CLWRF: WRF modifications for regional climate simulation under future scenarios

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1. Introduction

The use of Limited Area Models (LAM) as a dynamical downscaling tool to obtain regional climate information from Global Climate Models (GCMs) has become a discipline known as regional climate modelling. The WRF model has also been used as a Regional Climate Model (RCM) in different initiatives and research projects (Lo et al. 2008; Flaounas et al. 2010). WRF Working Group 16 is devoted to the adaptation of WRF for its use as an RCM (Leung et al. 2006). This work introduces some modifications relevant for regional climate modelling to the WRF v3.1.1 code.

RCMs add value to the large scale information provided by global models (Castro et al. 2005). This regional scale information is very valuable for the climate impact community, that usually requires information with very high spatial and temporal resolution, not available from GCMs. Climate and impacts communities demand some variables and capabilities not readily available in WRF-ARW version 3.1.1 (Skamarock et al. 2008). CLimate-WRF (CLWRF) provides some of these capabilities. Basically, CLWRF consists of a set of modifications of the WRF source code that add new variables and a more flexible selection of the GHG forcing. For instance, the global Community Atmosphere Model provides a simple way of specifying an “averaging flag” to the variables, indicating whether the output variables at a given time are instantaneous or they are averages, maximum or minimum values since the last output time. This behaviour has been mimicked by CLWRF for some variables, providing e.g. maximum temperatures obtained from the internal time-step values.

CLWRF is open[1] and has been shared with the WRF community contributing to the COordinated Regional Downscaling EXperiment (CORDEX[2]). Even though CLWRF has been developed by the Santander Meteorology Group (*Universidad de Cantabria*, Spain), the plan is to add more RCM-related capabilities in a coordinated way under the CORDEX-WRF[3] community. CLWRF is currently being used to produce CORDEX simulations for the African domain managed by the WRF4G framework (Fernández-Quiruelas et al. 2010).

The next section provides details of the modifications introduced and illustrates them with some results obtained from a sample 8-day simulation for the CORDEX-Africa domain for the period of 1997 November 1st 00 UTC to November 8th 00 UTC.

2. Modifications introduced

The modifications introduced in the code define new variables, so they must be added to the Registry. For this purpose, a `Registry.EM_CLWRF` file is provided. The modifications need to be activated at compile time (defining a preprocessor variable `-DCLWRF` in `configure.wrf`). The additional variables are stored in independent history files which need to be declared (see below) when using CLWRF.

Three types of modifications are currently added: flexible GHG scenarios for the CAM radiation scheme, mean and extreme values for several variables and other more specific variables, such as 7h to 7h precipitation, maximum 1h precipitation, etc.

a. *CAM Radiation scheme*

In WRF version 3.1.1, the CAM radiative scheme (Collins et al. 2004) prescribes the CO_2 mixing ratio from the SRES-A2 scenario while the rest of GHGs have fixed concentrations. CLWRF introduces a flexible way to assimilate variable mixing ratios for five gases: CO_2, N_2O, CH_4, CFC-11 and CFC-12. The mixing ratios are read by the model from an external ASCII file named `CAMtr_volume_mixing_ratio`. In this way, one only needs to change the ASCII file in order to make regional climate simulations under different GHG scenarios or sensitivity studies to the concentration of these gases.

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[1] The code and technical details are available from `http://www.meteo.unican.es/wiki/cordexwrf/SoftwareTools/ClWrf`

[2] `http://wcrp.ipsl.jussieu.fr/RCD_Projects/CORDEX/CORDEX.html`

[3] `http://www.meteo.unican.es/wiki/cordexwrf`

GHG mixing ratios are updated at each time-step of the simulation. The data in `CAMtr_volume_mixing_ratio` does not need to be temporally equi-distributed and the default WRF GHG mixing ratios can be recovered by introducing null values (-9999.999) on any column. Sensitivity results on different gas mixing ratios (Figure 1) shows high sensitivity to N_2O mixing ratios on surface temperature and pressure (other variables –not shown– such as precipitation or humidity have less sensitivity).

b. *Mean and extreme values between output times*

Climate models are run for long periods and, mainly due to storage constraints, the output frequency is usually low. The highest frequency usually stored is 3-hourly data. For some variables (e.g. surface wind), instantaneous values may not be representative of the 3-hour period and an averaged value for the last 3 hours would be preferred. Additionally, an indication of the variability within the period may add valuable information, for instance, to assess how representative the instantaneous value is. Also, maximum and minimum values (e.g. for temperature) are usually demanded. The 3-hourly frequency is usually enough to fairly sample the daily cycle, but the peak value is likely to be lost leading to an underestimation of the extremes.

CLWRF provides the mean, standard deviation, minimum and maximum values for several variables computed over the time-step values since the last output. The output file is independent of the main history file (`wrfout_`) and, thus, the output time can be controlled independently. For instance, instantaneous output may be saved 3-hourly, and the extreme output file be set to daily output frequency, saving the daily maximum, minimum, etc. This additional history file uses the auxiliary output file #7, which must be declared in the namelist.

The variables currently included in this file are the 2m temperature (T2), water vapor mixing ratio (Q2), surface wind (U10, V10) and time-step cumulus (RAINCV) and grid-scale (RAINNCV) rainfall. The new variables have their standard names followed by MEAN, STD, MIN or MAX. The time (in minutes since the simulation start date) when maxima or minima occur are also saved. These time variables are prepended by a `T`, e.g. TT2MAX saves the time when the maximum temperature occurs.

Figure 2 illustrates the extreme values computed by CLWRF. All the time step values were saved using the WRF time series capability for a single grid point. The sampling obtained by a 3-hourly output is compared with the extremes provided by CLWRF (that match those from the time step values)

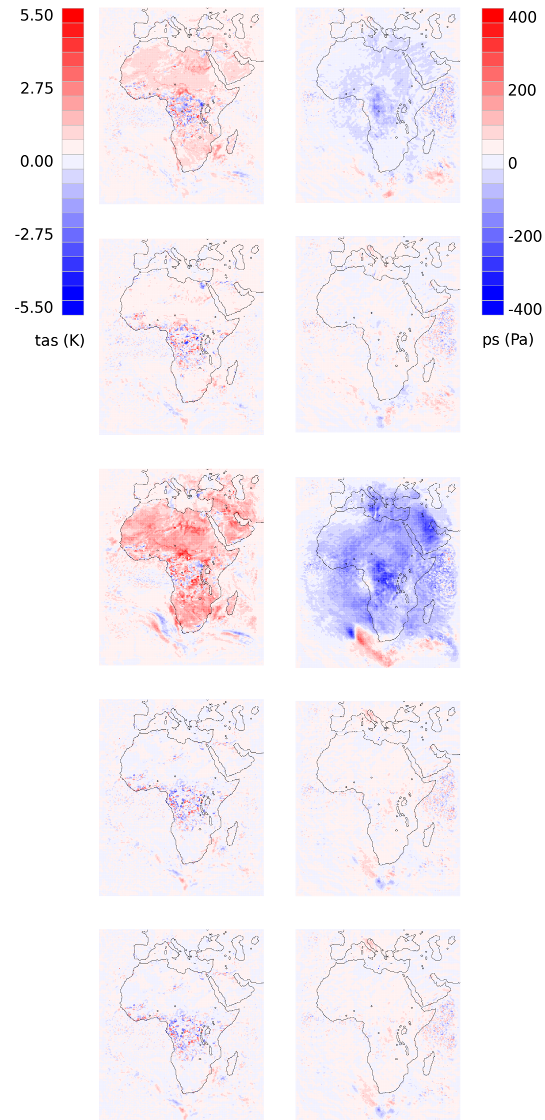

Figure 1: Differences after 8 simulated days (starting 8th November 2001) between the standard WRF-ARW simulation with prescribed SRES-A2 CO_2 mixing ratios and a simulation using CLWRF with the GHG increased 4 times. Differences are shown for surface temperature (K, left) and surface pressure (Pa, right). The different rows are for (1) All gases $\times 4$, (2) CO_2 $\times 4$, (3) N_2O $\times 4$, (4) CH_4 $\times 4$ and (5) CFCs $\times 4$.

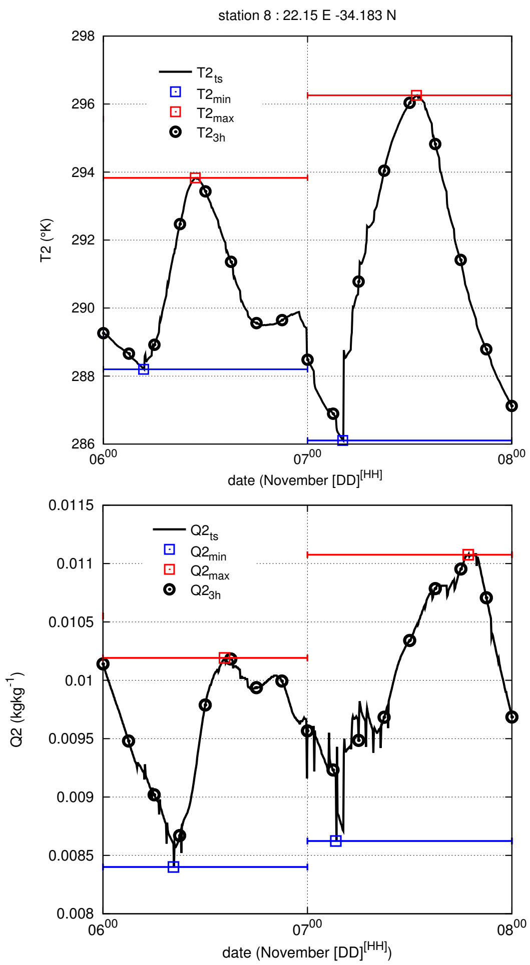

Figure 2: Time evolution of the temperature ($^{\circ}K$, top) and vapor mixing ratio ($kgkg^{-1}$, bottom) at 2m at a given point of the simulation domain. The dotted line shows the evolution according to '`tslist`' values (i.e. at each time-step of the simulation). The circles show the evolution according to values recorded in the standard output files every 3h. Squares and bars indicate the extreme values (squares, blue for minimum; red for maximum) and time interval of the extreme statistic. The location of the extreme in time is also provided by CLWRF.

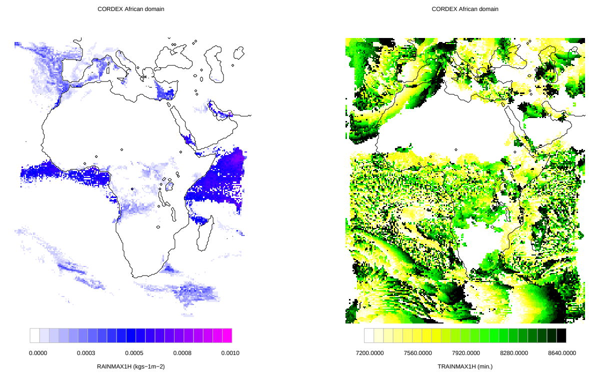

Figure 3: Maximum 1h rainfall intensity within 24 hours ($kgs^{-1}m^{-2}$, left) as simulated for November 7th, 1997. The time of maximum is also shown (minutes since the start of the simulation, right)

c. *Other variables produced by CLWRF*

CLWRF currently makes use of another 2 auxiliary files. The new registry duplicates the precipitation output to the auxiliary file #8. This allows saving the precipitation accumulated with a different day boundary. E.g. observational networks usually measure precipitation accumulated from 8:00 UTC to 8:00 UTC. If 3-hourly rainfall is being saved, the 8h to 8h rainfall cannot be recovered. The additional auxiliary file #8 could accumulate this rainfall by setting `auxhist8_begin_h = 8`, regardless of the saving frequency in the main output file.

The second auxiliary file enabled by CLWRF is used to store other variables usually defined with daily frequency. These variables are often requested by the impacts community, but are not readily available in WRF. Currently, we have implemented the sunshine duration (WMO 1996) and maximum 1h rainfall intensity within 24 hours. These variables are saved in the auxiliary file #9, which must be defined when using CLWRF. Figure 3 shows an example of the 1h maximum rainfall intensity (RAINMAX1H). The time of the maximum (TRAINMAX1H) is also saved in this additional file. The different precipitation timing in the extratropical regions (associated to passing fronts) and in the tropics is clearly observed.

The computation of these additional variables is done through a flexible module to compute diagnostics as the model runs. This allows easily adding new variables as they are required.

3. Summary and future plans

We presented a set of modifications to the WRF v3.1.1 code useful for regional climate experiments. The new code adds new variables and provides a more flexible way to alter the GHG forcing in the model.

A number of new features are currently under development. Namely, wind gust (following Brasseur 2001), total cloud, low/mid/high level cloud fraction. We also plan to extend the GHG mixing ratio ASCII file to other radiative schemes such as RRTMG (Mlawer et al. 1997). Some of these modifications are computer intensive (e.g. the wind gust) and take more memory (because of the newly defined variables), thus are not suited for the general WRF user.

CLWRF is an open source action and our purpose is to keep adding variables useful for the climate and impacts communities. In this sense, the collaboration with the CORDEX-WRF community may be crucial to define and implement new needs.

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