

## C-RISe: Coastal Risk Information Service

### What is the Problem?

The coastal populations of Mozambique, Madagascar and South Africa are highly vulnerable to the consequences of climate change and extreme events. In particular, Mozambique and Madagascar are exposed to storm surges associated with cyclones, and have economically important coastal ecosystems sensitive to a changing climate.

Access to improved regional information on coastal risk factors (sea level, wave and wind extremes) will support improved plans to protect coastal communities, ecosystems and economic activity. This information will also contribute to improving industrial and commercial competitiveness in the maritime sector and maritime safety.

**C-RISe** is a project funded by the UK Space Agency, through the International Partnership Programme. It is delivering, in a partnership between the UK, Mozambique, Madagascar and South Africa, information on sea level rise, storm surge, wind speed and wave heights derived from satellite altimetry and validated with local measurements. The goal is to enable local stakeholders to reduce the social and economic impact of coastal inundation and increasingly variable weather patterns.

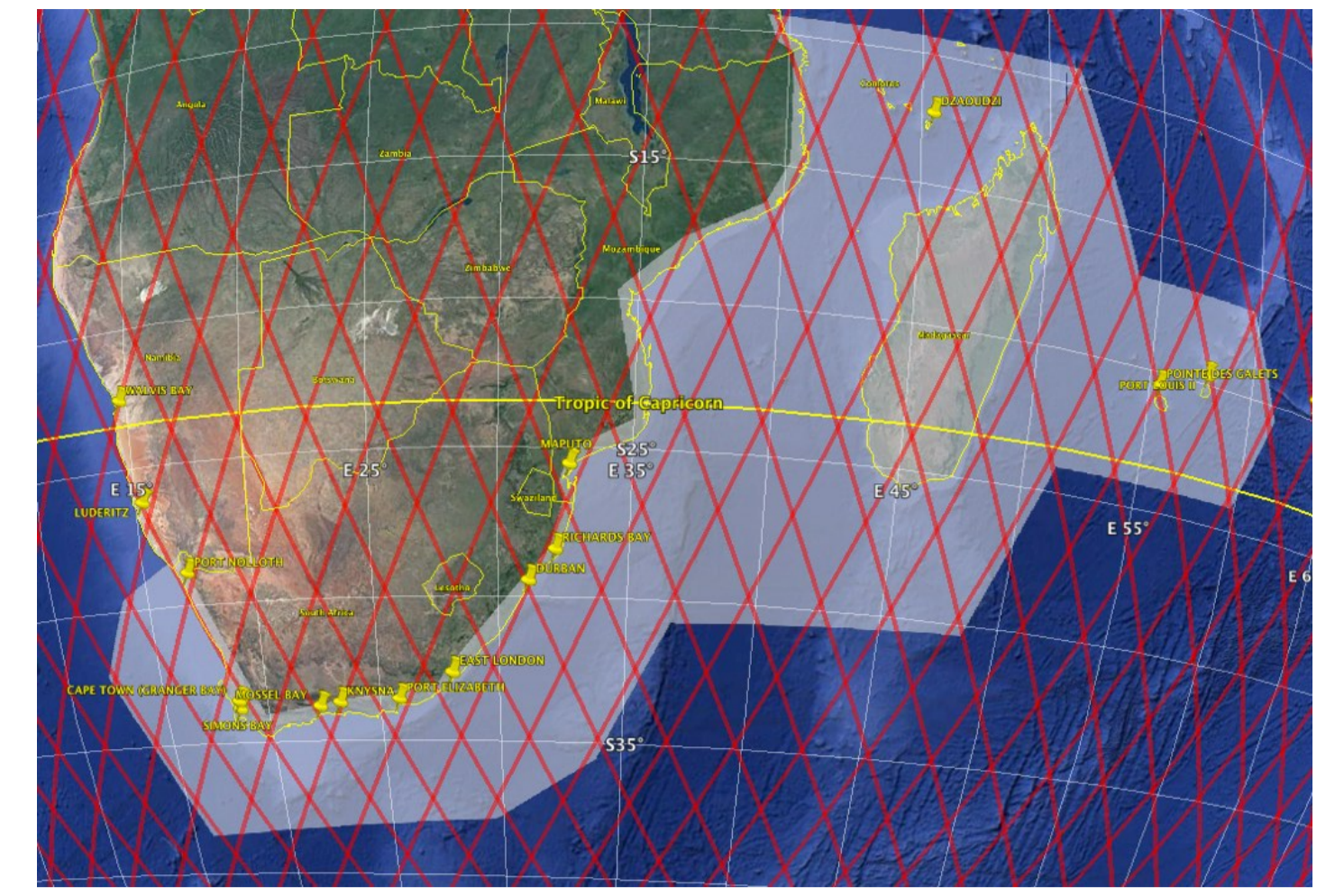


Figure 1: Coverage of C-RISe service, altimeter ground tracks, and locations of Tide Gauges

### C-RISe Objectives

C-RISe has three main objectives:

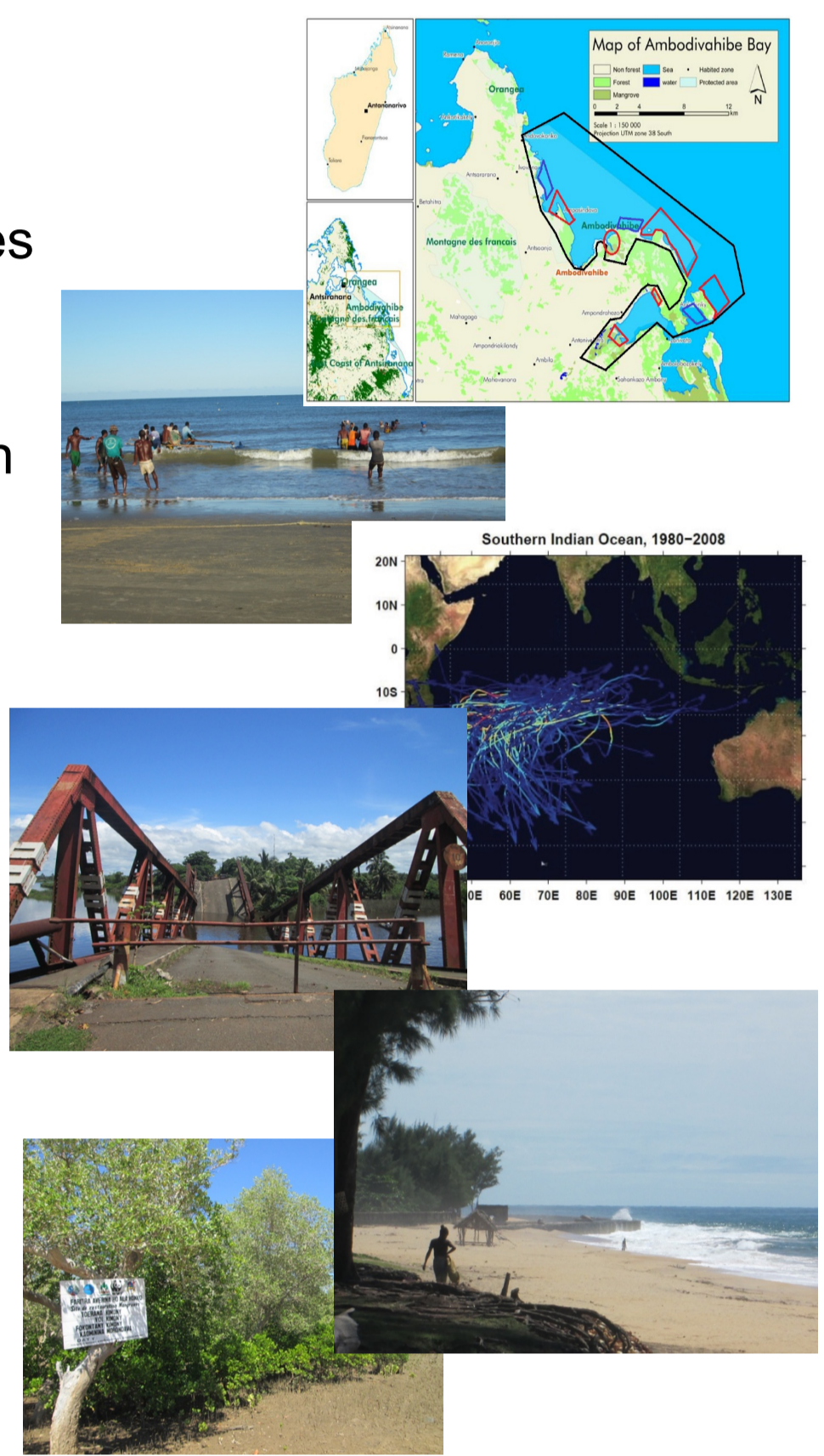
- Deliver a Coastal Risk Information Service, providing satellite-derived information about coastal vulnerability to environmental threats such as sea level rise and extreme wind and wave events.
- Apply and evaluate the service through a set of **Use Cases**, applying the C-RISe data products to end-use applications that meet local priorities.
- Build local capacity to use satellite data to provide scientific support to decision-makers for strategy development, governance and management of coastal areas to increase resilience to coastal hazards.

The development of local capacity to use coastal altimetry data in combination with other data sets and information sources is a key target, necessary to ensure a viable long-term service. Training is provided through a series of workshops together with online training material. These tools include Bilko (<http://www.learn-eo.org/software.php>), a tool first developed for UNESCO to provide a free Earth Observation image processing capability for educational use, now updated to include support for data from Sentinel satellites.

### Use Cases

There are five main themes for C-RISe Use Cases:

- **Marine Protected Area Management** - Information Services
- **Near Real Time Sea State Information**
  - Maritime safety, search and rescue support
  - Operational Planning: illegal logging, smuggling, pollution
  - Improved tropical storm information
- **Sea Level Analyses**
  - Tidal Analyses, extreme events, inter-annual variability
  - Understanding changing coastal risk
  - Port development, coastal defences
- **Wave and Wind Climatologies**
  - Operational planning
  - Coastal and Marine Atlas
  - Wind and wave energy resource
  - Infrastructure planning and developments
- **Climate change impact on marine ecosystems**
  - Mangroves, coral reefs, turtles, shrimp fisheries,
  - Algal blooms, sea water quality, pollution, acidification



## Application of Satellite Altimetry to Coastal Sea Level

In the past it has been difficult to retrieve useful data from satellite altimeters close to the coast, because of land contamination of the return waveform.

The National Oceanography Centre, UK (NOC) has developed the "ALES" altimeter re-tracker for coastal regions (ALES - M. Passaro et al., *Remote Sensing of Environment*, 2014). This approach has been applied to reprocess altimeter data from past missions to provide a continuous satellite altimeter coastal sea level time series of over 14 years.

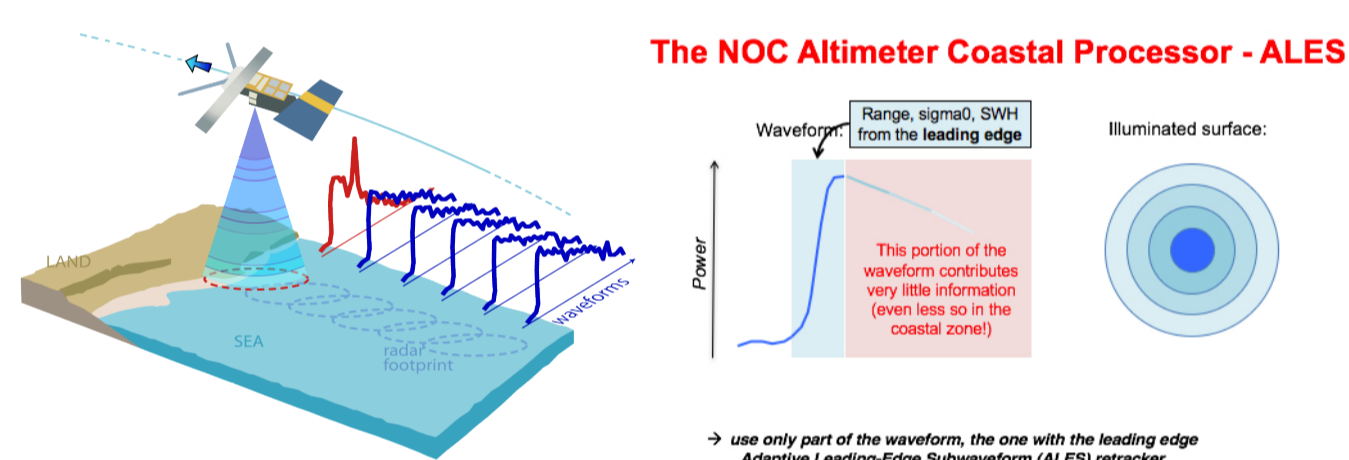


Figure 2: Principle of operation of the ALES altimeter coastal processor developed at NOC

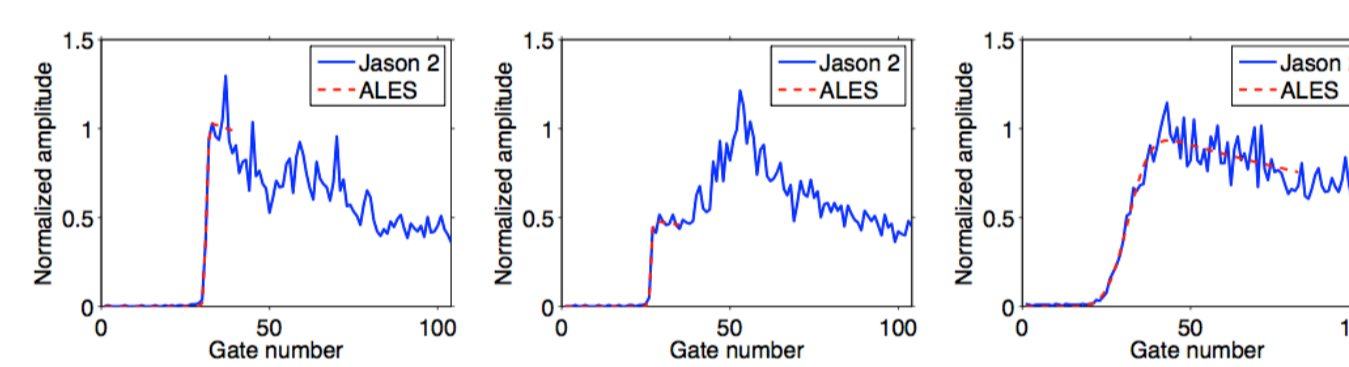


Figure 3: Examples of Jason-2 re-tracking by ALES, for SHW = 0.7m (left), 1.65m (centre), and 9.5m (right) (from Passaro et al., 2014)

## C-RISe Products

A 14-year coastal sea level data set for the SW Indian Ocean region has been generated with the NOC ALES processor. These data and analyses are being provided, with wave and wind climatologies and near real-time wave and wind data, to local users, through a bespoke data portal developed by CSIR.

Parameter	Description	Time Coverage	Satellites
Total Water Level Envelope, significant wave height, surface radar backscatter	Along track data from the NOC coastal processor	2002-2016	Jason-1, Jason-2, Jason-3
Significant Wave Height and Wind Speed Climatologies	Monthly, 1° x 1° gridded climatologies,	1992-2014	ERS-1, ERS-2, Envisat, Topex, Jason-1, 2, 3
Significant Wave Height, wind speed	Near Real Time along track data	Daily updated	Jason-2,
Wind speed and wind direction	Near Real Time data across scatterometer swath (25km resolution)	Daily updated	Metop/ ASCAT-A

Table 1. C-RISe satellite data products

### SATOC C-RISe Data Demonstration

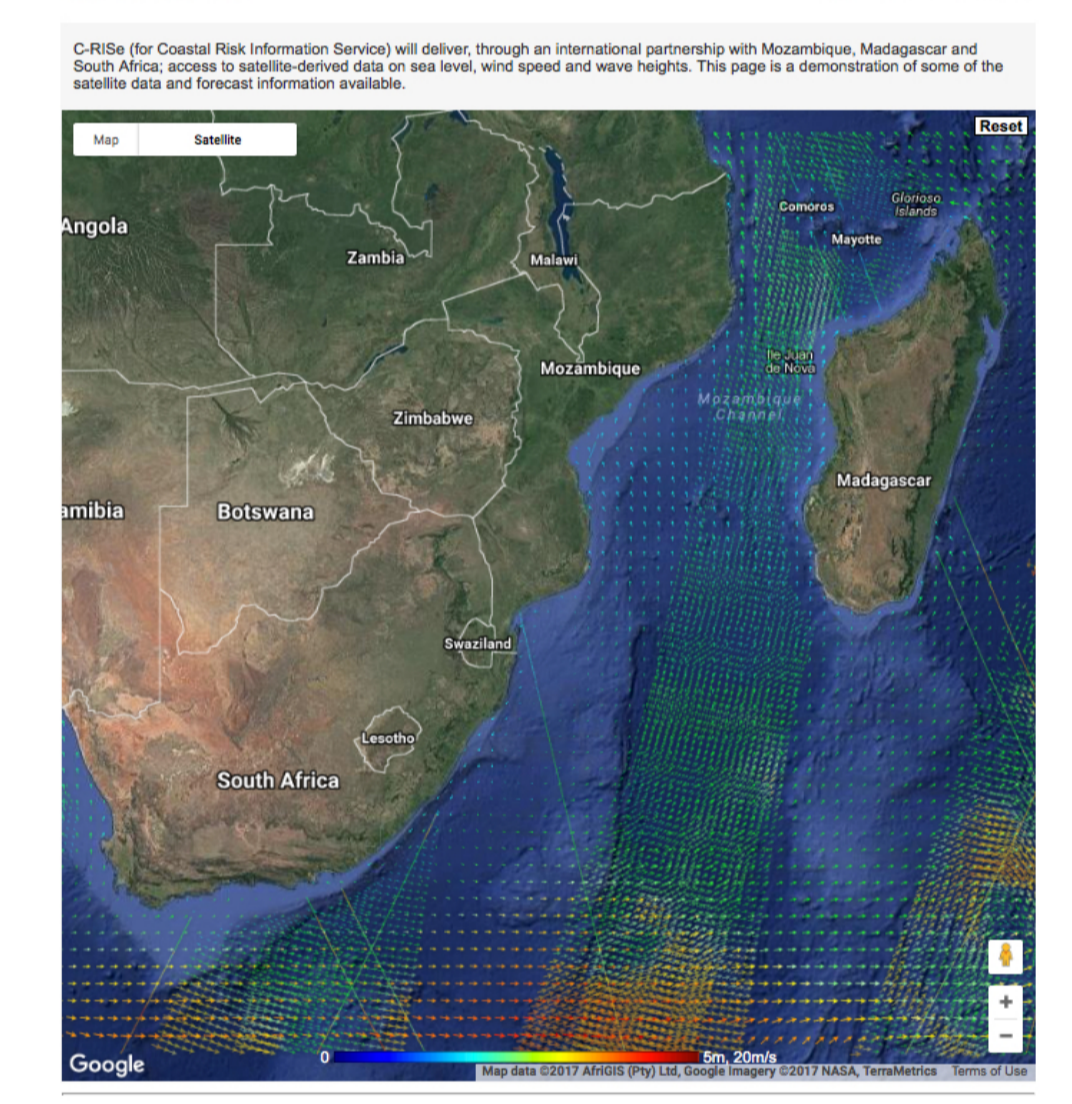


Figure 4: Demonstration of daily updated wind and wave data

## SW Indian Ocean Regional Sea Level Variability

Initial characteristics of regional variability in sea level have been derived from an analysis of the Sea Surface Height Anomaly (SSHA) - the anomaly with respect to the mean sea surface, with tides and atmospheric effects removed.

Below we see the annual cycle, and results from an Empirical Orthogonal Function (EOF) analysis showing the seasonal and inter-annual variability over the 14 year period of the data set

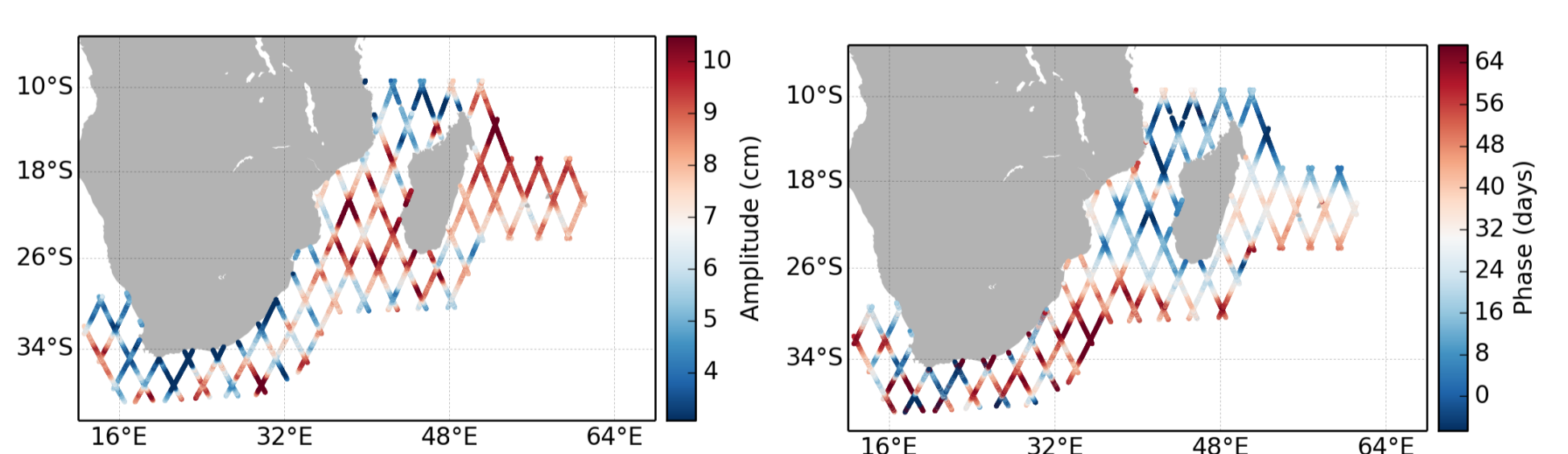


Figure 6. The Annual Cycle in Sea Surface Height Anomaly. Left: Amplitude, Right: Phase, given as the day in the year of the maximum in the Annual Cycle

**Annual Cycle:** The annual SSHA cycle is strongest to the South West and North East of Madagascar (9-10cm). The time of maximum is earliest in the North (early Jan), and latest of the SE Coast of South Africa (late Feb)

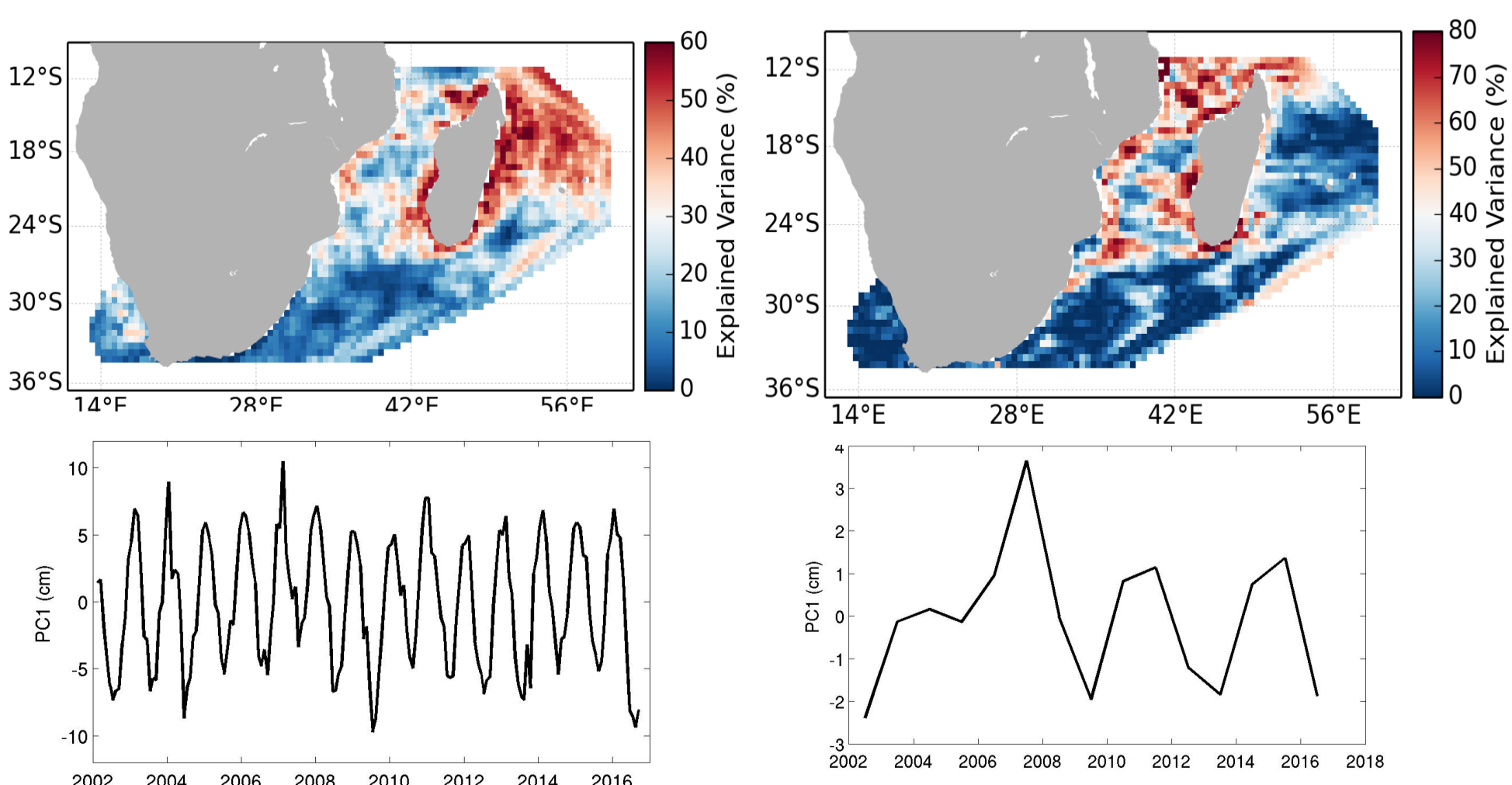


Figure 7. EOF (Empirical Orthogonal Function) analysis of C-RISe sea level. Variance explained by EOF1 (top) and principal component 1 (bottom) for monthly (left) and annual (right) means.

**Seasonal/Inter-annual Variability:** The annual monsoon cycle comes through strongly in the monthly mean data, strongest to the East of Madagascar. The EOF analysis of annual means shows different characteristics in the period 2002-2008, and 2009-2016

## Validation of Coastal Altimeter Sea Level Data

A python software package has been written to allow regional partners to validate the C-RISe altimeter sea level data against locally available tide gauge data (see Figure 1).

The results below are for Toamisina in Madagascar and show good agreement between the altimeter and tide gauge data.

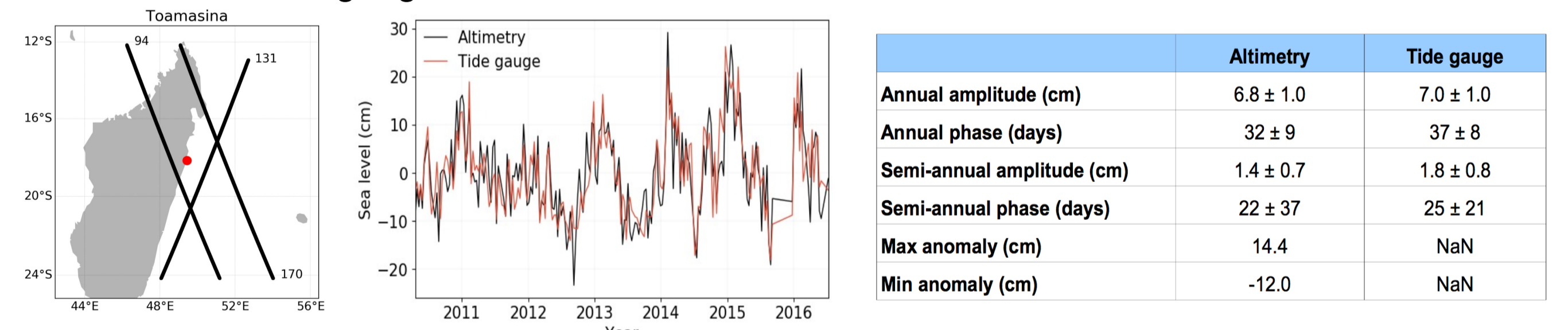


Figure 5: Validation of C-RISe altimeter data against the Toamisina tide gauge: (left) The Jason satellite tracks and location of the Tide Gauge; (Centre) Time series of altimeter (black) and tide gauge (red) data; (Right) parameters of the annual and semi-annual cycles of sea level from the altimeter and tide gauge data. Analysis by R Rajaonarivony (DGM) using C-RISe analysis software

## Long term "trends" in Sea Level

The figure on the left shows the annual trend in SSHA (over 2002-2016) from the C-RISe data set. This indicates an increase ~3 mm/yr or more over much of the region.

However, a 14 year period is not sufficient to determine long-term trends, as can be seen in the analysis on the right (Trenary and Han, JGR, 2013). This shows a decrease in SSHA from 1993 to 2000, followed by an increase from 2000 to 2007.

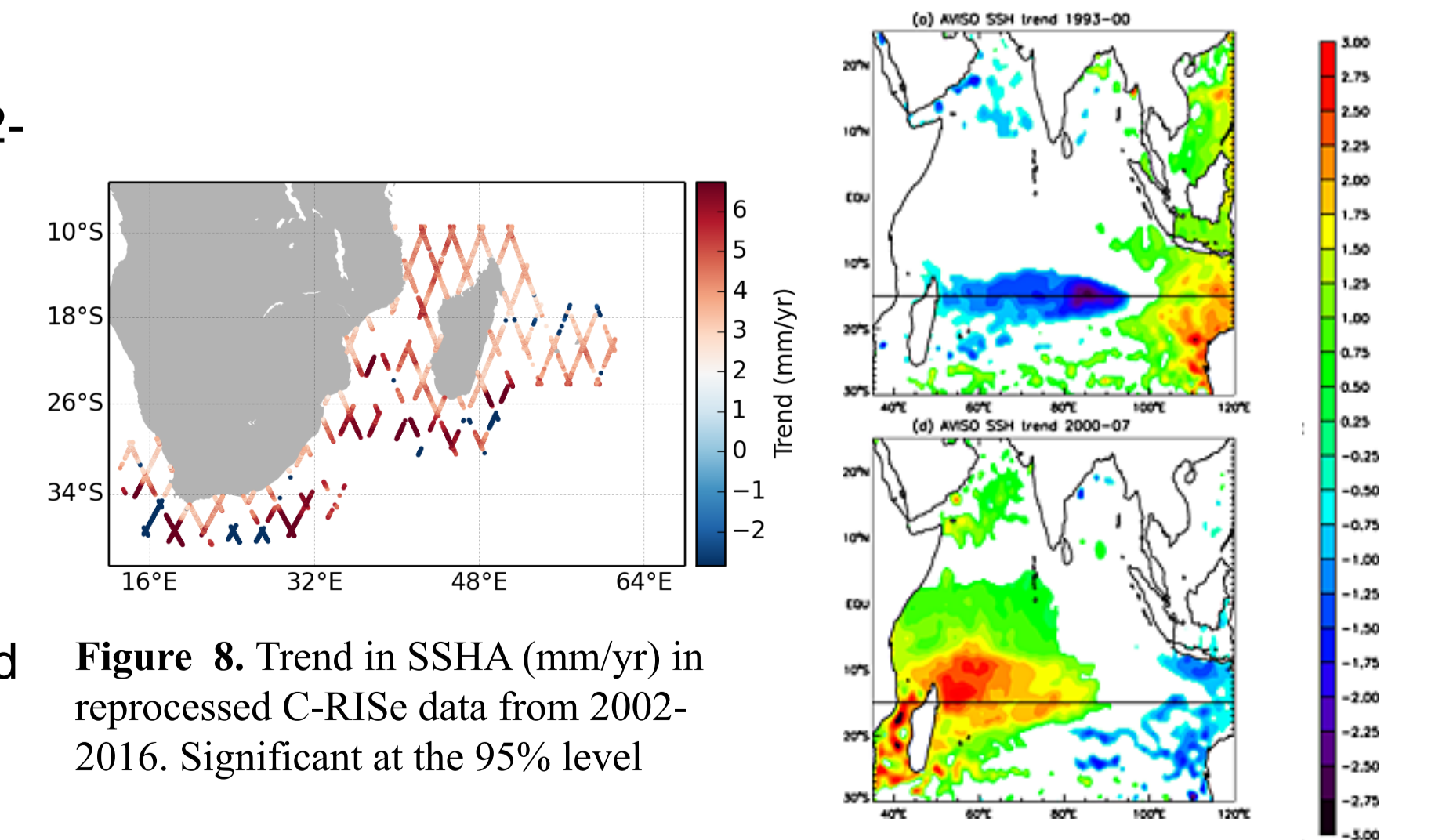


Figure 8. Trend in SSHA (mm/yr) in reprocessed C-RISe data from 2002-2016. Significant at the 95% level

Figure 9. Trend in SSHA (mm/yr) from AVISO. Top: 1993-2000, bottom: 2000-2007