SPECIAL PROJECT FINAL REPORT

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All the following mandatory information needs to be provided.

Project Title:	Effects of a stochastic gravity wave parameterization on the simulation of stratospheric dynamics
Computer Project Account:	SPITCHCG
Start Year - End Year :	2016 - 2018
Principal Investigator(s)	Chiara Cagnazzo Federico Serva
Affiliation/Address:	CNR-ISAC (now at CNR-ISMAR)
Other Researchers (Name/Affiliation):	N/A

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The aims of this Special Project have been to study the study the troposphere-stratosphere coupling and the role of small-scale processes (namely non-orographic gravity waves, NOGWs) by performing climate model experiments. Several simulations have been carried out with state-of-the-art atmospheric general circulation models (GCMs), and a stochastic NOGW scheme has been implemented in one of these models (ECHAM5). The allocated resources allowed to perform several multi-decadal simulations, of which outputs are currently being analyzed, and to contribute to ongoing international model intercomparison activities.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

The investigators experienced some technical issues during the course of this Special Project. In particular, the software (model compilation and post-processing) needed to be adjusted for the ECMWF infrastructure, and occasionally there were issues with the access to the server (e.g. due to token failure). At times the long-term archive of ECFS had unanticipated problems that caused some disruption to our workflows. However, the availability of online documentation, and in particular the useful advices from the ECMWF technical support team, allowed to solve all the issues we encountered in the most efficient way.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

The overall experience with the Special Project has been very positive. The interaction with ECMWF staff has been always very useful to quickly solve any kind of issue. In the course of the Project, the administrative procedures have been further improved, making the whole process even smoother.

Summary of results

(This section should comprise up to 10 pages, reflecting the complexity and duration of the project, and can be replaced by a short summary plus an existing scientific report on the project.)

During the course of this Special Projects, several simulations have been carried out. Here we present some results, but more results are discussed in the references listed below.

The first set of experiments, after the initial setup phase, consisted of two multi-decadal atmosphere-only simulations with the ECHAM5 model. Observed boundary conditions (sea surface temperature (SST), solar forcing, greenhouse gases) were imposed, following protocols defined for the QBOi initiative.

The main objective has been to diagnose the sensitivity of the model climate to the introduction of a stochastic gravity wave parameterization (see Serva et al., 2018 for more details). This was done by comparing reanalysis data (of ERA-Interim), with a control simulation (CTL) and a stochastic run (G02). The random perturbation applied to the non-orographic gravity wave (NOGW) scheme reduces the cold bias of the extratropical stratosphere, but tends to make the Quasi-Biennial Oscillation (QBO) in the equatorial stratosphere overly regular (see Fig. 1).

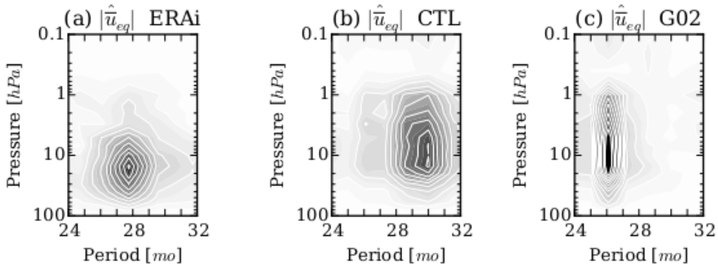

Figure 1: The Fourier spectrum of the QBO in the reanalysis and the two experiments described in the text. Note the simultaneous reduction of the period and the spread reduction, indicating a too regular QBO in the G02 experiment. From Serva et al., 2018.

With the same model configuration used for the experiments described above, three more idealized experiments were conducted (following the QBOi design). In the three cases, climatological boundary conditions are used (keeping their seasonal variability), and only carbon dioxide concentration and SSTs are altered. The perturbation experiments have twice (four times) the 2002 carbon dioxide concentration and a uniform +2 (+4) K SST anomaly imposed. The changes of the simulated climate, and in particular the response of the QBO are considered in Richter et al., 2019.

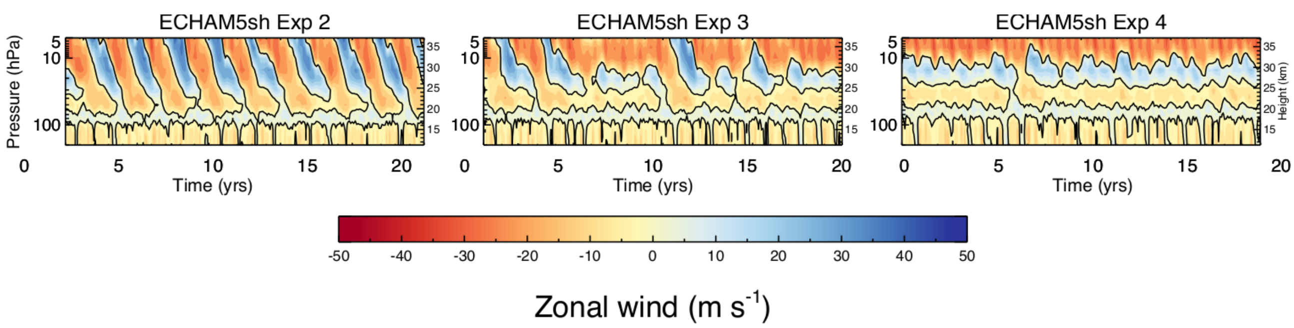

Figure 2: The equatorially averaged zonal mean zonal wind in the three idealized experiments described in the text. Note how the oscillation is progressively more erratic in the warmer climates. From Richter et al., 2019.

These set of experiments it is useful to gain a better understanding of the projected changes of the QBO in the future. While the models disagree with respect to the details of the changes (see the results for ECHAM5 in Fig. 2, here labelled ECHAM5sh – stochastic Hines), they all indicate a significant reduction of the QBO amplitude in warmer scenarios, mostly due to increased upwelling. Persisting uncertainties are caused by the response of the different NOGW schemes used by the different models. More details on the Phase 1 experiments of the QBOi project can be found in the papers listed in the reference section below, which are dedicated to the wave forcing and the lower mesospheric response.

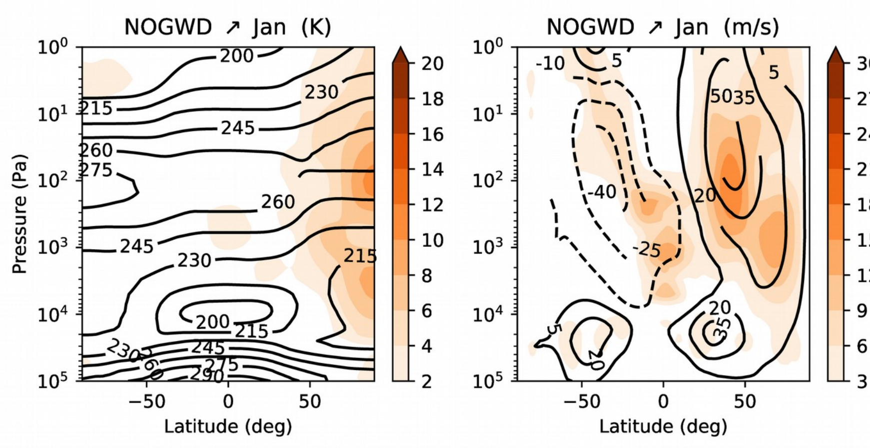

Figure 3: The zonal mean climatology (temperature, left and zonal wind, right) for January in an EC-EARTH run with doubled NOGW momentum flux at the launching level. Warming of the winter stratosphere and the reduction of the polar night jet strength are apparent. The interannual variability is shaded in colors.

Several simulations have also been carried out with the EC-EARTH model, which is however much more computationally expensive. The objective in this case has been to extend the model output in order to fulfil the requests of the DynVarMIP of the upcoming CMIP6. This made necessary to include more dynamical diagnostics (now included in the EC-EARTH model trunk, with the optional LDYNVAR flag) and to prepare an ad-hoc post-processing chain. Taking advantage of this exercise, the sensitivity of the (atmospheric) model has been tested, for example in terms of the sensitivity to the NOGW drag scheme. The response to an increased momentum flux at the lower level is shown in Fig. 3, based on a 10 year simulation.

During the third and final year, three centennial simulations have been performed. The design of these new experiments further extended the diagnostic outputs produced, in order to better study the tropical variability and organized convective systems. Two specific experiments, where an El Niño or a La Niña -like SST perturbations are applied, have been carried out. Their outputs will allow to study the tropical teleconnections and the stratosphere-troposphere coupling in different climate models. Note in Fig. 4 how the imposition of anomalies in the tropical Pacific leads to climate anomalies on a global scale (see e.g. the large response over the United States in the two experiments). Further analysis of these experiments, and comparison with other climate models, are now ongoing.

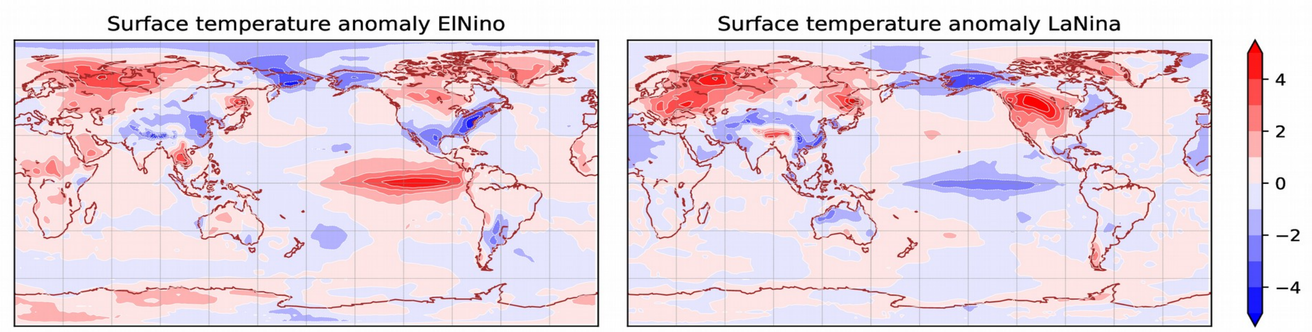

Figure 4: The surface temperature anomalies (as departure from the climatology experiment) in the two El Niño/La Niña simulations. Plots based on a ten years slice. Units are Kelvin.

List of publications/reports from the project with complete references

Butchart, N. et al.: Overview of experiment design and comparison of models participating in phase 1 of the SPARC Quasi-Biennial Oscillation initiative (QBOi), Geosci. Model Dev., 11, 1009-1032, doi:10.5194/gmd-11-1009-2018, 2018.

Serva, F. et al.: Impact of a stochastic nonorographic gravity wave parameterization on the stratospheric dynamics of a general circulation model, J. of Adv. Model. Earth Sys., 10, 2147–2162, doi: 10.1029/2018MS001297, 2018.

Richter, J. H. et al.: Response of the quasi-biennial oscillation to a warming climate in global climate models, Submitted to Q. J. R. Met. S., 2019.

Holt, L. et al.: An evaluation of tropical waves and wave forcing of the QBO in the QBOi models, Submitted to Q. J. R. Met. S., 2019.

Smith, A. K. et al.: The equatorial stratospheric semiannual oscillation and time-mean winds in QBOi models, Submitted to Q. J. R. Met. S., 2019.

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Many scientific questions remain open regarding the role of the stratosphere in the climate system, and model experiments are useful to gain a better understanding of the underlying processes. While the data produced have been already analyzed in some aspects, there is still much to study. In particular, the centennial simulations performed during the third (and final) year of this Special Project will be valuable for studying the internal variability of the climate system, especially regarding tropical processes, such as the El Niño and the QBO, and their global teleconnections.

Moreover, in the course of this project it became clear how it is important to characterize the sensitivity of the model climate in different configurations (e.g., varying the temporal and spatial resolution) and to stratospheric forcings (e.g., parameterized NOGWs). For this reason, the investigators of SPITCHCG applied for an additional Special Project (SPITSERV) devoted to the analysis of the sensitivity of the stratosphere of the OpenIFS model (based on ECMWF's IFS).