Satellite based data and products for air composition monitoring

Policies in emission reduction for pollutants and greenhouse gasses

What it observed and how

Examples on how to support monitoring for policy assessment

Federico Fierli, Mark Higgins, EUMETSAT
Based on the input of EUMETSAT, AC-SAF, Copernicus program

INTEGRATED ASSESSMENT OF AIR POLLUTION AND CLIMATE CHANGE FOR SUSTAINABLE DEVELOPMENT IN AFRICA SUMMARY FOR DECISION MAKERS

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WHAT HAPPENS IF WE DON'T ACT?

Without changes in policy, greenhouse gas emissions will triple by 2063.

Outdoor air pollution is projected to get worse, causing about 930,000 premature deaths per year in 2030 and about 1.6 million premature deaths per year in 2063.

Despite advances in clean cooking technologies, household air pollution would still cause about 170,000 premature deaths per year in 2030 (150,000 by 2063.)

Without action, economic growth compounded by population growth, unplanned urbanization, and unsustainable lifestyles will exacerbate pressures on resources, the environment, and human health, and could increase inequalities and limit Africa's ability to achieve sustainable development.

Goal for emission reduction is stated in the UN Sustainable Development Goals (SDGs) and the AU Agenda 2063

INTEGRATED ASSESSMENT OF AIR POLLUTION AND CLIMATE CHANGE FOR SUSTAINABLE DEVELOPMENT IN AFRICA

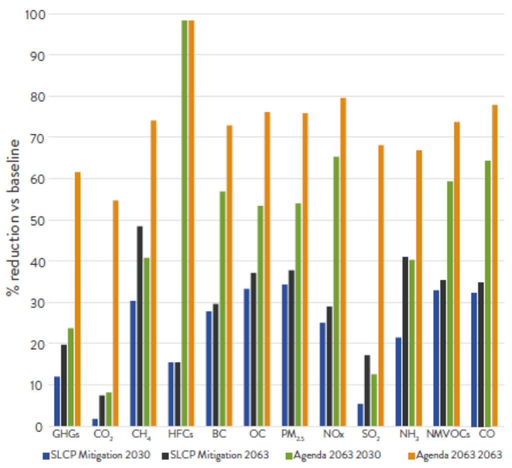
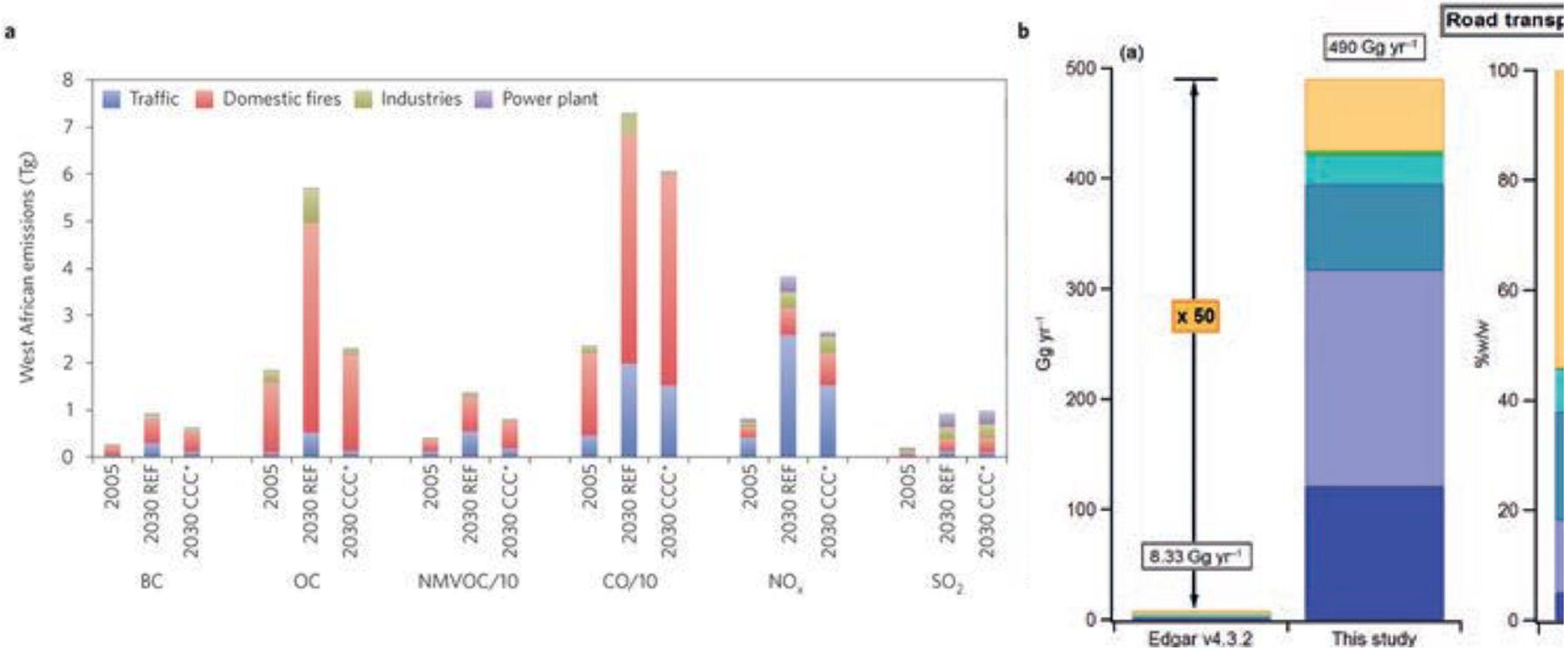


Figure S1 The percentage reduction in GHG, SLCP and air pollutant emissions in 2030 and 2063 for the SLCP Mitigation and Agenda 2063 scenarios versus the Baseline Scenario.

WIDESPREAD HUMAN HEALTH BENEFITS

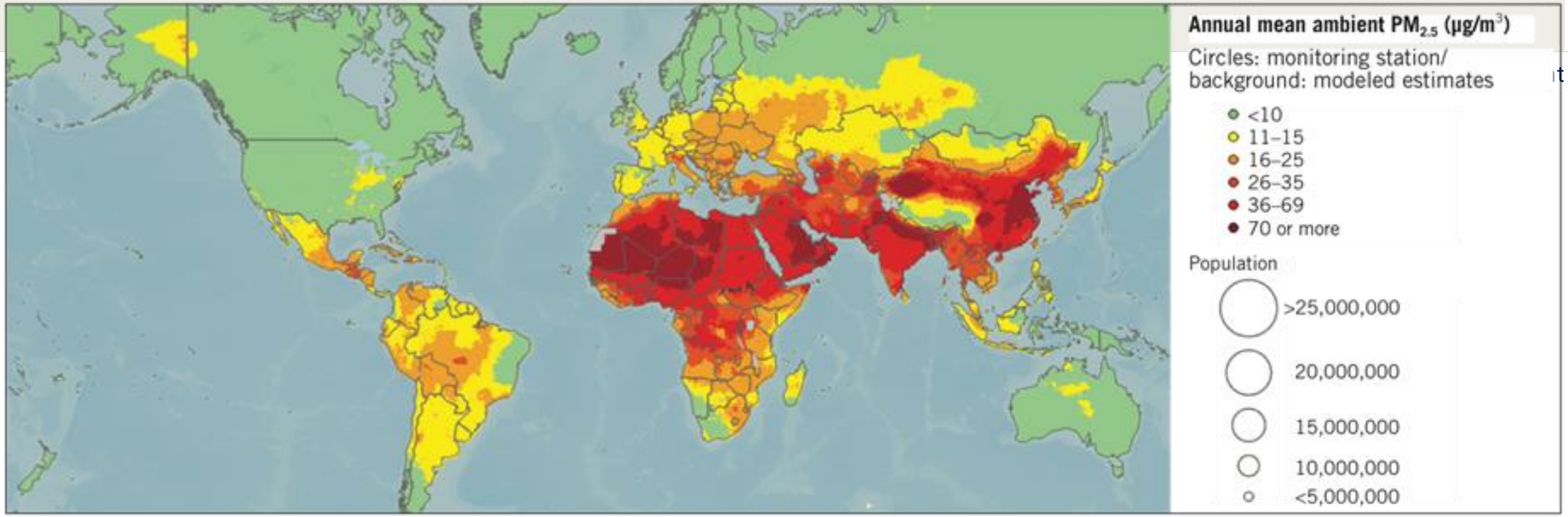
- The emission reductions that could be achieved by the 37 measures are estimated to prevent about **180,000 premature deaths per year by 2030** and **800,000 deaths per year by 2063** from outdoor air pollution.
- Figure S2(a) shows how exposure to $PM_{2.5}$ can be significantly reduced under the SLCP Scenario, and further reduced under the Agenda 2063 Scenario, across the five major regions of Africa, bringing values closer to the WHO Air Quality interim targets and guideline.
- Figure S2(b) shows the improvements that can be made in reducing annual premature mortality attributed to $PM_{2.5}$ in the five major regions.
- Figure S3(a) and (b) show similar trends for tropospheric ozone, the other main pollutant affecting human health in Africa, and for ozone-attributable deaths. The human health benefits over time associated with reduced exposure to $PM_{2.5}$ and ozone are qualitatively similar, with those associated with $PM_{2.5}$ being larger.

Demographic increasing pressure on emissions



Evans, M. J., et al., 2018: Policy-relevant findings of the DACCIWA project. doi:10.5281/zenodo.1476843

Global ambient air pollution, WHO Guideline values (annual mean), $PM_{2.5}$: 10 µg/m³, PM_{10}: 20 µg/m³



HEALTH & SUSTAINABLE DEVELOPMENT GOALS

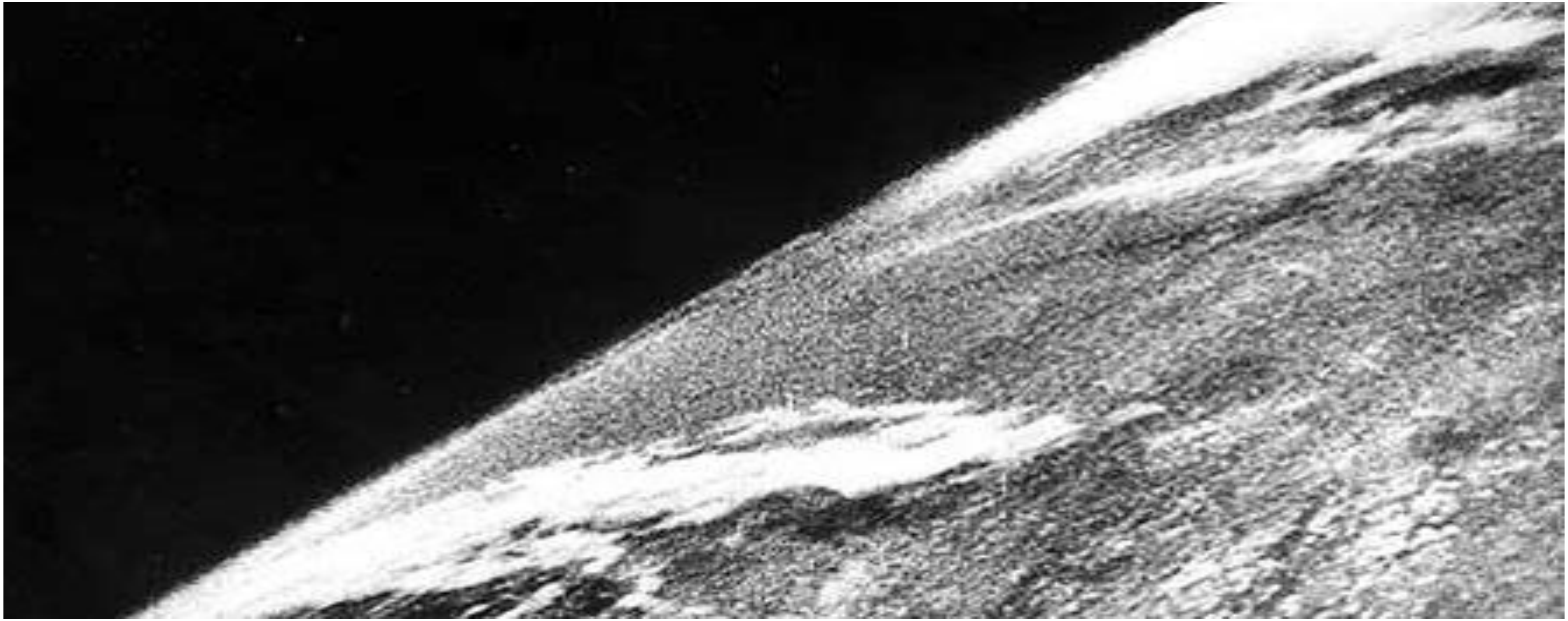
PREVENTING DISEASE THROUGH ACTIONS ACROSS THE SDG SPECTRUM

World Health Organization

- **Human Health**

  (Asthma, infections, Meningitis in Africa, Valley Fever in the America's)
- **Agriculture** (negative & positive impacts)
- **Marine productivity**
- **Improved Weather and Seasonal Climate Prediction**
- **Aviation** (air disasters)
- **Ground Transportation**

Origin of Earth images – 1946



golden age of earth observation

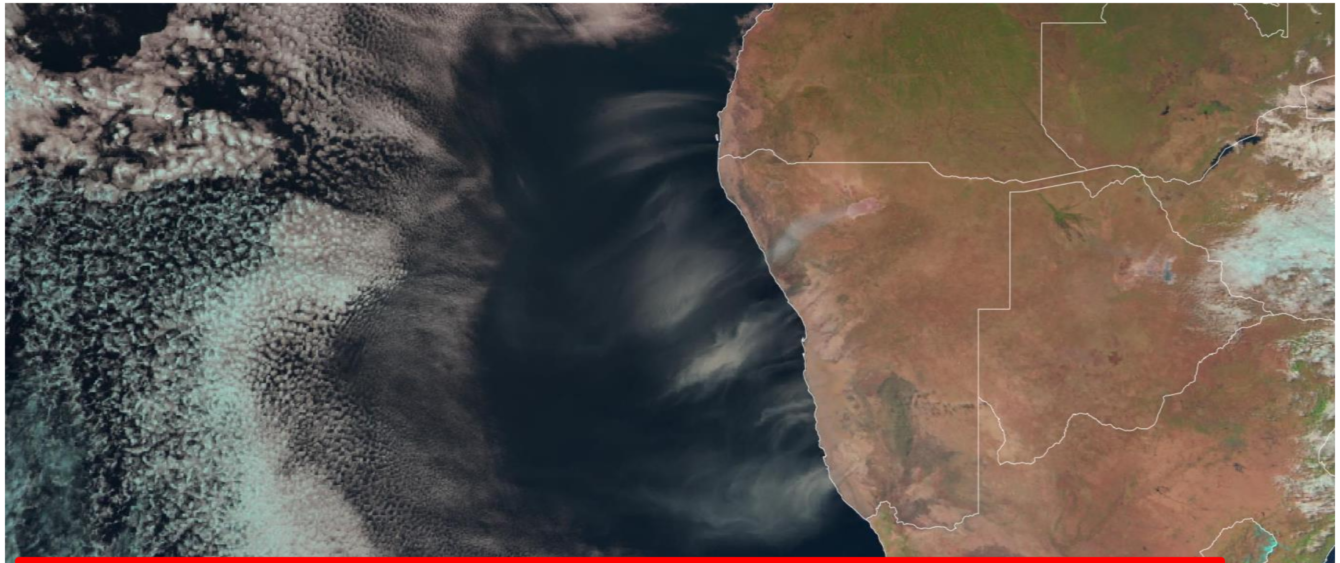
- 1990s: *± 10* earth observation satellites
- 2020s: *150+* earth observation satellites
- tremendous amount of information (and increasing …)
    - surface properties
    - wildfire characteristics
    - vegetation types
    - air pollution

Europe's unique monitoring position for air pollution

- MTG, Sentinels, Earth Explorer missions

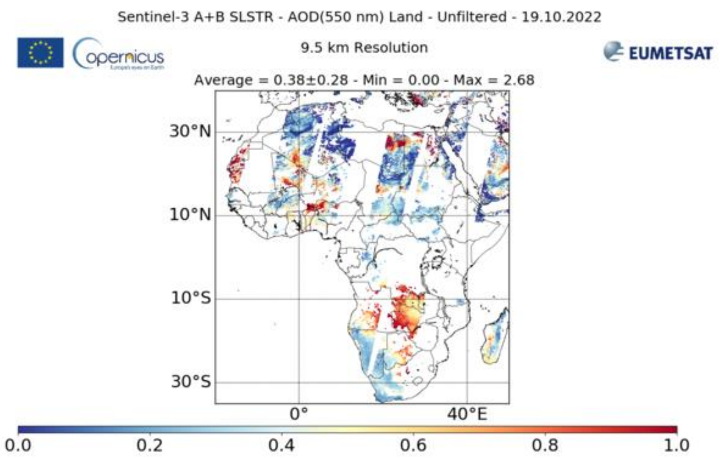
Monitoring aerosol

- Large number of species – distribution of aerosol (eg dust, smoke)
- Access to spatial and temporal scales impossible without the contribution of satellite
- Consistency of measurements worldwide
- Long-term coverage – climate data sets



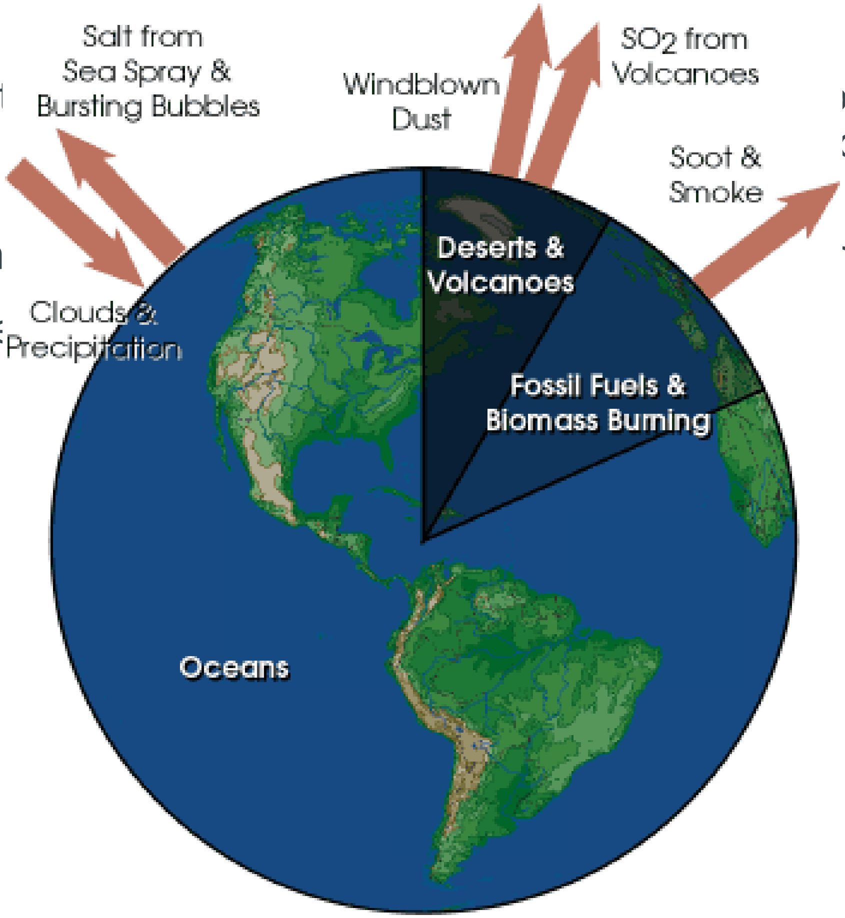
Example of Geostationary monitoring
FCI MTG – dust outbreaks from Namibia desert – data are pre-operational

Example of Polar monitoring
Sentinel-3 Aerosol optical depth – particulate from continental smoke and dust sources



Aerosol Types and Origin

- Aerosol particles larger than about 1 μm in size are produced by windblown dust and sea salt from sea spray and bursting bubbles.
- Aerosols smaller t ɪn processes such as conversion of sulfur dioxide (SO_2) gas (released from vol ɔrmation of soot and smoke during burning processes.
- After formation, th ɪospheric motions and are primarily removed by cloud and precipitation proce



Aerosol size distribution

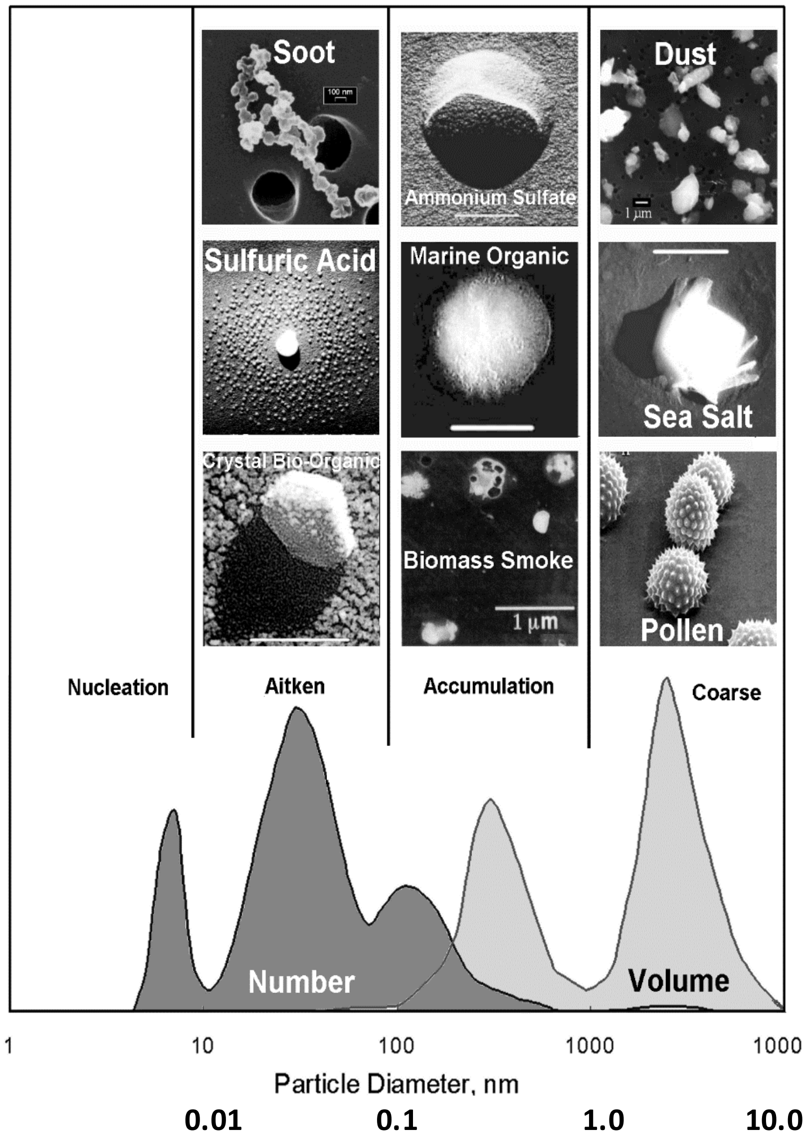
It presents 3 modes :

- « nucleation »: radius is between 0.002 and 0.05 mm. They result from combustion processes, photo-chemical reactions, etc.

- « accumulation »: radius is between 0.05 mm and 0.5 mm. Coagulation processes.

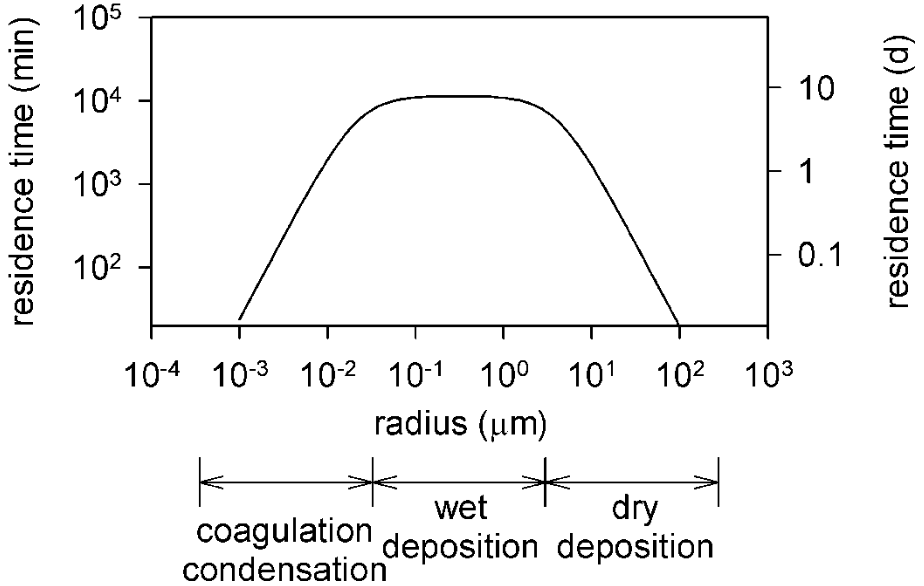
- « coarse »: larger than 1 mm. From mechanical processes like aeolian erosion.

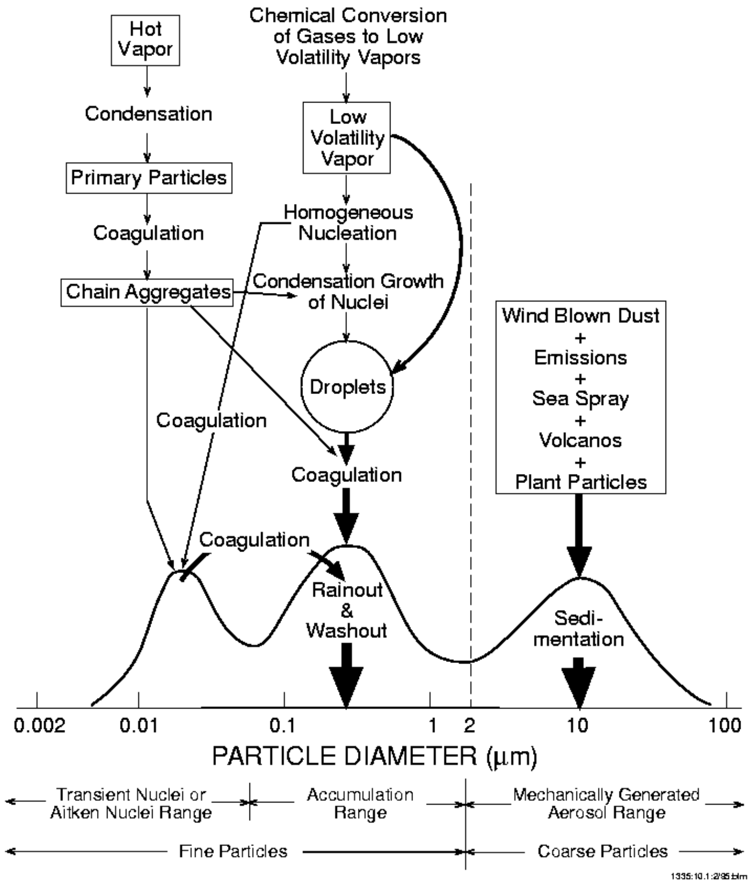
« fine » particles (nucleation and accumulation) result from anthropogenic activities, coarse particles come from natural processes.



Aerosols come from a variety of sources, and reside in the atmosphere for weeks

aerosols = particles suspended in a gas





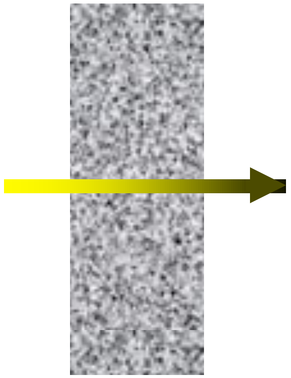
Seinfeld and Pandis

Key aerosol optical parameters

Optical depth

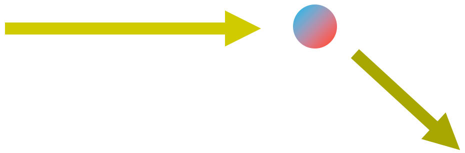
negative logarithm of the direct-beam transmittance

column integrated measure of the amount of extinction (absorption + scattering)



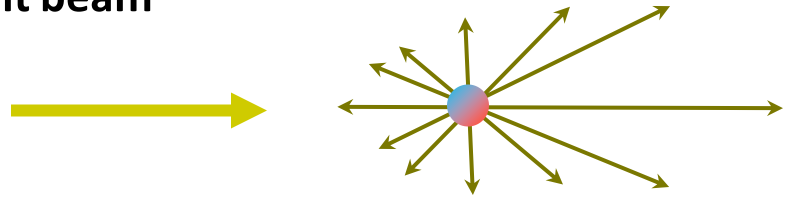
Single-scattering albedo v_0

given an interaction between a photon and a particle, the probability that the photon is scattered in some direction, rather than absorbed



Scattering phase function

probability per unit solid angle that a photon is scattered into a particular direction relative to the direction of the incident beam



Angstrom exponent a

exponent of power law representation of extinction vs. wavelength

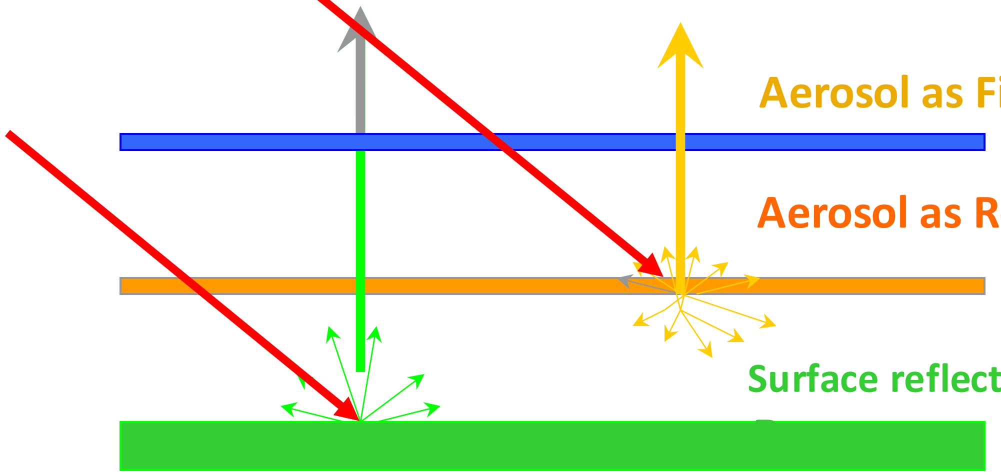
Apparent Surface Reflectance, R

copernicus.eumetsat.int

R_0

filter *reflector*

$$R = (R_0 + (e^{-t} - 1)\,P)\,e^{-t}$$



Aerosol as Filter: $T_a = e^{-t}$

Aerosol as Reflector: $R_a = (e^{-t} - 1)\,P$

Surface reflectance

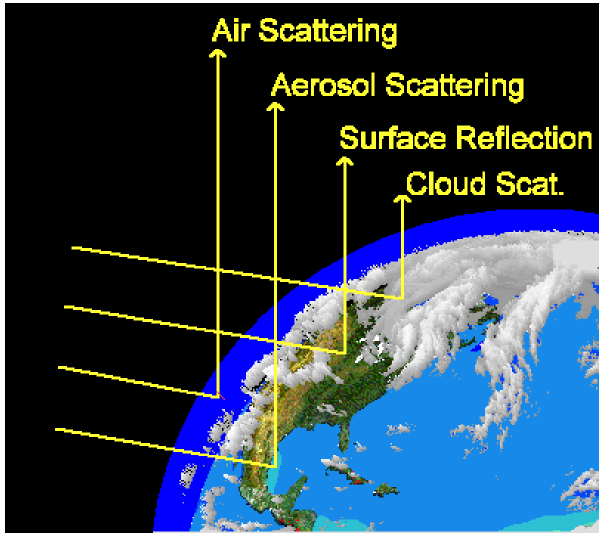
R

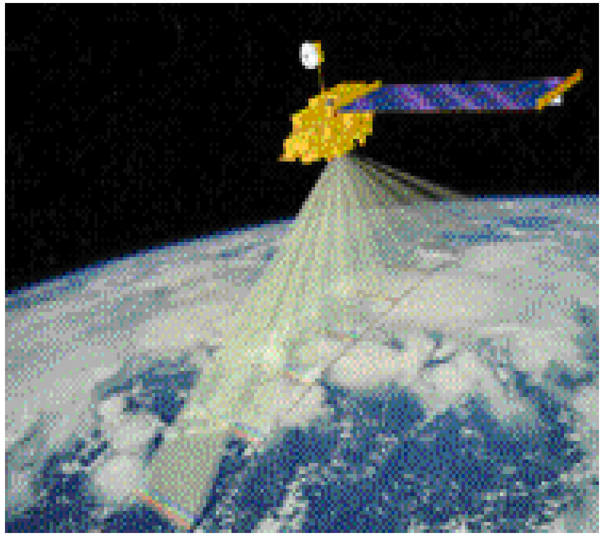
$$R = (R_0 + R_a)\,T_a$$

surface *aerosols*

Just like the human eye, satellite sensors detect the total amount of solar radiation that is reflected from the earth's surface (R_o) and backscattered by the atmosphere from aerosol, pure air, and clouds. A simplified expression for the relative radiation detected by a satellite sensor (I/I_o) is:

$$I = \int_{Height}\int_{Type}\int_{Size}\int_{Angle}\int_{Shape} H \bullet C \bullet D \bullet P \bullet S \; dH dC dD dP dS$$

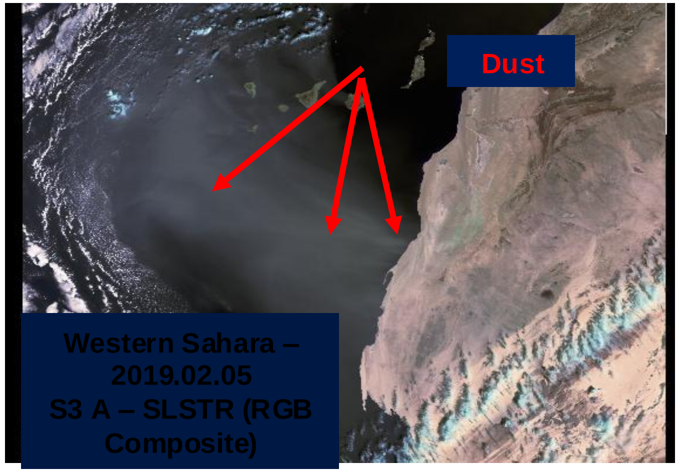


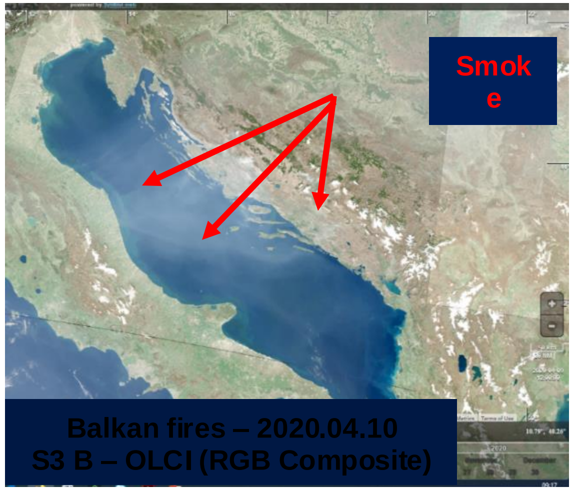


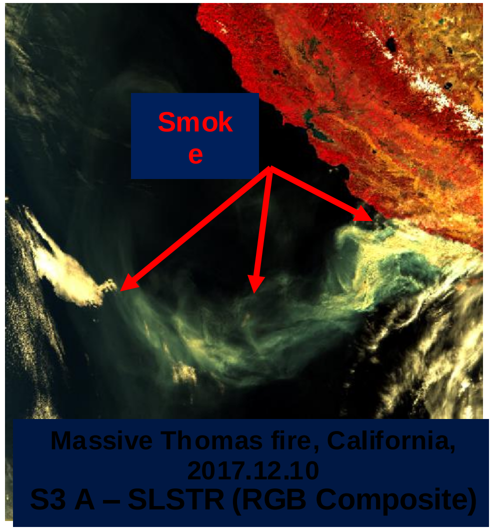
Observe smoke : In a nutshell

- A proxy of the aerosol amount in air

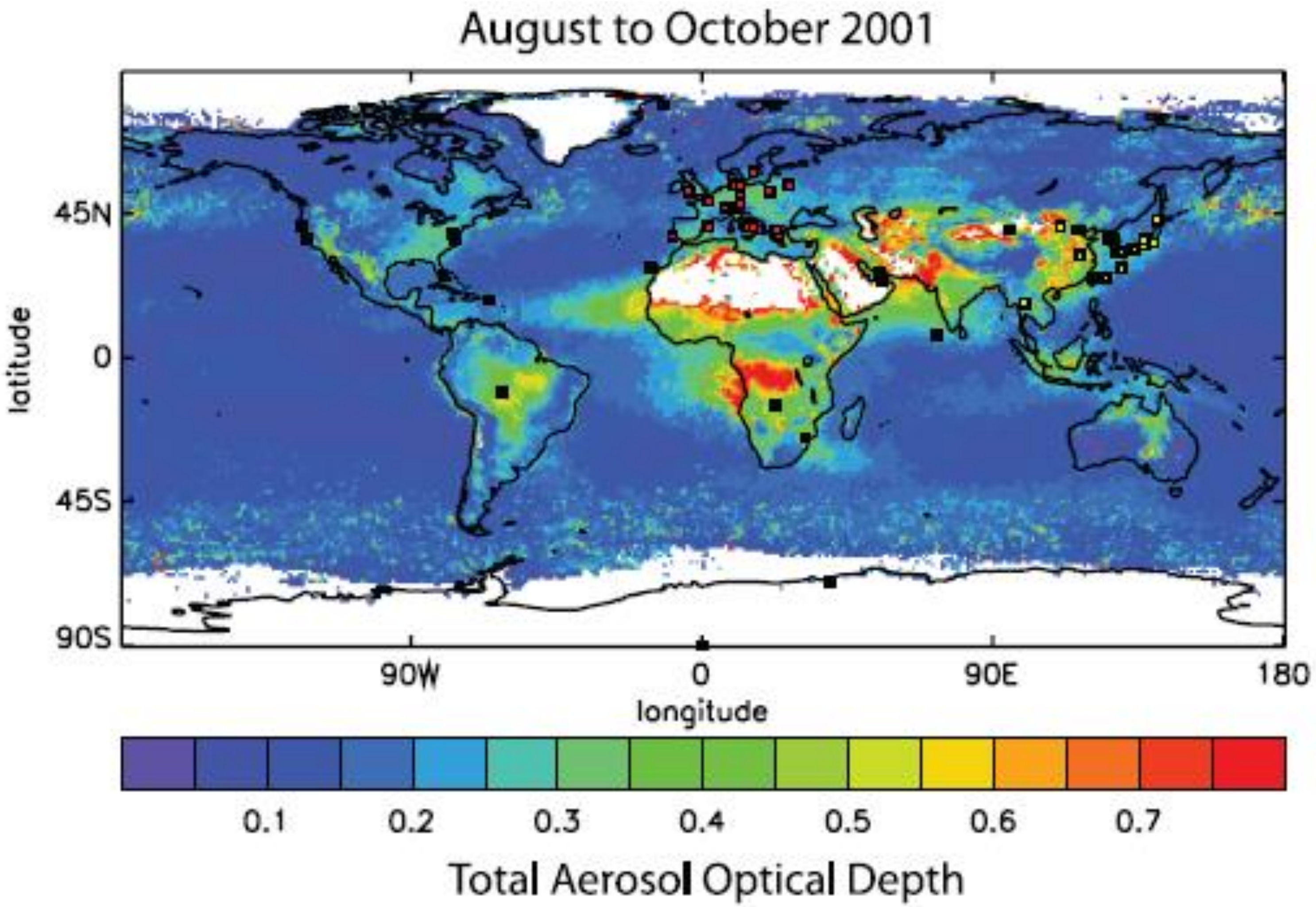
Looking at the







AEROSOL OPTICAL DEPTH



MODIS satellite data

Observe Smoke: Absorbing Aerosol Index (AAI)

We can exploit different wavelengths …

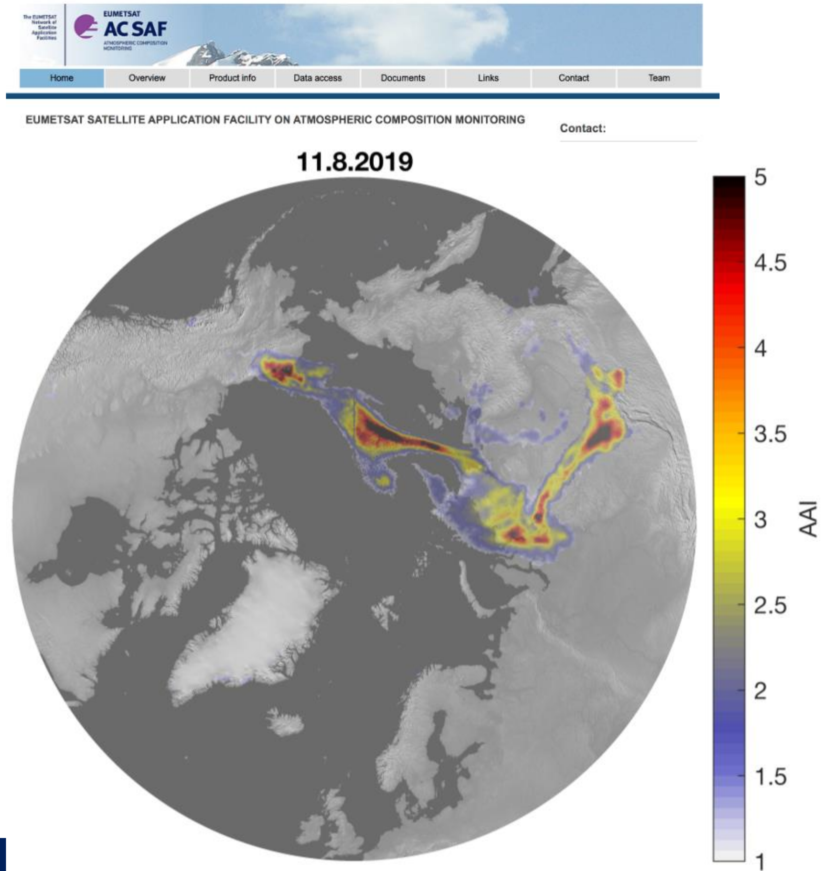
Defined using UV-wavelengths

Sensitive to absorbing aerosols: smoke, volcanic ash, desert dust

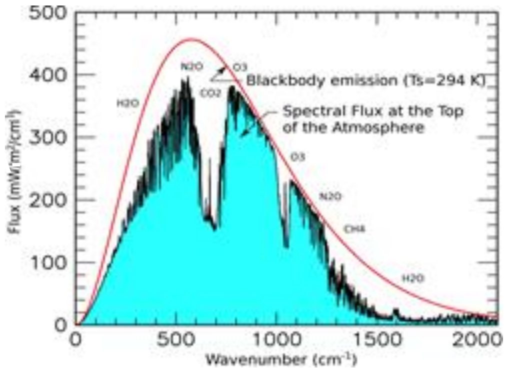
AAI separates the spectral contrast at two UV wavelengths caused by aerosol extinction from that of other effects (e.g. molec. scattering)

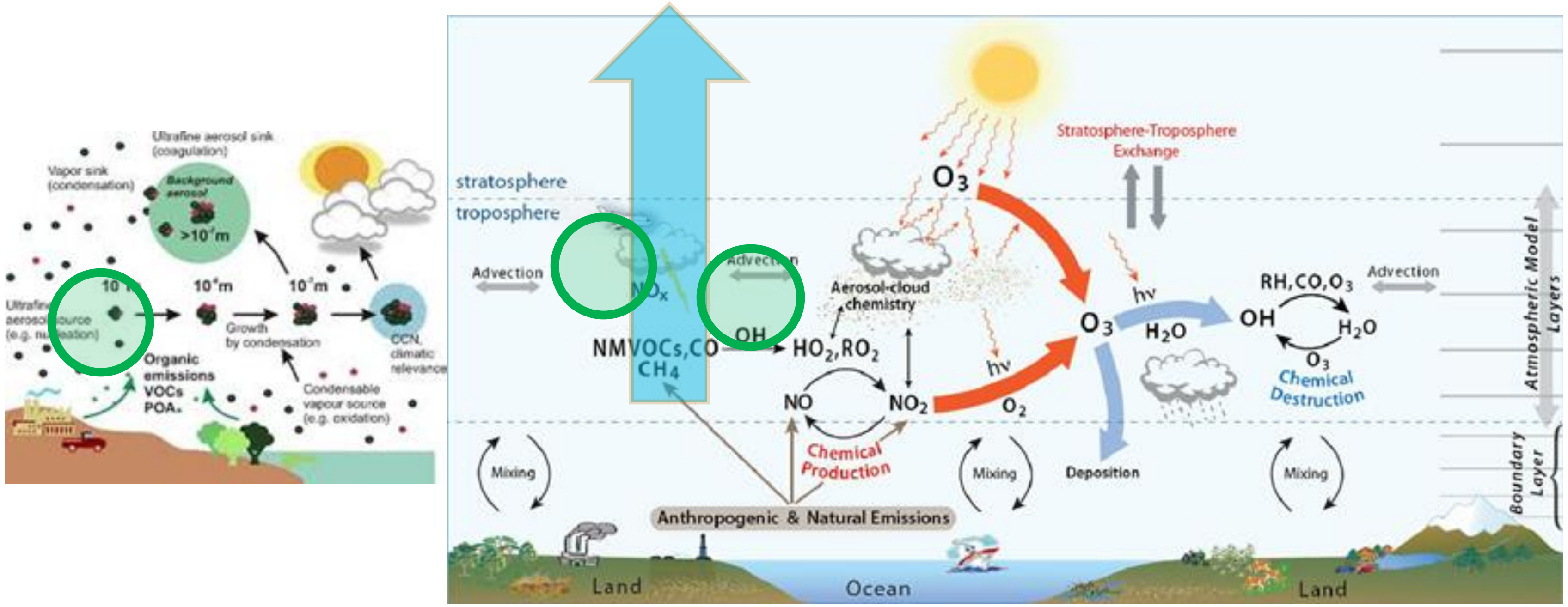
Clouds do not [redacted]
observation

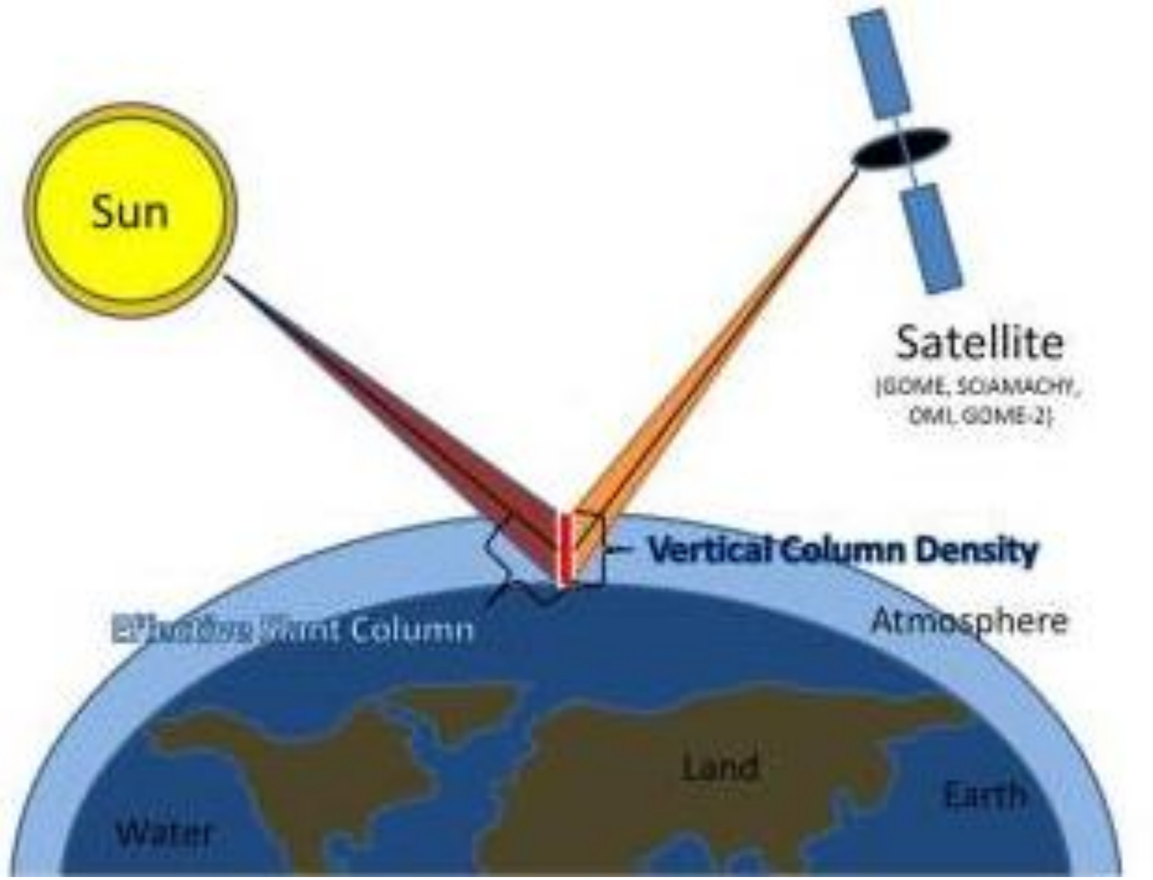
Used in EUMETSAT and Sentinel5P



What we see and what Satellites see





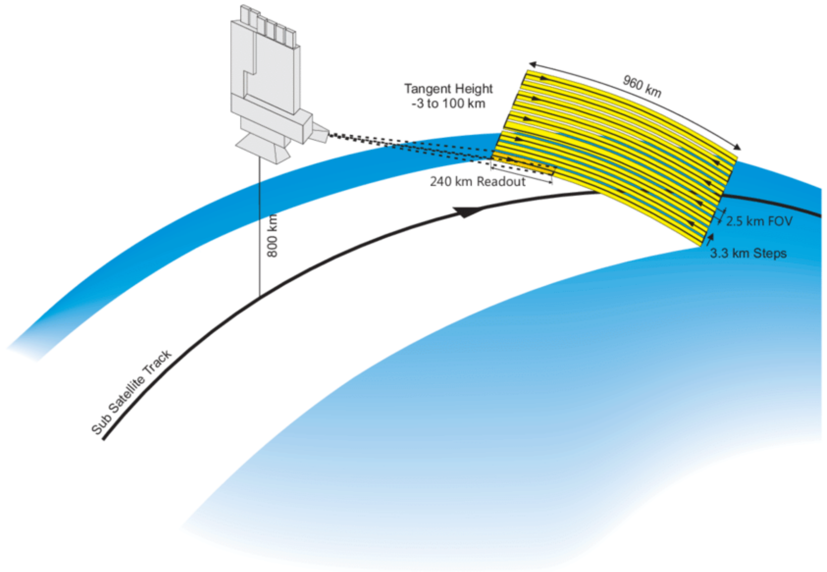


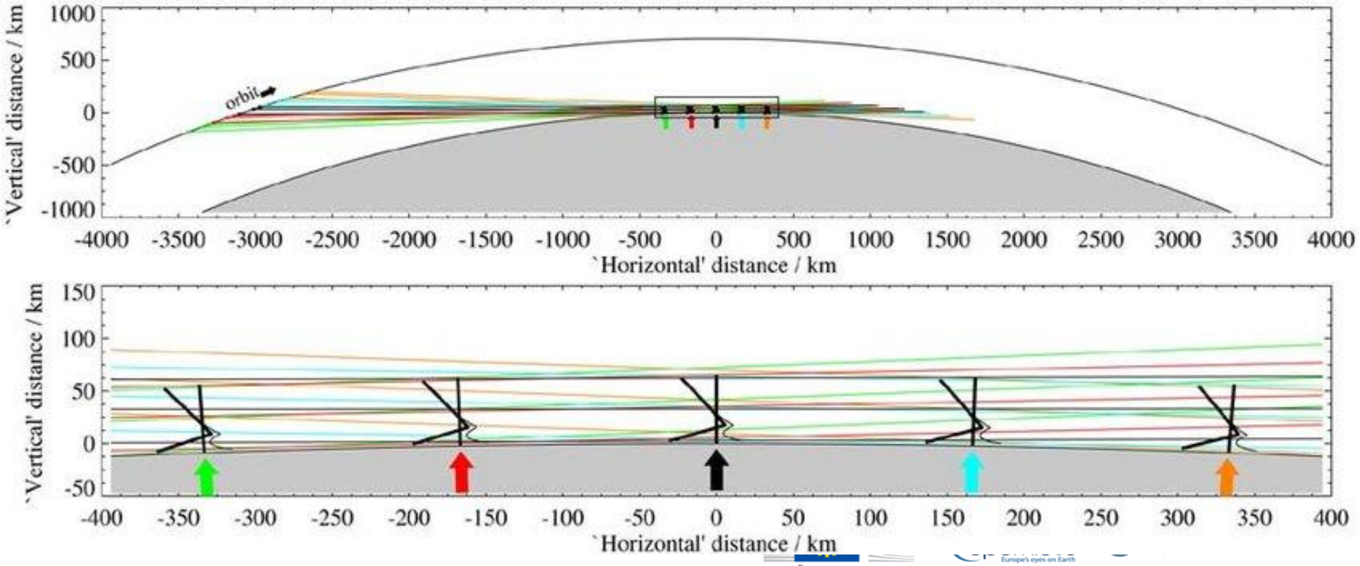
Satellite measurements
Radiation emerged from the interaction with the Atmosphere-Surface system

COMPARED TO

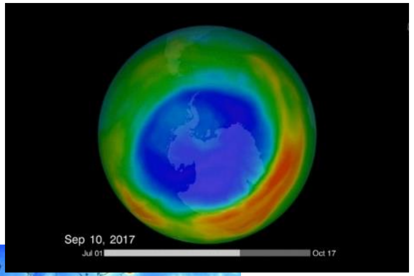
Modelleded measurements
- A priori information on the system (atmospheric scenarios)
- Model of the system (Forward model)

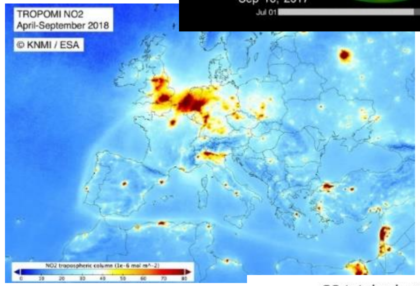
Limb scanning – vertical profiles

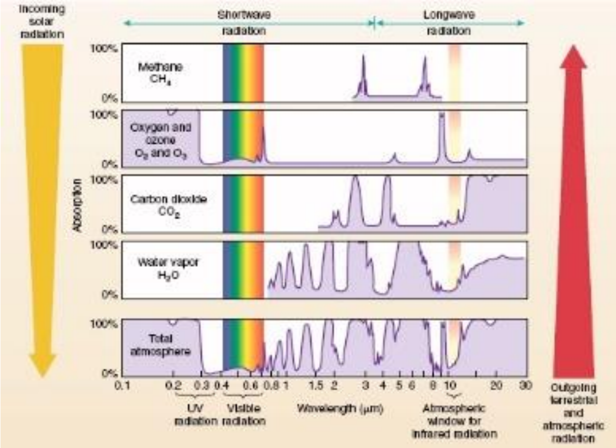


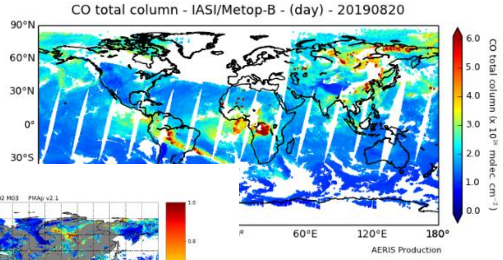


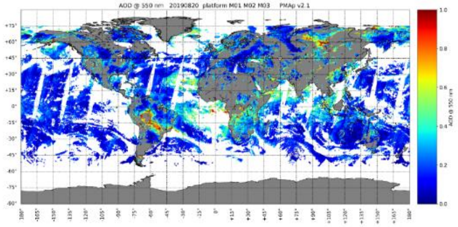
We walk the line ... chemistry – air quality climate

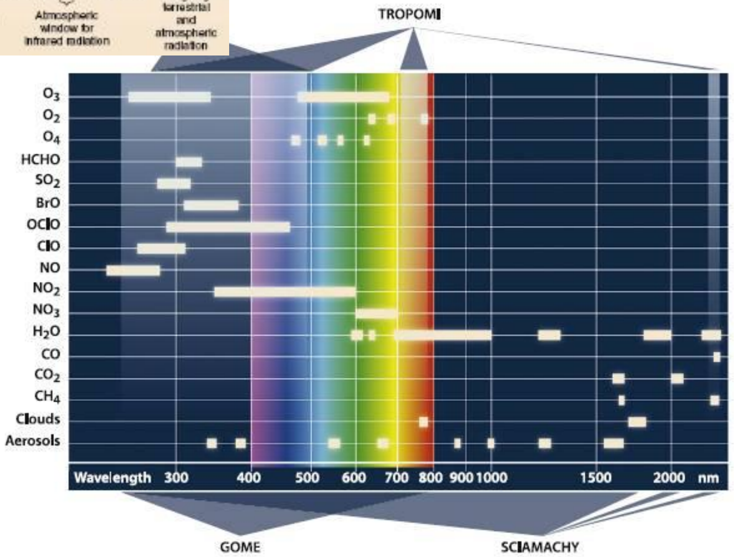




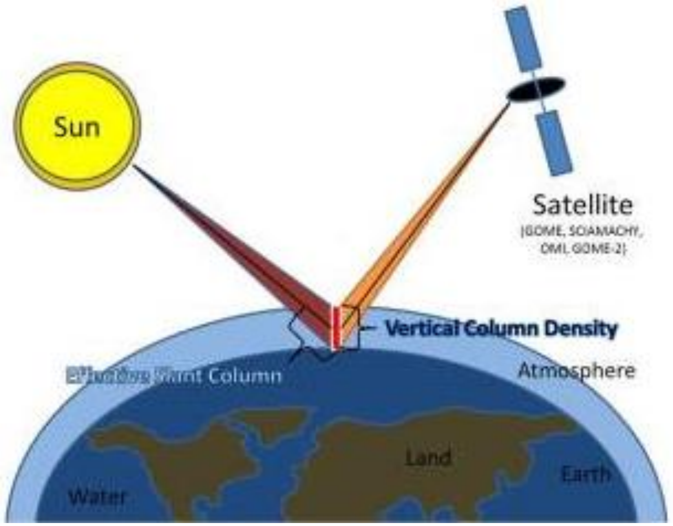


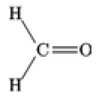


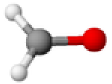


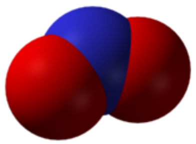


Monitoring gaseous pollutants









	PRESENT			FUTURE	
Product	**Metop GOME-2**	**Sentinel 5 and 5p**	**Metop IASI**	**Metop-SG IASI-NG**	**MTG-S S4/UVN**
O_3 total column	√	√	√	√	√
O_3 profile (incl. troposphere)	√	√	√	√	
O_3 tropospheric column	√				√
NO_2 total column	√	√			√
NO_2 tropospheric column	√	√			√
SO_2	√	√	√	√	√
SO_2 Layer Height		√	√	√	
HCHO	√	√			√
CHOCHO	√	√			√
BrO	√	√			
OClO		√			
HNO_3			√	√	
NH_3			√	√	
CO		√	√	√	
CH_4		√	√	√	
SIF	√	√			
CO_2					
H_2O	√	√			√
UV Products	√	√			√

Observed species are produced by anthropogenic and natural.

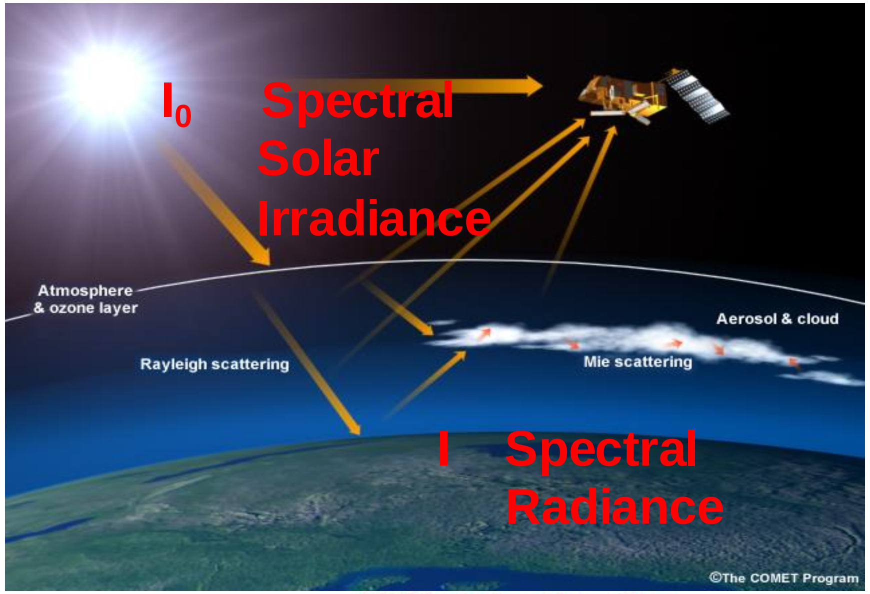
These are relevant for key policies.

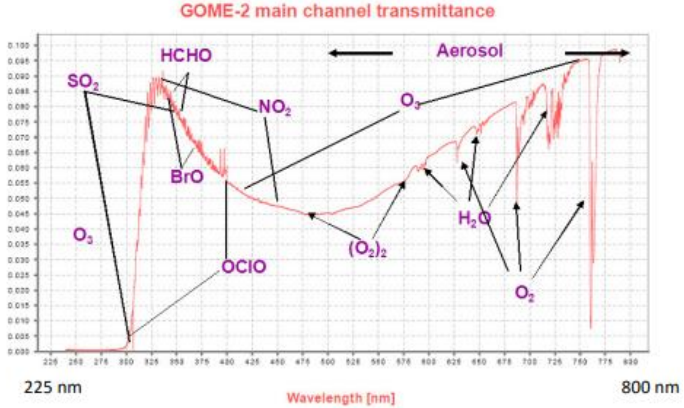
However –

Uncertainty can be high – concentrations are small

Observations are not at nose levels – need of interpretation

GOME-2 a good example for UV-VIS

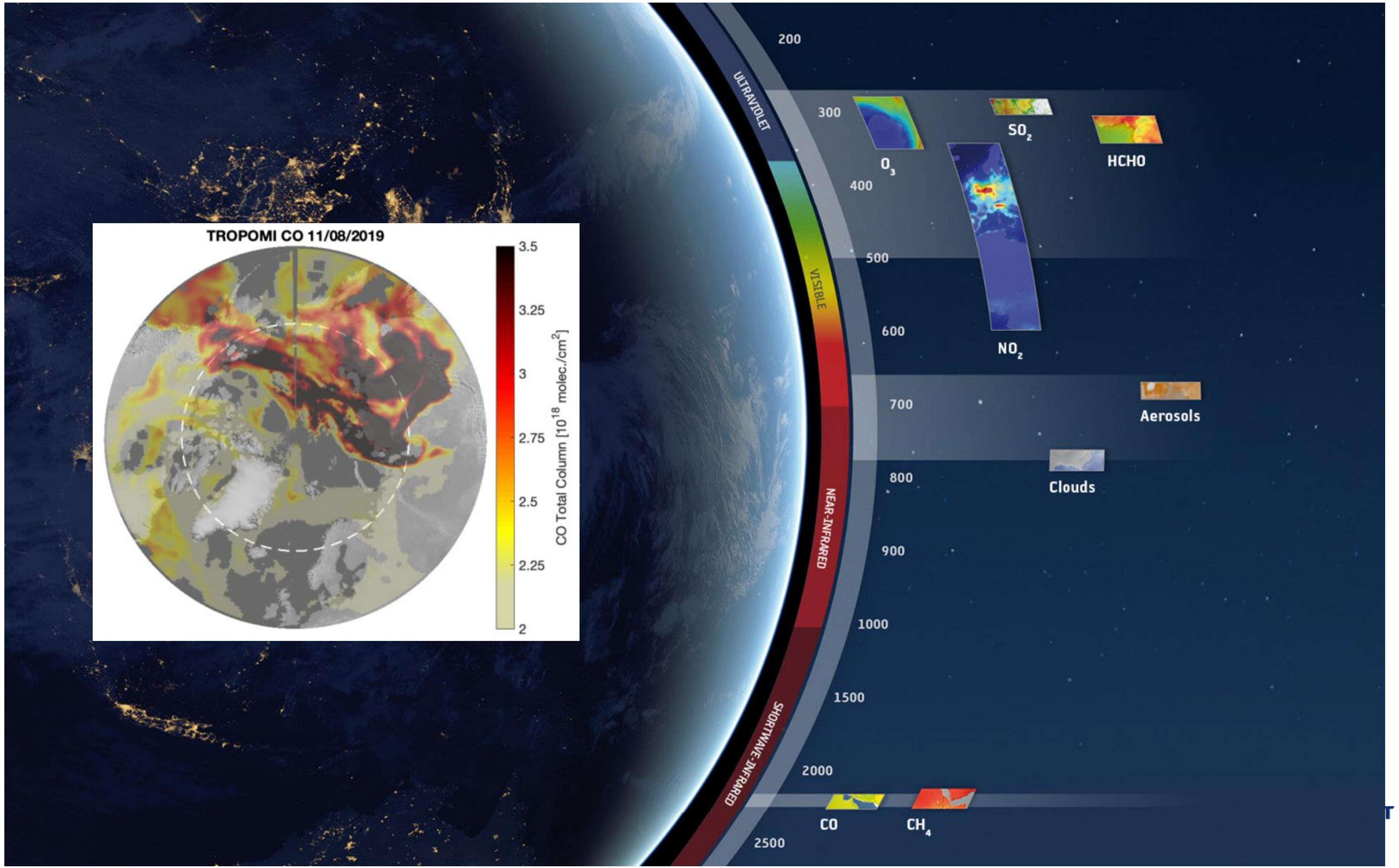




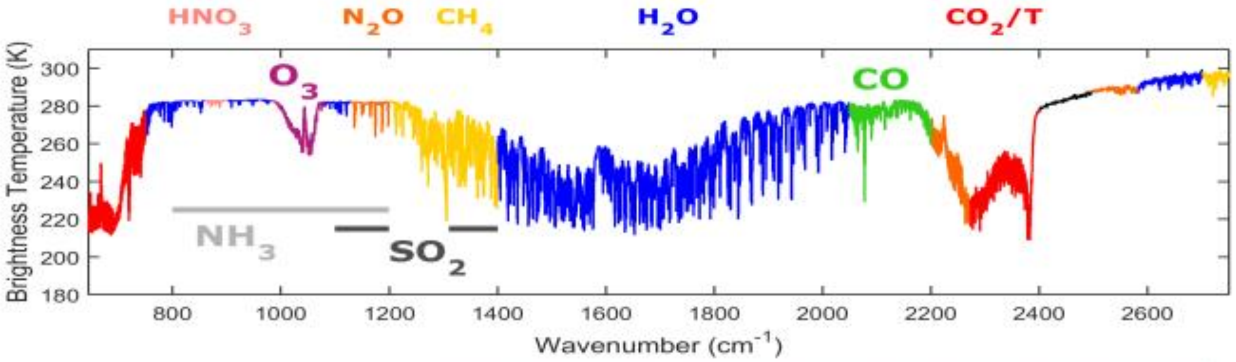
- Satellites provide amount of specific gas in total column / tropospheric column
- Satellite observation ≠ surface concentration
- Even though satellites have limited sensitivity close to surface concentrations, to a high degree satellites tell “the same story” as surface measurements.
- Observations can be limited by cloudiness and or polar winter (UV-VIS)
- Wind information is often very useful when analysing the data

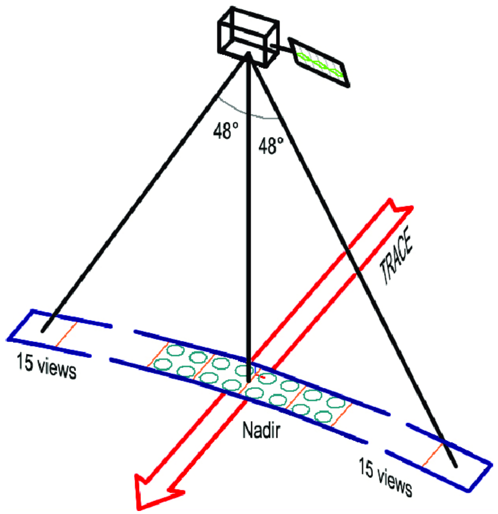
EUMETSAT AC SAF ATMOSPHERIC COMPOSITION MONITORING

Observe gaseous species: example of TROPOMI



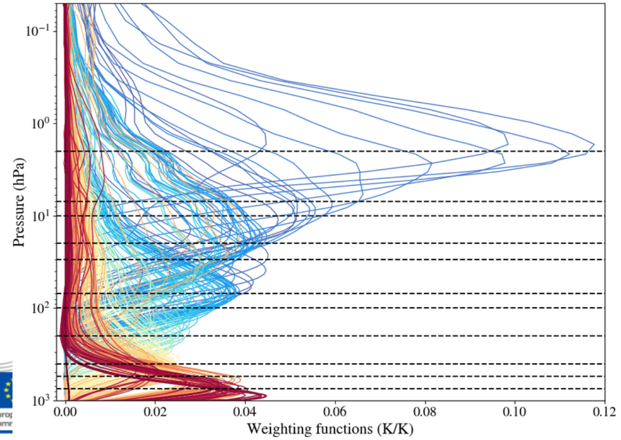
IASI on-board METOP-ABC





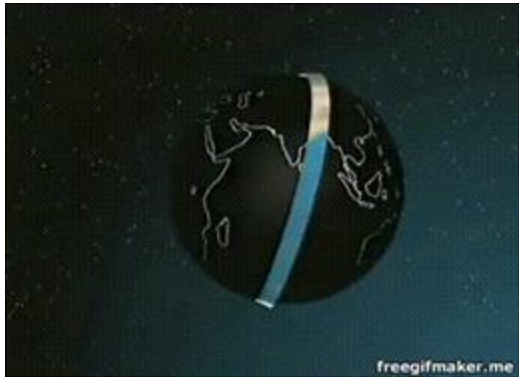
Now 33 species measured or *detected* by IASI

Greenhouse gases and ozone-related substances (13)	H_2O, CO_2, CH_4, N_2O, O_3, HNO_3, CFC-11, CFC-12, HCFC-22, CF_4, *SF_6*, *CCl_4*, *HFC-134a*
Air quality and VOCs (12)	CO, CH_3OH, HCOOH, CH_3COOH, CH_3COCH_3, C_2H_2, C_2H_4, NH_3, HCN, PAN, SO_2, OCS
Concentrated plumes (6)	HCl, H_2S, C_3H_6, C_4H_4O, HONO, *HCHO*



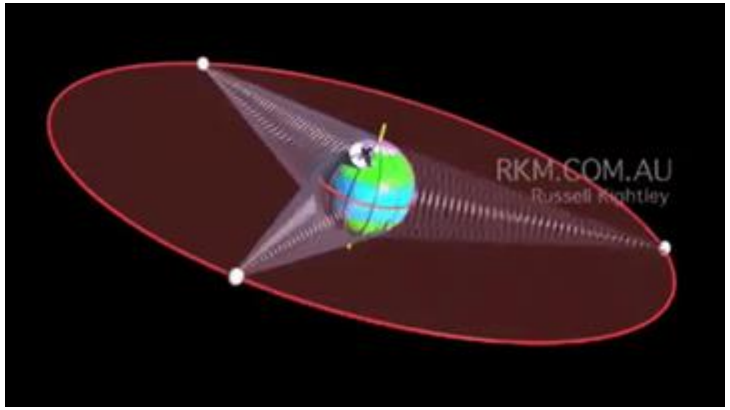
Satellite orbits

Advantages:
More near to Earth -> Higher spatial resolution
Used also for Active Obs.(Radar/Lidar) and PMW
Disadvantages:
Poorer time resolution -> needs of constellation



Advantages:
Better time resolution

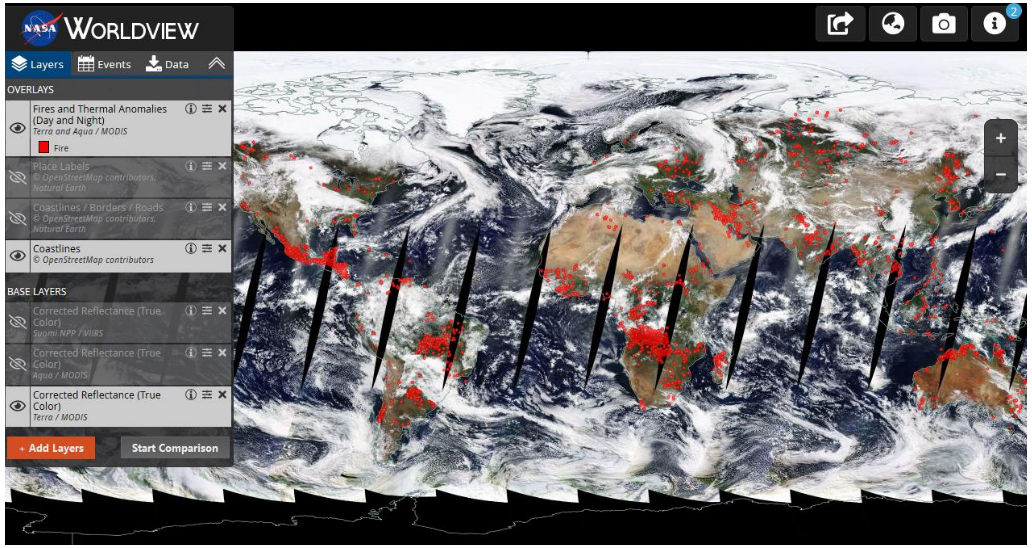
Disadvantages:
One side of the Earth -> needs of constellations
large viewing angles at the borders -> geometrical distorsions
Only VIS/IR and passive Obs.

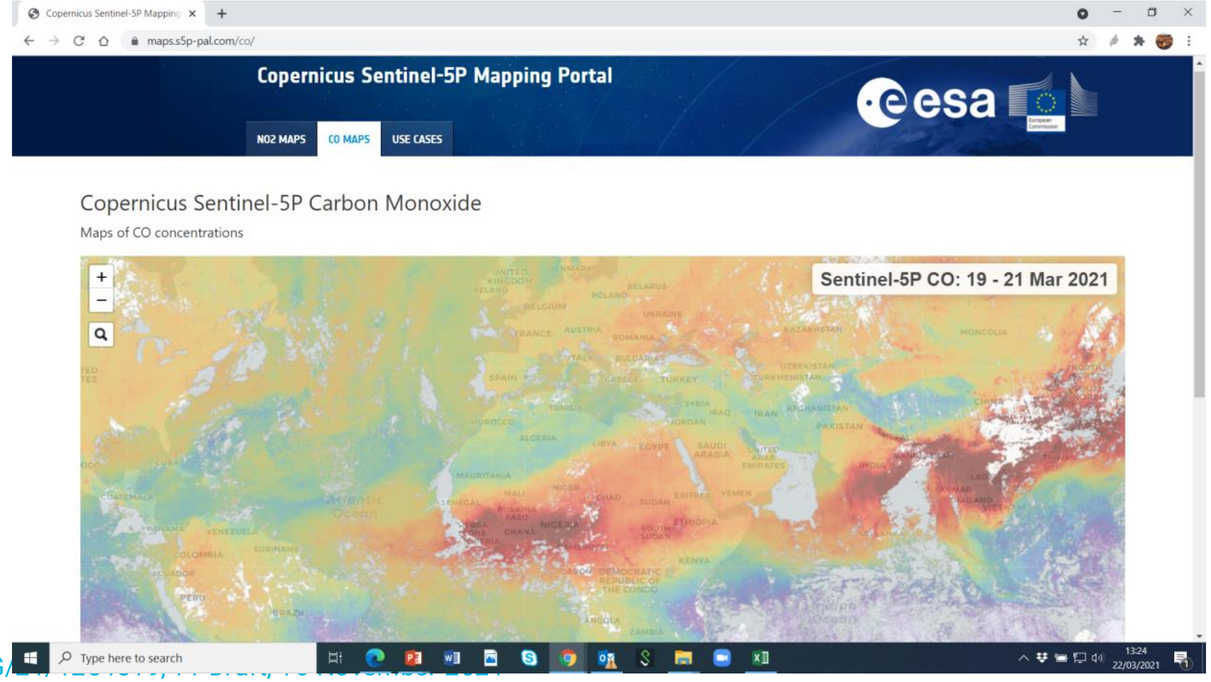


Observe from Polar orbit …

- Global, 1 km resolution (nadir)
- Limited temporal sampling

Accumulate data





Meteosat Third Generation (MTG): Mission overview

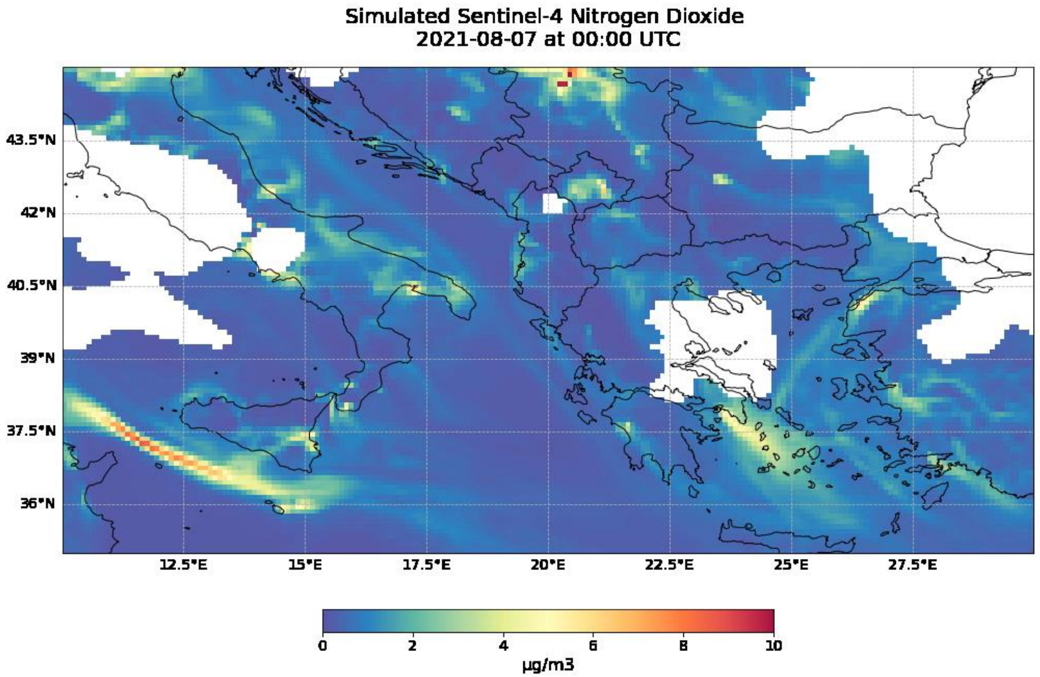
- **Imagery missions (MTG-I):**
  1. Full disk imagery every 10 minutes in 16 spectral bands with the Flexible Combined Imager (FCI). Fast imaging of European weather every 2.5 minutes
  2. Day/night Lightning Imager (LI)

- **Sounding mission (MTG-S):**
  1. 3D mapping of water vapour, temperature with Hyperspectral Infrared Sounder (IRS)
  2. Air quality monitoring and atmospheric chemistry in synergy with Sentinel-4 / Ultraviolet Visible & Near-infrared

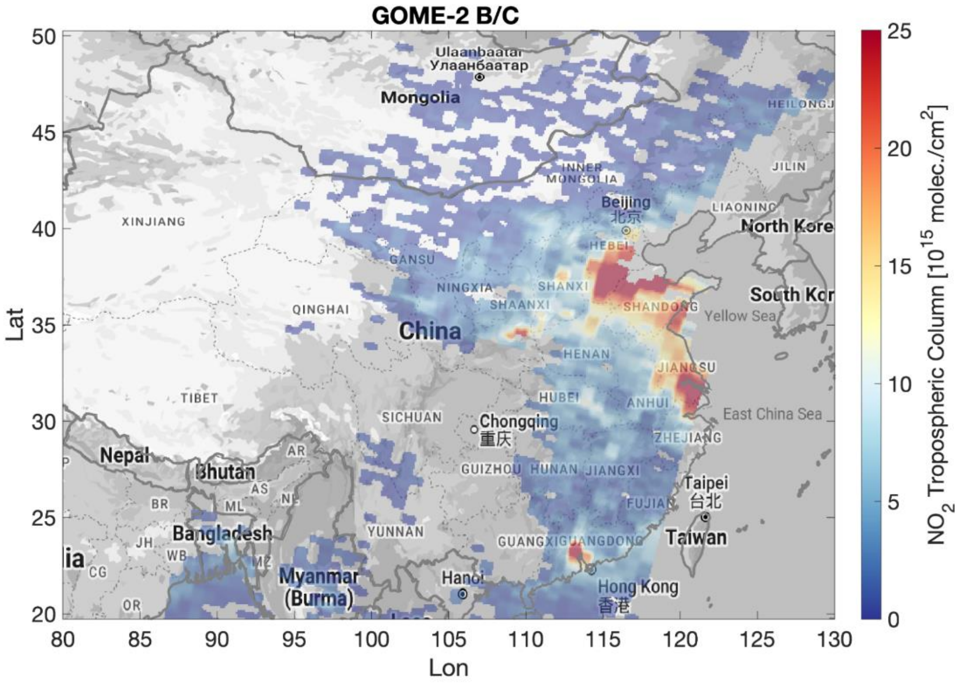
- Start of operations in 2022 and 2024
- Operational exploitation: 2022–2042

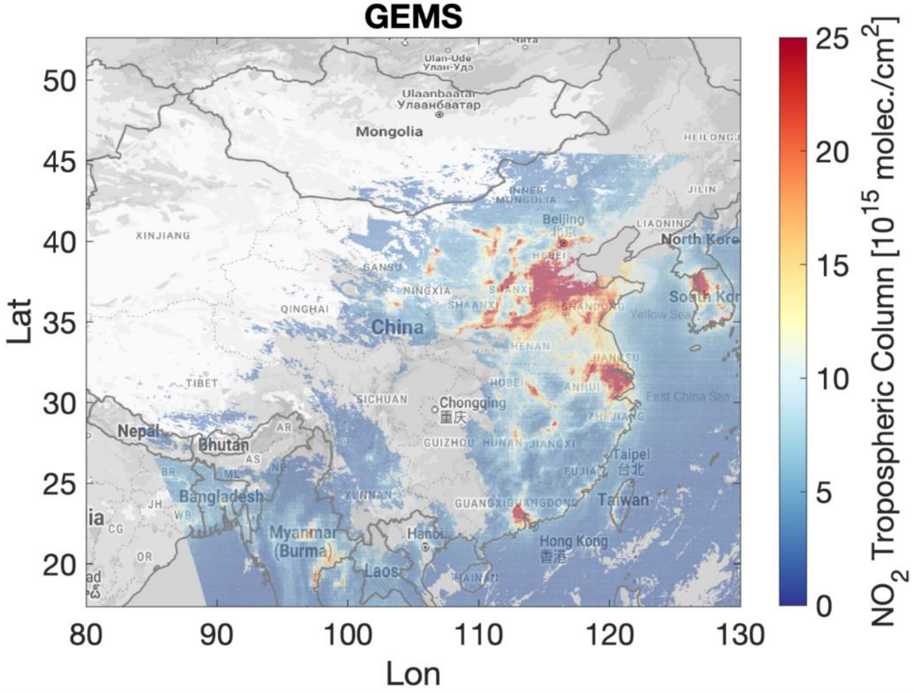
Synergies of CO2M - Sentinel-4

NO2 observations
Synergy to exploit with
CH4 – IRS on MTG-S
CO2 from IRS

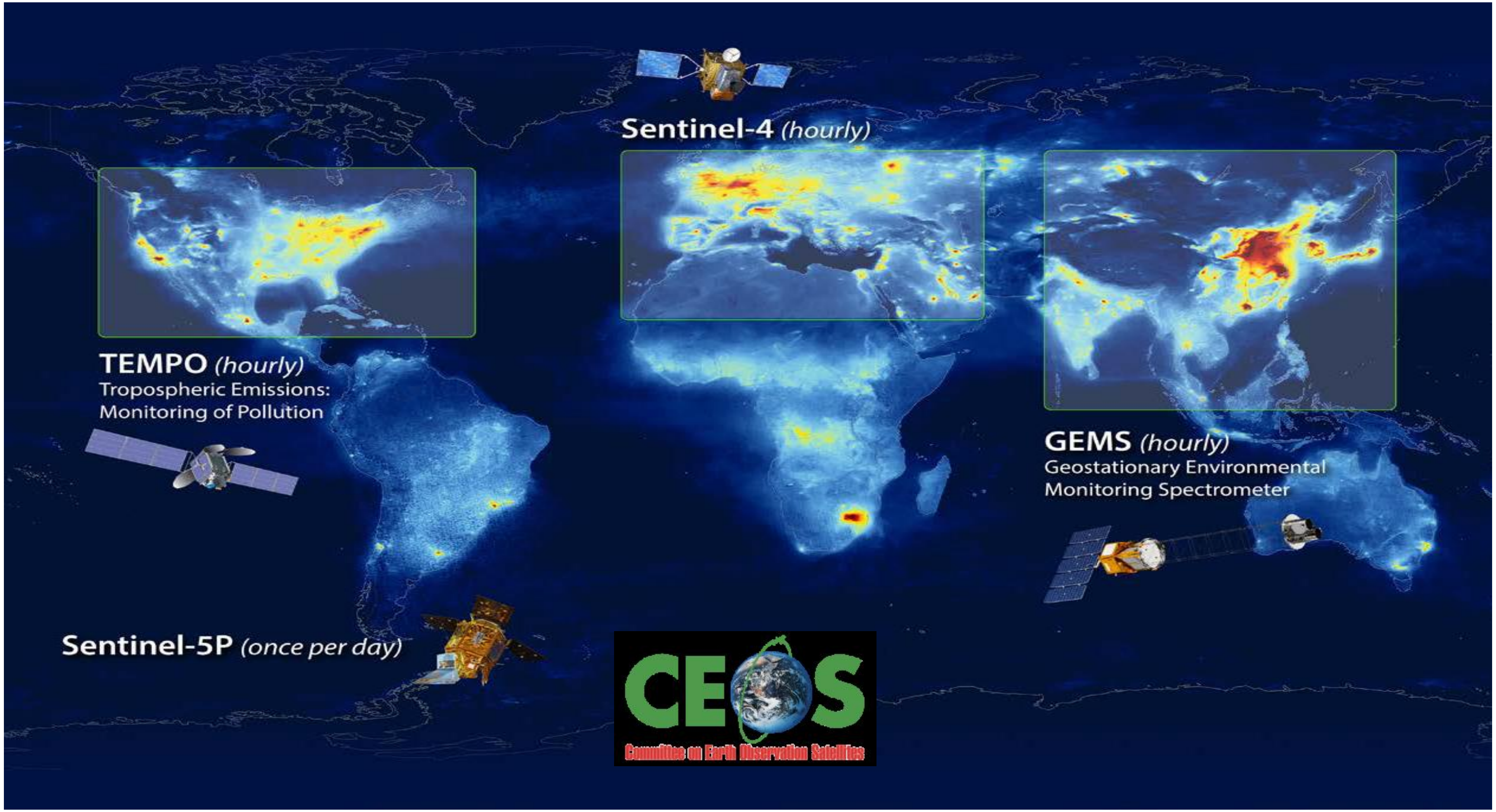


GEMS as Sentinel-4 precursor – LEO vs GEO





Sinergy – Constellation for Air Quality

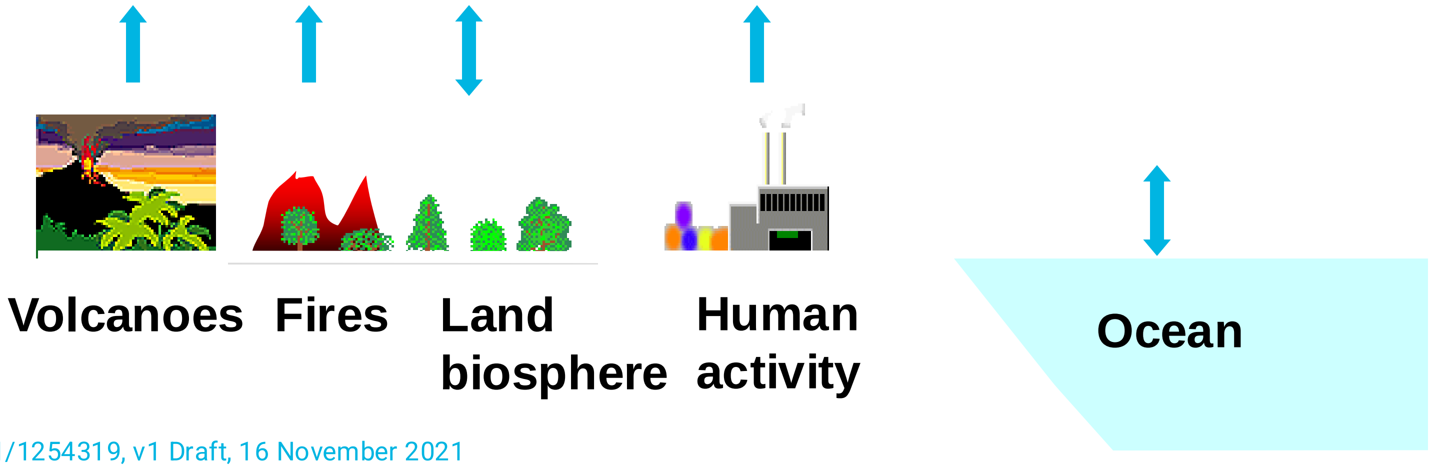


What determines a concentration C ?

Lightning

Transport

Chemistry
Aerosol microphysics



Eulerian form:

$$\frac{\partial C_i}{\partial t} = -\mathbf{U} \bullet \nabla C_i + P_i - L_i$$

Lagrangian form:

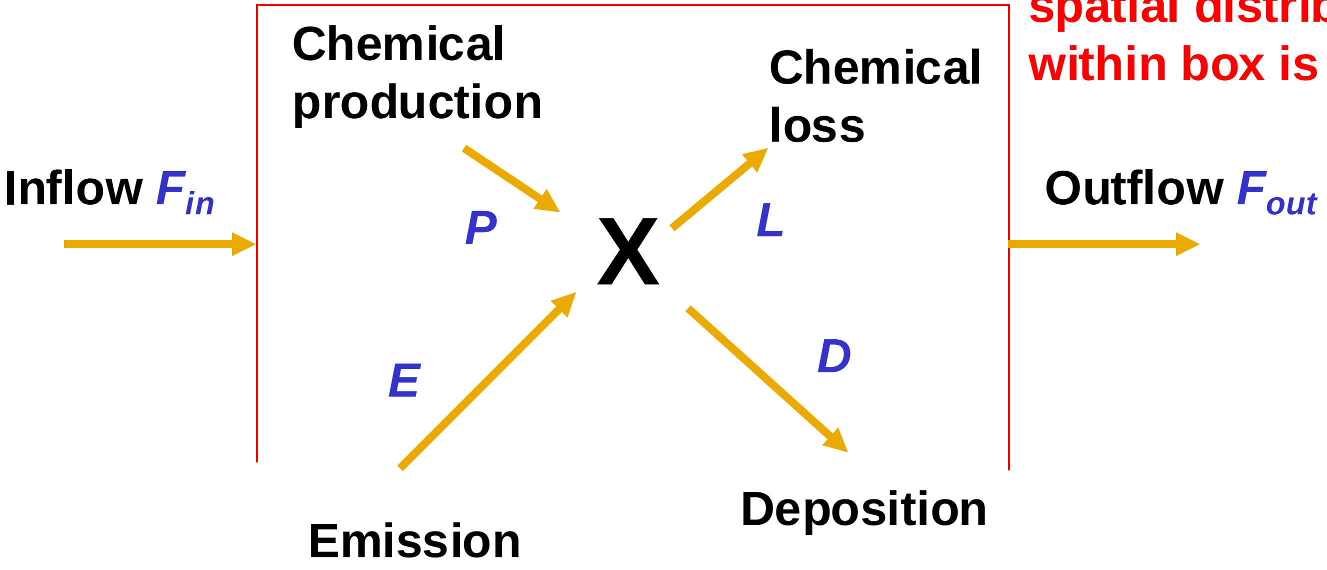
$$\frac{dC_i}{dt} = P_i - L_i$$

$\mathbf{U}$ = wind vector

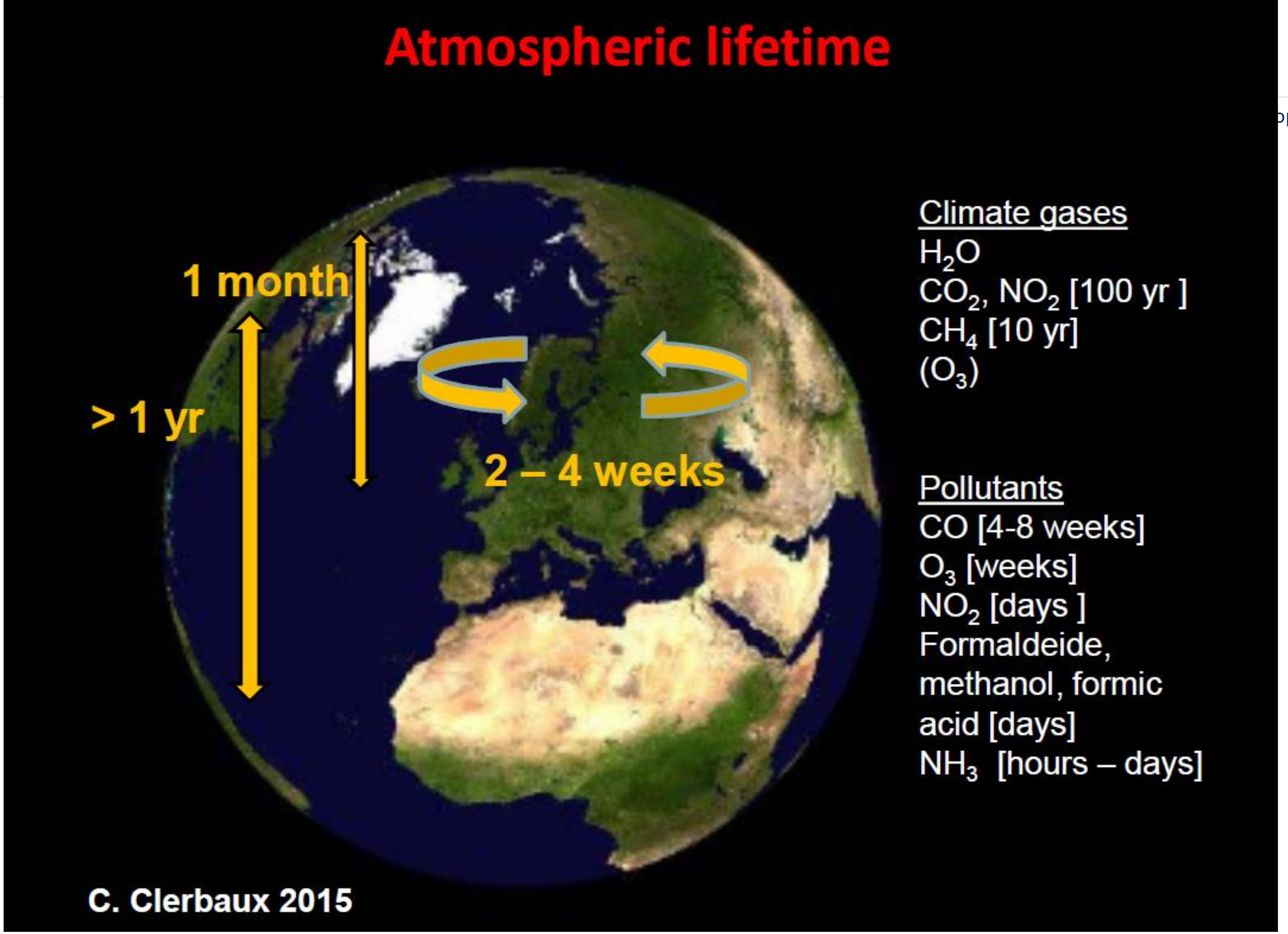
P_i = local source of chemical *i*

L_i = local sink

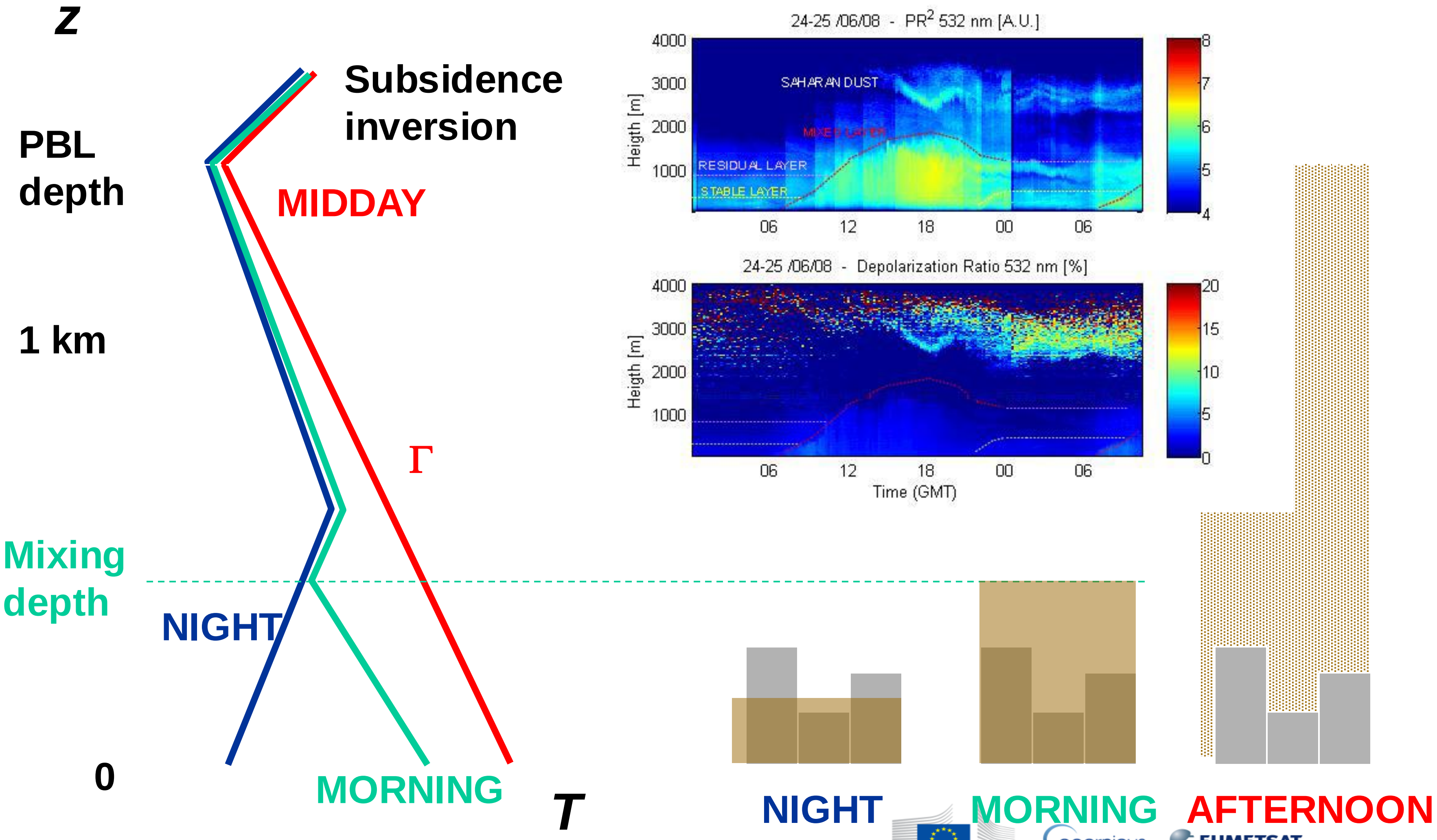
Atmospheric “box”; spatial distribution of X within box is not resolved

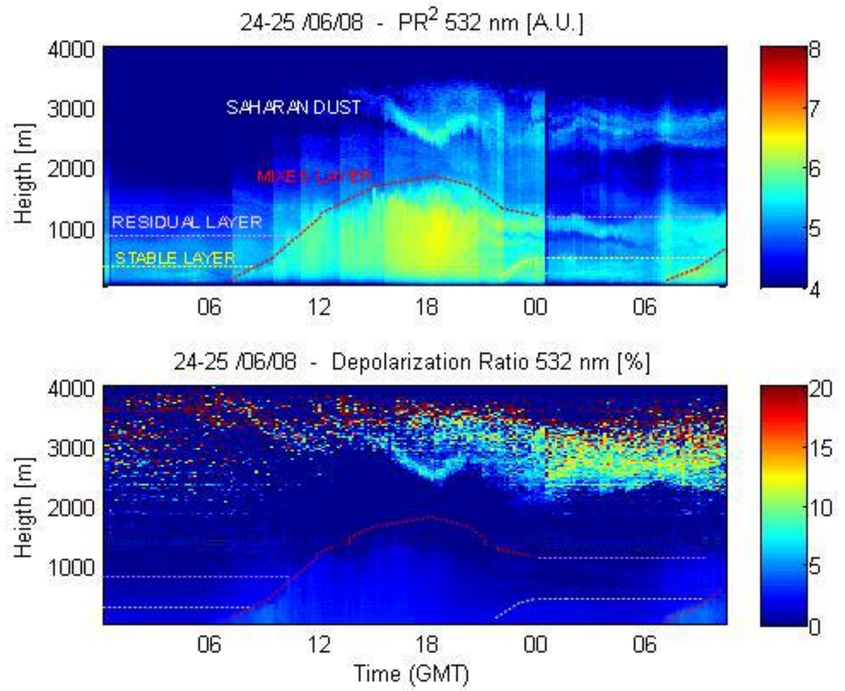


$$\text{Atmospheric lifetime: } \tau = \frac{m}{F_{\text{out}} + L + D}$$


Atmospheric lifetime
1 month
> 1 yr
2 – 4 weeks
Climate gases
H_2O
CO_2, NO_2 [100 yr]
CH_4 [10 yr]
(O_3)
Pollutants
CO [4-8 weeks]
O_3 [weeks]
NO_2 [days]
Formaldeide,
methanol, formic
acid [days]
NH_3 [hours – days]
C. Clerbaux 2015

DIURNAL CYCLE OF SURFACE HEATING/COOLING: ventilation of urban pollution





tropopause (10 km)

10 years

1 month

5 km

1 week

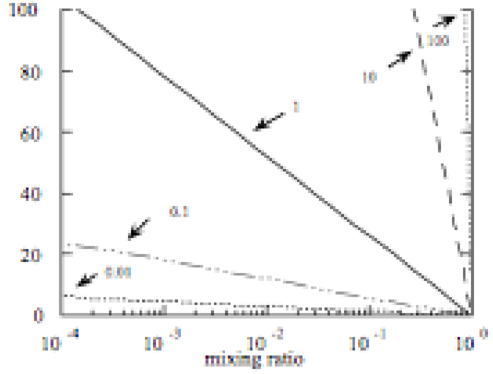
"planetary boundary layer"

2 km

1 day

0 km

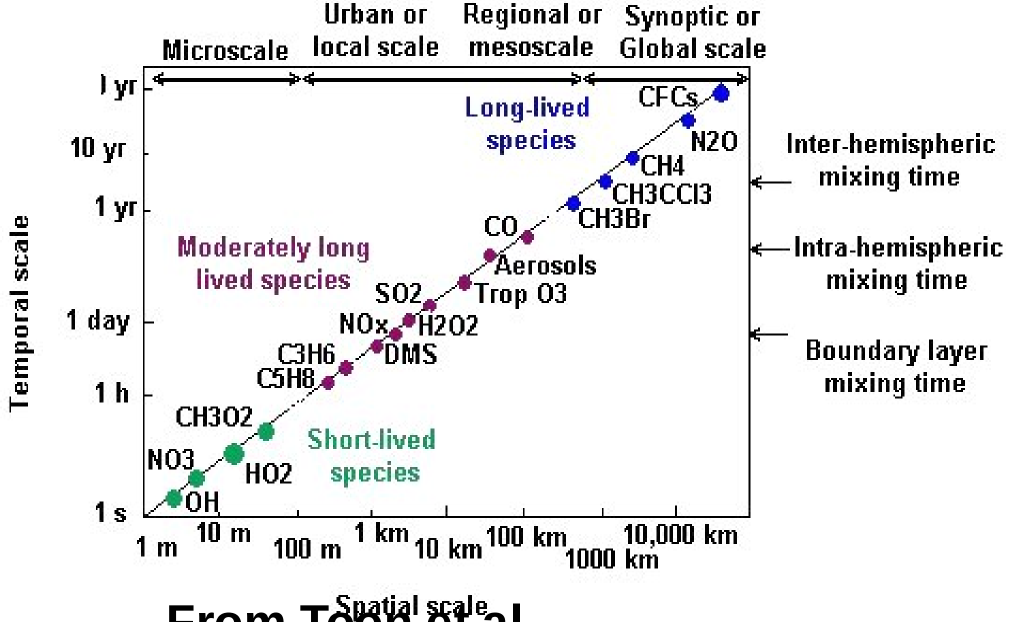
Chemical vs. transport lifetime



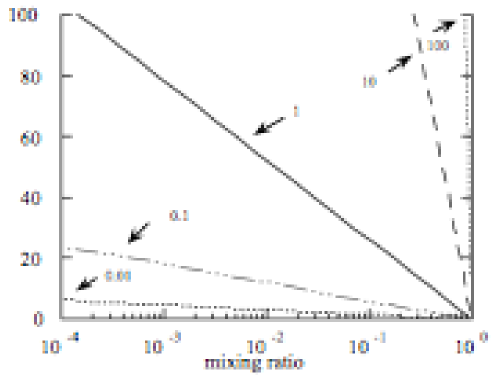
- When the chemical lifetime is 100 times larger than the dynamical lifetime, materials will have an almost constant mixing ratio to nearly 100 km altitude.
- However, when the chemical lifetime is 1% of the dynamical lifetime the mixing ratio falls very rapidly in the troposphere.

Lifetimes of some interesting materials

Material	M_{x}, Abundance (Tg)	P_{x}, Source (Tg/yr)	t_{x}, Lifetime (yr)
H_2O	$1.3x10^7$	$5x10^8$	0.025
CH_4	$5x10^3$	515	10
COS	5.2	1.2	4.3
SO_2	0.6-0.9	200	.003-.005
N_2O	$2.5x10^3$	12-21	120
CFC-11	6.2	0.25	50
CFC-12	10.3	0.37	102
CH_3Cl	5	3.5	1.5
NaCl	3.6	1300	0.003

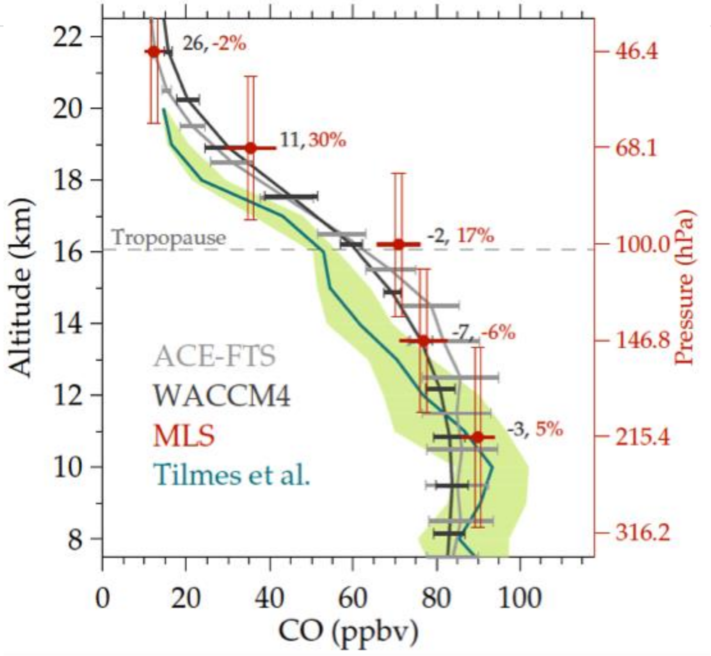


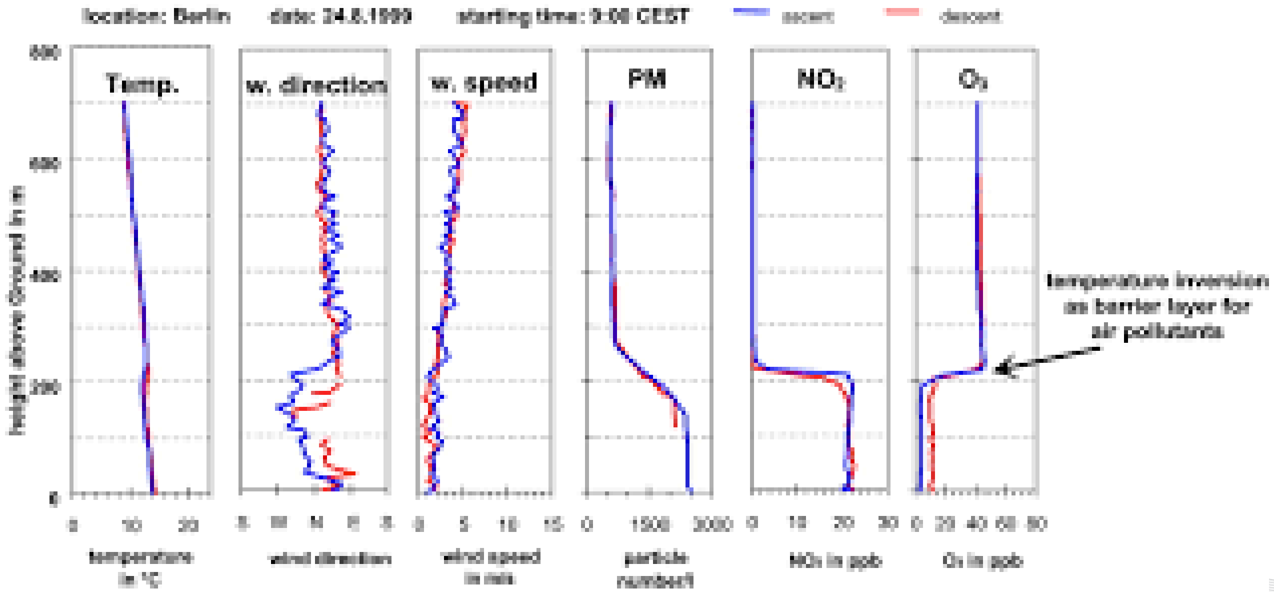
From Toon et al.

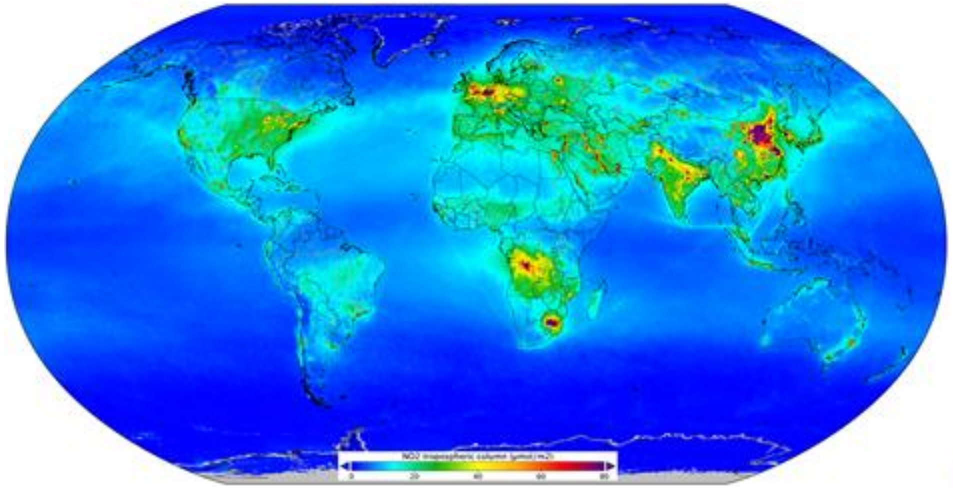


•When the chemical lifetime is 100 times larger than the dynamical lifetime, materials will have an almost constant mixing ratio to nearly 100 km altitude.

• However, when the chemical lifetime is 1% of the dynamical lifetime the mixing ratio falls very rapidly in the troposphere.

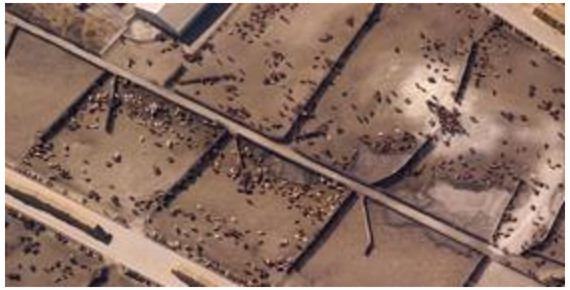


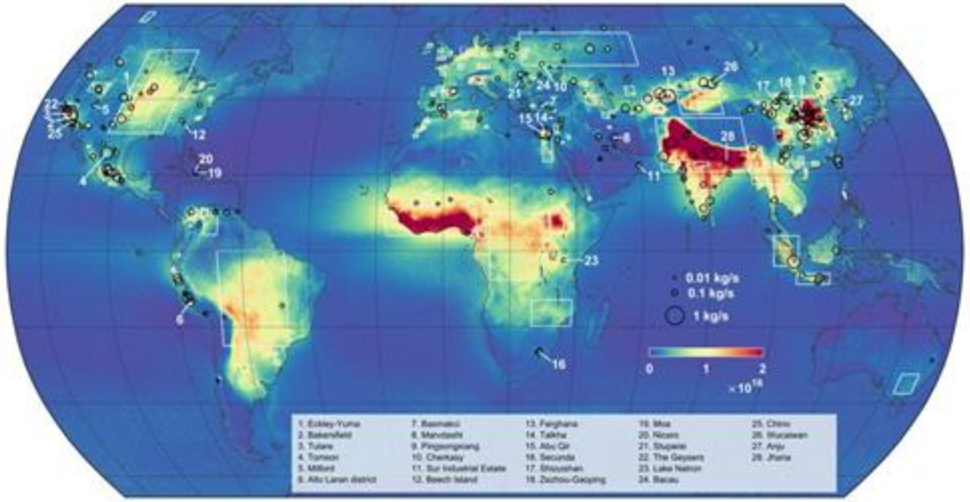




Nitrogen Dioxide from 1 month TROPOMI data
© Copernicus program

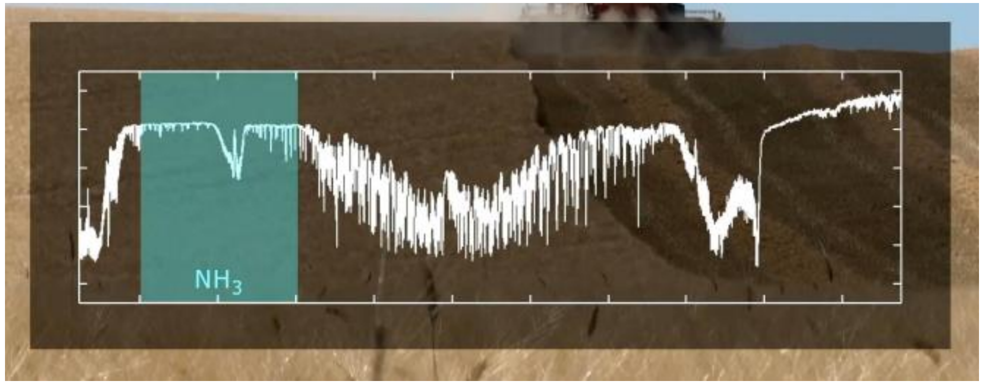


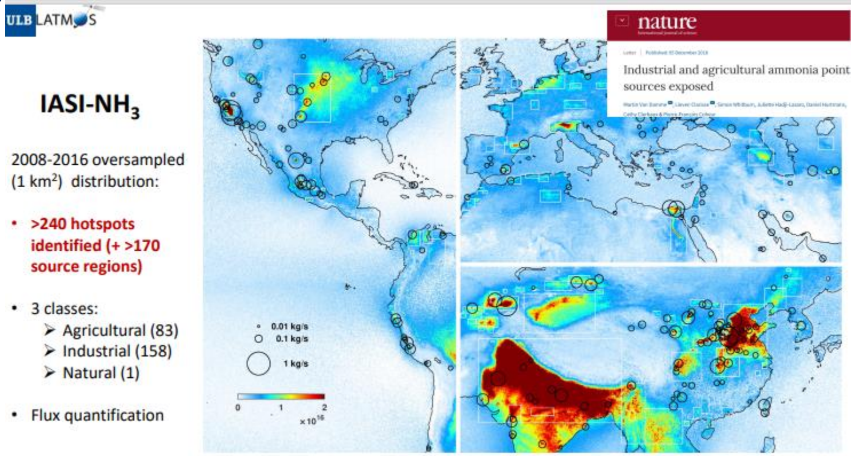


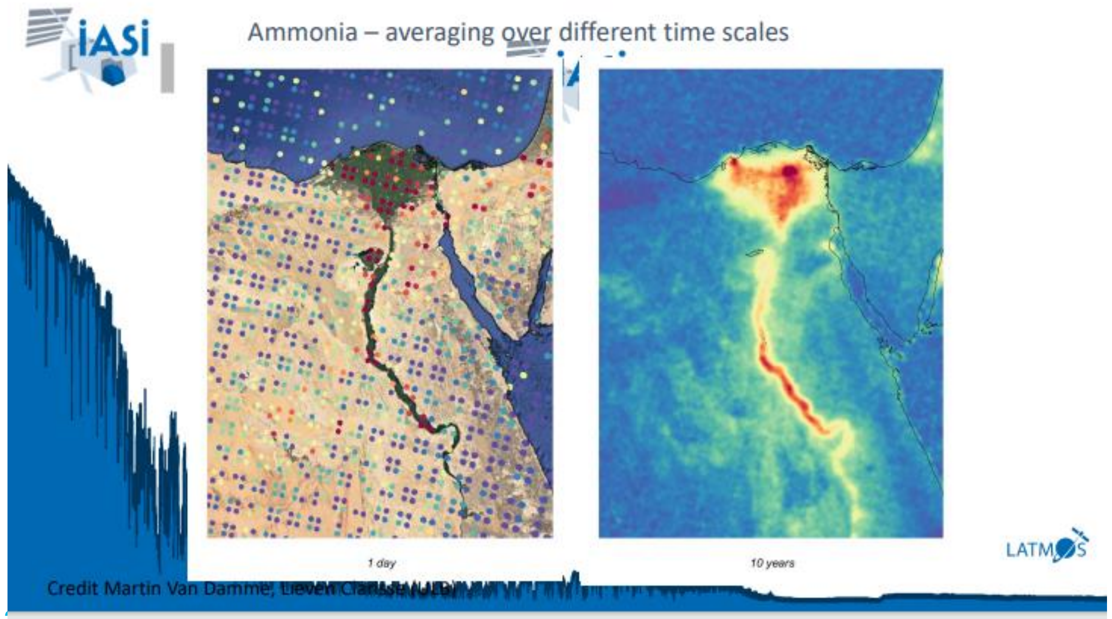


Ammonia fluxes based on 9 years of IASI data
© Martin Van Damme and Lieven Clarisse / ULB

Ammonia – IASI

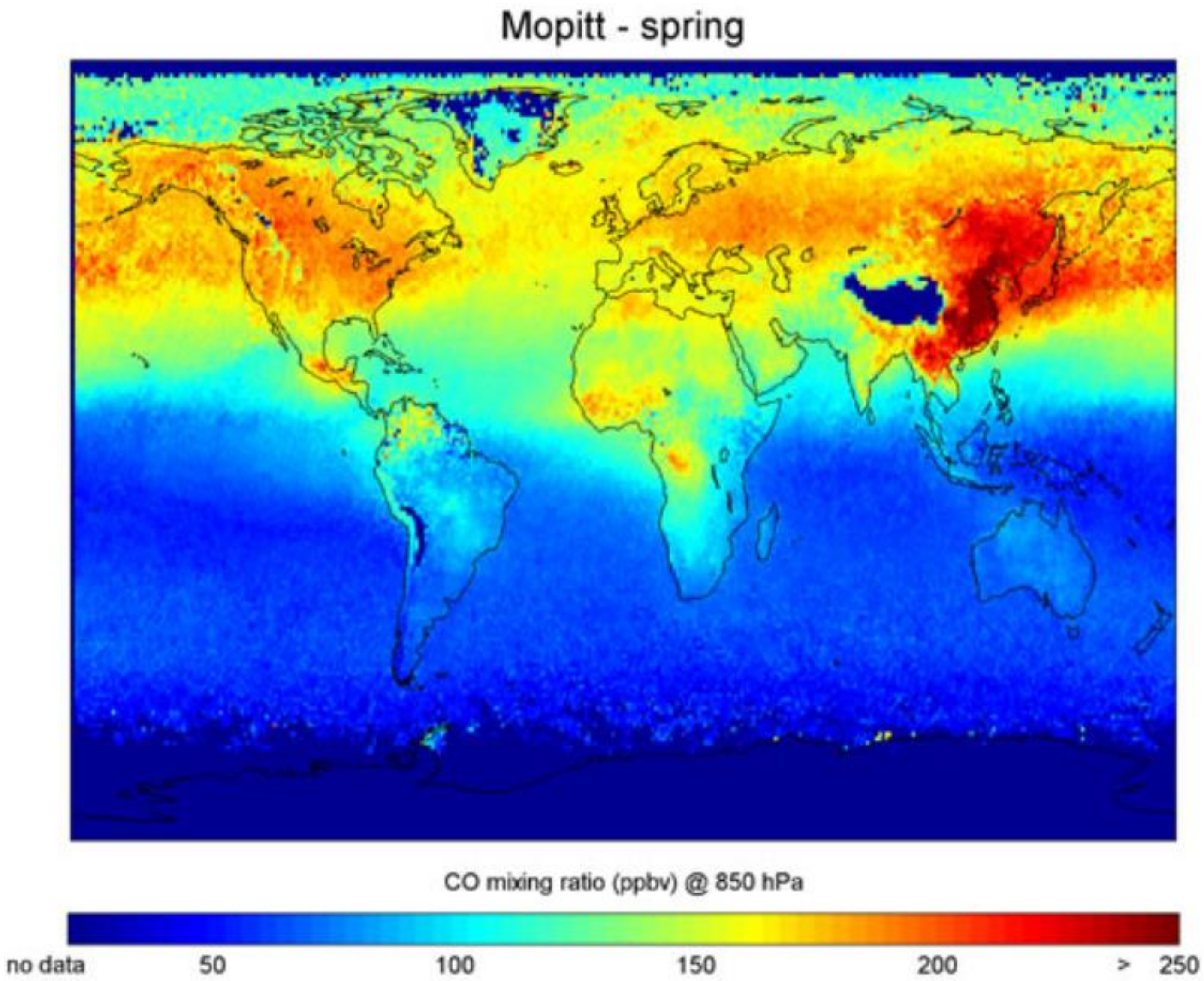




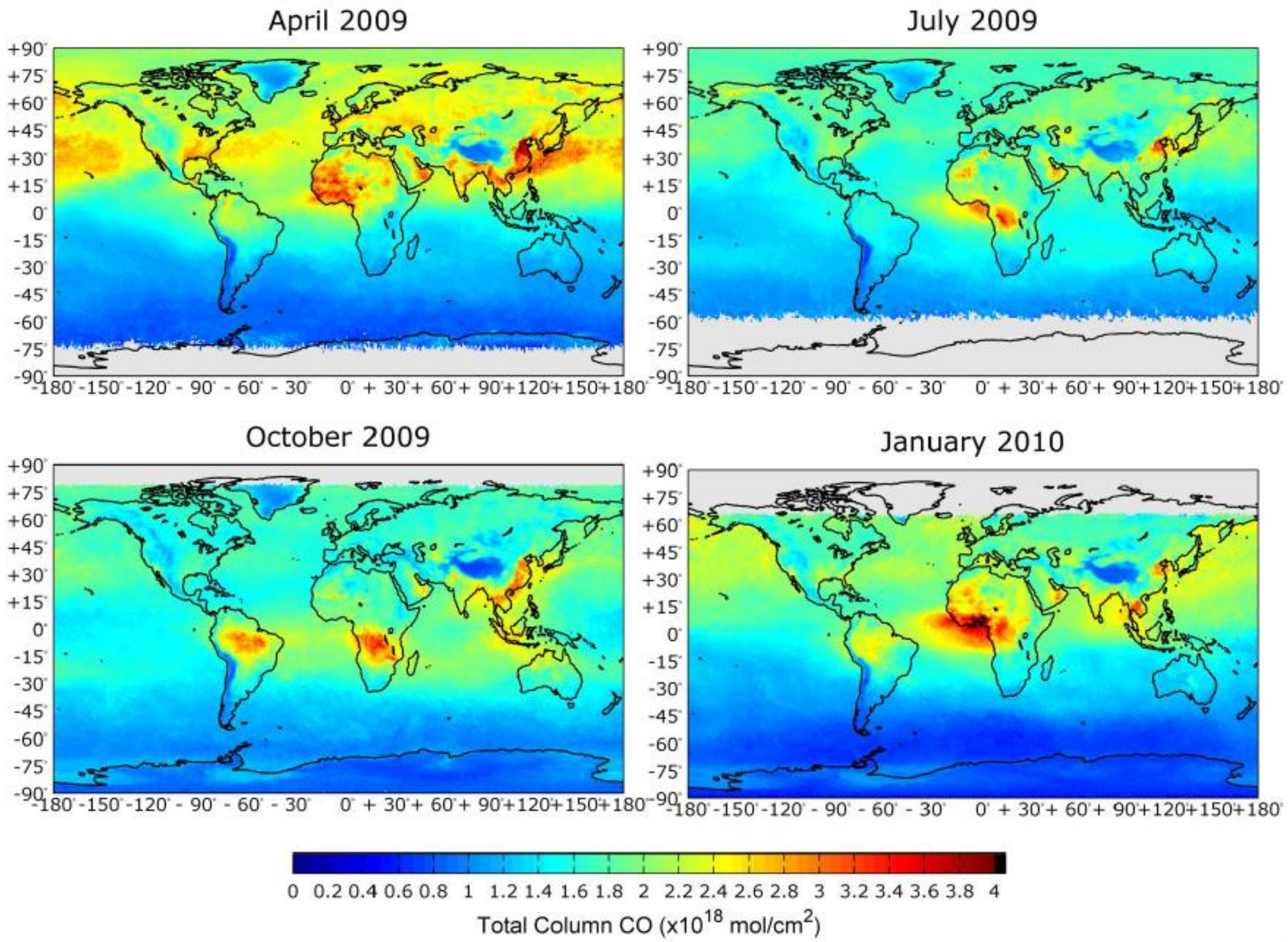


CO emitted by combustion, has atmospheric lifetime ~ 2 months: mixing around latitude bands

Satellite observations



Carbon monoxide (CO) : seasonal distribution

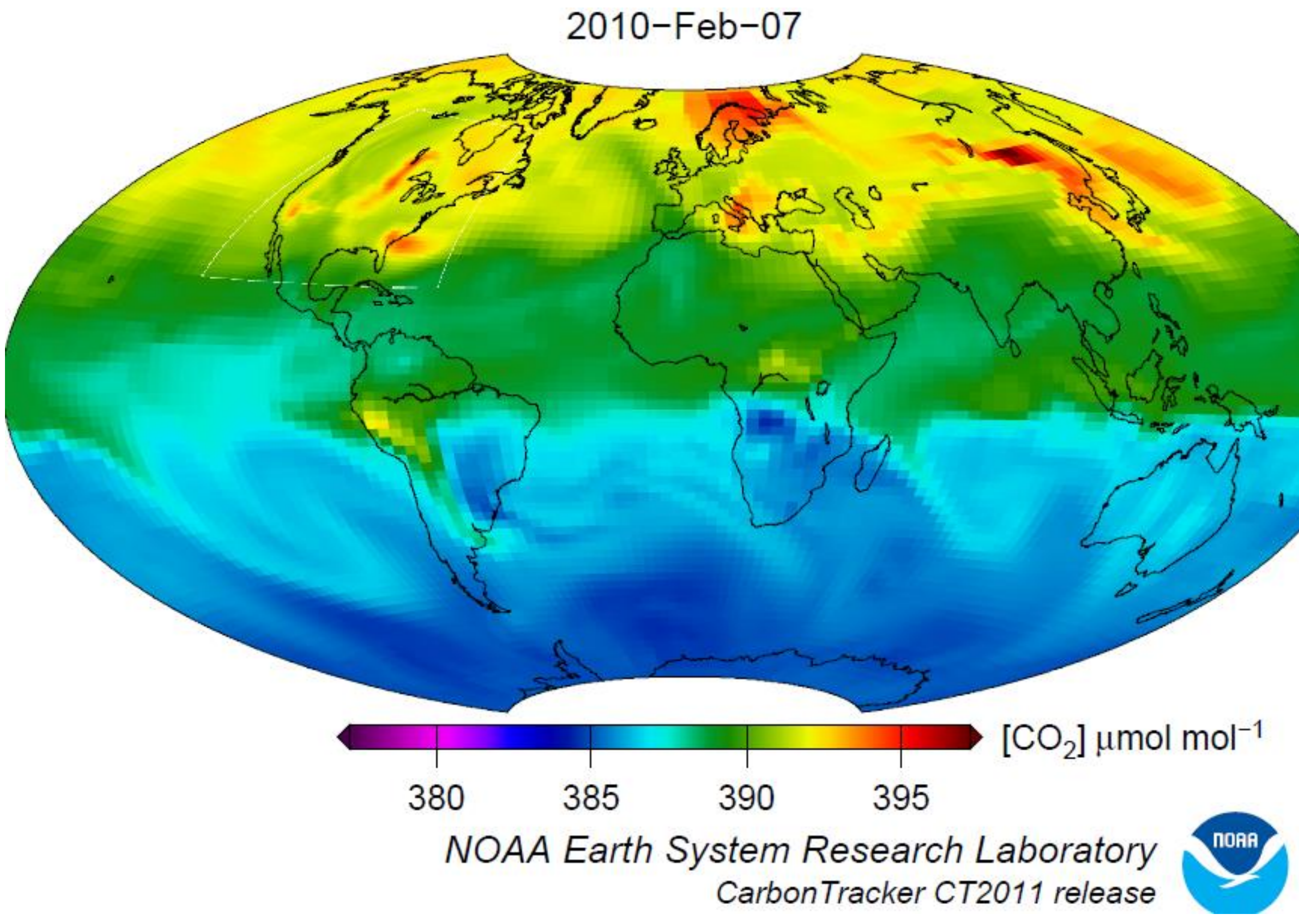


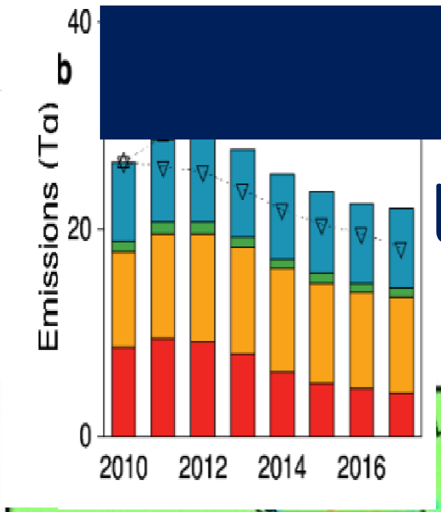
25

Clerbaux et al., ACP 2009

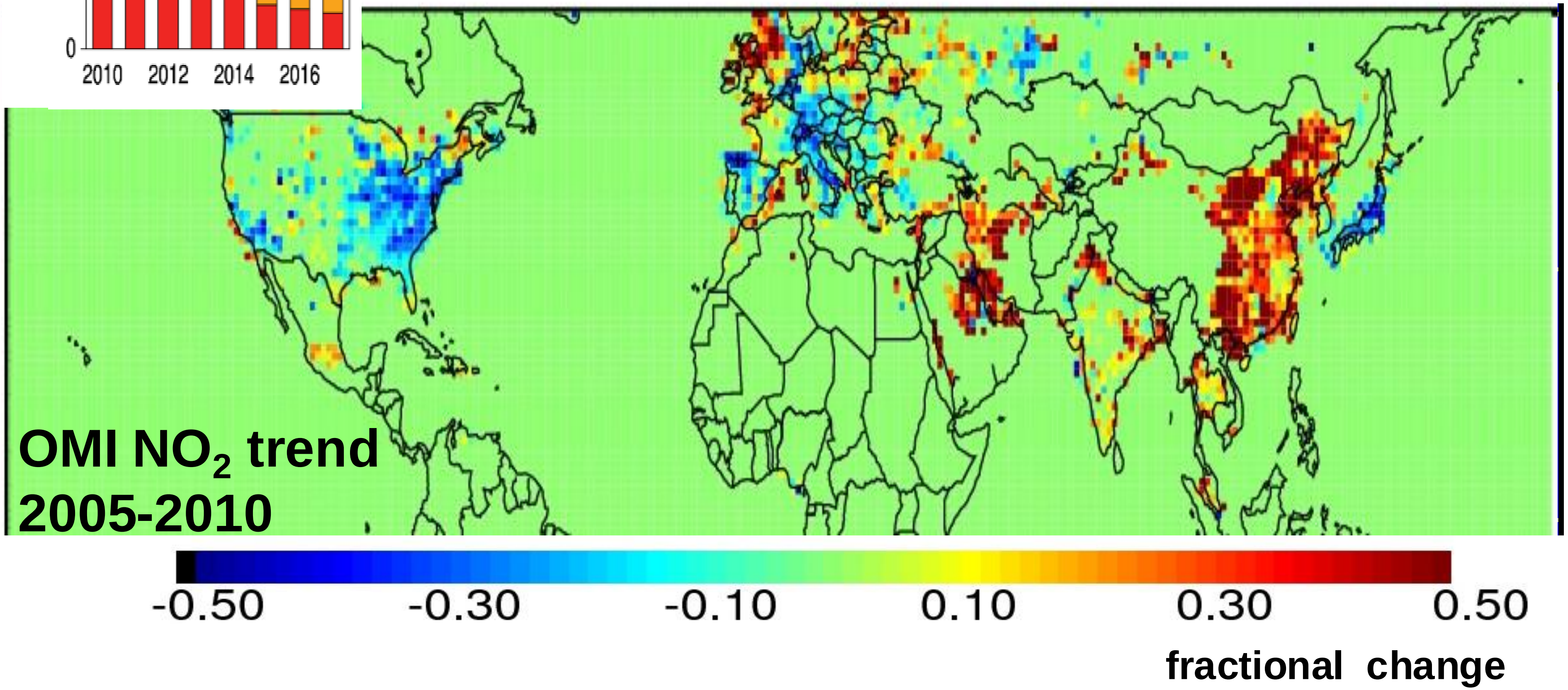
CO_2 emitted by combustion, has atmospheric lifetime ~ 100 years: global mixing

Assimilated observations





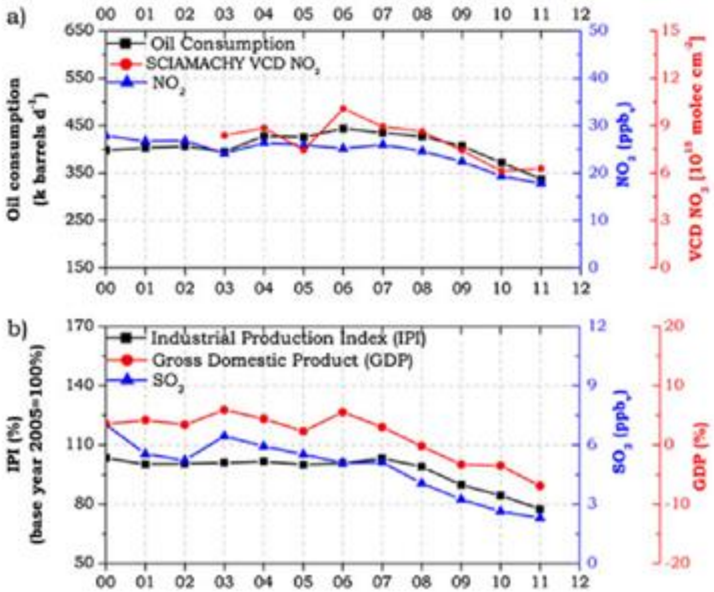
trends observed from space

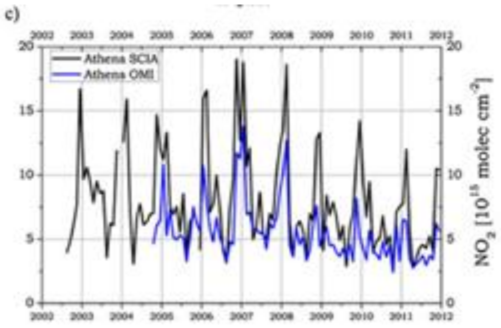


Verstraeten et al. [2014]

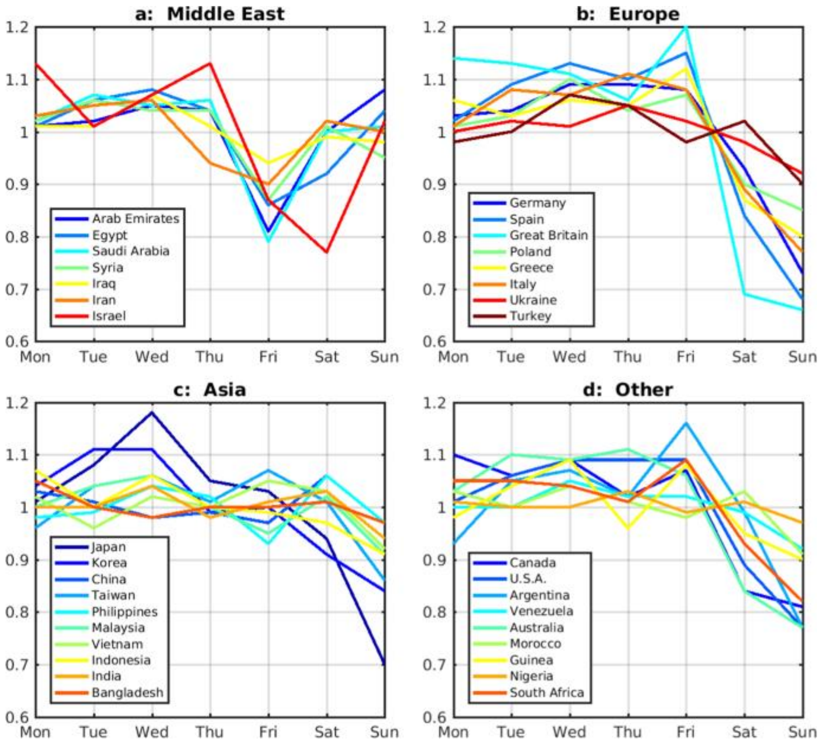
Examples on variability of short lived species

copernicus.eumetsat.int





Satellite evidence for changes in the NO_2 weekly cycle over large cities
•T. Stavrakou et al –Nature, 2020



Example: Changes in ammonia concentrations

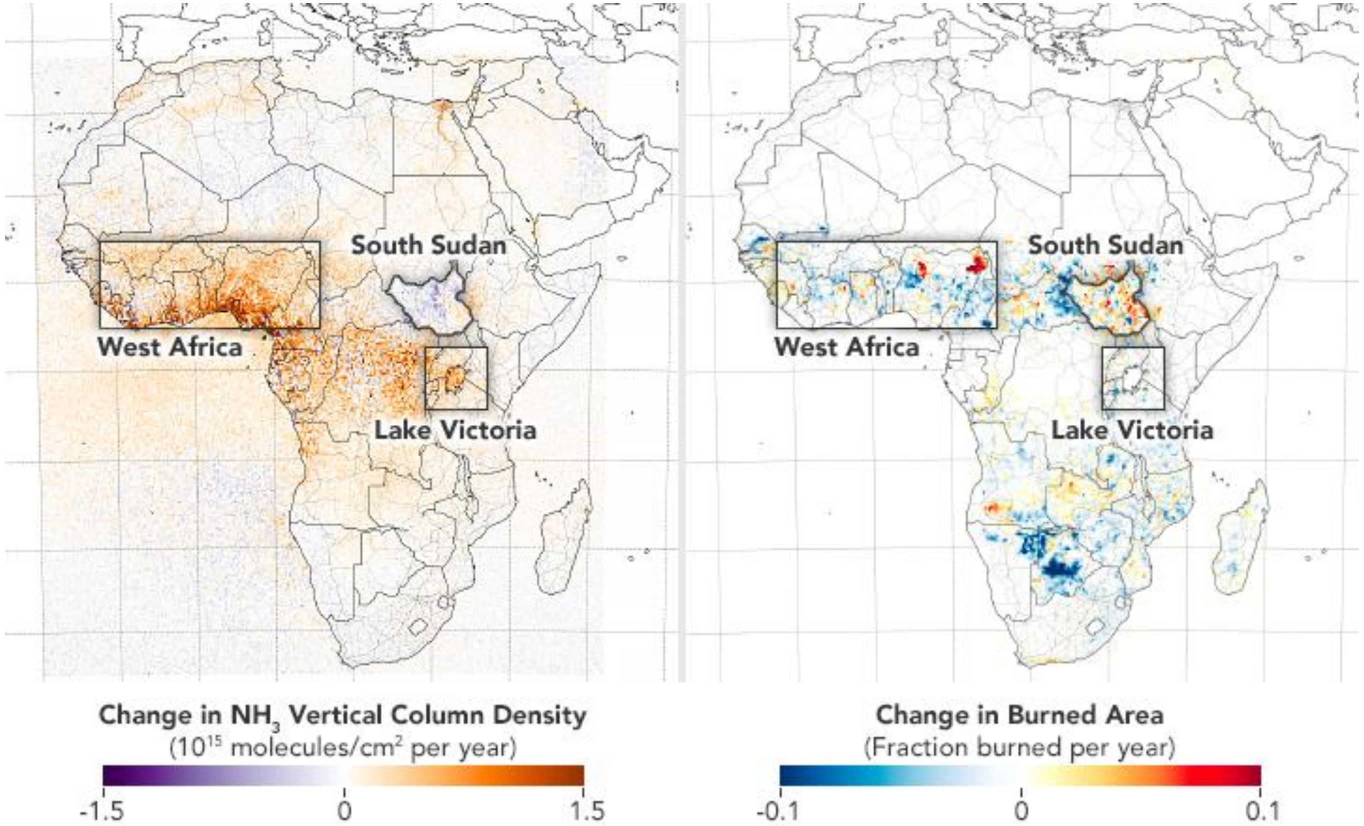
How IASI onboard METOP Support air quality monitoring

Changes related to increased agricultural
Productivity (South Sahel)

Different wildfire activity leads to reduction (South Sudan)

Analysis of 7 years of IASI data

https://acp.copernicus.org/articles/21/16277/2021/



Example: Changes in nitrogen dioxide concentrations

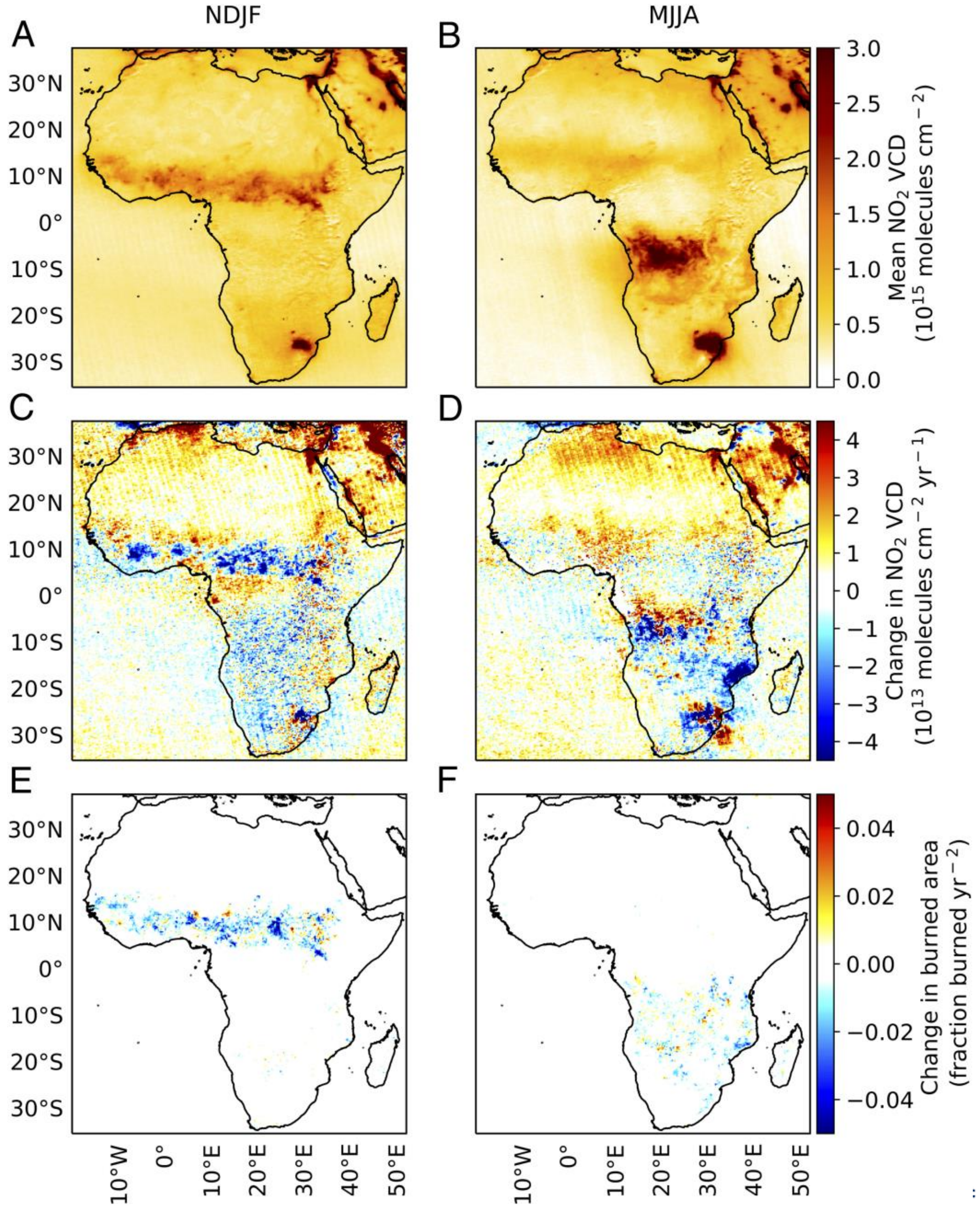
copernicus.eumetsat.int

GOME-2 and TROPOMI support air quality monitoring

Maximum concentration related to emissions in urban areas

Changes related to both increased anthropic pressure and natural sources (wildfires)

Analysis of 12 years of OMI, Sentinel-5P data from https://www.pnas.org/doi/10.1073/pnas.2002579118



Example: Changes in tropospheric ozone and crop yields

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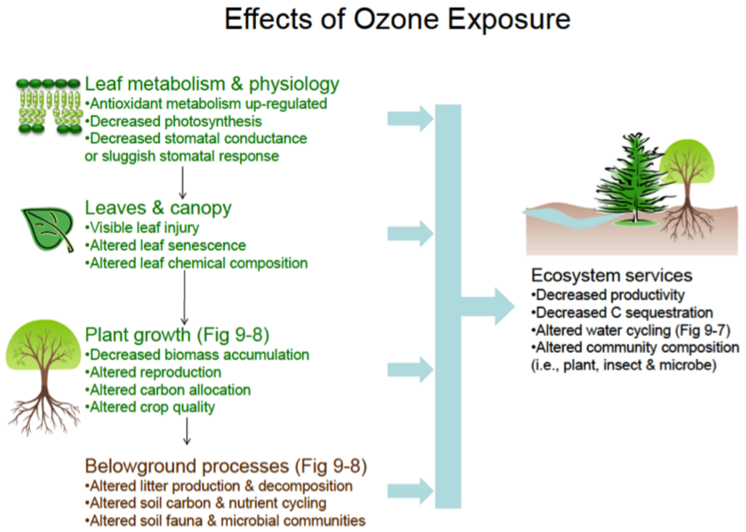
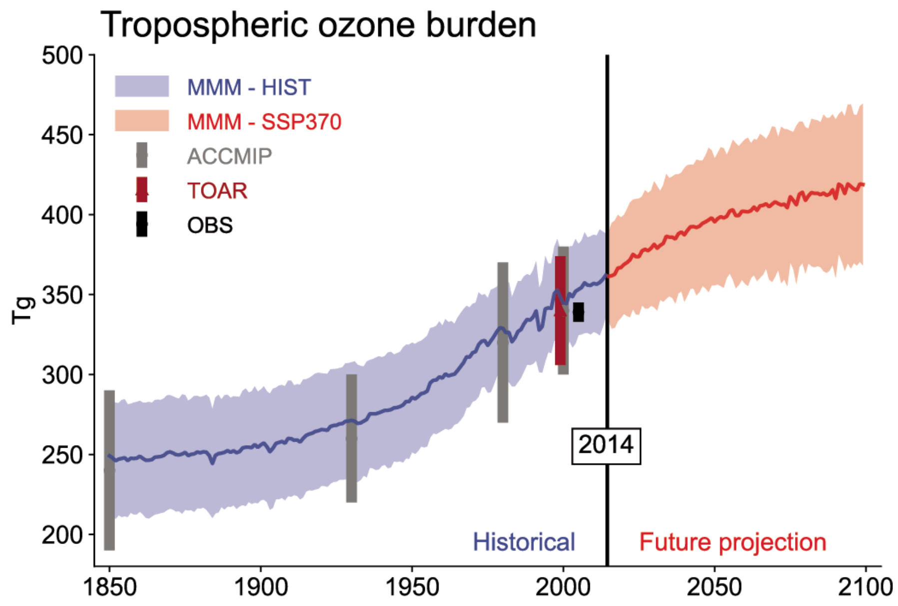


Ozone in the troposphere increases worldwide

Ref:
TOAR assessment
IPCC - WG1



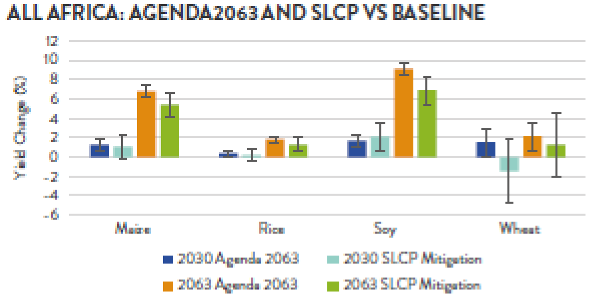
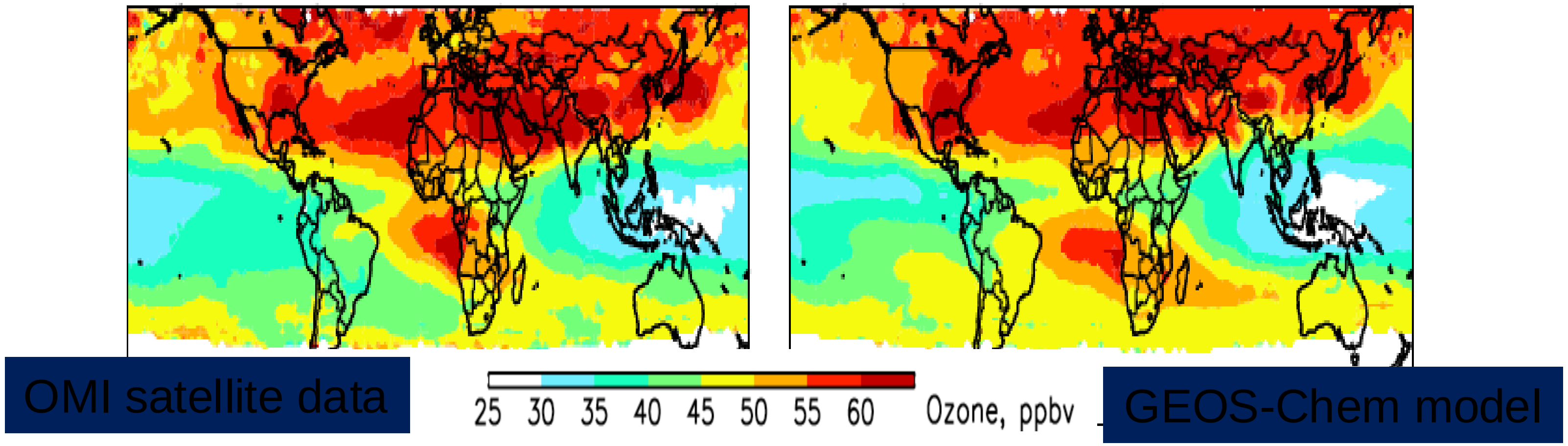


Figure S7 Simulated crop (maize, rice, soy and wheat) yield gain changes (per cent relative to baseline) under the SLCP scenario by 2030 (light blue) and 2063 (green) and the Agenda 2063 scenario by 2030 (blue) and 2063 (orange) in response to changes in ozone, CO_2, temperature, and precipitation, using data from the modeling for all of Africa, North, Central, West, Southern and East Africa. Uncertainty bars reflect the variability in climate and ozone across the five ensemble simulations completed for the baseline scenario and indicate when the modeled changes are statistically significant.

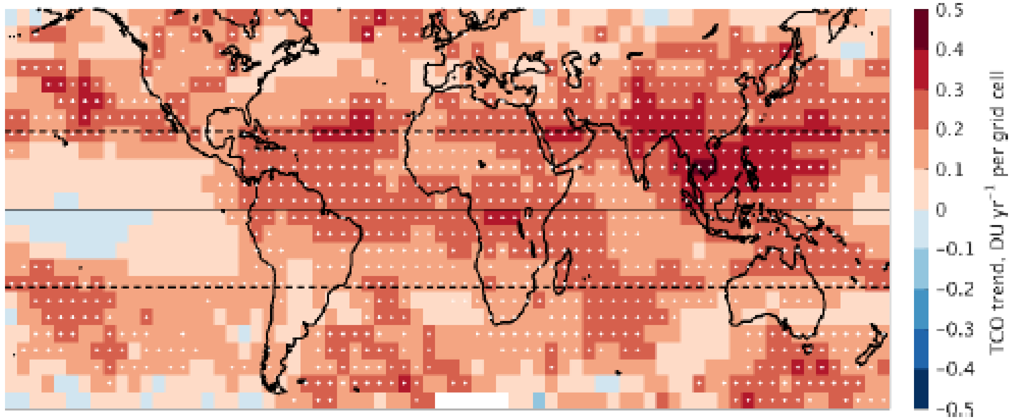
Global tropospheric ozone is rising…and we don't know why

Mean 500 hPa ozone in JJA 2013



- **Partly natural:** stratospheric influence, lightning, wildfires
- **Partly anthropogenic:** methane, intercontinental pollution, fires, ships, aircraft…

OMI tropospheric ozone column trend, 2005-2016:
increasing almost everywhere

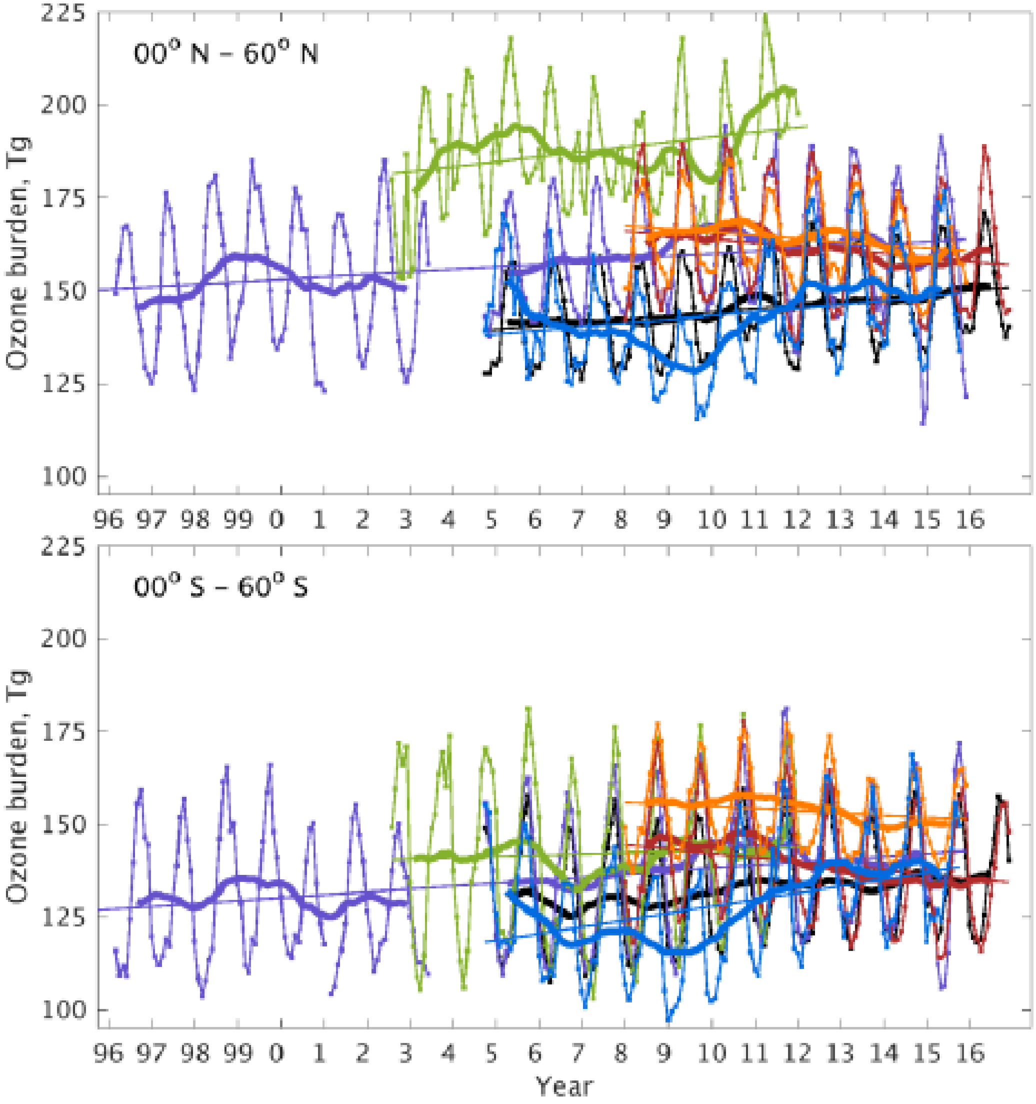


Models can reproduce present-day levels but not long-term trends

Cause of increase is not clear. Asian emissions? Ships? Aircraft? Wildfires? Increasing transport from stratosphere?

Hu et al. [2017], TOAR [2017]

Recent trends in tropospheric ozone seen from satellites



	change, Tg yr^{-1}	p-value
Black: OMI/MLS	0.95 +/- 0.55	0.00
Brown: IASI-FORLI	-1.01 +/- 1.17	0.09
Orange: IASI-SOFRID	-0.86 +/- 0.95	0.07
Purple: GOME/OMI	0.68 +/- 0.39	0.00
Blue: OMI-RAL	1.02 +/- 0.79	0.01
Green: SCIAMACHY	1.33 +/- 1.04	0.01

	change, Tg yr^{-1}	p-value
Black: OMI/MLS	0.83 +/- 0.64	0.01
Brown: IASI-FORLI	-1.14 +/- 1.14	0.05
Orange: IASI-SOFRID	-0.56 +/- 0.97	0.26
Purple: GOME/OMI	0.80 +/- 0.40	0.00
Blue: OMI-RAL	1.83 +/- 0.84	0.00
Green: SCIAMACHY	0.34 +/- 1.48	0.65

The need to control CO_2 emissions – preparing for monitoring

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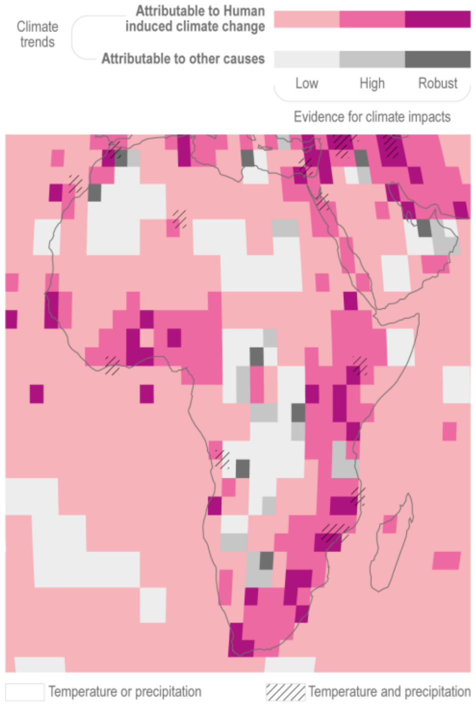
Climate impacts on human and natural systems are widespread across Africa, as are climate trends attributable to human-caused climate change



IPCC - Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change doi:10.1017/9781009325844.011.

CLIMATE CHANGE BENEFITS FOR AFRICA

- Implementing the 37 measures has the potential to greatly reduce regional climate change in Africa, significantly lessening further land degradation and desertification and improving food production and quality. If all the measures are implemented, in some areas there would be much smaller changes in local precipitation patterns than if there were no changes in policy. For example, the Assessment projects there will be reduced drying in the Sahel and West Africa in June–August and potentially also in southern parts of Africa in December-February due in part to reduced air pollution (Figure S5).

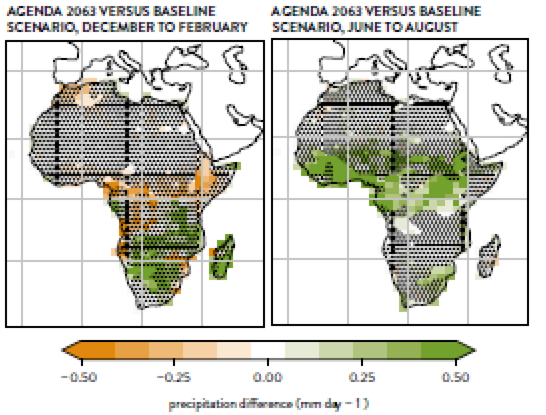
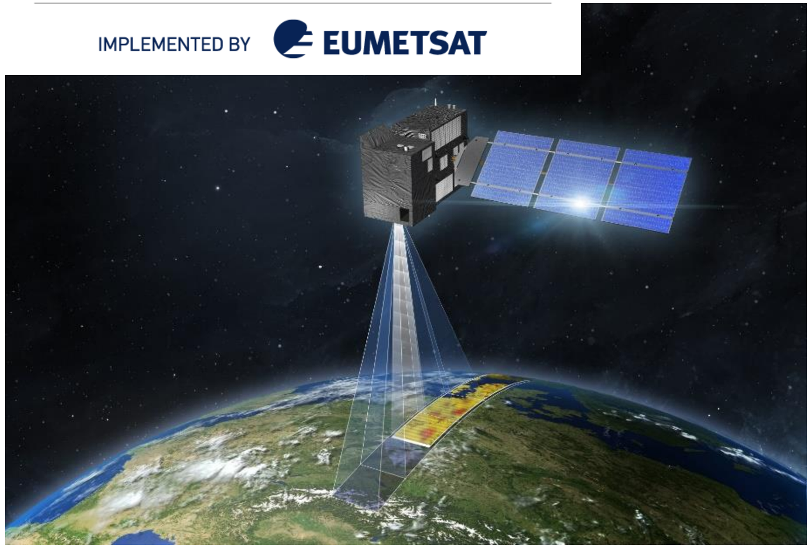


Figure S5 The difference between Africa seasonal average precipitation changes for 2050-2059 relative to 2015-2025 in the modeling for the Agenda 2063 and the baseline simulations for Dec-Feb (left) and Jun-Aug (right). Stippling indicates the differences are not statistically significant (95 per cent confidence).

INTEGRATED ASSESSMENT OF AIR POLLUTION AND CLIMATE CHANGE FOR SUSTAINABLE DEVELOPMENT IN AFRICA
SUMMARY FOR DECISION MAKERS
© 2022 United Nations Environment Programme ISBN: 978-92-807-3989-3

PROGRAMME OF THE EUROPEAN UNION
IMPLEMENTED BY EUMETSAT



Product	Spatial resolution	Precision
CO2	4 km²	0.5 – 0.7 ppm
CH4	4 km²	10 ppb
NO2	4 km²	$1.5x10^{15}$ molec/cm²
SIF*	4 km²	0.7 mW m^{-2} sr^{-1} nm^{-1}
Aerosol	16 km²	0.05 AOD, 500 m LH
Clouds	<5% of FOV	Water & cirrus clouds

VIS band also covers CHOCHO (glyoxal)
VIS & SWIR band also covers water vapour
*Top-of-Atmosphere Solar Induced Fluorescence

Atmosphere Monitoring

CHALLENGES OF OBSERVATION-BASED EMISSION MONITORING

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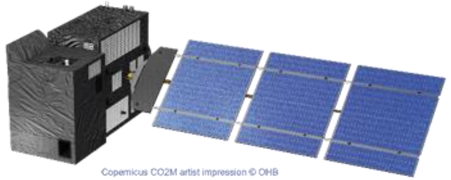
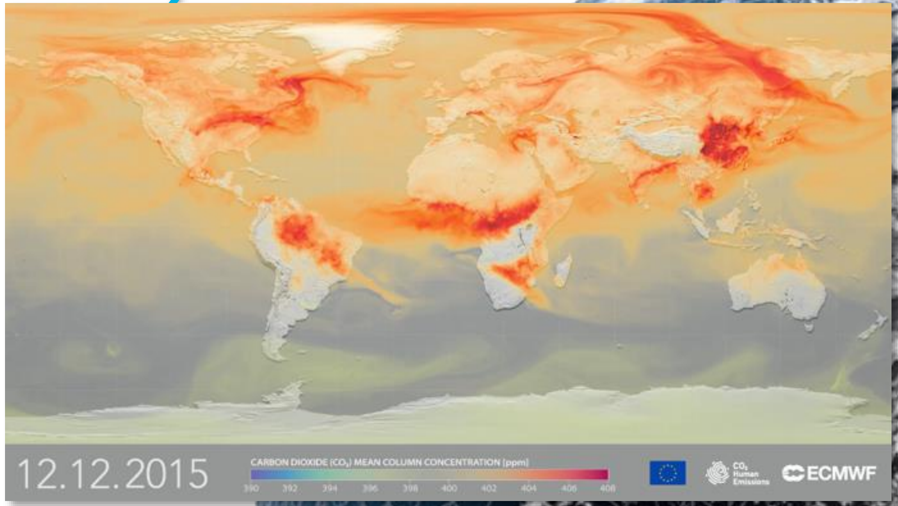
Satellites do not measure emissions directly; they measure the total impact of natural and anthropogenic emissions and removals on the atmosphere.

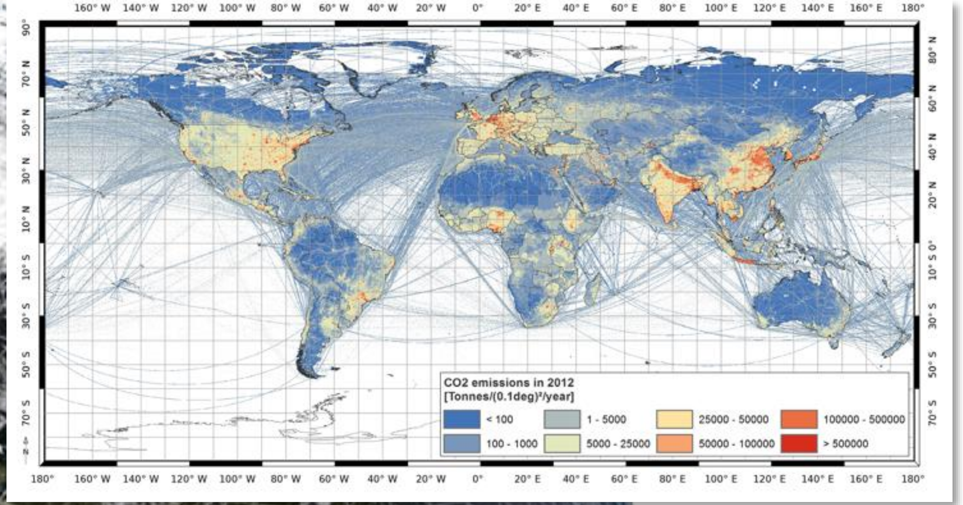


Copernicus CO2M artist impression © OHB

Earth System models are used to translate the **observations** into **emission estimates**.

Collaboration between space agencies, in-situ networks, and operational data assimilation centres.





Example: CO_2 monitoring from single point emissions

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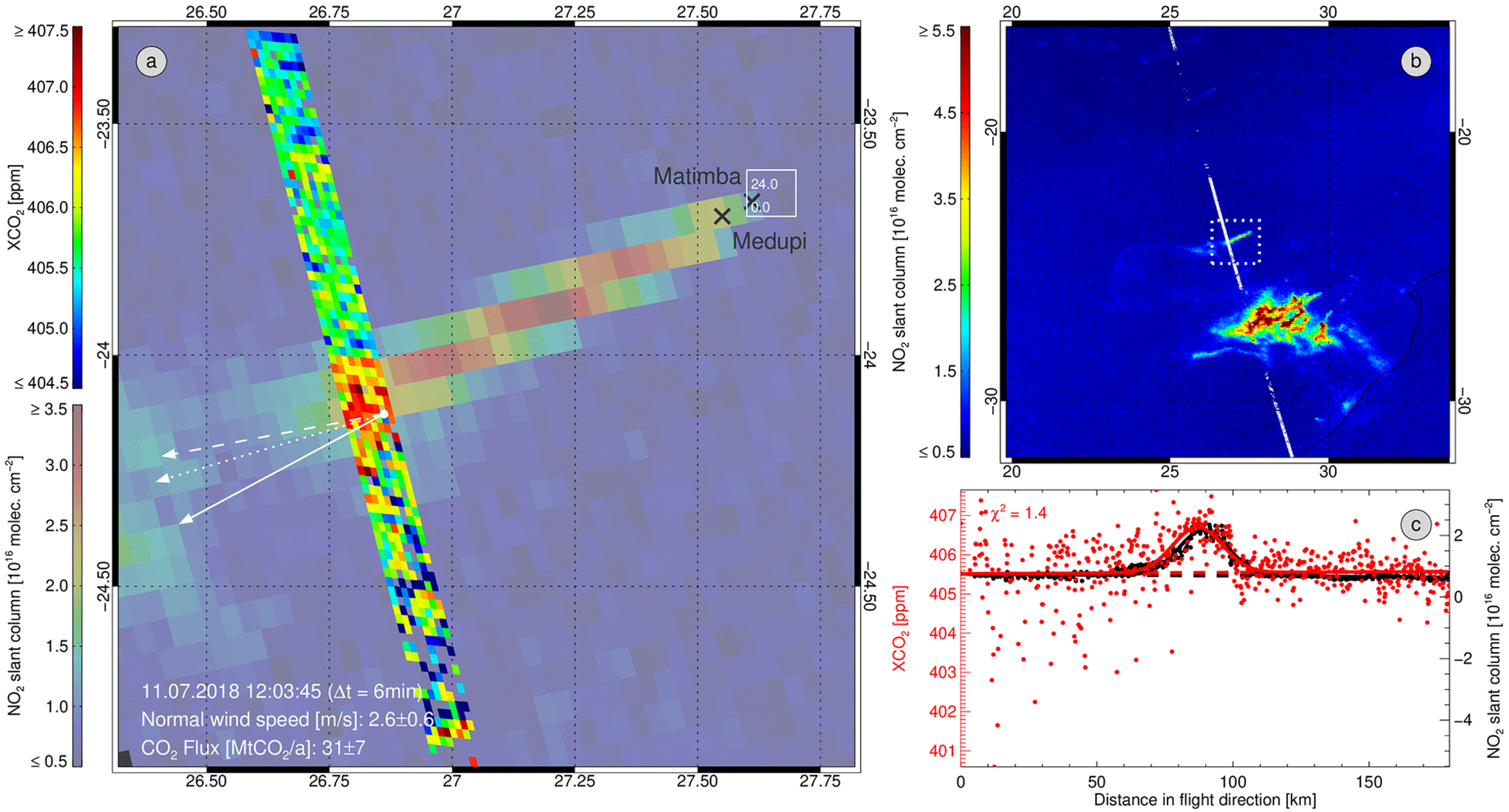


Experimental study on Matimba Power Station

Nitrogen Dioxide from TROPOMI data
© Copernicus program & CO2 from OCO2
Credit – Hakkarainen et al. 2020

Example: Estimate emissions

6604 X. Lin et al.: Monitoring and quantifying CO_2 emi...

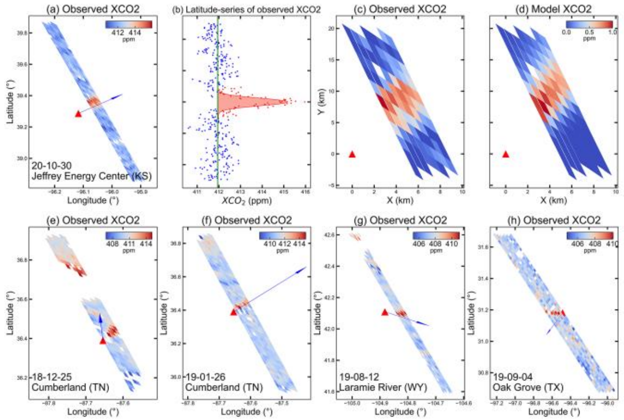


Figure 1. Estimation process of power plant emissions **(a–d)**. **(a)** CO_2 plume of the Jeffrey Energy Center power plant on 30 October 2020. **(b)** Change of XCO_2 in a latitude direction from **(a)**. The background value is determined from the average of the observations below the 90th percentile (green line), background points (blue) and plume points (red). **(c)** Zoomed-in image of **(a)** in relation to the area of our simulation. **(d)** The simulated normalized XCO_2 enhancement for the same region by the GPM. Panels **(e–h)** show cases of other power plant emission signals. The blue arrow represents the wind vector halfway the height of the PBL. The wind speeds in **(a)**, **(e)**, **(f)**, **(g)** and **(h)** are 2.9, 1.8, 6.1, 2.6 and 3.4 m s^{-1}, respectively.

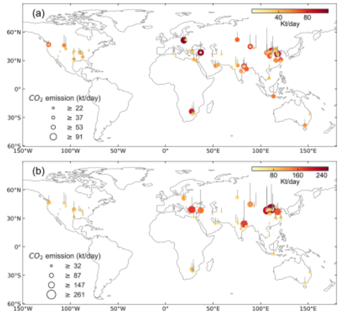


Figure 6. The detected global power plants with emission estimation results **(a)** and the sum of emission estimation results of all found observations at each power plant **(b)**. The gray vertical lines are an indication of the uncertainty of the estimated emissions. The color and size of the circles indicate the estimated emission.

https://doi.org/10.5194/egusphere-2023-2085
Preprint. Discussion started: 27 September 2023

EGUsphere Preprint repository

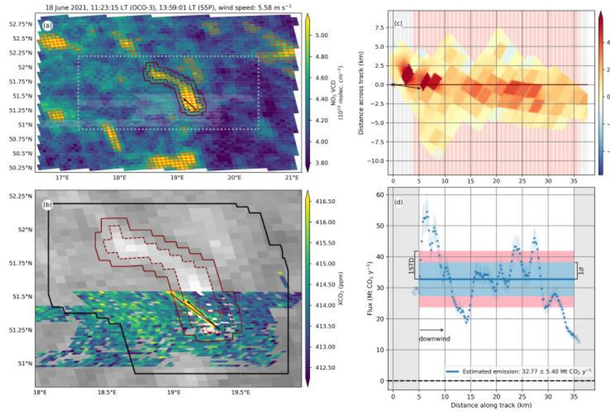


Figure 7. Overview of the top-down emission rate estimation steps for the scene on 18 June 2021. Analogous to Fig. 6.

Direct emissions estimate is a rapidly growing activity – Intensive use of AI/ML

Use of coordinated observations NO2

What is a wildfire

394 to 519 million hectars burned per year

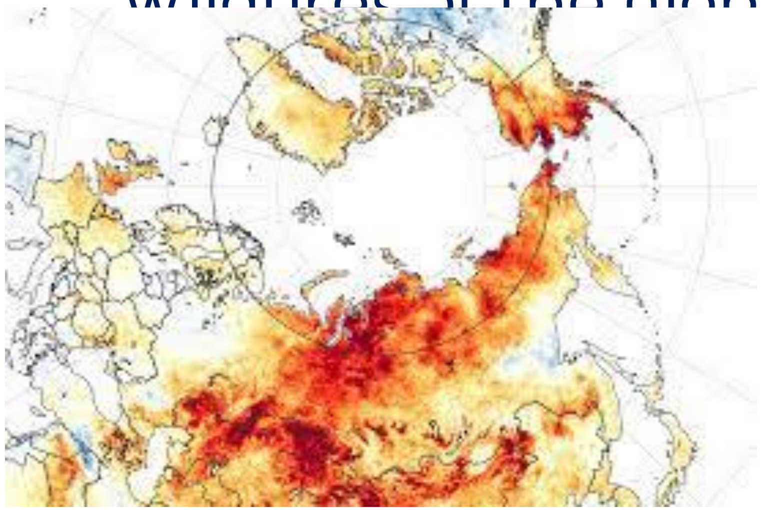
19000 fires in July 2019 spotted by Sentinel-2

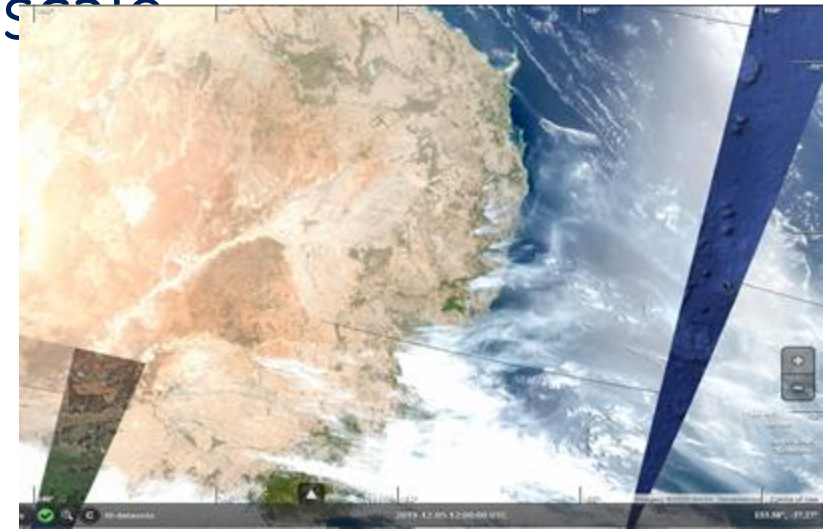
Indonesia in 1997 → 0.81 and 2.57 gigatonnes of CO_2 into the atmosphere, (13%–40% of the annual global carbon dioxide emissions from burning fossil fuels)

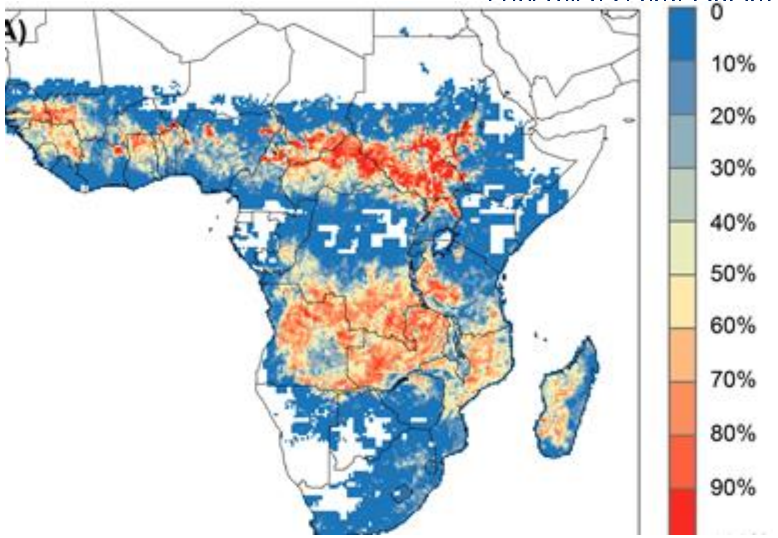
In June and July of 2019, fires in the Arctic emitted more than 140 megatons of carbon dioxide, according to

Atmosphere Monitoring Service

Wildfires at the global scale







IPCC 2019

Climate change is crucial for the current and future fire regime

Risk will increase including tropical forests

Prolonged fire seasons

However - burnt area decreased in 1979-2018 - possible bias in resolution

Global data – long-term coverage – high resolution – fires happens at small scales

Example: Synergy of observational datasets to monitor wildfires

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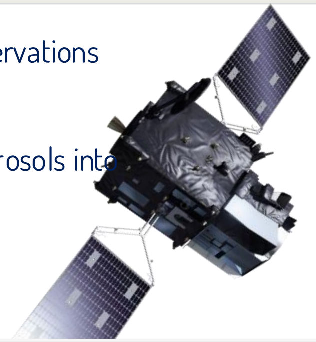
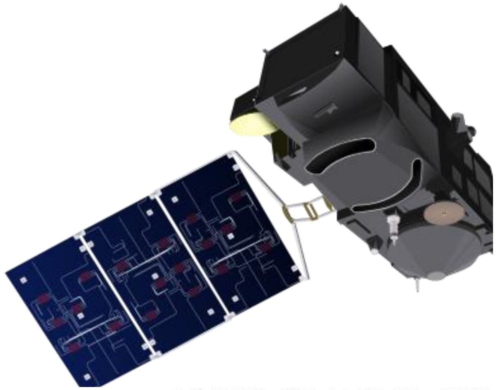
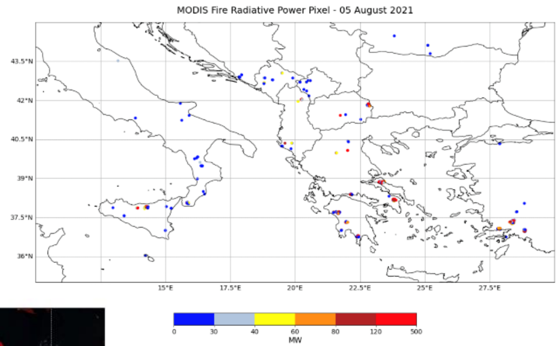
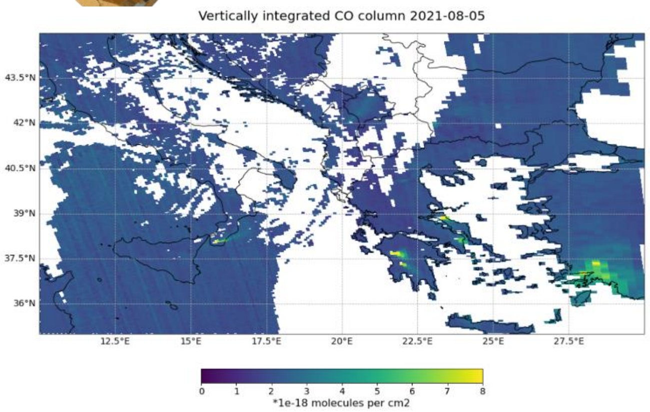
Pollutants, hot spots & intensity from satellite observations

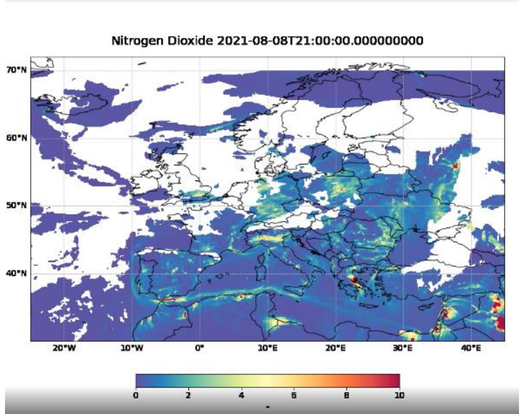
- ✓ Measurement of fire intensity
- ✓ Linked to emission of combustion gases & aerosols into the atmosphere

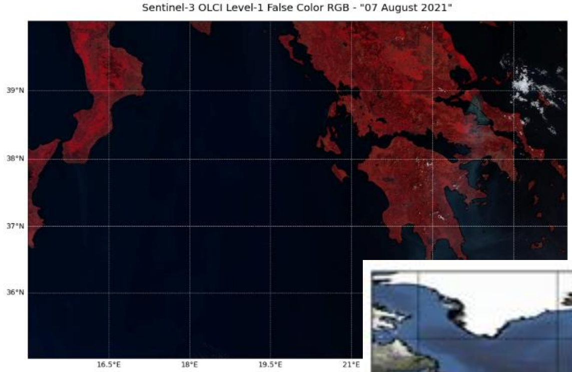


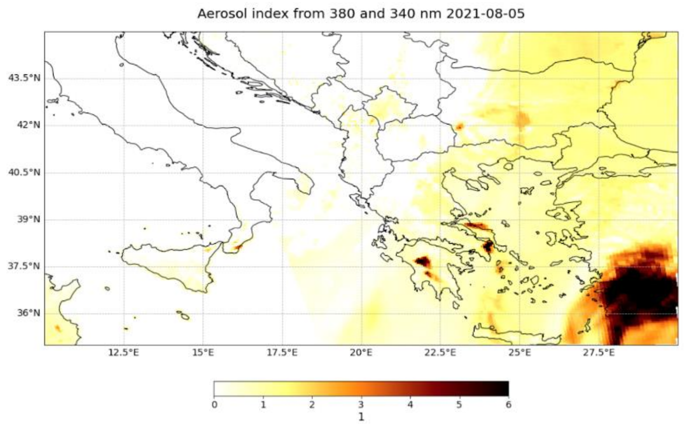








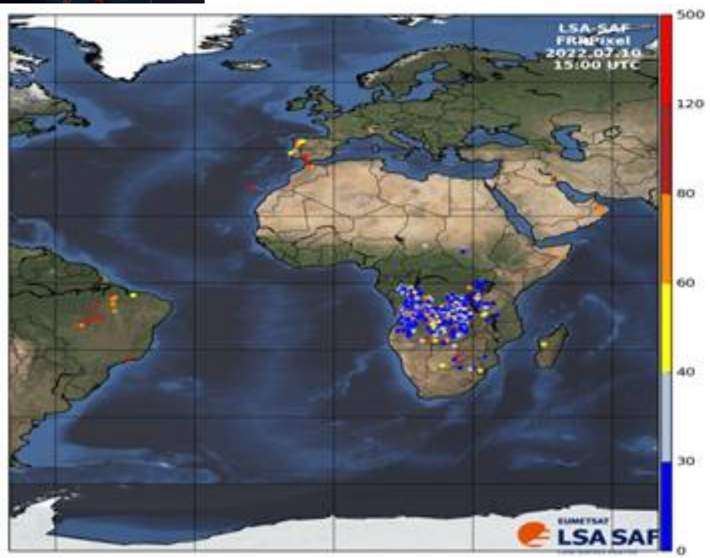




MSG/SEVIRI - every 15-minute allows:

- ✓ Strong seasonality
- ✓ Strong diurnal cycle

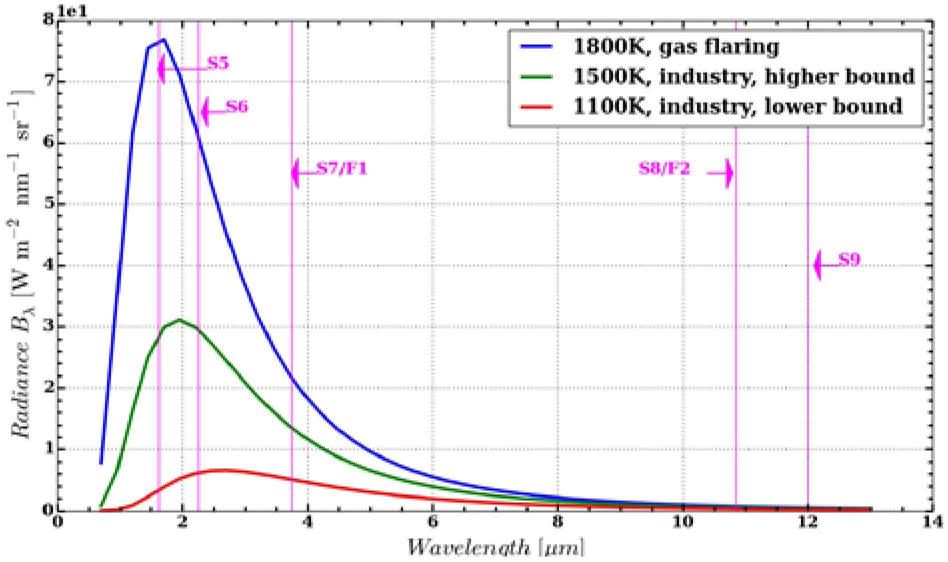
Fire Radiative Power



Fire Hot-Spot from space – In a nutshell

- A hot spot radiates a strong heating signal.
- Looking at the temperature contrast between the local hot-spot pixel and the surrounding background

Caseiro *et al.* (2018)

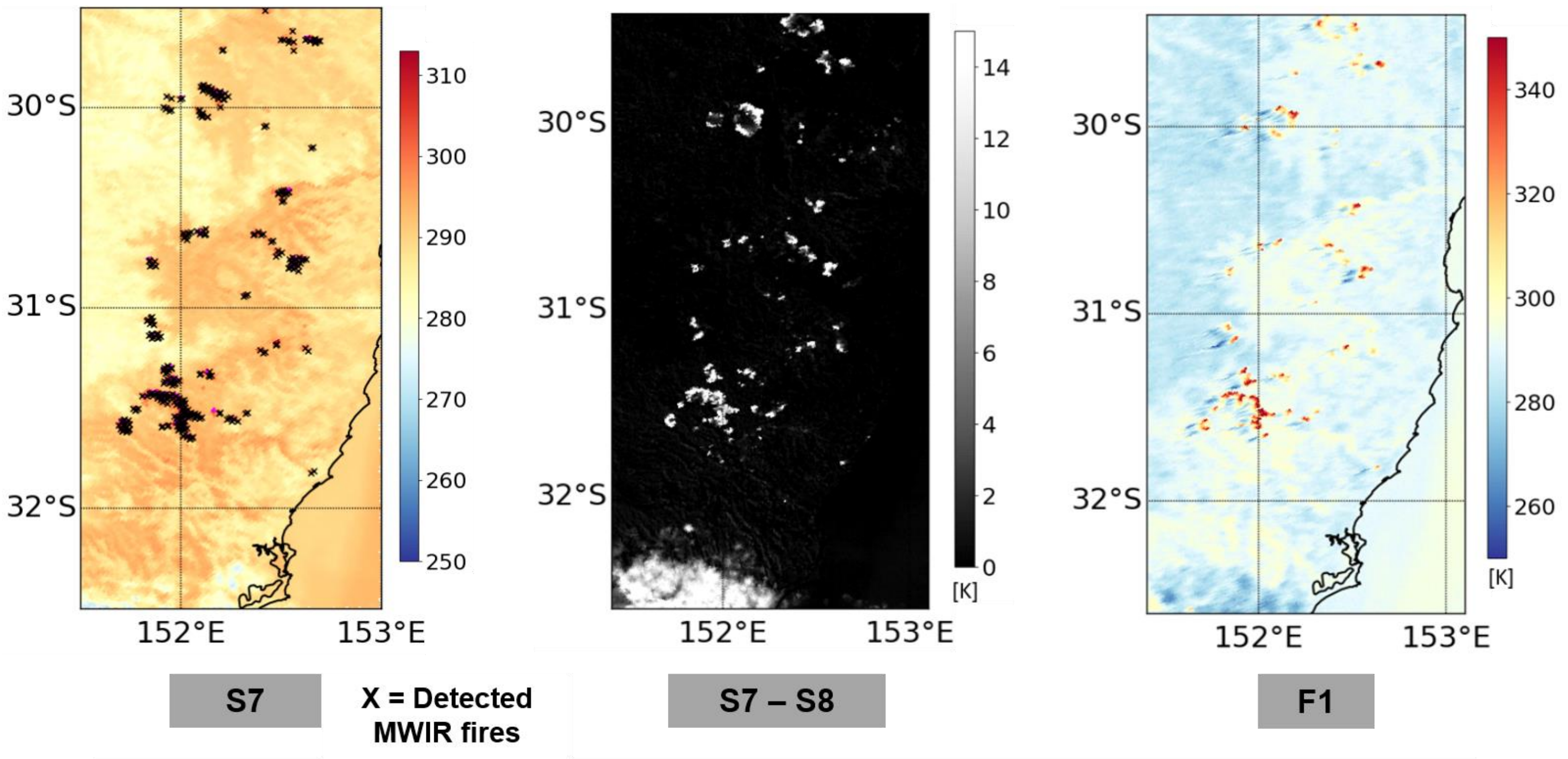


- **Hot-spot more emissive than the ambient background**
  - N = 100 => TIR (112 μm)
  - N = 1000 => MWIR (3.7 μm)
  - N >> 1000 => SWIR (1.5-2.25 um)

Table 1. Geometric features and further sensor parameters of the operational IR sensors MODIS, VIIRS and SLSTR in comparison with HSRS, flown on BIRD, TET-1 and BIROS.

Feature/Parameter	MODIS	VIIRS	SLSTR	HSRS
Launched in the year with *Satellite*	1999 "*Terra*", 2002 "*Aqua*", i.e., two nearly identical instruments	2011 "*Suomi NPP*", 2017 "*NOAA-20*"	2015 "*Sentinel-3A*", 2018 "*Sentinel-3B*"	2001 "*BIRD*" 2012 "*TET-1*" 2016 "*BIROS*"
Orbit altitude	705 km	829 km	815 km	500–560 km
Swath width	2330 km	3060 km	1407 km	162–178 km
Ground sampling distance (at the nadir)	1000 m	375 m	1000 m	170–185 m
MIR and TIR pixel saturation temperature (1)	MIR: 450 K, TIR: 400 K	MIR: 367 K, TIR: 300 K	MIR: 500 K, TIR: 400 K	MIR: 630 K TIR: 600 K
Minimum detectable area of a 1000 K THE (2)	~150 m^2	~20–30 m^2	~150 m^2	15–20 m^2
Revisit time	12 h (achived with two instruments)	12 h	24 h	12 h–3 d (3)

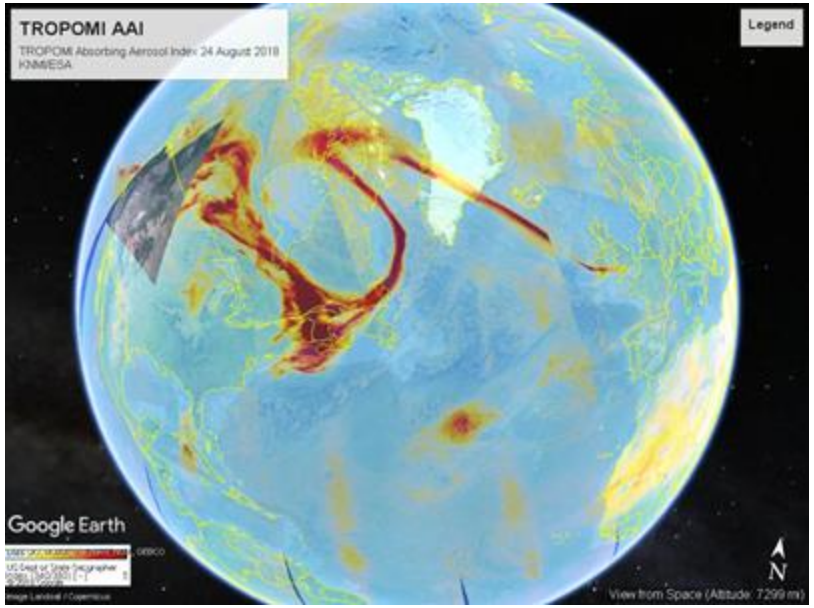
(1) In the IR bands used for observation of high-temperature events (HTEs), (2) at 300 K background temperature, see also Figure 15a in [3] for more details. (3) The revisit time of BIRD, TET-1 and BIROS is/was variable due to the possibility to move the line of sight (LoS) by +/− 30° from the nadir. This "roll-movement" of the LoS is a tool to enhance the field of regard (FoR) of the satellite sensor. This also allows observing an area of interest (AoI) three times within 3 days.


30°S
31°S
32°S
152°E
153°E
310
300
290
280
270
260
250
14
12
10
8
6
4
2
0
[K]
340
320
300
280
260
[K]
S7
X = Detected MWIR fires
S7 – S8
F1

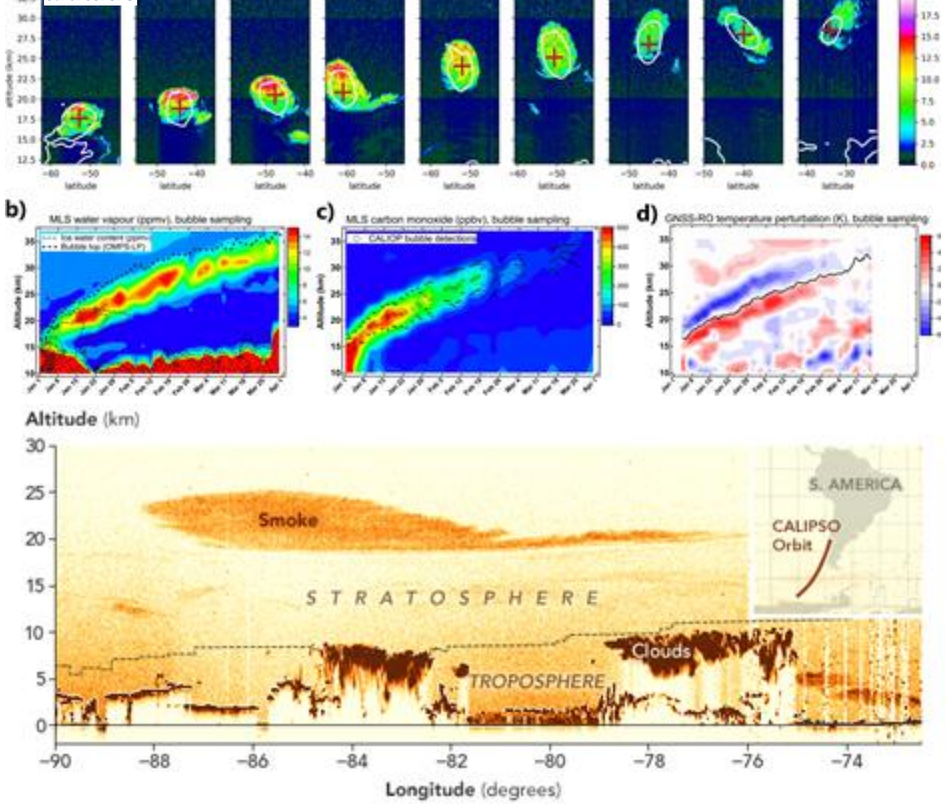
Wildfires: Monitoring from space

worldwide monitoring of wildfire smoke and air pollution

follow the smoke: smoke from Canada fires 2018 reached Europe

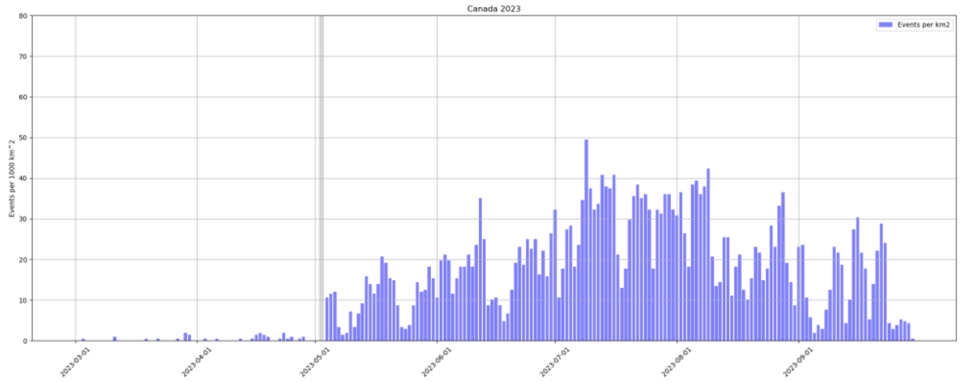


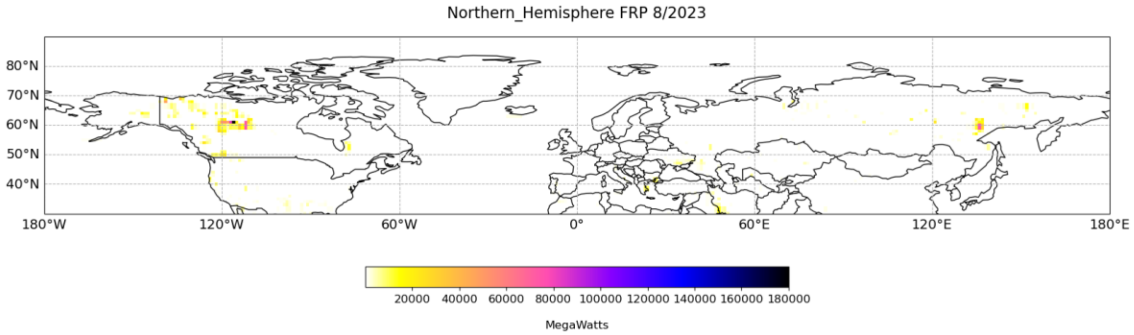
follow the smoke: Australia bushfire smoke 2020/2021 reached 35 km altitude

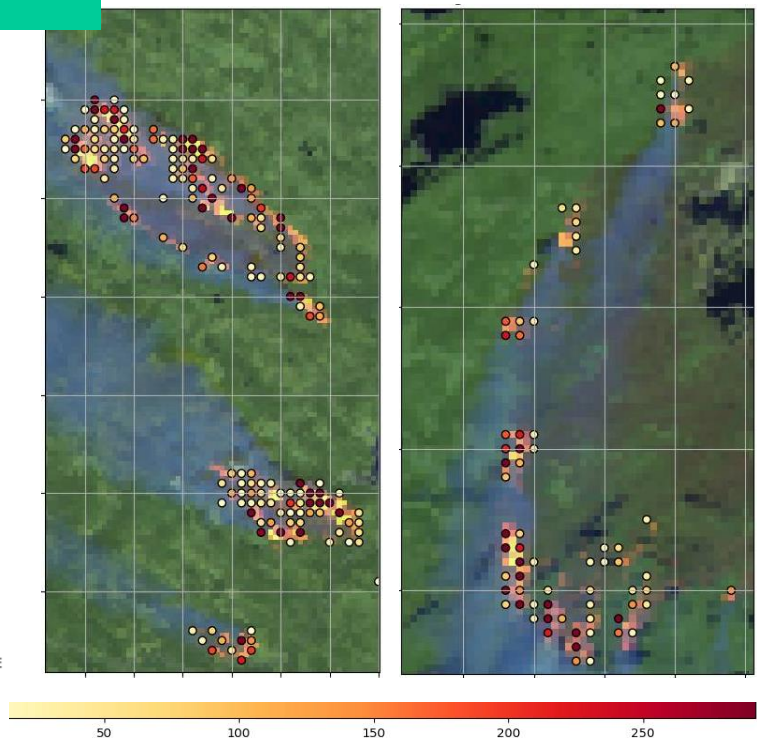


Individual 1 km hot spot and day-time imagery

Fire radiative power Sentinel-3 NRT product







1-km Fire Radiative Power [MW]
RGB Composite from SLSTR Solar Channels (R=2.2µm, G=1.6µm, B=0.6µm)

Flexible Combined Imager – Overview

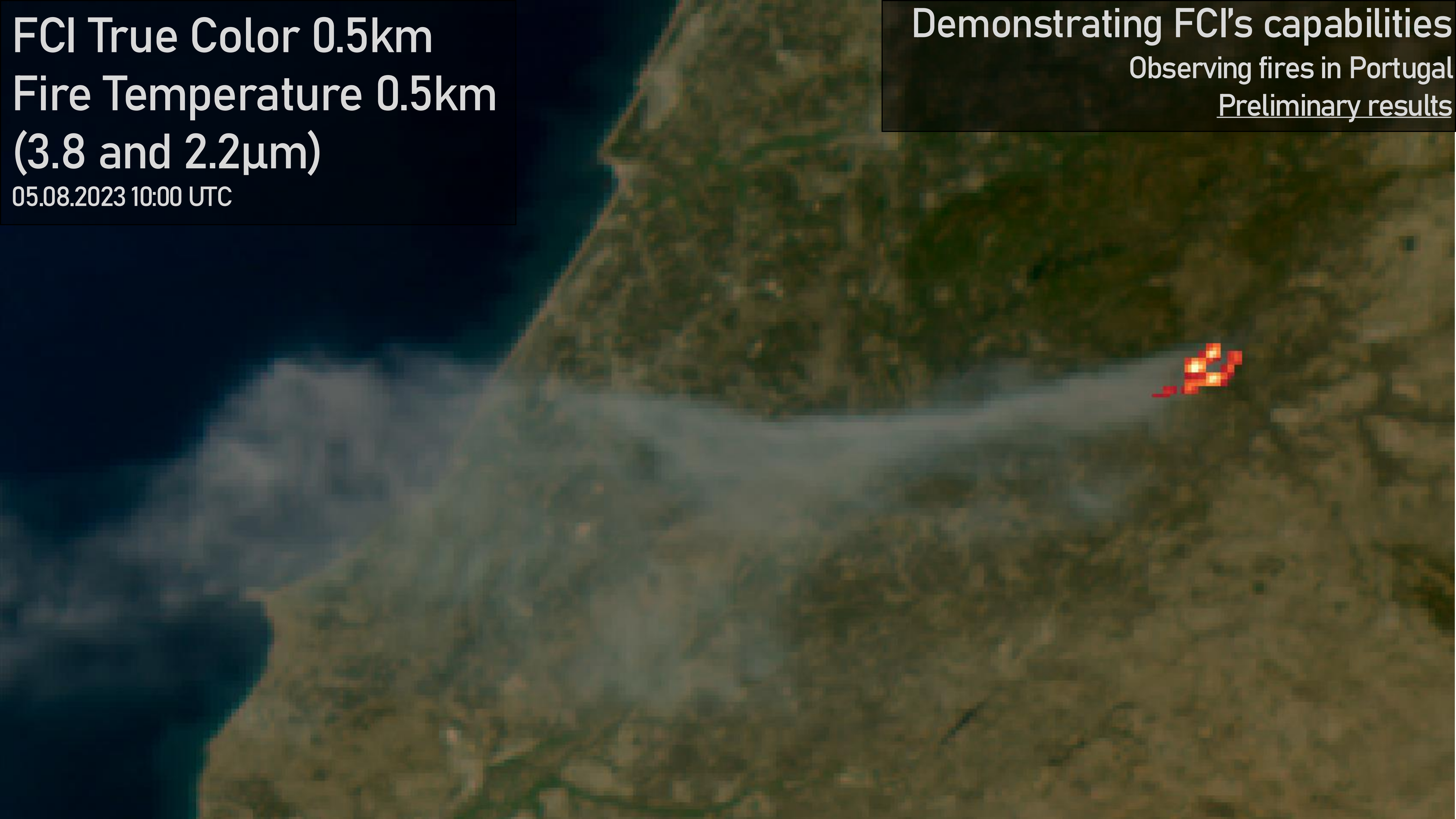
copernicus.eumetsat.int

- The FCI imager is one of the two main payloads onboard the Meteosat Third Generation Imaging (MTG-I) satellites, together with the Lightning Imager (LI).

- First FCI on MTG-I1: **full disk** scanning service (FDSS) with **10min** temporal resolution.
- Second FCI on MTG-I2: **rapid scanning** service (RSS) over Europe with **2.5min** temporal resolution.

The entire fire cycle can be observed by FCI with unprecedented temporal detail!


SEVIRI Natural Color 3km
Fire Temperature 3km
(3.8µm)
05.08.2023 10:00 UTC
MSG-SEVIRI
For comparison


FCI True Color 0.5km
Fire Temperature 0.5km
(3.8 and 2.2µm)
05.08.2023 10:00 UTC
Demonstrating FCI's capabilities
Observing fires in Portugal
Preliminary results


FCI True Color 0.5km
Fire Temperature 0.5km
(3.8 and 2.2µm)
16.08.2023 13:00-15:00 UTC
Demonstrating FCI's capabilities
Observing PyroCBs in Central Africa
Preliminary results

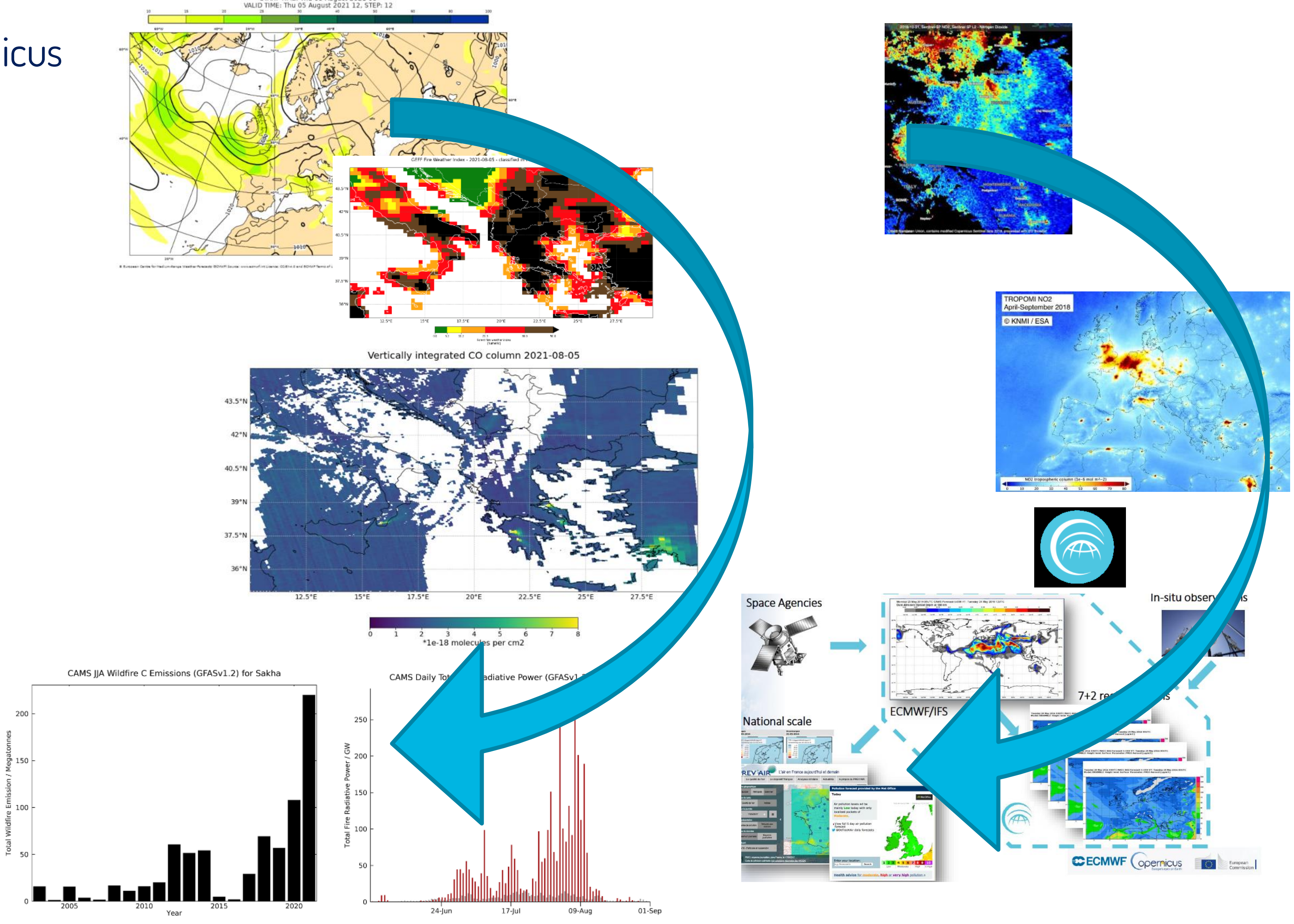
Synergy in Copernicus: part of an unique data value chain

copernicus.eumetsat.int

Bring to Users the concept of "Copernicus improves usability"

User journey encompassing:
→Forecast
→Monitoring and nowcasting
→Estimate of impacts

Integrated system:
→ Satellite and non satellite, models
→Support emission estimate
→Generate added value products
→Ensure Quality and usability



Outcomes

EUMETSAT and Copernicus missions are and will be unique to support policies in emission reduction for most species and to detect environmental risks

Observations needs support to be properly used – complexity – representativeness

Observations are used in services that provides added value products (CAMS)

Improve exploitation – eg combination with ground-based and in-situ

Applications of AI/ML