

Contribution of the MTG/IRS radiance assimilation in the characterisation of the atmospheric chemical composition

Francesca Vittorioso, Vincent Guidard, Nadia Fourrié

Now in:

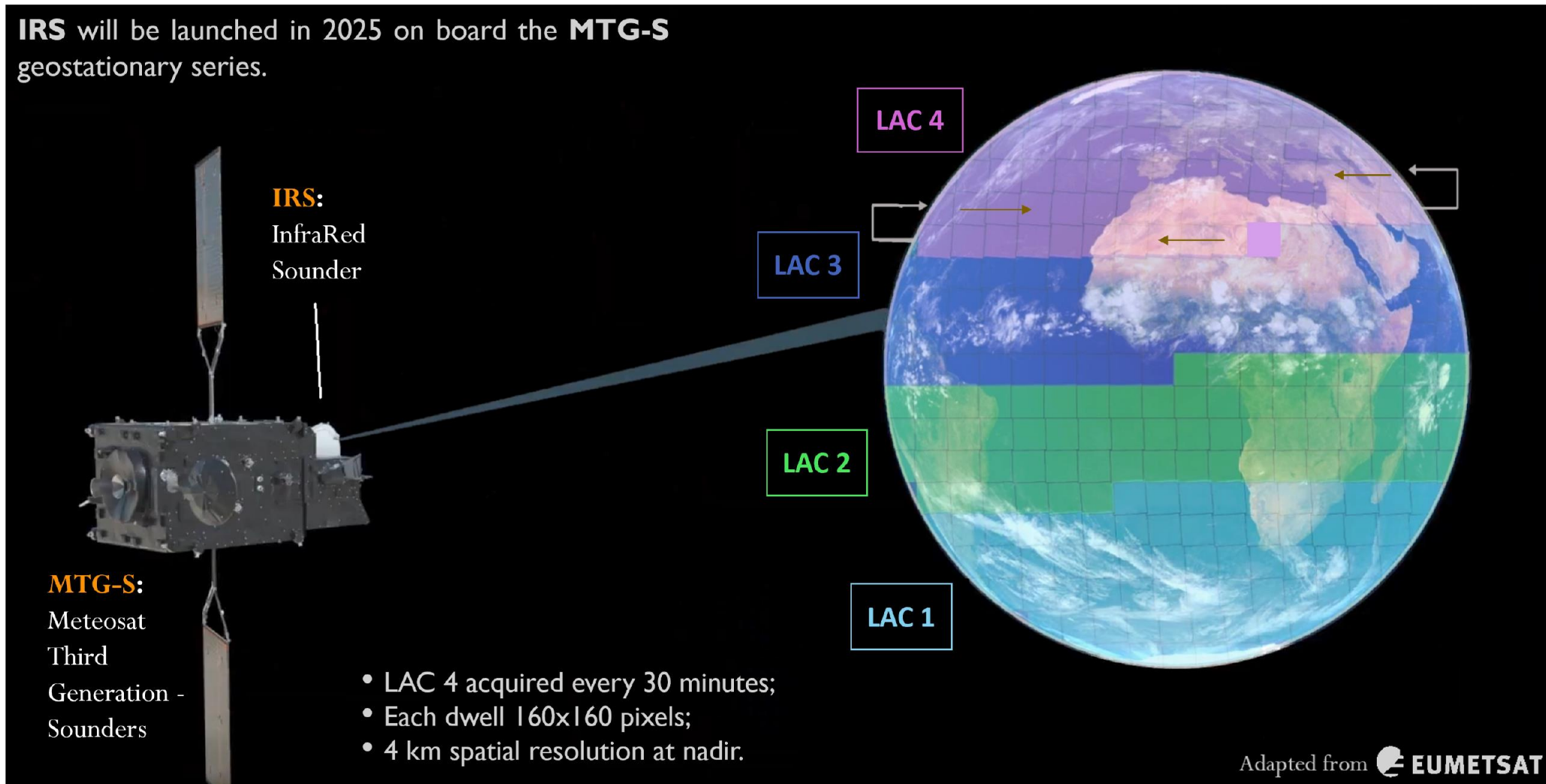


francesca.vittorios3@unibo.it



MTG-IRS

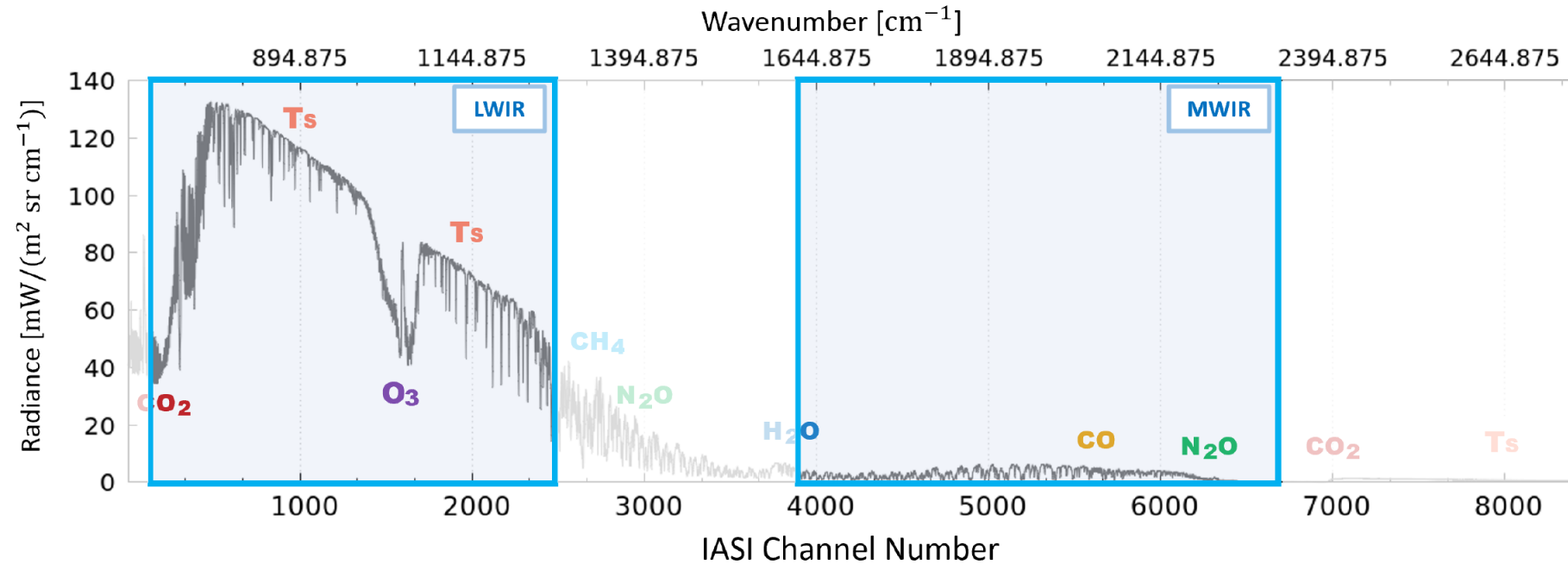
IRS will be launched in 2025 on board the **MTG-S** geostationary series.



MTG-IRS

IRS BAND	SPECTRAL RANGE	SPECTRAL SAMPLING	NUMBER OF CHANNELS
1. LWIR	679.70 – 1210.44 cm^{-1}	$\sim 0.603\text{cm}^{-1}$	881
2. MWIR	1600.00 – 2250.20 cm^{-1}	$\sim 0.604\text{ cm}^{-1}$	1079

Tot. 1960

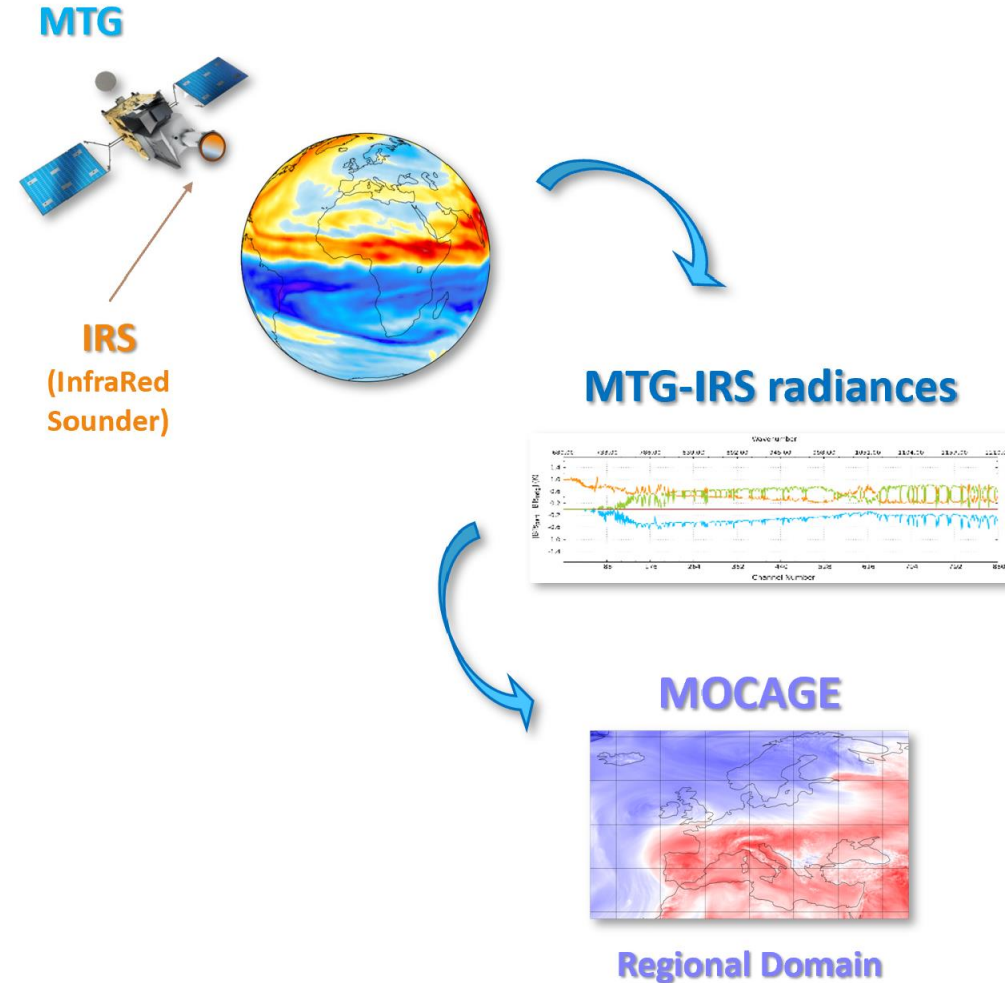


Objective

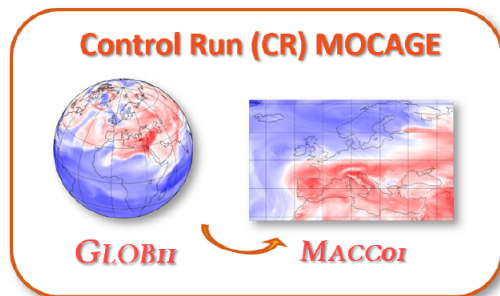
Evaluating the contribution of MTG/IRS radiance assimilation in a chemistry-transport model (MOCAGE) in order to characterize the atmospheric chemical composition over Europe.

➔ Focus on ozone

METHOD: Observing System Simulation Experiment

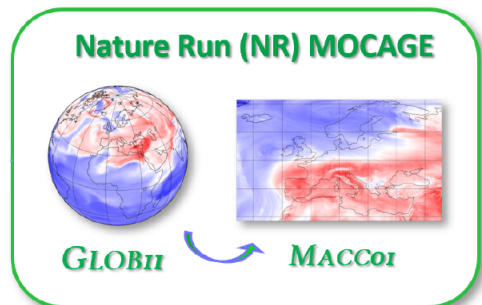


OSSE Framework: Chemistry Transport Model



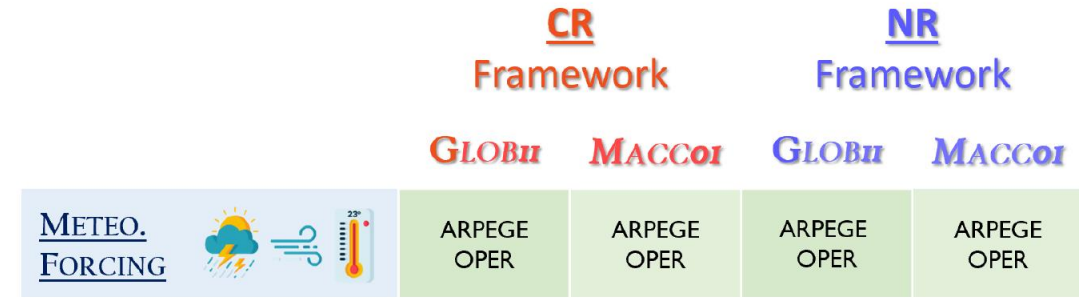
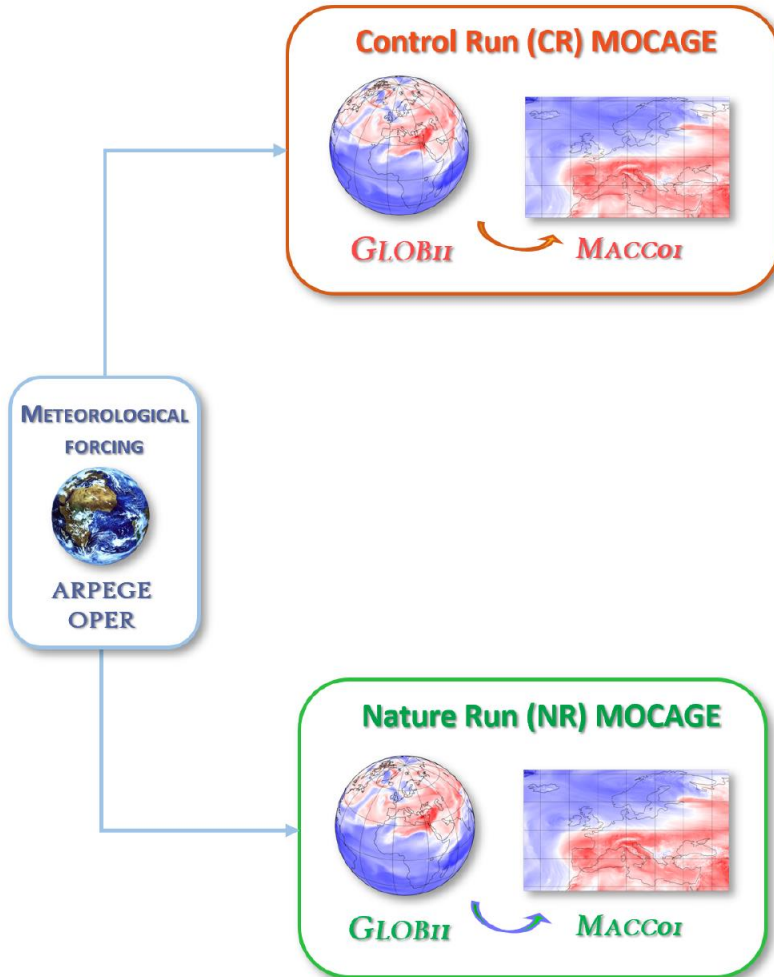
MOCAGE: Three-dimensional chemistry transport model, developed at CNRM since 2000.

RACMOBUS: 118 gaseous species, 434 chemical reactions, primary and secondary inorganic aerosols.

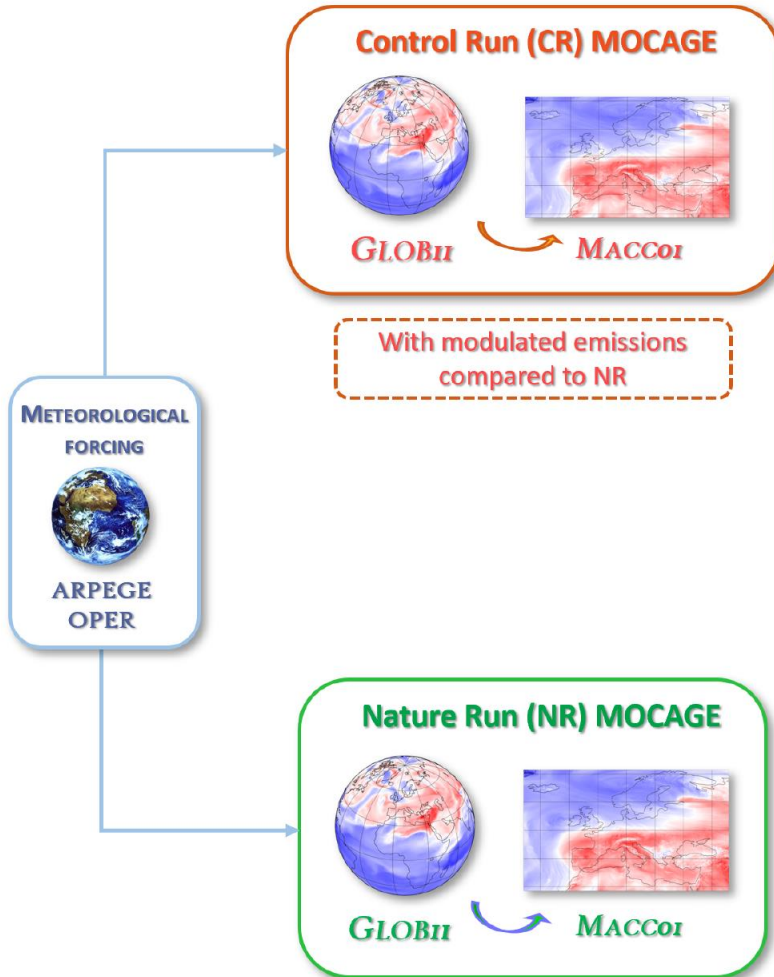


- **GLOBII**, global scale with a $1^\circ\text{lat} \times 1^\circ\text{lon}$ horizontal resolution;
- **MACCOI**, regional domain [28°N, 26°W and 72°N, 46°E], $0.1^\circ\text{lat} \times 0.1^\circ\text{lon}$ (~ 10 km at 45°N).
- 60 vertical hybrid σ -pressure levels configuration

OSSE Framework: CR vs NR

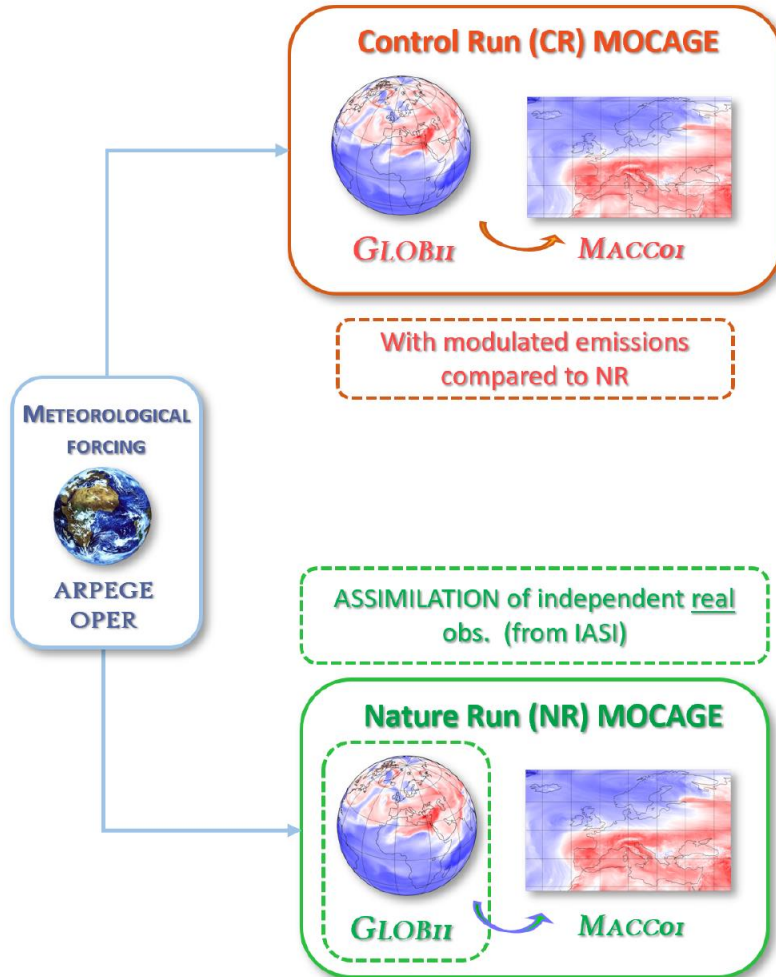


OSSE Framework: CR vs NR



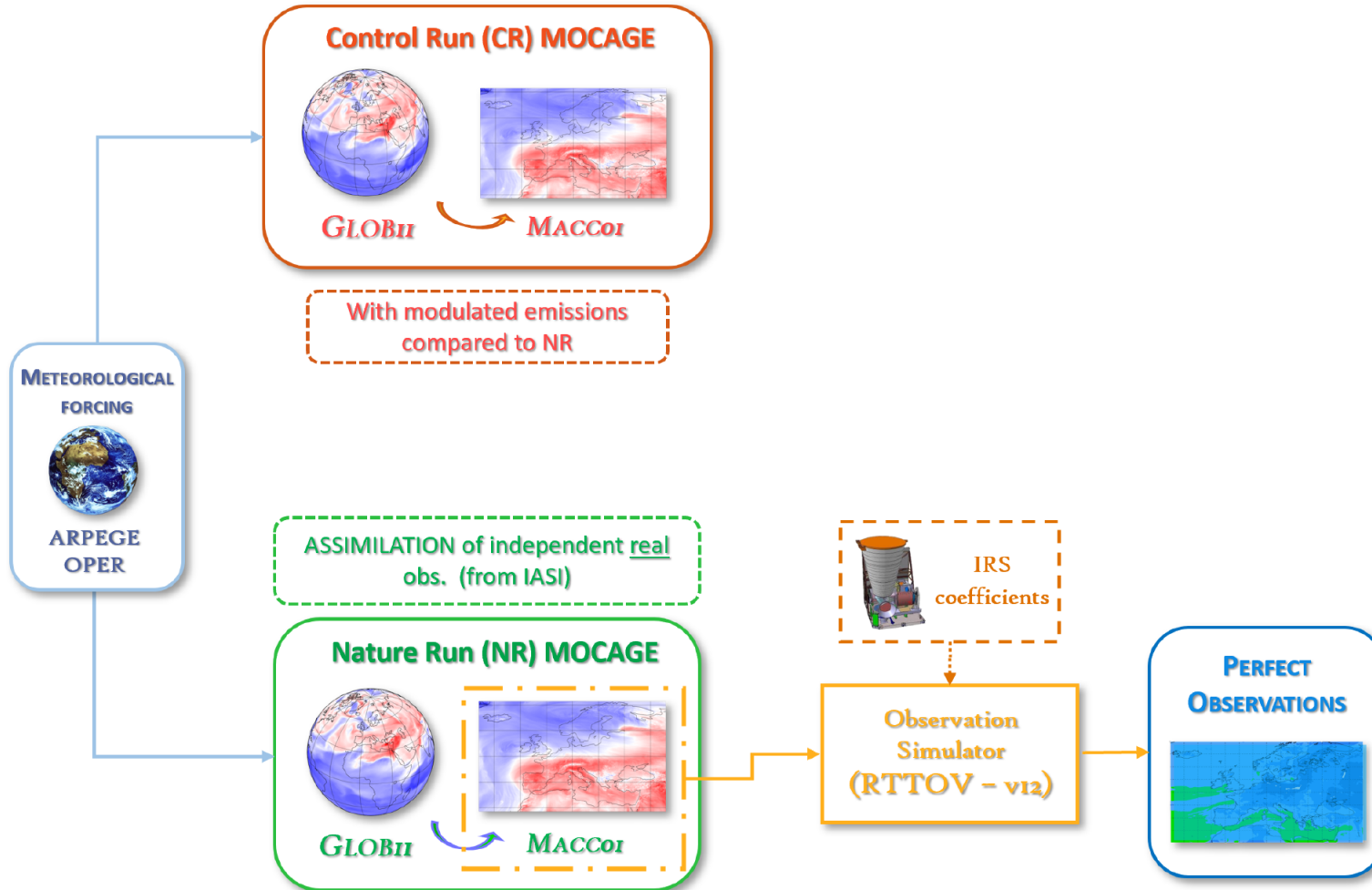
	CR Framework		NR Framework	
	GLOBii	MACCoI	GLOBii	MACCoI
METEOROLOGICAL FORCING	ARPEGE OPER	ARPEGE OPER	ARPEGE OPER	ARPEGE OPER
BIOGENIC EMISSIONS	CAMS-GLOB-bio and soil 2000	CAMS-GLOB-bio and soil 2000	MEGAN-MACC 2010 GEIA 1990	MEGAN-MACC 2010 GEIA 1990
ANTHROPIC EMISSIONS	CAMS-GLOB-ant 2000 GEIA	CAMS-REG-ap 2000 GEIA	MACCity 2016 RP60 2016	CAMS-REG 2017 GEIA
BIOMASS BURNING	MACCity 2000	MACCity 2000	GFAS 2019	GFAS 2019

OSSE Framework: CR vs NR

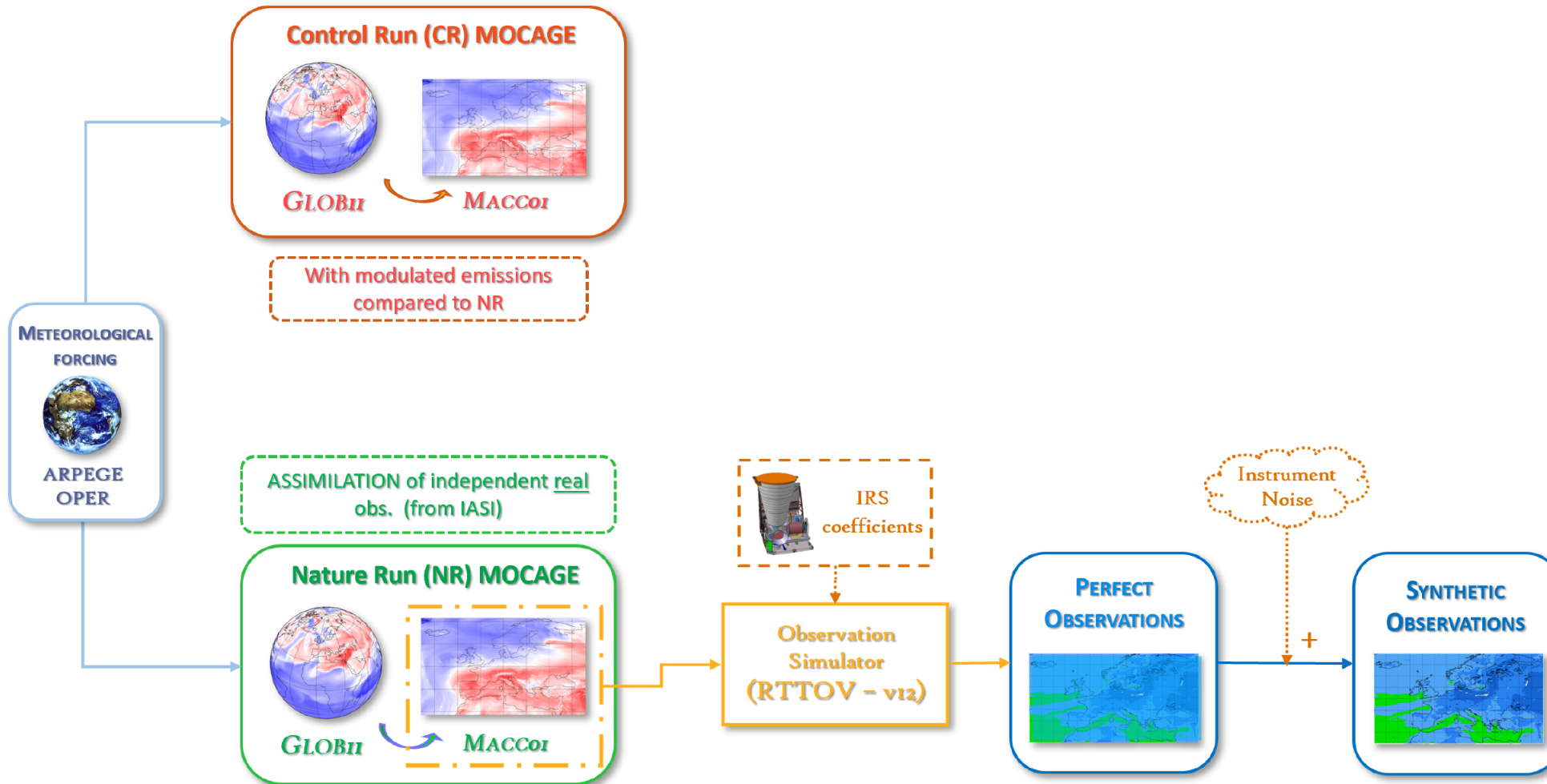


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BIOMASS BURNING	MACCity 2000	MACCity 2000	GFAS 2019	GFAS 2019
DATA ASSIMILATION	None	None	IASI LIC	None

OSSE Framework: Simulated Observations



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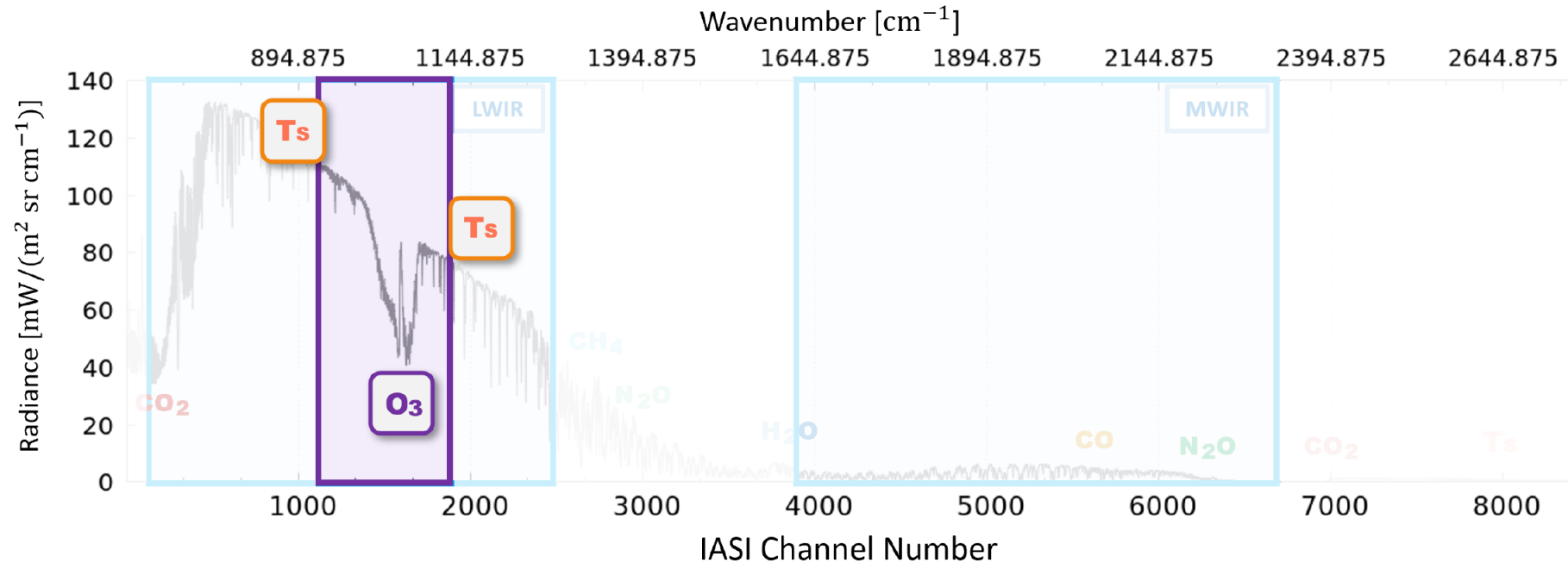


OSSE Framework: Simulated Observations

195
simulated channels

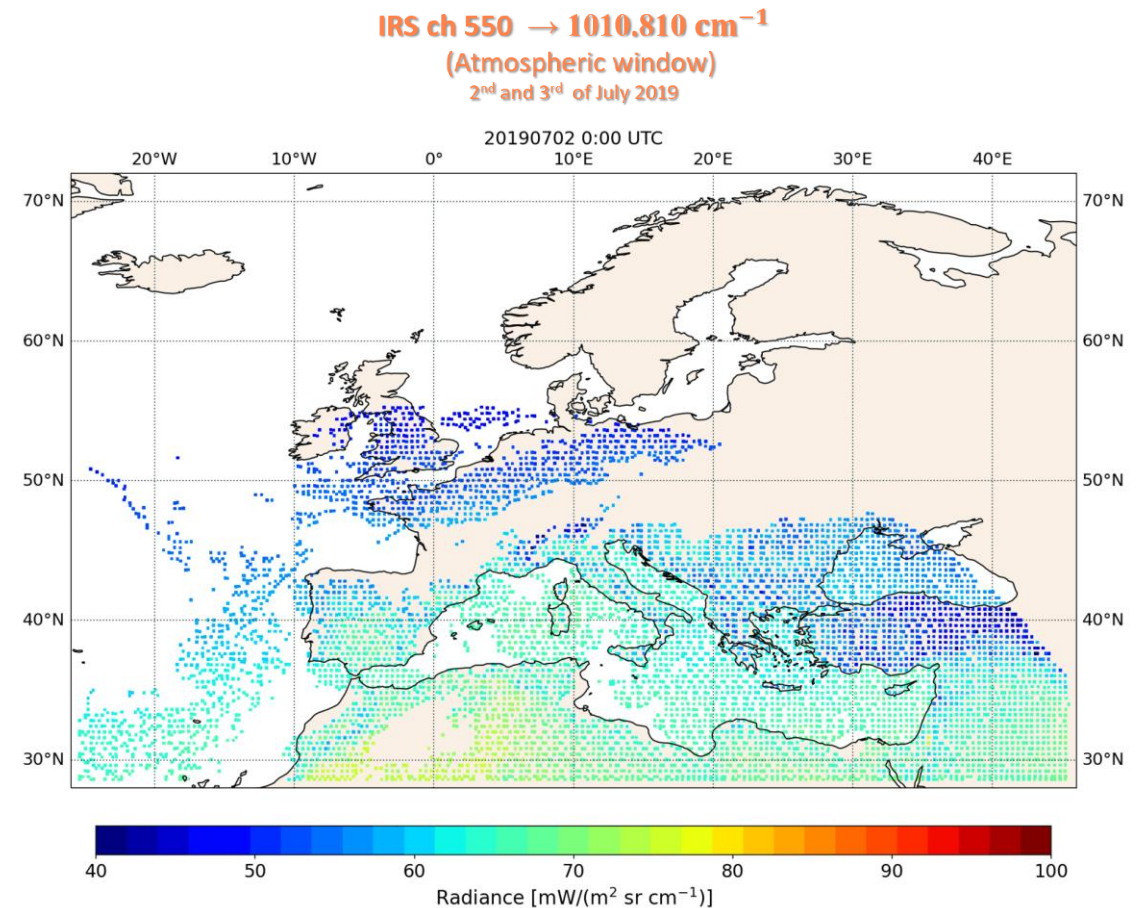
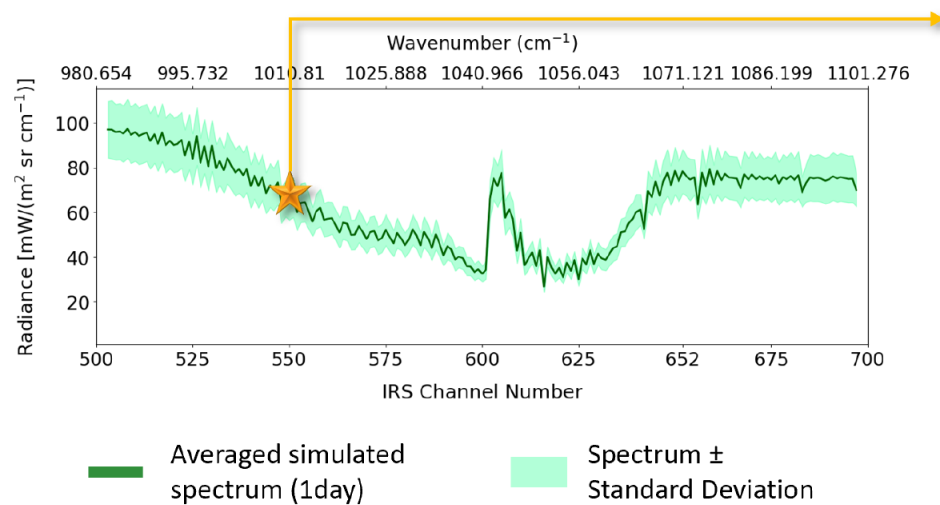
<u>WAVELENGTH</u>	982.464 – 1099.467 cm^{-1}
<u>CHANNEL NUMBER</u>	503 - 697

A band in the LWIR has been chosen to be simulated: ozone absorption band, surrounded by some channel in the atmospheric window.

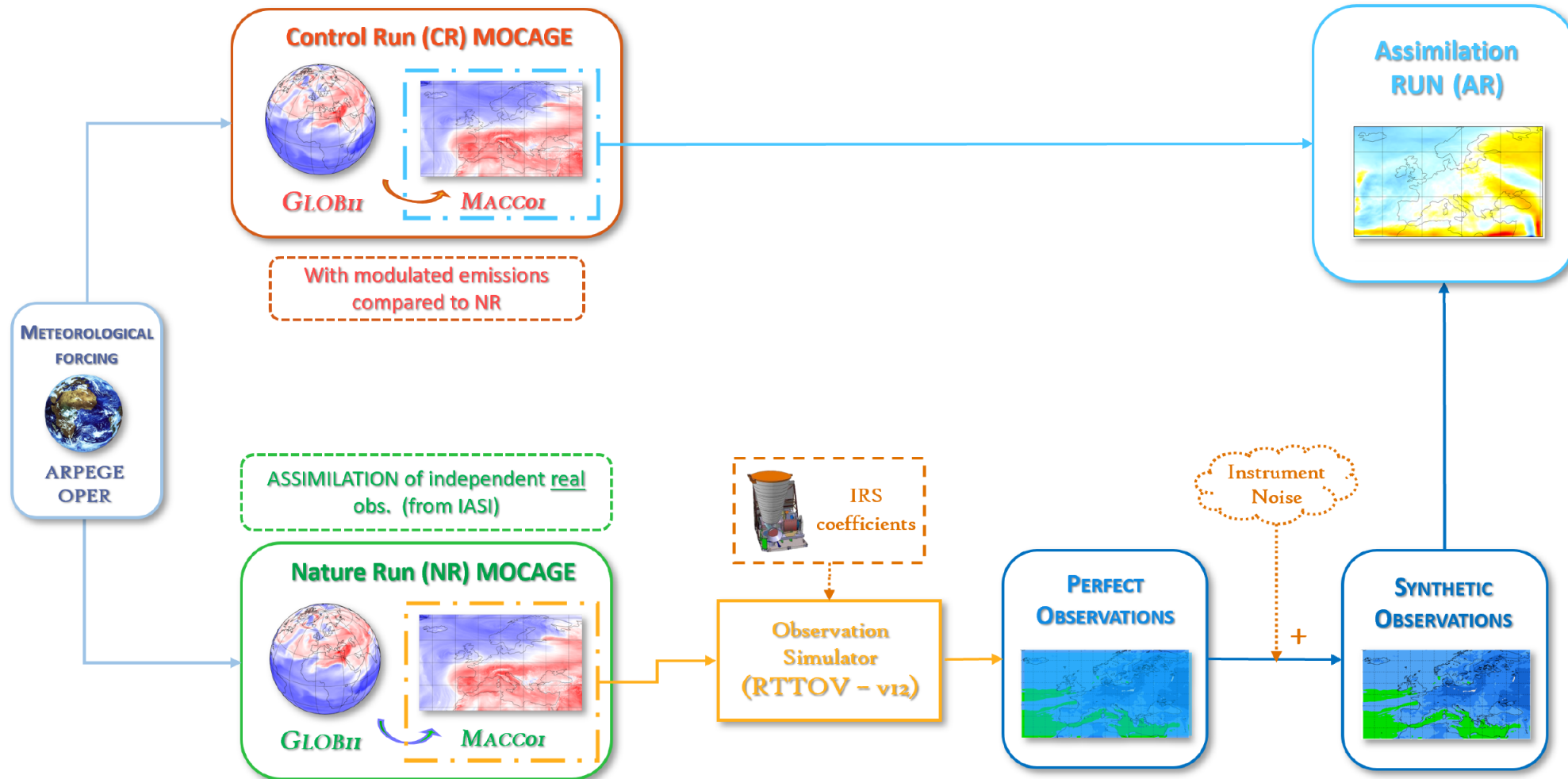


OSSE Framework: Simulated Observations

- ➔ **Clear-sky observations only**
(info from ARPEGE OPER)
- ➔ **Thinning:** only one pixel per 0.4° box has been simulated



OSSE Framework: Assimilation

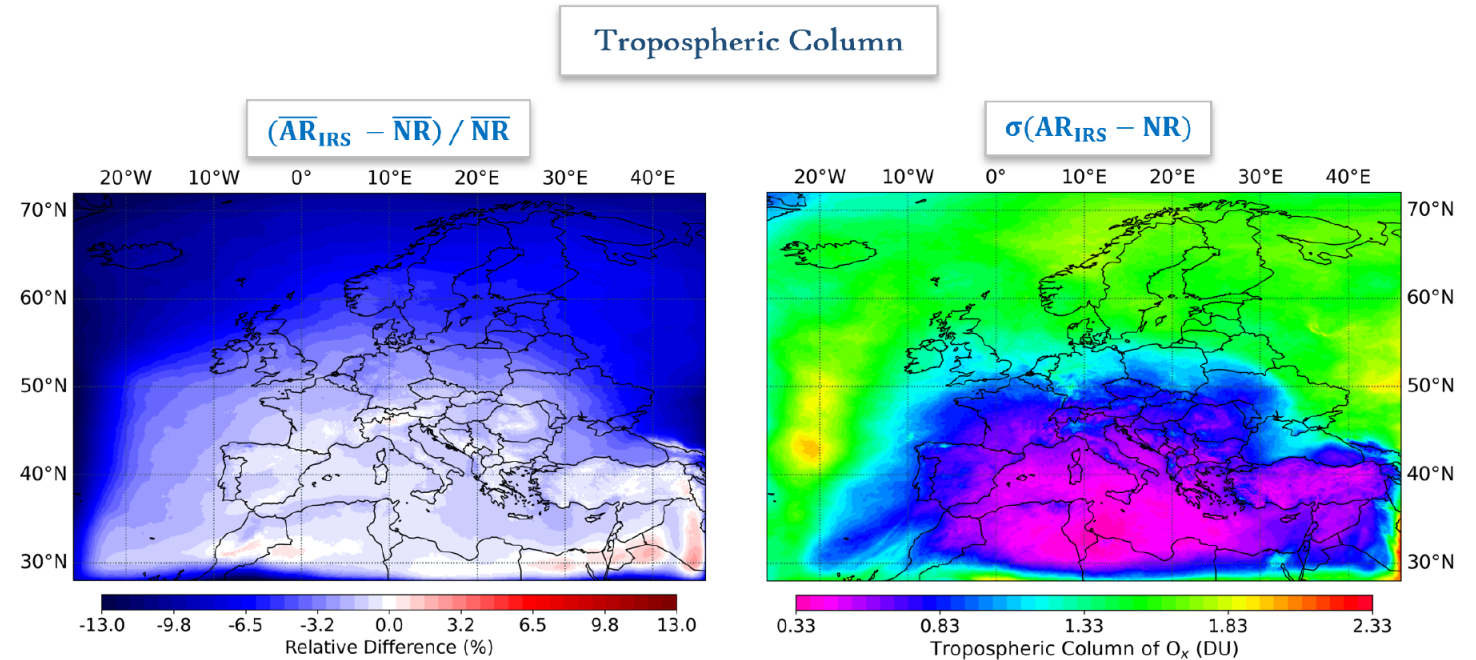


Contribution of IRS Assimilation

TROPOSPHERIC COLUMN

from surface till lev. 40 (i.e. ~300 hPa)

- NR and AR are very close to each other in the area where observations are simulated and assimilated:
 - Relative difference **up to 3%** over the Mediterranean basin (for CR up to 10 to 20%).
 - Maxima at the edges
- Minima of standard deviations over the Mediterranean Sea:
 - Values ~ 0.4 DU (CR vs NR ~ 2 DU).



✓ Assimilation of IRS radiances has a positive impact compared to no assimilation.

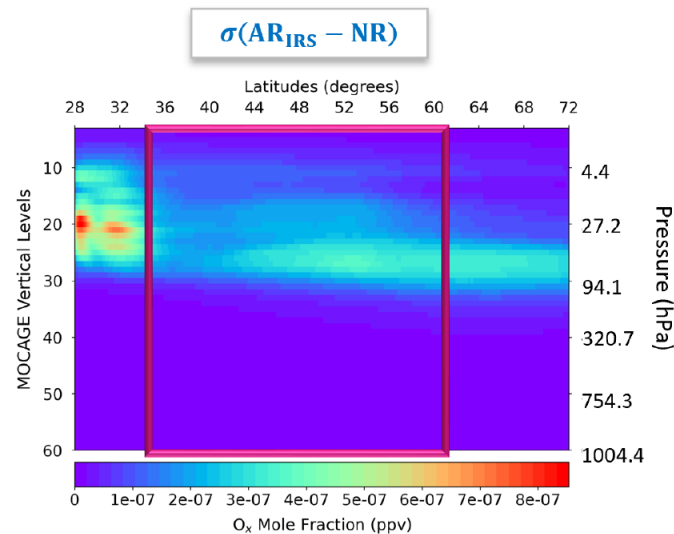
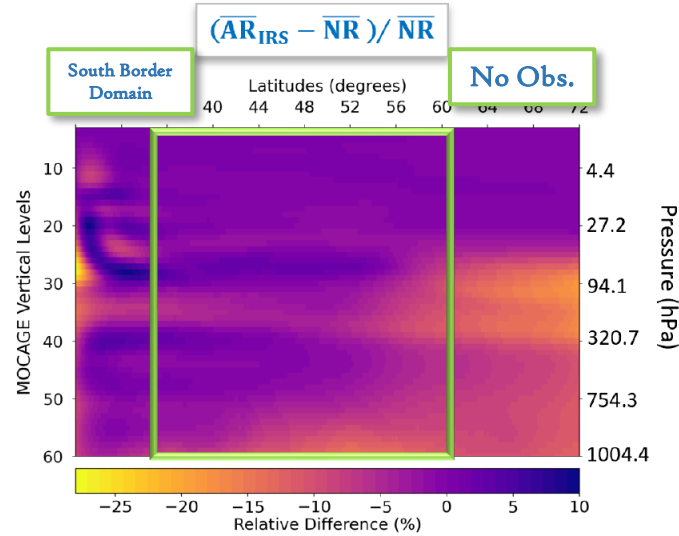
Contribution of IRS Assimilation

CROSS SECTIONS OF OZONE, AVERAGED OVER LONGITUDES.

- AR stronger than NR of 5-10% between model level 30 and 20 (i.e. 94 and 27 hPa - at the *ozonosphere*), 28° and 36°N.

→ **8% at the center of the domain.**
(NR > AR)

- Maxima of standard deviation of the differences in stratosphere at the bottom border.



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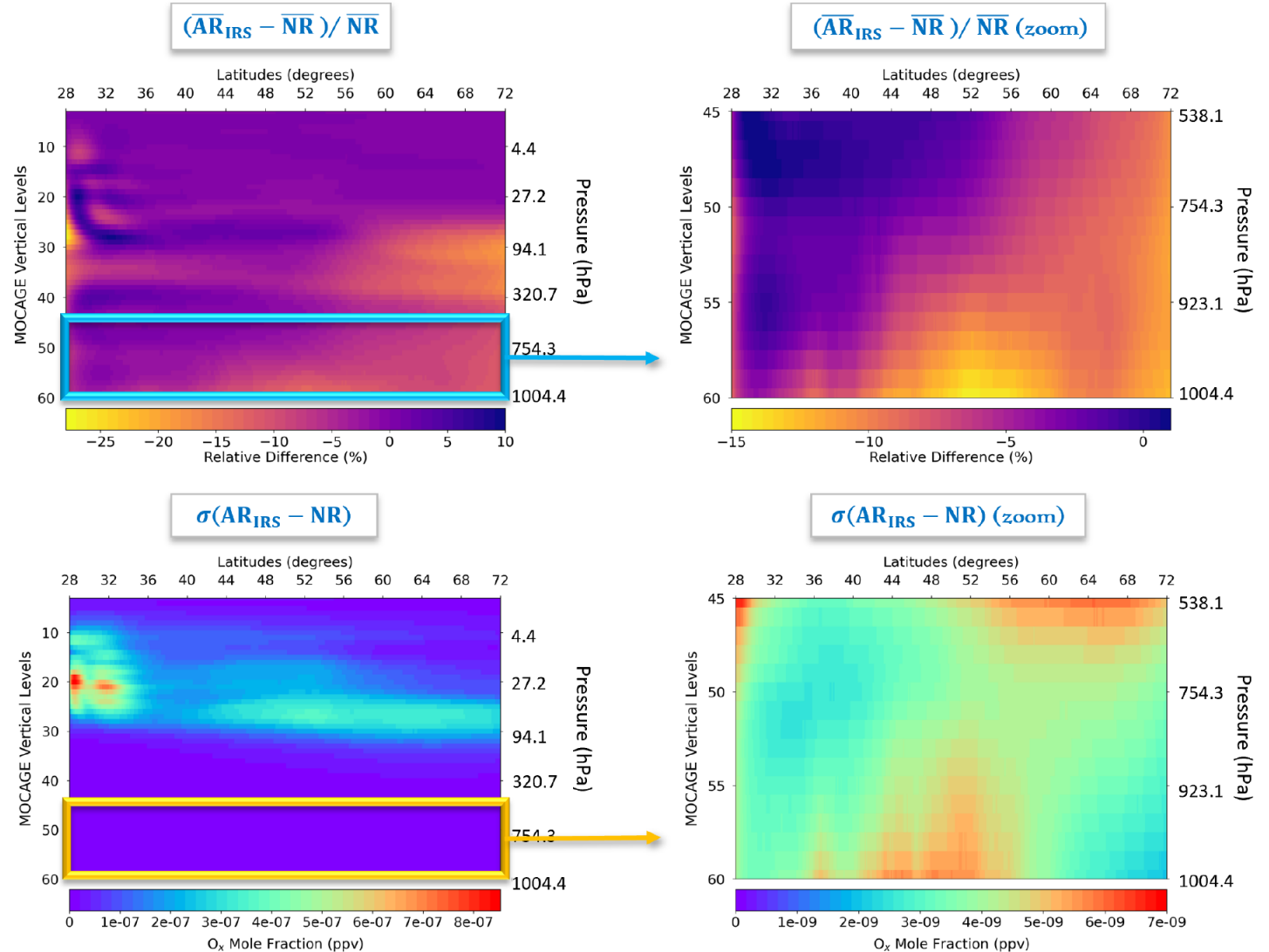
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- Lower-most troposphere:

→ **15% (NR > AR) 48-60°N**

→ For CR vs NR vertical variations where up to 25%.



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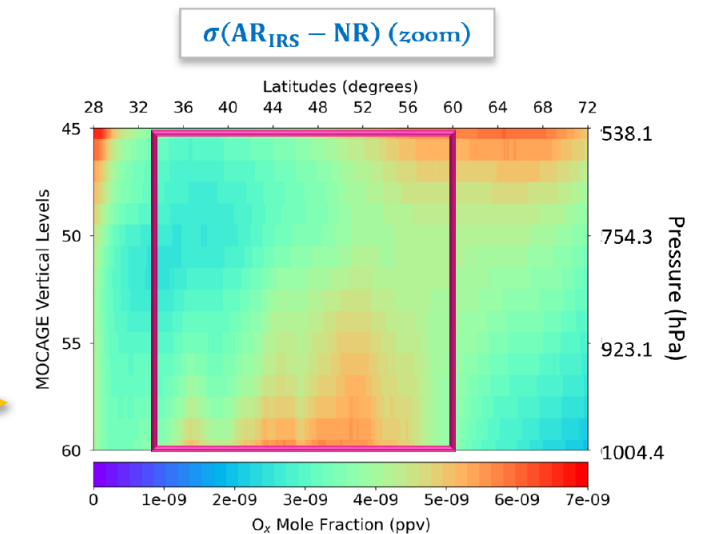
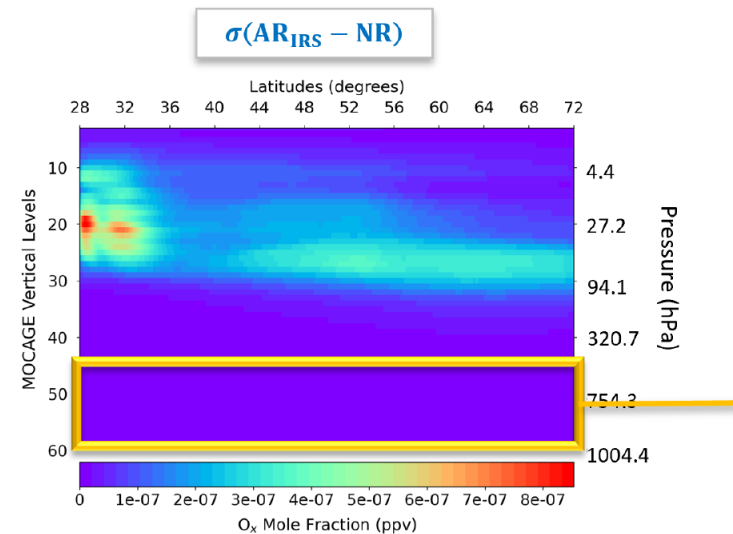
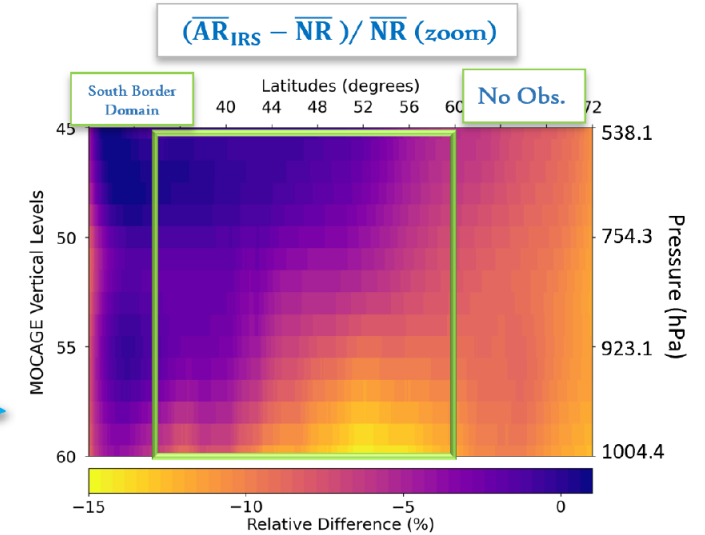
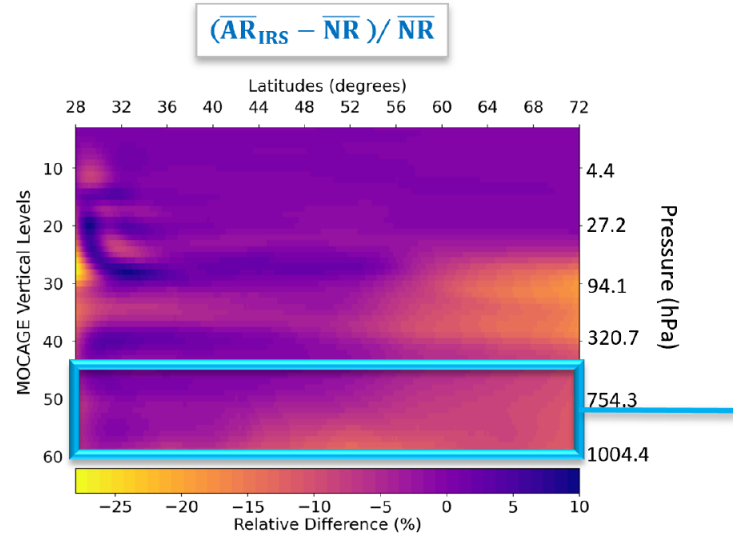
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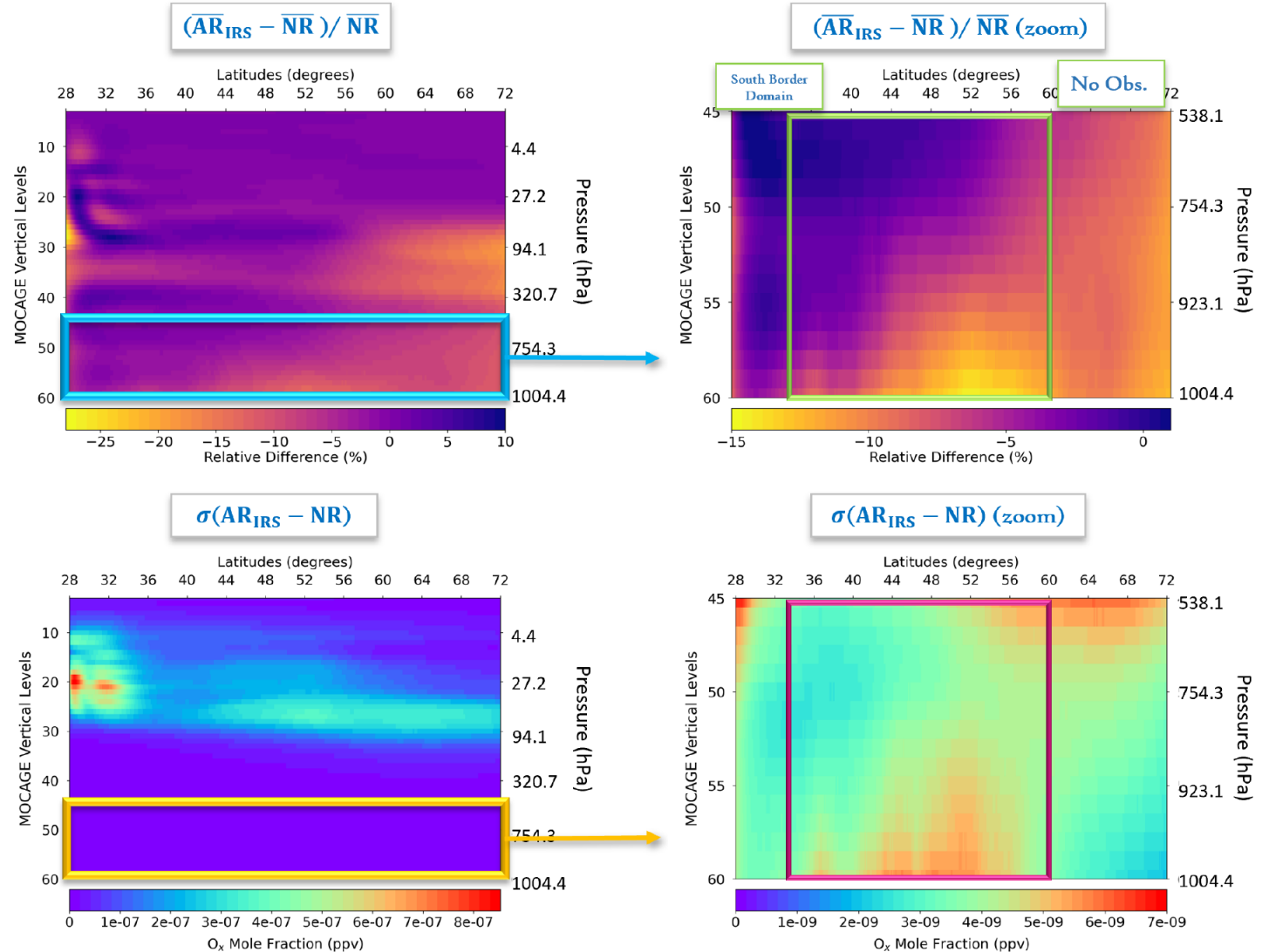
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✓ **Impact of IRS assimilation remarkable on the vertical column.**



Summary



Assimilation of IRS radiances into MOCAGE always has a positive impact compared to no assimilation (i.e. CR).

		$(\overline{CR} - \overline{NR}) / \overline{NR}$	$(\overline{AR\ IRS} - \overline{NR}) / \overline{NR}$
Total Columns		-13%	0 to -1% ↓
Tropospheric Columns		-20%	-3% ↓
Vertical Levels	Ozonsphere	-30%	-5 to +8% ↓
	Lower-most tropo.	-25%	-15% ↓

Vittorioso, F., Guidard, V., & Fourrié, N. (2024): Assessment of the contribution of IRS for the characterisation of ozone over Europe. Currently under review for the journal *Atmospheric Measurement Techniques*

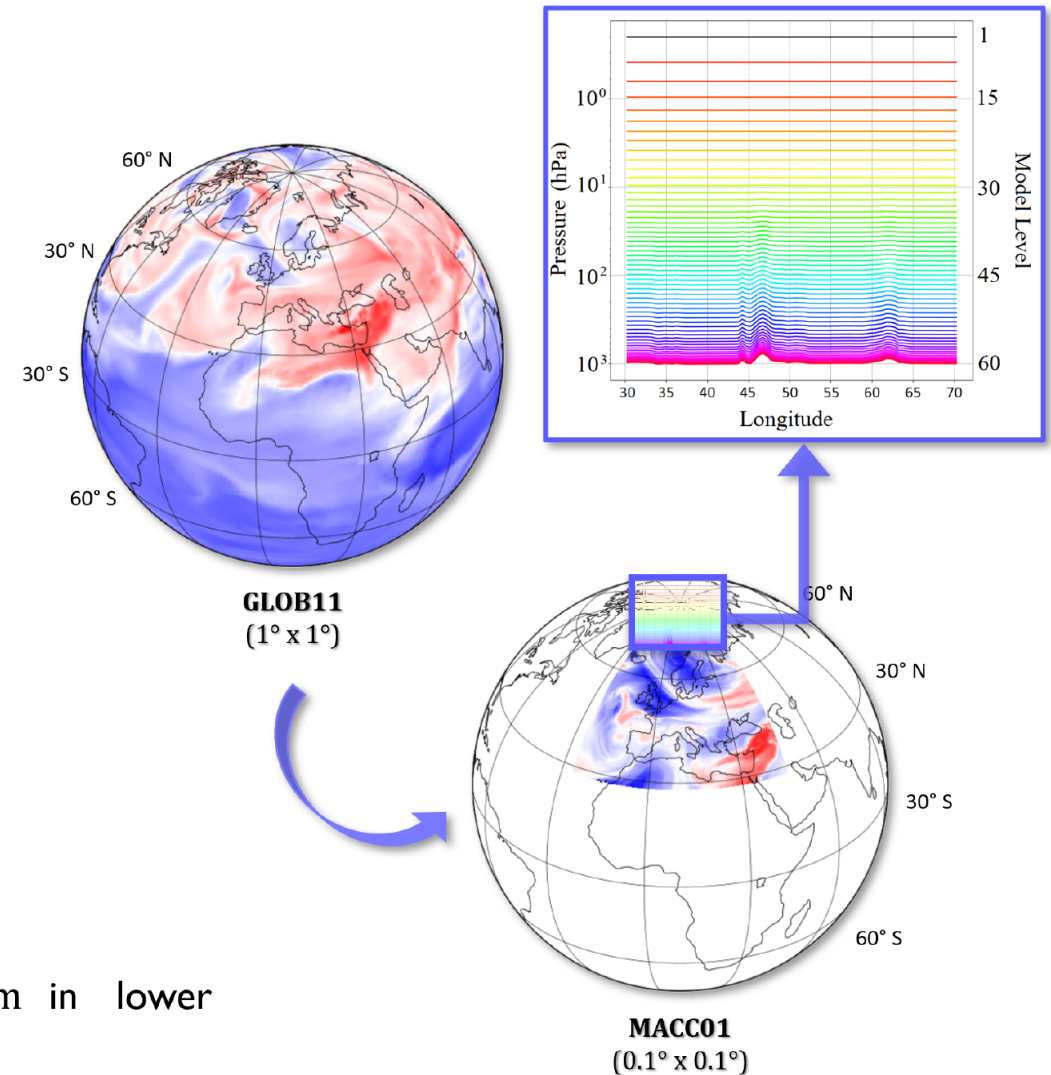


Thank you for your attention!



Chemistry Transport Model: MOCAGE

- Three-dimensional chemistry transport model, developed at CNRM since 2000.
- In this work, two geographical configurations using a nested grids capacity:
 - **GLOB11**, global scale with a $1^\circ\text{lat} \times 1^\circ\text{lon}$ horizontal resolution;
 - **MACC01**, regional domain [28°N, 26°W and 72°N, 46°E], $0.1^\circ\text{lat} \times 0.1^\circ\text{lon}$ (~ 10 km at 45°N).
- **60 vertical hybrid σ -pressure levels** configuration used for this work:
 - From surface to 0.1 hPa;
 - **Vertical resolution**: ~ 40 m in lower troposphere, 800 m in lower stratosphere, 2 km upper stratosphere.



MOCAGE

Different chemical schemes in order to reproduce the atmospheric chemical composition:

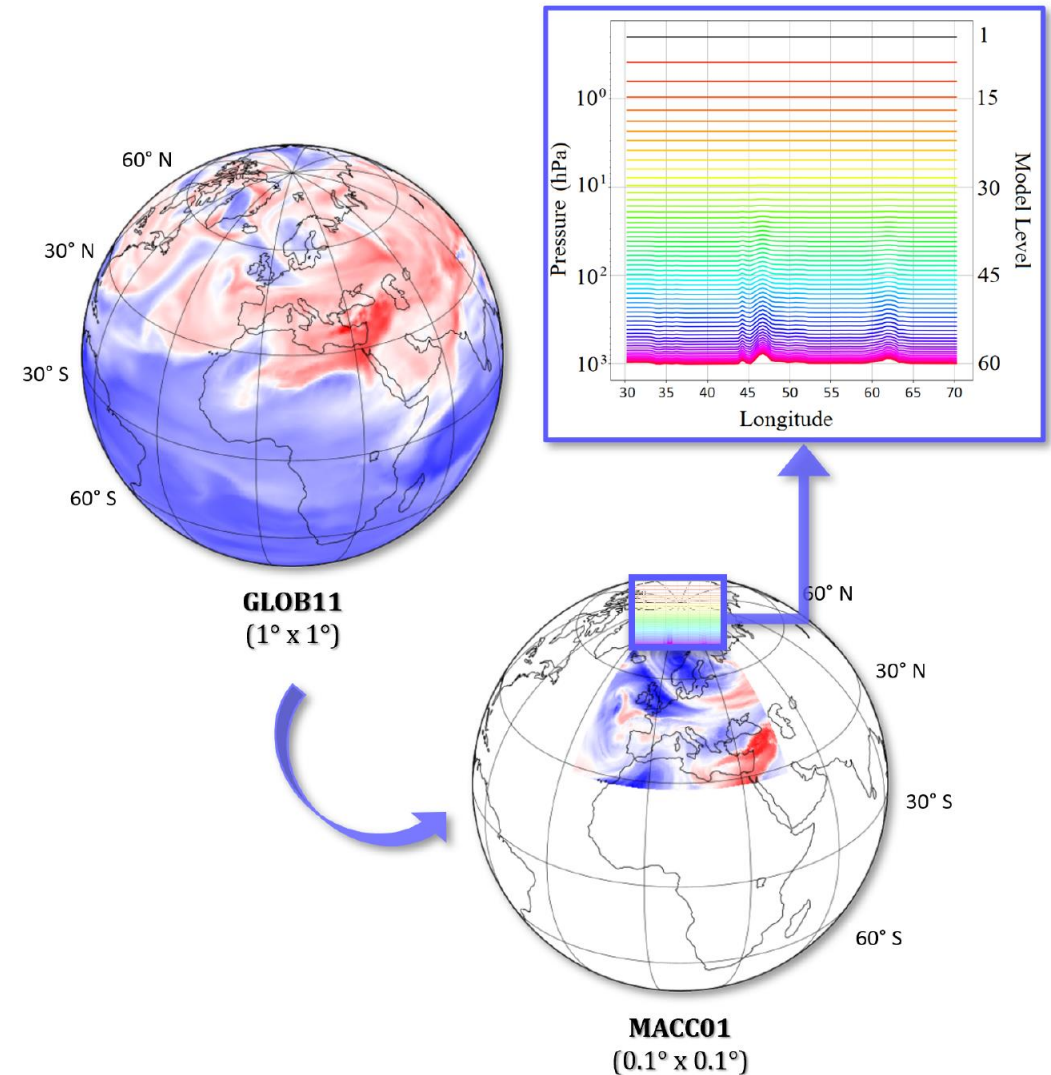
→ **RACM** (Regional Atmospheric Chemistry Mechanism) [Stockwell et al. (1997)] for troposphere;

+

→ **REPROBUS** (REactive Processes Ruling the Ozone BUdget in Stratosphere) [Lefevre et al. (1994)] in stratosphere;

=

RACMOBUS: 118 gaseous species, 434 chemical reactions, primary and secondary inorganic aerosols.



Methodology of Assimilation

3D-Var

$$J(\mathbf{x}) = \frac{1}{2} (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + \frac{1}{2} [\mathbf{y} - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x})]$$

The equation is annotated with a blue bracket labeled "BACKGROUND" over the first term and a pink bracket labeled "OBSERVATIONS" over the second term. The matrix \mathbf{B} in the first term is enclosed in a blue box.

The data assimilation method used for this study is the **three-dimensional variational method**:

- The statistically optimal atmospheric state, comprising **background model state** and the **observing system**, is obtained through minimization of the cost function J .

\mathbf{x} = state vector

\mathbf{x}_b = background state vector

\mathbf{y} = vector of observations

\mathbf{B} = covariance matrix of the background errors

\mathbf{R} = covariance matrix of the observation errors

H = observation operator

Adaptation of the literature method Emili et al. (2019), El Aabaribaoune et al. (2019).

Diagonal terms: 2% of the ozone concentration at each atmospheric level was attributed to the background standard deviation (σ_B); the variances (σ_B^2) were then computed and attributed to the diagonal.

Correlation terms: modelled using a diffusion operator.

Methodology of Assimilation

3D-Var

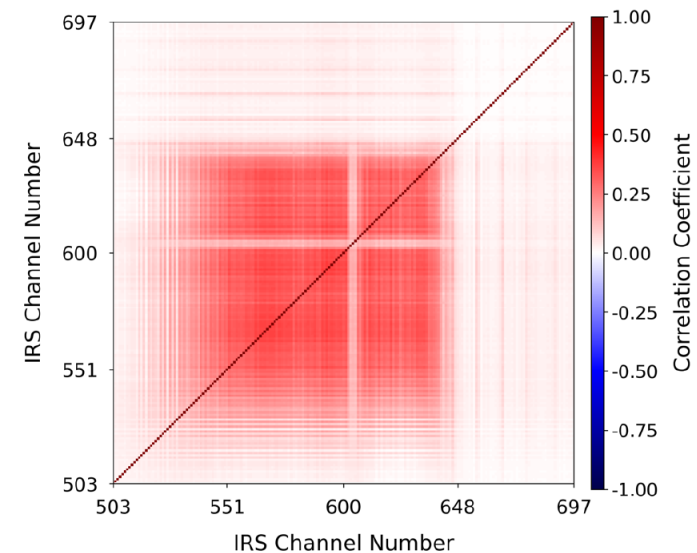
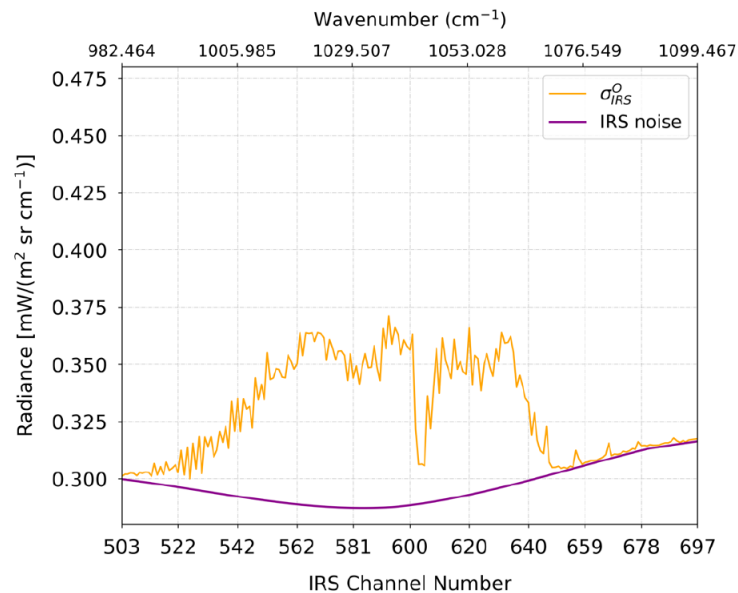
$$J(\mathbf{x}) = \frac{1}{2} (\mathbf{x} - \mathbf{x}_b)^T \mathbf{B}^{-1} (\mathbf{x} - \mathbf{x}_b) + \frac{1}{2} [\mathbf{y} - H(\mathbf{x})]^T \mathbf{R}^{-1} [\mathbf{y} - H(\mathbf{x})]$$

BACKGROUND OBSERVATIONS

→ **Desroziers' Diagnostics** [Desroziers et al. (2015)]:

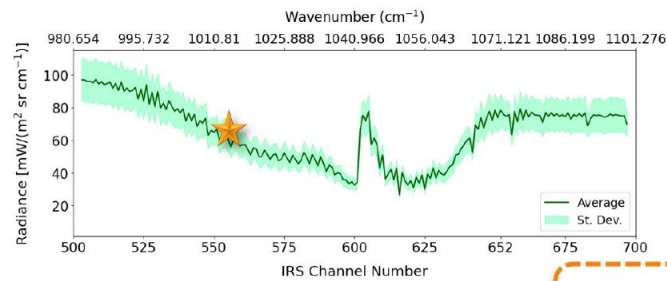
$$\mathbf{R} = E\{[\mathbf{y} - H(\mathbf{x}_a)] [\mathbf{y} - H(\mathbf{x}_b)]^T\}$$

(Obs. - Analysis) (Obs. - Backg.)



Statistics on the Observations

Hourly statistics over the domain

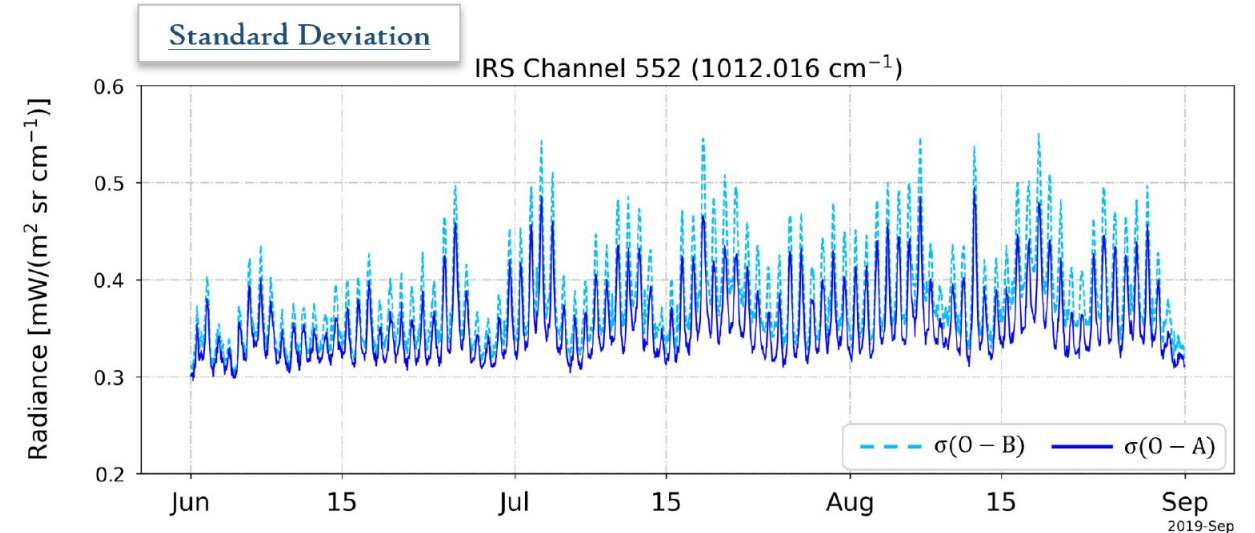
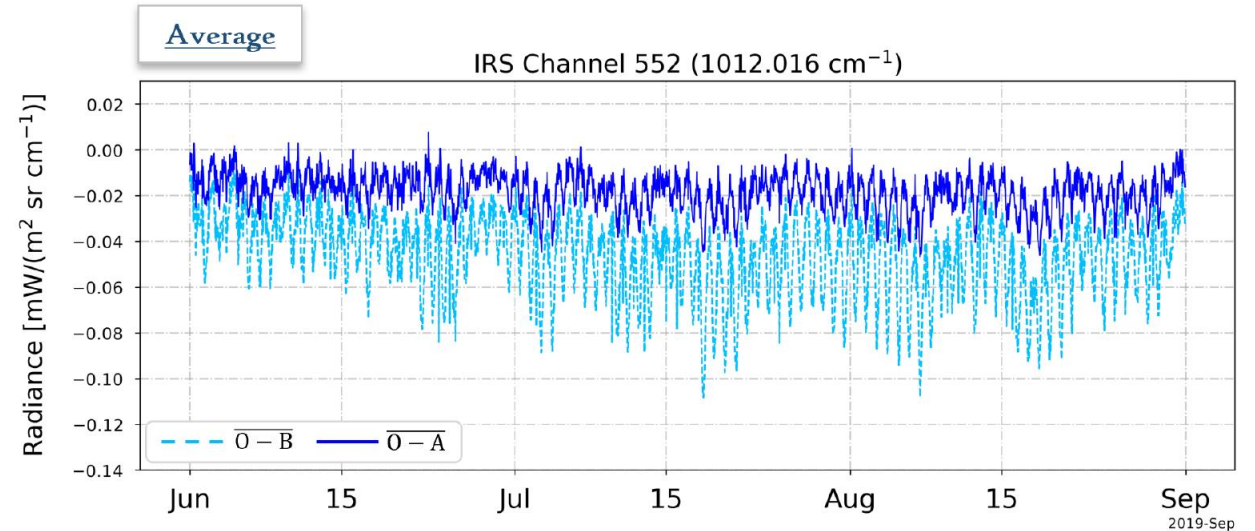


Channel 552
(1012.016 cm^{-1})

✓ **Bias** reduces through assimilation:

- Variability over the time period and during each hour in the day;
- Magnitude of variation smaller for O-A than for O-B.

✓ **Standard deviation** reduces through assimilation.



Perspectives

ASSIMILATION ASSESSMENT

- Comparison assimilation IRS vs assimilation IASI.

IMPROVING THE IRS ASSIMILATION PROCESSING

- **Principal Components (PCs) only will be distributed for IRS:**
 - ➔ A short study on the assimilation of reconstructed radiances should be carried out.
- **Channel Selection.**

IMPACT OF SYNERGY WITH OTHER INSTRUMENTS

- Sentinel-4 (also on board MTG-S).
- IASI, IASI-NG (in polar orbit).
- Surface data (complementary to IRS information).

TOWARDS THE TREATMENT OF OTHER SPECIES

- **Assimilation of radiances in the bands sensitive to other chemical species (and aerosols).**