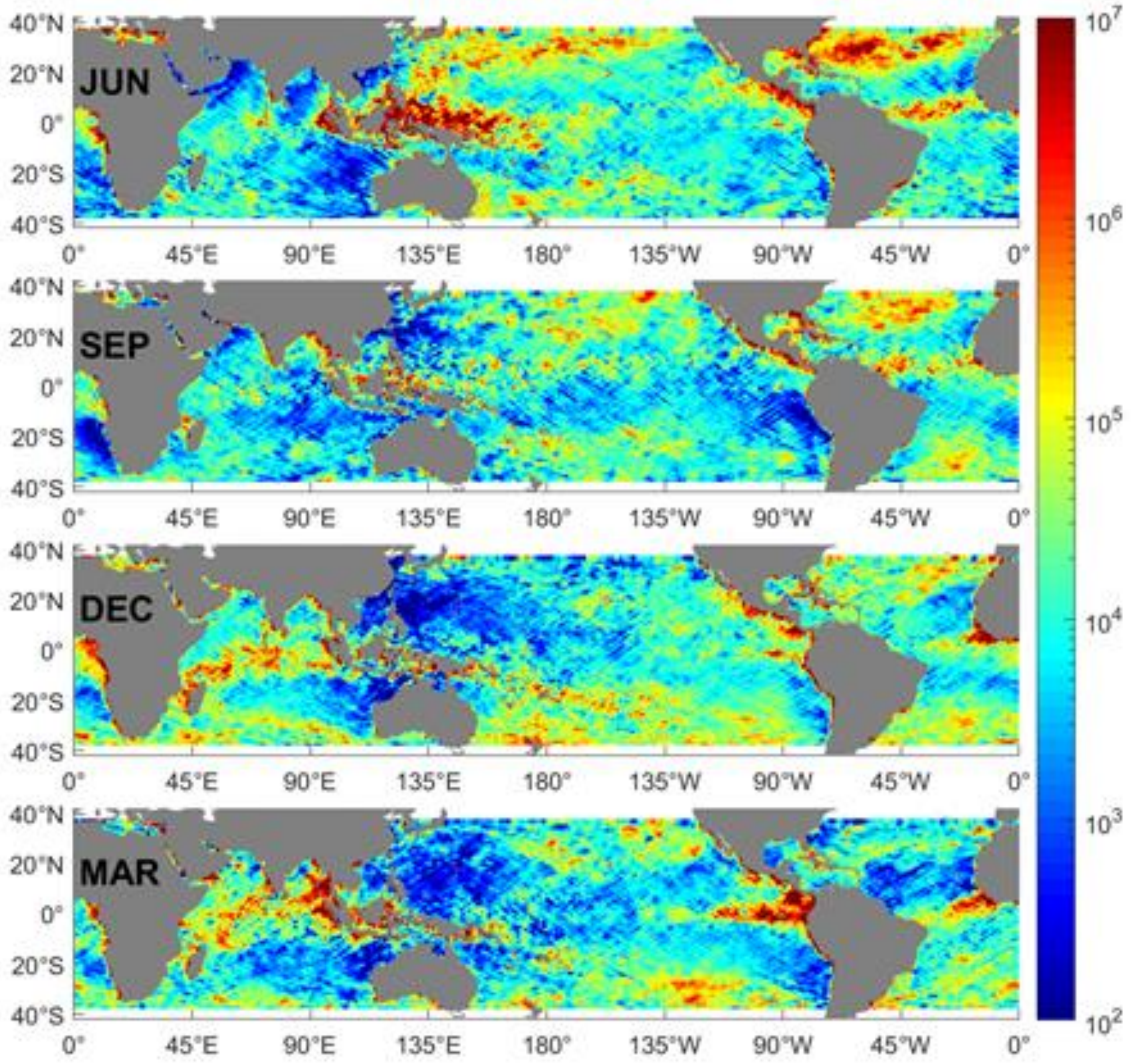
An airborne InSAR developed at NASA's JPL can cover two-orders of magnitude more area independent of cloud cover

- Example left shows high resolution coastal topography mapping and shoreline delineation capability from the GLISTIN Interferometer.

CYGNSS: Changes in Microplastic Concentration from Space

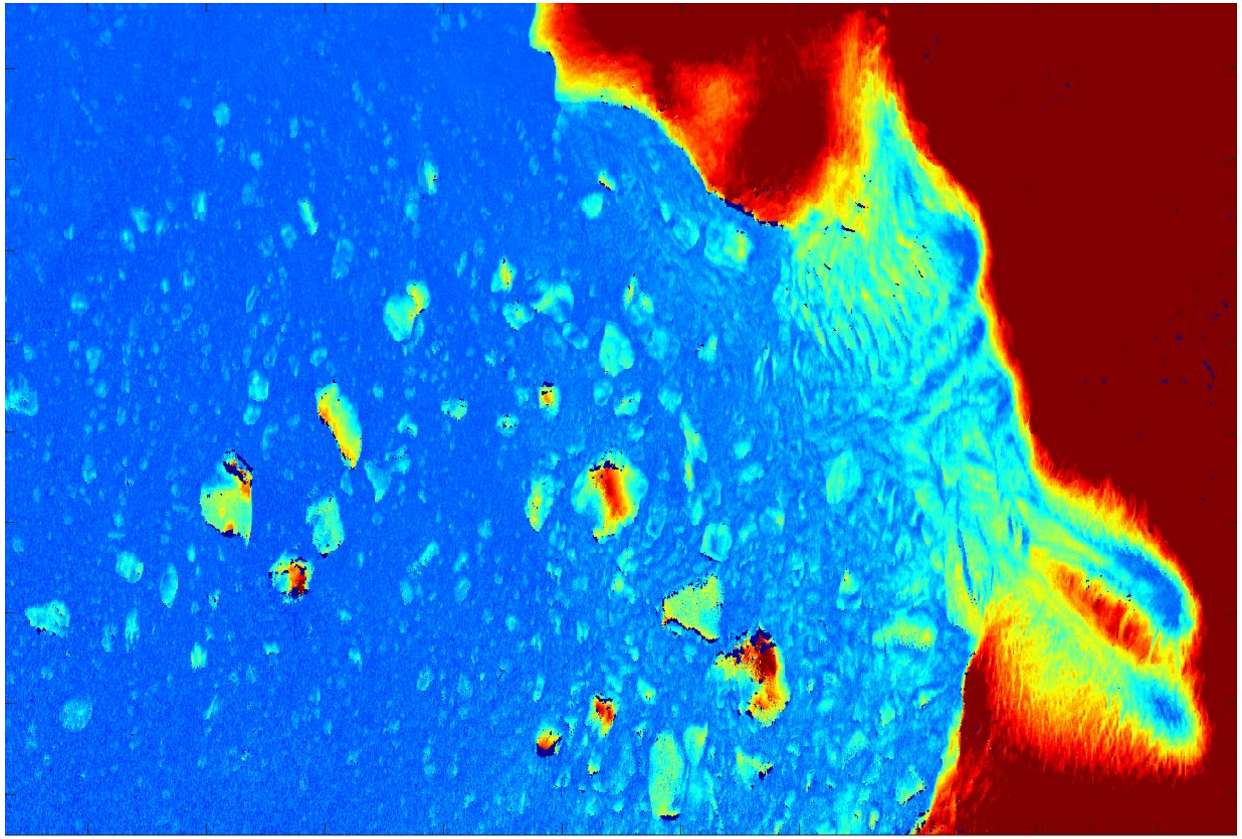
- Recent work for micro-plastic detection and tracking with GNSS-R
    - Measurement of ocean roughness anomaly by CYGNSS
    - Anomaly = Deviation of measured roughness from that predicted by scattering model forced by reanalysis wind speed
    - Highly correlated with ocean microplastic concentration
    - Monthly average microplastic number density concentration (#/km^2, log$_{10}$scale) for Jun-Sep-Dec 2017 and Mar 2018.
    - Both Atlantic and Pacific basins have generally higher concentrations in austral and boreal summer.
    - The northern Indian Ocean has highest concentrations in the spring.
    - Summer 2022 Field Campaigns (2) in the Great Pacific Garbage Patch

Seasonal variations in the Great Pacific Garbage Patch



Maritime security and (macro)debris

- Maritime domain awareness (MDA) and particularly ability to detect "objects" in a vast expanse is a long-standing problem
  - Detection and tracking of objects (e.g. vessels, marine debris objects, derelict fishing gear, bergy-bits) highly dependent on sea-state ("clutter") and classic swath/resolution trade-off.
- Many (SAR) assets in public and commercial arena addressing this problem but face fundamental trade-space challenges
  - quintessential "needle in a haystack" problem
- Single-pass interferometric SAR has shown analogous promise to progress the state-of-the-art in detection

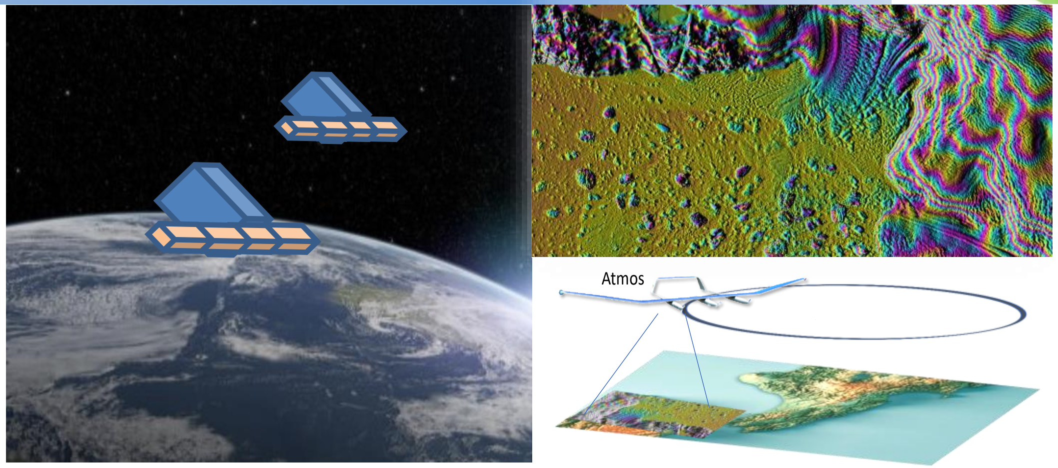


- New collaborative DLR/NZ study focused on identifying new measurements to advance the state-of-the-art based on airborne experiments
  - application of mm-wave single-pass interferometry for potential robustness to high sea-states and/or possible small (sub-pixel) detection;
  - extension to sea-ice, marine debris and pollutants

Takahē – a Tandem Ka-band & High-altitude platform Explorer for Ocean & Ice Monitoring

Mission Objectives:

- Provide science data that advances the state of the art in cryosphere research and maritime domain awareness and maritime security
- Global space mission addressing NZ environmental, social and science priorities
- Regional high-altitude platforms (HAP) for persistent monitoring
- Establish a national capability in RF payload development, SAR and innovation across hardware, data processing, and application domains
- Create a novel design that advances the state of practice in synthetic aperture radar space systems



Above: dual satellite formation flying cartoon. Upper right: illustrative SAR height map of glacial marine ouflow. Right: Persistent monitoring from HAPs.

Design:

- SmallSAT "node" based on existing technologies
  - *Ka-band center frequency* to maximize relative aperture, minimize snow/ice penetration, and optimize interferometric accuracy
  - DLR-developed techniques to *extend swath*
  - 4m long aperture, with simple, dual-hinge deployment
  - *Dual-satellite formation flying* option to allow for *advanced* ocean small object detection & groundbreaking freeboard retrieval
- Interferometric SAR payload on HAPs
  - X-band or Ka-band payloads to maximize aperture
  - *Novel processing algorithms* to manage HAPs slow speed & unpredictable trajectory

Performance:

- 2m x 2m single-look posting for sea-ice and small object detection (single satellite)
- Interferometric detection techniques allow for sub-metre object identification (dual-spacecraft or HAPs)
- 3-day or better repeat coverage from a single satellite (or pair)
- Hourly repeats for HAPs

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Summary

SWOT represents a scientific and technical breakthrough for oceanography and hydrology

- First observations of the ocean circulation at fine scale (10 km), and interactions with the tide
- improvement of dynamic and climate models for reanalysis of long series and ocean and hydrological forecasting
- Will be limited High Rate hydrology data over island nations but there will be some!

Launch 12 Dec 2022 : GO SWOT!

GNSS-R providing data for ocean winds, tropical storm evolution but also landfall inundation and debris tracking

- Future missions (government and commercial) will have advanced capabilities such as E5/L5 for altimetry, better resolution and coastal/terrestrial retrievals.
- Airborne missions play key observational roles

Airborne InSAR demonstrated potential for improving the state-of-the-art for maritime security and integrity

- Coastal topography and shoreline mapping
- Utilise scattering properties to improve SAR object detection

Multiscale mission concept in development (Takahē) utliising Small-SATs for broad-scale object detection, and HAPS for monitoring, tracking and characterisation/classification

More information is available on all of these capabilities!