The Bureau of Meteorology

New Ocean Remote Sensing Products and Opportunities for Operational Oceanography

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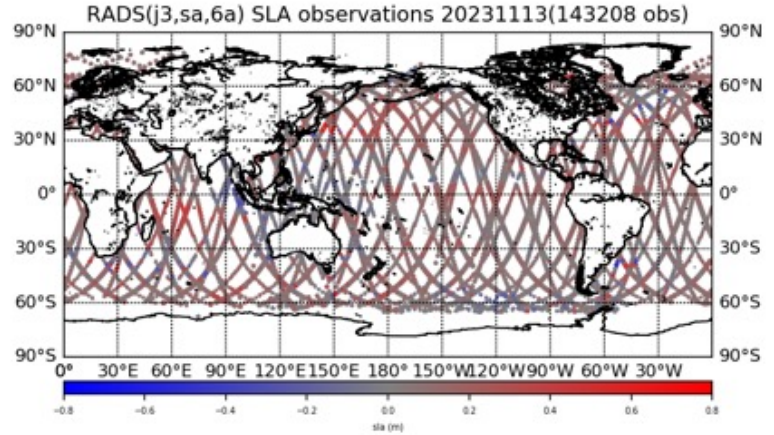
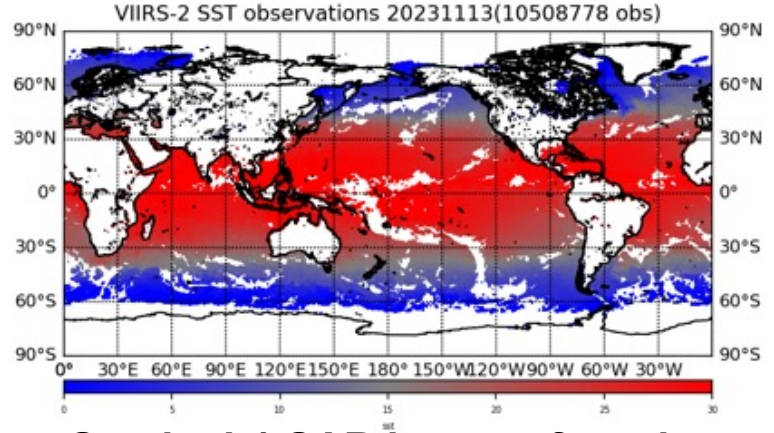
Forum for Operational Oceanography, Fremantle, WA, 29th November to 1st December 2023

What I will cover

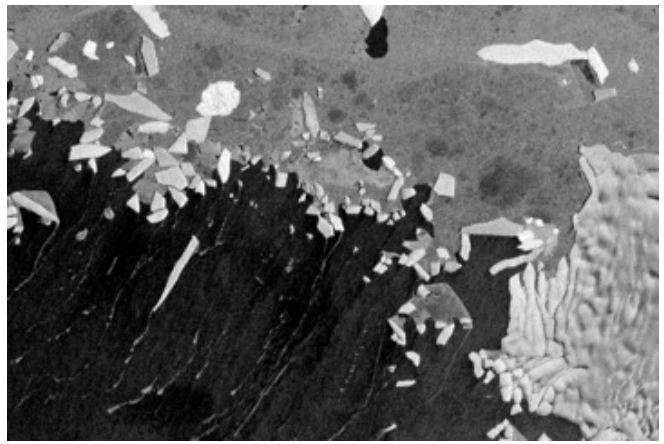
- **New and future ocean remote sensing products most useful for Bureau marine and ocean services:**
  - Sea Level Anomaly (SLA)
  - Sea Surface Temperature (SST)
  - Synthetic Aperture Radar (SAR) winds, waves, sea-ice, inundation, etc
- Potential impact on operational marine and ocean services



NOAA-20 VIIRS SST



Sentinel-1 SAR image of sea ice



How satellite SLA helps Bureau marine and ocean services

Current applications:

SLA data from Radar Altimeter Database System (RADS) are assimilated into:

- Operational global 10 km and regional 2 km ocean models
  → ocean state analyses and 7-day forecasts
  → tropical cyclone forecasts, marine industries, search & rescue, defence, etc

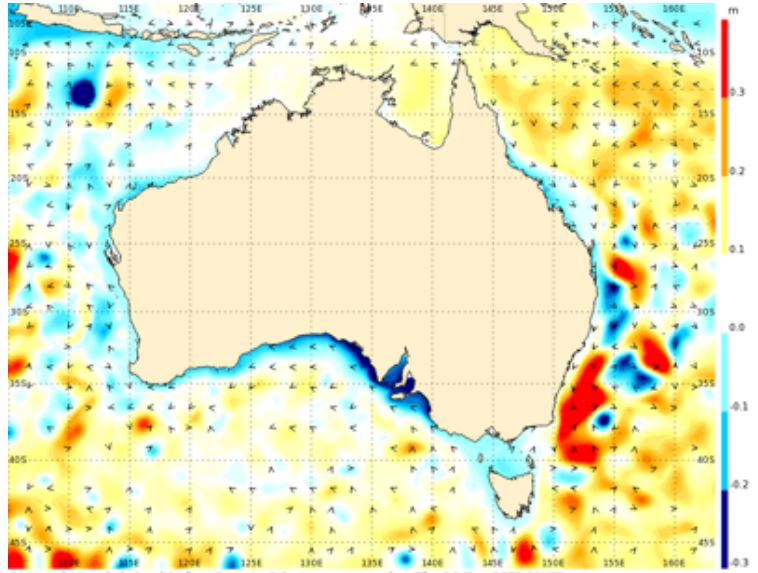
- *Demonstration* global 10 km ocean-ice coupled model

Future applications:

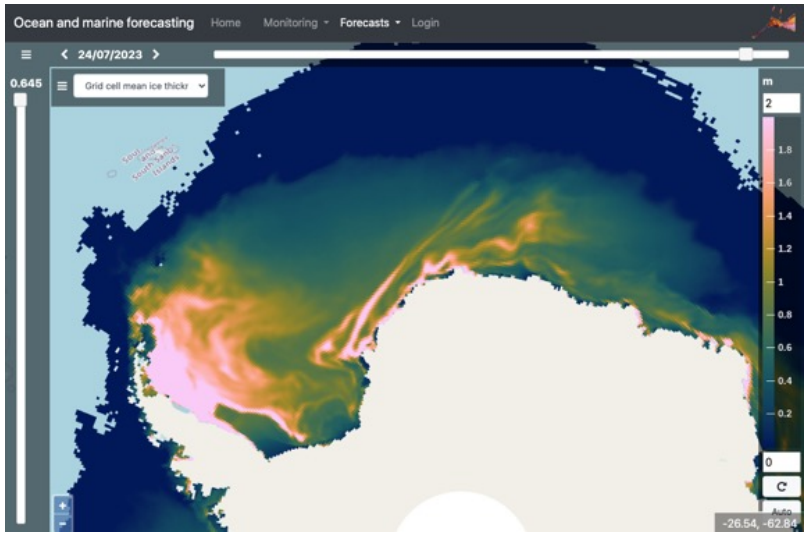
- Operational global 10 km ocean-ice coupled model (OceanMAPS v4.2)
  → sea-ice analyses and 7-day forecasts
  → safer ship navigation

- Operational global and regional, fully coupled atmosphere-ocean-ice NWP models
  → improved weather forecasts

SLA & Currents forecast 16 Nov 2023



Mean Ice Thickness 24 Jul 2023



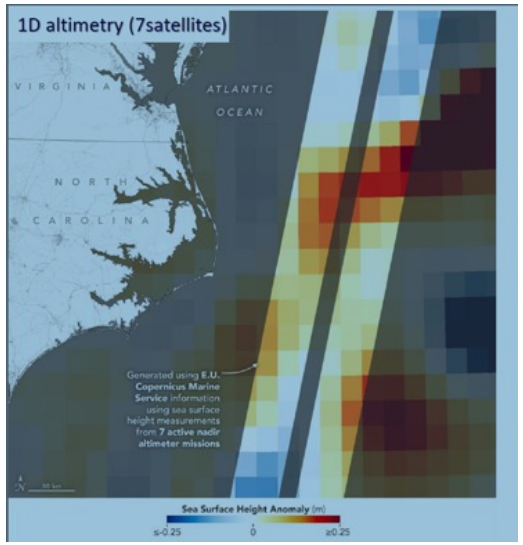
Altimeter missions relevant to Bureau marine and ocean services

Launch Year	Satellite	Altimeter	Latitude range (ºS/ºN)	Equatorial track separation (km)	Revisit Time (days)
2010	Cryosat-2 (ESA)	Siral	88		
2013	SARAL (CNES/ISRO)	AltiKa	90	75	35
2016	Jason-3 (NASA/EUMETSAT)	Poseidon-3B	66.15	315	9.9
2016	Sentinel-3A (ESA)	SRAL	81.35	104	27
2018	Sentinel-3B (ESA)	SRAL	81.35	104	27
2020	Sentinel-6A (ESA)	Poseidon-4		315	10
2022	SWOT (NASA/CNES)	KaRIn	78		20.9
>2032	S3NG-T (ESA)	Poseidon-5			

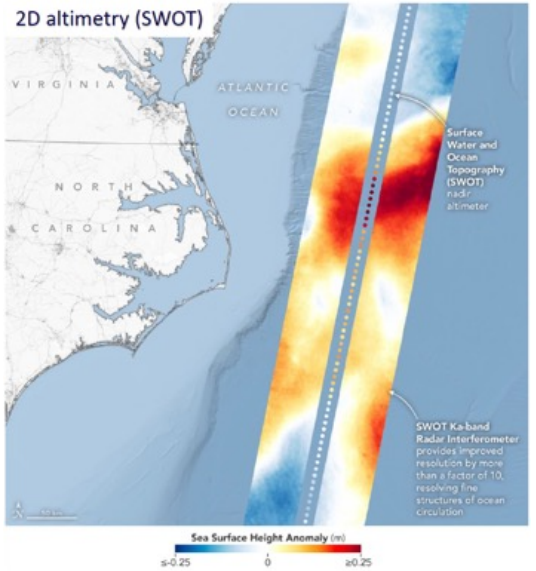
SWOT SLA Products (NASA/CNES)

- Along-track altimeter observations prior to SWOT provide limited spatial and temporal resolution of ocean mesoscale and sub-mesoscale dynamics
- SWOT's 120 km wide swath enables almost instantaneous 2D maps of sea level observations and their gradients, resolving features < 20 km
- But SWOT's wide swath presents challenge of assimilating SLA with large correlated observation errors
- SWOT SLA is expected to improve sea surface height and surface current errors in high-resolution (~1.5 km) regional ocean models (*e.g., King and Martin, 2021, Ocean Sci.*)
- Pre-validated SWOT SLA data (nadir only) currently available from RADS
- April 2024: End of validation phase – release of validated product

1D altimetry from 7 satellites (21 Jan 2023)



2D altimetry from SWOT (21 Jan 2023)



Source: Hamlington et al. (2023) Earth's Future

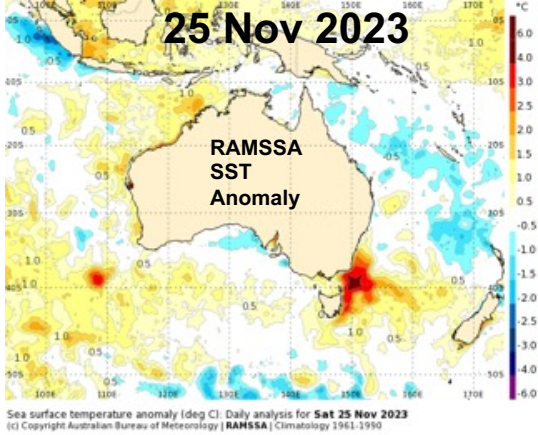
How satellite SST helps Bureau marine and ocean services

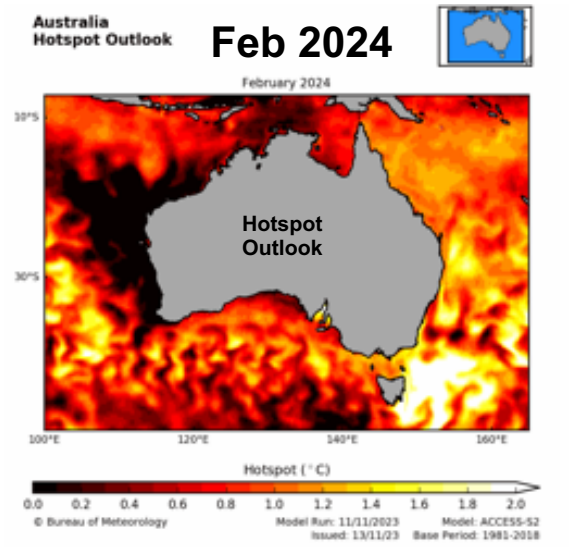
Current applications:

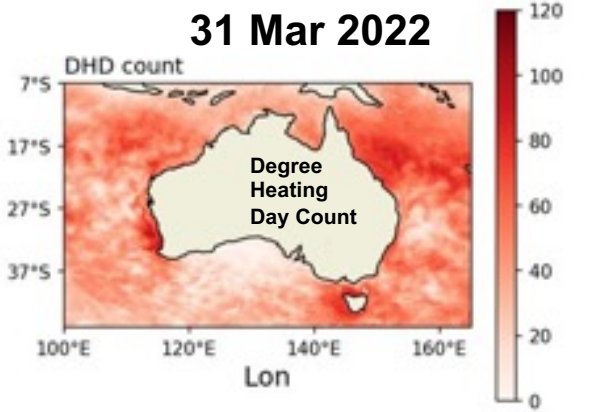
- global and regional ocean models (e.g., OceanMAPS v4.0i)
- global and regional Numerical Weather Prediction (NWP) models, providing:
  - analyses and forecasts of routine and severe weather events, including marine winds and tropical cyclones
  - ocean surface wind forcing for wave models (AusWave)
  - surface stress and heat fluxes for operational ocean models
- Regional SST analysis maps inform weather forecasters (Visual Weather) and general public (MetEye and http://www.bom.gov.au/marine/sst.shtml)
- Seasonal prediction model (ACCESS-S2), providing:
  - analyses and forecasts of marine heatwaves and thermal stress
- Climate Drivers (e.g., NINO and IOD indices)
- ReefTemp informs GBR Marine Park Managers on threats to corals

Future applications:

- Assimilation into global and regional, fully coupled atmosphere-ocean-ice NWP models
- Marine heatwave and thermal stress monitoring tools for Australian region (IMOS AusTemp)







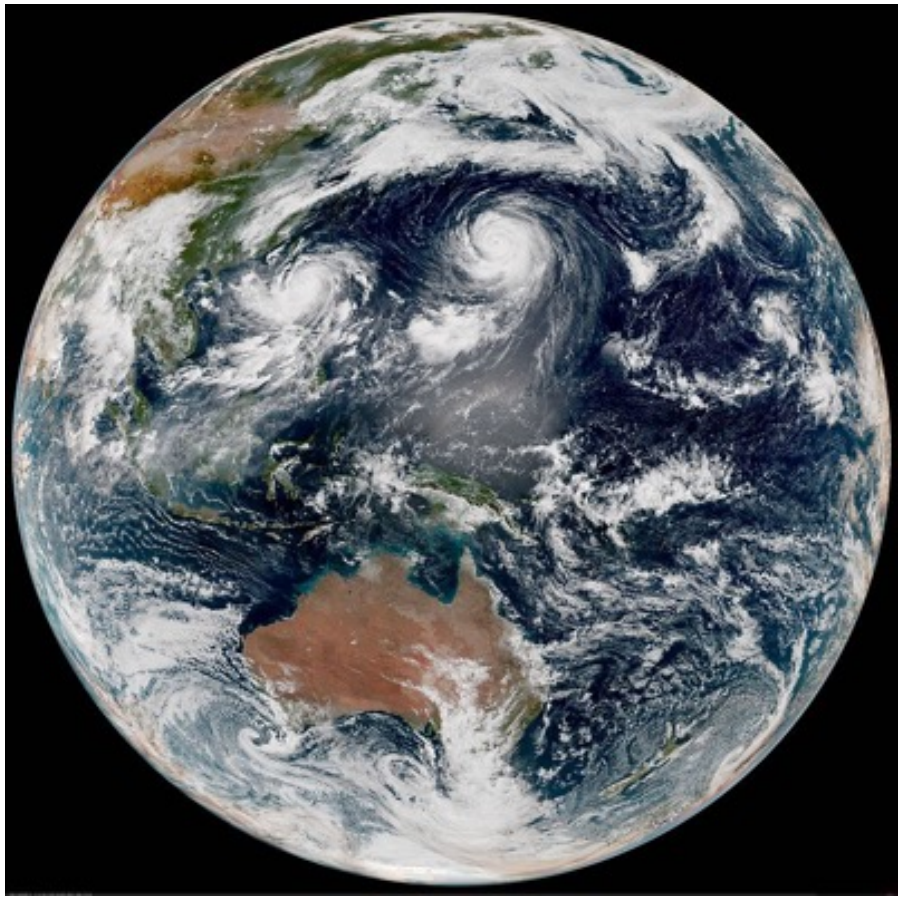
SST missions relevant to Bureau marine and ocean services

Start Year	Satellite	Radiometer	Swath (km)	Resolution at nadir (km)	Local Equator Crossing Time	Revisit Time at Equator (days)
2011	Suomi-NPP (NASA/NOAA)	VIIRS (IR)	3060	0.75	1:30 pm	16
2012	MetOp-B (EUMETSAT)	AVHRR/3 (IR)	2600	1.1	9:30 am	29
2012	GCOM-W1 (JAXA)	AMSR2 (MW)	1450	40	1:30 pm	1-2
2017	NOAA-20 (NOAA)	VIIRS (IR)	3060	0.75	1:30 pm	16
2018	MetOp-C (EUMETSAT)	AVHRR/3 (IR)	2600	1.1	9:30 am	29
2022	Himawari-9 (JMA)	AHI (IR)	GEO	2	GEO	10 min
2022	NOAA-21 (NOAA)	VIIRS (IR)	3060	0.75	1:30 pm	16
2024-25	GOSAT-GW (JAXA)	ASMR3 (MW)	1530	20	1:30 pm	3
2025	EPS-SG (ESA)	METImage (IR)	2670	0.5	9:30 am	
2026	TRISHNA (ISRO/CNES)	TIR	1026	0.057 (coastal)	1:00 pm	3
2029	LSTM (ESA) x 2	LSTM (IR)	670	0.050 (coastal)	12:30 pm	2
2029	SBG (NASA)	TIR	935	<0.060	Varying	2 - 3
2029-30	CIMR	imager (MW)	1900	< 15	6:00 am	1

Himawari-8/9 (JMA)

- Geostationary satellite located at 140.7°E
- Observes the Earth from 80°E to 160°W and from 60°N to 60°S
- Himawari-8: operational 7th July 2015 to 11th December 2022,
  Himawari-9: operational 12th December 2022 to present
- Advanced Himawari Imager (AHI), on board Himawari-8 and Himawari-9, provides full disk images every 10 minutes at 2 km spatial resolution for infra-red (IR) frequency data at nadir

Rayleigh-corrected, true-colour full disk Himawari-8 image
https://en.wikipedia.org/wiki/Himawari_8#/media/File:Himawari_8_Full_Disk_Aug_21_2015_0210Z.jpg

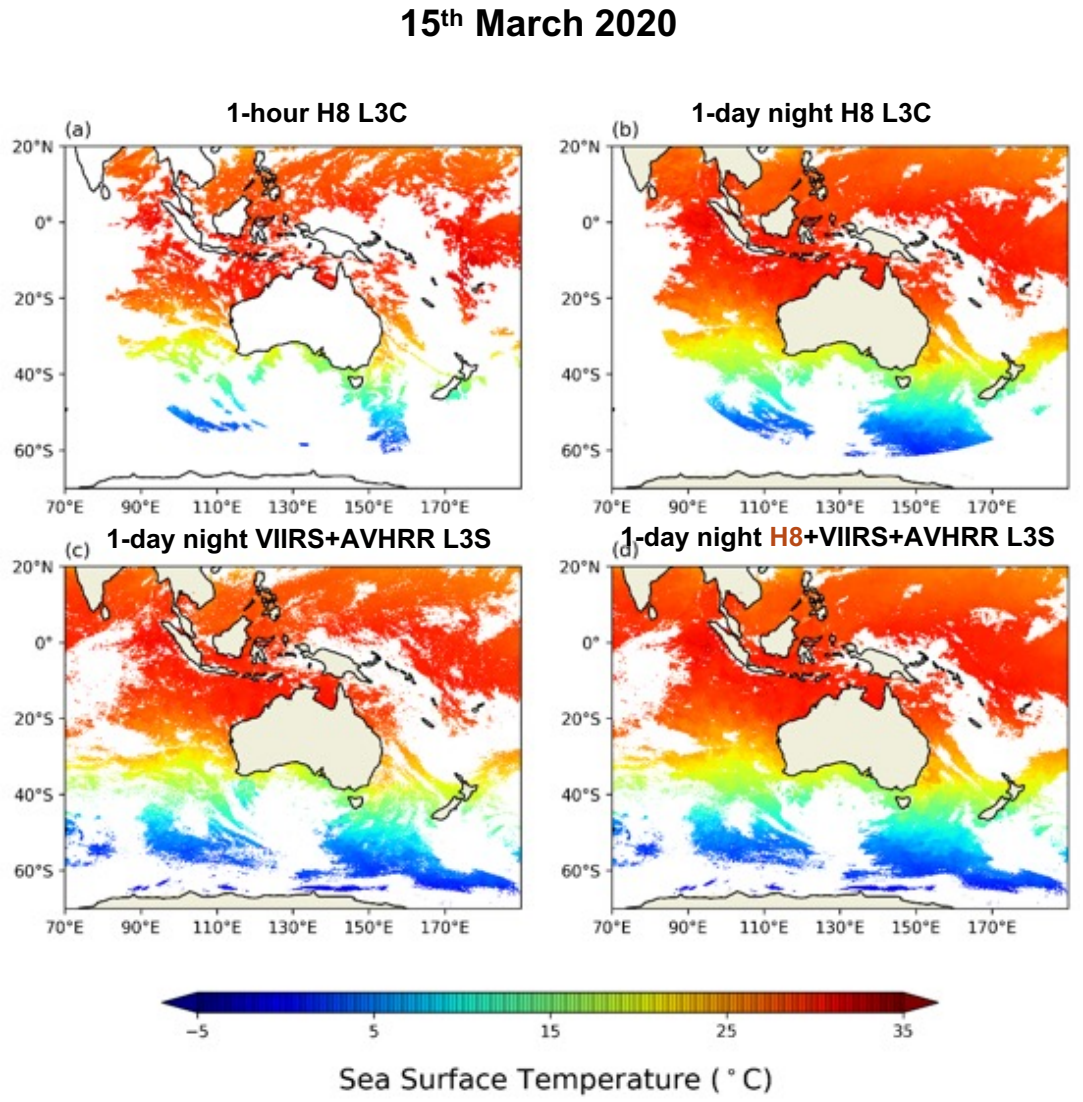


Himawari-8 SST products (BoM/IMOS)

- SST retrieval method based on ESA CCI SST code developed by Uni of Reading (*Merchant et al., 2019, Scientific Data*)

- IMOS reprocessed ("fv02") Himawari-8 SST products available 1 Sep 2015 to 11 Dec 2022:
  - 2 km 10-min L2P
  - 0.02º x 0.02º 1-hour, 4-hour and 1-day night L3C
  - Geo-Polar Multi-sensor L3S products compositing data from MetOp-B, MetOp-C, Suomi-NPP, NOAA-20 and Himawari-8

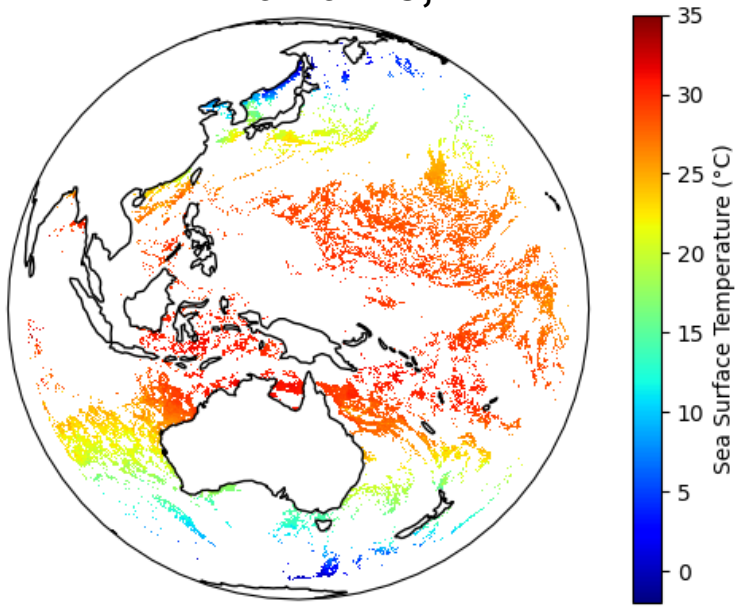
- **Data Access:** https://geonetwork.nci.org.au/ and https://portal.aodn.org.au (search for "Himawari-8 SST")



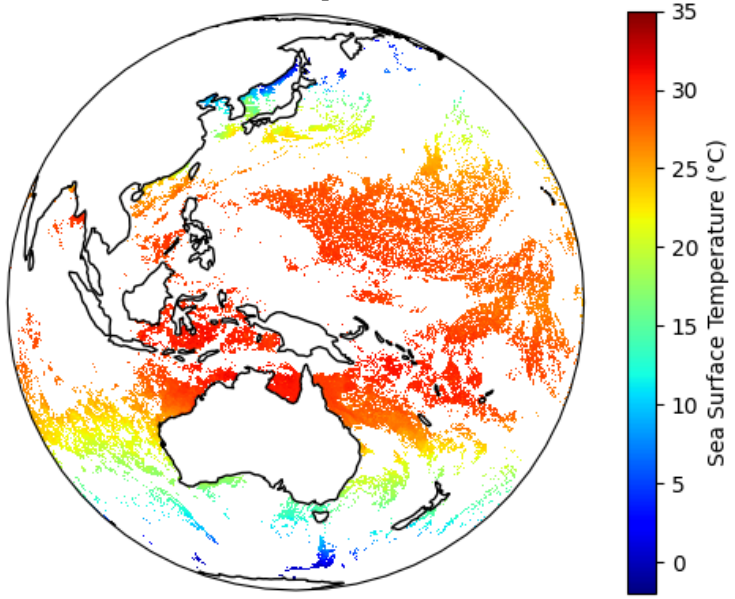
Himawari-9 SST Products (BoM/IMOS)

- Currently updating the IMOS Himawari-8 SST processing method for Himawari-9, in collaboration with University of Reading
- Expect fewer clear SST pixels identified as cloudy so potentially better real-time Geo-Polar Multi-sensor L3S SST spatial coverage
- Routine real time production of IMOS Himawari-9 L2P and L3C SST products with new method expected by June 2024.

20221108, 11:50
Himawari-8,

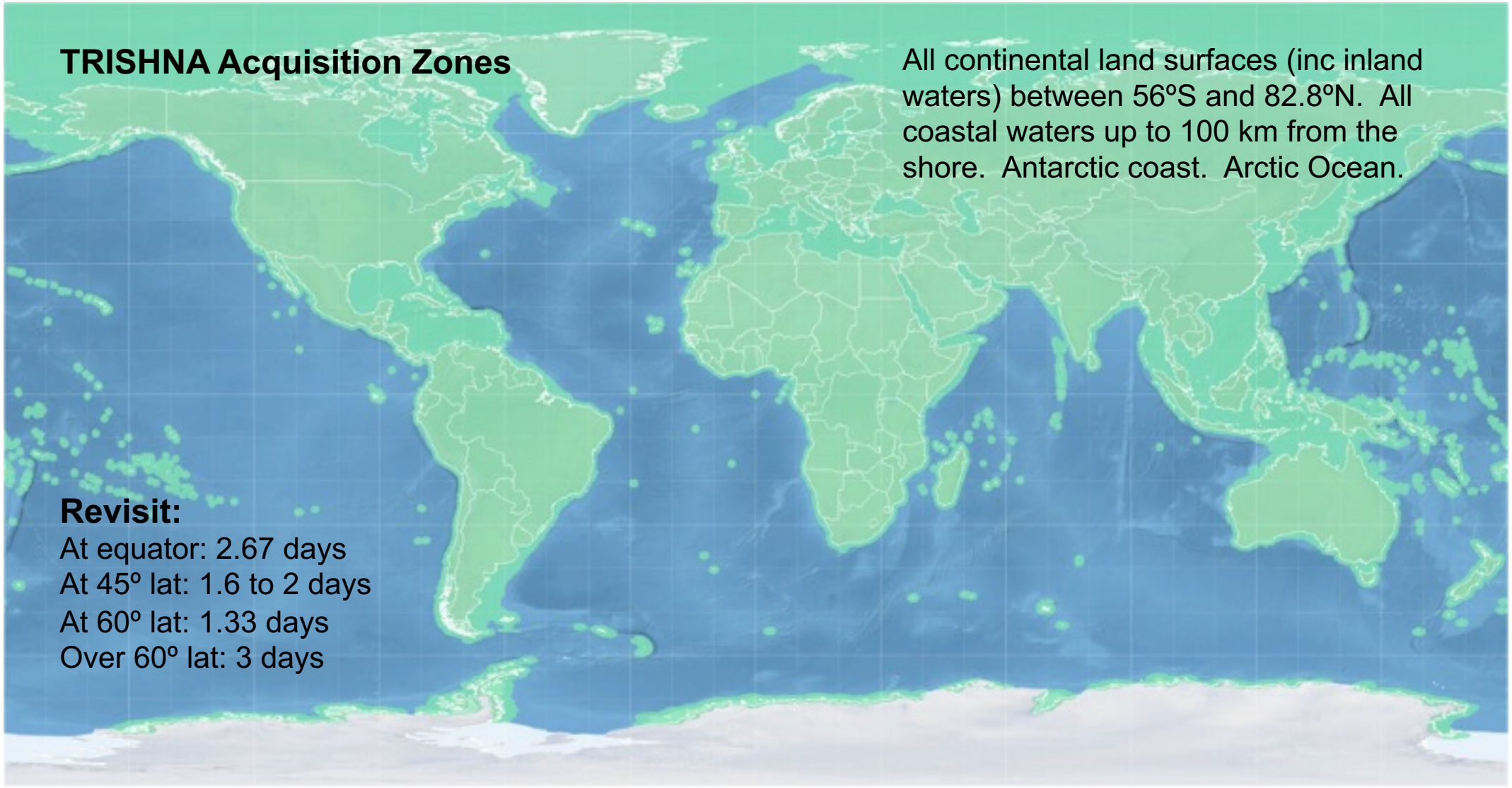


Himawari-9 with improved method



TRISHNA SST Products (ISRO/CNES)

Planned Launch: 2026; **Resolution:** 57 m at nadir; **Swath:** 1026 km; **NeDT:** 0.1 K (over oceans)



Source: Emmanuelle Autret, Ifremer, France

How satellite SAR data helps Bureau marine and ocean services

Current applications:

- monitoring and forecasting tropical cyclones
- sea ice and iceberg charting for safer and more efficient Antarctic shipping

Future applications:

- mapping and forecasting coastal inundation
- internal waves and internal tides for coastal ocean models for offshore industry
- sea-ice motion data for future atmosphere-ocean-ice coupled weather prediction models
- coastal winds and waves for shipping, port operations, recreation and offshore industry
- assist AMSA and AAD to rescue mariners and track oil spills

SAR missions relevant to Bureau marine and ocean services

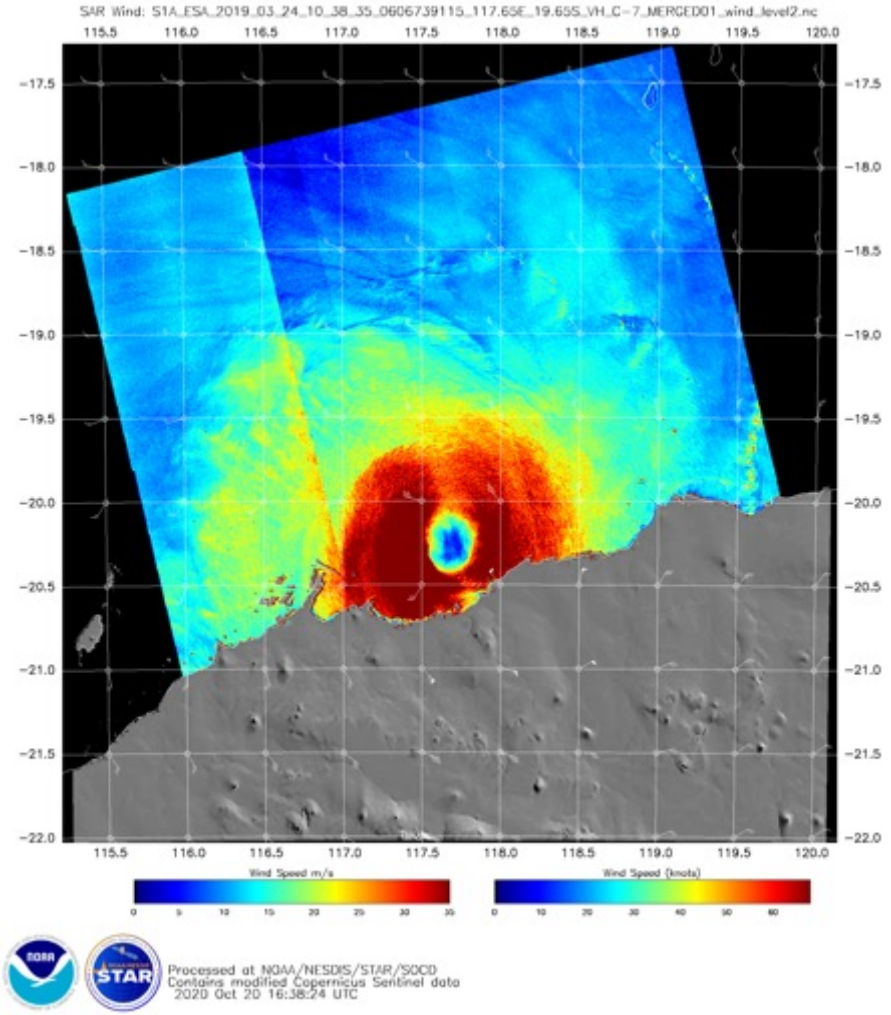
Launch Year	Satellite	Band	Polarisation	Swath (km)	Resolution (m)	Coverage Australian Sea Ice Zone (Days)
2007	Radarsat-2 (Canada)	C (5.3 GHz)	HH, HV, VV, VH	50-170	3 – 30	Commercial
2019	RCM (Canada)	C (5.4 GHz)	HH/HV/VV/VH	20-500	1 - 100	4 (from Jan 2024)
2014	Sentinel-1A (ESA)	C (5.4 GHz)	HH/HV, VV/VH	80 240	5 x 5 5 x 20	4-8
2018	ICEYE-1 (Finland)	X (9.6 GHz)	VV	80x40	10 x 10	Commercial
2018	NovaSAR-1 (UK)	S (3.2 GHz)	HH, HV, VV, VH	20-100	6 – 30	On demand
2022	EOS-04 (RISAT-1A) (ISRO)	C (5.4 GHz)	HH/HV, VV/VH, HH/HV/VV/VH	25−223	3 − 50	0
2024	NISAR SAR-L (NASA/ISRO))	L (1.26 GHz)	HH/HV, VV/VH, HH/HV/VV/VH	>240	3 − 48	2
2024	NISAR SAR-S (NASA/ISRO)	S (3.2 GHz)	HH/HV, VV/VH	>240	3 − 24	0
2025	Sentinel-1C (ESA)	C (5.4 GHz)	HH/HV, VV/VH	80 240	5 x 5 5 x 20	4-8

Bureau operational use of SAR data – Tropical Cyclones

On-demand Sentinel-1, RADARSAT-2 and RCM SAR C-band VV+VH Extra Wide Swath wind data for Tropical Cyclone monitoring over Metarea 10.

http://www.bom.gov.au/marine/maps/metarea-10.shtml

Tropical Cyclone Veronica (24 Mar 2019) off Pilbara Coast



https://www.star.nesdis.noaa.gov/socd/mecb/sar/AKDEMO_products/APL_winds/tropical/

Bureau operational use of SAR data – Ice Charting

Routine Sentinel-1 SAR C-band HH or HH+HV Wide Swath data for sea ice classification and iceberg detection over Antarctic Sea Ice Zone (45ºE to 160ºE).

https://www.dfat.gov.au/

Sentinel-1A SAR IW HH image of sea ice off Riiser-Larsen Peninsula (23-MAY-2023 01:36:05 UTC)

Source: PolarView Sentinel-1 Imagery Copyright © 2023 ESA

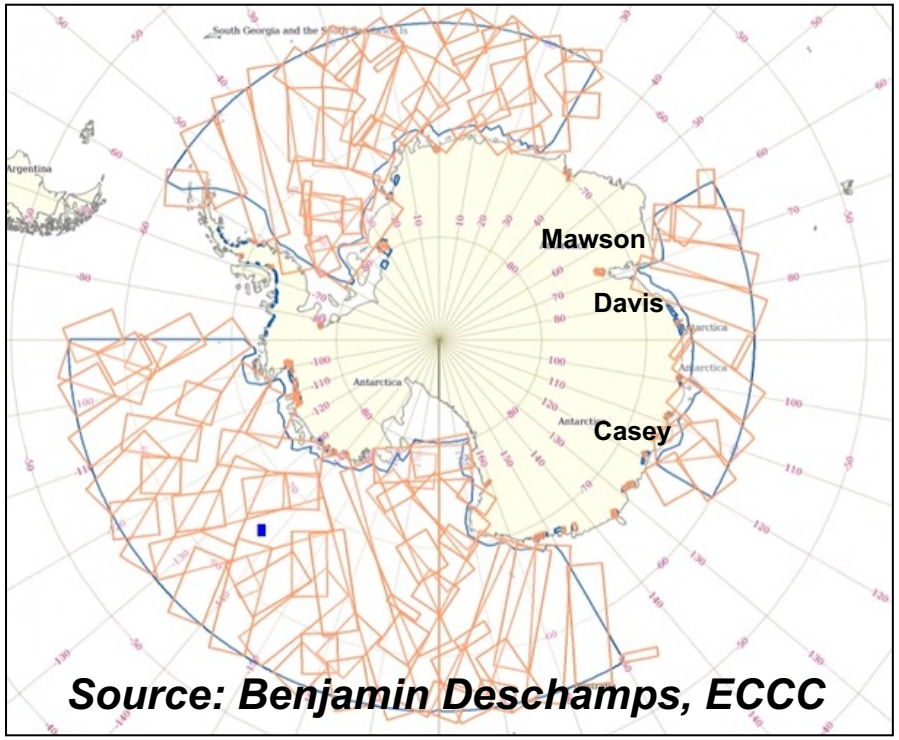
CSA's RCM C-band SAR Antarctic Coverage

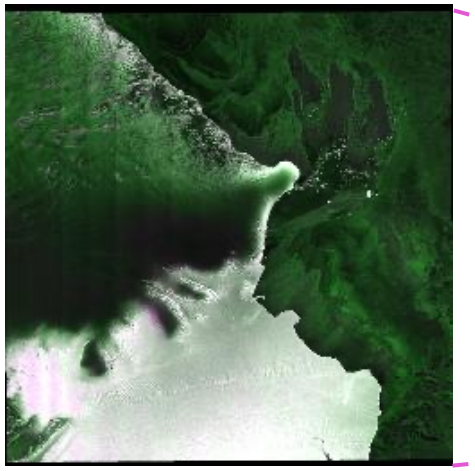
(Pierre-Phillipe Vézina, IICWG-24 Meeting, 25-29 Sep 2023, Cambridge)

International Ice Charting Working Group Coverages

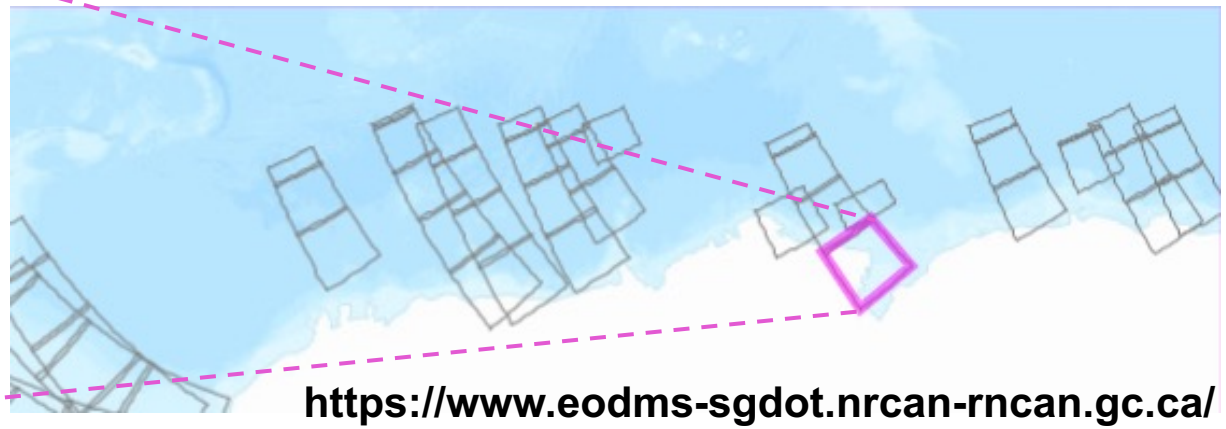
- To complement Sentinel-1A coverage to enhance safety of maritime operations in Antarctic ice-covered waters
- 100 m resolution, Low noise
- ScanSAR, swath width 500 km
- RCM Dual-pol HH+HV using all 3 satellites
- Test files available 3 – 11 Oct 2023
- Routine coverage planned to start Jan 2024
- Coverage will be reassessed when Sentinel-1C operational
- **Data Access:** EODMS

RCM IICWG Coverages over 4 days in Oct 2023



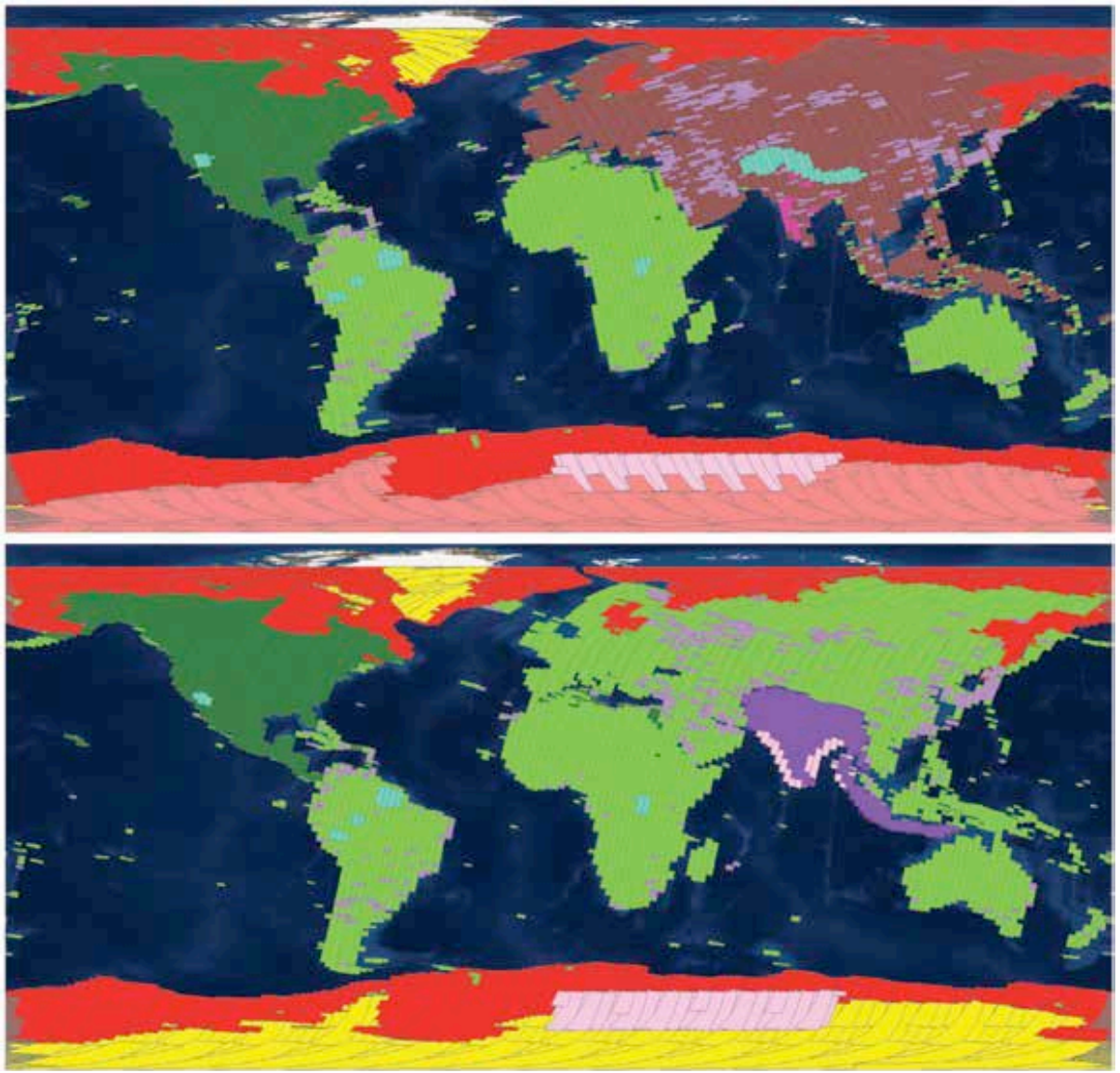


RCM ScanSAR image 2023-10-07T15:45:57



https://www.eodms-sgdot.nrcan-rncan.gc.ca/

NISAR (NASA/ISRO) L/S-Band SAR Planned Coverage



- **Australian continent and coasts**: L-band HH+HV SAR 48 m data every 12 days
- **East Antarctic Sea Ice Zone**: L-band VV 48 m SAR data every 2 days
- **Antarctic Ice Sheet**: L-band HH SAR data every 2 days

- Routine coverage should start 2025

- **Marine applications:** Tropical Cyclones, coastal winds and waves, internal waves/tides, oil spills, iceberg and ship detection, sea-ice motion and deformation

INSTRUMENT MODES

- Background Land (L-SAR only)
- North America SNWG Target (L-SAR only)
- Land Ice (L-SAR only)
- Sea Ice (L-SAR only)
- Low Data Rate Study Mode (L-SAR only)
- Urban Areas (L-SAR only)
- High Res Deformation-Landslide/Urban (Joint mode)
- Antarctic Region (Joint mode)
- ISRO Sea Ice (Joint mode)
- ISRO Agriculture + Instrument Calibration Sites (Joint mode)
- Systematic Coverage (Joint mode)
- Systematic Coverage and Deformation (Joint mode)
- Agriculture/Sea Ice (S-SAR only)

https://nisar.jpl.nasa.gov/documents/26/NISAR_FINAL_9-6-19.pdf

How new SLA, SST and SAR products will benefit Bureau marine and ocean services

- **SWOT 20 km SLA:** Expected to help constrain mesoscale and boundary currents in the Bureau's regional ocean models. Possible applications in shallow shelf waters affected by tides would require further investigation.

- **Himawari-9 2 km SST:** Reprocessed IMOS Himawari-8 1-hour L3C SSTs have been demonstrated to be useful for the Bureau's regional ocean models, particularly in near-coastal regions where microwave SSTs are lacking. With tuning, IMOS Himawari-9 SST is expected to have better spatial coverage and accuracy than IMOS Himawari-8 SST and benefit IMOS AusTemp (currently in development).

- **TRISHNA 57 m SST:** Will benefit development and validation of coastal ocean models.

- **RCM 100 m C-Band SAR:** From Jan 2024, routine SAR coverage of Australia's Antarctic Sea Ice Zone will double (to 2-4 days), significantly benefitting ship navigation.

- **NISAR 48 m L-Band SAR:** From 2025, routine SAR coverage of Australia's Antarctic Sea Ice Zone will double (to 1-2 days). This will benefit ship navigation and provide sea-ice motion data for atmosphere-ocean-ice coupled models. NISAR L-Band winds will also benefit Tropical Cyclone forecasts.

The Bureau of Meteorology

Thank you

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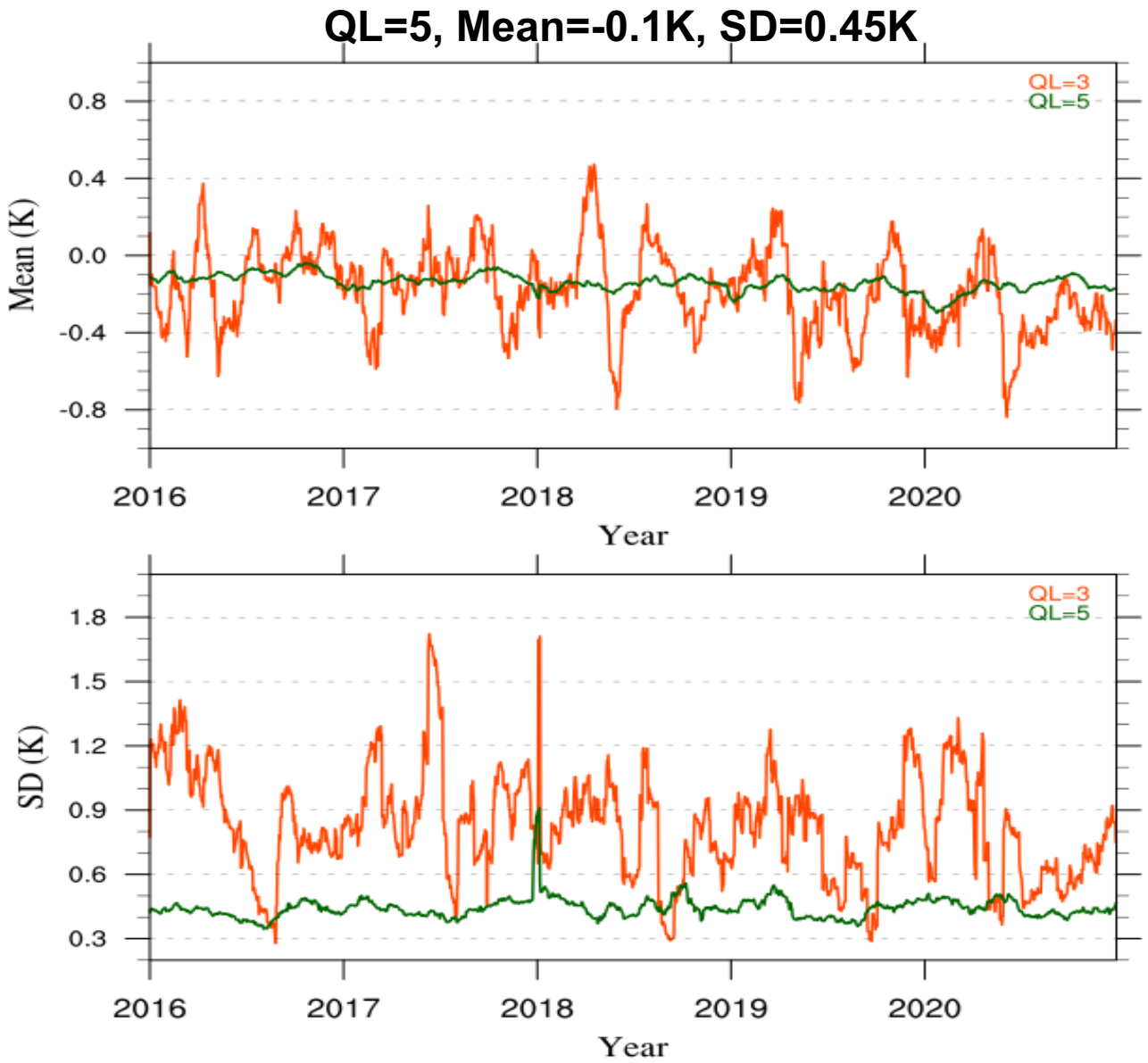
Supplementary Slides

Himawari-8 night L3C SST Validation against buoy SST

L3C-01day, night only, monthly statistics, Jan 2016 - Dec 2020

Note: Mean bias = SSTskin - in situ SSTdepth + 0.17 (in Kelvin), Match-up thresholds: < 10 km distance and ± 6 hours

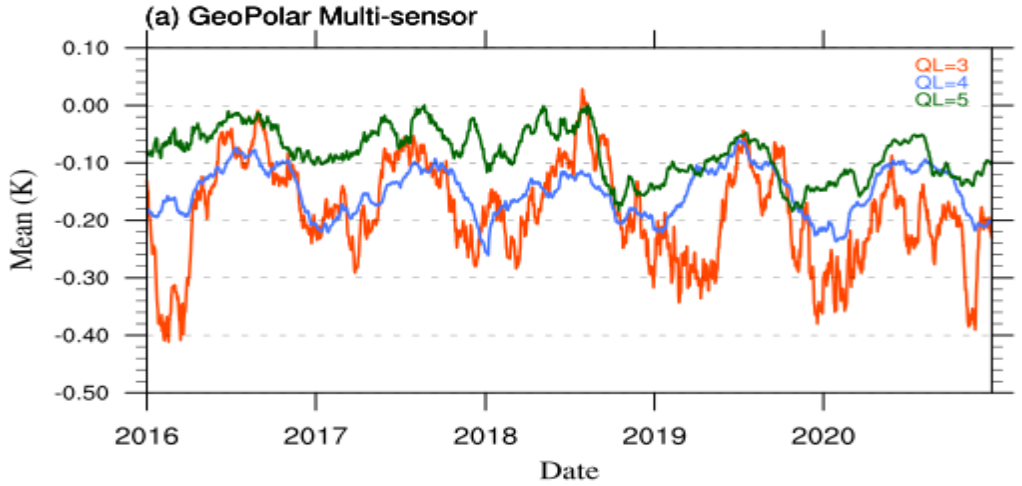


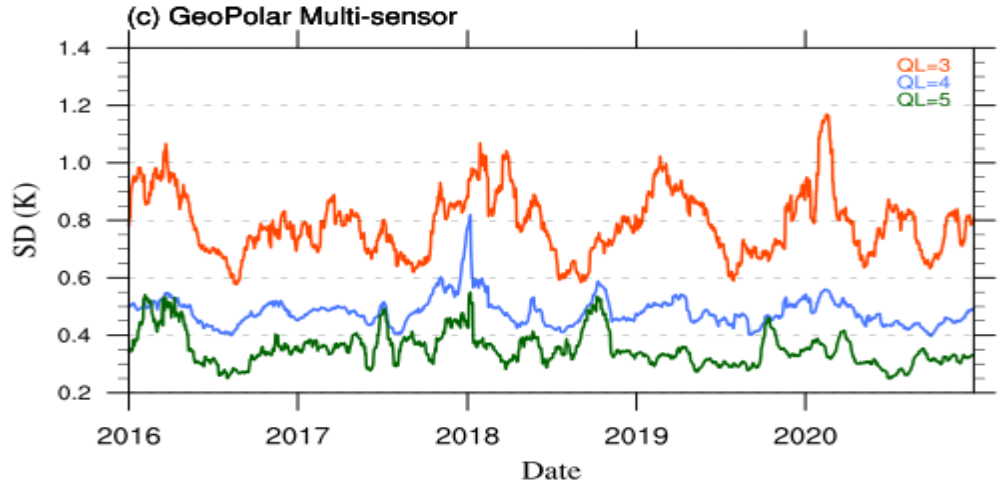
Multi-sensor L3S SST Validation against buoy SST

L3S-01day, night only, monthly statistics, Jan 2016 - Dec 2020

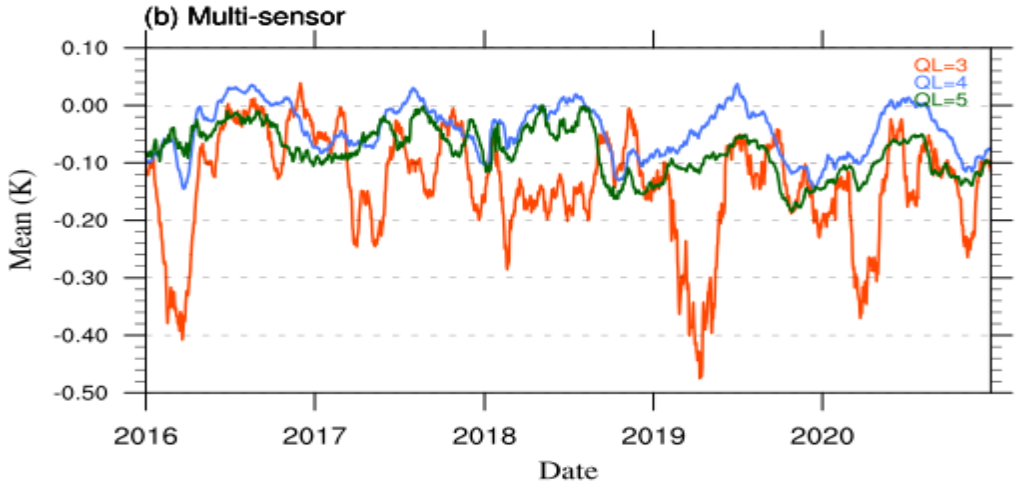
Note: Mean bias = SSTskin - in situ SSTdepth + 0.17 (in Kelvin), Match-up thresholds: < 10 km distance and ± 6 hours

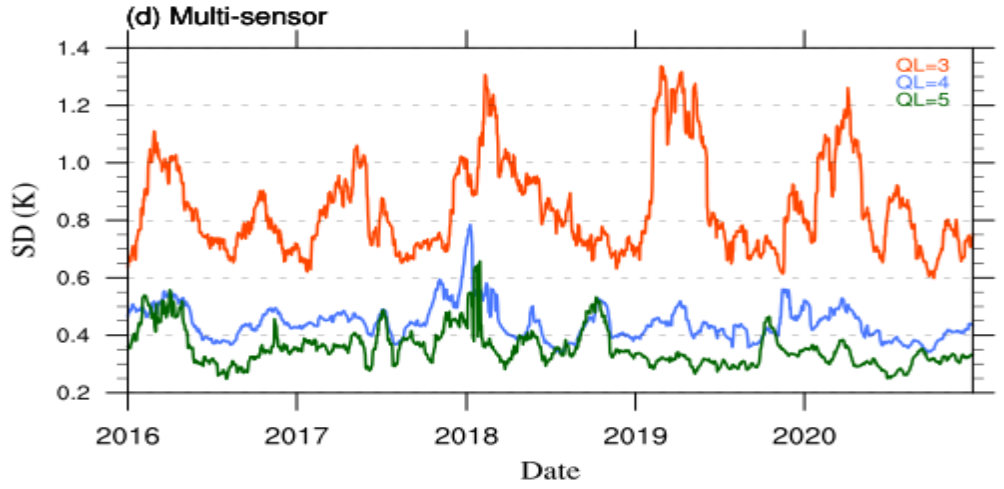
GeoPolar Multi-Sensor L3S





Multi-sensor L3S



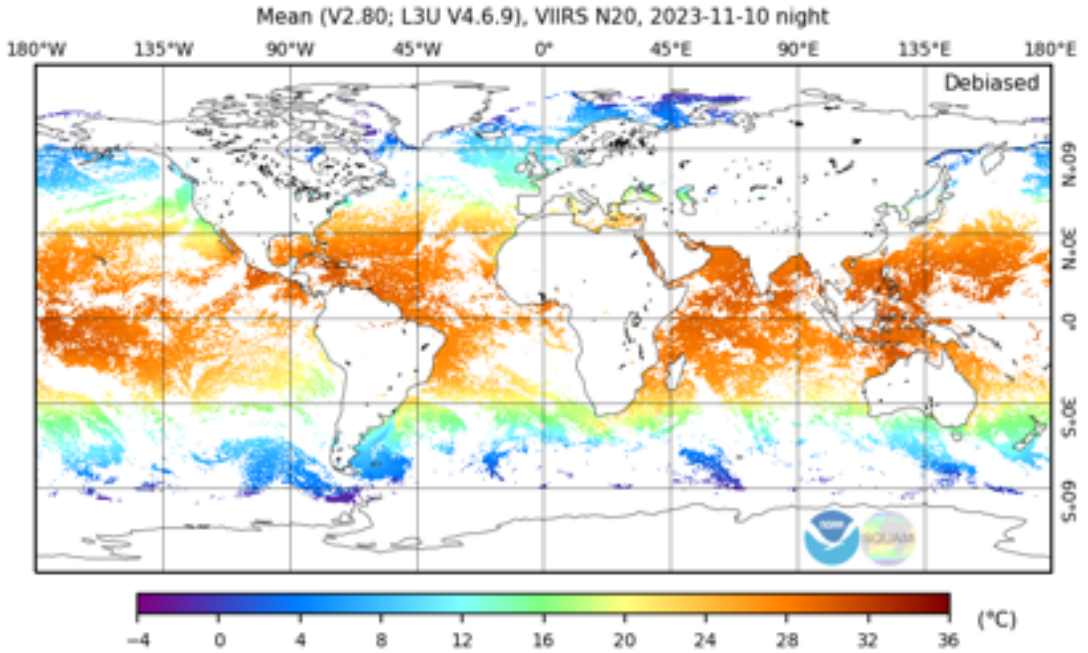


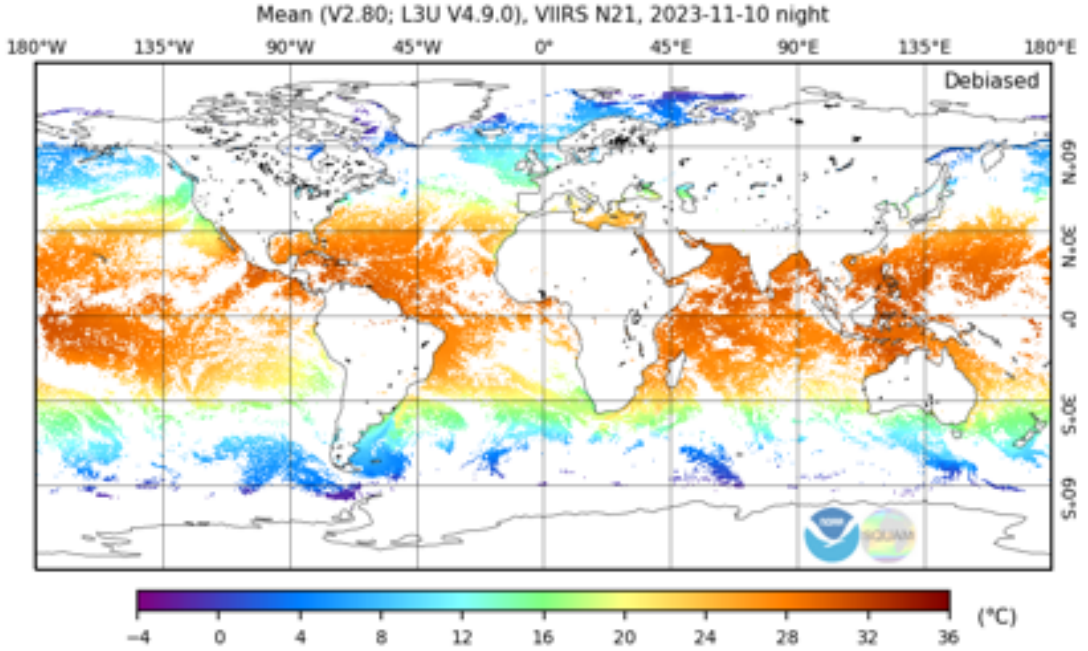
NOAA-21 VIIRS L2P/L3U SST (NOAA/NESDIS)

- Experimental NOAA-21 VIIRS L2P and L3U SST available from NOAA Coastwatch in near real-time and delayed mode "scientific quality" back to 19 March 2023 (https://coastwatch.noaa.gov/pub/socd2/coastwatch/sst/ran/viirs/n21/l3u).

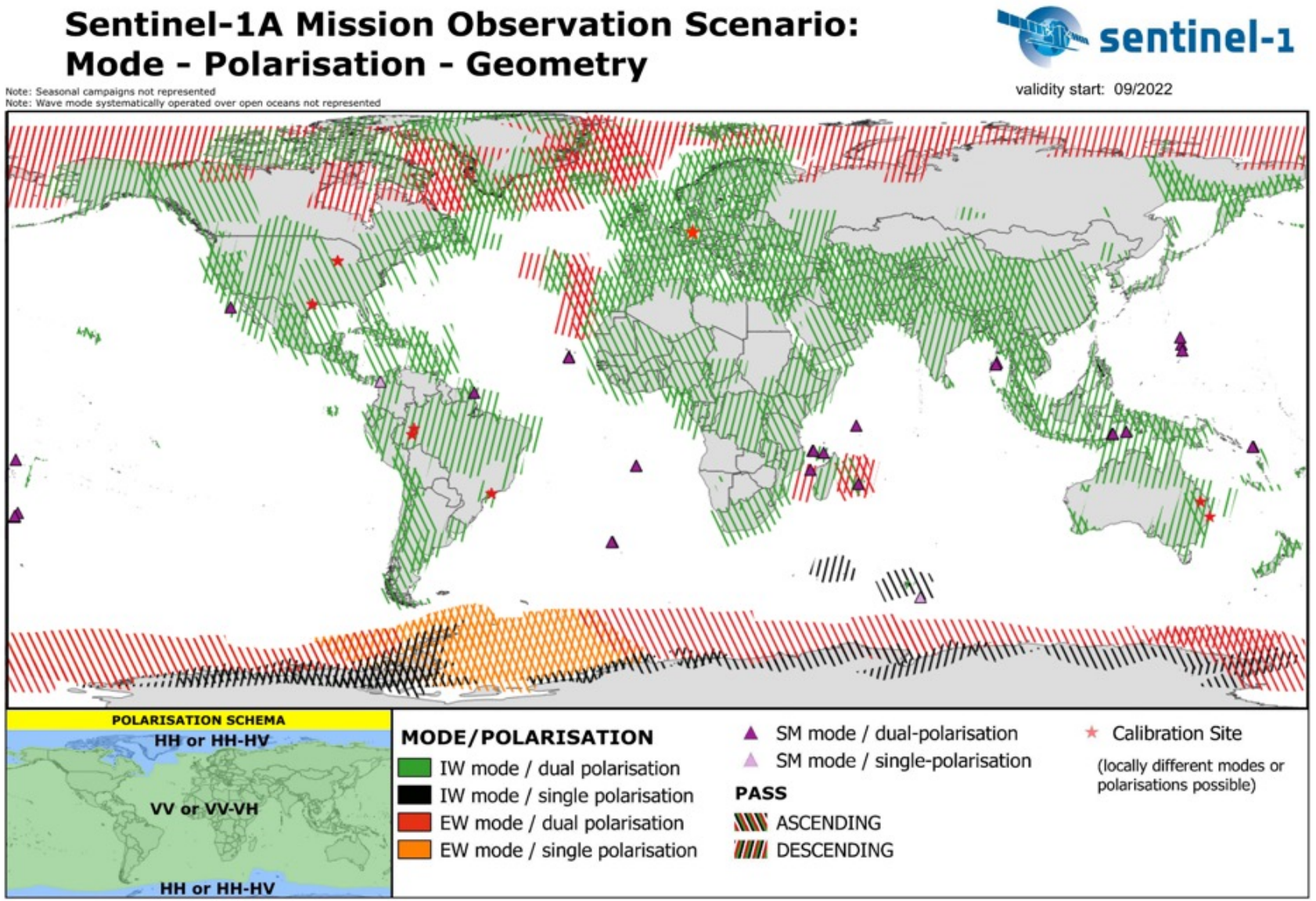
- Complements existing operational ACSPO NOAA-20 and Suomi-NPP VIIRS L2P and L3U SST products produced by NOAA/NESDIS/OSPO

- NOAA/NESDIS/OSPO aim to release operational NOAA-21 VIIRS L2P and L3U SST products in May 2024



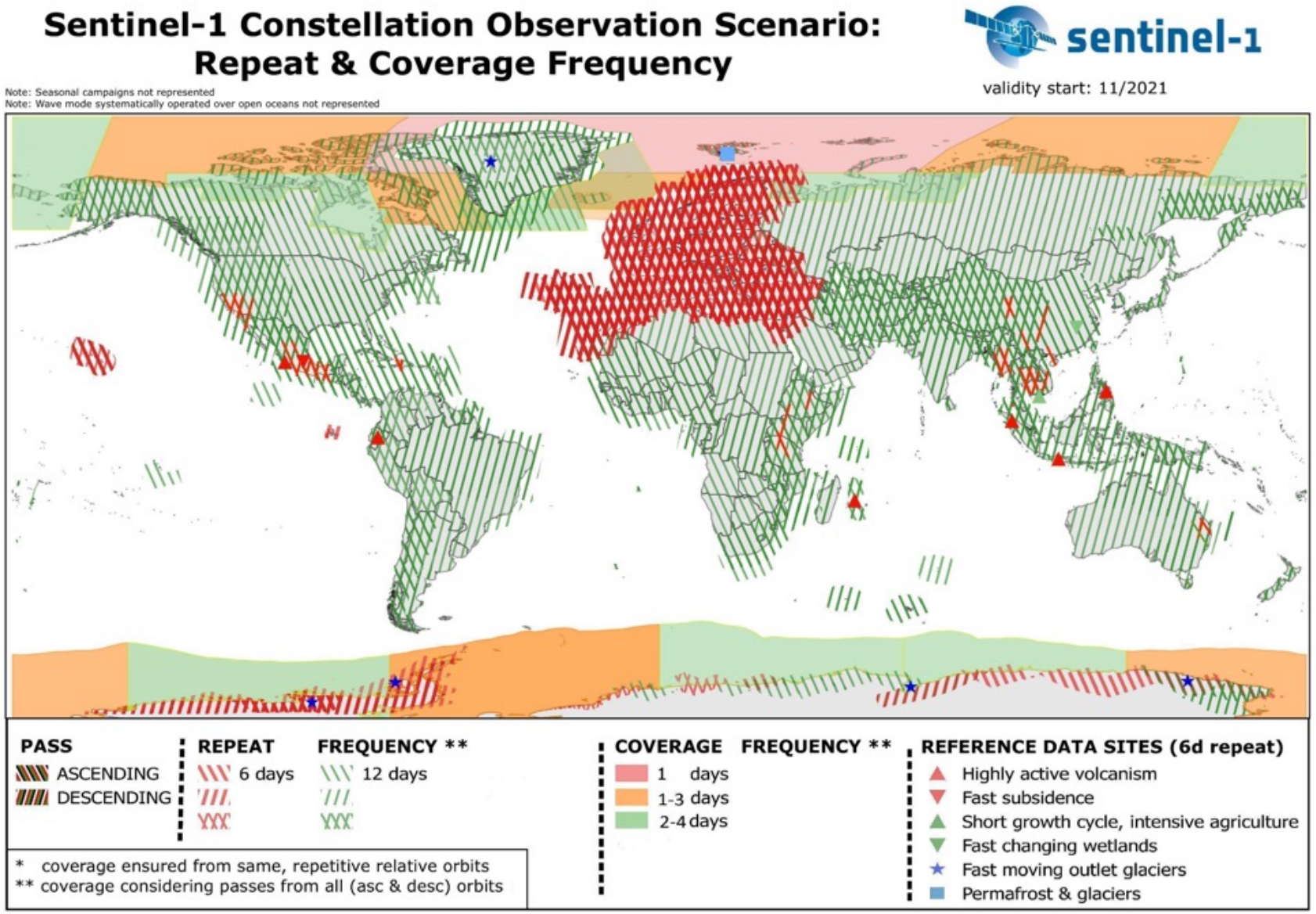


Sentinel-1A Mission Observation Scenario:
Mode – Polarisation - Geometry



https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario

Sentinel-1 2-satellite repeat and coverage



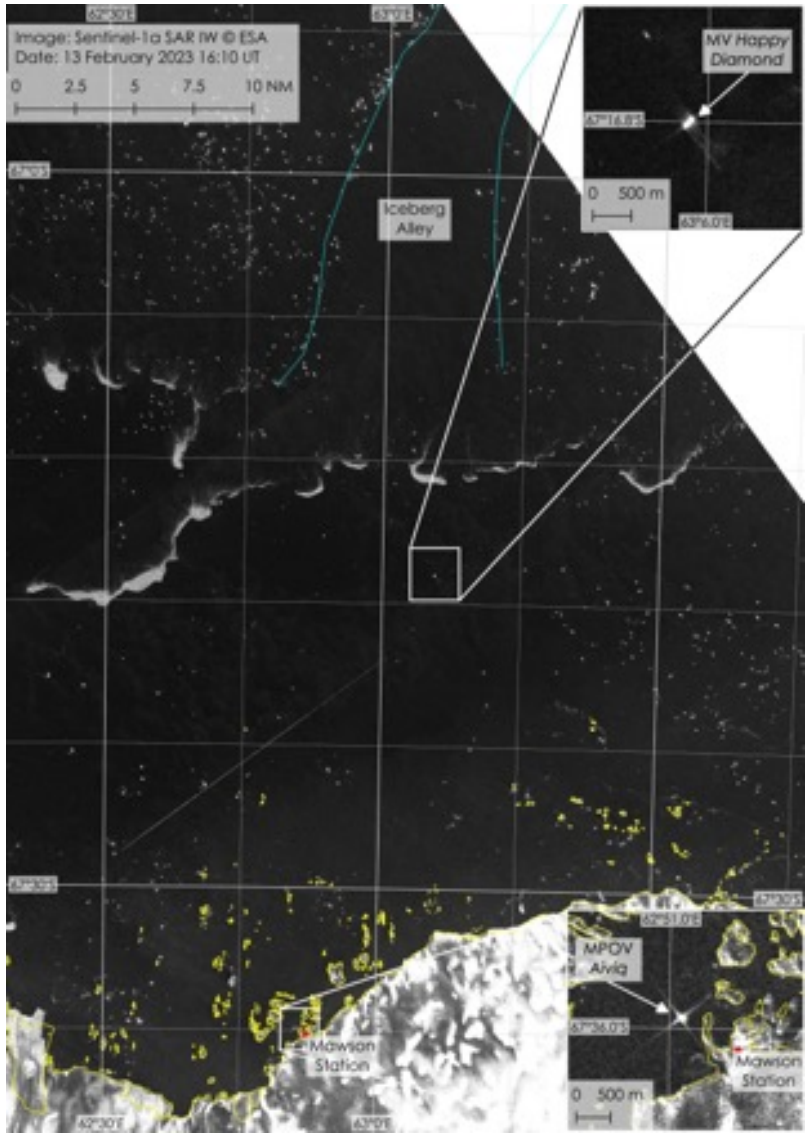
https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario

Ship Detection for Search & Rescue

- X/C/L-band HH or HH+HV SAR Stripmap or ScanSAR Wide Swath mode data can be used to detect ships as well as icebergs.
- The backscatter "double bounce" signal of HH co-polarised SAR data is different from ships compared with icebergs

https://www.amsa.gov.au/safety-navigation/search-and-rescue/australias-search-and-rescue-region

MV Happy Diamond and MPOV Alviq near Mawson Station, 13th Feb 2023



Credit: Jan Lieser (Bureau) using PolarView
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