Preliminary results from Sentinel 2 MSI imagery for coral reef mapping applications

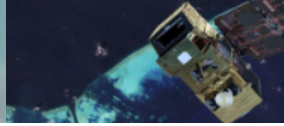
V.E. Brando; M. Bresciani; C. Giardino; J.D. Hedley; B. Koetz; T. Kutser; J La Porte; P.J. Mumby; S.R. Phinn; C.M. Roelfsema

CNR-ISAC, Italy; CNR-IREA, Italy; Environmental Computer Science, United Kingdom; ESA, Italy; Estonian Marine Institut, Estonia; ARGANS, United Kingdom; University of Queensland, Australia

The ESA Sen2Coral project

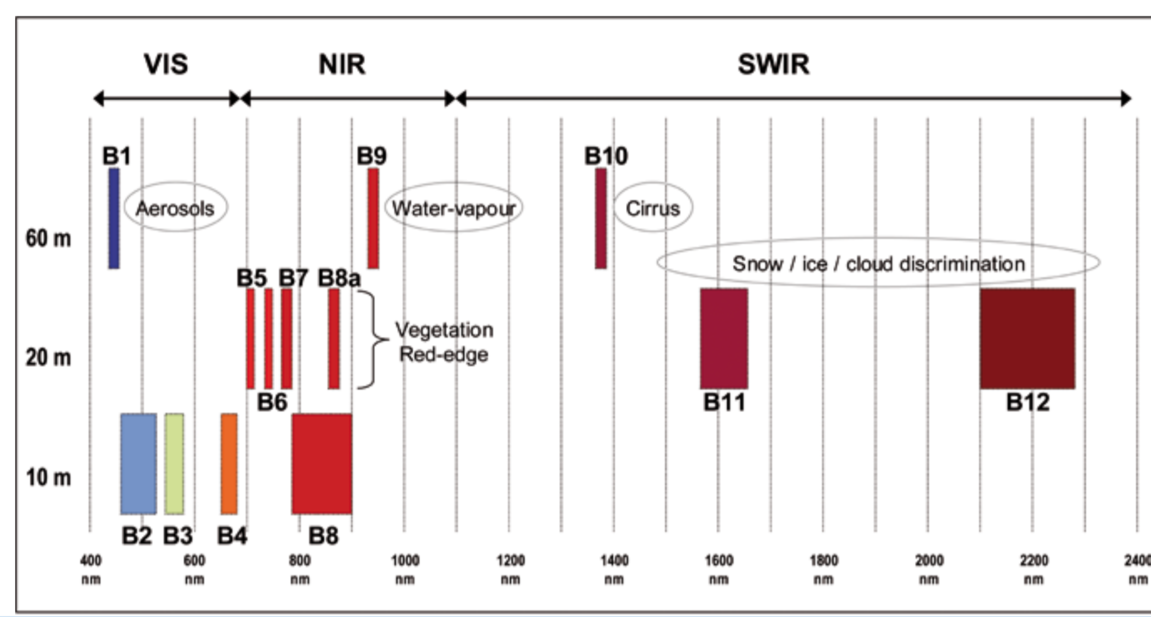
- Aims
  - Evaluate Sentinel2 MSI capabilities for Coral Reefs mapping on selected sites
  - Provide a validated processing chain for coral reef remote sensing
  - Develop a set of modules implemented as open source software within ESA's SNAP (SeNtinel's Application Platform)
  - Define observation scenarios for global coverage of coral reefs

Sentinel 2 MSI



SENTINEL-2 is a European wide-swath, high-resolution, multi-spectral imaging mission.

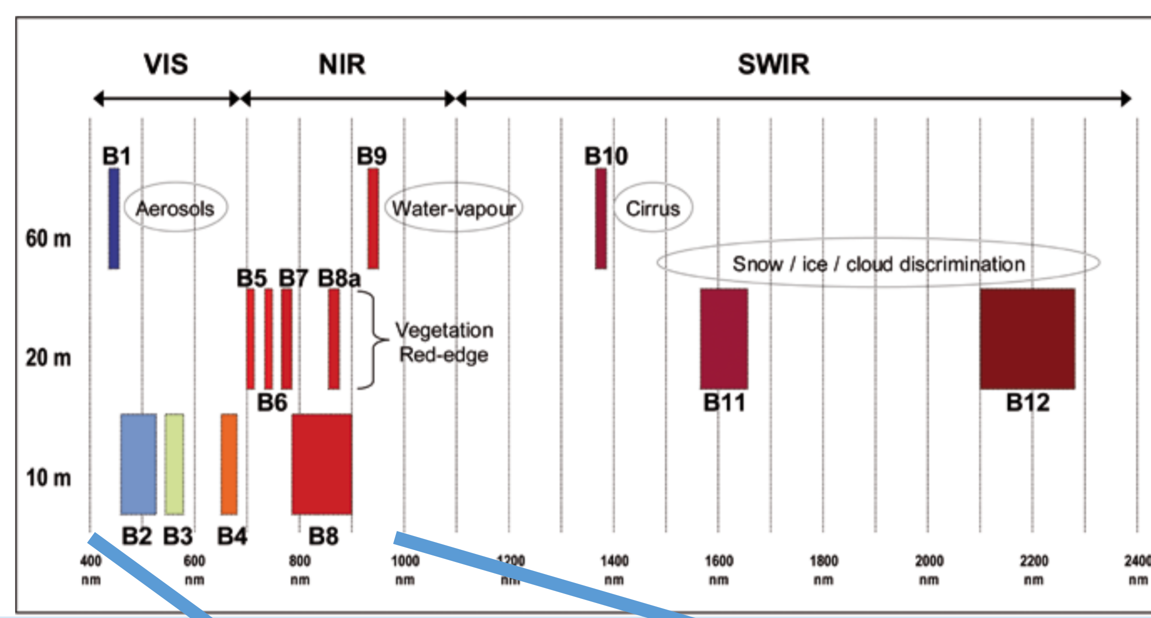
- twin satellites flying in the same orbit but phased at 180°
- high revisit frequency of 5 days at the Equator.
- orbital swath width of 290 km
- 13 spectral bands:
  - four bands at 10 m spatial resolution
  - six bands at 20 m spatial resolution
  - three bands at 60 m spatial resolution.

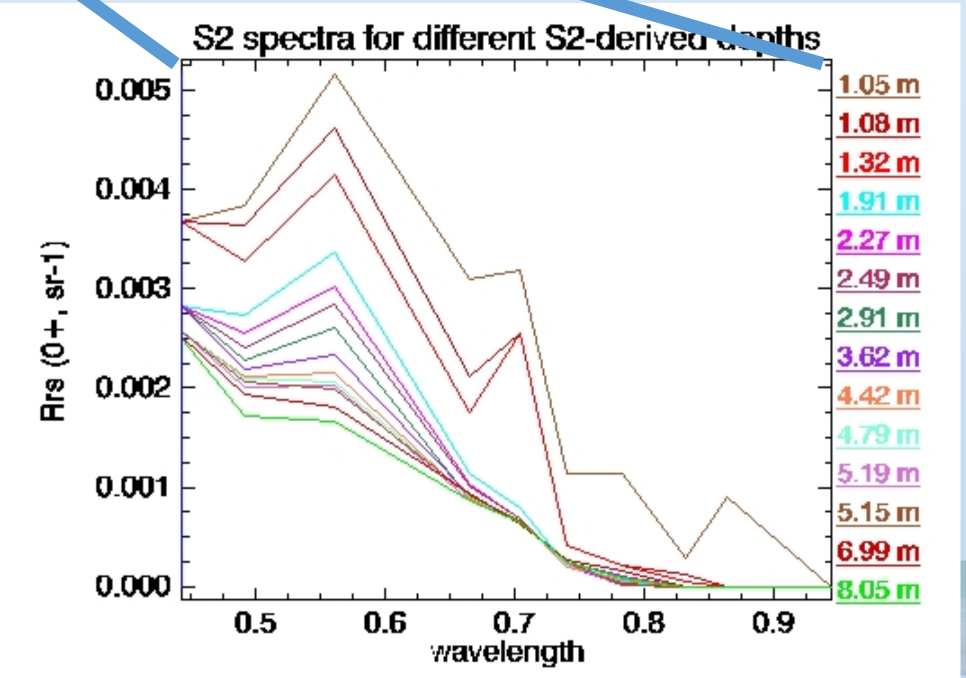


Sentinel 2 MSI

specific design features are:

- a narrow blue wavelength band (CDOM), 4 narrow red/NIR bands, a 1.6 micron band for improved cirrus cloud detection;
- spatial resolution of 10 m in water penetrating wavelengths 490 nm–665 nm;
- improved instrument radiometric digitization (12 bits) that may enhance performance in low-radiance marine applications





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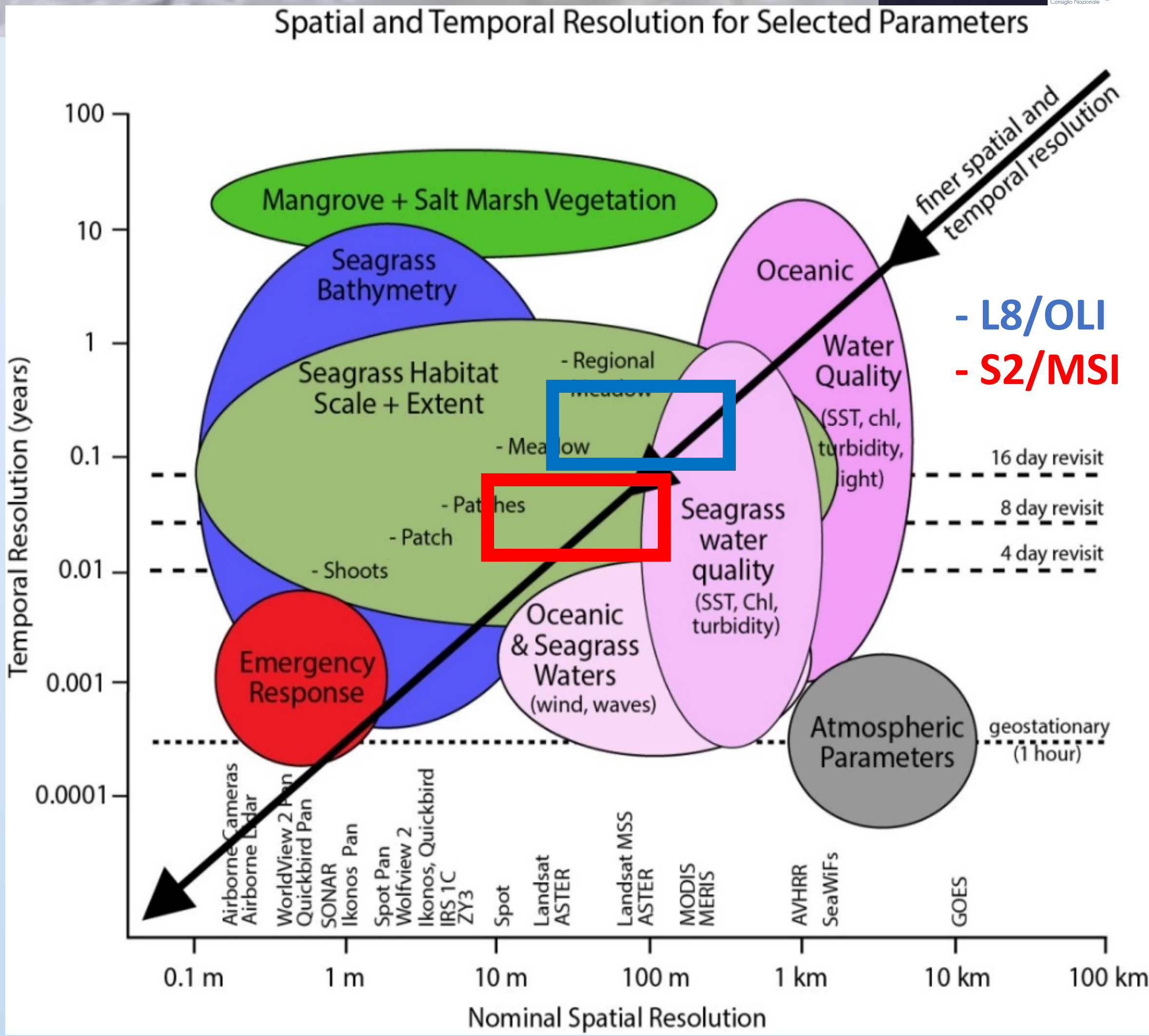
- revisit time of ten days (5d in 2017 with S2B), facilitating time series or change detection.



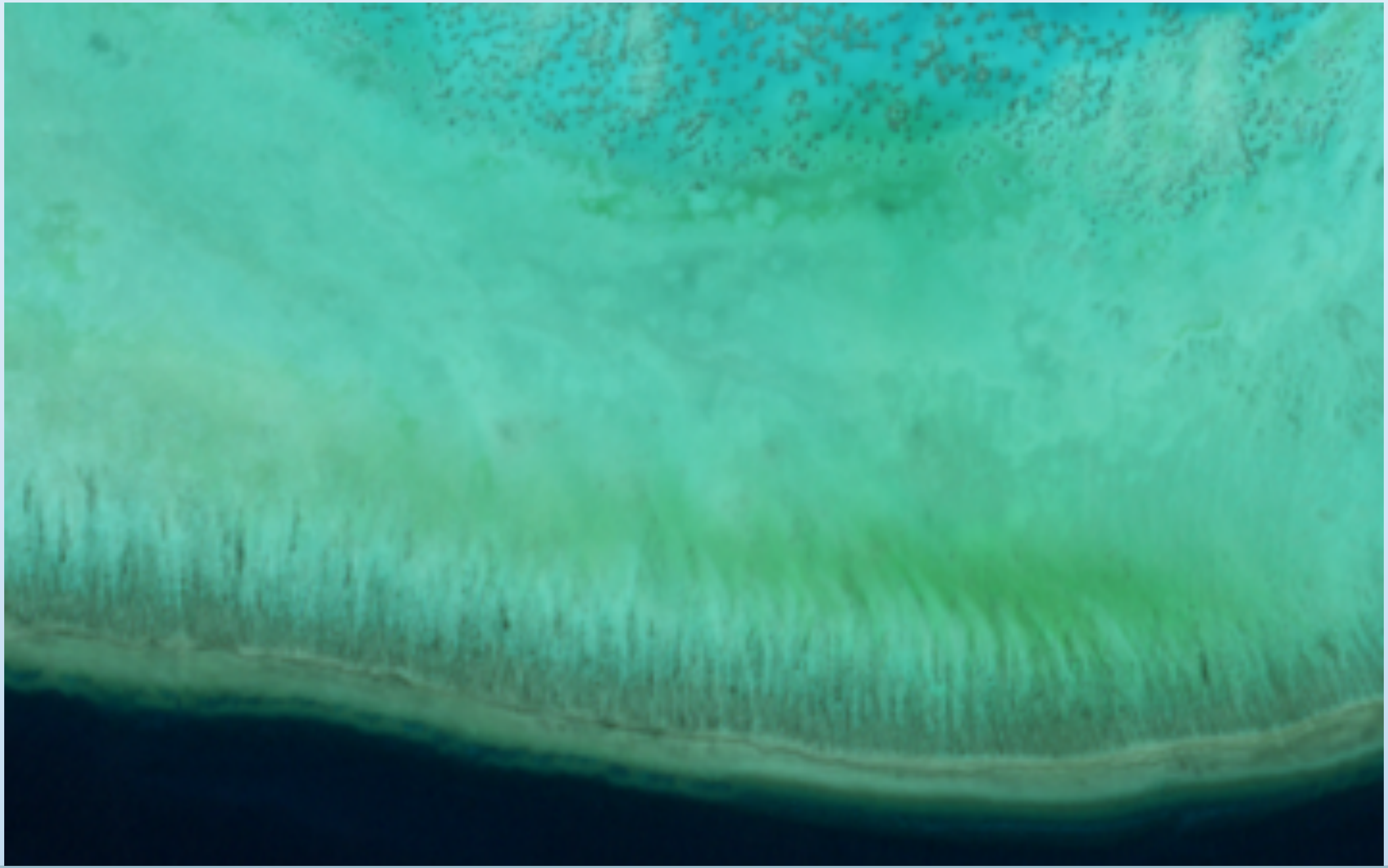
Phinn et al. 2013 in Hedley et al 2016

Heron Reef - 22 December 2015

Heron Reef - 1 January 2016

Heron Reef - 21 January 2016

Heron Reef - 31 January 2016



Sentinel 2 MSI

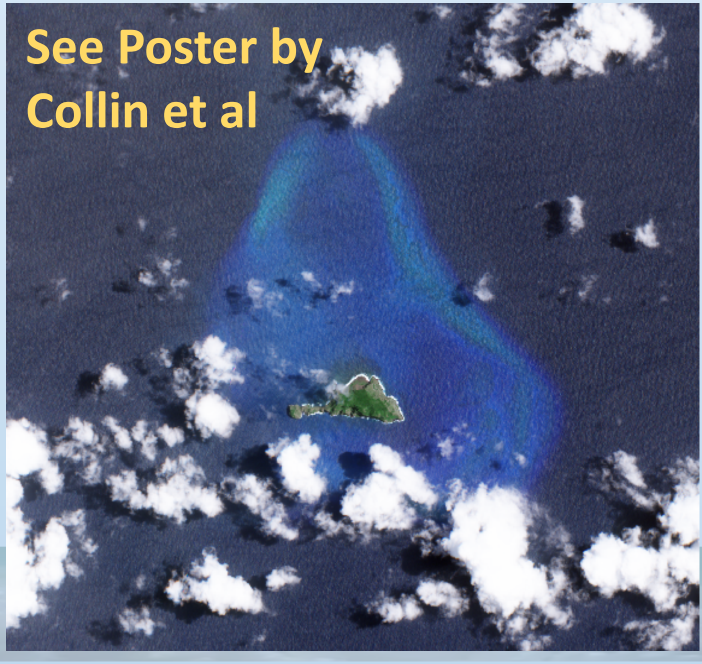
- The Sentinel 2 mission is focused on land and the coastal zone.
- The current mission requirement is for geographical coverage restricted to 20 km from the coastline of land masses larger than 100 km^2 so global coverage in a coral reef context is not achieved.
- There is the need to define observation scenarios for global coverage of coral reefs:
  - regular sampling on some 250 super sites following NOAA/UNEP priority sites approach
  - full coverage, but at what temporal resolution? once a year, once a season?

The ESA Sen2Coral project: study sites

Heron and Lizard Island, GBR, Australia

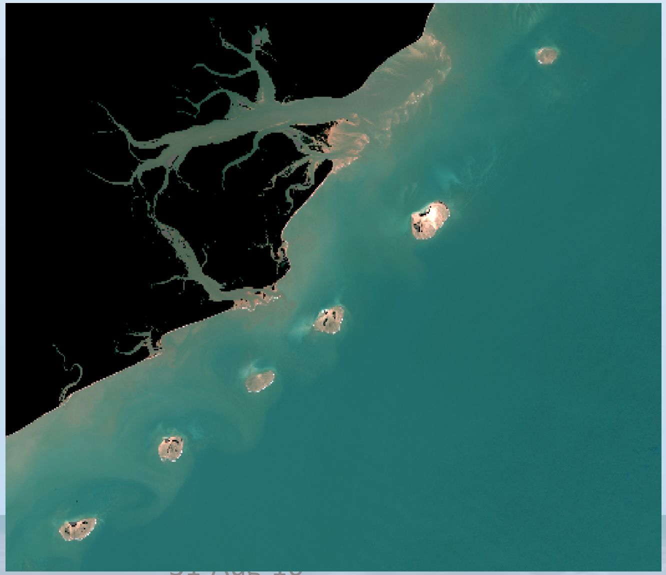
Lampi Island, Mergui Archipelago Myanmar

Fatu Huku, Marquesas Archipelago French Polynesia

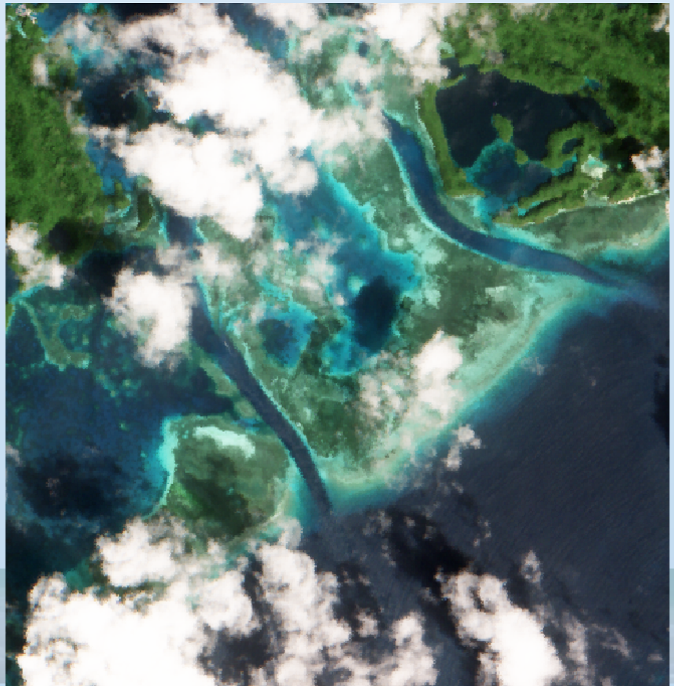


The ESA Sen2Coral project: study sites

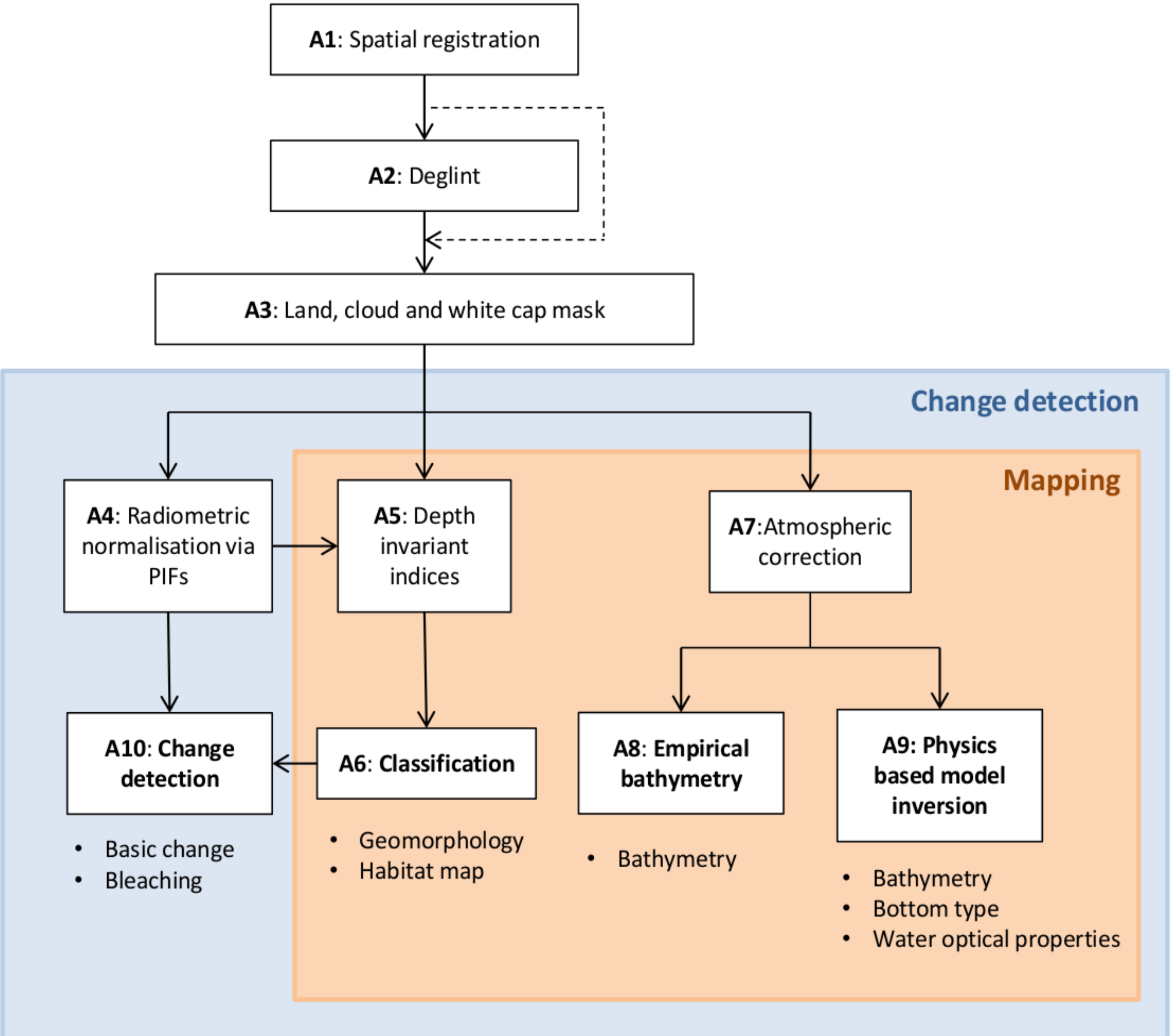
The Primeiras and Segundas Archipelago, Mozambique



Lighthouse and Ngederak Reef, Palau



Coral reef remote sensing processing chain

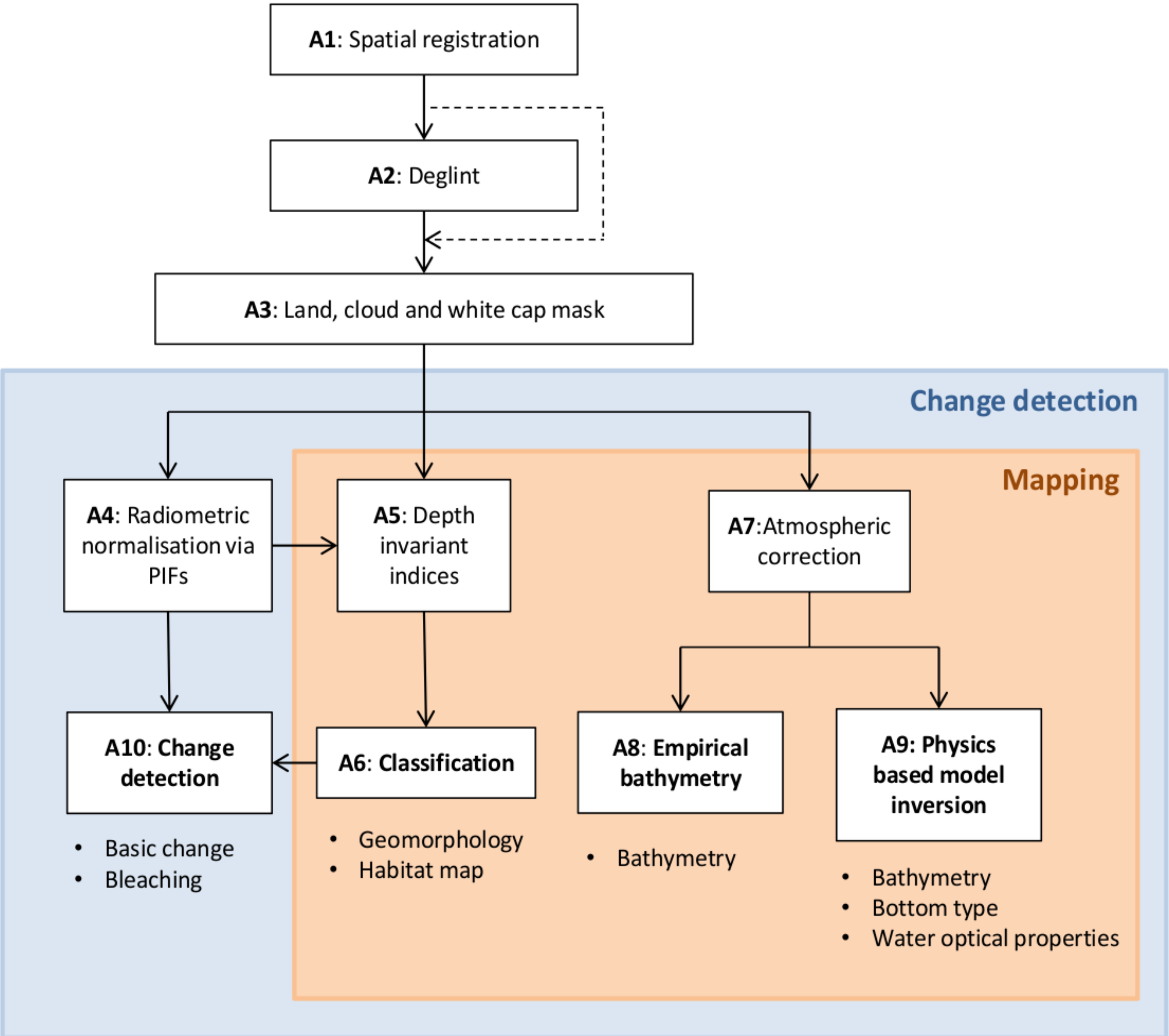


- Consistent with web resources, e.g. UNESCO Remote Sensing Handbook for Tropical Coastal Management

  http://www.unesco.org/csi/pub/source/rs.htm

- basic (pre-)processing tools
- Plus “state-of-the art” model inversion method

Coral reef remote sensing processing chain



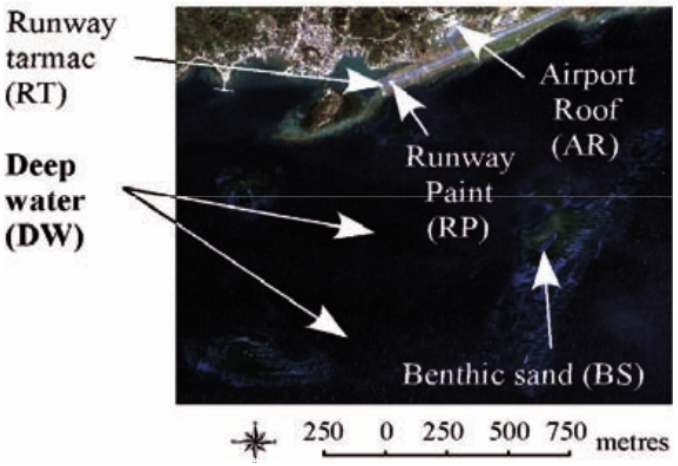
A4 : Radiometric normalisation via "Pseudo Invariant Features" (PIFs)

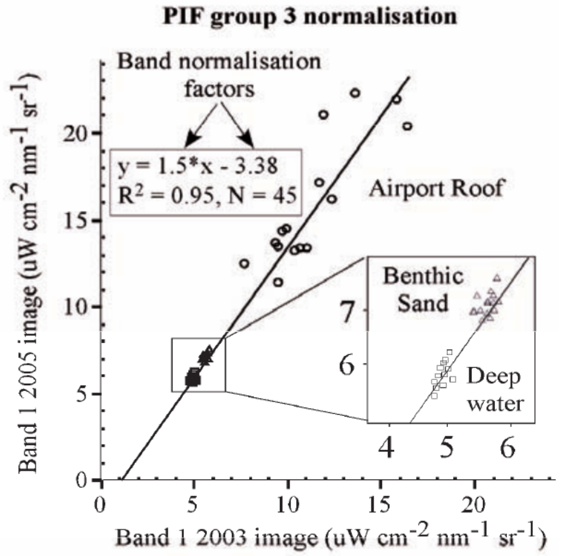
Empirical line - linear transform to align reflectance of light and dark PIFs across two images.

All published bleaching detections use empirical line image-to-image normalisation using PIFs.

Also common for change detection and suggested better than physical atmospheric correction.

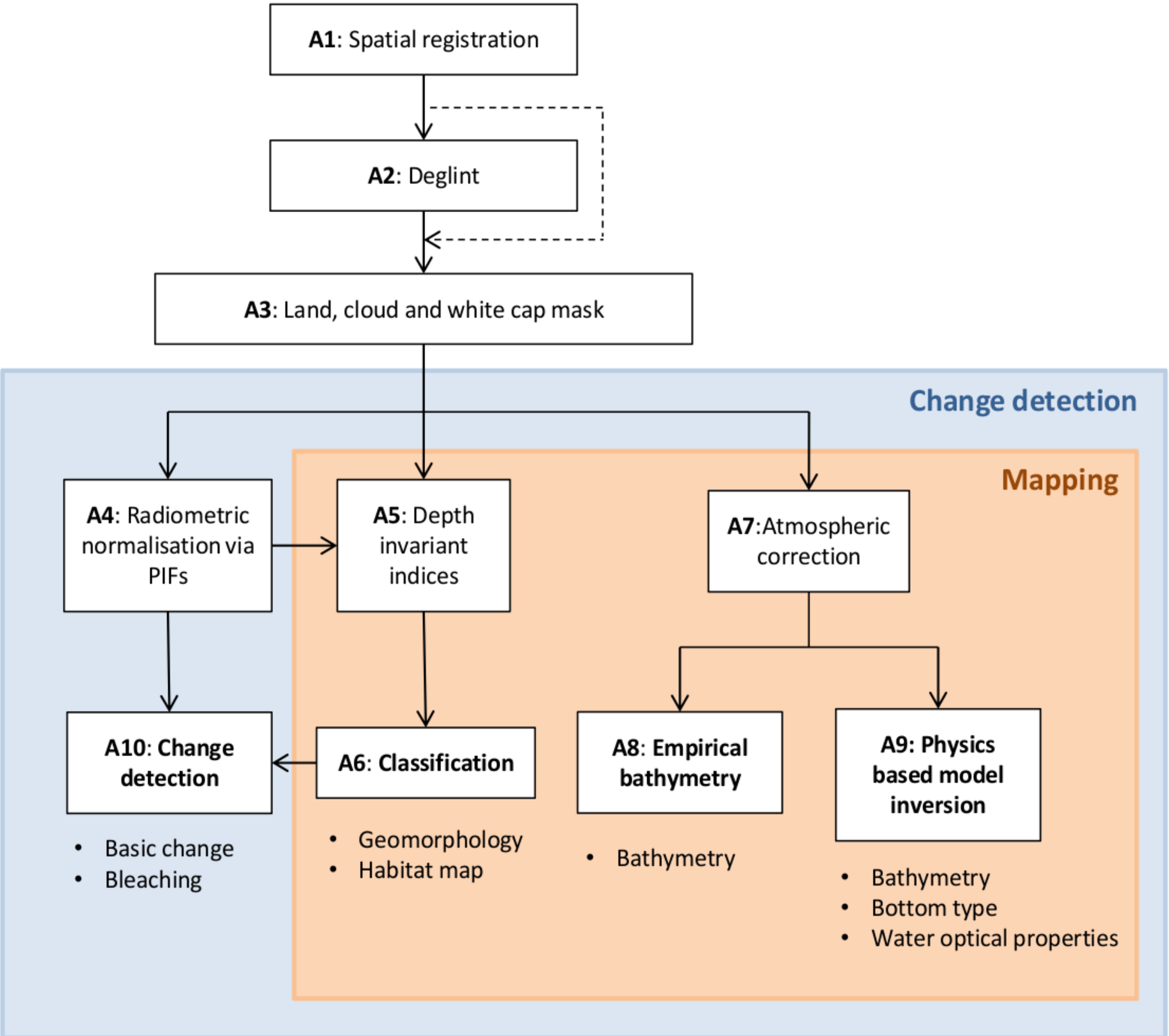
e.g. Rowlands et al. 2005





Coral reef remote sensing processing chain

Sen2Coral



A2 : Deglint

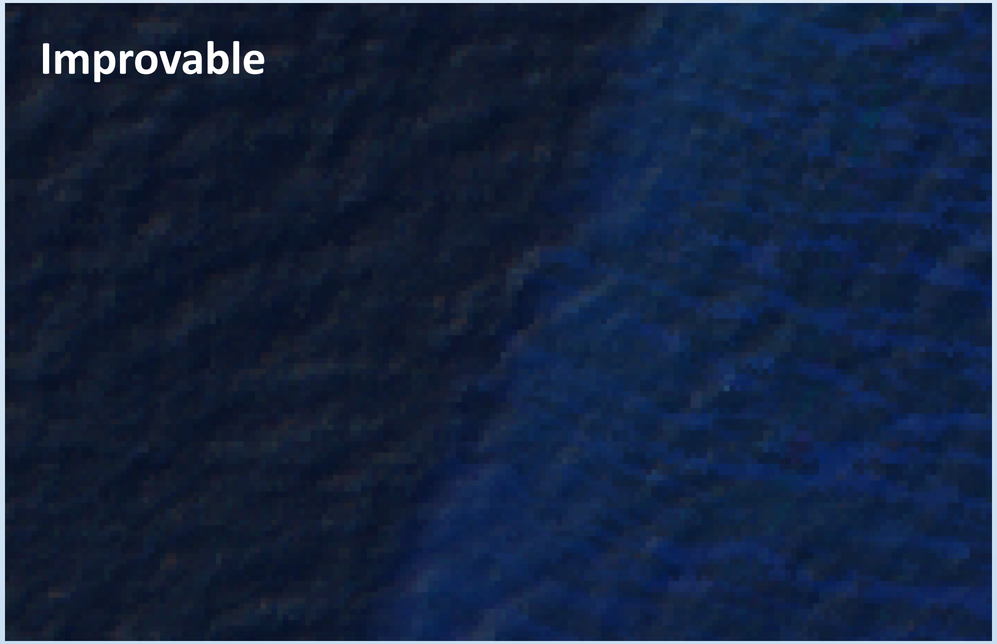
Removes sun glint reflected from waves by using a NIR band

- Essential component of the tool box but not always useful
- Improves visual appearance
- In shallow areas can over-correct because of subsurface NIR reflectance (makes pixels dark)
- Result is noisy - relies on good spatial and temporal band registration

Deglint: Specific issue with Sentinel 2

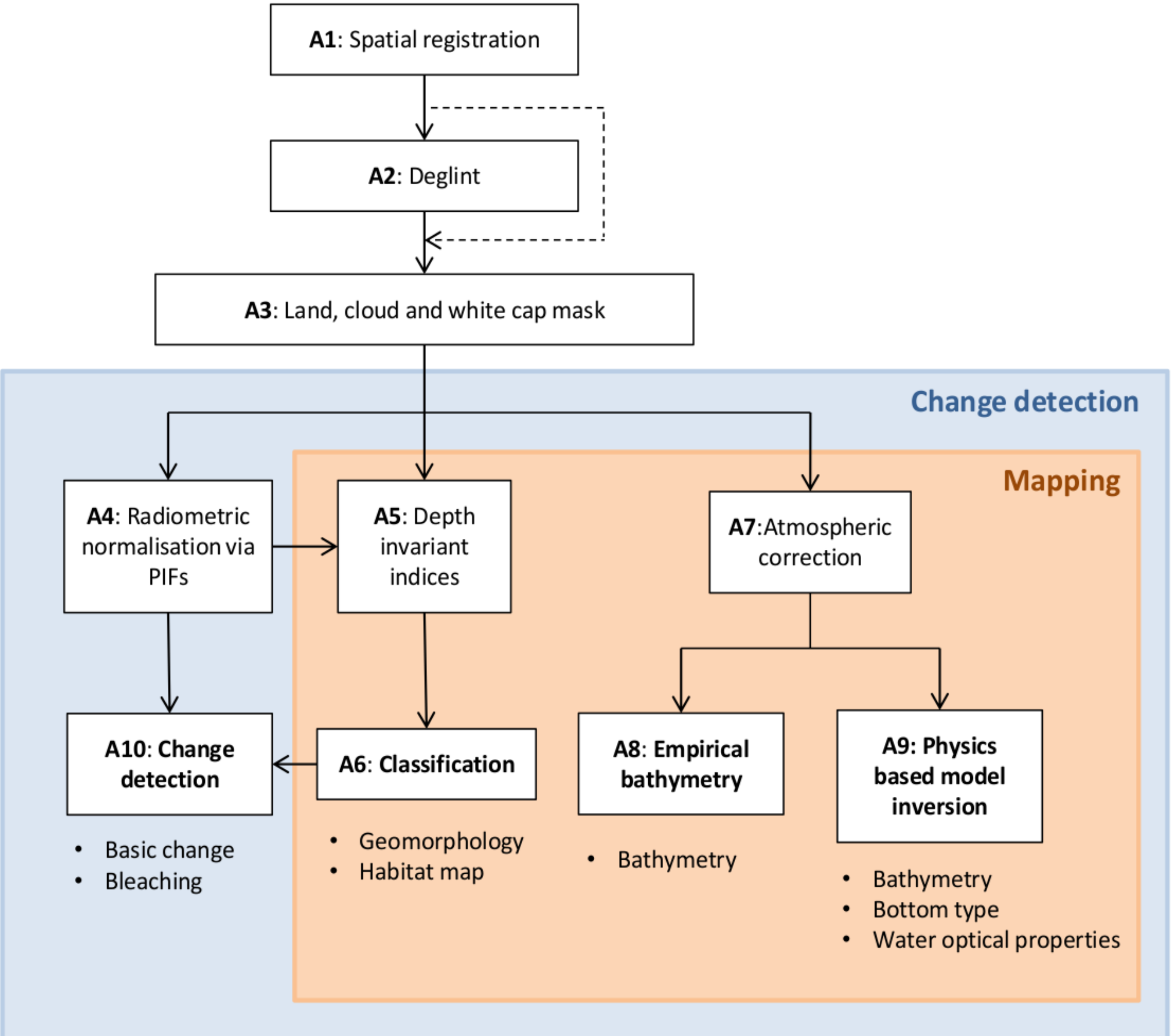
glint is frequently caused by waves smaller than the 10 m pixels.

- Can’t be corrected by this method because no basis to characterise the relationship.
- This component exists in many images - difficult to get a radiometrically correct surface correction.



This is more like “large pixel” sensor regime - MERIS etc. these correct for glint using Cox and Munk equations of surface slopes from wind speed - not valid in shallow waters.

Coral reef remote sensing processing chain

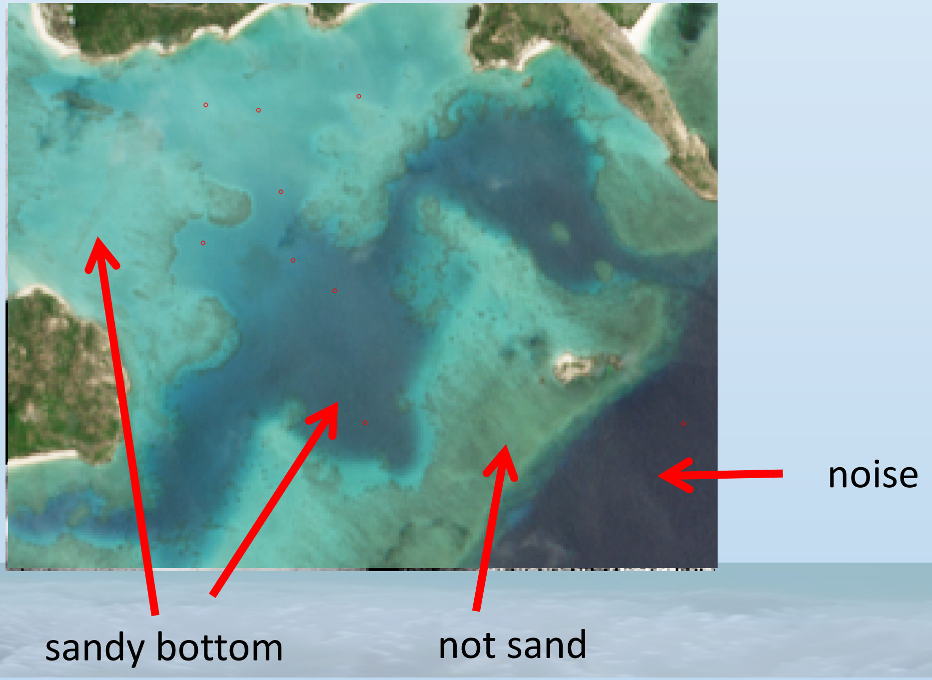


A5 : Depth Invariant Indices

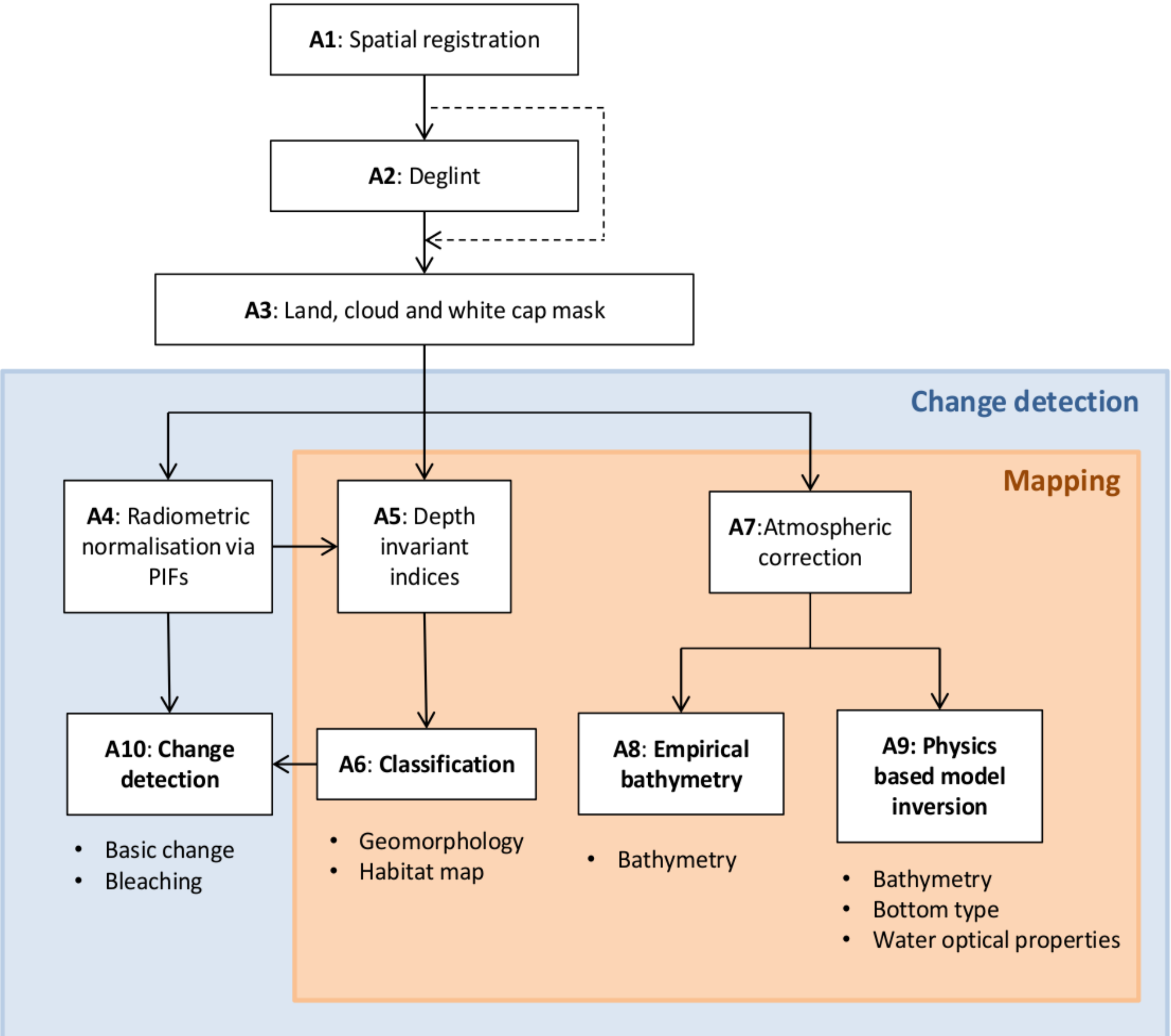
Purpose is to remove the effect of depth variation on reflectance prior to bottom type classification

→ The ratio of the logarithm of band pairs

→ Result is an index that should be the same for bottom types of the same reflectance at all depths



Coral reef remote sensing modular framework



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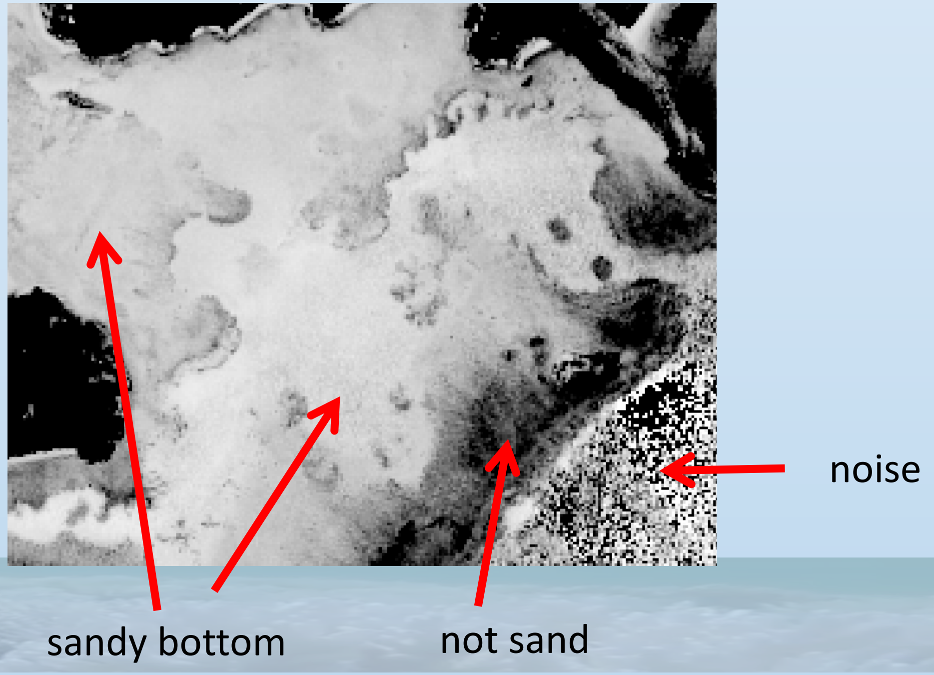
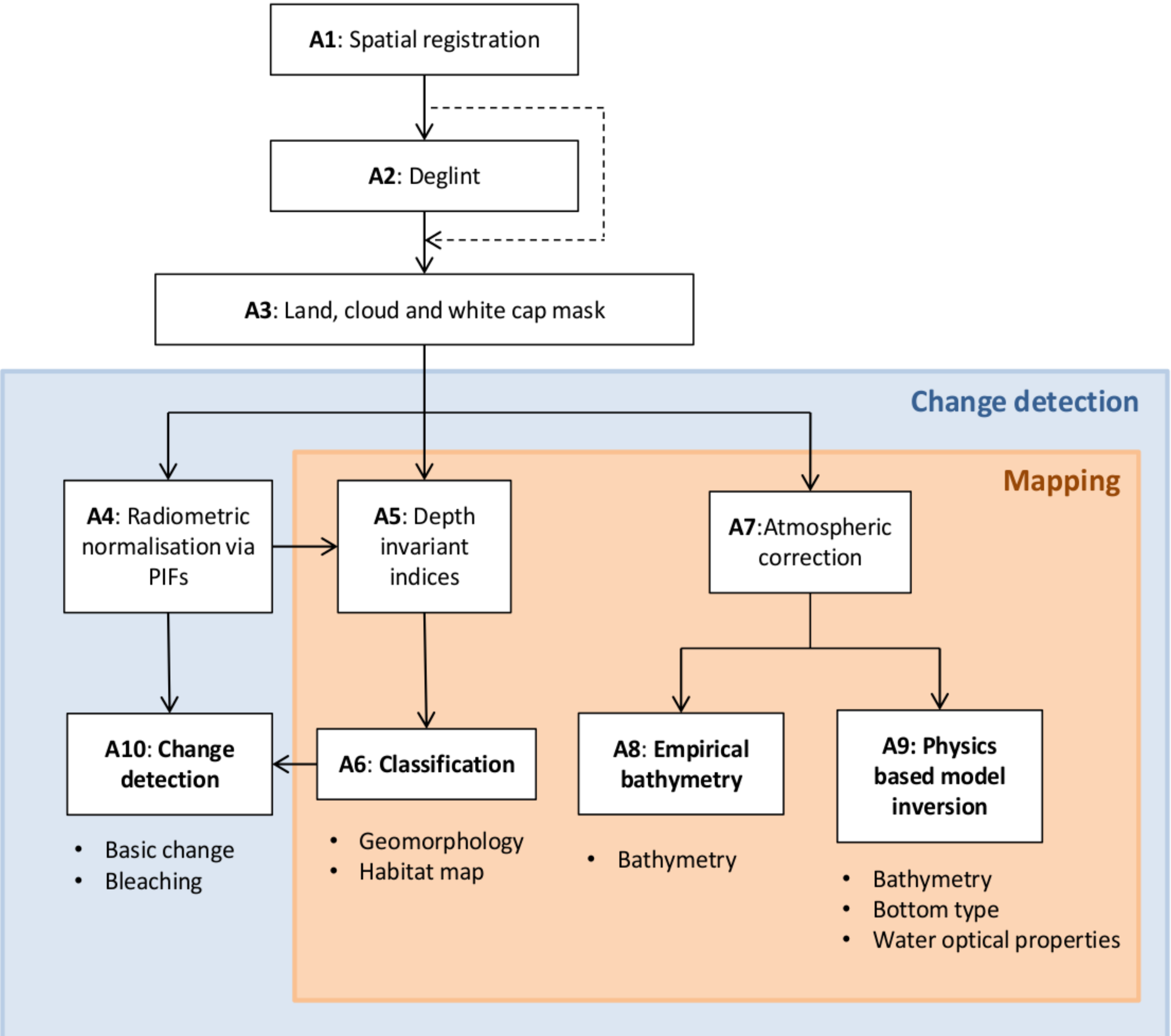


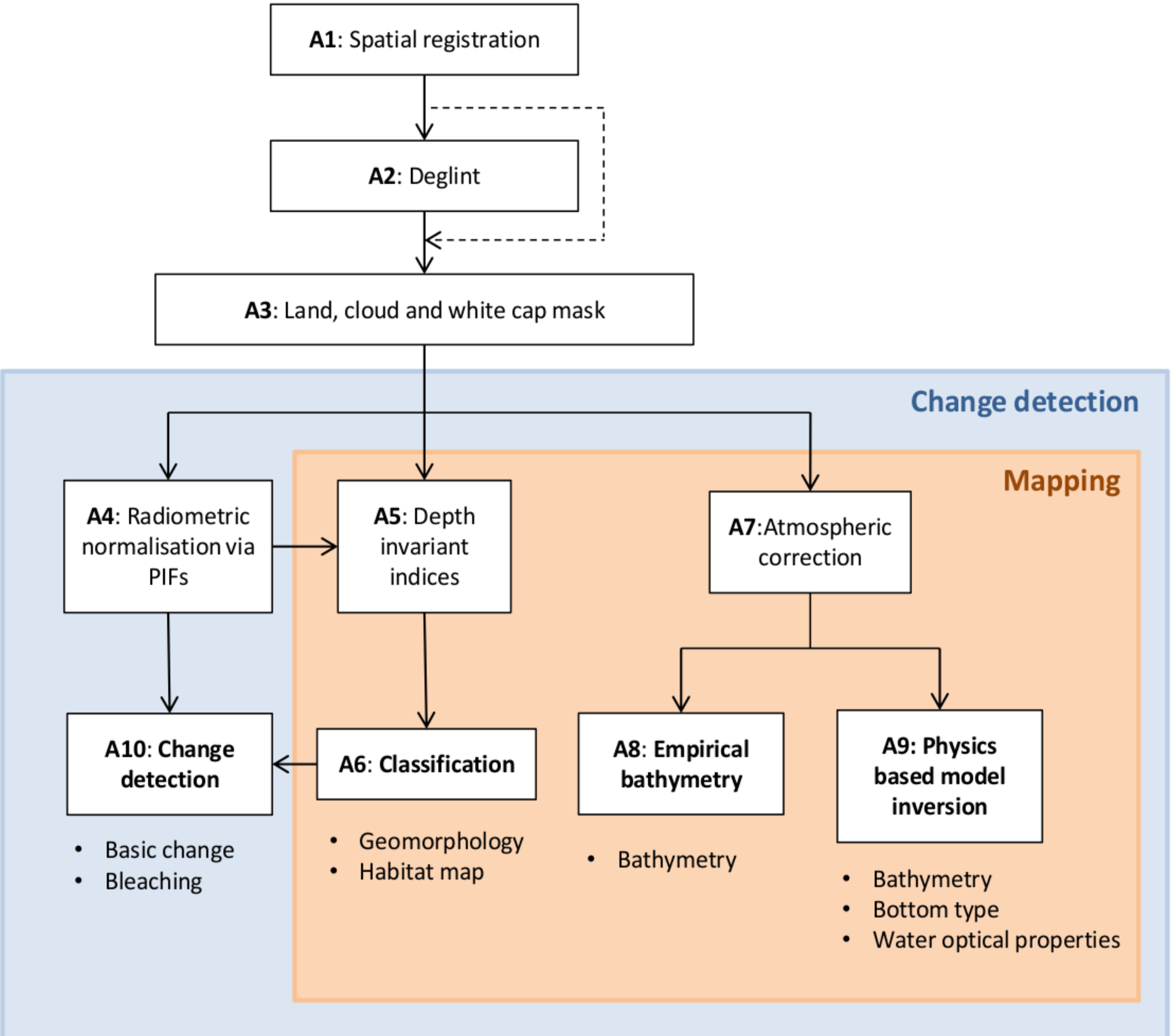
Coral reef remote sensing processing chain



A6 : Classification

- Generic “off the shelf” methods are used, k-means, maximum likelihood, etc.
- But can benefit from previous steps, masking, de-glint, depth invariant indices, etc.
- Supervised or unsupervised with subsequent class association.
- Usually use an excess of classes and merge classes afterwards.
- Contextual editing - if it is obviously wrong then fix it manually.

Coral reef remote sensing processing chain



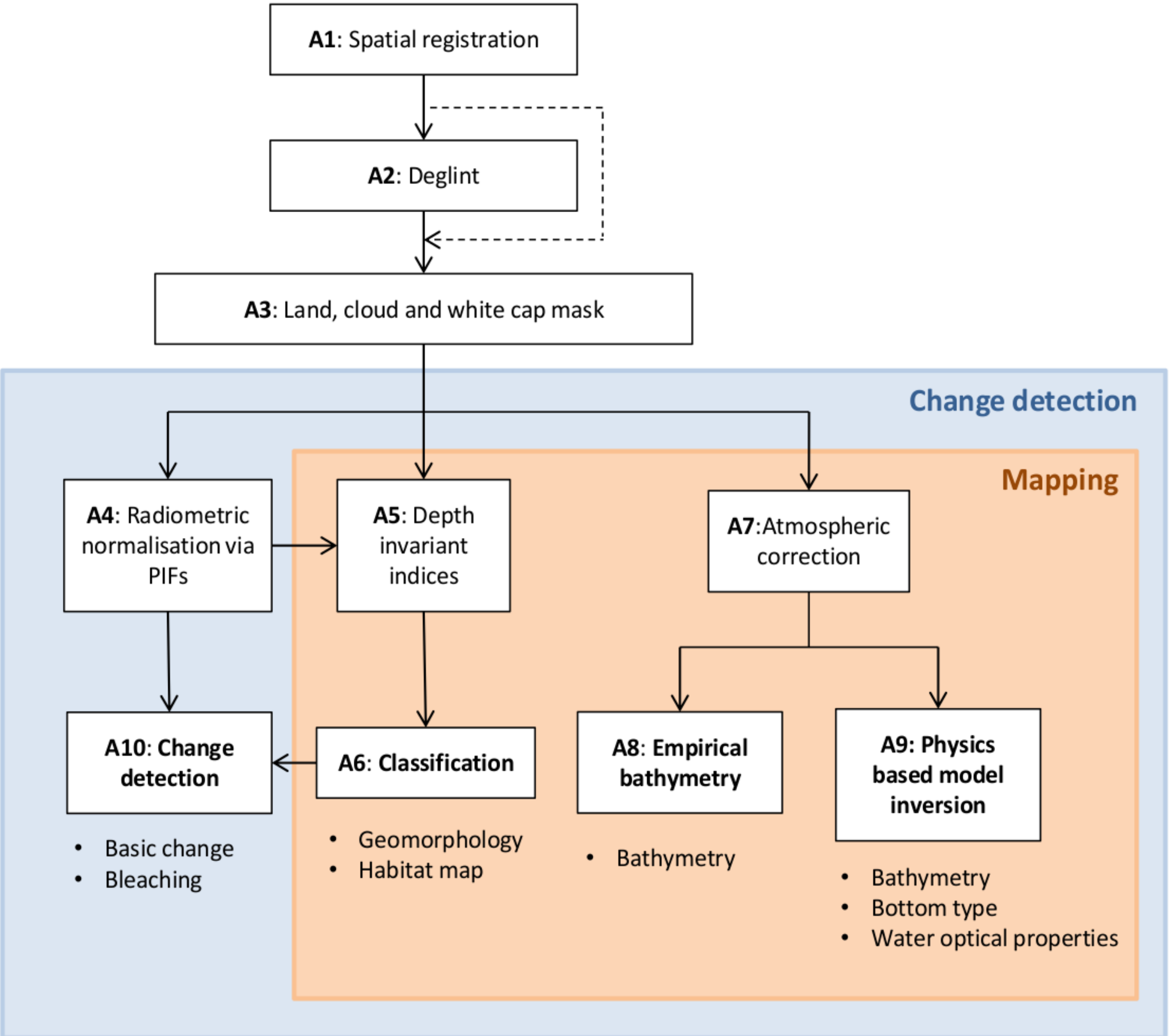
A7 : Atmospheric correction

A dedicated tool will not be developed in the project

Existing/available S2 processors will be evaluated:

- Sen2Cor
- Acolite
- OPERA
- 6s/MODTRAN LUTs
- etc

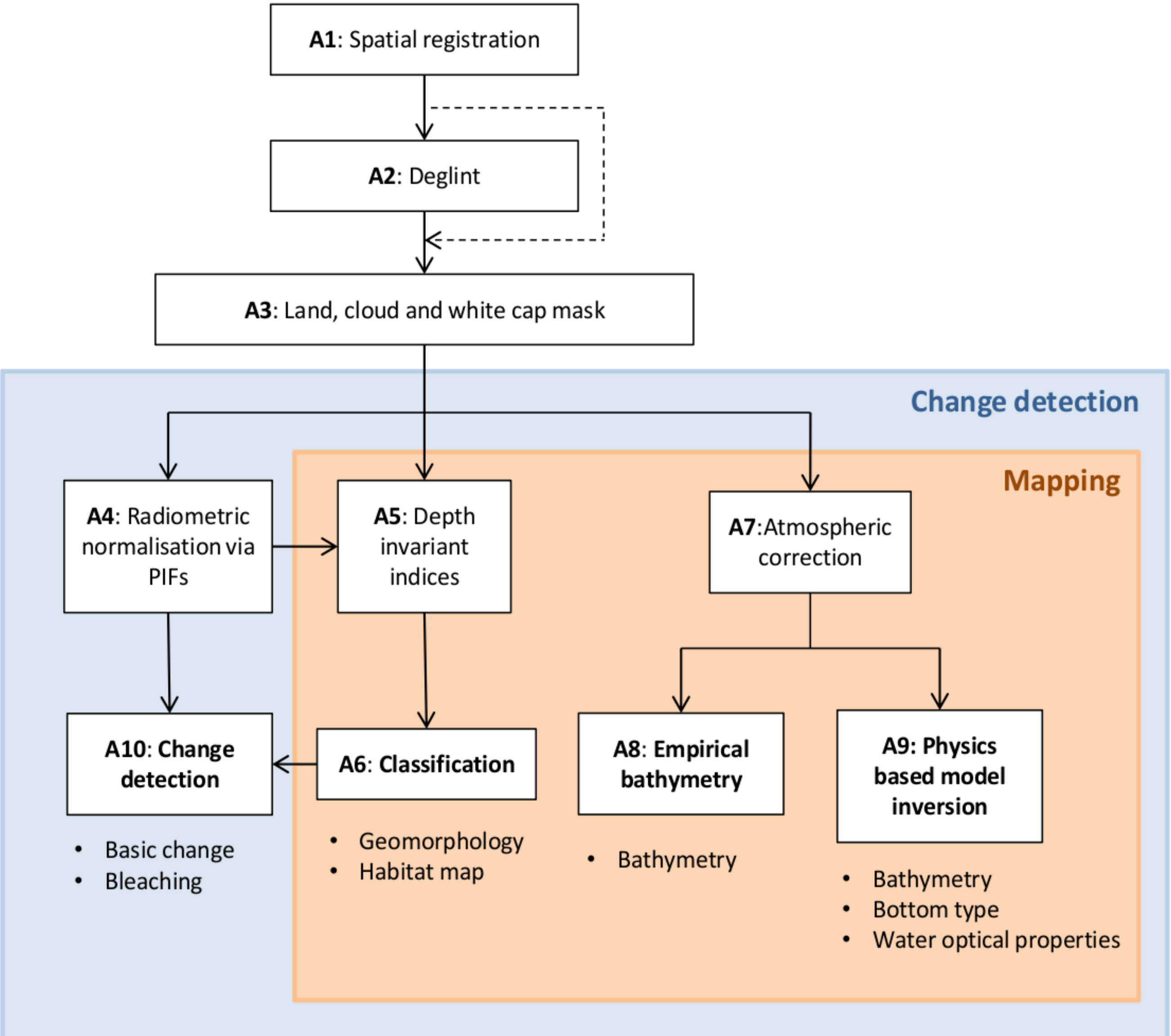
Coral reef remote sensing processing chain



A8 : Empirical Bathymetry

- Based on ratios of band logarithms (similar to depth invariant analysis)
- Not quite as good as physics-based inversion but simple to apply and results are reasonable
- Requires a decent size dataset of ground truth bathymetry data
- e.g. Lyzenga 1978

Coral reef remote sensing processing chain

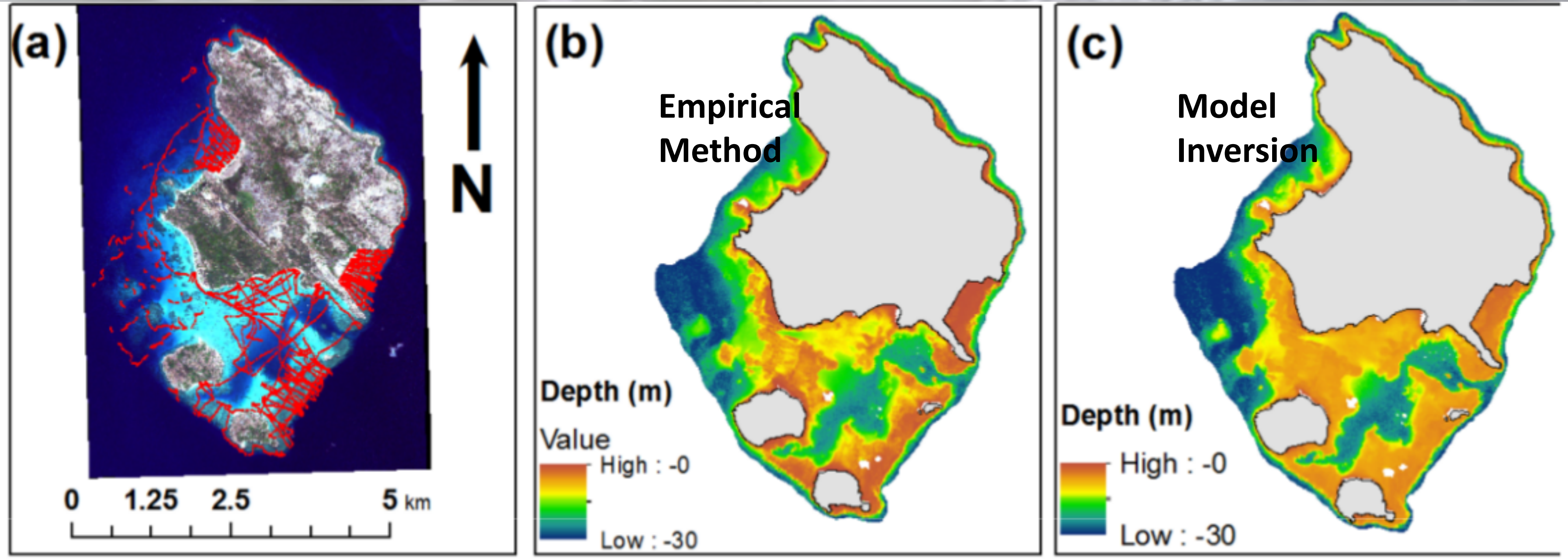


A9 : Physics-based Model Inversion Method

- Estimates depth, bottom type and water optical properties simultaneously (based on Lee et al, 1999, 2001)
- Quite complicated to implement, slower processing
- Requires **atmospheric correction**

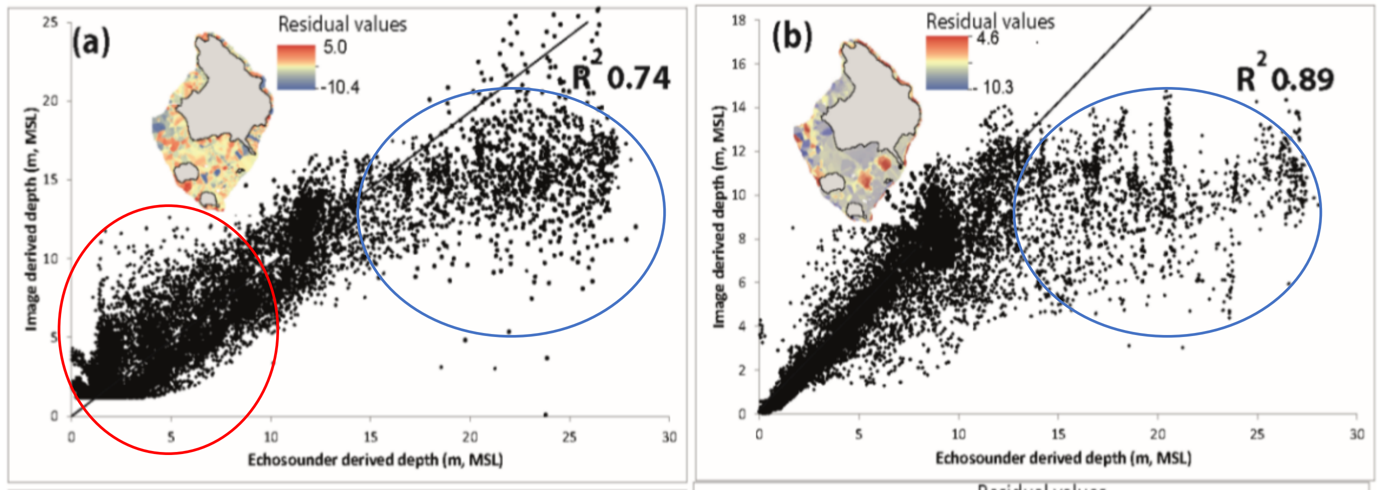
- **ALLUT (Hedley et al 2012)**
- **BOMBER (Giardino et al 2013)**
- **SAMBUCA (Brando et al 2009)**

Example bathymetry of Lizard Island from WorldView 2 (Hamylton et al. 2015)

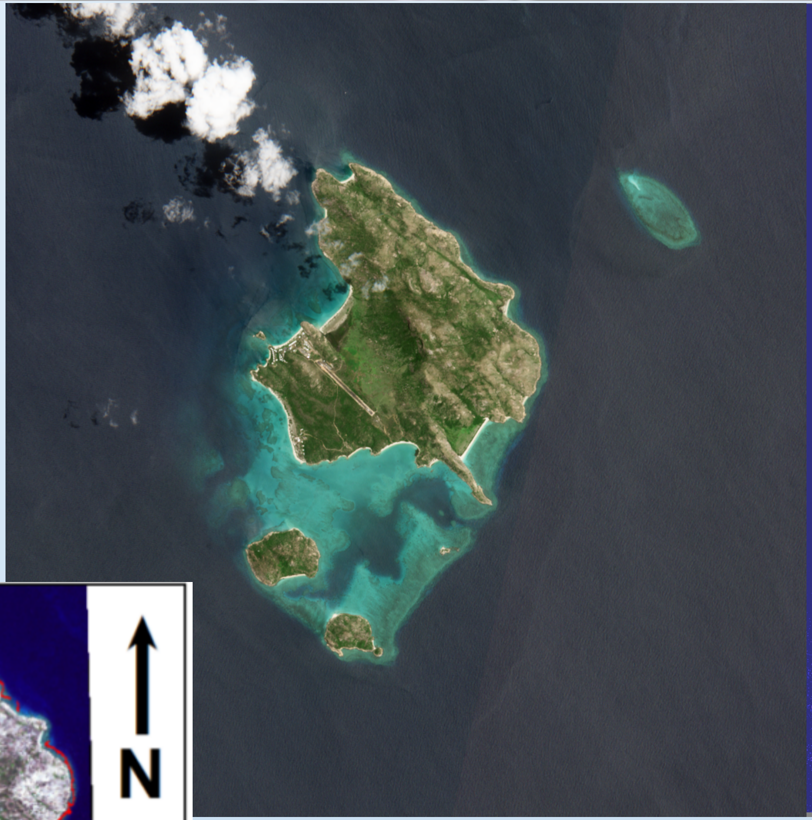


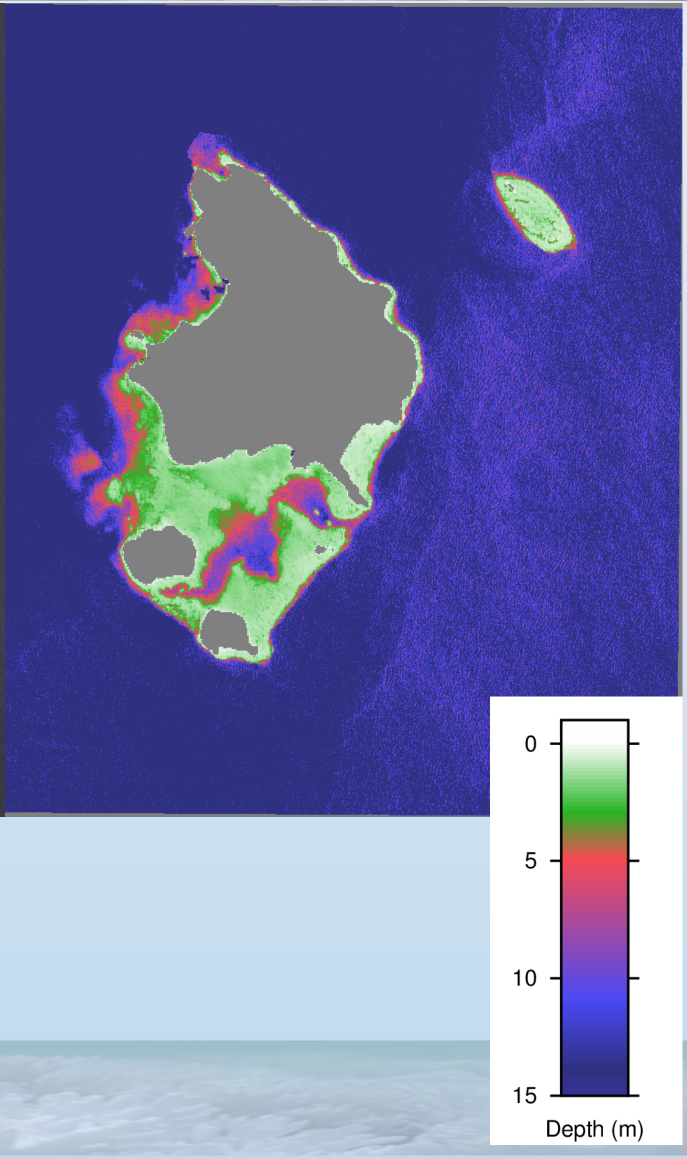
Both methods saturate at ~12 m

Empirical method is more susceptible to variation in bottom reflectance, possible cause of spread at 0-5 m



Example bathymetry of Lizard Island from Sentinel2 MSI (22 February 2016)





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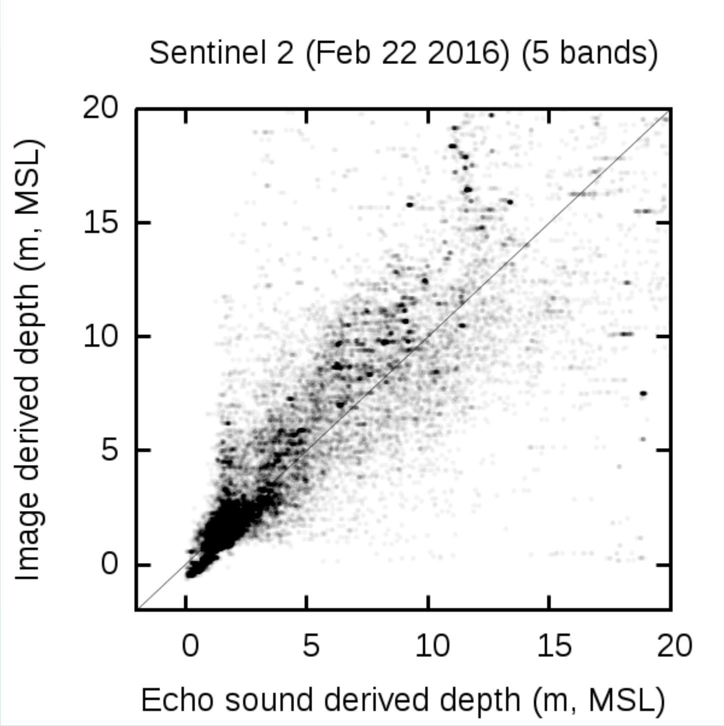
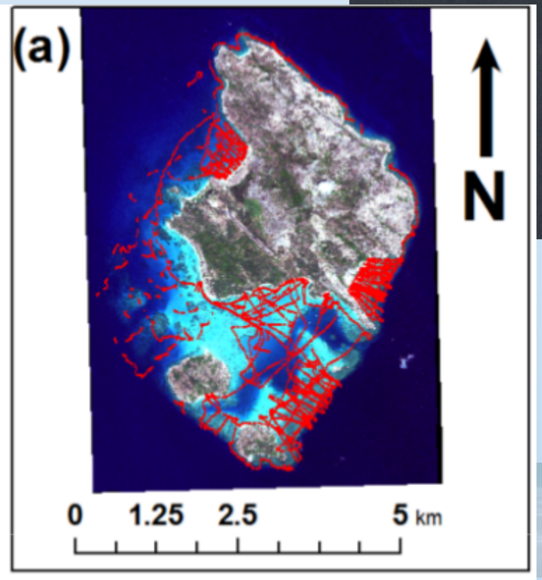
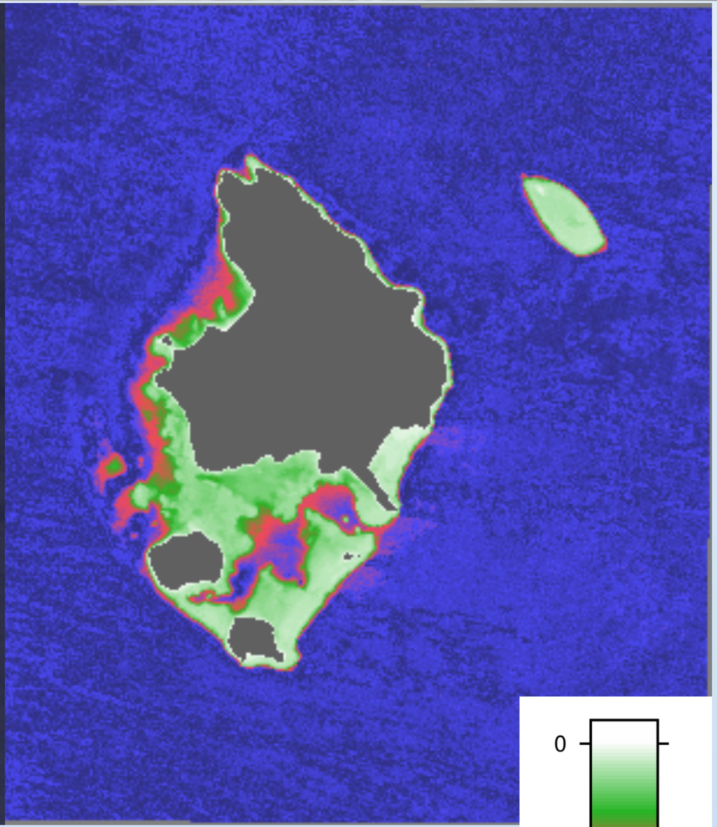
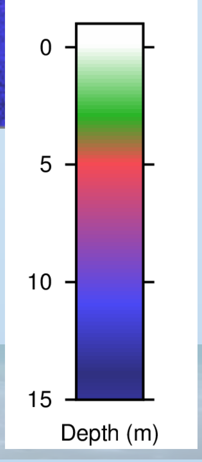


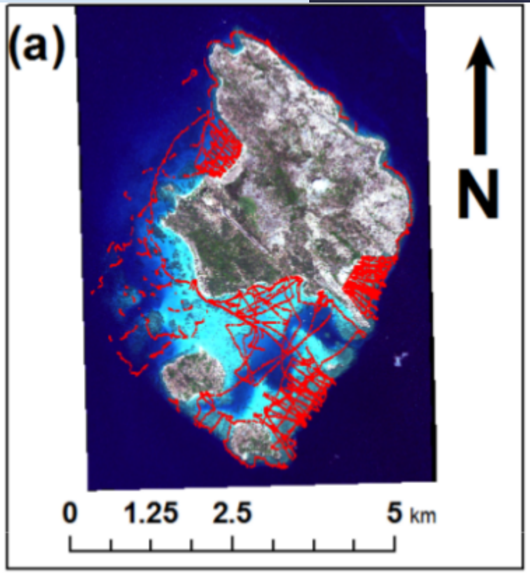


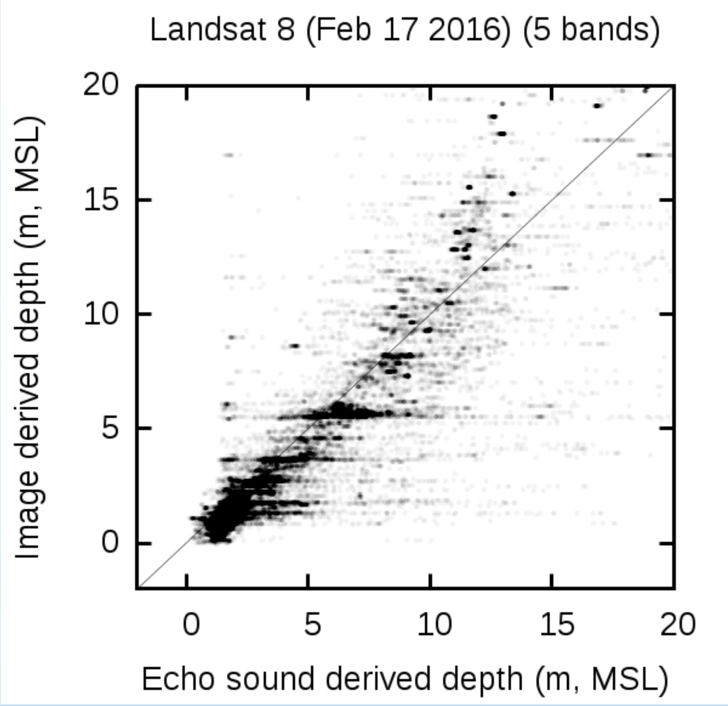
Example bathymetry of Lizard Island from Landsat-8/OLI (17 February 2016)

- **ALLUT (Hedley et al 2012)**

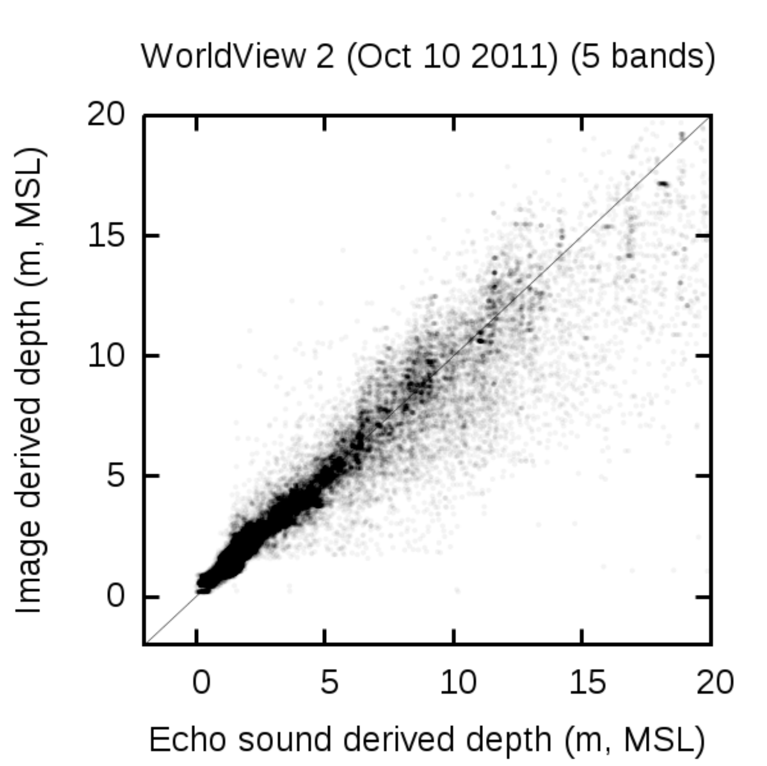


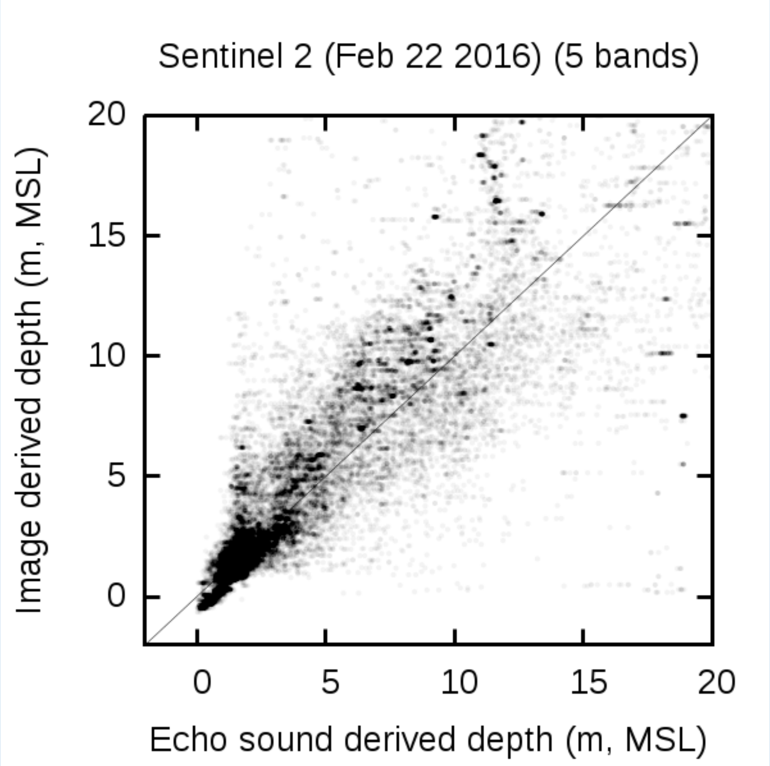


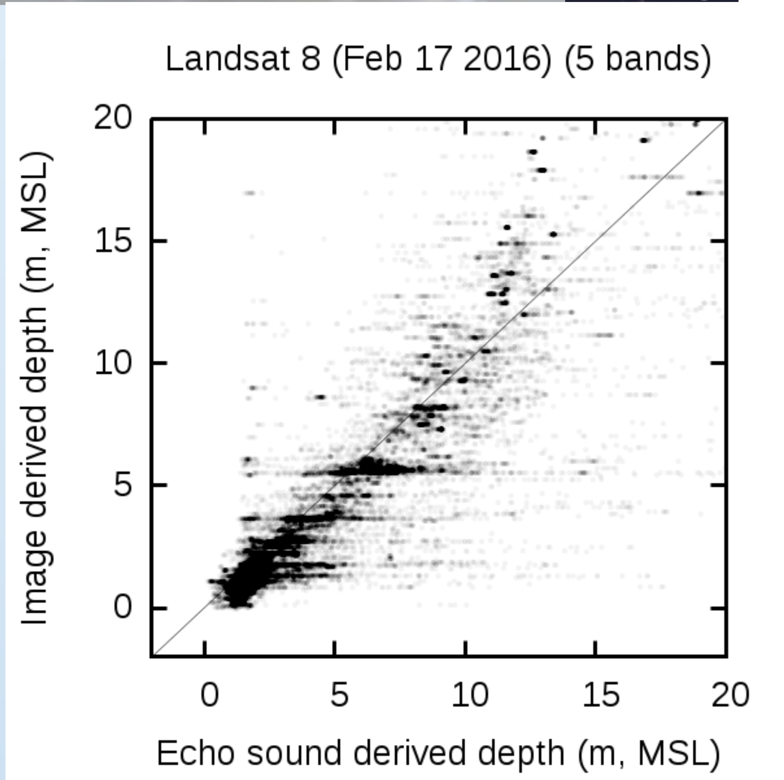




Example bathymetry of Lizard Island







Apparent degradation of accuracy for WV2 to S2 and L8: issue of scale? glint residuals?

Summary

- Sentinel 2 MSI spectral, radiometric, spatial and temporal resolution may provide new observing opportunities for coral reef science
- The dedicated remote sensing processing chain will enable users to analyse S2/MSI imagery and derive coral reef composition and condition mapping and monitoring products.
- we welcome the community feedback on:
  - proposed mapping and monitoring tools and products
  - observation scenarios for global coverage of coral reefs

_ <u>please register your interest as stakeholders and/or toolbox beta-testers</u>

References

- *Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services* (ESA SP-1322/2 March 2012) https://earth.esa.int/documents/247904/349490/S2_SP-1322_2.pdf
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Thank you

v.brando@isac.cnr.it

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- www: http://www.sen2coral.org
- Twitter: @sen2coral