Introduction to Fiducial Reference Measurements

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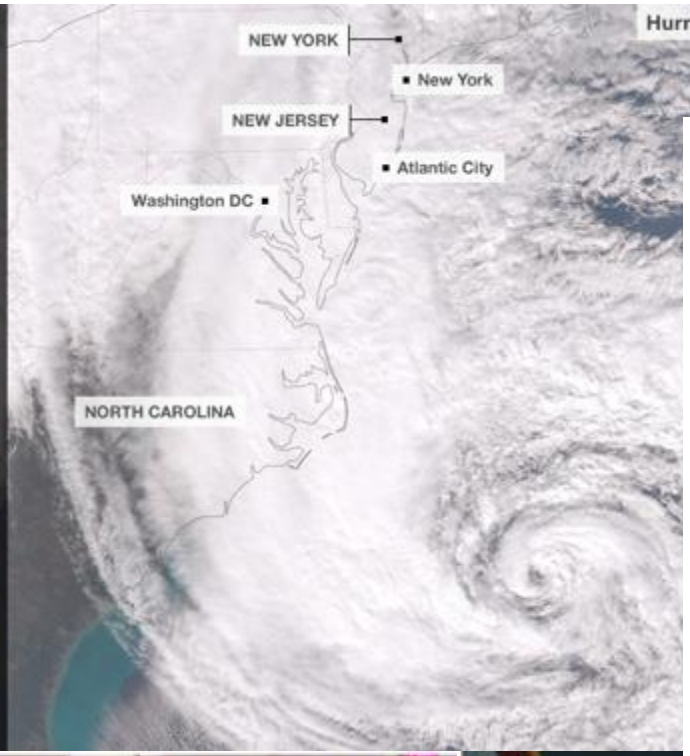
ESA/ESTEC, Noordwijk, the Netherlands

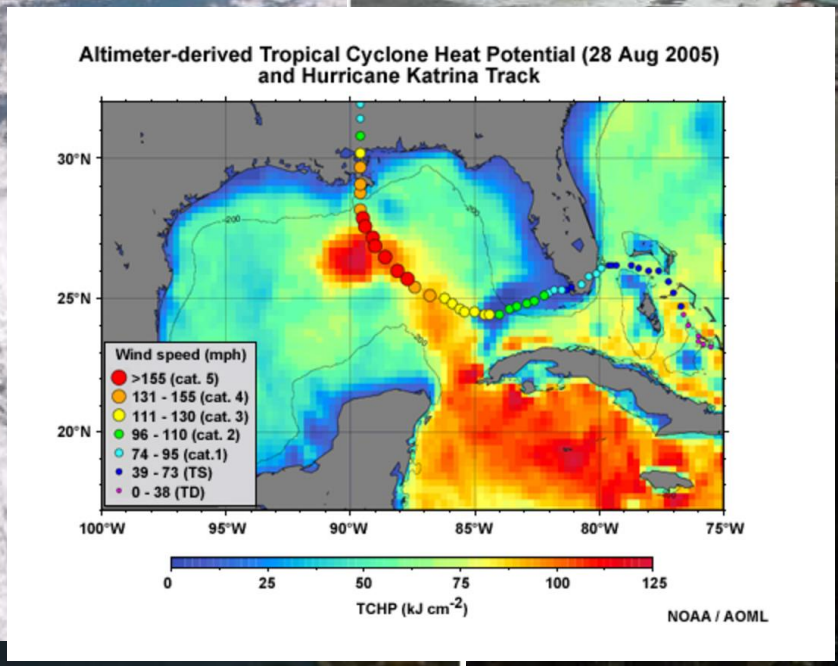
FRM4STS, National Physics Laboratory, London, 16-18th October 2017

Overview

- Why do we need FRM?
- Definition of FRM
- ESA Example projects and activities
    - FRM4SOC
    - FRM4ALT
    - AMT4SentinelFRM
    - FRM4STS
- Updates on Copernicus
- Updates on Sentinel-3

With increases in sea level rise, life and property threatening impacts such as storm surge become increasingly important

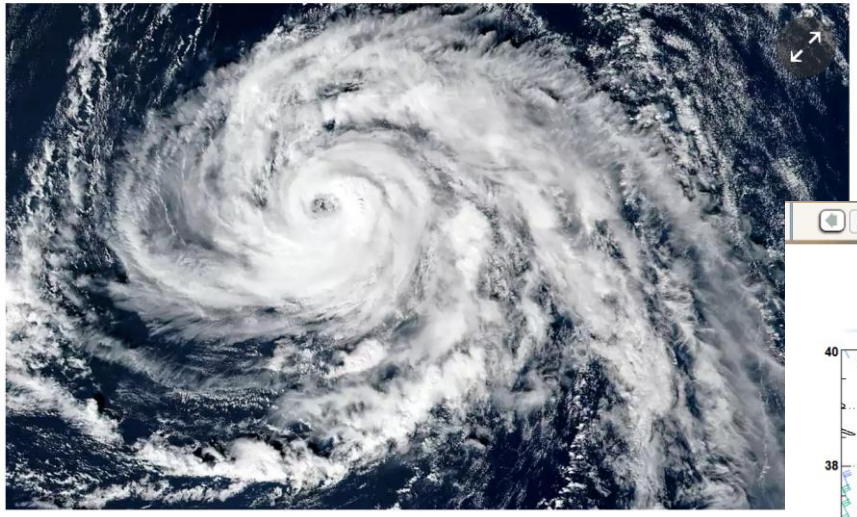


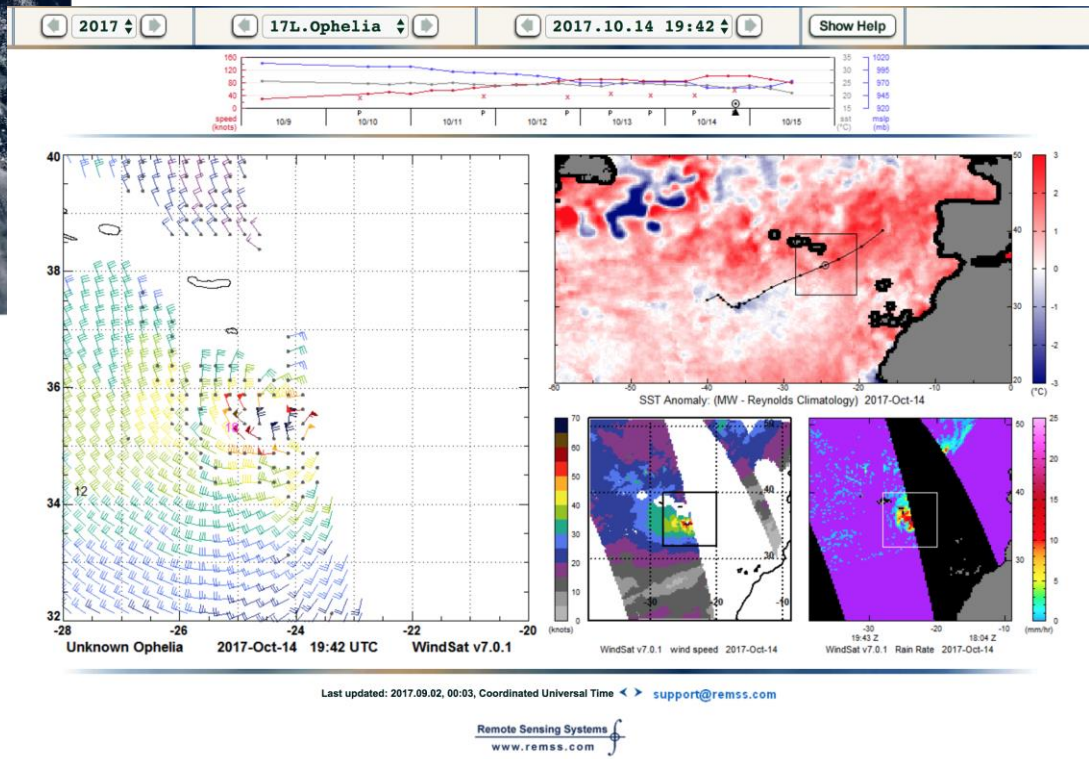


And Today…Ophelia

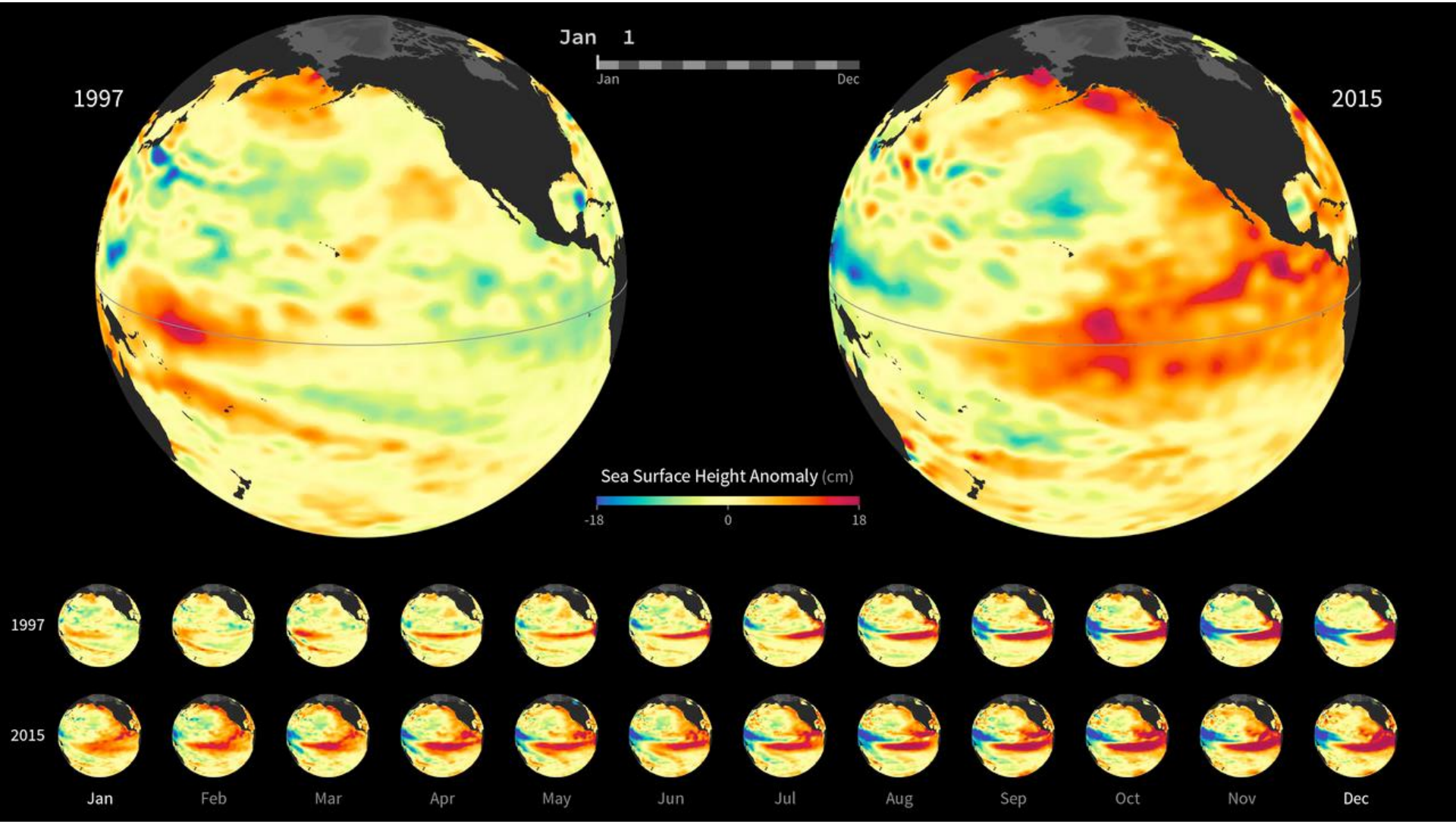
Weather warnings for UK as Hurricane Ophelia threatens 80mph gusts

Western parts of country told to expect transport disruption and flying debris as Ireland prepares for worst storm in decades





El Nino watch 2015
(https://svs.gsfc.nasa.gov/30629)



Hs from multiple Altimeters:
Note style of NWS for visualisation

File image courtesy Norwegian Petroleum

Climate Change 2014: Impacts, Adaptation, and Vulnerability

ipcc
INTERGOVERNMENTAL PANEL ON climate change

Coastal systems are particularly sensitive to three key drivers related to climate change: sea level, ocean temperature, and ocean acidity (*very high confidence*).

{5.3.2, 5.3.3.4, 5.3.3.5} Despite the lack of attribution of observed coastal changes, there is a long-term commitment to experience the impacts of sea level rise because of a delay in its response to temperature (*high confidence*). {5.5.8} In contrast, coral bleaching and species ranges can be attributed to ocean temperature change and ocean acidity. {5.4.2.2, 5.4.2.4} For many other coastal changes, the impacts of climate change are difficult to tease apart from human-related drivers (e.g., land use change, coastal development, pollution) (*robust evidence*, *high agreement*).

Coastal systems and low-lying areas will increasingly experience adverse impacts such as submergence, coastal flooding, and coastal erosion due to relative sea level rise (RSLR; *very high confidence*).

In the absence of adaptation, beaches, sand dunes, and cliffs currently eroding will continue to do so under increasing sea level (*high confidence*). {5.4.2.1, 5.4.2.2} Large spatial variations in the projected sea level rise together with local factors means RSLR at the local scale can vary considerably from projected global mean sea level rise (GMSLR) (*very high confidence*). {5.3.2} Changes in storms and associated storm surges may further contribute to changes in sea level extremes but the small number of regional storm surge studies, and uncertainty in changes in tropical and mid-latitude cyclones at the regional scale, means that there is *low confidence* in projections of storm surge change {5.3.3.2} Both RSLR and impacts are also influenced by a variety of local processes unrelated to climate (e.g., subsidence, glacial isostatic adjustment, sediment transport, coastal development) (*very high confidence*).

Climate Change 2014: Impacts, Adaptation, and Vulnerability

ipcc
INTERGOVERNMENTAL PANEL ON climate change

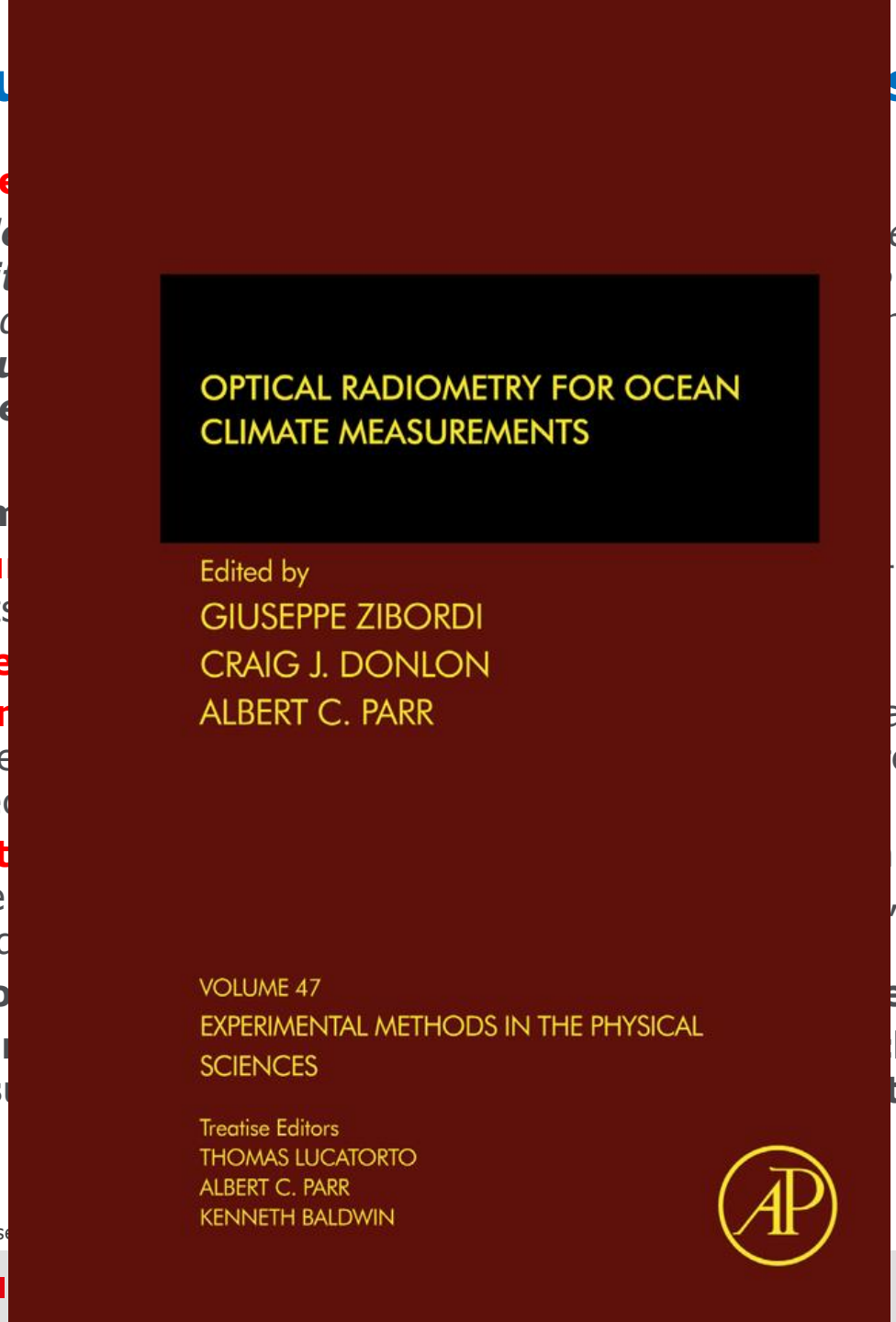
The population and assets exposed to coastal risks as well as human pressures on coastal ecosystems will increase significantly in the coming decades due to population growth, economic development, and urbanization (*high confidence*). The exposure of people and assets to coastal risks has been rapidly growing and this trend is expected to continue. {5.3.4.1, 5.4.3.1} Humans have been the primary drivers of changes in coastal aquifers, lagoons, estuaries, deltas, and wetlands (*very high confidence*) and are expected to further exacerbate human pressures on coastal ecosystems resulting from excess nutrient input, changes in runoff, and reduced sediment delivery (*high confidence*). {5.3.4.2, 5.3.4.3, 5.3.4.4}

For the 21st century, the benefits of protecting against increased coastal flooding and land loss due to submergence and erosion at the global scale are larger than the social and economic costs of inaction (*limited evidence, high agreement*). Without adaptation, hundreds of millions of people will be affected by coastal flooding and will be displaced due to land loss by year 2100; the majority of those affected are from East, Southeast, and South Asia (*high confidence*). {5.3.4.1, 5.4.3.1} At the same time, protecting against flooding and erosion is considered economically rational for most developed coastlines in many countries under all socioeconomic and sea level rise scenarios analyzed, including for the 21st century GMSLR of above 1 m (*limited evidence*, *high agreement*). {5.5.5}

Fidu s

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

- **The defining m**
  a. Have **docu** -comparison of instrument
  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.**



ESA has 4 marine Fiducial Reference Measurement (FRM) pilot projects

fiducial reference measurements for satellite ocean colour

https://frm4soc.org

Preparing above water radiometers and vicarious infrastructure in Europe for Ocean Colour FRM (SI Traceability)

FRM4ALT FIDUCIAL REFERENCE MEASUREMENTS FOR ALTIMETRY

http://www.frm4alt.eu/

Procedures and approached to maintain ground transponders with SI Traceability)

amt4sentinelfrm

http://amt4sentinelfrm.org

Collection of marine FRM for S3 SLSTR and OLCI, S2 MSI and S1 C-band SAR Dedicated support to collecting FRM measurements for Sentinel validation

fiducial reference temperature measurements

http://www.frm4sts.org/

Preparing ground truth radiometers and drifting buoy as FRM (SI Traceability)

Fiducial Reference Measurements for Satellite Altimetry (FRM4ALT)

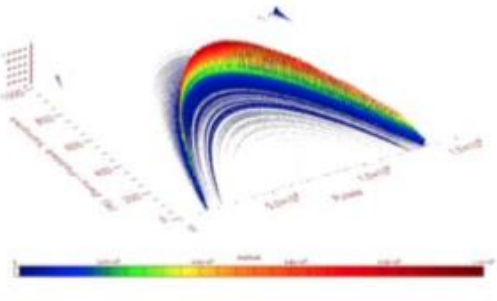
- ***Aim: Establish and demonstrate SI traceability of Fiducial Reference Measurements (FRM) and their use for satellite derived altimeter calibration and validation.***
- **350KEuro, 24 Months KO in Q1 2016**
- Develop, document and demonstrate SI traceability of Altimeter calibration using new transponder procedures and processes to maintain the Permanent Altimeter Calibration Facility (PACF) in Western Crete, Greece.
- Satellites: Jason-2, Jason-3, AltiKa, CryoSat2, HY-2A, Sentinel-3 SRAL

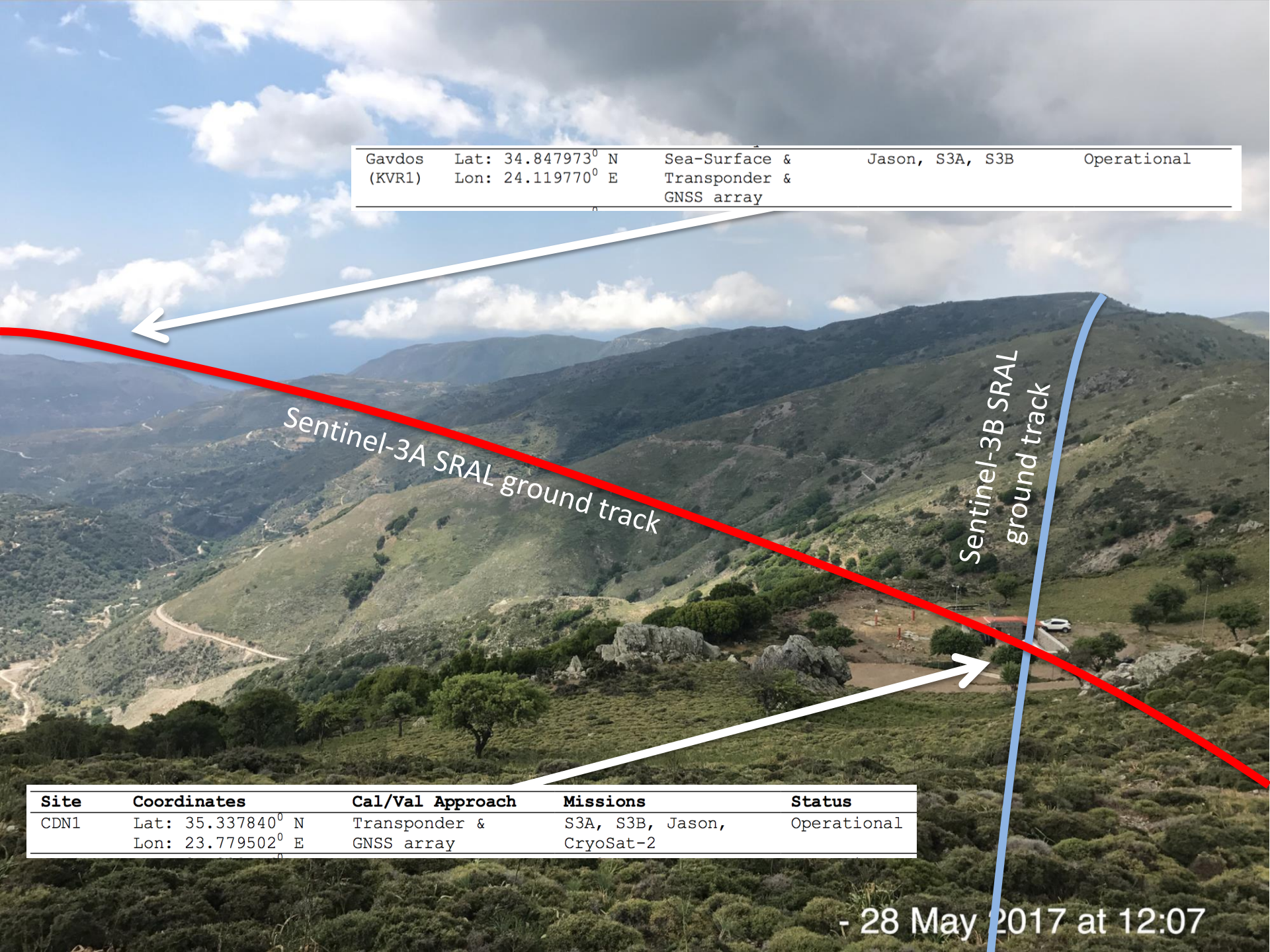
Contract in Negotiation with Space Geomatica, DTU and Technical University of Crete

DTU

Space Geomatica Ltd
Earth Observation Solutions

Technical University of Crete





Gavdos (KVR1)	Lat: 34.847973^0 N Lon: 24.119770^0 E	Sea-Surface & Transponder & GNSS array	Jason, S3A, S3B	Operational

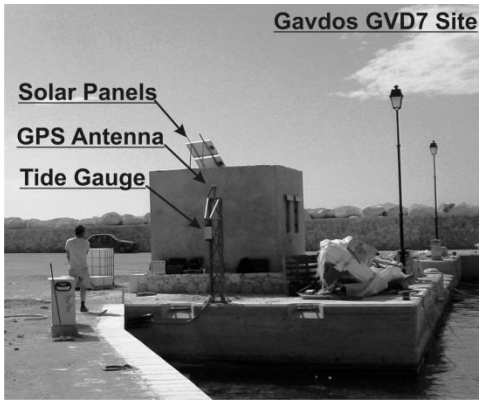
Site	Coordinates	Cal/Val Approach	Missions	Status
CDN1	Lat: 35.337840^0 N Lon: 23.779502^0 E	Transponder & GNSS array	S3A, S3B, Jason, CryoSat-2	Operational

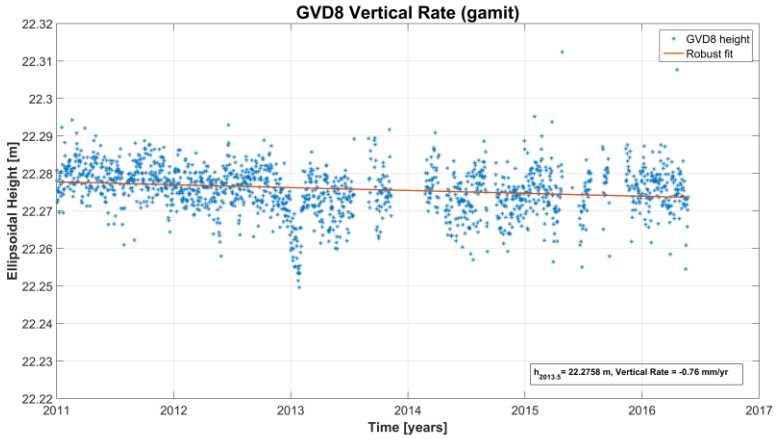
Cal/Val site Location

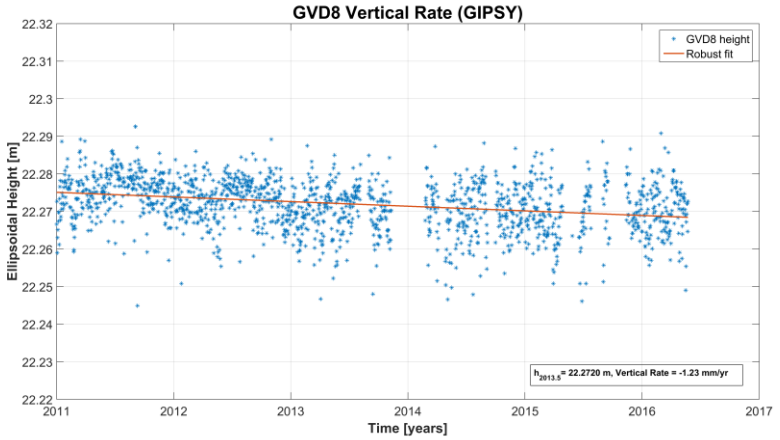
- Close to sea,
- Protected,
- Accessible, Amenities,
- Vertical motion monitor,
- Satellite visibility,
- Proper monumentation,
- Intl standards & specs,
- Diverse instrument types, models,
- Sense ocean for altimetry calibration,
- Local reference surfaces…

Ground stability of Cal/Val site

- Monitor ground deformation continuously,
- Uncertainty infiltrates in final Cal/Val results,
- Tie GNSS reference marks to stable control benchmarks.





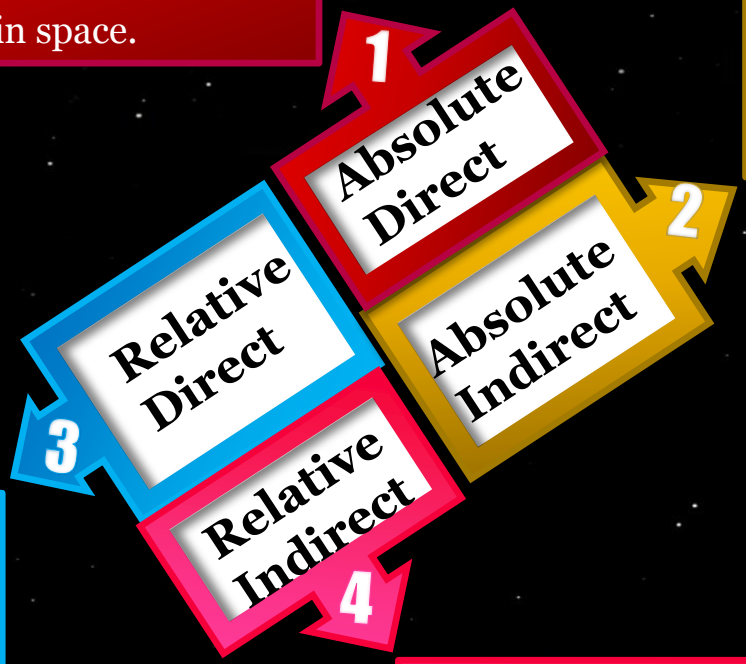


Satellite Altimetry Cal/Val

*"**Calibration:** Process of quantitatively defining the system responses to known, controlled signal inputs. **Validation:** Process of assessing, by independent means, the quality of the data products derived from the system outputs."* Committee on Earth Observation Satellites

Microwave transponders are to calibrate
- altimetric range;
- Sigma0;
- Time-tagging errors;
- Baseline orientation in space.

Permanent Cal/Val facilities equipped with GNSS, tide gauges, buoys, meteorological sensors, etc., established near, but not exactly under the valid satellite measurements



Multi-mission cross-over calibration between different altimetry missions.

Tide gauge network to determine regional & global long-term (seasonal) trends in sea-level variation.

(FRM4ALT Project, S. Mertikas)

Fiducial Reference Measurements for Satellite Ocean Colour (FRM4SOC)

fiducial reference measurements for satellite ocean colour

- Aim ***To establish and maintain SI traceability of Fiducial Reference Measurements (FRM) for satellite ocean colour radiometry (OCR).***
- Laboratory and field radiometer characterization experiments
- Laboratory comparison of radiance and irradiance sources
- Laboratory raound-robin performance assessment of field OCR used for satellite validation
- Workshop to establish requirements for European OCR vicarious adjustment infrastructure

- **500KEuro, 30 months, ITT issued December 2015, closing date: 12 Feb 2016.**

21 – 23 February 2017 at ESRIN, IT Options for future European satellite OCR vicarious adjustment infrastructure for the Sentinel-3 OLCI and Sentinel-2 MSI A/B/C and D instruments

- 38 attendees
  - USA : 5 from NOAA, Uni. of Miami, NIST Sea-Bird Scientific, NASA GISS
  - Canada : 1 from Dalhousie Uni.
  - Australia : 1 from Uni. Of Western Australia
  - Korea : 1 from KIOST
- EU : 30 from 7 countries
  - ESA, EUMETSAT
  - France : 7 from LOV, ACRI-ST, SOLVO
  - Italy : 7 from JRC, CNR, ISPRA, ESA
  - Estonia : 6 from Tartu Observatory and Estonian Marine Institute
  - UK : 4 from NPL and PML
  - Germany : 2 AWI
  - Belgium : 2 from RBINS, European Environment Agency
  - Ireland : 1 Techworks Marine

TARTU OBSERVATORY space research centre ACRI ST PML Plymouth Marine Laboratory NPL National Physical Laboratory museum

Comparison of Reference Irradiance and Radiance Sources (3 – 6 April 2017 at NPL, UK)

12 organisations from 9 countries

NPL (UK), pilot
TO (EE)
JRC (EU)
LOV (FR)
Satlantic (CA)
Cimel (FR)
In-situ Marine Optics (AU)
CSIRO (AU)
NIVA (NO)
NERC-FSF (UK)
NOAA (US)
DLR-IMF (DE)

Copernicus fiducial reference measurements for satellite ocean colour

CEOS https://frm4soc.org esa

FRM radiometer inter-comparison (8 – 13 May 2017 at TO, Estonia)

13 organisations from 8 countries

- ESA
- TO (EE), pilot
- AWI (DE)
- CIMA (PT)
- Cimel (FR)
- CNR (IT)
- HZG (DE)
- NPL (UK)
- PML (UK)
- RBINS (BE)
- Satlantic (CA)
- UT (EE)
- UVIC (CA)

Indoor / Outdoor

41 Radiometers calibrated!

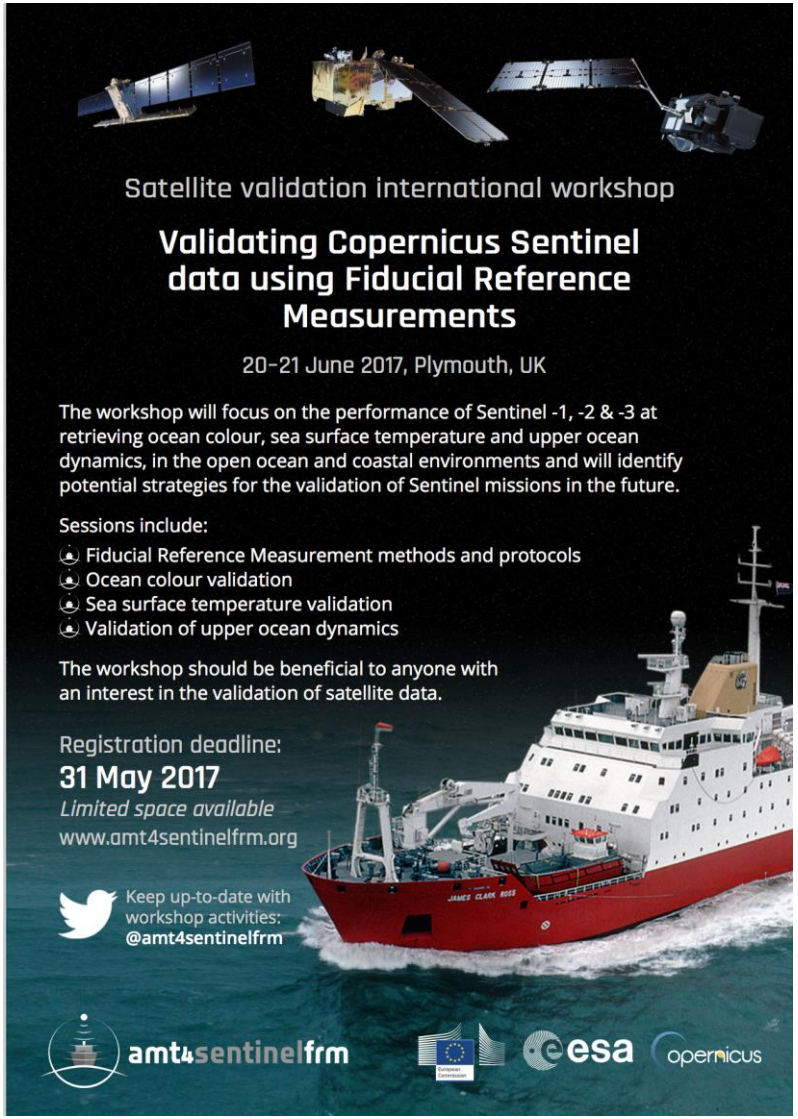
TARTU OBSERVATORY space research centre

ACRI ST

PML Plymouth Marine Laboratory

NPL National Physical Laboratory

museum



Workshop programme

Tuesday 20th June

Welcome plenary session
Craig Donlon, Steve Groom, Susanne Mecklenburg, Andy Rees, Gavin Tilstone

FRM procedures, methodologies and protocol
Jeremy Werdell (keynote), Andrew Banks, Giorgio Dall'Olmo, Craig Donlon, Hayley Evers-King, Rodney Foster, Tim Smyth, Kenneth Voss

Ocean colour validation: open ocean
Shubha Sathyendranath (keynote), Robert Brewin, George Graham, Christophe Lerebourg, Constant Mazeran, Emanuele Organelli, Stefan Simis, Menghua Wang

Ocean colour validation: coastal
David Doxaran, Silvia Pardo, Gavin Tilstone, Hans van der Woerd

Poster session and cocktail reception

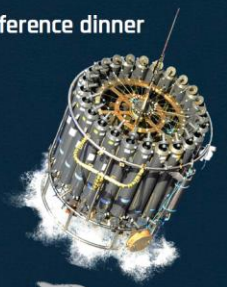
Wednesday 21st June

Ocean colour validation: coastal
Maycira Costa, Cédric Jamet, Nima Pahlevan

Sea surface temperature validation
Peter Minnett (keynote), Anne O'Carroll, Prasanjit Dash, Jean-François Piolle, Werenfrid Wimmer

Validation of upper ocean dynamics
Bertrand Chapron (keynote), Graham Quartly, Louis Marie, Francesco Nencioli

Conference dinner



PML Plymouth Marine Laboratory | University of Southampton | Ifremer

The workshop is hosted by the Atlantic Meridional Transect (AMT) for Fiducial Reference Measurements Campaign (AMT4SentinelFRM) which is led by Plymouth Marine Laboratory and includes two partners as subcontractors: the University of Southampton and the Institut Français de Recherche pour l'Exploitation de la Mer, Plouzane, France (IFREMER).

For further information about the workshop see our website, www.amt4sentinelfrm.org, twitter feed @amt4sentinelfrm or email comms.AMT4SFRM@pml.ac.uk

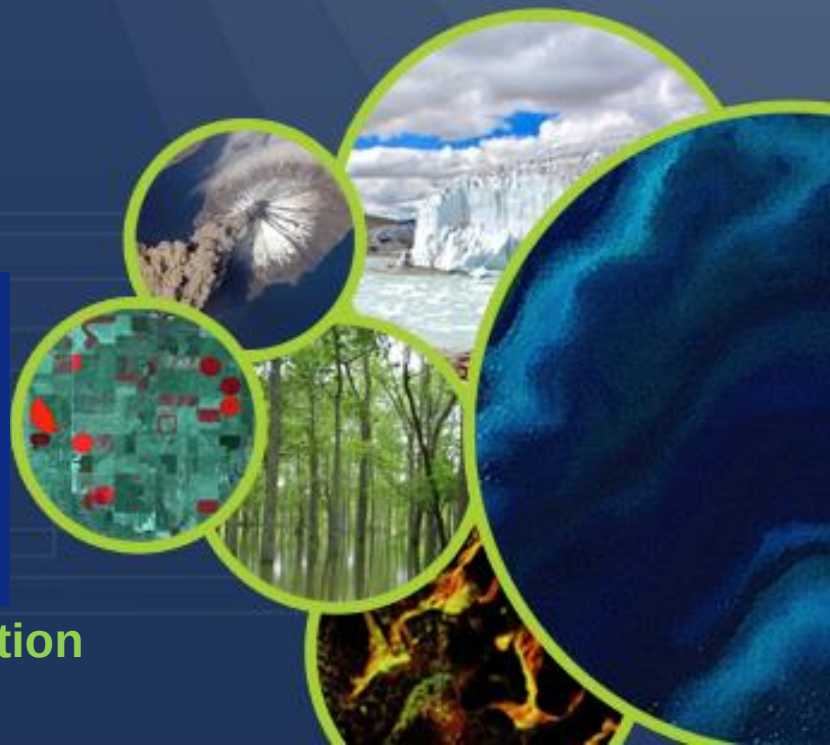
Satellite images courtesy of ESA, RRS James Clark Ross images by C. Gilbert and P. Bucktrout, British Antartic Survey.

FRM4STS: Fiducial Reference measurements for validation of Surface Temperature from Satellites (ceos cv8)

Nigel Fox

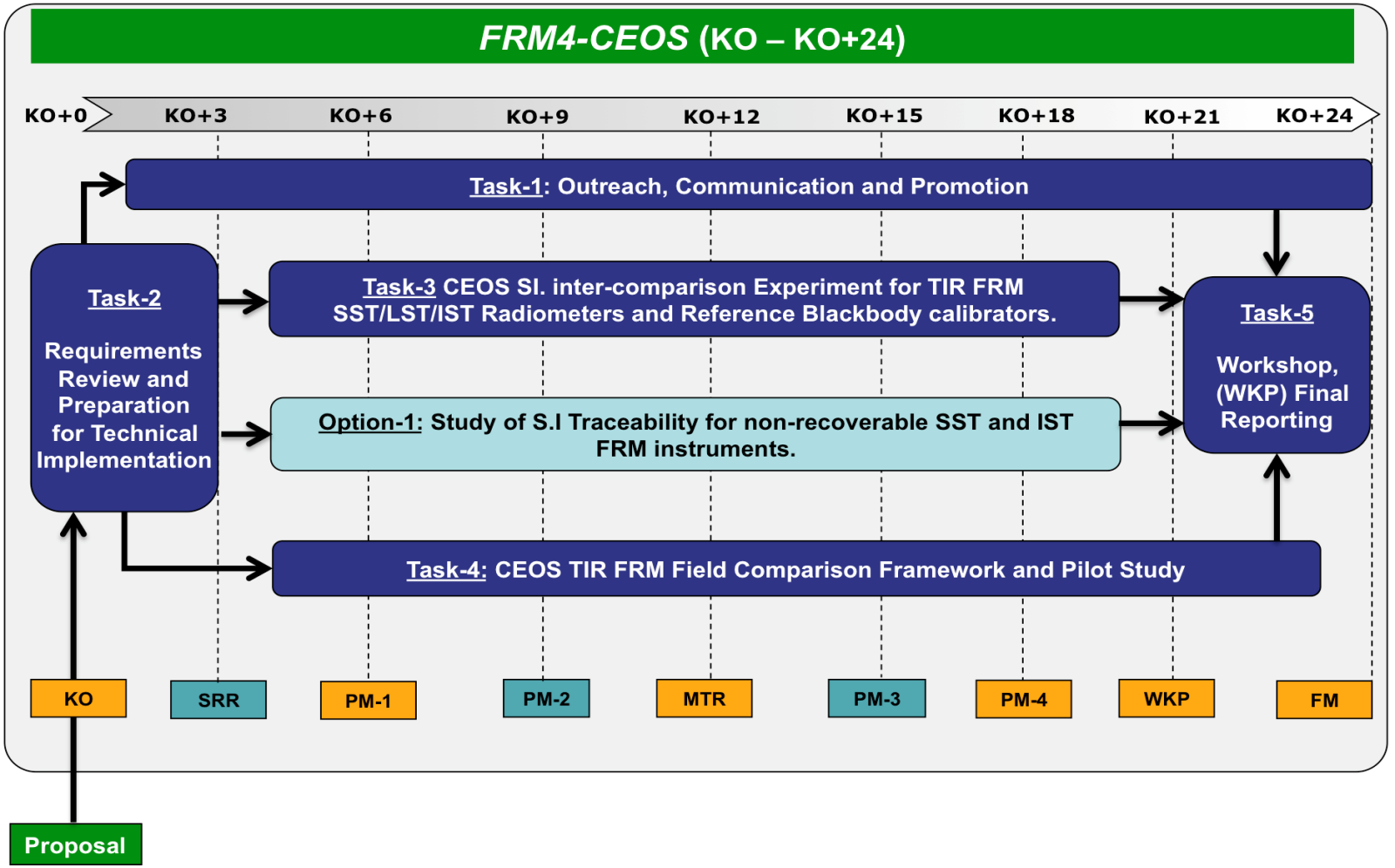
NPL (ESA Project)

WGCV Plenary # 40



Working Group on Calibration and Validation

Project Setup



Aim: **to establish and maintain SI traceability of global Fiducial Reference Measurements (FRM) for satellite derived surface temperature product validation**

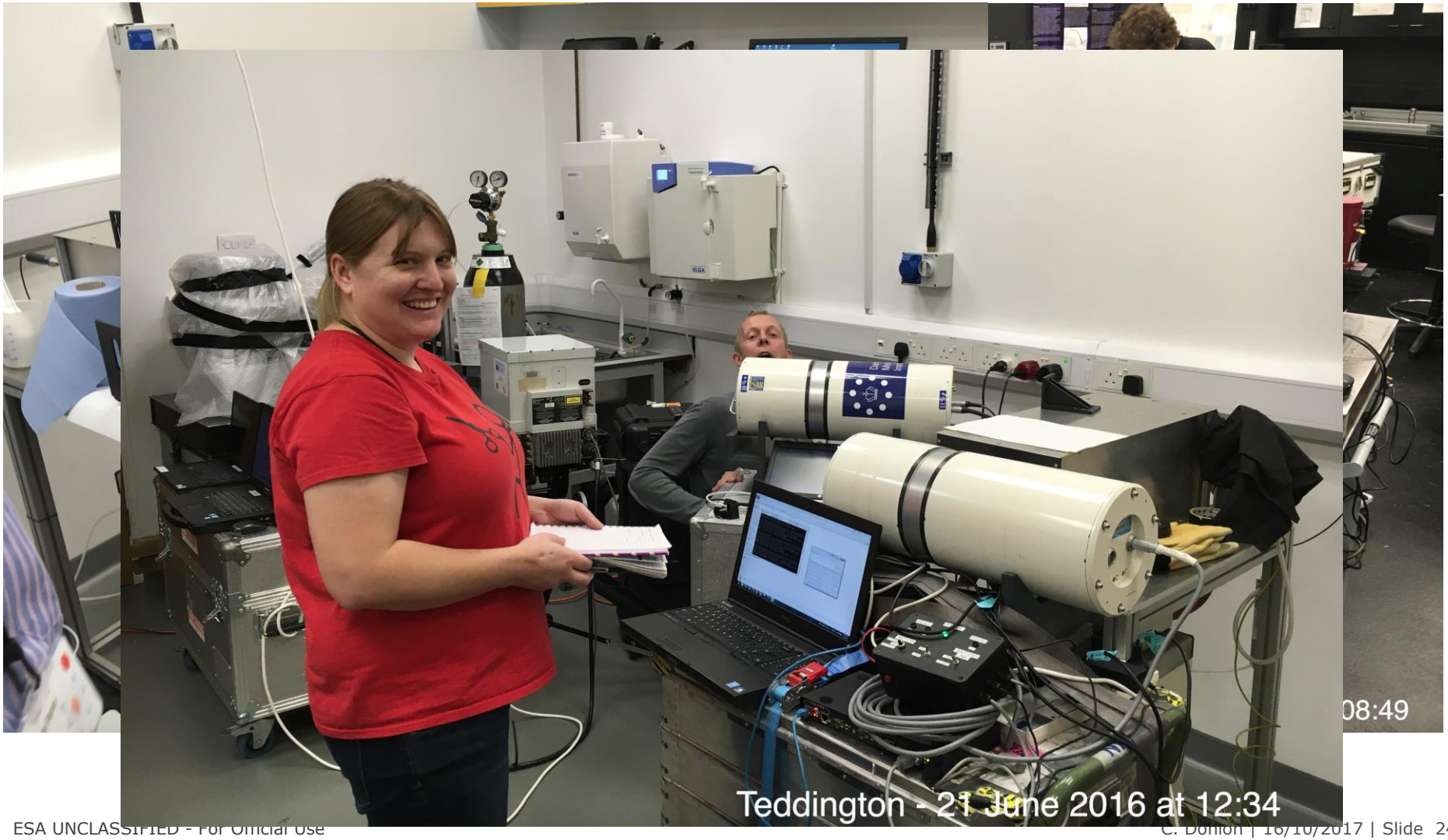
Requires:

- Comparisons to ensure consistency between measurement teams
- Accessible common descriptions and evaluation of uncertainties
- Robust links to SI
- Experiments to evaluate sources of bias/uncertainty under differing operational conditions **(Ocean/Land/Ice/Radiometers/Drifters)**
- International community buy-in (customer and supplier) of added value and how to achieve – through provision of guidance and best practises and access to standards and comparisons

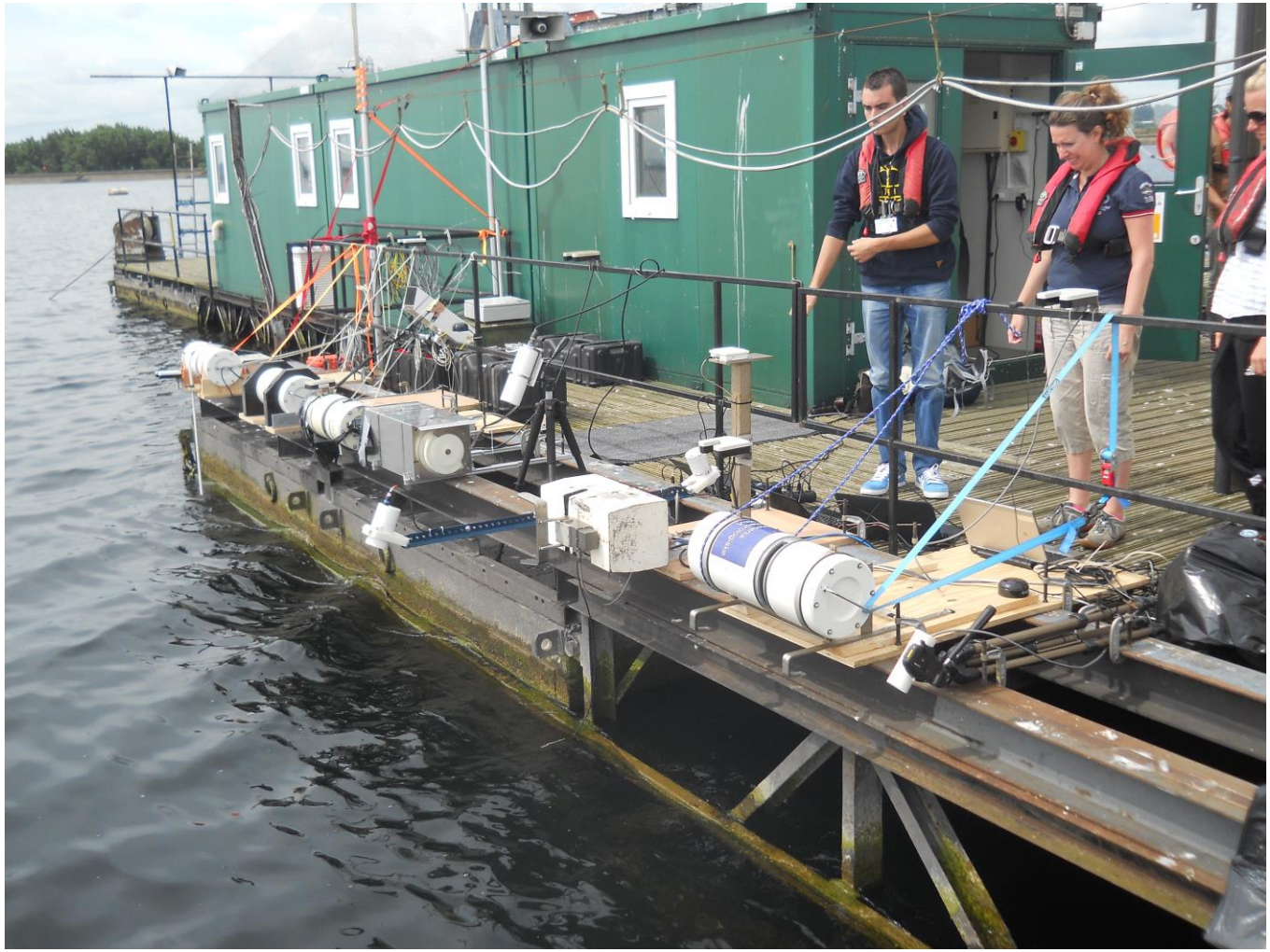
Context: CEOS plenary (2014) endorsed a project to carry out a series of comparisons of instrumentation & methods used to validate satellite IR measurements of surface (Ocean, Land) Temp to ensure international harmonisation

(an extension of previous 'Miami series')

ESA FRM4STS Inter-comparison @NPL London June 2016



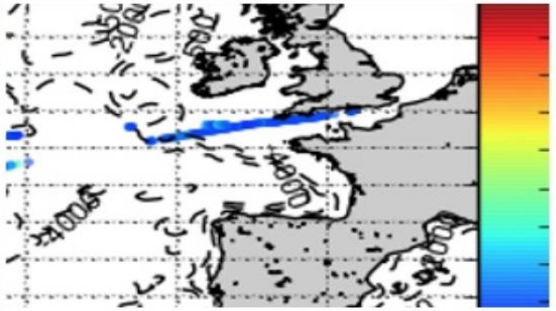
ESA FRM4STS Inter-comparison @NPL London June 2016

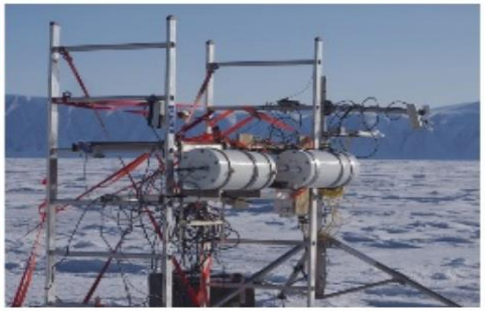


fiducial reference temperature measurements

fiducial reference temperature measurements

Home



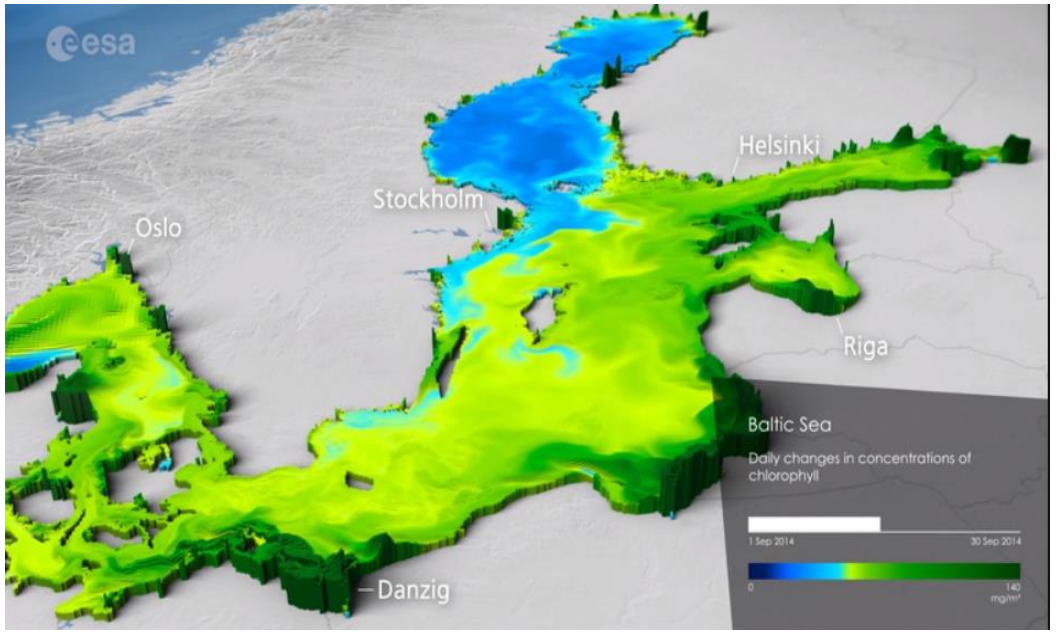


FRM4STS is an ESA funded project, to establish and maintain SI traceability of global Fiducial Reference Measurements (FRM) for satellite derived surface temperature product validation. The project will facilitate international harmonisation and interoperability through organisation of a set of inter comparisons under the Committee for Earth Observation Satellites (CEOS) and its Working Group on Calibration and Validation (WGCV).

SENTINEL-3A MISSION STATUS

The mission

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



The data

- All Level 1 and 2 products have been released to users
- Reprocessing including the commissioning phase
  - Altimetry: completed and data being made available to all users
  - Optical: planned for end-2017/early 2018
  - Preparation for the Sentinel-3B launch ongoing – see dedicated slide

SENTINEL-3 OUTLOOK

- Sentinel-3A in Routine Operations phase, mission status reports available at: https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-3/mission-status

- Sentinel-3B Satellite
  - Satellite **Final Acceptance Review** planned in **December 2017**
  - **Launch** expected **Feb/March 2018**
  - **9-month** in-orbit commissioning will include a **4-5 month** tandem flight with a 30s separation between S3A & S3B
  - **Optimised 140° phasing -** improves interleave between S3A and S3B for better SRAL meso-scale sampling of 4-7 days
  - Products will be released as soon as possible once they reach a suitable status of validation
  - **Full operational constellation** will then be **reached**

EUMETSAT esa

sentinel-3

MISSION STATUS : 7 September 2017

→ A BIGGER PICTURE FOR COPERNICUS

OVERALL MISSION

- The overall status of the spacecraft is nominal, with all subsystem performing nominally.
- All instruments, including OLCI, SRAL, SLSTR and MWR, are switched on and performing as expected.
- The Flight Operations Segment (FOS) for Routine Operations is operating nominally.
- The Payload Data Ground Segment (PDGS) for Land and Marine are operating as expected in the final stages of the mission ramp-up phase, with full operational capacity achieved on 5th July, which will be formally confirmed at the S3A Routine Operations Readiness Review on 16 October.
- The SLSTR instrument experienced a computer double bit-error on 30 July whilst passing through the South Atlantic Anomaly. As a result the instrument performed a safe, protective shutdown. The instrument decontamination started on 31 July and the instrument returned to nominal mode on 6 August. IR channel outage lasted from 14:33 on 30/7 to 11:04 on 6/8 and VIS channel outage from 15:50 on 31/7 to 08:39 on 4/8
- The orbit phasing between S3A and S3B has been confirmed to shift from 180 to 140 degree, as agreed for implementation by the EC in December 2016, implementation of this change is ongoing in the Ground Segment.
- ESA and EUMETSAT have jointly finalised the assessment and reached a technical agreement for the implementation of a Tandem phase, i.e. flying Sentinel-3B around 30 seconds apart from Sentinel-3A during the Sentinel-3B commissioning phase. The Tandem phase is planned to last 4-5 months with two drift phases of up to 6 weeks, one before and one after the Tandem period. The final implementation has been agreed with the Commission and activities have now started.

MISSION MANAGEMENT

- The Sentinel-3A mission has now reached the full operational capacity.
- The joint ESA-EUMETSAT mission management activities continue nominally.

DATA AVAILABILITY AND ACCESSS

- All Level 1 core data products have been released.
- OLCI and SLSTR Level 2 core data products over land and ocean were released to all users on 5 July 2017 (note: SRAL level 2 core data products over land and ocean have been released already at the end of 2016).
- Since June 2017 sample products for the Level 2 synergy product are available to expert users, with an official release being planned for autumn 2017
- The definition and implementation of the two new core data products, as requested by the European Commission, namely the Aerosol Optical Depth (AOD) and Fire Radiative Power (FRP) is on-going with sample products being available towards the end of 2017/early 2018 and an official release being planned shortly thereafter.
- The reprocessing of the SRAL data, including the commissioning phase, is completed and the data are now in the process of being made available to all users.
- A further SRAL reprocessing and the reprocessing of the OLCI and SLSTR data, including the commissioning phase, is planned for end of 2017/early 2018.

USER INTERACTION

- The next Sentinel-3 Quality Working Groups will take place for
  - SLSTR: winter 2017/2018 TBC
  - OLCI: autumn 2017 TBC
  - Altimetry: 14 November 2017
- The Joint ESA-EUMETSAT Routine Operations Readiness Review (RORR) is foreseen for 16 October 2017.

OUTLOOK

- Formalisation of Sentinel-3A full operations at the RORR in October 2017.

Report prepared by the ESA and EUMETSAT Sentinel-3 Operations Team

opernicus

Motivation

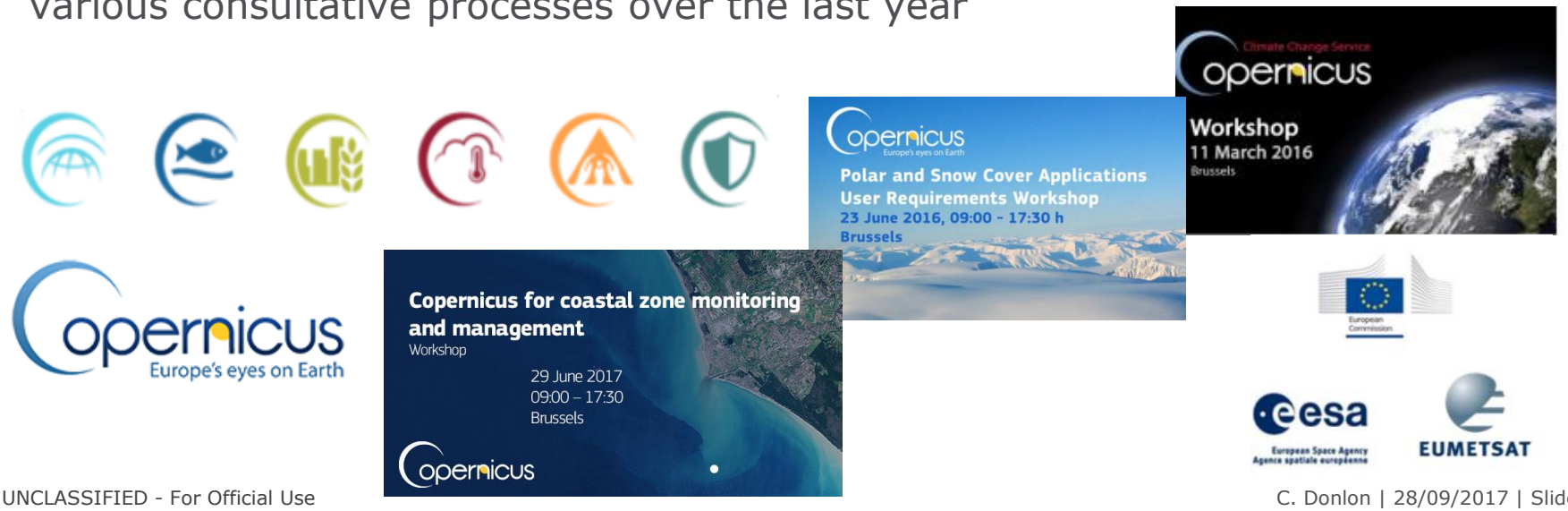
- The European Copernicus system, including the Copernicus Space Component (CSC), has been established as **the largest and most proficient EO system in the world**.
- The current Sentinels provide **~10 Tb/day** of world-class data to over **100,000 registered users** – fuelling Copernicus.
- **Service 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***?

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)

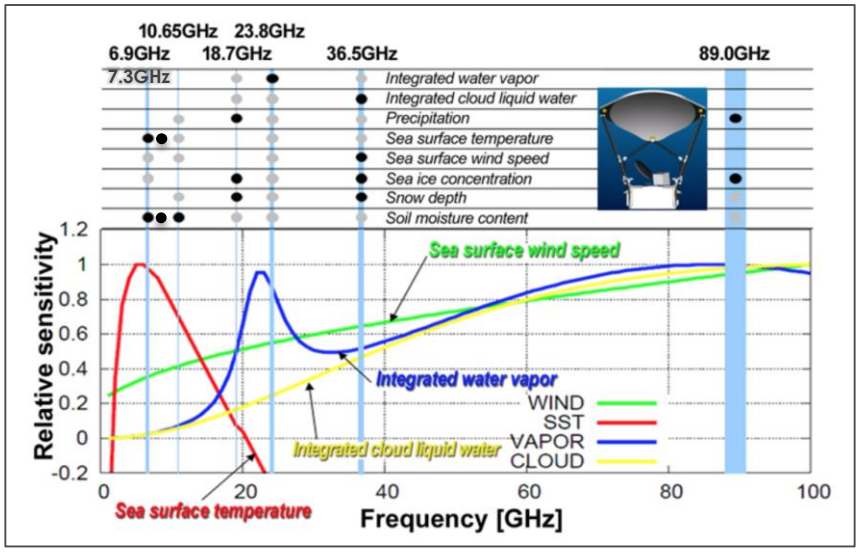
- **Potential** Copernicus High Priority Candidate Missions (HPCM) under discussion include:
    1. **Anthropogenic CO2 monitoring** Mission
    2. **High spatial-temporal resolution land surface temperature** (LST) monitoring mission (including coastal areas)
    3. **Passive microwave imaging radiometry** 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, 5, 6**

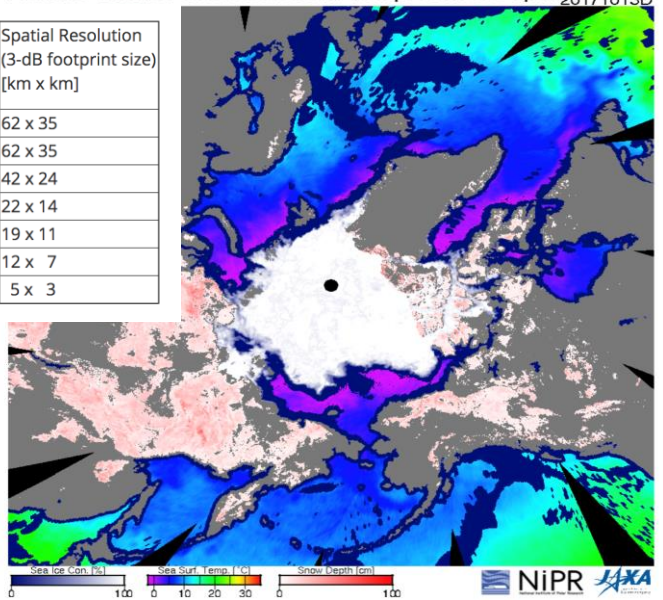
- **ESA Phase A/B1 studies for all HPCM are planned to start in early 2018**
- **The EC process of user needs and prioritisation is on-going and will continue in parallel**
- **Final selection of HPCM specific characteristics (e.g. spectral choice, number of satellites etc.) will be determined at the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

Baseline requirements identified by the Polar Expert Group (PEG)

- **Baseline continuity of AMSR/2 capability**
  - Can be a stand-alone AMSR/2-like instrument
  - Can be a complement to MetOP-SG MWI by providing missing low frequency C-band (6.9, 7.2GHz) and X-band (10.6GHz) channels
- **Primary Products in the high latitudes (>56N/S):**
  - **Sea Ice concentration** at 10km (implies <10km distance to sea ice edge) , daily (implies wide swath), 20% (10% goal)
  - **All weather SST** (implies 6.9-7.2GHz) at 10 km (implies 10km distance to coastline i.e.. low antenna sidelobes), daily 0.3K accuracy (implies wind, salinity, CLW etc.),
- **Other priority products:**
  - Ice Surface Temperature
  - Ice thickness Implies 1.2 GHz)
  - Ice Type
  - Snow depth and density on sea ice



Band [GHz]	Polarization	Spatial Resolution (3-dB footprint size) [km x km]
6.93	V,H	62 x 35
7.3	V,H	62 x 35
10.65	V,H	42 x 24
18.7	V,H	22 x 14
23.8	V,H	19 x 11
36.5	V,H	12 x 7
89.0	V,H	5 x 3



https://ads.nipr.ac.jp/vishop/#/monitor

Conclusions

FRM Matter to Copernicus

FRM mean that you make excellent measurements → Great for science!

FRM are striving to get as close to the "truth" as we can manage for a given variable

FRM allow us to reduce uncertainties

However..

- FRM are extremely challenging
- Require international consensus
- Involve by definition, National Metrology Institutes

FRM are certainly the future.

New missions coming (Sentinel-3B and HPCM studies)

FRM4STS is now leading the future for TIR FRM.


Thank You –
any Questions
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