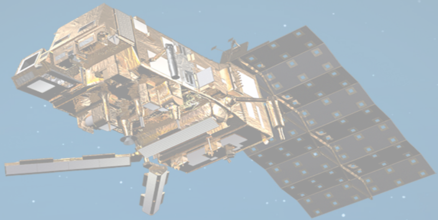


4D-Var assimilation of IASI ozone-sensitive radiances in operational global model ARPEGE

Olivier COOPMANN (*olivier.coopmann@umr-cnrm.fr*)

CNRM, Université de Toulouse, Météo-France, CNRS, UMR-3589

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

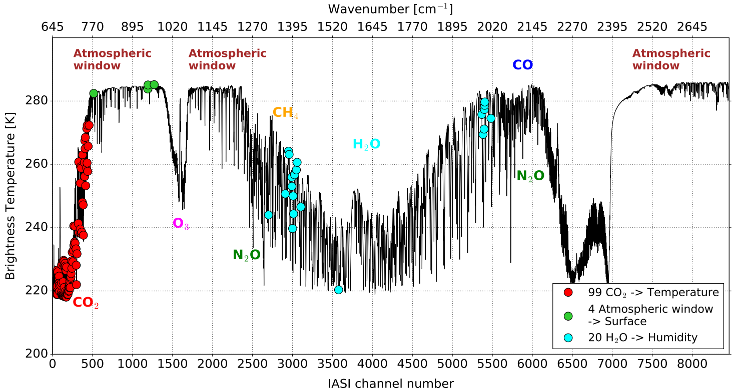
The 22nd International TOVS Study Conference (ITSC-22) Saint-Sauveur, Canada

IASI (Infrared Atmospheric Sounding Interferometer) satellite observations

- 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 O_3 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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  - 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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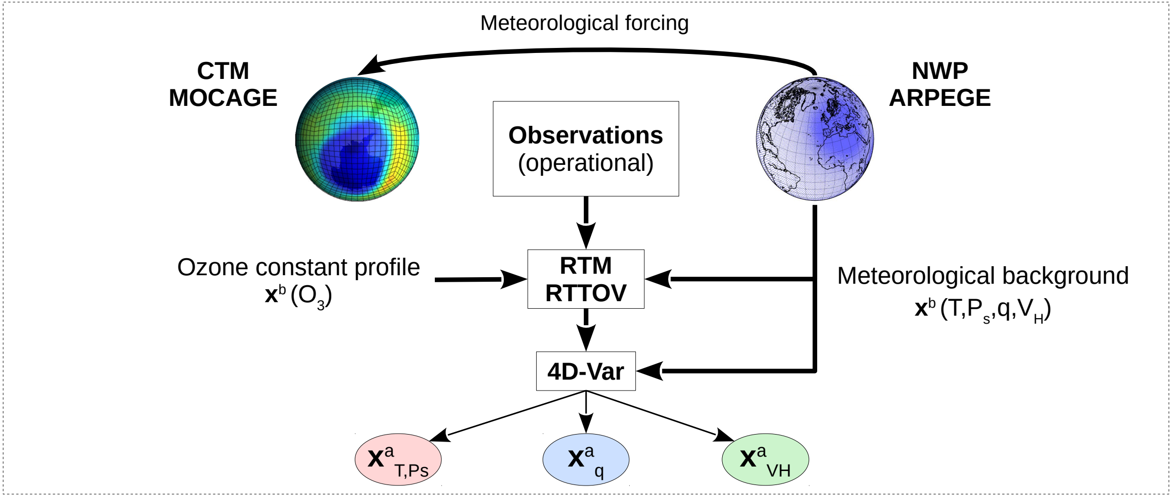
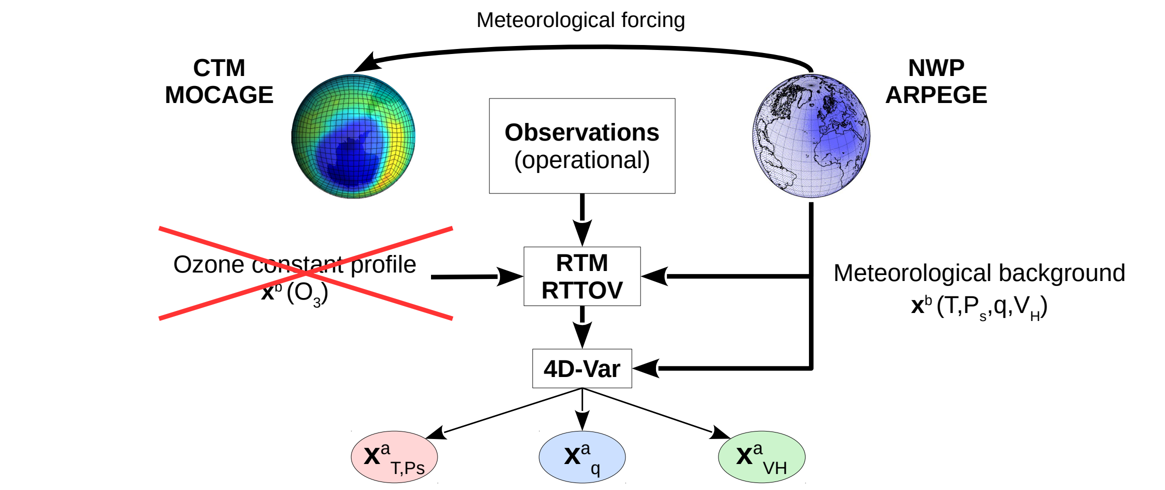
- **Why to couple the ARPEGE and MOCAGE models for ozone?**
  - The assimilation of ozone-sensitive observations by coupling meteorological and chemical models makes it possible to improve analyses of temperature and humidity (**1D-Var** study) [*Coopmann et al., 2018*], temperature and wind (**4D-Var** study) [*Allen et al., 2018*] or to reduce wind bias in the stratosphere (**4D-Var** study) [*Semane et al., 2009*].

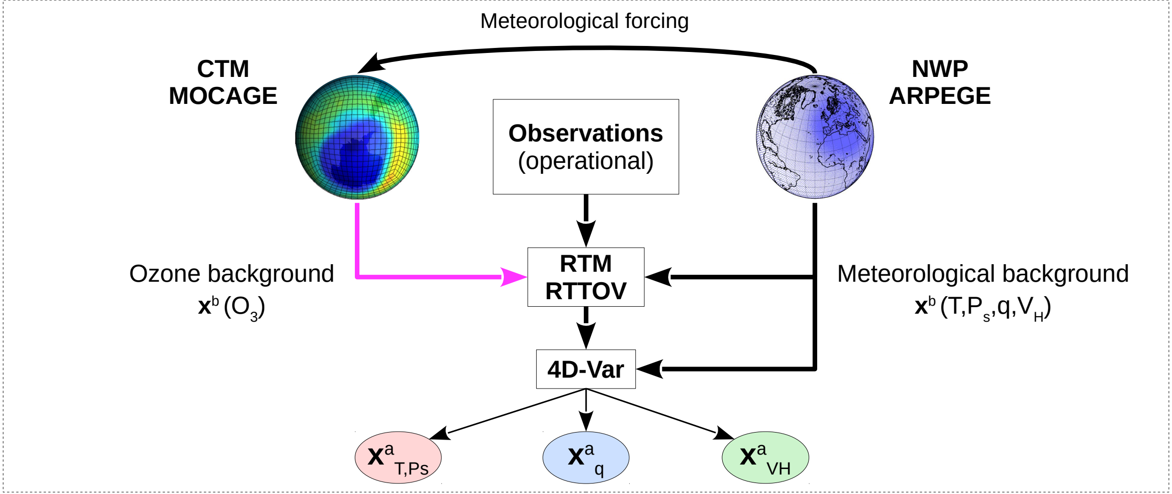
Current Setup:



Step 1:

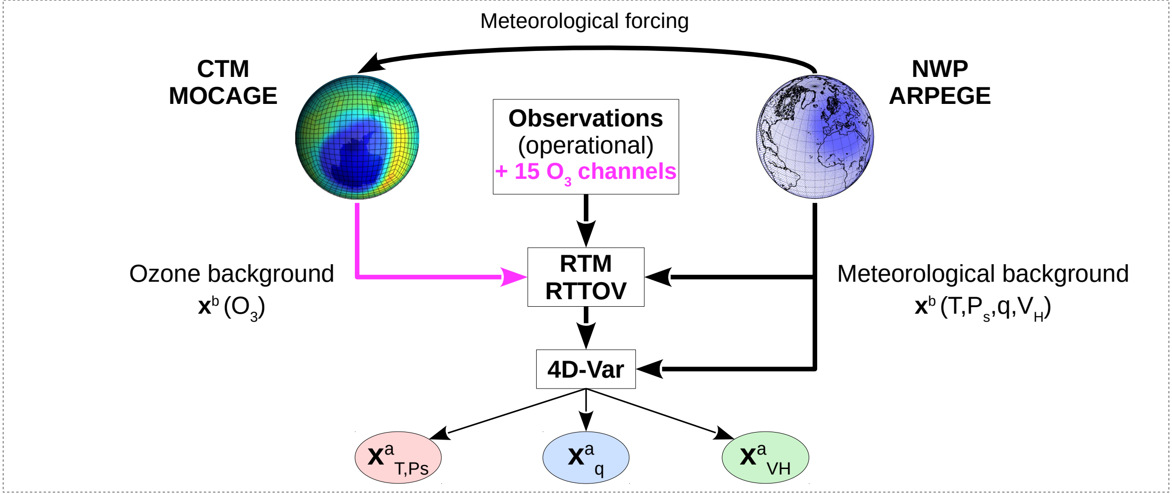

Meteorological forcing
CTM
MOCAGE
NWP
ARPEGE
Observations
(operational)
Ozone constant profile
$\mathbf{x}^b (O_3)$
RTM
RTTOV
Meteorological background
$\mathbf{x}^b (T,P_s,q,V_H)$
4D-Var
$\mathbf{X}^a_{T,Ps}$
$\mathbf{X}^a_{q}$
$\mathbf{X}^a_{VH}$

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



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

Step 2: Assimilate 15 additional ozone-sensitive IASI channels



Step 1: Use of MOCAGE ozone fields in the observation operator
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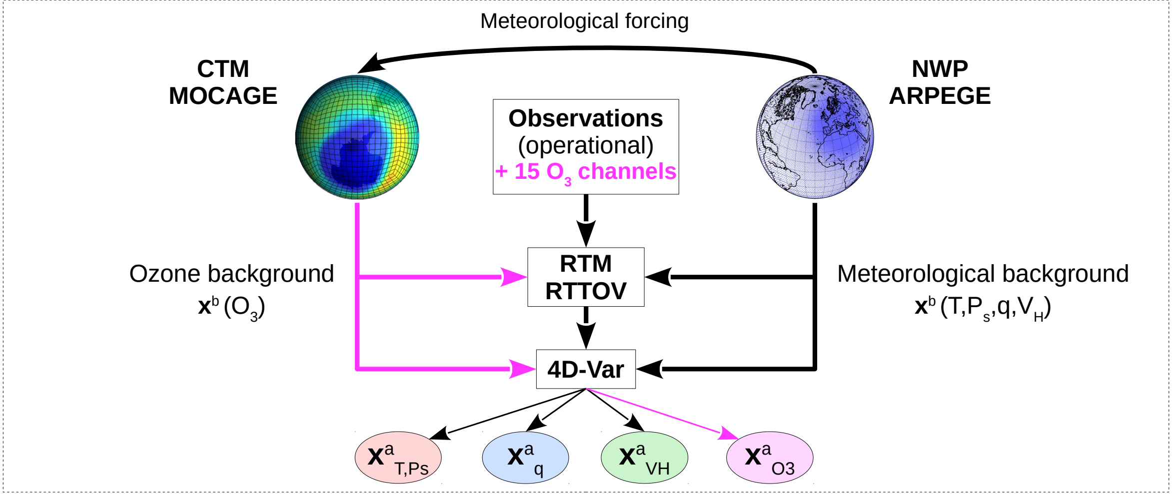
Step 3: Analyze ozone in addition to other variables



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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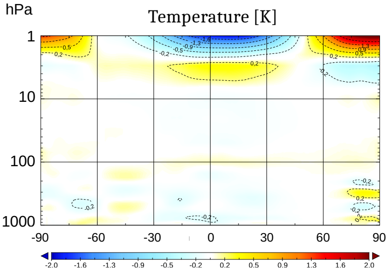
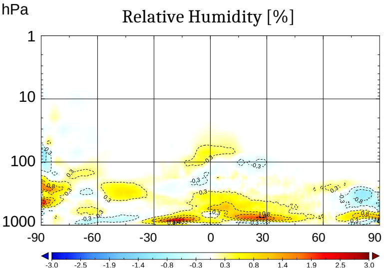
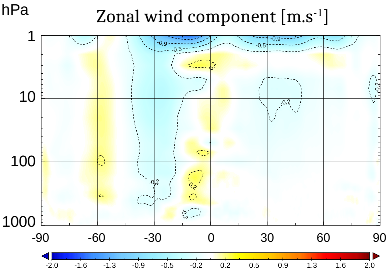
Temperature [K]



Relative Humidity [%]



Zonal wind component [$m.s^{-1}$]



$\Delta T(x^a_{EXP} - x^a_{REF})$ → min : **- 2,0 K** max : **2,2 K**

$\Delta HR(x^a_{EXP} - x^a_{REF})$ → min : **- 2,1 %** max : **2,5 %**

$\Delta U(x^a_{EXP} - x^a_{REF})$ → min : **- 1,6 $m.s^{-1}$** max : **0,3 $m.s^{-1}$**

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

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↓ **Use the realistic MOCAGE ozone fields**

Better **simulation** of these observations

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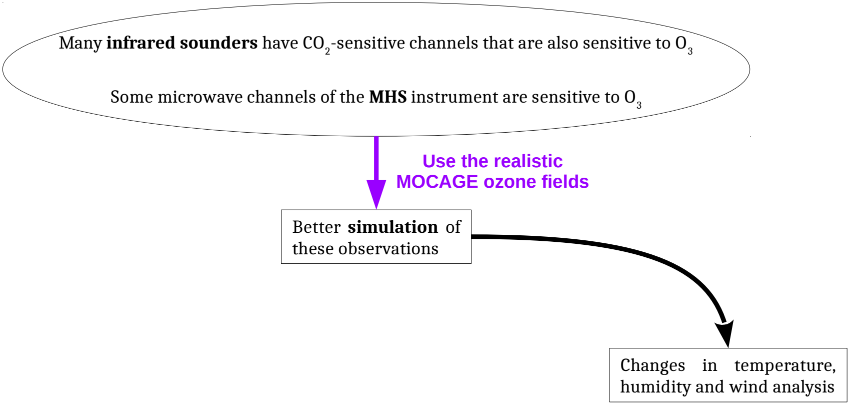

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→ Changes in temperature, humidity and wind analysis

→ Better **simulation** of temperature, humidity and wind radiosondes

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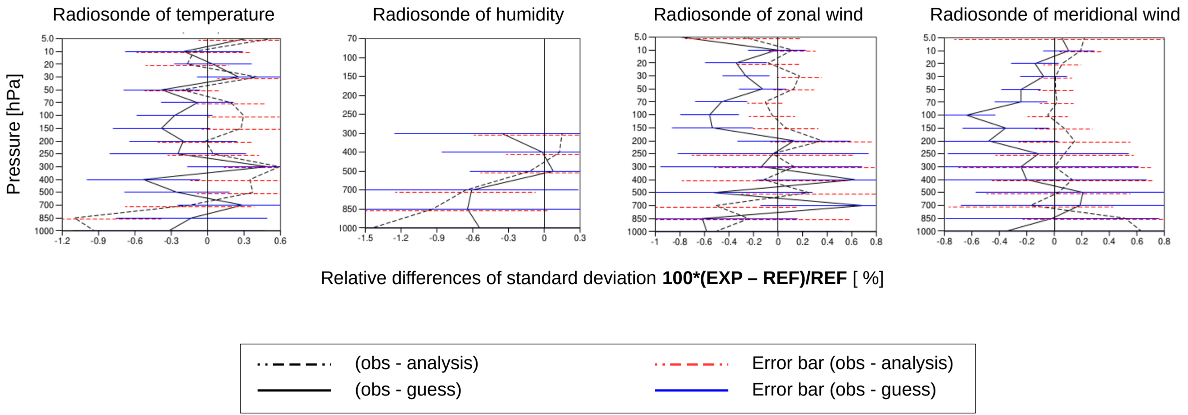

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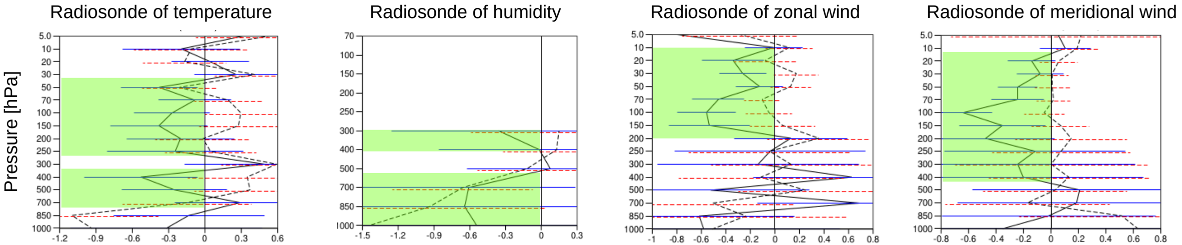

Relative differences of standard deviation **100*(EXP – REF)/REF** [%]

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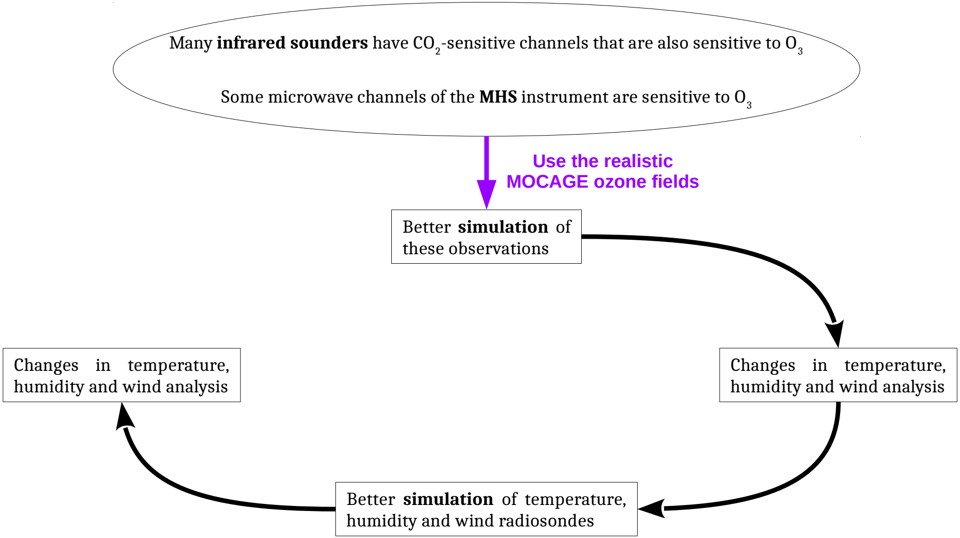

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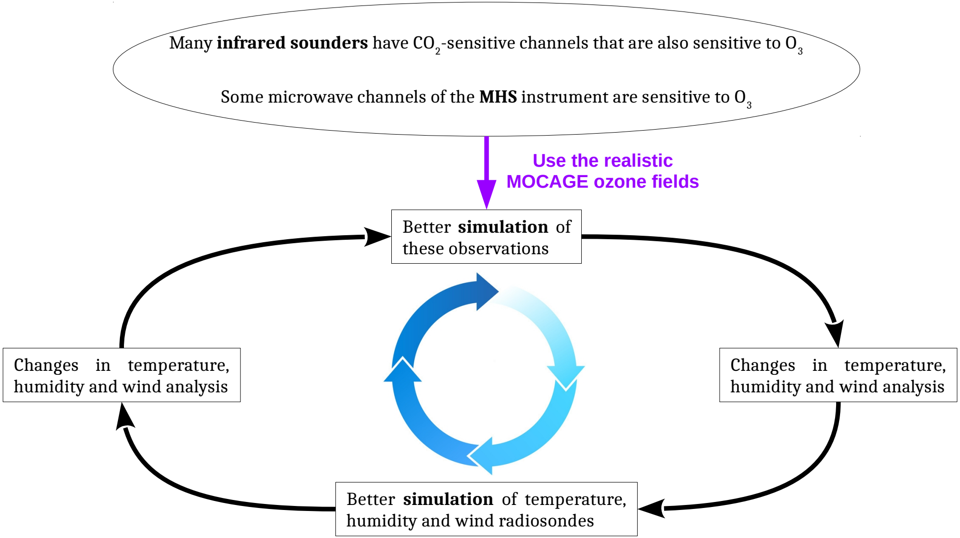

Impact of using realistic ozone fields on weather forecasts

- 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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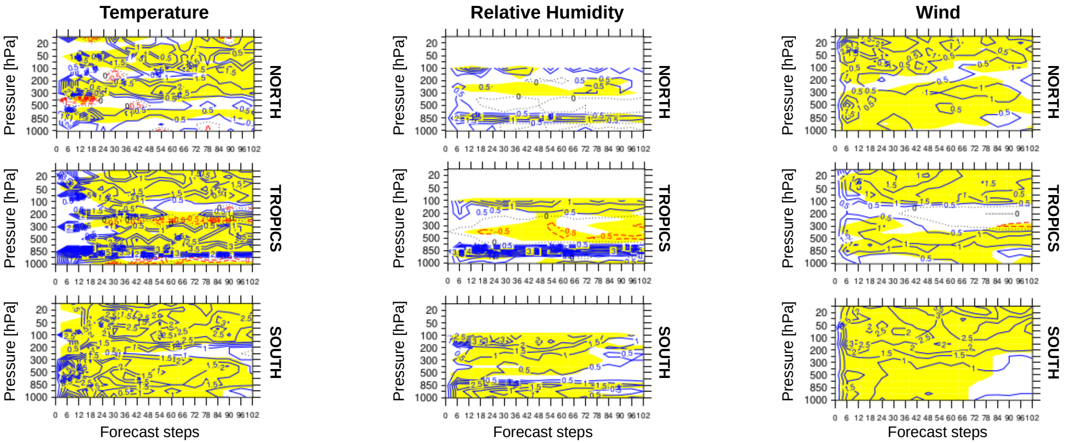

Improvement — Degradation — Statistically significant with 95 % of confidence (Bootstrap)

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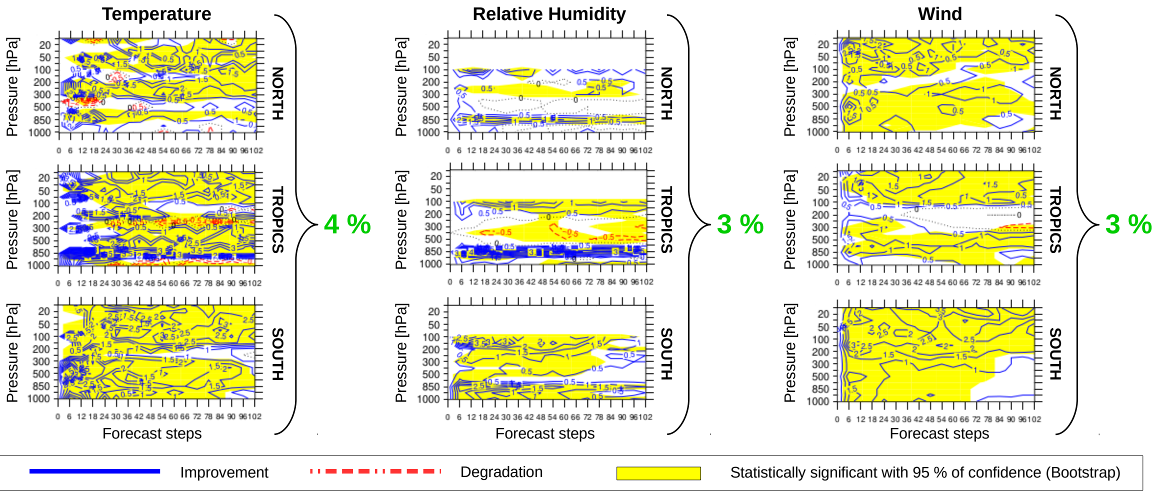
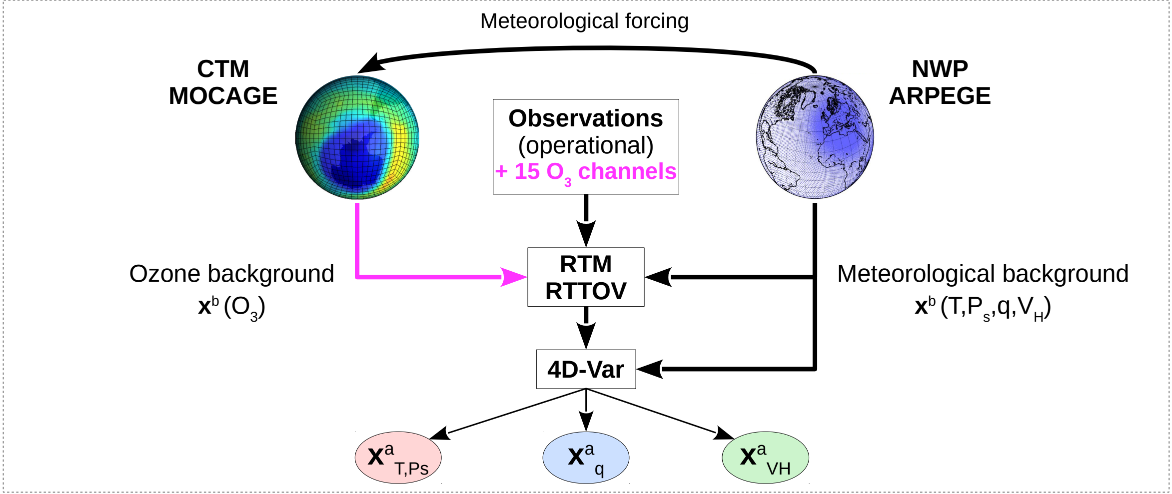


Step 1: Use of MOCAGE ozone fields in the observation operator

Step 2: Assimilate 15 additional ozone-sensitive IASI channels



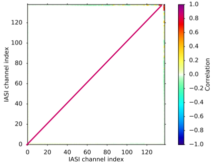
Method of the new selection of IASI ozone-sensitive channels described in [*Coopmann et al., 2019 in review*]:

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

Collard's selection

Selection of the most informative channels in ozone

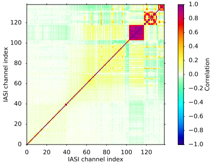
Use of a diagonal observation-error covariance matrix



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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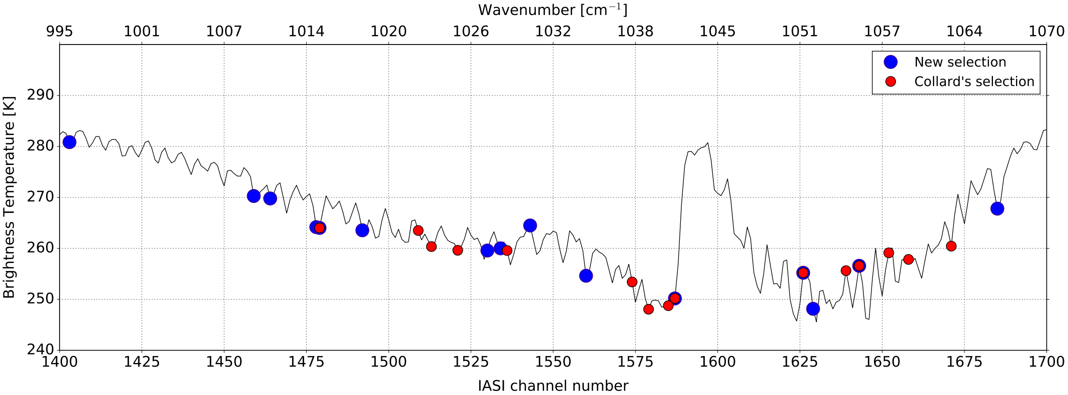
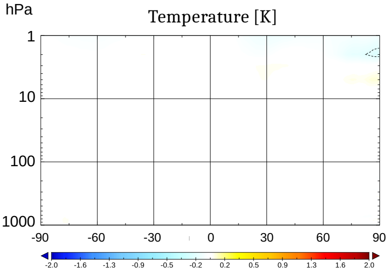
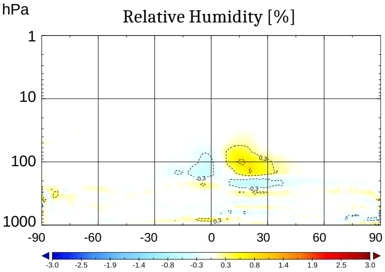
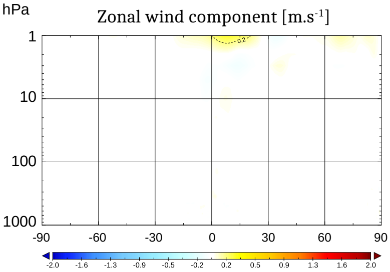


Impacts of assimilating ozone-sensitive IASI channels on meteorological analyses

- **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.







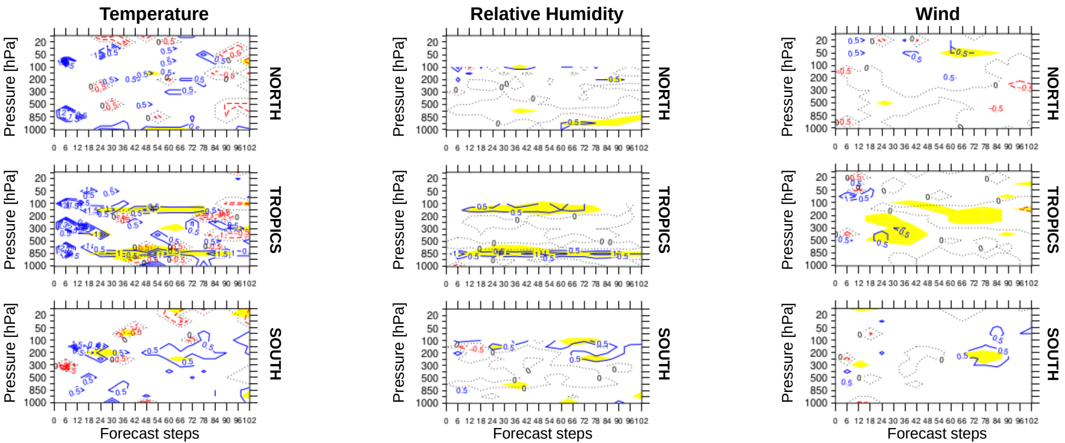
$\Delta T(x^a_{EXP} - x^a_{REF}) \rightarrow$ min : **- 0,2 K** max : **0,1 K**

$\Delta HR(x^a_{EXP} - x^a_{REF}) \rightarrow$ min : **- 1,4 %** max : **0,9 %**

$\Delta U(x^a_{EXP} - x^a_{REF}) \rightarrow$ min : **- 0,1 m.s^{-1}** max : **0,3 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



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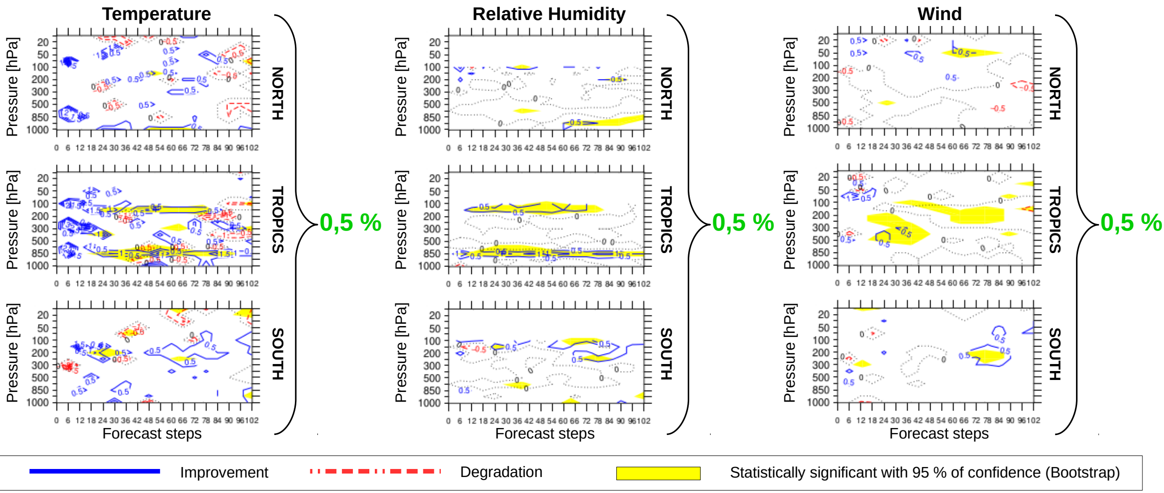

<u>Step 1</u>: Use of MOCAGE ozone fields in the observation operator

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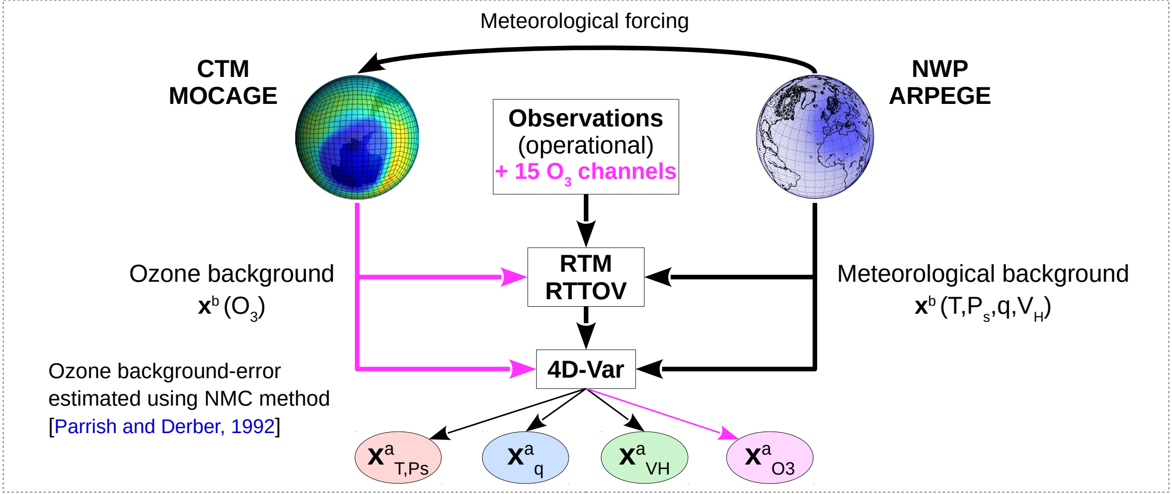
<u>Step 3</u>: Analyze ozone in addition to other variables



Step 3: Analyze ozone in addition to other variables

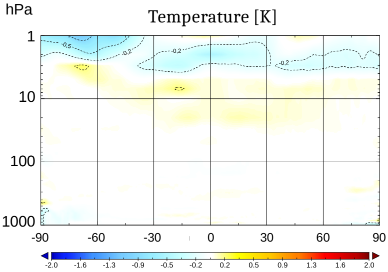
Impacts of ozone analysis on meteorological analyses?

- **<u>EXP15 experiment</u>**: (reference) use of MOCAGE ozone fields in the observation operator **+15 O_3 channels**

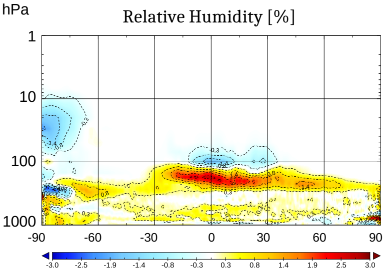
- **<u>EXP15O3 experiment</u>**: use of MOCAGE ozone fields in the observation operator **+15 O_3 channels + analyze ozone** in addition to other variables

- 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.

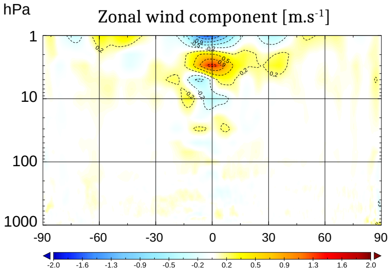
Temperature [K]



Relative Humidity [%]



Zonal wind component [$m.s^{-1}$]



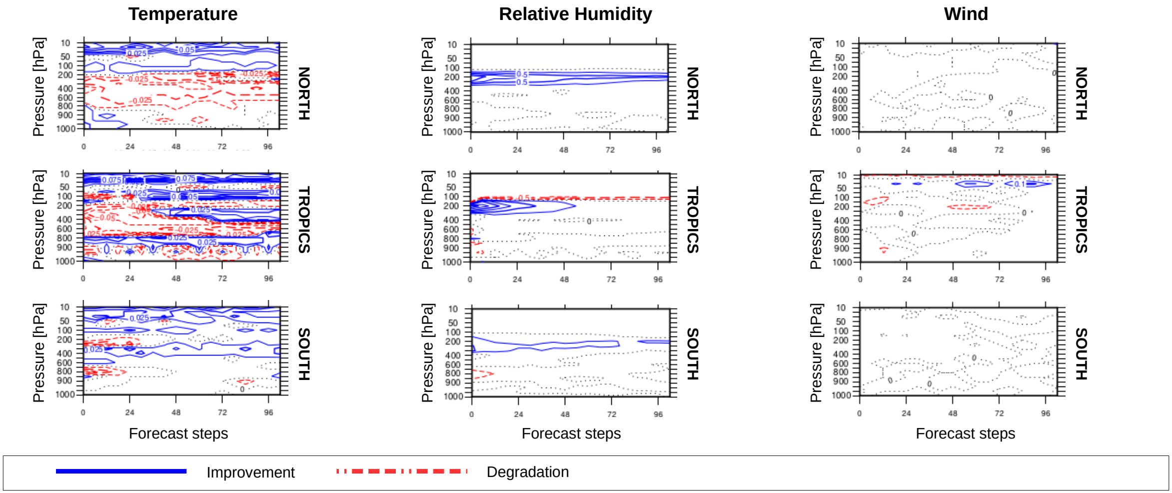
$\Delta T(x^a_{EXP} - x^a_{REF})$ → min : **- 1,1 K** max : **0,2 K**

$\Delta HR(x^a_{EXP} - x^a_{REF})$ → min : **- 2,8 %** max : **4,1 %**

$\Delta U(x^a_{EXP} - x^a_{REF})$ → min : **- 1,7 $m.s^{-1}$** max : **1,4 $m.s^{-1}$**

Impacts of ozone analysis on weather forecasts?

- Experience in progress but we can already look at the impacts on forecast **bias** between **EXP15O3** and **EXP15** from 12 to 30 July, 2016

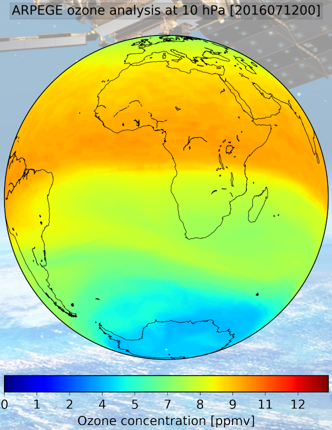


Conclusions and perspectives

- **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



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