# SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

**Reporting year** ……2017……………………………….……

**Project Title:** ……Effects of a stochastic gravity wave parameterization on the simulation of stratospheric dynamics……………………………….……

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**Computer Project Account:** ……SPITCHCG……………………………….……

**Principal Investigator(s):** ……Chiara Cagnazzo, Federico Serva .……

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**Affiliation:** …ISAC/CNR……………………………….……

**Name of ECMWF scientist(s) collaborating to the project** (if applicable) ……………………………………………………….…… // ……………………………………………………….……

**Start date of the project:** …2016……………………………………………….……

**Expected end date:** …2019……………………………………………….……

**Computer resources allocated/used for the current year and the previous one**
(if applicable)
Please answer for all project resources

| | | Previous year | | Current year | |
|---|---|---|---|---|---|
| | | Allocated | Used | Allocated | Used |
| **High Performance Computing Facility** | (units) | 1'000'000 | 1'000'000 | 2'000'000 | 175'000 |
| **Data storage capacity** | (Gbytes) | 25'000 | 20'000 | 30'000 | 2'000 |

## Summary of project objectives

(10 lines max)

The purpose of this Special Project is to study the impact of a stochastic modification of the parameterization of non-orographic gravity wave (NOGW) in a climate model, which are not resolved but must be accounted for a realistic simulation.

The proposed modification is rather simple and could be equally applied to other so called "globally spectral" parameterizations, and aims at introducing variability at unresolved scales, which is typically observed in the atmospheric sources of gravity waves (e.g., convective systems) but is otherwise absent in the model.

The main focus will be on the simulation of the stratospheric dynamics, which both in the polar and equatorial regions are strongly influenced by the specified NOGW forcing.

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## Summary of problems encountered (if any)

(20 lines max)

No particular problem was encountered, but support from the ECMWF staff has been appreciated on some issues, such as accessing the system.

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## Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

During the first year of the project several simulations have been performed on the CCA system. Two versions of the same atmospheric climate model (MAECHAM5, [Roeckner et al., 2003]) have been used, both with the Hines parameterization of NOGWs [Hines, 1997]: the deterministic (CTL) simulations have been done using the default model version, while the stochastic (G02) ones are performed using a modified version of the Hines parameterization.

In the default setting, a uniform forcing (in space and time) is applied at a fixed launched level, and the vertical propagation and effects on the atmosphere are computed. The forcing is assumed to be isotropic in eight horizontal azimuth, each labelled with $j$=1,...,8, and the momentum deposition in the vertical is assumed to occur when the wavenumber

$$\{m_j\}_{trial} = N_i (N m_M^{-1} + V_j - V_{ji} + \Phi_1 \sigma_j)^{-1}$$

exceeds a given critical value. This can occur both due to density effects (i.e., when the amplitude of the parameterized waves would be too large, which is typical in the thin mesospheric air) or to Doppler shifts by the mean flow (also at lower levels).

In our simple modification of the scheme, the forcing at the launching level $\sigma_j$ is made stochastic, and in order to preserve a realistic climate, constrained to follow a Gaussian PDF with the same mean of the default model and a standard deviation of 0.2 $m/s$.

Note that the procedure of assigning a given forcing (with or without spatio-temporal variations) is common to other parameterizations similar to that of Hines, and therefore this simple modification would be applicable to other NOGW schemes as well.

The first two simulations performed with the CTL and G02 model versions are two fifty years long integrations, from January 1959 to December 2009, using as boundary conditions observed SSTs, GHG, ozone concentrations, aerosol loadings and the measured variability in the solar irradiance, both total and in shortwave and longwave bands.

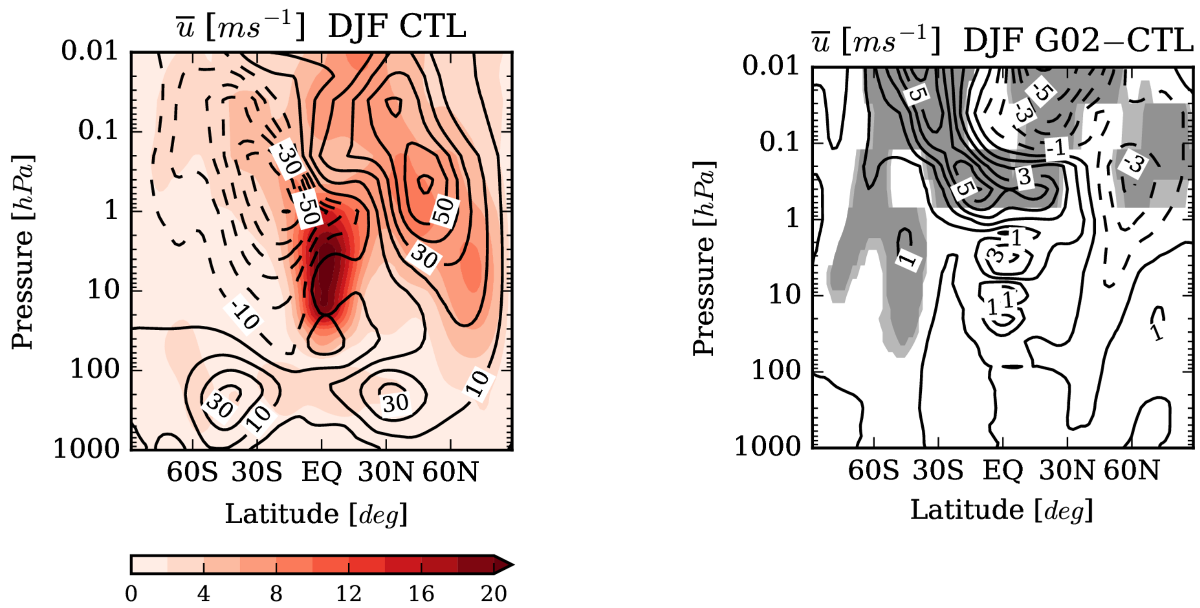



Figure 1: The latitude-height section of the zonal mean zonal wind for the CTL experiment (left, lines mean values, shading interannual variability), and the difference between G02 and CTL (right), with the 90 and 95 % confidence levels shaded in light and dark grey.

The zonal mean zonal wind for the boreal winter for the CTL experiment and the difference between G02 and CTL are reported in Figure 1. The CTL model version has a realistic structure and a marked polar vortex in the boreal stratosphere, while the vortex in G02 appears to be weaker, and the summer easterlies are less intense in the G02 model. This is an effect of the modification of the Hines parameterization, and is indicative of a stronger interhemispheric circulation in G02, which is driven by a stronger NOGW drag.

From Figure 2, it is clear that this drag depends non-linearly of the intensity imposed at the launching level, so that a relatively modest increase of the perturbation at the lowermost level can lead to a much stronger drag in the upper stratosphere and lower mesosphere, decelerating the mean flow and warming the atmosphere at the dissipation heights. Even if large forcing is occurring sporadically, it seems to be large enough to change the mean state also on the much longer monthly timescales.

As mentioned above, another climatic pattern which in climate models is critically dependent on the presence of NOGWs is the quasi-periodic alternation between easterly and westerly winds in the equatorial stratosphere, namely the Quasi-Biennial Oscillation (QBO).

A realistic QBO is internally generated by the CTL model version, and we can see from Figure 3 that the downward propagation is faster in stochastic model version: similarly to what happens at midlatitude, in the G02 model some stronger accelerations are obtained, leading to a more efficient forcing, particularly during the easterly phase of the QBO, as discussed in the work of [Giorgetta et al., 2006] also for the deterministic model version.

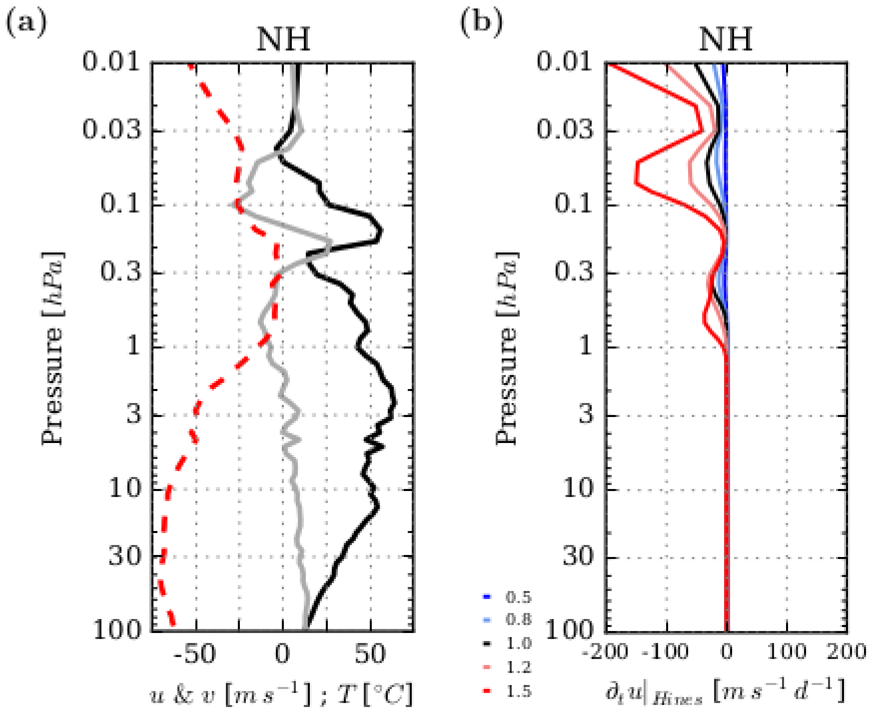



Figure 2: The zonal wind (black), the meridional wind (grey) and the temperature (red, dashed) in a gridpoint near 60 N in winter (a); the forcing computed for this atmospheric background by the Hines parameterization with forcing equal to 0.5, 0.8, 1.0, 1.2, and 1.5 m/s.

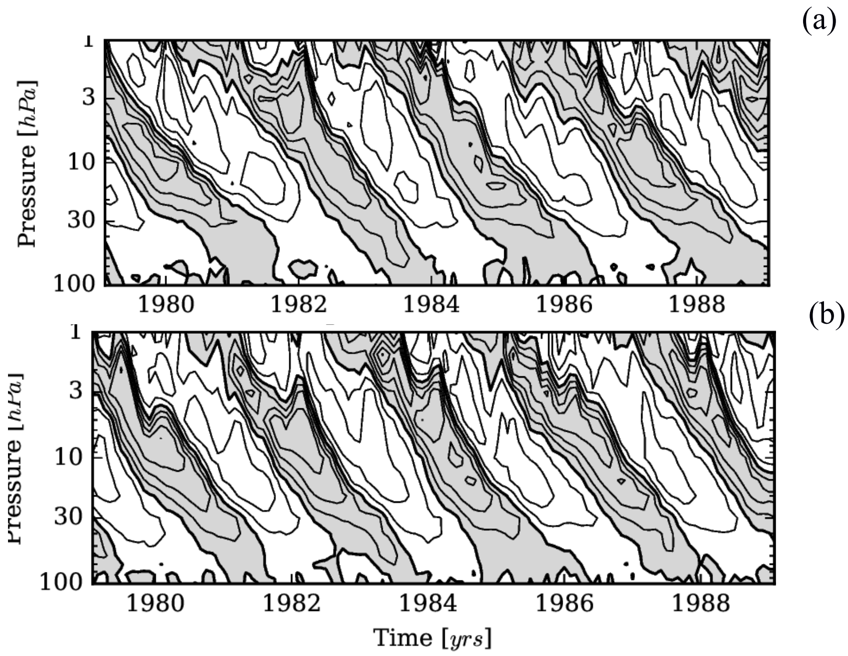
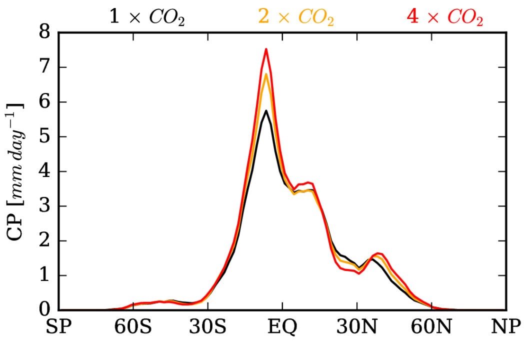



Figure 3: Excerpt of the time-height section of the deseasonalized zonal mean zonal wind at the equator for the CTL (a) and the G02 (b) historical experiments.

A second set of experiments (30 years integrations) has been made with the stochastic model version, using as boundary conditions climatogical conditions to reproduce (i) the year 2002, (ii) a world with twice the atmospheric carbon dioxide than the 2002 values, and SSTs warmer by 2 K and (iii) a world with four times the concentration of the year 2002 and SSTs warmer by 4 K.
All the other prescribed fields are set to a climatology or the 2002 values, to isolate the internal variability of the model.
Apart from the prescribed change in the surface temperatures, there are visible changes also in the simulated precipitation, with an increase of convective precipitation in the tropics (Figure 4), which inevitably affects also the stratosphere.



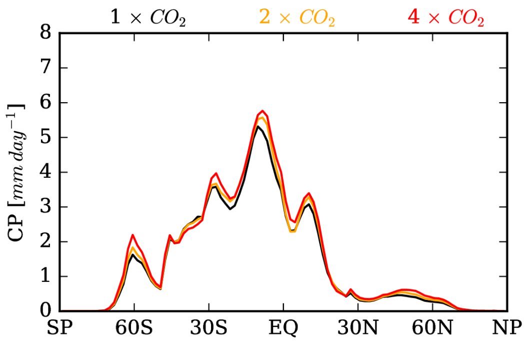




Figure 4: the zonally averaged precipitation in the DJF (left) and JJA (right) seasons, for the G02 model in the experiments with 1x (black), 2x (orange), 4x (red) $CO_2$ world.

It is evident from Figure 5 that the characteristics of the QBO are changed when the surface temperature and the carbon dioxide concentration are increased: in the model, the NOGW parameterization does not respond on the mean state variations, and the propagation of the alternating anomalies from the upper stratosphere is inhibited, at the point that a separation between

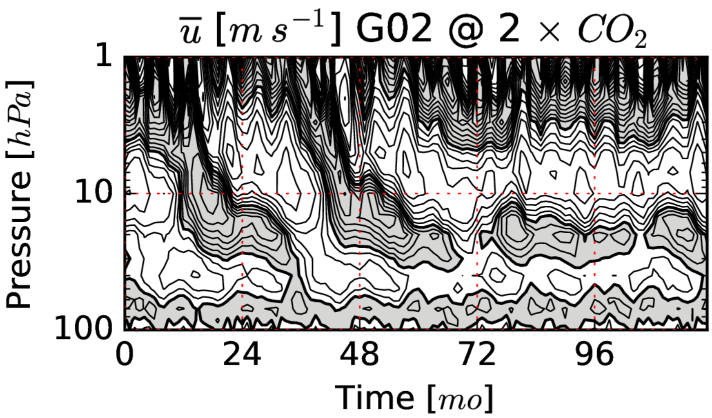



Figure 5: An excerpt of the time-height section of the equatorial zonal mean zonal winds in the 2x $CO_2$ world.

easterly and westerly jets is well visible since month 72. These separation is even stronger in the experiment where the carbon dioxide concentration is four times the 2002 value (not shown).

The experiments performed during this year follow the guidelines of the QBOi intercomparison project [Hamilton et al., 2015], which aim at evaluate the simulation of the QBO in the current generation of stratosphere-resolving climate models, and have been submitted to the multi-model database of the project.

## References

[Giorgetta et al., 2006] Giorgetta, M.A. and coauthors, Climatology and forcing of the quasi-biennial oscillation in the MAECHAM5 model, J. Clim., 19(16), 3882–3901, doi:10.1175/JCLI3830.1.

[Hamilton et al., 2015] Hamilton, K., S. M. Osprey, and N. Butchart, Modeling the stratosphere's "heart- beat", Eos, (96), doi:10.1029/2015EO032301.

[Hines, 1997] Hines, C.O., Doppler-spread parameterization of gravity-wave momentum deposition in the middle atmosphere. Part 2: Broad and quasi monochromatic spectra, and implementation, J. Atmos. Sol.-Terr. Phys., 59(4), 387–400, doi:10.1016/S1364-6826(96)00080-6

[Roeckner et al., 2003] Roeckner, E. and coauthors, The atmospheric general circulation model ECHAM5. Part I: Model description, MPI Report No. 349.

## List of publications/reports from the project with complete references

F. Serva , C. Cagnazzo, A. Riccio , E. Manzini, Impact of a stochastic nonorographic gravity wave parameterization on the stratospheric dynamics of a General Circulation Model , To be submitted, 2017

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## Summary of plans for the continuation of the project

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During the second half of the billing year, further experiments will be performed. Their start have been postponed due to technical difficulties with the model setup, which are now under consideration.

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