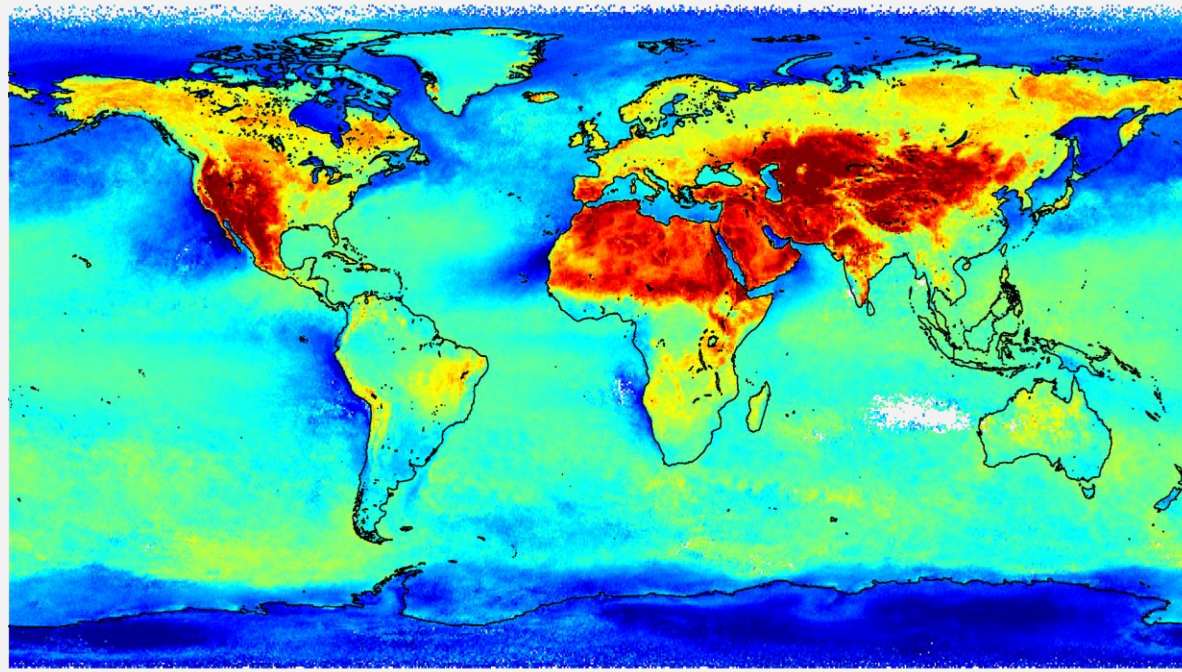
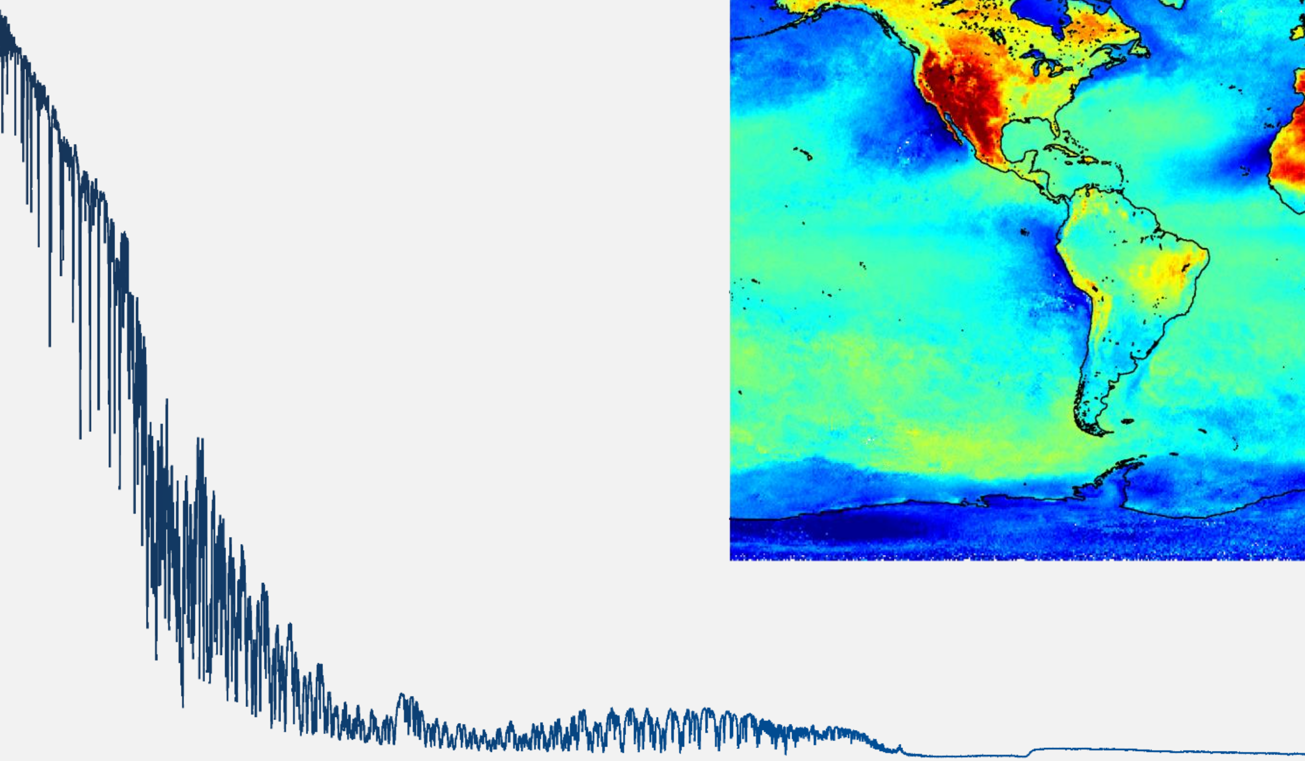
Measuring air pollution from thermal infrared satellite observations: when, where and how?



Thermal contrast – 06/2013 – AM



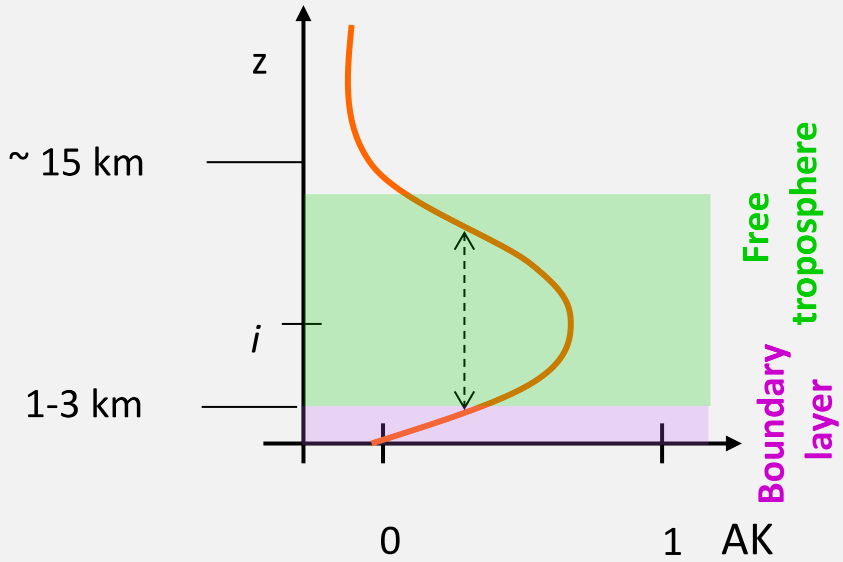
S. Bauduin
L. Clarisse, C. Clerbaux, P.-F. Coheur

Monitoring air quality using TIR observations

Difficulty: Sensitivity limited by the thermal contrast

$$\mathrm{TC} = T_{skin} - T_{air}$$

Typical vertical sensitivity function for a TIR nadir sounder (Averaging kernels AK)



→ Maximum sensitivity of TIR sounders in the mid troposphere

Recent studies have demonstrated the capabilities of IASI sounders to monitor near-surface pollution from local to global scales in favorable conditions

IASI

NH_3

Clarisse et al., *Nature Geoscience*, 2009
Clarisse et al., *JGR*, 2010
Van Damme et al., *ACP*, 2014
Van Damme et al., *JGR*, 2014
Van Damme et al., *AMT*, 2015
Whitburn et al., *JGR*, 2016, in review

SO_2

Bauduin et al., *JGR*, 2014
Boynard et al., *GRL*, 2014
Bauduin et al., *AMT*, 2016

CO

George et al., *ACP*, 2009
George et al., *AMT*, 2015
Bauduin et al., *JQSRT*, in prep.

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IASI

Neural network → NH_3

Conversion of radiance indexes into columns using LUT → SO_2

Method derived from OEM, but using a generalized S_ϵ

OEM → CO

NH_3:

Clarisse et al., *Nature Geoscience*, 2009
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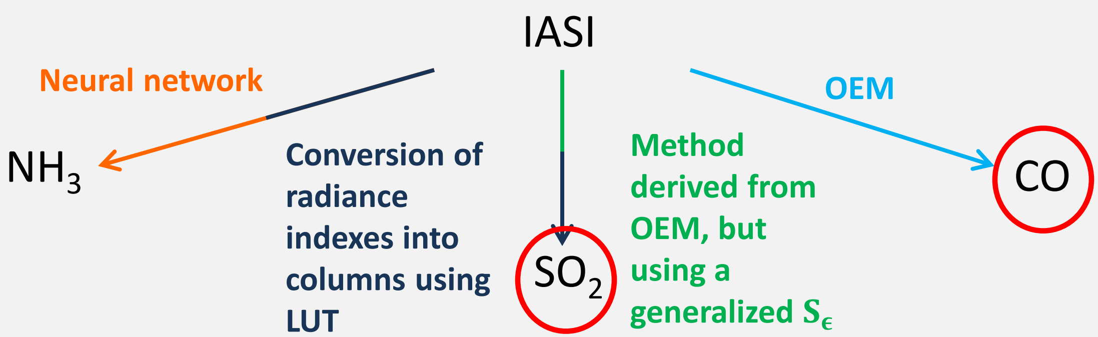

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More details

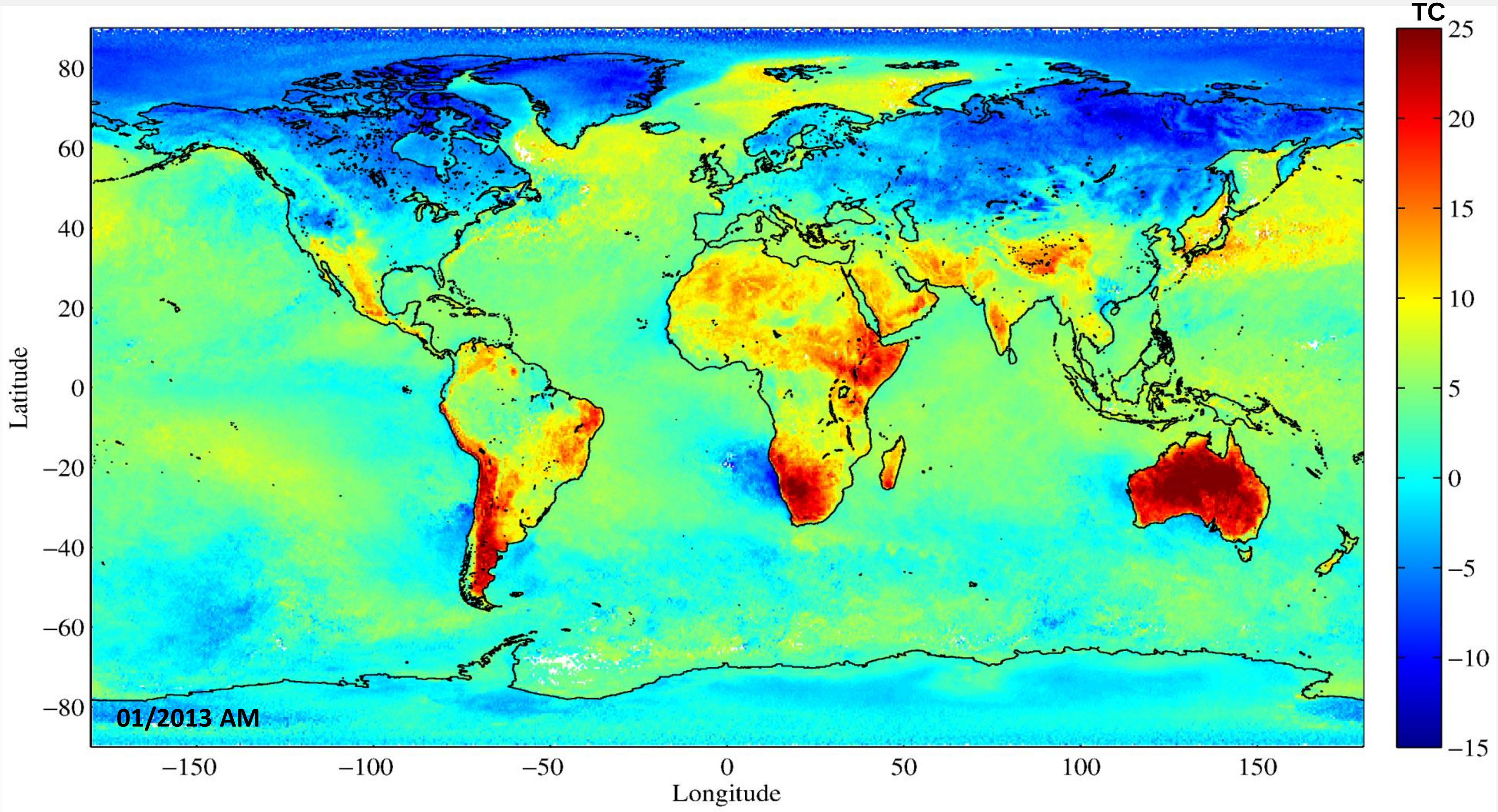
- Previously:
  - Presentation of Van Damme M. on the variability of NH_3 (Tuesday afternoon)
  - Poster n° S3-44 of Whitburn S. on NH_3 emissions from biomass burning (Tuesday)
- Coming today:
  - Presentation of Zondlo M. on the validation of IASI NH_3 columns (this afternoon)
  - Poster n° S9-69 of Whitburn S. on the neural network method (this afternoon)

When and where?

→ When and where the thermal contrast is large (both positive and negative)

When and where?

When and where the thermal contrast is large (both positive and negative)



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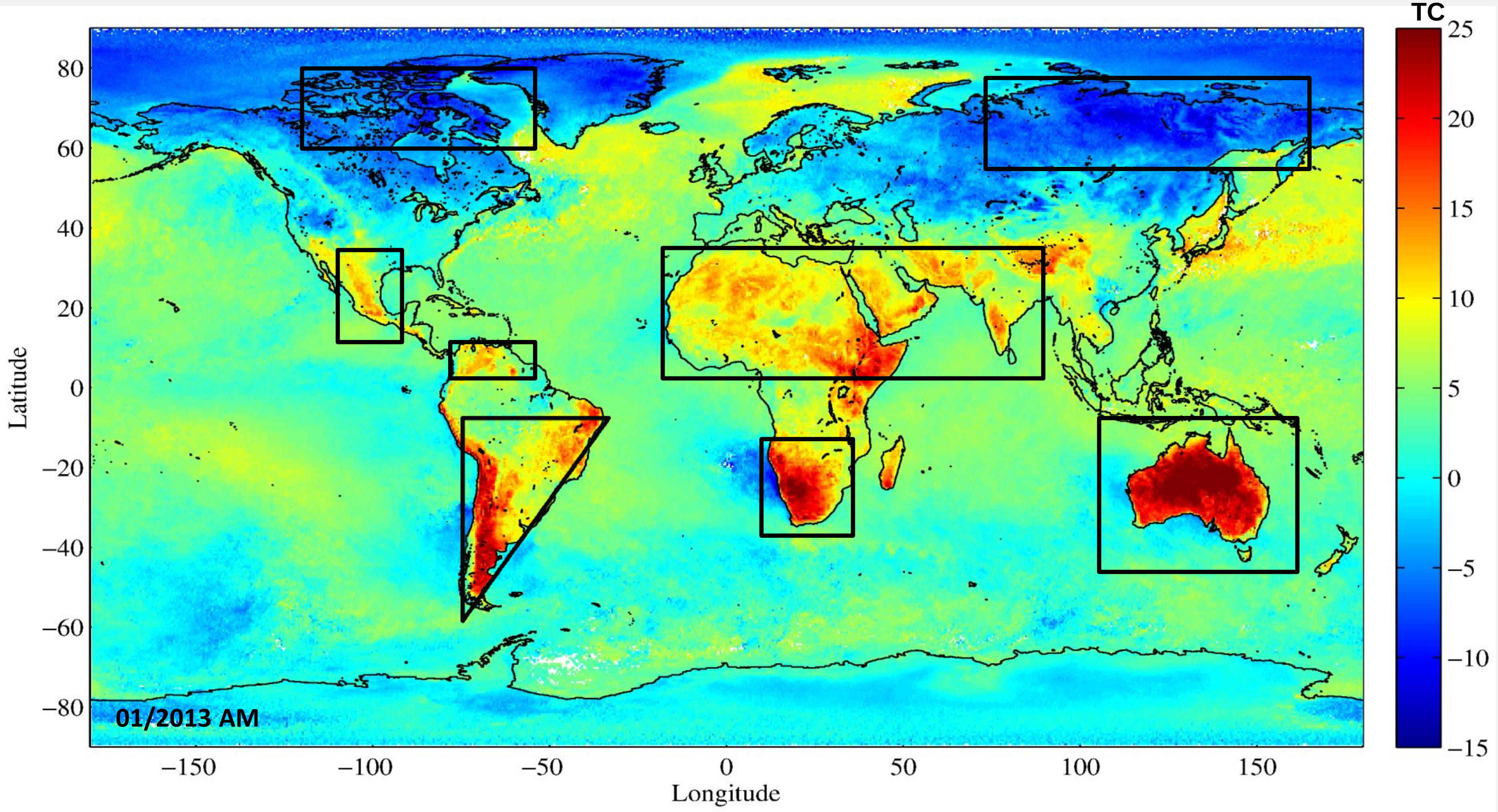

When and where?

The answer is in fact not straightforward!

- Seasonal variability of thermal contrast

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- Sensitivity depends on other factors:
  - Concentrations of the targeted species
  - These concentrations vary according to the source but also to the season
  - The presence of interfering species (e.g. H_2O) → spectral range

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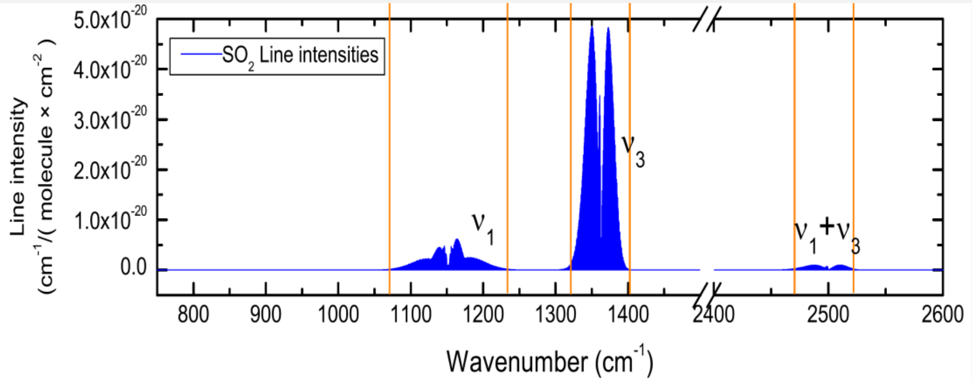
➡ **Review of results for SO_2 and CO**

What is easy with measuring near-surface SO_2?

- ✓ Because of its short lifetime, SO_2 emitted at the surface usually remains confined close to the surface
- ✓ SO_2 has 3 vibrational bands in the spectral range covered by IASI: v_1 (1152 cm^{-1}), v_3 (1362 cm^{-1}) and v_1+v_3 (2500 cm^{-1})

Clarisse et al., *AMT*, 2012



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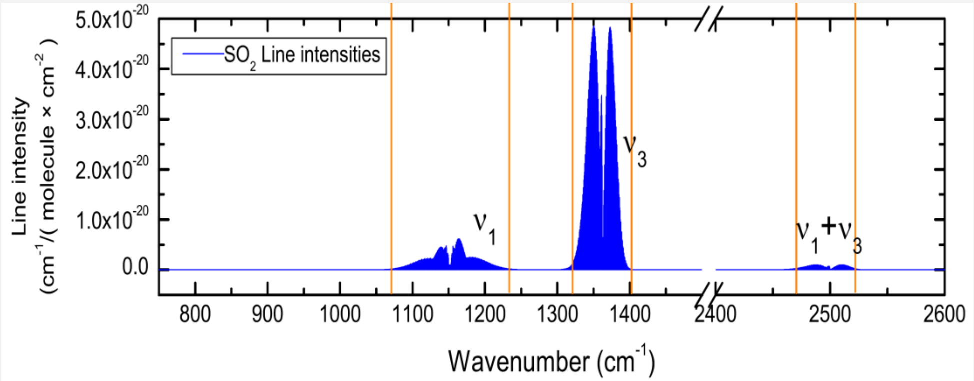
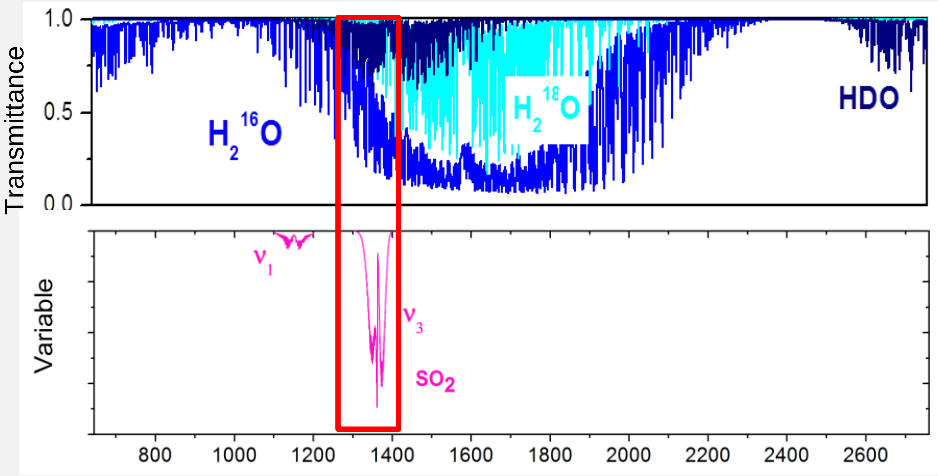


What is not easy with measuring near-surface SO_2?

- ✓ Concentrations of SO_2 close to ground are generally small
- ✓ The v_1 and the v_1+v_3 bands are hardly detected
- ✓ The v_3 band is detectable, but is located in the strong H_2O absorption → opacity in the lowest part atmosphere
- ✓ In case of volcanic eruption, need to distinguish volcanic plume from near-surface pollution/degassing

Clerbaux et al., *ACP*, 2009



First attempts: Norilsk[1] and North China Plain[2]

- Method based on the one presented by Carboni et al.[3]
- Relies on OEM
- Main idea: use of a total error covariance matrix $\boldsymbol{S}_\epsilon$ in the retrieval

ν_3 band

Presentation of E. Carboni (L. Ventress) on Tuesday

[1] Bauduin et al., IASI observations of sulfur dioxide (SO_2) in the boundary layer of Norilsk, *JGR*, 2014
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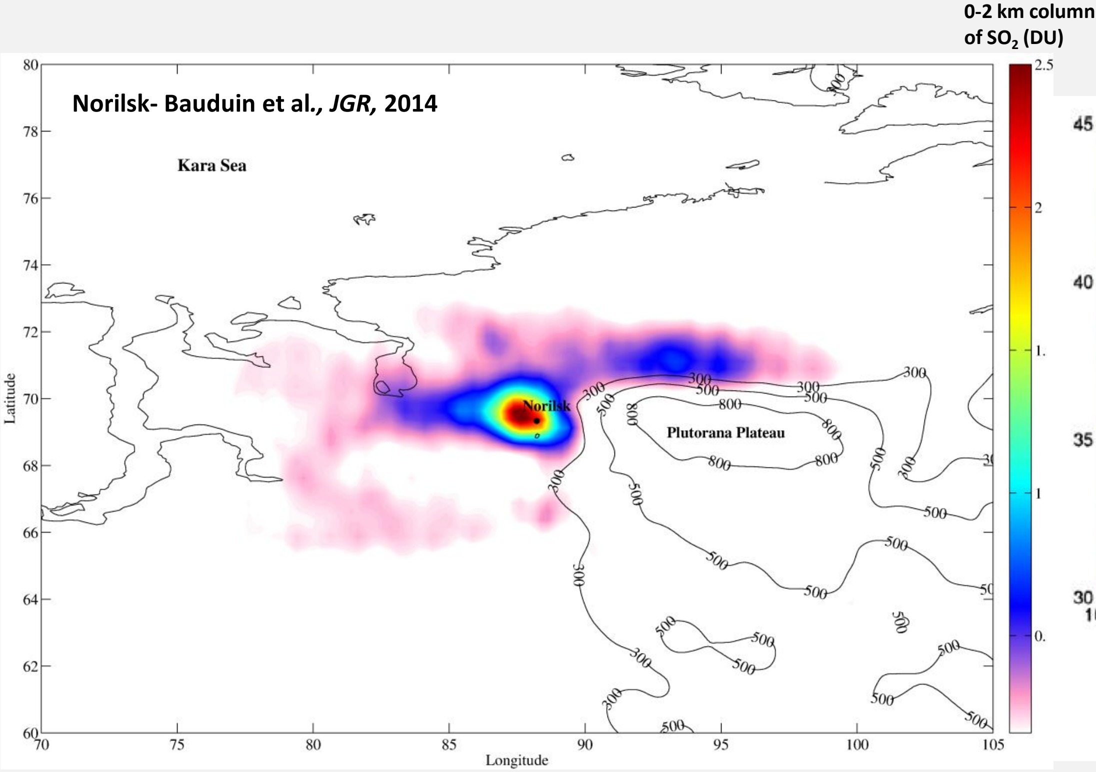
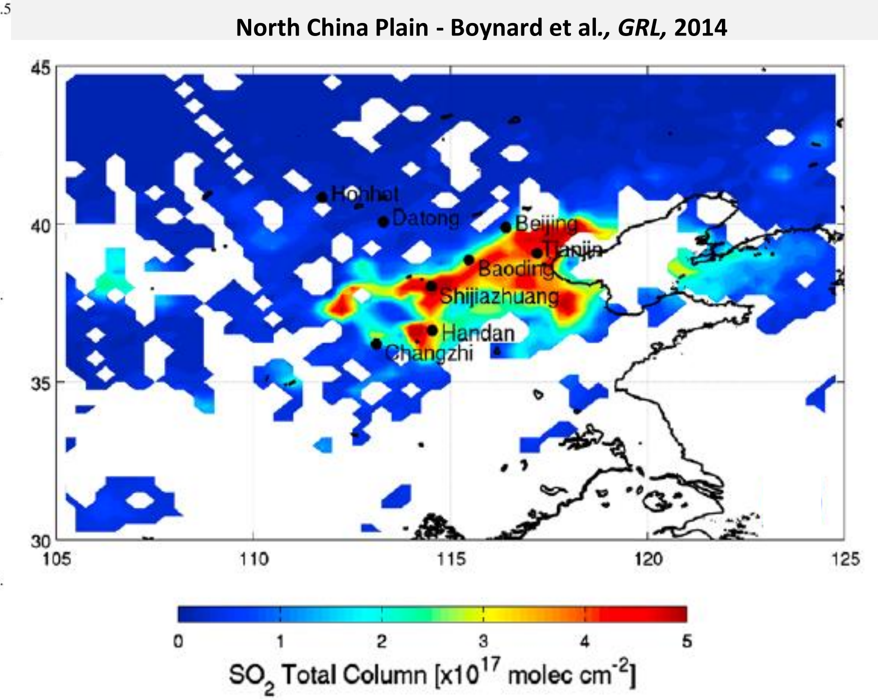
- Main idea: use of a total error covariance matrix $\boldsymbol{S}_{\epsilon}$ in the retrieval
- Sensitivity in winter

ν_3 band





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Global scale[1]

How?

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Presentation of M. Van Damme and E. Carboni (L. Ventress) on Tuesday

[1] Bauduin et al., Retrieval of near-surface sulfur dioxide (SO_2) concentrations at a global scale using IASI satellite observations, *AMT*, 2016
[2] Walker et al., An effective method for the detection of trace species demonstrated using the MetOp Infrared Atmospheric Sounding Interferometer, *AMT*, 2011
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- Conversion of these indexes by using look-up tables

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Measuring air pollution: SO_2

Global scale[1]

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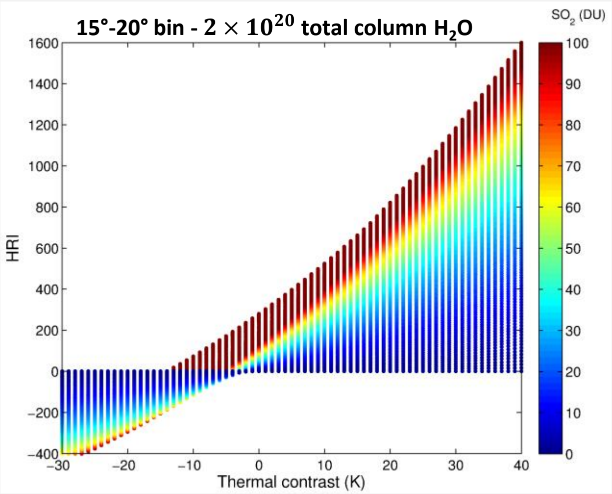
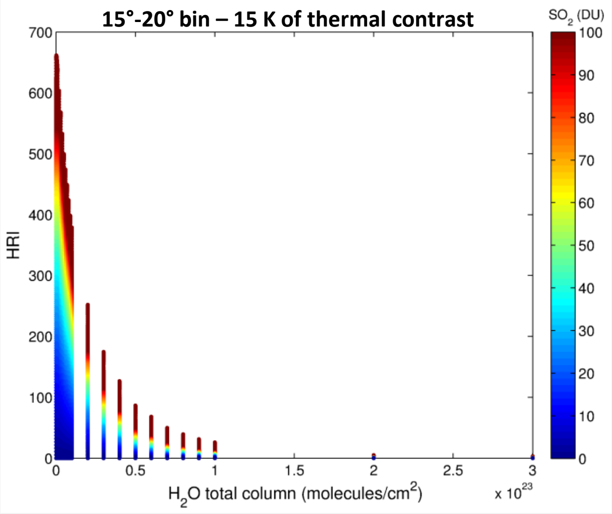
- Method based on the one presented by Walker et al. (2011)[2] and expanded by Van Damme et al. (2014)[3] for NH_3
- Based on the calculation of radiance indexes (HRI), which represent the strength of $\mathbf{v_3}$ **band** in IASI spectra
- Conversion of these indexes by using look-up tables
- 4D LUT: thermal contrast, total column of H_2O, zenithal angle and SO_2 column
- Associated tables of errors





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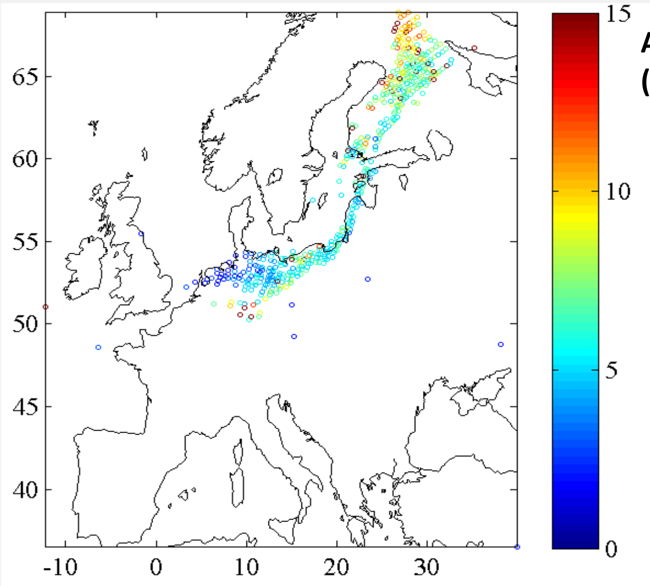
Measuring air pollution: SO_2

Global scale[1]

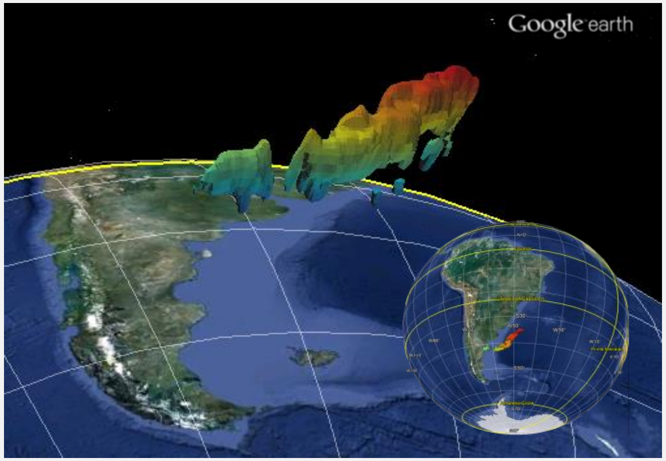
How?

ν_3 band

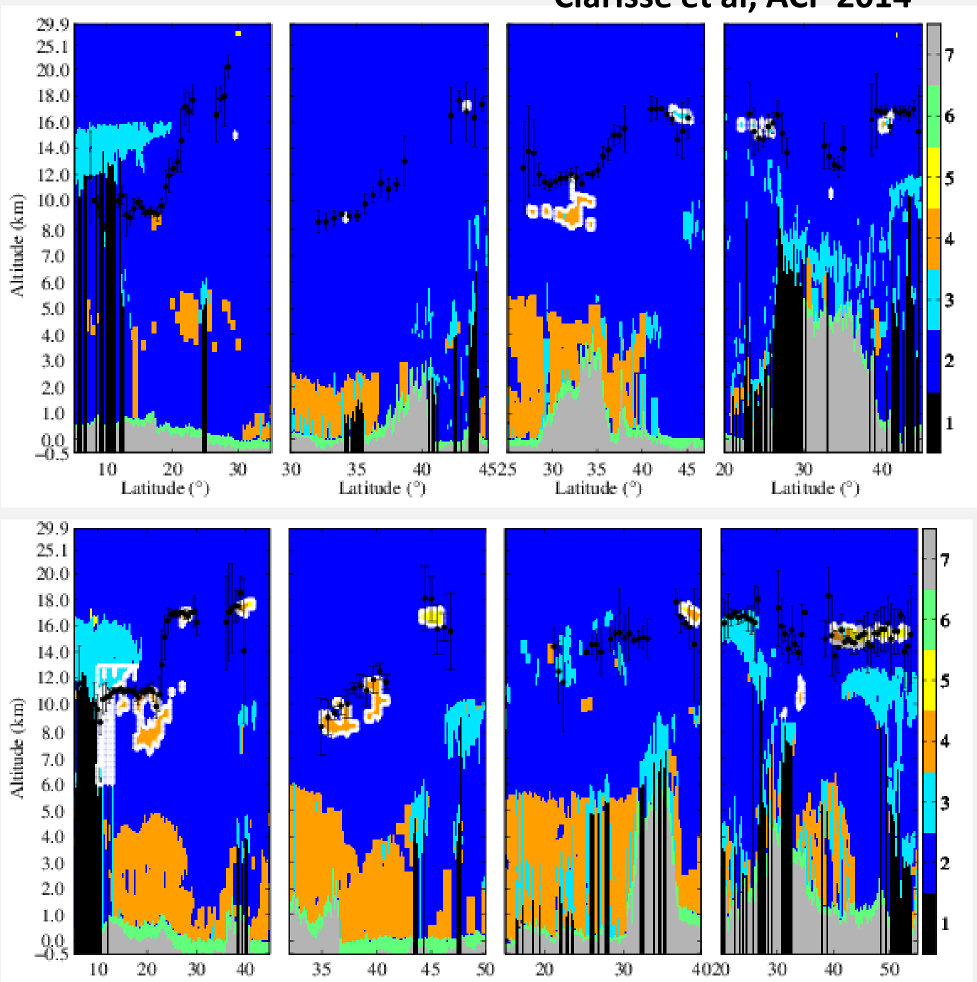
- Need in a first step to determine the altitude of the plume
- Method follows the work of Clarisse et al., *ACP*, 2014[2] for the Nabro eruption



Altitude (km)



Clarisse et al, ACP 2014



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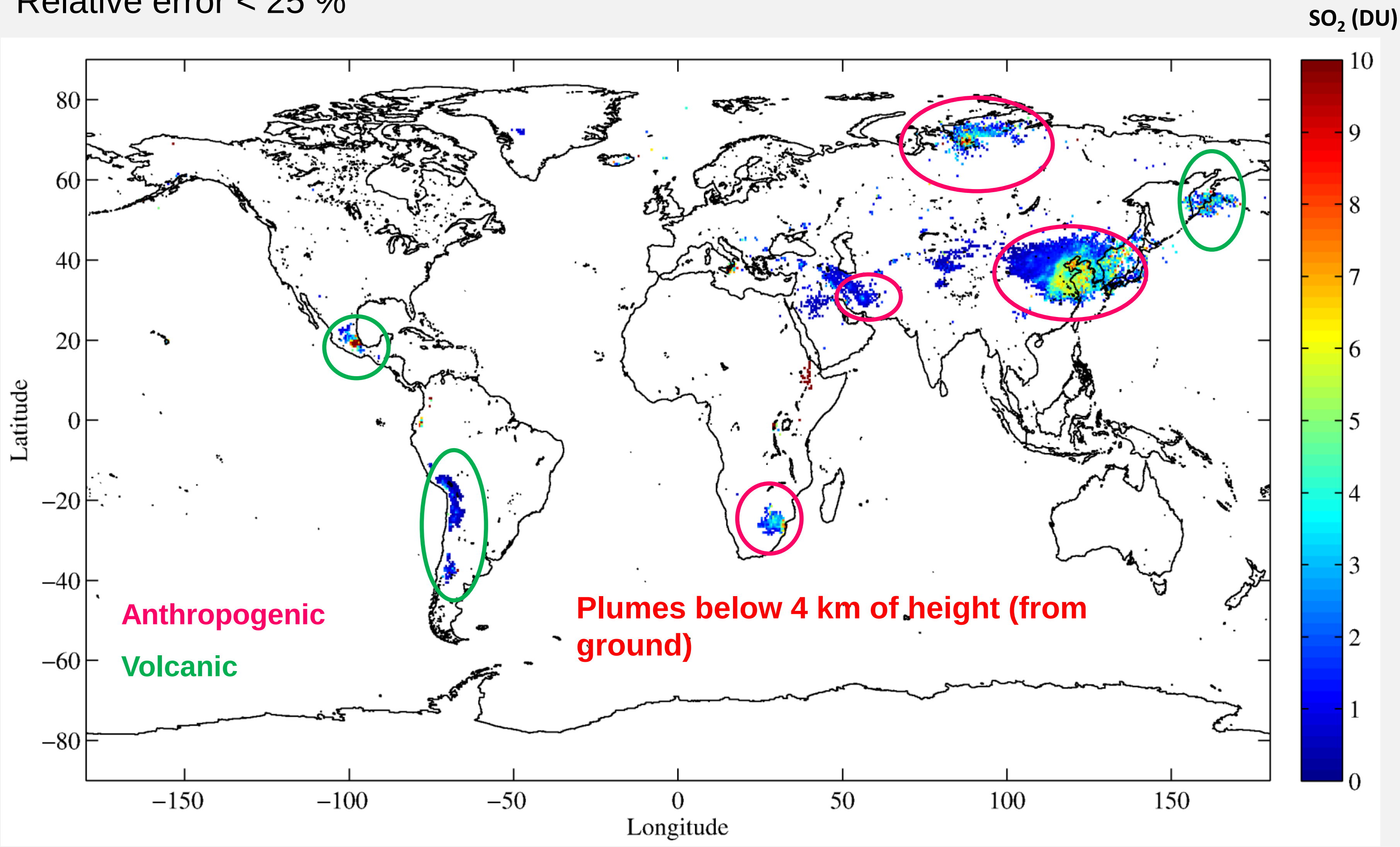
[2] Clarisse et al., The 2011 Nabro eruption, a SO_2 plume height analysis using IASI measurements, *ACP*, 2014.

Measuring air pollution: SO_2

Global scale

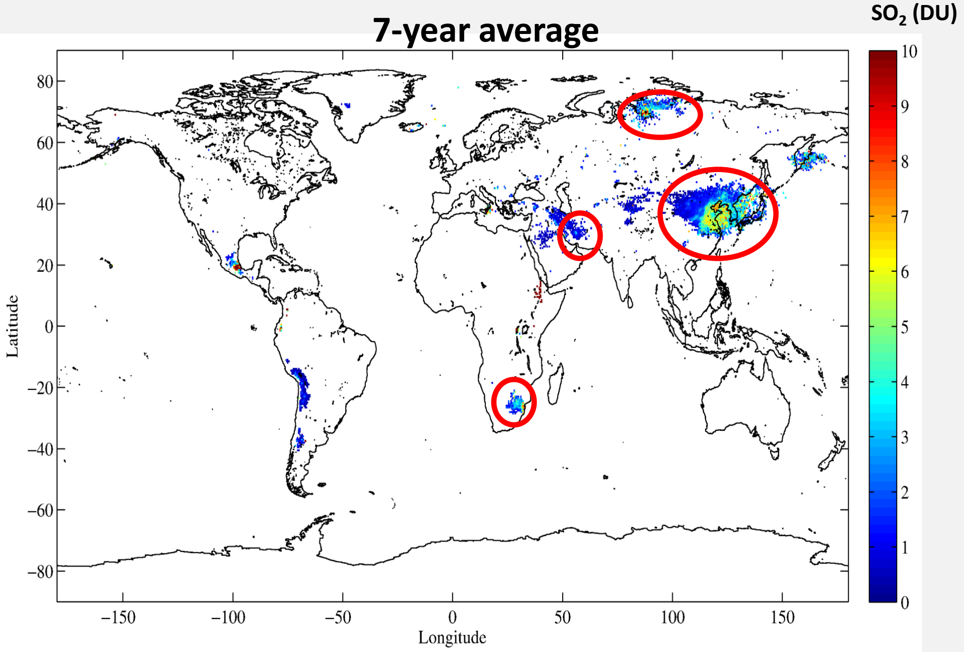
- The magnitude of the error is related to the sensitivity → can be used as a filter
- 7-year average (2008-2014, AM) of IASI measurements sensitive to near-surface SO_2
- Relative error < 25 %



Global scale

When and where?

- The magnitude of the error is related to the sensitivity → can be used as a filter
- Comparisons filtered SO_2 maps with TC and H_2O maps



Measuring air pollution: SO_2

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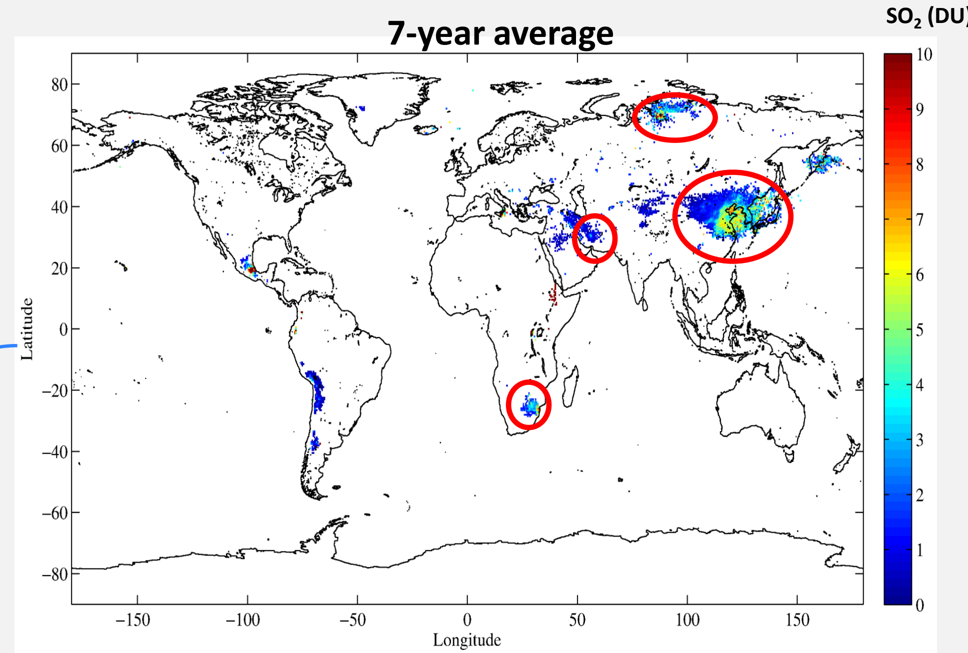
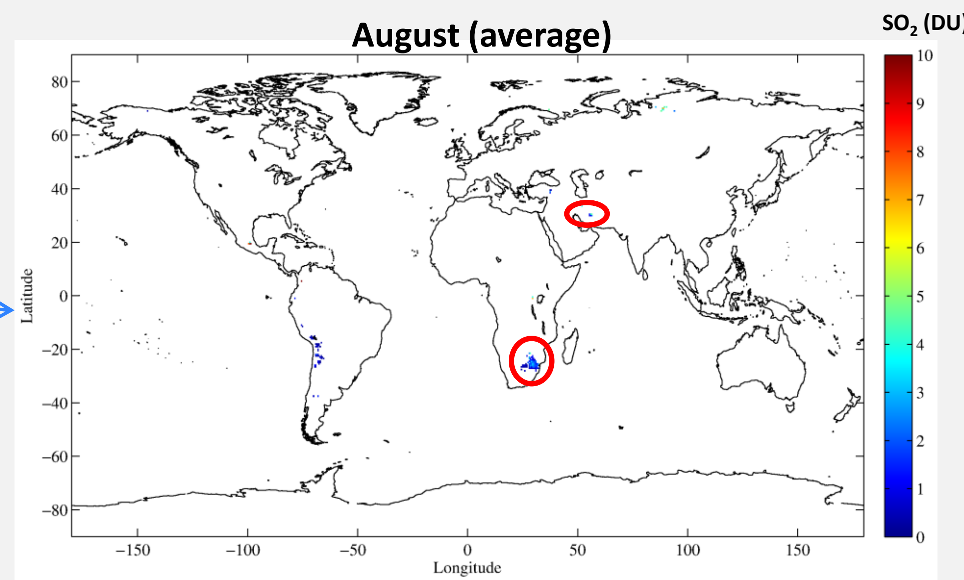
Loss of China and Norilsk





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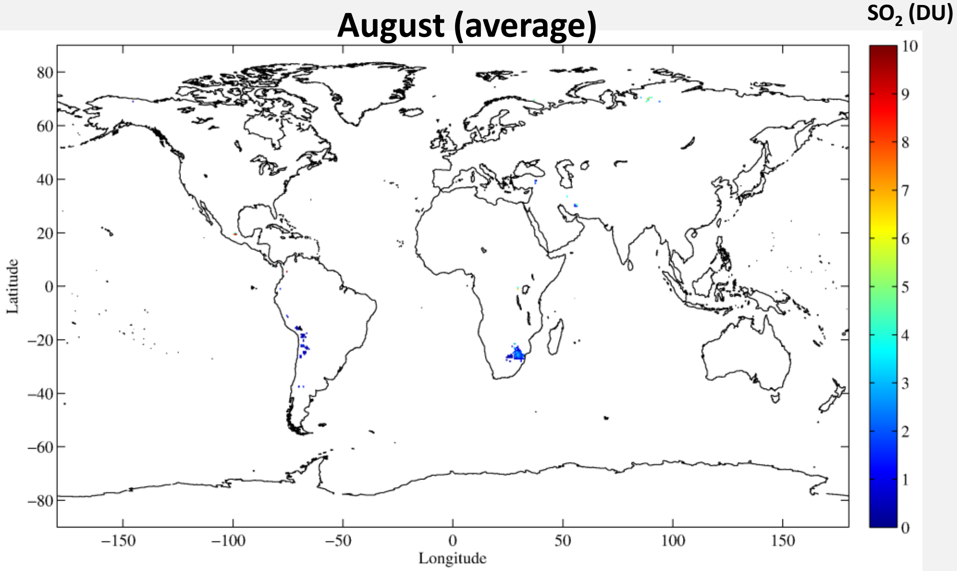

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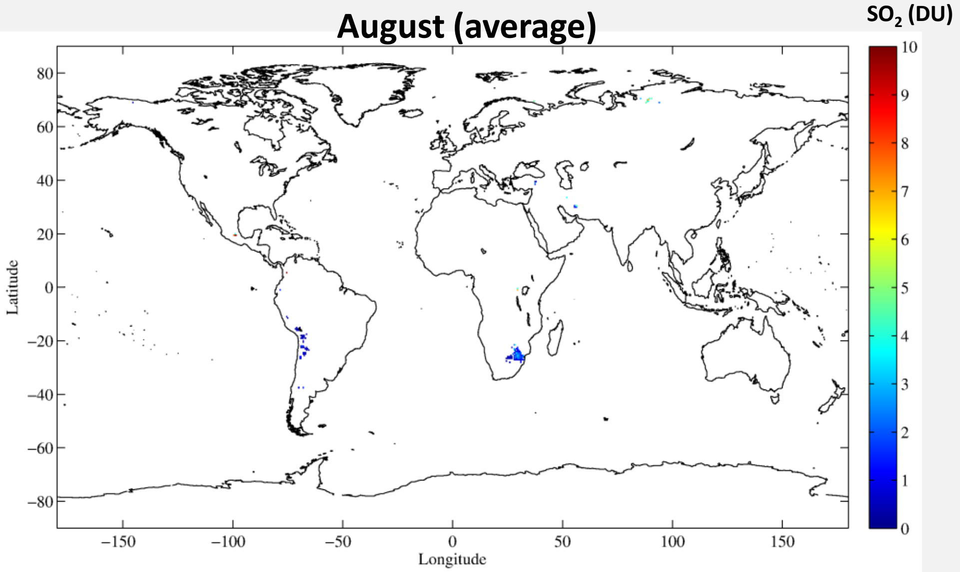

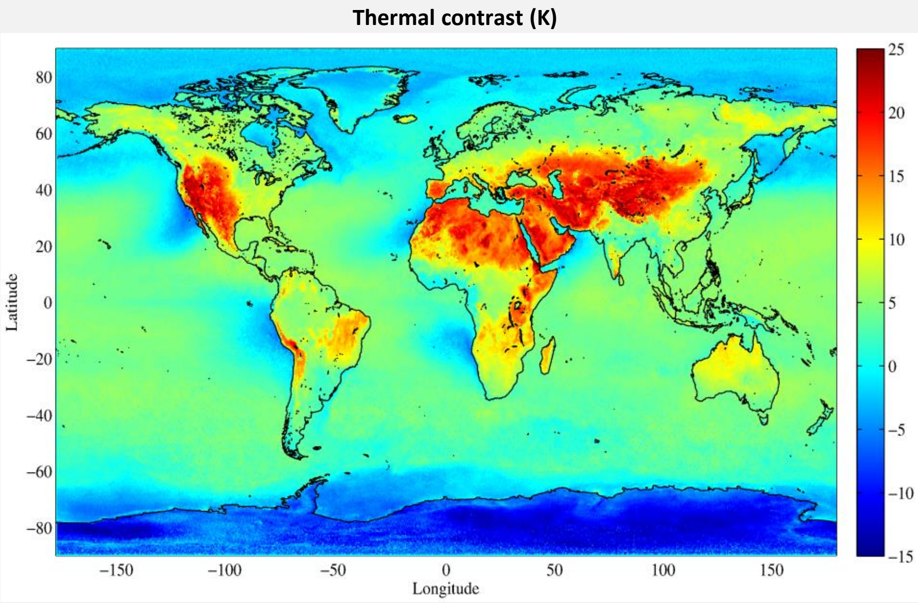

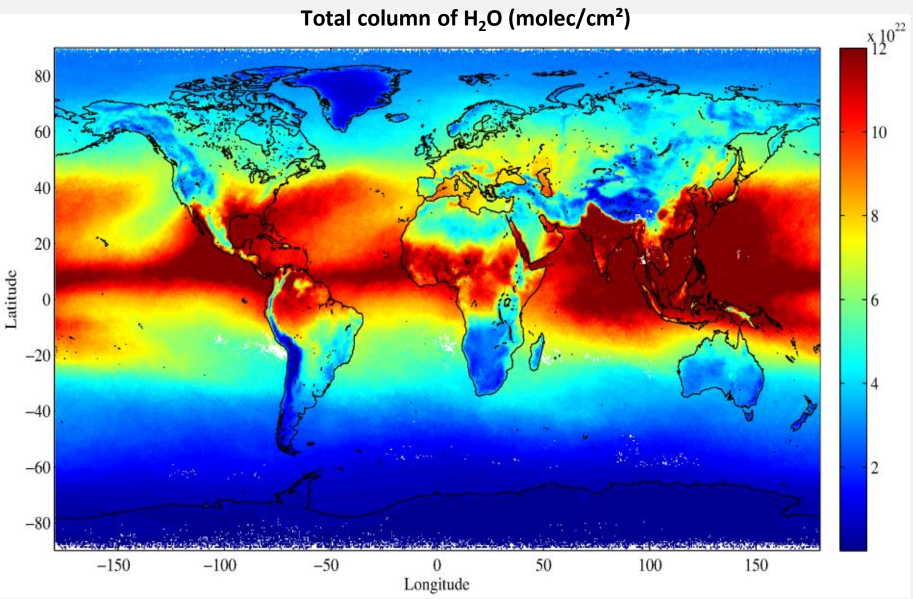

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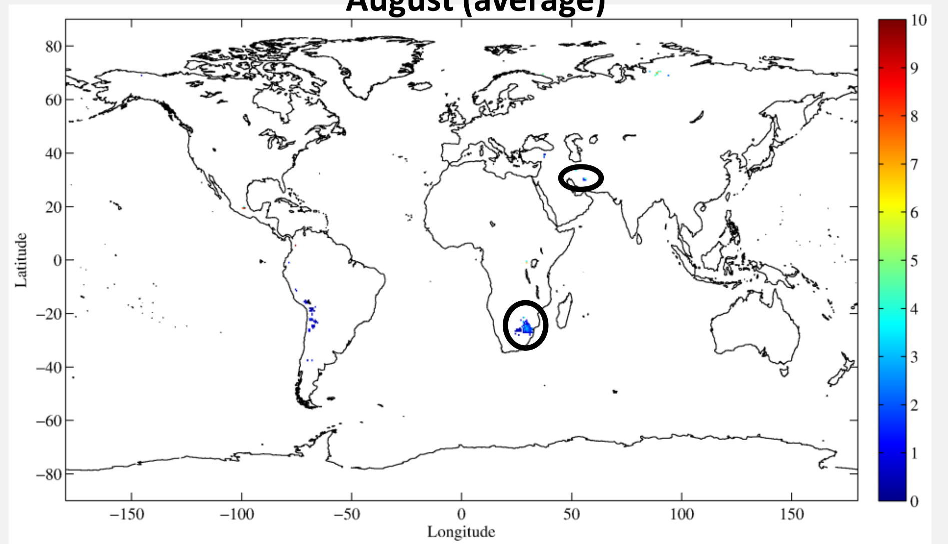
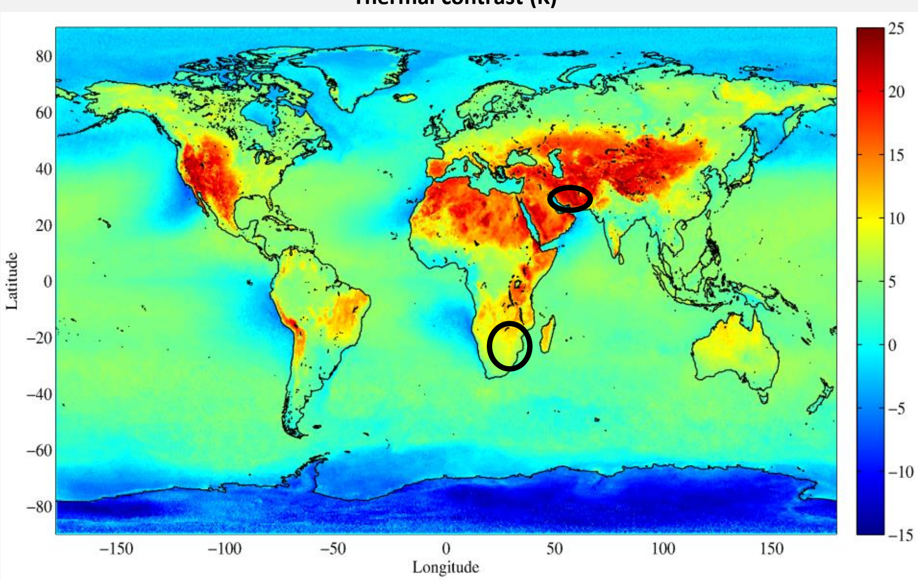
August (average)

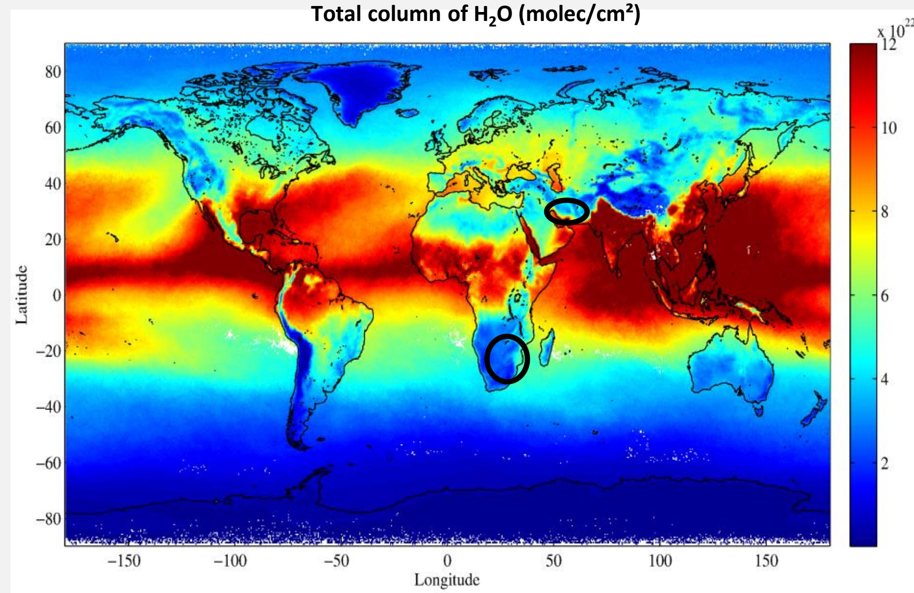
SO_2 (DU)



Thermal contrast (K)



Total column of H_2O (molec/cm²)



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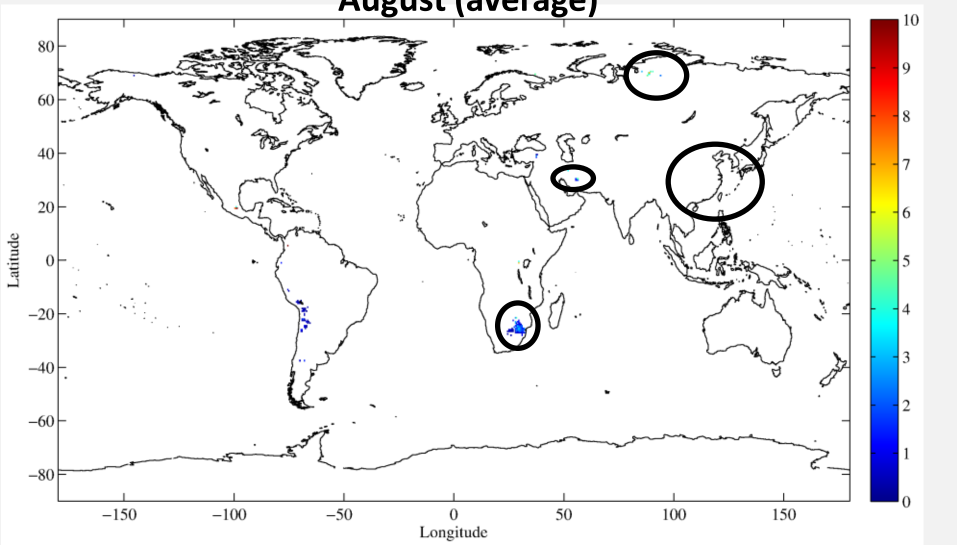

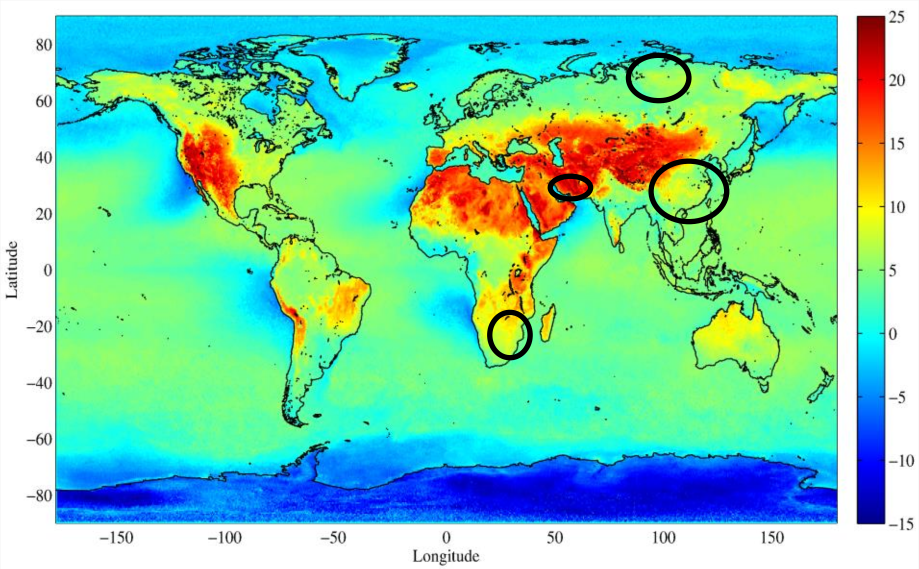

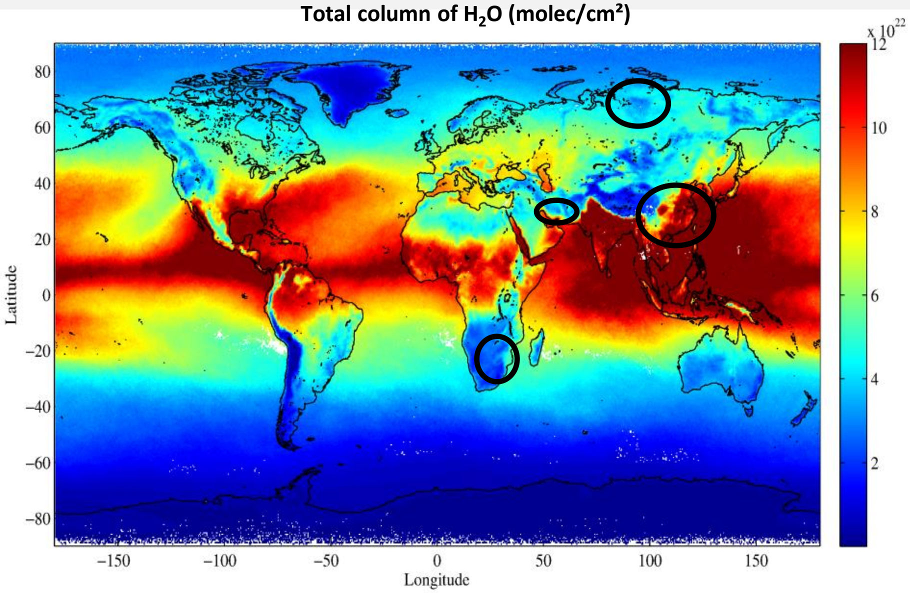

Measuring air pollution: SO_2

Global scale

When and where?

Regions	Periods	Sensitivity	Thermal contrast (K)	Total column of H_2O (molec/cm²)
Norilsk	DJF	✓	-15 K to -10 K	$0.8x10^{22}$
	MAM	↓	-5 K	$1.2x10^{22}$
	JJA	X	0 K	$5x10^{22}$
	SON	↑	-5 K	$1x10^{22}$
China	DJF	✓	5 K	$2\text{-}3x10^{22}$
	MAM	↓	15 K to 20 K	$4x10^{22}$
	JJA	X	10 K to 15 K	$12x10^{22}$
	SON	↑	10 K	$6x10^{22}$
South Africa	DJF	X	10K to 15 K	$5x10^{22}$
	MAM	↑	10 K	$2\text{-}4x10^{22}$
	JJA	✓	5 K to 10 K	$1\text{-}2x10^{22}$
	SON	↓	15 K	$2\text{-}4x10^{22}$
Iran	DJF	✓	10 K	$1x10^{22}$
	MAM	✓	20 K	$1\text{-}2x10^{22}$
	JJA	↓	25 K	$3x10^{22}$
	SON	✓	20 K	$2x10^{22}$

Global scale

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Global scale

<u>Conclusions</u>:

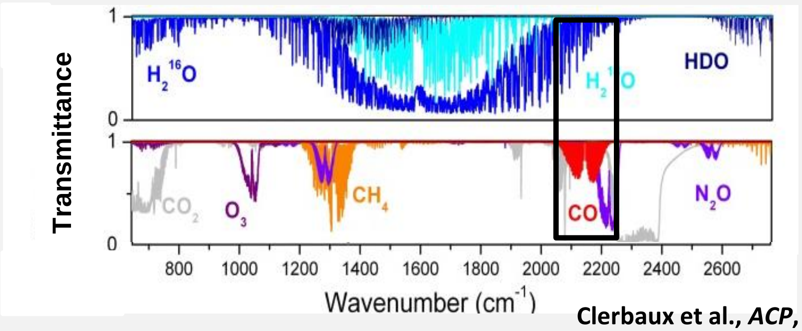
1) Favorable conditions: **|TC|>5K and H_2O<4x10^{22}** molecules/cm²

2) These conditions determined using the **LUT** approach and the filter relative error<25%

3) Only valid for the **v_3 band** → v_1 band less impacted by H_2O absorption

What is easy with measuring near-surface CO compared to SO_2?

- ✓ Strong 0-1 vibrational band between 2000-2250 cm^{-1}
- ✓ Less impacted by H_2O absorption



Clerbaux et al., *ACP*, 2009

*This work has started with the SIROCCO Project, funded by ESA, under contract number 4000107088. The project was conceived and supervised by A.G. Straume-Lindner and O. Witasse

Measuring air pollution: CO*

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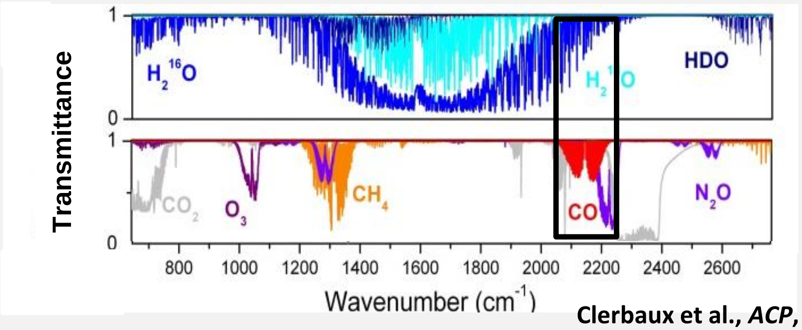

Clerbaux et al., *ACP*, 2009

What is not easy with measuring near-surface CO compared to SO_2?

- ✓ It is present in the whole troposphere → need to decorrelate low troposphere and high troposphere

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How?

Method

3-step analysis:

1) Spectral analysis: is it possible to detect a signal in IASI spectra due to an enhancement of CO close to the ground?

2) Theoretical characterization: influence of thermal contrast on error budget and information content

3) Test case: real retrievals performed above Mexico City and comparison with in-situ ground-based measurements

Bauduin et al., IASI sensitivity to near-surface carbon monoxide (CO): Theoretical analyzes and application to Mexico City, *in preparation for JQSRT*

How?

Method

3-step analysis:

1) Spectral analysis: is it possible to detect a signal in IASI spectra due to an enhancement of CO close to the ground?

2) Theoretical characterization: influence of thermal contrast on error budget and information content

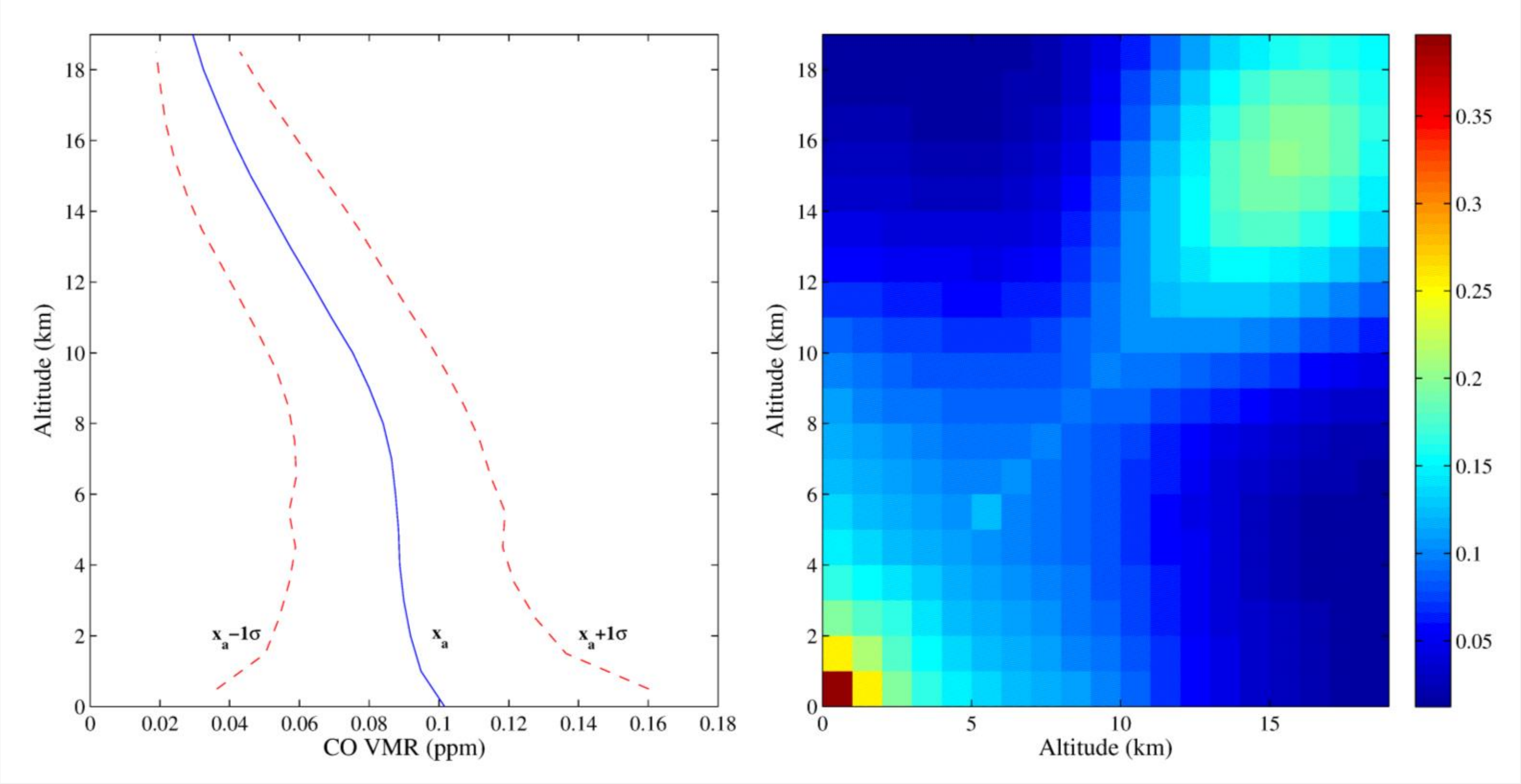
3) Test case: real retrievals performed above Mexico City and comparison with in-situ ground-based measurements

Bauduin et al., IASI sensitivity to near-surface carbon monoxide (CO): Theoretical analyzes and application to Mexico City, *in preparation for JQSRT*

How?

Real retrievals above Mexico City

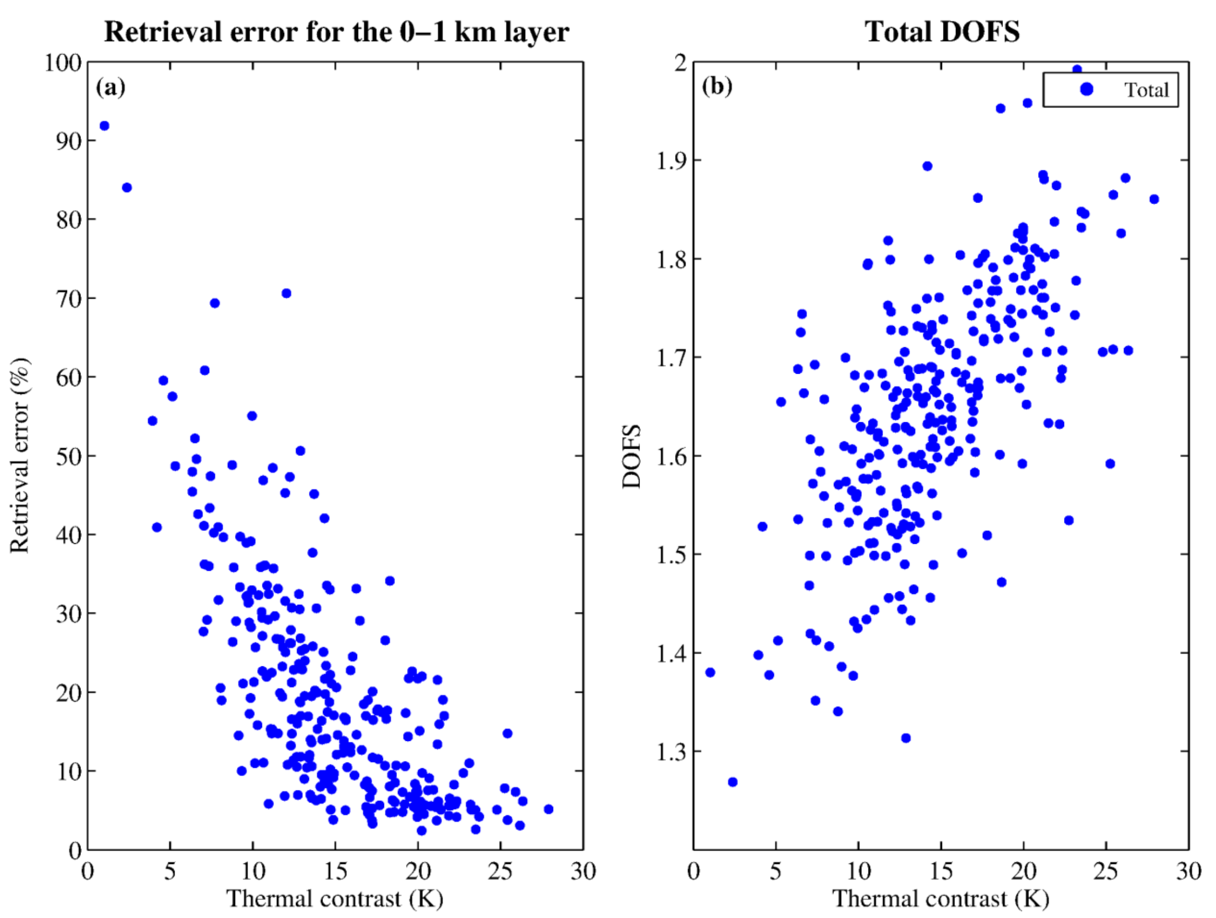
- Performed with the Atmopshit software
- Most of retrieval settings of the FORLI algorithm:
  - 2143-2181.25 cm^{-1}
  - Noise: 2×10^{-7} $W/(m^2\ sr\ m^{-1})$
  - A priori profile and covariance matrix
- Closest IASI measurement to Mexico City chosen



When and where?

Real retrievals above Mexico City

- Retrieval error and total DOFS direclty impacted by the thermal contrast
- Total DOFS reaches almost 2 for TC >15 K



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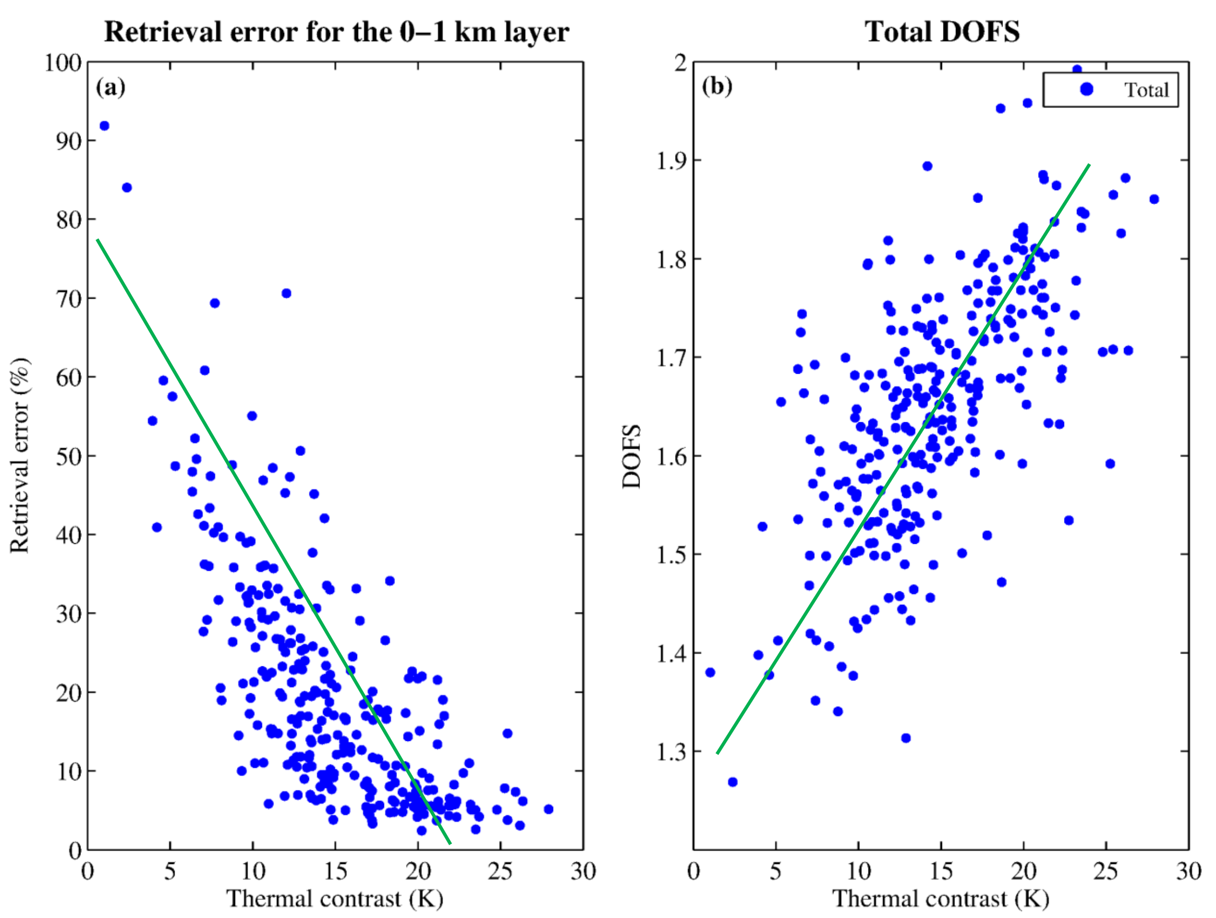

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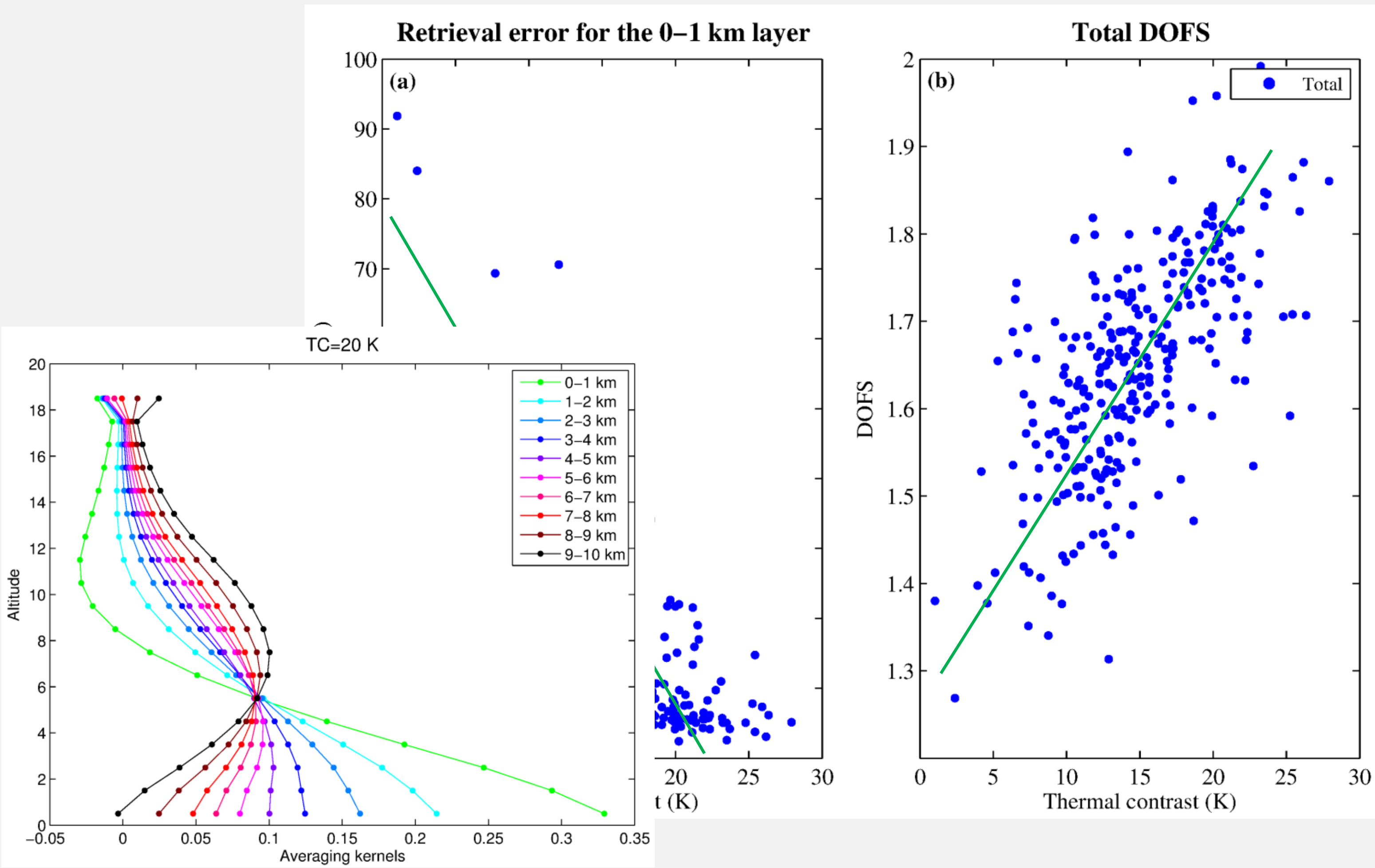
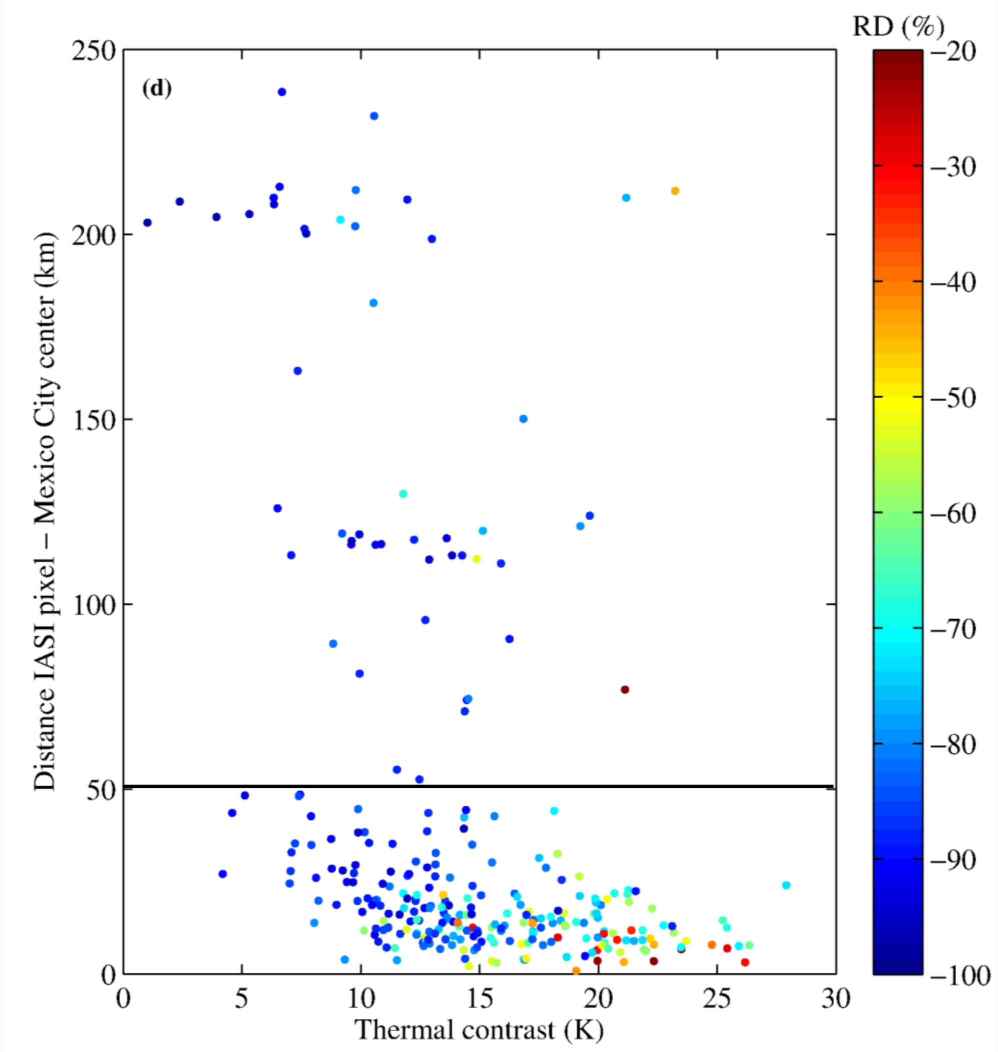


When and where?

Real retrievals above Mexico City

- Relative difference (RD) between IASI retrievals and in-situ ground-based mesurements (RAMA network)

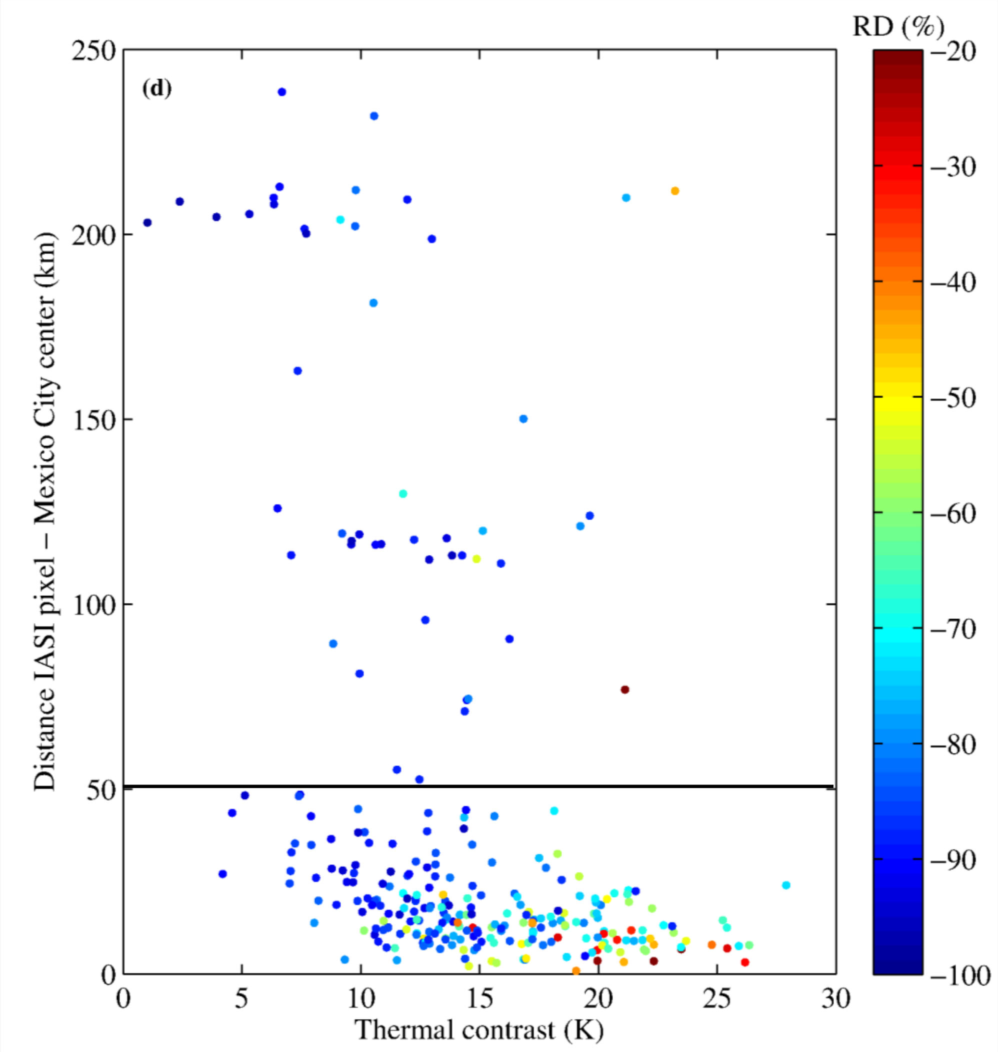


When and where?

Real retrievals above Mexico City

- Relative difference (RD) between IASI retrievals and in-situ ground-based mesurements (RAMA network)

- RD decreases with increasing the thermal contrast
  - can drop to -30% in some cases with TC>15 K



Sensitivity to near-surface CO

Conclusions:

1) IASI **starts** to **be sensitive** to near-surface CO from **|TC|=5K**

2) Values of **|TC|>10-15K** favors the **decorrelation** between the low and the high troposphere and **small retrieval error**

3) Performed characterization depends on the **chosen a priori** parameters

Measuring near-surface composition with IASI: when, where and how?

- Answer is not straightforward!
  - Seasonal variability of thermal contrast
  - Sensitivity depends on other factors:
    - Concentrations of the targeted species
    - These concentrations vary according to the source but also to the season
    - The presence of interfering species (e.g. H_2O)
    - Spectral range
  - The geophysical conditions that favor the sounding of the near-surface atmosphere can be different for different atmospheric species
  - Characterization depends on the a priori parameters
- Review of results for SO_2 and CO
  → **TC conditions encountered above land**

Thank you!