

4D-Var assimilation of IASI ozone-sensitive radiances in operational global model ARPEGE

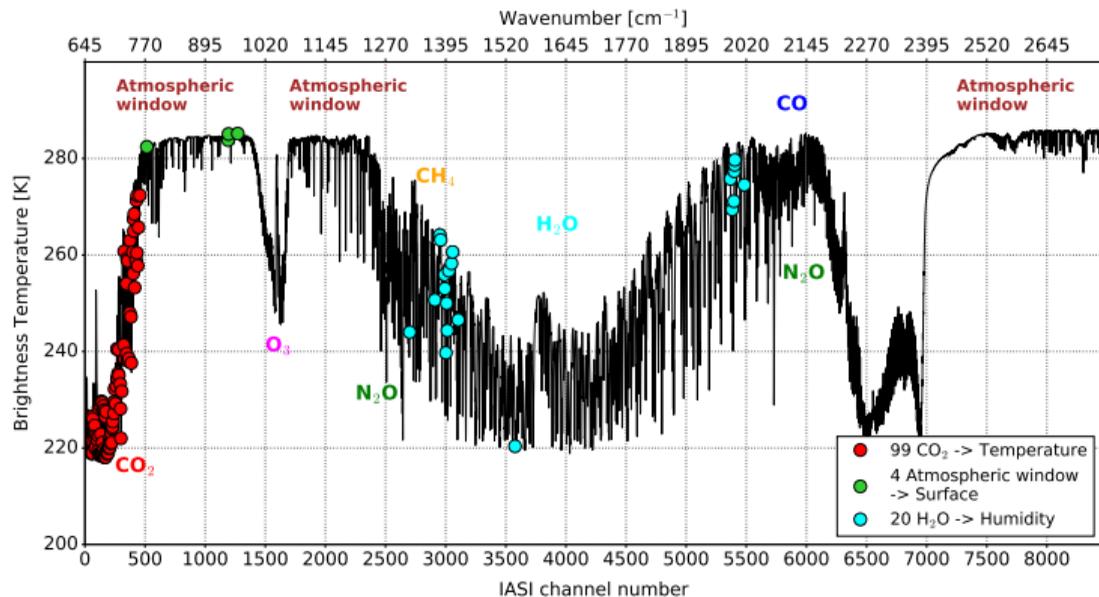
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Supervisors : **Vincent GUIDARD** and **Nadia FOURRIÉ**

- IASI's objectives are to provide vertical temperature and humidity profiles for **NWP** models and monitor climate variables (clouds, surface properties, aerosols, greenhouse gases). It is also an opportunity to study the chemical composition of the atmosphere
 - ~ 20 trace gases (CO_2 , CH_4 , O_3 , CO , N_2O , NH_3 , ...)
- 123** IASI channels were assimilated into operational NWP global model **ARPEGE** at Météo-France (only 1.5% of the full spectrum) at the beginning of my PhD

The IASI infrared spectrum from a standard midlatitude profile



Assimilation of IASI O₃ sensitive radiances in ARPEGE to improve weather forecasts

Method: Use of realistic ozone fields by coupling the NWP **ARPEGE** and Chemistry Transport **MOCAGE** models.

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- Ozone has a significant impact on the temperature fields of the model through the ozone-radiation interaction [*Cariolle and Morcrette, 2006*].

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- IASI ozone-sensitive channels are also sensitive to temperature, humidity and surface temperature and can provide additional information to improve analysis. [*Coopmann et al., 2018*].

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➤ Why to use realistic ozone fields?

- ➔ The use of 3D realistic ozone fields instead of a constant profile (currently used in ARPEGE) improves the simulation of **IASI** [*Coopmann et al., 2018*], **HIRS** [*Derber and Wu, 1998*] or **AMSU-B** [*John and Buehler, 2004*] observations, for example.

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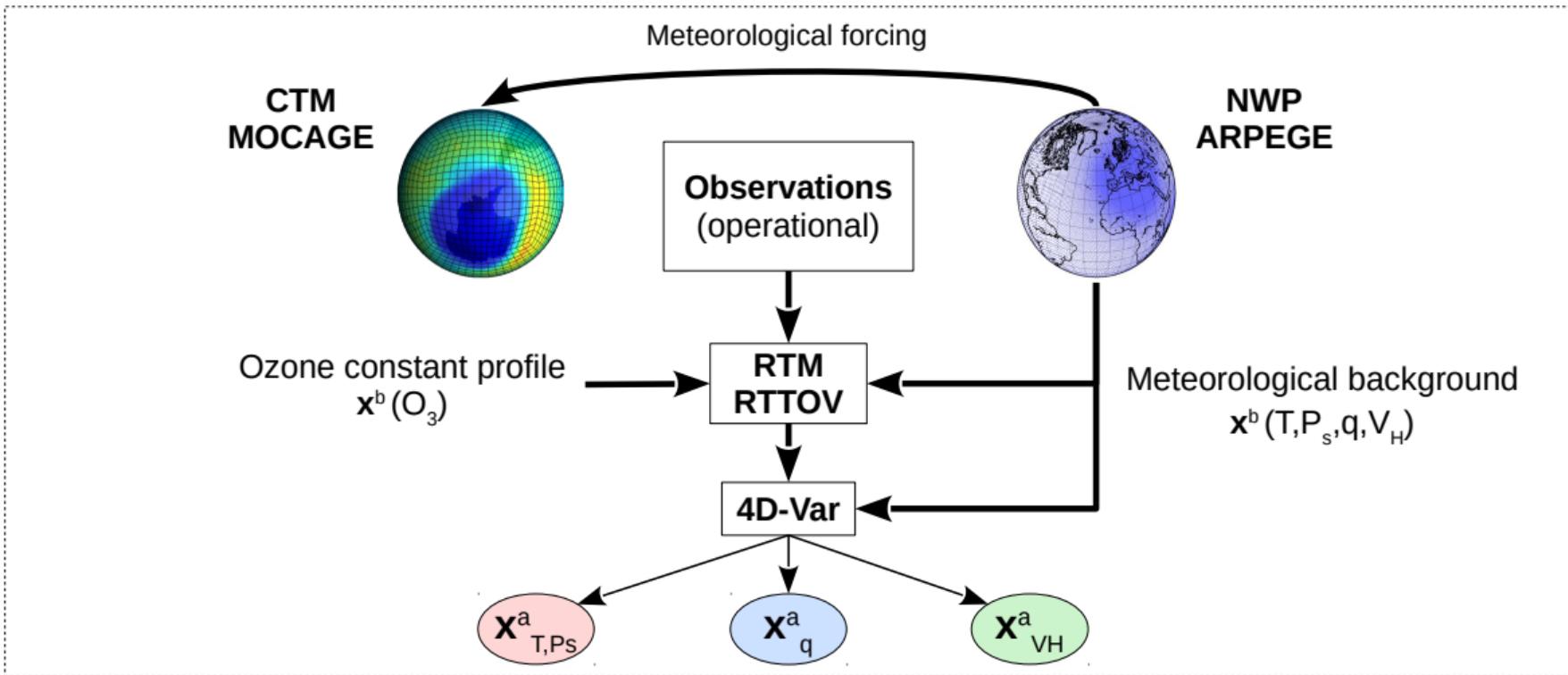
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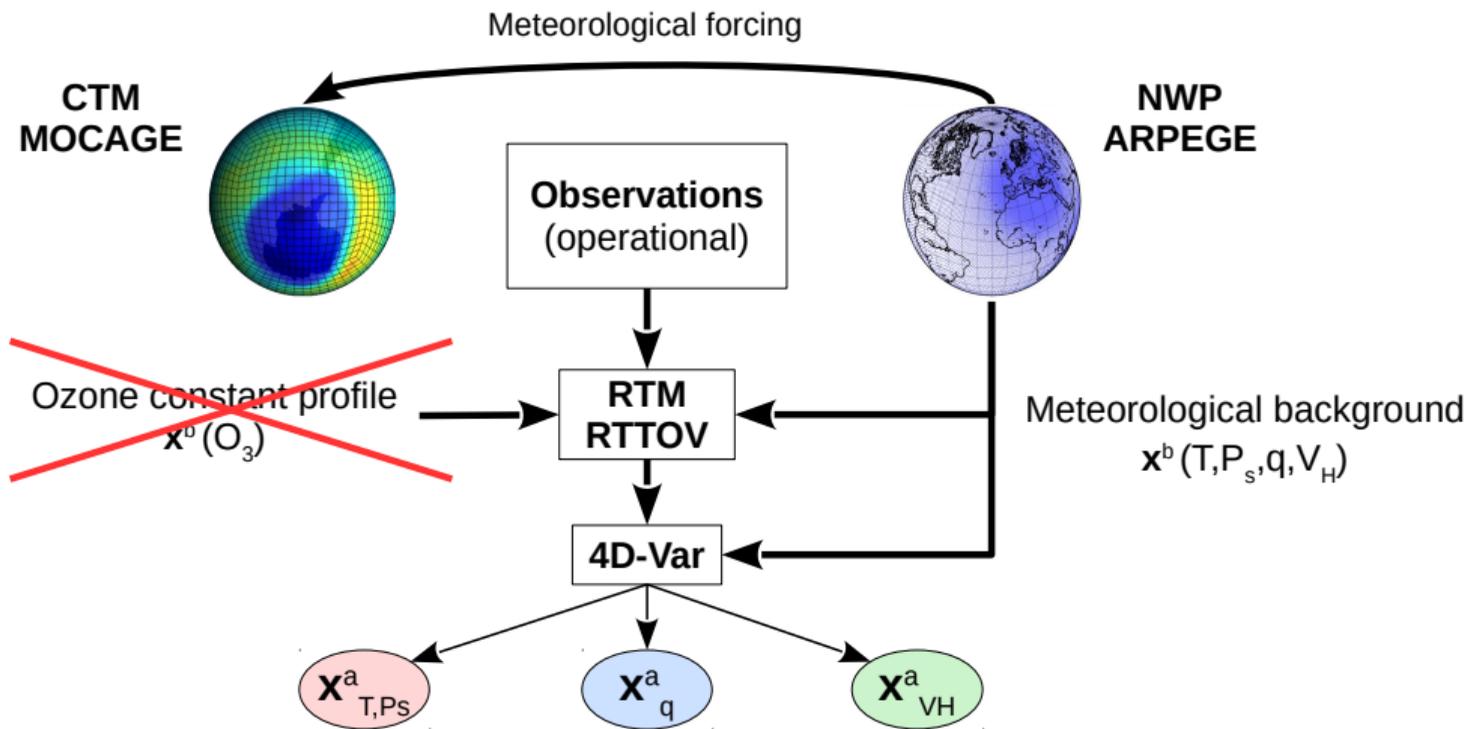
➤ Why to couple the ARPEGE and MOCAGE models for ozone?

- ➔ The assimilation of ozone-sensitive observations by coupling meteorological and chemical models makes it possible to improve analyses of temperature and humidity (**1D-Var** study) [*Coopmann et al., 2018*], temperature and wind (**4D-Var** study) [*Allen et al., 2018*] or to reduce wind bias in the stratosphere (**4D-Var** study) [*Semane et al., 2009*].

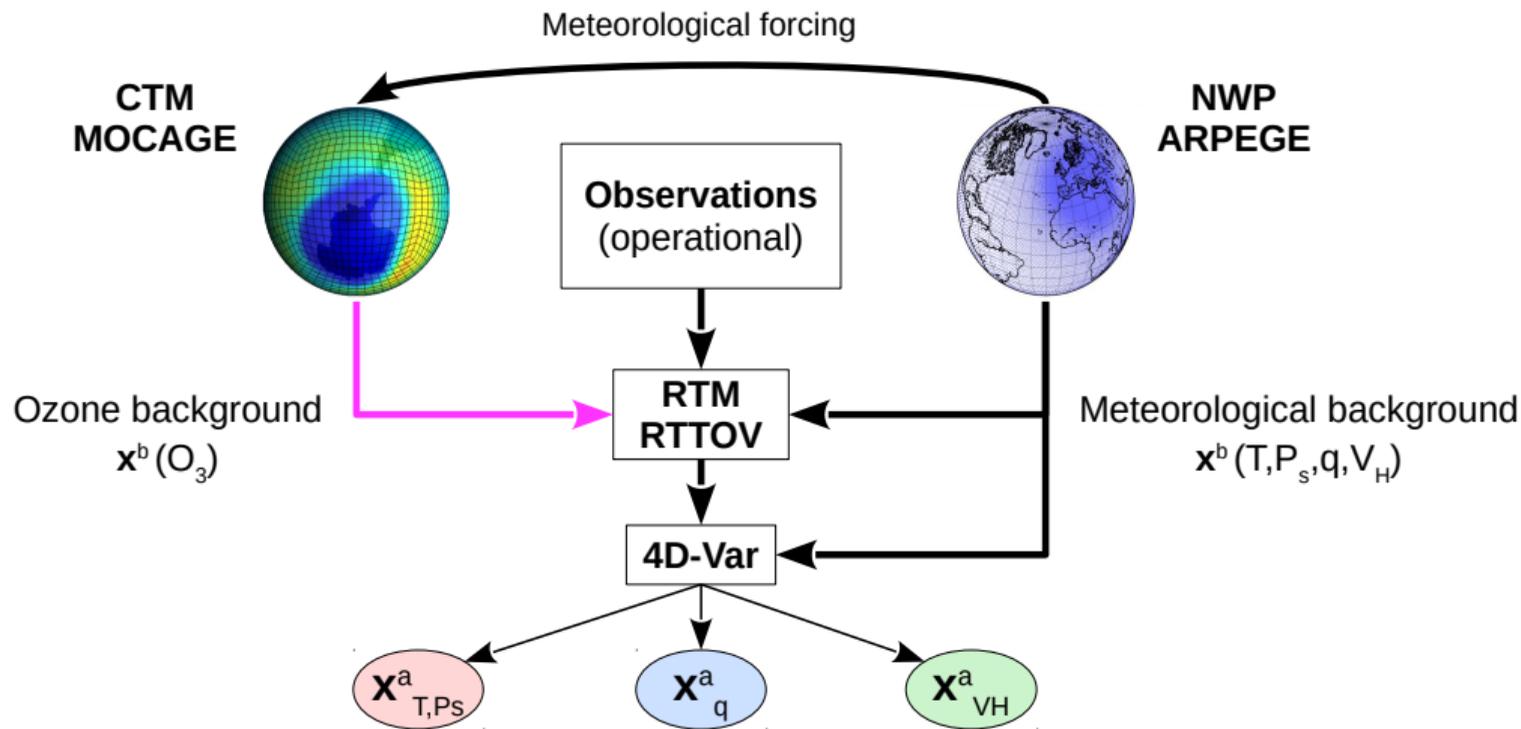
Current Setup:



Step 1:

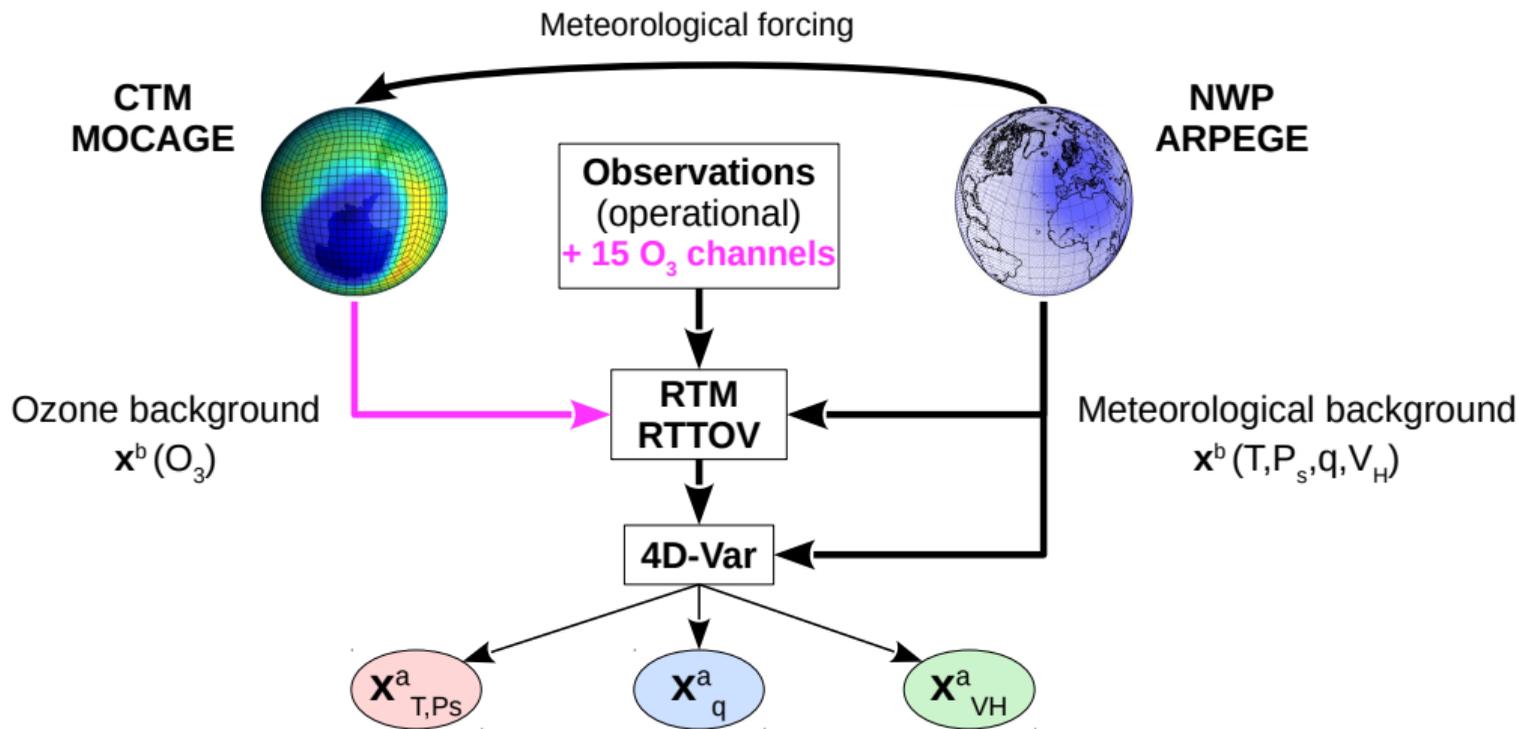


Step 1: Use of MOCAGE ozone fields in the observation operator



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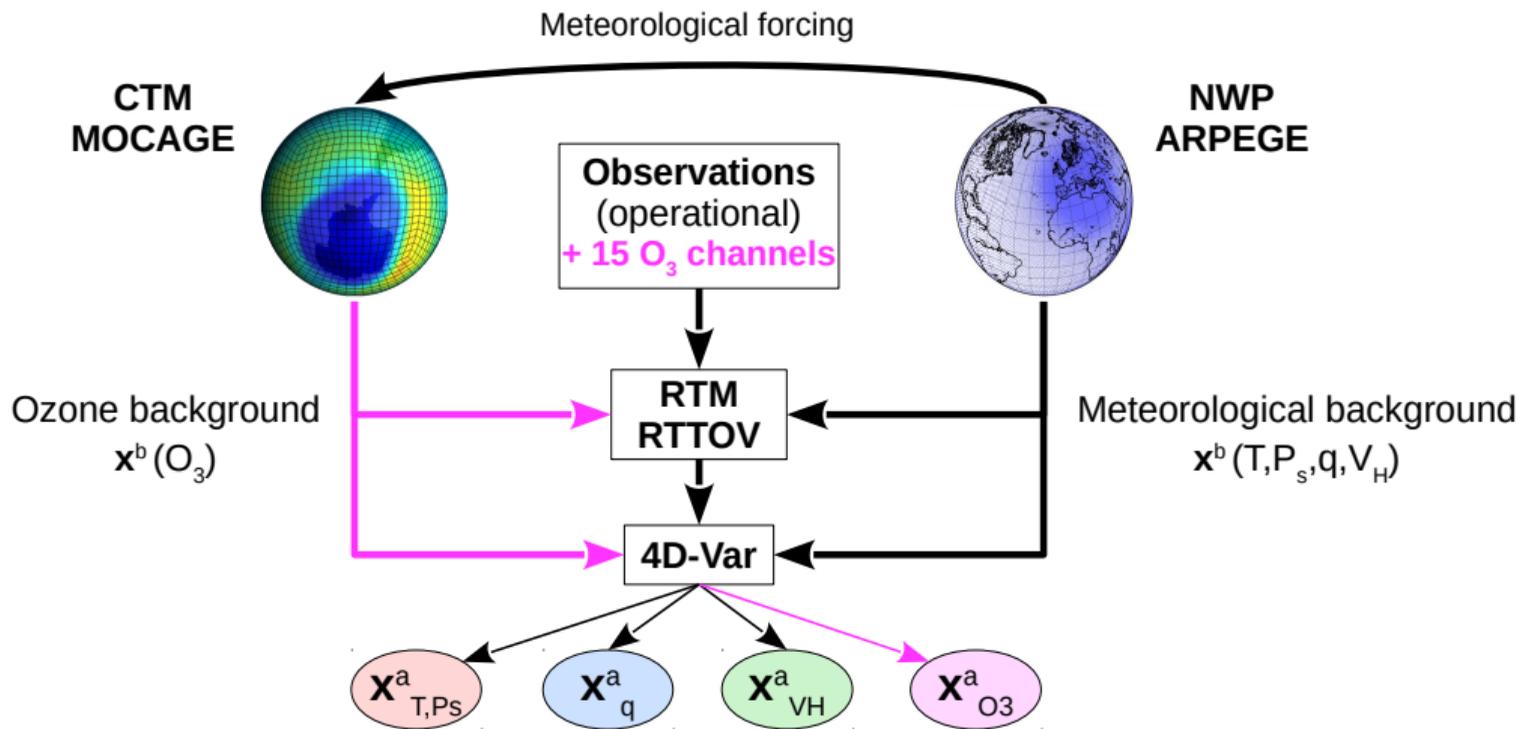
Step 2: Assimilate 15 additional ozone-sensitive IASI channels



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Step 3: Analyze ozone in addition to other variables

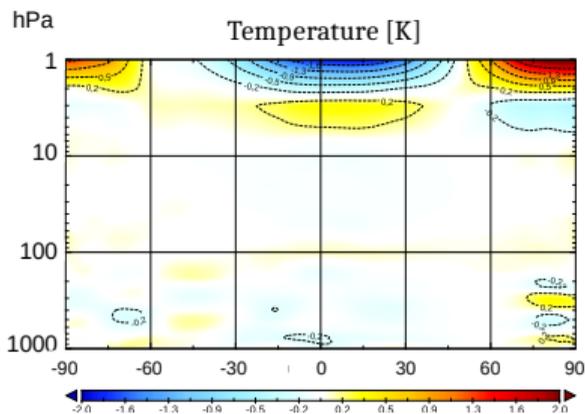


Impact of using realistic ozone fields on meteorological analyses

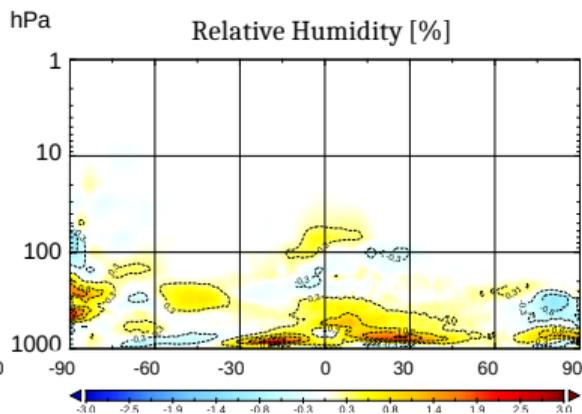
- REF experiment: use of the constant ozone profile in the observation operator
- EXP experiment: use of MOCAGE ozone fields in the observation operator
- Average of the differences in temperature, relative humidity and zonal wind component analysis between the **EXP** and **REF** experiments from July 12 to September 10, 2016.

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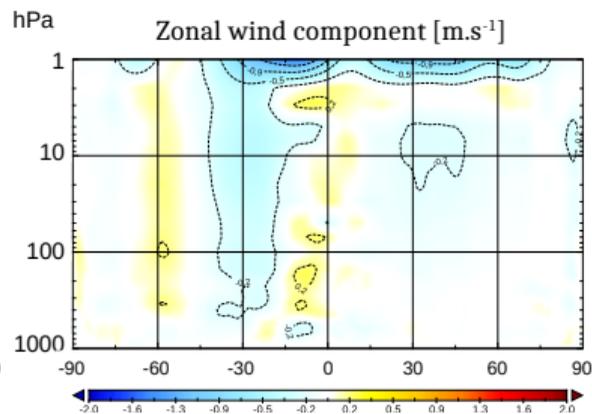
- **REF experiment:** use of the constant ozone profile in the observation operator
- **EXP experiment:** use of MOCAGE ozone fields in the observation operator
- Average of the differences in temperature, relative humidity and zonal wind component analysis between the **EXP** and **REF** experiments from July 12 to September 10, 2016.



$\Delta T(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : - 2,0 \text{ K max} : 2,2 \text{ K}$



$\Delta RH(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : - 2,1 \% \text{ max} : 2,5 \%$



$\Delta U(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : - 1,6 \text{ m.s}^{-1} \text{ max} : 0,3 \text{ m.s}^{-1}$

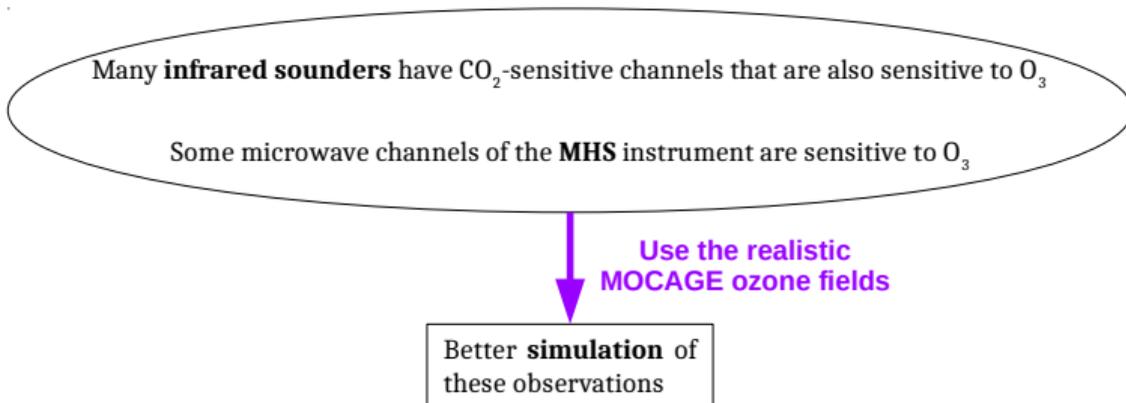
Why does the use of MOCAGE ozone have an impact on analyses without assimilation of ozone observations?

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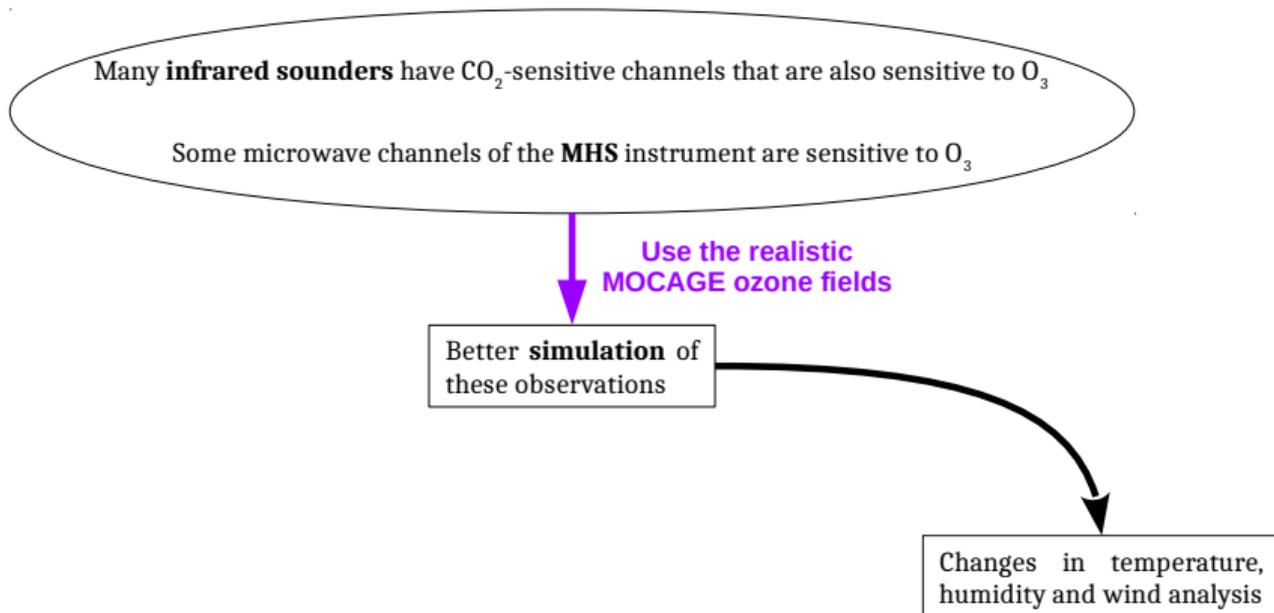
Many **infrared sounders** have CO_2 -sensitive channels that are also sensitive to O_3

Some microwave channels of the **MHS** instrument are sensitive to O_3

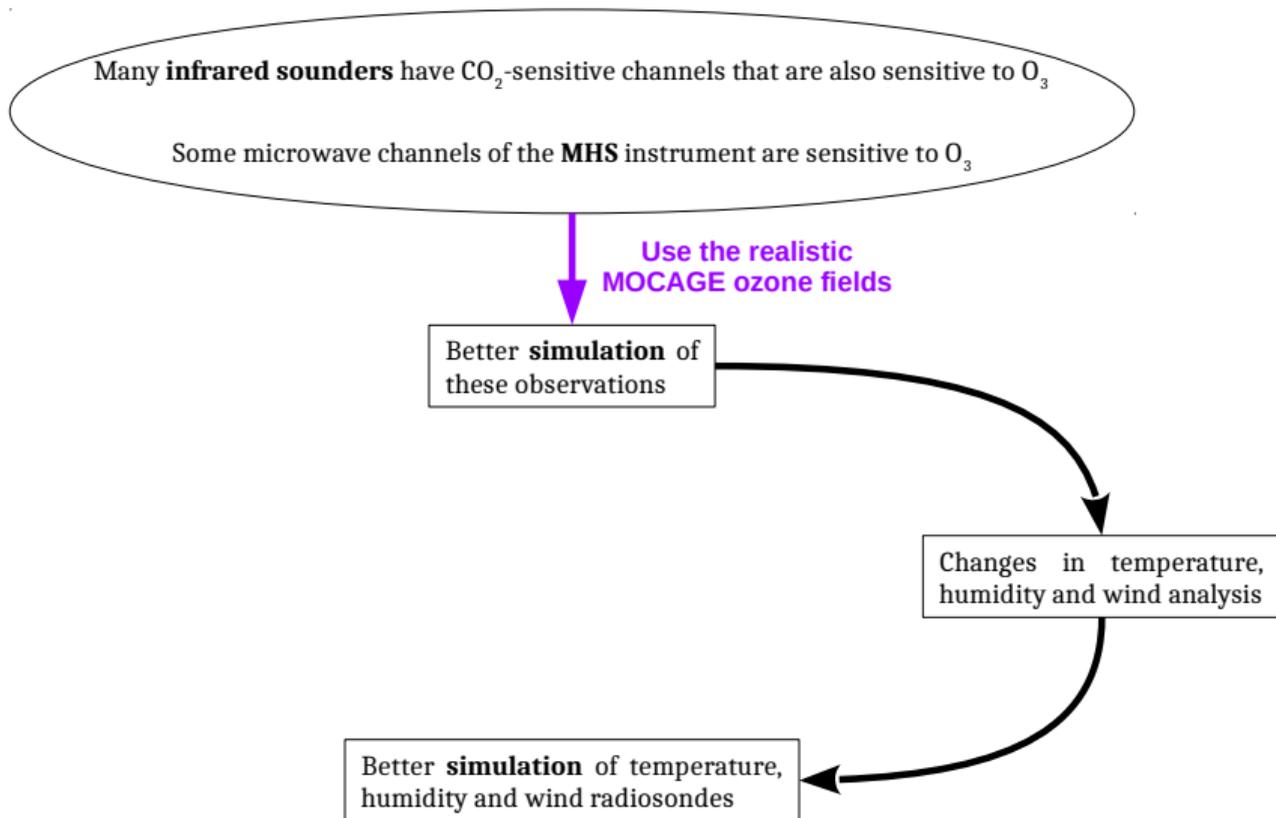
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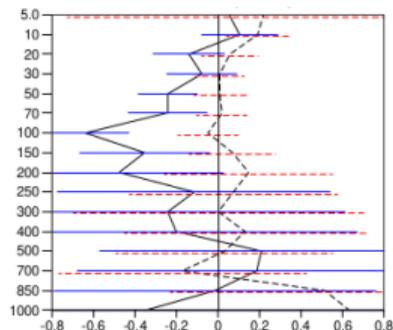
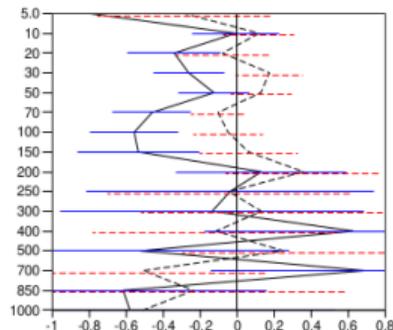
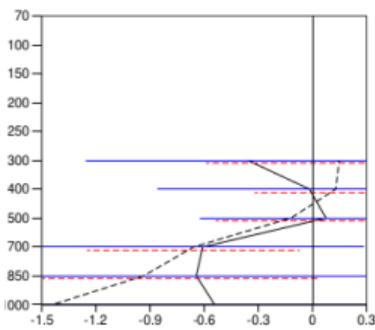
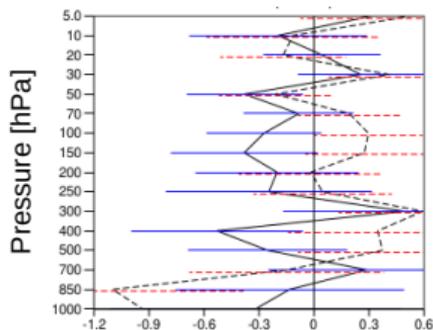
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Radiosonde of temperature

Radiosonde of humidity

Radiosonde of zonal wind

Radiosonde of meridional wind



Relative differences of standard deviation $100*(EXP - REF)/REF$ [%]



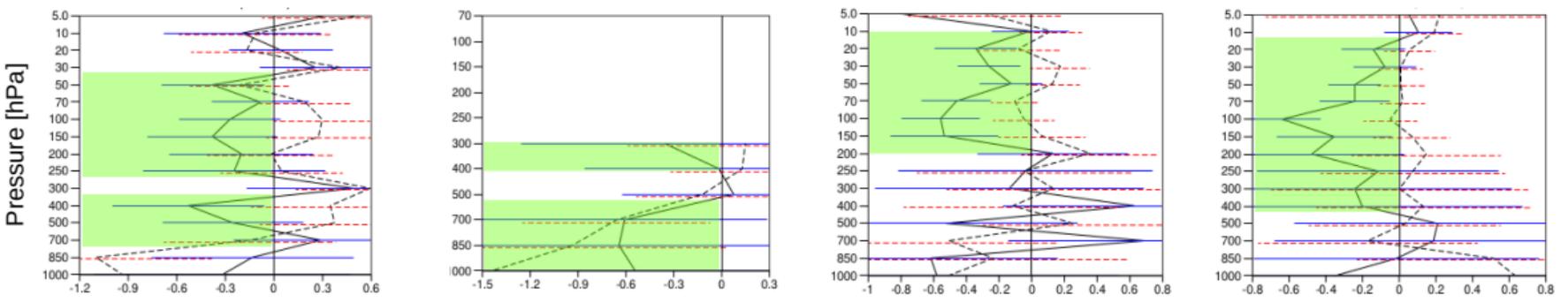
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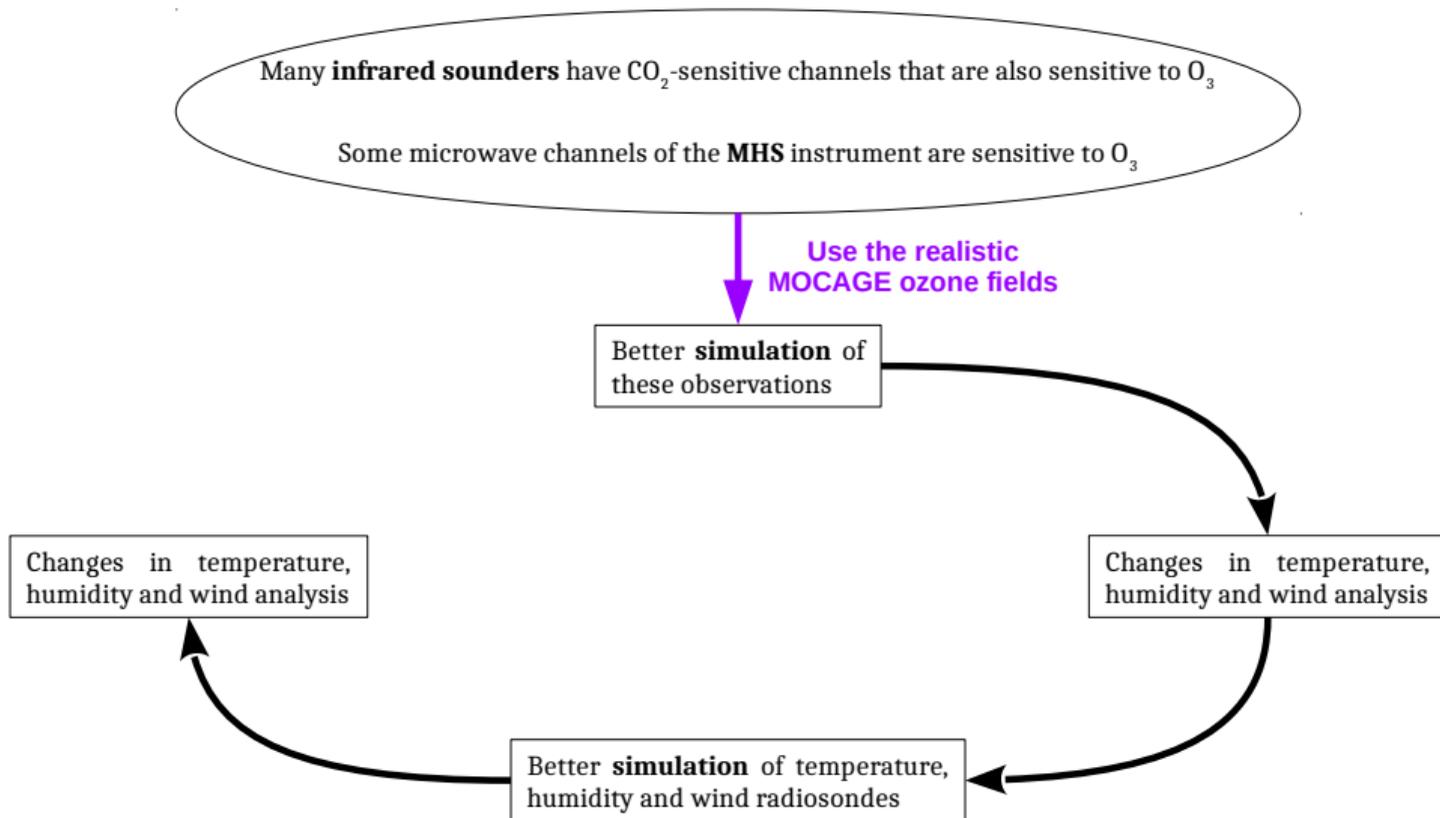
Radiosonde of meridional wind



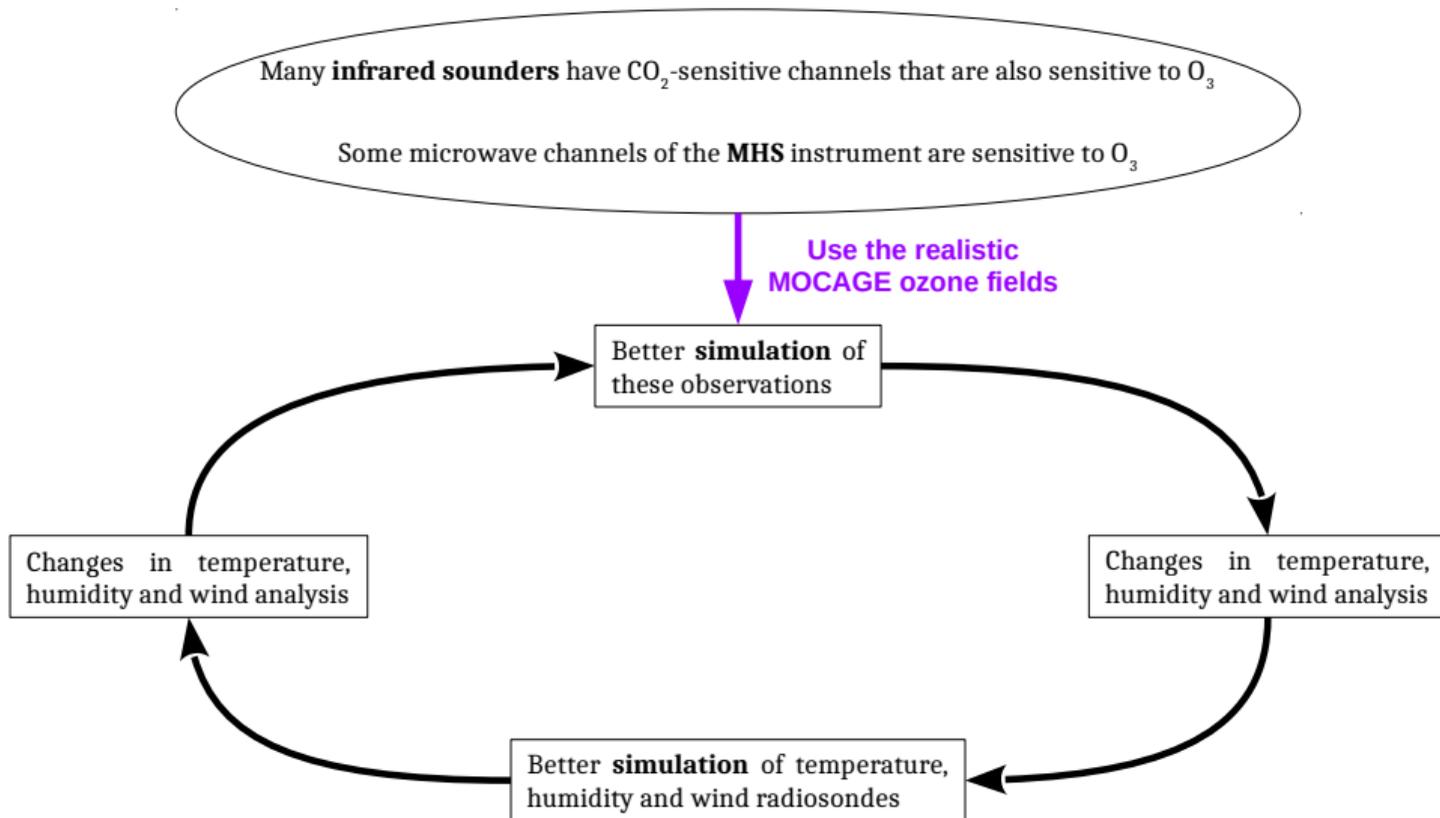
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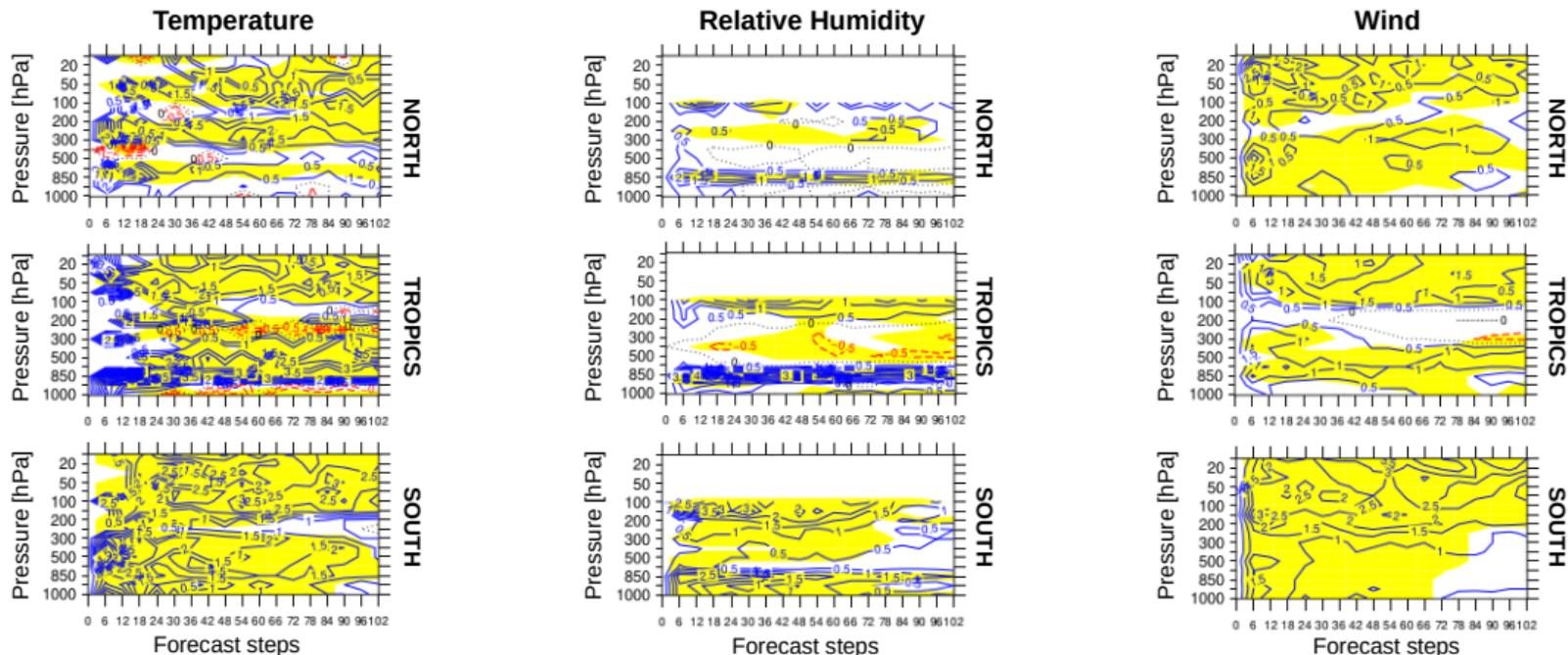


Impact of using realistic ozone fields on weather forecasts

- Normalized differences of Root Mean Square Errors between **EXP** and **REF** forecast by step w.r.t. pressure from July 12 to September 10, 2016

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Improvement



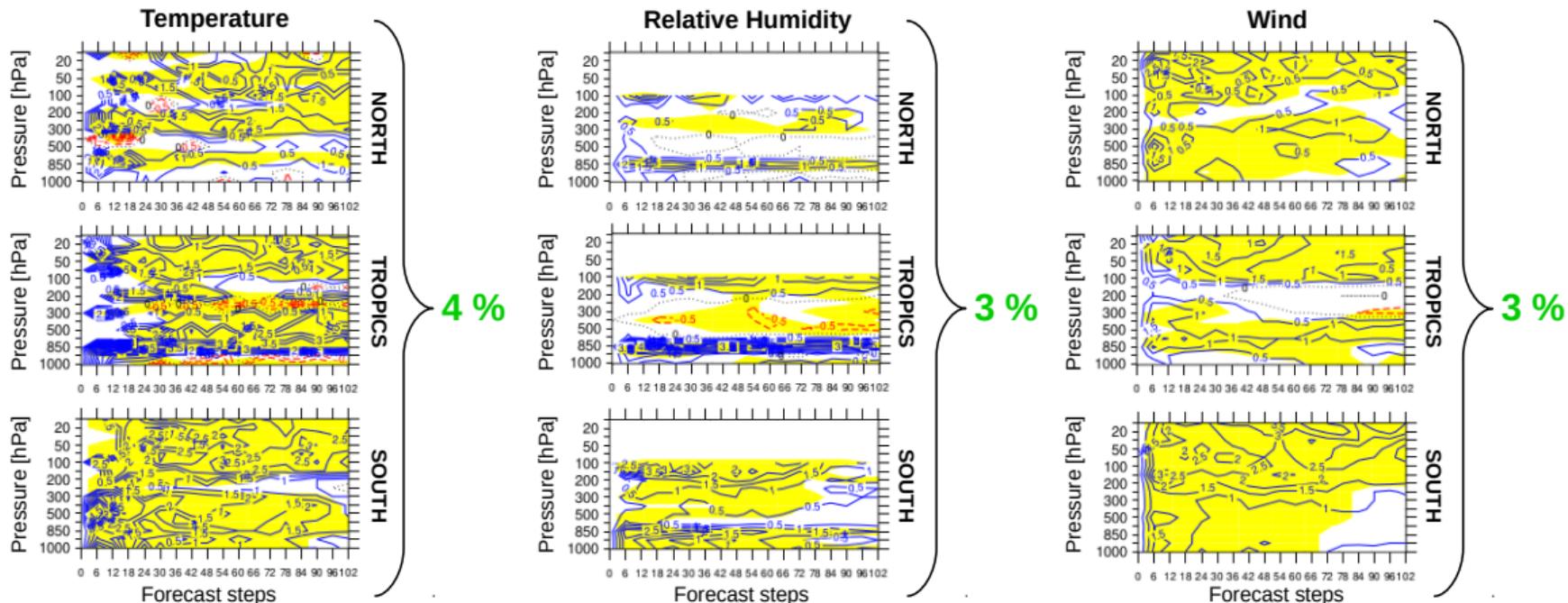
Degradation



Statistically significant with 95 % of confidence (Bootstrap)

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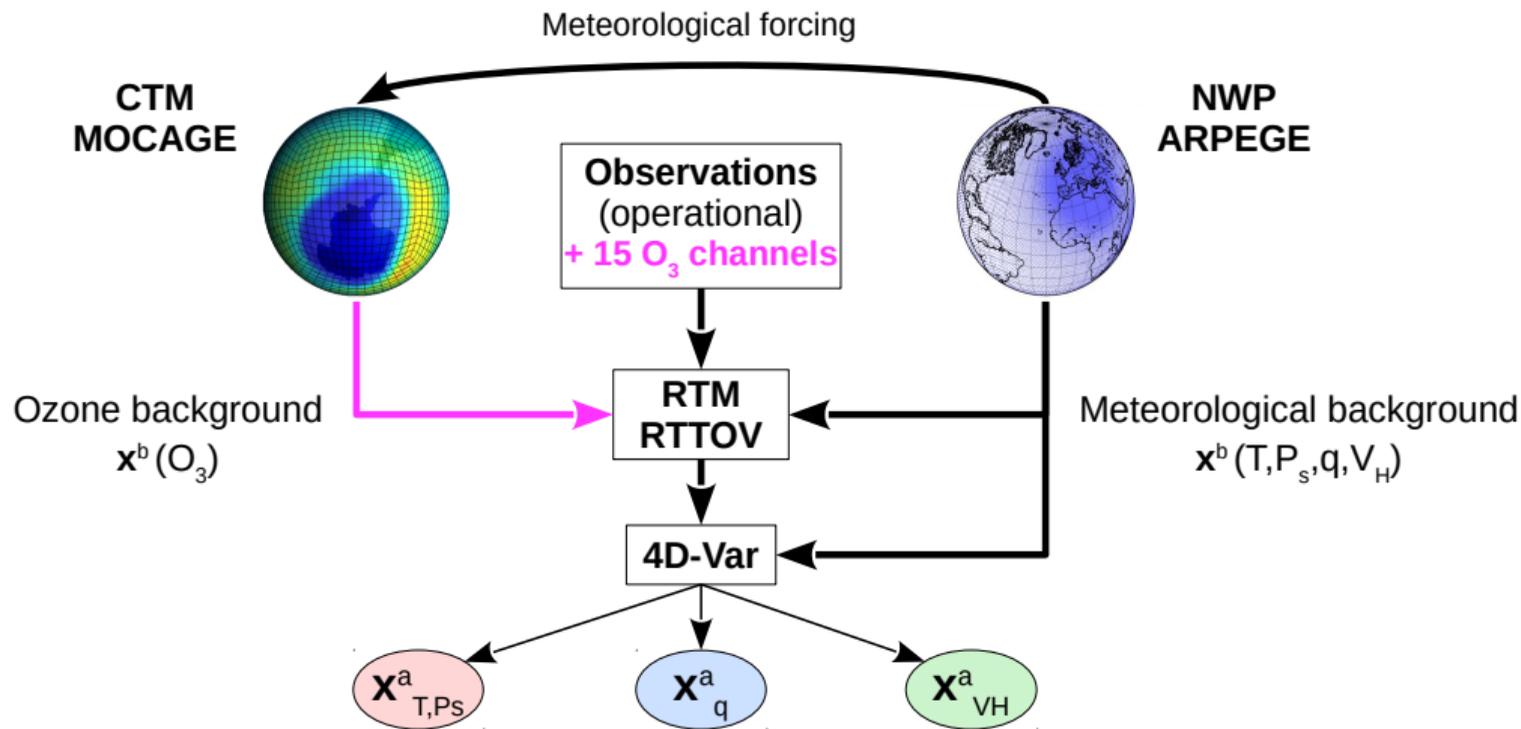
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Step 1: Use of MOCAGE ozone fields in the observation operator

Step 2: Assimilate 15 additional ozone-sensitive IASI channels



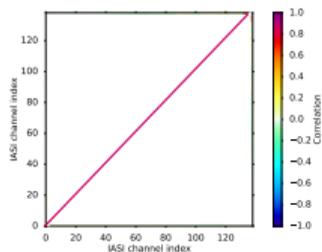
Method of the new selection of IASI ozone-sensitive channels described in [Coopmann et al., 2019 in review]:

Differences from the selection made by [Collard et al., 2007]:

Collard's selection

Selection of the most informative channels in ozone

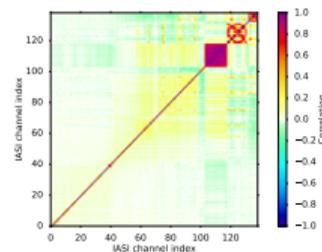
Use of a diagonal observation-error covariance matrix



New selection

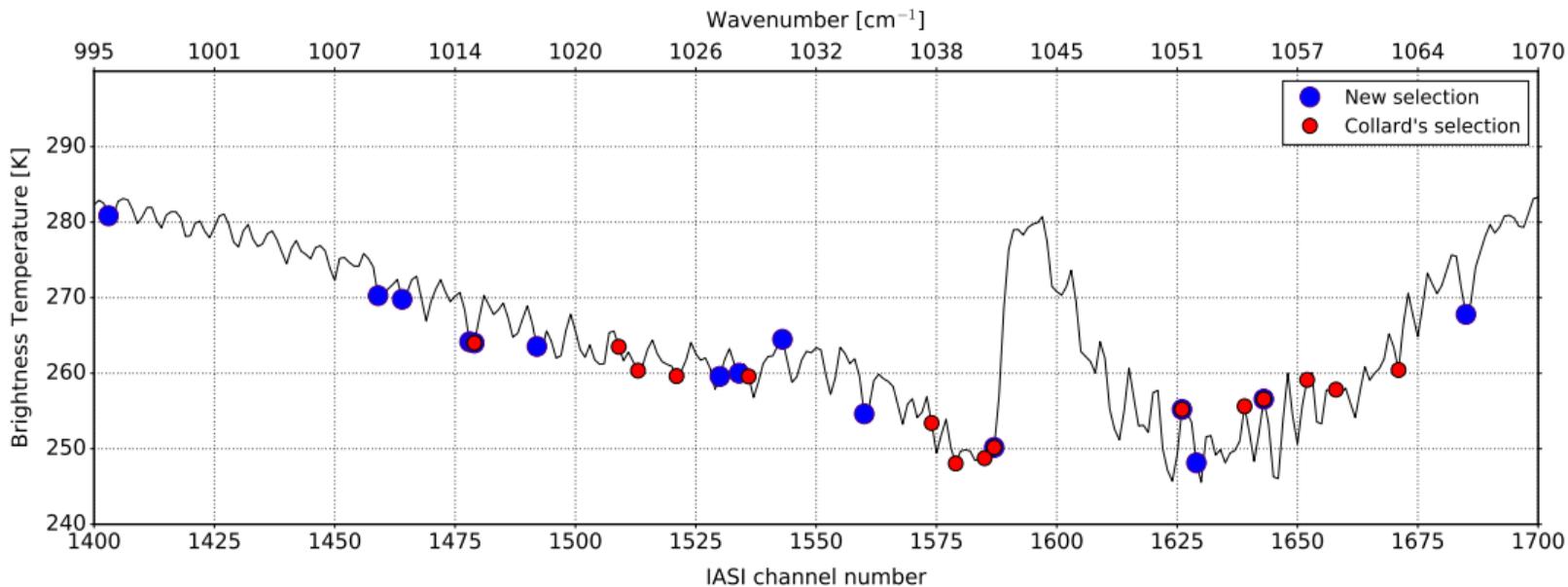
Selection of the most informative channels in temperature, humidity, surface temperature and ozone

Use of a full and diagnosed observation-error covariance matrix



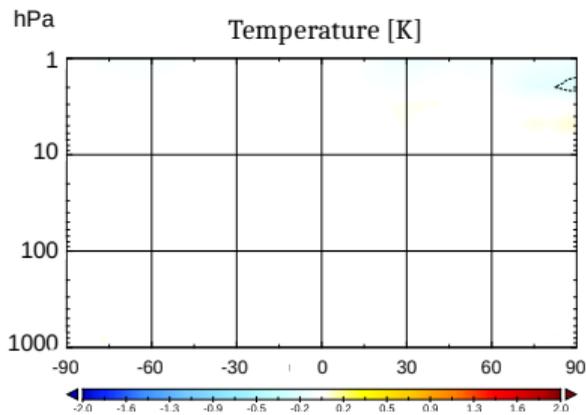
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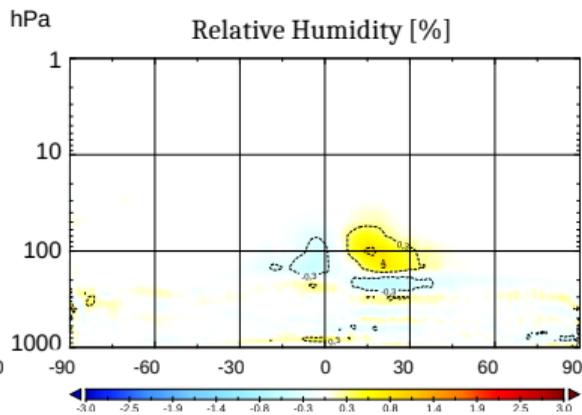


Impacts of assimilating ozone-sensitive IASI channels on meteorological analyses

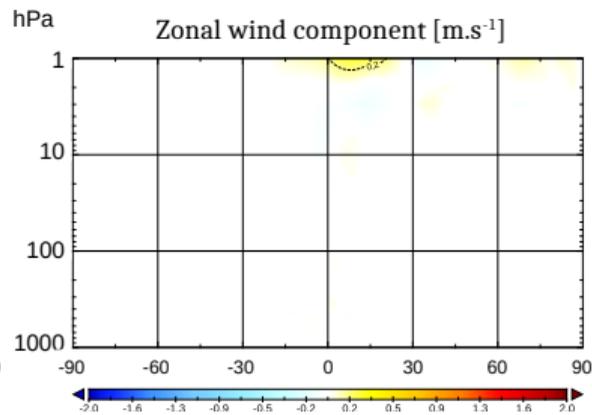
- **EXP experiment:** (reference) use of MOCAGE ozone fields in the observation operator
- **EXP15 experiment:** use of MOCAGE ozone fields in the observation operator + **15 ozone-sensitive channels**
- Average of the differences in temperature, relative humidity and zonal wind component analysis between the **EXP15** and **EXP** experiments from July 12 to August 31, 2016.



$\Delta T(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : -0,2 \text{ K} \text{ max} : 0,1 \text{ K}$



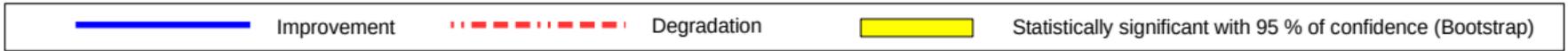
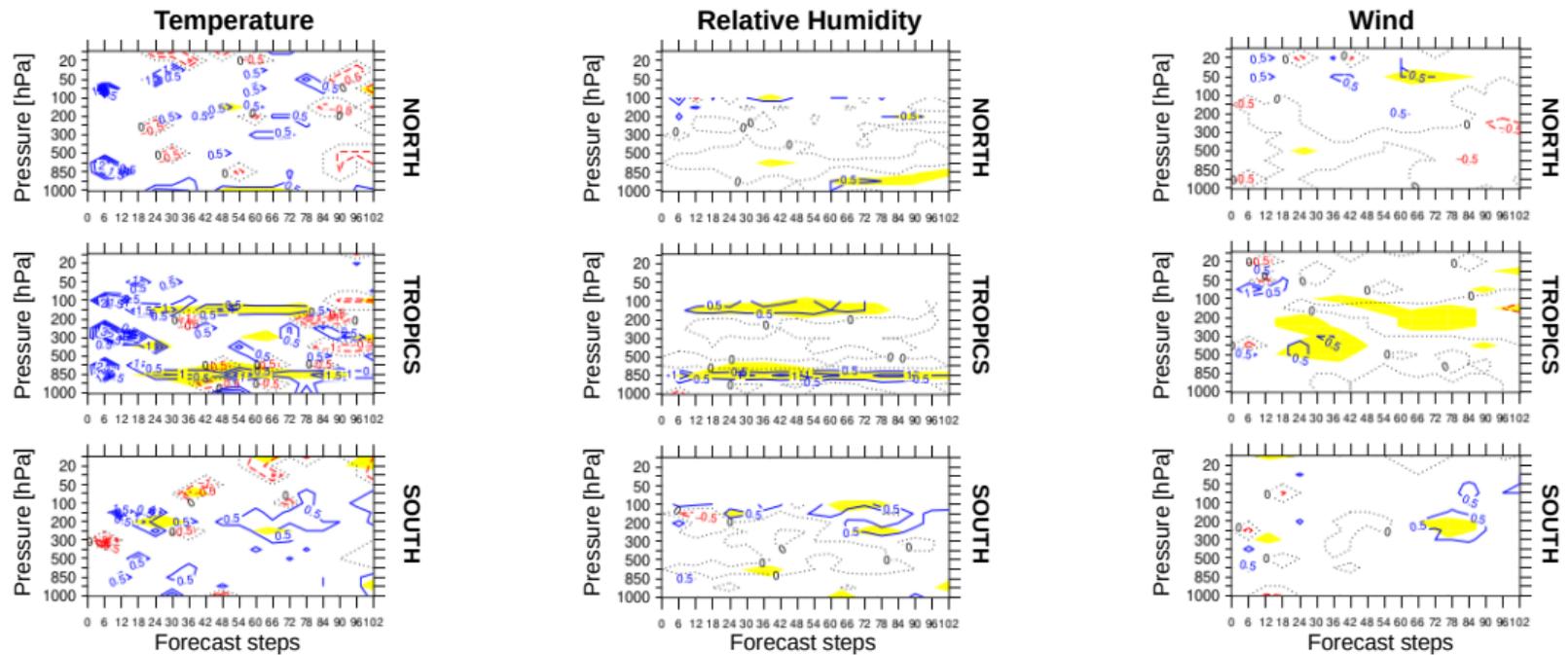
$\Delta HR(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : -1,4 \% \text{ max} : 0,9 \%$



$\Delta U(x_{EXP}^a - x_{REF}^a) \rightarrow \text{min} : -0,1 \text{ m.s}^{-1} \text{ max} : 0,3 \text{ m.s}^{-1}$

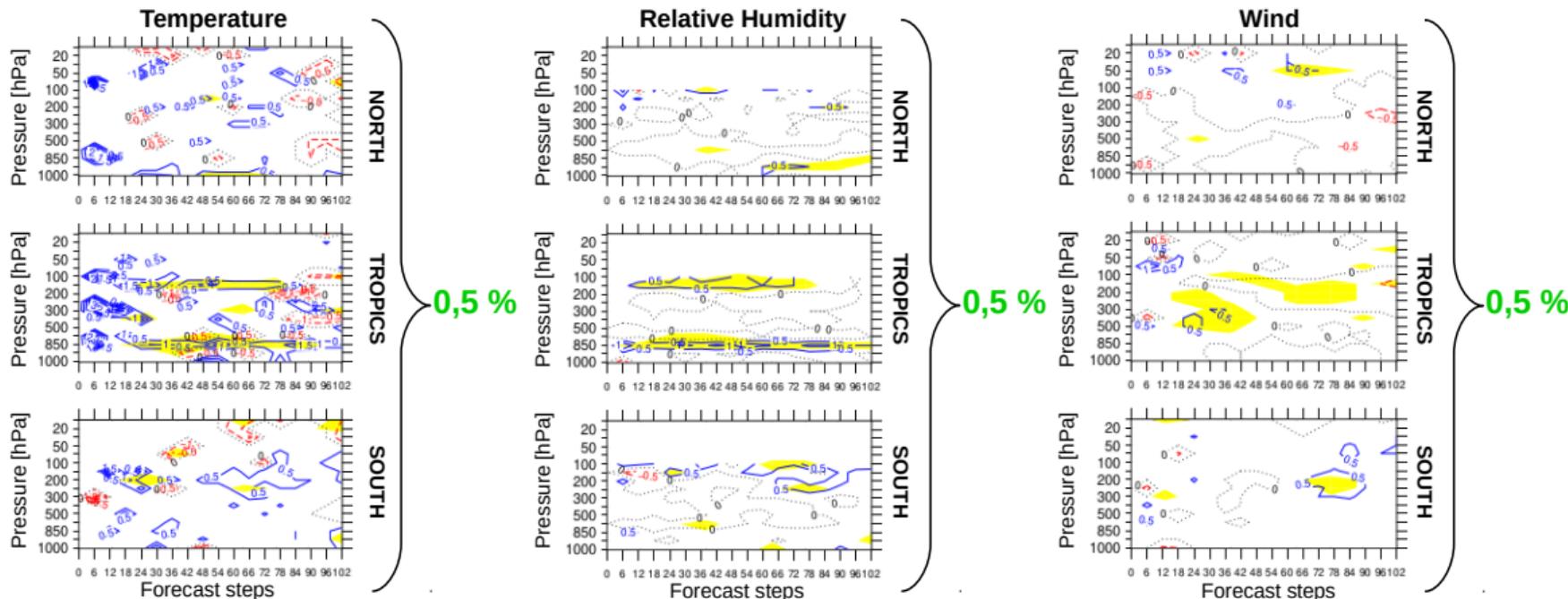
Impacts of assimilating ozone-sensitive IASI channels on weather forecasts

- Normalized differences of Root Mean Square Errors between **EXP15** and **EXP** forecast by step w.r.t. pressure from July 12 to August 31, 2016



Impacts of assimilating ozone-sensitive IASI channels on weather forecasts

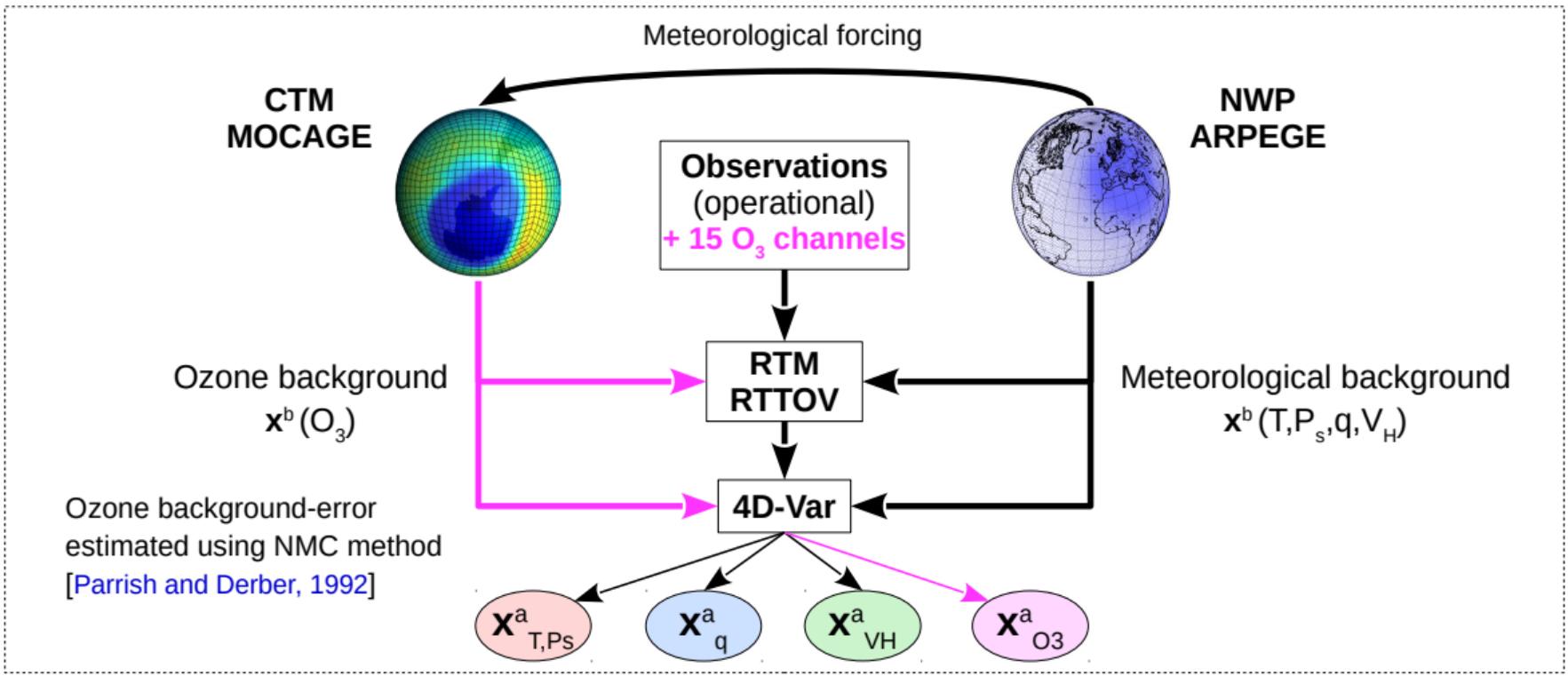
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Step 1: Use of MOCAGE ozone fields in the observation operator

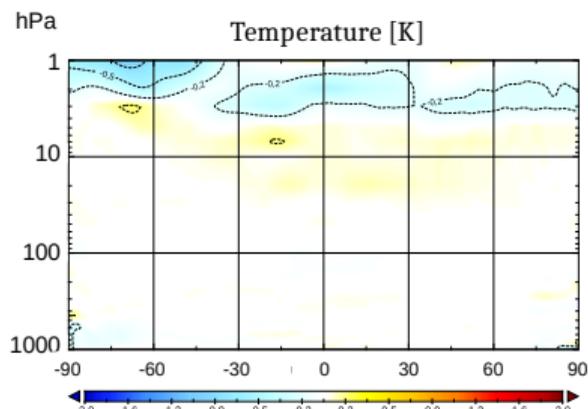
Step 2: Assimilate 15 additional ozone-sensitive IASI channels

Step 3: Analyze ozone in addition to other variables

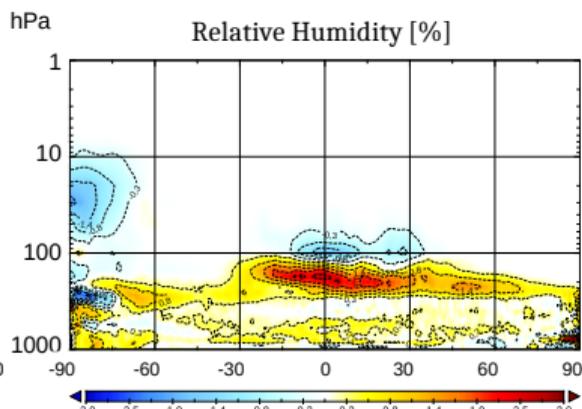


Impacts of ozone analysis on meteorological analyses?

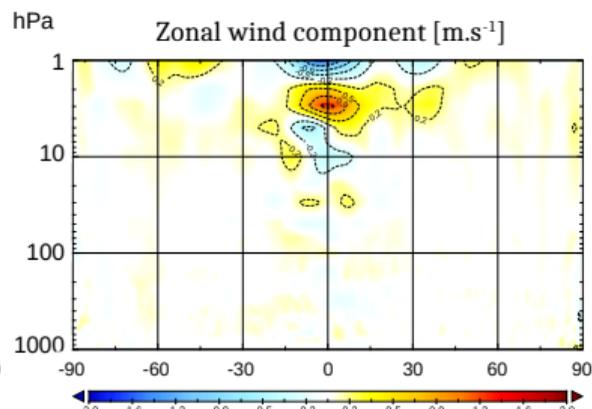
- **EXP15 experiment:** (reference) use of MOCAGE ozone fields in the observation operator **+15 O₃ channels**
- **EXP1503 experiment:** use of MOCAGE ozone fields in the observation operator **+15 O₃ channels + analyze ozone** in addition to other variables
- Average of the differences in temperature, relative humidity and zonal wind component analysis between the **EXP15** and **EXP** experiments from 12 to 30 July 2016.



$$\Delta T(\mathbf{x}_{\text{EXP}}^a - \mathbf{x}_{\text{REF}}^a) \rightarrow \text{min} : -1,1 \text{ K} \text{ max} : 0,2 \text{ K}$$



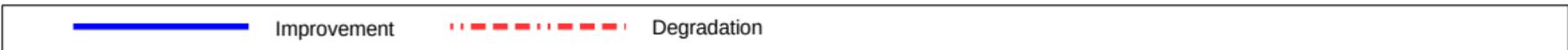
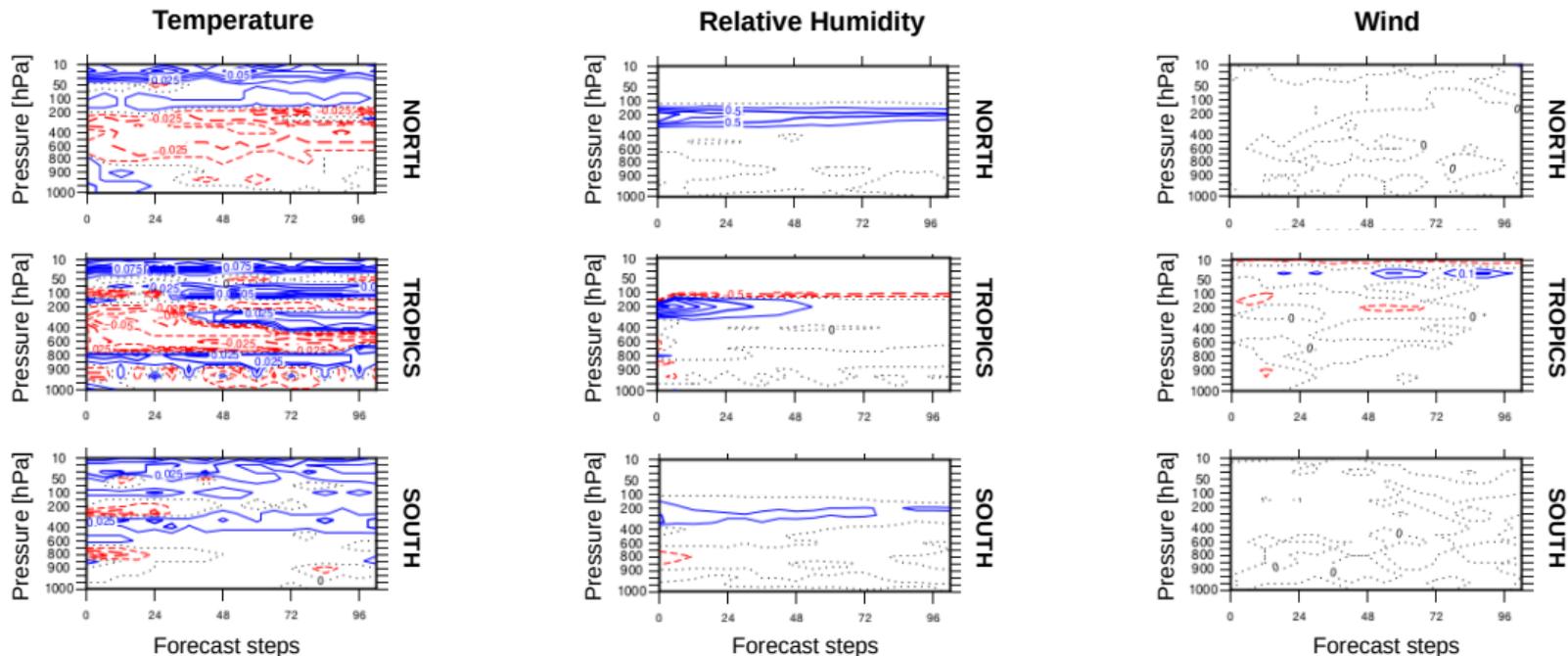
$$\Delta \text{RH}(\mathbf{x}_{\text{EXP}}^a - \mathbf{x}_{\text{REF}}^a) \rightarrow \text{min} : -2,8 \% \text{ max} : 4,1 \%$$



$$\Delta U(\mathbf{x}_{\text{EXP}}^a - \mathbf{x}_{\text{REF}}^a) \rightarrow \text{min} : -1,7 \text{ m.s}^{-1} \text{ max} : 1,4 \text{ m.s}^{-1}$$

Impacts of ozone analysis on weather forecasts?

- Experience in progress but we can already look at the impacts on forecast **bias** between **EXP1503** and **EXP15** from 12 to 30 July, 2016



- **Step 1:** The use of realistic ozone fields from MOCAGE has a positive impact on the assimilation of observations and analyses and makes it possible to improve overall forecasts of temperature (**4 %**), humidity (**3 %**) and wind (**3 %**).
- **Step 2:** The assimilation of 15 additional IASI ozone-sensitive channels has very small impacts on the analyses but this improves the temperature, humidity and wind forecasts by about **0.5 %**.
- **Step 3:** Analyzing ozone in 4D-Var allows to distribute the information and to give an additional degree of freedom to the other variables with a strong impact on the analyses and a decrease in the bias of forecasts mainly in temperature and humidity.
- **This coupling between the ARPEGE and MOCAGE models, by ozone, makes it possible to better assimilate infrared satellite observations as well as other observations with positive impacts on analyses and improvements in weather forecasts.**

- Improvements through the assimilation of profiles, total or partial ozone columns retrieved from satellite instruments (GOME, IMO, MLS, SBUV-2, OMPS, ...).
- Assimilation of other instruments: CrIS, AIRS, HIRAS (polar), SEVIRI, AHI, GIIRS (geostationary).
- Assimilation of new instruments: IASI-NG (polar), IRS (geostationary).



Thank you for your attention

INTERNATIONAL
A TOVS
WORKING GROUP



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The 22nd International TOVS Study Conference (ITSC-22) Saint-Sauveur, Canada

