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The new CMCC - Seasonal Prediction System

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SUMMARY This technical report describes the new Seasonal Prediction System (the CMCC-SPS) developed at CMCC to perform seasonal forecasts operationally. Compared to the previous system, the new model has a completely different dynamical core, based on the new CMCC Earth System Model (the CMCC-CEMS-NEMO, see research paper RP0248 [7]). Also, the new system features higher resolution of both the atmospheric and oceanic components, as well as a larger ensemble size (20 members) and more realistic initialization of the land, sea-ice and marine modules. These improvements are expected to have a positive impact on the predictive skill of the new system. The present document describes the operational seasonal forecast protocol. After a brief description of each system component, the initialization strategy is discussed along with the main characteristics of the forecast system from a technical point of view. A preliminary analysis of its performance and skill is presented for the currently available hindcast period 1981–1990.

INTRODUCTION

The slowly varying components of the Earth climate system (such as the ocean, sea- ice, snow cover and soil moisture) are known to contribute to seasonal predictability. Therefore, a more realistic representation of these components is fundamentally important. The new operational SPS was developed exactly in this perspective, aiming to achieve enhanced predictive skill in a variety of different aspects.

The dynamical core of the new SPS is totally different from that of the old system (see RP0147 [2]) and it is based on the CMCC- CESM-NEMO coupled model (described in details in RP0248 [7]).

The horizontal as well as the vertical resolution of the atmospheric and the oceanic components are increased. Another important feature of the new SPS is the more realistic initial conditions used for the oceanic, land-surface and sea-ice models.

Moreover, in order to increase the signal to noise ratio (*signal* being the predictable component of the climate variability, and *noise* the inherently unpredictable chaotic component), the ensemble size has been significantly increased in the new SPS (from 9 to 20 members).

CMCC-SPS COMPONENTS

The new SPS is based on the CMCC-CESM-NEMO coupled model, which is an Earth system model, capable to simulate past, present, and future climate states. It consists of several independent model components:

1. Atmosphere CAM5
2. Ice CICE4.0
3. Ocean NEMO3.4
4. Run-off- River Transport Model
5. Community Land Model 4.0

The coupling between these components is done through the CPL7 coupler (Craig et al., 2012 [5]). CPL7 controls the execution and time evolution of the complete system by synchronizing and controlling the flow of data between the various components.

It also communicates interfacial states and fluxes between the various component models while ensuring the conservation of fluxed quantities.

In CMCC-SPS, the coupling is performed every 90 minutes.

The atmospheric model is CAM5 (Community Atmosphere Model), a developed form of NCAR CCM3. CAM5 is the atmospheric component of the Community Earth System Model, version 1 (CESM1; Gent et al. 2011 [6]). It can be configured to use a spectral transform, a finite elements and a finite volume dynamical core. It also includes a prognostic model for the aerosol distribution.

In the CMCC-SPS, CAM5 uses the finite elements (HOMME- High Order Method Modeling Environment) dynamical core, and it has a horizontal resolution of about 110 km, 30 vertical levels and an integration time-step of 30 minutes.

The ice model (CICE- Community sea-Ice Model) is an extension of the Los Alamos National Laboratory (LANL) sea-ice model and was developed though collaboration with the CESM Polar Climate Working Group (PCWG).

In CMCC-SPS, CICE runs as a fully prognostic component. The sea-ice model has a horizontal resolution of about 25 km, a single ice category and an integration time-step of 30 minutes, as the atmospheric model.

The ocean model (NEMO 3.4) has a horizontal resolution of about 25 km, 50 vertical levels (31 in the first 500m) and an integration time-step of 18 minutes.

As discussed in detail in RP0248, the horizontal grids used by NEMO and CICE belong to the ORCA grid family. The specific mapping files (interpolation weights) between the ORCA grid and the atmospheric grid are created with the mapping tools provided by CESM.

The land model CLM (Community Land Model) is the result of a collaborative project between scientists in the Terrestrial Sciences Section of the Climate (TSS) and the Global Dynamics Division (CGD) at NCAR and the CESM Land Model Working Group.

The RTM (River Transport Model) was developed to route total runoff from the land surface model to either the active ocean, or to marginal seas with a design that enables the hydrologic cycle to be closed (Branstetter 2001 [3], Branstetter and Famiglietti 1999 [4]). The horizontal resolution and the integration time-step of RTM are the same as for CAM and for CLM.

The CMCC-CESM-NEMO components can be combined in numerous ways, depending on different science perspectives.

A particular mix of components, along with component-specific configuration and/or namelist settings is called a component set or "compset".

When run in the seasonal forecast framework, the model is set in transient configuration, which corresponds to $B20TRC5NEMO$ (long name $B\_1850-2000\_CAM5\_NEMO$) compset.

A CMCC-CESM-NEMO run can be initialized in one of three ways: startup, branch, or hybrid (see $http://www.cesm.ucar.edu/models/cesm1.2/cesm/doc/usersguide/book1.html$ for details).

Each CMCC-SPS run lasts 9 months, starting from a hybrid run.

A hybrid run allows bringing together combinations of initial/restart files from previous cases (specified by $RUN\_REFCASE$ in $env\_run.xml$ file) at a given model output date (specified by $RUN\_REFDATE$).

In hybrid configuration, the CAM and CICE models start from initial conditions while CLM and NEMO start from restart files.

In a hybrid run, the ocean model does not start until the second coupling time-step (in this configuration one hour and a half) and stops one hour and half (5 time-steps) before the correct end. As a result the model does not save the correct state in its final output. To fix this problem, an ad hoc modification was done to the routines $ocn\_comp\_mct.F90$ and $sbccpl\_cesm.F90$, so that the ocean starts its integration contemporarily to the other modules.

The following 8-months of the forecast period are run as restarts.

ATMOSPHERIC INITIAL CONDITIONS

Initial conditions for the various components are imposed to the new fully coupled CMCC-SPS model.

As was the case in the previous SPS (RP0147), the atmospheric component is initialized with data from the ERA-Interim reanalysis (Berrisford et al., 2009 [1]).

The multi-level fields (e.g. temperature, specific humidity, zonal and meridional wind) are interpolated from the 60 hybrid levels of ERA-Interim to the 30 hybrid levels of CAM5.

Surface initial conditions (surface pressure, surface geopotential, surface temperature, land-sea mask and snow depth) are horizontally interpolated from the ERA-Interim resolution

(T159) to CAM5 resolution (ne30np4).

For more details on the initialization procedures the reader is referred to RP0147.

LAND SURFACE INITIAL CONDITIONS

Initial conditions for the CLM model come from two different reanalyses, carried out with boundary conditions provided by NCEP and ERA-Interim atmospheric reanalysis datasets respectively.

The integration period is chosen to be 7-year long, considering that a spin-up of 2 to 3 years should be enough for superficial processes (depth processes would require a longer spin-up).

OCEAN AND SEA-ICE INITIAL CONDITIONS

The initial conditions for the ocean and the sea-ice components are provided by the reanalysis carried out monthly by the ODA group (Storto et al., 2011 [10]).

In comparison with the previous SPS version in use at CMCC, the oceanic initial conditions come from a 3D-var instead of an OI method.

Moreover the model used to produce the reanalysis has a higher resolution with respect to the former version (NEMO 1/4^o compared to OPA 2^o), both in the horizontal and in the vertical grid.

As far as the sea-ice component is concerned, the initial conditions come together with the reanalysis of the ocean each start-date, while in the previous SPS version, they were simple monthly climatological fields derived from a model climatology.

From a technical point of view, the CICE model was originally designed to start from two possible configurations: a sea-ice climatology or an analytical distribution. An ad hoc routine was developed in order to allow the model to read the actual IC provided by the reanalysis. This is done only for the first integration month, while for the following 8 months the model starts from its own restart conditions.

UNCERTAINTY OF INITIAL STATE

The uncertainty characterizing the initial state of the climate system is accounted for by using an ensemble of 20 perturbed ICs, which is a substantial increase with respect to the ensemble size of the previous system (9 realizations).

The perturbed initial states are obtained combining 10 atmospheric ICs with the two sets of land reanalysis (described in the land surface ICs section).

As was the case in the previous SPS, the perturbed atmospheric ICs are defined by using past atmospheric states (from the ERA-Interim reanalysis) at a 12-hour interval backwards from the respective start date (the first day of each month).

Because 5 of the atmospheric ICs are selected at mid-day, while the actual forecast run starts at mid-nigth, an atmospheric 12-h guess forecast is necessary to bridge the time lag.

HINDCASTS

The forecast system will be run over the retrospective period 1981–2010 in order to evaluate its biases and its predictive skill.

For each month a retrospective prediction is issued, lasting 9 months and consisting of an ensemble of 20 members.

So far, a subset of 5 members has been run. These retrospective forecasts cover only the period 1981–1990, because the oceanic reanalyses are not available yet for the entire hindcast period.

Preliminary results (maps) are shown for typical variables regarding the model climate bias and the anomaly correlation coefficient (ACC) for the abovementioned limited hindcast period.

MODEL CLIMATE BIAS

The model climate bias refers to the deviation of model climatology from the respective observed climatology. Here the climatology for a specific season is defined as the average of the the respective forecasts (3-month means) over the available hindcast period (1981–1990). The same period is used to define the observed climatology. For observations, the sea-surface temperature (SST) is taken from the HadISST dataset (Rayner et al. 2003 [8]); the precipitation (PREC) is taken from the CMAP dataset (Xie and Arkin 1997 [11]); the 2m-temperature (T2m) is taken from ERA-Interim reanalysis.

Figure 1 exhibits the model climate bias in SST for January initialization and for lead season 0 (JFM). The top panel is for the new CMCC-SPS, while the bottom panel refers to the old system. Despite a strong cold bias (of about -8 ^{o}C) over the Arctic, in most areas of the global ocean the deviation from the observed climatology is less than 1^{o}C. Stronger biases occur along the coasts (particularly the western coasts) of the Northern Hemisphere continents at middle and higher latitudes, which is a typical feature of SPS systems (Saha et al. 2006 [9]).

Compared to the old system (bottom panel), the new system exhibits an improved representation of SST over the eastern tropical Atlantic and off the coasts of China and Japan. In contrast, a certain deterioration is observed at the eastern equatorial Pacific.

Similarly, Figure 2 shows the model climate bias for lead season 1. In this case the above-mentioned improvements are more pronounced.

ANOMALY CORRELATION COEFFICIENTS

Figure 3 shows the ACC computed for T2m the lead season 0 for the new and the old CMCC-SPS. As expected, the highest skill is found over the tropics and in particular over the central and eastern tropical Pacific (ENSO region), which is understood given the strong atmosphere–ocean coupling in that region. Interestingly, despite some decrease in skill over some continental areas (e.g. in parts of Northern North America, South America, Australia and South Asia), the new system exhibits improved skill over Northern Europe and Northern Russia, Mediterranean Sea, North and Central Africa and over the Arabian Sea.

As one would expect, the predictive skill drops with lead time (Figure 4), but compared to the old system the new one shows higher ACC values over the El Nino region and over the abovementioned regions of Africa, Europe and Russia.

Figure 5 shows the ACC for precipitation at lead season 0. Again, as for SST and T2m, the skill is highest over the equatorial Pacific. Compared to the old system, higher predictive skill is found over the North Atlantic, while in some other areas (e.g. around Antarctica) the ACC is quite noisy indicating lack of statistical robustness. Speaking of statistical significance, it should be noted that the currently available hindcasts cover a very short period (1981–1990) which is marginally sufficient for this kind of analysis.

For lead season 1 (Figure 6), despite the usual decrease in skill, high ACC values persist over the equatorial Pacific. The ACC field over the continents is rather noisy, yet comparing to the old system, a certain improvement is seen over the eastern North Atlantic and Europe (pointing to increased NAO skill).

SUMMARY AND REMARKS

A new SPS has been developed at CMCC for operational seasonal forecast. The system is based on the CMCC Earth System model CMCC-CESM -NEMO.

So far the CMCC-SPS has been tested and evaluated in a reduced configuration of 5 members, over a retrospetive period of 10 years (1981–1990), showing reasonably good results in terms of ACC and climate model bias.

The next step will be the extension of the hindcast period (from 1981–1990 to 1981–2010) and the increase of the ensemble size (from 5 to 20 members).

As the predictive skill depends on both the hindcast period and –more strongly– the ensemble size, the system evaluation presented here is certainly not conclusive. In the final operational configuration, the skill of the new SPS is expected to increase in most areas.

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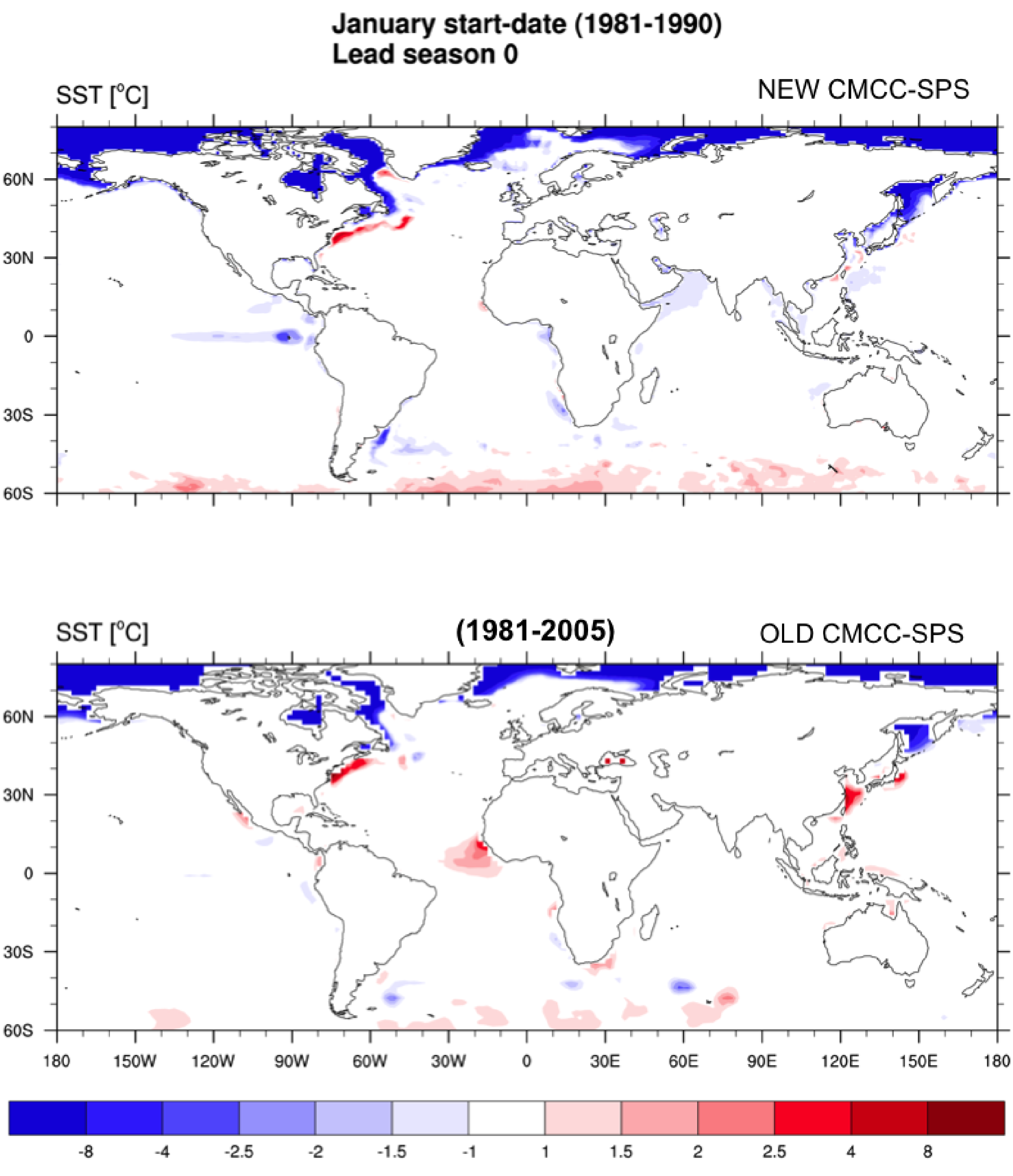

Figure 1:
SST model climate bias for the new (above) and the old (below) CMCC-SPS. The climatology is defined over the period of 1981–1990. The climate bias is obtained by subtracting the observed climatology from the model forecast climatology. Model climate bias for lead 0 time is shown for the new SPS (top) and for the old one (bottom). Units are in ^{o}C.

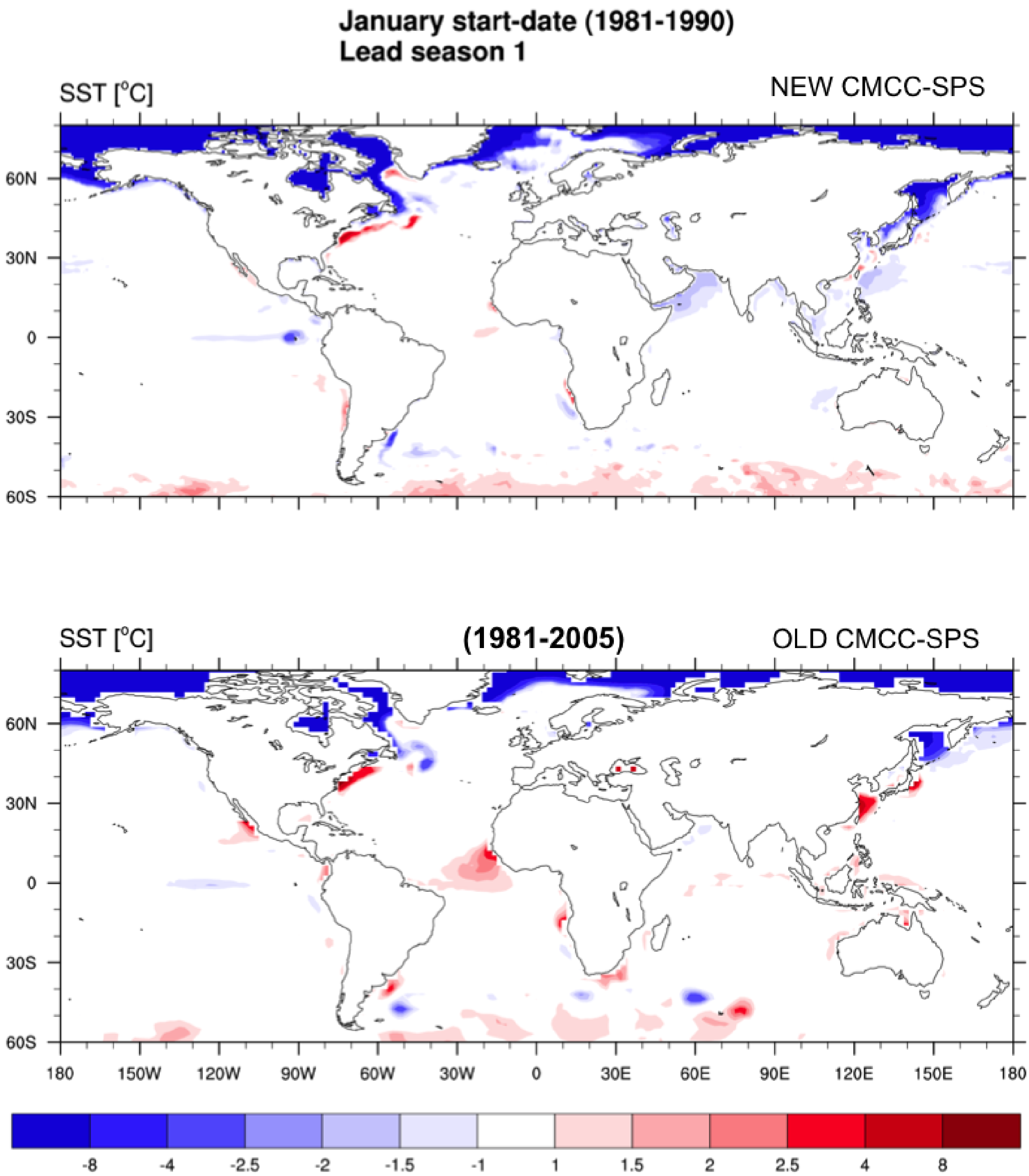

Figure 2:
As Figure 1 but for lead season 1.

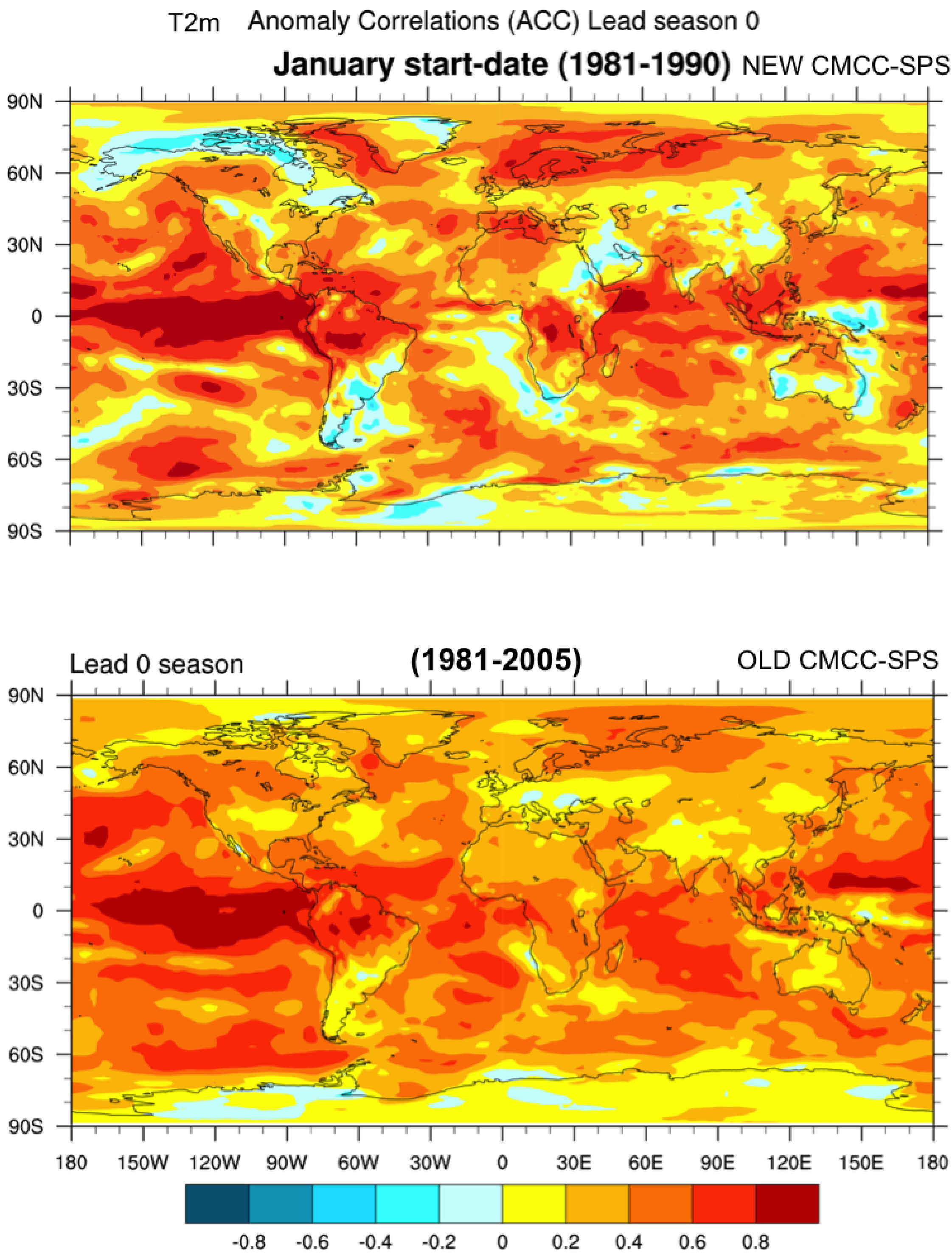

Figure 3:
Ensemble mean forecasts vs ERA-Interim T2m anomalies: point-by-point correlation of lead season 0 (target months 1-to-3). Starting date 1st January. Shaded areas where correlations are positive (yellow, orange and red shading) have a good skill. Where correlations are negative (blue shading) have a bad skill. Units are in ^{o}C.

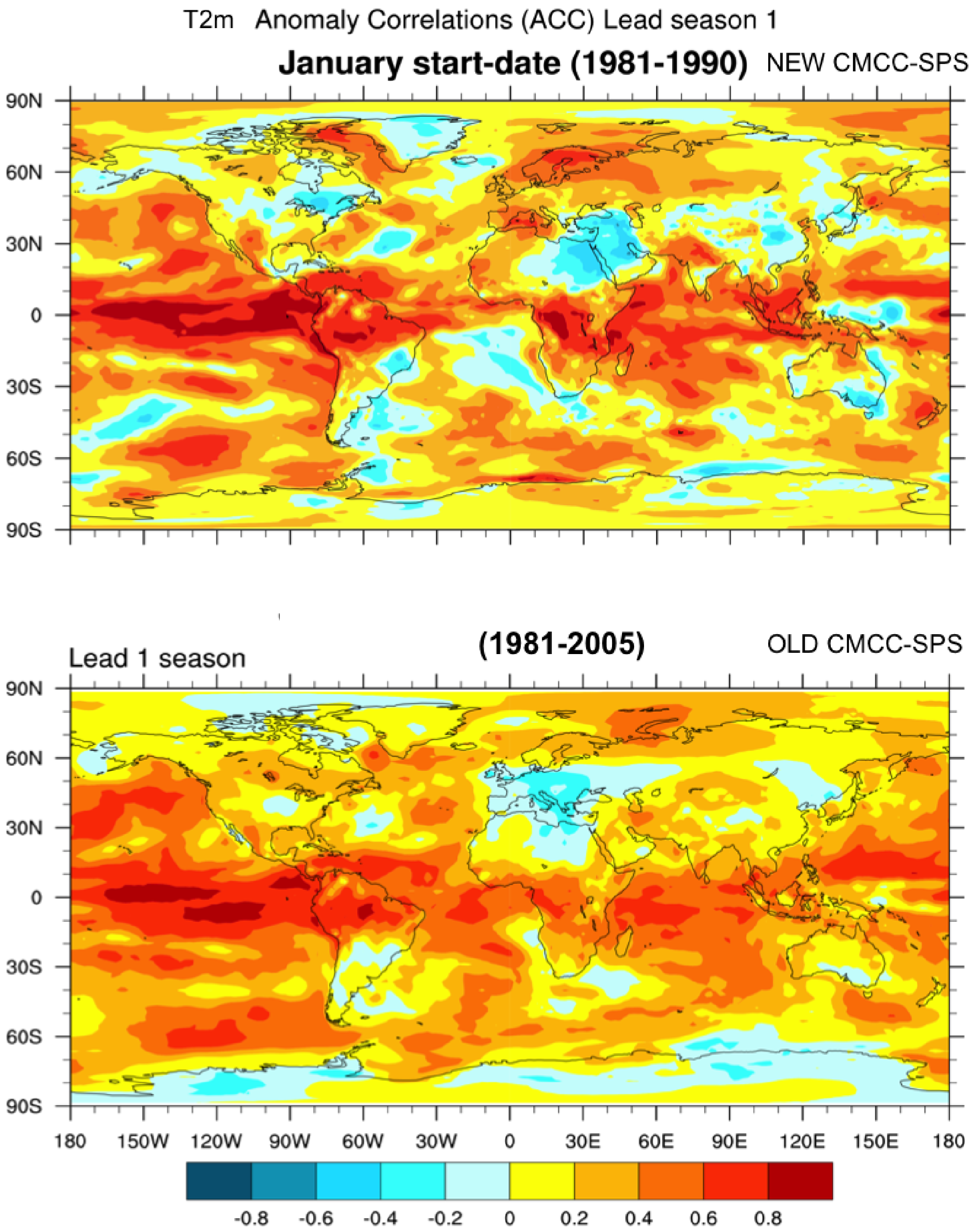

Figure 4:
As Figure 3 but for lead season 1 (target months 2-to-4).

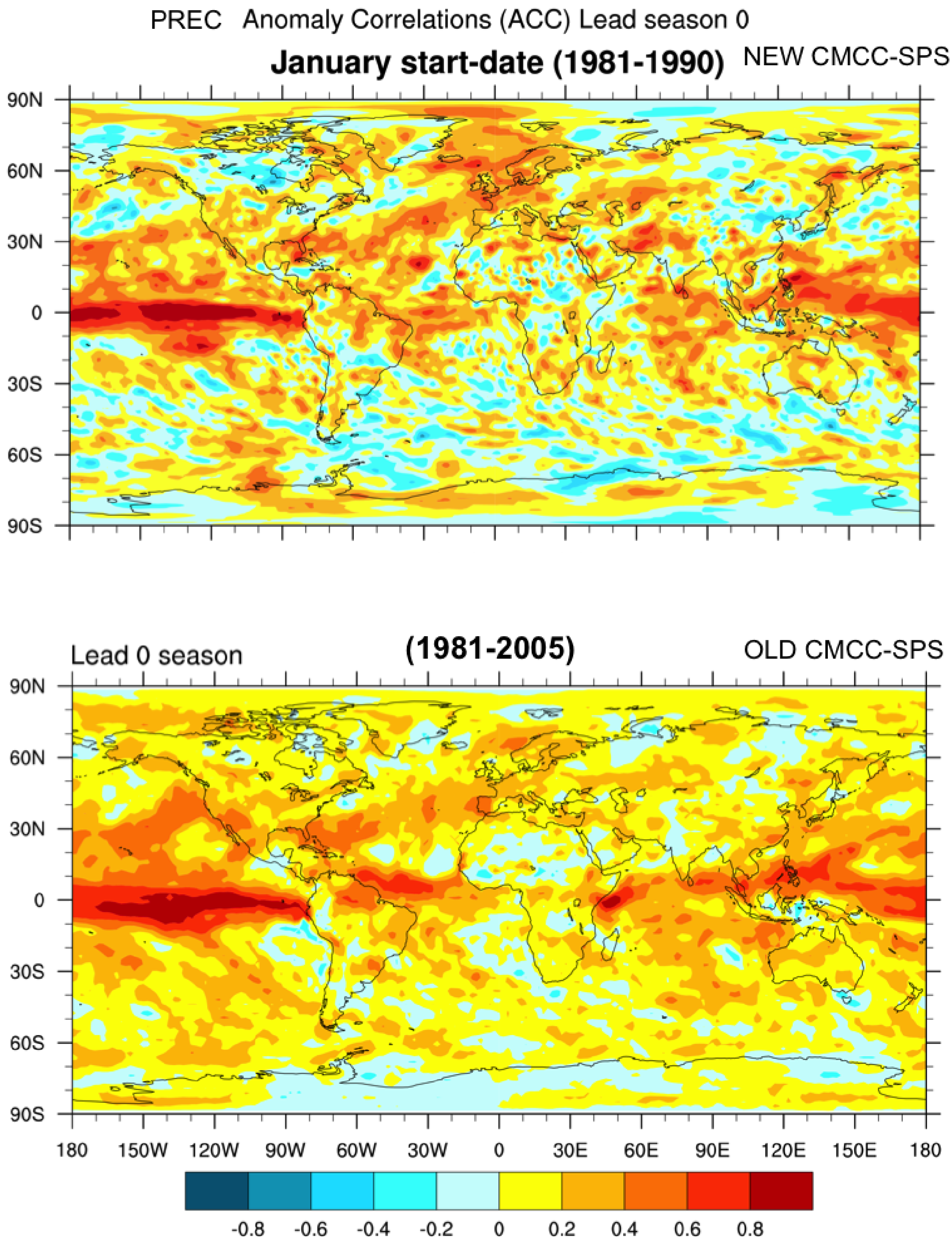

Figure 5:
As Figure 3 but for total precipitation anomalies. Units are in $mmday^{1}$.

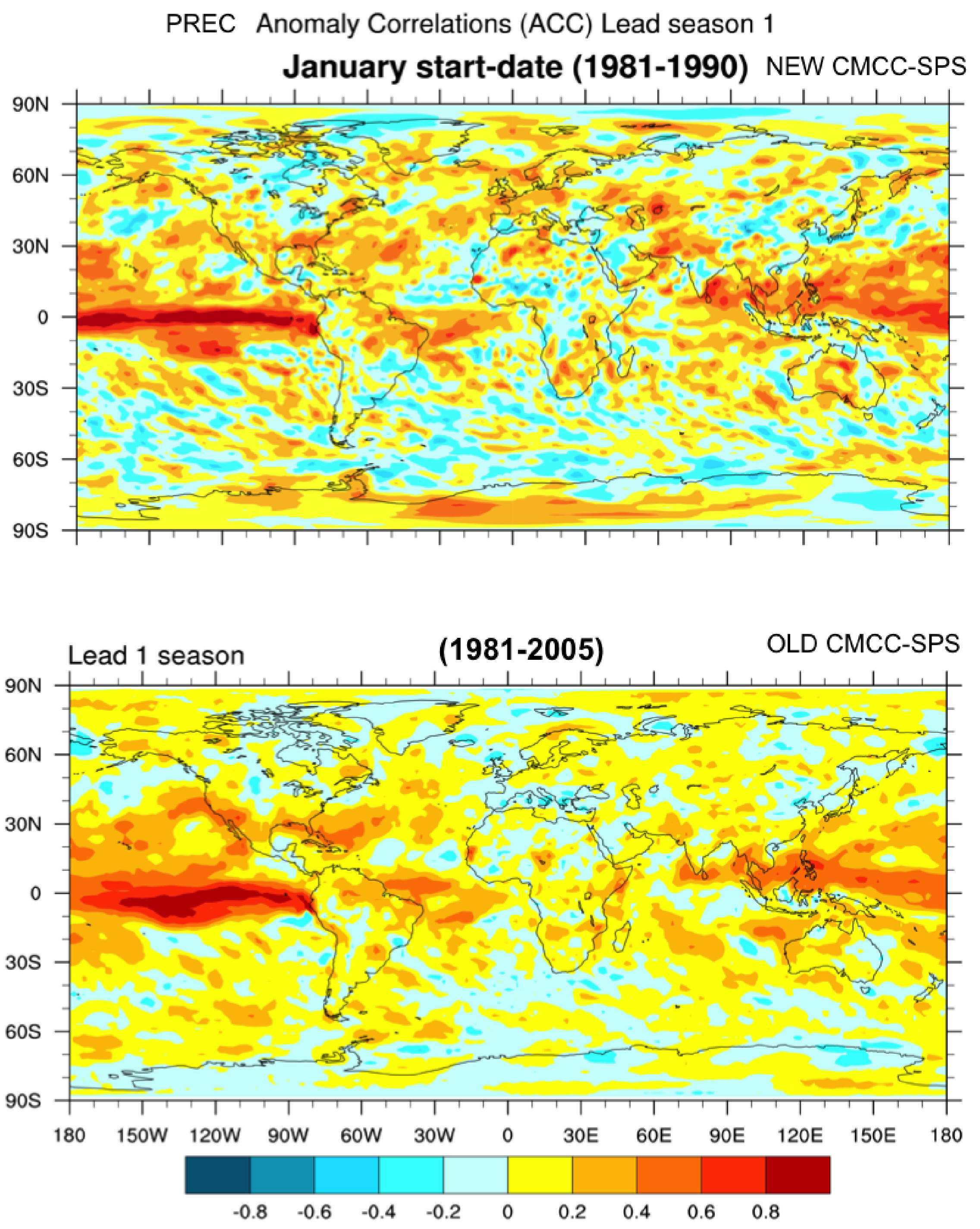

Figure 6:
As Figure 5 but for lead season 1.