SPECIAL PROJECT INTERIM REPORT

Interim 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	2010-2011
Project Title:	EC-EARTH: developing a European Earth System model based on ECMWF modelling systems
Computer Project Account:	SPNLTUNE
Principal Investigator(s):	Dr. W. Hazeleger
Affiliation:	KNMI
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Simona Stefanescu
Start date of the project:	1 Jan 2009
Expected end date:	31 Dec 2012

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)	5,000,000	~4,900,000	7,000,000	~5,000,000 (June 2009)
Data storage capacity	(Gbytes)	15 Tb	?	15 TB	?

Summary of project objectives

(10 lines max)

Develop a global Earth System model (EC-Earth) consisting of a state-of-the-art atmospheric general circulation model, a state-of-the-art ocean general circulation model, a sea-ice model, a land model, and an atmospheric chemistry model (see http://ecearth.knmi.nl), to be used for climate research and climate/decadal prediction studies. This is part of a seamless prediction strategy, linking NWP modelling at ECMWF to earth system modelling at Member States involved in EC-Earth. More specifically:

a) Development/tuning of the EC-EARTH earth system model consisting of the IFS (CY31R1) atmosphere model and the OPA/NEMO ocean model coupled using OASIS3, in the configuration HTESSEL-NEMO2/LIM2-OASIS3. The current version (EC-Earth V2.3) was released in June 2011. This latest version will be used to perform climate runs for the CMIP5 (Climate Model Intercomparison Project, stage 5) initiative.

b) Verify and tune the mean state, (interannual) variations and climate sensitivity of the latest version of EC-Earth, since this version will be used in the forthcoming Coupled Model Intercomparison Projects (CMIP5) that will form the basis of climate change assessments (e.g. IPCC). Later in 2011, we will start testing the next full version (V3) of EC-Earth.

Summary of problems encountered (if any)

(20 lines max)

No specific problems, although in the near-future we will likely need additional storage to accommodate (model level) output of the various test runs. Model level output is needed for detailed analysis and for using the global model output as boundary conditions for regional atmospheric models. Until now, we used about 75% of the intended resources for 2011. We expect that the second half of 2011 will see continued use for further testing, also fo the new version of EC-Earth (V3). Hence, we expect that, as in 2010, the total for 2011 will be largely used.

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 and Hazeleger et al (BAMS, 2010).

See summary at the end of this document.

List of publications/reports from the project with complete references

Hazeleger, W. et al. EC-Earth, 2010. A seamless Earth system prediction approach in action. *Bull. Am. Meterol. Soc*. **91**, 1357-1363, doi:10.1175/ 2010BAMS2877.1.

Haarsma, R.J., F. Selten, B. van der Hurk and W. Hazeleger, 2009. Drier Mediterranean soils due to greenhouse warming bring easterly winds over summertime central Europe. *Geophys. Res. Lett.*, **36**, L04705, doi:10.1029/2008GL036617.

EC-EARTH, Science and Implementation Plan, KNMI report nr 217.

Summary of plans for the continuation of the project

(10 lines max)

The consortium is currently using Version 2.3 of EC-EARTH as backbone version for national projects, EU-FP7 projects and for the CMIP5 (World Climate Research Program) projects. Later this year, version 3 based on IFS cycle36r4, NEMO V3 and LIM2 or LIM3 will become available. Moreover, the chemistry-transport model TM5 is already coupled to the current version. Aside from further development/testing of the current version 2.3 of EC-Earth, new components will henceforth be added to the model version to lead to Version 3 and Version 4 of EC-Earth, which will obviously involve further development, testing and tuning. In particular, we expect that tuning and development of version 3 will become a major activity during the last part of 2011. It is expected that ECMWF can take over modules developed within the EC-Earth project. In fact, this has already happened as the snow scheme of Dutra et al. (2010) has been implemented in IFS cycle 36.

To summarise, within this Special Project we will continue/start the following activities:

- 2011: Further test and optimise fully coupled EC-EARTH Version 2.3.
- 2011: Test and optimize fully coupled EC-EARTH Version 3.
- 2011: Test modifications, merging and testing new components (in particular TM5) in a iterative strategy in EC-EARTH Versions 2.3 and later version 3.
- 2011: Implement EC-EARTH in the ECMWF version management system as a branch of IFS
- 2012: Test and optimize fully coupled EC-EARTH Version 3 and comparison to ECMWF's Seasonal Forecast Version 4.
- 2012: Test modifications, merging and testing new components:
    - LIM3 new sea ice
    - LPJ and H-Tessel (including new anthropogenic components as urbanization and irrigation
    - PISCES ocean biogeochemistry
    - Full coupling TM5 (including M7 aerosol scheme online coupled to radiation scheme).
- 2012-2013: Test and optimize fully coupled EC-EARTH Version 3 and development towards Version 4, including atmospheric chemistry, dynamic vegetation, ocean biogeochemistry and integrated assessment models (IMAGE).

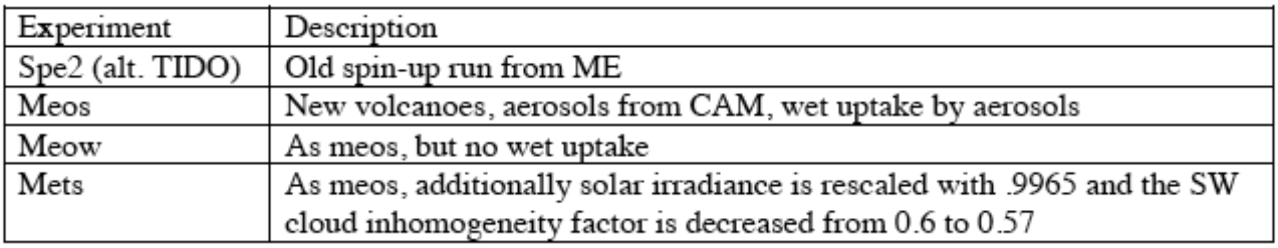
Summary of results of the current year (July 2010 to June 2011)

A large fraction of the work done under this special project revolved around making the model EC-Earth (V2.3) suitable to perform CMIP5 experiments. This again required a significant amount of testing. Moreover, a few errors and inconsistencies were discovered during this year, resulting in changes to the model, and, consequently, we had to (partially) redo testing and tuning of the model. Luckily, we could reuse the technique(s) we developed and used before (those mentioned in the reports of previous years), namely those required to compare the mean state, the seasonality and interannual variability. In fact, we have used these methods to compare the new testruns against each other, and against a previous control run.

We found that EC-Earth V2.2 contained a number of errors. First, the volcanic signal was too weak. Secondly, several errors were discovered in the treatment and inclusion of aerosols. Finally, the solar irradiance for CMIP5 had to be adjusted. As a result, a number of experiments had to be carried out to test the effect of correctly implementing the following features:

* modified volcanic aerosol optical depth and its inclusion in the radiation scheme
* various aerosol bug fixes
* inclusion of the wet uptake process by aerosols (which was already built in in IFS)
* decrease solar irradiance as specified by CMIP5
* adjustment of the cloud inhomogeneity factor (to retune the model)

Here we will show results of a selection of the testruns that were carried out, see the Table 1.



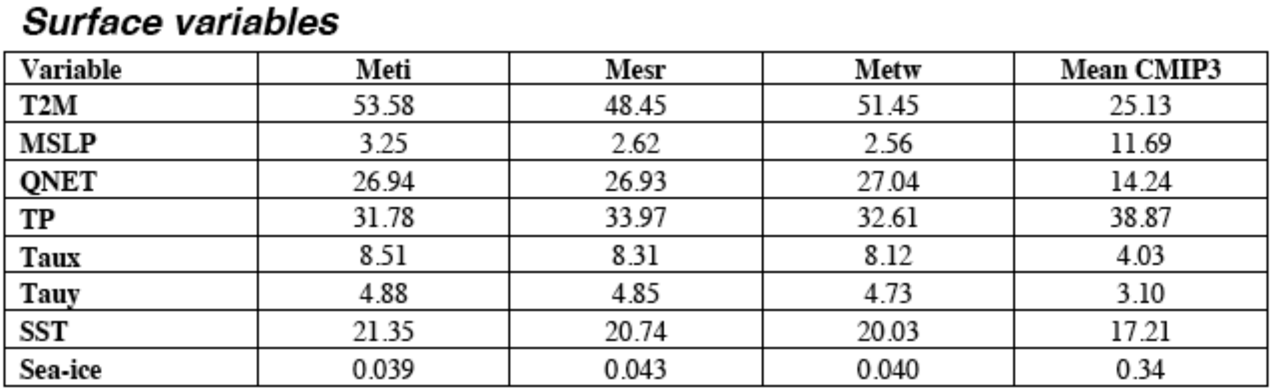
Experiment	Description
Spe2 (alt. TIDO)	Old spin-up run from ME
Meos	New volcanoes, aerosols from CAM, wet uptake by aerosols
Meow	As meos, but no wet uptake
Mets	As meos, additionally solar irradiance is rescaled with .9965 and the SW cloud inhomogeneity factor is decreased from 0.6 to 0.57

Table 1. Description of the various experiments, control experiments. The corresponding abbreviations for the temporal forcing runs are METI, METW and MESR, respectively.

As the CMIP5 experiments start from preindustrial conditions (year 1850), all runs start from the previous ~1000-yr control experiment that was run for 1850 conditions. For each of the 3 new sets of experiments, we did a control run (no temporal forcing, so perpetual 1850 conditions) and a run starting in 1850 going to 2005 with observed temporal forcing (GHGs, aerosols, volcans, solar irradiance, ozone). The former runs will provide insight in how much the new set up will drift away from the previous control run, whereas the latter set up will show if the simulated trends of the past 150 years have been altered because of the model changes.

1. The atmosphere – mean state and multi-year variability

Testing and tuning of the EC-Earth model requires guidelines that are as objective as possible. In our report of last year we introduced a climate metric in an attempt to more objectively improve various aspects of the mean state of the *current* climate. For that purpose we adopted the performance index of Reichler and Kim (2008) (henceforth RK), which has been used to compare the performance of various models contributing to CMIP3. It is based on the squared differences of a number of simulated parameters, such as 2 meter temperature (T2m), mean sea level pressure (MSL), precipitation and vertical distributions of various quantities, with observations, scaled with the interannual variance in the observed quantity. Here we use the same methodology to intercompare are experimental set ups (see Table 1). Table 2 shows the global performance indices for the 3 experiments (the control runs), which comprise of output from the time-varying runs for 1990-1999.

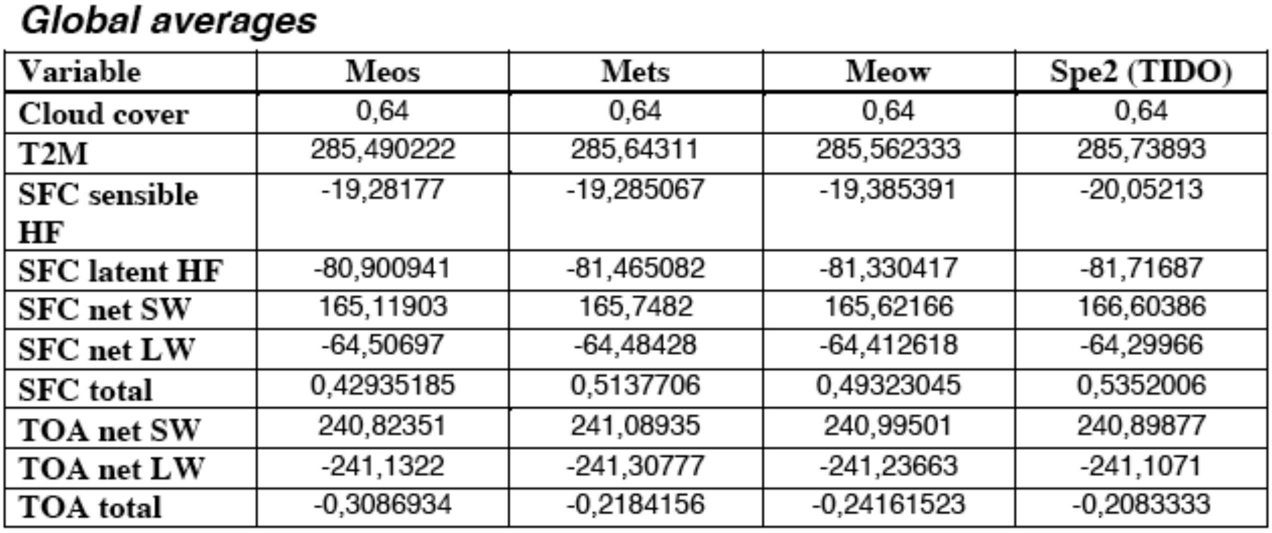


Surface variables

Variable	Meti	Mesr	Metw	Mean CMIP3
T2M	53.58	48.45	51.45	25.13
MSLP	3.25	2.62	2.56	11.69
QNET	26.94	26.93	27.04	14.24
TP	31.78	33.97	32.61	38.87
Taux	8.51	8.31	8.12	4.03
Tauy	4.88	4.85	4.73	3.10
SST	21.35	20.74	20.03	17.21
Sea-ice	0.039	0.043	0.040	0.34

Table 2. Global performance index (RK) for the 3 control experiments (1990-1999) and the average of all CMIP3 models. The lower the values, the better. (QNET: surface heat flux, TP: total precipitation, Tau: momentum flux).

The performance indices of the 3 experiments are very similar. None of the experiments sticks out as being better throughout or being worse throughout than the others. The EC-EARTH experiments are better than the average CMIP3 model only for MSL, TP and sea-ice, for all other variables the EC-EARTH model is doing worse. This finding is valid irrespective of the details of the model version that have been tested. Next, we compare the global mean quantities for the runs with perpetual 1850 conditions (Table 3).



Global averages

Variable	Meos	Mets	Meow	Spe2 (TIDO)
Cloud cover	0,64	0,64	0,64	0,64
T2M	285,490222	285,64311	285,562333	285,73893
SFC sensible HF	-19,28177	-19,285067	-19,385391	-20,05213
SFC latent HF	-80,900941	-81,465082	-81,330417	-81,71687
SFC net SW	165,11903	165,7482	165,62166	166,60386
SFC net LW	-64,50697	-64,48428	-64,412618	-64,29966
SFC total	0,42935185	0,5137706	0,49323045	0,5352006
TOA net SW	240,82351	241,08935	240,99501	240,89877
TOA net LW	-241,1322	-241,30777	-241,23663	-241,1071
TOA total	-0,3086934	-0,2184156	-0,24161523	-0,2083333

Table 3. Global mean quantities for the various model runs. T2m = 2m temperature, SFC = surface, HF = heat flux, SW = shortwave, LW = longwave, TOA = top of atmosphere.

There are some systematic differences between the old spin-up run and the new experiments. Net shortwave radiation at the surface is lower as a consequence of the changes to the treatment of aerosols. The reduced SW radiation results in lower T2m and subsequently surface heat fluxes. The energy balance at the surface remains more or less the same as in the old spin-up run except in MEOS where it gets smaller. The differences in TOA radiation are small, the net radiation balance gets slightly smaller in all new experiments. The largest difference to SPE2 is found for MEOS but still well below +/- 0.5 W/m2. It is of interest to infer how these global values relate to a time-varying quantity like surface air temperature.

2m temperature:

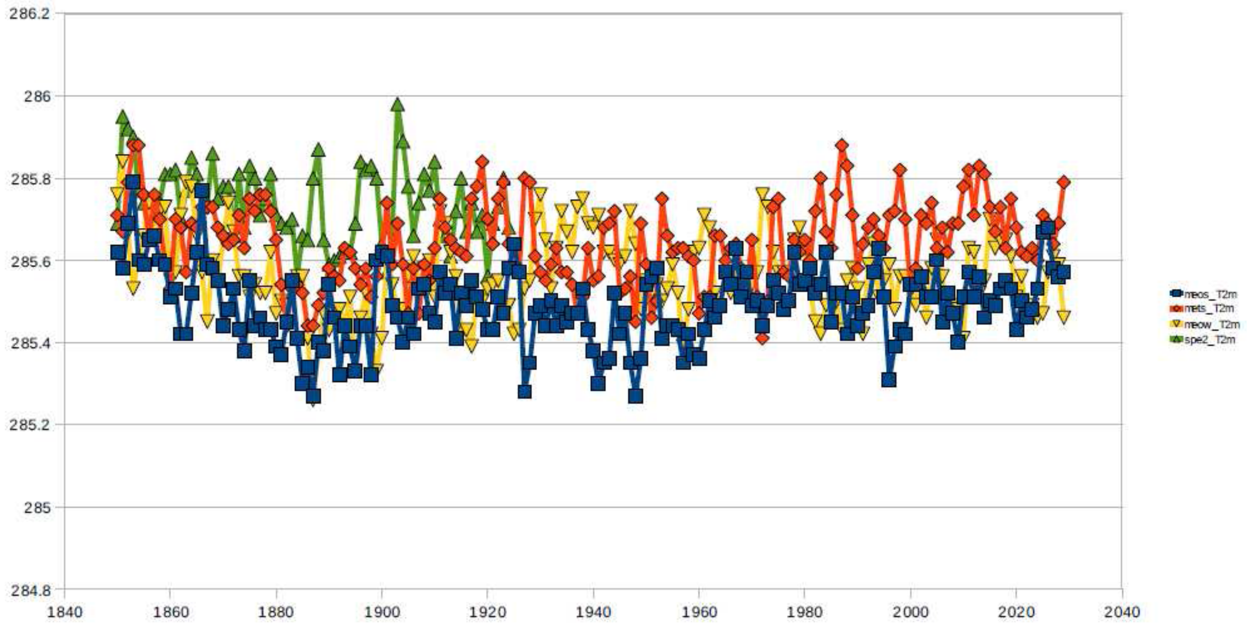
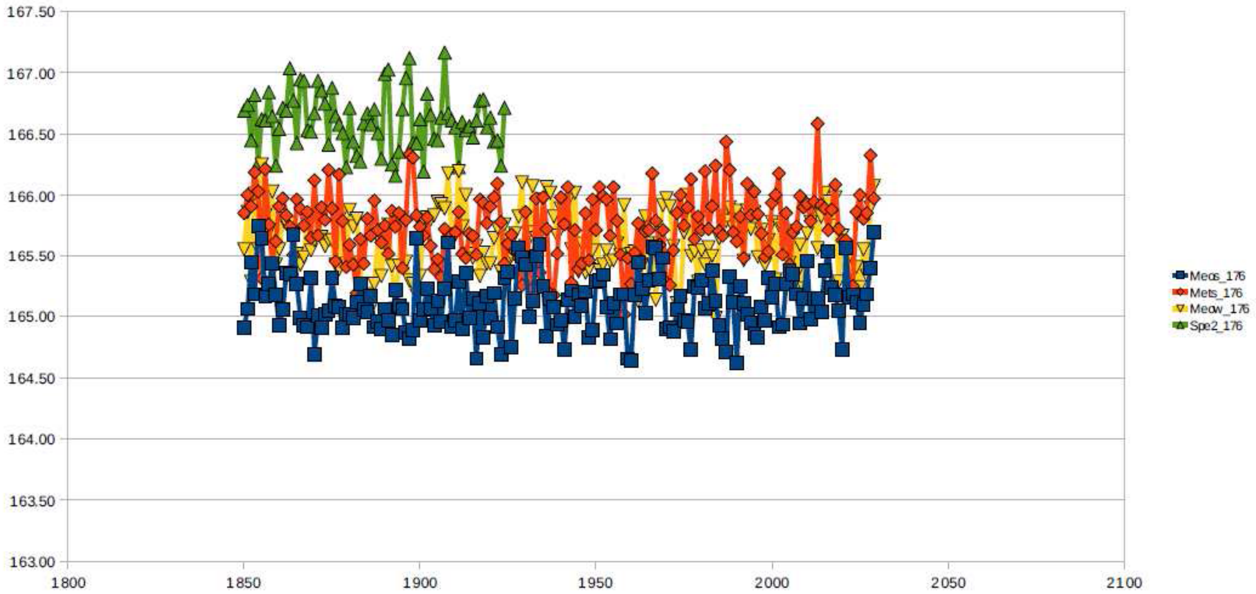


Figure 1. Temporal variation in 2m temperature for the 3 new control runs as compared to the old control run (1850 conditions).

Global average T2m is lower in the new experiments compared to the old spin-up (0.1 – 0.3K), see Fig. 1. METS is always warmest and meos always coldest of all experiments. Interesting is MEOW: its T2m during the period 1880 to 1925 is close to that of MEOW, after that there is a jump to the higher temperature level followed by a gradual decline over the next 50 years back to the level of MEOS. Another point worth noting: the difference in surface SW radiation between MEOS and MEOW (see below) seems to have little impact on the average T2m. The wet uptake thus modifies the surface radiation as expected, but it has little bearing for the surface temperature. On the other hand, the changes in METS have a persistent impact on T2m. The reduction of the SW cloud inhomogeneity factor apparently more than compensates for the reduction in the solar irradiance.

Surface Solar Radiation (net):



TOA Solar Radiation:

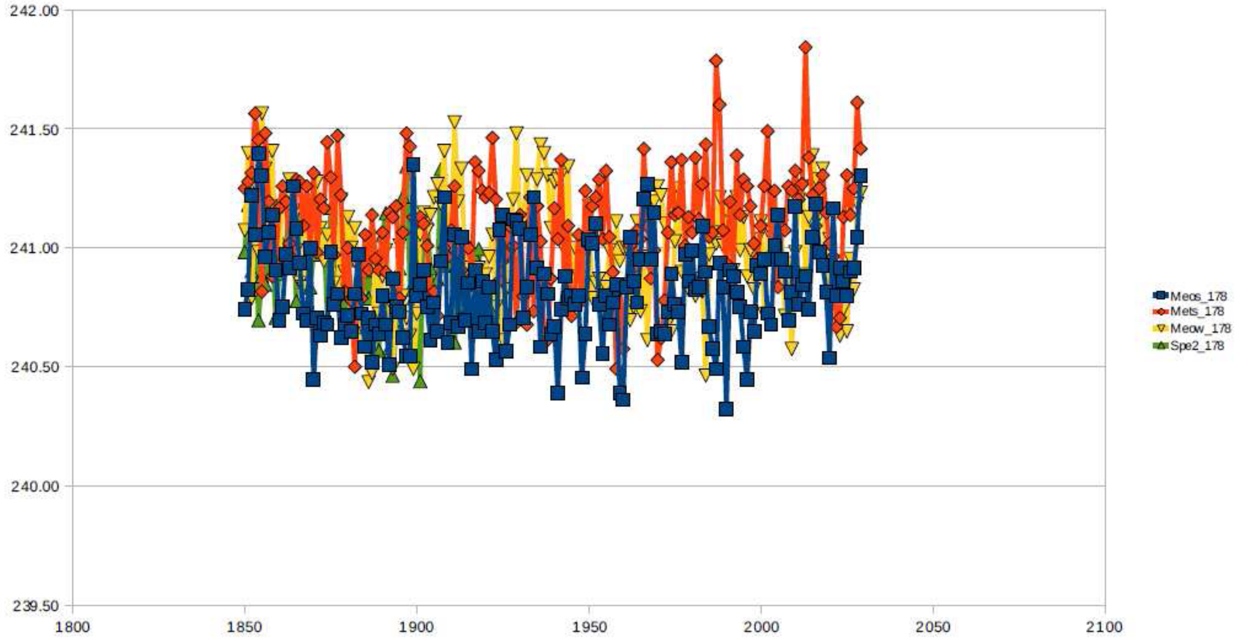


Figure 2. Temporal variation in surface and TOA shortwave radiation for the 3 new control runs as compared to the old control run (1850 conditions).

The changes in aerosol treatment likely affects the shortwave radiation budget, which is shown in Fig. 2. Surface SW is reduced in all new experiments as a consequence of the changes in the aerosol concentration. Including the wet uptake reduces the net SW radiation by another 0.5 W/m2. In METS, this would be further reduced by the decrease in solar irradiance, but this is compensated for, and even more than compensated for by the reduction of the SW cloud inhomogeneity factor.

The average net SW at TOA does not change much with the new code, but there seems to be a stronger year-to-year variability in METS, especially after more than 100 years of the simulation.

2. Ocean and sea ice – mean state and multi-year variability

Obviously, one expects the ocean changes to be smaller in magnitude and to occur more slowly.

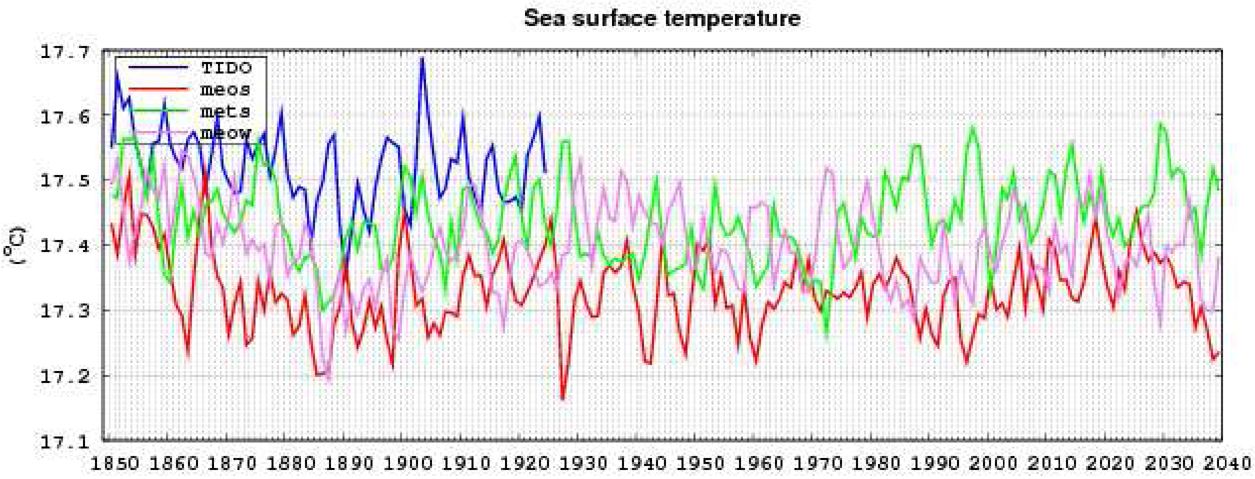


Figure 3. Variation of sea surface temperature SST for the 3 control experiments.

All new experiments (Fig. 3) exhibit slightly lower (0.1-0.2 K) global mean SST than what we had in the old spin-up (TIDO) experiment. The lowest SST is obtained with MEOS, while METS gives the highest SST of the new experiments on average. The year-to-year variability is similar in the new experiments and in the old spin-up. The maximum of the Atlantic MOC of the new experiments (not shown) is possibly somewhat higher than the AMOC from the old spin-up run, but still within the observational estimates. The lowest value in TIDO is ~12 Sv, while none of the new experiments goes much below 14 Sv. The maximum in MEOS and METS is 19 Sv and 18 Sv in MEOW which is close to the maximum value in TIDO during the 75 years of data that we have for this experiment. MEOS shows a peristsnt increase of the maximum AMOC from 1960 to2000, but then the trend is reverted and the AMOC returns back to the level of the other experiments.

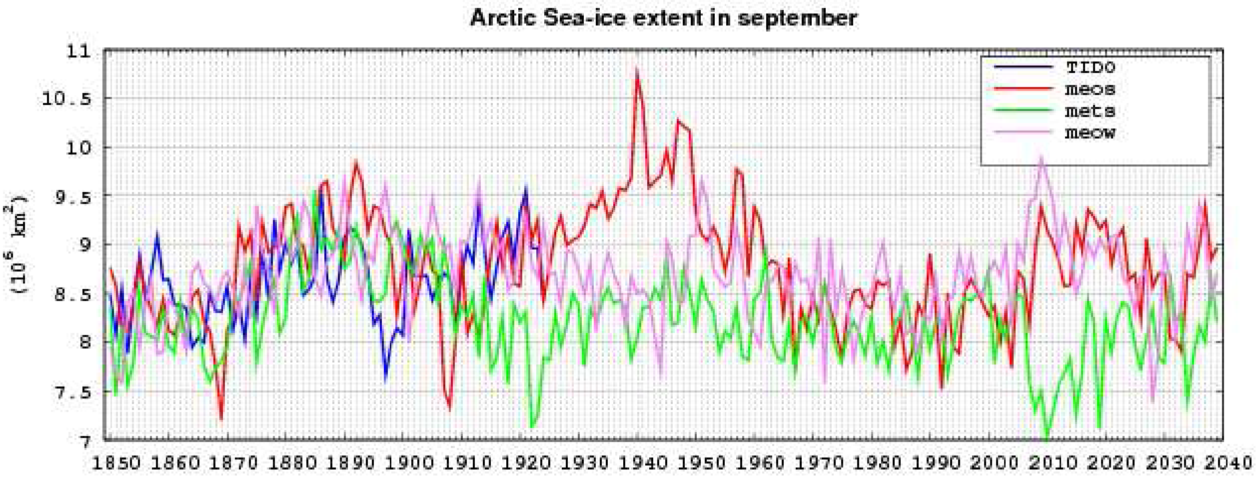


Figure 4. Variation of Arctic sea ice extent in September for the 3 new experiments.

The minimum Arctic sea-ice extent (Fig. 4) is possibly somewhat lower in the new experiments compared to the old spin-up. MEOS shows persistently a higher sea-ice concentration compared to other experiments between years 70 and 110 (1920-1960 in the figure), but then it goes back to the level of the others. The sea-ice concentration in September (Fig. 5) shows little difference between TIDO and the new experiments in the central Arctic and the Eurasian sector. The sea-ice concentration is substantially lower in the Baffin Bay compared to the old spin-up, with METS showing the lowest sea-ice concentrations of all new experiments. Minor differences are found in the Denmark Strait, where sea-ice extends further South in MEOW, whereas it stays or even recesses northwards in MEOS and METS.

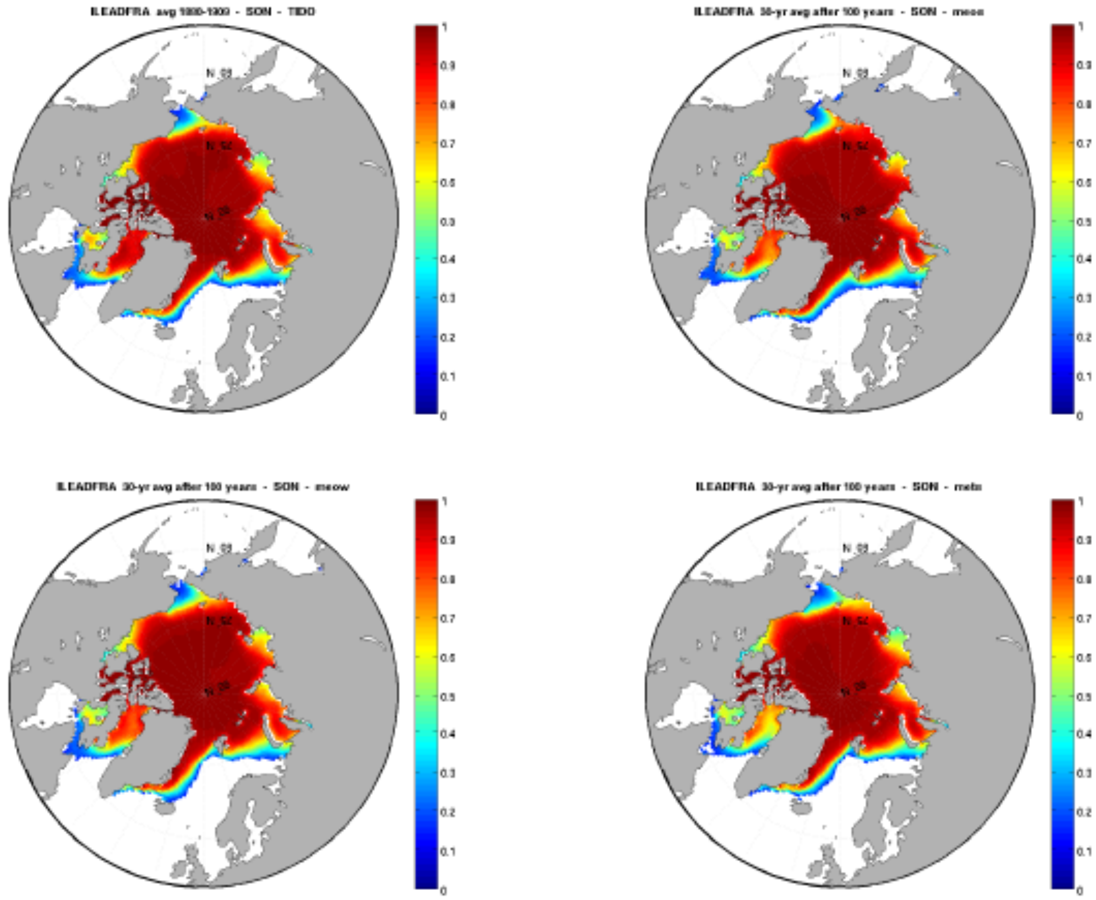


Figure 5. Geograpical distribution of Arctic sea ice (maximum extent).

The reduction in sea-ice with METS is puzzling. In mets, the solar irradiance is reduced, so this would give rise to more sea-ice. On the other hand, we increase the SW cloud inhomogeneity which seems to be the larger effect at high latitudes and more than compensates the reduction in incoming SW.

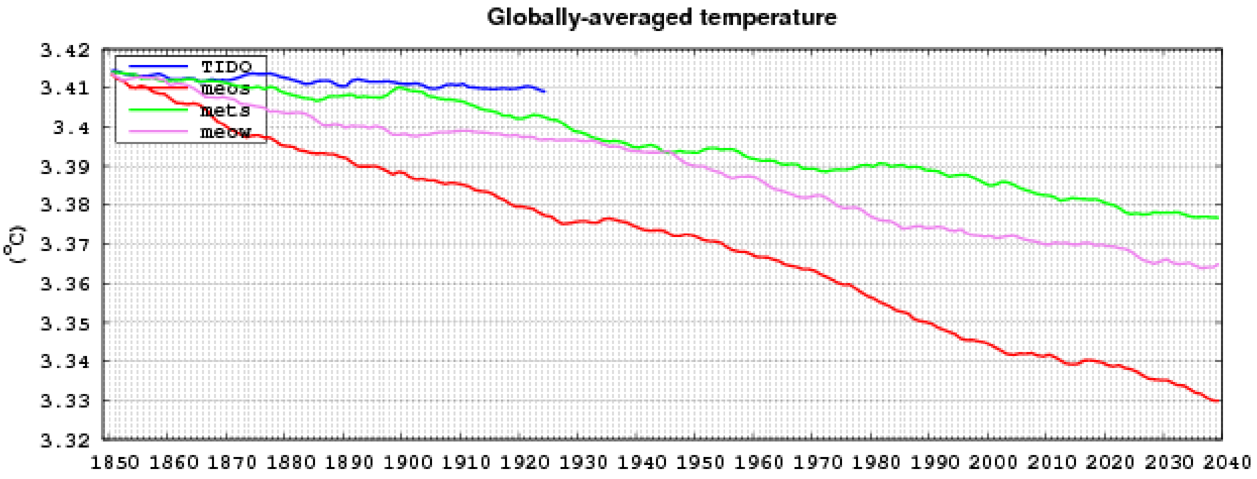


Figure 6. Depth-spatially averaged ocean temperature, indicative of the deep ocean temperature drift.

The top layers of the ocean (including SST) are colder in the new experiments compared to TIDO (Fig. 3), the temperature adjusts after ~50 years and there is no apparent trend afterwards. This is different when we look at the average temperature over all ocean layers (Fig. 6). All new experiments show a cooling with time, and this cooling does not stop in the first 200 years. The old spin-up experiment (TIDO) had a slight cooling trend even after 1000 years, but the trends in the new experiments are stronger. A back-of-the-envelope calculation reveals that the heat released by the ocean corresponds to a forcing of about 0.1 W/m2 (0.07 W/m2 in METS and 0.15 W/m2 in MEOS). Compared to the observed forcing of ~1.5 W/m2 from preindustrial to present day, this heat release is a small but probably non-negligible contribution. A more detailed analysis of the heat content in different layers of the ocean shows that the ocean temperature down to 1000 m seems to stabilise after ~150 years in METW and MESR, but the results remain somewhat inconclusive.

3. Variability and trends in the 20th century

In this section we study the runs with transient forcing and focus on the dominant variability and trends patterns. We should note, however, that these experiments did not start from a stable model climate. There is a drift in the model climate that may have an influence on the findings when comparing against observations, reanalysis or older model simulations.

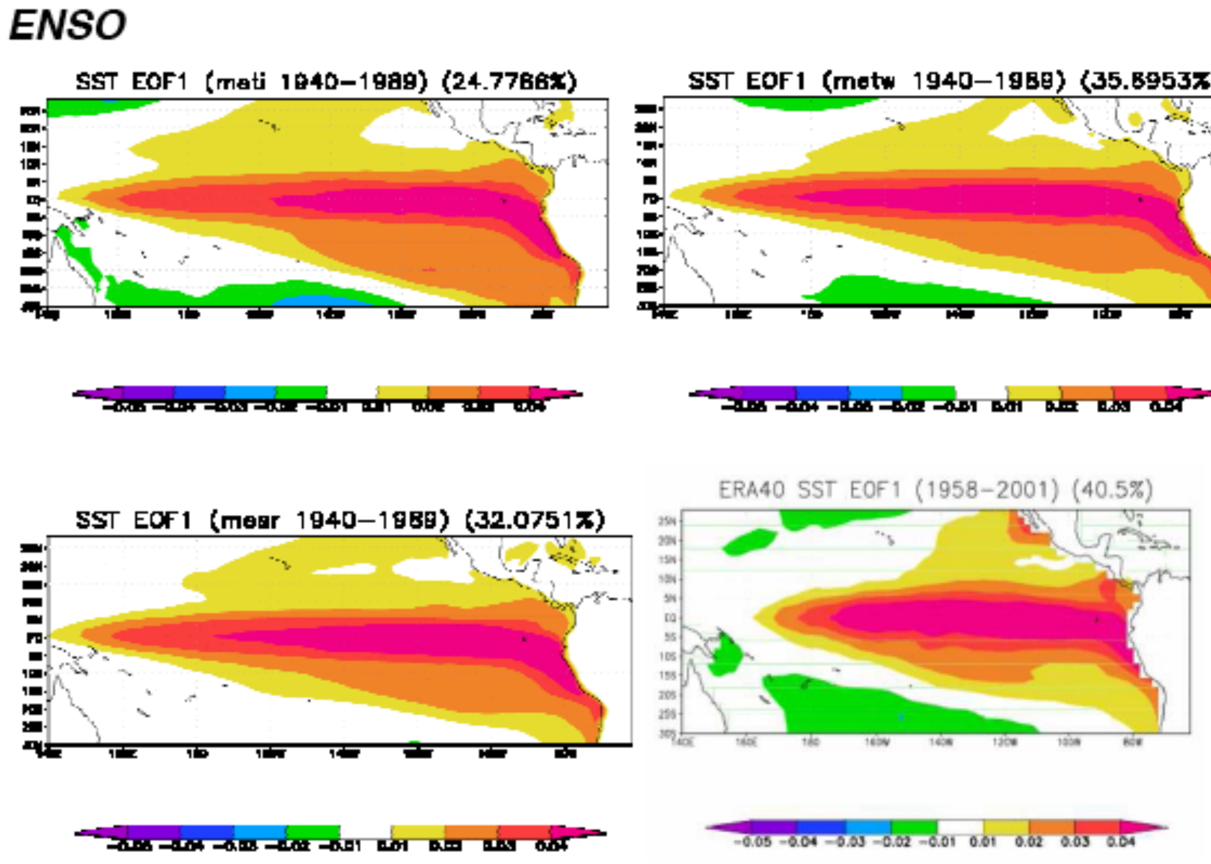


Figure 7. First EOF of SST for the 3 experiments, and ERA-40 for comparison, for the tropical Pacific region. The explained variance by the first EOF is given in parenthesis.

We first look at the simulated ENSO signal (Fig. 7). The pattern of the first EOF is similar in the 3 experiments, the difference between them is smaller than the difference between any of them and ERA-40. The "tongue" stretches too much westward and is not wide enough in North-South direction. The explained variance is smaller than in ERA-40, with METW being closest to the observed value. None of the three experiments has strong enough El Nino's while La Nina is probably well reproduced by METW and MESR (not shown). METI is too weak on both El Nino and La Nina. It is interesting to count the frequency of occurrence for El Nino and La Nina, see Table 4.

		Meti	**Metw**	**Mesr**	**ERA-40**
Nino3	**El Nino**	5	8	10	12
	La Nina	9	9	12	16
Nino4	**El Nino**	5	5	10	11
	La Nina	3	5	6	9

Table 4. Occurrence of El Nino's and La Nina's in the various experiments.

El Nino's and La Nina's occur more frequently in ERA-40 than in the EC-EARTH experiments. MESR is closest to ERA-40. Note that the length for the analysis is slightly different: 44 years for ERA-40 and 50 years for EC-EARTH. Taking this into account, the counts would be even less favourable for EC-EARTH. We now look at the simulated global temperature trends over the past 150 years (Fig. 8).

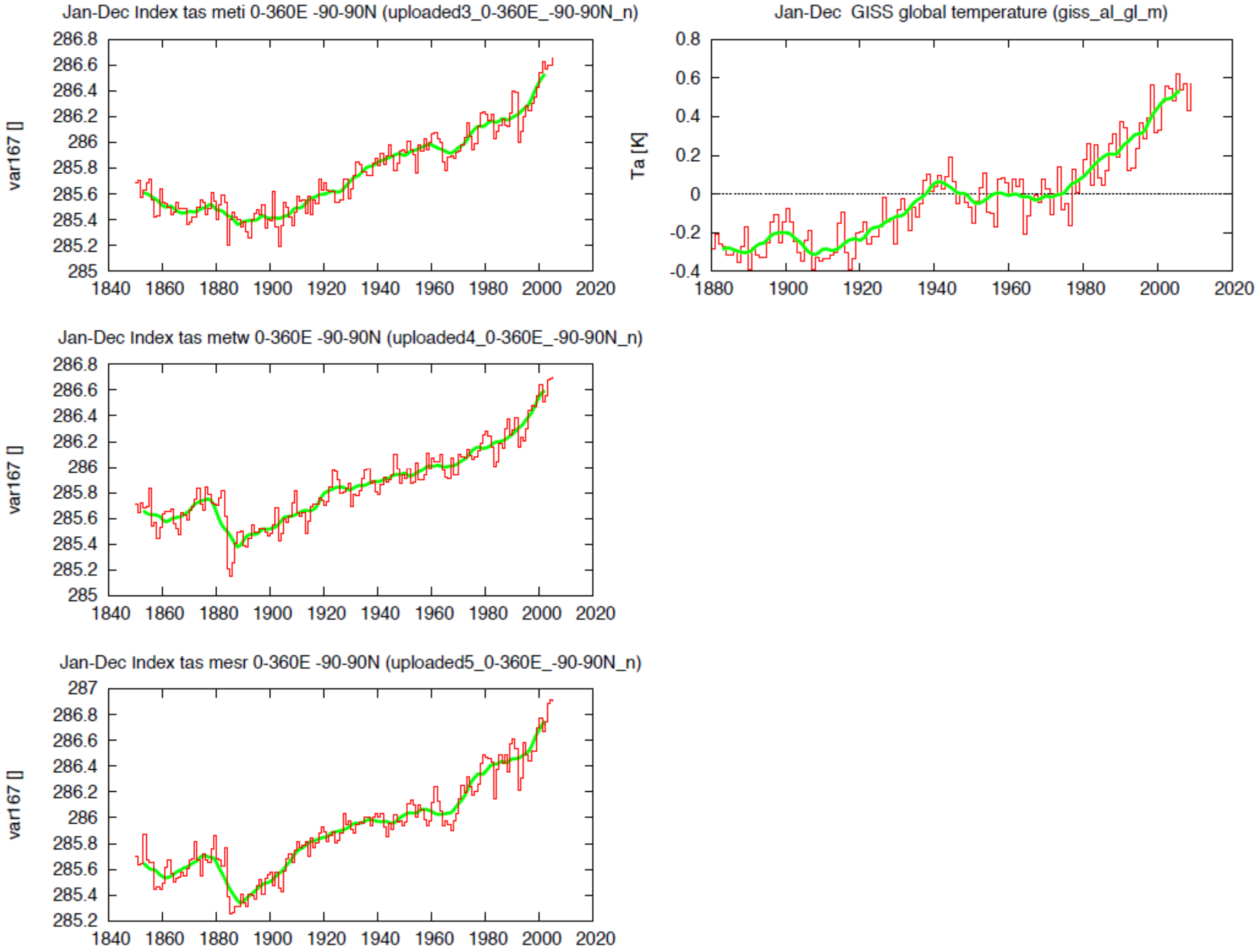


Figure 8. Simulated and observed (GISS) global temperature over the past 1.5 century. Note that the GISS data extend back to only 1880.

The Krakatoa eruption in 1882 had a strong impact on the EC-EARTH simulations that cannot be seen in GISS (to the extent that we can trust the underlying observations in GISS). On the other hand it is not too surprising that Krakatoa is so dominant in the EC-EARTH simulations. The forcing data (from GISS) show the highest stratospheric aerosol optical depth for the entire 1850 to present-day period right after the Krakatoa eruption (http://data.giss.nasa.gov/modelforce/strataer/). The impact of Krakatoa (possibly reinforced with later strong eruptions like Mt. Tarawera in 1886) persists for almost 20 years in the forcing data.

Experiment	**Regression 1900 – 2005**	**Regression 1950 – 2005**
GISS	8.5 ± 0.5	8.6 ± 0.7
Meti	12.3 ± 0.6	9.4 ± 0.7
Metw	11.2 ± 0.4	10.0 ±0.6
Mesr	13.0 ± 0.5	12.0 ± 0.8
Average CMIP3	10.5 ± 0.2	10.4 ± 0.3

(Units are 10^{-3} K/ppm)

Table 5. Global temperature trends, simulated and observed (GISS).

The trend in the new experiments is much larger than in GISS or in the average CMIP3 model (Table 5). The temperature hasn't "recovered" after the Krakatoa eruption in the 1880's and thus the trends for 1900–2005 may be somewhat high. The trends are strongly reduced if only years 1950–2005 are considered.

4. Concluding remarks

Each of the model configurations had its pro's and con's, but in the end it was decided to use the MESR configuration to perform the CMIP5 runs. This configuration has therefore now been implemented as V2.3. More generally, it is expected that the development/tuning efforts, as well as the climate sensitivity experiments, will also be beneficial for the performance of later cycles of the ECMWF modelling system. Hence, we expect that the cross-fertilization of NWPs and ESMs in general, and more specific within the framework of IFS and the seasonal forecast system, will have mutual benefits in terms of their respective performance requirements. The special project SPNLTUNE enables us to continue this work.

The EC-EARTH consortium consists of the following partners (signed Letter of Intent of EC-EARTH): DMI, Denmark ; University Utrecht , The Netherlands; Instituto de Meteorologia, Portugal; Centro de Geofísica,University of Lisbon, Portugal; KNMI, The Netherlands; Meteorologisk Institutt, Norway; Unité ASTR, Belgium; Met Éireann, Ireland; University College Dublin, Ireland; Vrije Universiteit Amsterdam, The Netherlands; Meteorologiska Institutionen, Stockholm, Sweden; Lund University, Sweden; ICTP, Italy; SMHI, Sweden; INM, Spain; ETH, Switzerland; BSC, Spain; Universiteit Wageningen, The Netherlands; IRV, Sweden; ICHEC, Ireland; IC3, Spain