Altimétrie spatiale

- la genèse
- les objectifs
- les missions spatiales
- les données
- les outils

Jérôme Benveniste
European Space Agency (ESA)
Senior Advisor, Directorate of Earth Observation Programmes
ESRIN, via Galileo Galilei, Frascati, I-00044 (Roma), Italy
Jerome.Benveniste@esa.int

Altimétrie spatiale

Inspired from:

François Barlier, Anny Cazenave, Philippe Escudier, Jean-Louis Fellous, Lee-Lueng Fu, Michel Lefèvre, Yves Ménard, Jean-François Minster, Rob Stewart, Byron Tapley, Stan Wilson, Charlie Yamarone, …. Many other colleagues

The Radar Altimetry Tutorial, Rosmorduc V. et al, Benveniste J. and N. Picot (eds)

Proceedings of "15 Years of Progress in Radar Altimetry Symposium, 2006

Proceedings of "20 Years of Progress in Radar Altimetry Symposium, 2012

Space Agencies web sites

And more sources…

- la genèse

Altimetry from Space — First Steps

1957	Sputnik I	First artificial satellite launch
1958	Vanguard I	Tracking showed earth to be "pear shaped"
1969		Study reports identify long-term altimeter
1972		goals of 10cm accuracy at 100km resolution

It all started with…

1973	Skylab	S193 Microwave Radiometer/Scatterometer and Altimeter — first spaceborne altimeter: "to provide information about ocean state effects on pulse characteristics"

Altimetry from Space — First Steps

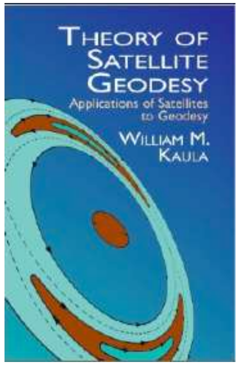
1969 Williamstown "Earth and Ocean Application Physics" Symposium Report:

A vision to determine the Dynamic Ocean Topography (DOT) by subtracting a geopotential surface (N) from the sea surface height (h), monitored by altimetry:

$$\text{DOT} = h - N$$

Symposium chaired by William Kaula (UCLA)

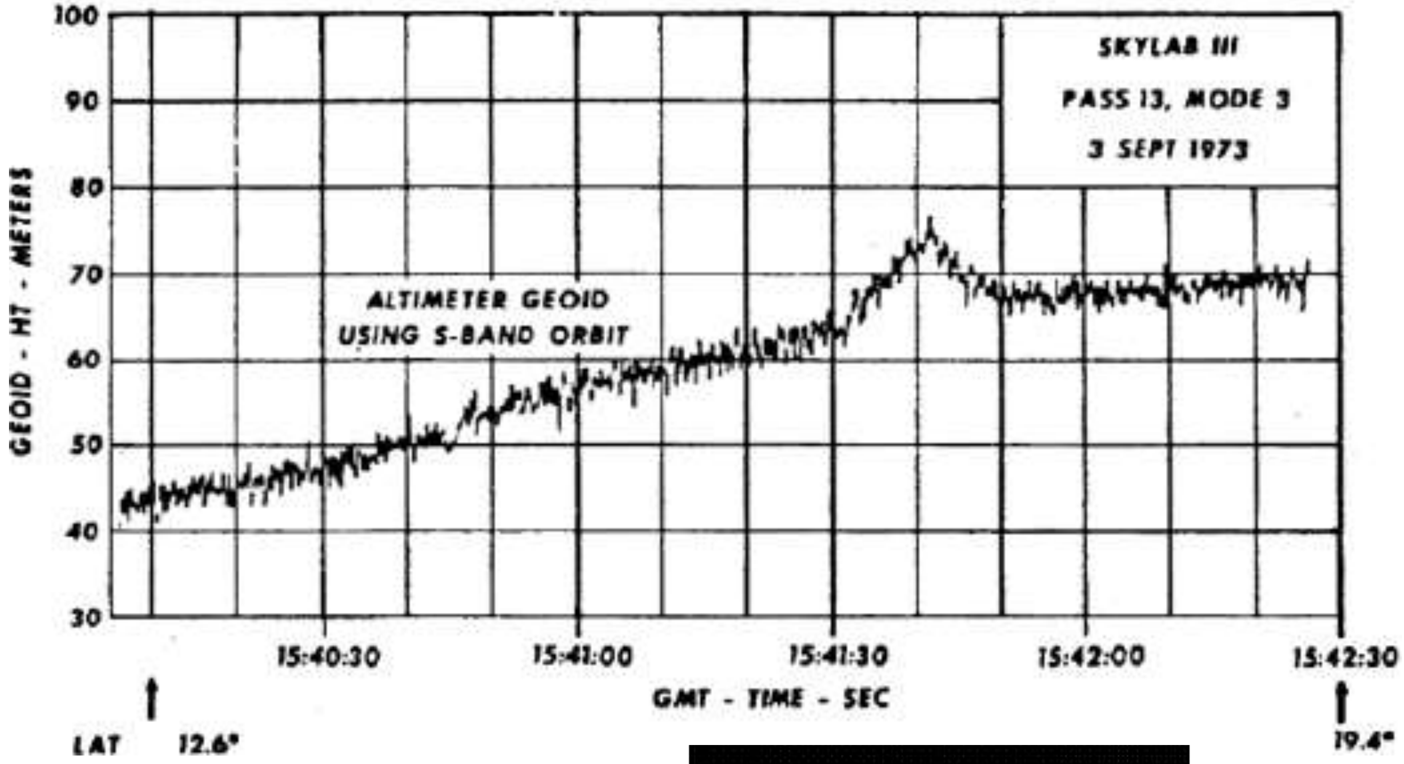
(May 19, 1926 — April 1, 2000)

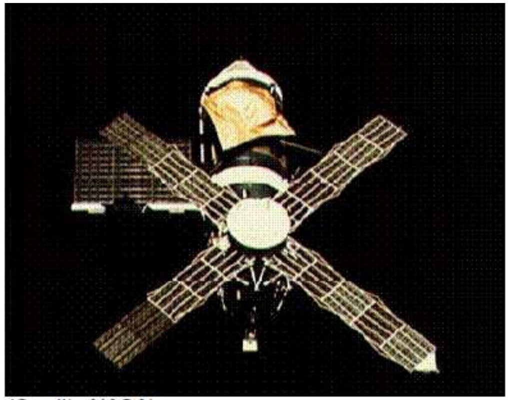


➔ *Program for NASA's Earth Exploration*

➔ *Skylab ... GEOS-3 ... Seasat*

Skylab III sees the geoid - 1973





(Credits NASA)

Altimetry from Space — First Steps

Space Oceanography, Navigation and Geodynamic (SONG) Workshop

Schloss Elmau (Germany) in January 1978

The driver for the ESA ERS-1/2 Programme

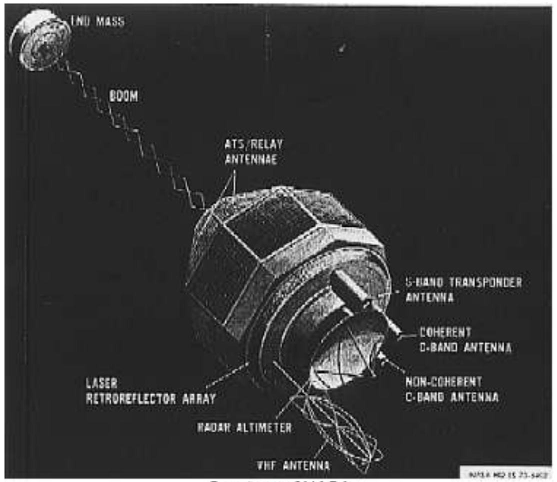
The Last Four Decades

1970's	1980's	1990's	2000's

1970 1975 1980 1985 1990 1995 2000 2005

SKYLAB **SEASAT**

GEOS-3



Courtesy of NASA

GEOSAT

ERS-1

TOPEX/Poseidon

ERS-2

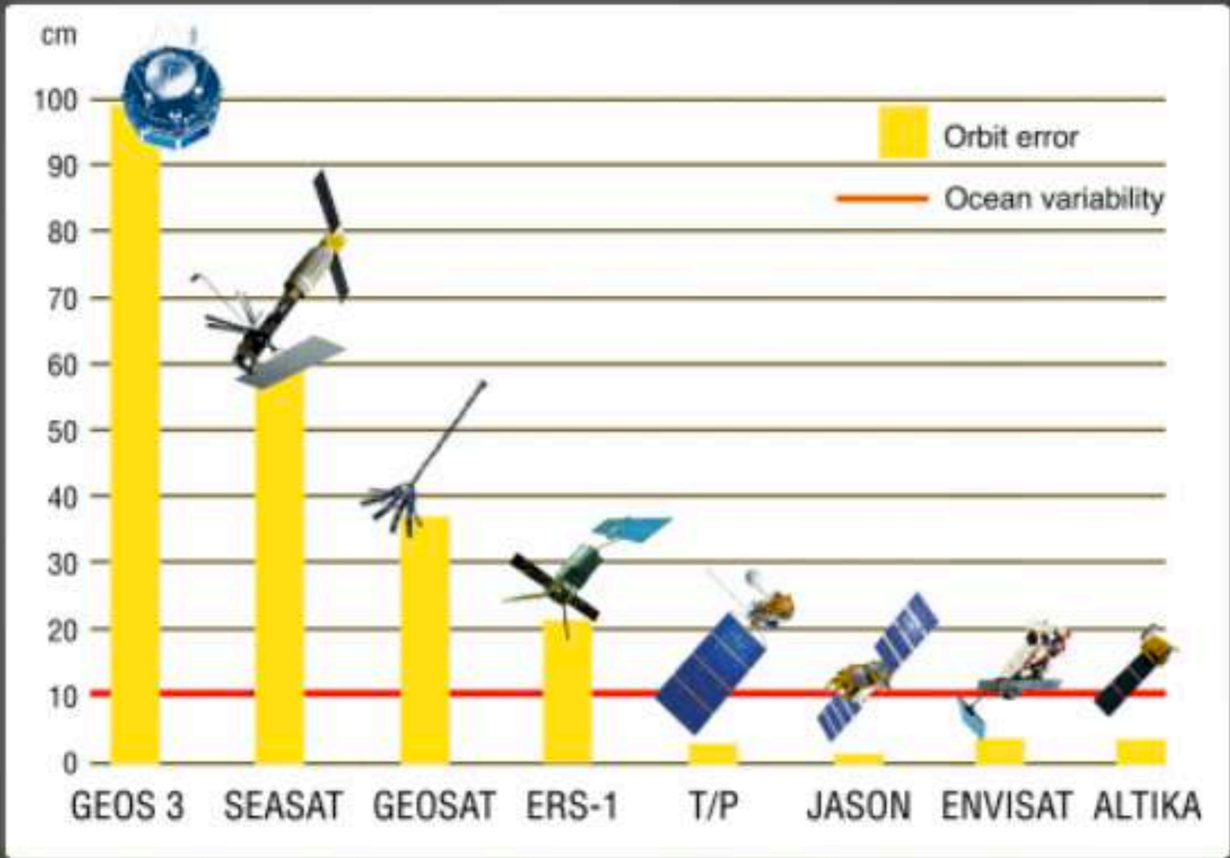
GEOSAT Follow On

Jason-1

ENVISAT

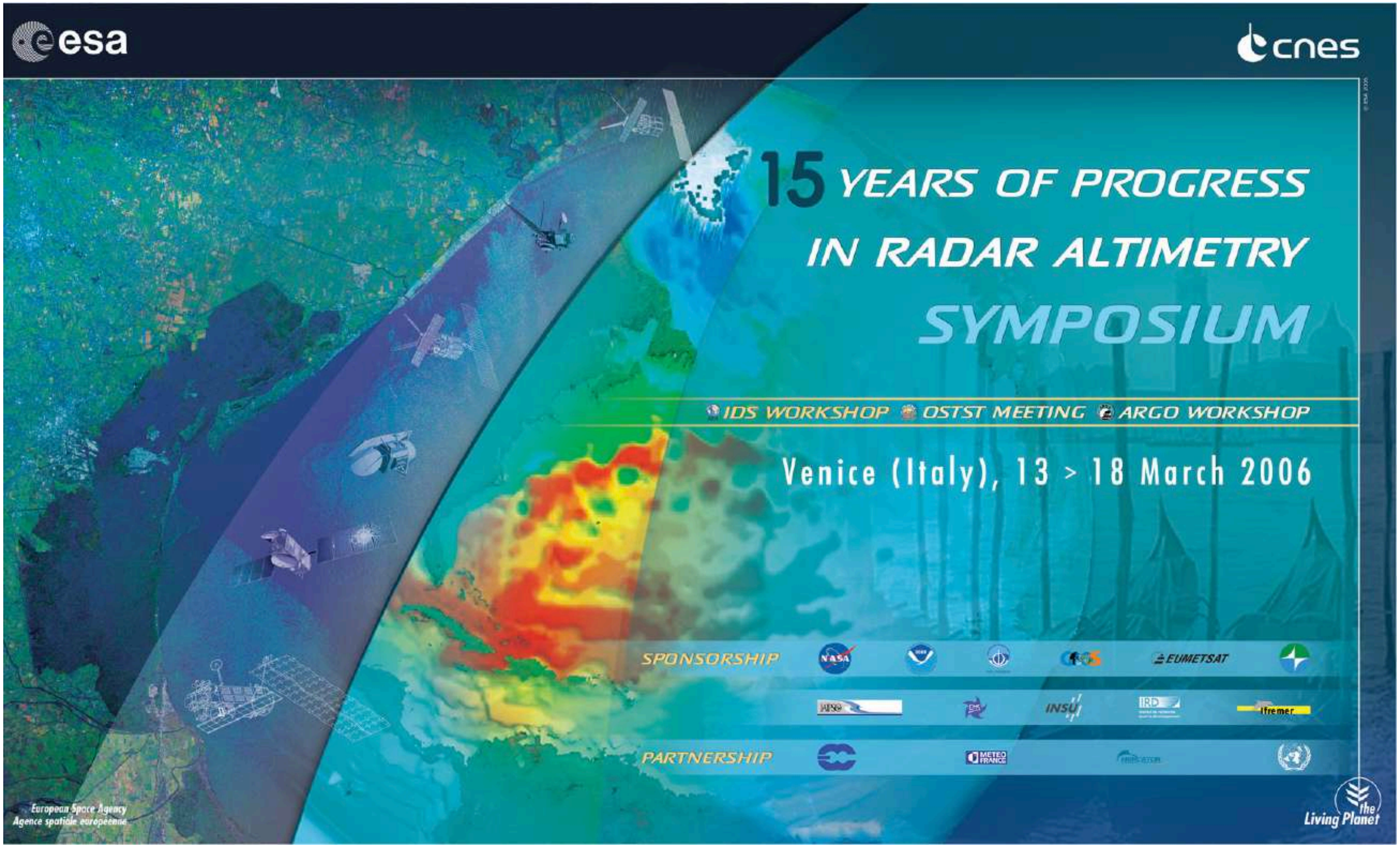
Jason-2

The Last Four Decades - Improvements



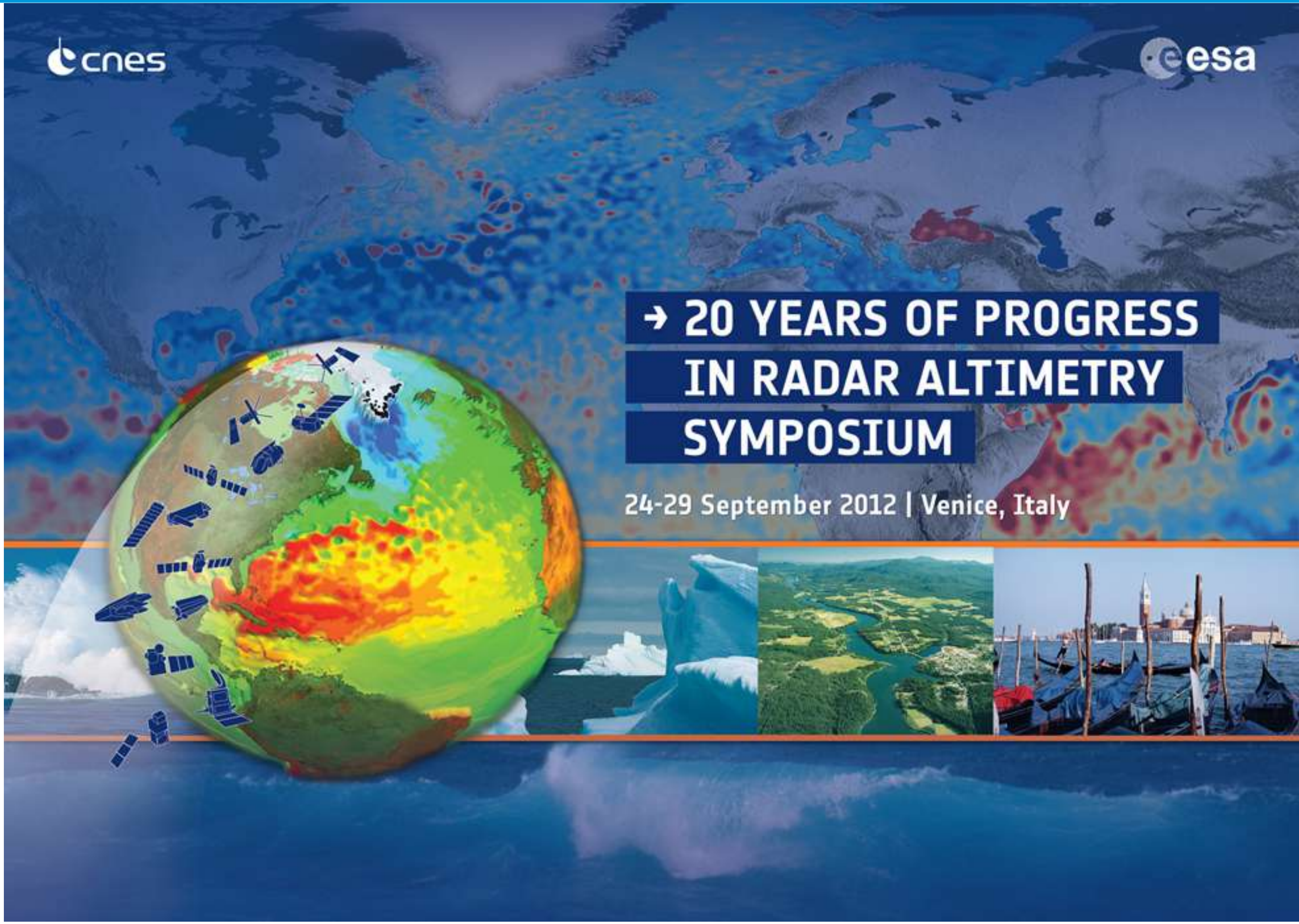
Improvements in measurement accuracy since the first satellite altimetry missions has enabled us to observe ocean variations at close quarters since 1992. (Credits Cnes).

The Last Four Decades



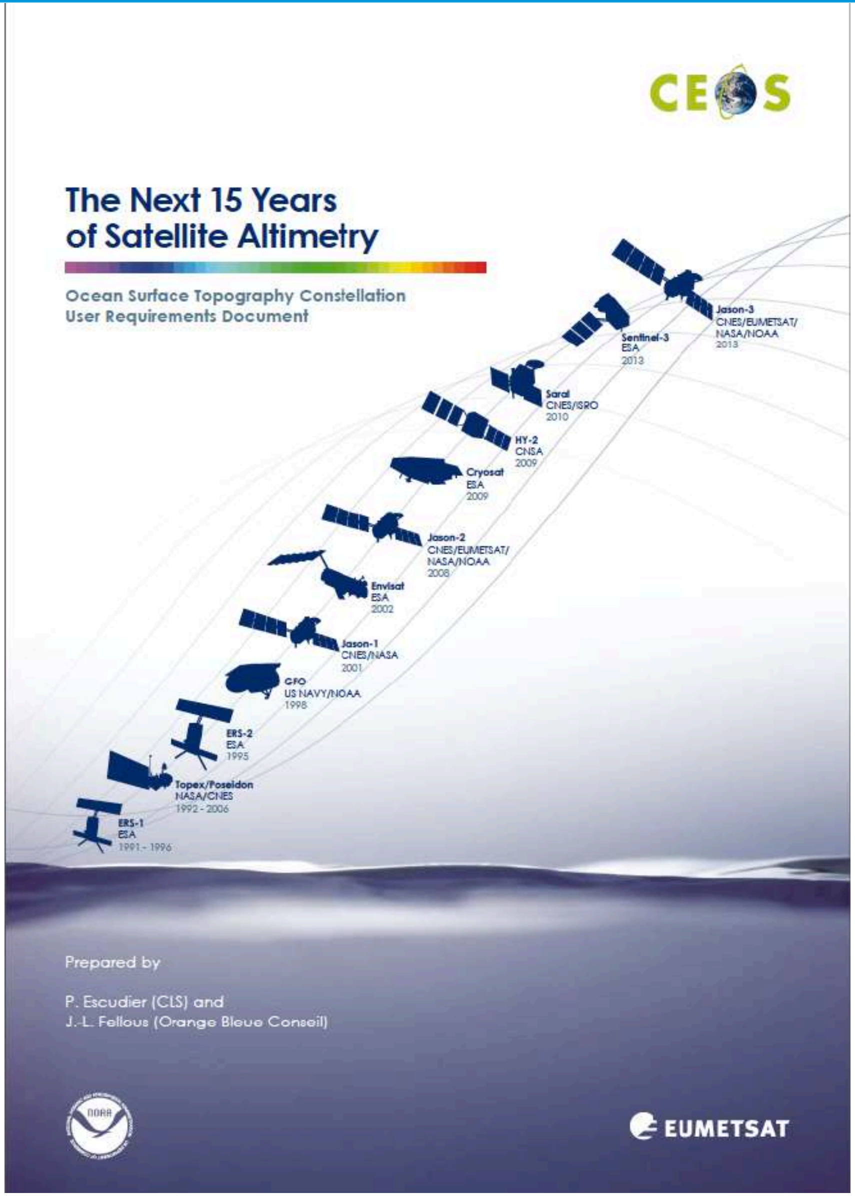
The Last Four Decades

The Last Four Decades



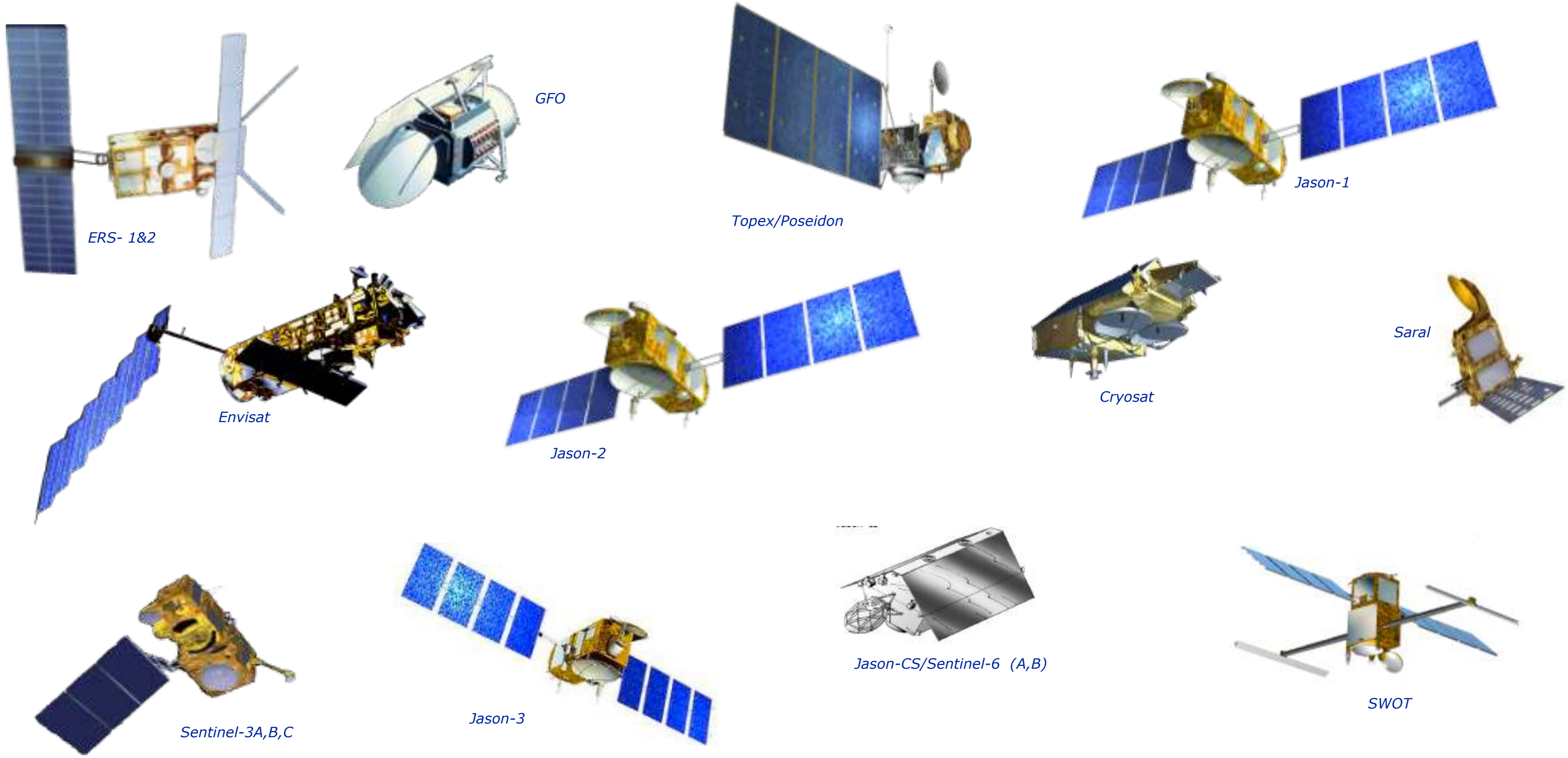
Agency

The Last Four Decades



(2009)

The Last Four Decades and Tomorrow…



- les objectifs

Alimetry Mission Objectives

esa

OCEAN

– Global dynamic topography and derived geostrophic currents
  – Monitoring dynamic ocean circulation patterns
– Ocean mesoscale variability, eddy kinetic energy, tides
– Marine geophysics - Global and regional sea level ,
– Coastal zone Ocean, Polar Oceans, enclosed seas
– Significant waveheight climatology and real time monitoring

CRYOSPHERE

– ice sheet elevation, sea-ice extent and thickness

HYDROLOGY

– Inland water: river and lake levels

Secondary objectives:

ionosphere, water vapour, wind speed (used for model validation)

Alimetry Mission Objectives

– The selection of orbit parameters reflects the priorities of the mission:

  – satellite altimeter missions with a repeat orbit period of one year or more were designed to measure the ocean geoid

  – those with shorter repeat periods, typically 10, 17 or 35 days, were designed primarily to measure dynamic ocean features (tides, geostrophic currents, eddies,),

  – the shorter the period the better fast signals are monitored

– The inclination of the orbit impacts the quality of deriving geostrophic current in both zonal and meridional directions.

  – A low inclination, say 66 degrees (TOPEX, Jason series), is preferred for applying geostrophy.

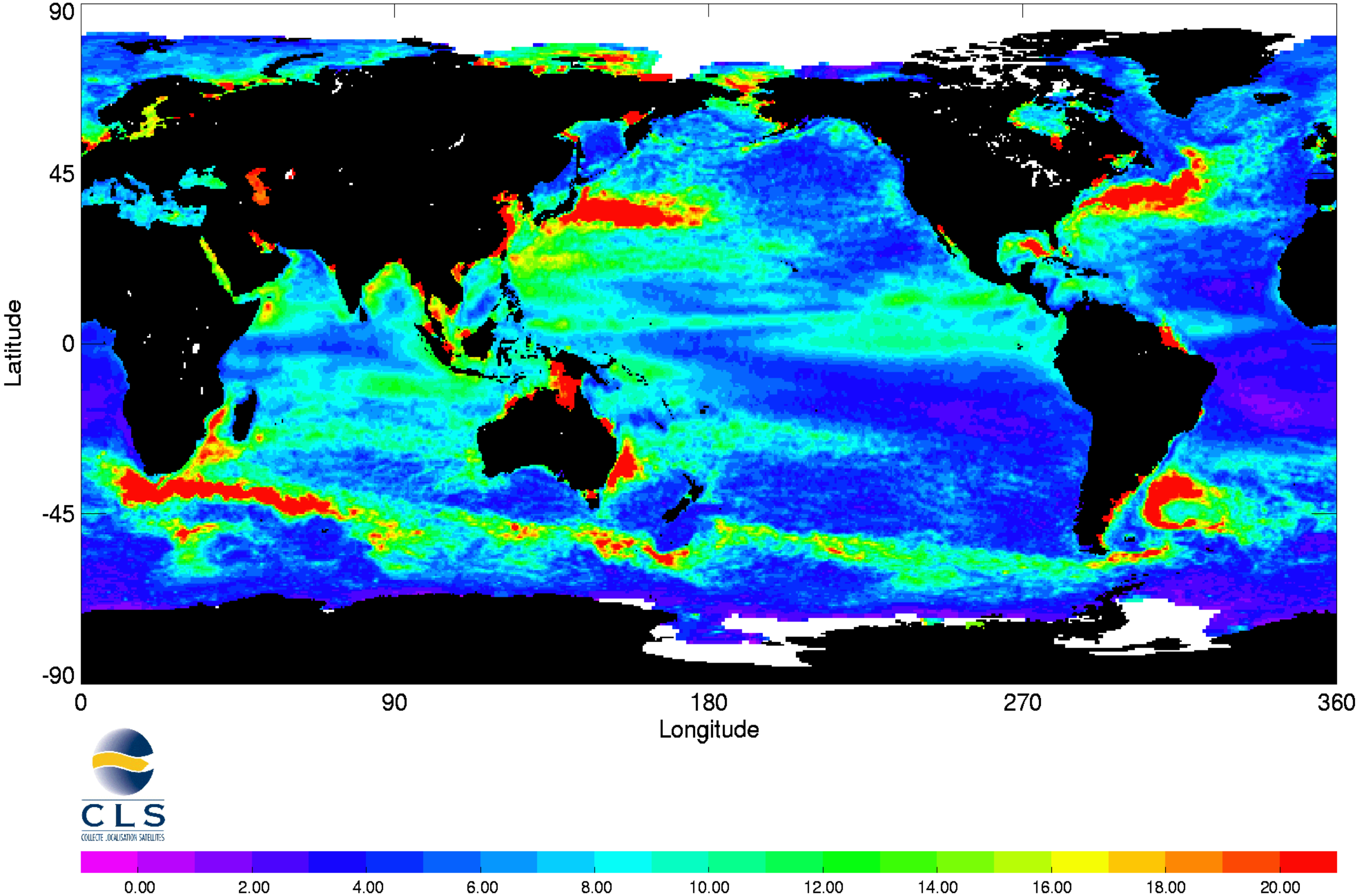
  – High inclination missions (ERS, Envisat, CryoSat) aloow to map the polar regions

Alimetry Mission Objectives

- A wealth of applications are possible using radar altimetry measurements, bringing together Geodesy and Physical processes Sciences (Oceanography, Glaciology, Hydrology, Solid Earth Physics)

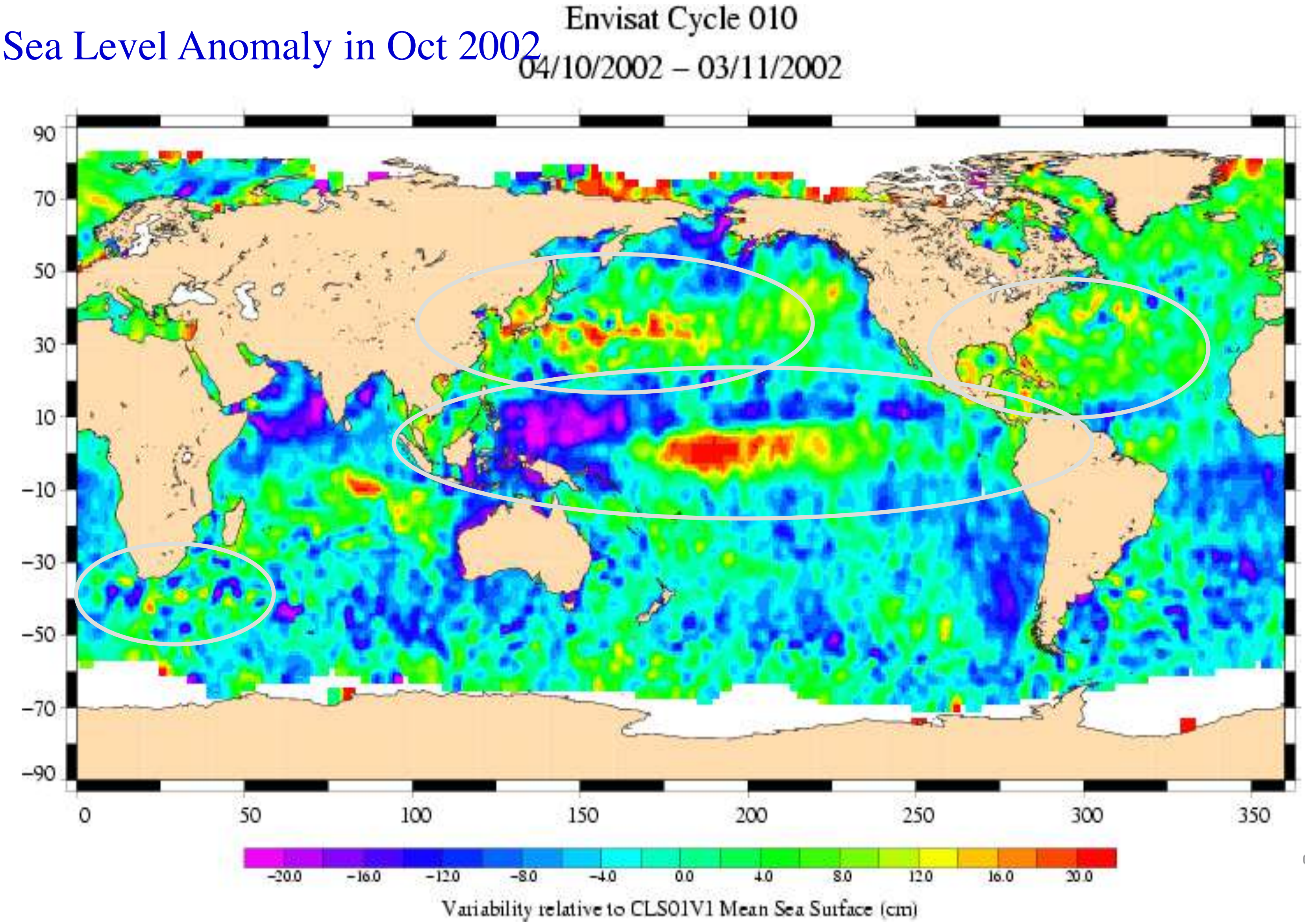
- Radar Altimetry is used by more than a thousand research teams around the world, as well as used by a number of operational monitoring and forecasting services.

Mesoscale Variability



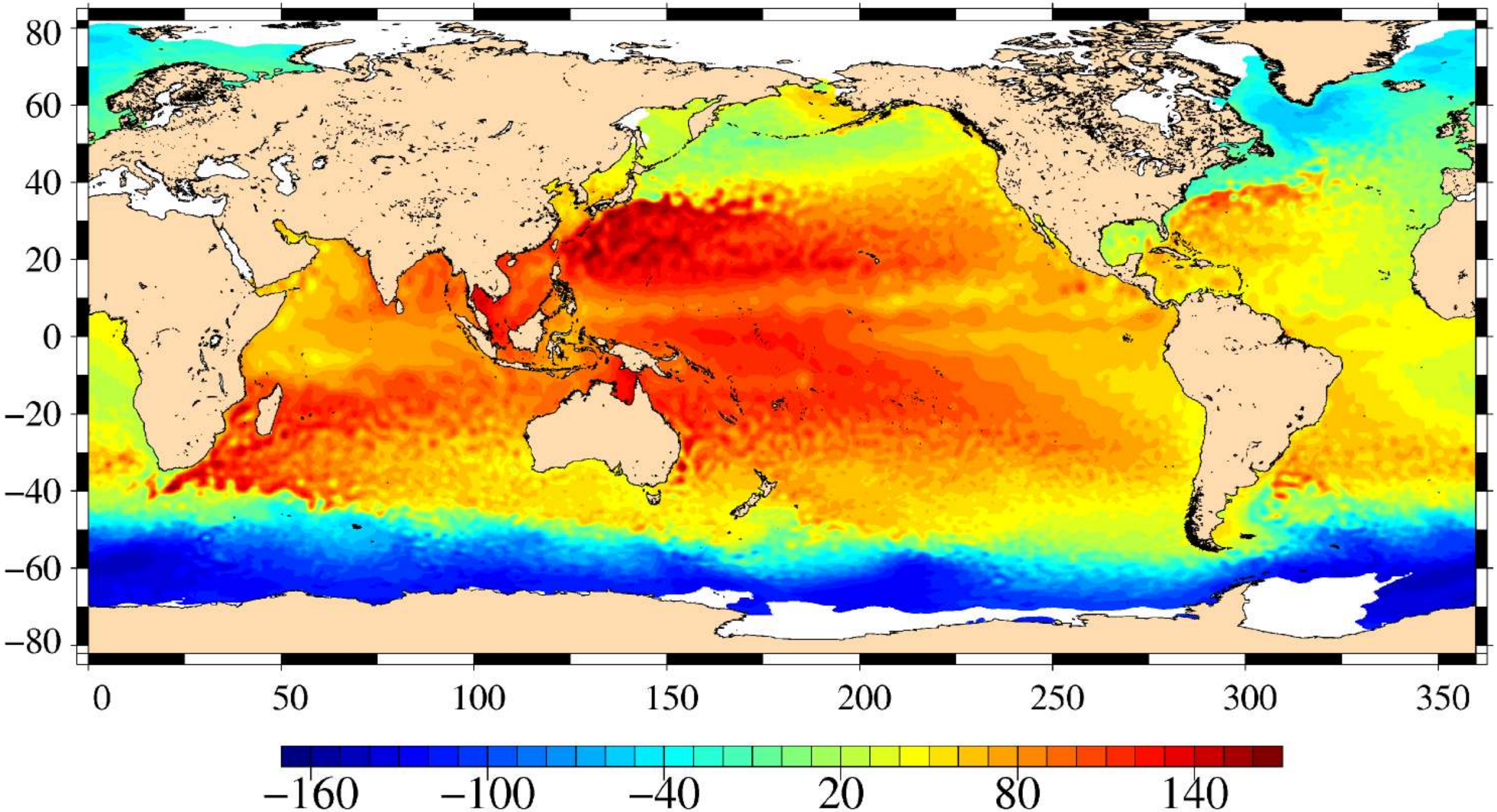
Mesoscale variability from ENVISAT RA-2

Sea Level Anomaly in Oct 2002

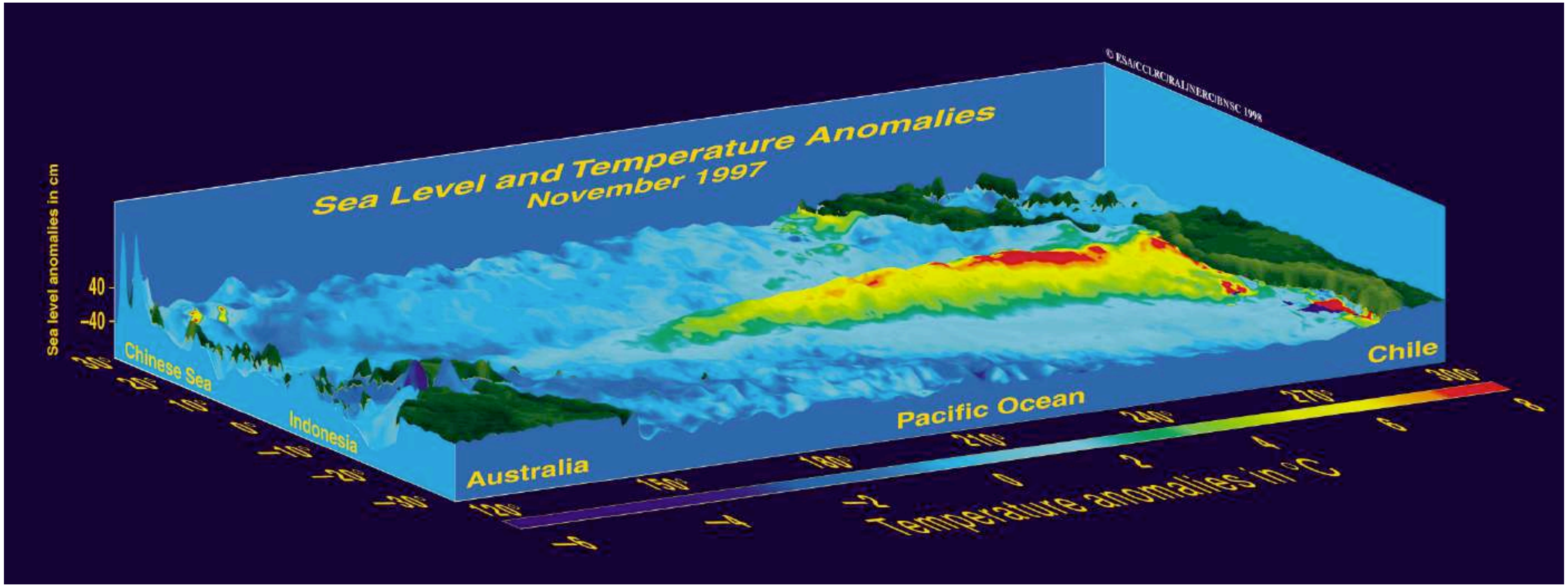


ce Agency

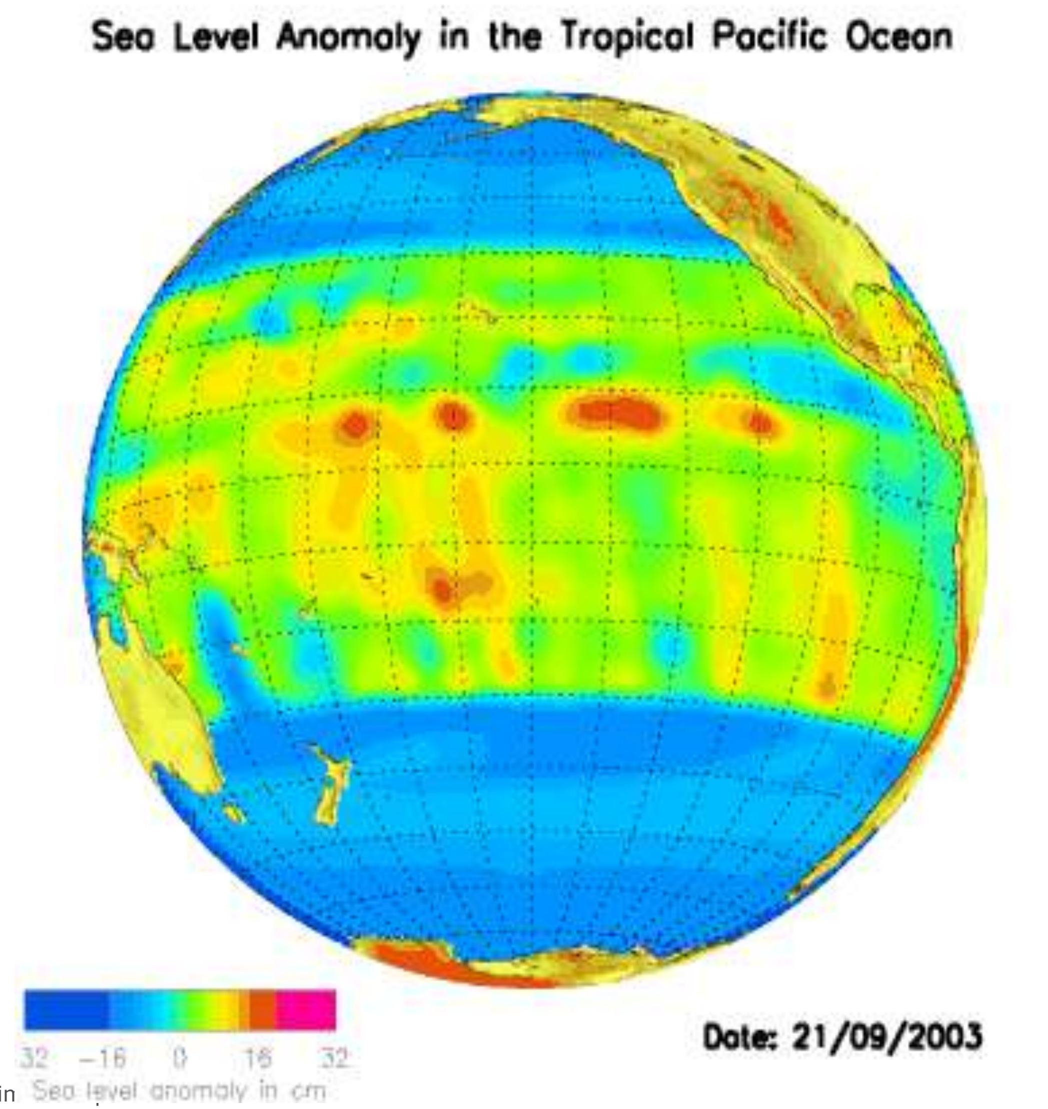
CNES-CLS Mean Dynamic Topography -2009



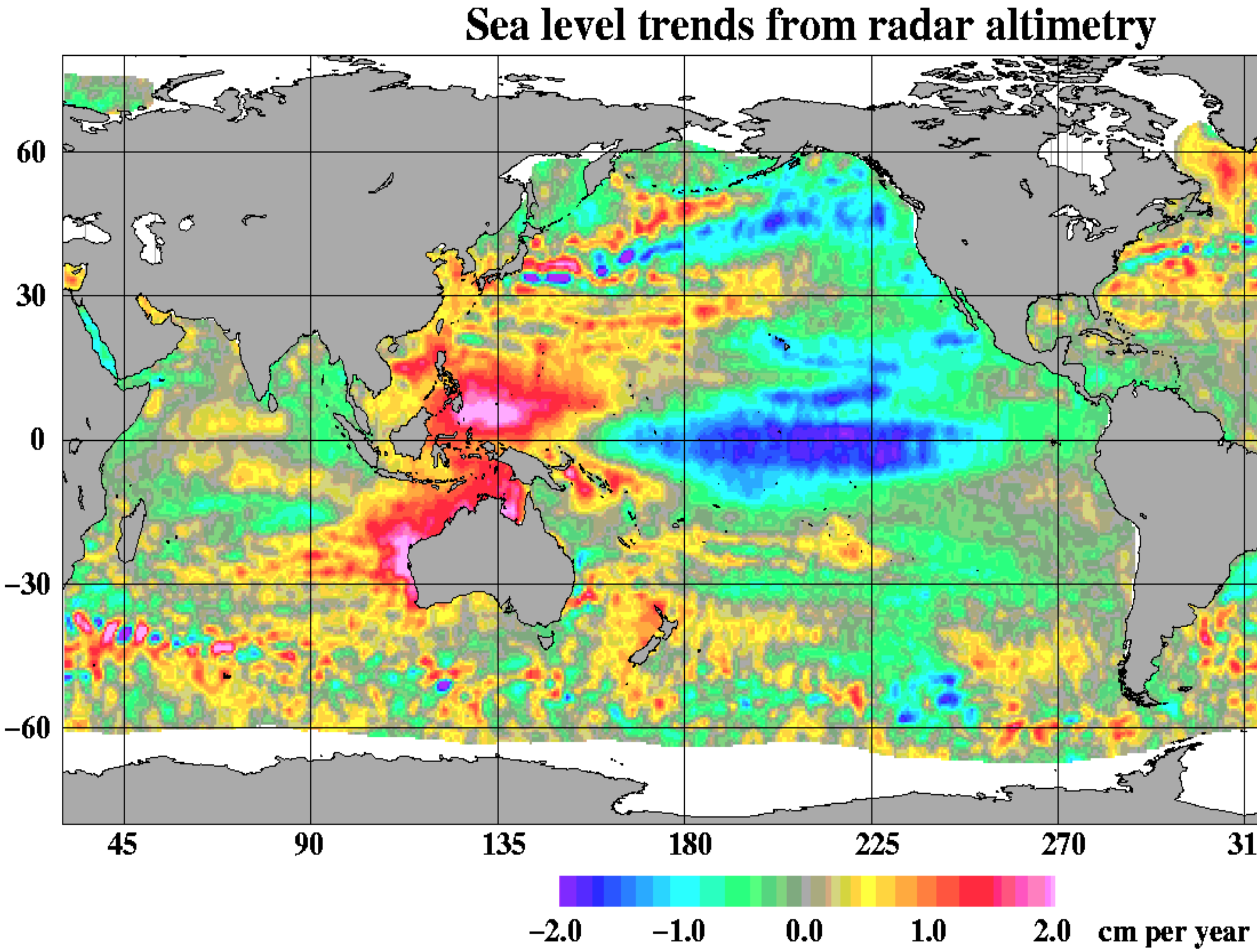
El Niño Observations with Altimeter and



El Niño Monitoring




Observing the oceans
from space
Ten years of
ocean observation
from space
This 1992-2001 time series of sea surface temperature and sea level changes illustrate the evolution of the Ocean year after year emphasizing the strong 97-98 El Niño/La Niña event. Data are from the NOAA/NASA Advanced Very High Resolution Radiometer and the TOPEX/POSEIDON satellites.
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Sea surface level
Sea surface temperature
cnes
NASA

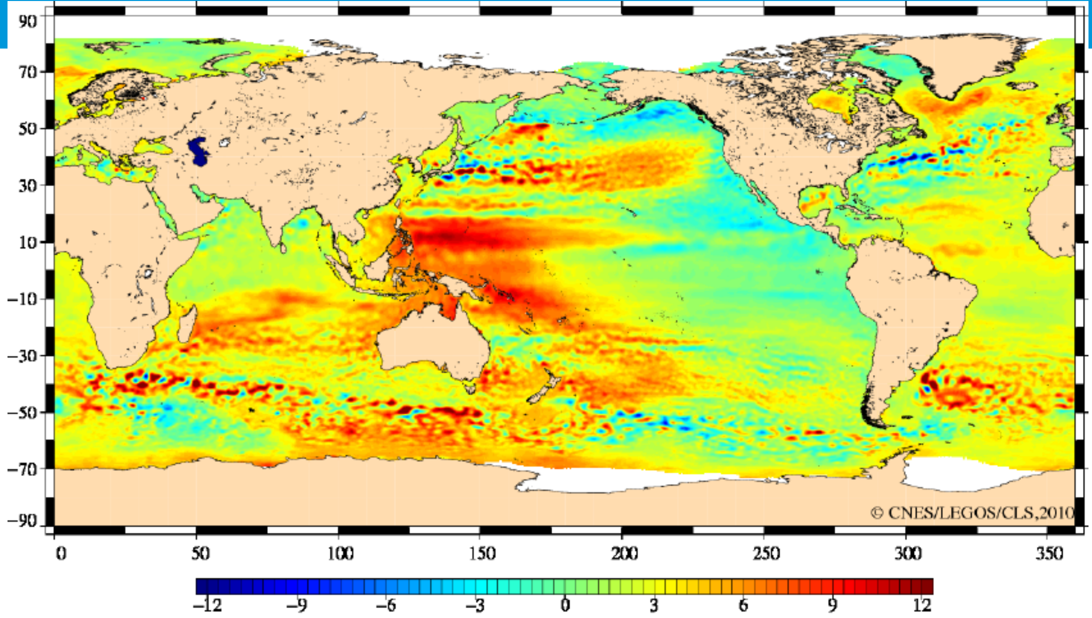


Courtesy of KMS

18 Years of Sea Level Trends from Radar Altimetry

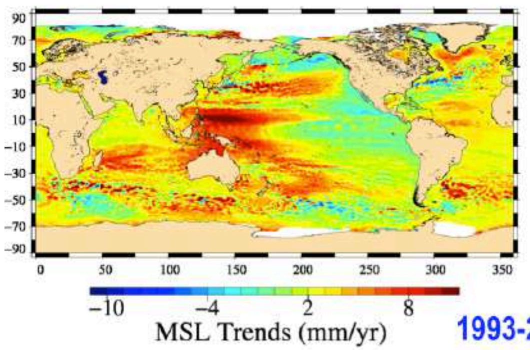
Reference: Too soon to have papers published using these barely released data

Topic: Physical Oceanography

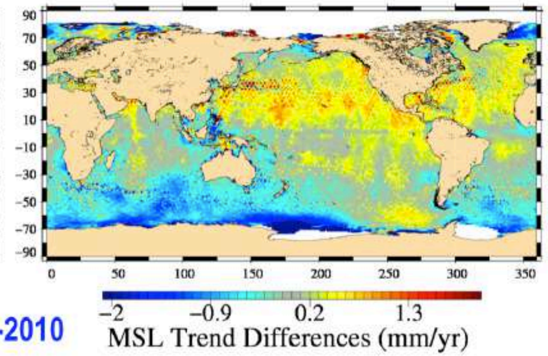


Regional MSL trends from Oct–1992 to Mar–2010 (mm/year)

Regional MSL trends from SLCCI project → Improvements of SLCCI project on regional MSL trends



1993-2010



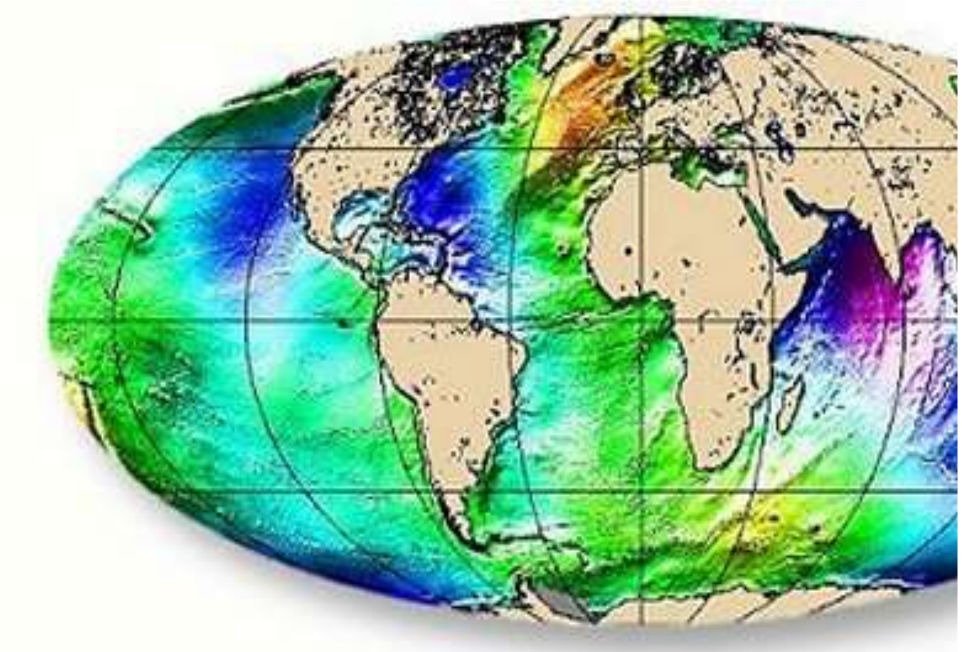
Scientific Highlight:
A unique 18 year reconstruction of radar altimetry readings showing sea level changes in unprecedented detail was unveiled in Venice on 24 September 2012 when over 500 international specialists met at an international conference on 20 years of Radar Altimetry. From the Sea Level CCI project, which was aimed at refining processing algorithm, selecting the most accurate ones by a panel of international scientists, a global map of regional Sea level trends was drawn. For the first time interannual variability can be detected in the sea level trends signal.

Data Used: Radar Altimetry from several ESA and third party missions.

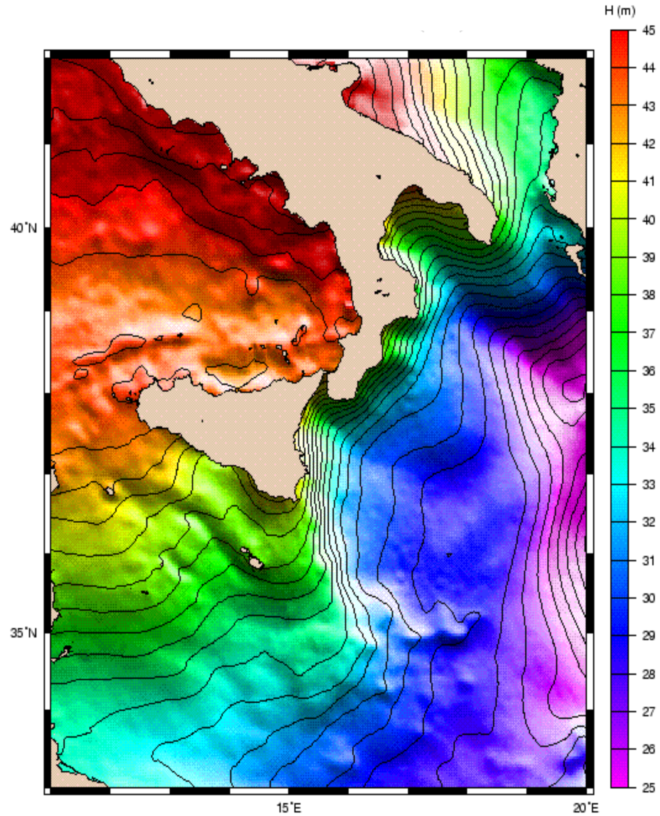
Scientific Impact - Very High ○ ; High X ; <u>Medium</u> ○ :

Why is it Relevant?: A community effort encouraged by

Mean Sea Surface



CLS MSS(2001)



Forecasting the ocean

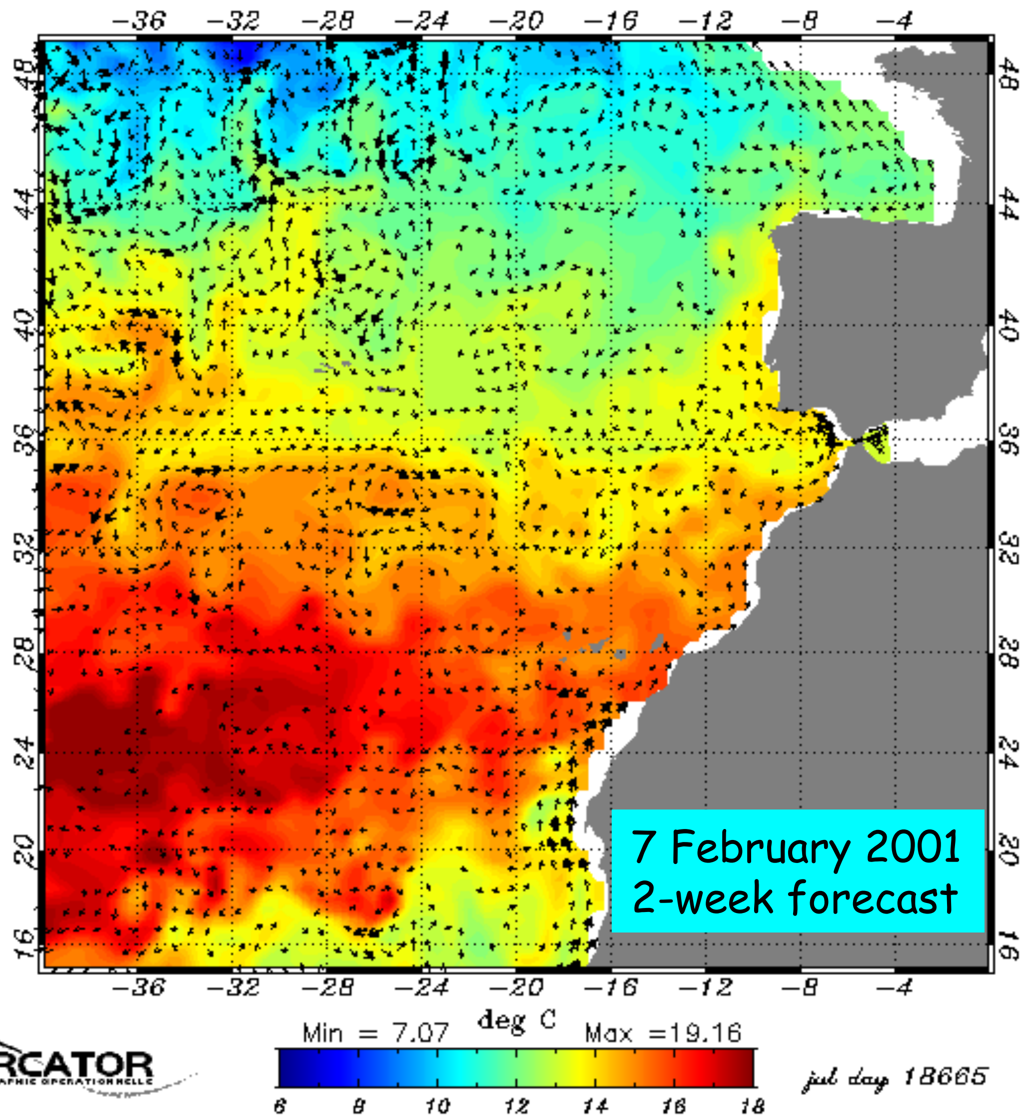
The spatial and temporal coverage of satellite measurements recently made it possible to describe the present ocean state.

From there, numerical models can predict the ocean's evolution, much like atmospheric forecast models predict future weather.

Operational ocean forecasting is becoming a reality

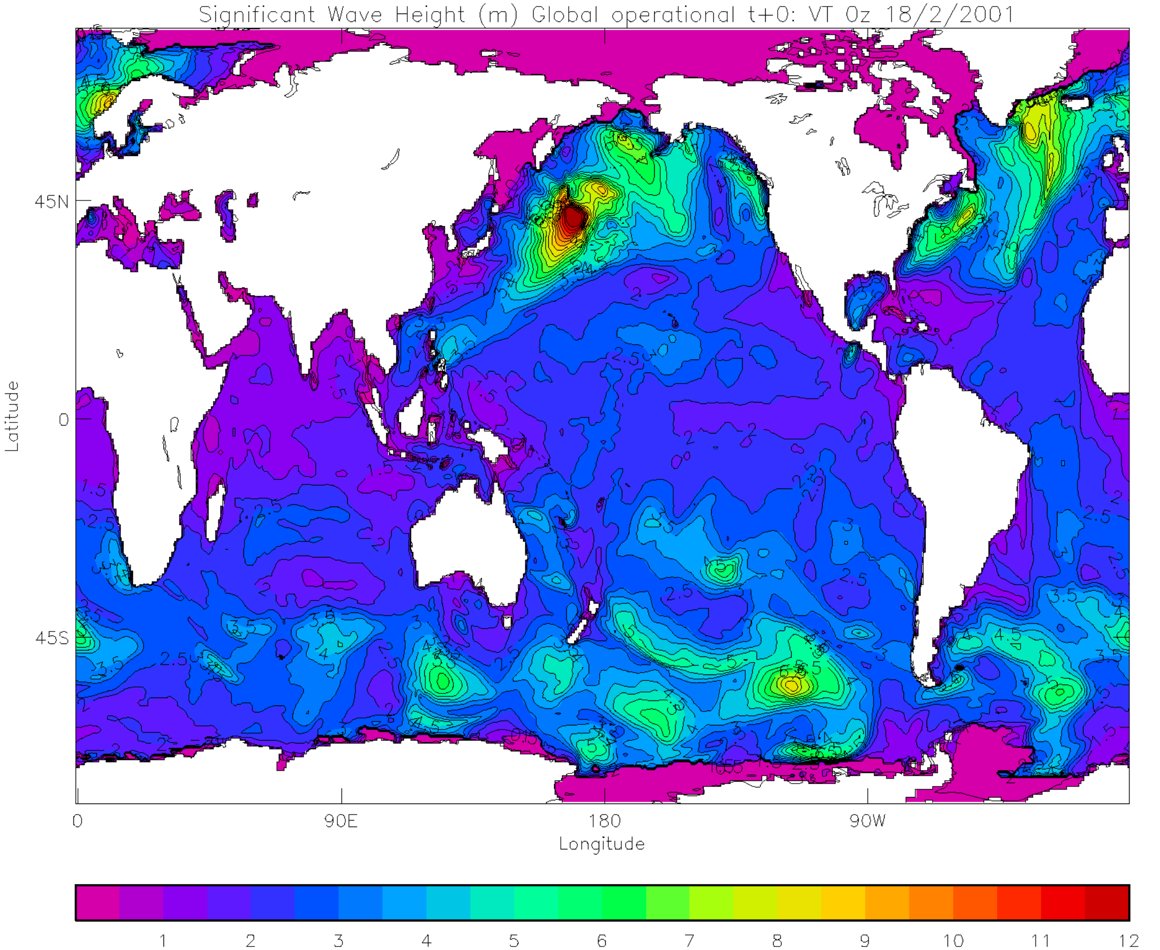
Temperature and current at a depth of 300 m predicted on 24/01/2001 with a 2-week lead (forecast for 07/02/2001)

Results from the MERCATOR project (France)

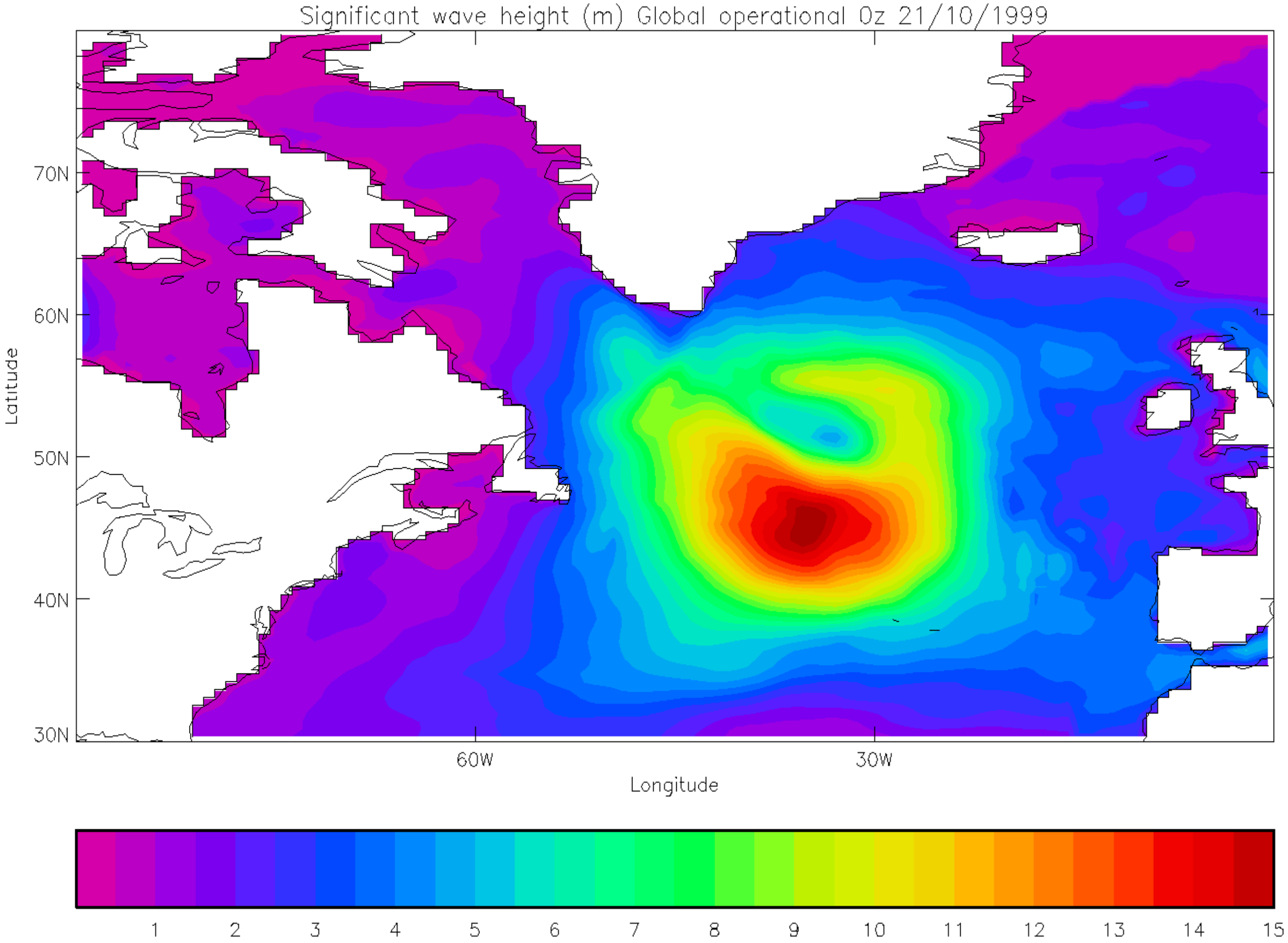


Met Office Global wave model

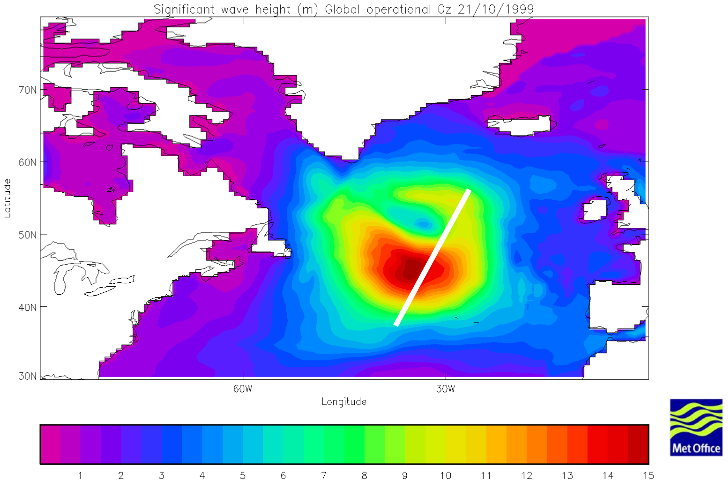
Significant wave height 00z 18 February 2001 (includes altimeter data)

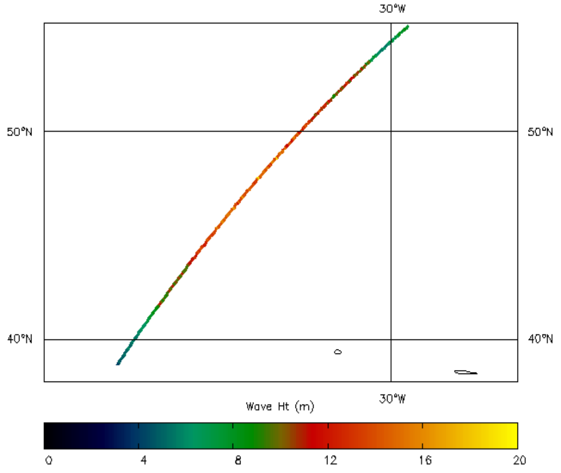


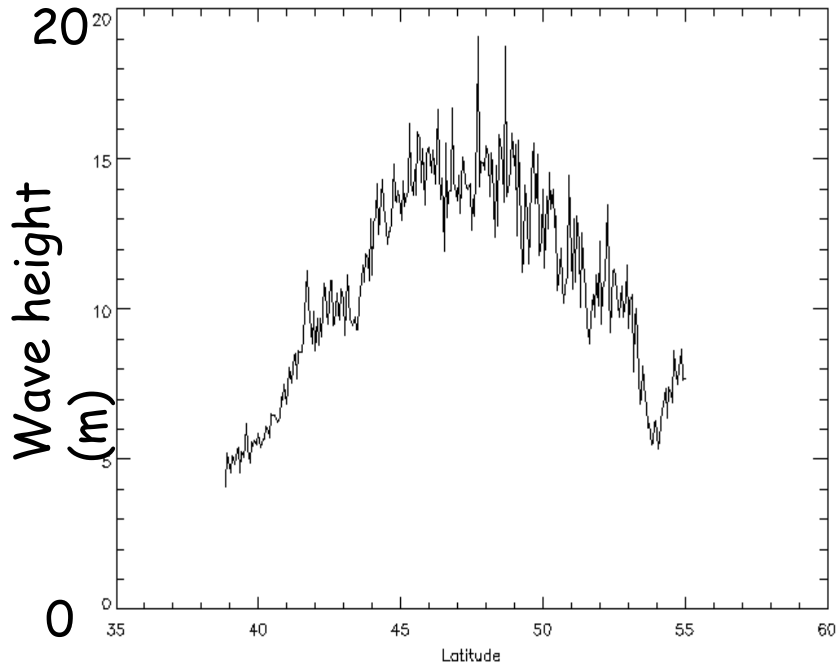
Ex-hurricane Irene 21/10/1999
Met Office global wave model (altimeter data included) sig wave height



Ex-hurricane Irene 21/10/1999







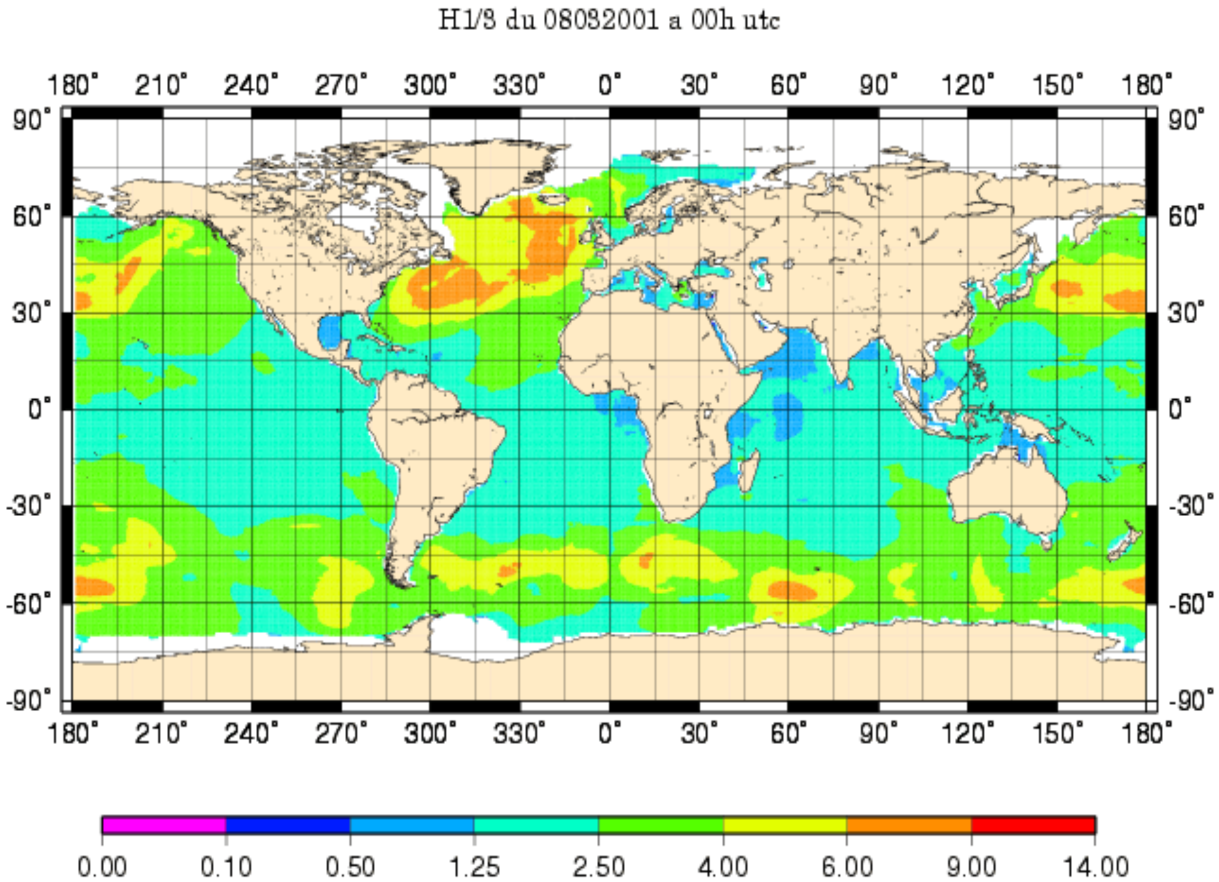
Altimeter track at 13.20

20 October 1999

École d'

European Space Agency

Map of Significant Wave height derived from the global wave model VAG from Meteo-France, 8 March 2001 at 0:00 UTC.



Analyses Increments (Analysis minus First Guess) from assimilation of ERS-2 altimeter wave height valid for 8 March 2001 at 00 UTC (only Increments larger than half a meter are represented).

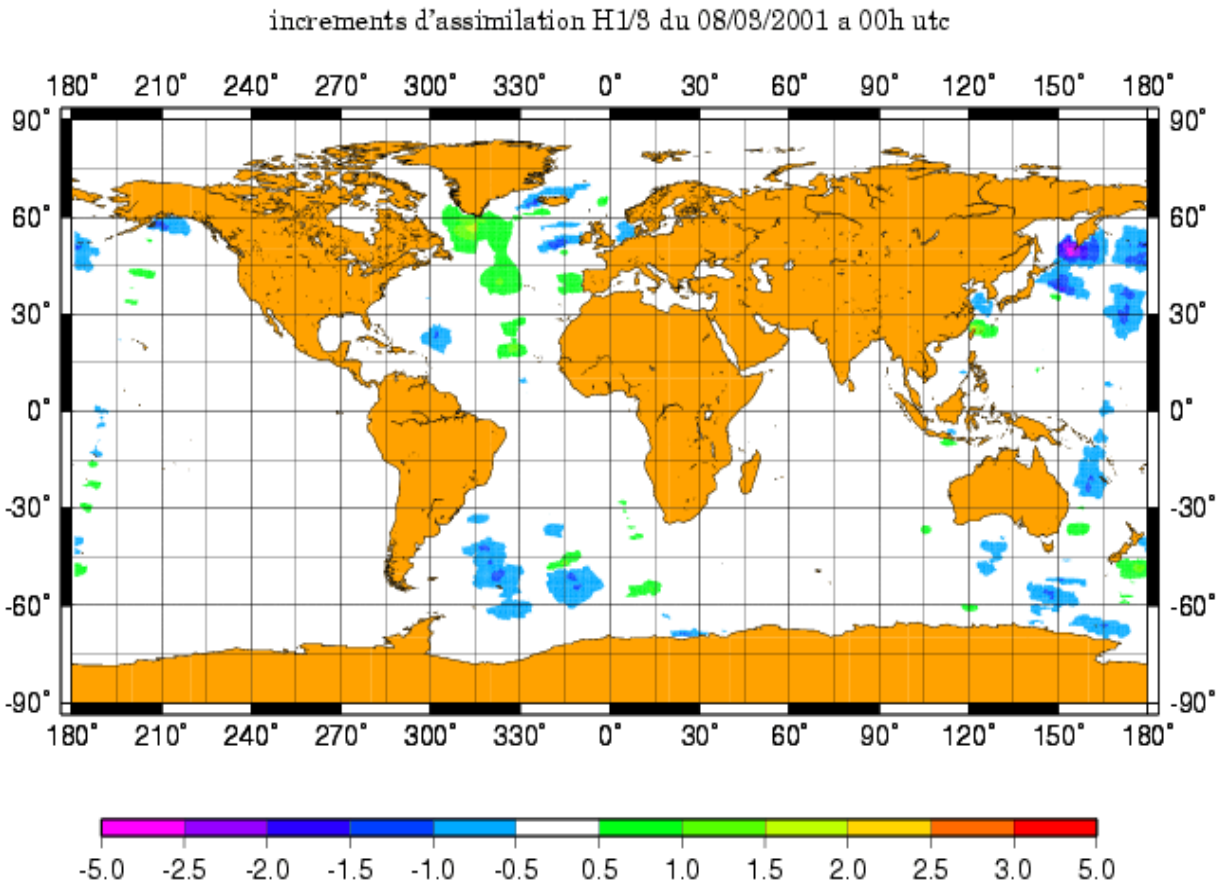
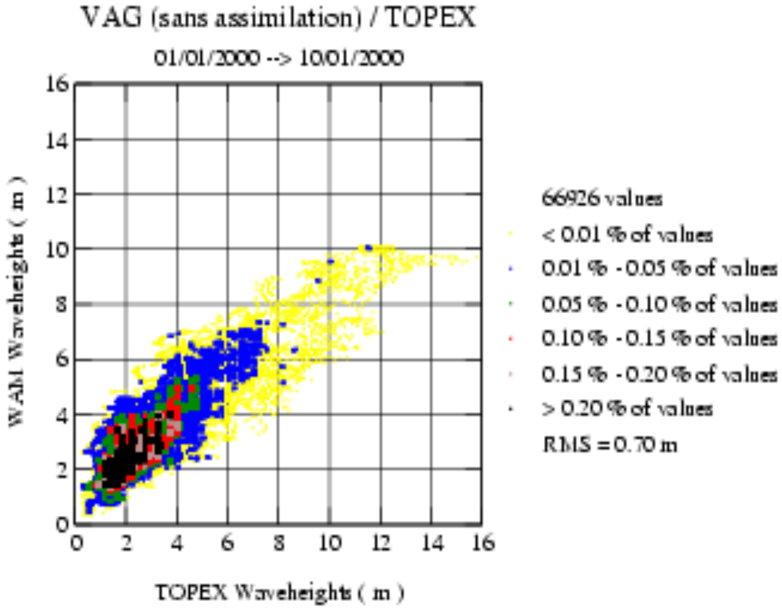
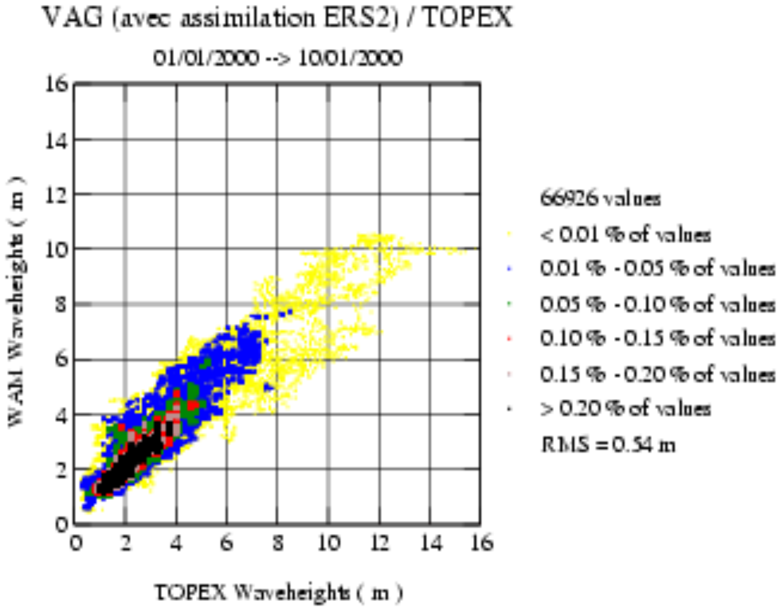


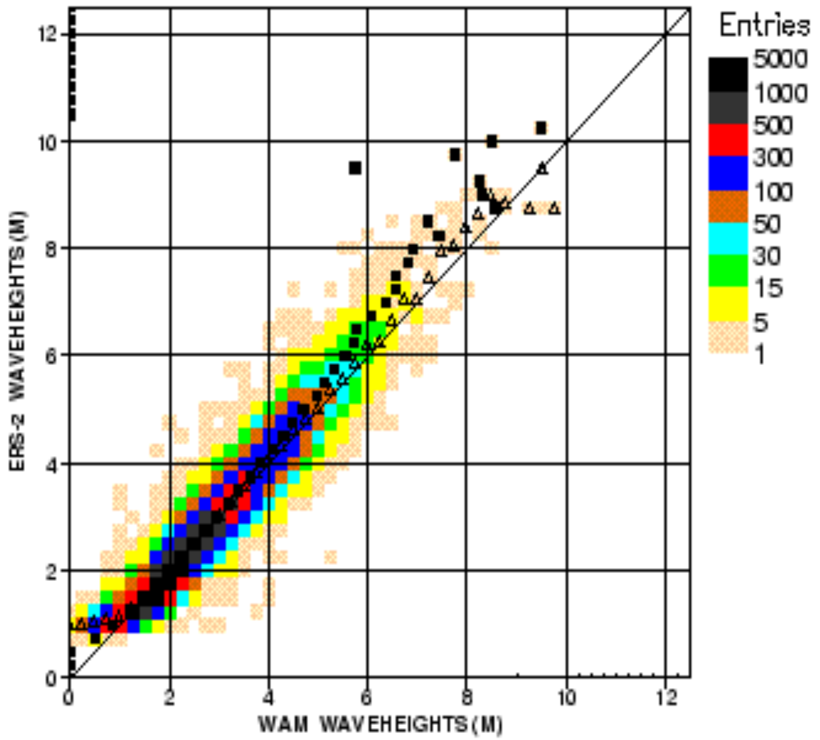
Figure 3. Comparison of model SWH with TOPEX SWH: left panel without assimilation, right panel with assimilation of ERS2 SWH for a ten days period over the whole globe.





METEO FRANCE

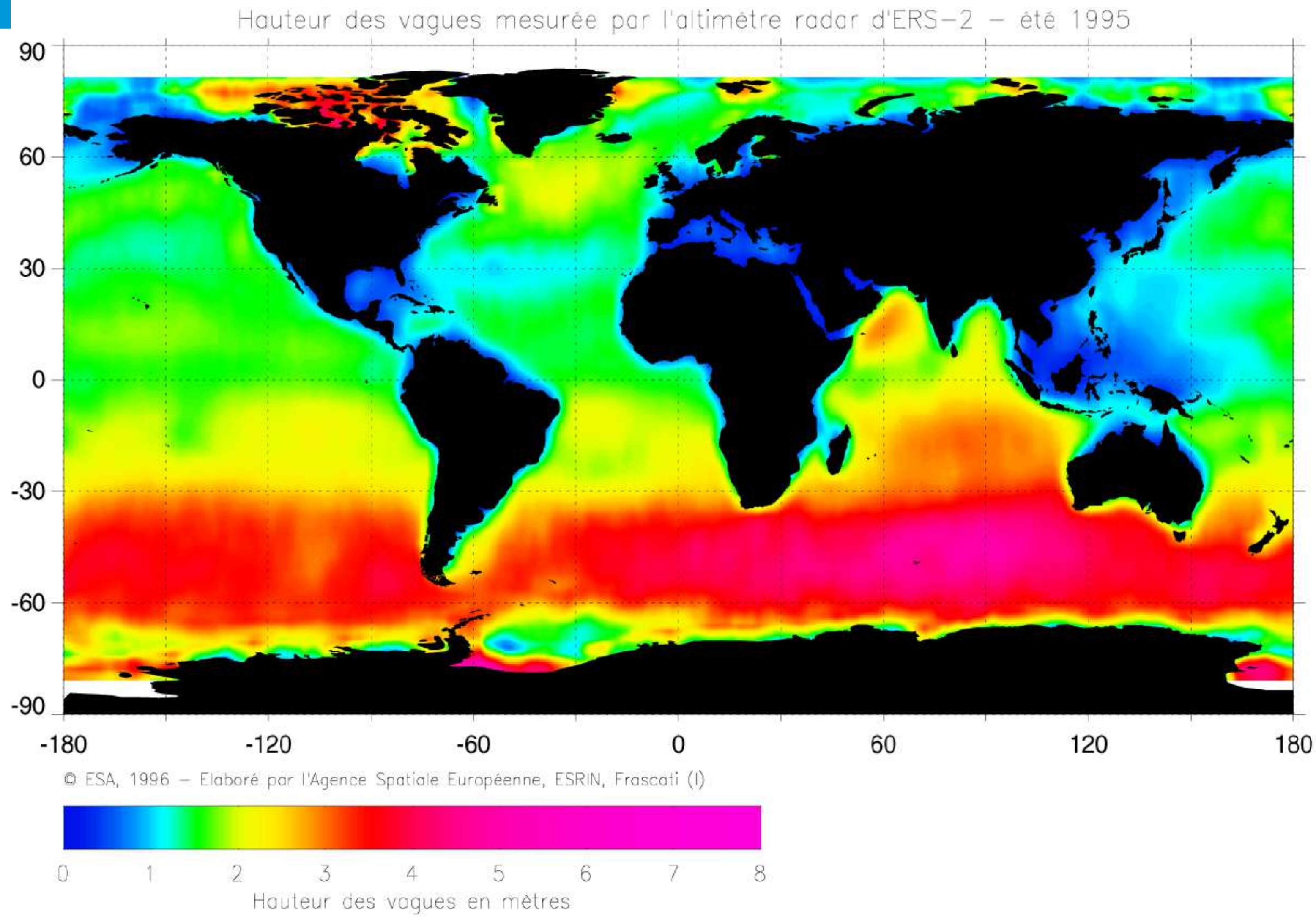
SWH Validation at ECMWF



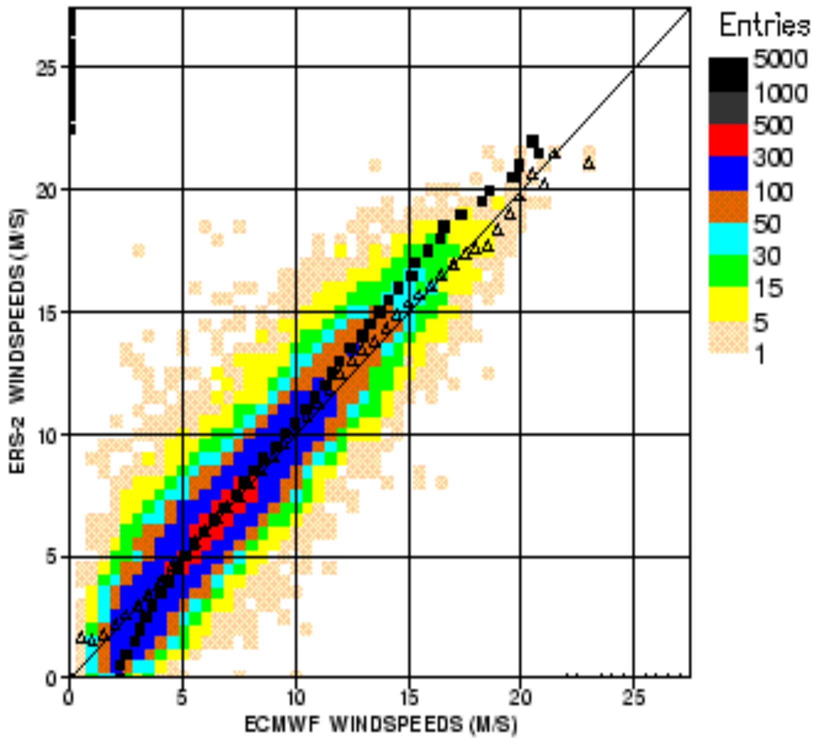
STATISTICS

ENTRIES	39327
MEAN WAM	2.5129
MEAN ERS-2	2.5389
BIAS (ERS-2 - WAM)	0.0260
STANDARD DEVIATION	0.3218
SCATTER INDEX	0.1281
CORRELATION	0.9589
SYMMETRIC SLOPE	1.0181 (0.0015)
REGR. COEFFICIENT	1.0163 (0.0015)
REGR. CONSTANT	-0.0149 (0.0041)

Figure 17. Comparison of ECMWF wave height results with ERS2 Altimeter wave height data for April 1999 (global)


Hauteur des vagues mesurée par l'altimètre radar d'ERS−2 − été 1995
90
60
30
0
-30
-60
-90
-180
-120
-60
0
60
120
180
© ESA, 1996 − Elaboré par l'Agence Spatiale Européenne, ESRIN, Frascati (I)
0 1 2 3 4 5 6 7 8
Hauteur des vagues en mètres

Wind Speed Validation at ECMWF

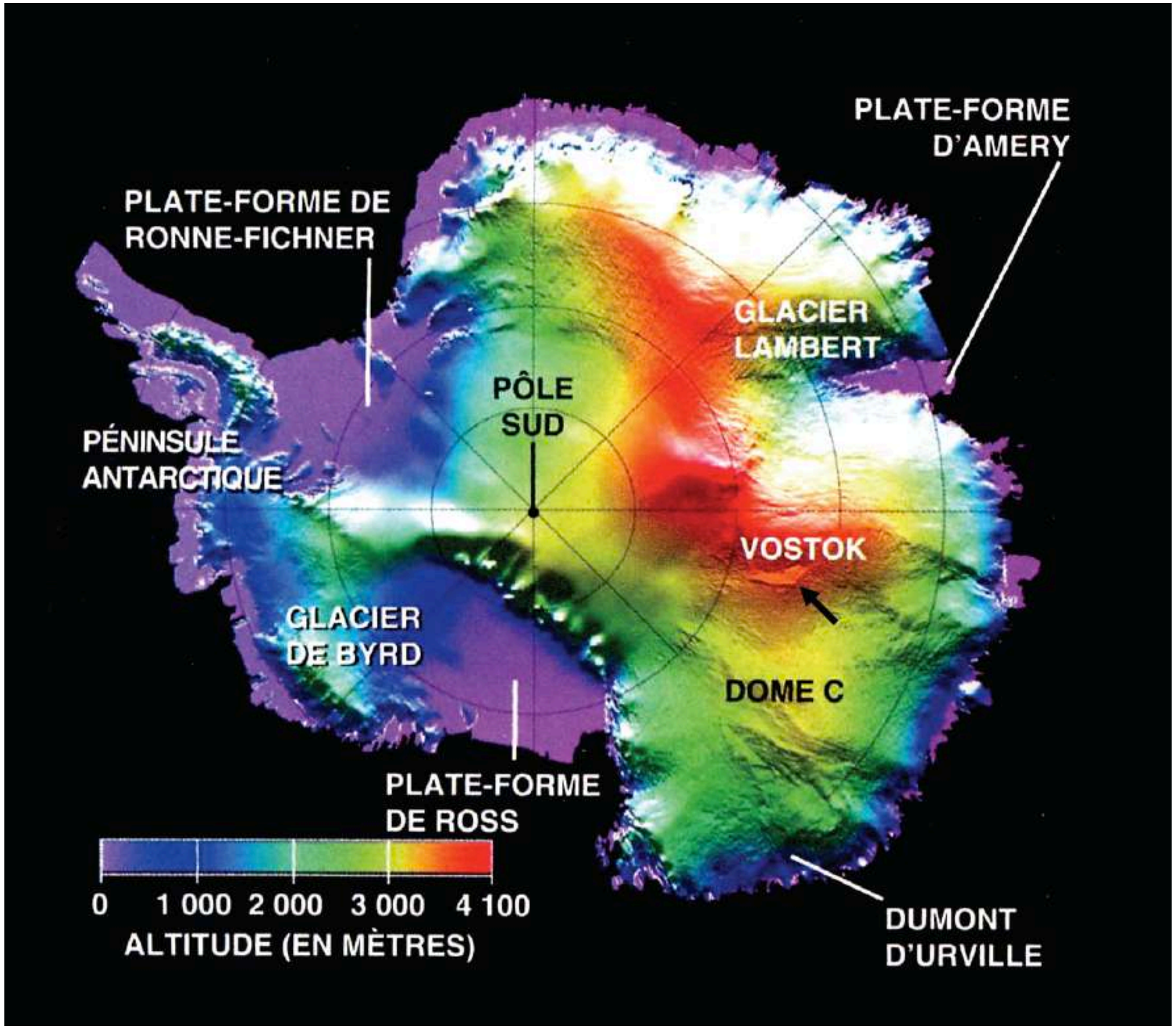


STATISTICS

ENTRIES	39327
MEAN ECMWF	7.2805
MEAN ERS-2	7.3910
BIAS (ERS-2 - ECMWF)	0.1104
STANDARD DEVIATION	1.4519
SCATTER INDEX	0.1994
CORRELATION	0.9241
SYMMETRIC SLOPE	1.0322(0.0021)
REGR. COEFFICIENT	1.0215(0.0021)
REGR. CONSTANT	-0.0458(0.0171)

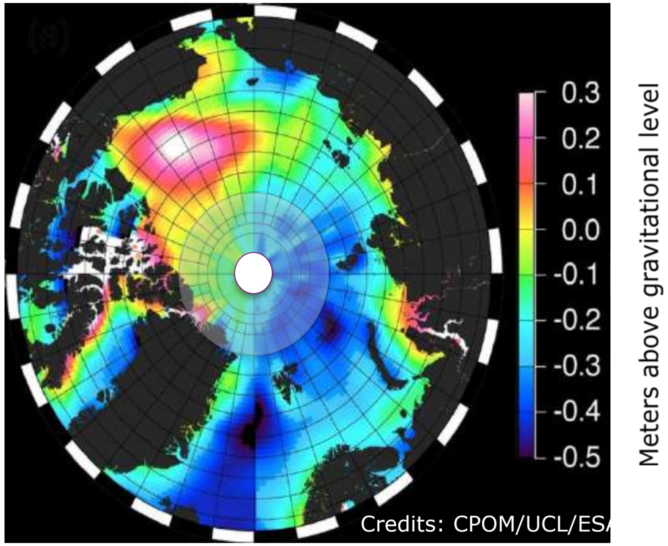
Figure 6. Comparison of ECMWF wind speed results with ERS2 Altimeter wind speed data for April 1999 (global)

Ice Sheets DEM and Mass Balance

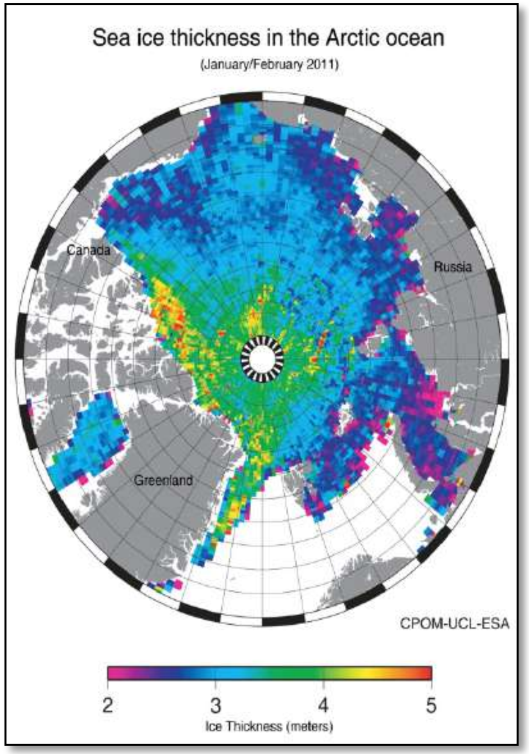


LEGOS

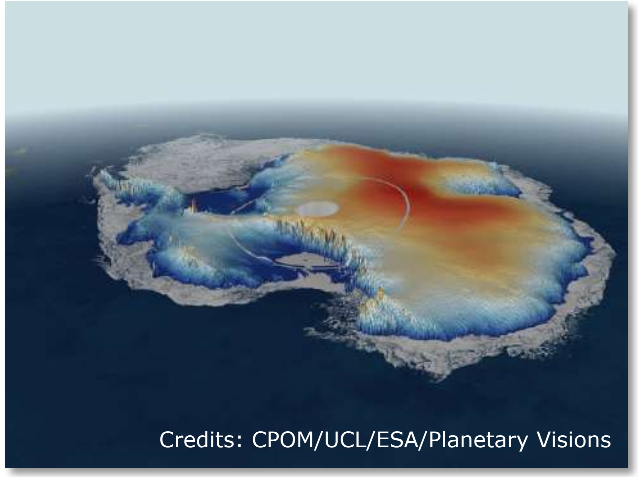
CryoSat Applications



Dynamic Topography: SAR mode operations reveal the first complete picture of ocean dynamic topography in the Arctic ocean up to 88° latitude



Arctic sea-ice thickness: First view of the sea-ice thickness across the entire Arctic Ocean basin



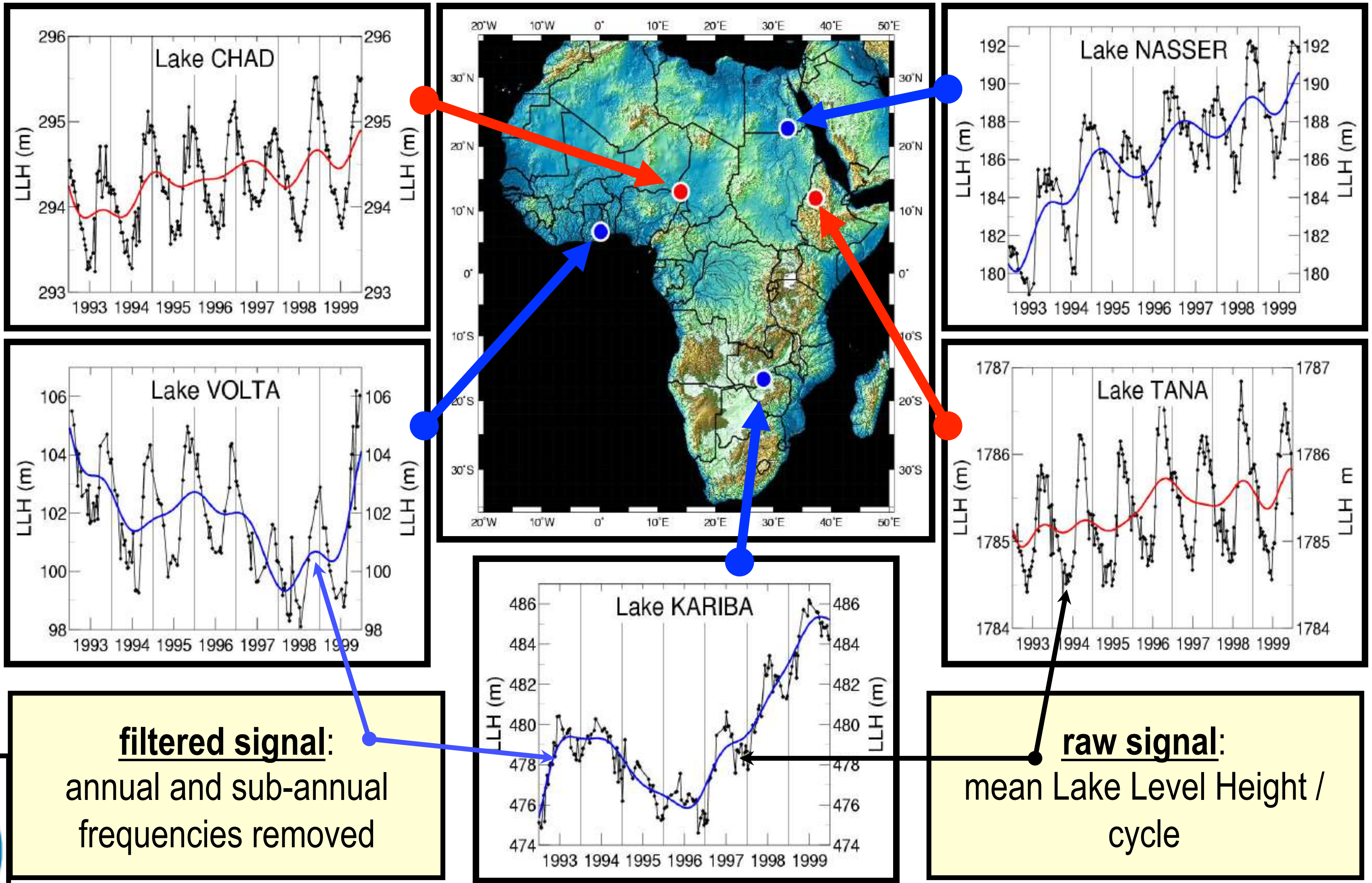
Antarctic ice sheet DEM 88°S: Details of the Antarctica ice-sheet measured by CryoSat

CryoSat paving the way for SAR altimetry use from AltiKa, S-3A/-3B & Jason-CS

“Non-East Africa’s” Lakes

unregulated level

reservoir



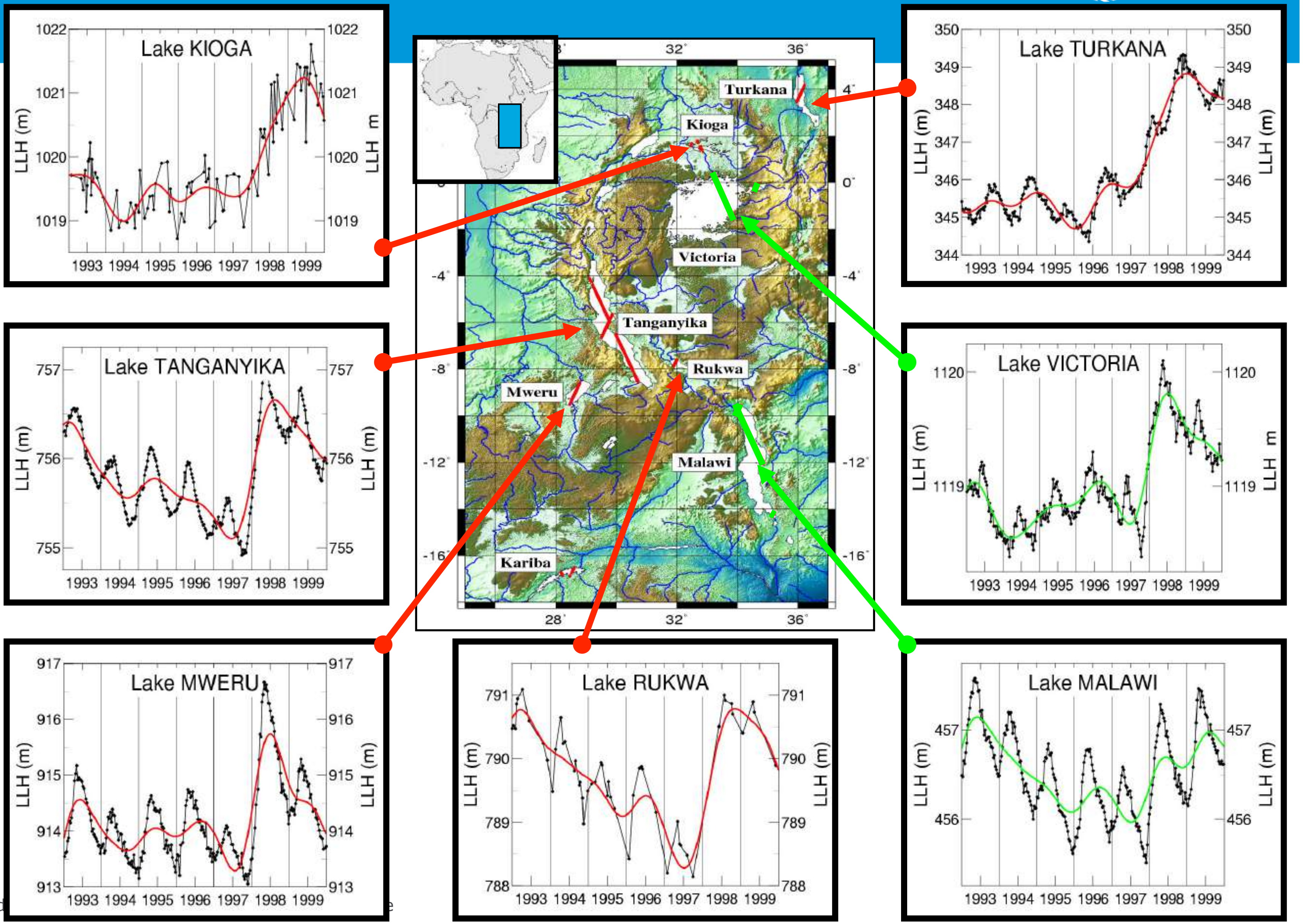
filtered signal: annual and sub-annual frequencies removed

raw signal: mean Lake Level Height / cycle

CLASSIFIED – For Official Use

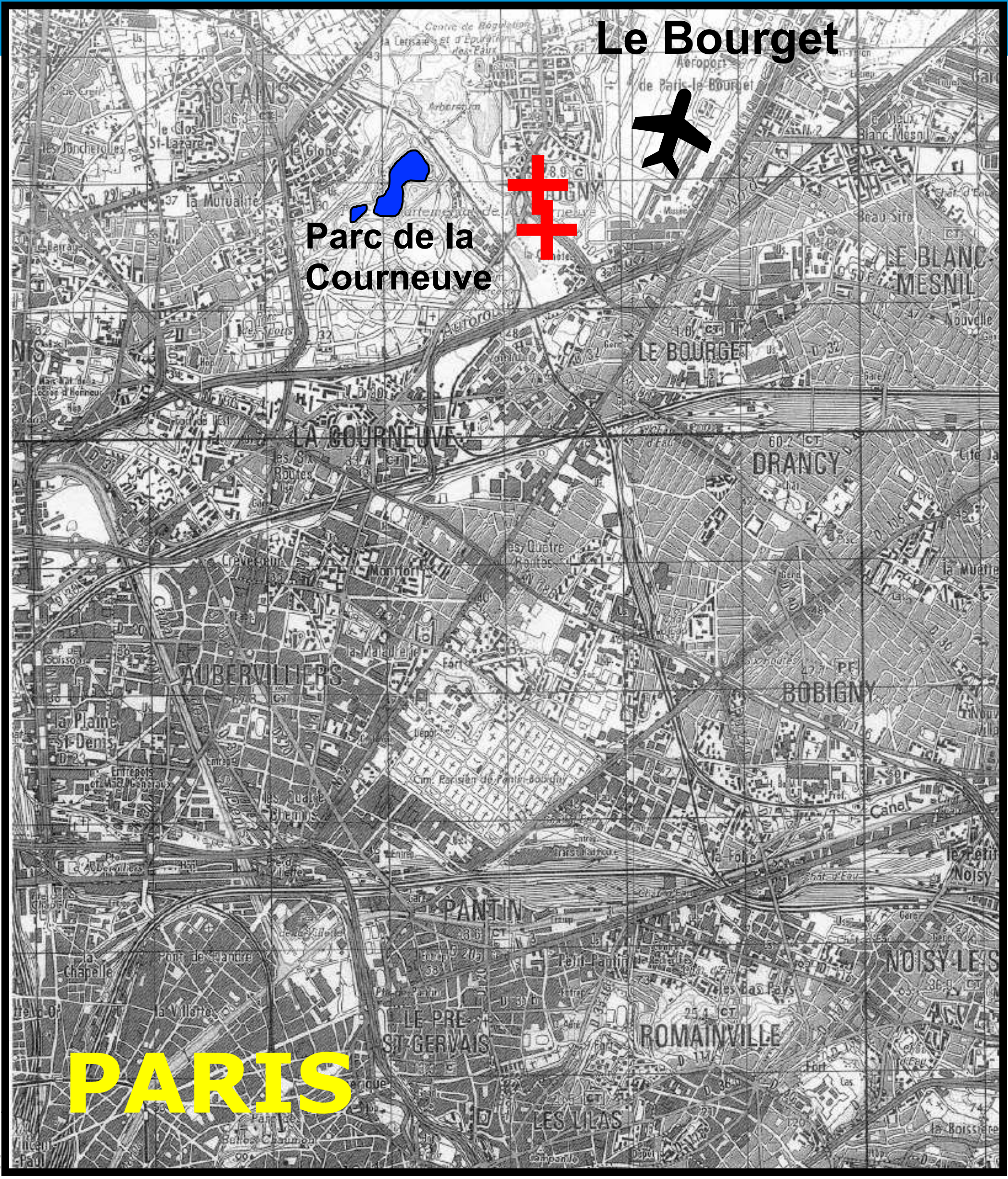
Thèse Franck Mercier, 2001

East Africa's Lakes



Thèse Franck Mercier, 2000

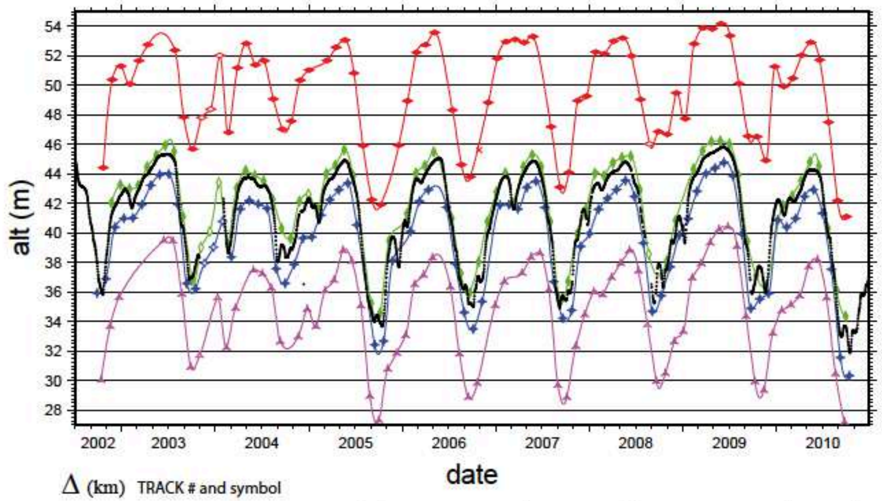
France: Mesures Spéculaires (ERS-2 35j)



- **mesures ERS-2:**
  33.9 et 33.4 m
- **IGN:**
  33 m

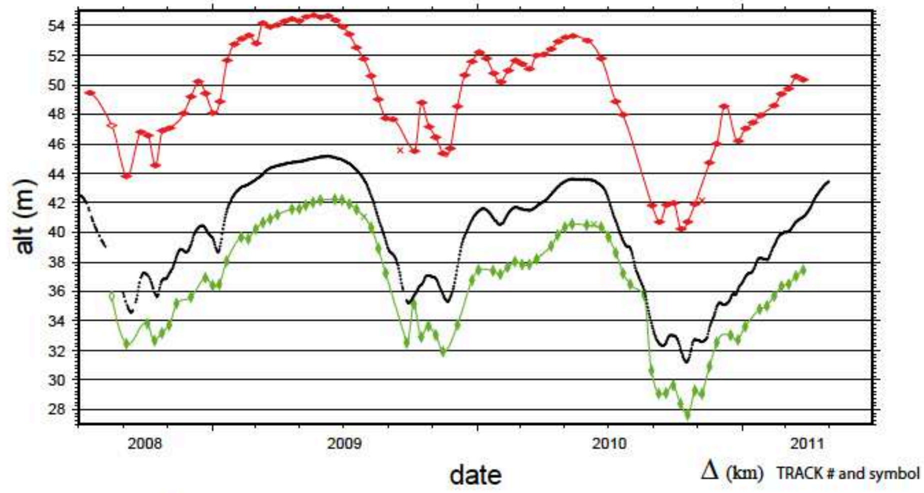
Thèse Franck Mercier, 2000

Amazon River Level



Δ (km) TRACK # and symbol

+260 579 Upstr
+10 493
-34 908 Downstr
-179 364



Δ (km) TRACK # and symbol

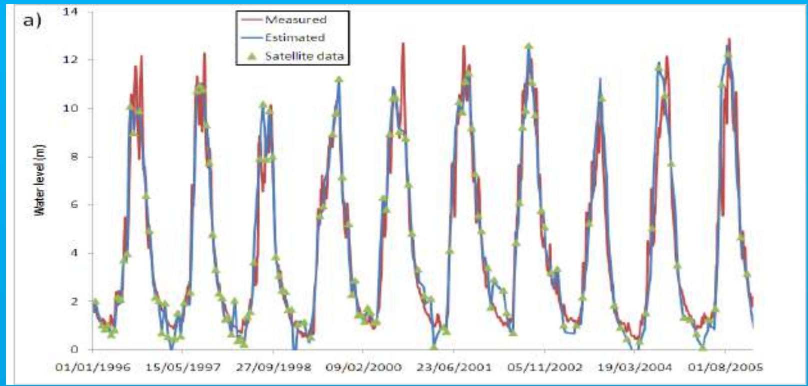
+288 178 Upstr
-95 493 Downstr

Example of pseudo-levelling of a gage (Fonte Boa, Solimoes river) bracket by 5 ENVISAT tracks (left) and by 2 Jason-2 tracks (right)

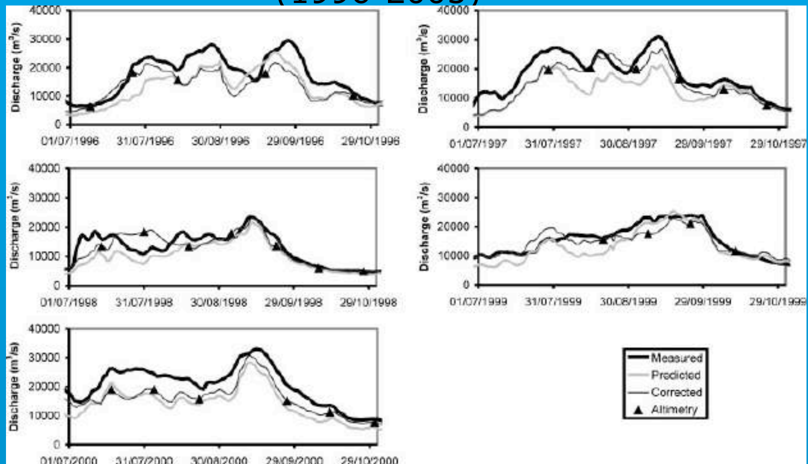
Calmant et al, 2012

Near-Real-Time River and Lake Water Level and Discharge

Birkinshaw, S. J., O'Donnell, G. M., Moore, P., Kilsby, C. G., Fowler, H. J. and Berry, P. A. M. (2010), Using satellite altimetry data to augment flow estimation techniques on the Mekong River. Hydrol. Process., 24: 3811–3825. doi: 10.1002/hyp.7811



Measured and estimated water levels at Nakhon Phanom on the Mekong (1996-2005)



Measured and estimated flows at Nakhon Phanom on the Mekong

Topic: Hydrology, water management.

Scientific Highlight: Exploitation of Radar Altimetry to measure continental surface water levels, assimilation in basin models, estimation of flow.

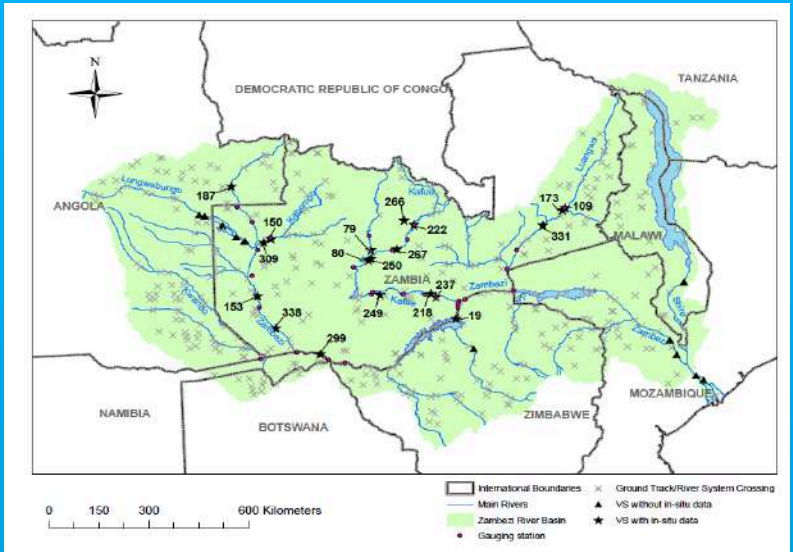
Data Used: Multi-Mission Radar Altimetry (ERS, Topex-Poseidon, Envisat, jason-1/2). Landsat imagery

Why is it Relevant?: Remote sensing data provides data in inaccessible locations and ungauged catchments. Satellite altimetry as a virtual gauge has the capability for near real time monitoring of inland waters and with hydrological modeling near real time discharge for flood forecasts. Utilizing retracked waveforms from ERS-2 and ENVISAT along the Mekong, comparisons against observed stage measurements show that the altimetric measurements have an average root mean square error of 0.5 m. Stage is insufficient because discharge is the primary requirement. Investigations were therefore undertaken to estimate discharges at a downstream site (Nakhon Phanom (NP)). The use of altimetric stage data is shown to improve estimated discharges. Current studies used as a pilot demonstration for near real time water and floods forecasts from Sentinel-3.

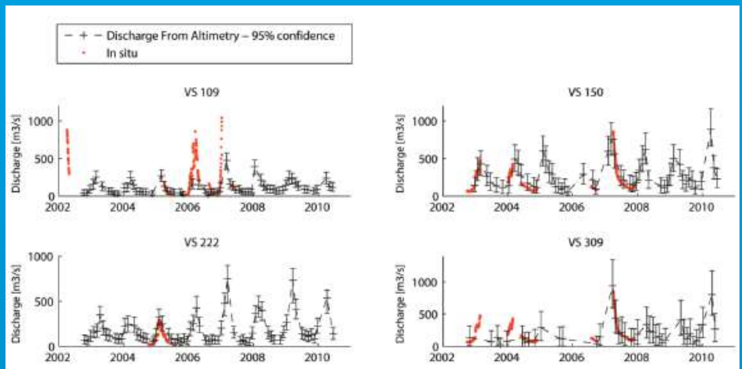
Scientific Impact - Very High ○ ; High X ; Medium ○

River Monitoring from Satellite Radar Altimetry

Michailovsky, C. I., McEnnis, S., Berry, P. A. M., Smith, R., and Bauer-Gottwein, P.: River monitoring from satellite radar altimetry in the Zambezi River basin, Hydrol. Earth Syst. Sci., 16, 2181-2192, doi:10.5194/hess-16-2181-2012, 2012.



Location of the virtual stations and monitoring stations in the Zambesi basin.



Comparison of measured and simulated discharge from altimetry and field measurements

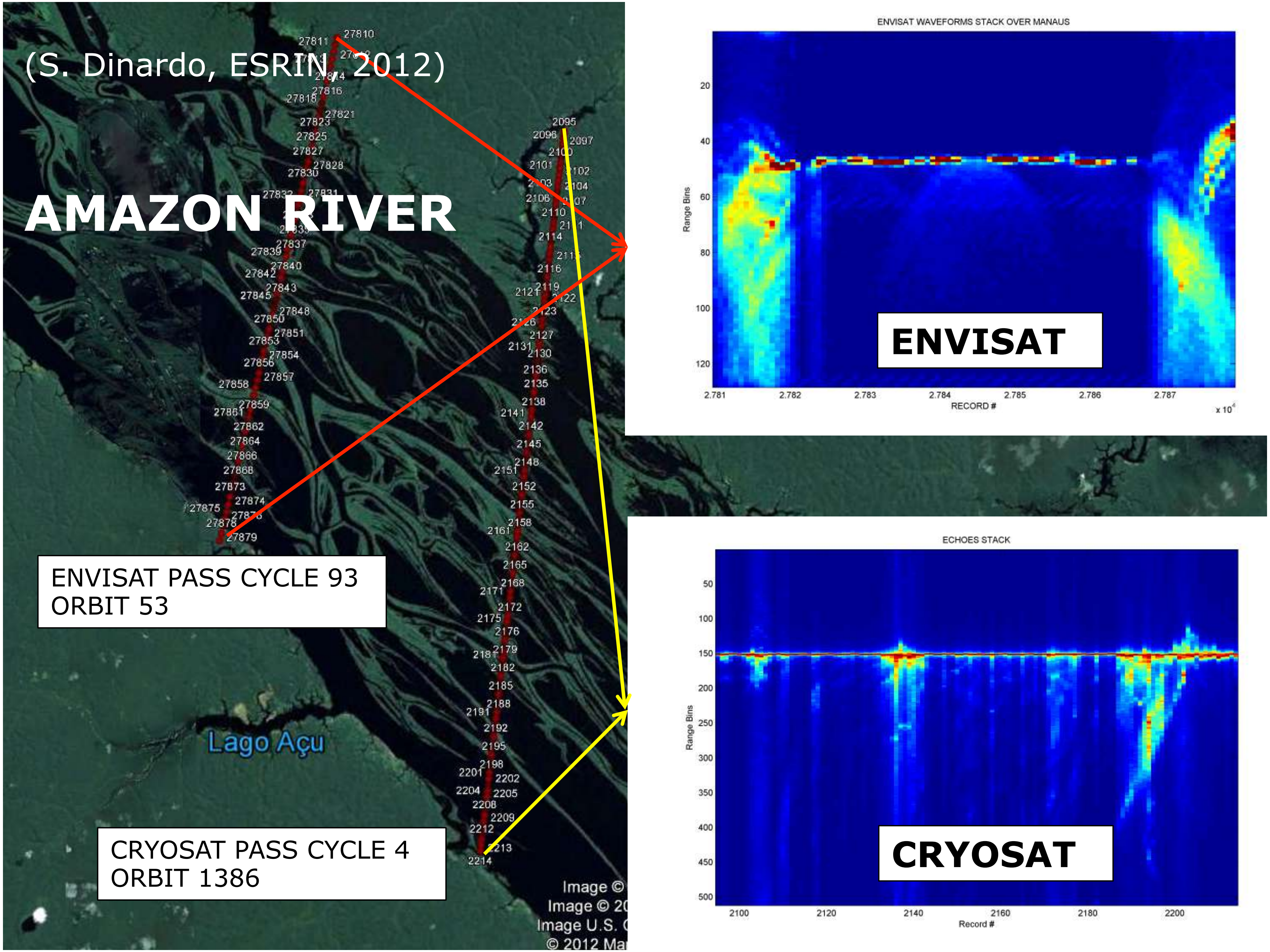
Topic: Hydrology, water management.

Scientific Highlight: The objective of this study is the assessment of the potential for river monitoring from radar altimetry in terms of water level and discharge in the Zambezi River basin.

Data Used: Retracked Envisat altimetry data were extracted over the Zambezi River basin to supply stage measurements for rivers down to 80m wide with an RMSE relative to in situ levels of 0.32 to 0.72m at different locations. The altimetric levels were then converted to discharge using three different methods adapted to different data-availability scenarios. with standard deviations between 5.7 and 7.2% of the mean annual in situ gauge.

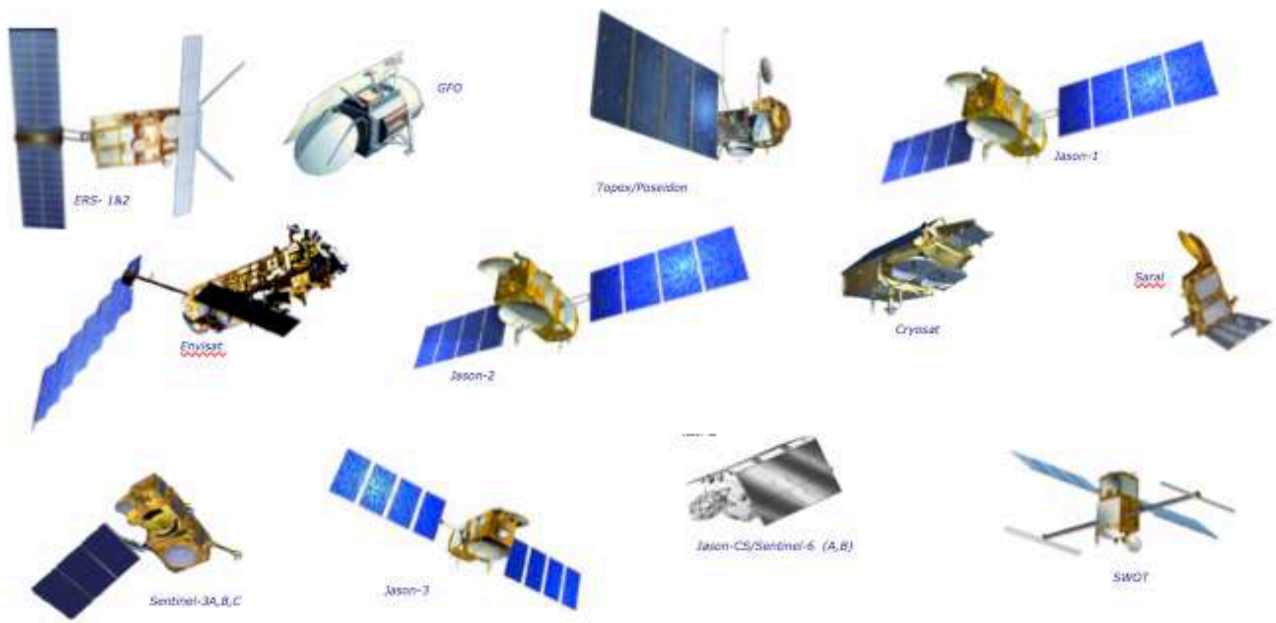
Why is it Relevant?: While no current remote-sensing technique is capable of directly measuring discharge, radar altimeters measure water surface elevation over rivers, which can then be converted to discharge. While the time resolution of Envisat remains insufficient for many applications, it is expected that assimilating these data within a basin-scale hydrological model will improve discharge estimates on finer time and spatial scales than the satellite resolution.

Scientific Impact - Very High ○ ; High X ; <u>Medium</u> ○ :



(S. Dinardo, ESRIN, 2012)
AMAZON RIVER
ENVISAT PASS CYCLE 93
ORBIT 53
CRYOSAT PASS CYCLE 4
ORBIT 1386
Lago Açu
ENVISAT WAVEFORMS STACK OVER MANAUS
Range Bins
RECORD #
x 10⁴
ENVISAT
ECHOES STACK
Range Bins
Record #
CRYOSAT

- les missions spatiales



Les missions spatiales

esa

Altimeter summary (Glackin, 2004; Glackin & Peltzer, 1999; Kramer, 2001)

Platform	Instrument	Country or agency	Frequencies (GHz)	1HZ sea-level measurement accuracy (cm)	Pulse limited footprint (km)	Orbit alt (km)	Launch date
Skylab	S-193	USA	13.9	90	8	435	May 1973
GEOS-3	ALT	USA	13.9	20/50	3.5	838	April 1975
Seasat	ALT	USA	13.5	10	1.7	799	June 1978
Geosat	Radar Alt	USA	13.5	5	1.7	800	March 1985
ERS-1	RA-1	ESA	13.8	5 to 7	1.7	784	July 1991
TOPEX/Poseidon	ALT, SSALT	USA/France	5.3/13.6	4.2	2.2	1336	August 1992
ERS-2	RA-1	ESA	13.8	5 to 7	1.7	784	April 1995
Mir-Priroda	Greben	Russia	13.8	10	2.3	400	April 1996
Geosat follow-On	RA	USA	13.5	3.5	2	800	February 1998
Jason-1	Poseidon-2	France/USA	5.3/13.6	3.3	2.2	1336	December 2001
ENVISAT	RA-2	ESA	3.2/13.6	4.5	1.7	800	March 2002
CryoSat	SIRAL	ESA	5.3/13.6	5 to 7	1.6	720	2005[a]
Jason-2/OSTM		France/USA	5.3/13.6	3.3	2.2	1336	2008[a]

[a] Estimated.

ELSEVIER

Available online at www.sciencedirect.com

SCIENCE DIRECT

Remote Sensing of Environment 94 (2005) 384–404

Remote Sensing of Environment

www.elsevier.com/locate/rse

From Evans et al., 2014

Seasat—A 25-year legacy of success

Diane L. Evans[a,*], Werner Alpers[b], Anny Cazenave[c], Charles Elachi[a], Tom Farr[a], David Glackin[d], Benjamin Holt[a], Linwood Jones[e], W. Timothy Liu[a], Walt McCandless[f], Yves Menard[g], Richard Moore[h], Eni Njoku[a]

Les missions spatiales

Name	Seasat	Geosat	ERS-1	ERS2	ENVISAT	TOPEX/POSEIDON	Jason 1/2
country	USA	USA	Europe	Europe	Europe	USA/France	USA/France
Mission Period	Jul., 1978 -Oct., 1978	Mar., 1985 -Dec., 1989	Jul., 1991 -May, 1996	Apr., 1995 - Jun.,2003	Mar.,2002 -present	Aug.,1992	Dec., 2001
Altitude of orbit(km)	800	800	785	785	785	1336	1336
Inclination of orbit(degree)	108	108	98.5	98.5	98.5	66	66
Equatorial Ground Track Interval (km)	800,160	164	20-80	80	80	318	318
Period (days)	3,17	17	3,35,168	35	35	10	10
Measurement Accuracy(cm)	5	4	3	3	3	2	2

+ CryoSat, SARAL/AltiKa,
Jason-3, Sentinel-3 (A,B,C), ICESat-2, Jason-CS/S6 (A,B), SWOT

GEOS-3

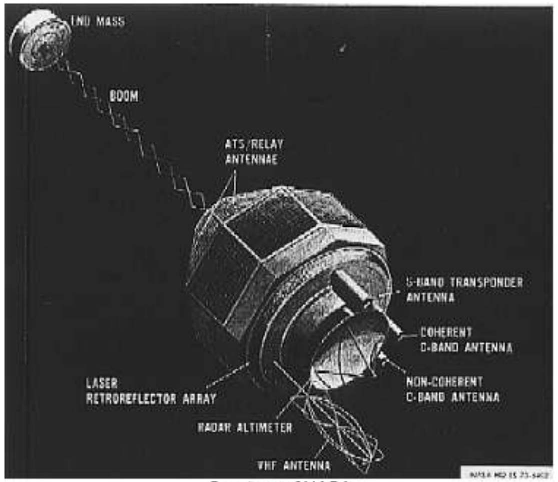
Mission Objectives:

The Geodetic and Earth Orbiting Satellite 3 (GEOS-3) was the third in a series of geodetic missions initiated by NASA. GEOS-3 objectives included defining the structure of the earth's irregular gravitational field and refining the locations and magnitudes of the large gravity anomalies, comparing results of the various systems onboard the spacecraft to determine the most accurate and reliable system, and mapping the ocean surfaces.

Mission Instrumentation:

The following instrumentation was onboard this spacecraft:

- Two C-band antenna
- S-band antenna
- ATS/relay antenna
- VHF antenna
- Radar altimeter
- Doppler beacon
- Retroreflector array

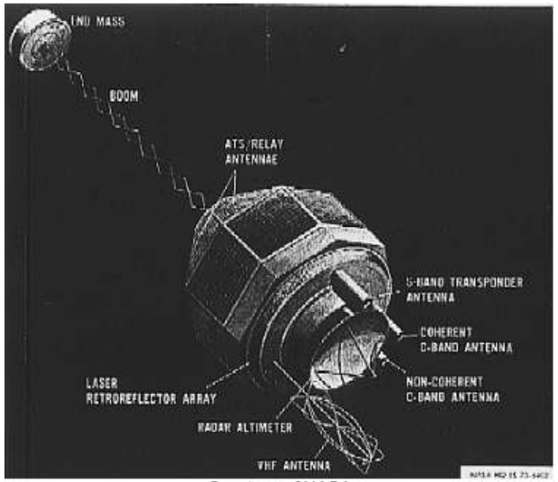


Courtesy of NASA

Data from the ILRS web site : http://ilrs.gsfc.nasa.gov/missions/satellite_missions

GEOS-3 Mission Parameters:

Sponsor:	NASA
Expected Life:	unknown
Primary Applications:	ocean mapping and gravity
Primary SLR Applications:	gravity
COSPAR ID:	7502701
SIC Code:	1127
NORAD SSC Code:	7734
Launch Date:	9 April 1975
End of mission:	1978
RRA Diameter:	57.2 cm
RRA Shape:	annulus
Reflectors:	264
Orbit:	circular
Inclination:	115 degrees
Eccentricity:	0.001
Perigee:	824 km
Period:	102 minutes
Weight:	346 kg



Courtesy of NASA

Seasat-1

Mission Objectives:

Seasat was the first satellite designed for remote sensing of the Earth's oceans with synthetic aperture radar (SAR). The mission was designed to demonstrate the feasibility of global satellite monitoring of oceanographic phenomena and to help determine the requirements for an operational ocean remote sensing satellite system. Specific objectives were to collect data on sea-surface winds, sea-surface temperatures, wave heights, internal waves, atmospheric water, sea ice features and ocean topography. The mission ended on 10 October 1978 due to a failure of the vehicle's electric power system. Although only approximately 42 hours of real time data was received, the mission demonstrated the feasiblity of using microwave sensors to monitor ocean conditions, and laid the groundwork for future SAR missions. The major difference between Seasat-A and previous Earth observation satellites was the use of active and passive microwave sensors to achieve an all-weather capability.

Laser data obtained by tracking stations of the day (prior to the formation of the ILRS) were used by NASA GSFC in the construction of tailored Seasat gravity models PGS-S1 and PGS-S2 (consisting of 16,500 observations).

Mission Instrumentation:

Seasat had the following instrumentation onboard:

- Radar altimeter
- Scatterometer system
- Synthetic aperture radar
- Visible and infrared radiometer
- Scanning multi-channel microwave radiometer
- Retroreflector array

Courtesy of NASA GSFC

Seasat-1

Mission Parameters:

Sponsor:	NASA
Expected Life:	1-3 years (stop functioning on 10 October 1978)
Primary Applications:	ocean topography
Primary SLR Applications:	calibrate radar altimeter
COSPAR ID:	7806401
SIC Code:	
NORAD SSC Code:	10967
Launch Date:	June 28, 1978
End of mission:	October 10, 1978
RRA Diameter:	
RRA Shape:	
Reflectors:	
Orbit:	near polar
Inclination:	108 degrees
Repeat cycle:	3 and 17 days
Eccentricity:	0.001
Perigee:	793 km
Period:	100 minutes
Weight:	2290 kg

Courtesy of NASA GSFC

ERS-1

Mission Objectives:

The European Remote Sensing satellite, ERS-1, is part of a family of multi-disciplinary Earth Observation Satellites (ERS-1, ERS-2, Envisat-1). In its first three years, ERS-1 has revolutionized many areas of the Earth sciences and their practical applications. The ERS user community is now made up of thousands of scientists and hundreds of universities, research institutes and firms from all parts of the world. ERS-2 is the follow-on mission to ERS-1 and was launched in April 1995. Both satellite having similar instrumentation, allowing applications to profit from the tandem operation of both satellites.

PRARE system failed shortly after launch and Satellite Laser Ranging (SLR) became the only technique for determining ERS-1 precision orbits. The SLR precision orbits are used to calibrate the radar altimeter. ERS-1 was the first European satellite to carry a radar altimeter.

The calibrated radar altimeter data is used to determine ocean surface heights. This ocean height data, in turn, is used to monitor global ocean circulation, regional ocean current systems, and study the marine gravity field.

Mission Instrumentation:

ERS-1 has the following instrumentation onboard:

- Synthetic aperture radar
- Wind scatterometer
- Radar altimeter
- Along-track scanning radiometer
- Microwave sounder
- Precise Range and Range-Rate Equipment (PRARE)
- Retroreflector array

ERS-1

Mission Parameters:

Sponsor:	European Space Agency
Expected Life:	3 years, (has been exceeded)
Primary Applications:	remote sensing and environmental monitoring
Primary SLR Applications:	calibration of satellite altimeter
COSPAR ID:	9105001
SIC Code:	6177
NORAD SSC Code:	21574
Launch Date:	July 17, 1991
End of mission:	March 10, 2000
RRA Diameter:	20 cm
RRA Shape:	hemispherical
Reflectors:	9 corner cube
Orbit:	circular
Inclination:	98.5 degrees
Repeat cycle:	35 days
Eccentricity:	0.001
Perigee:	780 km
Period:	100 minutes
Weight:	2400 kg

TOPEX/Poseidon

Mission Objectives:

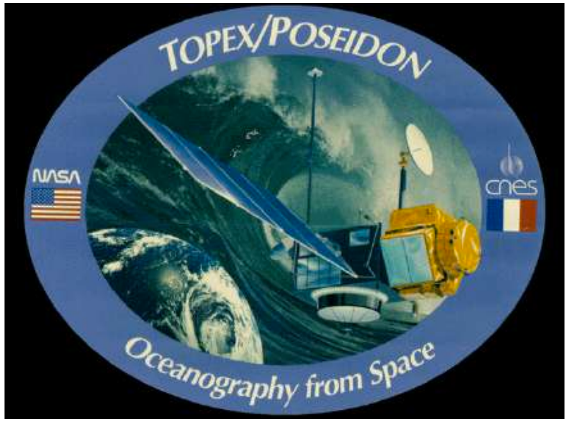
Ocean TOPography Experiment (TOPEX)/Poseidon, also known as Poseidon and it's follow on mission, Jason, were designed to explore ocean circulation and its interaction with the atmosphere. It complements a number of international oceanographic and meteorological programs, including the World Circulation Experiment (WOCE) and the Tropical Ocean and Global Atmosphere (TOGA) Program, both of which are sponsored by the World Climate Research Program (WCRP). TOPEX/Poseidon's three-year prime mission ended in fall 1995 and the mission successfully moved into its extended observational phase. Jason, launched in 2001, continues this program of long-term observations of ocean circulation from space. TOPEX/Poseidon was a joint project between the National Aeronautics and Space Administration (NASA) and the French Space Agency, Centre National d'Études Spatiales (CNES).

TOPEX/Poseidon measured sea level along the same path every 10 days using the dual frequency altimeter developed by NASA (NRA) and the CNES single frequency solid-state altimeter Poseidon). Measurements from NASA's Microwave Radiometer provide estimates of the total water-vapor content in the atmosphere, which is used to correct errors in the altimeter measurements. Three independent techniques (SLR, DORIS, and GPS) determine the satellite altitude, used to calibrate the altimeters. These combined measurements allow scientists to chart the height of the seas across ocean basins with an accuracy of 3 centimeters.

Mission Instrumentation:

TOPEX had the following instrumentation onboard:

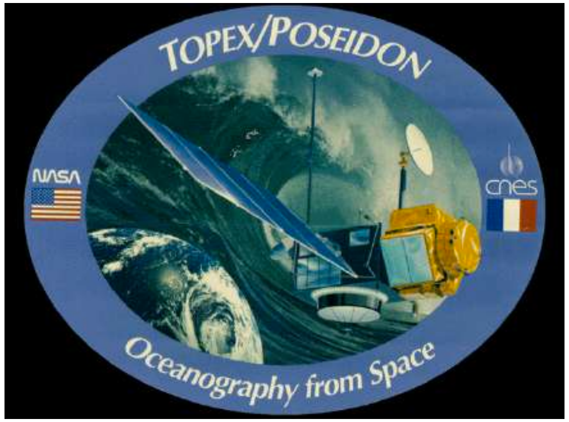
- Tracking and data relay satellite transmitter
- Microwave radiometer
- DORIS dual frequency system receiver
- Single and dual-frequency altimeters
- GPS receiver
- Retro-reflector array



TOPEX-Poseidon

Mission Parameters:

Sponsor:	NASA and CNES
Expected Life:	Several years
Primary Applications:	ocean circulation
Primary SLR Applications:	calibration of satellite altimeter
COSPAR ID:	9205201
SIC Code:	4377
NORAD SSC Code:	22076
Launch Date:	10-Aug-1992
End of mission:	18-Jan-2006
RRA Diameter:	150 cm array
RRA Shape:	annulus array
Reflectors:	192 corner cubes
Orbit:	Circular
Inclination:	66 degrees
Repeat cycle:	10 days
Eccentricity:	0.000
Perigee:	1340 km
Period:	112 minutes
Weight:	2,400 kg



ERS-2

Mission Objectives:

The European Remote Sensing satellite, ERS-2, is the follow-on mission to ERS-1 and was launched in April 1995. ERS-2 will over the years, 1995-98, continue the work begun by ERS-1; however the ERS-2 mission will have to deal with an even more demanding range of tasks. ERS-2 is equipped with additional new instruments that will measure the ozone content of the atmosphere and monitor changes in vegetation cover more effectively. What is more, the European Space Agency (ESA) exercised the option of operating the two craft "in tandem" for a period of time which opened up completely new perspectives for many research teams and high-tech firms.

After 16 years spent gathering a wealth of data that has revolutionised our understanding of Earth, ERS-2 satellite was retired. The science mission ended on July 4, 2011 (orbit # 84719). The lowering of the orbit began shortly after retirement and will last until early September 2011, when a number of long manoeuvres will exhaust the fuel and finally the batteries and communications will be disconnected.

Envisat-1 is the follow-on mission to ERS-2.

Mission Instrumentation:

ERS-2 has the following instrumentation onboard:

- Synthetic aperture radar
- Wind scatterometer
- Radar altimeter
- Along-track scanning radiometer
- Microwave sounder
- Global Ozone Monitoring Experiment (GOME)
- Precise Range and Range-Rate Equipment (PRARE)
- Retroreflector array

ERS-2

Mission Parameters:

Sponsor:	European Space Agency
Expected Life:	3-4 years
Primary Applications:	remote sensing and environmental monitoring
Primary SLR Applications:	calibration of satellite altimeter
COSPAR ID:	9502101
SIC Code:	6178
NORAD SSC Code:	23560
Launch Date:	April 21, 1995
End of mission:	July 6, 2011
RRA Diameter:	20 cm
RRA Shape:	hemispherical
Reflectors:	9 corner cube
Orbit:	circular
Inclination:	98.5 degrees
Repeat cycle:	35 days
Eccentricity:	0.001
Perigee:	785 km
Period:	100 minutes
Weight:	2516 kg

JASON-1

Mission Objectives:

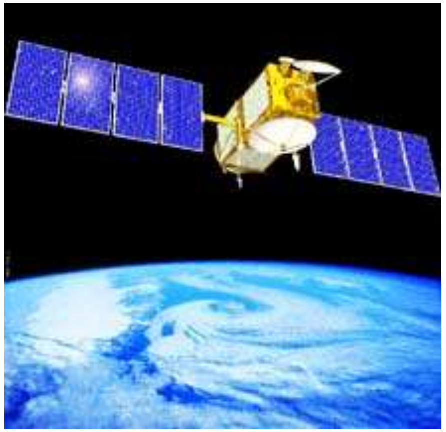
Jason is an oceanography mission to monitor global ocean circulation, discover the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Nio conditions and ocean eddies. The Jason satellite, a joint France/USA mission, is a follow-on to the highly successful TOPEX/Poseidon altimeter mission.

Jason is named after the mythological hero who led the Argonauts on the search for the Golden Fleece. "Jason" symbolizes both the hard-fought quest for a worthy goal and civilization's fascination with the ocean and its mysteries. The specification of "1" attests to the expectation that "Jason" is one of a series of TOPEX/Poseidon follow-on missions.

Mission Instrumentation:

Jason-1 has the following instrumentation onboard:

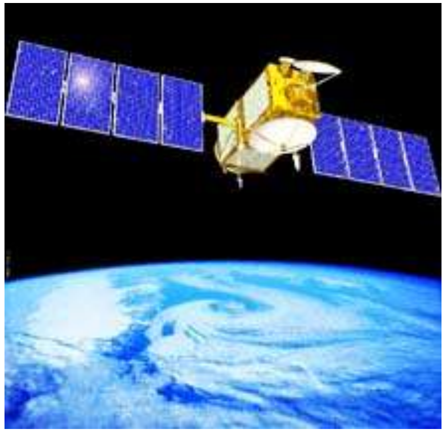
- Microwave radiometer
- DORIS dual frequency system receiver
- Dual-frequency solid-state altimeter
- GPS receiver
- Retroreflector array



JASON-1

Mission Parameters:

Sponsor:	NASA & CNES
Expected Life:	5 years
Primary Applications:	oceanography and climate change
Primary SLR Application(s):	calibrate satellite altimeter
COSPAR ID:	0105501
SIC Code:	4378
NORAD SSC Code:	26997
Launch Date:	December 7, 2001
End of mission:	July 1, 2013
RRA Diameter:	16 cm
RRA Shape:	hemispherical
Reflectors:	9 corner cubes
Orbit:	circular
Inclination:	66 degrees
Repeat cycle:	10 days
Eccentricity:	0.000
Perigee:	1336 km
Period:	112 minutes
Weight:	500 kg (fueled)



ENVISAT

Mission Instrumentation:

To meet the mission requirements a coherent, multidisciplinary set of sensors has been selected. Each instrument, with its distinct measurement capabilities, contributes to the mission. The instruments have been selected to supports synergism between their measurements and between scientific disciplines, thus making the total payload complement more than just the sum of the instruments. The instruments are:

- Michelson Interferometer for Passive Atmospheric Sounding (MIPAS)
- Global Ozone Monitoring by Occultation of Stars (GOMOS)
- SCanning Imaging Absorption spectrometer for AtMospheric CartograpHY (SCIAMACHY)
- MEdium Resolution Imaging Spectrometer (MERIS)
- Advanced Along Track Scanning Radiometer (AATSR)
- Advanced Synthetic Aperture Radar (ASAR)
- Radar Altimeter 2 (RA-2)
- MicroWave Radiometer (MWV)
- Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS)
- RetroReflector Array (RRA)

ENVISAT

Mission Parameters:

Sponsor:	European Space Agency
Expected Life:	5 years
Primary Applications:	remote sensing and environmental monitoring
Primary SLR Applications:	POD
COSPAR ID:	0200901
SIC Code:	6179
NORAD SSC Code:	27386
Launch Date:	1 March 2002
End of mission	8 April 2012
Normal Points Bin Size:	15 seconds
RRA Diameter:	20 cm
RRA Shape:	hemispherical
Reflectors:	9 corner cubes
Orbit:	circular, sun-synchronous polar
Inclination:	98.54 degrees
Repeat cycle:	35 days
Eccentricity:	0.001165
Perigee:	796 km
Period:	100 minutes
Weight:	8211 kg

ENVISAT Altimetry Mission Objectives

To ensure the continuity of the altimetric observations started with the ERS-1 satellite in 1991. The length of the altimeter record should exceed 15 years and will permit to examine changes on interannual to decadal time scales of:

- global and regional sea level, dynamic ocean circulation patterns
- significant waveheight climatology
- ice sheet elevation, sea-ice thickness
- river and lake levels

To provide for the enhancement of the ERS mission, notably in ocean and ice missions, by improving the quality of the measurements and monitoring capabilities:

- ocean mesoscale,
- significant wave height in NRT
- marine geophysics - particularly in polar oceans
- land, rivers, lakes and inland waters
- secondary objectives: ionosphere, water vapour, wind speed

ENVISAT Altimetry Mission Characteristics

- ENVISAT covers high latitude ocean, ice sheet and land surface areas not covered by Topex/Poseidon, GFO or Jason
- ENVISAT 35 day repeat cycle allows for dense ground-track spacing.

☞ ENVISAT fies on the same ground track as ERS-2, 30 minutes earlier.

- Optimum synergistic combinations with the simultaneous operating Jason/GFO altimetric missions for a wide range of applications. This advantage has clearly been demonstrated from the ERS missions, together with data from Topex/Poseidon (Le Traon and Ogor, 1998).

JASON-2

Mission Objectives:

Jason-2, also known as the Ocean Surface Topography Mission (OSTM), will continue the oceanography program begun by the TOPEX/Poseidon and Jason-1 missions. Jason will continue to monitor global ocean circulation, discover the tie between the oceans and atmosphere, improve global climate predictions, and monitor events such as El Nio conditions and ocean eddies. The CNES, Eumetsat, NASA, and NOAA cooperative mission will carry nearly the same payload as Jason-1. The satellite's payload will include the next generation of Poseidon altimeter (Poseidon-3, with the same general characteristics as Poseidon-2, but with a lower instrumental noise and an algorithm enabling a better tracking over land and ice). The accuracy should be of about 1 cm on the altimeter as well as the orbit measurements.

The Time Transfer by Laser Link (T2L2) payload, initially planned to be embarked on MIR in 1999, then with the ACES mission on the ISS, has recently been accepted by the French space agency CNES as a passenger of the Jason-2 altimetry satellite. T2L2 on Jason-2 will allow the precise characterization of the USO (ultra-stable oscillator) used by the DORIS positioning system. Relying on this clock, T2L2 may also be able to perform some orbit restitutions of Jason-2 uniquely by one-way laser ranging. Jason-2 represents an excellent opportunity as its high altitude allows for time transfer with very long integration times in common view mode for most of the continental links.

Mission Instrumentation:

Jason-2 will have the following instrumentation onboard:

- CNES Poseidon-3 altimeter
- NASA Advanced Microwave Radiometer (AMR), three-frequency
- CNES DORIS receiver
- NASA GPS receiver
- NASA retroreflector array
- Time Transfer by Laser Link (T2L2) payload

JASON-2

Mission Parameters:

Sponsor:	NASA, CNES, Eumetsat, NOAA
Expected Life:	5 years
Primary Applications:	oceanography and climate change
Primary SLR Application(s):	calibrate satellite altimeter
COSPAR ID:	0803201
SIC Code:	1025
NORAD SSC Code:	33105
Launch Date:	June 20, 2008
End of mission:	operating
RRA Diameter:	16 cm
RRA Shape:	hemispherical
Reflectors:	9 corner cubes
Orbit:	circular
Inclination:	66 degrees
Repeat cycle:	10 days
Eccentricity:	0.000
Perigee:	1336 km
Period:	112 minutes
Weight:	500 kg (fueled)

CRYOSAT-2

Mission Objectives:

A mission to measure change in the cryosphere, CryoSat-2 will measure the thickness of sea-ice and the surface elevation of ice sheets in both Northern and Southern hemispheres. For this, it uses an advanced radar altimeter combined with Precise Orbit Determination.

As the mission is intended to measure small secular change in a measure of distance it is necessary to use laser ranging for:

- calibration of the altimeter and
- support to the POD

The latter will primarily be performed with DORIS, but the SLR measurements will provide an essential independent tracking data type.

Unfortunately, the CryoSat-1 satellite was lost due to a launch failure on October 8, 2005

Mission Instrumentation:

CryoSat will have the following instrumentation onboard:

- SAR/Inteferometric Radar Altimeter (SIRAL)
- DORIS receiver
- Retroreflector array
- Three star trackers

CRYOSAT-2

Mission Parameters:

Satellite:	CryoSat-2
Sponsor:	ESA
Expected Life:	3 years
Primary Applications:	measure ice thickness
Primary SLR Applications:	precision orbit determination
COSPAR ID:	1001301
SIC Code:	8006
NORAD SSC Code:	36508
Launch Date:	CryoSat-1: October 8, 2005 (failed); CryoSat-2: April 8, 2010
End of mission:	operating, mission extended until 2017
Normal Points Bin Size:	15 seconds
RRA Diameter:	16 cm
RRA Shape:	hemispherical
Reflectors:	7 corner cubes (Meteor design)
Orbit:	circular, non sun-synchronous
Inclination:	92 degrees
Repeat cycle:	369 days
Eccentricity:	0.0
Altitude:	~720 km
Weight:	711 kg

SARAL/AltiKa

Satellite with ARgos and ALtika (SARAL) is a cooperative mission between CNES and the Indian Space Research Organization (ISRO) The mission is complemenatary to Jason-2 and will provide observations of ice, rain, coastal zones, and wave heights. SARAL results from the common interests of CNES and ISRO in studying the oceans from space using altimetry and providing maximum use of ARGOS (Advanced Research and Global Observation Satellite), a joint NOAA CNES data collection system.

Mission Objectives:

The main mission objectives of SARAL are to:

- Create precise, repetative global measurements of sea surface height, wave heights, and wind speed
- Ensure continutity of the altimetry service currently available from Envisat and Jason-1/-2
- Contribute to global ocean and climate studies to build a global ocean observing system

These objectives will be accomplished by studying mesoscale ocean variability through observations of:

- coastal areas
- inland waters
- surface of continental ice sheets

Courtesy of CNES

Mission Instrumentation:

The SARAL satellite will be provided by ISRO;

The mission will have the following instrumentation onboard:

- Altimeter/Radiometer (AltiKa) built by CNES
- DORIS built by CNES
- Laser Retroreflector Array built by CNES
- ARGOS-3 instrument

SARAL/AltiKa

Mission Parameters:

Satellite:	SARAL
Sponsor:	CNES and ISRO
Expected Life:	5 years (ARGOS); 3 years (AltiKa)
Primary Applications:	Earth sensing
Primary SLR Applications:	Precision orbit determination
COSPAR ID:	1300901
SIC Code:	3201
NORAD SSC Code:	39086
Launch Date:	Feb 25, 2013
End of mission:	Operating
NP Bin Size:	15 seconds
RRA Diameter:	TBD
RRA Shape:	Octagonal
Reflectors:	9 corner cubes
Inclination:	98.55 degrees
Eccentricity:	1.165 x 10-3
Altitude:	814 km
Weight:	350-400 kg

Courtesy of CNES

JASON-3

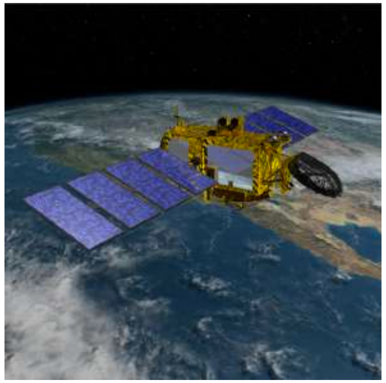
Mission Summary

Jason-3 is the fourth mission in U.S.-European series of satellite missions that measure the height of the ocean surface. Scheduled to launch in 2015, the mission will extend the time series of ocean surface topography measurements (the hills and valleys of the ocean surface) begun by the TOPEX/Poseidon satellite mission in 1992 and continuing through the currently operating Jason-1 (launched in 2001) and OSTM/Jason-2 (launched in 2008) missions. These measurements provide scientists with critical information about circulation patterns in the ocean and about both global and regional changes in sea level and the climate implications of a warming world.

The primary instrument on Jason-3 is a radar altimeter. The altimeter will measure sea-level variations over the global ocean with very high accuracy (as 1.3 inches or 3.3 centimeters, with a goal of achieving 1 inch or 2.5 centimeters). Continual, long-term, reliable data of changes in ocean surface topography will be generated and will be used by scientists and operational agencies (NOAA, European weather agencies, marine operators, etc.) for scientific research and operational oceanography for the benefit of society.

TOPEX/Poseidon and Jason-1 were cooperative missions between NASA and the French space agency, CNES. Additional partners in the Jason-2 mission included NOAA and Eumetsat. Jason-3 continues the international cooperation, with NOAA and Eumetsat leading the efforts, along with partners NASA and CNES.

Expected launch: 2015.



Scientific Instrument(s)

- Radar Altimeter
- Microwave radiometer
- DORIS (Doppler Orbitography and Radiopositioning Integrated by Satellite)
- Laser Retroreflector Array (LRA)
- Global Positioning System (GPS) receiver

SENTINEL-3A and -3B… 3C

SENTINEL-3 is an ocean and land mission composed of three versatile satellites (SENTINEL-3A, SENTINEL-3B and SENTINEL-3C). The mission provides data continuity for the ERS, ENVISAT and SPOT satellites.

Mission objectives:

- Measuring sea-surface topography, sea-surface height and significant wave height.
- Measuring ocean and land-surface temperature.
- Measuring ocean and land-surface colour.
- Monitoring sea and land ice topography.
- Sea-water quality and pollution monitoring.
- Inland water monitoring, including rivers and lakes.
- Aid ocean forecasts with acquired data.
- Climate monitoring and modelling.
- Land-use change monitoring.
- Forest cover mapping.
- Fire detection.
- Weather forecasting.
- Measuring Earth's thermal radiation for atmospheric applications.

The observations acquired by the mission are used in conjunction with other ocean-observing missions to contribute to the Global Ocean Observing System (GOOS) which aims to create a permanent system of ocean observation.

SENTINEL-3A and -3B

SENTINEL-3 makes use of multiple sensing instruments to accomplish its objectives:

- **SLSTR** (Sea and Land Surface Temperature Radiometer)
- **OLCI** (Ocean and Land Colour Instrument)
- **SRAL** (SAR Altimeter)
- **DORIS** (Doppler Orbitography and Radiopositioning Integrated by Satellite)
- **MWR** (Microwave Radiometer).

SLSTR and OLCI are optical instruments that are used to provide data continuity for ENVISAT's AATSR and MERIS instruments and the swaths of the two instruments overlap, allowing for new combined applications. OLCI is a medium-resolution imaging spectrometer, using five cameras to provide a wide field of view.

SRAL, DORIS, MWR and LRR are used for topographic measurements of the ocean and inland water. The SRAL altimeter is the main topographic instrument. The MWR radiometer measures water vapour, cloud water content and thermal radiation emitted by the Earth.

Mission Orbit:

Orbit Type: sun-synchronous
Orbit Height: 814.5 km
Inclination: 98.65º
Repeat Cycle: 27 days.

JASON-CS/SENTINEL-6 (J-CS A and B)

Mission Objective:

Continuity to the highly precise measurement of sea surface topography after Jason-3

Sentinel 6 mission:

Implemented through two Jason-CS (for Continuity of Service) satellites.

Orbit:

Same as Topex, J1, J2, J3 orbit

Altimeter:

'Interleaved' SAR and LRM (is now baseline)

Schedule:

Phase B now

Towards C/D/E

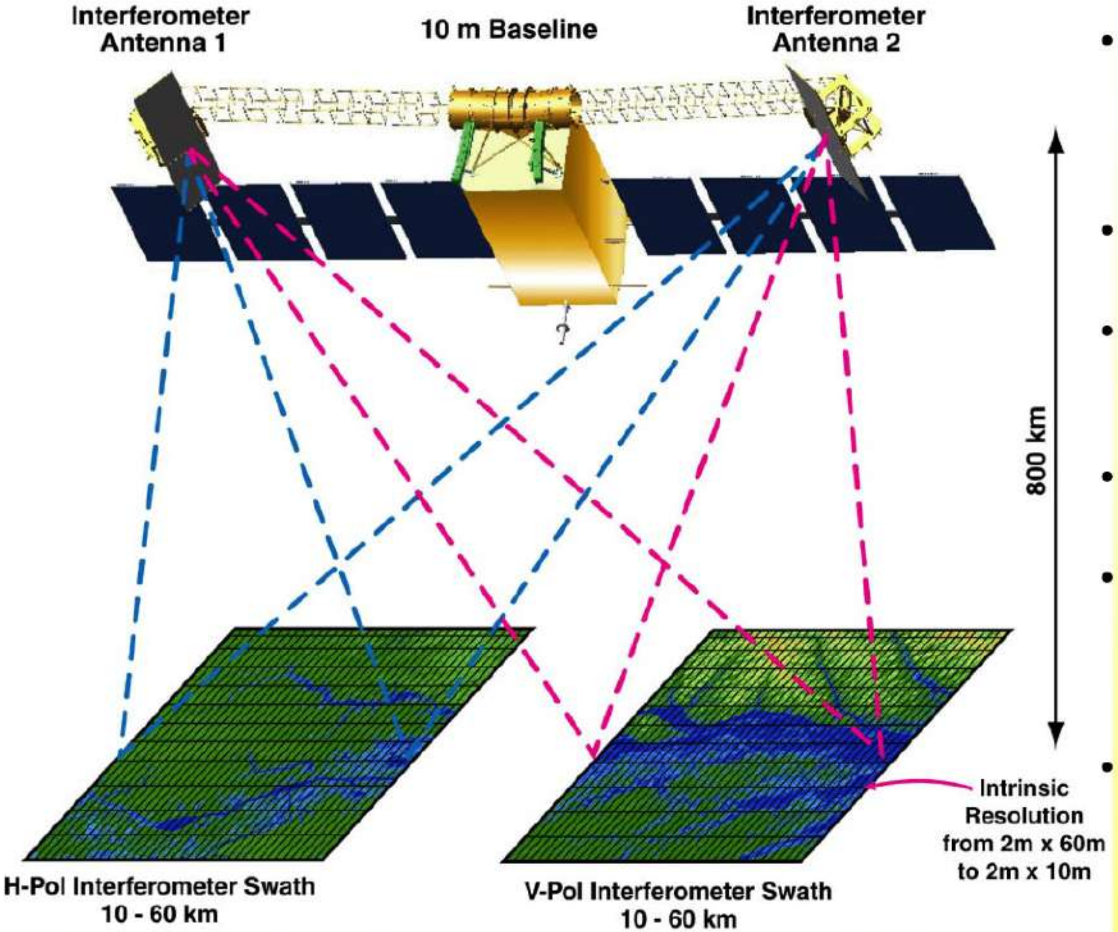
ESA subscriptions (optional program) December 2014

EUMETSAT subscriptions (optional program) mid 2015.

EU Copernicus DA's

SWOT – Surface Water, Ocean Topography

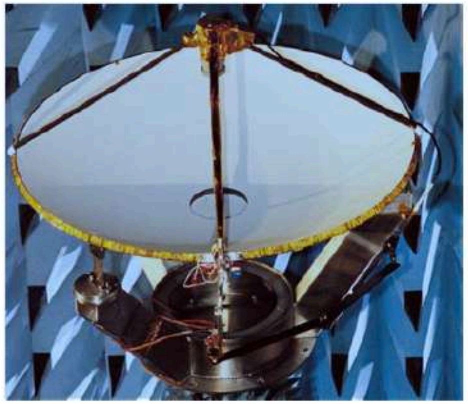
Interferometric Altimeter



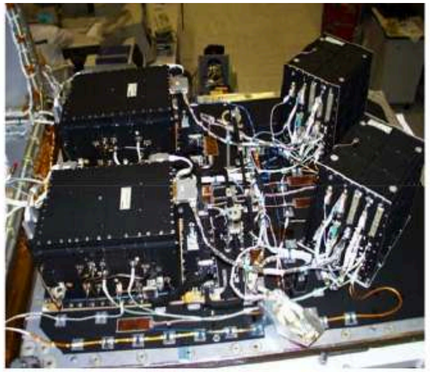
- Ka-band SAR interferometric system with 2 swaths, 50 km each
- WSOA and SRTM heritage
- Produces heights and co-registered all-weather imagery
- 200 MHz bandwidth (0.75 cm range resolution)
- Use near-nadir returns for SAR altimeter/angle of arrival mode (e.g. Cryosat SIRAL mode) to fill swath
- No data compression onboard: data downlinked to NOAA Ka-band ground stations

These water elevation measurements are entirely new, especially on a global basis, and

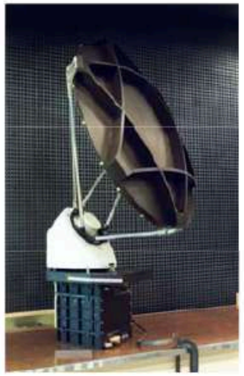
Typical components



Altimeter antenna



Altimeter

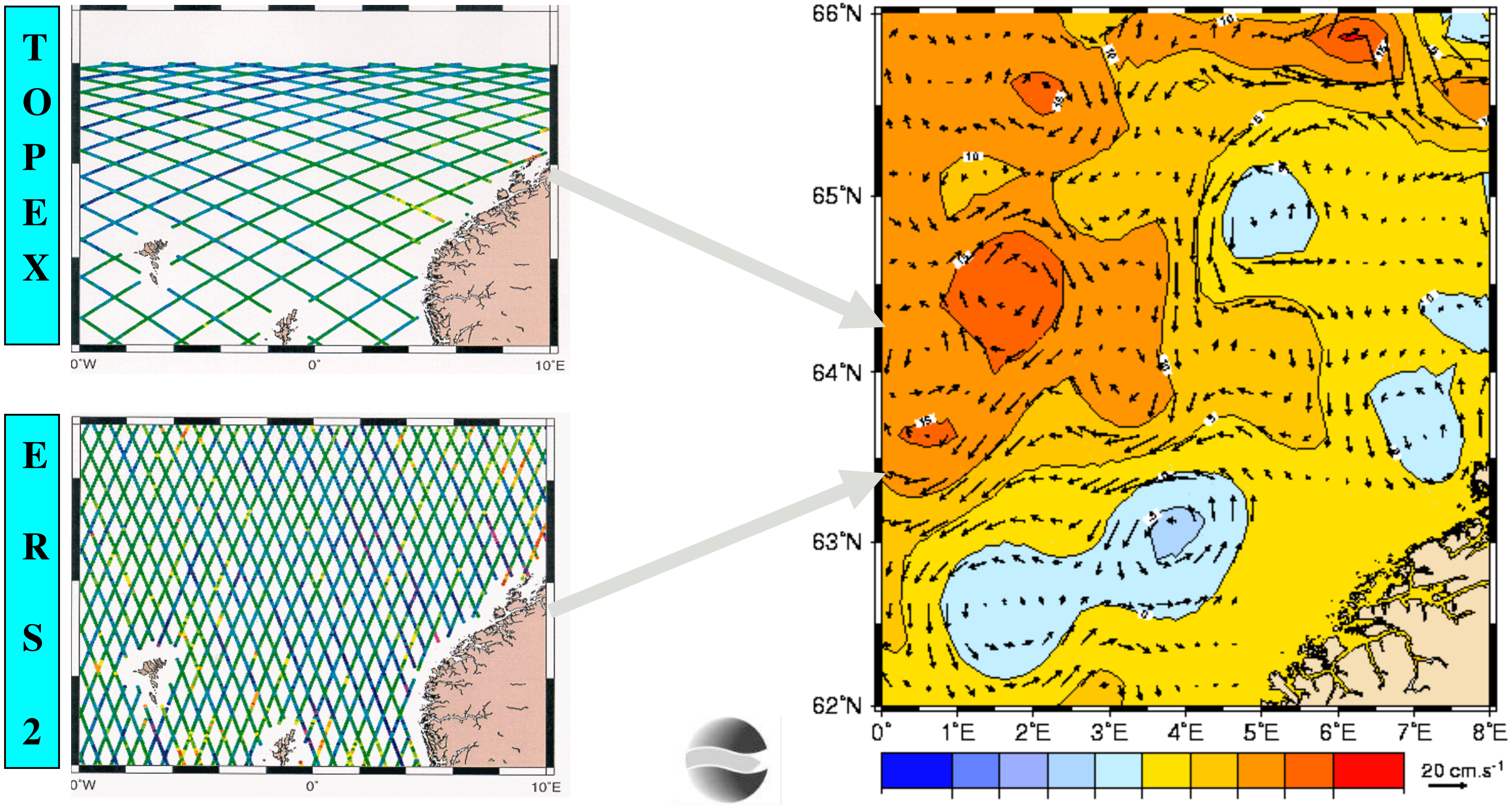


Radiometer

DORIS receiver

Jason-1 mission

Merging data from multiple altimeter missions is needed to obtain high-accuracy, high-resolution, ocean monitoring in near-real-time.



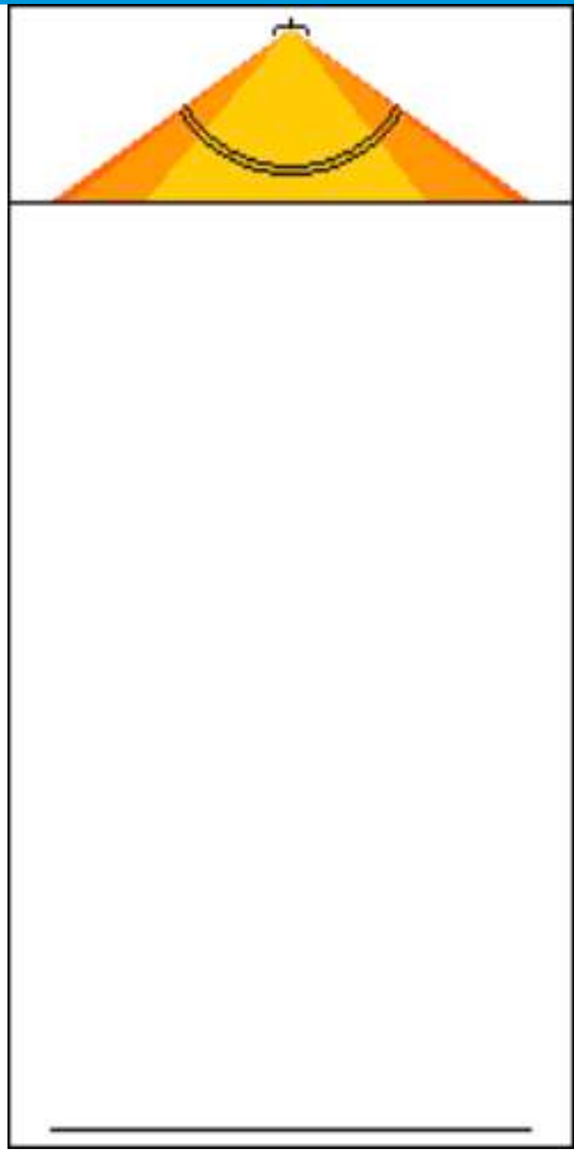
CLS

How does the radar altimeter make the measurement?

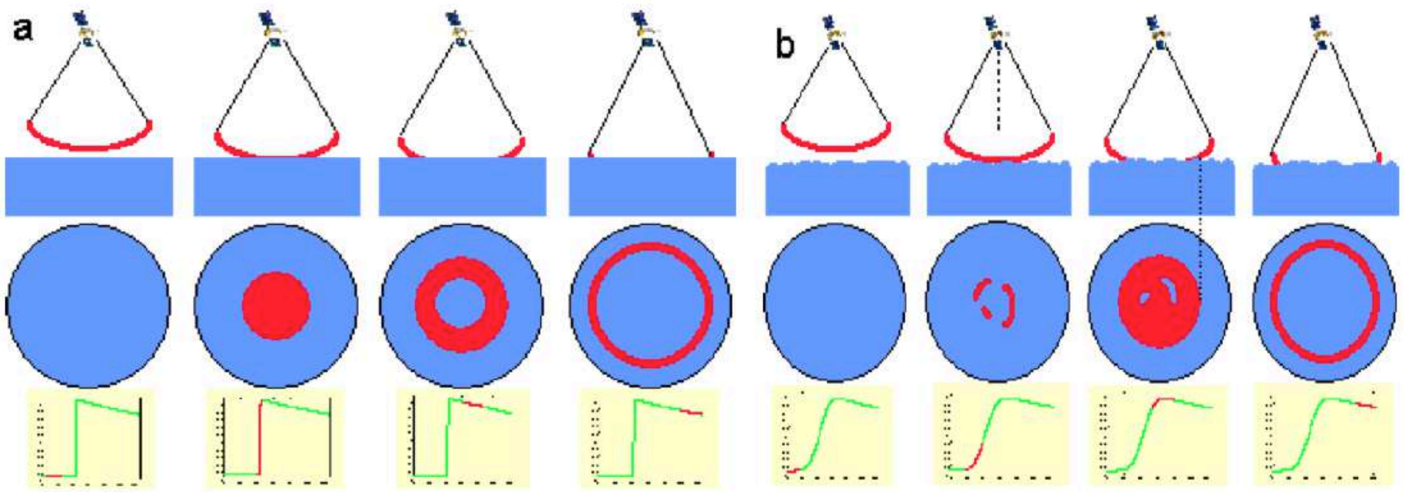
Radar Altimeter Measurement principle

1. The Radar Altimeter is an instrument for determining the two-way delay of the radar echo from the Earth's surface to a very high precision: less than a nanosecond. It also measures the power and the shape of the reflected radar pulses.
2. Measurement of the radar echo power and shape enables the determination of wind speed and significant wave height at sea, thus supporting weather and sea state forecasting.
3. The range resolution of the altimeter is about half a metre (3.125 ns) but the range measurement performance over ocean is about one order of magnitude better than this. This is achieved by fitting the shape of the sampled echo waveform to a model function which represents the form of the echo.

Return Power Waveform



Return Power Waveform



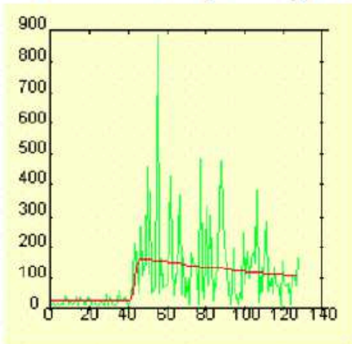
Ideally calm sea

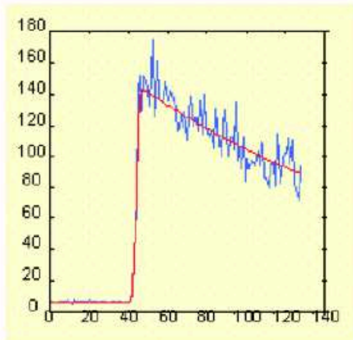
Rough sea

The footprint size is determined by the pulse duration (3 ns ⇔ 2 km for calm seas)

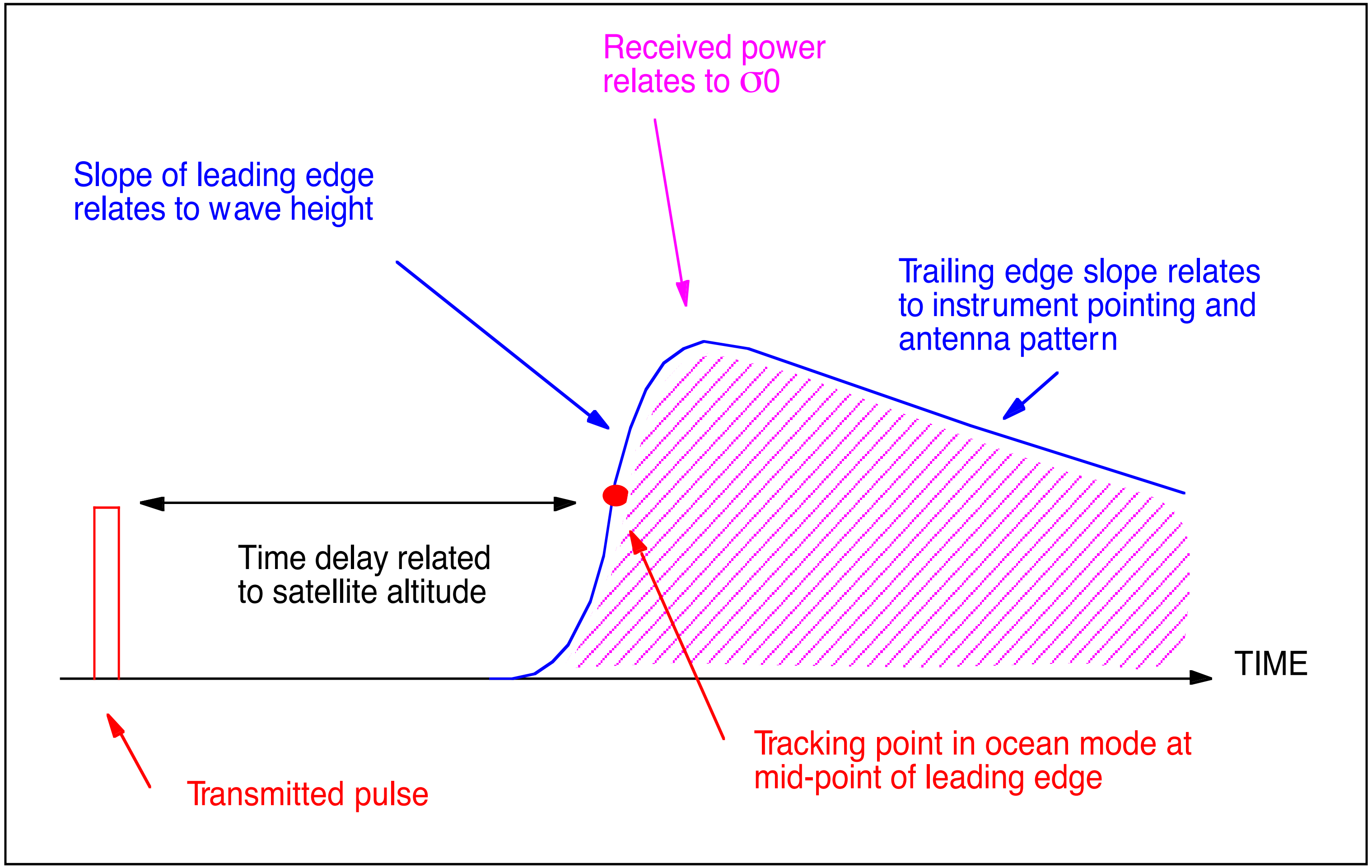
Green : Individual return pulse:

Red : Average of 90 return pulses

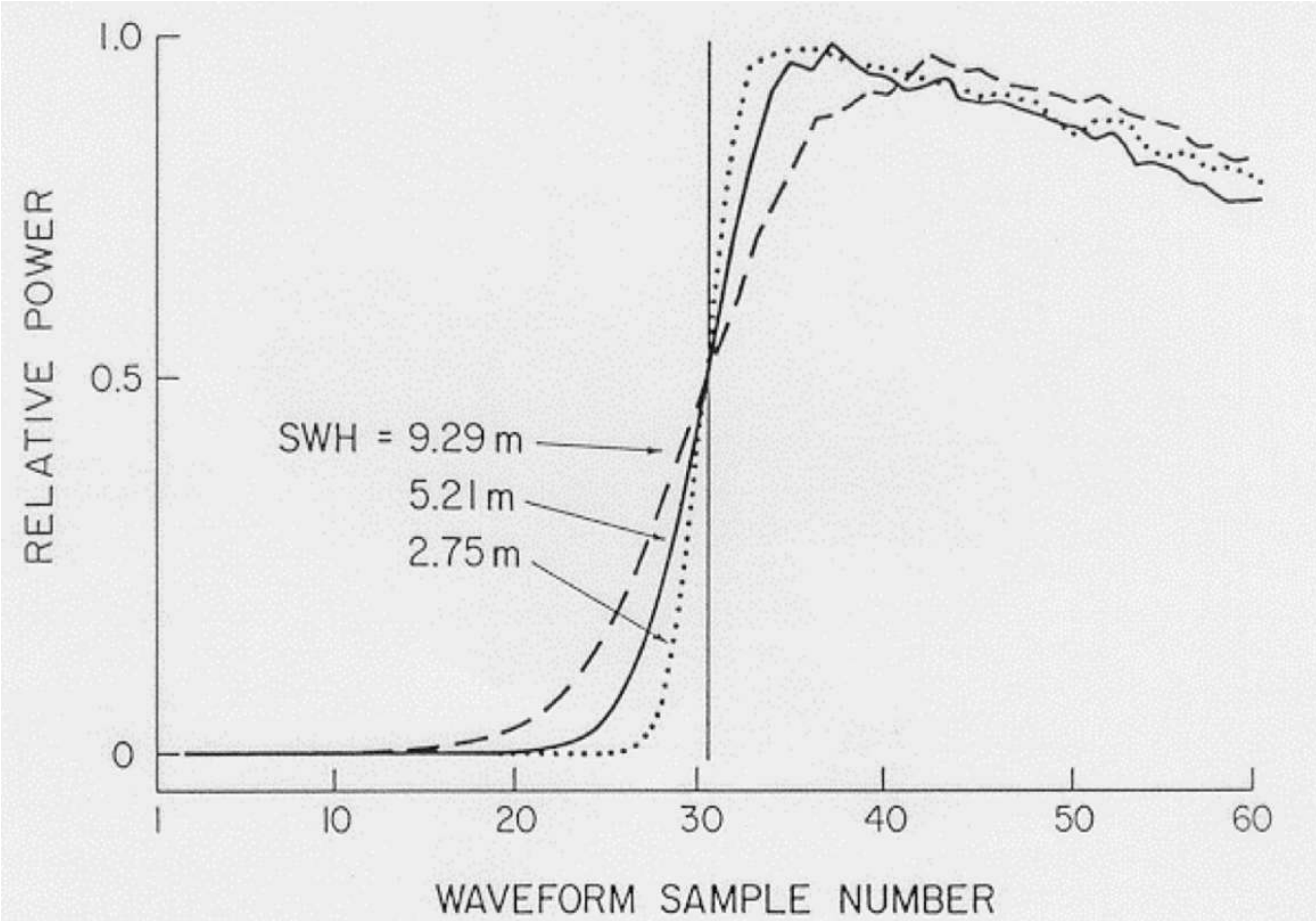




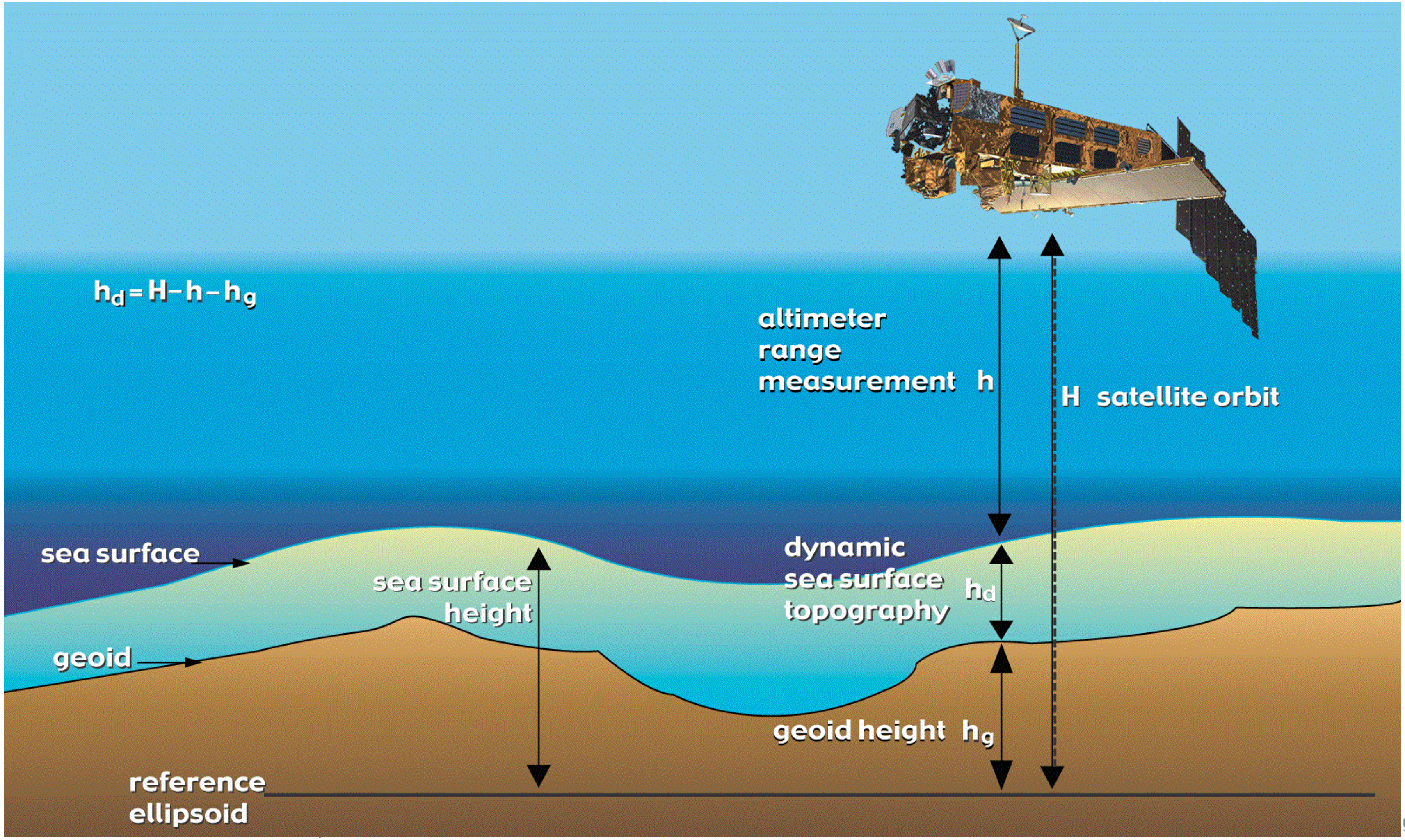
Return Power Waveform



Leading edge slope Vs SWH

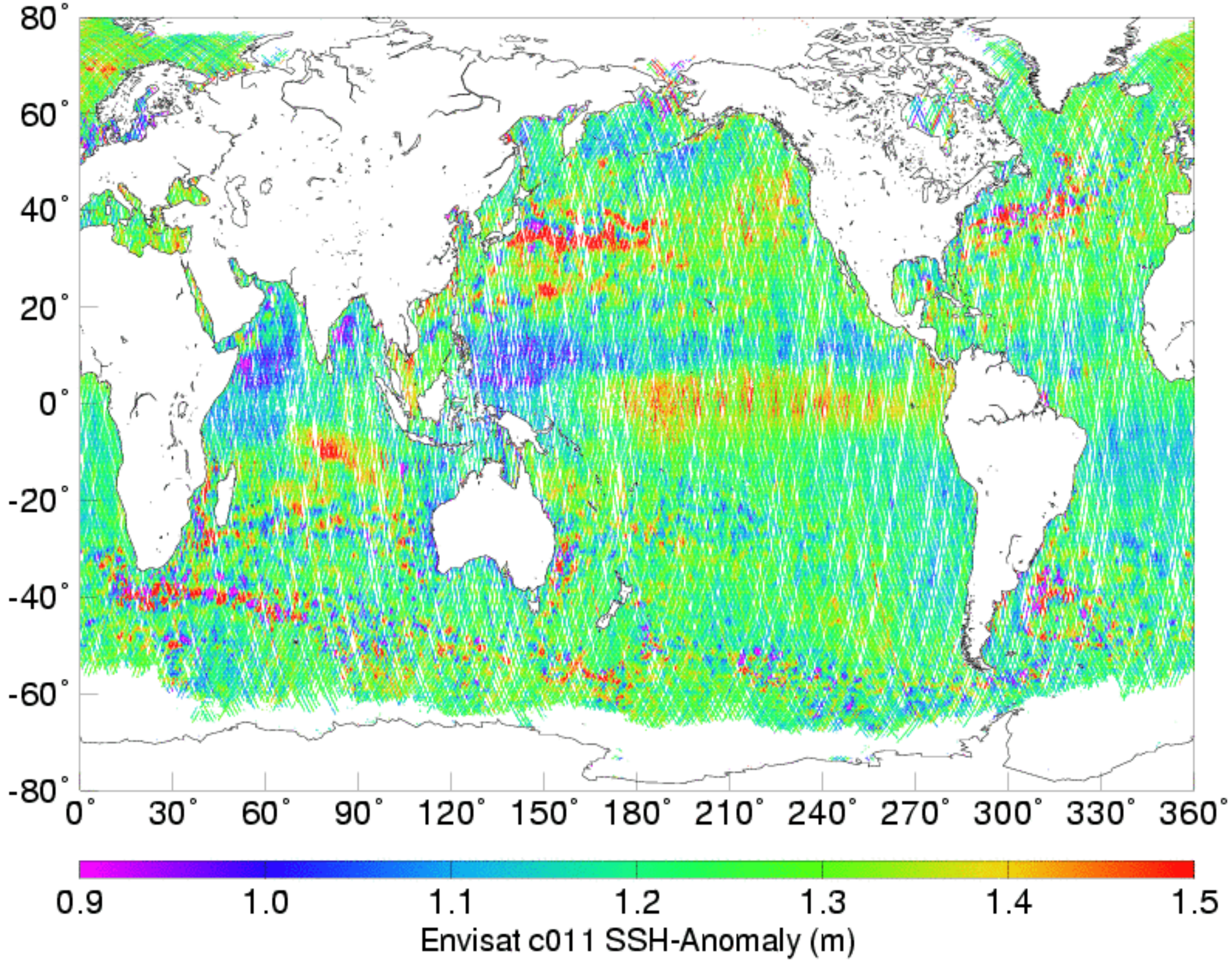


Radar Altimetry Principle



gency

Putting all the tracks together



Vertical Datum Applications

H_i (sea level over ellipsoid) = $S_g + S_s + S_v + S_t + E_o + E_r$

with S_g = Geoid signal

S_s = Stationary signal

S_v = Variability

S_t = tides signal

E_0 = Orbital error

E_r = remaining errors and corrections

(solid tides, loading effect, inverse barometer effect,...)

Leads to different types of oceanographic analysis:

- Meso-scale dynamic topography (currents, eddies, kinetic energy, ...)
- Large scale topography/large scale variability (basin gyres, strong currents, mean sea level, mean sea level rise?!,...)
- stationary signal (mean reference surface, estimation of the stationary dynamic topography)
- tides study (hydrodynamic models constrained by altimetric data)
- Assimilation to dynamic models of the oceanic circulation

Vertical Datum Applications

Land topography

- Global DEM obtained from the full 336 days of the ERS-1 geodetic phase (most accurate Global 1 km DEM)

Rivers and Lakes level

- Long term, global, surface water monitoring
- Study of the response of lakes to climate for water resources management, fisheries, water quality and conservation

Glaciology

- DEM
- Input data for forcing, initialisation or test of ice flow dynamic models
- Long term monitoring of the topography for seasonal or secular variations.
- Sea-ice thickness

Wind and Wave

Secondary mission of the Radar Altimeter

- SWH data assimilated into waves forecasting models
    - Key requirement : Fast Delivery data (within 3 hours time)
- Wind Speed not really assimilated but used to partition wave energy into “wind” and “swell” components and to validation atmospheric models.

Users

- Meteorological offices worldwide, ECMWF
- Metocean monitoring/forecasting service companies for
    - ship routeing & shipping operators
    - oil production companies
    - marine engineering operators

EXAMPLE OF RA FEATURES

The ENVISAT Radar Altimeter

- low height noise (pulse repetition frequency doubled)
- improved waveheight accuracy with two additional bins on the echo leading edge
- dual frequency (Ku and S band)
- 128 waveform bins + individual echo sampling
- robust on-board tracking and on-ground estimation
- three resolution modes (320, 80, 20 MHz)
    - Receiving window width: 64, 256, 1024 m
- autonomous resolution control

Summary of Radar Altimeters Characteristics

	Skylab	GEOS 3	SeaSat	Geosat	ERS-1	TOPEX/ Poseidon	ERS-2	Envisat	Jason
Launch	1973	1974	1978	1985	1991	1992	1995	2002	2001
Altitude (km)	435	840	800	800	800	1300	800	800	1300
RF power (W)	2000	2000	2000	20	50	20 / 5	50	50	?
Beam width (deg)	1.5	2.6	1.6	2.1	1.3	1.1	1.3	1.3	?
Footprint (km)	8	3.6	1.7	1.7	1.7	2.2	1.7	1.7	?
Pulse width (ns)	100	12.5	3	3	3	3	3	3	3
Second Frequency (GHz)						5.3 / -		3.2	
PRF (Hz)	100	100	1020	1020	1020	4000 / 1700	1020	1800	?
Second PRF (Hz)						1220		450	
Tracker Algorithm	2 gate	3 gate	split gate	split gate	SMLE	split gate / SMLE	SMLE	MFT / MLE	?
Noise (cm)	> 100	25	5	3	4	2 / 2	4	2	?

+ Jason-2, CryoSat, and future mission… Jason-3, S3, S6

- les données

Level 1b RA-2/MWR Data Product

Key characteristics:

- Conversion of satellite time to UTC (<10 μs error)
- Geolocation and orbit height (<30 cm NRT to ~3 cm off-line)
- Instrumental corrections applied:
    - IF filter (corrects power distortions of echo waveforms)
    - Internal range calibrations
    - Corrections for possible drift of reference timing source (USO)
- Waveforms included: individual (1800 Hz) and averaged (18 Hz)
- No retracking of waveforms performed (it's done at level 2)
- MWR brightness temperatures
- Provided as half-orbit, pole-to-pole (off-line products)

Level 2 RA-2/MWR Products

- Waveform data are fully processed to extract geophysical parameters – "retracking"
    - Four retrackers running in parallel, optimised for different surfaces:
        - Ocean (based on Hayne Model with modifications)
        - Ice 1 (continental ice – OCOG)
        - Ice 2 (continental ice – Brown-based model)
        - Sea Ice (threshold model)
- Geophysical corrections available
    - ionospheric correction (RA-2 dual-frequency / DORIS /Bent model)
    - wet tropospheric correction from on-board microwave radiometer
    - dry/wet tropospheric correction from ECMWF, IB correction
    - sea-state bias correction (under study for the novel S band)
    - tides, geoid,mean sea surface, land elevation, bathymetry
- Original waveform samples available

On-Ground Retrackers

All products, including Near Real Time, are built by processing the waveforms (retracking).

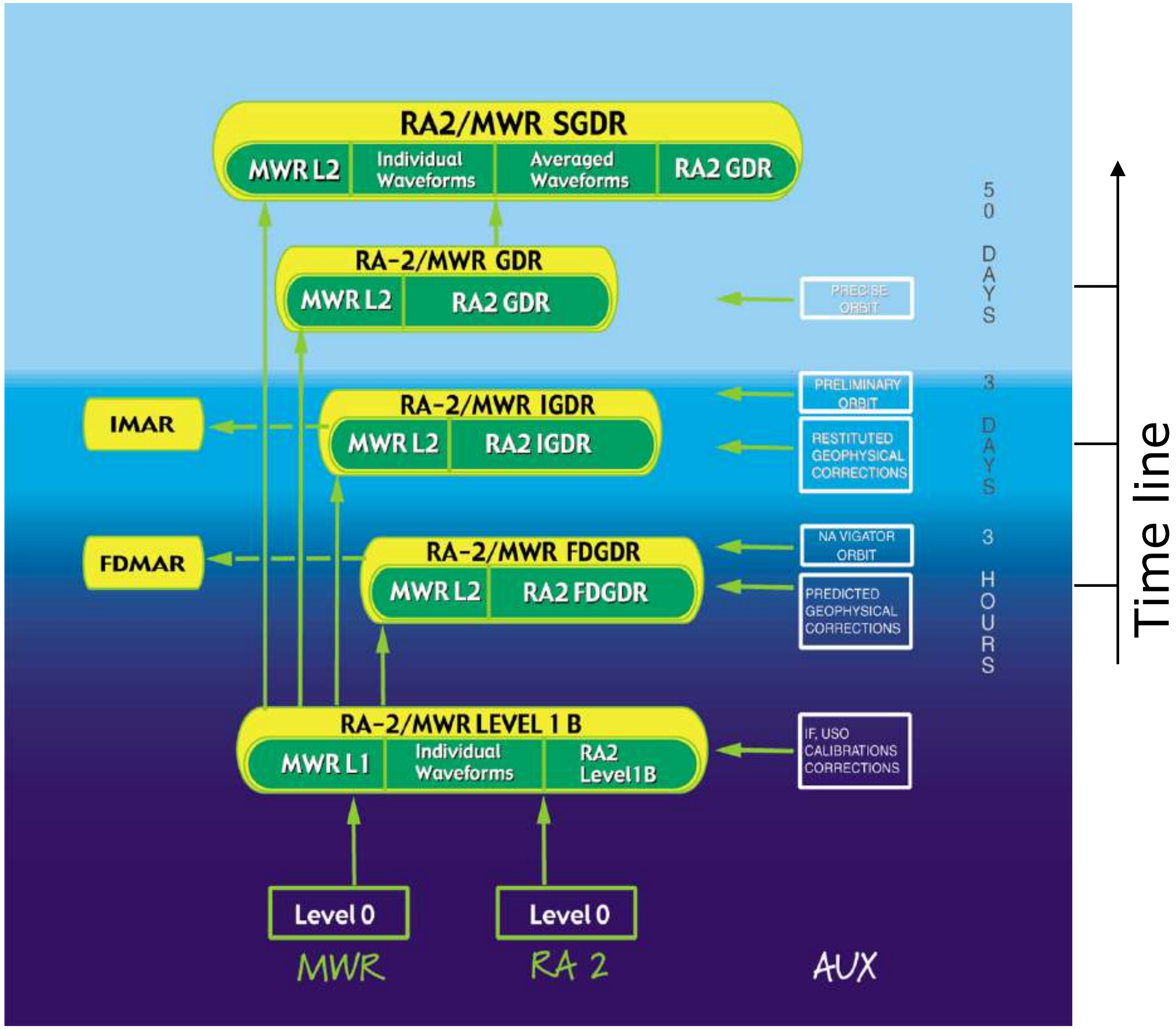
Four retrackers run in parallel all the time (over all surfaces).

- **Ocean** (optimised for ocean surfaces):
  - based on Hayne model with modifications.
- **Ice 1** (optimised for general continental ice sheets):
  - A model-free retracking: Offset Centre of Gravity echo model (used for ERS).
- **Ice 2** (optimised for ocean-like echoes from continental ice sheet interior):
  - a Brown-based model retracking algorithm.
- **Sea Ice** (optimised for specular returns from sea-ice):
  - a threshold retracking scheme for peaky waveforms

Data Products Usage

1. Level 0: for ESA only
2. Level 1b: for ESA only (processing, QC)
3. Level 2: for users
   a. **FDGDR => for near real time applications**
      - **FDMAR => for oceanographic near real time applications**
   b. **IGDR => for quasi near real time applications demanding better orbits**
      - **IMAR => for oceanographic quasi near real time applications demanding better orbits**
   c. **GDR => the final precision product: for all research and application**
   d. **SGDR => for research requiring waveform retracking**

RA-2/MWR Product Tree



Algorithm Development

- The Processing algorithms have been developed by Expert Laboratories in support of the Ground Segment development
- Algorithm specifications have been validated by prototyping
- The verified prototypes become reference processors to produce Test Data Sets designed to validate the Ground Segment Processor
- The algorithm specifications have been reviewed by external experts, discussed in workshop.

Calibration/Validation

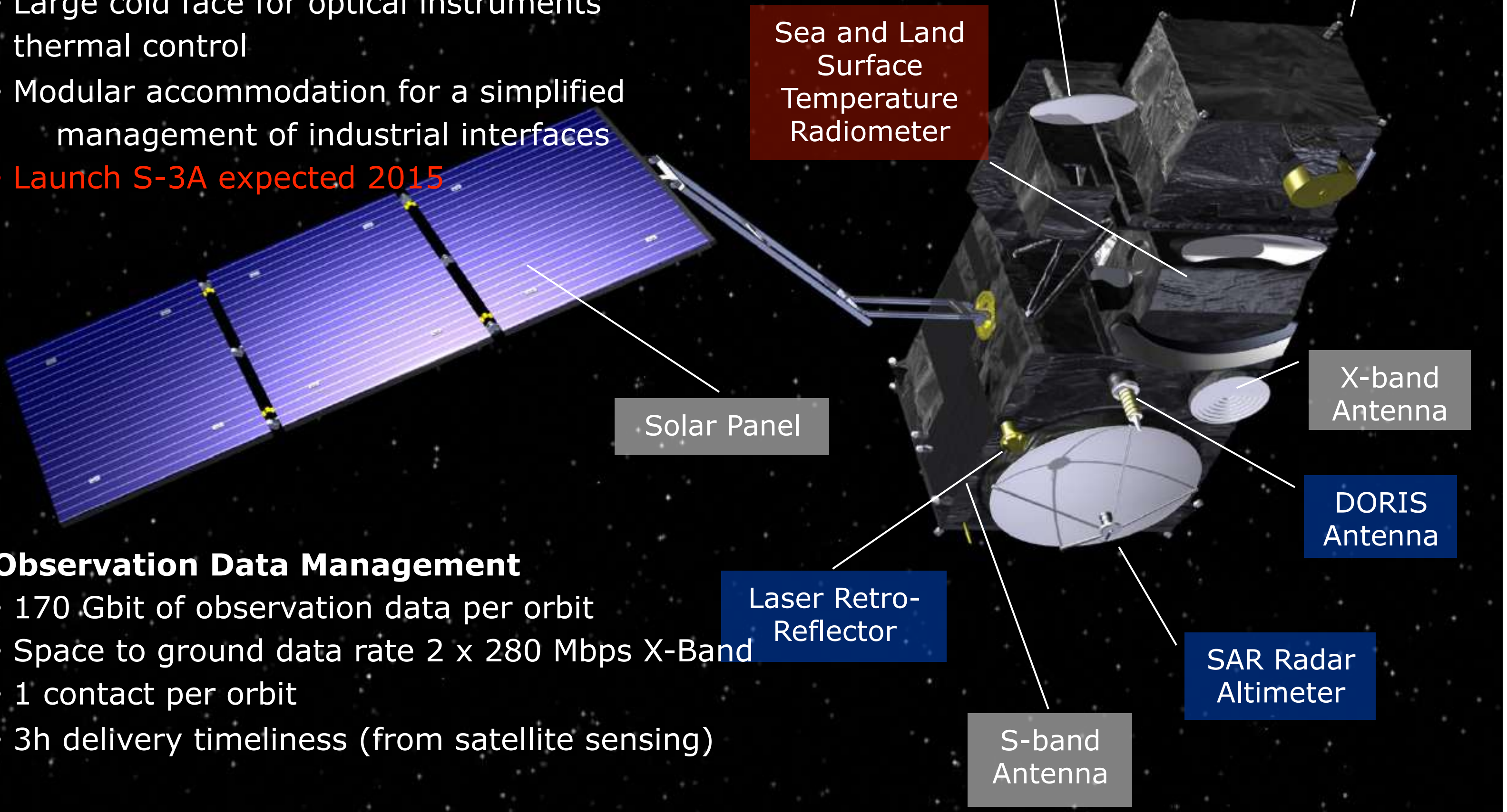
- Full exploitation of the data from RA-2 and unification of the data products with ERS-2 demand high-quality characterisation, performance analysis, calibration and validation, at Ku and S band, and cross-calibration with ERS-2 of the three instrument parameters.
- ESA's strategy was to perform during commissioning phase:
  - RA-2 and MWR instruments in-flight verification
  - Range absolute calibration
  - Sigma0 absolute calibration — a "first" in history of Radar Altimetry!
  - Cross-calibration of Range, Waveheight, Sigma0 with other altimeters
  - Products validation

http://envisat.esa.int

The Sentinel-3 Satellite

Main satellite characteristics

- 1250 kg maximal mass
- Volume in 3.89 m x 2.202 m x 2.207 m
- Average power consumption of 1100 W
- 7.5 years lifetime (fuel for 5 add. years)
- Large cold face for optical instruments thermal control
- Modular accommodation for a simplified management of industrial interfaces
- Launch S-3A expected 2015

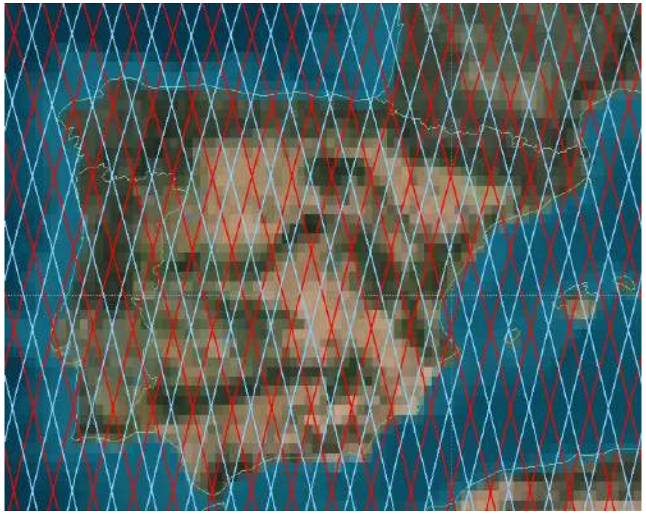


Observation Data Management

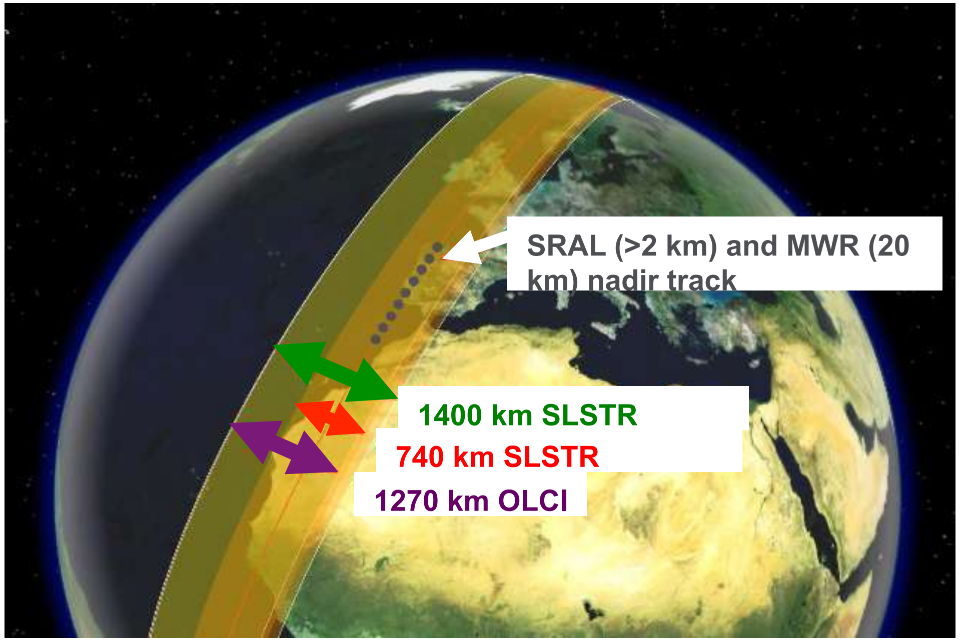
- 170 Gbit of observation data per orbit
- Space to ground data rate 2 x 280 Mbps X-Band
- 1 contact per orbit
- 3h delivery timeliness (from satellite sensing)

Sentinel-3 Orbit and Coverage

Topography Mission:
ground track repeatability, dense spatial sampling



Altimetry mission	Configuration	
Constellation	**1 Satellite**	**2 Satellites**
Main 27-day cycle inter-track separation at equator	**104 km**	**52 km**
4-day sub-cycle inter-track separation at the equator	**Min = 104 km** **Max = 728 km**	**Min = 57 km** **Max = 671 km**



Orbit type	Repeating frozen SSO
Repeat cycle	27 days (14 + 7/27 orbits/day)
LTDN	10:00 hr
Average altitude	815 km
Inclination	98.65 deg

Change of observation scenario (I)

LRM → SAR

Original operational baseline: split between LRM and SAR mode

Autumn 2013: Request by the Copernicus user community to extend usage of SAR mode for the S-3 SRAL instrument up to 100% of Earth coverage -> ESA/EUMETSAT assessment approved by EC now for implementation, subject to a detailed cost/schedule assessment and final go ahead by EU

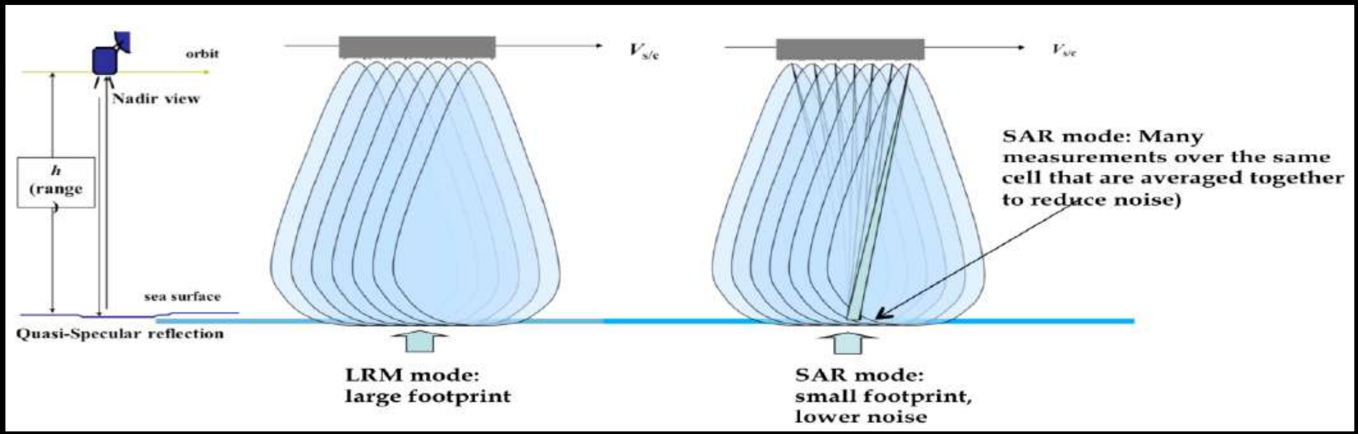
Note: it is assumed that the LRM shall be kept as a back-up to reduce operational risks and to allow a possible switch to the LRM scenario if necessary

During SAR mode, an increased number of waveforms is shot with respect to LRM → increased instrument power consumption increased instrument data rates; SAR mode benefit to users:

Increased resolution along-track

Scope for better accuracy over challenging surfaces

100% SAR mode



(Credits: H. Snaith and P. Cippolini, NOC, UK)

Change of observation scenario (II)
LRM → SAR

SAR technology is new and complex → Further work required to understand all in-orbit conditions and emerging processing systems. Noting CryoSat experience.

ESA considers beneficial that S-3 SAR L1 products are made available to the users.

Expected advantages

Foster a new generation of SAR altimetry specialists maintaining Europe at the competitive edge

Enhance maintenance and development of existing and new products over the Earth surface (ocean, ice and land) within GMES

Enhance uptake, application, and quality control (e.g. transponder calibration) of SRAL SAR data products by the GMES user community

Possibly reduce large-scale reprocessing efforts (because starting from intermediate L1 products rather than from L0)

→ All 3 products are to be read by Sentinel-3 Altimetry Toolbox

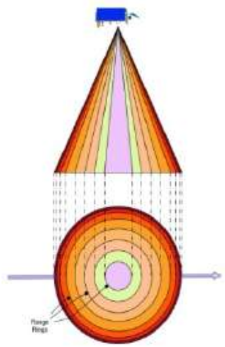
Product Level	Product Description	Relevance for
L1A	Unpacked L0 data processed to engineering parameters with geo-location information	SAR processing specialists allowing fundamental studies on SAR processing such as Doppler beam formation and calibration studies using ground-based Transponders
L1B-S	Geo-located, Calibrated gathered azimuth formed complex (I and Q) power echoes after slant/Doppler range correction	geophysical retrieval algorithm developers (over ocean, land and ice surfaces), surface characterisations studies (e.g. impact of sea state bias, wave directional effects etc) and QC systems
L1B	Geo-located, Calibrated Multi-looked power waveforms	geophysical retrieval algorithm developers and QC systems

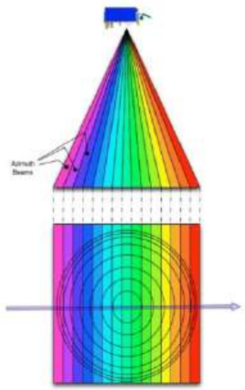
Sentinel-3 Future L1 User Products

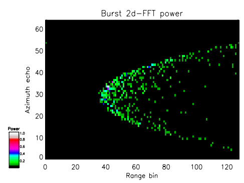
L0 → calibration → Azimuth FFT (beam formation) → Sorting and migration correction → Multilooking → L1B

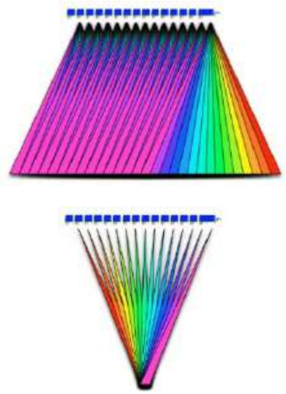
L1A

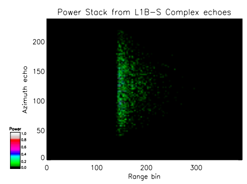
L1B-S

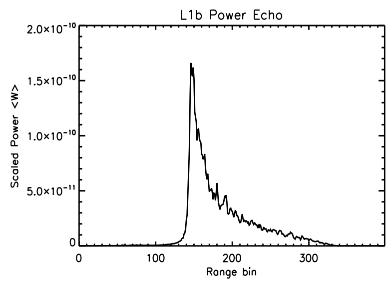












Sentinel-3 Future L1 User Products

- **L1 Products identified to become operational on Sentinel-3:**
  - ***L1A: Unpacked L0 complex echoes that have been sorted and calibrated.*** Geo-location information is also included. Product relevant to SAR processing specialists allowing fundamental studies on SAR processing such as Doppler beam formation and for calibration studies using ground-based Transponders.
  - ***L1B-S: Geo-located, calibrated azimuth formed complex (I and Q) echoes related to a given location on the ground, after slant range correction, the "stack".*** No averaging of individual waveforms (i.e.multi-looking) is applied. Relevant ancillary data (e.g. beam angles, calibration information, statistical description of the multi-looked average/stack etc) is included. Product relevant to geophysical retrieval algorithm developers (over ocean, land and ice surfaces), surface characterisations studies (e.g. impact of sea state bias, wave directional effects etc) and Quality Control systems.
  - ***L1B: Geo-located, calibrated, azimuth formed, slant range corrected and averaged together (i.e multi-looked) power echoes associated with a fixed point on the ground-track.*** This product is relevant to geophysical retrieval algorithm developers and Quality Control systems.

Sentinel-3 L2 User Products

"Reduced" Measurement Data File

1 Hz LRM/SAR Ku/C Data Set

Sub-set of 1Hz Ku/C band parameters from SRAL measurements performed in LRM/SAR Modes

→ 1Hz

"Standard" Measurement Data File

1 Hz LRM/SAR Ku/C Data Set

1Hz Ku/C band parameters from SRAL measurements performed in LRM/SAR Modes

20 Hz LRM/SAR_C Data Set

20Hz C band parameters from SRAL measurements performed in LRM/SAR Modes

20 Hz LRM/SAR_Ku Data Set

20Hz Ku band parameters from SRAL measurements performed in LRM/SAR Modes

→ 1Hz + 20 Hz

"Enhanced" Measurement Data File

1 Hz LRM/SAR Ku/C Data Set

1Hz Ku/C band parameters from SRAL measurements performed in LRM/SAR Modes

PLRM Ku/C band measurement

20 Hz LRM/SAR_C Data Set

20Hz C band parameters from SRAL measurements performed in LRM/SAR Modes

PLRM Ku/C band measurement

20 Hz LRM/SAR_Ku Data Set

20Hz Ku band parameters from SRAL measurements performed in LRM/SAR Modes

Waveforms

waveforms and associated parameters to reprocess the data
(at least in LRM)

PLRM waveforms

→ 1Hz + 20 Hz + WF

→ Products are to be read by Sentinel-3 Altimetry Toolbox

The Support to Scientific Users

1. Support to A.O. P.I.'s through dedicated Correspondents and Results Reporting Web Site.

2. Single web site for the exploitation and promotion of your A.O. project:

   http://eopi.esa.int

3. Easier and faster to start new A.O. projects under the new Data Policy.

4. Category 1 Advisory Group (International panel of scientists) to peer review new proposals.

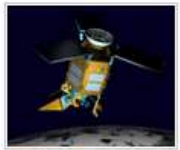

Login My Earthnet
Register
Google Custom Search
esa
Earth Online
Need Help? Contact here
European Space Agency
Data Access
Missions
Earth Topics
PI Community
Explore more...
You are here Home › PI Community
Follow | Share |
Results
ENVISAT-MERIS vegetation decline analysis: comparison with Terra-MODIS vegetation indices datasets over the lower Amu Darya River Basin (Northern Uzbekistan)
Land surface dynamics is one of the key drivers for the assessment of global environmental change and remote sensing based methods are the most important tools for its accurate monitoring. Here, ...
Satellite altimetry-based sea level rise over the past 20 years
Sea-level rise is one of the most threatening consequences of ongoing global warming and is a major indicator of climate change . Since the early 1990s global mean sea level (GMSL) trends have been...
REPROCESSED COASTAL ALTIMETRY DATA: DESIGN AND VALIDATION OF A NEW MULTI-MISSION METHODOLOGY
Coastal Satellite Altimetry data, including those from ESA ENVISAT mission, have not been fully exploited yet, because the sea level estimation in coastal areas is considered unreliable. ...
Mapping the oceanic internal wave phase speed in the South China Sea by ERS-2 and Envisat SAR images
Oceanic internal waves play an important role in nutrient distribution, primary productivity, acoustic propagation, coral reef growth, and submarine navigation. It is very difficult to measure the ...
Next
PI Community
PI Community Home
Results
Search Results and Projects
Apply for Data
Focus on PI
Toolboxes
Training
Proceedings
Events
News
MyEarthnet
Apply for Data
Fast Registration
Full Proposal
Campaigns
Announcement of Opportunities
3rd Party
Read more
News
Sentinel-1 poised to monitor motion
Stromboli Volcano - Earth Watching
Ice sheet highs, lows and loss
Summer School success
Sentinel data use - Terms & conditions
Lifetime of gravity measurements heralds new
Versatility extends life of water mission
Next
Upcoming Events
8th Coastal Altimetry Workshop
Earth Observation for Ocean-Atmosphere
Understanding the Carbon and Water Cycles
5th International GOCE User Workshop
Ocean Salinity Science & Salinity Remote
POLinSAR 2015 and 1st BIOMASS Science
ADM-Aeolus Science and Cal/Val Workshop
FRINGE 2015
2nd SMOS Science Conference
Related Links
Data User Programme
EOMD Programme
ESA SEOM
STSE
CCI
Copernicus
Sentinel Online
Dragon Cooperation Programme
Tiger Initiative
Earth Explorers
Earth Watching

Browse Projects and Results

- By Geo Search
- By Application
- By Country
- By PI
- By Mission
- By Study Area
- By Keyword Entry

Open Opportunities for Researchers

- S5PVT



This call aims to engage leading expertise for the Calibration and Validation of the Sentinel-5 Precursor (S5P) atmospheric monitoring mission.

- S3VT

The S3VT call is open to relevant and interested groups and individuals worldwide; group responses are particularly welcome.

- Swarm

Interested users may - at any time - submit proposals for the use of Swarm validated Level 1b and Level 2 data through a dedicated interface.

- G-POD

ESA is offering all scientists with the possibility to perform bulk processing exploiting the large ESA Earth-observation archive together with ESA available GRID computing and dynamic storage resources.

Training

- 5th Advanced Training Course on Land Remote Sensing 2014
  08 - 12 Sep 2014
- 2nd ESA Advanced Training Course on Atmospheric Remote Sensing
  27 - 30 Oct 2014
- 3rd ESA Advanced Course on Radar Polarimetry
  19 - 23 Jan 2015
- SMOS training course
  18 - 22 May 2015

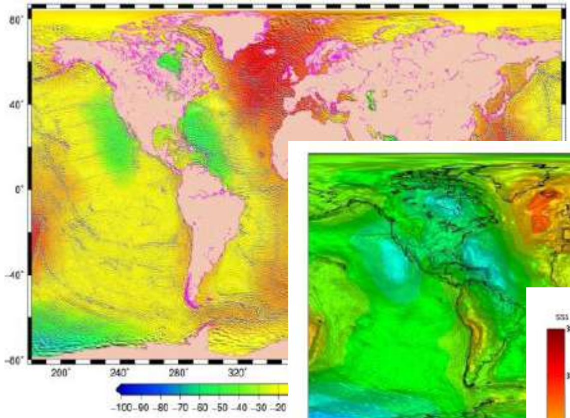
Proceedings

- PolInSAR 2013
- Earth Observation and Cryosphere Science
- Sentinel-3 OLCI/SLSTR and MERIS/(A)ATSR 2012
- SEASAR 2012
- First Sentinel-2 Preparatory Symposium
- Atmospheric Science 2012
- 4th International GOCE User Workshop
- FRINGE 2011
- 20 years of ERS Missions
- PolInSAR 2011
- SEASAR 10
- FRINGE 09
- Atmospheric Science 2009
- 2009: PolInSAR
- 2008: ALOS Symposium
- 2008: MERIS & AATSR
- 2008: SEASAR
- 2007: FRINGE
- 2007: Second Space for Hydrology Workshop
- 2007: ENVISAT Symp
- 2006: GOCE
- 2006: MSG
- 2006: SMOS
- 2006: EPS-METOP
- 2006: Atmos. Science
- 2006: Altimetry Symp.
- 2006: SeaSAR

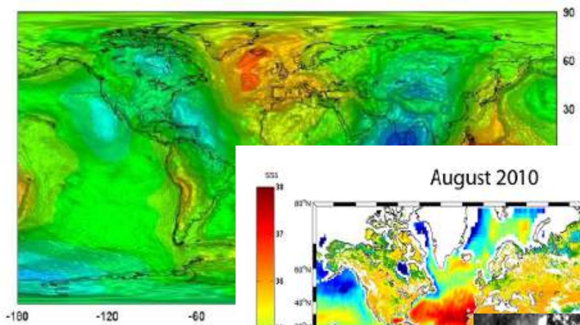
Toolboxes

- NEST (Next ESA SAR Toolbox)
- Basic ERS & Envisat (A) ATSR and Meris Toolbox (BEAM)
- Basic ERS & Envisat Atmospheric Toolbox (BEAT)
- Basic Radar Altimetry Toolbox (BRAT)
- POLSARPRO
- GOCE User Toolbox (GUT)
- CryoSat User Tool (CUT)

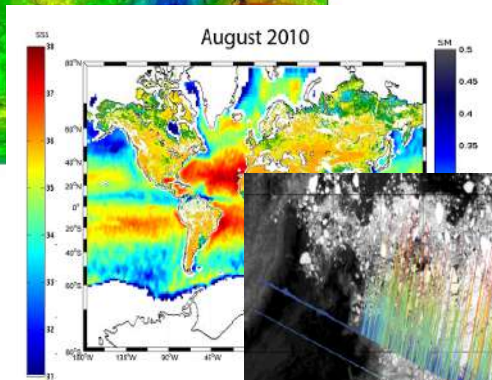
ESA mission synergies



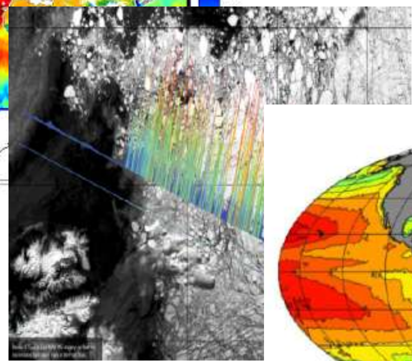
SSH *(Envisat, S-3, Jason-CS)*



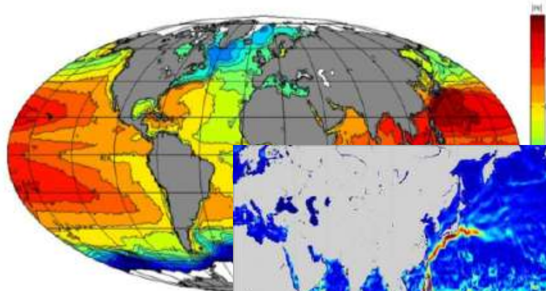
High precision Geoid (*GOCE*)



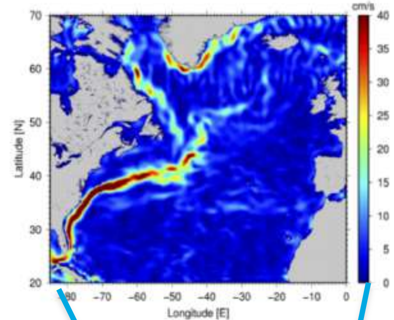
Ocean salinity (*SMOS*)

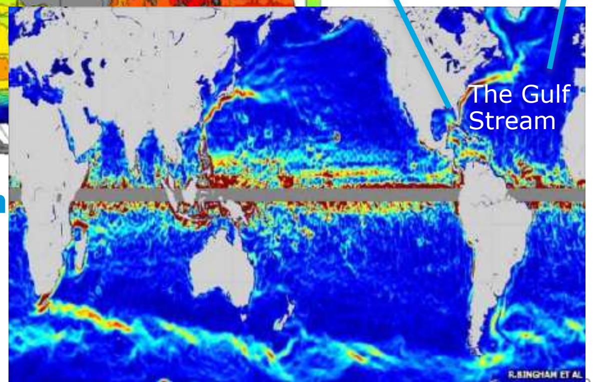


Ice/Water surface (*CryoSat, S-3*)



Global ocean Dynamic Topography





Ocean currents (Alt + Geoid + SSS + models)

- les outils

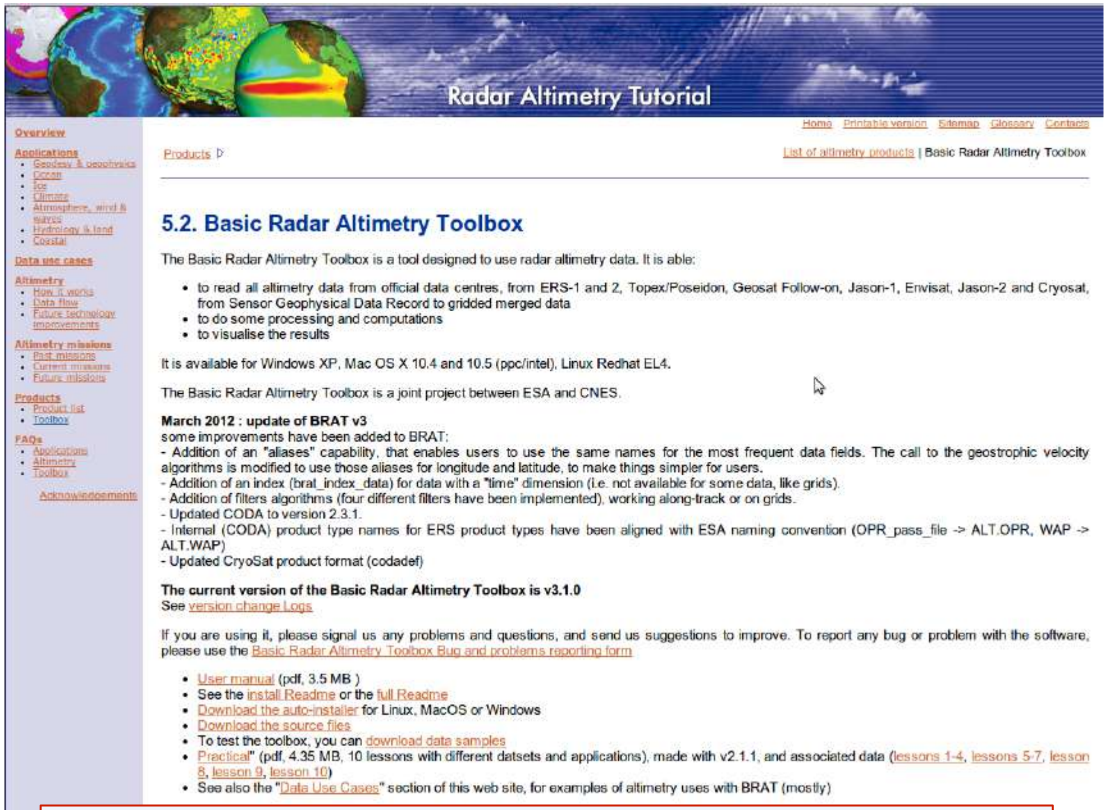
The Basic Radar Altimetry Toolbox (BRAT)

The Radar Altimetry Tutorial (RAT)

Future Evolutions:
The Sentinel-3 SAR Altimetry Toolbox

BRAT - Introduction

- The **B**asic **R**adar **A**ltimetry **T**oolbox (BRAT) was launched in 2005 as a joint project funded by ESA (European Space Agency) and CNES (Centre National d'Etudes Spatiales).
- Last version 3.10 was launches in March 2012 and had around 1200 unique downloads (that about new users per week!).



Radar Altimetry Tutorial

Home | Printable version | Sitemap | Glossary | Contacts

Products ▷ List of altimetry products | Basic Radar Altimetry Toolbox

Overview

Applications
- Geodesy & geophysics
- Ocean
- Ice
- Climate
- Atmosphere, wind & waves
- Hydrology & land
- Coastal

Data use cases

Altimetry
- How it works
- Data flow
- Future technology improvements

Altimetry missions
- Past missions
- Current missions
- Future missions

Products
- Product list
- Toolbox

FAQs
- Applications
- Altimetry
- Toolbox

Acknowledgements

5.2. Basic Radar Altimetry Toolbox

The Basic Radar Altimetry Toolbox is a tool designed to use radar altimetry data. It is able:

- to read all altimetry data from official data centres, from ERS-1 and 2, Topex/Poseidon, Geosat Follow-on, Jason-1, Envisat, Jason-2 and Cryosat, from Sensor Geophysical Data Record to gridded merged data
- to do some processing and computations
- to visualise the results

It is available for Windows XP, Mac OS X 10.4 and 10.5 (ppc/intel), Linux Redhat EL4.

The Basic Radar Altimetry Toolbox is a joint project between ESA and CNES.

March 2012 : update of BRAT v3
some improvements have been added to BRAT:
- Addition of an "aliases" capability, that enables users to use the same names for the most frequent data fields. The call to the geostrophic velocity algorithms is modified to use those aliases for longitude and latitude, to make things simpler for users.
- Addition of an index (brat_index_data) for data with a "time" dimension (i.e. not available for some data, like grids).
- Addition of filters algorithms (four different filters have been implemented), working along-track or on grids.
- Updated CODA to version 2.3.1.
- Internal (CODA) product type names for ERS product types have been aligned with ESA naming convention (OPR_pass_file -> ALT.OPR, WAP -> ALT.WAP)
- Updated CryoSat product format (codadef)

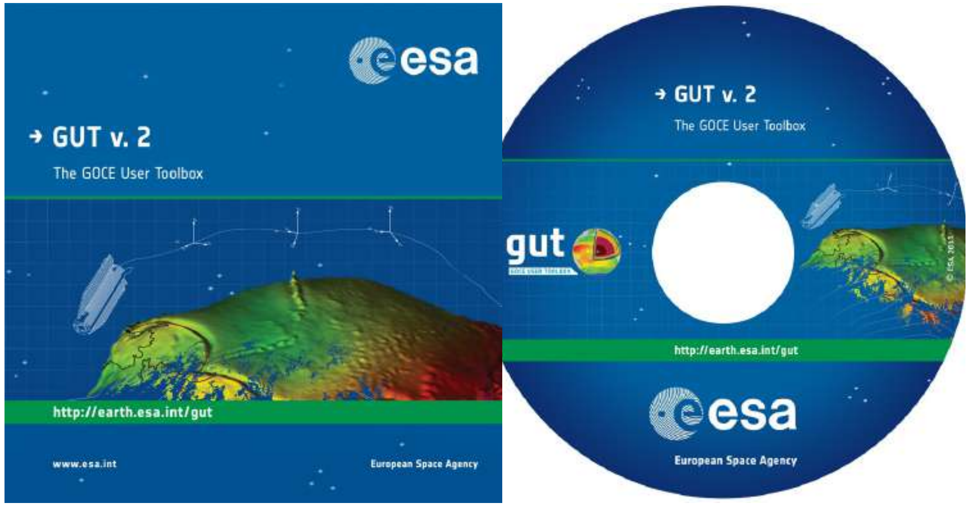
The current version of the Basic Radar Altimetry Toolbox is v3.1.0
See version change Logs

If you are using it, please signal us any problems and questions, and send us suggestions to improve. To report any bug or problem with the software, please use the Basic Radar Altimetry Toolbox Bug and problems reporting form

- User manual (pdf, 3.5 MB)
- See the install Readme or the full Readme
- Download the auto-installer for Linux, MacOS or Windows
- Download the source files
- To test the toolbox, you can download data samples
- Practical" (pdf, 4.35 MB, 10 lessons with different datsets and applications), made with v2.1.1, and associated data (lessons 1-4, lessons 5-7, lesson 8, lesson 9, lesson 10)
- See also the "Data Use Cases" section of this web site, for examples of altimetry uses with BRAT (mostly)

Tool available for free download at
- earth.esa.int/brat
- altimetry.info

BRAT - Dissemination



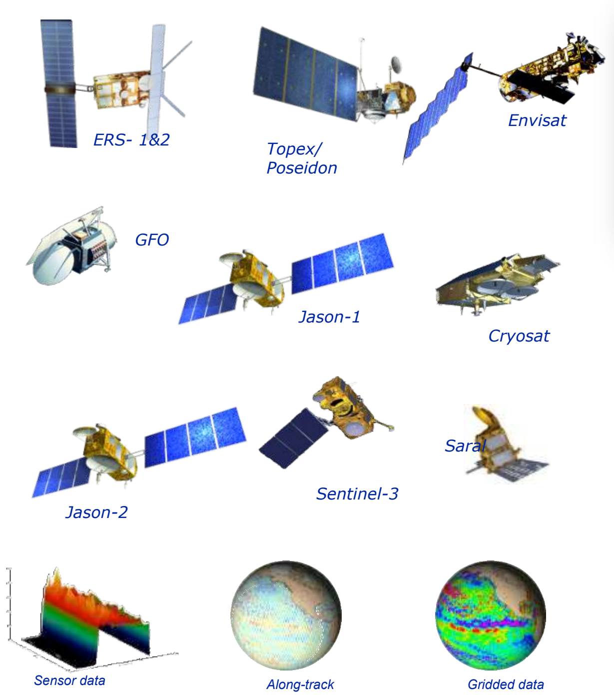
Tool available for free download at

- earth.esa.int/brat
- altimetry.info

BRAT: Tools for altimetry training

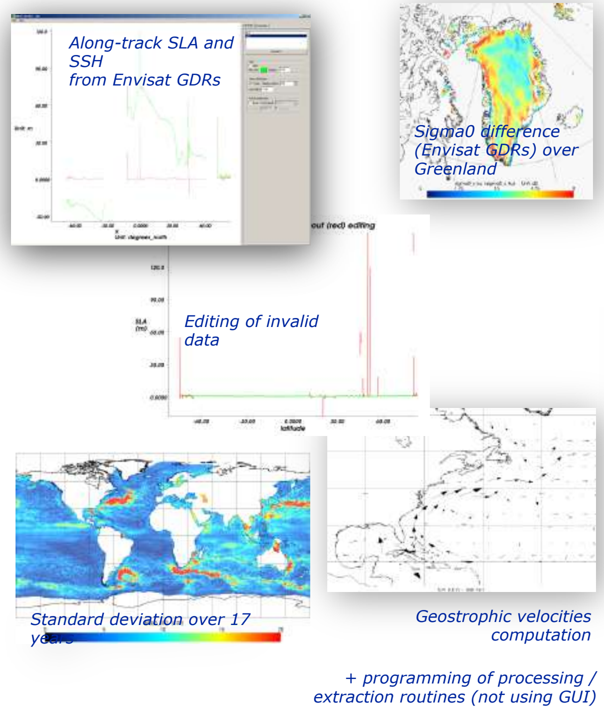
A joint ESA-CNES project, to make easier the use of altimetry

read most distributed altimetry data



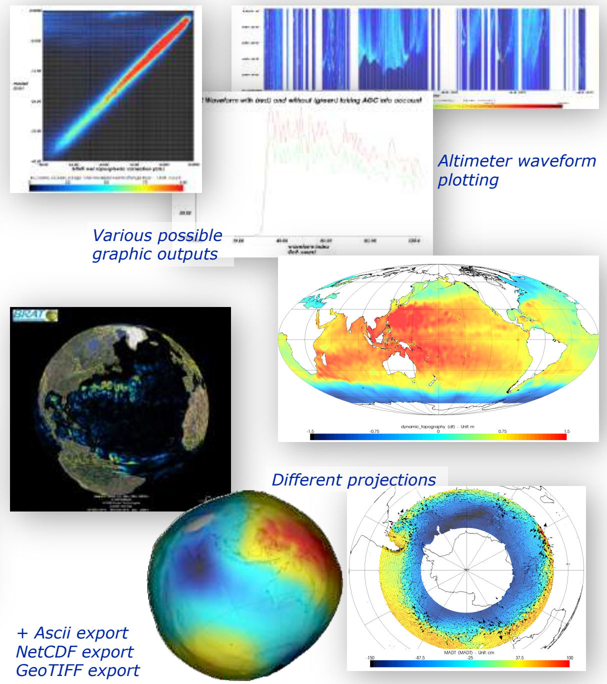
APIs, on-line command mode, graphical user interface

process & select data



APIs, on-line command mode, graphical user interface

visualize & export the results



APIs, graphical user interface

The Radar Altimetry Tutorial gives information about altimetry and applications, an overview of the missions.
It also presents a series of data use cases, showing the basic methods for some of the most frequent manners of using altimetry data.

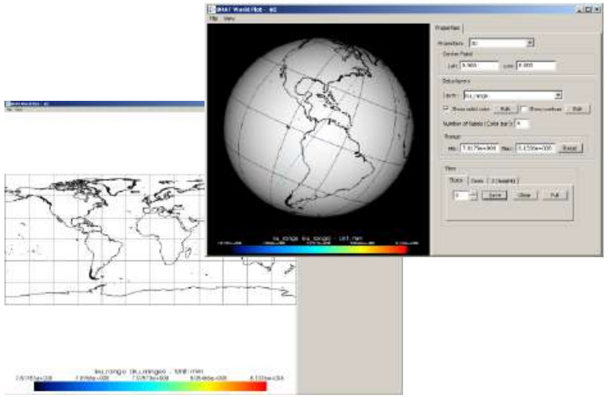
http://www.altimetry.info and http://earth.eo.esa.int/brat/

BRAT: Tools for altimetry training

Training in altimetry using BRAT

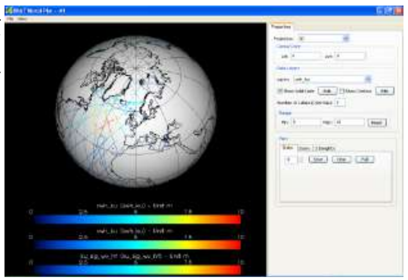
Toolbox used in remote sensing curricula all around the world. The Tutorial provides basic material for teaching altimetry.

• altimetry data are “1D”
→ most people think of satellite outputs as images…



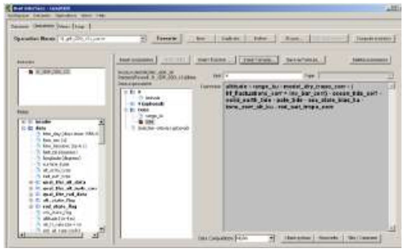
• show how much data are taken during e.g. 1 day, to explain the advantages and limitation of altimetry for real-time applications.

One day of SWH for Jason-1, Envisat and Jason-2 (image courtesy Eumesat/ IODE)

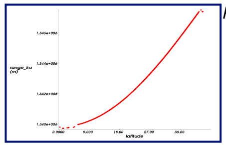


Documents on www.altimetry.info

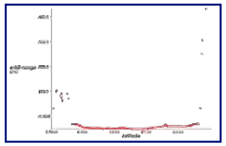
• Show how sea surface heights and sea level anomalies are computed
→ explains how it is done, errors & improvements



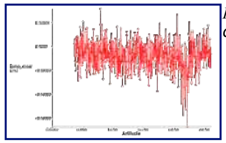
• Add corrections one by one to show their imports.



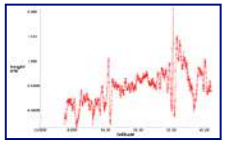
Range Ku



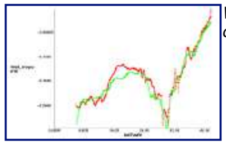
Altitude - Range Ku



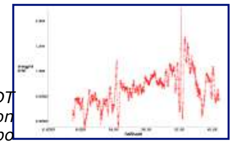
Ionospheric correction



Raw ADT – iono corr

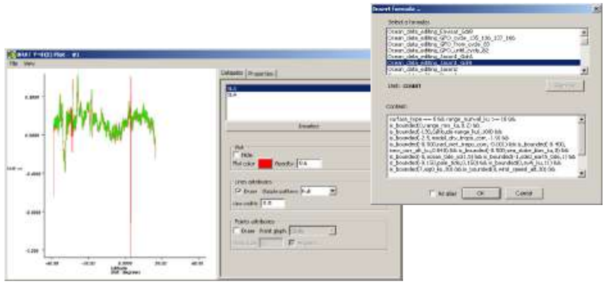


Wet Tropospheric correction

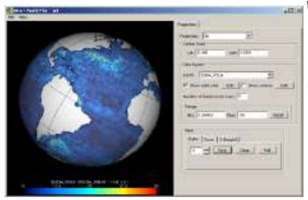


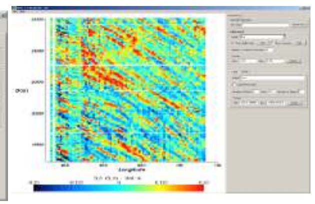
Raw ADT – iono correction – wet tropo correction

• Data editing, and selections
→ explanations on measurements & invalid data

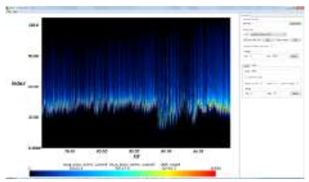


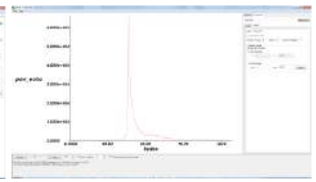
• Different teaching modules:
- Work on gridded data, including statistics





- Visualization of waveform data



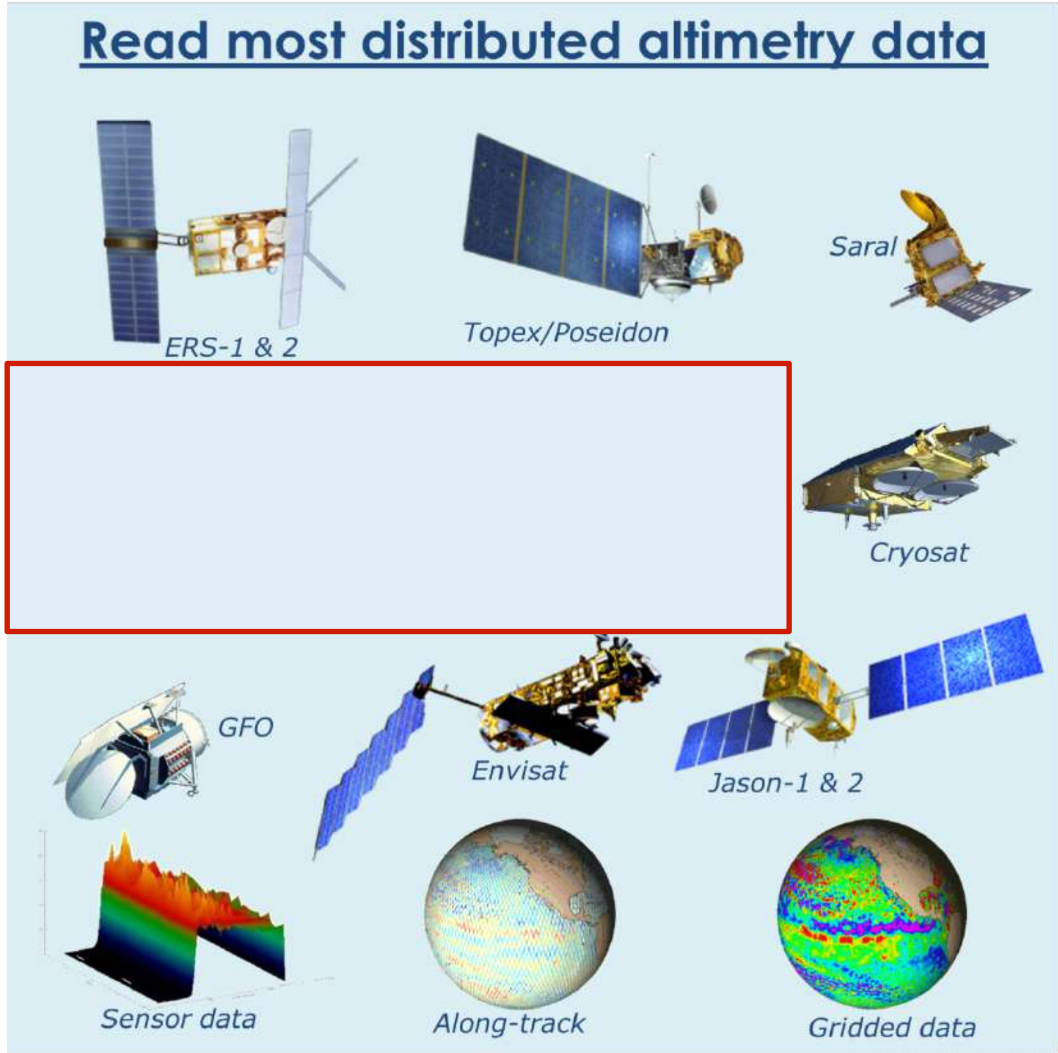


BRAT – Data Reading Capabilities

- BRAT is used to read and display all the past and present Radar Altimetry missions' products.

→ **Sentinel-3 Products are to be read by Sentinel-3 Altimetry Toolbox**

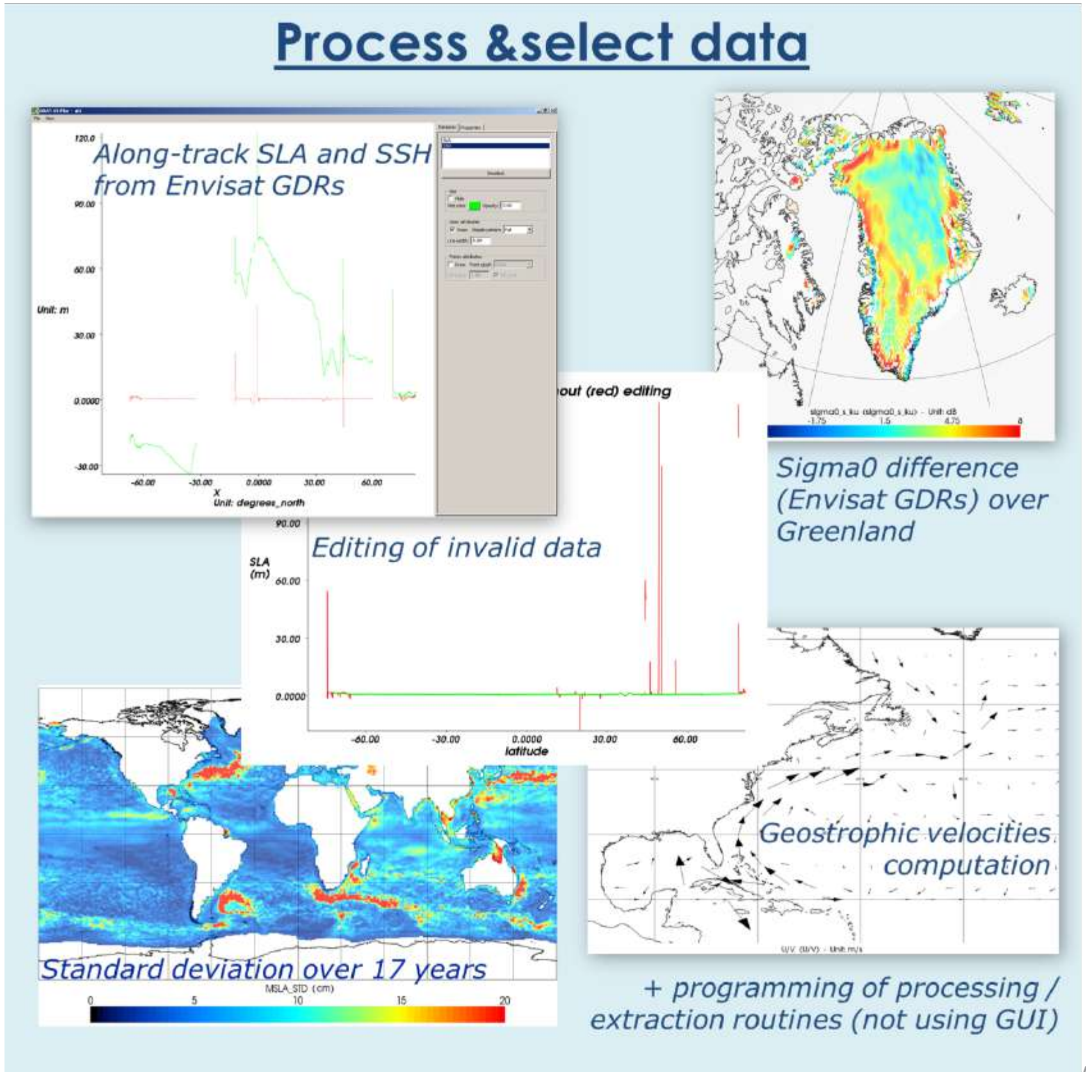
→ **Cannot be handled by BRAT**



BRAT – Processing Capabilities

- BRAT provides support for ingesting, processing (computation of formulas involving combinations of data fields; resampling of data; data selection using one/several criteria), generating statistics.

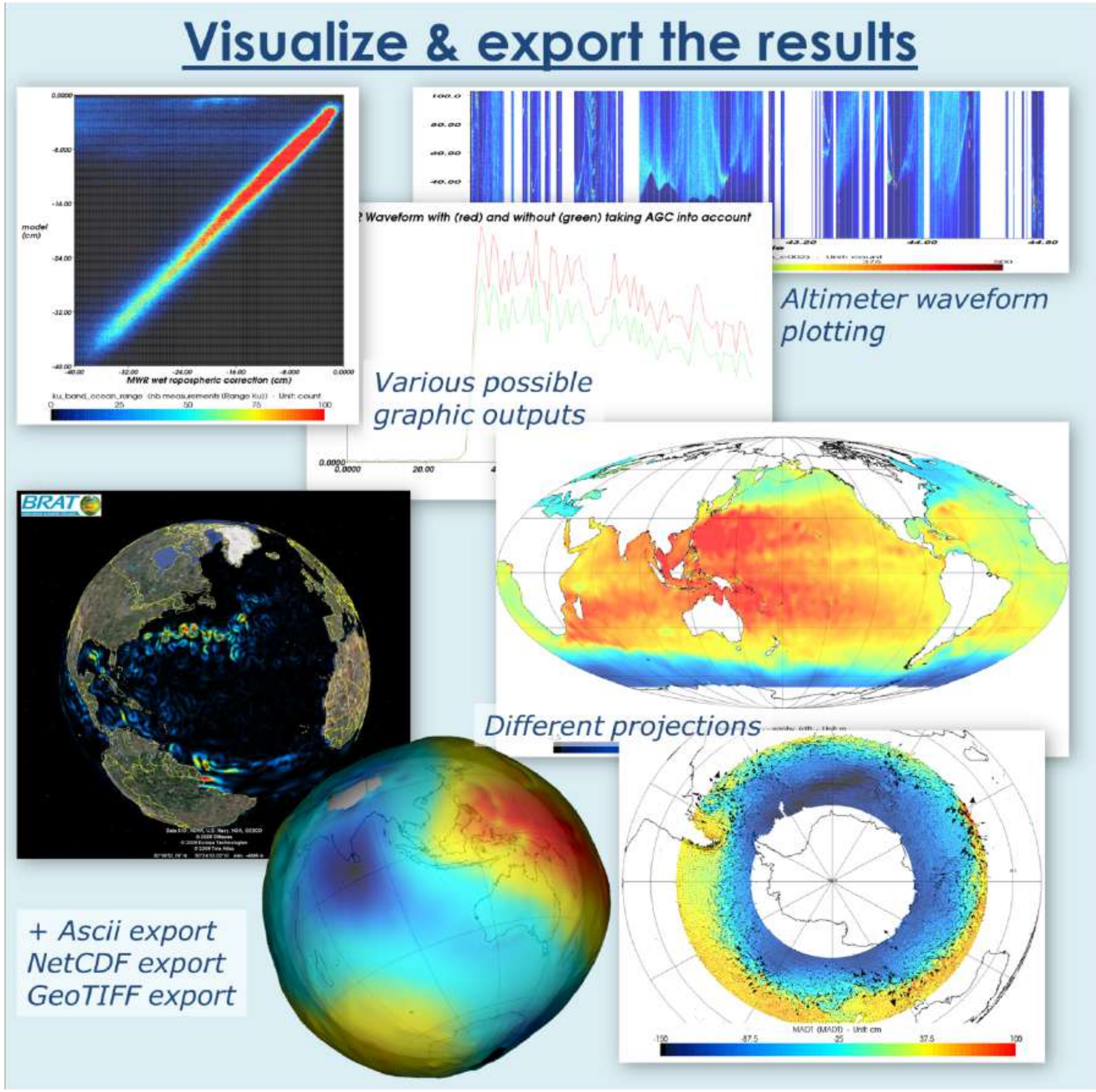
→ **New/Updated formulas for Sentinel-3 Altimetry Toolbox**



BRAT – Visualizing and Exporting

1. BRAT can also visualising and exporting the results in Image format (PNG, Geotiff, etc.) and in simple Google Earth's KML.

→ The Sentinel-3 Altimetry Toolbox will improve the export capabilities allowing better KML support and automatic (scripting) image generation.



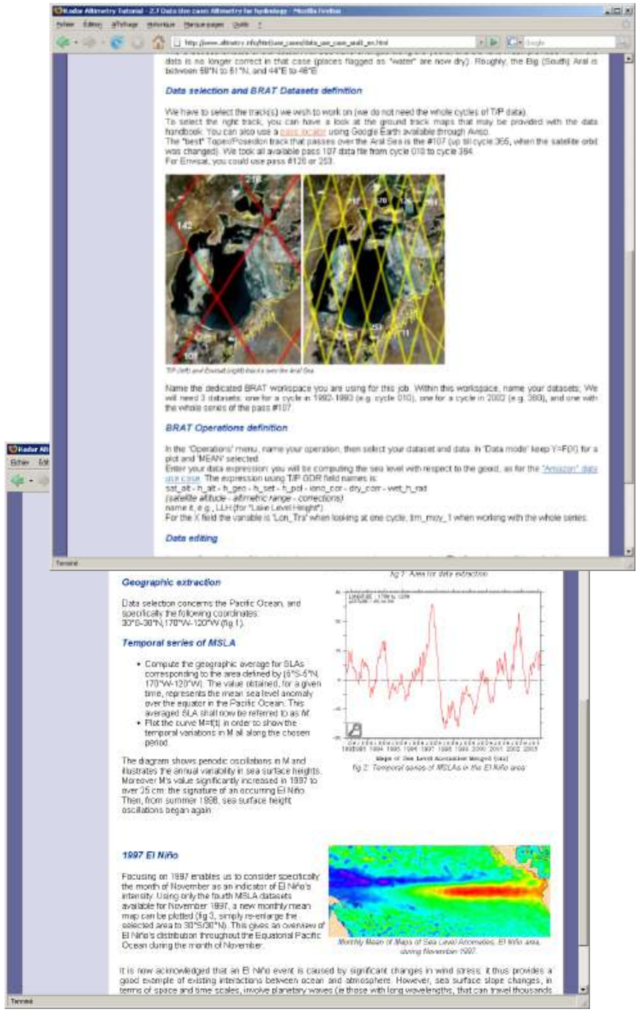
BRAT - Under the hood

1. BRAT consists of several modules operating at different levels of abstraction. These modules can be Graphical User Interface (GUI) applications, command-line tools, interfaces to existing applications (such as IDL and MATLAB) or application program interfaces (APIs) to programming languages such as C and Fortran.

→ The Sentinel-3 Altimetry Toolbox will follow the same structure.

Radar Altimetry Tutorial

1. The Radar Altimetry Tutorial (RAT) is also part of the BRAT suite and gives general information about altimetry, the techniques involved and their applications, as well as an overview of the missions. It also presents a series of data use cases, covering all uses of altimetry over ocean, cryosphere and land, showing the basic methods for some of the most frequent manners of using altimetry data.



→ The Sentinel-3 Altimetry Toolbox will have more tutorial material

Further Toolbox development activities

1. Data Improvements
2. Computation
3. User Interface
4. Data Export
5. Underneath the Hood
6. Technical Documents & User Manual

Toolbox development activities

1. Data Improvements
    a. Netcdf 4 read/write
    b. Sentinel-3 Data
        – L1A, L1BS, L1B, L2 (in the different flavours)
    c. Cryosat-2 Ocean Products and Baseline C
    d. ERS Reaper Products
    e. Geosat GDR data
    f. Update of River and Lake Products Handling

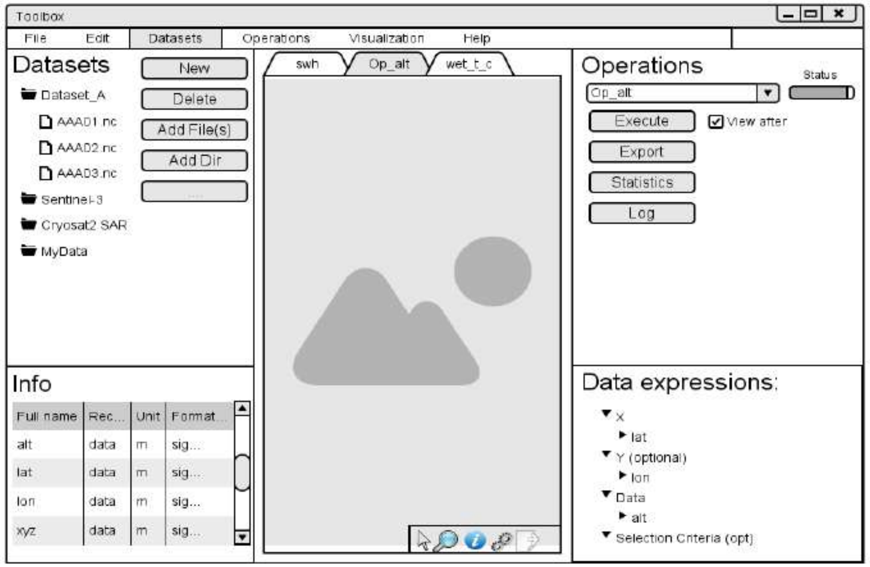
Toolbox development activities

1. Data Improvements
2. Computation
    a. Update Built-in Formulas
    b. Coastal and Inland Waters Altimetry Formulas
    c. User-Defined Algorithm Module & Python API
    d. Interpolation Algorithm Module
3. User Interface
4. Data Export
5. Underneath the Hood
6. Technical Documents & User Manual

Toolbox development activities

User Interface

- Update Visualization Component
  - Enhanced Display Background
    - High Resolution for Coastal zone for instance
  - Plot Track Data
  - Regression Line Plotting
  - Several updates/corrections



New user interface (Mockup)

Toolbox development activities

1. Data Improvements
2. Computation
3. User Interface
4. Data Export
    a. ASCII Export Viewer
    b. Addition of Image Export
    c. Improvements in KMZ/KML Export
5. Underneath the Hood
6. Technical Documents & User Manual

Toolbox development activities

- Underneath the Hood
  a. Support 64 bits system
  b. External Code Contributions
     – Reading of Hydroweb Products
     – Reading 3D Data
     – HY-2A Products
     – Computation of Alternative SSB
     – Statistics Computation
     – Unit Aware Inequality Operators

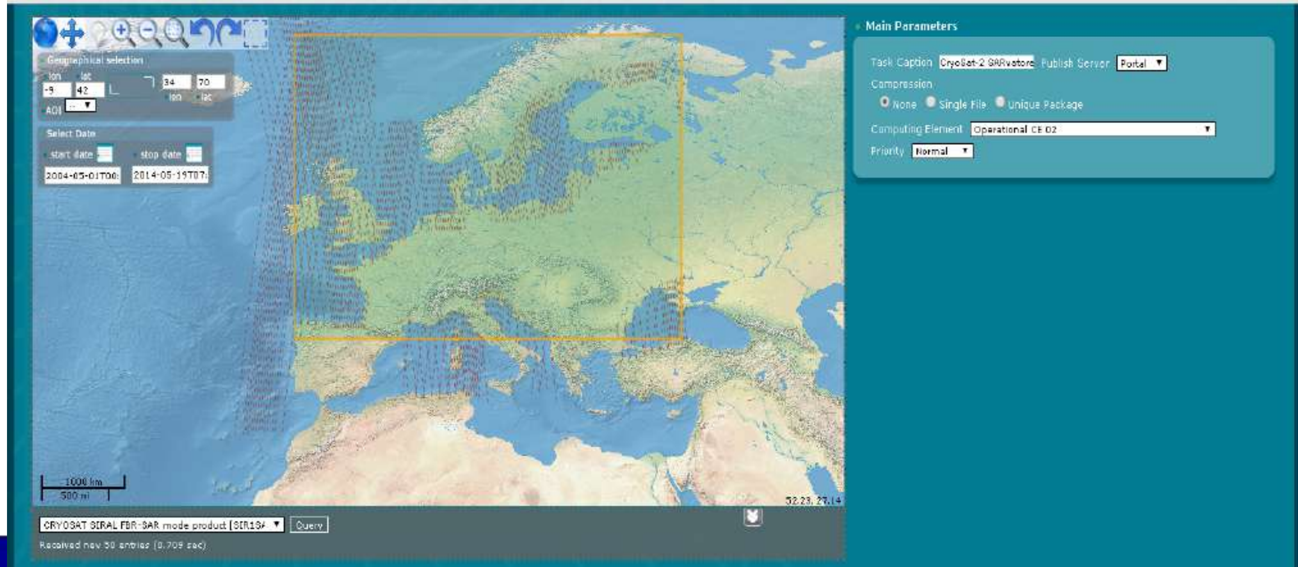
Windows / Linux / Mac OS X

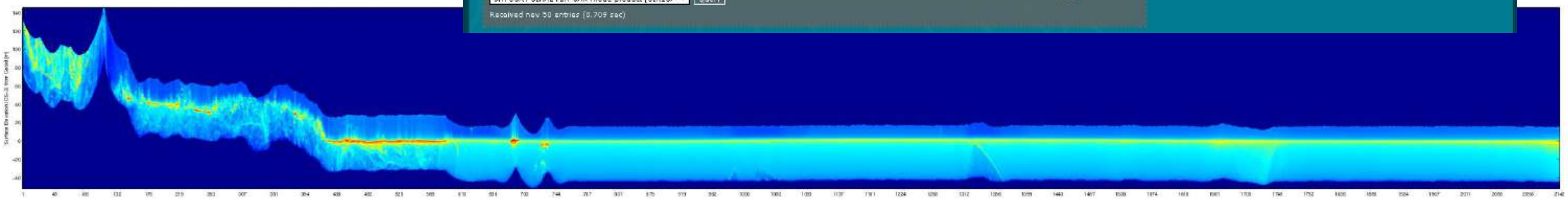
Open-Source Software.
To be done via source code repository.

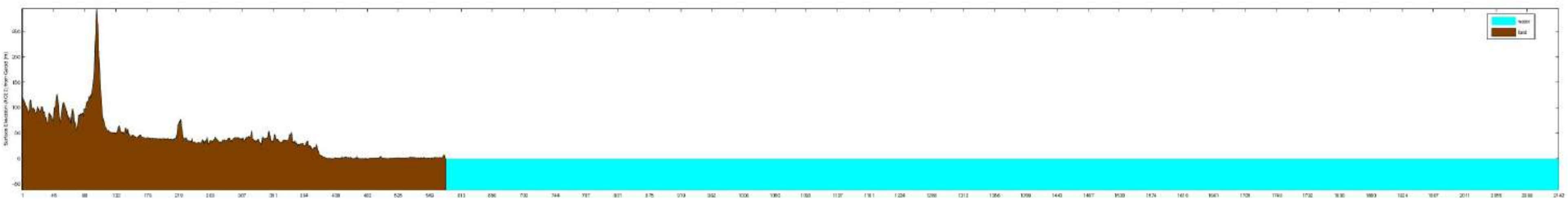
SAR Processing On Demand: SARvatore

SAR Processing On Demand Service available at:

https://gpod.eo.esa.int/services/CRYOSAT_SAR/







A TYPICAL ESA R&D PROGRAMME

seom

scientific exploitation of operational missions

seom
scientific exploitation of operational missions

ACTION LINES

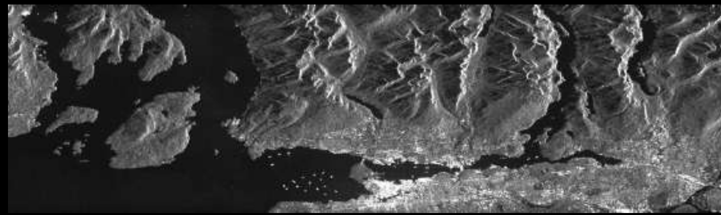
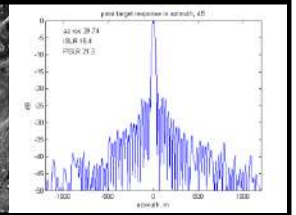
esa

Research and Development Studes	Launching state-of-the-art R&D studies for scientific exploitation of operational missions
Scientific Toolboxes development	Developing, validating and maintaining open-source, multi-mission, scientific software toolboxes
Science Users Consultations	Organising a series of regular international thematic workshops for science users consultation and gathering science users feedback
Training Next Generation of Earth Observation Scientists	Offering a multi-year programme of advanced international training courses, summer schools and educational materials
Promoting Science Data use and Results	Promoting scientific use of data and ensuring a responsive ESA channel for regular, timely, high-quality scientific publications

seom
scientific exploitation
of operational missions

ION LINES

Research and Development Studies

Scientific Toolboxes development


Science Users Consultations

Training Next Generation of Earth Observation Scientists

Promoting Science Data use and Results

seom
scientific exploitation of operational missions

Workshops/Symposia

esa

Science User Consultations

• **Living Planet Symposium 2013**: the 2013 Living Planet Symposium organised with UKSA, Edinburgh, United Kingdom 9 -13 September
www.esa.int/LivingPlanet2013 (with **1700 *participants*** *from* **60 *countries)***

• **COASTALWorkshop :** 8TH Coastal Altimetry workshop focused on the future Sentinel-3 Topography Mission 23-24 October 2014
http://www.coastalaltimetry.org

Ref. ESA/PB-EO(2013)5, EOEP-4 D&E component Draft workplan 2013

Workshops/Symposia

User Training

- **TRAINING COURSE on OCEAN REMOTE SENSING**, Cork Ireland , 23-27 Sept.2013
    - ~ 60 students

- **SAR Altimetry Training**
    - Lake Constance (DE)
    - 21 and 22 October 2014

seom
scientific exploitation of operational missions

OUTLOOK

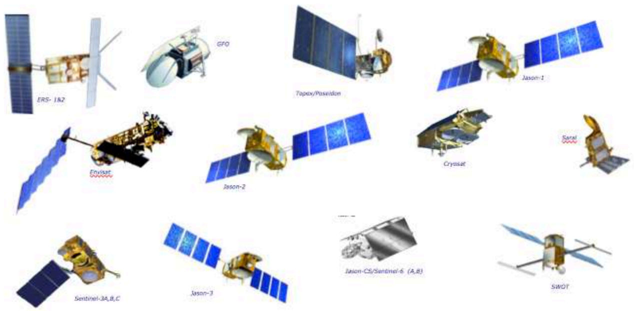
esa

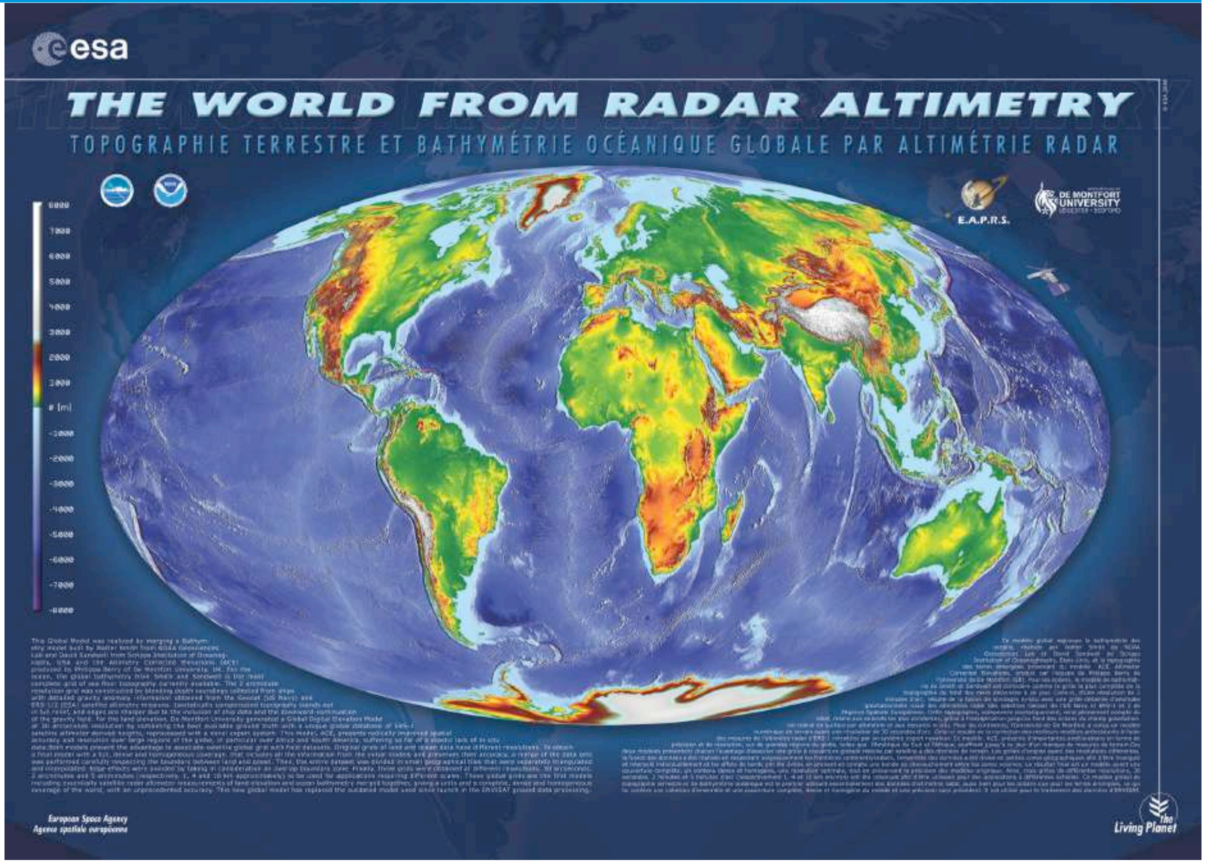
1. New exploitation element focused on scientific exploitation (Sentinels)
2. Opportunities for R&D (EMITS)
3. Preparation of scientific toolboxes (open source)
4. Regular Training for next generation EO scientists
5. Regular Science users workshop consultations
6. Workplan based on recommendations gathered and approved at PBEO (every year)

Altimétrie spatiale

- la genèse
- les objectifs
- les missions spatiales
- les données
- les outils

Thank you for your attention!





Further inquiries @: Jerome.Benveniste@esa.int

or better:

Altimetry.Info@esa.int