

Olivier Membrane<sup>1</sup>, Cyril Crevoisier<sup>1</sup>, François Danis<sup>1</sup>, Albert Hertzog<sup>1</sup>, Colm Sweeney<sup>2</sup>, Laurence Picon<sup>1</sup>, Georges Durry<sup>3</sup>, Nadir Amarouche<sup>4</sup>, Andreas Engel<sup>5</sup>, Harald Boenisch<sup>5</sup>

1. Laboratoire de Météorologie Dynamique, CNRS/IPSL, Paris, France, 2. University of Colorado, Boulder and NOAA/ESRL, Boulder Colorado, 3. GSMA, CNRS, Université de Reims, Reims, France  
4. INSU Division Technique CNRS, Meudon, France, 5. Institute for Atmospheric and Environmental Sciences, University of Frankfurt, Frankfurt, Germany

contact: [olivier.membrane@lmd.polytechnique.fr](mailto:olivier.membrane@lmd.polytechnique.fr)

## Context

Over the past decades many methods have been developed to monitor the evolution of greenhouse gases (GHG): ground networks (NOAA, ICOS, TCCON...), aircraft campaigns (HIPPO, Contrail, CARIBIC...), satellite observations (TIR: IASI, AIRS..., SWIR: Gosat..., Profiles: ACE-FTS). Nevertheless, precise and regular vertical profile measurements are still missing from the observing system. To address this need an original and innovative atmospheric sampling system called AirCore has been developed at NOAA (Karion et al. 2010). This new system allows balloon measurements of GHG vertical profiles from the surface up to approximately 30 km.

## 1. Objectives

### 3 scientific objectives

- **Transport model validation** : Number of levels, Impact of spatial resolution, Underlying convection processes
- **Satellite-based GHG remote sensing validation** : - total columns: GOSAT, OCO-2... Merlin, CarbonSat.. - tropospheric column: AIRS, IASI and IASI-NG - vertical profile: ACE-FTS
- **Ground FTS measurements validation** : TCCON & underlying spectroscopy

In this study comparisons of vertical profiles retrieved with various AirCores (LMD and Frankfurt University) are presented. Particular focus is made on : repeatability of the measurements; impact of the vertical resolution; usefulness of AirCore measurements to validate and interpret atmospheric transports models and satellite observations.

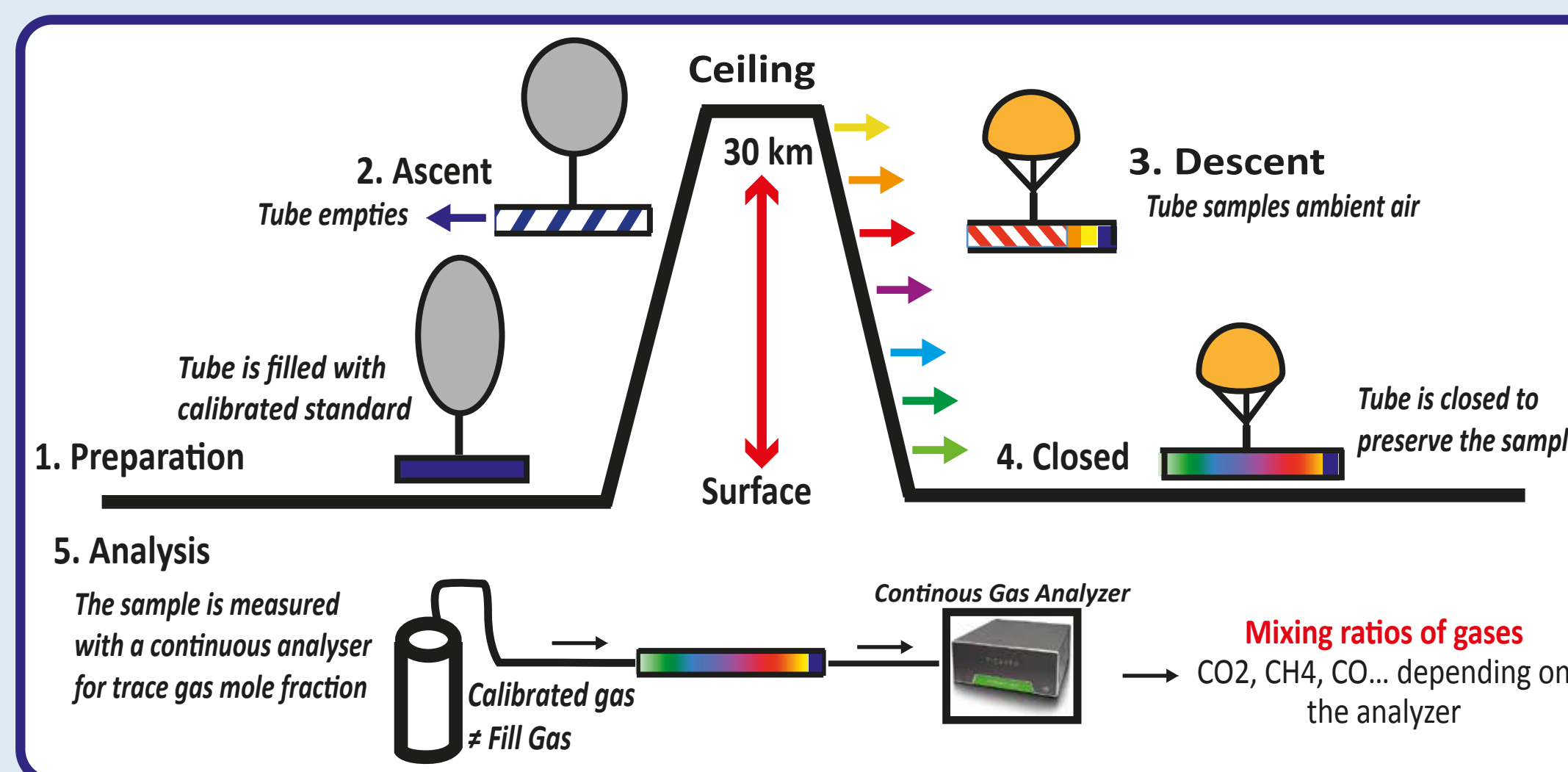
## 2. Method

### What's an Aircore ?

An AirCore is an atmospheric sampling system that allows greenhouse gas measurements

- Long stainless steel tube (over 100m)
- Ambient Pressure
- Ambient Temperature
- AirCore Temperature
- GPS (latitude, longitude, altitude)

### The AirCore principle in 5 easy steps

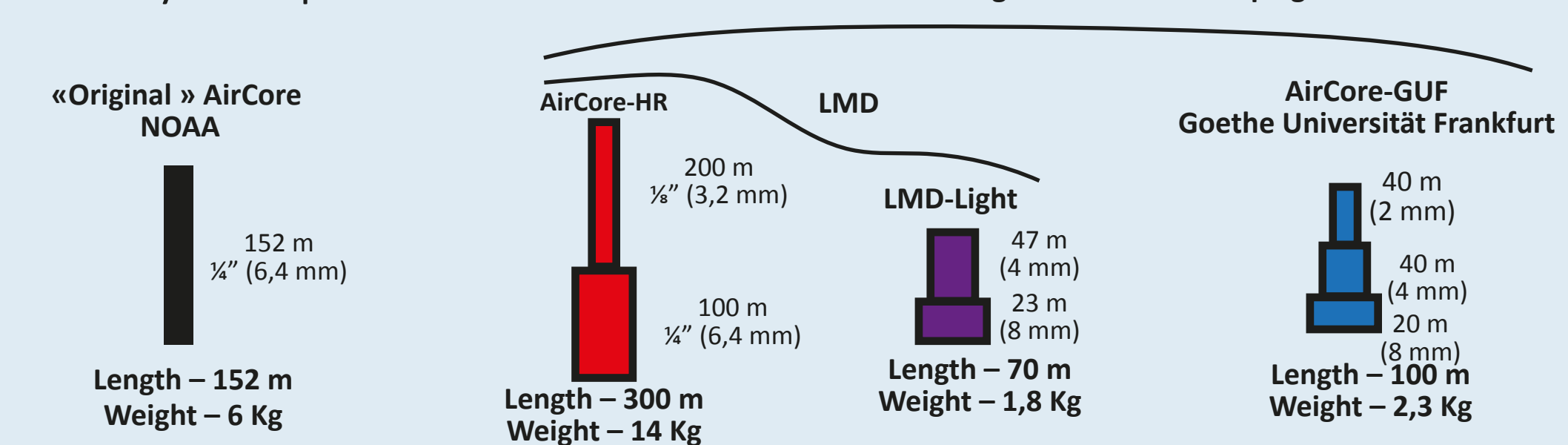


## Design & resolution

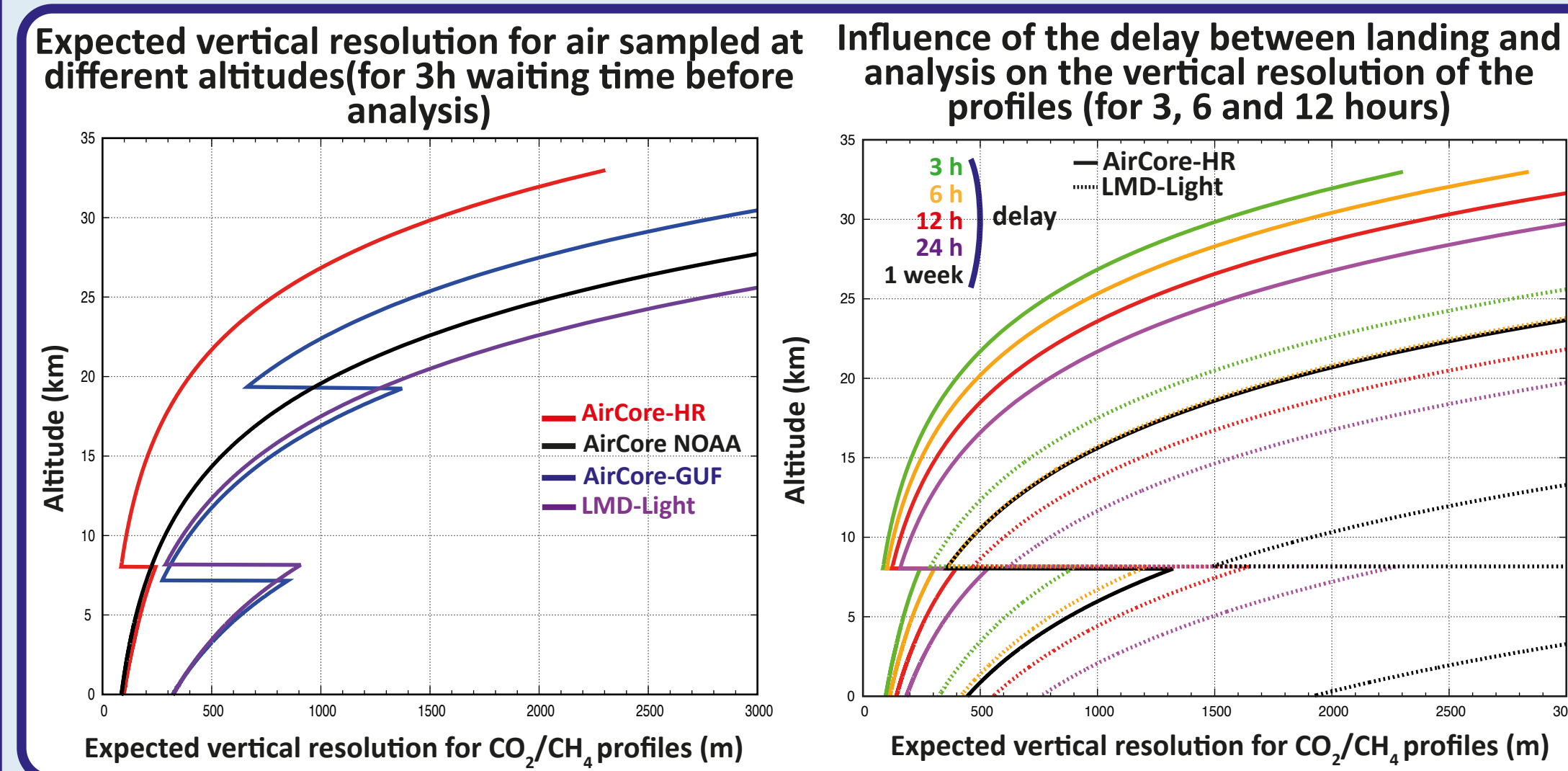
AirCores can be designed in various configurations, combining sections of tubing of different lengths and diameters. After the concept of the AirCore was tested at NOAA, several new designs have been developed by various research teams, aiming to test high vertical resolution and light weight systems.

The design characteristics (length, diameter) directly impact the expected vertical resolution that is governed by:

- Molecular Diffusion
- Taylor Dispersion



The theoretical vertical resolutions achievable for the 4 AirCores presented here are detailed in the following figure.

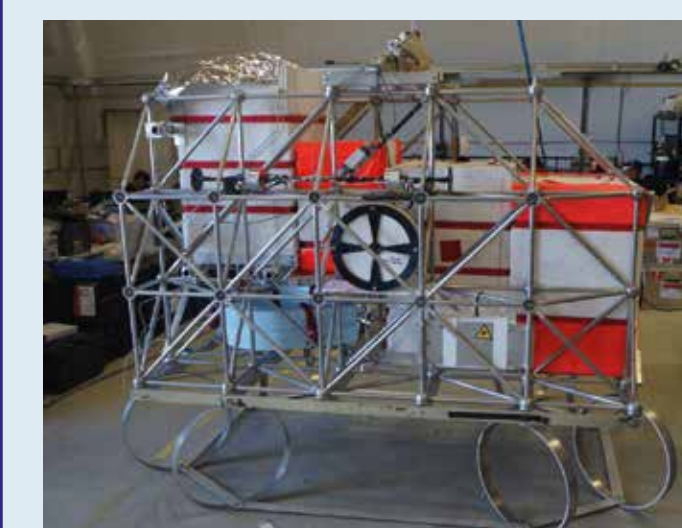


- High resolution: 100m at the surface up to 200m at 8km, then 100m at 8km up to 1 km at 30 km.
- delay between landing and analysis is critical  
Longer delay = more diffusion = lower resolution

## 3. Stratospheric balloon flights

### Stratoscience 2014 & 2015

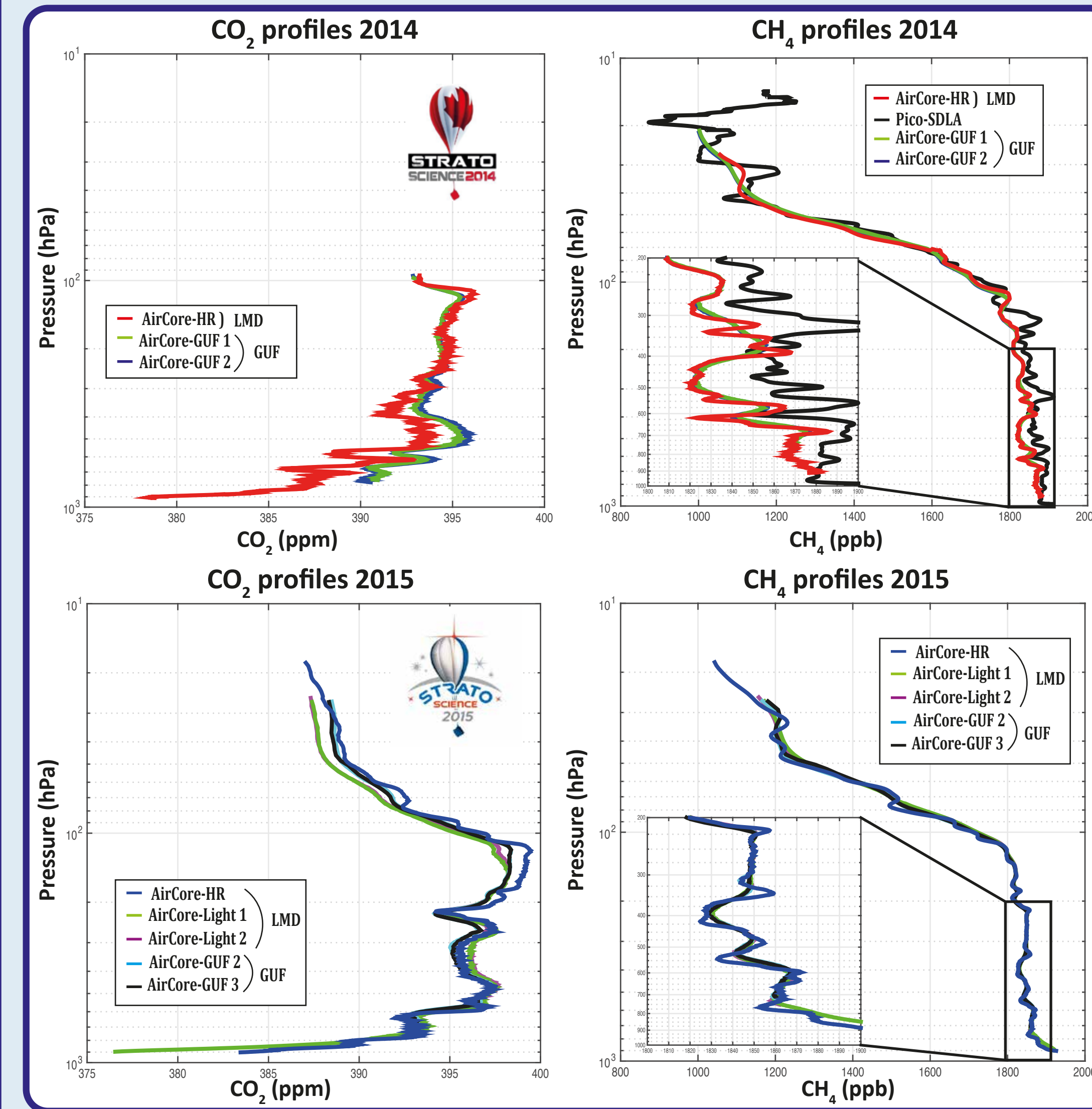
Our instruments were flown during the annual StratoScience stratospheric balloon campaigns operated by the French space agency CNES and the Canadian space agency CSA in Timmins (Ontario, Canada) in August 2014 and 2015.



The multi-instrument Gondola carried several instruments that measured CO<sub>2</sub> and CH<sub>4</sub> in situ:

- AirCore-HR (LMD)
- 4 Light AirCores (low resolution) : 2 from LMD and 2 from Goethe University Frankfurt (GUF)
- the Pico-SDLA (based on laser spectrometry) from GSMA, University of Reims & INSU Division Technique

### 2014 and 2015 measurements



Pico-SDLA Data : courtesy of G.Durry / GSMA  
AirCore-GUF Data : Courtesy of H.Boenisch / Frankfurt University

## Description of the measurements

### General comments

- AirCore profiles reveal thin structures of the atmosphere air mass vertical transport
- CO<sub>2</sub>
    - Strong decrease in the first layers above ground : Coherent with uptake by vegetation during summer season
    - Highest value of CO<sub>2</sub> just around the tropopause.
    - Exchange between upper troposphere and lower stratosphere.
  - CH<sub>4</sub>
    - mixing ratios are quite stable in the troposphere.
    - zoomed figure allows to identify vertical atmospheric transport signatures.
    - structures in the stratosphere, possibly caused by orographic
    - Slope in the stratosphere: strong decrease from 1800 ppb near the tropopause to 1100 ppb at 30 hPa.

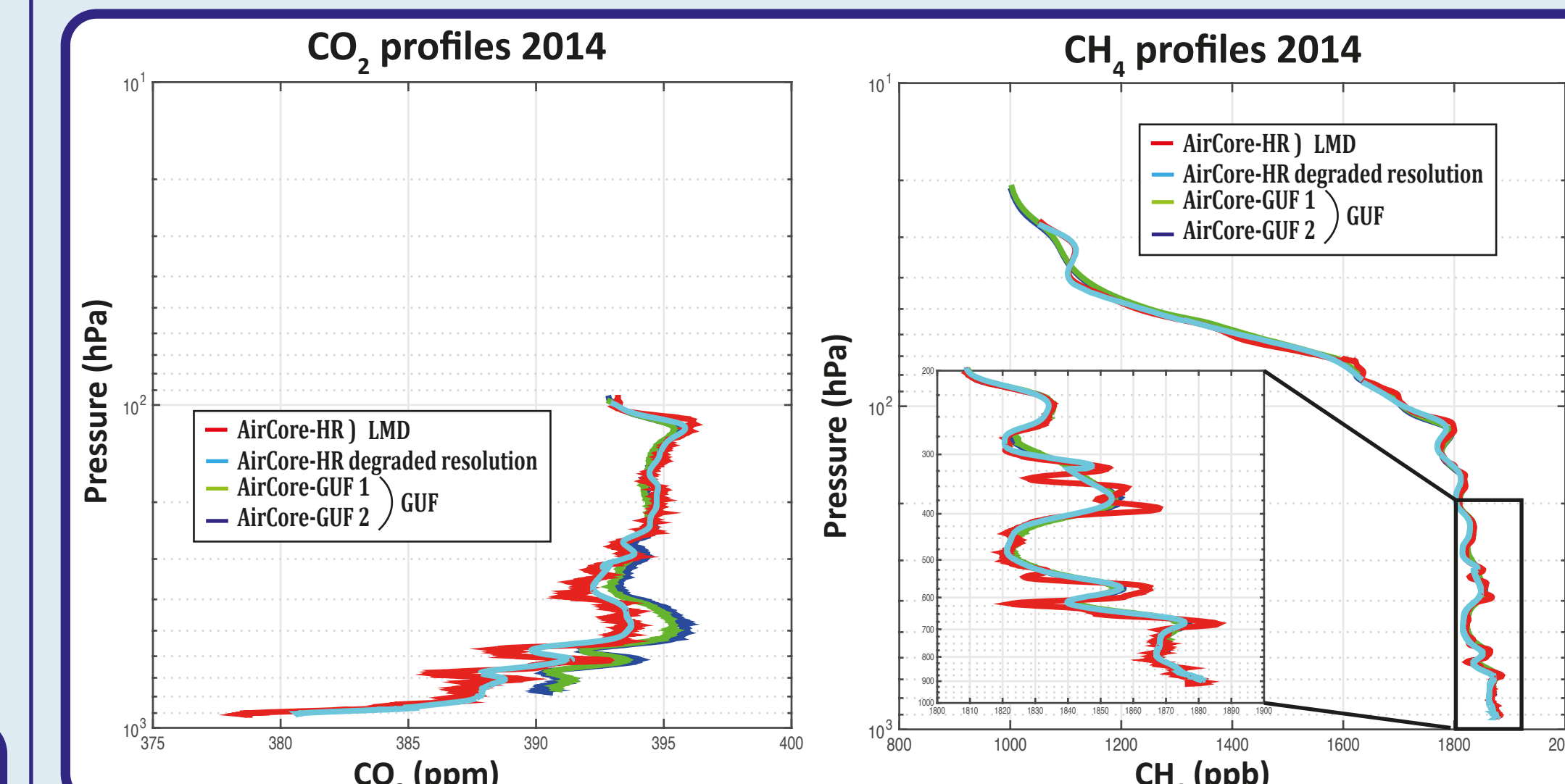
### Conclusions

- Overall good agreement between AirCore measurements. → measures are repeatable.
- 2014 - transport signatures in the CH<sub>4</sub> profiles are anti-correlated with those in the CO<sub>2</sub>
- Although there is bias with Pico-SDLA CH<sub>4</sub> (Pico-SDLA measured on the way up, AirCores sampled on the way down. Pico-SDLA profiles aren't corrected to the WMO Scale) there is an excellent agreement on the position and inclination of the slope in CH<sub>4</sub>
- 2015 - Excellent agreement on CO<sub>2</sub> and CH<sub>4</sub> from 5 different AirCores
- Year-to-Year comparison
  - Overall increase of ~2 ppm of CO<sub>2</sub> coherent with the annual growth rate
  - increase of ~10 ppb CH<sub>4</sub> near the surface
  - Very Good stability of CH<sub>4</sub> over the atmospheric

## 4. Intercomparing various resolutions

In order to verify the theoretical calculation of the vertical resolution and to compare profiles of the AirCore-HR with lower resolution AirCores the high resolution AirCore profiles have been degraded.

Degradation of the AirCore-HR profiles is performed using a gaussian filtering with a standard deviation of the GUF-AirCores vertical resolution at each given altitude.

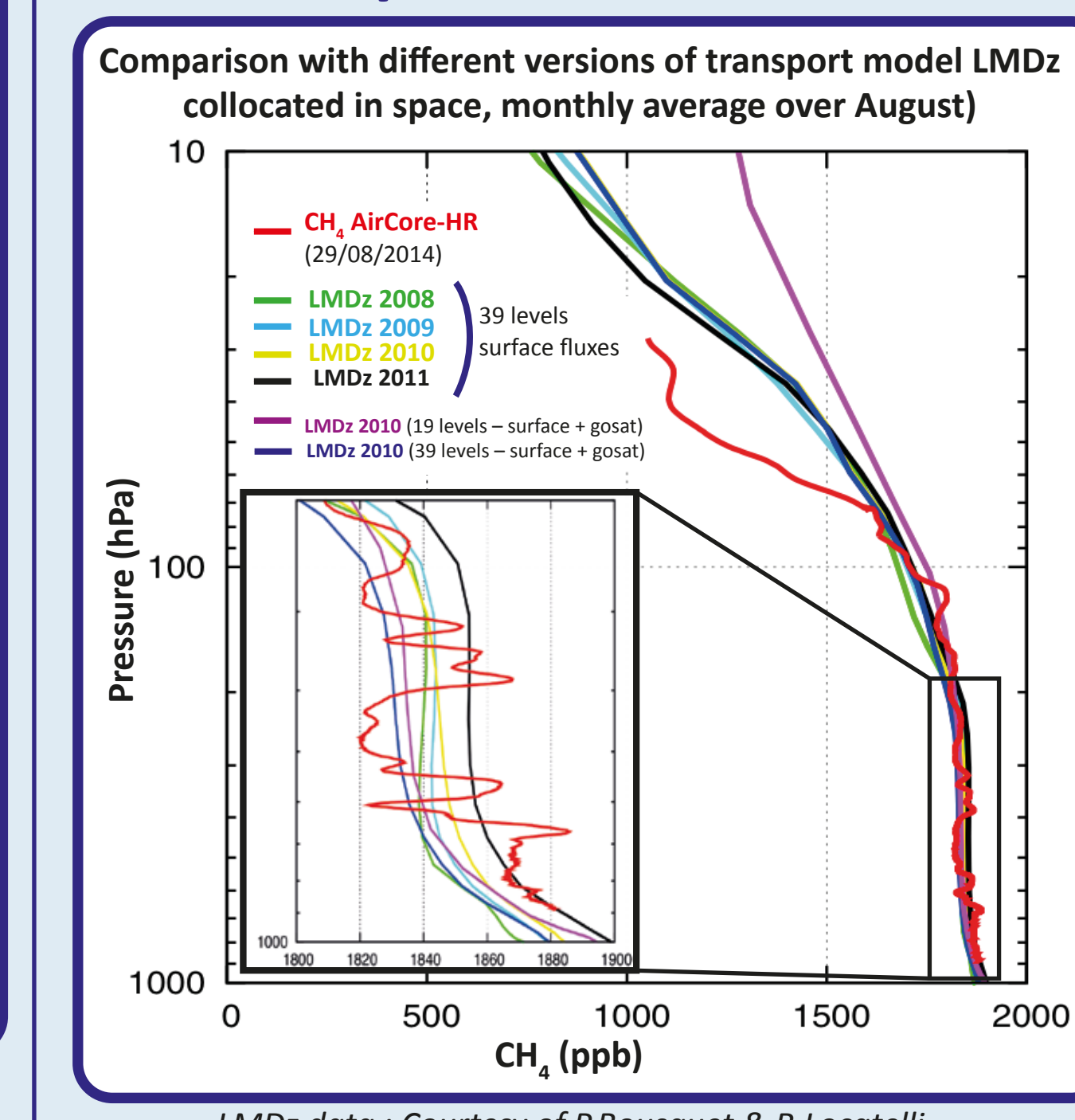


- Perfect agreement between degraded AirCore-HR profile and GUF-AirCores for CH<sub>4</sub>
- Excellent agreement in terms of structures for CO<sub>2</sub> but biases in mixing ratios remain.

## 5. Applications of AirCore Data

Three applications of AirCore data were tested with the AirCore-HR CH<sub>4</sub> profile from the Timmins 2014 flight. The comparisons are collocated in space with the landing coordinates of the flight and in time with the landing time when possible.

### For transport model validation...

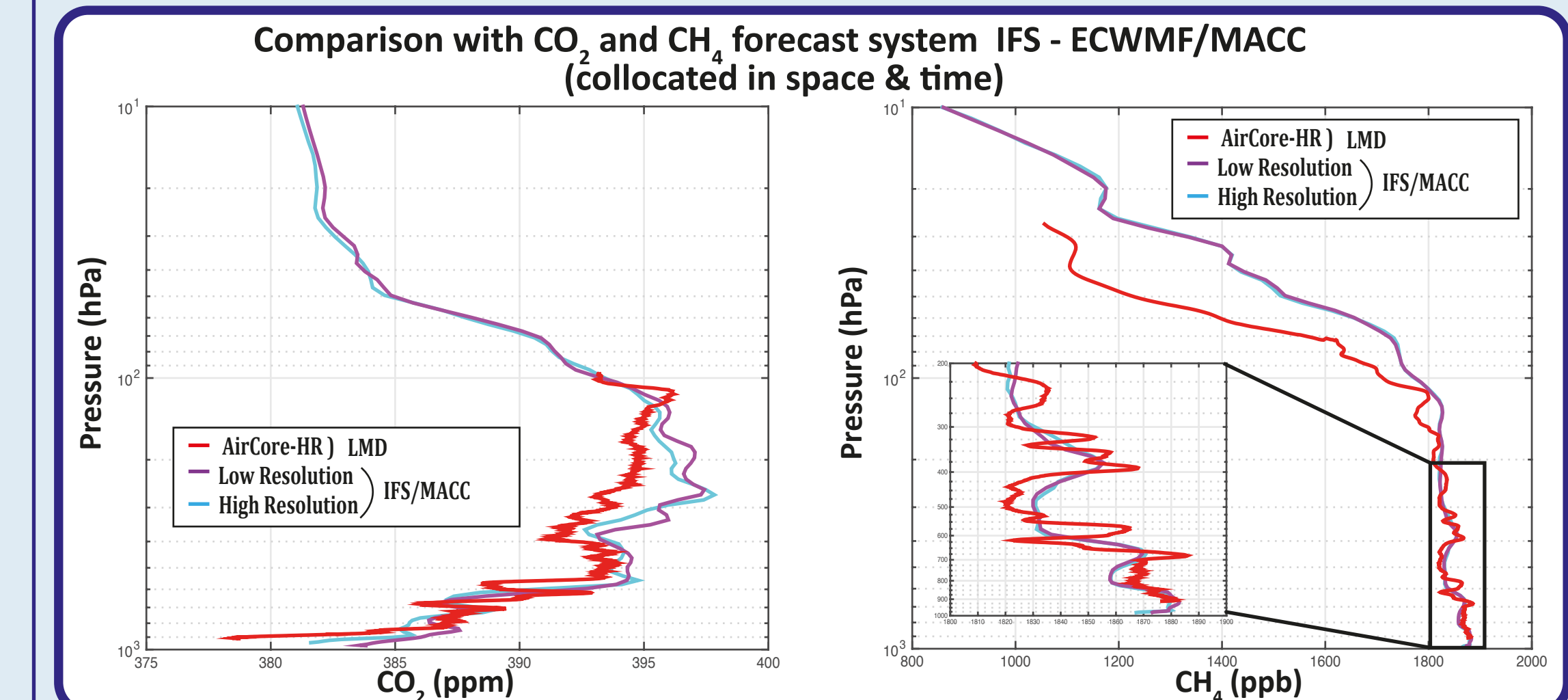


Geographically collocated comparisons were performed with different version of transport model LMDz. For different years from 2008 to 2011 using surface fluxes. And using optimized fluxes with additional gosat input and new physics for 2010. (Locatelli et al. 2013)

- General agreement in the troposphere but bias in the stratosphere
- Increasing the number of layers from 19 to 39 improves the description of the stratosphere (problem of chemistry/transport remaining ?)
- Year-to-Year increase of CH<sub>4</sub> in the troposphere : model captures the average

## ...forecast system validation...

Comparisons collocated in space and time were performed using Integrated Forecast System (IFS) from European Centre for Medium-Range Weather Forecast (ECMWF) prefiguring the Copernicus Atmospheric project. The CO<sub>2</sub> and CH<sub>4</sub> forecasts computed by IFS are provided for 137 vertical levels and two different surface resolutions. "High resolution" cover a surface of 16x16 km<sup>2</sup> and "low resolution" cover a surface of 40x40 km<sup>2</sup>. (Massart et al. 2013)



IFS Data : Courtesy of S.Massart & A.Augusti-Panareda

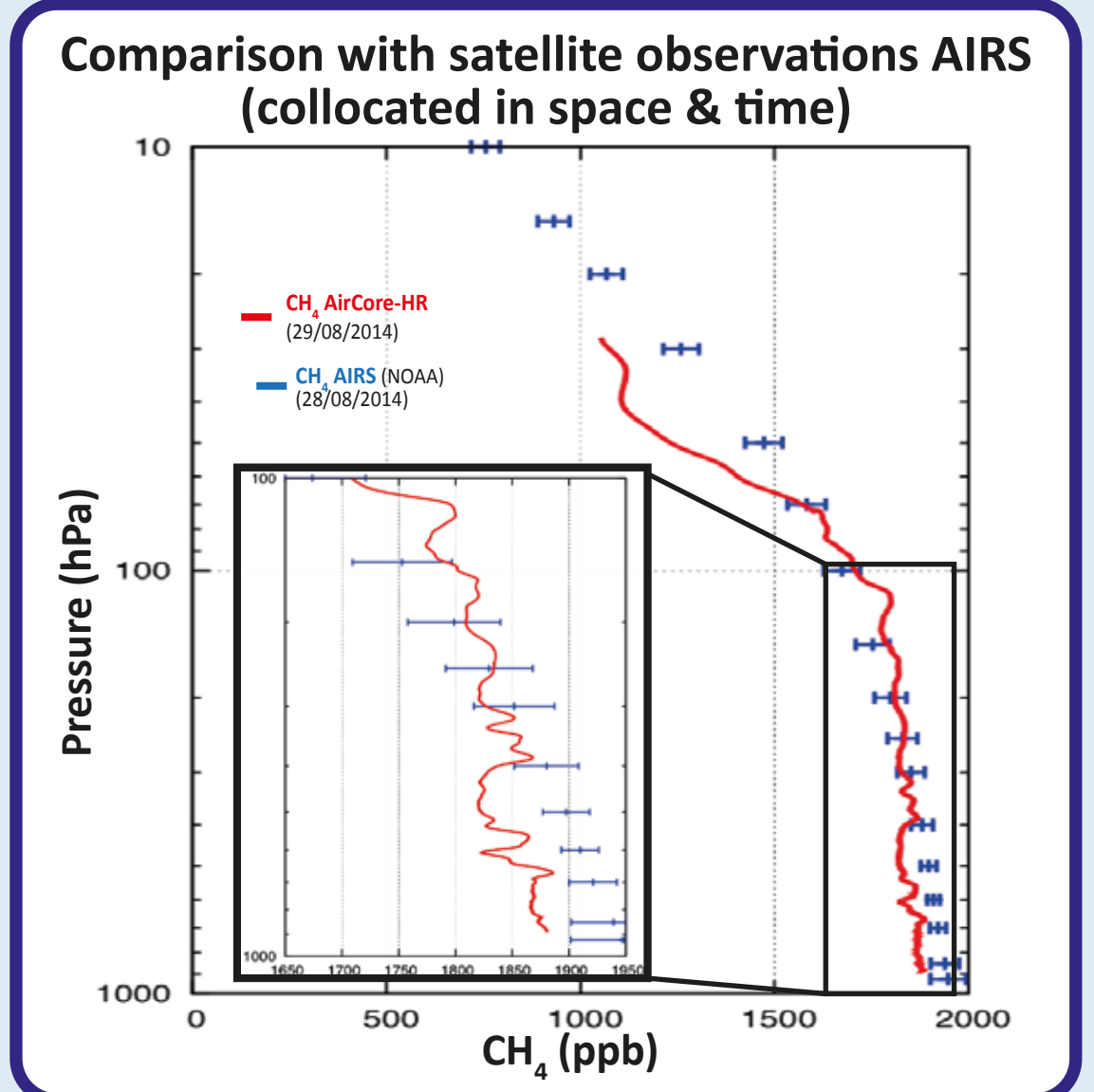
- Very good agreement in the troposphere for both CO<sub>2</sub> and CH<sub>4</sub> (air mass signatures)
- Not satisfactory above the tropopause although both forecasts and in-situ profiles captures the start of the decrease and orographic waves in the stratosphere at the same altitude.

## ...satellite observation validation

Comparisons collocated in space and time were performed with AIRS satellite CH<sub>4</sub> retrievals from NOAA.

The comparison is not fair because the AirCore-HR is compared directly with the retrieved profile without applying the averaging kernels to the AirCore-HR values. Abeit we can already notice :

- Good agreement in the mid-troposphere where vertical sensitivity of AIRS is highest
- Offset near the surface and above the tropopause (Influence of the a priori?)



## 6. Conclusion

- High resolution AirCore measurements are achievable and can be used to validate the theory on AirCore sampling and theoretical vertical resolution.
- AirCore measurements are repeatable. CH<sub>4</sub> measurements are very stable.
- AirCores provide valuable knowledge on the variations of methane and carbon dioxide for spaceborne measurements and model simulations.
- A global network of AirCores for regular vertical profile measurements would bring valuable information to the satellite and modeling communities.

### Future campaigns

AirCore-light: Trainou site, Loiret, France, June 2016  
AirCore-HR + AirCore-light: CNES campaign in Kiruna, Sweden, September 2016

### AirCore Community

An "AirCore community" of 4 research teams has been created (NOAA, LMD, University of Groningen, Frankfurt University)  
first meeting: CNES HQ, Paris, 2014 July 7<sup>th</sup>  
second meeting: CNES HQ, 2015 October 14<sup>th</sup>  
next meeting : to be organised... anyone interested is welcome to join !

## Acknowledgments

This work is supported by funding from CNES-CSTB and Ecole polytechnique. PhD work is funded by Climate-KIC and UPMC.

## References

- Karion et al. (2010) AirCore: An Innovative Atmospheric Sampling System, Journal of Atmospheric and Oceanic Technology, Volume 27, Issue 11, pp 1839-1853.
- Durry et al. (2004) In situ sensing of the middle atmosphere with balloonborne near-infrared laser diodes, Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, Elsevier, Volume 60, Issue 14, December 2004, Pages 3371-3379.
- Locatelli et al. (2013) Impact of transport model errors on the global and regional methane emissions estimated by inverse modelling, Atmospheric Chemistry and Physics, Volume 13, Issue 19, pp 9917-9937.
- Massart et al. (2014) Assimilation of atmospheric methane products into the MACC-II system: from SCIAMACHY to TANSO and IASI, Atmospheric Chemistry and Physics, Volume 14, Issue 12, pp 6139-6158.
- Membrane et al. (in prep.) AirCore-HR: A high resolution column measurement to enhance the knowledge on the vertical distribution of CO<sub>2</sub> and CH<sub>4</sub>