CEOS Meeting
29 June 2017, Paris

Cal/Val activities for IASI-NG

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The IASI instrument

•IASI (Infrared Atmospheric Sounding Interferometer) is a Fourier Transform Spectrometer that measures infrared radiation emitted from the Earth.

•It has been developed by CNES, in collaboration with EUMETSAT.

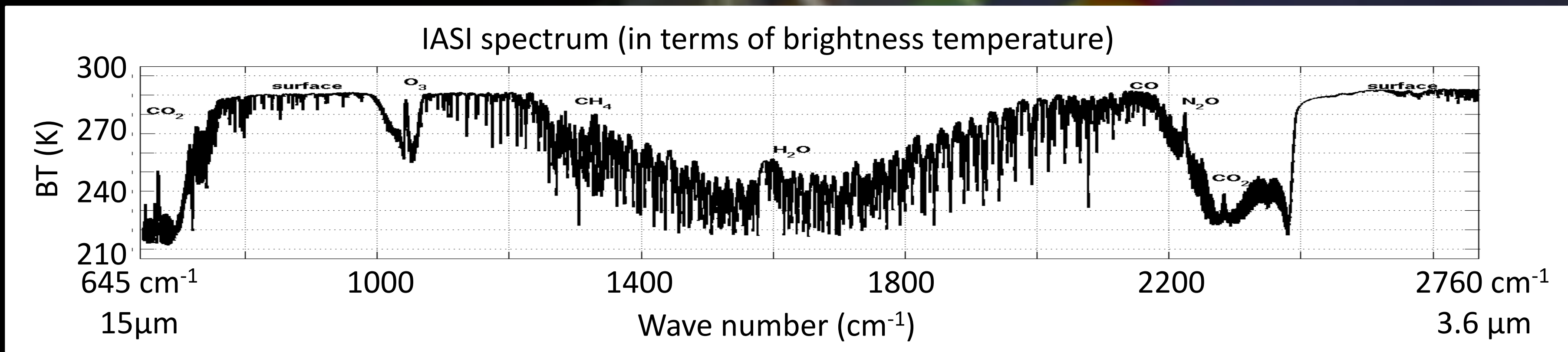
•IASI provides

-8461 spectral channels between 645 and 2760 cm^{-1} (15.5 - 3.63 µm)

-with a spectral resolution of 0.5 cm^{-1} after apodisation ("Level 1c" spectra)

-the spectral sampling interval is 0.25 cm^{-1}.

-nadir FOV: 12 km at nadir.

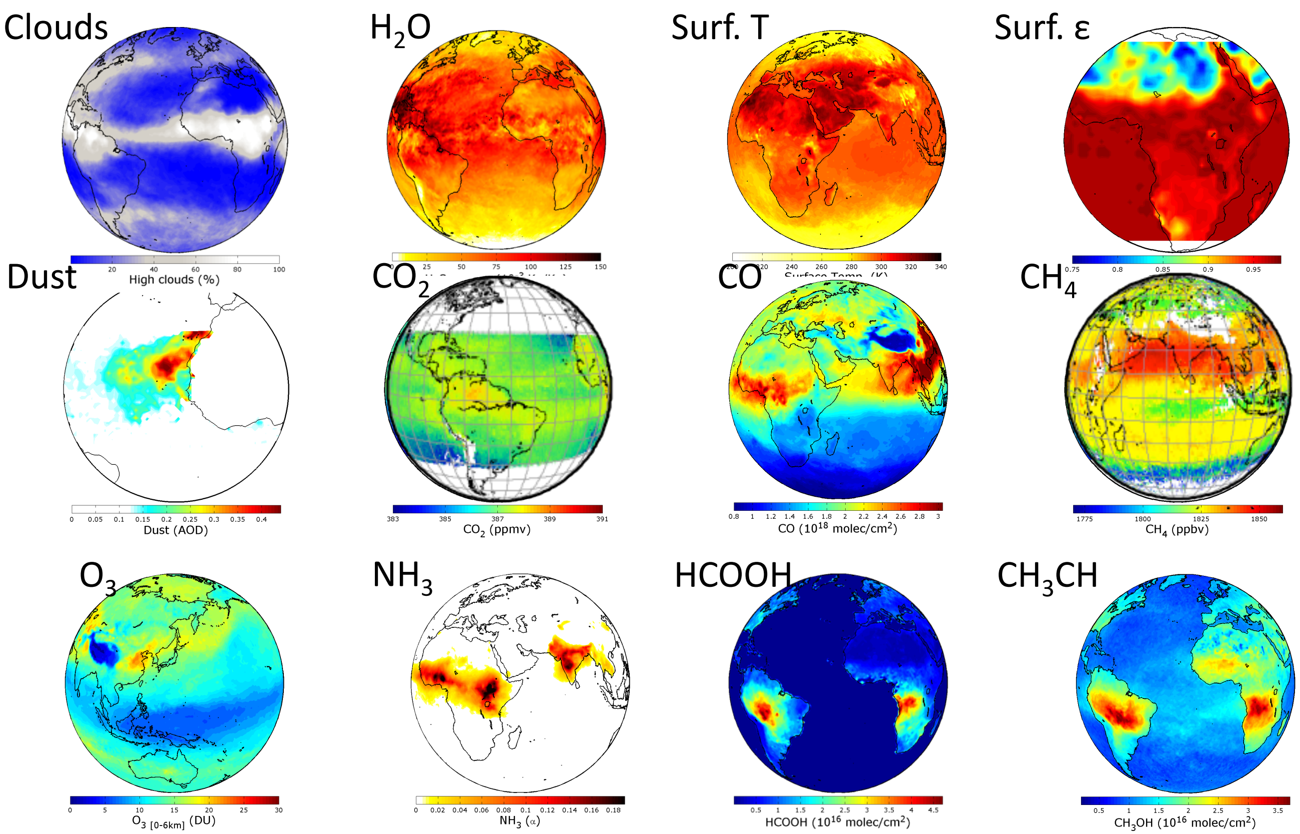


Retrievals of several atmospheric and surface variables over land/sea by day/night.

A whole suite of atmospheric variables retrieved from IASI

•IASI addresses the needs of three communities that are more and more connected:

Numerical Weather Prediction | Atmospheric Composition | Climate



Hilton et al. 2012
Clerbaux et al., 2016

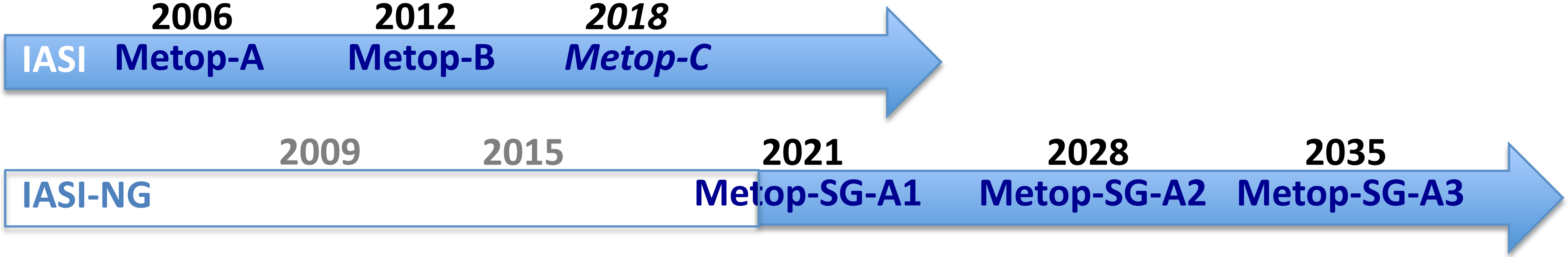
•More than 25 species are observed, some well quantified (O_3, CO, CH_4), some only detected (SO_2, HNO_3, NH_3, formic acid, methanol) in special situations (fires, volcanoes).

•Monitoring of several Essential Climate Variables

From IASI to IASI-NG

	2006	2012	*2018*
IASI	Metop-A	Metop-B	*Metop-C*

From IASI to IASI-NG



(MetIMAGE, MWS, IASI-NG, RO, UVNS/Sentinel 5, 3MI)

- **Objectives of the mission:**
  - To assure the continuity of IASI for NWP, atmospheric chemistry and climate applications.
  - To improve the vertical coverage of the atmosphere (lower part of the troposphere, the UT/LS region).
  - To improve the precision of the retrievals and to allow the detection of new species.

- **Characteristics**:

-spectral coverage: 645 - 2760 cm^{-1}

-spectral resolution: 0.25 cm^{-1} after apodisation (*0.50 cm^{-1} for IASI*)

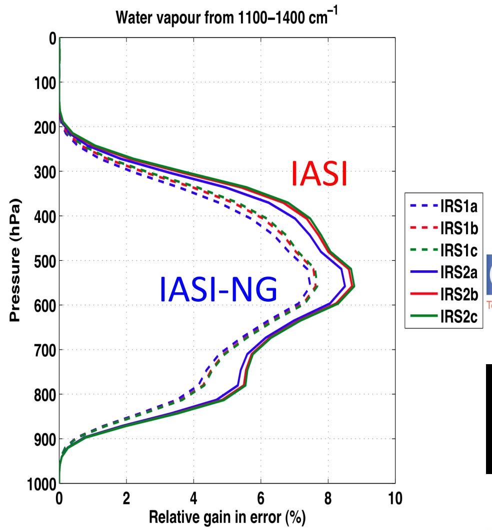
-spectral sampling: 0.125 cm^{-1} (*0.25 cm^{-1} for IASI*).

-reduction of the radiometric noise by at least a factor of ~2 as compared to IASI.

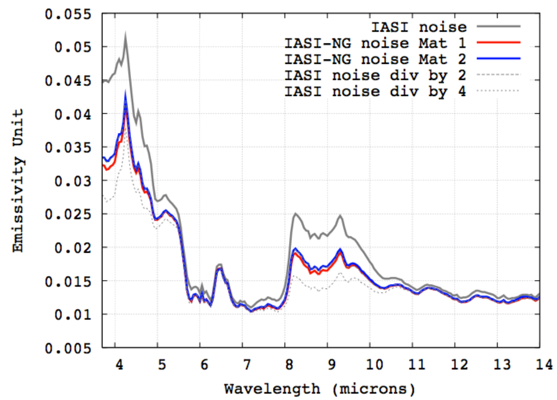
Crevoisier et al., AMT, 2014

Impact of improved spectral and radiometric caracteristics

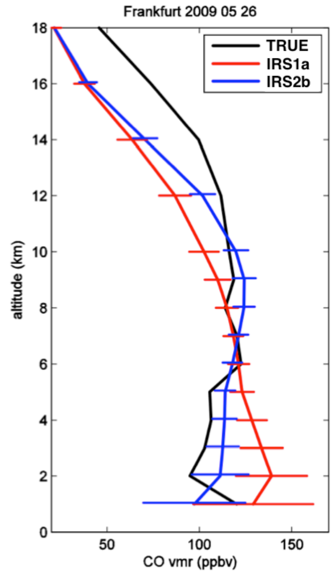
For most of the atmospheric species, there is no difference between KBr and ZnSe scenarios.



H_2O: it is mostly the spectral resolution that matters

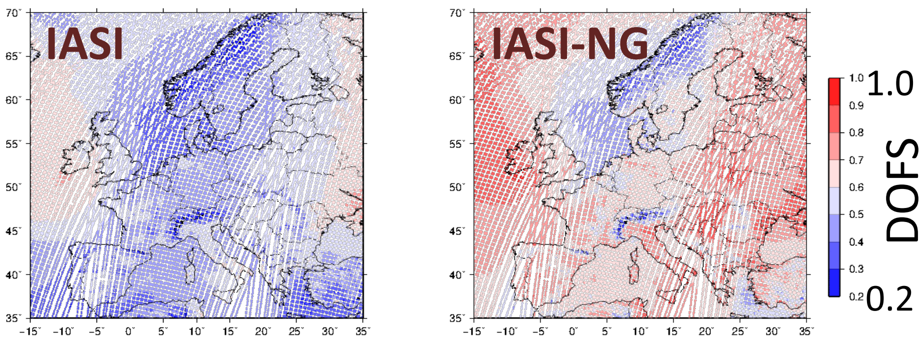


Surface emissivity



Obs
IASI
IASI-NG

Carbon monoxide



Ozone (0-6 km)

Noise	Improvement of the CH_4 precision
IASI	39 %
KBr	20 %
ZnSe	20 %

Methane

Crevoisier et al., AMT, 2014

IASI-NG: summary

	IASI		IASI-NG		
Chemistry	***DOFs***	***Error (%)***	***DOFs***	***Error (%)***	***What the 'NG' brings***
O_3	3-4	PBL : 60% Tropo : 11%	4-5	PBL : 40% Tropo : 8%	More information in PBL
CO	1-2	PBL : 16% Tropo : 8%	2-3	PBL : 10% Tropo : 6%	More information in PBL
HNO_3	1 or less		2		Both tropo and strato
NH_3[a]	detected	-	measured	-	> instrumental noise
Methanol[a]	detected	-	measured	-	> instrumental noise
C_2H_4[a]	detected	-	measured	-	> instrumental noise
SO_2-volcanos	If > 2DU	-	If > 1 DU	-	+ Altitude of the plume
Climate	***DOFs***	***Error (%)***	***DOFs***	***Error (%)***	***What the 'NG' brings***
H_2O	5-6	~13%	6-7	~10%	Error improved by 1.5
T	6	~0.6K	12	~0.45 K	Error improved by 2.5
CO_2	1 or less	~1%	1-2	<1%	Low troposphere
CH_4	1or less	~3%	1-2		Less interferences
N_2O	detected	-	measured	-	
Aerosols	dust				More types
Emissivity		0,04 @4µm		0,02 @4µm	

Calibration/Validation of IASI-NG

- Strong heritage from IASI and other IR sounders: several activities can be directly applied to IASI-NG.

- **For level1**: expertise of monitoring and intercomparison activities performed at CNES/ EUMETSAT and some labs, especially in the framework of GSICS.

- **For level2**:

  - The challenge: more than 25 atmospheric species retrieved or detected, in addition to thermodynamics, clouds, aerosols, surface characteristics.

  - Aiming automatisation of validation and monitoring tools.

  - But:

  - Requirements for IASI-NG are tighter
  - Some new products required for IASI-NG
  - dedicated campaigns when no coordinated network and routine data flux exist)

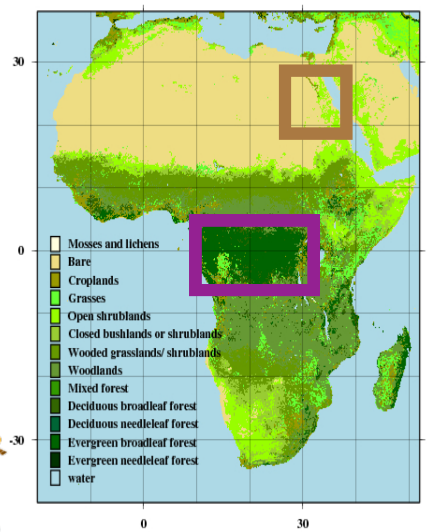
Thermodynamics variable

Product	Vertical Resolution	Accuracy	Reference data source
Temperature profile	LT, MT: 0.8 km UT, S: 2 km	LT, MT: 0.8 K UT, S: 1.2 K	Sondes RO dry-T strato NWP analysis Can we demonstrate 0.8K?
Specific humidity profile	LT: 1.2 km MT, UT: 1.5 km S: 3 km	LT: 5 % MT, UT: 7 % S: 20 %	Sondes NWP analysis Ground-based Lidar, MWR Can we demonstrate 5% ? Other? LHD?
Water vapour total column	N/A	5 %	Ground-based GPS High resolution radiometer? Other?

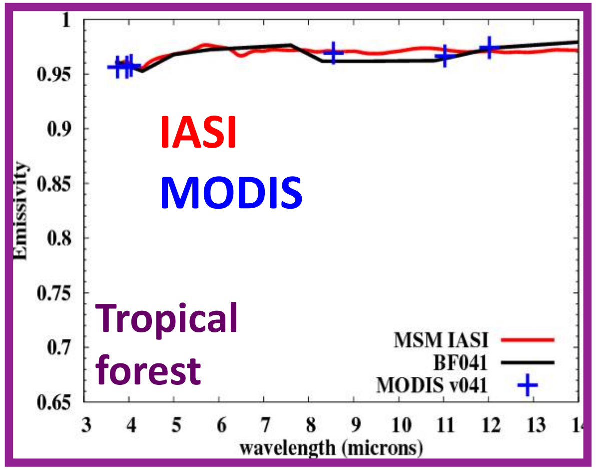
- A lot has been done with IASI.
- Challenges:
  - Going towards operational.
  - how to validate improved precision wrt IASI?

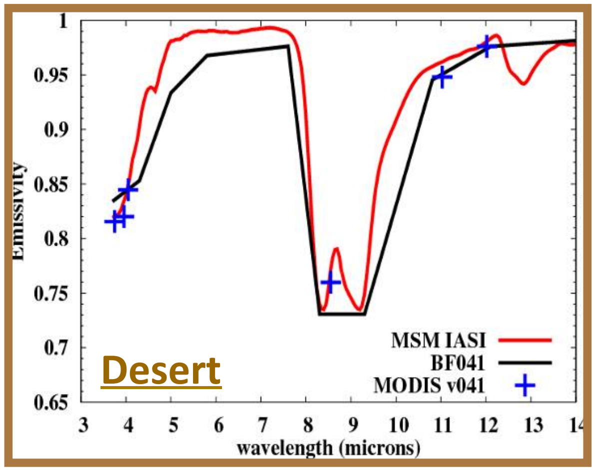
Surface characteristics

Product	Vertical Resolution	Accuracy	Reference data source
Sea surface temperature	N/A	0.3 K	Buoys OSTIA High resolution LEO/GEO radiometers
Land surface temperature	N/A	1 K	Ground-based radiometers Space-based high resolution radiometers, e.g. SEVIRI LSA
Ice surface temperature	N/A	1 K	In situ measurements... High-resolution radiometers?
Land and ice surface emissivity	N/A	1 %	Direct measurments? Aircraft (ARIES?)



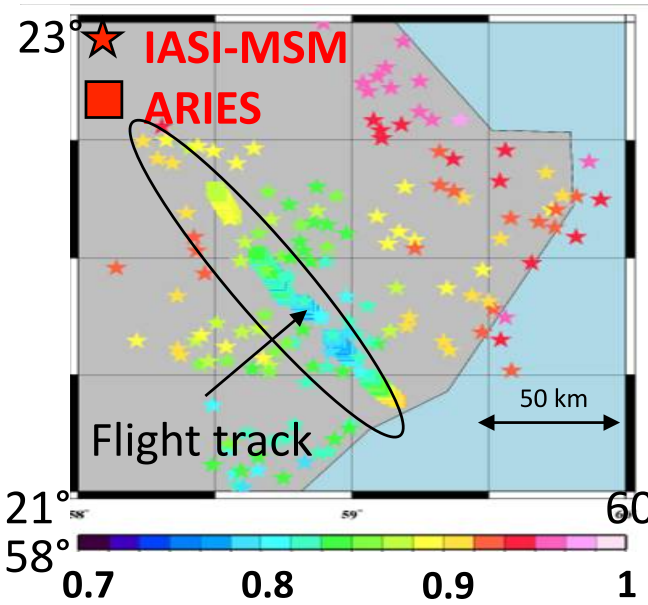
Emissivity spectrum retrieved retrieved from IASI

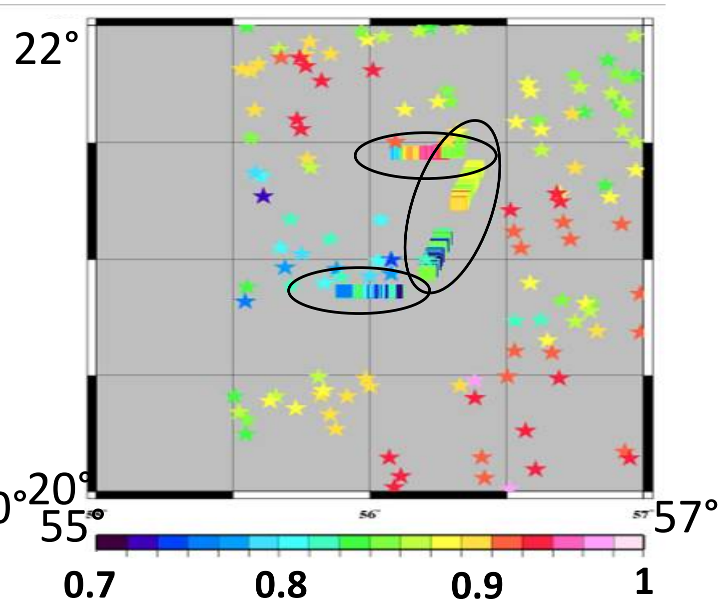


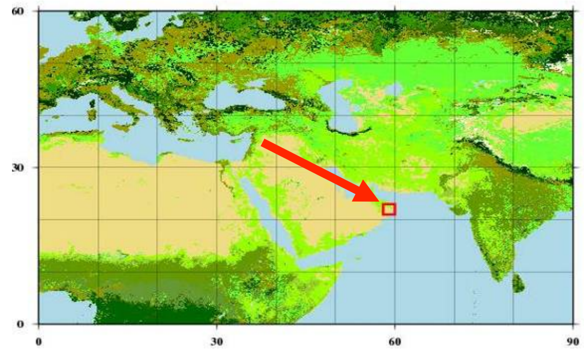


Comparison of IASI and ARIES emissivity from the MEVEX Oman campaign, May 2009

Emissivity at 9 microns:







Capelle et al., 2014

Clouds

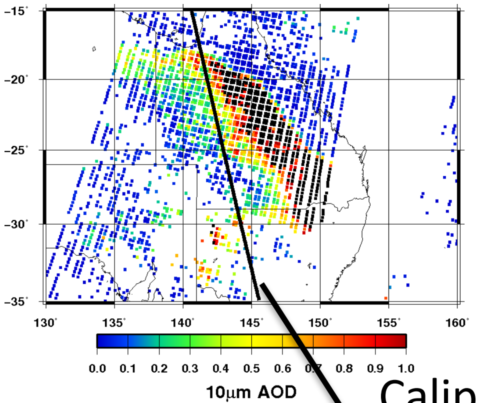
Product	Vertical Resolution	Accuracy	Reference data source
Cloud detection and fractional coverage	6 km	10 %	GEO/LEO imagery Ground-based WSI, other ?
Cloud top phase	N/A	10 %	???
Cloud top height /pressure	N/A	0.2 km	Ground-based cloud radar, Lidars Space-based active sensors (CALIPSO, EarthCare...)
Cloud drop effective radius at cloud top	N/A	5 µm	???
Cloud liquid water path from MWS and IAS	N/A	5 %	Ground-based radar, MWR? Space-borne data: EartCare, CloudSat? Can we demonstrate 5% ?

- Very few validations have been done with IASI.
- Statistical comparison of cloud climatologies (e.g GEWEX cloud assessment).
- Common plan with 3MI would be an asset.

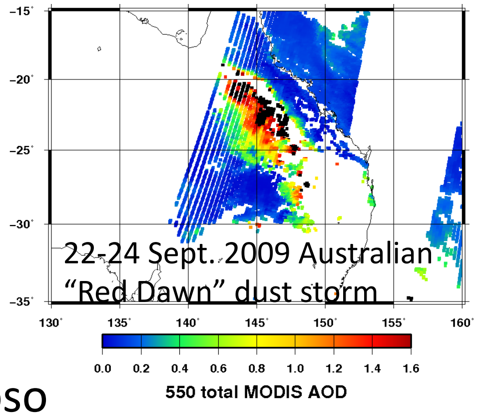
Aerosols

Product	Reference data source
Dust AOD at 10 µm	GEO/LEO imagery Aeronet
Dust mean altitude	Ground-based and airborne lidars, space lidars
Effective radius	?

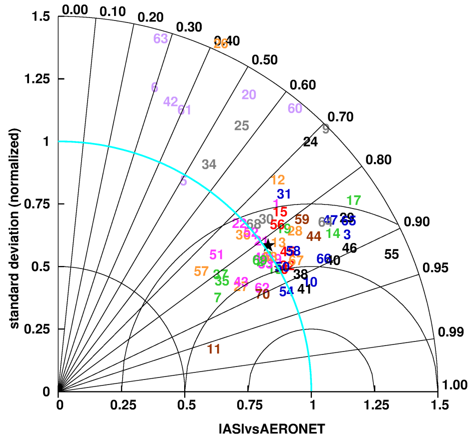
IASI AOD



MODIS AOD

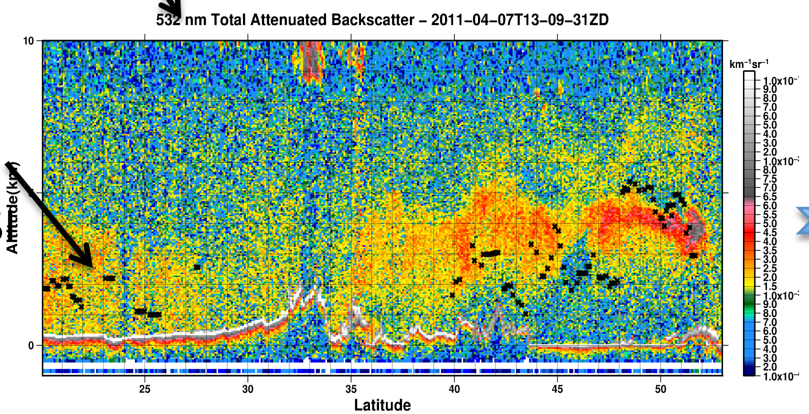


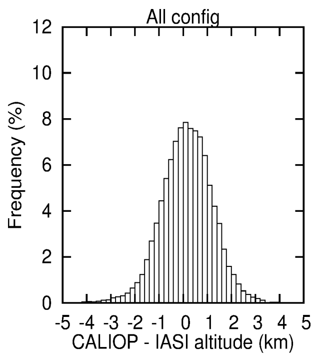
Validation of IASI AOD with Aeronet



Calipso

Mean altitude from IASI





Validation of IASI alt. with Calipso
-0.26 ± 1.02km

Capelle et al., RSE, 2017

Atmospheric composition

Product	Vertical Resolution	Accuracy	Reference data source
Carbon monoxide profile	3 km	3 km LT: 30 % MT: 25 % HT, S: 20 %	In situ measurements (airborne, ground) Space-borne missions? Other?
Carbon monoxide partial column	3 km	10 %	NDACC ground stations
Ozone profile	3 km	LT,MT, UT: 20 % S: 10 %	O_3 sondes Other space missions? Model?
Ozone total column	N/A	5 %	Ground Brewer, Dobson
Sulphur dioxide total column	N/A	50 %	?
Nitric acid partial column	T, S	20 %	NDACC?

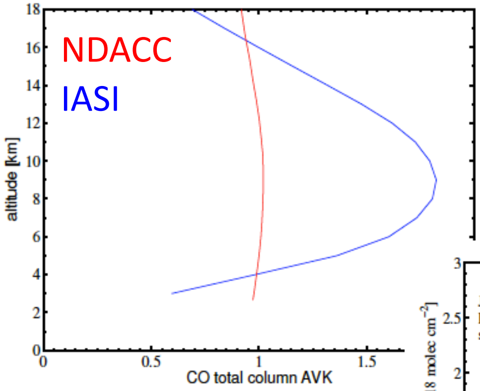
The challenge: more than 25 atmospheric species retrieved or detected.

How to fully validate columns?

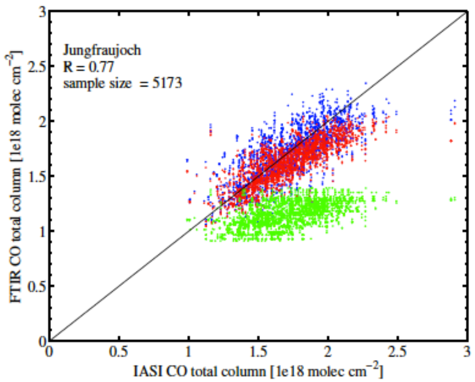
An example: Validation of IASI CO

NDACC

Averaging kernel at Izana



Total columns



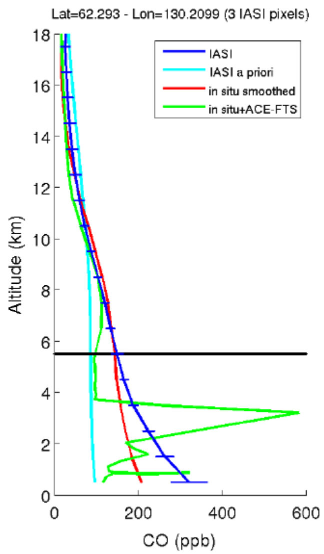
No-correction
Altitude corrected
Full correction

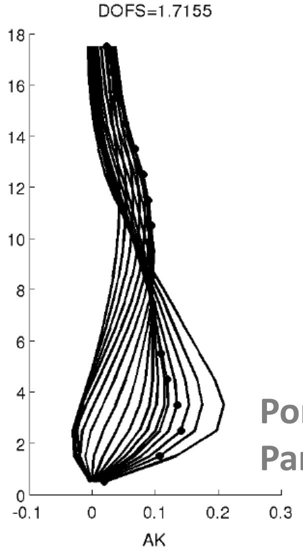
$$x_s = x_a + A\,(x - x_a)$$

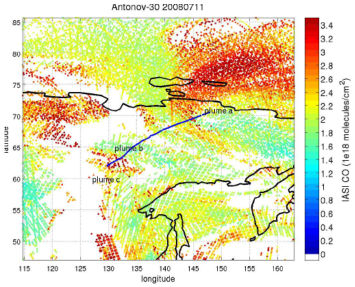
Kerzenmacher et al., 2012

Also done for NH3 (Dammers et al., 2016), and Ozone Total and Partial Column

Aircraft





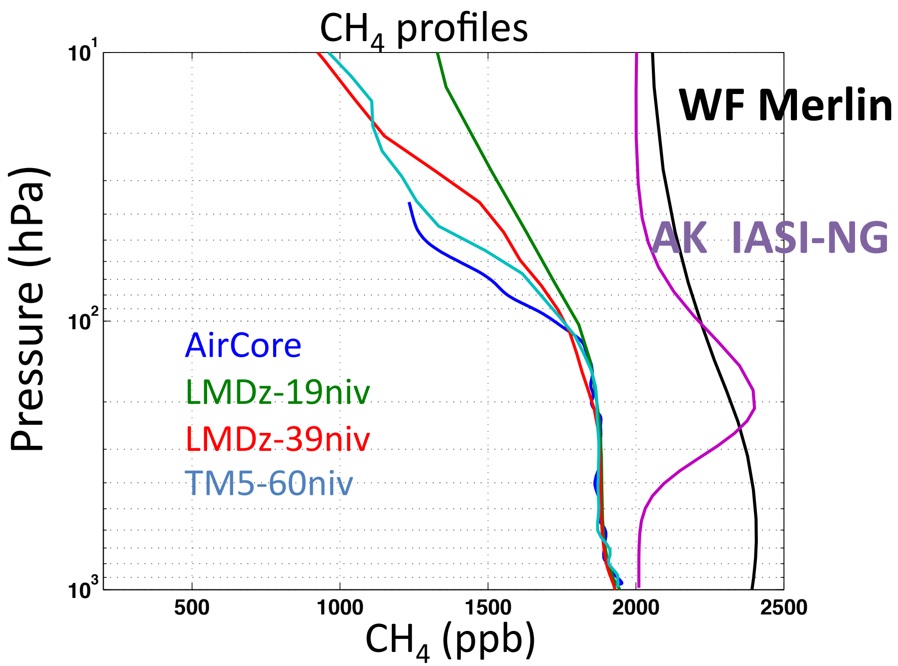


Pommier et al., 2010
Paris et al., 2009

- In IPY/POLARCAT biomass burning plumes transport has been observed from Siberia and Kazakhstan across the North Pole to North America.
- Biomass burning plumes have been used as a contrasted signal to validate spaceborne IASI measurements of pollutants (CO).

Greenhouse gases

Product	Vertical Resolution	Accuracy	Data source
Methane mid-tropo. column	N/A	<1%	AirCores, Aircraft, Space Carbon mission?, Ground-based FTIR (NDACC) Models/Assimilation (CAMS)
Carbon dioxide mid-tropo. column	N/A	<1%	
Nitrous oxide mid-tropo. column	N/A	10 %	



•Mean value: ~1800 ppb.
•Stratospheric decrease: -800 ppb over 100 hPa (~10 km).
•Strong differences between atmospheric models.

• **Merlin total column**

→ between the 4profiles:

différence in XCH4 between 6 and 12 ppb…

• **IASI/IASI-NG : mid-tropospheric column**

→ between the 4 profiles:

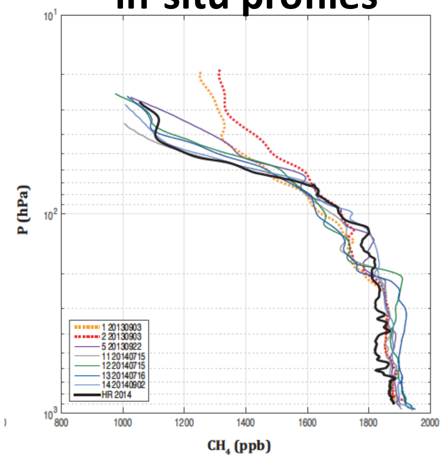
differences ranging from 13 to 26 ppb…

Example of validation of IASI CH_4 mid-tropospheric column

- AirCore: atmospheric air sampler to measure 0-30 km profiles of CO_2, CH_4, CO, C13, H_2O/HDO, NH_3, …
- Originally designed at NOAA (Karion et al., 2010). Several EU teams now making measurements: LMD/LSCE, U. Groningen, U. Frankfurt, FMI, etc.

→ Use of profiles measured at Timmins (Canada), Kiruna (Sweden), Trainou-Orléans and Sodankylä to validate IASI CH_4 mid-tropo. columns:

AirCore CH_4 in-situ profiles



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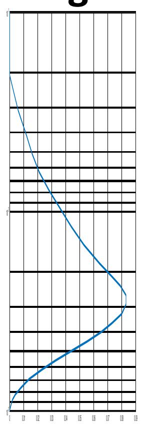
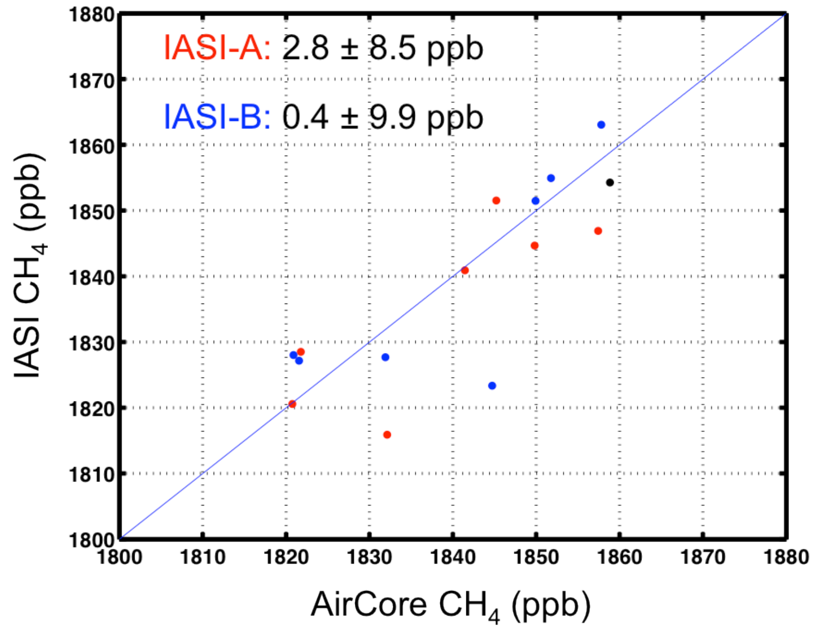
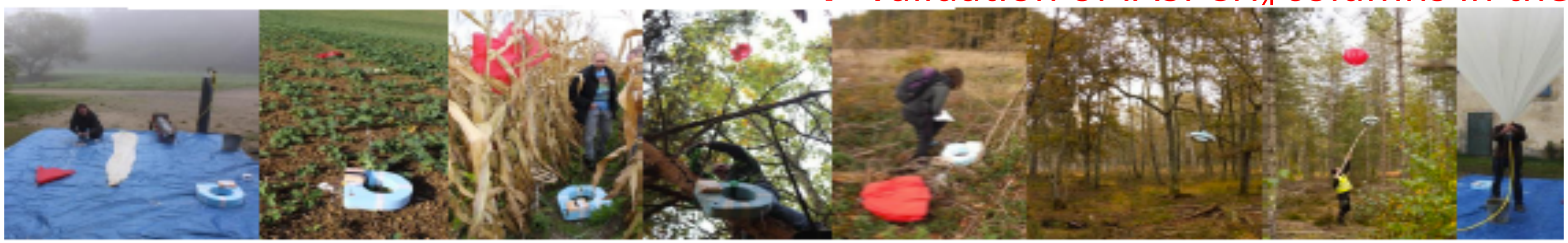
IASI CH_4 Weighting Function





Membrive et al., AMT, 2017

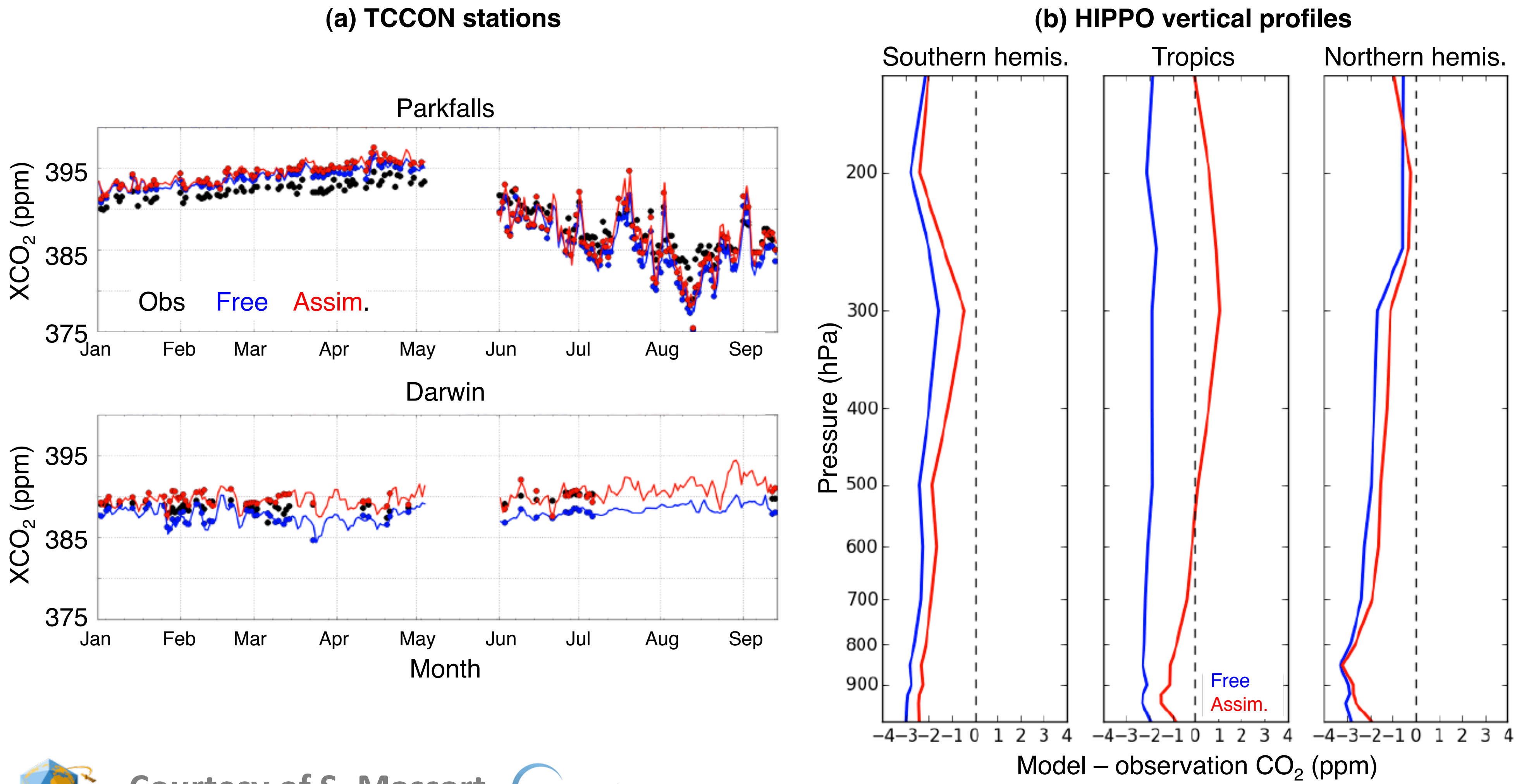
→ Validation of IASI CH_4 columns in the NH.



LMD

Validation through data assimilation and evaluation with TC

- IASI CH_4 from LMD and TANSO-FTS CH_4 from SRON are assimilated within C-IFS at ECMWF (CAMS).
- Evaluation is performed against TCCON stations (XCH4) and HIPPO aircraft profiles.



Courtesy of S. Massart

Validation strategy for IASI-NG… and any other mission

1. Compliance matrix

What data (and their merits) for what product?

2. Short-term validation

- Aircraft campaigns (SAFIRE, DLR, FAAM facilities)
- Balloon campaigns (CNES balloon program)
- Combined ground-aircraft-balloon-surface campaigns at super sites

3. Long-term validation

- Satellite inter-comparisons
- ground networks → need for continuous support!!
- Model comparison/data assimilation (indirect)

4. Pre-launch validation requirements

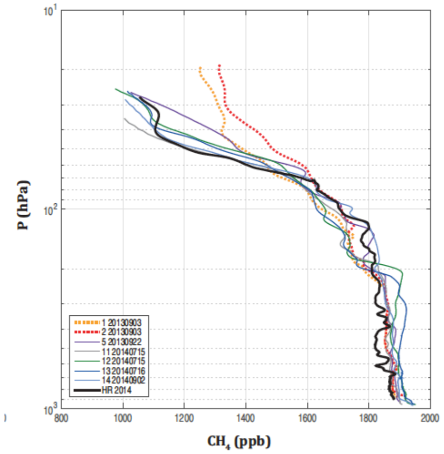
- Selection of ground-based supersites
- Instrument upgrade/validation ?
- Validation test campaign

Validation strategy

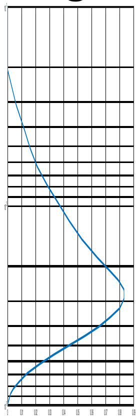
- **Coordination of validation activities between missions would be a real asset:**
  - within Metop-SG (IASI-NG, 3MI, Sentinel5/UVNS, etc).
  - between different platforms.
  - → Best use of funding, man-power, aircraft availability, scientific objectives.

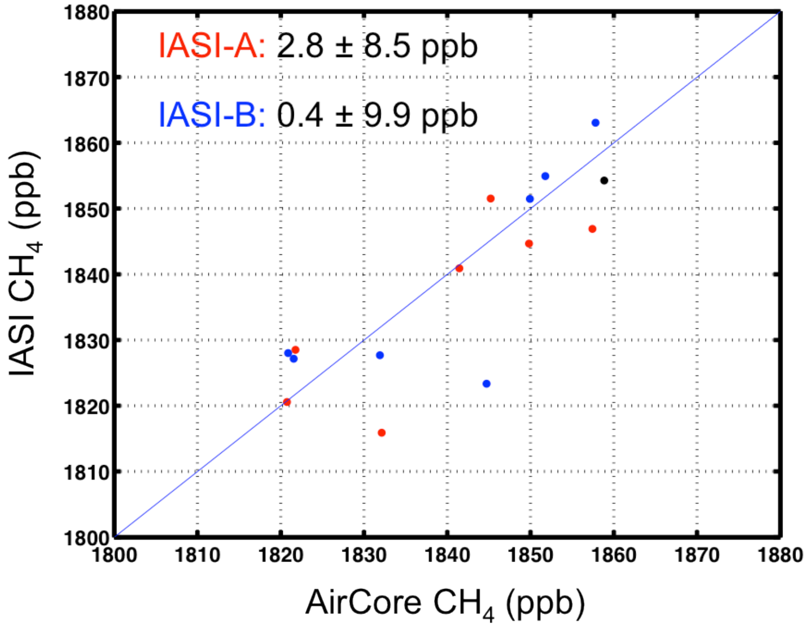
- **Specifically for GHG:**
  - joint validation strategies between Merlin, MicroCarb and IASI-NG (all launched around 2021).
  - preparatory activities are on-going:
    - → **Multi-instrument campaigns at Trainou-Orléans (LMD-LSCE-LERMA):**
      - 2 week-campaign in April 2017: ICOS/TCCON + EM27/SUN (KIT/LERMA) +0-3 km aircraft + AirCore-light + OCO-2 (target mode) + IAGOS (10 km).
      - plan: a campaign every 3 months.
    - → **CoMet campaign (coordinated by DLR):**
      - May 2018.
      - flights between TCCON EU stations.

Example of validation of IASI CH4 mid-tropospheric column

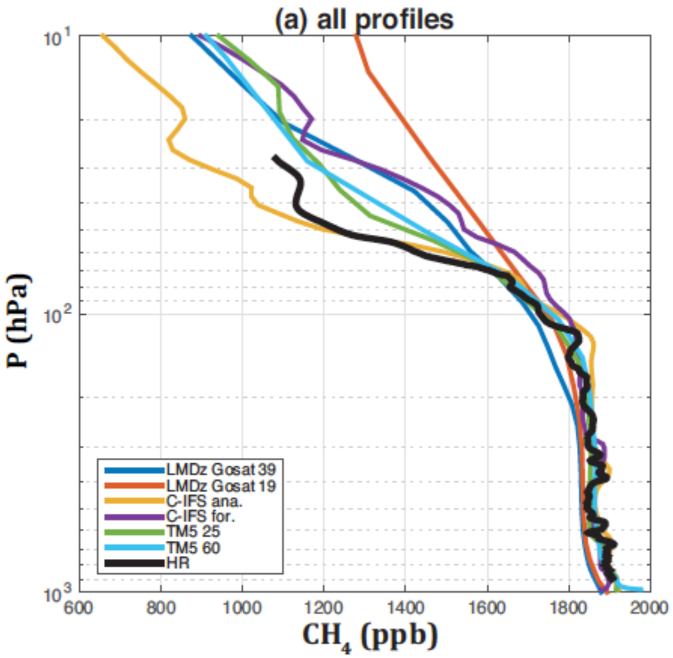


IASI CH_4
Weighting Function





→ Validation of IASI CH_4 columns in the NH.



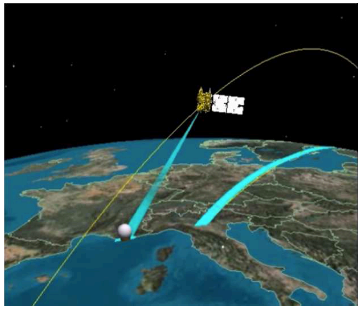
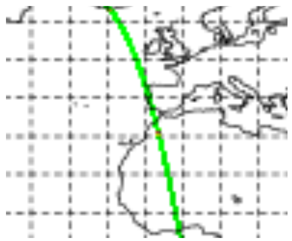
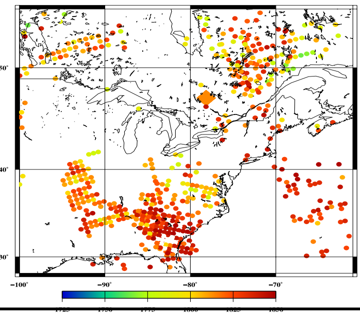
LMDz - AirCore = 12 ppbv

TM5 - AirCore =13 ppbv

C-IFS - AirCore = 19ppbv

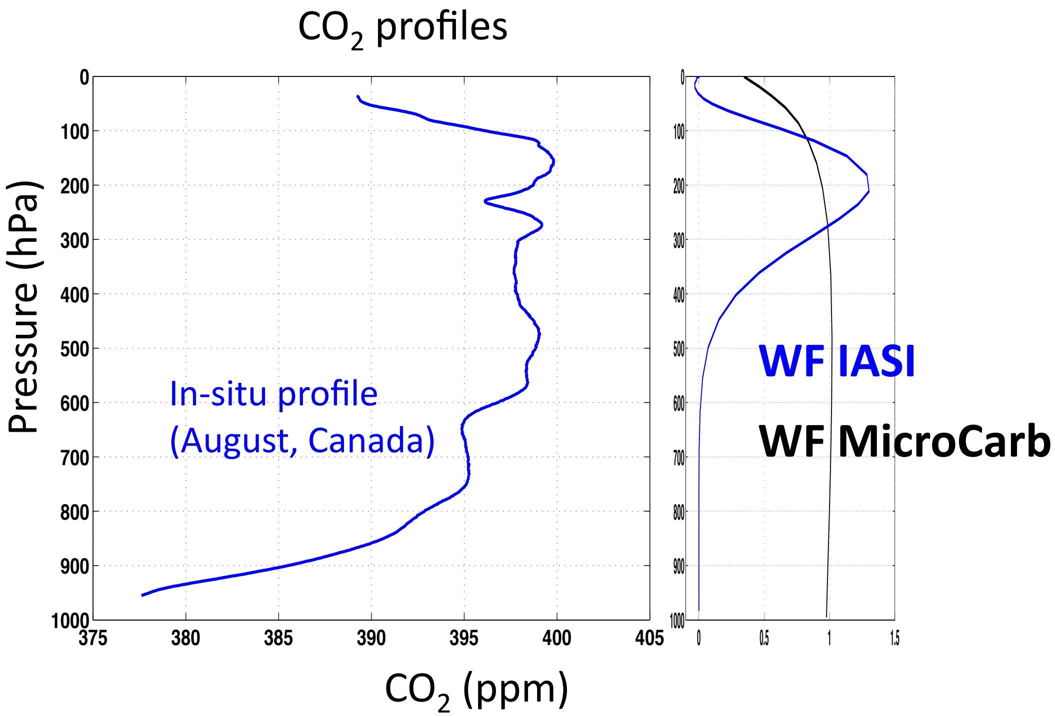
→ Systematic overestimation of CH_4 in the stratosphere by the models

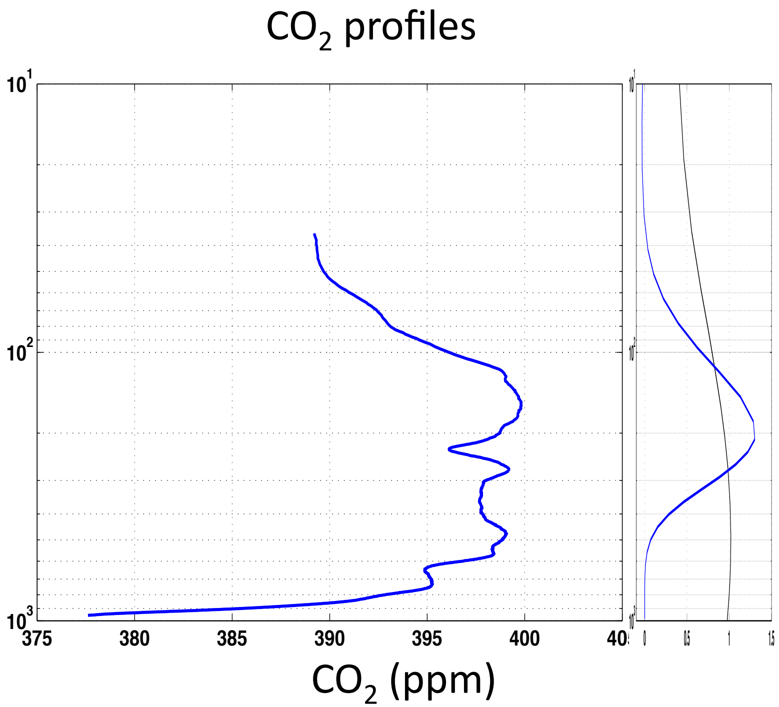
3 CNES missions

	MicroCarb	Merlin	IASI/IASI-NG
Date of launch	**2021**	**2021**	2007-2012-2018 **2021**-2028-2035
Local time	10:30	6:00-18:00	9:30-21:30
Level 2	Total column of XCO2	Total column of XCO4	mid-tropo. column of CO2 and CH4
Syst. error	< 0.1 ppm	< 3 ppb	< 1 ppm | < 5 ppb
Random error	< 1 ppm	< 27 ppb	< 3ppm | < 12 ppb
Geometry	Swath: 13km 3 FOV 40km2	50km	Swath: 2000 km FOV: 12 km@nadir
			

Coordination of validation activities between these 3 missions would be highly valuable!!

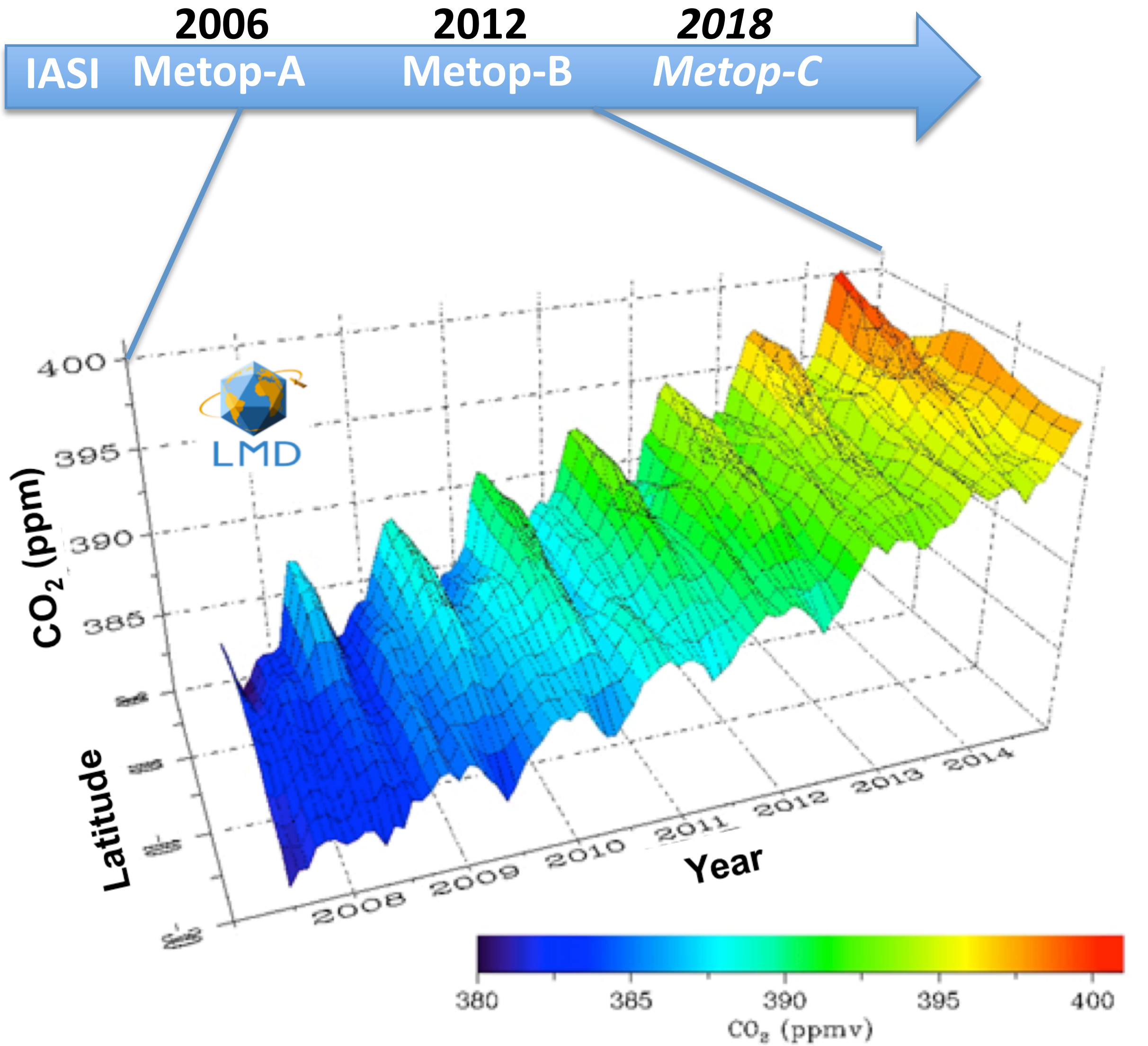
Validating CO2 columns?



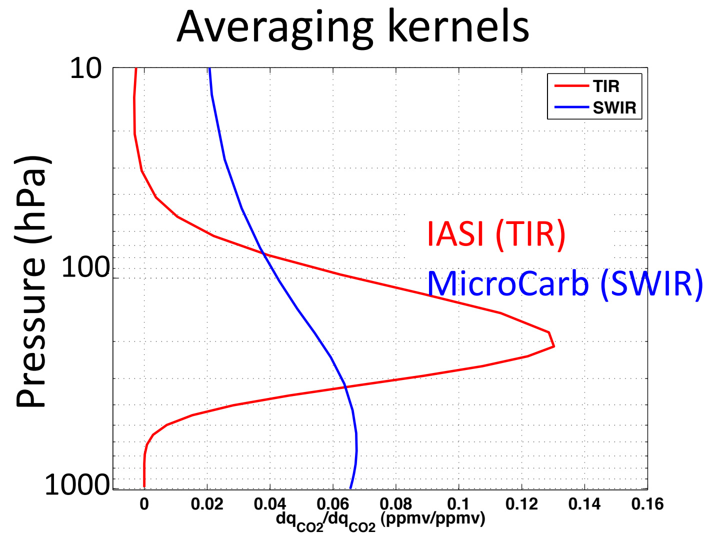


- Mean value: ~395 ppb.
- Strong variation near the surface (< 4 km).

From IASI to IASI-NG



Mid-tropospheric columns of CO_2

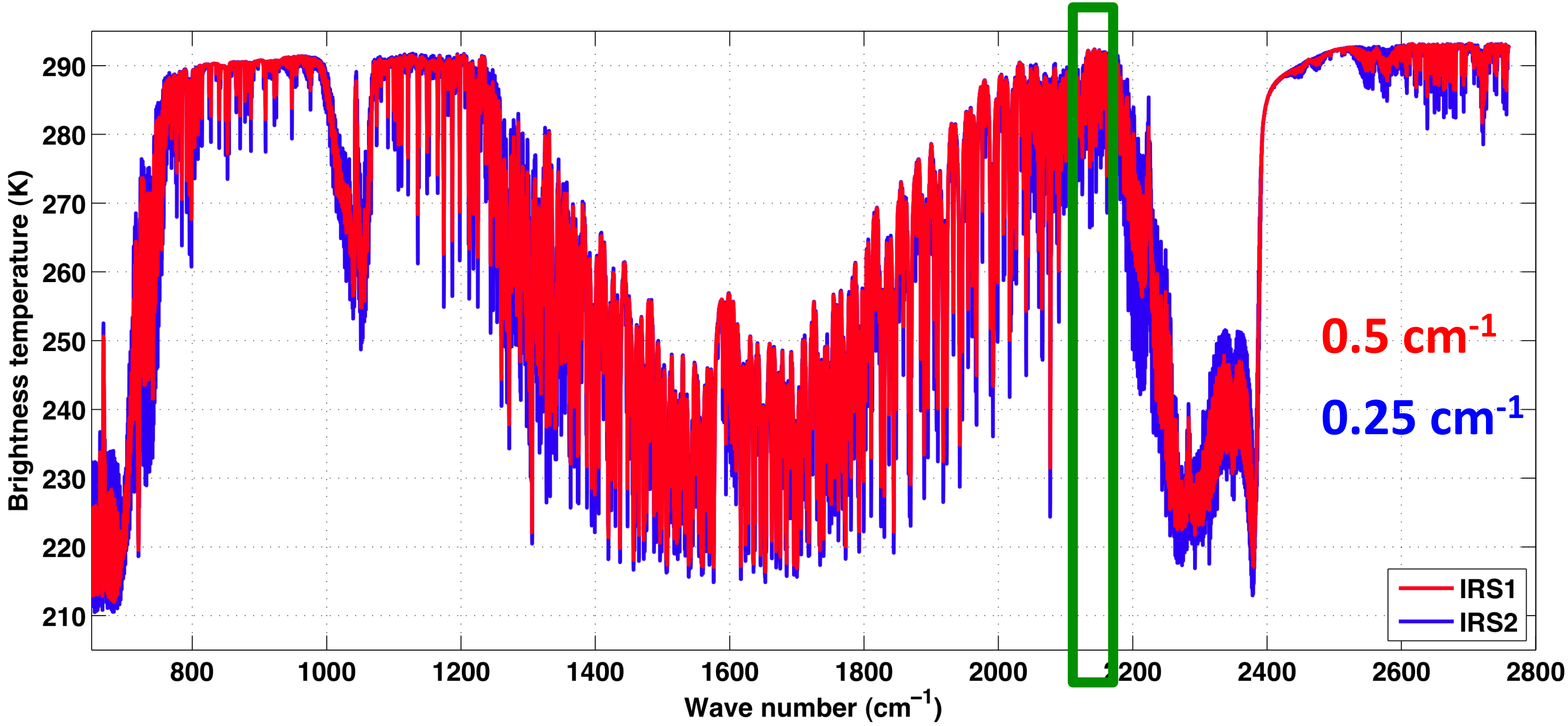


IASI vs. IASI-NG

IASI and IASI-NG spectrum

Averaged over the whole tropical TIGR situations

Computation with the 4A/OP RT code, using the GEISA-11 spectroscopic database



Validation plan

Goal:
- To assess the usefulness of GHG columns products for their intended scientific applications
- To assess the products quality by comparing them to data which are regarded as a reference.

Central questions:
- How representative are the satellite retrieved products for the actual atmospheric state?
- What are the systematic and random errors?
- How well are the temporal variations of XCO2/XCH4 captured (daily to annual)?
- How well are spatial structures captured, from local emission sources to global features?

How:
- Definition of quantity to be validated.
- Identification of already existing and planned instruments, networks, programs, and satellite missions which are potentially suited to be included in the validation organization.
- Identification of potential gaps (updating of existing sensors ? to start the development of missing validation instruments or concepts?)

→ organization of the scientific community (both at national and international levels).

Scope:
Short-term, long-term or campaign-based validation activities.

Validation plan: example of Merlin

	XCH4	DAOD	Met. parameter	Representativity	SSE	Clouds	On-line freq.	Spect. purity	Albedo	Canopy
GAW surface networks: Mixing ratios values Mixing ratios trends	+ +++									
Surface, passive TCCON, NDAC	++									
Surface, active LIDAR DIAL and others Ceiloeter, Radar	+++	+++	++	+++		+++ +++	+++			
Balloon, in-situ Aircore, pico-SDLA	+++	+++	+++	++						
Aircraft, in-situ CRDS, TDLAS	++	5++	+++	++						
Aircraft, passive r.s. DOAS , …	++									
Aircraft, active IPDA LIDAR	+++	+++		+++	+++	+++	+++	+++	+++	+++
Satellite, passive DOAS, FTIR Cloud Imager SWIR	++					++			++	
Satellite, active Lidar, Radar				++	++	++				++
Models MACC, Copernicus	o				o					

Table 5.1.1: Synthesis table of the MERLIN products and parameter (row 1) versus the instruments of the validation platforms and activities (column 1) discussed in this document. Several level validation are estimated : o : comparison, + : indirect validation, ++ : direct validation with hypotheses, +++ : prioritized direct validation

- ICOS, NOAA/ESRL, etc through GAW.

- TCCON, *COCCON* → total columns

Lidars

Balloons (AirCore, Amulse, pico-SDLA, SPECIES)

AirCraft:

- in-situ (CRDS, Amulse, SPECIES)
- Passif (Bremen MAMAP, *UK GHOST, ESA ACADIA, SRON SPEX*)
- Actif (CHARM-F)
- Drones?

Satellites

Models, Assimilation

Balloon-borne measurements

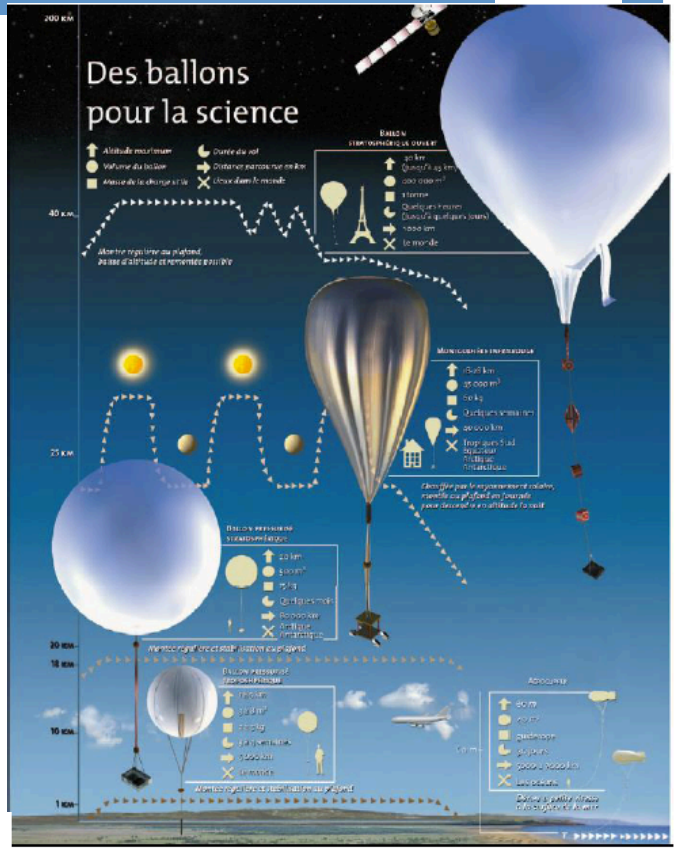
- **CNES balloon facilities:**

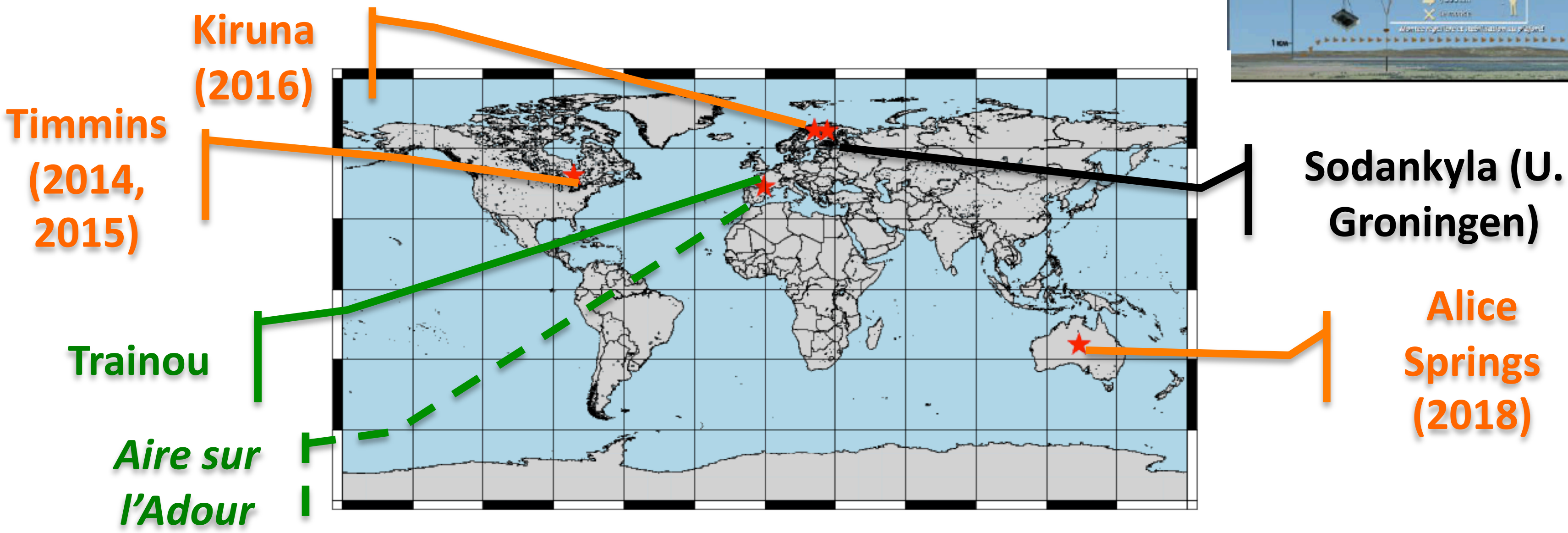
•Annual BSO campaigns:

- Open Statospheric Balloons for heavy payloads (>100kg)
- 3 sites: Timmins (Canada), Kiruna (Sweeden) and a future tropical site.

•Meteorological balloons (<3 kg) from Aire-sur-Adour (ASA).

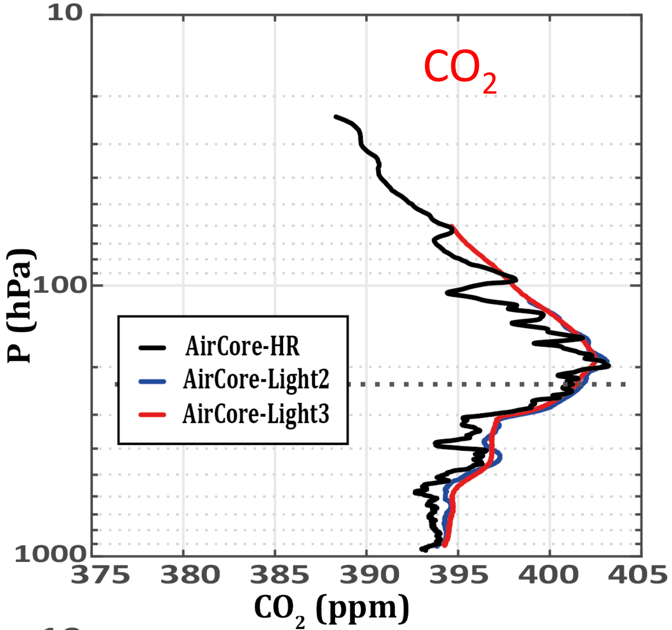
•BPS ballons (e.g. Stratéole-2, ConcordIASI): See P. Cocquerez presentation.

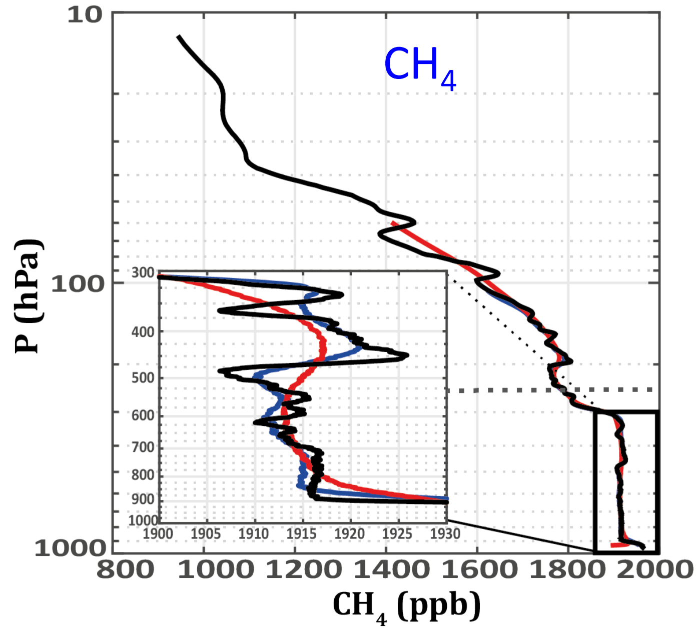




Balloon-borne measurements

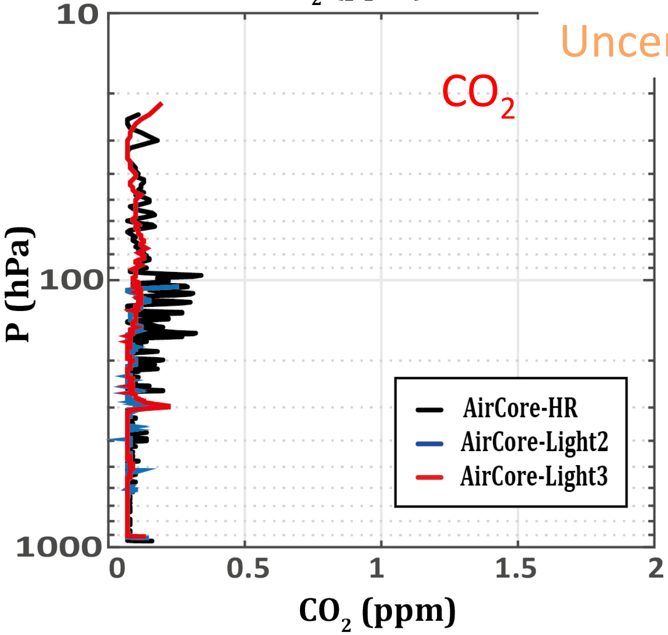
AirCore profiles and associated uncertainties

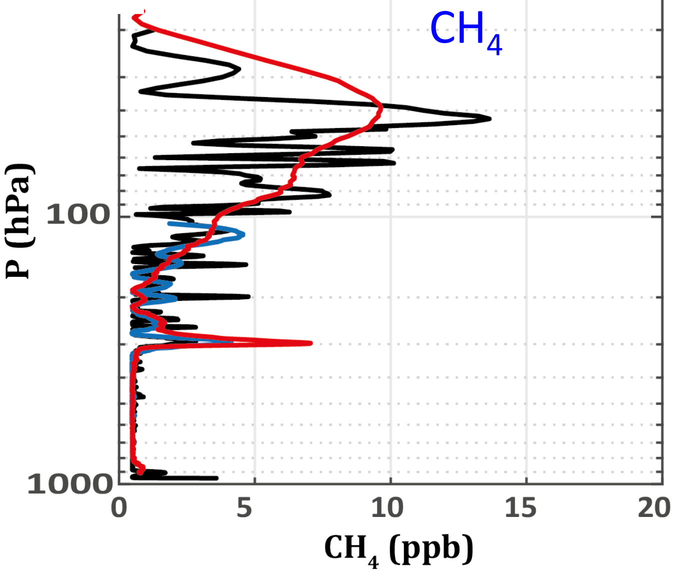




- Excellent agreement between the AirCores, especially for CH_4 (within 2 ppb when resolution taken into account)

Uncertainties





- For CO_2: <0.2ppm
- For CH_4: <3ppb
- Important vertical gradients translate into large uncertainties.

Way forward

- **Creation of a new « super-site » in the South-West of France:**
  - ASA is the main candidate due to available CNES infrastructure + man power.
  - Could combine: continuous measurements of CO2/CH4/CO for ICOS + FTS (either TCCON or COCCON type instruments) + regular balloon launches (AirCore, maybe Amsule) + regular SAFIRE flights.
  - Could be used to host specific campaigns.
  - Interest of a station in French Guyana to be assessed.

- **Need for coordinated measurement campaigns:**
  - Involvement of different vectors/space mission/scientific objectives.
  - 3 main regions of interest:
    - mid-latitudes (linking TCCON/ICOS stations)
    - tropics (benefiting from new balloon site?)
    - high-latitudes (from Kiruna: BSO + meteorological balloons + TCCON/NDACC + COCCON + YAK) → a great project!

- **Participating to the funding of TCCON/NDACC networks would be greatly appreciated.**

The CoMet campaign

Carbon Dioxide and Methane Missions for HALO

The CoMet campaign

Carbon Dioxide and Methane Missions for HALO

CoMet: Complementary and Innovative Payload

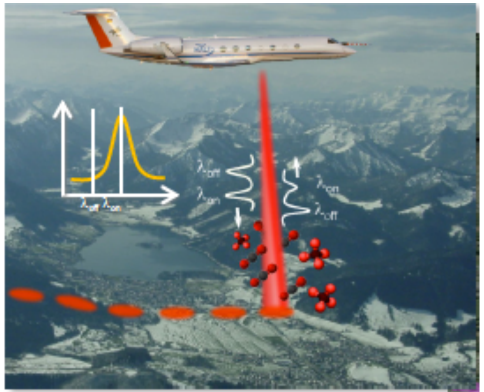
- ✓ **Active Remote Sensing (CHARM-F, Lidar):**
  high accuracy,
  day / nighttime, high latitudes
  insensitive to clouds and aerosol
  future satellite instruments
- ✓ **Passive Remote Sensing (MAMAP)**
  very precise
  well adapted to local sources
  similar to current satellite instruments

→ Measurement of GHG columns (**XCO_2 and XCH_4**) between ground and flight level

- ✓ **In-situ instruments (JIG, JAS)**
  highest accuracy and precision
  WMO standard
  Isotope analysis for source identification

→ Accurate profiling

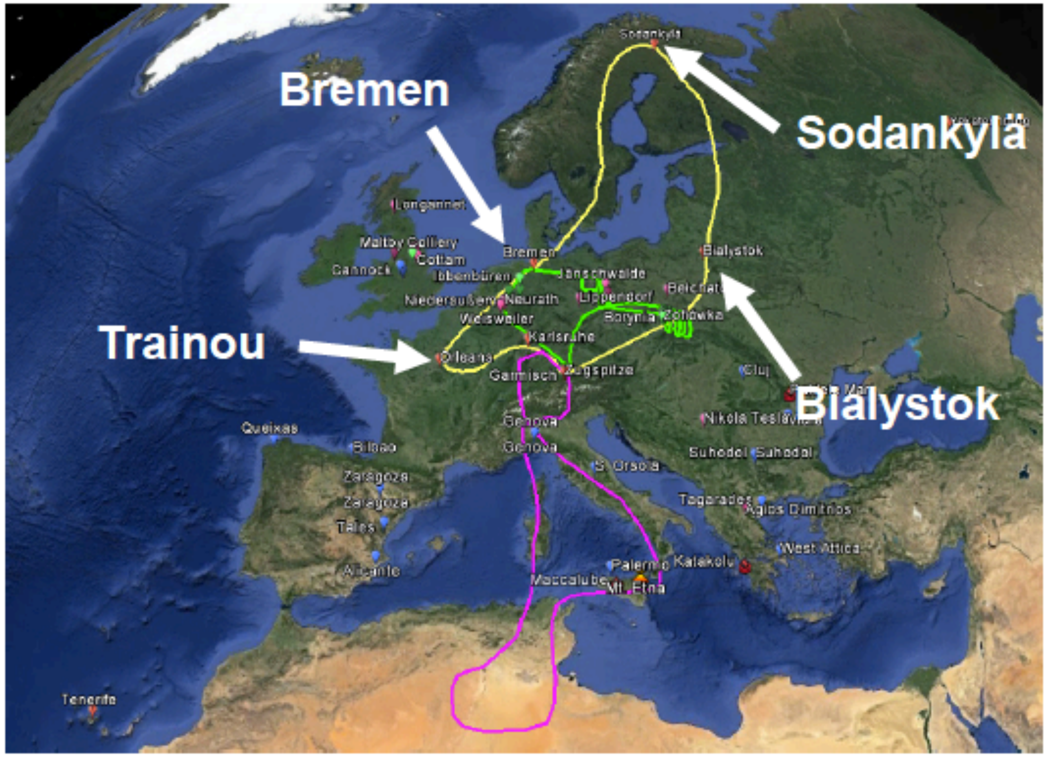
- ✓ **Ancillary information (BAHAMAS, mini-DOAS, dropsondes)**
  meteorology, source information



The CoMet campaign

Carbon Dioxide and Methane Missions for HALO

Tentative HALO Flights

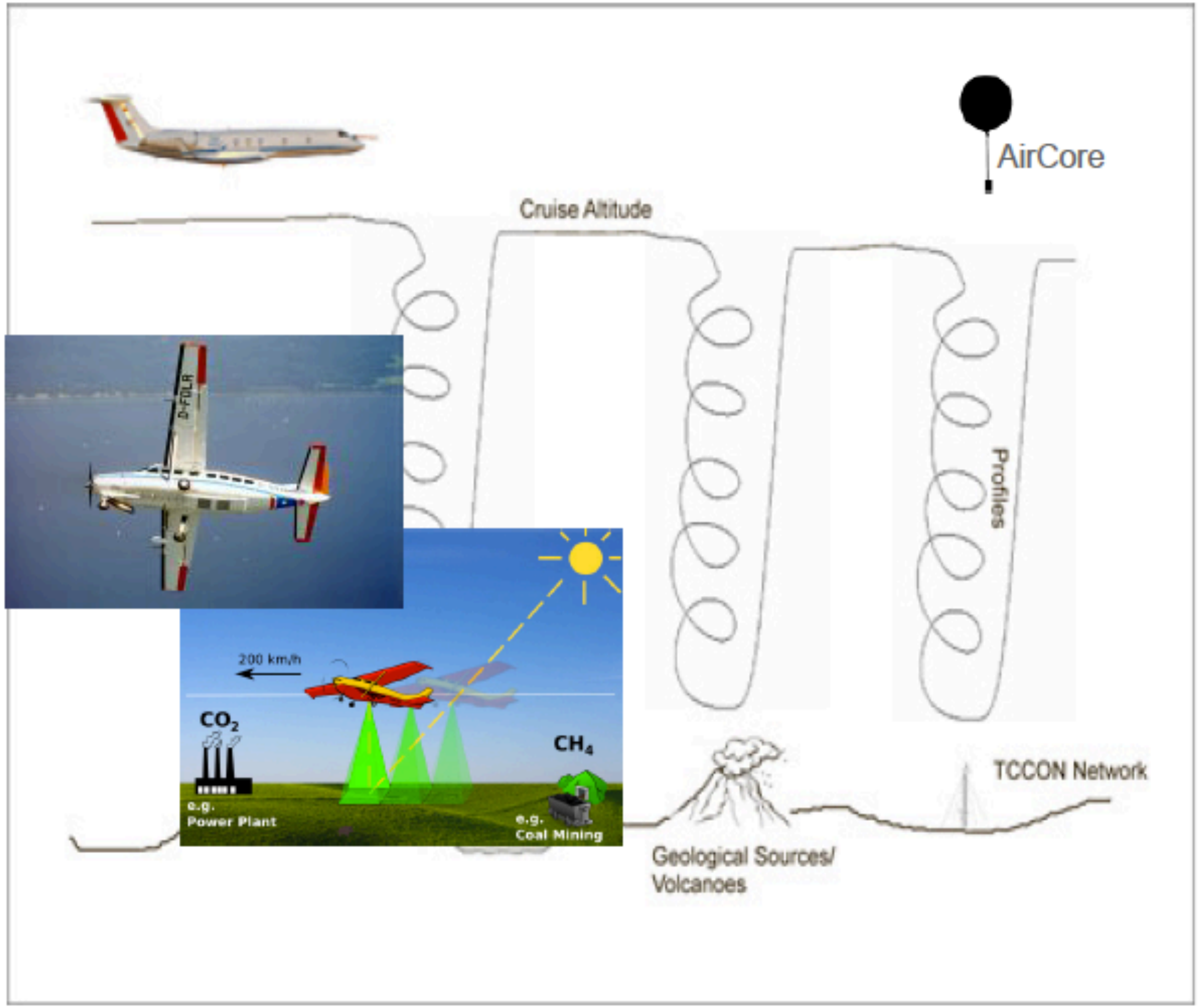


Scientific Flights: 18 April – 17 May 2017
63 Flight hours, ~8 Flights
Base: Oberpfaffenhofen (EDMO)

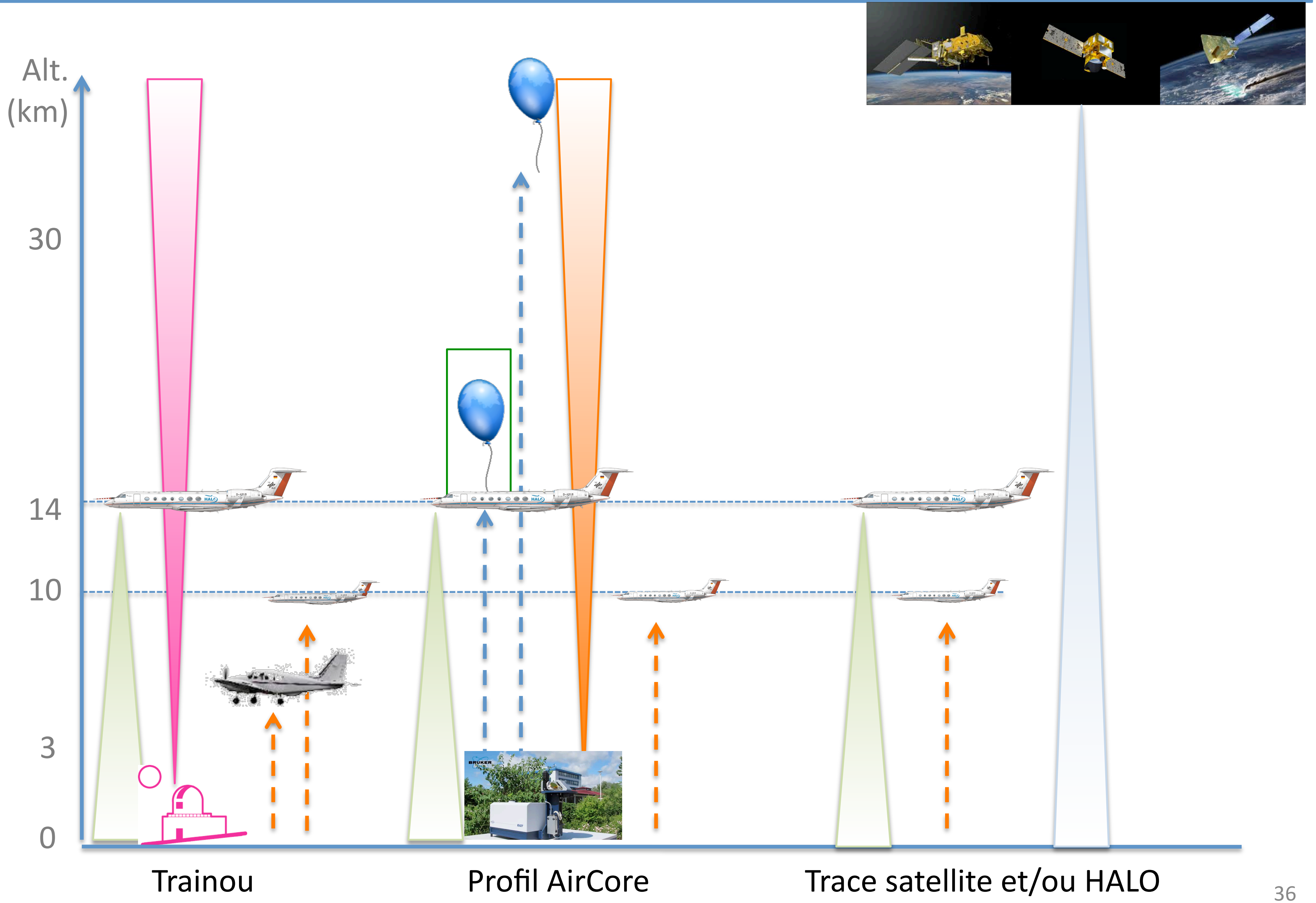
- **TCCON sites + AirCore launches**
- Latitude gradients
- Coal mines (Poland)
- Power plants
- Landfills
- Urban area (e.g. Berlin)
- Volcanoes
- Orography
- Vegetation
- Albedo variations
- …..

Carbon Dioxide and Methane Missions for HALO

Measurement Strategies of CoMet



En résumé…



Alt.
(km)
30
14
10
3
0
Trainou
Profil AirCore
Trace satellite et/ou HALO