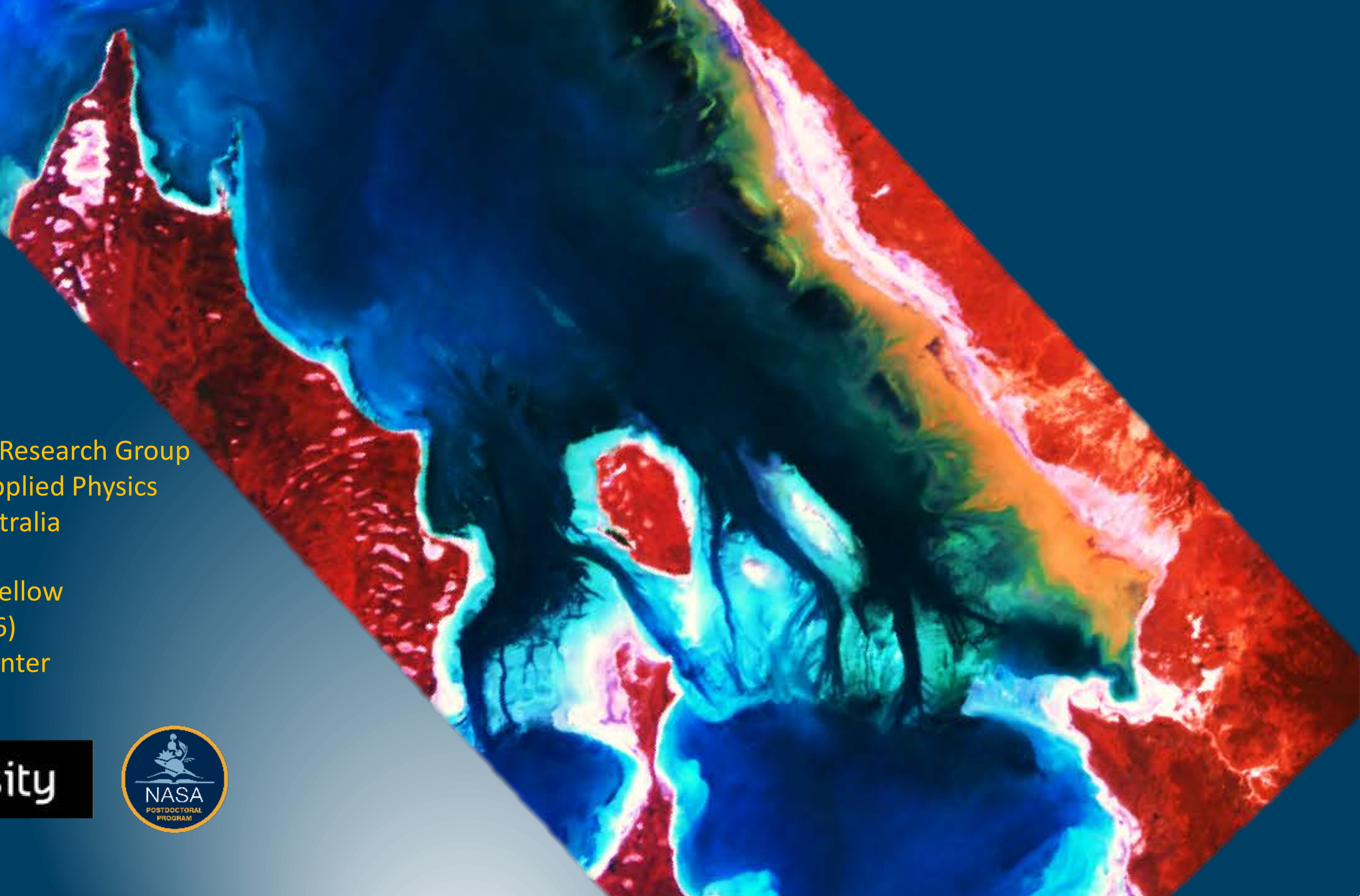
# Challenges in detecting trend and seasonal changes in bathymetry derived from HICO imagery: a case study of Shark Bay, Western Australia

Rodrigo Garcia[1], Peter Fearns[1], Lachlan McKinna[1,2]

[1]Remote Sensing and Satellite Research Group
Department of Imaging and Applied Physics
Curtin University, Western Australia

[2]NASA Postdoctoral Program Fellow
Ocean Ecology Laboratory (616)
NASA Goddard Space Flight Center
Greenbelt, MD



**Curtin University:**

- HICO User’s since 2011
- Previous experience with airborne hyperspectral surveys, radiative transfer, bio-optics…
- Interest in bathymetry & habitat mapping for environmental management

**Research question:**

- Can HICO data be used to detect change in bathymetry through time?

# Study site: Shark Bay, Western Australia

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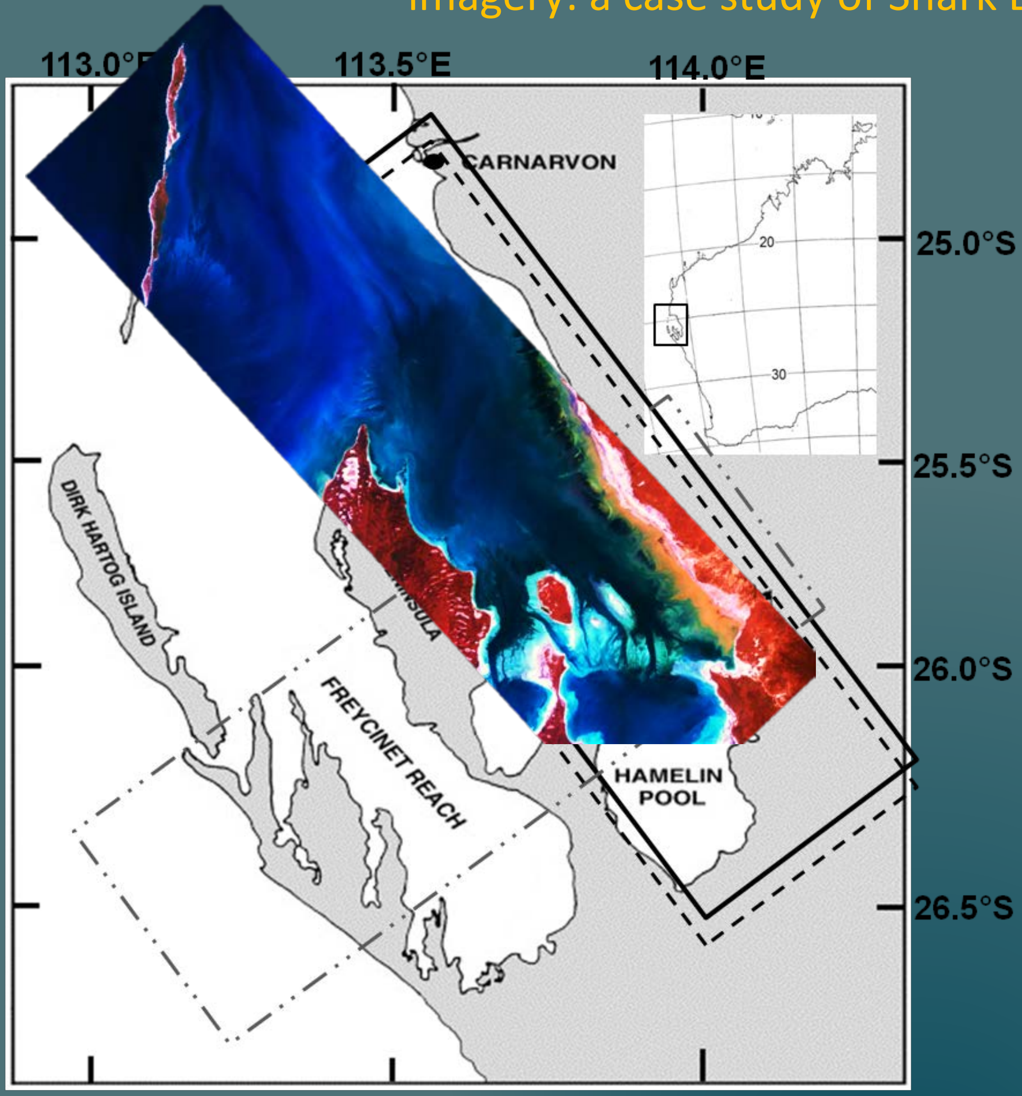



- World Heritage Area
  - Very remote, approx. 700 km (440 miles) North of Perth
  - 12 species of seagrass that cover approx. 4200 $km^2$ (Walker et al. 1988)

- The rectangles represent different swath orientations of the HICO sensor.

# HICO image processing for assessing temporal change

1. Removing the atmospheric radiance signal from at-sensor top-of-atmosphere radiance (Tafkaa-6S)
   - $\rho^* \rightarrow R_{rs}$

2. Correcting for sun-glint and air-to-water interface
   - $R_{rs} \rightarrow r_{rs}{}^{deglint}$

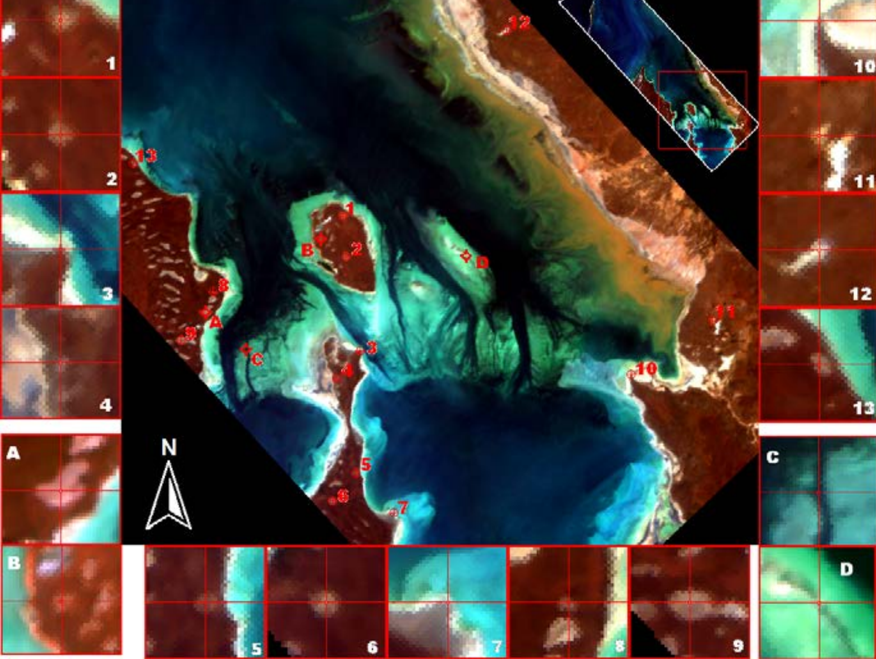
3. Shallow water inversion model to retrieve depth and <u>uncertainty</u>
   - $r_{rs}{}^{deglint} \rightarrow Depth$

4. Post-image smoothing

5. Tide Correction

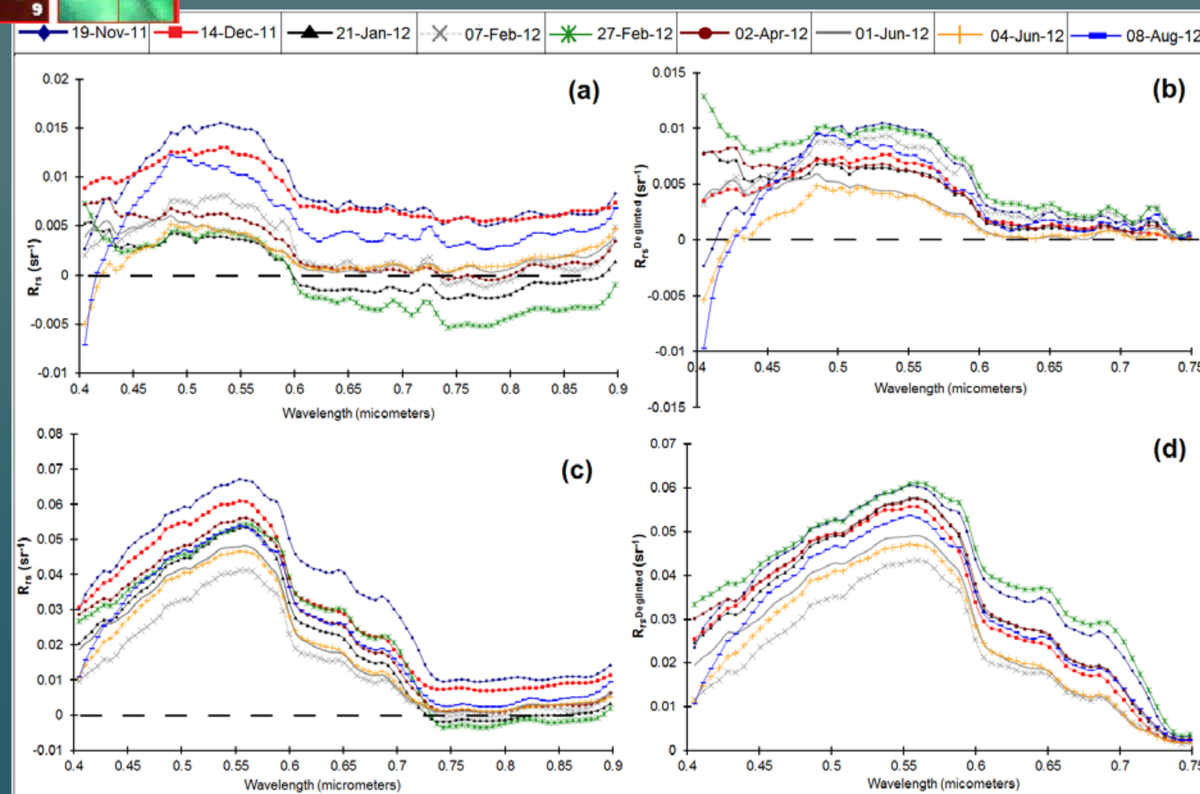
6. Geo-registration

7. Change Detection Analysis




# Atmospheric correction & sunglint correction

- Tafkaa-6S Atmocor
- Used co-incident MODIS Aqua imagery to estimate $\tau(550)$, cwvap, ozone
- Sunglint $\Delta R_{rs}(750)$
- Basic land/cloud masking if $R_{rs}(750\ \text{nm}) > R_{rs}(400\ \text{nm})$

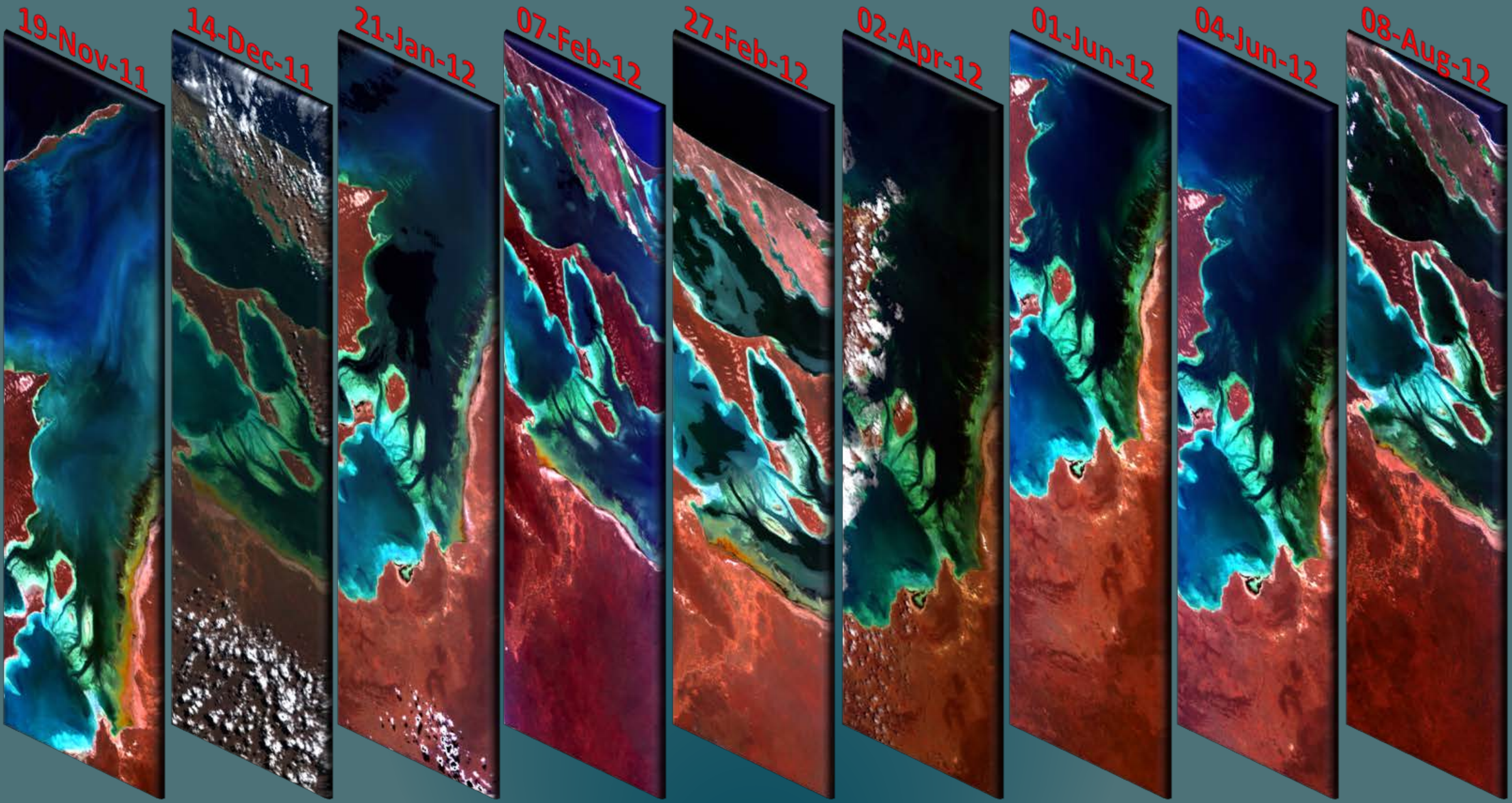


# HICO image processing for assessing temporal change

1. Removing the atmospheric radiance signal from at-sensor top-of-atmosphere radiance (Tafkaa-6S)
   - $\rho^* \rightarrow R_{rs}$
2. Correcting for sun-glint and air-to-water interface
   - $R_{rs} \rightarrow r_{rs}^{deglint}$
3. Shallow water inversion model to retrieve depth and uncertainty
   - $r_{rs}^{deglint} \rightarrow$ *Depth*
4. Post-image smoothing
5. Tide Correction
6. Geo-registration
7. Change Detection Analysis

# Study site: Shark Bay, Western Australia

HICO $r_{rs}^{deglinted}$ imagery spanning 10 months: November 2011 to August 2012



# 3. Retrieving Bathymetry

## Bottom Reflectance Un-mixing Computation of the Environment (BRUCE) model

- Physics-based shallow water model (Klonowski et al. 2007)

$$r_{rs}(\lambda) = f\left(a(\lambda), b_b(\lambda), \rho(\lambda), H, \theta_v, \theta_w\right)$$

$$\downarrow$$

$$r_{rs}(\lambda) = f\left(\boldsymbol{P}, \boldsymbol{G}, \boldsymbol{X}, \boldsymbol{H}, \boldsymbol{B_{sg}}, \boldsymbol{B_{sed}}, \theta_v, \theta_w\right)$$

Semi-analytical, and functions of scalar parameters

- Non-linear optimisation (Levenberg-Marquardt) algorithm:

**Find** ***$P, G, X, H, B_{sg}$* and *$B_{sed}$*** such that

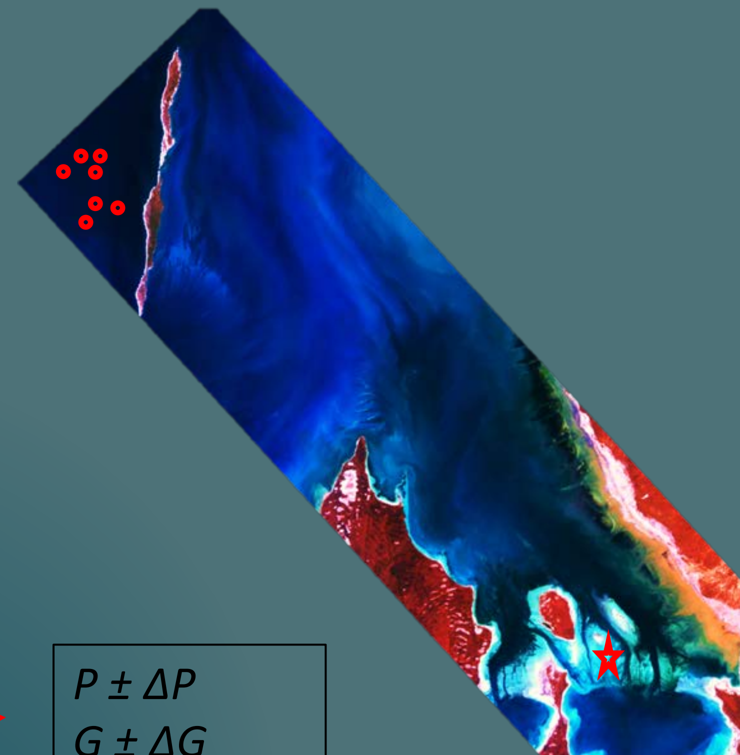
$r_{rs}^{model} - r_{rs}^{measured} \approx 0$

$$\text{cost function} = \sqrt{\sum_{i}^{N} \left(r_{rs,i} - \widehat{r_{rs,i}}\right)^2}$$

# 3. Retrieving Bathymetry

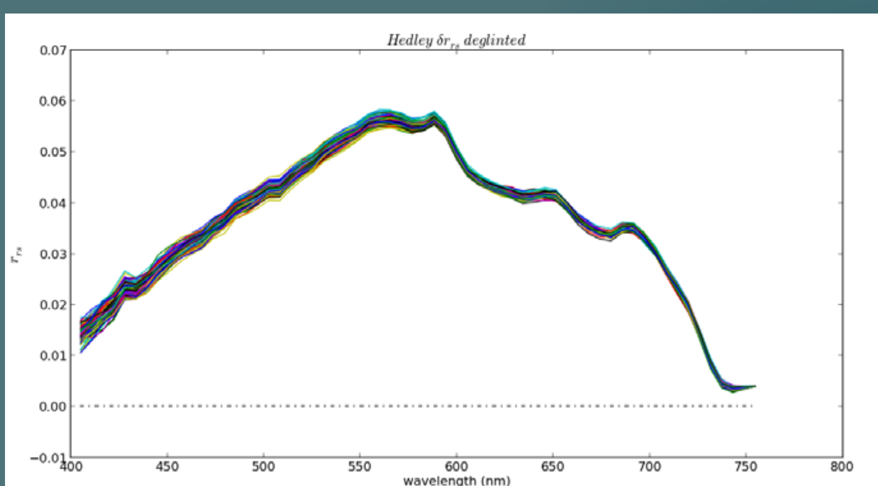
## Bottom Reflectance Un-mixing Computation of the Environment (BRUCE) model

Propagation of spectrally correlated sensor and environmental noise through the inversion process (Hedley et al. 2010; 2012)



**Estimate $\delta r_{rs}$ by sampling an "homogenous" deep water region**

**20 noise perturbed shallow water spectra: $r_{rs} + \delta r_{rs}$**




**Invert with BRUCE 20x**

$P \pm \Delta P$

$G \pm \Delta G$

$X \pm \Delta X$

$\boldsymbol{H \pm \Delta H}$

$B_{sd} \pm \Delta B_{sd}$

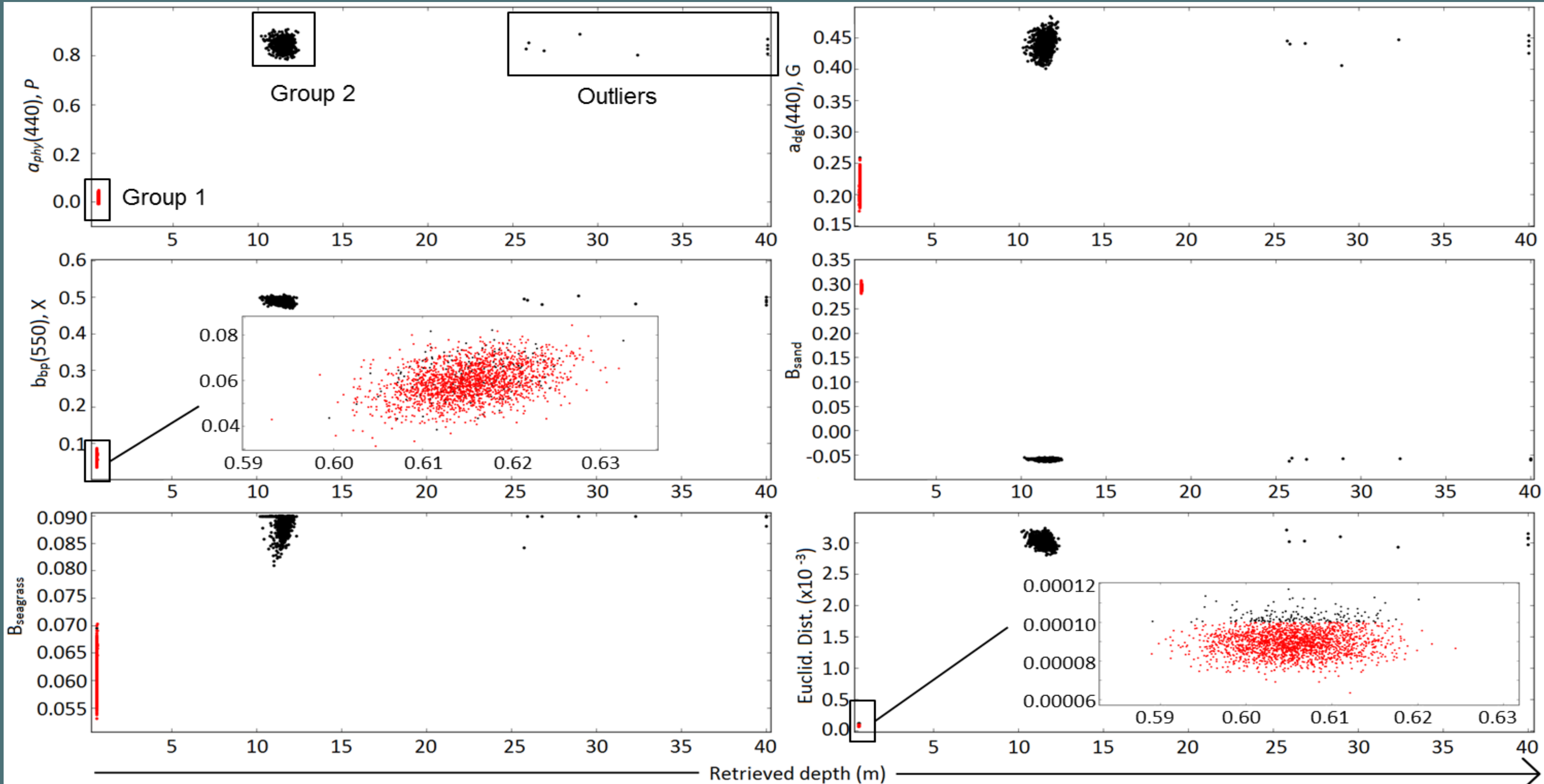
$B_{seg} \pm \Delta B_{seg}$

# 3. Retrieving Bathymetry

## Bottom Reflectance Un-mixing Computation of the Environment (BRUCE) model

**Why use the UR-LM method?** The standard approach of using a fixed initial guess to invert each noise perturbed spectra gives high uncertainty due the **convergence to local minima** by the LM method.

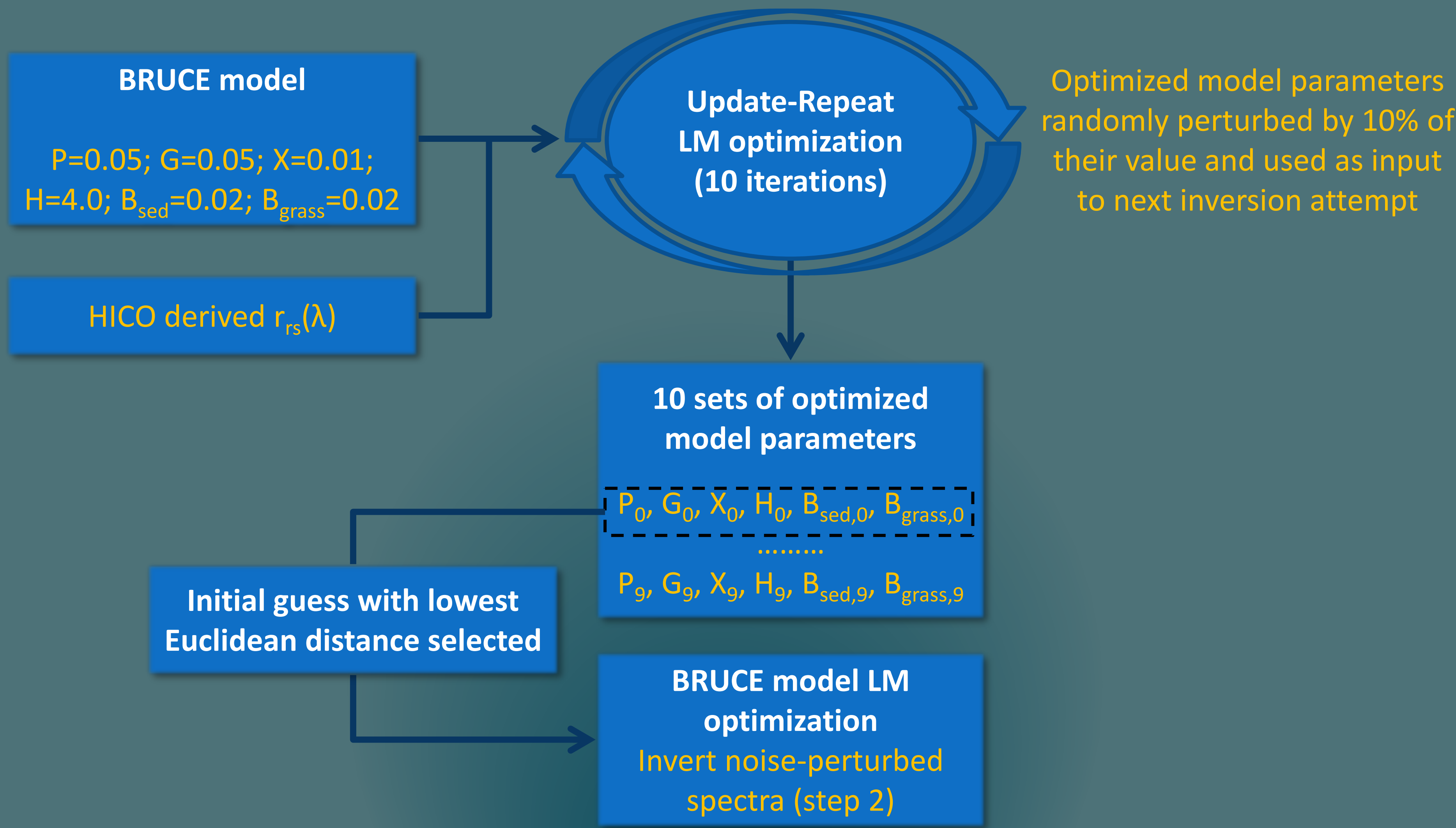
**Depth = (4.37 ± 5.57) meters → 127% uncertainty**



# 3. Retrieving Bathymetry

## Bottom Reflectance Un-mixing Computation of the Environment (BRUCE) model

A brief search of parameter space to find the optimal initial guess parameters, $P$, $G$, $X$, $H$, $B_{sg}$ and $B_{sed}$ for each HICO-$r_{rs}$ pixel (Garcia et al., under review);

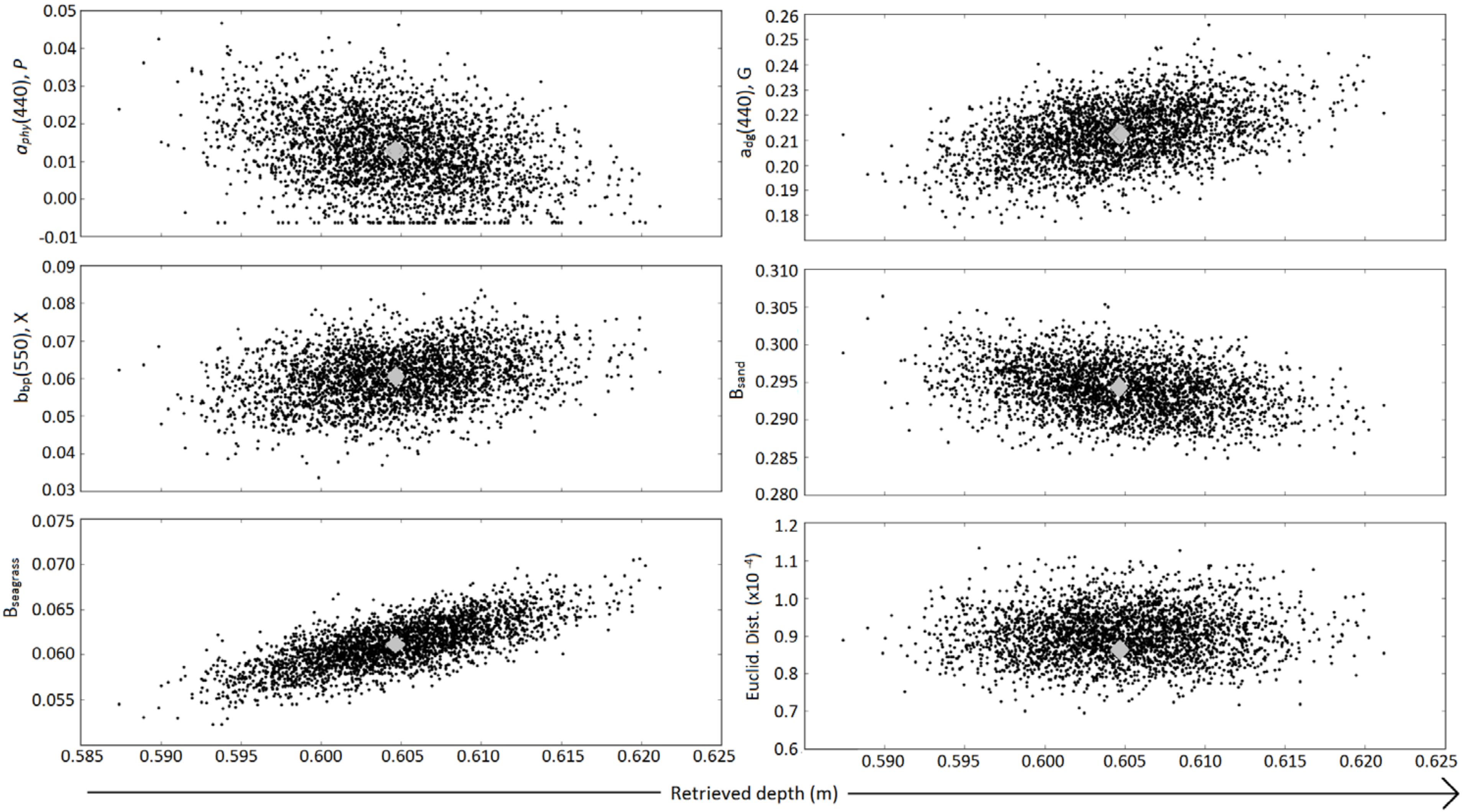


# 3. Retrieving Bathymetry

## Bottom Reflectance Unmixing Computation of the Environment (BRUCE) model

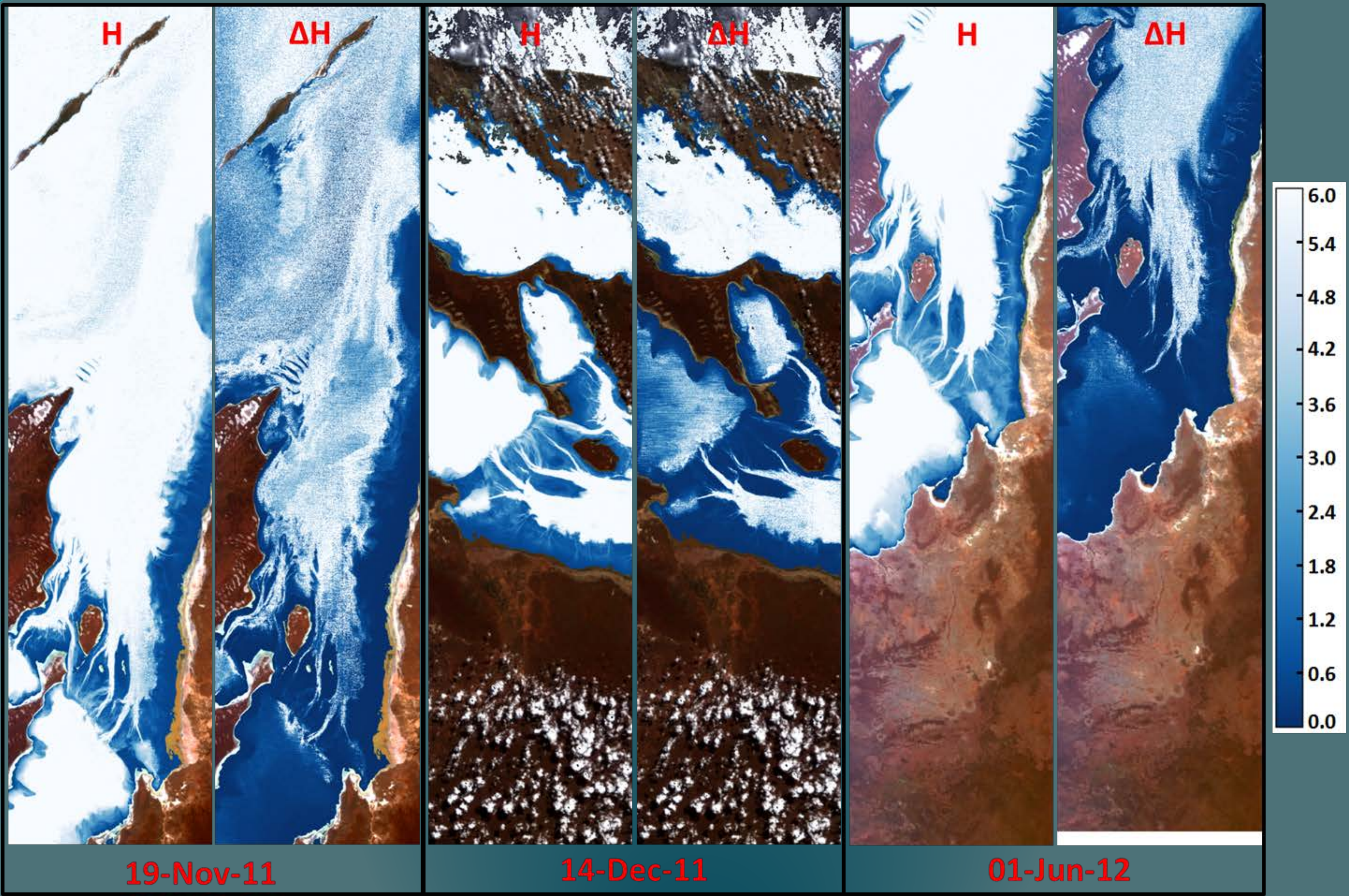
The UR-LM method guides the LM optimization to the optimum minimum (Group 1).

**Depth = (0.60 ± 0.01) meters**



# 3. Retrieving Bathymetry

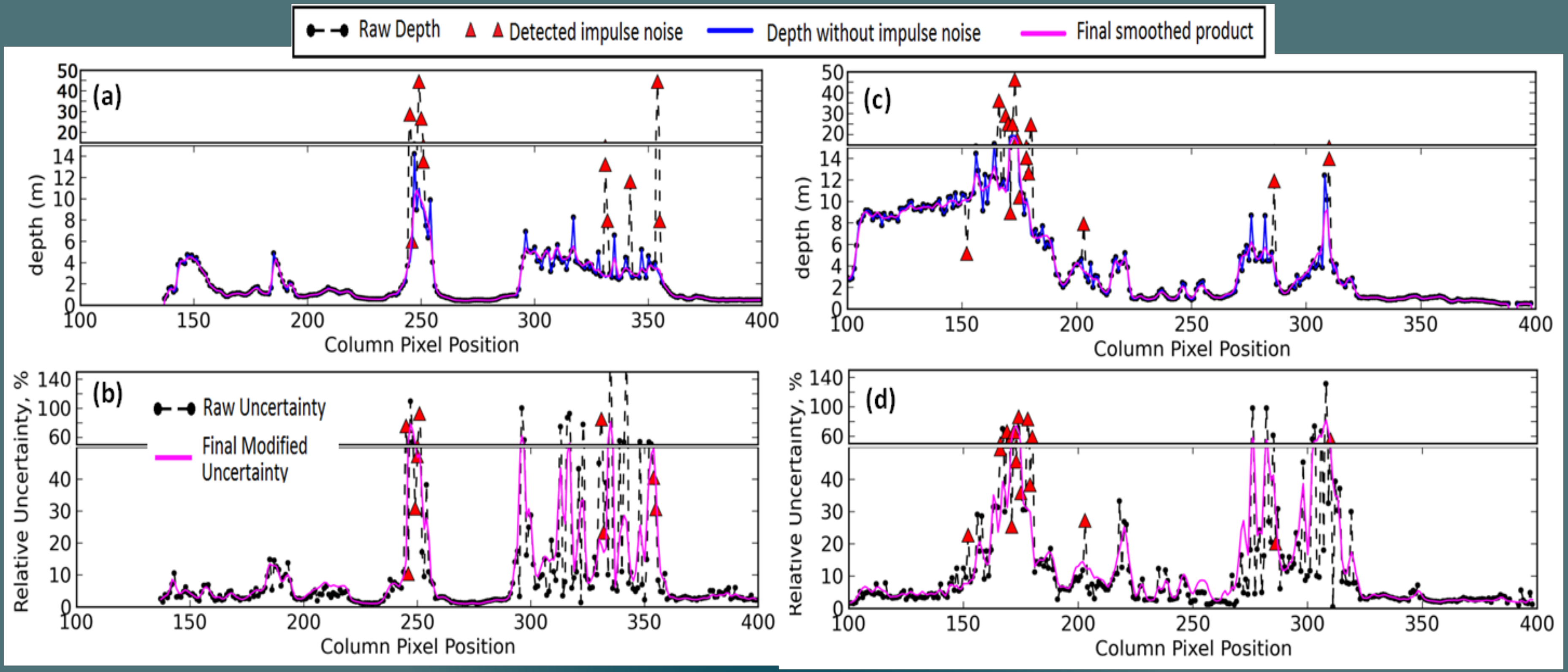
## Bottom Reflectance Un-mixing Computation of the Environment (BRUCE) model



# 4. Post-processing Image Smoothing and Tide Correction

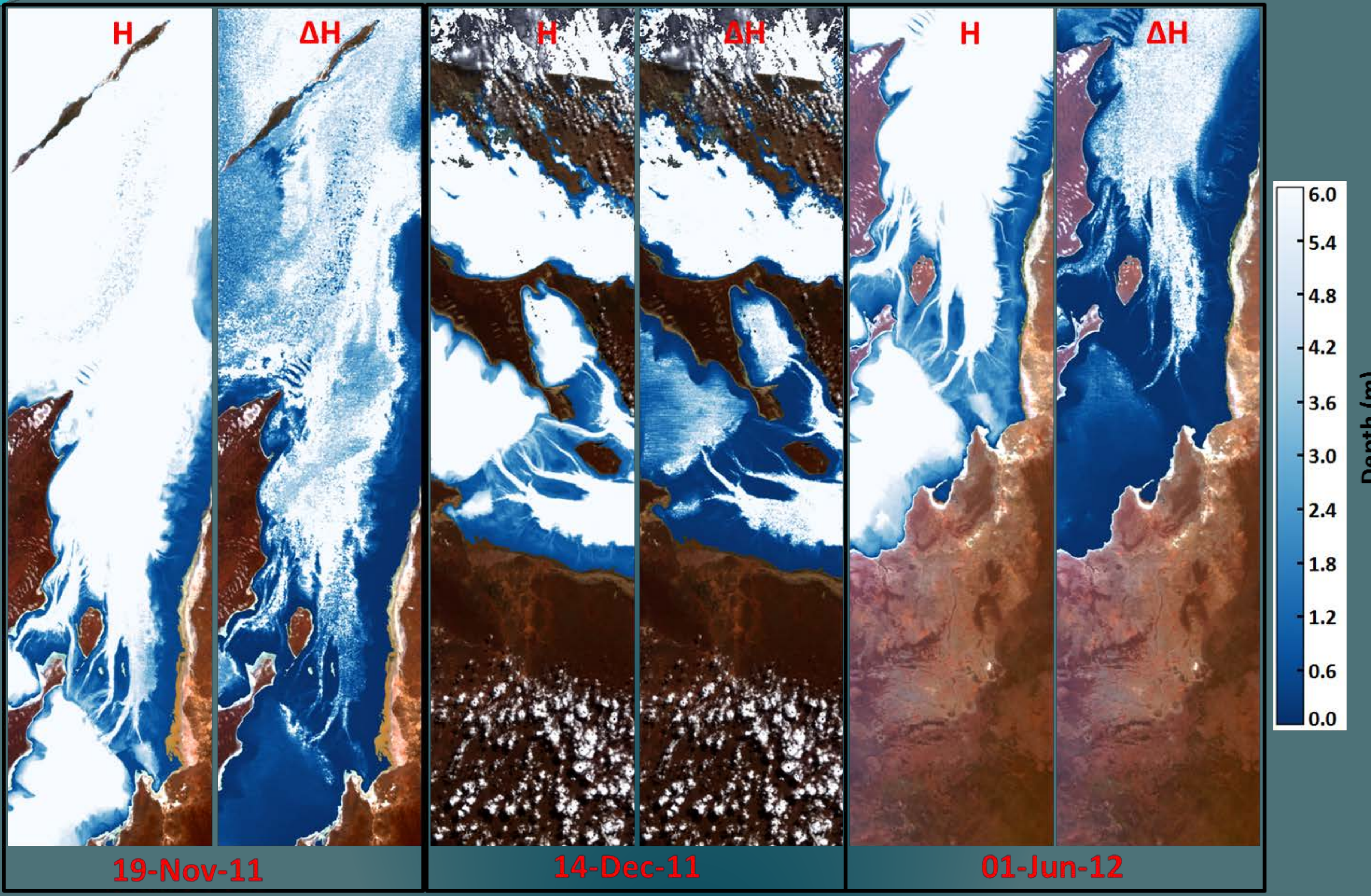
- Bathymetry images contain impulse (salt-and-pepper) noise, which are typically add abrupt and unrealistic changes in depth

- Removing these pixels with a two-step smoothing approach:
    1. Impulse noise pixel selection and subsequent replacement with an adaptive median filter
    2. Application of $2^{nd}$ order binomial smoother

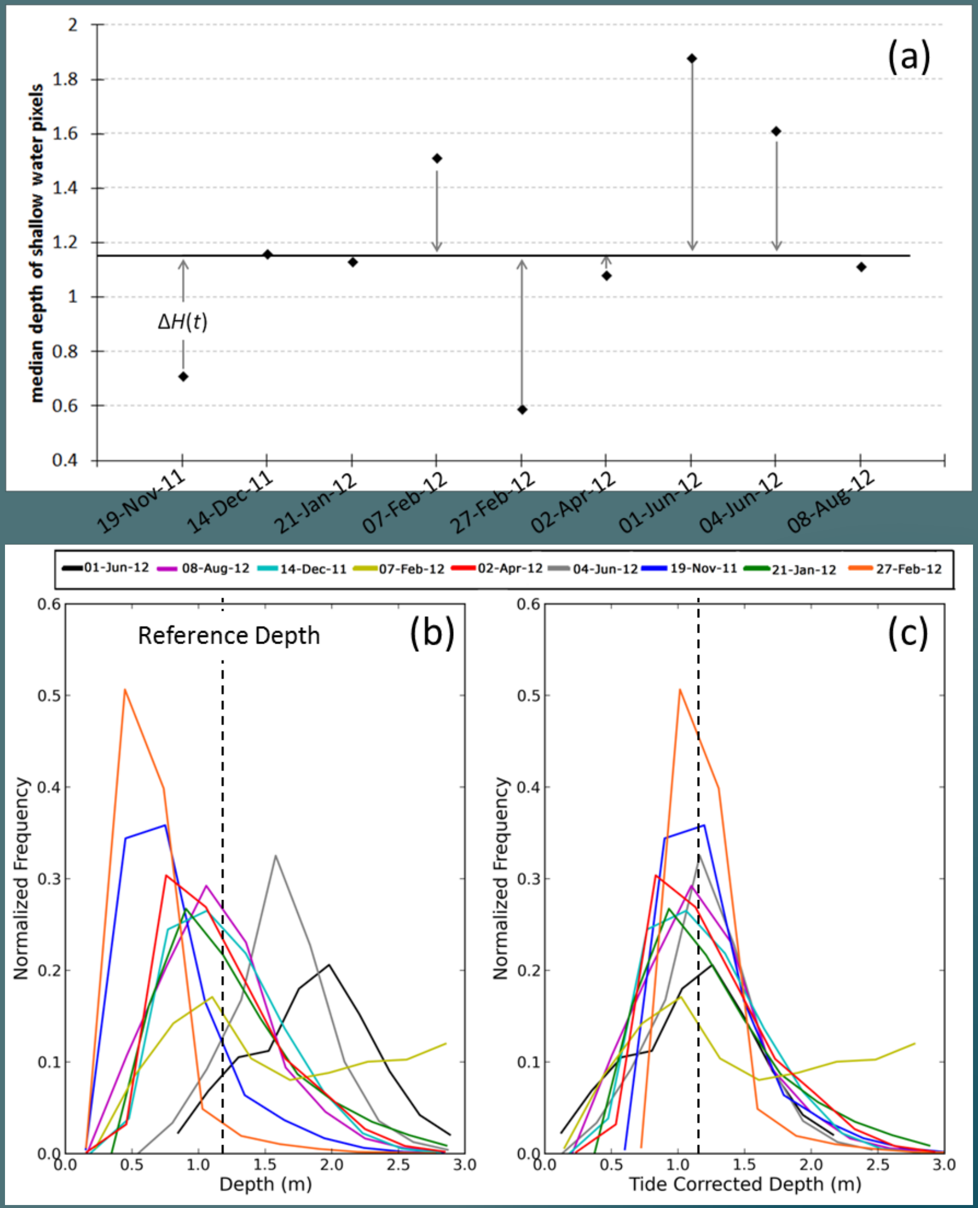


# 4. Post-processing Image Smoothing and Tide Correction

## Smoothed Bathymetry and Uncertainty



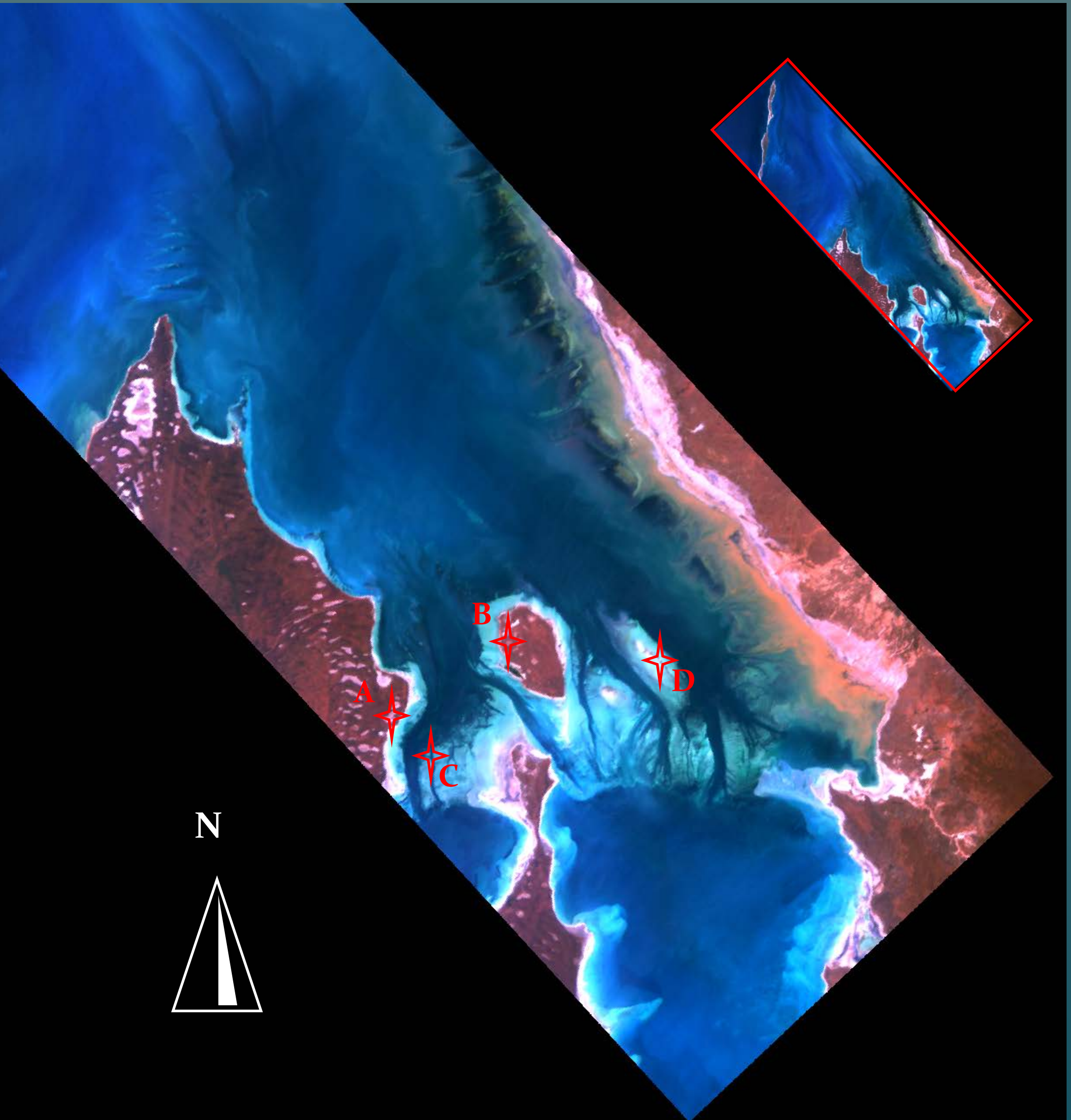
# 5. Post-processing Image Smoothing and Tide Correction




- Removing influence of tide to delineate changes in depth caused by resuspension and sedimentation
- Lack of in situ tide height data, and therefore an empirical tide correction technique was developed

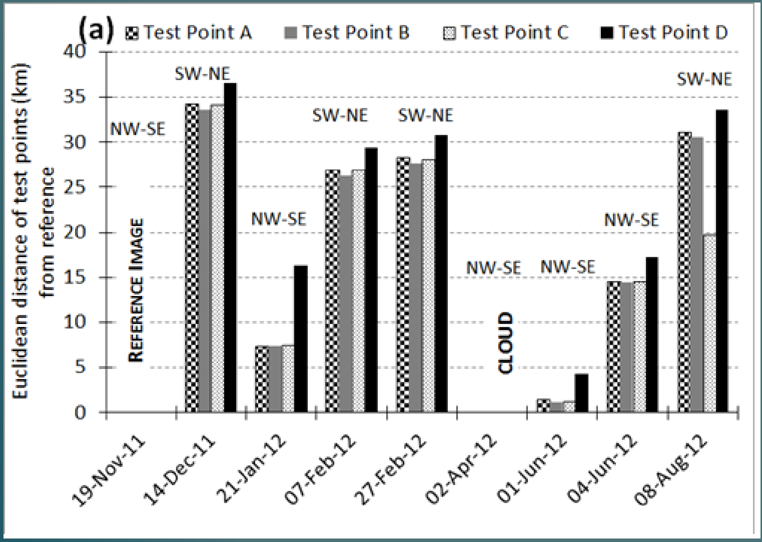
# 6. Geo-location Issues

Time series analysis requires relatively high geolocation accuracy, to ensure that a change in depth at two instances in time is a real temporal change



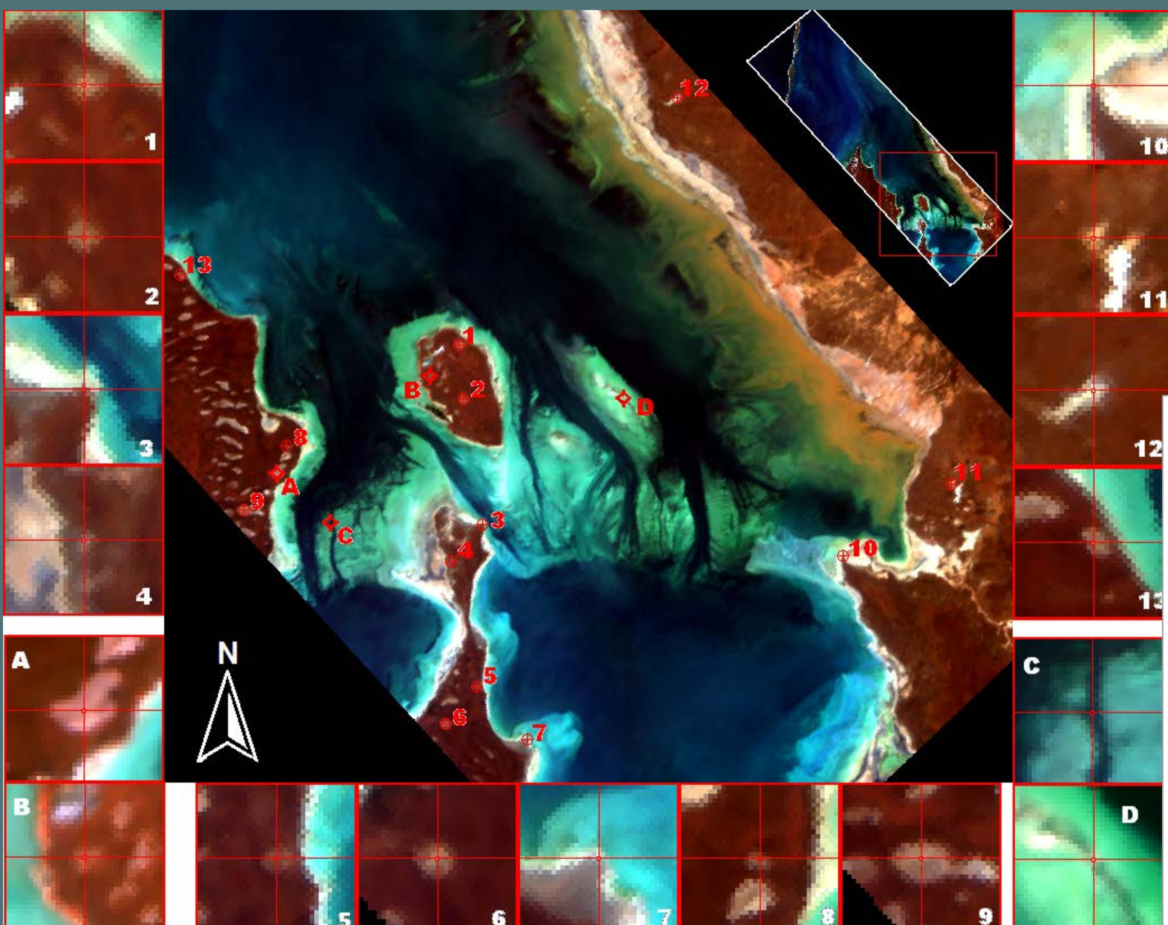

A geolocation accuracy of 1/5th of pixel is needed to detect 90% of real temporal changes (Dia and Khorram, 1998) → 20m for HICO

The provided Geographic Lookup Tables (GLTs) are inadequate for time series analysis



# 6. Geo-location Issues

## Geo-Registration using Ground Control Points

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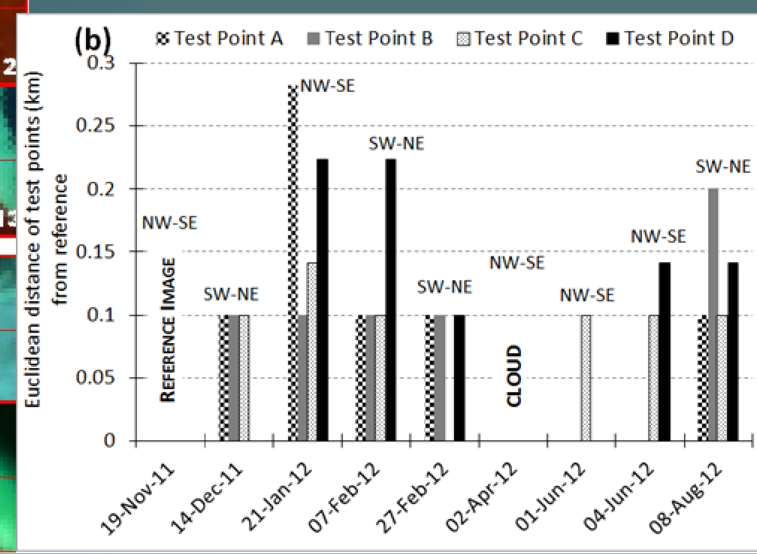
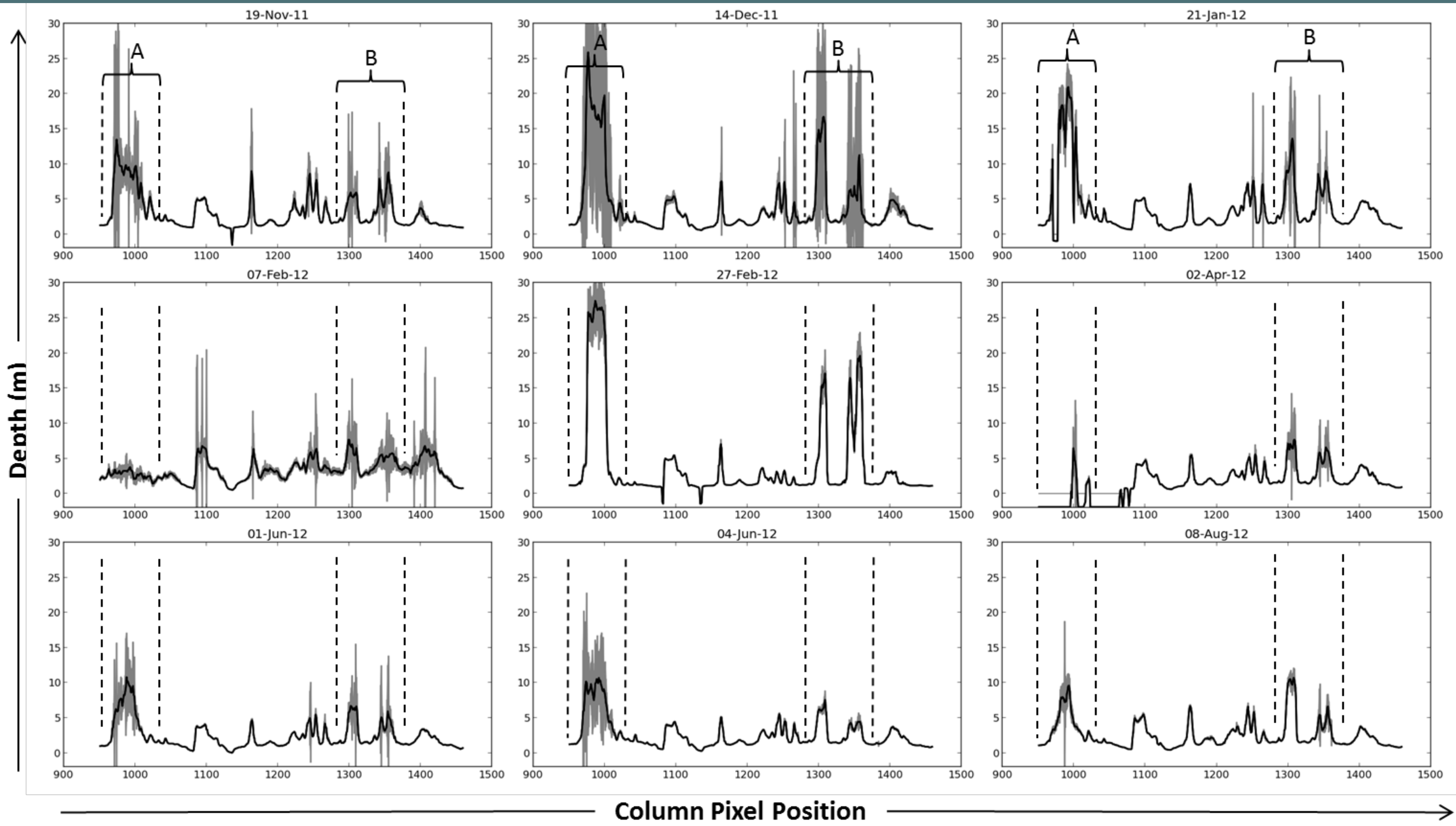


# 7. Change detection analysis

Is it possible to detect temporal change (at two time points) above uncertainty?

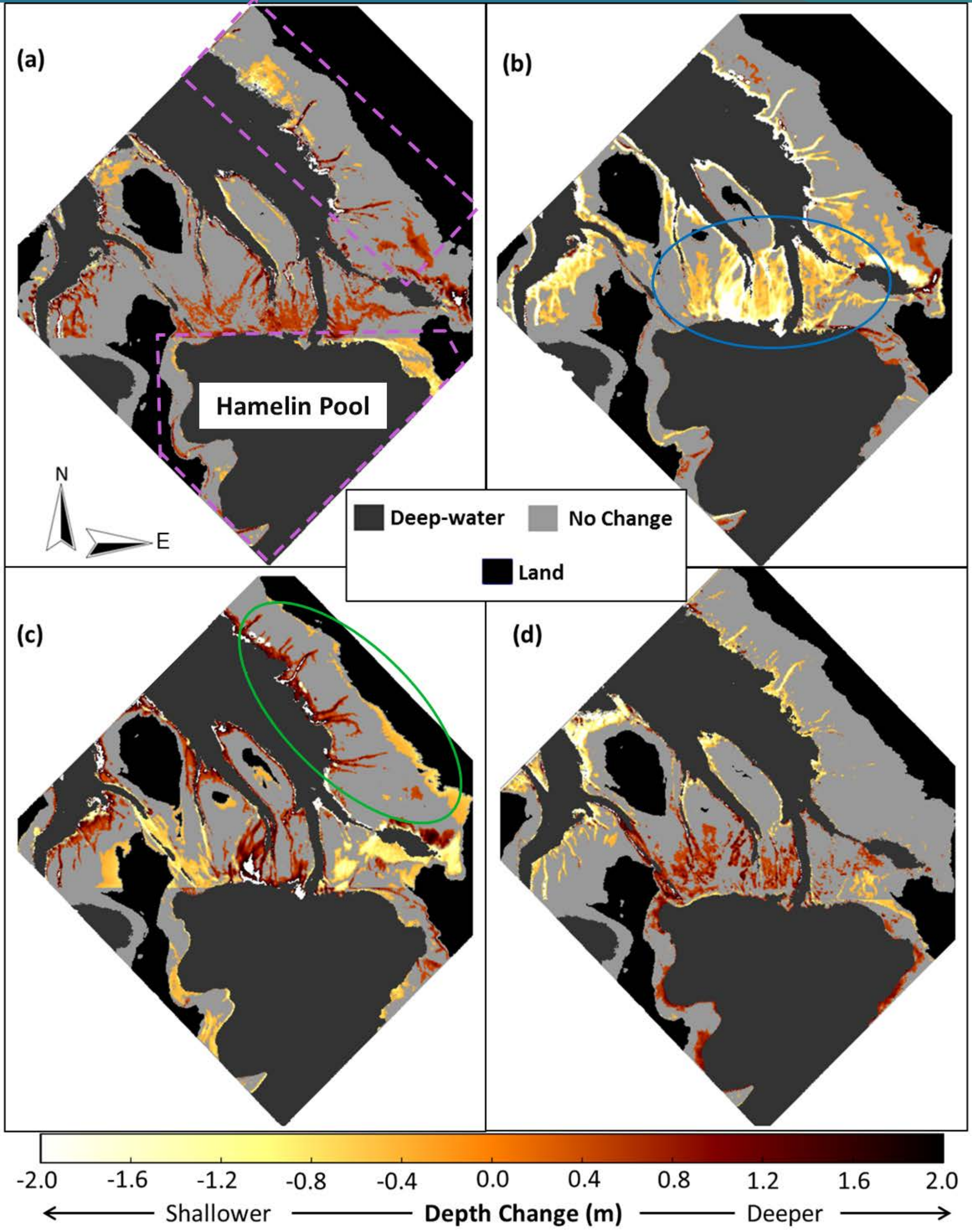


# 7. Change detection analysis

Is it possible to detect temporal change (at two time points) above uncertainty?

Pixels have to satisfy the following two criteria to be classed as having observed change:

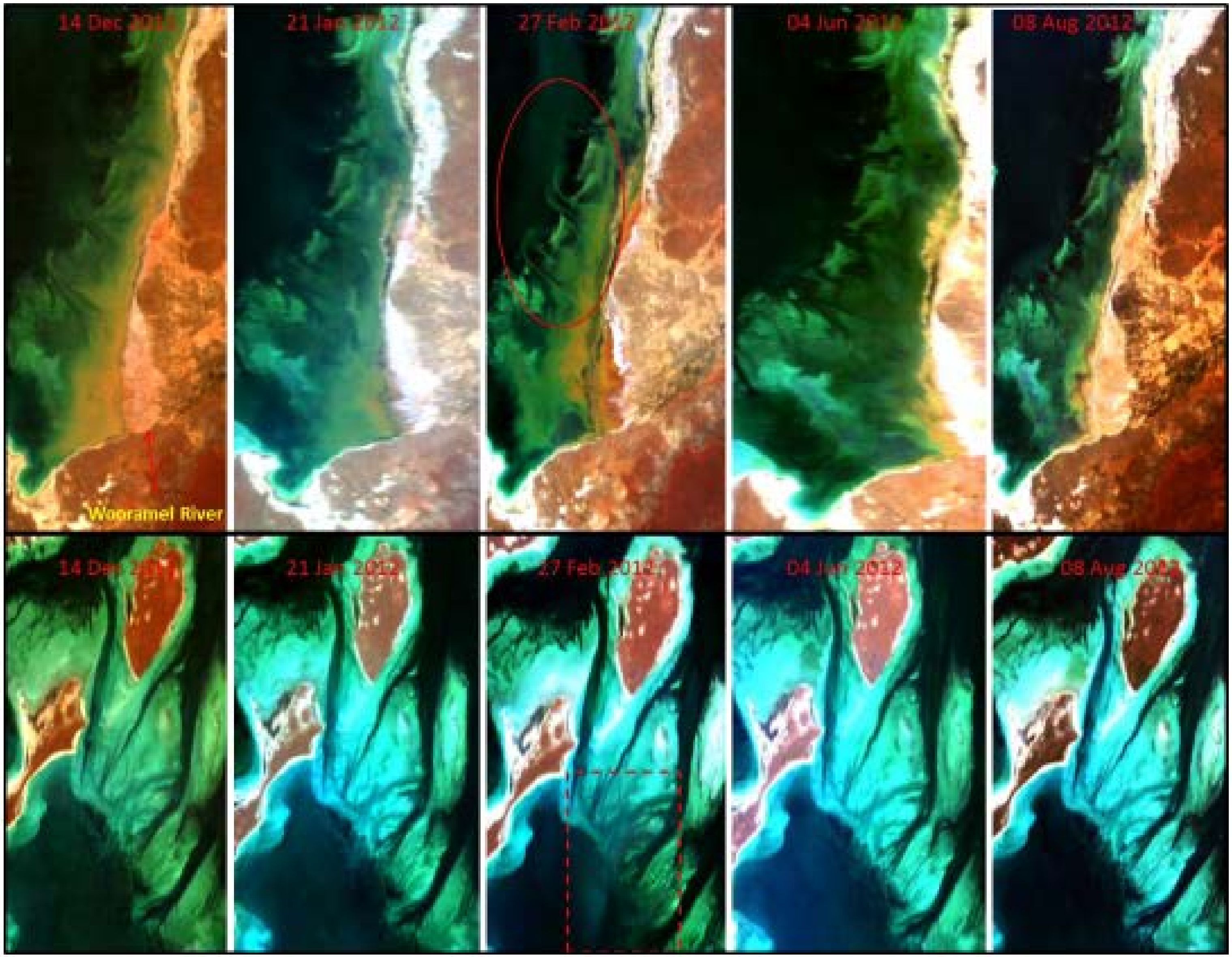
1. A difference in depth (between two time points) greater than the baseline variability (0.36m);
2. Per-pixel *t*-test analysis; Null hypothesis of “no change in depth” is rejected for pixels with $p < 0.05$ (5% significance level).




Change detection analysis of HICO-derived, tide corrected, bathymetry of the Faure Sill, between the dates of:

(a) 14-Dec-2011 and 21-Jan-2012;
(b) 21-Jan- and 27-Feb-2012;
(c) 27-Feb- and 04-Jun-2012;
(d) 04-Jun- and 08-Aug-2012

Separate image-based tide corrections were performed for the dashed magenta regions presented in (a).


21 Jan 2012
27 Feb 2012
04 Jun 2012
08 Aug 2012
Wooramel River

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## Detecting trend and seasonal changes in bathymetry derived from HICO imagery: A case study of Shark Bay, Western Australia

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Rodrigo A. Garcia [a,*], Peter R.C.S. Fearns [a], Lachlan I.W. McKinna [a,b]

[a] Remote Sensing and Satellite Research Group, Department of Imaging and Applied Physics, Curtin University, GPO Box U1987, Perth, Western Australia 6845, Australia
[b] Ocean Ecology Laboratory, Code 616, NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

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Geolocation accuracy

A B S T R A C T

The Hyperspectral Imager for the Coastal Ocean (HICO) aboard the International Space Station has offered for the first time a dedicated space-borne hyperspectral sensor specifically designed for remote sensing of the coastal environment. However, several processing steps are required to convert calibrated top-of-atmosphere radiances to the desired geophysical parameter(s). These steps add various amounts of uncertainty that can cumulatively render the geophysical parameter imprecise and potentially unusable if the objective is to analyze trends and/or seasonal variability. This research presented here has focused on: (1) atmospheric correction of HICO imagery; (2) retrieval of bathymetry using an improved implementation of a shallow water inversion algorithm; (3) propagation of uncertainty due to environmental noise through the bathymetry retrieval process; (4) issues relating to consistent geo-location of HICO imagery necessary for time series analysis, and; (5) tide height corrections of the retrieved bathymetric dataset. The underlying question of whether a temporal change in depth is detectable above uncertainty is also addressed. To this end, nine HICO images spanning November 2011 to August 2012, over the Shark Bay World Heritage Area, Western Australia, were examined. The results presented indicate that precision of the bathymetric retrievals is dependent on the shallow water inversion algorithm used. Within this study, an average of 70% of pixels for the entire HICO-derived bathymetry dataset achieved a relative uncertainty of less than ±20%. A per-pixel *t*-test analysis between derived bathymetry images at successive timestamps revealed observable changes in depth to as low as 0.4 m. However, the present geolocation accuracy of HICO is relatively poor and needs further improvements before extensive time series analysis can be performed.

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/ Explore by Topic / Technology and Innovation / Orbital 'camera' snaps marine topography

Saturday, 12 April 2014

## Orbital 'camera' snaps marine topography

Written by Geoff Vivian

"Deriving bathymetry from platforms such as airborne imagery has been around since the 1970s, however those algorithms were very scene-specific and couldn't be transferred to other regions of the world," Mr Garcia says.

*Image: Maitri*

**IN A world first, a Curtin University physicist used data from the International Space Station to map coastal bathymetry (underwater terrain).**

Curtin PhD candidate Rodrigo Garcia says they chose Shark Bay for the project because the World Heritage listed site has the largest-known seagrass meadows.

"We were just thinking of what we can use the data there for, whether we can help assess changes in depth for benthos," he

# Conclusion

We investigated challenges faced with temporal analysis of HICO-derived bathymetry

- Search for optimal initial guess produced precise retrievals of bathymetry for shallow water pixels (< 6 m)

- Retrieved bathymetry "*can*" detect temporal changes in depth of less than 1 m

- Post-processing image smoothing and tide correction aid temporal analysis

- Atmospheric correction still requires further improvements

**rodrigo.garcia@postgrad.curtin.edu.au**

# *Community uptake*

Increase user numbers, i.e. bigger user community – some problems *may* be solved faster

- Workshops, special sessions etc.
- Press releases
- IOCCG Newsletter
- Special HICO edition in journal?

- Open access – data + code
- Demonstration datasets

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# Additional material….


18-05-2011
POSODONIA AUSTRALIS
FAURE SILL


18-05-2011
AMPHIBILOUS ANTARTICA
FAURE SILL


18-05-2011
SHELLY SAND
FAURE SILL


Denham Sand
16/5/11 4:20pm

# Tide offsets