

Requirements for the monitoring of CO₂ from space:

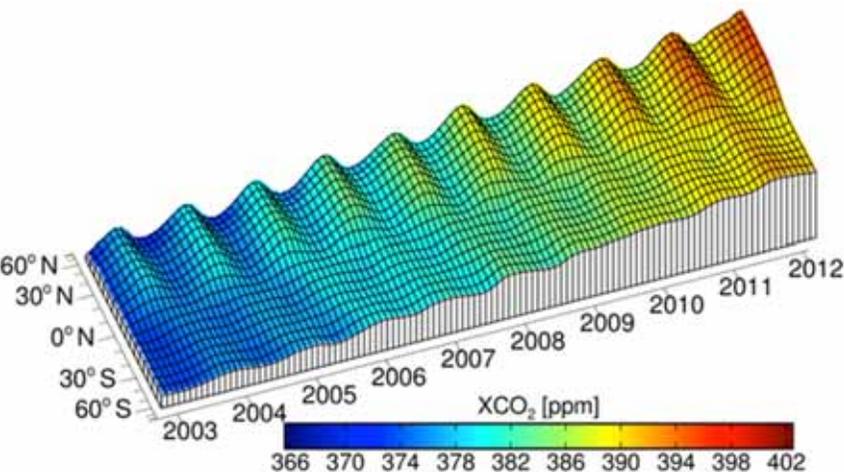
Is it realistic to aim at the monitoring of anthropogenic emissions?

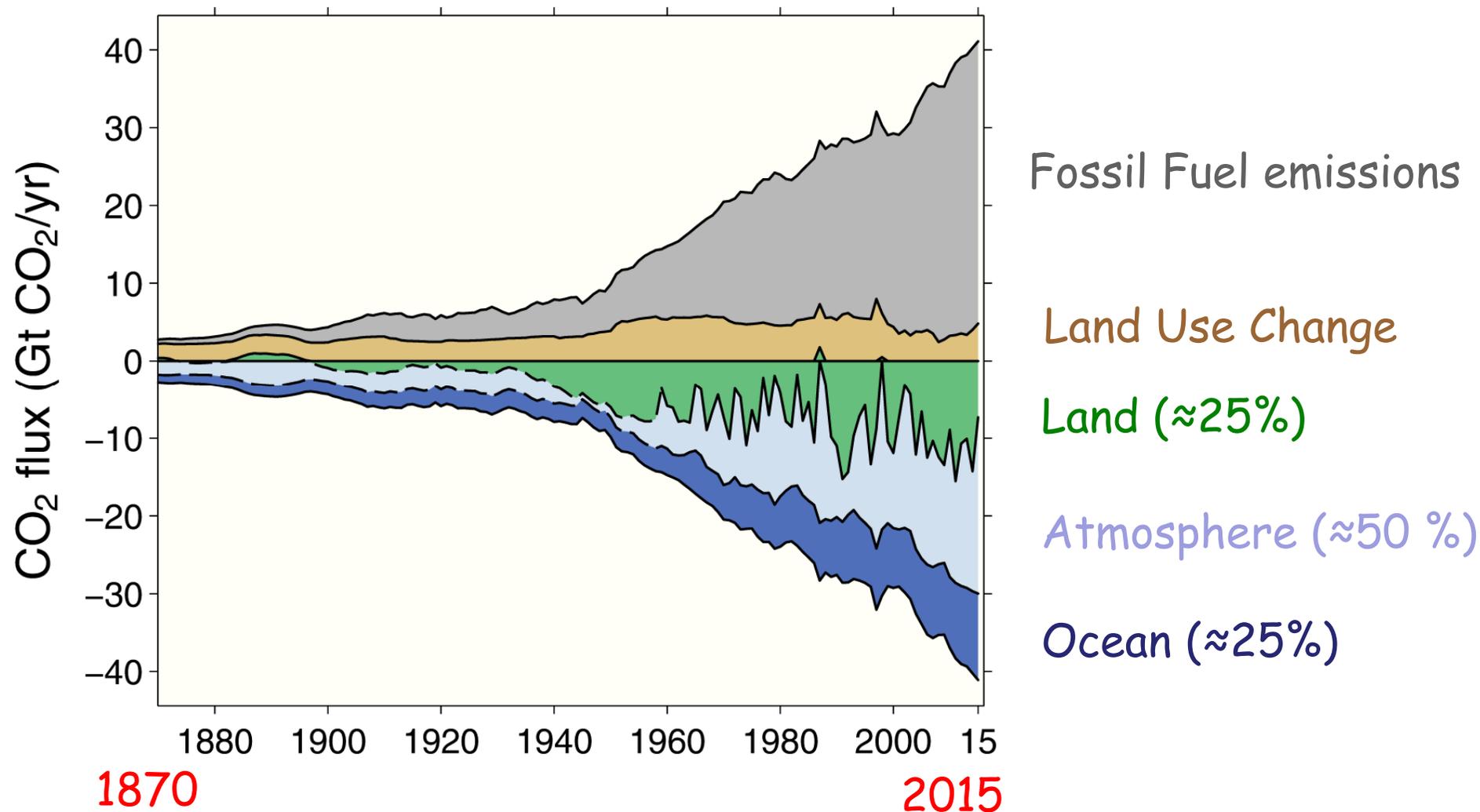
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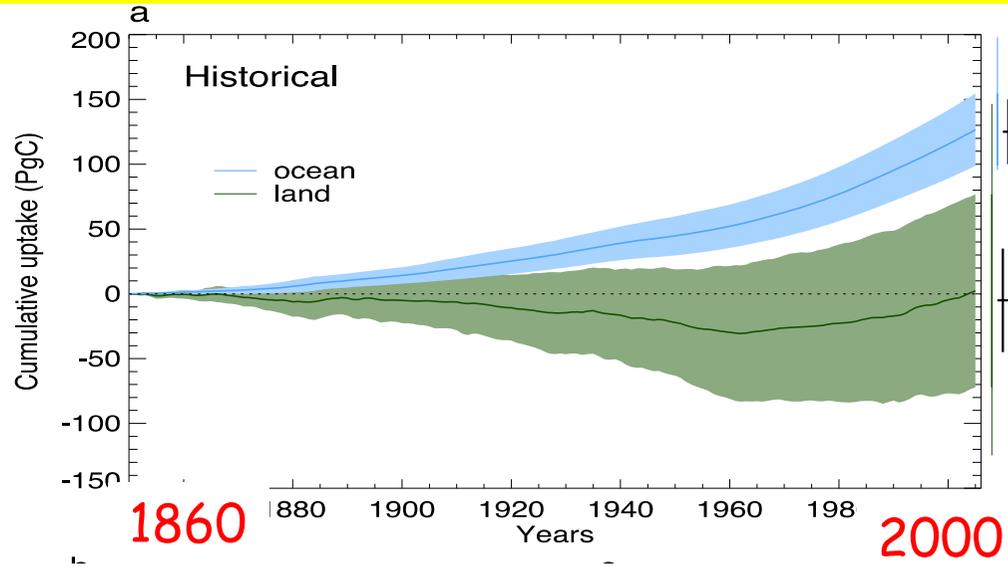
The land sink is highly variable on an annual basis
 Strong correlation with El Niño events
 Driven by weather anomalies; not yet properly understood.



Key question : Future of natural sinks



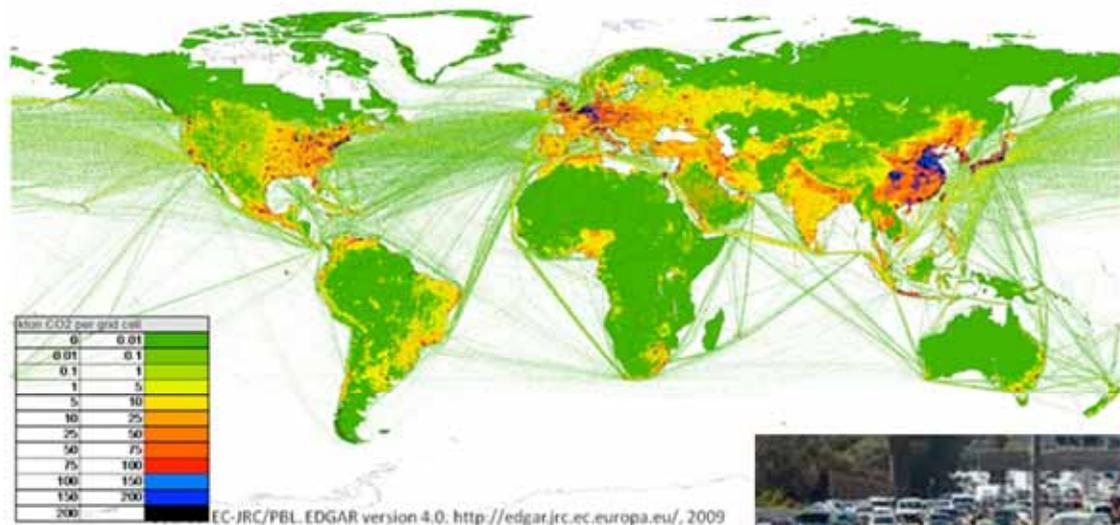
Historical



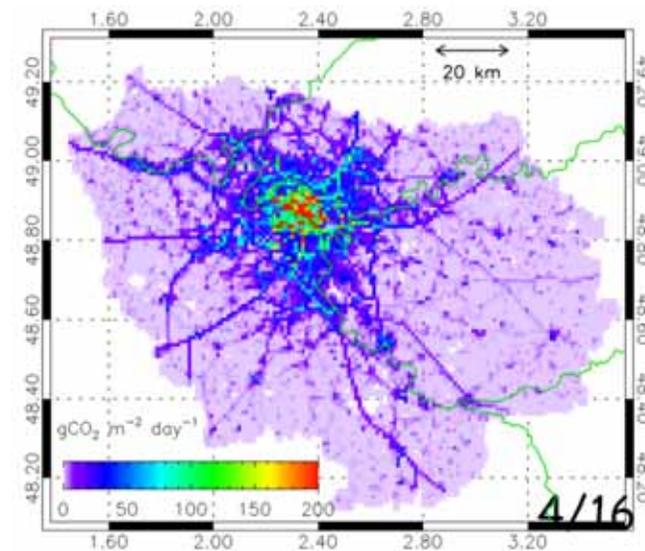
Cumulative Ocean Sink

Land sink, including impact of land use change

IF there is an international agreement to curb CO_2 emissions, there is a need for a **independent monitoring** of these emissions. Current uncertainties range from a few % to $\approx 20\%$ at the annual-country scale. Much larger uncertainties for finer scales



EDGAR inventory





Space missions for CO₂ and CH₄ monitoring



ESA / EnviSat / **Sciamachy** [2002-2012] : First mission using solar channels.
Poor spectral and spatial resolution. First attempts

EumetSat / CNES / IASI [2006-current] : Operational weather mission.
Sensitive to CO₂ in the mid-upper

NASA / **OCO** [2009] : Lost at launch

JAXA / **GOSAT** [2009-current] : First
Global observations.

NASA / **OCO-2** [2014-current] : Global
precision measurements, but biased

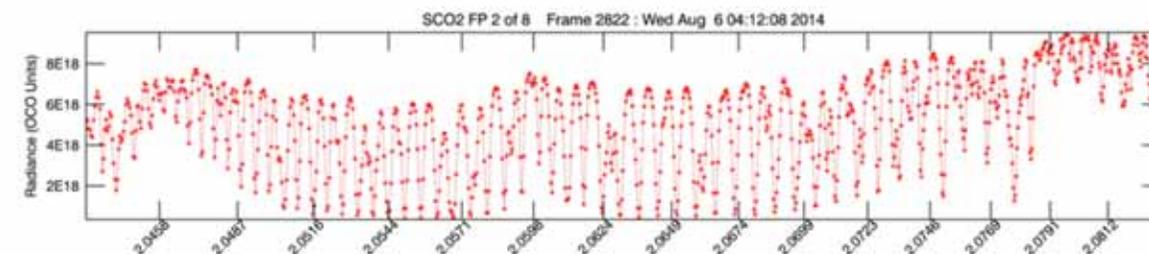
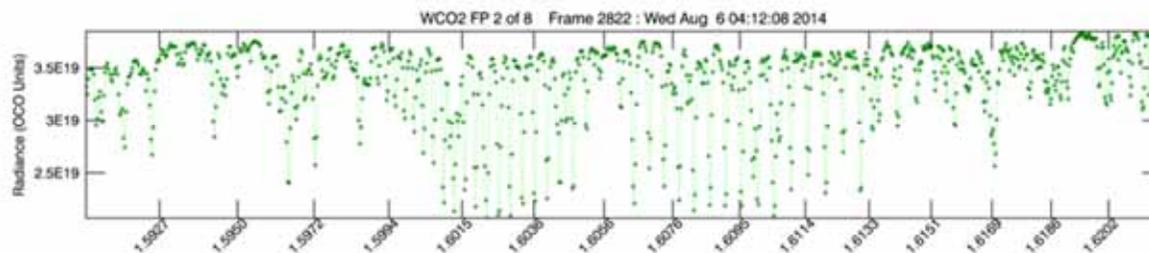
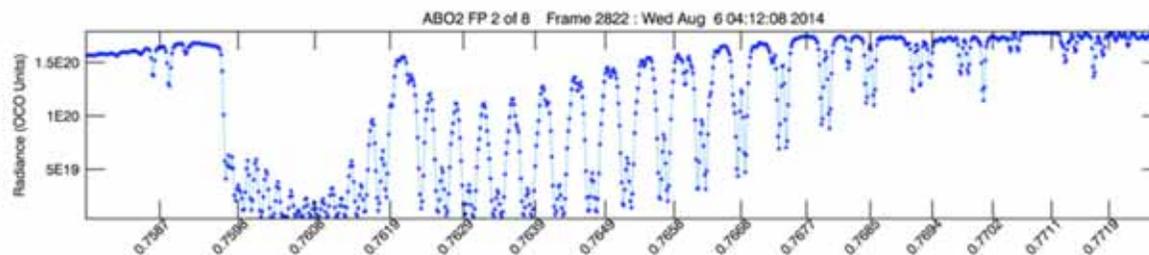
China / **Tansat** [2017-current] : Data

Future...

DLR/CNES/**Merlin** : Active (Lidar)

CNES/**MicroCarb** : CO₂ on a MicroSat

ESA/**Sentinel-7** : CO₂ and CH₄ sensing with imagery capabilities



Anthropogenic emissions : Requirements ?

To **verify compliance** with international agreements such as Paris-COP21, the needs are for

- national scale,
- yearly,
- accuracy \approx a few %

Seems unrealistic for many reasons, one being the distinction of natural and anthropogenic fluxes

Focus is then on "**point sources**" such as large cities or power plants.

- Larger signal
- Biogenic contribution may be neglected (really ?)

Can one aggregate point sources emissions for something useful at the national scale ? Depends on the contribution of Large cities and PP to the national total

Monitor the real impact of national or local policies

The needs are then for

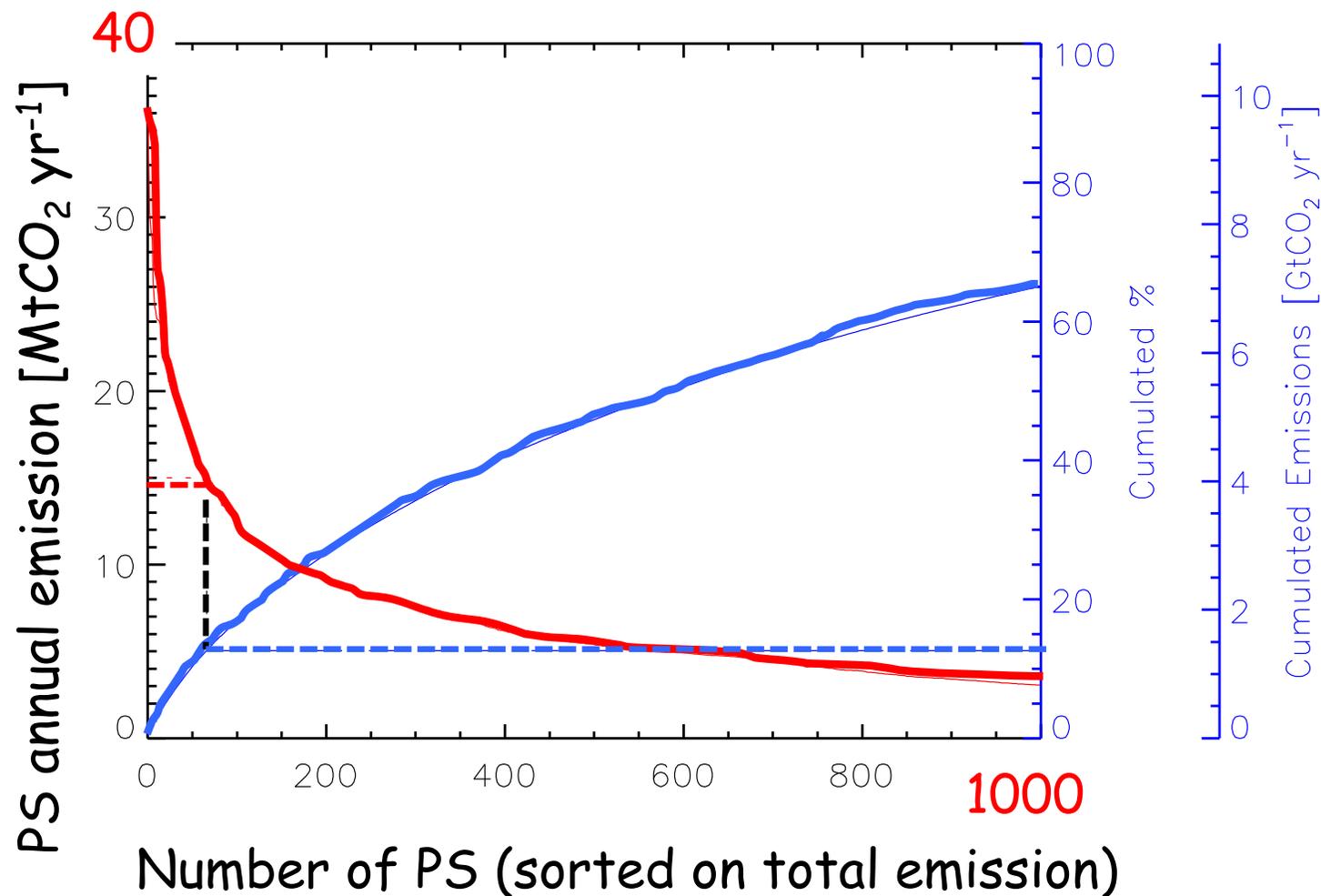
- local scale
- yearly
- accuracy \approx a few percent

Would be nice to retrieve emissions at very small scale (< 100 m) for an attribution of the emission to specific contributors. No such plan

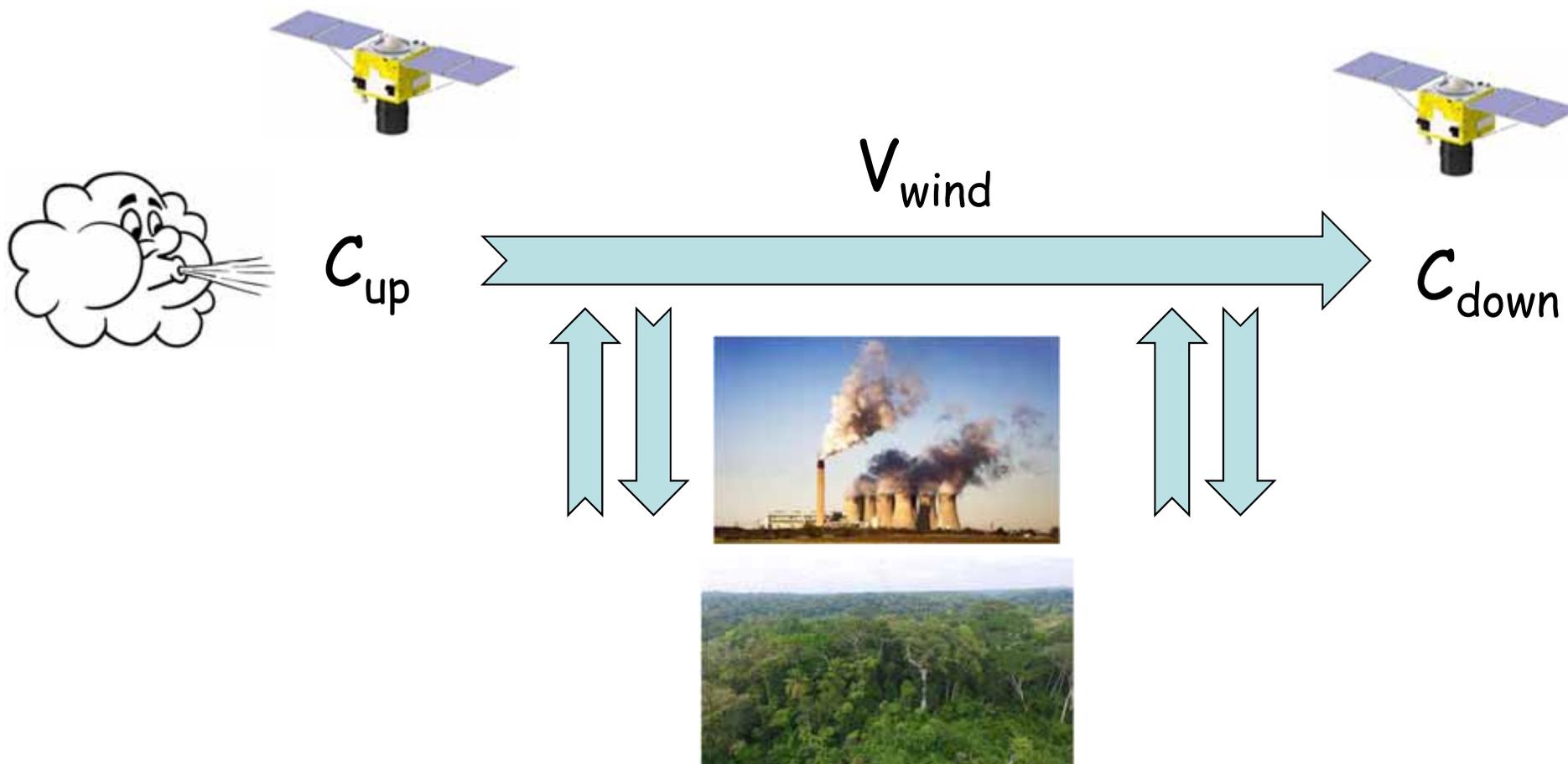
Point Sources (PS) identified in the Carma database contribute to $\approx 30\%$ of the total anthropogenic CO_2 emissions

The large PS may be monitored from space

Question : What fraction of the total do these PS contribute to ?



Large PS ($>10 \text{ MtCO}_2 \text{ yr}^{-1}$) contribute $\approx 25\%$ of the total



$$F_{source} - F_{sink} \approx P_{surf} (C_{up} - C_{down}) V_{wind}$$

- The flux estimate is not for the location where the concentration is measured
- Need for accurate knowledge on the atmospheric transport
- Anthropogenic and natural fluxes impact the measurements



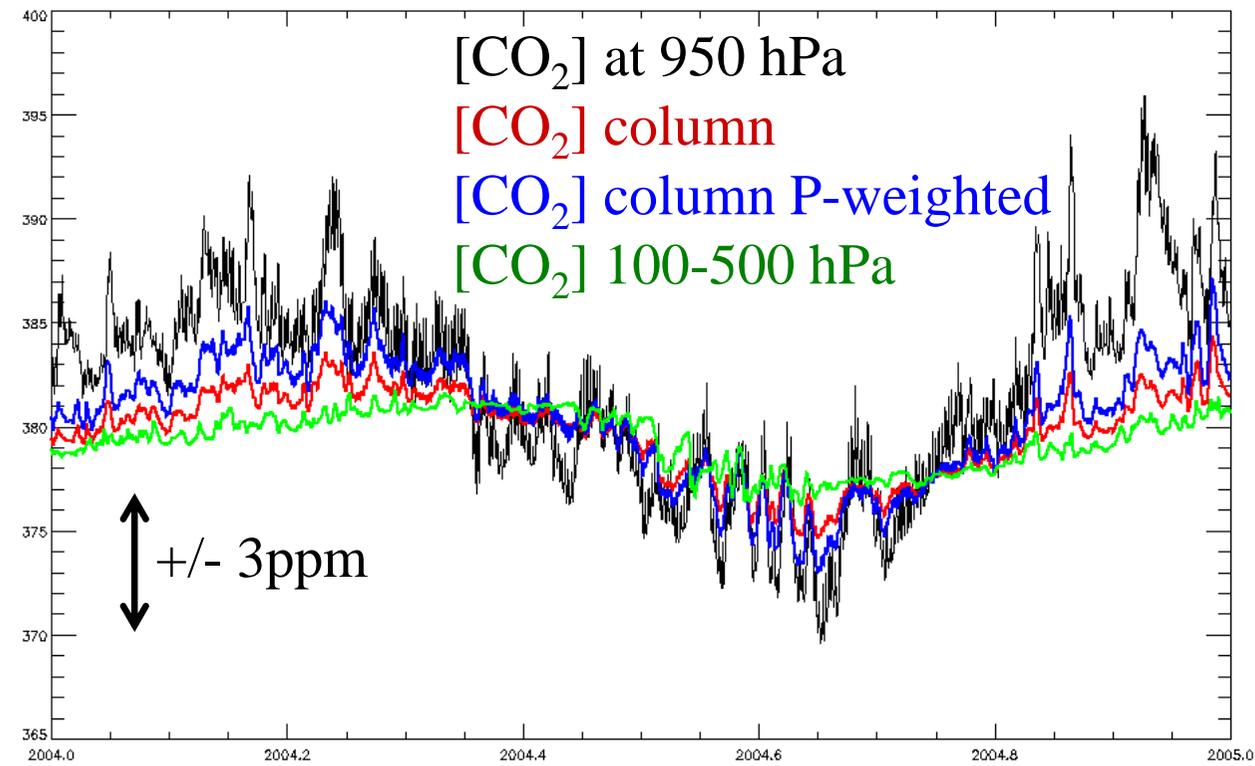
Very demanding requirements



For CO_2 , the "signal" which must be measured is on the order of 1 ppm for a background concentration of ≈ 400 ppm.

For CH_4 , the signal is ≈ 20 ppb for a background concentration of 1800 ppb

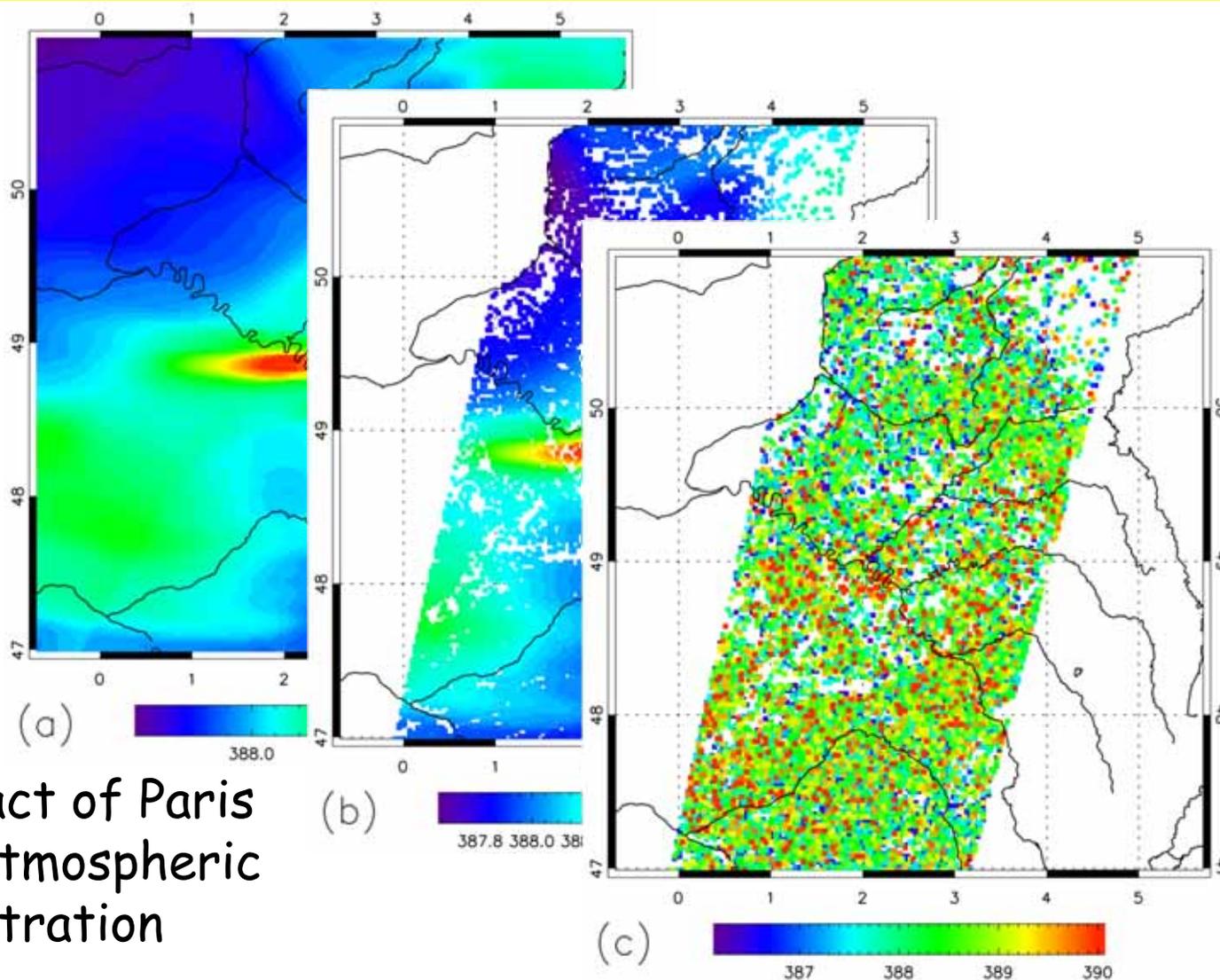
Difficult to measure atmospheric concentration at sub percent accuracy



January

December

The large number of satellite observations may compensate the measurement precision IF biases are limited.

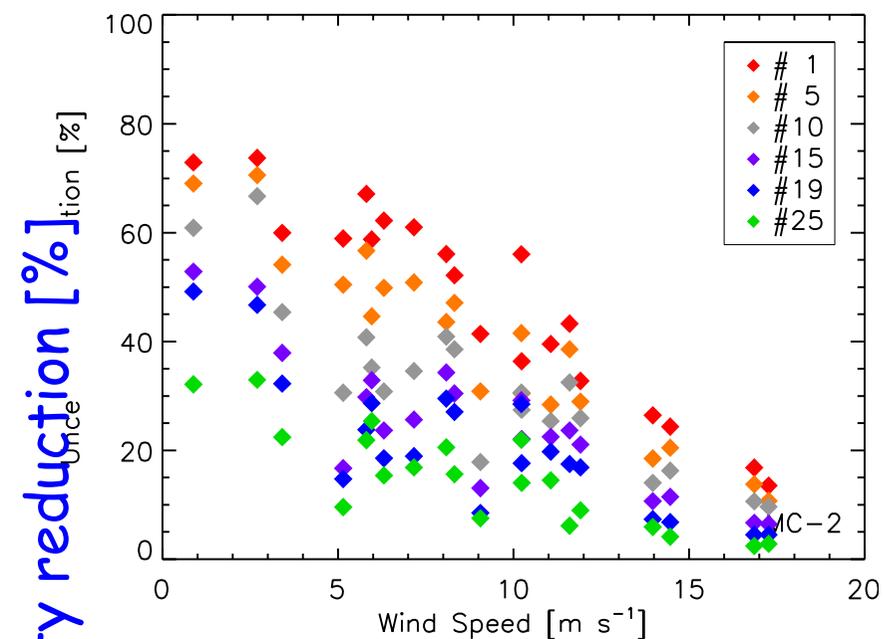


Simulate Impact of Paris emissions on atmospheric column concentration

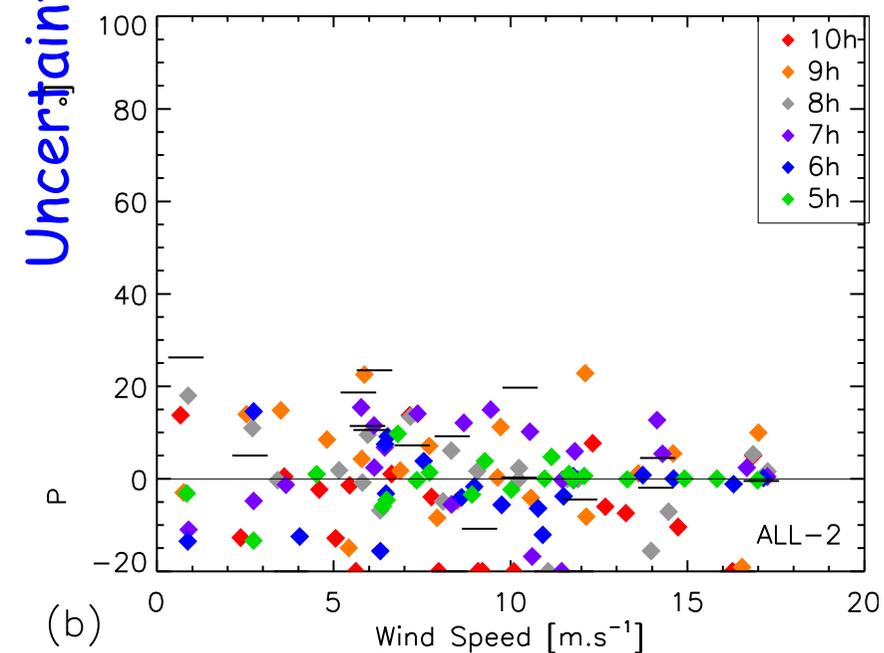
Satellite limited swath and cloud cover

Noise in satellite observation has an amplitude similar to Paris signal

Difficult to distinguish Paris plume on the satellite image, but statistical inversion may, given the proper information on atmospheric transport



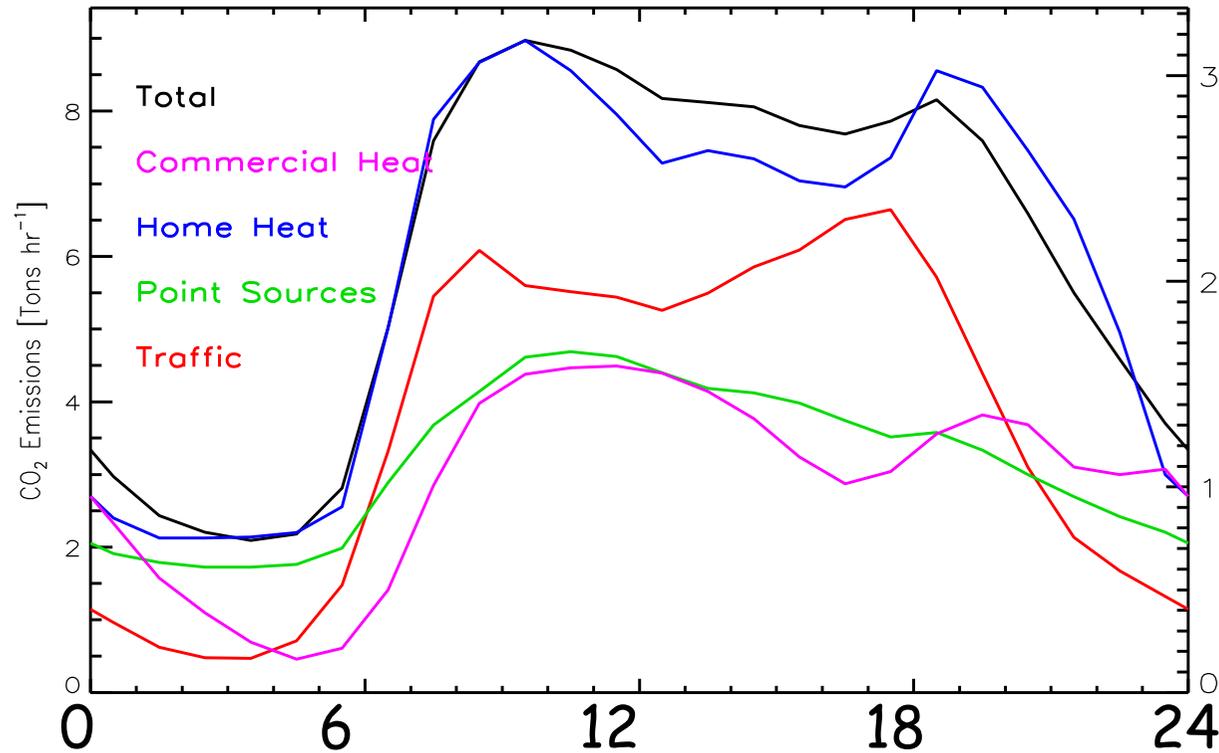
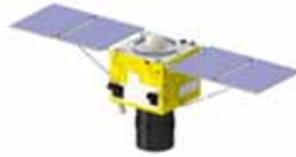
Analysis made in the context of the CarbonSat preparatory studies
 Simulated atmospheric transport and satellite observation
 Assume atmospheric transport and emission distribution is perfectly known
 Potential for significant uncertainty reduction, in particular for known wind speeds



When more realistic conditions are considered, the results are less appealing

- Sources other than those of Paris
- Large scale atmospheric transport
- Biases in observations
- Unknown spatial distribution of source

Wind speed [m s⁻¹]



Satellite at a given local time. Sample the emissions from a few hours before
 Extrapolation to daily total highly uncertain
 Multiple satellite or geostationary : Only daytime

Can one assume that the daily cycle is known when the total emission is unknown?

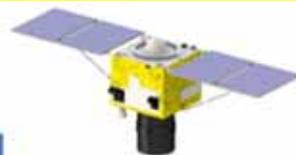
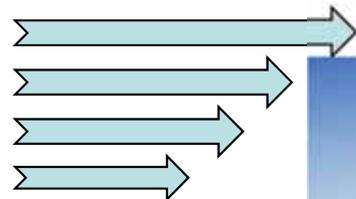


The Satellite can only sample clear sky

Emissions (heating) are likely correlated to cloudiness.

A city emission estimate based on clear-sky observation only will likely be biased.

Bias amplitude depends on season, city, ...



$$F_{\text{source}} \approx P_{\text{surf}} (C_{\text{up}} - C_{\text{down}}) V_{\text{wind}}$$

Accuracy of the knowledge on the wind speed ?

Large uncertainties on the vertical transport. What is the *effective* wind speed ?

Favourable conditions for low wind speed (high concentrations). But relative uncertainty is then large



Ancillary information



Based on satellite data only, the monitoring of anthropogenic emissions with a decent accuracy appears next to impossible

There may be hope in the combined use of other data

- Surface concentration measurements (much better temporal coverage)
- Prior estimates based on activity information
- Information on the daily cycle of activities
- Gases other than CO_2 for an easier identification of the anthropogenic plume

A clear analysis of the potential of such combination remains to be done (studies ongoing in the context of the Sentinel-7 preparatory)



Conclusions



There is a clear need to monitor CO_2 anthropogenic emissions from space.

The difficulty of such objective is not appreciated

The objective in terms of accuracy and spatial/temporal scale not clearly stated

Acquiring high quality CO_2 column concentrations is only one step.

Uncertainties in the atmospheric transport limit the potential of the space imagery, even if one could obtain perfect input data

Methods to combine satellite data with other information remains to be developed

Some additional difficulties have not been discussed :

- A state that want to cheat may easily reduce a PS emission on short period when a satellite overpass is expected (and clear sky)
- High latitude cities with no sufficient sunlight during winter (highest emissions)
- Persistent cloud cover