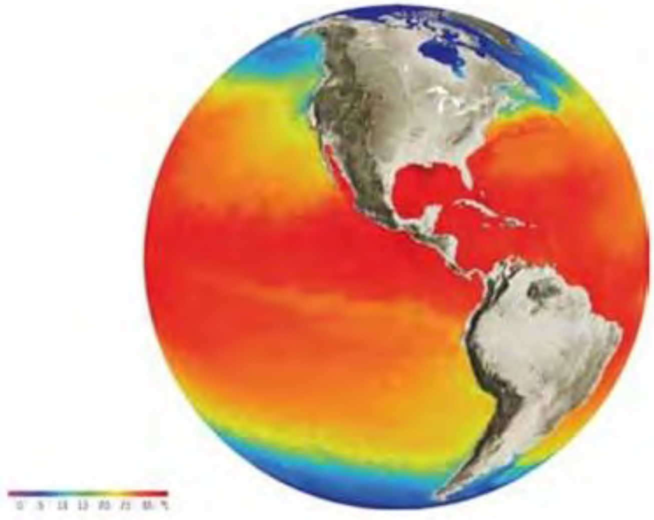
Satellite Sea Surface Temperature – current and future observations at ESA

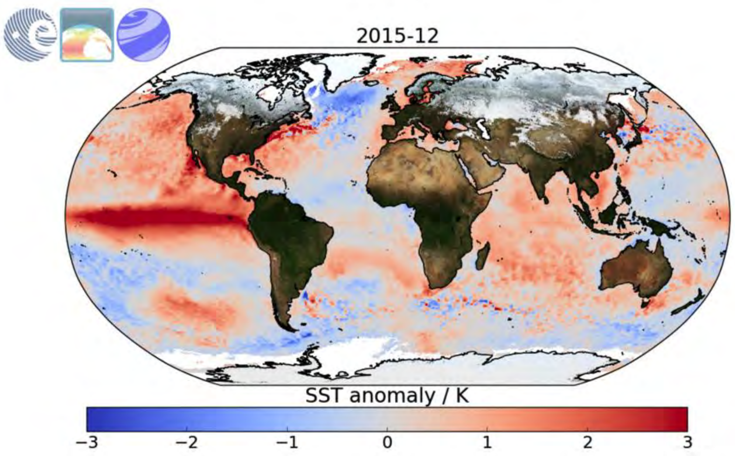
C Donlon
ESA/ESTEC, Noordwijk, the Netherlands

Observations and analysis of SST and SI for NWP and Climate
ECMWF, Reading UK, 22-25 January 2018

Overview

- Satellite SST measurements
- SST Requirements
- ESA Thermal infrared satellite activities
- ESA Microwave radiometry activities
- Fiducial Reference Measurements
- Future outlook



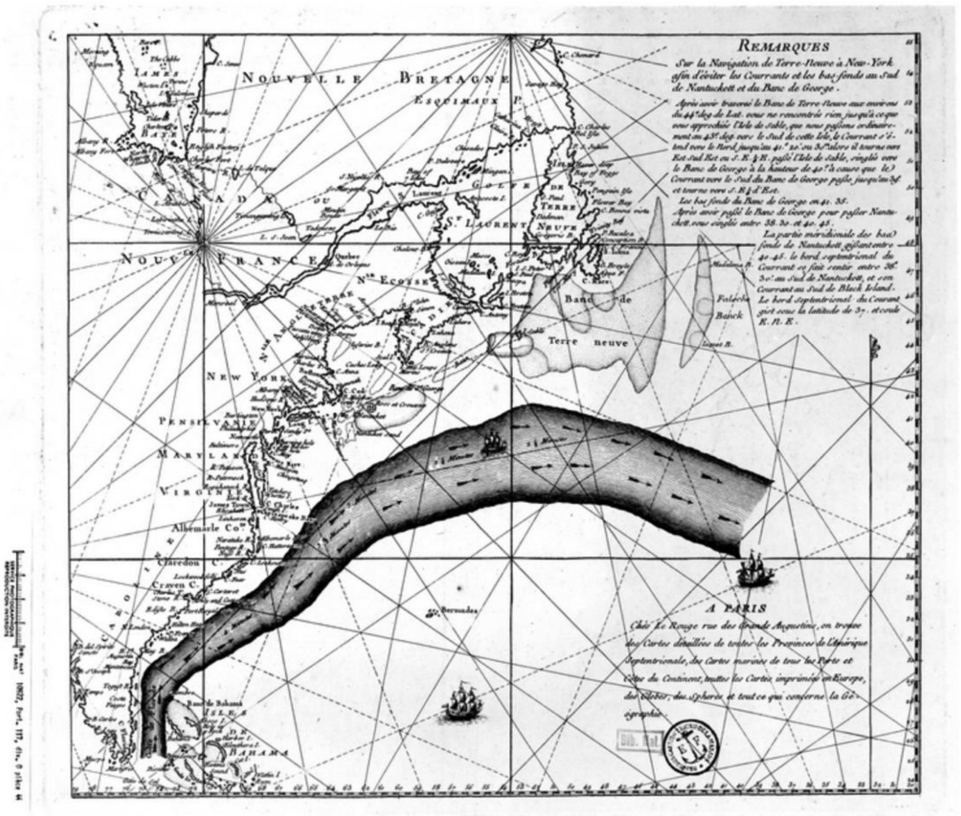


(O. Embury)

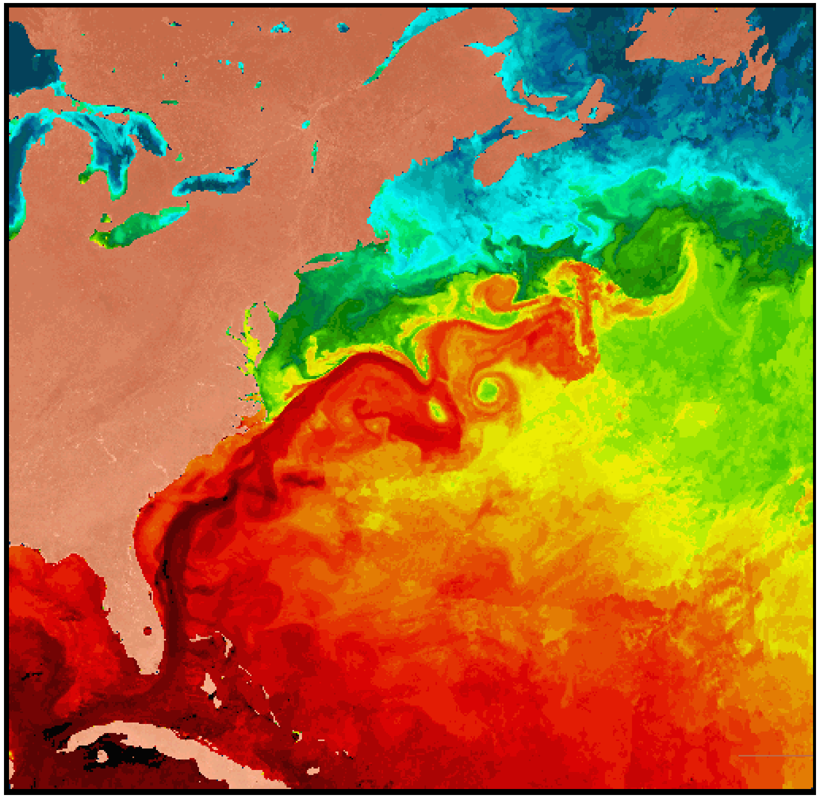

24
CTC-3

Early SST measurements

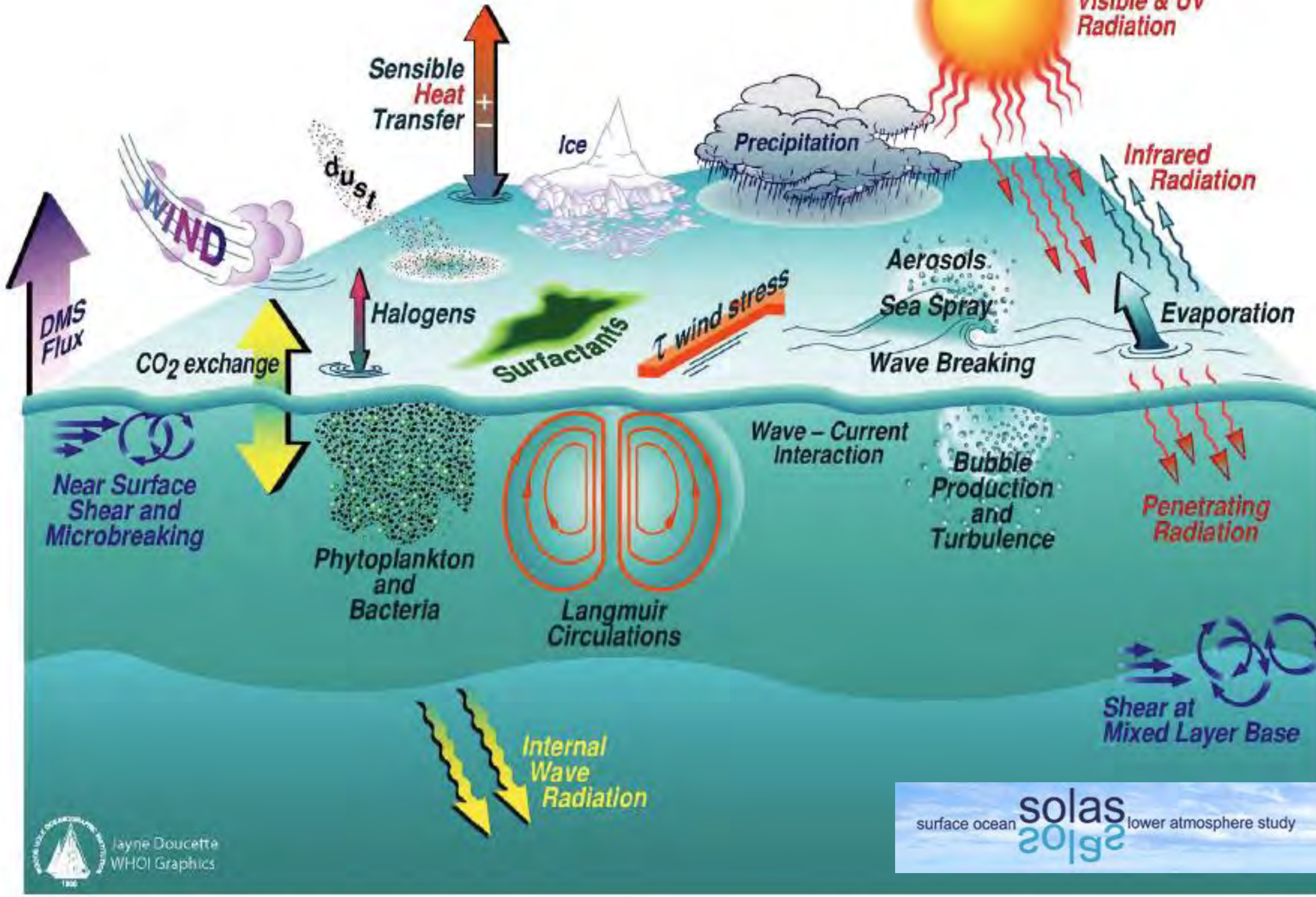
Franklin – Folker Chart of the Gulf Stream (1768) compiled from ships logs over many years



AVHRR satellite composite image of a similar area

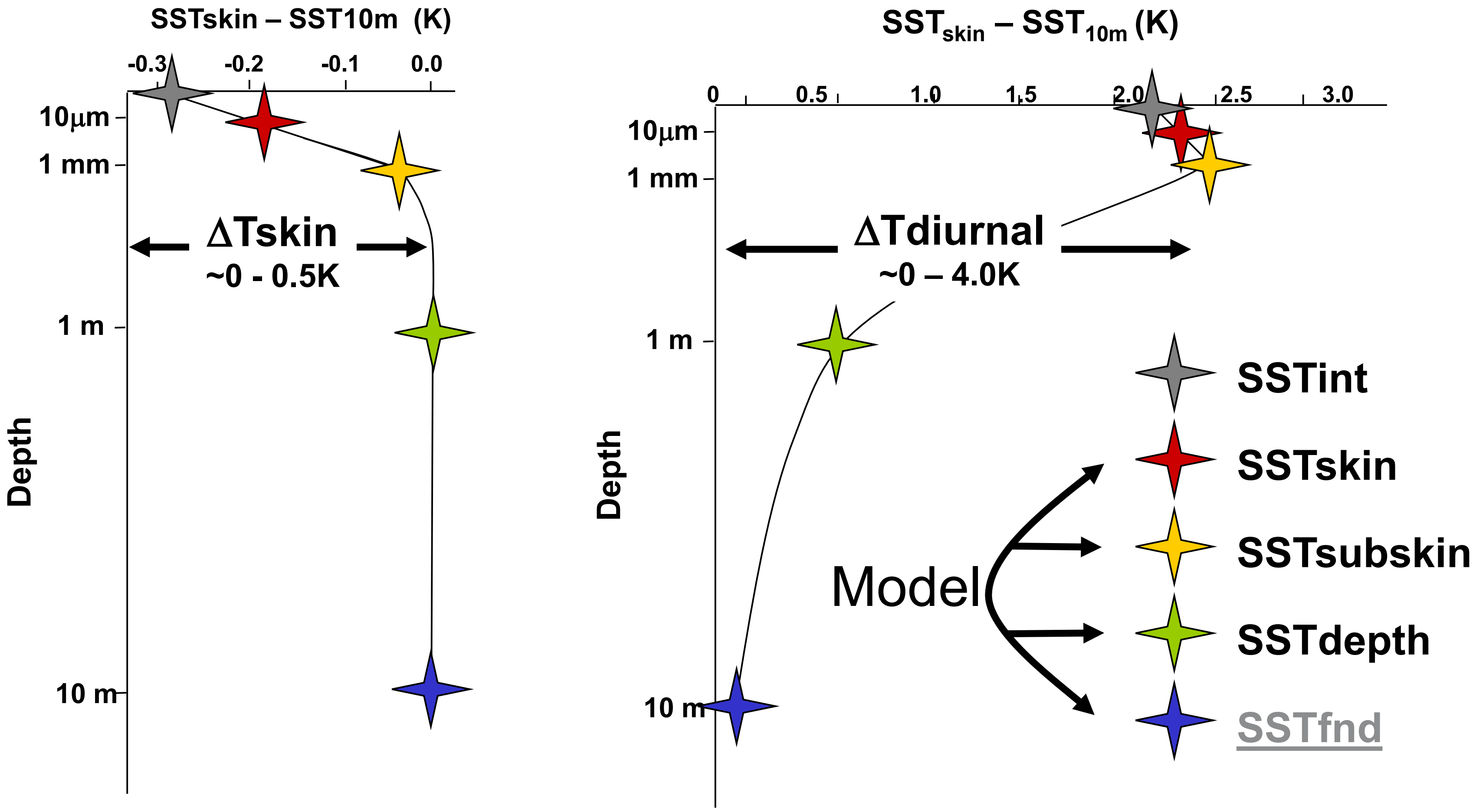


Satellite instruments generally measure 2D surface expressions of 4D structures



Interpretation framework for SST

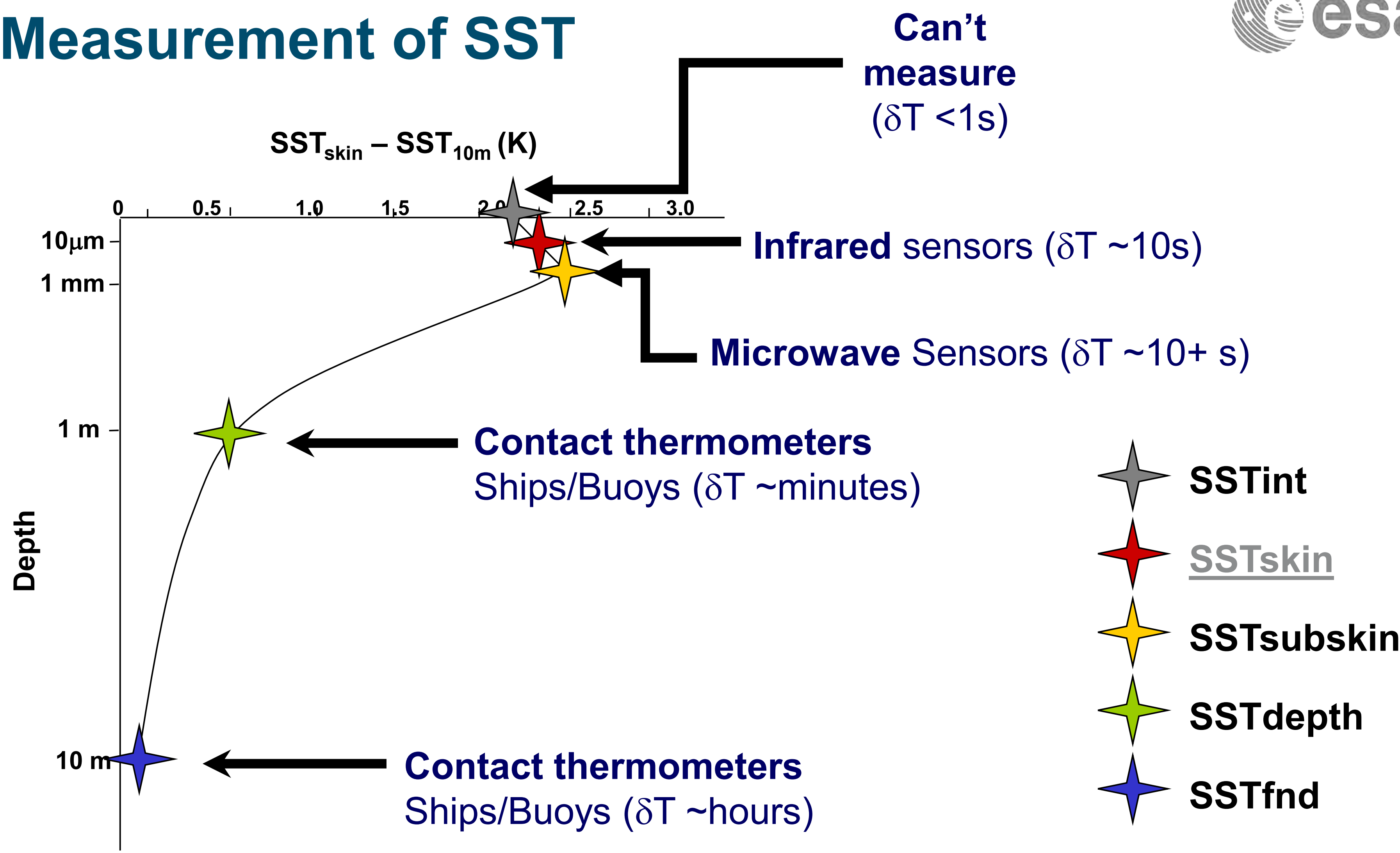
Donlon et al, BMS, 2007, http://dx.doi.org/10.1175/BAMS-88-8-1197



(a) **Night time** situation, light wind

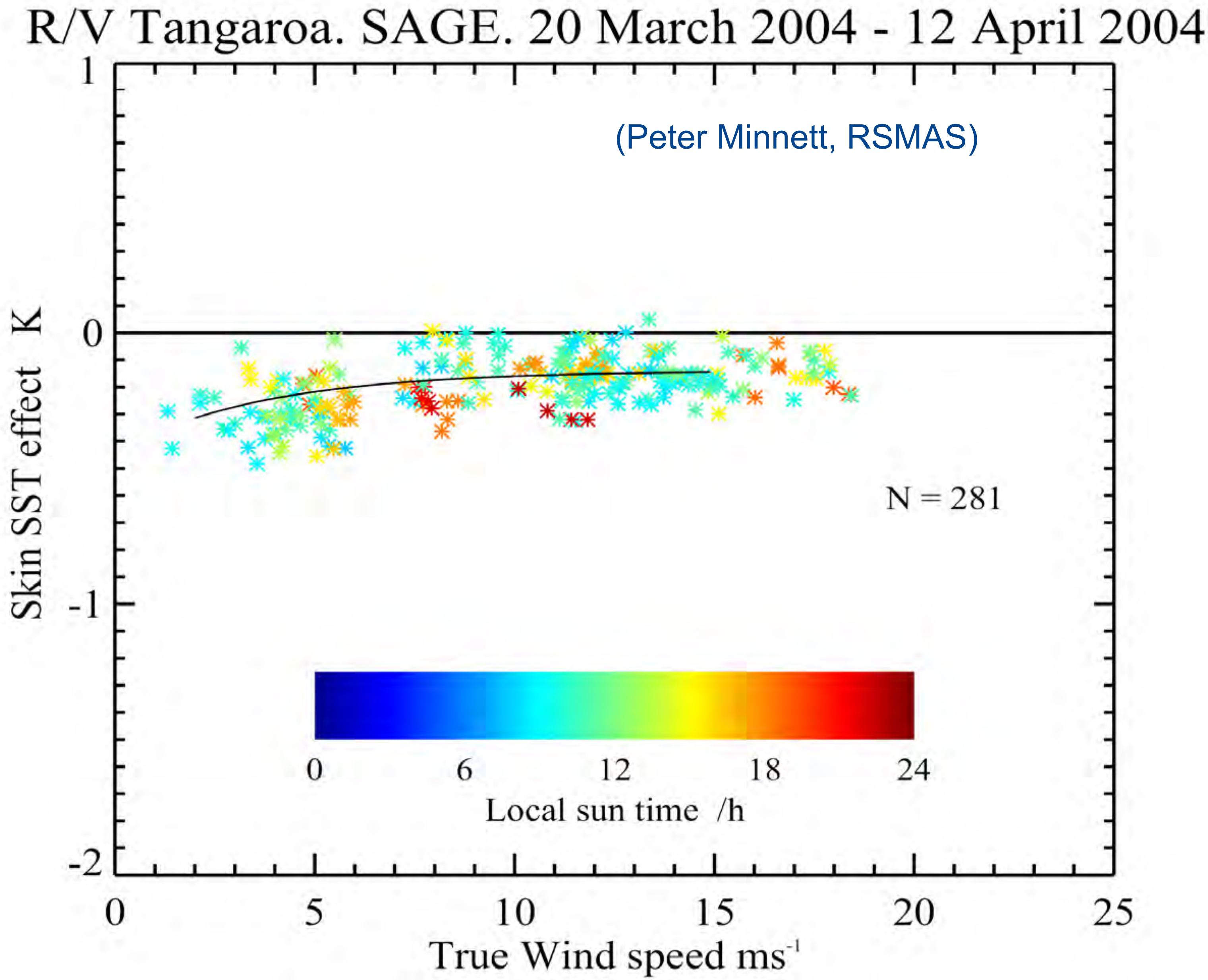
(b) **Day time** situation, strong solar radiation and light winds

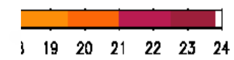
Measurement of SST



Day time situation, strong solar radiation and light winds

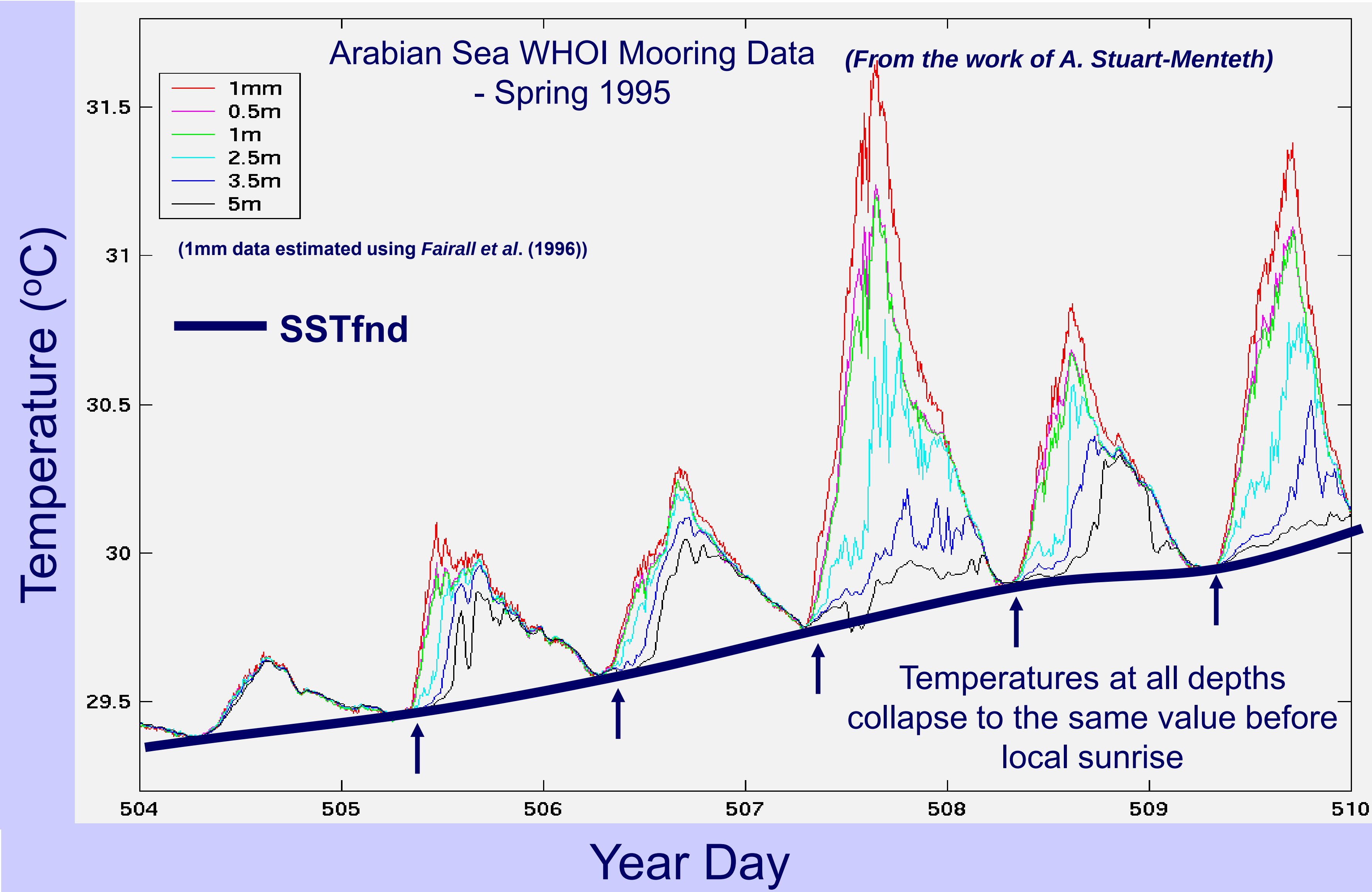
Validating the SST framework



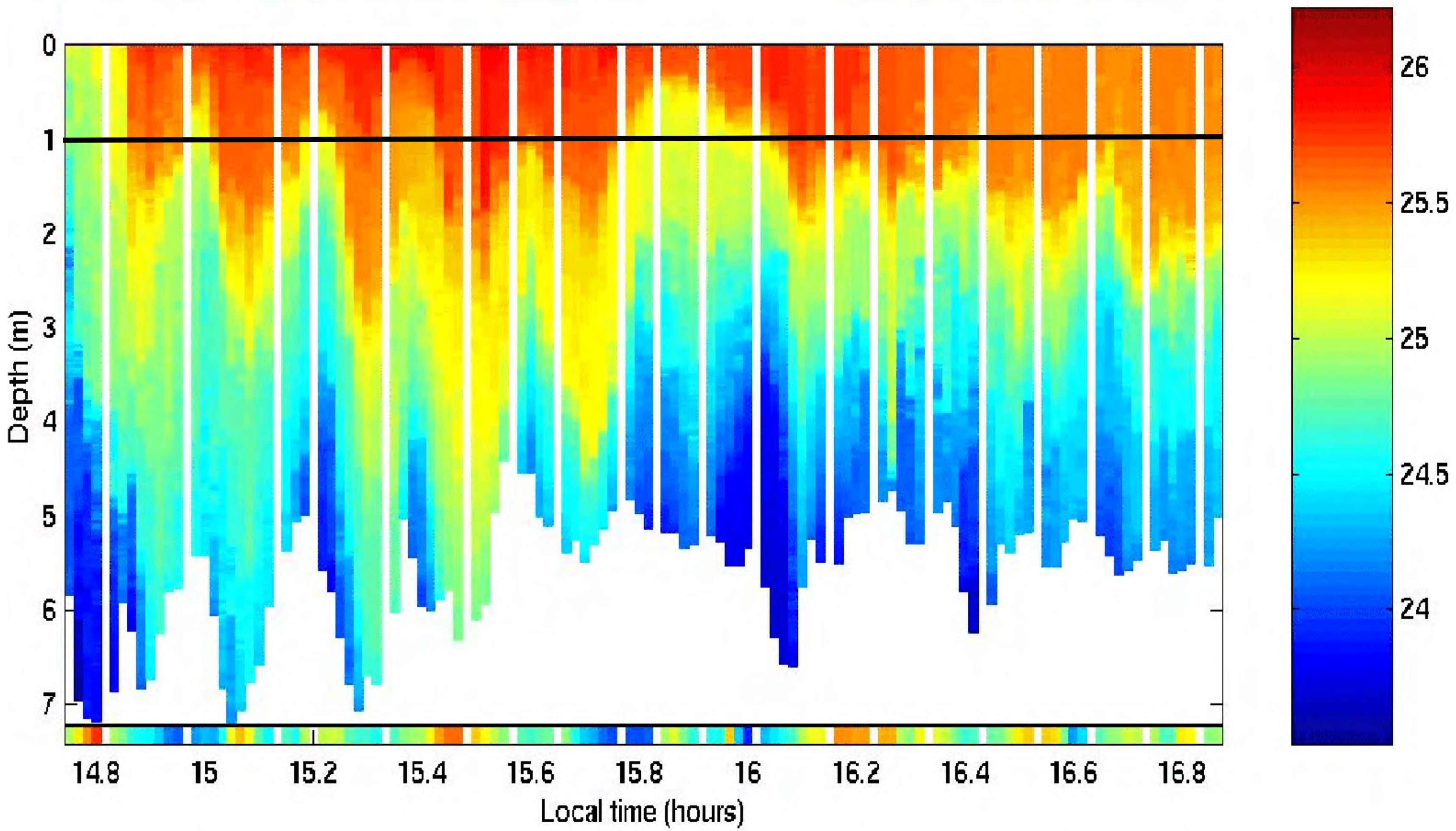


Do … e Sea Surface Skin
Te… .CO;2

Diurnal SST stratification (variability)



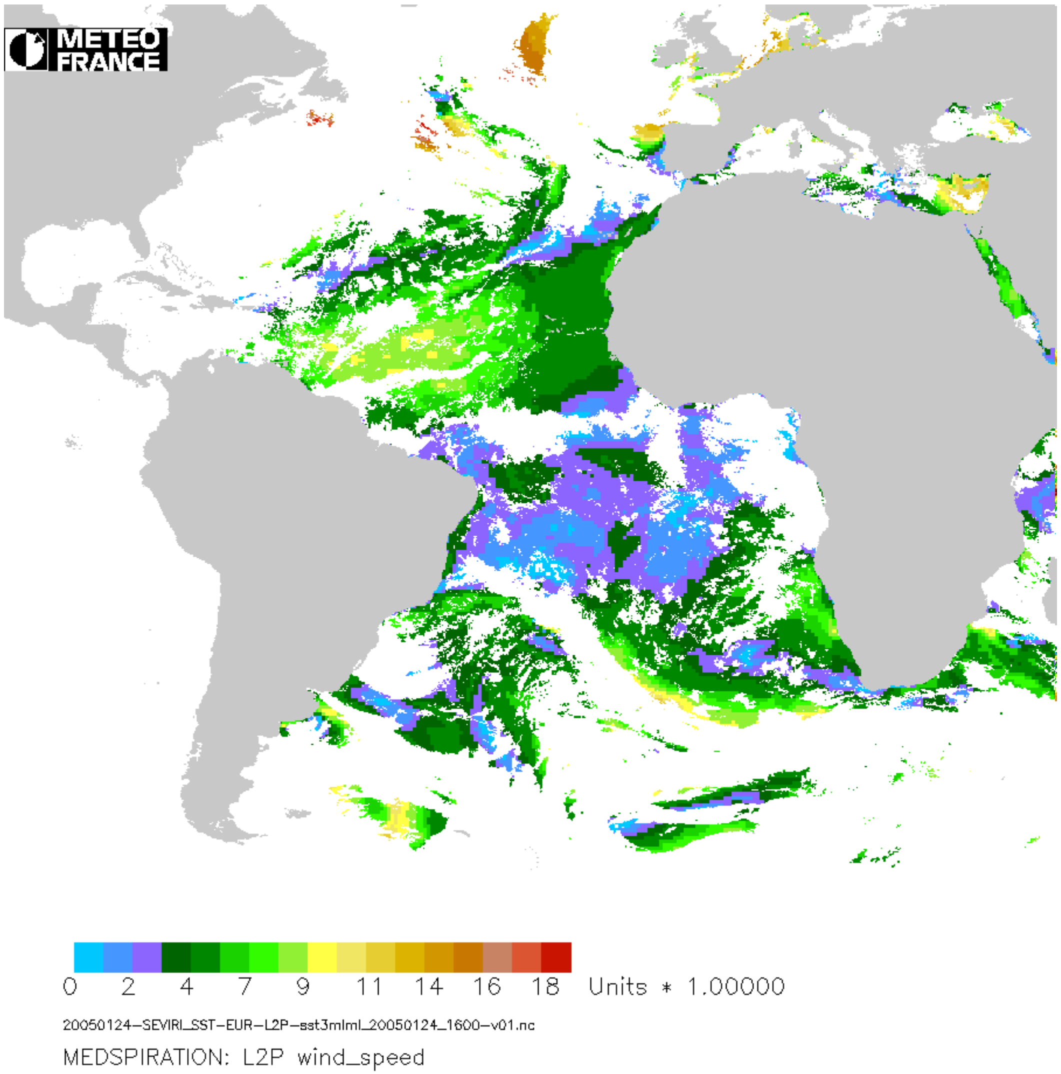
Time evolution of near-surface thermal gradients at the same location

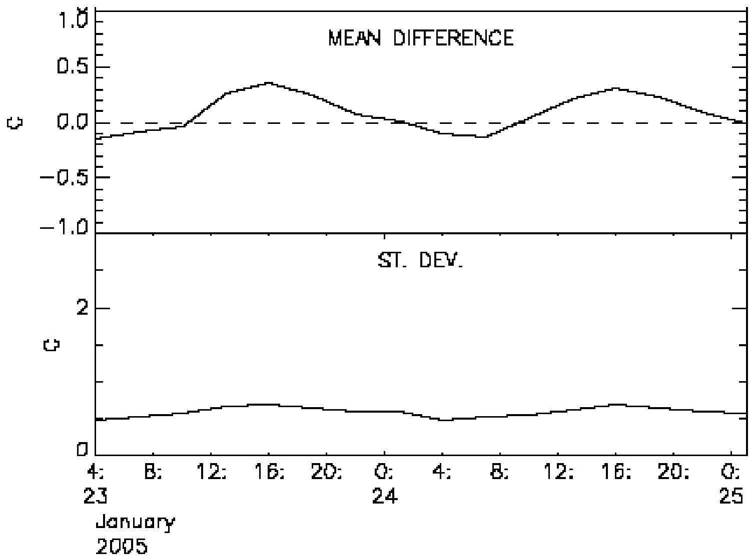


SkinDeEP profiles on 12 October 1999. Off Baja California, R/V *Melville*., From Ward, B. and P. J. Minnett, 2001

Diurnal SST signatures: Atlantic (MSG SEVIRI)

(ESA Medspiration)





Basin wide deviation of 0.08 K each day

Arctic DV: Northern Novaya Zemlya

ELSEVIER
Remote Sensing of Environment
Volume 115, Issue 10, 17 October 2011, Pages 2594-2602

Diurnal variability in sea surface temperature in the Arctic

Steinar Eastwood [a], Pierre Le Borgne [b], Sonia Péré [b], David Poulter [c]

⊞ Show more

https://doi.org/10.1016/j.rse.2011.05.015

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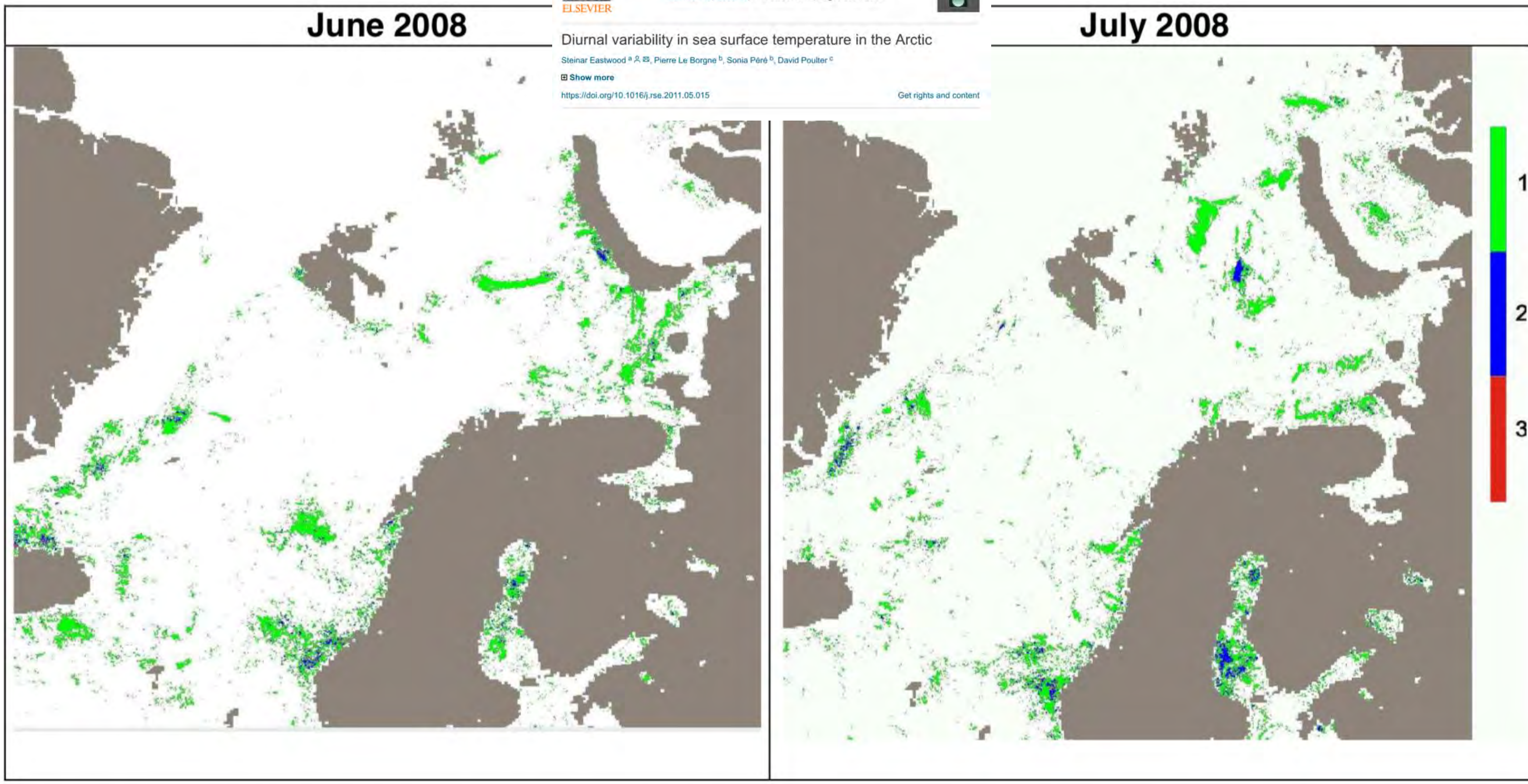
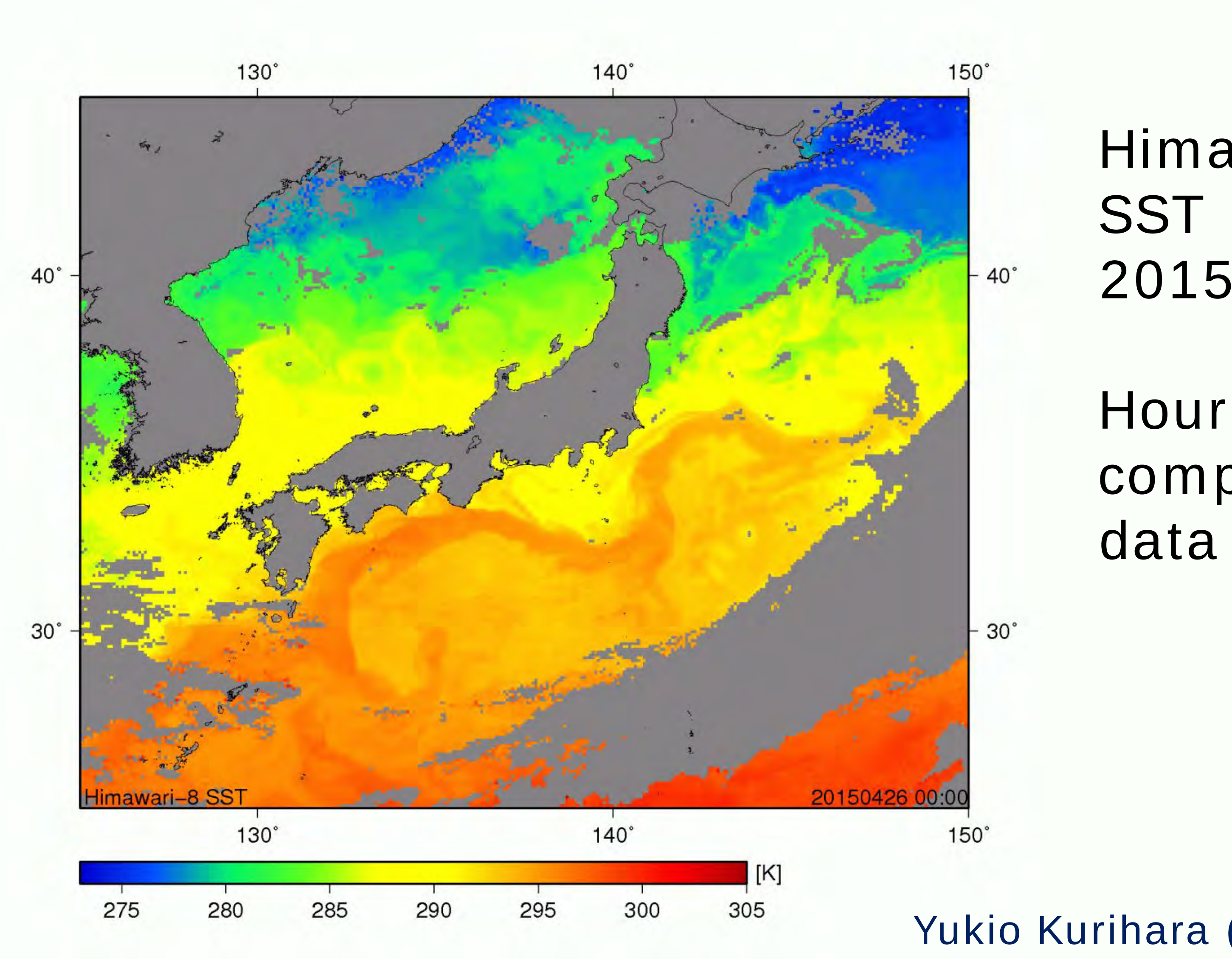


Figure 3: **Occurrence of significant daily DW events in the Arctic in summer 2008 in June (left panel) and July (right panel).**

Regional SST every 10 minutes



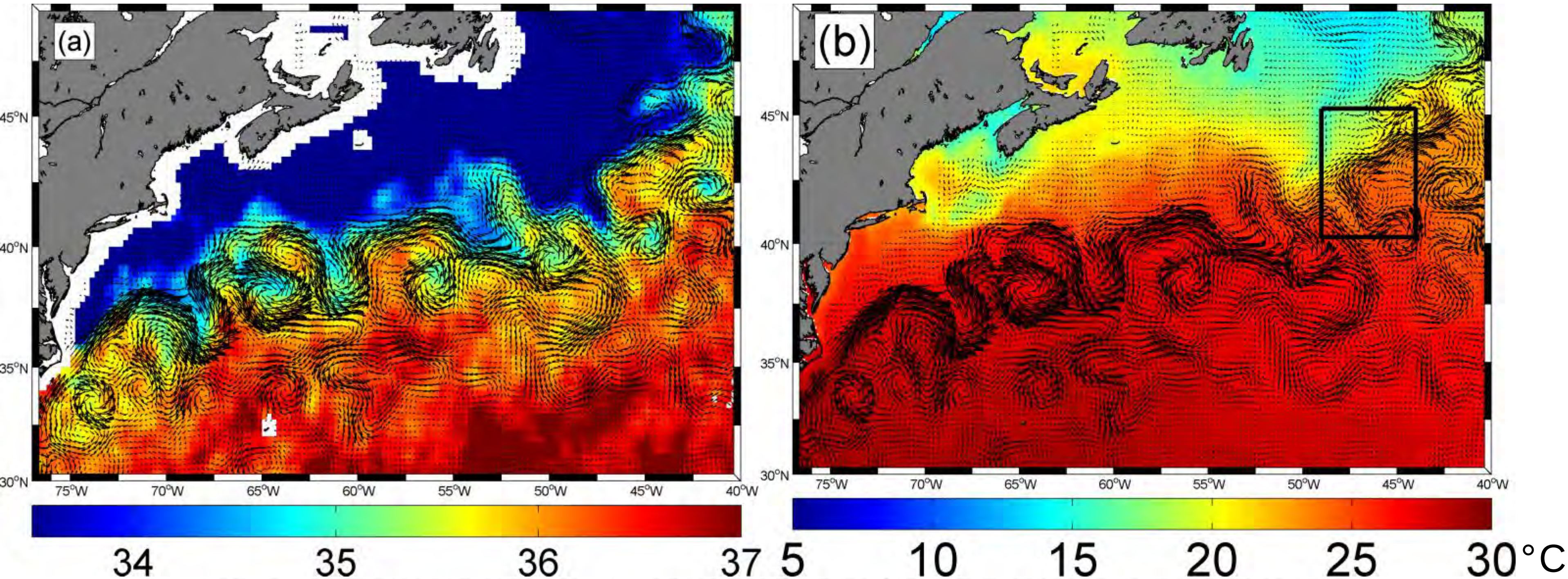
Himawari-8
SST
2015-04-26

Hourly composite data

Yukio Kurihara (JAXA)

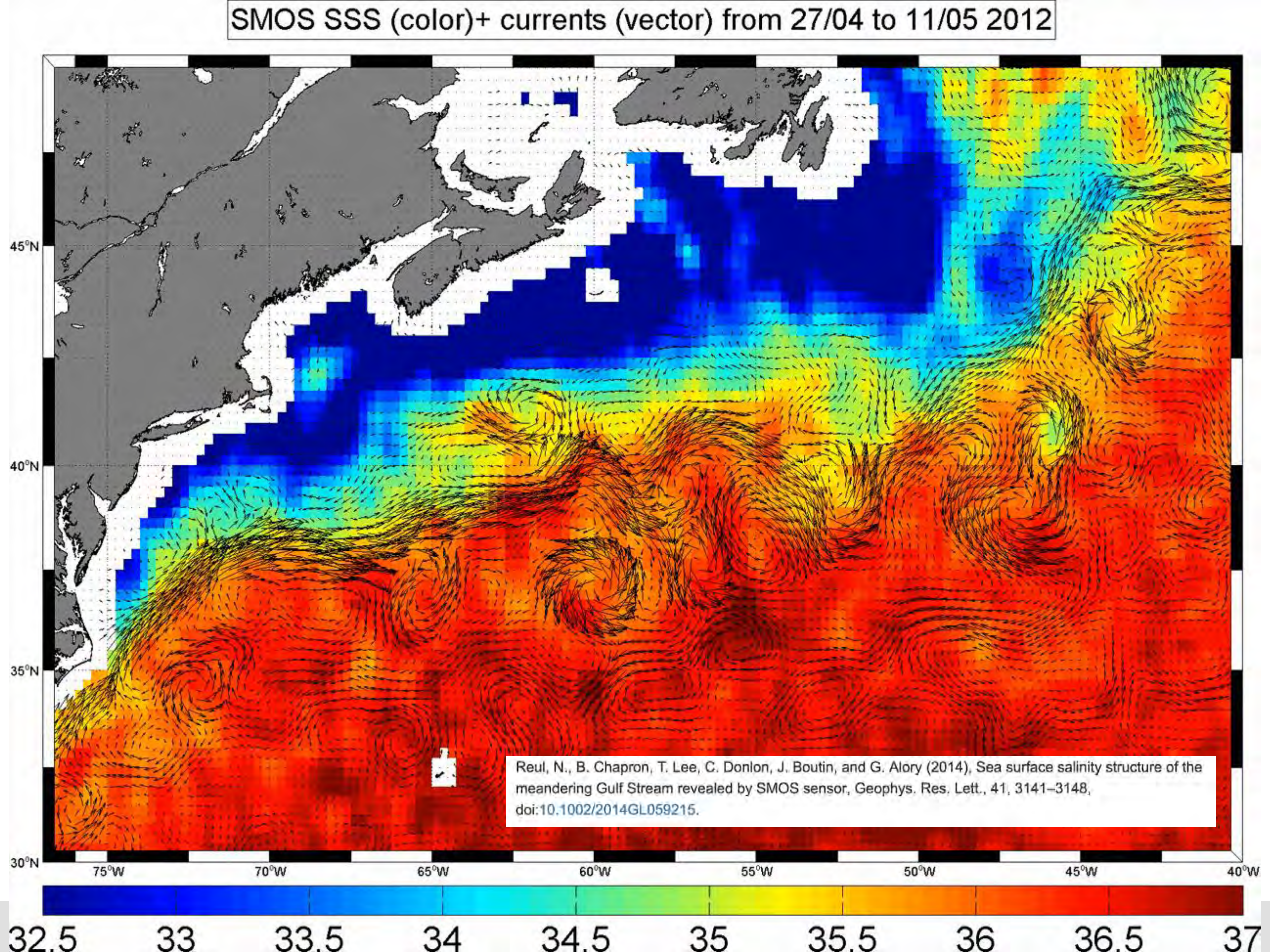
DV "Structure" masking: 15 to 25 August 2012

smos+ sos
support to science element



Reul, N., B. Chapron, T. Lee, C. Donlon, J. Boutin, and G. Alory (2014), Sea surface salinity structure of the meandering Gulf Stream revealed by SMOS sensor, Geophys. Res. Lett., 41, 3141–3148, doi:10.1002/2014GL059215.

- SMOS reveals SSS structure of the Gulf Stream with an unprecedented Space and time resolution
- Cold/fresh Core rings are better captured by SSS observations than by SST during summer.
- Implications for assimilation and interpretation


SMOS SSS (color)+ currents (vector) from 27/04 to 11/05 2012
45°N
40°N
35°N
30°N
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
Reul, N., B. Chapron, T. Lee, C. Donlon, J. Boutin, and G. Alory (2014), Sea surface salinity structure of the meandering Gulf Stream revealed by SMOS sensor, Geophys. Res. Lett., 41, 3141–3148, doi:10.1002/2014GL059215.
32.5
33
33.5
34
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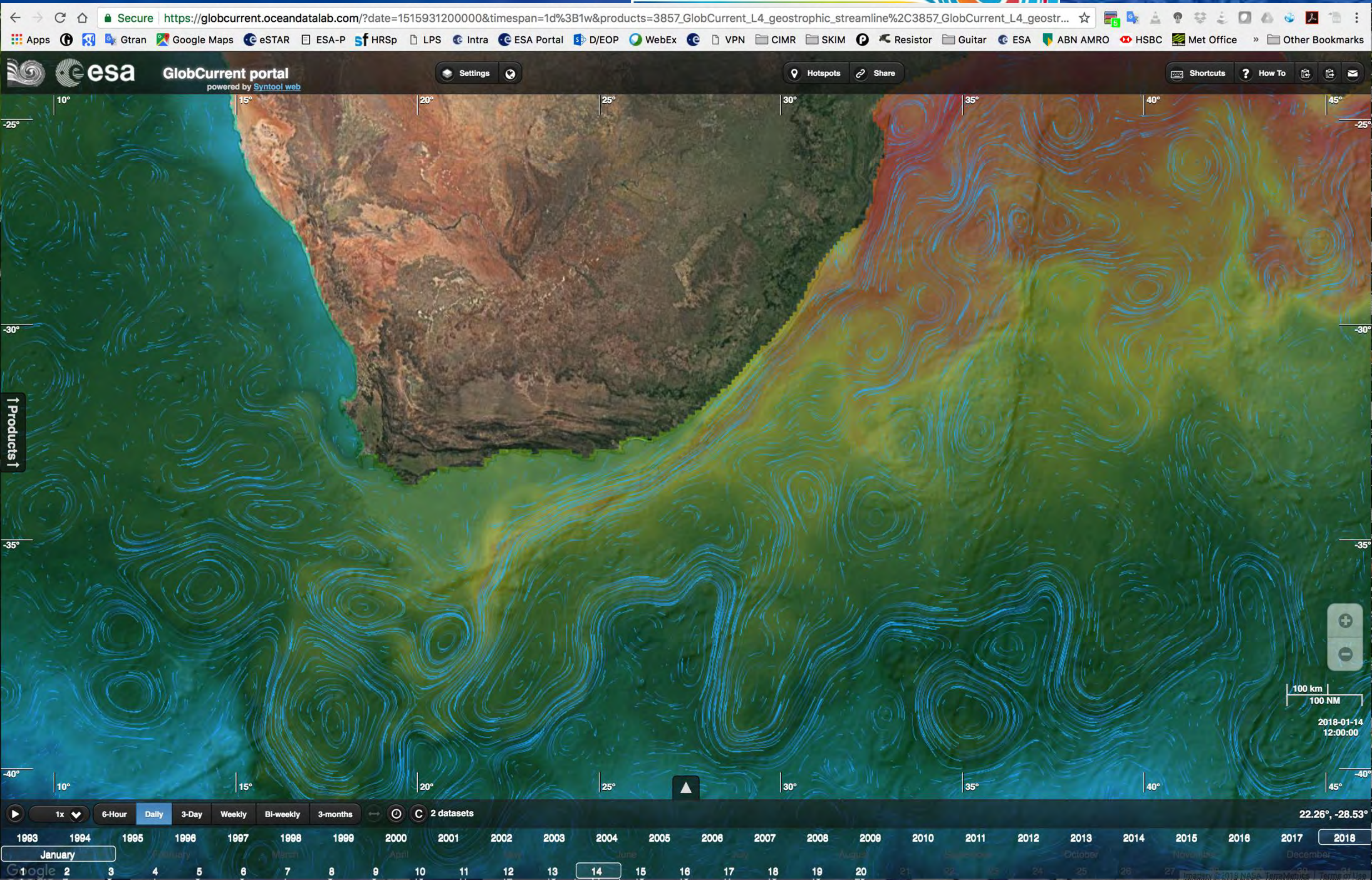
36.5
37

Ifremer

esa



oceandatalab

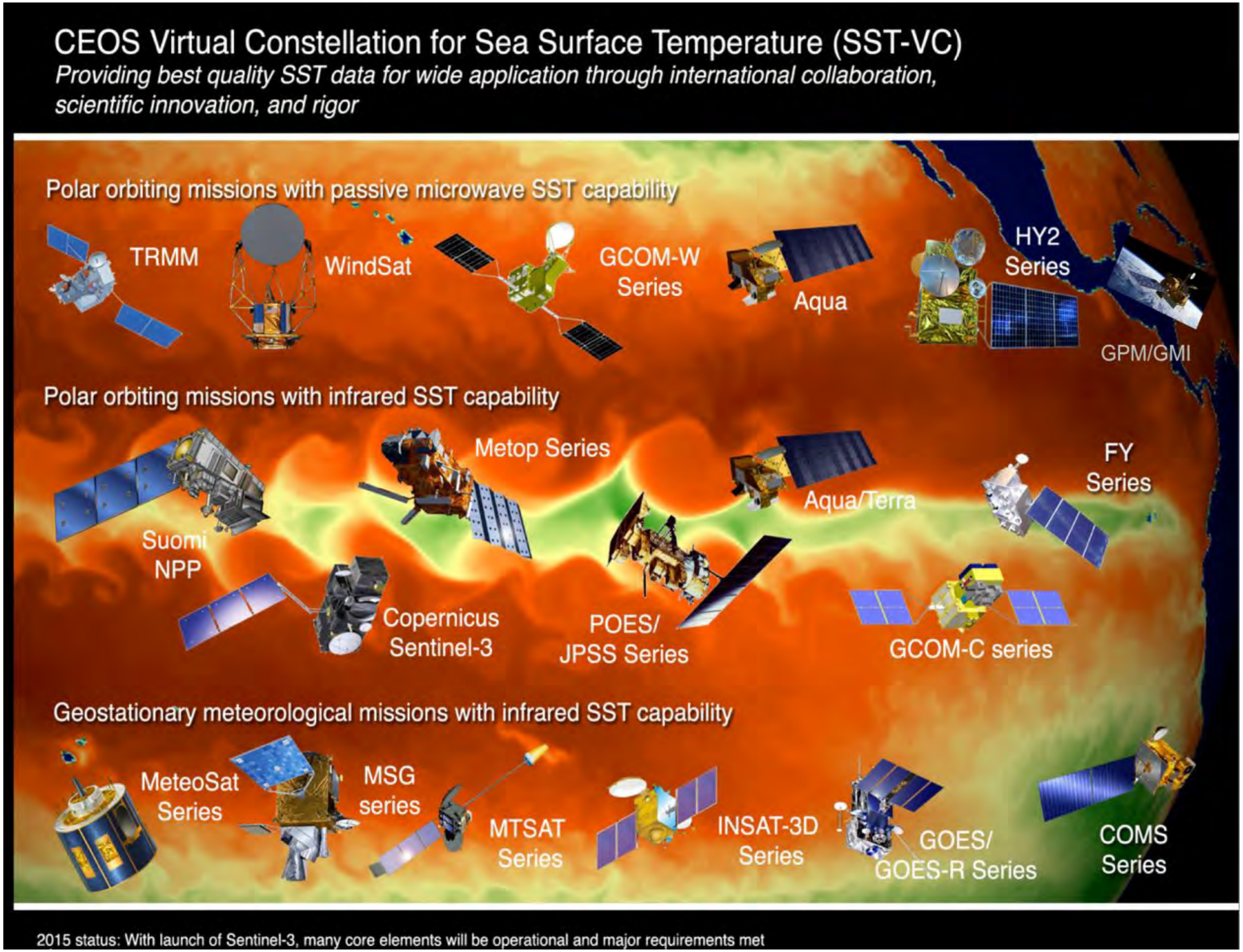
PML Plymouth Marine Laboratory

isardSAT

EXETER

CLS

International Context



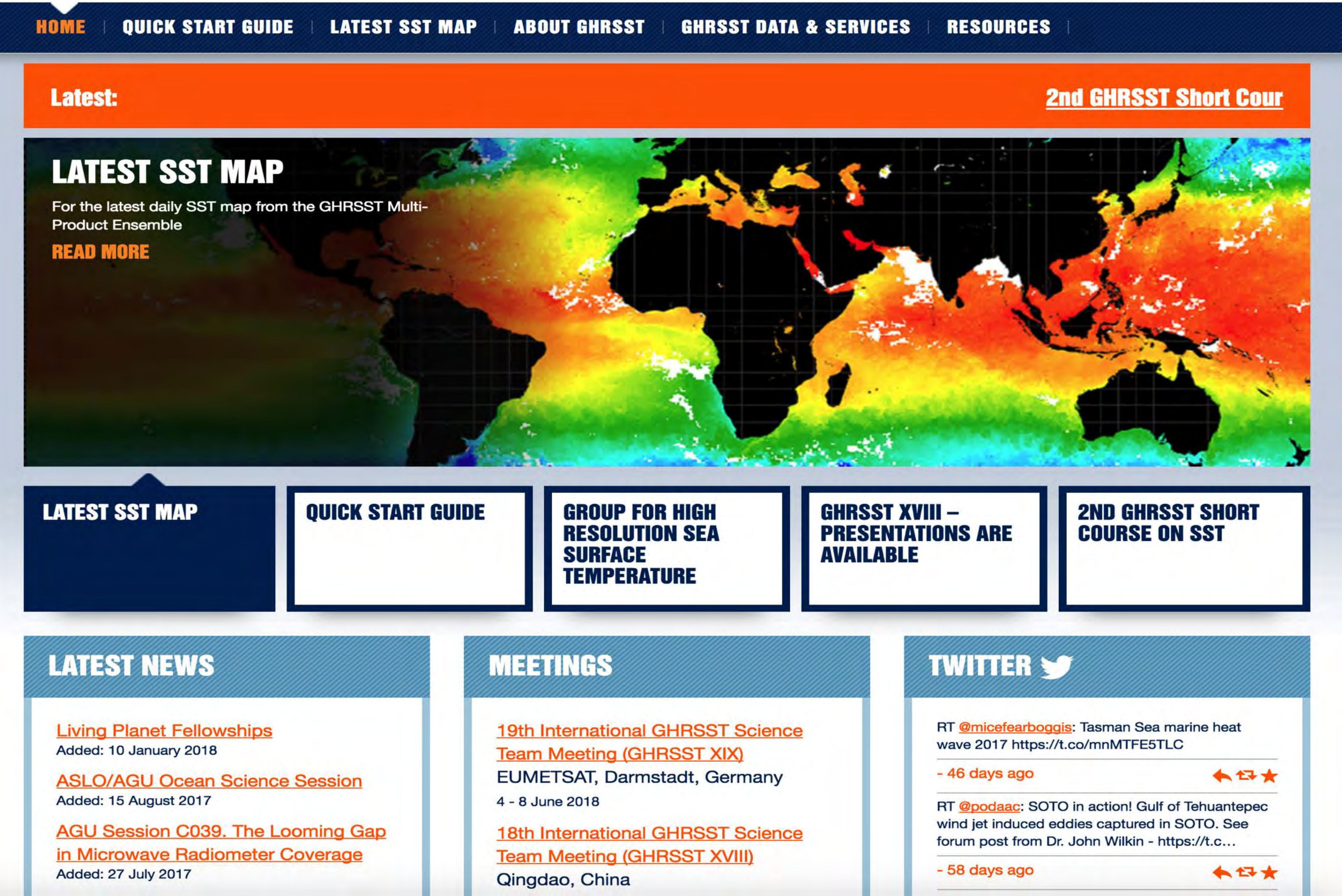
ESA
NASA
NOAA
EUMETSAT
JAXA
CMA
NSOAS
...

SST aspects Coordinated by CEOS SST-VC and GHRSST

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

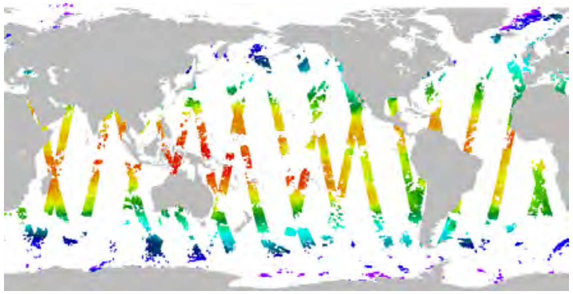
Transitioned from ESA R&D to to operations at EUMETSAT

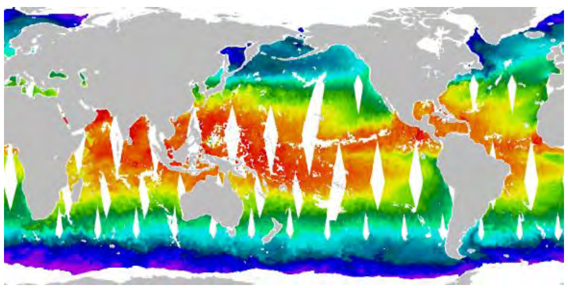
EUMETSAT

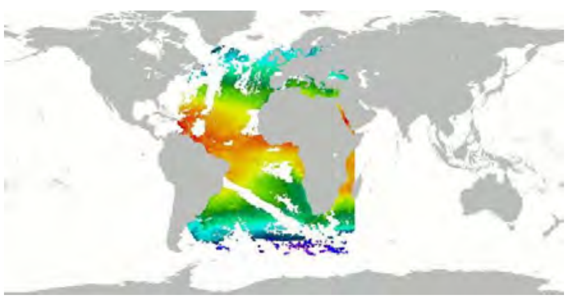


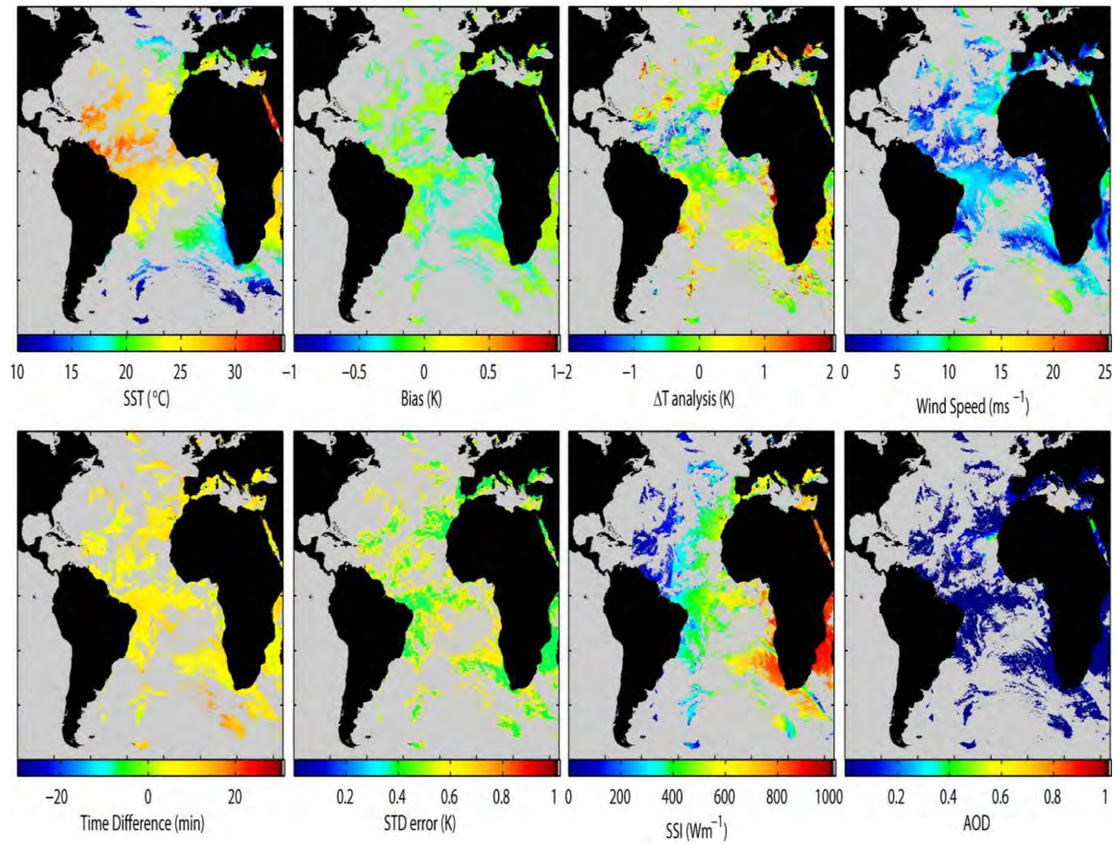
GHSST International Science Team

Many satellite data sets…in a common format



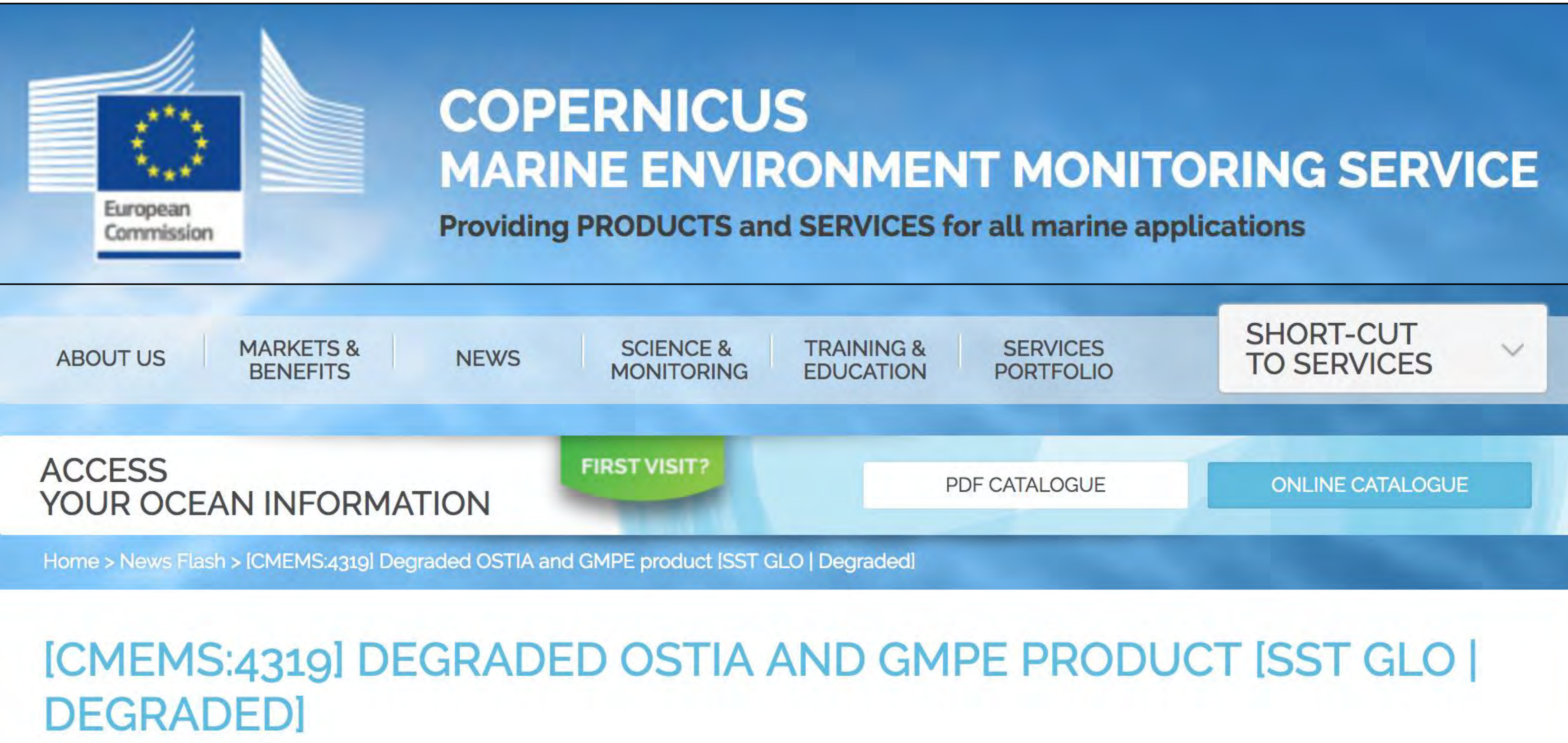






Ancillary information in L2P products: dynamic flags

Multi-Product L4 SST Ensemble: Medspiration → Operations



http://ghrsst-pp.metoffice.com/pages/latest_analysis/sst_monitor/weeqbl/index.html

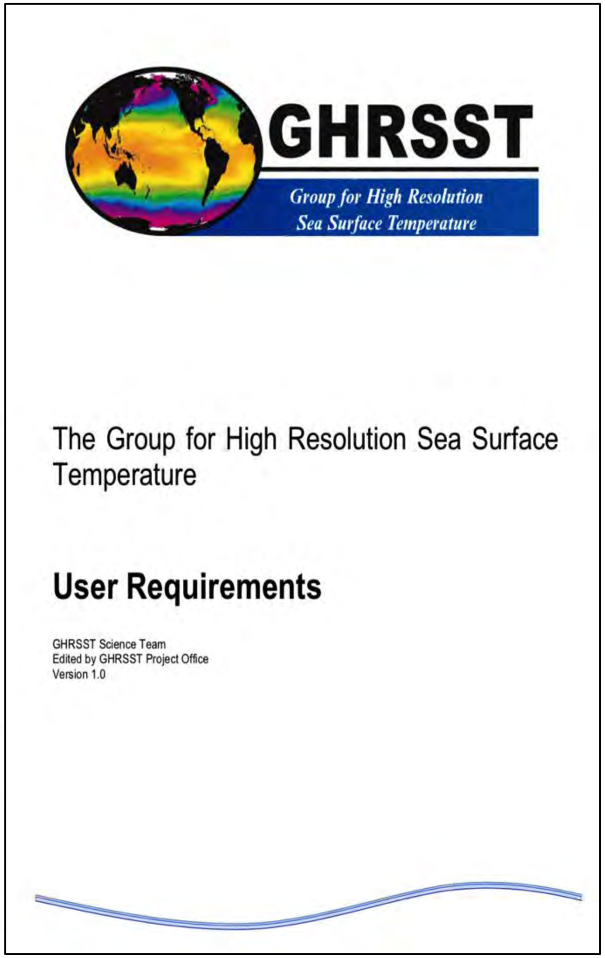
Met Office

SST Requirements (GHRSST)

- GHRSST conducted a wide international survey of operational, climate and scientific SST User needs.
- These have been translated into general SST User Requirements set out into the table below.
- Additional service requirements are found in the GHRSST User Requirements Document.

Application	Horizontal Resolution (km)	Temporal Resolution (hours)	Delivery Timeliness (hours)	Accuracy (°C)	Stability (°C/yr)
Numerical Weather Prediction - Global - Regional	 5 1	 24 < 6	 3 < 1	 0.3 0.3	 - -
Ocean Forecasting - Coastal Ocean - Open Ocean	 < 1 5 - 10	 < 6 < 6	 1 1	 < 0.1 < 0.1	 - -
Seasonal and Interannual Forecasting	10 100	24 24	24 24	< 0.1 < 0.25	0.01
Climate Monitoring and Research	100	24	1 month	0.1	0.01
Coral Reef Management Systems	< 1	1 and 24	24	< 0.3	0.01
Fisheries	< 1	1 and 24	< 3	0.5	-
Coastal and Inland Waters	< 1	1 and 24	1	< 0.3	-
Recreational	< 1	24	1	0.5	-

Table 7-1: Summary of key applications and their SST target requirements.


GHRSST
Group for High Resolution Sea Surface Temperature

The Group for High Resolution Sea Surface Temperature

User Requirements

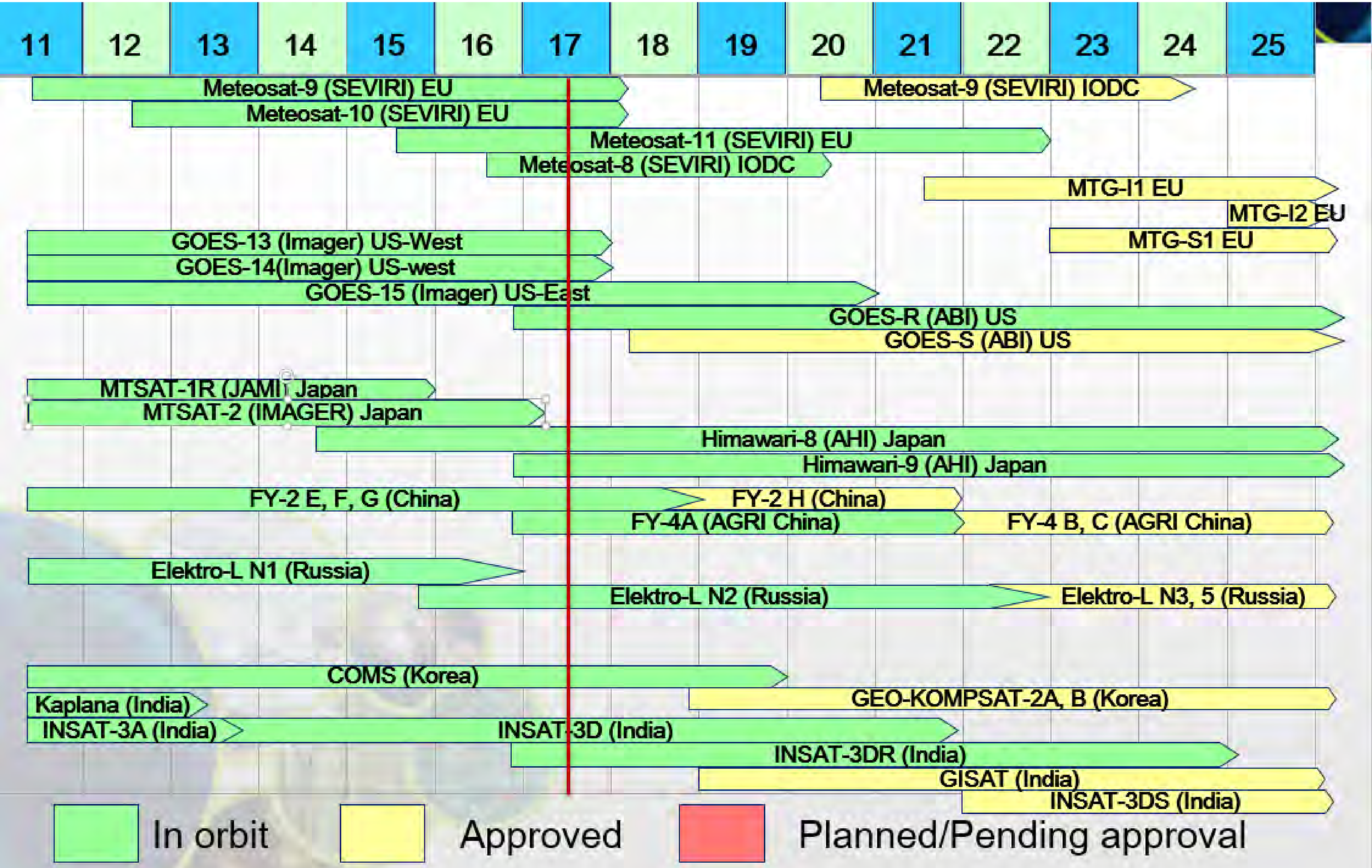
GHRSST Science Team
Edited by GHRSST Project Office
Version 1.0

European SST measurement capability today

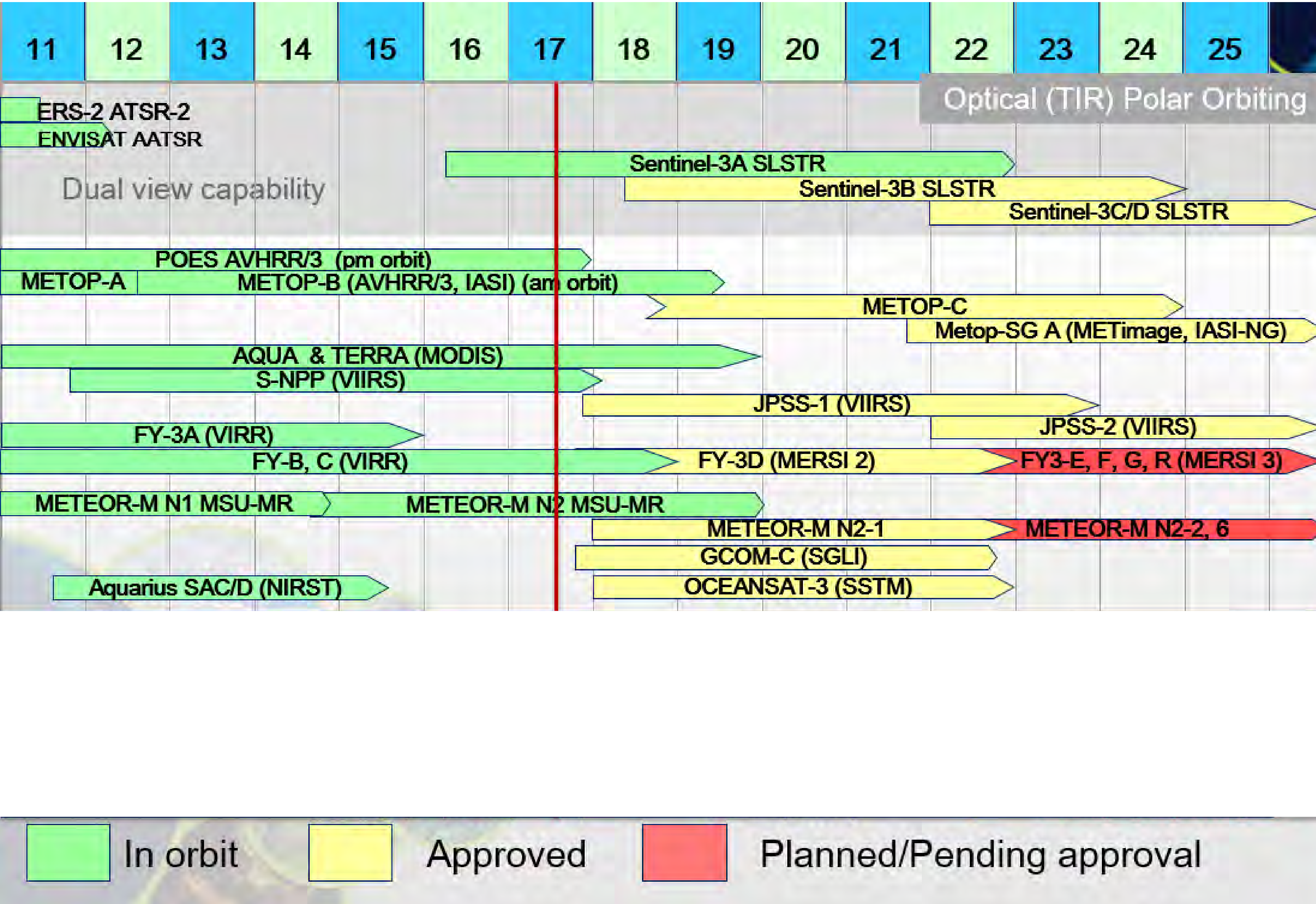
- International coordination and exchange
  - GHRSST and CEOS SST-VC
- Thermal Infrared Radiometry
  - Polar orbiting → Copernicus Sentinel-3/MetOP
  - Geostationary → MSG/MTG
- Microwave Radiometry
  - Polar Orbiting → Potential Copernicus Mission
- *In situ* and Fiducial Reference Measurements (FRM)
  - FRM4STS, AMT4Sentinel, TIR Radiometers

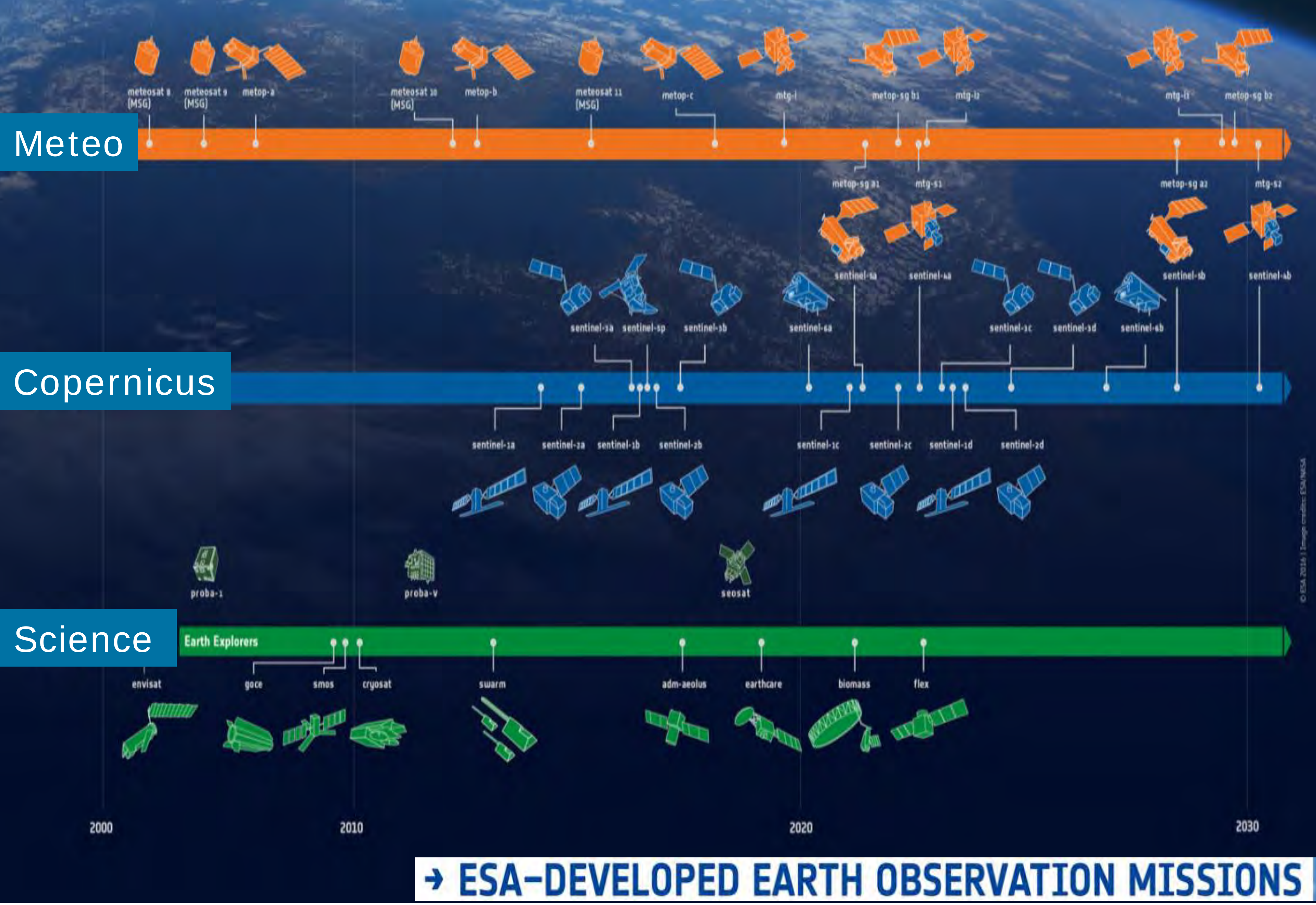
- Each have complementary aspects that deliver excellent synergy -- In fact, all of these are required for an effective SST measurement system

Geostationary Imagers

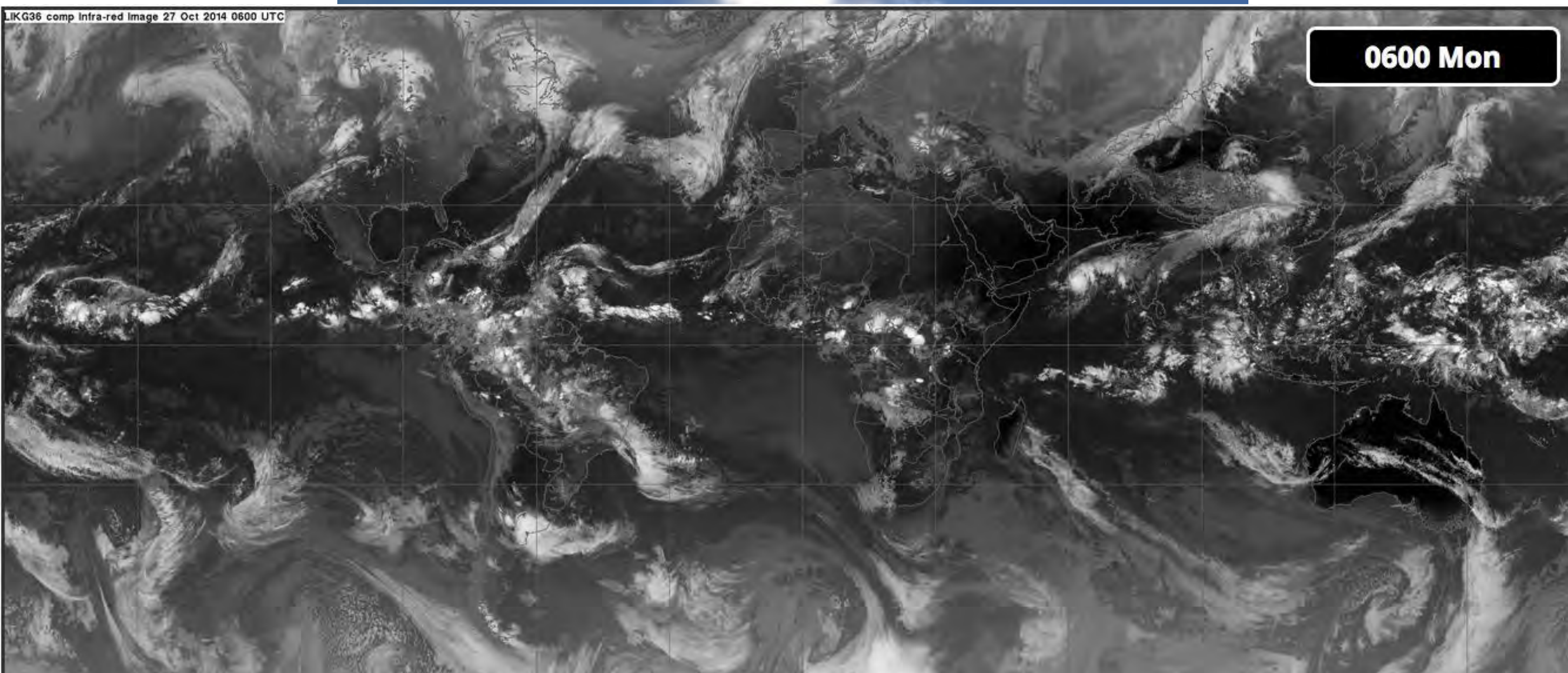


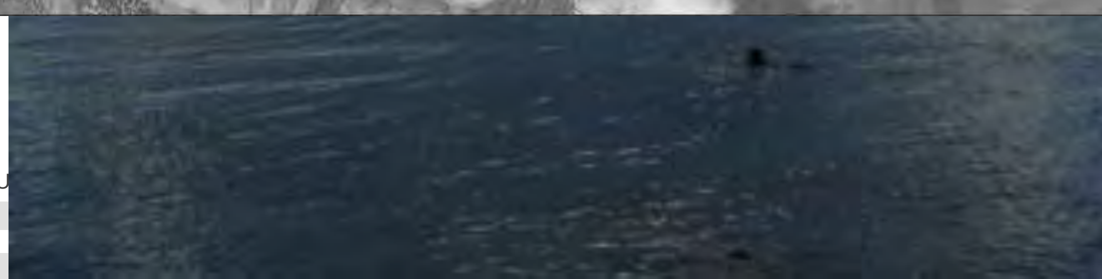
Polar Orbiting Thermal infrared Radiometers




Meteo
meteosat 8 (MSG)
meteosat 9 (MSG)
metop-a
meteosat 10 (MSG)
metop-b
meteosat 11 (MSG)
metop-c
mtg-i1
metop-sg b1
mtg-i2
mtg-i3
metop-sg b2
metop-sg a1
mtg-s1
metop-sg a2
mtg-s2
Copernicus
sentinel-5a
sentinel-4a
sentinel-5b
sentinel-4b
sentinel-3a
sentinel-5p
sentinel-3b
sentinel-6a
sentinel-3c
sentinel-3d
sentinel-6b
sentinel-1a
sentinel-2a
sentinel-1b
sentinel-2b
sentinel-1c
sentinel-2c
sentinel-1d
sentinel-2d
proba-1
proba-v
seosat
Science
Earth Explorers
envisat
goce
smos
cryosat
swarm
adm-aeolus
earthcare
biomass
flex
2000
2010
2020
2030
ESA-DEVELOPED EARTH OBSERVATION MISSIONS

esa

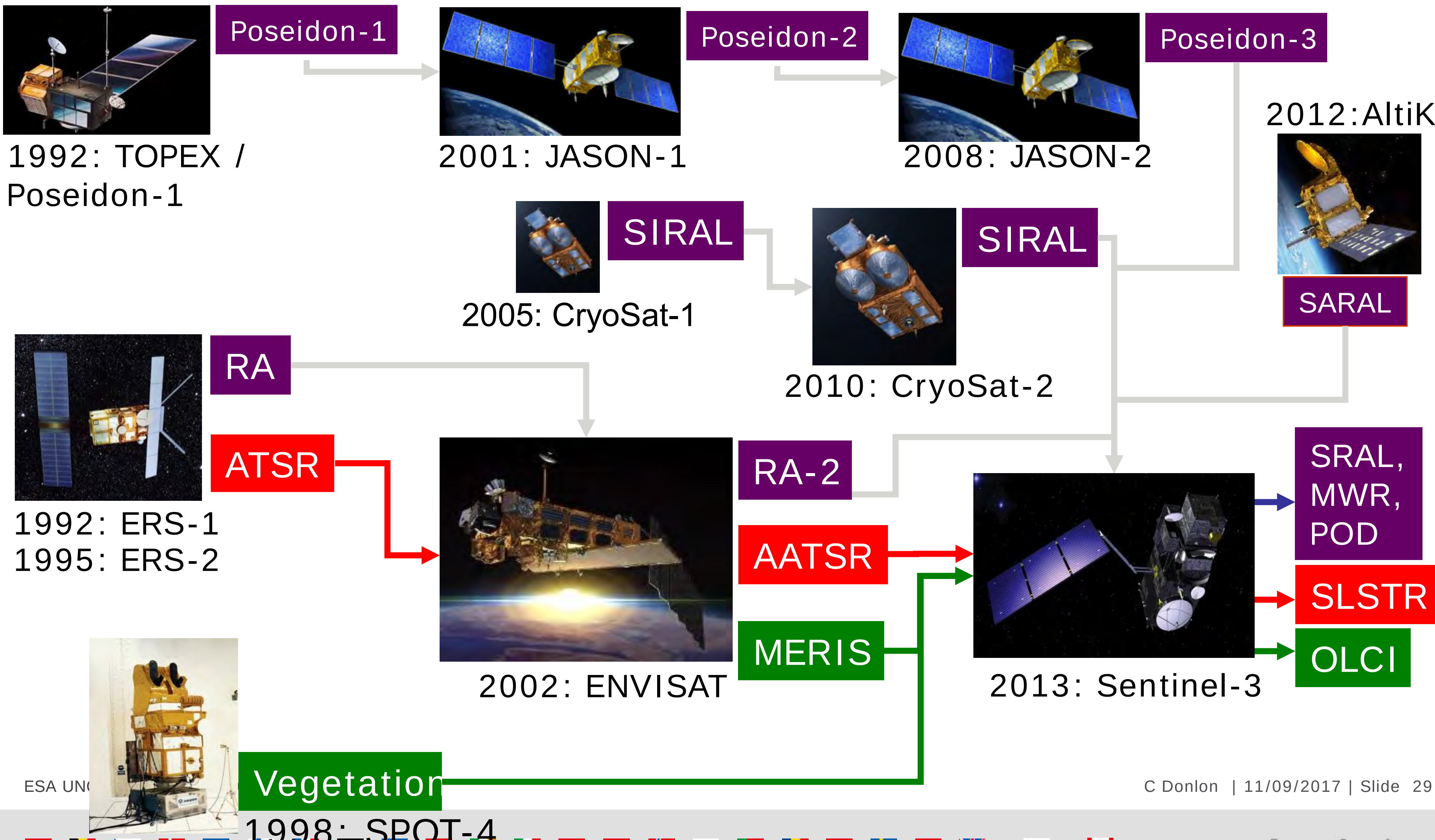


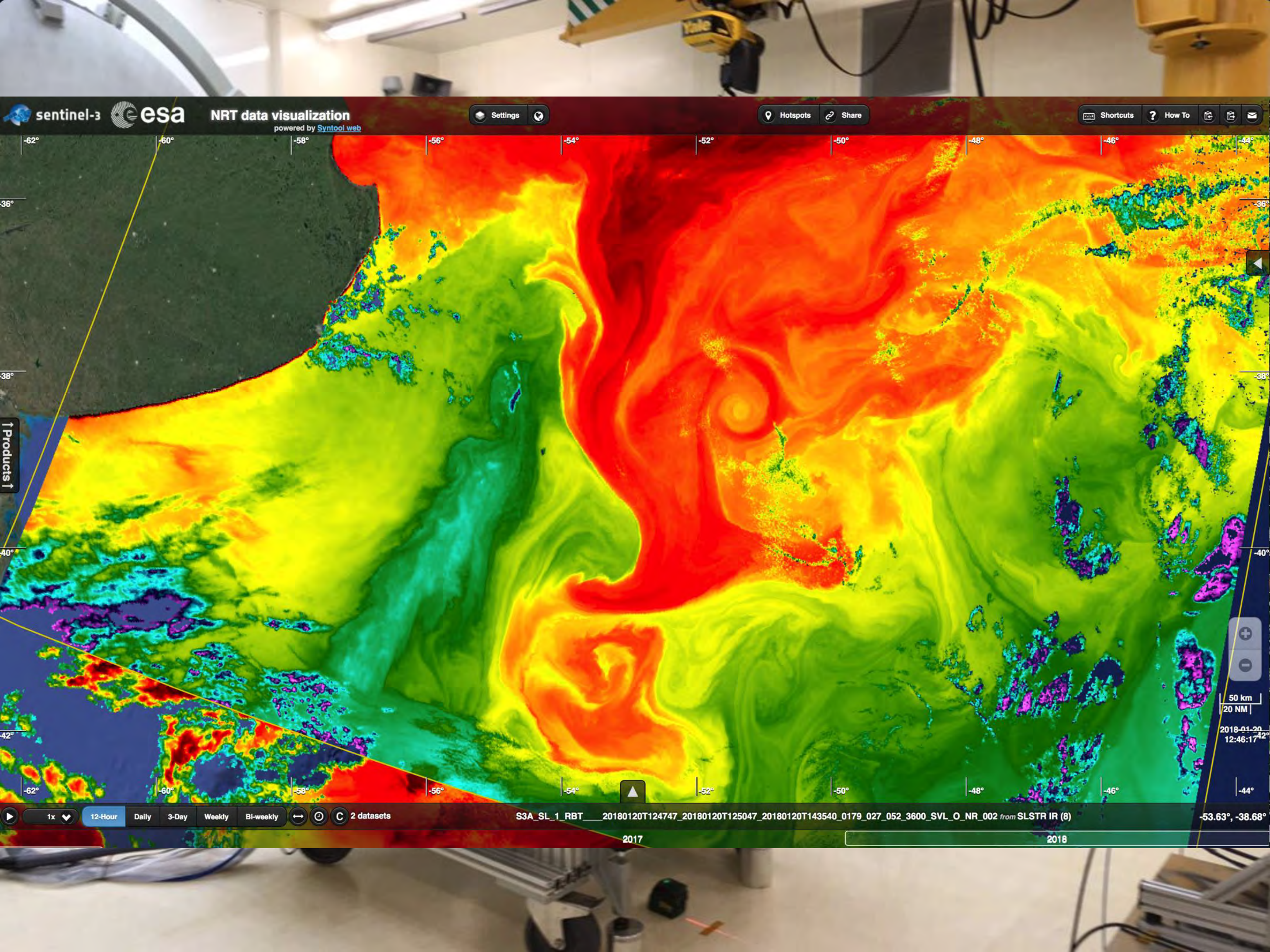


Met Office

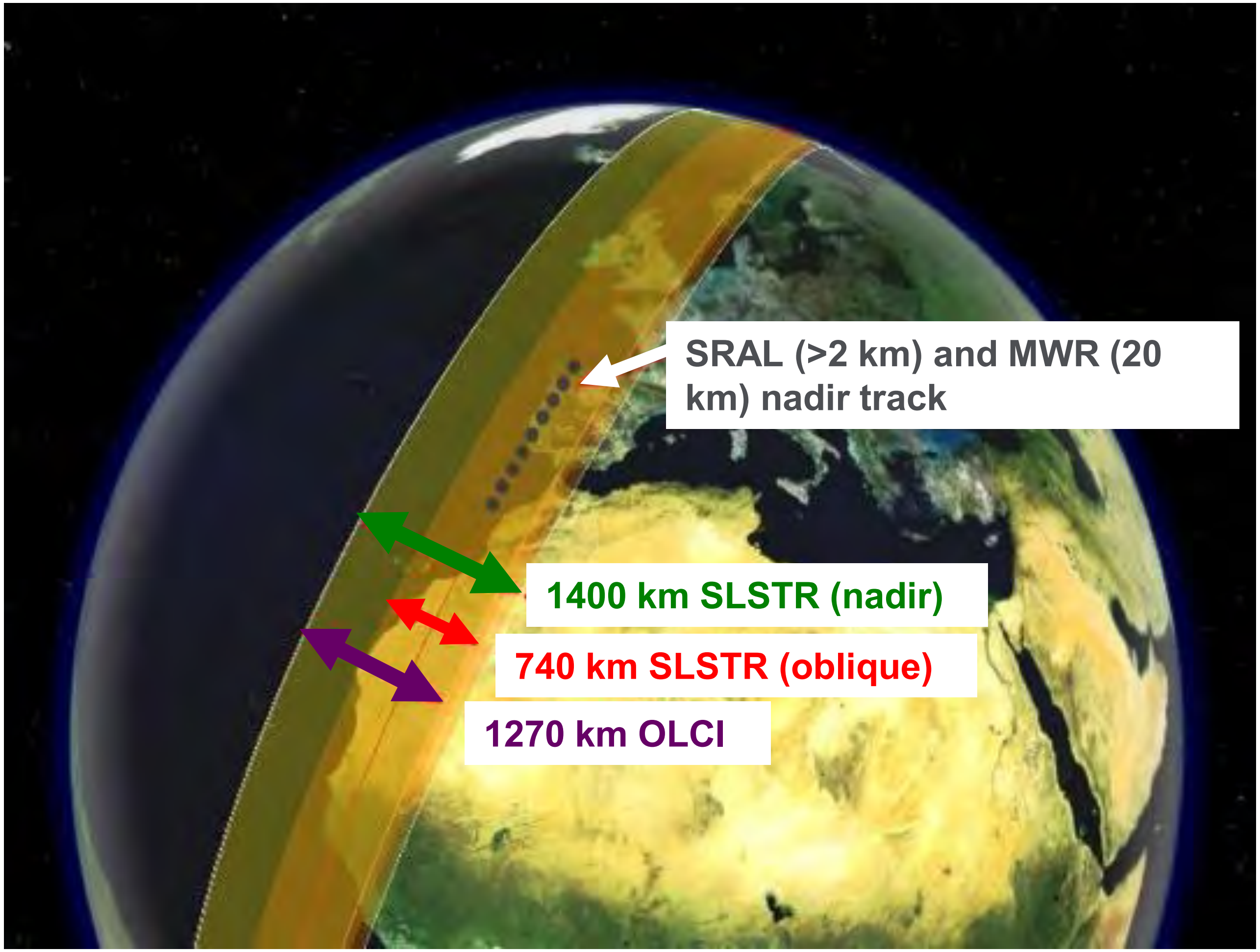

European Commission
esa
European Space Agency
Sentinel-3
→ A BIGGER PICTURE FOR COPERNICUS

Sentinel-3 Mission Heritage



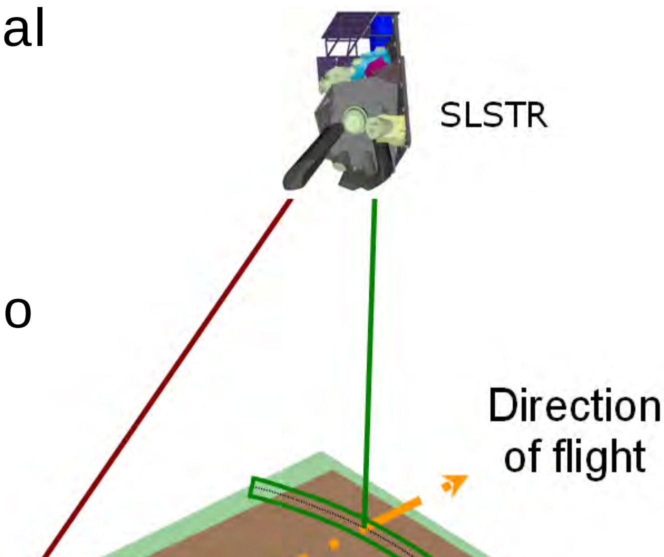

sentinel-3
esa
NRT data visualization
powered by Syntool web
Settings
Hotspots
Share
Shortcuts
How To
Products
1x
12-Hour
Daily
3-Day
Weekly
Bi-weekly
2 datasets
S3A_SL_1_RBT____20180120T124747_20180120T125047_20180120T143540_0179_027_052_3600_SVL_O_NR_002 from SLSTR IR (8)
-53.63°, -38.68°
2017
2018
50 km
20 NM
2018-01-20
12:46:17
-62°
-60°
-58°
-56°
-54°
-52°
-50°
-48°
-46°
-44°
-36°
-38°
-40°
-42°
Yale

Sentinel-3 Collocated measurements

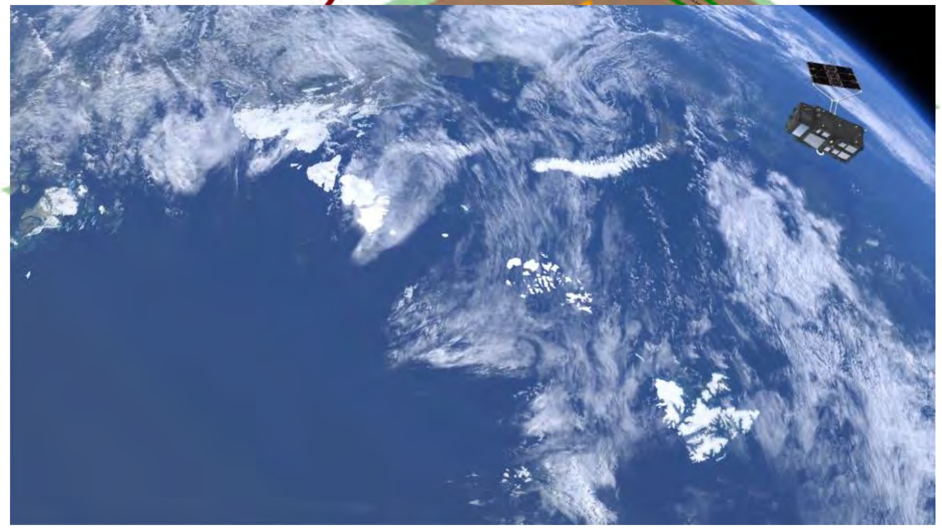


S3 SLSTR: Basic Geometry

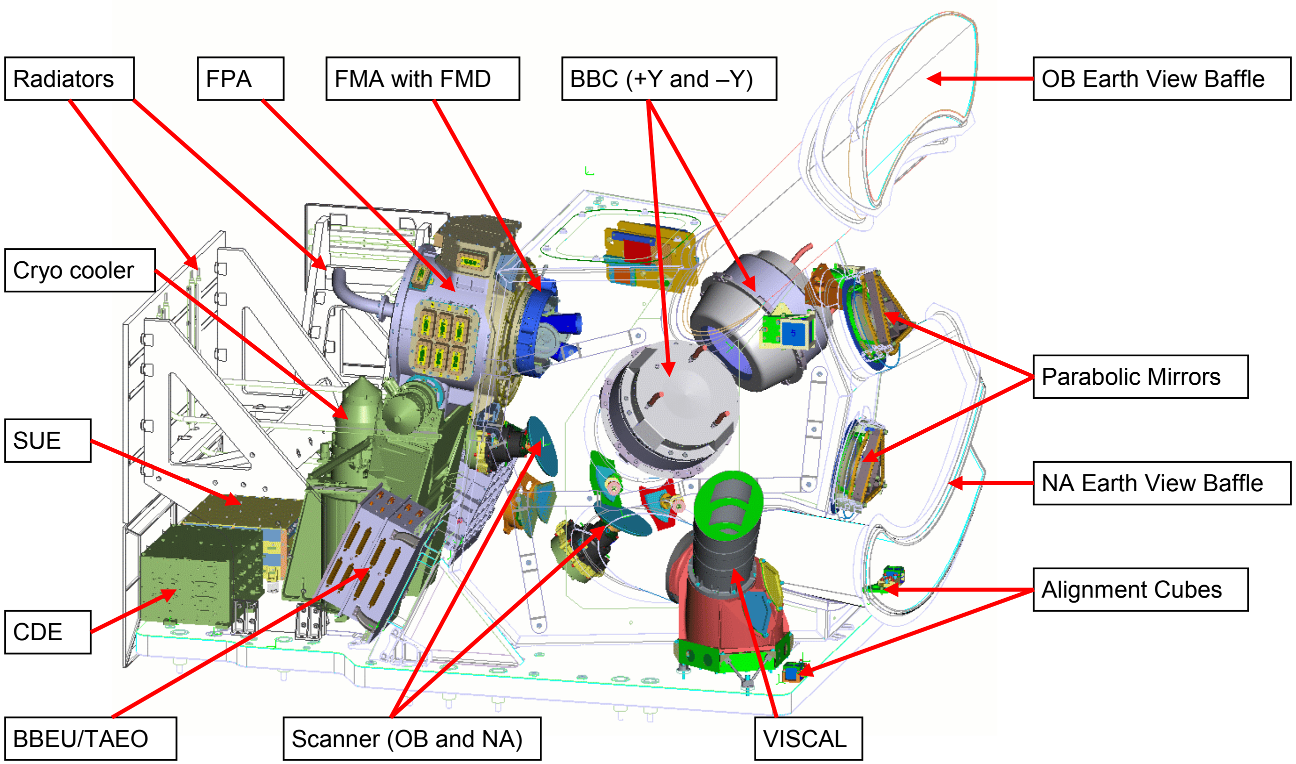
- To enable a wider swath SLSTR uses two scan systems (nadir and oblique) and optical paths
- A flip mirror (new) is used to select which optical path is directed to the detectors
- The nadir swath has a westerly offset to completely overlap the OLCI swath and mitigate sun-glint

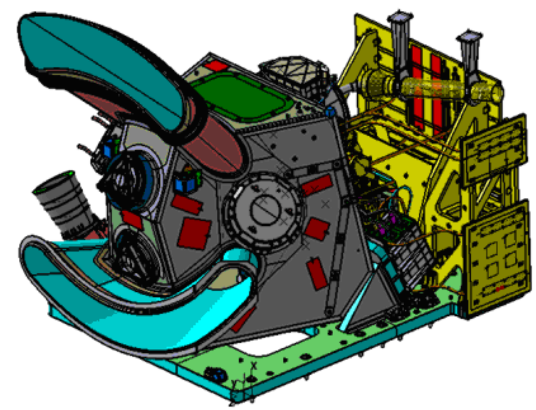


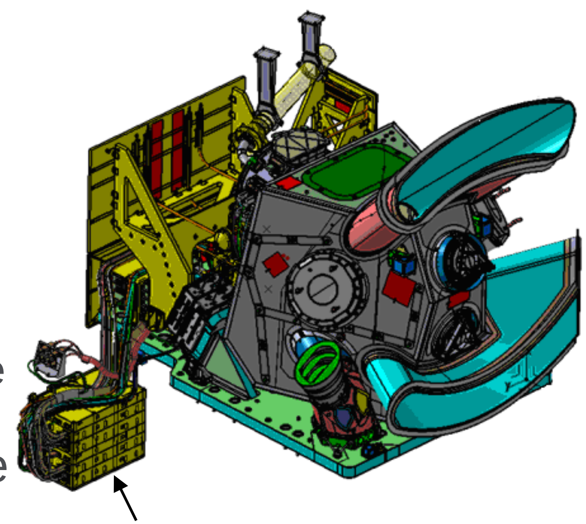
- The oblique view 55°inclination maintains a longer atmospheric path length compared to nadir
  - better atmospheric correction
- <u>Both scan chains view the same blackbody and VISCAL targets</u>



S3 SLSTR: Instrument







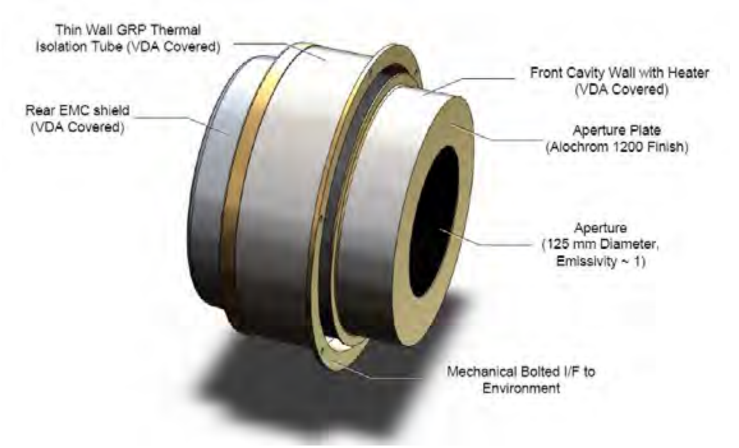
SLSTR is composed of two main units:

- SLOSU (Optical Scanning Unit) and
- CPE (Control and Processing Electronics). mounted inside the satellite on a dedicated panel

SLOSU is composed of an Opto-mechanical Enclosure (OME) and a Detection Assembly (DA)

S3 SLSTR: Calibration

SLSTR is a self-calibrating IR instrument.



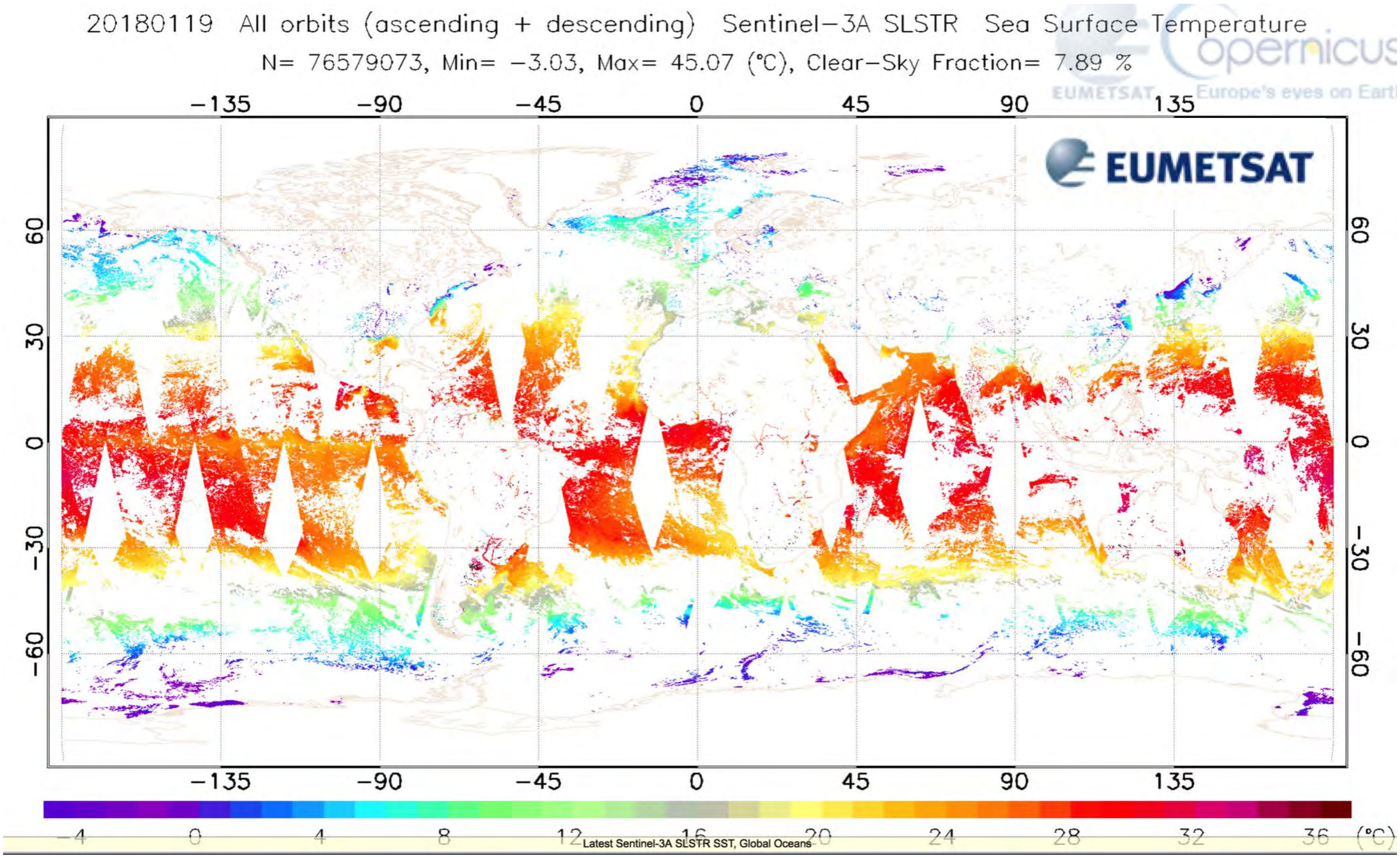
SLSTR uses an on-board calibration system:

- TIR channels use two specially designed and highly stable blackbody cavities observed every scan
- Fire Channels rely on pre-launch calibration and use of hot BB (dynamic range >600 K) as best effort

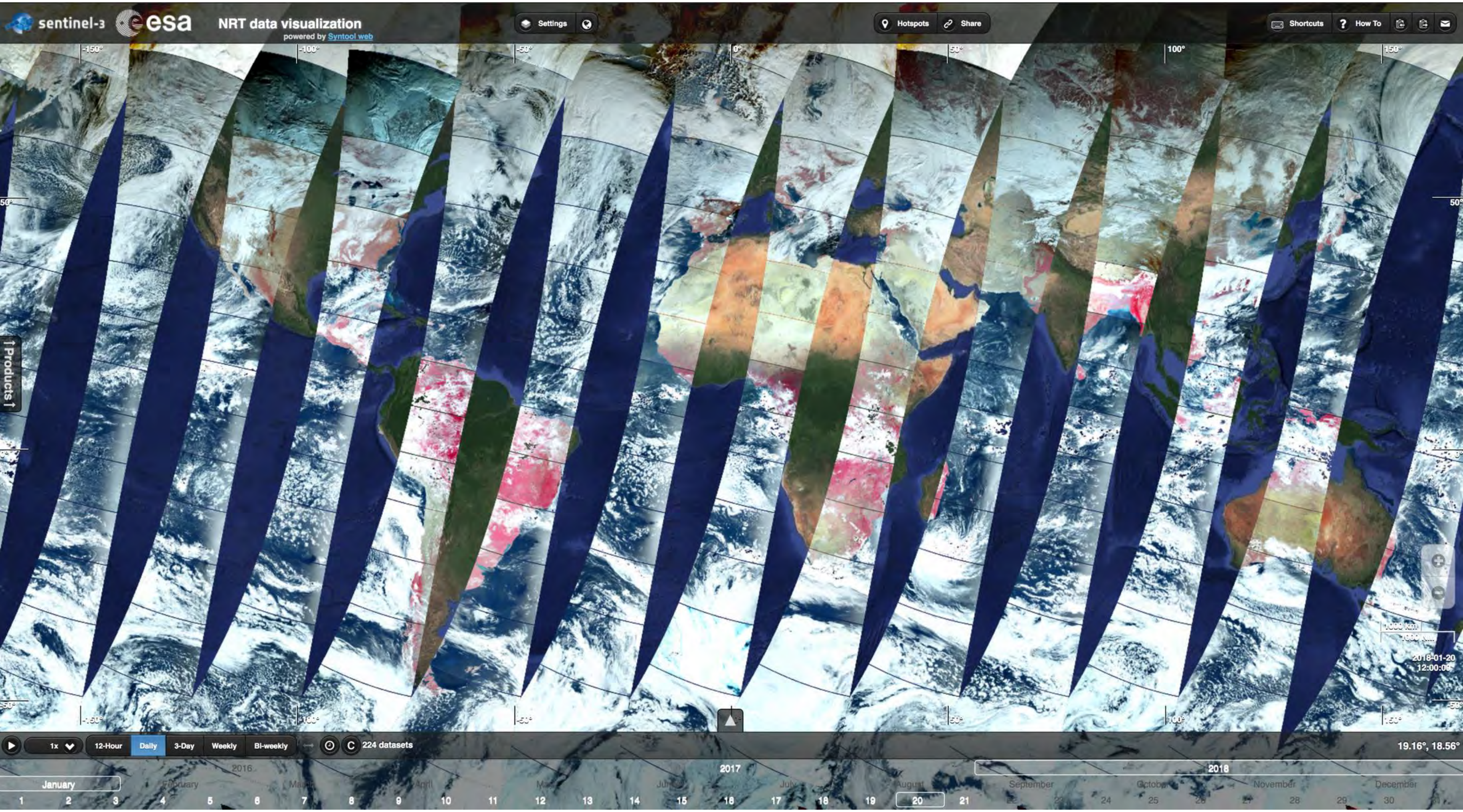
Vicarious VIS/SWIR calibration

- Solar diffuser illuminated once per orbit at at the the S. Pole terminator.
- Additional regular views of stable earth sites (Desert, snow) used to characterize / correct for calibration drift.

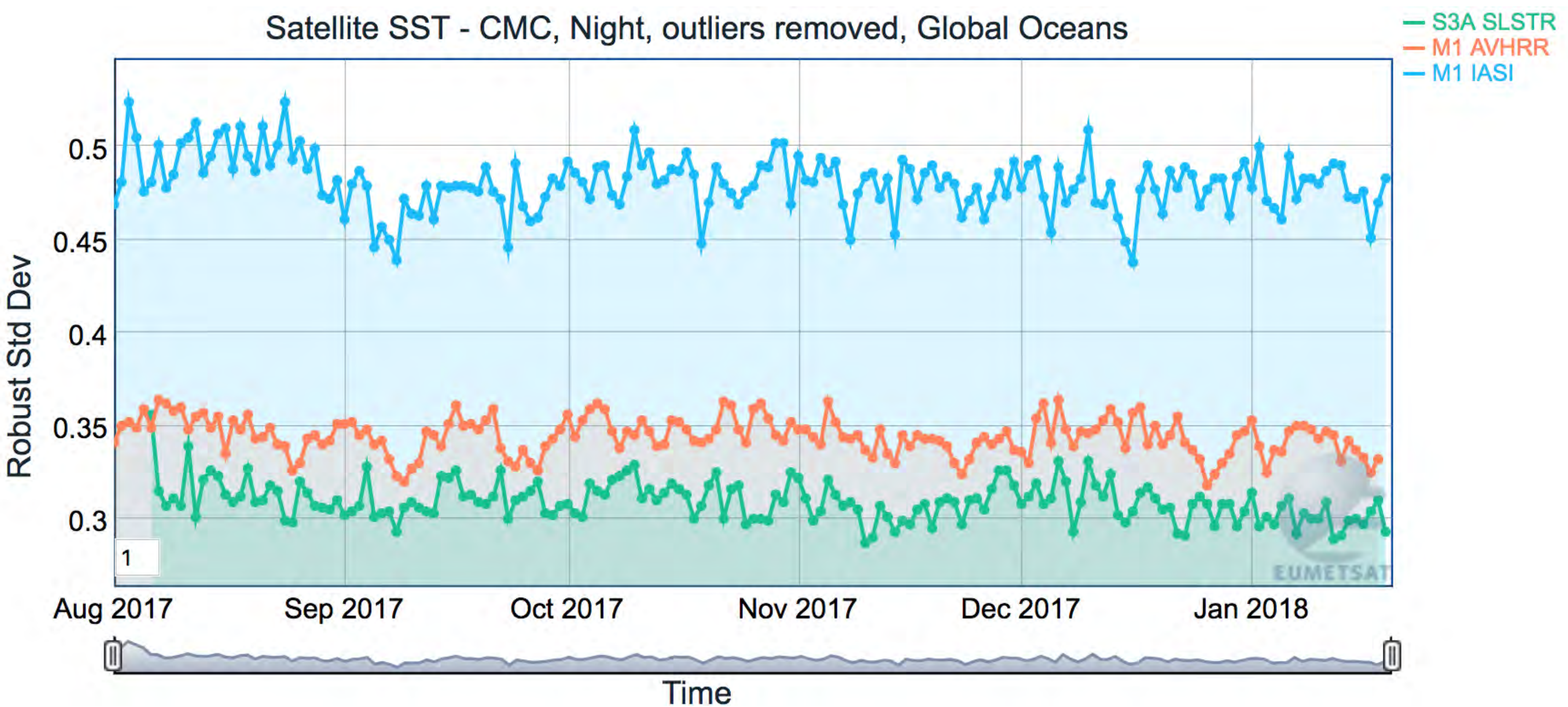
Sentinel-3A SLSTR 2018/01/18



Clouds Clouds Clouds...remain the primary source of uncertainty.



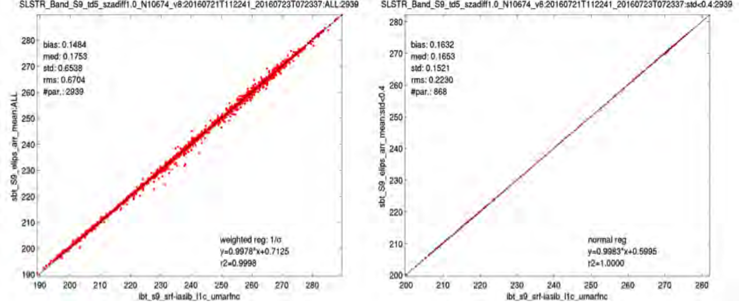
METIS Verification
SLSTR, Metop AVHRR and IASI
SST vs CMC 10km

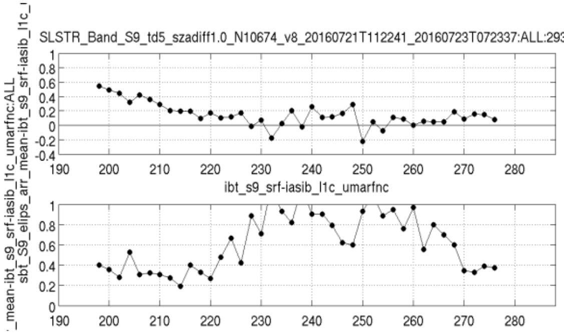


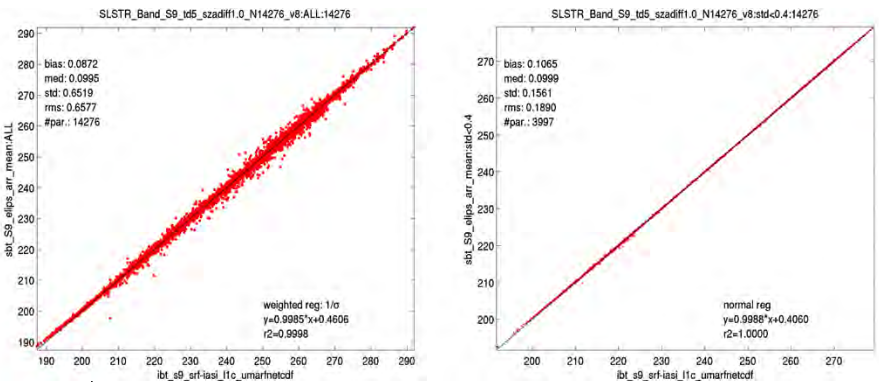
http://metis.eumetsat.int/sst/index.html#

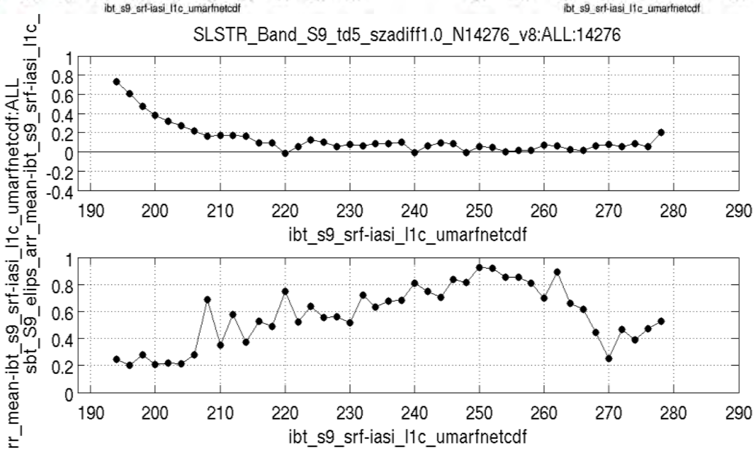
TIR Radiometric Calibration: e.g. SLSTR vs IASI

- SLSTR vs IASI-A
- Timediff: 5 min
- Distance: within pixel
- Satellite zenith angle: deltaSZA/SZA <=1%
- 5 SNO events: 27-28/04; 04-06/06; 23-25/06; 12-14/07; 01-02/08
- 100% matchups









- SLSTR vs IASI-B
- Timediff: 5 min
- Distance: within pixel
- Satellite zenith angle: deltaSZA/SZA <=1%
- 5 SNO events: 17-19/04; 06-08/05; 13-15/06; 21-23/07;28-30/08
- 100% matchups

- Directly compared S3A SLSTR S8/S9 and MetopA/IASI
- SLSTR agrees well with IASI for BT 230-270 K with near zero bias
- Consistent results between SNO events
- Separate contribution from north (250-270 K) and south (~<250 K) SNOs
- Higher bias in very cold temperature range (<230 K) and higher noise around 250 K requires further investigation

Sentinel-3A Mission Status

- Sentinel-3A launched in February 2016
- Nominal operations of space and ground segment
- Sentinel-3A Routine Operations Readiness Review in October 2017 to confirmed formal transition into full routine operations

- All Level 1 and 2 products have been released to users
- Reprocessing including the commissioning phase

Sentinel-3 is a multi-Satellite mission

Sentinel-3A: 2015-

To meet Mission Requirements

The Sentinel-3 Mission is composed of two identical satellites

Flown together in the same orbital plane separated by 140°

Follow-on Satellites (Sentinel-3C and Sentinel-3D) are now being procured.

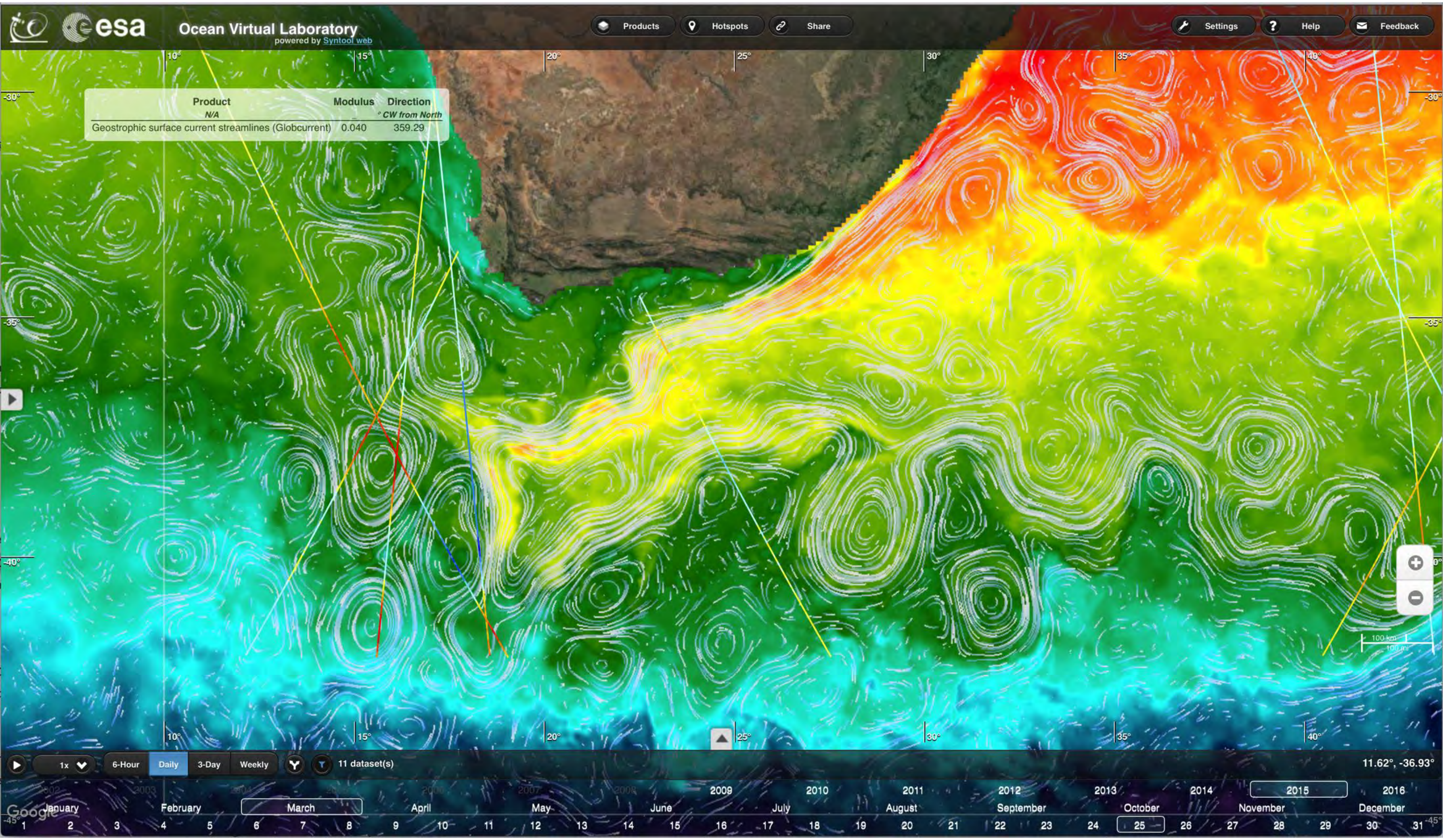
Sentinel-3B: 2018-

Sentinel-3B is coming soon...

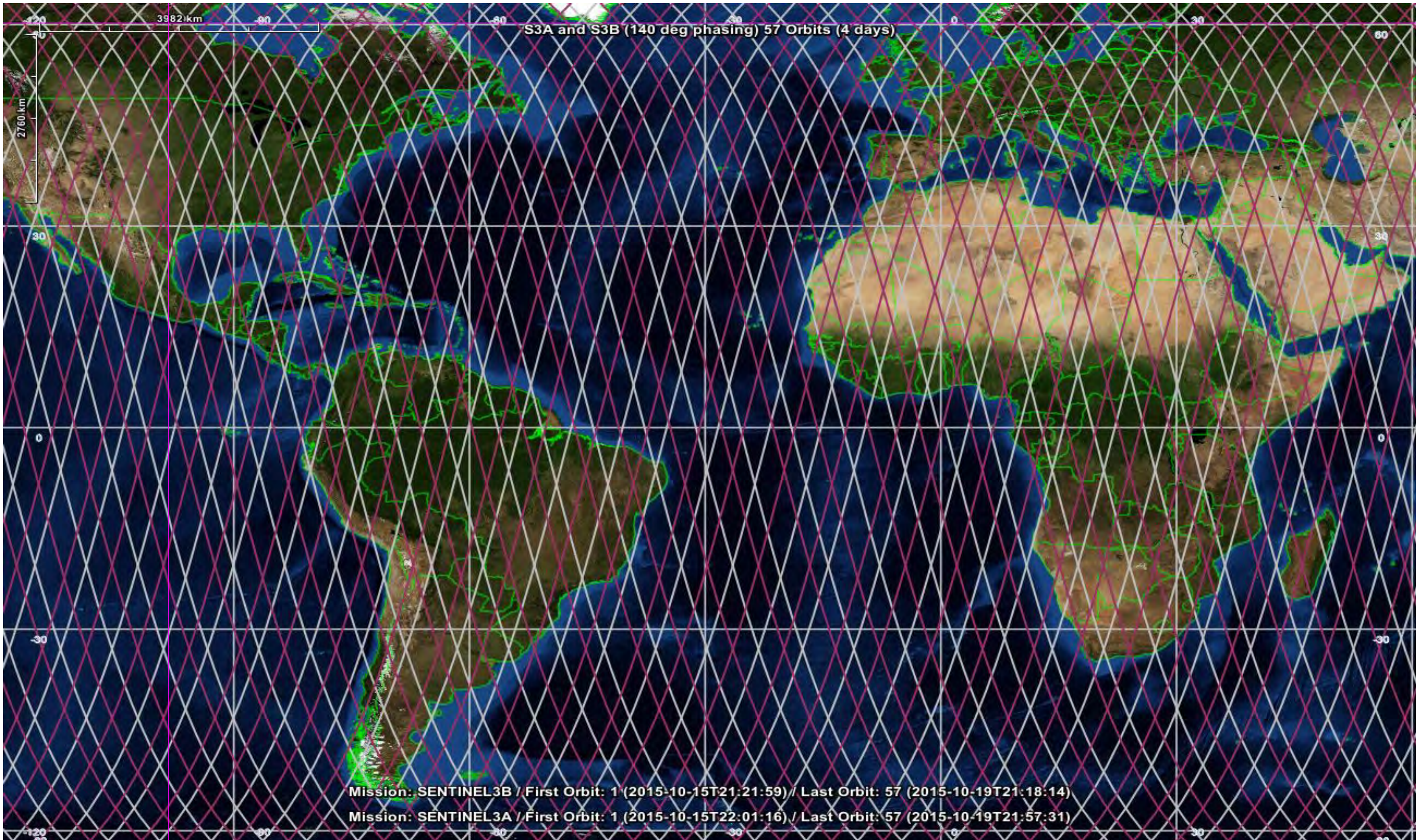
Sentinel-3B Current Status

- SLSTR Instrument Integrated on satellite in March 2017
- Final TVAC with OLCI PFM integrated, in September 2017
- Final Acceptance Review Completed in December 2017
- Launch using Rockot from Plesetsk (same as S3A) anticipated in mid April 2018
- Products will be released as soon as possible once they reach a suitable status of validation
- Full operational constellation will then be reached
- 9-month in-orbit commissioning
    - Optimised 140° phasing - improves interleave between S3A and S3B for better SRAL meso-scale sampling of 4-7 days
- Commissioning will include a 4-5 month tandem flight

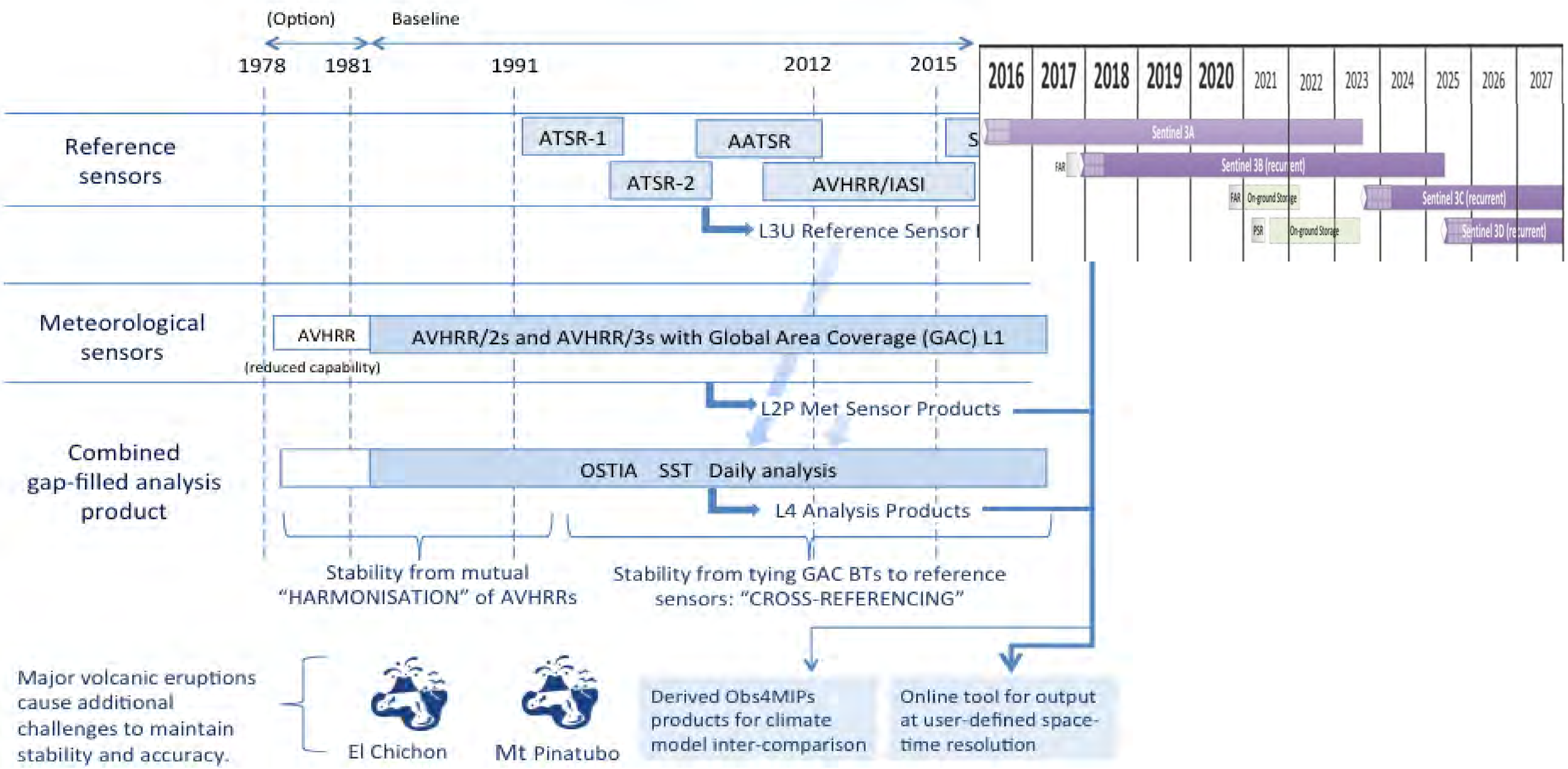
Mesoscale features



Optimising the Constellation: Change of Sentinel-3B orbit phasing from 180° to 140°. Coverage shown here after 4 days

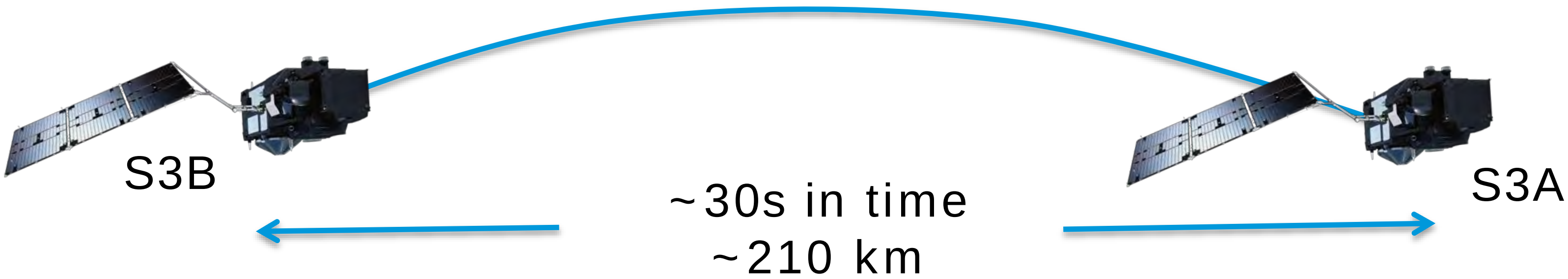


The ESA CCI SS Climate data record today and tomorrow.



Sentinel-3 Tandem Rationale

- A tandem phase operation of the A/B pair with ~30 s separation in time between satellites on near identical ground-track for ~4-5 months will be flown during Phase E1.



- At ~30s, the atmospheric and oceanic variability will be reduced to negligible levels → reduced uncertainty when comparing data.
- At ~30s, more dynamic targets such as convective cloud tops and hot deserts can be included in verification work.
- multiple coincidences extracted across a full range of atmospheric conditions at all latitudes will give the statistical power to characterise relative calibration to the precision required.
- We can run S3A and S3B instruments in different modes
- We are interested in new science aspects of the Tandem phase.

Sentinel-3 Tandem Implementation

Launch S3B higher than S3A. The Launch of S-3B will already initiate the drift to arrive close to S-3A.

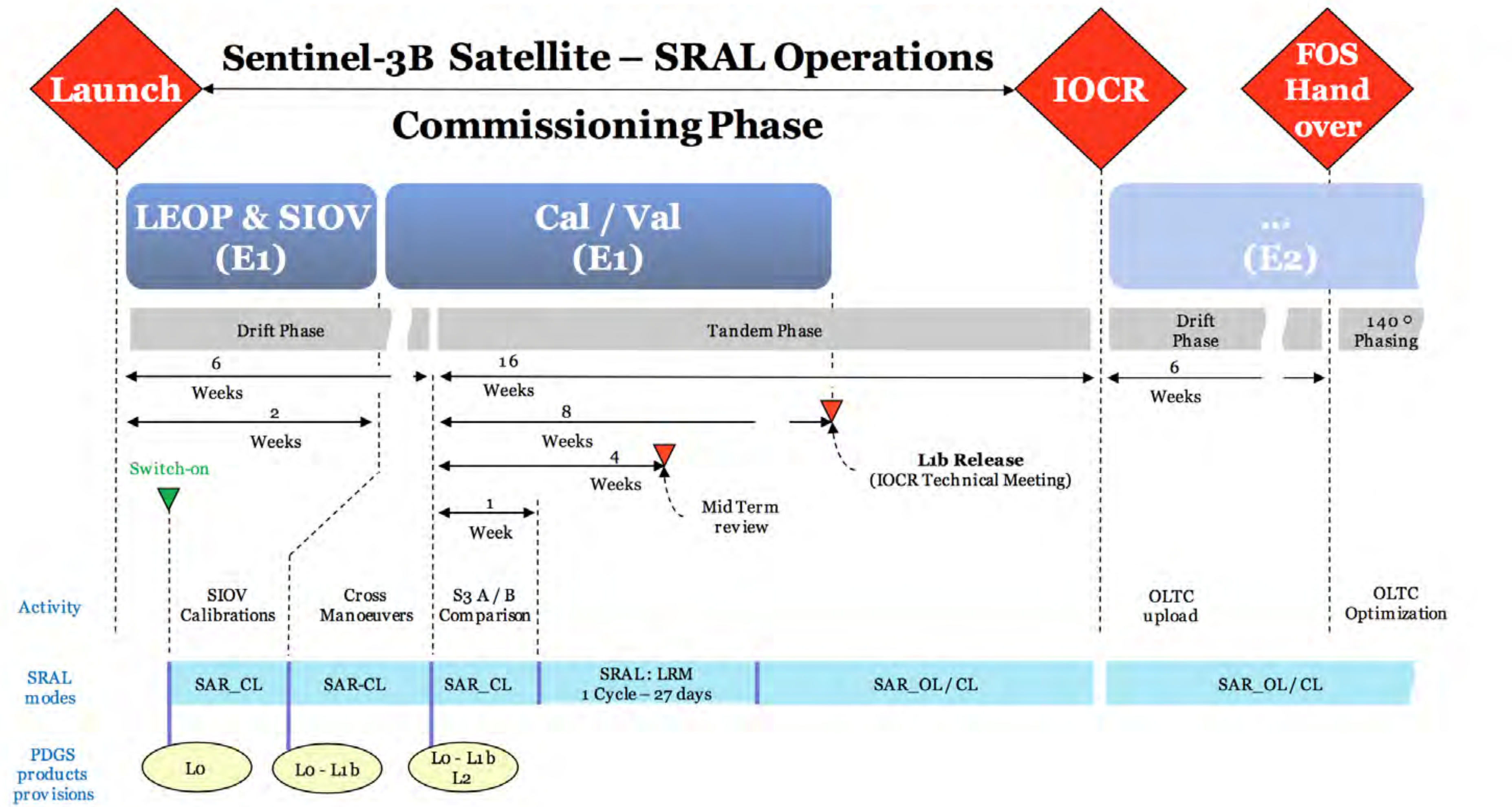
Drift phase1: S-3B to reach S-3A, over 1.5 months. While still in sufficient safety distance from the S-3A position, SIOV/LEOP and commissioning of S-3B command and control can be performed. S-3B data commissioning can start.

Tandem Phase: Once S3-B command and control commissioning is confirmed to be OK, the approach to the actual tandem position will be initiated. A Tandem phase of 4-5 months then follows:

- S-3A maintains normal operations.
- S-3B flyis ahead of S-3A with a time distance of 30 seconds (separation in position of 210 km)
- S-3B continues commissioning activities

Drift phase2: S-3B to move away from S-3A and arrive at its baseline position at +/- 140 deg to S-3A. Typical duration of this phase ~1.5 months.

Tandem Phase Operations Overview



CEOS

Committee on Earth Observation Satellites

Passive Microwave Radiometer Continuity

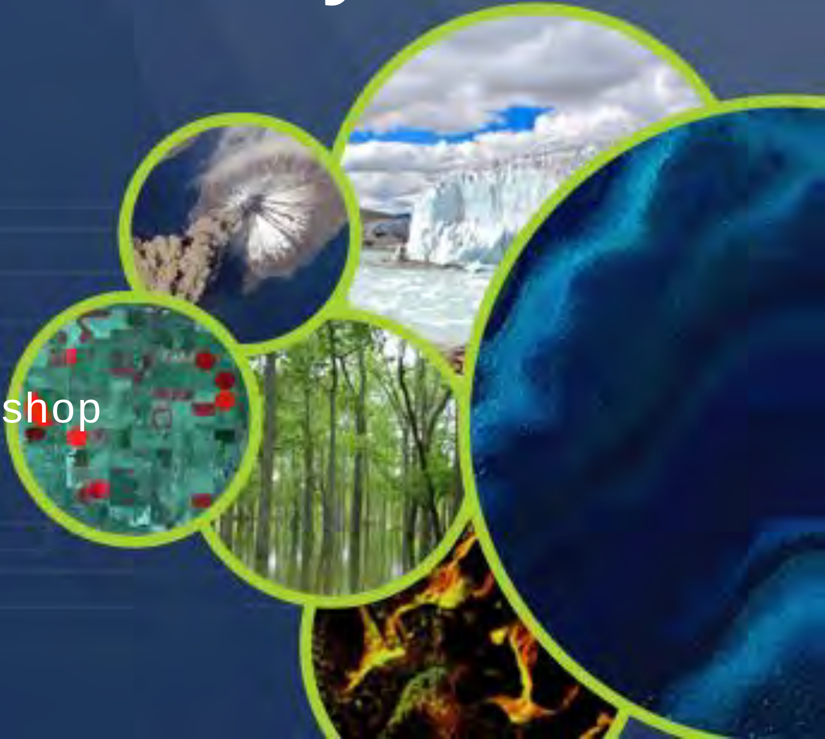
CEOS Sea Surface Temperature Virtual Constellation SST-VC

SIT Tech Workshop 2017 Agenda Item 22

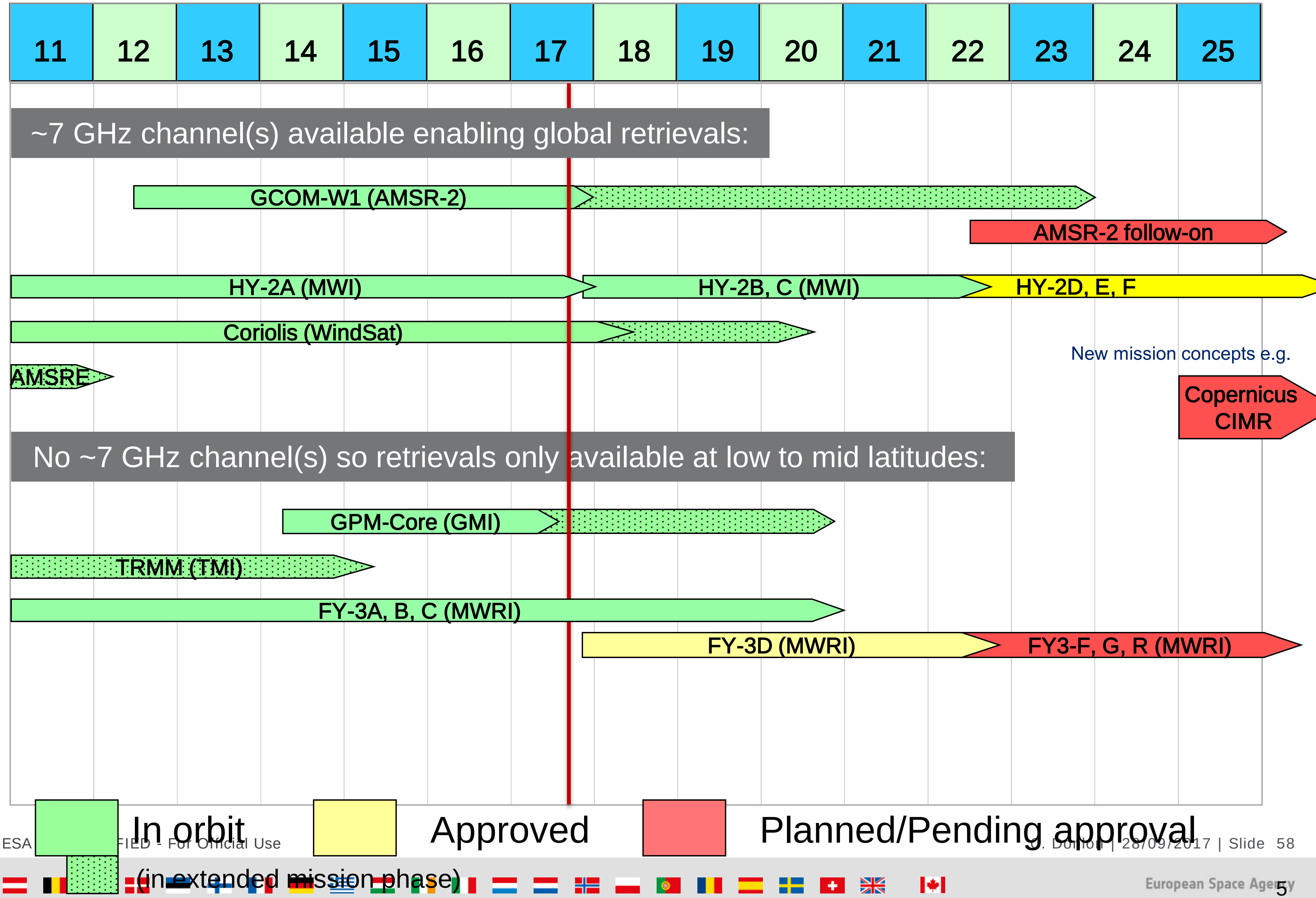
CEOS Strategic Implementation Team Tech Workshop

ESRIN, Frascati, Italy

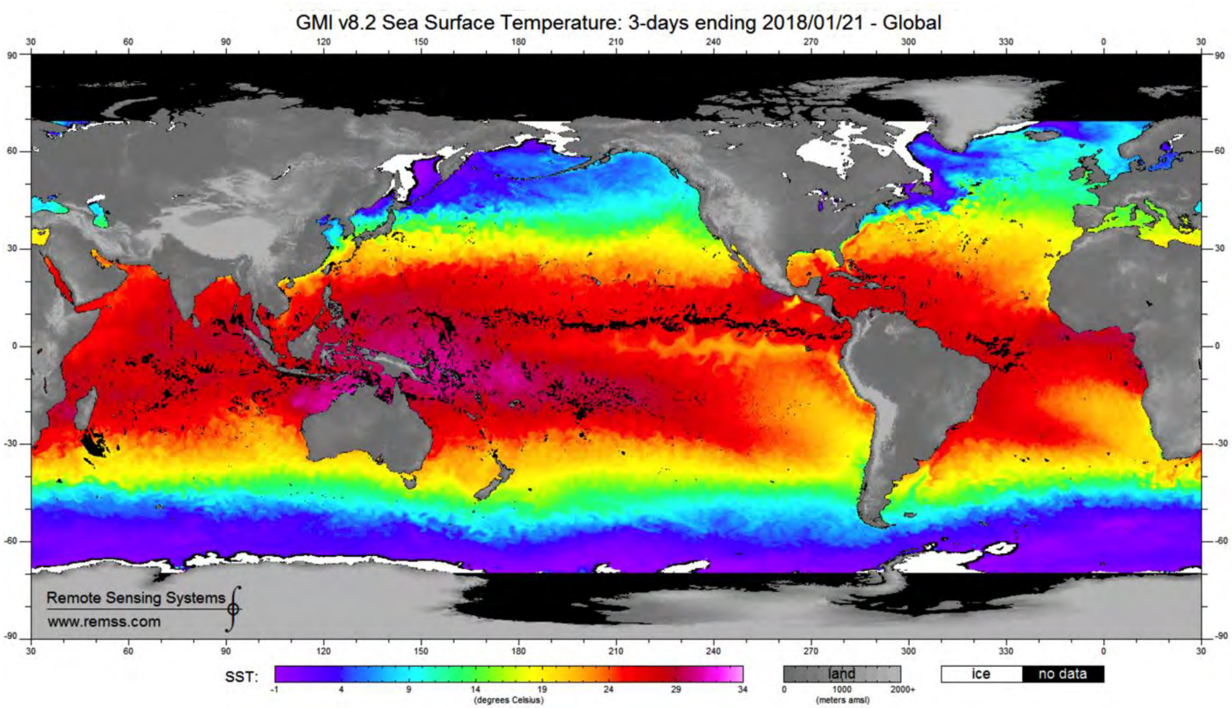
13th September 2017



Polar Orbiting Microwave Radiometers



SST and Microwave Radiometry



- For global SST need 6-7GHz and 11GHz
- At these wavelengths penetration depth is 2-3mm
- Therefore sub-skin SST, rather than skin SST from IR radiometers

All weather advantage (not precipitating)

Combined ability for retrieval of SST plus salinity, wind, rainfall etc useful for operational oceanography

FOV wider than IR SST due to weak thermal emission at these wavelengths

- Wider antenna needed to achieve better spatial resolution

Summary of use of PMW for SST

- **Use of Microwave Radiometers (MW) for SST retrievals is an essential component of global constellation of SST sensors.**

- **Provides temperature of ocean under clouds, not possible from infrared sensors, albeit with poorer spatial resolution. Important in high-latitude regions and in areas of extensive and persistent cloud cover or in case of a large volcanic event.**

- Impact studies of SST analyses / ocean forecasts show MW radiometry is also needed for:
  - Verification of SST analyses (and inter-comparisons) at the poles.
  - Aerosol regions (robust to IR sensitivity displayed in these regions).
  - Improves feature definition (e.g. fronts) esp. where persistent cloud.
  - Impact studies show improvement in RMSD (e.g. 0.02K global to 0.05K regional). Particularly important at high latitudes.
  - In addition retrievals of Ocean Surface Salinity Measurements give better performance when using SST analyses including PMW data (e.g. Meissner et al, TGRS-2016-00278)

Summary to CEOS

Currently there are risks and gaps identified in constellation, therefore continuity and redundancy of Microwave Radiometry for SST continues to be sought.

- **These data are particularly important for SST analyses and ocean models at high latitudes, aerosol regions, persistent cloudy regions, feature definition and overall contribute to an improvement in ocean forecast skill.**
- Given the current risk to the current and continued PMW constellation for SST and the need for a redundant capability of PMW with ~7 GHz, ***CEOS is requested to continue to coordinate and encourage its agencies to ensure the continuation of the existing capability and to facilitate the coordination of agencies to ensure continuity and redundancy of PMW for SST.***
- AMSR-2 follow-on is not yet approved, but study on possible payload to the GOSAT-3 satellite is being conducted in JFY 2017. The SST-VC note that approval of this mission would give the greatest opportunity for continuation of PMW for SST applications.
- Significant progress is being made with CMA on cooperation with SST, together with the SST-VC and GHRSST

Revisit the Microwat 5-25 km (NEdT<0.3K) real aperture 6.6 GHz SST retrievals

Conical Scanner 5-10m, <10 rpm, 4x Feeds, 6.9 and 18.7 GHz channels, fully polarimetric

www.microwat.org

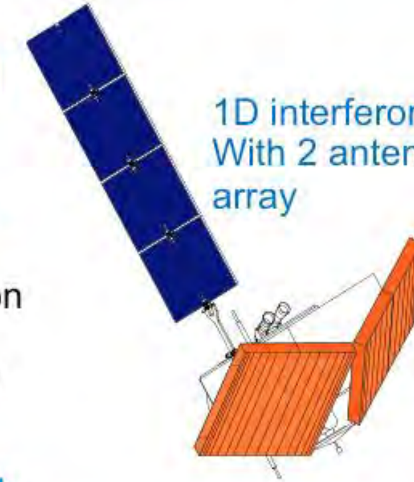
High sensitivity instrument due to longer integration time and Fore/Aft view

Robust calibration process and RFI detection and mitigation is under investigation

microwat
support to science element

Technology/Science Challenges

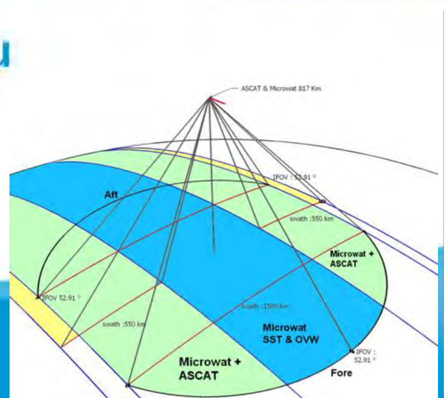
- Passive Microwave radiometers for SST are essential yet continuity is fragile (only GCOM-Wx, AMSR-2)
- However, some significant challenges to the concept:
  - Large LV required due to large (solid) antenna size (7 x 5 m)- needed for 6.9 GHz channel achieving required spatial resolution
  - Deployment of Triptic type antenna is complicated
  - Momentum compensation is challenging- must be dealt with to ensure bearing lifetime→ mission lifetime
- New study: Advanced Radiometer for SST just started
  - Study to look at making Microwat compatible with **VEGA**- flexible mesh antenna
  - Will also use trade-off alternative 1D interferometer concept- may be challenging to accommodate on VEGA.
- Further information: www.microwat.org
- **Thank you**

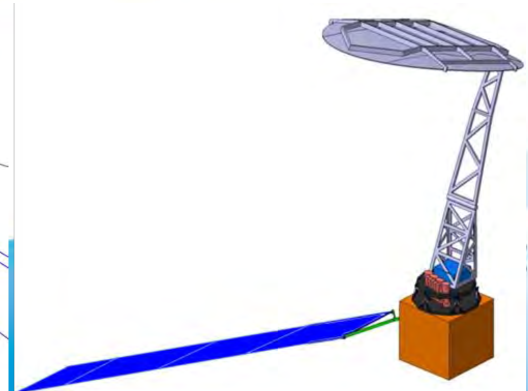


1D interferometer
With 2 antenna
array

Real
aperture
with Mesh
antenna
similar in
appearance
to SMAP

(credit: NASA)





ASTRIUM
AN EADS COMPANY

MW Radiometer SST channel selection

Table 3. The standard deviation of the SST retrieval error and root-mean-squared predicted SST uncertainty from an information content analysis across all profiles for varying numbers of channels with the sensitivity to wind speed doubled in the Jacobian matrix.

Number	4-Variable Retrieval				5-Variable Retrieval			
	Simulated Retrieval		Information Content		Simulated Retrieval		Information Content	
of Channels	Channel Added	σ_{SST} (K)	Channel Added	σ_{SST} (K)	Channel Added	σ_{SST} (K)	Channel Added	σ_{SST} (K)
1	6.9 V	0.642	6.9 V	0.703	6.9 V	0.557	6.9 V	0.602
2	7.3 V	0.568	7.3 V	0.632	7.3 V	0.507	6.9 H	0.532
3	18.7 H	0.495	6.9 H	0.504	10.7 H	0.450	7.3 V	0.472
4	6.9 H	0.470	36.5 H	0.436	36.5 H	0.417	36.5 H	0.413
5	23.8 V	0.462	10.7 V	0.416	6.9 H	0.399	10.7 V	0.398
6	7.3 H	0.459	18.7 V	0.408	10.7 V	0.388	18.7 V	0.392
7	10.7 H	0.457	7.3 H	0.403	23.8 V	0.382	7.3 H	0.388
8	10.7 V	0.456	23.8 H	0.400	23.8 H	0.380	23.8 H	0.386
9	89 V	0.455	23.8 V	0.395	18.7 V	0.377	23.8 V	0.383
10	36.5 V	0.455	18.7 H	0.394	18.7 H	0.375	18.7 H	0.380
11	18.7 V	0.457	36.5 V	0.392	7.3 H	0.373	36.5 V	0.379
12	89 H	0.462	10.7 H	0.391	89 H	0.372	10.7 H	0.378
13	36.5 H	0.466	89 H	0.390	89 V	0.372	89 H	0.377
14	23.8 H	0.467	89 V	0.389	36.5 V	0.371	89 V	0.376

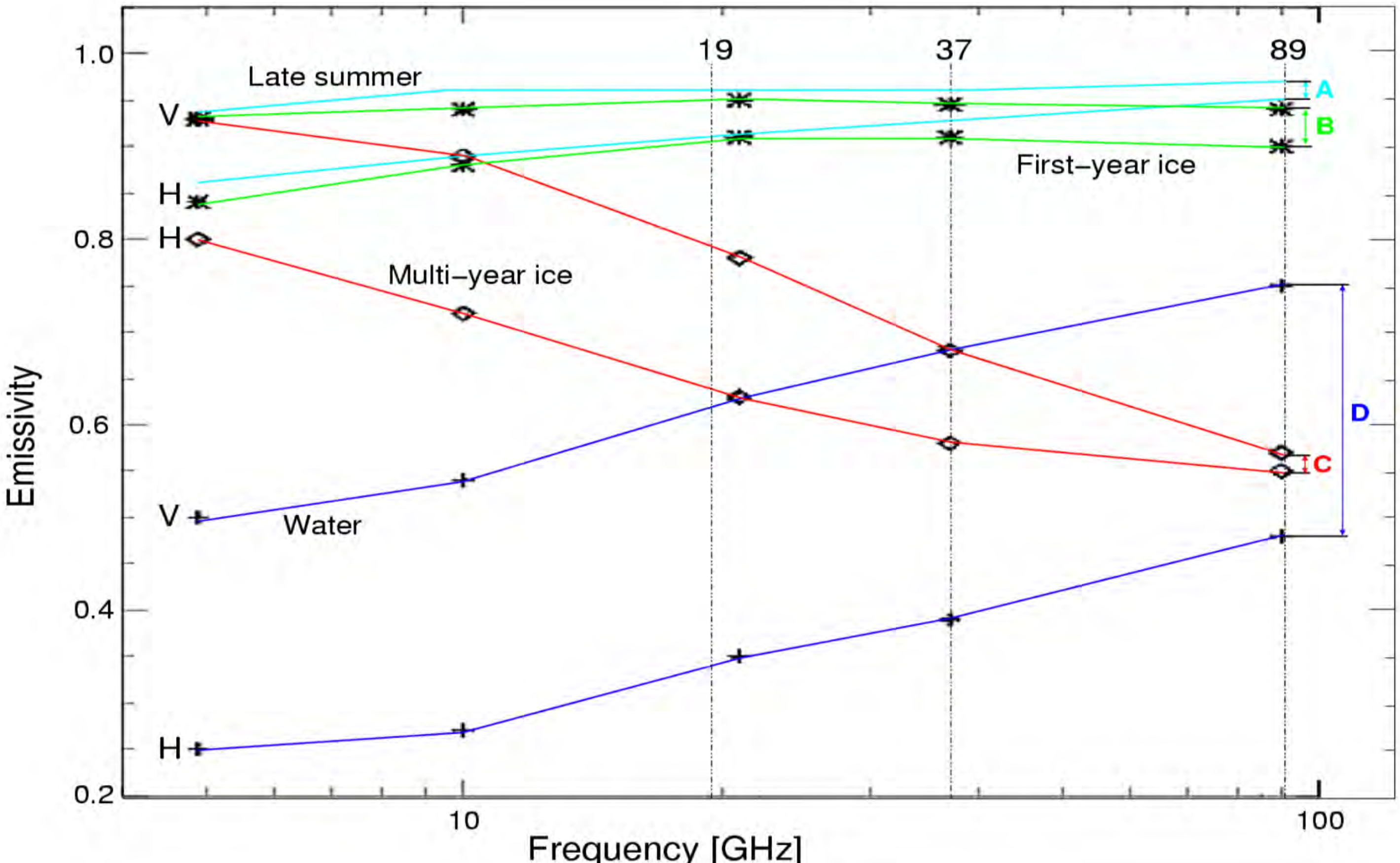
The recommended channel set is 6.9 V, 6.9 H, 7.3 V, 10.7 V and 36.5 H. The 6.9 V and 7.3 V channels provide the greatest SST sensitivity to the retrieval and the contribution of TCWV is separated out with the addition of the 36.5 H channel. The 6.9 H and 10.7 V channels add in discrimination of the wind speed effects.

The Role of Advanced Microwave Scanning Radiometer 2 Channels within an Optimal Estimation Scheme for Sea Surface Temperature

Kevin Pearson [1,*], Christopher Merchant [1,2], Owen Embury [1,2] and Craig Donlon [3]

Remote Sens. 2018, 10, 90; doi:10.3390/rs10010090

Sea Ice MW Radiometer Channel Selection



(after *Spreen et al.* (2008) – see also *Eppler et al.* (1992) for a similar plot)

For SST and Sea Ice concentration measurements: There is a clear need to improve the spatial resolution of 6-7 GHz Microwave Radiometer measurements to ~5-10 km

Copernicus Expansion: Motivation

- The European Copernicus system, including the Copernicus Space Component (CSC), has been established as the largest and most proficient EO system in the world.
- The current Sentinels provide ~10 Tb/day of world-class data to over 100,000 registered users – fuelling Copernicus.
- Service application dependencies are now in place and there are great expectations for the future Copernicus system.
- User needs and requirements have also evolved in the new Copernicus paradigm

- How might the CSC build on the current Sentinel series?
  - How might the system *extend* to provide *enhanced continuity*?
  - How might the system *expand* to address *new user needs*?

Copernicus
Europe's eyes on Earth

European Commission

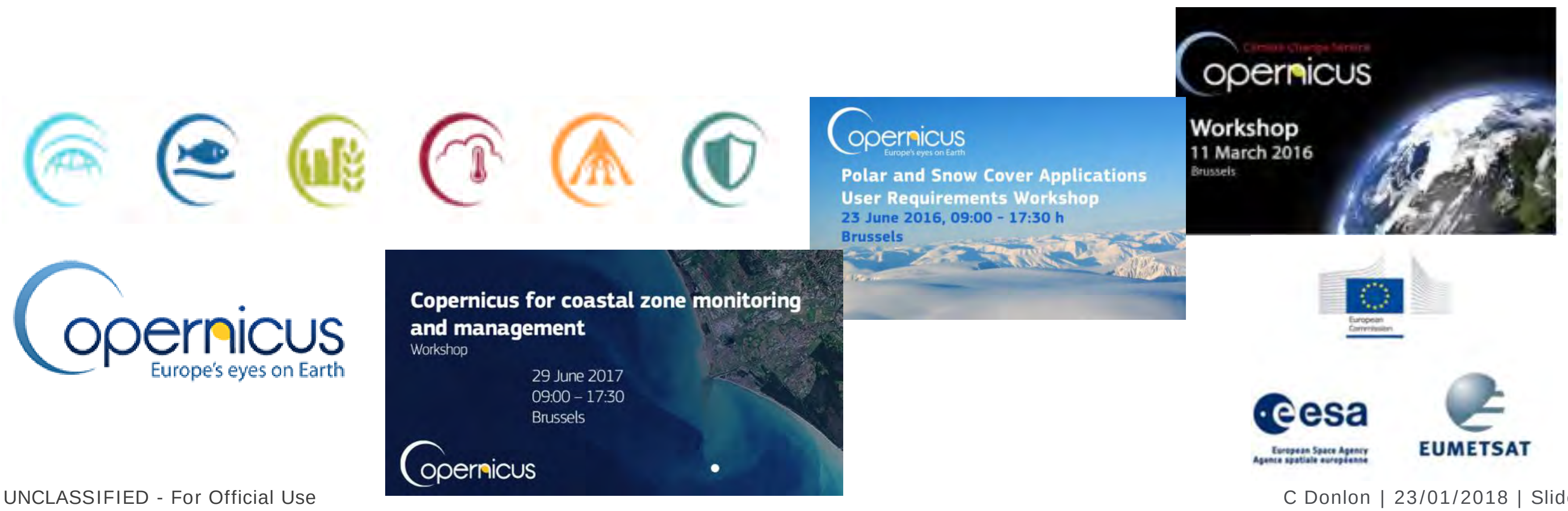
esa
European Space Agency
Agence spatiale européenne

EUMETSAT

A Long Term Scenario (LTS)

- Fundamental aspects of a LTS:
  - assure user-driven continuity and increase the robustness of the existing CSC in the future (Priority)
  - increase the quality and quantity of the existing measurements
  - expand observation types according to policies and user needs
  - employ latest technologies for maximum efficiency
  - Partnerships and cooperation are essential to success

- Key driver is the evolving needs of the services prioritized by EC through various consultative processes over the last year



Copernicus High Priority Candidate Missions (HPCM)

- Potential Copernicus High Priority Candidate Missions (HPCM) under discussion include:
  1. Anthropogenic CO_2 monitoring Mission
  2. High spatial-temporal resolution land surface temperature (LST) monitoring mission (including coastal areas)
  3. Passive microwave imaging radiometry mission
  4. Polar ice and snow topography mission
  5. Hyper-spectral imaging mission (including coastal areas)
  6. L-band SAR mission

- Pre-phase A studies ongoing for 2, 4, 6

- ESA Phase A/B1 studies for all HPCM are planned to start in early 2018
- The EC process of user needs and prioritisation is on-going and will continue in parallel
- Final selection of HPCM specific characteristics (e.g. spectral choice, number of satellites etc.) will be determined at the end of Phase A/B1

Copernicus Polar Ice and Snow Passive Microwave Imaging Radiometer

ESA Open Invitation To Tender [FR]

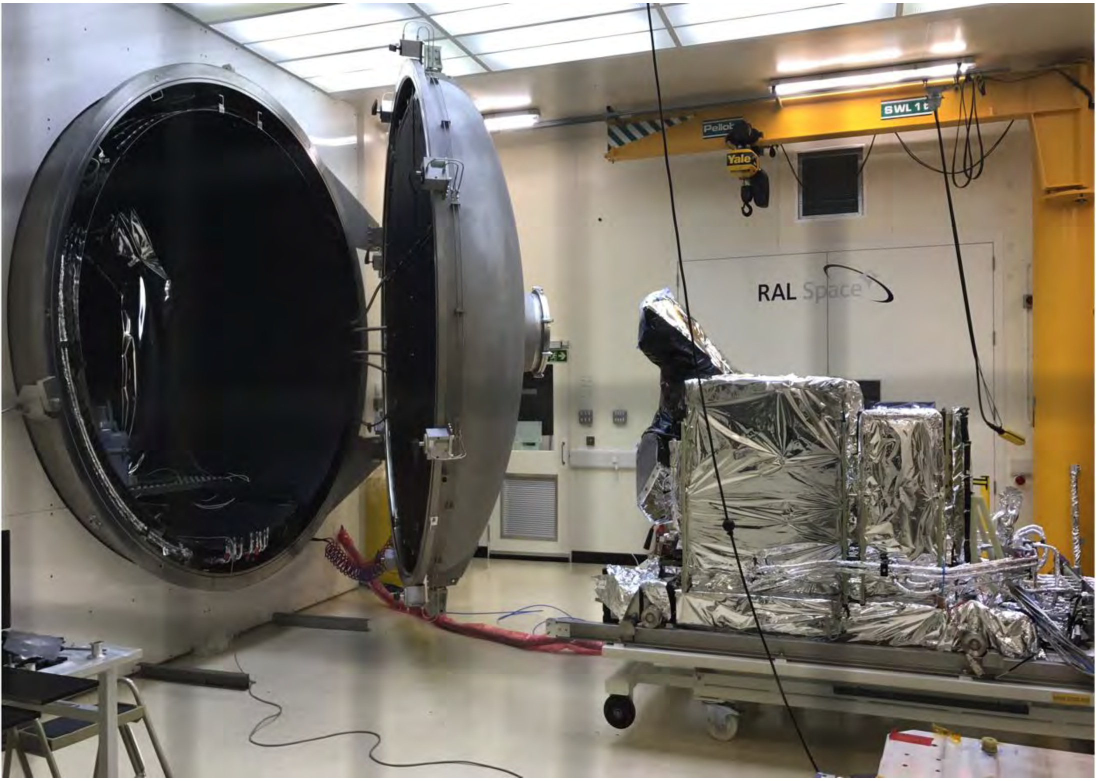
AO9186

Title: PHASE A/B1 OF PASSIVE MICROWAVE IMAGING MISSION (CIMR)
Open Date: 15/12/2017
Closing Date: 23/02/2018 13:00:00
Status: ISSUED
Reference Nr.: 17.156.19
Prog. Ref.: CSC Ev.Instr.Mod.;Fut.Mis.Prep.
Budget Ref.: E/E101-E5 - CSC Ev.Instr.Mod.;E/E104-E5 - Fut.Mis.Prep.
Special Prov.: AT+BE+CH+CZ+DE+DK+EE+ES+FI+FR+GB+GR+IE+IT+LU+NL+NO+PL+PT+RO+SE+SI+CA

- Procurement of a Phase A/B1 Copernicus Expansion candidate mission.
- Microwave Imaging Multi-Spectral Radiometer for sea ice concentration and SST to serve operational systems at almost all weather conditions, day and night.
- Spatial resolution (5-10 km), temporal resolution (sub-daily) and high accuracy (in particular near the ice edges).

http://emits.sso.esa.int/emits/owa/emits.main

Fiducial Reference Measurements



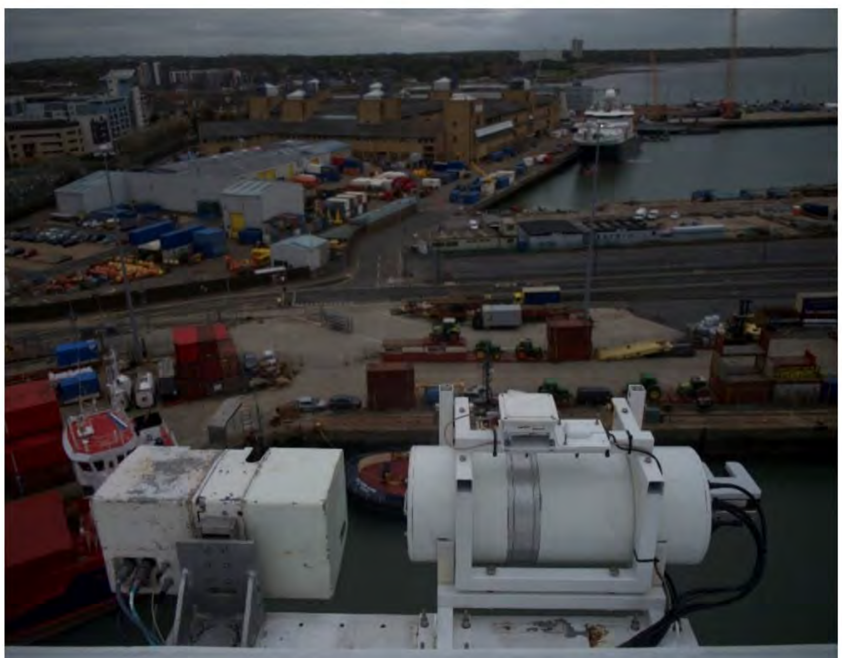
SLSTR Pre-flight Calibration, STFC-RAL, UK, December 2016

Inter-comparison

One of the aims of the International Shipborne Radiometer Network (ISRN) is to facilitate inter-comparisons between radiometers. teh purpose of such inter-comparisons is not only to ensure traceability of the infrared radiometers but also field inter-comparisons to not only evaluate the measured SSTskin but also the uncertainties. The FRM4STS project conducted the laboratory and limited water based part of such an inter-comparison in 2016. The FRM4STS inter-comparison did not include a ship based comparison, however the ISRN carried out a demonstrator inter-comparison on the M/V Queen Mary 2 in 2015 with one ISAR and one SISTeR instrument.

SST Inter-comparison on the QM2

The image blow shows the SISTeR (left) and ISAR (right) instruments mounted on the QM2 in Southampton. The inter-comparison between the two instruments was carried out between 11. September 2015 to 5. November 2015. Because of interference issues with the rain gauges the usable data was limited to 22. October 2015 to 5. November 2015.



SI traceability: LCE (June 2016)

Necessary for all participants to assess biases to SI under Laboratory conditions

ITS-90

T= ~250 – 325 K
Non-vacuum

NPL BB

PTB BB

NPL Rad (AMBER)

PTB Rad

Rad 1

Rad 2

Rad 3

Rad 4

Rad n

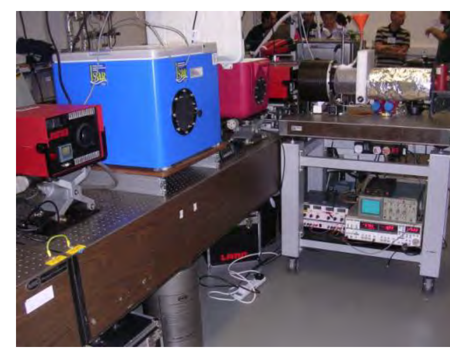
BB1

BB 2

BB 3

BB 4

BB n

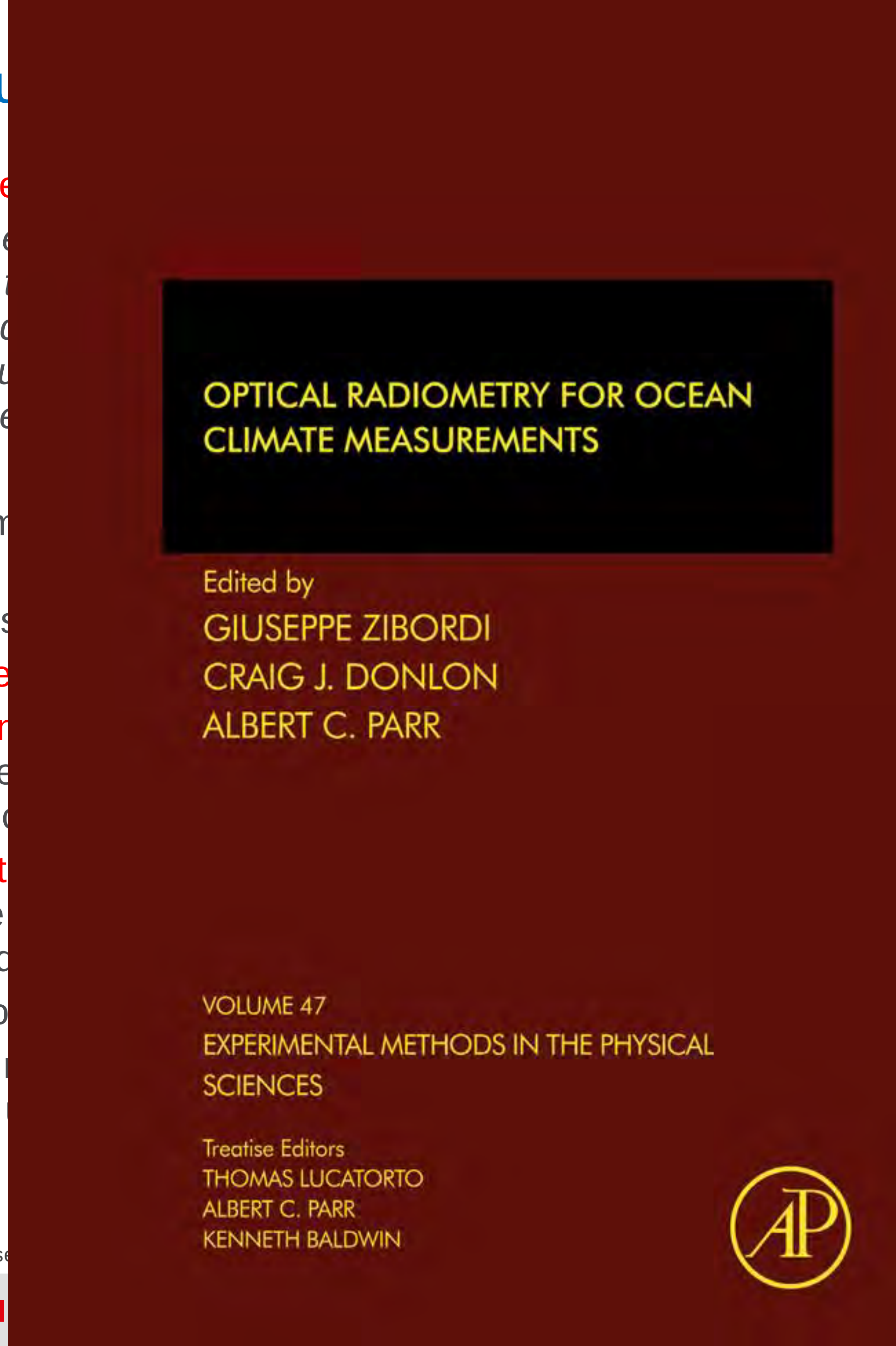


fiducial reference temperature measurements

Room Environment with variable T

- Fiducial Refere
- *the suite of inde e the maximum Scientific Utili mission by delivering, to users, the re rm of independent validation resu estimation, over the duration of the*

- The defining m
  a. Have docu -comparison of instruments
  b. Are indepe
  c. Include ar and derived measureme e appropriate to SI ideally dire
  d. Are collect unity-wide manageme , documents etc.) are defined and
- FRM are as clo e can get!
- FRM are requi haracteristics of satellite meas ties.



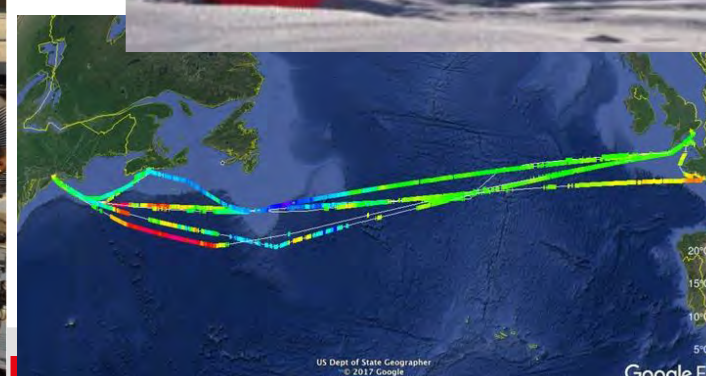
fiducial reference temperature measurements

(13 participants / 4 Continents)

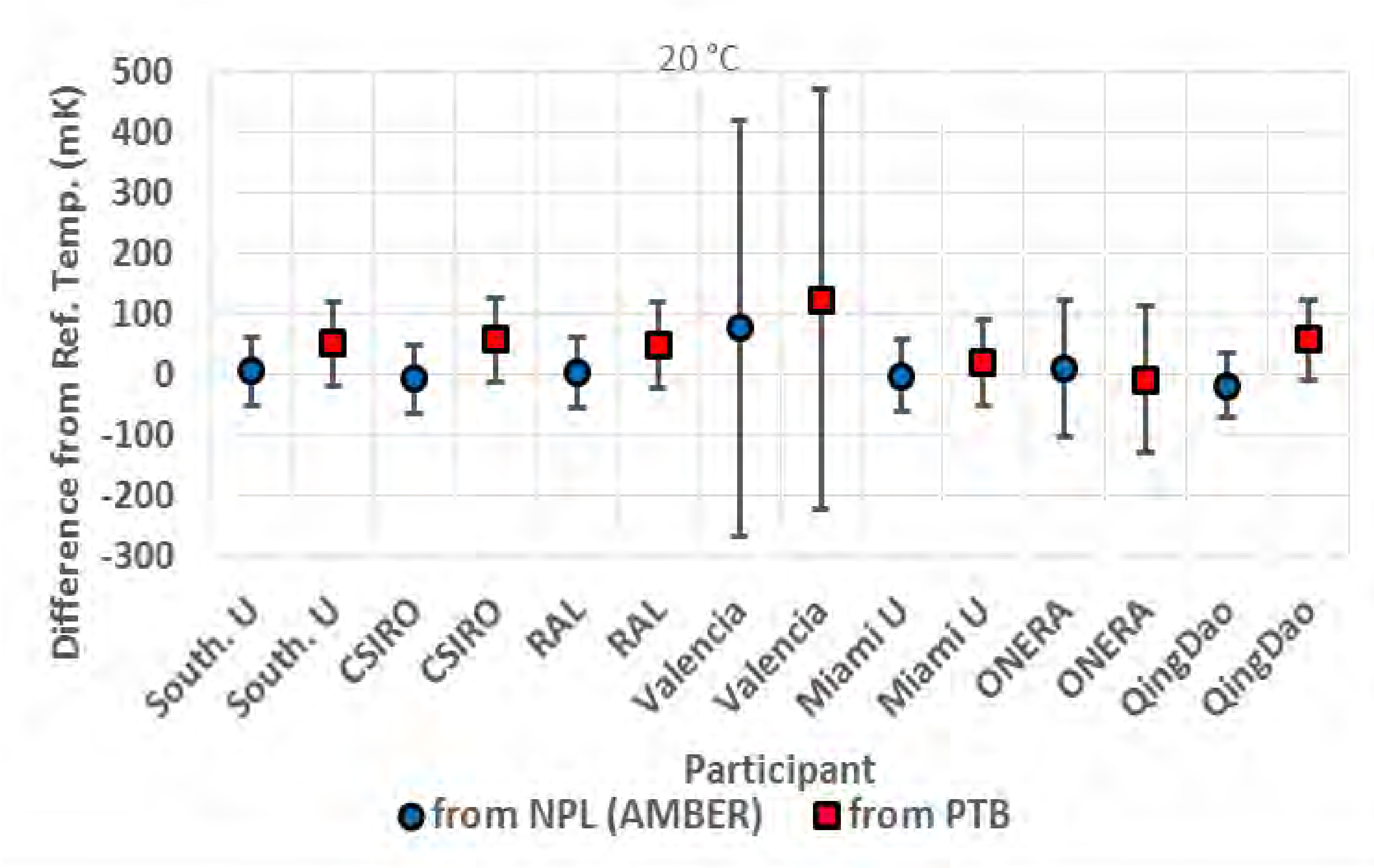
1. Miami University (USA)
2. ONERA (France)
3. University of Valencia (Spain)
4. University of Southampton (UK)
5. Qing Dao (China) -1
6. Qing Dao (China) -2
7. RAL (UK)
8. CSIRO (Australia)
9. KIT (Germany)
10. DMI (Denmark)
11. GOTA (Canary Islands
12. JPL NASA (USA)
13. Ian Barton (Australia)







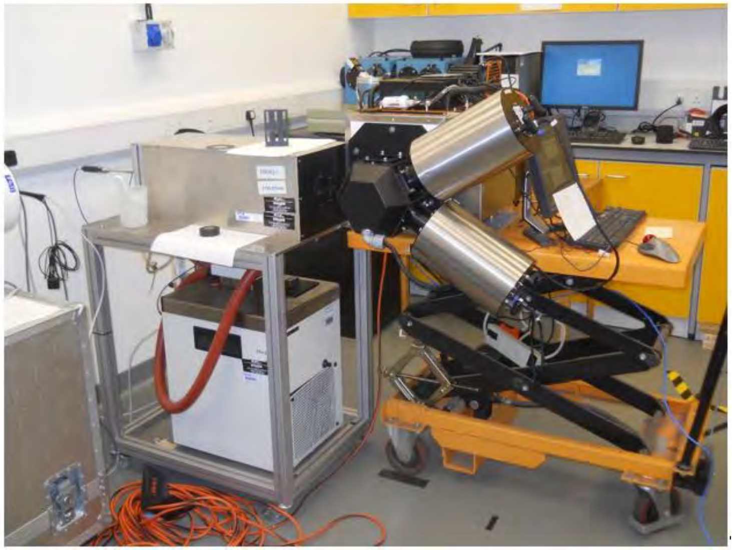

Difference between the mean of the values reported by participating blackbodies from the values measured by AMBER (shown in blue) and PTB (shown in red) for a nominal blackbody temperature of 20 °C.



Radiometer comparison

National Physical Laboratory

1. Miami University (USA)
2. ONERA (France)
3. University of Valencia (Spain)
4. University of Southampton (UK)
5. Qing Dao (China) -1
6. Qing Dao (China) -2
7. RAL (UK)
8. CSIRO (Australia)
9. KIT (Germany)
10. DMI (Denmark)
11. GOTA (Canary Islands
12. JPL NASA (USA)
13. Ian Barton (Australia)



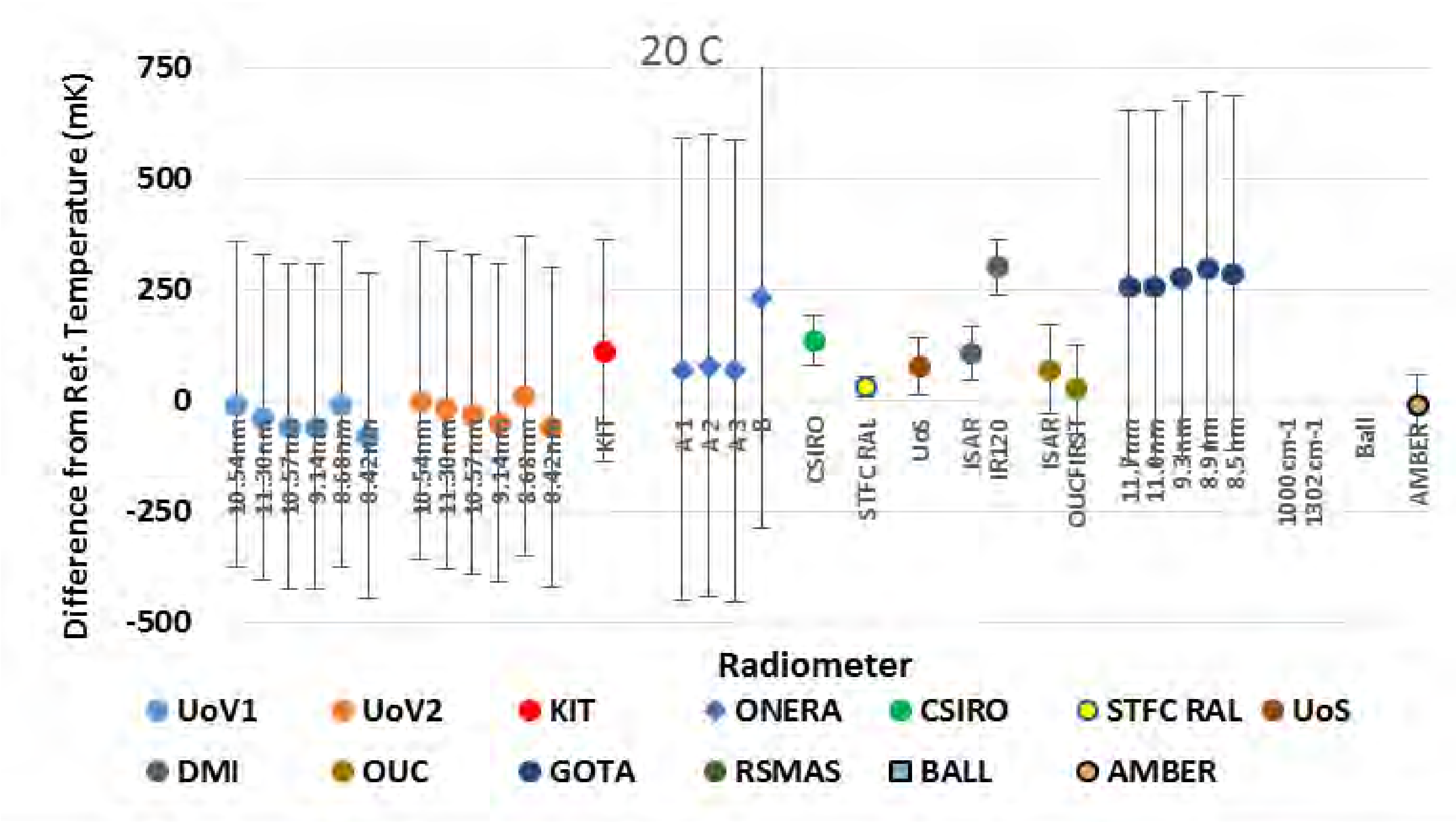
MAERI (UofM) viewing NPL ammonia Heat pipe

SISTER (RAL) viewing NPL ammonia Heat pipe

240 K to 318 K

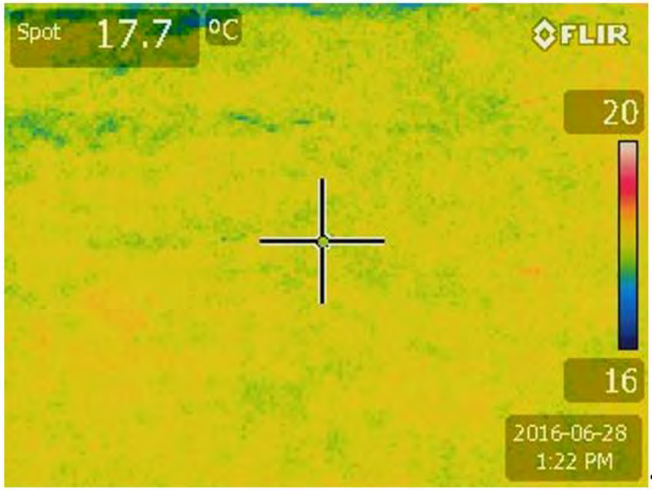
fiducial reference temperature measurements

Plot of the mean of the differences of the radiometer readings from the temperature of the NPL reference blackbody, maintained at a nominal temperature of 20°C.



WST comparison

1. University of Valencia (Spain)
2. University of Southampton (UK)
3. Qing Dao (China) -1
4. Qing Dao (China) -2
5. RAL (UK)
6. CSIRO (Australia)
7. KIT (Germany)
8. DMI (Denmark)
9. GOTA (Canary Islands)
10. JPL NASA (USA)



fiducial reference temperature measurements

Difference from mean for SST designed radiometers only

NPL National Physical Laboratory

fiducial reference temperature measurements

esa

Fiducial Reference Measurements for Validation of Surface Temperature from Satellites (FRM4STS)

Technical Report 3
A Framework to Verify the Field Performance of TIR FRM

ESA Contract No. 4000113848_15I-LG

Frank Göttsche, KIT
Folke S. Olesen, KIT
Jacob L. Høyer, DMI
Werenfred Wimmer, Southampton University
Tim Nightingale, STFC

APRIL 2017

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Issue 3
Revision 1
Date of Issue 24 April 2017
Status ISSUED
Document Type TR-3

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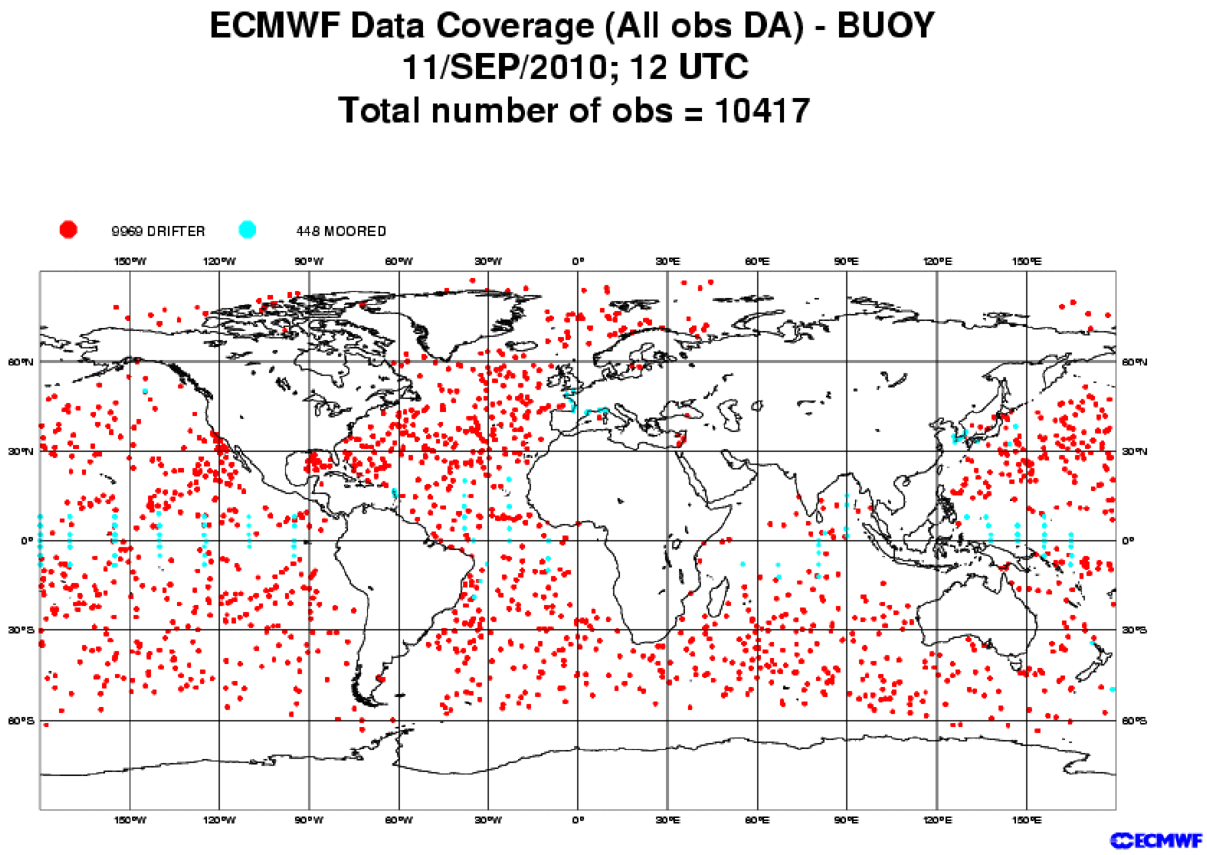
Digitally signed by Craig Donlon
DN: cn=Craig Donlon, o=European Space Agency, ou=ESTEC, email=craig.donlon@esa.int, c=NL
Reason: I am approving this document
Location: Noordwijk, The Netherlands
Date: 2017.04.26 08:54:31 +02'00'

mean difference from mean (°C)

All radiometers Included	SST-Measuring Radiometers Only	SST-Measuring Radiometers excl. CSIRO
°C	°C	°C
0.123	0.084	0.037
-0.159		
-0.189	-0.228	
-0.020	-0.053	-0.106
0.117		
0.125	0.090	0.044
0.033	-0.002	-0.054
0.206	0.174	0.119
0.593		
-0.109		

Modern in situ: buoys



Conclusions

- We are in VERY good shape for SST in Europe
- Thermal infrared capability is excellent (polar and Geostationary)
- But, there are significant issues to address:
    - Lack of ~7GHz Microwave Radiometry in the near future
    - Need for better FRM validation
    - Clear need to be fully aware of the measurement characteristics (DV, Skinsst, etc.)
- Copernicus continues to develop and expand to meet the needs of Services
- Sentinel 3B launch in 2018
- Copernicus Microwave Imager Phase A/B1 starts in 2018

Thank you - any questions?

For more information http://www.esa.int

Contact: craig.donlon@esa.int