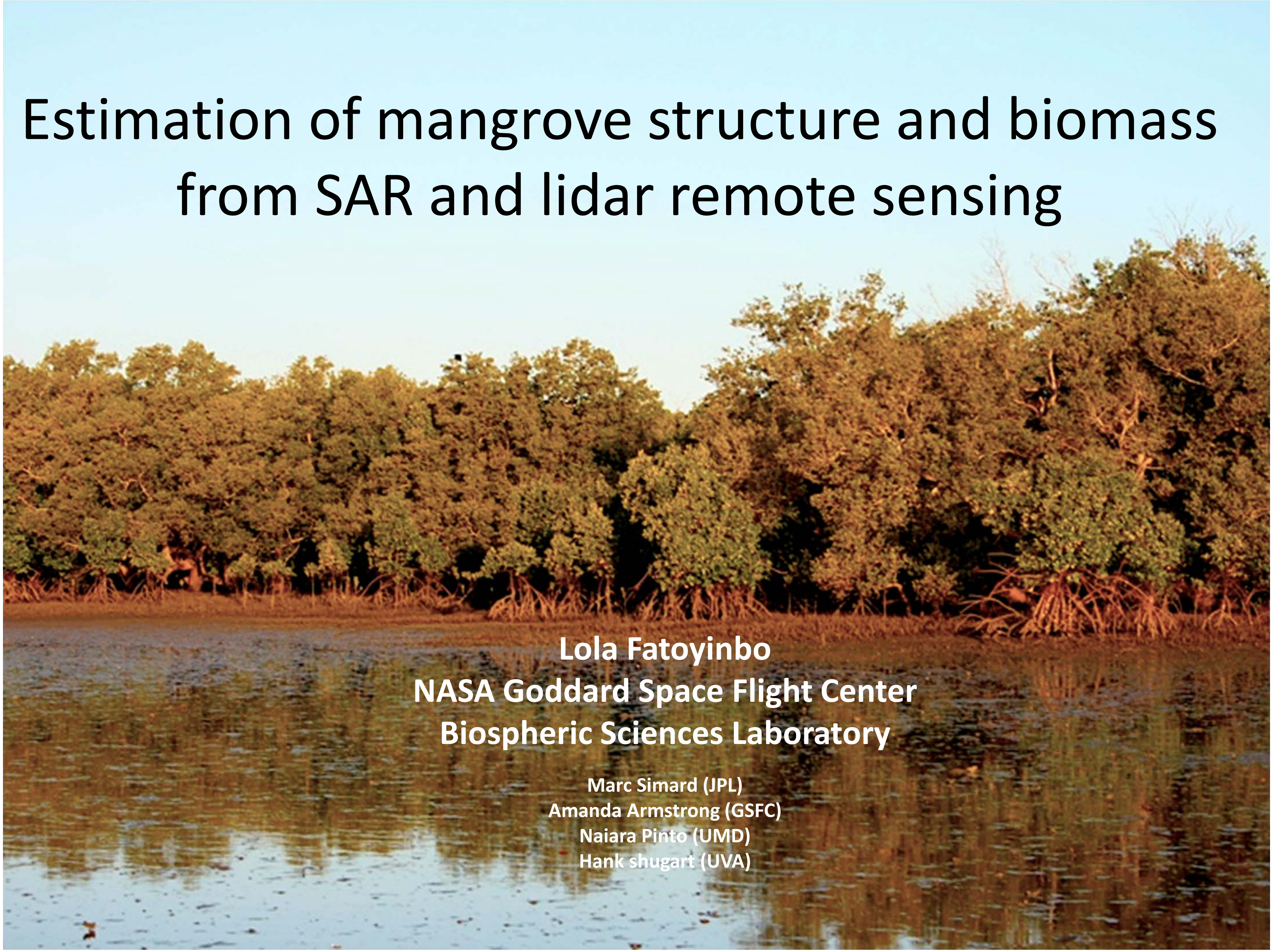


Estimation of mangrove structure and biomass from SAR and lidar remote sensing

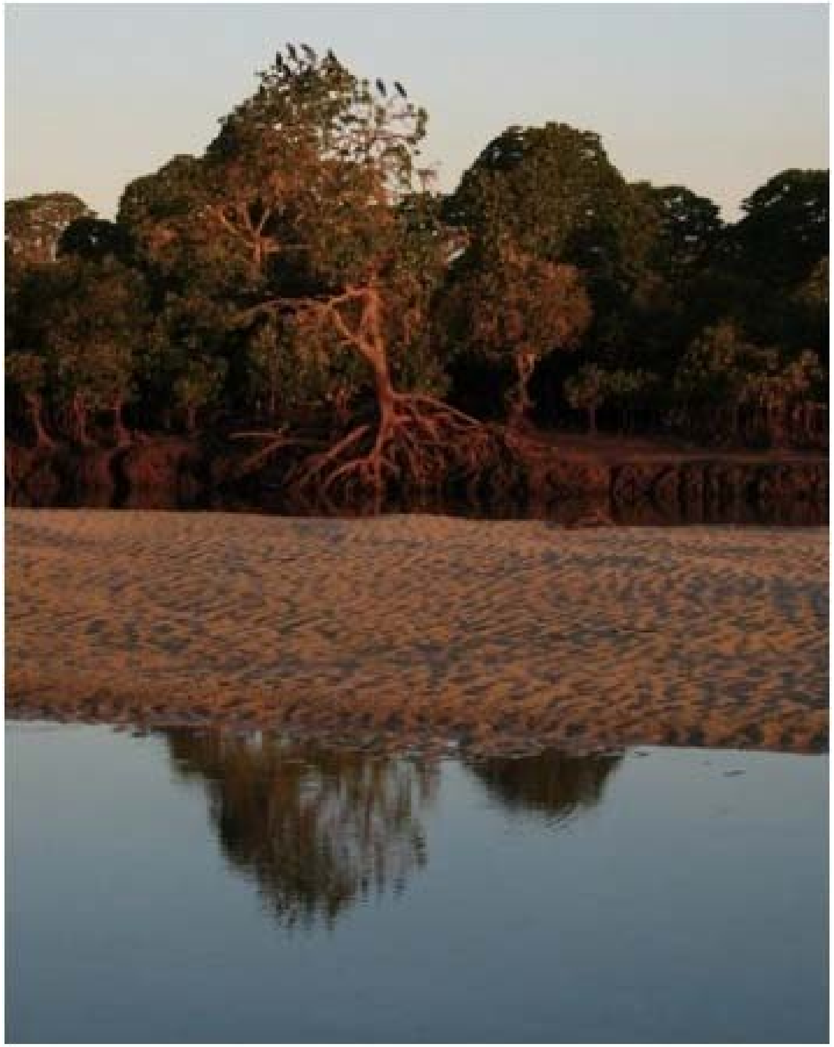
Lola Fatoyinbo
NASA Goddard Space Flight Center
Biospheric Sciences Laboratory

Marc Simard (JPL)
Amanda Armstrong (GSFC)
Naiara Pinto (UMD)
Hank shugart (UVA)

Mangroves 101

Mangrove forests are coastal wetlands that contribute to biodiversity and act as major biogeochemical links between upland and coastal regions.

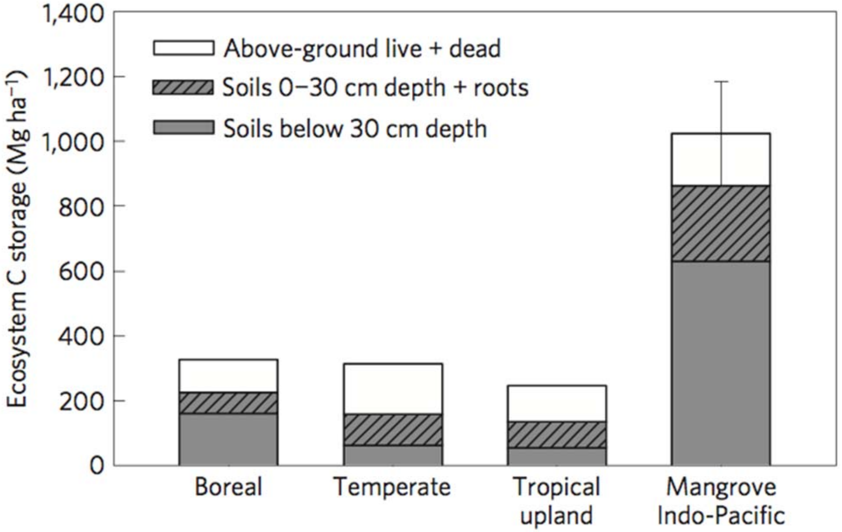
- Biodiversity: Habitats for over 1300 species of animals, including many economically important fish and shrimp species.
- Biogeochemistry: Among the most productive ecosystems on Earth with 2.5g C m-2 per day
  - 25% accumulates in mangrove sediments
  - 25% recycled
  - 50% exported to oceans and contributes 10% of C to Global Dissolved Organic Carbon
- They act as a protection of shoreline against topical storms, hurricanes and tidal surges



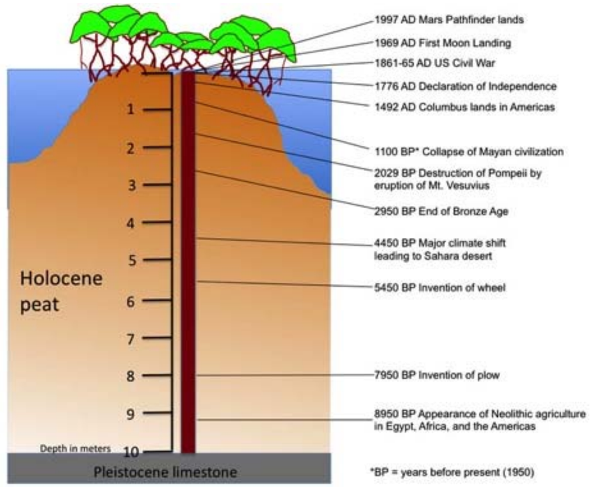
Mangroves and Carbon

- Mangroves are among the most carbon-rich forests in the tropics, containing on average 1,023 Mg carbon per hectare in above and belowground C .
- Organic-rich soils range from 0.5 m to more than 3 m in depth and account for 49–98% of carbon storage in these systems.

- The estimated economical of mangrove services value varies between \$200k to \$900k per km^2 per year (UNEP report 2006)
- New Initiatives such as Reduced Emissions from Deforestation and Degradation (REDD+) and the UN Blue Carbon Initiative are developing frameworks to compensate states for their C storage.



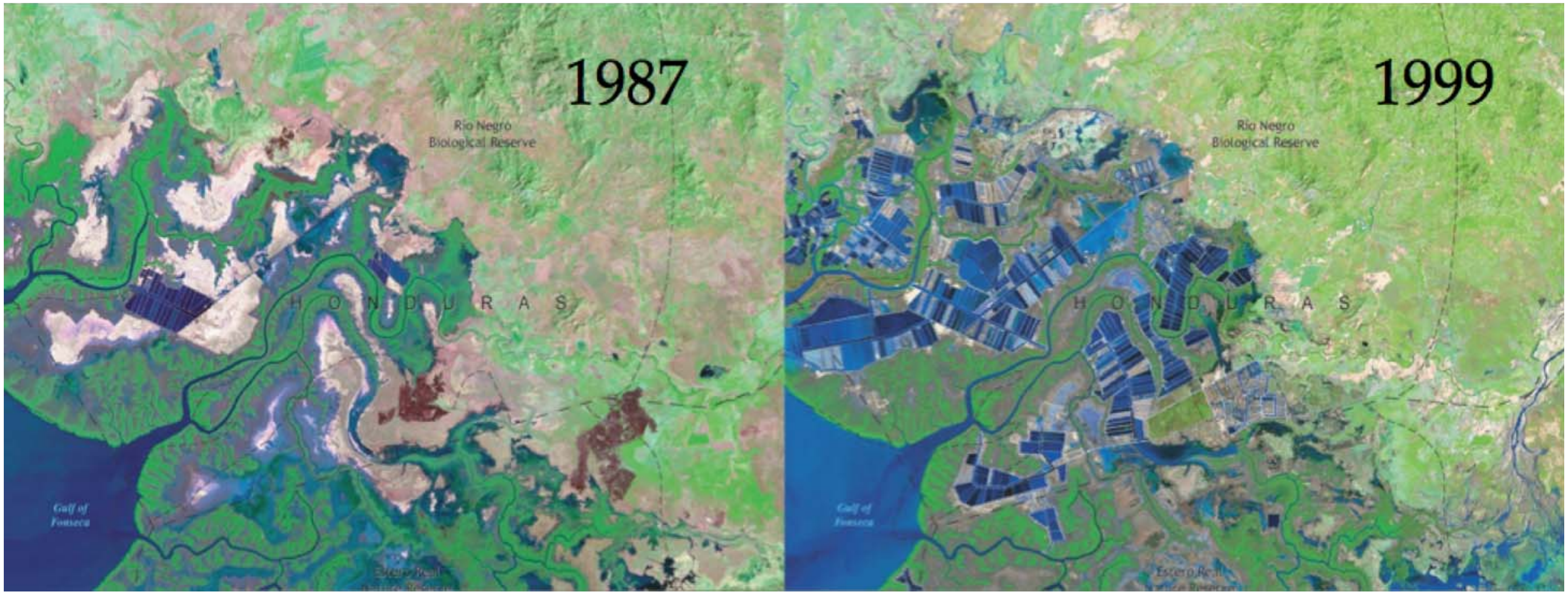
Comparison of mangrove C storage with that of major forest domains (from Donato et al. 2011).



Mangroves are endangered

But as a result of their location and economic value, they are among the most rapidly changing landscapes.

- 35% to 50% of mangrove forests have disappeared in the past 60 years, although no systematic baseline data is available;
- The greatest current threats to mangroves derive from human activities: aquaculture, freshwater diversions, overharvesting and urban and industrial development.
- The effects of climate change, such as sea-level rise and increased extreme climatic events (e.g. hurricanes), may also increase the vulnerability of this ecosystem



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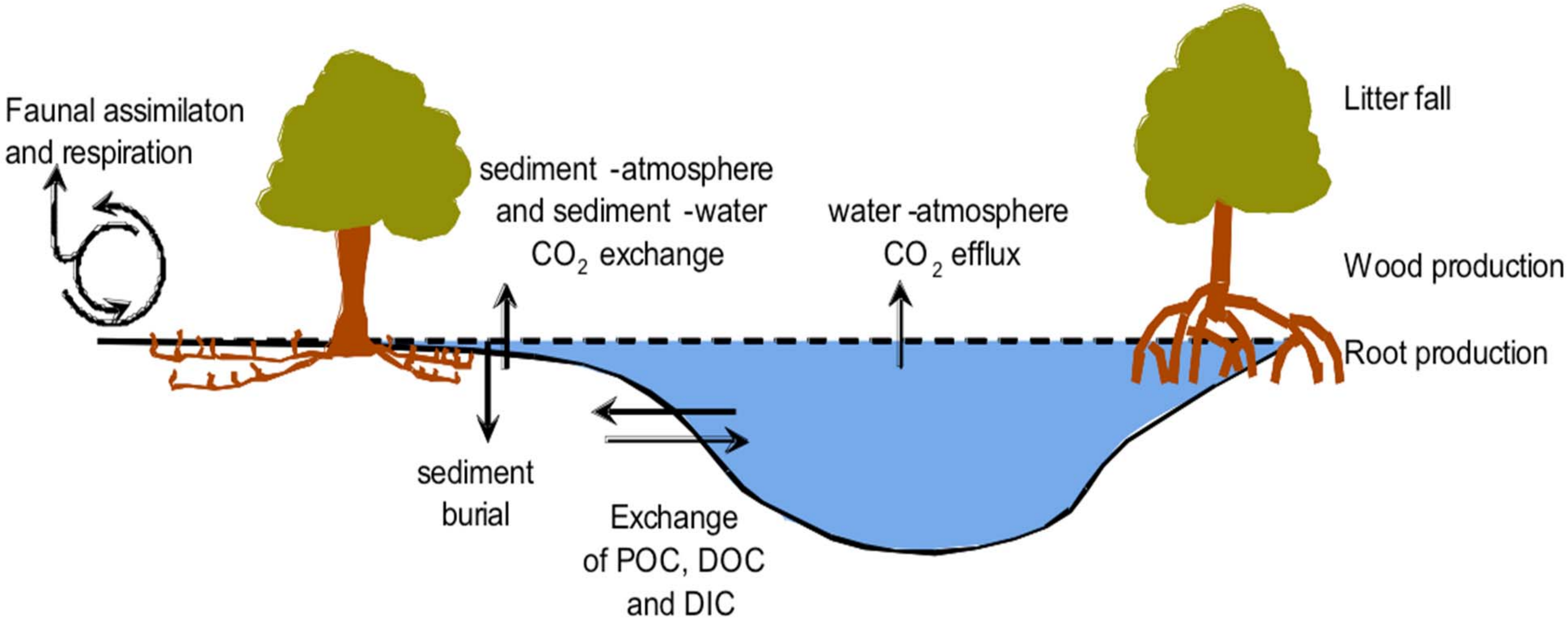
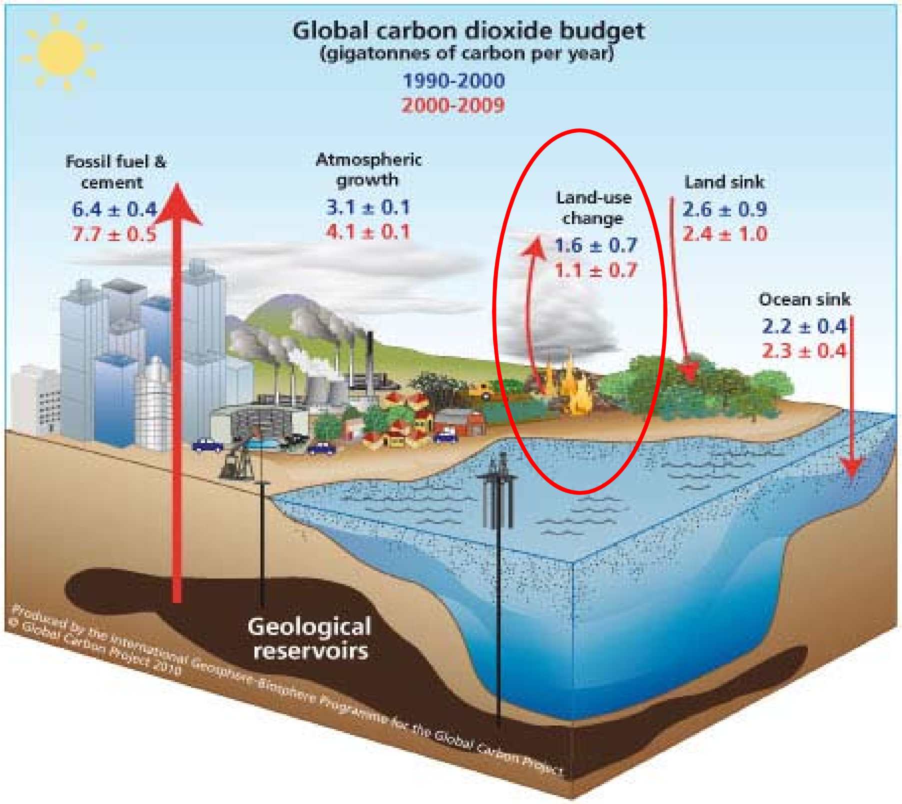
Productivity Patterns



Summary of the major components in **mangrove carbon budgets :** primary production (litter fall, wood and root production) and various sink terms.

How do mangroves fit into the Global C cycle?

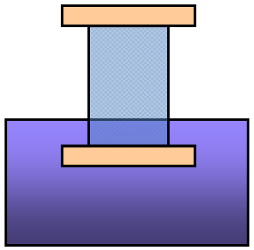


Mangrove deforestation generates emissions of 0.02–0.12 Petagrams carbon per year—potentially **as much as around 10% of emissions from deforestation globally**, despite accounting for just 0.7% of tropical forest area.

Uncertainties of biomass measurements

- Currently, the uncertainty in the magnitude of carbon emissions from land use changes is 66% of the input.
- Most of this uncertainty is due to errors in biomass estimation

1.5 ± 1.0



Land Use Change

Carbon Fluxes

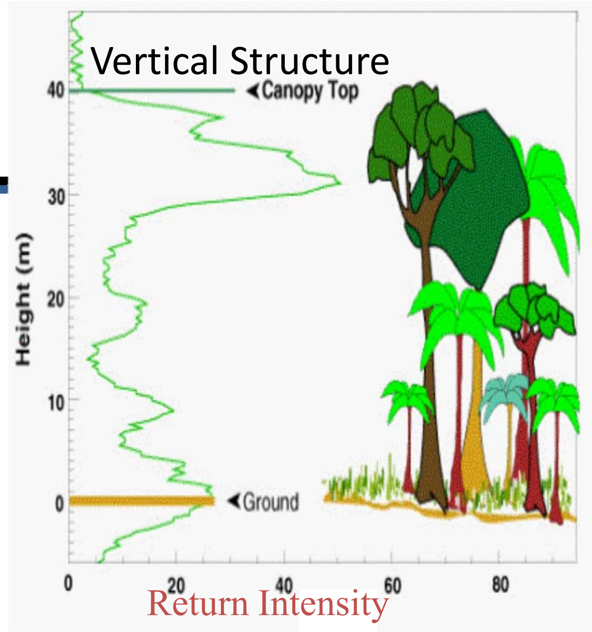
Extent and Change in Land Cover

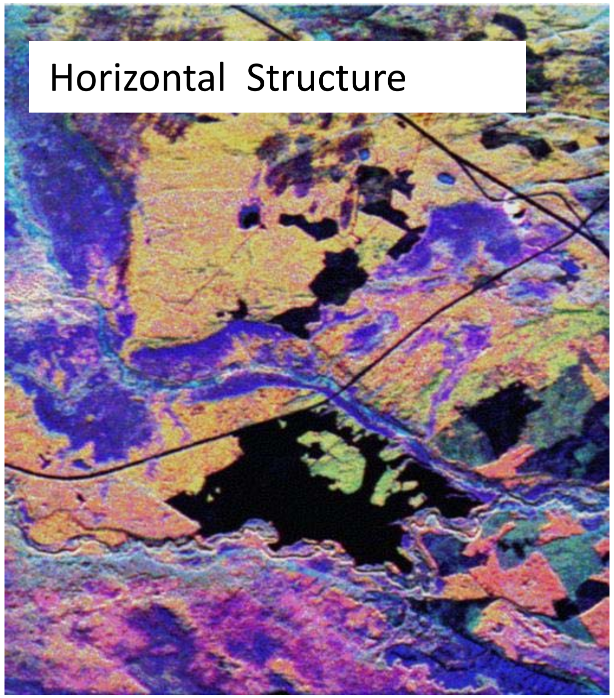
Structure and Biomass

Vegetation structure measurements

To better understand C emissions and ecosystem structure from mangroves and other ecosystems we need to accurately quantify ecosystem biomass, extent and change by measuring horizontal and vertical heterogeneity

- Horizontal structure: in terms of land cover and land cover change
- Vertical structure: in terms of forest height and biomass



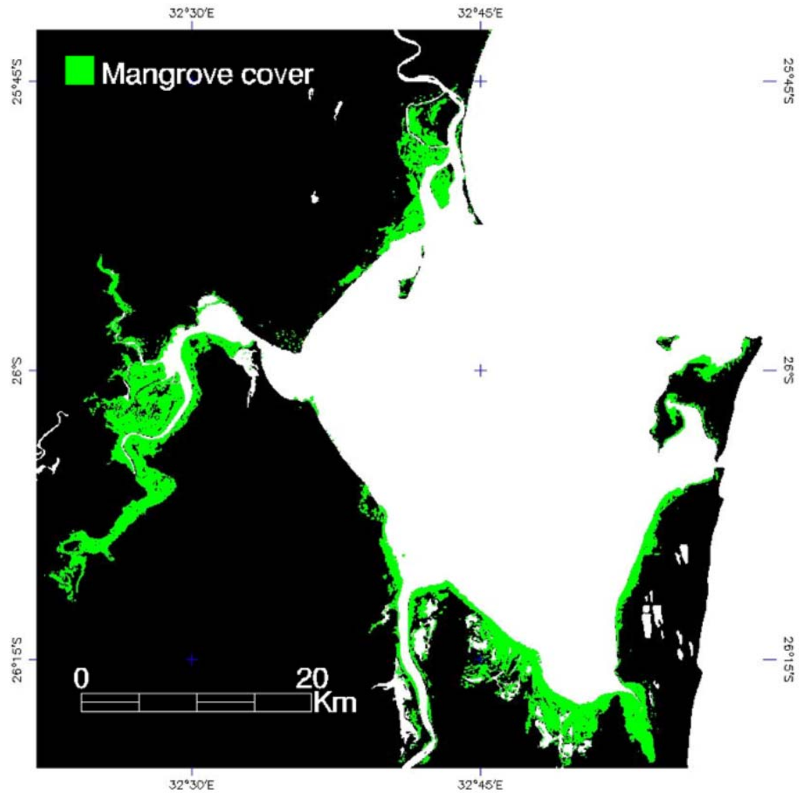


- Three complementary technologies meet these science requirements:
  - Lidar
  - Interferometric Synthetic Aperture Radar (InSAR)
  - Polarimetric SAR (PolSAR)

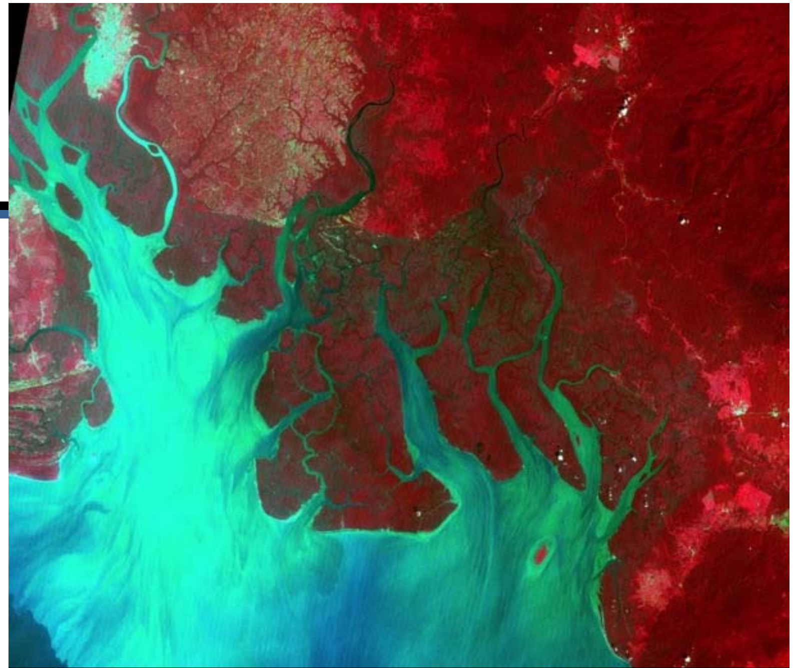
Horizontal Structure of Mangroves

Horizontal Structure from Landsat

- Baseline landcover maps of mangrove cover were scarce and estimates varied greatly per country
- Our initial goal was to cover Mozambique, then the continent of Africa
- Now there is the USGS Global Mangrove Map (Giri et al, 2011)

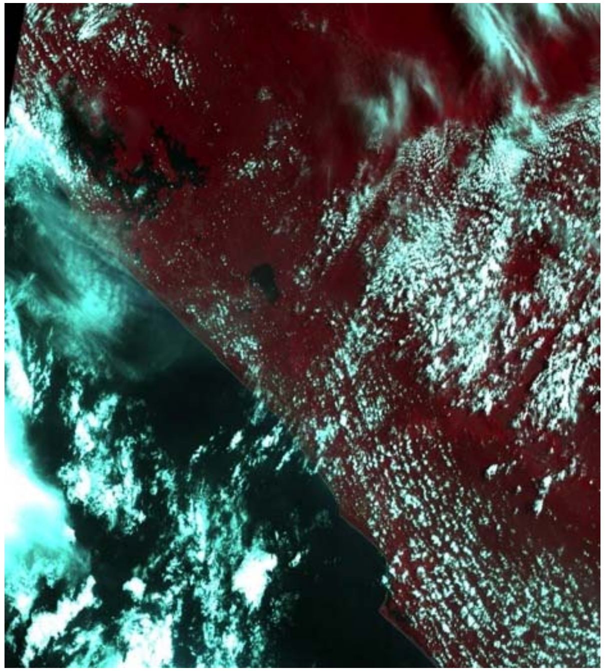


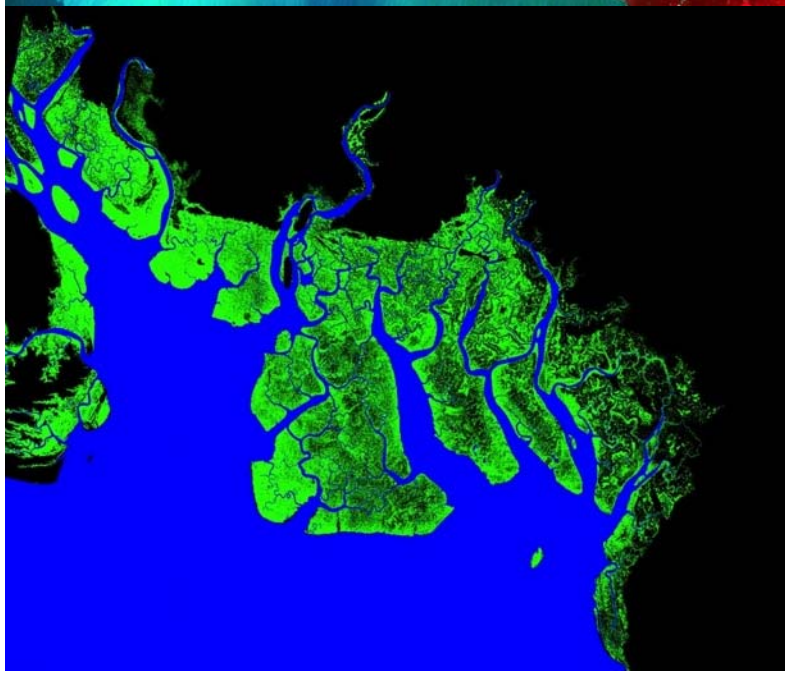
Goddard SPACE FLIGHT CENTER



- Classified 117 Landsat GeoCover scenes from 2000 era covering all mangrove areas in Africa
- Mosaic of all scenes to cover the continent
- Individual country maps:
  - Facilitation of access for governments
  - Comparison with previous estimates

BUT

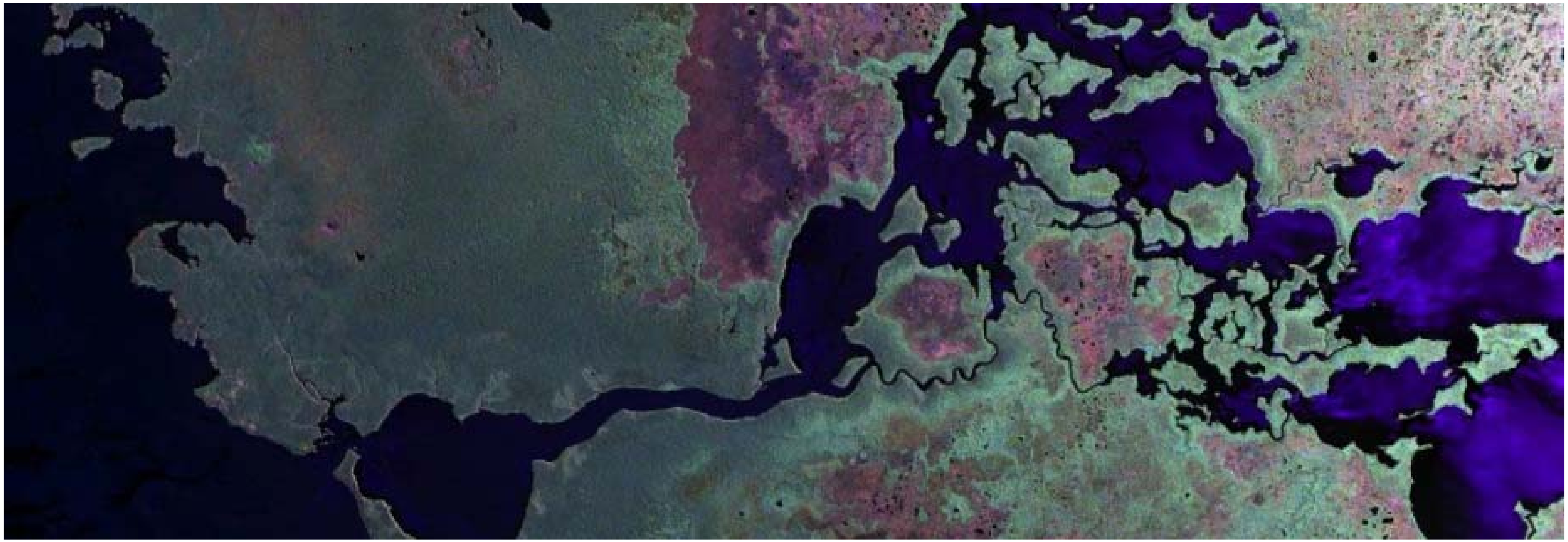




- Clouds in the Landcover Maps
- Difficulty of differentiating between mangrove forests and rainforests in Central Africa

Horizontal Structure with L-band SAR

- Polarimetric SAR imaging is sensitive to the forest spatial structure and standing biomass in ways not possible with optical data:
  - It is not affected by clouds
  - SAR data can also be used for forest cover classification and land cover change measurements.
  - In addition to deforestation, we can also detect degradation
- In forests, there is a positive relationship between measured backscatter and aboveground biomass.

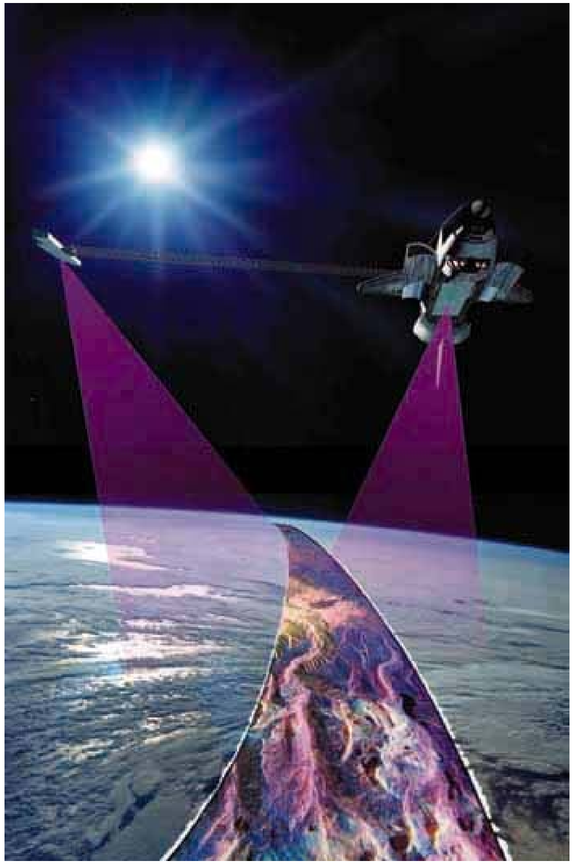


Vertical Structure and Biomass of Mangroves

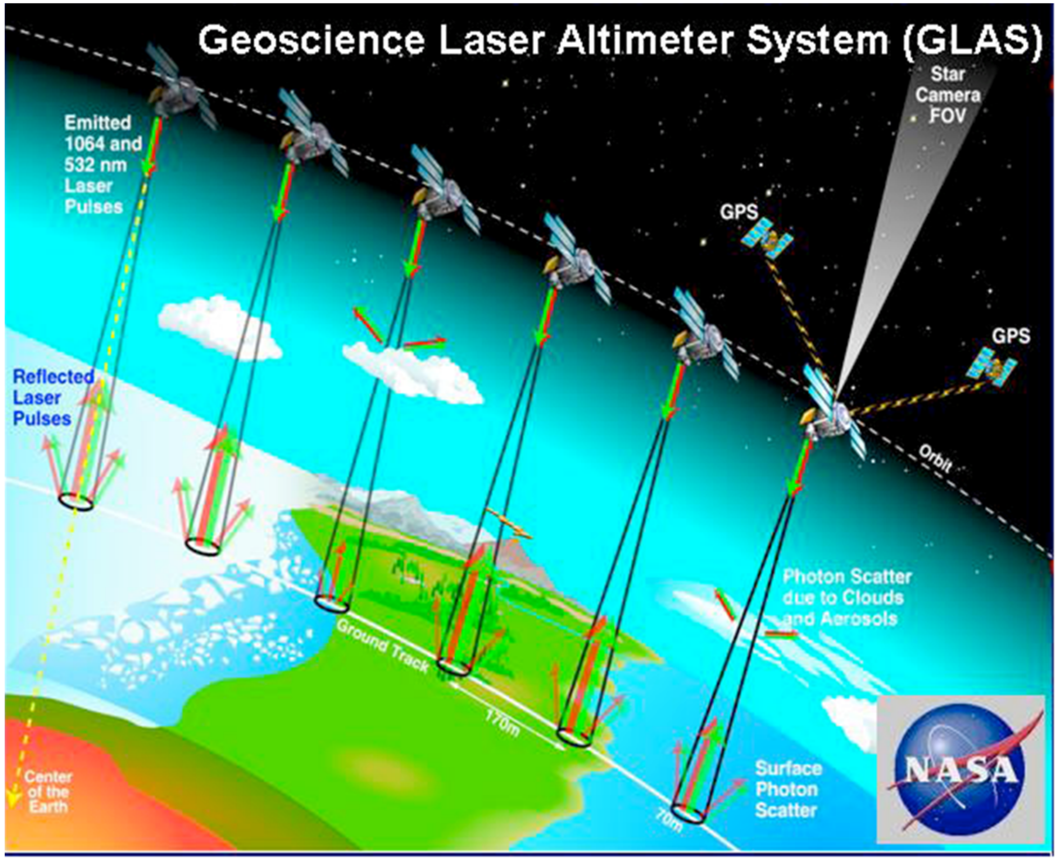
Vertical Structure from Radar & Lidar data

Using SRTM, Field and GLAS for mangrove 3-D structure

SRTM

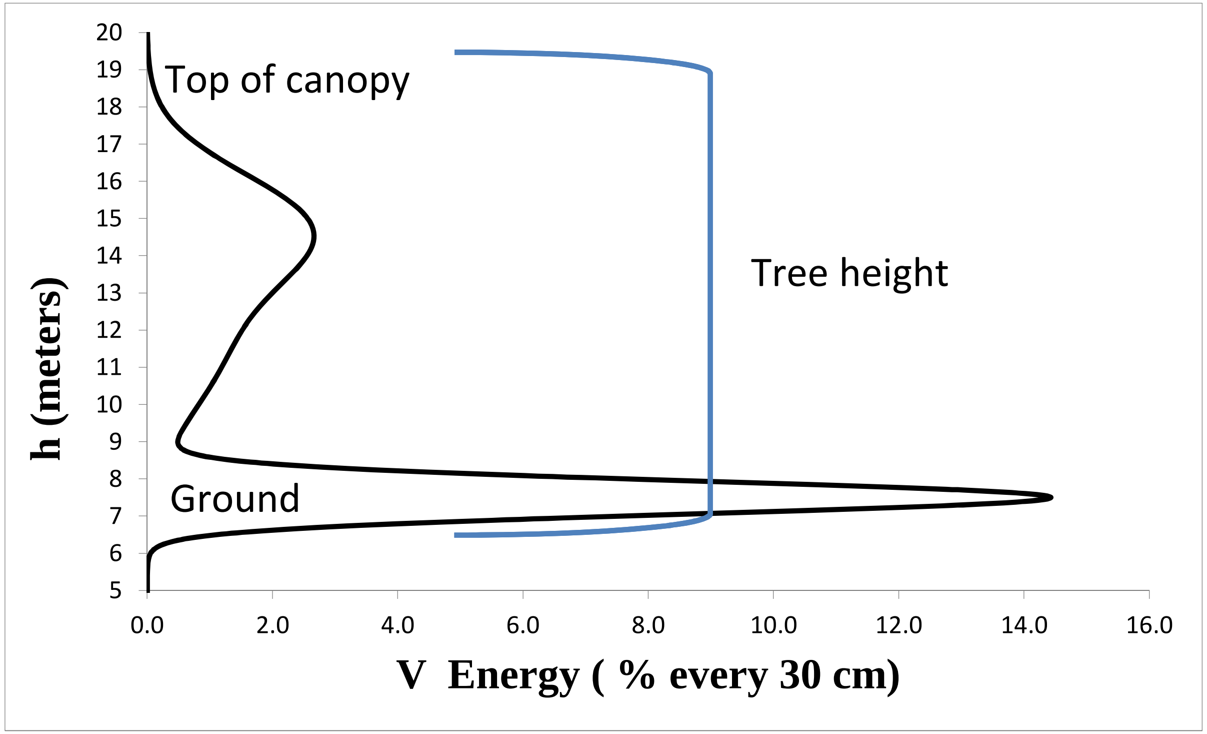


IceSat GLAS



ICESat/GLAS

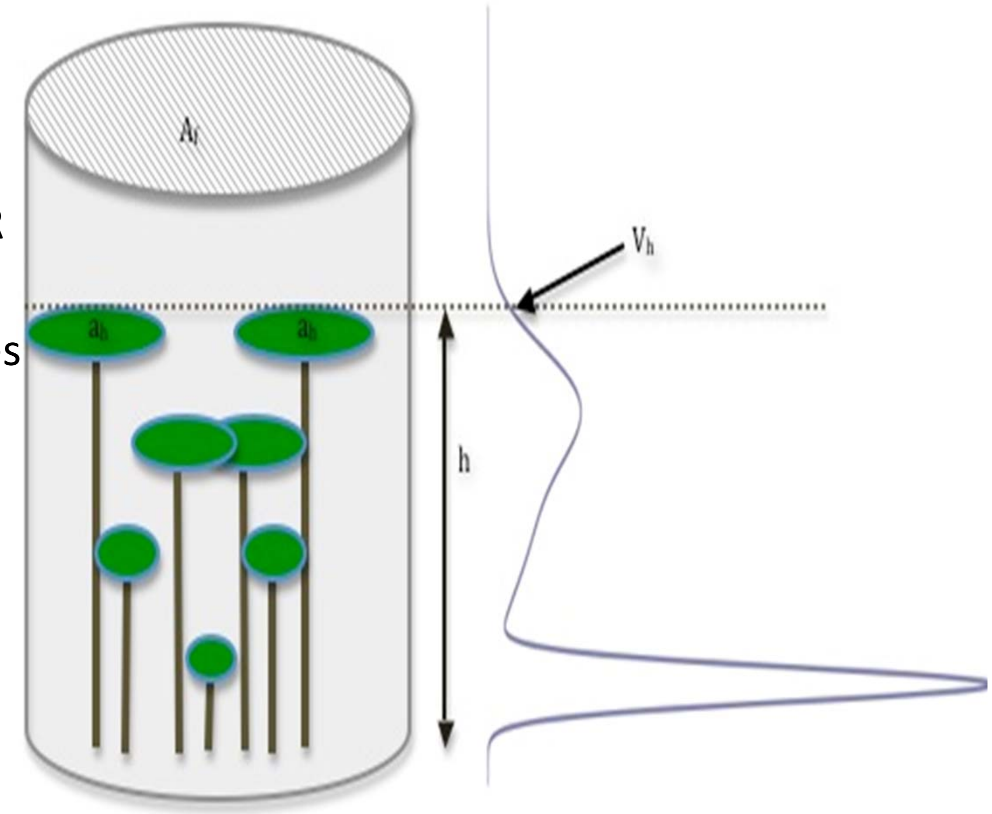
- Measures surface elevation along a ground track for 33 days every 4 months
- Best alternative for global canopy height calibration
- Lidar advantage over field data is geolocation accuracy, high sampling density, 3-D geometry of the canopy
- Footprint size of 65-70 m, sampling every 170 m



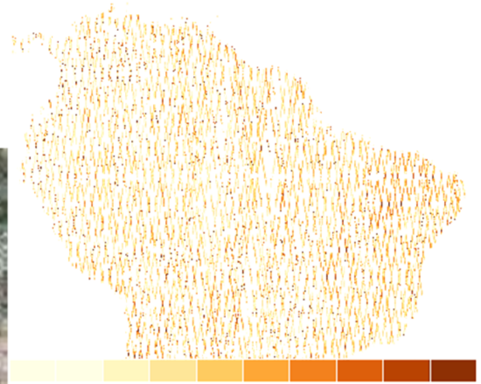
What is tree height? Where is the top of the canopy? Where is the ground?

VERTICAL STRUCTURE FROM RADAR & LIDAR DATA

- We used the GLA14 (Global land altimetry) data product to estimate canopy height.
- GLAS footprints are not available in all mangrove areas.
- The shape and position describe the canopy vertical structure within the LiDAR footprint.
- We only used data from cloud-free profiles
- We excluded waveforms with a single Gaussian peak

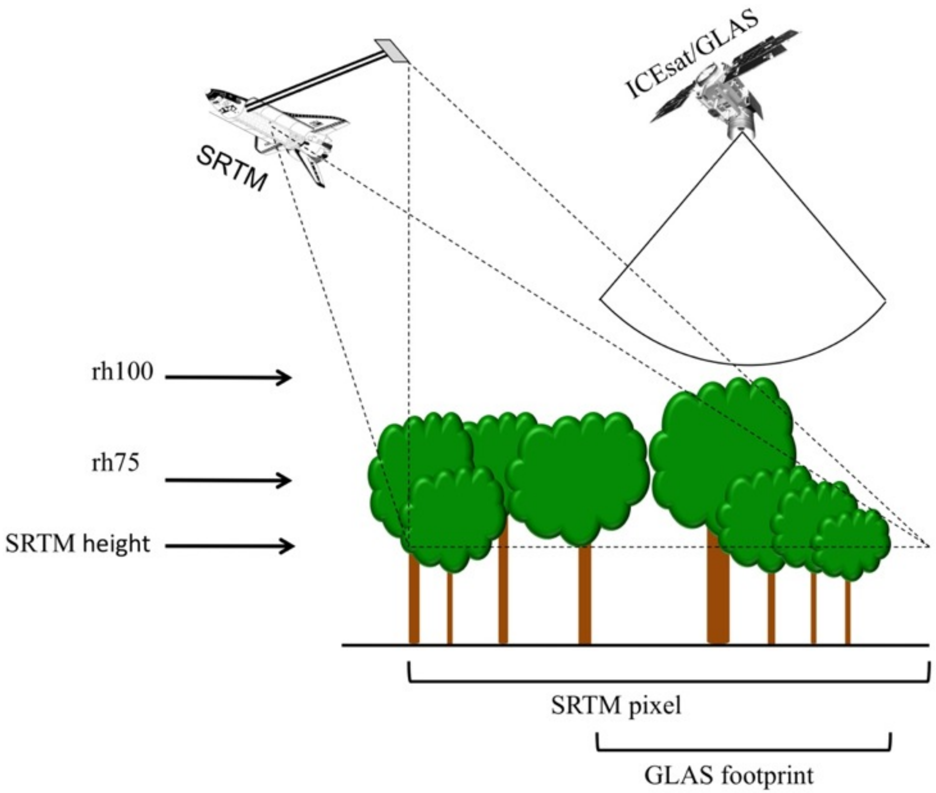


ICESat/GLAS coverage



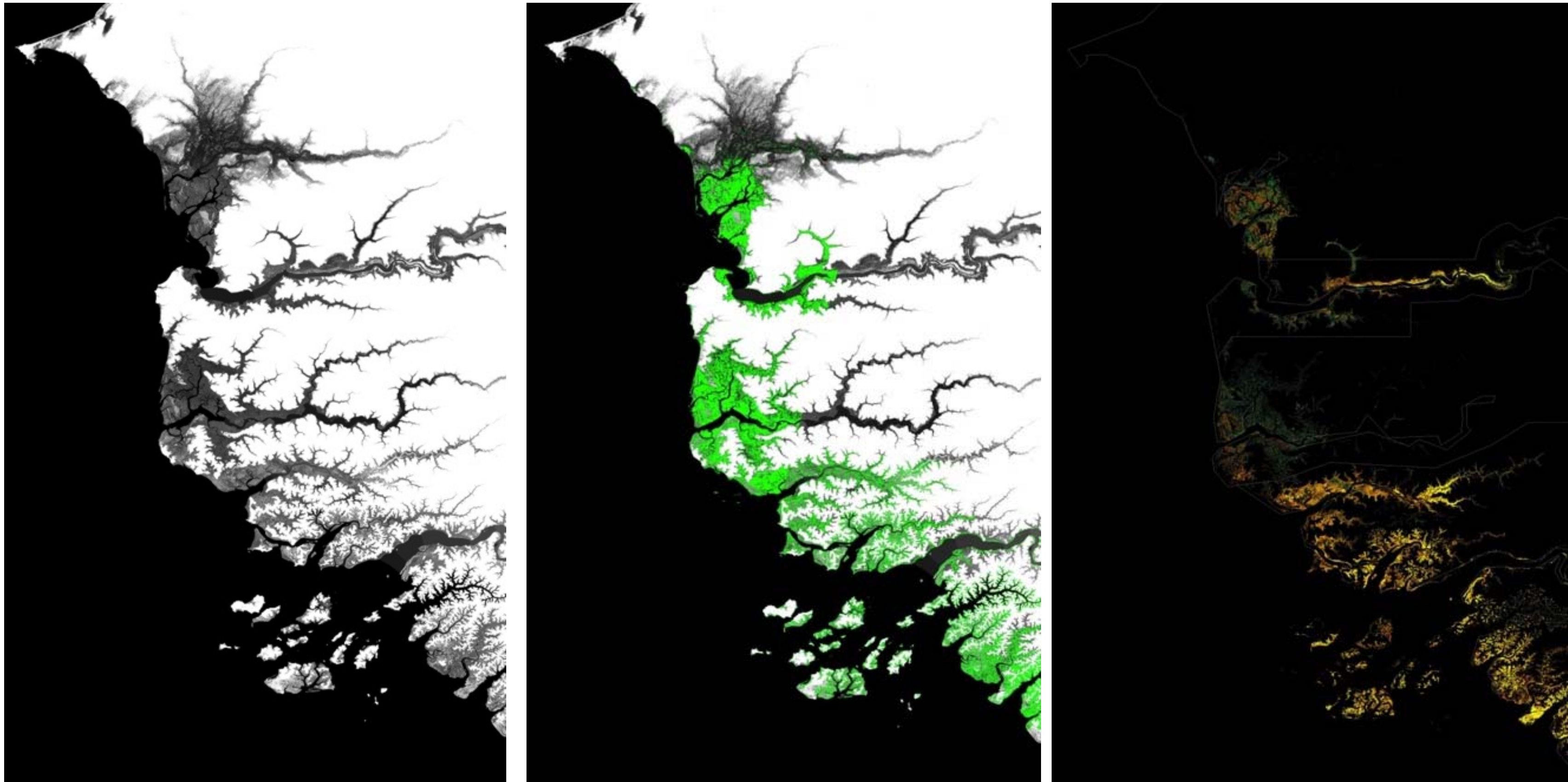
Vertical Structure from InSAR

- The C-band Radar signal penetrates into the canopy to scatter with all forest components and the ground.
- The radar height estimate (i.e. radar phase center) lies somewhere within the canopy volume, which can be used to estimate canopy height.
- Mangrove height estimates work well because mangroves grow at sea level



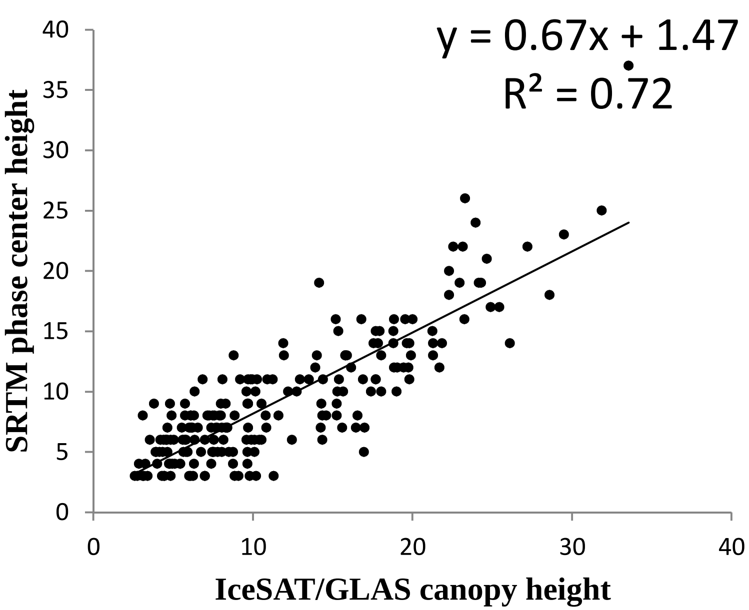
Vertical Structure from Interferometric SAR

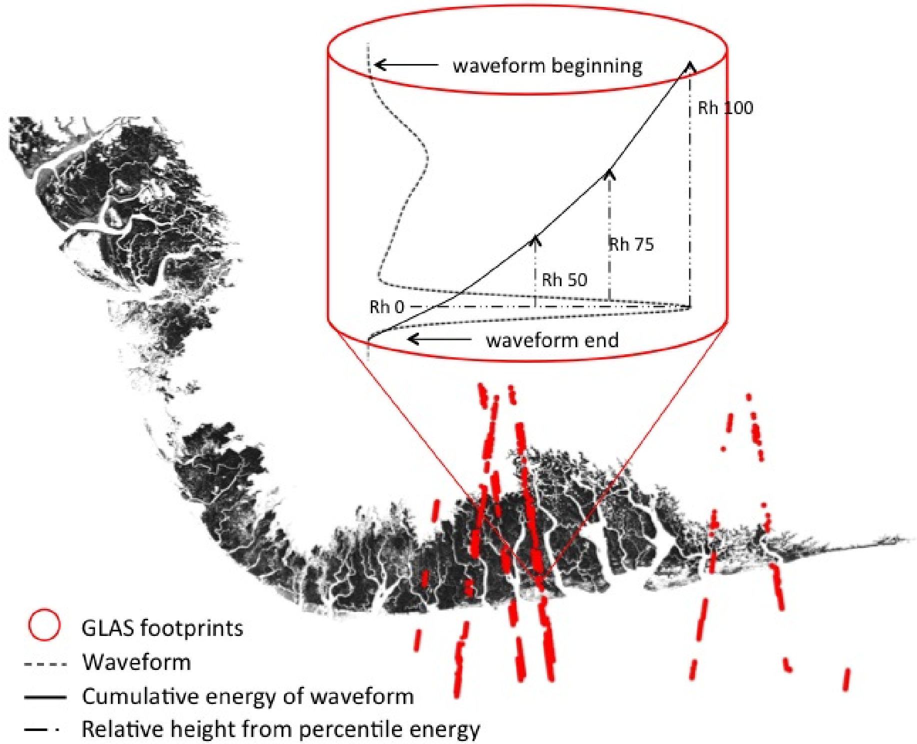
- SRTM is used to build a single SRTM DEM covering coastal areas.
- Using the mangrove landcover map, we masked all non-mangrove areas on the SRTM DEM.
- This results in an uncalibrated height map of the mangrove areas.



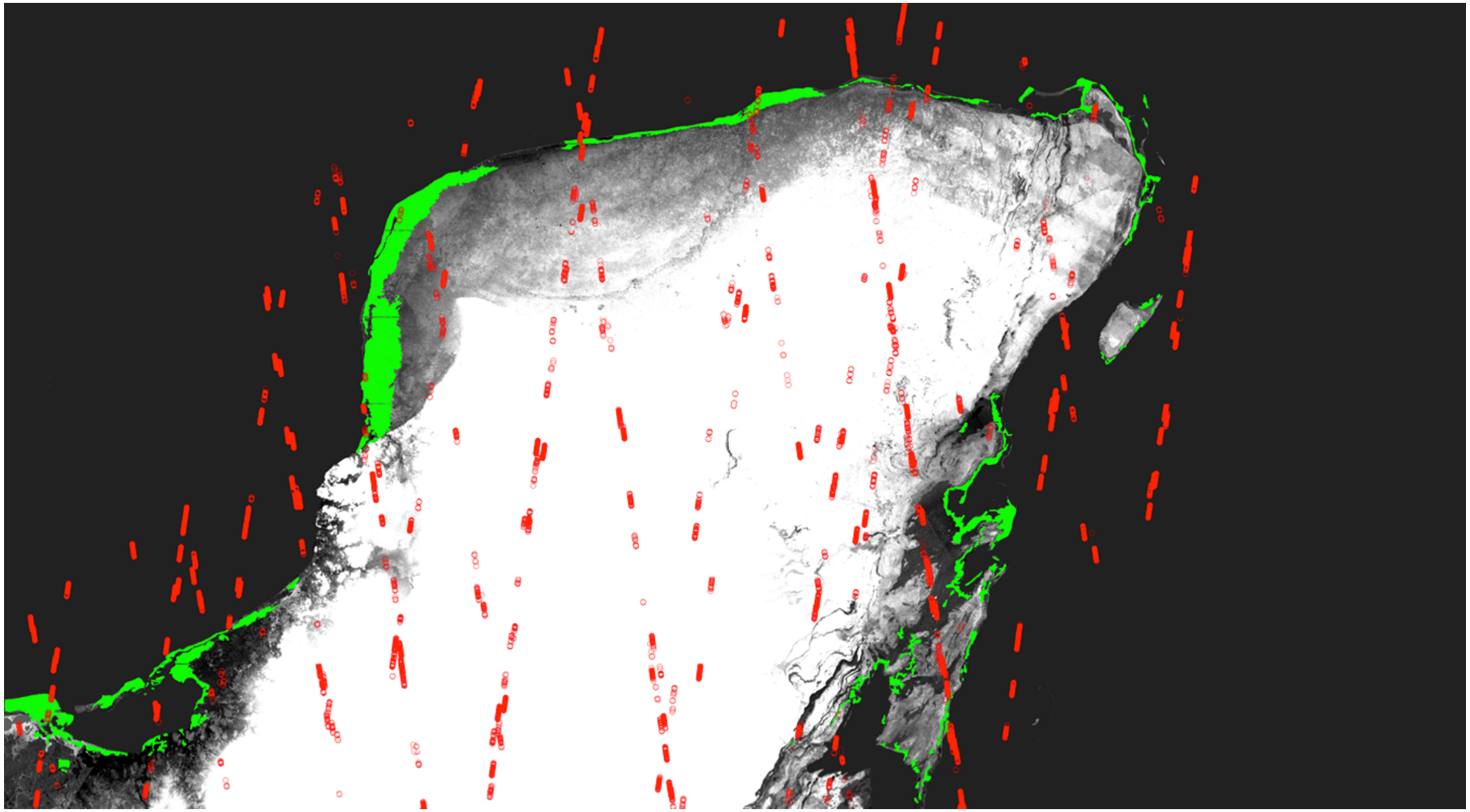
InSAR-Lidar Fusion

- The SRTM values corresponding to the GLAS shots were extracted
- We derived linear regressions between the GLAS point's rh_{100} values and DEM height values to determine the regression equation.

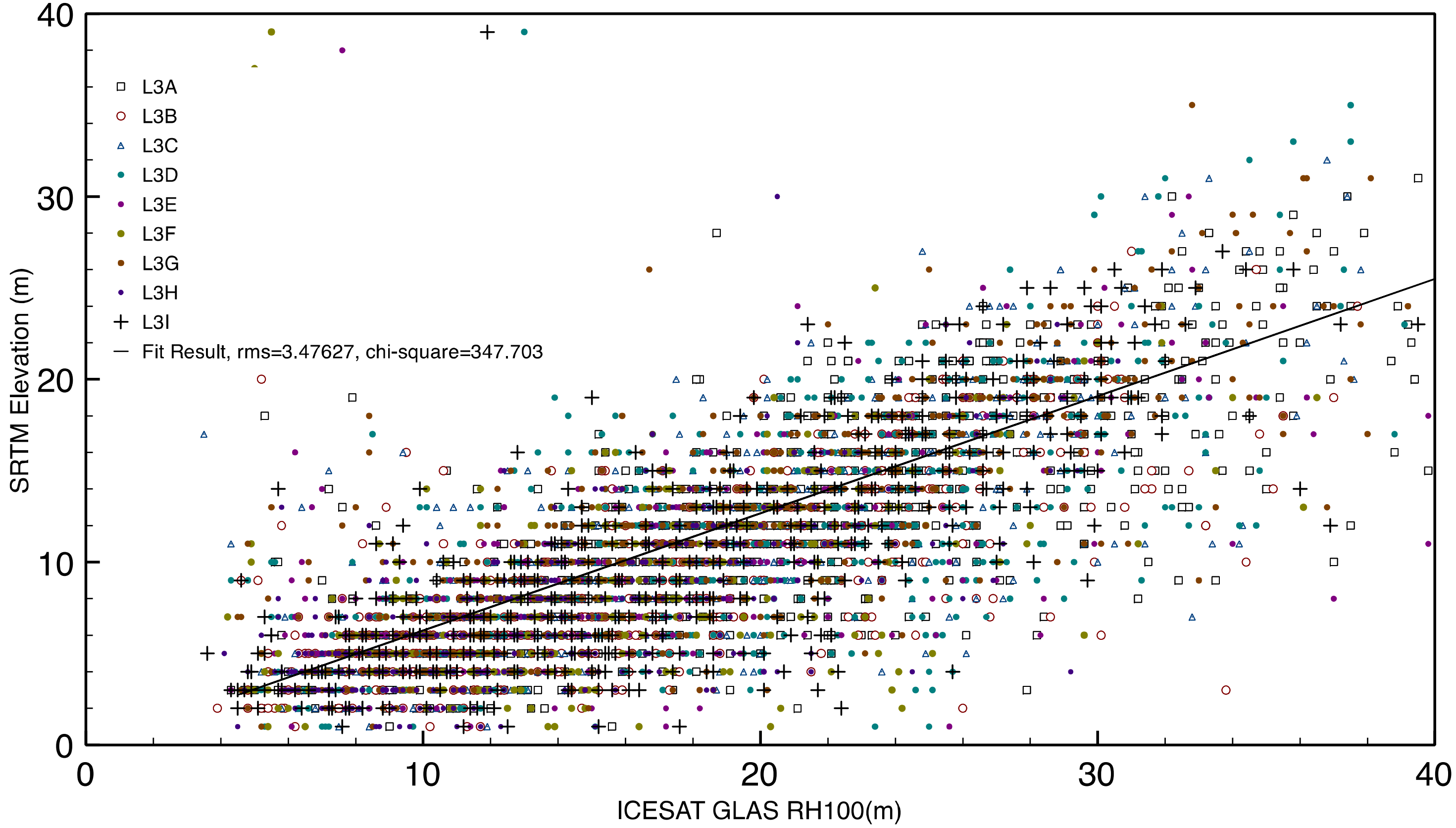




IceSAT/GLAS data over the Yucatan



SRTM calibration using ICESat/GLAS and field work

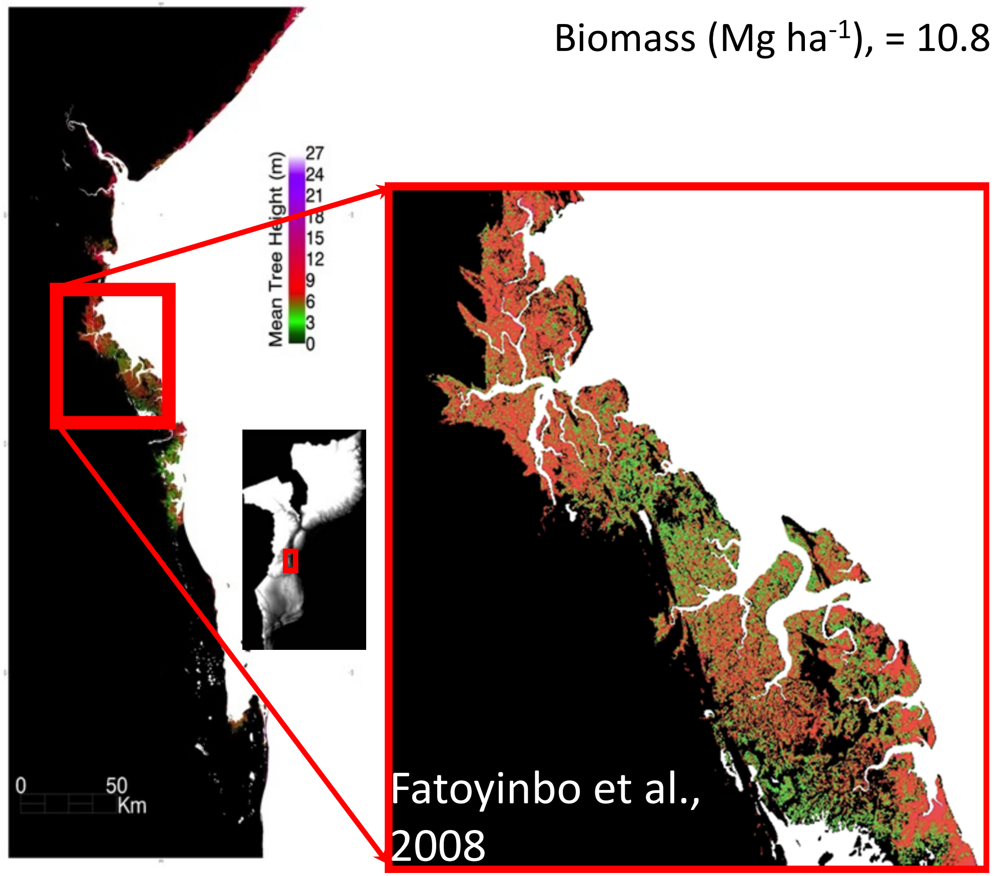


Height and Biomass estimation

- Studies of forest biomass worldwide have shown that there is a strong correlation between tree size (diameter and height), and tree biomass.

- For mangrove forests, a global stand height-biomass allometric equation was calculated by Saenger and Snedaker (1993):

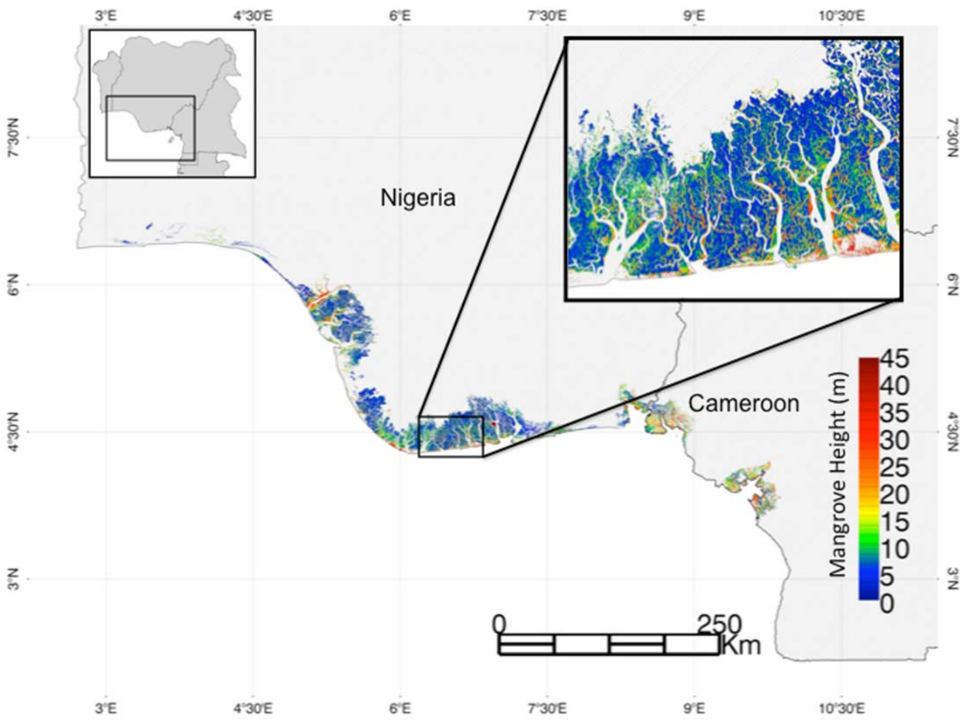
$$\text{Biomass (Mg ha}^{-1}\text{)}, = 10.8 * \textit{Height (m)} + 35$$



- We were able to produce height and biomass maps for Mozambique based on field data and SRTM alone, with an RMSE of 1.6 m and 65 Mg/ha.

- Then we expanded our work to the entire African continent where we used GLAS height as calibration with an RMSE of 3.5 m

Height and Biomass Map of Mangrove Forests of Africa

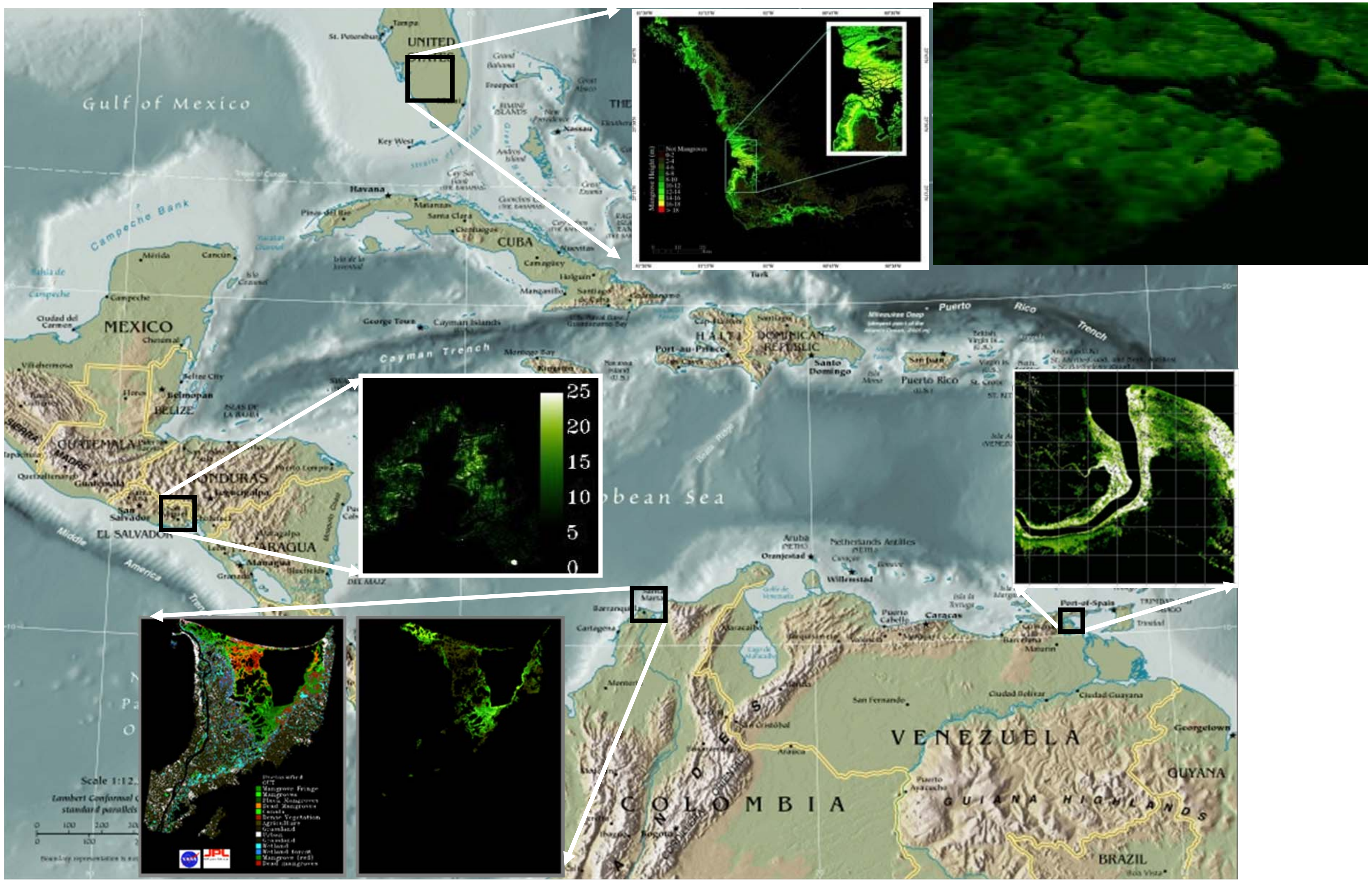


Fatoyinbo & Simard, IJRS 2013

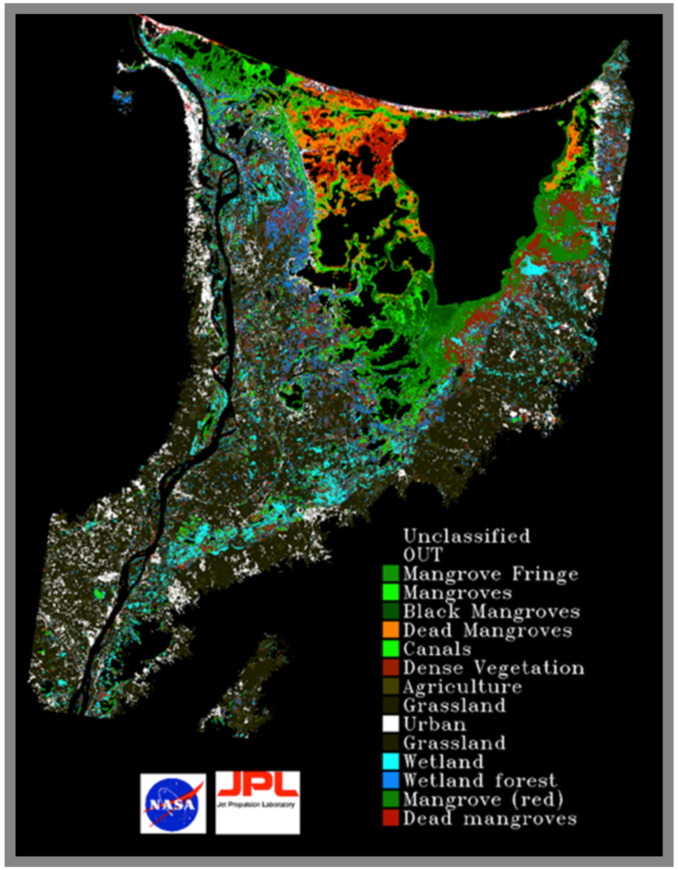
Country	Area in km^2	Total Biomass in Mg	Mean Biomass in Mg/ha
Angola	154	1,441,200	93
Benin	18	137,719	76
Cameroon	1,483	25,334,900	171
Congo	15	267,603	178
Cote d'Ivoire	32	406,516	124
Djibouti	17	1,653,170	90
DRC	183	51,570	140
Egypt	1	8,344	117
Equatorial Guinee	181	2,922,420	161
Eritrea	49	640,038	129
Gabon	1,457	23,840,000	162
Gambia	519.11	5,509,300	106
Ghana	76	742,925	97
Guinea	1,889	18,153,800	108
Guinea Bissao	2,806	31,712,300	113
Kenya	192	2,294,820	119
Liberia	189	2,141,860	113
Madagascar	2,059	24,856,900	121
Mauritania	0.4	4,156	95
Mozambique	3,054	30,974,100	101
Nigeria	8,573	94,788,000	111
Senegal	1,200	11,462,100	95
Sierra Leone	955	10,655,600	112
Somalia	30	436,907	143
Soudan	4	135,626	113
South Africa	12	40,018	100
Togo	2	15,861	78
Tanzania	809	11,037,800	136
Africa	25,960	301,665,553	116

Google earth files: http:www-radar.jpl.nasa.gov/coastal

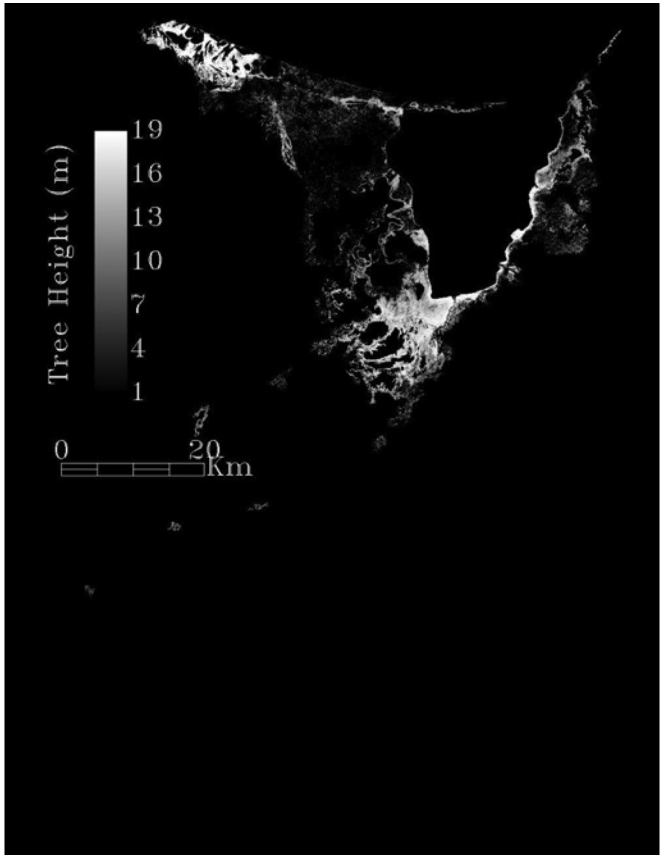
Americas



Cienaga Grande de Santa Marta, Colombia



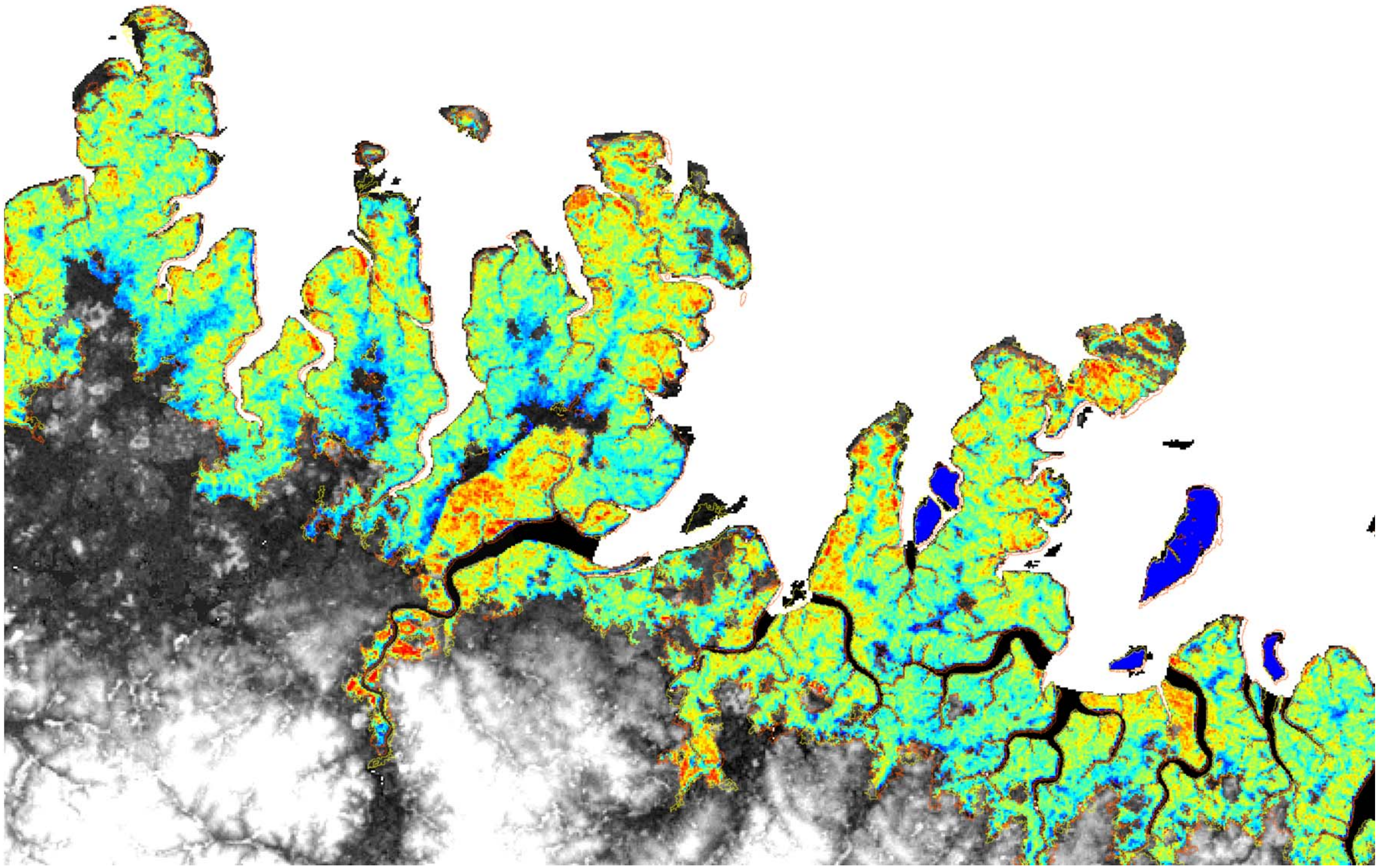
Landsat Land Cover Classification



Mean Mangrove Tree Height

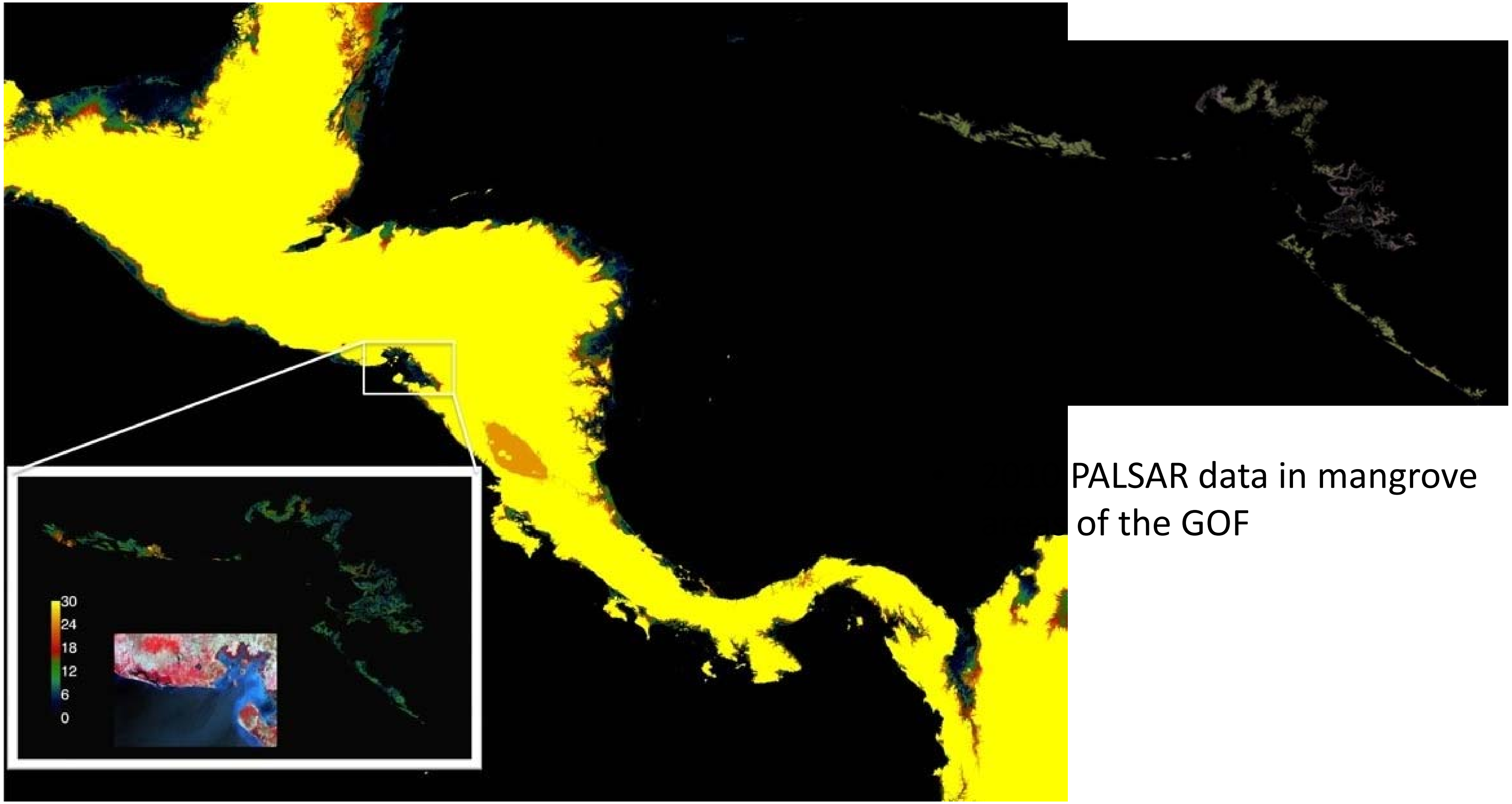
Simard et al. Remote Sensing of the Environment, 2008.

Brazil, Mexico and Costa Rica



Gulf of Fonseca Height Map

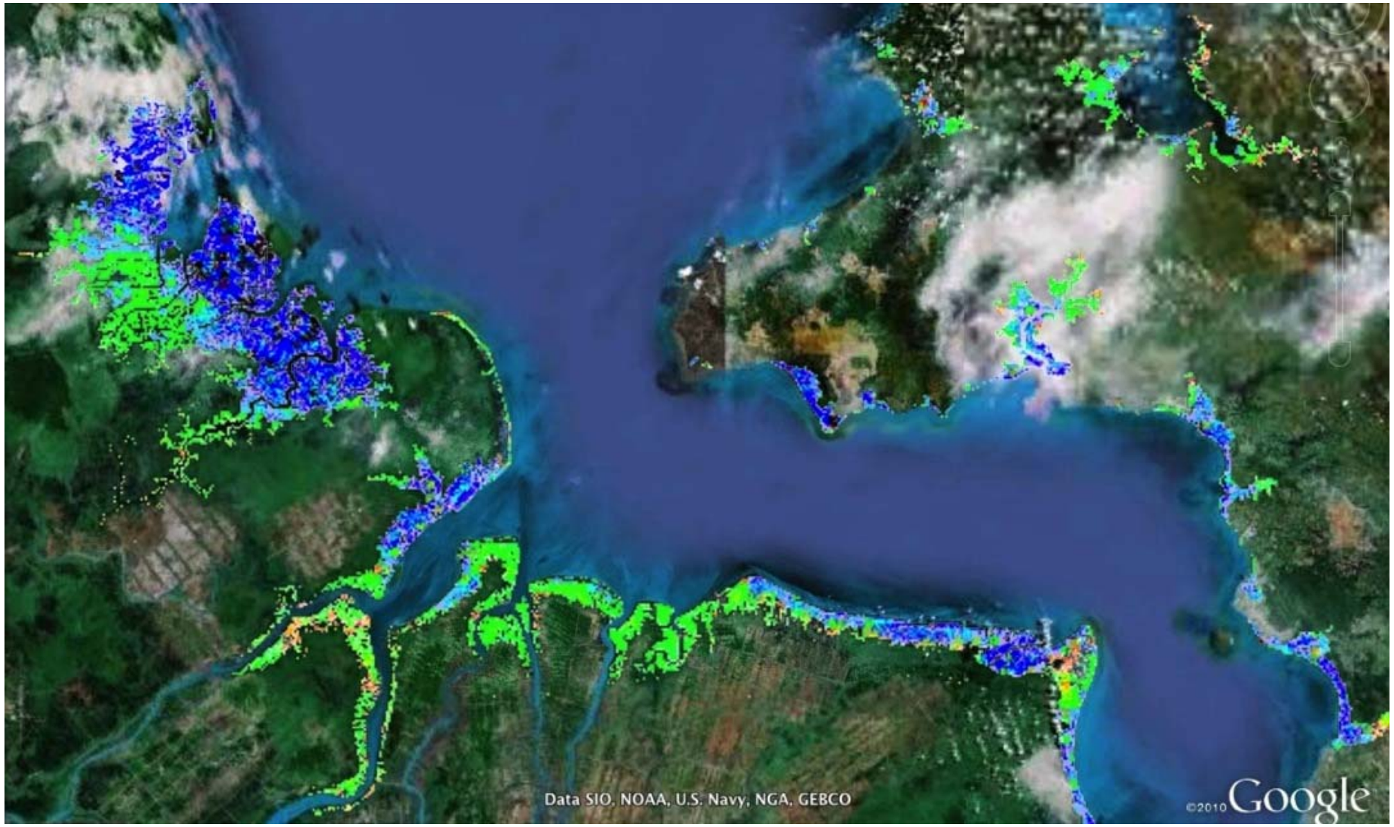
- example of a mean tree height map for the Golf of Fonseca in El Salvador, Honduras and Nicaragua



PALSAR data in mangrove of the GOF

Global Map of Mangrove height and biomass

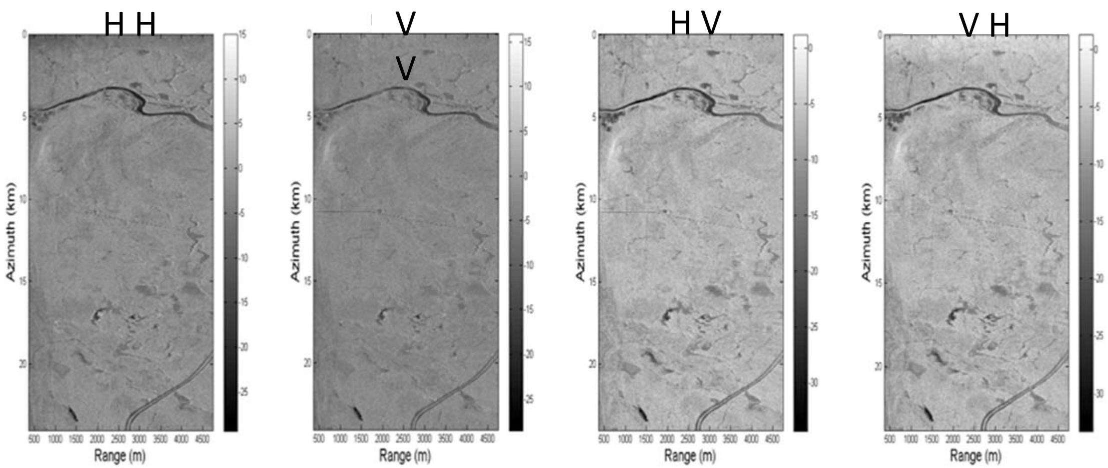
- Expand mangrove height and biomass measurements from SRTM and GLAS to the entire globe
- thanks to new global maps of mangrove cover (Giri et al 2011), improvements from ALOS/PALSAR landcover mapping and field data in South and Central America

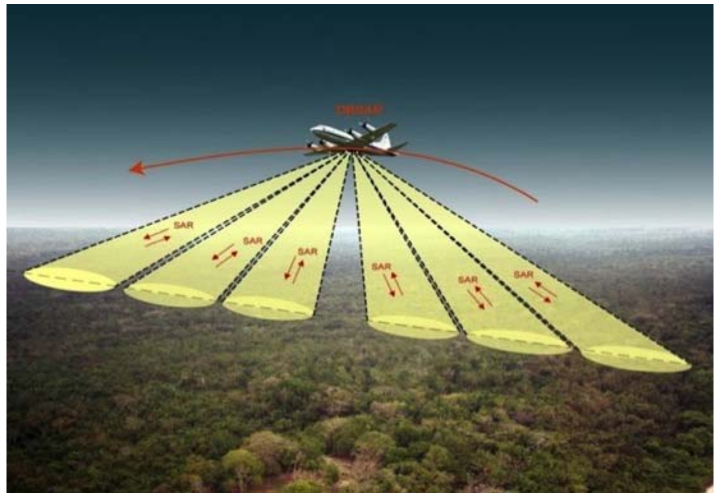


NEW INSTRUMENT UPDATE

DBSAR Digital Beamforming SAR

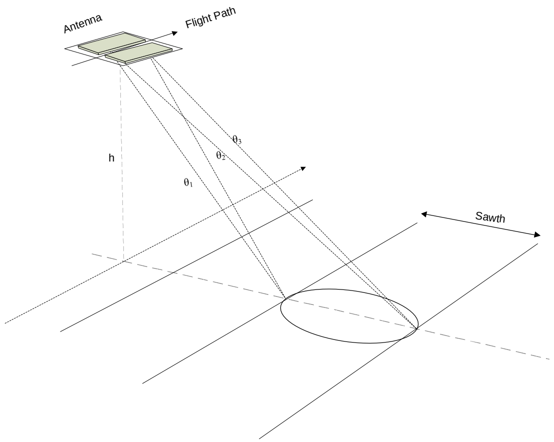
- DBSAR is a polarimetric L-band (1.26 GHz) airborne imaging radar system developed at GSFC to formulate, implement and test new radar techniques
- DBSAR combines digital beamforming, reconfigurable architecture, and real-time processing.
- Multimode operation: SAR, scatterometer, altimeter
- Digital beamforming permits the implementation of non-conventional measurement techniques, which can overcome fundamental limitations of conventional radar systems such as:
  - increasing the measurement swath without reducing the received antenna gain,
  - synthesizing of multiple beams on both sides of the aircraft using a single nadir-looking antenna

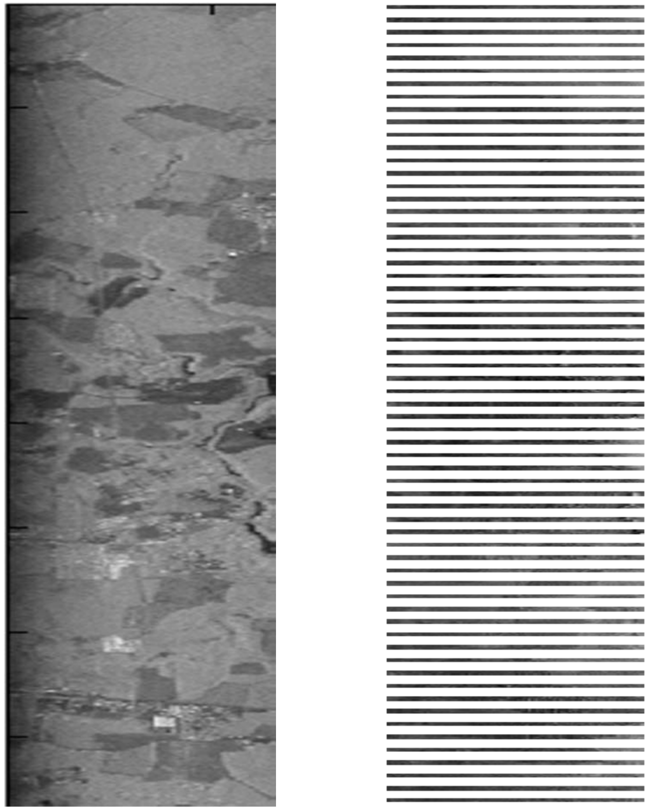




DBSAR's Single Pass InSAR Measurements

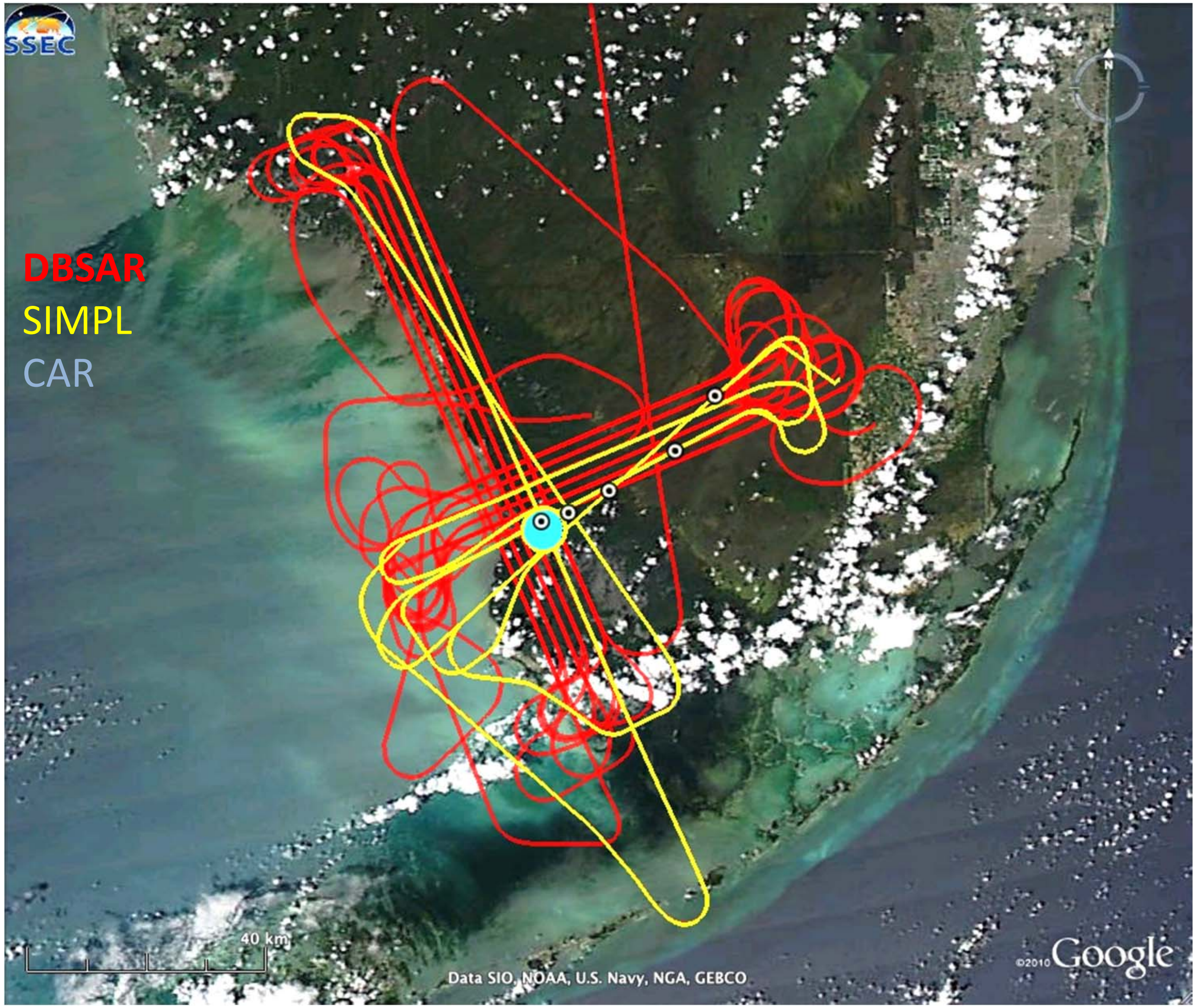
- DBSAR's digital beamforming enables the implementation of single-pass Interferometric techniques (DBInSAR).
- InSAR measurements are sensitive to the spatial variability of vertical structure parameters and can provide quantitative information on the layered structure of the vegetation, such as the depth and density.





DBSAR intensity (left) and interferometric height (right) images acquired over the Wallops Flight Facility, VA, on Sept 9, 2011

Eco3D Campaigns 2011 &2012

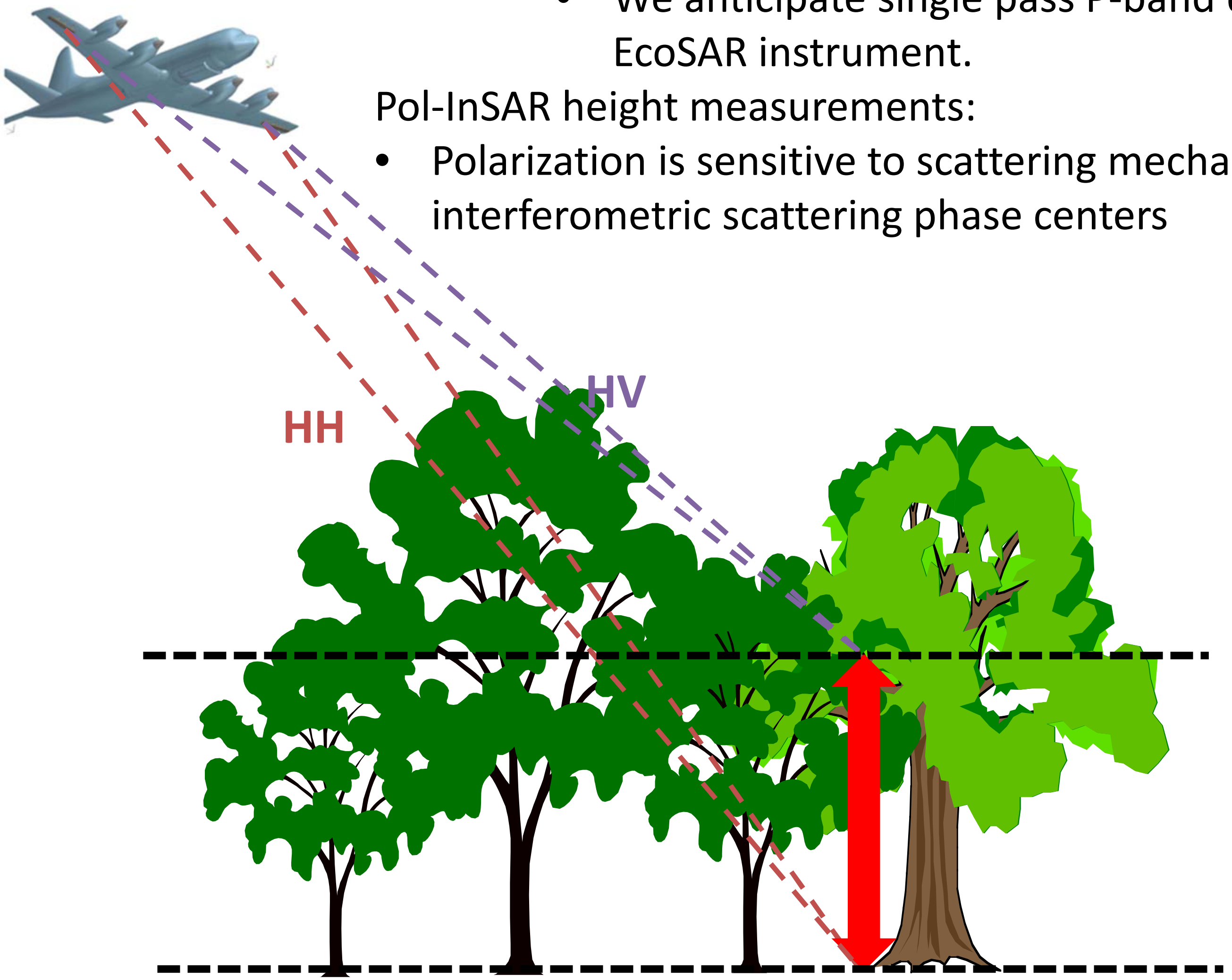


Biomass and forest structure from PolInSAR

- Technique that has never been used in mangroves
- We anticipate single pass P-band data from upcoming EcoSAR instrument.

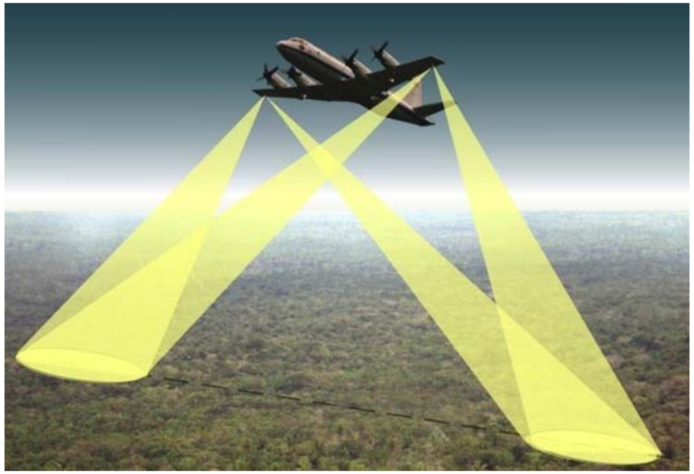
Pol-InSAR height measurements:

- Polarization is sensitive to scattering mechanisms with different interferometric scattering phase centers



EcoSAR Summary

- EcoSAR is an advanced airborne polarimetric and interferometric P-band (435 MHz) SAR instrument in development at NASA/Goddard Space Flight Center through NASA's Earth Science Technology office Instrument Incubator Program (IIP).



- EcoSAR will provide two- and three dimensional fine scale measurements of terrestrial ecosystem structure and biomass. These measurements directly support science requirements for the study of the carbon cycle and its relationship to climate change.

- The EcoSAR instrument will employ digital beamforming and use a reconfigurable architecture to select and adjust important parameters including number of beams, beam direction, pulse duration, and signal bandwidth (range resolution).

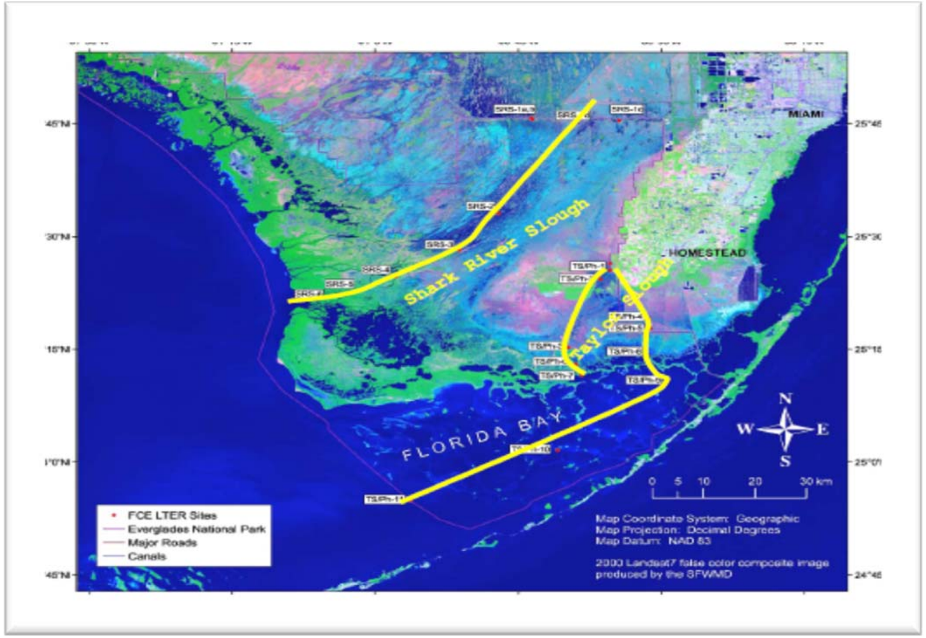
Total Carbon Storage in Mangroves
Above and Belowground C

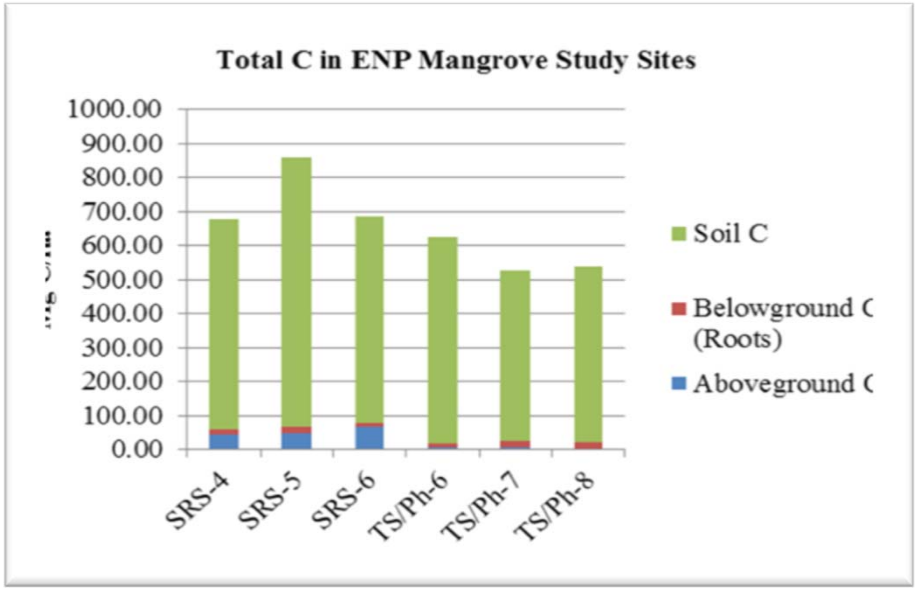
NASA LCLUC Program

Marc Simard, Victor Rivera-Monroy,
Rinku Roy Chowdhury, Lola Fatoyinbo

Total Carbon Storage Mangroves

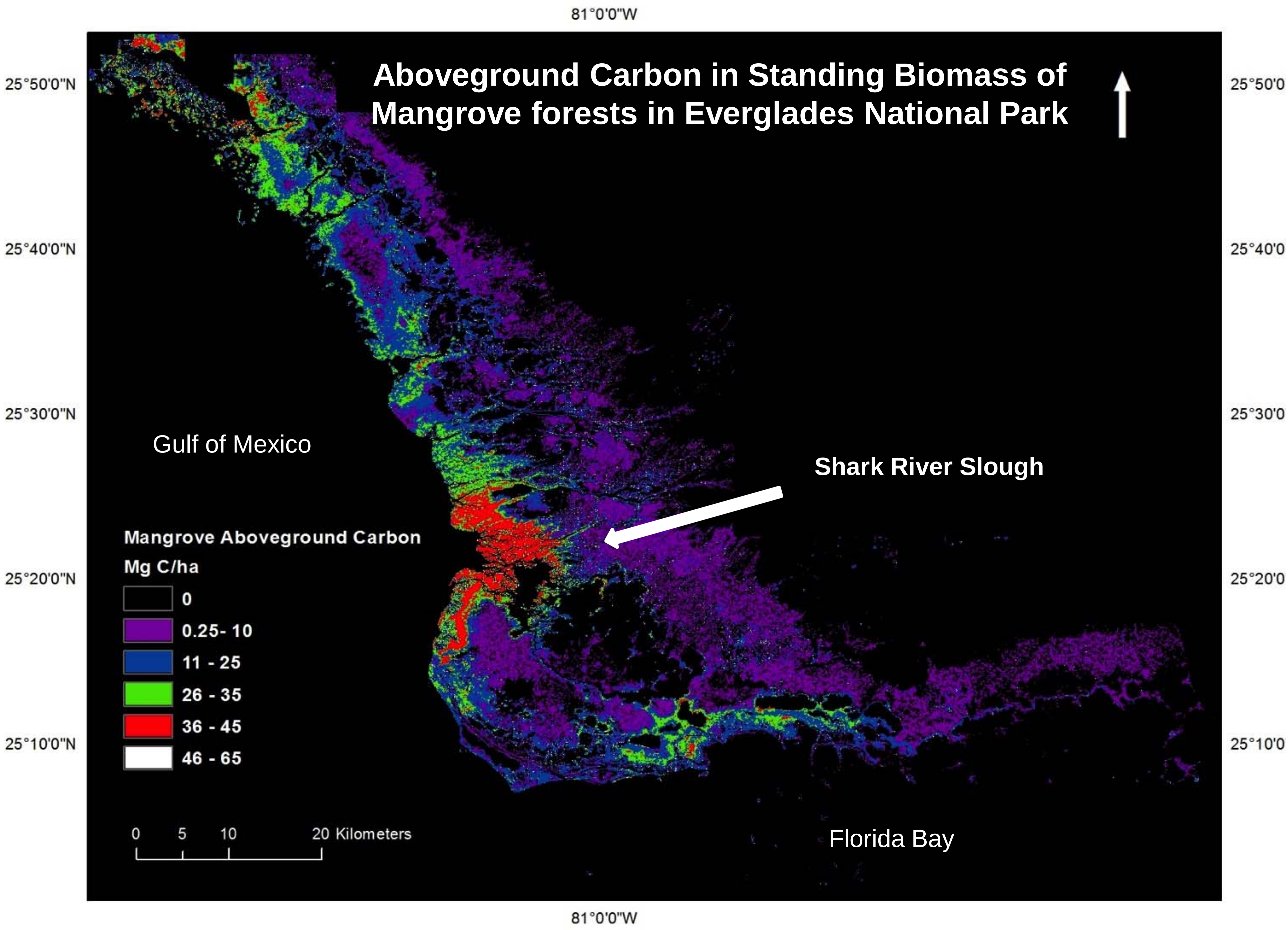
Florida Coastal Everglades LTER Study Sites

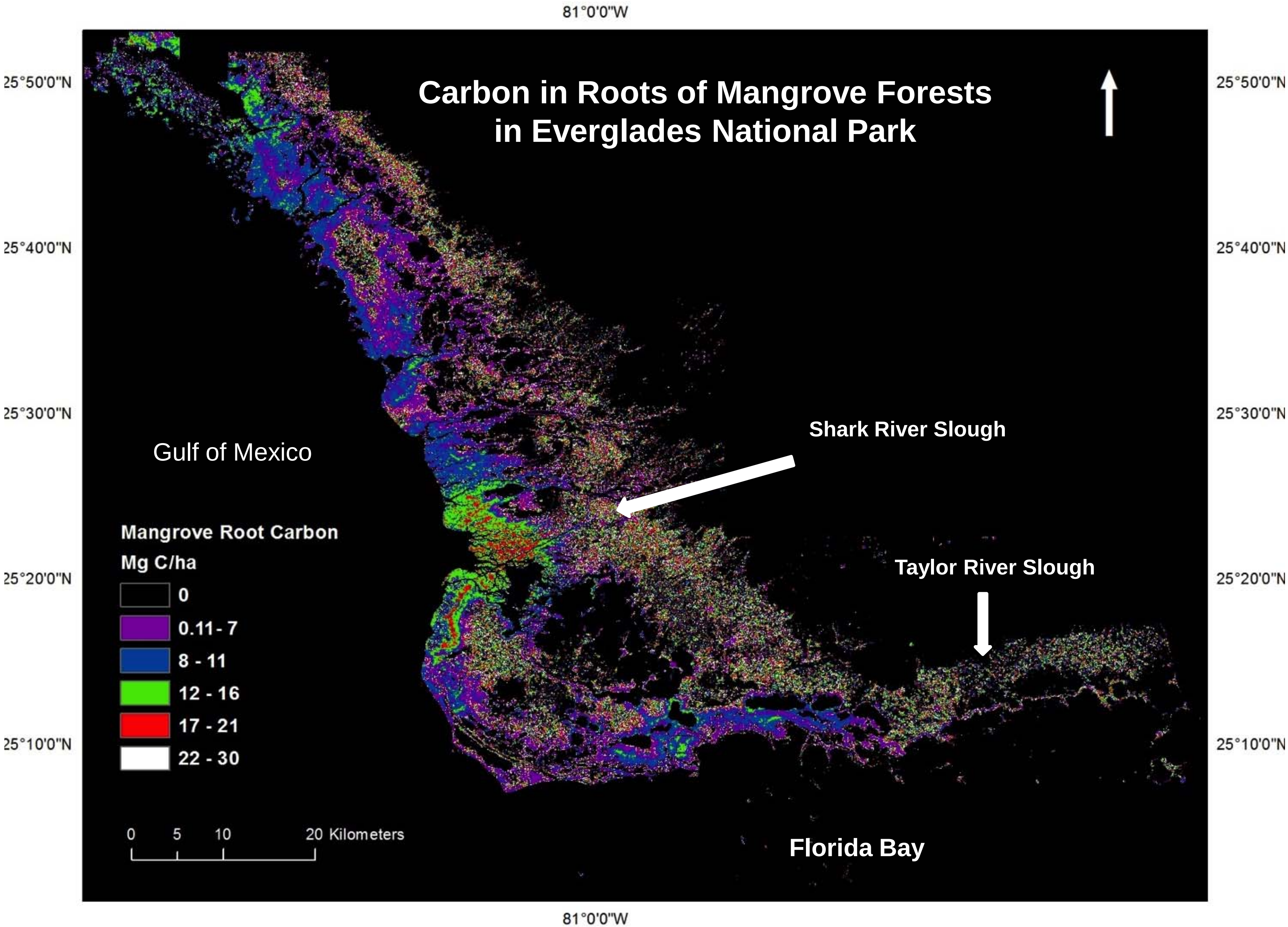


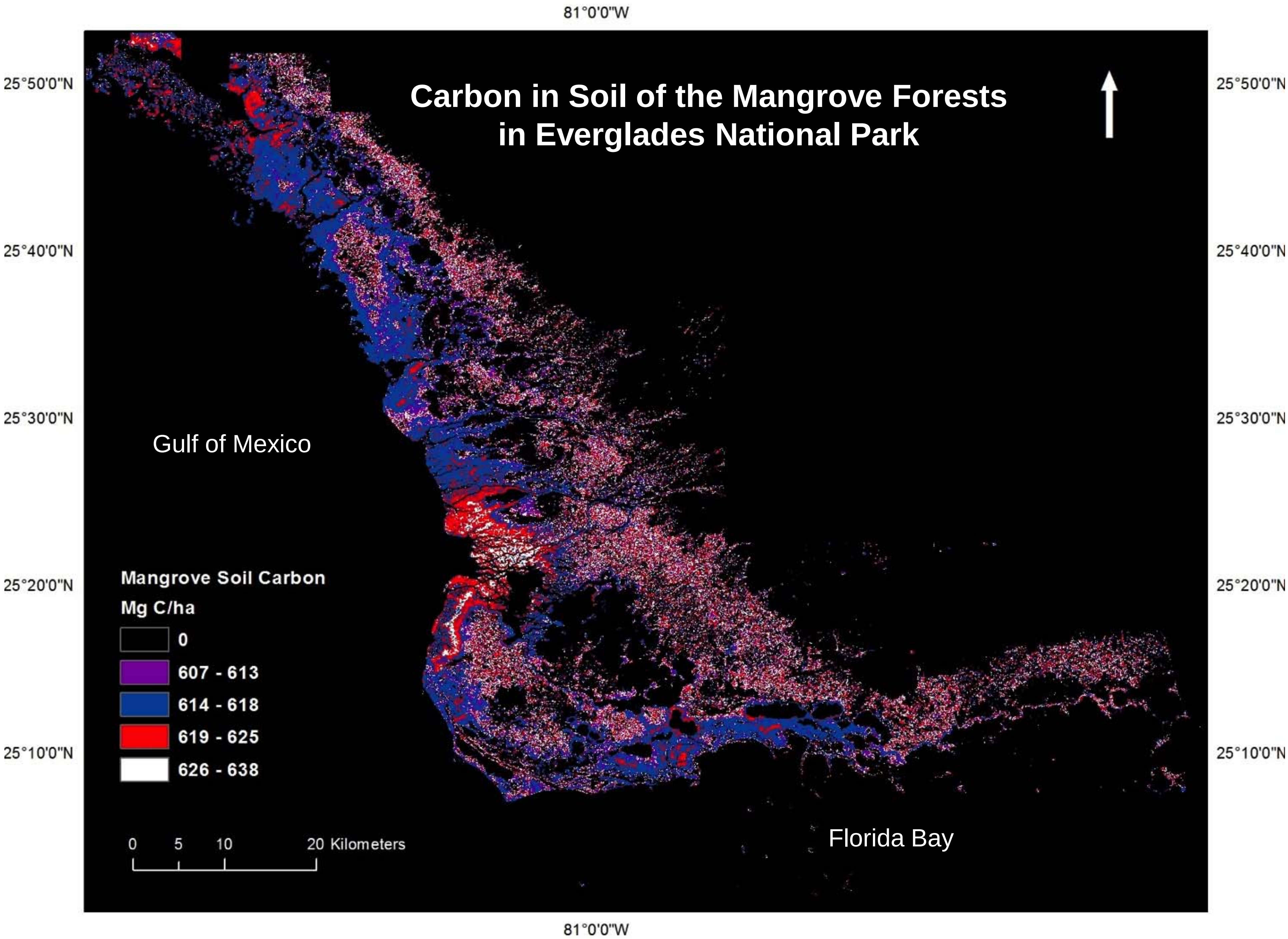


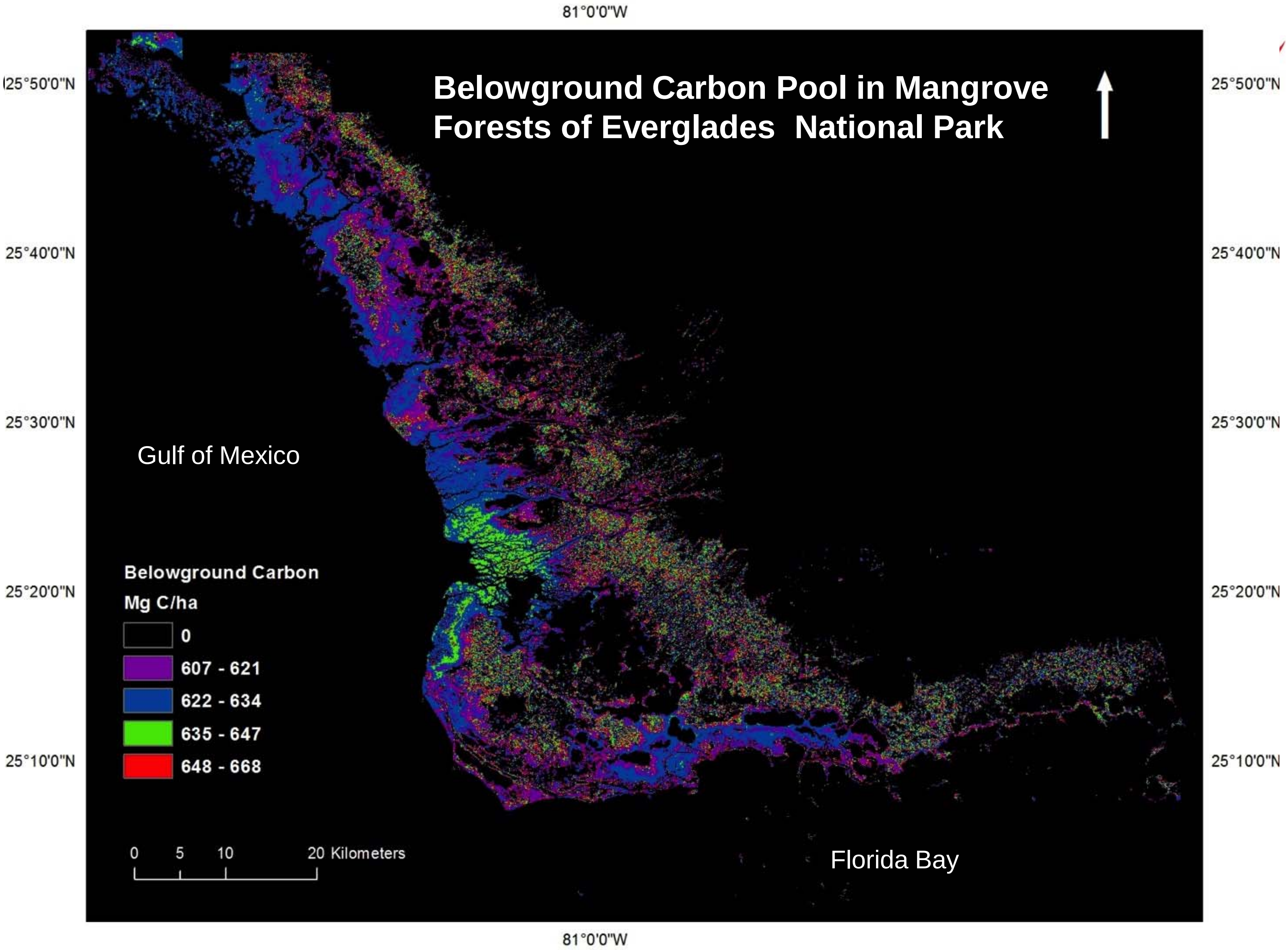
Total Carbon Storage in ENP mangroves = 990,724 ,732 Mg C

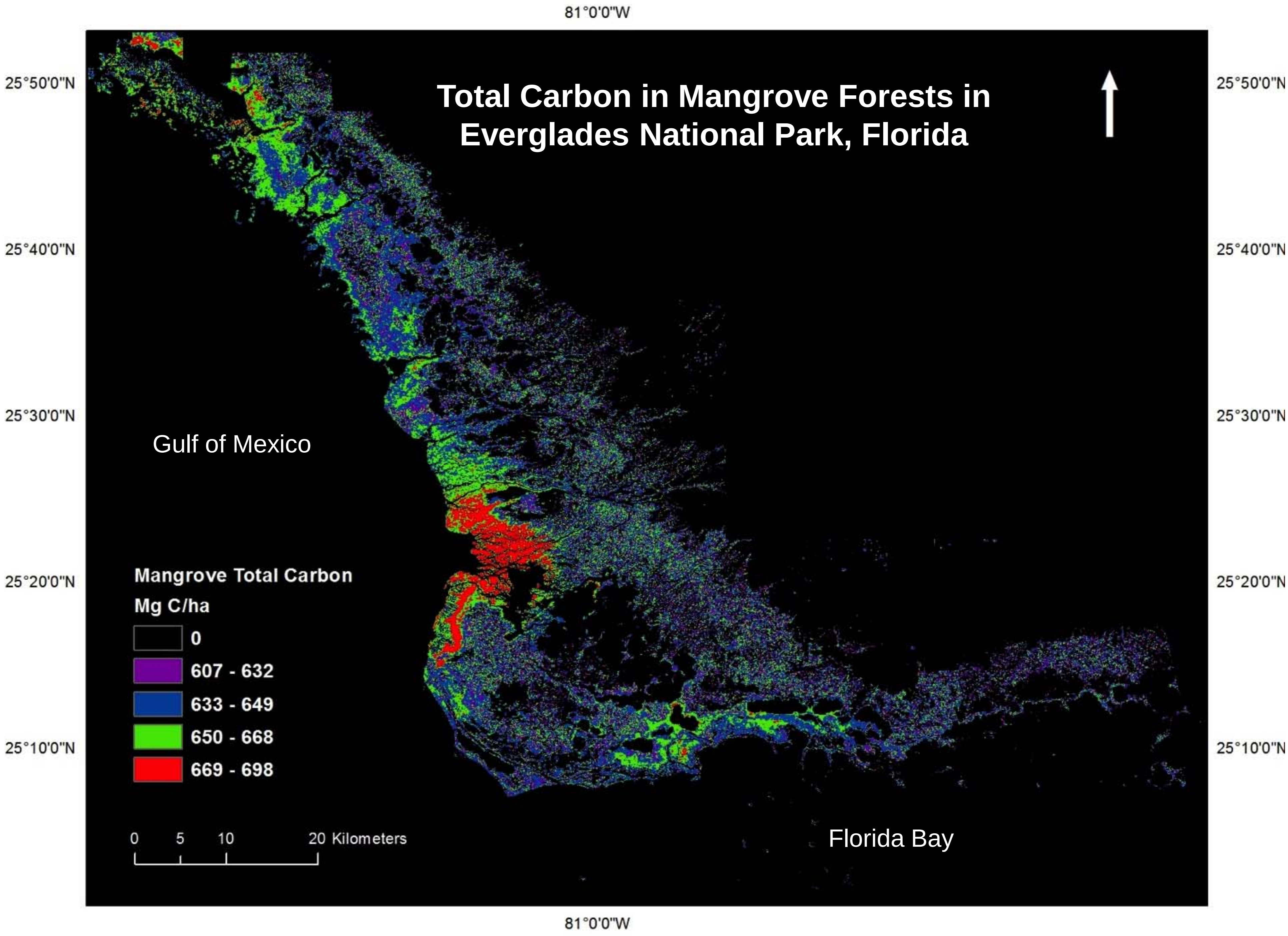
(7144 Mg C/ha)


81°0'0"W
Aboveground Carbon in Standing Biomass of
Mangrove forests in Everglades National Park
25°50'0"N
25°40'0"N
25°30'0"N
25°20'0"N
25°10'0"N
25°50'0
25°40'0
25°30'0
25°20'0
25°10'0
Gulf of Mexico
Shark River Slough
Mangrove Aboveground Carbon
Mg C/ha
0
0.25- 10
11 - 25
26 - 35
36 - 45
46 - 65
0 5 10 20 Kilometers
Florida Bay
81°0'0"W

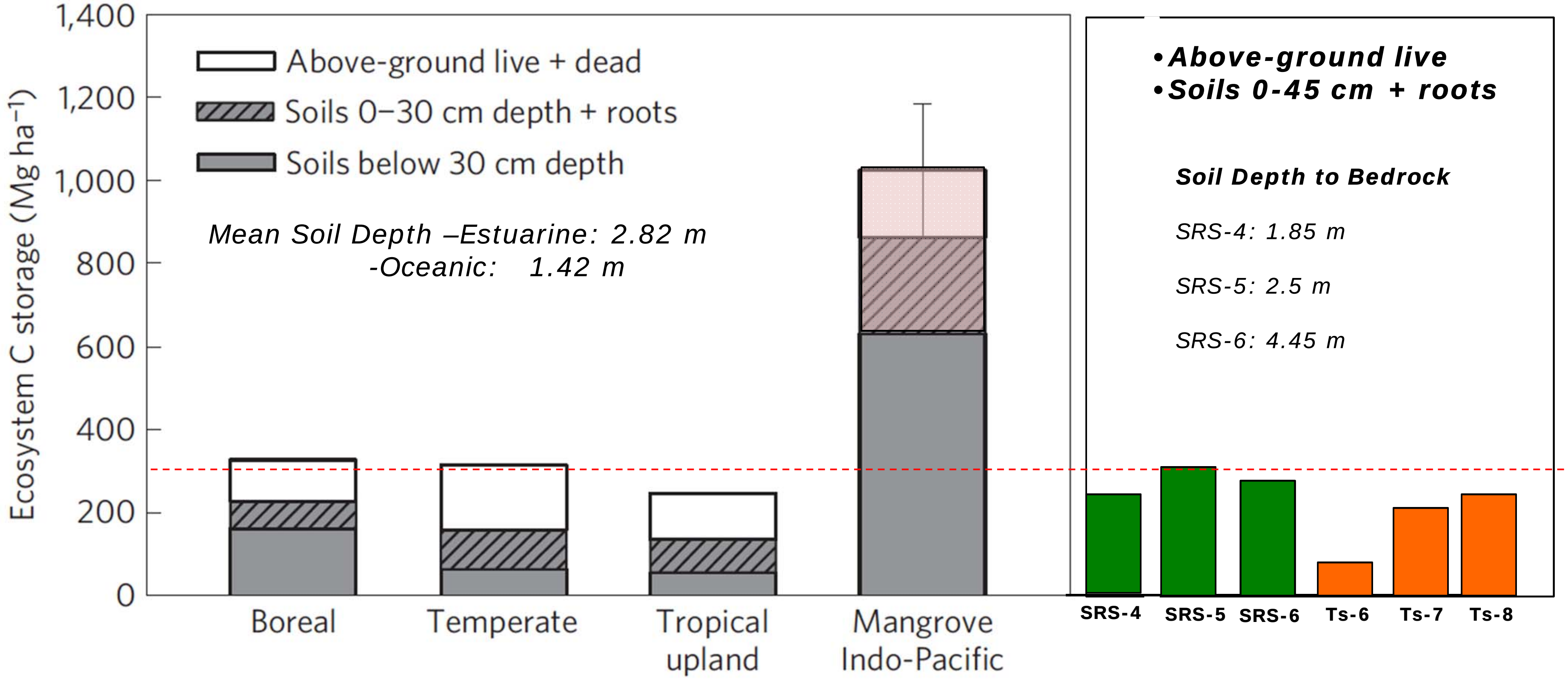

81°0'0"W
Carbon in Roots of Mangrove Forests
in Everglades National Park
25°50'0"N
25°40'0"N
25°30'0"N
25°20'0"N
25°10'0"N
Shark River Slough
Gulf of Mexico
Taylor River Slough
Mangrove Root Carbon
Mg C/ha
0
0.11 - 7
8 - 11
12 - 16
17 - 21
22 - 30
0 5 10 20 Kilometers
Florida Bay
81°0'0"W


81°0'0"W
25°50'0"N
25°40'0"N
25°30'0"N
25°20'0"N
25°10'0"N
Carbon in Soil of the Mangrove Forests
in Everglades National Park
Gulf of Mexico
Mangrove Soil Carbon
Mg C/ha
0
607 - 613
614 - 618
619 - 625
626 - 638
0 5 10 20 Kilometers
Florida Bay


81°0'0"W
Belowground Carbon Pool in Mangrove
Forests of Everglades National Park
25°50'0"N
25°40'0"N
25°30'0"N
25°20'0"N
25°10'0"N
Gulf of Mexico
Belowground Carbon
Mg C/ha
0
607 - 621
622 - 634
635 - 647
648 - 668
0 5 10 20 Kilometers
Florida Bay
81°0'0"W


81°0'0"W
25°50'0"N
25°40'0"N
25°30'0"N
25°20'0"N
25°10'0"N
Total Carbon in Mangrove Forests in
Everglades National Park, Florida
Gulf of Mexico
Mangrove Total Carbon
Mg C/ha
0
607 - 632
633 - 649
650 - 668
669 - 698
0 5 10 20 Kilometers
Florida Bay
81°0'0"W

Aboveground and Belowground Carbon Pools FCE-LTER
Comparison with Indo-Pacific mangroves and other forests



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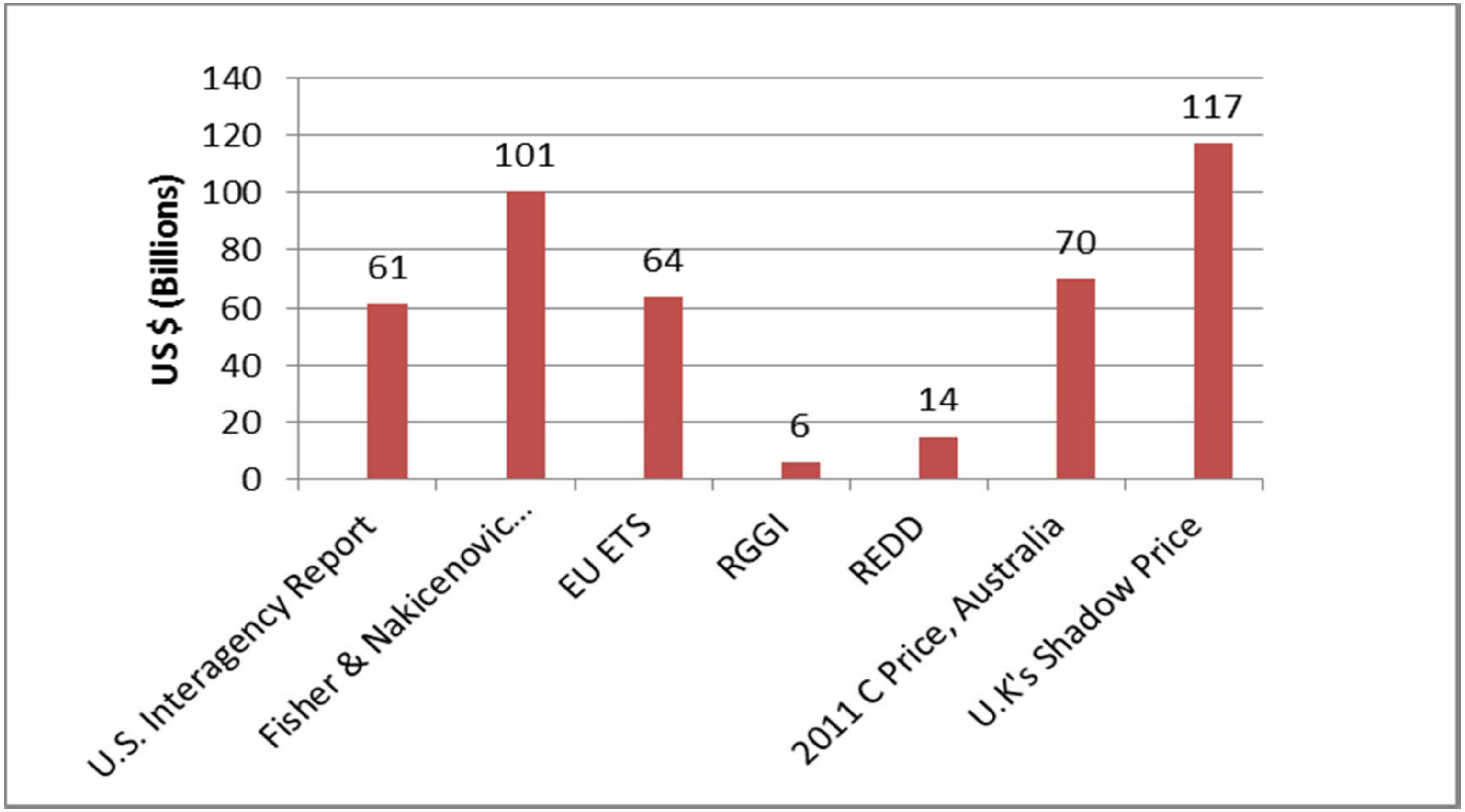
Mangroves among the most carbon-rich forests in the tropics

Daniel C. Donato[1]*, J. Boone Kauffman[2], Daniel Murdiyarso[3], Sofyan Kurnianto[3], Melanie Stidham[4] and Markku Kanninen[5]

Value of Total C of ENP Mangroves



Values range from US $ 6 billion to US $ 117 billion

Conclusions

- Mangrove ecosystems are very important component in the global C cycle, because of high C storage and emissions
- We can get reasonable estimates of forest structure and biomass from spaceborne instruments, but
- None of the spaceborne sensors I mentioned are operational! (SRTM-2000, GLAS-2009, PALSAR-2011)
- Producing C emission and deforestation estimates from space in these ecosystems is a challenge, but must be addressed.


Thank you!
Any questions?
DANGEROUS
BEND