IAGOS
Monitoring atmospheric composition and air quality using commercial aircraft for 25 years … and more to come

Bruno Piguet, Philippe Dandin

and the IAGOS team

JÜLICH Forschungszentrum · cnrs · KIT Karlsruhe Institute of Technology · DLR · METEO FRANCE · MANCHESTER 1824 · TROPOS

Outline

www.iagos.org

Motivation and delivered service
Description of operation
Links between IAGOS and operational programs

Why use commercial aircraft?

www.iagos.org

Physically and Dynamically Active Region

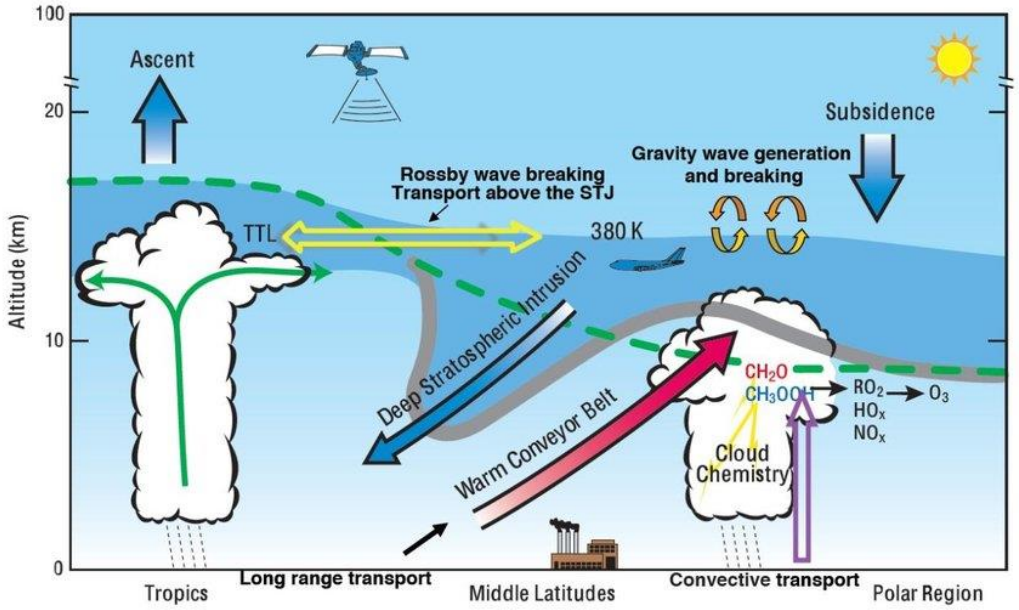
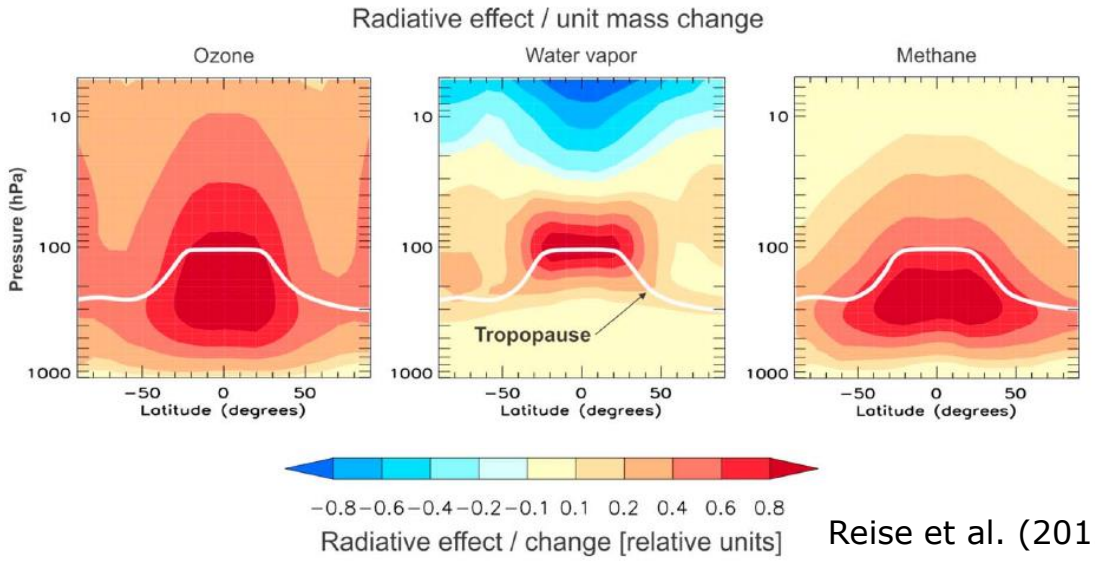


Image UCAR

Climate Sensitive Region



Reise et al. (2012)

- Satellites low vertical resolution
- Gradients around tropopause difficult to capture
- Sensitive to small changes in atmospheric composition
- Research aircraft campaigns – targeted but not global or continuous for monitoring
- Commercial aircraft 90% of flight in UTLS

The meeting point of constraints and opportunities

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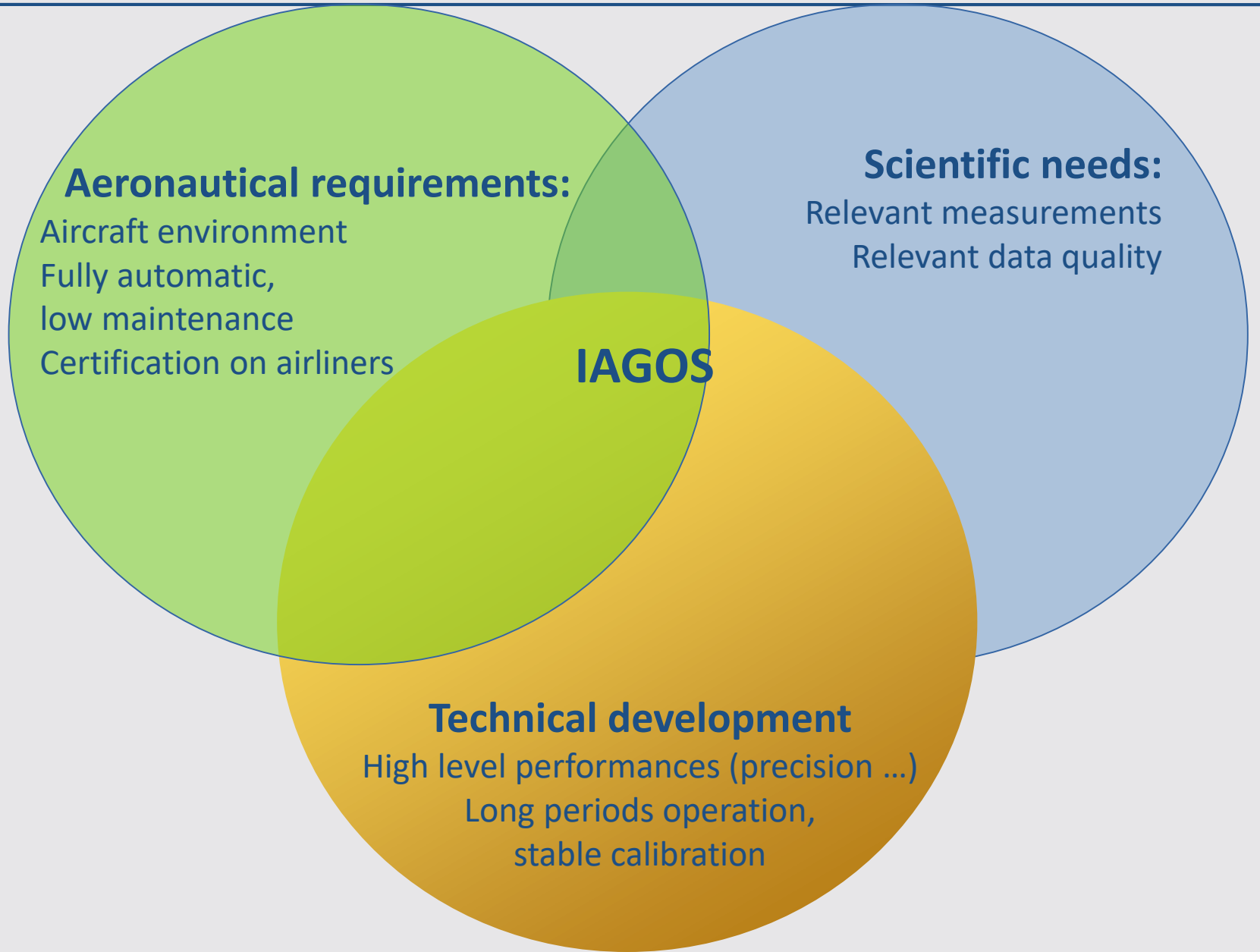

IAGOS as part of an integrated global observing strategy

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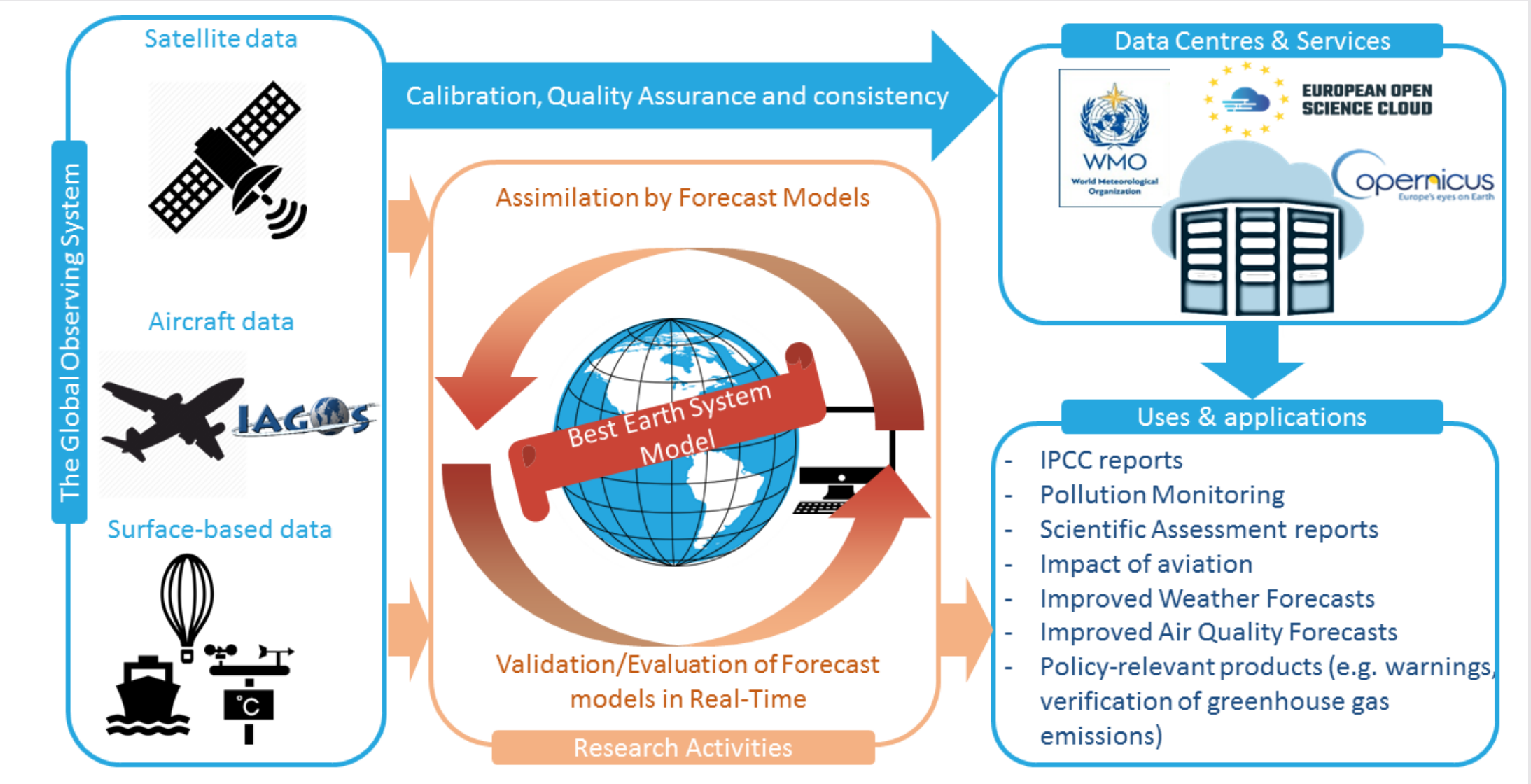


Outline

- Motivation and data usage
- **Description of operation**
- Links between IAGOS and operational programs

IAGOS in a nutshell

www.iagos.org

6 AIRLINES

8 AIRCRAFT
Airbus A330/A340

8 RESEARCH INSTITUTES

25 YEARS
of data since 1994

330 VISITED AIRPORTS

400 PEER REVIEWED PUBLICATIONS

2 METHODS

100 Atmospheric Components
1 Aircraft, 4 flights per month

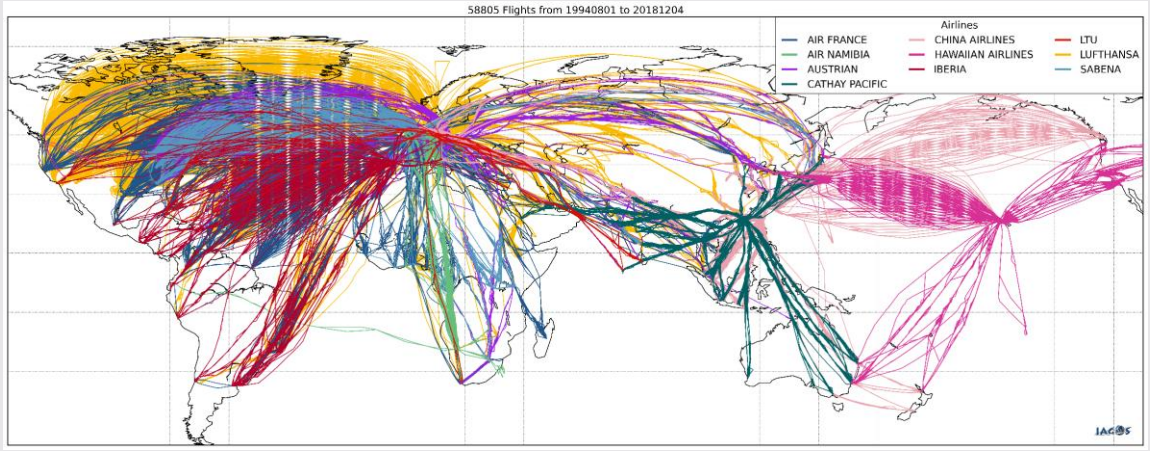
6 Essential Climate Variables
7 Aircraft, daily flights

60,000 FLIGHTS

JÜLICH Forschungszentrum · cnrs · KIT Karlsruhe Institute of Technology · DLR · METEO FRANCE · MANCHESTER 1824 · TROPOS · Lufthansa · AIRFRANCE · CHINA AIRLINES · CATHAY PACIFIC · IBERIA · HAWAIIAN AIRLINES

The IAGOS Fleet 2019

www.iagos.org



Data access through
www.iagos.org

Lufthansa AIRFRANCE CHINA AIRLINES CATHAY PACIFIC IBERIA HAWAIIAN AIRLINES

Two operating modes

www.iagos.org

IAGOS-Core

- Permanent installation of instruments in the avionics bay of Airbus A330/A340
- Continuous operation with 500 flights per aircraft per year
- Regular global-scale in-situ monitoring of atmospheric composition : ozone, water vapour, carbon monoxide, greenhouse gases (CH4,CO2), NOx, aerosols, clouds

CARIBIC

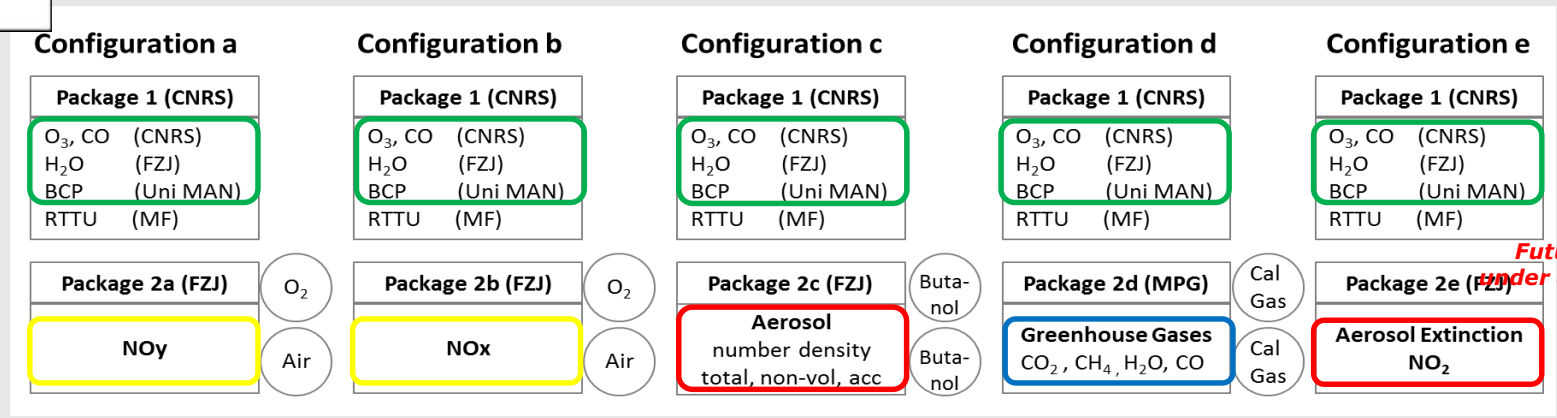
- One cargo container with 19 instruments
- Flies twice a month, 50 flights per year
- Detailed processes around the tropopause

The IAGOS-CORE Packages

www.iagos.org

IGACO TARGET VARIABLE LIST

Chemical species	Air Quality	Oxidation Capacity	Climate	Stratospheric Ozone Depletion
O_3	✓	✓	✓	✓
H_2O (water vapour)	✓	✓	✓	✓
CO	✓	✓		
CO_2			✓	
CH_4		✓	✓	✓
HCHO	✓	✓		
VOCs	✓	✓		
N_2O			✓	✓
$NO_x = NO+NO_2$ HNO_3	✓ ✓	✓ ✓	✓	✓ ✓
SO_2	✓	✓	✓	✓
BrO, ClO, OClO HCl, $ClONO_2$ CH_3Br, CF_3Br, CFC-11, CFC-12, HCFC-22				✓ ✓ ✓ ✓
aerosol optical properties	✓		✓	✓
actinic flux	✓	✓		



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Water Vapour Measurements

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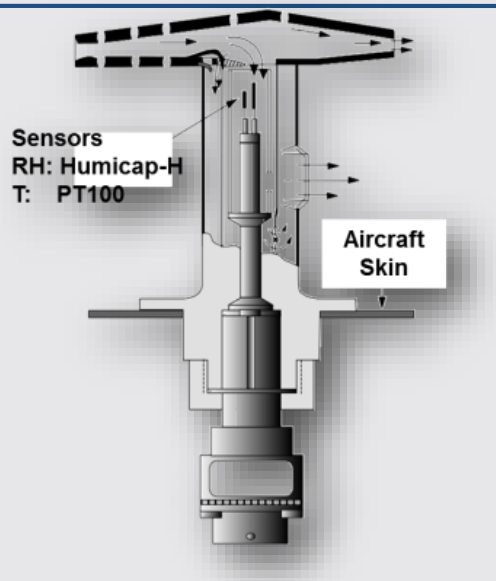
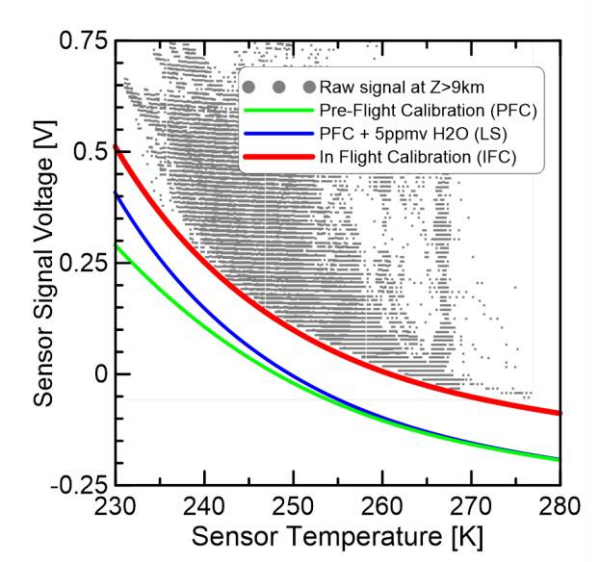
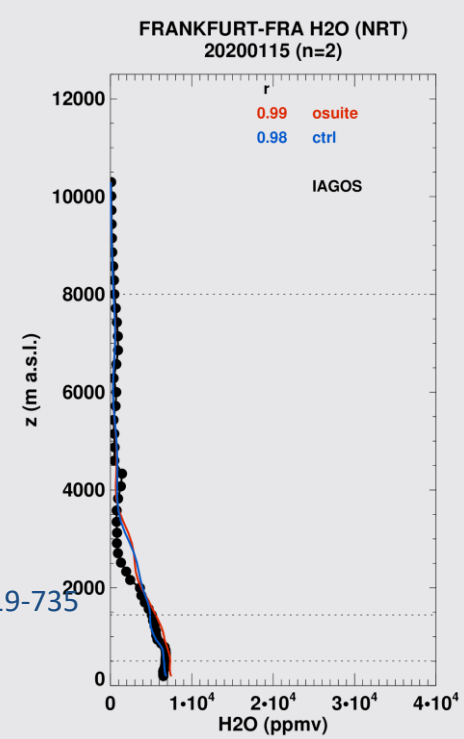
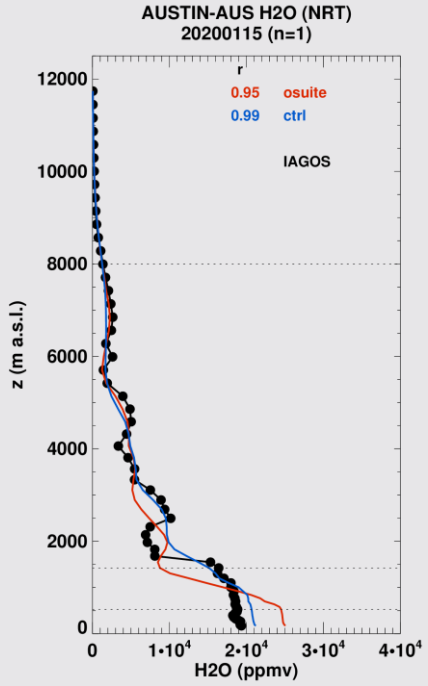
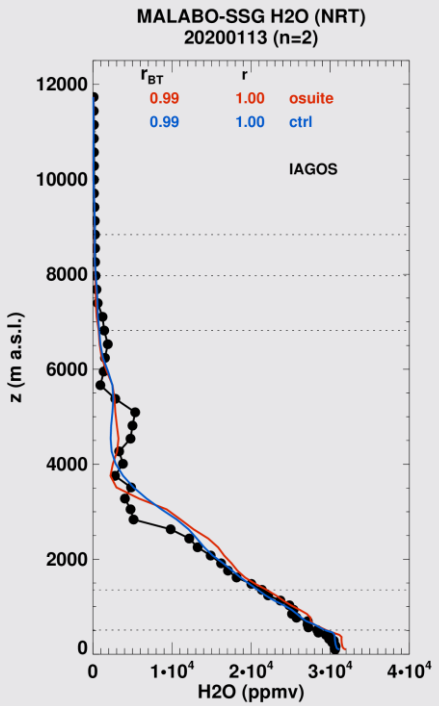


Petzold et al. https://www.atmos-chem-phys-discuss.net/acp-2019-735









Evaluation of in-flight calibration method

Raw signal of the MOZAIC humidity sensor aboard one MOZAIC aircraft as a function of the sensor temperature inside the aeronautic housing obtained at cruise altitude (z = 9 - 12 km).

Green line: zero signal from pre-flight calibration (PFC);

Blue line: superposition of zero signal from PFC and contribution by 5 ppmv water vapour;

Red line: zero signal from In-Flight Calibration (IFC).

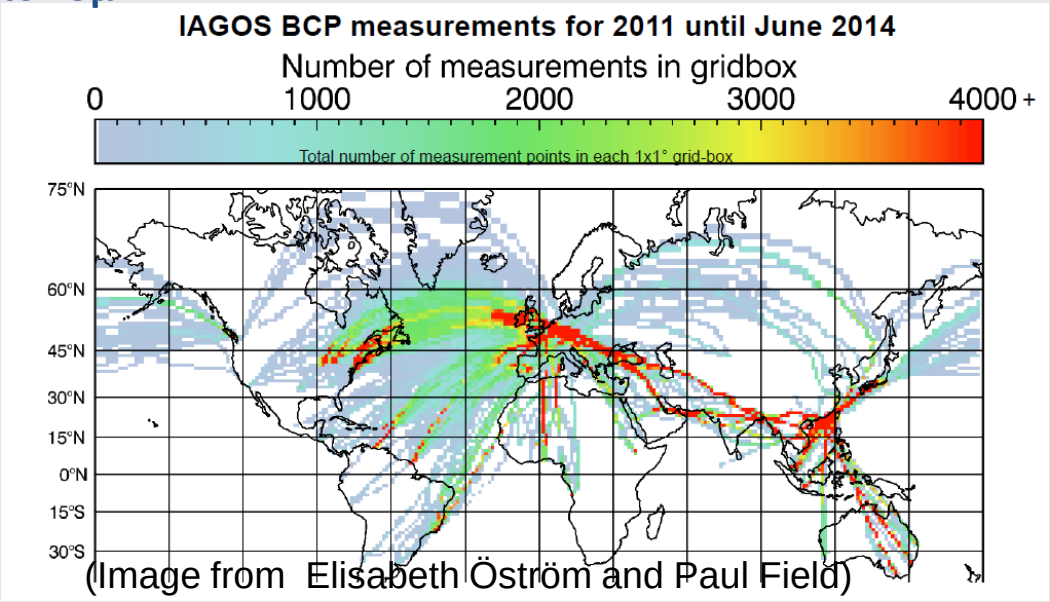
Droplets measurements : Back-scatter Cloud Probe

www.iagos.org

Measures particles in the size interval from 5 to 75µm.

Can have a (de)polarization channel : BCPD

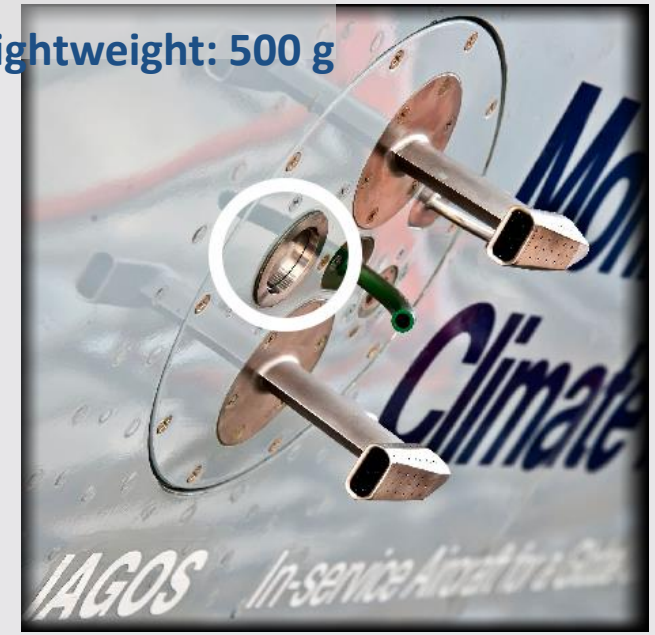
Deployed since 2011



(Image from Elisabeth Öström and Paul Field)

Compact: 500 cm³

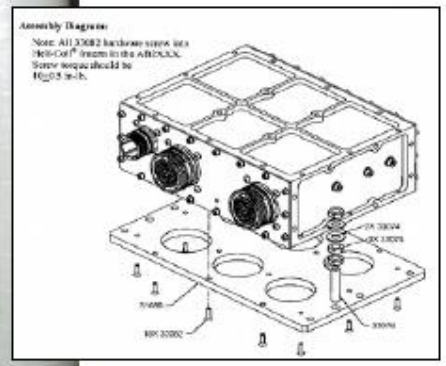
Lightweight: 500 g



Operational application : help aircraft avoid flying into clouds that can be dangerous

- At cruise level, High ICW content detection
  → avoid engine damage, Pitot tube freezing
- Liquid water detection, associated with temperature measurement
  → Icing avoidance

Steps toward real-time transmission



• Post - mod scheme:

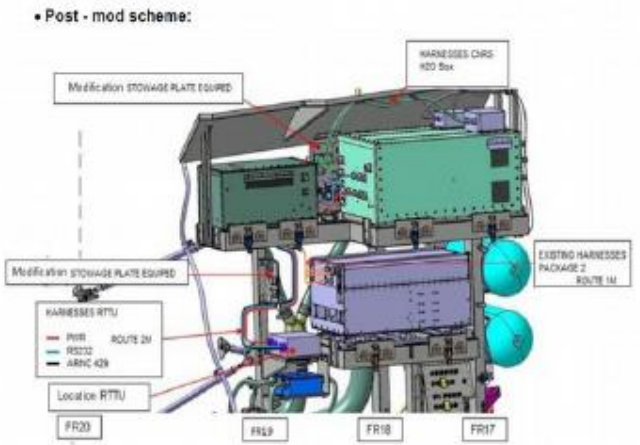


FIG 03 FRONT FACE

The RTTU is a modem, connected to the P1 package, ensuring the communication with the Satcom unit

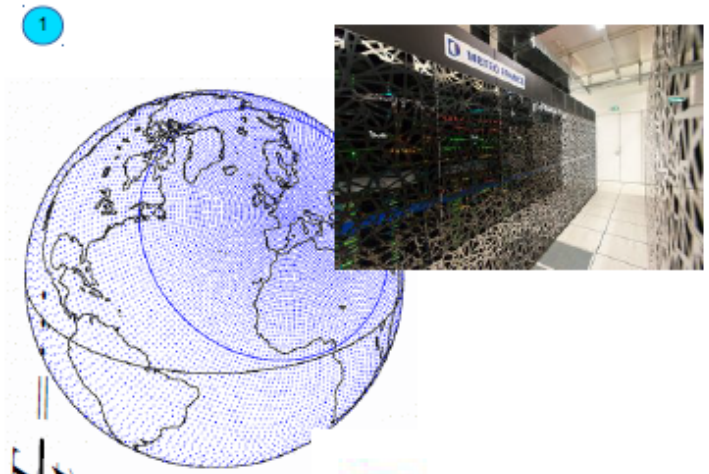
Developments, certification by ATMOSPHERE & sabena technics TAT GROUP + METEO FRANCE

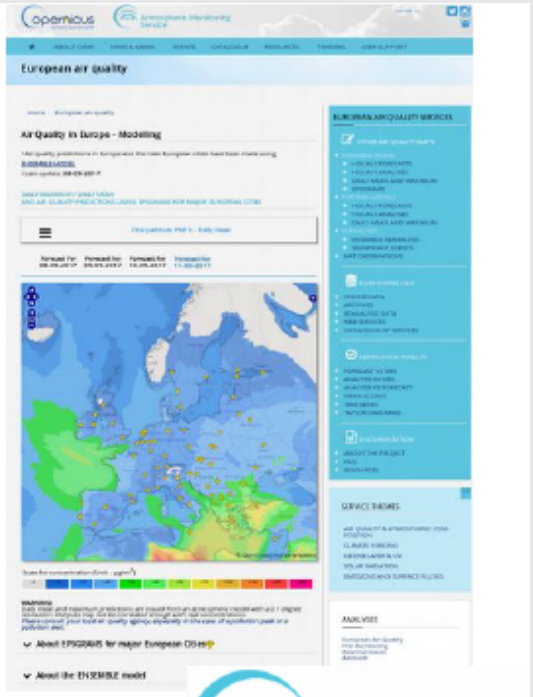
Real-time transmission to serve monitoring and forecasting systems

www.iagos.org

$$dp = -\rho g\, dz = -\rho\, d\Phi$$

$$\frac{\partial T}{\partial t} =$$





EUMETNET
EUROPEAN METEOROLOGICAL SERVICES NETWORK

Atmosphere Monitoring Service

Copernicus
Europe's eyes on Earth

Real time : within 3 hours (*real* real time)

Useful for remote sensing data qualification, monitoring and control, towards assimilation.

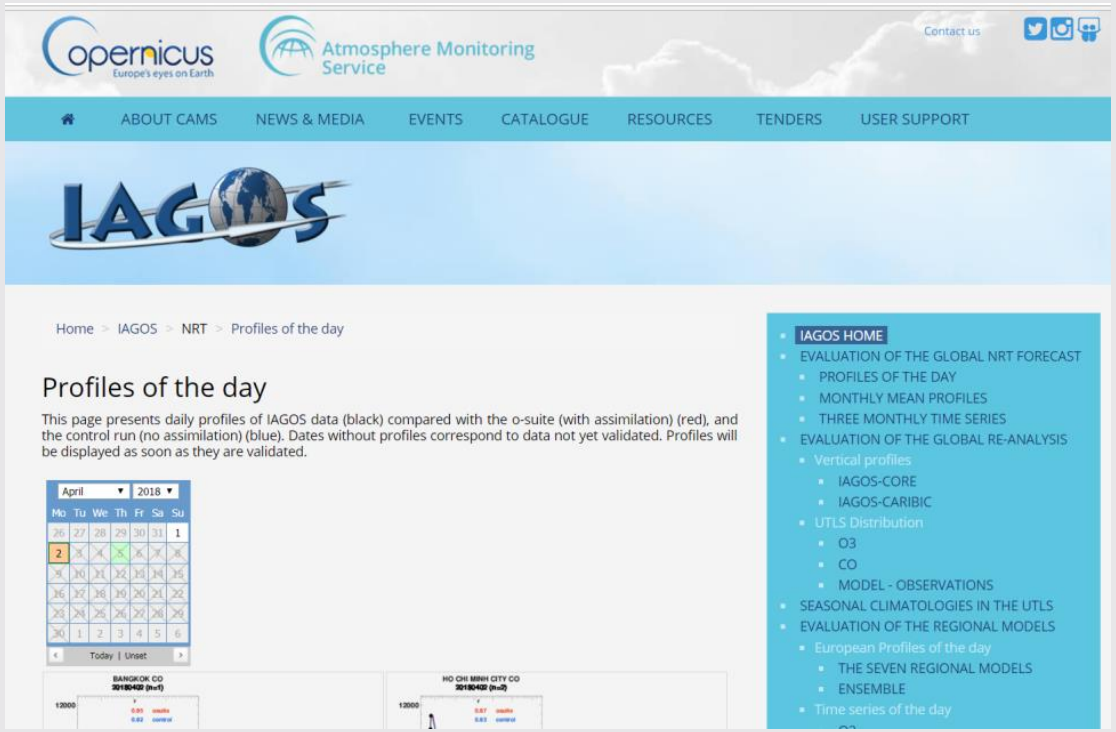
Target main user : ECMWF and its partners, involved in Copernicus Atmosphere

A classical data flow relying on existing operational infrastructures (AMDAR)
RTTU → Satellite telecom operator → Eumetnet E-ADAS → WMO Information System

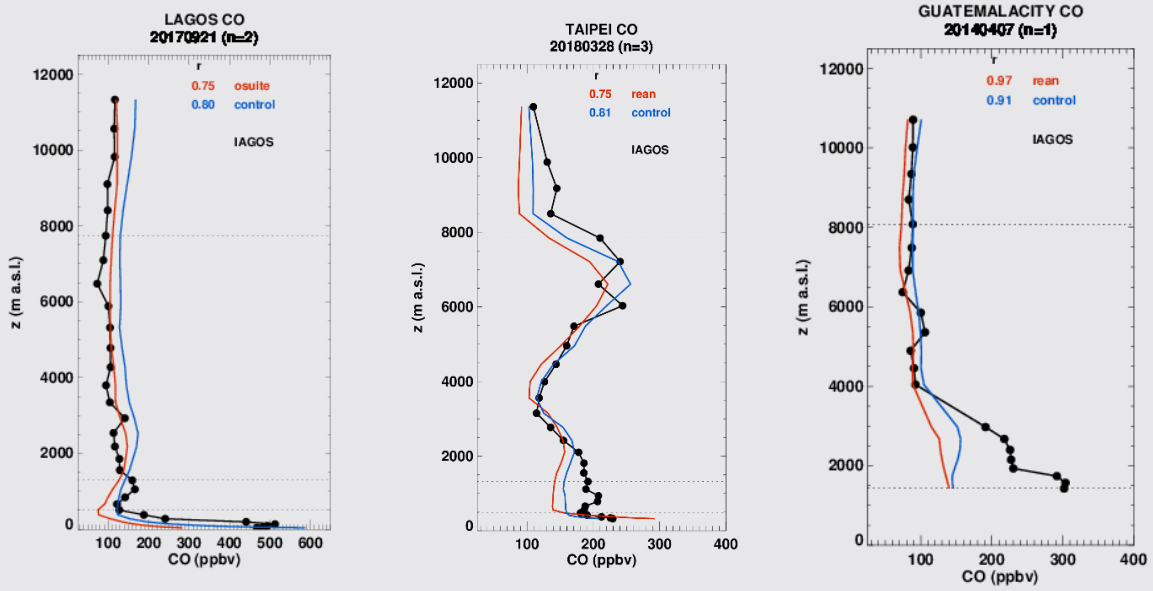
METEO FRANCE

Daily Monitoring of Global Atmospheric Composition

www.iagos.org



For the Copernicus Atmosphere Monitoring Service, IAGOS provides daily profiles of ozone and carbon monoxide at airports around the world



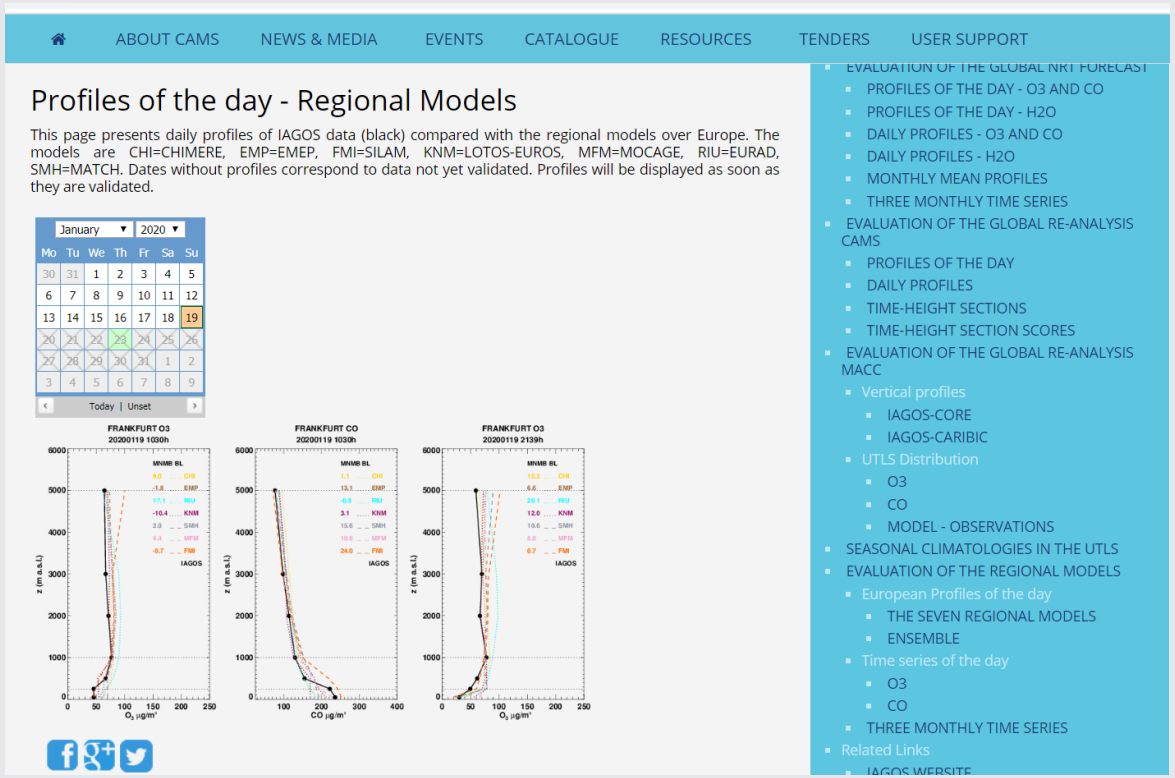
CAMS provides

- Global daily forecasts of Atmospheric composition (40km)
- Regional daily forecasts of atmospheric composition (10km)
- Global reanalysis 2003-2016 (80km)

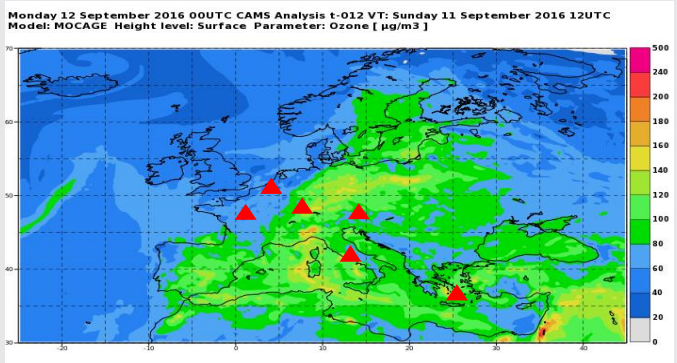
Latest profiles available at www.iagos.fr/cams

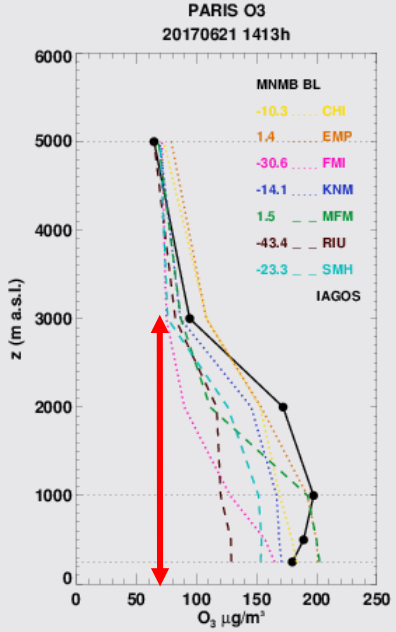
Daily Monitoring of Air Quality in Europe

www.iagos.org



IAGOS provides daily profiles of ozone and carbon monoxide at airports in Europe (Frankfurt, Paris, Amsterdam Vienna)





Anomalies throughout depth of troposphere

CAMS provides

- Regional daily forecasts of atmospheric composition (10km)
- 7 regional European models and Ensemble: CHIMERE (INERIS), EMEP (MetNO), EURAD (Uni Cologne), LOTOS_EUROS (KNMI), MATCH (Sweden), MOCAGE (MF), SILAM (FMI)

Benefits of commercial aircraft for routine measurements

www.iagos.org

IAGOS measures: H2O, O3, CO, clouds, Winds and temperature, CH4, CO2, NOx, aerosols

Monitoring at cruise (9-12km) altitude for climate, and weather forecasting

Profiles (0-12km) for air quality monitoring

Real time transmission for forecast validation

More about IAGOS:

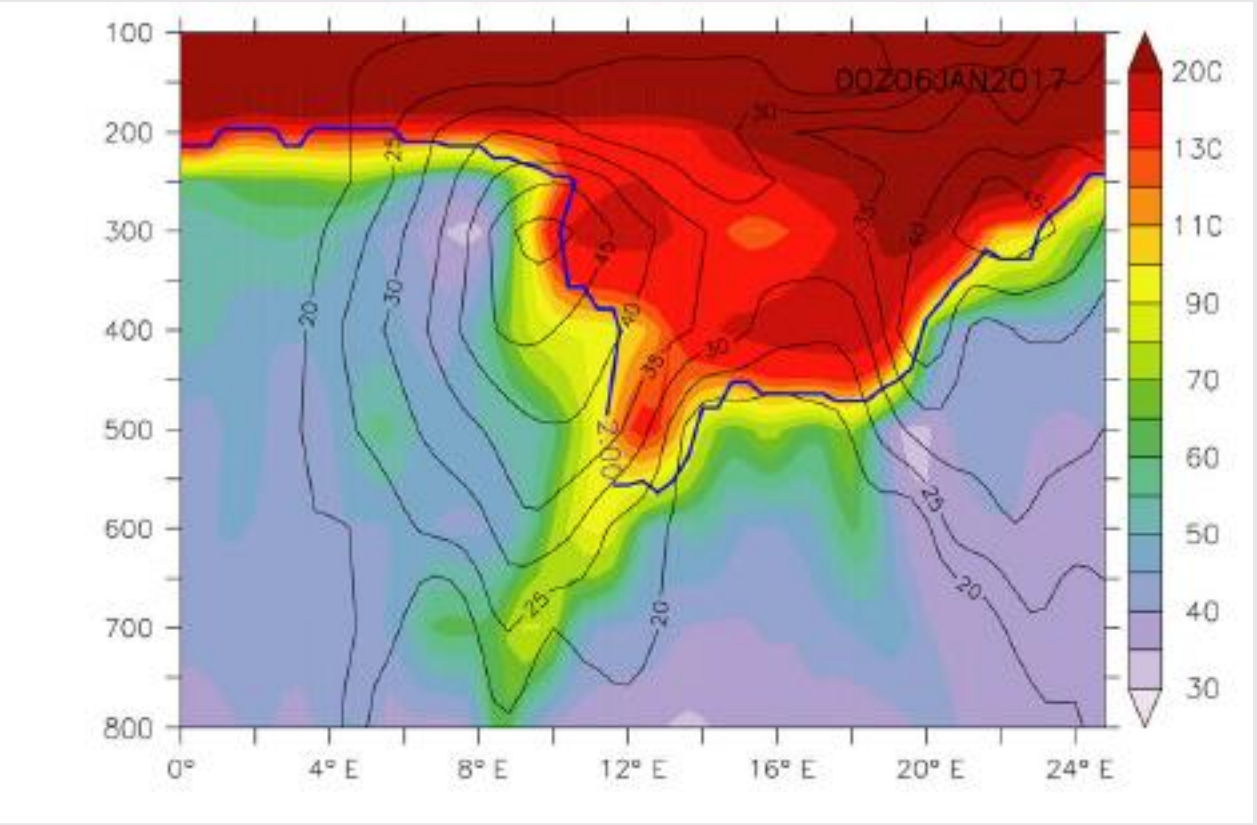
@IAGOS_RI

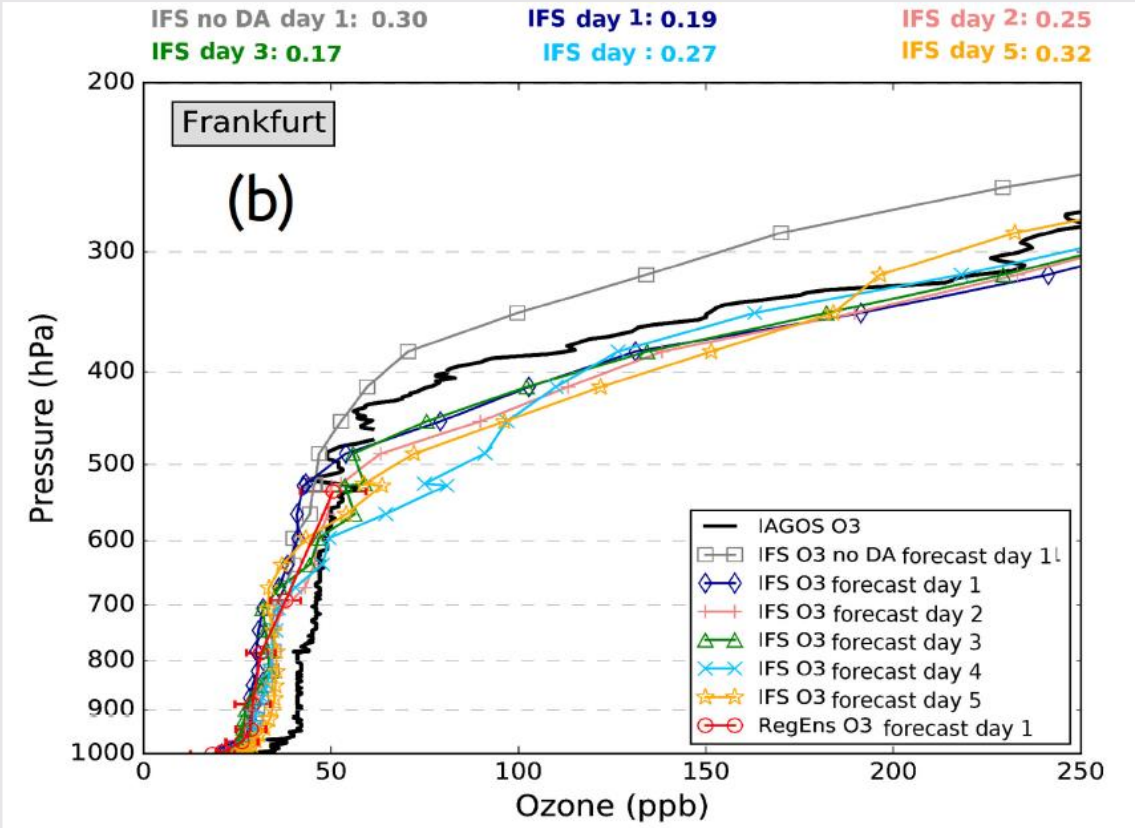
www.iagos.org

Depth of troposphere and stratospheric intrusions

www.iagos.org

A deep stratosphere-to-troposphere ozone transport event over Europe simulated in CAMS global and regional forecast systems (Akritidis et al., 2018)





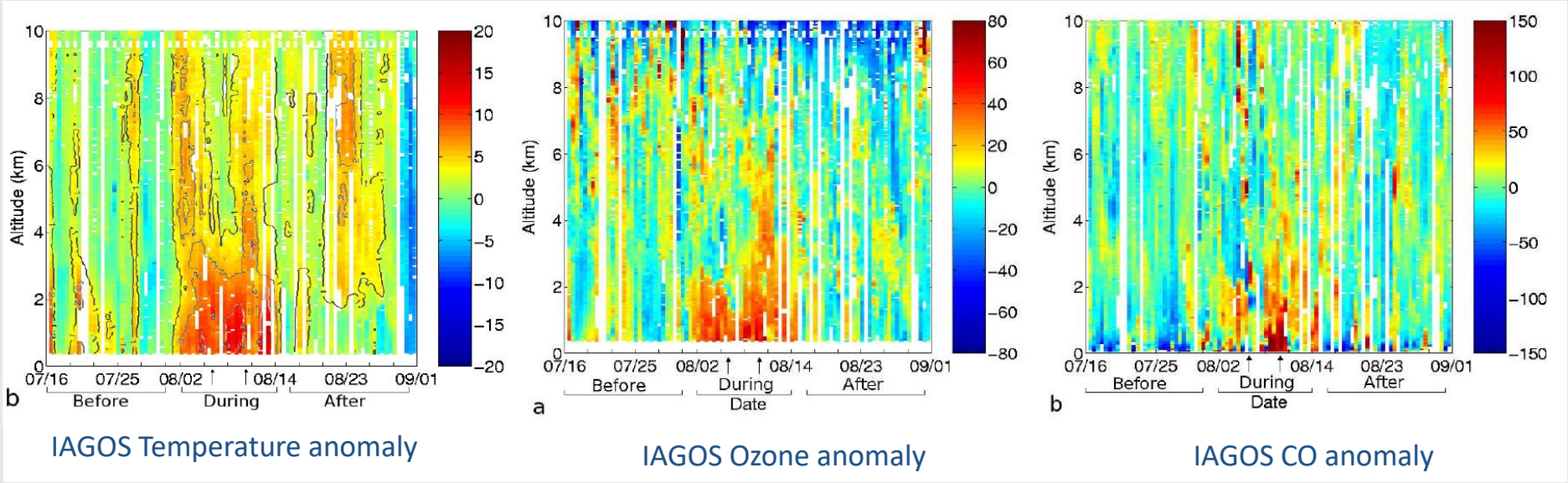
Heatwave 2003: Importance of measurements throughout the troposphere

www.iagos.org

Country	Deaths
France	15,000
Italy	3100
Portugal	2100
UK	2000
Netherlands	1500
Germany	300

one third of the deaths caused by the heatwave were caused by poor air quality.

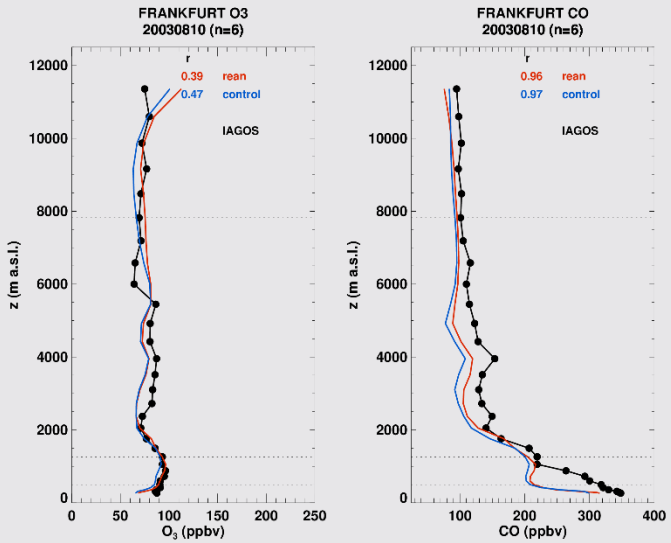
Tressol et al 2008



IAGOS Temperature anomaly

IAGOS Ozone anomaly

IAGOS CO anomaly



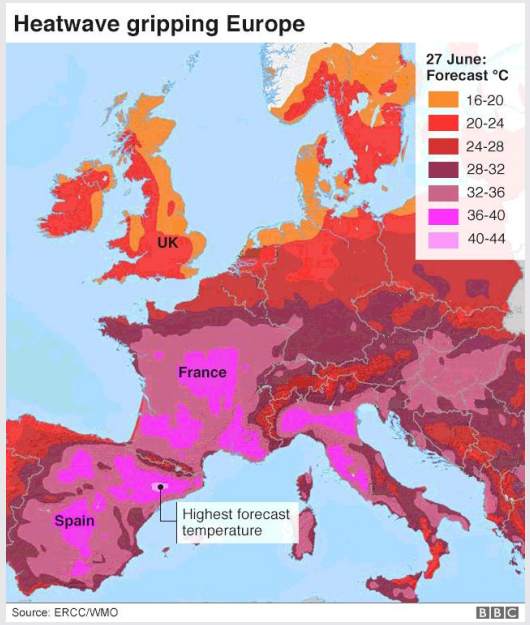
CAMS Reanalysis 2003-2016

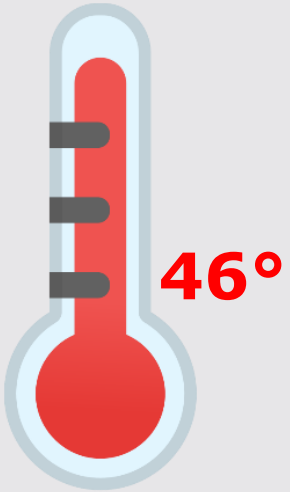
Air quality parameters observed by IAGOS:

- Ozone O_3
- Carbon Monoxide CO
- Nitrogen Oxides NO, NO_2 , NO_x

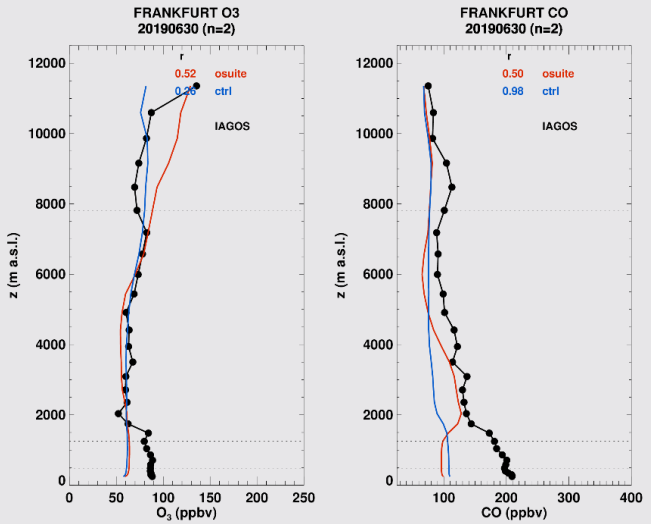
Heatwave June 2019

www.iagos.org

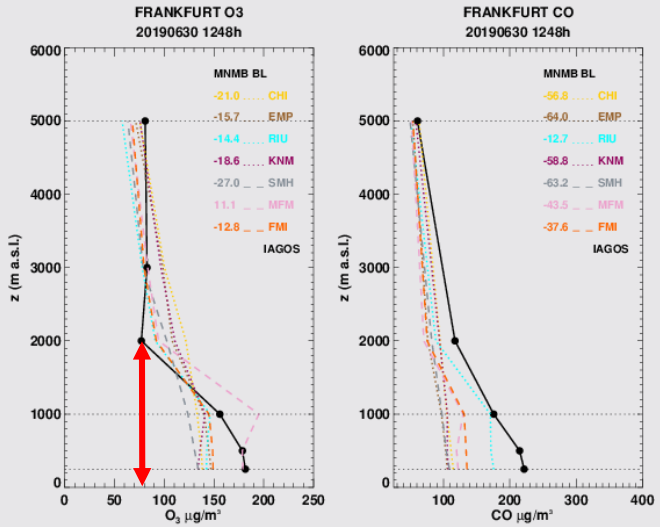


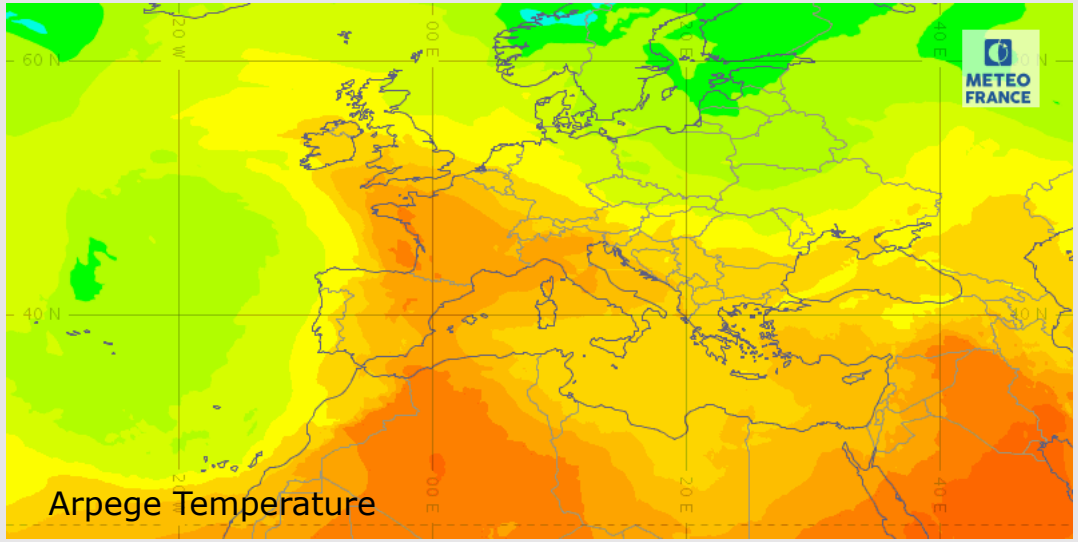


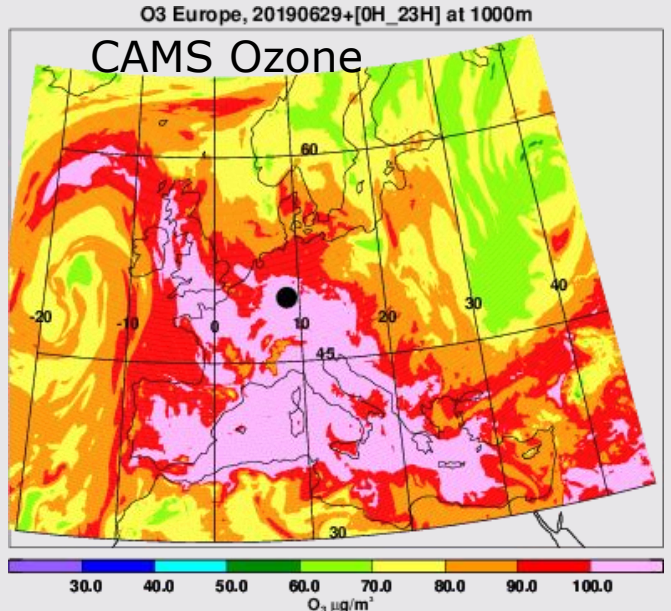
CAMS Global models



CAMS Regional Models

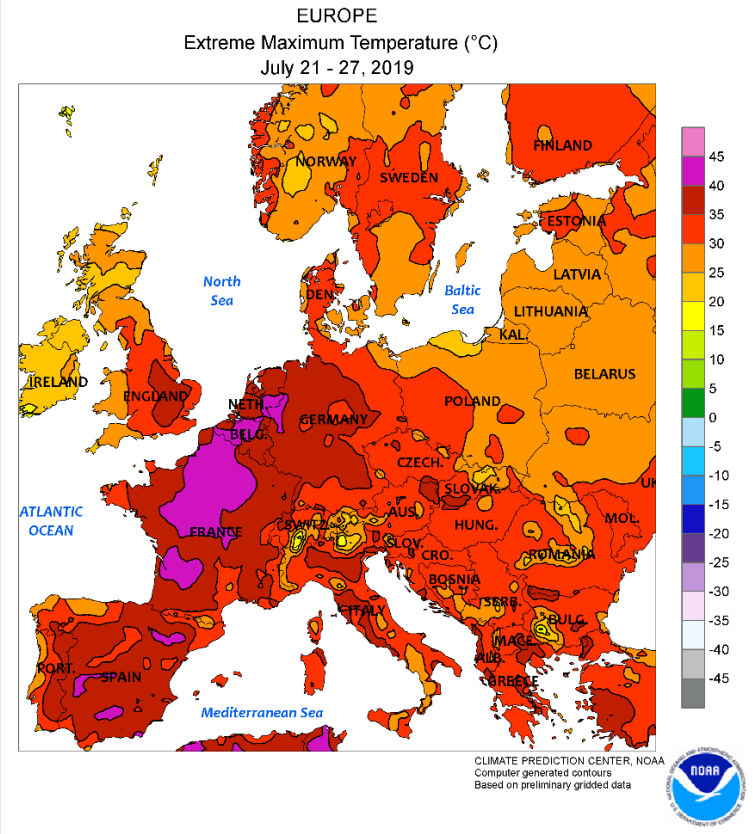




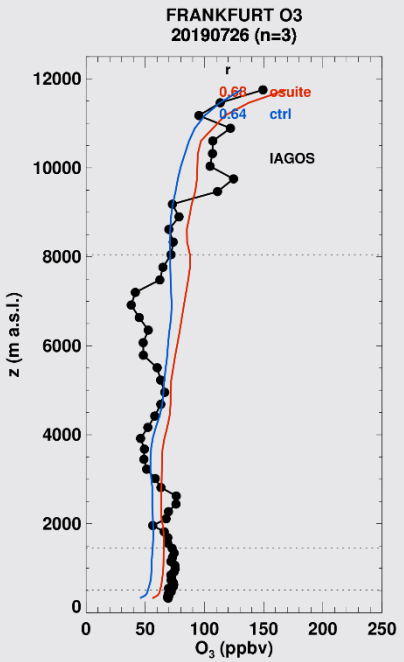


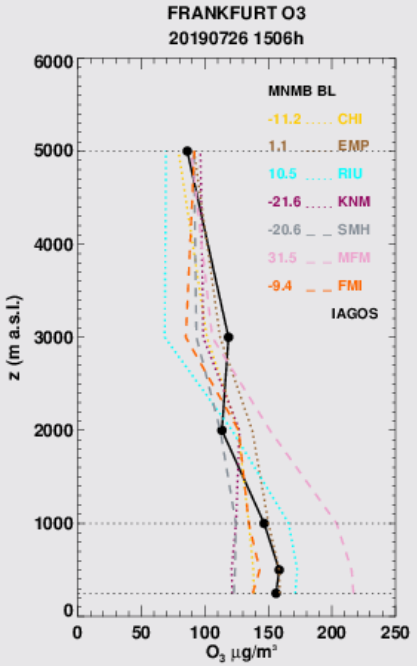
Heatwave July 2019

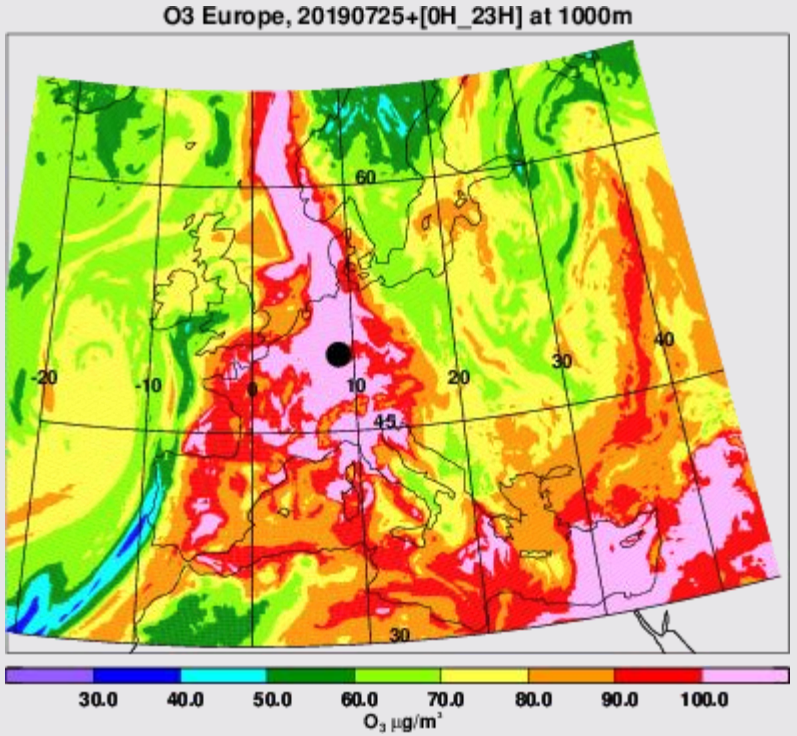
www.iagos.org



Global models+IAGOS Regional models+IAGOS







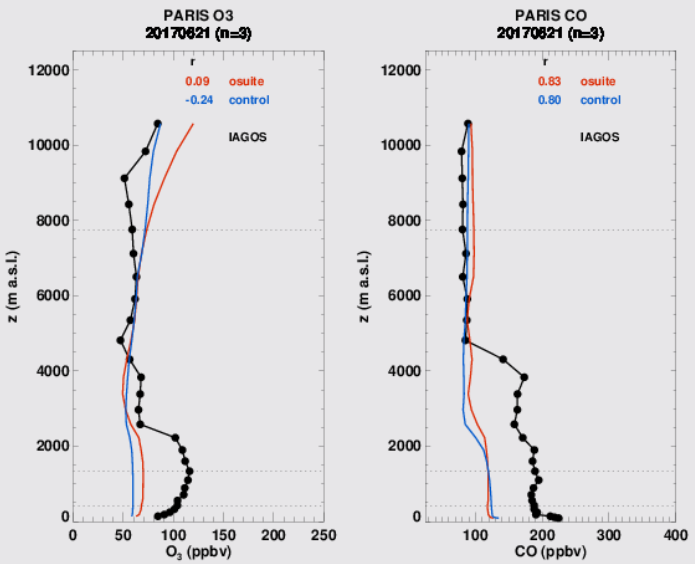
Les canicules de juin et juillet ont provoqué 1 500 morts en France

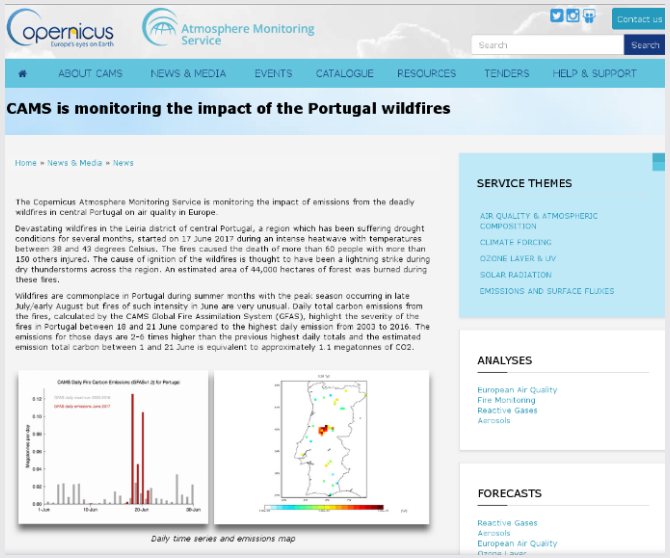
Les décès imputables aux vagues de chaleur ont été dix fois moindres qu'en 2003, a précisé la ministre des solidarités et de la santé, Agnès Buzyn.

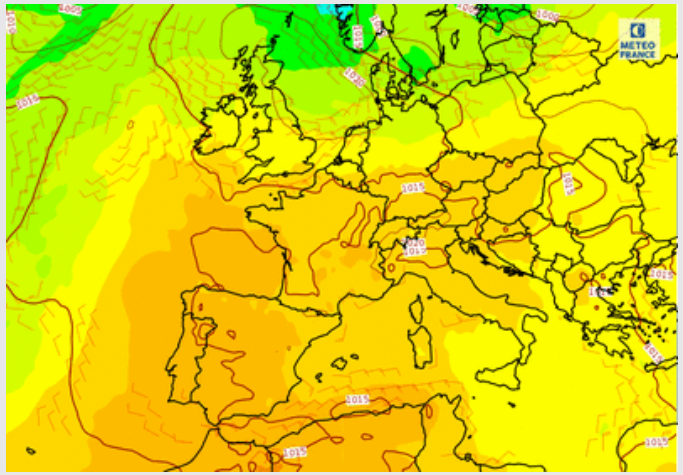
Le Monde avec AFP • Publié le 08 septembre 2019 à 13h26 - Mis à jour le 09 septembre 2019 à 10h11

Portuguese Wildfires June 2017

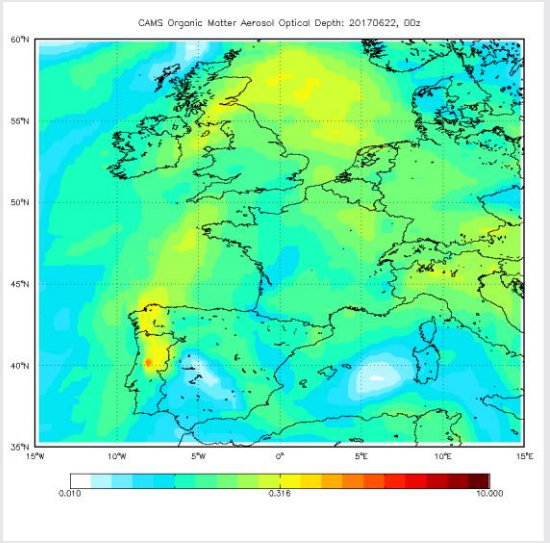
www.iagos.org







Meteo France (Arpege) temperatures



CAMS Organic Matter Aerosol Optical Depth

North American/ Arctic Wildfires 2019

www.iagos.org

NEWS ► CAMS MONITORS UNPRECEDENTED WILDFIRES IN THE ARCTIC

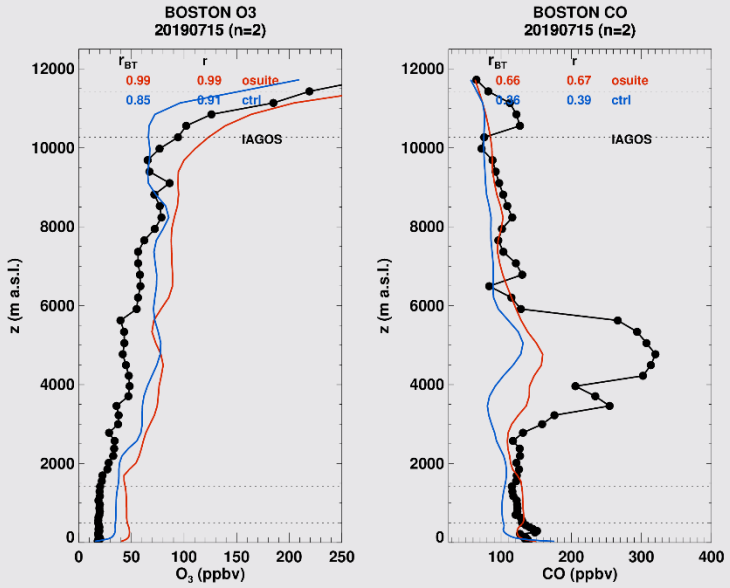
CAMS monitors unprecedented wildfires in the Arctic

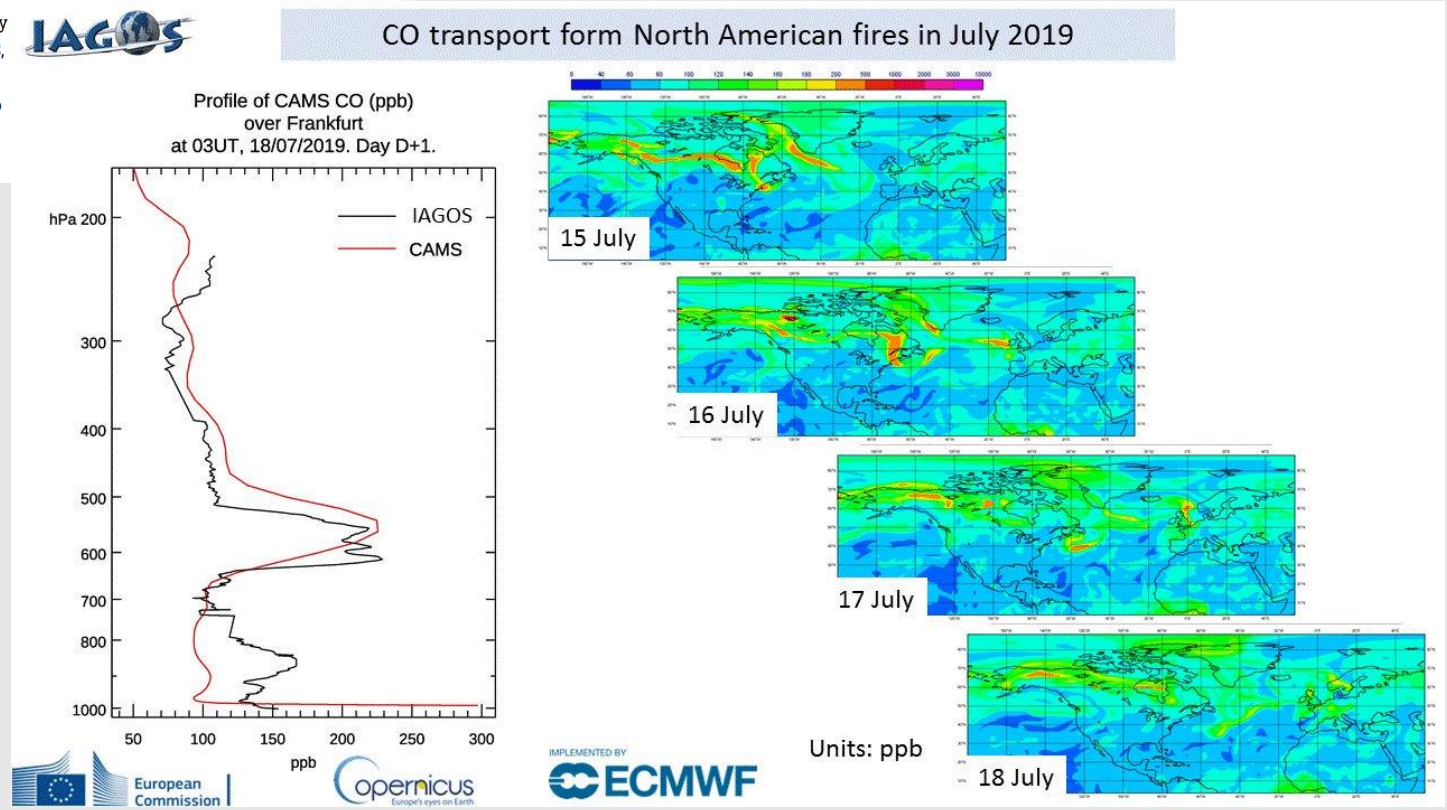
DATE: 11th July 2019

Over the last six weeks, the Copernicus Atmosphere Monitoring Service (CAMS) has tracked over 100 intense and long-lived wildfires in the Arctic Circle. In June alone, these fires emitted 50 megatonnes of carbon dioxide into the atmosphere, which is equivalent to Sweden's total annual emissions. This is more than was released by Arctic fires in the same month between 2010 and 2018 put together.

Although wildfires are common in the northern hemisphere between May and October, the latitude and intensity of these fires, as well as the length of time that they have been burning for, has been particularly unusual. CAMS, which is implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF) on behalf of the EU, incorporates observations of wildfires from the MODIS instruments on NASA's Terra and Aqua satellites into its Global Fire Assimilation System (GFAS) to monitor the fires and estimate the emission of pollutants from them.

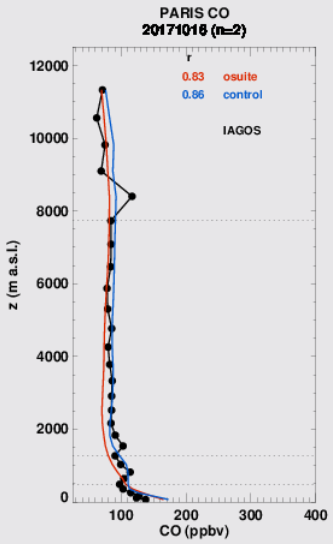
'Unprecedented': more than 100 Arctic wildfires burn in worst ever season

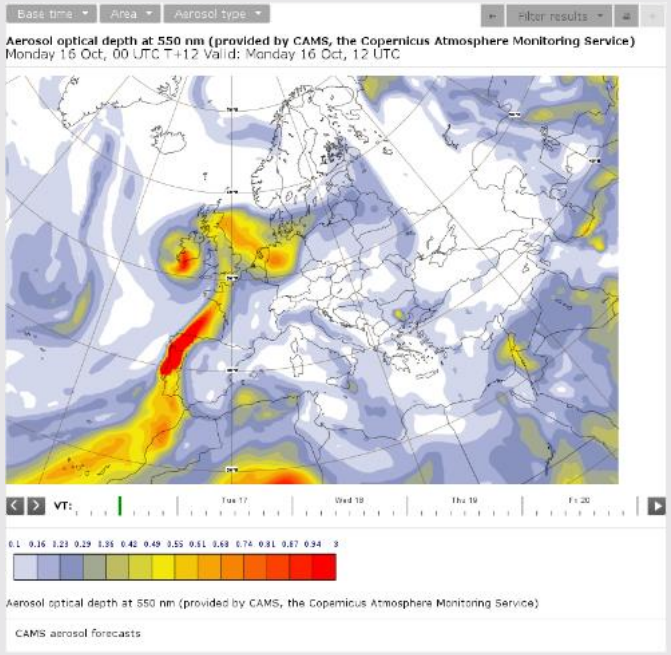


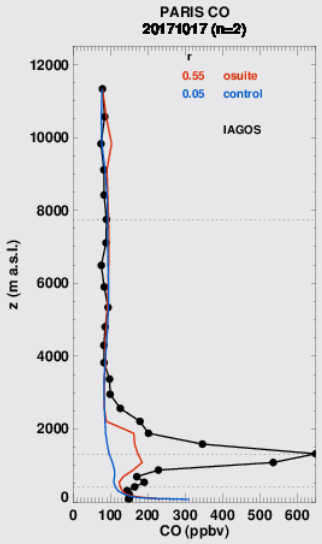


Hurricane Ophelia October 2017

www.iagos.org







Apocalypse wow: dust from Sahara and fires in Portugal turn UK sky red

Unusual glow comes about as result of Storm Ophelia picking up sands from north Africa and particles from Iberian forest fires

Nadia Khomami
@nadiakhomami
Mon 16 Oct 2017 16.18 BST
1889 401

▲ London skies turn red as Ophelia picks up Sahara sands – video

The strange reddish sky reported over parts of the UK may appear to some a sign of impending apocalypse or a celestial Instagram filter, but experts say there is a scientific explanation.

The hue is a remnant of Storm Ophelia dragging in tropical air and dust from the Sahara, while debris from forest fires in Portugal and Spain is also playing a part, according to the BBC weather presenter Simon King.

Beast from the East February 2018

www.iagos.org

Europe freezes as 'Beast from the East' arrives

28 February 2018 Share

European scenes of ice and snow filmed on Monday

Much of Europe has been blanketed in snow as cold weather spreads as far south as the Mediterranean coast.

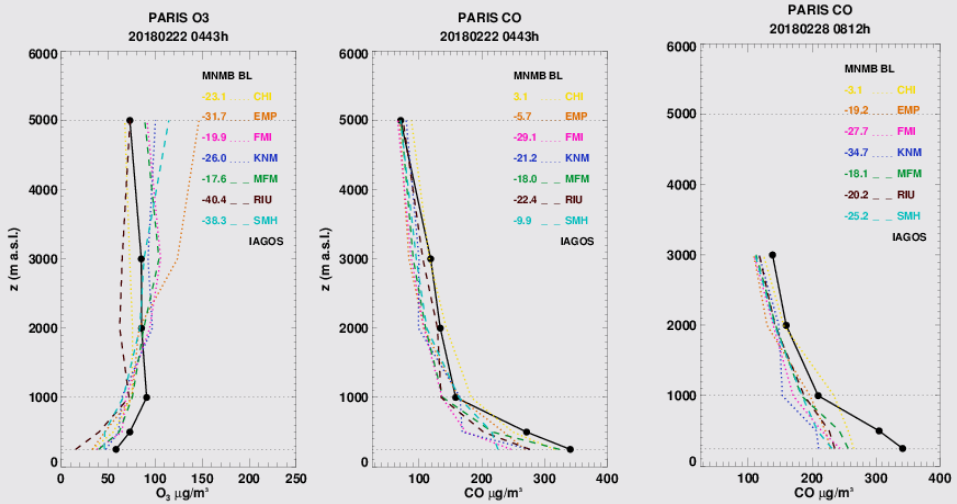
The cold spell, nicknamed "the Beast from the East" in the UK, is carrying freezing winds across the continent, and temperatures as low as -30C (-22F).

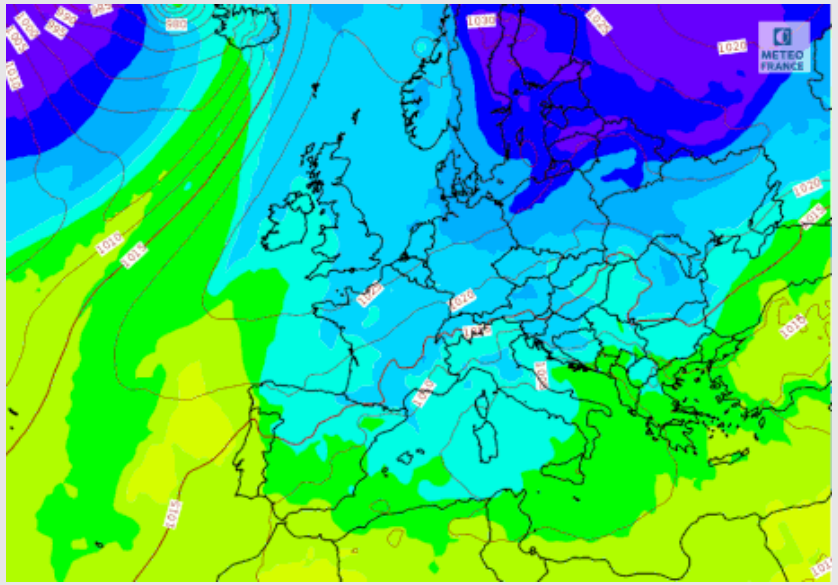
At least 10 people have died since Monday, including many who were sleeping rough in cities.

Aid groups have opened shelters and are providing hot food and blankets for thousands of people.

The cold weather - called the "Siberian bear" by the Dutch and "snow cannon" by

CAMS Regional Models



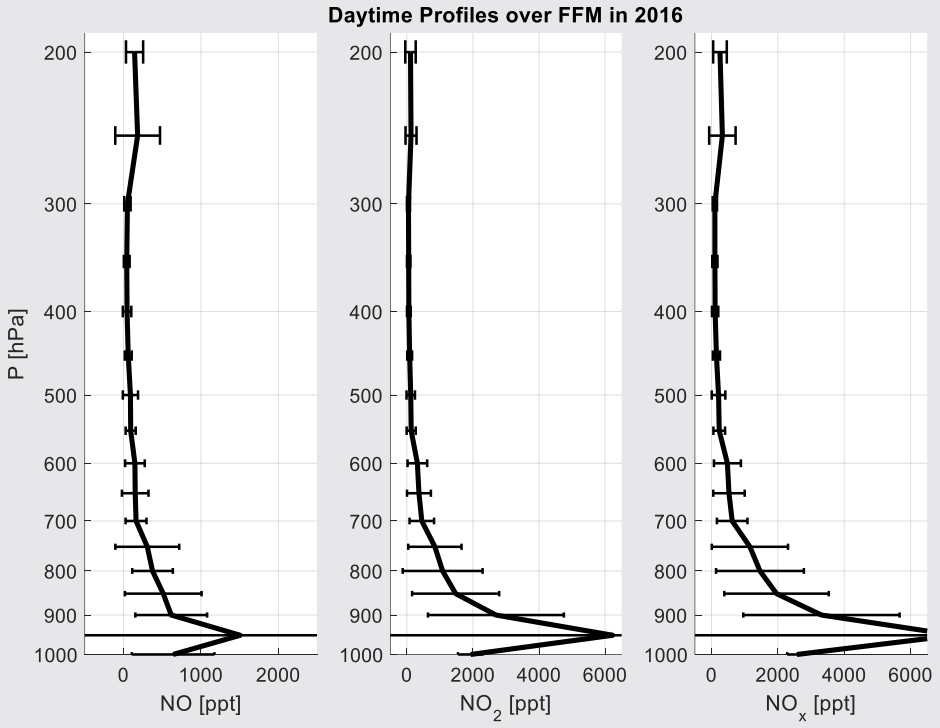


Arpege Temperatures (MF)

Conclusions

www.iagos.org

- IAGOS is effective at monitoring air quality
- IAGOS Ozone and CO are used in daily validation of the CAMS models (regional, global and reanalysis)
- Long-term trends of CO and O_3 allow assessment of air pollution control.
- Next IAGOS will provide this service for water vapour, NOx CO2 and CH4 measurements

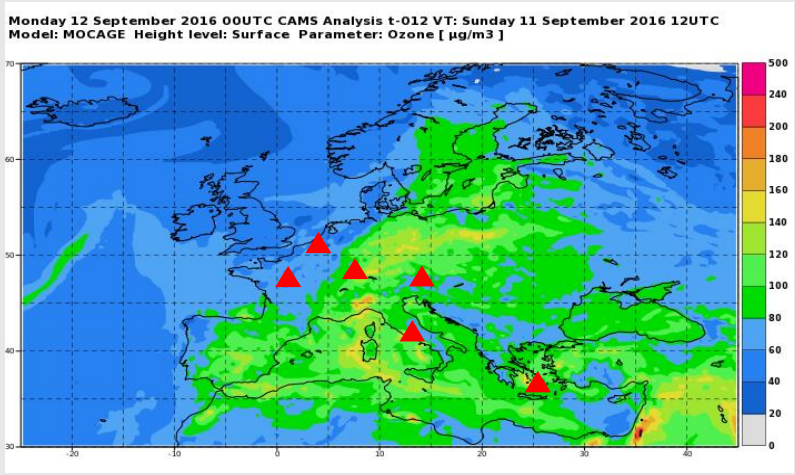


Daily Monitoring of Air Quality in Europe

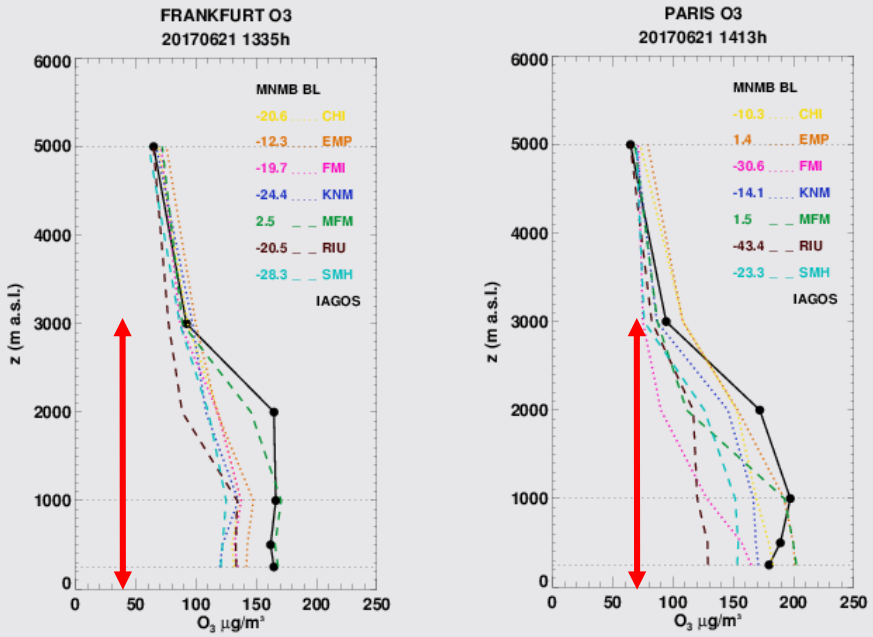
www.iagos.org

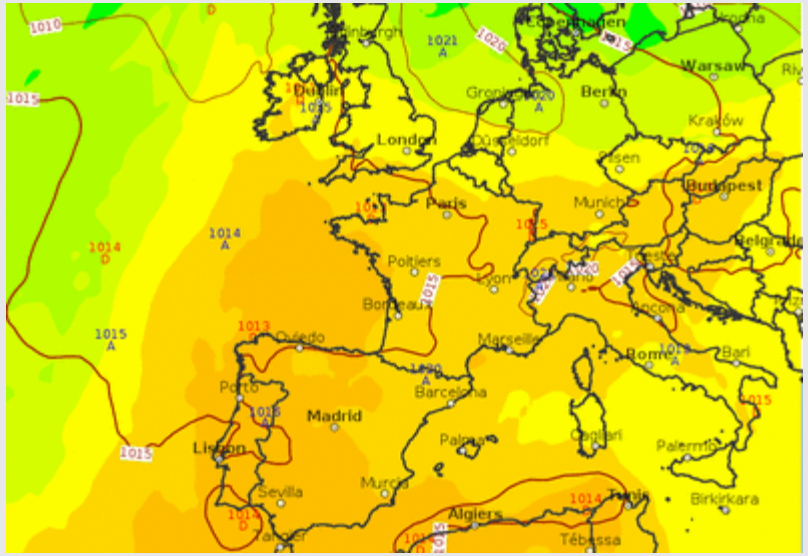
Regularly Visited European Airports:
Paris, Frankfurt, Amsterdam, Vienna

7 regional European models and Ensemble:
CHIMERE (INERIS), EMEP (MetNO), EURAD (Uni Cologne), LOTOS_EUROS (KNMI), MATCH (Sweden), MOCAGE (MF), SILAM (FMI)



European Domain, 10km resolution





Early Heatwave 20 June 2017

IAGOS Measurements

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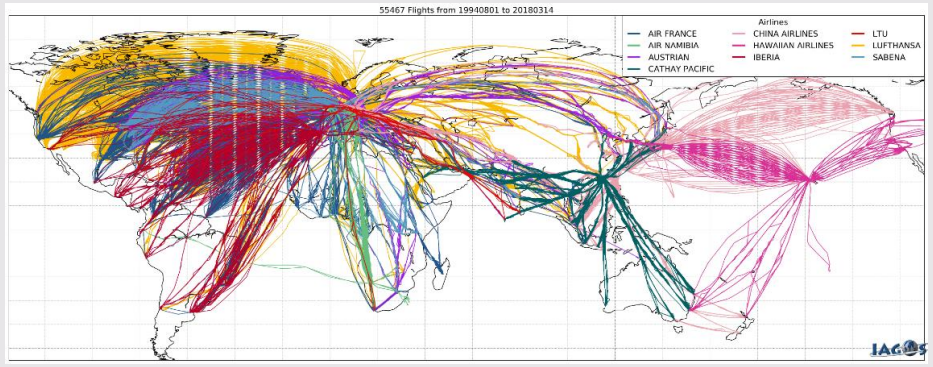
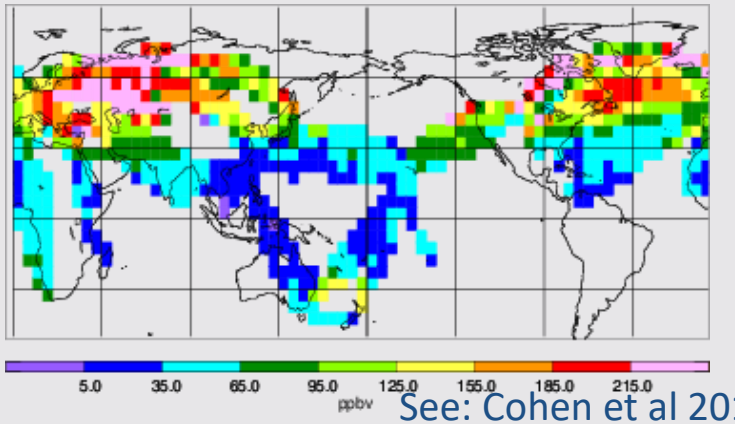
Cruise Altitude

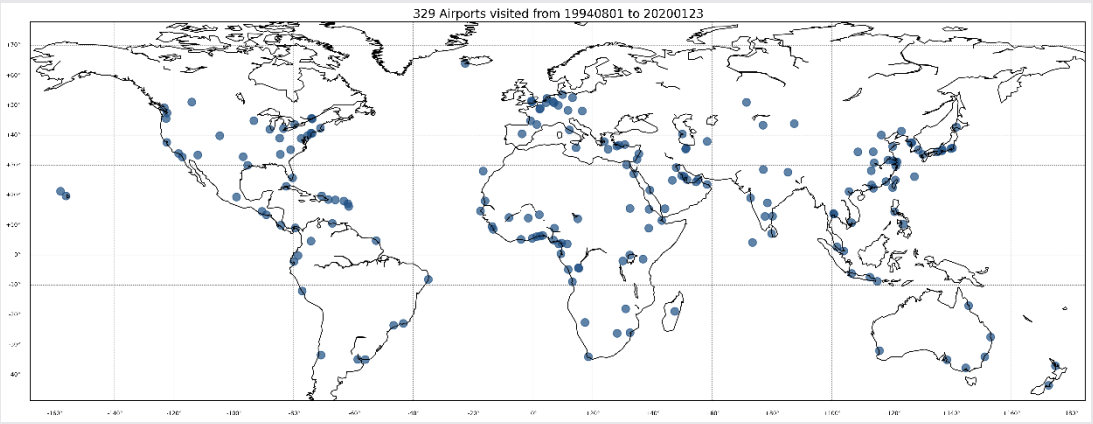


Climatologies and trends in UTLS

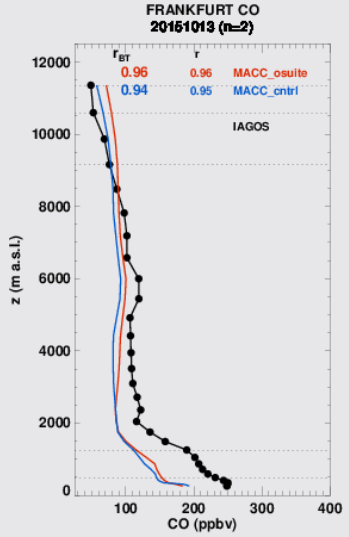


See: Cohen et al 2018

Landing-Take-off Profiles



Vertical Profiles for Air Quality studies, case studies



See: Petetin et al. 2016