Impacts of Spatial and Spectral Resolution on Hyperspectral Remote Sensing of Aquatic Vegetation

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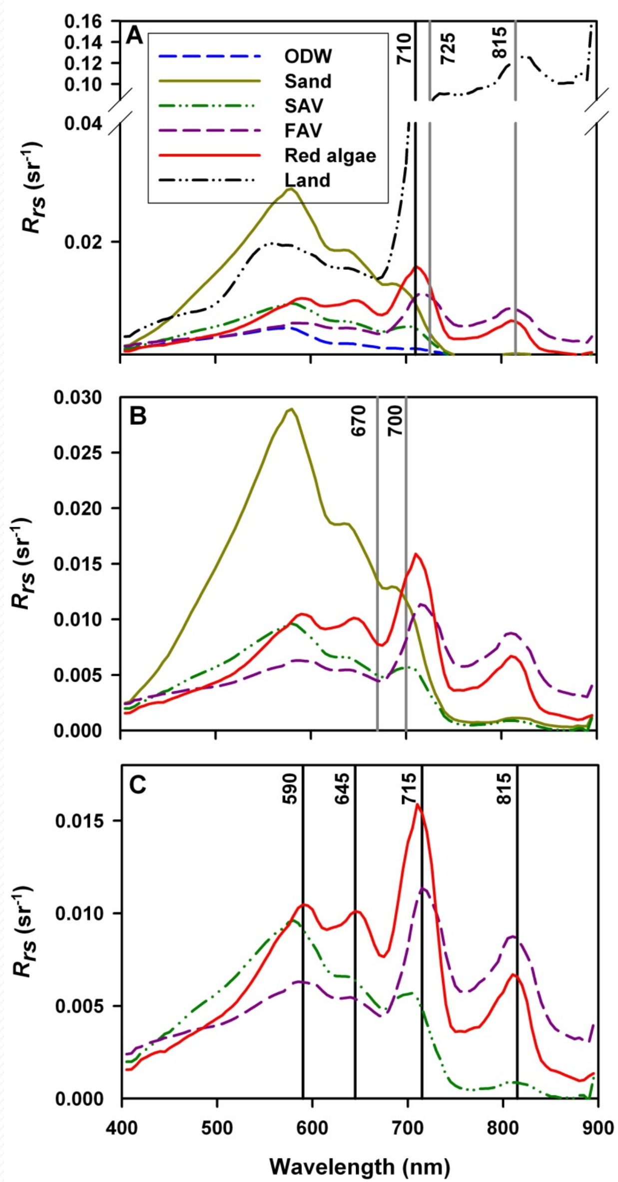
Motivation for Remote Sensing of Coastal Environments

- Highly valuable, highly visible
- Very productive
  - Biogeochemistry
  - Carbon flux
  - Fisheries
- Shoreline protection
  - Flooding, storm inundation
  - Erosion
- Esthetic
  - Recreation, tourism
- Heavily impacted
  - Water quality
  - Flow patterns
  - Erosion
  - Loss of habitat
  - Climate change
    - Sea level rise
    - Storm intensity
    - Ocean warming
    - Ocean acidification

Challenges for Remote Sensing of Coastal Environments

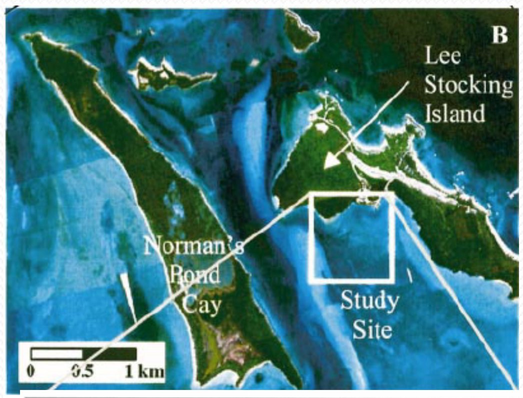
- Dark water targets in close proximity to bright land
- Spatial heterogeneity requires high spatial resolution
- Submerged habitats represent unique optical targets
  - Darker than land
  - Brighter than optically deep water
  - Unique range of spectral signatures
    - Bare sand and mud
    - Green seagrass meadows
    - Red, brown and green seaweeds
    - Corals
  - Affected by water depth, transparency and color
- Atmospheric correction is critical

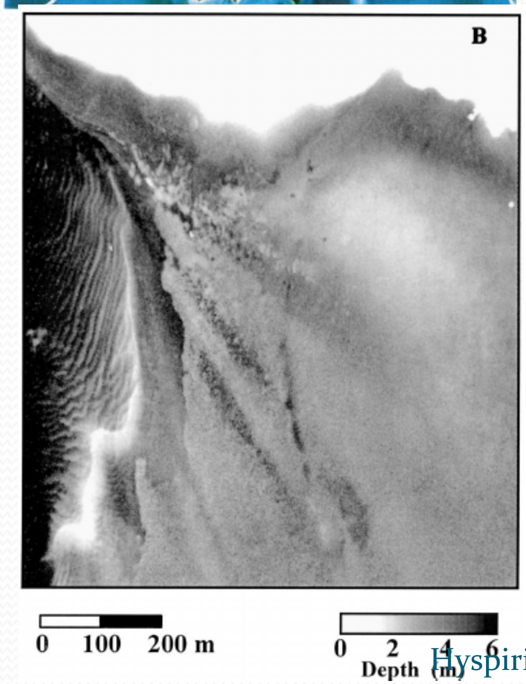


The Aquatic Macrophyte Opportunities:

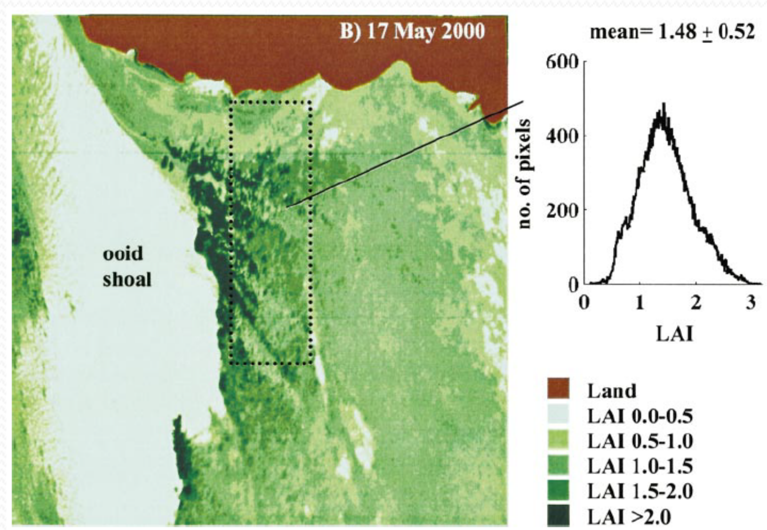
- Floating canopies provides a strong reflecting target
  - No overlying water column
  - California kelp forests
    - *Macrocystis pyrifera*
    - *Nereocystis luetkeana*
  - Gulf Of Mexico and Gulf Stream
    - *Sargassum fluitans*
- Seagrasses grow in optically shallow water – within the visible range of remote sensing

In clear, blue Bahamian waters, past experiments demonstrated utility of HS imagery for mapping

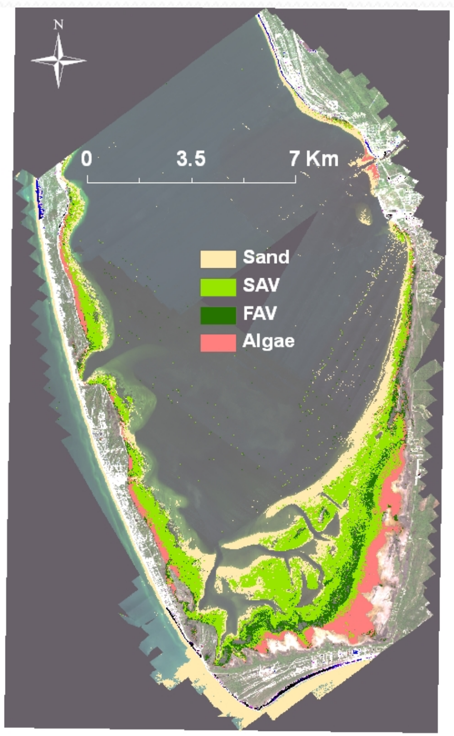




- Bathymetry
- Sand & seagrass distribution
- Seagrass abundance



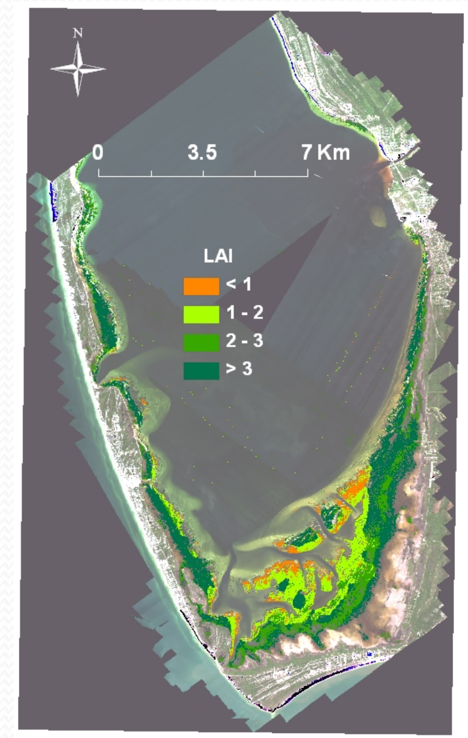
In more complex waters of coastal Florida Past experiments demonstrated utility of HS imagery for mapping:



- Sand
- Submerged seagrass
- Floating seagrass
- Benthic algae

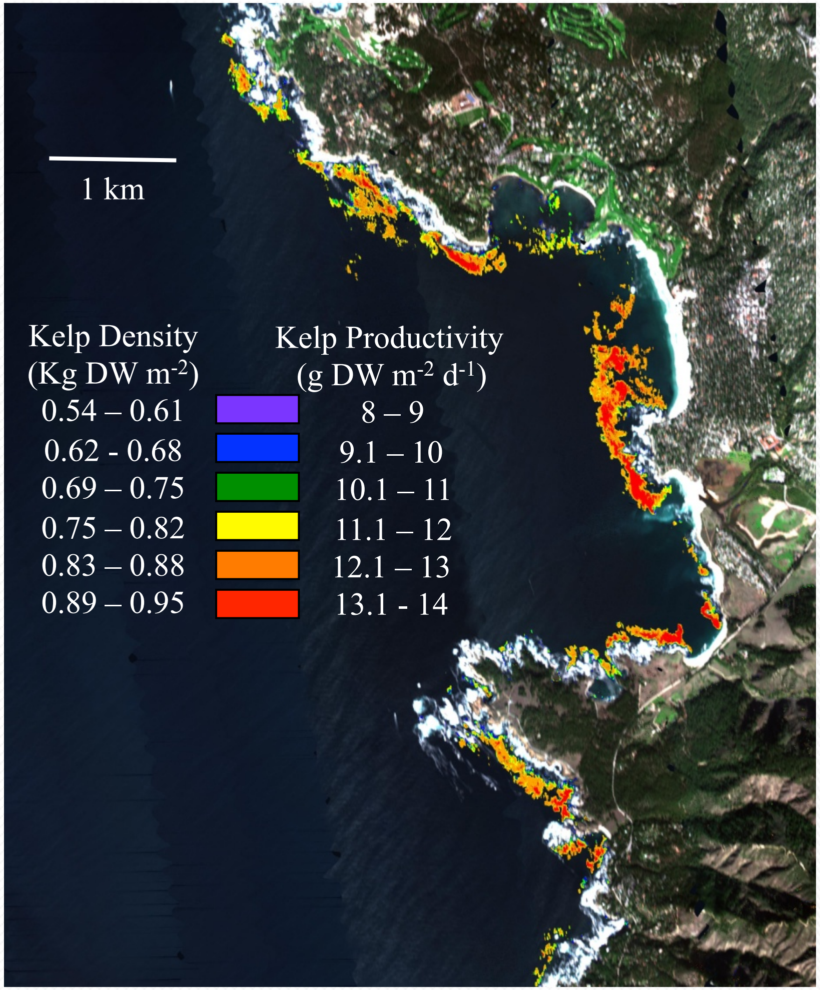
And for quantifying

- Abundance of submerged seagrass



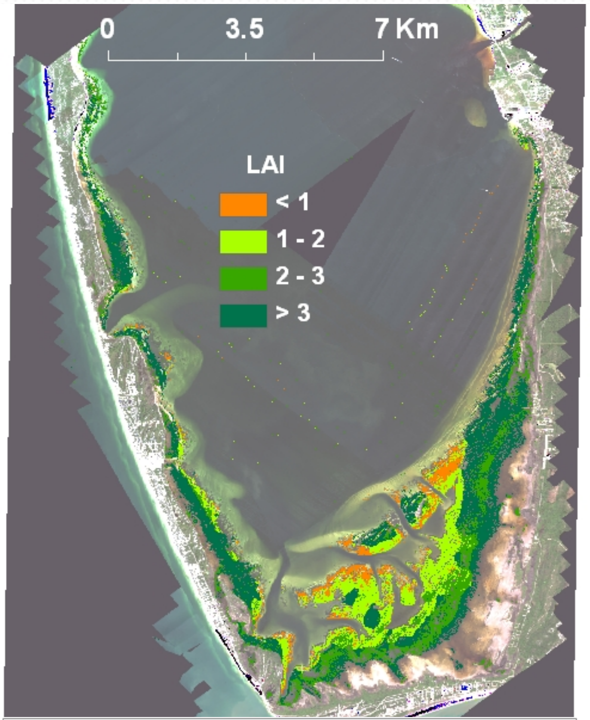
But bathymetry is problematic

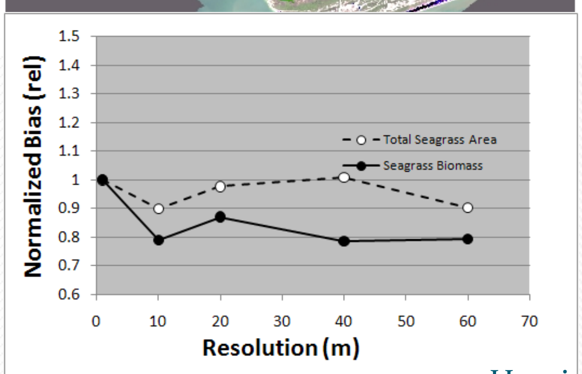
In more complex waters of coastal California past experiments demonstrated utility of HS imagery for mapping giant kelp



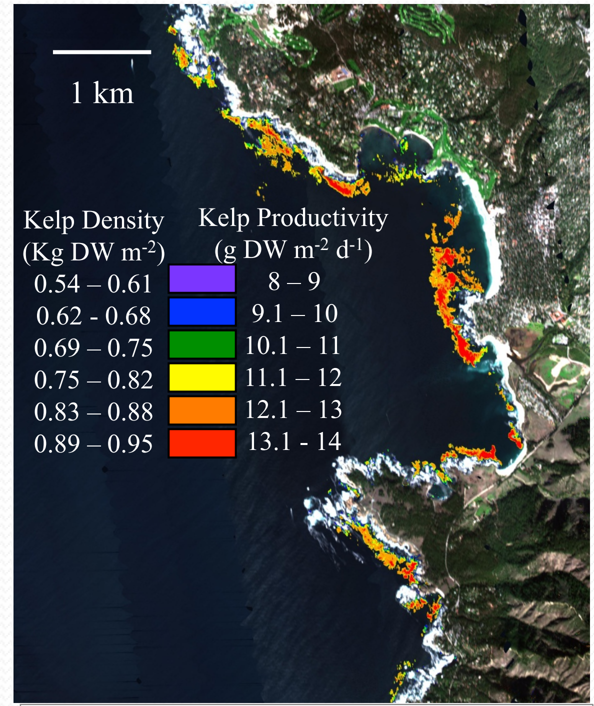
- Distribution
- Abundance
- Productivity
- However, the results are sensitive to spatial resolution of the imagery

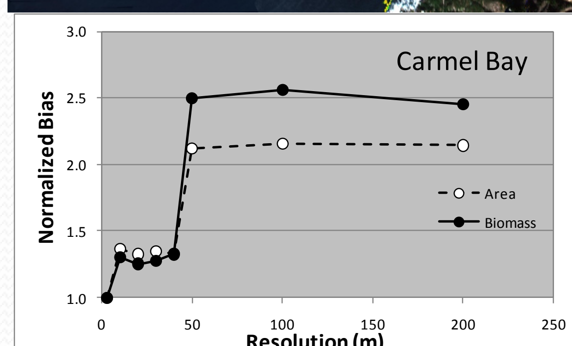
Size matters….



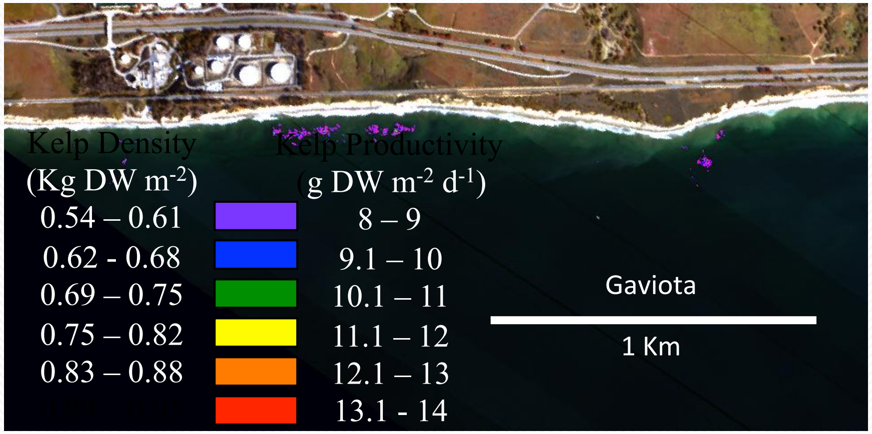


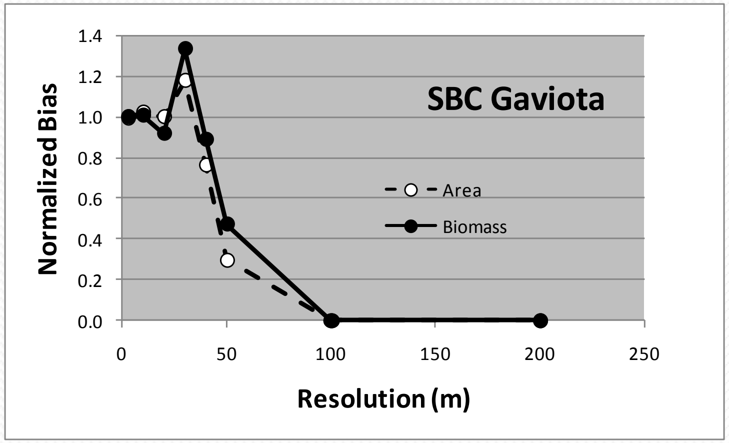
- Retrieval accuracy decreases with pixel resolution
- Error appears consistent within a scene
- But not across scenes

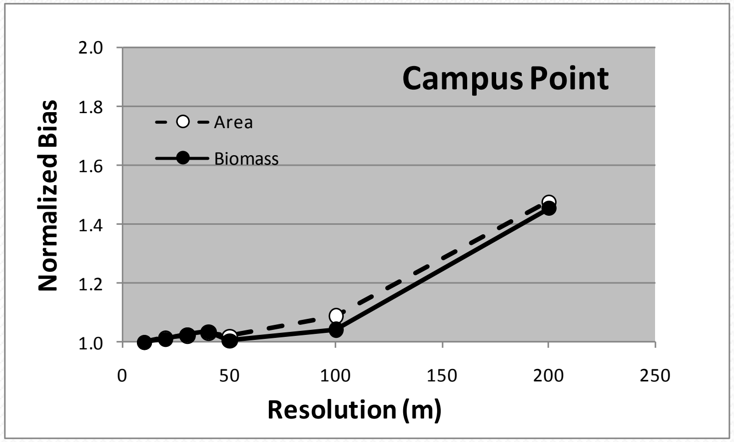




Size matters….







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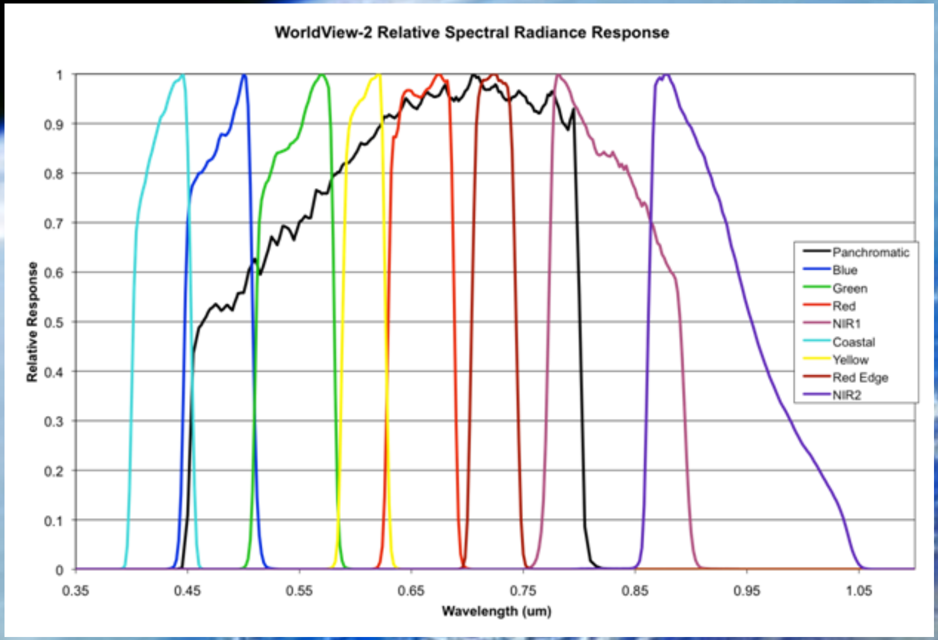
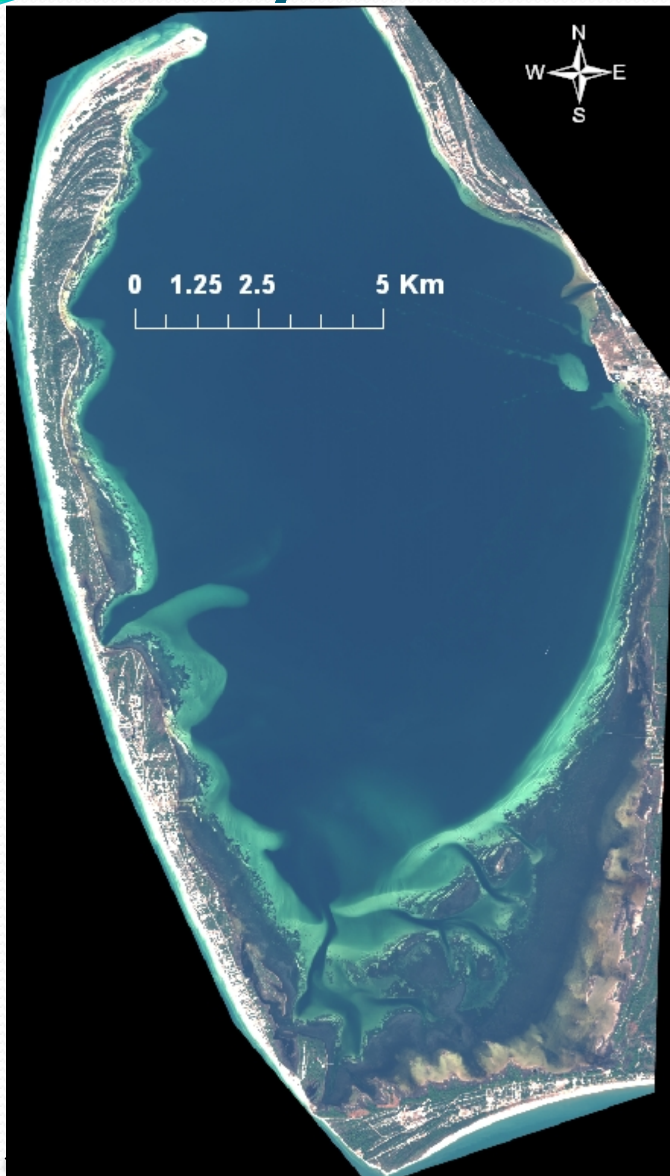
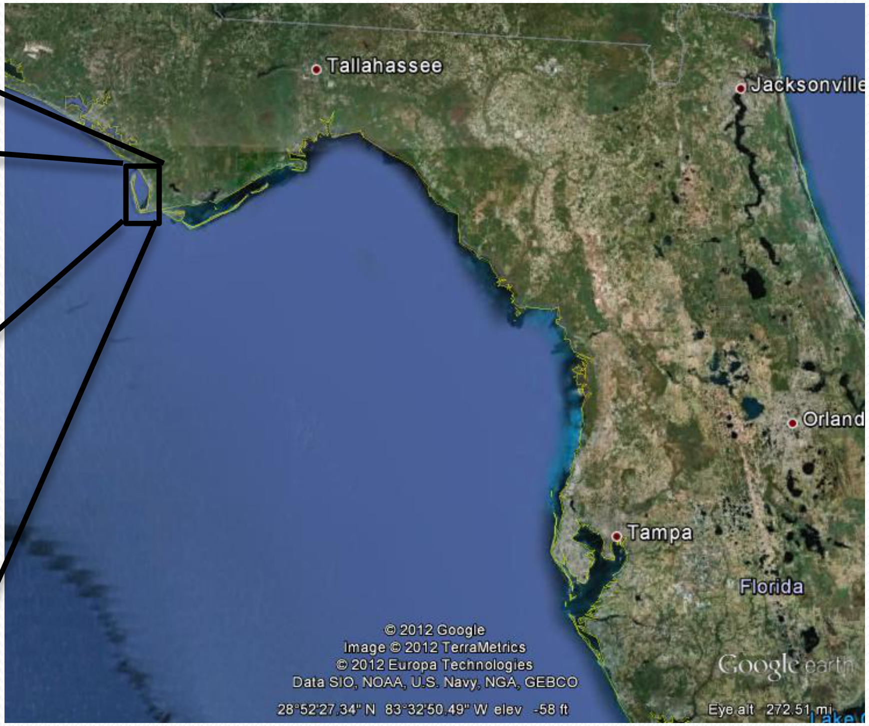
So, how does spectral resolution affect our retrievals?

- WorldView-2
  - Operated by Digital Globe, Inc
  - 8 multispectral bands
  - 3 m resolution (0.5 m pan)
  - 12 bit dynamic range
  - Pointing capability
    - Optimize view angle
    - Avoid glint



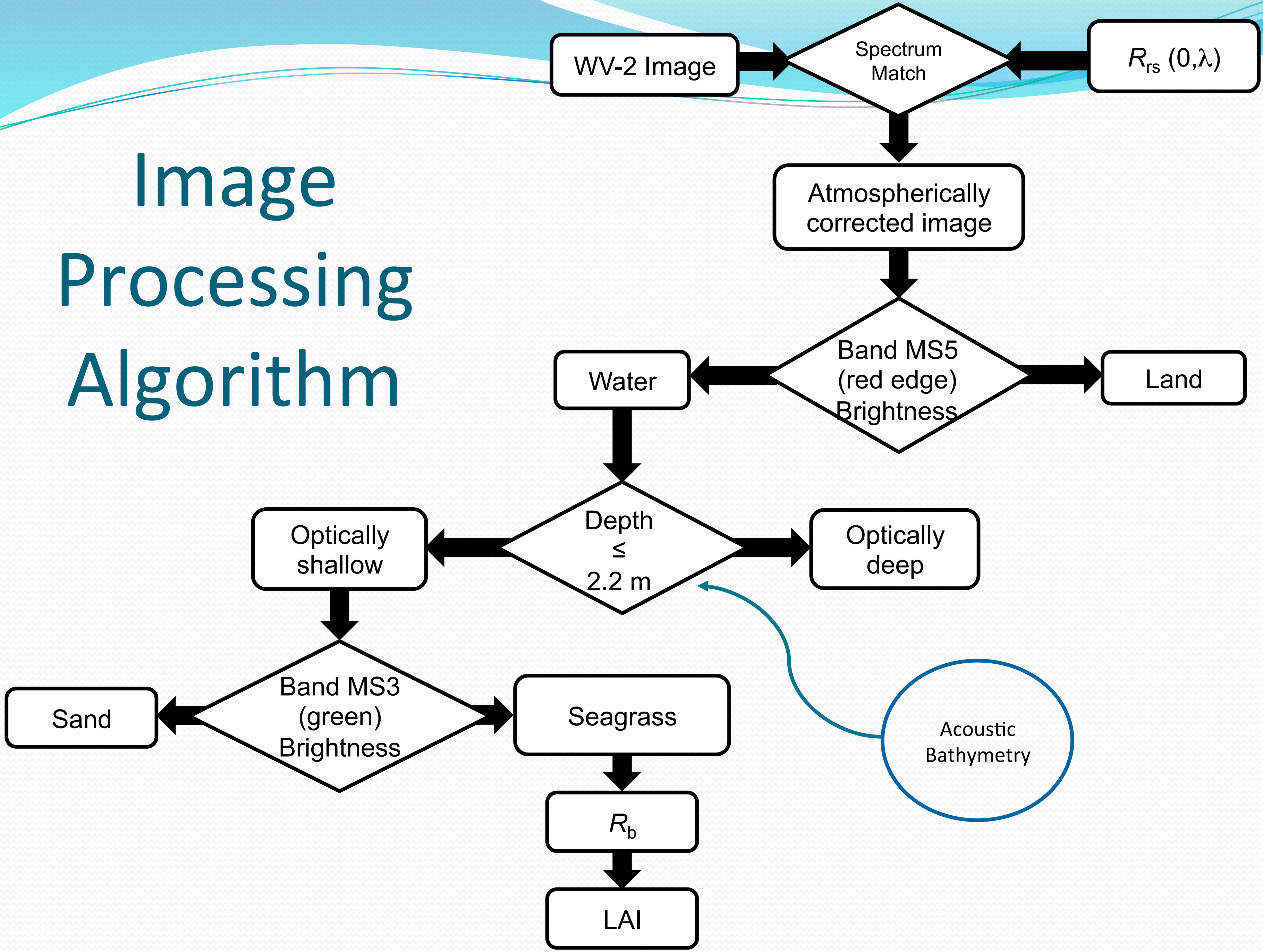
Study Site: St Joseph's Bay, FL, USA



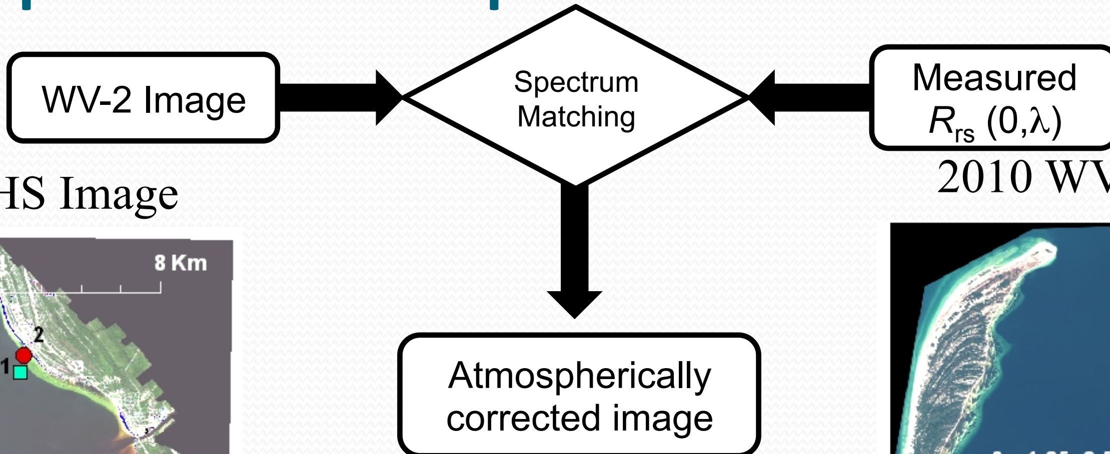


- Optically deep basin (>3 m)
- Shallow fringe (<2 m) consisting of
  - Bare sand
  - Seagrass meadows
  - Benthic algae
- Highly colored water column
  - CDOM
  - Phytoplankton
  - Detritus/Sediment

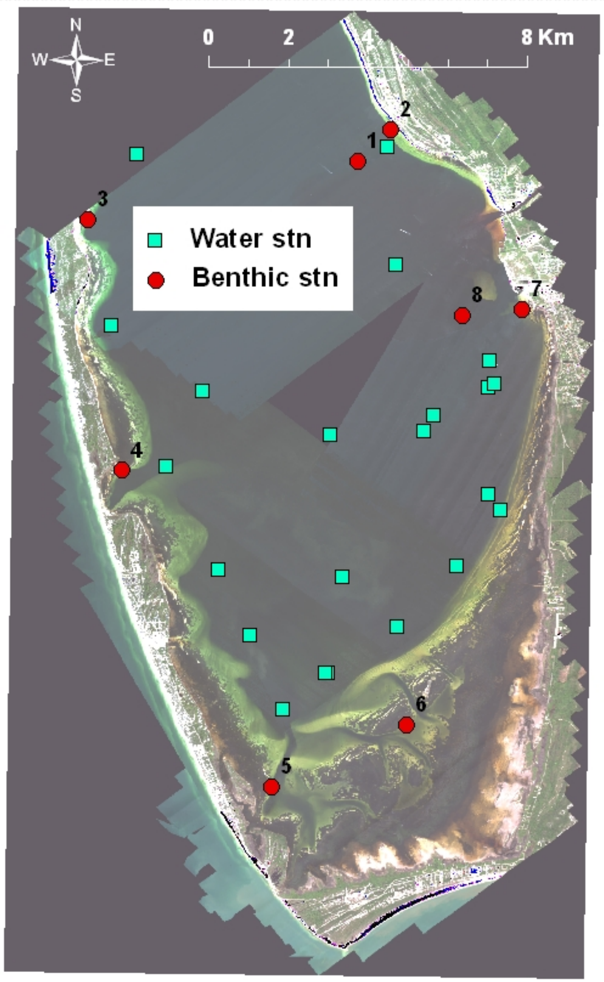
Image Processing Algorithm

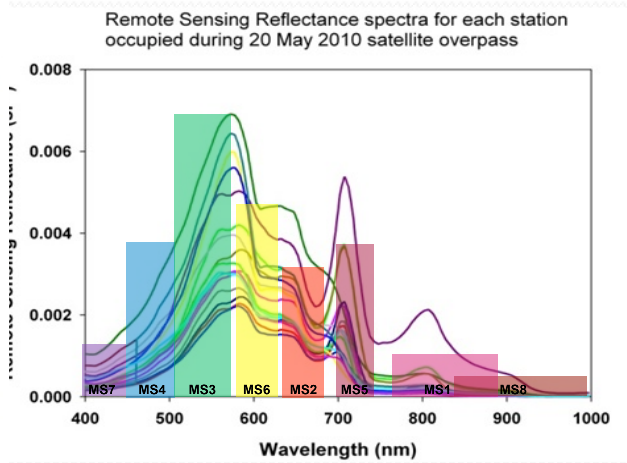


Step 1: Atmospheric Correction

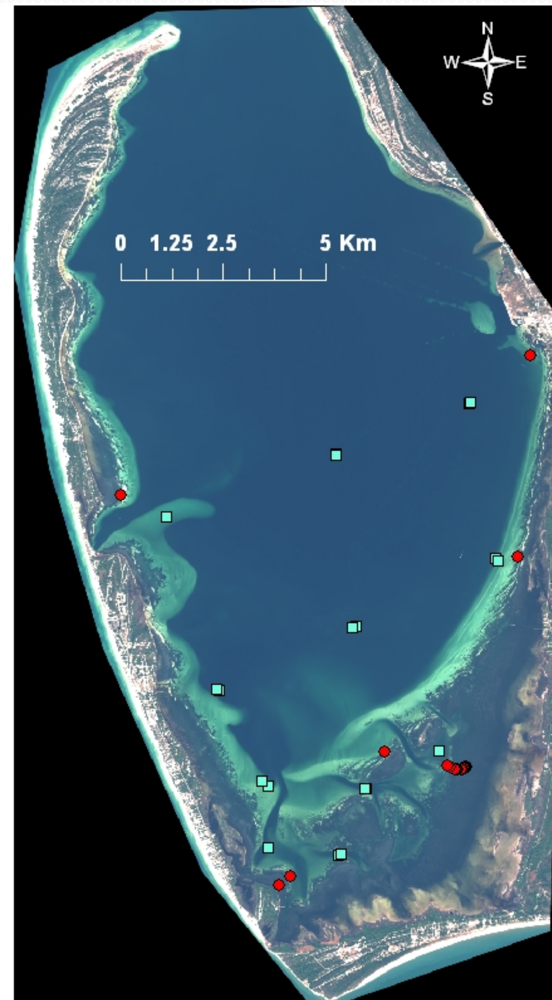


2006 SAMSON HS Image





2010 WV-2 MS Image

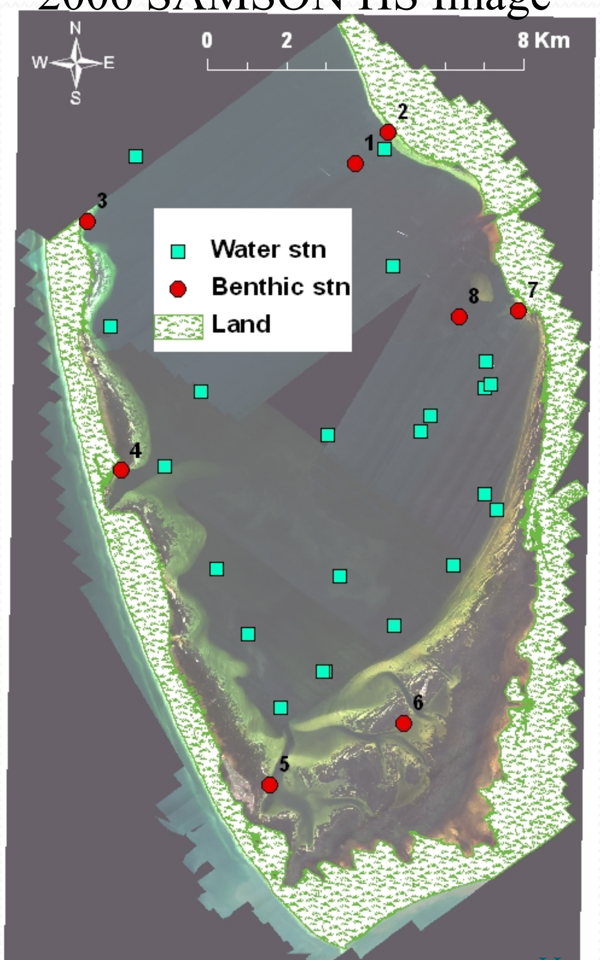


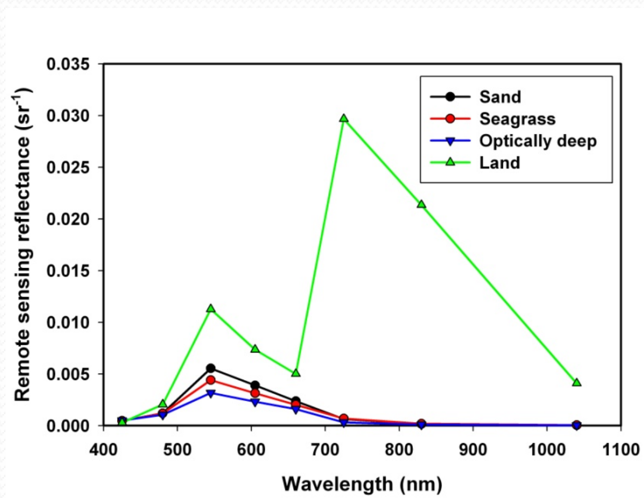
Step 2: Remove Land Pixels

Atmospherically corrected image → Band MS5 (red edge) Brightness → Land

Band MS5 (red edge) Brightness → Water

2006 SAMSON HS Image





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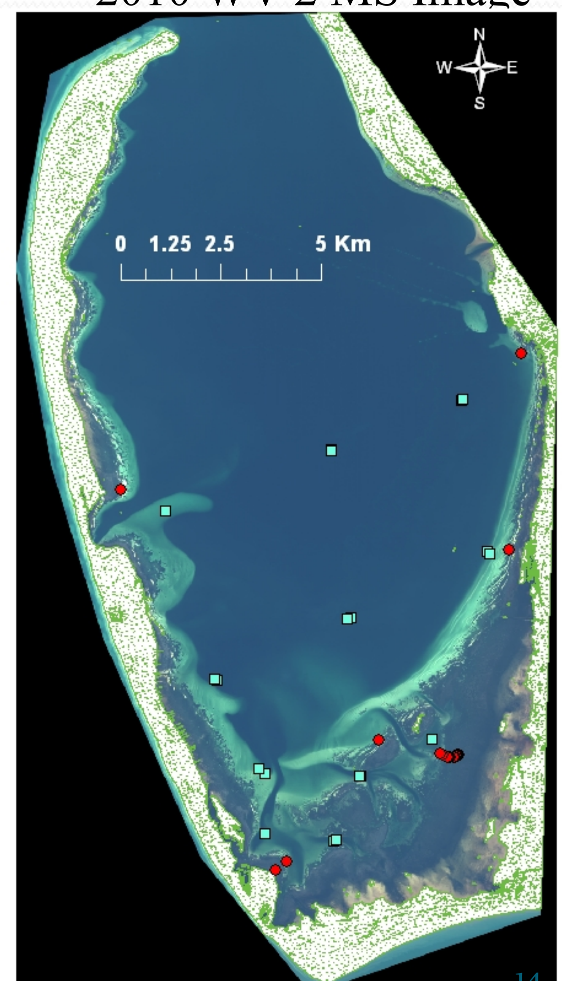
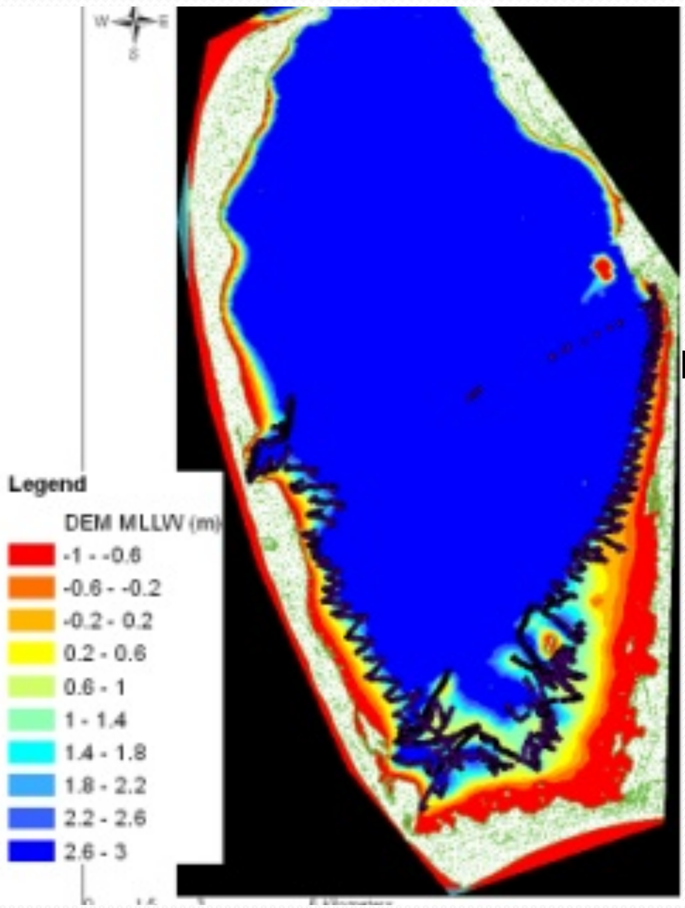
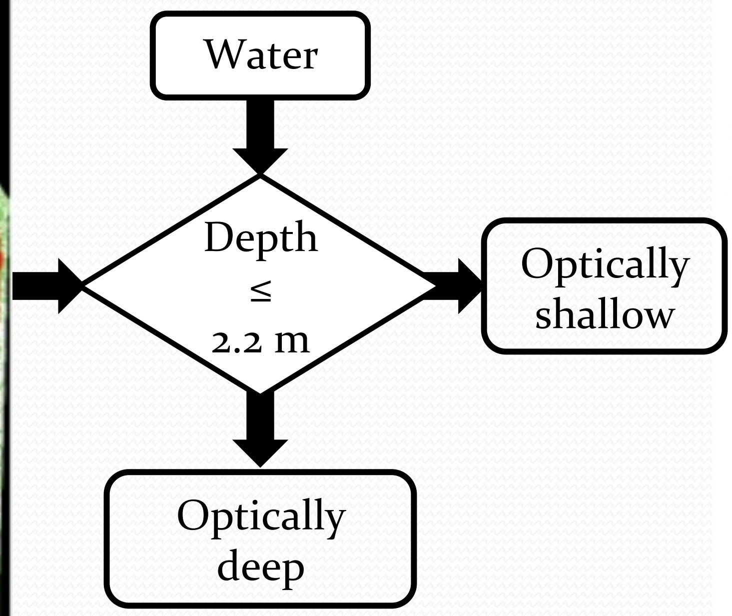
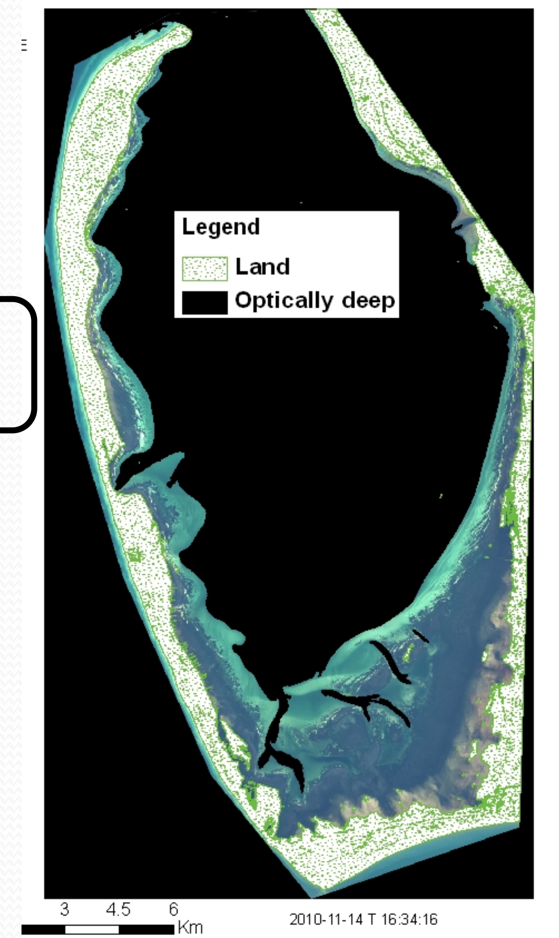


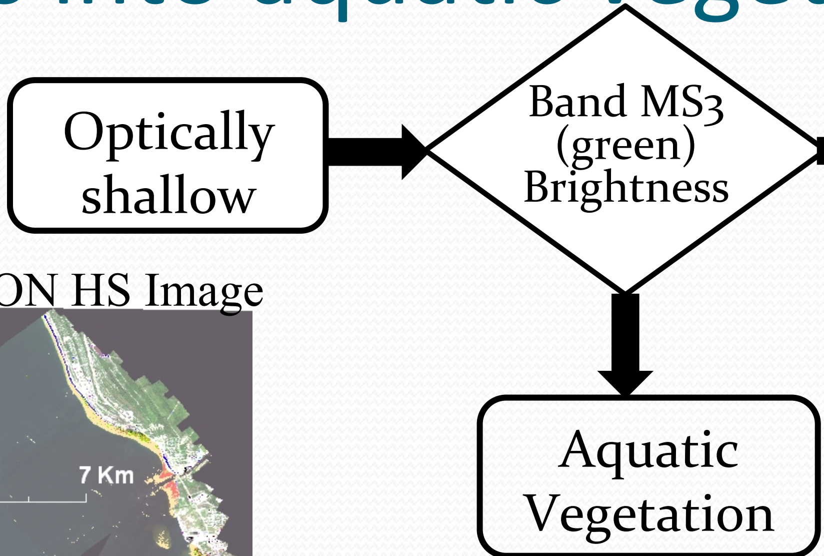
Step 3: Remove optically deep water pixels using acoustic DEM:



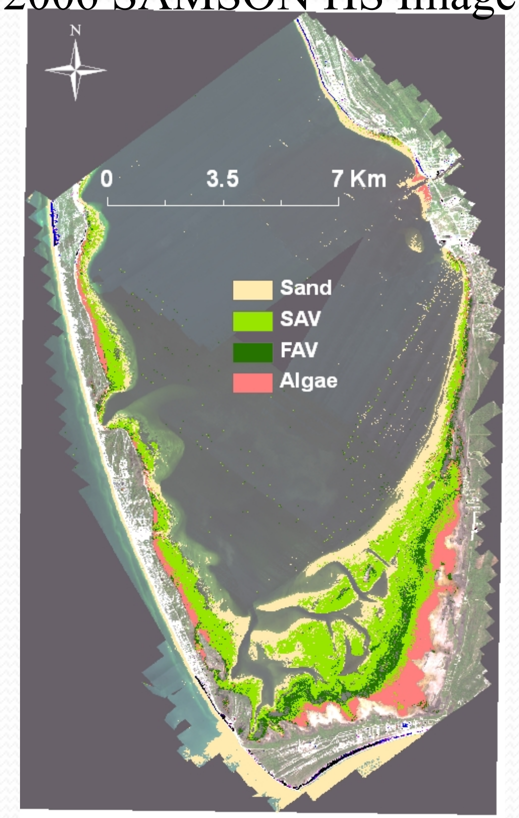




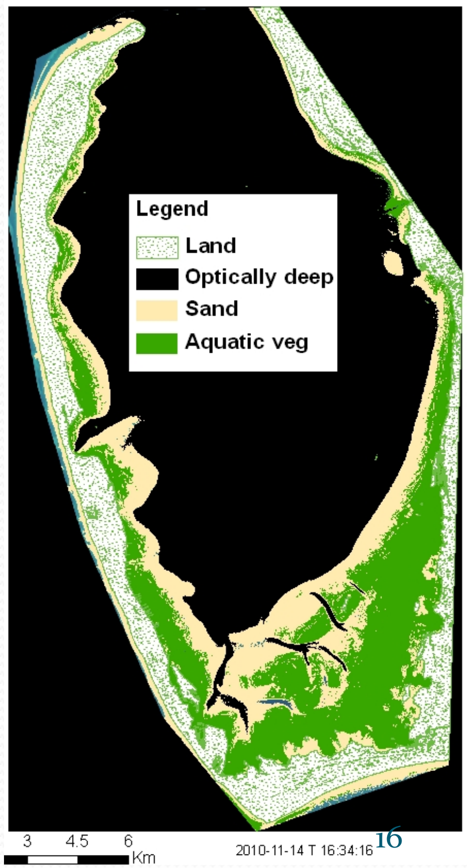
Step 4: Separate optically shallow pixels into aquatic vegetation and sand



2006 SAMSON HS Image



2010 WV-2 MS Image



Step 5: Retrieve R_b for seagrass pixels

Acoustic Bathymetry

+

Seagrass

+

IOPs

- R_{rs} from WV-2 imagery
- $Q_b = E_u(z_b)/L_u(z_b) = \pi$
- K_{Lu} & K_d from *Hydrolight* using measured IOPs

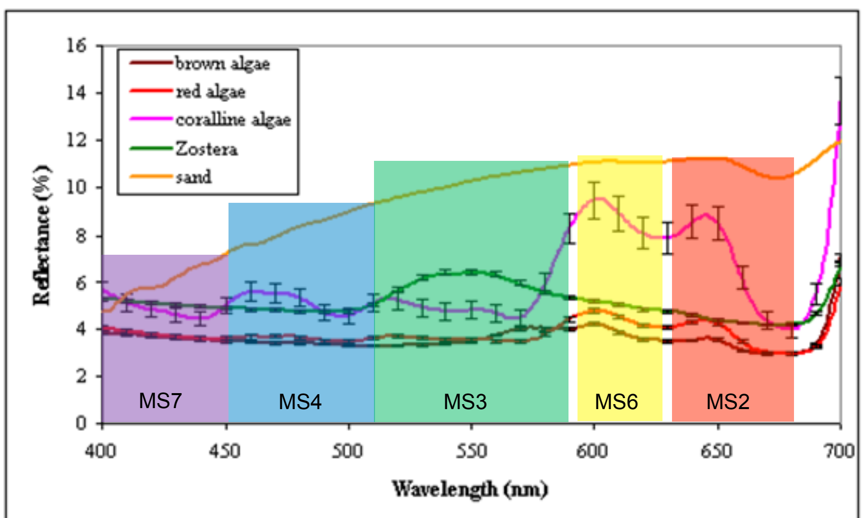
$$R_b = \frac{R_{rs} Q_b}{t} \frac{\exp\left[-K_{Lu} z_b\right]}{\exp\left(K_d z_b\right)}$$

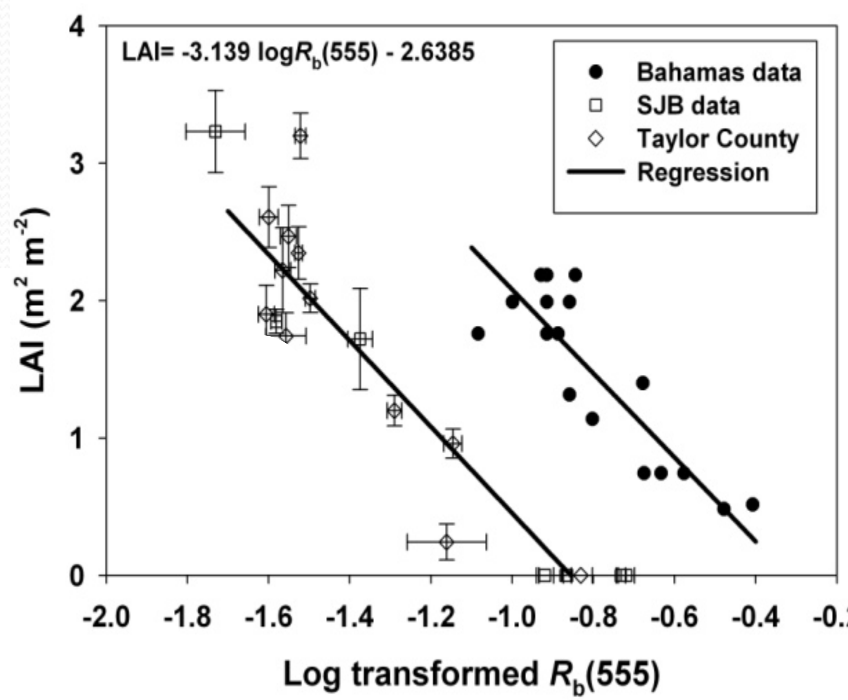
- z_b – bottom depth from acoustic survey
- t – air/sea transmittance of $L_u(0.54)$

Dierssen, H., R. Zimmerman, R. Leathers, T. Downes, and C. Davis. 2003. Remote sensing of seagrass and bathymetry in the Bahamas Banks using high resolution airborne imagery. Limnol. Oceangr. **48: 444-455.**

$$R_b = \frac{R_{rs} Q_b}{t} \frac{\exp\left[-K_{Lu} z_b\right]}{\exp\left(K_d z_b\right)} \rightarrow \text{LAI}$$

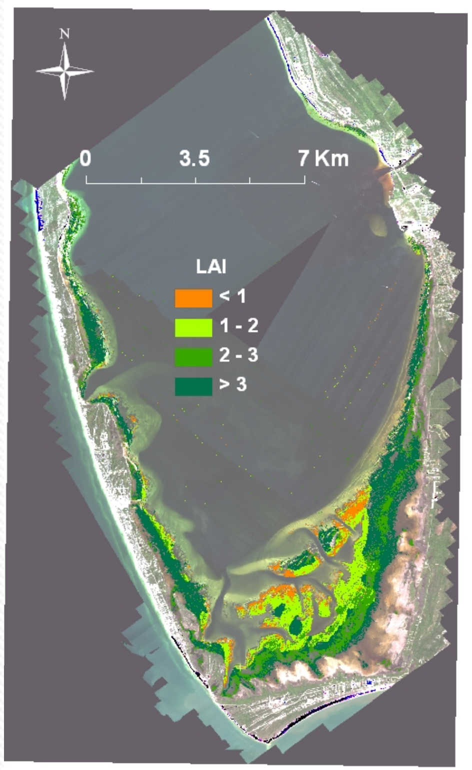
- Log $R_b(555)$ predicts LAI
- Florida and Bahamas slopes consistent
- X-intercept results from brightness of sand bottom (siliclastic vs. carbonate)
- Benthic algae are seen as seagrass
  - Spectral band resolution did not permit optical differentiation of seagrasses from benthic algae





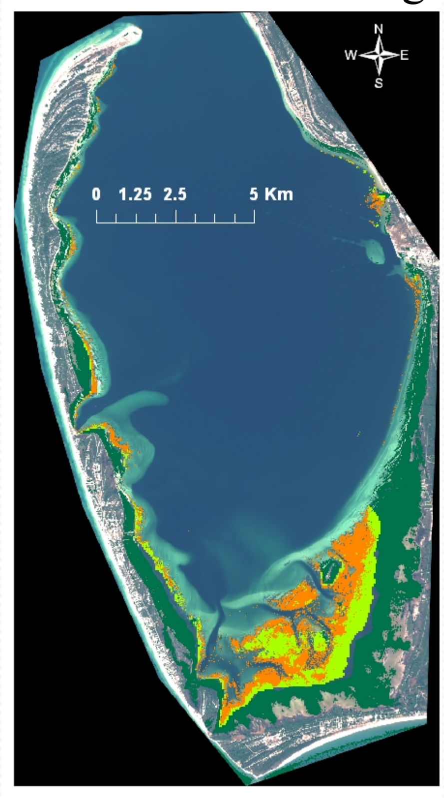
Quantifying the Abundance of Submerged Aquatic Vegetation in Nearshore Coastal Environments

2006 SAMSON HS Image

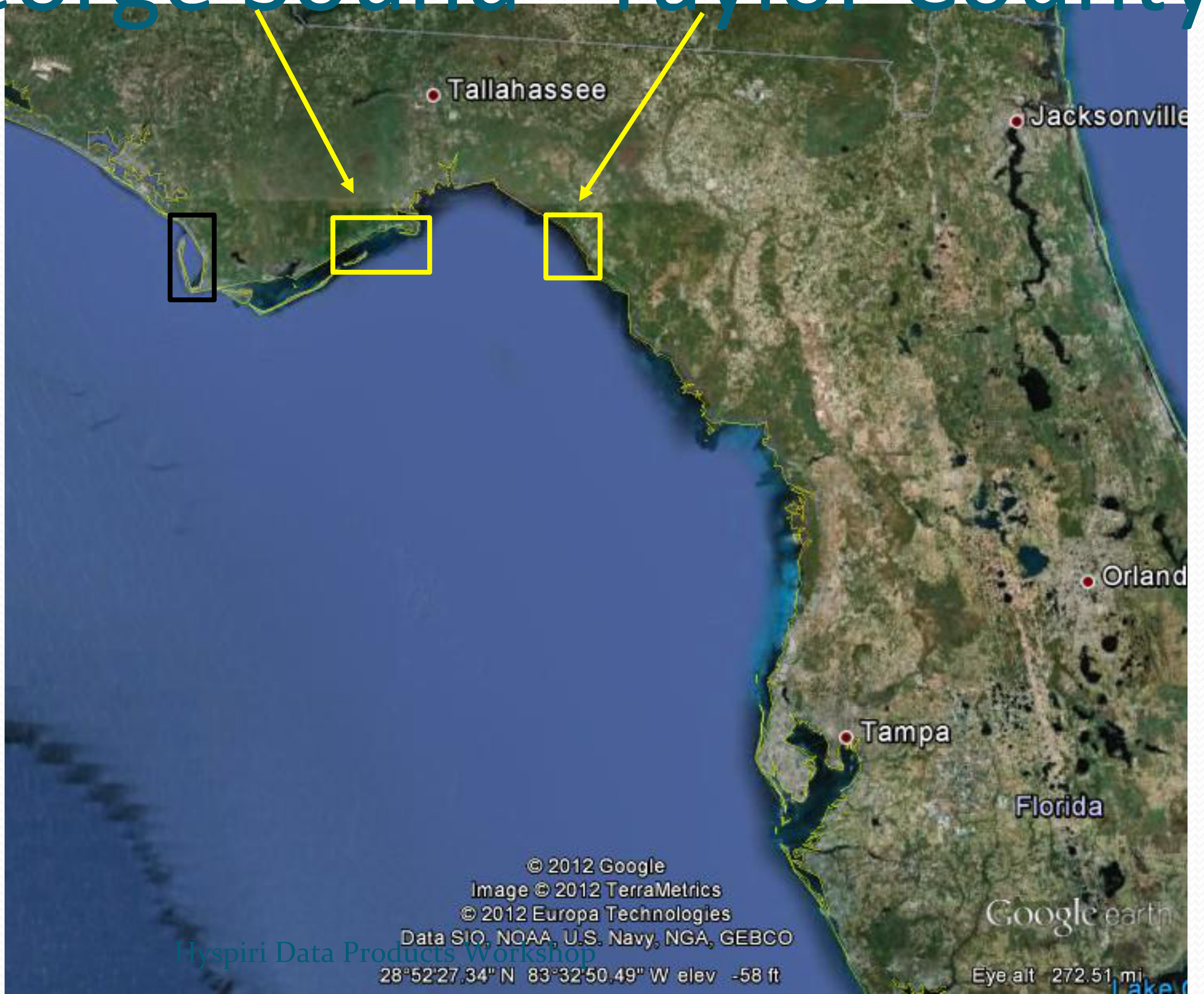


Target	2006 Hyperspectral	2010 Multispectral	Difference (%)
Water depth at overpass (rel MLW)	0.4	-0.5	
Total Area Covered	149	184	0
Benthic Classification Accuracy	100%	100%	0
Optically Shallow Area (km^2)	37	57	34
Bare Sand Area (km^2)	14	27	49
Benthic Vegetation Area (km^2)	24	30	21
SAV Area (km^2)	15	11	-35
FAV Area (km^2)	3	19	82
Benthic Algae	5	N.A.	

2010 WV-2 MS Image

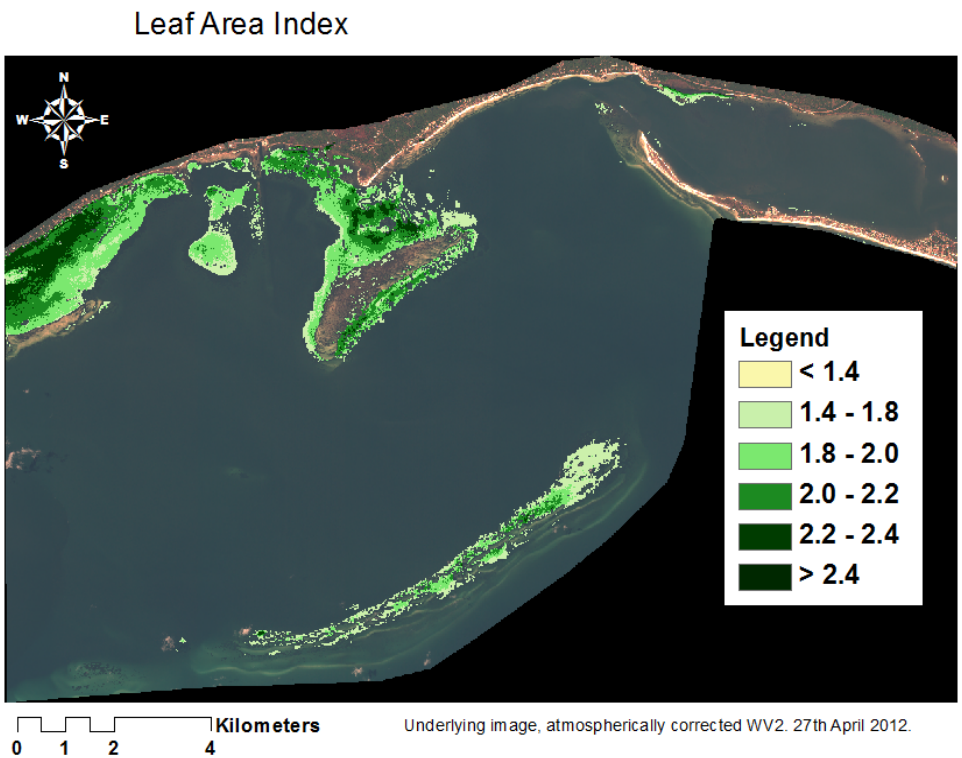


Two additional sites –
St. George Sound   Taylor County, Fl

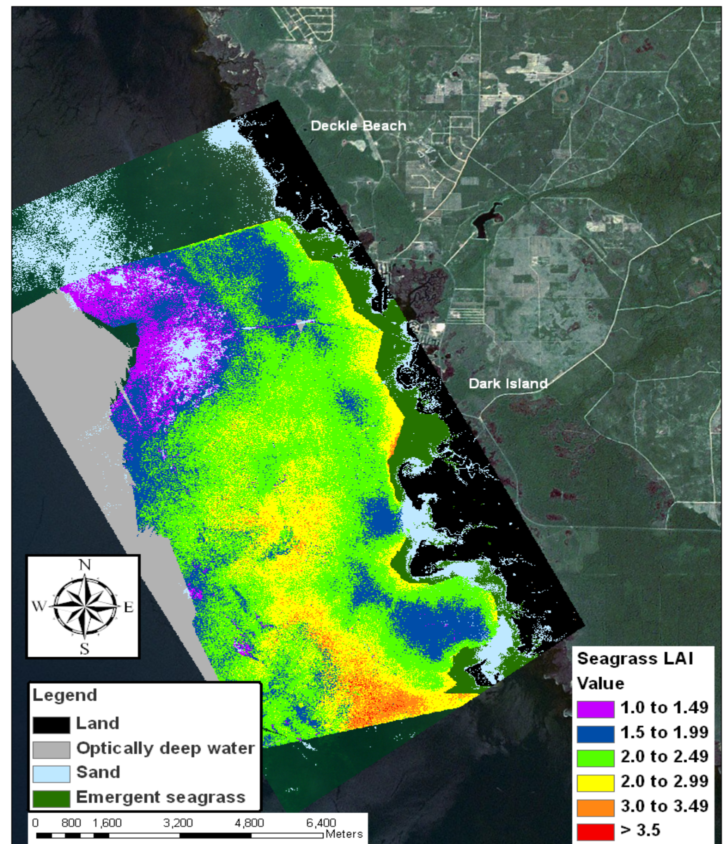


Quantifying the Abundance of Submerged Aquatic Vegetation in Nearshore Coastal Environments

2012 WV-2 MS Image
St George Sound, FL



2010 WV-2 MS Image
Taylor County, FL



Conclusions

- Aquatic macrophyte abundance readily quantified from imaging spectroscopy
- Spatial resolution affects retrieval statistics
  - Loss of texture and patch detail
  - Over-estimates size of large patches
  - Small patches disappear
  - Largest effects between 10 and 50 m resolution
- Spectral resolution affects resolution of plant functional types
  - MS imagery easily discriminates between vegetated areas and sand
    - Sufficient for quantifying seagrass abundance in coastal waters
  - Discrimination among vegetation functional types not possible
    - Optically deep green water looks like SAV
    - Seagrasses and seaweeds not separable
- Bathymetry is essential; optical retrieval unreliable
  - LIDAR bathymetry library growing
  - Once obtained, likely to be valid for considerable time in most areas

Future Work

- The glint issue can be tested experimentally
  - Hyspiri Discussion Group 2009-2010
    - Not a serious problem for classifying seagrass and bright sand in clear (blue) waters
    - Ability degrades with turbidity & depth
    - Need to assess impacts of glint
      - in turbid or colored coastal waters
      - on biomass estimates
- MS-sharpening as a way to increase spatial resolution of HS image?
- Analogous to pan-sharpening of MS imagery
- Could be tested by co-ordinated imaging of same region from 2 sensors
    - E.g. HICO and WV2