Satellite remote sensing of trace gases - Nadir sounding geometry

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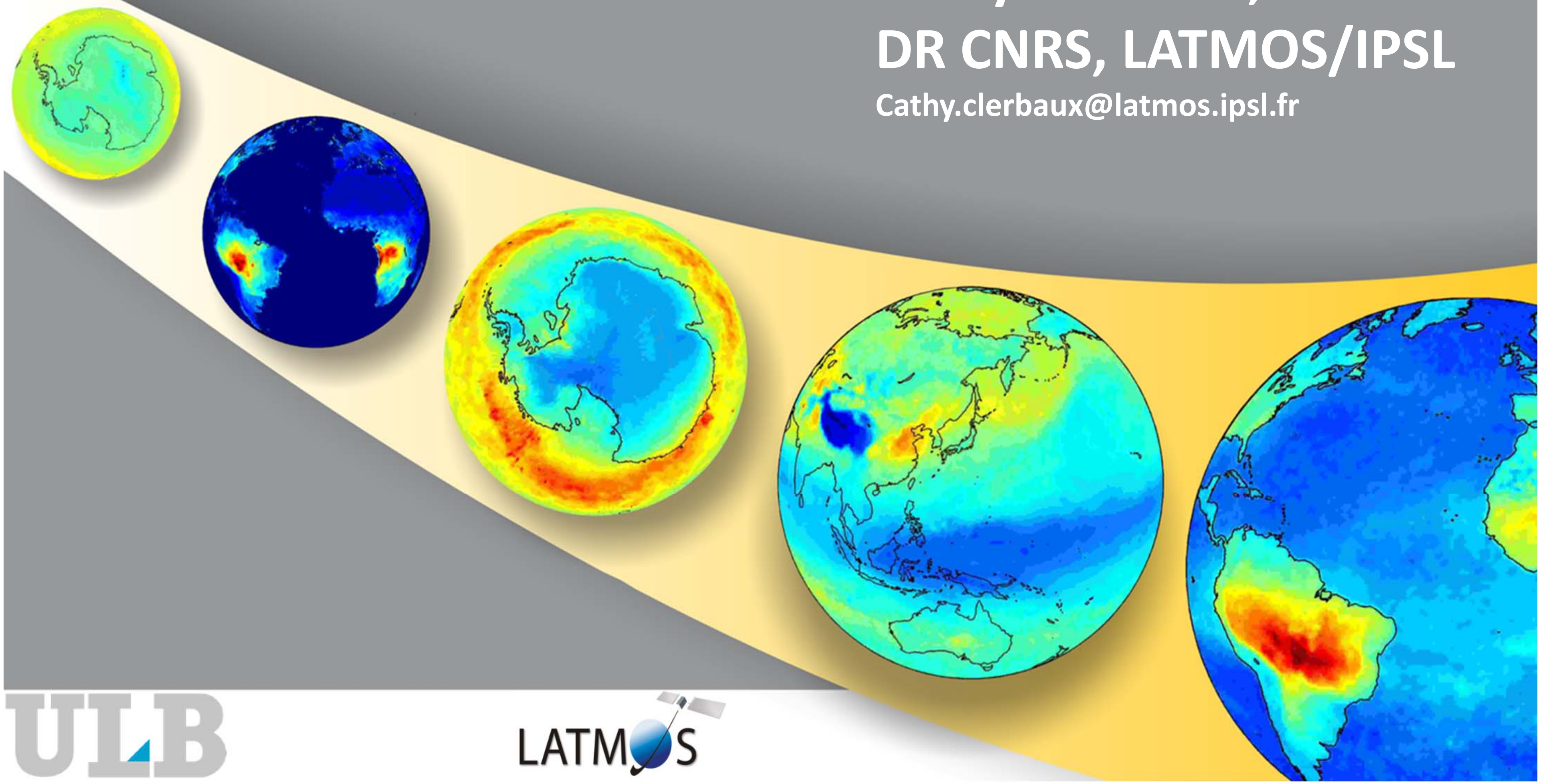
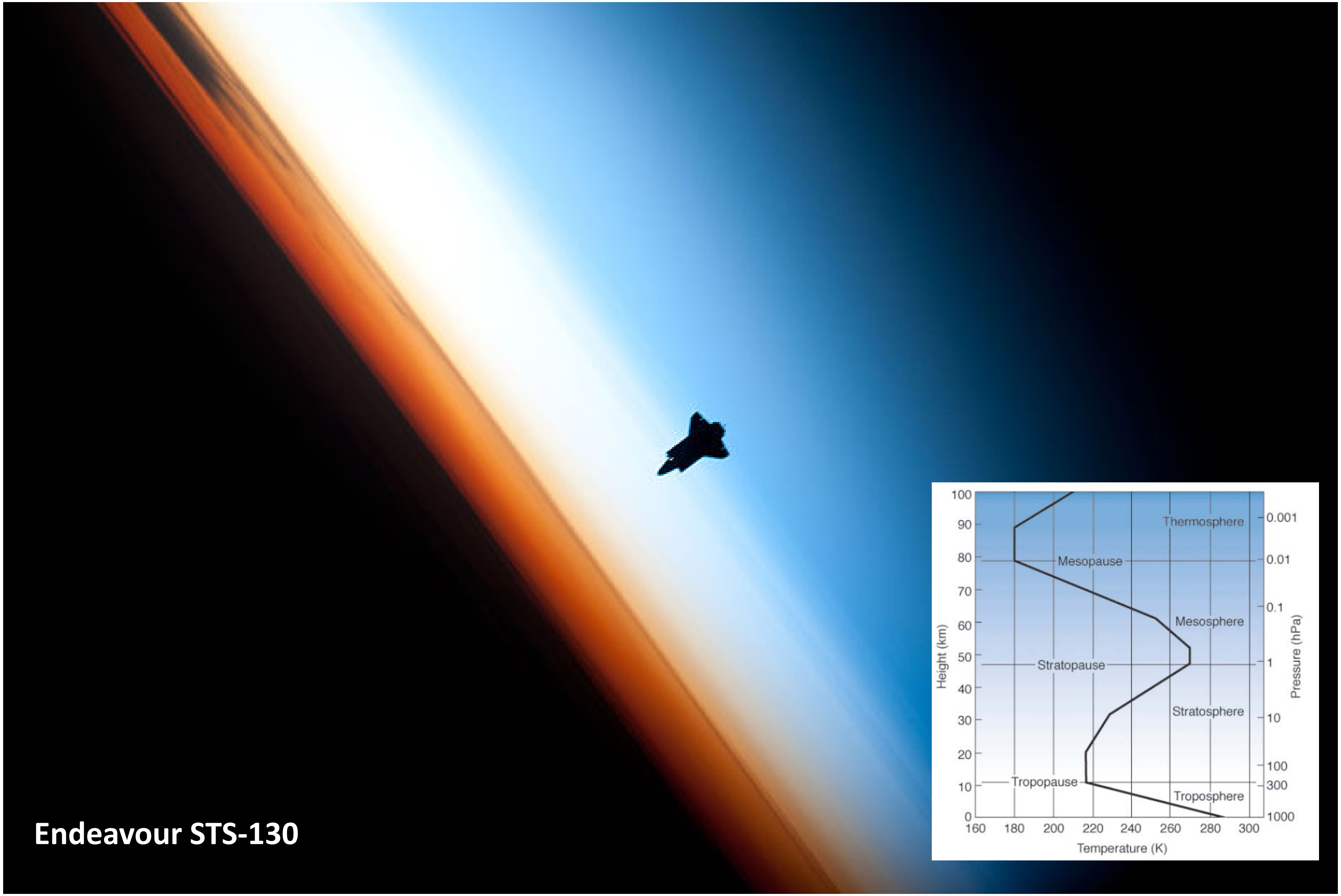


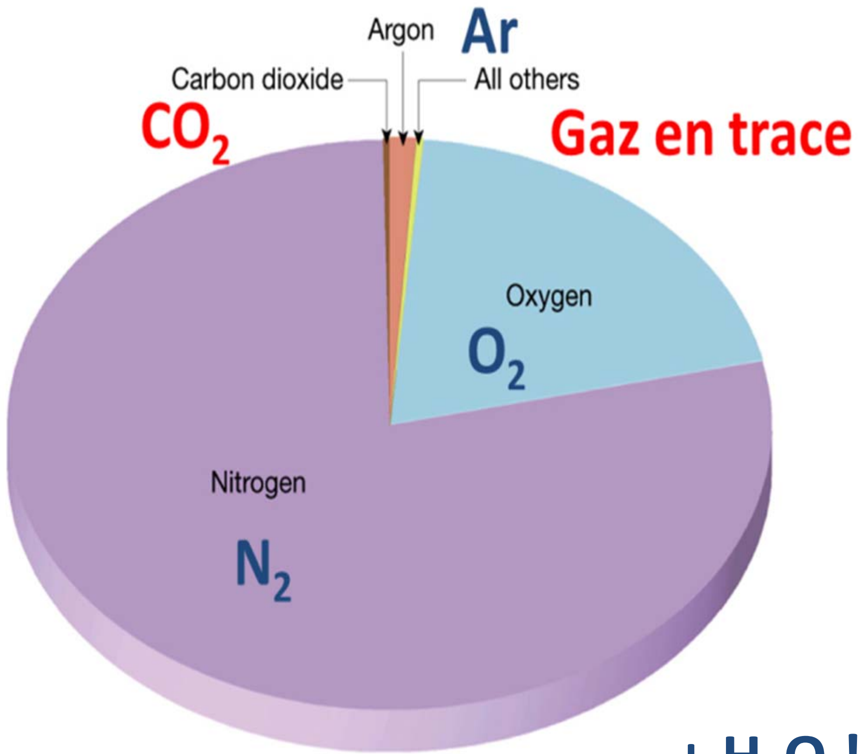
ULB

LATMOS

Sounding the bottom of the atmosphere…



Atmospheric composition



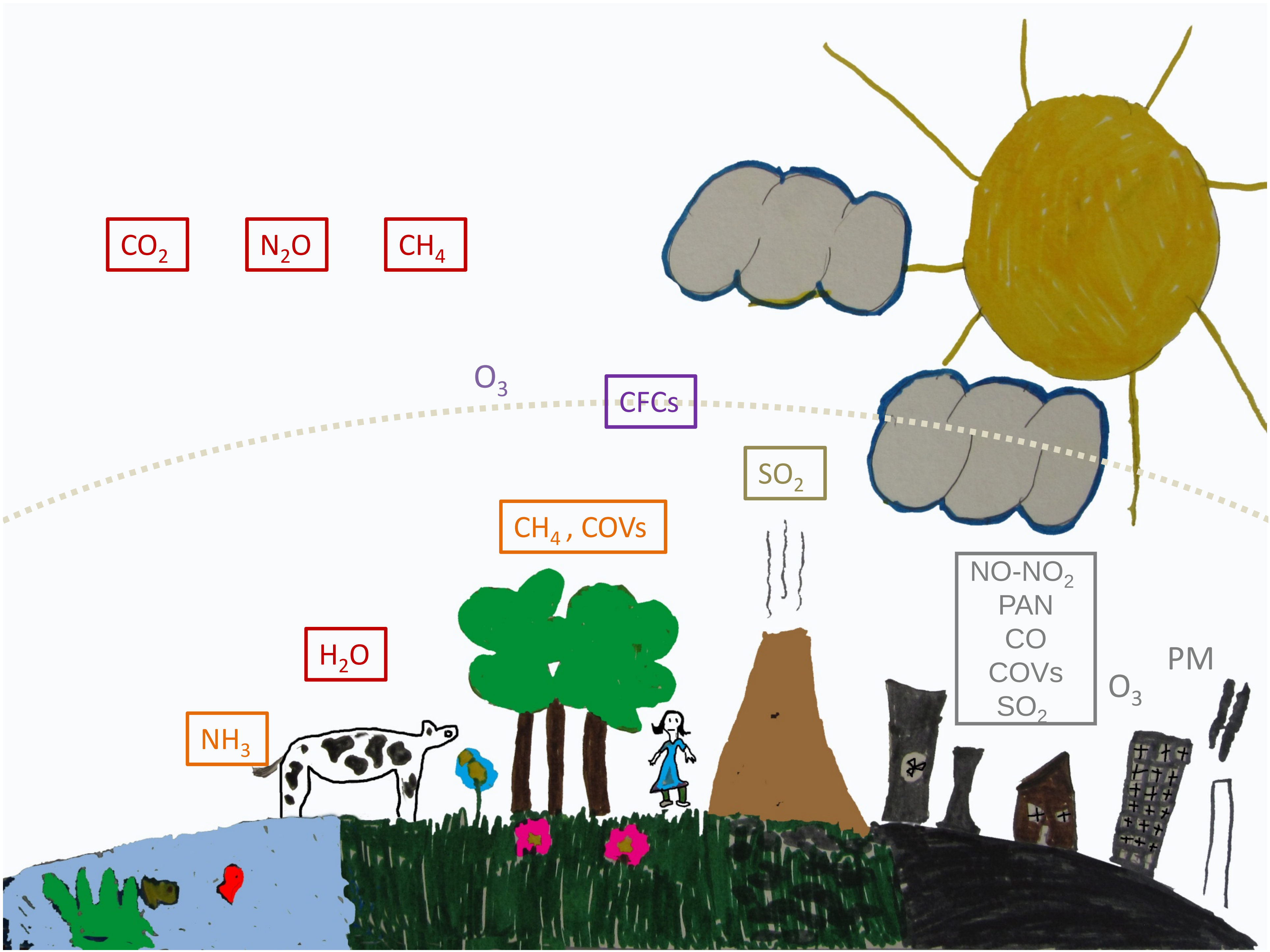
+ H_2O !

N_2+ O_2+ Ar + H_2O + CO_2 + **trace gases**

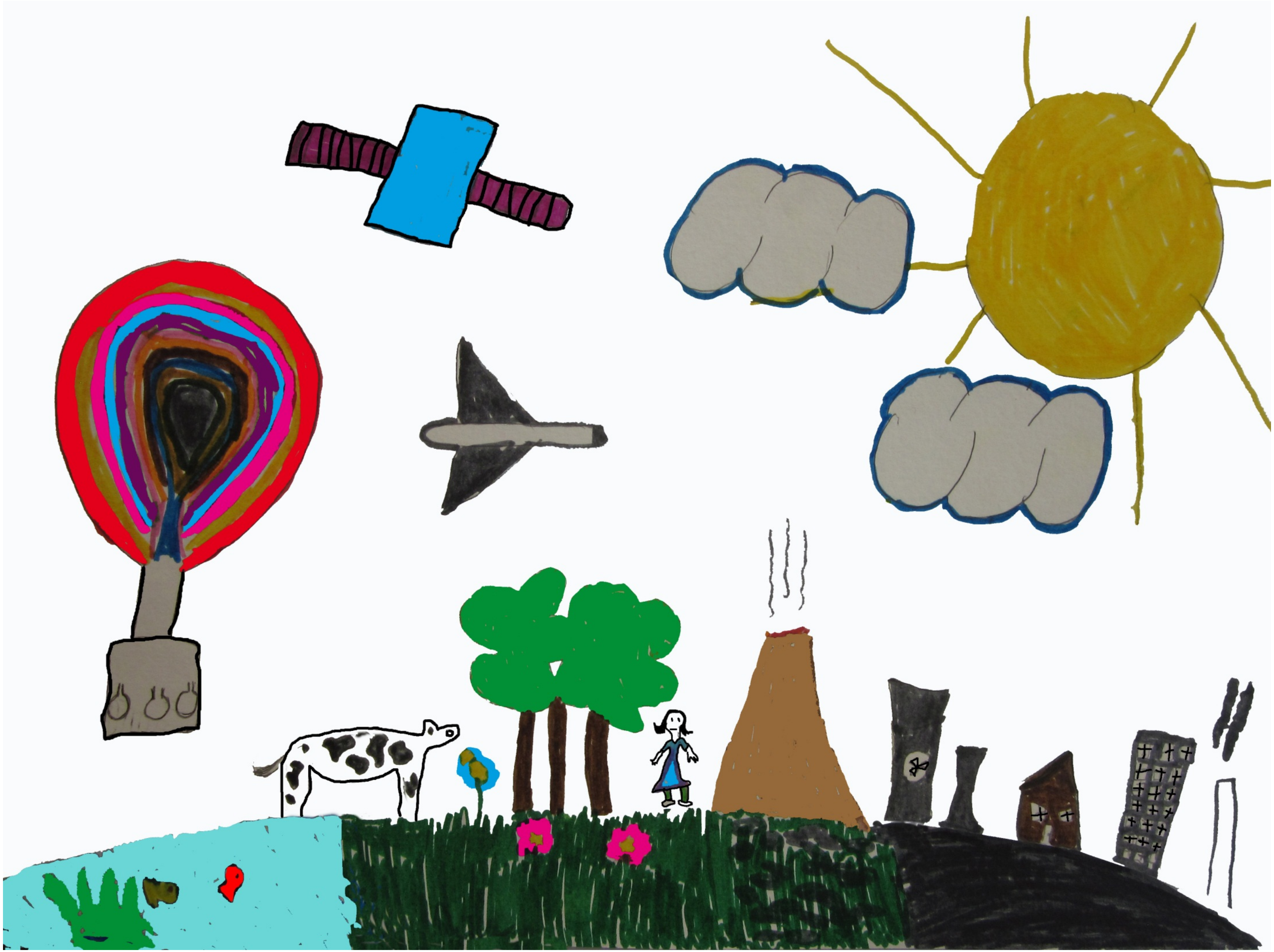
> 99.9 % < 0.10 %

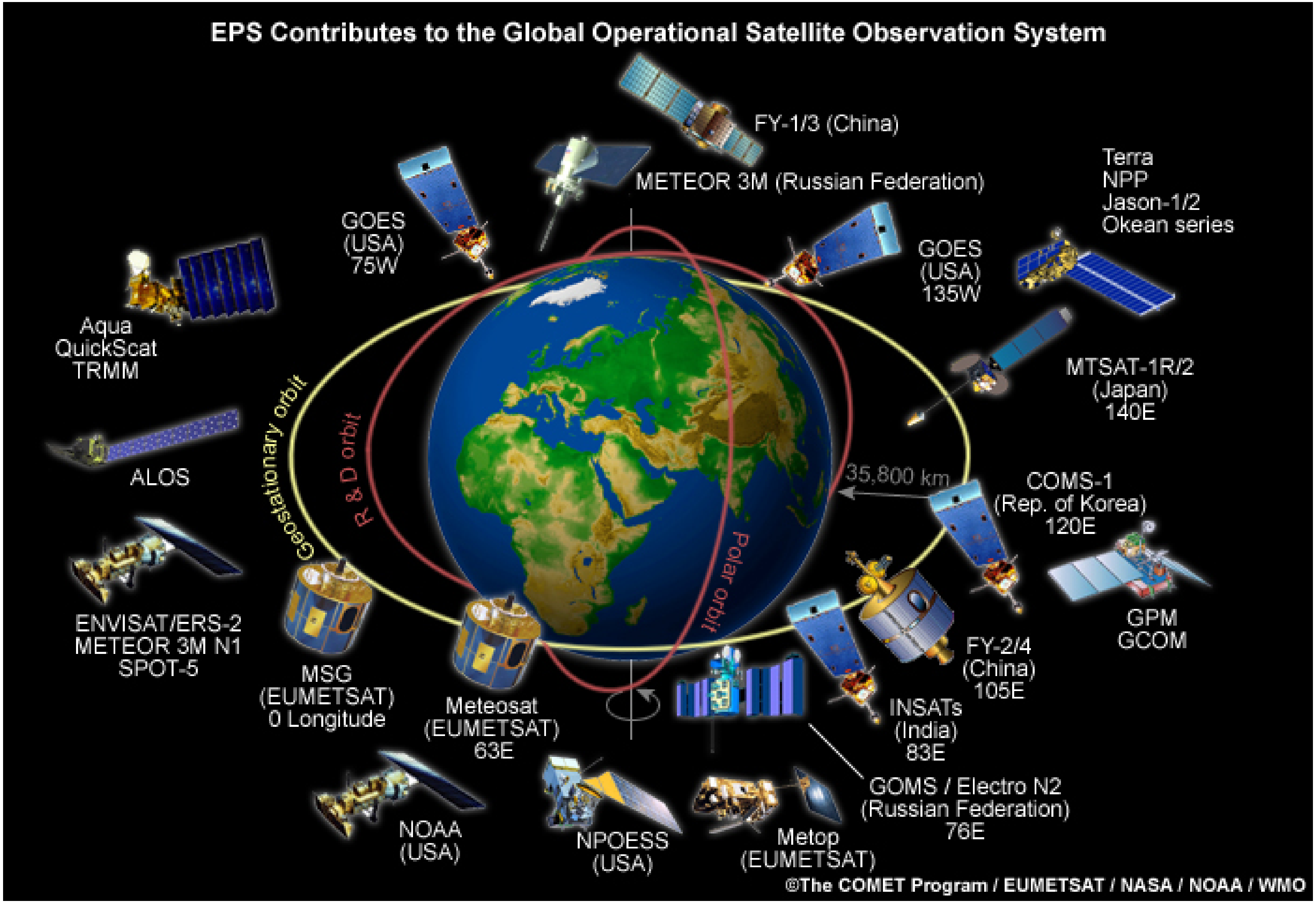
1 ppm = 1 10^{-6}
1 ppb = 1 10^{-9}
1 ppt = 1 10^{-12}

Constituant	Formule chimique	Masse moléculaire (12C = 12)	Pourcentage en volume par rapport à l'air sec (10^{-2} v/v)
Atmosphère totale			
Air sec		28,9644	100,0
Vapeur d'eau	H_2O	18,0153	Variable
Diazote	N_2	28,0340	78,084
Dioxygène	O_2	31,9988	20,948
Argon	Ar	39,9480	0,934
Dioxyde de carbone	CO_2	44,0099	0,0370
Néon	Ne	20,1830	$1{,}818.10^{-3}$
Hélium	He	4,0026	$1{,}818.10^{-3}$
Méthane	CH_4	16,0430	$\approx 1{,}7.10^{-4}$
Hydrogène	H_2	2,0159	$\approx 5{,}0.10^{-5}$
Protoxyde d'azote	N_2O	44,0128	$\approx 3{,}1.10^{-5}$
Monoxyde de carbone	CO	28,0106	$\approx 1{,}2.10^{-5}$
Ozone	O_3	47,9982	$2\text{-}200.10^{-6}$
Ammoniac	NH_3	17,0306	$\approx 0{,}1$ à 1.10^{-6}
Dioxyde d'azote	NO_2	46,0055	$\approx 1.10^{-7}$
COV (composés organiques volatils)	$C_xH_yO_z$	variable	$\approx 0{,}1$ à 1.10^{-6}
Dioxyde de soufre	SO_2	64,063	$\approx 2.10^{-8}$
Sulfure d'hydrogène	H_2S	34,080	$\approx 2.10^{-8}$



CO_2
N_2O
CH_4
O_3
CFCs
SO_2
CH_4 , COVs
NO-NO_2
PAN
CO
COVs
SO_2
O_3
PM
H_2O
NH_3





EPS Contributes to the Global Operational Satellite Observation System
FY-1/3 (China)
METEOR 3M (Russian Federation)
Terra
NPP
Jason-1/2
Okean series
GOES
(USA)
75W
GOES
(USA)
135W
Aqua
QuickScat
TRMM
MTSAT-1R/2
(Japan)
140E
ALOS
Geostationary orbit
R & D orbit
35,800 km
COMS-1
(Rep. of Korea)
120E
Polar orbit
ENVISAT/ERS-2
METEOR 3M N1
SPOT-5
GPM
GCOM
FY-2/4
(China)
105E
MSG
(EUMETSAT)
0 Longitude
Meteosat
(EUMETSAT)
63E
INSATs
(India)
83E
GOMS / Electro N2
(Russian Federation)
76E
NOAA
(USA)
NPOESS
(USA)
Metop
(EUMETSAT)
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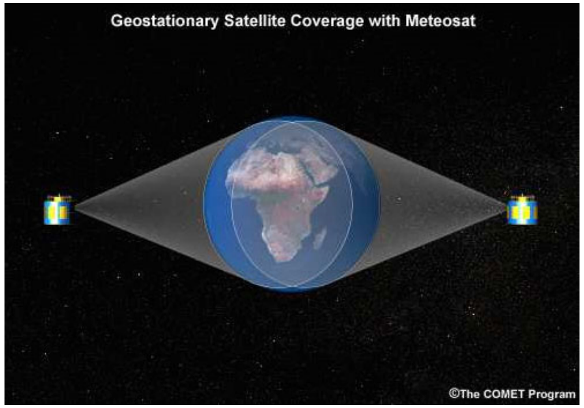
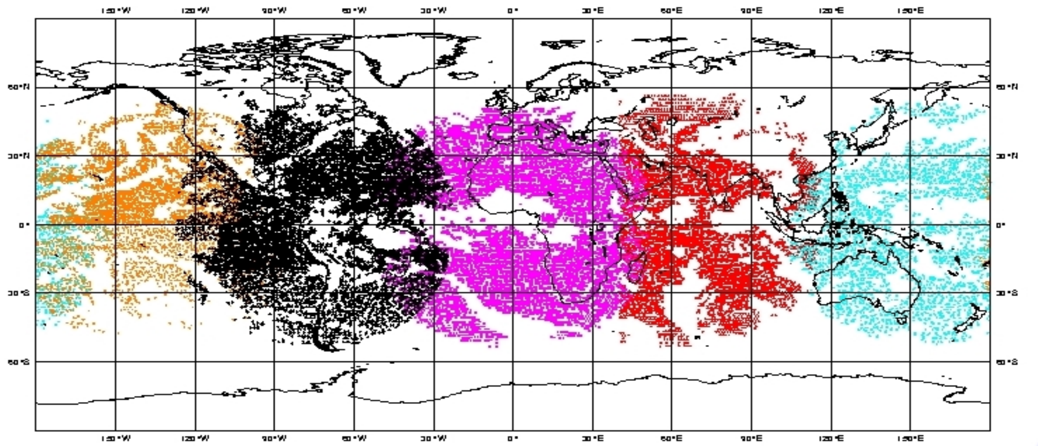
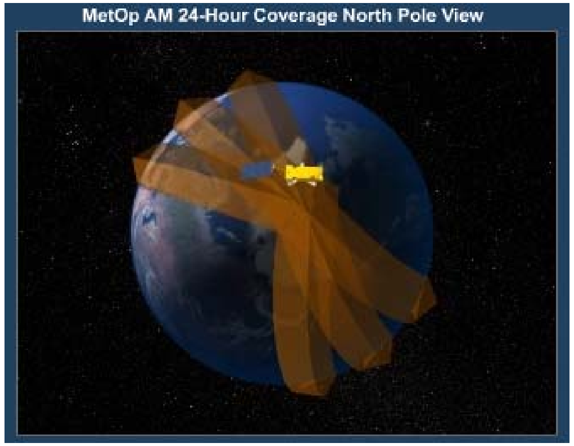
Satellite atmospheric sounding

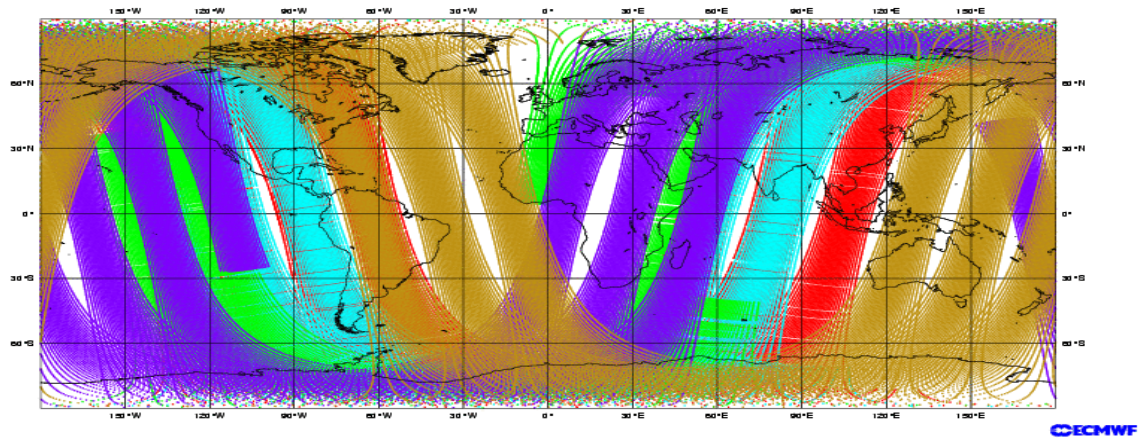
Geostationnary orbit, 32 000 km





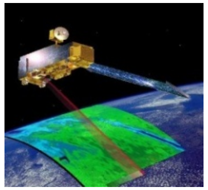
Polar orbit, around 700-800 km



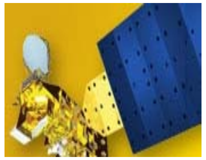


Current nadir-looking satellite-borne missions

US/EOS



Terra 1999
Mopitt



Aqua 2002
AIRS

Aura 2004
TES/OMI

EU/EPS

Metop-A 2006
MetOp-B 2012
Metop-C 2018

IASI
GOME-2

GOSAT

US/NPP Suomi

CrIS
OMPS

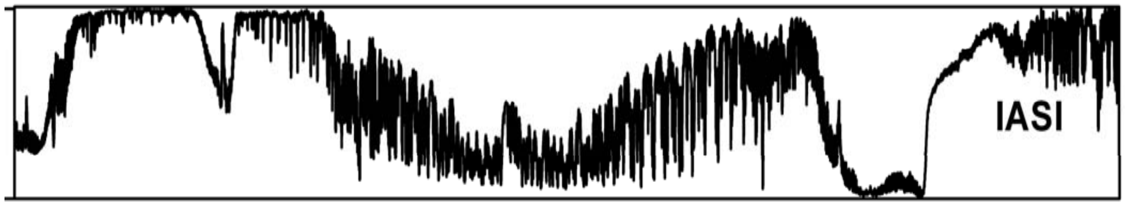
OCO-2

+ Calipso on the A-train

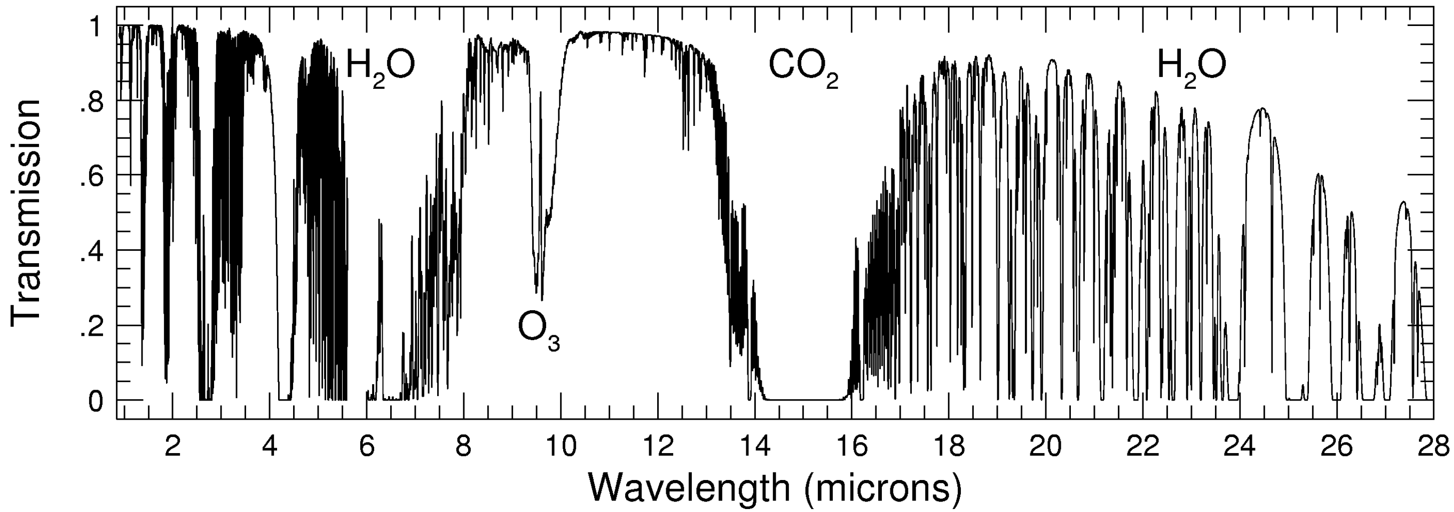
Atmospheric sounding

What we see…

What a nadir-looking thermal infrared instrument sees…



How radiation and molecules interact



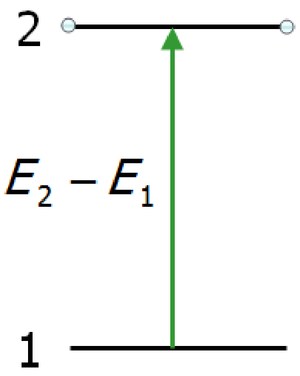
42000 06200

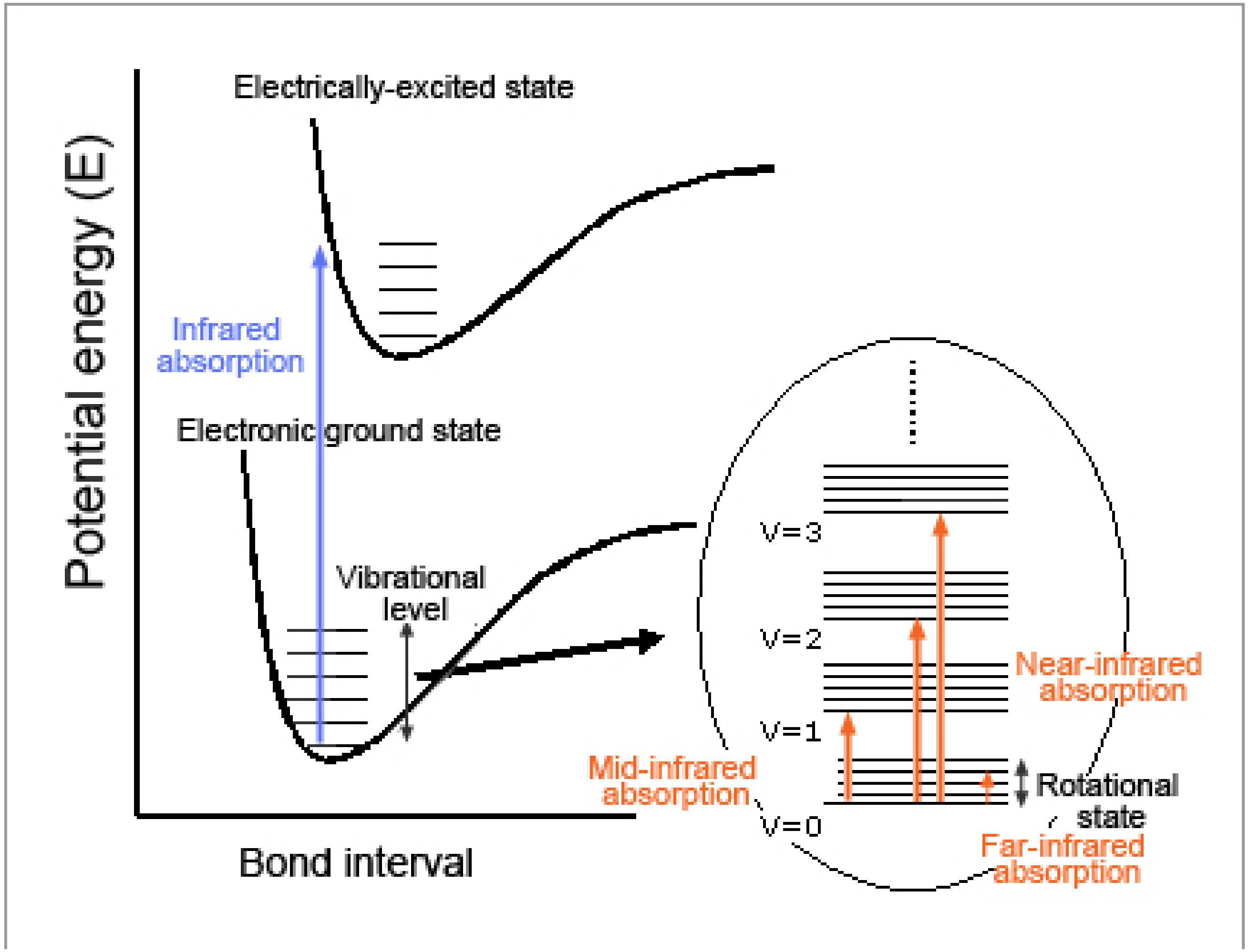
How radiation and molecules interact

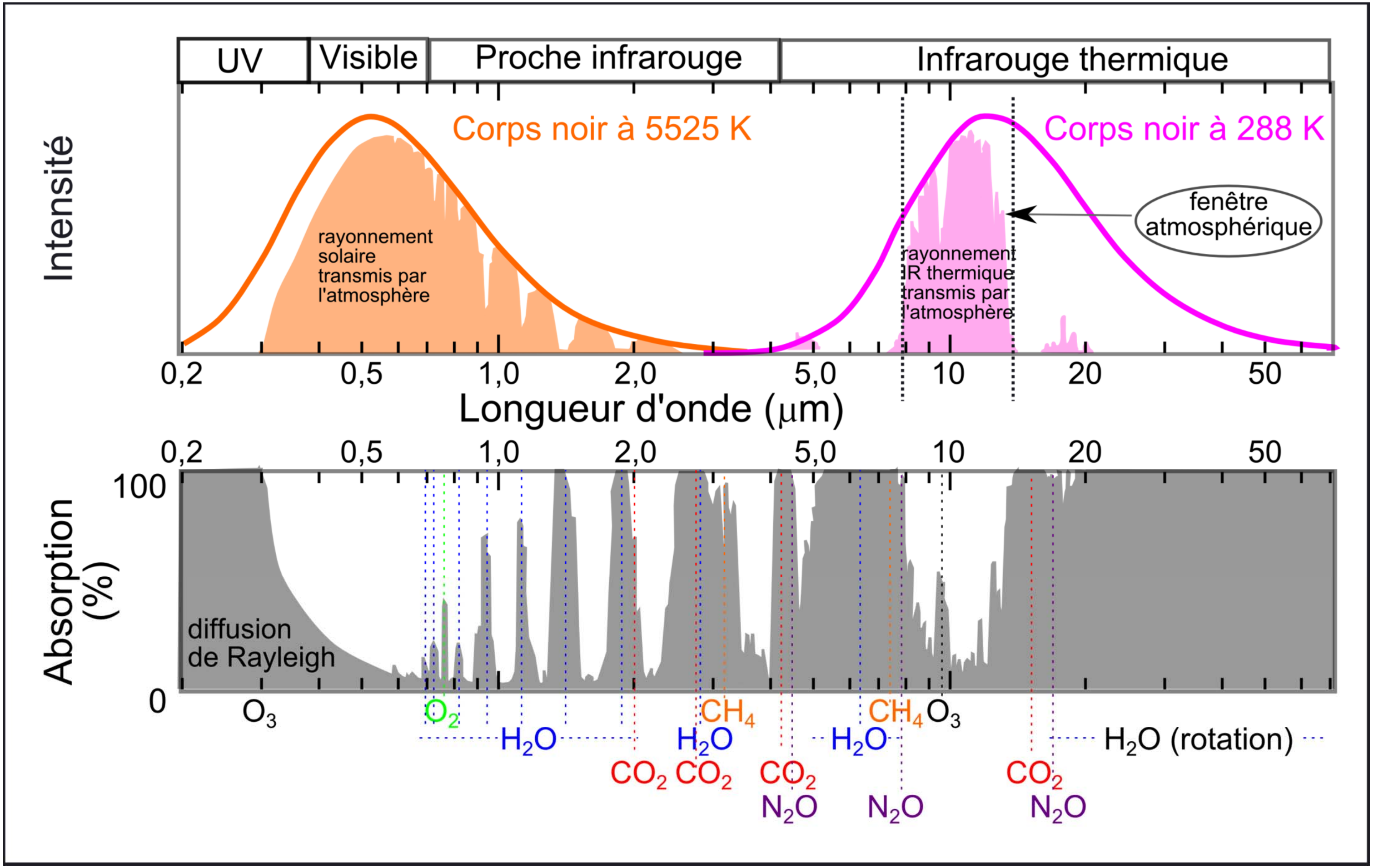
$$E = E_{el} + E_{vib} + E_{rot}$$

Position

$\tilde{\nu}_{21} = E_2 - E_1$

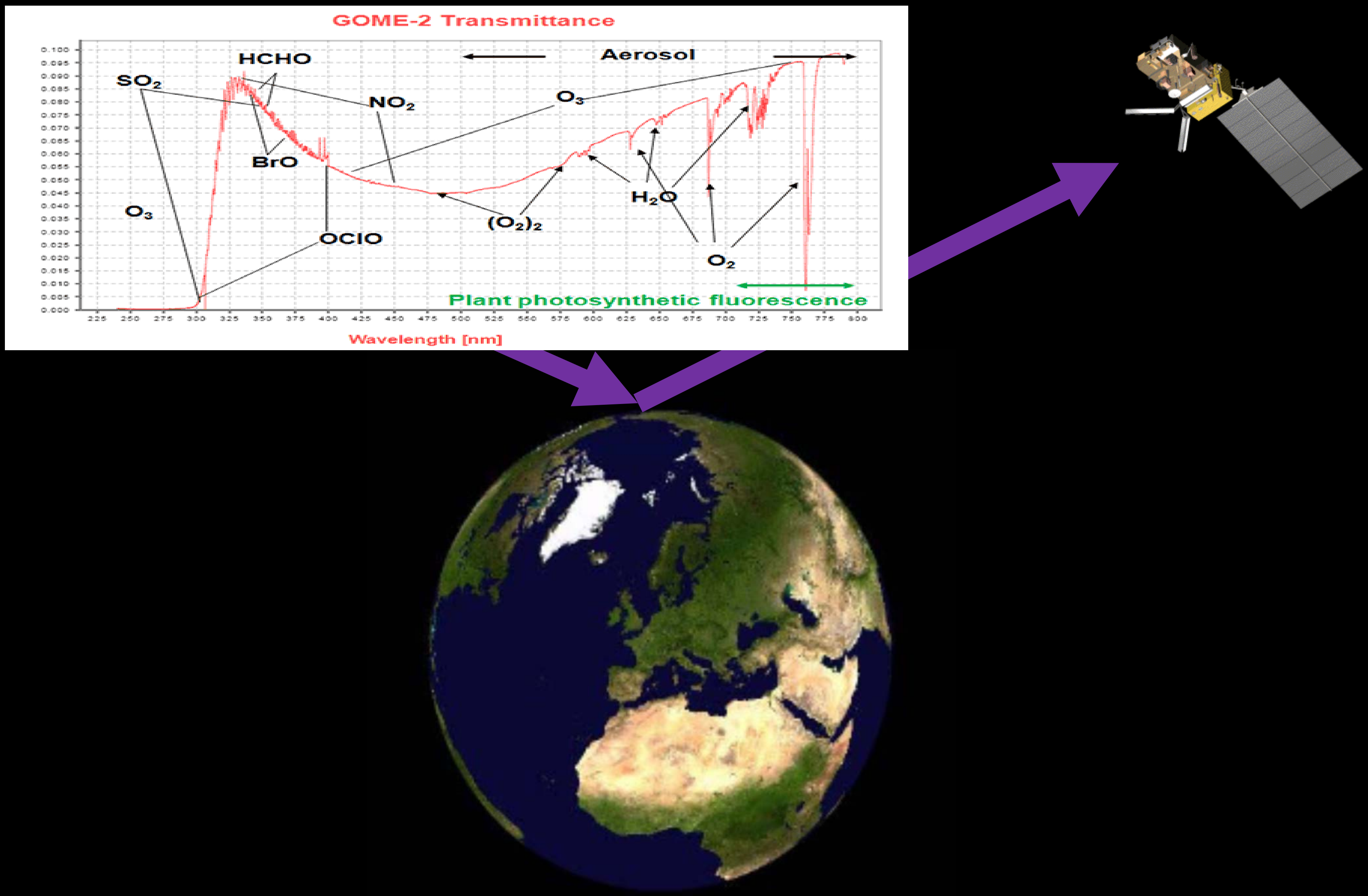




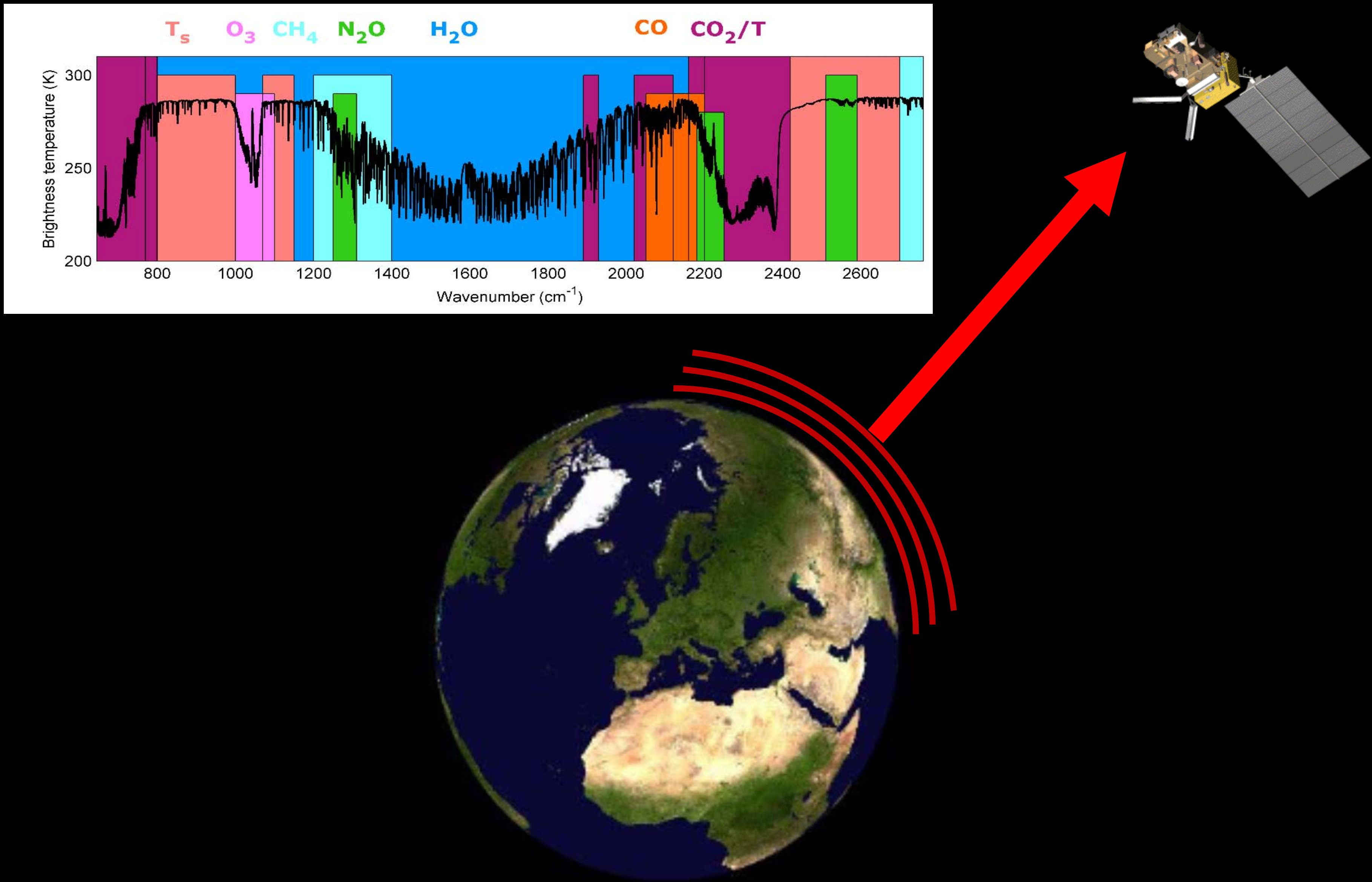


Electronic transitions **Ro-vbrational transitions** **Rotational transitions**

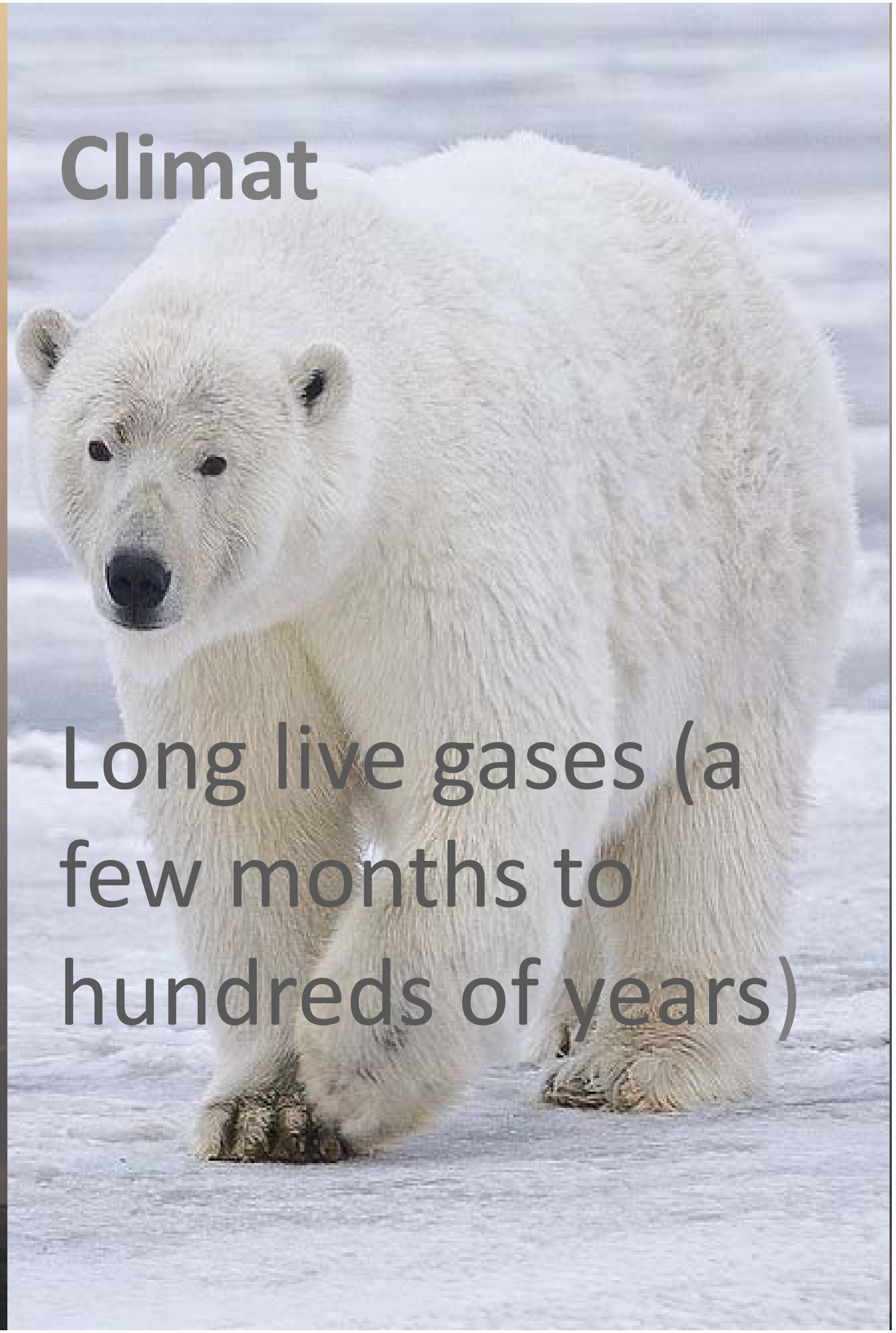
What can be seen by GOME-2?



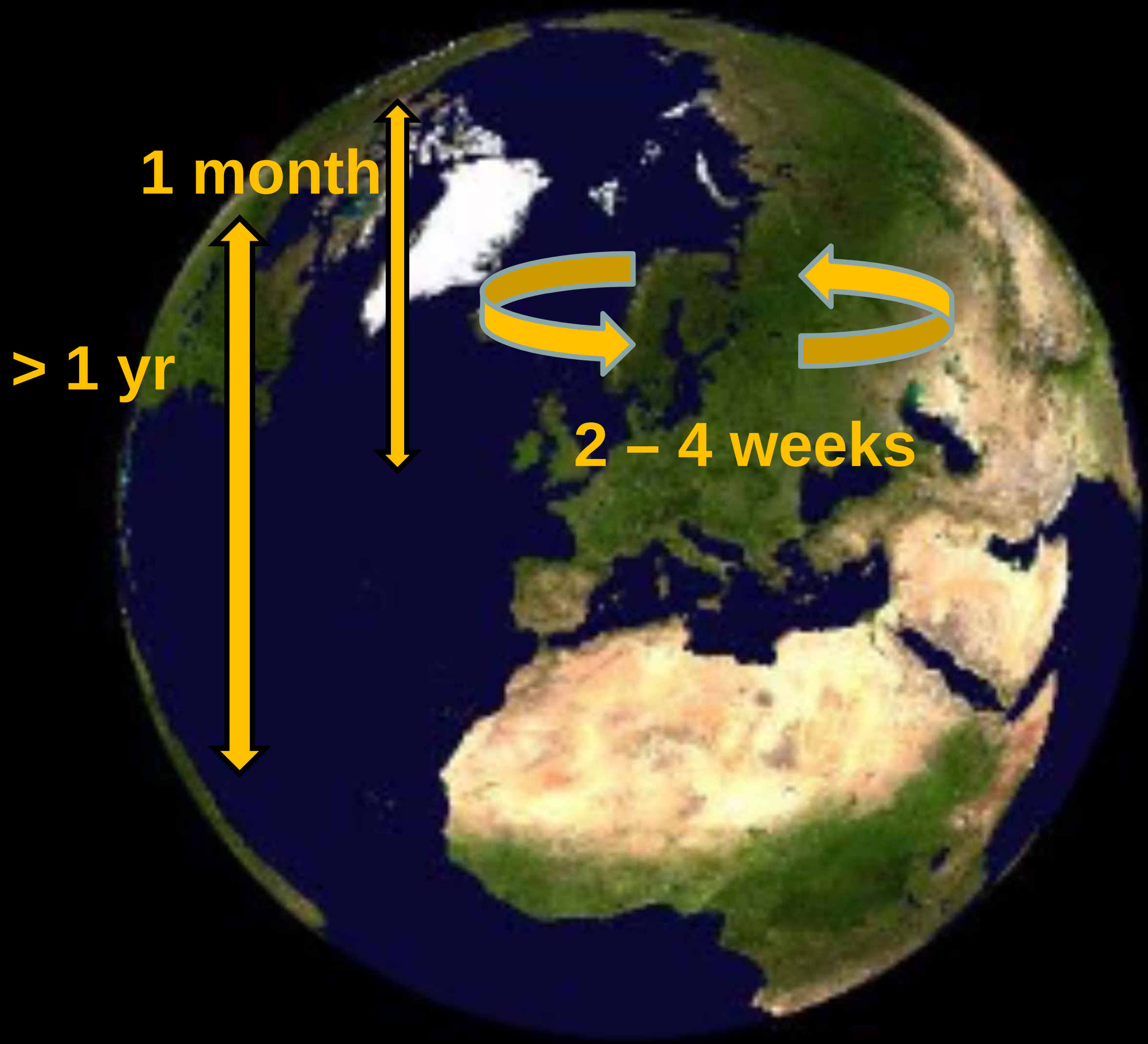
What can be seen by IASI?




Pollution
Short live trace gases
(a few seconds to a few weeks)


Climat
Long live gases (a few months to hundreds of years)

Atmospheric lifetime



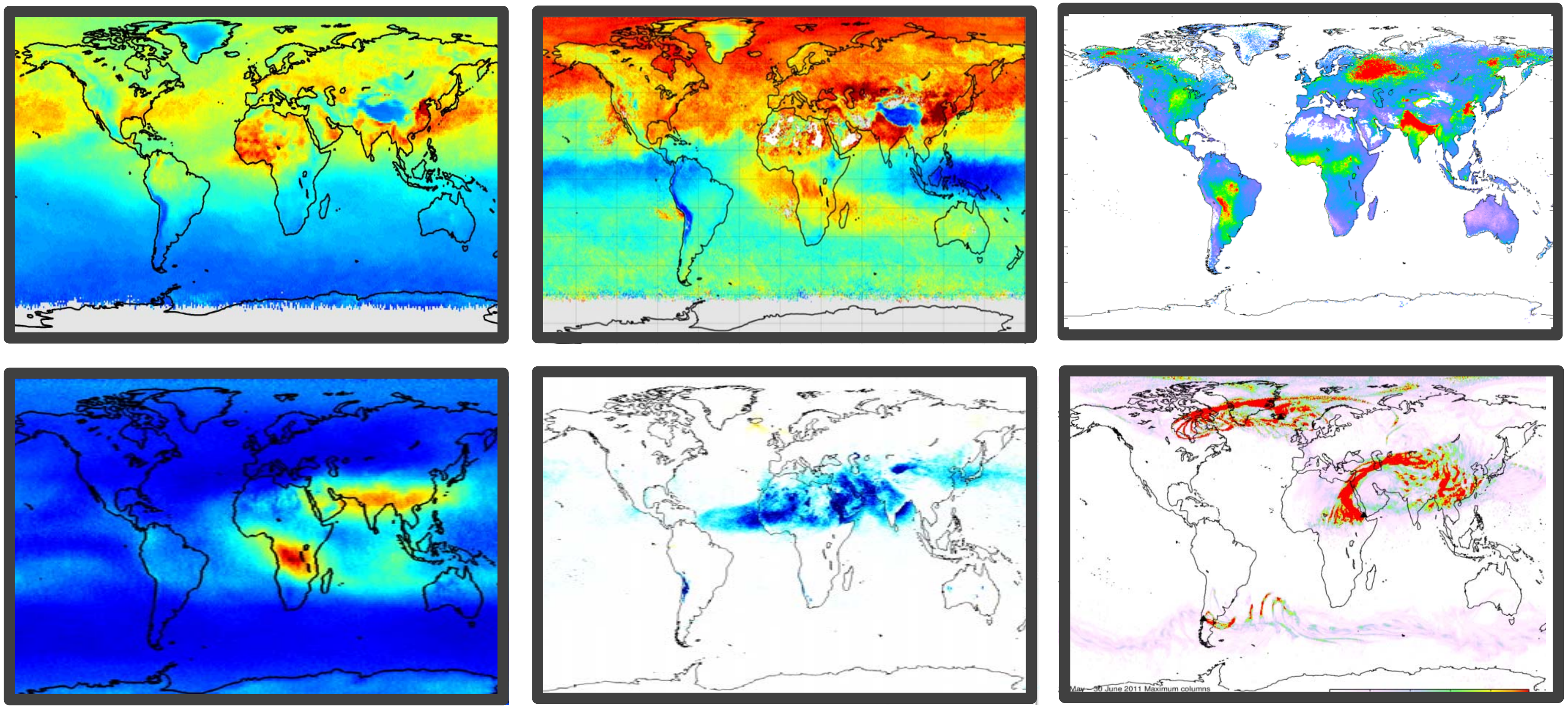
<u>Climate gases</u>

H_2O
CO_2, NO_2 [100 yr]
CH_4 [10 yr]
(O_3)

<u>Pollutants</u>

CO [4-8 weeks]
O_3 [weeks]
NO_2 [days]
Formaldeide, methanol, formic acid [days]
NH_3 [hours – days]

Whose map is it (retrieved from TIR IASI)?



Tropo O_3 , C_2H_2, column CO column, ammonia column ?
Ash-volcano, dust (sand) ?

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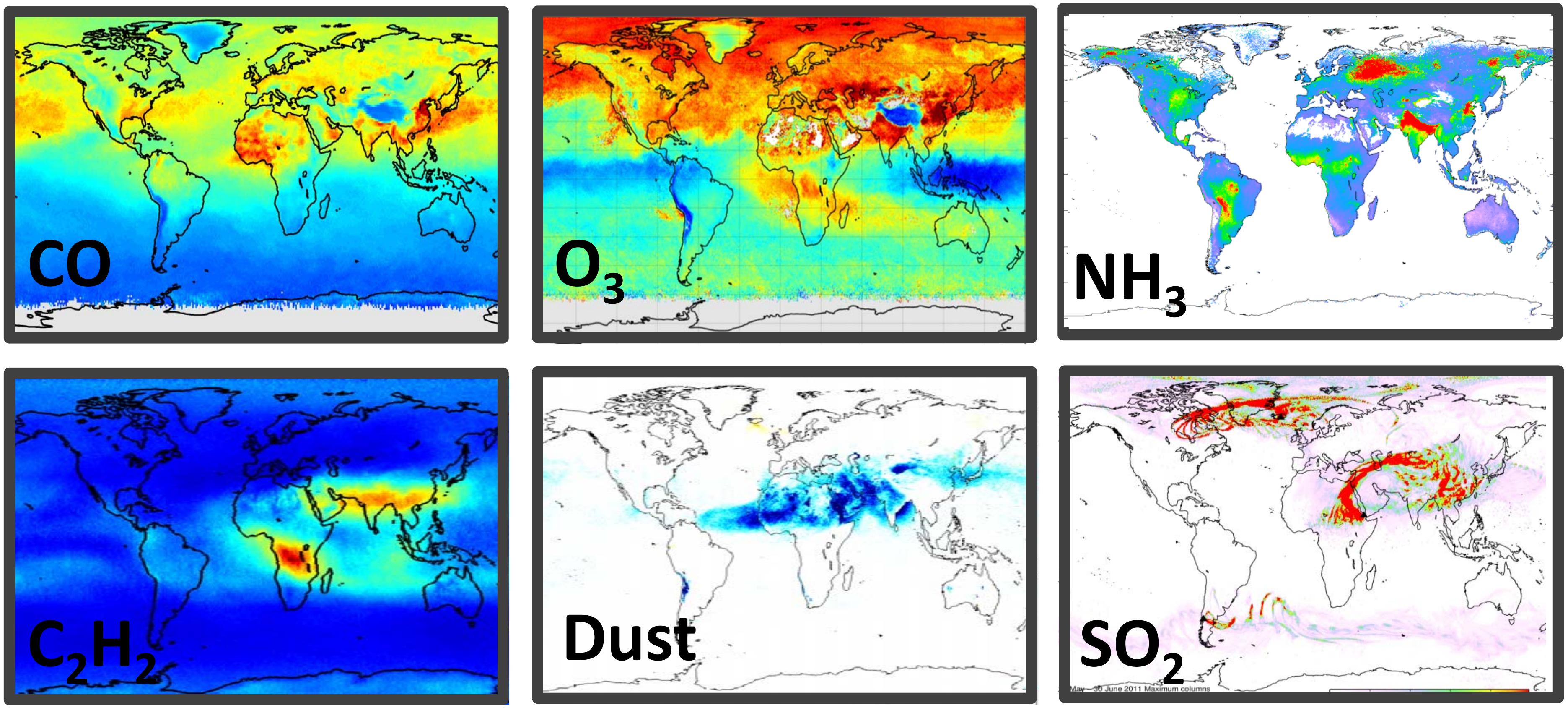
Whose map is it?



→ Gases and particles behave differently depending on their lifetime

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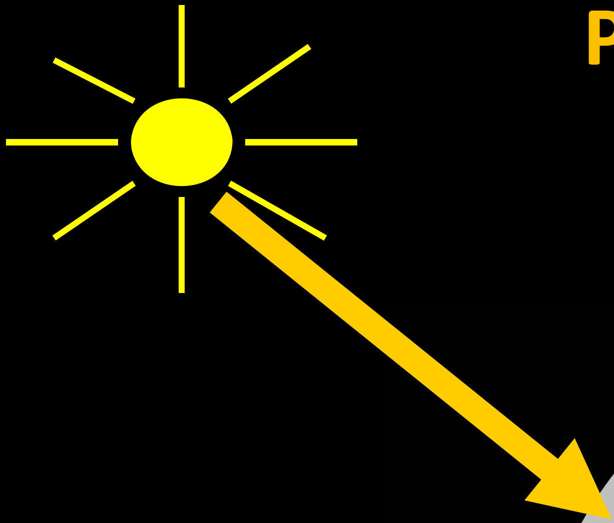
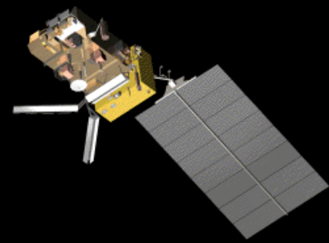
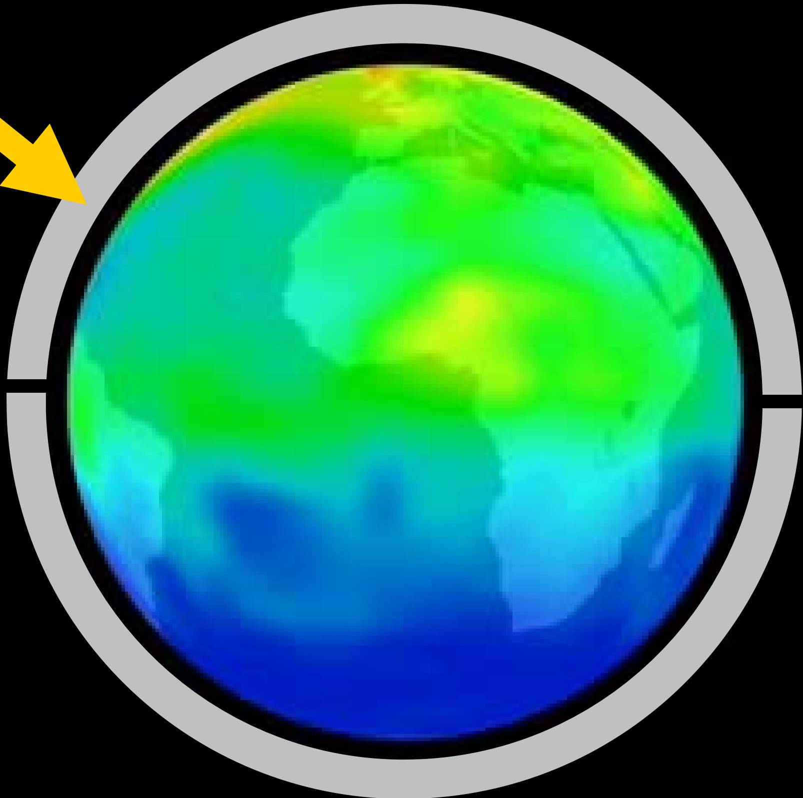


Pollution from space



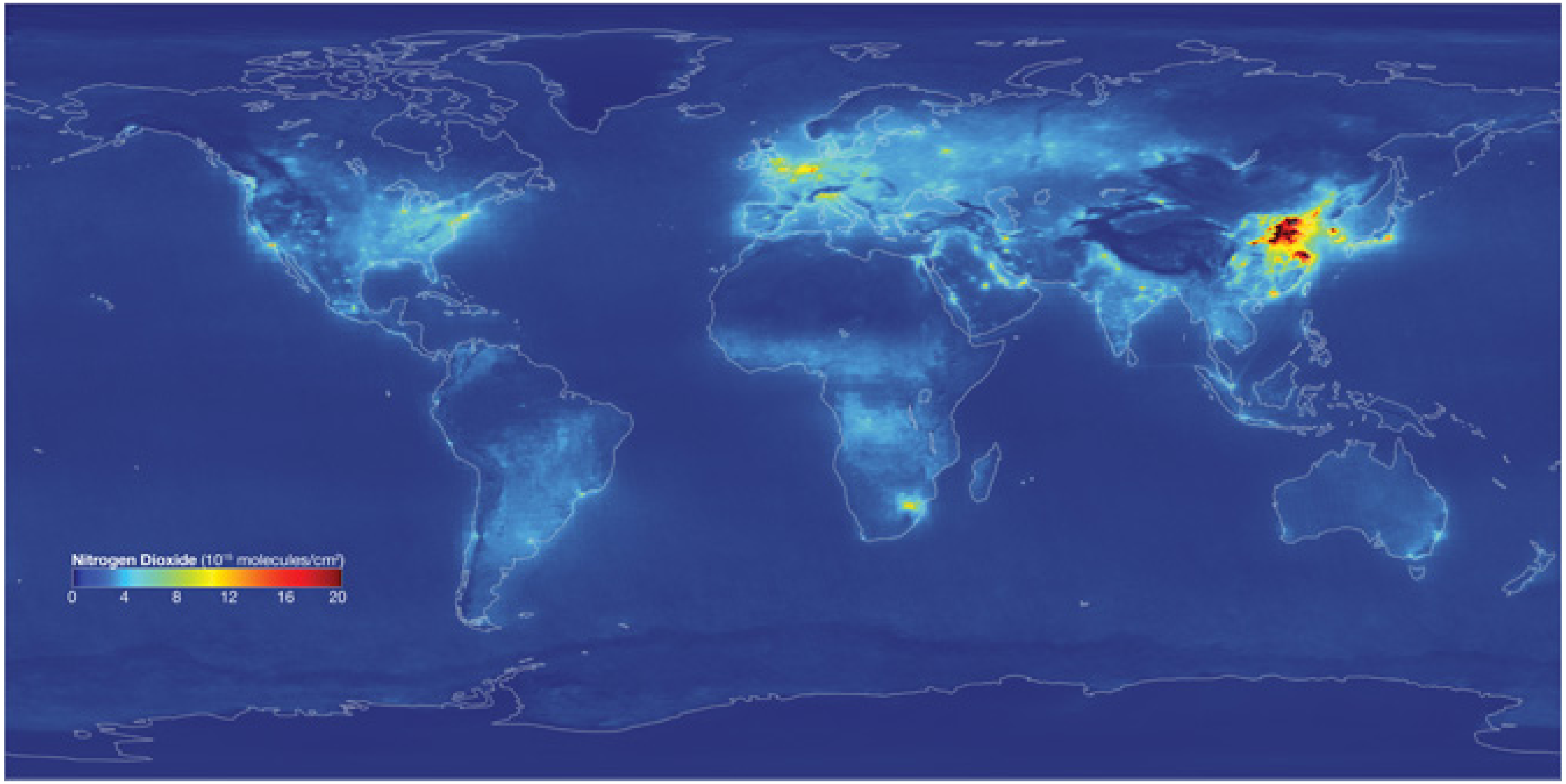
4 examples



1/ NO_2
2/ CO
3/ Tropo O_3
4/ coarse PM
5/ NH_3

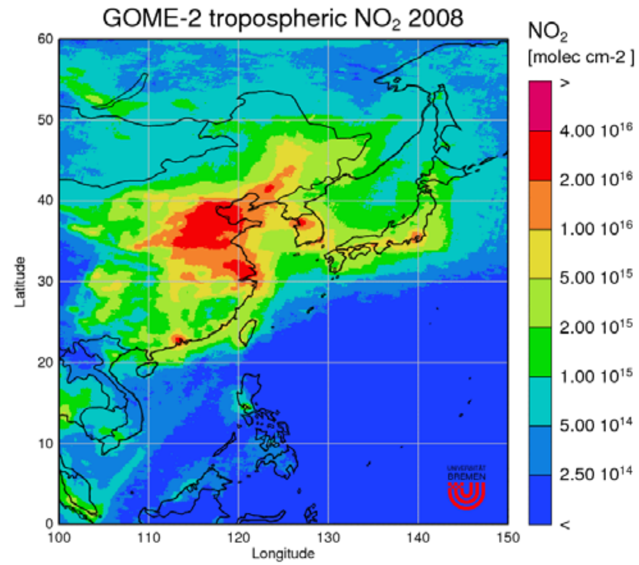
OMI/AURA

NO_2



Credit NASA

NO_2



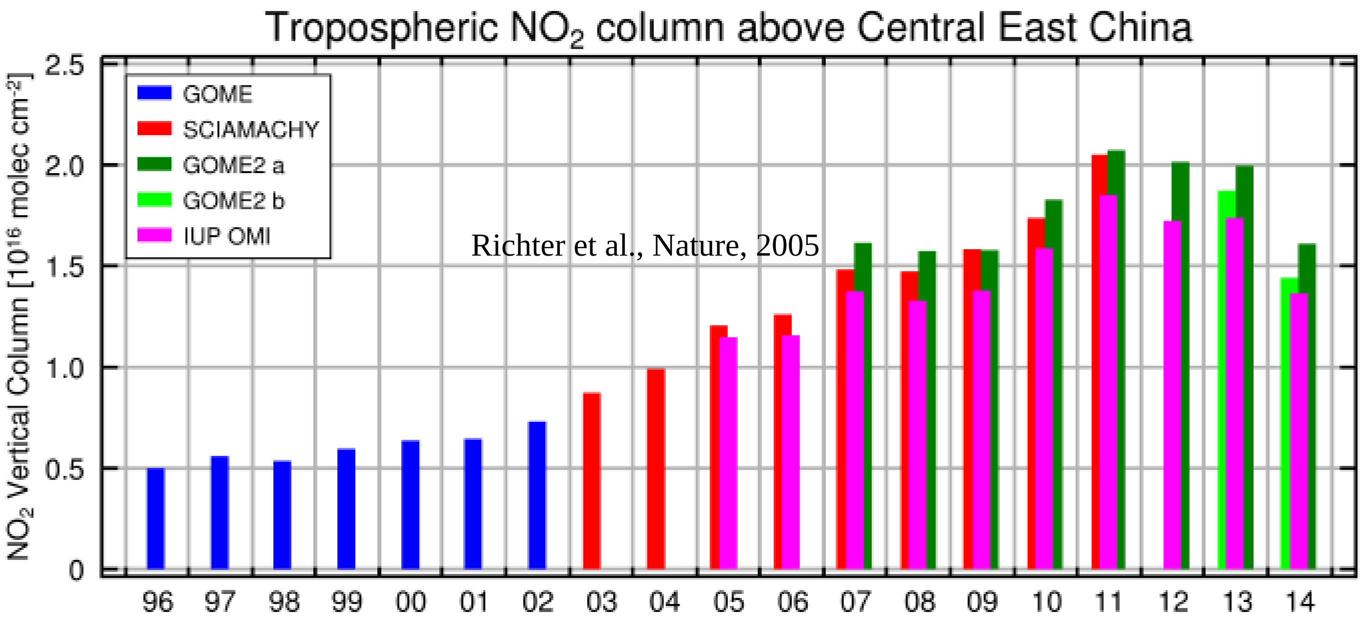


Figure 2: Tropospheric vertical columns of NO_2 retrieved from measurements of the GOME, SCIAMACHY, GOME2 A, GOME2 B and OMI instruments over East Central China (30°N - 40°N, 110°E - 123°E). All data are IUP retrievals using the same AMF and reference sector stratospheric correction and a cloud screening of 0.2.

Andreas Richter EGU 2015

Pollution – rest days - NO_2

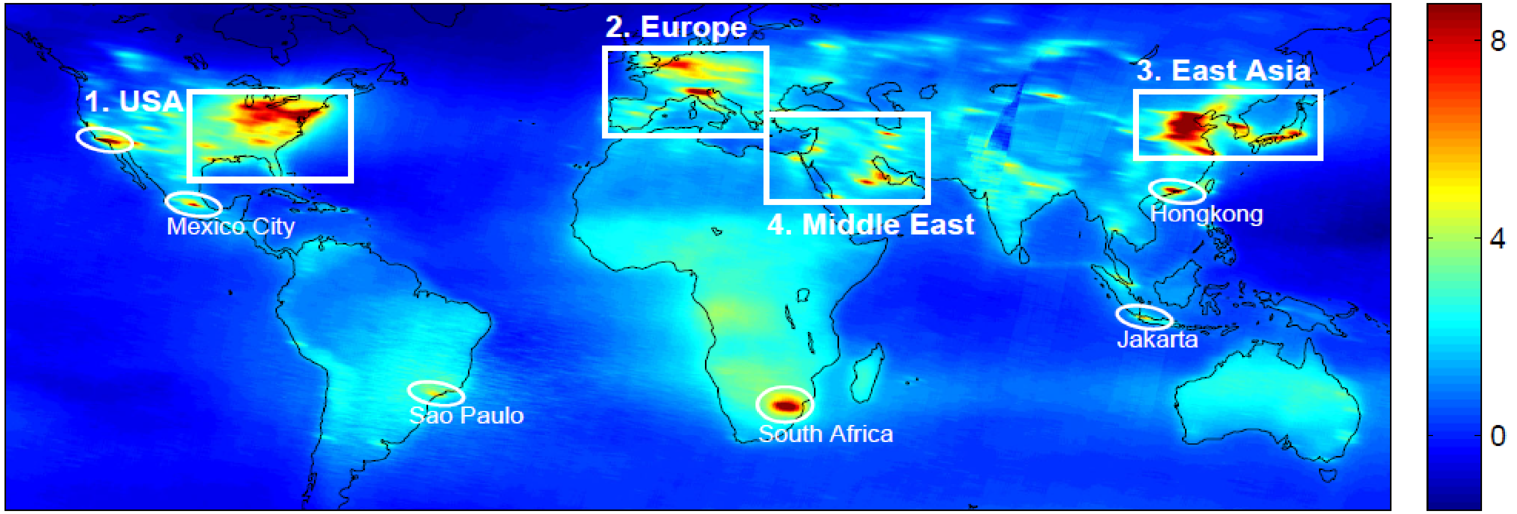
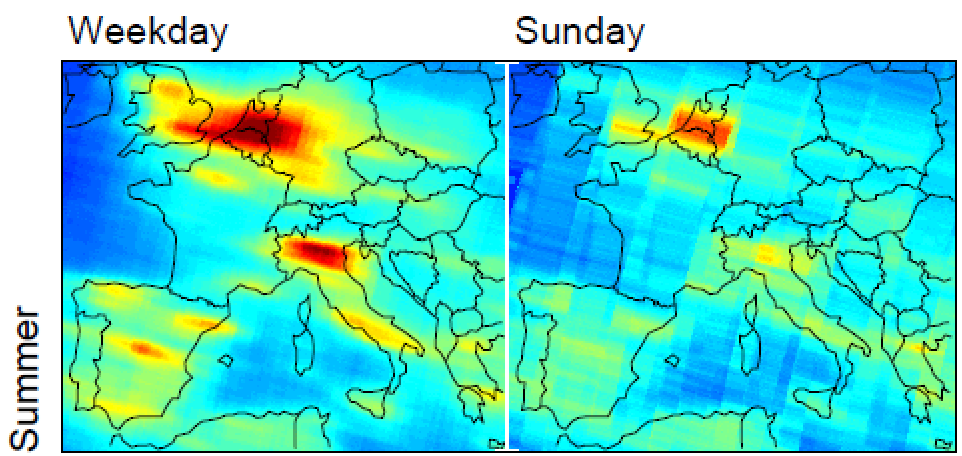
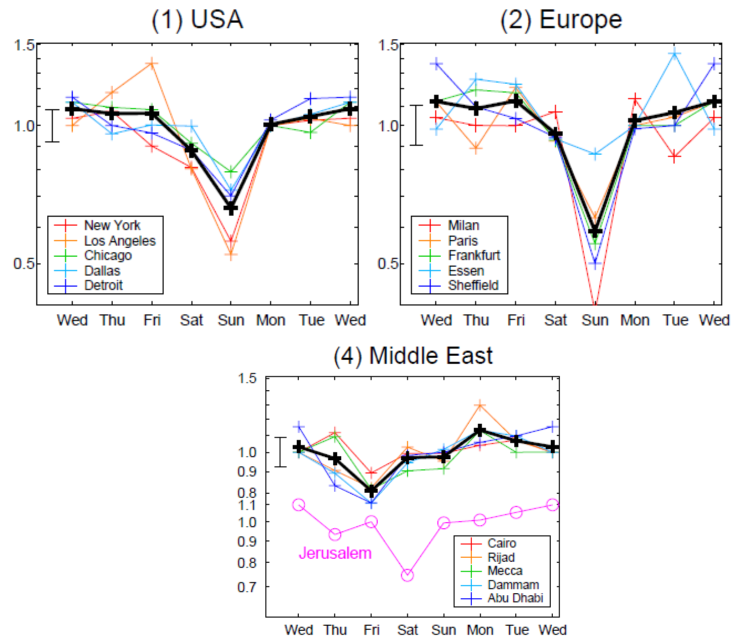


Fig. 1. Six years mean (1996–2001) of global tropospheric NO_2 Vertical Column Density in 10^{15} molecules/cm^2. The weekly cycle of the framed areas 1. US East Coast, 2. Europe, 3. East Asia and 4. Middle East, as well as 5. the marked individual Metropolises are considered in detail in this study.

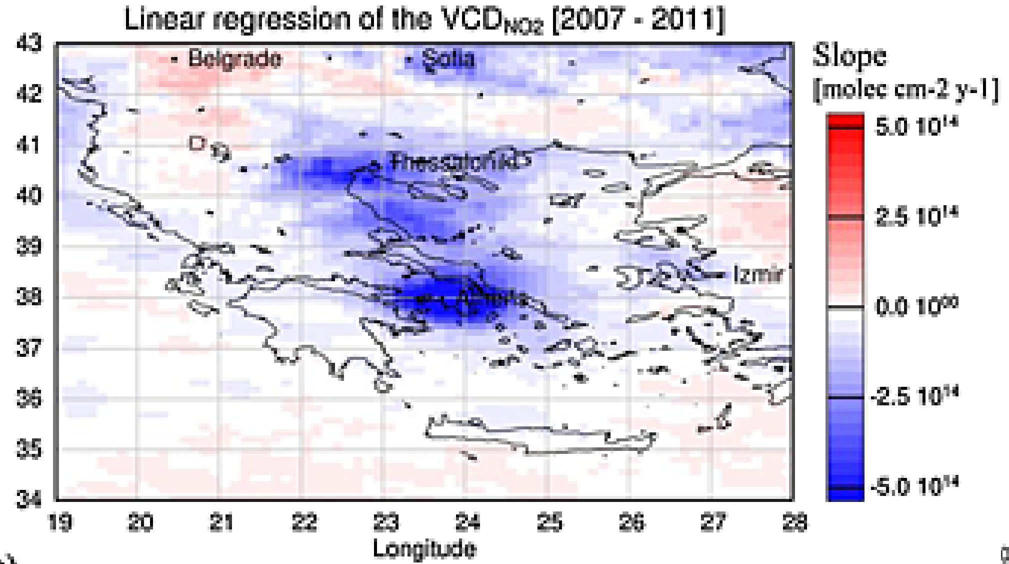




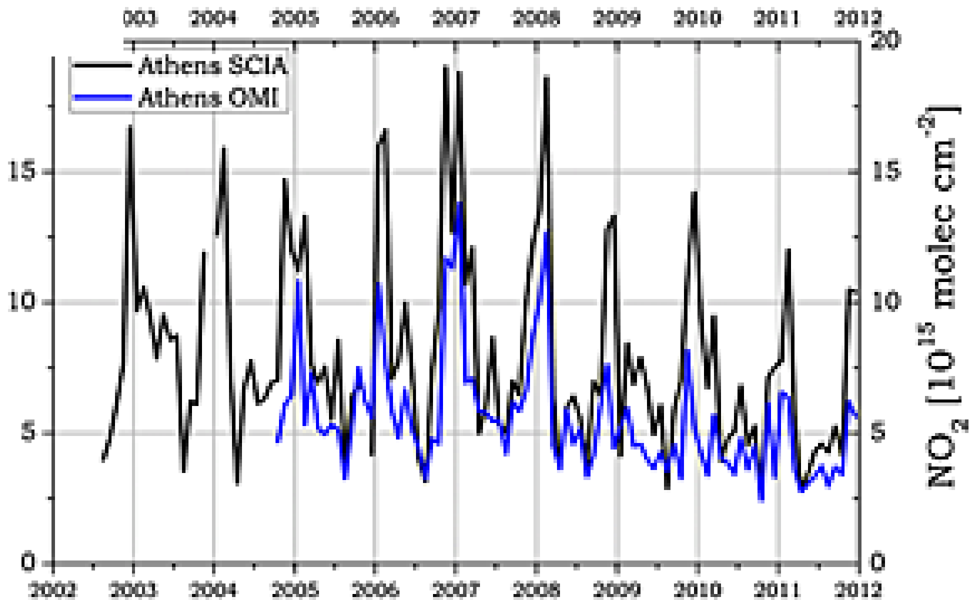
Beirle et al., ACP 2003

Pollution – Economic crise - NO_2

a)



b)

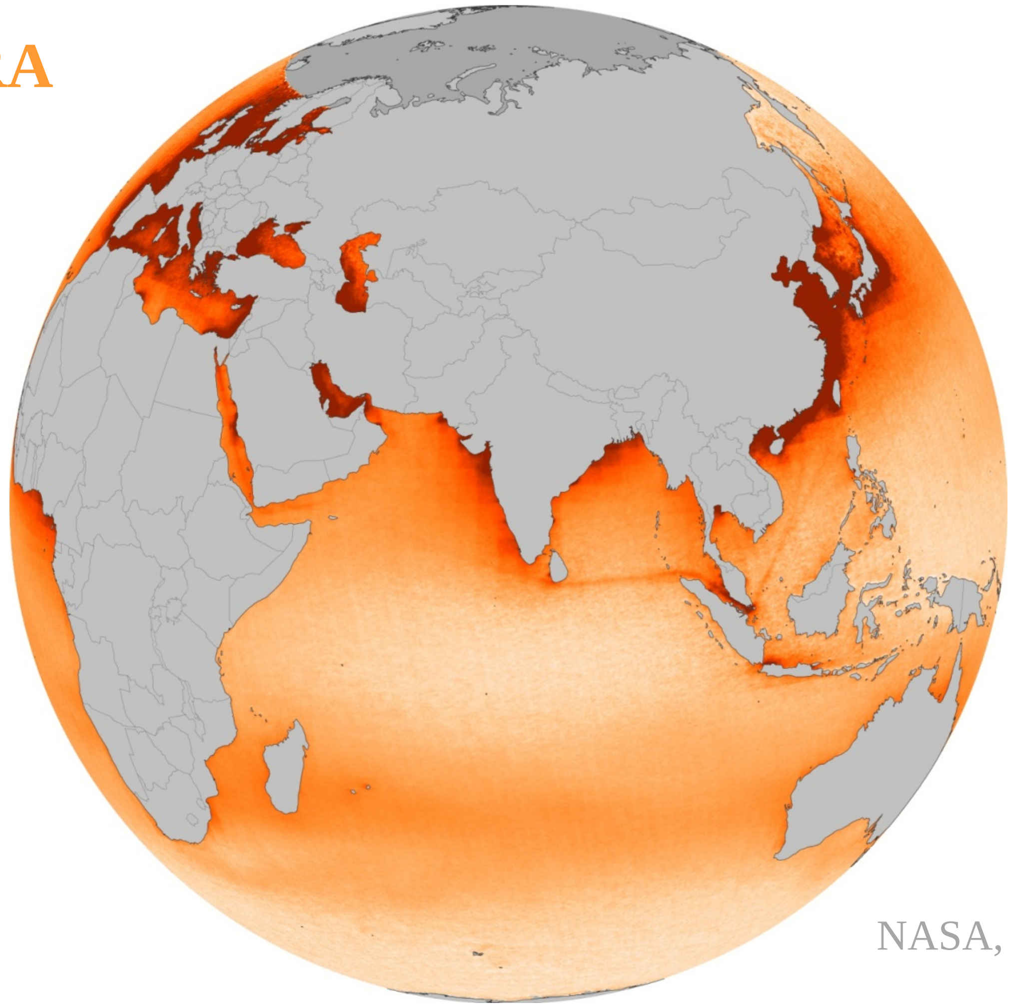


30-40% decrease since 2008

Vrekoussis, et al., GRL 2013.

Pollution – Boats - NO_2

OMI/AURA

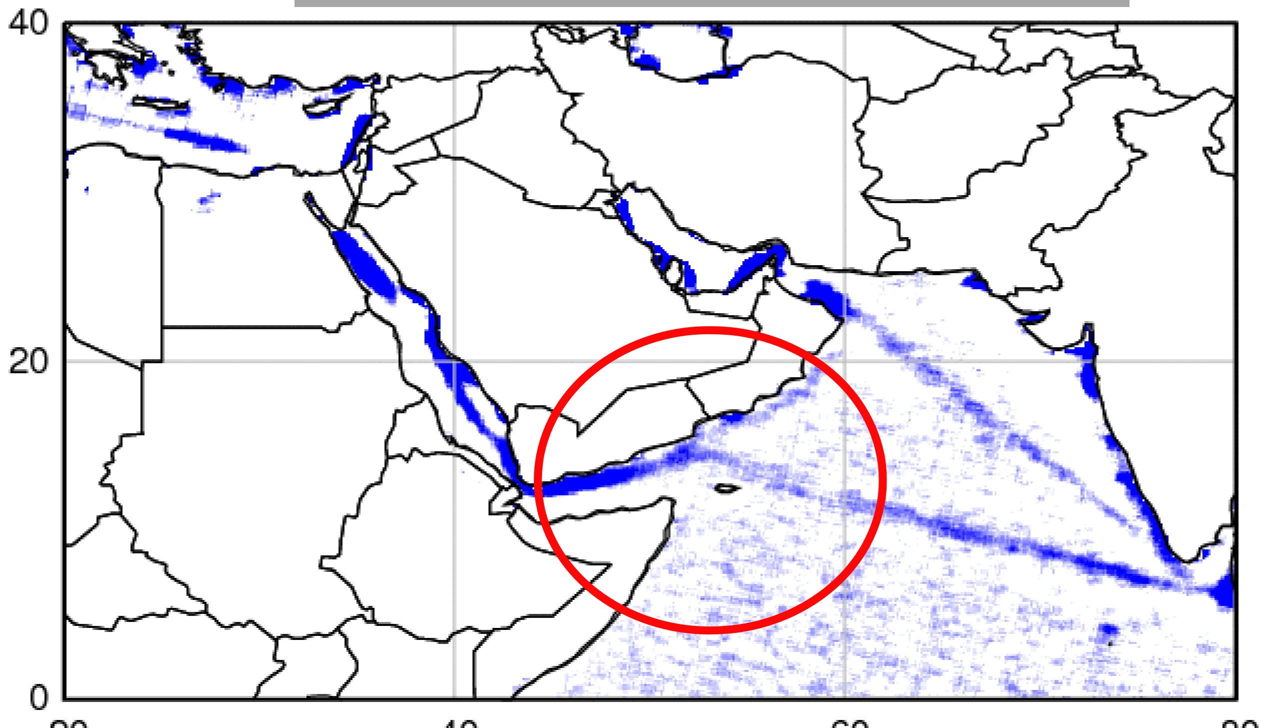


NASA, Earth Observer

Indian Ocean : Boats travelling from Sri Lanka to Singapour, Singapour to China; Red Sea, Mediterranean area

Pollution – Boats - NO_2

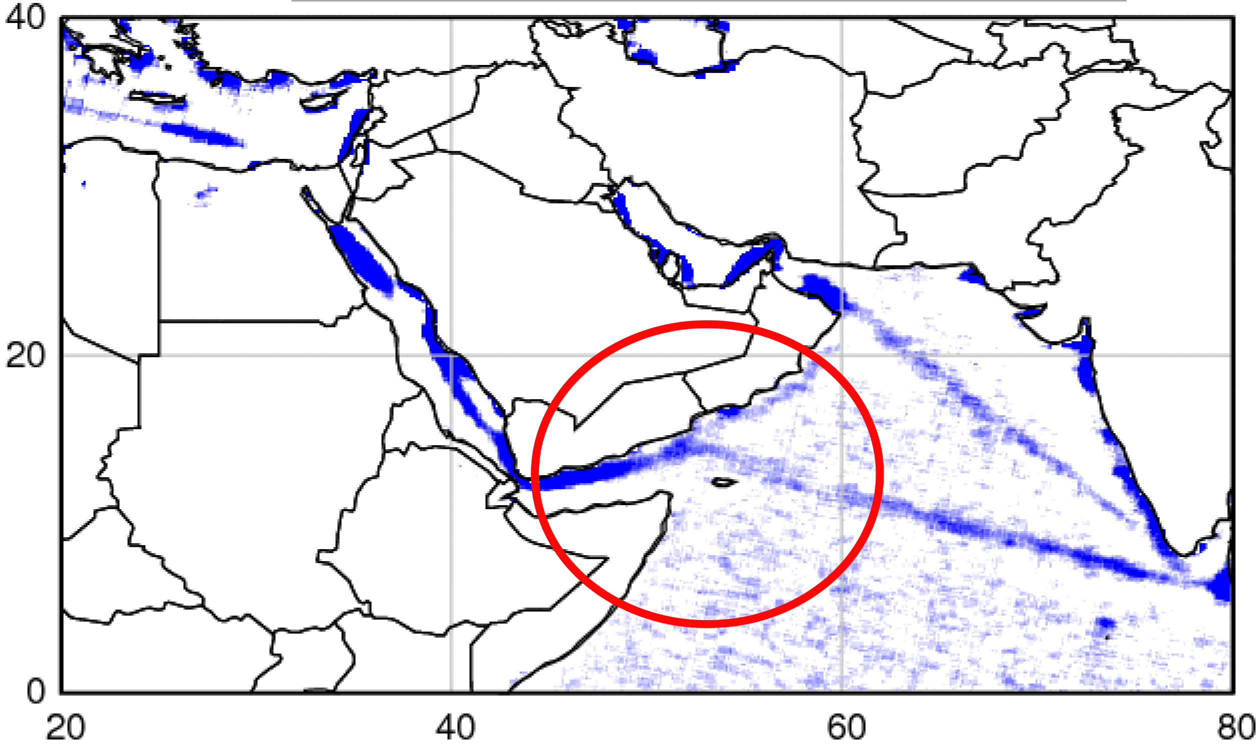
Période 2007-2009



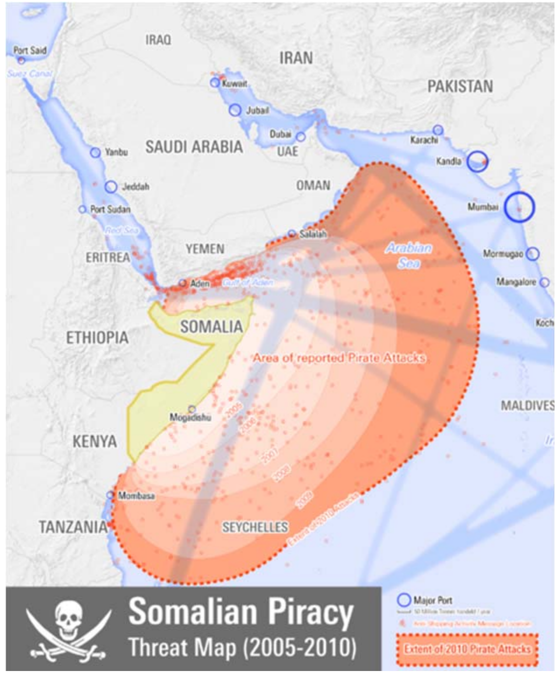
GOME2- Credit J. Burrows/A.Richter

Pollution – Boats - NO_2

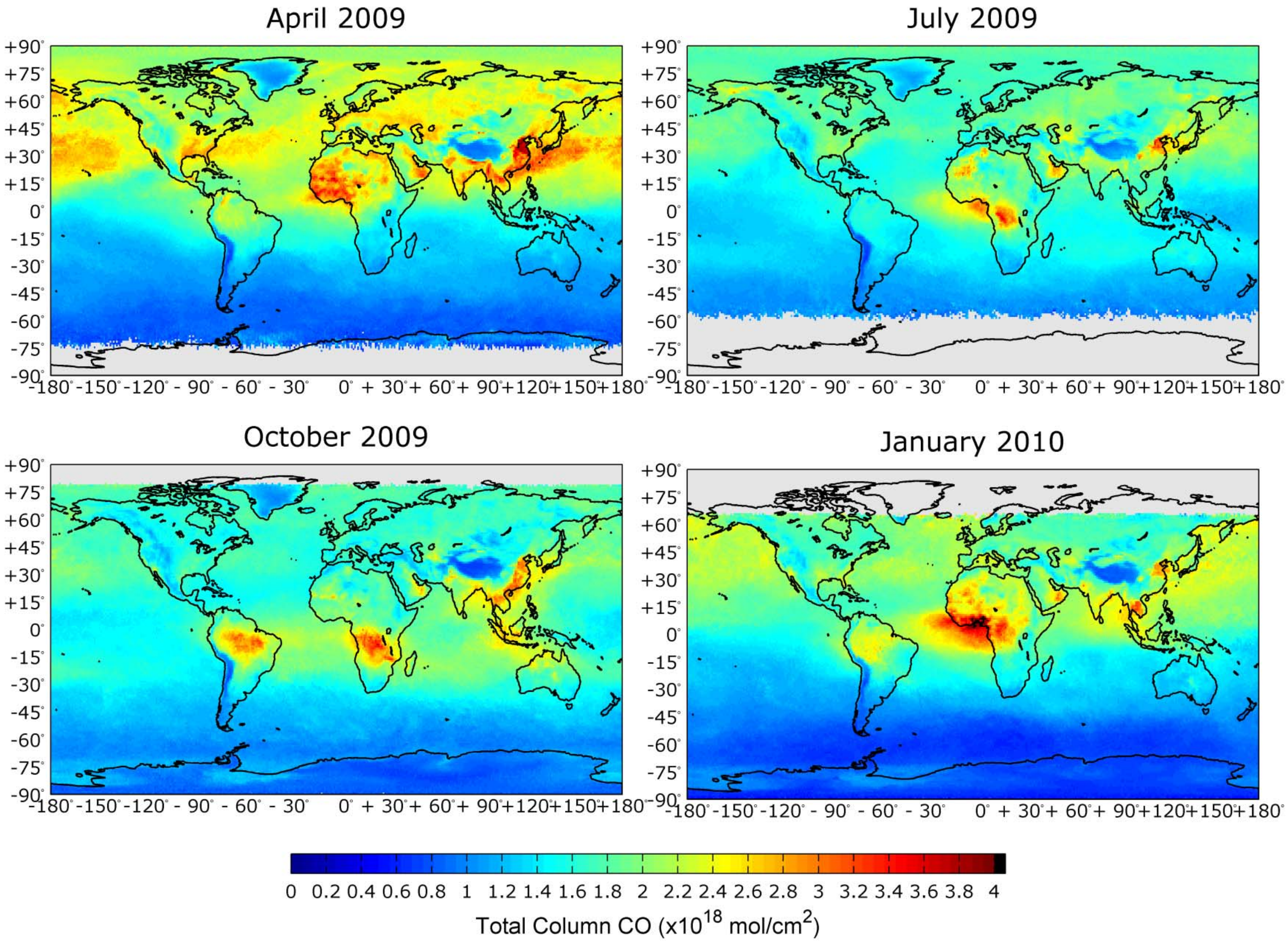
Période 2007-2009



GOME2- *Credit J. Burrows/A.Richter*

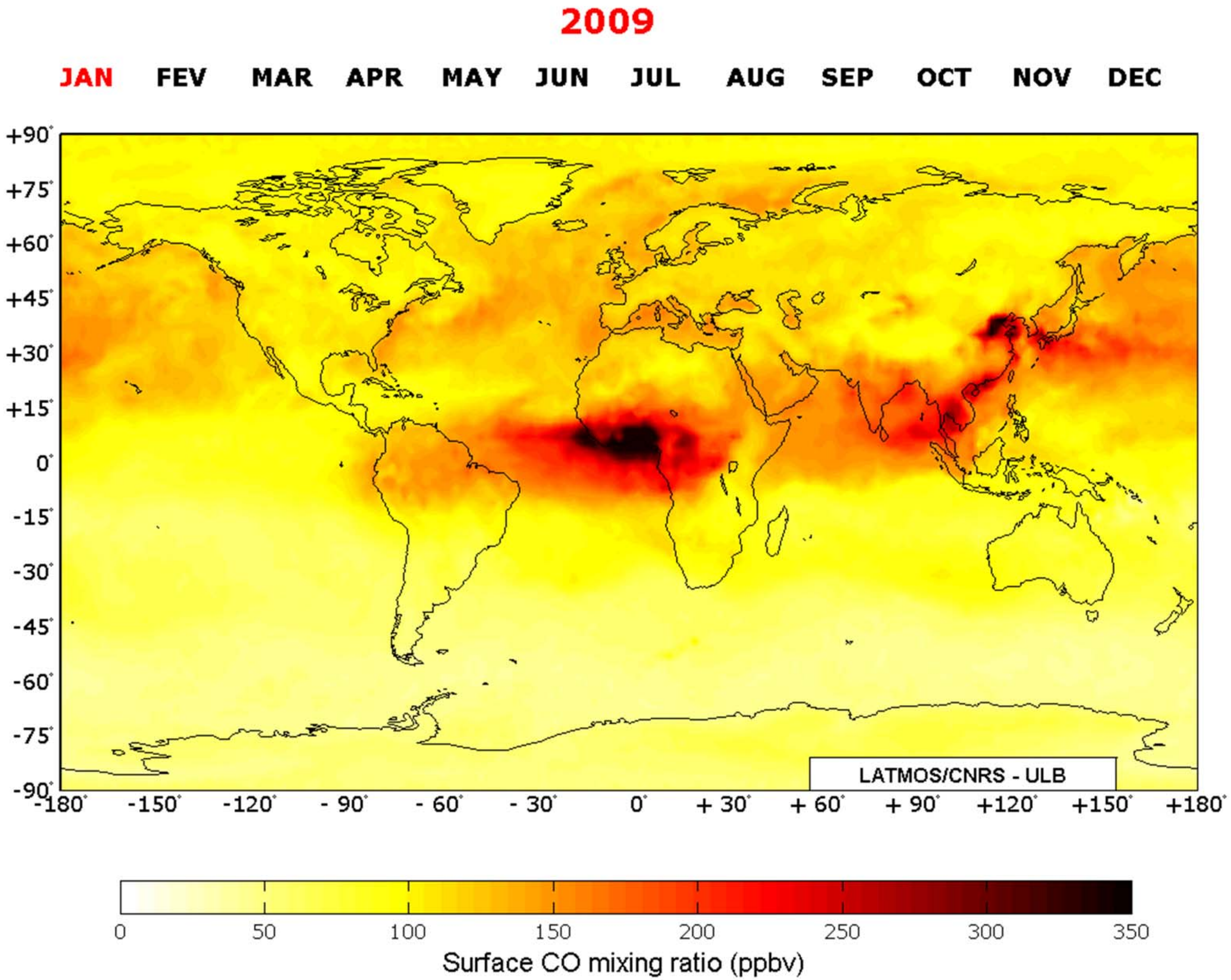


Carbon monoxide (CO) : seasonal distribution



Clerbaux et al., ACP 2009

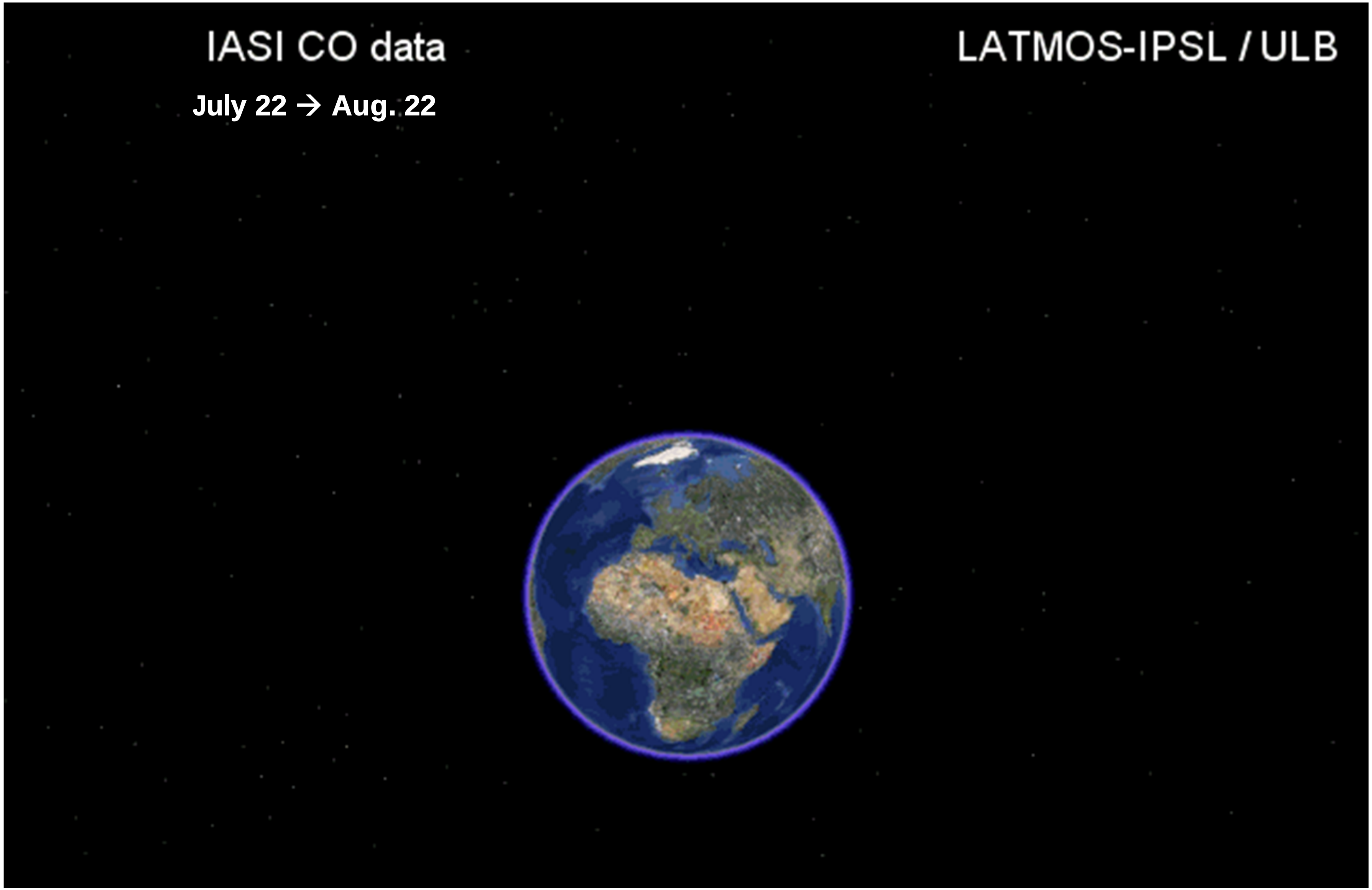
CO



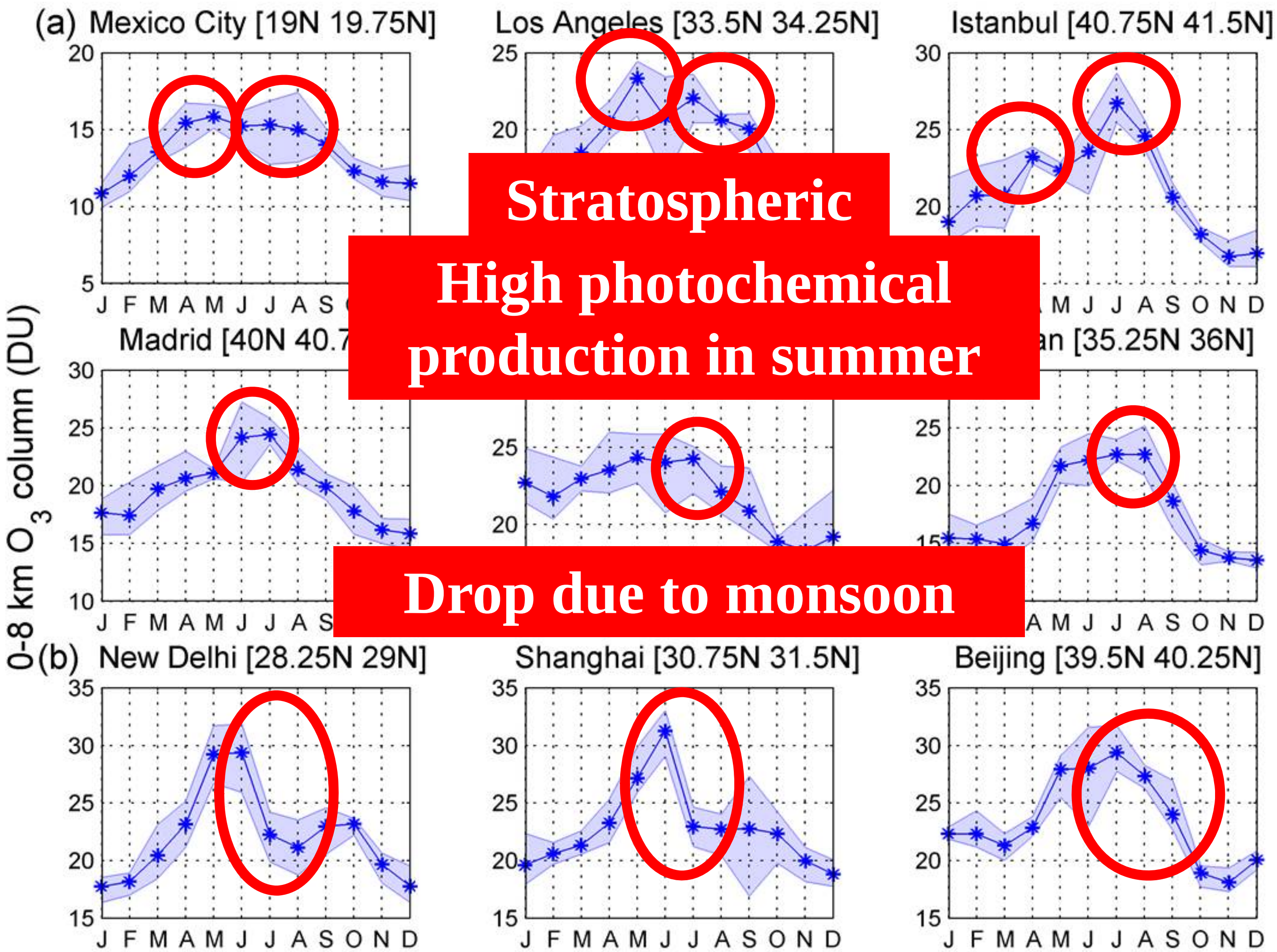
Courtesy M. George, LATMOS

Large fires: Moscou August 2010

Large fires: Moscou August 2010

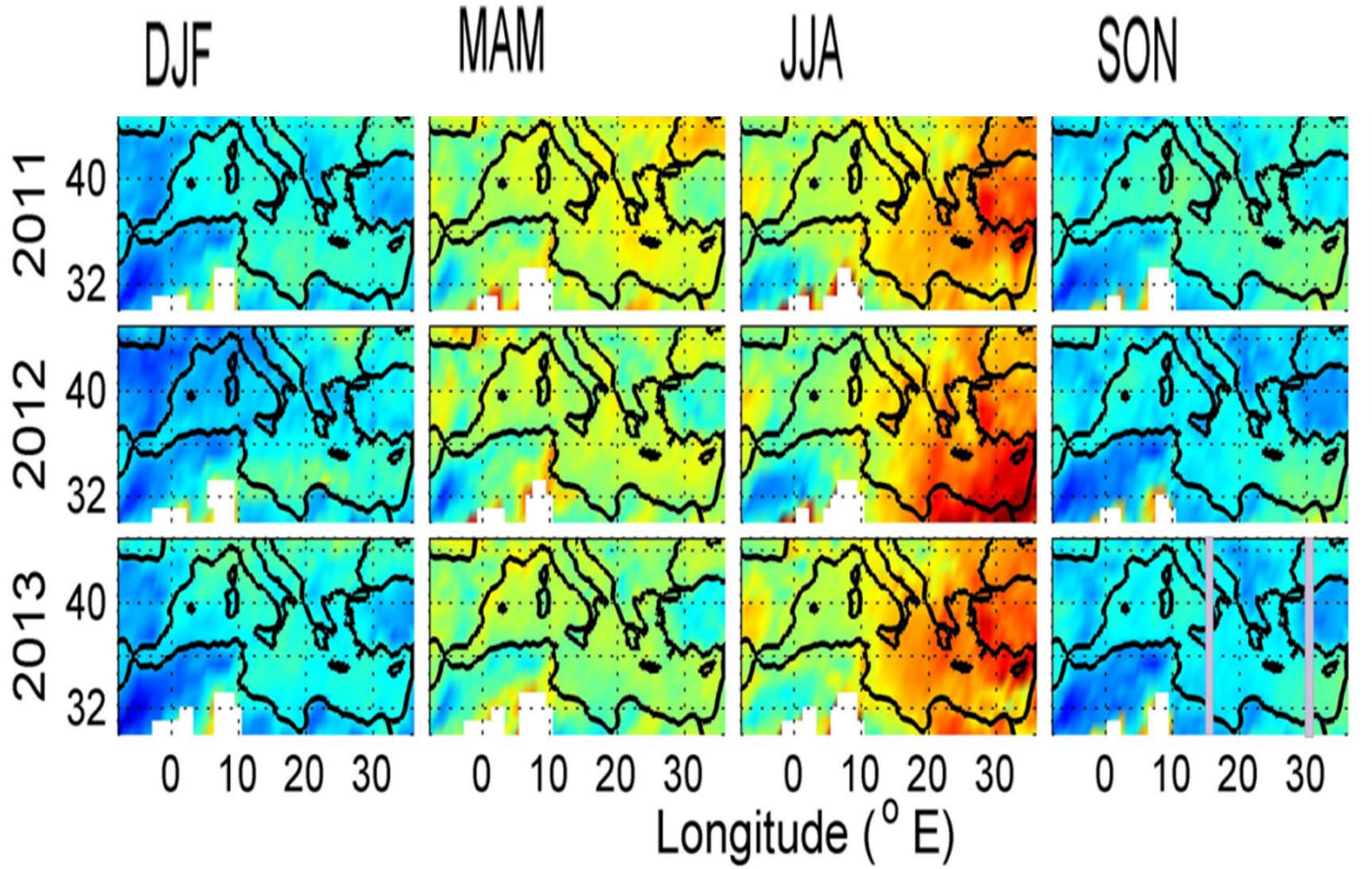


Ozone : seasonal variability over cities



Safieddine et al., JGR 2013

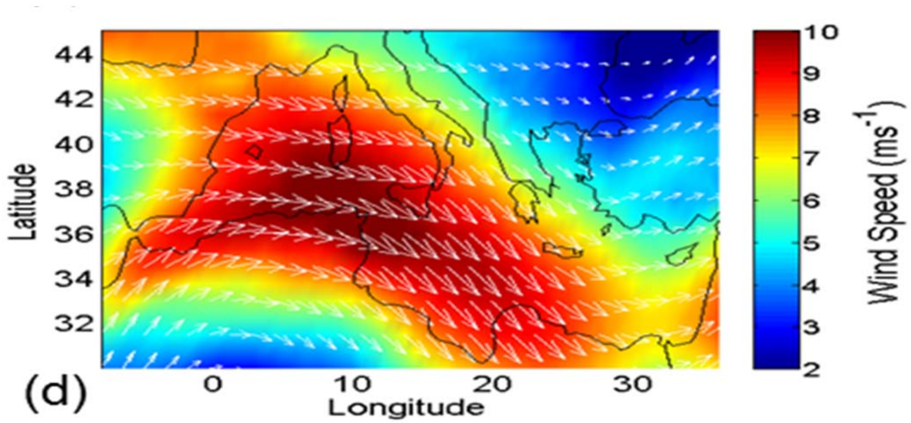
Ozone : seasonal variability over Mediterranean area

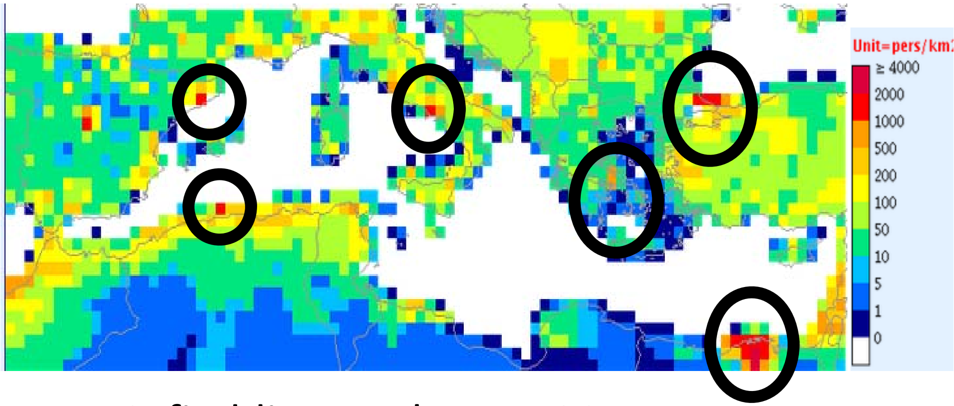


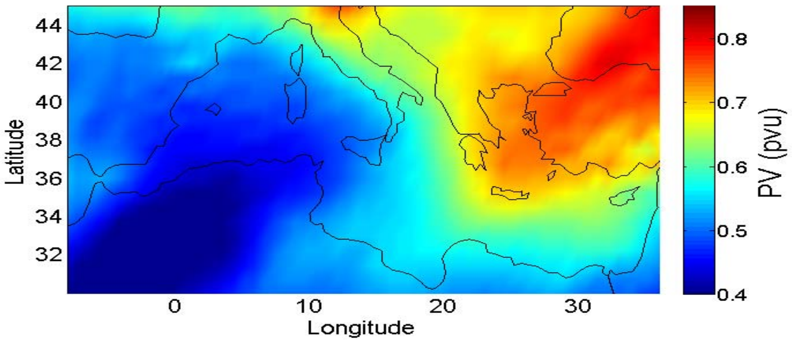
Safieddine et al., ACP, 2014

Ozone : seasonal variability over Mediterranean area

High and alerting tropospheric O_3 values are recorded in summer, especially to the east of the basin because of:







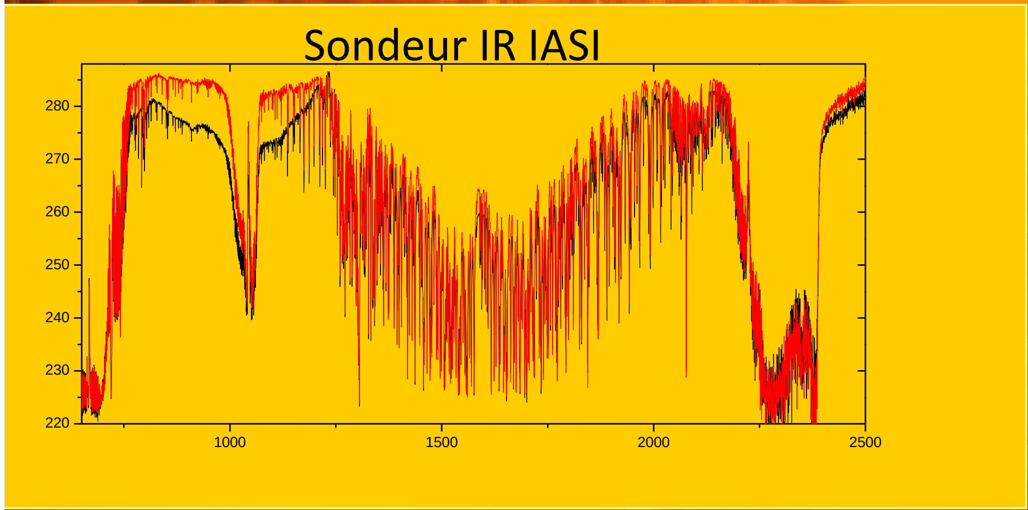
Safieddine et al., ACP, 2014

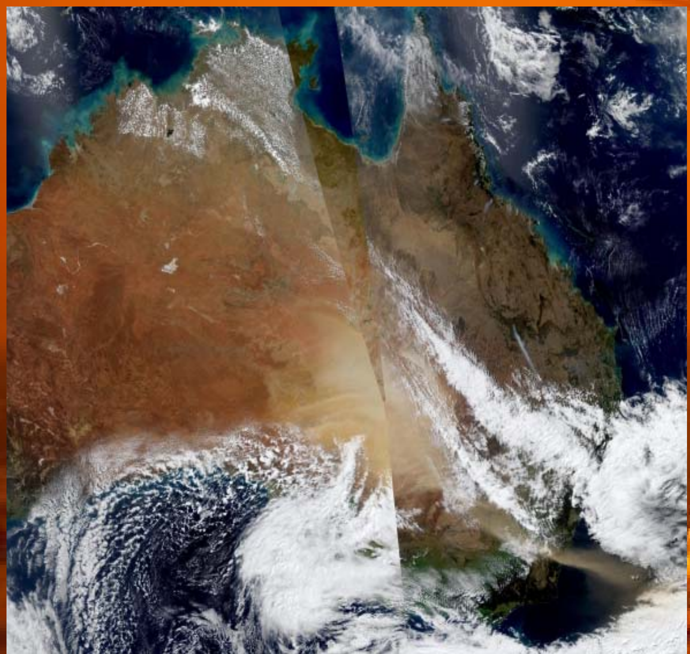
Coarse PM: eg dust, ash, …

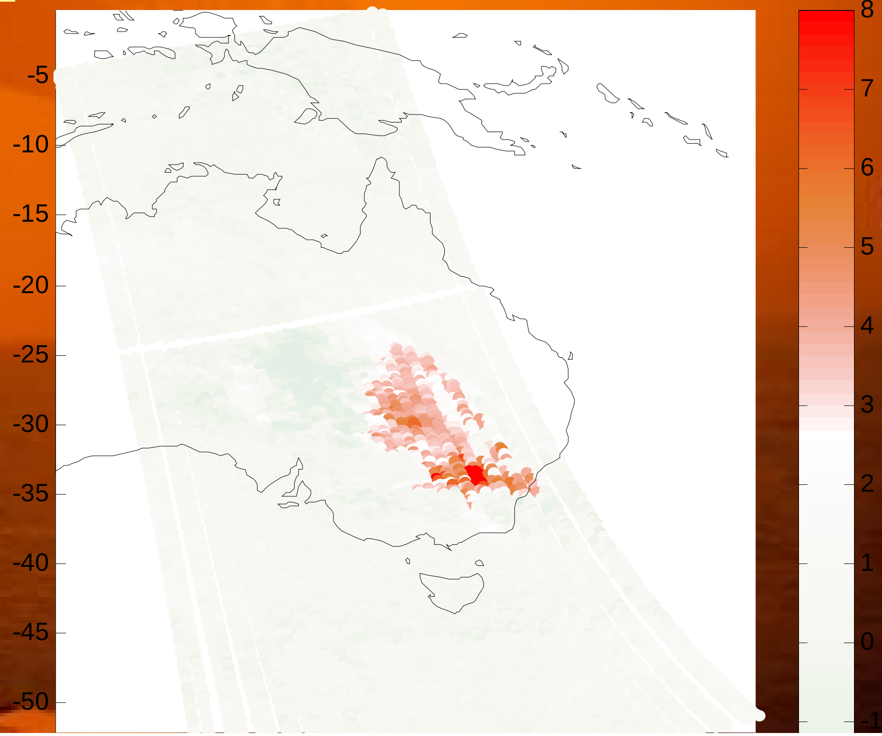
Sand storm

23 septembre over Sydney...

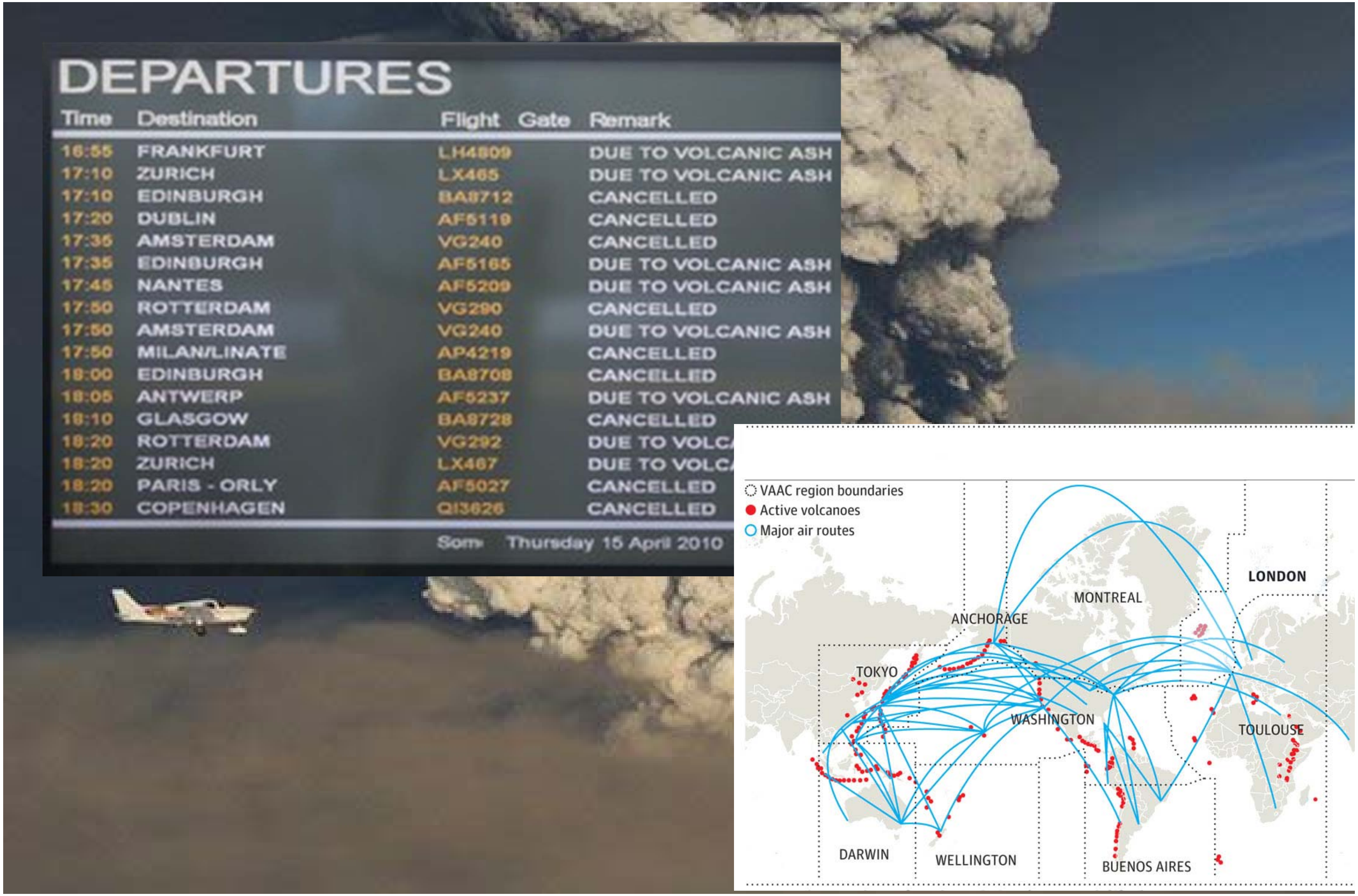
5 millions of tons/600 km



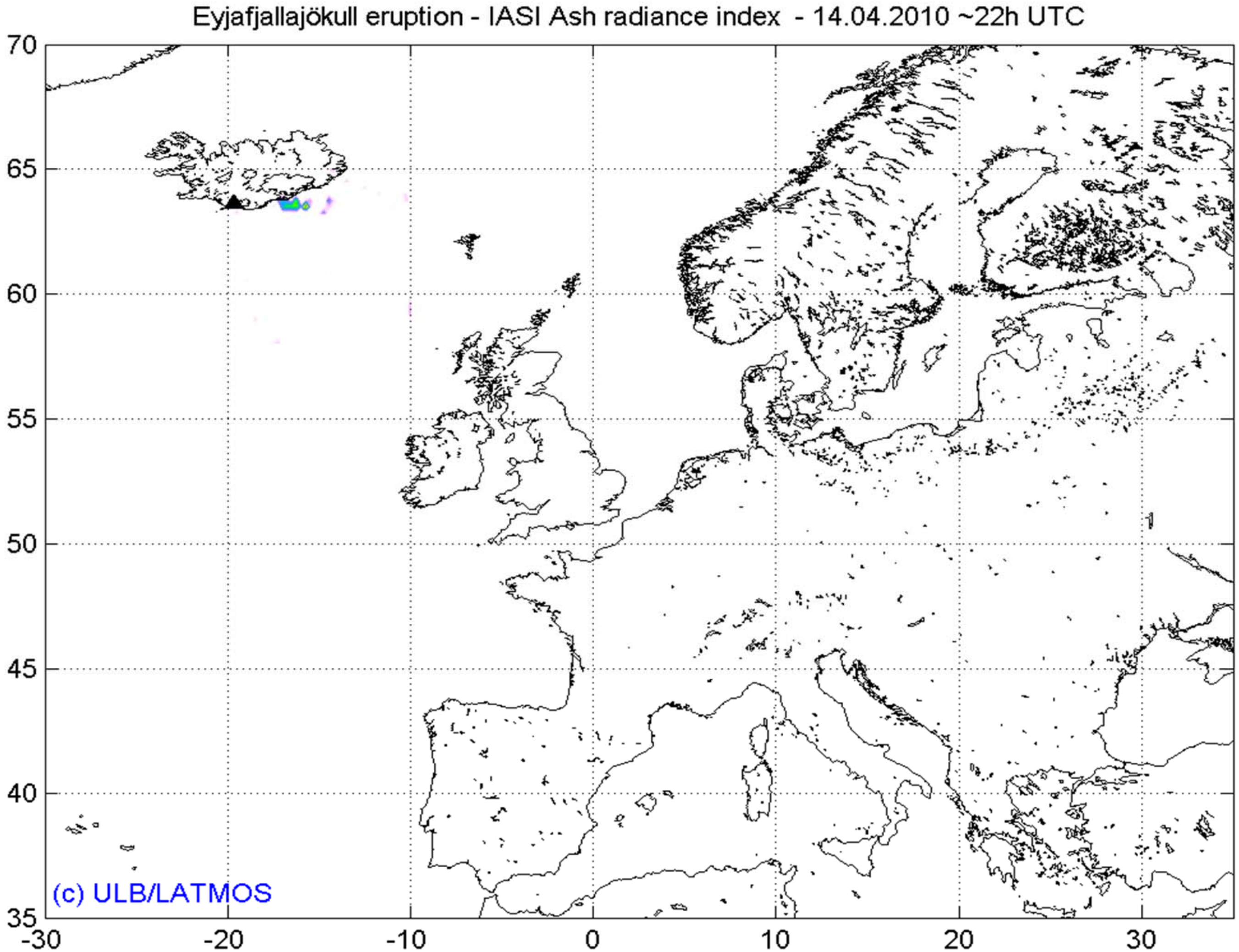




Volcanic eruptions

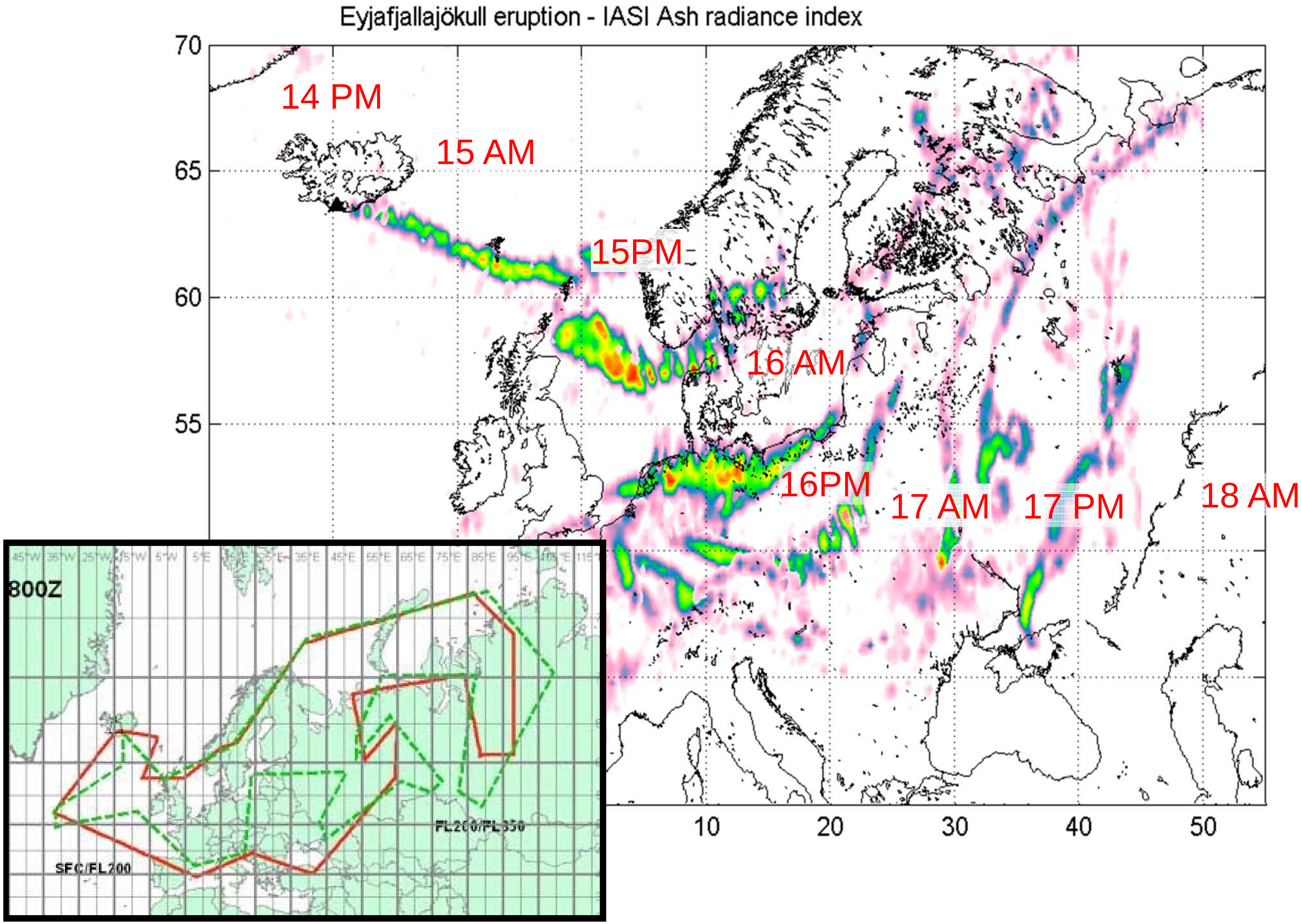


Volcanic eruptions

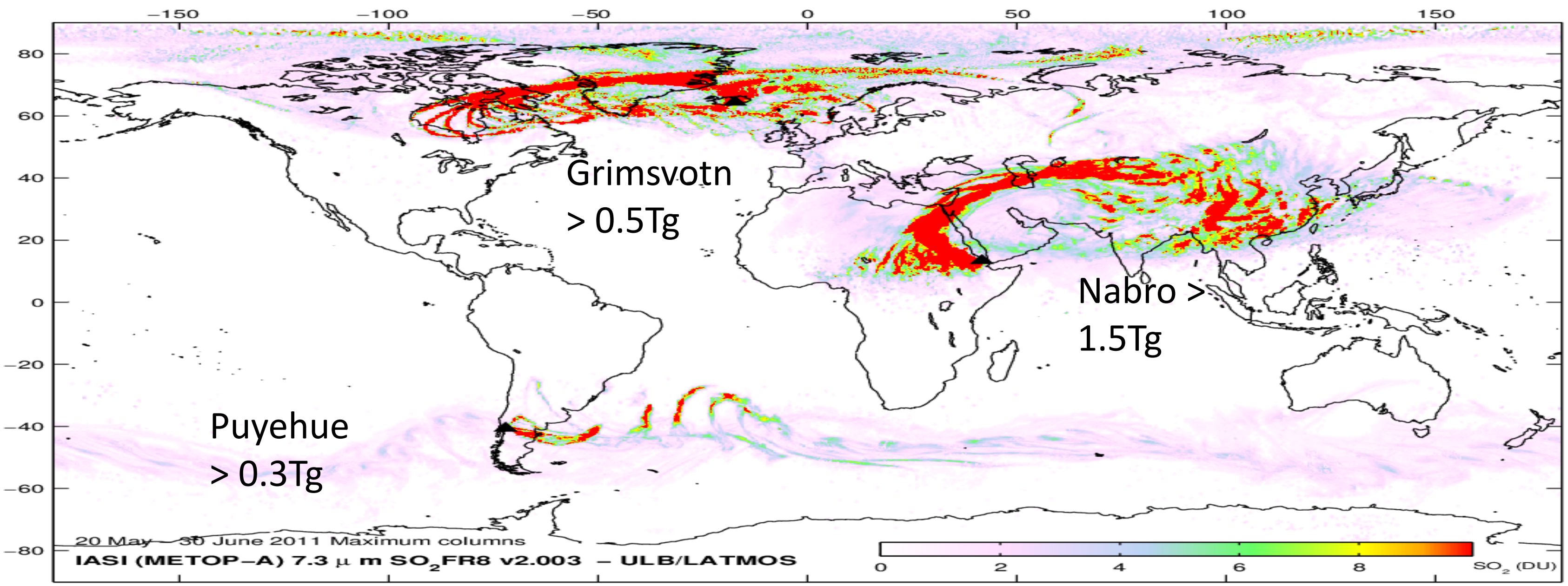


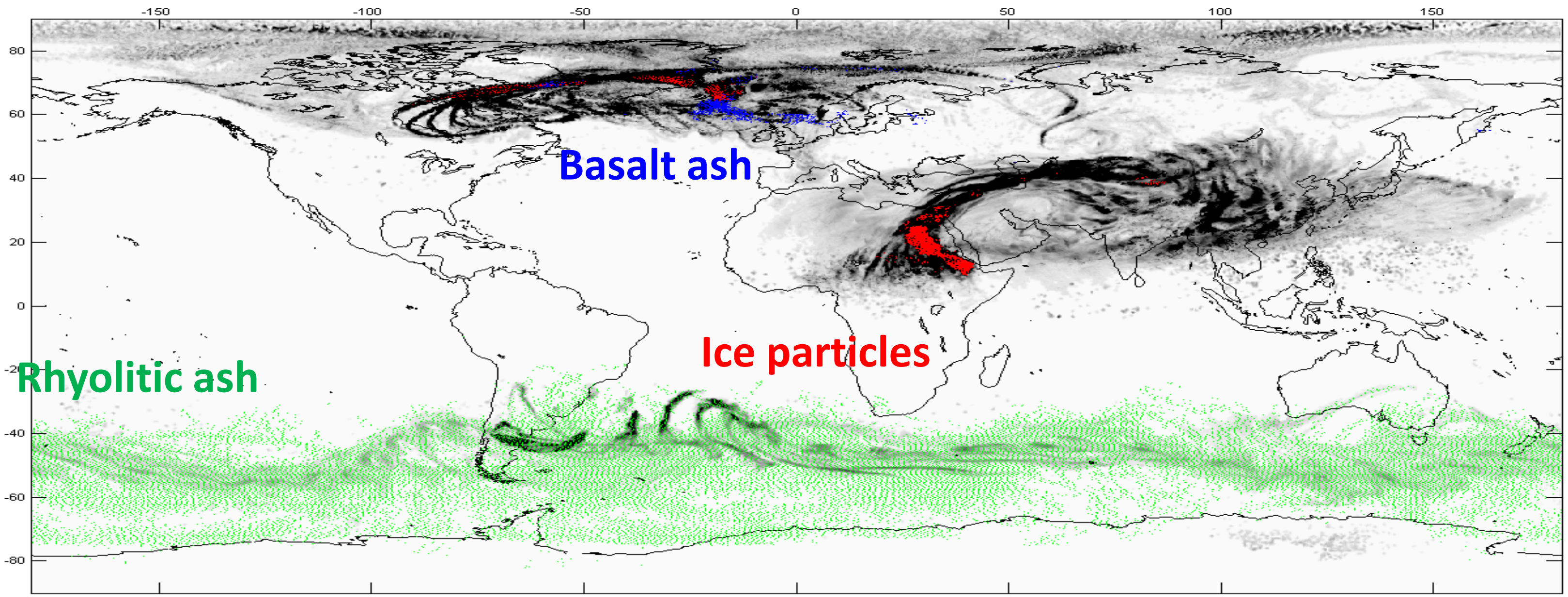
Credit L.Clarisse, ULB

Volcanic eruptions



Volcanic eruptions



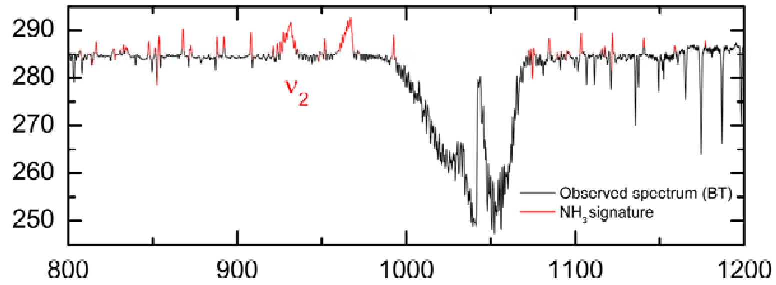


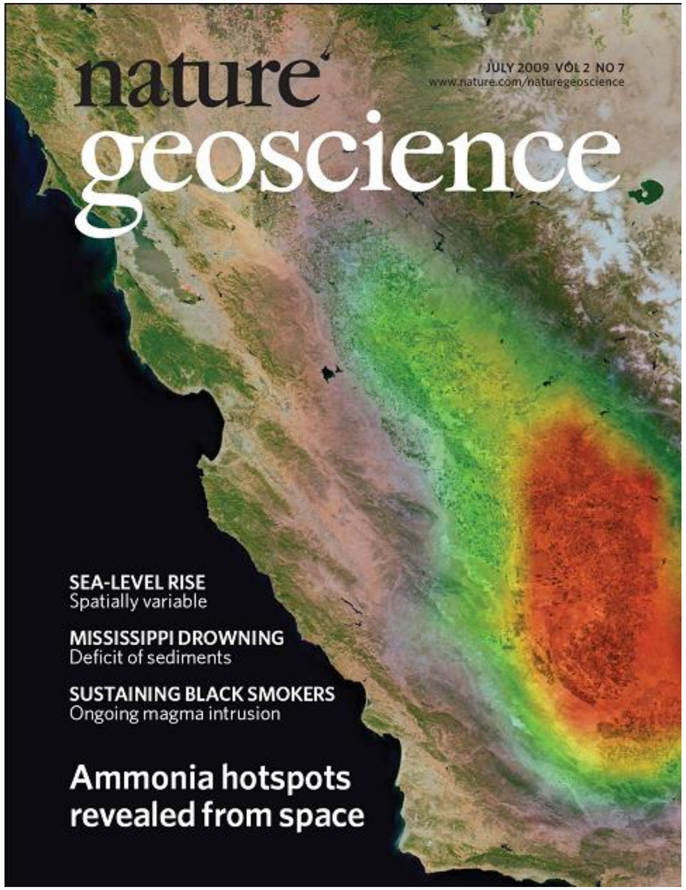
Credit L.Clarisse, ULB

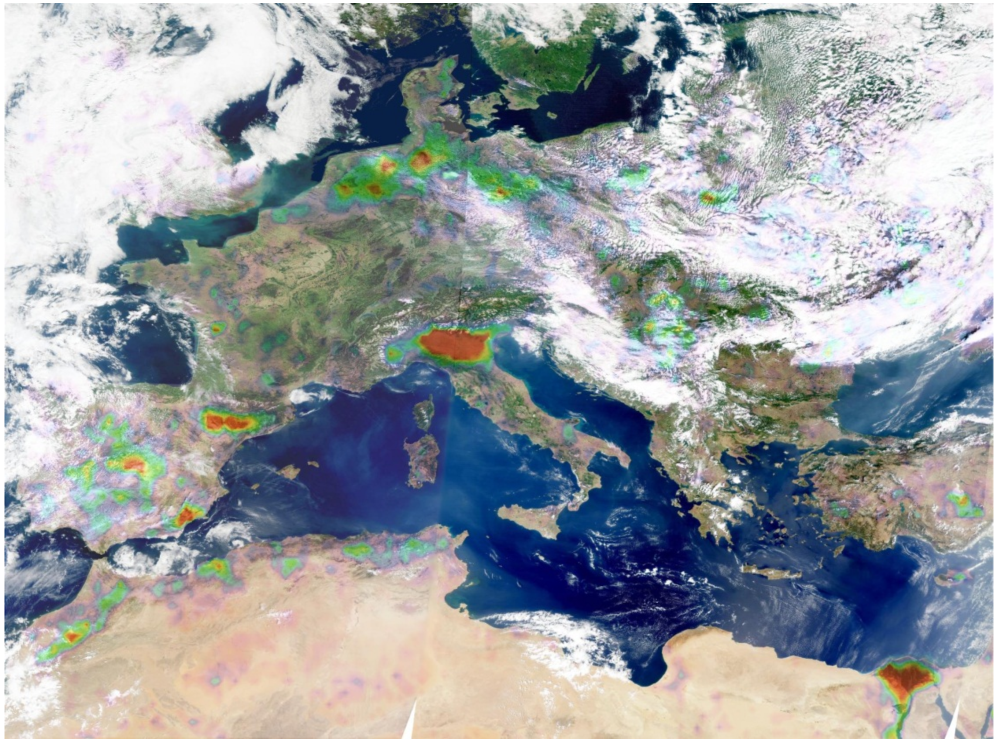
Ammonia

Ammonia

... dealing with a signal hardly detectable ...







Clarisse et al., Nature Geo 2009

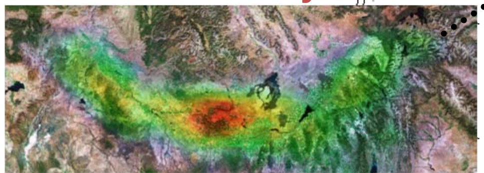
Ammonia 2008 average – IASI data

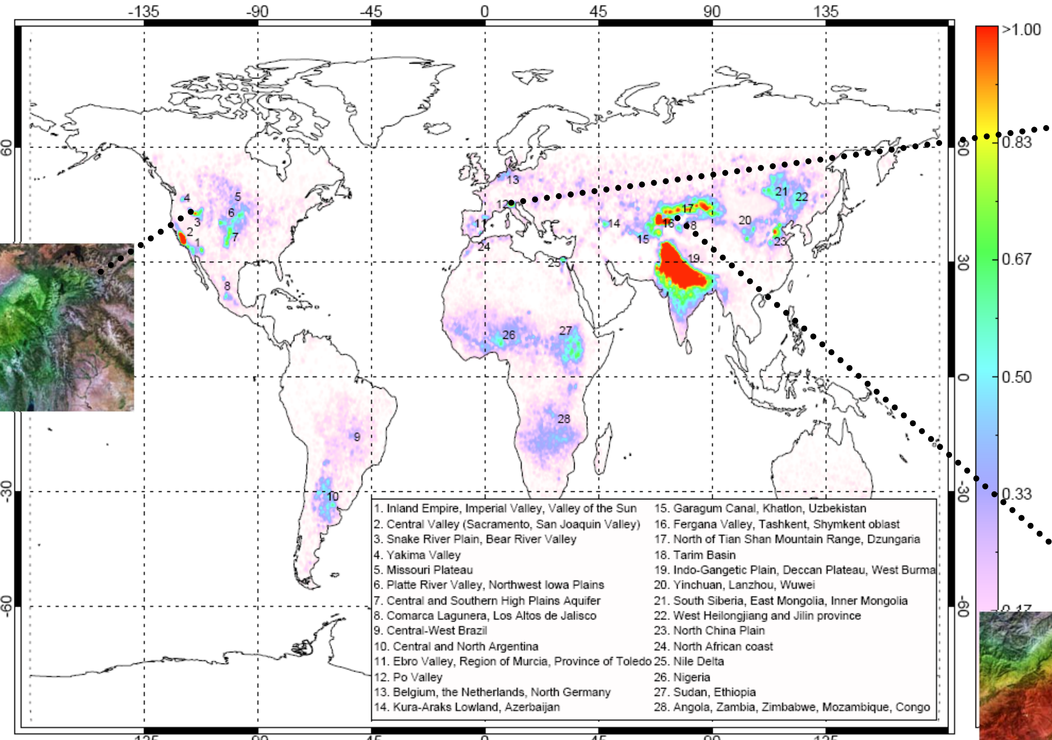
Ammonia

Mapping from local to global scale

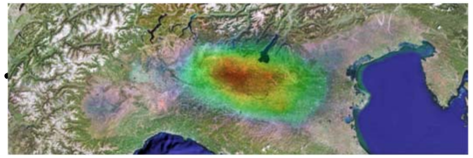
→ 28 emission hotspots identified

Snake river Valley

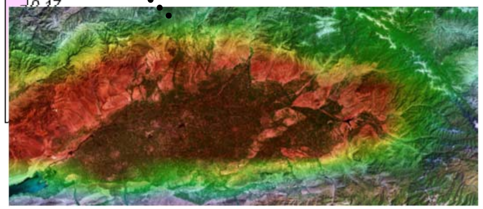




Po Valley



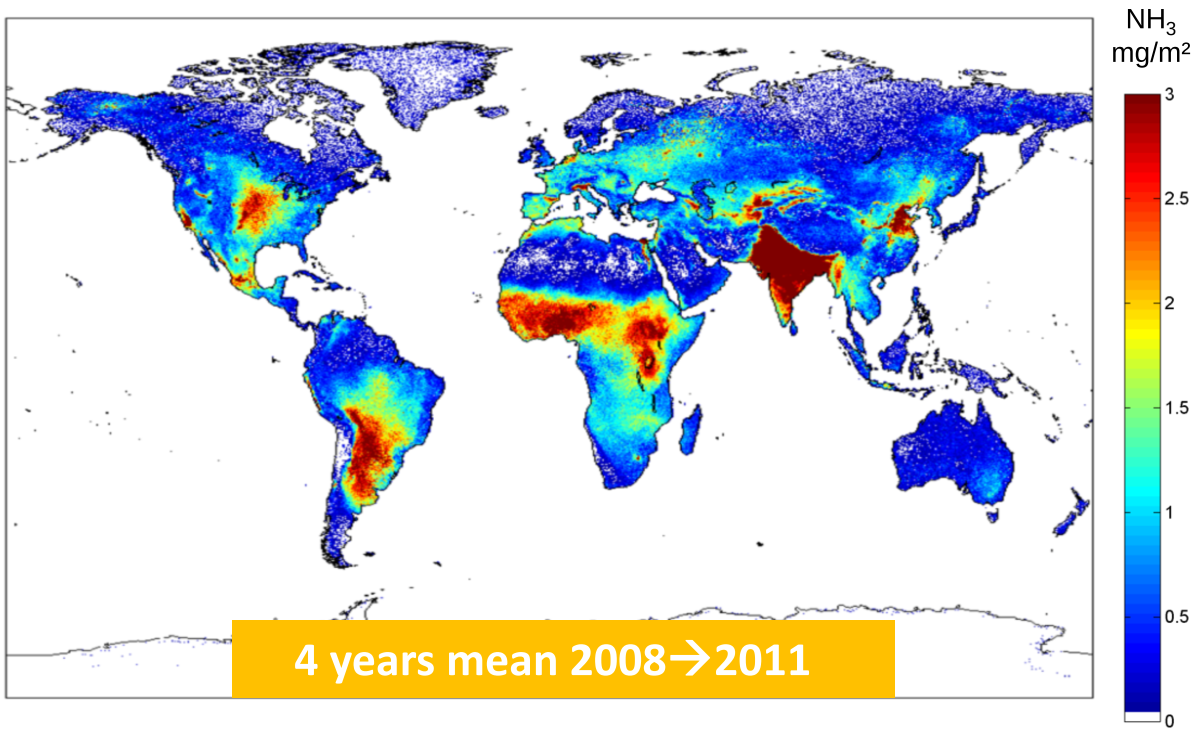
Fergana Valley



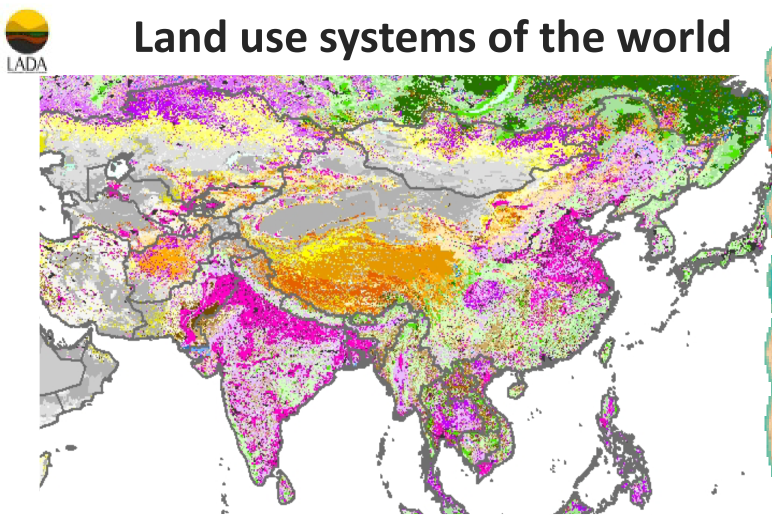
Clarisse et al., Nature Geo 2009

Ammonia
(NH_3)

Courtesy
Martin Van Damme (ULB)



Land use systems of the world



What can we see from space?


Sand over Sydney


Fires in Moscou


Ozone at the Pole


Eyjafjöll Volcano

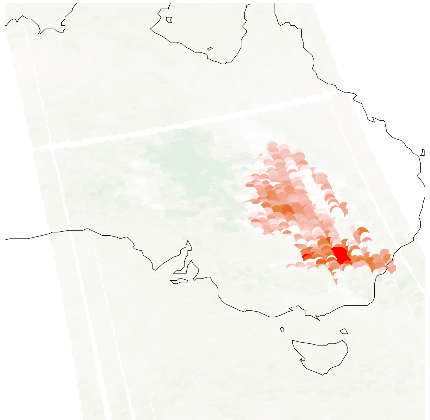

Ozone peaks


Economic crisis

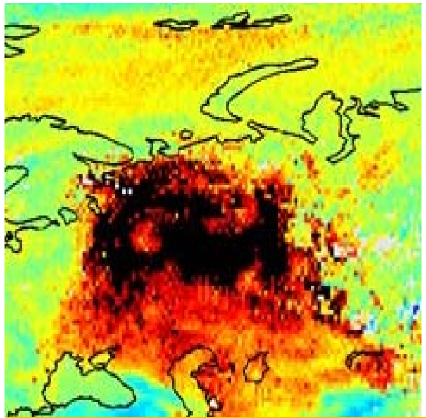

Silk Road


Strong pollution

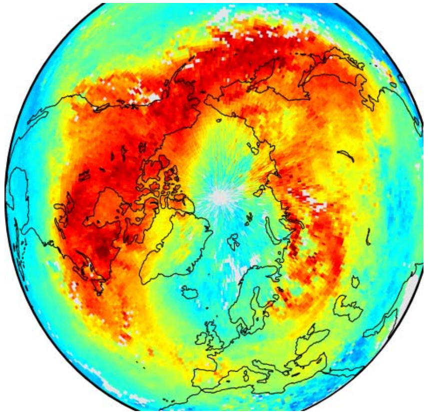
What can we see from space?



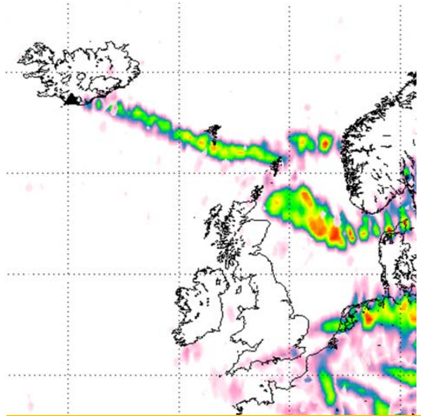
Sand over Sydney



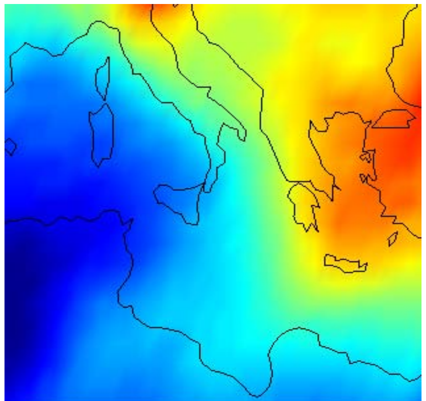
Fires in Moscou



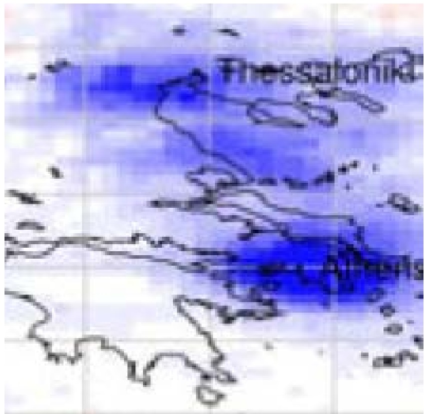
Ozone at the Pole



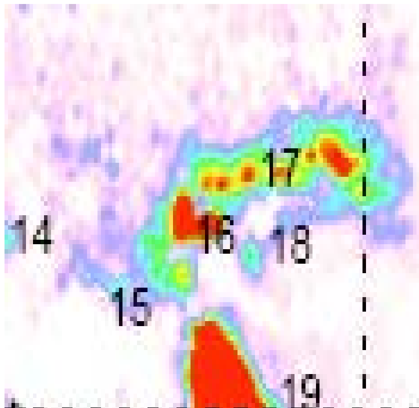
Eyjafjöll Volcano



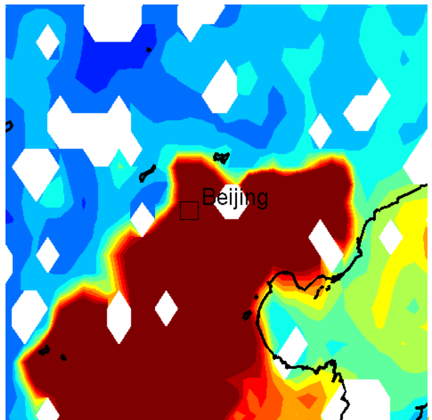
Ozone peaks



Economic crisis



Silk Road



Strong pollution

What can't we see from space?

Radioactivity (eg Fukushima) because detectors don't see gamma rays and atmosphere is not transparent to gamma-rays

Short scale phenomena because of the pixel size (horizontal) and/or sensitivity

Short live species because concentration are too low

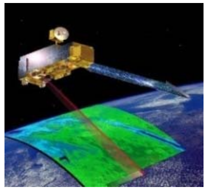
Highly resolved **vertical information**

Emission flux

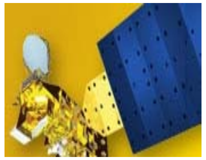
>> we need **ground-based** and **aircraft measurements**
>> we need **atmospheric models** to integrate the data (data assimilation, inversion sources)

Future nadir-looking satellite-borne missions

US/EOS



Terra 1999
Mopitt



Aqua 2002
AIRS

Aura 2004
TES/OMI

EU/EPS

Metop-A 2006
MetOp-B 2012
Metop-C 2018

IASI
GOME-2

GOSAT

US/NPP Suomi

CrIS
OMPS

OCO-2

EU/Sentinel 4 precursor
TROPOMI

Merlin, Earthcare

EU/EPS-SG-sentinel 5

Metop-SG-A1	***IASI-NG***
Metop-SG-A2	*UVS*
Metop-SG-A	***3MI***

+ Geo orbit :
US TEMPO
EU/MTG-sentinel 4 : IRS, UVN
Asia: GEMS

+ Calipso on the A-train

Data availability and download:

Total O3, NO_2, formaldehyde

http://o3msaf.fmi.fi/ **GOME2**

http://www.temis.nl **GOME2, OMI**

CO

https://eosweb.larc.nasa.gov/project/mopitt/mopitt_table **MOPITT**

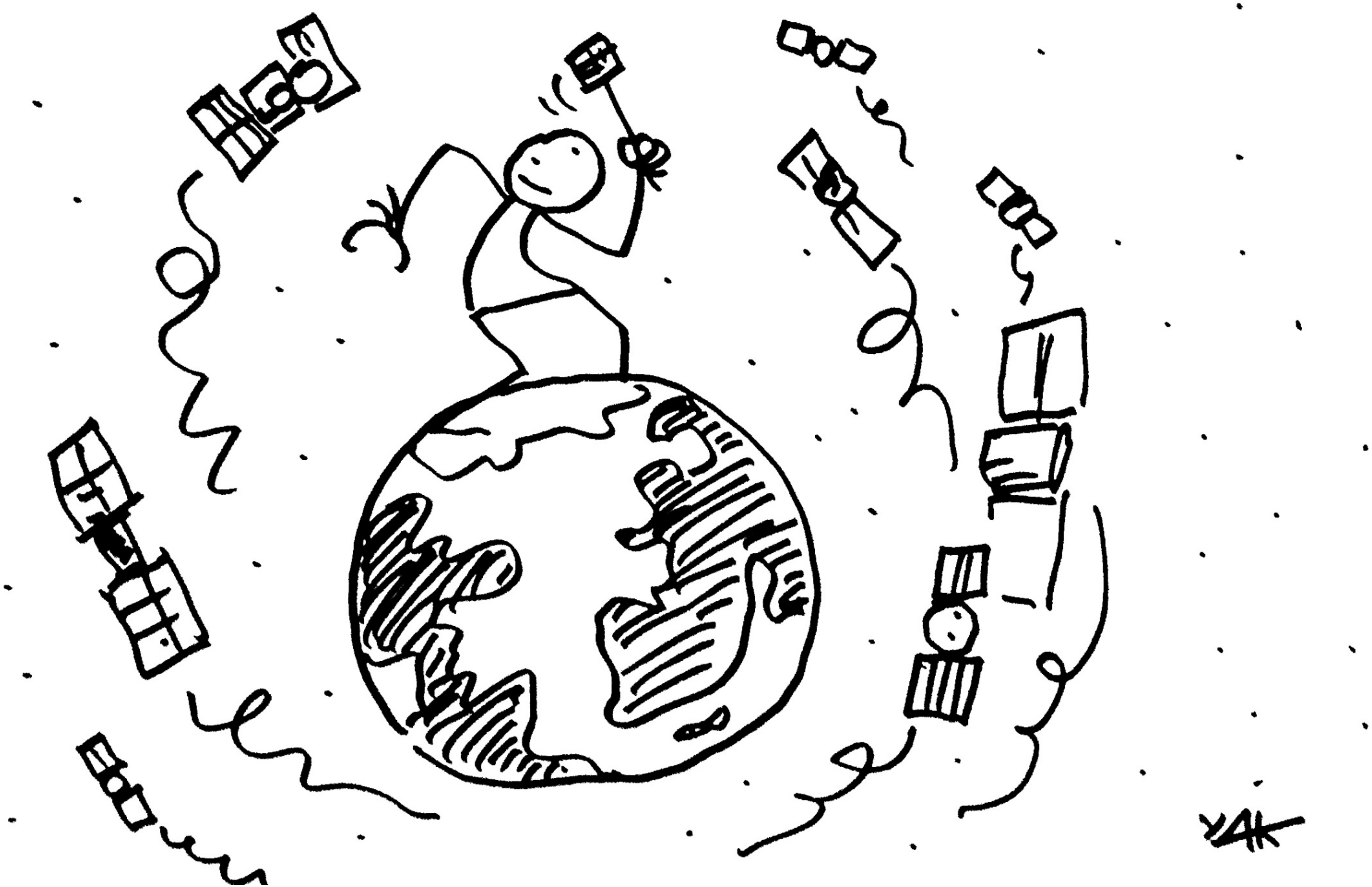
http://www.pole-ether.fr/ **IASI**

NH_3 upon request to me

Interesting websites to look at:

SO2 volcano alerts for aviation: http://sacs.aeronomie.be/

MACC forecasts: https://www.gmes-atmosphere.eu/services/raq/raq_nrt/


YAK