SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	The dynamics of the stratosphere in the OpenIFS climate model
Computer Project Account:	SPITSERV
Start Year - End Year :	2019 - 2021
Principal Investigator(s)	Federico Serva
Affiliation/Address:	Consiglio Nazionale delle Ricerche (CNR), Istituto di Scienze Marine, Rome
Other Researchers (Name/Affiliation):	Chiara Cagnazzo (CNR)

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

The initial plan of the Special Project was to investigate the sensitivity of the OpenIFS model to different configurations (spatial and vertical resolution in particular) with a focus on the changes in the stratospheric dynamics. Due to delayed availability of the model version, the simulations have been carried out mostly with the IFS version used as atmospheric component of the EC-EARTH climate model. Improvements of the modelled stratospheric dynamics are quantified by comparing with a previous EC-EARTH model version and reanalysis data.

………

Summary of problems encountered

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

As stated, we experience some difficulties due to the availability of the planned model version. Since our initial request was based on the available model configurations, we decided to release part of the allocations to optimize use of resources. The Special Project team kindly helped us in these adjustments, when needed.

………

Experience with the Special Project framework

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

As in previous cases, the experience was very good. The team supported us in case of questions and for any required changes in the allocations, and the software we required was well supported by the cca environment. The administrative procedures are clearly defined and reporting is reasonable in terms of timing and level of detail.

………

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.)

Most resources have been used to develop and test the EC-EARTH (v 3.1) climate model, which uses IFS Cy36r4 as atmospheric component. The EC-EARTH consortium is participating to the Coupled Model Intercomparison Project Phase 6 (CMIP6), and some of the simulation outputs created on the cca infrastructure has been uploaded to the ESGF database.
The IFS model was significantly modified for use in climate simulations, for example with the objective of reducing moisture imbalances and ensuring conservation, which may affect reliability of multidecadal experiments. Several improvements developed for more recent IFS versions were also backported, like for the case of the spectral gravity wave scheme.
The current capability of the EC-EARTH model to simulate a stratospheric quasi-biennial oscillation are discussed in the recently published work by Doescher et al., (2022). Basic analysis of the quasi-biennial oscillation (QBO) were included in the EC-EARTH 3 description paper for the CMIP6 exercise, and more analyses are ongoing. Besides the new runs done under the DynVarMIP project of CMIP6, we did basic analysis of the atmosphere-ocean and atmosphere-ocean-vegetation (Fig. 1), finding no appreciable difference in the basic features.

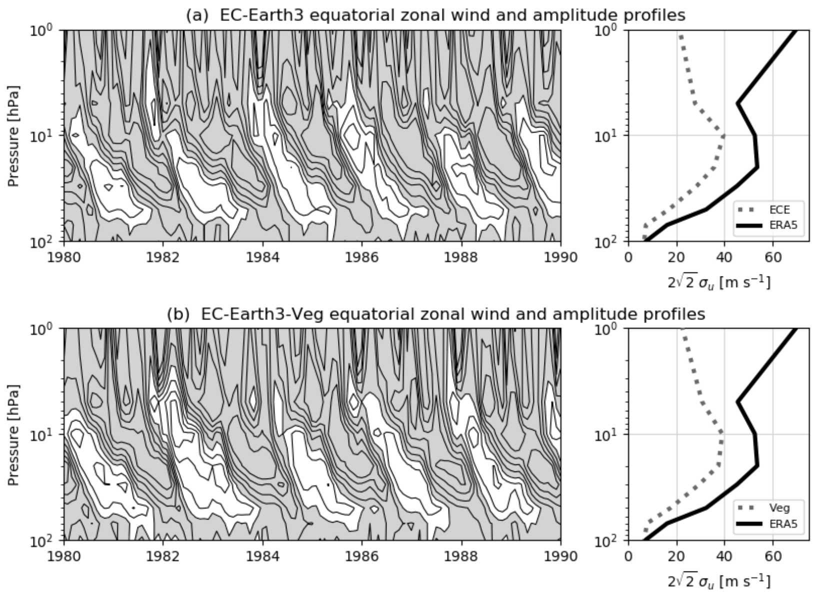

Figure 1: Time-pressure zonal mean zonal winds at the equator (easterlies are shaded, contour interval 5 m/s) and oscillation amplitudes, estimated from their overall standard deviations, for the atmosphere-ocean (a) and the atmosphere-ocean-vegetation model (b). ERA5 amplitudes are reported for comparison.

The resources allowed us to test and perform a multi-decadal simulation enabling the additional output required by the DynVarMIP set of experiments, for the atmosphere-only (AMIP) run. At the current phase this requires a substantial increase in the model I/O, as data with full spatial resolution and all model levels are required to perform offline calculation of the residual (non-Eulerian) circulation. The residual zonal mean circulation for the previous phase (CMIP5) and current version of EC-EARTH are shown in Fig. 2. A paper on the comparison of v2 and v3 (data for CMIP6 already published in the public database) is currently being prepared.

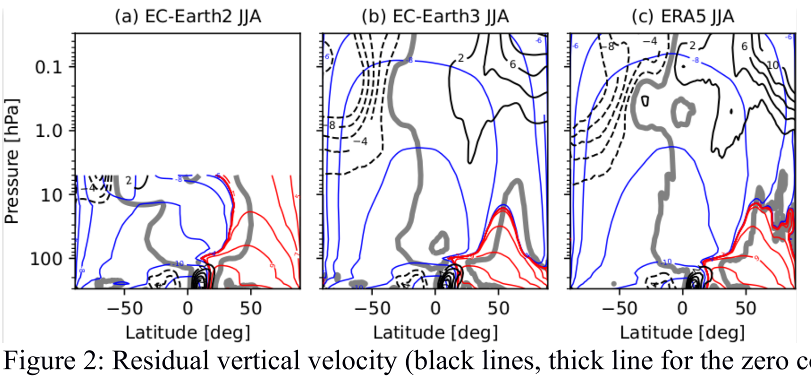

Figure 2: Residual vertical velocity (black lines, thick line for the zero contour), residual stream function (blue/red lines for negative/positive values) for CMIP5 (a), CMIP6 (b) models and ERA5 (c).

From Fig. 2, the different vertical extent of the two model versions is clear. The simplified representation of the stratosphere in the CMIP5 model version causes a too strong downwelling in the winter stratosphere and damped zonal circulation, while the CMIP6 version compares well with ERA5 results. Results for the upper stratosphere and lower mesosphere are difficult to assess in general due to the limited amount of observations available at these heights. This kind of study can be useful to identify model biases and try reducing them with further model development.

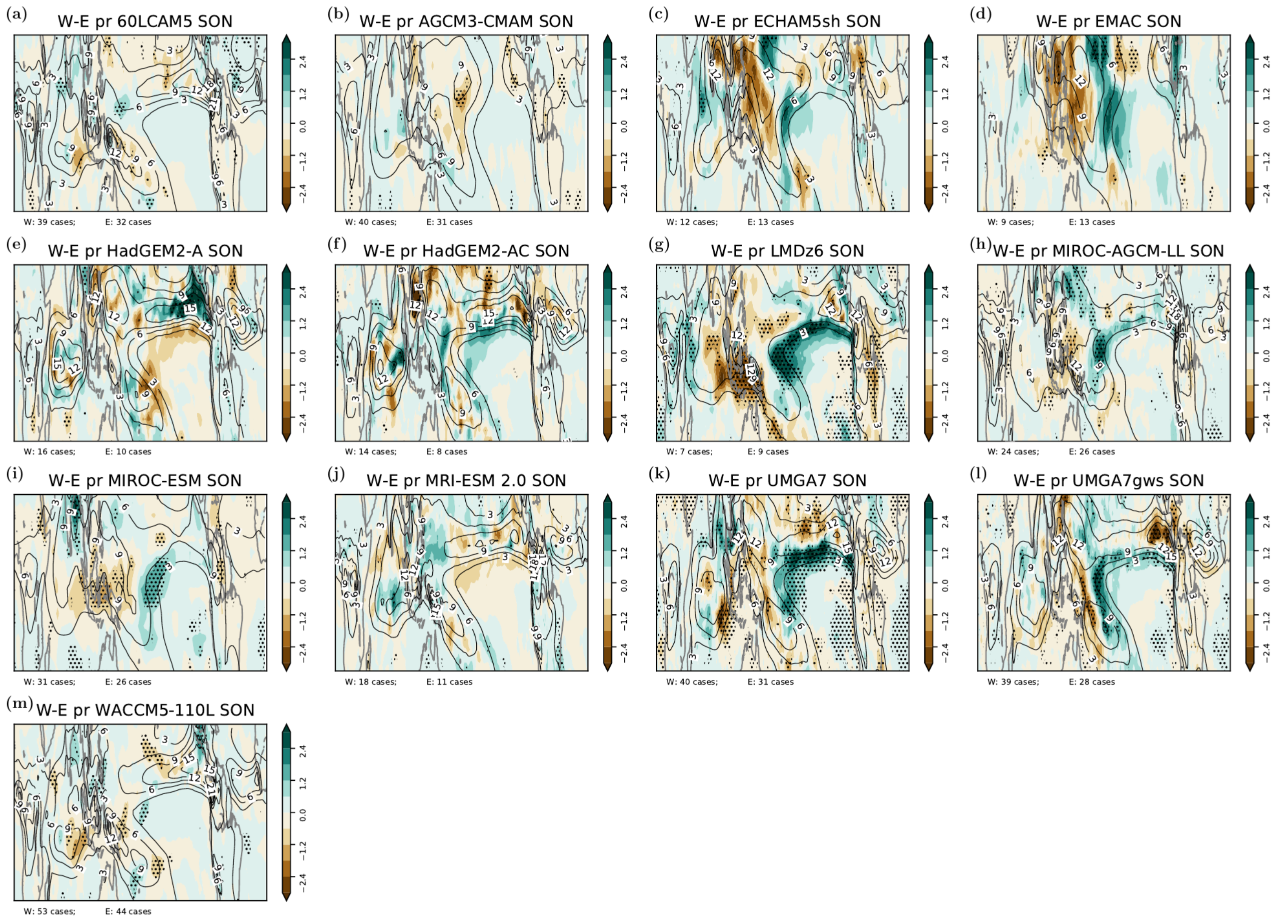

Figure 3: Westerly minus easterly QBO composites for surface precipitation (shadings, mm/day) in QBOi models, with climatological precipitation shown with black contours. Significant differences at the 5% significance level are stippled. Adapted from Serva et al., 2022.

The availability of computational resources also allowed us to rerun some experiments performed within the Quasi-Biennial Oscillation initiative (QBOi) under the SPARC-WCRP auspices. In particular, both experiment 1 (AMIP, present-day), 2 (AMIP, time slice) and El Niño-Southern Oscillation (ENSO) runs have been carried out and uploaded to the shared repositories (as r2i1p1 variant, after fixing an error in the boundary condition files). Data from the Exp1 run was used in a multi-model comparison paper which was recently published (Serva et al., 2022), for which we show an example if Fig. 3. The analyses focused on the interaction between QBO winds in the lower stratosphere and their tropical teleconnections. We find that the ECHAM5sh model performed similarly to other ECHAM-based models with respect to upper tropospheric and stratospheric variability, but the too weak amplitude of the QBO in the lower stratosphere reduced the signal on the surface climate (precipitation W-E composites are shown in Fig. 3 for the models in the September-October-November period), given by spatial shifts of the major convective areas. It should be noted however that the strength and position of the Pacific tropical convective area is biased in this model.

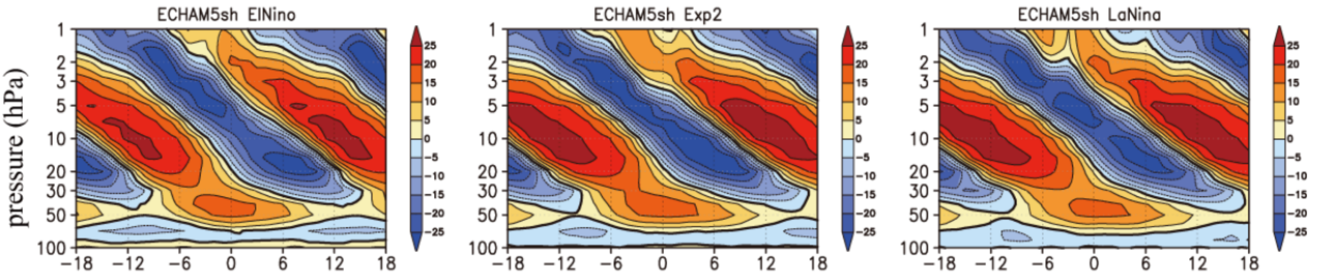

Figure 4: QBO easterly composites (zonal winds, units m/s) for the positive ENSO (left), neutral ENSO (center), negative ENSO (right) for ECHAM5sh simulations. Between the positive and negative phase, phase speed increase and some amplitude change are found. Figure produced by Dr. Y. Kawatani (JAMSTEC).

Coordinated ENSO experiments, where the same repeated warm/cold sea surface temperature anomaly is imposed, are useful to evaluate the relationship between ENSO, the QBO and their role in the global climate. Analysis is ongoing on outputs generated by ~10 different models under the QBOi project. Preliminary results indicate that most models simulate an ENSO impact on the QBO (see Fig. 4 for ECHAM5sh), but with large inter-model spread. The availability of circulation diagnostics will allow us to understand the reasons of the model differences, with respect to momentum budgets and simulated global impacts.

List of publications/reports from the project with complete references

Serva et al., QJRMetS, 2022, https://doi.org/10.1002/qj.4287
Doescher et al., GMD, 2022, https://doi.org/10.5194/gmd-15-2973-2022

The following works are currently in preparation based on the data produced during the SP:
Serva et al., Stratospheric dynamics of EC-EARTH in CMIP5/6
Kawatani et al., ENSO and changes in the gravity wave forcing of the QBO
Richter et al., QBO-MJO connection in the QBOi models
Naoe et al., ENSO and QBO teleconnections in ENSO experiments
……

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.)

Resources have been allocated for a follow-up Special Project focused on the IFS and EC-EARTH models, aiming at understanding the model biases with respect to stratospheric processes. As detailed in the relevant report (SPITSERV, started 2022), coordinated nudging experiments will allow us to study the impacts of removal of persisting model biases, as for example the very limited upper stratospheric variability.

……