ARRHENIUS: a Geostationary Carbon Process Explorer for Africa, Europe and the Middle-East

(ARRHENIUS = AbsoRption spectRometric patHfindEr for carboN regIonal flUx dynamicS)

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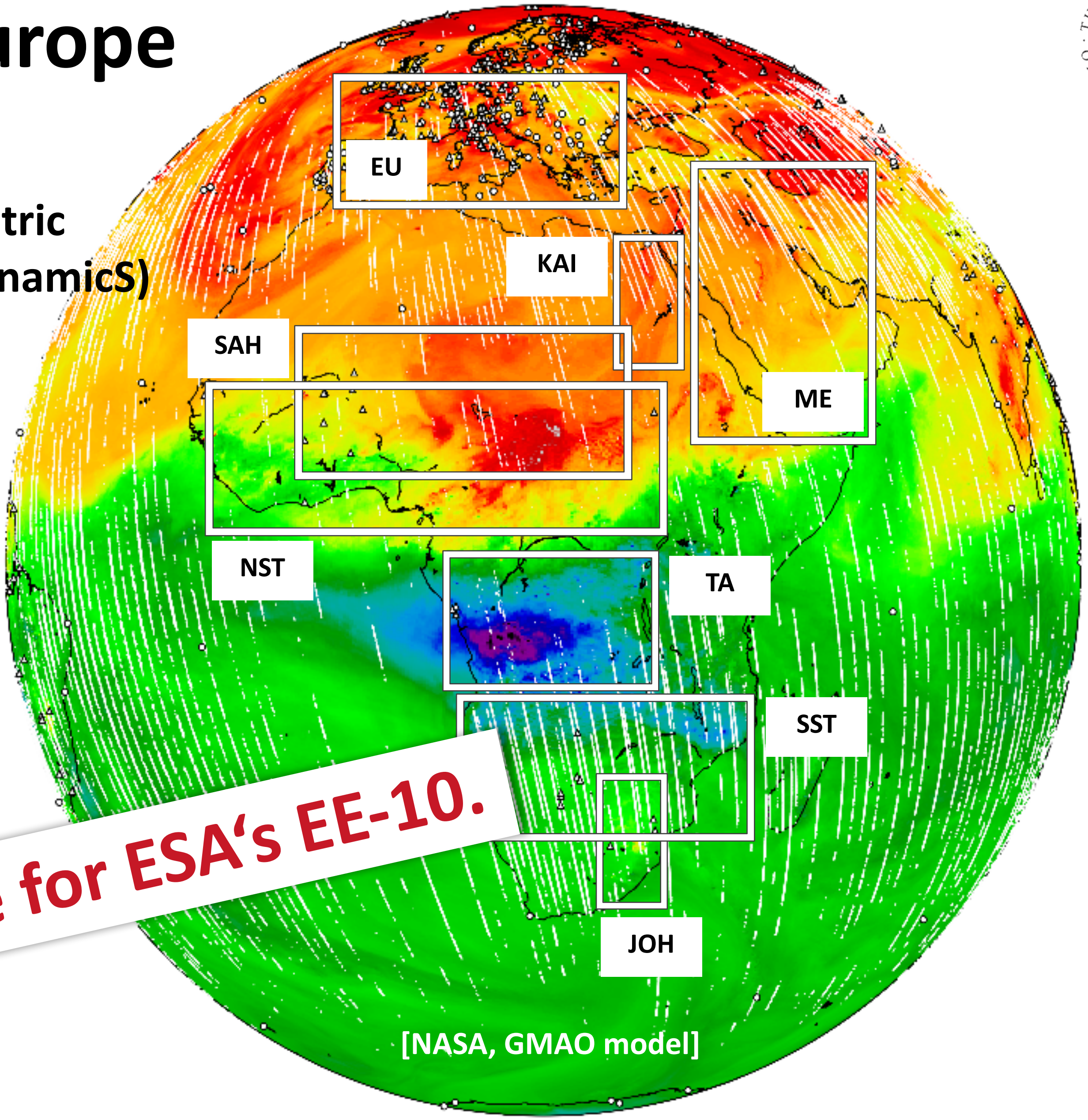

Candidate for ESA‘s EE-10.

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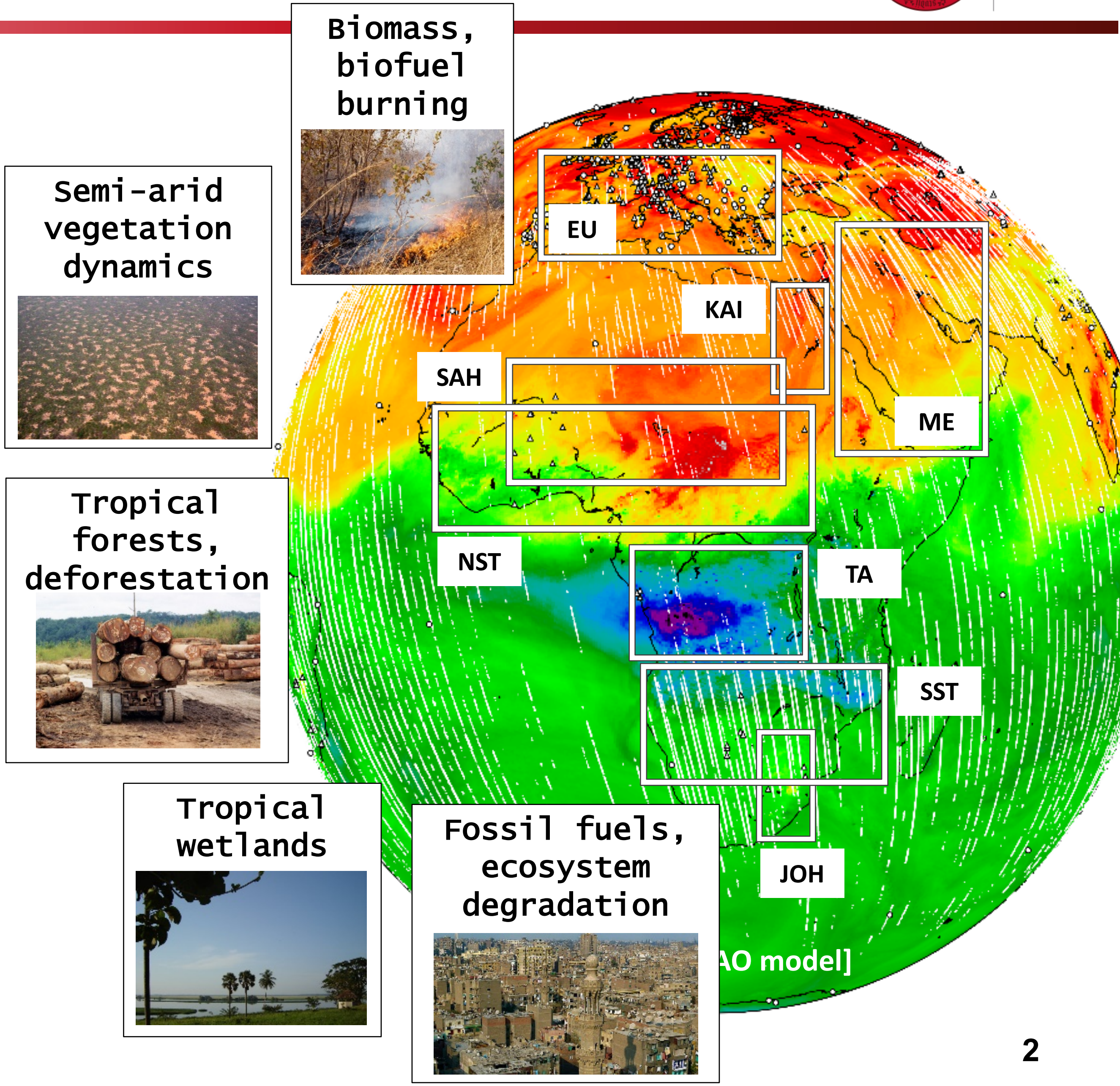
WHAT FOR?

- Understand **terrestrial carbon cycle processes** that determine the **global carbon sink**.
- **Quantify carbon-feedbacks** in response to **climatic, meteorological, and human forcing**.
- Ultimately, improve the **carbon cycle representation** in Earth System Models to estimate **climate sensitivity**.



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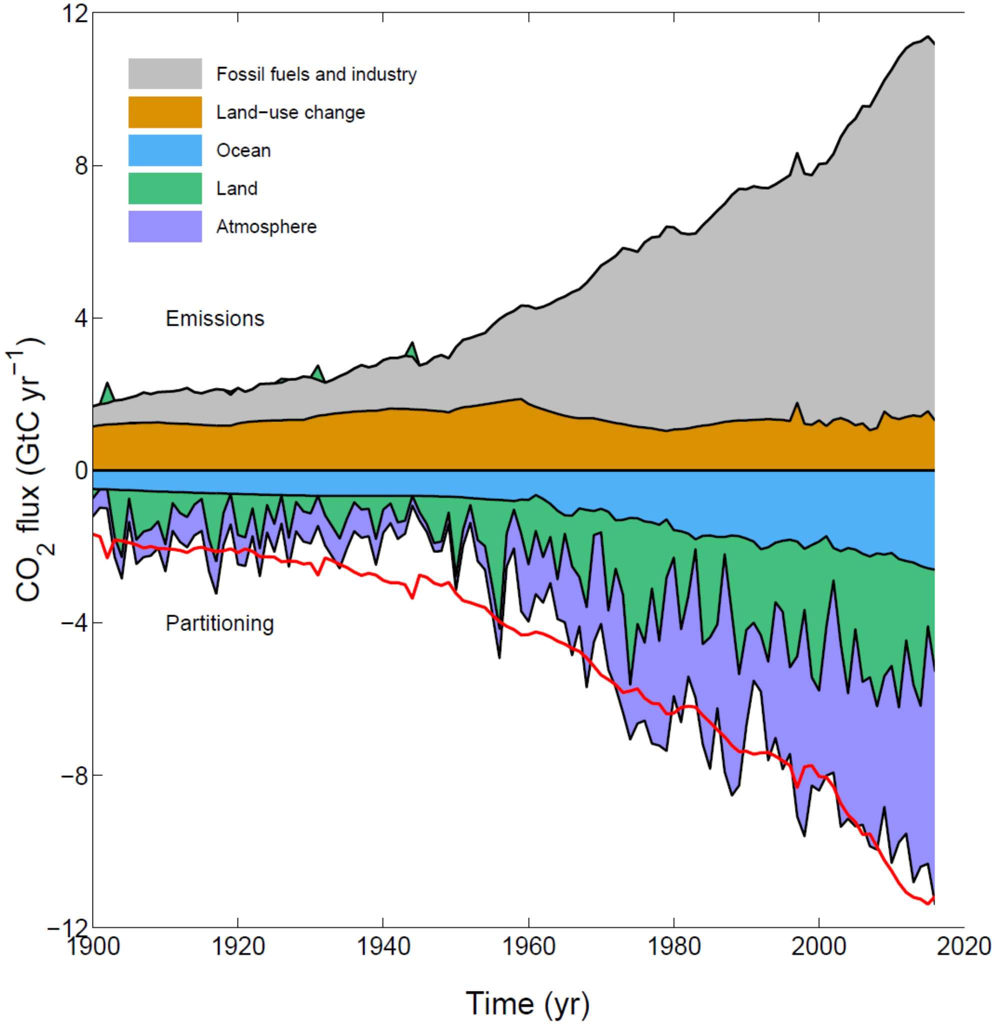
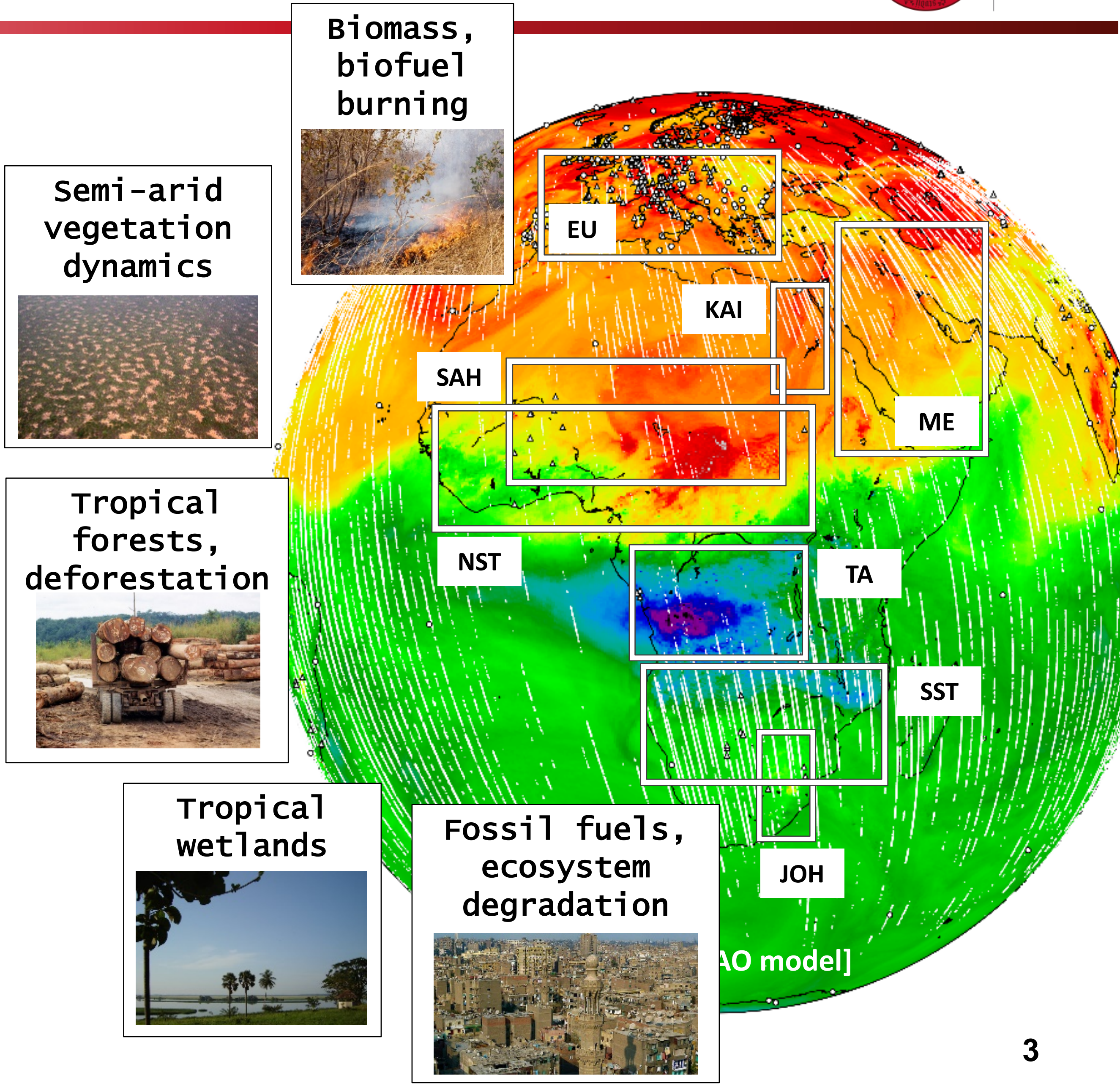
Sources and sinks of anthropogenic CO_2.



LeQuéré et al., ESSD, 2018



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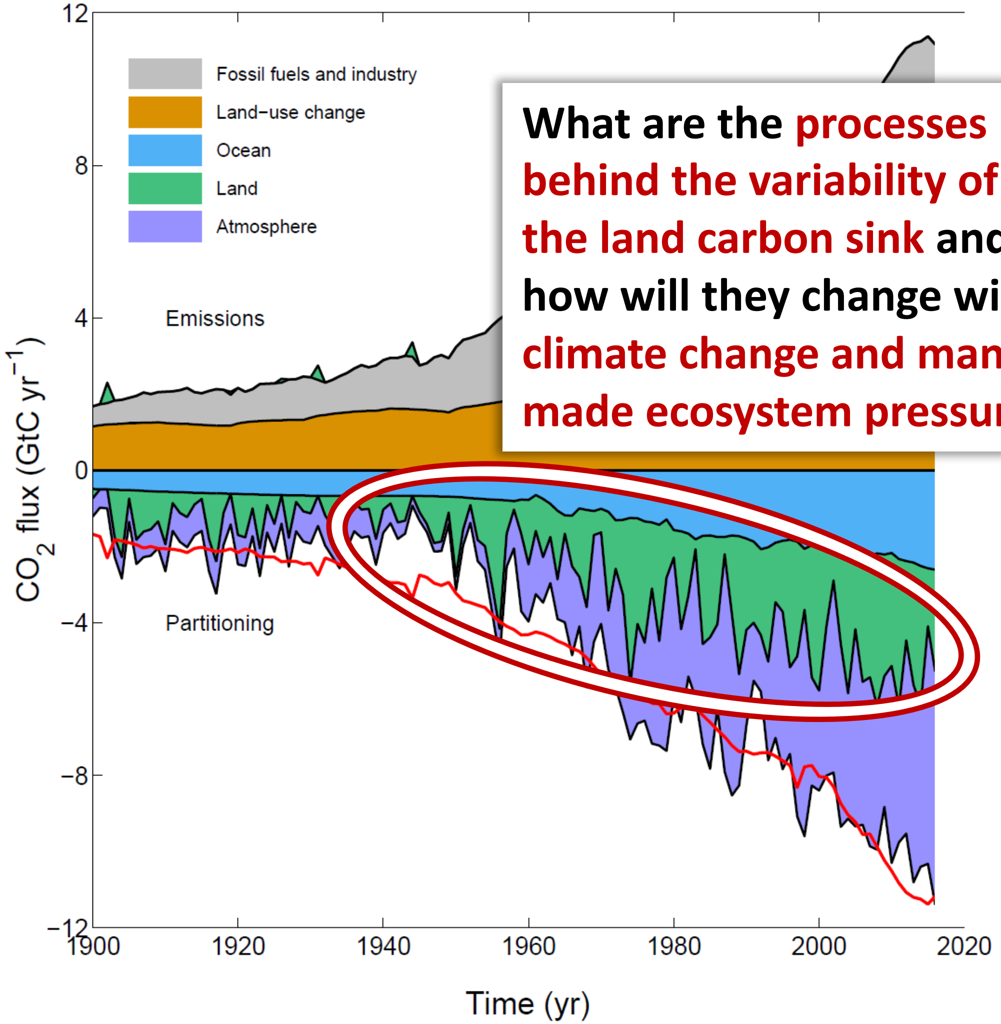


What are the **processes behind the variability of the land carbon sink** and how will they change with **climate change and man-made ecosystem pressure**.

LeQuéré et al., ESSD, 2018

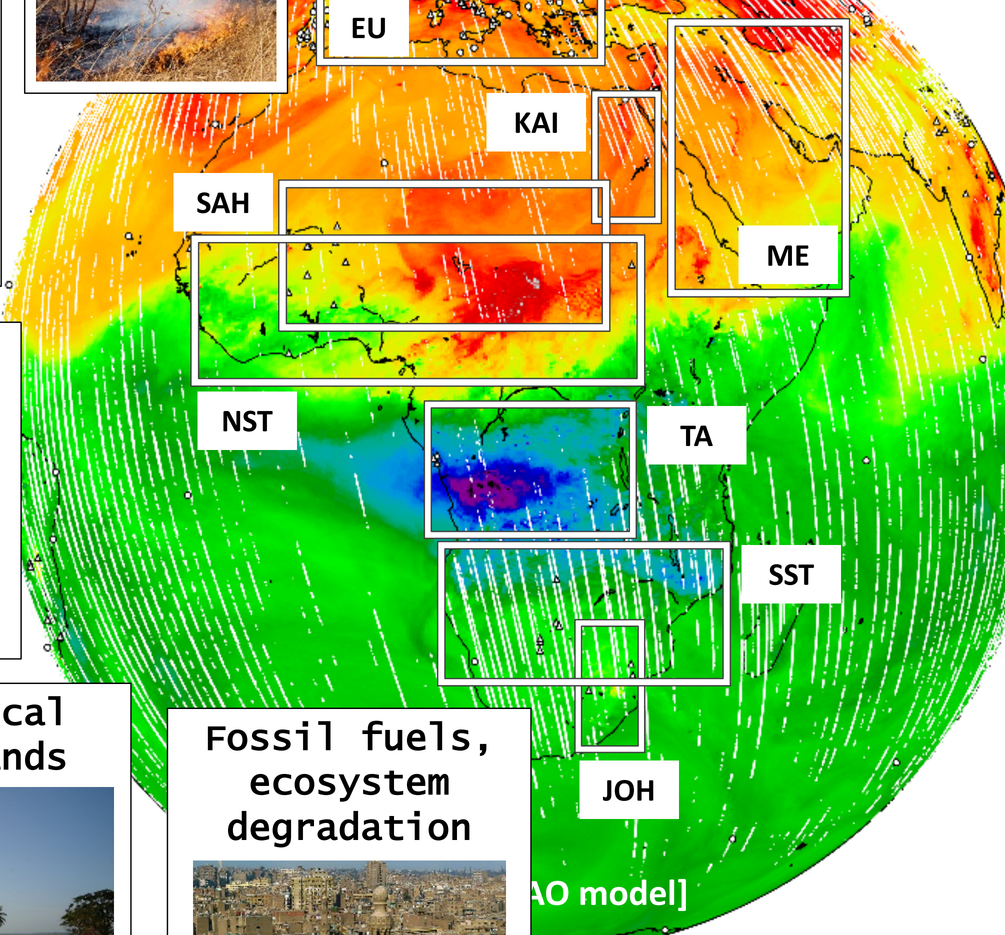
Biomass, biofuel burning

Semi-arid vegetation dynamics

Tropical forests, deforestation

Tropical wetlands

Fossil fuels, ecosystem degradation



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WHY THERE? WHY THEN?

- The African continent is **heavily undersampled.**
- By 2030, **highest population growth** rates on the planet will be in Africa (growing **emissions and ecosystem degradation**).
- By 2030, Europe will **transition to a low-carbon** economy.
- Middle-East **fossil fuel industry will adapt** to changes in consumer patterns.

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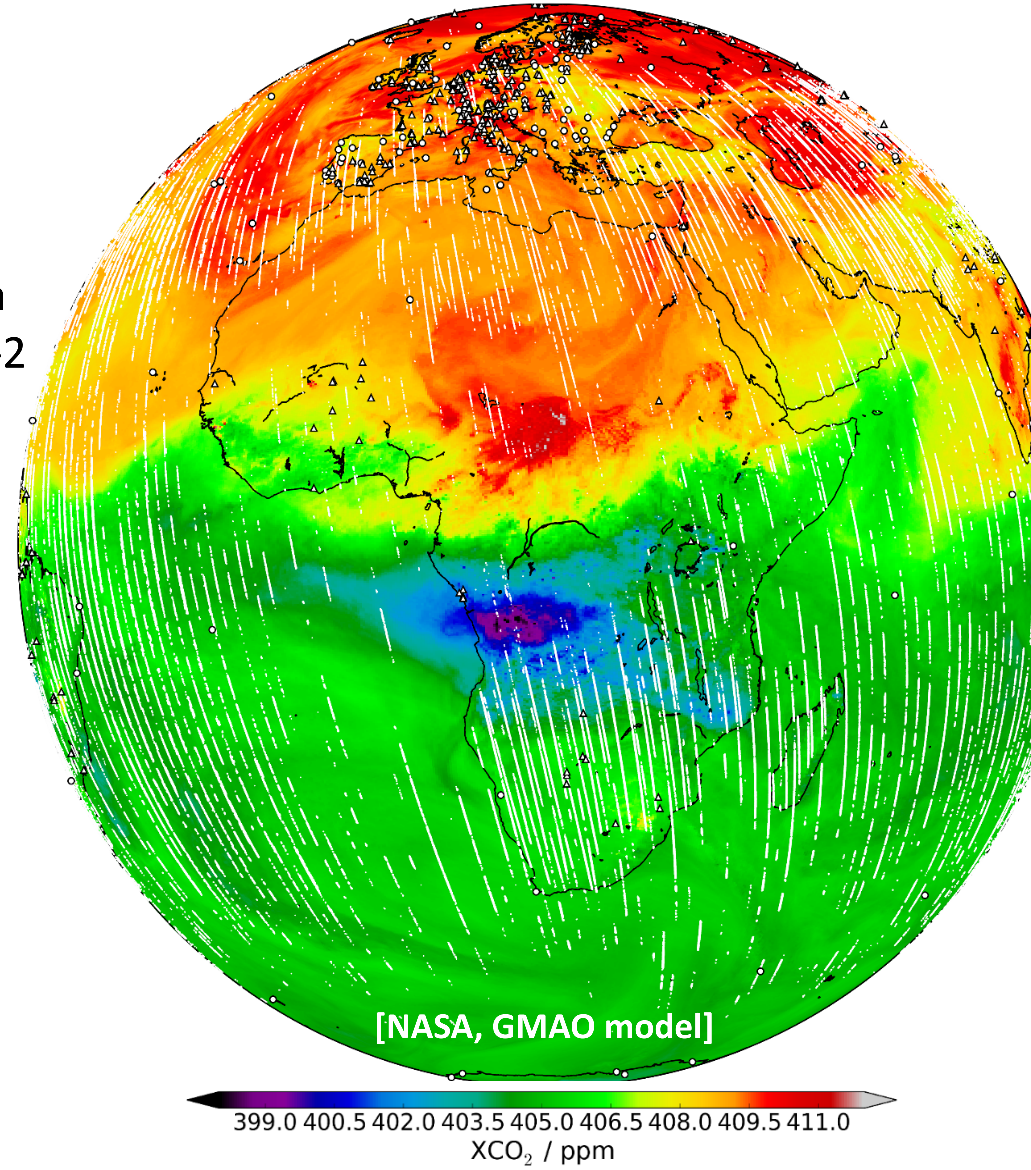
We need denser sampling in space and time!

White stripes: 1 month of decent quality OCO-2 soundings; white dots and triangles: in-situ GAW stations and FLUXNET stations.



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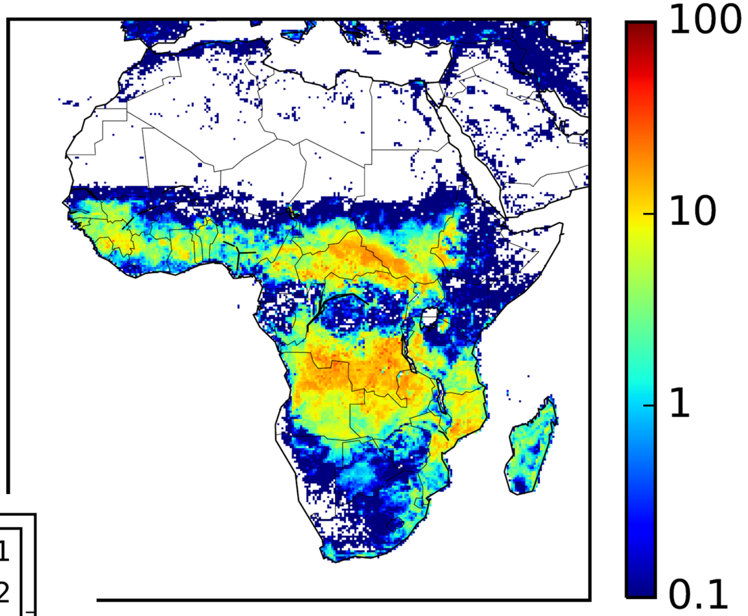
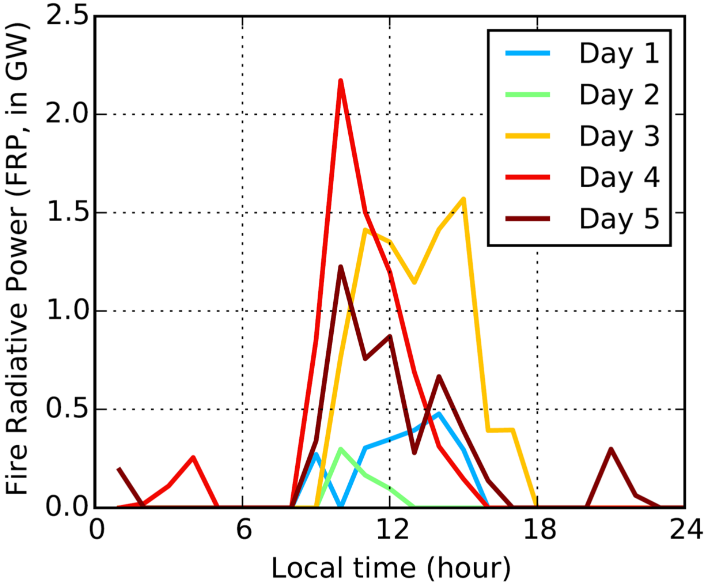
CO emissions from fires (average 1997-2016) [gCO/m^2/a]



Diurnal cycle of fire emission for 5 illustrative consecutive days in Central Africa



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We need think in terms of 2030s and later!

Africa will dominate the worlds population dynamics (consequences: urbanization, ecosystem degradation).

Countries accounting for 75% of the worlds population change [UN-WPP, 2017]

Country or area	*Annual population increase 2010-2015 (millions)*	*Cumulated percentage*
India	15.615	18.4
China	7.455	27.2
Nigeria	4.521	32.5
Pakistan	3.764	36.9
Indonesia	3.128	40.6
Ethiopia	2.434	43.4
Dem. Republic of the Congo	2.335	46.2
United States of America	2.258	48.9
Egypt	1.934	51.1
Brazil	1.833	53.3
Bangladesh	1.810	55.4
Mexico	1.714	57.4
Philippines	1.598	59.3
United Republic of Tanzania	1.556	61.1
Uganda	1.246	62.6
Turkey	1.189	64.0
Kenya	1.177	65.4
Iraq	1.071	66.7
Viet Nam	1.020	67.9
Afghanistan	0.987	69.0
Iran (Islamic Republic of)	0.959	70.1
Angola	0.898	71.2
Sudan	0.852	72.2
Saudi Arabia	0.826	73.2
Mozambique	0.758	74.1
Algeria	0.751	75.0
South Africa	0.741	75.8
WORLD	84.968	100.0

Rank	*Country or area*	*Annual population increase 2045-2050 (millions)*	*Cumulated percentage*
1.	Nigeria	7.904	14.8
2.	India	4.496	23.2
3.	Dem. Republic of the Congo	4.089	30.8
4.	United Republic of Tanzania	2.982	36.4
5.	Pakistan	2.787	41.6
6.	Ethiopia	2.410	46.1
7.	Uganda	2.258	50.3
8.	Niger	1.965	54.0
9.	Angola	1.729	57.2
10.	Egypt	1.572	60.1
11.	United States of America	1.507	63.0
12.	Iraq	1.497	65.8
13.	Kenya	1.407	68.4
14.	Mozambique	1.360	70.9
15.	Sudan	1.310	73.4
16.	Philippines	1.126	75.5
	WORLD	53.523	100.0

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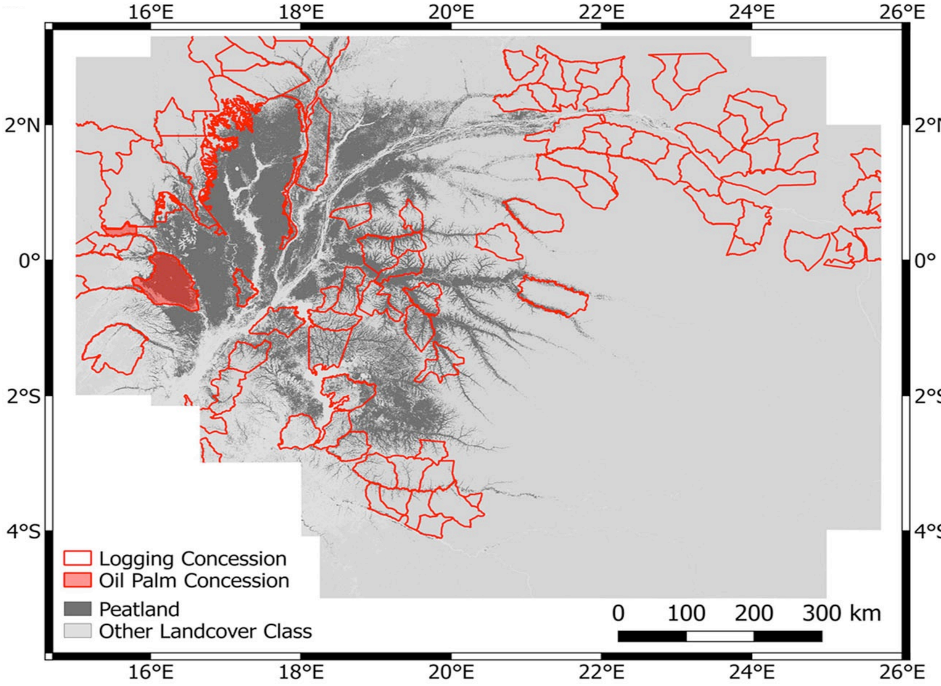
Presumably world's largest tropical peatland area in Congo (Cuvette depression) – only discovered recently [Dargie et al., 2017]



Peatland within the Cuvette central depression threatened by logging and oil palm concessions [Figure 2a of Dargie et al., 2018, distributed under Creative Commons Attribution 4.0 International License.

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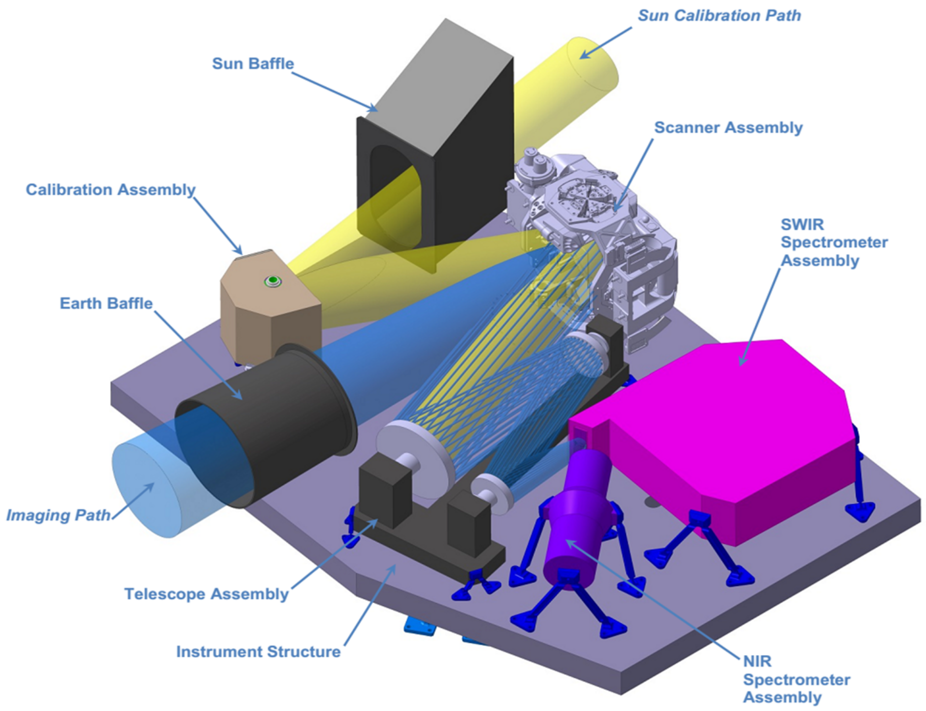
HOW?

- **Quasi-contiguous mapping** of atmospheric CO_2, CH_4, CO and SIF.
- **Freely selectable** scientific focus regions.
- **Flexible process-oriented sampling** approach.
- **Several region revisits per day** to study **process dynamics.**
- **Active and intelligent cloud avoidance** to overcome data scarcity.
- Lessen **sampling biases**, avoid **missing events** (e.g. fires), and reduce **data gaps**.

State-of-the-art imaging spectroscopy in solar backscatter configuration (heritage: GOSAT, OCO-2, Sentinel-5, Sentinel-7)

Sketch of ARRHENIUS spectrometer assembly (aperture 12-15 cm)



For details of instrument and performance see Butz et al., AMT, 2015.

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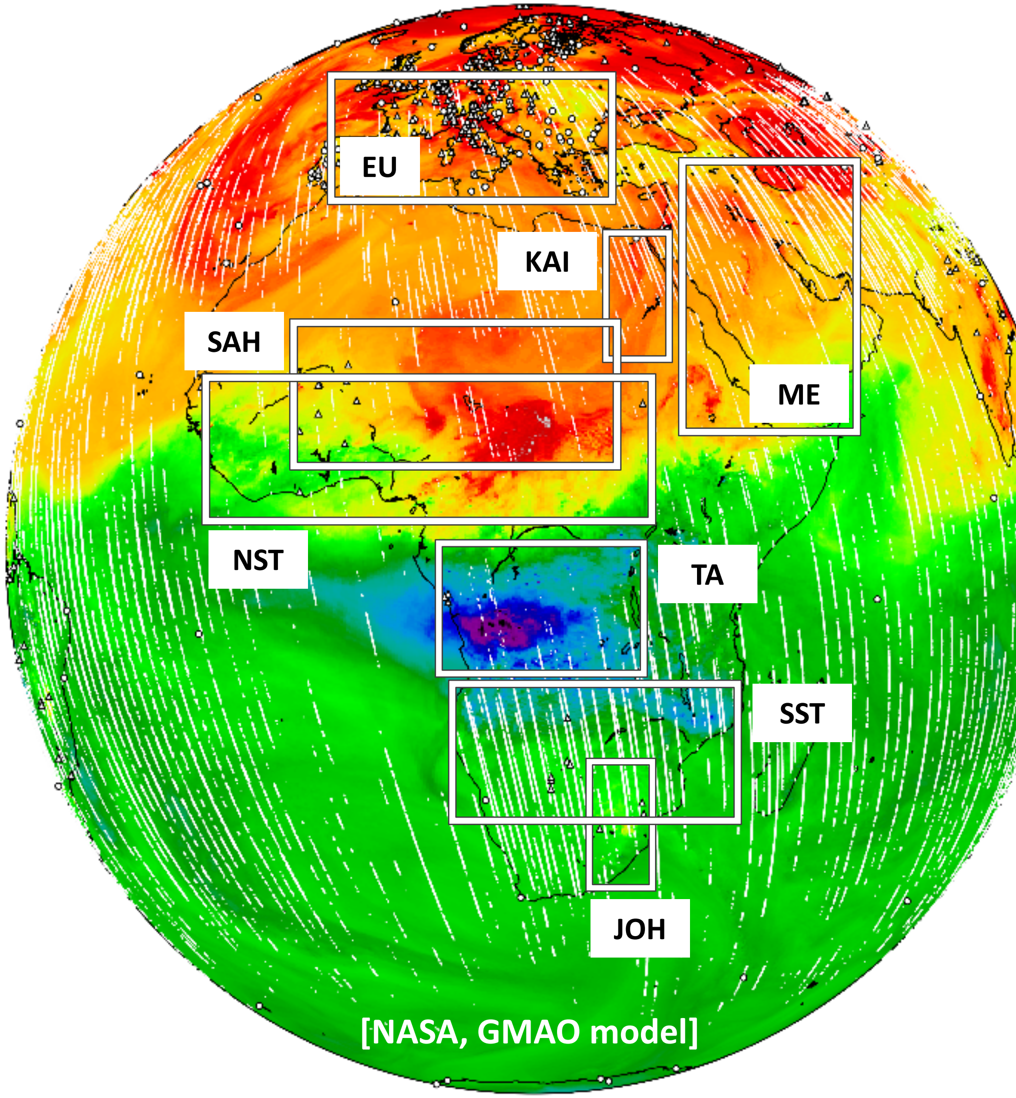

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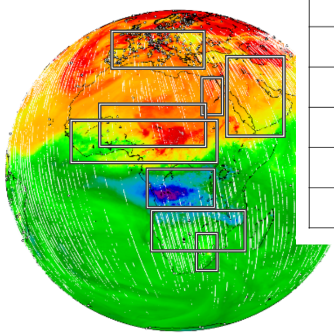

Illustrative process-oriented observation schedule: to be consolidated.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Over-ruling priority	TA whenever cloudless at most twice per day											
Priority chain	NST JOH ME VAL EU SST KAI SAH	NST JOH ME VAL EU SST KAI SAH	NST JOH ME VAL EU SST KAI SAH	EU ME SAH KAI JOH VAL SST NST	EU ME SAH KAI JOH VAL SST NST	SST EU ME SAH KAI VAL JOH NST	SST EU ME SAH KAI VAL JOH NST	SST EU ME SAH KAI VAL JOH NST	SAH SST EU KAI JOH VAL ME NST	SAH SST EU KAI JOH VAL ME NST	NST JOH ME VAL EU SST KAI SAH	NST JOH ME VAL EU SST KAI SAH
<5UT 5UT 6UT 7UT 8UT 9UT 10UT 11UT 12UT 13UT 14UT 15UT 16UT >16UT	VAL ME JOH NST JOH NST VAL JOH NST JOH VAL	VAL ME JOH NST JOH NST VAL JOH NST JOH VAL	VAL ME JOH NST JOH NST VAL JOH NST JOH VAL	VAL ME KAI EU EU KAI SAH VAL EU EU KAI SAH VAL	ME VAL KAI EU EU KAI SAH VAL EU EU KAI SAH VAL	ME VAL SST EU SST VAL EU SST EU SST VAL	ME VAL SST EU SST VAL EU SST EU SST VAL	ME VAL SST EU SST VAL EU SST EU SST VAL	VAL ME KAI SAH SST KAI SAH VAL SST SAH KAI VAL	VAL ME KAI SAH SST KAI SAH VAL SST SAH KAI VAL	VAL ME JOH NST JOH NST VAL JOH NST JOH VAL	VAL ME JOH NST JOH NST VAL JOH NST JOH VAL

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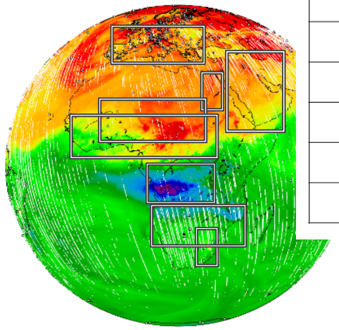

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Priority chain	NST	NST	NST	EU	EU	SST	SST	SST	SAH	SAH	NST	NST
	JOH	JOH	JOH	ME	ME	EU	EU	EU	SST	SST	JOH	JOH
	ME	ME	ME	SAH	SAH	ME	ME	ME	EU	EU	ME	ME
	VAL	VAL	VAL							KAI	VAL	VAL
	EU	EU	EU							JOH	EU	EU
	SST	SST	SST							VAL	SST	SST
	KAI	KAI	KAI							ME	KAI	KAI
	SAH	SAH	SAH							NST	SAH	SAH

<5UT, 5UT, 6UT, 7UT, 8UT, 9UT, 10UT, 11UT, 12UT, 13UT, 14UT, 15UT, 16UT, >16UT

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	VAL	VAL	VAL							VAL	VAL	VAL
	ME	ME	ME							ME	ME	ME
	JOH	JOH	JOH							KAI	JOH	JOH
	NST	NST	NST						SST	SAH	NST	NST
	JOH	JOH	JOH	EU		SST	SST	SST	KAI	SST	JOH	JOH
	NST	NST	NST	KAI	KAI	VAL	VAL	VAL	SAH	KAI	NST	NST
	VAL	VAL	VAL	SAH	SAH	EU	EU	EU	VAL	SAH	VAL	VAL
	JOH	JOH	JOH	VAL	VAL	SST	SST	SST	SST	VAL	JOH	JOH
	NST	NST	NST	EU	EU	EU	EU	EU	SAH	SST	NST	NST
	JOH	JOH	JOH	EU	EU	SST	SST	SST	KAI	SAH	JOH	JOH
	VAL	VAL	VAL	KAI	KAI	VAL	VAL	VAL	VAL	KAI	VAL	VAL
				SAH	SAH					VAL		
				VAL	VAL							

We suggest to explore an **on-demand scheduling system** driven by scientific user needs?

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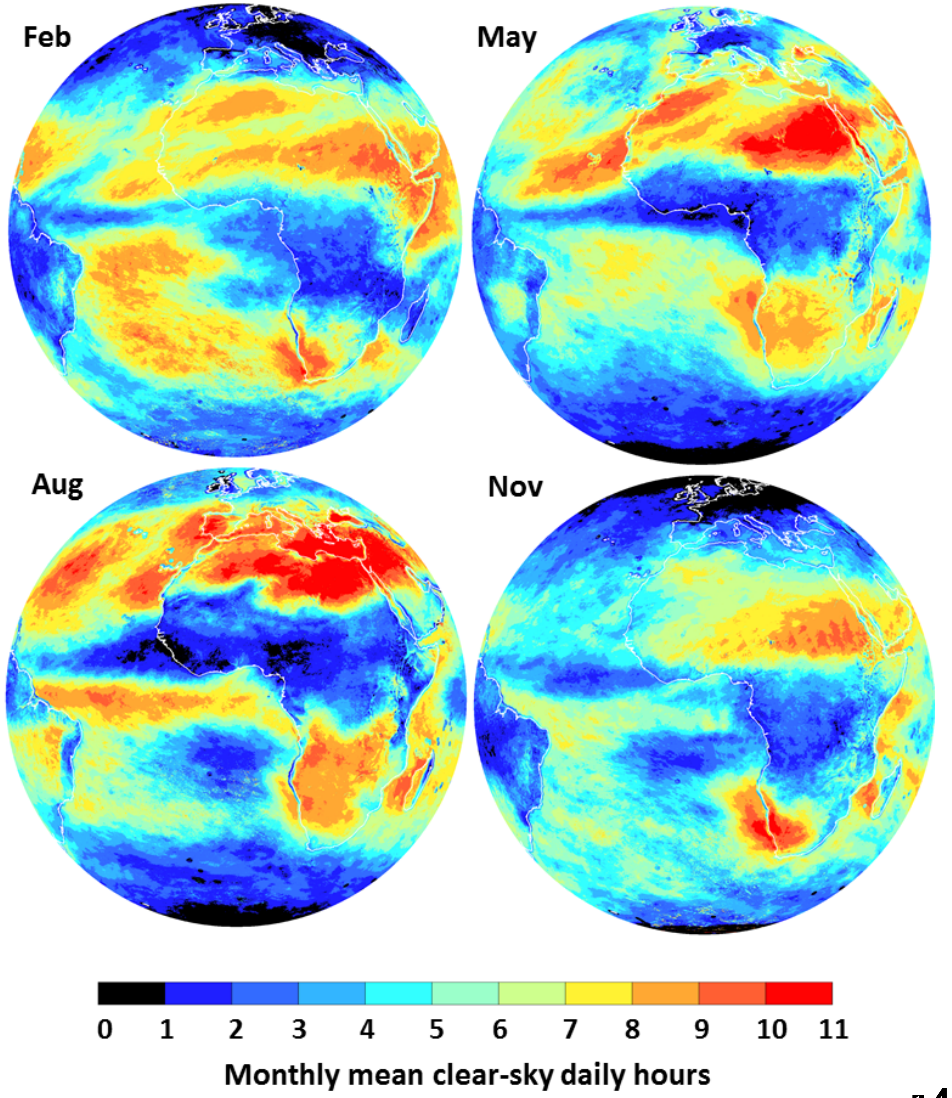
Active cloud-avoidance through near-real-time cloud information from MTG-FCI, i.e. point to the focus regions at the right time.

SEVIRI-based clear-sky (opt. thickness <0.1) hours for 2013



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HOW DOES IT FIT INTO GLOBAL GHG OBSERVATIONS?

- ARRHENIUS will be the **process-oriented complement** to the surveillance missions **Sentinel-5 and Sentinel-7**.
- In fact, ARRHENIUS needs **LEO missions** to provide **the global carbon context and boundary conditions** for its focus region approach.
- **Meteosat Third Generation – Flexible Combined Imager** will be ARRHENIUS' companion instrument providing cloud-cover information that will **guide pointing to cloudless regions** with short lead times.
- Other synergies open with **MTG-S4** (e.g. NO_2, HCHO), **MTG-IRS** (CO, aerosols), **land surface** carbon missions (e.g. BIOMASS, FLEX).
- ARRHENIUS could be the **European contribution to a GEO-Greenhouse Gas constellation** together with a GeoCarb(-follow-on) and an Asian contribution.

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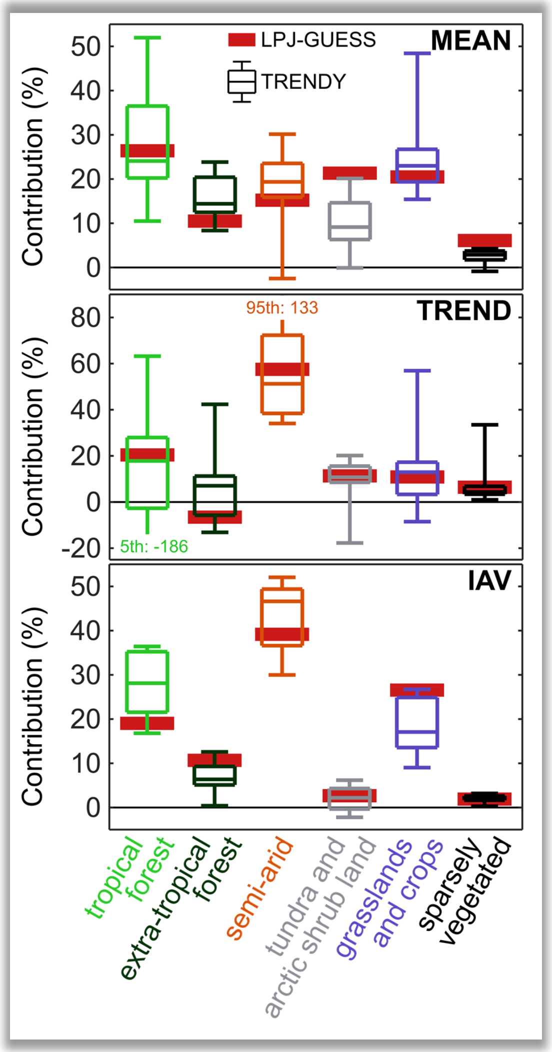
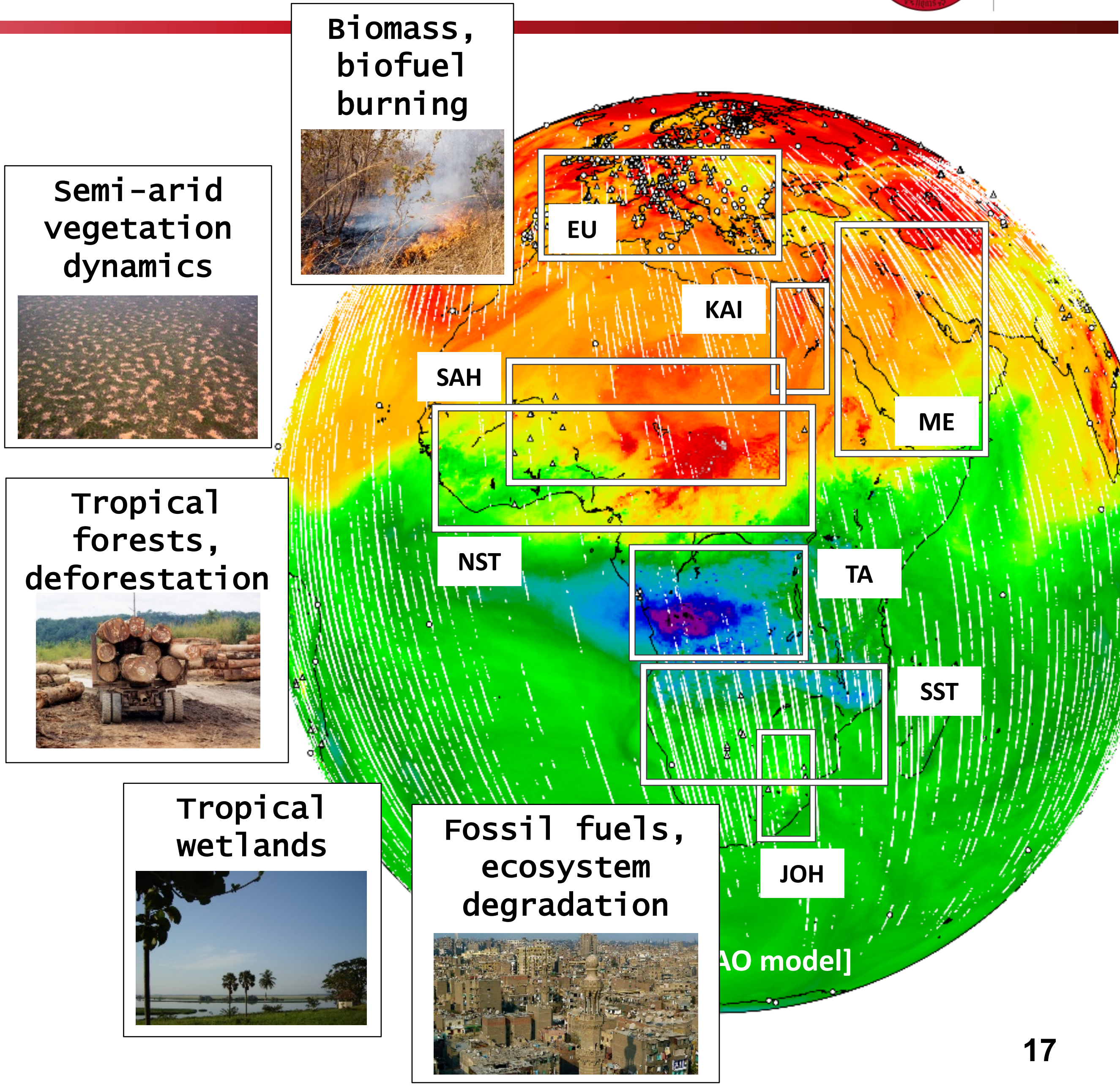
Semi-arid regions (vegetation dynamics, biomass burning, …) and tropical forests control the trend and the interannual variation (IAV) of the land carbon sink.

Fractional contribution to the land carbon sink (mean, trend, IAV)



Modified from Ahlström et al., 2015.



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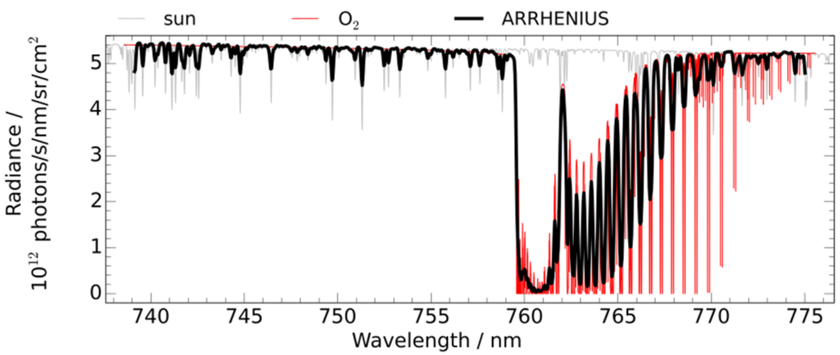
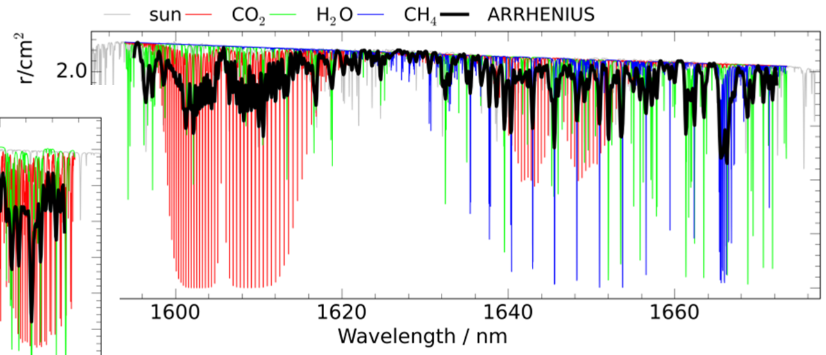
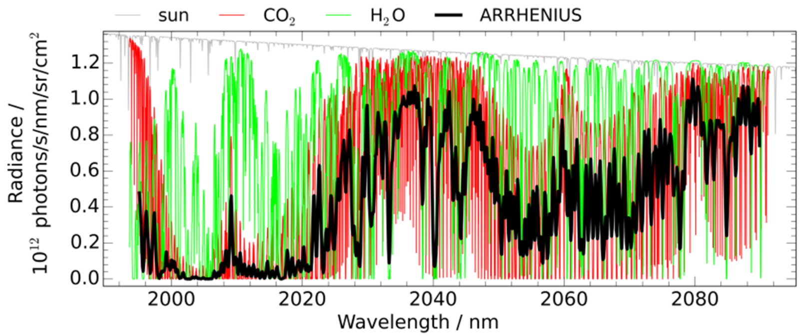
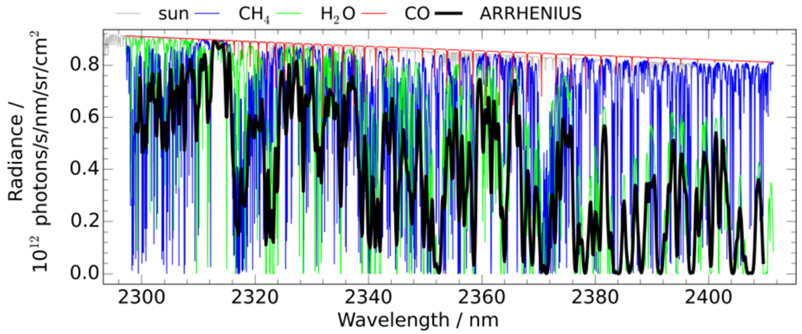
(heritage: GOSAT, OCO-2, Sentinel-5, Sentinel-7)

Typical ARRHENIUS measurements
(above dark surface)









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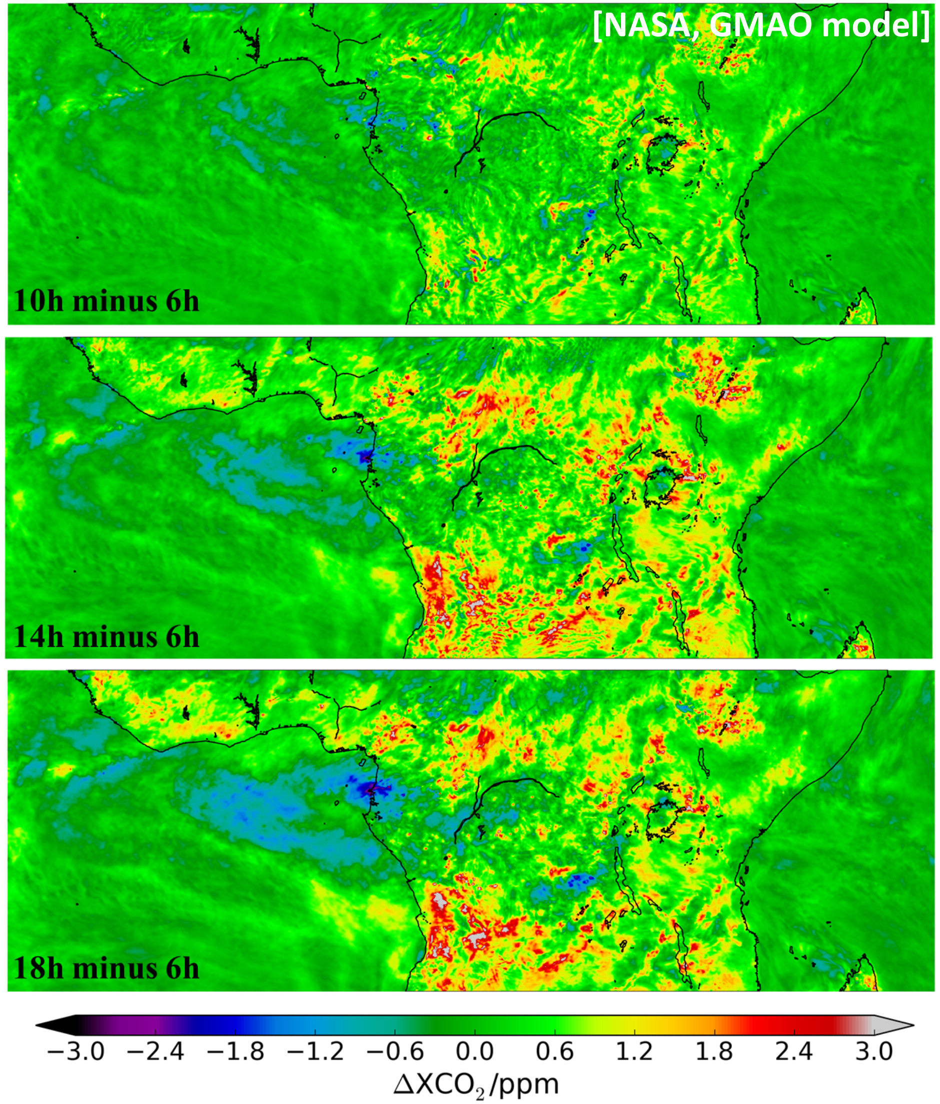
Daytime differences in XCO_2: gain insight into process dynamics through sub-daily temporal resolution.

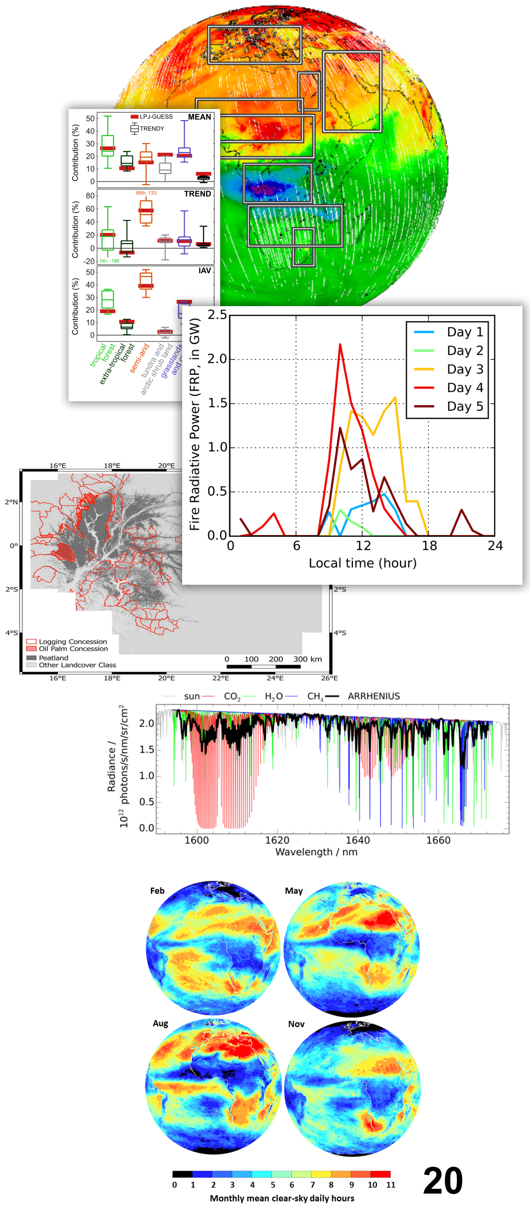
… and through process marker (CO, SIF, NO_2, HCHO) fingerprinting



ARRHENIUS: a Geostationary Carbon Process Explorer

… in a nutshell …

- Understand **terrestrial carbon cycle processes** and **climate-carbon feedbacks** in regions that are currently **severely undersampled**.
- African carbon cycle **highly variable and uncertain**; African will lead **population dynamics by 2030**.
- **Quasi-contiguous mapping** of atmospheric CO_2 and CH_4 together with **process markers (CO, SIF)**.
- **Scientific focus regions** sampled **several times per day** to avoid missing events, sampling biases.
- Active **cloud-avoidance** through cloud-informed pointing (via **MTG-FCI**).
- ARRHENIUS needs **LEO (S5, S7, …) carbon context**; ARRHENIUS needs **meteorological sounders** (MTG, …).
- ARRHENIUS will be the **explorative process-oriented asset** of a global atmospheric composition constellation (e.g. together with other **GEO** missions, **HEO** missions, **land surface carbon** missions …)



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