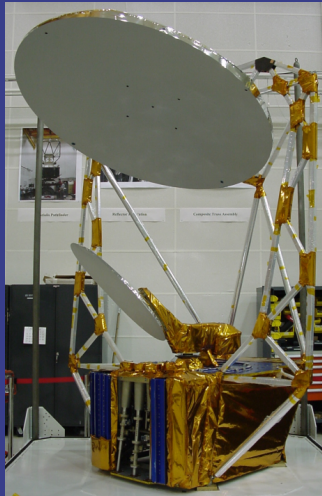




NRL Remote Sensing Division Code 7200



The Joy of Remote Sensing: *From "Back-of-the-envelope" to Programs*



Virginia Tech GIS & Remote Sensing 2014 Research Symposium



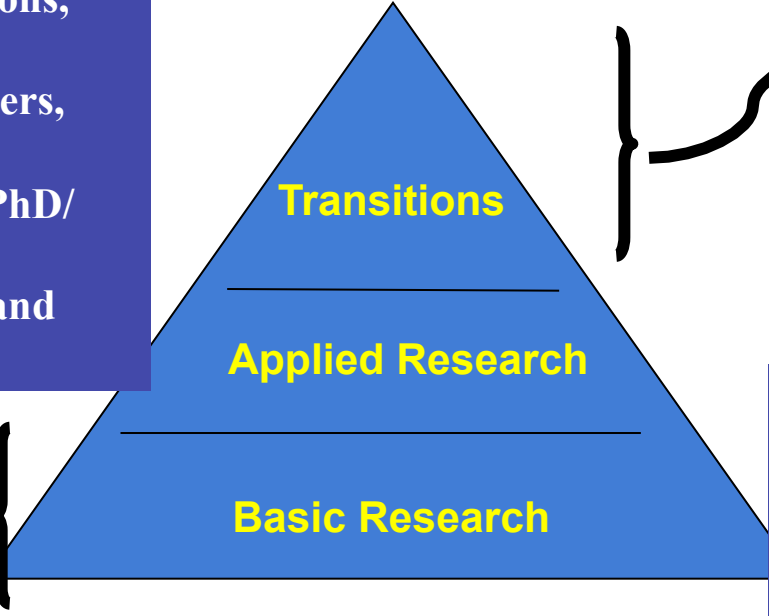
Richard Bevilacqua
Superintendent, Remote Sensing Division
Naval Research Laboratory



Established in 1923, NRL is the Navy's corporate Laboratory conducting a broadly based multidisciplinary program of scientific research and advanced technological development directed toward maritime applications of new and improved materials, techniques, equipment, systems and ocean, atmospheric, and space sciences and related technologies.



- Science Metrics**
- Papers, patents, citations, royalties
 - Nat'l Academy members, society fellows
 - Percent of staff with PhD/advanced degrees
 - Prestigious scientific and engineering awards



Operational DoD Community

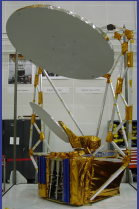
- DoD Metrics**
- Transitions & quick responses
 - BRAC military value rankings
 - Studies by DSB, NDU, NRAC, NAS, etc
 - Outside customers

Science Community

Environmental Research is an important part of the NRL mission



NRL Remote Sensing Division Code 7200



Division Mission: Pushing the Envelope

The NRL Remote Sensing Division is the Navy's center of excellence for remote sensing research and development, conducting a broad program of basic and applied research across the full electromagnetic spectrum using active and passive techniques from ground-, air-, and space-based platforms.

- The Division includes both remote sensing technology and phenomenological expertise within the same organization.
- The Division emphasizes an interdisciplinary approach to remote sensing challenges.
- Present research areas include astronomy, atmospheric, earth and ocean science.





NRL Remote Sensing Division: *Crabs to the Crab Nebula*

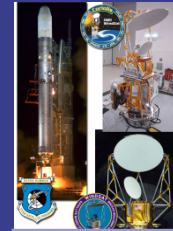
Astronomy



Polar Ozone and Aerosol Measurement (POAM II and III)



Ground-based mm-wave spectroscopy



WindSat



WSII

Middle Atmosphere

Passive Microwave

Optical: Naval Prototype Optical Interferometer (NPOI)



Remote Sensing:
Measurement of signatures and interpretation in terms of a phenomenology or physical/chemical property of the medium



Phased Array Radar (FOPAIR)

Radio: Long-Wave Array (LWA)

SEALAB

Hyperspectral Imaging

SAR



IR: Herschel Space Observatory



Sensor Development



Calibration



Exploitation



Ground truth



Field Measurements



HICO



Free Surface Hydro. Lab

Hydrodynamics

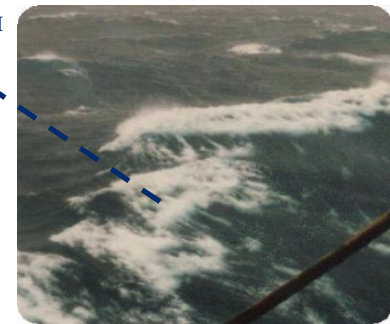
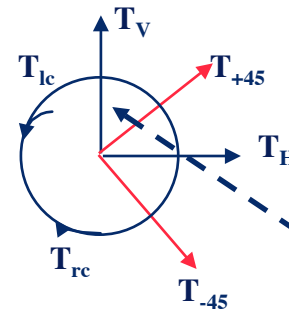


Remote Sensing of Winds over the Ocean

- Winds over the ocean are important for weather and climate, and have important significance for naval operations.
- A few preliminaries:
 - $Tb \equiv (c^2/2kv^2)I\nu$ In the Rayleigh-Jeans limit ($h\nu \ll kT$) $Tb = \epsilon T$
 - Polarimetry : The polarization state of radiation contains a great deal of information about the medium (in which the radiation has interacted) which can be exploited in remote sensing.

The Stokes Vector:

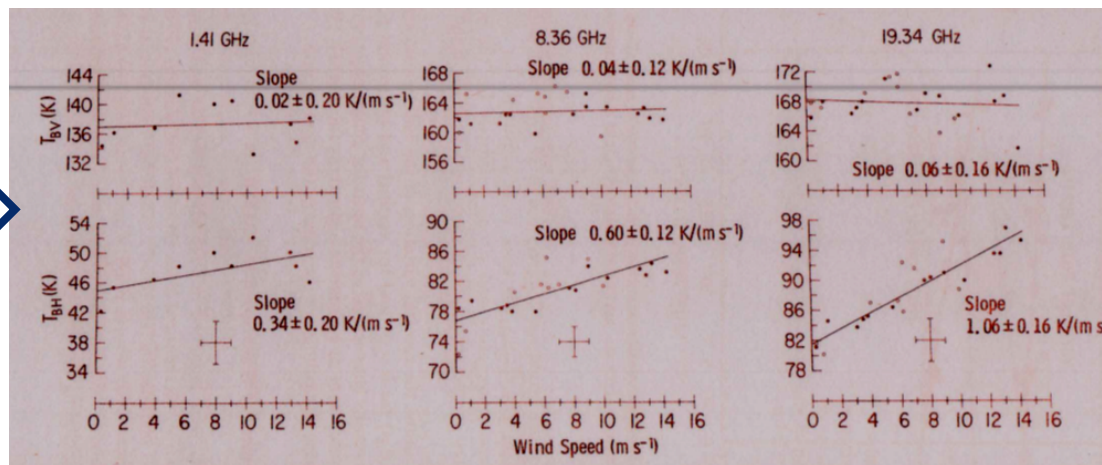
$$I_s = \begin{bmatrix} I \\ Q \\ U \\ V \end{bmatrix} = \begin{bmatrix} T_v \\ T_h \\ T_{45} - T_{-45} \\ T_{lc} - T_{rc} \end{bmatrix} = \begin{bmatrix} \langle E_v E_v^* \rangle \\ \langle E_h E_h^* \rangle \\ 2 \operatorname{Re} \langle E_v E_h^* \rangle \\ 2 \operatorname{Im} \langle E_v E_h^* \rangle \end{bmatrix}$$





Wind Speed

**NRL Tower Experiments:
1970-1976**



Hollinger, 1971

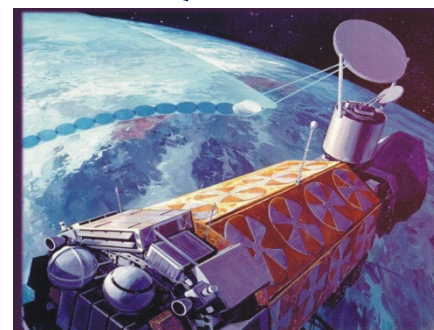
**NRL Aircraft measurements:
1976-1980**



Retrieval Model Development

Special Sensor Microwave Imager (SSM/I):

- Primary military and civilian microwave imager from 1986 projected through 2018.
- Operational global ocean wind speed measurements
- Assimilated into operational weather models
- Cost avoidance of millions of dollars per year in ship routing storm avoidance



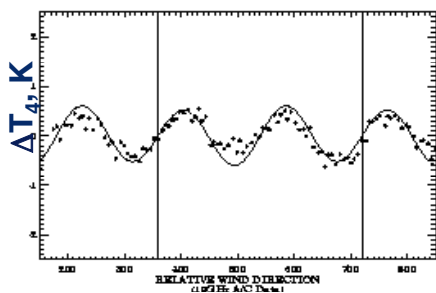
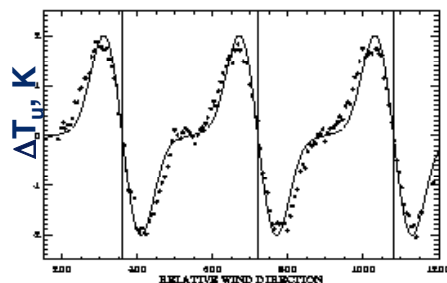
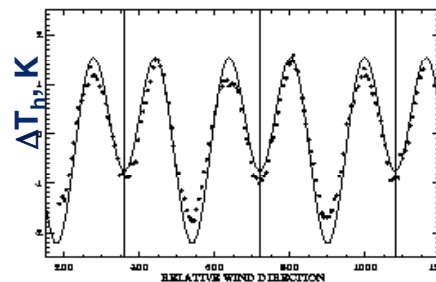
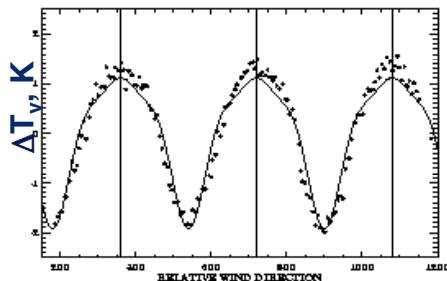
First SSM/I launch: 1987



Wind Vector (wind speed and direction)

- SSMI/S wind speed error found to have a wind direction bias:
 - Implies a wind direction dependence of the polarimetric radiation field: consistent with model calculations.

(Wind Speed = 9 m/s; Vertical Lines Identify Upwind Direction)



Wind direction dependence arises from anisotropic distribution and orientation of wind driven waves

Polarimetric NRL/JPL Aircraft Experiment and model development: 1994-1998



NRL WindSat: launched in Jan, 2003 and still operational



- First fully polarimetric microwave radiometer in space.
- Demonstrated the measurement of wind speed and direction from space using passive microwave radiometry.



WindSat/Coriolis – Mission Overview



- Demonstrate Ocean Surface Wind Speed and Direction Measurement Capability From Space With Polarimetric Microwave Radiometry
 - Wind Vector Is a High Priority EDR for the Navy
 - Risk Reduction for NPOESS Microwave Imager (Now DWSS MIS)
- NRL Responsible for Science, Payload Development, Mission Operations, Vehicle Integration, and Cal/Val
 - Successful Ops (*11 years and counting!*)
 - An Inter-Agency (IPO/Navy/USAF) Cooperation Success Story
- WindSat/Coriolis Successfully Demonstrated Capability of Polarimetric Microwave Radiometry to Measure Ocean Surface Wind Vector
- Currently the Only US Sensor Capable of Providing Global Ocean Surface Vector Winds

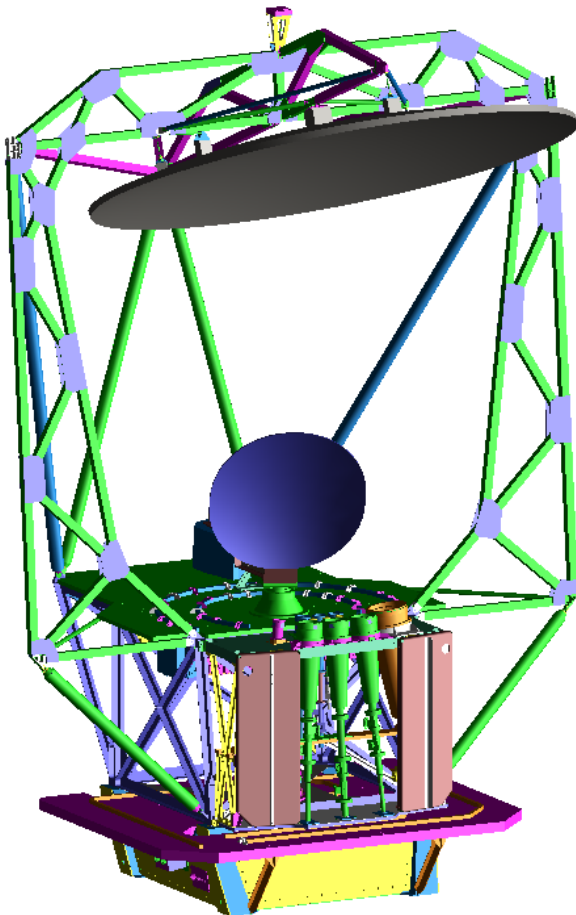
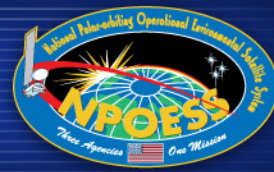


WindSat data operationally assimilated into numerical weather models and used for other DoD and civilian applications

Launched January 6, 2003



WindSat Payload Configuration



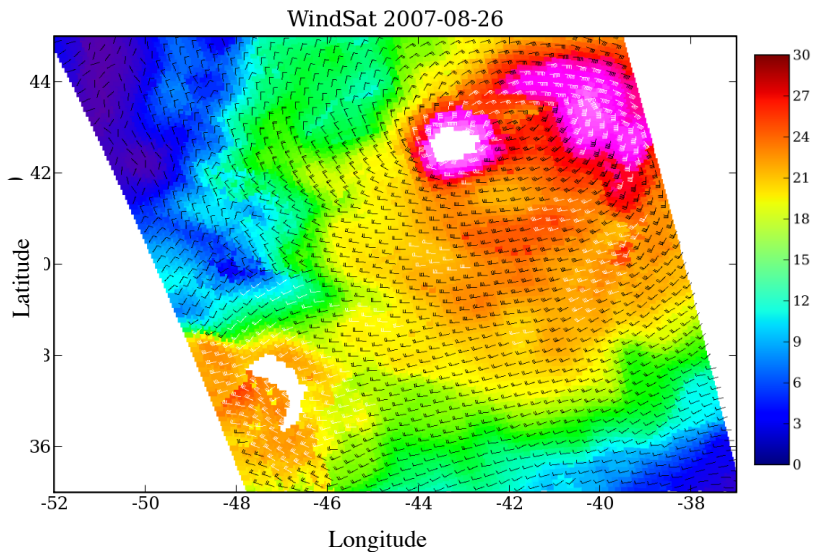
Freq, GHz	Channels	BW, MHz	EIA, deg	IFOV, km
6.8	v, h	125	53.5	40x60
10.7	v, h, ± 45 , lc, rc	300	49.9	25x38
18.7	v, h, ± 45 , lc, rc	750	55.3	16x27
23.8	v, h	500	53.0	12x20
37.0	v, h, ± 45 , lc, rc	2000	53.0	8x13

Height	10.5 ft
Width	8.25 ft
Mass	661 lbs.
Power	311 Watts
Spin Rate	31.6 rpm

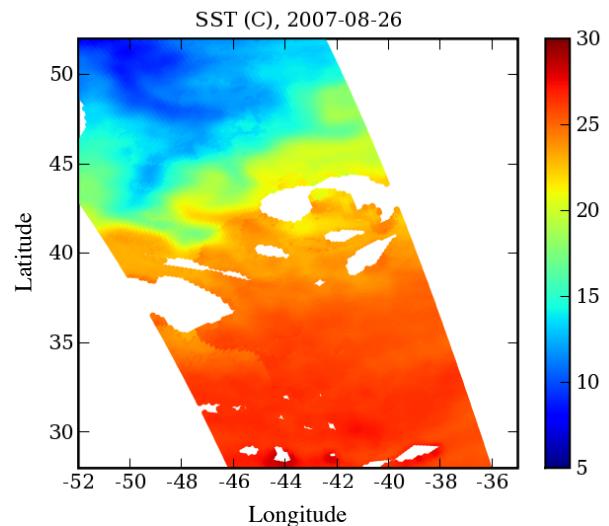


WindSat Produces Multiple Simultaneous EDRs

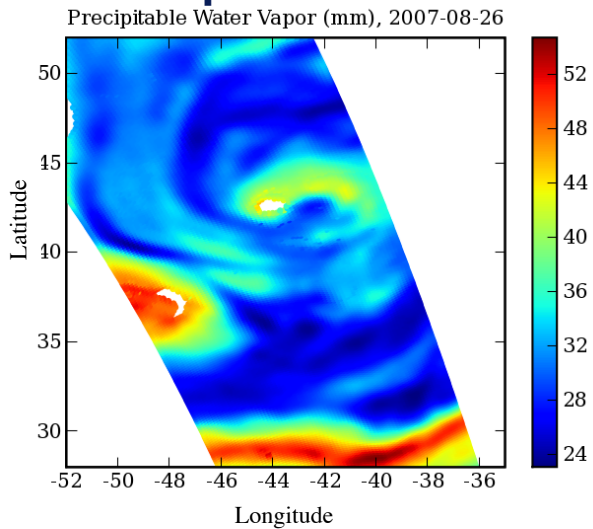
Wind Vector



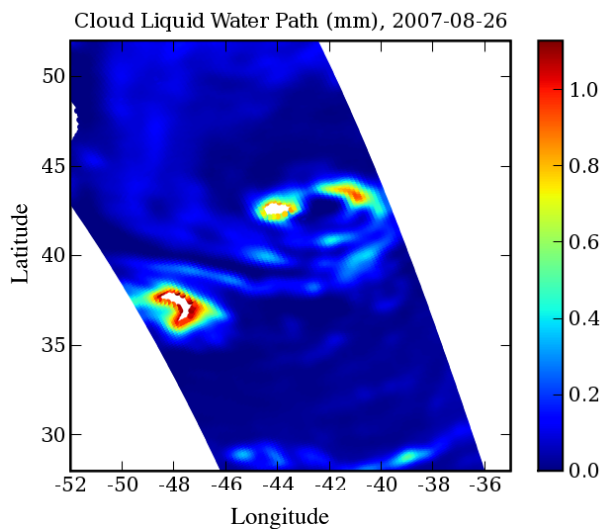
SST



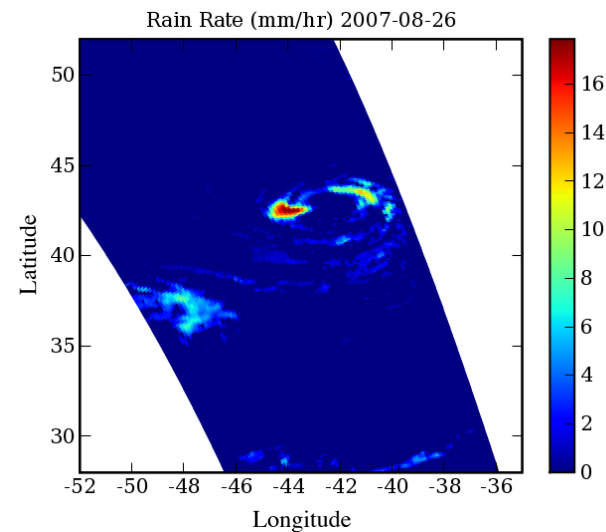
Precipitable Water



Cloud Liquid Water



Rain Rate



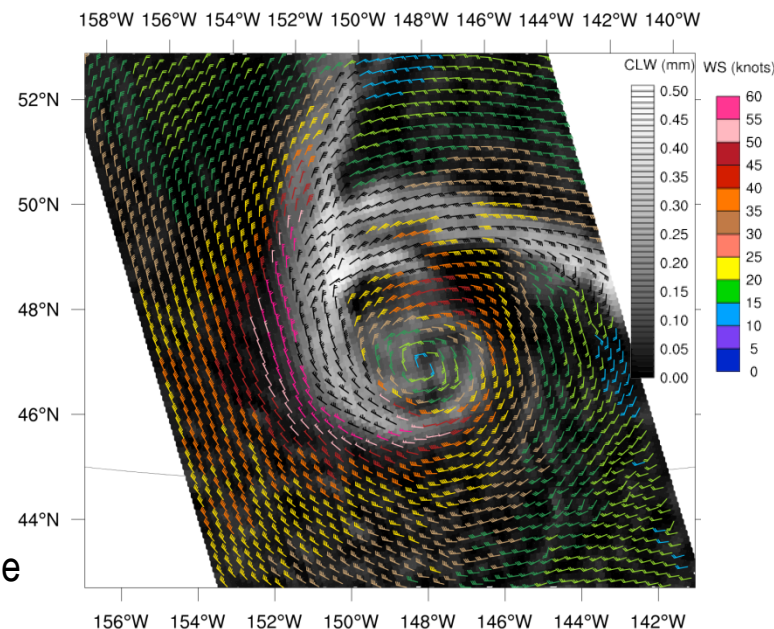


WindSat Operational Data Utilization



- WindSat data processed in near real time (NRT) at Fleet Numerical Meteorological and Oceanographic Center (FNMOC)
 - Data Provided to Users on Shared Processing Network [NESDIS, NAVO, NRL-Monterey (NRL-MRY), AFWA, CSU/CIRA]
 - Data pulled by many US and international users
- WindSat data products are operationally assimilated into numerical weather prediction (NWP) models
 - Navy NOGAPS: wind fields and water vapor
 - NOAA/NCEP Global Forecast System: wind fields
 - UK Met Office Unified Model: wind fields, radiances
- WindSat products used for tropical cyclone monitoring and forecasting
 - NRL-MRY, Joint Typhoon Warning Center, National Hurricane Center
 - Microwave Imagery, Wind Fields, Precipitation, Water Vapor, and SST

Extra-Tropical Cyclone in Northern Pacific



WindSat Has Transitioned from R&D to Operations

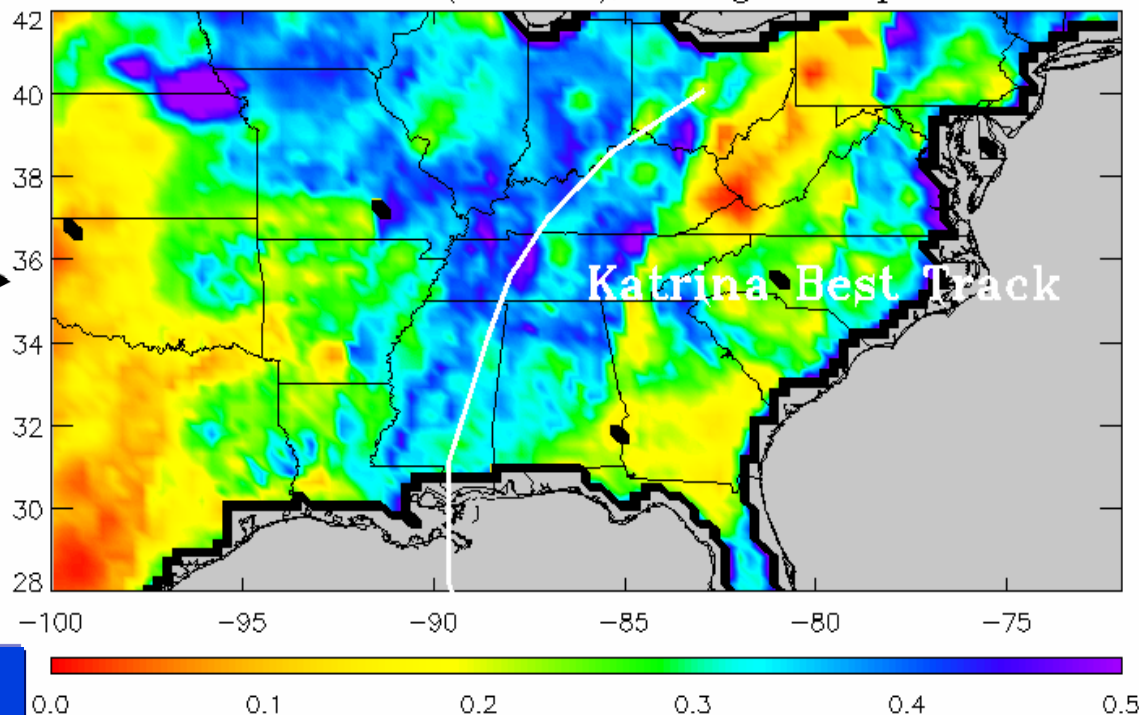


WindSat Soil Moisture Post-Katrina

- Using WindSat data, NRL produced the first global soil moisture product sufficiently accurate for assimilation into hydrological and meteorological models.
- Resolution is coarse (50 km)



WindSat Soil Moisture (Fraction), 30 Aug - 4 September 2005



Current Research Direction:
Combine passive microwave with vis/IR satellite measurements to produce a 1 km data product

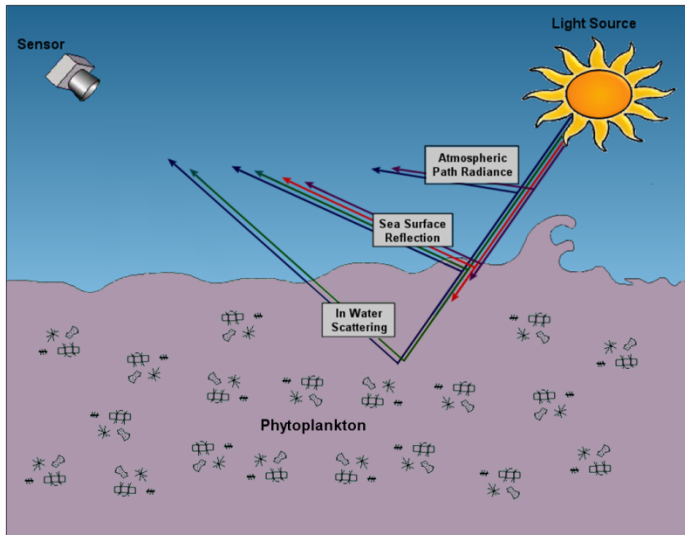
Other WindSat Research Issues:

- Retrievals in rain (requires precipitation modeling)
- Snow on ice
- Snow over land



Remote Sensing of Ocean Color

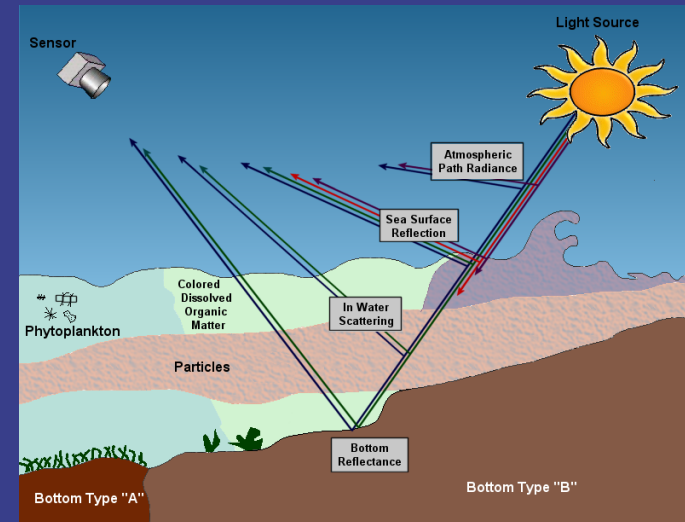
Open Ocean (Case 1 waters)



- Optically simple.
- Color dominated by the optical properties of pure water and phytoplankton and associated degradation products.
- Space-based multispectral EO imagers successful in measuring environmental properties including chlorophyll concentration, laser penetration depth, and diver visibility.

- Optically complex.
- Presence of high levels of CDOM, sediment, and bottom reflectance severely confound algorithms based on multispectral sensors.
- Hyperspectral sensors and algorithms are required in order to deconvolve complex optical signatures.

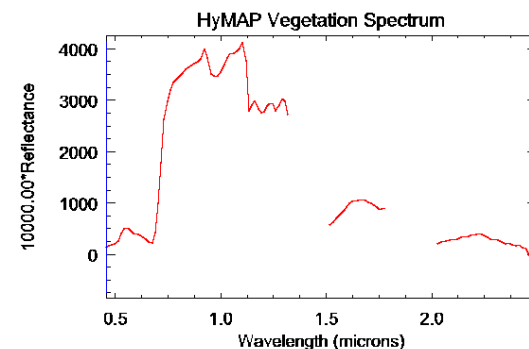
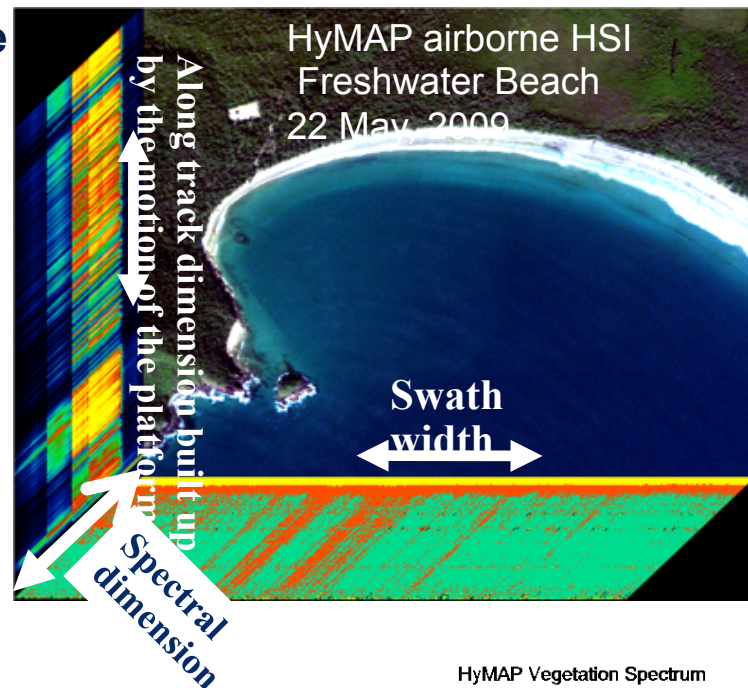
Coastal Regions (Case 2 Waters)





Hyperspectral Imaging for Environmental Characterization

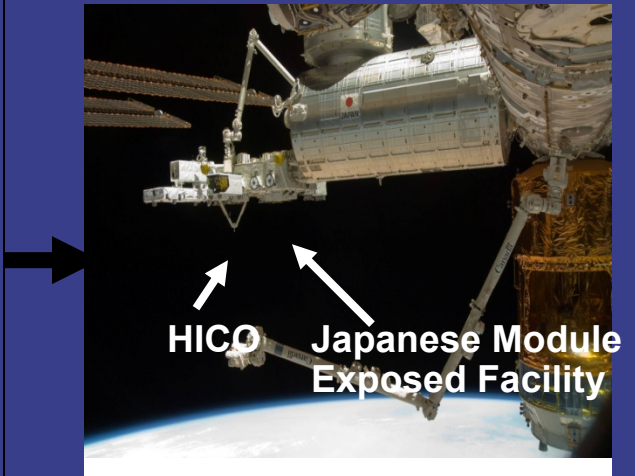
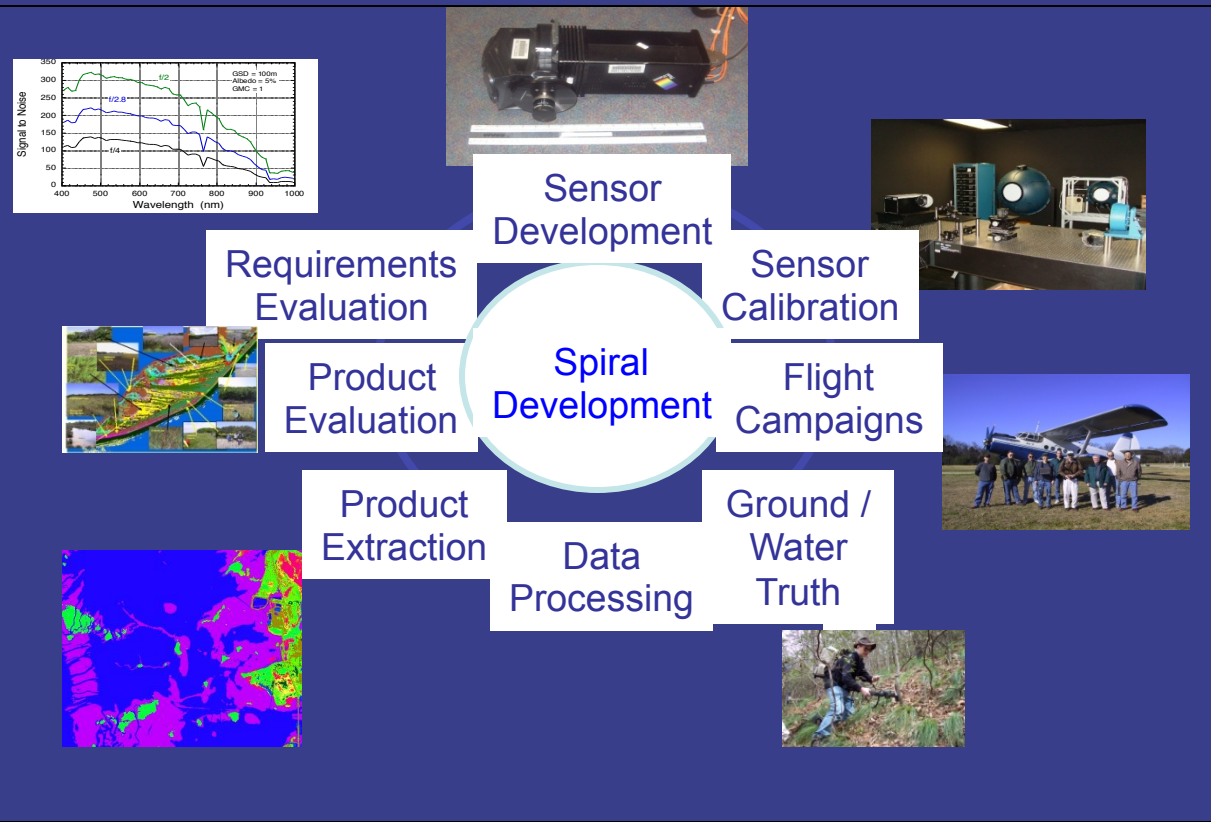
- A hyperspectral imager records the spectrum of the reflected light from each pixel in the scene
- This extra spectral information can be exploited to retrieve more information about the scene
- Coastal hyperspectral data products:
 - over water
 - water optical properties
 - absorption $a(\lambda)$
 - scattering $b(\lambda)$
 - visibility
 - bathymetry
 - bottom type
 - chlorophyll concentration
 - Colored Dissolved Organic Matter (CDOM)
 - Total Suspended Sediment (TSS)
 - over land
 - vegetation type maps
 - soil type maps
 - beach trafficability ...



The method of analysis and the imager performance requirements depend on the scene and the desired information



NRL Remote Sensing Division: Hyperspectral Imaging for Coastal Ocean Characterization



Hyperspectral Imager for the Coastal Ocean (HICO) launched on 9/10/09 and deployed aboard the JEM attached to the ISS: pathfinder for maritime HSI.

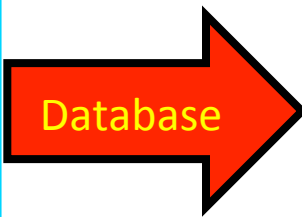
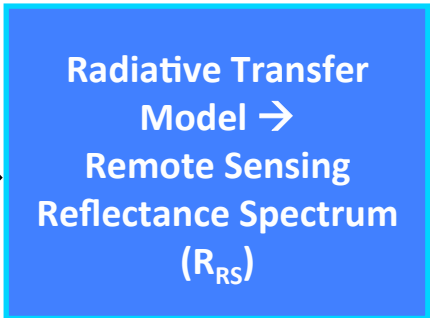
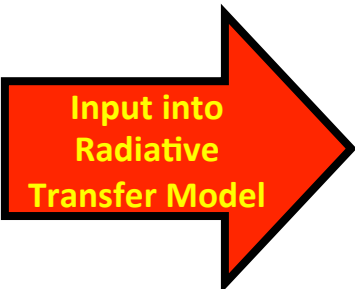


HICO image of Bosphorus Strait, October 11, 2009. Scene approximately 42 x 190 km

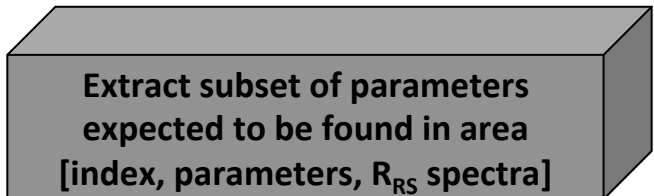
Retrieval of in-water parameters from HSI: Coastal Waters Signatures Toolkit (CWST)

Parameters:

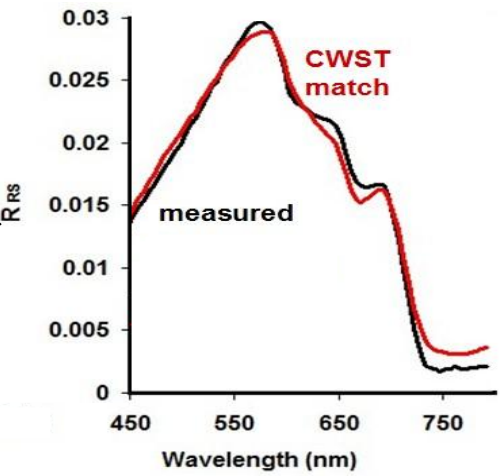
Phytoplankton
Sediment
CDOM
Depth
Bottom Spectra



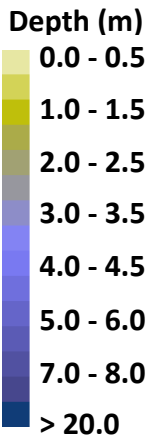
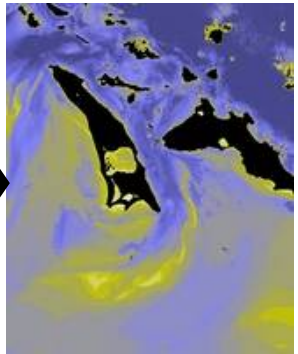
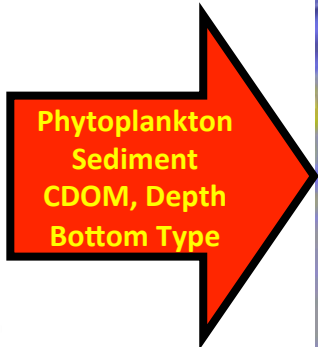
Bottom	Reflectance			
Sar	Pigment		Absorption	
Bro	Index	Depth	Bottom	
Yel			Pigment	
Sea				
	111	0.0	14	1
	112	0.5	3	1
	113	1.0	14	4
	114	2.0	14	2



Calibrated At Sensor Radiance



Compare measured spectrum to selected spectra to find best match - takes time



Lee Stocking Island, The Bahamas

Metric is Euclidean Distance



Example HICO Retrieval Products

Lee Stocking Island, Bahamas 16July2010:

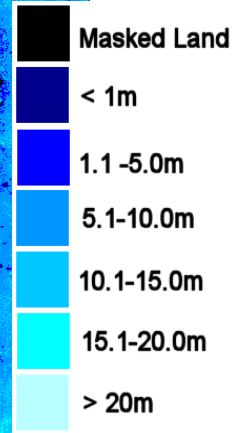
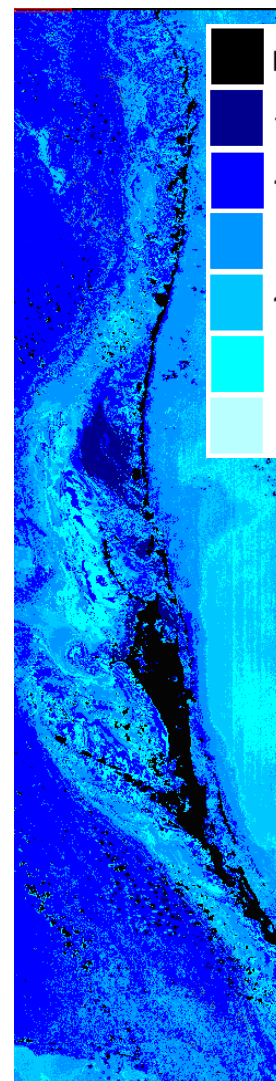
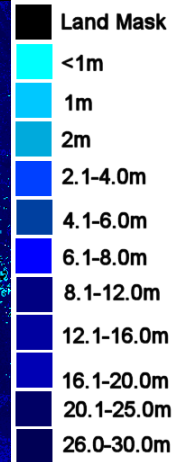
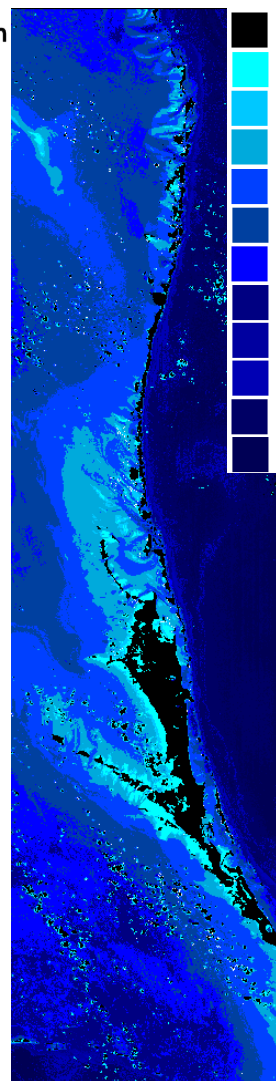
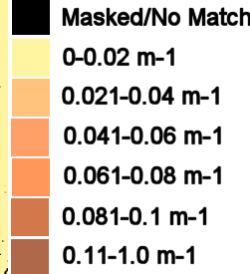
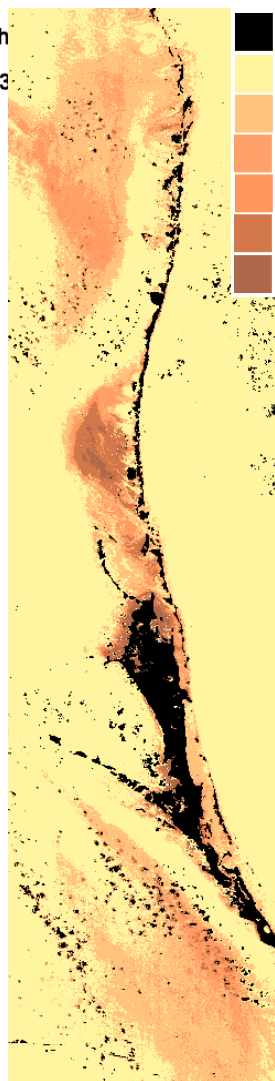
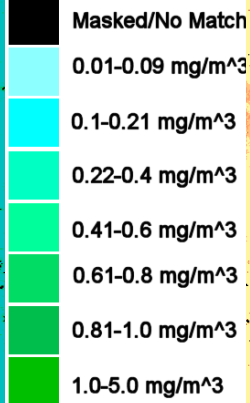
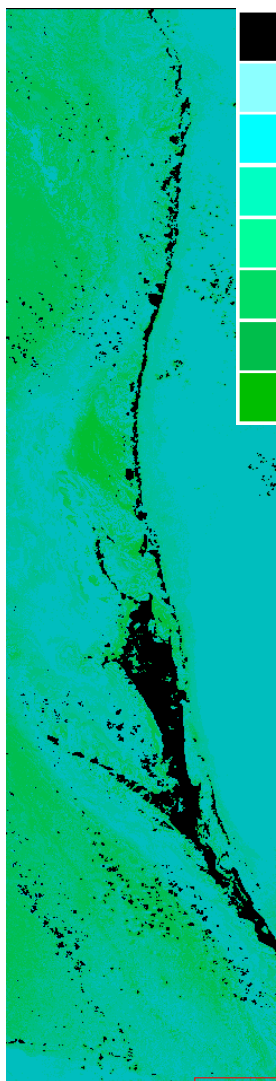
RGB Image $\approx 42 \times 192$ km





Example HICO Retrieval Products

Lee Stocking Island, Bahamas 16 July 2010:



Retrieved Chlorophyll

Retrieved CDOM

Retrieved Depth

Horizontal Visibility

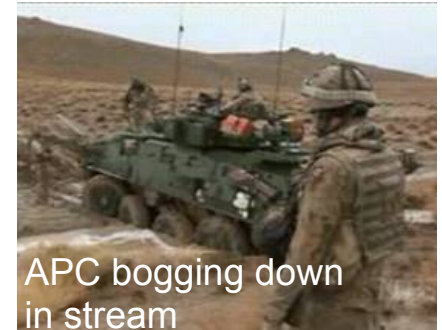


Remote Sensing of Trafficability

“Trafficability”: the ability to move people and equipment through a region, especially the ability of the substrate to support people/equipment

Problem: Expeditionary/amphibious forces, spec-ops forces, & humanitarian assistance/disaster relief response officials are hindered by lack of trafficability info about target beaches & inland routes (e.g, what type of vehicles the terrain can support).

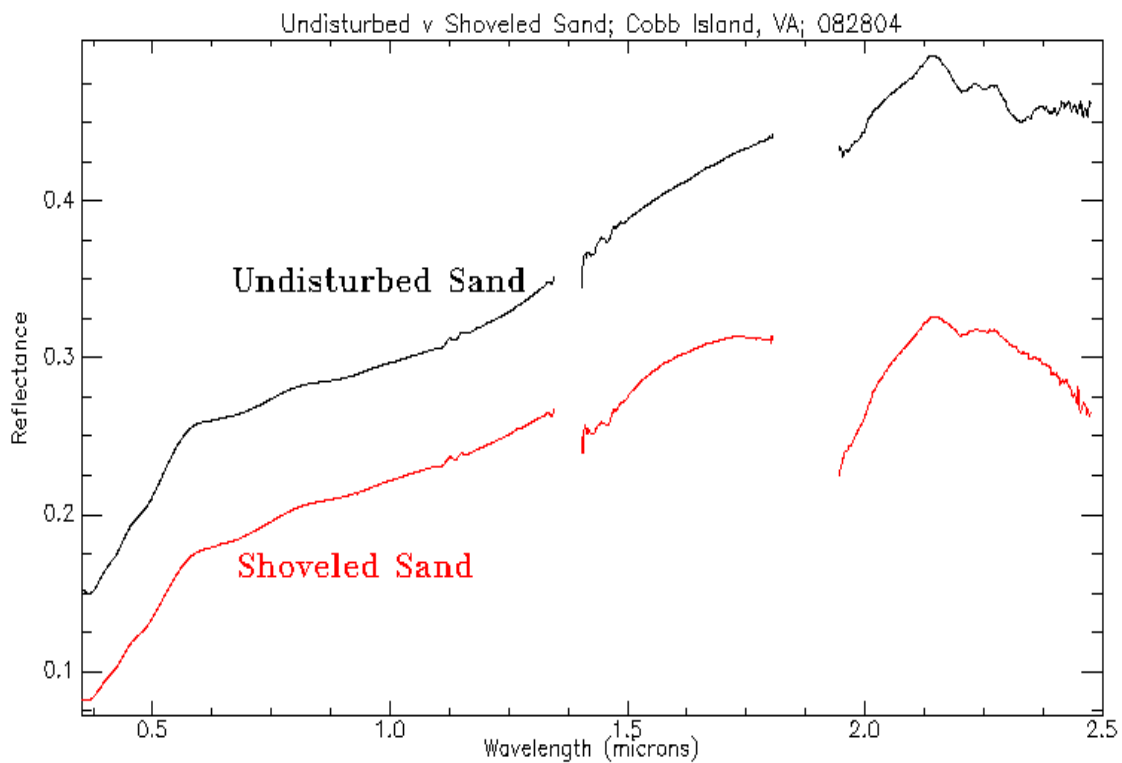
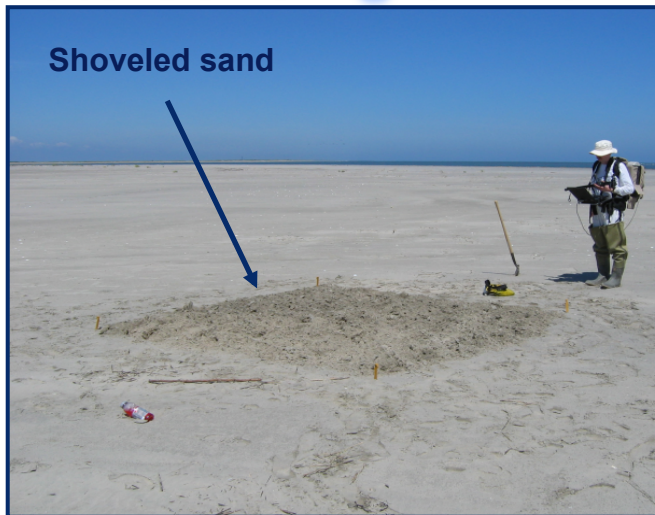
- Currently trafficability information is obtained by running models, which require terrain and bearing strength information:
 - Required measurements obtained *in situ*
 - Slow and expensive
 - Involves sending combat engineers into harms way to make the required measurements



Proposed Solution: Remote Sensing for wide-area characterization coupled with soil models, using innovative combination of algorithms & sensors



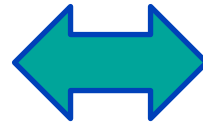
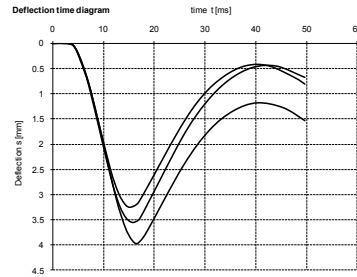
Remote Sensing of Trafficability



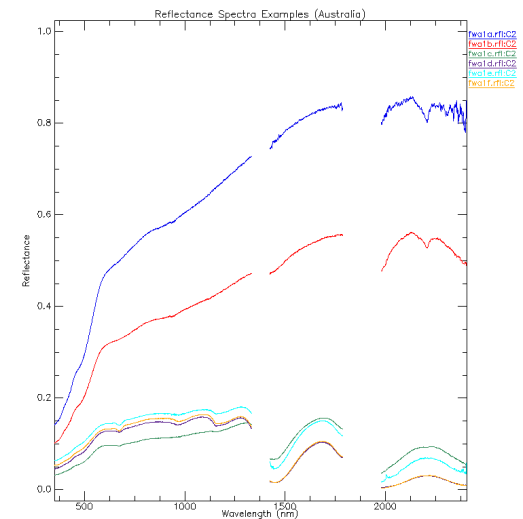
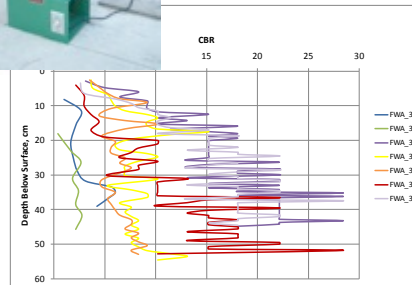
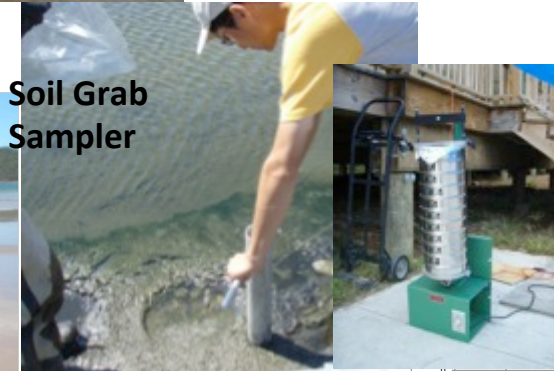


Linking Spectral and Geotechnical Measurements

Geotechnical measurements on beaches



Spectral measurements on beaches





Remote Sensing of Trafficability

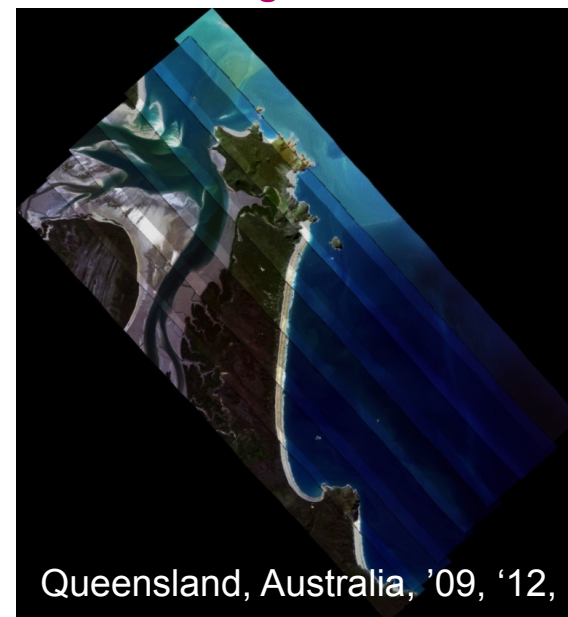
Coral Coast



HyMap HSI Quicklook Composite, 1/24/09

Hawaii

Mangrove Coast



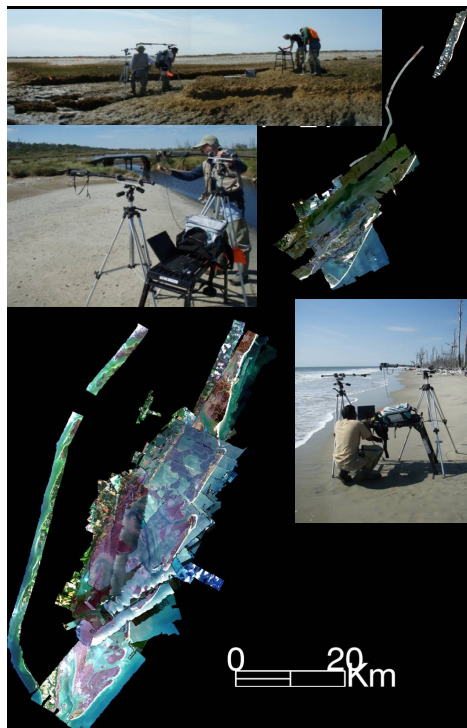
Queensland, Australia, '09, '12, '13

Volcanic Coast



Marianna Islands & Guam
MI-HARES 2010

Barrier Island Coast



Virginia Coast Reserve

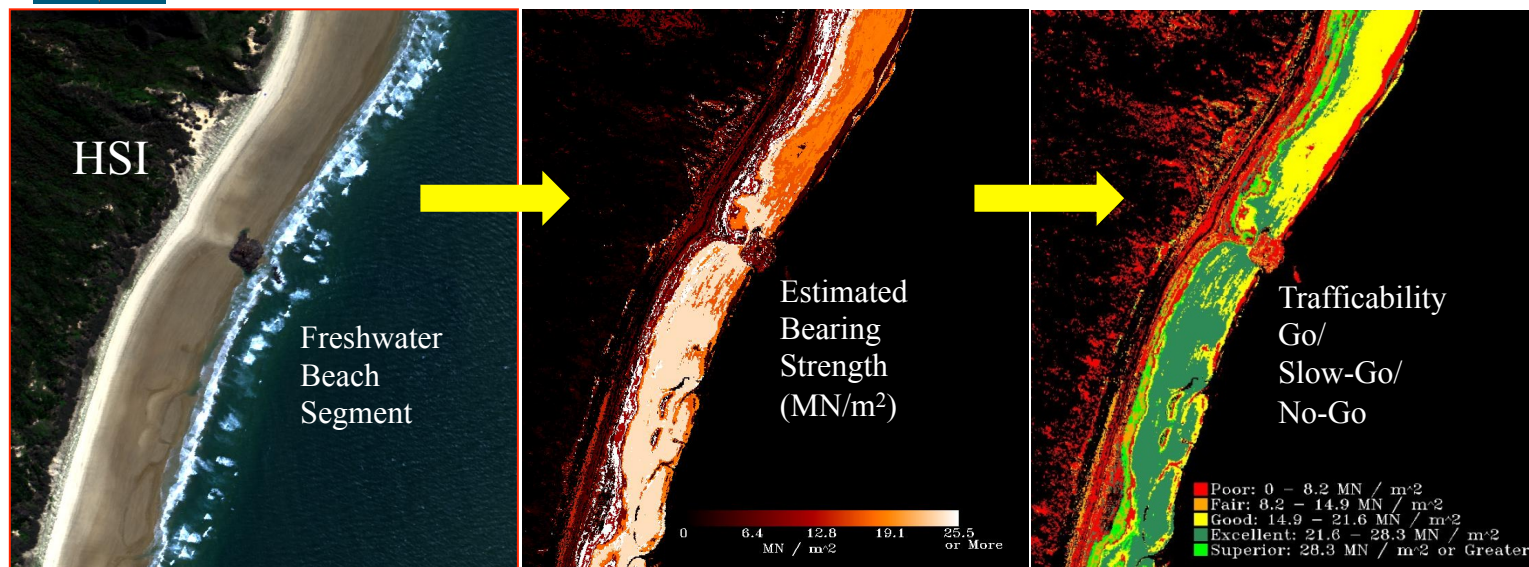
Retrieval Methodology

- Make *in situ* mechanical strength and radiance measurements to generate a look-up-table (LUT) relating the two.
- Make airborne radiance measurements and use LUT to derive soil strength.



Trafficability From Hyperspectral Remote Sensing

Coalition Warfare Program Grant: FY12 and 13



THEMAS 2012 Results

Single-Look HSI-Derived Trafficability

SWBTA May 2012

Using NRL-Hyperspectral Imagery Trafficability Tool (HITT)

Conducted second field measurement campaign in Australia in June 2013: participated in TALISMAN SABER'13



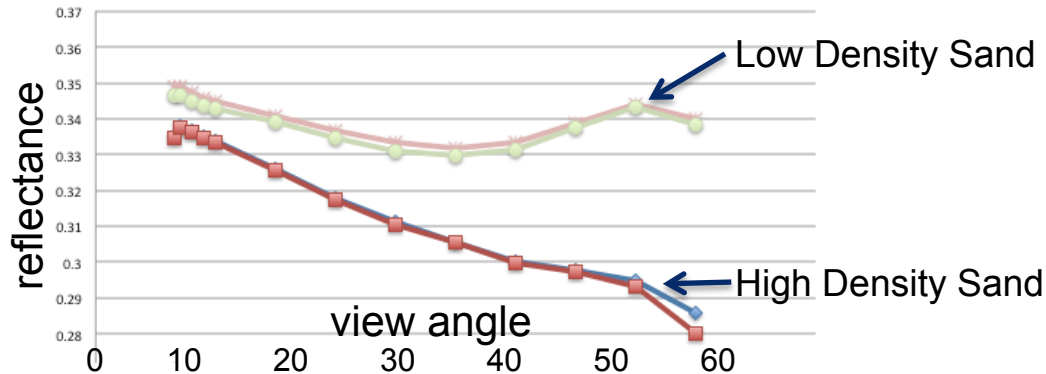
Roy Hughes (DSTO), James Eggleton (DSTO), and Chip Bachmann (NRL) on aboard USS Bonhomme Richard prior to TS'13

Requested by the Marines to conduct field campaign in Pohang, South Korea in April 2014 associated with the Ssang Yong 2014 amphibious exercise, providing a trafficability map for the beach in Pohang and soil measurements in a region of tactical interest



Trafficability: Current Research

Lab multi-angle measurements



- Mixture of large minerals with small ones fills pores and increases density, but decreases reflectance
- Contrast between high and low density sand
 - **Increases at larger view angles**
 - **Is opposite of that expected from radiative transfer theory, which is based on a single particle type**

Field Measurements



Develop a physically-based retrieval methodology: requires improved forward model

Multi-Sensor Investigation:

- VNIR HSI: surface composition, grain size
- Thermal: reveal thin crust
- SAR: moisture
- LiDAR: slope



The Future



Important current environmental remote sensing research areas:

- Global soil moisture (including heavily forested and near coastal areas).
- Sea ice thickness.
- Remote sensing of snow depth.
- Quantification of aerosol radiative forcing.
- Characterization of exchange between the upper troposphere and lower stratosphere.
- Characterization of impact of climate change on coastal ocean productivity.
- Vertical profiles of in-water constituents in the ocean.
- Characterization of methane hydrates.