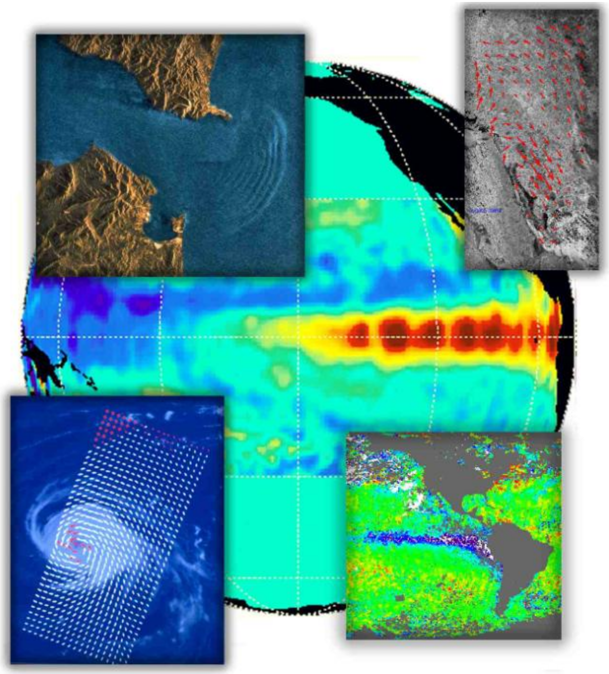
Status and Outlook for the Space Component of an Integrated Ocean Observing System



Mark R. Drinkwater - ESA

with contributions from:

H. Bonekamp, B. Chapron, C. Donlon, J.-L. Fellous, P. DiGiacomo, E. Lindstrom, S. Wilson

Prologue

OceanObs'09

- Many times we have heard the words "*We are in the "Golden Age of satellite oceanography*".

✓ Since 1999 ~30 new Ocean-related satellite missions launched by 13 contributing Agencies, representing 36 countries

✓ Provision of >25 millions QC'd measurements/day for assimilation

launched Wed 23rd

✓ Launch of 2 new dedicated ocean satellites ~~imminent~~ - Oceansat-2 (ISRO), SMOS (ESA)

✓ ~13 other new R&D and Operational missions approved and currently under development

☞ Satellite oceanography has become a truly international endeavour

Outline

- Evolution over the last decade
- State of the Space Infrastructure today
- Future Challenges – for the next decade

Evolution over the last Decade - since OceanObs99

Requirements Approach

- Requirements consolidated and aligned considering:
  - Numerical Weather Prediction
  - Safety at Sea & Met-Ocean Forecasting
  - Operational Ocean Forecasting
  - Climate Research
  - Societal Benefit Areas
  - Marine/Environmental Policies
- GODAE provided fundamental impetus for effective use of satellite data into ocean forecasting systems
  - Drives timeliness, latency and product access requirements
  - Drives product quality and validated bounds of uncertainty
- GCOS Implementation Plan provides a roadmap and structured approach to sustained monitoring

Evolution in Ocean Observing System Advocacy

During the last decade:

- Consolidation of political advocacy amongst:
  - IOC (UNESCO); WMO; UNEP; ICSU
  - CEOS & CGMS
- Helped in addressing priority variables in IGOS-P Ocean Theme Team (2000):
  - OST, OVW, Sea State, SST, OC, SSS
- Primary knowledge challenges being addressed:
  - Sea-ice thickness (IceSat/CryoSat)
  - Salinity (SMOS/Aquarius);
  - Geoid (GRACE/GOCE)
- Transition of Ocean Theme from IGOS-Partnership into GEOSS Framework coordinated via GEO
  - Promise of broader reach of advocacy & broader benefits

Lessons Learned

OceanObs'09

During the last decade:

Significant advance and refinement in use of global timeseries of EO data beyond single-satellite, single-sensor analyses

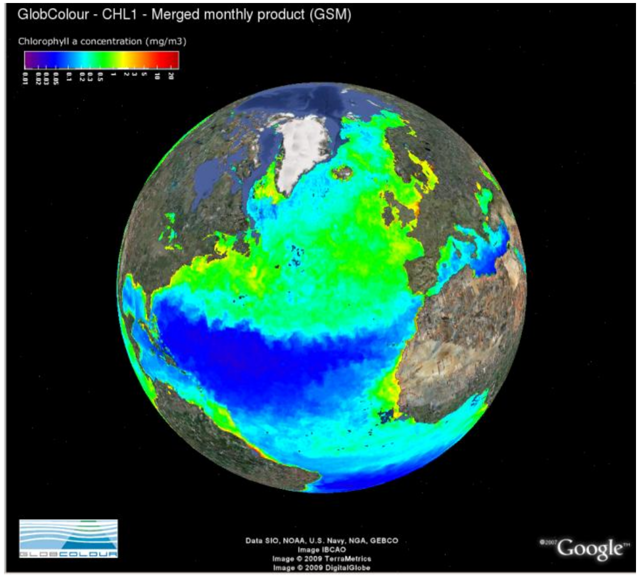
- Parameter focus: combining similar parameter data from multiple sensor sources and platforms
  - e.g. SST – Microwave, IR satellite sat. sensors + surf. drifters
- Specific issues focus: combination of complementary products from multiple sensor sources and platforms
  - e.g. Sea-level rise – Sat. Altimetry, Argo, Sat. Gravimetry

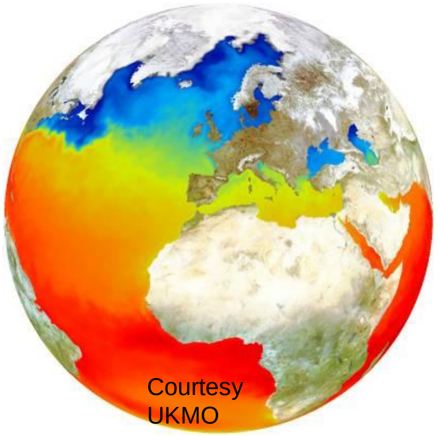
State of the Space Infrastructure Today

Multi-Sensor Datasets

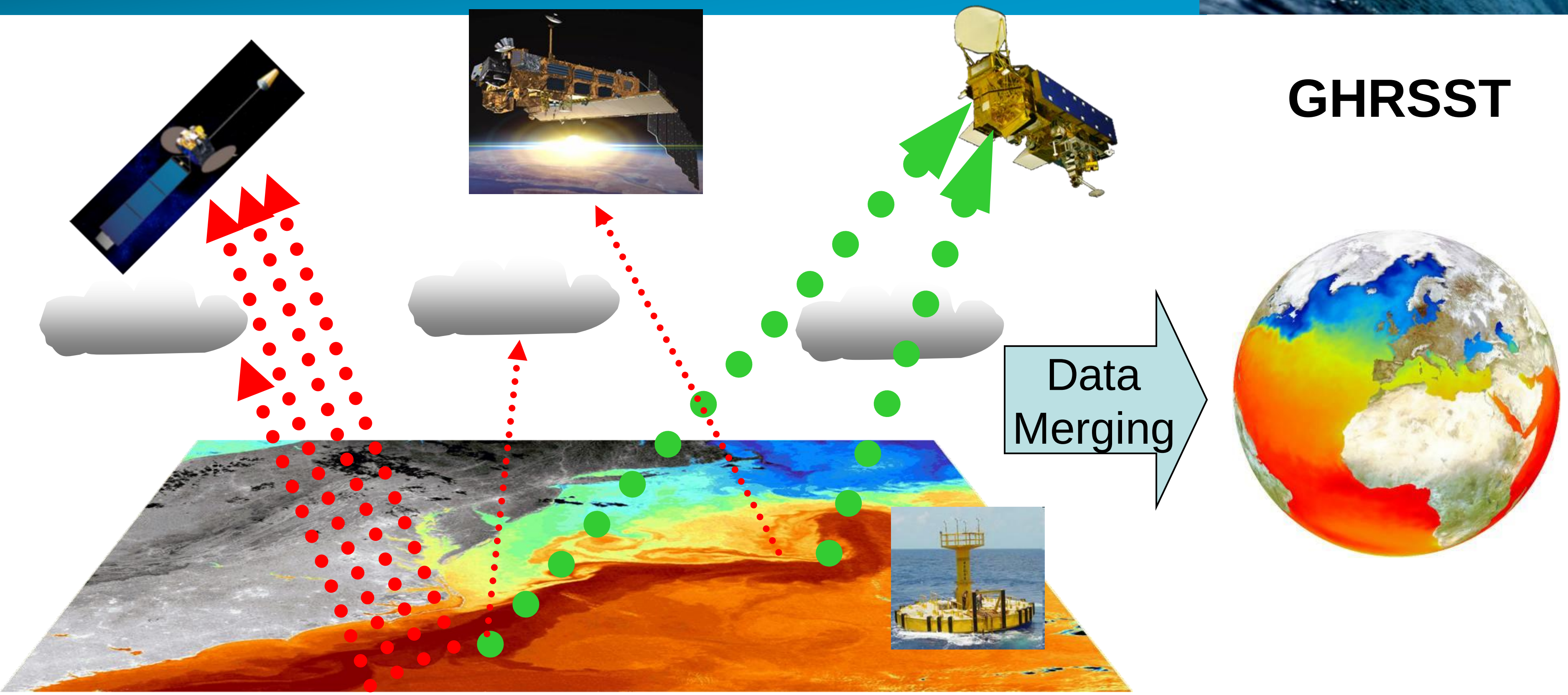
Data availability from complementary instruments enabled progress in synergetic product development

- Examples:
  - AVISO: multiple altimeter OST products
  - GHRSST: multisat. SST products
  - GlobColour: multi-sat OC products
- Multi-Sensor geophysical datasets require;
  - Common sensor data formats
  - Single-sensor uncertainty statistics
  - Inter-sensor bias estimates
  - Rigorous calibration/validation





Exploiting Complementarity

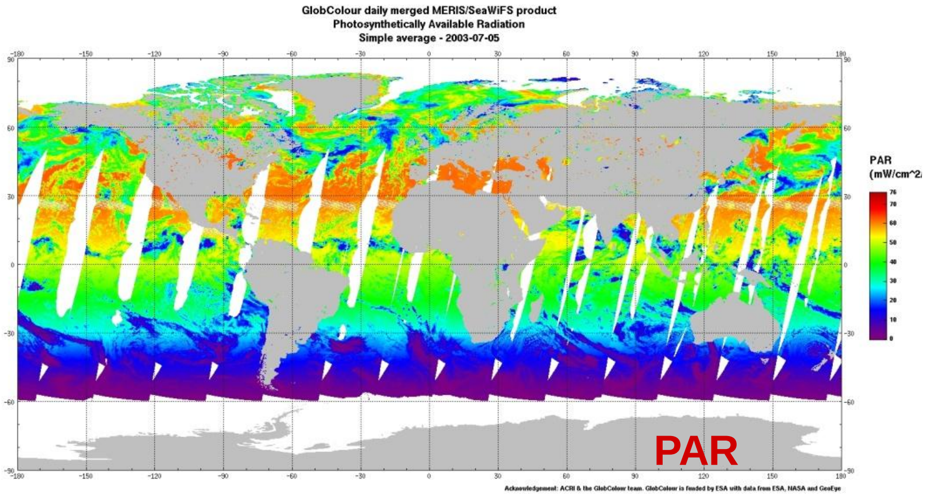


- Polar Orbiting infrared has ***high accuracy & spatial resolution***
- Geostationary infrared has ***high temporal resolution***
- Microwave Polar orbiting has ***all-weather capability***
- In situ data provide ***reality in all weather conditions***

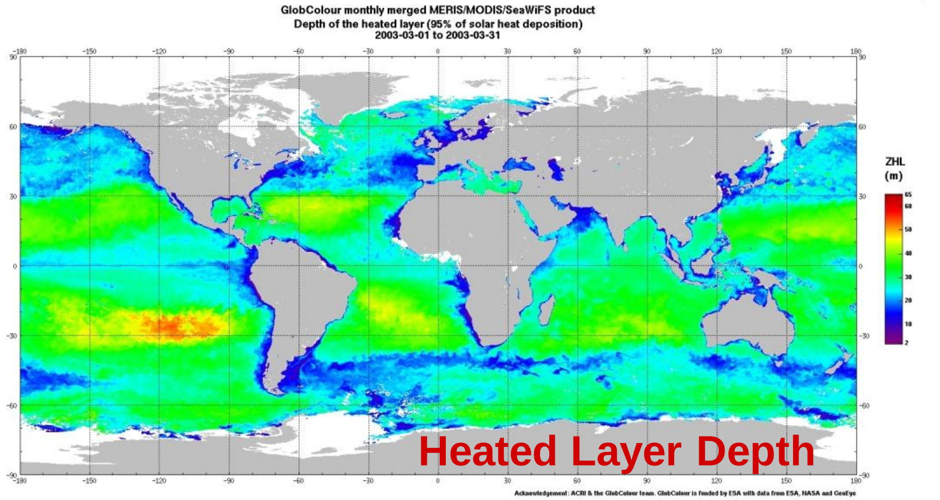
Courtesy GHRSST team

MODIS/MERIS/SeaWIFS

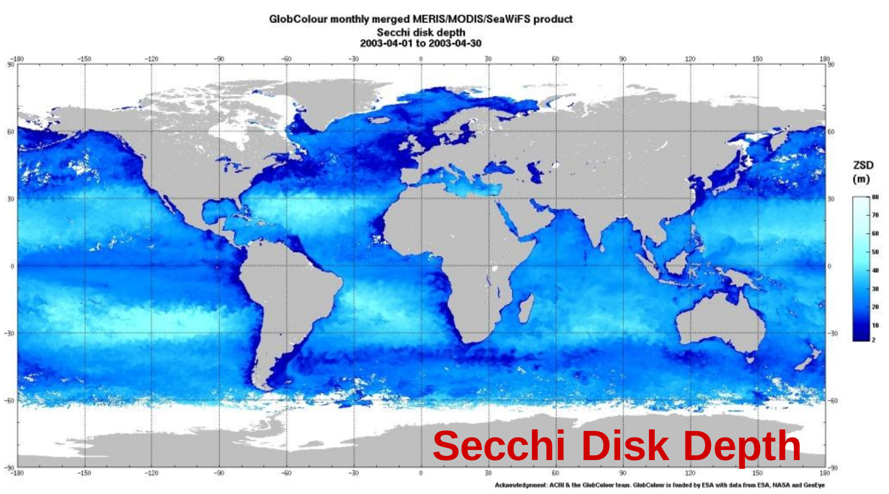
OceanObs'09



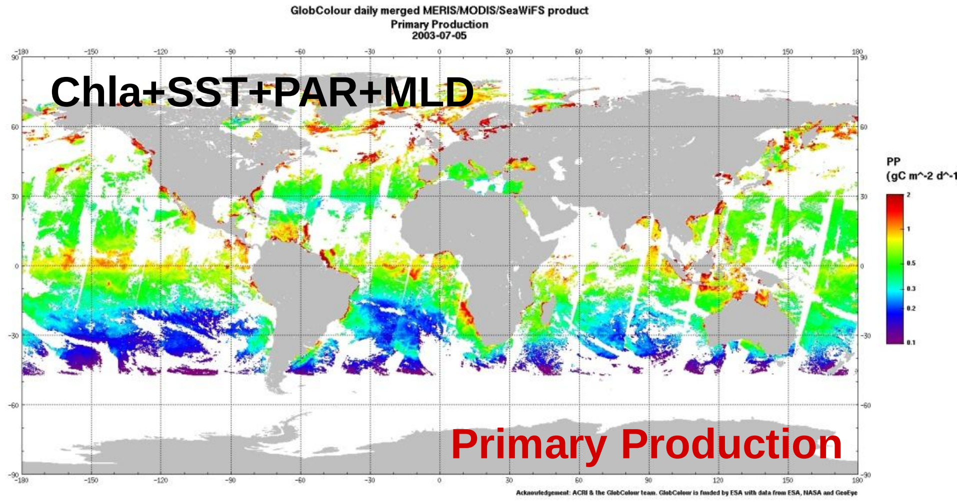
Frouin (2009)



Morel, A., et al. (2007)



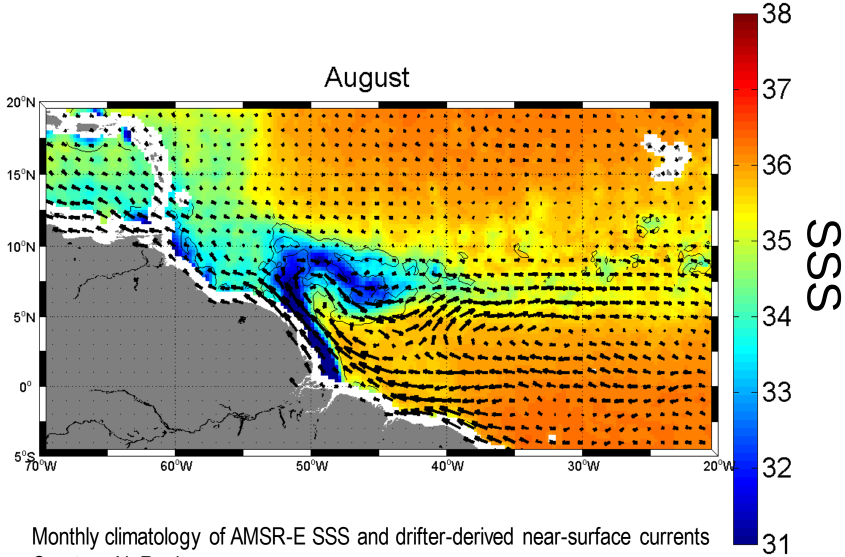
Morel, A., et al. (2007) & Doron et al (2006)



Antoine and Morel (1996) & Antoine et al (1996)

Integration: Satellite + In-situ + Models

- Data integration and synthesis (satellite + in-situ) yields new analysis tools and dynamical frameworks
- Must develop multi-variate assimilation schemes to cope with growing volumes of new data
  - Assimilation not possible without measurement uncertainties (Single Sensor Error Statistics)
- BUT, large amounts of valuable data hidden in archives must be harvested for:
  - verifying measurement uncertainties
  - specifying parameter error covariance between variables
- Future observing system elements must be optimised with respect to knowledge from historical data



Monthly climatology of AMSR-E SSS and drifter-derived near-surface currents
Courtesy N. Reul

Virtual Satellite Constellations

- No single Agency can comprehensively fulfill all satellite ocean observing system requirements
  - Cooperation, coordination, and optimisation essential
- Virtual Constellations are coordinated sets of space assets relying on voluntary engagement
- Three prototype (+1 new) Ocean Virtual Constellations currently in progress by CEOS space agencies:

  Ocean Surface Topography (OST-VC)

  Ocean Surface Vector Wind (OSVW-VC)

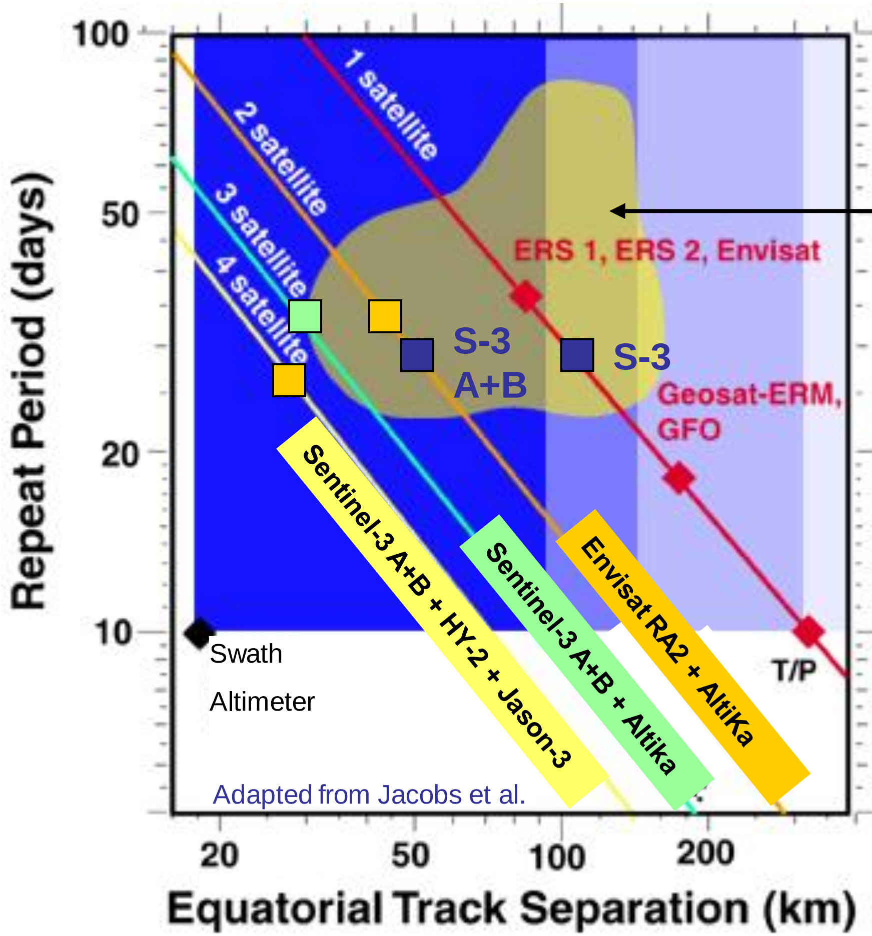
  Ocean Color Radiometry (OCR-VC)

  Sea Surface Temperature (SST-VC)

CEOS
Committee on Earth Observation Satellites

- VCs provide an on-ramp for new Agencies to participate
- But agencies must make real contributions (manpower, finances, policy) to realise the potential benefits of VCs

Altimetry Resolution/Sampling



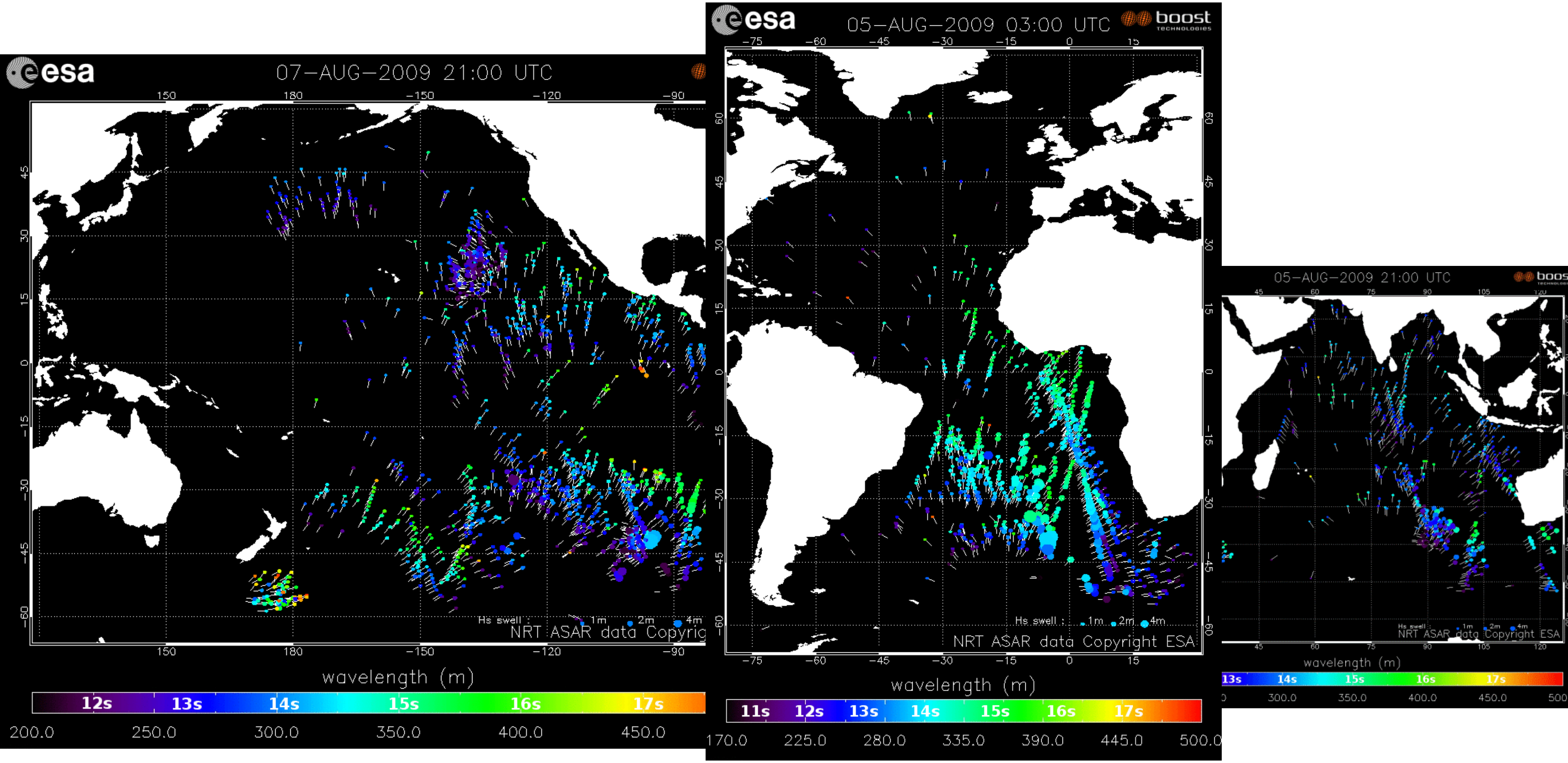
Region of observed mesoscale activity

- Envisat RA-2
- Jason-1 & 2
- SARAL/AltiKa
- HY-2A
- CryoSat-2 SIRAL
- Sentinel-3A,B SRAL
- Jason-3
- GFO-2

Ideal mesoscale sampling requires a coordinated Virtual Constellation of several altimeters: one precise reference mission (tide-free orbit) + 2 or more in optimised sun-synch. orbits. Significant coverage improvement possible with swath altimetry.

Future Challenges – for the Next Decade

Exploit Emerging Products (1)

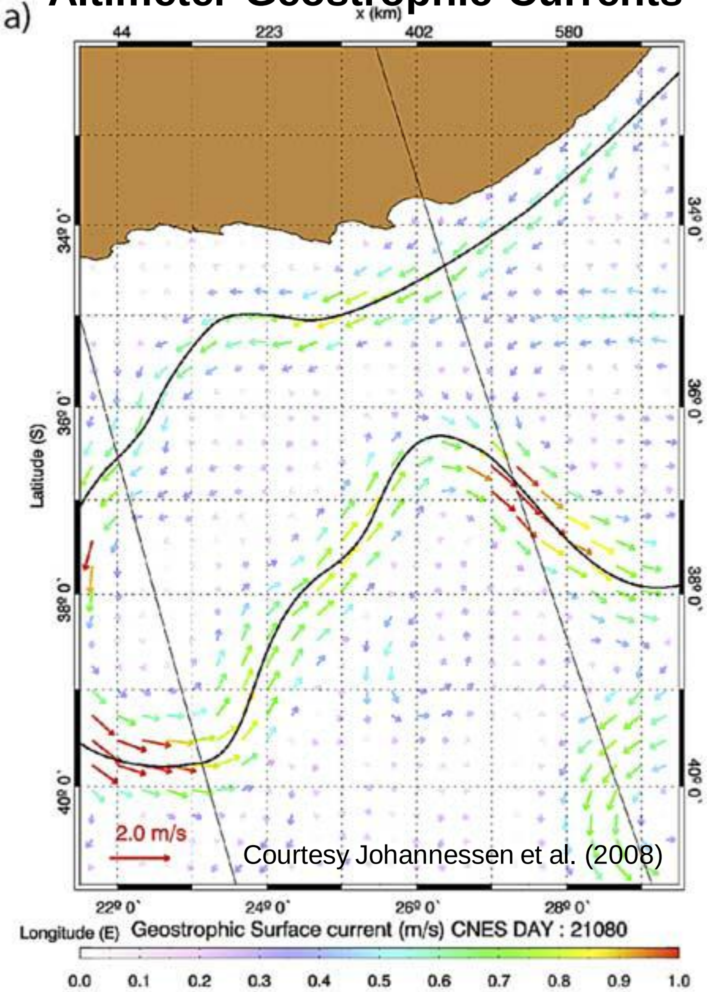


Global NRT ASAR Swell Wave tracking is a reality:

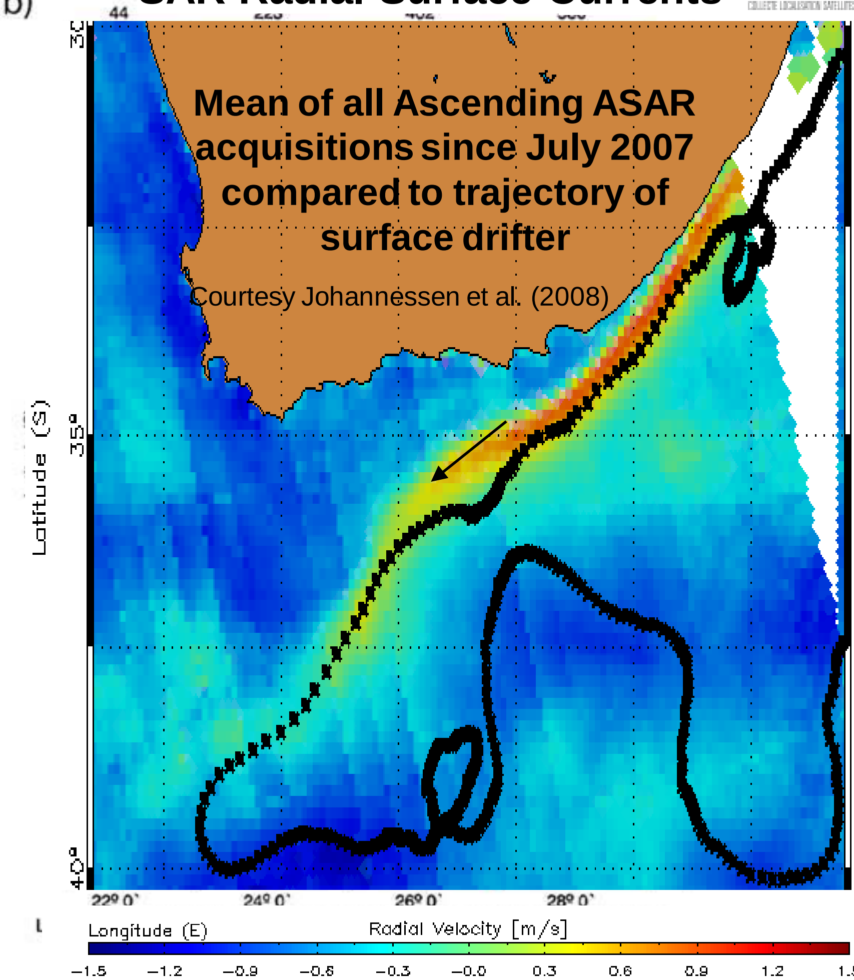
– models must learn to benefit from these quantitative data (wave period & velocity)

Exploit Emerging Products (2)

a) **Altimeter Geostrophic Currents**

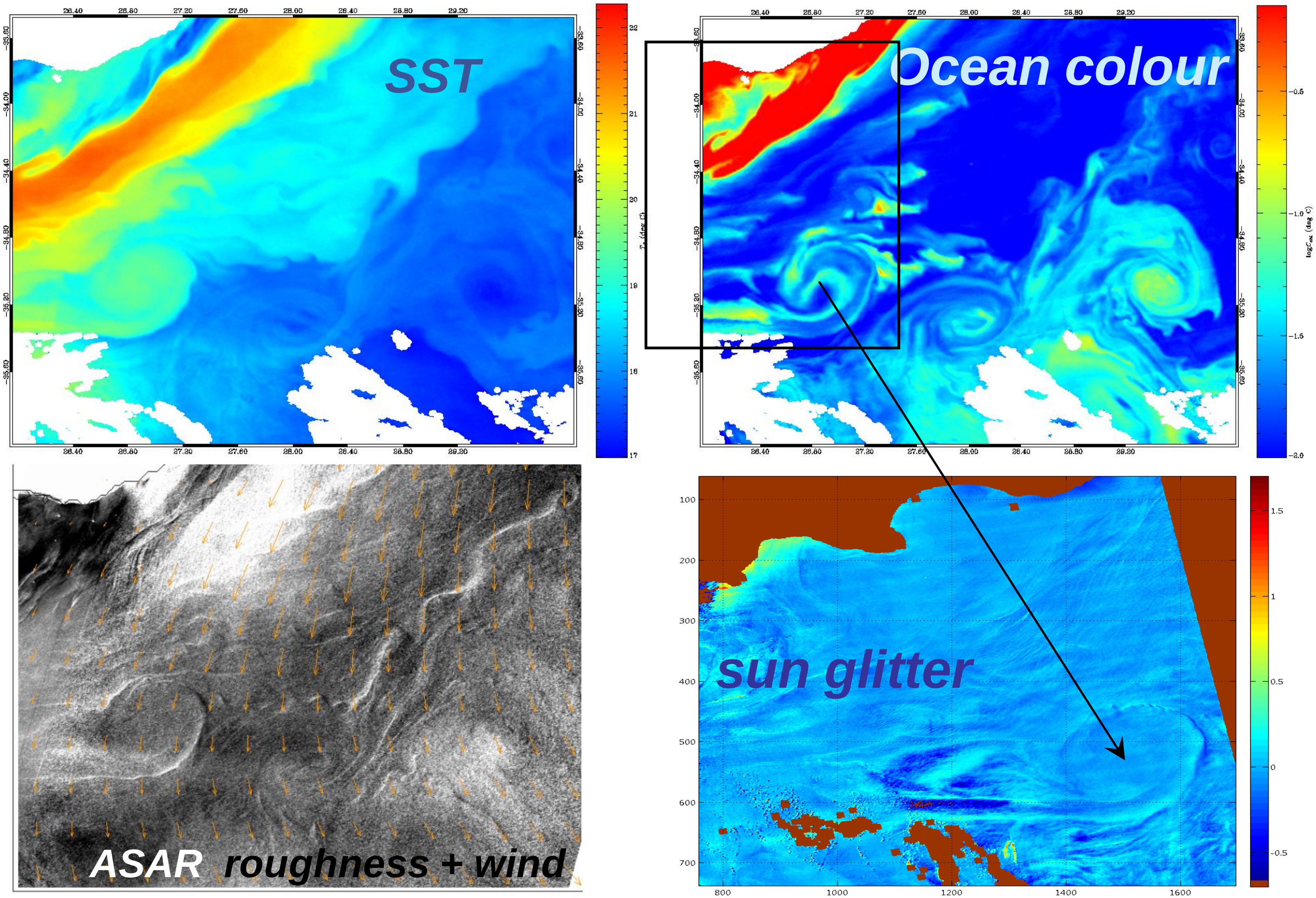


b) **SAR Radial Surface Currents**



Such surface current products present a new challenge to model data assimilation

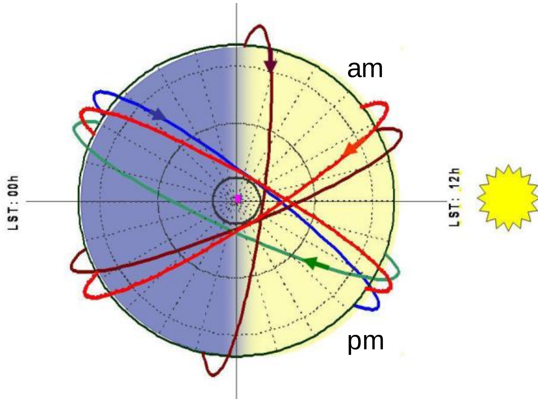
Exploit Synergies: sub-Mesoscale Processes

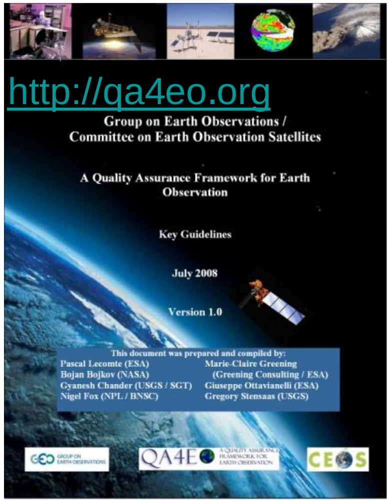


Courtesy Isern-Fontanet, Johannessen, Chapron, Kudryavtsev, Collard

Infrastructure Challenges

- **Periodic Analysis of Infrastructure**
  - Quantify benefits of new R&D systems (OSSE's)
  - Assess gaps or shortcomings of infrastructure
- **Optimise Time/Space Sampling**
  - Minimise Duplication (via VC coordination)
  - Optimise orbits (a la GOS, & IJPS Met sats)
  - Combine advantages of Microwave and Vis/IR systems
- **Instrument Calibration**
  - Adoption of Standards & Quality Indicators (QA4EO)
    - Climate timeseries require strict standards & Cal. reference
  - Lab reference/standards for on-ground inst. characterisation
  - Inter-sat. instrument Calibration/bias estimation
  - GSICS & CEOS CVWG coordination of standards and methodology
- **Sustaining and enhancing infrastructure**





http://qa4eo.org

Group on Earth Observations /
Committee on Earth Observation Satellites

A Quality Assurance Framework for Earth Observation

Key Guidelines

July 2008

Version 1.0

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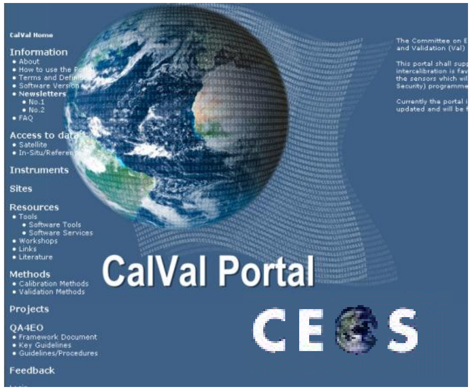
QA4EO A QUALITY ASSURANCE FRAMEWORK FOR EARTH OBSERVATION

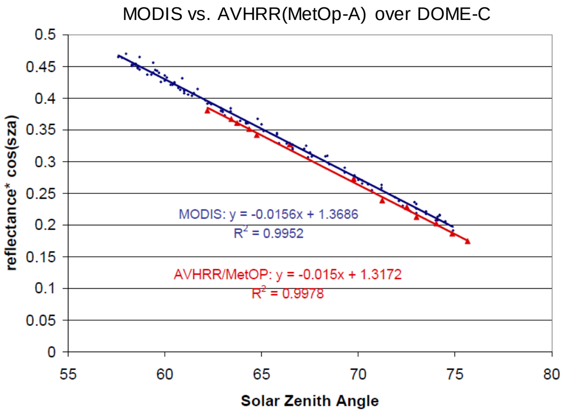
Data Challenges



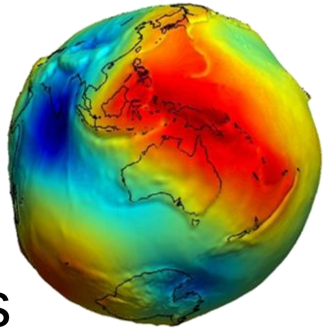
- **Product Harmonisation & Consistency**
  - Adopt Product standards & best practices
  - Develop and apply Robust QA/QC methods

- **Product Validation/Performance monitoring**
  - Identify common Cal/Val sites/protocols
  - Common Diagnostic Data Sets (eg. GHRSST)
  - Maintain Matchup Archives (eg. SeaBASS)
  - Central Cal/Val repository - http://calvalportal.ceos.org
  - Satellite inter-calibration
  - → Coordination via GSICS and CEOS CVWG

- **Data Delivery**
  - Free, Open, Timely data access
  - Simple, robust data delivery from a <u>single</u> entry point
  - Unify Product Tools (eg. SeaDAS; BEAM)



Coming Soon: new datasets



- GOCE – first high-res. geoid release early 2010
- SMOS (2009) & Aquarius (2010) – SSS data > mid-2010
- CryoSat-2 (2010) – all-weather, sea-ice thickness products
- Operational Ocean Colour
  - GOCI instrument (on COMS1 GEO sat) to demonstrate potential benefits of high repetetivity imaging @500m of Korean waters
  - NPP (2010) - VIIRS instrument
- Operational Ocean/Ice all-weather global SAR imaging
  - Sentinel-1A C-band SAR (2011)
- Operational, collocated Altimetry/SST/Ocean Colour
  - Sentinel-3a,b – SAR Alt, Vis/ThIR Radiometer, Vis/IR Spectrometer (2013)

Enhancing the Infrastructure

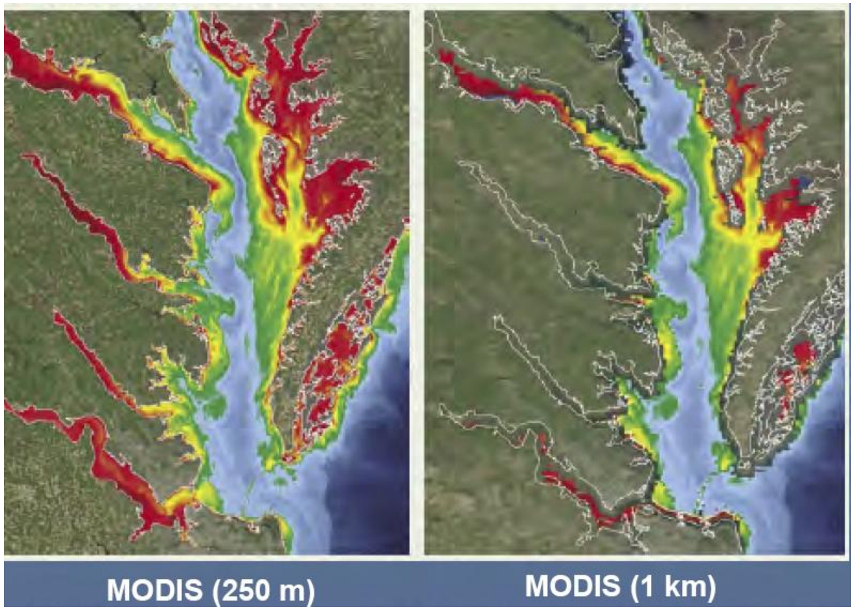
OceanObs'09

What is feasible in the decade ahead in terms of specific new technical concepts under development?

- Second Generation Altimetry
  - 1-d SAR Alt (300m along-track) for high-res. coastal OST
  - Conically scanning Alt (CFOSAT) for wind & wave directional spectra
  - Stepwise development of assimilation framework for 2nd generation Alt en route to operational readiness for 3rd generation altimetry
- Third Generation Altimetry
  - 2-d interferometric Swath Alt (eg. SWOT concept) of OST
  - Along-track Interferometric Alt of surface currents (eg. WaveMill concept)
- Highly-Elliptical Orbiting Imagers
  - Twin-sat. Molniya-orbit constellation, for quasi-permanent polar imaging (e.g. "Arktika") in Visible and IR
- Geostationary Ocean Colour
  - NASA Geo-Cape Concept (NRC Decadal Report)
  - ESA Geo-Oculus Concept – high time & space resolution

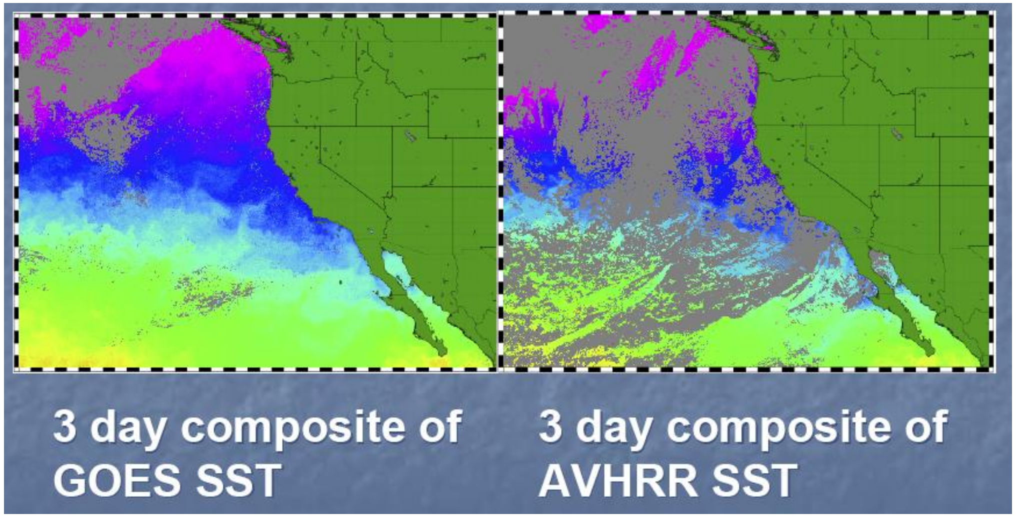
Pushing Spatio-Temporal Resolution

Improvement from 1km – 250m GSD allows to monitor complex estuarine environments (*red = turbid water)



Courtesy B. Arnone

Courtesy P.diGiacomo, NOAA



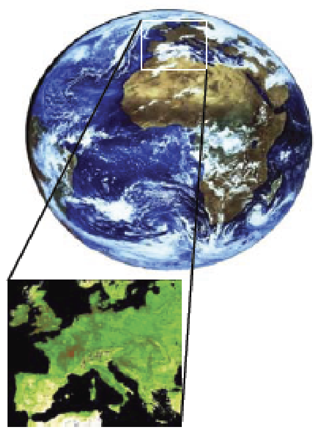
Geostationary satellites demonstrate that increased temporal resolution increases probability of coverage in areas of persistent cloud

Geo-Oculus

Objective

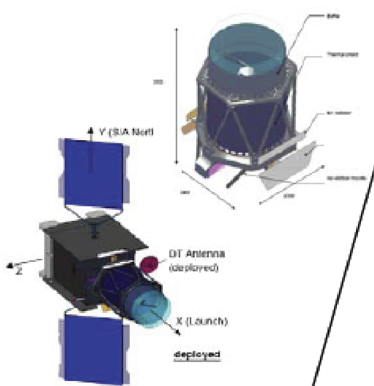
15 minute rapid sampling, NRT optical imagery (10-200 m res.) for specific event monitoring from GEO

Geostationary Orbit
fast access
high revisit
increased sampling capability
continuous data link



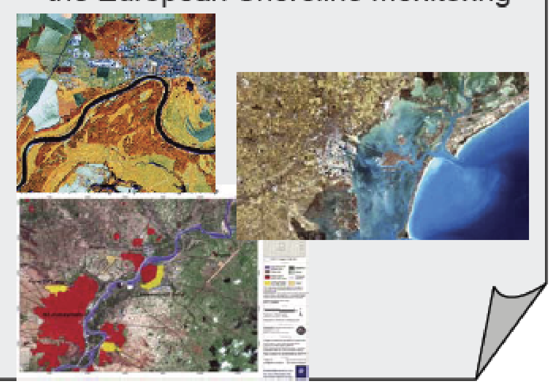
High Resolution
10 – 200 m

Agility
pin-pointing of target



Primary Mission Objectives:
+ Disaster Monitoring — **PAN**
+ Fire Monitoring — **MWIR-TIR**
+ Algal Bloom Detection / Monitoring
+ Water Quality Monitoring with respect to European Regulation — **UV-VNIR**

Secondary Mission Objectives:
+ Oil Slick Environmental Information
+ Erosion / Sediment Transport on the European Shoreline Monitoring

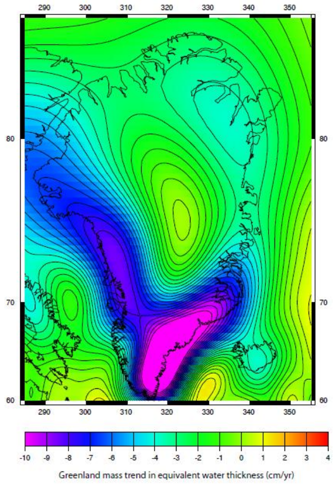


Courtesy ESA/EADS Astrium

New Infrastructure Challenges

OceanObs'09

- Operational time-variable satellite Gravity
  - GRACE follow-on required to continue measurement of mass variability and exchanges in the Earth System
  - GRACE data is forcing further model development
  - → Challenge: coupled models to reproduce observed variability
    - e.g. land/ocean/atmosphere/ice freshwater exchanges



- GNSS-Reflectometry operational demonstration
  - Derivation of mean-square slope using DMC satellite
  - Test from Int. Space Station?

- Secure & sustain essential supporting metrological networks
  - International Laser Ranging Service
  - International GNSS Service
  - → engage and support GGOS as champion of these networks

Summary

- Solid progress towards more coherent and internationally-coordinated, satellite infrastructure
- Core measurements being addressed, with additional critical new variables (e.g. SSS, sea-ice thickness)
- Virtual Constellations can fulfil a vital international coordinating and optimisation role – given the right tools
- Significant challenges remain:
  - to optimise infrastructure and to link complementary observing system elements
  - to encourage involvement of new participating Agencies in Virtual Constellation framework and unrestricted data sharing
  - to promote and achieve widespread adoption of best practices
  - to achieve unrestricted and free product access
  - for data assimilation methods to adapt to new data products
  - to guarantee sustainability of the essential system elements