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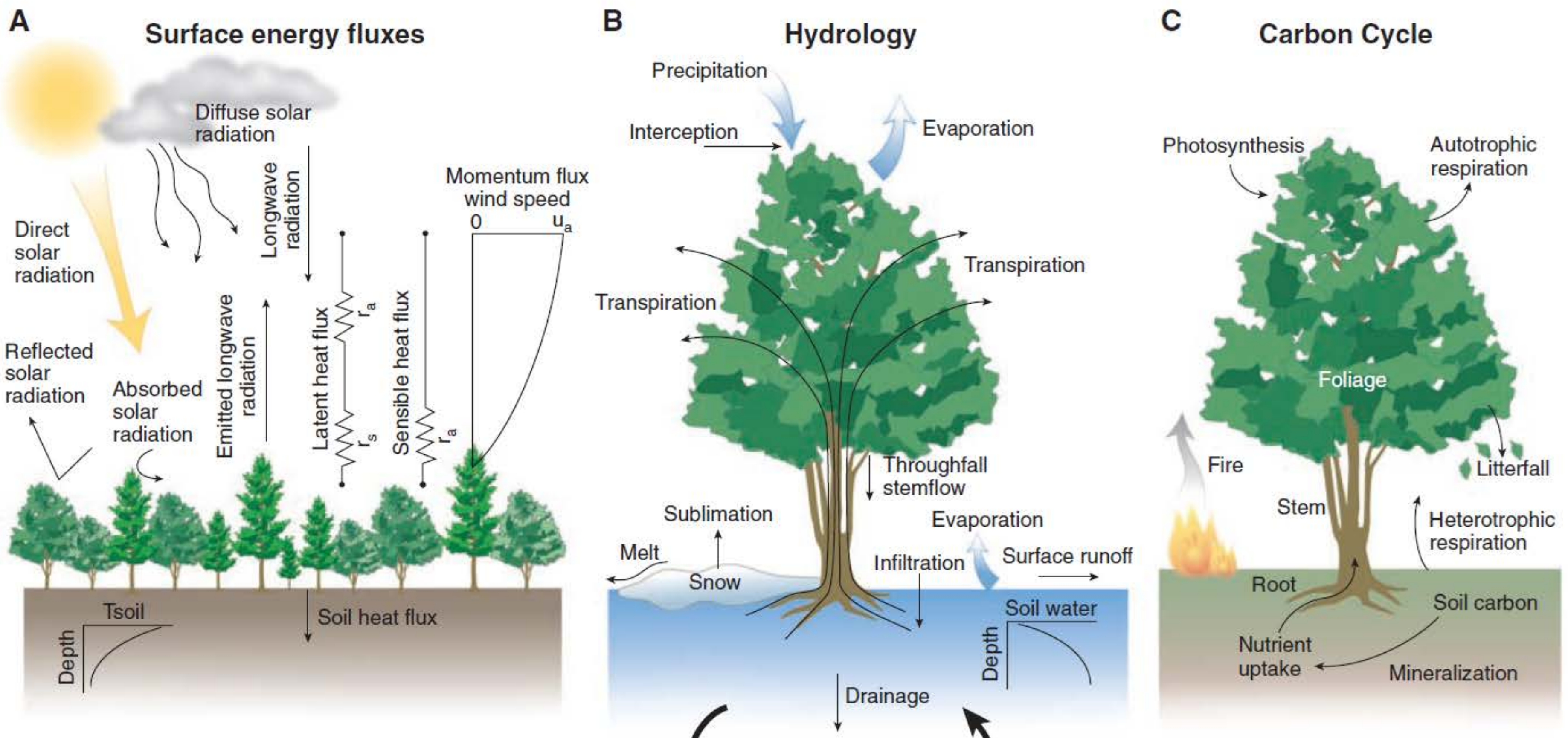
Earth Observation of Forests to Support the UN Sustainable Development Goals

Heiko Balzter

Member
Equality Challenge Unit

Spatial ecohydrology of forests



Bonan, G. (2008): Forests and Climate Change: Forcings, Feedbacks, and the Climate Benefits of Forests . *Science* 320 (5882), 1444-1449.

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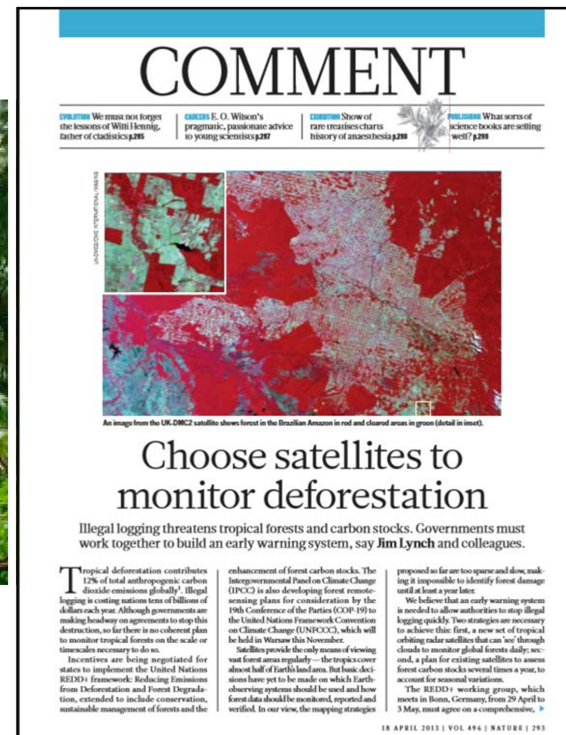
Monitoring and managing global forest resources

We are working to develop and deploy products and services derived from **satellite enabled data** to address the practical challenges of environmental management - as faced by global agencies and national states.

Our focus is addressing the management of tropical forests to stabilise the world's climate and protect biodiversity.

nature
International weekly journal of science



COMMENT

EVOLUTION We must not forget the lessons of Willi Hennig, father of cladistics p.295

CAREERS E. O. Wilson's pragmatic, passionate advice to young scientists p.297

EXHIBITION Show of rare treatises charts history of anaesthesia p.298

PUBLISHING What sorts of science books are selling well? p.299

An image from the UK-DMC2 satellite shows forest in the Brazilian Amazon in red and cleared areas in green (detail in inset).

Choose satellites to monitor deforestation

Illegal logging threatens tropical forests and carbon stocks. Governments must work together to build an early warning system, say **Jim Lynch** and colleagues.

Tropical deforestation contributes 12% of total anthropogenic carbon dioxide emissions globally[1]. Illegal logging is costing nations tens of billions of dollars each year. Although governments are making headway on agreements to stop this destruction, so far there is no coherent plan to monitor tropical forests on the scale or timescales necessary to do so.

Incentives are being negotiated for states to implement the United Nations REDD+ framework: Reducing Emissions from Deforestation and Forest Degradation, extended to include conservation, sustainable management of forests and the enhancement of forest carbon stocks. The Intergovernmental Panel on Climate Change (IPCC) is also developing forest remote-sensing plans for consideration by the 19th Conference of the Parties (COP-19) to the United Nations Framework Convention on Climate Change (UNFCCC), which will be held in Warsaw this November.

Satellites provide the only means of viewing vast forest areas regularly — the tropics cover almost half of Earth's land area. But basic decisions have yet to be made on which Earth-observing systems should be used and how forest data should be monitored, reported and verified. In our view, the mapping strategies proposed so far are too sparse and slow, making it impossible to identify forest damage until at least a year later.

We believe that an early warning system is needed to allow authorities to stop illegal logging quickly. Two strategies are necessary to achieve this: first, a new set of tropical orbiting radar satellites that can 'see' through clouds to monitor global forests daily; second, a plan for existing satellites to assess forest carbon stocks several times a year, to account for seasonal variations.

The REDD+ working group, which meets in Bonn, Germany, from 29 April to 3 May, must agree on a comprehensive,

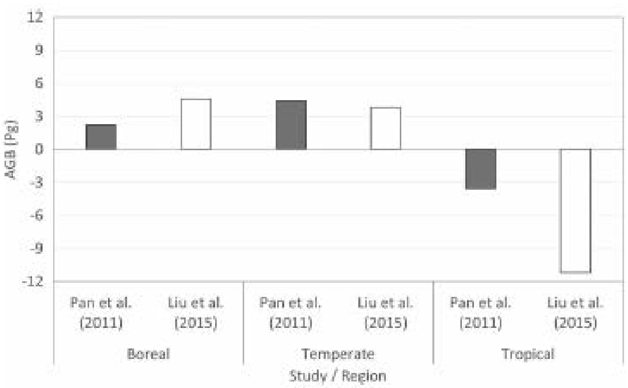
18 APRIL 2013 | VOL 496 | NATURE | 293

Lynch, J., Maslin, M., Balzter, H. and Sweeting, M. (2013): Sustainability: Choose satellites to monitor deforestation, *Nature* 496, 293-294

Uncertainties in tropical forest biomass maps

- Estimates of biomass stocks and change vary widely between different studies.
- **Uncertainties need to be reduced.**

Change 2000-2007:



Rodriguez-Veiga, P., Wheeler, J., Louis, V., Tansey, K. and Balzter, H. (2017): Quantifying forest biomass carbon stocks from space. *Current Forestry Reports* 3(1), 1-18. https://link.springer.com/article/10.1007/s40725-017-0052-5

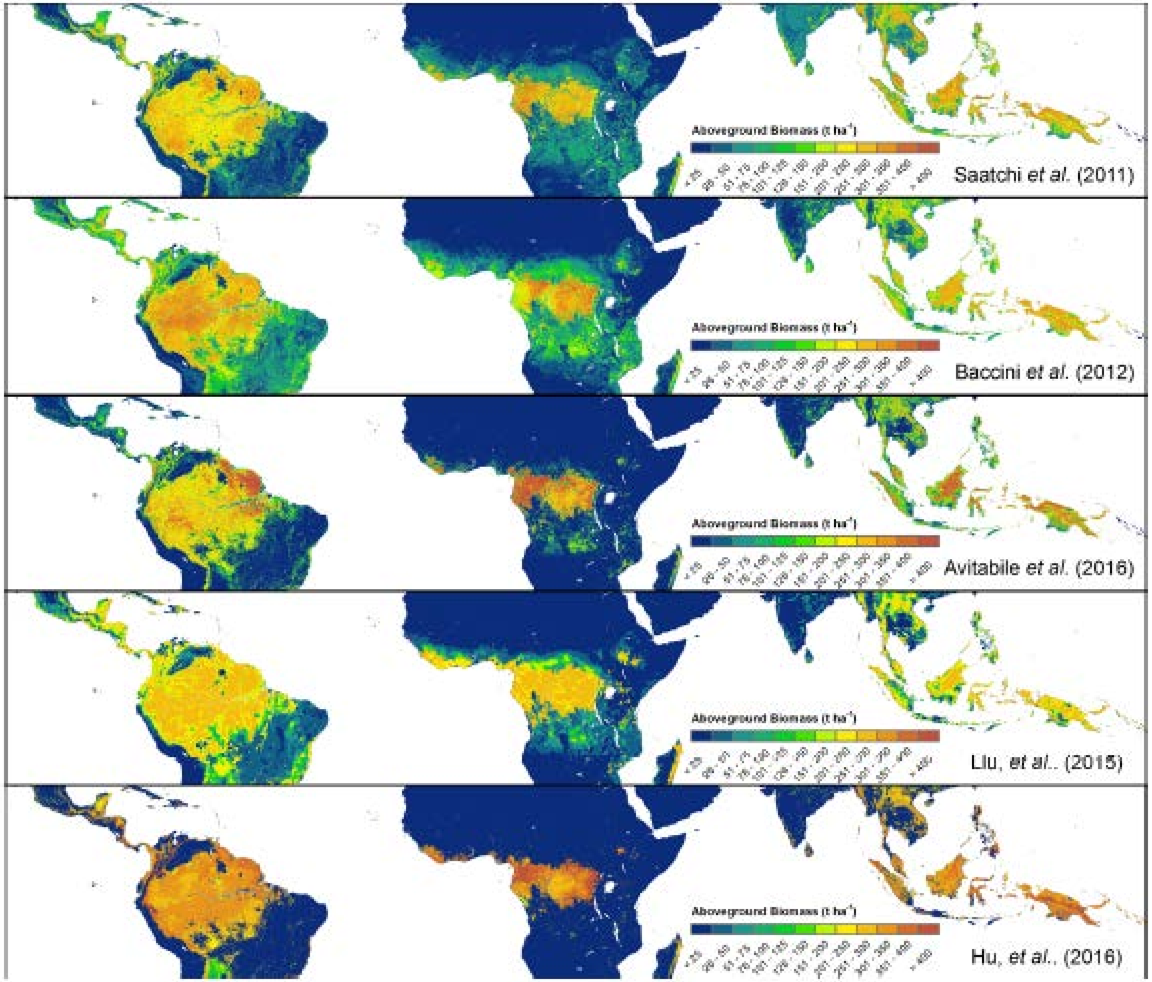


Fig. 2 Pantropical carbon maps from Saatchi et al. [15••], Baccini et al. [13] and the fused version from Avitabile et al. [95•]. Global maps from Hu et al. [97] and Liu et al. [72••] are also displayed over the pantropical area

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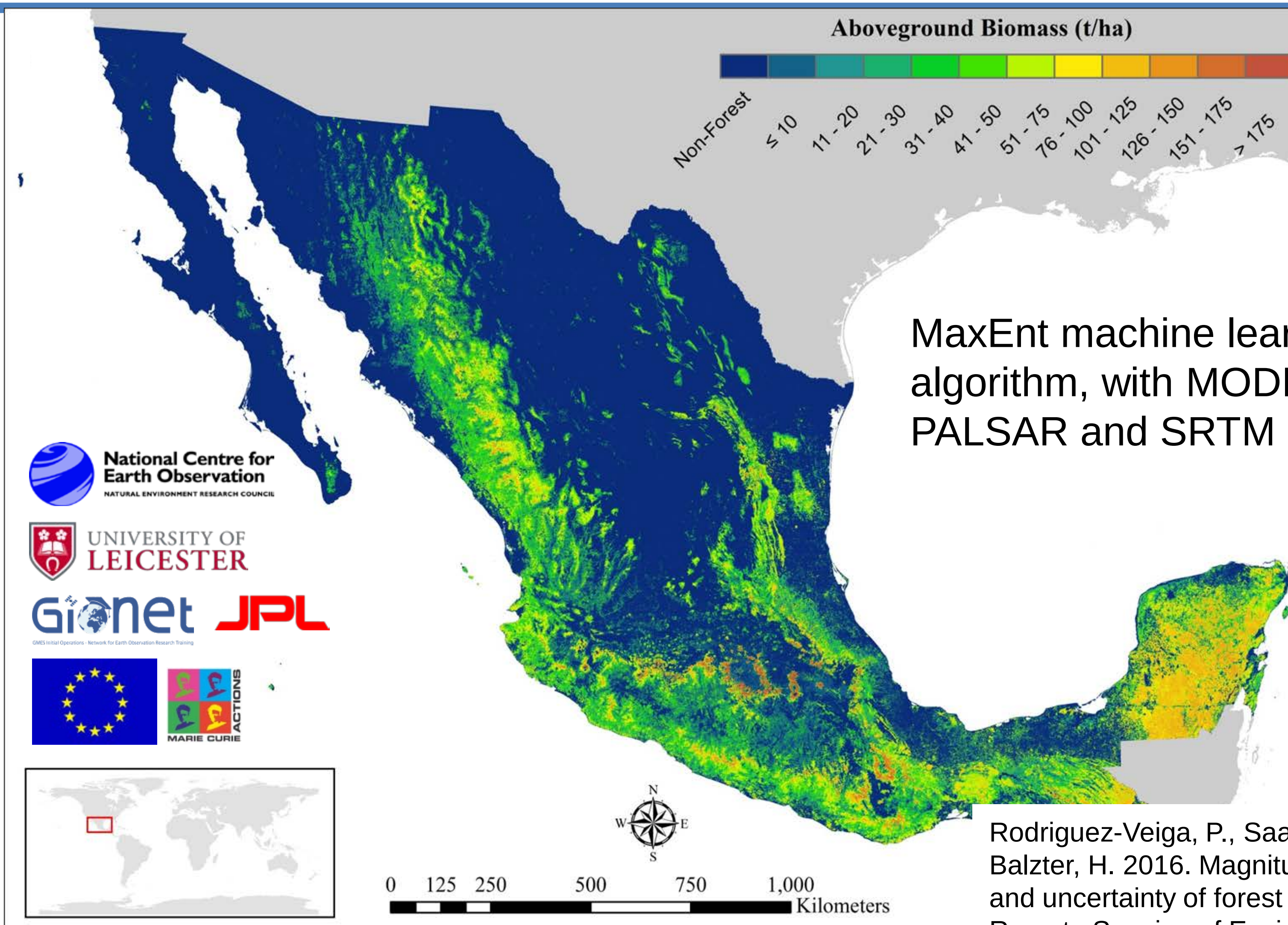
Forest Biomass in Mexico at 250m resolution

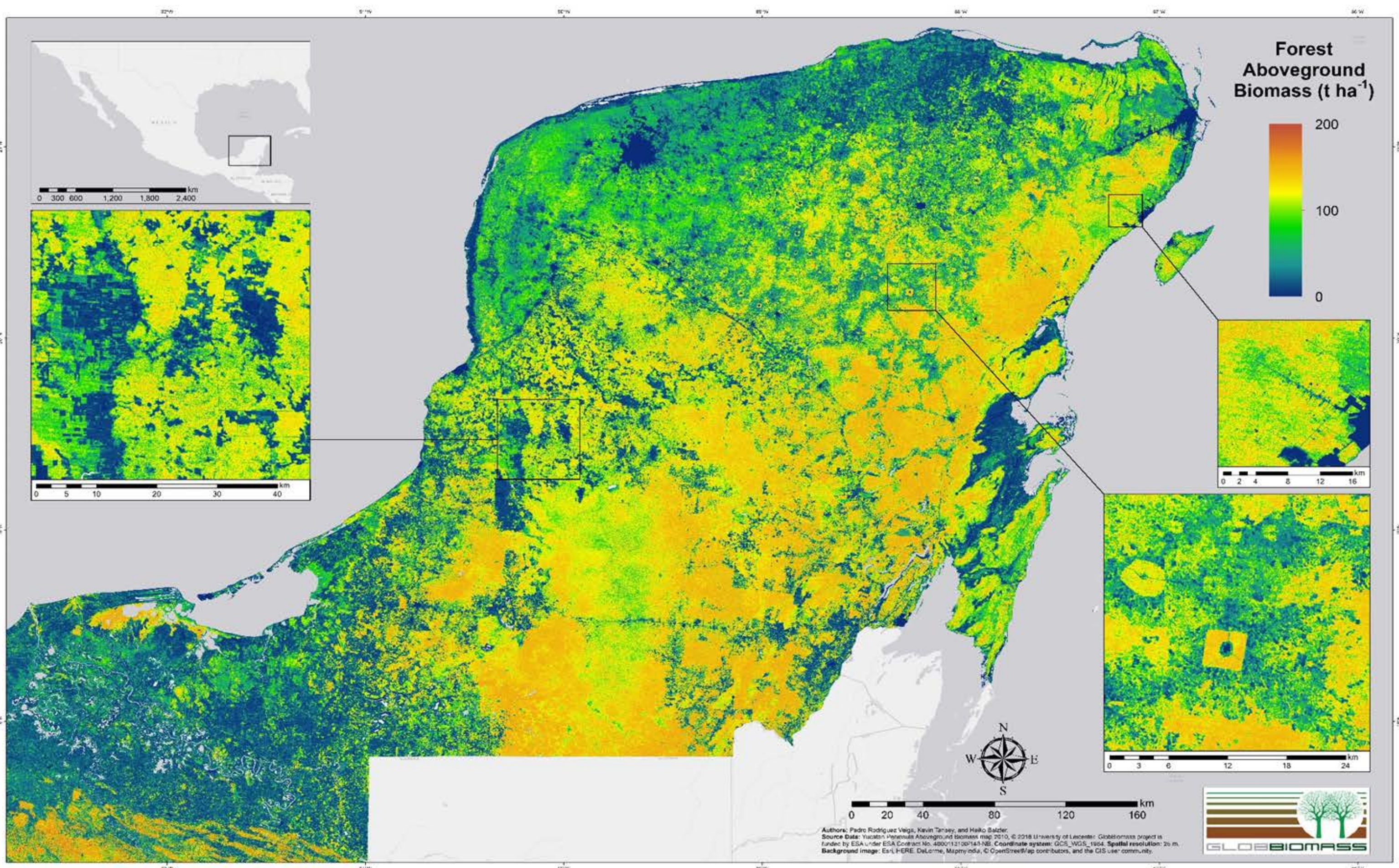


MaxEnt machine learning algorithm, with MODIS, ALOS-PALSAR and SRTM DEM as inputs

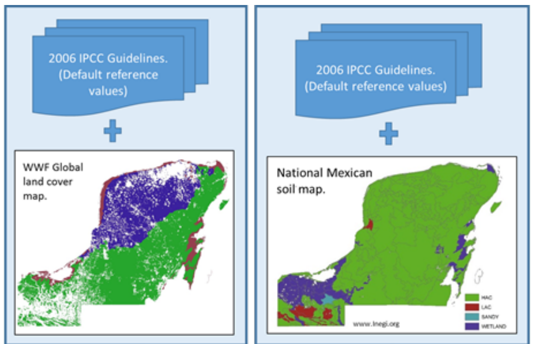
Rodriguez-Veiga, P., Saatchi, S., Tansey, K. & Balzter, H. 2016. Magnitude, spatial distribution and uncertainty of forest biomass stocks in Mexico. Remote Sensing of Environment, 183, 265-281.

Yucatan Peninsula biomass map 2010, 25 m resolution

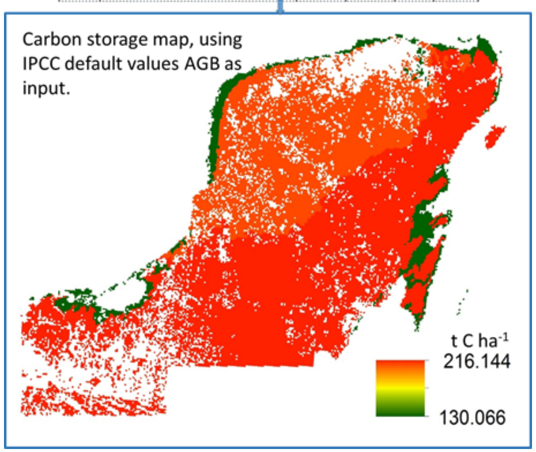
- Improved spatial resolution to 25 m
- Multi-sensor machine learning approach (MaxEnt) with optical and SAR data

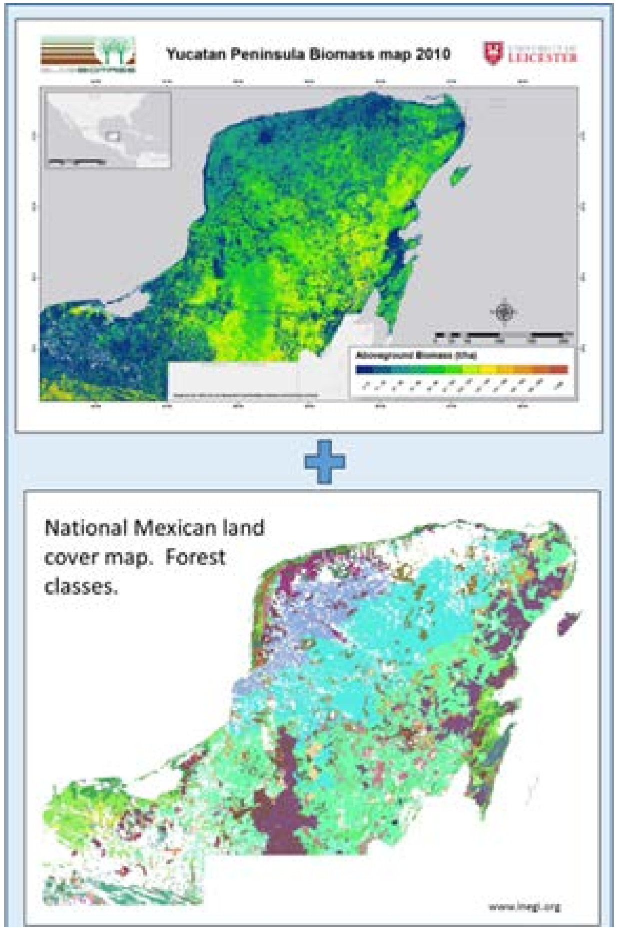


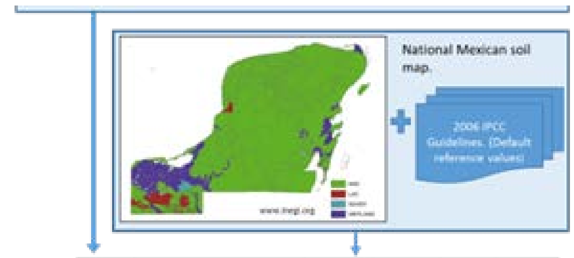
Forest biomass from EO for ecosystem services accounting



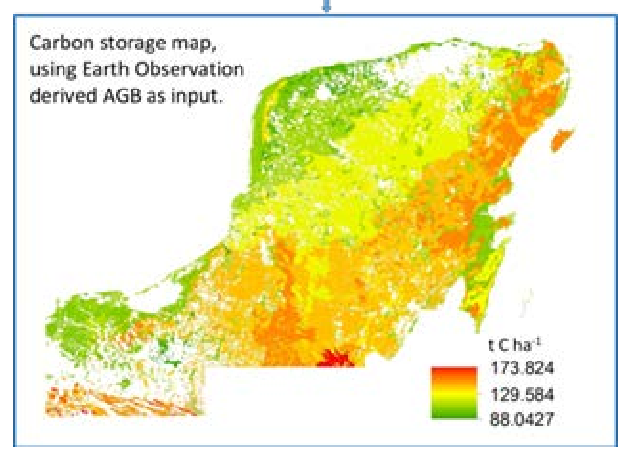
lucode	LULC	C_above	C_below	C_soil	C_dead
1	Tropical & Subtropical Moist Broadleaf Forests	105.6	25.344	67	18.2
2	Tropical & Subtropical Dry Broadleaf Forests	100.8	28.224	64.8	18.2
14	Mangroves	44.16	12.8064	73.1	0







lucode	LULC	C_above	C_below	C_soil	C_dead
1	Bosque mesã'filo de montaã	61.2	29.3	65.0	18.2
2	Manglar	15.1	7.2	72.5	18.2
3	Bosque cultivado	12.1	5.8	56.2	18.2



GLOBBIOMASS data can be used with the InVEST carbon storage model to assess this ecosystem service. Average biomass from EO per land cover class (Mexican classification system) allows more realistic representation of ecosystem services.

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NCEO, Official Development Assistance (ODA) Programme

EO research for land-atmosphere services in DAC Countries

WP1 Soil moisture and drought in the Horn of Africa

WP2 Forest carbon stocks and deforestation processes in East Africa

WP3 Landscape burning and large-scale air quality in Asia

WP4 Delivering UK EO knowledge at international agency level

- **NCEO's research contributes to the UN 2030 Agenda for Sustainable Development:** Goals 2 (WP1 aims at food security and sustainable agriculture), 6 (WP1 aims at sustainable water management),
- Goals 3 (WP3 aims at healthy lives and clean air),
- Goals 13 (WP2 aims at climate mitigation by reducing deforestation), 15 (WP1 and WP2 are protecting, restoring and promoting sustainable use of agricultural and forest ecosystems)
- Goal 17 (WP4 is strengthening the implementation of the Global Partnership for Sustainable Development).

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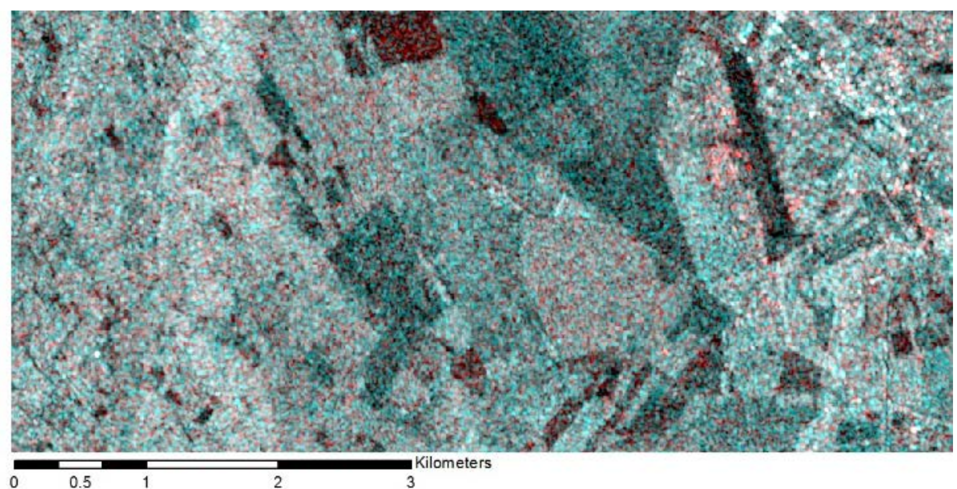
Comparison of sensors

Landsat 7

Landsat 8

Sentinel-2

Sentinel-1 SAR



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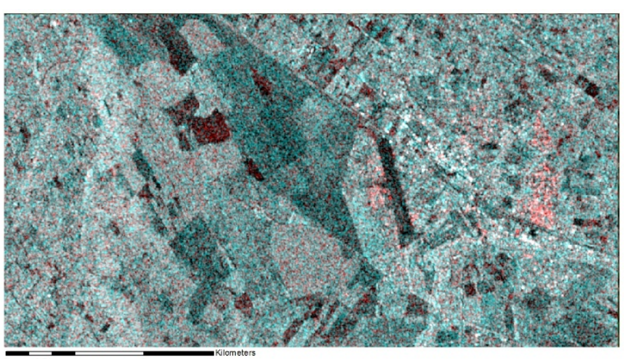
Sentinel-1 SAR

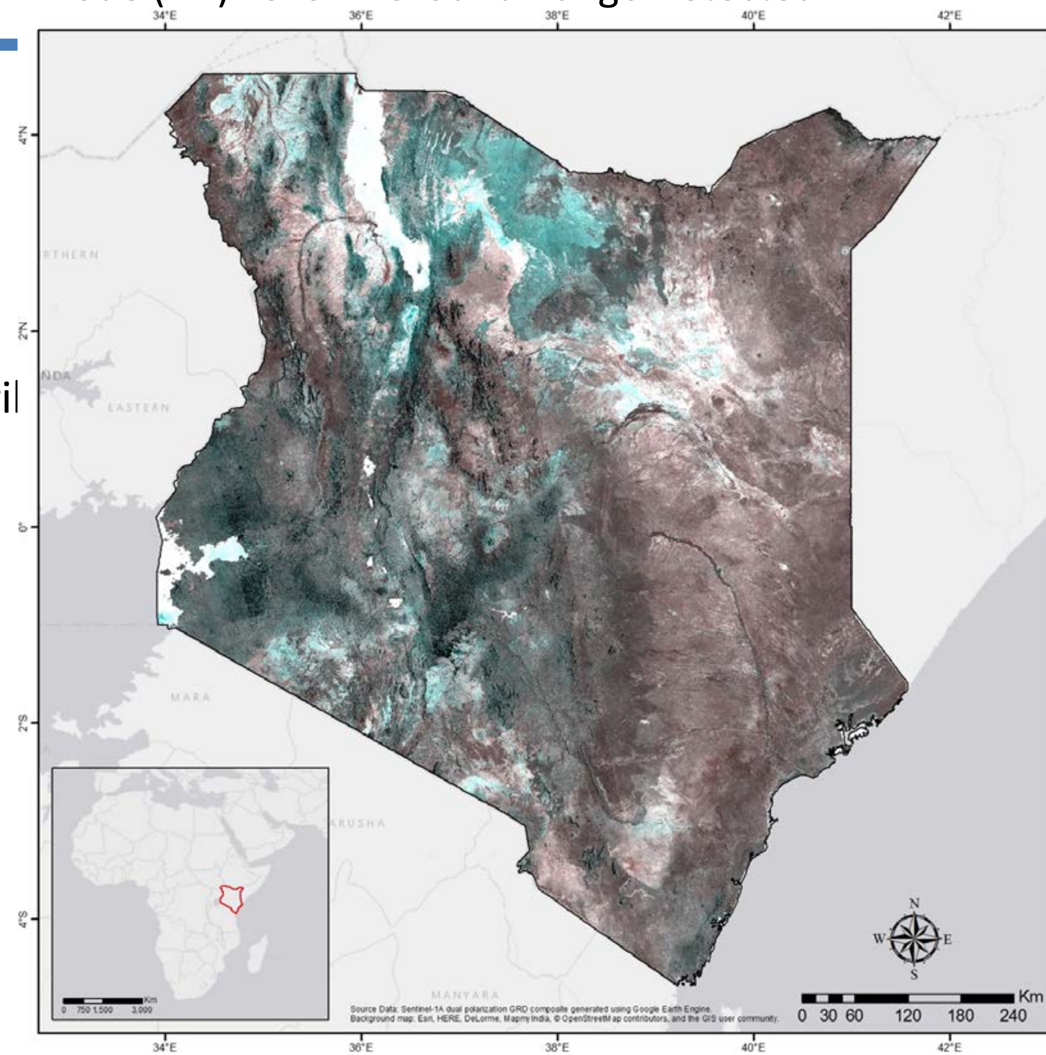
Interferometric Wide-Swath Mode (IW) Level-1 Ground Range Detected

Composite: 102 dual polarization (VV, VH) scenes

10 m pixel size

Temporal coverage: Dec 2014 - April 2016. 50 percentile.
Visualization: RGB (VV,VH,VH)





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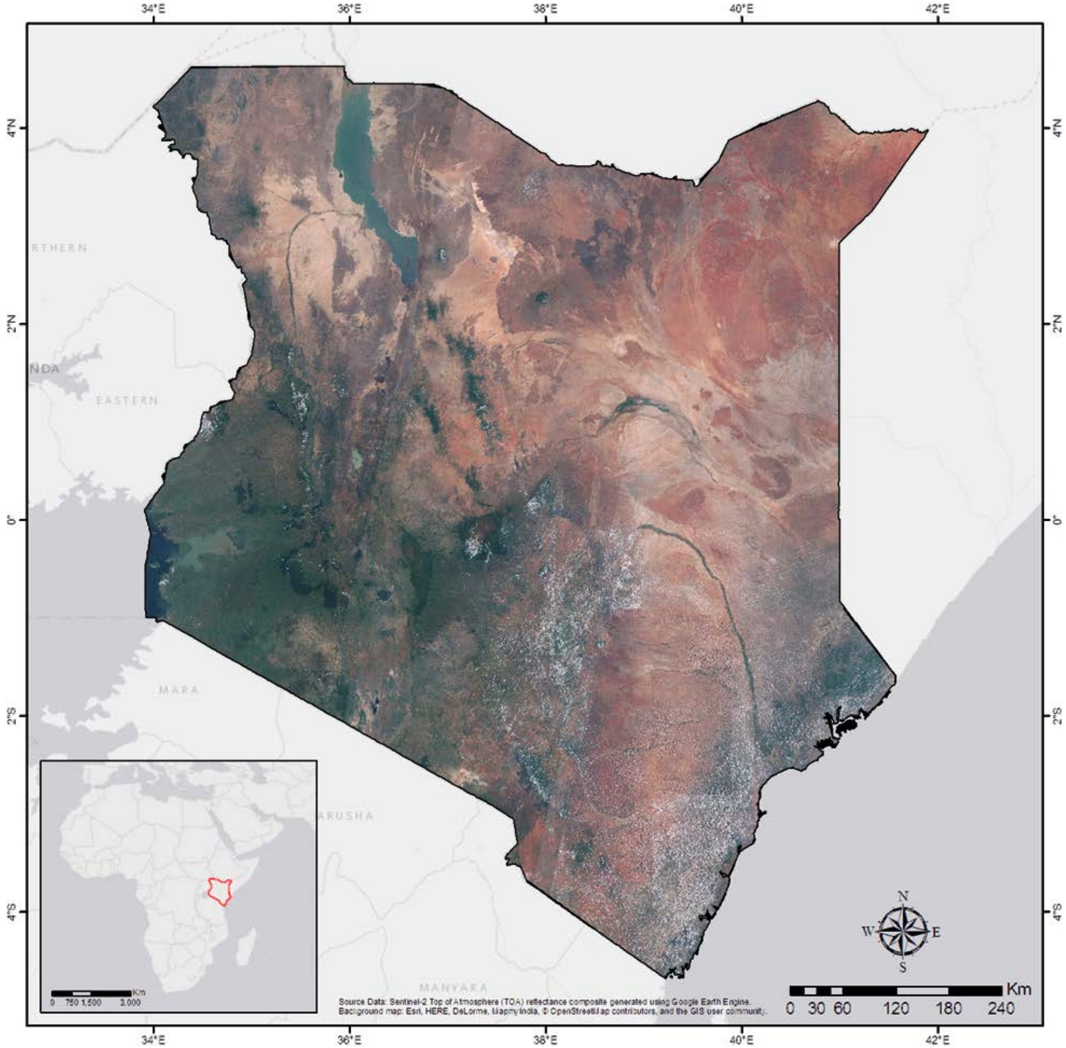
Sentinel-2 Top Of Atmosphere Reflectance

Composite: 892 TOA reflectance scenes

10 m pixel size.

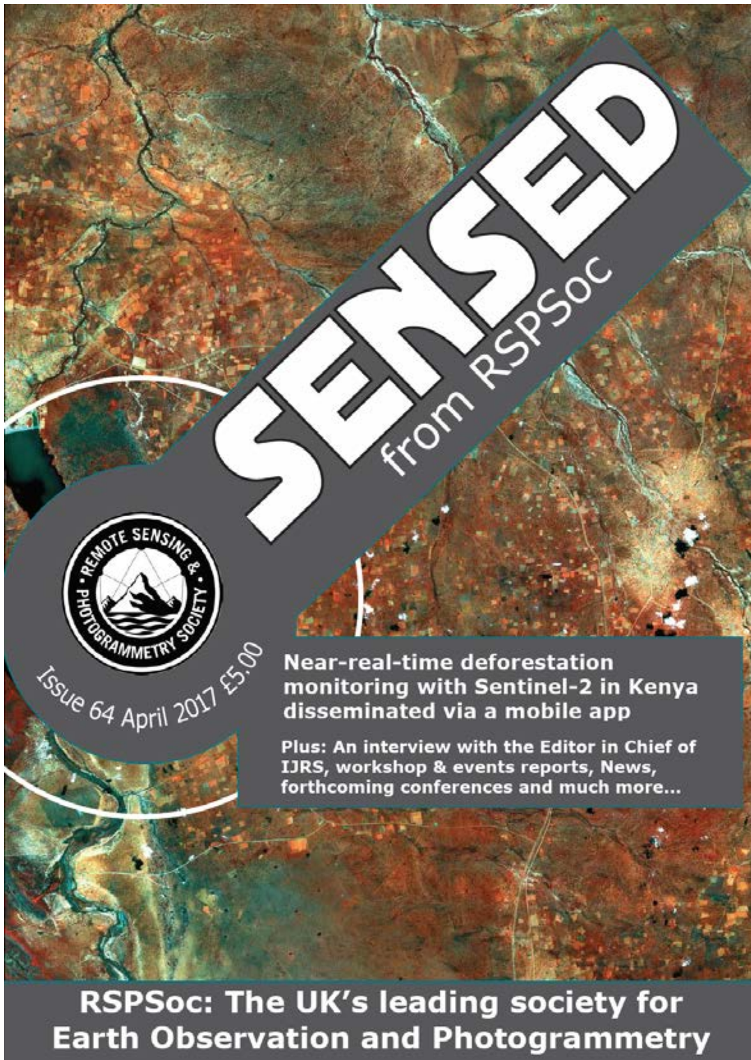
Temporal coverage: Jun 2015 - April 2016. 50 percentile. Visualization: RGB (4,3,2)

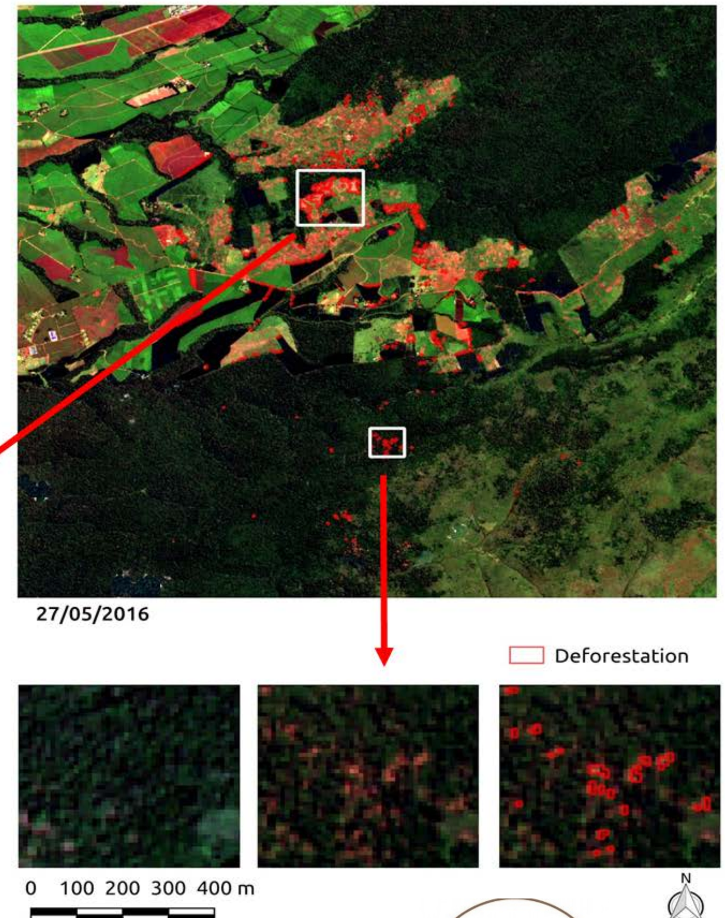


Forest Cover Change Detection in Kenya from Sentinel-2

Automated forest change detection every 5 days at 10 m resolution.
→ Rapid detection of deforestation and forest degradation

Copernicus masters
Finalist 2017





International Partnership: Forest 2020

https://ecometrica.com/forests2020

AIMS

- Improve forest monitoring systems in >6 developing countries
- Improve effectiveness of UK ICF forest investments
- Improve global forest monitoring practices for REDD+, timber trade ar livelihoods
- Strengthen UK collaborations in the application of science and technology to sustainability – **contribution to GFOI**
- A major effort to improve monitoring systems covering over 300 million hectares of tropical forests

Forests 2020: a £30m (£15m from UK) investment to advance the application of earth observation to forests in developing countries

International Climate Fund

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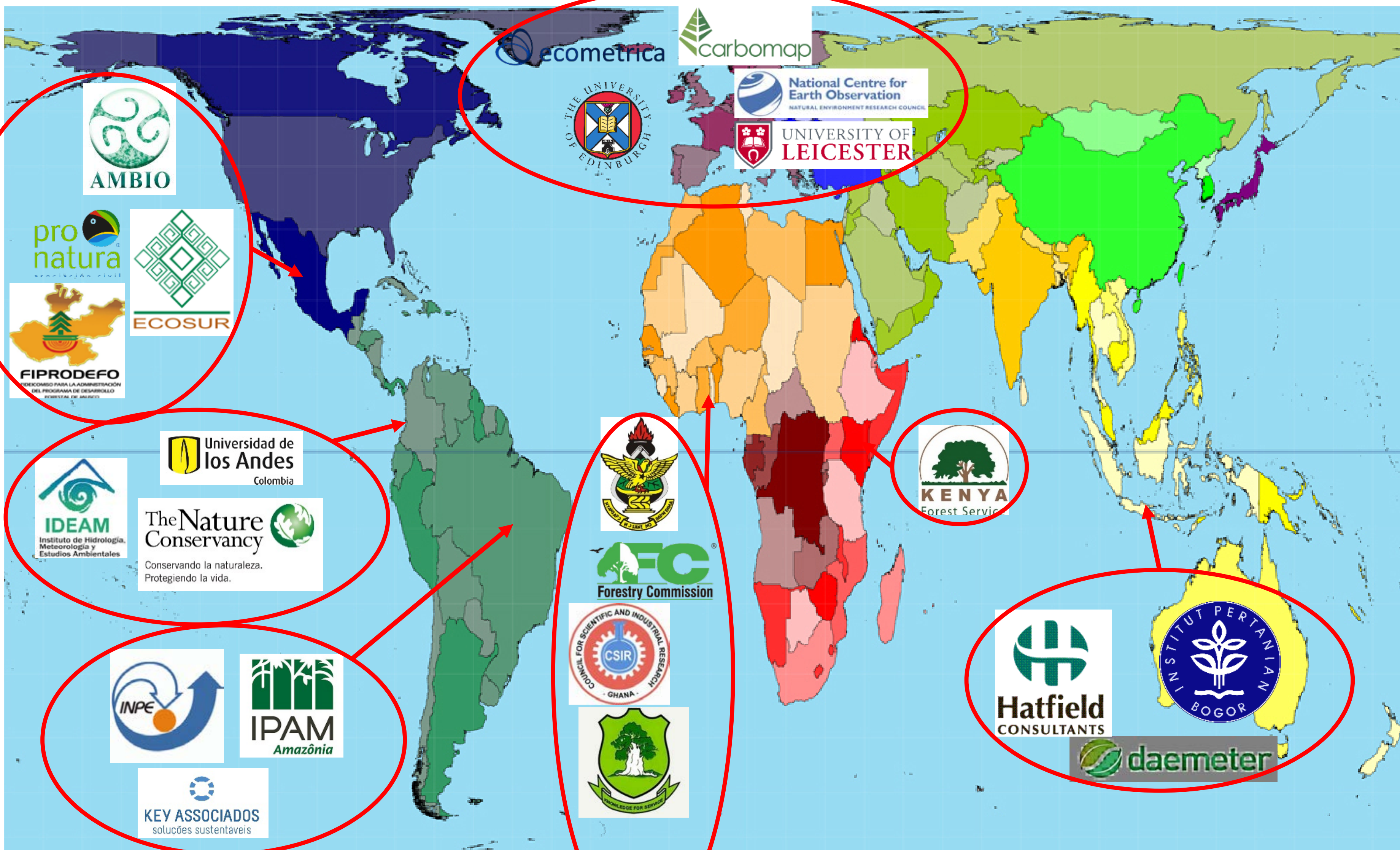
ecometrica
bringing clarity

Forests 2020 partners

carbomap



International Partnership: EASOS

- **During 2014, the combined impact on the Malaysian economy of flooding, marine pollution and illegal logging was estimated to be more than $12.5bn.**
- Delivering an integrated Earth and Sea Observing System addressing the needs of 23 Malaysian government agencies.
- Lead: Catapult. £8m overall budget.
- Partners: Janus TCD, Stevenson Astrosat, Geocento, Ambiental, Plymouth Marine Laboratories, AutoNaut, Riskaware, Telespazio VEGA, Earth Observation Inc, University of Leicester, Sterling Geo, Oxford University and eOsphere.

EASOS EARTH AND SEA OBSERVATION SYSTEM

Looking ahead:
Geomorphometry for retrieval of tropical forest structure

- In Tapajos, geomorphometric variables are indicators of tropical forest structure.
- Basal Area (BA), Height (H) and Canopy Openness (CO) were estimated:

$RMSE_{BA}$ = 3.73 m^2/ha (20%)

$RMSE_{H}$ = 1.70 m (12%)

$RMSE_{CO}$ = 1.78% (21%)

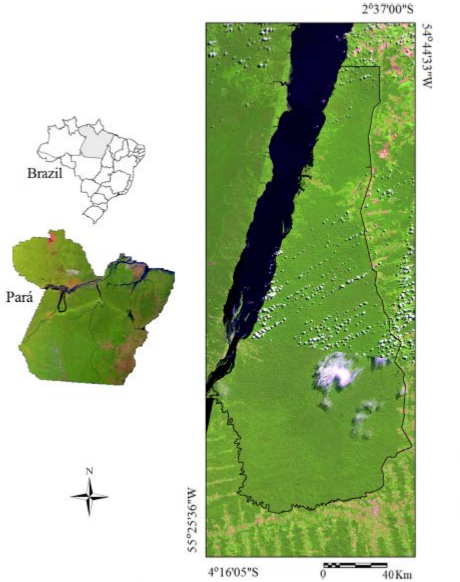


Fig 1. Study area in the Tapajós National Forest.

doi:10.1371/journal.pone.0152009.g001

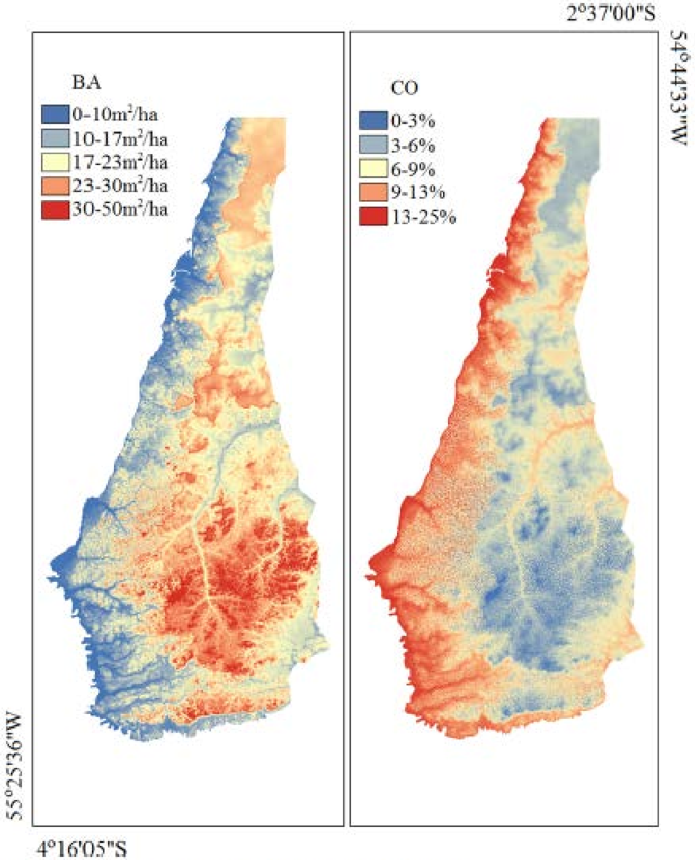


Fig 3. Maps of estimated BA and CO for Tapajós National Forest.

doi:10.1371/journal.pone.0152009.g003

Da Conceição Bispo, P., dos Santos, J.R., de Morisson Valeriano, M., Lima de Alencastro Graça, P.M., Balzter, H., França, H. and da Conceição Bispo, P. (2016): Predictive models of primary tropical forest structure from geomorphometric variables based on SRTM in the Tapajós region, Brazilian Amazon, *PLoS ONE* 11(4), e0152009. http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0152009

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Forest canopy structure from LiDAR

The California Rim Fire started in a remote canyon in Stanislaus National Forest on 17 August 2013 from an illegal campfire. It burned >1000 km^2 and firefighting costs exceeded $127 million.

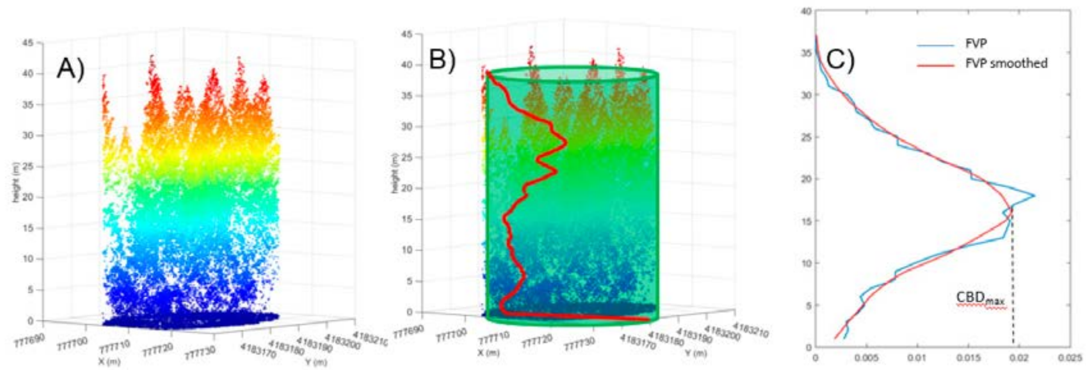
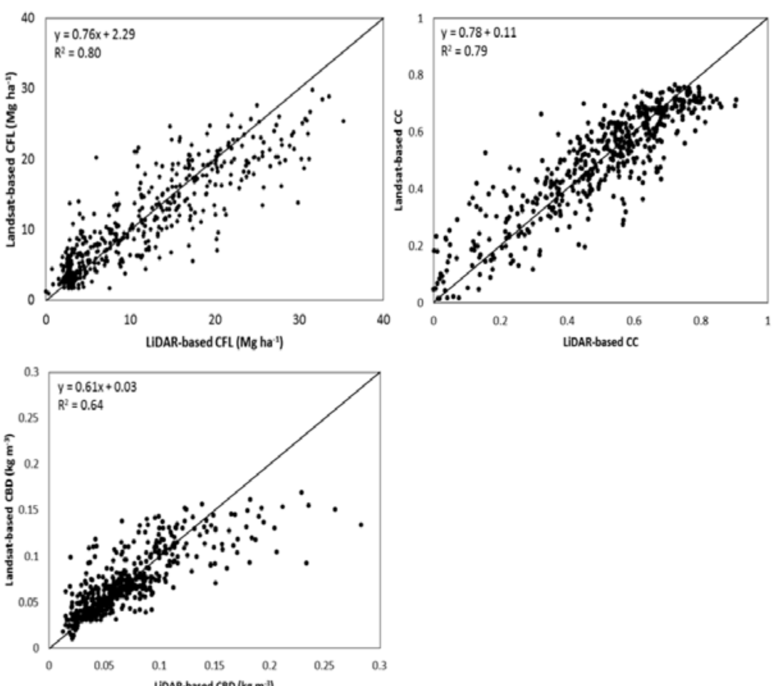


Figure 2. Schematic representation of the method used to estimate canopy bulk density (CBD) from the airborne LiDAR data. (**A**) LiDAR point cloud of a 0.09 ha plot; (**B**) Vertical distribution of canopy elements derived from the LiDAR pseudo-waveform; (**C**) Derivation of the fuel vertical profile from LiDAR data and estimation of CBD using the maximum of the smoothed FVP.



Estimating canopy fuel load (CFL), canopy cover (CC) and canopy bulk density (CBD) from LiDAR point clouds.

García, M., Saatchi, S., Casas, A., Koltunov, A., Ustin, S.L., Ramirez, C. and Balzter, H. (2017): Extrapolating Forest Canopy Fuel Properties in the California Rim Fire by Combining Airborne LiDAR and Landsat OLI Data. *Remote Sensing* 9(4), 394. http://www.mdpi.com/2072-4292/9/4/394

Detecting invasive tree diseases

- Invasive tree diseases are of increasing concern for forest managers.
- Airborne Light Detection and Ranging (LiDAR) provides structural information about forests.
- *Phytophthora ramorum* infections in Larch forests lead to fragmented canopy structure (right image)

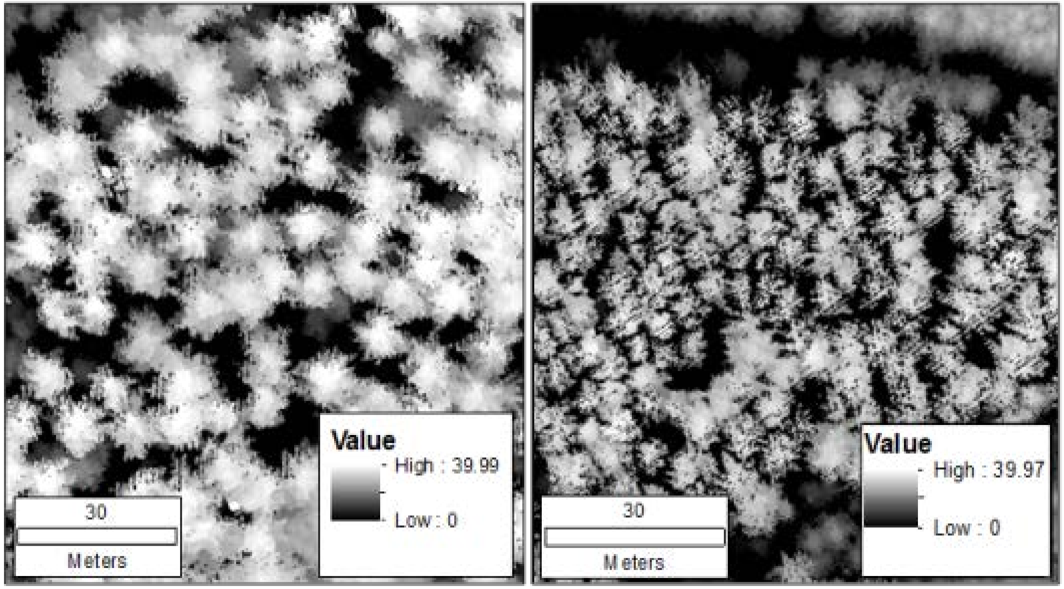
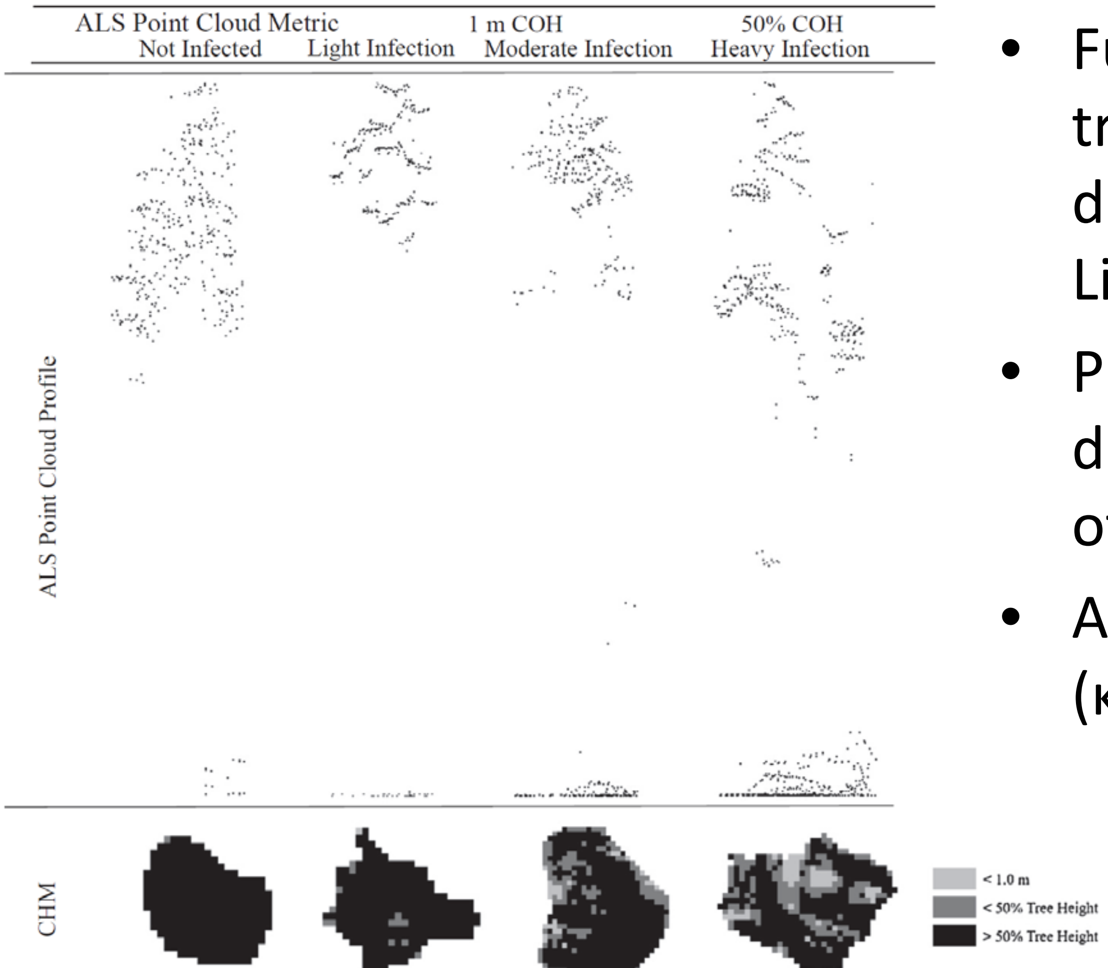


Figure 1 – Left: CHM for healthy stand of larch (*Larix decidua*). Right: CHM for stand of larch (*Larix kaempferi*) infected with *P. ramorum*.

Barnes, C., Balzter, H., Barrett, K., Eddy, J., Milner, S. and Suarez, J. (2017): Individual Tree Crown Delineation from Airborne LiDAR for Diseased Larch Forest Stands, *Remote Sensing* 9(3), 231.
http://www.mdpi.com/2072-4292/9/3/231/pdf

Crown structure of diseased trees



- Fungal infections of Larch trees in Wales were detected from airborne LiDAR (k-NN method)
- Principle: Impact of the diseases on fragmentation of the tree crown
- Accuracy up to 72% (κ=0.32)

Barnes, C., Balzter, H., Barrett, K., Eddy, J., Milner, S. and Suárez, J.C. (2017): Airborne laser scanning and tree crown fragmentation metrics for the assessment of Phytophthora ramorum infected larch forest stands, *Forest Ecology and Management*, 404, 294-305.

Conclusion

- Forests provide a whole host of ecosystem services, including freshwater provision, carbon capture and storage and clean air.
- Rapid detection of deforestation can form an important element in National REDD+ Strategies and Implementation Plans, and benefit socio-economic and environmental development in DAC countries.
- Capacity building, training and collaborative Earth Observation research can play an important role in official development assistance (ODA).
- The focus has to be on the benefits to the DAC country.

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Acknowledgements

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UK SPACE AGENCY

THE ROYAL SOCIETY

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European Environment Agency

NERC DOCTORAL TRAINING

STERLING GEO ENGINEERING GEOGRAPHY

THE NATIONAL TRUST

defra Department for Environment Food and Rural Affairs

EPSRC Pioneering research and skills

GEOSPATIAL INSIGHT LTD

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CATAPULT Satellite Applications

Thank you

ODA principles

The OECD Development Assistance Committee (DAC) defines ODA as "those flows to countries and territories on the DAC List of ODA Recipients and to multilateral institutions which are:

i. provided by official agencies, including state and local governments, or by their executive agencies; and

ii. each transaction of which:

a) is administered with the promotion of the economic development and welfare of developing countries as its main objective; and

b) is concessional in character and conveys a grant element of at least 25 per cent (calculated at a rate of discount of 10 per cent)."

UN Sustainable Development Goal 13: Climate Action

TARGETS	INDICATORS
13.1 Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries	13.1.1 Number of countries with national and local disaster risk reduction strategies 13.1.2 Number of deaths, missing persons and persons affected by disaster per 100,000 people
13.2 Integrate climate change measures into national policies, strategies and planning	13.2.1 Number of countries that have communicated the establishment of an integrated policy/strategy/plan to mitigate and adapt to climate change […]
13.3 Improve education, awareness-raising and human and institutional capacity on climate change mitigation, adaptation, impact reduction and early warning	13.3.1 Number of countries that have integrated mitigation, adaptation, impact reduction and early warning into curricula 13.3.2 Number of countries that have built capacity to implement adaptation, mitigation & tech transfer […]
13.A Implement the commitment by developed-countries to mobilizing $100 billion annually by 2020 to address the needs of developing countries for mitigation actions and fully operationalize the Green Climate Fund […]	13.A.1 Mobilized amount of United States dollars per year starting in 2020 accountable towards the $100 billion commitment
13.B Promote mechanisms for raising capacity for effective climate change-related planning and management in least developed countries and small island developing States […]	13.B.1 Number of least developed countries and small island developing States that are receiving specialized support, and amount of support for effective climate change-related planning and management […]

UN Sustainable Develop Goal 15: Life on Land

TARGETS	INDICATORS
15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements	15.1.1 Forest area as a proportion of total land area 15.1.2 Proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type
15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally	15.2.1 Progress towards sustainable forest management
15.3 By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world	15.3.1 Proportion of land that is degraded over total land area
15.4 By 2030, ensure the conservation of mountain ecosystems, including their biodiversity, in order to enhance their capacity to provide benefits that are essential for sustainable development	15.4.1 Coverage by protected areas of important sites for mountain biodiversity 15.4.2 Mountain Green Cover Index
15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species	15.5.1 Red List Index

UN Sustainable Develop Goal 15: Life on Land

TARGETS	INDICATORS
15.6 Promote fair and equitable sharing of the benefits arising from the utilization of genetic resources and promote appropriate access to such resources, as internationally agreed	15.6.1 Number of countries that have adopted legislative, administrative and policy frameworks to ensure fair and equitable sharing of benefits
15.7 Take urgent action to end poaching and trafficking of protected species of flora and fauna and address both demand and supply of illegal wildlife products	15.7.1 Proportion of traded wildlife that was poached or illicitly trafficked
15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species	15.8.1 Proportion of countries adopting relevant national legislation and adequately resourcing the prevention or control of invasive alien species
15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts	15.9.1 Progress towards national targets established in accordance with Aichi Biodiversity Target 2 […]
15.A Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems	15.A.1 Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems
15.B Mobilize significant resources from all sources and at all levels to finance sustainable forest management and provide adequate incentives to developing countries to advance such management, including for conservation and reforestation	15.B.1 Official development assistance and public expenditure on conservation and sustainable use of biodiversity and ecosystems
15.C Enhance global support to combat poaching and trafficking of protected species, including by increasing the capacity of local communities to pursue sustainable livelihood opportunities	15.C.1 Proportion of traded wildlife that was poached or illicitly trafficked

WP2: Forest carbon stocks and deforestation processes in East Africa

- ***Challenge:***
- Loss of forest (deforestation, degradation) is the second most important source of greenhouse gases after fossil fuel burning.
- Huge losses of ecosystem services result to national economies.
- Better biophysical information, with uncertainties, on forest resources are required to quantify and update national forest carbon accounts, and to report and verify REDD+ projects (Reducing Emissions from Deforestation and forest Degradation).
- *Our objective is to conduct a feasibility study into the utility of the latest EO-based carbon assessment methods to provide timely information to information users in-country.*

WP2 Forest carbon stocks and deforestation processes in East Africa

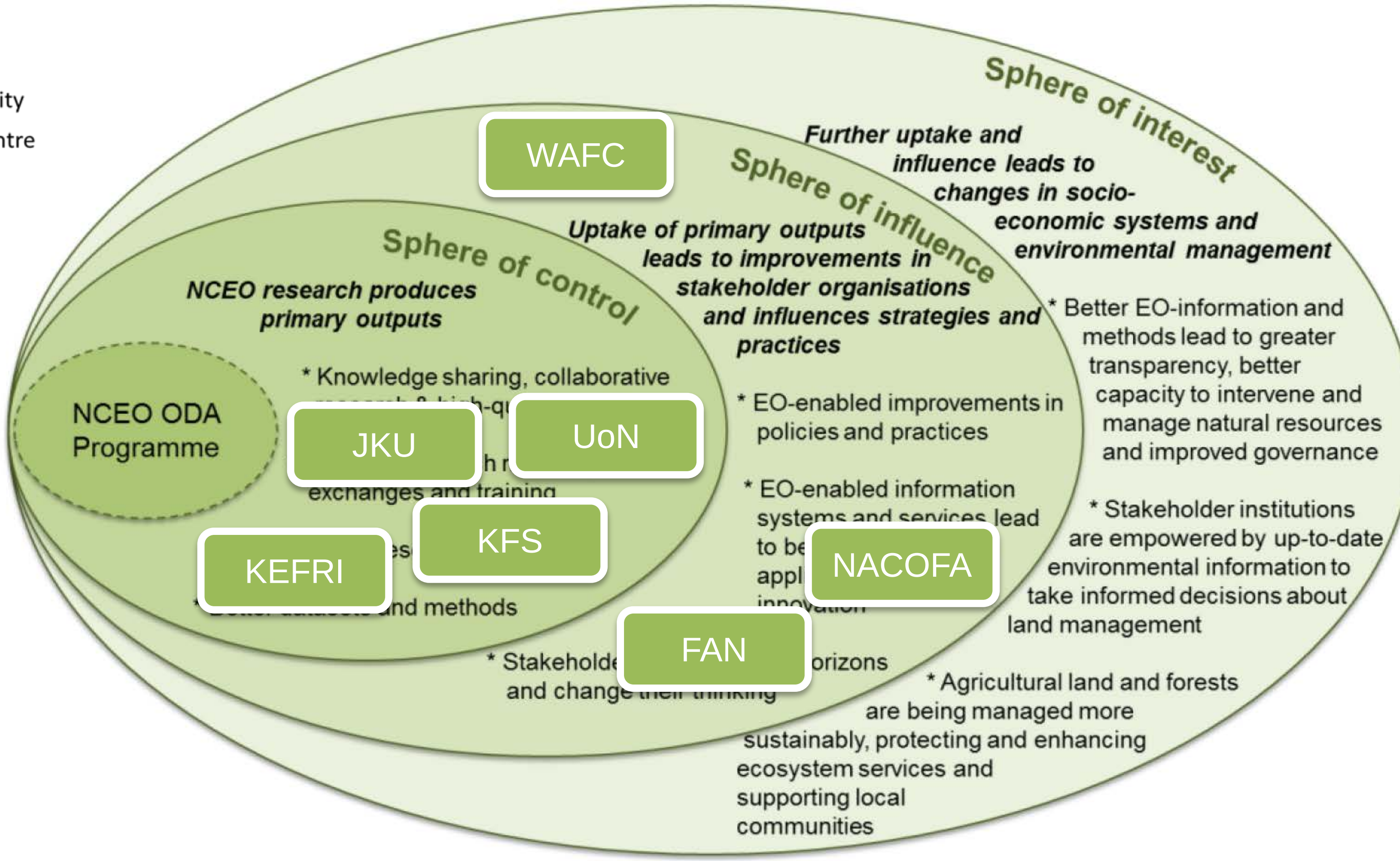
- ***Research action:***
- Investigate the suitability of new research using satellite data and models to assess both carbon pools and fluxes.
- Produce a baseline aboveground forest biomass map of Kenya from radar (ALOS-PALSAR 2) and multispectral imagery (Sentinel-2) using a machine learning algorithm (MaxEnt) and ICESAT-GLAS vertical canopy structure.
- Assessment of dynamic change through deforestation (and, if feasible, degradation) monitoring methods will utilise Landsat and Sentinel-2 (Sentinel-1 for persistently cloudy areas).
- A terrestrial carbon assimilation framework (CARDAMOM) will assimilate these EO data and incorporate carbon pools (e.g. soil carbon) from non-EO data, producing estimates of carbon stocks with uncertainties.

WP2 Stakeholders

KFS	Kenya Forest Service
KEFRI	Kenya Forest Research Institute
NACOFA	National Alliance of Community Forest Associations
FAN	Forest Action Network
UoN	University of Nairobi
JKU	Jomo Kenyatta University
WAFC	World Agroforestry Centre

Spheres of influence

KFS	Kenya Forest Service
KEFRI	Kenya Forest Research Institute
NACOFA	National Alliance of Community Forest Associations
FAN	Forest Action Network
UoN	University of Nairobi
JKU	Jomo Kenyatta University
WAFC	World Agroforestry Centre



Oil pollution in the Amazon

Hyperion satellite images can detect rainforest affected by oil spills under the canopy

Hydrocarbon pollution affects leaf chemistry (water content, chlorophyll content, leaf thickness)

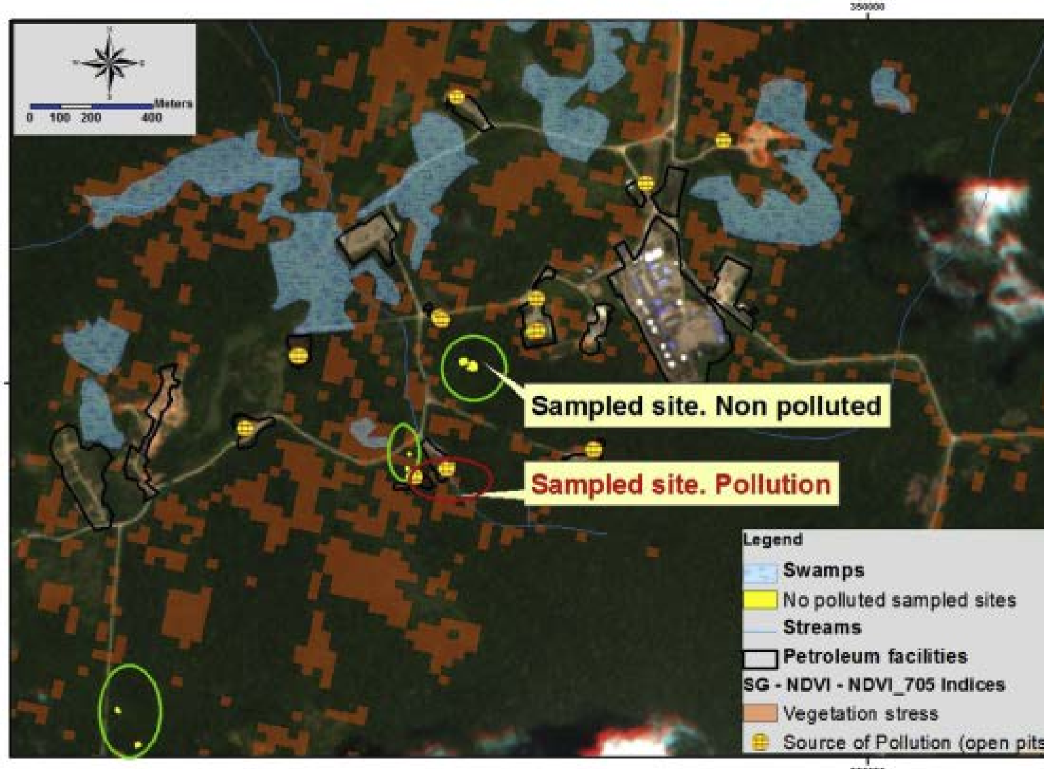


Fig. 12. Areas detected as vegetation stress in petroleum productive area. Open pits identified as source of pollution and RAPID EYE images (background) have been provided by t Environmental Ministry of Ecuador (PRAS-program).

Courtesy of Paul Arellano

Arellano, P., Tansey, K., Balzter, H. and Boyd, D. (2015): Detecting the effects of hydrocarbon pollution in the Amazon forest using hyperspectral satellite images. *Environmental Pollution* 205, 225–239.