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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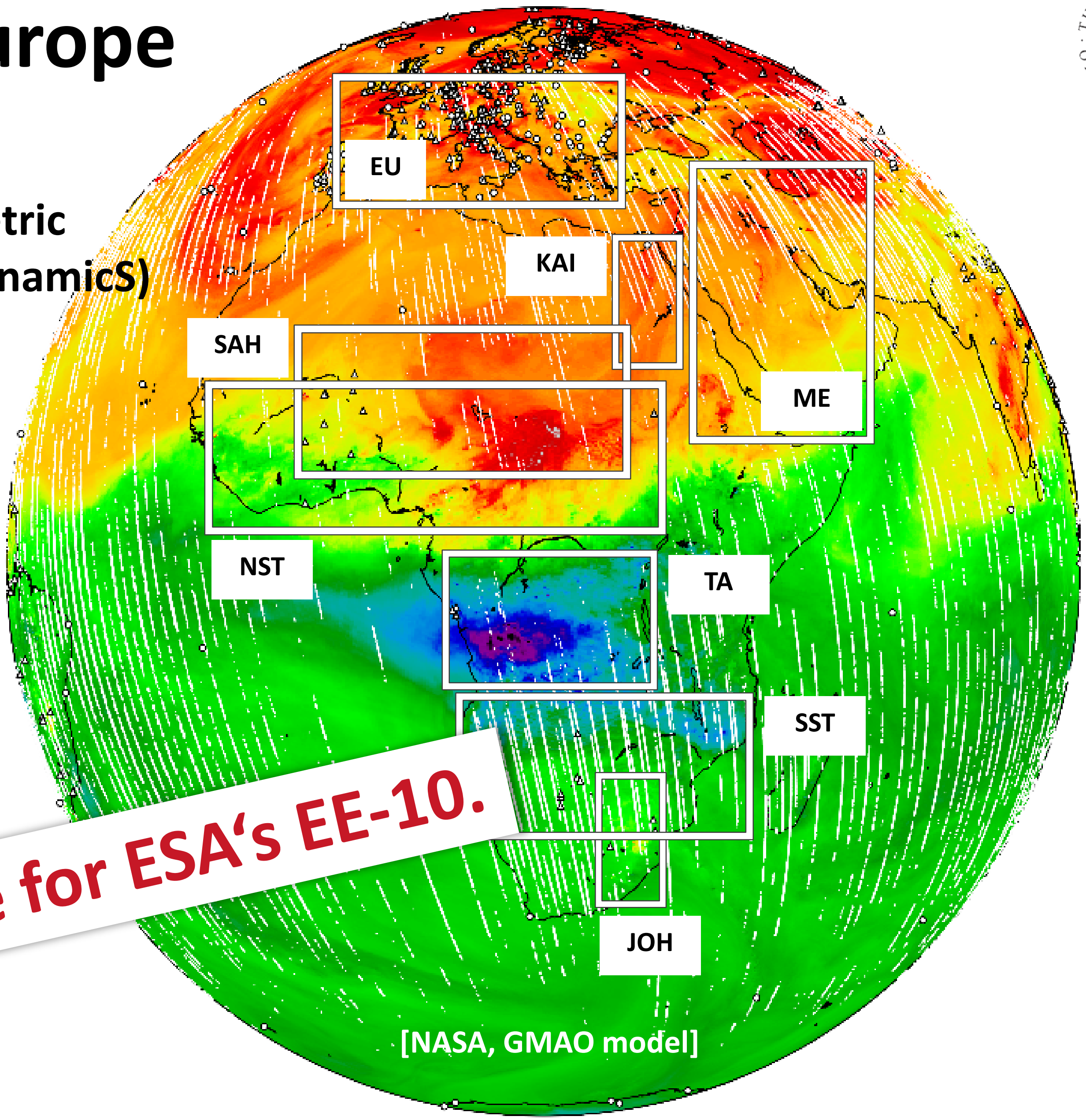
Julia Marshall (MPI BGC, D)
Charles Miller (JPL, USA)
Ray Nassar (ECCC, CA)
Johannes Orphal (KIT, D)
Guido van der Werf (U Amsterdam, NL).

Candidate for ESA's EE-10.



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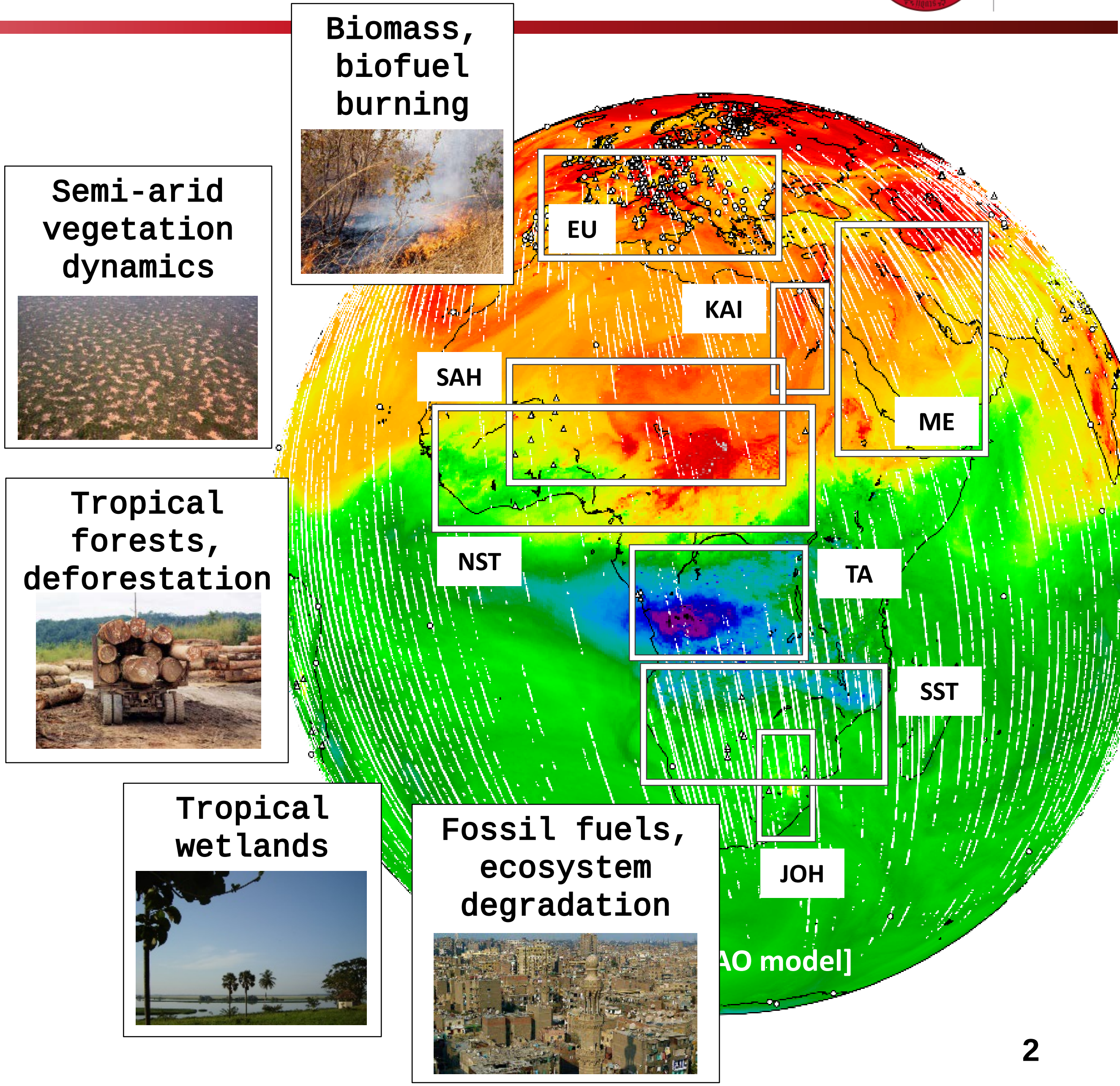
WHAT FOR?

- 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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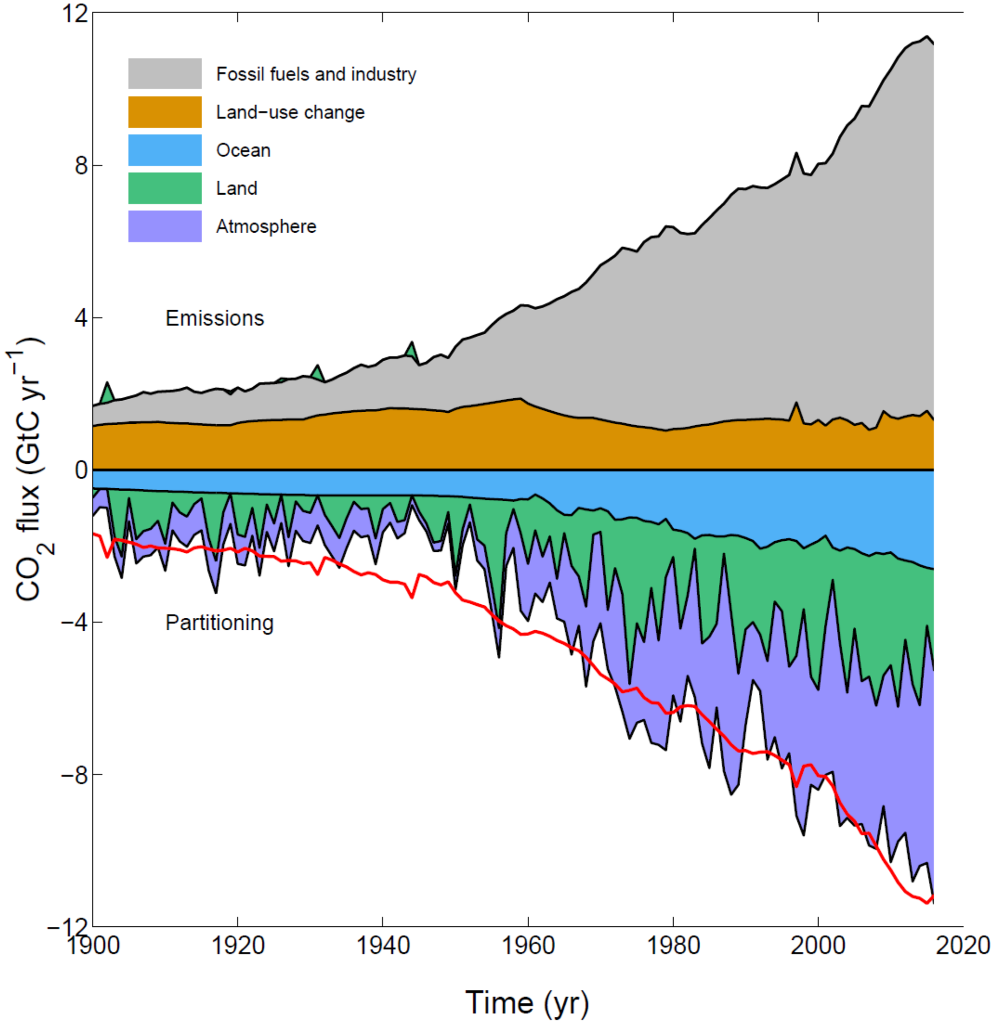
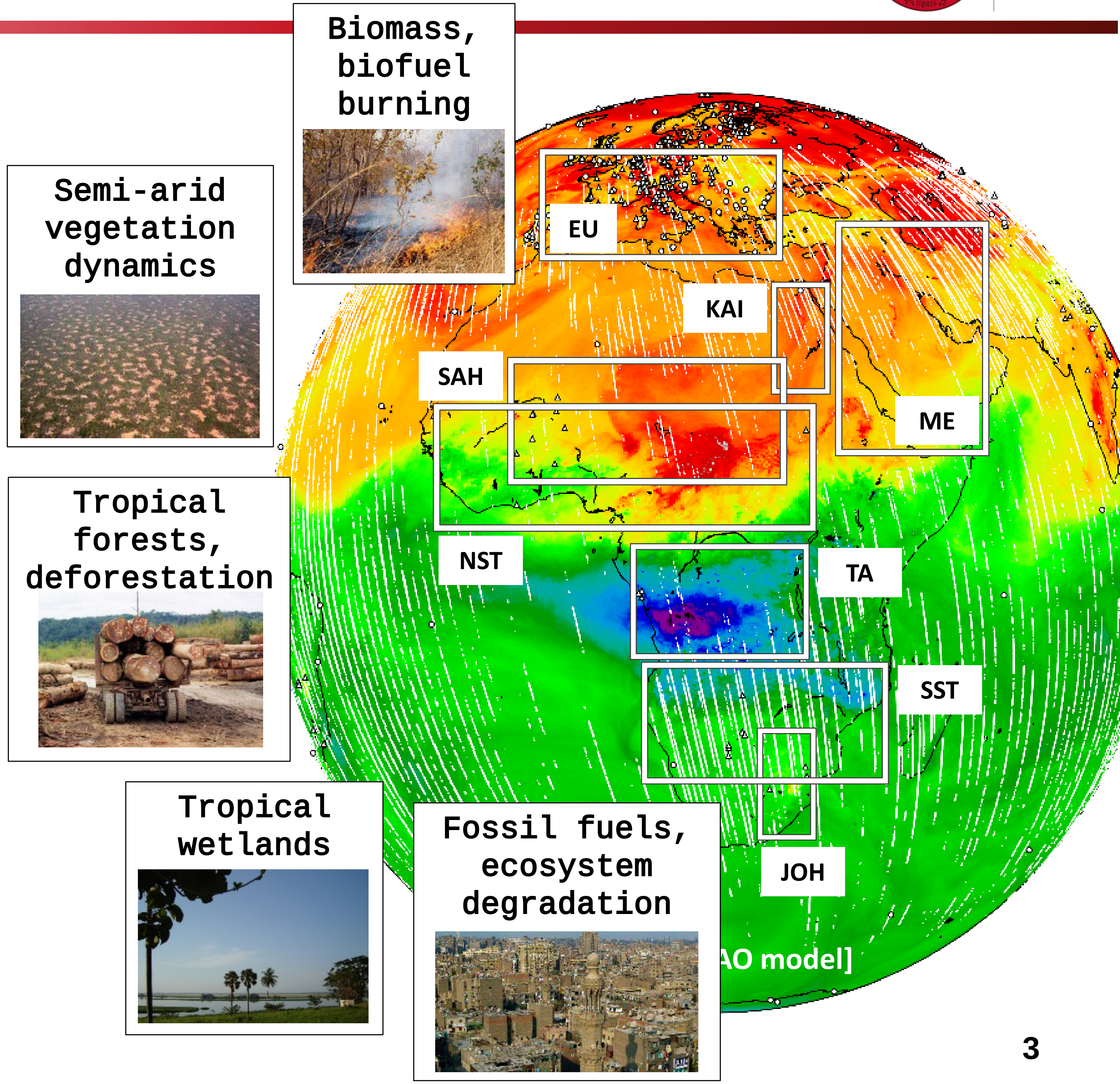
Sources and sinks of anthropogenic CO_2.



LeQuéré et al., ESSD, 2018



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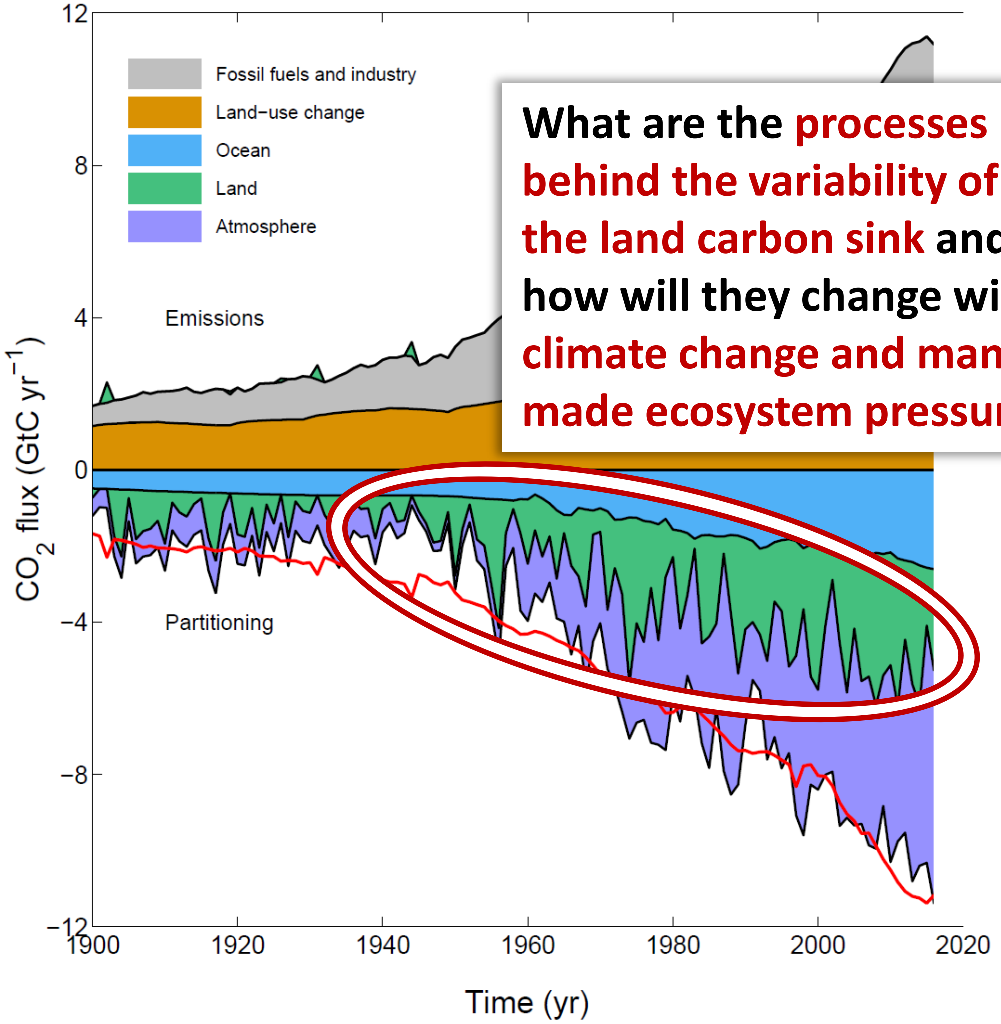
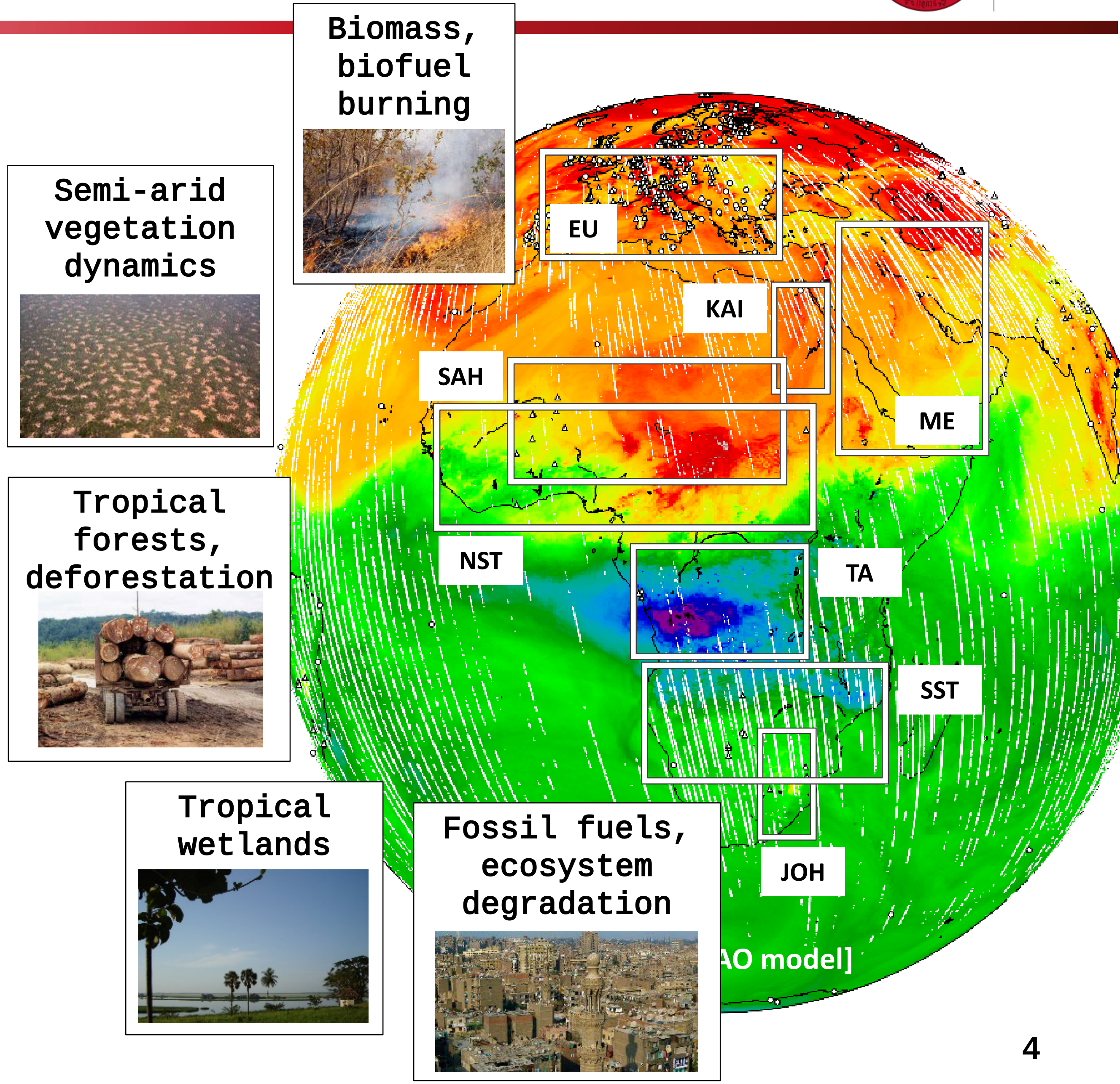


What are the **processes behind the variability of the land carbon sink** and how will they change with **climate change and man-made ecosystem pressure**.

LeQuéré et al., ESSD, 2018



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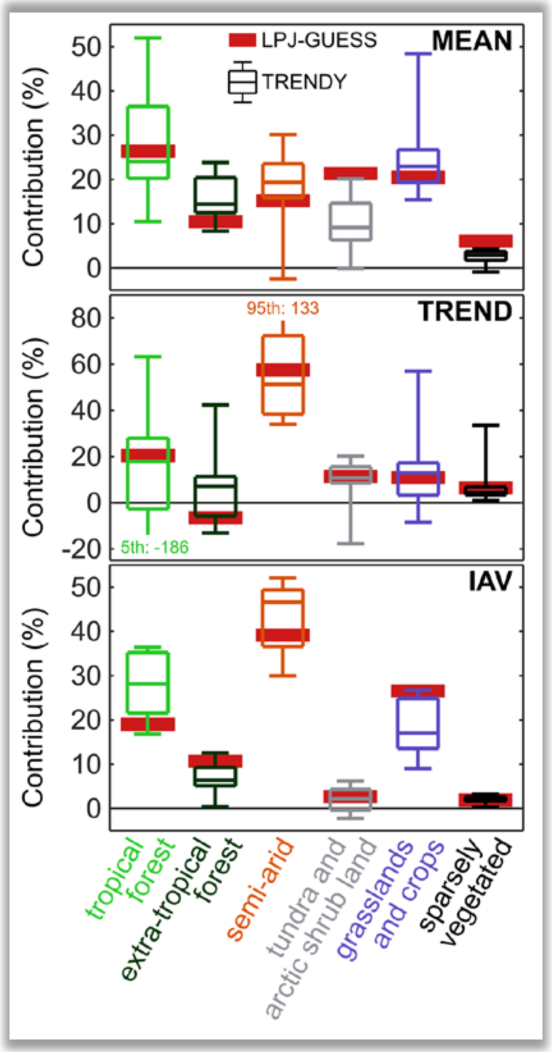
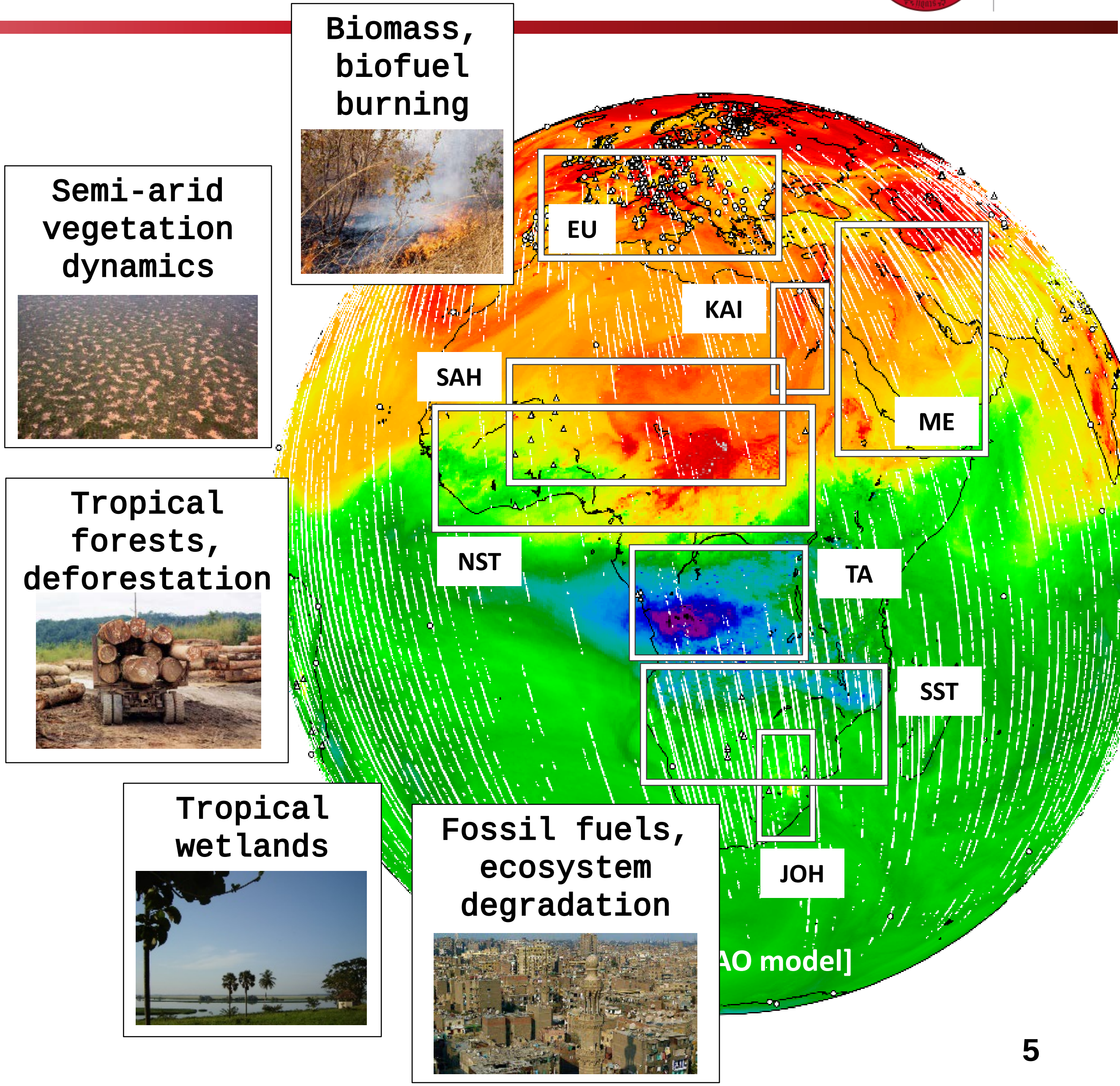
Semi-arid regions (vegetation dynamics, biomass burning, …) and tropical forests control the trend and the interannual variation (IAV) of the land carbon sink.

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



Modified from Ahlström et al., 2015.



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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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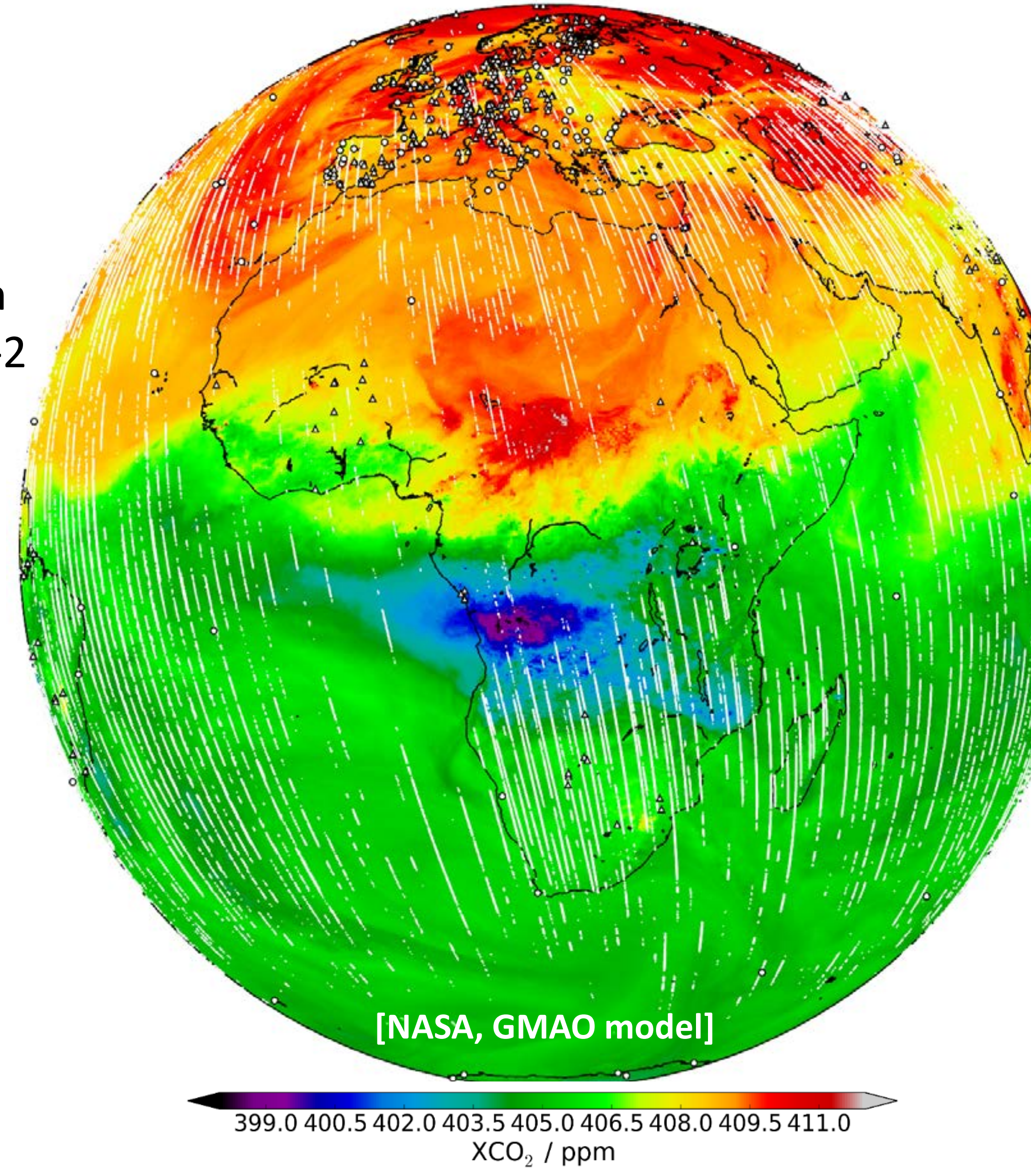
We need denser sampling in space and time!

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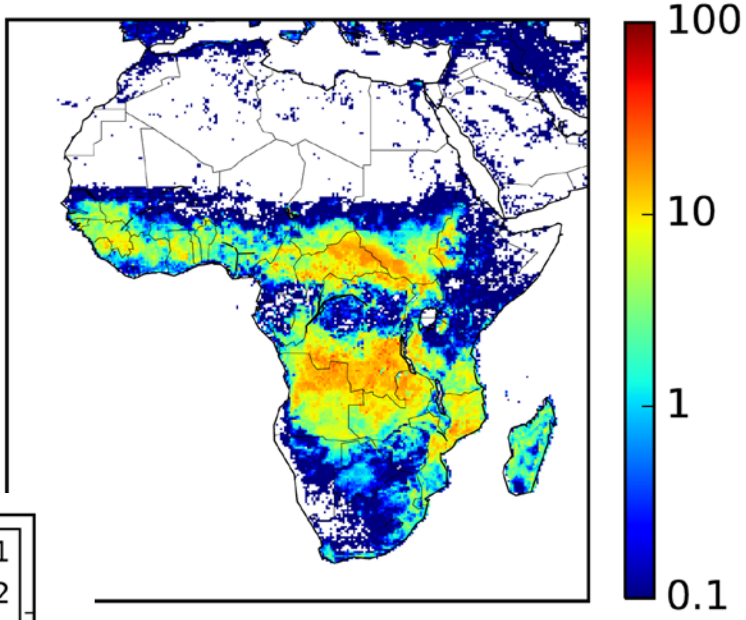
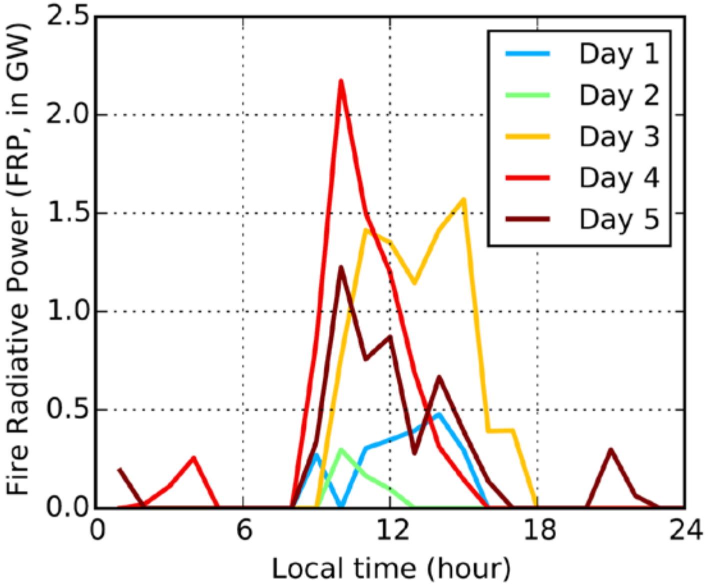
CO emissions from fires (average 1997-2016) [gCO/m^2/a]



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*	*Rank*	*Country or area*	*Annual population increase 2045-2050 (millions)*	*Cumulated percentage*
India	15.615	18.4	1.	Nigeria	7.904	14.8
China	7.455	27.2	2.	India	4.496	23.2
Nigeria	4.521	32.5	3.	Dem. Republic of the Congo	4.089	30.8
Pakistan	3.764	36.9	4.	United Republic of Tanzania	2.982	36.4
Indonesia	3.128	40.6	5.	Pakistan	2.787	41.6
Ethiopia	2.434	43.4	6.	Ethiopia	2.410	46.1
Dem. Republic of the Congo	2.335	46.2	7.	Uganda	2.258	50.3
United States of America	2.258	48.9	8.	Niger	1.965	54.0
Egypt	1.934	51.1	9.	Angola	1.729	57.2
Brazil	1.833	53.3	10.	Egypt	1.572	60.1
Bangladesh	1.810	55.4	11.	United States of America	1.507	63.0
Mexico	1.714	57.4	12.	Iraq	1.497	65.8
Philippines	1.598	59.3	13.	Kenya	1.407	68.4
United Republic of Tanzania	1.556	61.1	14.	Mozambique	1.360	70.9
Uganda	1.246	62.6	15.	Sudan	1.310	73.4
Turkey	1.189	64.0	16.	Philippines	1.126	75.5
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		WORLD	53.523	100.0

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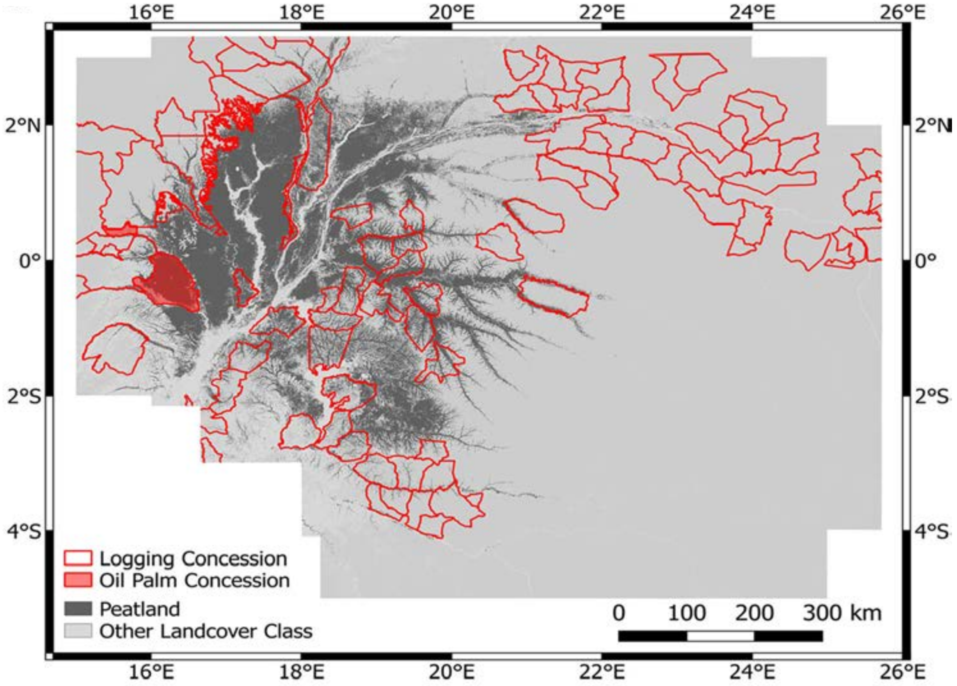
Presumably world's largest tropical peatland area in Congo (Cuvette depression) – only discovered recently [Dargie et al., 2017]



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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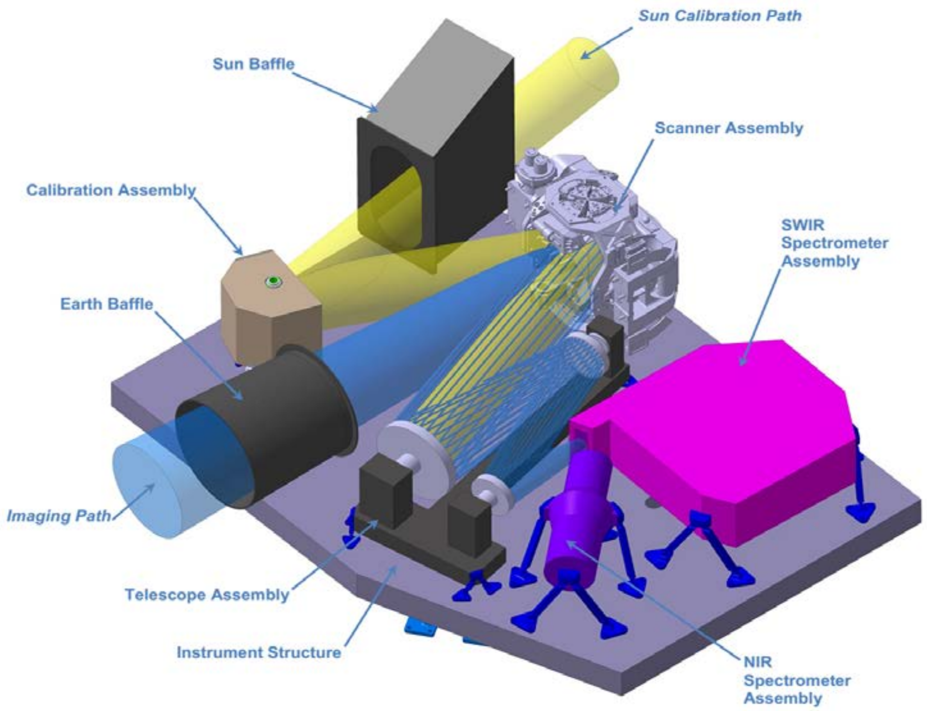
HOW?

- **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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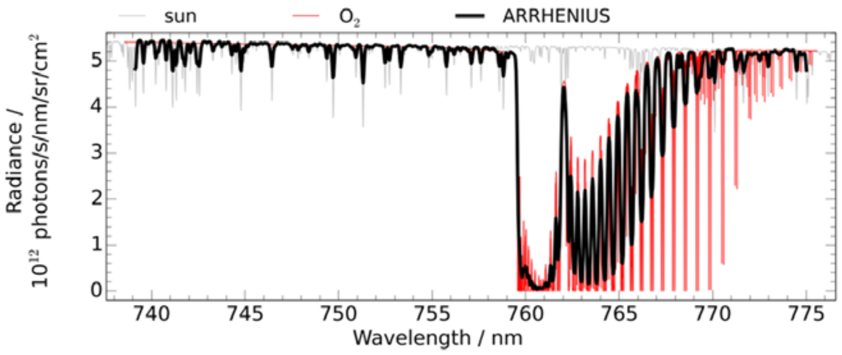
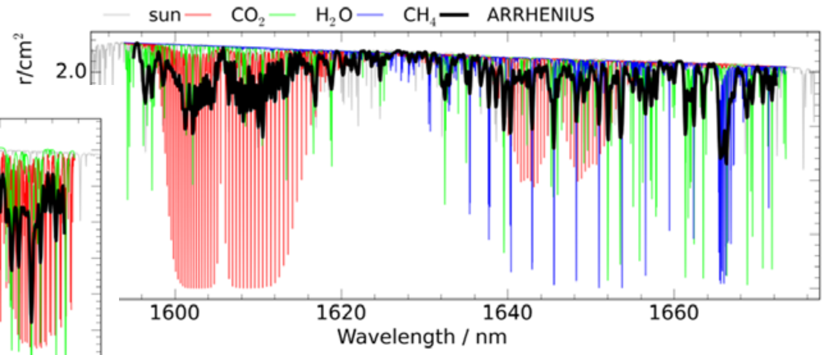
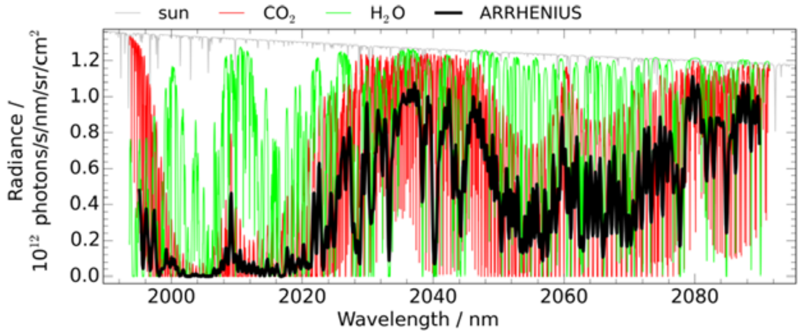
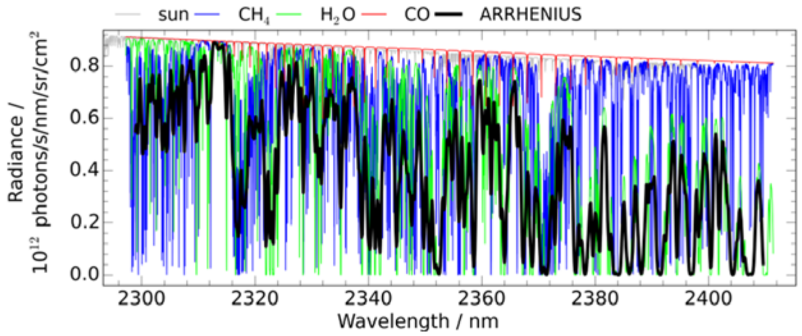
Typical ARRHENIUS measurements (above dark surface)









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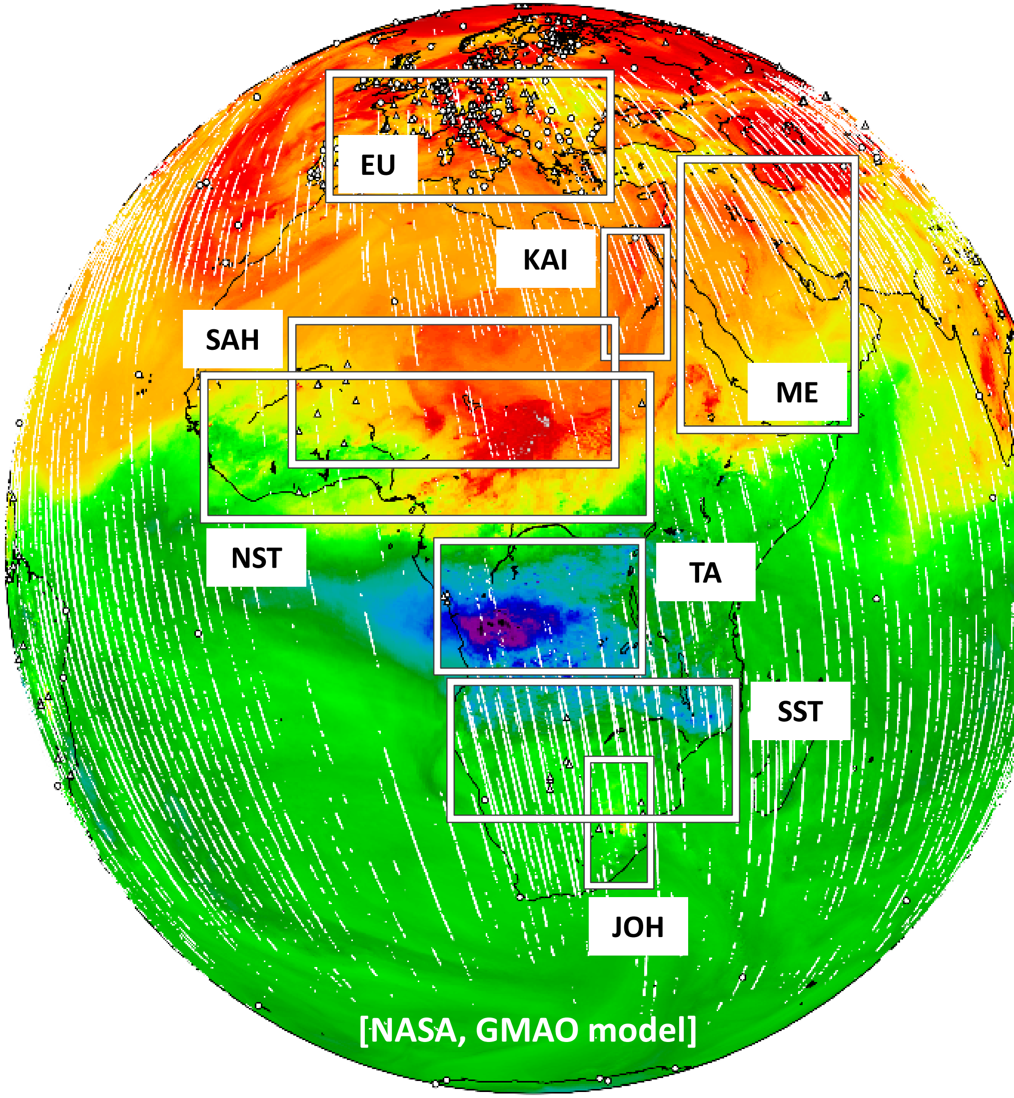

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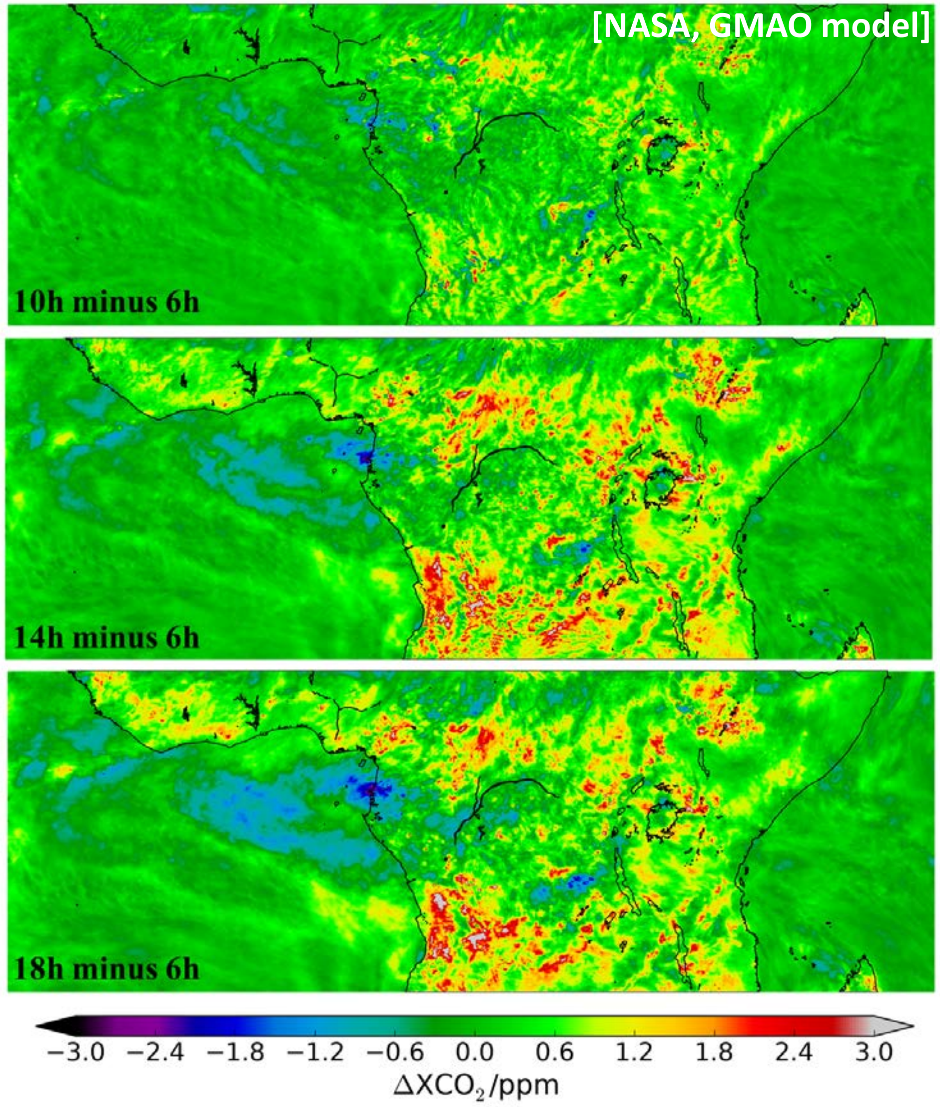
Daytime differences in XCO_2: gain insight into process dynamics through sub-daily temporal resolution.

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



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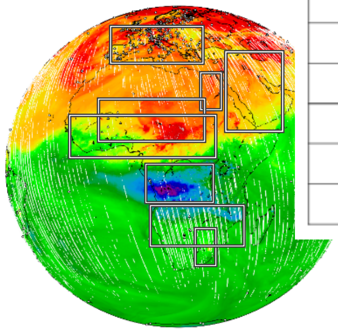

Illustrative process-oriented observation schedule: to be consolidated.

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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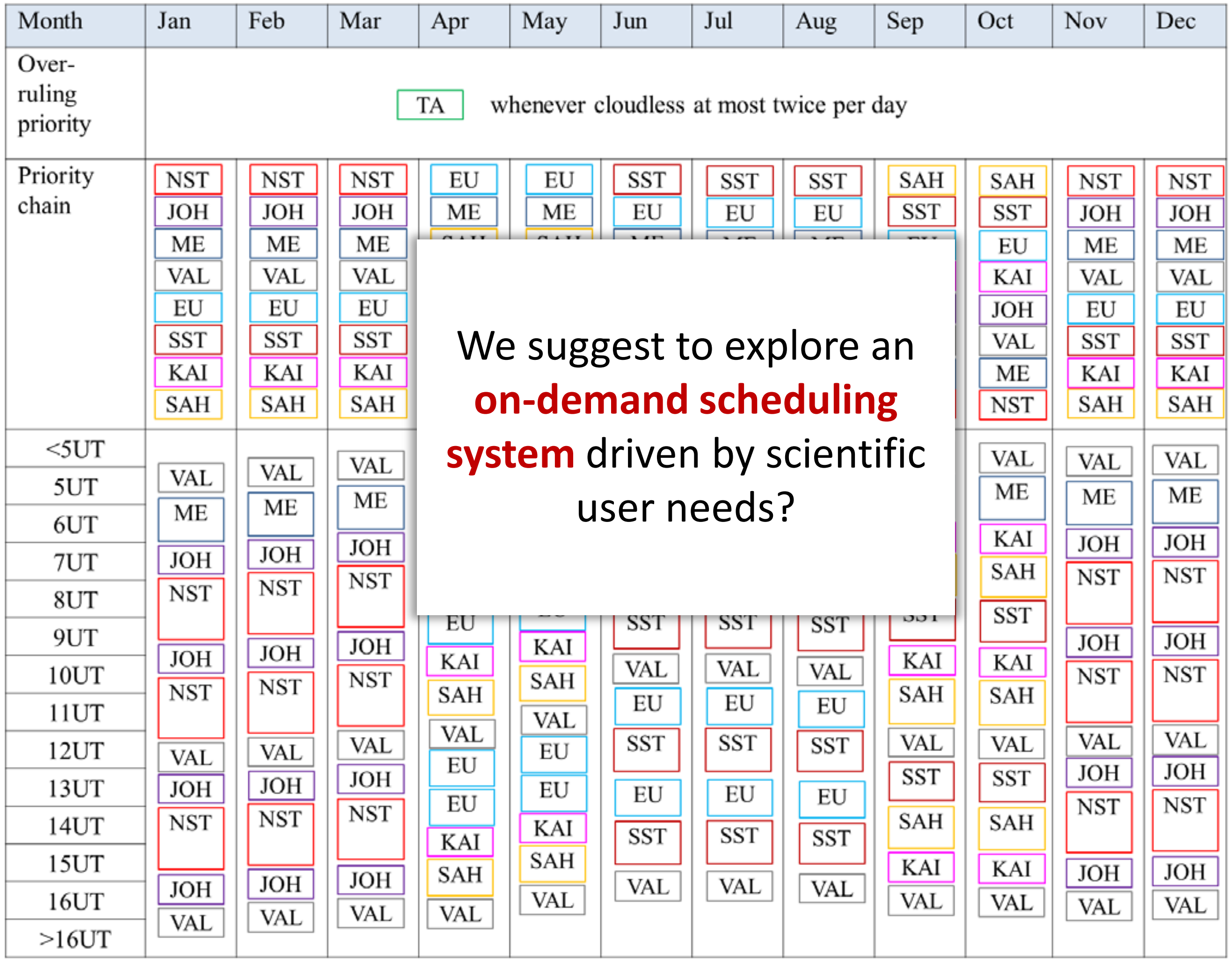
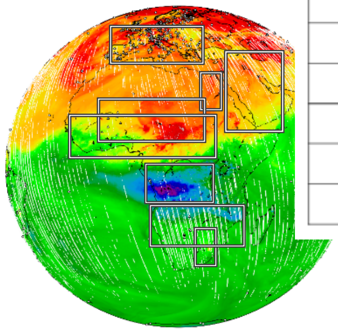


We suggest to explore an **on-demand scheduling system** driven by scientific user needs?



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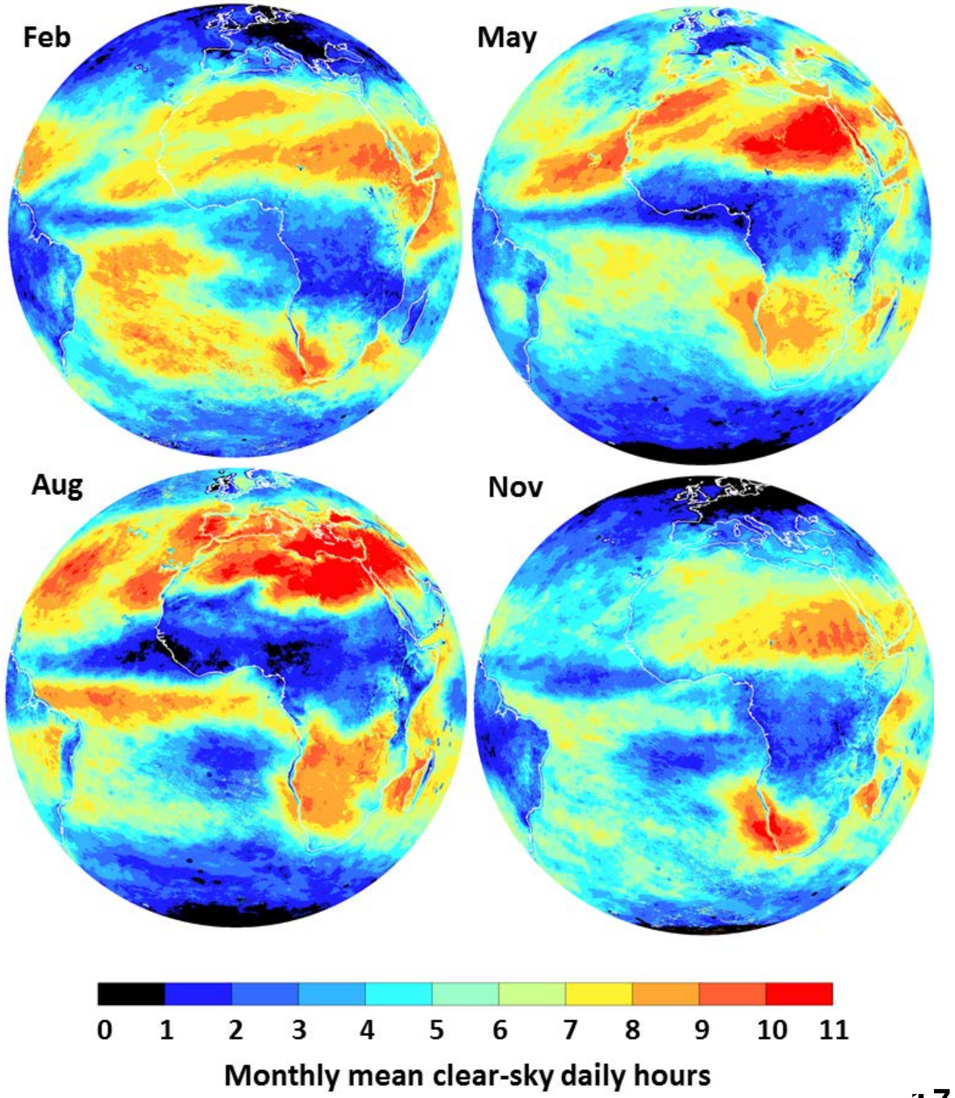
Active cloud-avoidance through near-real-time cloud information from MTG-FCI, i.e. point to the focus regions at the right time.

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



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HOW DOES IT FIT INTO A GLOBAL CONSTELLATION?

- 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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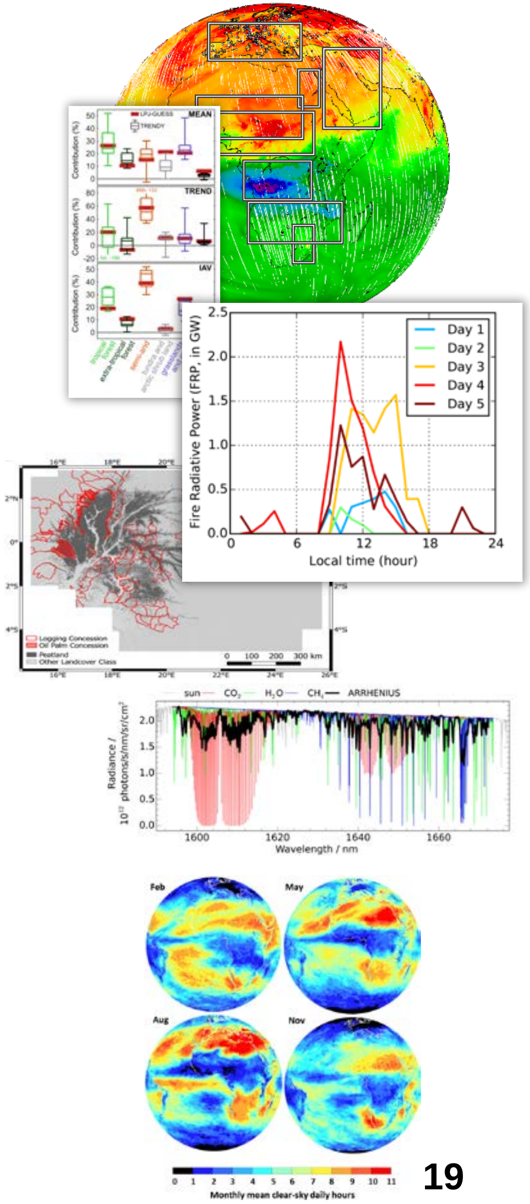
… in a nutshell …

- 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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