The potential impact of ozone sensitive data from MTG-IRS

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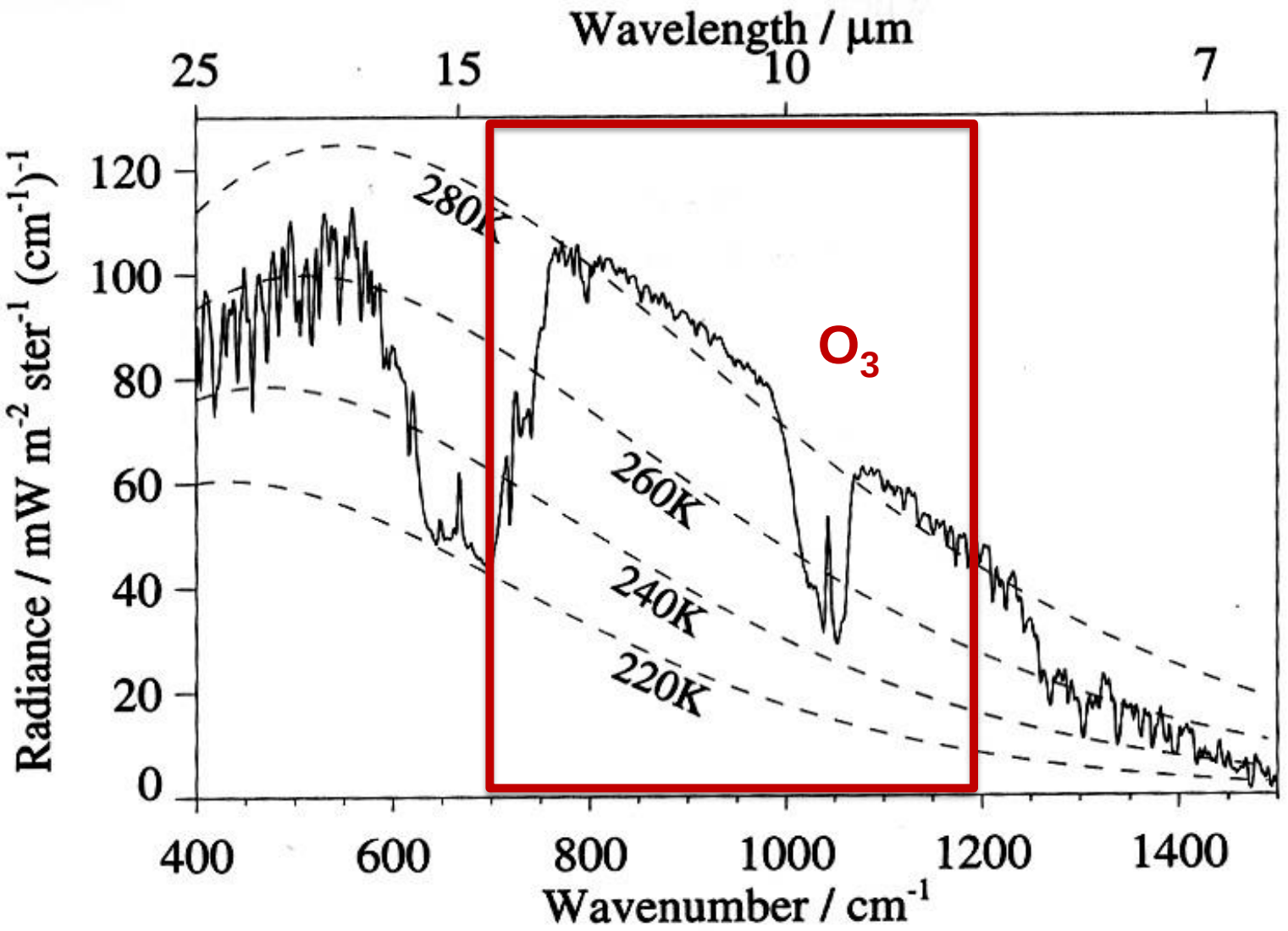
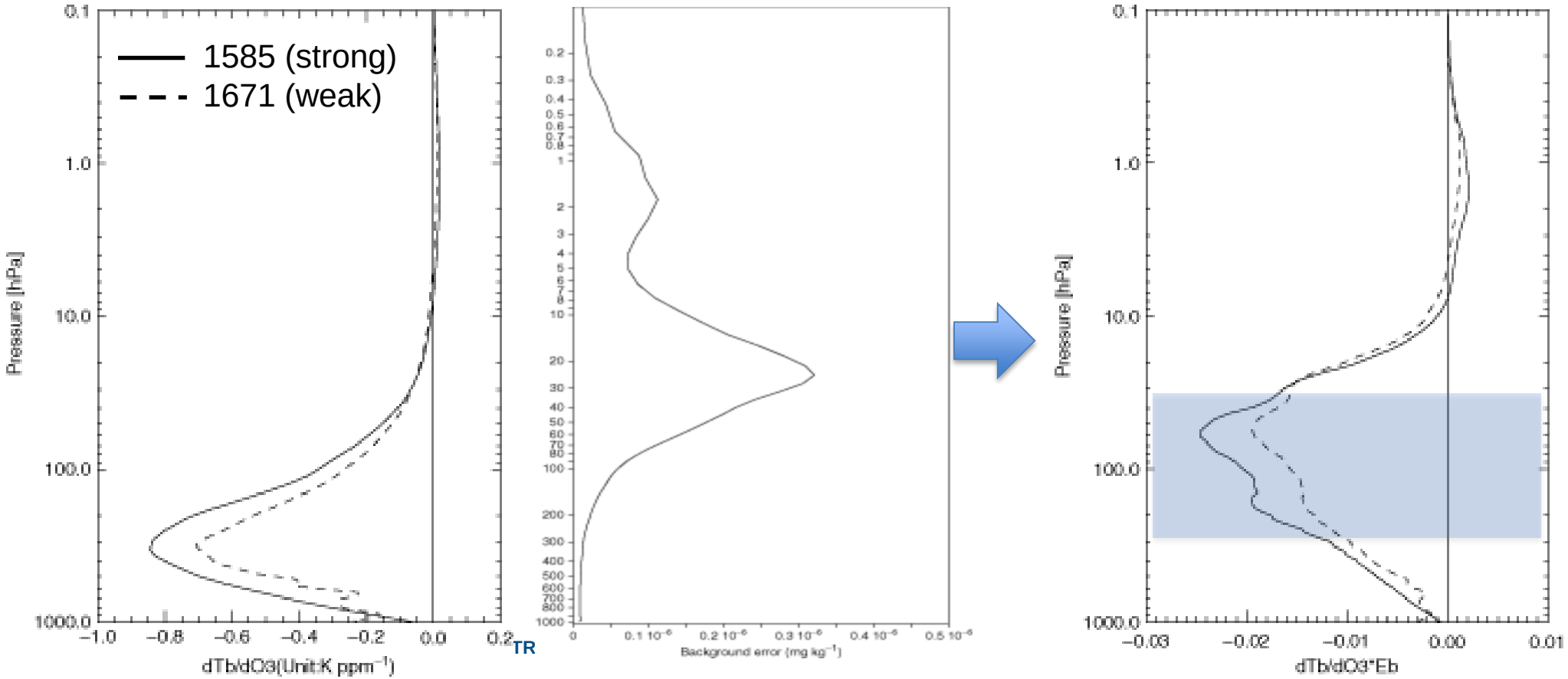
The MTG IRS Long-Wave InfraRed band



Can the IR O3-sensitive radiances (IR/O3) contribute to NWP?

IR/O3 radiance assimilation:

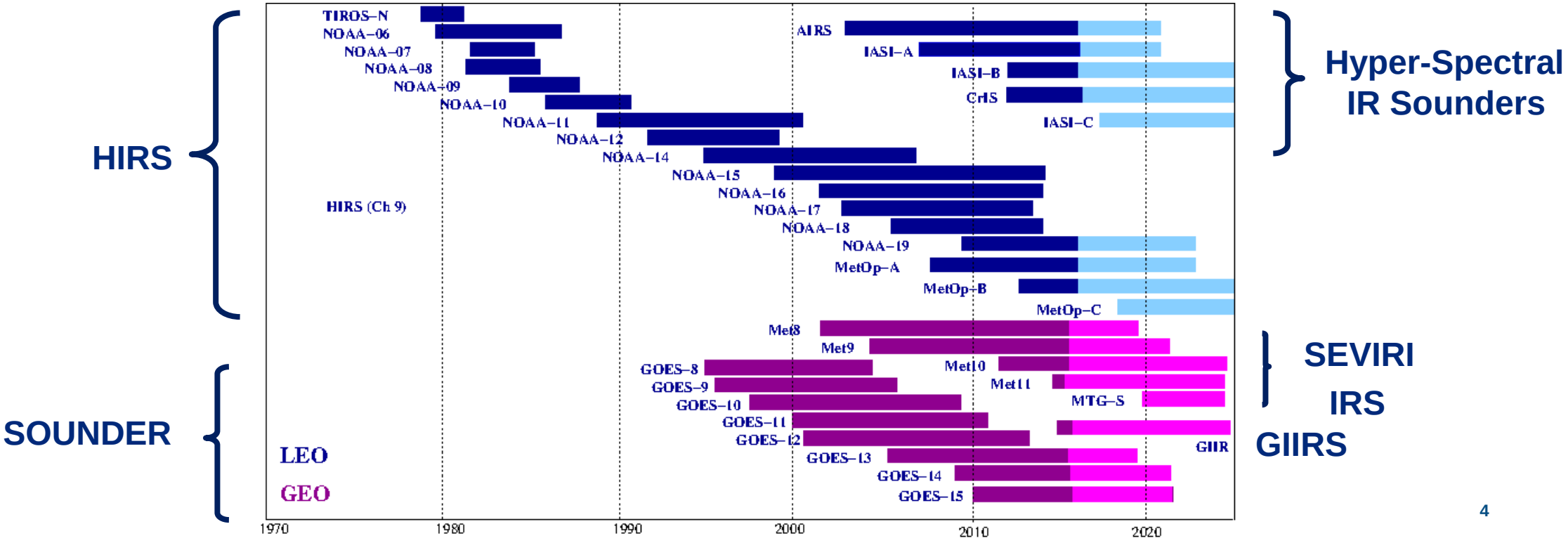
- The IR/O3 radiances are under-used in NWP (with many differences between centres):
  - ✗ High sensitivity to clouds and surface emission.
  - ✓ They show the highest sensitivity to the UTLS region



(Han and McNally, 2010)

IR/O3 radiance assimilation:

- The IR/O3 radiances are under-used in NWP (with many differences between centres):
  - High sensitivity to clouds and surface emission.
  - Uncertainties in radiative transfer knowledge of the ozone channels.
  - **The full potential of these radiances still has to be demonstrated**
  - ✓ They show the highest sensitivity to the UTLS region
  - ✓ Entering a data-rich period with long-term historical record of data.
  - ✓ **The full potential of these radiances still has to be demonstrated**



The ECMWF experience in assimilating IR/O3 channels

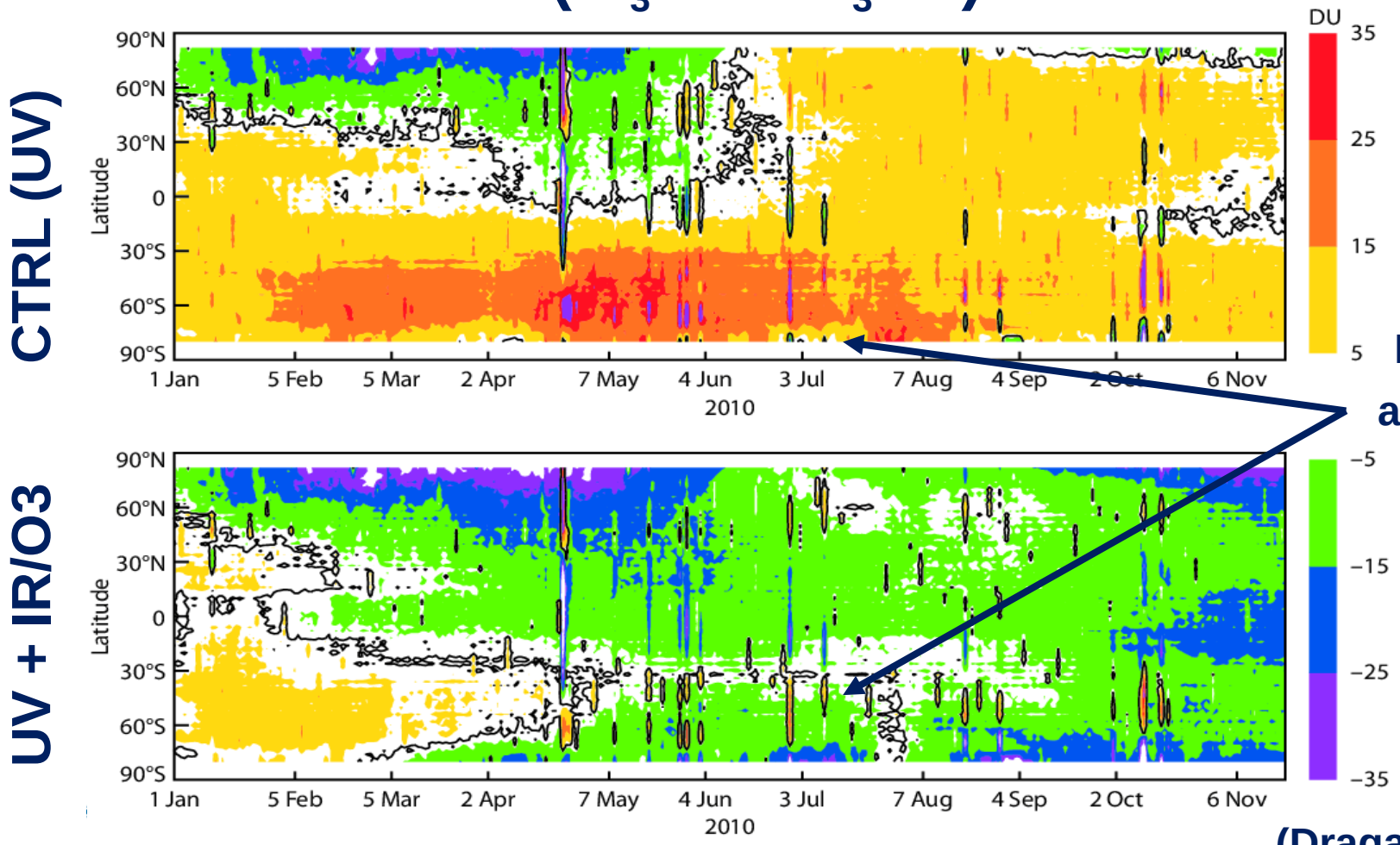
- ECMWF has been assimilating IR/O3 channels in its High Res suite since Nov 2011.
- IR/O3 data assimilation started with the use of HIRS (channel 9) and measurements by the hyper-spectral IR sounders AIRS, and IASI, extended to the NPP CrIS later. These instruments are all flown by LEO satellites.
- One of the reasons was to improve the IFS ozone analyses, which were only constrained by UV ozone retrievals (UV/O3) until Nov 2011.
  - UV/O3 have limited sensitivity in the troposphere and UTLS region.
  - UV/O3 present sampling limitations during night-time (or in the polar night conditions).

IR/O3

Impact of the IR/O3 assimilation on the O_3 analyses:

- Long data assimilation experiments were run over the Jan-Nov 2010 period using IASI, AIRS, HIRS:

$$\Sigma \left(O_3^{(MLS)} - O_3^{(An)} \right)$$

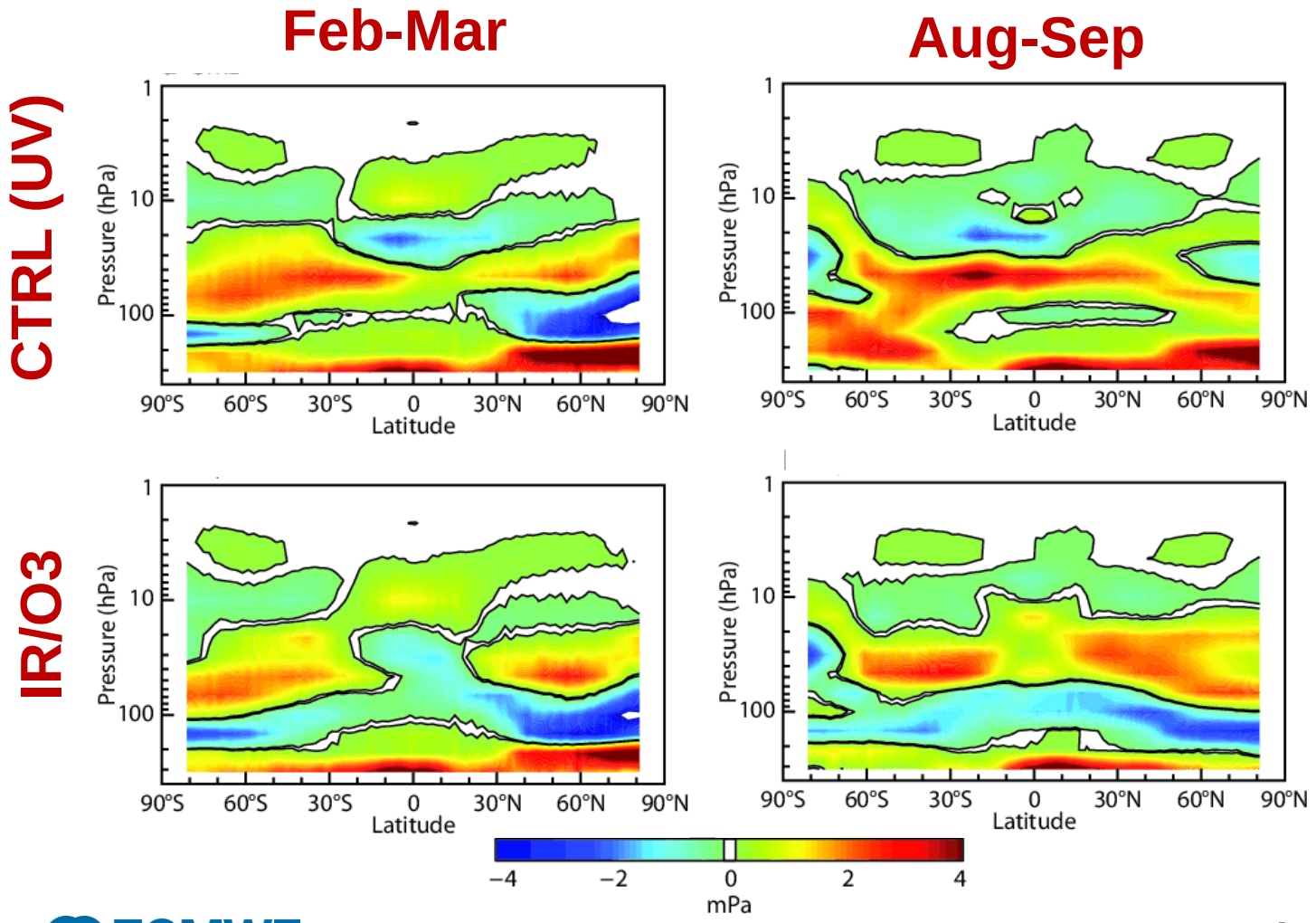


Large improvements at high latitudes in the winter-spring times

(Dragani and McNally,[6] 2013)

Impact of the IR/O3 assimilation on the O_3 analyses: MLS-An

- Long data assimilation experiments were run over the Jan-Nov 2010 period

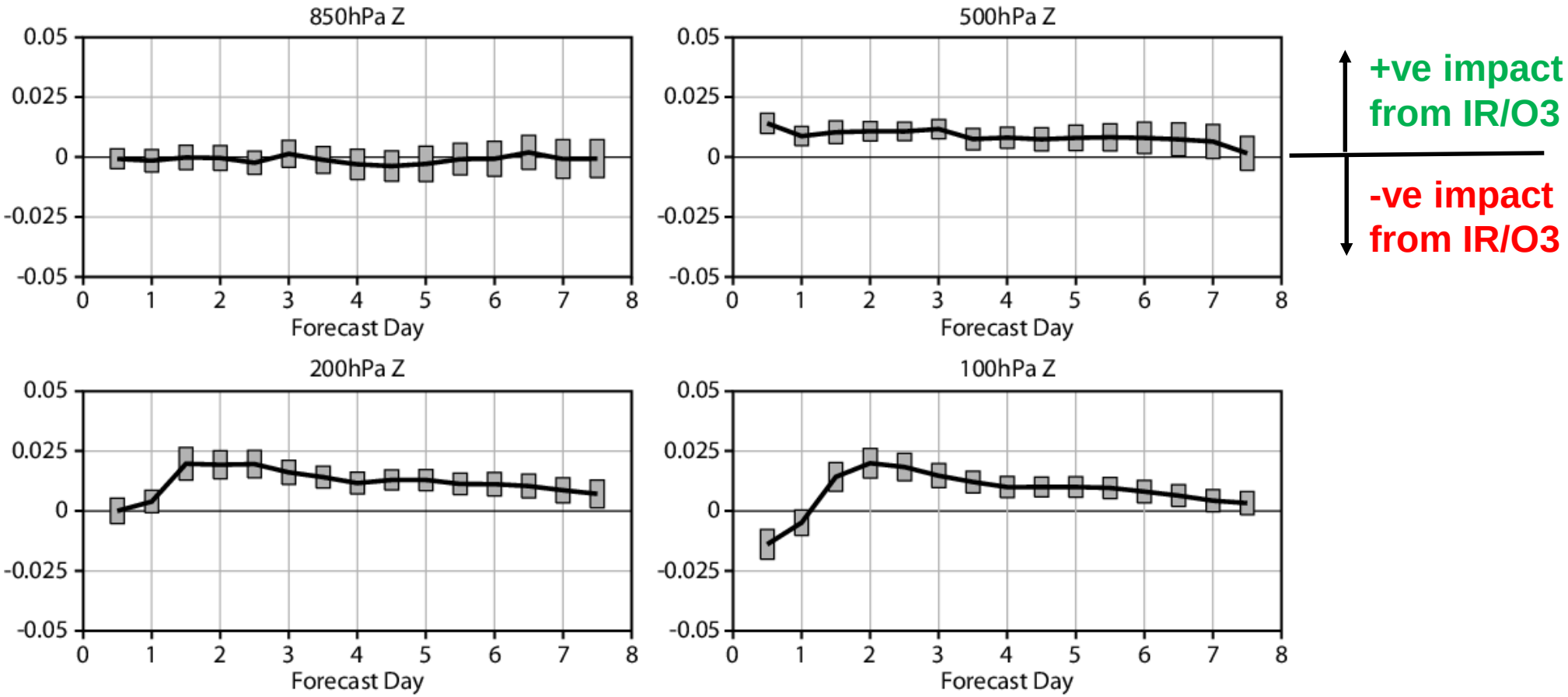


- **Redistribution of O3 in the extra-tropics in the summer hemisphere.**
- **Large improvements at high latitudes in the winter-spring times.**
- **Large improvements in the tropics. hemisphere.**

(Dragani and McNally, 2013)

Impact of the IR/O3 assimilation

RMSE(Z), CTRL-IR/O3



(1 Feb- 20 Nov 2010, population 293)

Mechanisms to impact other meteorological fields

- A 4D-Var data assimilation is an initial condition problem.
- It aims at finding a trajectory of model states associated to different variables - linked through the model governing equations and physical parametrizations - that best fits the available data.
- The solution is the $\mathbf{x}(t_0)$ that minimizes a cost function ➔ $\nabla J(\mathbf{x}(t_0)) = 0$
- The 4D-Var minimisation process can be regarded as a series of transformations of the observation departure, applying successively the operators: $\mathbf{R}^{-1}$, $\mathbf{H}^{T}$, $\mathbf{M}^{T}$, **B;**

$$\nabla J(\mathbf{x}(t)) = \mathbf{B}^{-1}[\mathbf{x}(t) - \mathbf{x}_b(t)] + \mathbf{M}^{T}\mathbf{H}^{T}\mathbf{R}^{-1}[HM(\mathbf{x}(t)) - \mathbf{y}]$$

Balance effect

Changes resulting from the use of background error correlations and balance relationships in 3D and 4D-Var (multivariate) data assimilation schemes.

Tracer effect

Changes in other variables resulting from the application of the dynamical equations.

Obs operator effect

Changes induced by the application of the observation operator, e.g. in the case of the assimilation of radiances that all use the same radiative transfer model.

Cycling effect

Any changes to a field **X** that occur in one analysis time window result in adjustments to other variables when the assimilation system is cycled over many time windows.

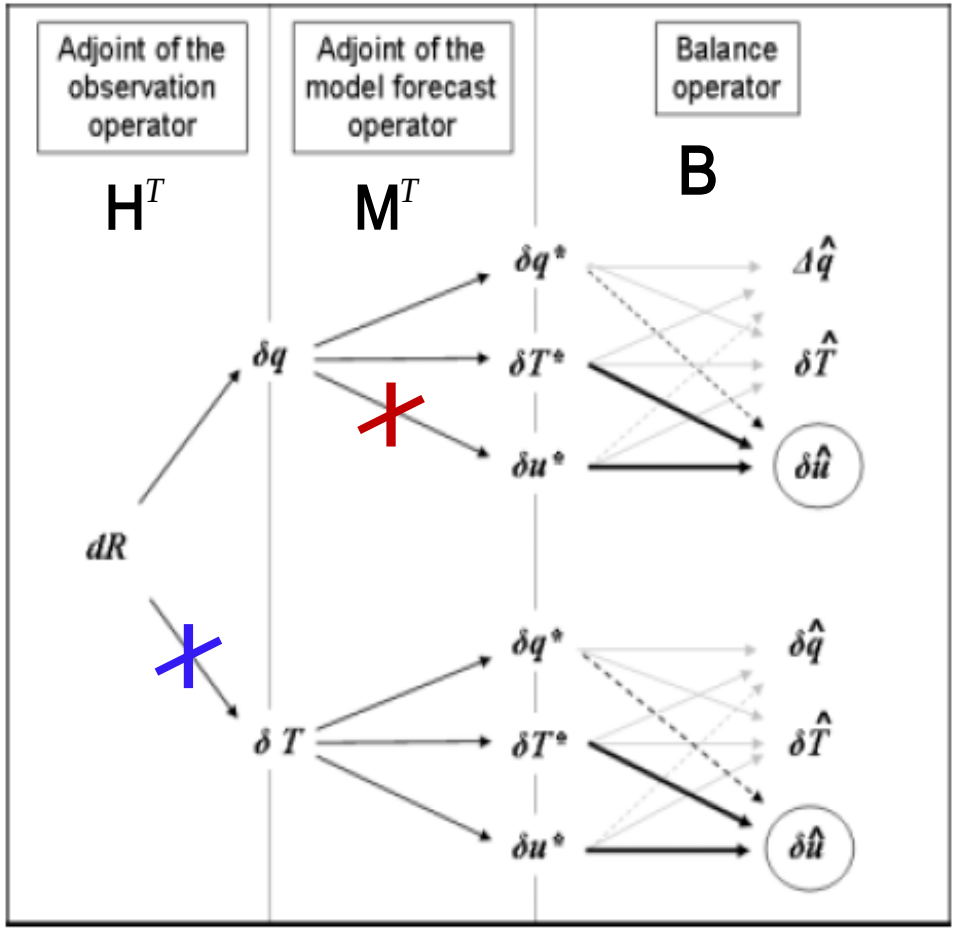
Case study 1: assimilation of humidity CSRs

- **Peubey and McNally (2009)** studied the impact of assimilating humidity-sensitive radiances from Clear-Sky Radiances (CSRs) on the ECMWF analyses and attempted to identify the dominant effect that produced changes in temperature and wind.

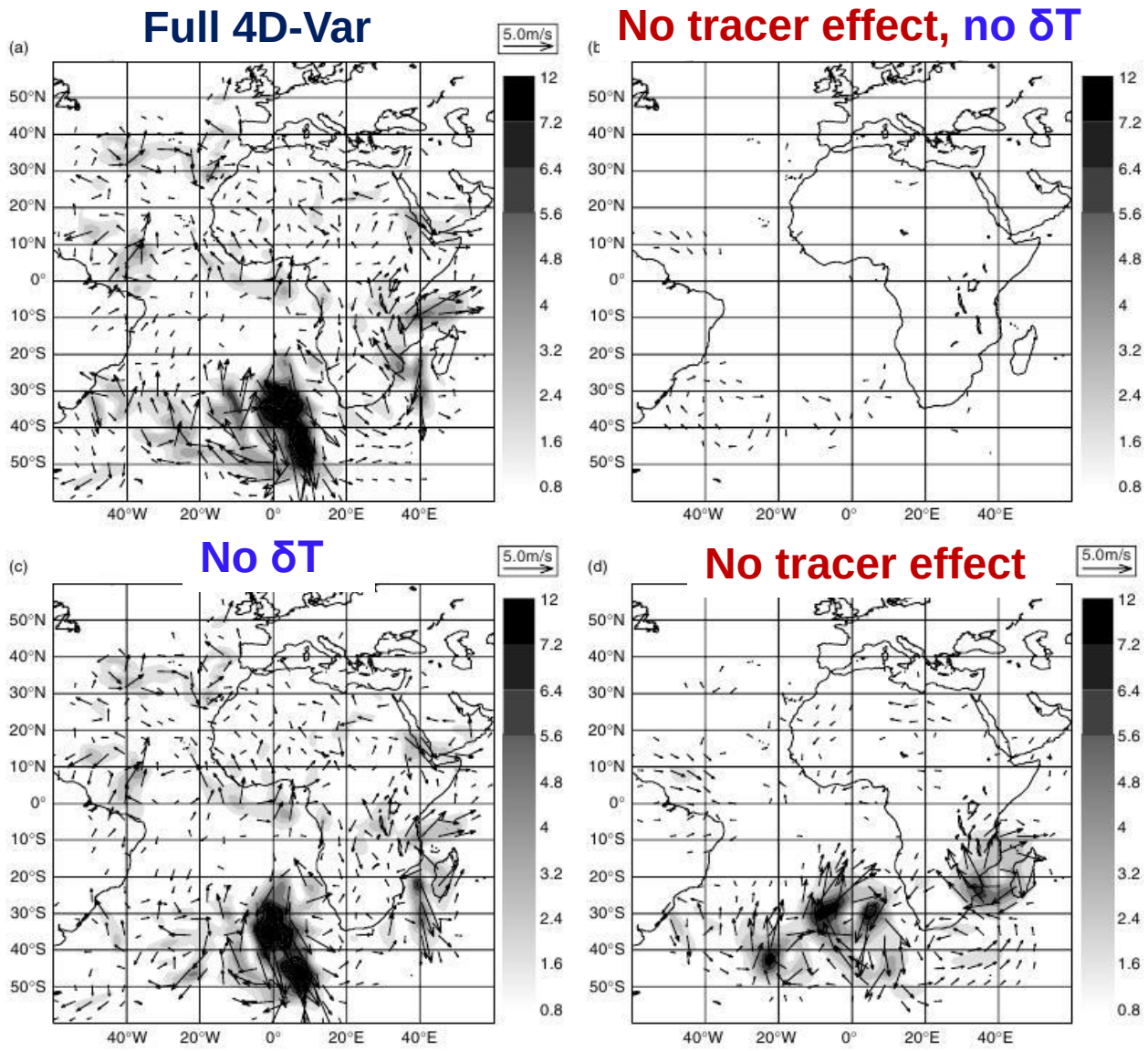
- Three experiments based on a reduced observing system were set-up after removing the contributions from:

  1. The obs operator ➔ **No δT**
  2. The tracer effect ➔ **No tracer effect**
  3. Both ➔ **No δT, No tracer effect**

- The impact was assessed against a baseline (=no satellite data) and the full 4D-Var, used as a control.



Impact of the humidity CSR assimilation on winds



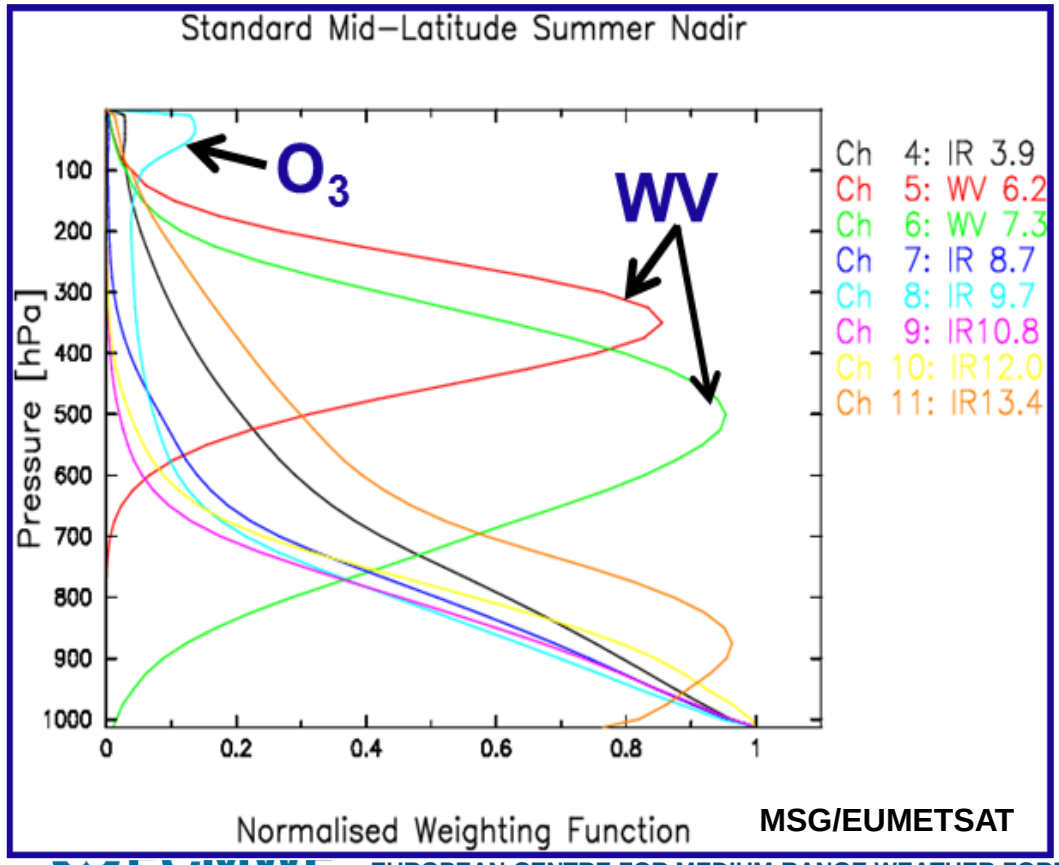
Wind speed and wind increments at 300hPa

The **tracer effect** is the dominant mechanism to produce wind at 300 hPa that are in better agreement with the full 4D-Var system.

(Peubey and McNally, 2009)

Case study 2: assimilation of SEVIRI IR/O3

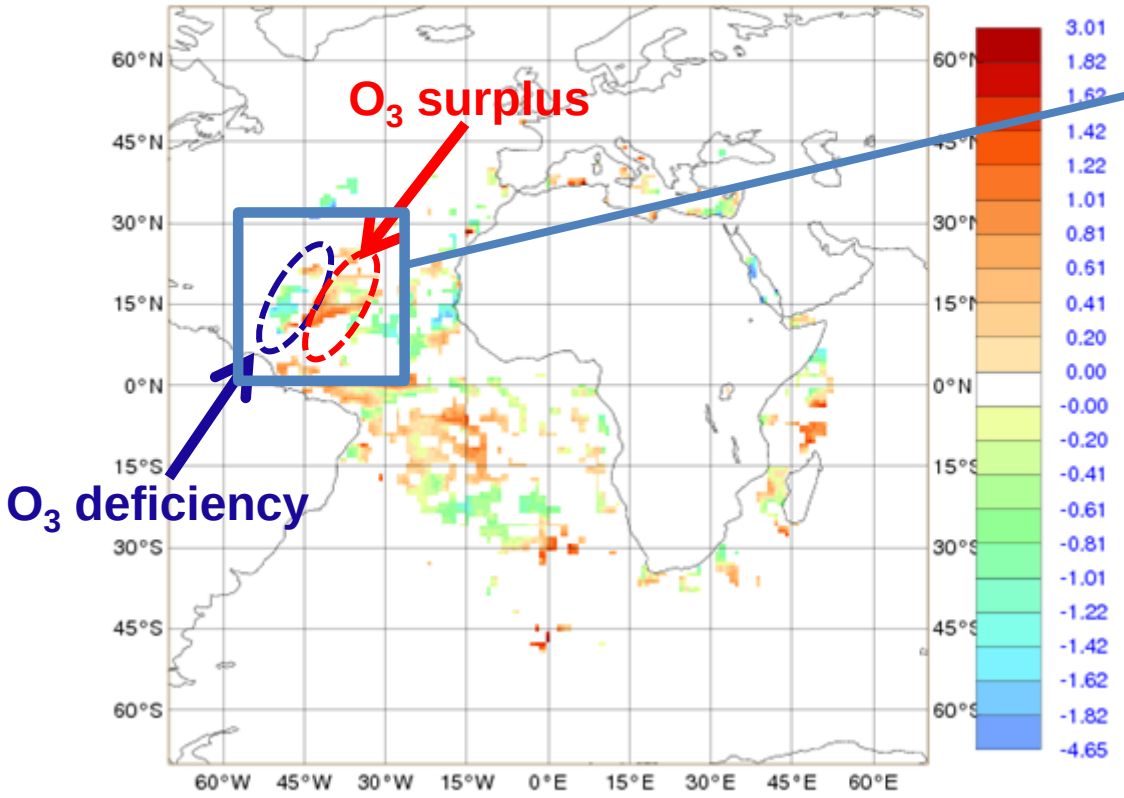
- **Lupu and McNally (2013)** applied the methodology used by Peubey and McNally (2009) to assess the tracer effect from the assimilation of the IR/O3 channel measured by the MSG SEVIRI instrument.



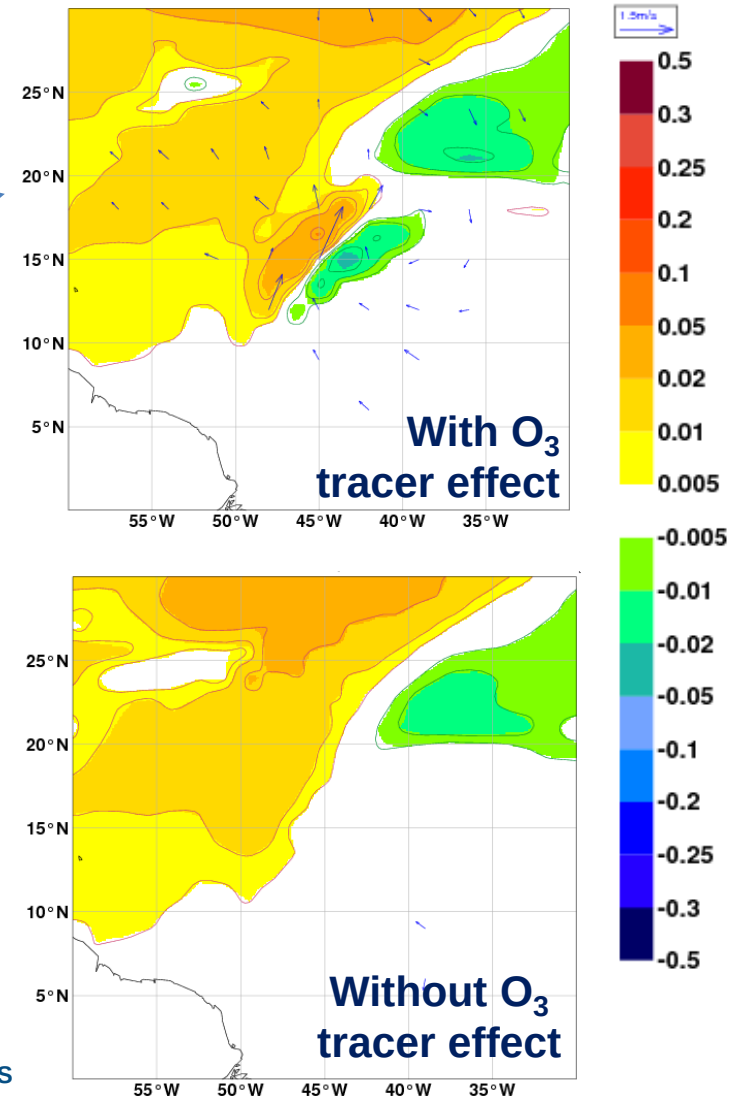
- This SEVIRI IR/O3 channel (9.7 μm) peaks in the upper-troposphere and lower-stratosphere.
- The hourly frequency make these obs. attractive to obtain 4D-Var based wind information over 12-h assimilation window.

Impact of the IR/O3 SEVIRI assimilation on O3 and winds

Mean O-B departures for IR/O_3 radiances after one 12-hour 4D-Var cycle

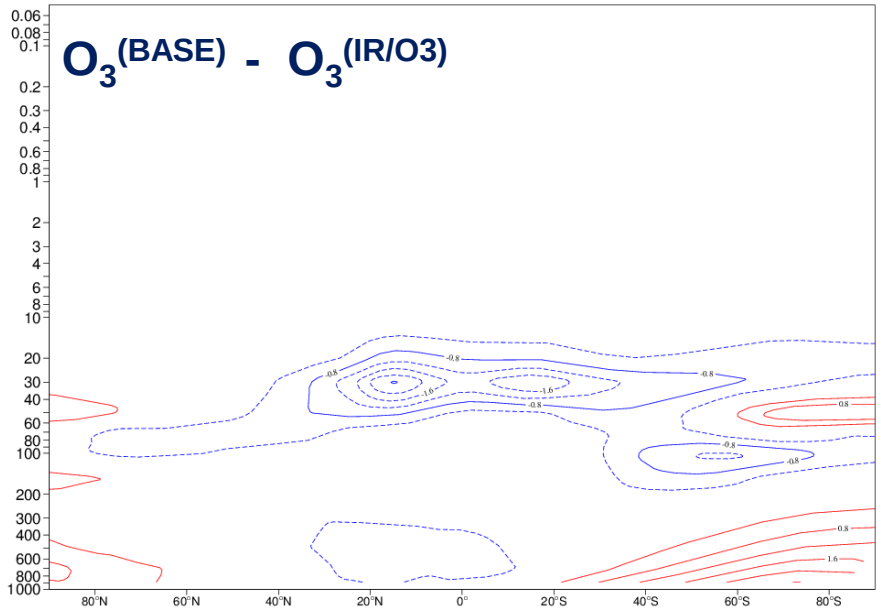


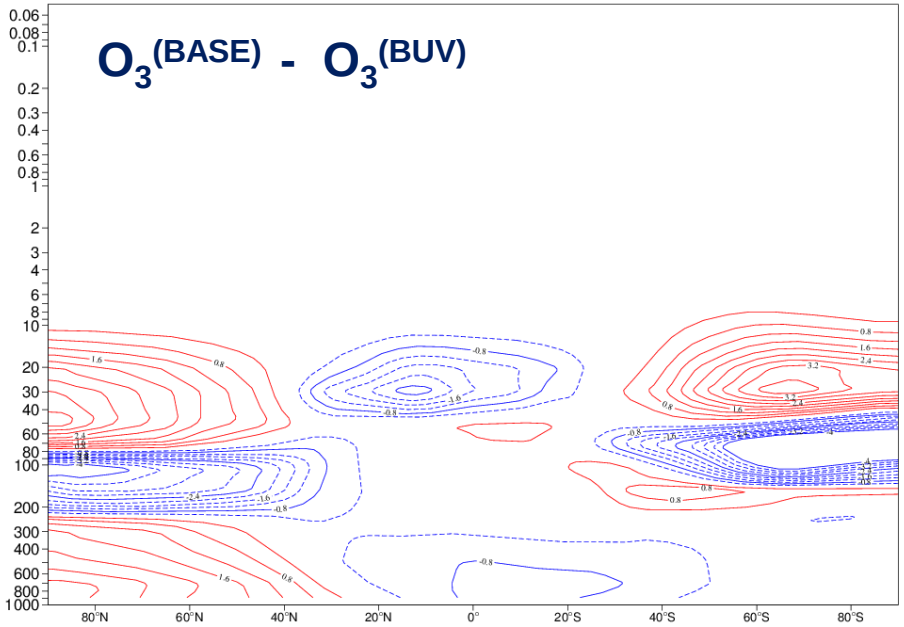
$O_3^{(IR/O3)} - O_3^{(Base)}$ [150hPa] (mmr)



Assimilation of SEVIRI IR/O3 with O3 tracer enabled

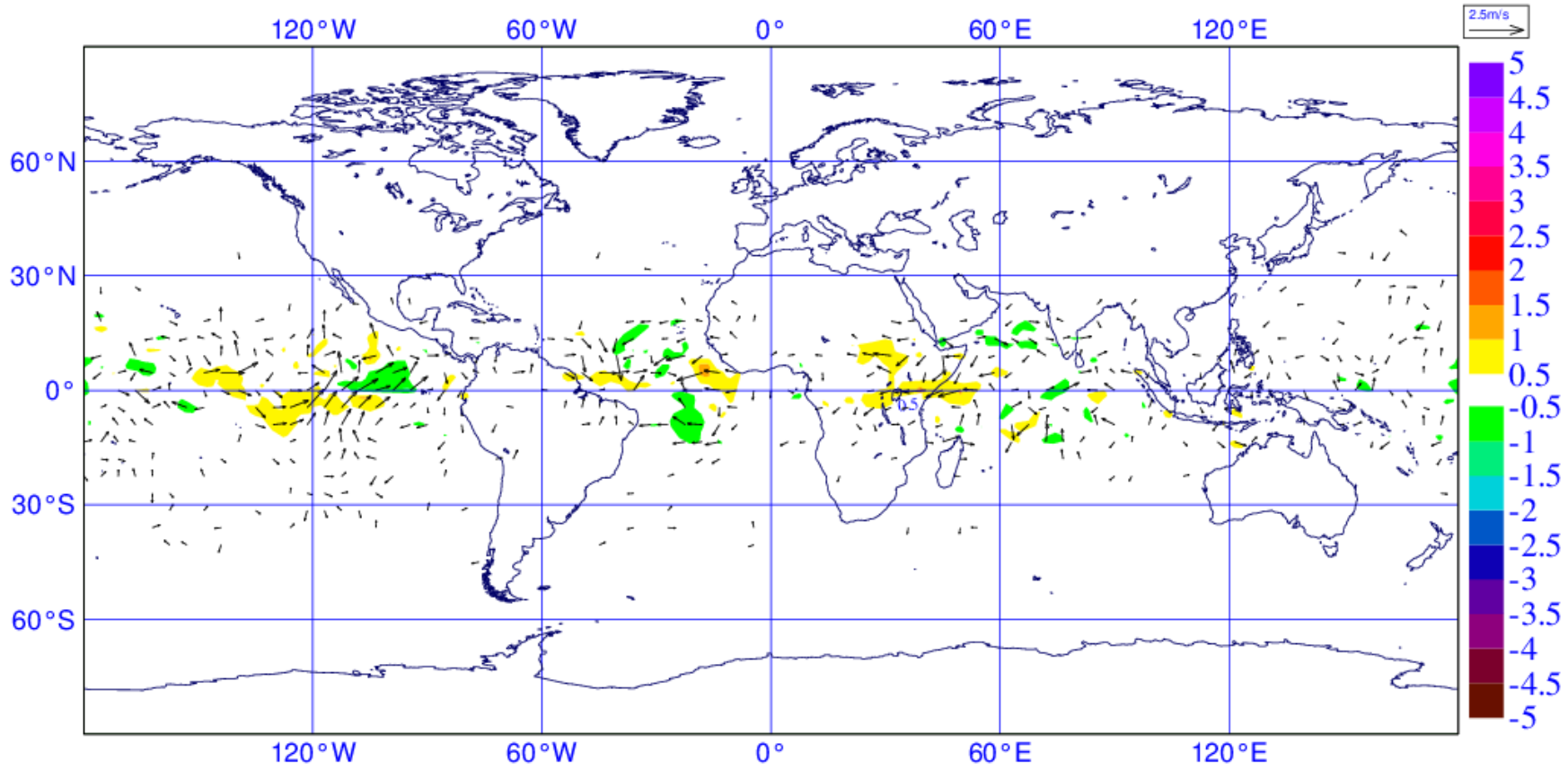
- The assimilation of the IR/O3 channel measured by the MSG SEVIRI instrument can impact the wind field.
- The following experiments were designed and run for the period May-Jun 2010:
  - **Base**: conventional observations + SCATT + GPSRO
  - **IR/O3**: Base + MET9 SEVIRI IR/O3 (over sea)
  - **BUV**: Base + BUV data (TCO3 from OMI and SCIAMACHY, and partial columns from NOAA-17/18 SBUV/2)
  - **BUV+MET9O3**: Base + BUV data + SEVIRI IR/O3 (over sea)





Mean wind analysis difference at 150 hPa:

$VW^{(IR/O3)} - VW^{(BASE)}$



Changes in the mean tropical winds are less than 1m/s

Wind analysis scores from SEVIRI observations

- Wind analysis errors are calculated as departures from the ECMWF operational analysis (T1279L91, full observing system), considered as the best estimate of the true wind field (as in Peubey and McNally, 2009):

$$RMSE_j = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\left(u_i - u_i^r\right)^2 + \left(v_i - v_i^r\right)^2\right]}$$

High Res analyses

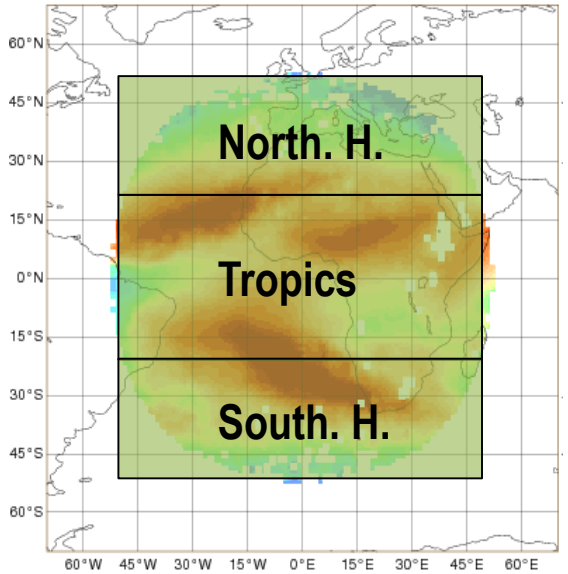
i^{th} grid-point

4D-Var cycle

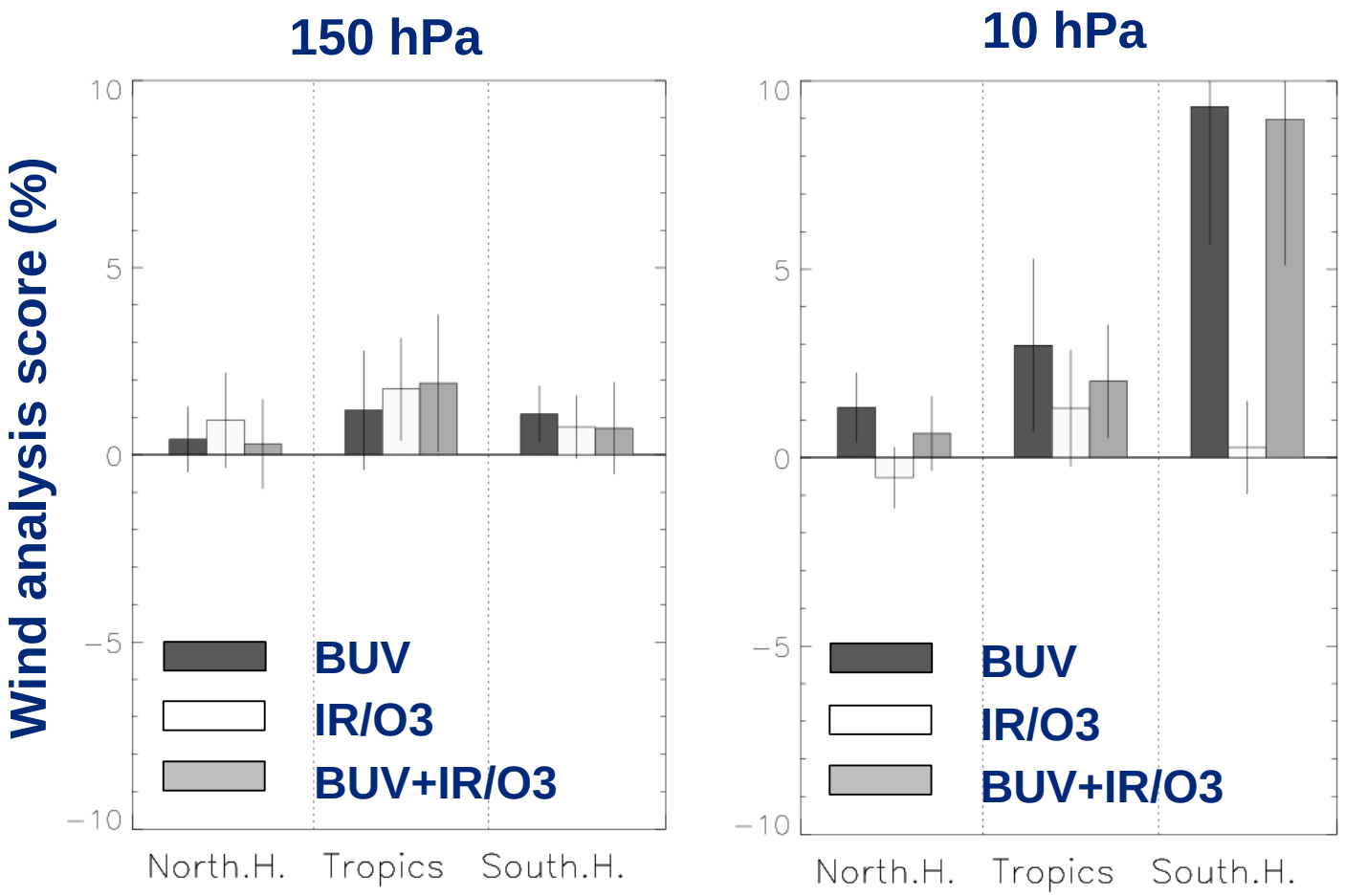
- For each experiment the analysis error is compared to that of Base to provide an "Wind analysis score":

$$\Delta\left(RMSE\right) = \frac{\sum_{j=1}^{m}\left(RMSE_j - RMSE_j^{Base}\right)}{\sum_{j=1}^{m} RMSE_j^{Base}}$$

$$\Delta\left(\overline{RMSE}\right) = \begin{cases} 1 \text{ (or 100\%)} \rightarrow \text{Exp = High Res} \\ 0 \rightarrow \text{Exp = Base} \end{cases}$$



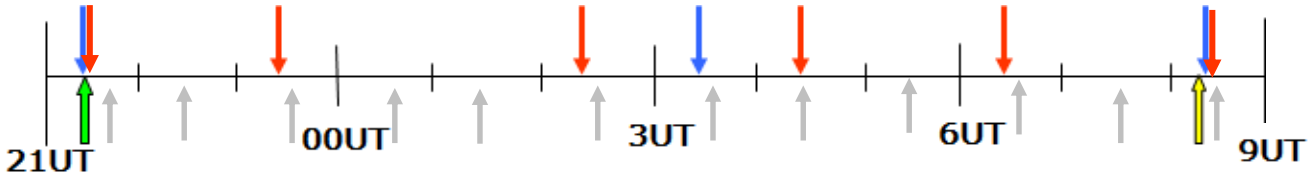
Wind analysis scores (May – Jun 2010)

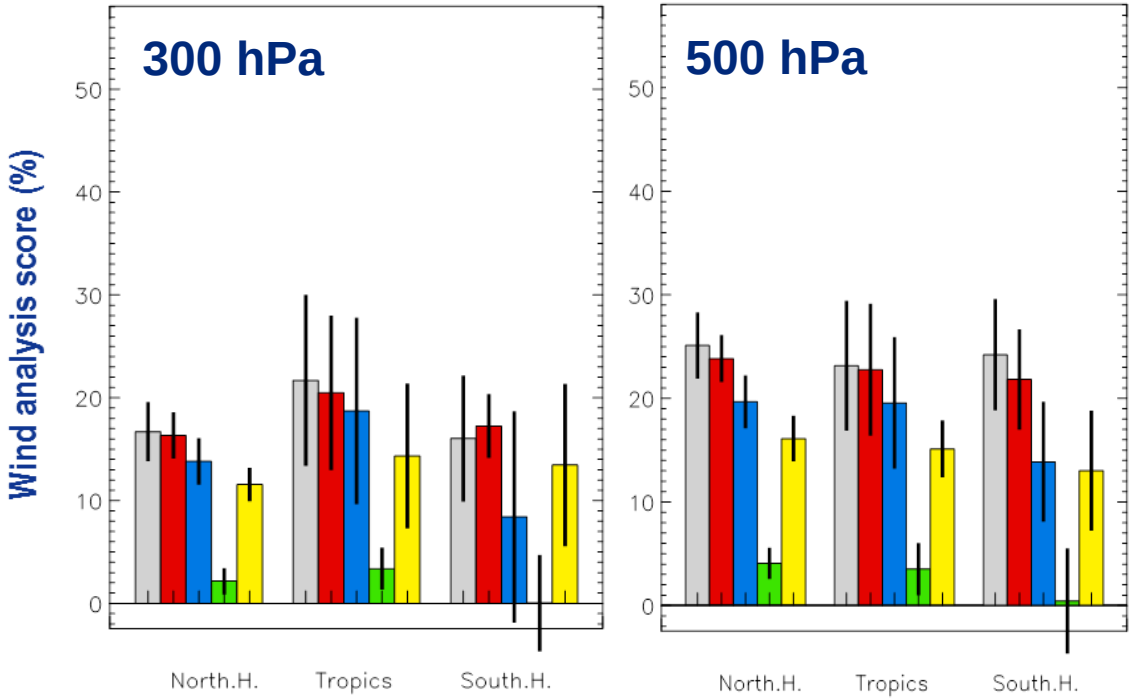


- The assimilation of the MET9 SEVIRI IR/O3 with O_3-tracing feature can improve the wind field (i.e. improve agreement with the full 4D-Var system) around 150 hPa in the tropics.
- At 150 hPa, the assimilation of BUV L2 O3 and IR/O3 can be used synergistically in the tropics.
- At 10 hPa, the impact on winds is mostly associated to the assimilation of the BUV L2 O3 data.

Sensitivity of the tracing mechanism to the frequency of the assimilated images

- The effect of the CSR image frequency has been examined with different numbers of CSR data per 12-h assimilation window:





12 images
6 images
3 images
1 image (beginning)
1 image (end)

(Peubey and McNally, 2009)

Conclusions

- The IR/O3 channels are generally under-used in NWP.
- By exploiting mechanisms like the 4D-Var tracing, the assimilation of the IR/O3 channels can infer information about the atmospheric flow, especially in the UTLS region.
- A study based on the assimilation of the CSR humidity channels showed that
  - **The higher the frequency** of the observations is within an assimilation window, **the more pronounced the impact on the winds** through the tracing mechanism results.
  - **Observations measured at** a time close to **the end of the assimilation window produce a larger impact than those** measured **at** a time close to **the beginning** of it.
- Possible limitations are:
  - the sensitivity to clouds and surface emissivity ← they need to be taken into account and modelled accurately to properly get the signal.
  - Possible Impact in regions of the atmosphere with lower sensitivity (tail of Jacobians) → synergy with height-resolved O3 observations from other sources (e.g. UV)
- The wealth of IR/O3 data measured by IR sounders, and their long-term availability makes it an attractive source of information for both NWP and reanalysis applications

References:

- Dragani, R. and McNally, A. P. (2013). Operational assimilation of ozone-sensitive infrared radiances at ECMWF. *Q. J. R. Meteorol. Soc*., **139**, 2068–2080, doi: 10.1002/qj.2106.
- Han W. and McNally, A. P. (2010). The 4D-Var assimilation of ozone-sensitive infrared radiances measured by IASI. *Q. J. R. Meteorol. Soc*., **139**, 2025–2037, doi: 10.1002/qj.708.
- Lupu, C. and McNally (2013). Wind tracing with ozone-sensitive radiances from SEVIRI, EUMETSAT/ECMWF Fellowship Programme, Research Report No 31.
- Peubey, C. and McNally, A. P. (2009). Characterization of the impact of geostationary clear-sky radiances on wind analyses in a 4D-Var context. *Q. J. R. Meteorol. Soc*., **135**, 1865–1876, doi: 10.1002/qj.500.