The International SST FRM Network: 25 years pf SSTskin measurements

Craig Donlon
ESA/ESTEC, Hd .System Architecture Office

NOC, 22nd April 2024

OUR FUTURE CLIMATE: SIX SCENARIOS

+1.1°C WHERE WE ARE NOW

Global warming due to increased human-driven greenhouse gases in the atmosphere

+1.4°C TAKING THE GREEN ROAD

If net zero emissions are achieved by 2050 (SSP1-1.9)

+1.5°C

PARIS AGREEMENT GOAL

+1.8°C LIMITING GLOBAL WARMING

If net zero emissions are achieved in second half of 21st century (SSP1-2.6)

+2.7°C NO EXTRA CLIMATE POLICIES

If current greenhouse gas emissions persist until mid-21st century (SSP2-4.5)

+4.4°C FOSSIL-FUELLED DEVELOPMENT

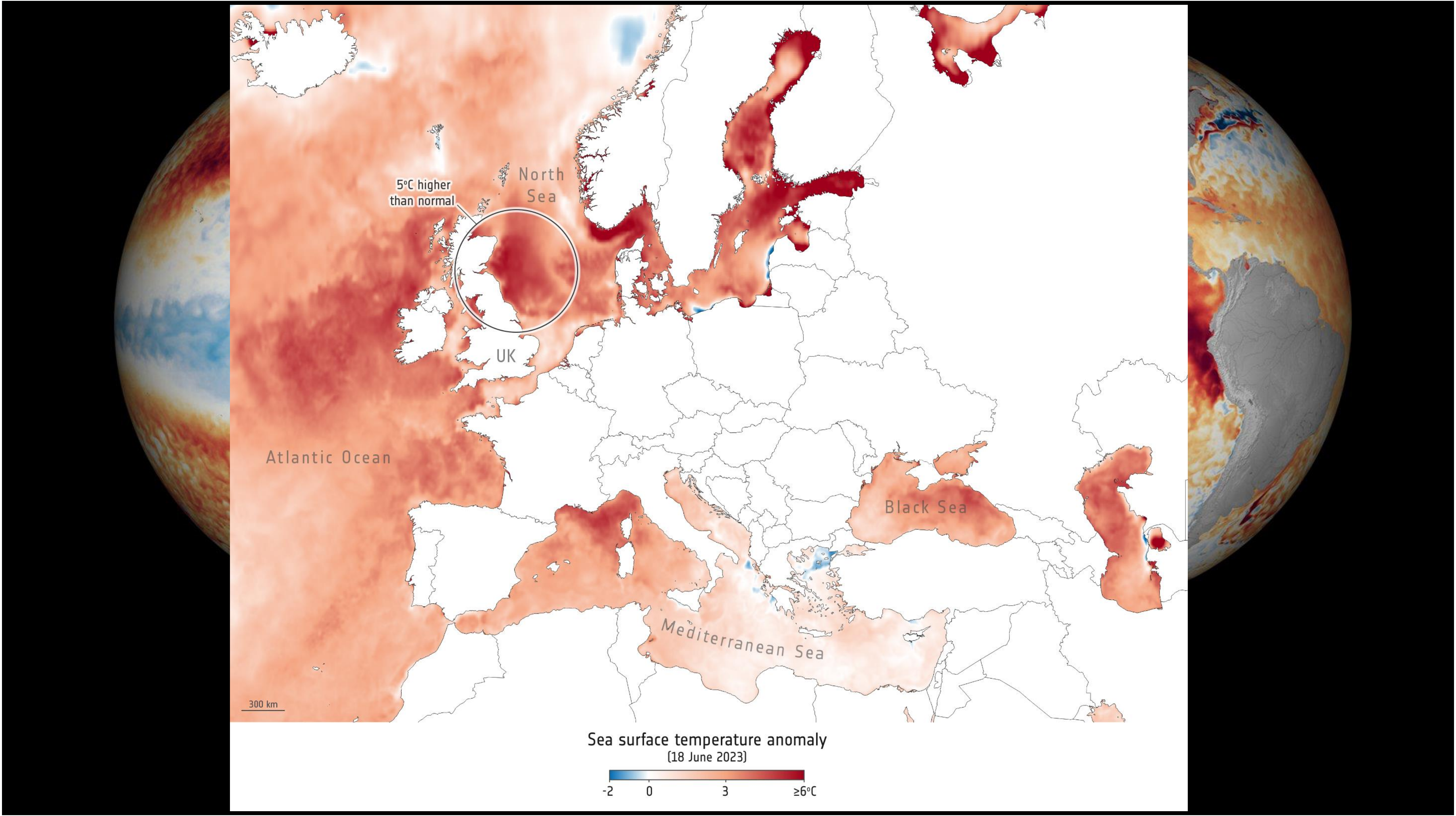
An energy and resource intensive scenario for the 21st century (SSP5-8.5)

"It is unequivocal that human influence has warmed the atmosphere, ocean and land"

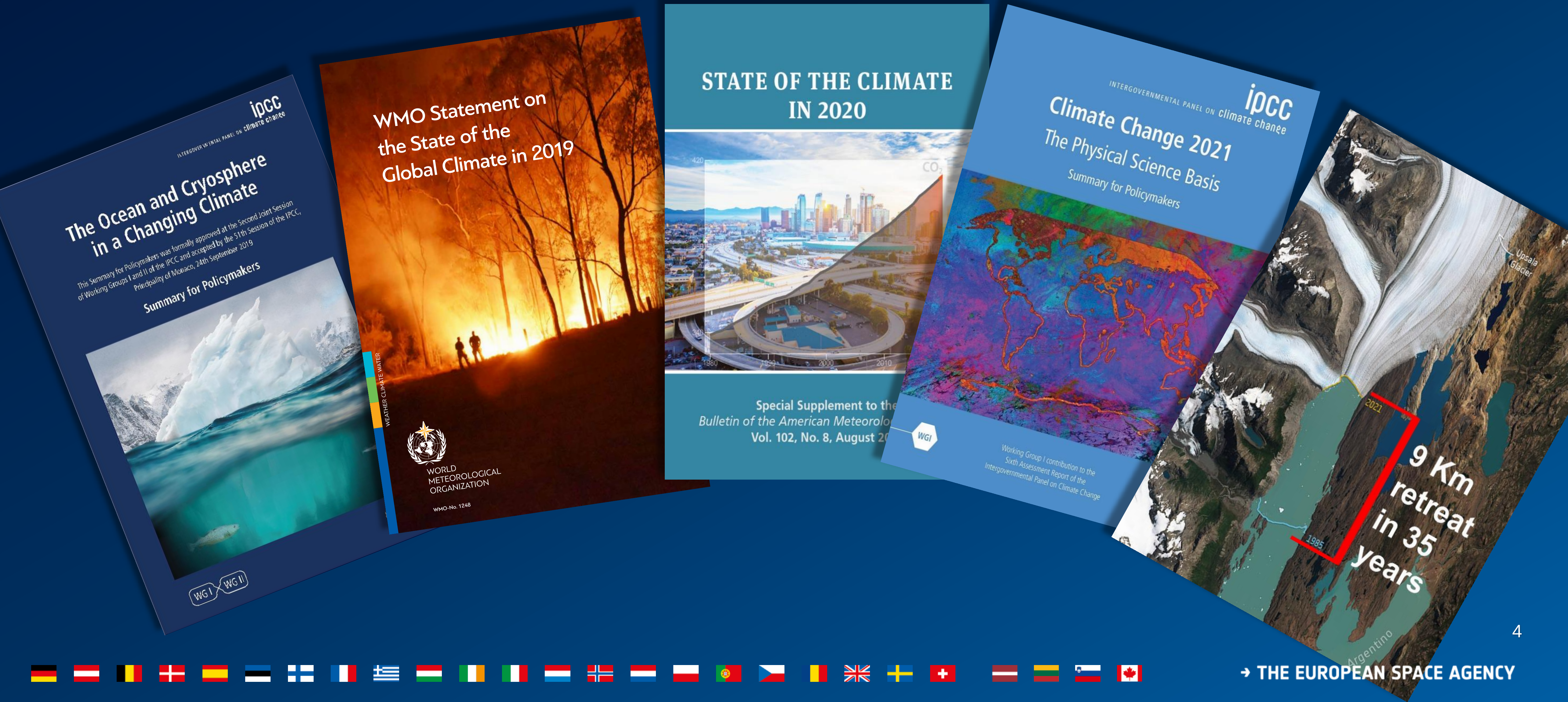
IPCC AR6 2021

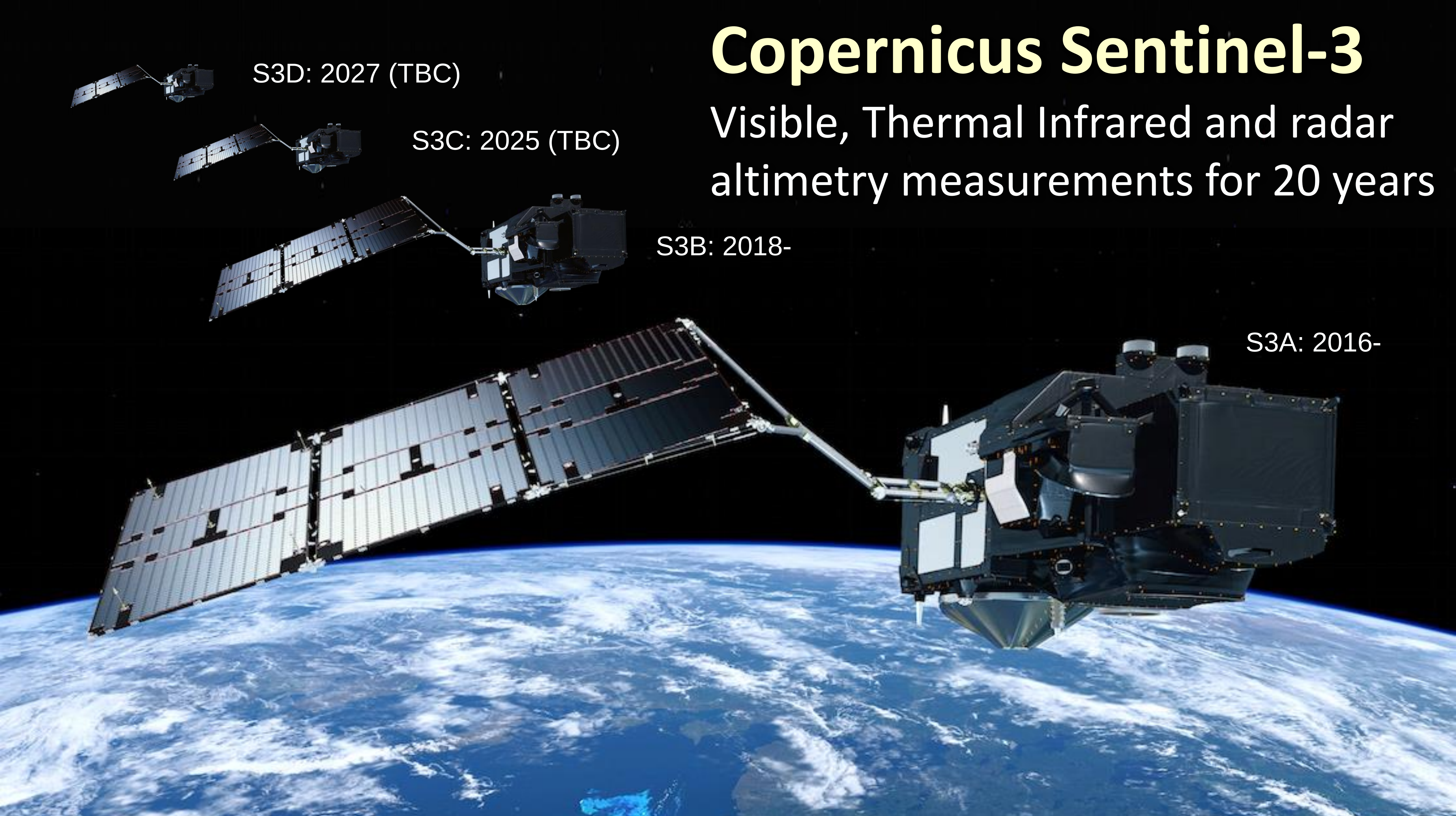
GLOBAL MEAN TEMPERATURE INCREASE BY 2100 (RELATIVE TO 1850-1900)

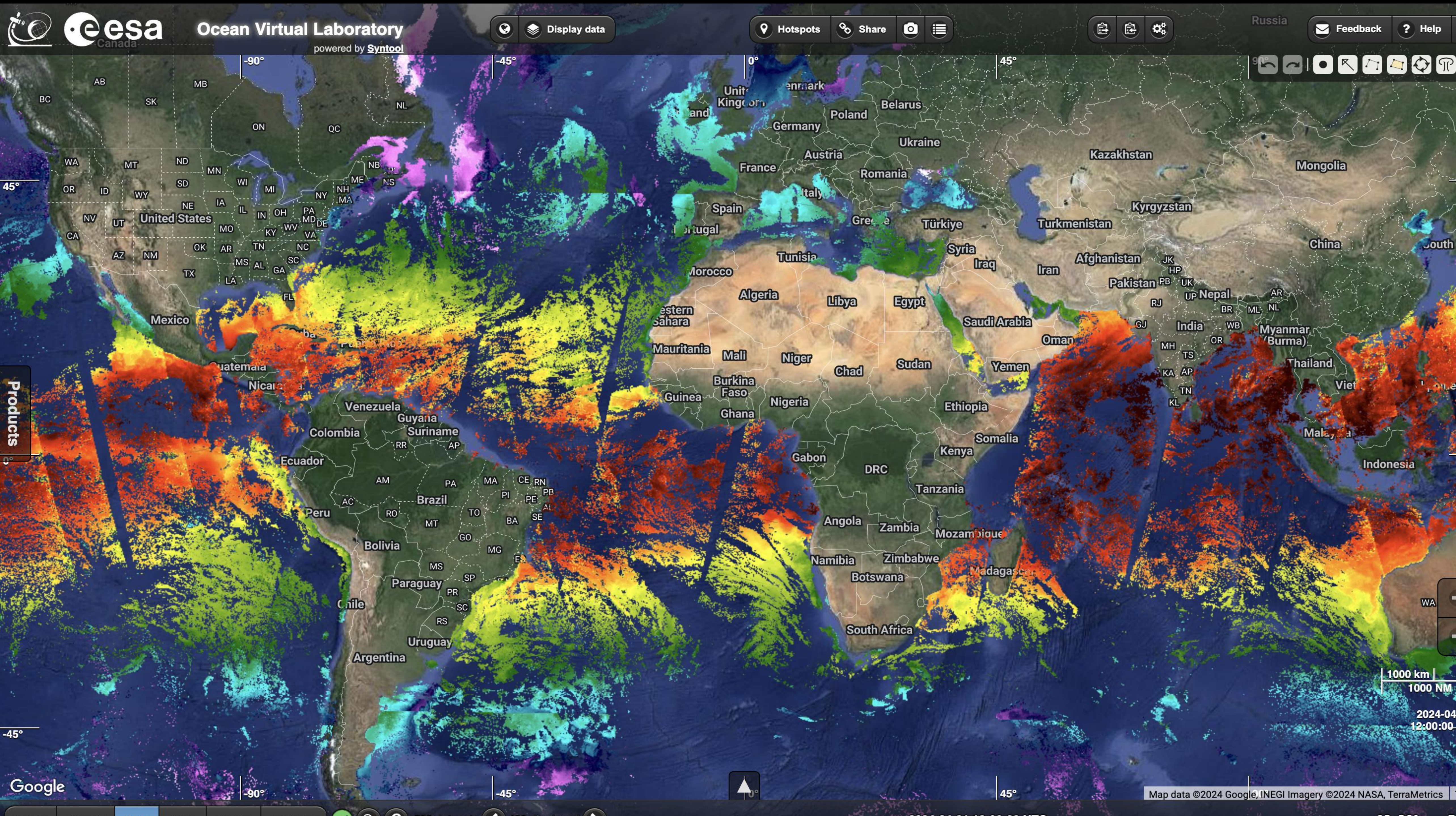
Source: IPCC Assessment report Working Group 1, Table SPM.1


North Sea
5°C higher than normal
UK
Atlantic Ocean
Black Sea
Mediterranean Sea
300 km
Sea surface temperature anomaly
(18 June 2023)
-2
0
3
≥6°C

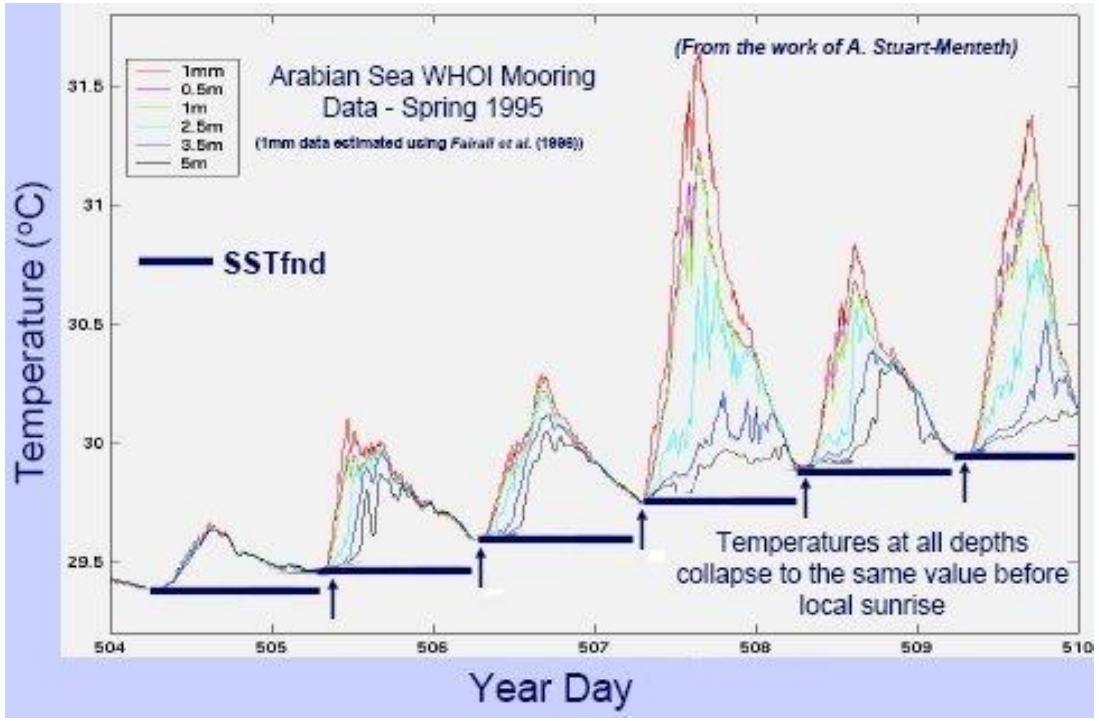
EO provides unequivocal evidence and facts in climate reports

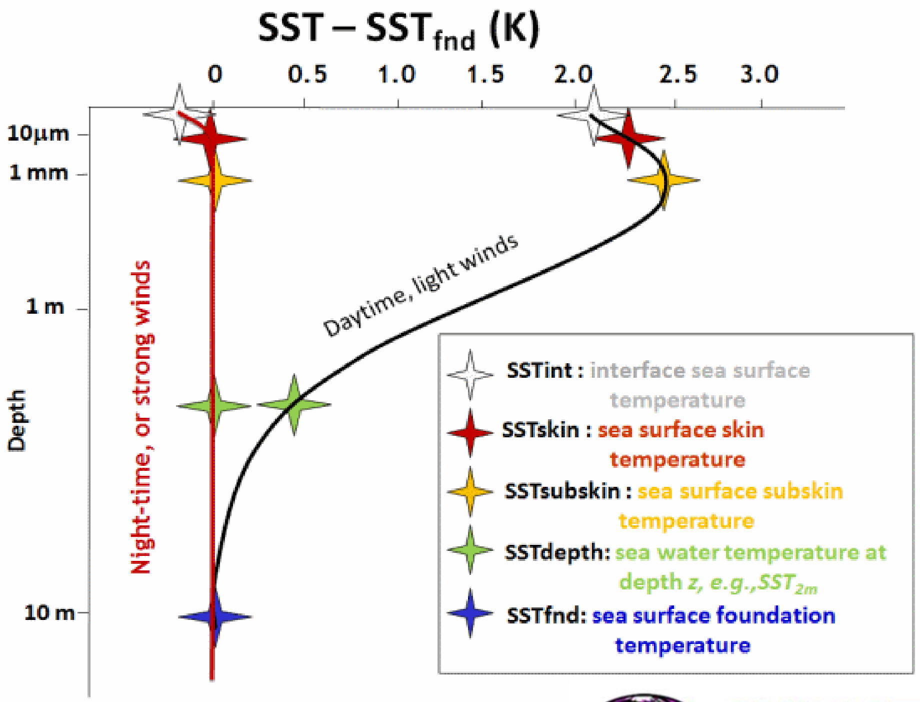



Copernicus Sentinel-3
Visible, Thermal Infrared and radar altimetry measurements for 20 years
S3D: 2027 (TBC)
S3C: 2025 (TBC)
S3B: 2018-
S3A: 2016-


esa
Ocean Virtual Laboratory
powered by Syntool
Display data
Hotspots
Share
Feedback
Help
Products
-90°
-45°
0°
45°
United States
Mexico
Venezuela
Colombia
Ecuador
Peru
Brazil
Bolivia
Paraguay
Chile
Uruguay
Argentina
Germany
Poland
Belarus
Ukraine
Austria
France
Romania
Spain
Türkiye
Kazakhstan
Mongolia
Kyrgyzstan
Turkmenistan
China
Afghanistan
Pakistan
Nepal
India
Iran
Iraq
Syria
Tunisia
Morocco
Algeria
Libya
Egypt
Saudi Arabia
Oman
Yemen
Mauritania
Mali
Niger
Chad
Sudan
Guinea
Nigeria
Ghana
Ethiopia
Somalia
Kenya
Gabon
DRC
Tanzania
Angola
Zambia
Namibia
Botswana
Zimbabwe
South Africa
Thailand
Indonesia
Myanmar (Burma)
1000 km
1000 NM
Google
Map data ©2024 Google, INEGI Imagery ©2024 NASA, TerraMetrics

Our challenges…





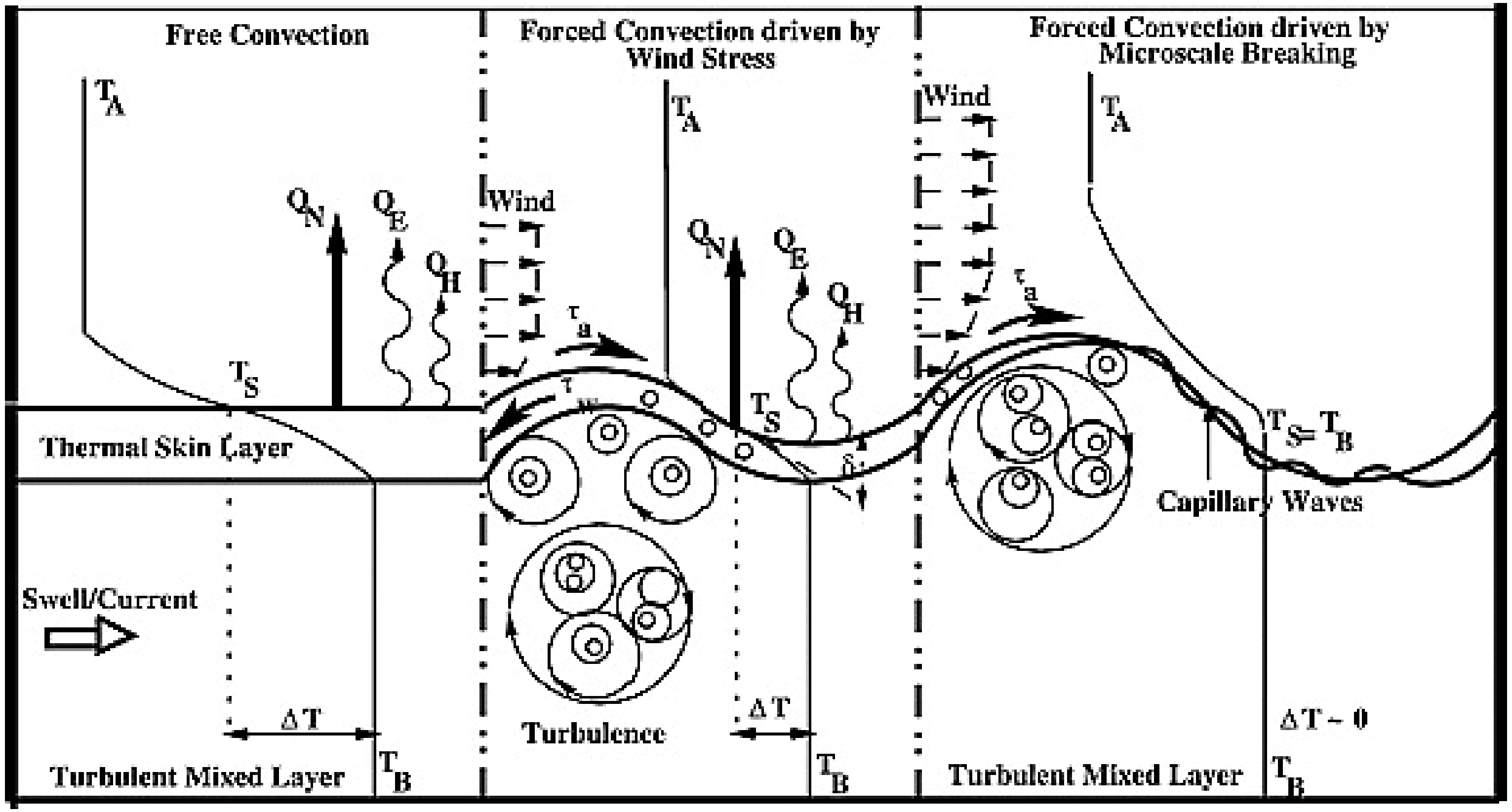
GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

The Gran Cafe Roma, Frascati, Rome Italy.

Considered the birthplace of the SST Foundation Temperature (SSTfnd) when Ian and several others discussed the scientific need for this.

(P. Minnett)

Cpomplexity…and importance



(S. Castro)

Global Biogeochemical Cycles

Research Article | Open Access

Key Uncertainties in the Recent Air-Sea Flux of CO_2

D.K. Woolf, J.D. Shutler, L. Goddijn-Murphy, A.J. Watson, B. Chapron, P.D. Nightingale, C.J. Donlon, J. Piskozub, M.J. Yelland, I. Ashton, T. Holding, U. Schuster, F. Girard-Ardhuin ... See all authors

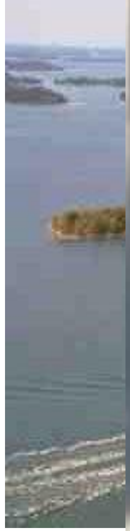
First published: 05 September 2019 | https://doi.org/10.1029/2018GB006041 | Citations: 51

SECTIONS PDF TOOLS SHARE

Abstract

The contemporary air-sea flux of CO_2 is investigated by the use of an air-sea flux equation, with particular attention to the uncertainties in global values and their origin with respect to that equation. In particular, uncertainties deriving from the transfer velocity and from sparse upper ocean sampling are investigated. Eight formulations of air-sea gas transfer velocity are used to evaluate the combined standard uncertainty resulting from several sources of error. Depending on expert opinion, a standard uncertainty in transfer velocity of either ~5% or ~10% can be argued and that will contribute a proportional error in air-sea flux. The limited sampling of upper ocean fCO_2 is readily apparent in the Surface Ocean CO_2 Atlas databases. The effect of sparse sampling on the calculated fluxes was investigated by a bootstrap method, that is, treating each ship cruise to an oceanic region as a random episode and creating 10 synthetic data sets by randomly selecting episodes with replacement. Convincing values of global net air-sea flux can only be achieved using upper ocean data collected over several decades but referenced to a standard year. The global annual referenced values are robust to sparse sampling, but seasonal and regional values exhibit more sampling uncertainty. Additional uncertainties are related to thermal and haline effects and to aspects of air-sea gas exchange not captured by standard models. An estimate of global net CO_2 exchange referenced to 2010 of −3.0 ± 0.6 Pg C/year is proposed, where the uncertainty derives primarily from uncertainty in the transfer velocity.

Measuring the SSTskin



People… and many more…



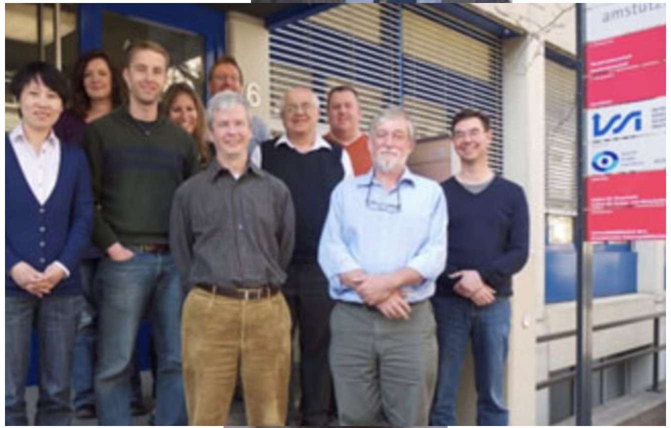














Combined action to study the oceans thermal skin.

Project ID: ENV4950149

Financiado con arreglo a: FP4-ENV 2C

Combined action to study the oceans thermal skin.

Desde 1996-03-01 **hasta** 1998-05-31

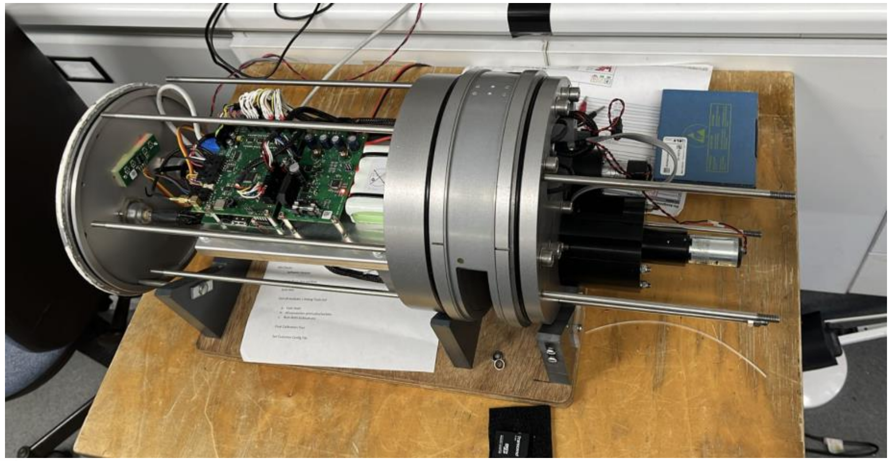
Detalles del proyecto

Coste total:	**Tema(s):**
No disponible	030101 - Methodological research
Aportación de la UE:	**Régimen de financiación:**
No disponible	CON - Coordination of research actions
Coordinado en:	
United Kingdom	

New Approaches

Infrared Sea Surface Temperature Autonomous Radiometer

The Infrared Sea surface temperature Autonomous Radiometer (ISAR) has been developed to provide accurate and reliable measurements of the radiative sea surface temperature (SSTskin) to an accuracy of ±0.1 K without the need of operator intervention. Infrared emission from the sea surface and atmosphere are measured in the spectral waveband 9.8–11 μm. The ISAR system has been specifically designed to address the problem of sea-water spray or rain, which without adequate environmental protection of delicate infrared radiometer fore-optics, could introduce significant errors in the SSTskin measurement. Furthermore it provides a self calibrating infra red radiometer system that can operate autonomously for extended periods when deployed from a ship of opportunity (SOO).



SI traceability

- **Climate data records from satellites** are a fundamental at ESA – **we are committed** to deliver *Climate Space*
- **Metrology is essential** due to the overwhelming volume of data from space: small errors have major impacts on climate time series
- We are **embedding Metrology** (uncertainty and traceability) into all of our satellite engineering and scientific processes:
  - In our satellite designs and data processing
  - Via Fiducial Reference Measurements (FRM) for validation
  - For our flying constellations using tandem flights
  - By implementing QA4EO uncertainty modelling techniques

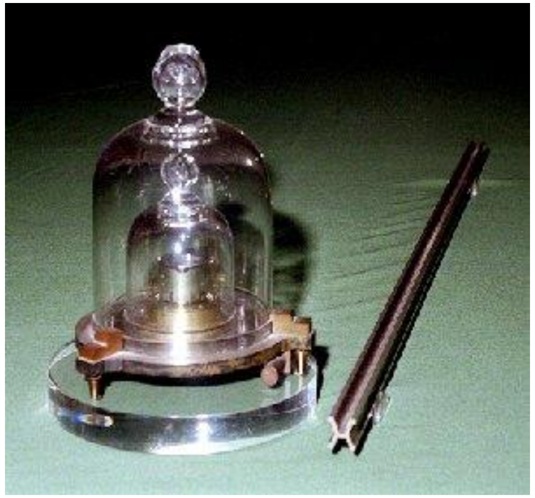
ESA recognises **the essential role of the International System of Units (SI) in providing confidence in the accuracy and global comparability of measurements** needed for protection of the environment, global climate studies and scientific research including the use and future development of UTC

Core principles of metrology

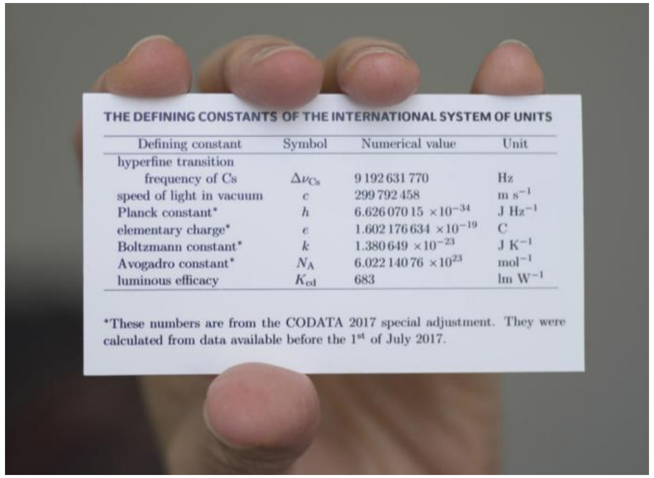
STABILITY
Century scale

INTEROPERABILITY
equivalence world wide

COHERENCE
Combining different measurements



20 May 1875



THE DEFINING CONSTANTS OF THE INTERNATIONAL SYSTEM OF UNITS

Defining constant	Symbol	Numerical value	Unit
hyperfine transition frequency of Cs	$\Delta\nu_{Cs}$	9 192 631 770	Hz
speed of light in vacuum	c	299 792 458	$m\ s^{-1}$
Planck constant*	h	$6.626\,070\,15 \times 10^{-34}$	$J\ Hz^{-1}$
elementary charge*	e	$1.602\,176\,634 \times 10^{-19}$	C
Boltzmann constant*	k	$1.380\,649 \times 10^{-23}$	$J\ K^{-1}$
Avogadro constant*	N_A	$6.022\,140\,76 \times 10^{23}$	mol^{-1}
luminous efficacy	K_{cd}	683	$lm\ W^{-1}$

*These numbers are from the CODATA 2017 special adjustment. They were calculated from data available before the 1st of July 2017.

20 May 2019

TRACEABILITY

UNCERTAINTY

COMPARISON

Fiducial Reference Measurements (FRM)

esa

Fiducial Reference Measurements (FRM) are a suite of **independent, fully characterized, and traceable ground measurements** that follow the guidelines outlined by the GEO/CEOS Quality Assurance framework for Earth Observation (QA4EO).

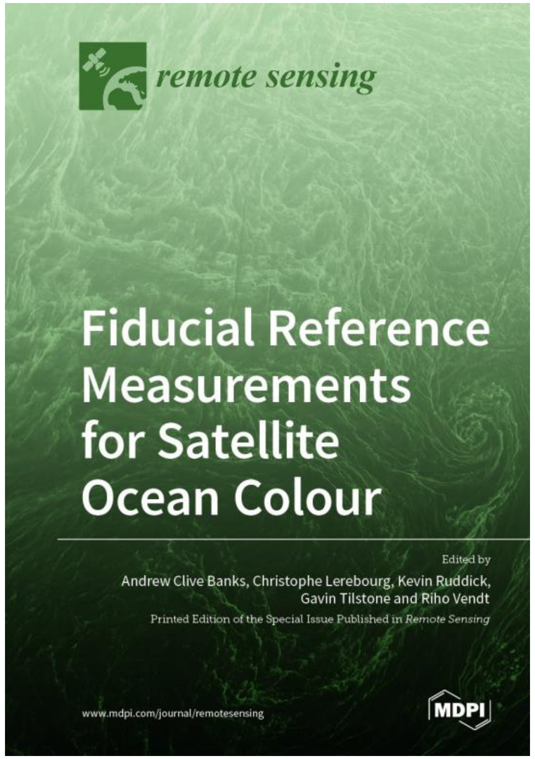
ships4sst
https://ships4sst.org/

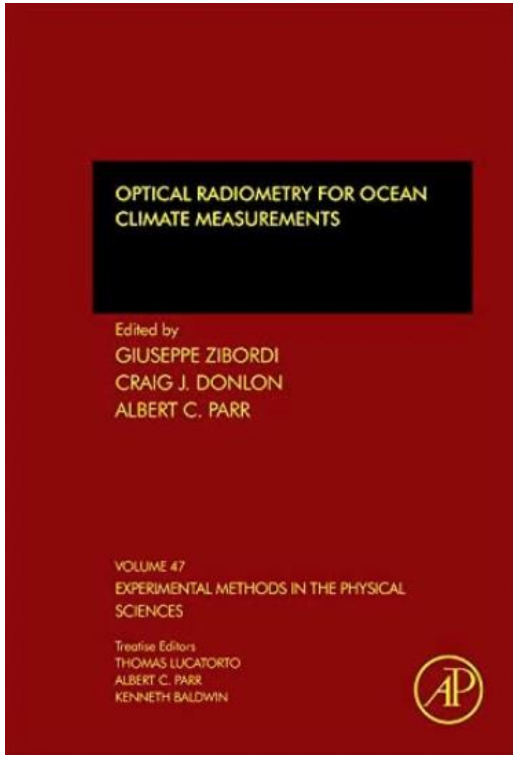
fiducial reference measurements for satellite ocean colour
https://frm4soc.org/

fiducial reference temperature measurements
http://www.frm4sts.org/

FRM4ALT Fiducial Reference Measurements for Altimetry
https://www.frm4alt.eu

fiducial reference measurements for vegetation
https://frm4veg.org/





FRM-BOUSSOLE: Buoy for the acquisition of long-term optical time series

http://www.obs-vlfr.fr/Boussole

Pandonia FRM: Fiducial Reference Measurements for Ground-Based Direct-Sun Air-Qu

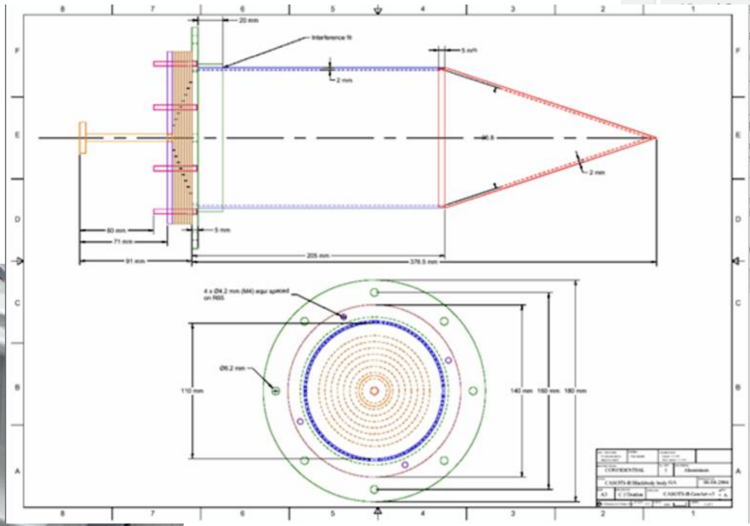
https://www.pandonia-global-network.org/

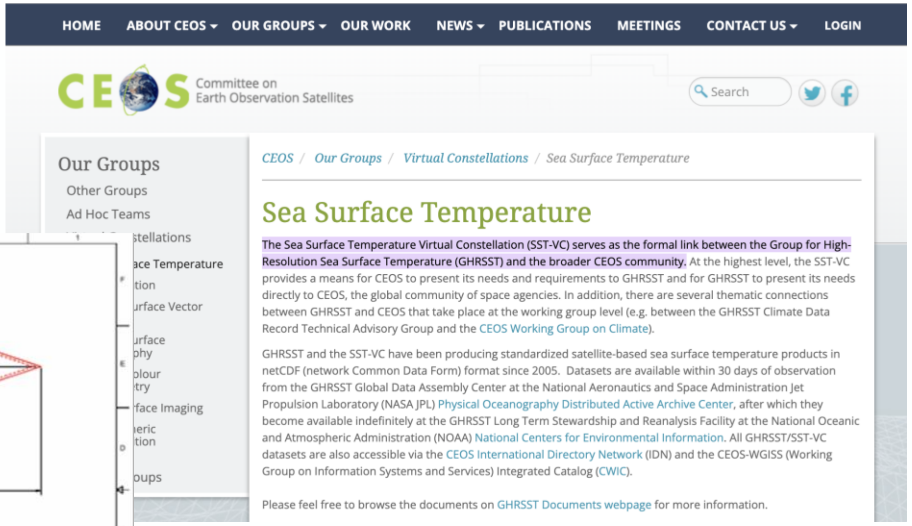
Fiducial Reference Measurements for Ground-Based DOAS Air-Quality Observations FRM4DOAS

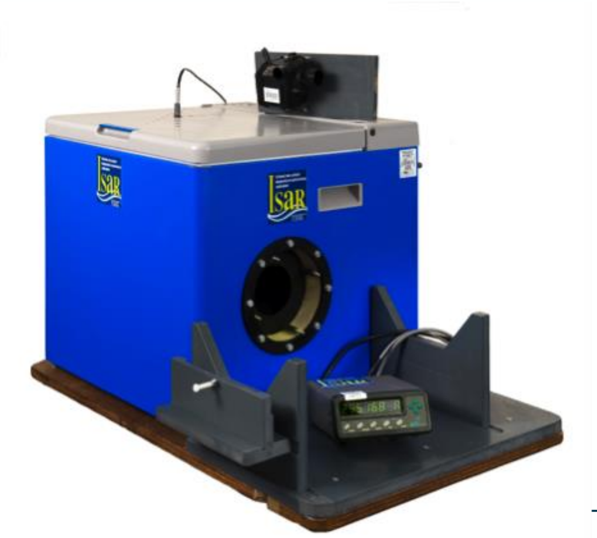
https://frm4doas.aeronomie.be/

Maintaining quality

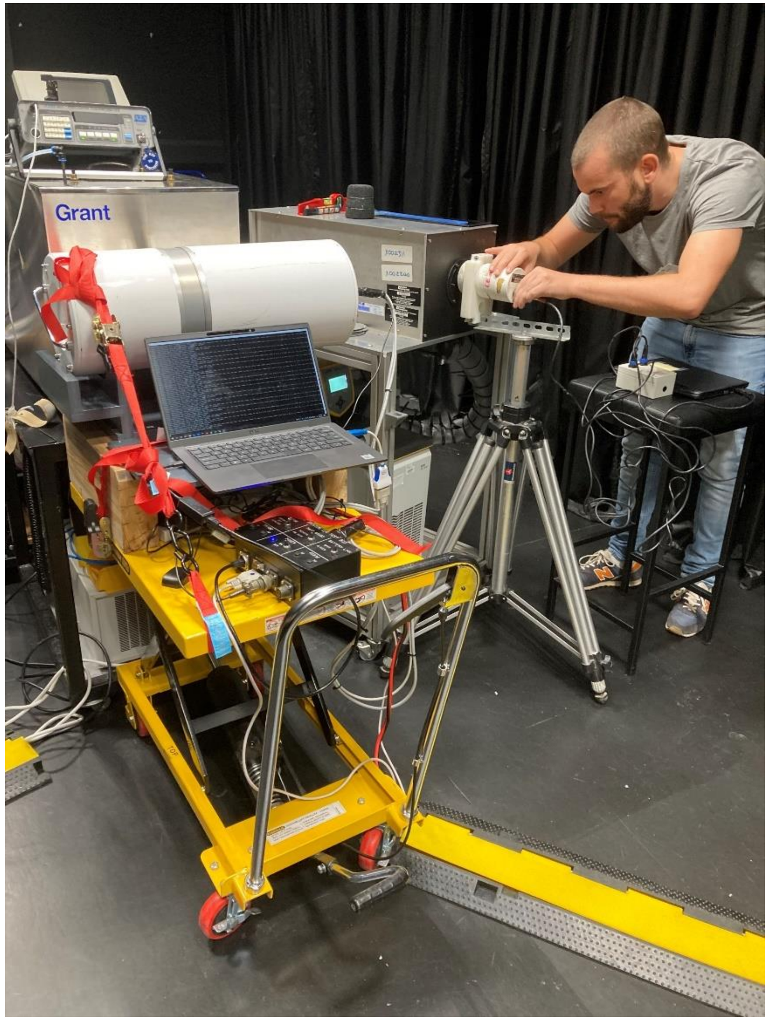
Essential challenge – we knew there were challenges to the validation data we had







Lab comparison
13th -17th June, 2022, @ NPL, Teddington, UK

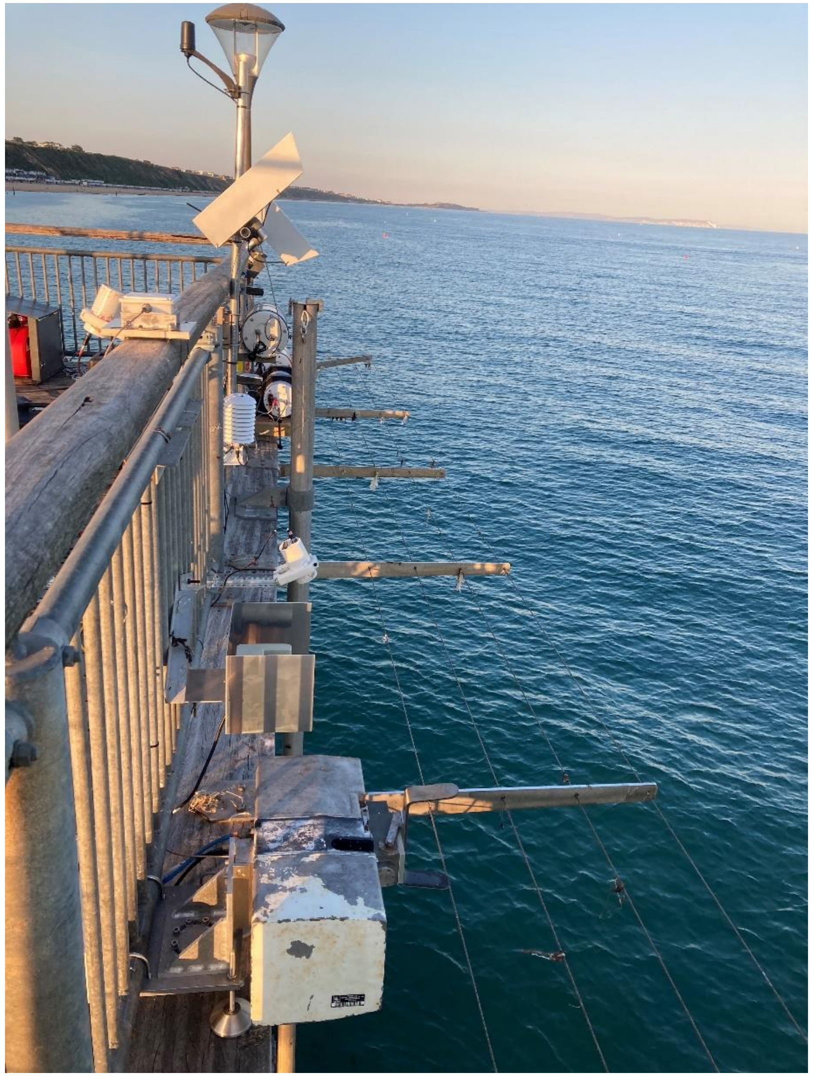


Radiometer comparison

Blackbody comparison

Field comparison

Preparation



After set-up

Standards based measurements

Editorial Type: Article
Article Type: Research Article

The Miami2001 Infrared Radiometer Calibration and Intercomparison. Part II: Shipboard Results

I. J. Barton, P. J. Minnett, K. A. Maillet, C. J. Donlon, S. J. Hook, A. T. Jessup, and T. J. Nightingale

Print Publication: 01 Feb 2004
DOI: https://doi.org/10.1175/1520-0426(2004)021<0268:TMIRCA>2.0.CO;2
Page(s): 268–283

Article History | Download PDF | Get Permissions

The Miami2001 Infrared Radiometer Calibration and Intercomparison. Part I: Laboratory Characterization of Blackbody Targets

J. P. Rice, J. J. Butler, B. C. Johnson, P. J. Minnett, K. A. Maillet, T. J. Nightingale, S. J. Hook, A. Abtahi, C. J. Donlon, and I. J. Barton

Print Publication: 01 Feb 2004
DOI: https://doi.org/10.1175/1520-0426(2004)021<0258:TMIRCA>2.0.CO;2
Page(s): 258–267

Editorial Type: Article
Article Type: Research Article

The 2016 CEOS Infrared Radiometer Comparison: Part II: Laboratory Comparison of Radiation Thermometers

E. Theocharous, N. P. Fox, I. Barker-Snook, R. Niclòs, V. Garcia Santos, P. J. Minnett, F. M. Göttsche, L. Poutier, N. Morgan, T. Nightingale, W. Wimmer, J. Høyer, K. Zhang, M. Yang, L. Guan, M. Arbelo, and C. J. Donlon

Print Publication: 01 Jun 2019
DOI: https://doi.org/10.1175/JTECH-D-18-0032.1
Page(s): 1079–1092

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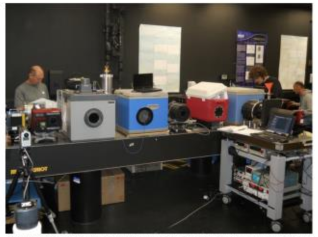
Blackbody comparison



Eight of the blackbodies which participated in the 2016 blackbody comparison lined up on an optical bench

NPL < back to main site | Browse | Search | Publications

CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part I: Laboratory and Ocean surface temperature comparison of radiation thermometers.

Tools

Theocharous, E; Usadi, E; Fox, N P (2010) CEOS comparison of IR brightness temperature measurements in support of satellite validation. Part I: Laboratory and Ocean surface temperature comparison of radiation thermometers. NPL Report. OP 3

2022 CEOS International Thermal Infrared Radiometer Comparison. Part II: Field Comparison of Radiometers

Yoshiro Yamada,[a] Subrena Harris,[a] Werenfrid Wimmer,[b] Raymond Holmes,[b] Tim Nightingale,[c] Arrow Lee,[c] Nis Jepsen,[d] Nicole Morgan,[e] Frank-M. Göttsche,[f] Raquel Niclòs,[g] Martín Perelló,[g] Vicente Garcia-Santos,[g] Craig Donlon,[h] and Nigel Fox[a]

[a] National Physical Laboratory, Teddington, United Kingdom
[b] University of Southampton, Southampton, United Kingdom
[c] Rutherford Appleton Laboratory, Science and Technology Facilities Council, Oxon, United Kingdom
[d] Danish Meteorological Institute, Copenhagen, Denmark
[e] CSIRO/Australian Bureau of Meteorology, Battery Point, Tasmania, Australia
[f] Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
[g] University of Valencia, Valencia, Spain
[h] European Space Agency, Noordwijk, Netherlands

(Manuscript received 3 May 2023, in final form 8 January 2024, accepted 19 January 2024)

ABSTRACT: An international comparison of field-deployed radiometers for sea surface skin temperature (SST_{skin}) retrieval was conducted during two weeks in June 2022. The comparison comprised a laboratory comparison and a field comparison. The field comparison of the radiometers took place on the second week at a seaside pier on the south coast of England. Six thermal infrared radiometers were compared with each other while continuously viewing the closely adjacent surface of the sea from the end of the pier. This paper reports the results of this field comparison. All participants' radiometers agreed with the refer… uncertainties. The SST_{skin} va… as in the previous compariso… for each participant was foun… parison an insignificant but… have been detected without… ble internal reference source… the laboratory comparison ar…

KEYWORDS: Ocean; Sea s…

2022 CEOS International Thermal Infrared Radiometer Comparison. Part I: Laboratory Comparison of Radiometers and Blackbodies

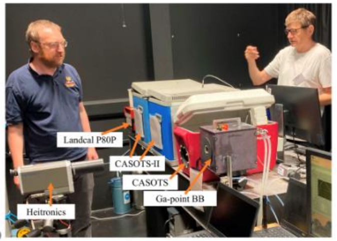
Yoshiro Yamada,[a] Subrena Harris,[a] Michael Hayes,[a] Rob Simpson,[a] Werenfrid Wimmer,[b] Raymond Holmes,[b] Tim Nightingale,[c] Arrow Lee,[c] Nis Jepsen,[d] Nicole Morgan,[e] Frank-M. Gött… Raquel Niclòs,[g] Martín Perelló,[g] Craig Donlon,[h] and Nigel Fox[a]

[a] National Physical Laboratory, Teddington, United Kingdom
[b] University of Southampton, Southampton, United Kingdom
[c] Rutherford Appleton Laboratory, Science and Technology Facilities Council, Oxon, United Kingdom
[d] Danish Meteorological Institute, Copenhagen, Denmark
[e] CSIRO/Australian Bureau of Meteorology, Battery Point, Tasmania, Australia
[f] Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany
[g] University of Valencia, Valencia, Spain
[h] European Space Agency, Noordwijk, Netherlands

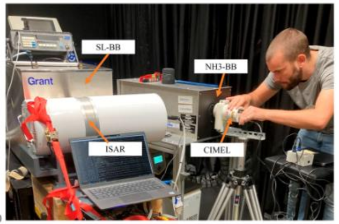
(Manuscript received 3 May 2023, in final form 3 November 2023, accepted 7 February 2024)

ABSTRACT: An international comparison of field deployed radiometers for sea surface skin temperature (SST_{skin}) r… trieval was conducted in June 2022. The campaign comprised a laboratory comparison and a field comparison. In the lab… ratory part, the radiometers were compared with reference standard blackbodies, while the same was done with th… blackbodies used for the calibration of the radiometers against a transfer standard radiometer. Reference values were pr… vided by the National Physical Laboratory (NPL), traceable to the primary standard on the International Temperatu… Scale of 1990. This was followed by the field comparison at a seaside pier on the south coast of England, where the radi… meters were compared against each other while viewing the closely adjacent surface of the sea. This paper reports the r… sults of the laboratory comparison of radiometers and blackbodies. For the blackbody comparison, the brightne… temperature of the blackbody reported by the participants agreed with the reference value measured by the NPL transf… standard radiometer within the uncertainties for all temperatures and for all blackbodies. For the radiometer compariso… the temperature range of most interest from the SST_{skin} retrieval point of view is 10°–30°C, and in this temperature rang… and up to the maximum comparison temperature of 50°C, all participants' reported results were in agreement with the re… erence. On the other hand, below 0°C the reported values showed divergence from the reference and the differences ex… ceeded the uncertainties. The divergence shows there is room for improvement in uncertainty estimation at lower temperatures, although it will have limited implication in the SST_{skin} retrieval.

KEYWORDS: Ocean; Sea surface temperature; Infrared radiation; Instrumentation/sensors; Remote sensing; Measurements



a)



b)

FIG. 1. View of laboratory during comparison measurements: (a) BB comparison, showing, from left to right, Landcal P80P, CASOTS-II, CASOTS-II, CASOTS, and Ga-point BB. Facing the BBs is the Heitronics transfer radiometer. (b) Radiometer comparison measurements showing, at left, ISAR measuring the SL-BB and, at right, CIMEL being prepared for NH3-BB measurement.

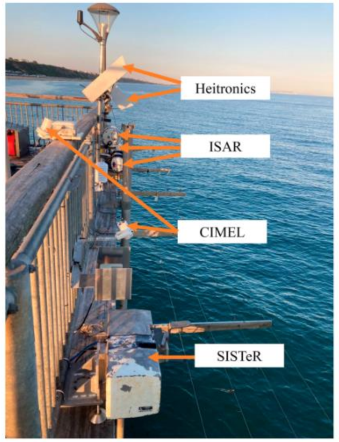
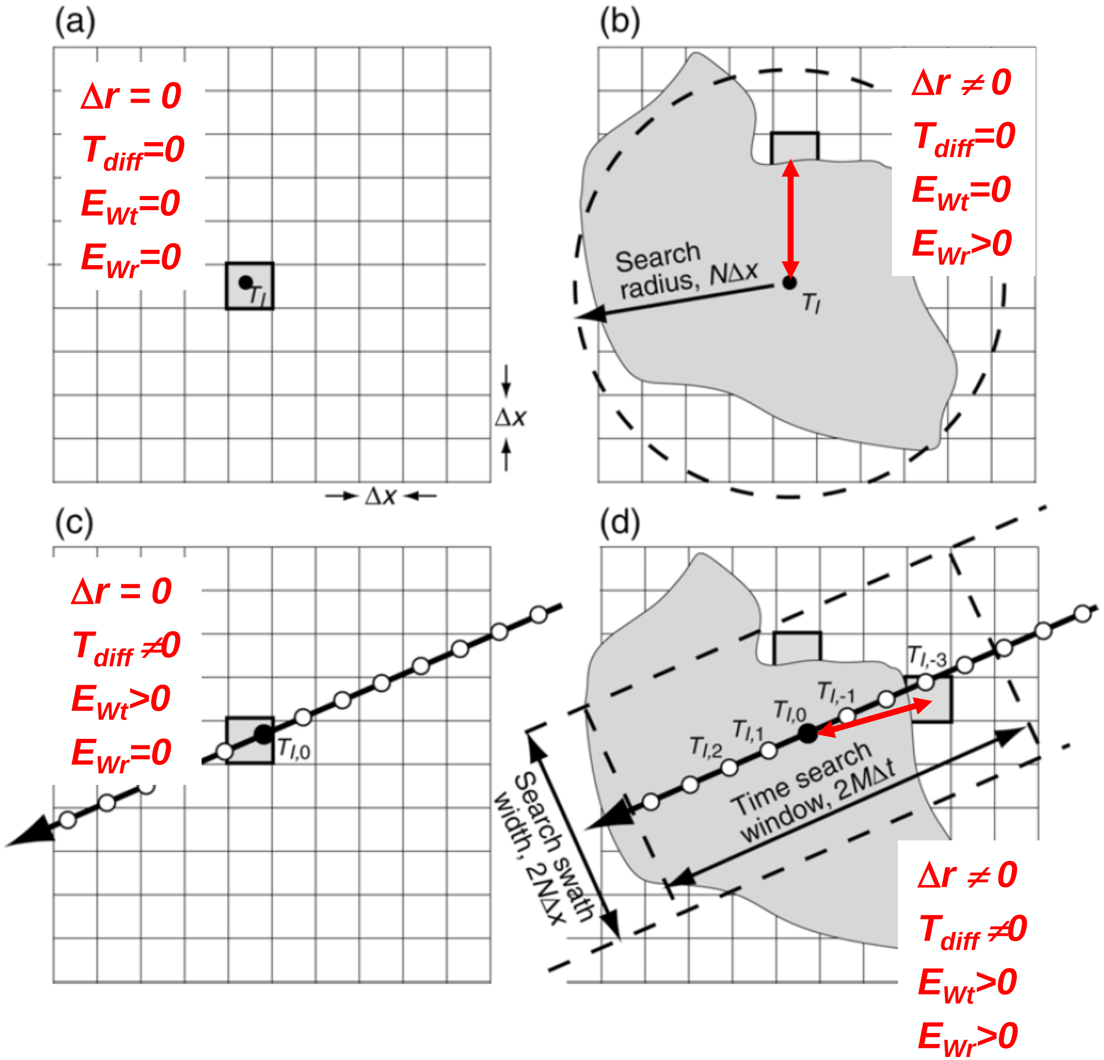


FIG. 2. Radiometers installed side by side retrieving the SST_{skin} at Boscombe Pier.

E_{Wt} = time displacement error
E_{Wr} =spatial displacement error



E_{Wt} = time displacement error,

mismatch in time, t_{dif} between the *in situ* sample and the satellite overpass.

It can be estimated as

$$E_{Wt} = t_{dif} \cdot \partial V/\partial t$$

E_{Wr} = spatial displacement error

when the *in situ* sample is displaced from the matched image pixel by a distance Δr.

It can be estimated as

$$E_{Wr} = \Delta r \cdot \partial V/\partial r$$

In situ measurement uncertainties

In order to estimate $\boldsymbol{E_S}$ it is necessary to estimate $\boldsymbol{E_w}$ and if possible to minimise it. It can be broken down into several different types of error:

$$E_W = E_{Wt} + E_{Wr} + E_{Wm} + E_{Ws} + E_{Wz}. \quad (5)$$

- E_{Wt}: Time mismatch error
- E_{Wr}: Location mismatch error
- E_{Wm}: In situ Instrument measurement error
- E_{Ws}: Point-in-area sampling error
- E_{Wz}: Sampling depth error

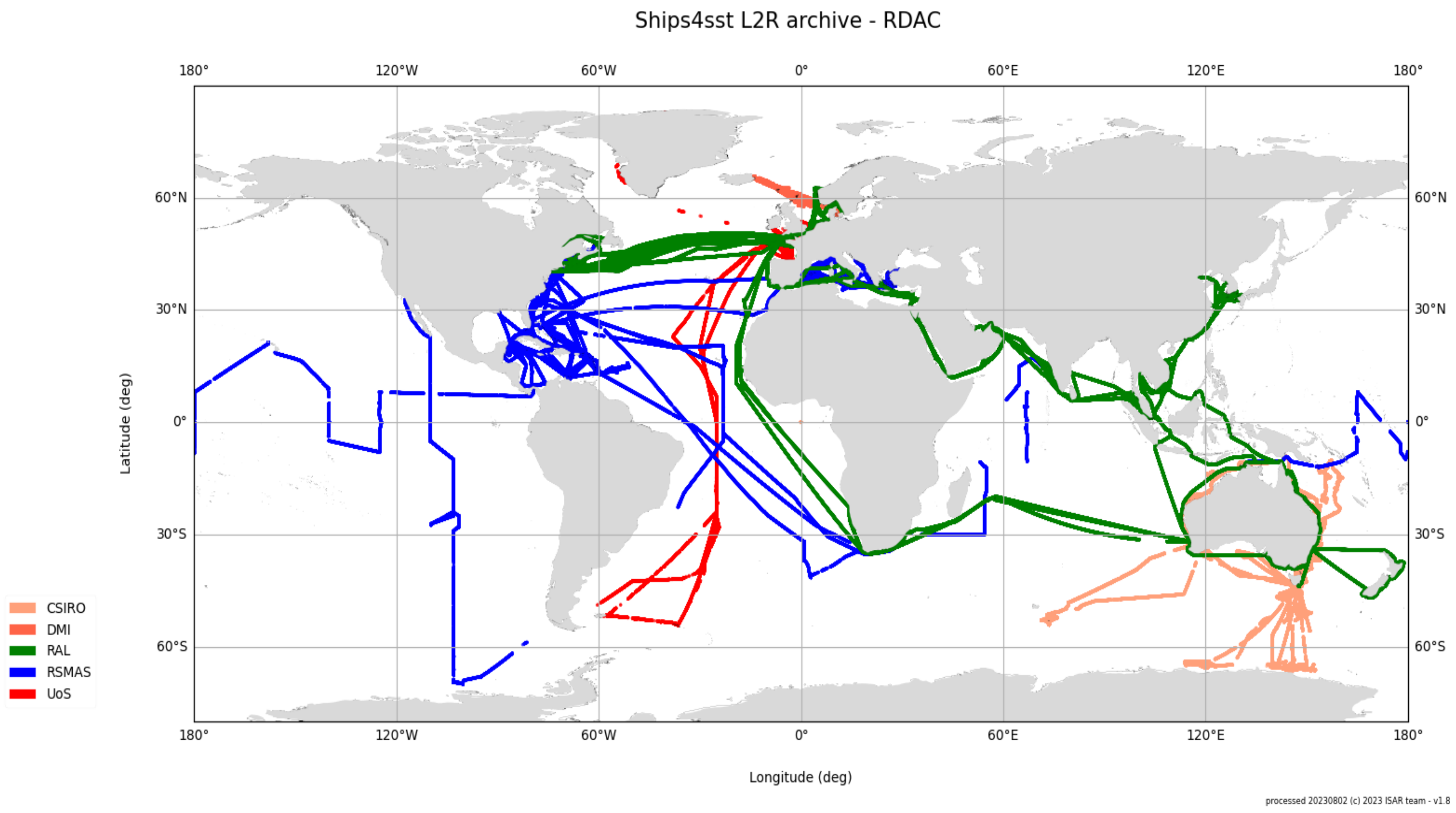
ISFRN

The scope of the ISFRN activity can cover all aspects of the science and technology of shipborne radiometers used to measure SST.

This includes

- exchange of operating advice and information that promote **best practice for radiometer deployments,**
- **establishing protocols** for shipborne radiometry including the validation of observations traceable to NMI reference standards,
- **agreeing formats** for skin SST data retrieved from ship radiometers,
- **setting procedures for quality control** in order to meet agreed standards of accuracy, and
- provide a single access point of the data collected around the world.

ISFRN Archive Map



Abreviation	Ships name	Operator
ADV	MV Adventure of the Seas	RSMAS
ALE	MV Allure of the Seas	RSMAS
DCY	RRS Discovery	UoS
EQX	MV Celebrity Equinox	RSMAS
JCR	RRS James Clark Ross	UoS
NOR	M/V Norrana	DMI
PtA	MV Pont Aven	UoS
QM2	MV Queen Mary 2	RAL
MaU	RV Minerva Uno	RSMAS
RHB	RV Ronald H.Brown	RSMAS
INV	RV Investigator	CSIRO

Validation results – statistics

- 2020 – S3 A vs B – WST CV5

A

Day						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	-0.05	0.26	96	19	281.83	302.56
2a	0.17	0.42	538	44	279.12	304.09
2b	**0.03**	**0.30**	**403**	**31**	**281.83**	**302.56**
3	0.22	0.45	2005	57	279.12	304.14
4	0.20	0.48	5528	103	279.12	304.98

Night						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	0.08	0.20	297	32	277.93	301.45
2a	0.01	0.32	686	49	276.62	301.45
2b	**0.03**	**0.23**	**1037**	**43**	**276.56**	**301.57**
3	-0.01	0.34	2656	62	276.55	301.75
4	-0.02	0.34	6908	106	275.67	303.42

B

Day						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	-0.12	0.22	167	19	283.30	299.22
2a	0.02	0.36	530	42	278.64	300.63
2b	**-0.09**	**0.28**	**646**	**31**	**283.30**	**299.48**
3	0.02	0.38	1978	54	278.64	303.02
4	0.03	0.40	6163	107	278.64	304.17

Night						
Grade	MDif f	RSD	No	Overpass	Min Temp	Max Temp
1	0.02	0.19	192	28	280.73	301.07
2a	-0.04	0.23	580	54	279.80	303.63
2b	**-0.02**	**0.22**	**732**	**43**	**276.69**	**303.05**
3	-0.07	0.25	2386	65	276.64	303.93
4	-0.08	0.30	6448	109	276.64	303.93

(W. Wimmer)

What did we achieve?

- **We wanted a dream**: a cost-effective fleet of SSTskin radiometers operating on ships around the world
- **We saw a lack of a low cost ocean-going solutions** - we had space industry designs for ships which was (and remains) inappropriate: more emphasis on practical solutions that can be maintained at sea were needed.
- **We focus on L2 comparisons**: we are not measuring the same thing from a ship as we measure from space (HPBW &Emissivity):
- We had a strong drive from the outset for **collaborative approaches**
- We had a strong **emphasis on excellent performance** so that we could trust the data in validation work
- We recognised the need and Importance of an **SI standards-based approach** to improving knowledge of radiometer calibration
- We learned from the ocean colour community that **data processing software could be a source of uncertainty** and took steps to compare code bases and approaches
- **We maintain the need for field experience**: these are scientific instruments and need care and attention!
- **"Fixing bad design" was an early red herring – yet bad design persists:** When 1 molecule of water covers your window you measure the temperature of that molecular water layer…

We have the ISFRN in place for many years and we are here to celebrate 25 years of activity!

Thank you Any Questions?

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