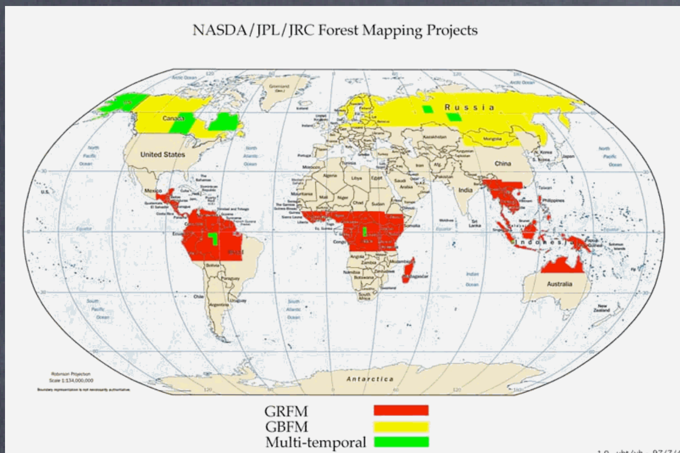
Recent Advances in the Use of Microwave Data for the Study of LCLUC Applications

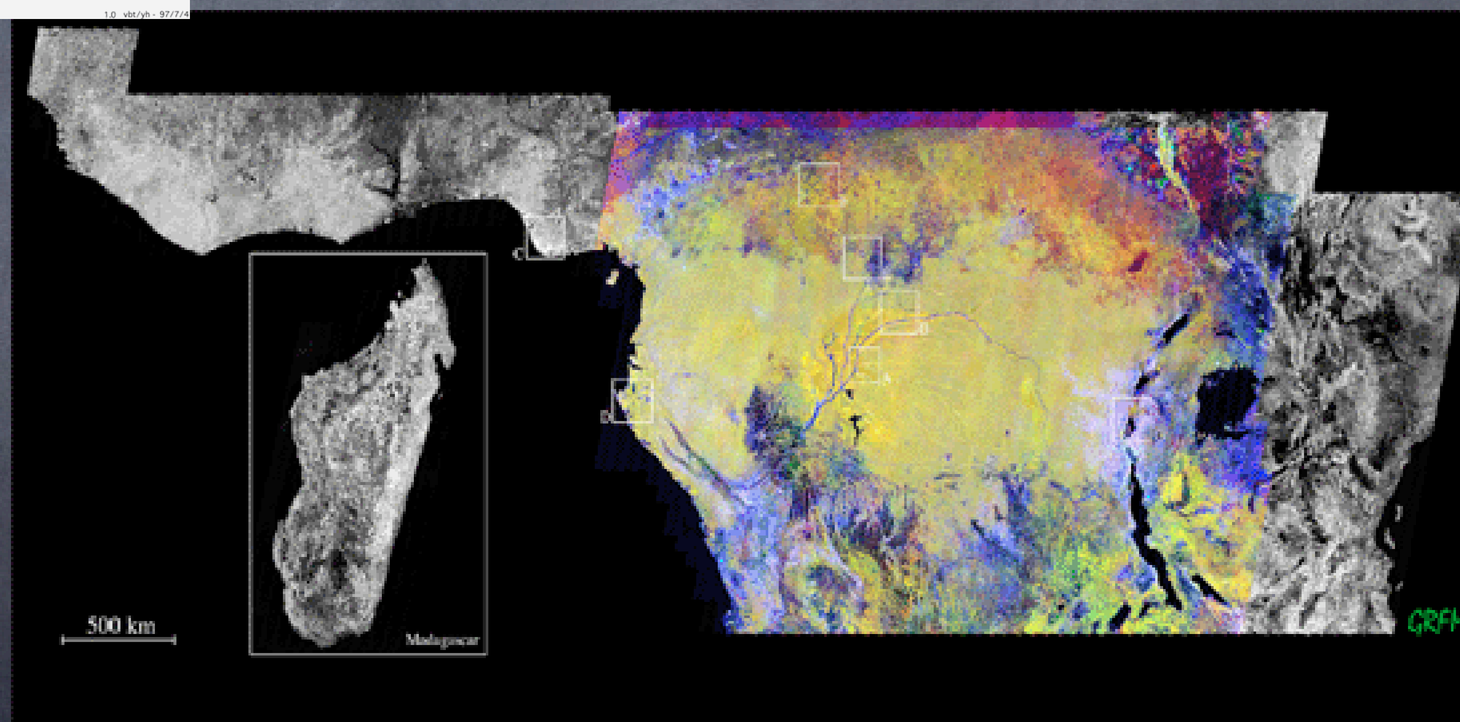
Marc Simard
marc.simard@jpl.nasa.gov
Caltech/Jet Propulsion Laboratory

Jet Propulsion Laboratory

Radar Forest Mapping



- JERS-1 Global Forest Mapping (JAXA + JPL + JRC + ASF)



First coverage was acquired during January-March 1996
Second during October - November 1996

Jet Propulsion Laboratory

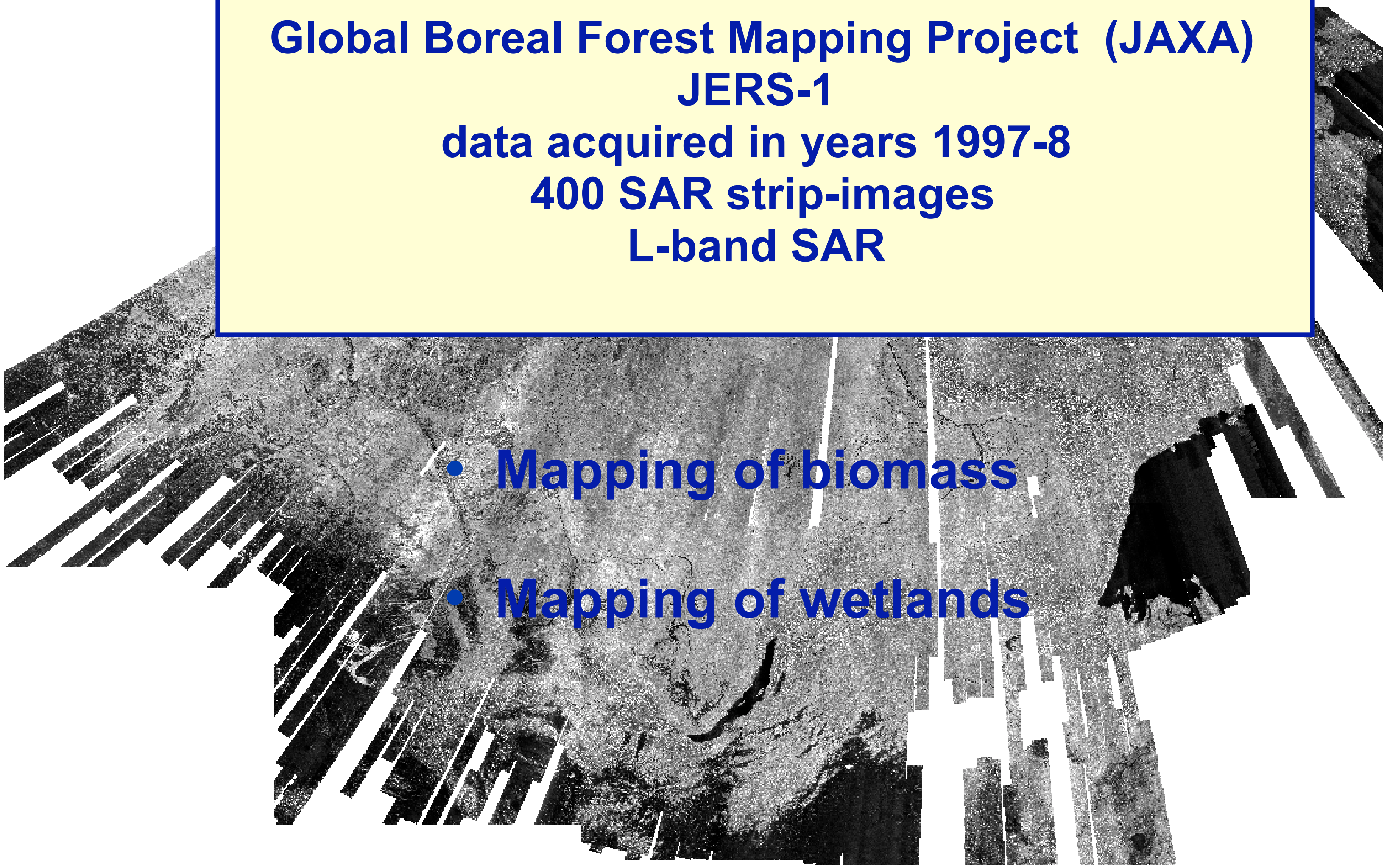
Wetlands mapping in Siberia by classification of the GBFM radar mosaic using backscatter and terrain topographic features

Jan Kropacek, Gianfranco De Grandi,

Joint Research Centre,
Institute for Environment and Sustainability,
Ispra, Italy.

GBFM Siberia Mosaic

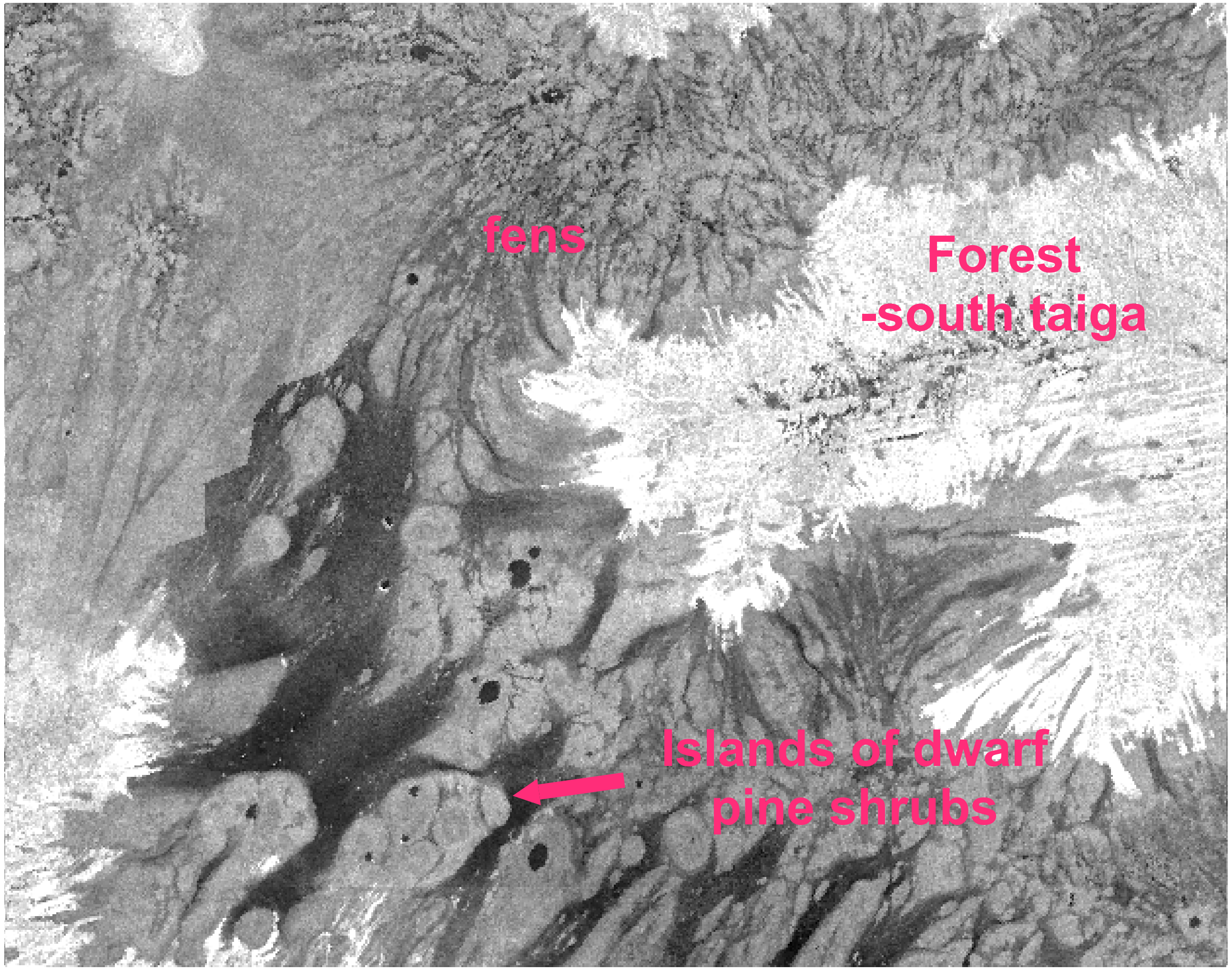
Global Boreal Forest Mapping Project (JAXA)
JERS-1
data acquired in years 1997-8
400 SAR strip-images
L-band SAR



- **Mapping of biomass**
- **Mapping of wetlands**

Institute for Environment and Sustainability

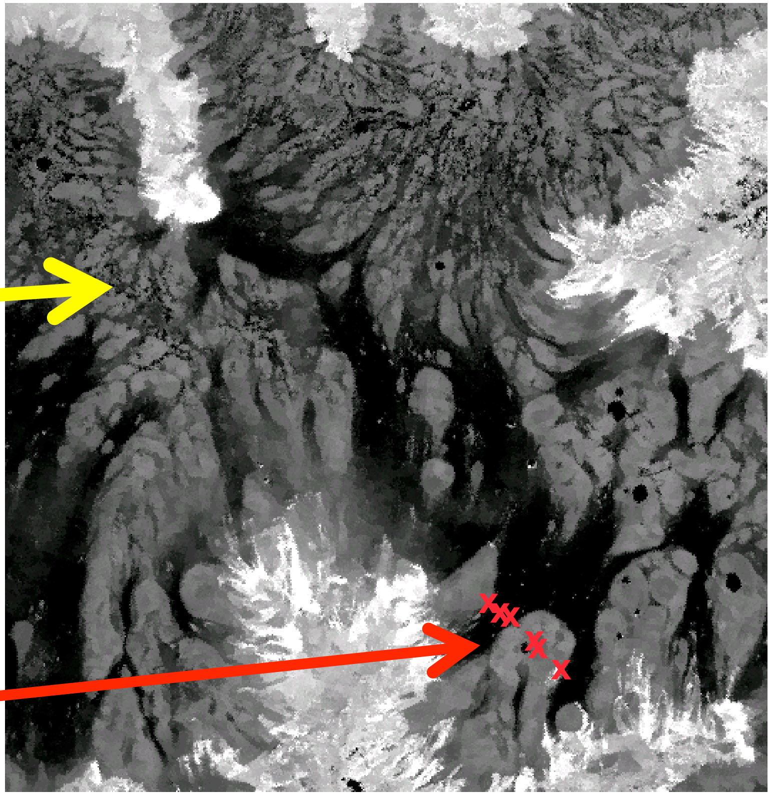
Vasjugan mire site



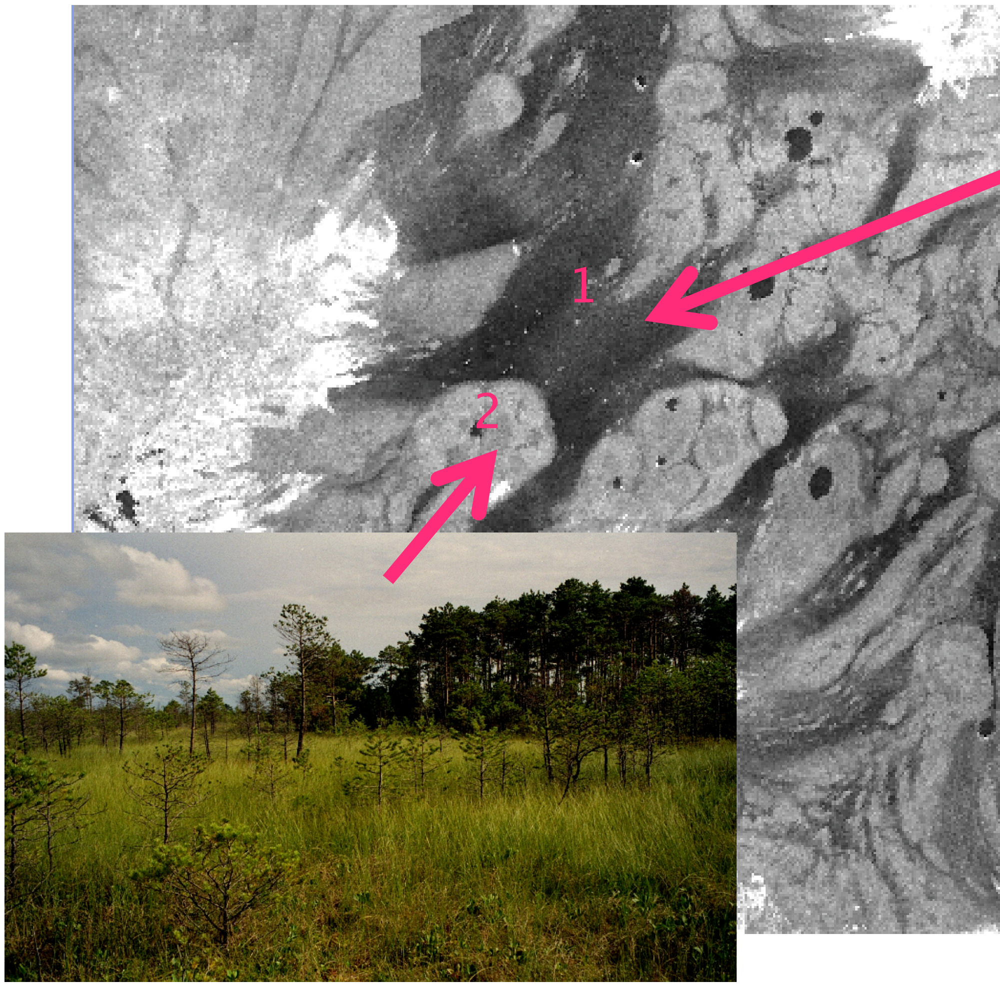
Ground information from our Russian partners

- **Field botanical survey**
- **Localized ground photographs**
- **Landsat scene classifications**

PK	Relevies	Author	Date_	Landunit
0	2293-2296	ED	26/08/1998	Minerotrophic birch shrubs with sparse birch-p
0	2291-2292	ED	26/08/1998	Minerotrophic birch shrubs with sparse birch-p
0	2289-2290	ED	26/08/1998	Oligotrophic sedge-Sphagnum fen
1	2286	ED	26/08/1998	Ryam
4	2284-2285	ED	26/08/1998	Ridge-hollow complex
0	2187	ED	21/08/1998	Oligotrophic sedge-Sphagnum fen
0	2188-2190	ED	21/08/1998	Oligotrophic sedge-Sphagnum fen
0	2191	ED	21/08/1998	Minerotrophic sedge brown moss fen

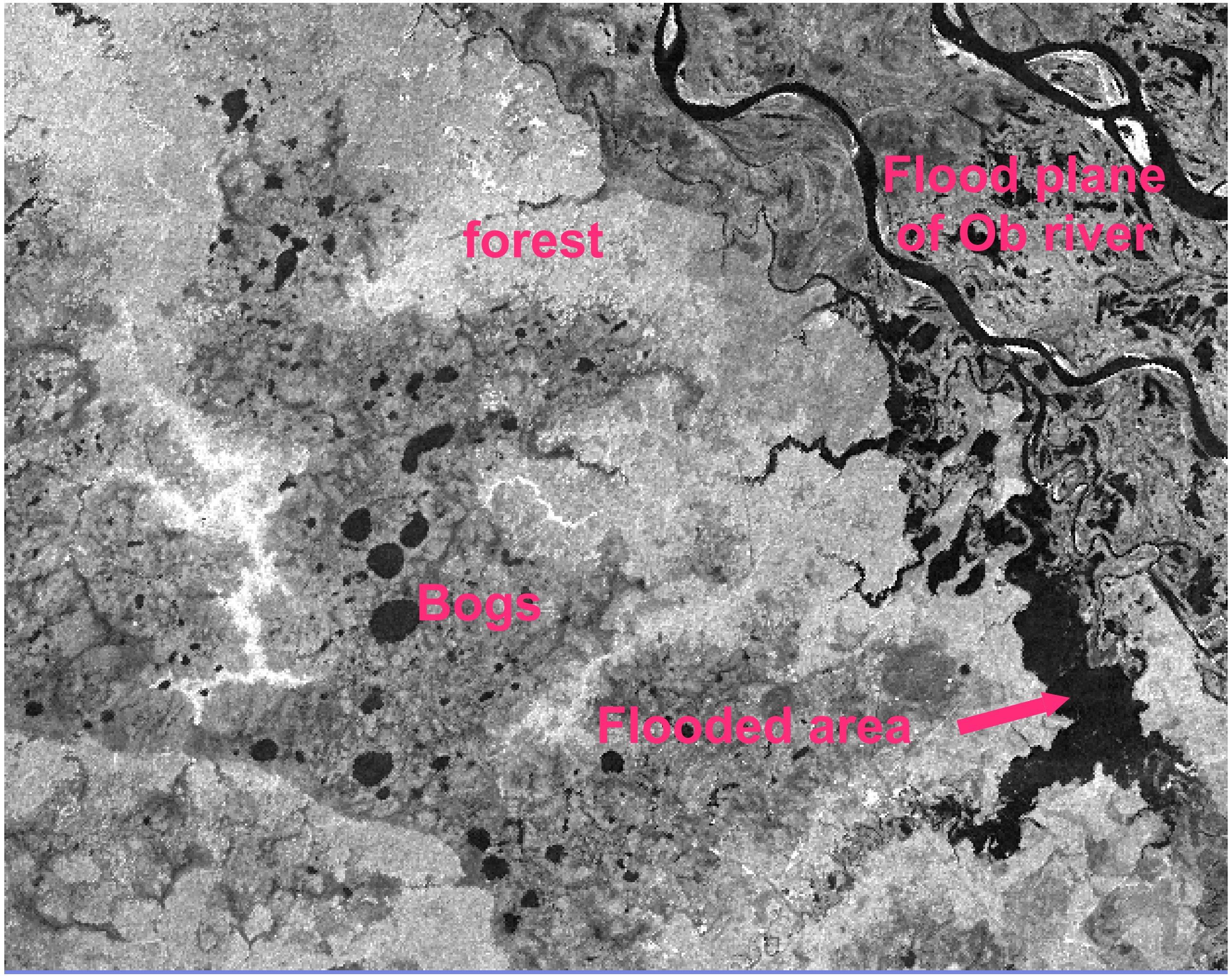


Documentation of visited sites:

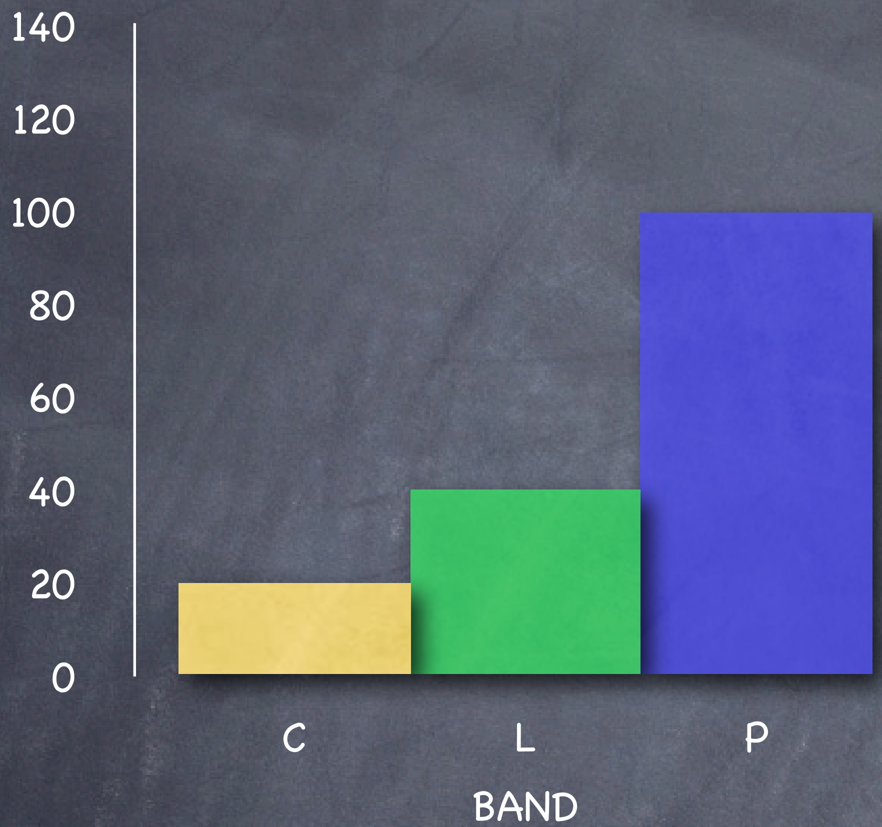


Institute for Environment and Sustainability

Chanty-Mansijsk site



Radar Backscatter and Biomass



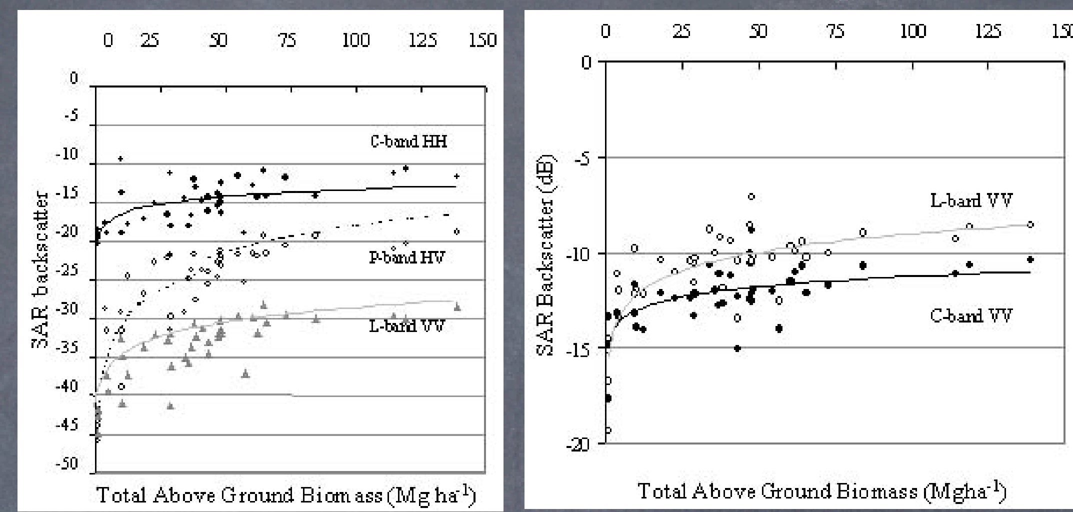


Figure from A.K. Milne et al. "The Use of Airsar Data for Assessing the Potential of Future Spaceborne Sar for Regional Estimation of Woodland Biomass in Australia " , ACRS 2000.

Dobson M.C., Ulaby F.T., Le Toan T., Beaudoin A., Kasischke E.S., Christensen N., Dependence of Radar Backscatter on Coniferous Forest Biomass. IEEE Transactions on Geoscience and Remote Sensing, Vol. 30 (2), March, pp. 412-415, 1992.

62% at P, 37% at L and 25% at C . Biomes occupying 38% (81% of mass) of Earth's vegetated surface have biomass>100t/ha (Imhoff, TGARS, V33,no2, 1995)

Improve sensivity range at L-band with texture and structure knowledge (Wang et al, TGARS, 2006, Quinones and Hoeakman, TGARSS 2006, Kasischke et al. 1995)

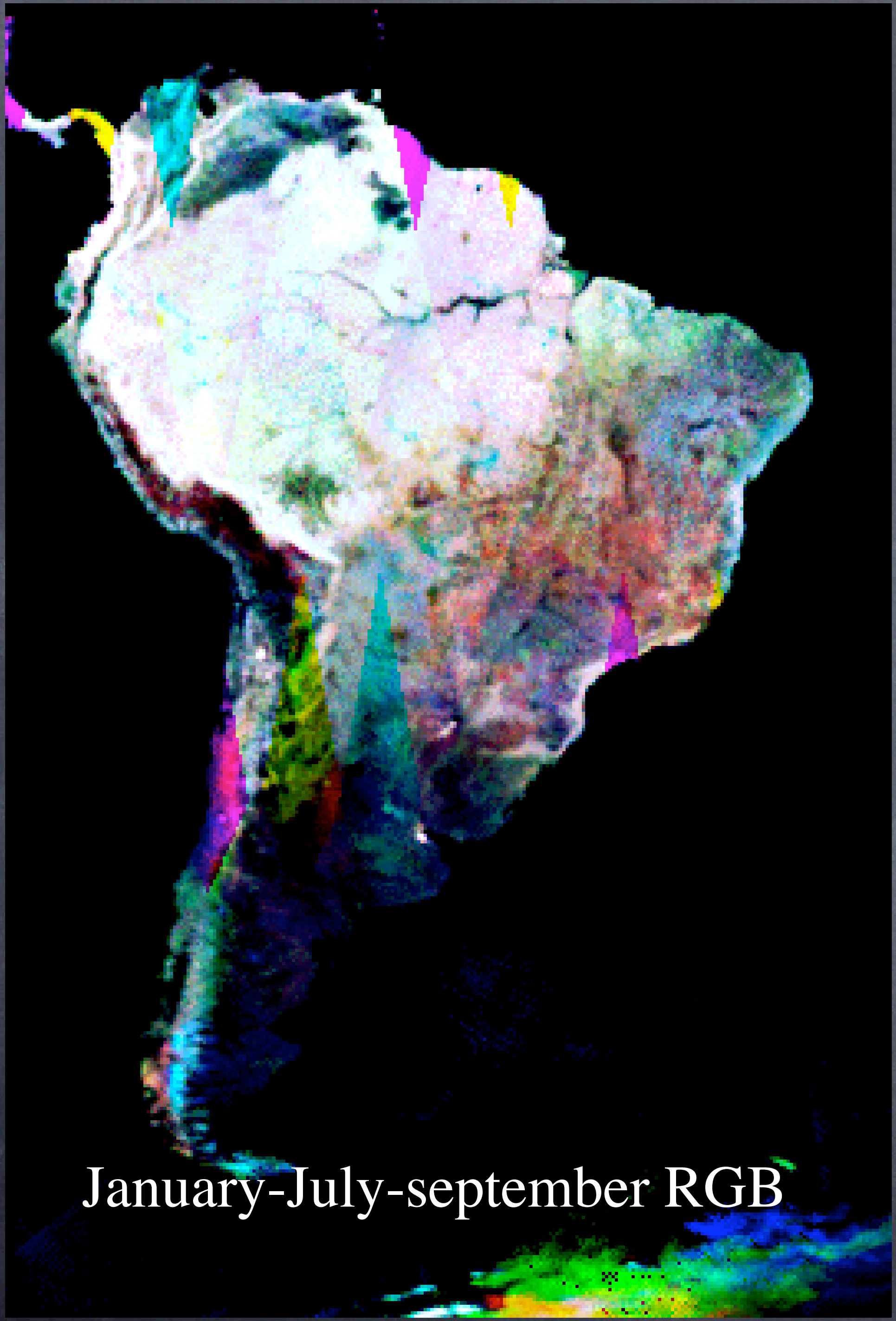
Jet Propulsion Laboratory

C-band Radar

- C-band polarimetric for crop classification (80%: Stankiewicz, TGARS 2006) and land cover specific soil moisture with < 15% error (Loew et al, 2006 at DLR) and low biomass wetland water level (Grings et al. , TGARS 2006)
- C-band ratio VV/HH (r2=0.8) to estimate LAI in boreal forest (Manninen et al., TGARS, 2005).

JPL Jet Propulsion Laboratory

NASA

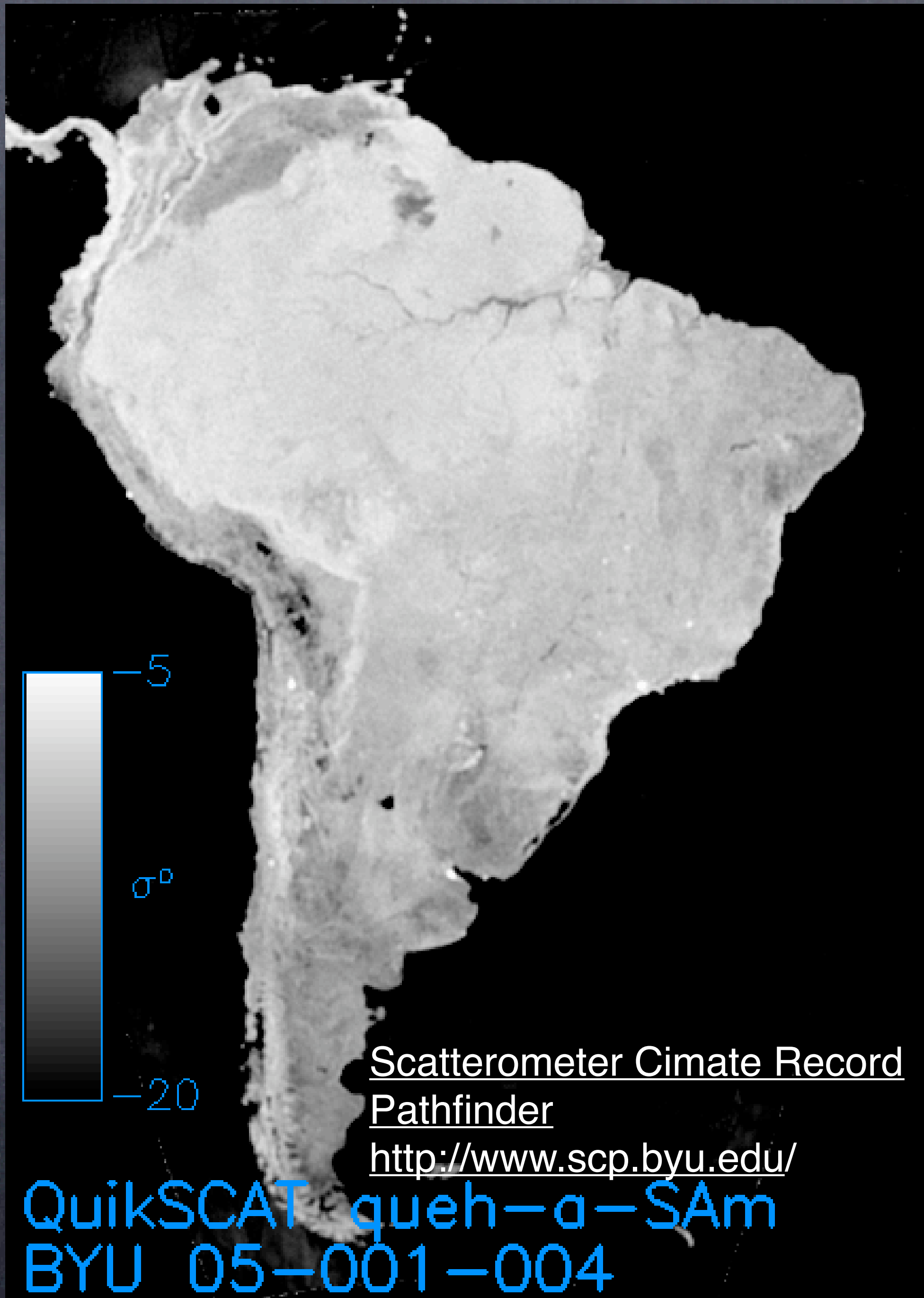


Quickscat

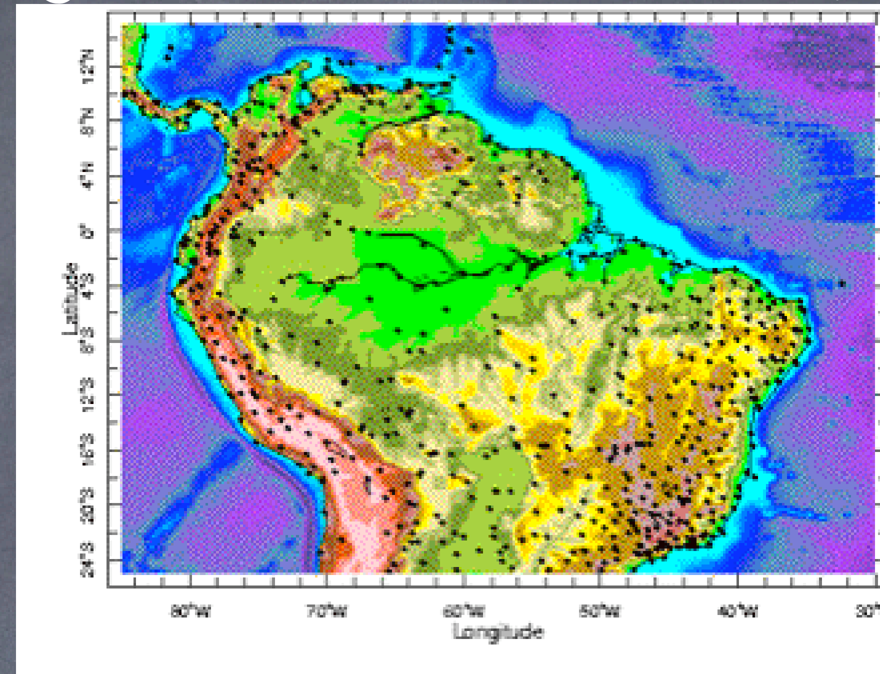
- Daily data since July 19, 1999
- 13.4GHz Ku-band
- Dual like-polarization HH, VV
- Incidence angles 46 and 54.1
- Swath 1400 and 1800 km
- Enhanced 4.5km pixel

Jet Propulsion Laboratory

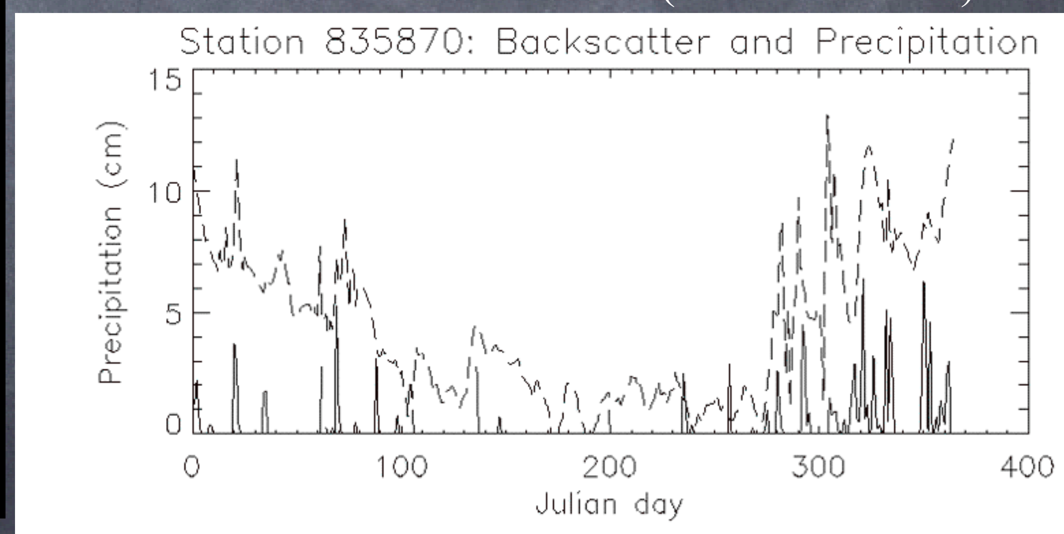
Vegetation + Moisture Cycles



Scatterometer Cimate Record Pathfinder
http://www.scp.byu.edu/



http://lwf.ncdc.noaa.gov/oa/ncdc.html
National Climate Data Center (NCDC/NOAA)

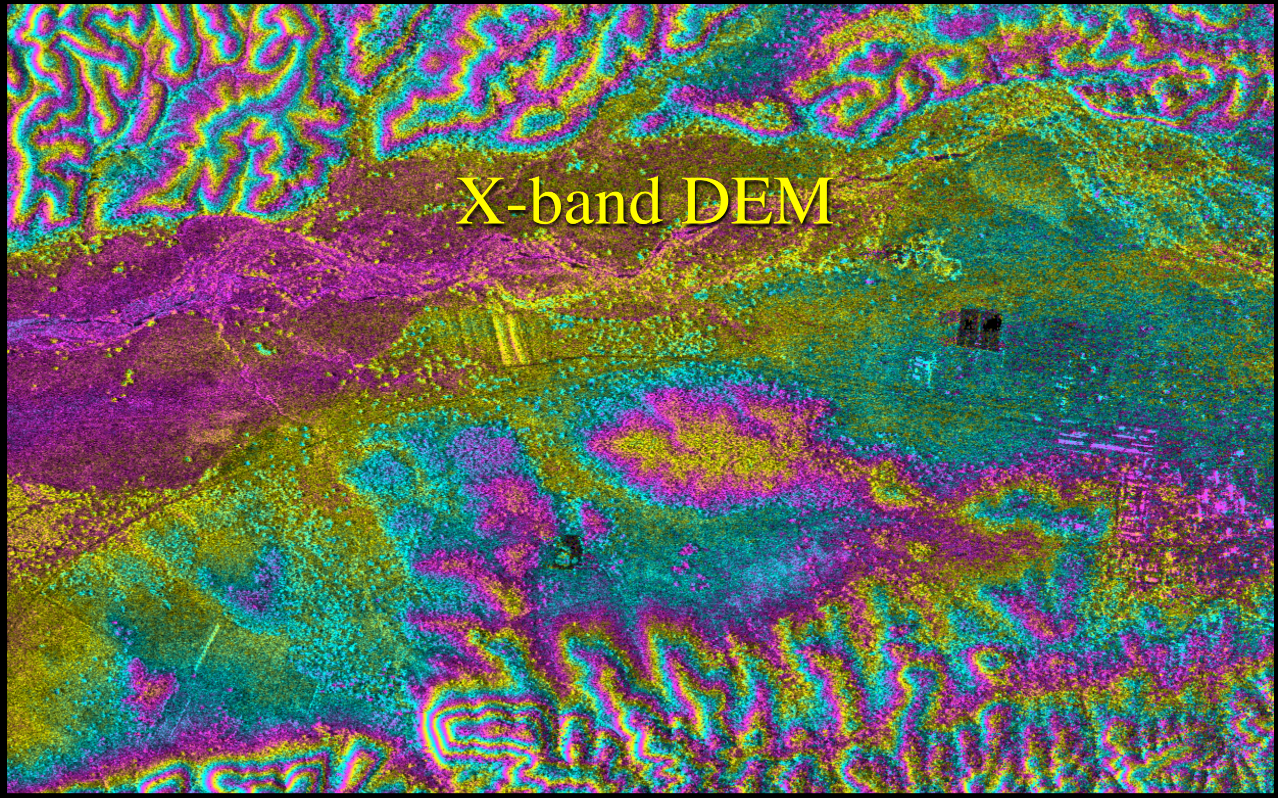


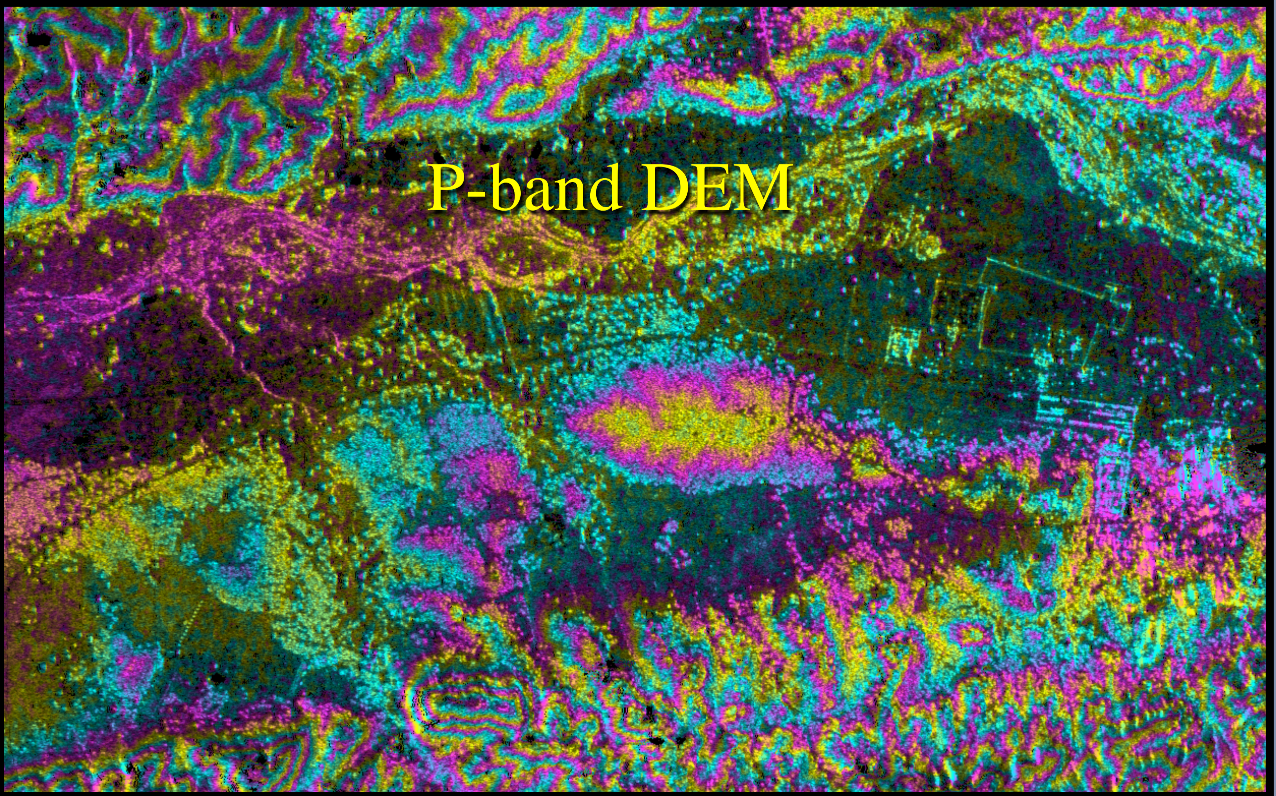
Radar Interferometry

Jet Propulsion Laboratory

Mapping Beneath the Vegetation:

The GeoSAR Mapping Instrument

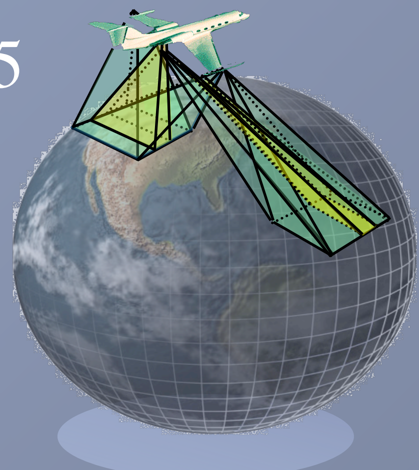




by
Dr Scott Hensley

NASA

June 8, 2005



JPL
Jet Propulsion Laboratory

EARTHDATA

What is GeoSAR?

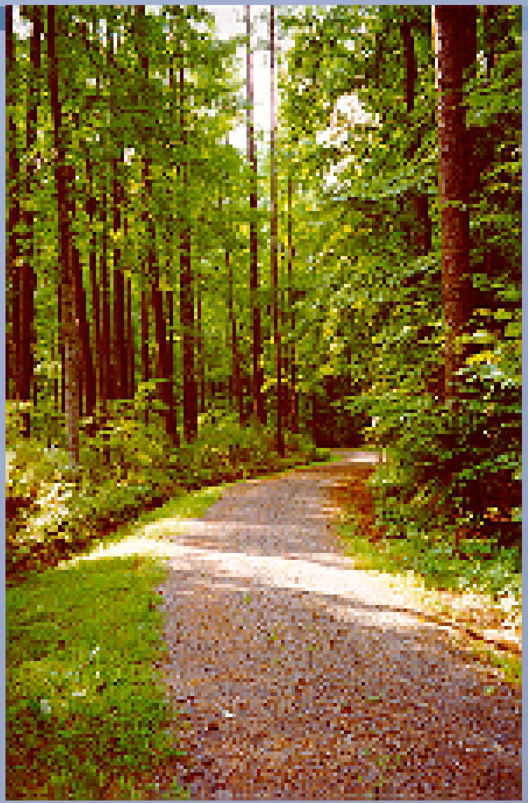
An interferometric airborne radar mapping system that uses two frequencies to generate digital elevation models (DEMs) and orthorectified radar reflectance maps near the tops of trees as well as beneath foliage.

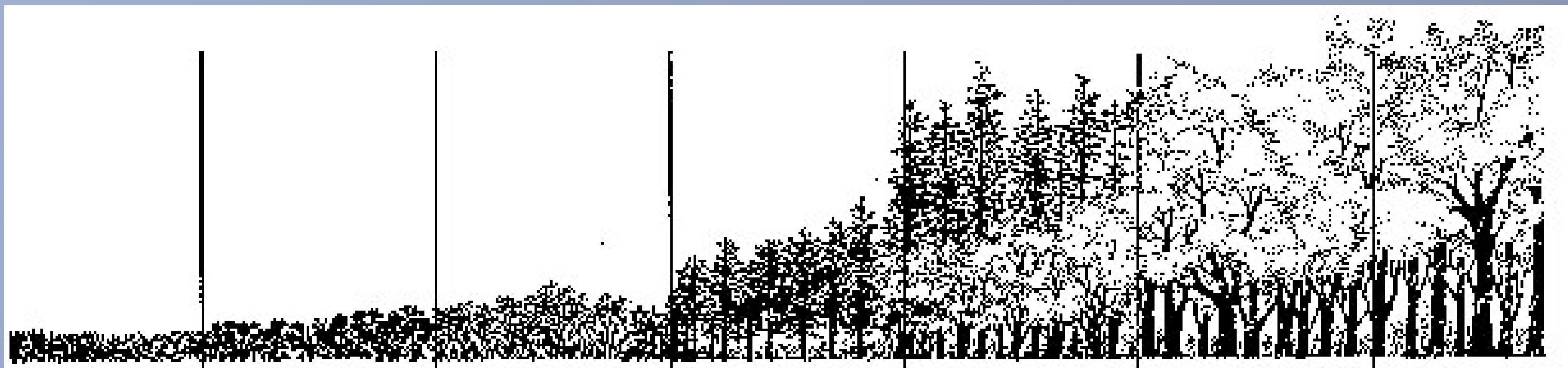
Project started in 1996 with funding by DARPA (JPL hardware). Then the National Geospatial Agency (NGA formerly NIMA) funded a second 3 year program (Phase II) to commercialize the sensor. GeoSAR Phase II program ended in 2003 with Earthdata International operating the sensor commercially.

- System has continued to evolve with incorporation of a new digital recording system and a profiling LIDAR

EarthData's modified Gulfstream-II jet

Duke Vegetation

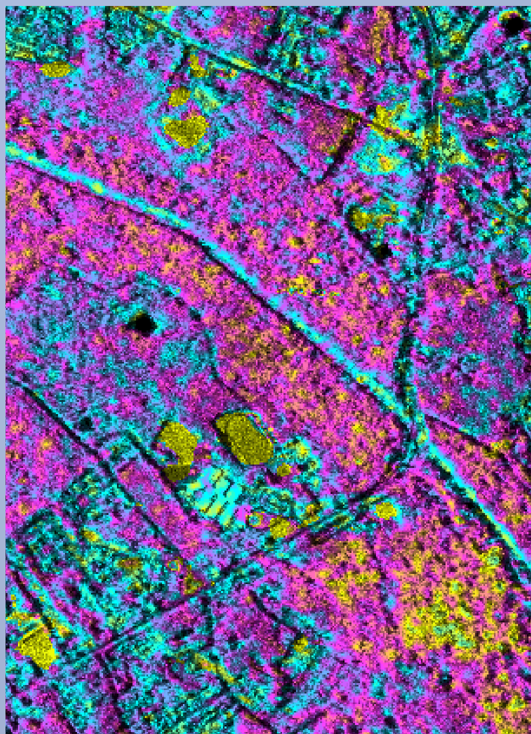




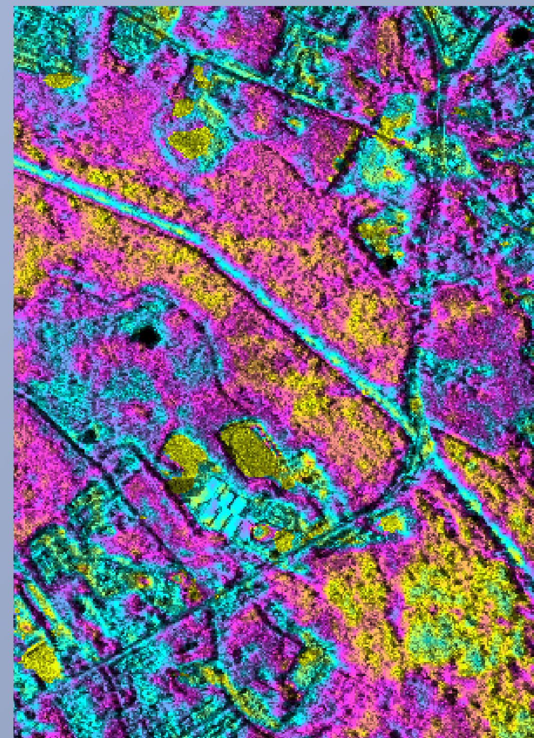
1st Year	2nd Year	3-18 Years	19-30 Years	30-70 Years	70-100 Years	100 plus Years
Horseweed Dominant; Crabgrass, pigweed	Asters Dominant; Crabgrass	Grass scrub Community; broomsedge grass, pines come during this stage	Young pine forest	Mature pine forest; understory of young hardwoods	Pine to hardwood transition	Climax Oak-hickory forest

Penetration Dependence on Frequency

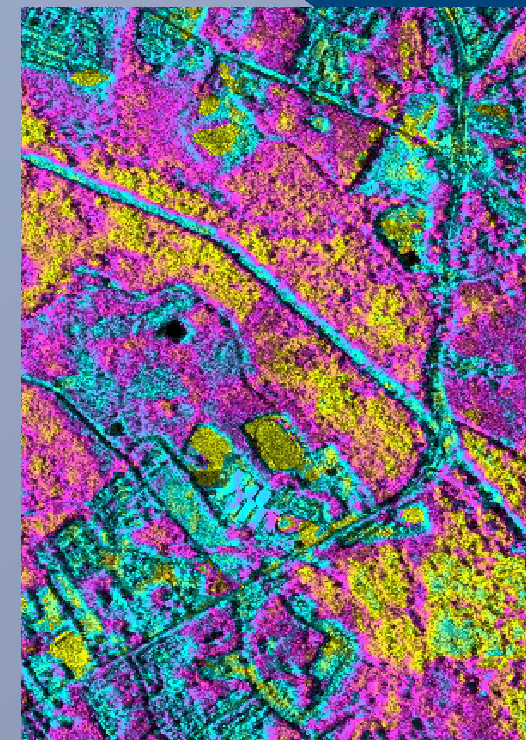
L-band Minus P-band



C-band Minus P-band

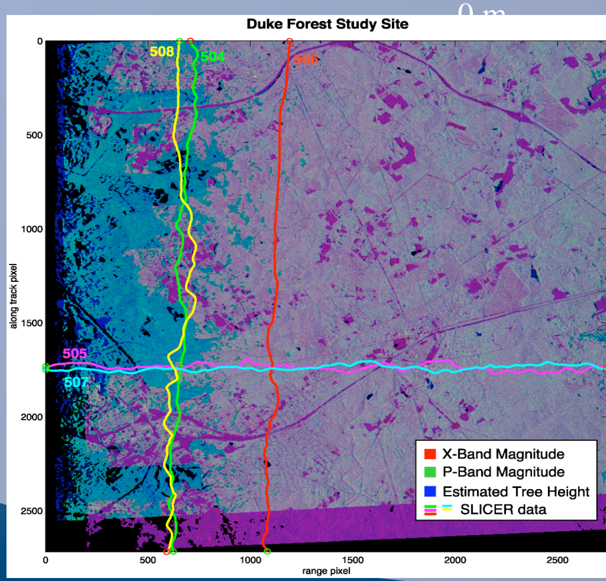


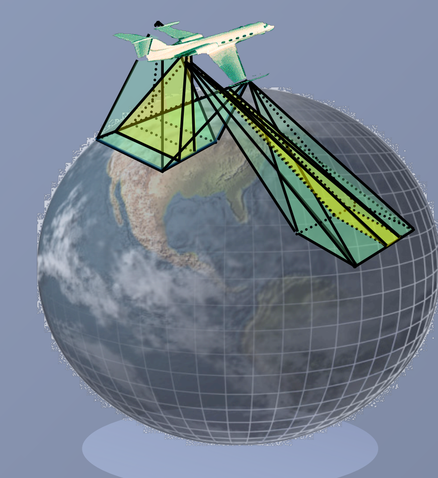
X-band Minus P-band



0 m

35 m

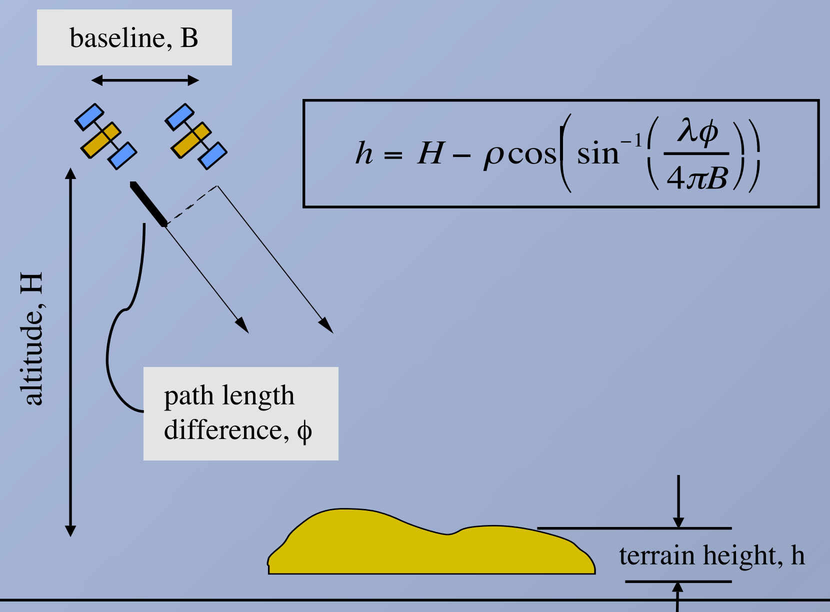




Extracting Vegetation Height Estimates

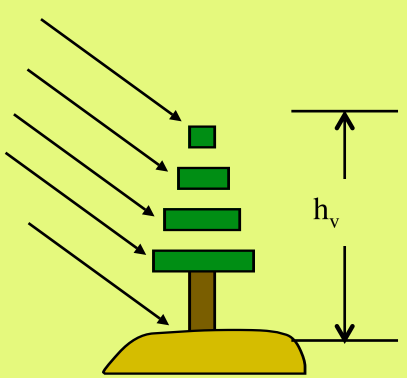
Use of Interferometry for Estimationg Vegetation Height

classic interferometric application to infer terrain height



$$h = H - \rho\cos\left(\sin^{-1}\left(\frac{\lambda\phi}{4\pi B}\right)\right)$$

When the signal return comes from multiple heights, a unique signature is observed by the interferometer



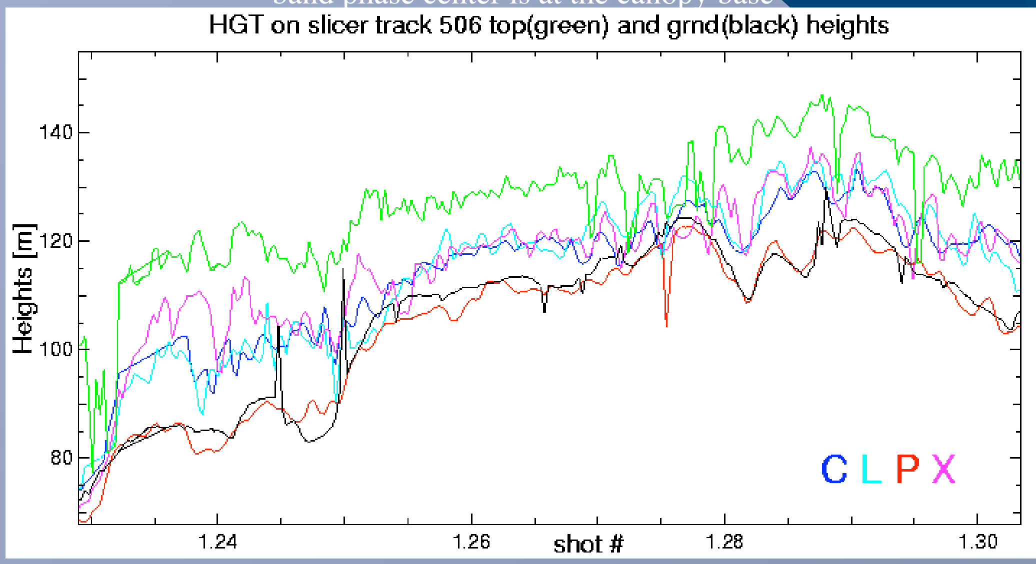
$$\gamma_{vol} = |\gamma_{vol}|e^{i\phi_{vol}} = \frac{\int \sigma(z)e^{ik_z z}dz}{\int \sigma(z)dz}$$

$$\gamma_{vol} = e^{ik_z h_v/2}\mathrm{sinc}\, k_z h_v/2$$

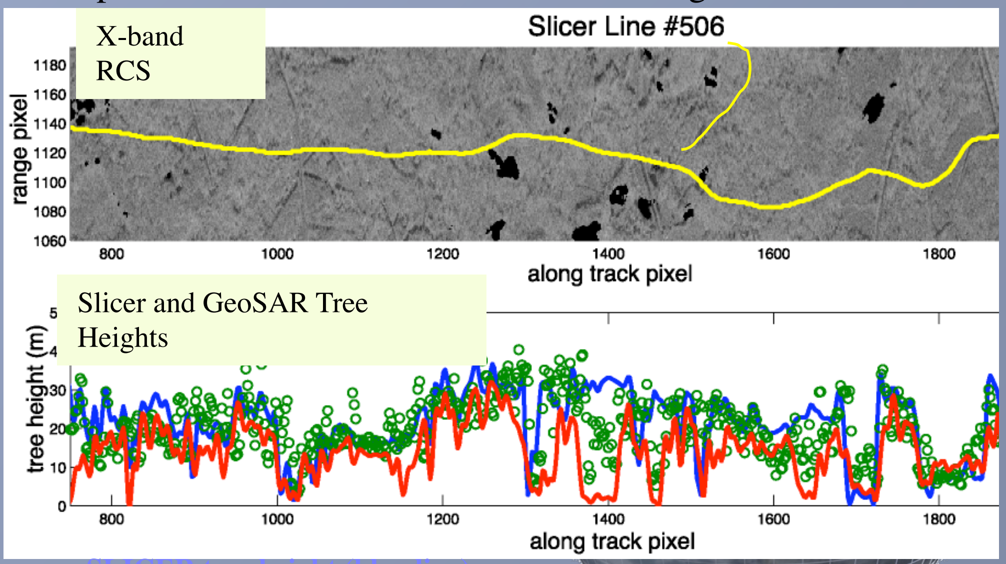
$$h_v \approx \sqrt{\frac{24}{k_z^2}\left(1-|\gamma_{vol}|\right)}$$

GeoSAR Swath: 10km

L-, C-, and X-band all penetrate into the canopy about the same distance. P-band phase center is at the canopy base

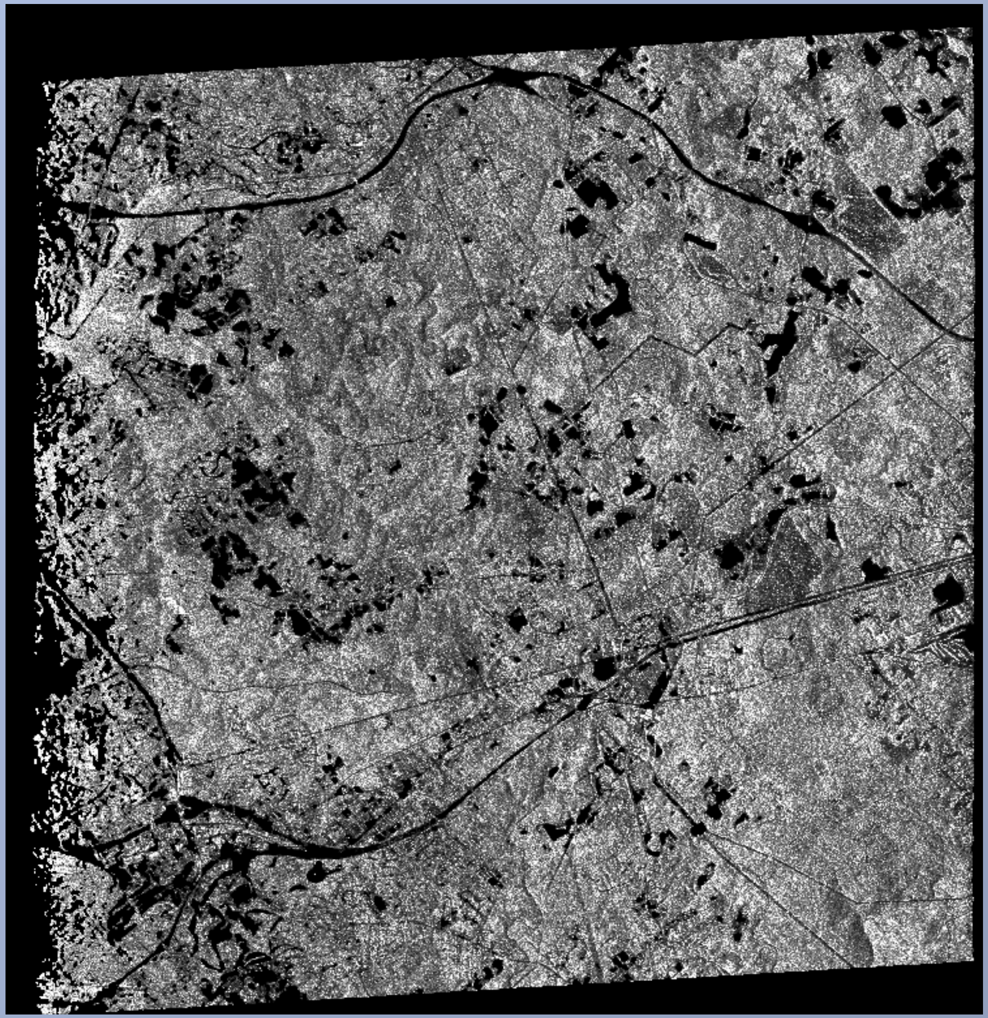


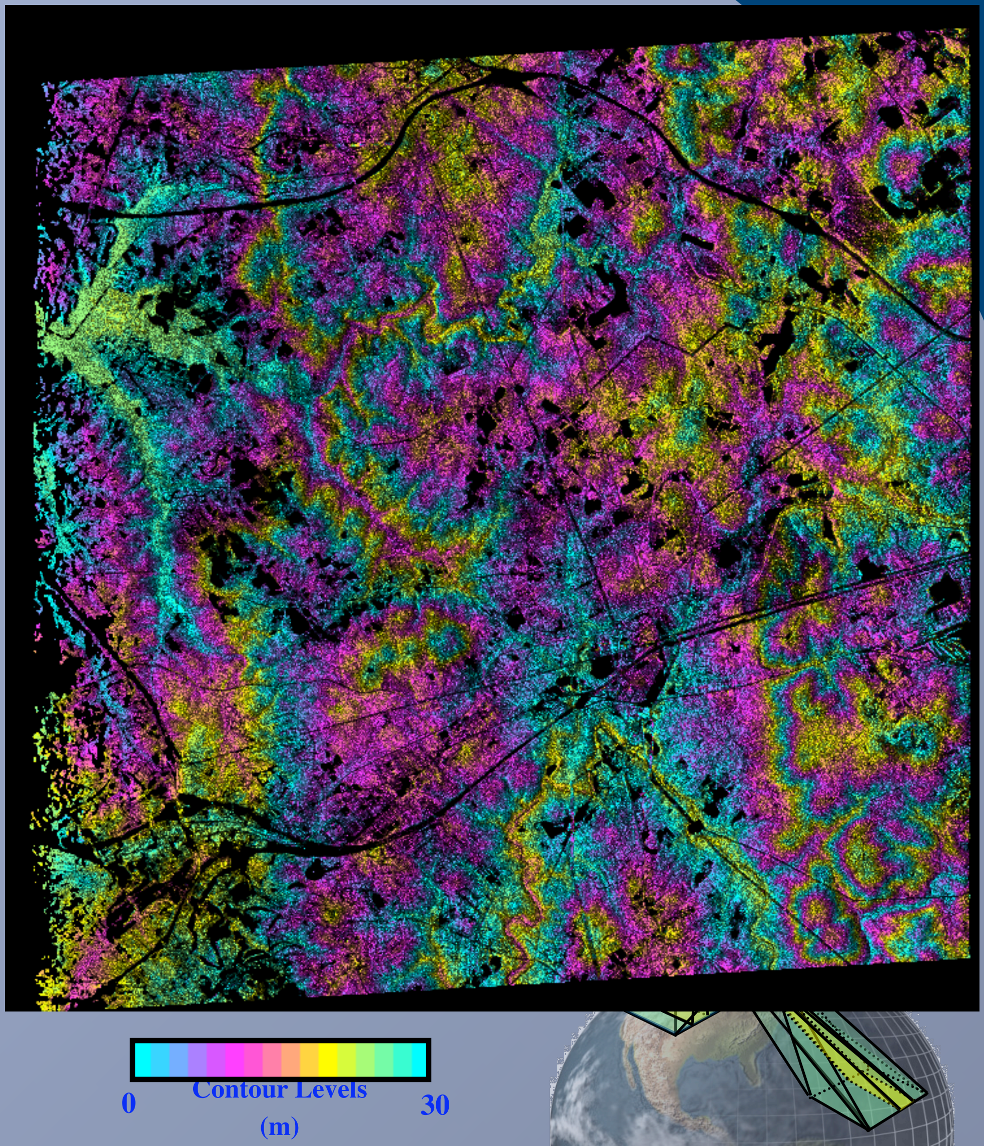
Comparison between LIDAR and Radar Height Estimates



- SLICER tree height (blue line)
- GeoSAR X- minus P-band height (red line)
- GeoSAR X-band interferometric estimate of tree height (green circles)

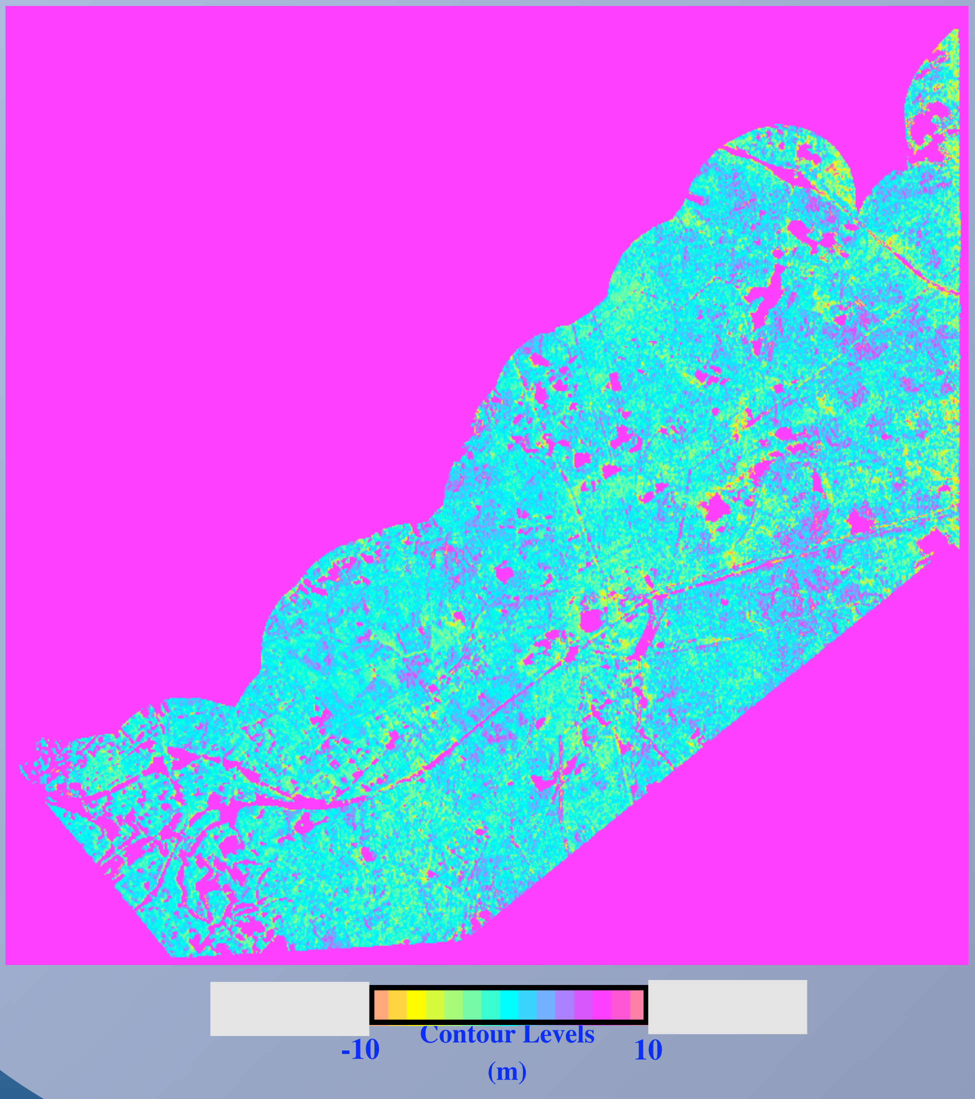
P-band Data at Duke Forest



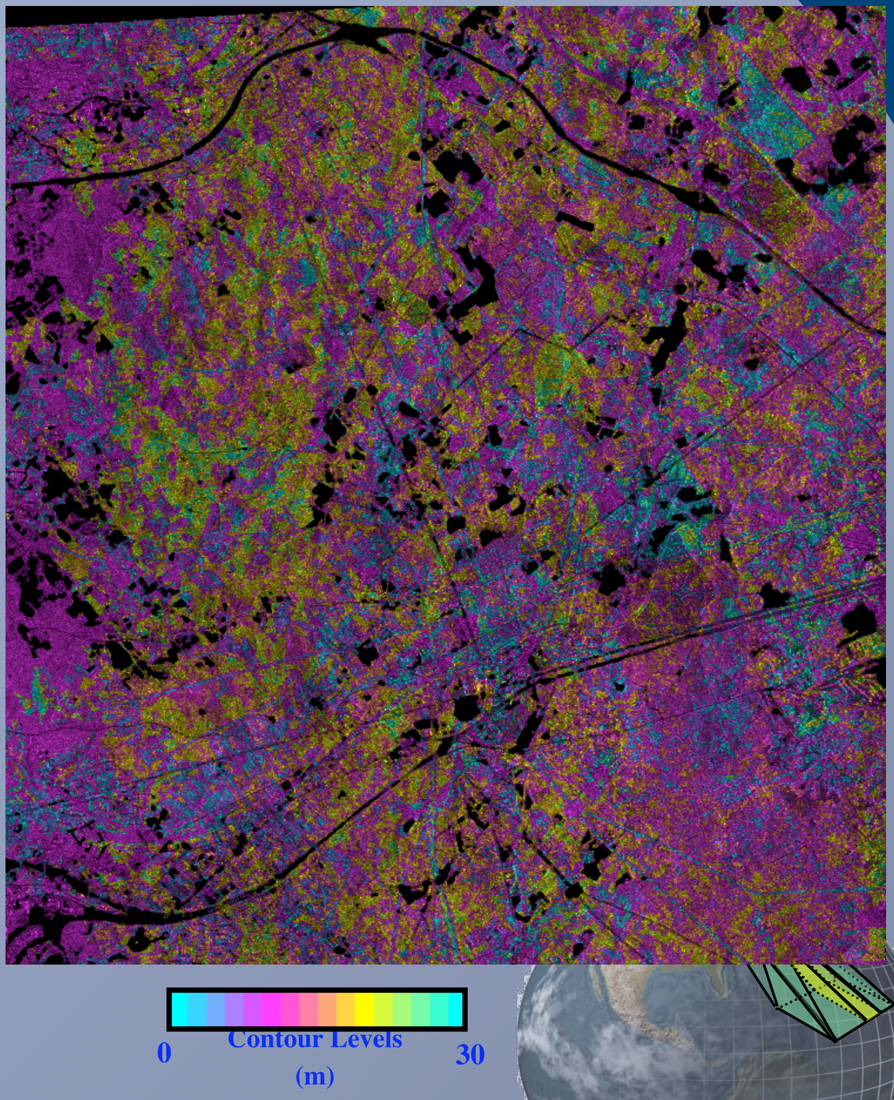


P-band Compared to X-band and LIDAR TGS

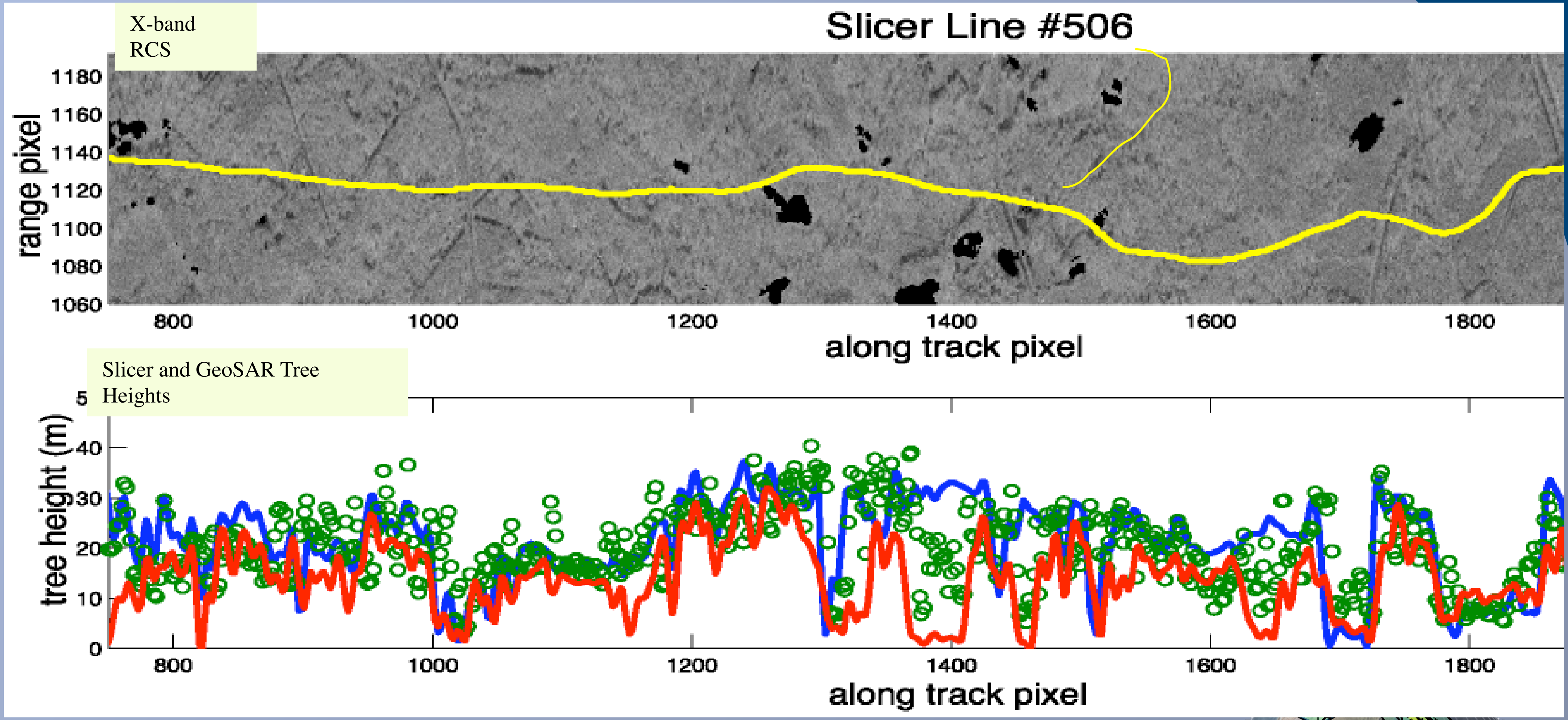
P-band - LIDAR TGS



P-band - X-band



Extracting Vegetation Height Estimates

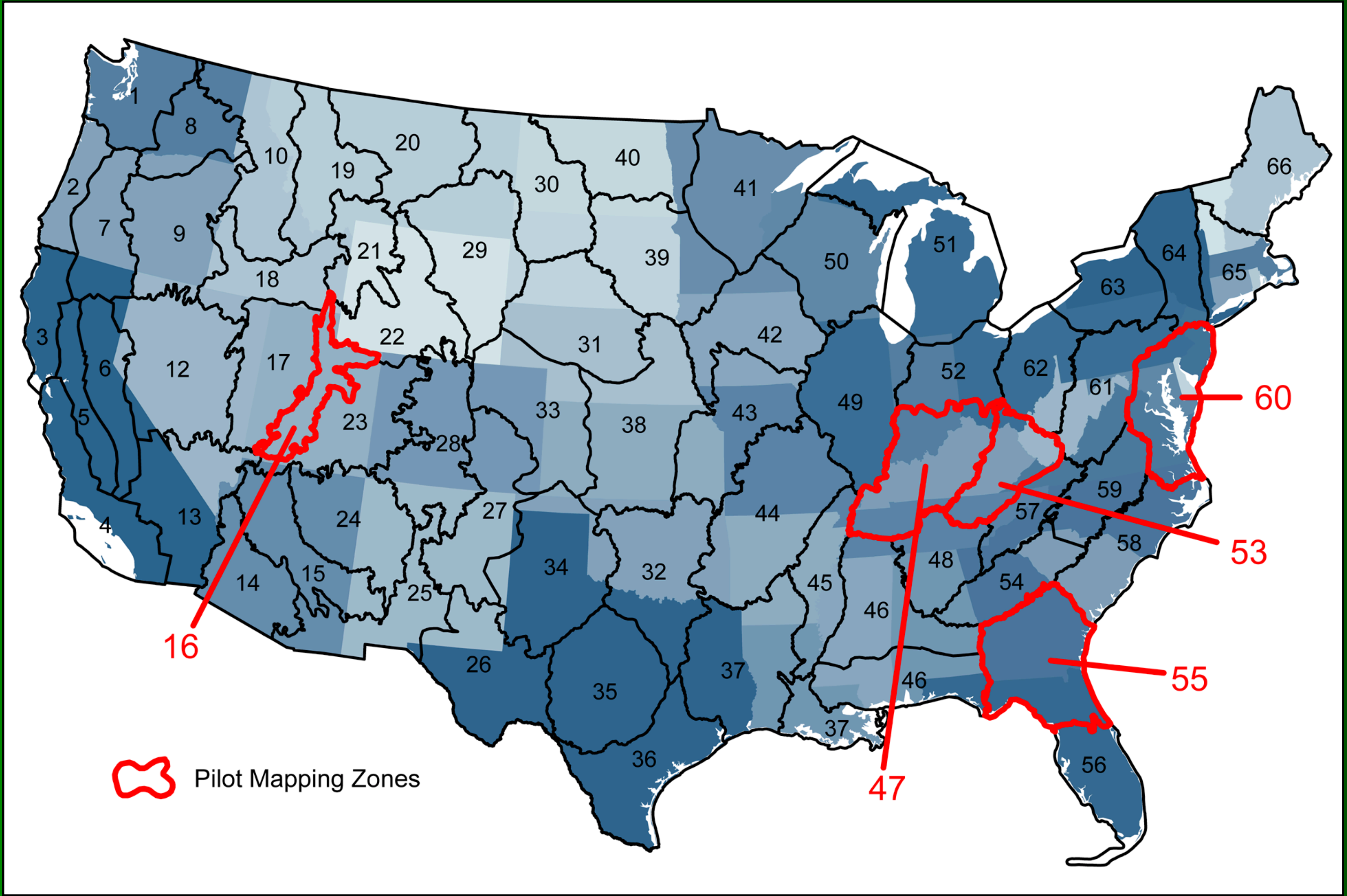


- SLICER tree height (blue line)
- GeoSAR X- minus P-band height (red line)
- GeoSAR X-band interferometric estimate of tree height (green circles)

SRTM

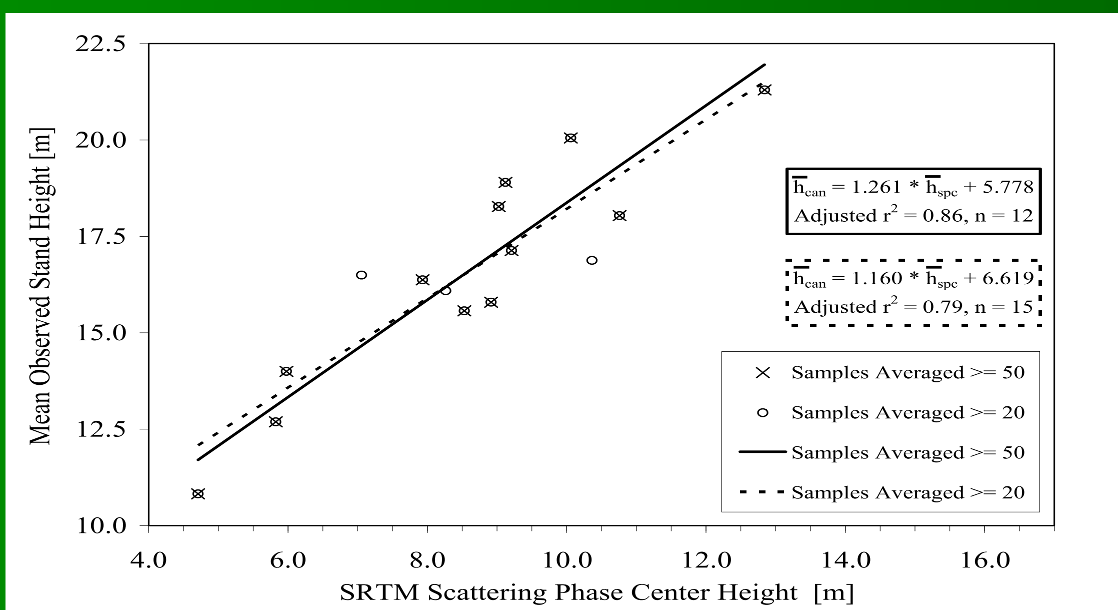
Jet Propulsion Laboratory

Pilot Phase Mapping Zones: Results



J.Kellndorfer, National Biomass and Carbon Dataset 2000

Pilot Studies for SRTM Height Retrieval: Georgia



- Kellndorfer, J.M., W.S. Walker and L.E. Pierce, M.C Dobson, J. Fites, C. Hunsaker, J. Vona, M. Clutter, "***Vegetation height derivation from Shuttle Radar Topography Mission and National Elevation data sets.***" Remote Sensing of Environment, Vol. 93, No. 3, 339-358, 2004.

Forest Height and Biomass Validation with FIA Data

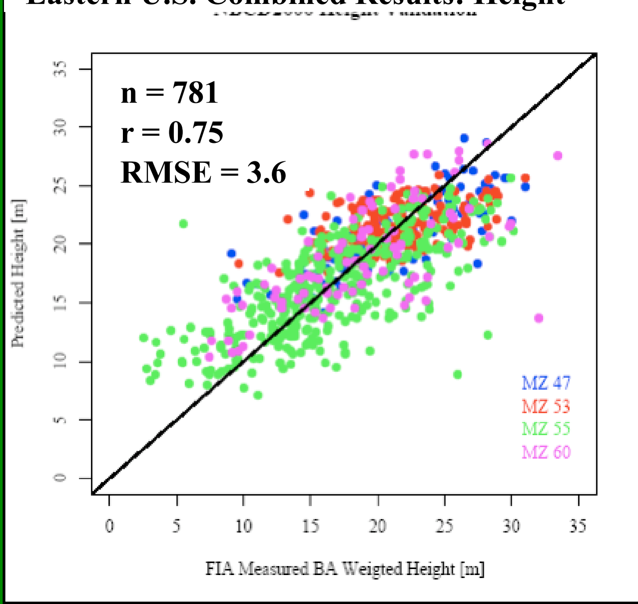
Results: Basal-Area Weighted Height

Mapping Zone	Basal-Area Weighted Height (BAWHT; m)	
	r_{test}	$RMSE_{test}$
16 (n=293/102)	0.87	2.9
47 (n=359/124)	0.69	3.6
53 (n=544/190)	0.51	3.3
55 (n=767/380)	0.70	4.0
60 (n=271/100)	0.77	3.7

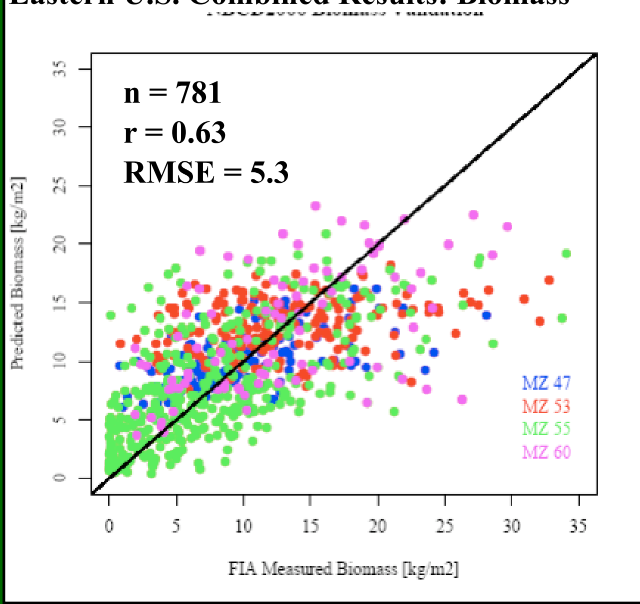
Results: Aboveground Live Dry Biomass

Mapping Zone	Aboveground Live Dry Biomass (ALDB; kg/m²)	
	r_{test}	$RMSE_{test}$
16 (n=293/102)	0.74	4.4
47 (n=359/124)	0.50	4.6
53 (n=544/190)	0.36	5.8
55 (n=767/380)	0.68	5.2
60 (n=271/100)	0.70	4.9

Eastern U.S. Combined Results: Height

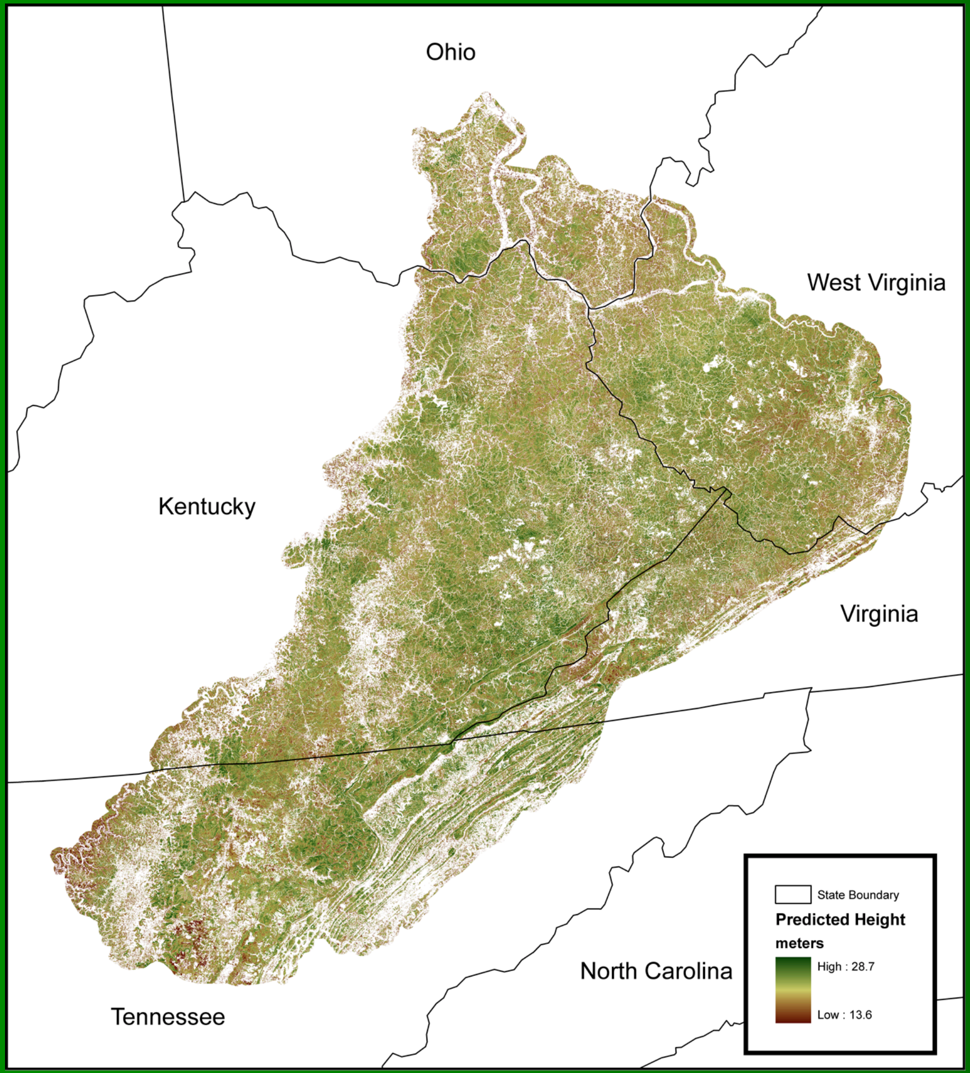


Eastern U.S. Combined Results: Biomass

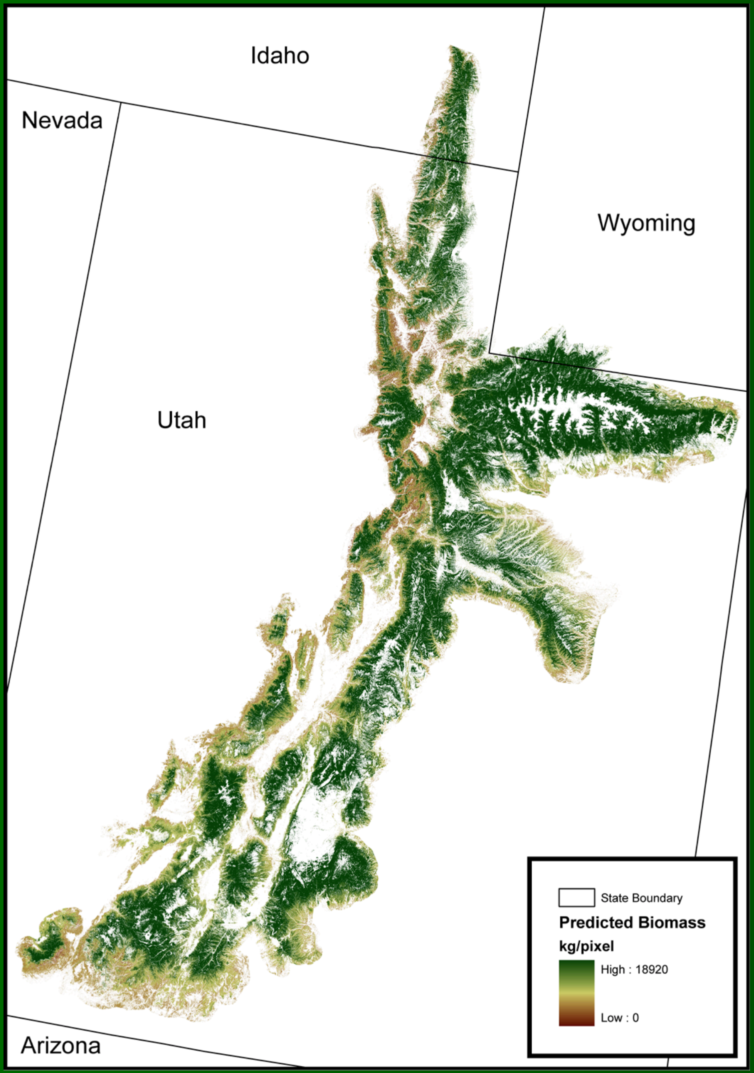


Results: Example Map Products

Mapping Zone 53:
Predicted Basal-Area Weighted Height

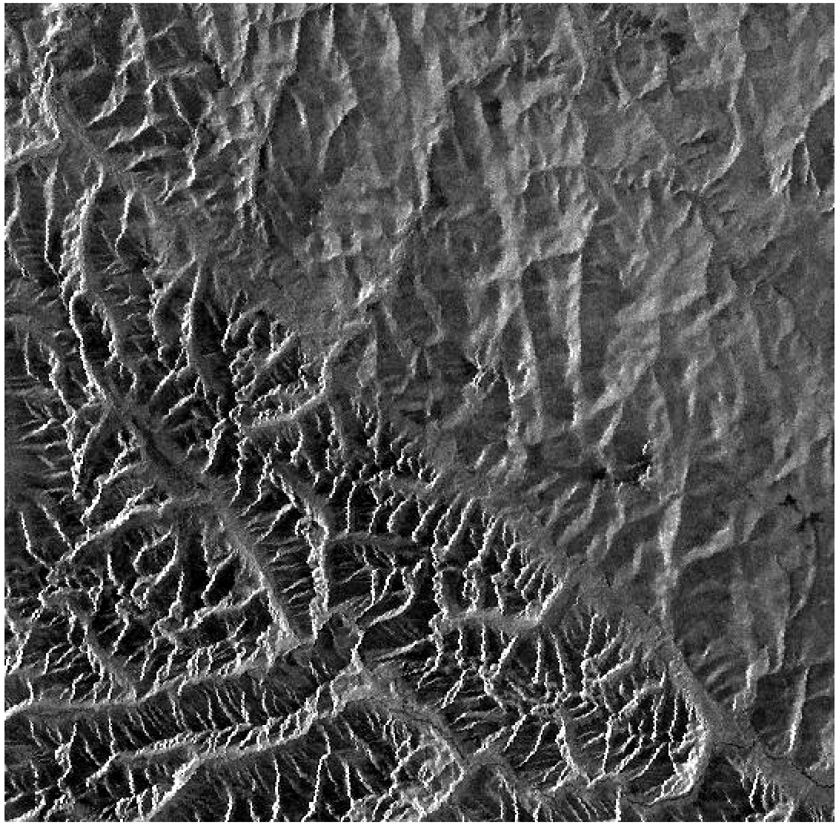


Mapping Zone 16:
Aboveground Live Dry Biomass

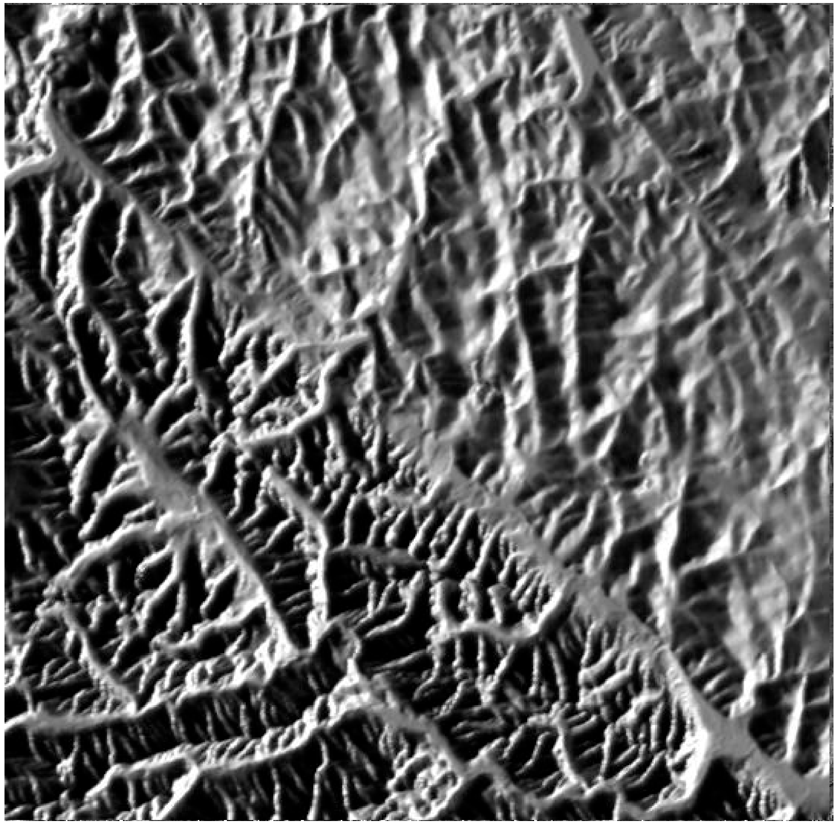


Miss-match between the mosaic and the DEM

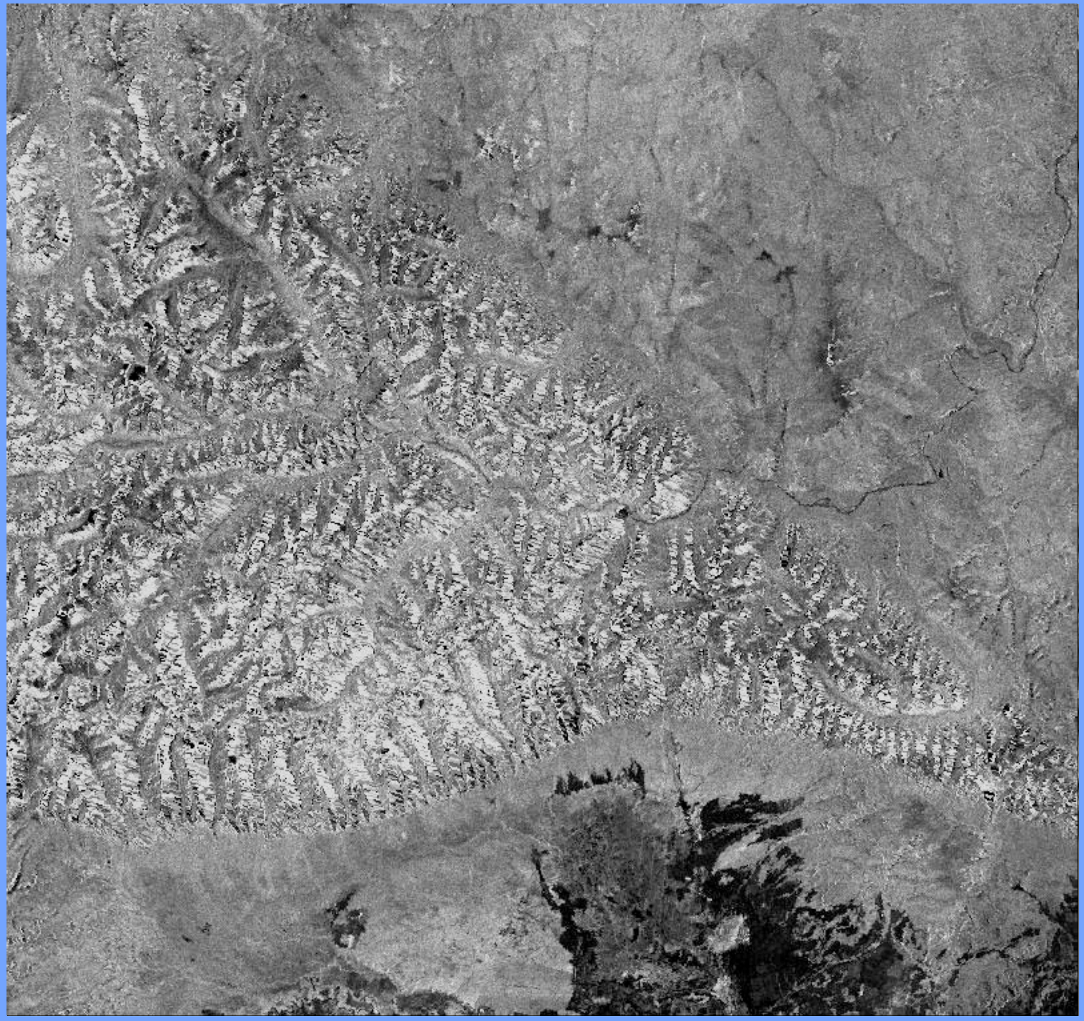
Siberia Mosaic



SRTM



Result of the co-registration and corrections



Original radar image

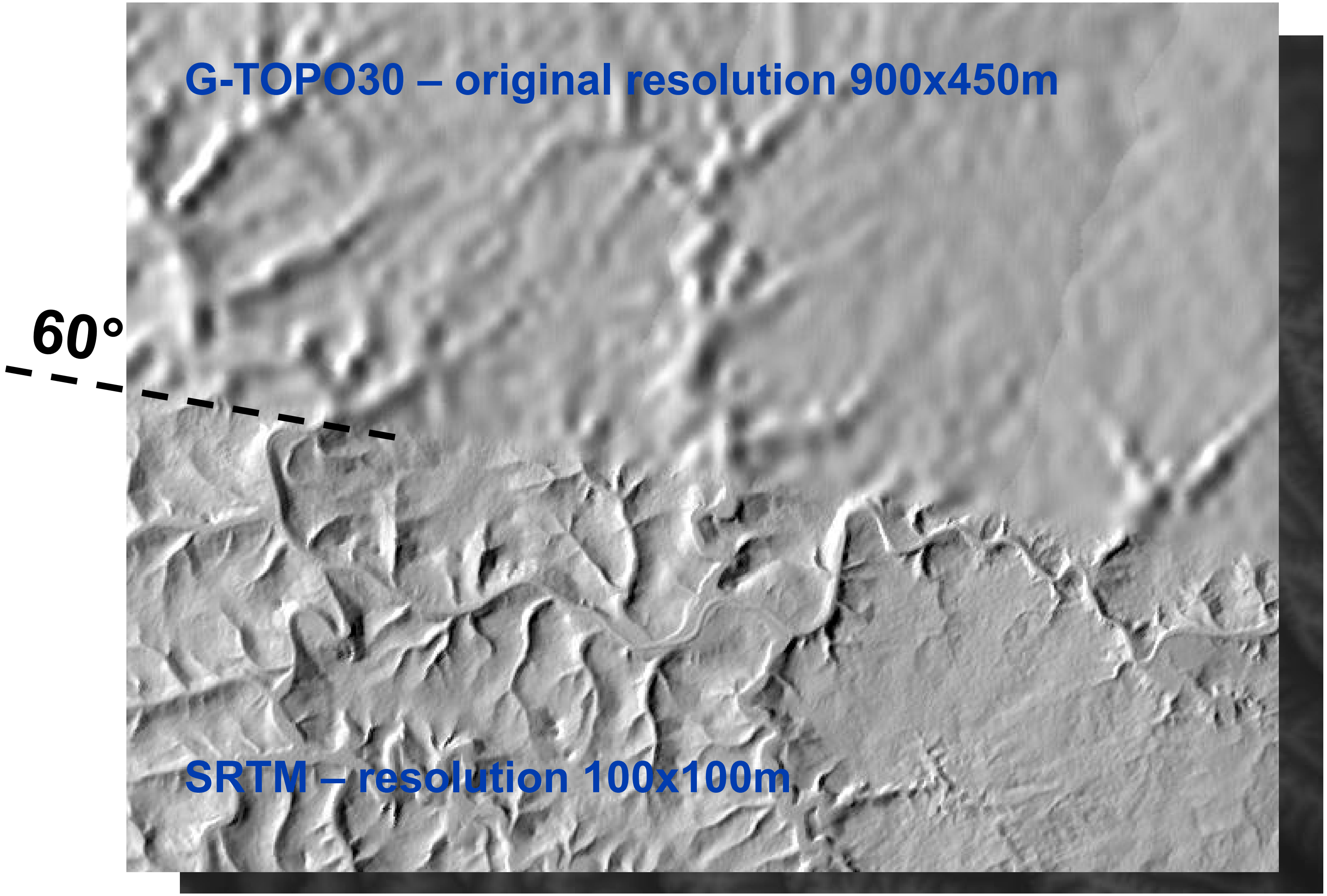
Simulation image based on DEM

Radar image - accurately co-registered with DEM

Radiometric effect of topography removed

Geometric effect of topography removed

Digital Elevation Model used



What's Out There Now?

Jet Propulsion Laboratory

ENVISAT ASAR (2002-)

Repeat 35days, full coverage 1 to 3 days.

Image Mode (IM)	VV or HH polarisation images from any of 7 selectable swaths. Swath width between approximately 56 and 100 km (swath 1) across-track. Spatial resolution of approximately 30 km (swath 7) and 100 km (swath 1) across-track. Spatial resolution of approximately 30 m (for precision product).
Alternating Polarisation Mode (AP)	Two co-registered images per acquisition, from any of 7 selectable swaths. HH/VV, HH/HV, or VV/VH polarisation pairs possible. Spatial resolution of approximately 30 m (for precision product).
Wide Swath Mode (WS)	400 km by 400 km wide swath image. Spatial resolution of approximately 150 m by 150 m for nominal product. VV or HH polarisation
Global Monitoring Mode (GM)	Spatial resolution of approximately 1000 m in azimuth by 1000 m in range for nominal product. Up to a full orbit of coverage. HH or VV polarisation.
Revisit time	No Constraints 5 (0°) 7(45°) 11(60°) 16(70°)

- There are three ways to apply for Category 1 use data, depending on the type of data requested.
  - A simple Registration is all that is required for data that are systematically acquired, generated and disseminated on line..
  - Via a Proposal - When the data requirements are subject to specific acquisitions or dissemination constraints.
  - Via an ESA Announcements of Opportunity (AO) - When the data fall into the specific subject covered by the AO.
  - Applications for Category 1 use data can be submitted directly to ESA, using the Earth Observation Principal Investigator (EOPI) web interface or by contacting EOPI@esa.int
  - http://eopi.esa.int/esa/esa?cmd=submission&aoname=cat1

JPL
Jet Propulsion Laboratory

RADARSAT

- Radarsat 1 C-HH (since 1995)
- Radarsat 2 Summer 2007 (+7years)
  - repeat 24 days
  - C-band HH, HV, VH, VV

Fine	50 km	8 x 8 m	30° - 50°	HH+HV or VH +VV
Standard	100 km	25 x 26 m	20° - 49°	HH+HV or VH +VV
Wide	150 km	30 x 26 m	20° - 45°	HH+HV or VH +VV
ScanSAR Narrow	300 km	50 x 50 m	20° - 46°	HH+HV or VH +VV
ScanSAR Wide	500 km	100 x 100 m	20° - 49°	HH+HV or VH +VV
Extended Low	170 km	40 x 26 m	10° - 23°	HH
Extended High	75 km	18 x 26 m	49° - 60°	HH
Fine Quad-pol	25 km	12 x 8 m	20° - 41°	HH+VV+HV+VH
Standard Quad-pol	25 km	25 x 8 m	20° - 41°	HH+VV+HV+VH
Ultra-Fine	20 km	3 x 3 m	30° - 40°	(HH) or (HV) or
Multi-Look Fine	50 km	8 x 8 m	30° - 50°	(HH) or (HV) or

JPL
Jet Propulsion Laboratory

NASA

ALOS PALSAR JAN 2006-

- 3 instruments:
  - PRISM The Panchromatic Remote-sensing Instrument for Stereo Mapping (PRISM) is a panchromatic radiometer with 2.5m spatial resolution at nadir. 35 or 70km.
  - AVNIR-2 The Advanced Visible and Near Infrared Radiometer type 2 (AVNIR-2) is a visible and near infrared radiometer for observing land and coastal zones. 4bands 0.42 to 0.89 um. 10 m resolution.
  - PALSAR The Phased Array type L-band Synthetic Aperture Radar (PALSAR) is an active microwave sensor using L-band frequency

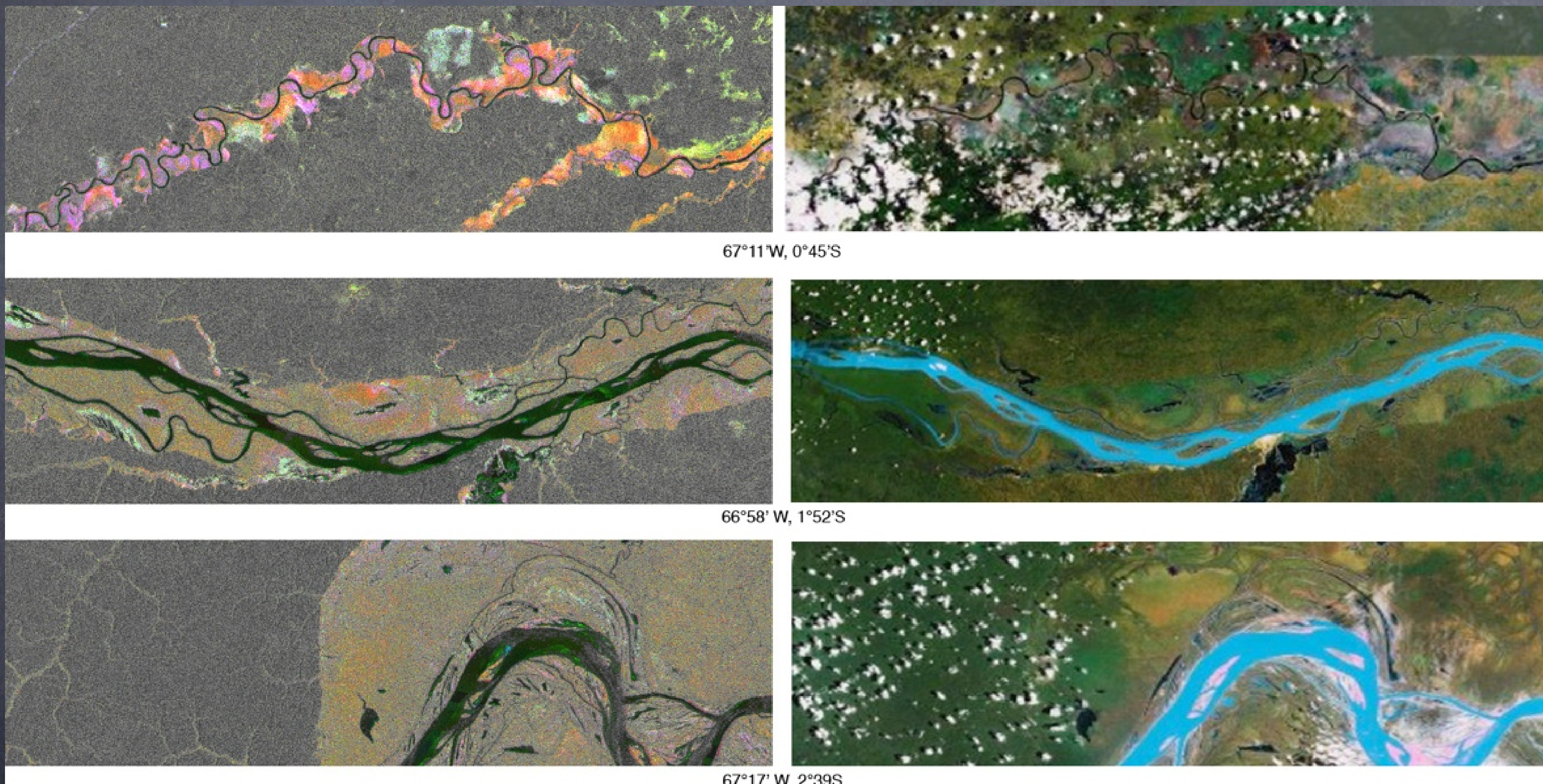
Fine	HH or VV HH+HV or VV+VH	7 to 44m 8 to 88m	40 to 70km
ScanSar	HH or VV	100m (multilook)	250 to 350km
Polarimetric (experimental)	HH+HV+VH+VV	24 to 89m	20 to 65km

Revisit Time: 2 days

Equator 60% coverage/day

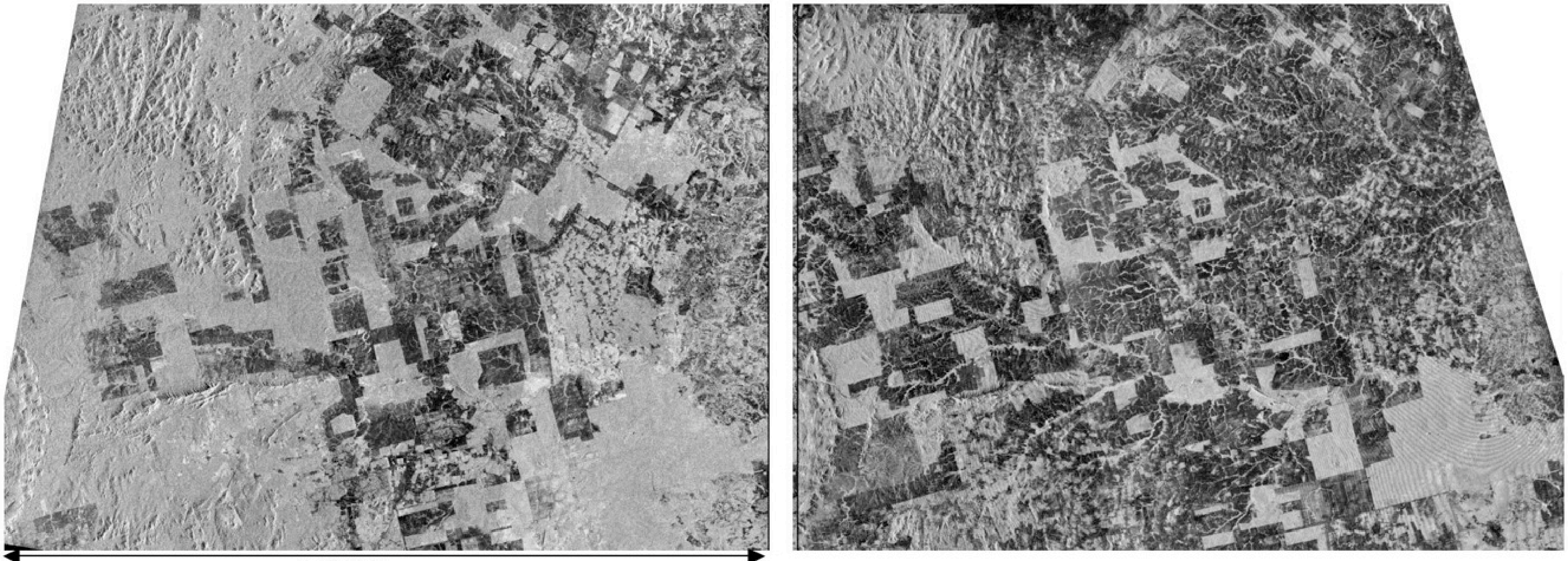
Jet Propulsion Laboratory

ALOS PALSAR



- Figure by Bruce chapman (JPL)
- courtesy JAXA/ASF

Radar
The Tool to Map Deforestation

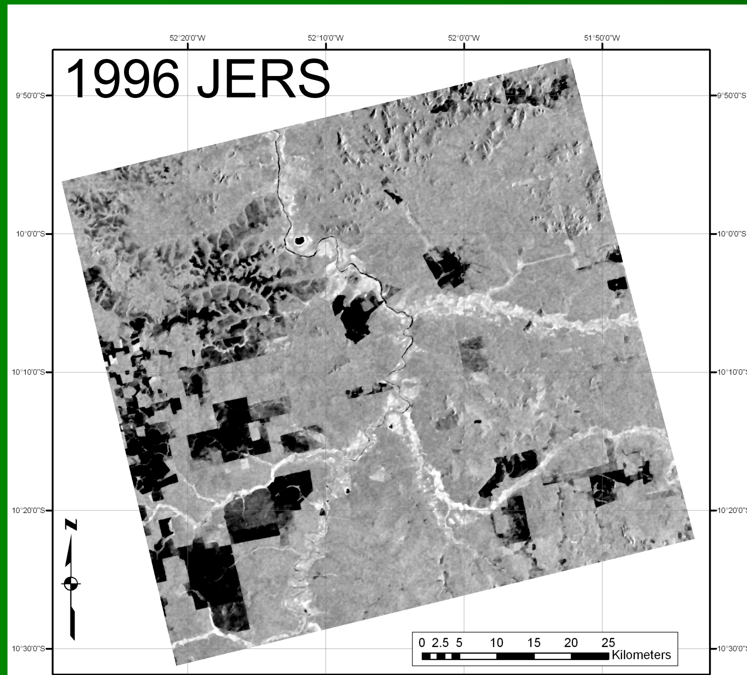


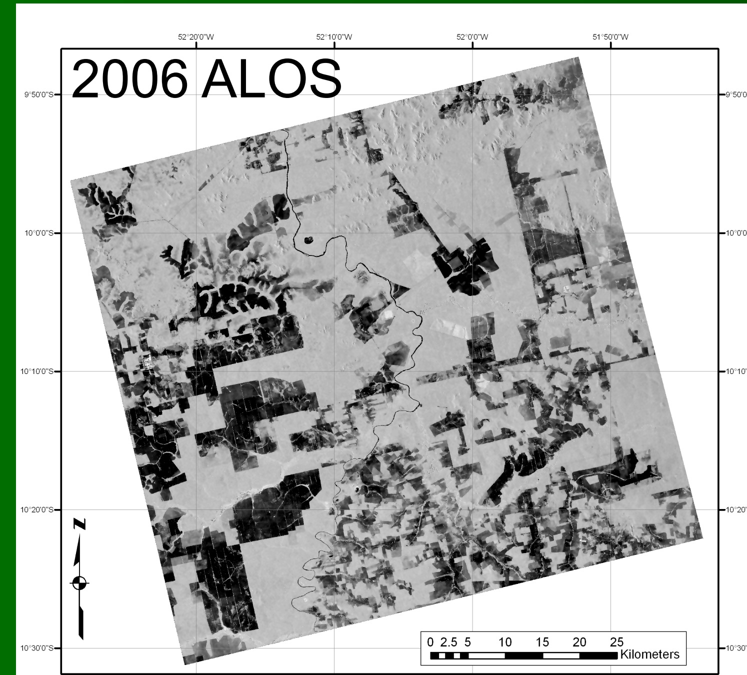
October 1996 (JERS-1)

June 2006 (PALSAR)

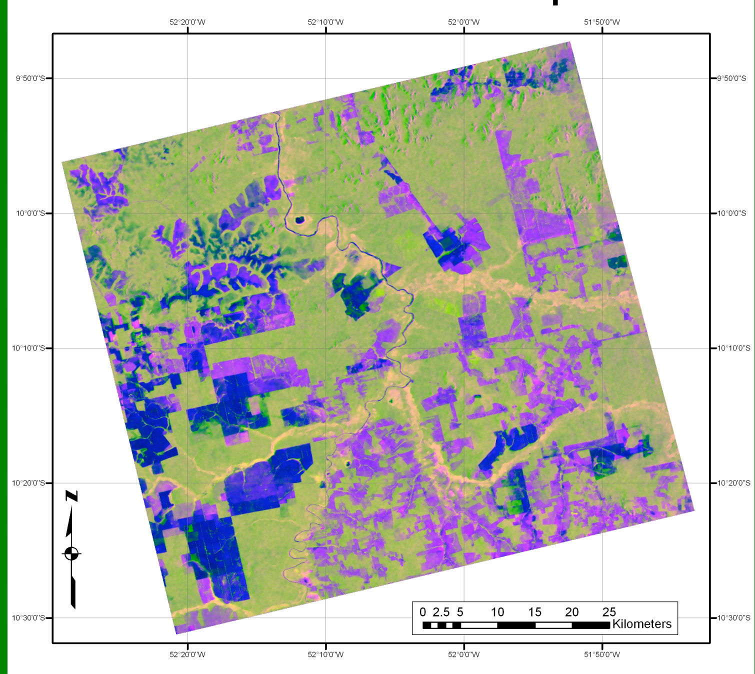
From JAXA website

Amazon Radar Deforestation Assessment

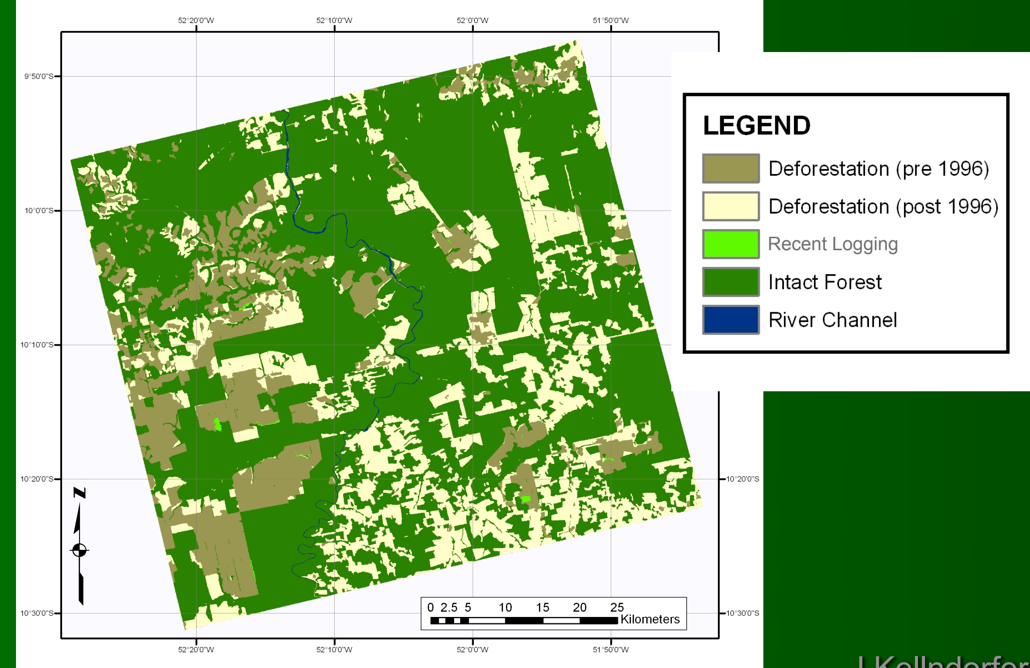




2006/1996 Color Composite



Radar Change Detection



The Woods Hole Research Center ©

J.Kellndorfer

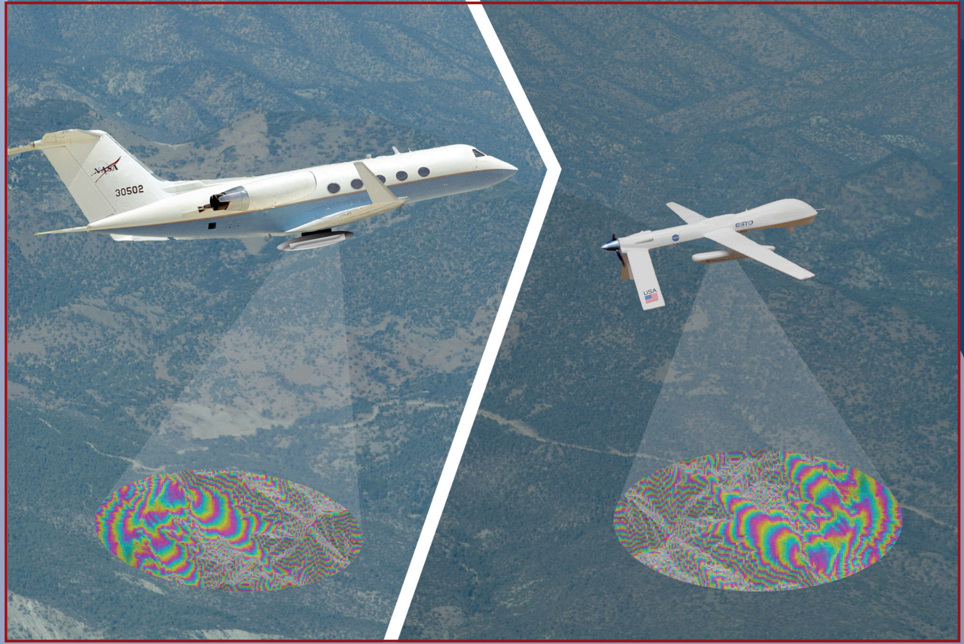
JPL

UAVSAR System Overview

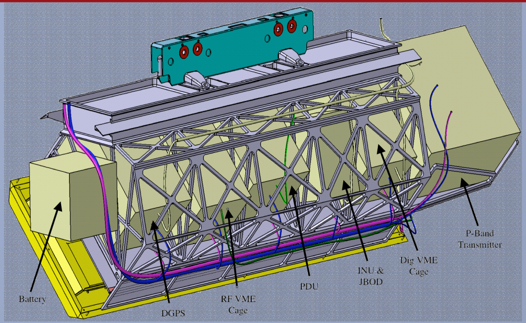
NASA

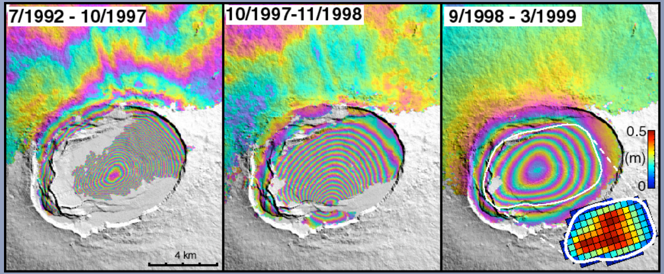
Salient Features

- *Robust repeat pass interferometry for deformation measurements*
- *Fully polarimetric at L-Band (1.2 GHz,80 MHz BW)*
- *Initial tests on NASA's Gulfstream III*
- *Plans allow for transition to a UAV platform*
- *Steerable electronically scanned array antenna*
- *Flight path controlled to be within a 10 m tube using real-time GPS and modified autopilot*
- *Autonomous radar operation in flight*
- *Flexible, light-weight, reconfigurable design*



Instrument Pod Internal Layout





Volcanic Surface Deformation

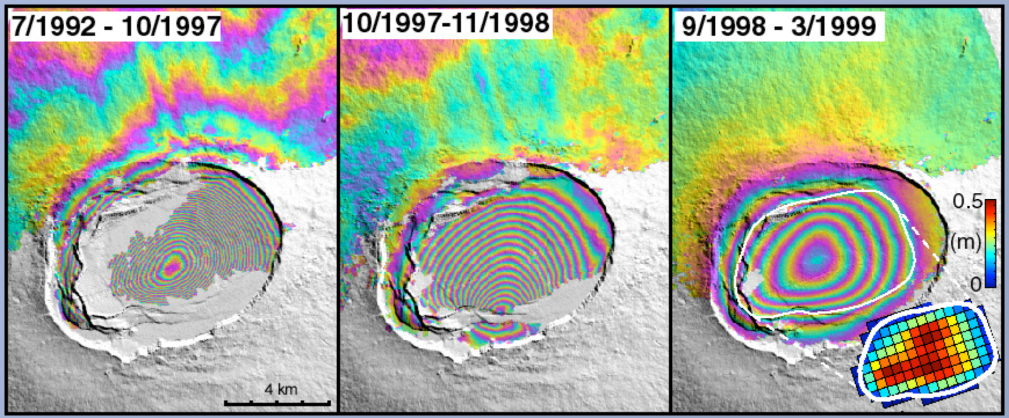
Science

- *Global and regional volcanic inflation, flooding, land and coastal erosion, fault strain, fire hazard, tectonic strain, precision topography*
- *Local continuous observation of deformation for prediction of eruption, landslide and flooding*
- *Provide crustal structure, high temporal resolution, regional deformation processes for increased predictability of earthquake and volcanic activity.*

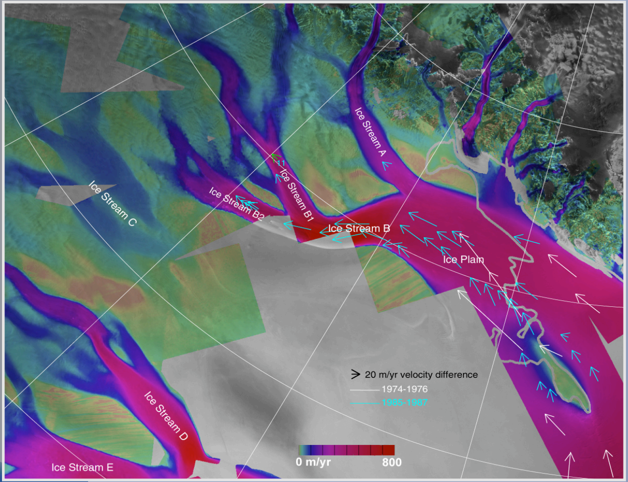
ESTO
Earth Sun System Technology Office

The Role of Airborne InSAR

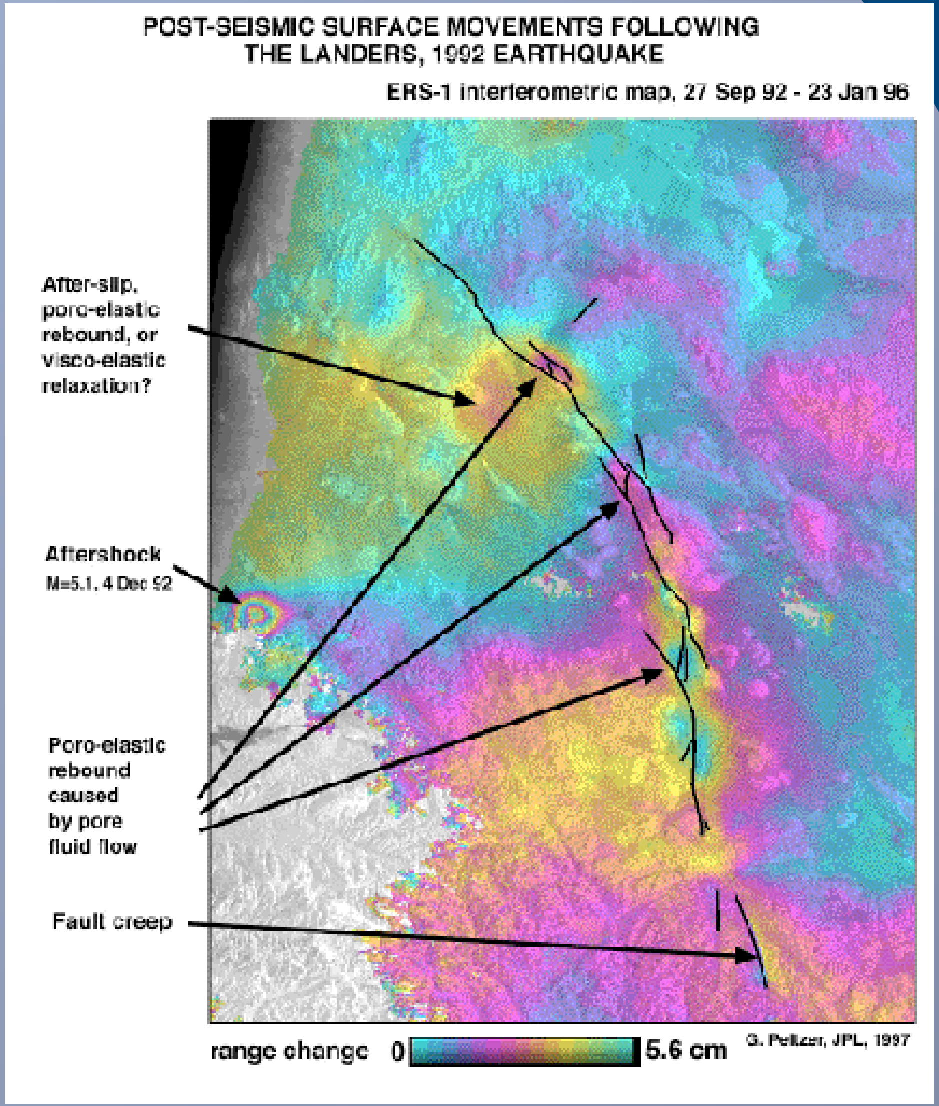
Airborne InSAR can contribute to local measurements of rapidly evolving surfaces



Evolution of volcanic magma chambers



Rapid evolution of ice



Post/Inter-seismic deformation

Earth Sun System Technology Office

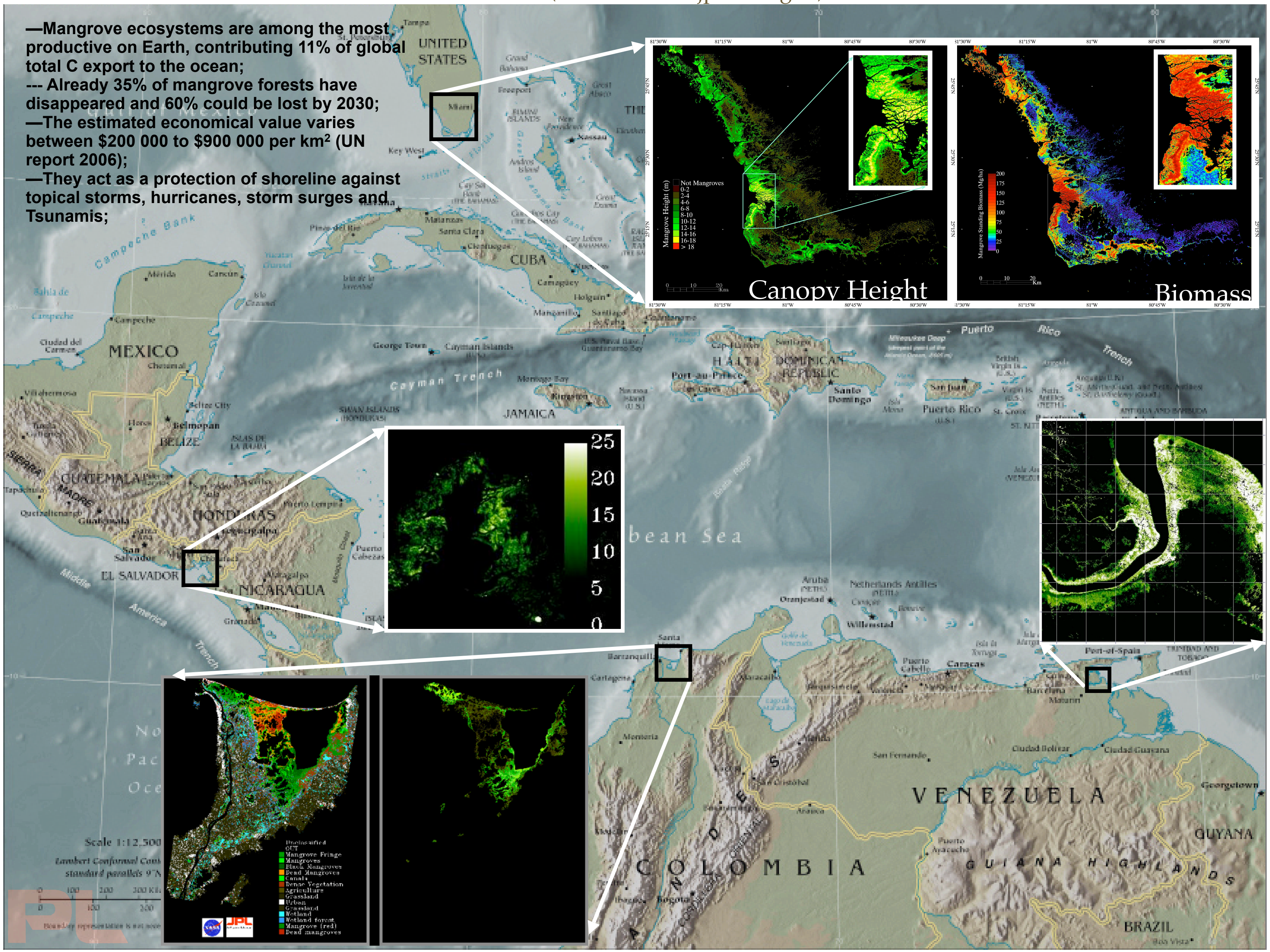
Key Dates

- The UAVSAR has completed its CDR and is expected to begin flight testing in early 2007.
  - First Flight: March 2007
  - Engineering Checkout Flights: March- June 2007
  - Calibration/Characterization Flights: June - August 2007
  - Repeat Pass/Deformation Science: August 2007 - June 2008

Mapping Mangrove Forest Height and Biomass Using SRTM
Calibrated with Lidar (ICEsat/GLAS and airborne) and Field Data.

Marc Simard (marc.simard@jpl.nasa.gov)

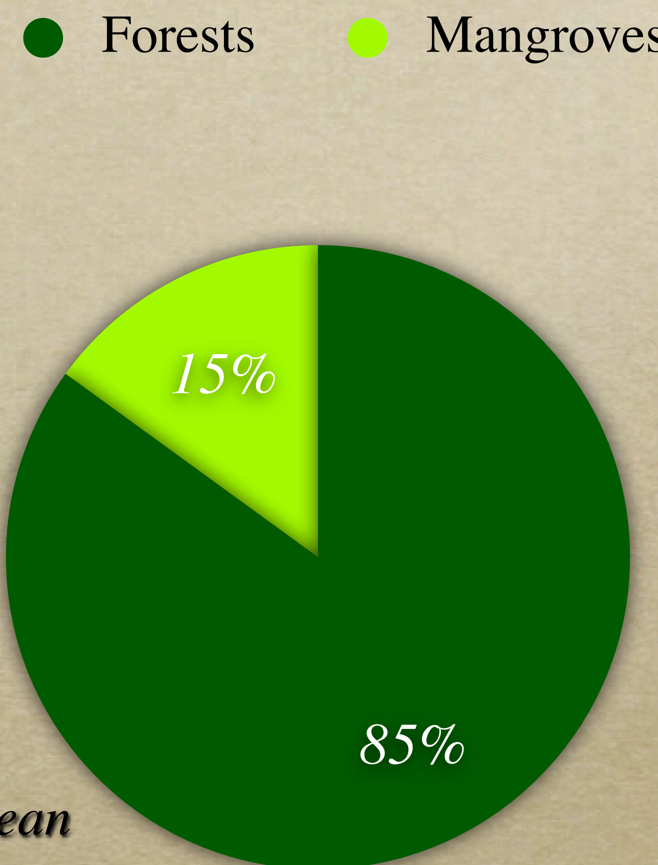
—Mangrove ecosystems are among the most productive on Earth, contributing 11% of global total C export to the ocean;
--- Already 35% of mangrove forests have disappeared and 60% could be lost by 2030;
—The estimated economical value varies between \$200 000 to \$900 000 per km^2 (UN report 2006);
—They act as a protection of shoreline against topical storms, hurricanes, storm surges and Tsunamis;



Why Mangroves?

- *Biodiversity*
  - *Habitats of 1300 species of animals*
    - *628 mammals, birds, reptiles, fish and amphibians*
- *Among the most productive ecosystems on earth*
  - *170k km^2 with mean 2.5g C m^{-2} per day*

    - *Annual input into ocean $46X10^{12}$ g C*
      - *Contributing 11% of global total export to ocean*
    - *Annual accumulation of carbon in modern sediments $23X10^{12}$g C yr^{-1}*
      - *Contributing 15% of carbon accumulation in modern sediments.*

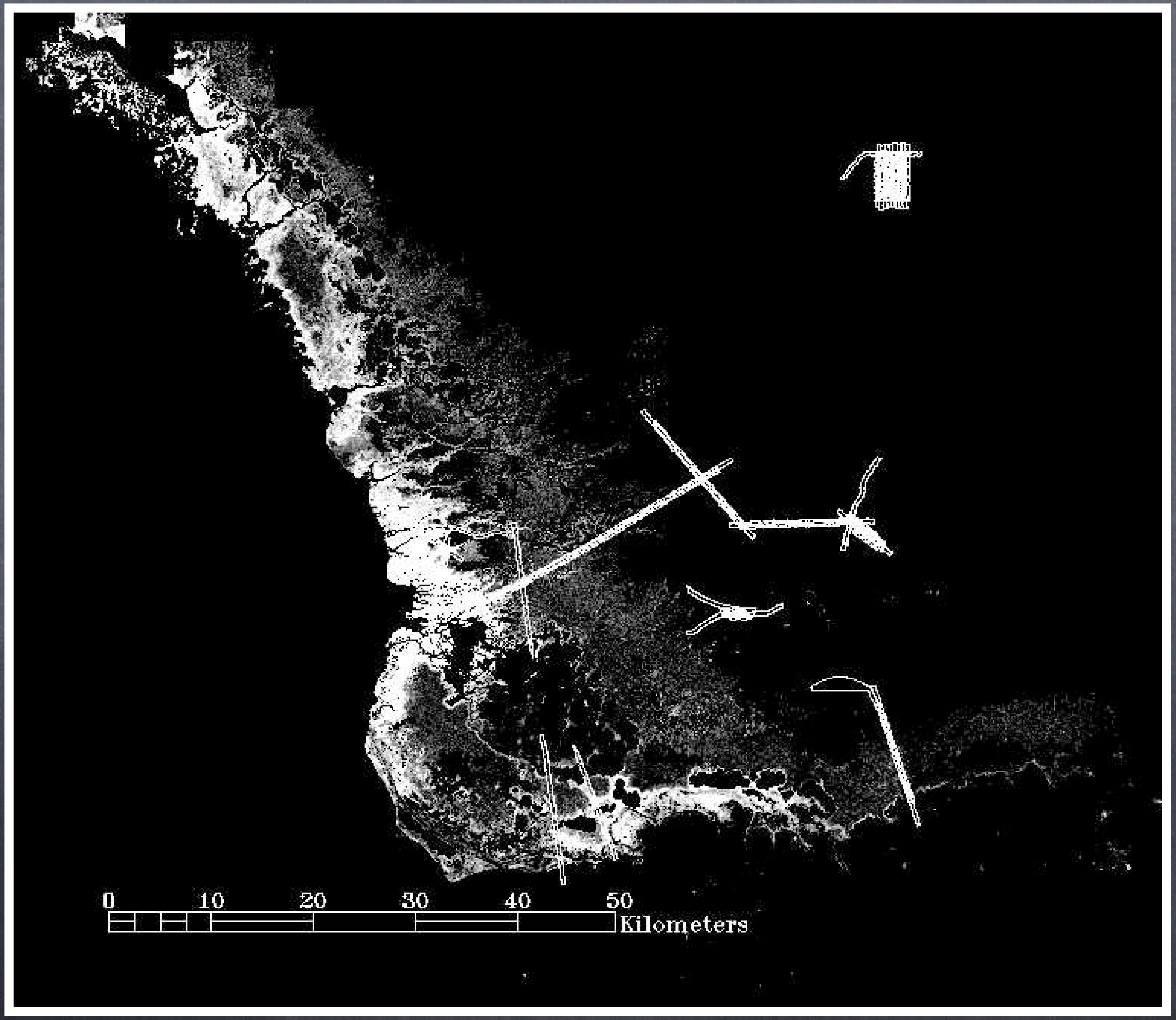


Mangroves Are Endangered

- *Endangered by Urbanization, exploitation and sea level rise*
- Already **35%** of mangrove forests have **disappeared** and **60%** could be lost by **2030;**
- The estimated **economical** value varies between $200k to **$900k** per km^2 per year (UNEP report 2006);
- They act as a **protection** of shoreline against topical storms, **hurricanes** and **Tsunamis**

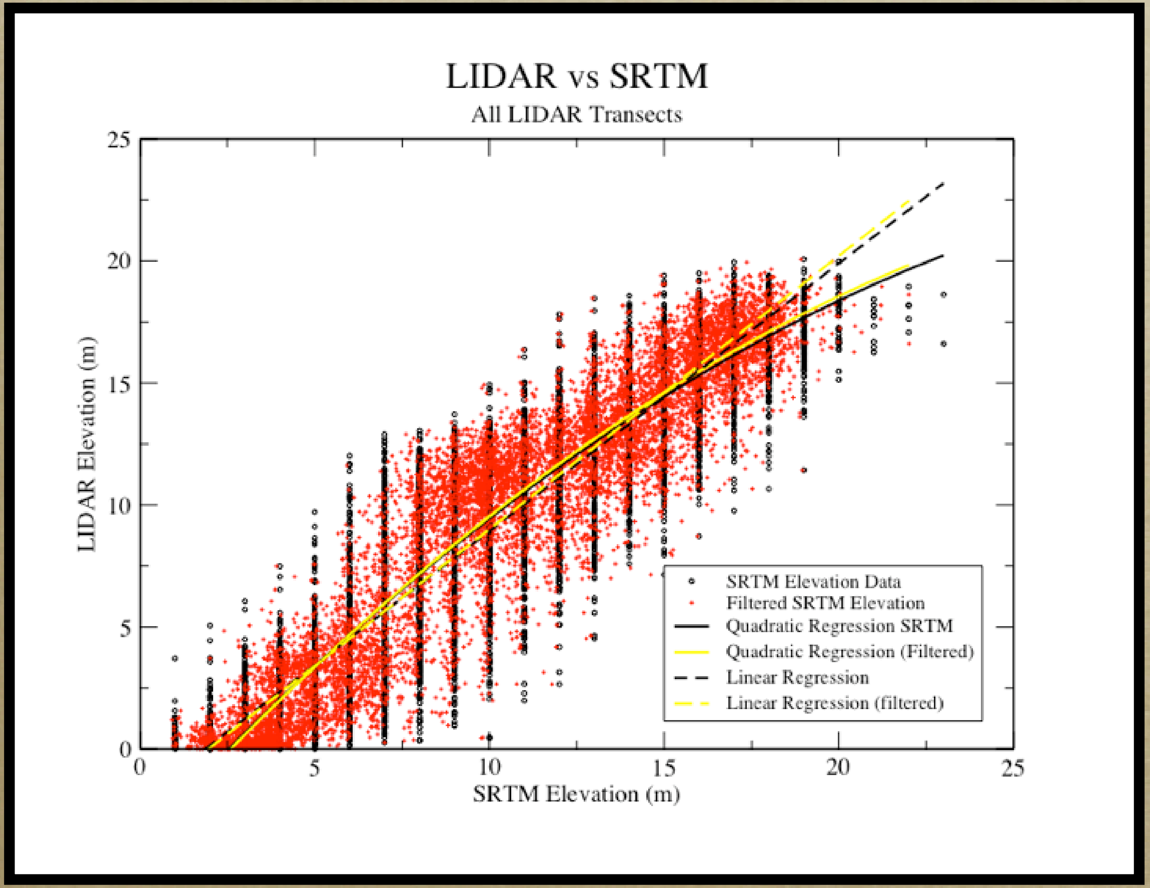
Jet Propulsion Laboratory
California Institute of Technology

Airborne Lidar Transects



Jet Propulsion Laboratory

Mean Tree Height
Lidar vs SRTM



- *$H_l = -3.9+1.56H_{srtm} - 0.22H_{srtm}$^2*
- *$H_l=-2.19+1.12H_{srtm}$*
- *2m error per pixel (30m)*
- *between 400 and 900 lidar pulses per SRTM pixel.*

Mapping Mangrove Forest Height in the Everglades National Park (ENP) Using SRTM

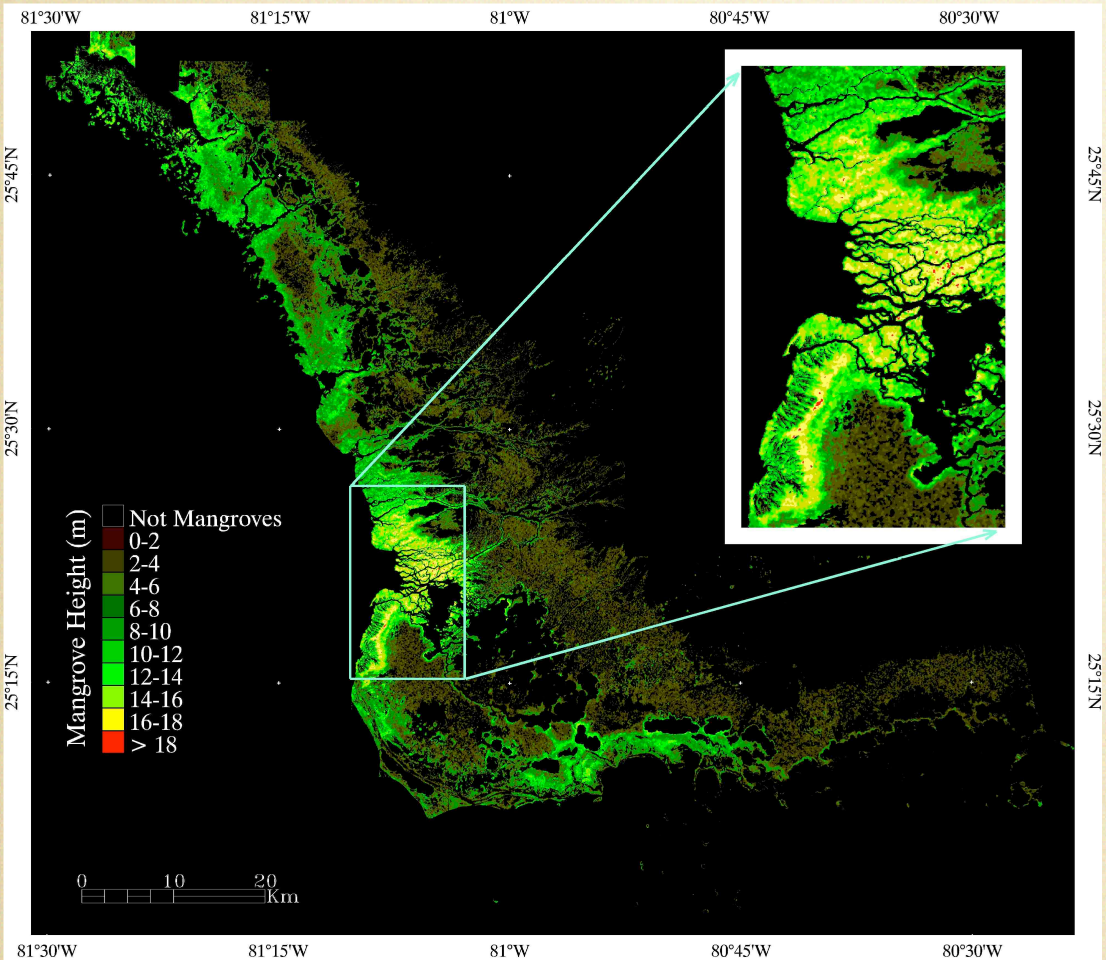


Figure 1: Map of mean mangrove tree height using SRTM data with 30m spatial resolution for the ENP (south Florida). Height was calibrated/validated with airborne LIDAR and USGS DEM and has a 2m estimation error. Most tall trees are found at the mouth of the Shark River (zoom)

—Already **35%** of mangrove forests have **disappeared** and **60%** could be lost by **2030;**
—The estimated **economical** value varies between $200 000 to **$900 000** per km^2 (UN report 2006);
—They act as a **protection** of shoreline against topical storms, **hurricanes** and **Tsunamis**;
—The U.S. government has allocated 7.8 billion dollars for **restoring the ecosystems of the Everglades** (CERP, 2000). In order **to document** the **impact** and **success** of the Everglades restoration project, the current spatial distribution and productivity of mangrove forests in the region must be recorded to **establish a baseline** for future comparisons.

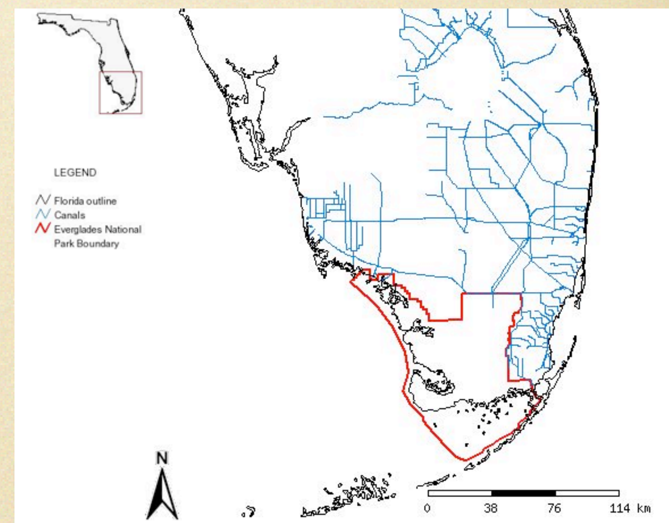
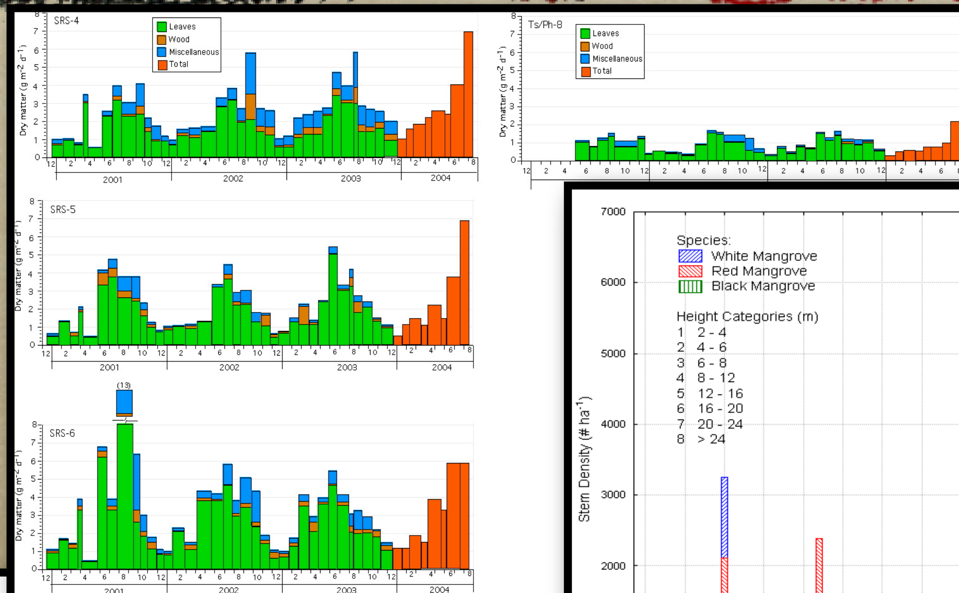
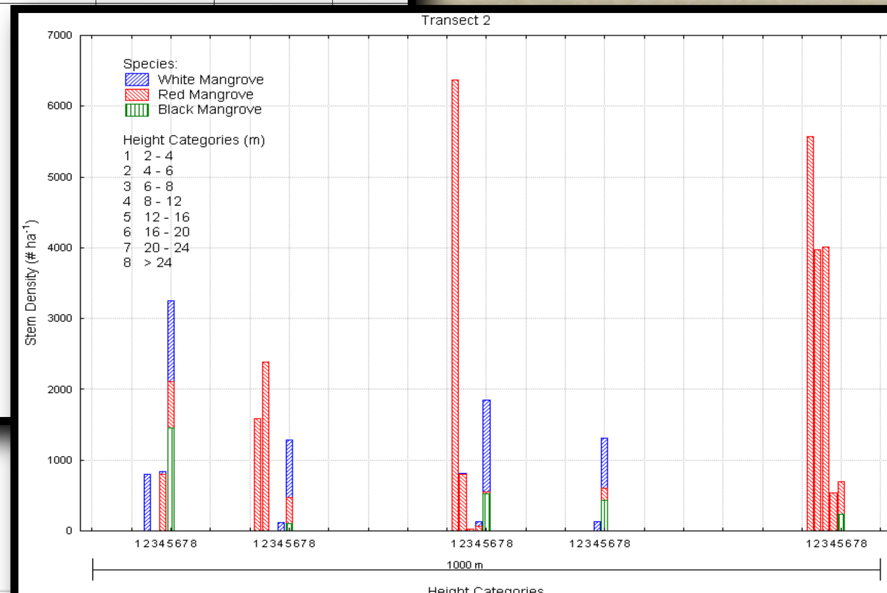


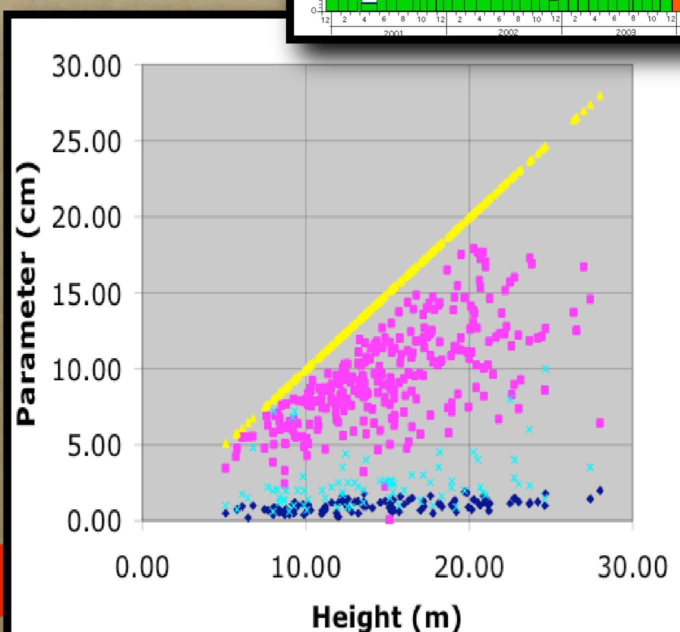
Figure 2: The ENP is located on the southern tip of South Florida(red). Mangrove forests occupy 150 thousand ha within ENP.

Marc Simard et al., “Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data”, *Photogrammetric Engineering and Remote Sensing,* SRTM special issue, April 2006

Field data:
Tree and Forest Structure, Productivity







Jet Propulsion Laboratory

Mapping Biomass of Mangrove Forest in the Everglades National Park (ENP) using SRTM

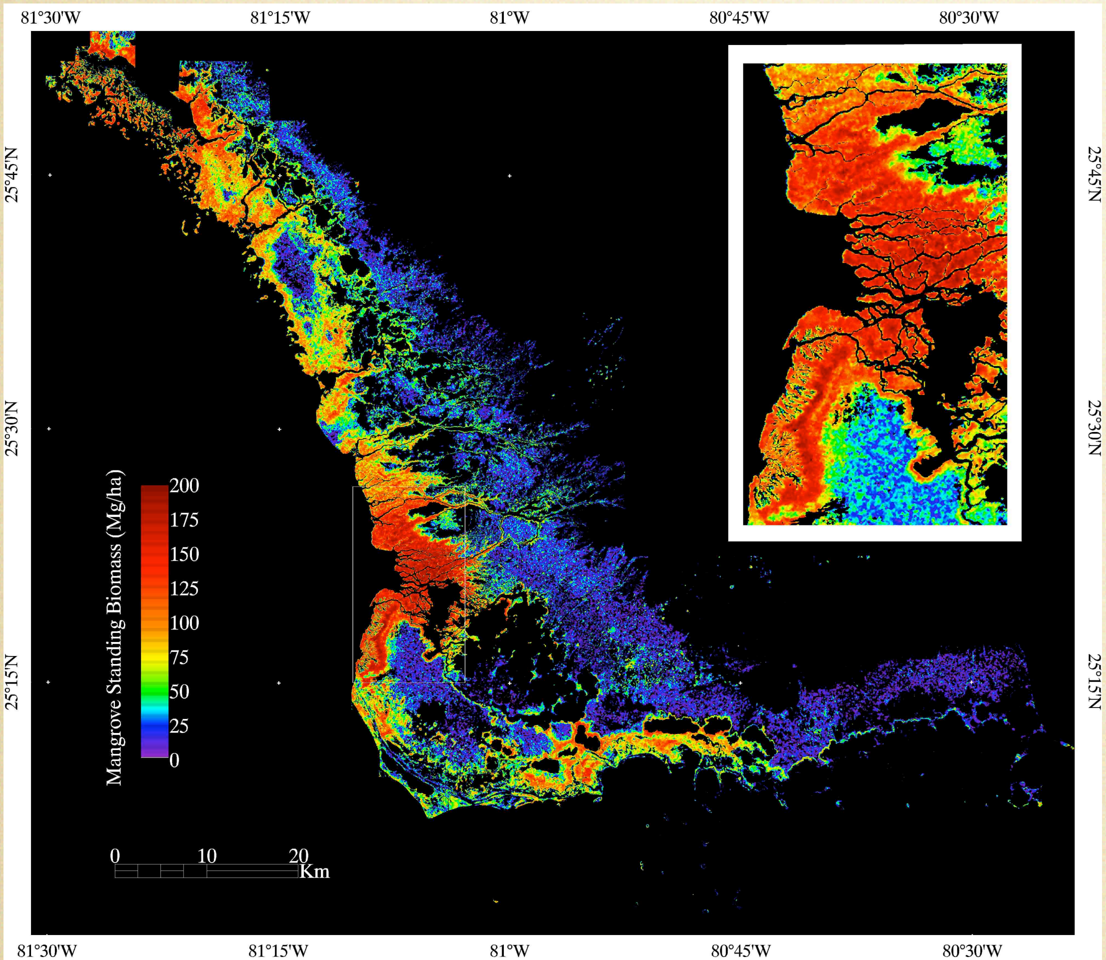


Figure 3: Biomass Map built using SRTM mean tree height estimate and biomass-height regression obtained from field data. We estimated the total biomass contained in Mangrove Forest of the ENP to 5.6Mt.

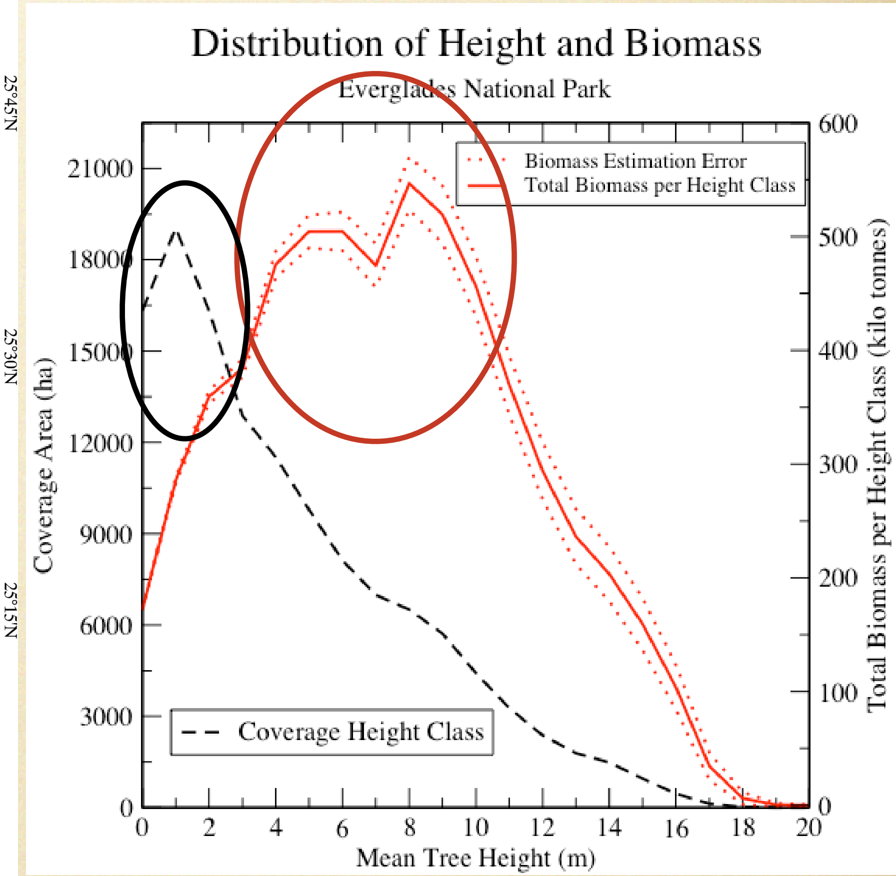
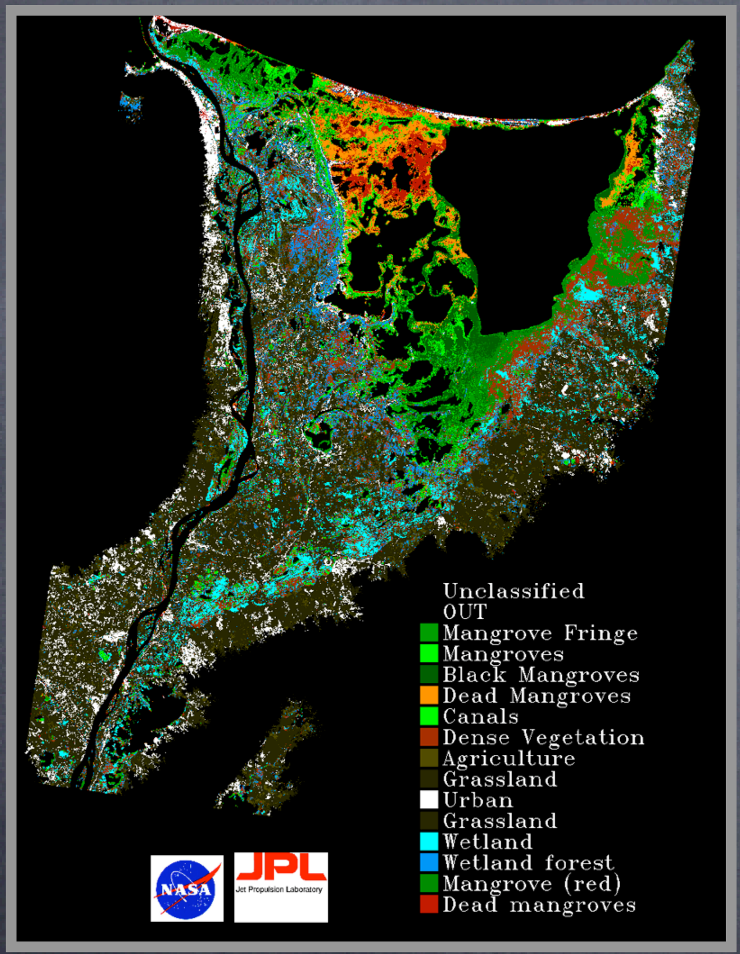


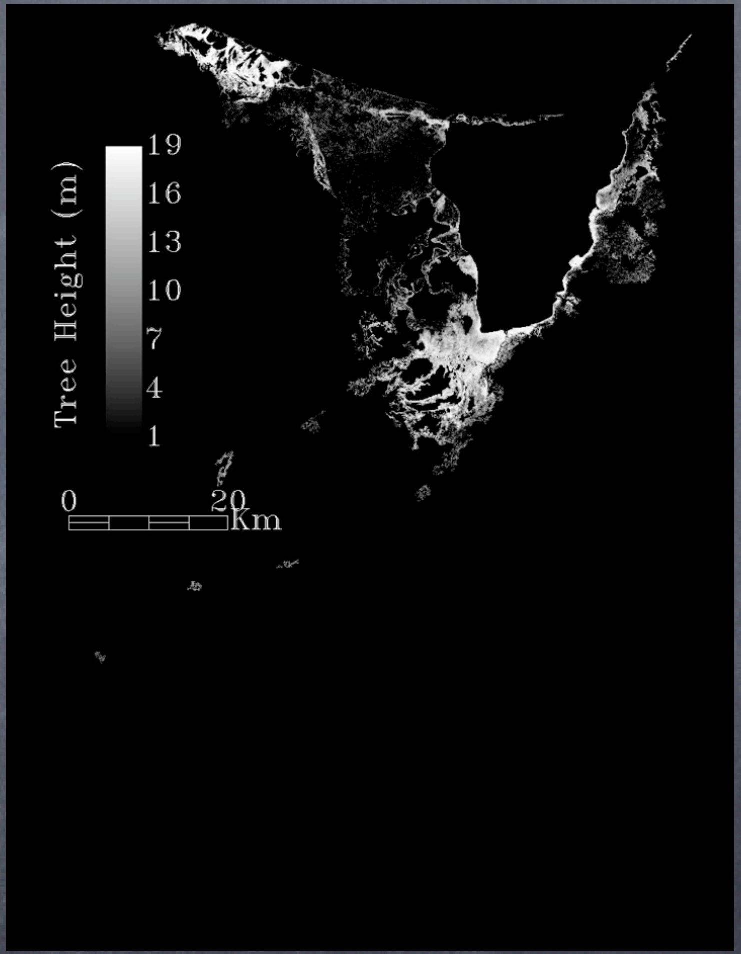
Figure 4: Area coverage (black, left scale) and total biomass (red, right scale) as a function of mean tree height. Most biomass ENP is contained in mid-size mangroves although scrub mangroves dominate in coverage

Marc Simard et al., "Mapping Height and Biomass of Mangrove Forests in Everglades National Park with SRTM Elevation Data", *Photogrammetric Engineering and Remote Sensing,* SRTM special issue, April 2006

Cienaga Grande de Santa Marta, Colombia Calibrated with ICEsat LIDAR Waveforms



Landsat Land Cover Classification



Mean Mangrove Tree Height

- Simard et al. Remote Sensing of the Environment, 2007.

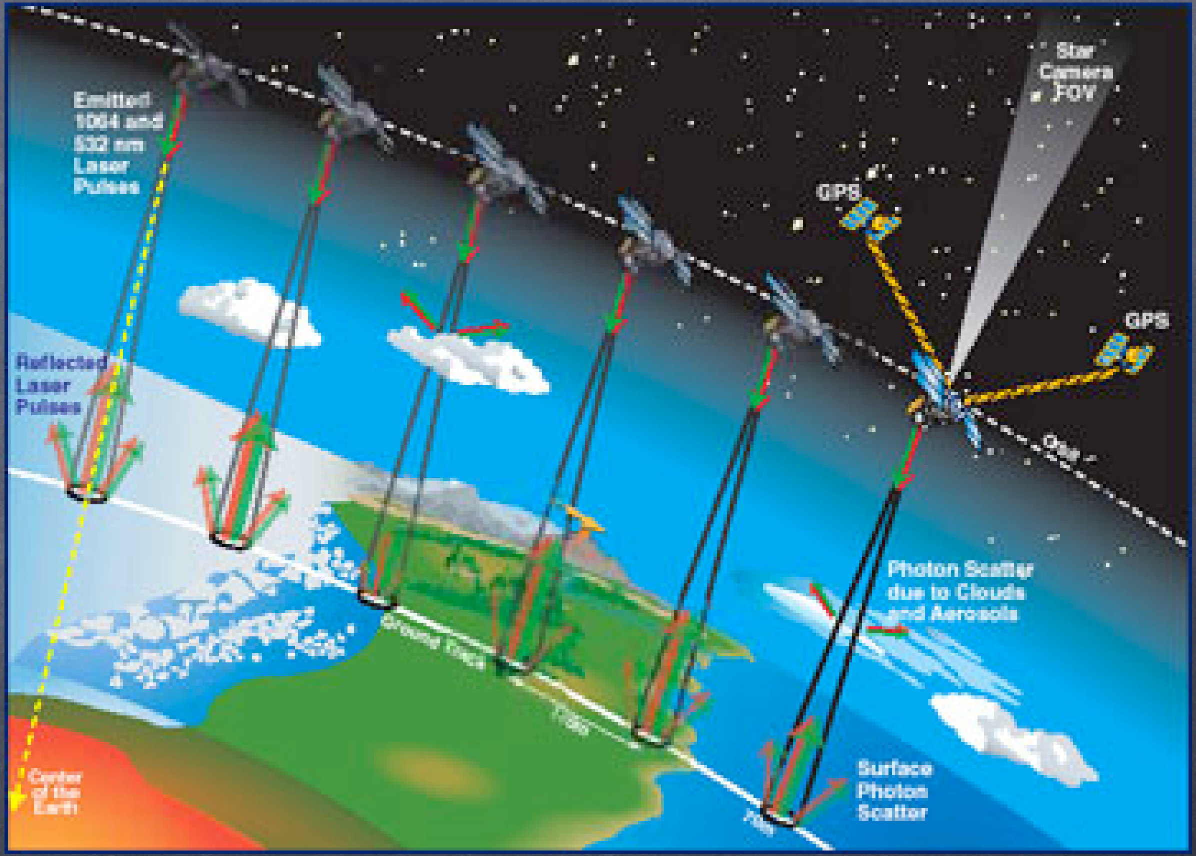
JPL
Jet Propulsion Laboratory

NASA

ICEsat/GLAS

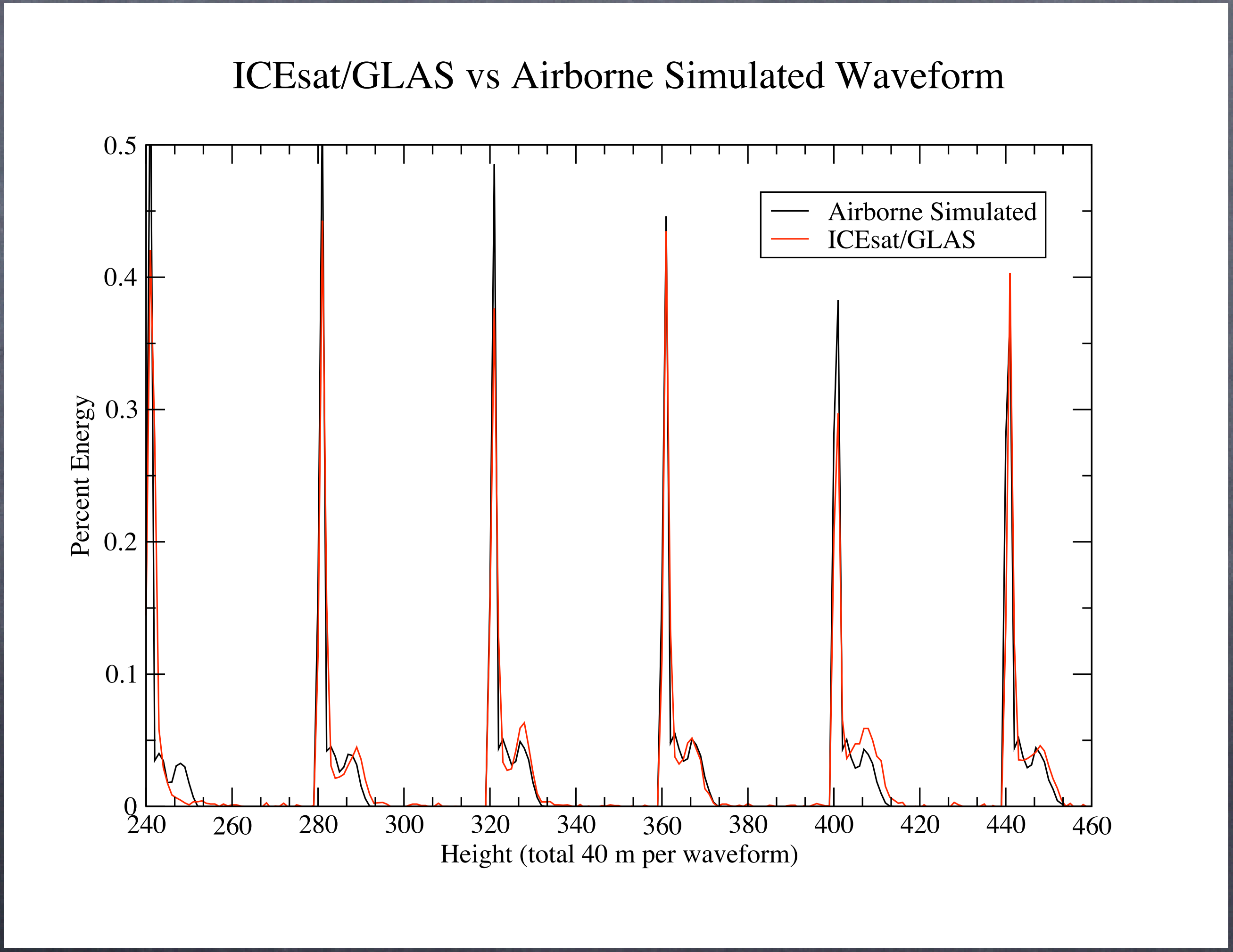
Geoscience Laser Altimeter System

- 172m spacing
- 64m footprint



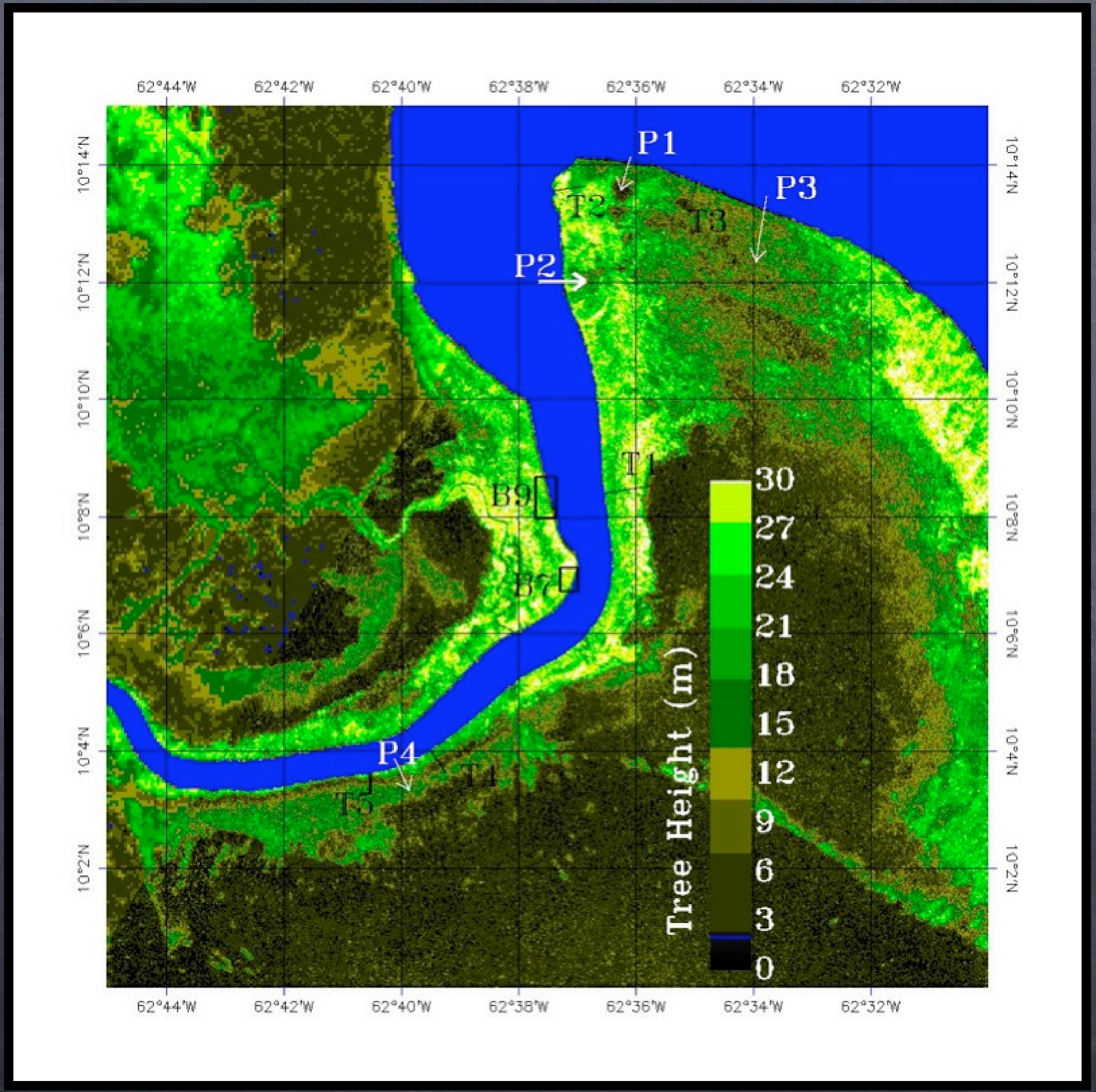
Jet Propulsion Laboratory

Canopy Structure with LIDAR Waveform



Jet Propulsion Laboratory

San Juan River, Venezuela



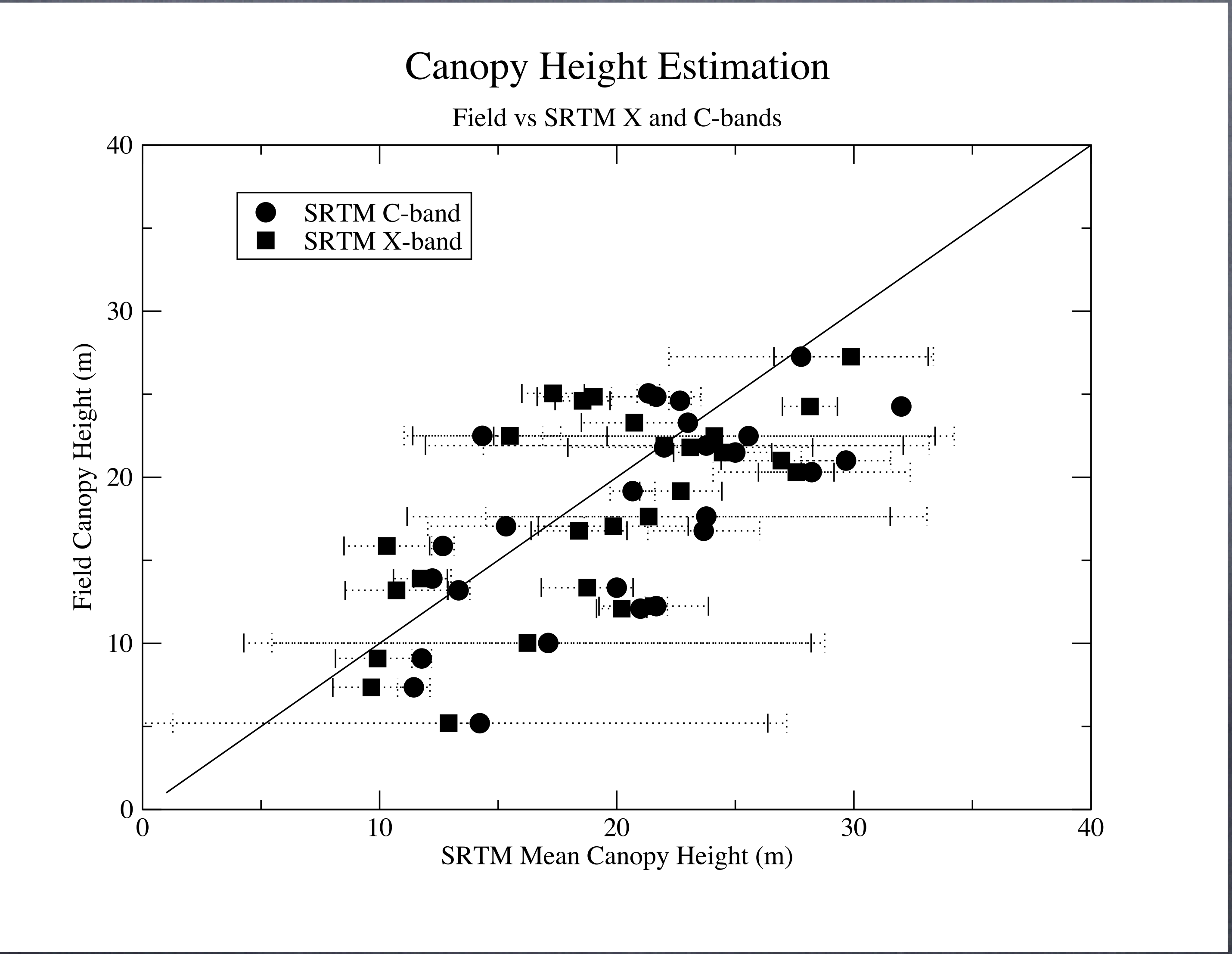
Jet Propulsion Laboratory

Ground Thruth

JPL
Jet Propulsion Laboratory

NASA

Comparison SRTM C and X band

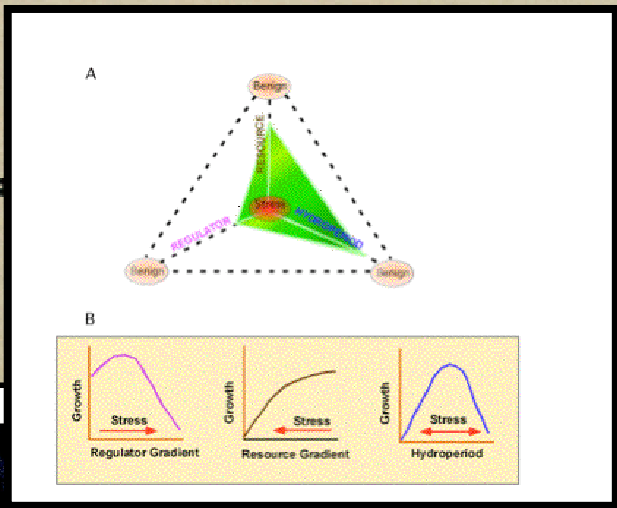


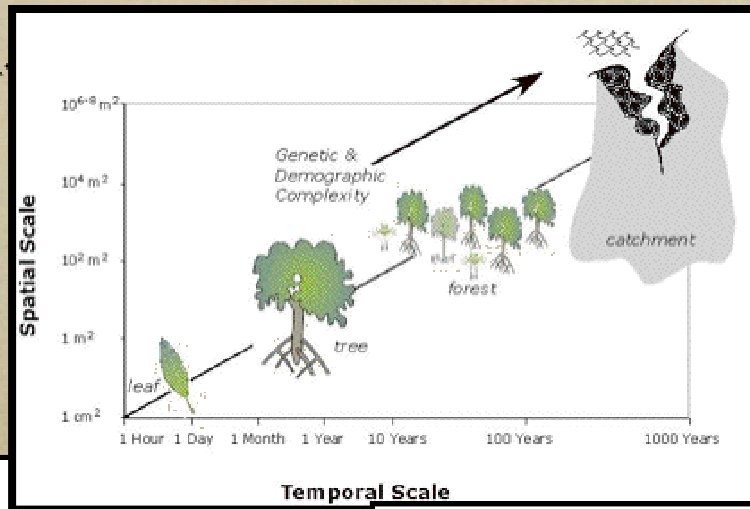
Back to Florida with Productivity Modeling

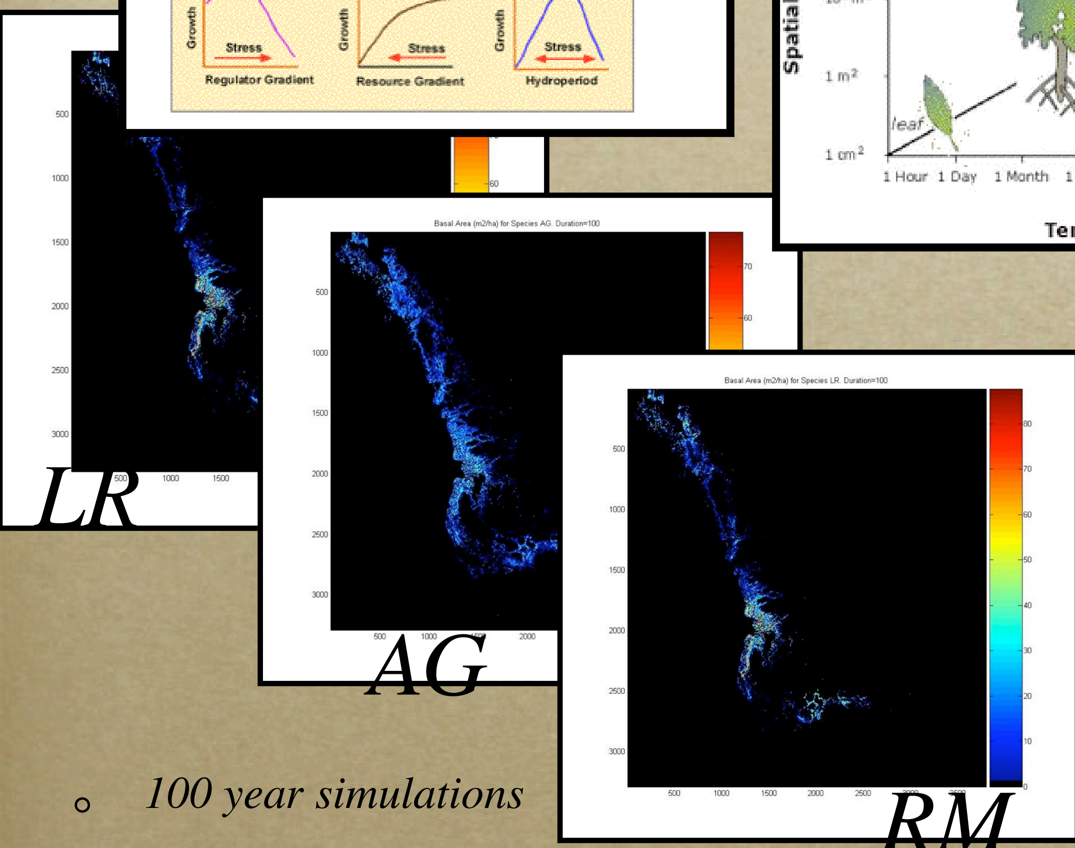
Jet Propulsion Laboratory

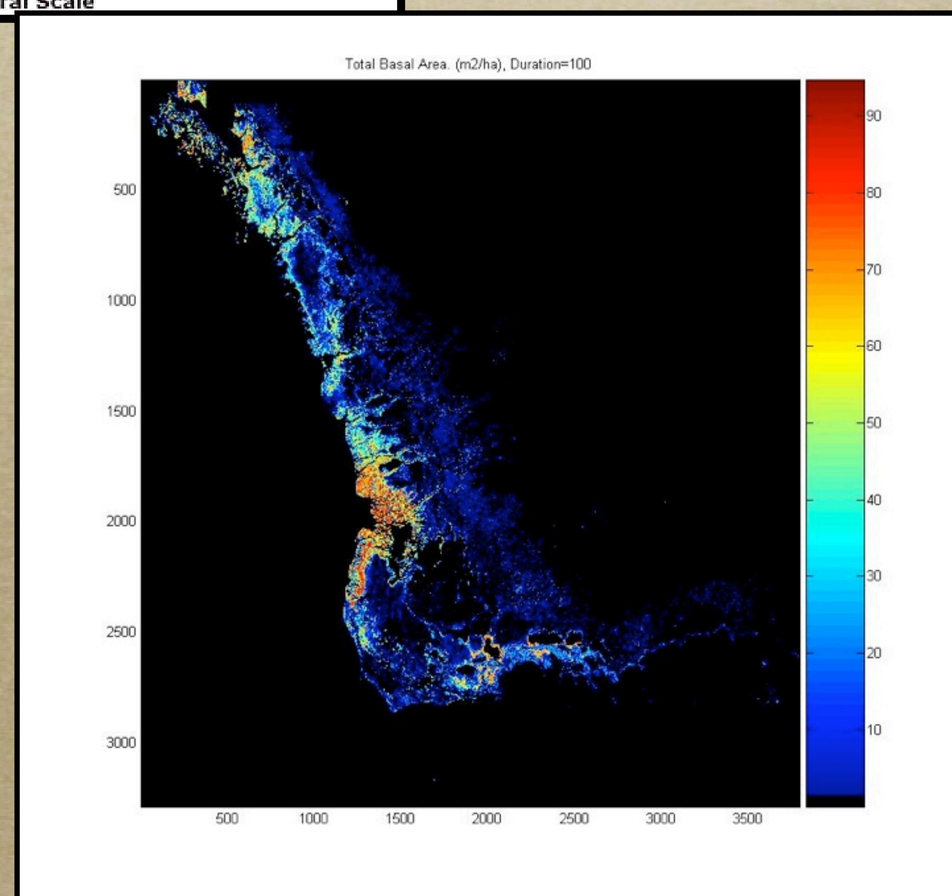
Modeled (FORMAN) Basal Area

Rivera-Monroy, Simard, Twilley (Louisiana SU)





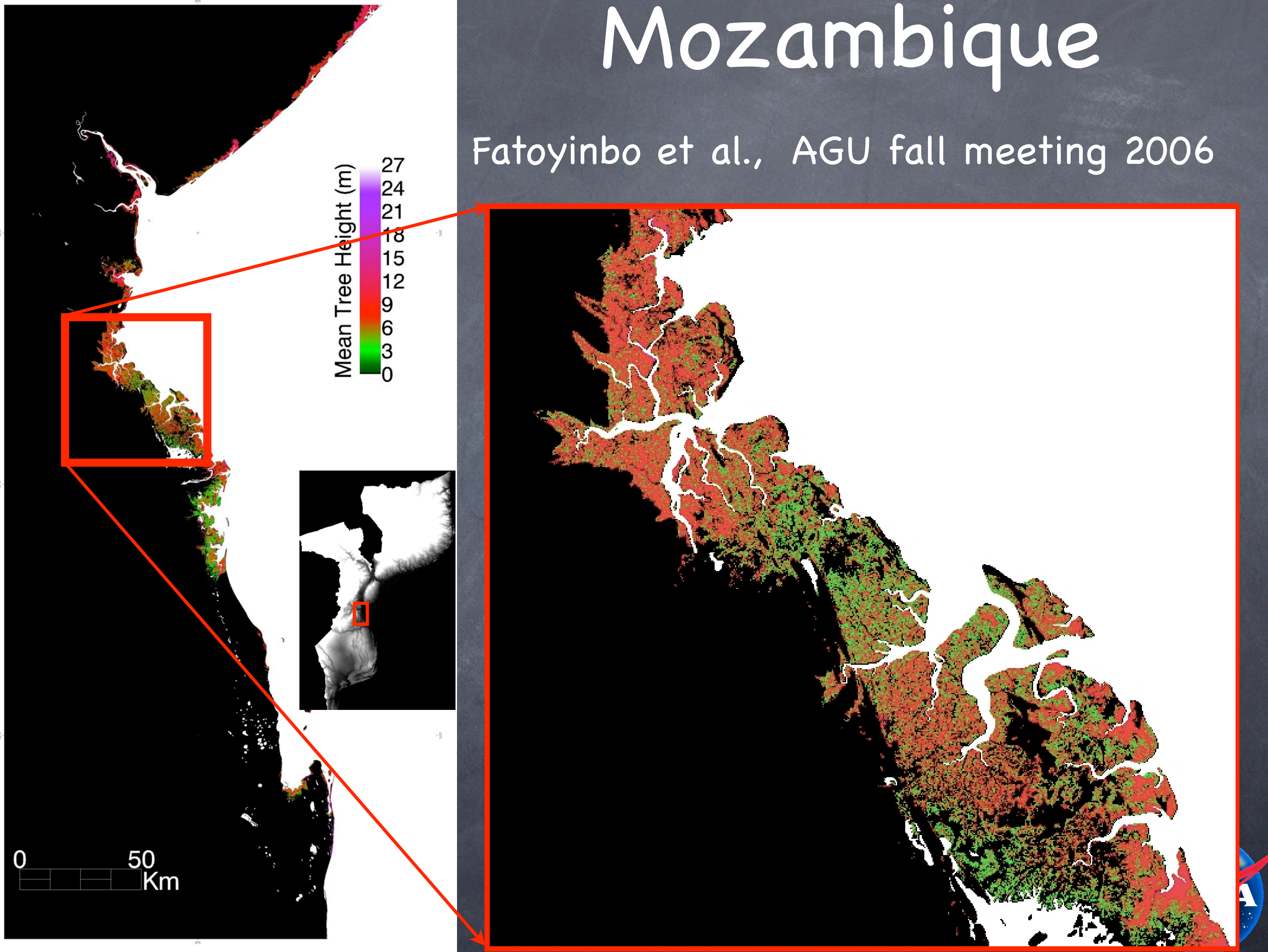




- *100 year simulations*
- *Specie and Light Competition*
- *Nutrient Availability from field and SRTM*
- *Salinity from field*
- *2208 g C m2 y-1*

Mozambique

Fatoyinbo et al., AGU fall meeting 2006



Hurricane impact

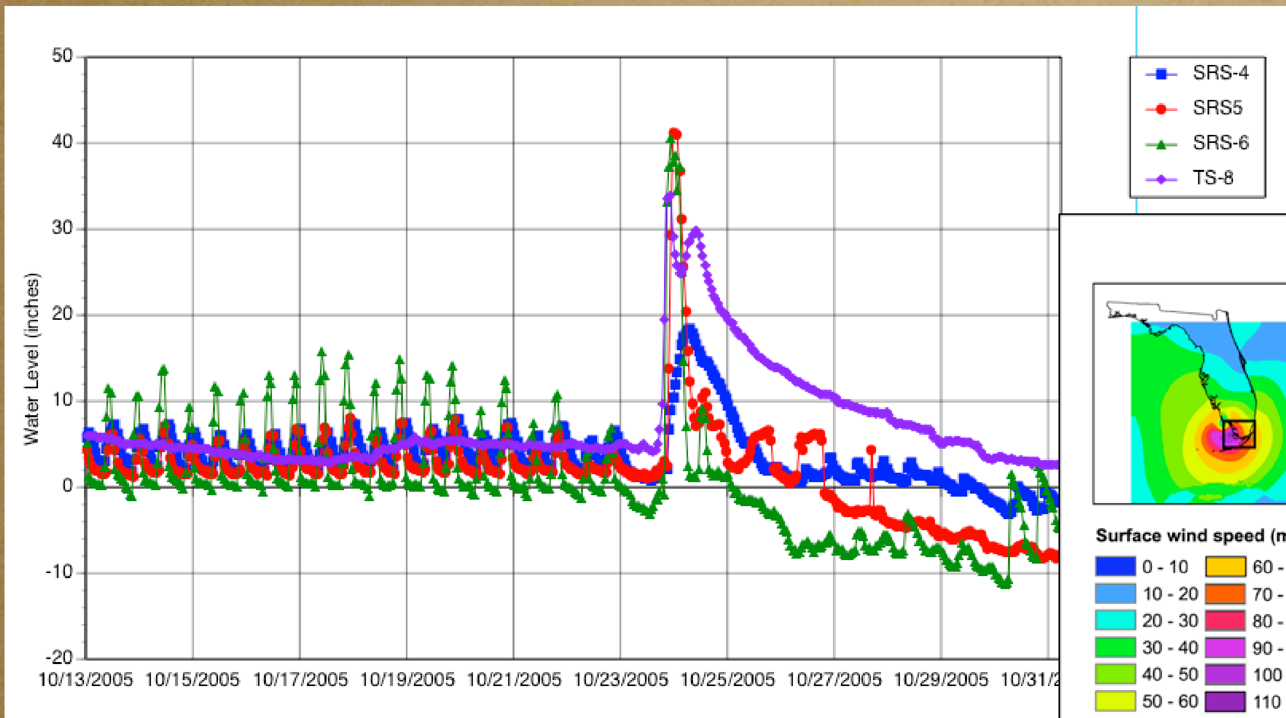
Two Category 1 hurricanes

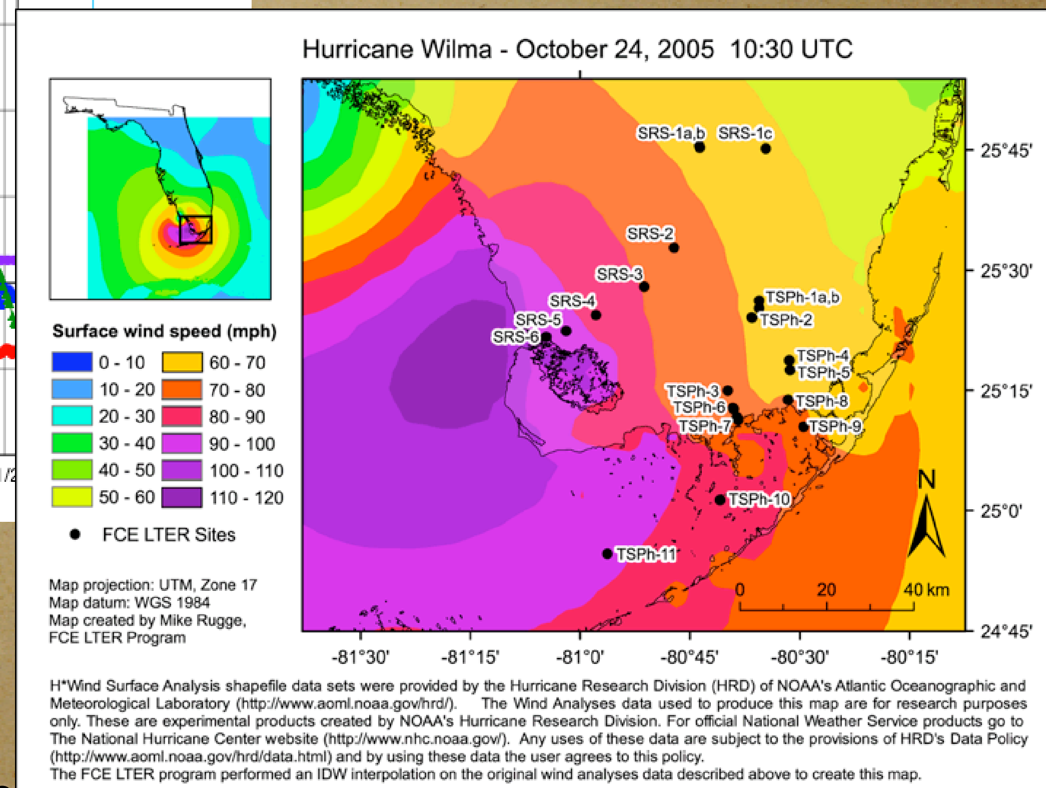
Katrina august 25th, 2005

Wilma October 24th, 2005

AMSR-E

Storm Surge





- Predicted 3 to 5 m, but the water level was on average about 1 m above ground;
- There may have been a major sudden increase (2m) as indicated by the sediment deposition in the tower but our Water Level recorder did not register this event.

Field Surveys

November 05-January 06

Transect	Mortality	Orientation	Crown
Broad River 8-12m	11%	N-E	100%
Harney River 12-15m	14%	N	100%
Shark River	3%	N	100%

Tree sizes already increases from North to South Due to Hurricane Andrew in 1992

Sediment Deposition

- The general composition is:
calcareous material-low in organic matter and high in **Phosphorus**.

- Sediment layer deposited by **Hurricane Wilma** in riverine forests in Shark River (SRS-6): Average layer depth is **4 cm**.

- Implications regarding sea level rise:

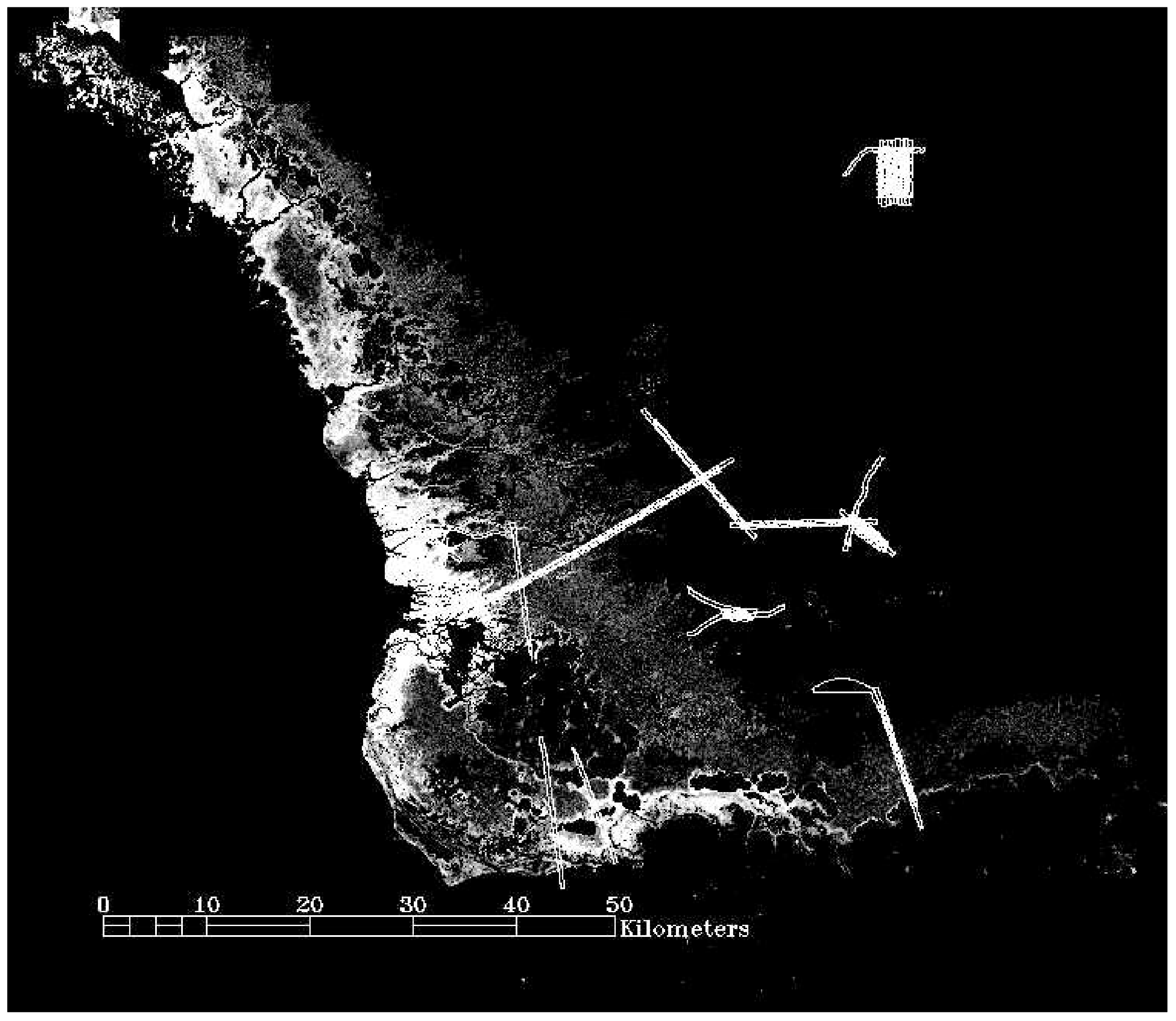
- **Hurricanes** can have both **short** and **long**-term **detrimental** effects on mangrove **productivity** help maintain a high relative elevation of mangrove soils.

- Hurricane **Wilma** (October 24, 2005) deposited approximately **3-4 cm** of mineral sediment on top of mangrove soils along the western region of south Florida up to 1-2 km inland.

- Mean accretion rates estimates for Shark River: **6.7 ± 0.6 mm yr-1** (Whelan et al. 2005) sea level rise for South Florida: **3 mm year-1** (Wanless et al. 1994) -> offset seal level for at least a **decade**.

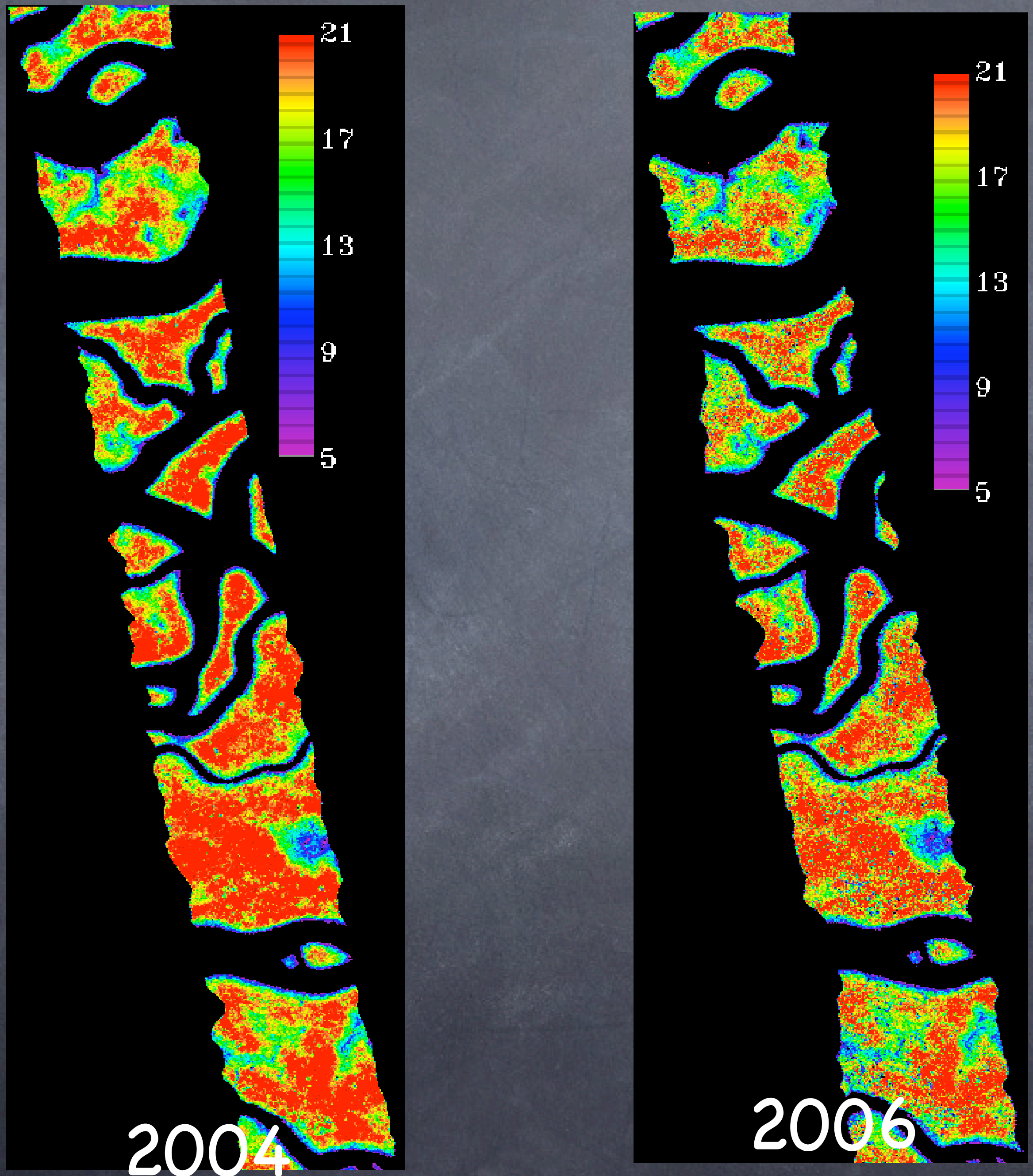
- Dead wood contributes to formation of soil and potential material to **maintain high accretion rates** on the long term.

Airborne Lidar Transects

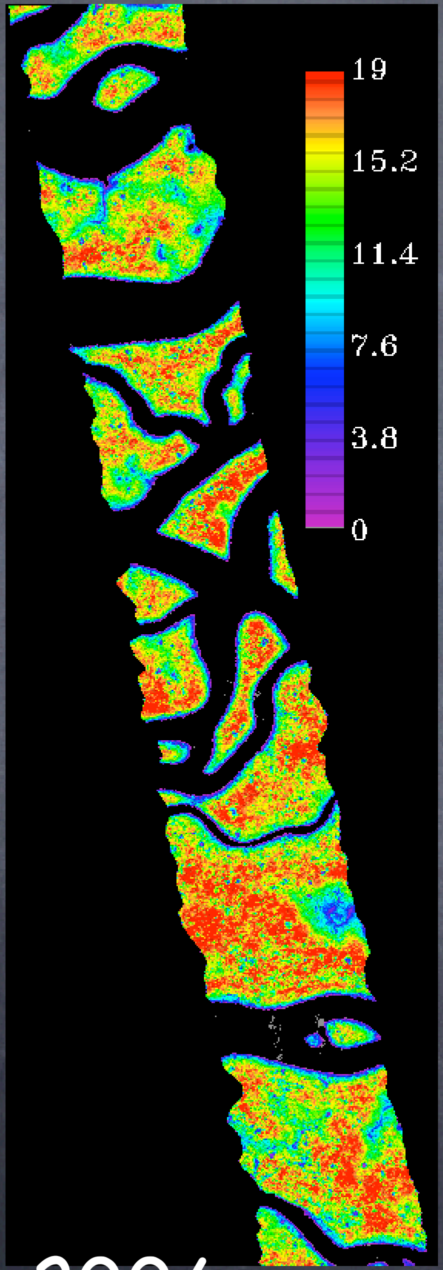


Jet Propulsion Laboratory

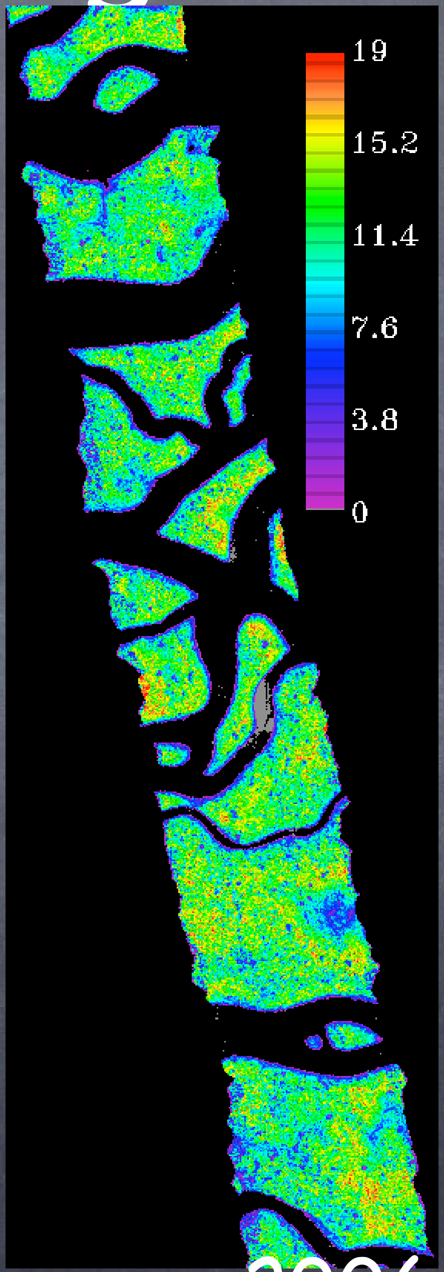
Maximum Height within 5m



Mean Height

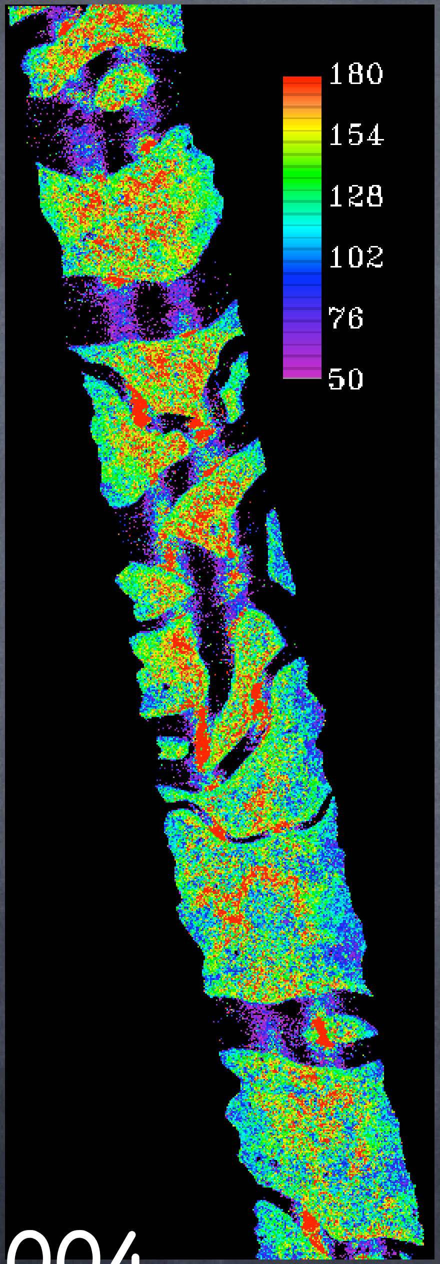


2004

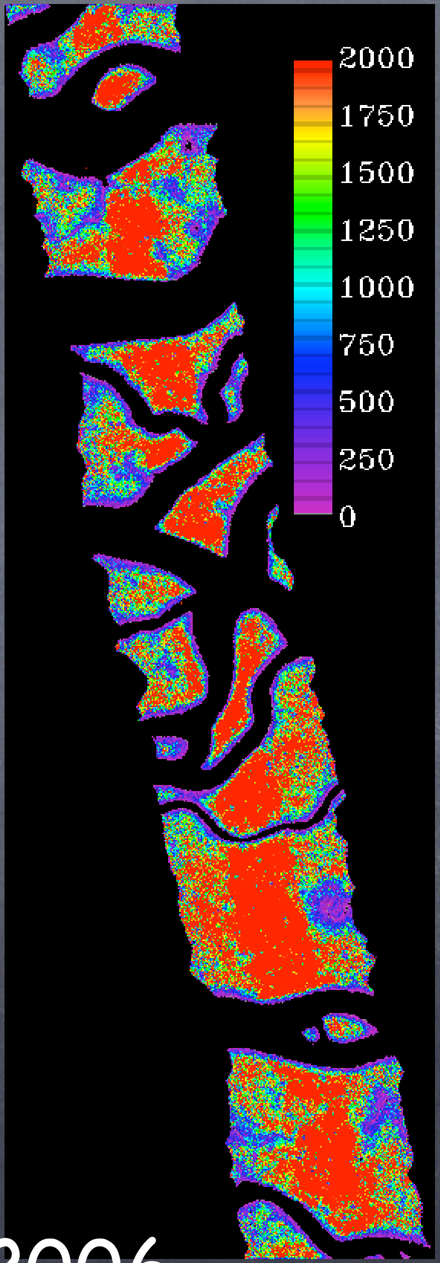


2006

Variance



2004



2006

Jet Propulsion Laboratory

What's next?

- Build a Catalog of Lidar Waveform to Calibrate SRTM
- Map Entire Caribbean Coast in 3D and Use ALOS to Estimate Biomass
- Study Impact of Hurricanes and Storm Surge Inland.

Jet Propulsion Laboratory