Recent advances in land surface modelling for NWP at ECMWF

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ABSTRACT

The land surface physical parameterization used operationally in the Integrated Forecast System (IFS) at the European Centre for Medium-range Weather Forecasts (ECMWF) has been fully revised in its soil, vegetation, and snow components. The current scheme has an improved match to soil moisture and snow field-site observations with beneficial impact on the turbulent fluxes and near surface temperature and moisture as verified by conventional synoptic observations. The gain in hydrological consistency is of crucial importance in order to ease the data assimilation of land surface satellite observations in water sensitive channels (e.g. ASCAT-C-Band active microwave, AMSR-E C-band passive microwave, SMOS L-band passive microwave, etc.). Independent offline verification studies show that the land surface hydrological cycle is in a better agreement with large-scale basins runoff and terrestrial water storage exchange on monthly time-scale. The impact of the revised land surface hydrology is estimated in 1-year global integrations with specified Sea Surface Temperatures (hindcast experiments) showing an overall improvement of the model climate particularly evident near the surface and areas/seasons sensitive to the introduced physical parameterization.

1. Introduction

The recent advances on the land surface modelling at ECMWF encompass a new soil hydrology (Balsamo et al., 2009a) and a new snow scheme (Dutra et al., 2010a) which have been both included in the operational forecast system with documented positive impact on both global hydrological water cycle and near surface temperatures. In particular the soil hydrology has been shown to affect the quality of seasonal prediction in extreme events associated to soil moisture-precipitation feedback as the European summer heatwave in 2003 (Weisheimer et al., 2010). The new snow scheme has been shown to improve the thermal energy exchange with a substantial reduction of near-surface temperature errors in snow-dominated areas. More recently, the inclusion of a monthly climatology for vegetation Leaf Area Index (LAI, following Jarlan et al., 2008, Boussetta et al., 2010) replacing a fixed maximum LAI has shown a reduction of near-surface temperature errors in the tropical and mid-latitude areas particularly evident in spring and summer. The participation in international projects such as the GLACE2 project (Koster et al. 2010) and the AMMA project (Agusti-Panareda et al. 2009, de Rosnay et al. 2009) of the ECMWF model coupled with a realistic set of soil moisture fields have improved the understanding of the mechanisms and areas of strong coupling between the land surface and the atmosphere. Exploratory studies on the value of realistic land surface initialization on the ECMWF precipitation skill have been showing a good level of accuracy over continental USA and Europe. Plans for International research activities in the land surface modelling involve participation into WATCH and the follow-on to the Global Soil Wetness Project.

A brief description of the main hydrological components of the land surface model with selected validation results are presented in the next two sections followed by a summary and outlook for future research activities.

2. The Land Surface Model

The Tiled ECMWF Scheme for Surface Exchanges over Land (TESSEL) illustrated in Van den Hurk et al. (2000) is the backbone of the current operational land surface scheme at ECMWF. It includes up to 6 land surface tiles (bare ground, low and high vegetation, intercepted water, and shaded and exposed snow). The soil freezing is parameterized according to Viterbo et al. (1999). Recent revisions concerning the soil and snow hydrology as well as vegetation characteristics are illustrated in Fig. 1 and described in the next sections.

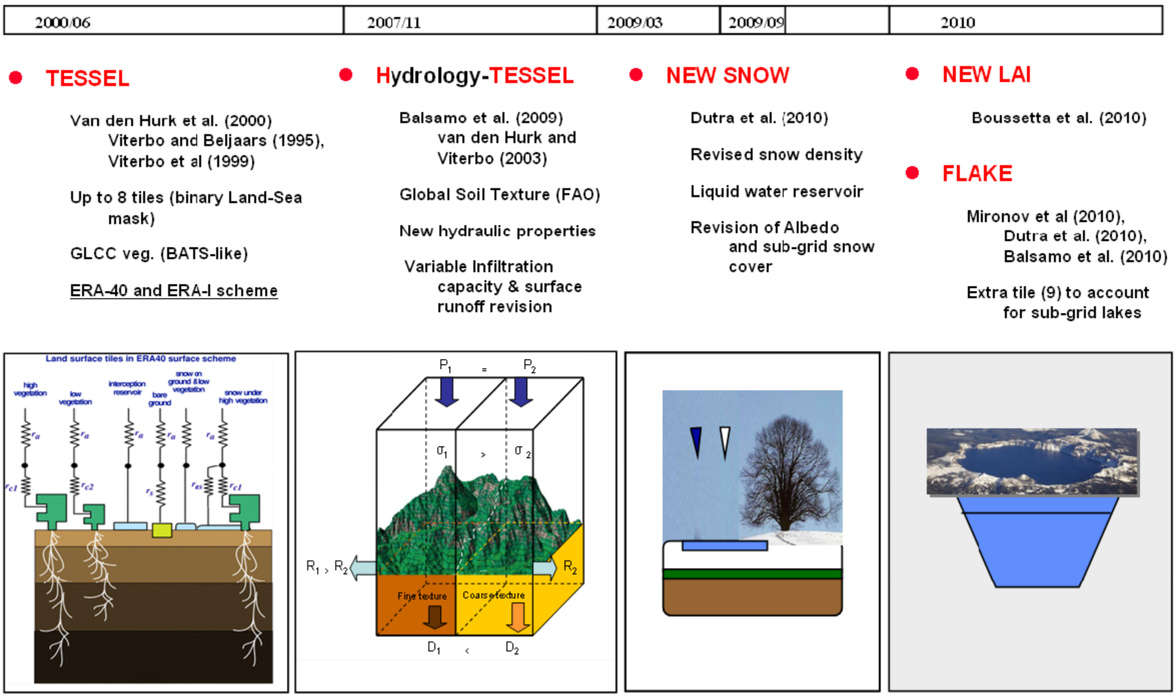

Figure 1: Sketch of the recent revisions to the land surface model with the timeline for activation in the operational IFS. The references Dutra et al, and Balsamo et al (snow and lakes) should be 2010 (if it is easy to edit the figure)

2.1. Soil hydrology

A revised soil hydrology in TESSEL was investigated by Van den Hurk and Viterbo (2003) for the Baltic basin. These model developments were a response to known weaknesses of the TESSEL hydrology: specifically the choice of a single global soil texture, which does not characterize different soil moisture regimes, and a Hortonian runoff scheme which produces hardly any surface runoff. A revised formulation of the soil hydrological conductivity and diffusivity, spatially variable according to a global soil texture map, and surface runoff based on the variable infiltration capacity approach, were proposed revisions. Balsamo et al. (2009a) verified the positive impact of HTESSEL from field site to global atmospheric coupled experiments in data assimilation cycles.

2.2. Snow hydrology

A fully revised snow scheme has been introduced in 2009 to substitute the previous scheme (based on Douville et al. 1995). Changes concerned the snow density and the introduction of a diagnostic liquid water storage in the snow-pack which is allowed to intercept rainfall. The snow/forest albedo and the snow cover fraction have also been revised and forest albedo in presence of snow has been retuned. A detailed description of the new snow scheme and a verification from field site experiments to global offline simulations is presented in Dutra et al. (2010a). The results obtained showed an improved behaviour of the simulated snow-pack with positive effects on the timing of runoff and terrestrial water storage variation and a better match of the albedo to satellite products.

2.3. Vegetation seasonality

In the current operational scheme the Leaf Area Index (LAI), which expresses the phenological phase of vegetation (growing, mature, senescent, dormant), is kept constant and assigned by a look-up table depending on the vegetation type. Vegetation thus appears to be fully developed throughout the year. A LAI monthly climatology datasets based on MODIS satellite product (as described in Jarlan et al. 2008) is evaluated for near-future implementation in the operational system.

2.4. Lakes

A new lake tile based on the Fresh-water Lake model (FLake, Mironov et al., 2009) has been introduced in the land surface scheme for research purposes and has been validated in global offline simulations (Dutra et al., 2010b, Balsamo et al., 2010c). In-land water bodies enhance evaporation in temperate climate. Recent advances on lake depth mapping (Kourzeneva 2010) and the availability of high resolution lake temperature observations are promising for future implementation of the scheme.

3. Results of the validation

3.1. Site validation

The HTESSEL scheme is compared to TESSEL on the root-zone soil moisture evolution on 2 contrasting field sites experiments (SEBEX Sahel and BERMS Canada, Fig. 2) while the SNOWHTESSEL is evaluated on a forest and open site (SNOWMIP2 Fraser, US, Fig. 3).

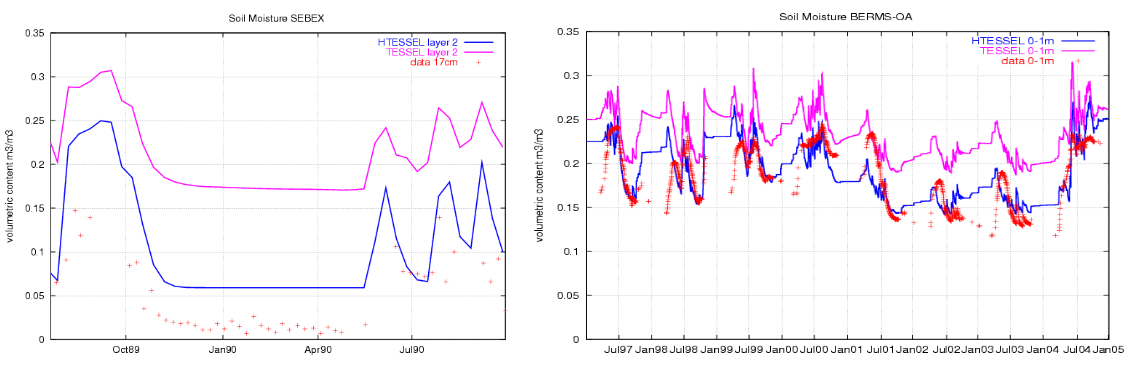

Figure 2: Evolution of soil moisture in TESSEL (magenta line) and HTESSEL (blue line) compared to observation (red +) for 2 contracting sites: SEBEX- Sahel (left) and BERMS Old Aspen Boreal forest Canada (right).

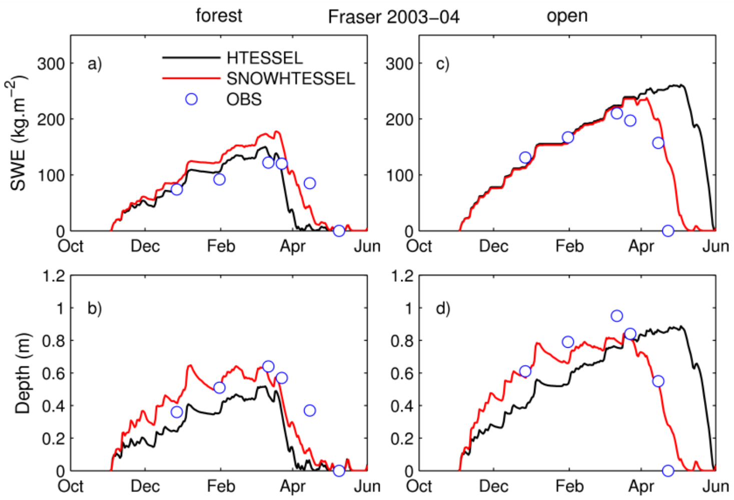

Figure 3 Model-simulated snow mass (a,c) and snow depth(b,d) in SNOWHTESSEL (red) and HTESSEL (black) compared to observations (blue) on SNOWMIP2 Fraser forest (a,b) and open (c,d) site (Colorado)during the 2003-04 winter season.

3.2. Global offline simulations

The revised land surface hydrology for both soil and snow have been extensively validated using the atmospheric forcing provided by the Global Soil Wetness Project II (Dirmeyer et al., 1999, 2002) covering a 10-year period (1986-1995). A summary of the runoff improvements obtained in the upgrades from TESSEL to HTESSEL and SNOWHTESSEL is reported in Table 1.

Table 1: Runoff RMSE (mm/day) for GSWP2 global offline simulations (1986-1995) verified with GRDC observations on snow-free basins for TESSEL, HTESSEL, and snow-dominated basins for HTESSEL, SNOWHTESSEL.

Area-weighted average of snow-free basins: Northeast-Europe, Central-Europe (~1 632 601 km^2)	**Runoff RMSE** (mm/day)	Observed area-weighted average Runoff (from GRDC) 0.76 mm/day
TESSEL	0.28	
HTESSEL	0.17	
Area-weighted average of snow basins: Yukon, Podka., Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtish, Neva (~12 334 161 km^2)	**Runoff RMSE** (mm/day)	Observed area-weighted average Runoff (from GRDC) 1.96 mm/day
HTESSEL	0.75	
SNOWHTESSEL	0.51	

The runoff error, calculated against observed monthly river-discharges from the Global Runoff Data Centre (GRDC) of the scheme including snow and soil revisions is therefore estimated to be 23% of the observed runoff in dominant snow-free basins (over Europe) and 26% in snow-dominated basins. Those results are likely to be affected by the coarse spatial resolution of the simulations (with GSWP2 being on a 1°x 1° degree grid).

3.3. Forecasts sensitivity experiments

Sets of 10-day forecasts covering one full year are performed at T399 (about 50 km horizontal resolution) with the operational IFS CY36R1 and TESSEL, HTESSEL, SNOWHTESSEL and SNOWLAIHTESSEL configurations (as described in sections 2.1-2.3). Forecasts are run 10 days apart to cover the period between 1st of January to 31 December 2008 (37 forecasts per experiment). The effect of the model on near surface temperature is evaluated for short-term forecasts (FC+36-hour). The 2m temperature sensitivity of SNOWHTESSEL compared to the TESSEL configuration is shown in Fig. 4 for both the winter (DJF) and summer (JJA) seasons. Improvements on 2m temperature forecasts are shown in Figure 5. The metric shows the mean absolute error difference calculated with respect to the operational 2m temperature analysis.

SNOWHTESSEL is shown to improve particularly the temperate climates where evapotranspiration processes are most active. The temperature sensitivity shows positive and negative patterns which are associated to the spatially varying soil texture and the revised soil hydrology.

The changes introduced in SNOWHTESSEL are very effective at high latitude and therefore the two revisions have complementary impact (as already demonstrated for the runoff). In fact, the sensitivity at northern latitudes consists of a cooling (Fig. 4) associated to the snow pack providing a greater insulation of the soil underneath, and therefore a weaker coupling of the surface to the atmosphere. This is particularly relevant during episodes of nocturnal radiative cooling where stronger inversions can develop (not shown). The thermal shielding effect of the revised snow has hydrological consequences as the soil remains largely unfrozen and permeable to infiltration also during the cold

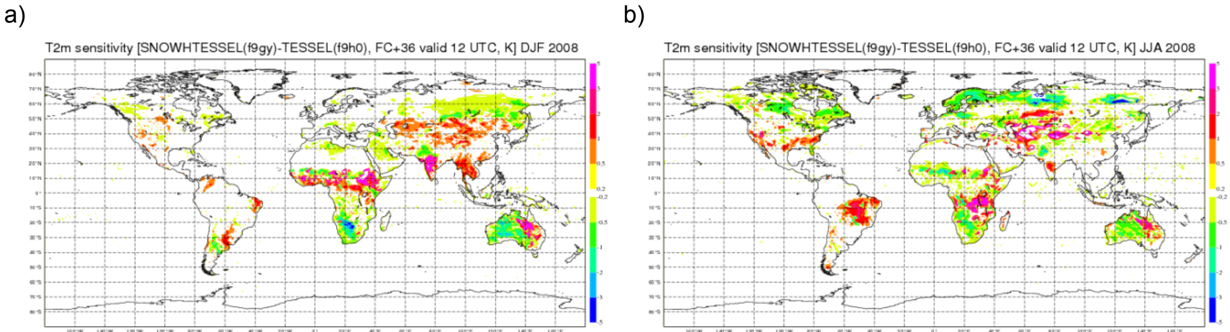

Figure 4: Sensitivity of 36-hour (12 UTC) T2m forecasts NH Winter (a) and summer (b) for SNOWHTESSEL compared to TESSEL, verified against the ECMWF operational T2m analysis. Negative values indicate cooling.

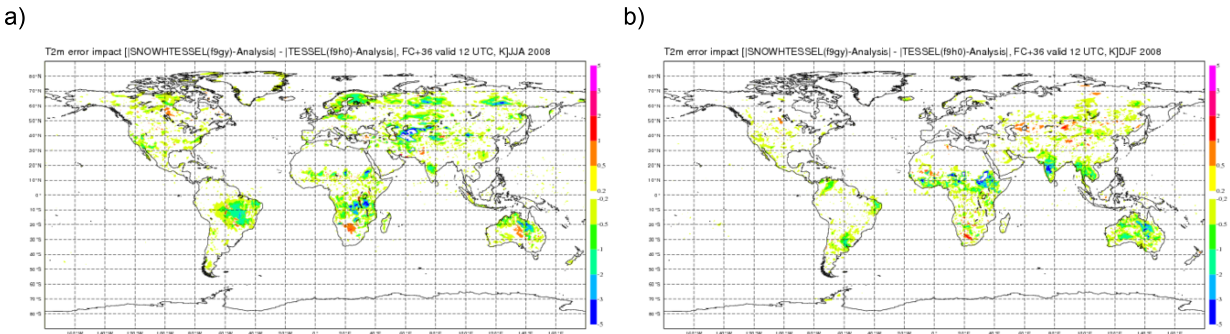

Figure 5: Impact of 36-hour T2m forecasts in NH Winter (a) and summer (b) for SNOWHTESSEL compared to TESSEL, verified against the ECMWF operational T2m analysis. Negative values indicate forecast error reduction.

season. When coupled to a river routing model (Pappenberger et al. 2009) HTESSEL and SNOWHTESSEL are proven to bring an improvement correlation to daily river discharge time-series (Balsamo et al. 2010b).

The monthly LAI climatology is evaluated as well (SNOWLAIHTESSEL) and it is shown to affect particularly tropical areas where the seasonality is rather marked due to the Monsoon precipitation. The sensitivity indicates generally a warming as shown in Fig. 6 for Spring as a consequence of lower LAI and reduced evaporation (which provides more energy to the sensible heat flux). The impact is a reduction of the systematic 2m temperature errors particularly in tropical regions (Fig. 6, lower panel).

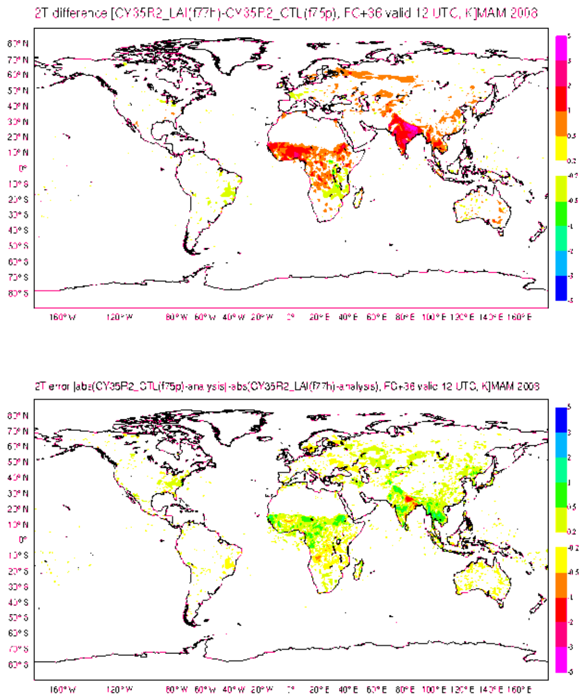

Figure 6: Sensitivity (upper panel) and Impact (lower panel) of monthly LAI climatology in Spring (MAM) as in Fig 4 and 5.

3.4. Long integrations experiments

Long integration experiments covering one full year and with daily specified SSTs (hindcasts) are performed at T159 (about 125 km horizontal resolution) to confirm the forecast sensitivities obtained in short-term forecasts. In Fig. 7 the mean annual 2m temperature forecast errors evolution is shown.

The 2m temperature errors are shown to decrease mostly in areas where the land surface changes are sensitive and with overall good impact on the climate. The largest areas of errors remain in dry-lands.

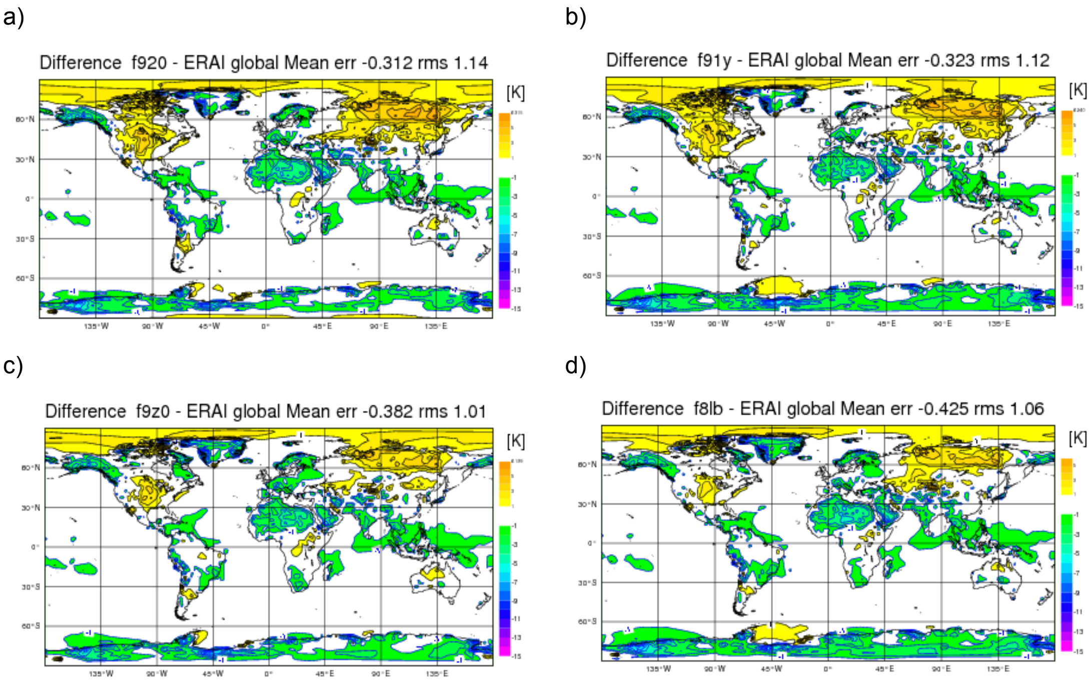

Figure 7: Mean annual 2m temperature errors in long integration compared to ERA-Interim for: (a) TESSEL (b) HTESSEL (c) HTESSELSNOW, (d) SNOWLAIHTESSEL

3.5. Preparatory studies for future model intercomparison projects

Given that land surface hydrology is dominated by the quality of precipitation a new 3-hourly global precipitation dataset extracted from ERA-Interim reanalysis is evaluated against datasets with focus over the U.S.A. and Europe for use in land surface modelling activities. In particular the most recent Global Precipitation Climatology Project monthly product (GPCP v2.1), the U.S.A. Department of Agriculture (USDA) official precipitation climatology (PRISM), and the European Land Data Assimilation System (ELDAS) datasets are used. The results show that, over the U.S.A., the ERA-Interim precipitation has comparable quality to GPCP v2.1 (see Table 2) for annual averages and a correlation of 0.85 with respect to the PRISM dataset (2000-2008). Over Europe results seems comparable or better (correlation of 0.88) with respect to the ELDAS dataset (2000) (Table 3).

Table 2: Average of 2000-2008 monthly bias, RMSE (mm/day) and correlation coefficient with respect to PRISM dataset (Di Luzio et al., 2008) over USA.

	GPCP V2.1 (mm/day)	ERA-Interim (mm/day)	GPCPV V2.0 (mm/day)
BIAS	0.081	-0.013	-0.068
RMSE	0.675	0.852	0.816
Correlation	0.899	0.853	0.816

Table 3: Average of 2000 monthly bias, RMSE (mm/day) and correlation coefficient with respect to ELDAS dataset (Rubel and Brugger, 2009) over Europe.

	GPCP V2.1 (mm/day)	ERA-Interim (mm/day)	GPCPV V2.0 (mm/day)
BIAS	0.214	-0.063	-0.52
RMSE	0.805	0.793	1.130
Correlation	0.875	0.884	0.725

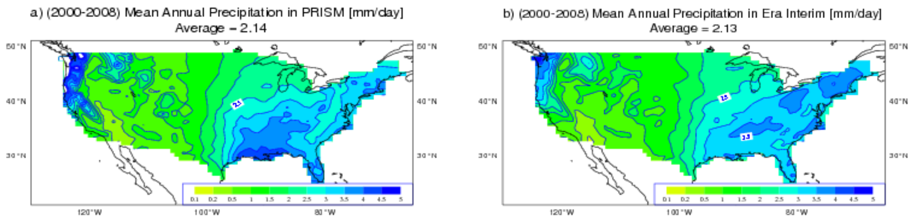

Figure 8: Annual mean precipitation (2000-2008) for a) PRISM, b) ERA-Interim. In panels c) the bias of ERA-Interim and in d) the bias of ERA-Interim-rescaled.

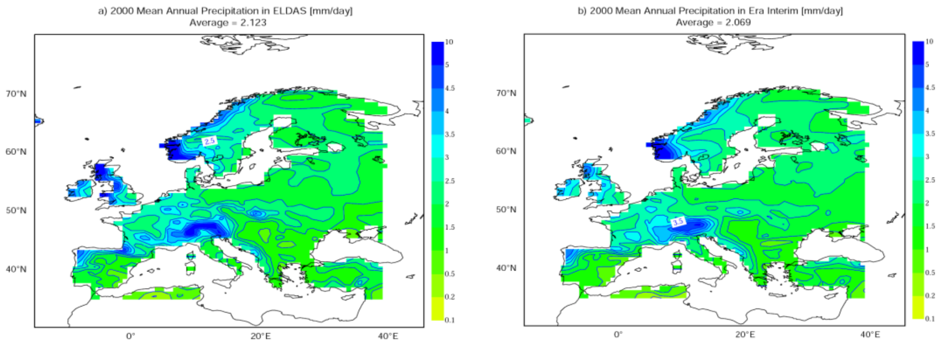

Figure 9: Annual precipitation in 2000 for a) ELDAS, b) ERA-Interim.

4. Summary and Outlook

The land surface model has been revised regarding its land surface hydrological component (soil and snow) and the description of vegetation seasonality (monthly LAI) with positive impact in the forecasts. Future improvements of the land surface physics will focus on the refinements of the land hydrology particularly on tropical areas and dry-lands (where large diurnal cycle errors occur) and on the inclusion of new relevant tiles (in particular lakes and urban areas). Preliminary work on river discharges verification at daily time-scales showed the benefits of the improved land surface physics and will be continued. Participation to land surface multi-model projects is anticipated to be beneficial for model development and with this focus ERA-Interim forcing have been validated. Finally a vegetation/carbon model will be introduced in (within the Geoland2 project) in order to model Carbon dioxide net ecosystem exchange at the surface.

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