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D3.1: Report on the incorporation of the stratosphere in ESMs

1. Introduction

The main objective of WP3 is to reduce uncertainties in the representation of climate variability on intra-seasonal, seasonal, interannual and decadal timescales for better climate predictions by including dynamical stratospheric processes in state-of-the-art Earth System Models. The evidence that stratospheric variability has a significant impact on the tropospheric climate (among many: Cagnazzo and Manzini 2009, and Ineson and Scaife 2009) motivates this approach. Specifically, the overall WP objectives are:

1) Improve the understanding and the modelling of the stratosphere - troposphere dynamical feedback. Evaluate the implication of the stratosphere climate predictability on seasonal to decadal timescales.

2) Reduce uncertainties in the exchange of water vapor and other gases between the troposphere and the stratosphere. Reduce uncertainties in the distribution of water vapor in the upper troposphere.

In order to achieve these objectives, a dynamically resolved stratosphere has been incorporated in five coupled atmosphere-ocean-sea-ice models (Milestone M3.1 "*Stratosphere implemented in ESMs*"). This has been done by increasing the vertical resolution of the atmospheric model components, by rising up the model top and by including the parameterization of momentum flux deposition by gravity waves that are not explicitly resolved in the models, by modifying the radiative transfer scheme if necessary, as well as retuning of horizontal diffusion if necessary. The new high top model systems have thereafter been used to perform a set of pre-industrial/control and historical (1850-2005) coupled simulations. Here we describe the models and first results from the evaluation of the available simulations. Detailed quantitative analysis will be the reported following deliverables: D3.2 "*Report on the stratosphere-troposphere dynamical feedback*" and D3.3 "*Report on the troposphere-stratosphere system in the tropics*".

2. The models

Five ESMs participate to WP3 and have incorporated the stratosphere. Table 1 summarizes the model characteristics.

2.1 CMCC Model – Partner: CMCC

The CMCC model is base on the ECHAM5 atmosphere (Roeckner et al. 2006) and OPA8.2/LIM ocean/sea-ice (Madec et al. 1999; Fichefet and Morales-Maqueda 1997) models and the OASIS3 coupler (Valcke 2006). The coupling methodology and implementation is described in Fogli et al. (2009). The incorporation of the resolved stratospheric component implies the use of the middle atmosphere version (Manzini et al. 2006) of the atmospheric model in the couple system. The middle atmosphere version has at 80 km (0.01 hPa) and includes the parameterization of momentum

Table 1. Summary of the WP3 model characteristics

	CMCC-CMS	CMCC-CESM	IPSL-CM5	MPI-ESM	HadGEM	EC-EARTH
model components	ECHAM5 OPA8.2+LIM	ECHAM5 OPA8.2+LIM	LMDz NEMO	ECHAM6 MPIOM	HadGEM2-CC	IFS NEMO2+LIM
atmospheric resolution	T63L95	T31L39	96x72x39	T63L47	N96L60	T159L62 / T159L91
ocean resolution	2 deg x 31 levels	2 deg x 31 levels	2 deg	1.5 deg x 40 levels	1 deg x 40 levels	1 deg x 42 levels
model top	0.01 hPa	0.01 hPa	70 km	0.01 hPa	84km	5 hPa / 0.01 hPa
100-1 hPa resolution	44 levels	17 levels	1 km	15 levels	24 levels	10 / 29 levels
stratosphere	orog. and non-orog. mom. cons. GWD	orog. and non-orog. mom. cons. GWD	orog. and non-orog. mom. cons. GWD	orog. and non-orog. mom. cons. GWD	orog. and non-orog. mom. cons. GWD	Orog. GWD + Rayleigh friction above stratop.
extra components		ocean biogeochemistry and land vegetation carbon cycle		carbon cycle with land vegetation and ocean biogeochemistry	ocean biogeochemistry and land vegetation carbon cycle; aerosols	

conserving orographic and non-orographic gravity wave drag. The shortwave radiation scheme covers the 185-4000 nm spectral interval with a spectral resolution of 6 bands separating the UV and visible ozone absorption (Cagnazzo et al. 2007). A source of water vapor in the stratosphere and mesosphere by methane oxidation has been added. The oceanic component has a resolution of about 2 degrees in horizontal and 31 vertical levels.

The CMCC model is used in two settings. The first one (CMCC-CMS) is the Climate Model with a well-resolved Stratosphere; it has a high vertical resolution (95 levels from the surface up to 80 km) and a horizontal resolution of T63 (about 1.9 x 1.9 deg). In this configuration the model internally generates the QBO in the equatorial stratosphere (Giorgetta et al. 2006). The second model configuration (CMCC-CESM) is the Carbon Earth System Model and is designed to simulate the carbon cycle for climate change research. The CMCC-CESM (Fogli et al. 2009) includes processes related to the biological and geochemical parts of the carbon cycle: SILVA land and vegetation model (Alessandri 2006) and PELAGOS ocean biogeochemistry (Vichi et al. 2007). The CMCC-CESM model has also top at 80 km, but a lower vertical resolution (39 levels) and a horizontal resolution of T31 (3.75 deg x 3.75 deg) with respect to CMCC-CMS. In this version, the model does not reproduce a spontaneous QBO but it reproduces a realistic extra-tropical stratospheric variability.

2.2 IPSL-CM5 – Partner: CNRS

The IPSL-CM5 model is based on the LMDz atmospheric GCM (Hourdin et al. 2006) extended to the stratosphere (Lott et al. 2005). For the ocean it uses the OPA model (Madec et al. 1999), for the sea ice model the LIM model from Louvain la Neuve (Vancoppennole et al. 2008), and for the vegetation the ORCHIDEE model (Kriner et al. 2005). The coupling between the various components is done by the OASIS coupler (Redler et al. 2010). In the atmosphere, the top is at around 70km, and the integration of the stratospheric levels necessitates the use of the non-orographic Hines (1997) gravity waves scheme described in Manzini et al. (1997). Still for the stratosphere, the parameters that control the orographic gravity waves scheme have been reduced substantially (see Lott et al. 2005) compared to the tropospheric versions of LMDz (as in Lott 1999). In terms of resolution, the atmospheric component has a uniform horizontal grid 73x96, yielding a resolution in latitude of around 2.5° and in longitude of 3.76°. In the vertical, the atmospheric model as 39 levels, and a vertical resolution of 1.5-2km in the low troposphere. Finally, the ocean model has of 2°x2° horizontal resolution and 31 levels in the vertical.

2.3 MPI-ESM (COSMOS model) - Partner: MPG

The MPI-ESM (COSMOS) is based on the new ECHAM6 atmospheric GCM, the successor of ECHAM5 (Roeckner et al., 2006), and an improved version of the MPIOM ocean GCM (Jungclaus et al., 2006). Atmosphere and ocean are coupled on a daily base by the OASIS3 coupler. The atmosphere model has a triangular truncation at wavenumber 63 and an associated grid with a horizontal resolution of 1.9°. The vertical grid resolves the atmosphere in 47 levels up to 0.01 hPa (~80 km). The model includes the Hines parameterization (Hines, 1997a,b) for the upward propagation of unresolved gravity waves and their dissipation causing tendencies in the horizontal winds. Its implementation follows Manzini et al. (2006). The MPIOM ocean model has a typical resolution of 1.5° near the equator and a 40 level grid in the vertical. The JSBACH land model, embedded in ECHAM6 and the HAMOCC ocean biogeochemistry model included in MPIOM calculate the terrestrial and marine parts of the global carbon cycle.

2.4 HadGEM model – Partner: METO

The HadGEM2-CC model is based on the Met Office Hadley Centre HadGEM2-ES model (Collins et al. 2008), vertically extended to 84km, using 60 vertical levels, with a horizontal resolution of 192 longitudes x 145 latitudes. The model includes modifications to the radiation scheme and radiation spectral files, a source of water that represents the water produced by methane oxidation in the stratosphere and mesosphere, and a non-orographic gravity wave parameterization scheme (Scaife et al. 2002). The model has an internally generated quasi-biennial oscillation (QBO) of the tropical zonal mean zonal wind (Scaife et al. 2000) of ~28-months period in good agreement with observations. The ocean model has a resolution of 1 degree (finer in the tropics) and 40 vertical levels.

2.5 EC-EARTH model – Partner: DMI

The EC-EARTH model (Hazeleger et al. 2010) in use at DMI consists of the IFS atmosphere (from ECMWF) and NEMO/LIM ocean/sea-ice models, and of the OASIS2 coupler. The standard configuration of EC-EARTH runs at T159 horizontal resolution (equivalent to 125 km x 125 km) and 62 vertical layers with the top of the atmosphere at 5 hPa for the atmosphere (hereafter, low-top model version), and 1 x 1 degree (with tropical refinement) in horizontal and 42 vertical levels for the ocean. To incorporate the stratospheric processes, the standard EC-EARTH model is vertically extended to 0.01 hPa, using 91 vertical layers of which 29 layers locate between the 100 and 1 hPa (hereafter, high-top model version). The physical parameterizations in both the high-top and the low-top versions are kept the same. The non-orographic gravity wave drag is not explicitly parameterized in the model. Instead, a simple Raleigh friction above the stratopause is introduced to account for effect due to the missing sub-grid scale waves. The high-top model simulate realistic extra-tropical circulation and variability in the stratosphere but does not reproduce the QBO, likely due to the lack of non-orographic gravity wave drag parameterization.

3. Simulations

The simulations performed are summarized in Table 2. Some of these simulations are carried out in collaboration with WP6 and WP7.

Table 2. Details of the simulations: completed, ongoing and foreseen

	CMCC-CMS	CMCC-CESM	IPSL-CM5	MPI-ESM	HadGEM	EC-EARTH
AMIP	1950-2005		1950-2005	1979-1999		1979-2008
Pre-industrial	350 yrs	500 yrs	500 yrs	260 yrs	240 yrs	750 yrs* 350 yrs
Historical	1850-2005	1850-2005	1850-2005	1850-2005	1860-2005	1850-2005
RCP4.5	2005-2035-2100		2005-2095	2005-2035-2100	2005-2100	2006-2100
RCP8.5		2005-2100	2005-2095	2005-2100	2005-2100	
Potential Predictability	1960-1990 2005-2035			1979-1999		1970-2008 2005-2035

* with the low-top version only

Table 3. Forcing used for the historical simulations

	CMCC-CMS CMCC-CESM	IPSL-CM5	MPI-ESM	HadGEM	EC-EARTH
Solar cycle TSI	Anomaly from CMIP5 (SOLARIS)		CMIP5	CMIP5	CMIP5
Solar cycle spectral	CMIP5		CMIP5	CMIP5	CMIP5
WMGHG	CMIP5 (1)	CMIP5	CMIP5	CMIP5	CMIP5
Ozone	CMIP5-Bell-Osprey	prescribed via REPROBUS	CMIP5-Bell-Osprey	CMIP5-Bell-Osprey	CMIP5-Bell-Osprey
Volcanic aerosols	no	prescribed via INCA	yes	yes (2)	no
aerosols	prescribed anthropogenic sulphate - CMIP5	prescribed aerosols via INCA	spatially resolved aerosol optical properties (3)	yes (4)	prescribed anthropogenic sulphate - CMIP5

(1) CO_2, CH_4, N_2O, Kyoto Protocol: HFCs, PFCs, and SF_6; Montreal Protocol: CFCs, HCFCs, Halons, CCl_4, CH_3Br, CH_3Cl

(2) The dataset used for the historic period was monthly stratospheric optical depths, at 550nm, from 1850 to 2000 (Sato et al., 1993, http://data.giss.nasa.gov/modelforce/strataer/), which was averaged over the four equal area latitudinal zones and converted into aerosol concentrations (Stott et al., 2006 and figures therein).

(3) Spatially resolved aerosol optical properties based on scalable aerosol climatology, differentiating natural fine and coarse mode aerosols and anthropogenic, emission dependent, fine mode aerosols.

(4) 7 aerosol species, 6 with dedicated interactive (or online) schemes, 1 from fixed climatology. Sulphate from CMIP5 sulphur dioxide emission dataset and interactive DMS emissions from ocean model; biomass, fossil-fuel black carbon, fossil-fuel organic carbon from CMIP5 primary emission datasets; mineral dust and sea-salt computed interactively from modelled near-surface windspeed (both aerosols), soil moisture, bare soil fraction (mineral dust only).; secondary organic aerosol from terpene emissions ("biogenic") prescribed as a fixed climatology of mass-mixing ratio, derived from STOCHEM (Derwent et al. 2006). Aerosols are coupled with radiation (direct and indirect effects), chemistry (sulphur cycle oxidants), ocean (DMS emissions, fertilisation by mineral dust).

The simulations are listed as completed (black), ongoing (red) and foreseen (blue). In addition to the simulations reported in Table 2, CMCC and MPG are planning to perform the CMIP5 idealized 1% CO_2/yr simulations. MPG will also perform emission-driven and abrupt climate change experiments (refer to WP7). Concerning EC-EARTH, a 750-year long pre-industrial/control experiment with the low-top configuration only has been completed. The forcing used for the historical simulations are summarized in Table 3.

4. Model evaluation

The analysis of the simulation is ongoing. In the following, we report the status and plan for model evaluations and preliminary results.

Highlights in the evaluation of the capability of the high top model systems include the following (to be covered within the full WP duration):

- Surface climate drift (diagnosed by trends in global annual mean time series of 2m temperature, and Arctic and Antarctic sea-ice concentrations);
- Top of the atmosphere (TOA) radiation close to be balanced (diagnosed by global annual mean time series of the top of the atmosphere net radiative flux);
- Annual mean and seasonal distributions of sea surface temperature, precipitation and OLR, averaged over many years;
- ENSO and MJO diagnostics;
- Polar, mid-latitude and tropical tropospheric climate and variability;
- Mean and variance of zonal mean meteorological quantities in the troposphere and stratosphere, for a range of time scales;
- Tropical and extra-tropical stratospheric variability (QBO and SSWs)

4.1 Troposphere and surface climate

In this section, the mean surface climate is first evaluated by plotting the time series of the annual mean / monthly mean temperature close to / at the surface for the pre-industrial / historical simulations.

Figures 1-A and 1-B show time series of the 2-m temperature (close to the surface) for the CMCC-CMS, IPSL-CM5, MPI-ESM and EC-EARTH model. The results for the EC-EARTH model are for the low-top version simulation. Figure 1-C shows the time series of the global annual mean surface temperature from HadGEM simulations.

The CMCC-CMS, MPI-ESM, IPSL-CM5, and HadGEM models show virtually no drift of the temperature close to the surface. The average pre-industrial temperature is about 13.5^{o}C for the CMCC-CMS and HadGEM model, 13.7^{o}C for the MPI model and 12^{o}C for the IPSL model. The EC-EARTH model reports an average temperature of about 13^{o}C, with a small drift (-0.05 K/century for EC-EARTH over 600 yrs). Results from CMCC-CESM are reported in WP7.

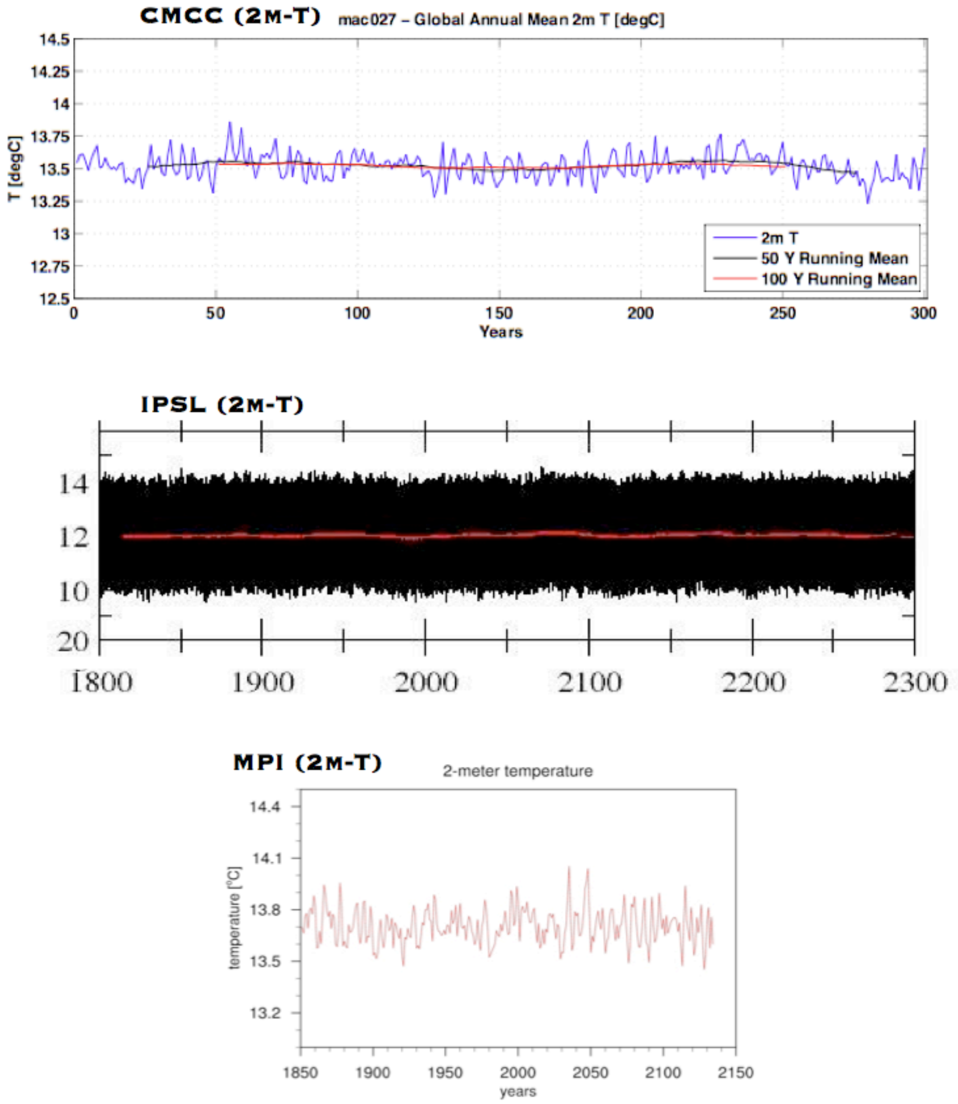

Figure 1-A: Time series of the global annual mean 2m temperatures for CMCC-CSM (blue) IPSL (red) and MPI-ESM (red) for the pre-industrial simulation (CMCC: 300-yr, IPSL: 500-yr, and MPI: 300-yr). 50-yr (black) and 100-yr (red) running mean are also shown for the CMCC model. The black shade for the IPSL model is the time series of the 2m temperature monthly mean.

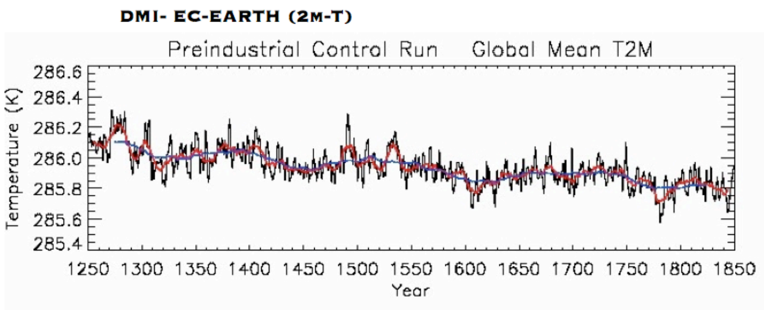

Figure 1-B: Time series of the global annual mean 2m temperature (black) for the EC-EARTH model, low-top version. Low-pass running means shown also (red and blue curves)

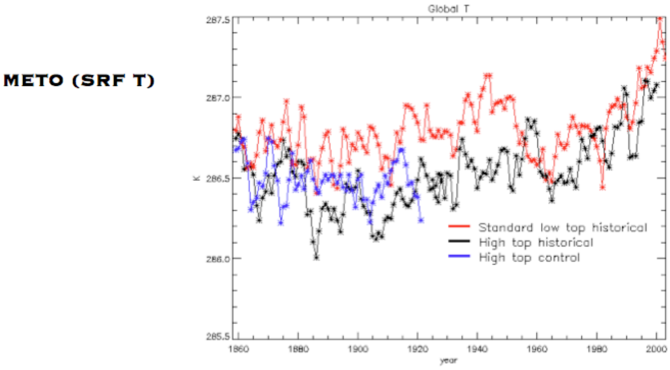

Figure 1-C: Time series of the global annual mean surface temperature for the pre-industrial simulation (blue) and historical simulation (black, 1860 to 2005) run with the HadGEM high top configuration, and historical simulation (red) run with the HadGEM low top (standard) simulation.

Time series of global annual mean TOA, SST and Arctic and Antarctic sea-ice concentrations (not shown) confirm that the CMCC-CMS, COSMOS, IPSL-CM5, and HadGEM models have acceptably small climate drift and reasonable surface climate. The EC-EARTH model has fewer years in its high-top configuration (control and historical). Tropospheric mean climate and variability at different timescales in the pre-industrial/control and historical runs is currently being analysed.

4.2 Stratosphere

Preliminary analysis of the stratosphere indicates that the high top ESMs are able to reproduce the monthly and seasonally averaged zonal mean temperature and zonal wind climatology and interannual standard deviation reasonably well (not shown). A notable feature of new stratospheric components of the models is the ability to reproduce key aspects of the stratospheric variability compared to versions of the model without a proper representation of the stratosphere. In the tropics, the CMCC-CMS and HadGEM2-CC models can reproduce a realistic QBO (Figures 2-A and B).

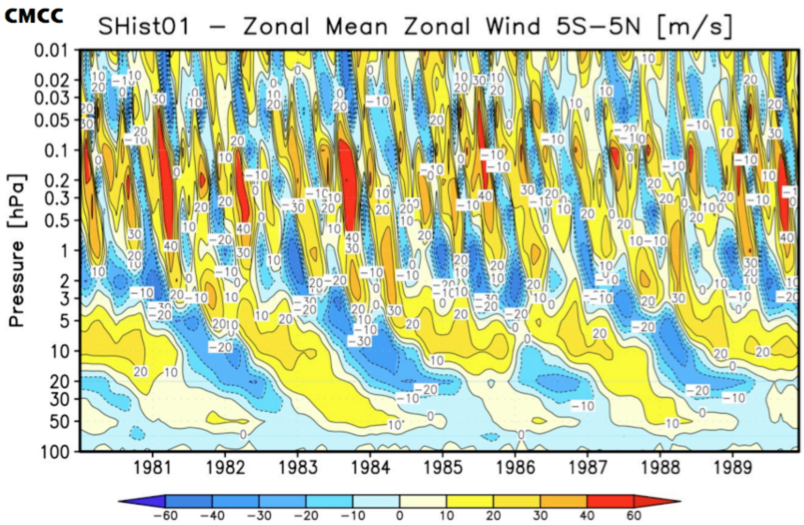

Figure 2-A: Time series (10-yr) of the monthly zonal mean zonal wind (ms^{-1}) averaged (5^oS-5^oN) from CMCC-CMS from the historical run

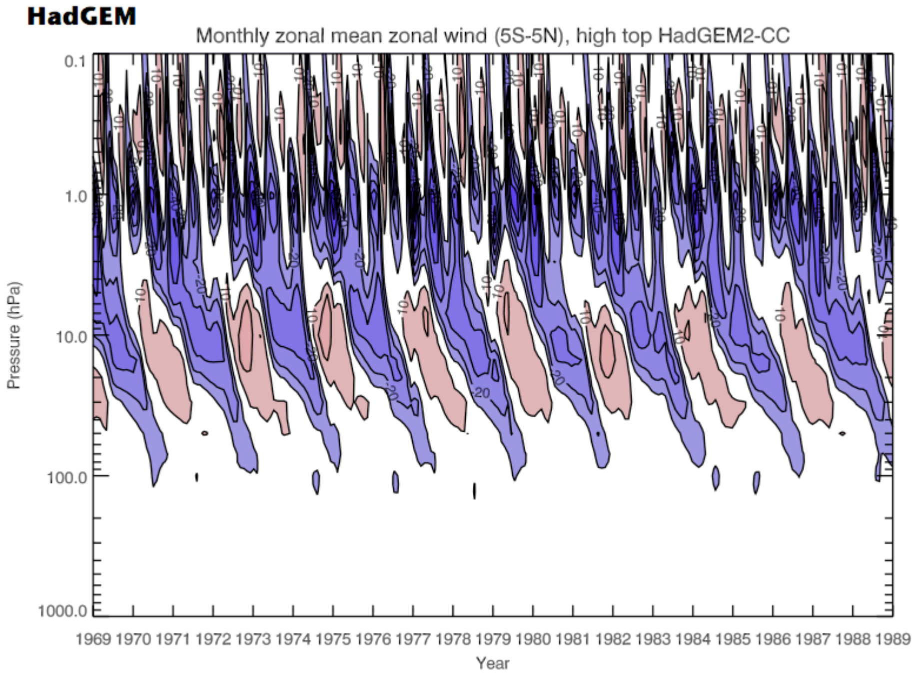

Figure 2-B: Time series (20-yr) of the monthly zonal mean zonal wind (ms^{-1}) averaged (5^oS-5^oN) from HadGEM2-CC, high top version, from the historical run. Negative values shaded blue and positive shaded red.

In both models, the period of the oscillation is ~28-months, in good agreement with observations. However, both the westerly and the easterly phases are less regular in CMCC-CMS than in HadGEM2-CC, with occasionally deeper (reaching lower altitudes, higher pressures) westerly phases in CMCC-CMS. Quantitative analysis of the variability in the QBO and its forcing will be the reported in deliverable D3.3 "*Report on the troposphere-stratosphere system in the tropics*".

Stratospheric extra-tropical variability is manifested by the occurrence of major stratospheric warming (SSW) events. Modelling SSW events is of primary importance, as they are the clearest manifestation of the coupling of the stratosphere–troposphere system. In the standard definition, a major SSW event occurs if the 10-hPa meridional zonal mean temperature gradient between 60^oN and the North Pole is positive and the zonal mean zonal wind at 10hPa and 60^oN becomes easterly, for at least 4 days. Therefore, and easy visual diagnostic of SSW is to plot the daily evolution of zonal mean zonal winds at 60^oN, 10 hPa (Figures 3 and 4).

Figure 3 shows the daily evolution of zonal mean zonal winds at 60^oN, 10 hPa for HadGEM, MPI-ESM and CMCC-CMS, for the extended winter season (1 November to 1 April). The shading / dashed envelopes extending below the zero wind line are indicatives of the occurrence of the major SSW events. Figure 3 therefore shows that there are clearly a number of major SSW events throughout the winter season and the early spring for all the high-top climate models. Differences in the seasonality of the envelopes may be due not only to the model configurations, but also to the number of years considered in calculating the plots and the radiative forcing of the simulations. While 100-yr (285-yr) from the preindustrial control runs are used in the case of the of the CMCC (MPI) model, the HadGEM results are from the historical run. Figure 3 also clearly illustrates that major SSW events are instead virtually absent or show a smaller frequency of occurrence in the low-top HadGEM version (top panel, in red).

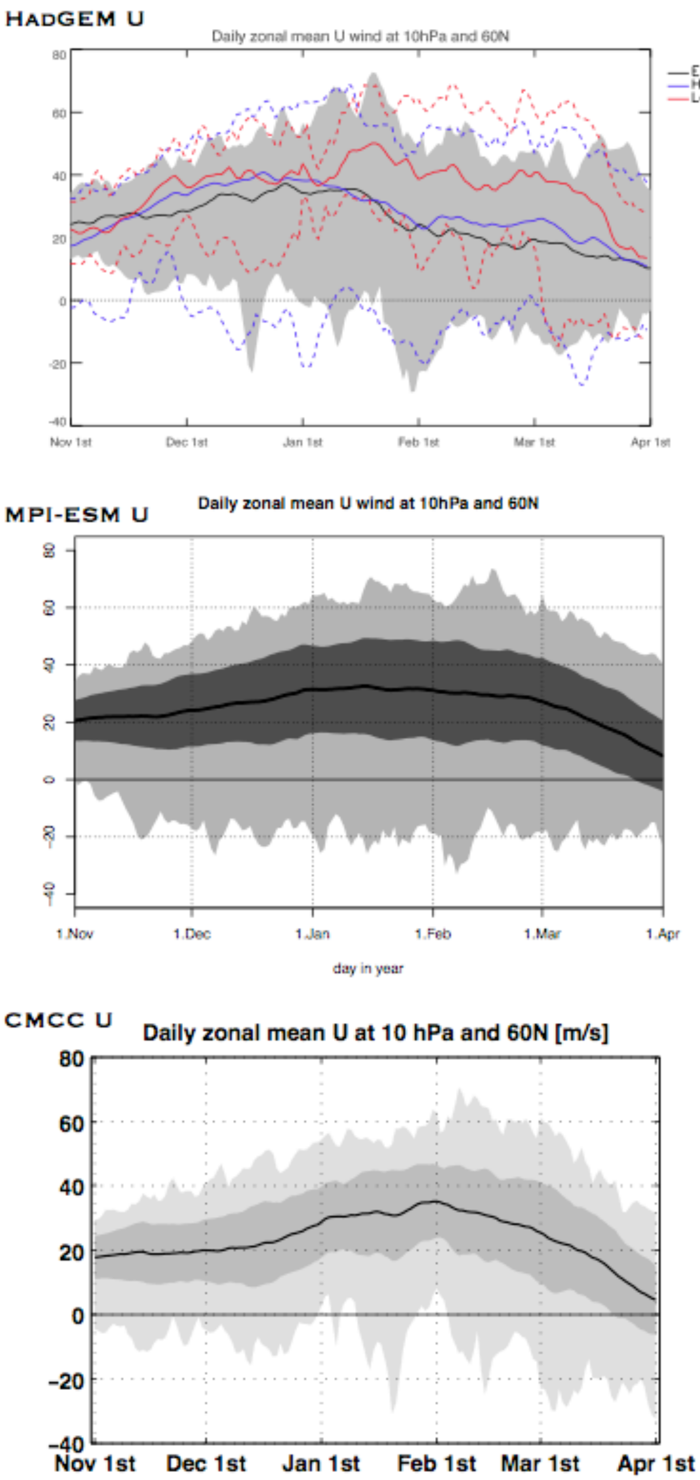

Figure 3: November to April daily zonal mean zonal wind (ms^{-2}) at 60^oN, 10 hPa. Climatology depicted in solid for (top panel): ERA40-I (black), low-top (red) and high top (blue) HadGEM; (middle panel) MPI-ESM and (bottom panel) CMCC-CMS (both in black). Grey envelopes (where plotted) represent individual maxima and minima and ±1 standard deviation (dark grey for CMCC-CMS and MPI-ESM, colour dashed lines for HadGEM). CMCC (100-yr) and MPI (285-yr) are from the preindustrial control and HadGEM from the historical simulations.

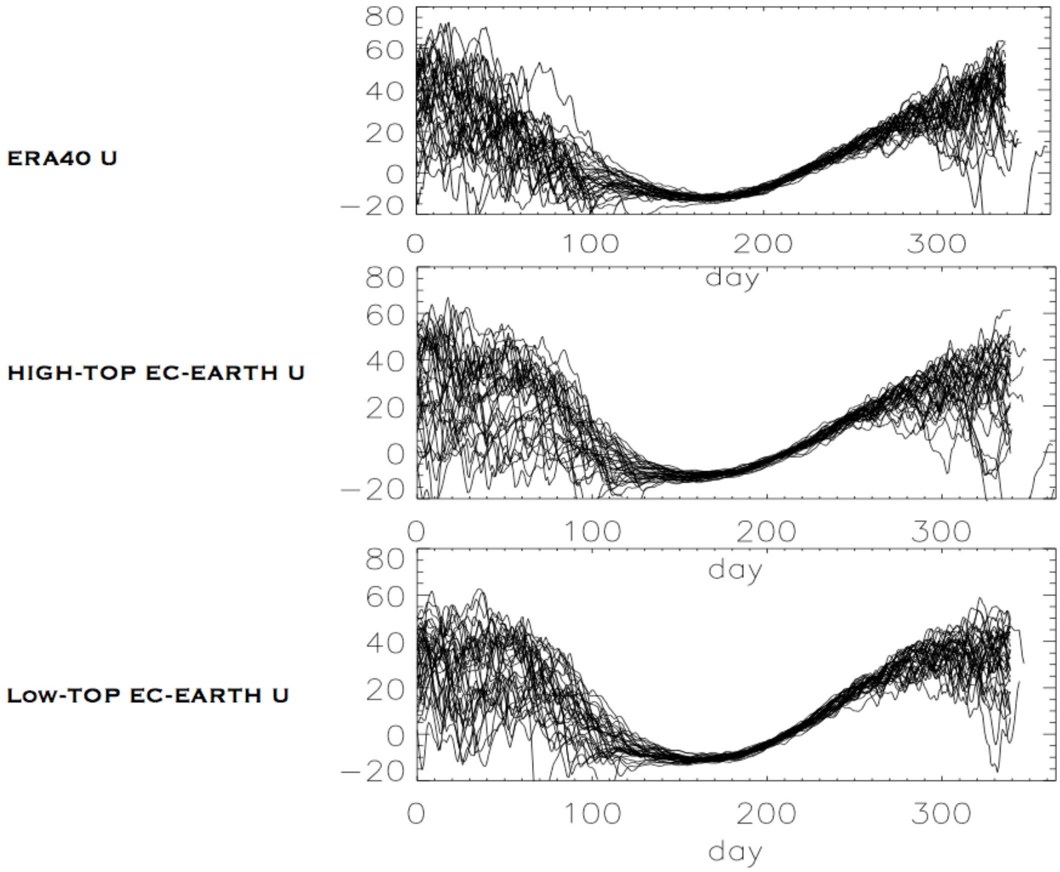

Figure 4: January to December daily zonal mean zonal wind (ms^{-2}) at 60^{o}N, 10 hPa. Individual years are shown for ERA40 (top), high-top EC-EARTH (middle) and low-top EC-EARTH (bottom) model versions. The wind data are from a present day simulation.

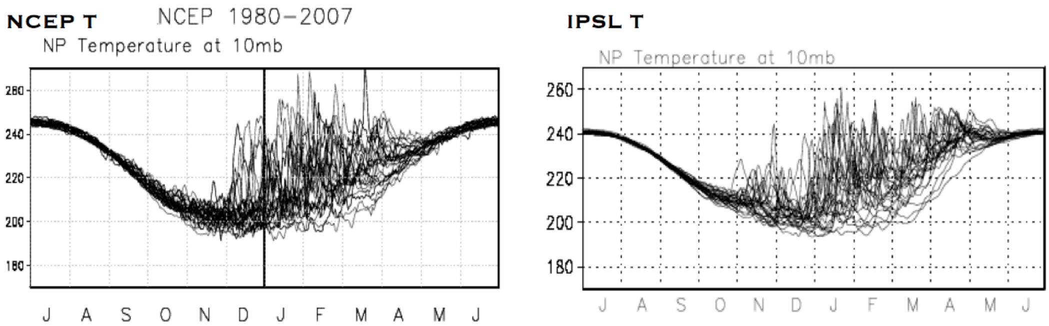

Figure 5: July to June daily zonal mean temperature (K) at 80^{o}N, 10 hPa. Individual years are shown for (let) NCEP and (right) IPSL model from the historical simulation.

Figure 4 shows the daily evolution of zonal mean zonal winds at 60^{o}N, 10 hPa for the high-top and low-top configurations of the EC-EARTH model and ERA40. In this case, the individual time series are shown, from January 1 to December 31. Also in this case, the visual inspection of Figure 4 reveals a higher frequency of negative zonal mean zonal winds during winter in the high-top model with respect to the low-top model.

In summary, both Figures 3 and 4 show that in the extra-tropics the modelling of SSWs in the ESMs has been significantly improved, confirming the expectations from results of AMIP simulations (Cagnazzo and Manzini 2009).

In the case of the IPSL model (Figure 5), the daily evolution of zonal mean temperature at 80^{o}N, 10 hPa is shown and compared to NCEP. In this case, sharp peaks in the temperature time series illustrate the occurrence of SSW. Visually, there is a good agreement between the "cloud" of SSW events from IPSL and NCEP.

Quantitative analysis on the SSW events and analyses of wave propagation into the stratosphere in the pre-industrial and historical runs will be the reported in deliverable D3.2 "*Report on the stratosphere-troposphere dynamical feedback*".

5. Conclusions

Stratospheric model components have been successfully implemented in the ESMs participating in WP3. First results indicate that the new high-top models provide a good representation of the stratospheric climate and variability. Four of the models (CMCC-CMS, MPI-ESM, IPSL-CM5 and HadGEM2-CC) have completed long pre-industrial control simulations. For these models essentially no climate drift is reported in key climate parameters such as global surface temperature, top of the atmosphere radiation and Arctic and Antarctic sea ice amounts. One model (EC-EARTH) has performed the pre-industrial control simulation with the low-top version only, the high-top pre-industrial control simulation being planned. Historical simulations (1860-2005) and RCP4.5 have been completed or are in progress or planned.

A first notable achievement of the implementation of the stratosphere has been a significant improvement in the stratospheric variability both in the tropics and in the extra-tropics. In the tropics, two of the models are able to internally generate a realistic QBO. In the northern hemisphere extra-tropical regions, preliminary results show that the high top models perform well in reproducing intra-seasonal and interannual variability as manifest by the occurrence of major stratospheric sudden warming events.

References

Alessandri, A. (2006): Effects of Land Surface and Vegetation Processes on the Climate Simulated by an Atmospheric General Circulation Model. PhD Thesis in Geophysics, Bologna University Alma Mater Studiorum, 114 pp.

Cagnazzo, C. and E. Manzini, 2009 Impact of the Stratosphere on the Winter Tropospheric Teleconnections between ENSO and the North Atlantic and European Region. J. Climate, 22, 1223-1238.

Cagnazzo C., Manzini, E., Giorgetta, M. A., Forster, P. M. De F., and Morcrette, J. J.: Impact of an improved shortwave radiation scheme in the MAECHAM5 General Circulation Model, Atmos. Chem. Phys., 7, 2503-2515, 2007.

Collins, W. J., N. Bellouin, M.Doutriaux-Boucher, N. Gedney, T. Hinton, C. D.Jones, S.Liddicoat, G.Martin, F.O'Connor, J. Rae, C.Senior, I. Totterdell, S.Woodward. T. Reichler and J. Kim, 2008: Evaluation of HadGEM2 model. Hadley Centre Technical Note (74).

Fichefet, T. and Morales-Maqueda, M.A. (1997): Sensitivity of a global sea ice model to the treatment of ice thermodynamics and dynamics. J. Geophys. Res. 102, 12,609 – 12,646.

Fogli, P.G. and Coauthors, 2009: INGV-CMCC Carbon: A Carbon Cycle Earth System Model, CMCC online RP0061: http://www.cmcc.it/publications-meetings/publications/research-papers/rp0061-ingv-cmcc-carbon-icc-a-carbon-cycle-earth-system-modelhttp://www.cmcc.it/publications-meetings/publications/research-papers/rp0061-ingv-cmcc-carbon-icc-a-carbon-cycle-earth-system-model

Giorgetta et al., 2006: Climatology and Forcing of the Quasi-Biennial Oscillation in the MAECHAM5 Model, J. Climate, 22, 3882-3901.

Hazeleger, et al, 2010: EC-Earth: A Seamless Earth System Prediction Approach in Action. B. Amer. Met. Soc., 91, 1377-1388.

Hines, C. O., 1997a. Doppler spread parameterization of gravity wave momentum deposition in the middle atmosphere. Part I: Basic formulation. J. Atmos. Solar Terr. Phys., 59, 371 – 386.

Hines, C. O.,1997b. Doppler spread parameterization of gravity wave momentum deposition in the middle atmosphere. Part II: Broad and quasi monochromatic spectra and implementation. J. Atmos. Solar Terr. Phys., 59, 387 – 400.

Hourdin, F., I. Musat, S. Bony, P. Braconnot, F. Codron, J.-L. Dufresne, L. Fairhead, M.-A. Filiberti, P. Friedlingstein, J.-Y. Grandpeix, G. Krinner, P. Levan, and F. Lott, The LMDZ4 general circulation model: climate performance and sensitivity to parametrized physics with emphasis on tropical convection, Climate Dynamics, 27, 787-813, DOI: 10.1007/s00382-006-0158-0 , 2006

Jungclaus, J.H. , N. Keenlyside, M. Botzet, H. Haak, J.-J. Luo, M. Latif, J. Marotzke, U. Mikolajewicz, and E. Roeckner, Ocean circulation and tropical variability in the coupled model ECHAM5/MPI-OM, J. Climate, 19, 3952-3972, 2006.

Krinner, G., N. Viovy, N. de Noblet, J. Ogée, J. Polcher, P. Friedlingstein, P. Ciais, S. Sitch, et I.C. Prentice, 2005. A dynamic global vegetation model for studies of the coupled atmosphere-biosphere system, Global Biogeochemical Cycles, 19, GB1015, doi:10.1029/2003GB002199.

Madec, G., Delecluse, P., Imbard, I. and Levy, C. (1999): OPA 8.1 Ocean General Circulation Model reference manual. Note du Pôle de modélisation No. 11, Inst. Pierre-Simon Laplace (IPSL), France, 91 pp.

Lott, F.,L. Fairhead, F. Hourdin and P. Levan, The stratospheric version of LMDz: Dynamical Climatologies, Arctic Oscillation, and Impact on the Surface Climate. Climate Dynamics, 25, 851-868, DOI: 10.1007/s00382-005-0064-x, 2005.

Manzini, E., McFarlane, N. A. and McLandress, C., 1997. Impact of the Doppler spread parameterization on the simulation of the middle atmosphere circulation using the MA/ECHAM4 general circulation model . J. Geophys. Res., 102, 25751 – 25762.

Manzini, E., M. A. Giorgetta, M. Esch, L. Kornblueh, and E. Roeckner, 2006: The influence of sea surface temperatures on the northern winter stratosphere: Ensemble simulations with the MAECHAM5 model. J. Climate, 19, 3863–3881.

Ineson, S. and A. A. Scaife, 2009: The role of the stratosphere in the European climate response to El Niño, Nature Geoscience, 32, DOI:10.1038/NGEO381.

Redler, r., S. Valcke and H. Ritzdorf, 2010: OASIS4 - A Coupling Software for Next Generation Earth System Modelling, Geoscience Model Development, 3, 87 - 104, DOI:10.5194/gmd-3-87-2010

Roeckner, E., R. Brokopf, M. Esch, M. Giorgetta, S. Hagemann, L. Kornblueh, E. Manzini, U. Schlese, and U. Schulzweida (2006): Sensitivity of simulated climate to horizontal and vertical resolution in the ECHAM5 atmosphere model. J. Climate, 19, 3771-3791.

Scaife, A. A., N. Butchart, C. D. Warner, D. Stainforth, W. Norton, and J. Austin (2000), Realistic quasi-biennial oscillations in a simulation of the global climate, Geophys. Res. Lett., 27(21), 3481-3484.

Scaife, A. A., N. Butchart, C. D. Warner, R. Swinbank, 2002: Impact of a Spectral Gravity Wave Parameterization on the Stratosphere in the Met Office Unified Model. J. Atmos. Sci., 59, 1473–1489.

Valcke, S. (2006): OASIS3 User Guide (prism_2-5), PRISM Report No 2, 6th Ed., CERFACS, Tolouse, France, 64 pp.

Vancoppenolle, M., T. Fichefet, H. Goosse, S. Bouillon, C. K. Beatty and M. A. Morales Maqueda (2008). LIM3, an advanced sea-ice model for climate simulation and operational oceanography. Mercator Newsletter, 28.

Vichi, M., Pinardi, N., Masina, S. (2007): A generalized model of pelagic biogeochemistry for the global ocean ecosystem: Part I. Theory. J. Mar. Syst. 64, 89-109.