European Commission's 7th Framework Programme
Grant Agreement No. **226520**

Project acronym: **COMBINE**

Project full title: **Comprehensive Modelling of the Earth System for Better Climate Prediction and Projection**

Instrument: Collaborative Project & Large-scale Intergrating Project

Theme 6: *Environment* Area 6.1.1.4: *Future Climate*

ENV.2008.1.1.4.1: *New components in Earth System modelling for better climate projections*

Start date of project: 1 May 2009 Duration: 48 Months

Milestone Reference Number and Title:
M4.3 Prototype of permafrost module implemented in ESMs

Lead work package for this milestone: WP4

Organization name of lead contractor for this milestone: CNRS

Due date of milestone: month 24 (April 30, 2011)
Actual submission date: October 30, 2011

M4.3 Prototype of permafrost module to be implemented in ESMs

Milestone M4.3 is about implementing a representation of permafrost in Land Surface Schemes used in Earth System Models. Three partners (METO, CNRS and MF-CNRM) were involved in this task, with different objectives: studying frozen areas, active layer thickness and their evolution in the future, but also the impact of frozen soils on surface hydrology, in particular river discharge. Finally, in common with WP1, METO and CNRS had also planned to implement representation of the impact of permafrost on the soil carbon cycle.

The starting point for the different partners was quite different (Table 1):

- JULES (used by METO) already included a simple active layer thickness representation.
- There was a version of ORCHIDEE (used by CNRS) including a representation of the impact of permafrost (and its changes) on the carbon cycle (Khvorostyanov et al, 2008, Koven et al, 2009) but it did not include a representation of the permafrost impact on surface hydrology.
- Finally, MF-CNRM's Land Surface Scheme ISBA did not include any representation of permafrost.

Status of the permafrost module development as of October 20th, 2011:

All involved partners have developed and/or started to evaluate the physical part of their permafrost modules. METO has focused on studying the frozen areas simulated by the simple representation of permafrost in the JULES Land Surface Scheme, while CNRS and MF-CNRM have focused more on developing permafrost modules, which represent the impact of permafrost on river discharges. The hydrological and carbon cycle permafrost modules implemented in ORCHIDEE are now being merged in one single version.

Table 1. Earth System Models, associated Land Surface Models and processes represented in the pre-existing and new permafrost modules.

Partner	CNRS	METO	MF-CNRM
ESM	IPSL-CM5	HadGEM2-ES	CNRM-CM5
Land surface scheme	ORCHIDEE	JULES	ISBA
Processes included in permafrost representation	Hydrology + carbon cycle, carbon cycle representation pre-existing	Hydrology + carbon cycle, hydrology representation pre-existing	Hydrology

APPENDIX: Detailed reports of the partners on the current status associate with M4.3

METO: JULES is used to represent the land surface within the Hadley Centre climate model. Whilst JULES is not a specific permafrost model, it ought to be capable of simulating the physical processes behind the dynamics of permafrost and frozen ground with some realism. This ability was evaluated using simulations of JULES over the Arctic driven by observed meteorological data. JULES is generally able to recreate the known permafrost regions in the Arctic but with an over estimation of the total permafrost area. However, the total permafrost area is notably reduced when a new multi-layer snow scheme (Best et al., 2011) is implemented. Other modifications made to JULES include (1) extending the soil column to a depth of 60 m but this had little effect on the simulation of permafrost (Dankers et al. (2011). (2) increasing the soil resolution by reducing the layer thickness to 10cm and increasing the number of layers to 70cm. This increased the accuracy of the simulated active layer thickness but didn't impact the modelled permafrost extent. JULES simulations of changes in permafrost extent show a loss of permafrost of between 0.5 and 0.8 million km^2 per decade over the second half of the 20^{th} century.

Analysis of HadGEM2-ES shows that like JULES it over-estimates the permafrost extent in the present day with ~25 million km^2 of permafrost compared with the observed extent of ~22 million km^2. By 2100 HadGEM2-ES projects a reduction permafrost extent to between 7 and 18 million km^2 depending on RCP scenario. This is a loss of between 30 and 60 %. The extension of RCP8.5 suggests a permafrost-free Arctic by 2150.

CNRS: In the framework of the COMBINE European project, a soil-freezing scheme was implemented into the land-surface scheme (LSM) ORCHIDEE with a view of improving the ability of LSM, and thus global climate models, at representing the processes and ongoing climatic changes in the Arctic.

The aforementioned soil-freezing scheme includes both the thermal and hydrological processes related to soil freezing. Its numerical robustness, its sensibility and its physical accuracy were evaluated against the benchmark of one-dimensional solutions and experiments. Its performances were then tested against field dated at different scales. We hereafter give an insight of those comparisons performed against hydrological and thermal variables.

At the plot scale, with detailed local climatological forcing and known hydraulic and thermal properties, the soil freezing scheme performs very well (Fig. 1): latent heat effects help correcting the winter cold bias and completely offset the summer warm bias; in terms of runoff, accounting for the increased impermeability of frozen soils allows to represent the spring runoff peak.

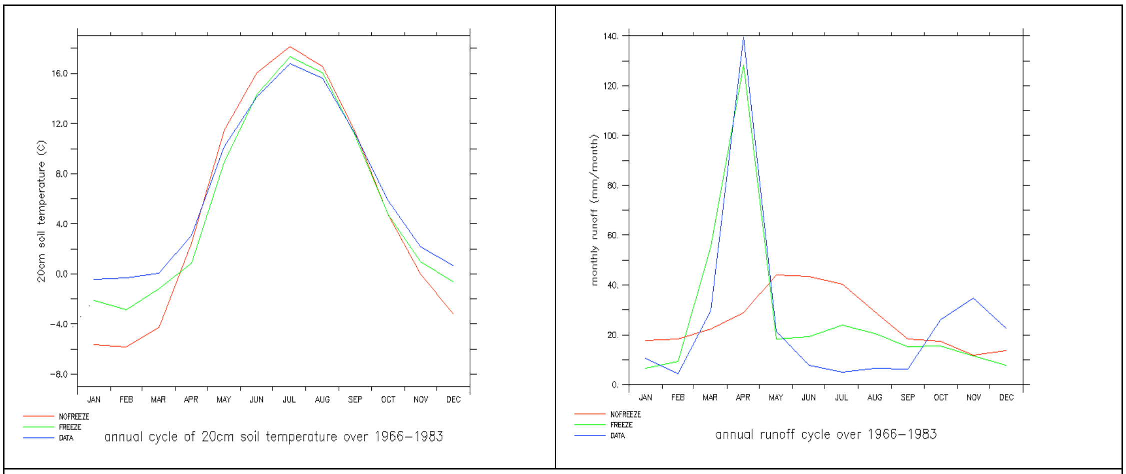

Fig. 1. Mean annual cycle of soil temperature at 20 cm (a) and of overland flow (b) simulated at Valdai (Russia) over 18 yrs. Atmospheric forcing and field data were provided in the framework of the PILPS 2d experiment (Schlosser et al., 1997). Red and green curves respectively refer to the model without and with the soil freezing scheme; the blue curve represents the data.

As the surface model, ORCHIDEE is designed to compute the surface processes at a scale of a few tens to a few hundreds of kilometers. The relevance of comparisons of model outputs at those scales against point data relating to soil temperature, soil moisture, sensible or latent fluxes, is altered by the extreme spatial variability of those variables at the scale of the model's grid cell. Comparison against spatially averaged products at the extent of satellite data appears far more promising for LSM-validations, yet such products, especially regarding to soil moisture, are operationally still in their infancy (Wagner et al., 2007). River discharges constitute another kind of spatially integrated variables, which our model was tested against (Fig. 2).

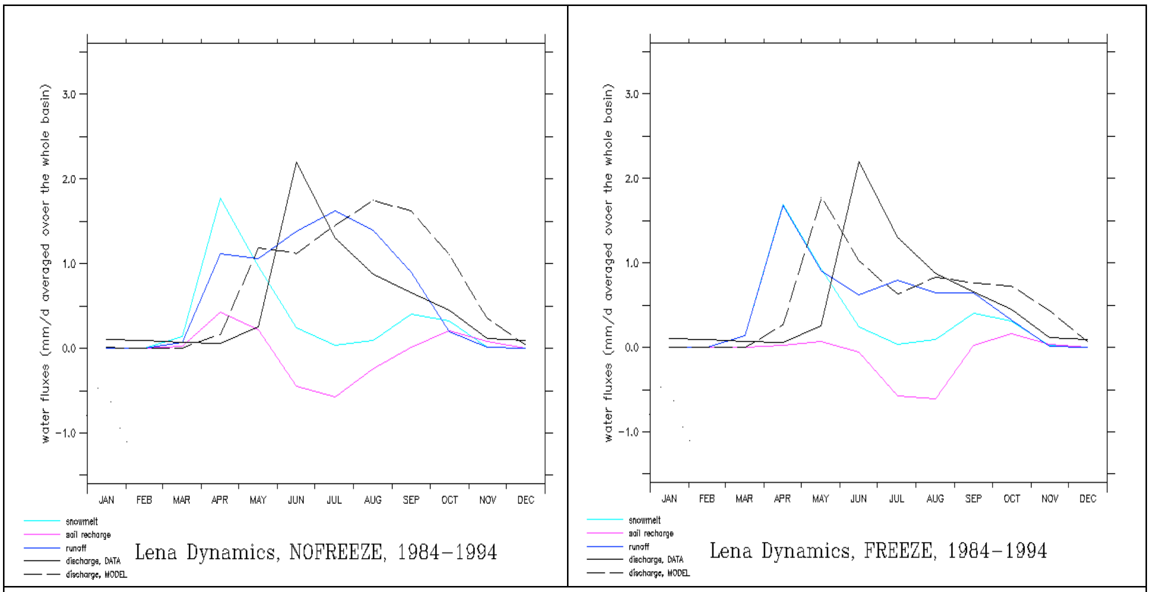

Fig. 2. Comparison of the modelled hydrological dynamics of the Lena basin with and without the freezing scheme, and against measured discharged at the outflow of the Lena, averaged over the years 1984 to 1994.

Soil freezing considerably improves the seasonal shape of the modelled runoff, but also its amplitude. Not accounting for latent heat effects indeed leads to unrealistically low evaporation rates over the basin and an unrealistic runoff. Further validation results are now available in Gouttevin et al. (2011).

MF-CNRM: The permafrost module has been implemented in the land surface scheme ISBA, used in the CNRM ESM. It needed the ISBA land surface scheme to compute explicitly the water and heat fluxes into the soil column. Such a soil-diffusion version of ISBA, named ISBA-DF, was validated at the local scale over the SMOSREX experimental site, showing very good results in simulating the soil moisture and temperature profile as well as the surface latent and sensible energy fluxes (Decharme et al. 2011). Whether the ground is frozen or not, it is also important to test such a scheme against observations. So this scheme is currently being evaluated at the regional scale over France using the SAFRAN-ISBA-MODCOU (SIM) system. This system allows an evaluation of the discharges simulated by SIM against more than 550 in-situ gauging measurements located over the entire France domain. The results show that the model improves the simulation of the river discharges compared to the previous version of the ISBA scheme. In the near future, the evaluation will be extended to the global scale. In addition, the scheme will be implemented over "cold processes" site experiments to finalize the development of the permafrost module. The next stage will be to simulate the current distribution of the permafrost at the global scale.

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