Imagerie Hyperspectrale Infrarouge pour le sondage des gaz dans l'atmosphere (depuis l'espace)

3ème colloque scientifique de la SFTP-GH
Porquerolles, 15-16 Mai 2014

NOVELTIS : P. Prunet, C. Camy-Peyret, O. Lezeaux, N. Lautié, A. Klonecki, E. Dufour, C. Standfuss, B. Tournier, S. Bijac, E. Bernard, E. Jeansou

Eléments de:
LATMOS, LSCE, LISA, LMD, ULB, SRON, IUP-Bremen, CNES, EUMESAT, ESA, OHB, ENEA

NOVELTIS

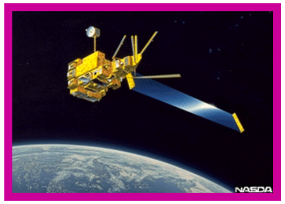
Sondage Atmosphérique haute resolution spectrale dans l'infrarouge … Vers l'imagerie Hyperspectrale

1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006

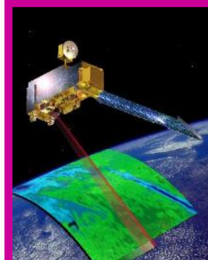
Contribution majeure à la mesure de la constitution atmosphérique.

Forte implication de la communauté scientifique Française et Européenne pour la chimie, la qualité de l'air, le climat

IMG/ADEOS



MOPITT/TERRA

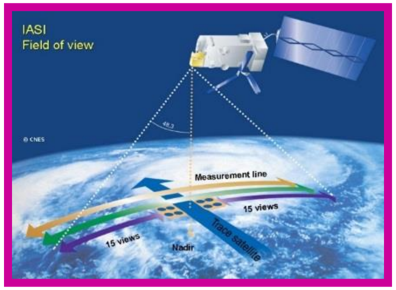


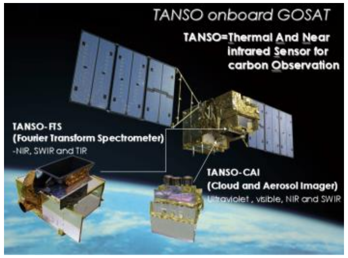
TES/AURA

MIPAS/Envisat

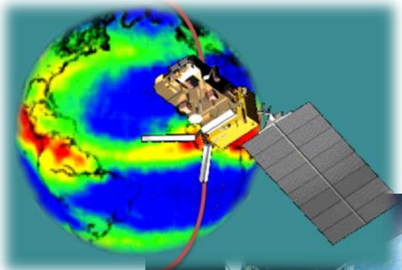
2006 2007 2008 2009 2010 2011 2012 2013 2014 … 2019 2020 2021

IASI/MetOp ….. **IASI/MetOp B … MetopC**



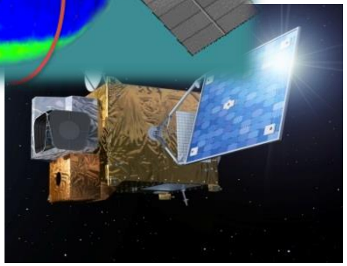


TANSO/GOSAT



IASI-NG/MetOp-SG

Sentinel 5 (UVNS)



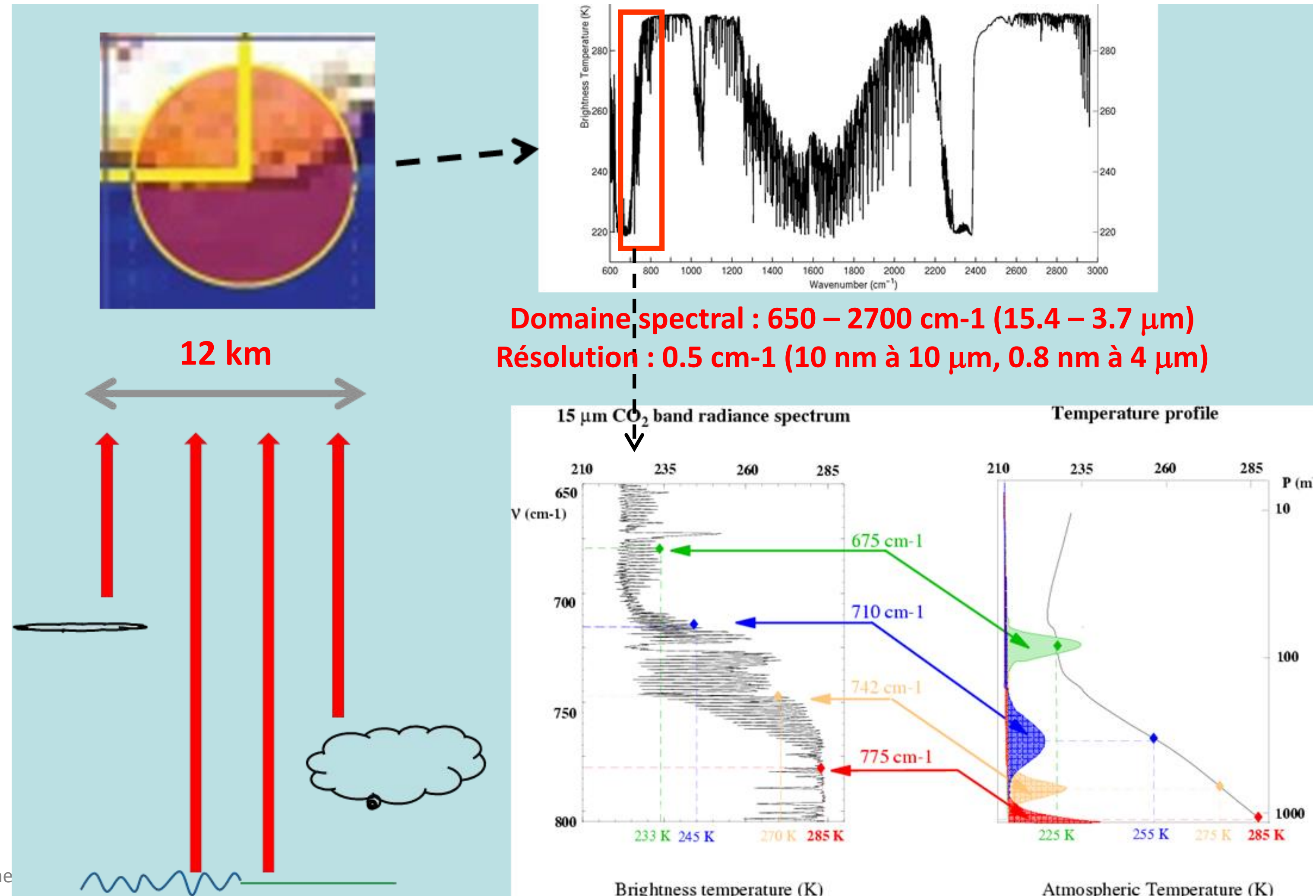
IRS/MTG-S & Sentinel 4

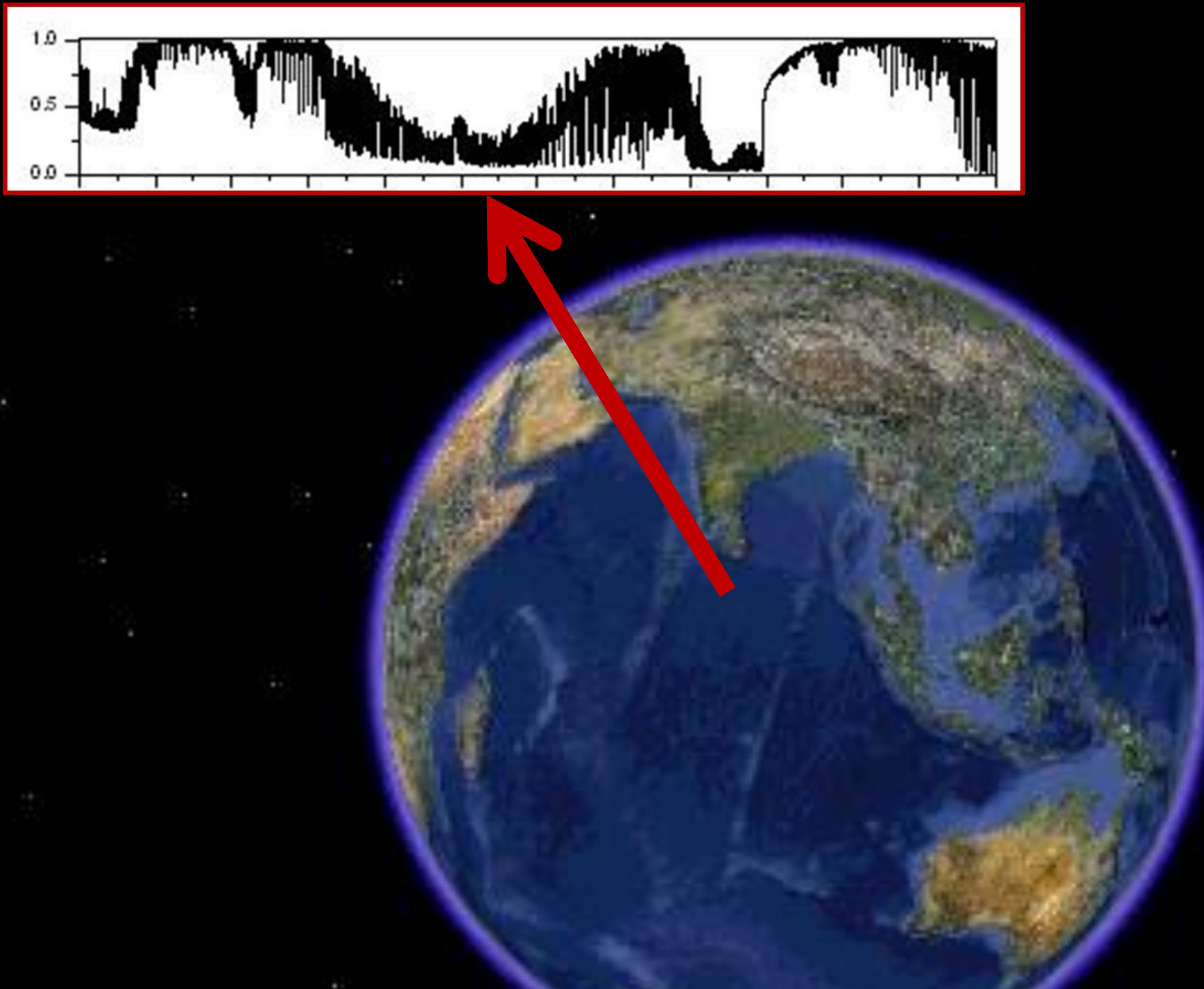
Principe de la mesure

Sondage atmosphérique : sensible au rayonnement de l'atmosphère ET de la surface. Difficulté à séparer les deux contributions dans la zone de plus grand intéret : la basse atmosphère.

Mesurer la structure verticale de l'atmophère et les espèces chimiques par la haute resolution spectrale

- **Nécessité d'une connaissance fine de la surface (et des nuages) pour bien restituer l'atmosphere (couplage imagerie sous-pixel)**
- **Information sur la surface temperature, émissivité spectrale)**





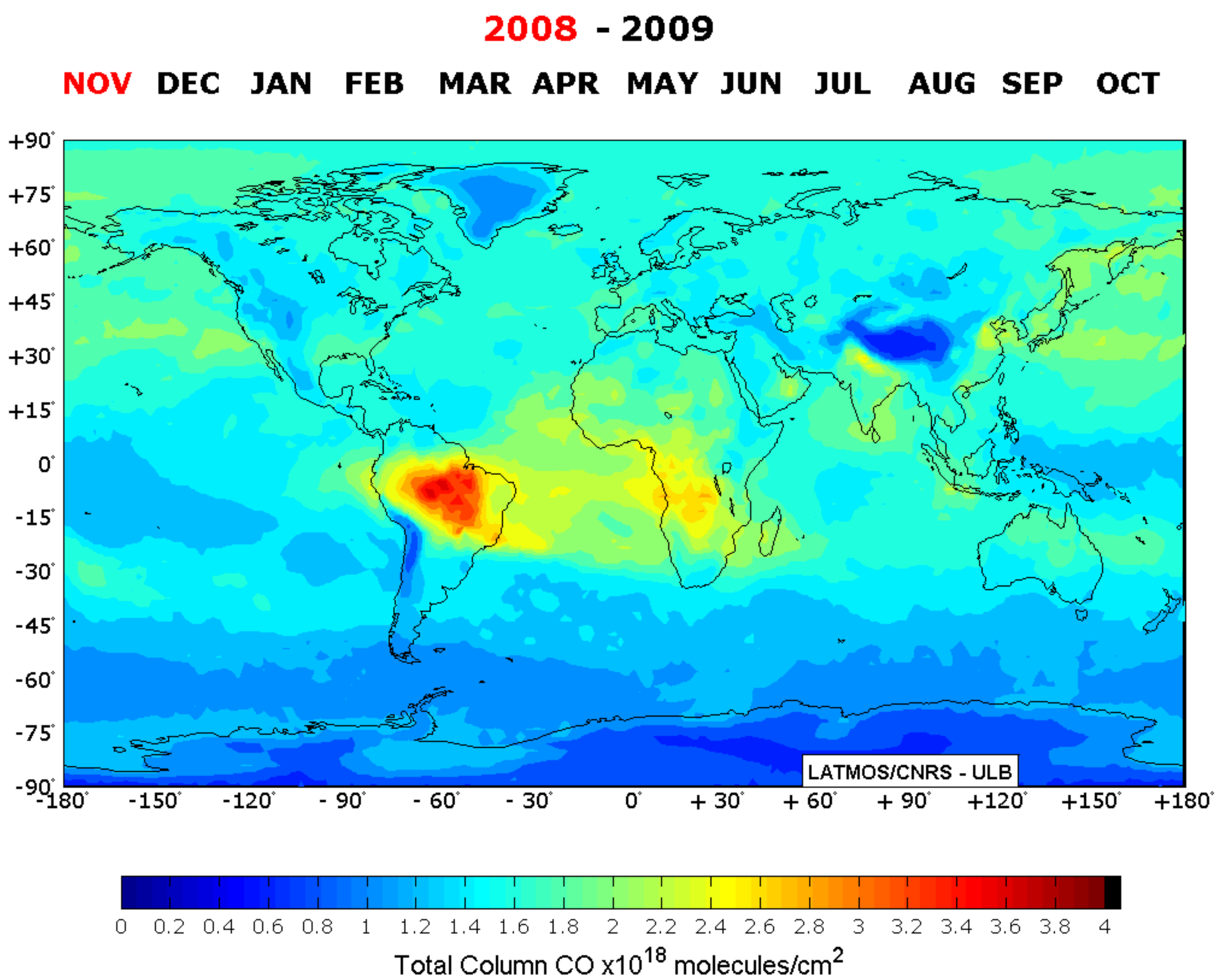
8431 channels /spectra

~15 GB data/day

~1,3 million spectra/day

Courtesy M. George, C Clerbaux, LATMOS

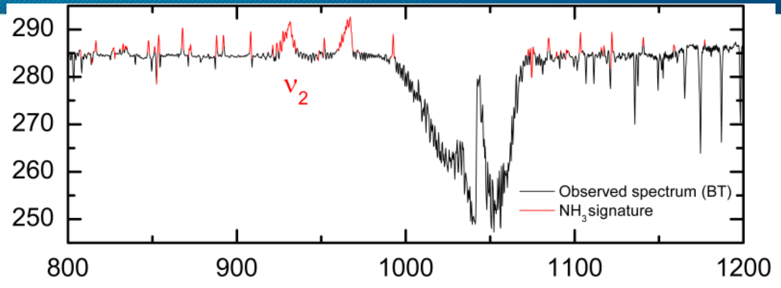
Carbon monoxide

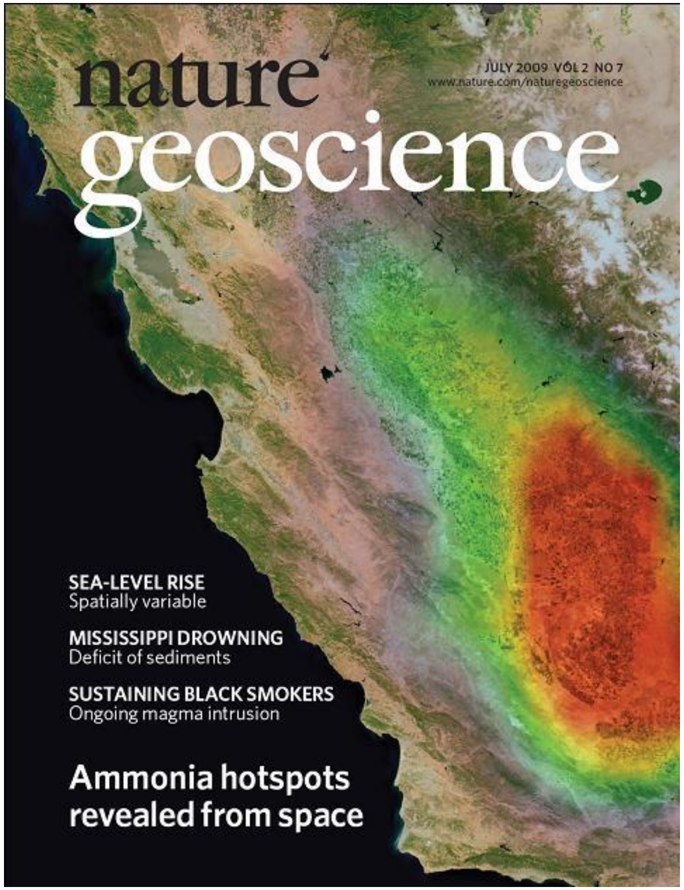


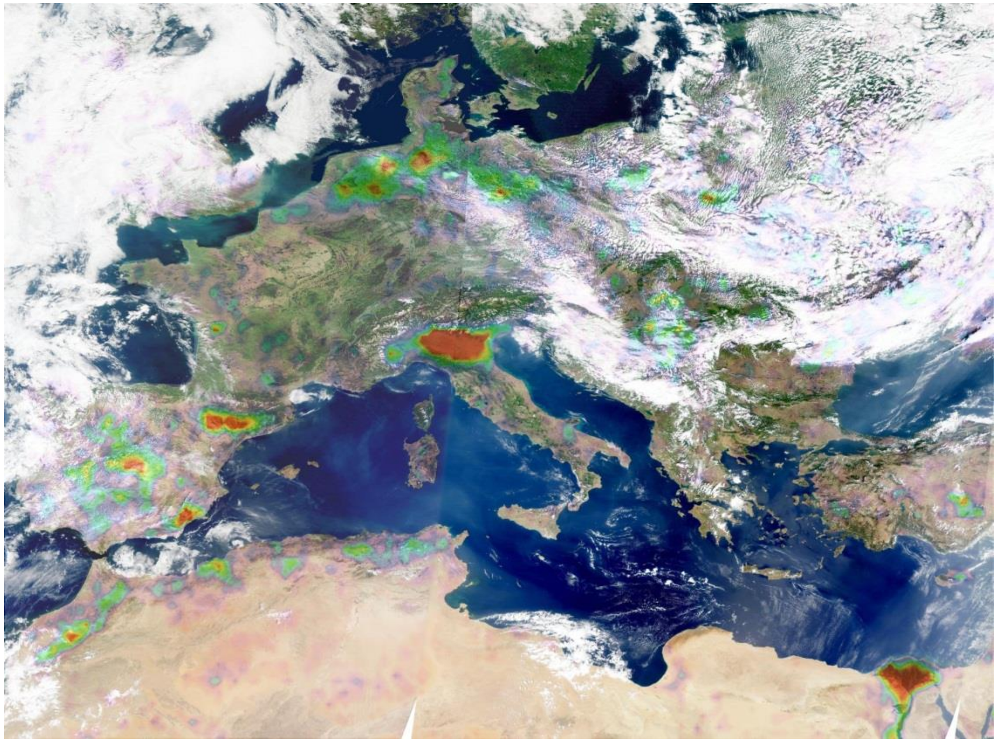
Courtesy C. Clerbaux, LATMOS

Ammonia 2008 average – IASI data

… dealing with a signal hardly detectable …



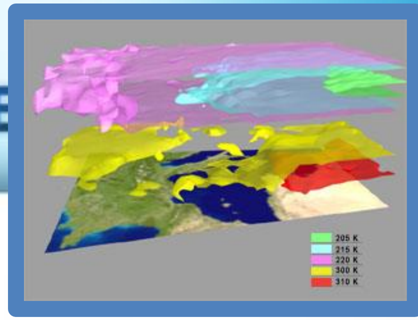


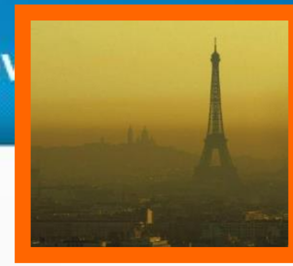


Clarisse et al., Nature Geo 2009

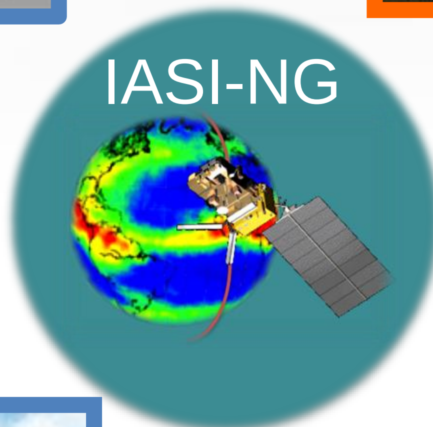
IASI-NG improved contributions to…

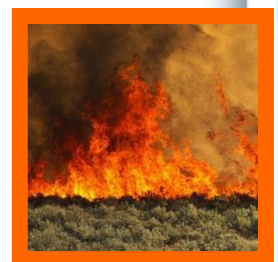
Atmospheric profiling





Improvement on pollution forecast
3 EU controlled pollutants (CO, O_3 and NH_3)

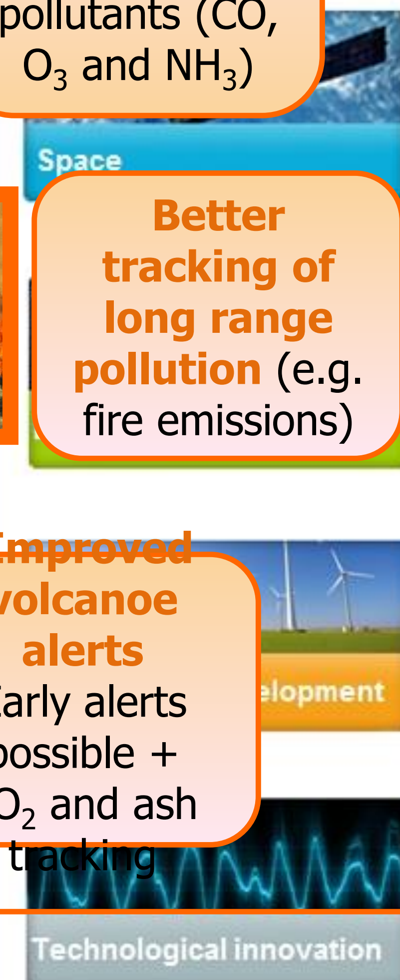




Better tracking of long range pollution (e.g. fire emissions)

Essential Climate Variables monitoring and understanding
Clouds, GHG, aerosols

Improved volcanoe alerts
Early alerts possible + SO_2 and ash tracking



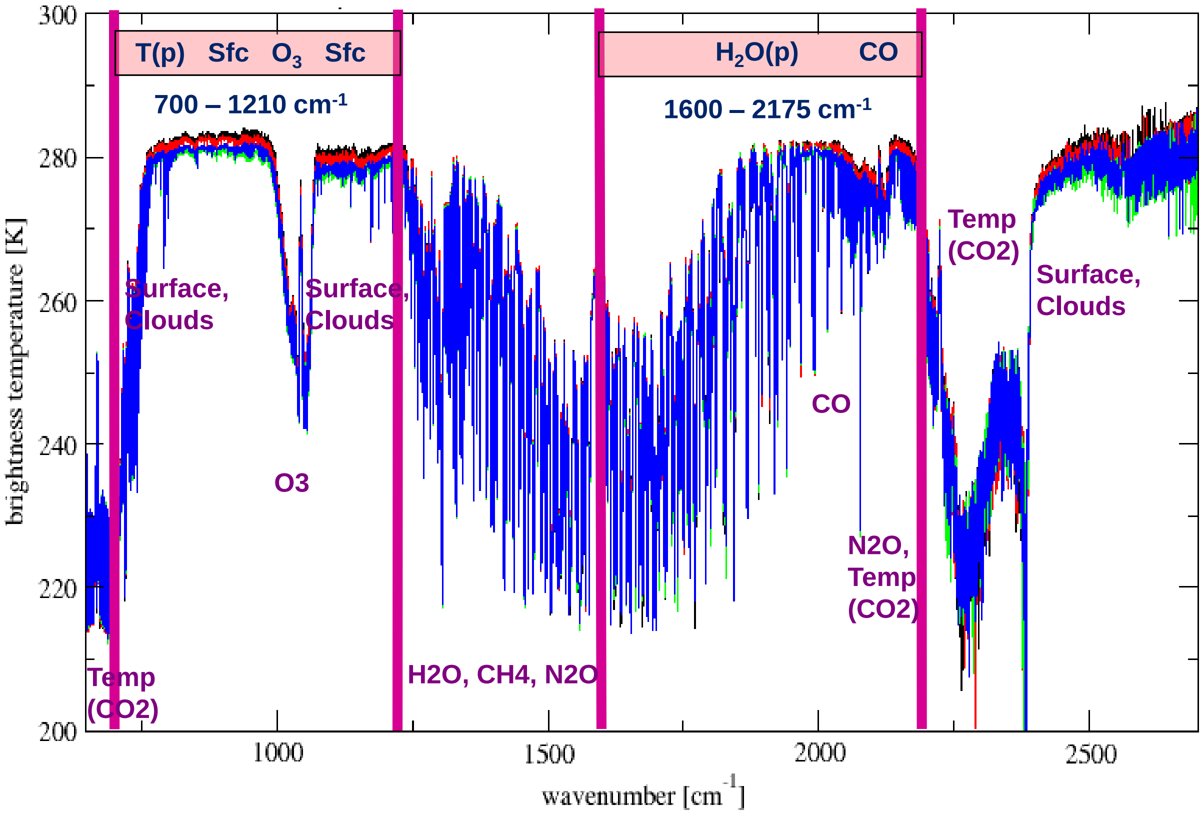
For T, WV, O_3, CO, CO_2, etc : more information on the vertical.
For weak absorbers : improved detection limit + more species measured instead of detected

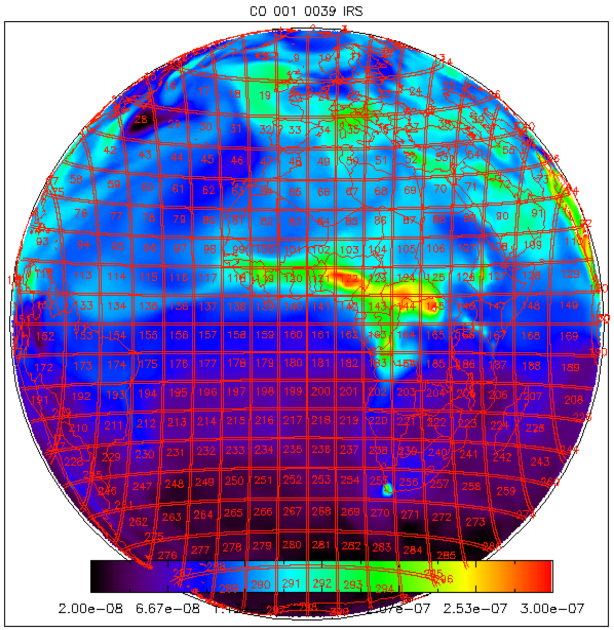
Courtesy C. Clerbaux, LATMOS

NOVELTIS

MTG-IRS Concept: High Spectral, Spatial and Temporal sampling

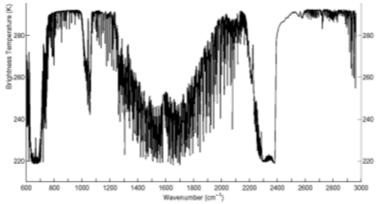
MTG-IRS primarily for Meteorology but …
MTG-IRS mission will provide Atmospheric composition information on diurnal variations of CO, O3, NH3, SO2, CO2 … with unprecedented space/time sampling





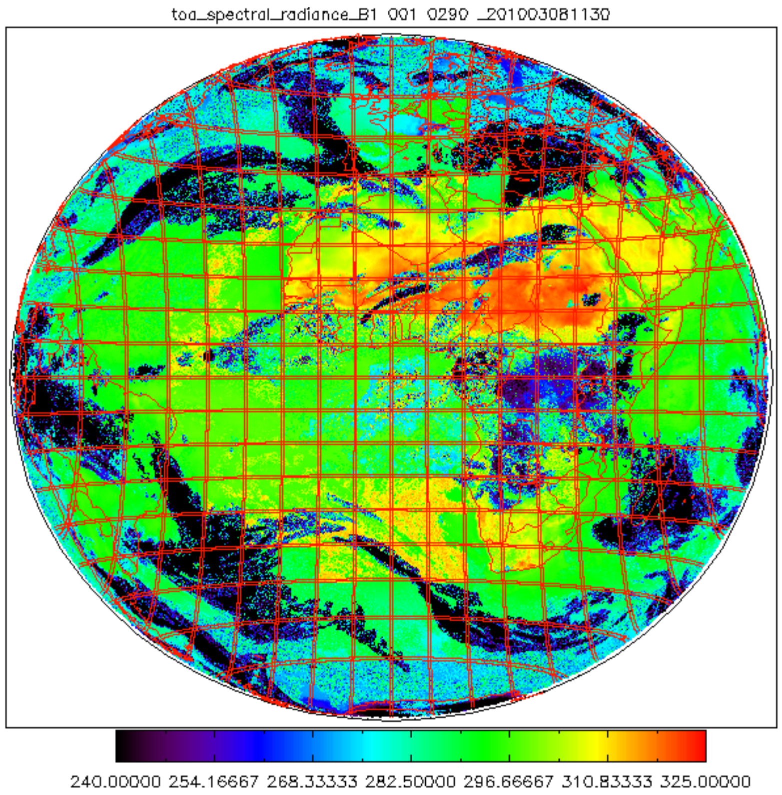
EUMETSAT

Exploiter toute l'information



Hypercube : 2 500 000 pixels sur une image, 1700 canaux par pixel.
Hypercube toute les heures (ou les 6 heures).
200 millions de spectres / 24 heures, 1.5 Tb / 24h pour les L1b

- **Nécessité de compresser l'information**
  - **Compression "classique" sans perte insuffisante**
  - **Compression avec perte : comprendre le signal, enlever le bruit (e.g. : PC compression)**
  - **Compression dans les 3 dimensions : spectrale, temporelle, spatiale**
- **Intérêt d'exploiter simultanément l'information spectrale, spatiale, temporelle**
  - **Combler les "trous" spatiaux et temporels**
  - **Exploiter la dynamique des structures (e.g. : déduire le vent des champs 3D d'humidité)**
- **Bien exploiter l'information : risque de limitation des modèles météo qui assimilent les mesures.**

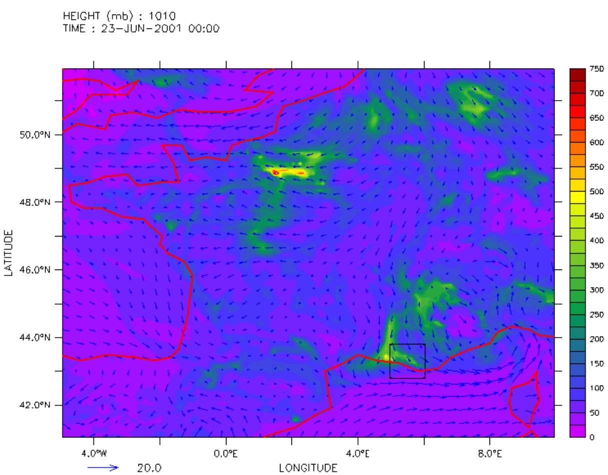


NOVELTIS

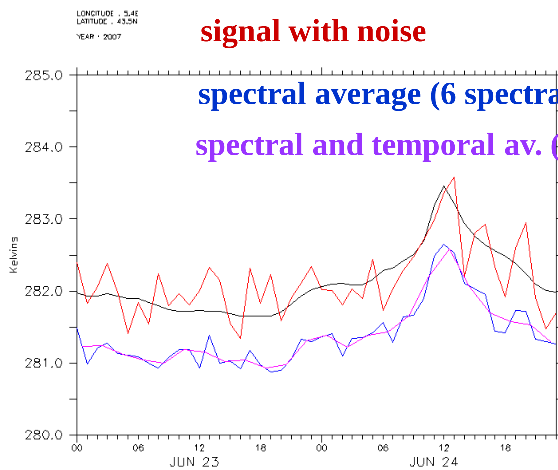
Exploiting imagery and spatio/temporal sampling

Take benefit of the high sampling rate of the MTG sounder (0.5 hour over Europe) using the information at different times of the day (hence different thermal contrast) to extract the peak pollution events at the right time and place

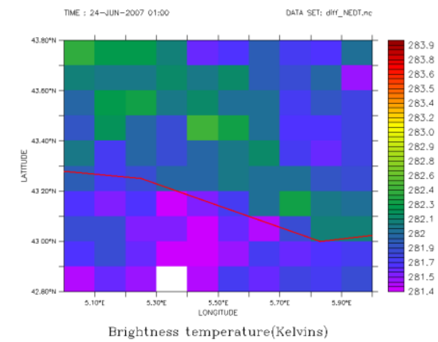
CO surface from MOCAGE simulation, 23-24 June 2001



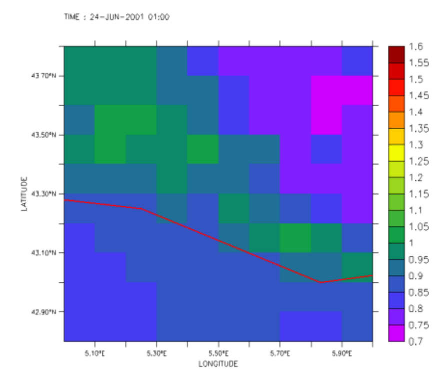
IRS signal with no noise (2158.16 cm-1)

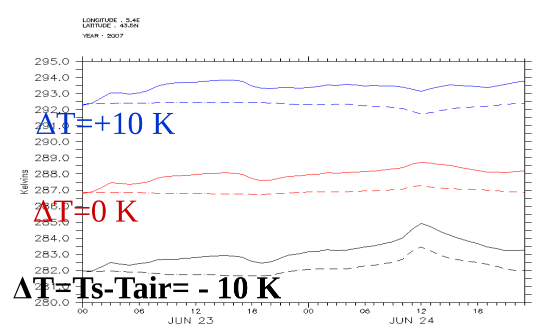


IRS Brightness Temperature (K)
with noise and spectral average



CO total column (mol/cm^2*10^{18})





Analysis in favourable conditions :

High CO in the boundary layer (40% of the column)

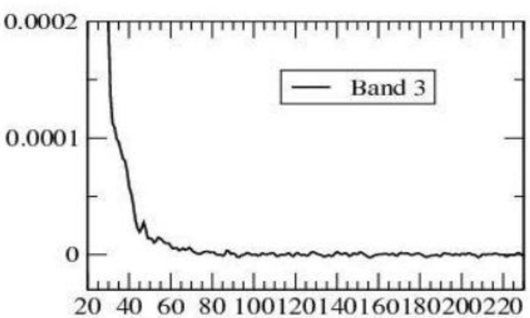
High temperature gradient between the surface (Ts) and overlying air :

No variation of other variables (T, …)

Compression par composantes principales : mise en oeuvre, évaluation et validation opérationnelle sur IASI

x (m channels x n spectra)	training set of IASI spectra
$\bar{x}$ (m channels)	Mean of the training set x
N (m channels x m channels)	noise normalisation matrix
E (m channels x s components)	The s most significant eigenvectors of the covariance matrix of the noise normalized training set N^{-1} x

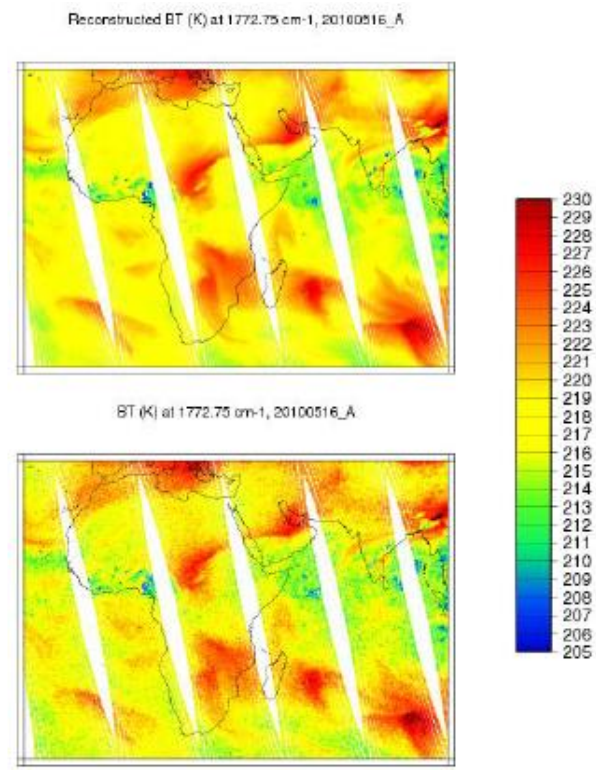
	Raw	Compression	Reconstruction
Radiance spectrum	x	$p = E^T N^{-1}(x - \bar{x})$	$\tilde{x} = NEp + \bar{x}$
Noise covariance matrix	R	$E^T N^{-1} R N^{-1} E^T$	$NEE^T N^{-1} R N^{-1} E^T EN$



Taux de compression typiques (dimension spectrale) :

- **IASI : 20**
- **MTG-IRS : 5 - 8**

Réduction du bruit de mesure

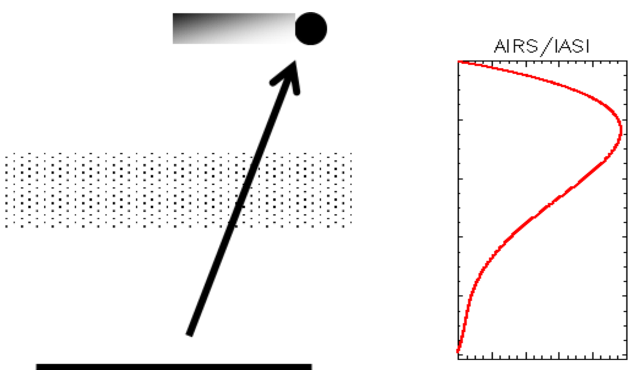


T. Hulberg, EUMETSAT

Enjeux : pollution dans la couche limite, sources et puits de polluants et GHG : Détecter et quantifier les gaz dans les basses couches

Thermal infrared sounding (TIR)

TOVS, AIRS, IASI, GOSAT
Mid troposphere sensing

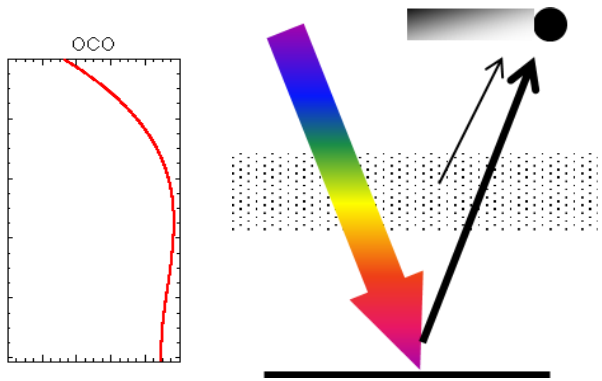


Sensible au gradient thermique vertical : bon dans la troposphere, bon dans les basses couches en presence de contraste thermique surface/basse atmosphere

IASI-NG, MTG-IRS

Swort Wave Infrared Sounding (SWIR)

Sciamachy, GOSAT
Total column



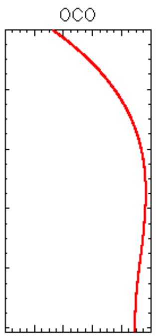
Absorption par les gaz du signal solaire réfléchi, plus sensible aux basses couches

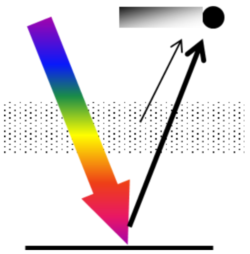
OCO-2, CarbonSat, Sentinel-5

Potentiel de la synergie spectrale SWIR-TIR pour les gaz basses couches : Travaux à mener et à supporter sur GOSAT (CO2, CH4), Sentinel 5 / IASI-NG (CO, CH4)

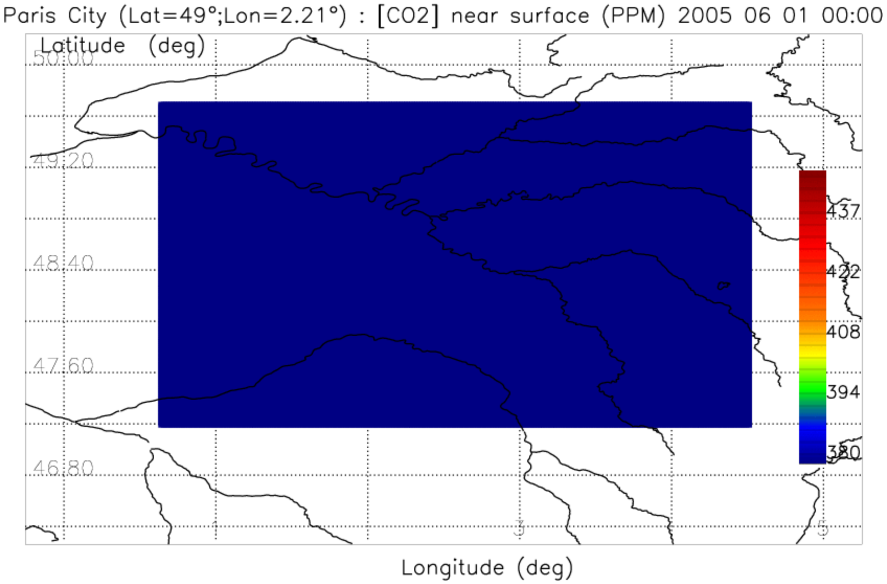
Enjeux : pollution dans la couche limite, sources et puits de polluants et GHG : Détecter et quantifier les gaz dans les basses couches

Détecter et quantifier les sources antropiques (locales) pour du service : nécessité de **précision** (par le spectral et le radiométrique), de **resolution spatiale** (1 km), et d’**imagerie**

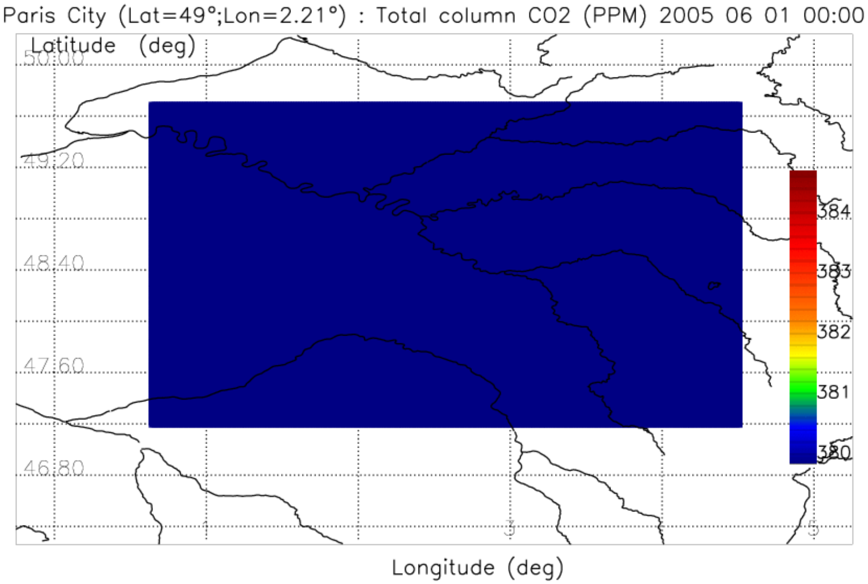




Surface atmospheric signature



Remote-sensed atmospheric signature

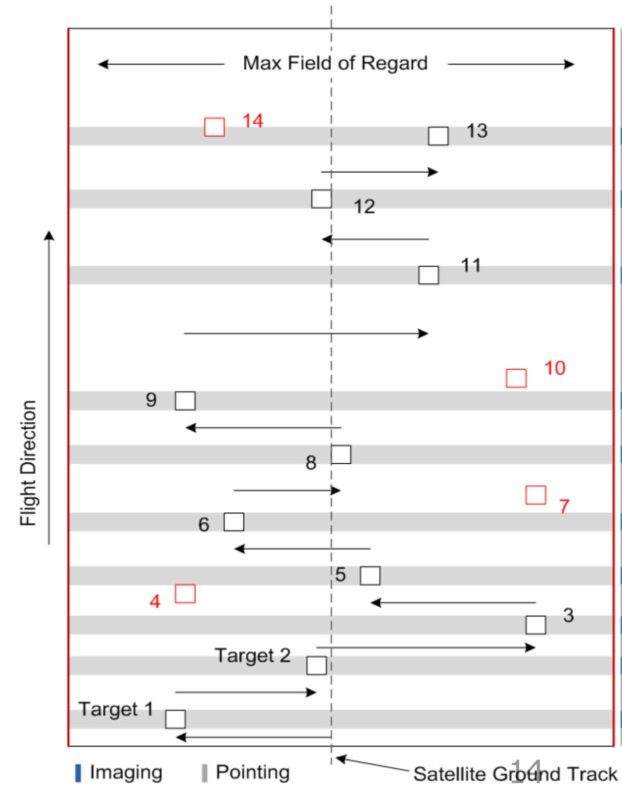


GEM (Gas Emission Mission)

- **ESA “Space and Energy” framework : innovative new EO for the Energy Sector**
  - **SWIR spectro-imager to measure (detection/quantification) anthropogenic emissions of CH_4 and CO_2 for GHG emission inventory and leaks detection over 20x20 km scenes at 600 m resolution combined with global accessibility and a revisit time between 1 and 5 days (Expected Accuracy For XCH4: random error: 5 - 10 ppb; Systematic error: 1 - 3 ppb; for XCO2: random error: 1 ppm; systematic error: 0.2 – 0.5 ppm)**

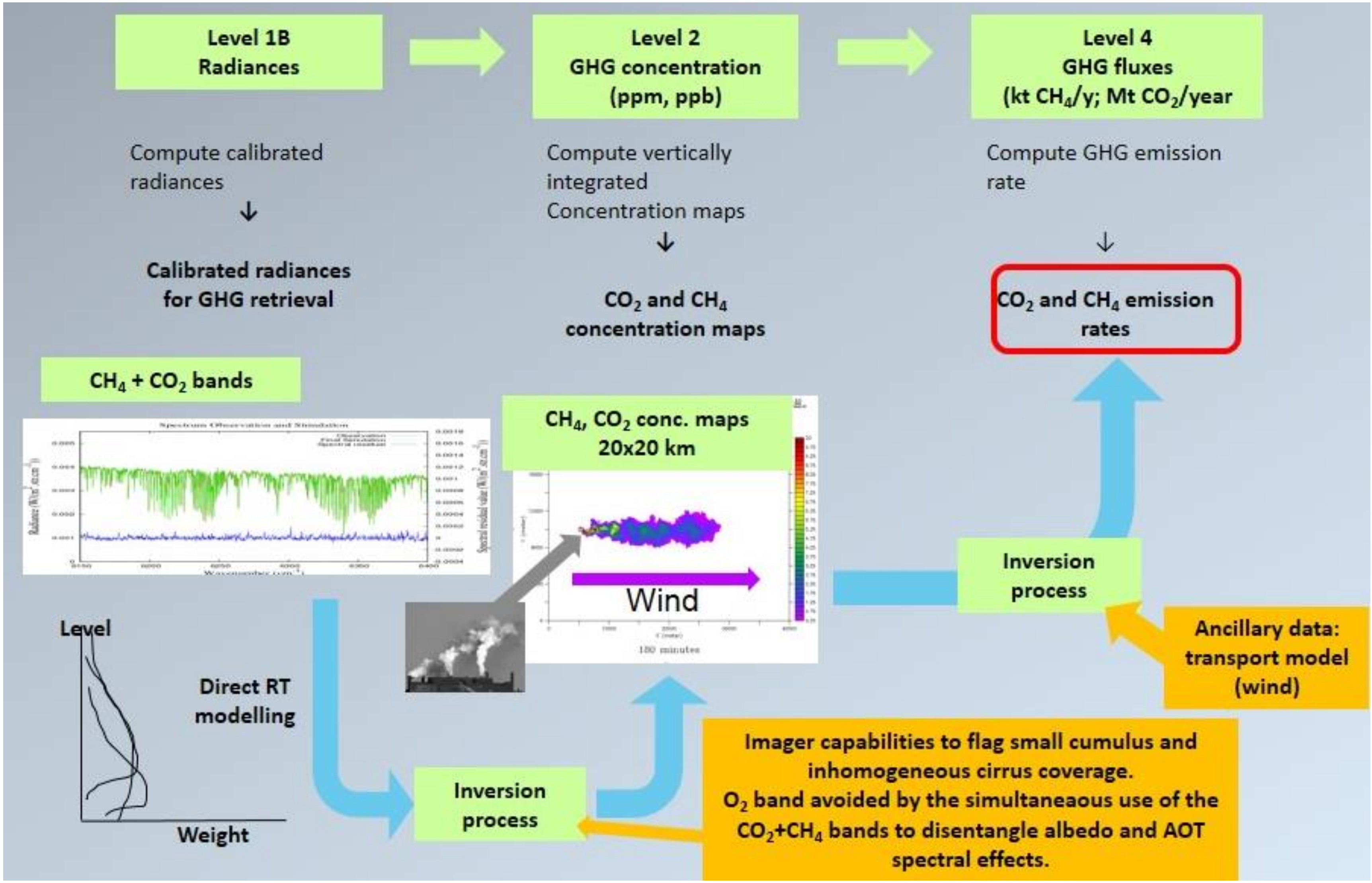
CH_4: 2 kt/yr (1kt = 10^3 t) ~7 000 targets

CO_2: 1 Mt/yr (1Mt = 10^6 t) ~3 000 targets



Sketch of the observation strategy

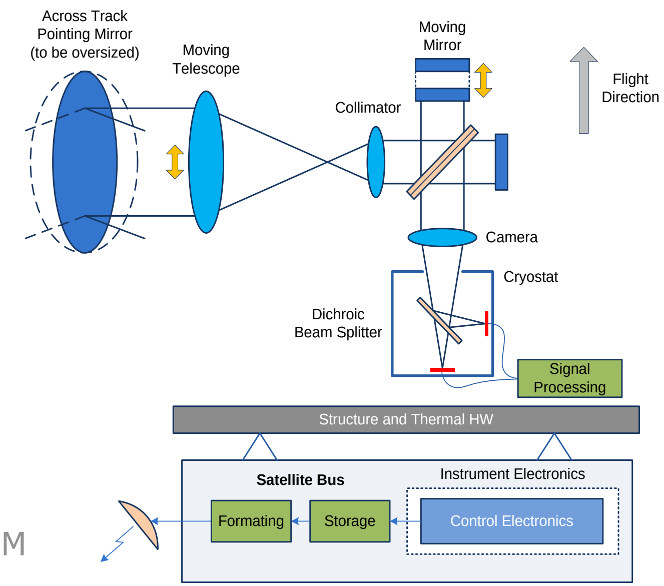
GEM observation technic and scientific processing



GEM Specification & Design

	Requirement	Achievable baseline	Comment
Swath	20 km x 20 km	20 km x 20 km	
GSD	500m (G) 1000m (T)	625 m	32 pixels over 20 km are assumed
CH_4 band	5977 cm^{-1} – 6023 cm^{-1}	5977 cm^{-1} - 6023 cm^{-1}	Filter design task
CH_4 resolution	0.25 cm^{-1} (G) 0.50 cm^{-1} (T)	0.40 cm^{-1} (0.1 nm)	It is preferred to choose the same resolution for both (CH_4 and CO_2) bands
CO_2 band	6222.8 cm^{-1} - 6281 cm^{-1}	6222.8 cm^{-1} - 6281 cm^{-1}	Filter design task
CO_2 resolution	0.20cm^{-1} (G) 0.40cm^{-1} (T)	0.40 cm^{-1} (0.1 nm)	It is preferred to choose the same spectral resolution for both (CH_4 and CO_2) bands
SNR CH_4	350 @ 0.50 cm^{-1} (G) 250 @ 0.25 cm^{-1} (T)	~350 @ 0.4 cm^{-1}	Optimise the coverage of the CH_4 $2\nu_3$ band Q branch at 6005 cm^{-1}
SNR CO_2	350 @ 0.4 cm^{-1} (G) 250 @ 0.2 cm^{-1} (T)	~300 @ 0.4 cm^{-1}	Select the CO_2 band least perturbed by H_2O

Preliminary instrument performance parameters



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Instrument functional block diagram

	Single satellite mission	Constellation of 5 satellites
Instrument	100 - 130	Avg. 60 – 78 (recurring unit cost = 0.5 of first one)
Platform	40 – 60	Avg. 36 – 40
Launch	18 – 30 (PSLV/VEGA shared launch)	45 – 50 (Falcon 9/ Soyuz Fregat dedicated launch)
G/S and Ops	20	25
Operations (7.5 years)	8	10
Total mission ROM cost	186 – 248 M€	536 – 651 M€

Total mission ROM cost (M€)

Merci pour votre attention et vos questions

www.noveltis.com

Email: pascal.prunet@noveltis.fr
Phone: +33 5 62 88 11 18