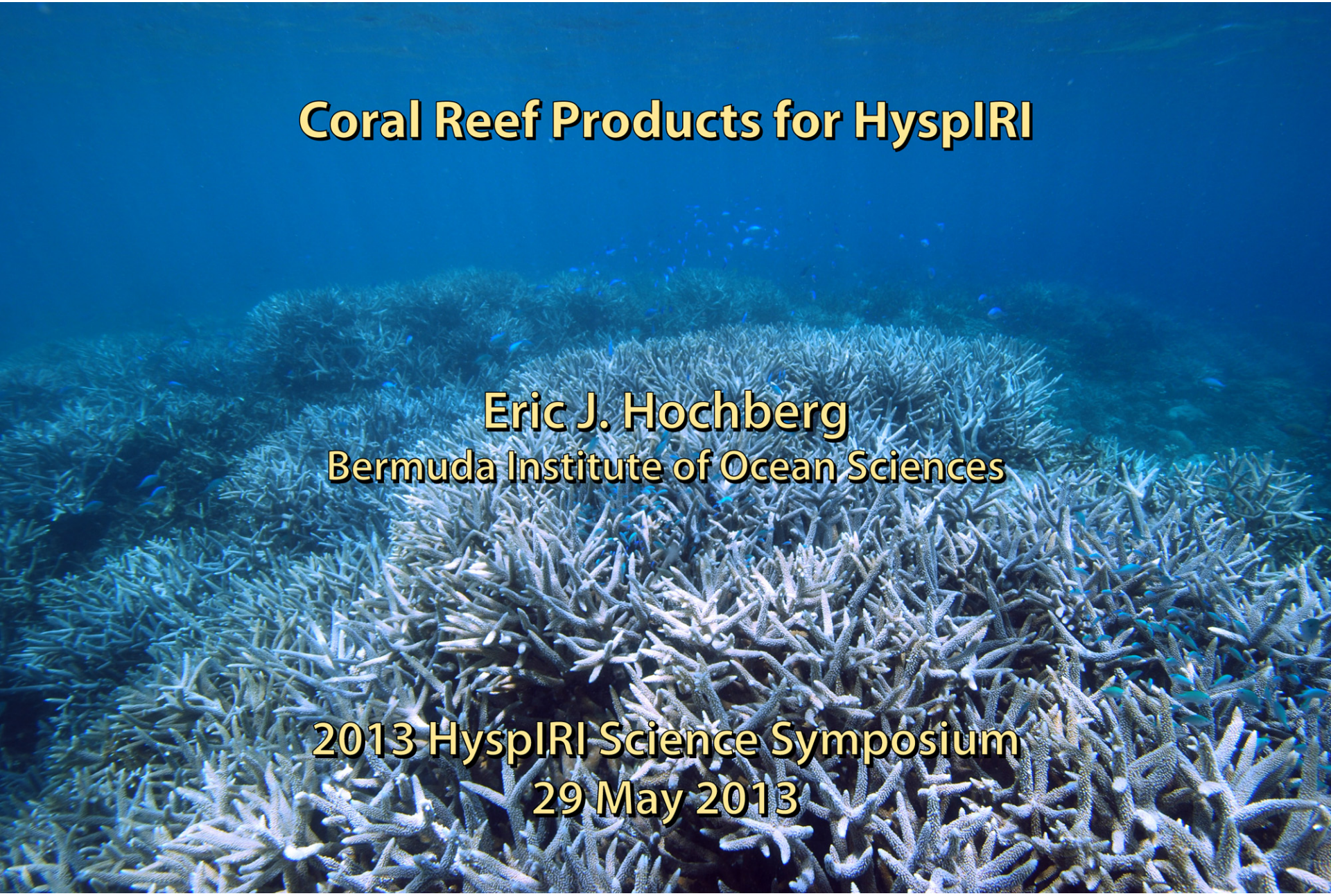
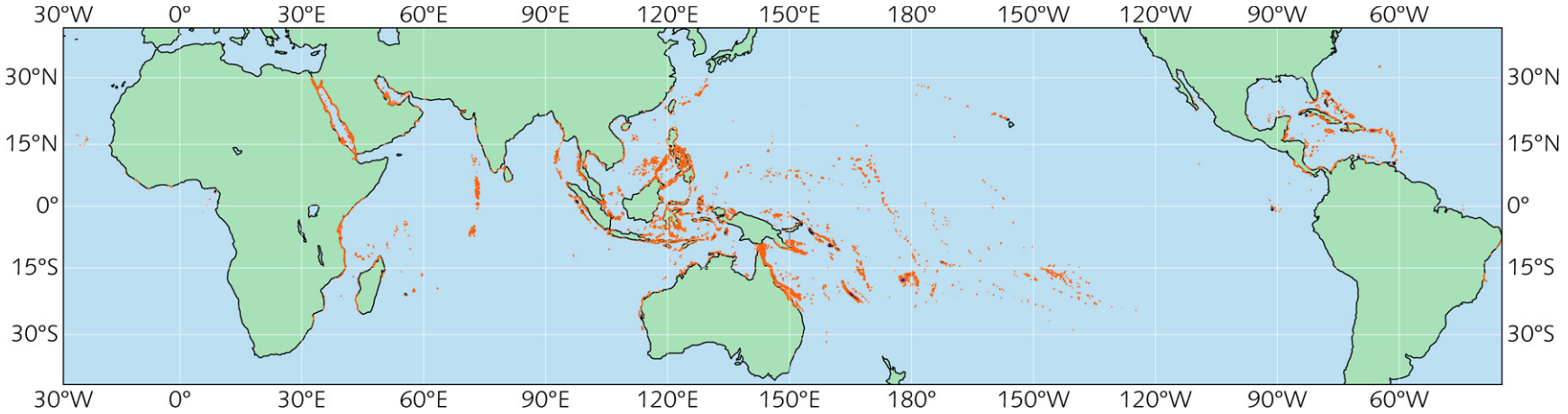


Coral Reef Products for HyspIRI

Eric J. Hochberg
Bermuda Institute of Ocean Sciences

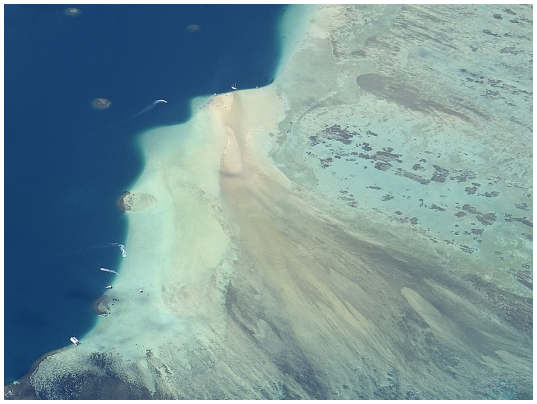
2013 HyspIRI Science Symposium
29 May 2013

Coral Reefs: Global Distribution and Importance



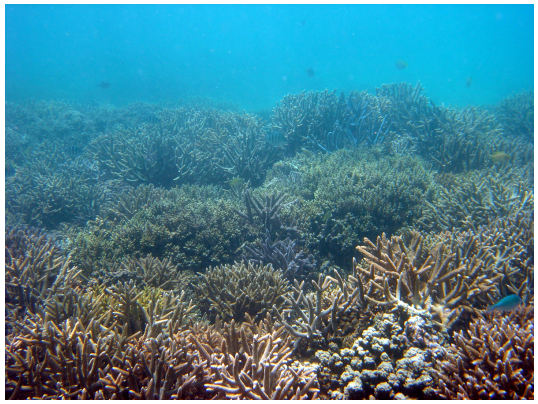
Focus for traditional culture and food source for innumerable small subsistence economies

Protection to shorelines from storm and wave damage and barriers that provide safe passage for shipping



Superlative recreational resource and the foundation of a multibillion dollar tourist industry worldwide

Major locus of global biodiversity, providing an ecological reserve of genetic complexity

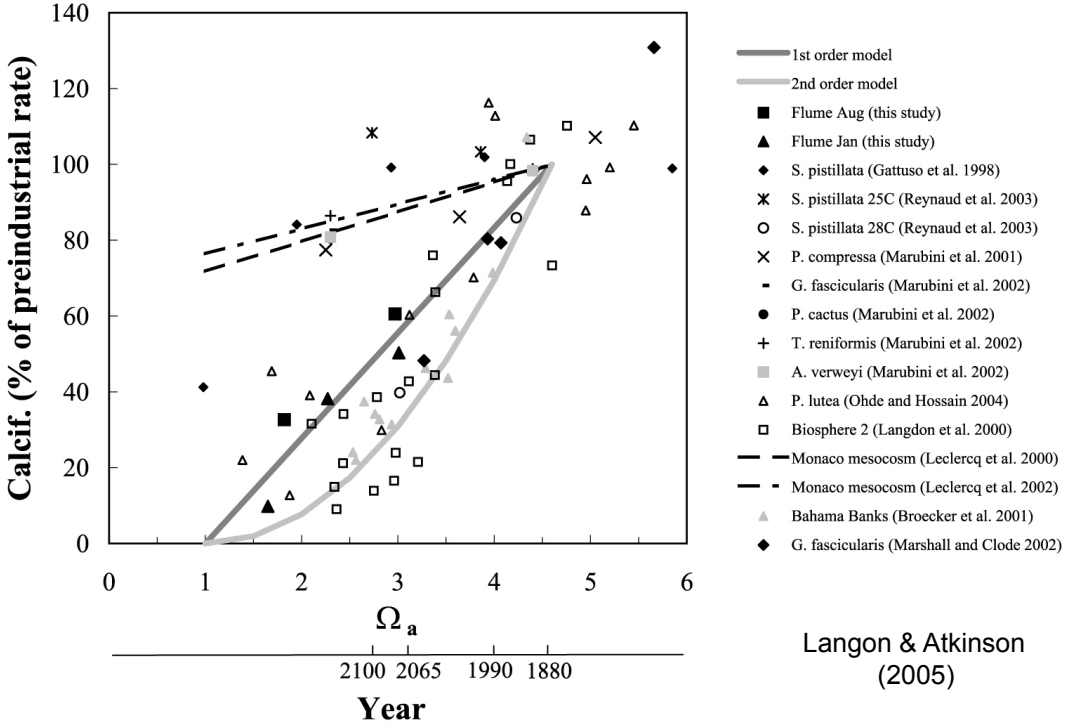


Global Stresses to Reefs

SST: Increased Coral Bleaching

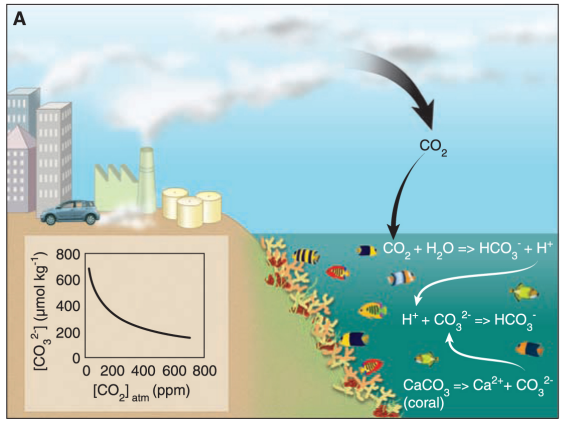
SST: increased Coral Disease

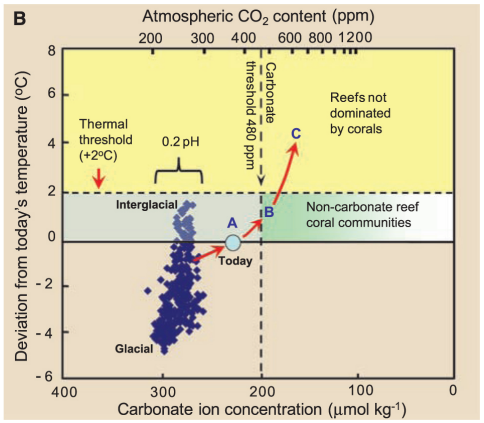
Ocean Acidification: Decreases in Calcification Rates



Langon & Atkinson (2005)

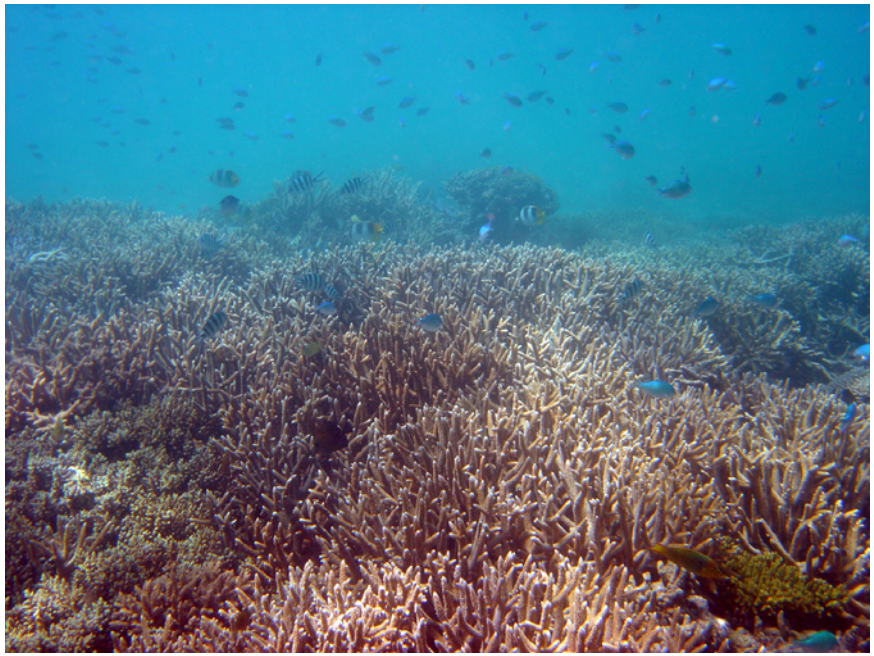
Synergistic Effects



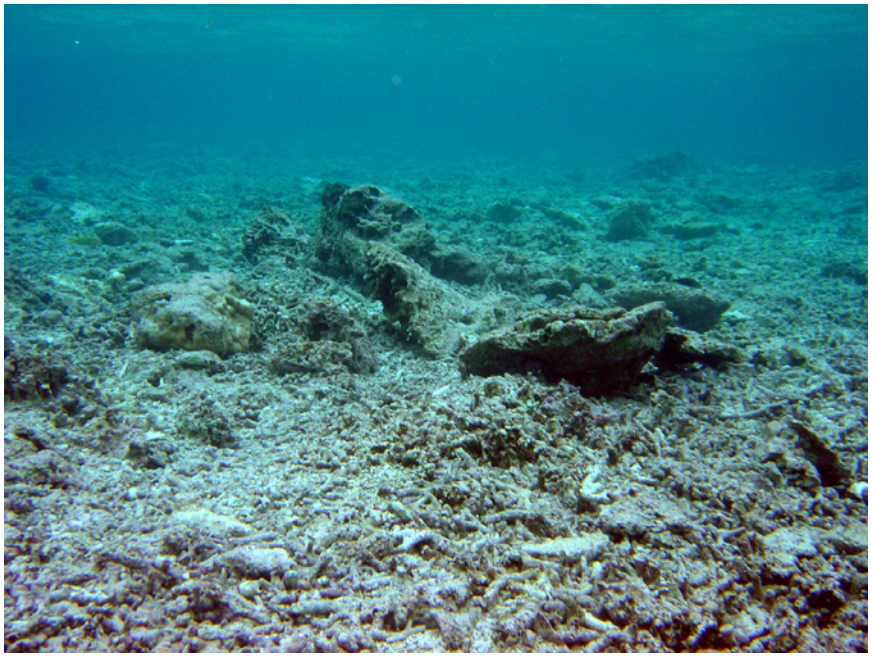


Hoegh-Gulberg et al. (2007)

The Primary Coral Reef Problem:
Phase Shifts from Coral-Dominated to Algae-Dominated

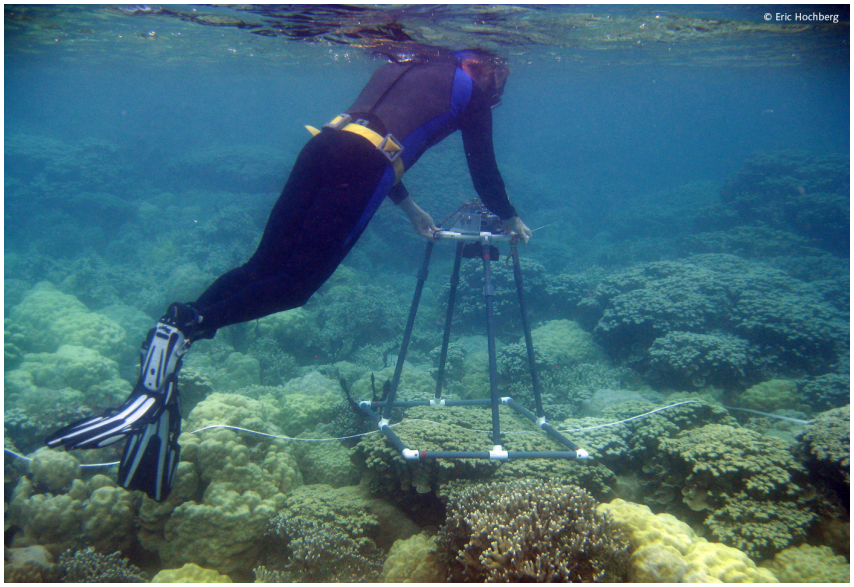


- Rough
- High productivity/calcification
- “Healthy”



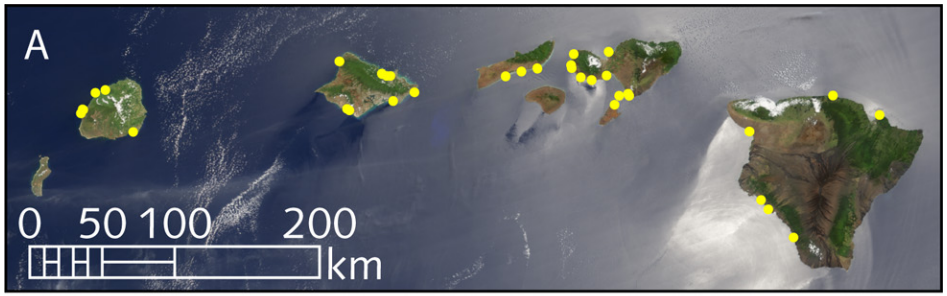
- Smooth
- Low productivity/calcification
- Not “healthy”

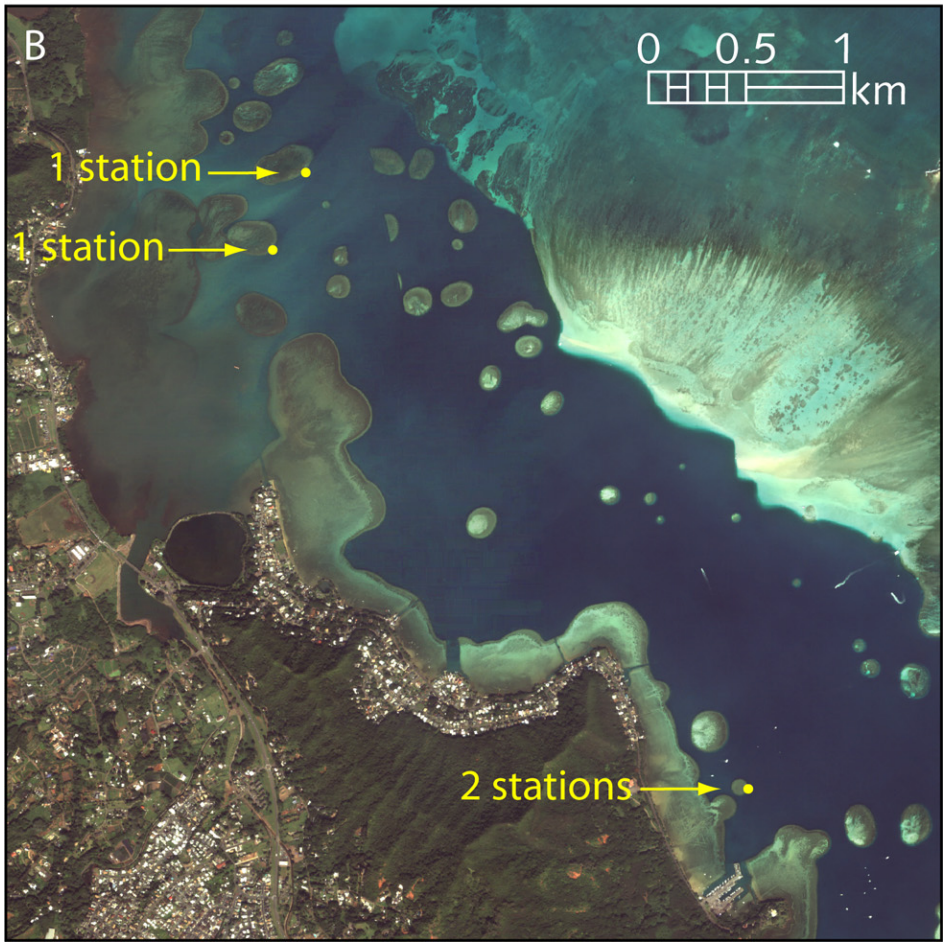
State of the Art in Coral Reef Assessment



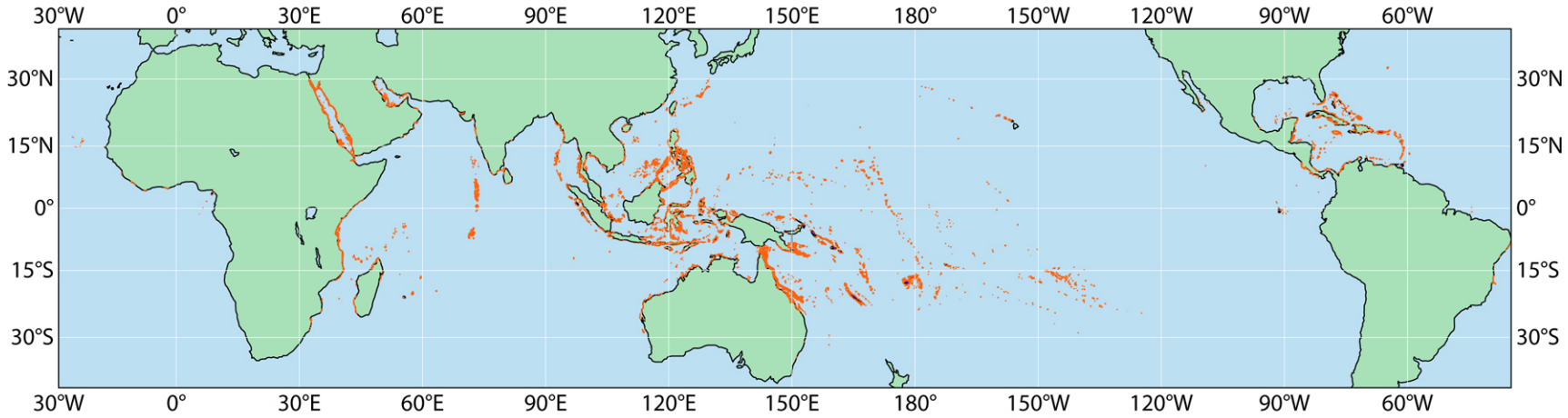
Photoquadrat Transects: detailed laborious, small footprint

“Manta-Tows”: quick, semi-quantitative, larger footprint

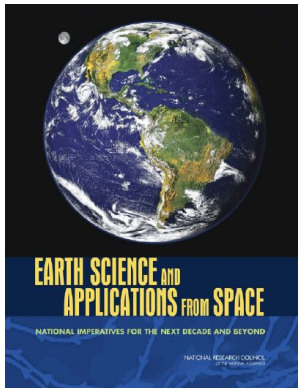




Coral Reefs: Sampling Problem



- ~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
- *Current estimates of reef loss are based on direct observation of only 0.01–0.1% of the world's reef area*
- **Only satellite remote sensing can provide the uniform data set required for assessment of the global status of coral reefs**

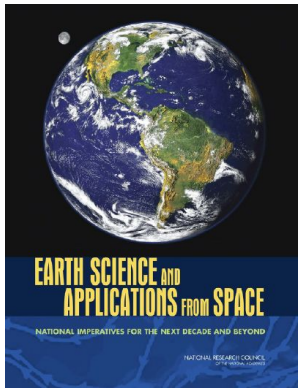


HyspIRI MISSION

p. 113 “A capability to detect such changes provides possibilities for early warning of detrimental ecosystem changes, such as drought, reduced agricultural yields, invasive species, reduced biodiversity, fire susceptibility, altered habitats of disease vectors, and changes in the health and extent of coral reefs.”

p. 114 “**Background**...Requirements for ecosystem studies include information on canopy water content, vegetation stress and nutrient content, primary productivity, ecosystem type, invasive species, fire fuel load and moisture content, and such disturbances as fire and insect damage. In coastal areas, measurements of the extent and health of coral reefs are important.”

p. 114 “**Science Objectives**...Observations can also detect changes in the health and extent of coral reefs, a bellwether of climate change. Those capabilities have been demonstrated in space-borne imaging spectrometer observations but have not been possible globally with existing multispectral sensors.



LAND-USE CHANGE, ECOSYSTEM DYNAMICS, AND BIODIVERSITY

p. 191 "*Mission to observe distribution and changes in ecosystem function.* An optical sensor with spectral discrimination greatly enhanced beyond that of Landsat and MODIS is required to detect and diagnose changes in ecosystem function, such as water and nutrient cycling and species composition. Such observations include nutrient and water status, presence of and responses to invasive species, health of coral reefs, and biodiversity."

BOX 7.3 ECOSYSTEM PROPERTIES FOR WHICH SATELLITE DATA ARE REQUIRED

Terrestrial Ecosystems	Coastal and Open-Ocean Ecosystems
Distribution and changes in key species and functional groups of organisms	Coral-reef health and extent
Disturbance patterns	Photosynthesis
Vegetation stress	Sediment fluxes
Vegetation nutrient status	Phytoplankton community structure
Primary productivity	Algal blooms
Vegetation cover	CO_2 concentration
Standing biomass	
Vegetation height and canopy structure	
Habitat structure	
Human infrastructure	
Atmospheric CO_2 and CO concentration	

TABLE 7.1 Land-Use Change and Ecosystem Dynamics Panel Priority New Missions

Summary of Mission Focus	Variables	Type of Sensor	Coverage	Spatial Resolution	Frequency	Synergies with Other Panels	Related Planned or Integrated Missions
Ecosystem function: climate and land-use impacts on terrestrial and coastal ecosystems	*Terrestrial:* Distribution and changes in key species and functional groups of organisms, disturbance patterns, vegetation stress, vegetation nutrient status, primary productivity, vegetation cover *Coastal:* coral-reef health and extent	Hyperspectral	Global, pointable	50-75 m	30 day, pointable to daily	Climate Health Solid Earth	HyspIRI

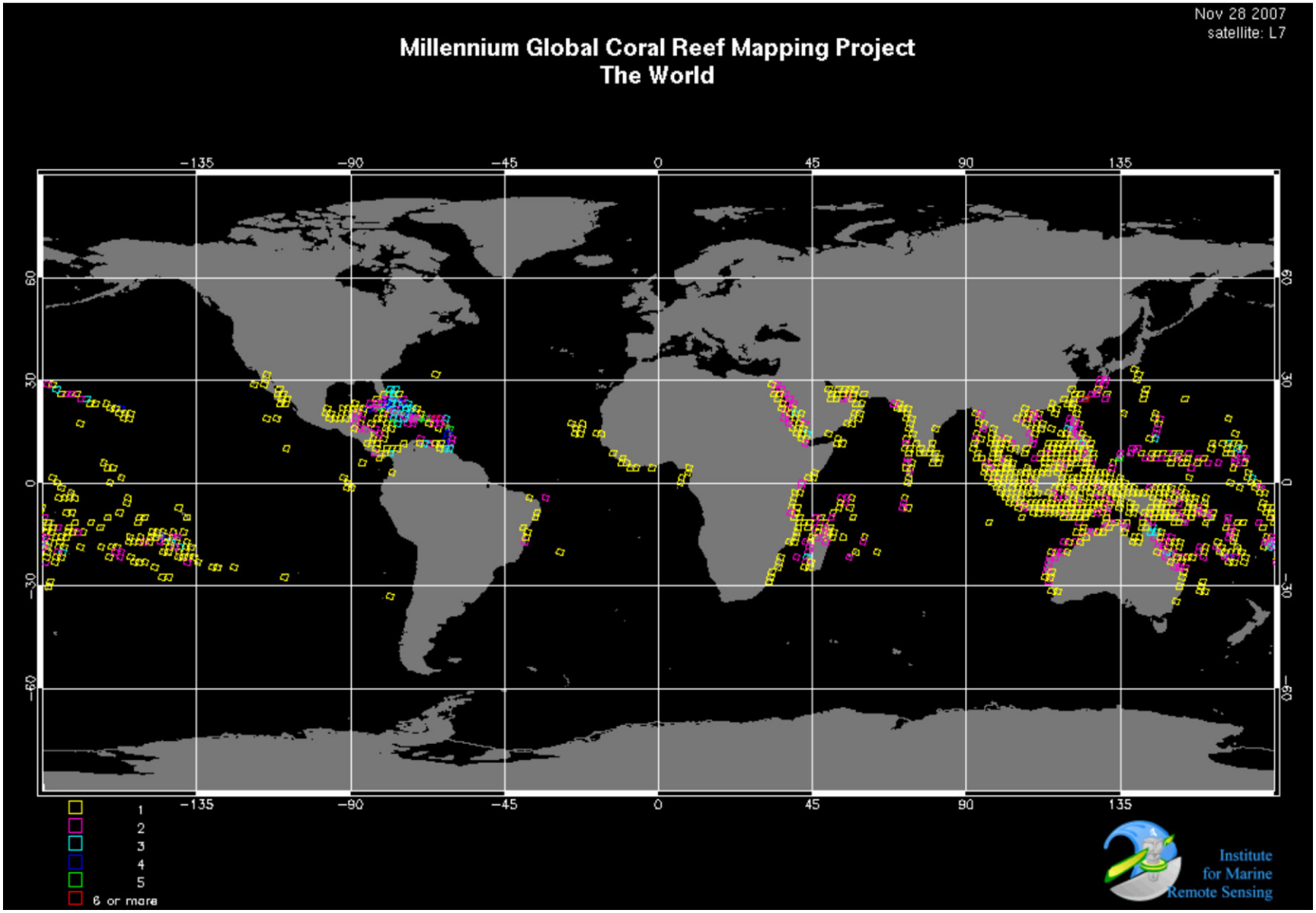
Ecosystem Function

Mission Summary—Ecosystem Function

Variables:	Distribution and changes in key species and functional groups of organisms; disturbance patterns; vegetation stress; vegetation nutrient status; primary productivity; vegetation cover; coral-reef health and extent
Sensor(s):	Hyperspectral
Orbit/coverage:	LEO/global-pointable
Panel synergies:	Climate, Health, Solid Earth
New science:	Land ecosystem chemistry, diversity, leaf water stress; coral reef health and extent
Applications:	Ecosystem interactions with changing climate, agriculture, invasive species, disturbance, management, urbanization

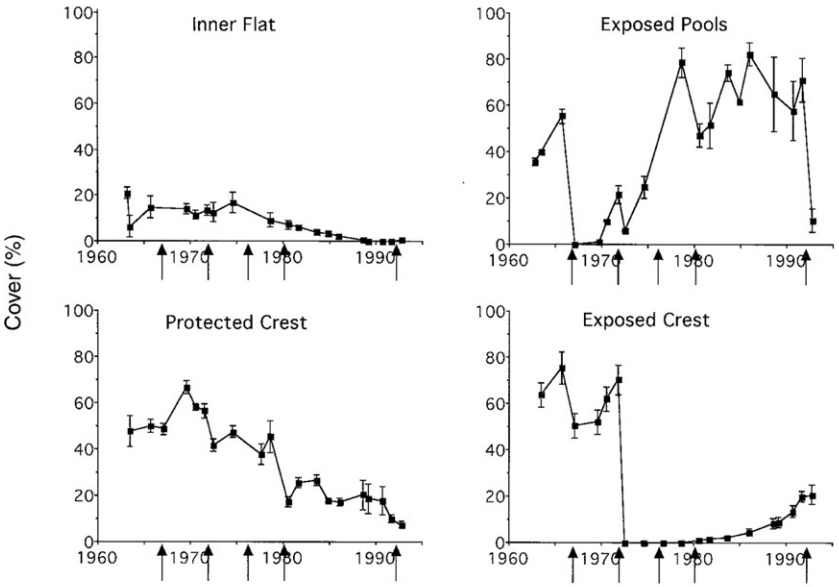
Ecosystem function, the first mission concept listed in Table 7.1, is aimed at detecting a suite of functional responses of ecosystems to direct human and climate impacts and providing detailed information for improved management of ecosystems. This mission builds on legacy remote sensing measurements of chlorophyll and visible reflectance and will use direct and inferential techniques for observing the spatial pattern of additional key functional properties of ecosystems. The properties targeted reveal ecosystem responses critical for understanding the effects of climate, land use, and resource use. Key properties are listed in Box 7.3 and include indexes of ecosystem composition (distribution of and changes in key species or functional groups of organisms and disturbance patterns) and ecosystem health and dynamics (leaf water stress and energy-water-carbon-nutrient fluxes). The mission focuses on terrestrial ecosystems but would also address coral-reef health and extent.

Coral Reef Extent — A Good Start

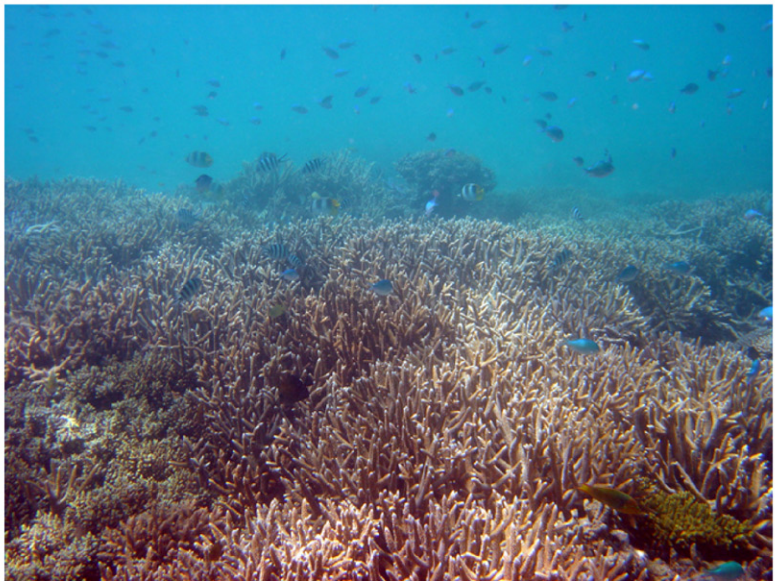


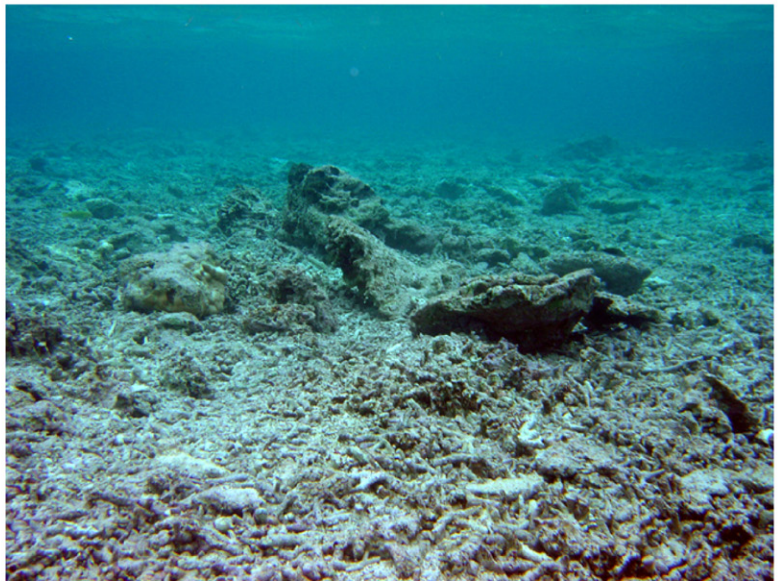
Coral Reef Health — Reducible to a quantitative measure

Connell et al. (1997)



- When corals die their skeletons are rapidly colonized by algae
- Healthy reefs usually increase coral coverage during recovery from stress
- Degraded reefs gradually become dominated by algae and rubble
- With the loss of reef-builders, the carbonate structure erodes, ultimately becoming a flat bottom with shifting rubble and sand
- **A key quantitative parameter to assess the health of a reef is the distribution of living coral, algae and sand**
- **Such a quantitative index can be effectively utilized to evaluate the relative impacts of natural phenomena and human activities to reef communities**

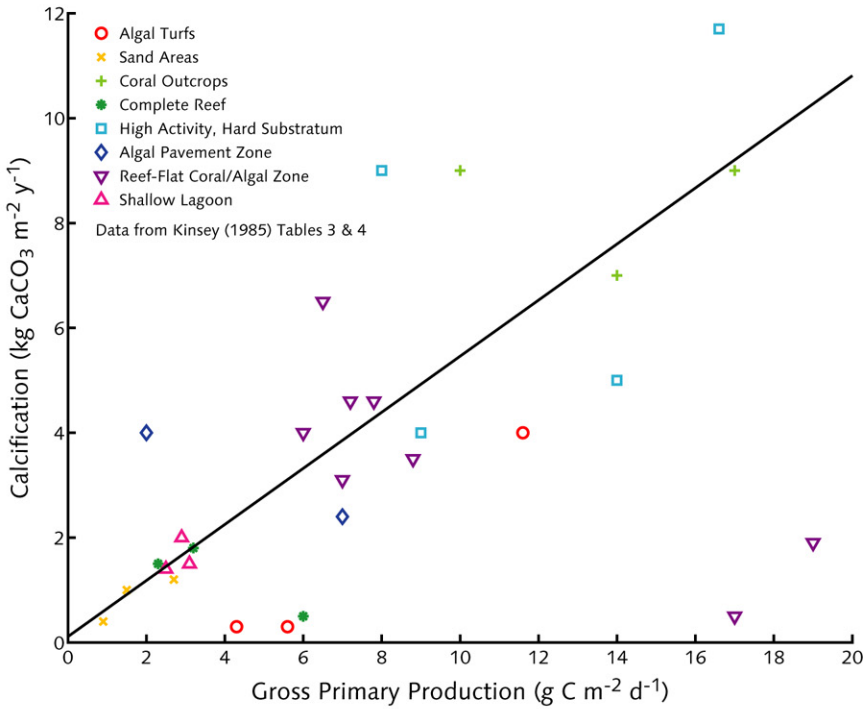




Coral Reef Function

Published values for specific biotopes in coral reef environments (after Kinsey 1984)

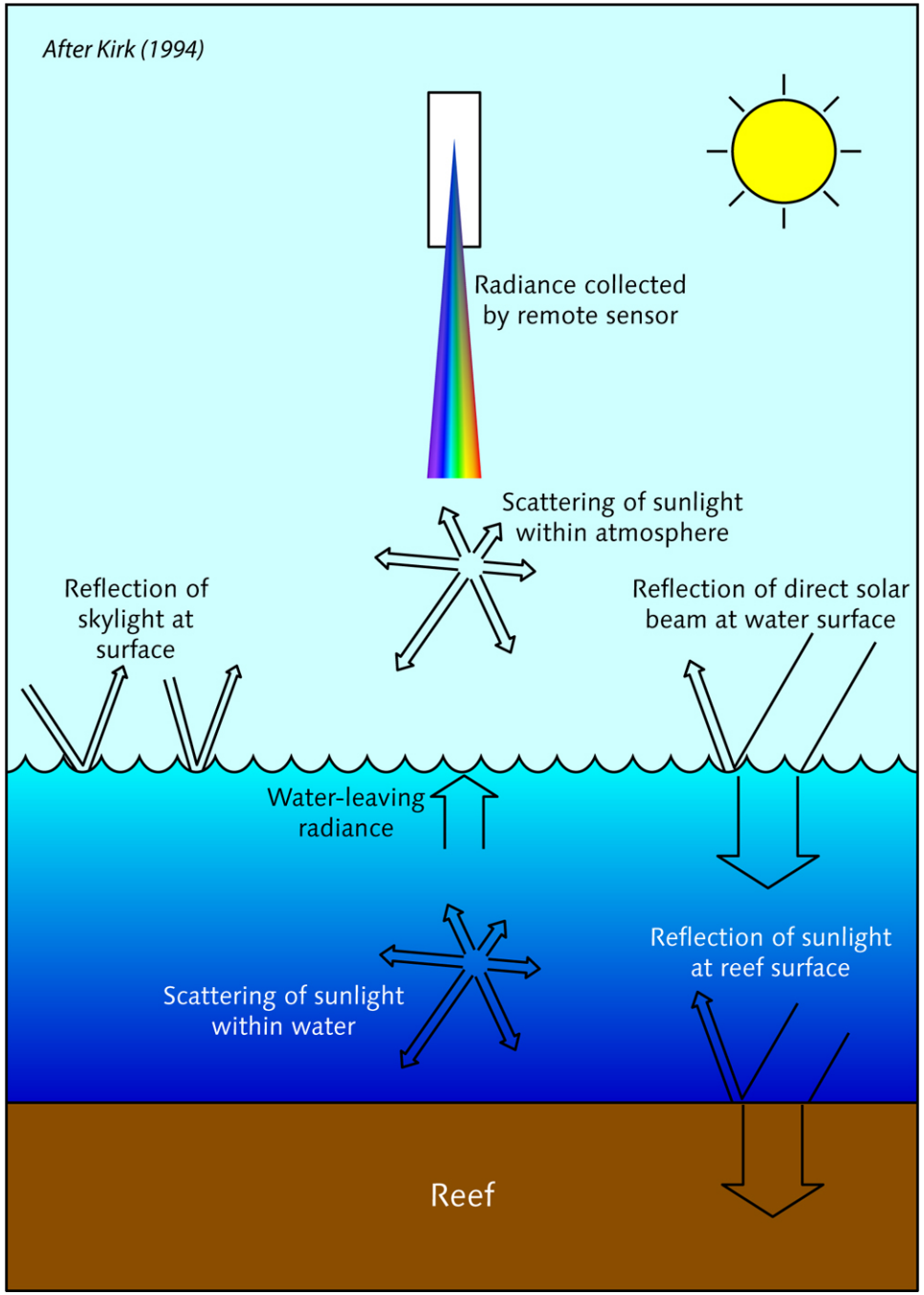
Reference	Location	P (mol O_2 m^{-2} d^{-1})
Algal turfs & algal/sand flats		
Smith (1973)	Enewetak	0.97
Smith & Marsh (1973)	Enewetak	0.87
Kinsey (1979)	Lizard Island	0.36
"	Kaneohe Bay	0.47
Hargraves (1982)	Carrie Bow Key	~1.67
Sorokin (1982)	Various Indo-Pacific	0.17-0.33
Vooren (1981)	Curacao	0.16
Hawkins & Lewis (1982)	Barbados	0.08
Rogers & Salesky (1981)	St. Croix (turf)	0.25
	" (macroalgae)	1.23
Coralline encrusting algae		
Vooren (1981)	Curacao	0.08
Hawkins & Lewis (1982)	Barbados	0.07
"Sand" areas		
Sournia (1976)	Takapoto	~0.17
Sorokin (1982)	Various Indo-Pacific	0.05-0.11
Kinsey (1977)	One Tree Island	0.08
Kinsey (1979)	Kaneohe Bay	0.23
Kinsey (1979)	One Tree Island	0.13
Coral outcrops		
Kinsey (1979)	6 sites GBR	1.42-3.08
"	*Leptoria phrygia* patch	0.67
"	*Acropora pulchra* patch	1.5
"	*Porites andrewsi* patch	1.17
Atkinson & Grigg (1984)	French Frigate Shoals	
	Porites compressa/lobata	~0.83



- The relative distribution of coral, algae and sand also allows for straightforward estimates of productivity using concepts of standard metabolic rates for reef community types
- Higher-order models are under development
- Calcification is correlated with productivity

Five sources of light received by a remote sensor pointed at a coral reef.

Only light reflected at the reef surface can provide information about the reef.



Hochberg & Atkinson (2003)

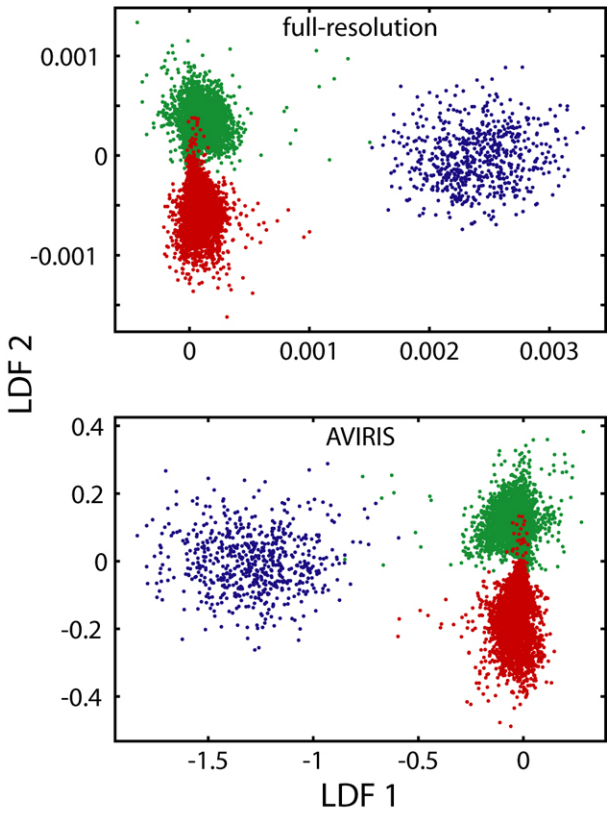
Table 1
Classification error matrices for in situ spectral reflectances of three coral reef classes: coral, algae, and carbonate sand

(A) Full-resolution: overall accuracy = 98%

		Actual class		
		Algae	Coral	Sand
Predicted class	Algae	2726 (99.2)	75 (3.3)	1 (0.3)
	Coral	23 (0.8)	2168 (96.6)	0 (0.0)
	Sand	0 (0.0)	1 (0.0)	320 (99.7)

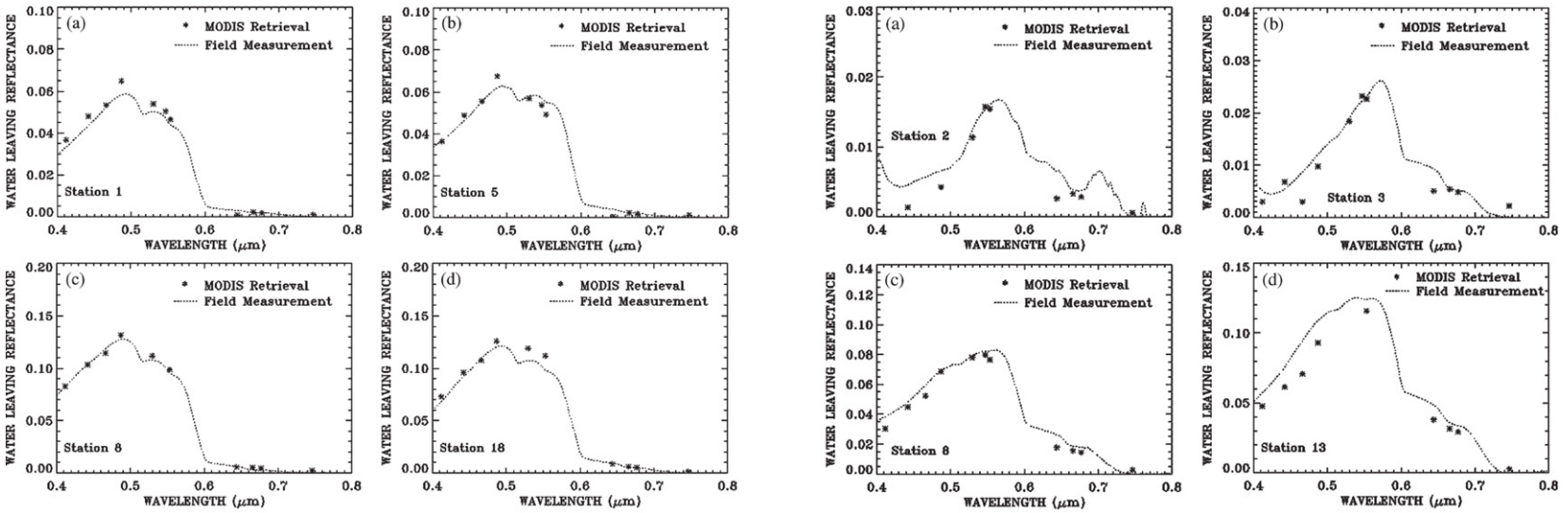
(C) AVIRIS: overall accuracy = 98%

		Actual class		
		Algae	Coral	Sand
Predicted class	Algae	2725 (99.1)	74 (3.3)	1 (0.3)
	Coral	24 (0.9)	2170 (96.7)	0 (0.0)
	Sand	0 (0.0)	0 (0.0)	320 (99.7)



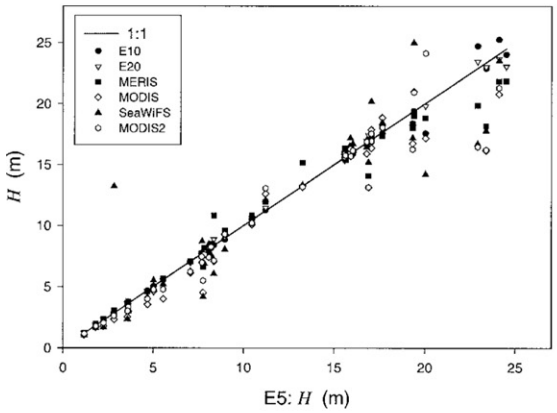
Conclusion: Contiguous, 10-nm-wide wavebands over range 400–700 nm provides excellent spectral discrimination between coral, algae, and sand

Gao et al. (2007)

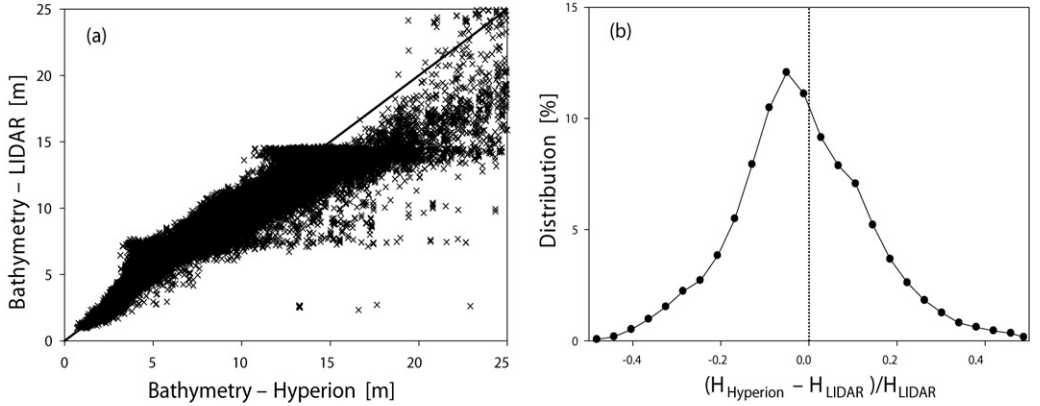


Conclusion: Combined wavebands across both NIR and SWIR (i.e., 0.865, 1.04, 1.24, 1.64, and 2.25 μm) provide very good atmospheric correction

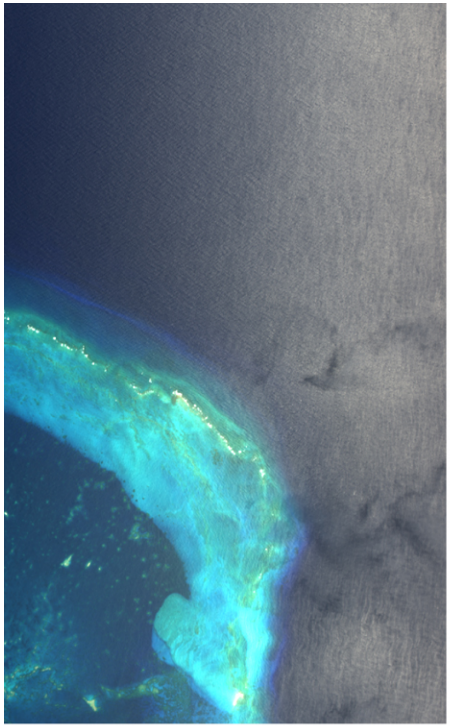
Lee & Carder (2002)

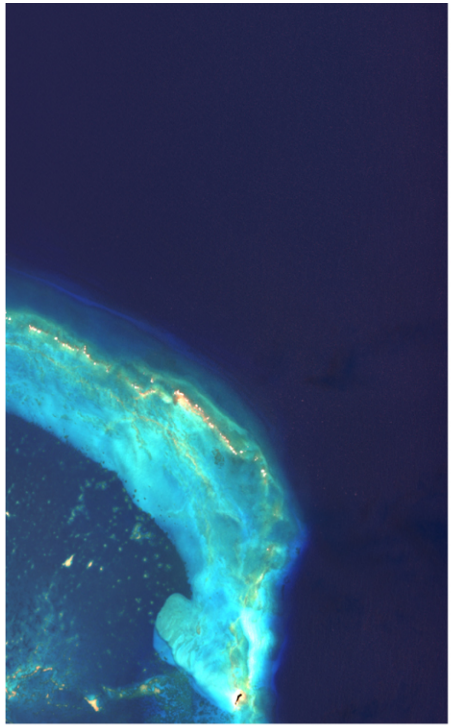


Lee et al. (2007)



Conclusion: Contiguous, 10-nm-wide wavebands over range 400–800 nm is excellent band set for retrieval of shallow water bathymetry

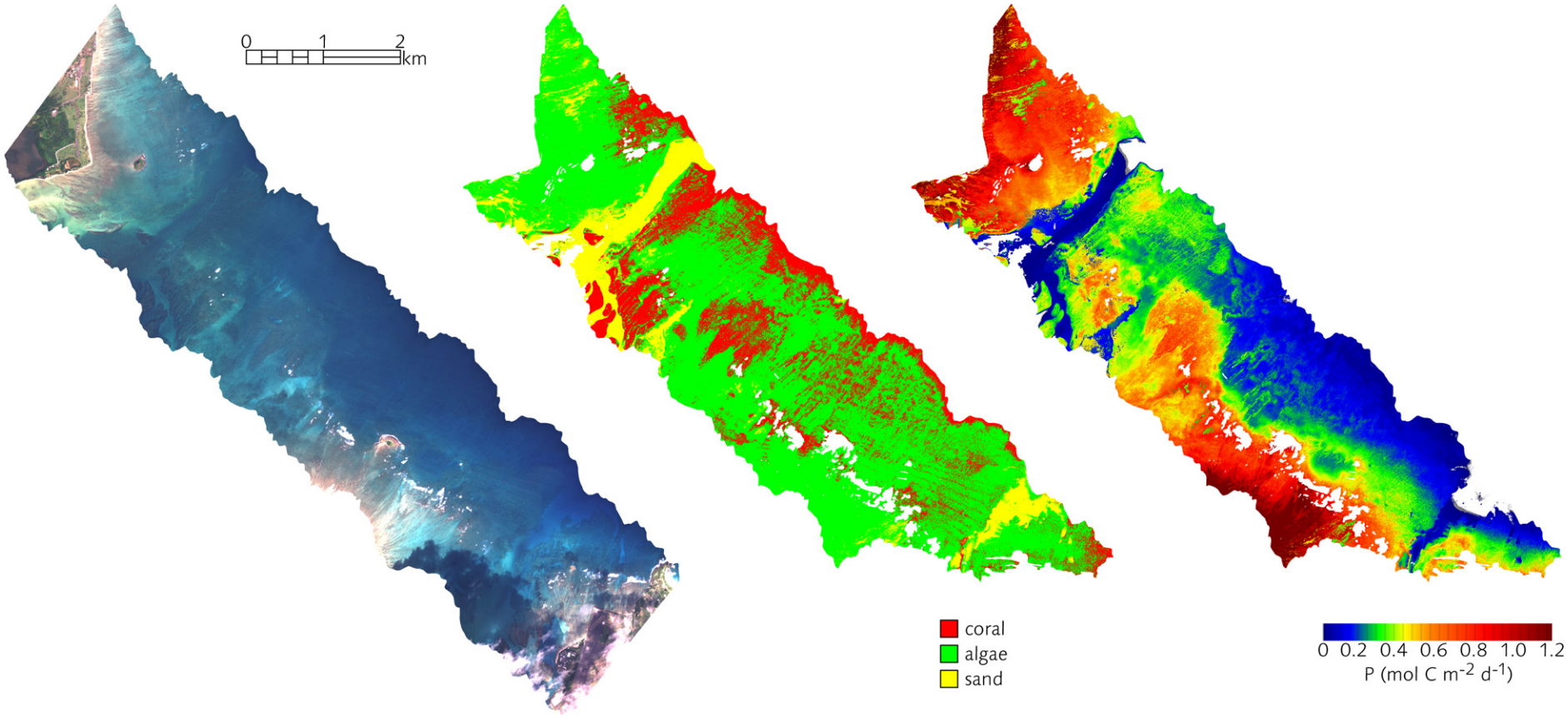




Various Workers & HyspIRI Sun Glint Subgroup

Conclusion: Glint is readily correctable, provided (1) suitable reference waveband(s) at wavelengths > 900 nm and (2) good atmospheric correction

Coral Reef Products



Pseudo-true-color picture

Map of bottom-types

Map of productivity

HyspIRI Coral Reef Science

Data products will be used to answer specific environmental questions on the ratios of coral, algae and sand with respect to geographical limits, regional oceanography, reef morphology, seasonality and human use patterns and impacts.

- Determine the coral/algae/sand ratios in pristine reefs versus human impacted reefs.
- Determine how coral/algae/sand ratios vary with reef morphology, underlying geology, latitude, seasonality, disturbance events, and oceanographic conditions of wind, waves, and nutrients.
- Determine the spatial scales of responses in coral/algae/sand ratios to environmental changes.
- Develop appropriate indices for these ratios to help regional and local monitoring efforts.
- Determine how coral/algae/sand ratios interact with centers of coral diversity.
- Advise managers, locally and internationally, regarding how to respond to regional and local changes in reef composition.
- Show how global space-based data can alter local perception of problems and help with management efforts.
- Identify how series of regional reefs add to regional productivity and recruitment to fisheries.
- Identify reefs that are suitable for more intensive monitoring and scientific investigation.
- Determine how coral/algae/sand is distributed in response to impacts from localized sedimentation, runoff and nutrients.
- Provide input to hydrodynamic and biogeochemical models for reef function, and aid existing monitoring programs.
- Identify specific, abnormal reef environments, either by reef morphology or coral/algae/sand index ratios.
- Support many small scale existing studies. Available data will allow local scale studies to be put in a larger context through large data-base.