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MICROCARB: THREE-DIMENSIONAL MODELING OF THE $O_2(^1\Delta)$ DAYGLOW AND IMPLICATIONS FOR OZONE IN THE MIDDLE ATMOSPHERE

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Context

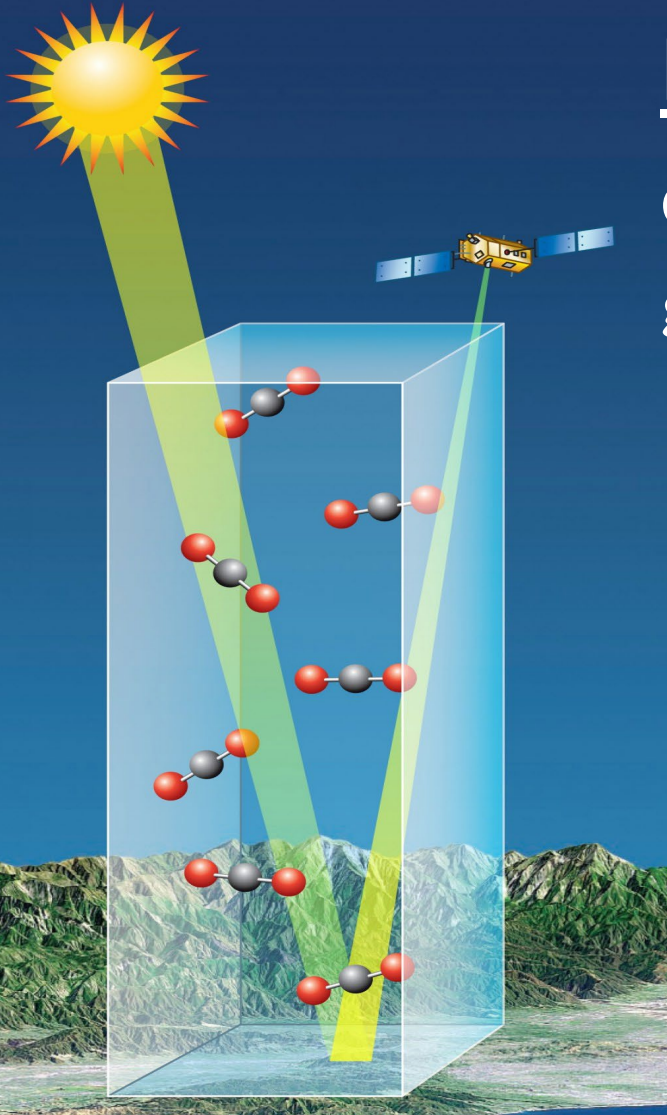
MicroCarb (launch planned for 2025)

Objective: to map, on a global scale, the sources and sinks of the greenhouse gas CO_2 .

$$r_{\text{CO}_2} = \frac{\text{CO}_2 \text{ column}}{\text{O}_2 \text{ column} / 0,21}$$

Up to now, the way of measuring the O_2 column by satellite can induce significant errors in the CO_2 concentration

MicroCarb innovation: Addition of a new way of measuring the O_2 column to obtain more accurate CO_2 measurements.



Objective/ Methods



Unfortunately, this new method is hindered / contaminated, by an emission called $O_2(^1\Delta)$ DAYGLOW



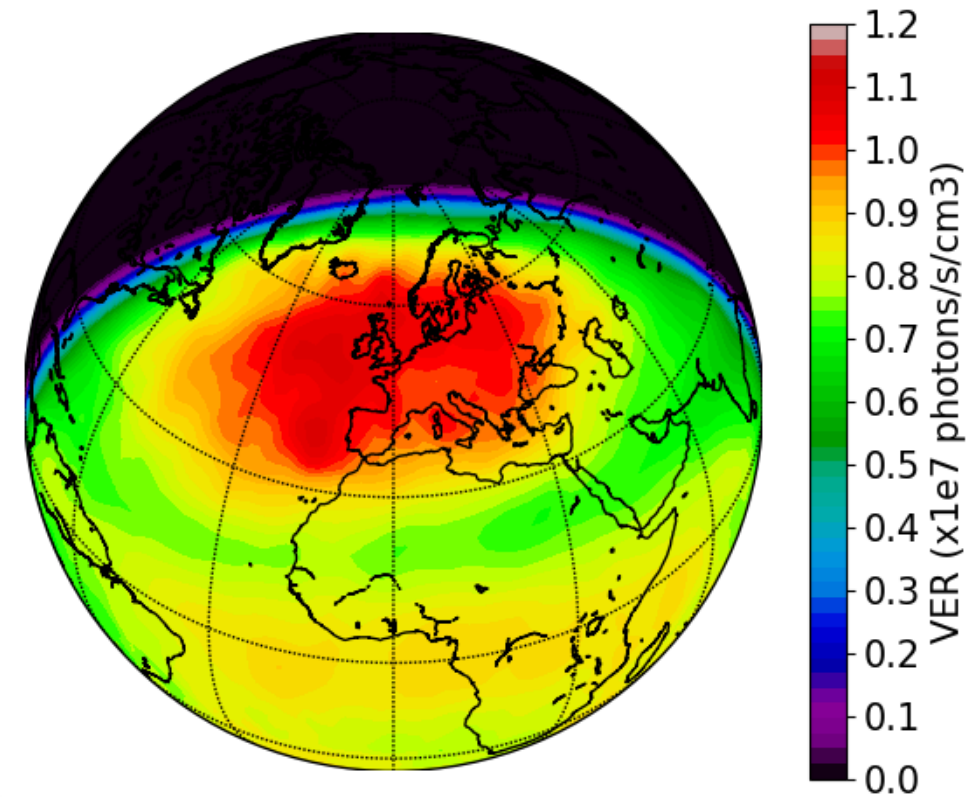
Our objective is to improve the quantitative understanding and the knowledge of the $O_2(^1\Delta)$ dayglow to eliminate it in MicroCarb observations.



We have developed a model of this DAYGLOW in an advanced chemical – transport model: REPROBUS

REPROBUS will provide priori quantitative information on the $O_2(^1\Delta)$ dayglow for MicroCarb mission in order to eliminate this contamination in the observations.

REPROBUS
 $O_2(\Delta)$ dayglow VER at 0.9 hPa



Results

We evaluated our developed model in comparison to satellite observations



- REPROBUS presents an **dayglow deficit** compared to observations
- We found that this deficit is due to an **ozone deficit** which is historical in transport chemistry models

We managed to resolve this historical ozone deficit and consequently the dayglow deficit, thanks to temperature



MicroCarb: Three-dimensional modelling of the $O_2(^1\Delta)$ dayglow and implications for ozone in the middle atmosphere

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I- The $O_2(^1\Delta)$ dayglow measured by The MicroCarb Mission

The MicroCarb is a future space mission of the French national center for space studies (CNES). The launch is planned for 2024 in a sun-synchronous orbit at 650 km. The objective of MicroCarb is to map, on a global scale, the seasonal and diurnal variations of the greenhouse gas CO_2 .

Traditionally, satellites (OCO2, SCIAMACHY, COSE-1) measure the mean CO_2 mixing ratio (χ_{CO_2}) from the CO2 and O2 channels.

When the CO2 column is measured in the 1.6 and 2.1 μm absorption bands and the O2 column in the 0.76 μm absorption band.

However, these O2 and CO_2 absorption bands are spectrally distant. This results in significant uncertainties in the mixing ratio of CO_2 , due to the strong spectral properties of the atmosphere that may lead to different radiance profiles for photons.

The innovation for the MicroCarb relative to other satellites of this O2 absorption band centered at 0.76 μm comes from the CO2 bands.

Problem: In this band also occurs the $O_2(^1\Delta)$ emission at 0.77 μm (see next slide) by the mean photolysis in the upper atmosphere and re-emission.

The objective of this slide is to improve the quantitative understanding and the knowledge of the $O_2(^1\Delta)$ dayglow by an advanced chemical transport model.

II- Modelling of the $O_2(^1\Delta)$ dayglow with the REPROBUS model

REPROBUS is a Chemistry-Transport model (Jougllet et al., 2010) with a horizontal resolution of $2^\circ \times 2^\circ$ that extends from the ground to 500 km to about 50 km in altitude.

- The model calculates the dynamics of 60 species by means of a composition set of 120 gas phase reactions and 63 photoionization rates. Heterogeneous processes are also taken into account.
- The winds and temperature used by REPROBUS are from the ECMWF analysis.
- The chemical rate constants and absorption cross-sections are in general drawn from the JPL 04 compilation (Sander et al., 2006).

We implemented in REPROBUS all photochemical processes relative to the $O_2(^1\Delta)$ dayglow as shown in Fig.1.

Reproduction of $O_2(^1\Delta)$ dayglow intensity by the photochemical model.

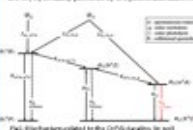


Figure 1: Chemical reactions leading to the $O_2(^1\Delta)$ dayglow. The diagram shows the conversion of $O_2(^1\Delta)$ to $O_2(^1\Sigma)$ and back, and the production of $O_2(^1\Delta)$ from $O_2(^1\Sigma)$ via the reaction $O_2(^1\Sigma) + h\nu \rightarrow O_2(^1\Delta)$. The diagram also shows the reaction $O_2(^1\Delta) + O_2 \rightarrow O_2(^1\Sigma) + O_2$.

Figure 2: $O_2(^1\Delta)$ dayglow intensity (in Rayleigh) as a function of altitude (in km) and latitude (in degrees). The plot shows a peak in intensity around 100 km altitude, with higher values at higher latitudes.

III- Comparison to observations

III-1 SABER measurements - Integrated $O_2(^1\Delta)$ dayglow

$O_2(^1\Delta)$ integrated dayglow, March 2007, 344.1 LT

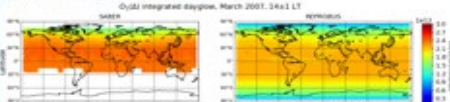


Figure 3: Comparison of integrated $O_2(^1\Delta)$ dayglow between SABER (left) and REPROBUS (right) for March 2007 at 344.1 LT. The plots show intensity in Rayleigh as a function of latitude and longitude.

Figure 4: Integrated $O_2(^1\Delta)$ dayglow between 2000 km and 100 km measured by SABER (left) in March 2007 at 344.1 LT, and calculated by the REPROBUS model (right).

Figure 5: Relative difference between SABER and REPROBUS for the integrated $O_2(^1\Delta)$ dayglow. The plot shows a positive bias in the mid-altitude range (around 100-200 km) and a negative bias at higher altitudes.

III-2 SABER measurements - $O_2(^1\Delta)$ vertical profile

July 2008 - March 2009 - 0800 UT (UTC+02:00)

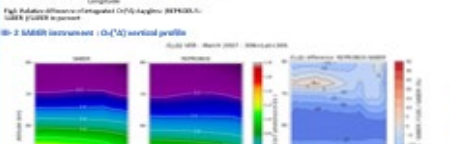


Figure 6: Vertical profiles of $O_2(^1\Delta)$ dayglow from SABER (left) and REPROBUS (right) for July 2008 - March 2009 at 0800 UT. The plots show intensity in Rayleigh as a function of altitude (in km).

Figure 7: Relative difference between SABER and REPROBUS for the vertical profile of $O_2(^1\Delta)$ dayglow. The plot shows a positive bias in the mid-altitude range (around 100-200 km) and a negative bias at higher altitudes.

IV- Efforts to improve the agreement between the model and observations

IV-1 Effect of temperature in the atmosphere

The vertical profiles of the temperature used by REPROBUS are based on the ECMWF operational analysis. We investigated the effect of temperature in the model at the mesosphere with a new simulation based by ECMWF analysis (Blanchet et al., 2020). ECMWF based on a decade of developments in mesospheric chemistry, time dynamics and data assimilation (Blanchet et al., 2020).

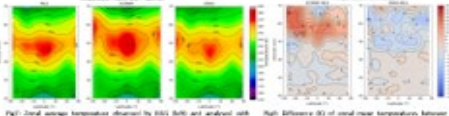


Figure 8: Comparison of $O_2(^1\Delta)$ dayglow intensity with ECMWF operational analysis (left) and ECMWF reanalysis (right) for March 2007 at 344.1 LT. The plots show intensity in Rayleigh as a function of latitude and longitude.

Figure 9: Relative difference between ECMWF operational analysis (left) and ECMWF reanalysis (right) for $O_2(^1\Delta)$ dayglow. The plot shows a positive bias in the mid-altitude range (around 100-200 km) and a negative bias at higher altitudes.

IV-2 Investigation of the mesosphere $O_2(^1\Delta)$ deficit at 48-65 km

To try to reduce the ozone deficit at around 50 km, we introduced in the model a new source of ozone coming from the "chemically depleted region" ($4^\circ E - 4^\circ W$) as described by Jougllet et al. (2014).

$$O_3 + h\nu \rightarrow O_2(^1\Delta) + O(^1D)$$

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$$O_3 + h\nu \rightarrow O_2(^1\Delta) + O(^1D)$$

Figure 10: Relative difference between REPROBUS and SABER for the vertical profile of $O_2(^1\Delta)$ dayglow. The plot shows a positive bias in the mid-altitude range (around 100-200 km) and a negative bias at higher altitudes.

V- Conclusion

- As preparation for MicroCarb, we simulated 3D vertical profiles of the $O_2(^1\Delta)$ dayglow in the atmosphere (mesosphere).
- The modelled $O_2(^1\Delta)$ dayglow is in good agreement with the modelled $O_2(^1\Delta)$ dayglow in the atmosphere (mesosphere).
- The agreement is in a lack of $O_2(^1\Delta)$ in the mesosphere (50-100 km) where the modelled $O_2(^1\Delta)$ dayglow is very variable in time and space.
- The ECMWF reanalysis is in better agreement with the observed temperature, which is critical for the modelled $O_2(^1\Delta)$ dayglow.
- The "chemically depleted region" ($4^\circ E - 4^\circ W$) at 50 km altitude in the model, but not included by adding the proposed ozone source of Jougllet et al. (2014) at 50 km altitude in the model, but not included by adding the proposed ozone source of Jougllet et al. (2014) at 50 km altitude in the model.

VI- References

Blanchet, J. L., Marchandise, C., Lefèvre, F., Hauchecorne, A., Jougllet, D., 2020. <https://doi.org/10.1029/2019JD013111>

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ACCURATE CLIMATOLOGY OF THE $O_2(^1\Delta)$ DAYGLOW FOR MICROCARB MISSION