BIOMASS: A MISSION TO DETERMINE GLOBAL BIOMASS

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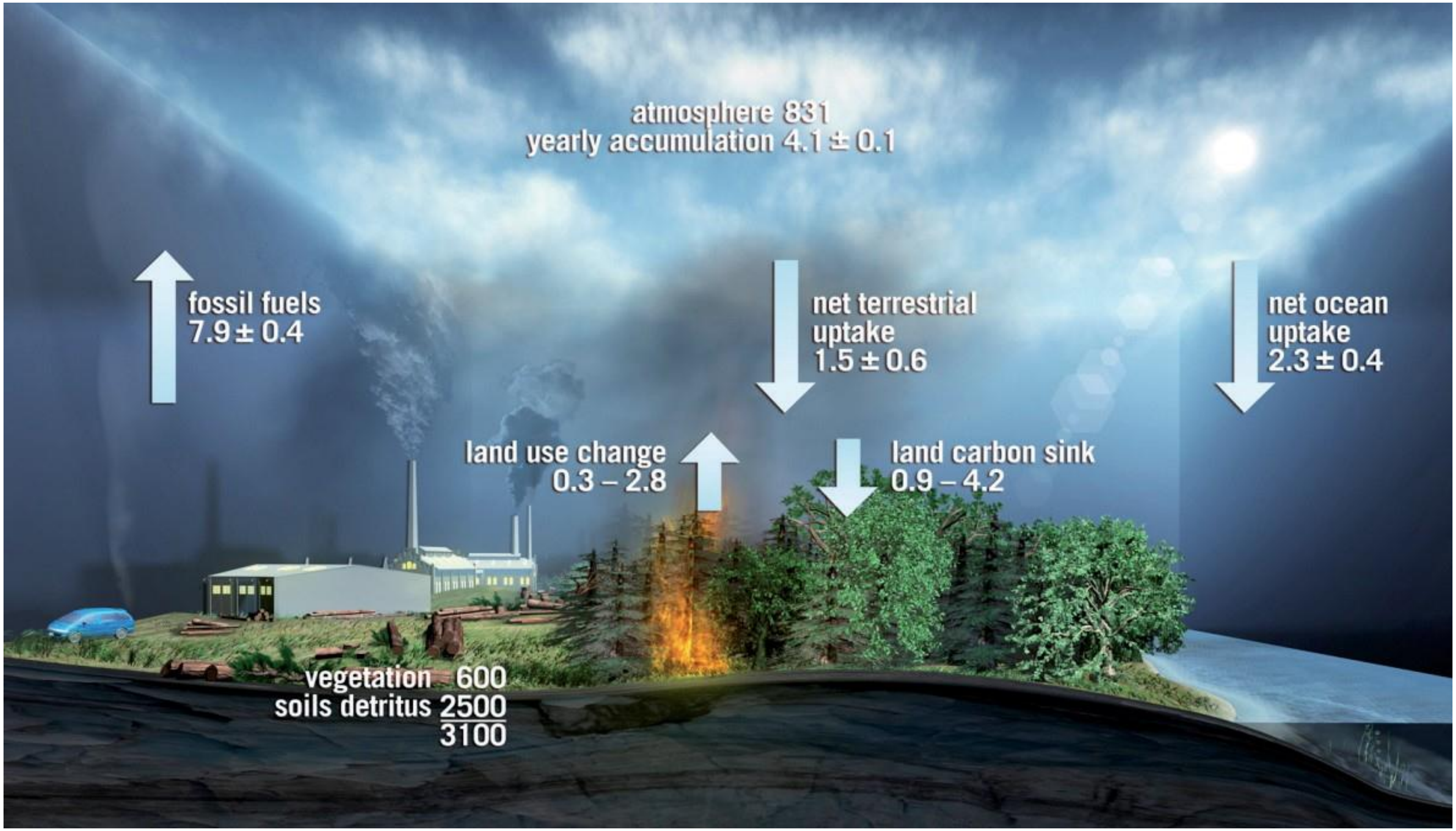
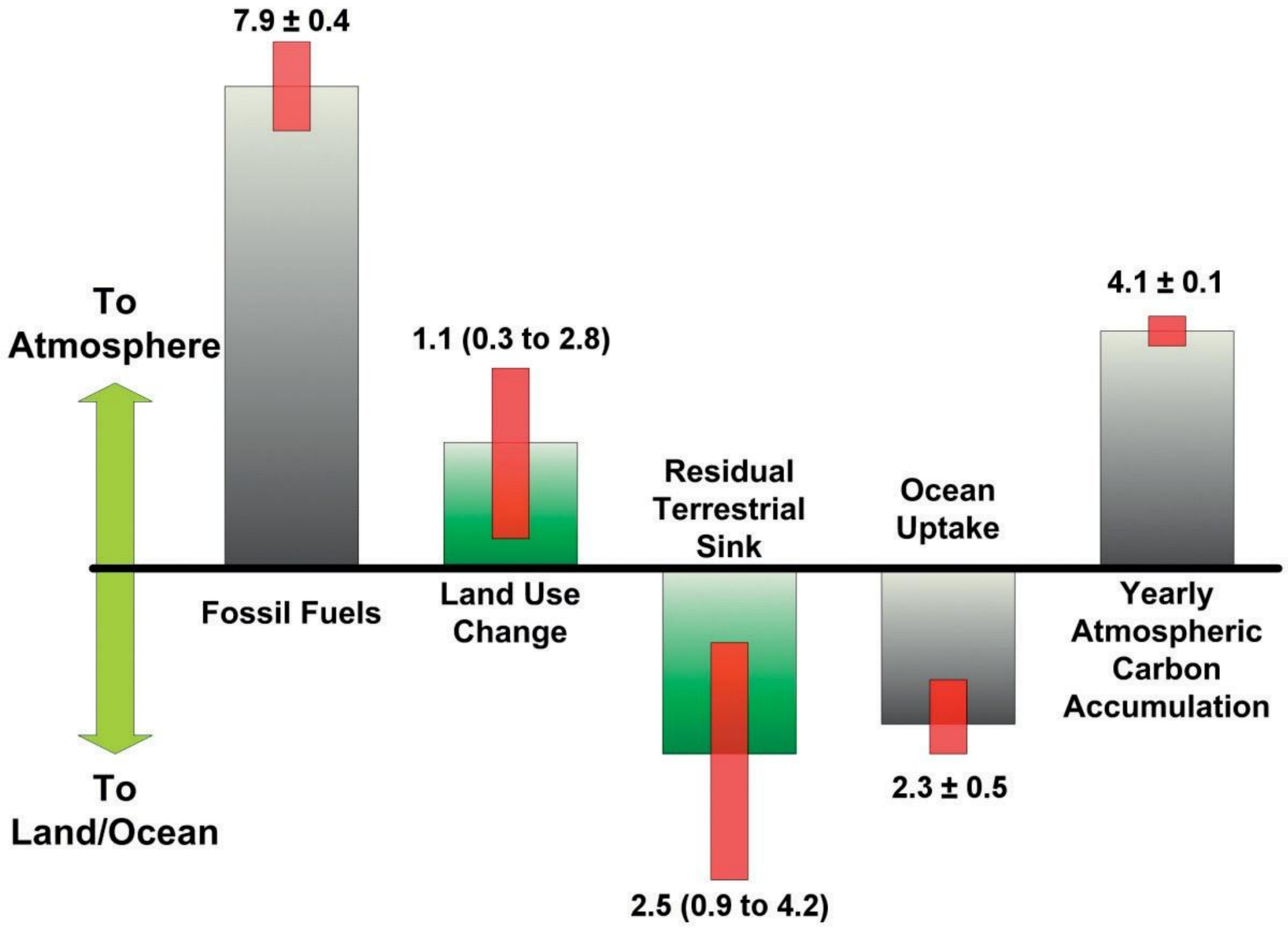
Why we need improved observations of forest biomass and its changes

- Forest biomass is a fundamental quantity needed for carbon emissions calculations
- Biomass tells us about forest resources, which are crucial for ecosystem services and human well-being
- Increase in biomass by forest growth is the only carbon sink recognised by international treaty
- The spatial distribution of biomass provides:
  - a key constraint on land surface models
  - insight into the landscape disturbance regime
- Knowledge about biomass is basic to the UNFCCC Reduction of Emissions from Deforestation and Degradation initiative (REDD+)

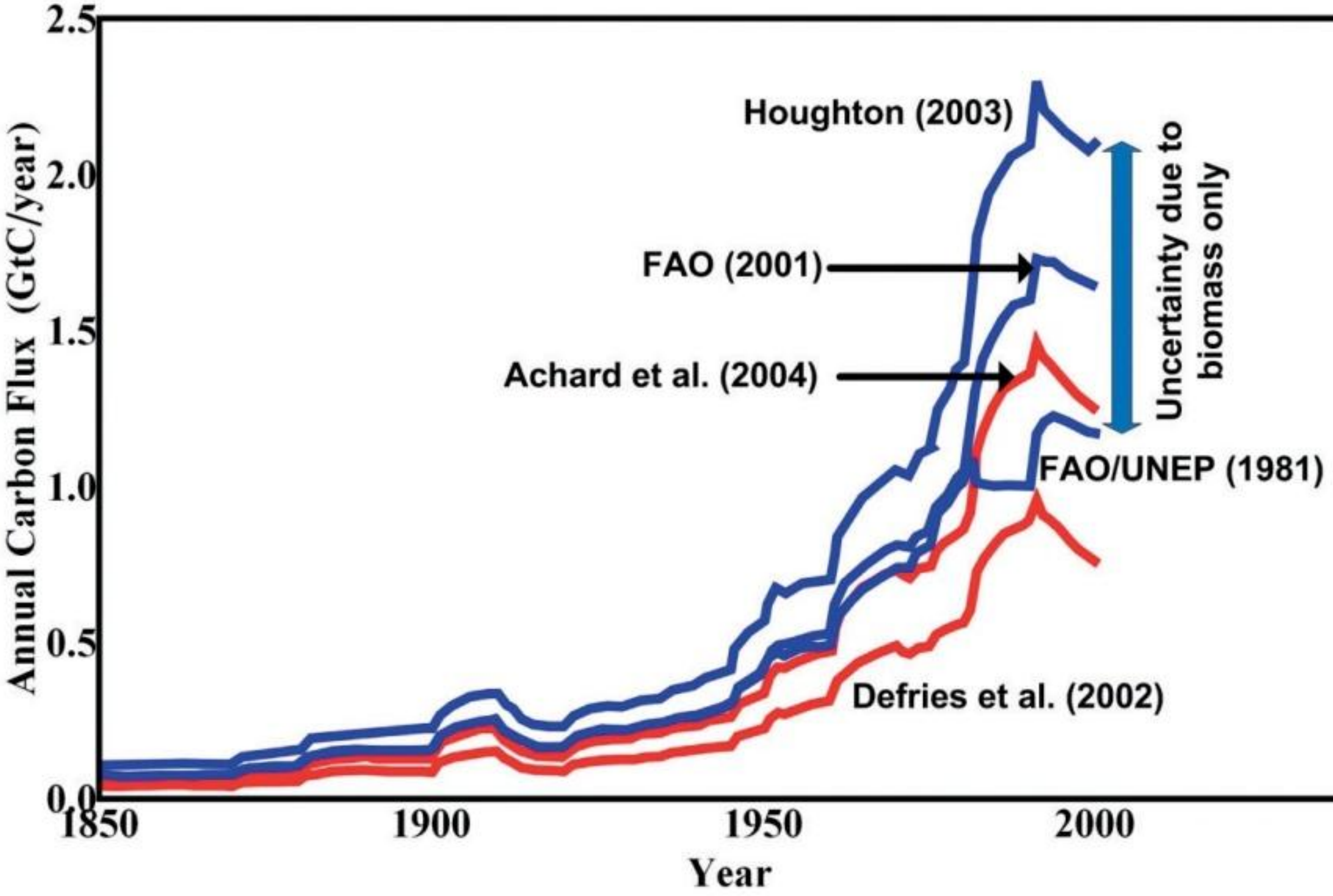
The carbon cycle: 2000-2009



Anthropogenic carbon fluxes (2000-2009)



Variation in Estimated Land Use Change Fluxes



Differences in estimates of LUC flux come from:

- Different estimates of deforested area
- Different estimates of biomass in deforested area

Why such disparity?

Carbon emitted = C_{em} = 0.5 x A x B x E

B = Mean biomass of deforested area

A = Area deforested

E = Emission efficiency

Uncertainty:

$$\frac{\Delta C_{em}}{C_{em}} \approx \frac{\Delta A}{A} + \frac{\Delta B}{B} + \frac{\Delta E}{E}$$

REDD+

UNFCCC COP16, Cancun decision 1

The COP encourages developing countries to contribute to climate change mitigation by undertaking activities relating to Reducing Emissions from Deforestation and forest Degradation, conserving and enhancing forest stocks and sustainable management of forests.

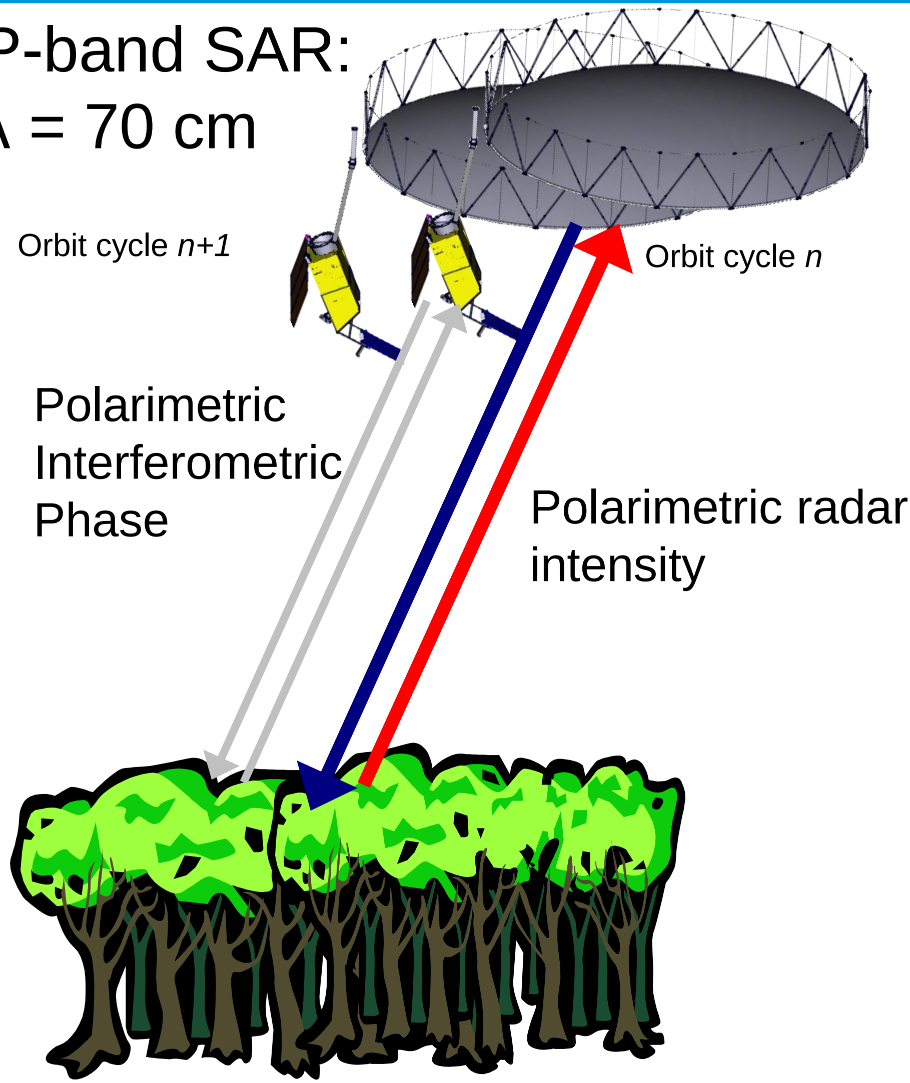
- Developing countries are entitled to financial support from developed countries for the purposes of reporting their GHG emissions and actions.
- Countries must develop national Measurement, Reporting, and Verification systems to monitor progress towards achieving REDD+ goals if they are to receive support.

Required measurement properties

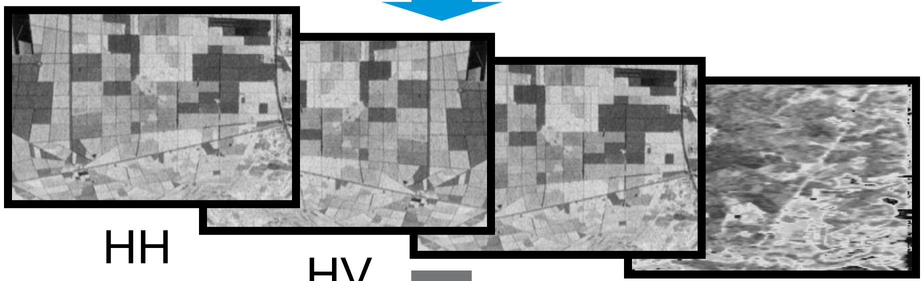
- The key region where information is needed is the tropics:
  - deforestation (98% of the Land Use Change flux)
  - regrowth (52% of the global biomass sink)
  - REDD+
- Temperate forest growth (regrowth, afforestation) contributes about 23% of the mid-latitude sink
  - 50% of this is in China
- Measurements need to be where the changes occur and at the scale of change: 1-4 ha.
- Forest height helps to constrain biomass estimates

Biomass Observation Concept

P-band SAR:
λ = 70 cm



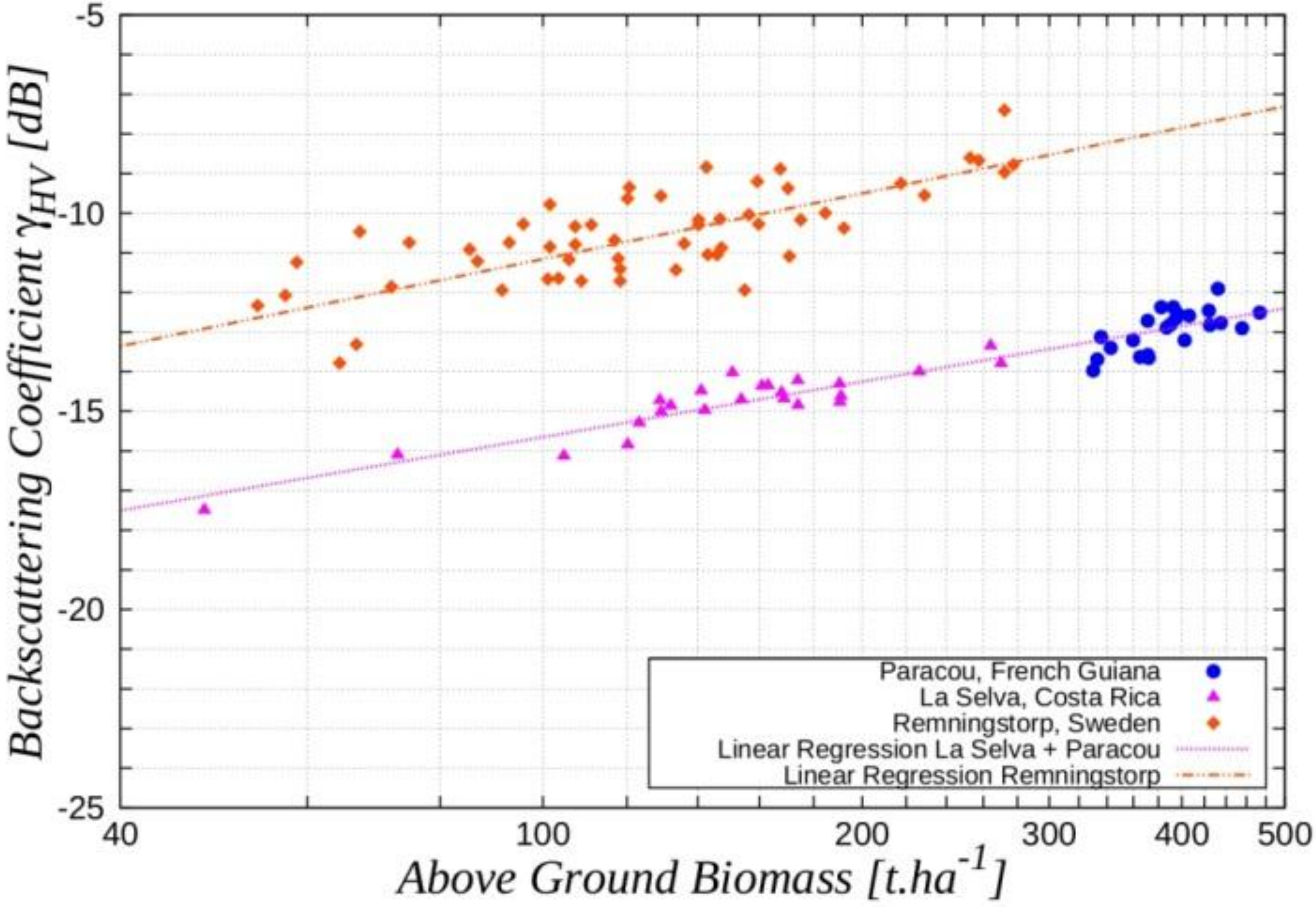
Calibration, Ionospheric correction



Retrieval algorithm

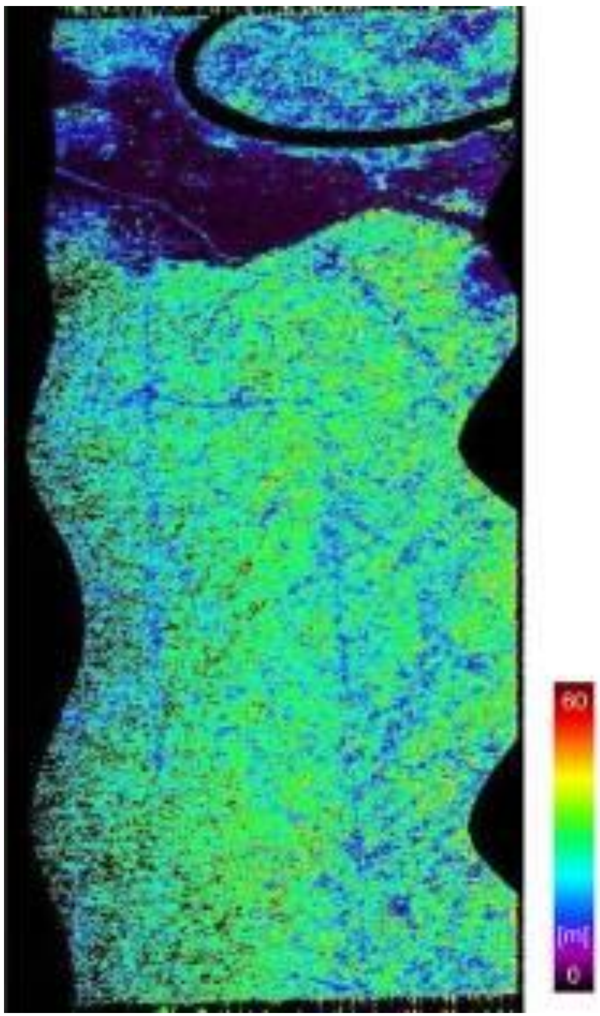
- Forest biomass
- Forest height
- Forest biomass temporal change
- Deforestation

The sensitivity of P-band backscatter to biomass



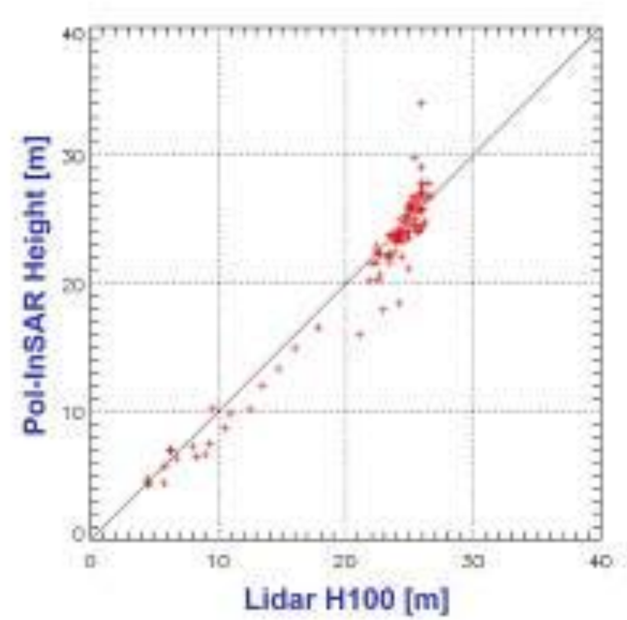
Forest height from Pol-InSAR

Mawas, Indonesia



60 m

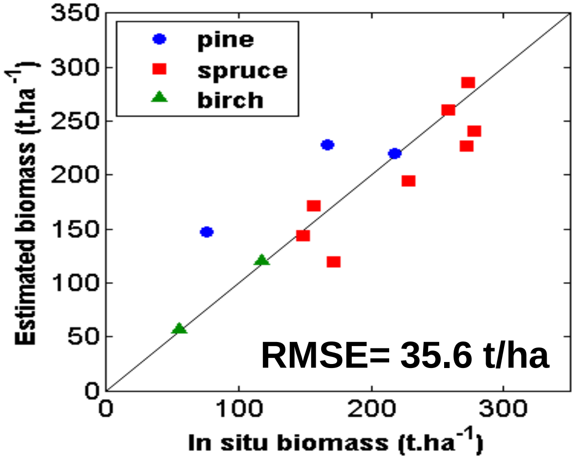
0 m



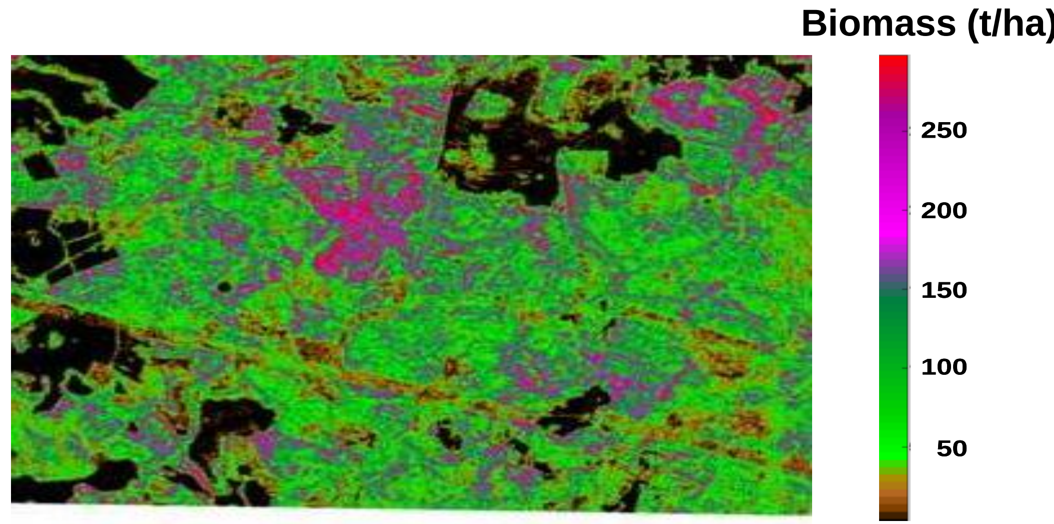
Pol-InSAR vs lidar height

Improving retrieval using polarisation & height

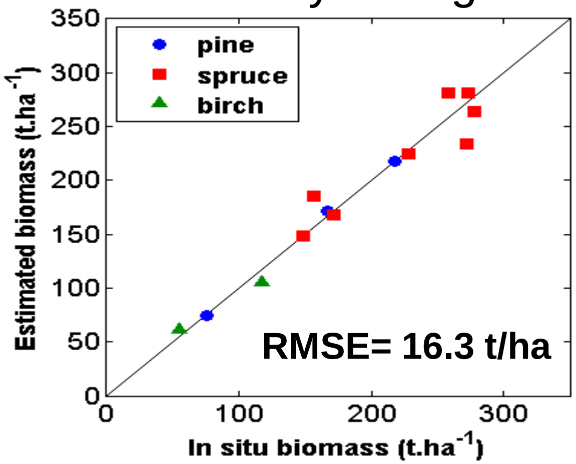
Polarised intensities only



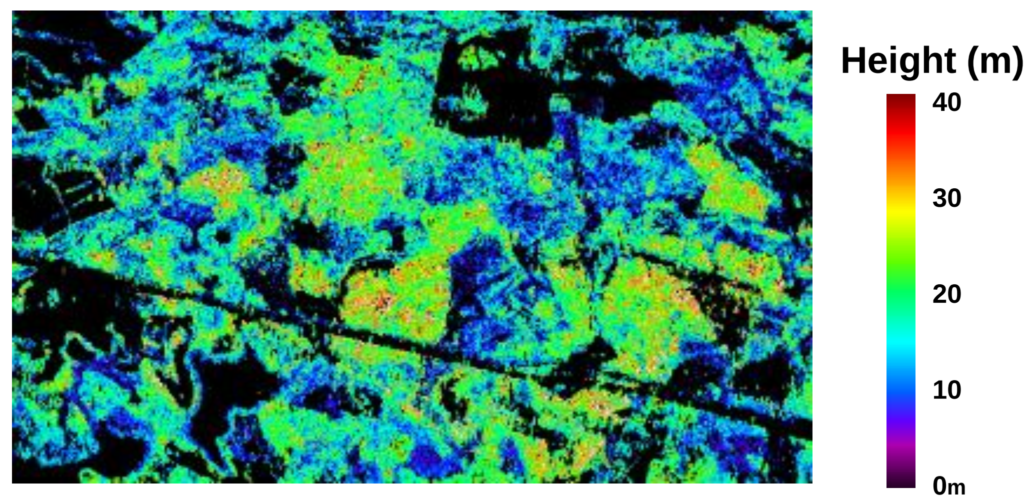
Intensity retrieval



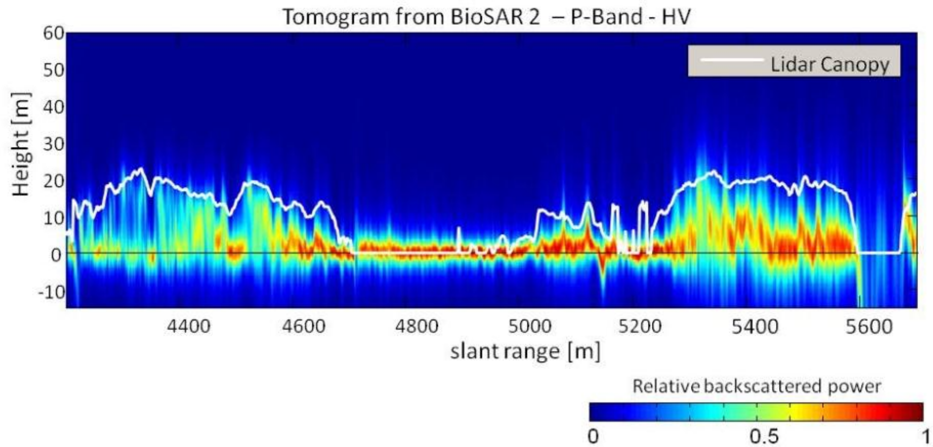
Intensity + height

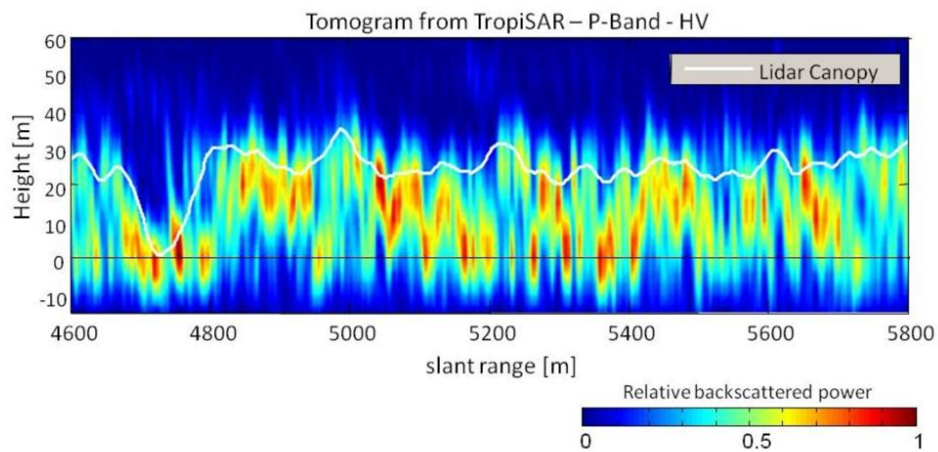


Height retrieval

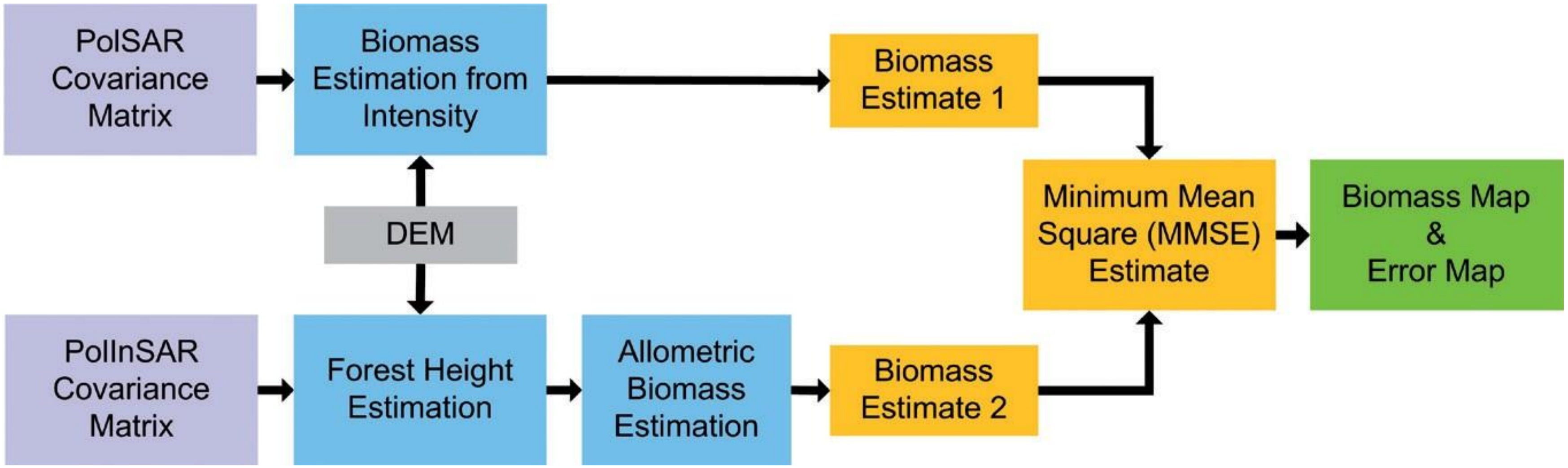


SAR Tomography

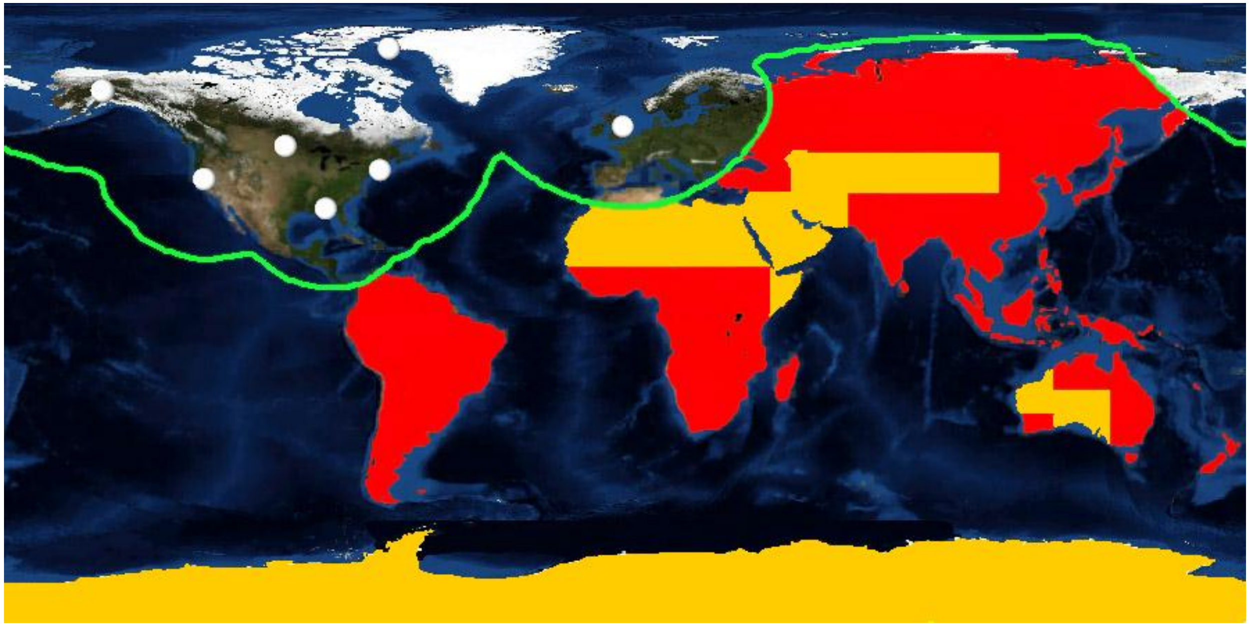




Biomass estimation from covariance and Pol-InSAR height measurements



Implications of US Space Object Tracking Radar Restrictions



Loss of coverage
• primary objectives (red)
• secondary (yellow)

Almost no effect on:

- tropical forests - the priority areas for biomass and REDD+
- China: the major temperate forest carbon sink
- the vast Siberian forests

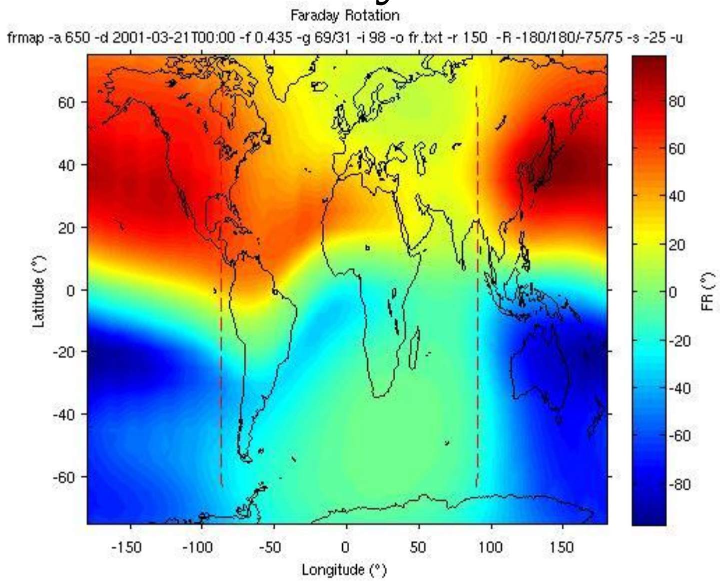
Loss of Northern polar regions (ice imaging).

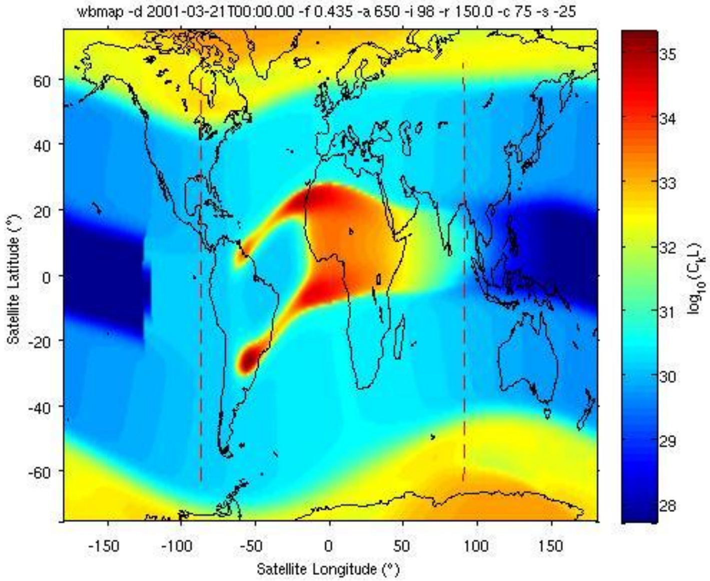
Summary

- BIOMASS is optimised to measure biomass from space by using the longest possible wavelength (P-band).
- A single P-band radar satellite can provide independent biomass and height estimates, giving access to the crucial tropical biomass estimates (climate and REDD+).
- By measuring biomass change at the scale and location at which disturbance occurs, BIOMASS will:
  - eliminate the biases that plague current estimates of the Land Use Change flux
  - provide estimates of the carbon sink in regrowth and afforestation
  - give unique data for testing and initialising land surface models and parameterising models of landscape carbon dynamics.

Uncorrected P-band Ionospheric Effects

Faraday Rotation **Principal effects** Scintillation





Predictions for 00:00 on UT 21/3/2001 (near solar maximum; sunspot number = 150) and geomagnetic index K_p =3. Midnight at image centre.

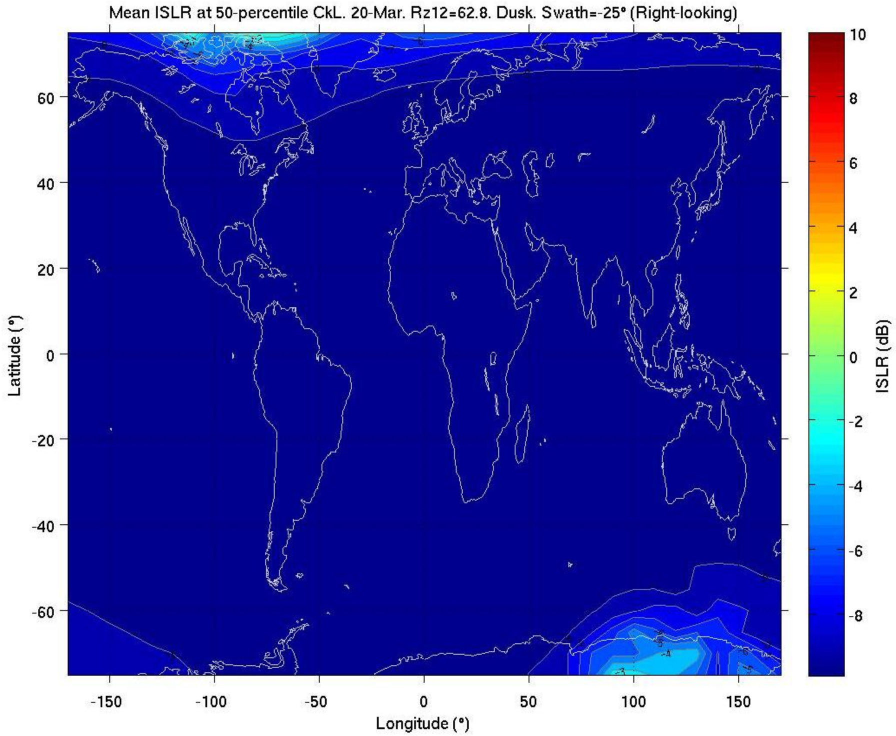
FR affects balance of polarisation channels

Scintillation measured by strength of turbulence, CkL:

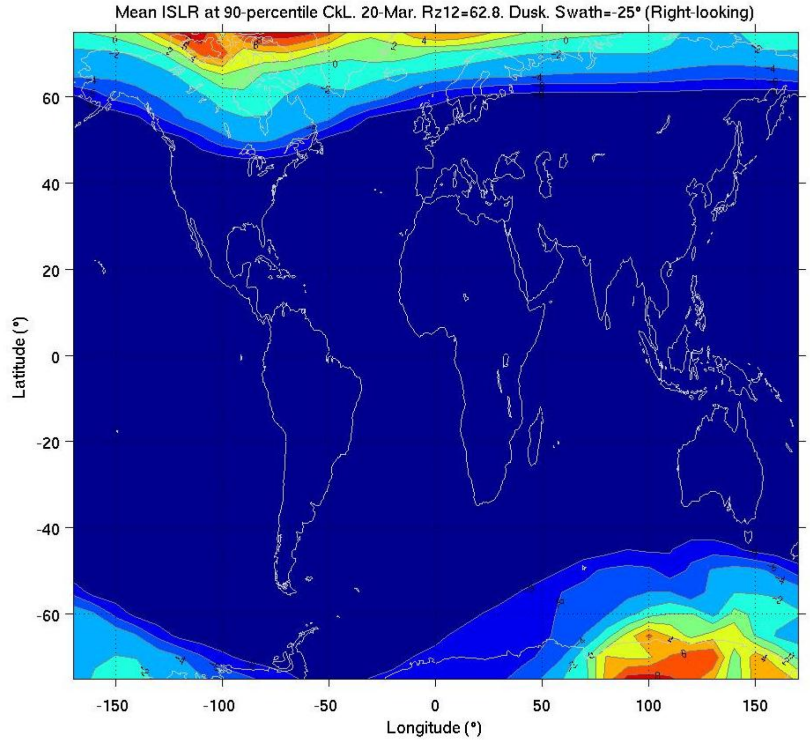
- corrupts impulse response function
- post-sunset equatorial hotspot
- endemic at high latitudes

Scintillation: ISLR Predictions along the BIOMASS Dawn-Dusk Orbit, Dusk Side

50% confidence



90% confidence



Calculations for March, median sunspots, right-looking SAR, dusk side (LTDN=1800) descending satellite.
Dawn side results are similar.
Scintillation effects are negligible except at the highest latitudes and then only in the N American sector under disturbed conditions.
As regards biomass estimation, only the (non-critical) northernmost boreal forest is affected, but ice applications need signal correction.

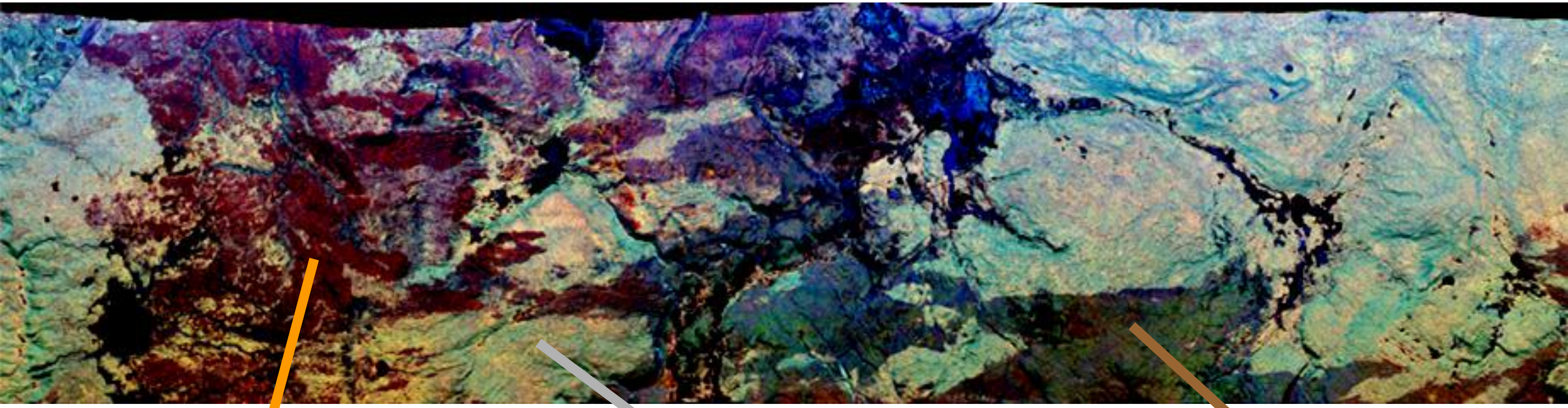
BIOMASS primary products

Forest biomass	200 m resolution accuracy of 20%, or 10 t/ha for biomass < 50 t/ha annual
Forest height	200 m resolution accuracy of 20% for forest height > 10 m annual
Deforestation detection	50 m resolution 90% classification accuracy annual

Global coverage subject to Space Object Tracking Radar restrictions.
Change products will be derived from the primary products.

Landscape carbon dynamics are written in biomass

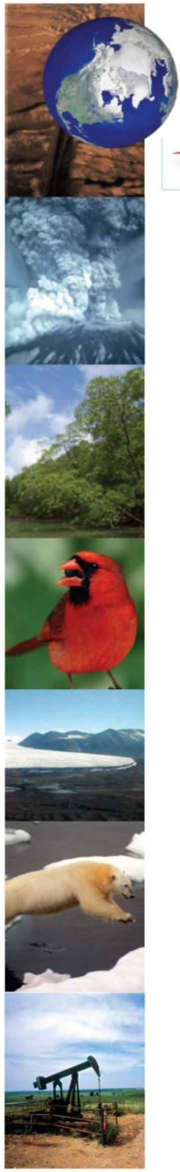
Polarimetric P-band SAR image of Yellowstone Park (2003)



A week after burn
P-HV = - 27 dB

60-80 years after burn
P-HV = - 12 dB

15 years after burn
P-HV = - 19 dB



Emissions from Deforestation
Harris & Saatchi et al. 2011

Intersecting Annual Deforestation Map by Forest Carbon Map
Calculating the emission from deforestation, degradation, excluding fate of the forest

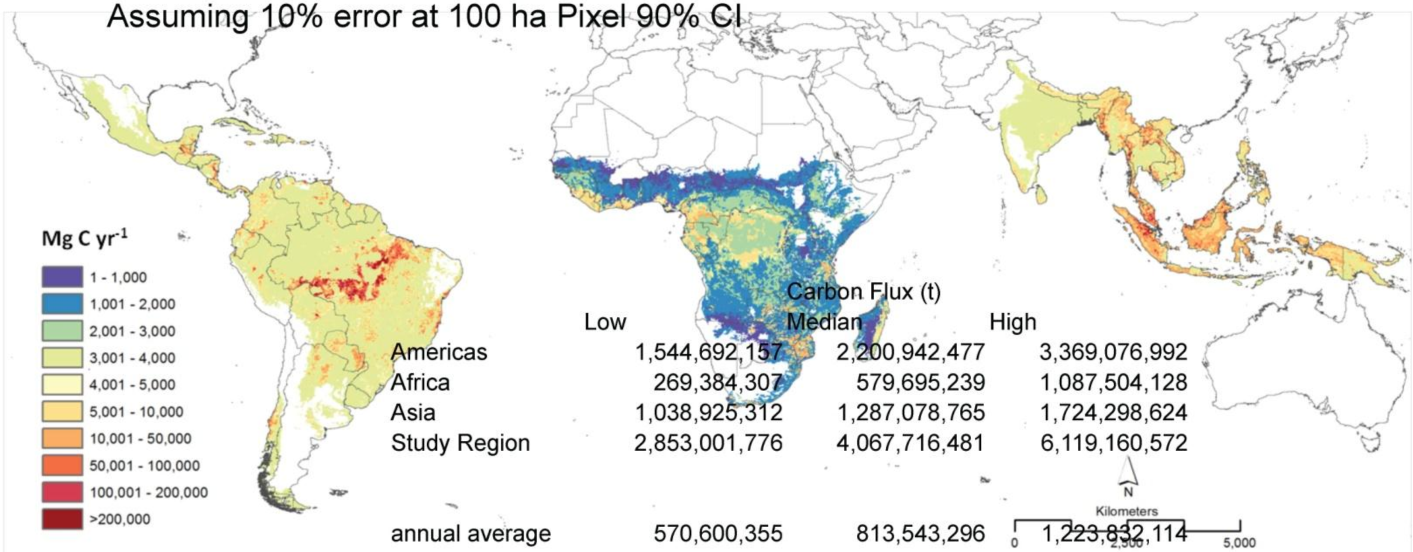
Current Uncertainty

All combined	+- 0.33 Pg C per year
Forest Loss	+- 0.20 Pg C per year
Biomass	+- 0.14 Pg C per year
AGtoBG	+- 0.03 Pg C per year

Post-BIOMASS Uncertainty

All combined	+- 0.12 Pg C per year
Forest Loss	+- 0.07 Pg C per year
Biomass	+- 0.06 Pg C per year
AGtoBG	+- 0.03 Pg C per year

Assuming 10% error at 100 ha Pixel 90% CI



	Carbon Flux (t) Low	Median	High
Americas	1,544,692,157	2,200,942,477	3,369,076,992
Africa	269,384,307	579,695,239	1,087,504,128
Asia	1,038,925,312	1,287,078,765	1,724,298,624
Study Region	2,853,001,776	4,067,716,481	6,119,160,572
annual average	570,600,355	813,543,296	1,223,832,114

Variability in Land Use Change flux estimates

IPCC 2007: Net Land Use Change emissions = **1.1 PgC yr^{-1} [0.3 – 2.8]**

Transcom: net tropical source = **1.1 ± 0.8 PgC y^{-1}**

In situ data, net tropical source = **1.3 ± 0.7 PgC yr^{-1}**

- Gross emissions = 2.9 ± 0.5 PgC yr^{-1}
- Regrowth = 1.6 ± 0.5 PgC yr^{-1} (Pan et al., 2011)

Two recent studies based on **Icesat lidar height measurements**:

- Gross emissions = **1.1 PgC yr^{-1}** (Baccini et al. 2012)
- Gross emissions = **0.8 PgC yr^{-1}** (0.6 to 1.2, 90% CI) (Harris et al, 2012)

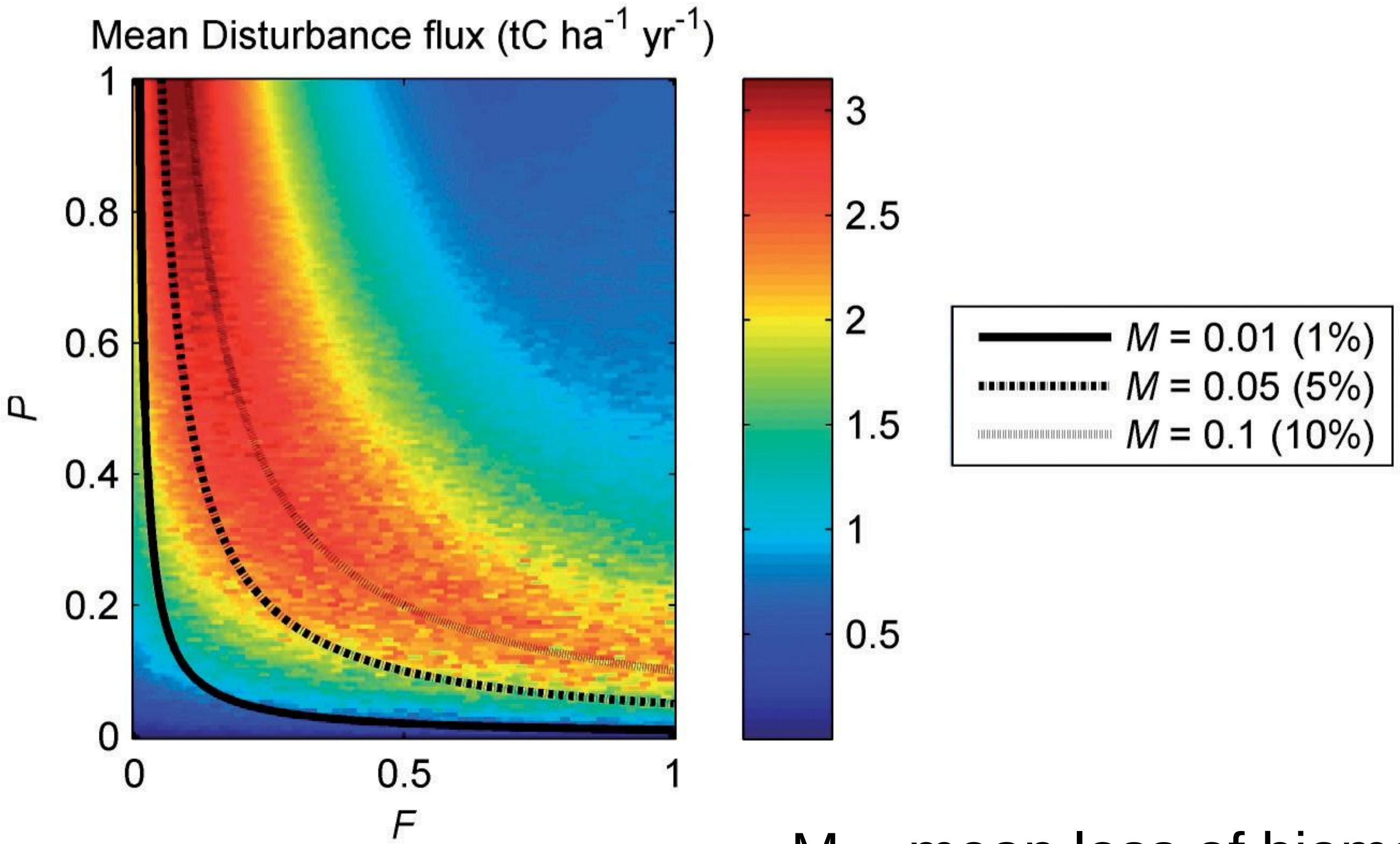
Estimated **degradation** flux = 5% to 130% of the deforestation flux.

Land to atmosphere carbon fluxes from atmospheric inversion (PgC yr^{-1})

Negative values (yellow) indicate land uptake of carbon: **carbon sinks.**

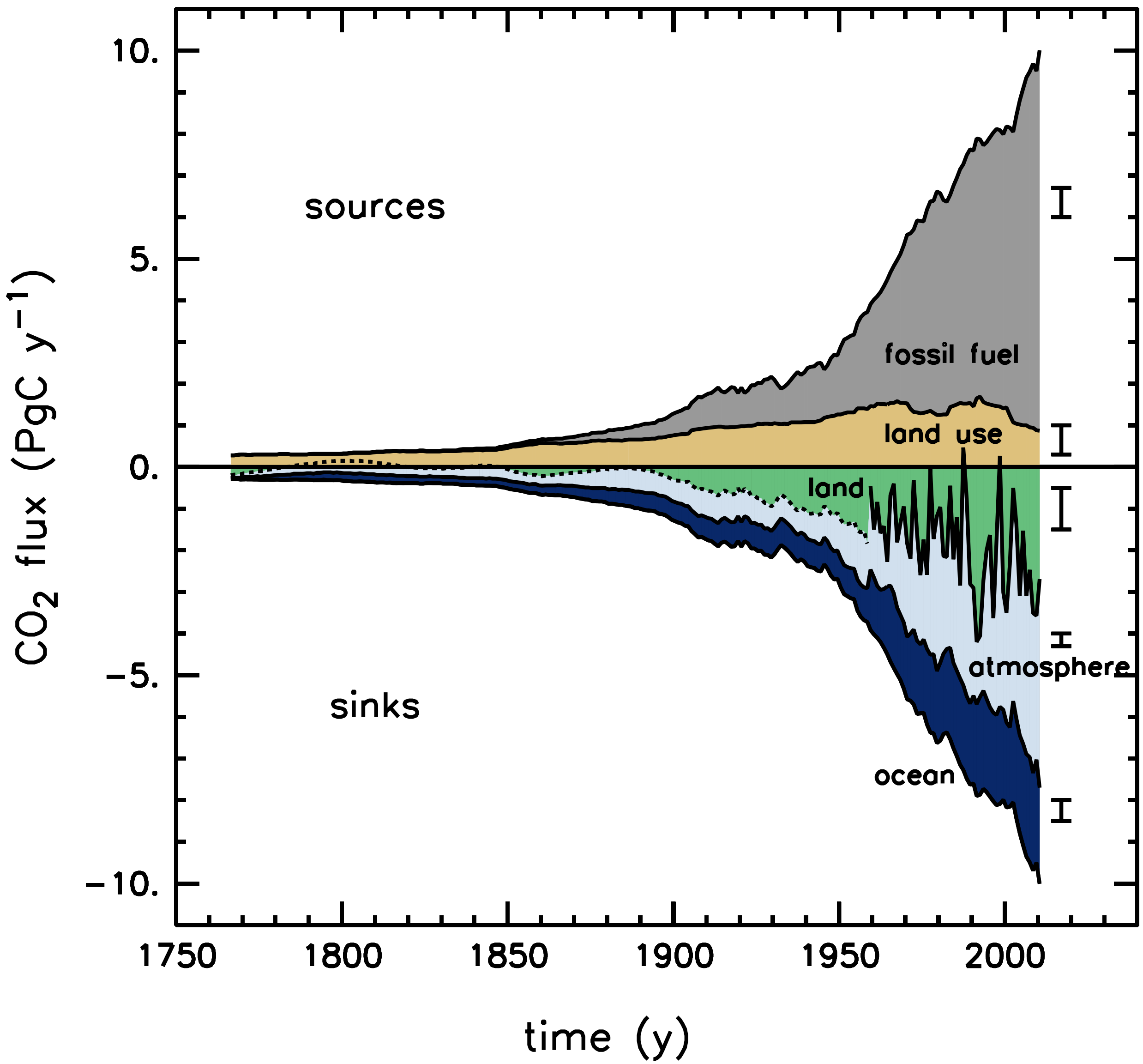
	Rödenbeck et al., 2003	Jacobson et al., 2007	Stephens et al., 2007	Transcom 1996 - 2008
S. Hemi (<20^{o}S)	0.0 ± 0.2	-2.4 ± 2.0	0.1 ± 1.1	-0.3 ± 0.4
Tropics (20^{o}S to 20^{o}N)	-1.0 ± 0.4	4.2 ± 2.7	0.7 ± 1.4	1.1 ± 0.8
N. Hemi (>20^{o}N)	-0.7 ± 1.0	-2.9 ± 1.0	-2.2 ± 0.6	-2.0 ± 0.5

Carbon flux depends on the disturbance regime



M = mean loss of biomass
F = severity of disturbance
P = probability of disturbance

Human Perturbation of the Global Carbon Budget



2000-2010

(PgC y^{-1})

7.9±0.5

1.0±0.7

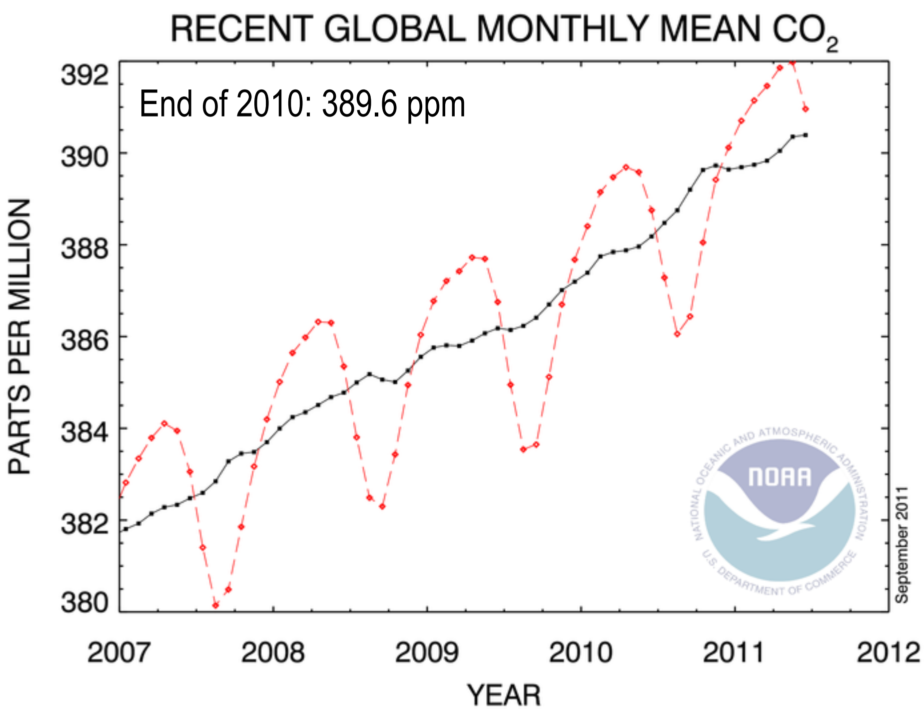
2.5±1.0
(Residual)

4.1±0.2

2.3±0.5
(5 models)

Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

Atmospheric CO_2 Concentration



Annual Growth Rates (decadal means)

1970 – 1979: 1.3 ppm y^{-1}

1980 – 1989: 1.6 ppm y^{1}

1990 – 1999: 1.5 ppm y^{-1}

2000 – 2010: 1.9 ppm y^{-1}

Annual Mea	Growth Rate (ppm y^{-1})
2010	2.36
2009	1.63
2008	1.81
2007	2.11
2006	1.83
2005	2.39
2004	1.58
2003	2.20
2002	2.40
2001	1.89
2000	1.22

Global Carbon Project

Data Source: Thomas Conway, 2011, NOAA/ESRL + Scripts Institution

Earth System Science Partnership DIVERSITAS GLOBAL IGBP CHANGE IHDP WCRP World Climate Research Programme

Fate of Anthropogenic CO_2 Emissions (2010)

9.1 ± 0.5 PgC y^{-1}

+

0.9 ± 0.7 PgC y^{-1}

5.0 ± 0.2 PgC y^{-1}

50%

2.6 ± 1.0 PgC y^{-1}

26%

Calculated as the residual of all other flux components

24%

2.4 ± 0.5 PgC y^{-1}

Average of 5 models

Global Carbon Project 2010; Updated from Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS

Carbon uptake by forests

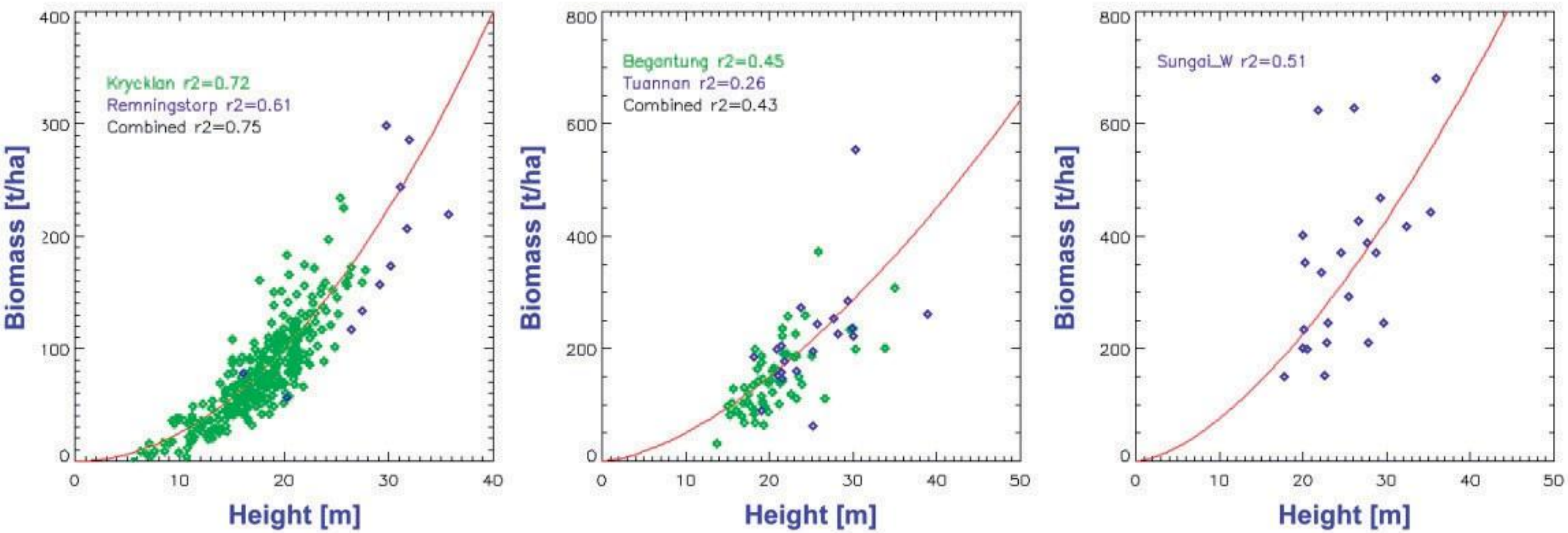
Biomass increment (PgC yr^{-1})	1990-1999	2000-2007
Boreal	0.12	0.12
Temperate	0.35	0.45
Tropical intact	1.17	0.87
Tropical regrowth	1.36	1.50
All tropics	2.53	2.37

Tropical forest height estimates from Icesat-GLAS lidar

Height maps produced from GLAS (sampled data, interpolated) for tropical broadleaf:

- Lefsky (2010), resolution based on MODIS image segments: 10-30 m, peak at **25 m**.
- Los et al. (2012), $0.5^{o} \times 0.5^{o}$ resolution (50 km at the equator):   30-60 m, peak at **40 m**.
- Simard et al. (2011), 1 km resolution: mean height = **37 m**.

Height-biomass allometry



Temperate & boreal : $B = 1.66 \times l_a \times H^{1.6}$

Tropical: $B = 0.07 \times H^{2.4}$

Primary science objectives

Objective	Product
Greatly improve current estimates of **forest carbon stocks**	Consistent global maps of **forest biomass and height** at scale of 4 ha
Reduce uncertainty in **tropical Deforestation and Forest Degradation emissions** to a level comparable to uncertainty in net ocean flux	Annual maps of **reductions in biomass** globally
Improve estimates of **terrestrial carbon sinks** from regrowth and reforestation	Map of **increases in biomass** globally during mission lifetime

Research objectives

- Reducing the major uncertainty in tropical Land Use Change and forest degradation carbon flux
- Providing support for UNFCCC and REDD+
- Inferring landscape carbon dynamics and prediction
- Initialising and testing the land component of Earth System models
- Providing key information on forest resources and ecosystem services, including biodiversity
- Sub-surface geology
- DTMs under dense vegetation
- Glacier and ice sheet velocities