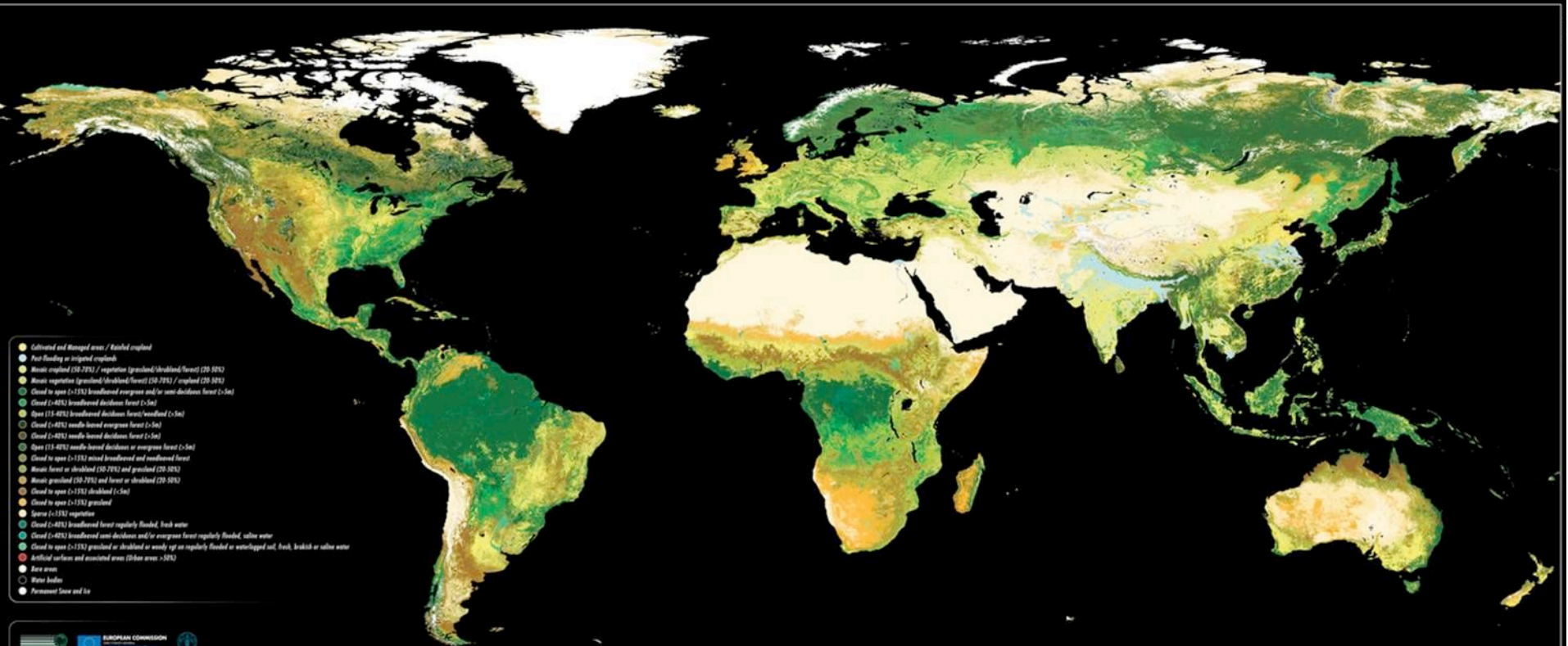









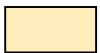









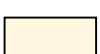


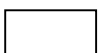


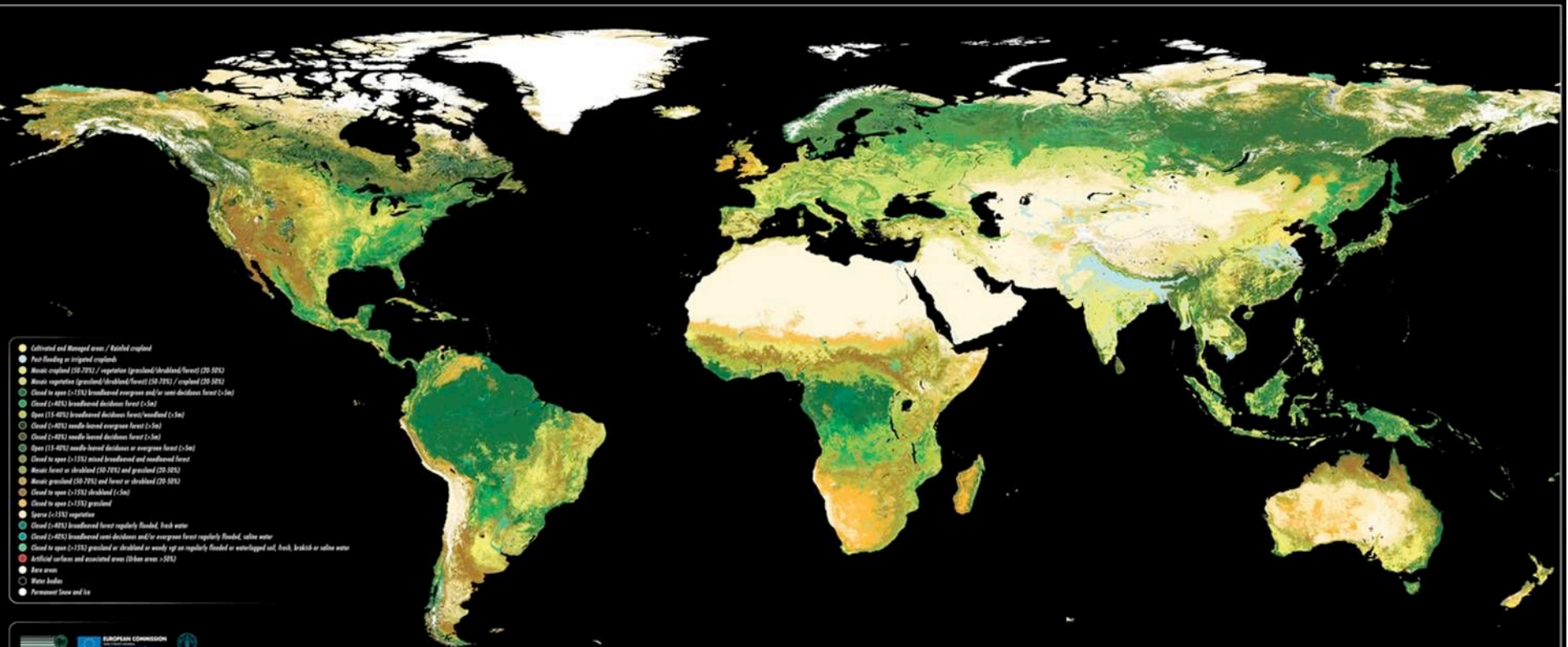
# Carbon cycle missions: present capabilities and future promises

EO data that **should** really improve C cycle calculations

# Land Cover



	Cultivated and Managed areas		Mosaic forest or shrubland (50-70%) and grassland (20-50%)
	Post-flooding or irrigated croplands		Mosaic grassland (50-70%) and forest or shrubland (20-50%)
	Mosaic cropland (50-70%) / vegetation (grassland/shrubland/forest) (20-50%)		Closed to open (>15%) shrubland (<5m)
	Mosaic vegetation (grassland/shrubland/forest) (50-70%) / cropland (20-50%)		Closed to open (>15%) grassland
	Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)		Sparse (<15%) vegetation
	Closed (>40%) broadleaved deciduous forest (>5m)		Closed (>40%) broadleaved forest regularly flooded, fresh water
	Open (15-40%) broadleaved deciduous forest/woodland (>5m)		Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded, saline water
	Closed (>40%) needle-leaved evergreen forest (>5m)		Closed to open (>15%) grassland or shrubland or woody vgt on regularly flooded or waterlogged soil, fresh, brackish or saline water
	Closed (>40%) needle-leaved deciduous forest (>5m)		Artificial surfaces and associated areas (Urban areas >50%)
	Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)		Bare Areas
	Closed to open (>15%) mixed broadleaved and needleleaved forest		Water Bodies
			Permanent Snow and Ice



- Cultivated and managed areas / Harvested cropland
- Pastureland or irrigated cropland
- Moist cropland (10-70%) / vegetation (grassland/shrubland/forest) (20-50%)
- Moist vegetation (grassland/shrubland/forest) (20-70%) / cropland (20-50%)
- Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)
- Closed (>40%) broadleaved deciduous forest (>5m)
- Open (15-40%) broadleaved deciduous forest/woodland (>5m)
- Closed (>40%) needle-leaved evergreen forest (>5m)
- Closed (>40%) needle-leaved deciduous forest (>5m)
- Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)
- Closed to open (>15%) mixed broadleaved and needle-leaved forest
- Moist forest or shrubland (20-70%) and grassland (20-50%)
- Moist grassland (20-70%) and forest or shrubland (20-50%)
- Closed to open (>15%) shrubland (>5m)
- Closed to open (>15%) grassland
- Sparse (<15%) vegetation
- Closed (>40%) broadleaved forest regularly flooded, brackish water
- Closed (>40%) broadleaved semi-deciduous and/or evergreen forest regularly flooded, saline water
- Closed to open (>15%) grassland or shrubland or woody wet or regularly flooded or waterlogged soil, brackish or saline water
- Artificial surfaces and associated areas (Urban areas >50%)
- Bare areas
- Water bodies
- Permanent Snow and Ice



European Space Agency  
Agence spatiale européenne

**Land Cover 300m April 2005/May 2006** [ENVISAT Meris]

Living Planet

# **Land Cover Change: Reduced Emissions from Deforestation and Forest Degradation (REDD)**

## **The JAXA ALOS-PALSAR L-Band radar sensor**

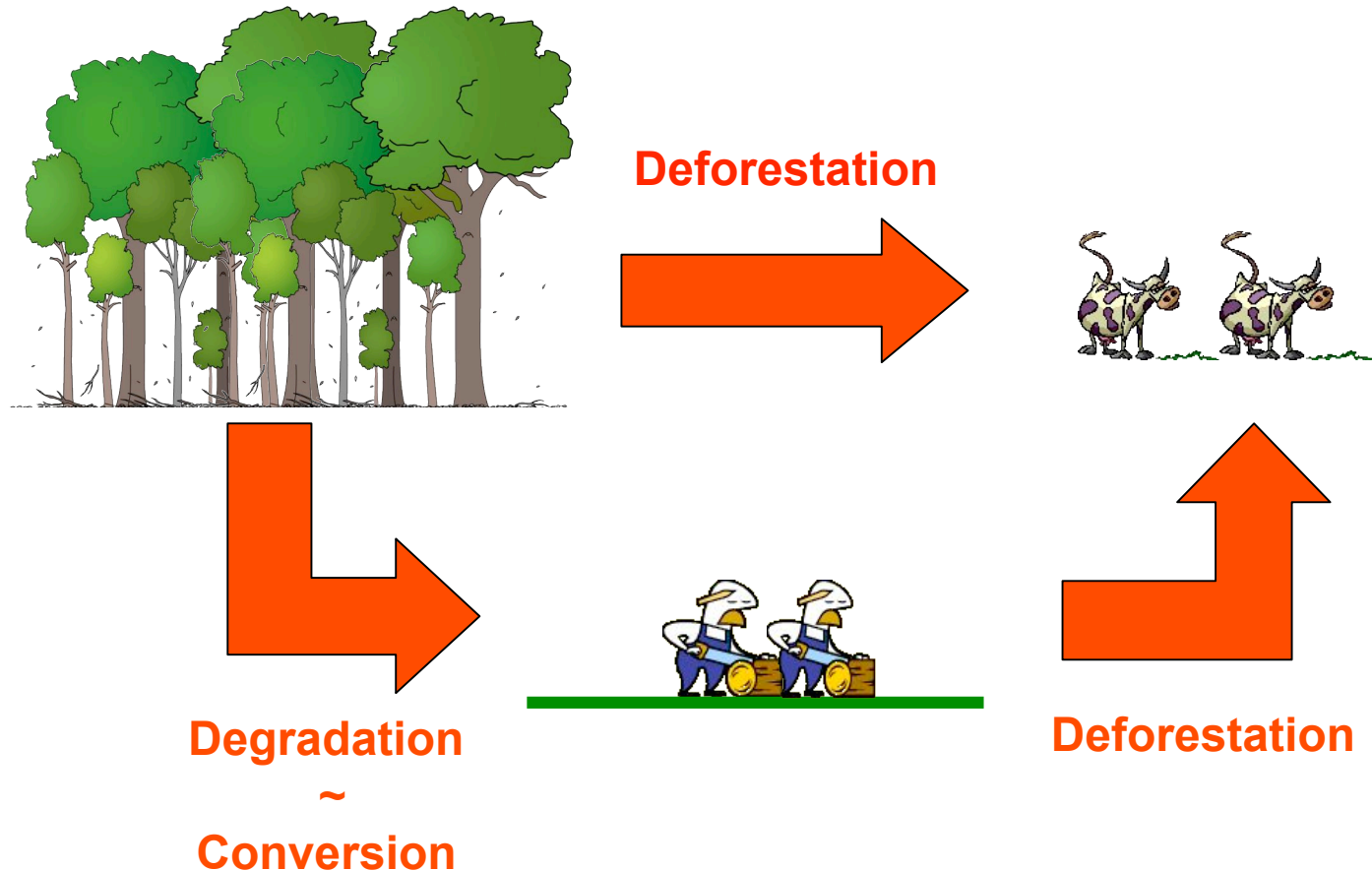
## Range of estimates in mean annual emissions due to deforestation (GtC/y)

### Remote sensing estimates

		Houghton 2003	De Fries et al. 2002	Achard et al. 2002
<b>1980s</b>	<b>Land use change</b>	<b>2.0 (0.9 to 2.8)</b>	<b>0.6 (0.3 to 0.8)</b>	
	<b>Residual land sink</b>	<b>-2.3 (-4.0 to -0.3)</b>	<b>-0.9 (-3.0 to 0.0)</b>	
<b>1990s</b>	<b>Land use change</b>	<b>2.2 (1.4 to 3.0)</b>	<b>0.9 (-.5 to 1.4)</b>	<b>1.0 ± 0.2</b>
	<b>Residual land sink</b>	<b>-3.4 (-5.0 to -1.8)</b>	<b>-2.1 (-3.4 to -0.9)</b>	<b>-2.2 (-3.2 to -1.2)</b>

# REDD expected process definition

To account for **gross carbon emission reductions** and non-CO2 emission reductions only in **existing forest areas on a national basis**.



*( no overlap with other UNFCCC activities afforestation, reforestation, plantation for bio-energy CDM)*

# Gross carbon emissions (concept)

Gross carbon  
emissions

Gross deforestation

Gross degradation

$A_{loss}$  = Area of deforestation (ha)

$C_{loss}$  = Carbon emission from deforestation (t/ha)

} for forest types  $i \dots m$

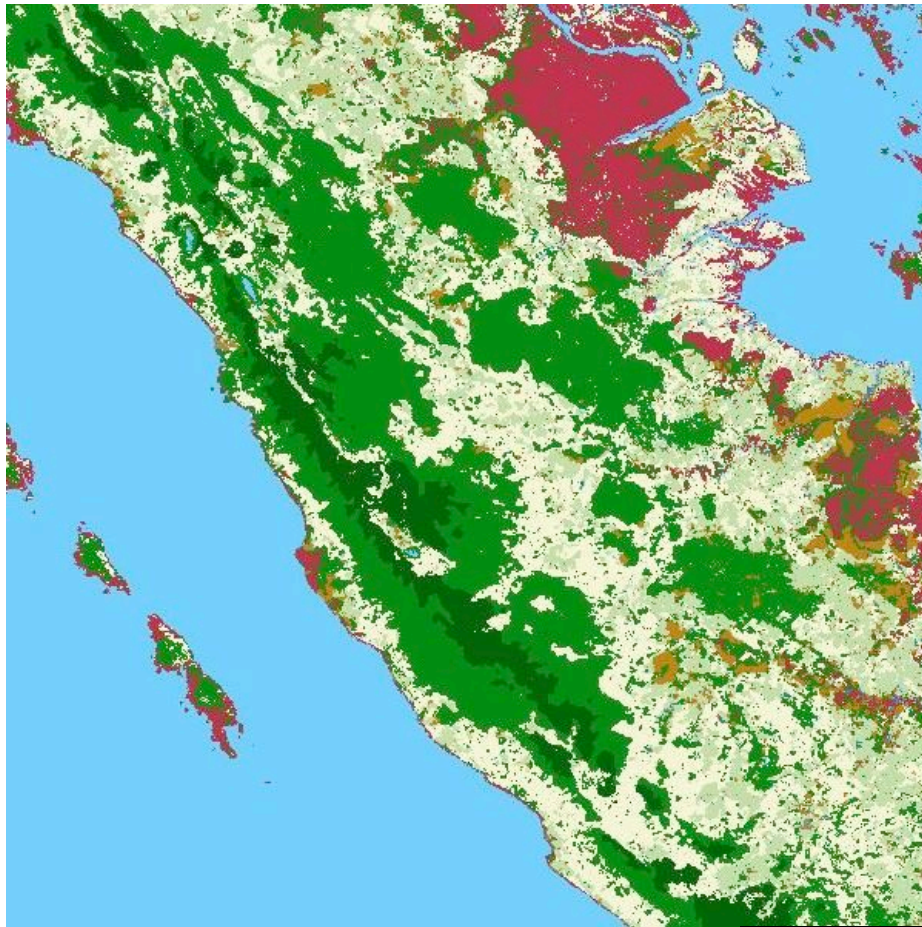
$A_{dgr}$  = Area affected by degradation (ha)

$C_{dgr}$  = Carbon emission from degradation (t/ha)

} for degrad. types  $j \dots n$

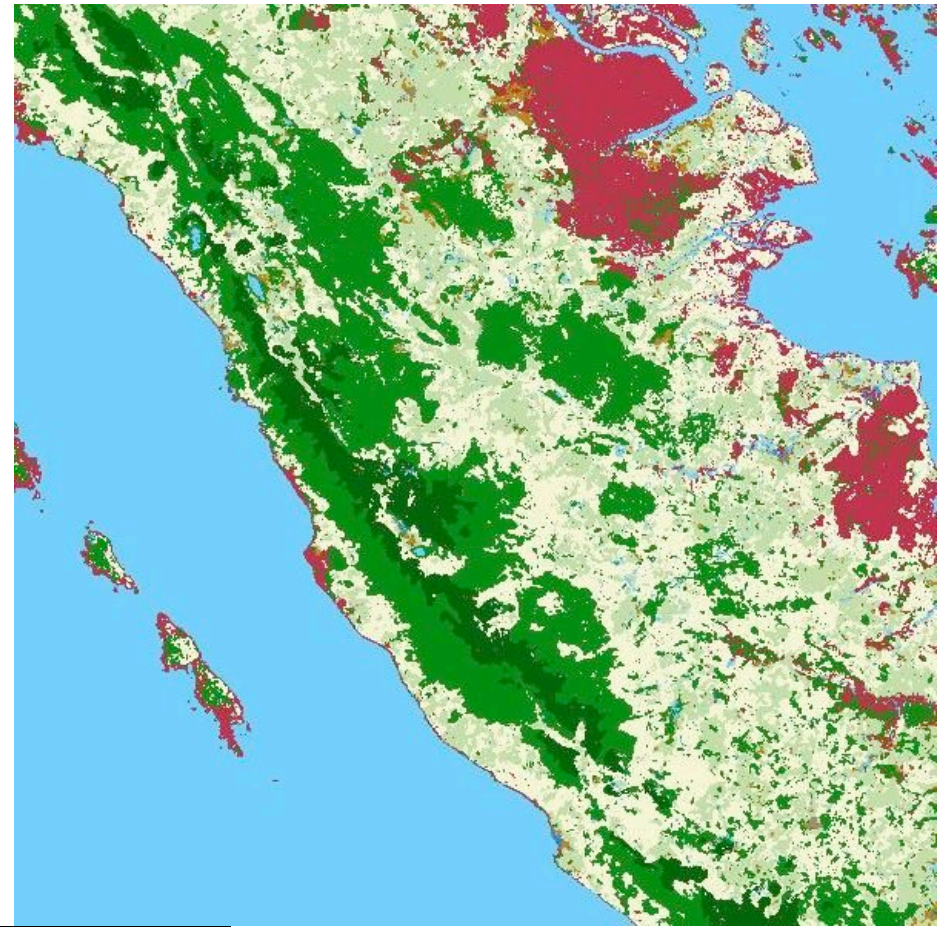
Area change is most dynamic: needs to be observed from  
satellite

# Deforestation in Sumatra



March 1999

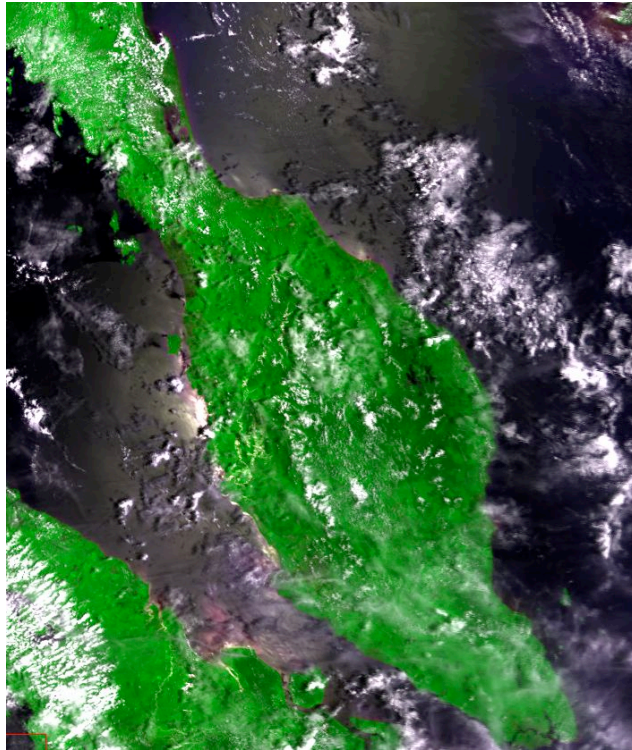
Courtesy of Dirk Hoekman  
SARVision



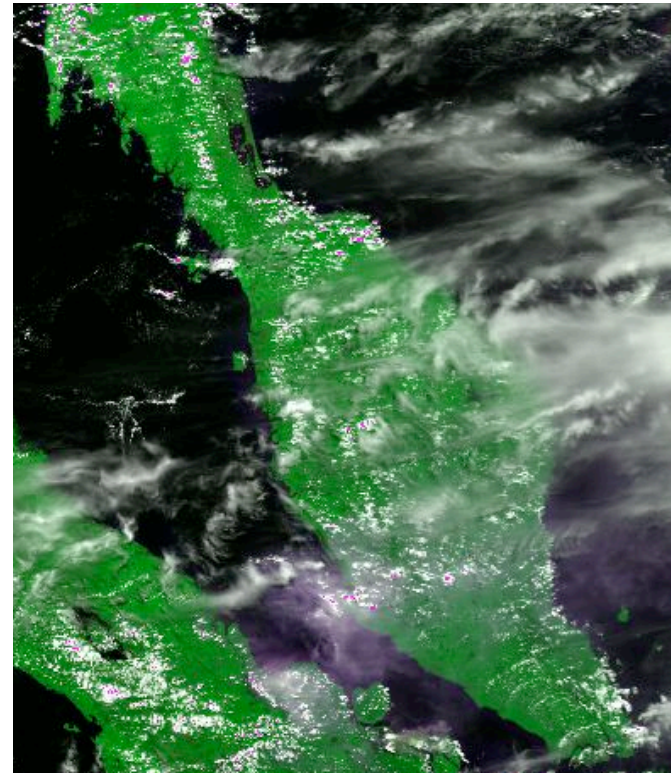
September 2002

WATER
PERM. BARE
BARE / BURNT
YOUNG VEG. / ALANG-ALANG
NON-FOREST VEG.
INUNDATED LAND / SAWAH
MANGROVE / SWAMP <50m
FOREST
MONTANE FOREST

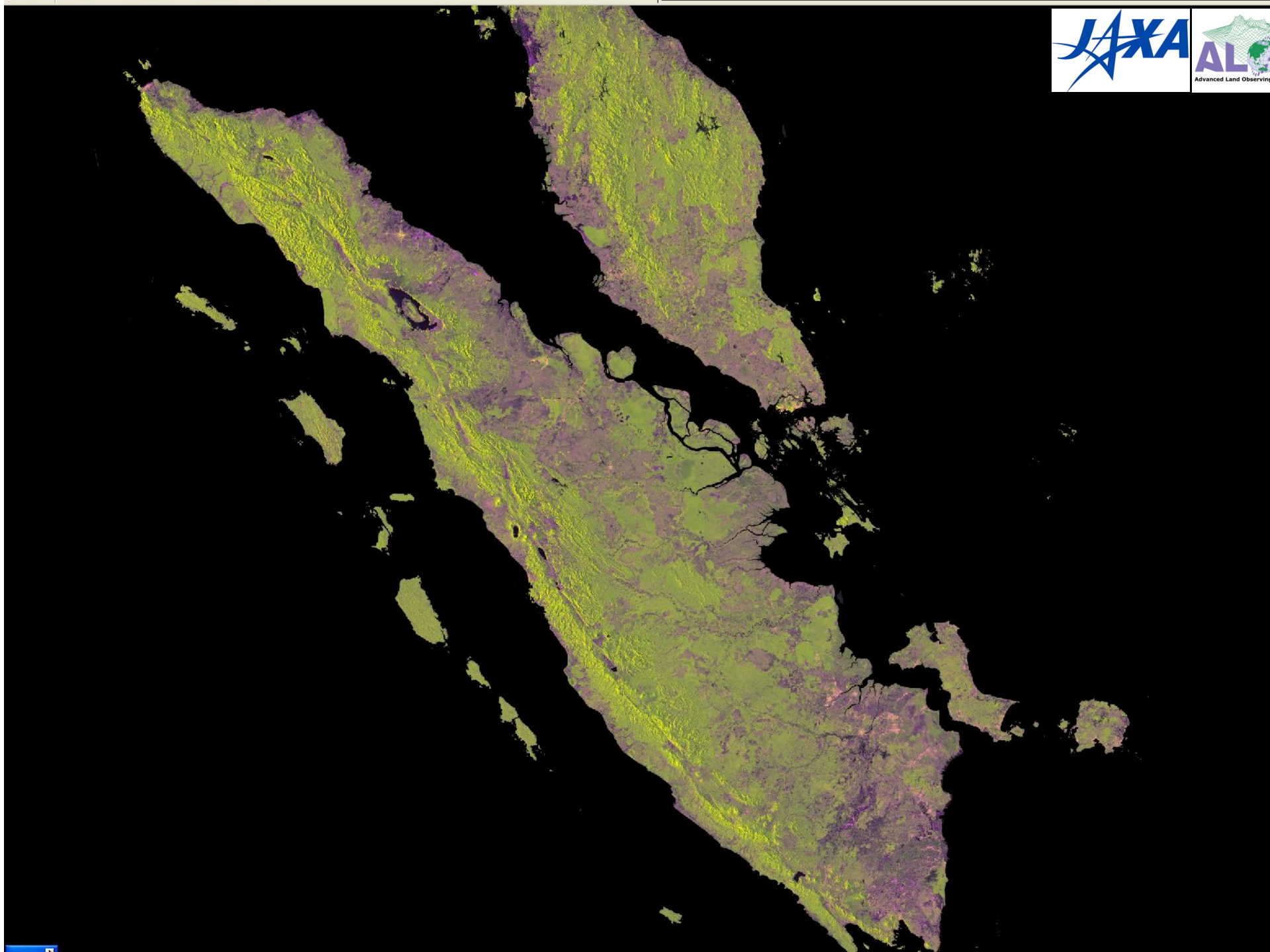
## Malaysia in Haze-free and Hazy Conditions from MODIS Data



Haze-free image from 19  
March 2004 during North-East  
Monsoon  
(November – March)

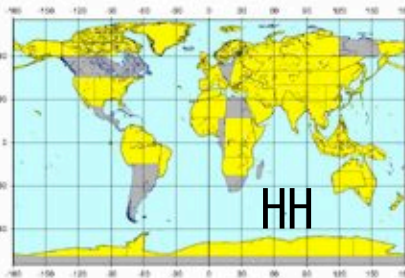


Hazy image from 10 August  
2005 during South-West  
Monsoon  
(July – September)

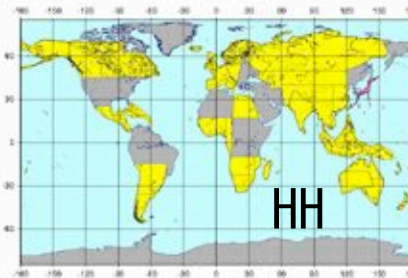


# Building a global archive for forest monitoring: PALSAR Observation results

63%  
(65,900 scenes)

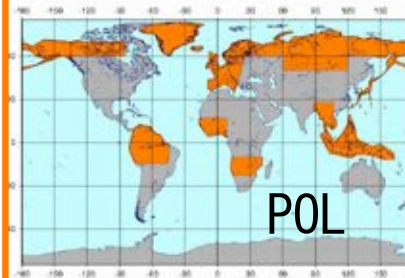


CYCLE\_08 / 05-Dec.-2006

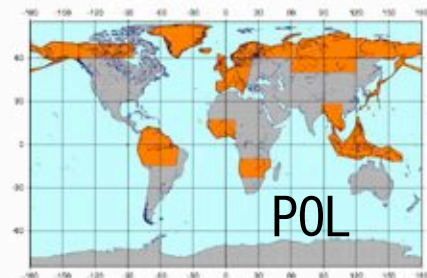


CYCLE\_09 / 20-Jan.-2007

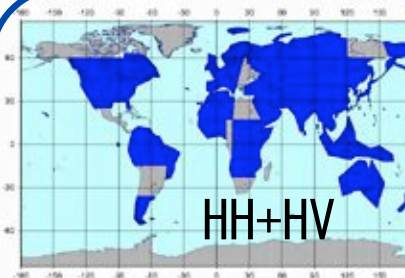
65%  
(42,900 scenes)



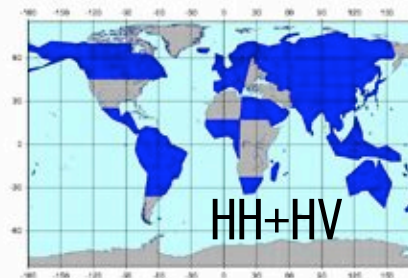
CYCLE\_10 / 07-Mar.-2007



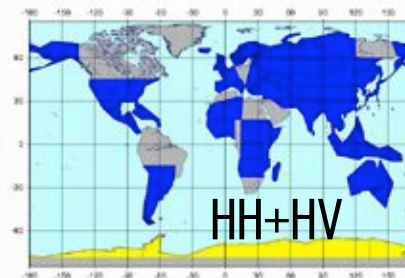
CYCLE\_11 / 22-Apr.-2007



CYCLE\_12 / 07-Jun.-2007

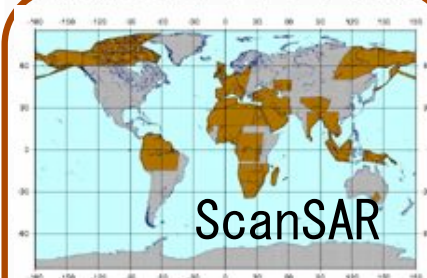


CYCLE\_13 / 23-Jul.-2007



CYCLE\_14 / 07-Sep.-2007

80%  
(125,900 scenes)

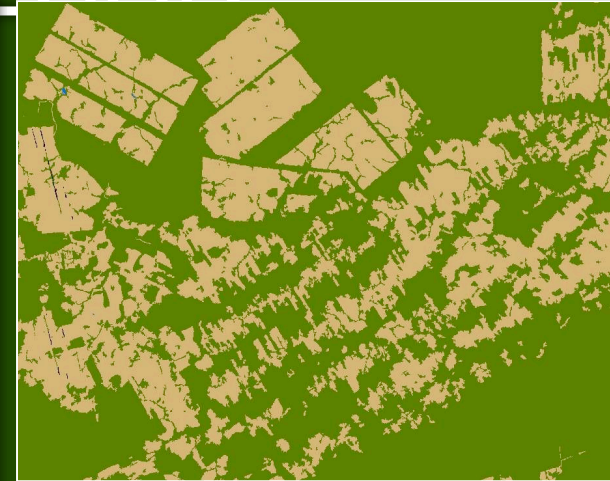
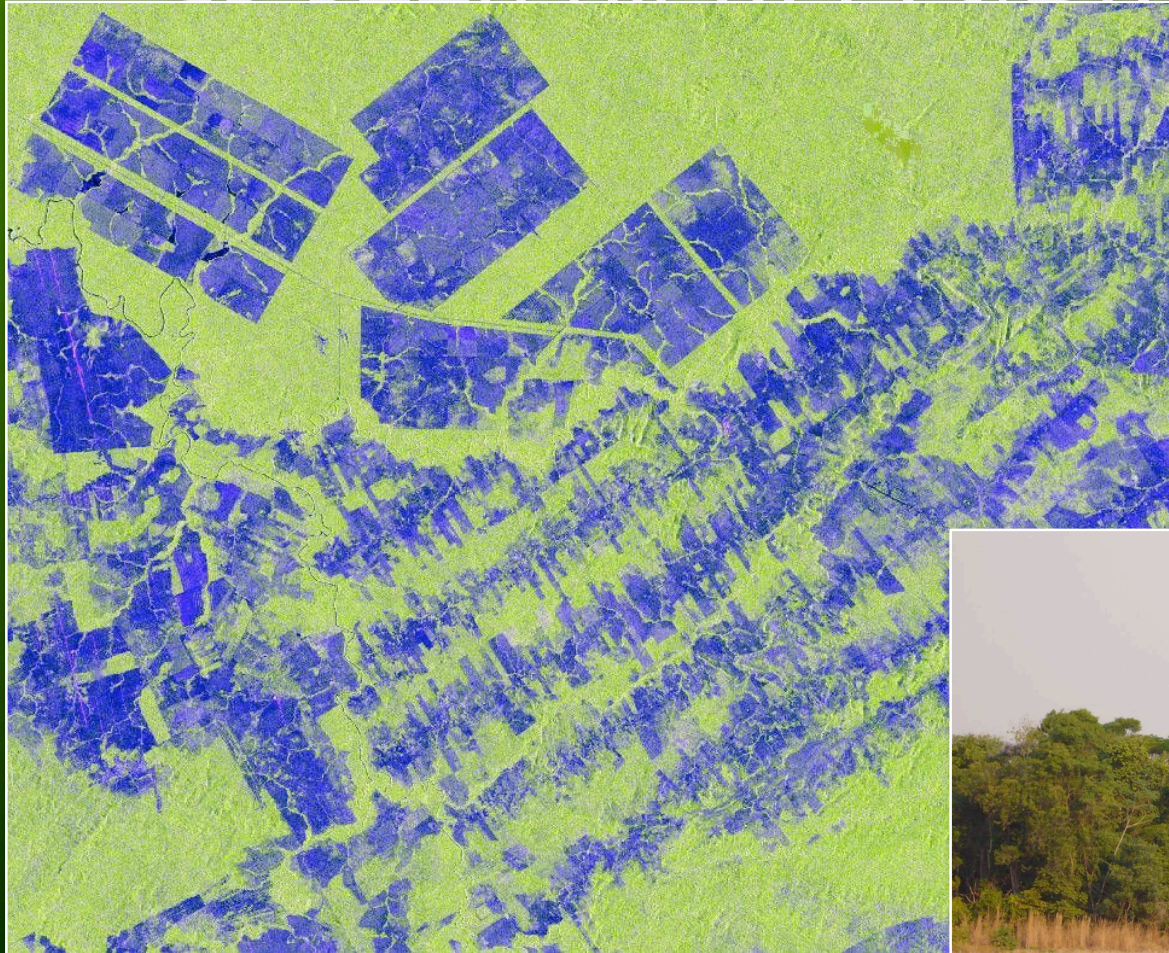


CYCLE\_08 / CYCLE\_14

55%  
(16,700 scenes)

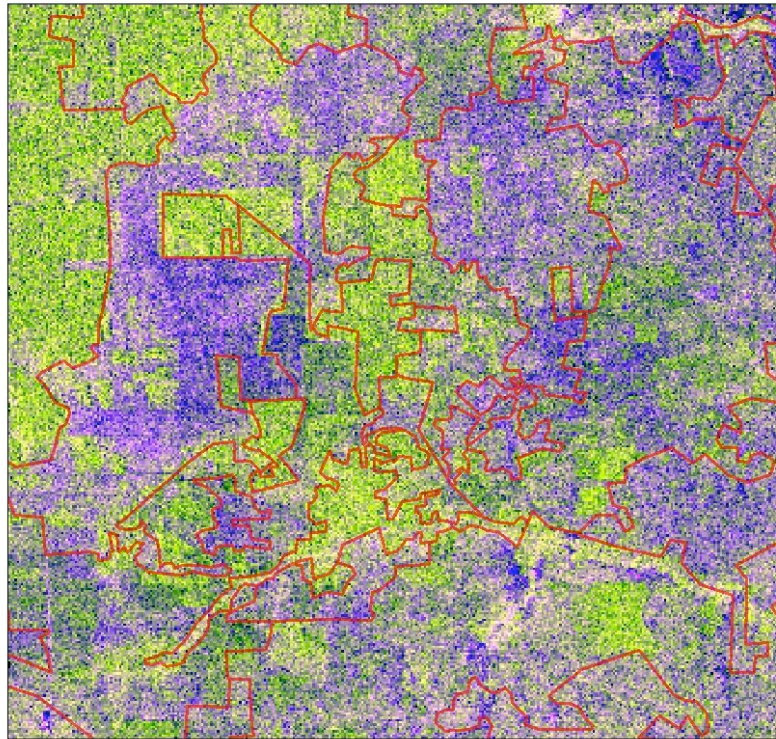
# Small-Holder meets Large-Holder

as seen by ALOS/PALSAR

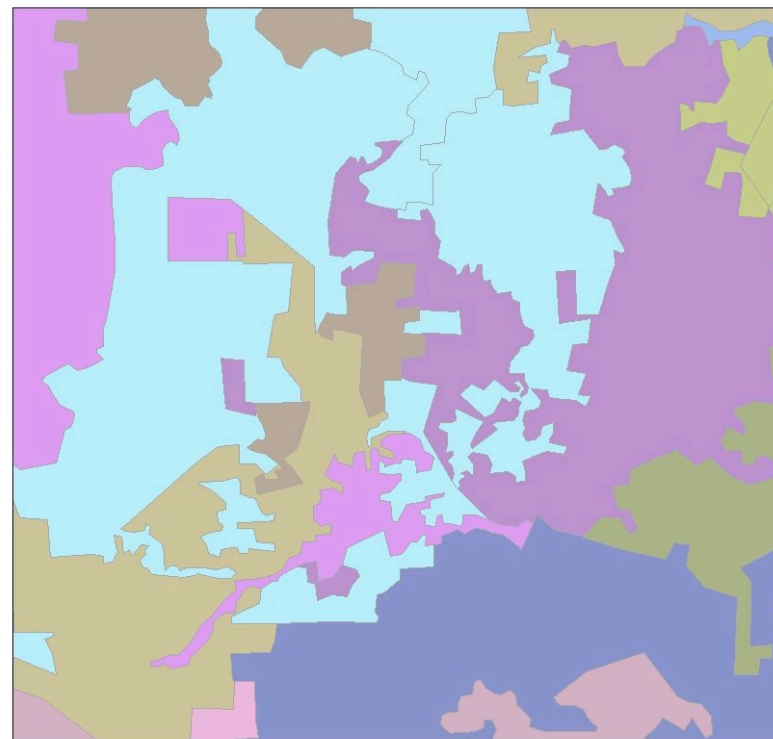


Josef Kelldorfer et al, Woods  
Hole Research Center, 2008

# Comparison between PALSAR data and land cover map, Riau province, Sumatra



Section of PALSAR data; R = HH, G = HV, B = HH-HV

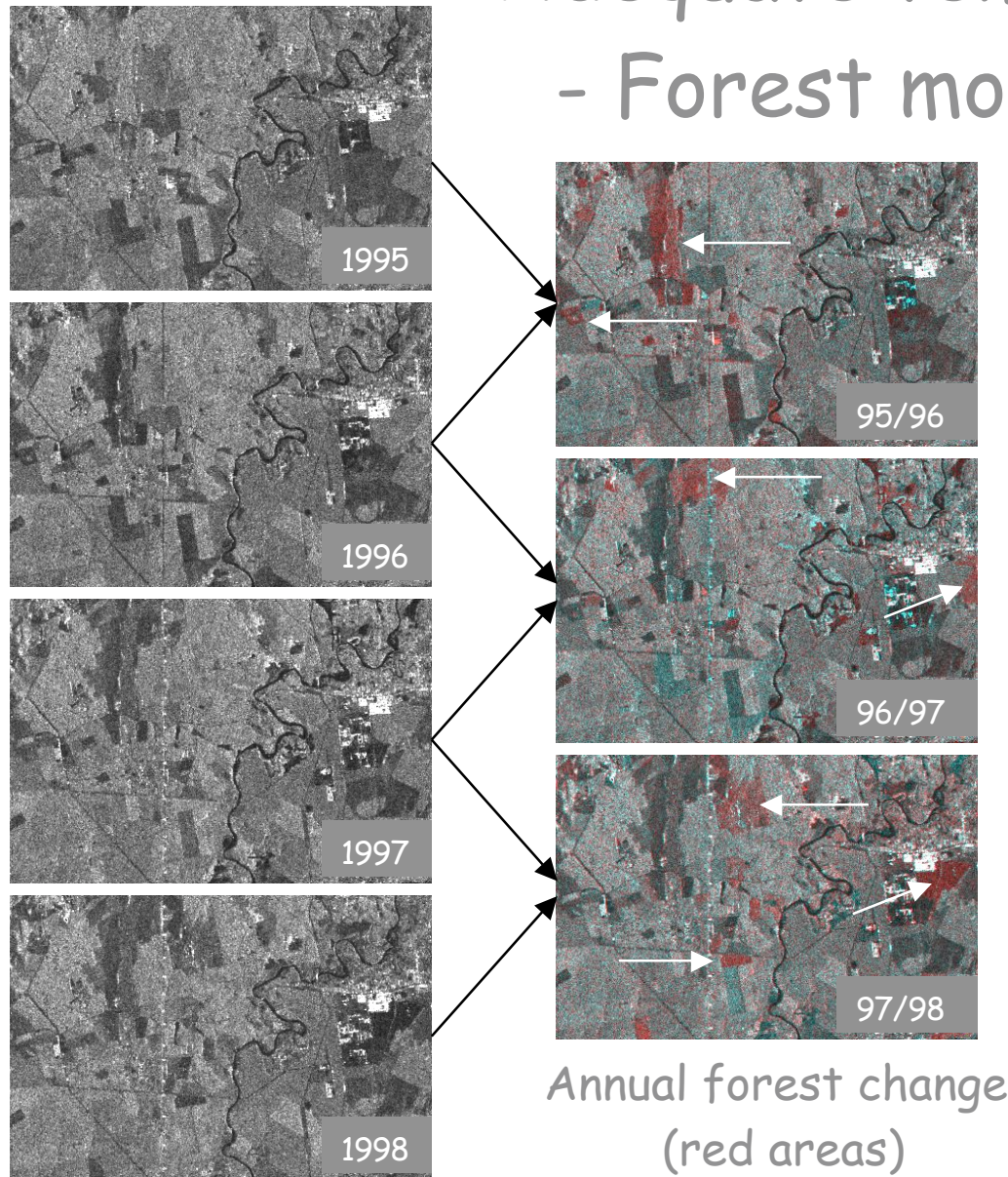


Section of land cover map, courtesy of WWF Indonesia

## LAND COVER

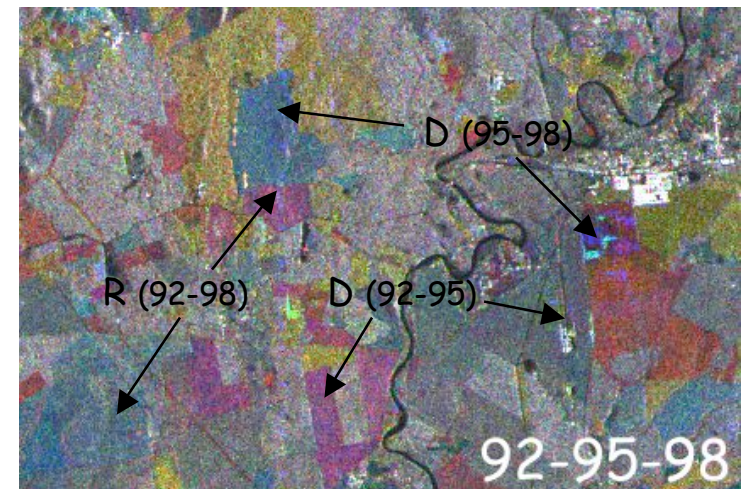
- Accacia Plantation
- Burnt
- Cleared
- Cleared post Accacia harvested
- Cleared, for Oil Palm Plantation
- Cloud
- Dry Lowland Forest medium open canopy
- Dry Lowland Forest very open canopy
- Forest Re-growth (Belukar)
- Forest Re-growth on Swampy
- Grassland
- Mill-Oil
- Mixed Agriculture
- Mixed Garden
- Mosaic of Small Holder Oilpalm and Rubber
- Oil Palm Plantation
- Overgrowing Clear cut-Shrubs
- Peat Swamp Forest medium open canopy
- Peat Swamp Forest rather closed canopy
- Peat Swamp Forest very open canopy
- Rubber Plantation
- Settlement
- Shrubs (Semak/Belukar Muda)
- Shrubs on Swampy
- Small Holder Oil Palm
- Small Holder Rubber
- Small Holder Young Oil Palm Plantation
- Swamp Forest medium open canopy
- Swamp Forest rather closed canopy
- Swamp Forest very open canopy
- Swamp Grasses/Fermland
- Town
- Water Body
- Young Accacia Plantation
- Young Oil Palm Plantation

# Adequate temporal repetition - Forest monitoring ~ annual



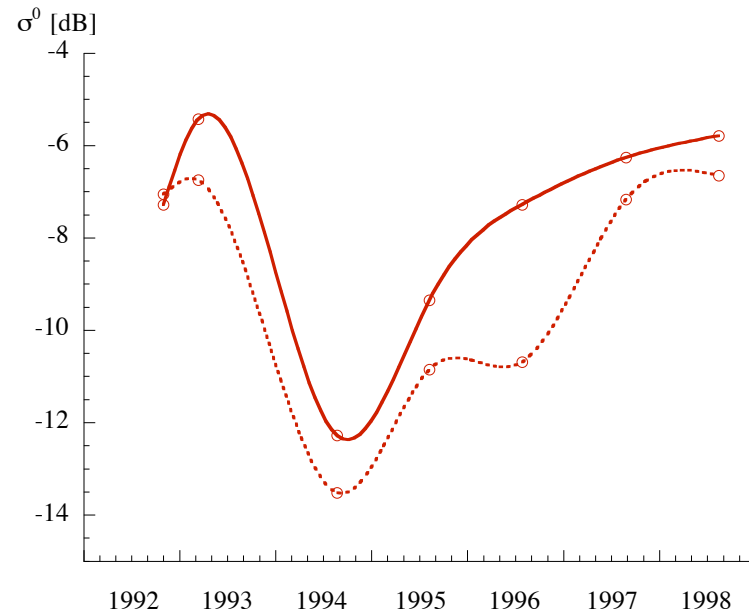
SAR time sequence

Annual forest change  
(red areas)

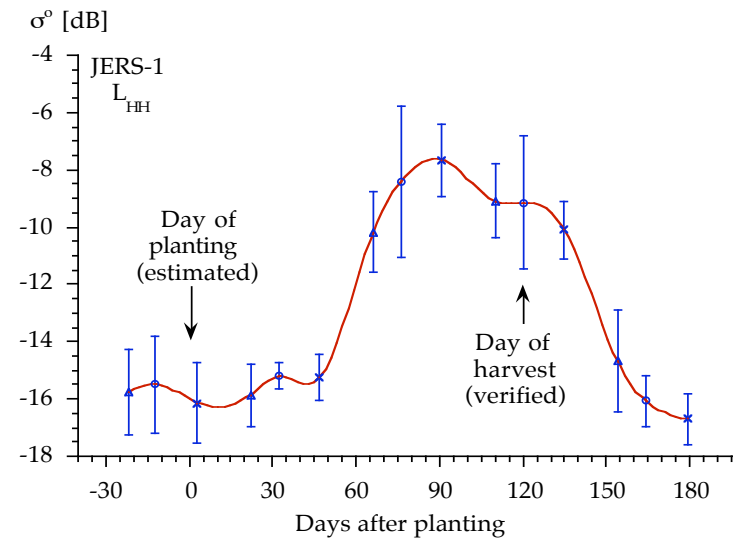


Slides produced from JERS-1  
data, courtesy of Ake  
Rosenqvist, JAXA and JRC  
Ispra

# Adequate temporal repetition



Forest changes ~ annual



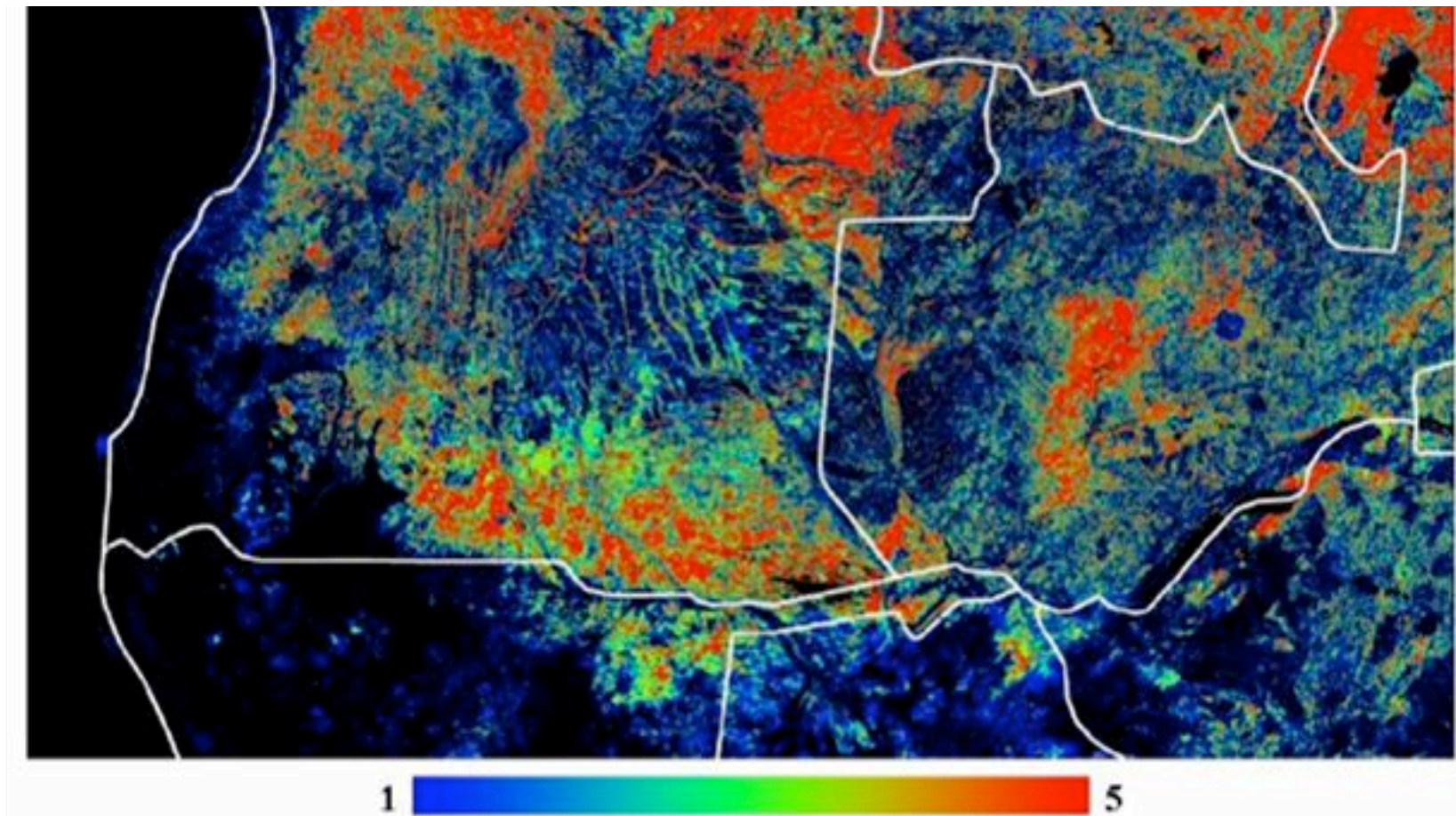
Agriculture ~ monthly

- Adapted repetition required to capture temporal change;
- Land use/land cover stratification necessary in acq. plan.

Slide from Ake Rosenqvist, JAXA and JRC Ispra

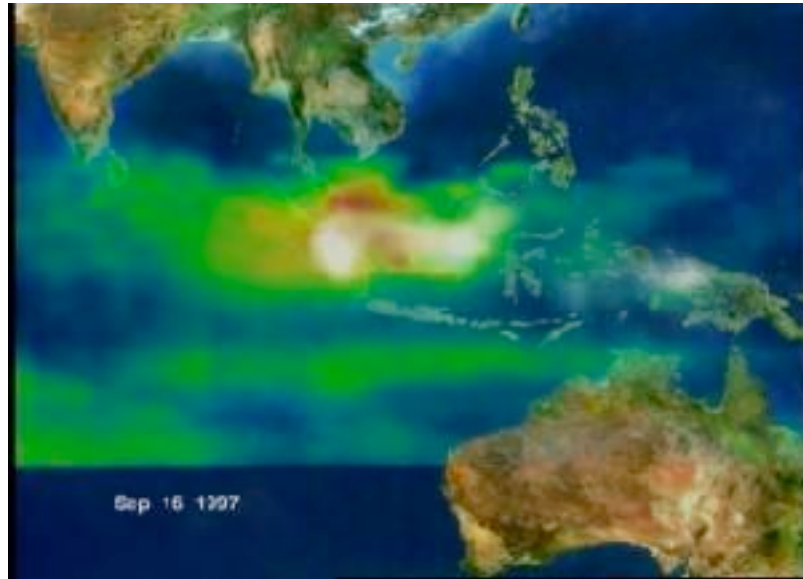
# Fire

Fire perturbs a greater area per year (millions of km<sup>2</sup>) over a wider variety of biomes than any other 'natural' disturbance.



**Number of fires in 2000-2004 over  
Angola, Zambia and surrounding countries.**

# Tropical peatland fires in Borneo

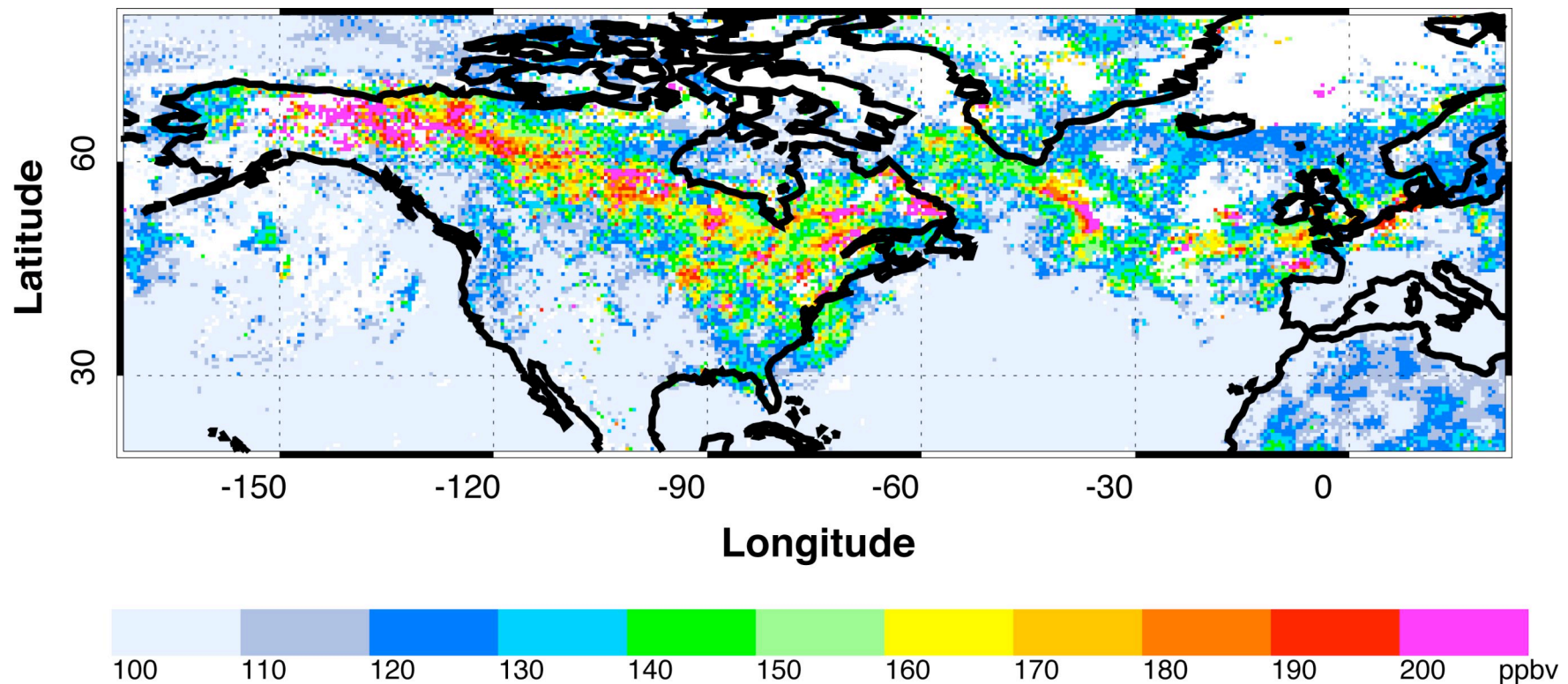


**Haze from Indonesian peat-land fires blankets SE Asia. 0.81 – 0.95 billion tonnes of carbon were emitted from peat-land fires during 1997/98.**



**16th August 2005: “Smoky haze chokes Southeast Asia .... Again hundreds of fires burn deep into the underlying peat spreading smoke across the region”**

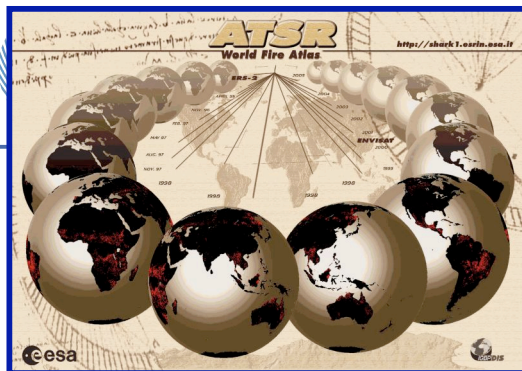
# Burning leaves strong marks in the atmosphere (MOPITT CO)



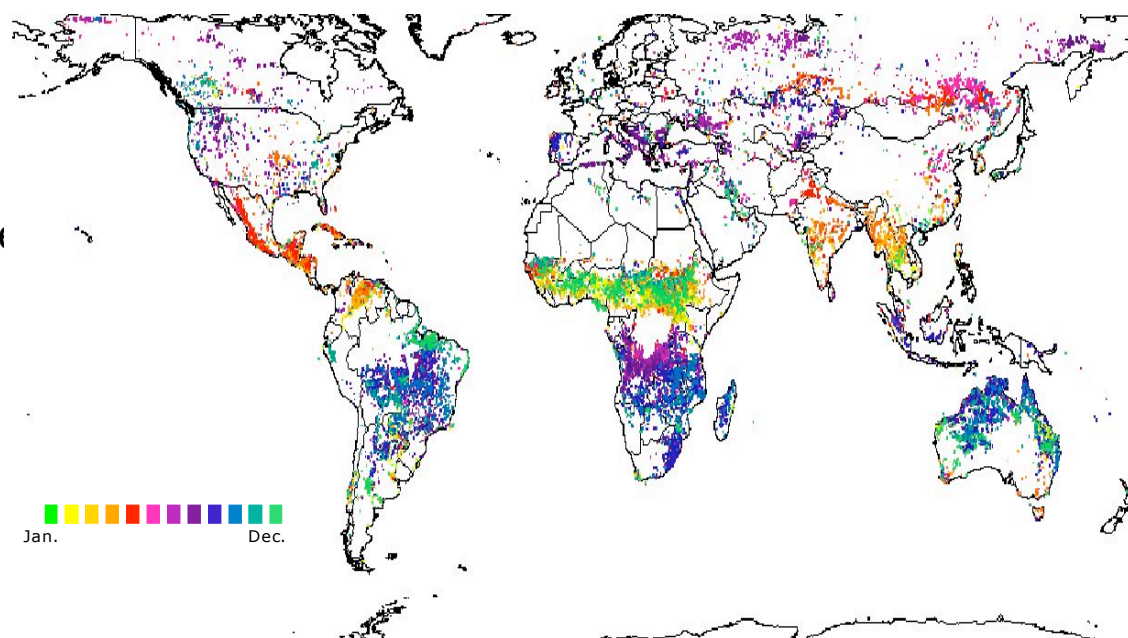
The intense wildfires in Alaska in July 2004 produced plumes of pollution that can be traced across North America and the Atlantic Ocean (Dave Edwards, NCAR).



# World Fire Atlas



- 4 308 or 312K – 3.7μm channel
- 4 Global
- 4 1995-present
- 4 ATSR-2 + AATSR
- 4 1km\*1km
- 4 3-day repeat
- 4 monthly files in ascii format (Date, Lat and Long)



Seasonal distribution of fires in 2000

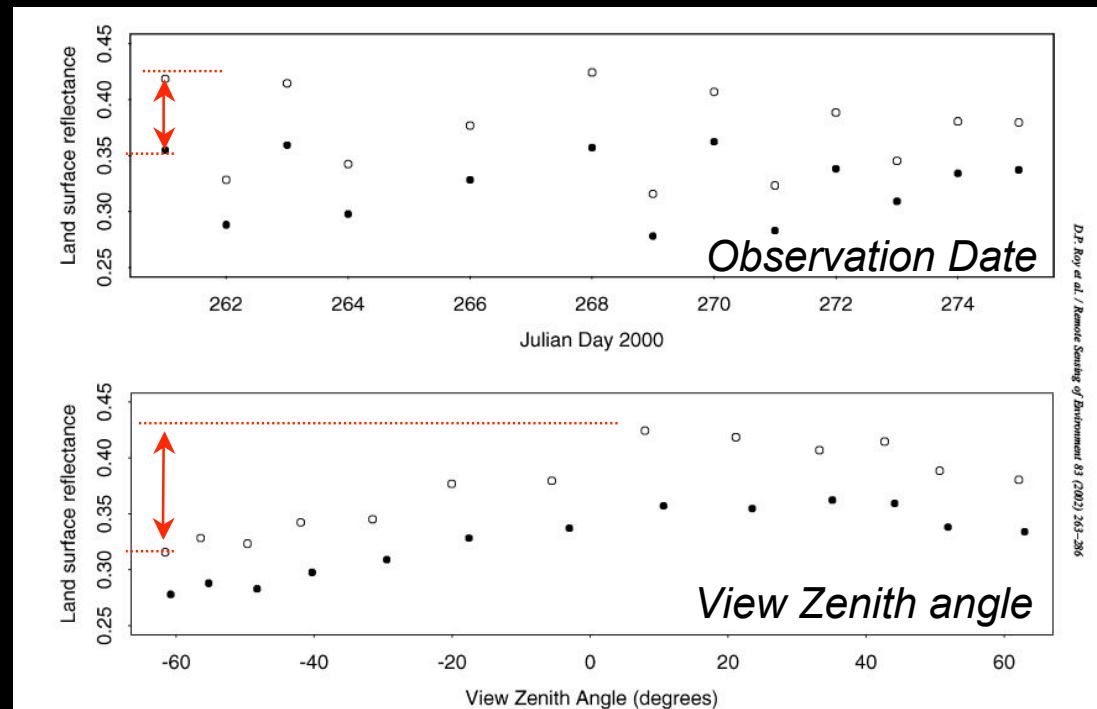
4 <http://dup.esrin.esa.int/ionia/wfa/>

4 Underestimation, industrial sites not masked, night-time

# Products: MODIS Burned Area (NASA & UCL Variant)

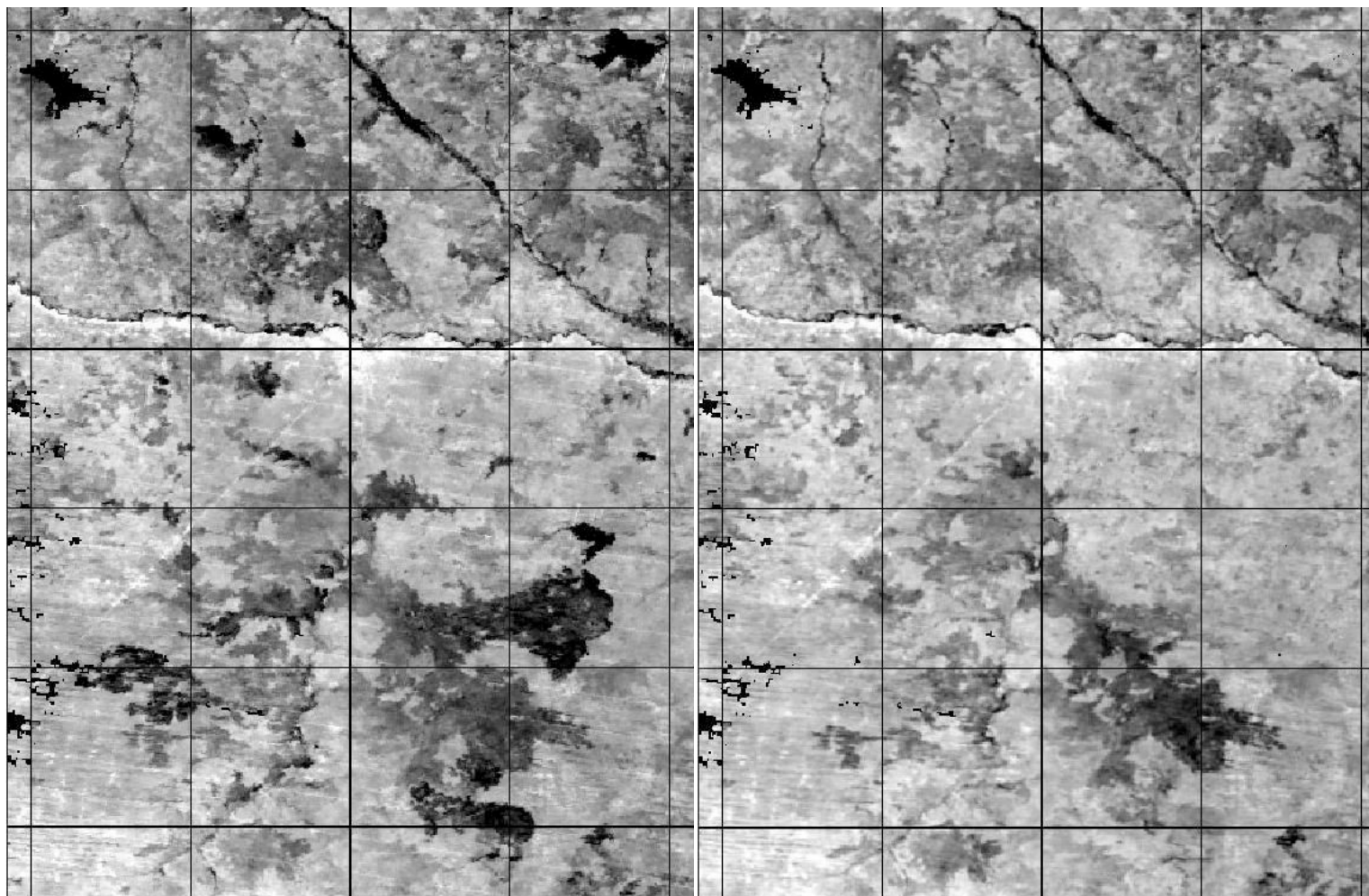


- | Spectral reflectance changes when a surface is burned
- | Almost all methods use simple spectral/temporal change
- | But BRDF effects provide similar magnitude variability



○ = unburned  
● = burned

# MODIS Burned Area: Collection 5

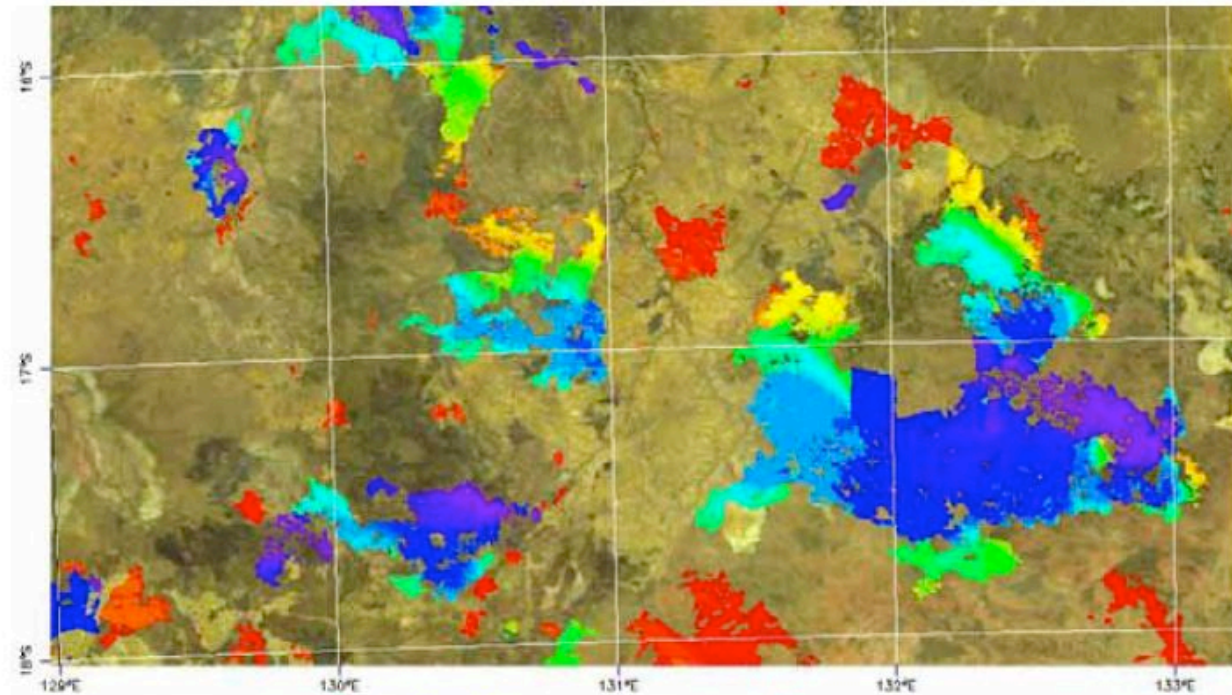


measurement

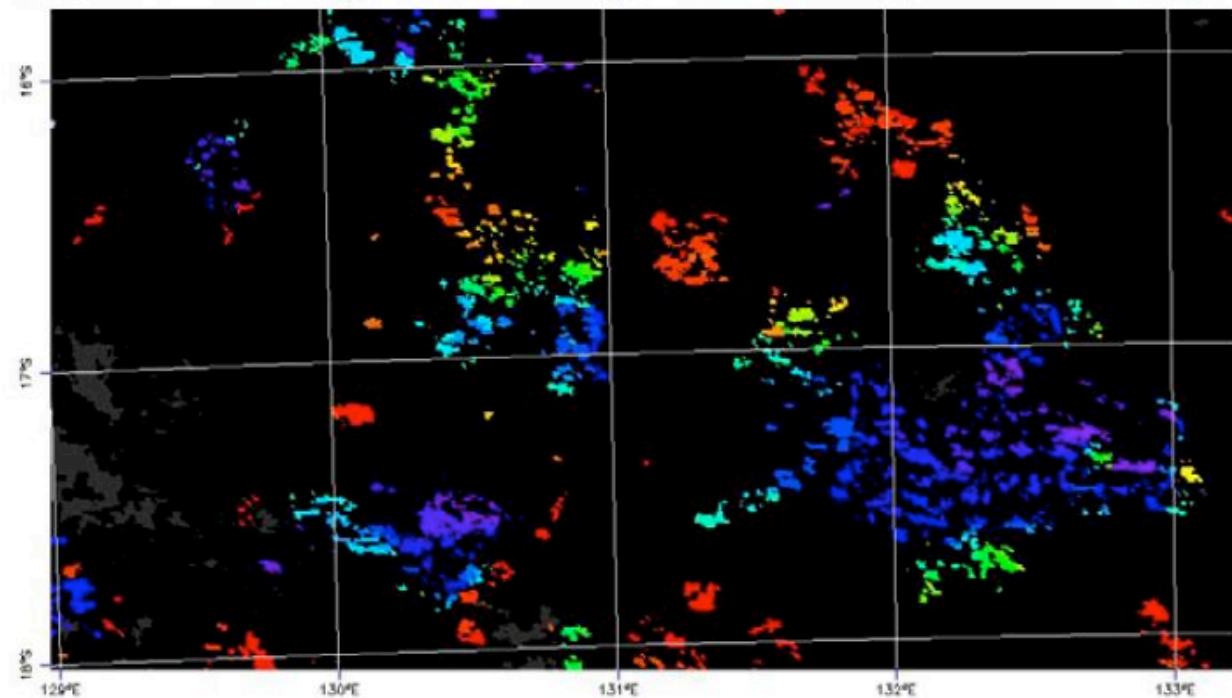
model prediction

**Australian fires  
(New Territories):**

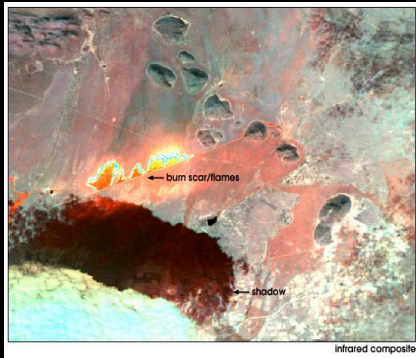
**Area burnt in  
one month in  
2002**



**Active fires**

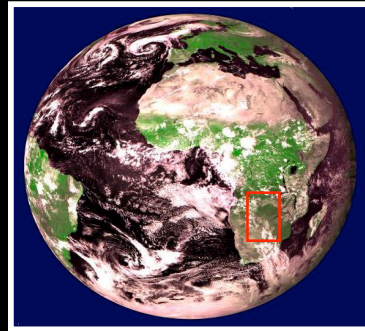


# Products: Fire Radiative Power (KCL → EUMETSAT)

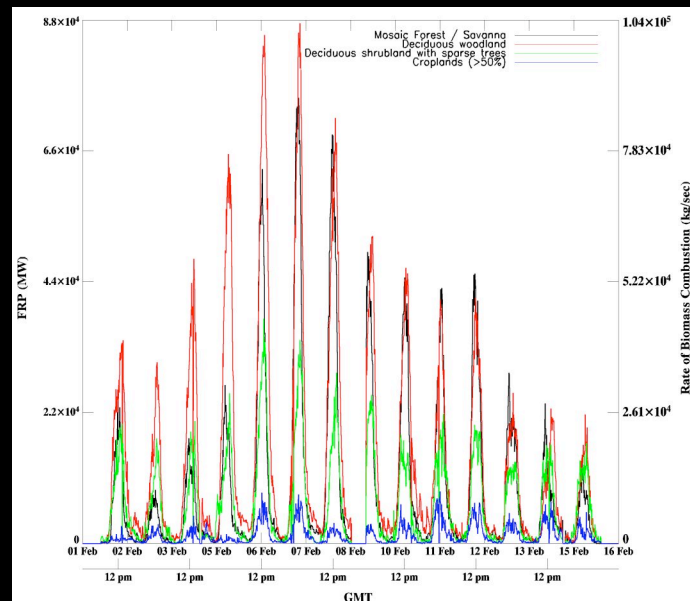


MSG SEVIRI

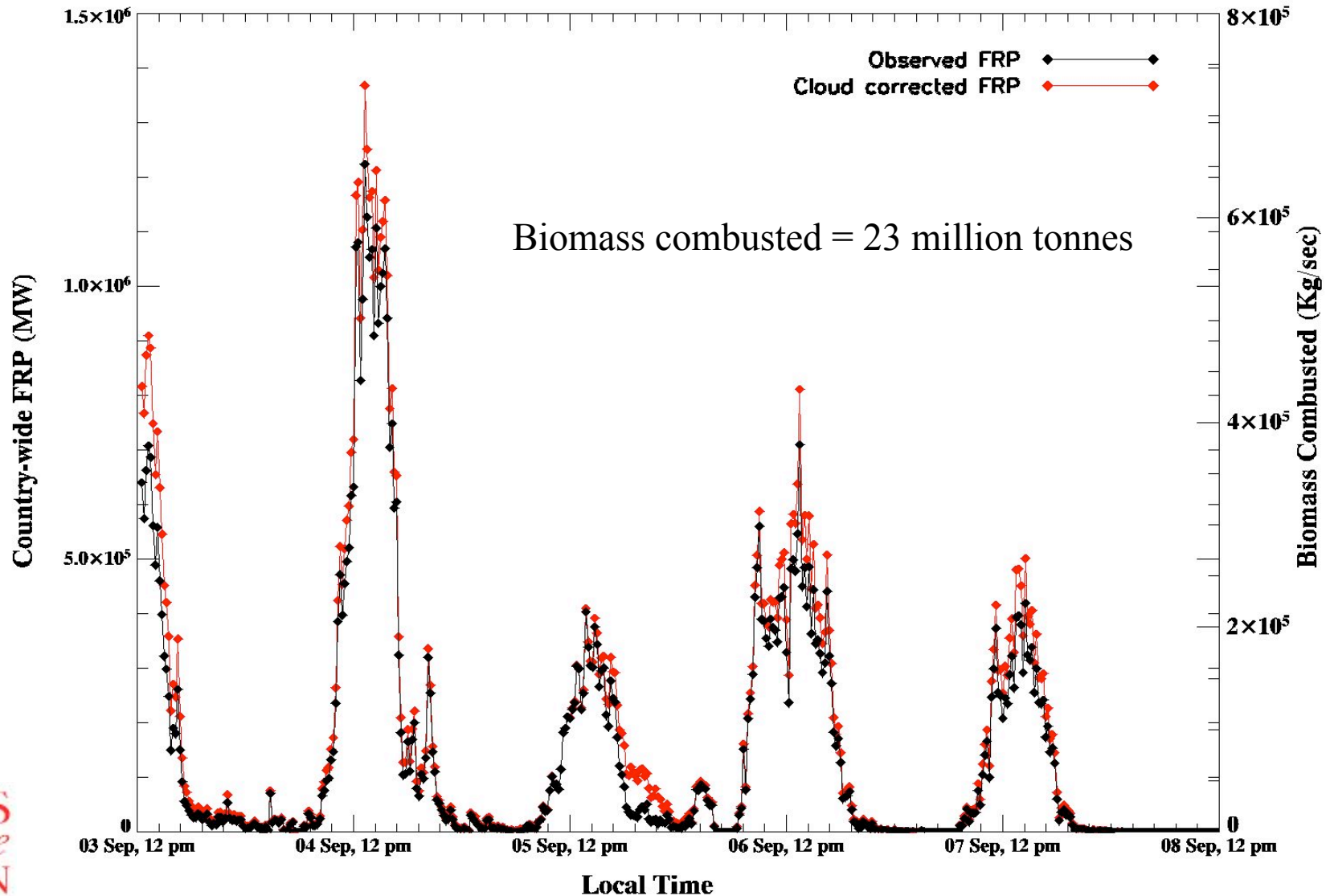
- | Vegetation releases fixed amount of energy when burned
- | A proportion emitted as radiation – detectable by EO



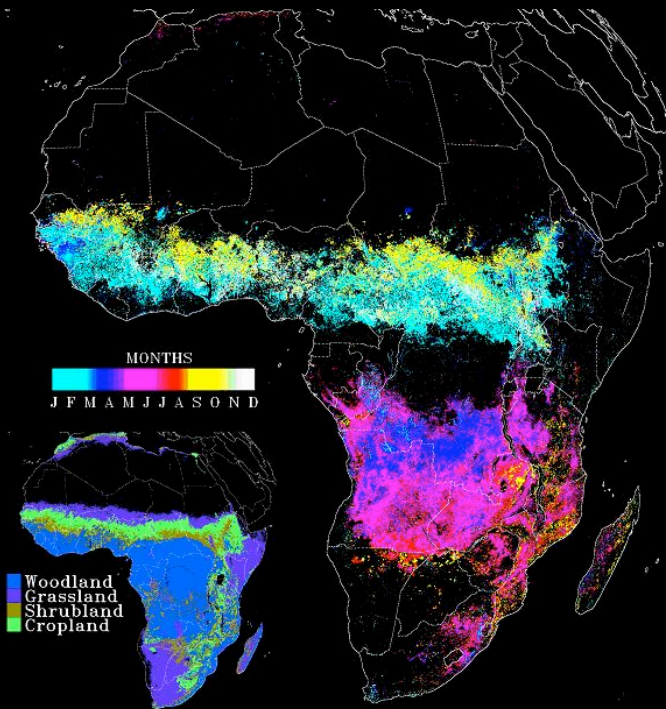
*Large  
emissions  
variability*



# Southern Africa FRP, 3-8 September 2003

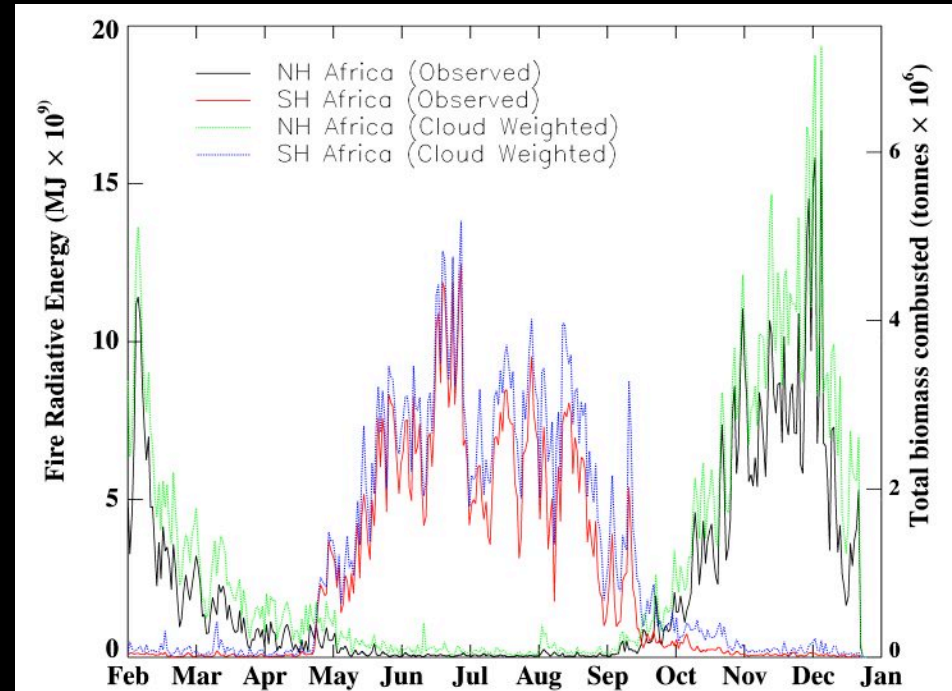


# Products: Fire Radiative Power (KCL → EUMETSAT)



*SEVIRI FRP*

[Very strong seasonal cycle]



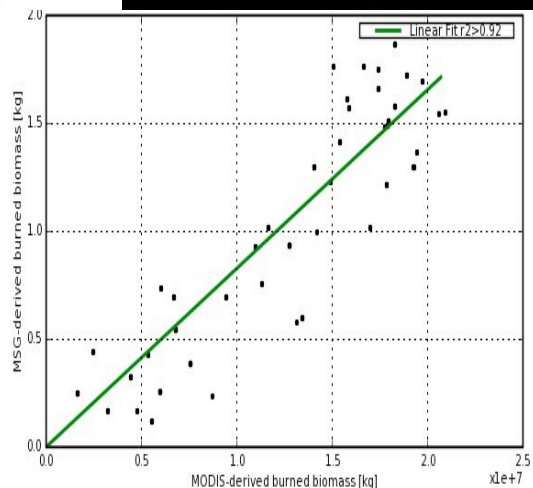
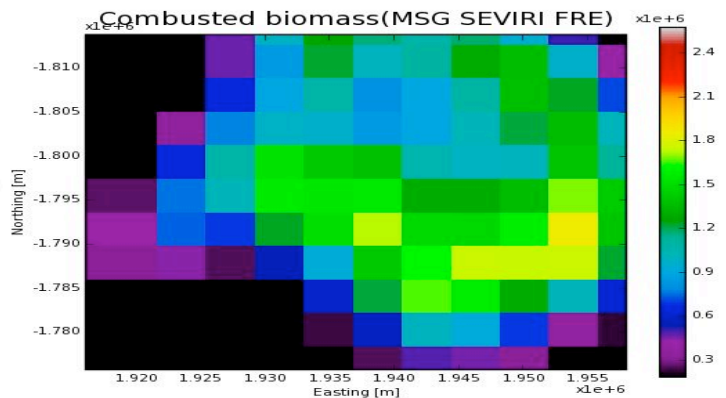
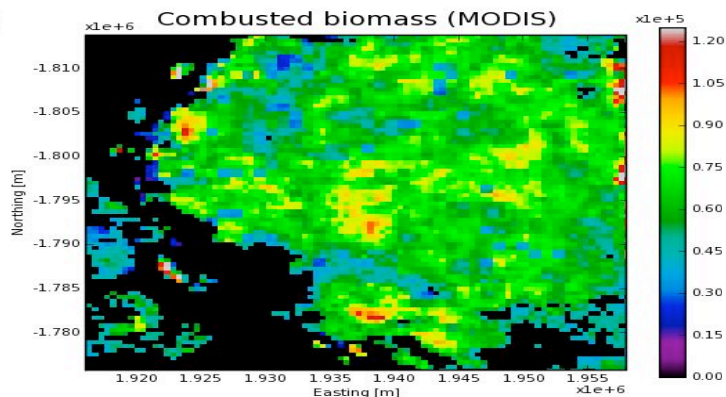
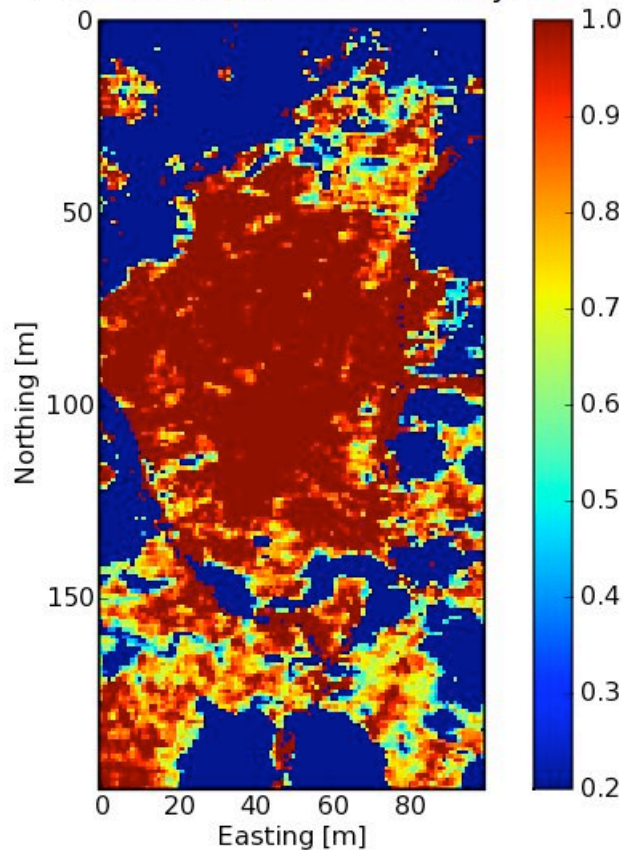
*FRP-derived Total C Emissions*

→ NH Africa 135 - 190 Tg

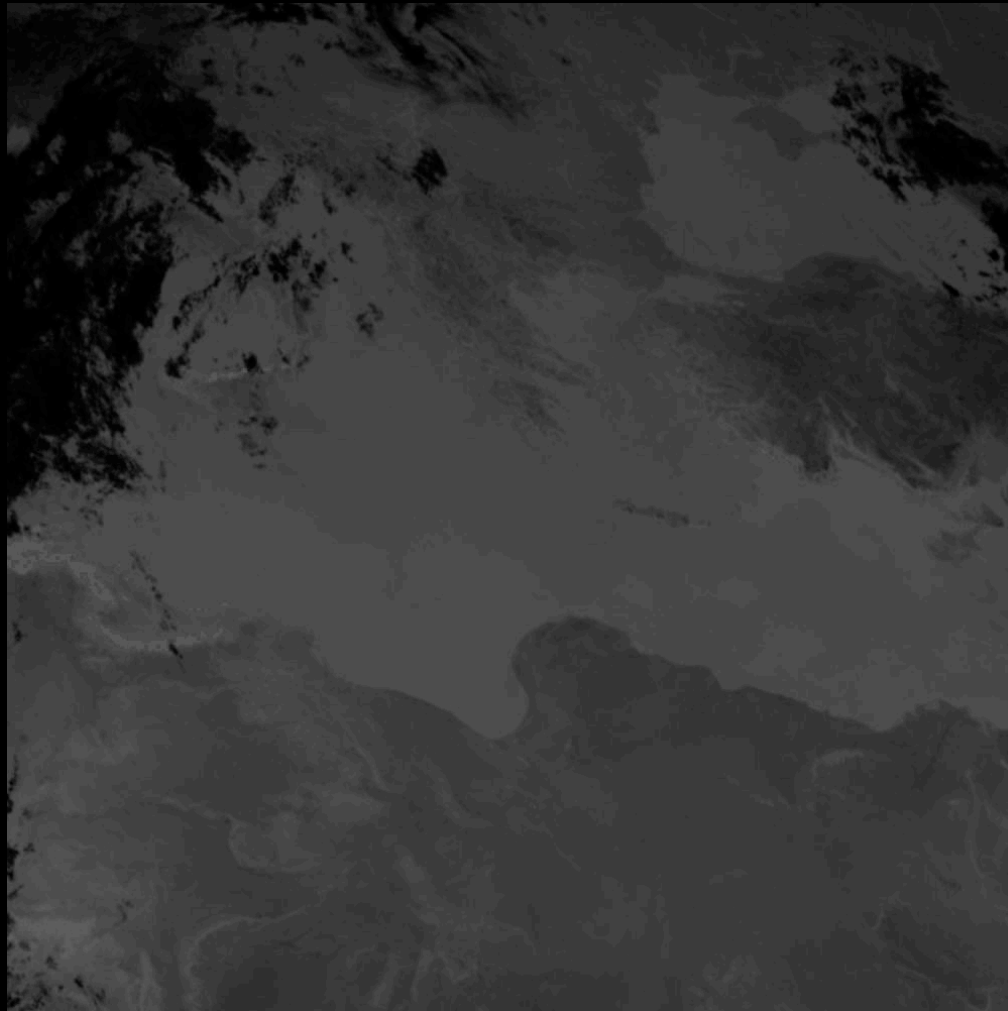
→ SH Africa 150 - 190 Tg

# FRP and Burned Area: Comparison and Synergy

f\*cc from linear mixture analysis



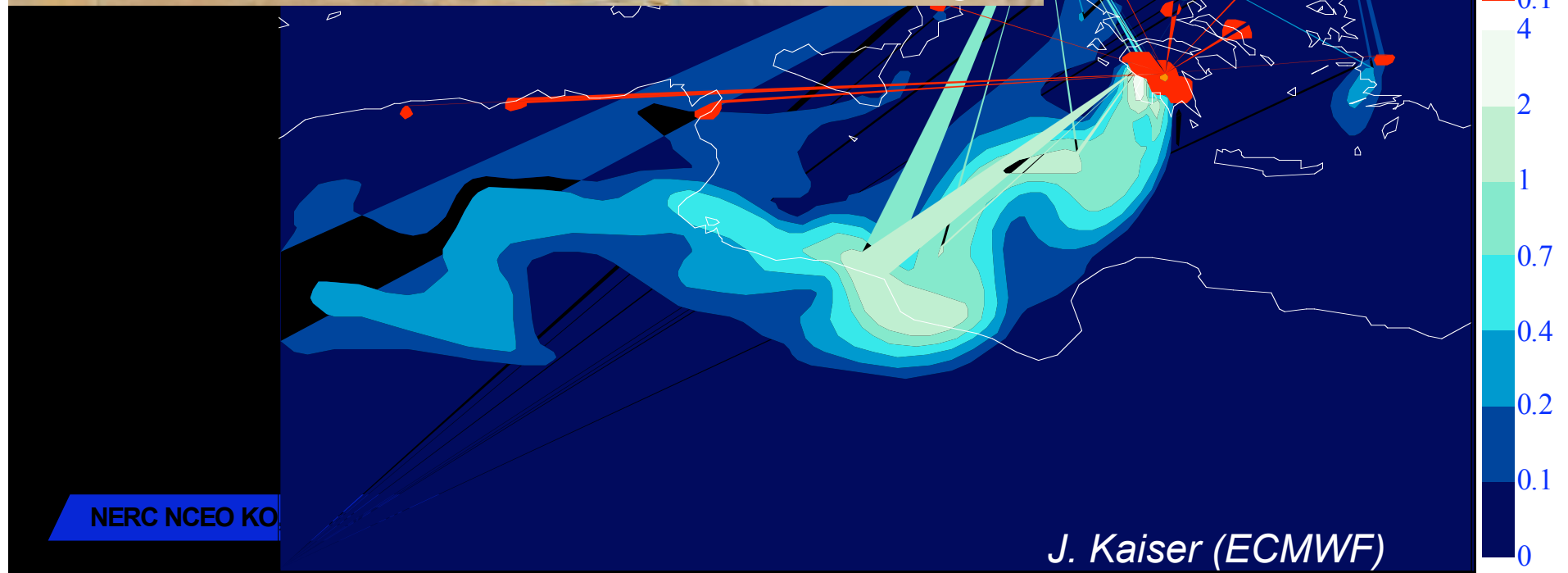
## Use as Source Term in Atm. Transport Models



*2007 Greek Fires*

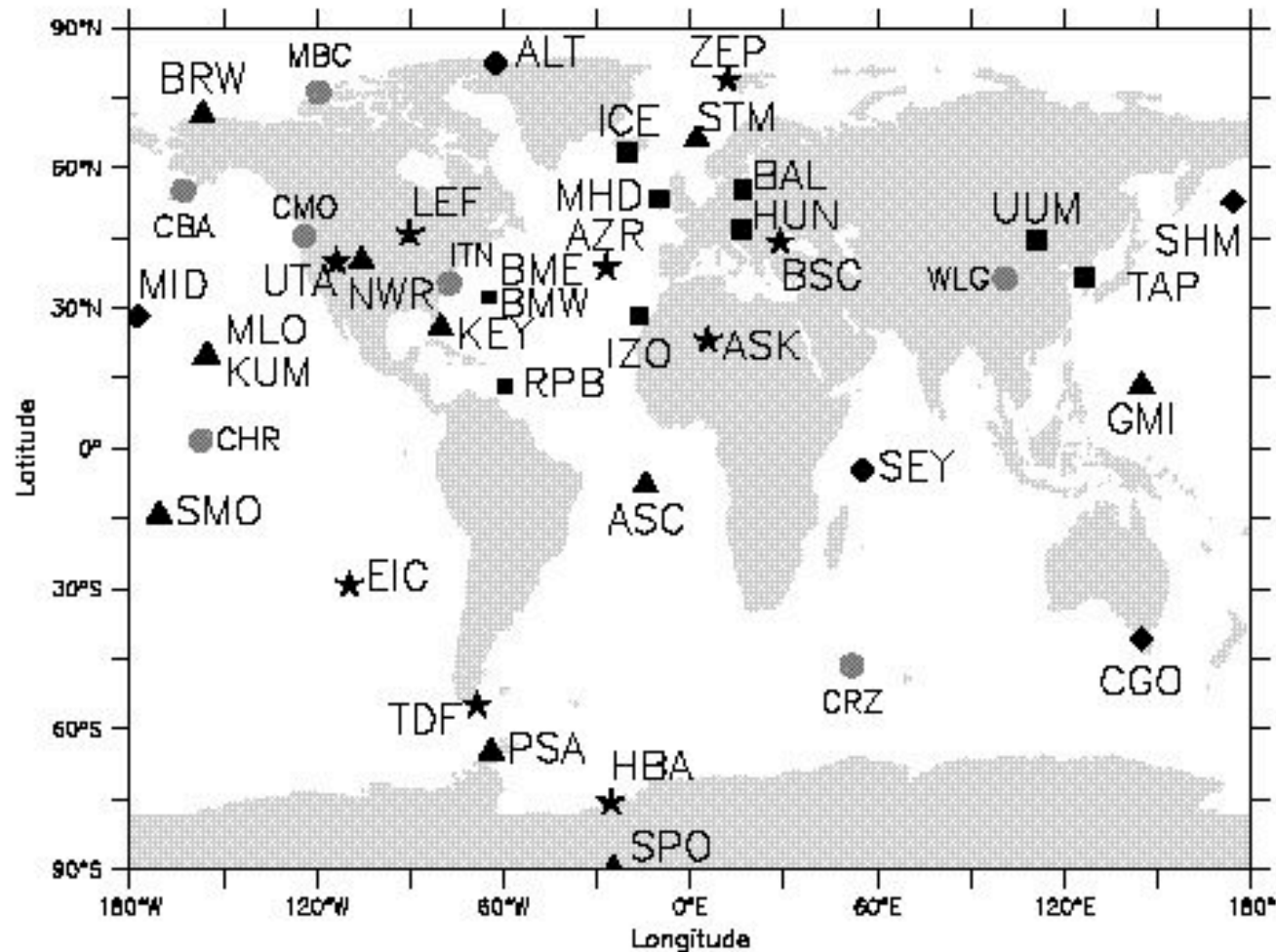
- | Geostationary data used to calculate FRP on 15 min temporal frequency
- | FRP converted to estimate of fuel consumption rate
- | Emissions factors used to convert this to emissions of BC and OC aerosol
- | Injected into ECMWF GEMS aerosol transport model (25 km grid)

# Greek Fires (SEVIRI FRP in GEMS System)

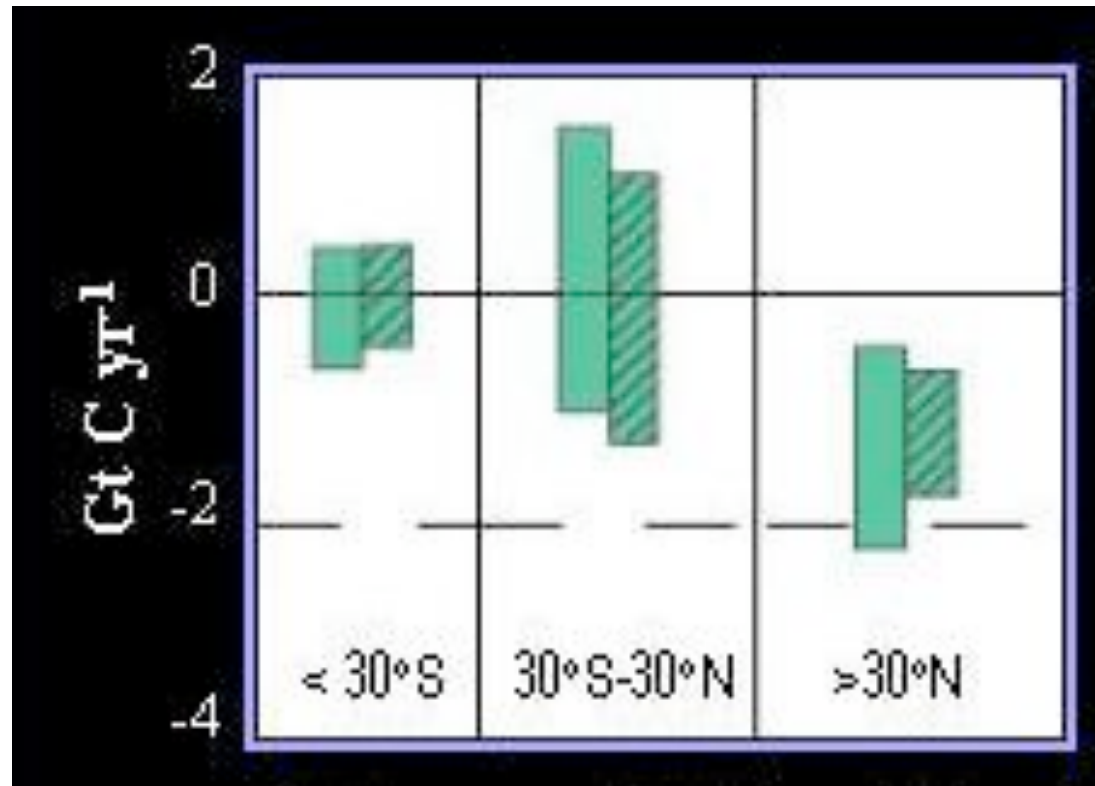


# CO<sub>2</sub> from space

# Inference of sinks from flask measurements



# Current knowledge on carbon sources and sinks (from atmospheric inversions)



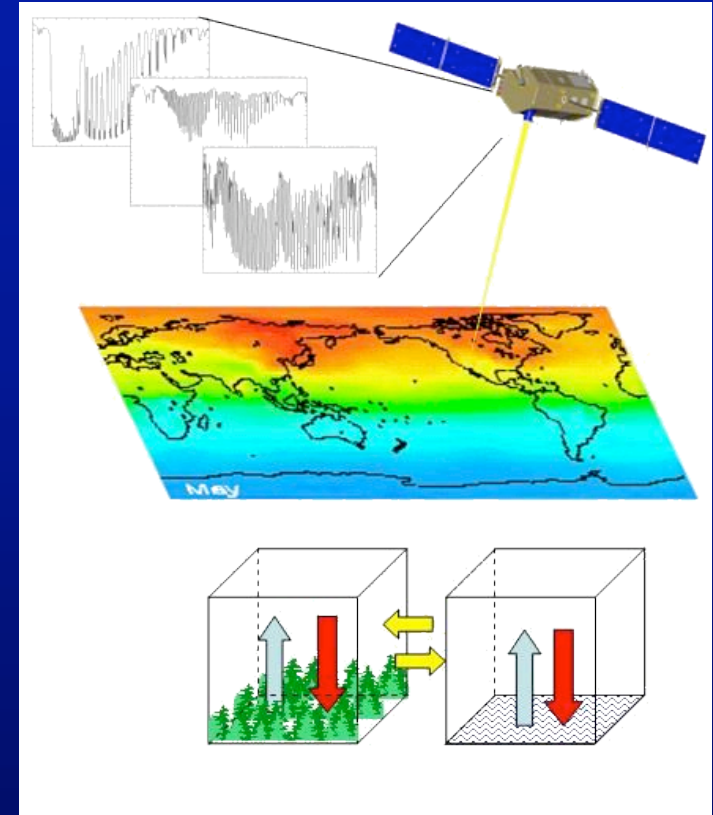
Land carbon sinks (<0) and sources (>0) for the 1980s (plain bars) and for 1990-1996 (hatched bars) (Heimann et al., 2001)

# The NASA Orbiting Carbon Observatory (OCO)

OCO will acquire the space-based data needed to identify CO<sub>2</sub> sources and sinks on regional scales over the globe and quantify their variability over the seasonal cycle

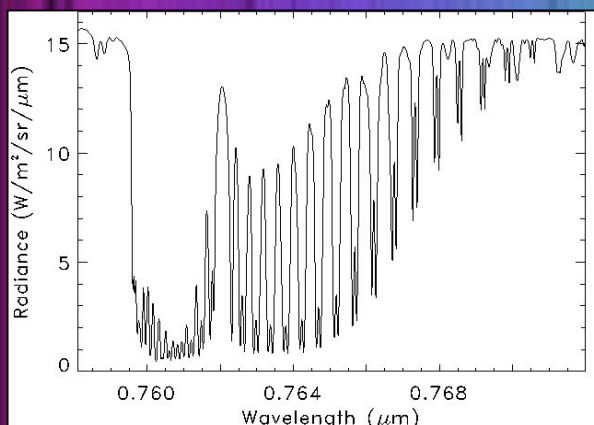
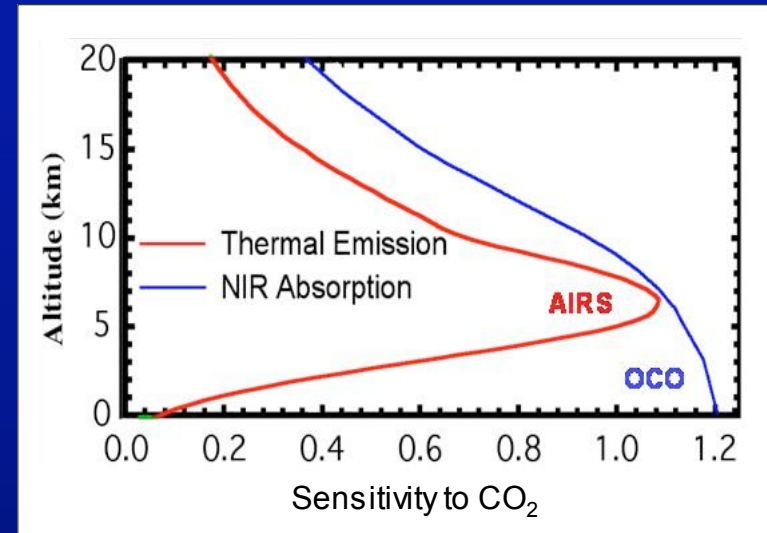
## Approach:

- n Collect spectra of CO<sub>2</sub> and O<sub>2</sub> absorption in reflected sunlight
- n Use these data to resolve variations in the *column averaged CO<sub>2</sub> dry air mole fraction,  $X_{CO_2}$*  over the sunlit hemisphere
- n Validate measurements to ensure  $X_{CO_2}$  accuracies of 1 - 2 ppm (0.3 - 0.5%) on regional scales at monthly intervals

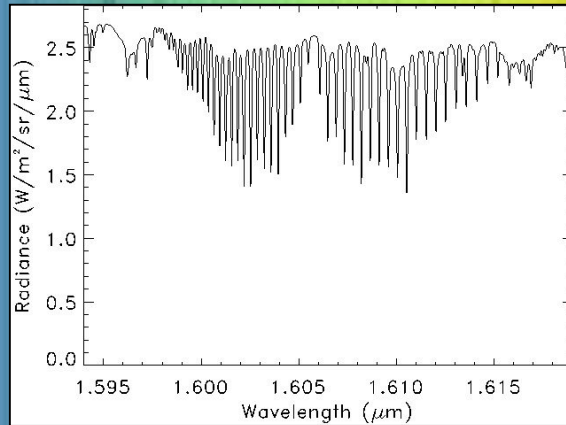


# Making Precise CO<sub>2</sub> Measurements from Space

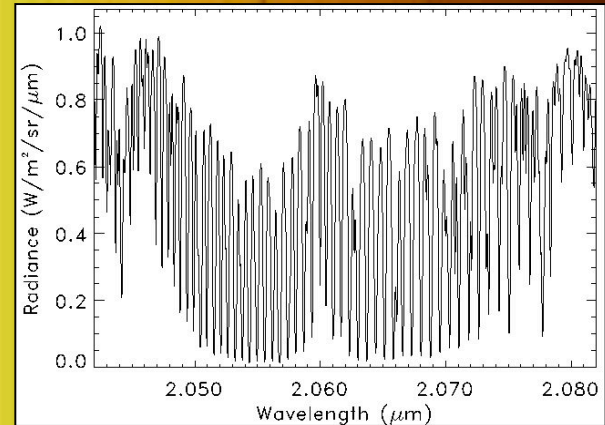
- n High resolution spectra of reflected sunlight in near-IR CO<sub>2</sub> and O<sub>2</sub> bands used to retrieve  $X_{\text{CO}_2}$ 
  - 1.61  $\mu\text{m}$  CO<sub>2</sub> band: Column CO<sub>2</sub>
  - 2.06  $\mu\text{m}$  CO<sub>2</sub> band: Column CO<sub>2</sub>, clouds/aerosols
  - 0.76  $\mu\text{m}$  O<sub>2</sub> A-band: Surface pressure, clouds/aerosols
- è Self-consistent retrieval, no additional information needed
- n High spectral resolution enhances sensitivity and minimizes biases



Scattering from  
Clouds/Aerosols, Surface  
Pressure, Temperature



Column CO<sub>2</sub>

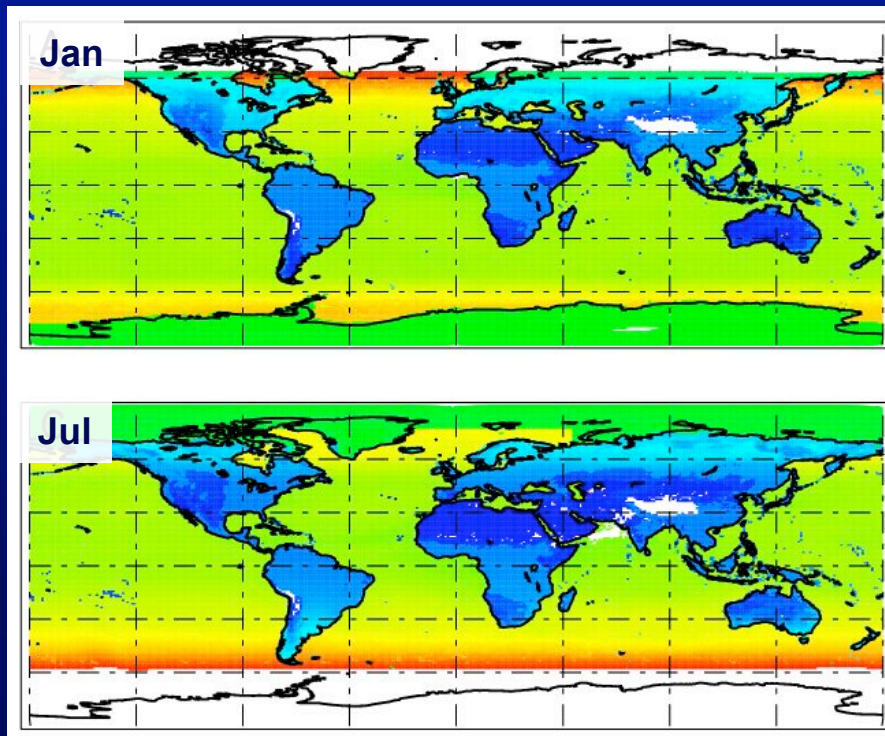


Scattering from Clouds/Aerosols,  
H<sub>2</sub>O, Temperature

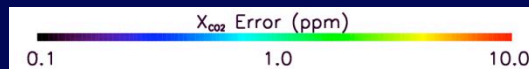
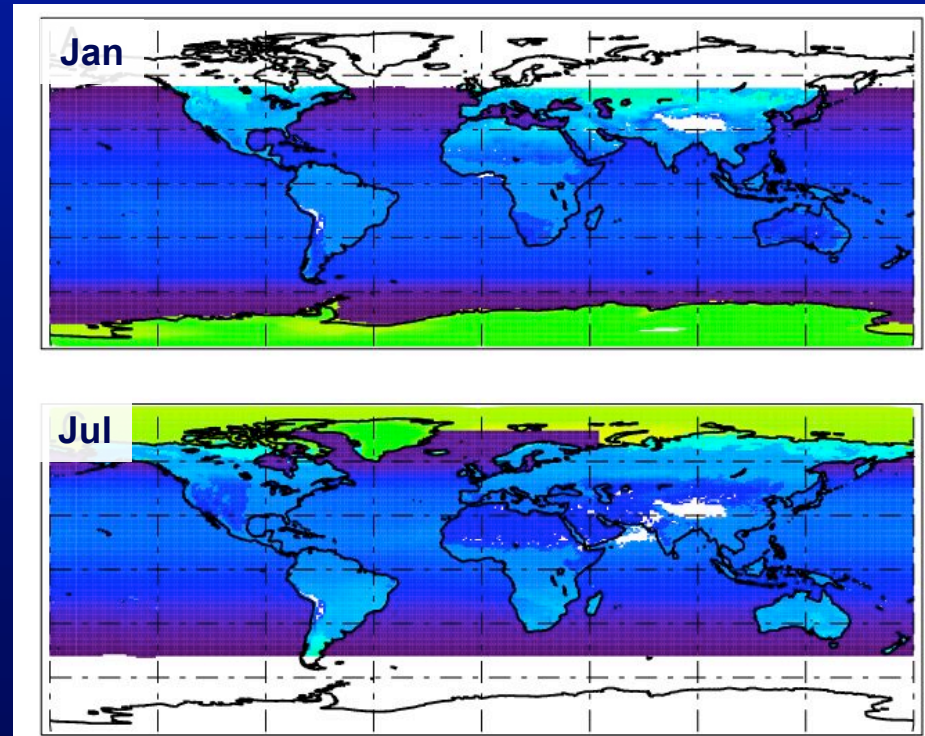
# Global Single Sounding $X_{\text{CO}_2}$ Retrieval Error

- n Surface type and pressure climatology + AOD histogram
- n No systematic errors included here (*i.e. perfect Forward Model*)

Nadir



Glint



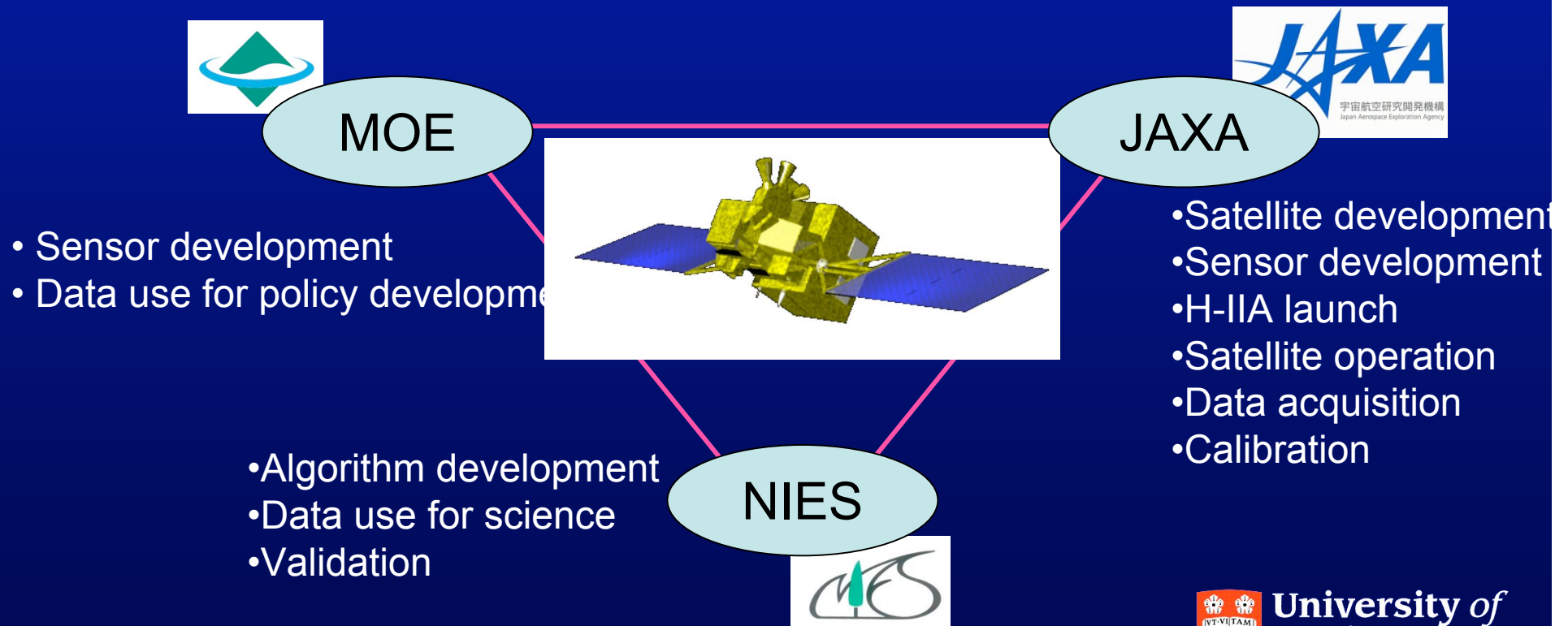
# Comparison of *SCIAMACHY* and *OCO*



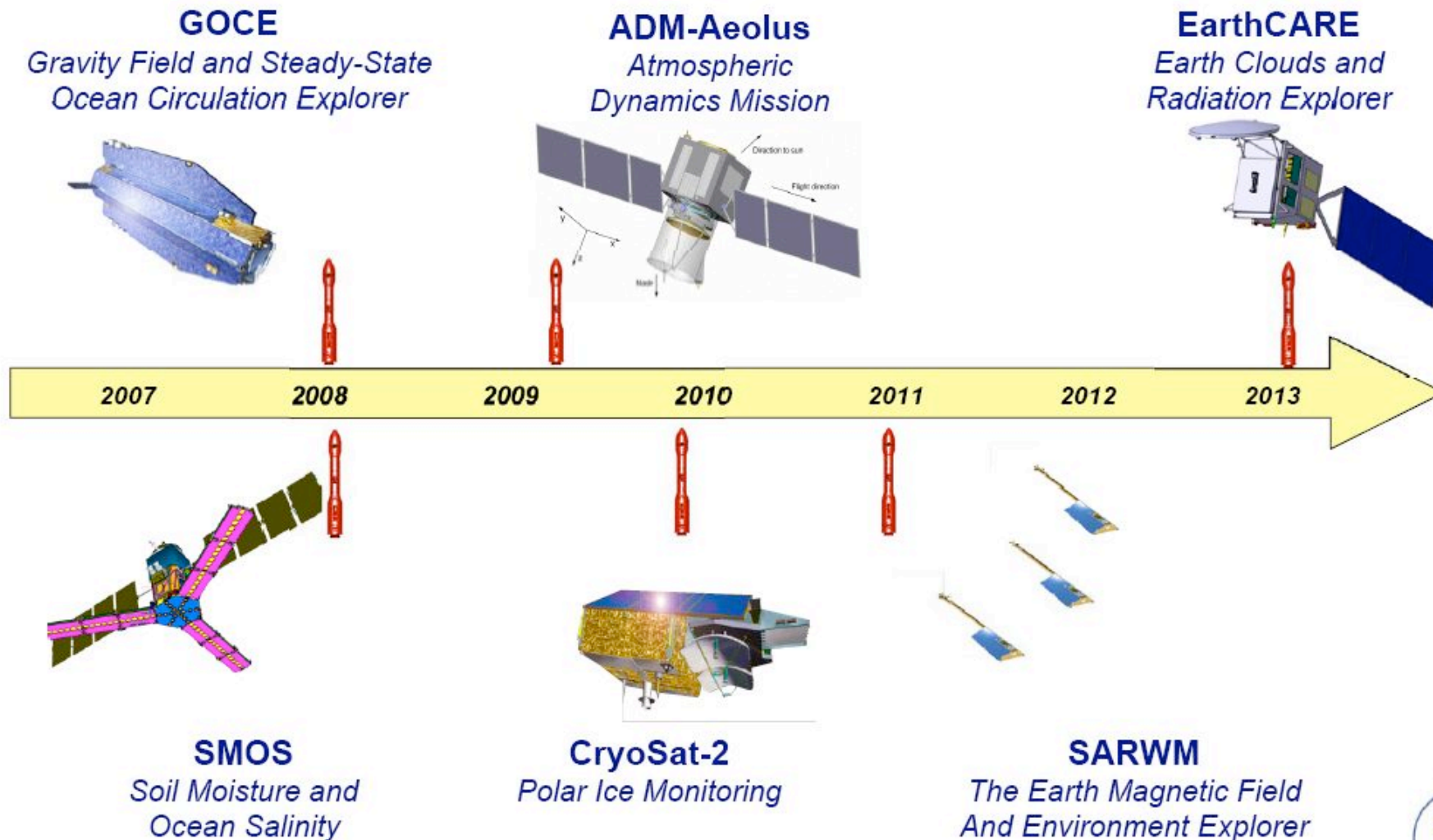
	<b>OCO</b>	<b>SCIAMACHY/ENVISAT</b>
Launch	Scheduled for 12/2008	March 2002
Objective	CO <sub>2</sub> solely	Many atmospheric trace gases
Modes	Nadir, glint, target	Nadir (limb, occultation)
Range	3 narrow NIR bands	8 Channels from UV to NIR
Resolution	High: 0.05 nm – 0.1 nm	Low/medium: 0.2 – 1.5 nm
Ground Pixel	3 km <sup>2</sup>	60 x 30 km <sup>2</sup>
Retrieval	Optimal Estimation	FSI-WFM (linear least-square fit)

# Greenhouse Gases Observing Satellite (GOSAT)

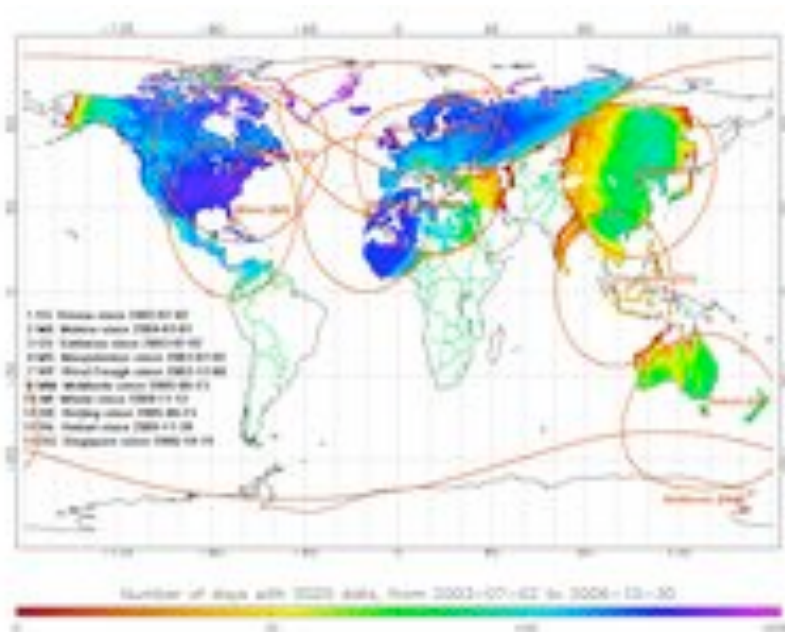
- a satellite to monitor the global distribution of CO<sub>2</sub> and CH<sub>4</sub>.
- launch in Jan 2009.



## 6 Missions under development to be launched in the next 6 years

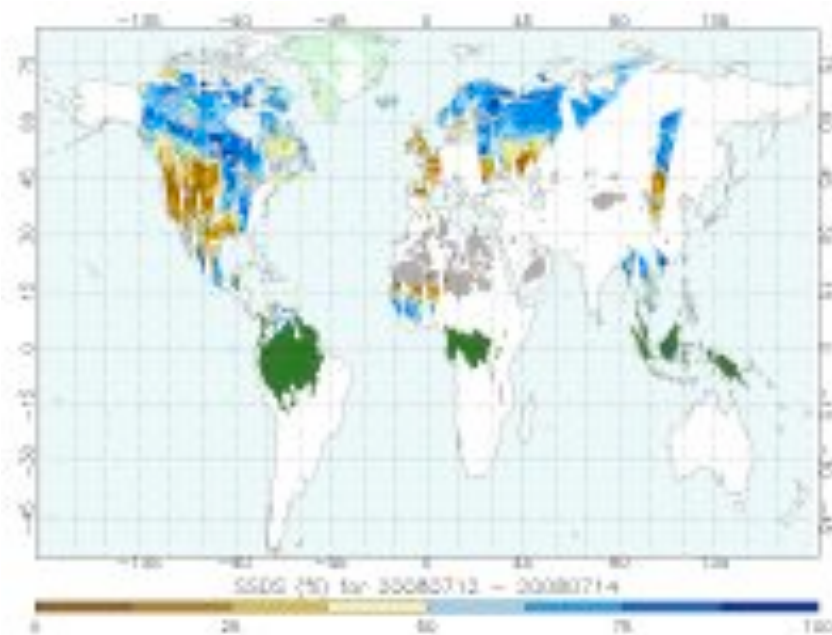


# Soil moisture



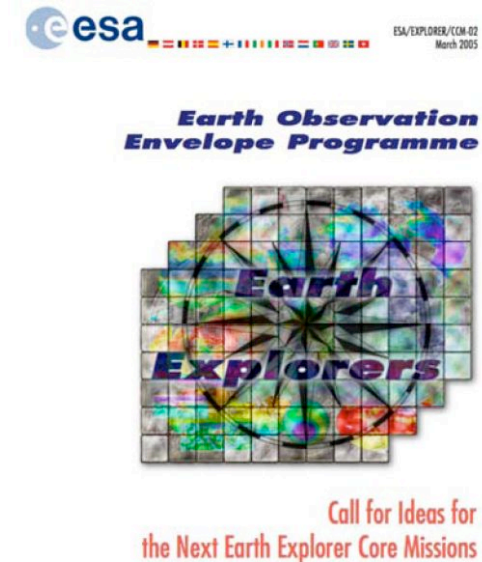
Coverage

Degree of saturation



## Call for ideas issued in 2005

- n Science priorities
  - The Global Water Cycle
  - The Global Carbon Cycle
  - Atmospheric Chemistry
  - The Human Element
- n 24 proposals evaluated
- n 6 Candidate Missions selected for further study
  - **BIOMASS**: BIOMASS Monitoring Mission for Carbon Assessment
  - **TRAQ**: TRopospheric composition and Air Quality
  - **PREMIER**: Process Exploration through Measurements of Infrared and millimeter Emitted Radiation
  - **FLEX**: Fluorescence Explorer
  - **A-SCOPE**: Advanced Space Carbon and Climate Observation of Planet Earth
  - **CoRe-H2O**: Cold Regions Hydrology High-resolution Observatory
- n Expected launch 2014-2015



European Space Agency  
Agence spatiale européenne

# Biomass

# Range of uncertainty in carbon stored as biomass

<b>Forests</b>	<b>Area (10<sup>6</sup> km<sup>2</sup>)</b>	<b>Vegetation C (low-high)</b>	<b>Soils (mean)</b>	<b>Total (low-high)</b>
<b>High lats</b>	<b>10.3</b>	<b>46-115</b>	<b>266</b>	<b>312-380</b>
<b>Mid lats</b>	<b>5.9</b>	<b>37-77</b>	<b>84</b>	<b>122-161</b>
<b>Low lats</b>	<b>12.8</b>	<b>48-265</b>	<b>131</b>	<b>180-396</b>
<b>Totals</b>	<b>29.0</b>	<b>132-457</b>	<b>481</b>	<b>613-938</b>

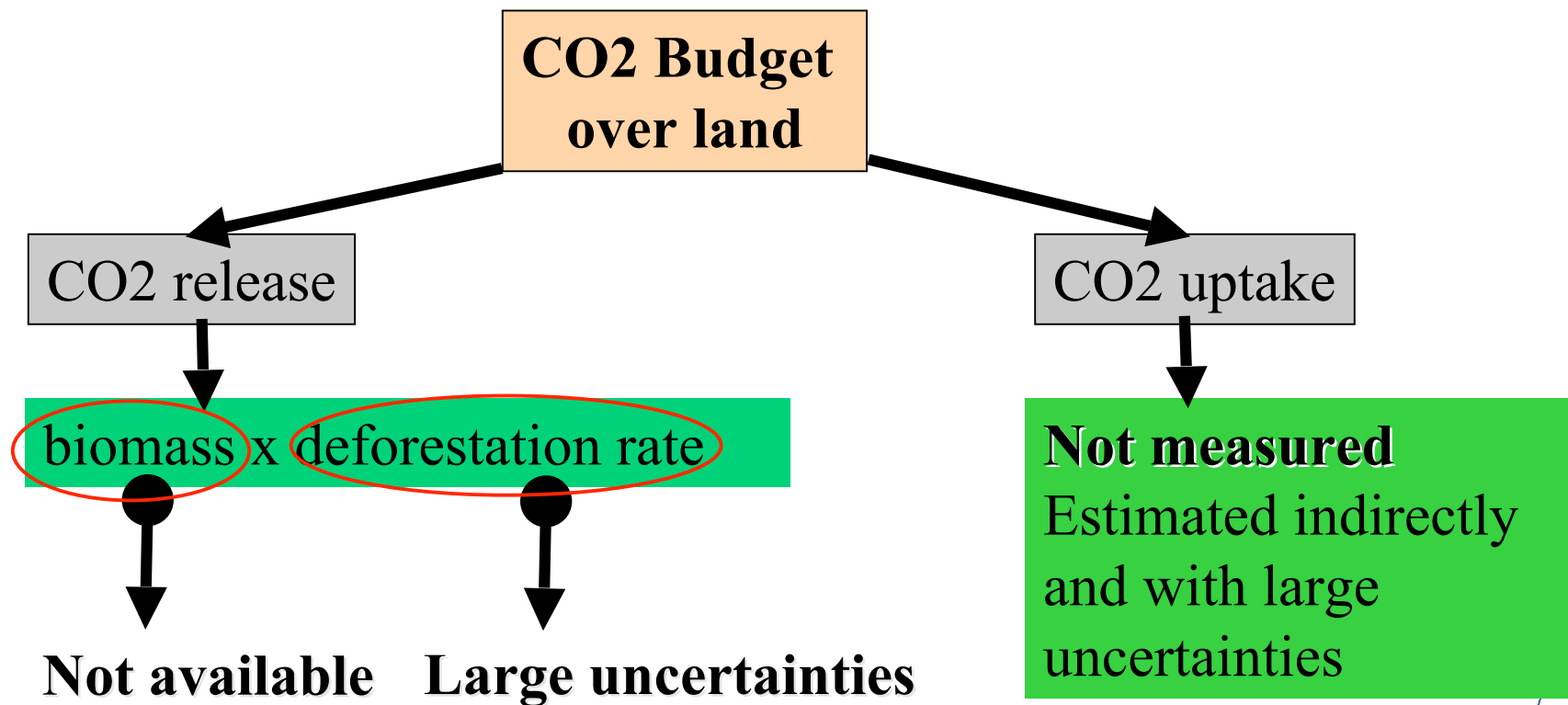


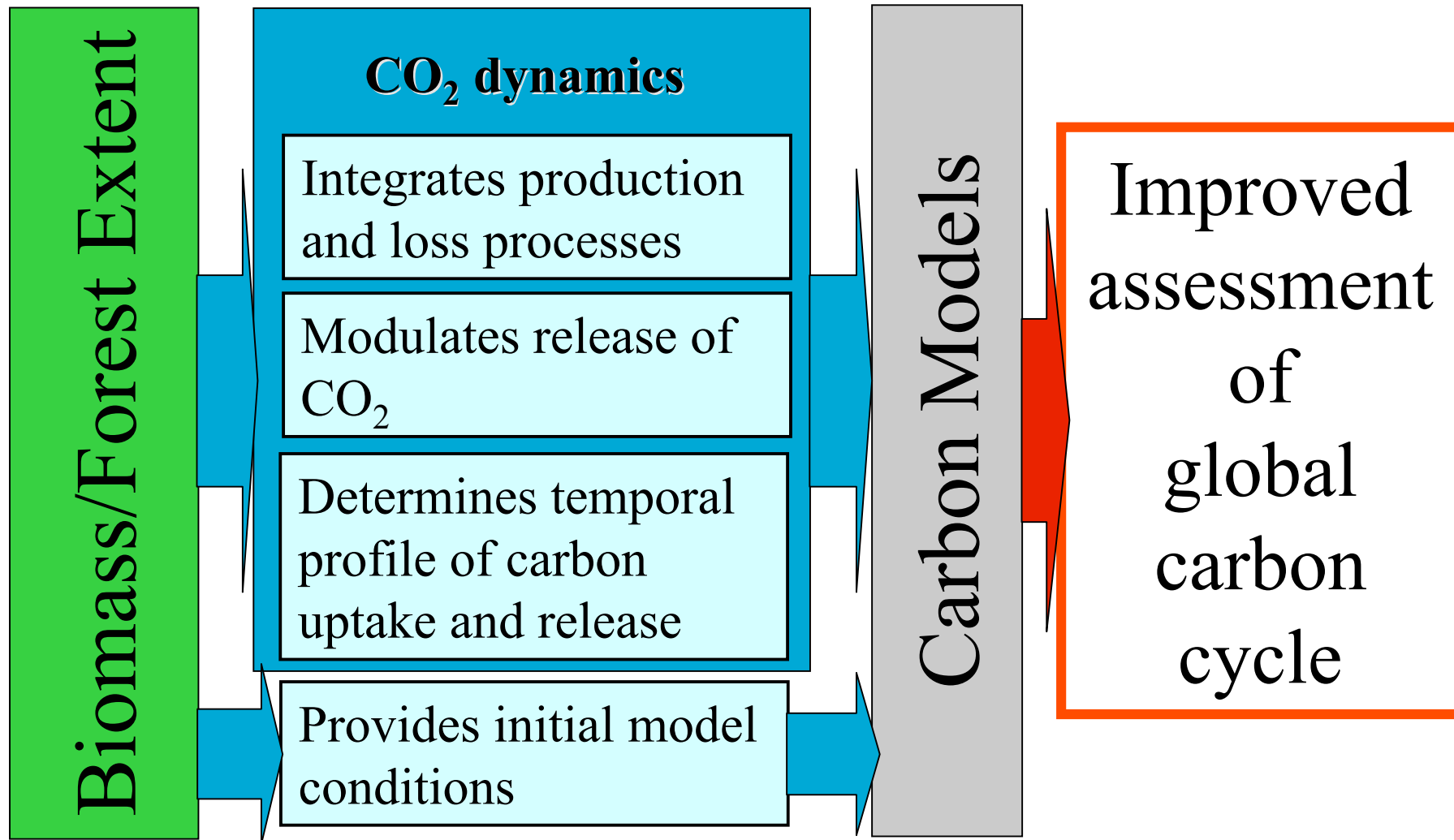
# BIOMASS

**Malcolm Davidson**, A. Thompson, C. Lin, P. Benzi, F. Heliere (ESA-ESTEC)  
*and the BIOMASS MAG* (T. Le Toan, S. Quegan, H. Baltzer, P. Paillou, K.  
Papathanassiou, F. Rocca, L. Ulander, S. Plummer, S. Saatchi\*, H. Shugart\* )

\* US Observers

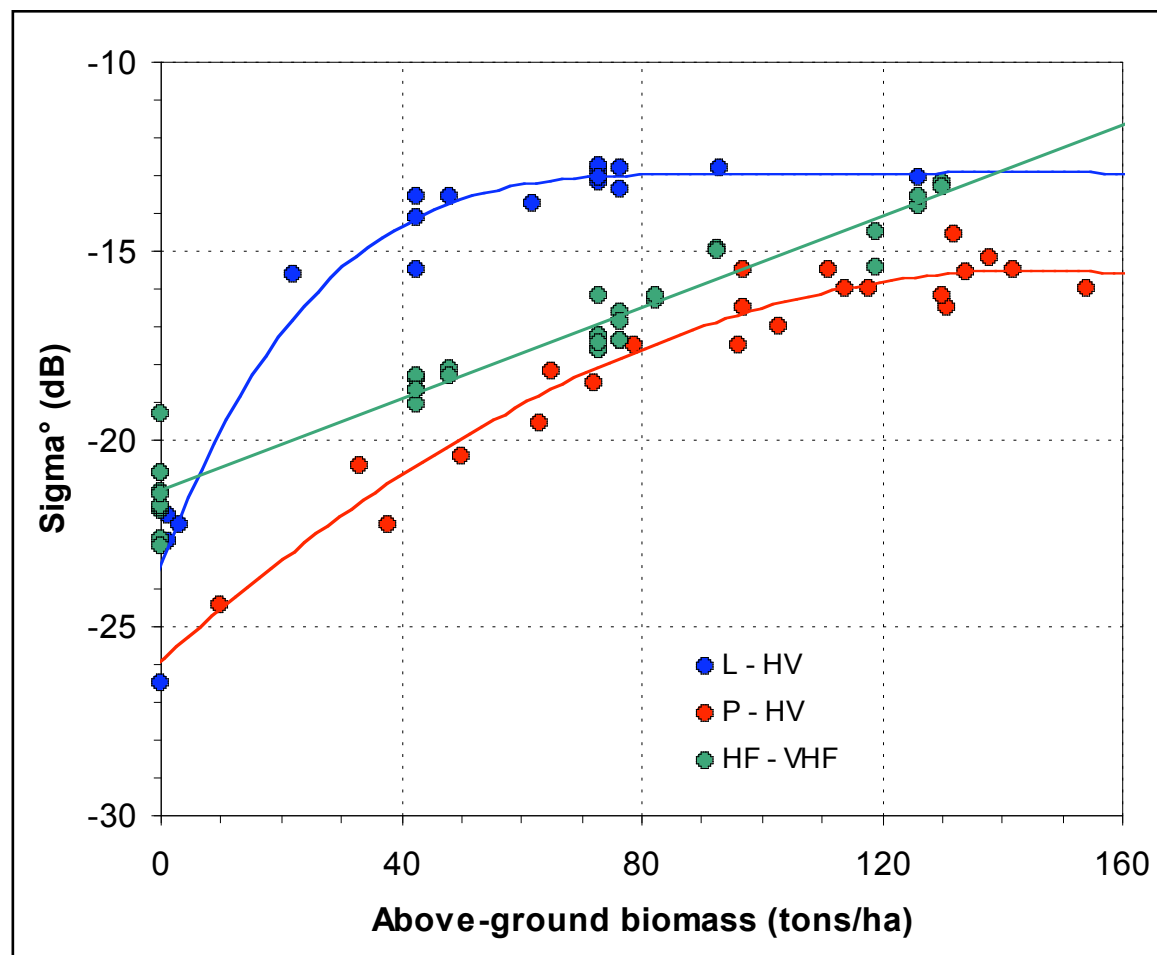
- Forest biomass information represents a key parameter which will improve our present assessments and future projections of the carbon cycle



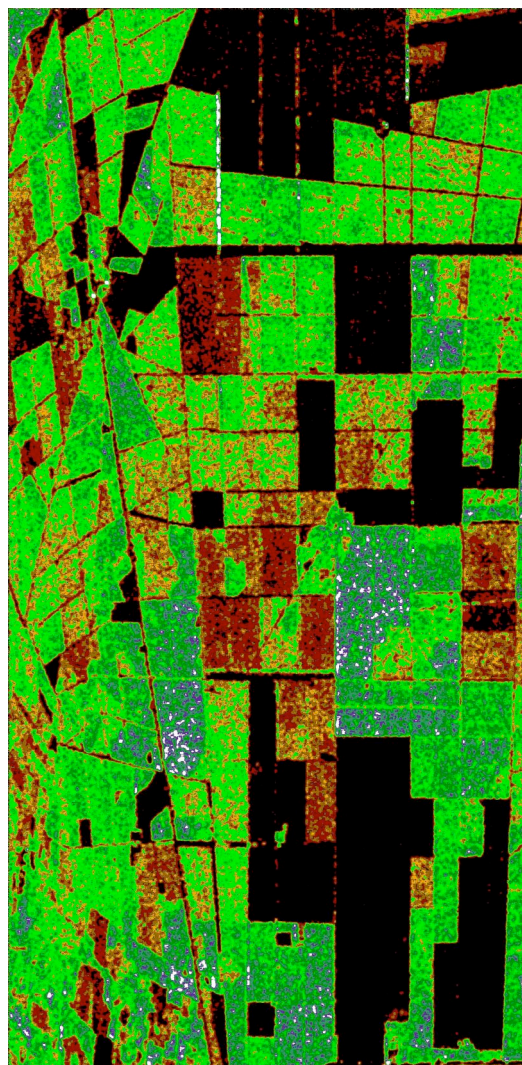


# Relation of radar backscatter to above-ground biomass at L, P, VHF bands

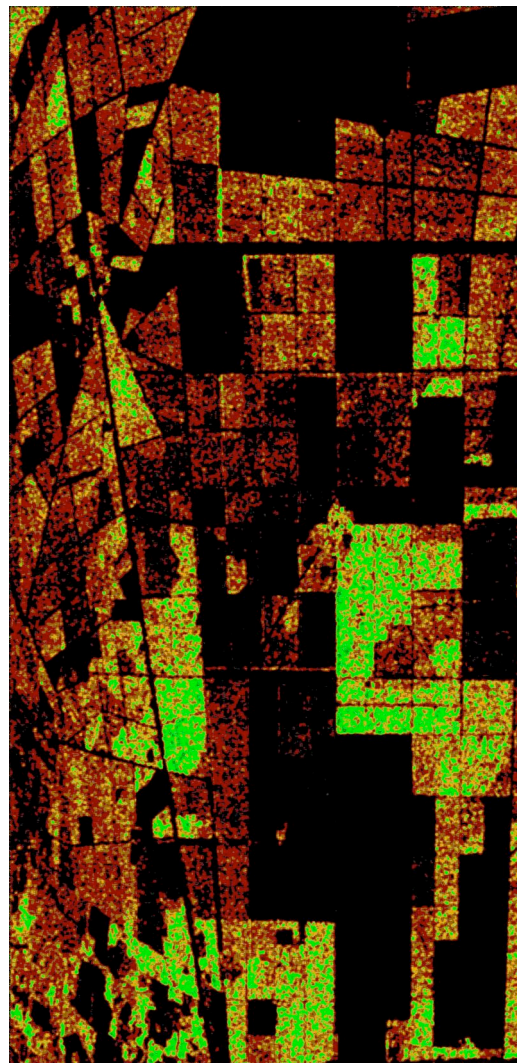
Landes forest,  
France



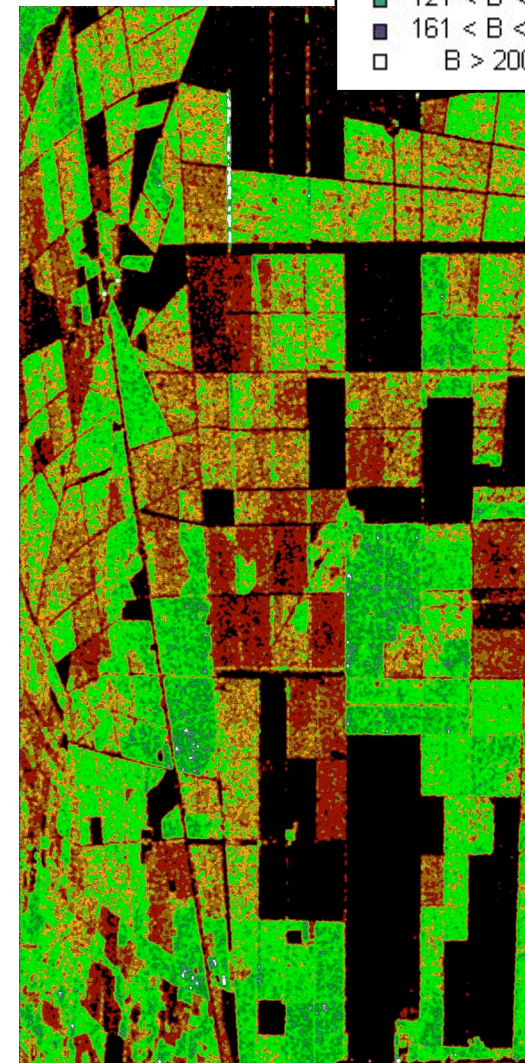
# Airsar Landes



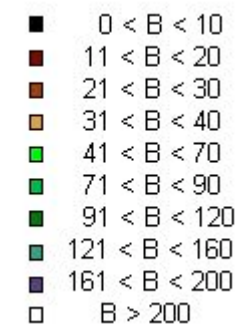
Above ground biomass



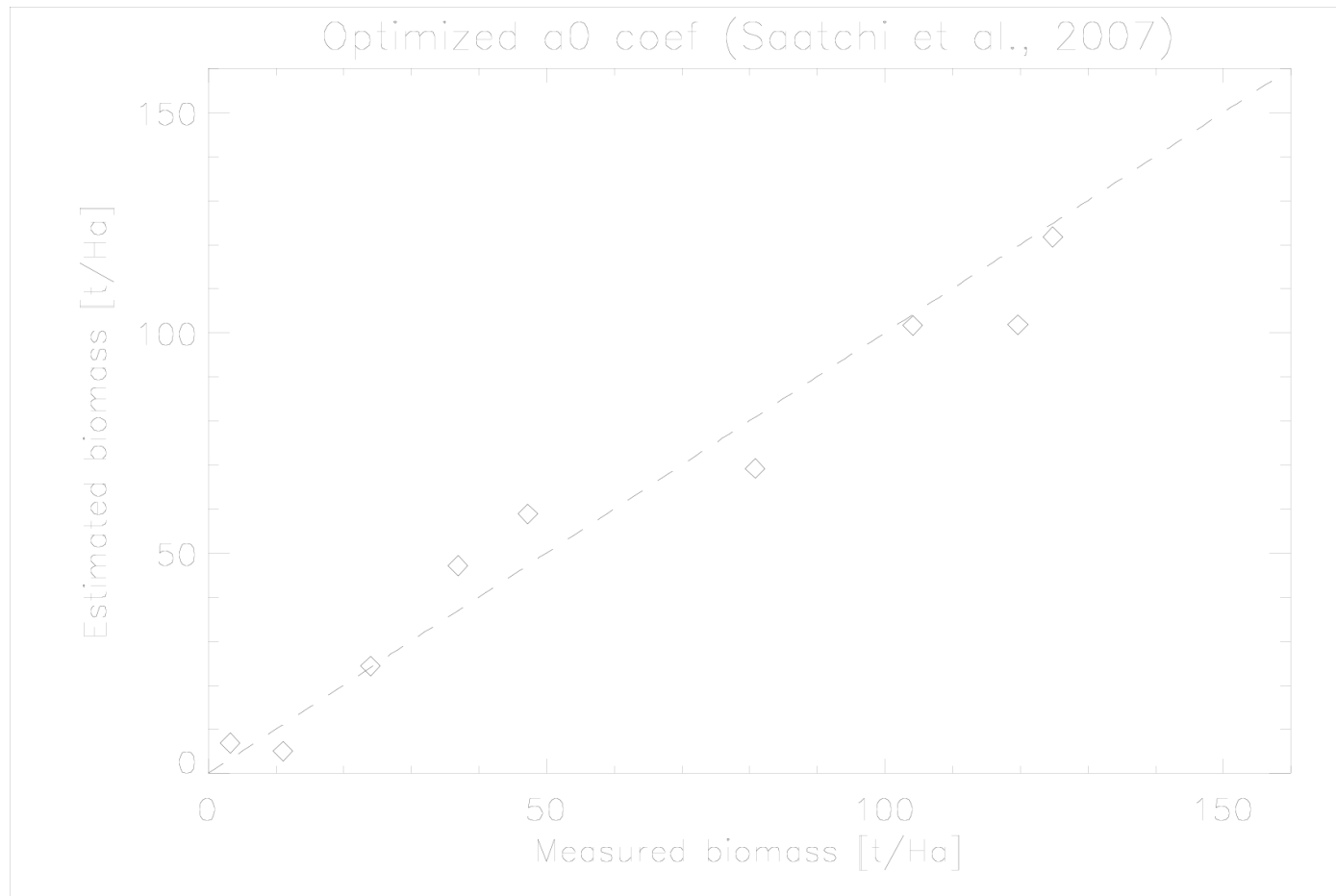
Crown biomass



Stem biomass



# Landes AIRSAR



RMSE= 10 tons/ha



Information Product	Mission Requirements	
Forest Biomass (above ground)	<ul style="list-style-type: none"> <li>• 20% accuracy</li> <li>• 100-300m resolution/16 looks</li> <li>• 2 biomass maps/year</li> <li>• Polarimetric Interferometric mode</li> <li>• Global coverage of forests</li> </ul>	
Forest Disturbance	<ul style="list-style-type: none"> <li>• Maps of disturbed area with 10% classification accuracy</li> <li>• 100m resolution/16 looks</li> <li>• 1-2 forest disturbance maps every 2 months</li> <li>• Global coverage of forests</li> </ul>	
Forest Regrowth	<ul style="list-style-type: none"> <li>• Biomass information 20% accuracy</li> <li>• Biomass rate of change – 20% accuracy</li> <li>• 100-200m resolution/16 looks</li> <li>• 2 revisits/year</li> <li>• Global coverage with focus on tropical forests</li> </ul>	
Forest seasonal floods	<ul style="list-style-type: none"> <li>• Inundation area information – 10% classification accuracy</li> <li>• 100m resolution/16 looks</li> <li>• 1 revisit/month during flood season</li> <li>• tropical forests (main target) + boreal wetlands (secondary target) for methane emission</li> </ul>	

## Final Remarks

- u There is a wealth of new data waiting to be exploited for better quantitative understanding of the terrestrial carbon cycle.
- u We are at the beginning of developing rigorous methods that consistently couple models and data through observation operators and data assimilation.
- u We need people to make this happen.

