Opportunities & Challenges for leveraging the European Sentinel(-3) Missions in support of NOAA User Needs

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STAR JPSS Annual Science Team Meeting

15 May 2014
College Park, Maryland USA

NOAA Satellites and Information
National Environmental Satellite, Data, and Information Service

Opportunities & Challenges for Leveraging Non-NOAA Satellite Data

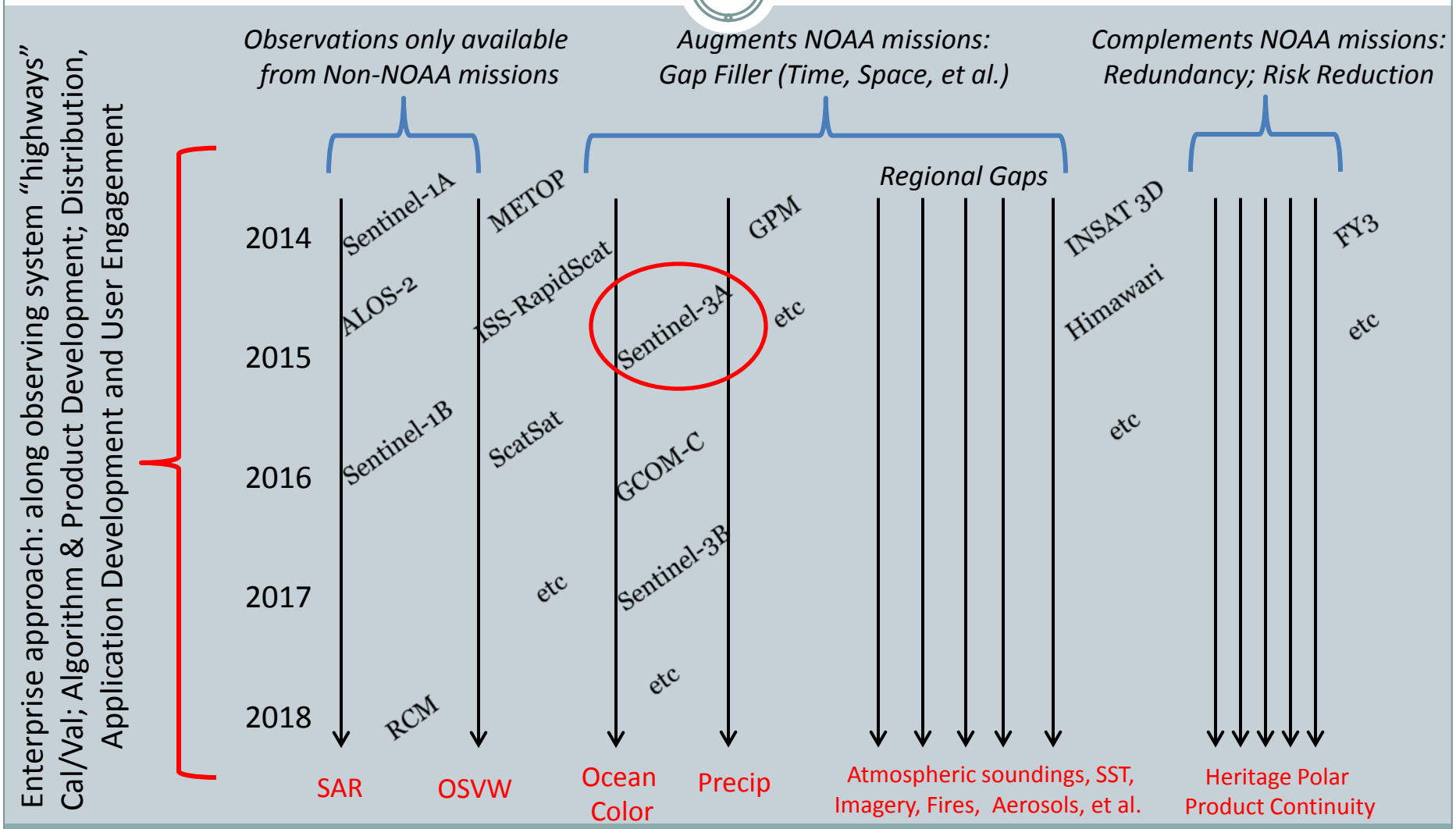
- Many key satellite data streams needed by users (e.g., ocean winds, SAR, sea-surface salinity) are only available from non-NOAA external sources, both foreign and domestic.

- Likewise, user needs for greater spatial and temporal coverage in other data sets (e.g., ocean color, SST) also require the use of non-NOAA satellite data sets to augment existing/planned NOAA assets.

- That said, there is not presently a clear path or institutional framework within NOAA for the systematic acquisition of many external satellite data sets (and their operational generation) in support of user needs; existing efforts are largely bottom-up, ad hoc and best effort endeavors.

- Other challenges include the need to redefine the "operational" paradigm – has to be more than just the near-real time provision of data. Reprocessing, blended products et al. are required to support user needs (as nicely illustrated in following presentation by M. Eakin).

Observing System Highways :
"Plug & Play" data from multiple non-NOAA missions, leveraging existing science et al. infrastructure in NOAA/NESDIS



Copernicus dedicated missions: the Sentinels

- Flagship of the European Space Policy
- Led by the European Union
- Europe's contribution to GEOSS
- European capacity for global, timely and easily accessible information about climate, environment & security


S1A/B: Radar Mission

S1-A Launched
3 April 2014


S2A/B: High Resolution Optical Mission


S3A/B: Medium Resolution Imaging and Altimetry Mission

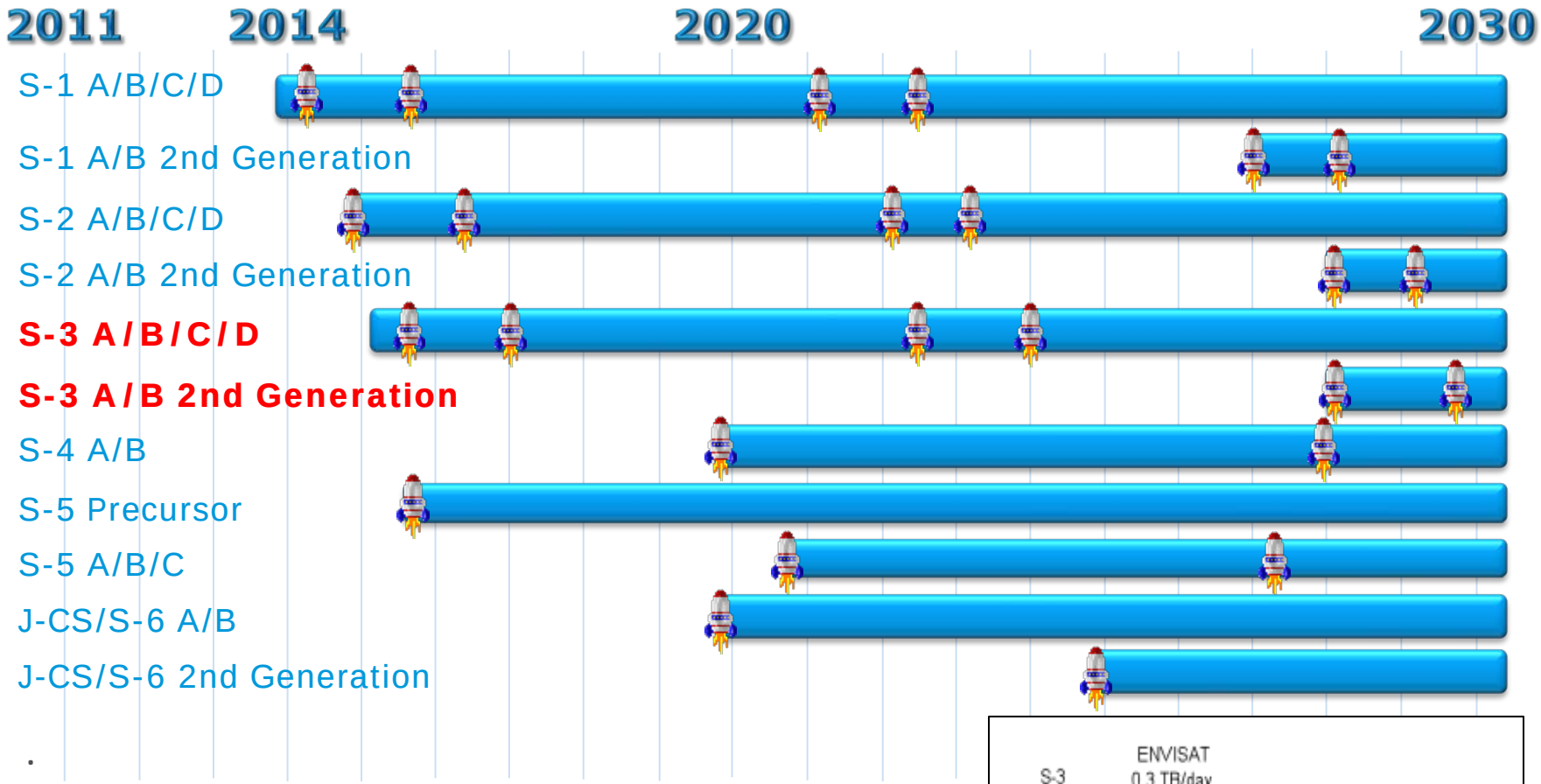

S4A/B: Geostationary Atmospheric Chemistry Mission

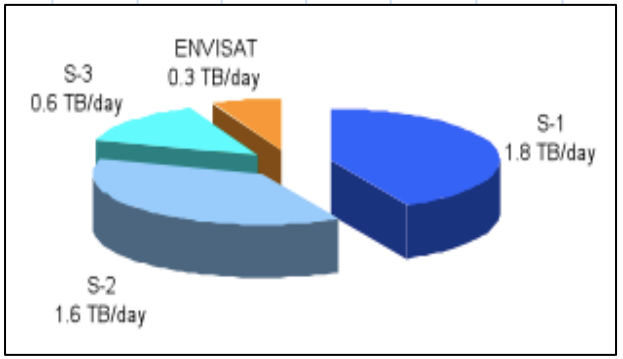

S5P: Low Earth Orbit Atmospheric Chemistry Precursor Mission


S5A/B/C: Low Earth Orbit Atmospheric Chemistry Mission


Jason-CS/Sentinel-6 A/B: Altimetry Mission

Europe's long-term operational programme





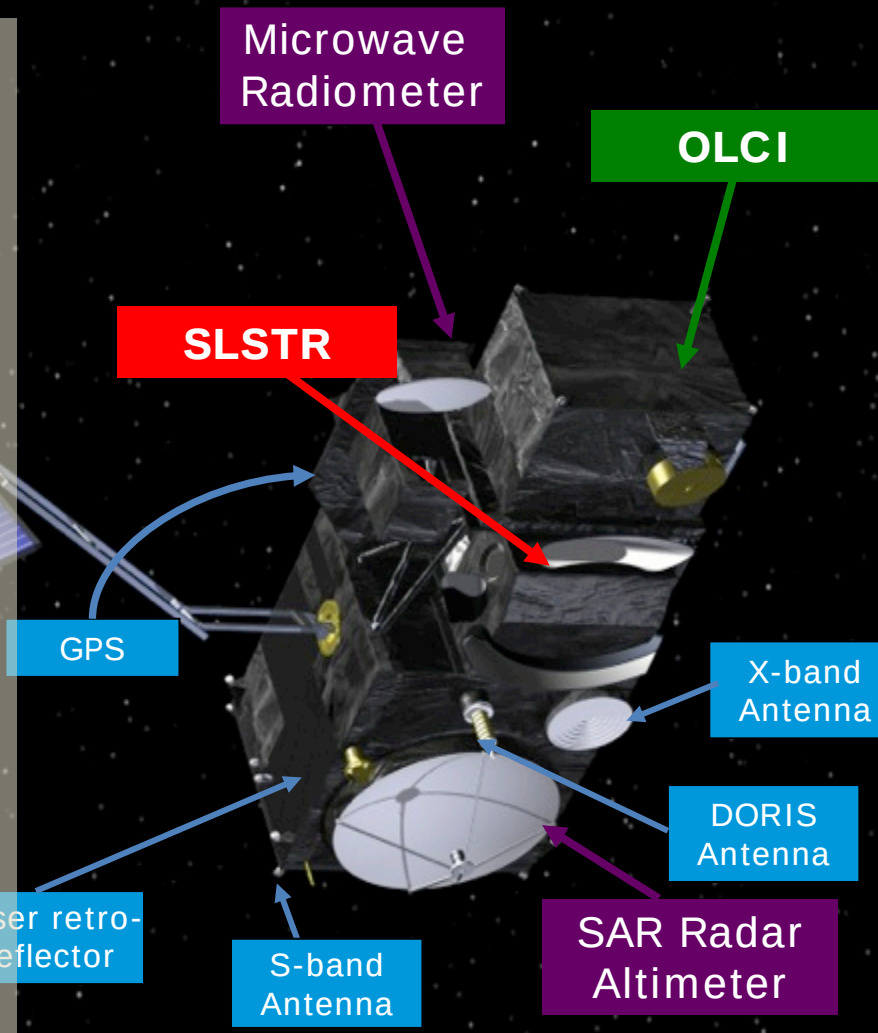
The Sentinel-1,-2,-3 A-series production is equivalent to ~25 ENVISAT missions

SENTINEL-3 Satellite

Operational mission in high-inclination, low earth orbit

- **Ocean and Land Colour Instrument (OLCI):**
  - 5 cameras, spectral range from 400 to 1020 nm
  - 15 (MERIS) & 6 additional bands; Swath: 1270 km
  - Camera tilt in west direction (12.20°)
  - Full res. 300m acquired systematically (land/ocean)
  - Reduced res. 1200m binned on ground (L1b)
  - Ocean coverage < 4 days, (< 2 days, 2 satellites)
  - 100% overlap with SLSTR
- **Sea & Land Surface Temperature Radiometer (SLSTR):**
  7 AATSR & 2 additional bands, plus 2 additional Fire channels, with 500 m (solar) and 1 km (TIR) ground res. Swath: 1420 km/750 km (single or dual view)
- **Topography package:**
  SRAL Ku-C altimeter (LRM & SAR measurement modes), MWR, POD (with Laser Retro Reflector, GPS and DORIS)

Full performance will be achieved with 2 satellites in orbit



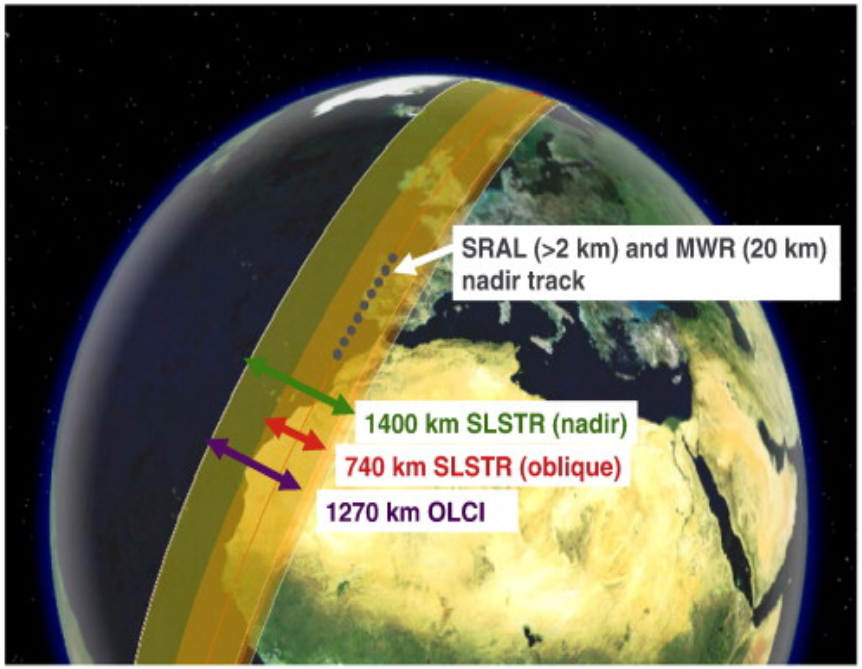
Sentinel-3 Orbit

Orbit characteristics

repeat cycle	27 days	
Equator crossing time	10:00 descending	
orbit	altitude 815 km	inclination 98.65^0
lifetime	7.5 years	

OLCI data distribution timeliness	NRT 3 hours	NTC 1 month

OLCI	coverage at Equator	coverage at lat > 30^0	requirement
1 satellite	< 3.8 days	< 2.8 days	< 2 days
2 satellites	< 1.9 days	< 1.4 days	< 2 days



OLCI	GB/day	TB/year
Level-0	134.98	48.11
Level-1	422.07	150.45
Level-2 marine	506.20	180.43

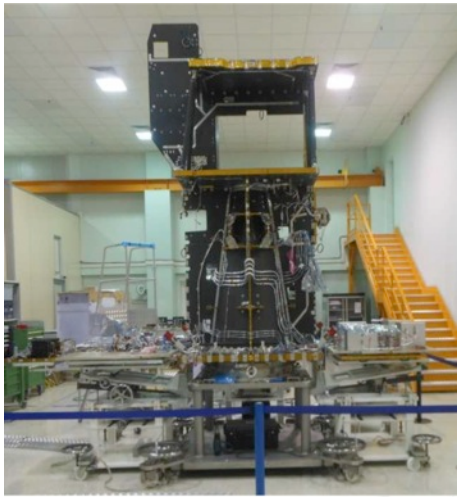
Sentinel-3 Satellite Status

- **Quite advanced development status for both S-3A & S-3B satellites**
  - S-3A Platform AIT completed;
  - Instrument integration and testing at satellite level started
  - Topography Payload (GPS, LRR, DORIS, SRAL and MWR) mechanically and electrically integrated in the S-3A Platform
  - S-3B Platform integration at TAS-I, Rome, almost completed, delivery to Prime for Satellite AIT planned in Q1 2014
- **S-3A readiness for launch driven by SLSTR**
  - issues with Flip Mirror, Cryocooler, Blackbodies
- **S-3A FAR expected in April 2015**
- **S-3A Launch date: end of June 2015**

consistent with the launch period agreed with Eurockot

- **S-3B FAR 1 year later**

S3A Satellite at TAS-F, Cannes with Topo P/L installed



S3B Platform electrical integration at TAS-I, Rome

OLCI Core User Products

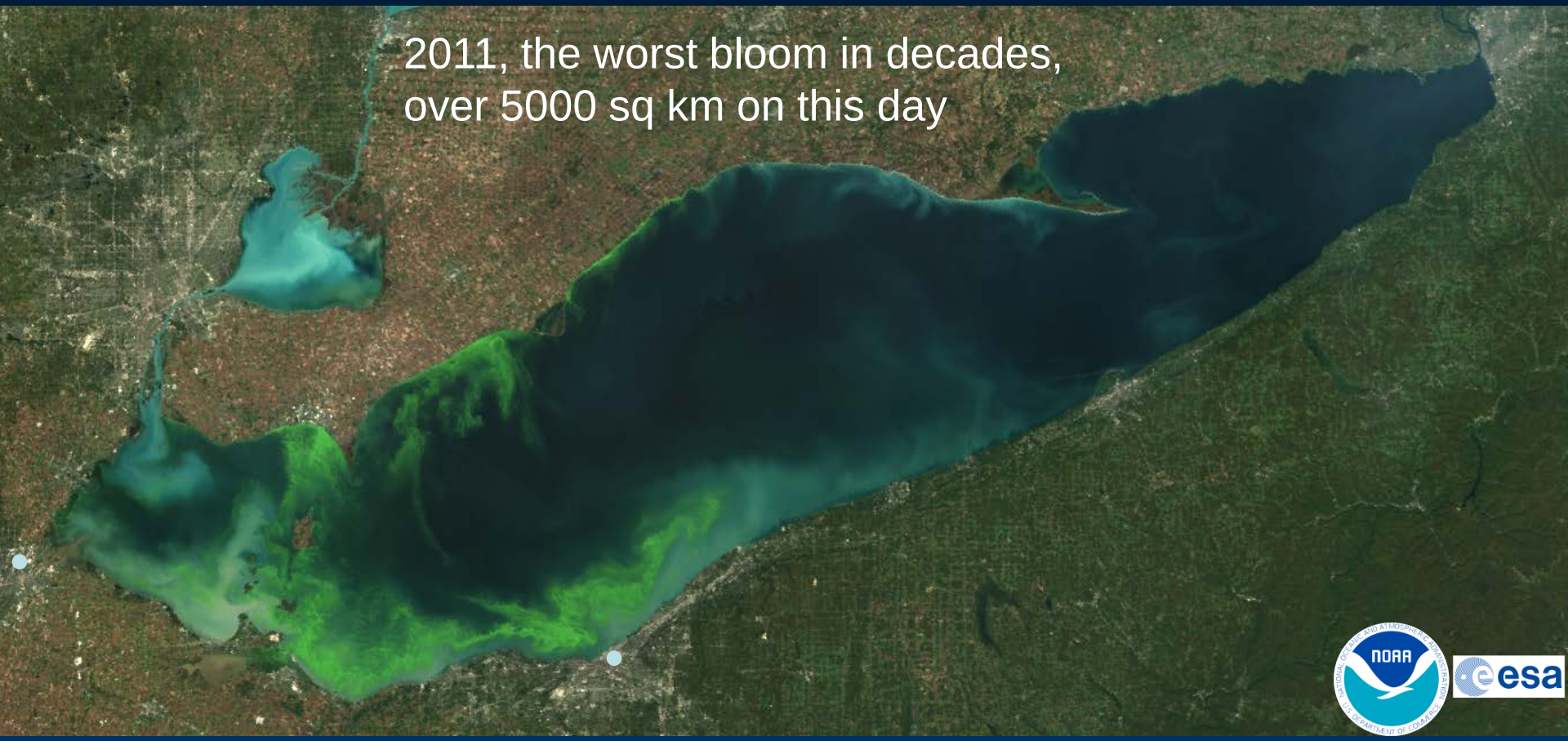
	Product Type	Resol.	GB / orbit	Comparison with MERIS
Level 1	Ortho-geolocated TOA Radiance at 21 bands	FR	27.9	MERIS FR+RR 10 GB/orbit
		RR	1.7	
Level 2 **Water**	Water Leaving Reflectance (16 bands) Chlorophyll (OC4Me & NN) TSM_NN KD490 (Morel et al.) CDM Absorption PAR AOT at 865 nm & Angstrom Integrated Water Vapour	FR	25.8	
		RR	1.6	
Level 2 **Land**	FAPAR Terrestrial Chlorophyll Index Integrated Water Vapour	FR	7.32	
		RR	0.50	

- Similar product suite as for MERIS
- Product portfolio corresponds to Copernicus service projects needs of well identified operational communities
- Systematic processing of all OLCI data in 300m/1200 m
- Data format: netCDF with CF compliant metadata
- Algorithm development follows very closely the MERIS concept
- Uncertainty per pixels

Conclusion

- Sentinel-3 is an operational mission
- will secure the continuity of ocean and land colour observations for the next decade
- OLCI design is inherited from that of MERIS, with many improvements
- Similar or improved performance than MERIS
- Free, full and open data access
- Missions Performance Framework being established
- Launch end of June 2015 on Rockot from Plesetsk
- OLCI Prototype Processors delivered & first PDGS successfully accepted
- User support tools under development

2011 Lake Erie cyanobacteria bloom



09 October : Data from MERIS
(European Space Agency

Weekly Lake Erie Bulletin,MERIS 2009-2011

Experimental
Lake Erie Harmful Algal Bloom Bulletin
2011-008
08 September 2011
National Ocean Service
Great Lakes Environmental Research Laboratory
Last bulletin: 22 July 2011

Bloom from MERIS

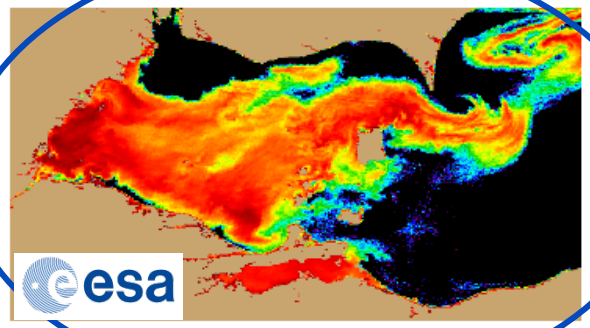


Figure 1. MERIS image from the European Space Agency. Imagery shows the spectral shape at 681 nm from September 03, where colored pixels indicate the likelihood of the last known position of the *Microcystis* spp. bloom (with red being the highest concentration). *Microcystis* spp. abundance data from shown as white squares (very high), circles (high), diamonds (medium), triangles (low) , + (very low) and X (not present).

Forecast (with Great Lakes CFS)

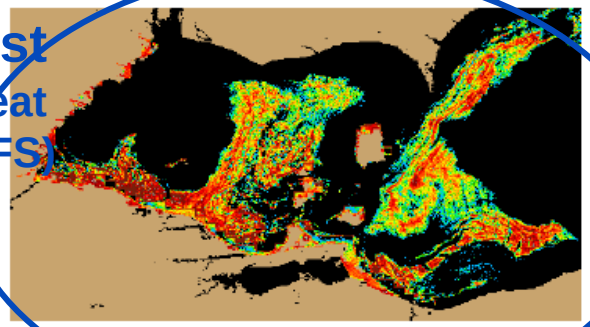


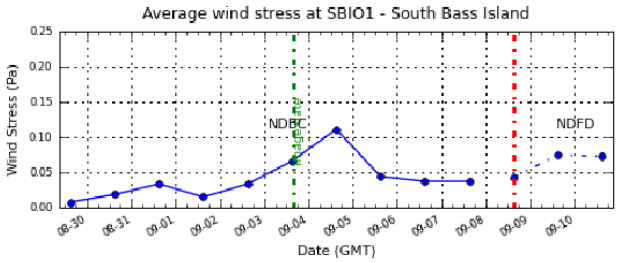
Figure 2. Nowcast position of *Microcystis* spp. bloom for September 08 using GLCFS modeled currents t move the bloom from the September 03 image.

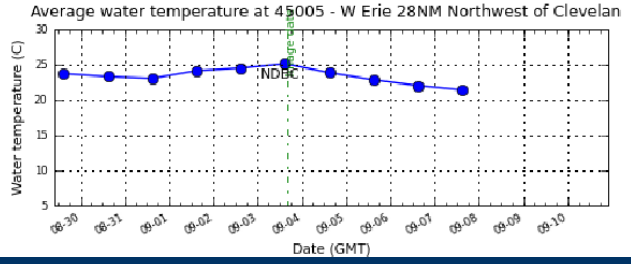
Conditions: A massive *Microcystis* bloom persists throughout most of Lake Erie's Western Basin.

Analysis: As indicated in satellite imagery from Saturday (9/3/2011), an enormous *Microcystis* bloom was present in western Lake Erie. The southern extent of the bloom was remotely observed along the coast of Ohio from Maumee Bay to Catawba Island. The northern extent of the bloom was observed to be consistent along the Michigan coast from Northern Maumee Bay to the mouth of the Detroit River. The eastern-most portion of the bloom was observed past Point Pelee and to the northeast up in to Rondeau Provincial Park.

At the mouth of the Detroit River, a five day nowcast shows a southward suppression of the western-most portions of the bloom. However, the bloom is likely to still persist in much of the Western Basin. The nowcast also suggest the bloom has spread to the east of Sandusky and into the Cleveland area. **(Note: Due to a lack of clear imagery the bloom has not been remotely observed in the Cleveland area.)** A three day forecast also suggests that the bloom will persist to the north of Cleveland through the weekend. Water temperatures remain above 20 degrees Celsius and are forecast to decrease into the weekend; however, conditions remain favorable for bloom growth.

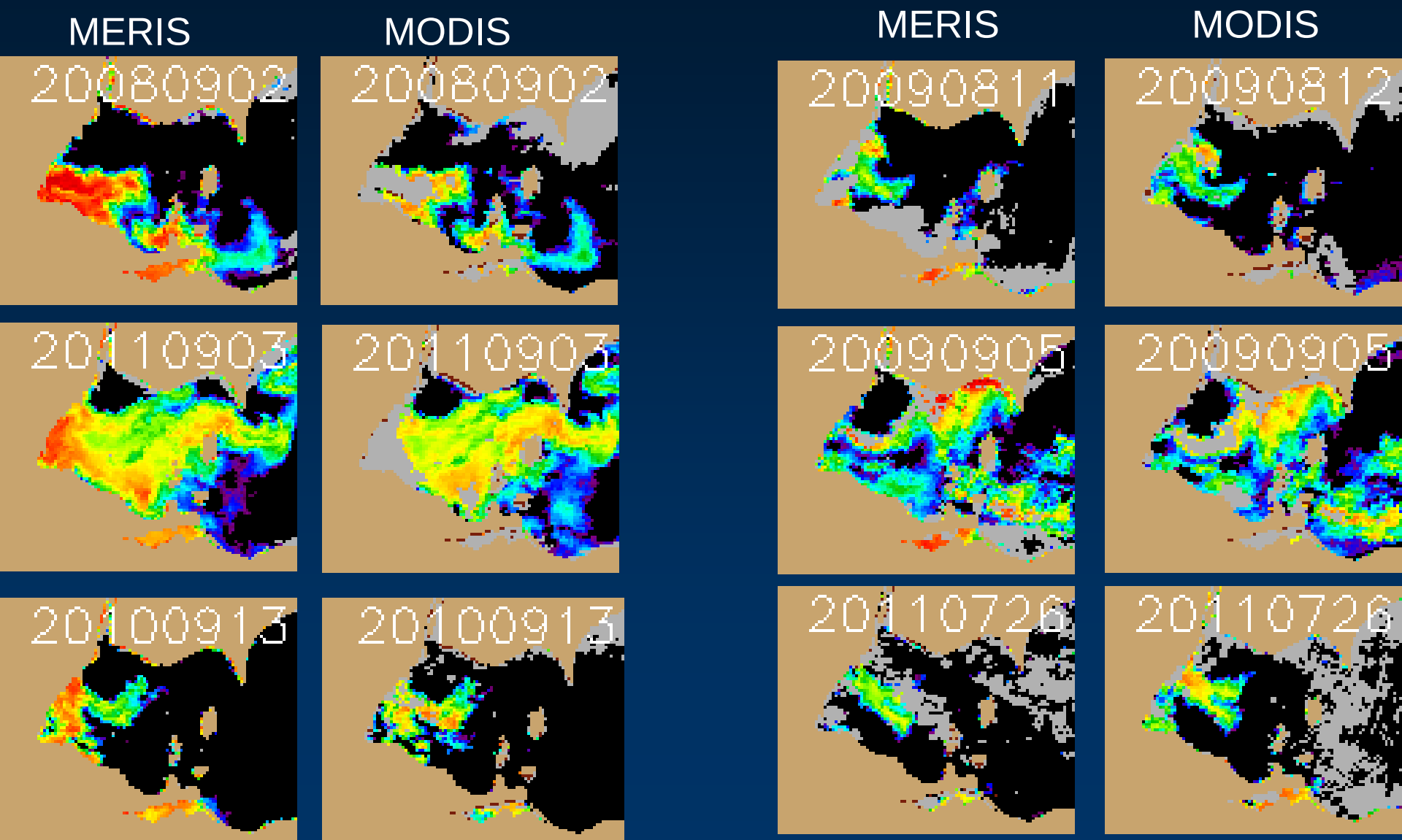
Briggs, Wynne





Loss of MERIS: MODIS comparable but less sensitive)

(Wynne, Stumpf & Briggs., 2013 Intl J. Remote Sensing)



Weekly Bulletin Switch to MODIS for 2012-2013

2012 (and 2013) Bulletins: MERIS data stopped, shifted to MODIS.

Impact: Loss of resolution, MODIS is noisier and less sensitive. But MODIS algorithm is equivalent to MERIS.

Transports with the NOAA Great Lakes Coastal Forecast System

Experimental Lake Erie Harmful Algal Bloom Bulletin

National Centers for Coastal Ocean Science and Great Lakes Environmental Research Laboratory

23 August 2013; Bulletin 15

Microcystin concentrations in some areas of the bloom near Maumee Bay may reach 56 ug/L. Dense cyanobacteria is present along some of the western shore. There may be small patches of scum from the Bass Islands west to Maumee Bay.

Slight eastward transport is forecasted for the next few days. Winds today >15 knots could possibly cause mixing of the bloom. Low winds (<8 knots) are expected over the weekend which could cause the bloom to intensify at the surface and produce patchy areas of scum.

- Dupuy, Stumpf, Tomlinson

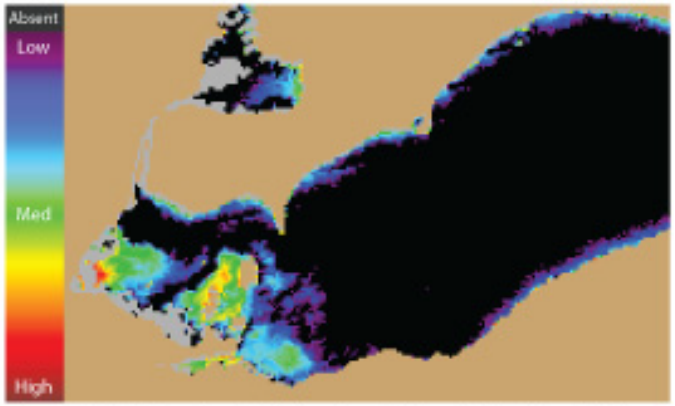


Figure 1. MODIS Cyanobacterial Index from 20 August 2013. Grey indicates clouds or missing data. Black represents no cyanobacteria detected. Colored pixels indicate the presence of cyanobacteria. Cooler colors (blue and purple) indicate low concentrations and warmer colors (red, orange, and yellow) indicate high concentrations. The estimated threshold for cyanobacteria detection is 35,000

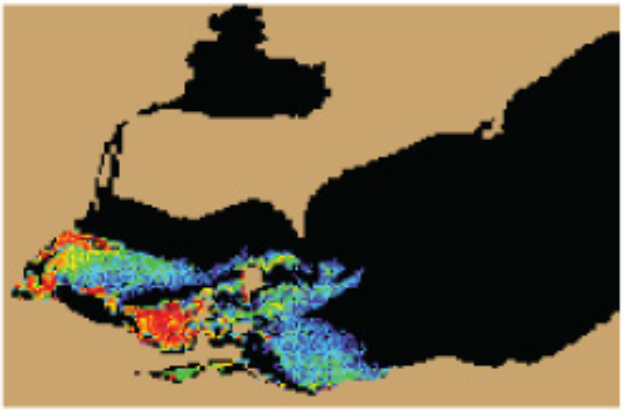


Figure 2. Nowcast position of bloom for 23 August 2013 using GLCFS modeled currents to move the bloom from the 20 August 2013 image.

Over 700 subscribers to bulletin

Copernicus: ESA Earth Observation Program
Sentinel Missions are the lead for the Space Segment

Sentinel-1A/B
(3 Apr 2014, 2016)

C-band synthetic aperture radar (SAR)

Applications:
- Sea Ice/Cryosphere
- Marine winds and waves
- Oil spills
- Ship detection
- Coastal monitoring, etc.

Sentinel-2A/B
(2015, 2017)

Optical imagery -13 bands for land observation (MSI)

Applications:
- Land management
- Biomass
- Water management
- Urban Mapping

Sentinel-3A/B
(2015, 2017)

Sea and Land Surface Temperature Radiometer (SLSTR), Ocean and Land Color Instrument (OLCI), Synthetic aperture radar altimeter (SRAL)

Applications:
- Ocean color and land reflectance
- Sea, land, and ice surface temperature
- Fire monitoring
- Sea surface topography, winds, significant wave height

Sentinel: Experimental Readiness at NOAA

Focus Areas: Sentinel-3 data

- Why is Sentinel-3 data needed?
  - Extensive user needs/requirements, including as documented as part of the NOAA Sentinel Interest Workshop, held August 2011 in Silver Spring, MD
  - Also, "2+1" operational framework: Requirement for ocean color and other data sets to maintain at least two operational sources, with one (experimental) back-up ready to be promoted to operations upon loss of existing data stream
- In this context, Sentinel-3 a/b will provide another source of operational satellite data, *complementing* as well as *augmenting* what VIIRS provides, especially given it has:
  - Global 300 m resolution
  - Mid-morning acquisition
  - Additional spectral bands
- NOAA will in turn contribute to the partnership in numerous ways, including:
  - Provision of VIIRS data to address existing operational gaps following the loss of the Envisat platform in 2012
  - Serving as members of the Sentinel-3 Validation Team (S3VT), with several approved projects (PIs: DiGiacomo; Leuliette); will also provide critical cal/val data sets, e.g., MOBY data to support OLCI vicarious calibration

Sentinel: Experimental Readiness at NOAA
Focus Areas

- Access
- Communications
- Landing Zone
- Dissemination / Distribution
- Algorithm and Data Product Development, Assessment and Science Maintenance, including:
  - Native EUMETSAT core user/mission products
  - NOAA heritage/unique generated products
- Cal/Val
- Applications Development & Collaboration

Sentinel: Experimental Readiness at NOAA

May 2014 Status

- Frank Monaldo: New lead of STAR Data Management Group (DMWG); DMWG facilitating the Sentinel readiness activities.
- Sentinel-1a: Successful launch April 2014. Data flow not yet established – but sample data sets received and processed...
- Telecommunications (EUMETSAT) : Boulder test to occur (June?) to test connectivity between Europe and U.S. via Internet-2; but ultimately link will be via Silver Spring, then…
- Local telecommunications (10Gbit connection; Silver Spring <-> NCWCP): Appear to be installed and ready; not yet tested.
- Landing zone: Storage and server installed and ready.
- Test data sets: Coordination by Phil Keegstra (CoastWatch).
- To do items: Landing zone tests, processing and distribution strategy/tests, requirements summary (all agencies), scope and complete user request(s), level 0 access (e.g., ocean color) still TBD .

Sentinel: Experimental Readiness at NOAA

Overall Project Summary (May 2014)

- Potentially all Sentinel platforms. But S-1 and S-3 emphasis at present.
- S-3 ocean color: Important aspect of the (NOAA) Ocean Color Radiometry Virtual Constellation. JPSS and GCOM-C other elements.
- NOAA STAR Data Management Group. Foci for collaboration.
- Biweekly telecons between US agencies and EUMETSAT & ESA.
- NOAA best effort: Experimental/Pre-operational access, availability and utilization of Sentinel data and products with cal/val support; operational capacity and plans still to be determined.
- Collaborative and opportunistic. Largely bottom up, best effort basis.
- Free and open availability of data / products.
- Expect at least MERIS heritage products for ocean color; but also can /will generate NOAA heritage and unique products via the NOAA MSL12 system.

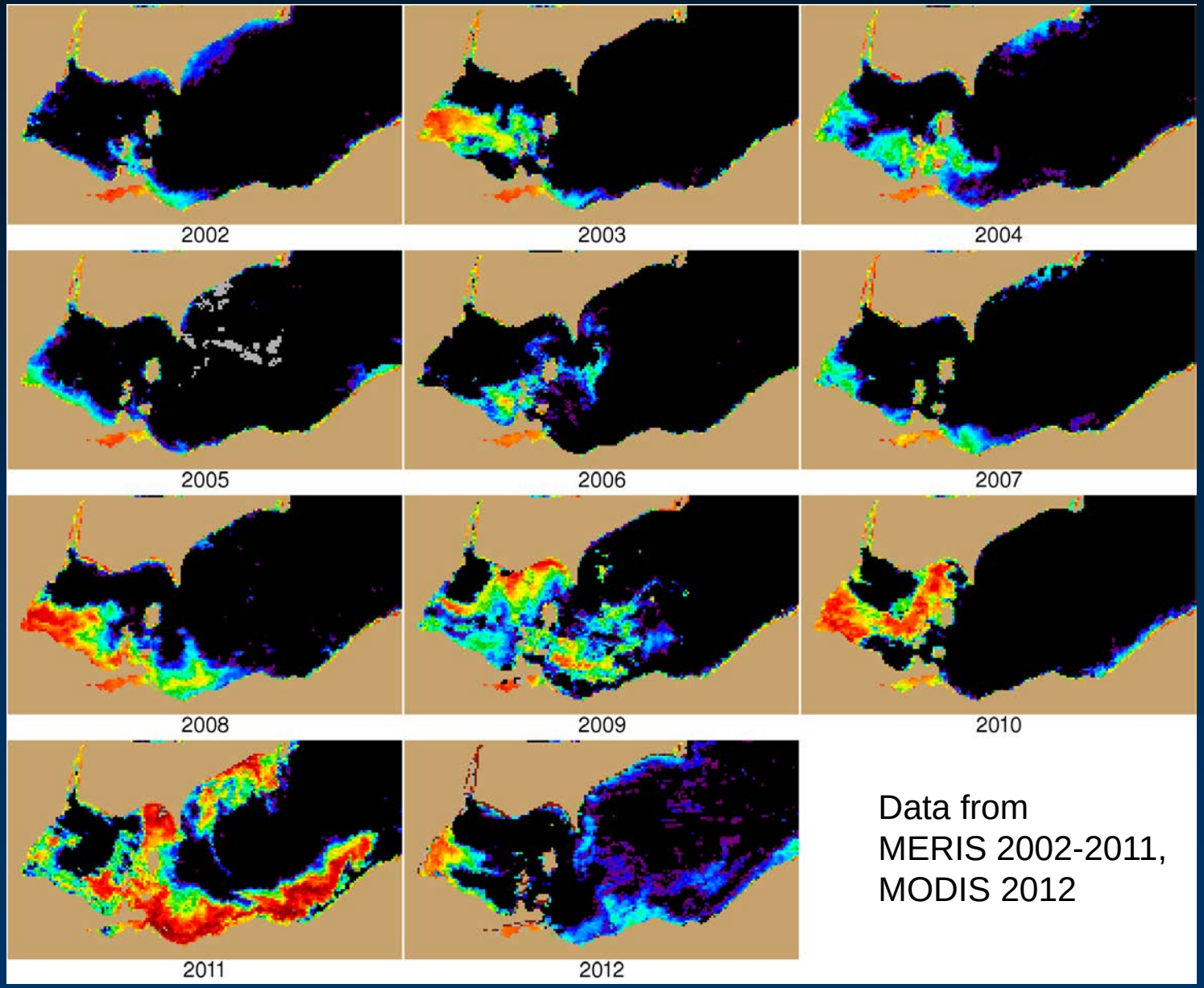
So, the question is…….

So, the question is…….

- How do we (NOAA) proceed with the acquisition, development and (operational) distribution et al. of non-NOAA data (foreign & domestic) in the JPSS (polar)/GOES-R (geo) era in support of user needs?

Backup slides

11 years of satellite data provide bloom extent

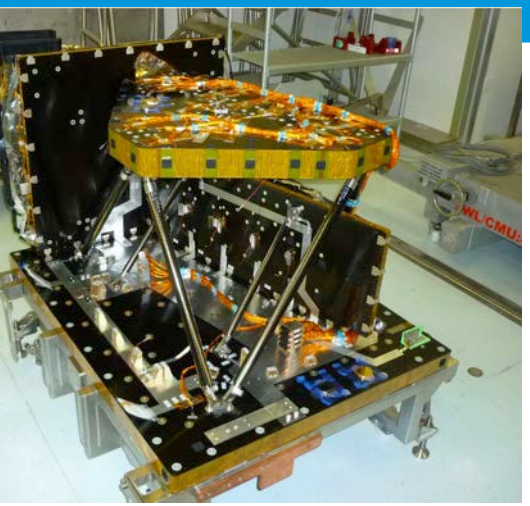


S-3 Payload Data Ground Segment

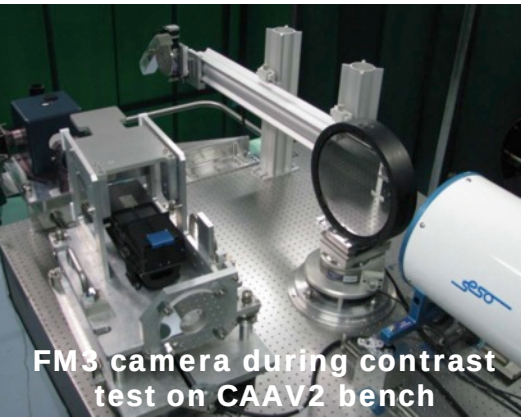
- **Flight Operations Segment** (Satellite commanding & control)
  - ESA (ESOC) to operate until end of commissioning phase
  - EUMETSAT to operate in routine operations phase
- **X-band Core Ground Station at Svalbard (Norway)**
- **Marine Centre at EUMETSAT:** L0 ,L1 ,L2 marine products
- **Land Processing and Archiving Centres (PAC):**

  DLR (OLCI L2 land), **CLS** (SRAL L2 land), **ACRI** (SLSTR & S-3 SYN)
- **Topographic & Optical Prototype Processors delivered**
- **First payload data GS version successfully accepted**
- **Missions Performance Framework:**
  - Cal/val, quality control, end-to-end system performance
  - Includes MPC (ITT issued), QWG, Expert Support Labs
  - S3 Val Team formed as output of a ESA/EUMETSAT AO for collaborative Validation Proposals ➔ 37 Ocean proposals accepted
  - 1st S3VT meeting in Nov 2013, ESRIN ➔ Consolidate S3VT activities ➔ Draft S3VT Implementation Plan

S-3A OLCI development status



OLCI structure: Camera bench (top), baseplate (bottom) and VAM bench (vertical)

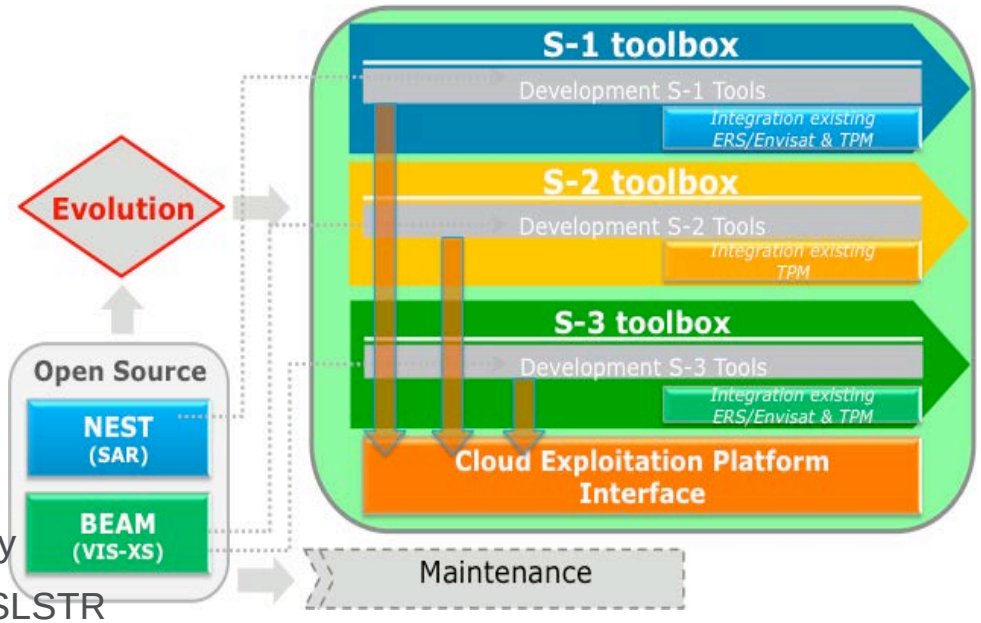


FM3 camera during contrast test on CAAV2 bench

- **Pushbroom Imaging Spectrometer (VIS-NIR) – similar to MERIS, but with improvements:**
  - more spectral bands (from 15 to 21): 400-1020 nm
  - broader swath: 1270 km
  - camera tilt in west direction (12.20°)
  - absolute accuracy 2% (relative 0.5%)
  - polarisation sensitivity < 1%
- **Assembly, Integration & Testing (AIT) for the five cameras completed**
- **Integration of 5 cameras at instrument level on-going**
- **Camera test results reveal overall good level of compliance to the performance requirements ➔ similar / better performances than MERIS:**
  - better spectral dispersion
  - better straylight characterization
  - better inter-channel spatial co-registration

Sentinel Toolbox Development

- **BEAM 4.11 (current version)**
- **BEAM 5 release end of March 2014**
  - CoastColour Processor
  - IdePix Processor
  - Optical Water Types Processor
  - LST Processor
  - Python API
- **BEAM maintenance ensured until 1st S3 Toolbox release**
  - Based on BEAM architecture & functionality
  - Dedicated tools and processors for OLCI, SLSTR
  - Direct access to in-situ databases via Data Web Services (e.g. MERMAID, GHRSST)
  - Extension to Cloud Exploitation Platforms for large-scale data processing
  - Interoperability of S-1, S-2 and S-3 Toolboxes
  - Support of VIIRS L1, OCM L1 products by compatible SeaDAS modules
- **TBX development coordination through Developer Forum**
- **First S3TBX release in Sep. 2014**



Data access per user type

Systematic acquisition, processing and distribution of all Sentinel data in the Copernicus Core Payload Data Ground Segment

Copernicus Services Infrastructure

Catalogues & dedicated servers
EUMETCAST system for S3 Marine

Scientific & Other Use Infrastructure

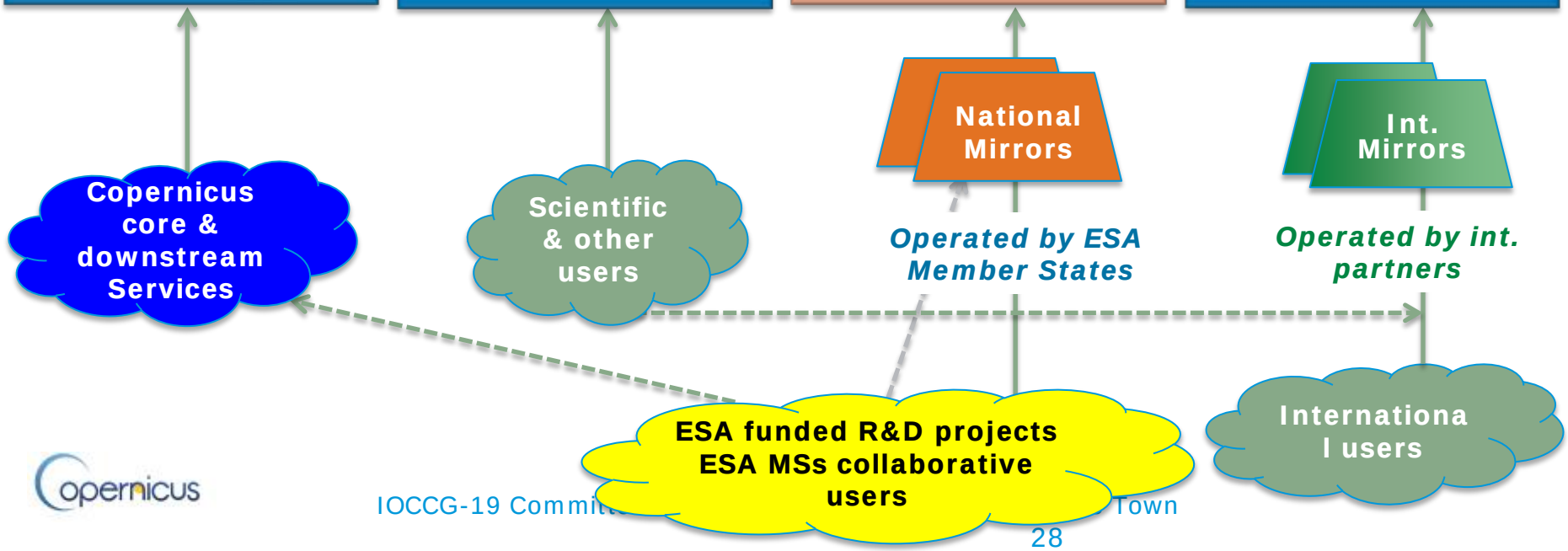
Rolling archive supporting product discovery and http downloads, EUMETCAST services for S3 Marine

ESA Collaborative Infrastructure

Rolling archive supporting dedicated product discovery and ftp & http downloads

EU International Agreements

Rolling archive supporting dedicated product discovery and ftp & http downloads, EUMETCAST services for S3 Marine



More information