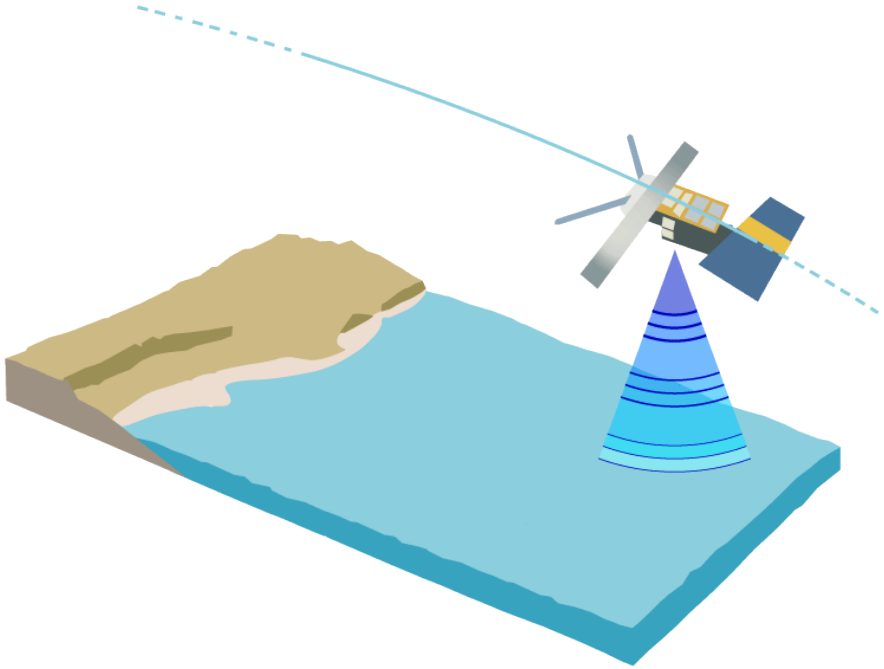
The contribution of altimetry to storm surge modelling in the eSurge project



Paolo Cipollini[1], Kevin Horsburgh[1], Phillip Harwood[2], Craig Donlon[3]

[1] National Oceanography Centre, UK

[2] CGI, Leatherhead, UK

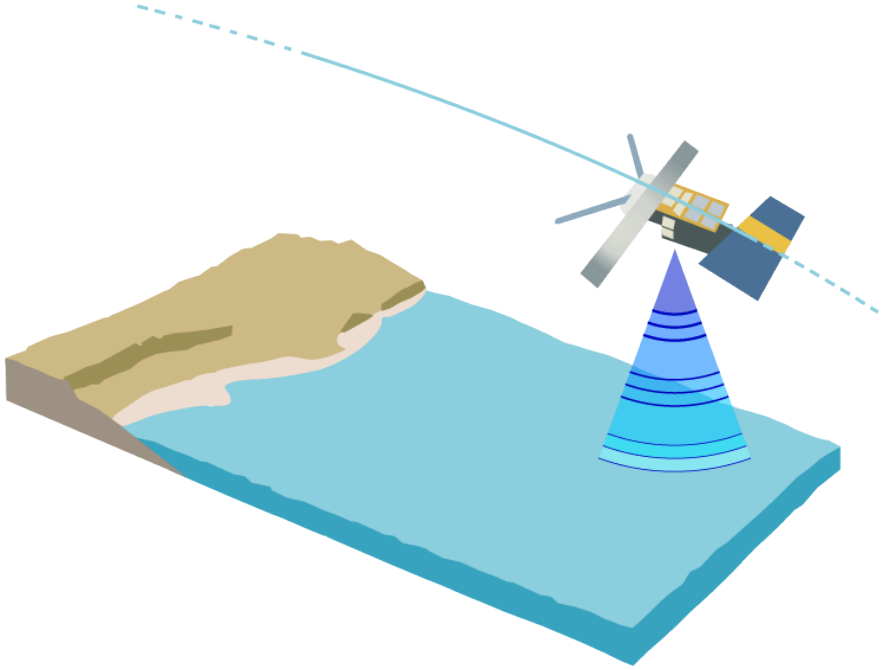
[3] ESA/ESTEC, The Netherlands

eSurge

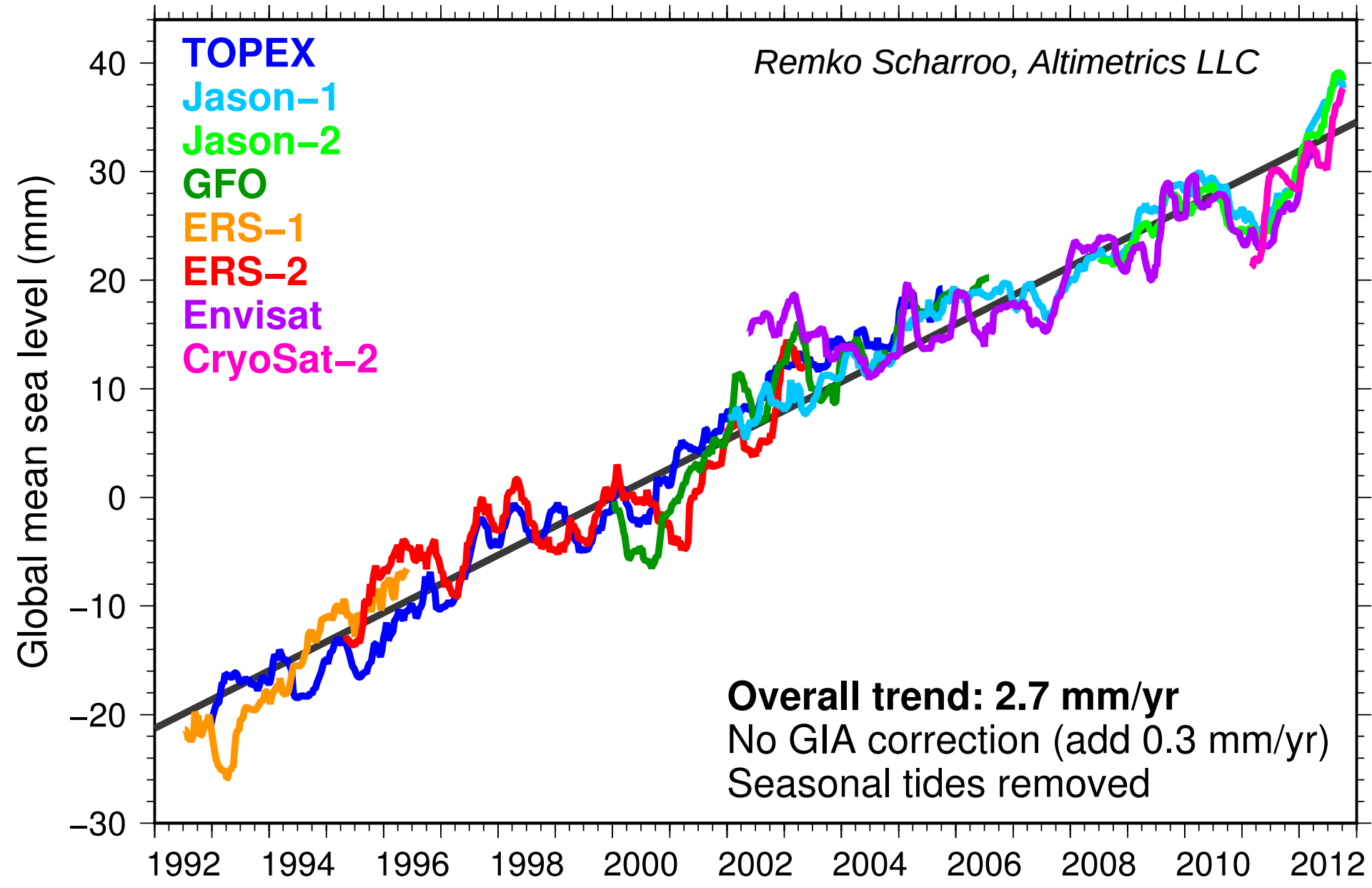
13TH INTERNATIONAL WORKSHOP ON WAVE HINDCASTING AND 4th COASTAL HAZARDS SYMPOSIUM
BANFF, ALBERTA, CANADA October 27 - November 1, 2013

Satellite Altimetry

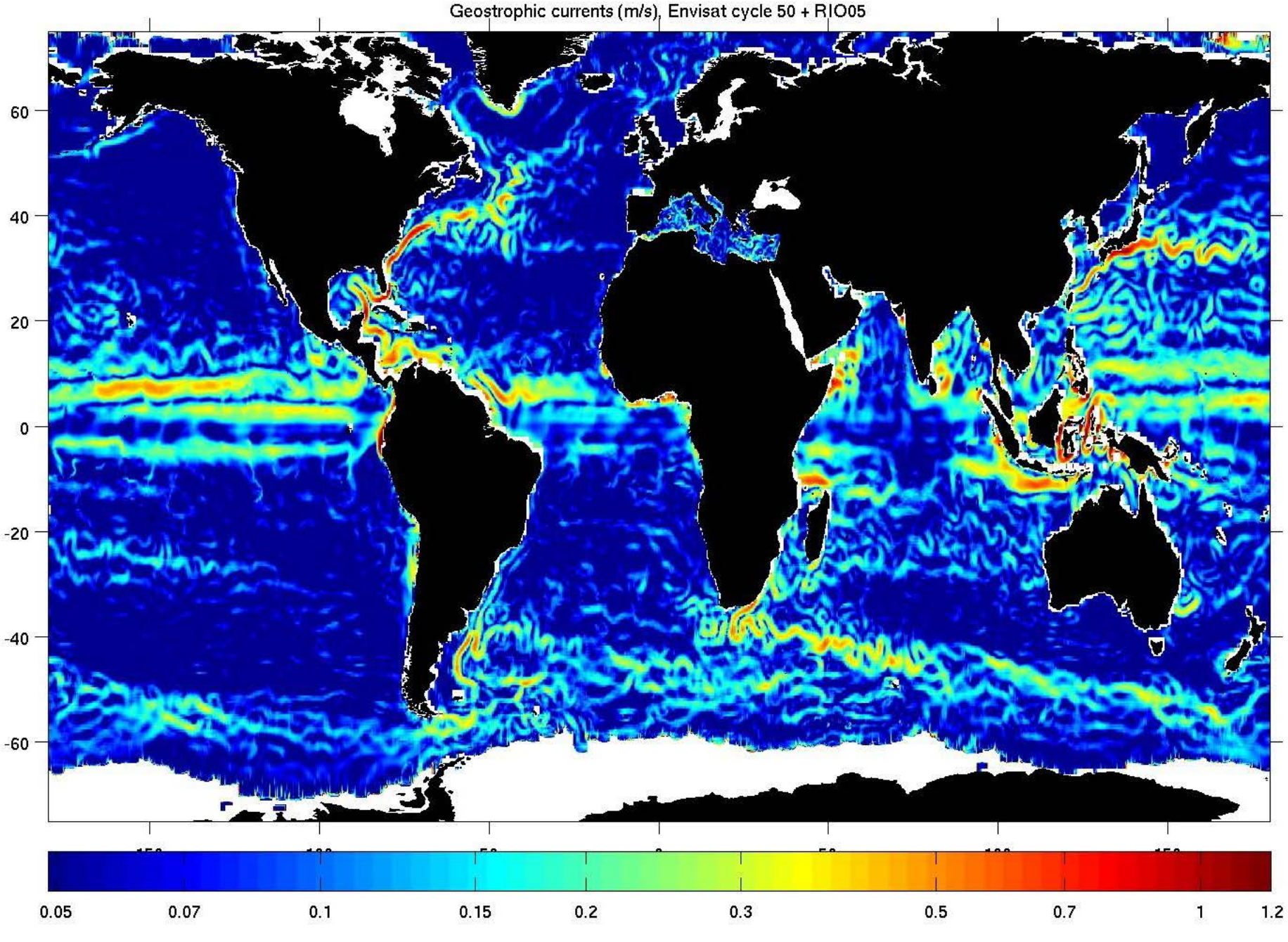
- one of the most successful EO techniques
  - synoptic, sustained view of surface ocean dynamics (currents, eddies, planetary waves)
  - accurate, long-term global and regional sea level monitoring



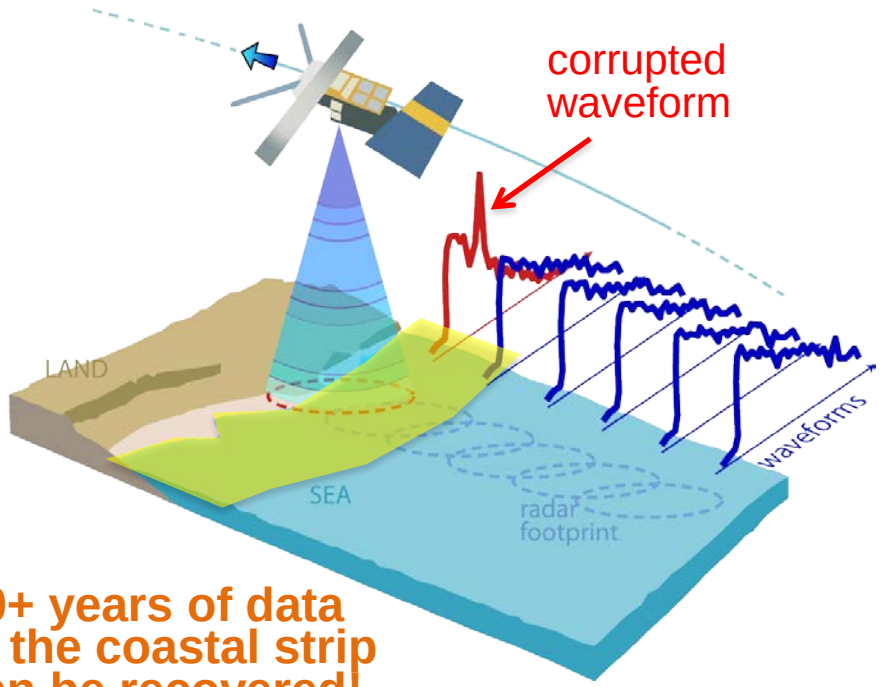
SEA LEVEL RISE - global



SURFACE CURRENTS



Why do coastal altimetry?



20+ years of data in the coastal strip can be recovered!

Standard altimetry does not quite go all the way to the coast!

Traditionally, data in the **coastal zone** are flagged as bad and left unused

(coastal zone: as a rule of thumb 0-50 km from coastline, but in practice, **any place where standard altimetry gets into trouble** as radar waveforms are non-standard and/or corrections become inaccurate)

In recent years a significant community of researchers has started to believe that **most of those coastal data can be recovered** and that coastal altimetry can be **a legitimate component of coastal observing systems!** *(see OceanObs'09 Community White Paper on coastal altimetry)*

Why do coastal altimetry?

- to elucidate coastal dynamics
- to support coastal management
- to link open ocean variations of sea level to those at the coast (tide gauges)
- **to study extreme events (surges)**
- to study the coastal wave field

Why do coastal altimetry?

- because it is global – i.e. includes many stretches of the world's coasts where altimetry is the only measurement available!
- because we have 21 years of data already
- because new and forthcoming missions (SAR altimeters such as Cryosat, Sentinel-3, Jason-CS; Ka-band altimeters such as AltiKa) have intrinsically better coastal capabilities
- users (scientists, coastal managers, environmental agencies) are asking for it

What the users require

- Joint PISTACH/COASTALT survey carried out in 2008
- Modelling community is an important user community
- Wind and Waves matter to many users in addition to SSH
- Near-real-time delivery of coastal altimetry
- Important climate applications
  - Long-term aim: global climatology of coastal sea level (and waves)
  - Examples:
    - Agulhas Current Transport time-series - need coastal altimetry as current is very close to coast. And similarly on the Arctic margins.
- Need clear quality flags together with all the separate corrections
- Need good documentation → doing NetCDF product specification and user handbooks
- easy access to the data
- storm surges (and their climatology) now emerging as crucial application

“Retracking” of the waveforms

= fitting the waveforms with a waveform model, therefore estimating the parameters

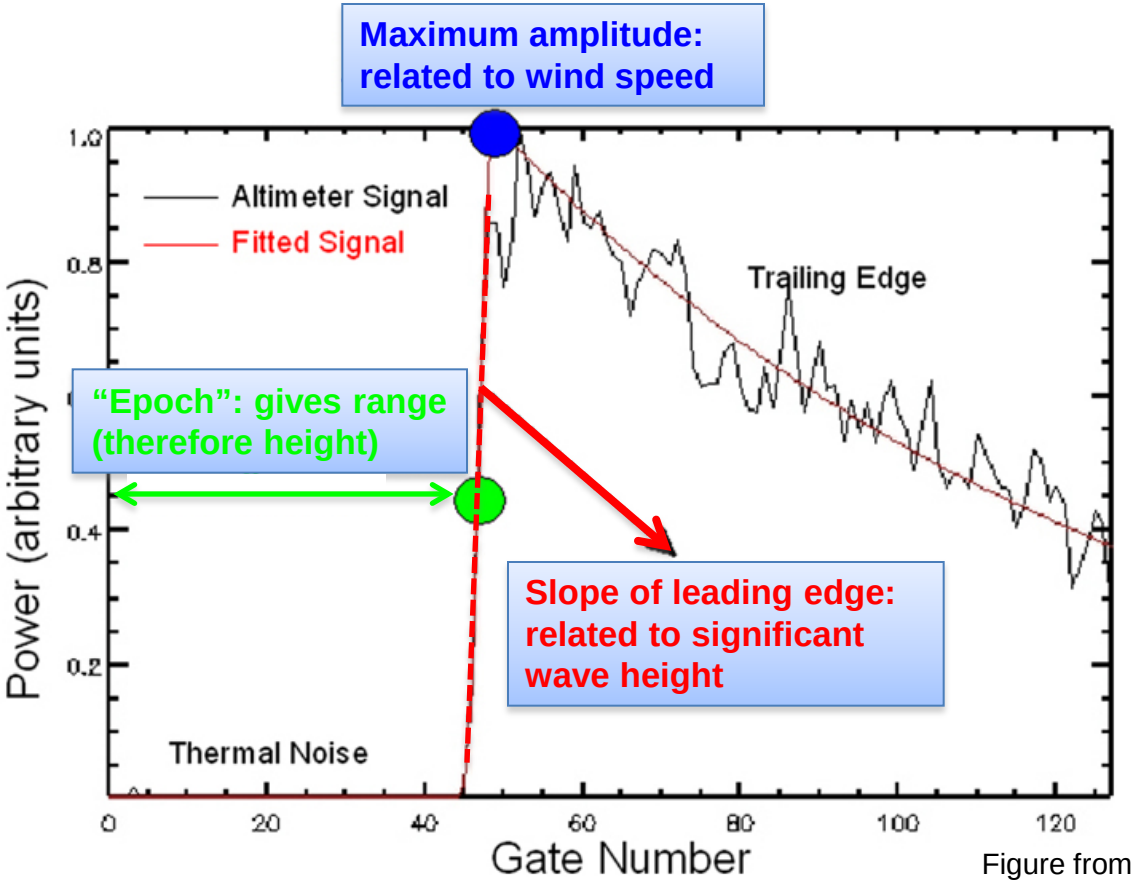
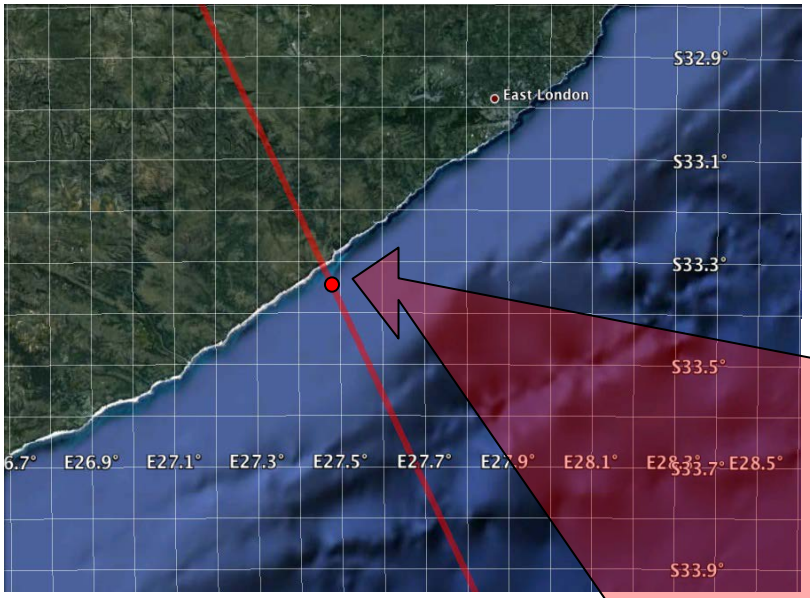


Figure from J Gomez-Enri et al. (2009)

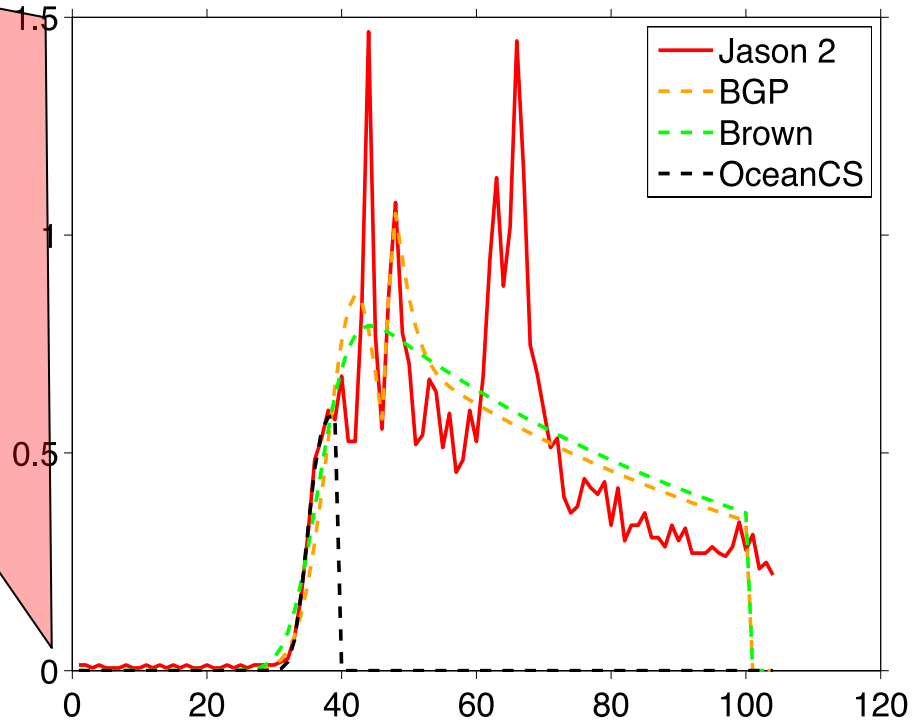
Retracking coastal waveforms

- waveforms in coastal zone and island passes have been extensively studied
- effects of land and effects of calm waters in the coastal strip are observed
  - Land normally gives ‘dark’ features (less signal)
  - Calm water cause quasi-specular reflections → bright features or “bright targets”
  - These features migrate in the waveform/gate number space following hyperbolae (a parabolic shape is usually a good approximation)
- Our suggested solution: a retracker that only fits the ‘good’ portion of the waveform (the leading edge), neglects the rest
  - “OceanCS” retracker by Yang et al 2012, further developed at NOC by Passaro et al., 2013 “‘ALES” retracker

Retracking – an example



Jason-2 Example

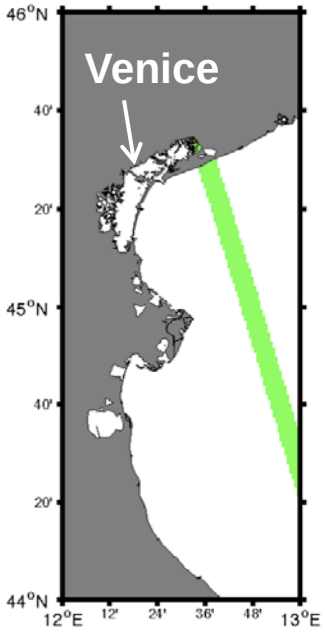


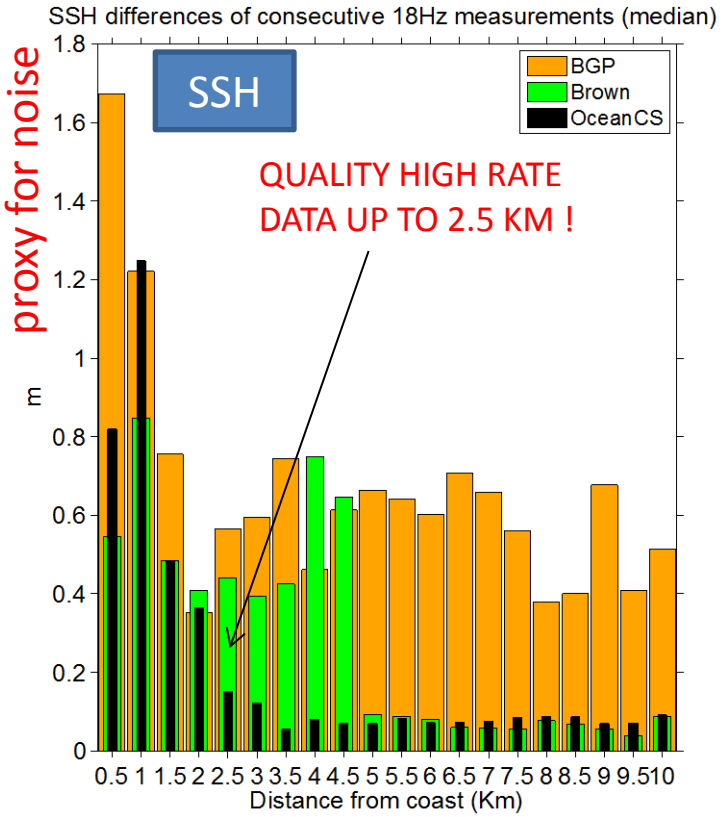
Jason-2 pass 096 over the coast of South Africa and example of **coastal waveform** for cycle 83 and its retracking with various models: **BGP (Halimi et al., 2013)**, **Brown (1977)**, **OceanCS (Yang et al., 2012)**

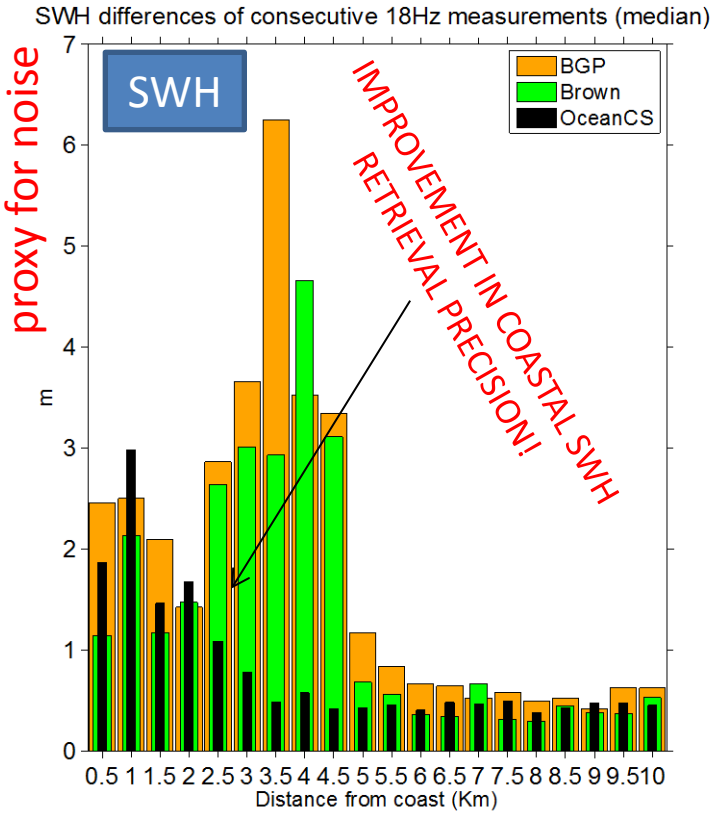
M. Passaro, NOC

With specialized retrackers we get much closer to the coast

Envisat example, 20 cycles of pass 0543 over Northern Adriatic







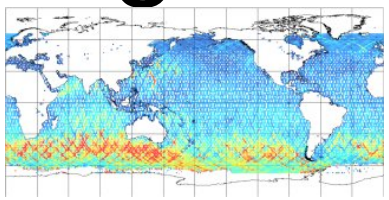
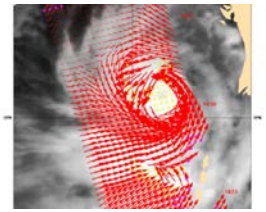
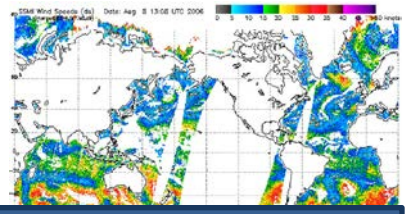
The specialized coastal retrackers (like Ocean CS and its follow-on ALES) display encouraging performance: **"Open ocean" precision in SSH and SWH UP TO 2.5 KM FROM THE COAST; Precise leading edge fitting, virtually equivalent to classic schemes away from the coast**

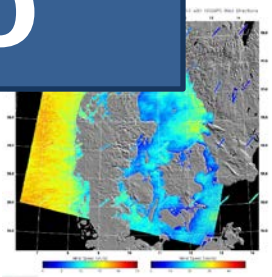
Application to surge studies: eSurge

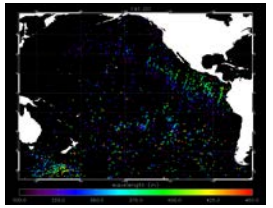
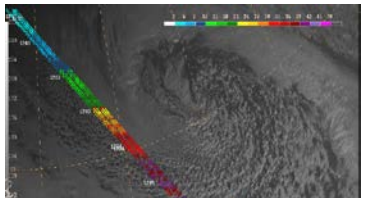
- **eSurge**: ESA DUE (Data User Element) Project for 2011-2014
  - DUE runs user-driven projects to transfer research to applications
- **eSurge objectives:**
- *To contribute through Earth Observation to an integrated approach to storm surge, wave, sea-level and flood forecasting as part of a wider optimal strategy for building an improved forecast and warning capability for coastal inundation.*
- *To increase the use of the advanced capabilities of ESA and other satellite data for storm surge applications*

Components of eSurge Data

- Altimeter (ERS, Envisat, Geosat, TOPEX, JASON, CryoSat)
- Passive Microwave (SSM/I, AMSRE, TMI, WindSat)
- Scatterometer (ERS, QuickScat, ASCAT,
-
-
- Storm Surge model output and forcing
- Flood maps
- In situ (e.g. tide gauges)



first port of call for users looking for satellite data for coastal flooding:

www.storm-surge.info

Reprocessed Envisat coastal altimetry data now available

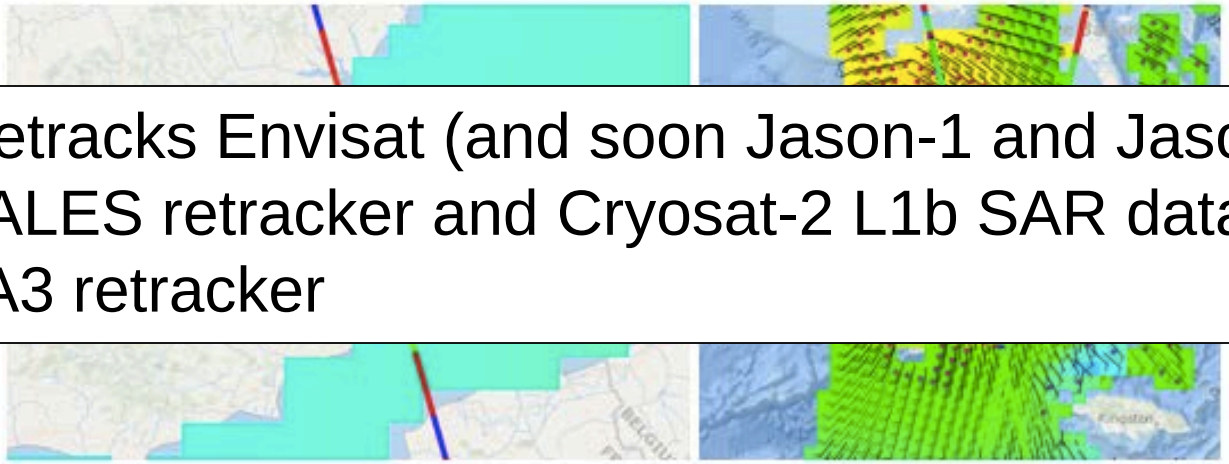
by Phillip Harwood on Fri, 2013-10-25 14:43

The eSurge project has just released new coastal altimetry data for the Envisat mission. Envisat altimeter tracks have been reprocessed using our new ALES (Adaptive Leading Edge Sub-Waveform) retracker. Data are available for all storm surge events in our database during the lifetime of the Envisat mission (May 2002 to April 2012).

These and other data can be downloaded from the eSurge database. All data are freely available, though we would appreciate users providing feedback as to how they are using this data, and we ask that the eSurge project be credited in any subsequent publications. See the data user handbook for more details.

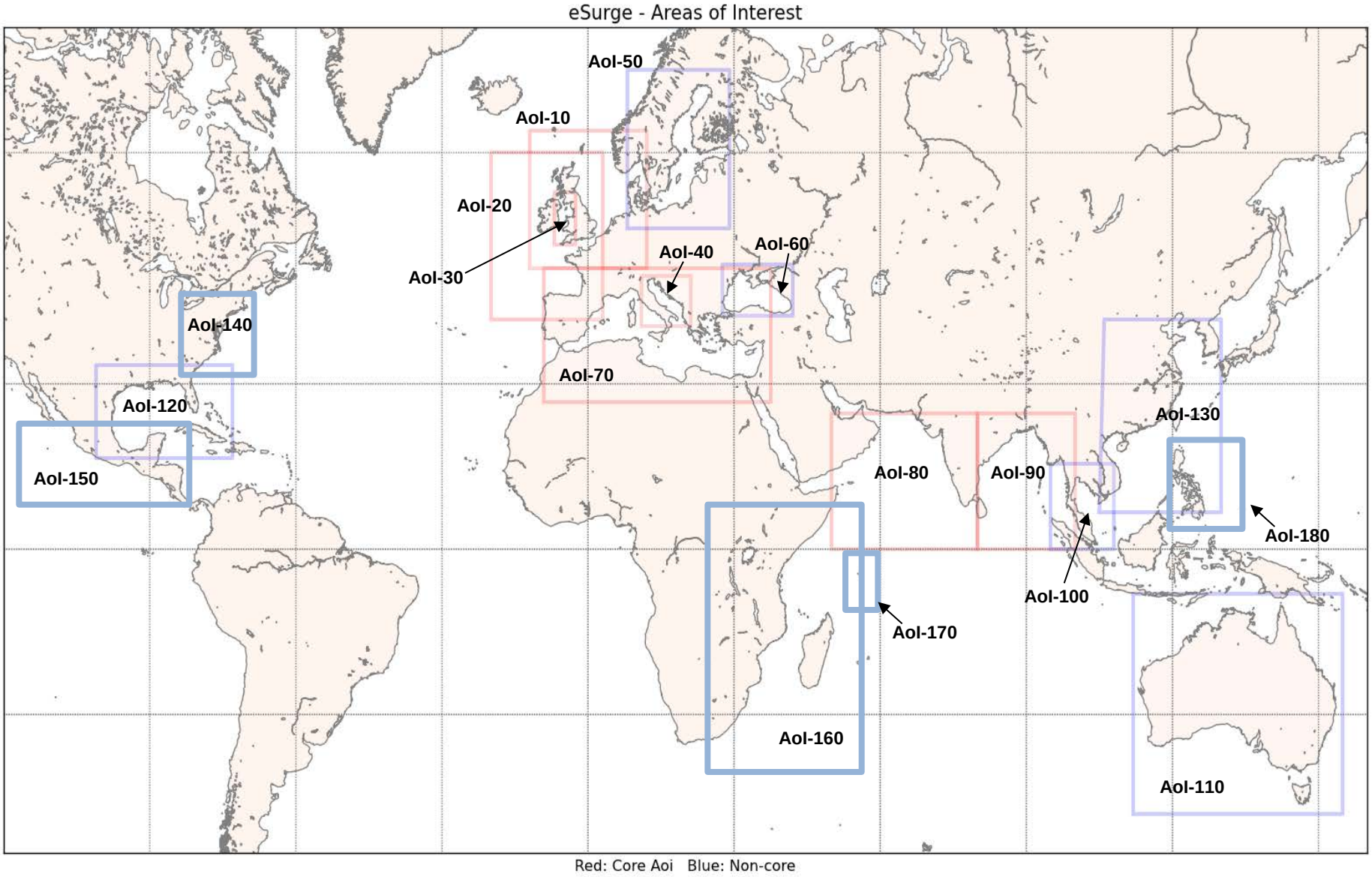
To give feedback on the data, or to request new events, please contact us either through the website or at **eSurge@outlook.com**.

For more information on ALES, see this poster presented by Marcello Passaro et al. at OSTST 2013.



Left: Coastal altimetry and model hindcast for Event Gudrun in the North Sea.

- eSurge retracks Envisat (and soon Jason-1 and Jason-2) data with the ALES retracker and Cryosat-2 L1b SAR data with the SAMOSA3 retracker


eSurge - Areas of Interest
AoI-50
AoI-10
AoI-20
AoI-30
AoI-40
AoI-60
AoI-140
AoI-70
AoI-120
AoI-130
AoI-150
AoI-80
AoI-90
AoI-180
AoI-100
AoI-170
AoI-160
AoI-110
Red: Core Aoi Blue: Non-core

All data are available online

eSurge

Data Access

The eSurge database is now available as a beta version for user feedback.

Project News

Coastal Altimetry with Cryosat SAR data
Tuesday 19th March 2013

Successful launch of SARAL
Monday 25th February 2013

Acqua alta and snow in Venice
Tuesday 12th February 2013

New UK flood defences announced
Thursday 7th February 2013

60th anniversary of the 1953 North Sea floods

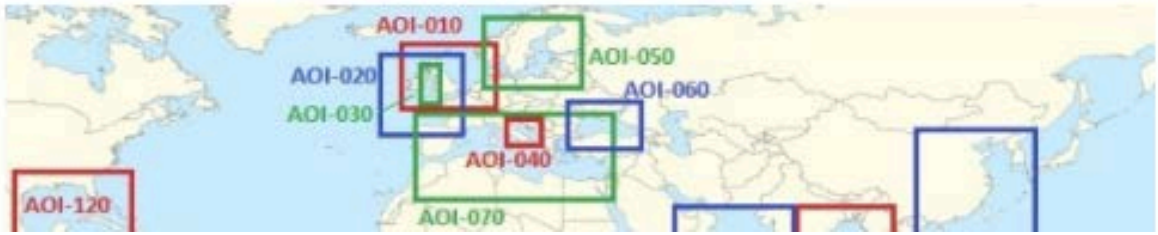
The eSurge database is currently available as a beta test version: see the known issues page. We would welcome user feedback on this version.

Home

eSurge Data Access

The eSurge database contains surge events (SEVs) grouped according to the area of interest (AOI) to which they are associated. To browse for an event, click on an AOI in the map below. A short presentation introducing the database is available here.

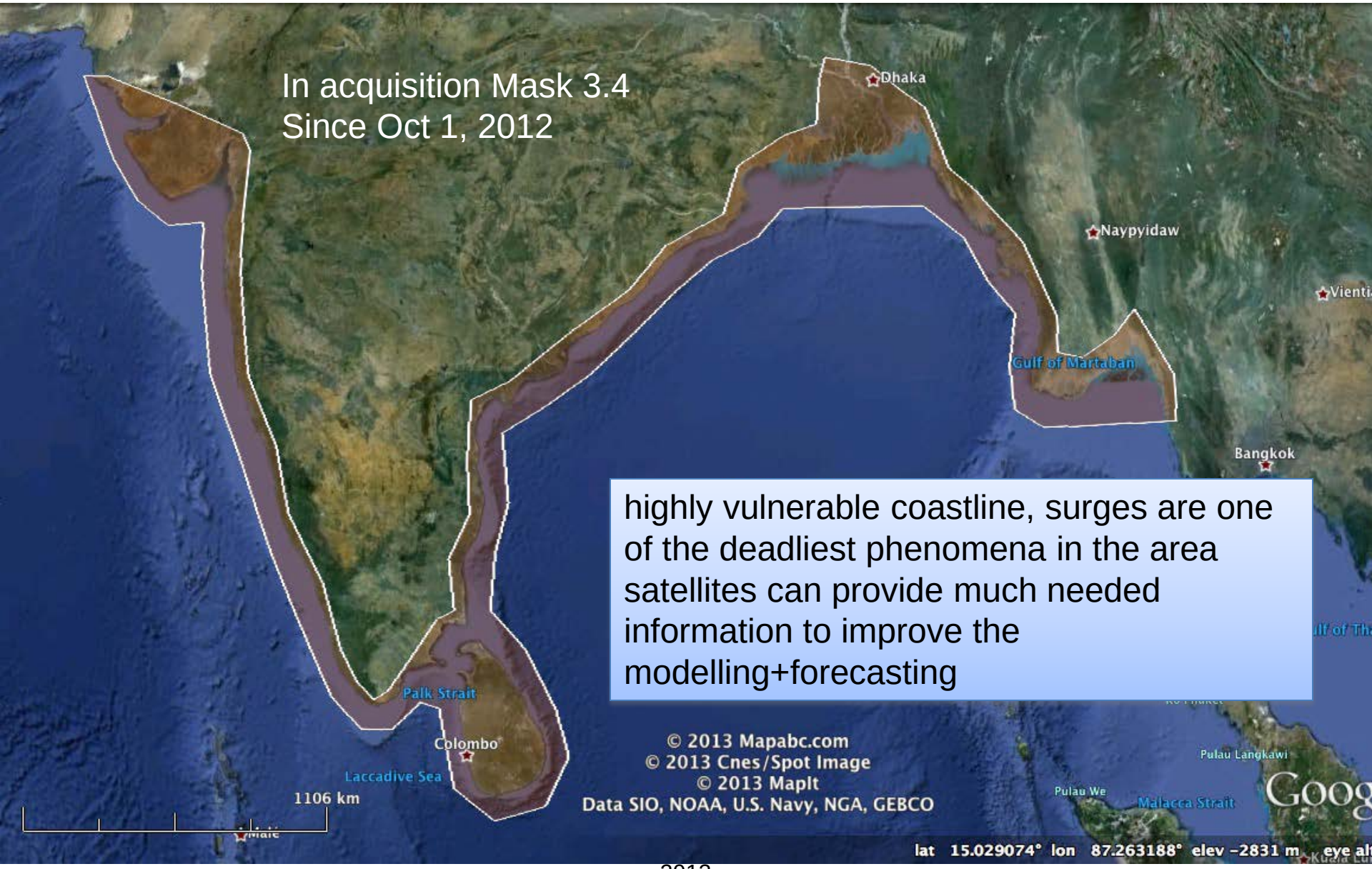
Please note: We are currently populating this database, so not all data sets are present yet. If the data you are looking for are not yet here please check back soon. To see how the complete database will look, see the examples of Cyclone Sidr (2007), Windstorm Xynthia (2010), Hurricane Katrina (2005), SE Ireland floods (2004), and Winter Storm Gudrun/Erwin (2005).

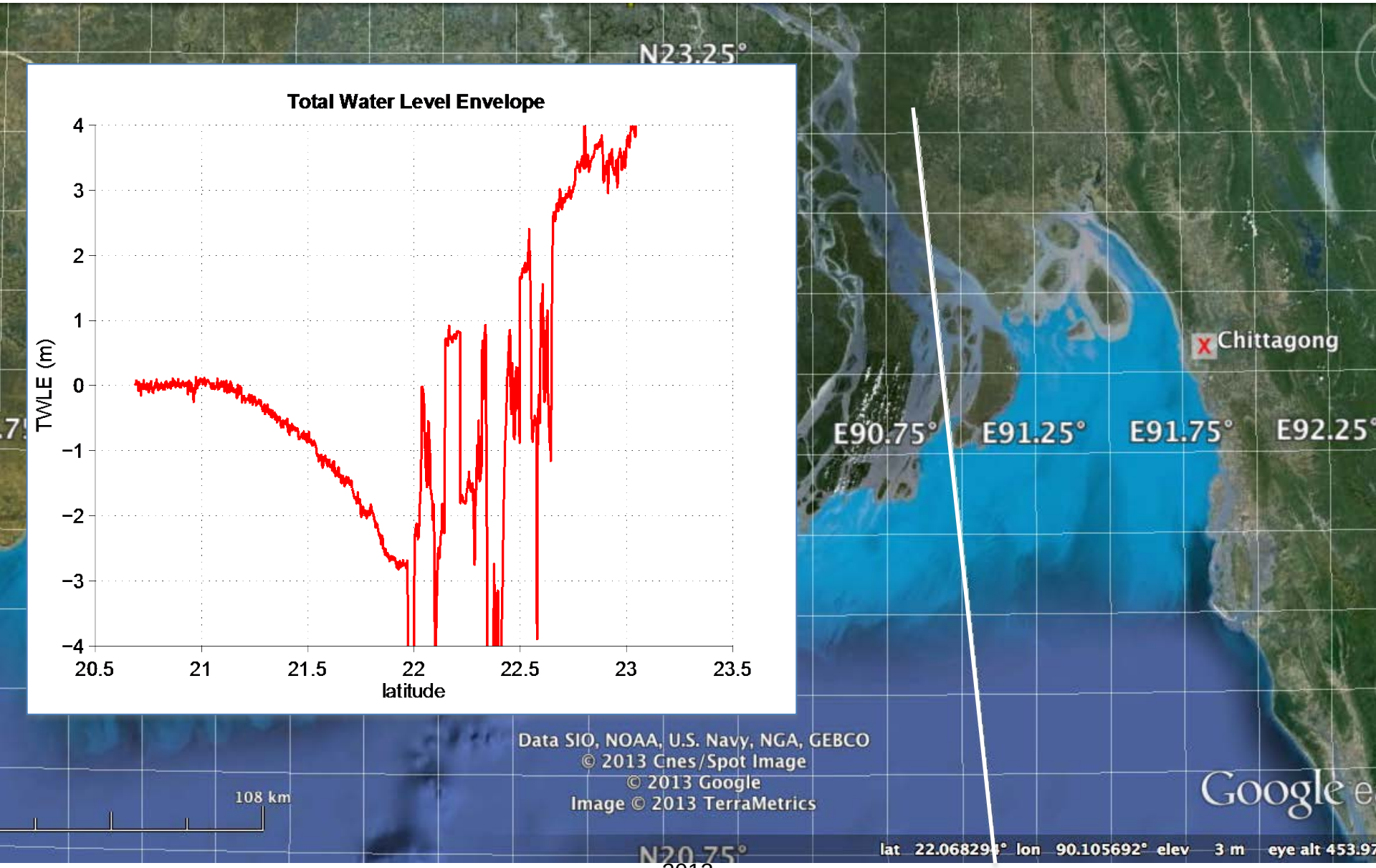


www.storm-surge.info

Region: Indian coast

eSurge AOI-80 and AOI-90


In acquisition Mask 3.4
Since Oct 1, 2012
Dhaka
Naypyidaw
Gulf of Martaban
Bangkok
highly vulnerable coastline, surges are one of the deadliest phenomena in the area satellites can provide much needed information to improve the modelling+forecasting
Palk Strait
Colombo
Laccadive Sea
1106 km
© 2013 Mapabc.com
© 2013 Cnes/Spot Image
© 2013 MapIt
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Pulau Langkawi
Pulau We
Malacca Strait
lat 15.029074° lon 87.263188° elev -2831 m


Total Water Level Envelope
TWLE (m)
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3
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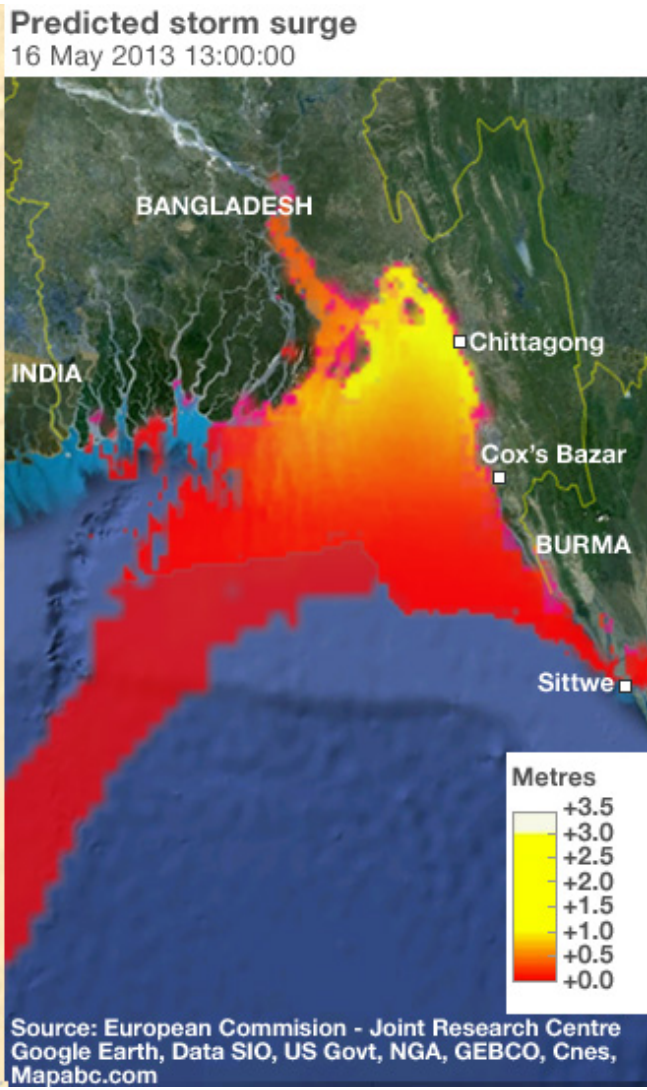
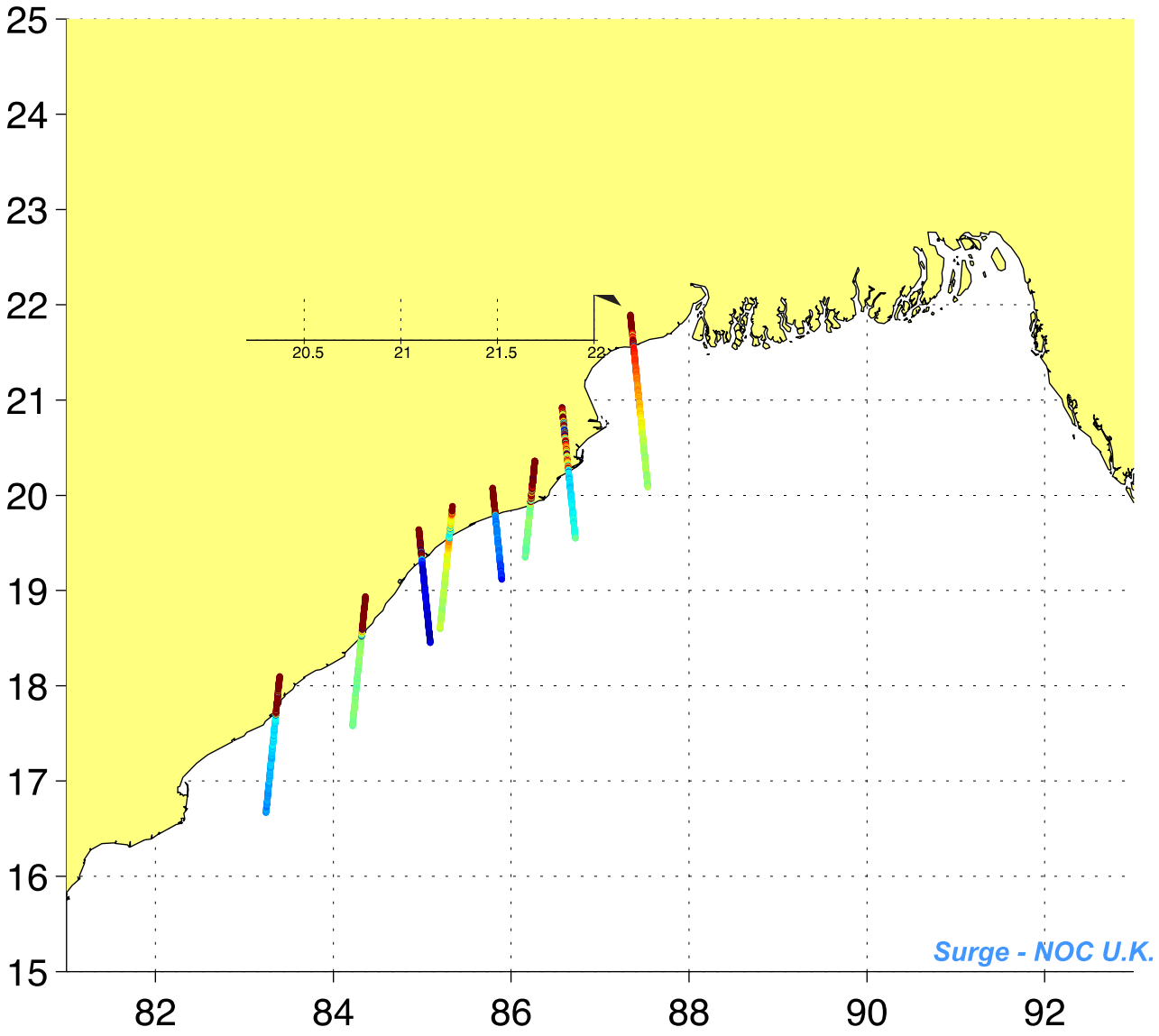
1
0
−1
−2
−3
−4
20.5
21
21.5
22
22.5
23
23.5
latitude
N23.25°
Chittagong
E90.75°
E91.25°
E91.75°
E92.25°
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2013 Cnes/Spot Image
© 2013 Google
Image © 2013 TerraMetrics
108 km
Google
lat 22.068294° lon 90.105692° elev 3 m eye alt 453.97

Event: Cyclone Mahasen

16 May 2013

Landfall 16 May 2013 0800 UTC

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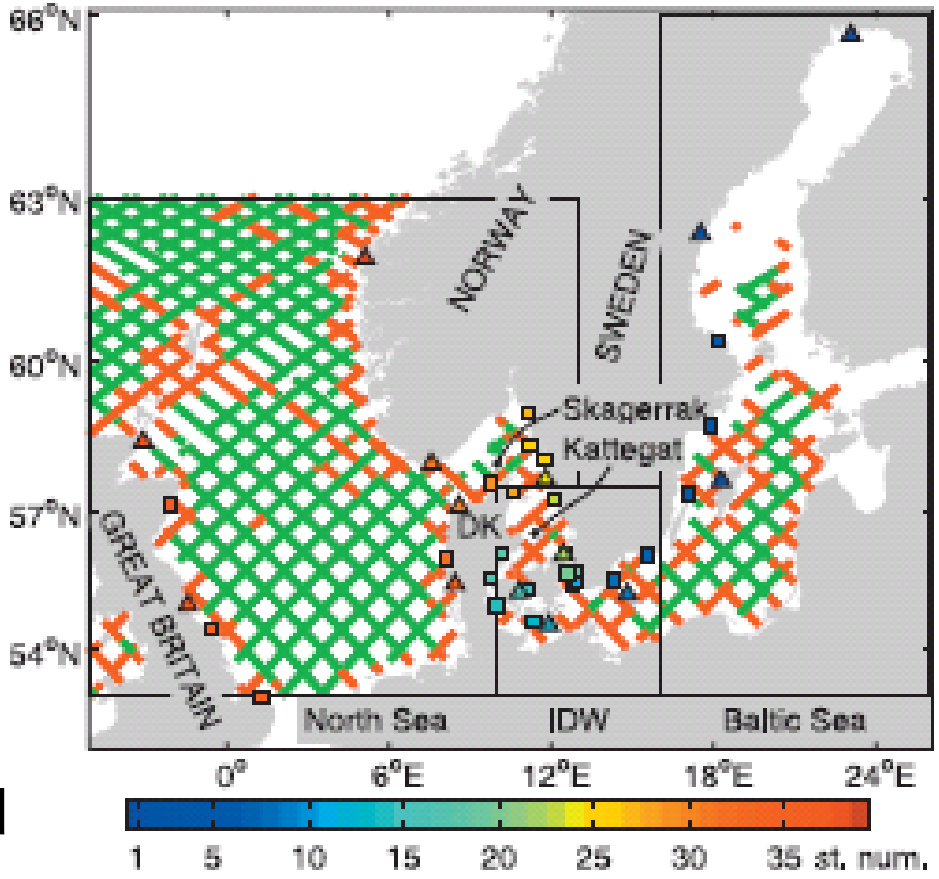
21.5
22
Surge - NOC U.K.

How to use the altimetric data

- **Blended** : most naturally used for assimilation into models, hindcasts/forecasts
- **Single altimetric profiles**:
  - Verification
  - Model ensemble pruning
- **Near Real Time**:
  - challenging! (error on NRT orbit)
  - there may be cases where the *relative* height profile is still useful in an assimilation exercise (Example: Adriatic, to get the *seiche* phase right)
  - remains useful for verification in real time
  - is being pioneered over Indian Coast and North Sea in **eSurge Live**, from Summer 2013

Blending Altimetry with Tide Gauges -1

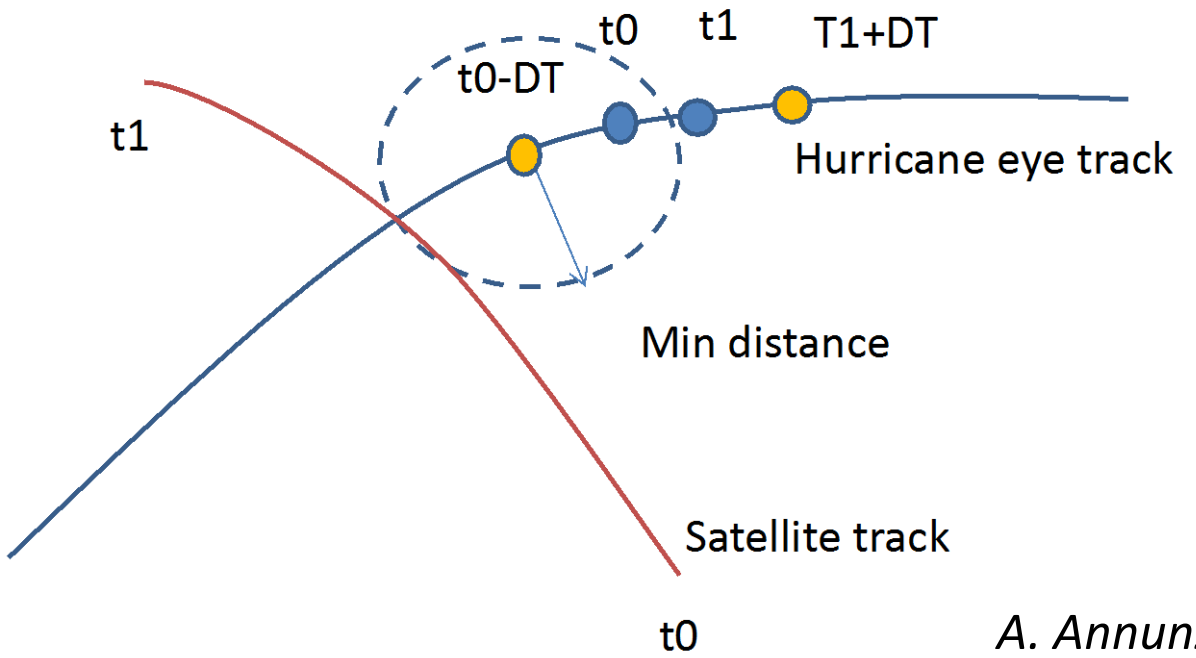
- The project will perform a series of hindcasting experiments to investigate how best to assimilate the available data into existing storm surge models, and to demonstrate the consequent improvements. Coastal altimetry measurements will be blended with tide gauge data for assimilation in hydrodynamic models and for real time processing, using a method already demonstrated by DMI



Single altimetric profiles: sampling issues

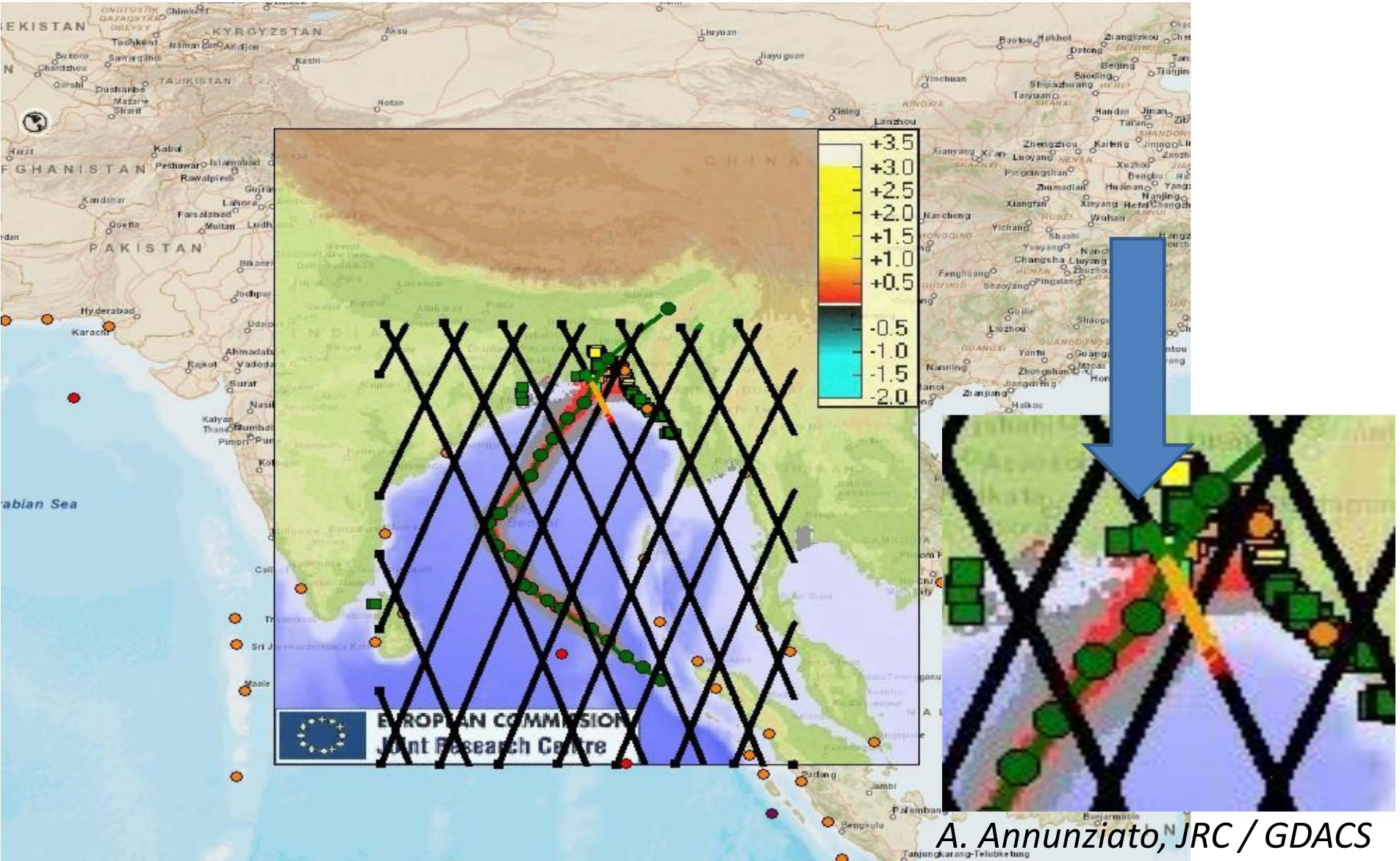
- Not all the tracks are useful for modelling comparison
- We need to filter the tracks that fits in space and time with the Hurricane Track
  - DT= 12 h
  - Min Distance=200 km

Track is selected



A. Annunziato, JRC / GDACS

Jason2: Filtering on space (DeltaX=200 km) and time (deltaT=12h), only 1 track is useful (15 May 12:40)

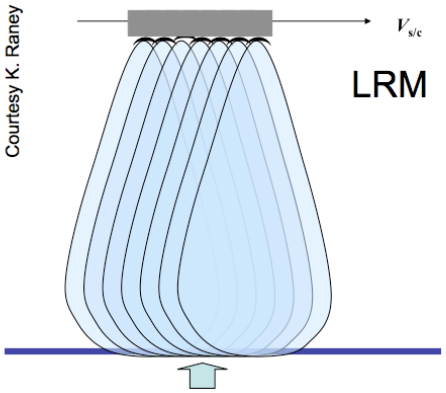


A. Annunziato, JRC / GDACS

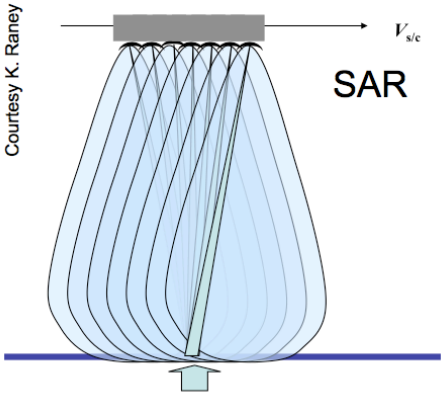
Conclusions

- Storm surges are a natural application for coastal altimetry, if the community can find ways of using the data to improve model forecasts
- ESA supporting further development of coastal processor via eSurge
- Specialized retrackers improve sea level retrieval near coast from older missions
- SAR Altimetry (Cryosat-2 & Sentinel) very promising
- Data need to be exploited in synergy with in situ data and/or models to make up for inadequate sampling

The SAR altimetry revolution

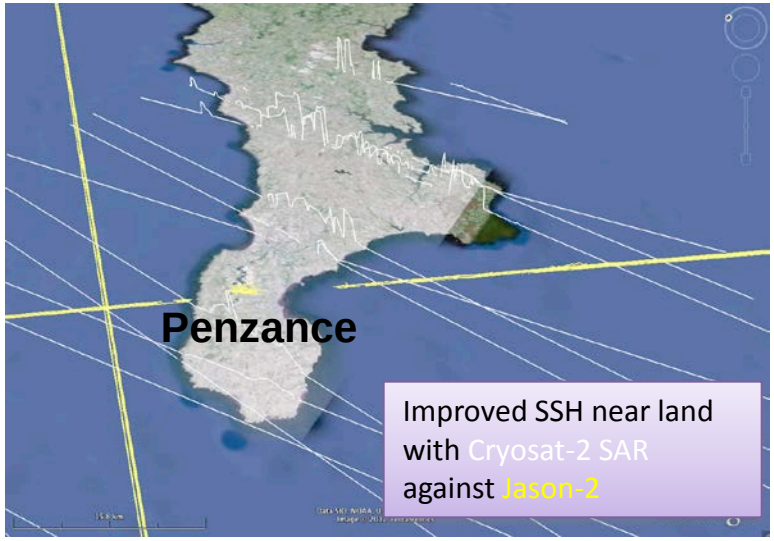


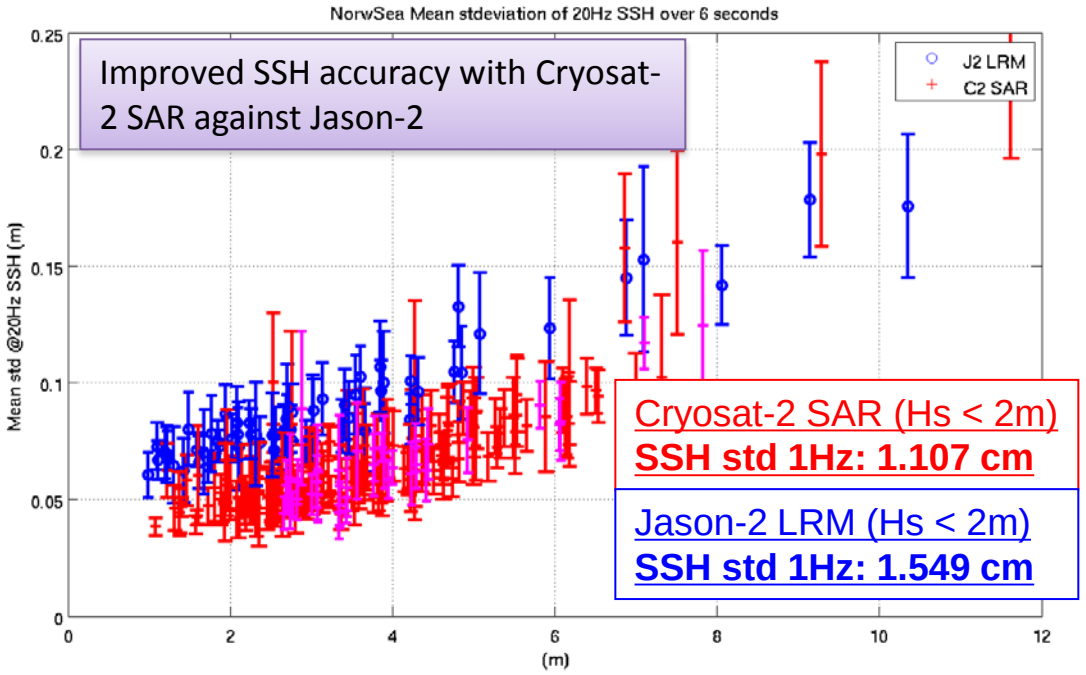
- Conventional pulse-limited aka Low-Rate Mode (PRF ~ 2kHz)



- Delay Doppler aka SAR (Bursts & PRF ~ 20kHz)

- SAR mode altimetry is flown on Cryosat-2 (and will be on Sentinel-3)
- More "looks" = improved SSH retrieval accuracy
- Finer spatial resolution along track
  - ~ 300 meters along-track
- Less contamination close to land
  - Application to coastal altimetry



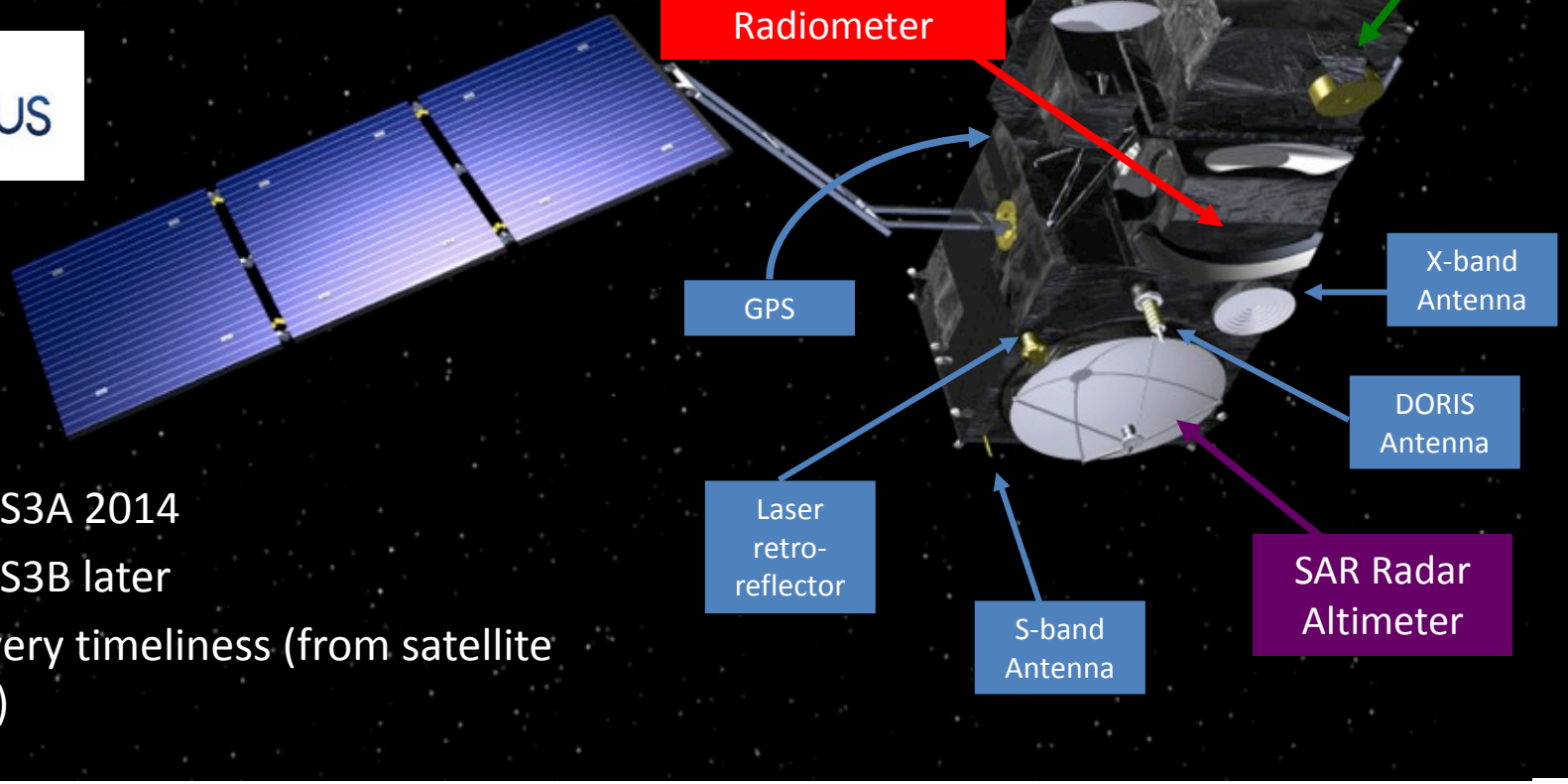


Christine Gommenginger, NOC

Sentinel-3: Payload

Main satellite characteristics

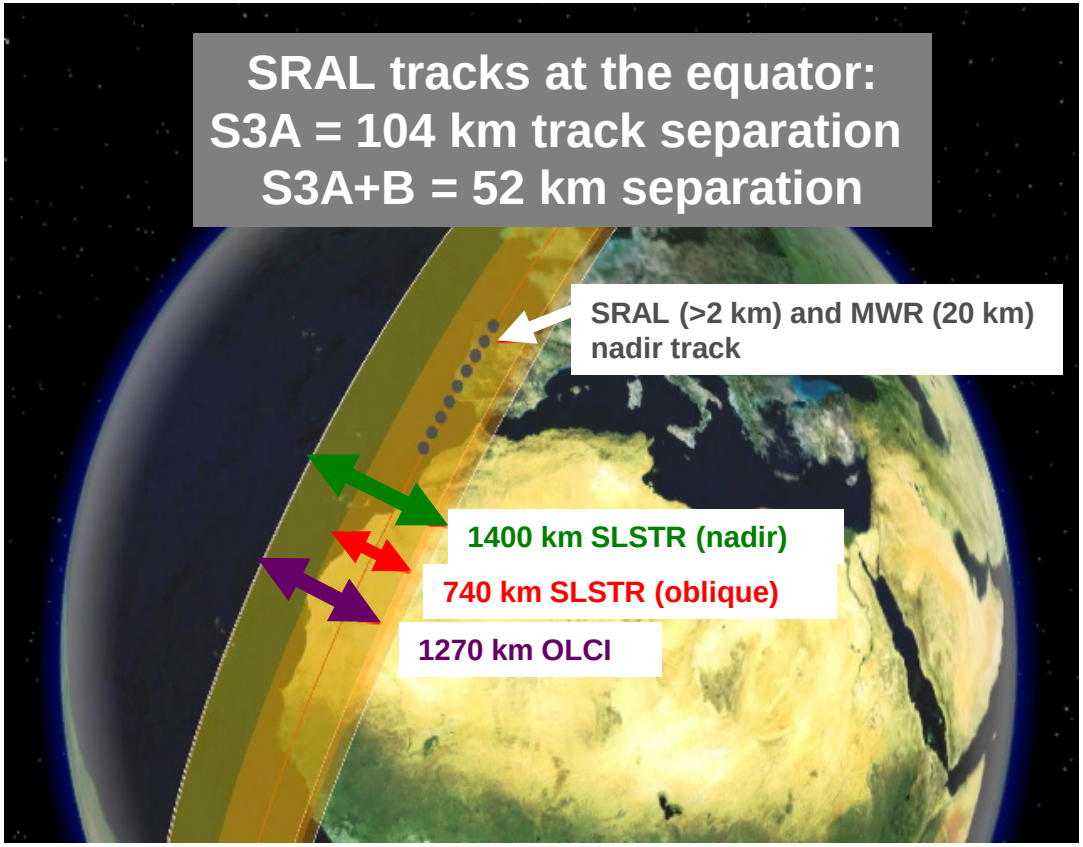
- 1250 kg maximal mass
- Volume in 3.89 m x 2.202 m x 2.207 m
- 7.5 years lifetime (fuel for 5 add. years)



- Launch S3A 2014
- Launch S3B later
- 3h delivery timeliness (from satellite sensing)

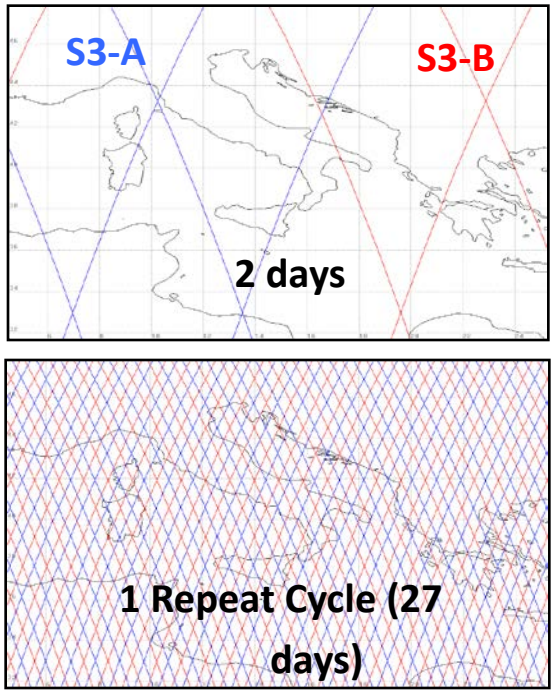
Sentinel-3: Instrument Swath and Satellite Orbit

Instrument Swath Patterns



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

Ground Track Patterns



SRAL orbit drivers:

- Ground track repeatability,
- Dense spatial sampling

Orbit control requirement:

- Ground track dead-band ±1km

New SRAL L1 Products

The data identified to become Sentinel-3 operational products are the following:

- ***L1A: Unpacked L0 complex echoes that have been sorted and calibrated.*** Geo-location information is included in this [illegible] relevant to SAR proces[illegible] proces[illegible] ground[illegible]

L1A: Product development (science and engineering) supporting operational users

- ***L1B-S[illegible] located, calibrated azimuth formed complex (I and Q) echoes after slant/Doppler range correction over a fixed point on the ground-track.*** Relevant ancillary data (e.g. beam angle[illegible]ation etc) is included. There is[illegible]oking/stacking) performed on [illegible]scription of the multi-looked av[illegible] This product is 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-SAR: S&E development supporting operational users

- ***L1B: Geo-located [illegible] Q) echoes after sla[illegible] averaged together (i.e multi-looked/stacked) over a fixed point on the ground-track.*** This product is relevant to geophysical retrieval algorithm developers and Quality Control systems.

L1B: Operational users (no change to products)

- Topography Mission Instruments development is complete and integration/tests in the Sentinel-3A spacecraft are currently in progress
- Sentinel-3B Topography payload is well advanced and delivery of the last instrument is expected in spring 2014
- Further improvements of the Topography mission -with respect to the original baseline- are considered for implementation:
  - **100% SAR operation**
  - Additional Level1 User Products