

MOMENTUM: MesOscale Modelling for ExoMars TGO/NOMAD To Understand gravity waves in the Martian atmosphere

## Context

Studying the present Martian climate provides insights into both its past atmospheric evolution and broader planetary processes. Observations and climate models are closely interlinked: models aid data retrieval, while observations constrain and validate simulations. Discrepancies between the two can identify missing or poorly represented processes. Since observations are often limited in space and time, models fill critical gaps, requiring accurate representation of known atmospheric features. Model resolution, constrained by computational power, limits the explicit treatment of small-scale dynamics, which must be parameterised. Among these, gravity waves—generated by topography or weather systems—play a key role in transferring energy and momentum to the upper atmosphere. Despite their relatively small spatial scale, they exert significant thermal and dynamical forcing, making their inclusion in Martian climate models essential for accurate simulation of the planet's atmospheric system.

## Objectives

The goal of the MOMENTUM project is to gain a better understanding of the impact of gravity waves on large scale circulation and to improve Global Climate Models (GCMs) to more accurately represent these effects in climate simulations. By using observations from the Nadir and Occultation for MArS Discovery (NOMAD) instrument onboard the ExoMars Trace Gas Orbiter (TGO), we can look for signatures of gravity waves and attempt to quantify their potential effects on the mean flow. These observed effects can then be compared to those calculated in the GCM by the gravity wave drag (GWD) parameterisations, which are not well constrained. There are several parameters that can be adjusted in these schemes, and with the observations, we can work towards a more realistic simulation. The direct effect of gravity waves on the simulated wind fields can modify the overall global circulation and have secondary effects on the thermal structure in the upper atmosphere. The region where waves are thought to break is a key transition zone between the upper and lower atmosphere, so this is an important process to represent well in a GCM.

## Conclusions

We see gravity waves frequently in the TGO/NOMAD observations and are building a climatology of activity over several Martian years. We see some differences in sunrise and sunset behaviour, particularly in the southern hemisphere winter.

By analysing the temperatures and wave activity observed by NOMAD, we have been able to tune the GEM-Mars GCM parameterisations of gravity wave drag to better match the observations and provide more realistic simulations.

This project has enabled us to have high-resolution simulations of the Martian atmosphere, and more simulations are planned to understand better the seasonal and diurnal differences in wave activity.

We have found several examples of cold pockets likely due to wave activity where there is potential for the formation of CO<sub>2</sub> ice clouds. This provides the opportunity to study this further and improve the model implementation of these types of clouds.

This project has also allowed for other improvements to the model, such as the implementation of a better formulation for the radiative transfer in non-local thermodynamic equilibrium conditions.

## Keywords

Mars atmosphere, gravity waves, Global Climate Modelling, parameterisations