Coral Reef Colour: In Situ and Remote Hyperspectral Sensing of Reef Structure and Function

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Coral Reef Background

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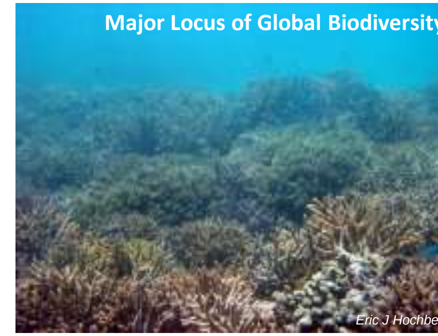
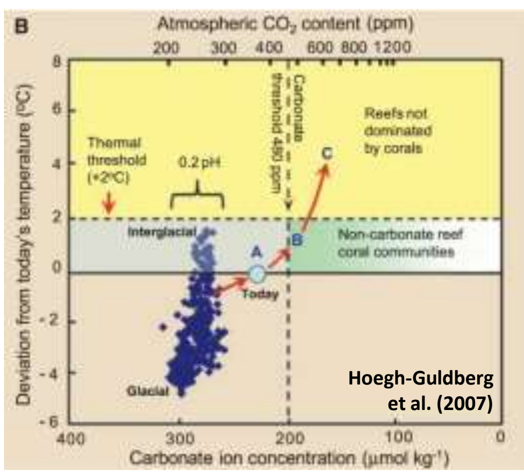
Importance

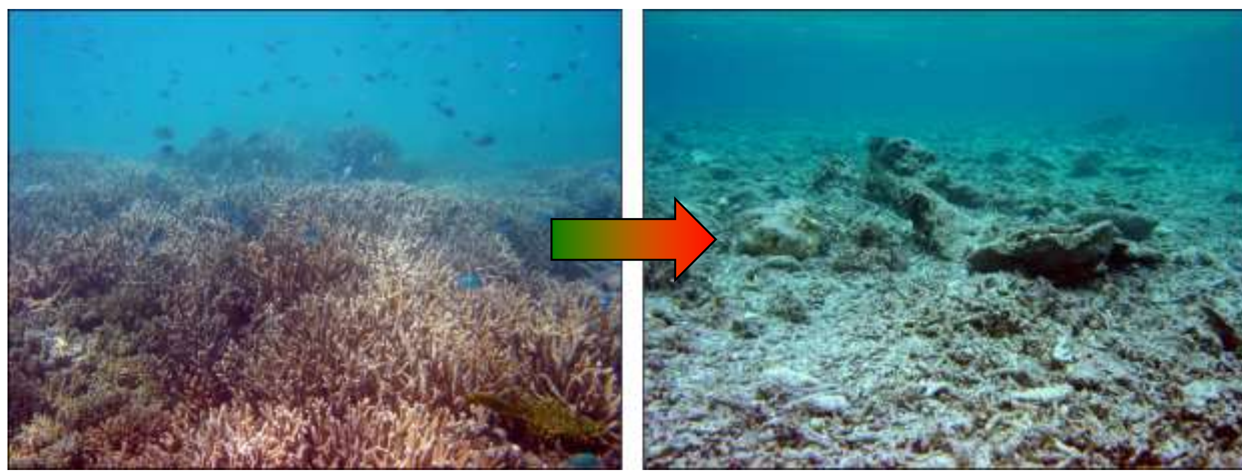


Coral reefs do not influence the short-term global carbon cycle, but...

Concern

...they are among the first ecosystems to respond critically and dramatically to climate change.





Climate change may exacerbate local impacts, leading to reef degradation worldwide.

Assessing Coral Reef Condition

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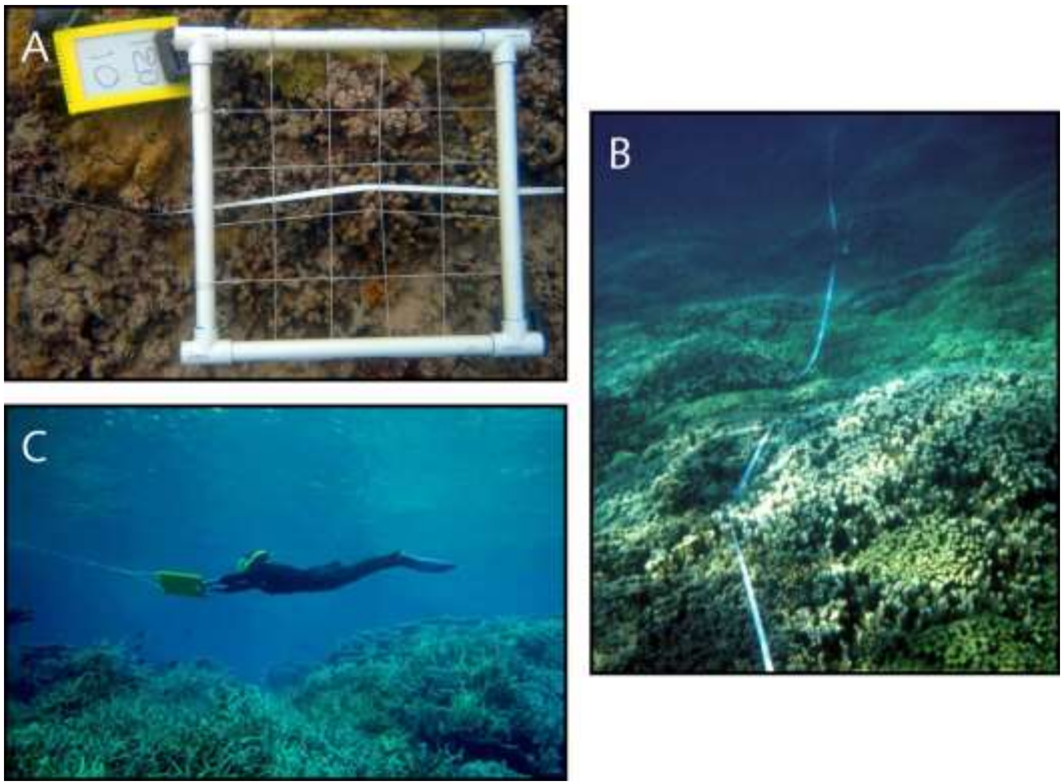
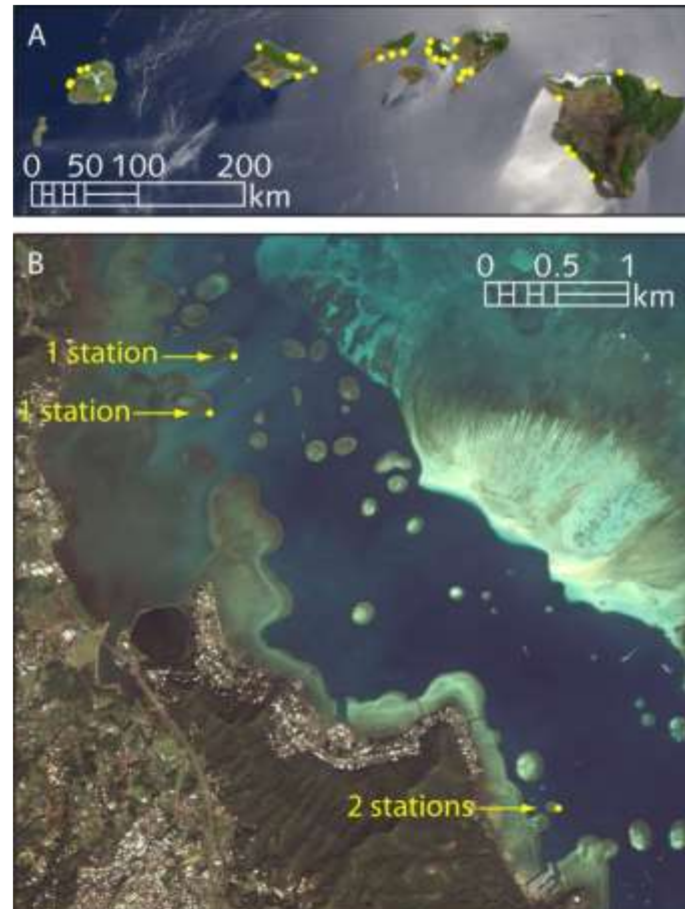
All reef assessments are based on extremely sparse in situ data, collected using non-uniform methods.

The primary metric for reef condition is proportional cover of benthic types, especially coral, but values have not been standardized across reefs.





Global Coral Reef Distribution

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- 9,000 reefs in the world, covering 500,000 km^2
- Spread across 200,000,000 km^2 of ocean
- Quantitative in situ surveys cover only 10s to 100s of km^2 worldwide
- ***Only 0.01–0.1% of the world's reef area***

- ***Remote sensing is the only available tool to acquire synoptic, uniform data on reef condition at regional to global scales***

In-Water Spectral Measurements

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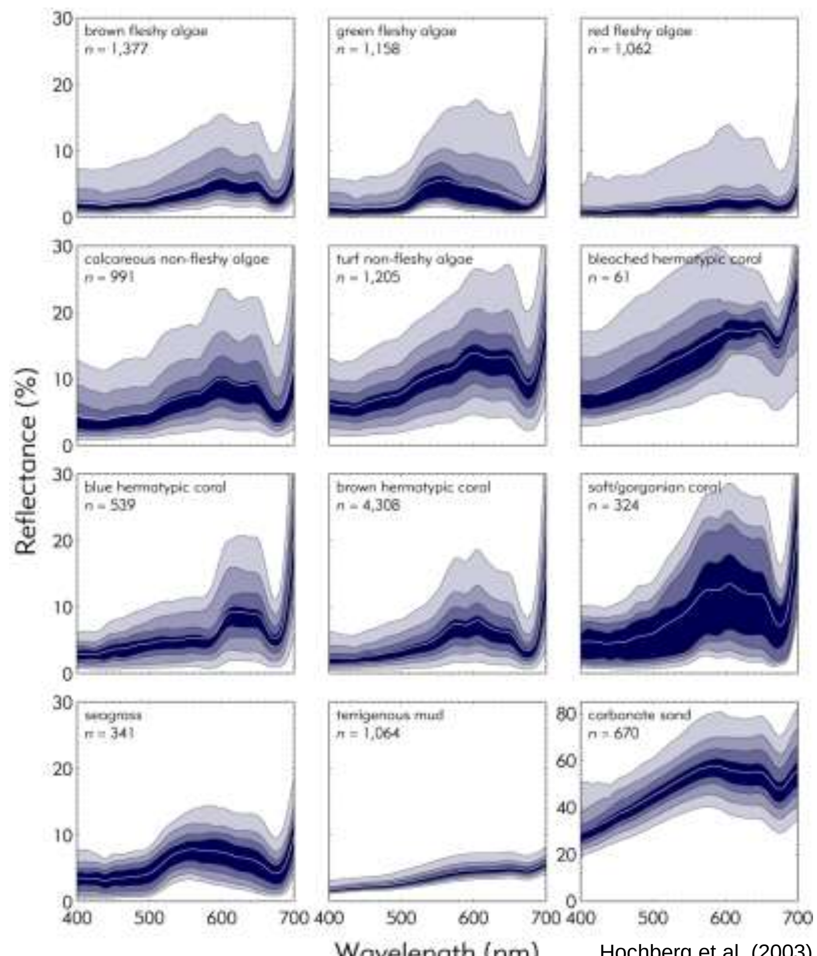
1990s: 30-m-long fiber, spectrometer on boat

2000s: Spectrometer in underwater housing



Hochberg et al. (2003)

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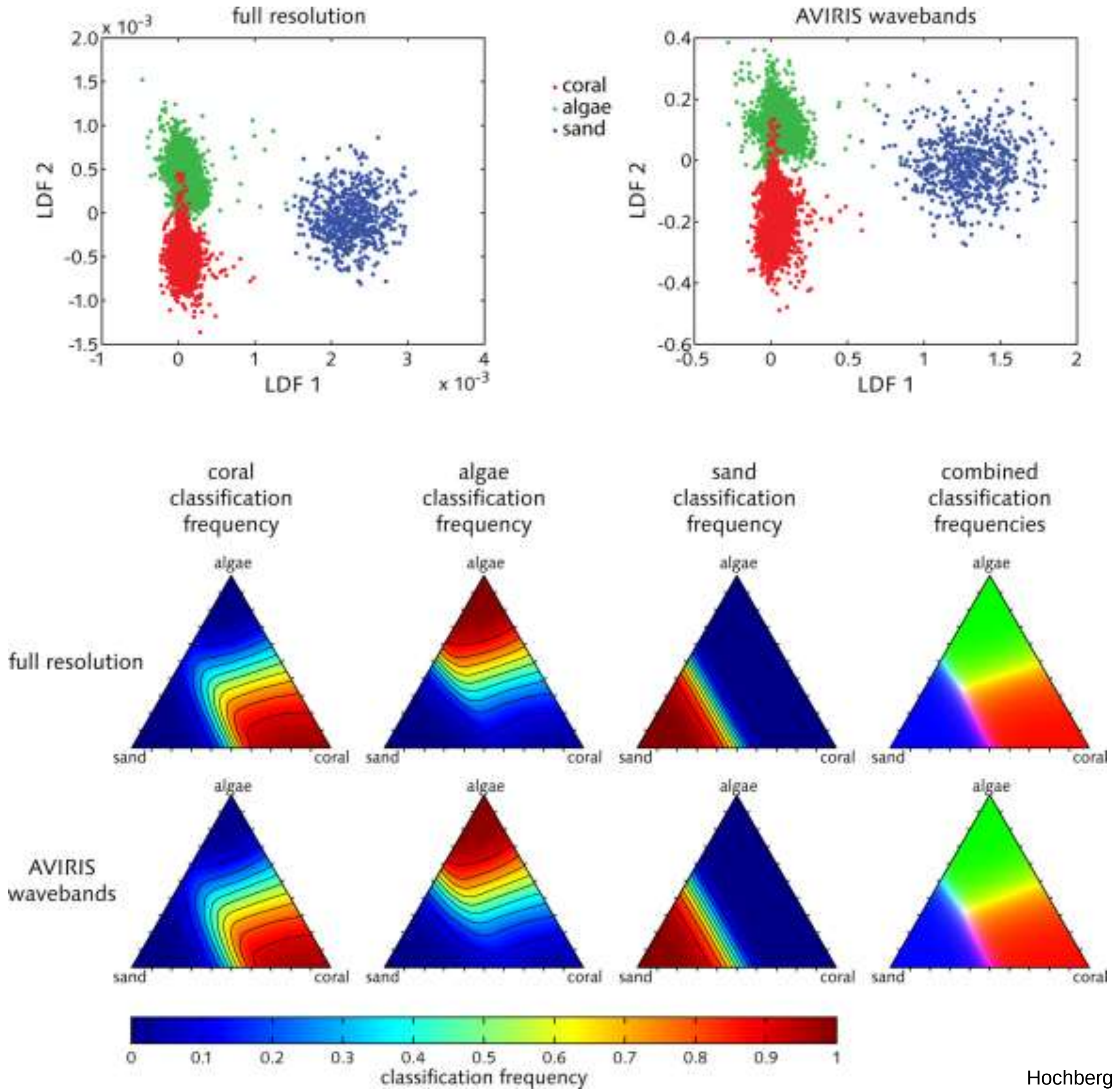
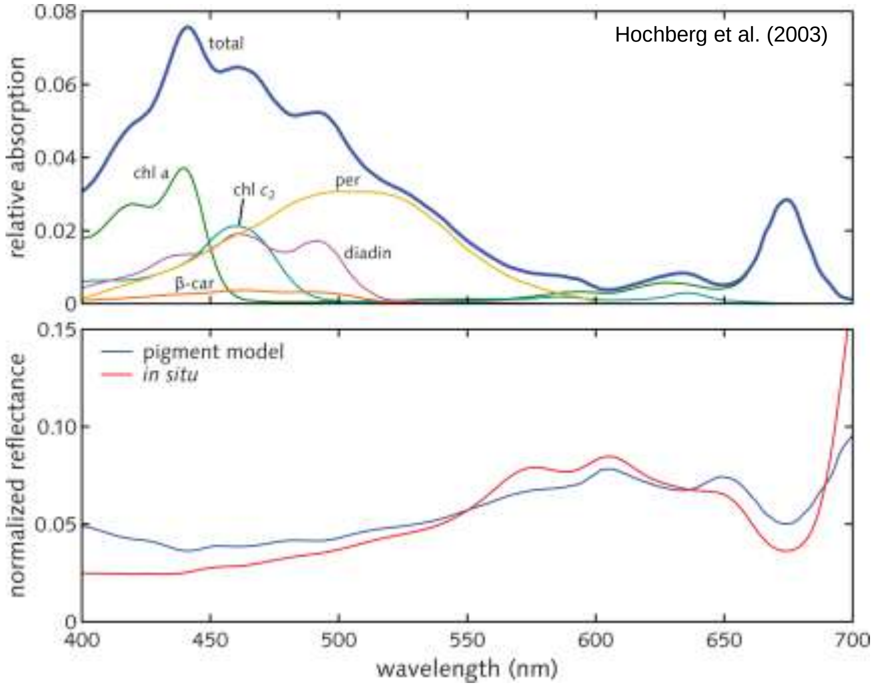
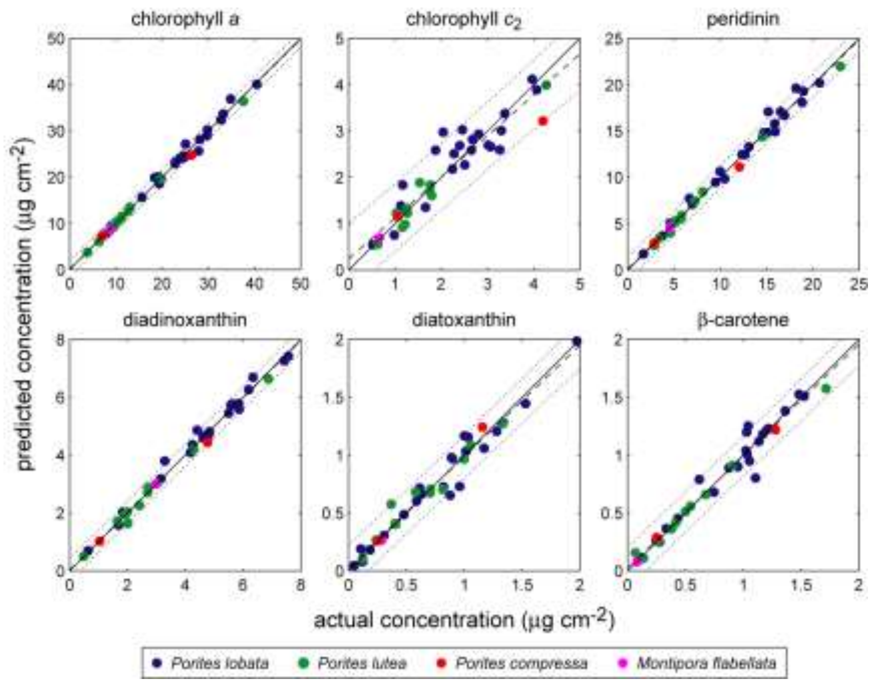
Spectral Discrimination



Hochberg & Atkinson (2003)

Evaluating Coral Pigment Levels





Hochberg et al. (2006)

- The coral reflectance spectrum is driven by zooxanthellae pigments
- It is possible to invert coral reflectance to derive pigment concentrations

Coral Pigment Phenology

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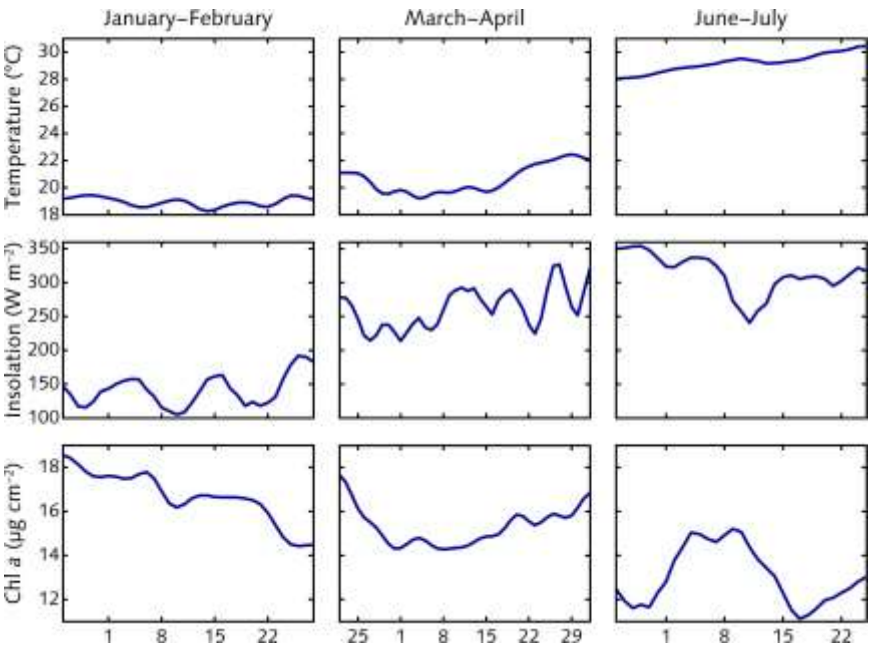
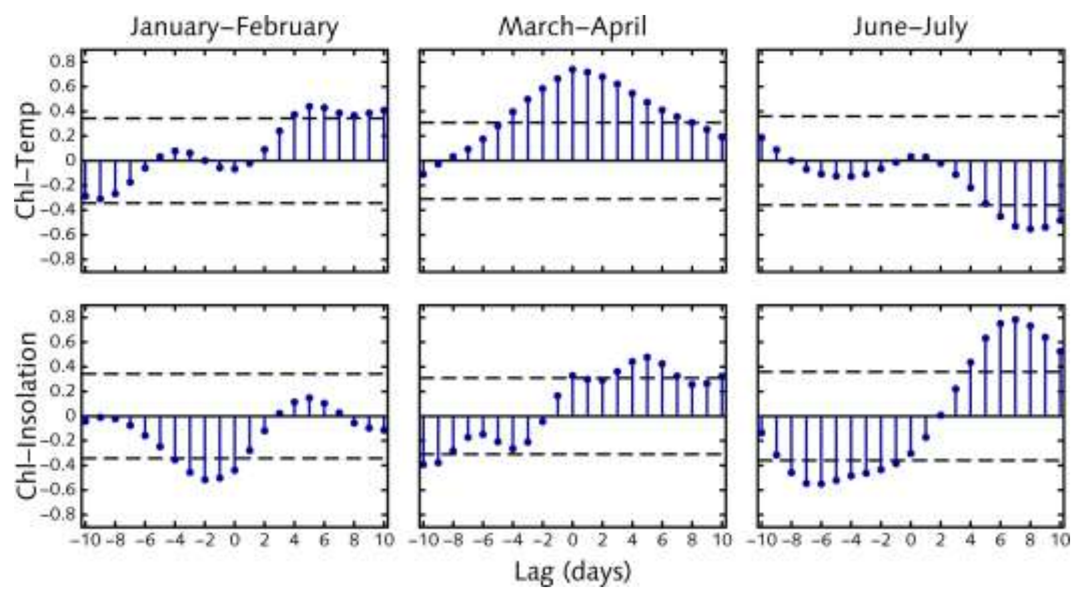


- Temperature increases from winter through summer
- Insolation increases from winter through summer
- Chlorophyll *a* generally decreases from winter through summer
- No very obvious relationships



- Changes in chl *a* occur both after and before changes in the environmental variables.
- The strength, direction, and lag of the correlations all vary with season.

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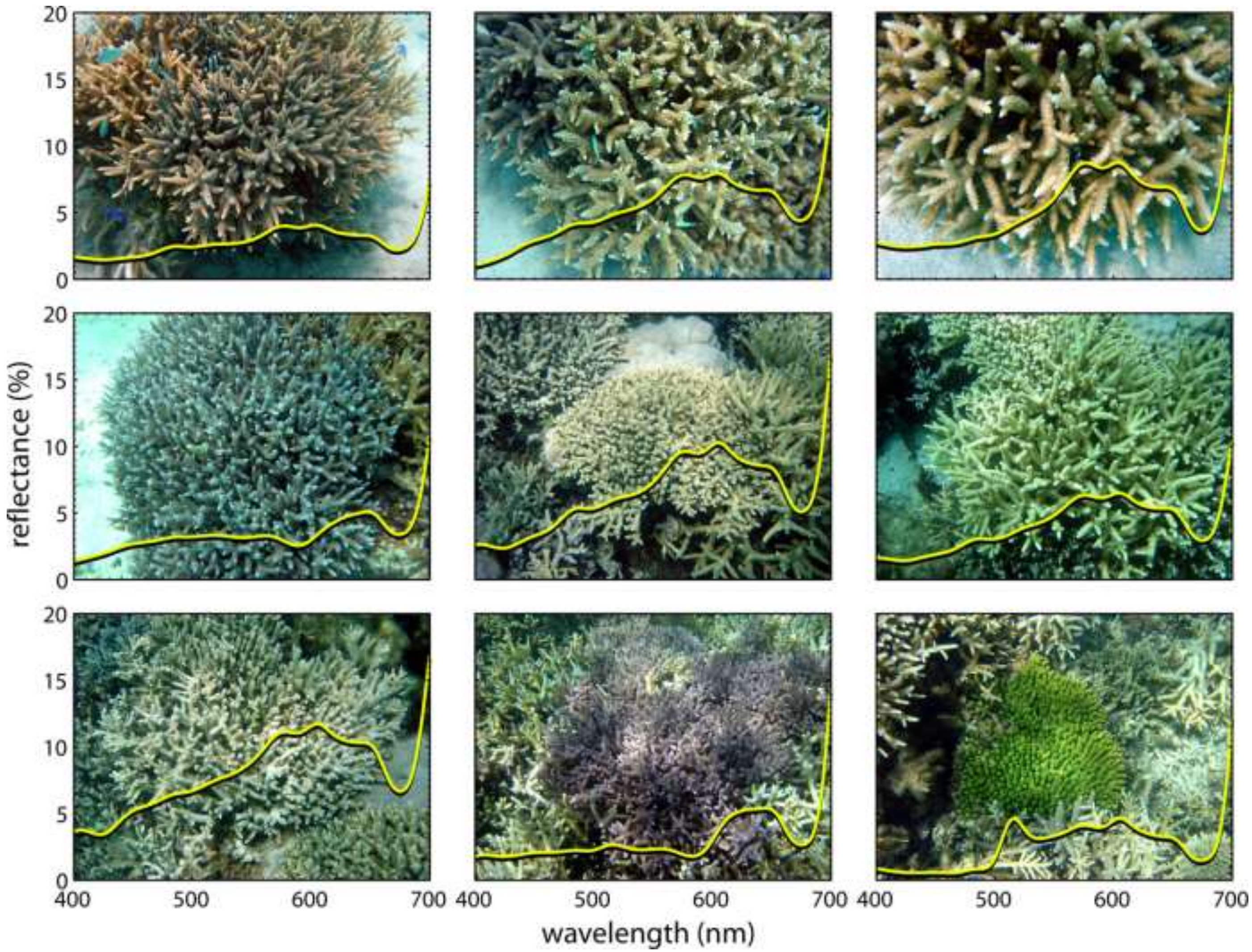
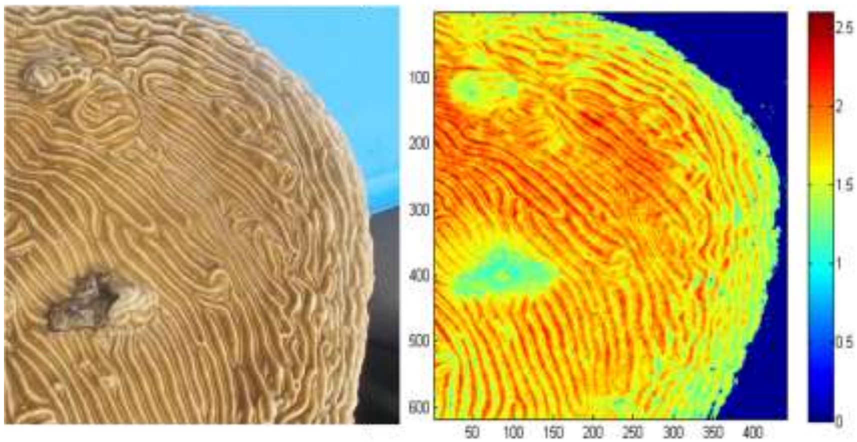
Optical Diversity

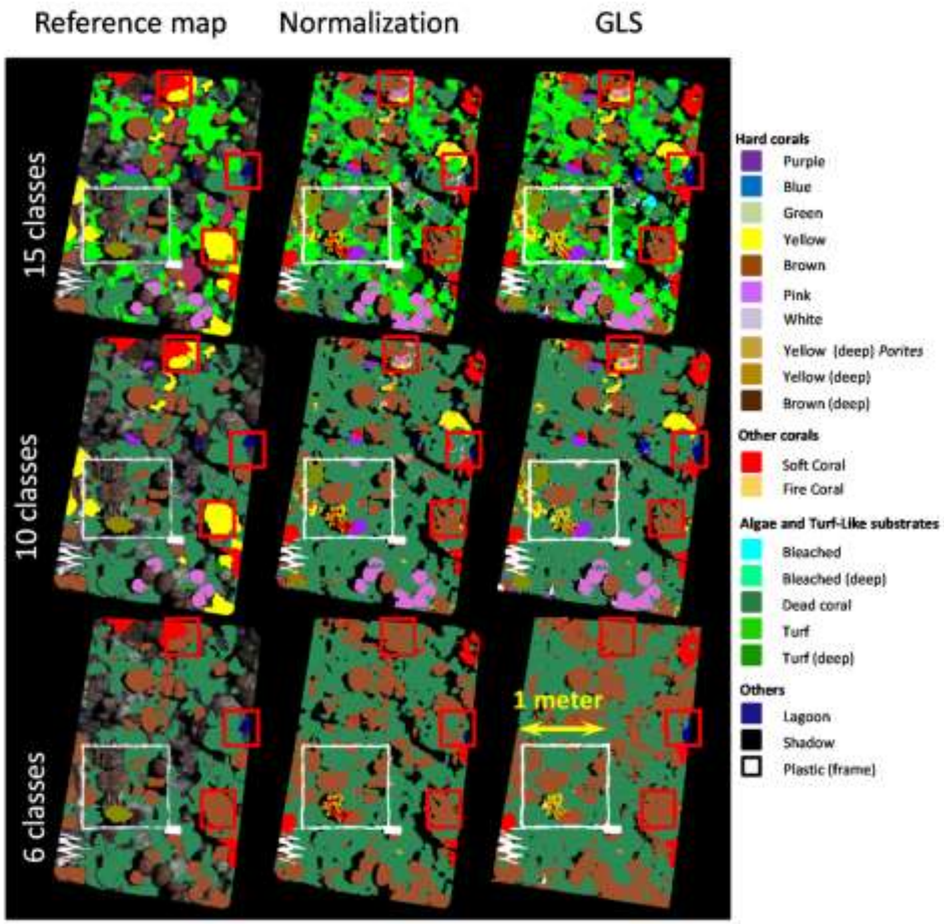


- Coral species cannot be spectrally discriminated
- Diversity of optical types may be correlated to diversity of species types

Near Spectral Imaging

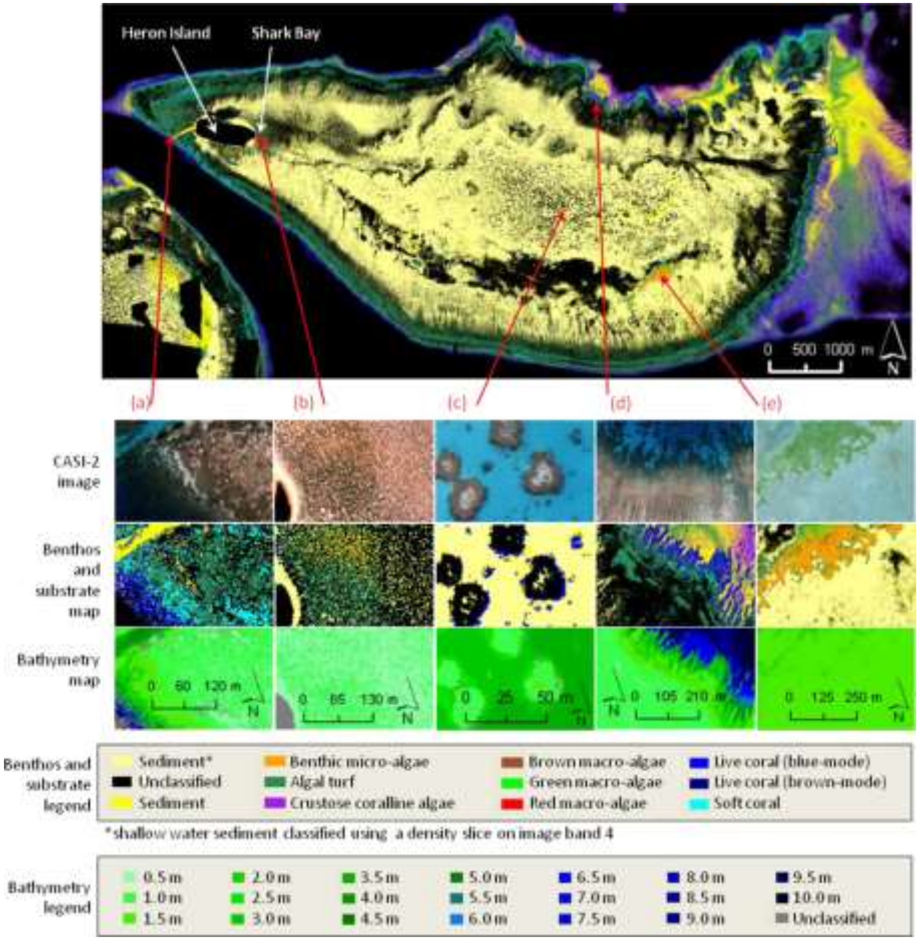


Brandon Russell & Heidi Dierssen

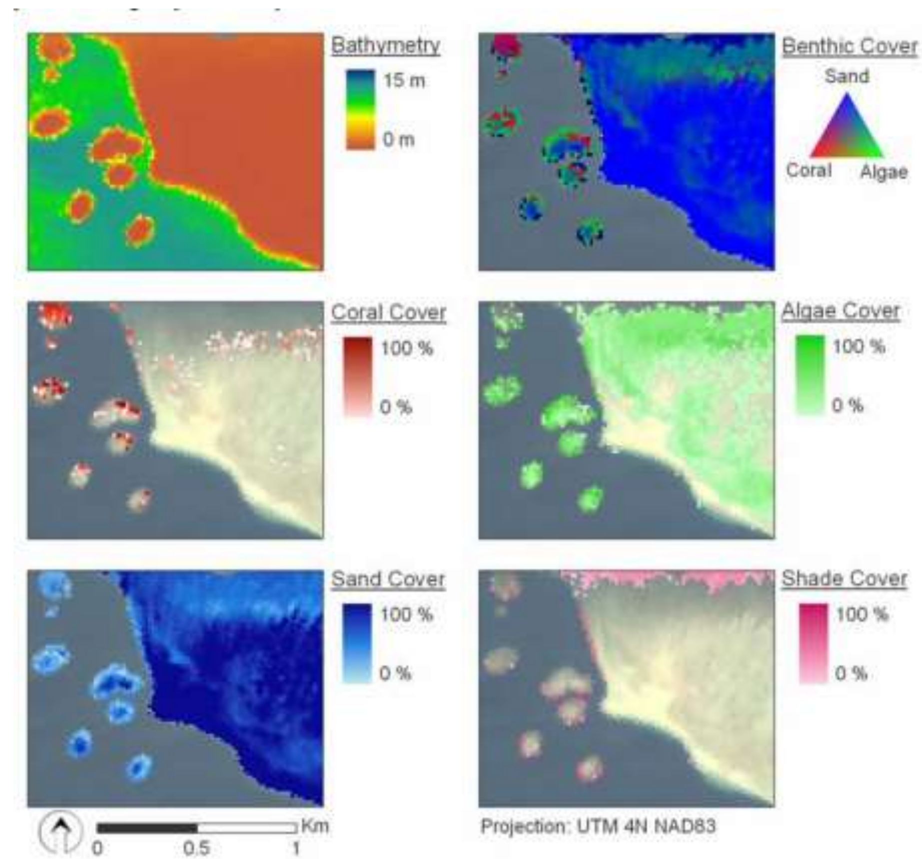


Caras & Karnieli (2015)

Remote Spectral Imaging



Leiper et al. (2014)



Goodman & Ustin (2007)

Radiative Transfer Corrections

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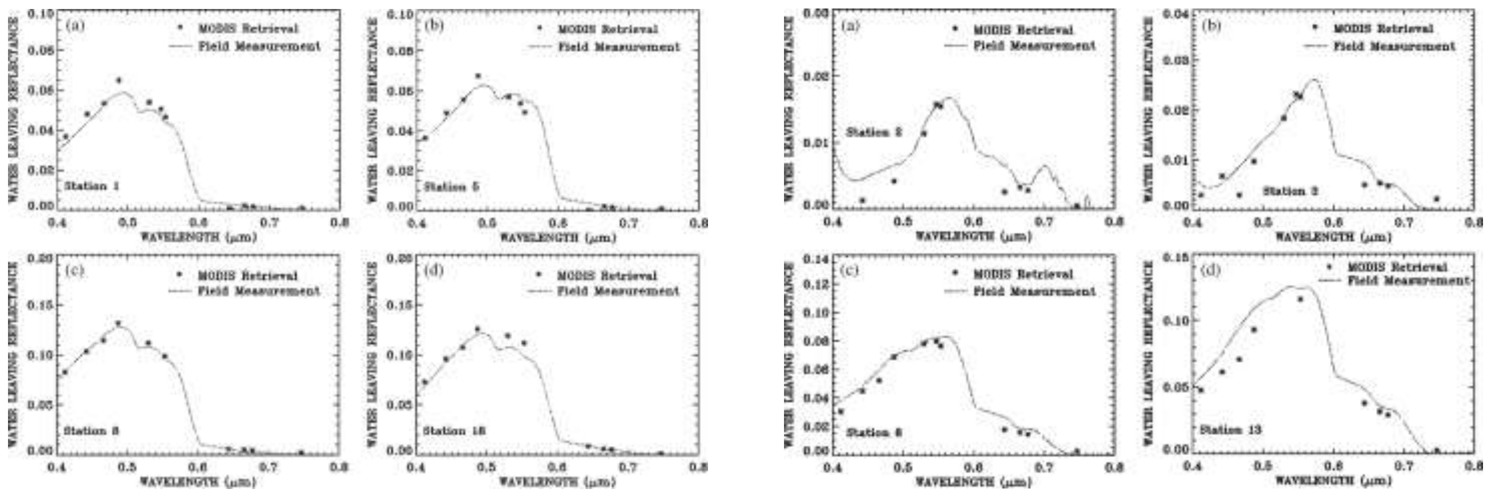
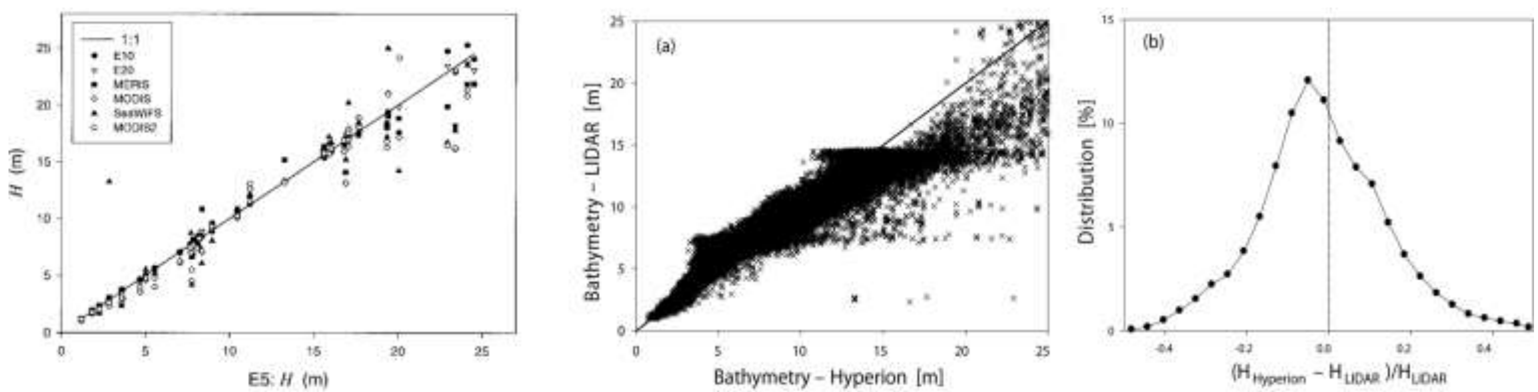


Gao et al. (2007): Combined wavebands across NIR/SWIR (0.865, 1.04, 1.24, 1.64, and 2.25 µm) provide very good atmosphere correction



Lee & Carder (2002), Lee et al. (2007): Contiguous, 10-nm-wide wavebands over range 400–800 nm is excellent band set for retrieval of shallow water bathymetry

Community Light-Use Efficiency

Primary production is a function of light absorption

$$P = LUE \times A \times PAR$$

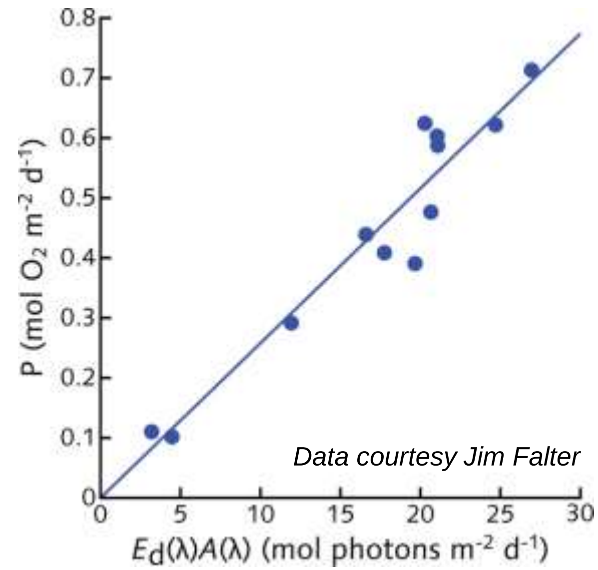
Light-use efficiency is primary production normalized by light absorption

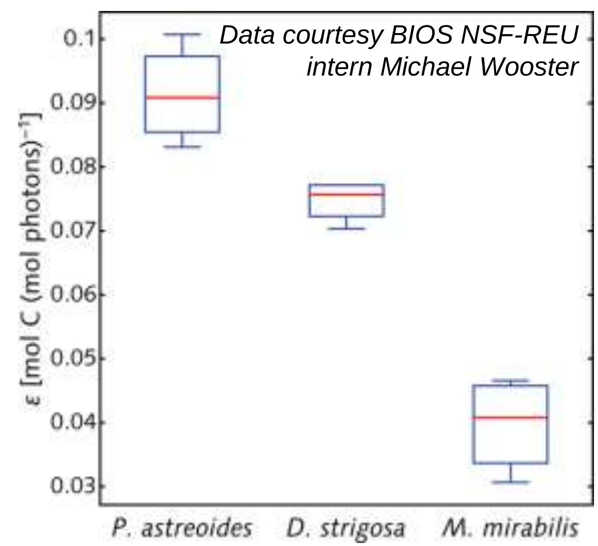
$$LUE = \frac{P}{A \times PAR}$$

- Functional Convergence Hypothesis: Natural selection should produce plants that optimize resource allocation relative to photosynthetic capacity, thus maximizing carbon gain

  ➔ With the same resource limitations, different plants should have the same LUE

- LUE should scale with *A*, making it possible to estimate LUE with optical measurements ➔ remote sensing





Coral Reef Forcing

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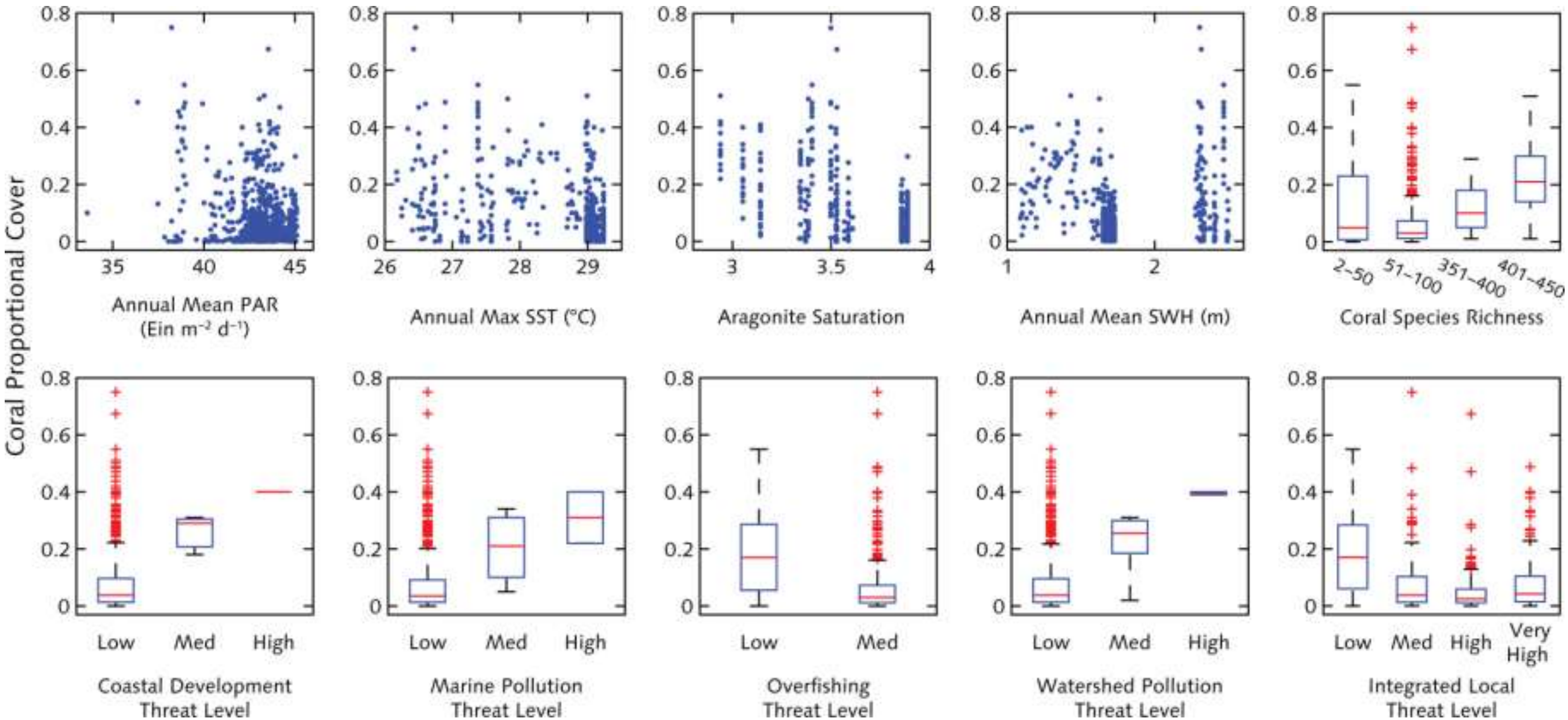

Existing survey data (US Caribbean, Hawaii, Great Barrier Reef) do not follow expected trends with respect to biogeophysical forcing parameters.

Either our understanding of reefs is incorrect, or our data have insufficient density and/or (more likely) scale.

BIOS

CORAL: COral Reef Airborne Laboratory

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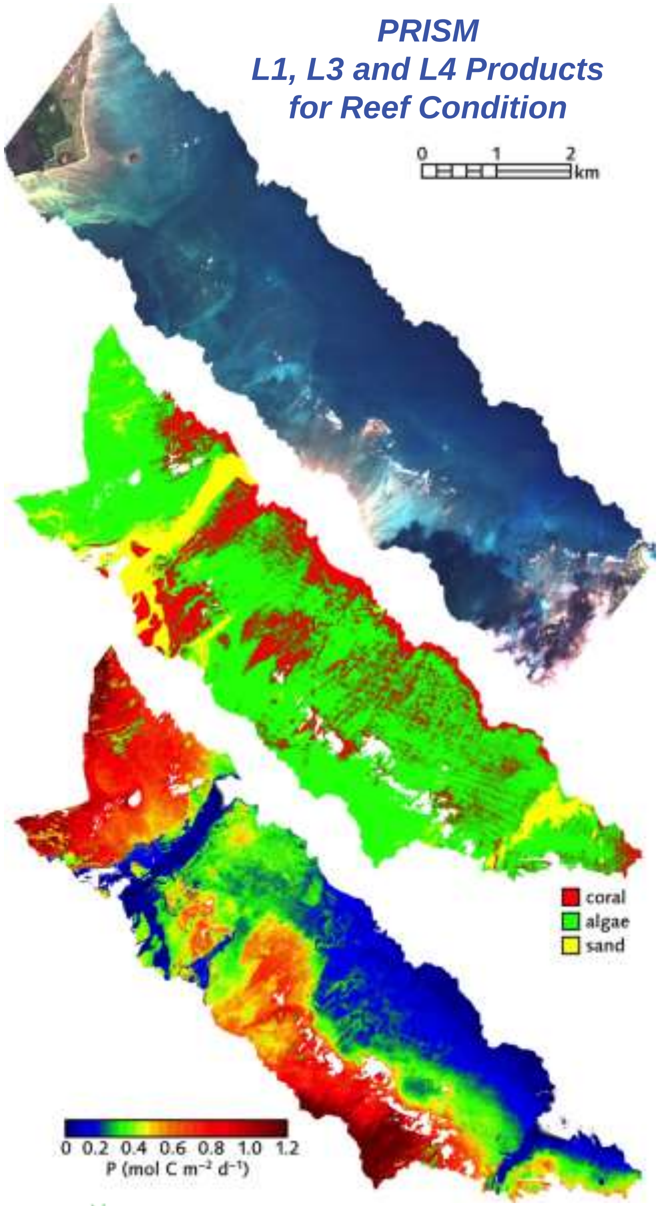
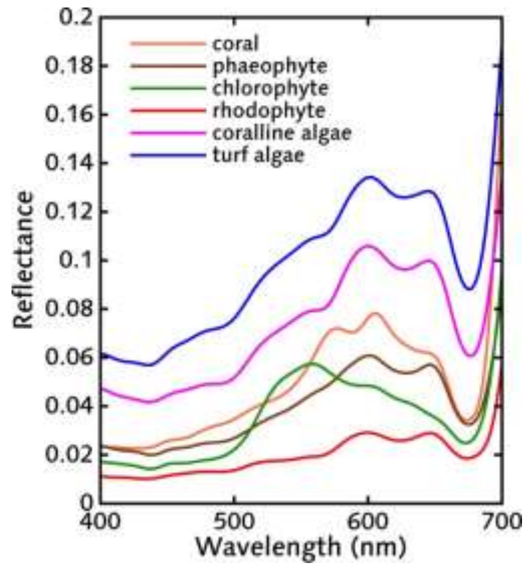
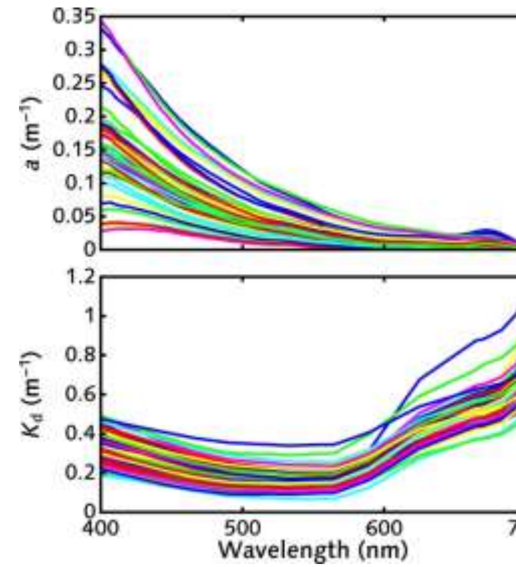
PRISM L1, L3 and L4 Products for Reef Condition



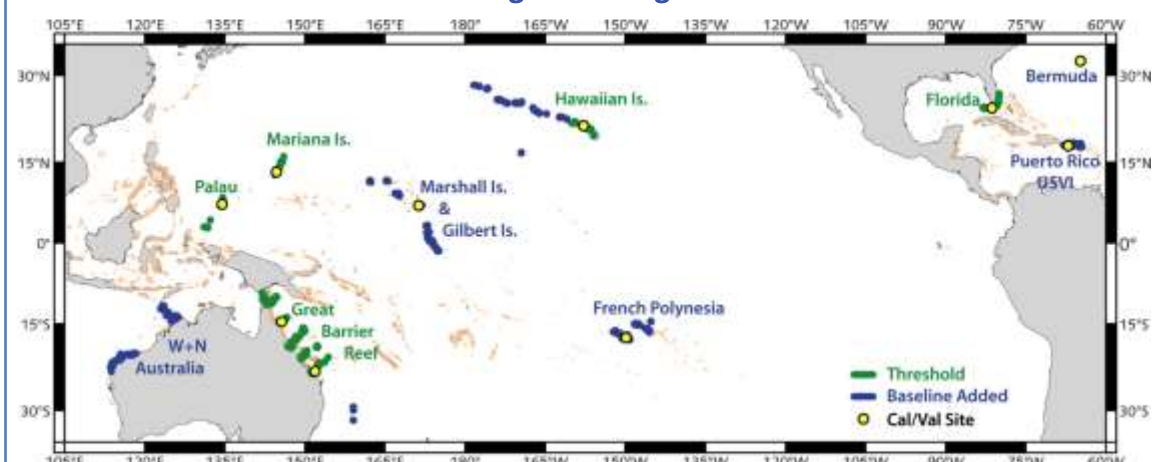
Benthic Reflectance Cal/Val



Water IOP/AOP Cal/Val



Threshold and Baseline Investigation Regions



Developmental to Operational

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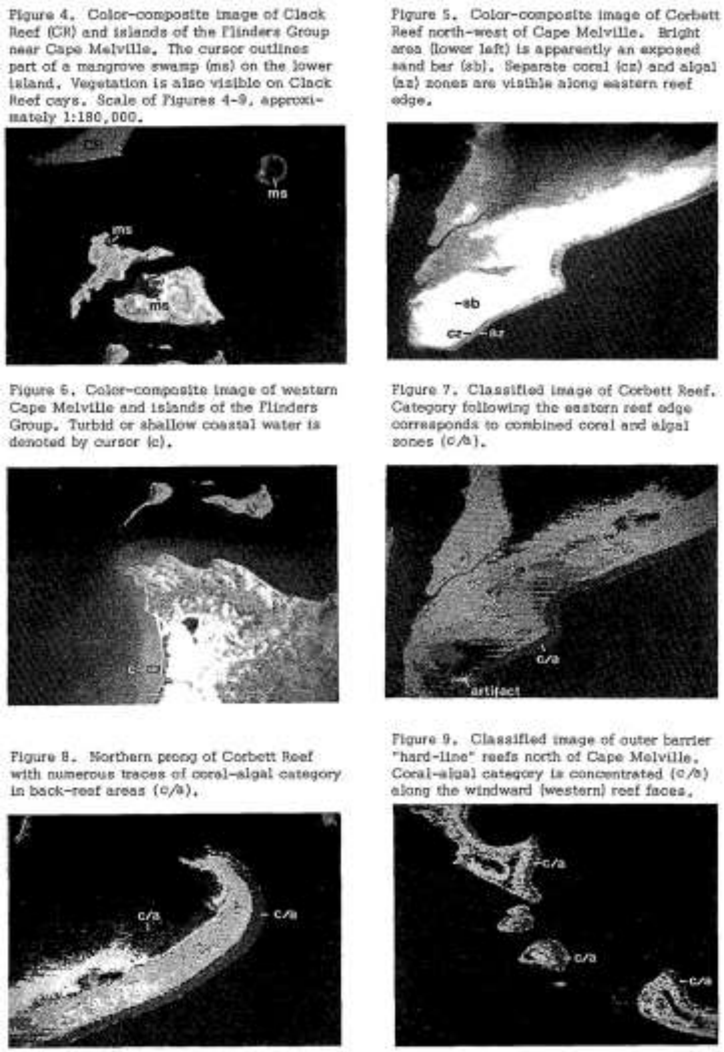
Figure 4. Color-composite image of Clack Reef (CR) and islands of the Flinders Group near Cape Melville. The cursor outlines part of a mangrove swamp (ms) on the lower island. Vegetation is also visible on Clack Reef cays. Scale of Figures 4-9, approximately 1:180,000.

Figure 5. Color-composite image of Corbett Reef north-west of Cape Melville. Bright area (lower left) is apparently an exposed sand bar (sb). Separate coral (cz) and algal (az) zones are visible along eastern reef edge.

Figure 6. Color-composite image of western Cape Melville and islands of the Flinders Group. Turbid or shallow coastal water is denoted by cursor (c).

Figure 7. Classified image of Corbett Reef. Category following the eastern reef edge corresponds to combined coral and algal zones (c/a).

Figure 8. Northern prong of Corbett Reef with numerous traces of coral-algal category in back-reef areas (c/a).

Figure 9. Classified image of outer barrier "hard-line" reefs north of Cape Melville. Coral-algal category is concentrated (c/a) along the windward (western) reef faces.

Smith et al. (1975) Automated Mapping and inventory of Great Barrier Reef Zonation With LANDSAT Data. *OCEAN 75 Conference* 775-780

- Satellite remote sensing of coral reefs actually predates CZCS
- As of early 2015, coral reef remote sensing remains developmental: only a long series of one-off studies, no standard algorithms, no large-scale programs
- June 2015 marks the pivot to operational: CORAL
- High-spatial-resolution spectral imaging satellites are coming: Sentinel-2, EnMAP, PRISMA, HyspIRI
- Standard algorithms are now a requirement
- Spectral imagery is a fundamental requirement
- Reef change is slow (except with major acute disturbances), so seasonal to yearly observations
- Algorithms will not be perfect, and they may initially provide a limited set of products (benthic cover, bathymetry)
- Algorithms will improve and include more products (e.g., pigments) over time
- This is the “CZCS phase” of coral reef remote sensing — fortunately ocean colour provides an excellent model to follow
- Regional to global data products will open new science inquiries and will become a major asset to resource management