Recent changes in the ISBA-CTRIP land surface system for use in the CNRM-CM6 climate model and in global off-line hydrological applications

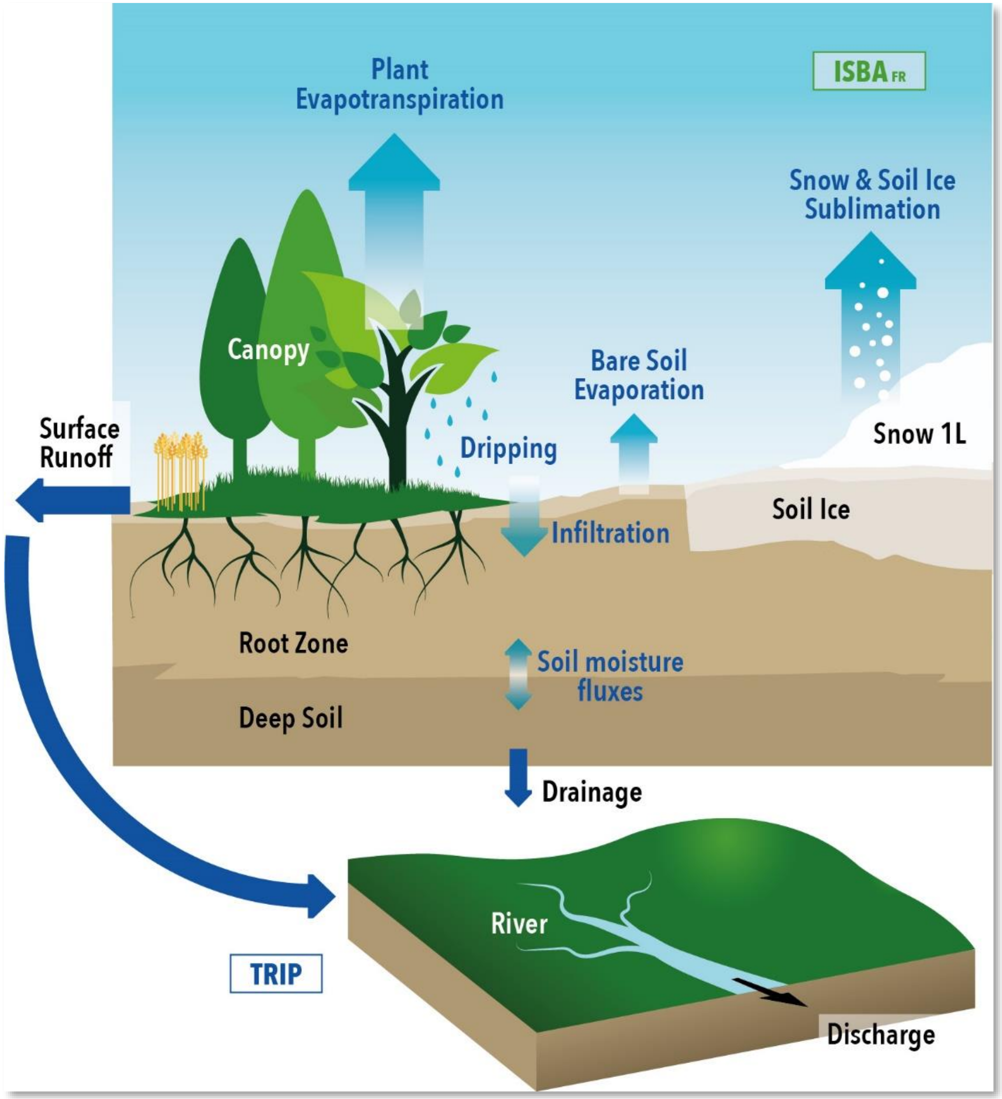
Under review in *Journal of Advances in Modeling Earth Systems*

Bertrand Decharme, Christine Delire, Marie Minvielle, Jeanne Colin, Jean-Pierre Vergnes, Antoinette Alias, David Saint-Martin, Roland Séférian, Stéphane Sénési, Aurore Voldoire

Tanks also due to Ramdane Alkama, Aaron Boone, Eric Brun, Jean-Christophe Calvet, Dominique Carrer, Hervé Douville, Stéphanie Faroux, Laurent Franchisteguy, Florence Habets, Patrick LeMoigne, Eric Martin, Joël Noilhan, Emilie Joetzjer, Sophie Tytecas

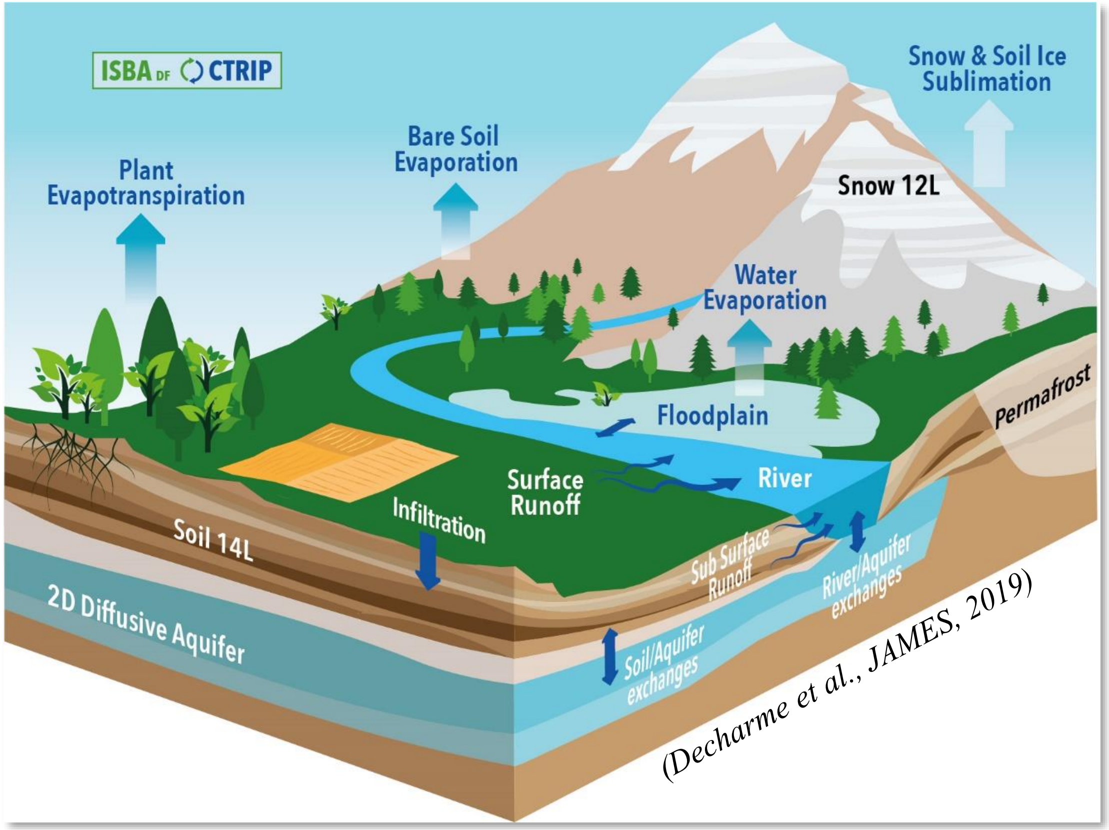
ISBA$_{FR}$-TRIP (SURFEXv5.2) in CNRM-CM5 : *sfxcm5*

- ➢Force-Restore method for soil hydrology (3-Layers) and temperature (4-Layers) using Jarvis-type transpiration scheme
    - ➢*Noilhan & Planton, 1989*
    - ➢*Boone et al., 1999*
- ➢Soil freezing/melting only in the upper soil
    - ➢*Boone et al., 2000*
- ➢Exponential K_{sat} profile with soil depth
    - ➢*Decharme et al. 2006*
- ➢1-Layer snow scheme
    - ➢*Douville et al., 1995*
- ➢Sub-grid processes for runoff simulation (topography, rainfall intensity, vegetation 12 patches)
    - ➢*Decharme & Douville, 2006*
- ➢Simple river routing scheme (TRIP) with constant flow velocity ($0.5 m.s^{-1}$) using a river network at 1° resolution
    - ➢*Oki & Sud, 1998*
- ➢A simple one-way coupling between ISBA and TRIP to stimulate river discharges at the global scale
    - ➢*Decharme & Douville, 2007*



(Decharme & Douville, Clim. Dyn. 2007)

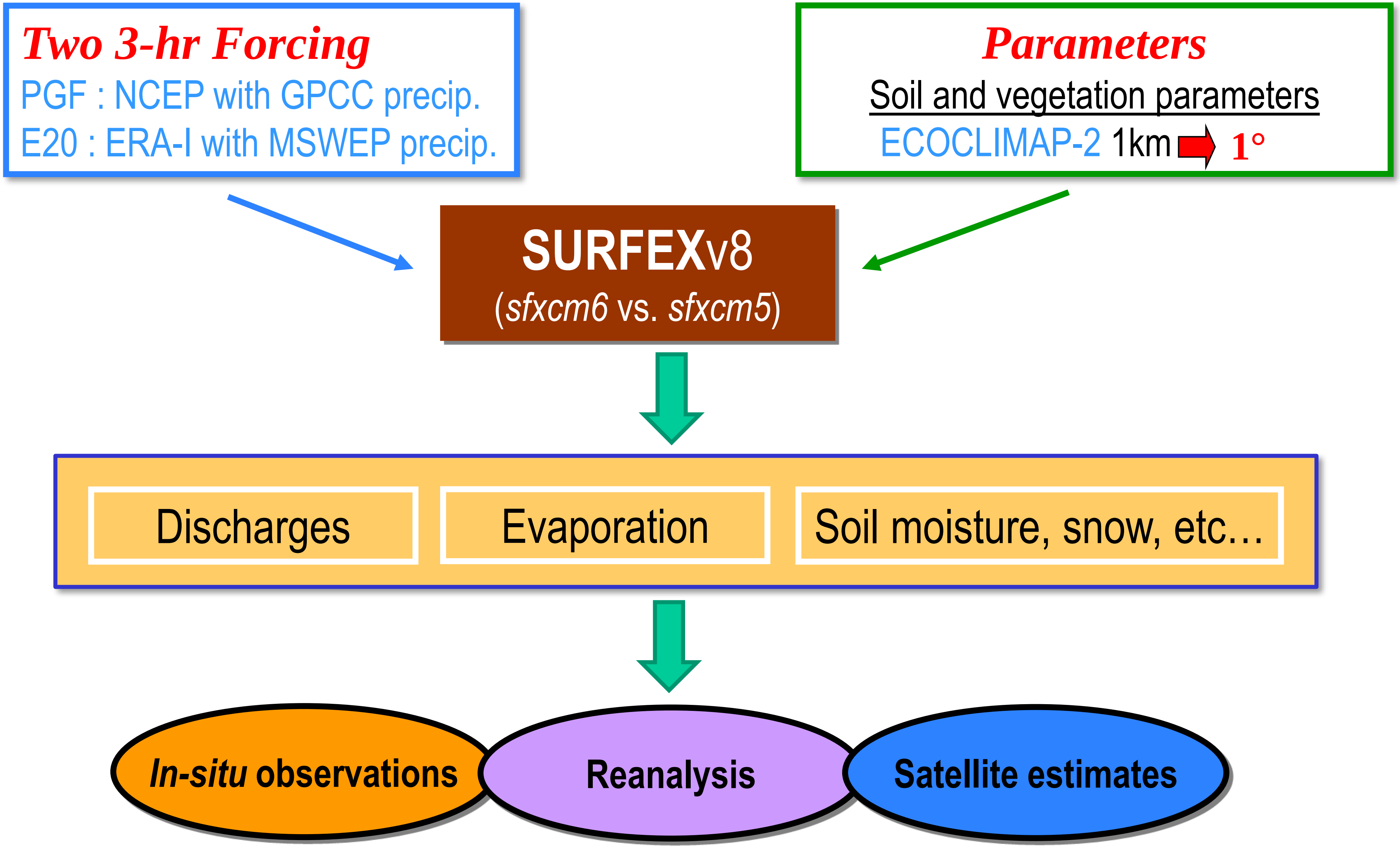
ISBA$_{DF}$-CTRIP (SURFEXv8.0) in CNRM-CM6 : *sfxcm6*



(Decharme et al., JAMES, 2019)

- 14-Layers explicit soil scheme with the same sub-grid processes for runoff than previously
  - *Boone et al., 2000*
  - *Decharme et al., 2011 & 2013*
- Soil organic carbon effects on soil properties
  - *Decharme et al., 2016*
- 12-Layers explicit snow scheme (mass and heat)
  - *Boone and Etchevers, 2001*
  - *Decharme et al., 2016*
- Transpiration via carbon cycling in the vegetation but LAI prescribed (AST option)
  - *Calvet et al., 1998*
  - *Joetzjer et al., 2014*
- Variable flow velocity according water mass and river network at 0.5°
  - *Decharme et al., 2011*
- Explicit two-way coupling between ISBA and CTRIP via a standardized coupling interface in SURFEX using OASIS-MCT
  - *Voldoire et al. 2017*
- Two-dimensional diffusive aquifer scheme allowing exchanges with the river and upward capillarity fluxes to the subsoil
  - *Vergnes et al., 2012 & 2014*
  - *Vergnes and Decharme, 2012*
- Floodplains dynamical scheme allowing floodwater evaporation and soil re-infiltration
  - *Decharme et al., 2008 & 2012*
- SURFEX interfaced with the XIOS I/O server in order to provide high performance output for massively parallel simulations

Experimental design : Global evaluation at 1° over 1979-2010



Two 3-hr Forcing

PGF : NCEP with GPCC precip.

E20 : ERA-I with MSWEP precip.

Parameters

Soil and vegetation parameters

ECOCLIMAP-2 1km → 1°

SURFEXv8

(*sfxcm6* vs. *sfxcm5*)

Discharges

Evaporation

Soil moisture, snow, etc…

***In-situ* observations**

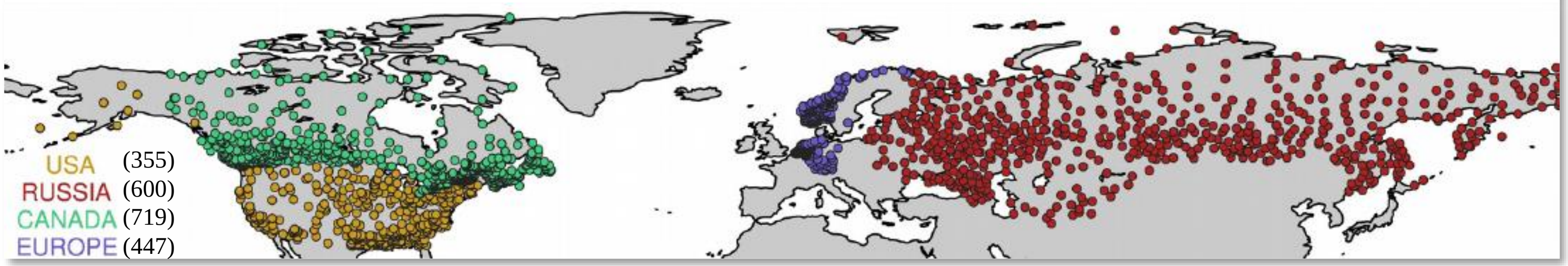
Reanalysis

Satellite estimates

(Decharme et al., JAMES, 2019)

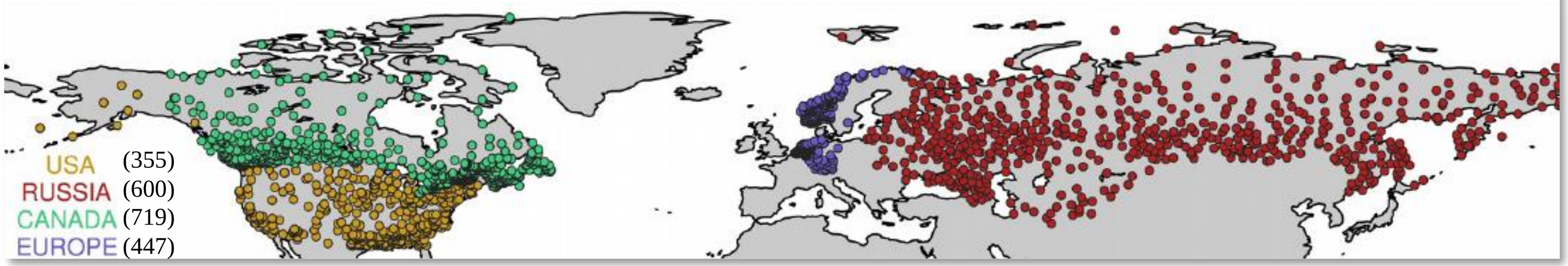
Daily snow depth measurements

Daily observations gathered by Eric Brun at 2121 stations (open areas with low vegetation) from the last century to the present

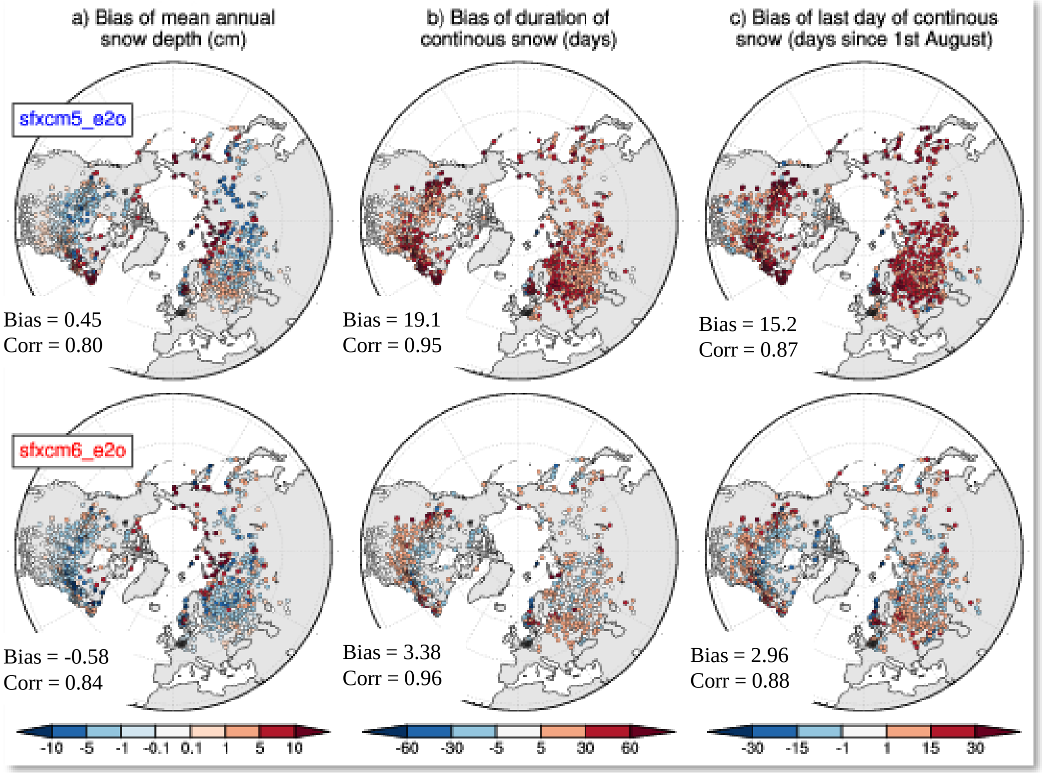


Daily snow depth measurements

Daily observations gathered by Eric Brun at 2121 stations (open areas with low vegetation) from the last century to the present



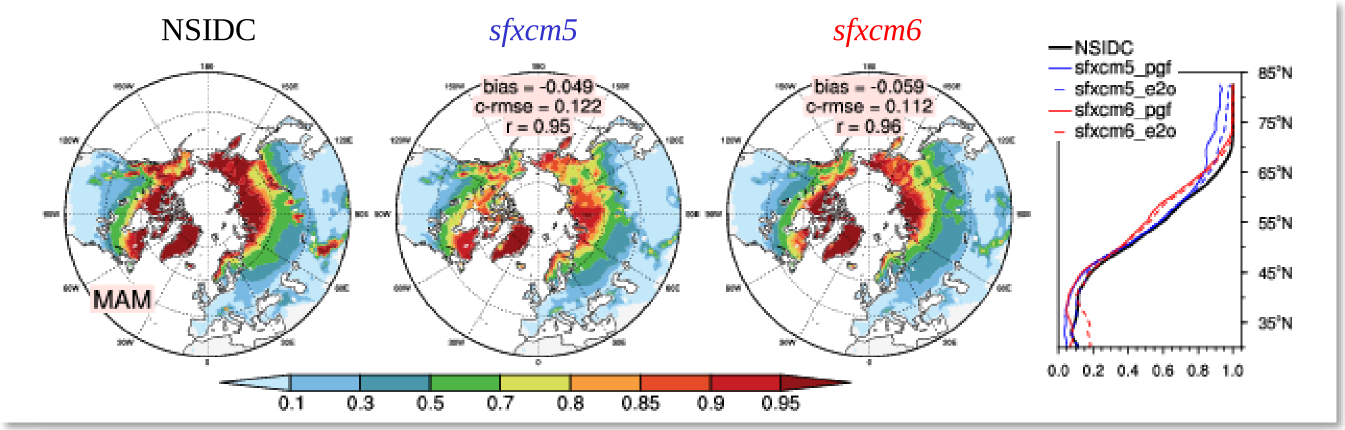
1271 stations selected over 1979-2010 following *Brun et al. (2013)* criteria



- ➢ (a) Snow depth bias scores are not very different between *sfxcm5* and *sfxcm6*, even though the mean snow depth is lower with the new snow scheme because it simulates larger snow density
- ➢ (b) The duration of the snow season is better simulated with *sfxcm6* especially because…
- ➢ (c) *sfxcm6* springtime snowmelt is faster and much better reproduced compared to *sfxcm5* (spectral albedo in ES; *Decharme et al., 2016*)
- ➢To sum-up, the snow seasonal cycle is much better reproduced using *sfxcm6* compared to *sfxcm5* but…

Climatological snow cover 1979 – 2010

Simulated **spring** snow cover compared to satellite estimates (NSIDC; *Brodzik & Armstrong, 2013*)

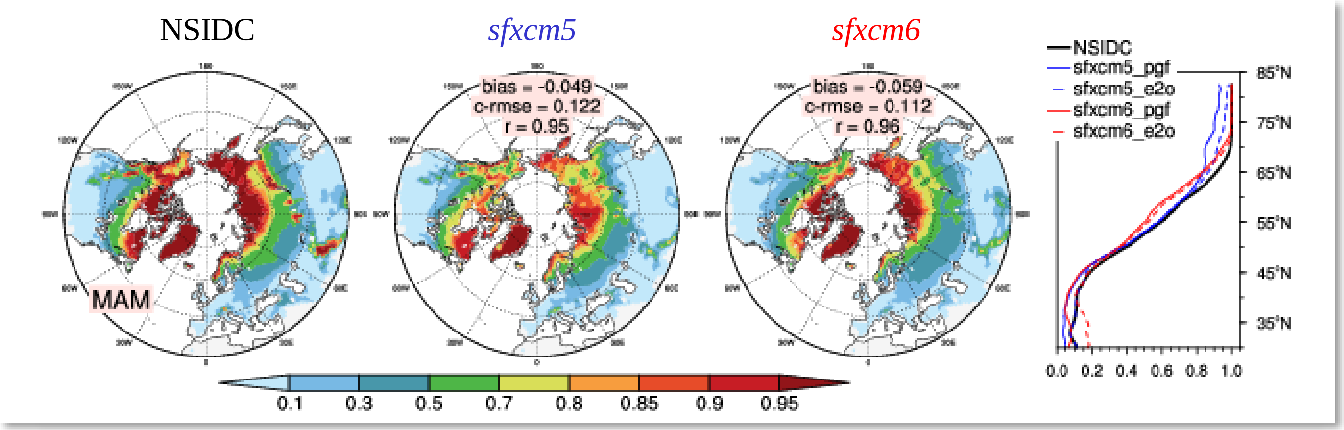


- ➢ *sfxcm6* (with both forcings) underestimates the snow extent, especially between 50° and 70° north, pointing to an early snowmelt over the boreal forest

- ➢ Need a separate energy budget for forests (MEB; *Boone et al. 2017*) ?

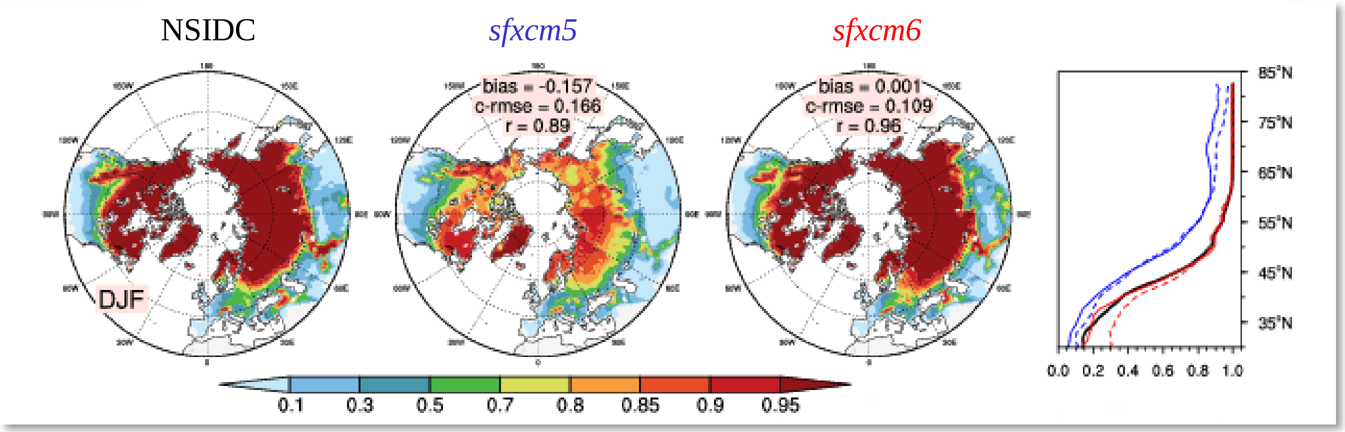
Climatological snow cover 1979 – 2010

Simulated **spring** snow cover compared to satellite estimates (NSIDC; *Brodzik & Armstrong, 2013*)



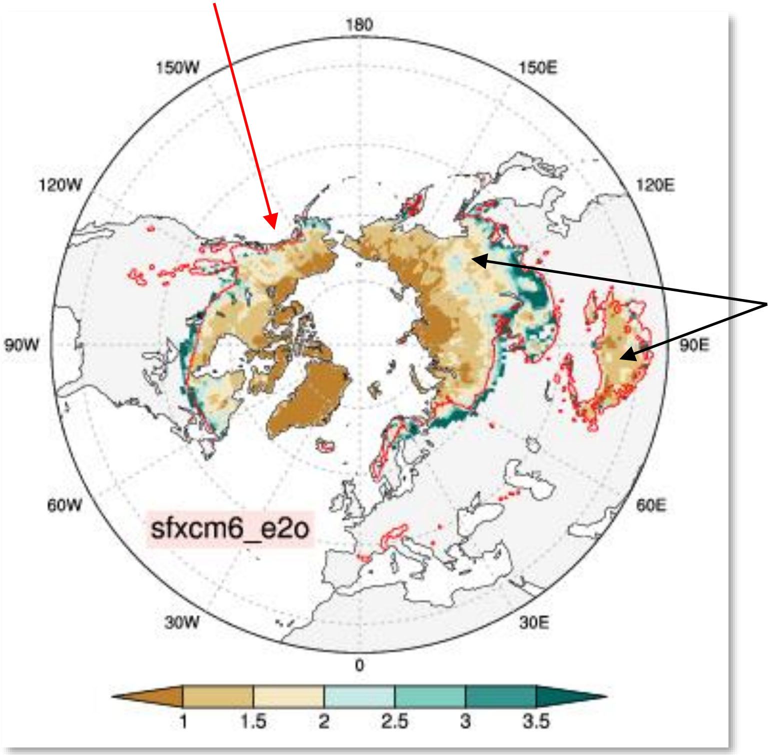
- ➢ *sfxcm6* (with both forcings) underestimates the snow extent, especially between 50° and 70° north, pointing to an early snowmelt over the boreal forest
- ➢ Need a separate energy budget for forests (MEB; *Boone et al. 2017*) ?

Simulated **winter** snow cover compared to satellite estimates (NSIDC; *Brodzik & Armstrong, 2013*)



- ➢ Fortunately, the snow cover is drastically improved by *sfxcm6* during winter (and autumn)

Permafrost limits & Active Layer Depth 1990 – 2010



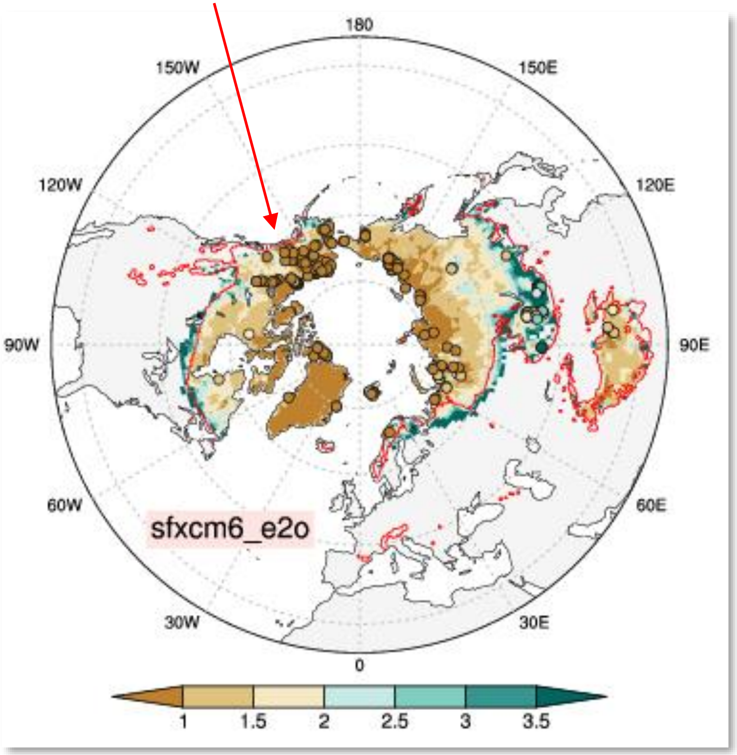
Permafrost limits from *Brown et al. (2002)*

Simulated active layer depth with *sfxcm6*

- Permafrost boundaries are globally well reproduced by *sfxcm6*
- but they extend slightly too far south in both western Siberia and eastern Canada
- Soil too cold because no MEB-litter (*Napoly et al., 2017*) or artic snow (*Barrere et al., 2017*) ?

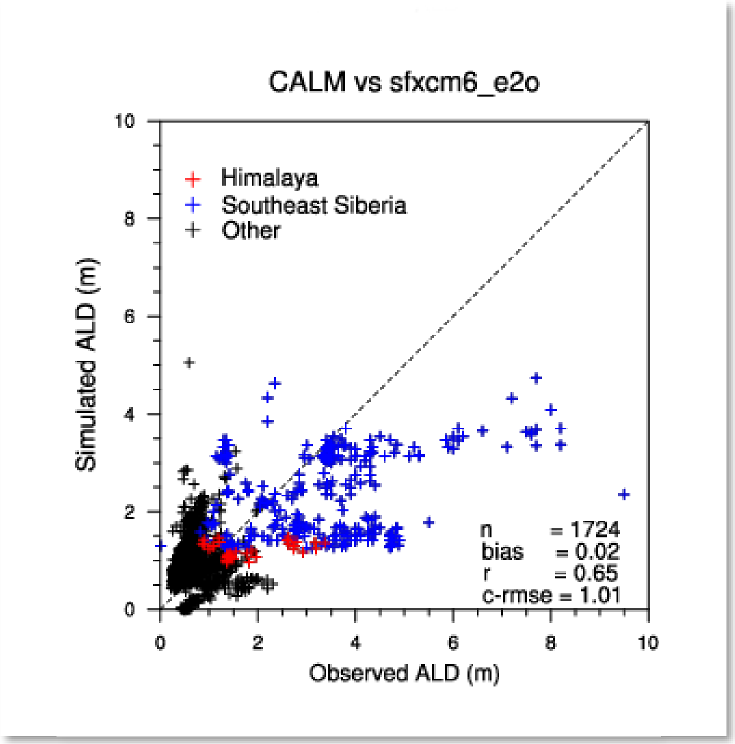
Permafrost limits & Active Layer Depth over 1990 – 2010

Permafrost limits from *Brown et al. (2002)*



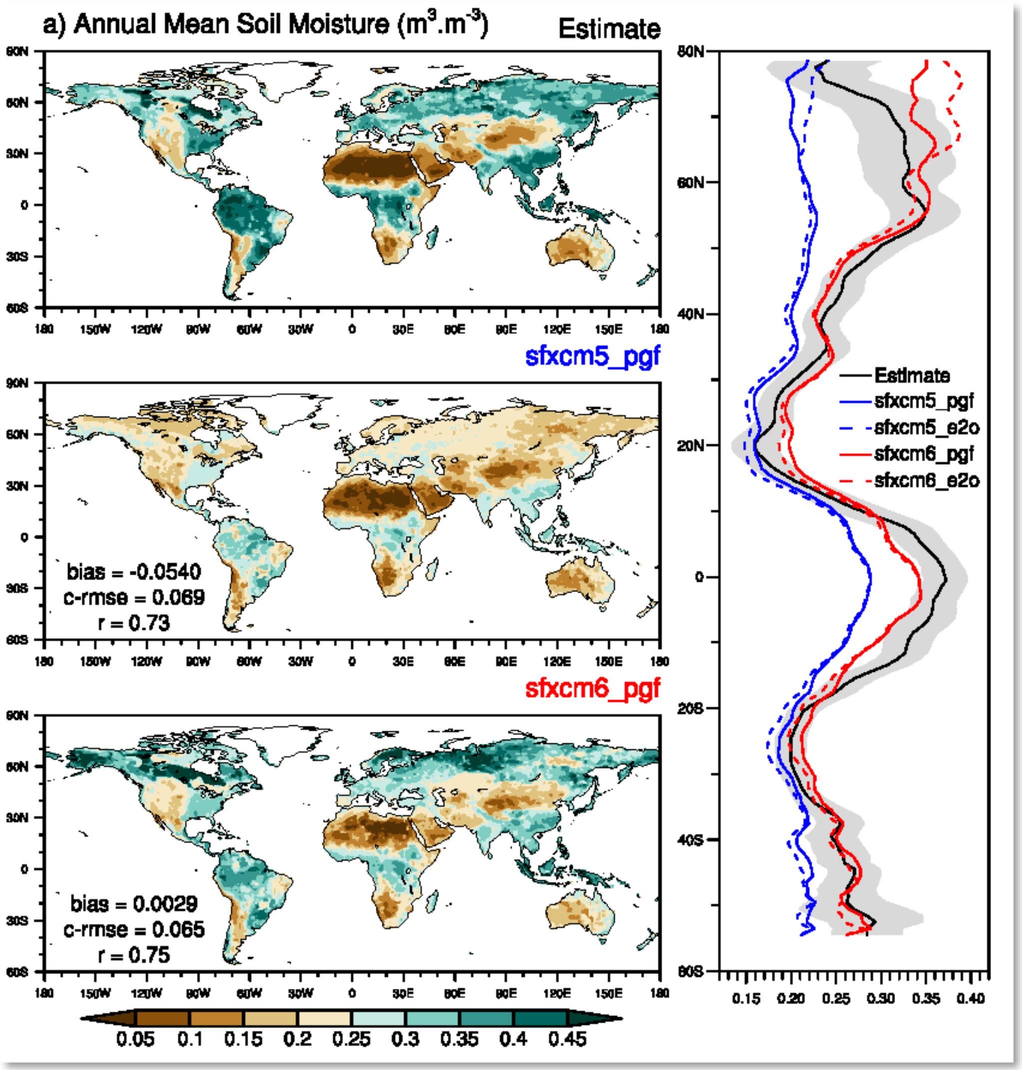
- ➢Permafrost boundaries are globally well reproduced by *sfxcm6*
- ➢but they extend slightly too far south in both western Siberia and eastern Canada
- ➢ Soil too cold because no MEB-litter (*Napoly et al., 2017*) or artic snow (*Barrere et al., 2017*) ?

CALM network (*Brown et al., 2000*)



- ➢ALD spatial distribution is well reproduced
- ➢The largest error is located over isolated or sporadic permafrost due to the low resolution of the atmospheric forcing
- ➢ALD errors are reasonable with regard to low resolution and to results of other models used in climates models

Root zone soil moisture over 1980 – 2010



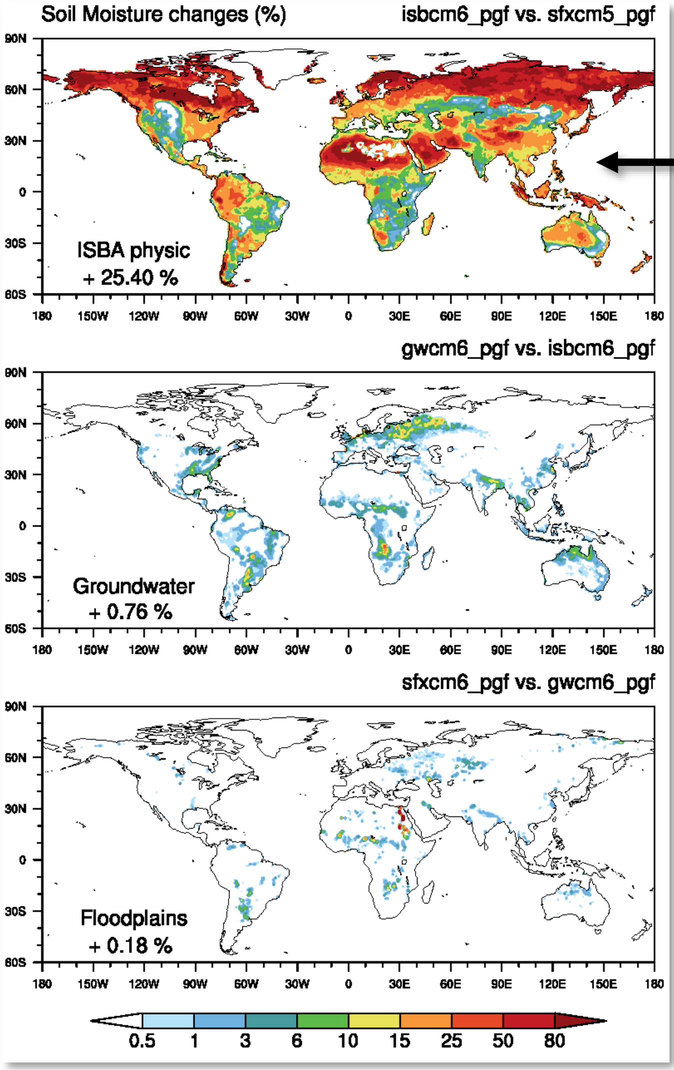
Comparison between simulated and estimated root zone soil moisture

➢ Estimate: average of GLEAM (*Martens et al., 2017*) and ERA-I/Land (*Balsamo et al., 2009*) soil moisture datasets

➢ The soil water content is significantly increased from *sfxcm5* to *sfxcm6* and more in agreement with estimates (but perhaps too wet in boreal regions)

➢Results agrees with previous global land surface model intercomparison projetcs (GSWP1, GSWP2) showing ISBA$_{FR}$ (*sfxcm5*) among driest models

Root zone soil moisture over 1980 – 2010



Comparison between several physics

Changes in soil moisture from $ISBA_{FR}$ to $ISBA_{DF}$

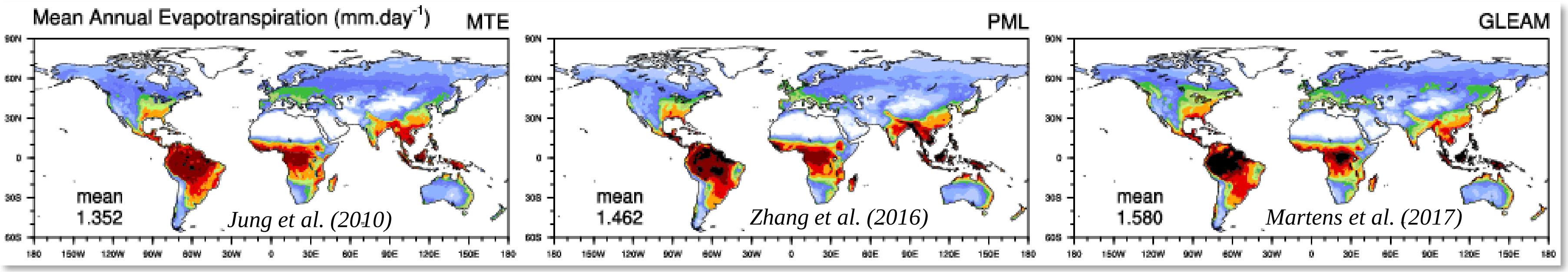
➢The dominant effect is linked to change in soil scheme (field capacity in $ISBA_{FR}$ certainly too low)

➢The mixing between mineral and organic soil properties increases soil porosity and limits hydraulic conductivity leading to wet soil conditions especially in boreal regions

➢A plug effect in permafrost areas due to the deep soil freezing (not represented in $ISBA_{FR}$) also contributes to maintaining very moist soils all year

➢Impact of upward capillarity fluxes from groundwater to sub soil (as well as floodwater infiltration) is globally limited but can be locally important.

Evapotranspiration over 1982 – 2008

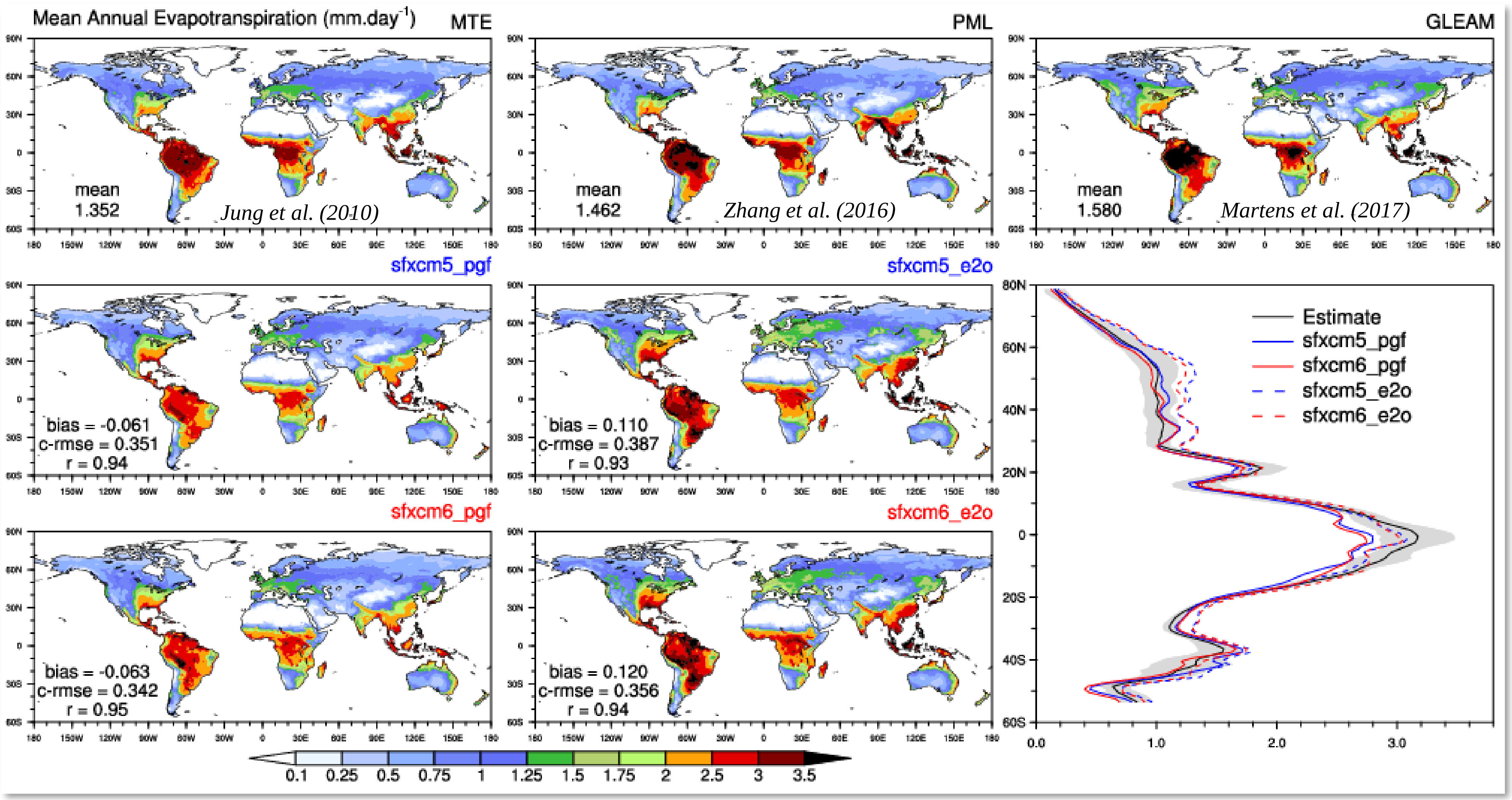


Jung et al. (2010)

Zhang et al. (2016)

Martens et al. (2017)

Evapotranspiration over 1982 – 2008



Mean Annual Evapotranspiration (mm.day^{-1})

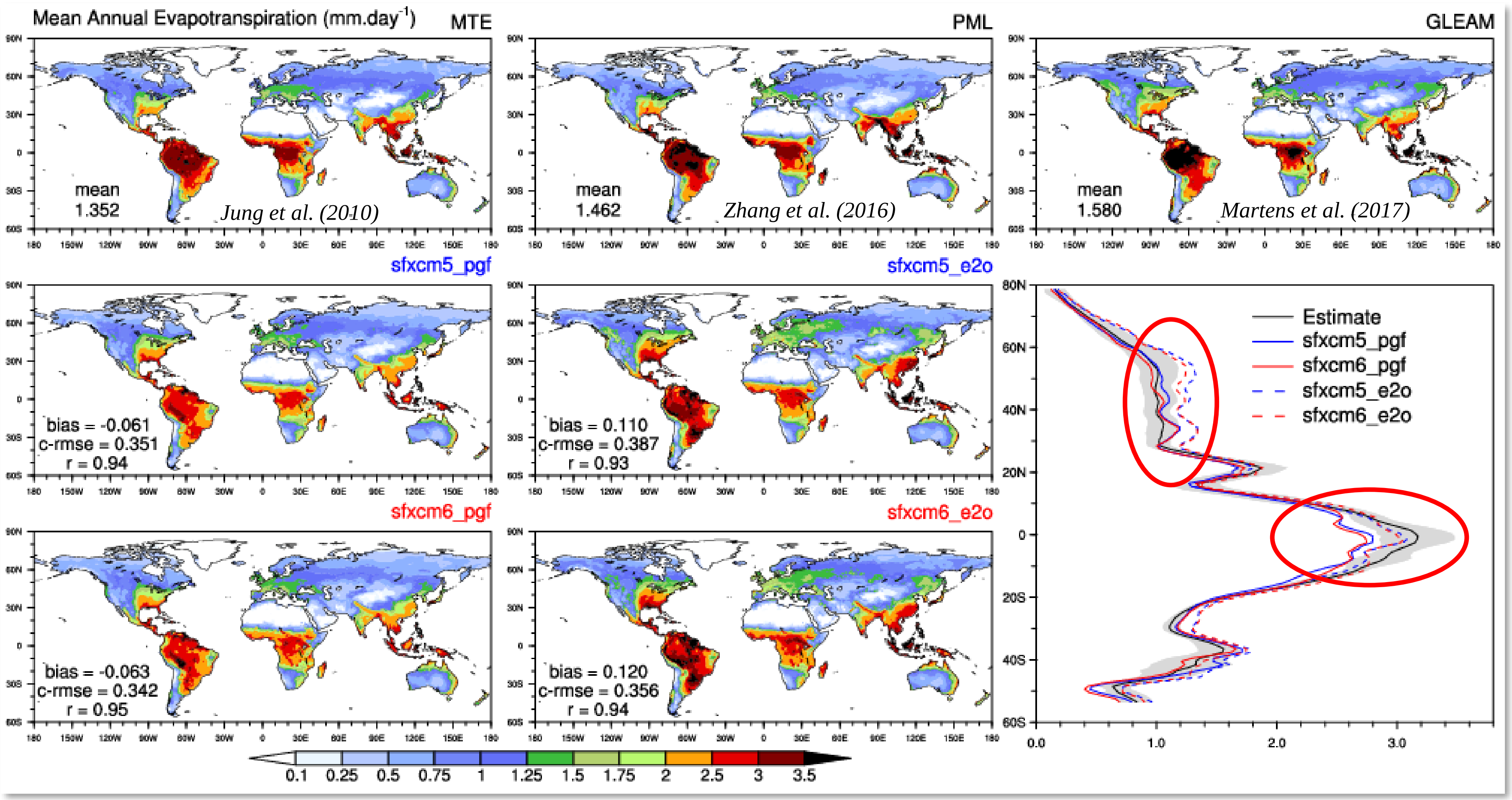
Jung et al. (2010)

Zhang et al. (2016)

Martens et al. (2017)

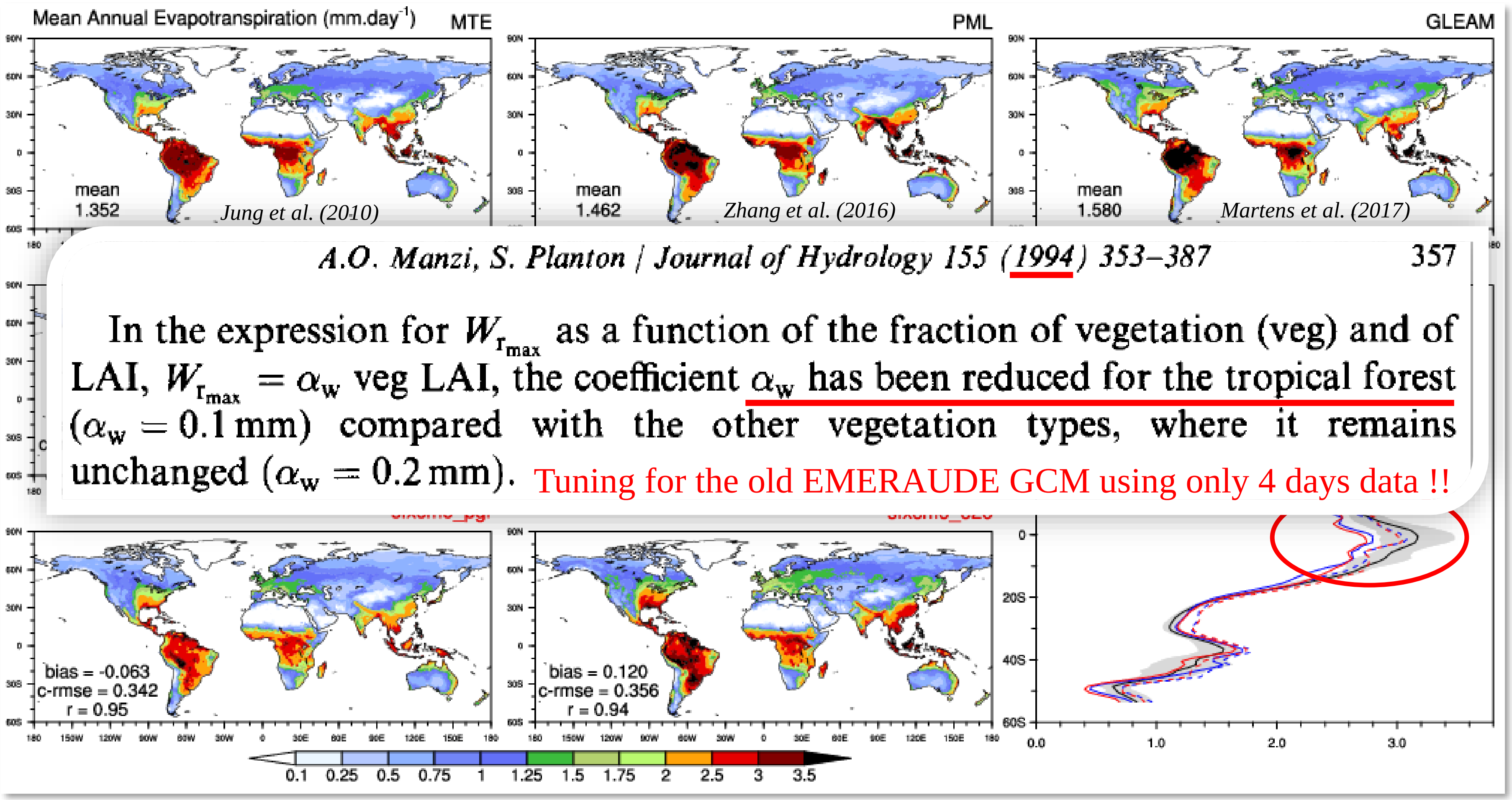
- ➢Evap. largely more sensitive to atmospheric condition than in land surface physic (not new… well know !)
- ➢Both models versions show an acceptable agreement with estimates

Evapotranspiration over 1982 – 2008



- ➢Evap. largely more sensitive to atmospheric condition than in land surface physic (not new… well know !)
- ➢Both models versions show an acceptable agreement with estimates
- ➢Overestimation over temperate latitudes (especially with ERA-I) : LAI too fast ?
- ➢General underestimation over tropical forests : Transpiration param of forest (*Joetzjer et al., 2015*) and/or Direct canopy evaporation ?

Evapotranspiration over 1982 – 2008

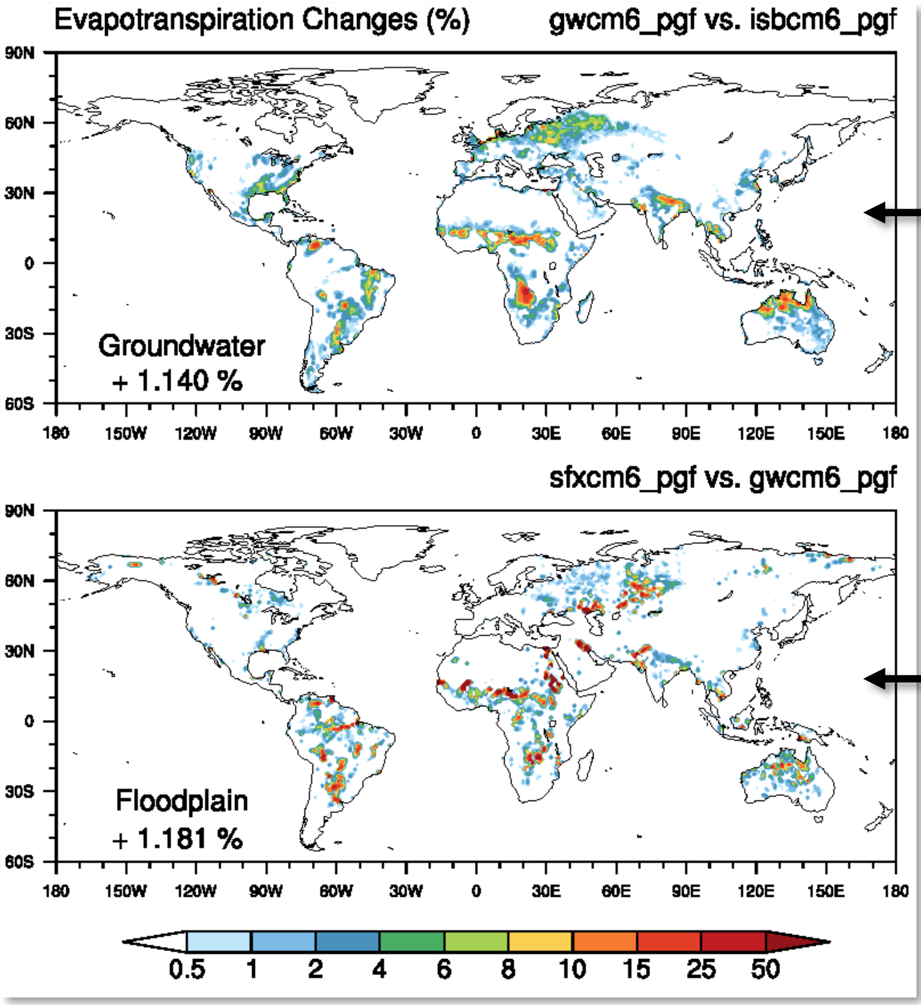


A.O. Manzi, S. Planton / Journal of Hydrology 155 (1994) 353–387 357

In the expression for $W_{r_{\max}}$ as a function of the fraction of vegetation (veg) and of LAI, $W_{r_{\max}} = \alpha_w$ veg LAI, the coefficient α_w has been reduced for the tropical forest ($\alpha_w = 0.1\,\text{mm}$) compared with the other vegetation types, where it remains unchanged ($\alpha_w = 0.2\,\text{mm}$). Tuning for the old EMERAUDE GCM using only 4 days data !!

- ➢Evap. largely more sensitive to atmospheric condition than in land surface physic (not new… well know !)
- ➢Both models versions show an acceptable agreement with estimates
- ➢Overestimation over temperate latitudes (especially with ERA-I) : LAI too fast ?
- ➢General underestimation over tropical forests : Transpiration param of forest (*Joetzjer et al., 2015*) and/or Direct canopy evaporation ?

Evapotranspiration over 1982 – 2008



Impacts of upward capillarity fluxes from aquifers

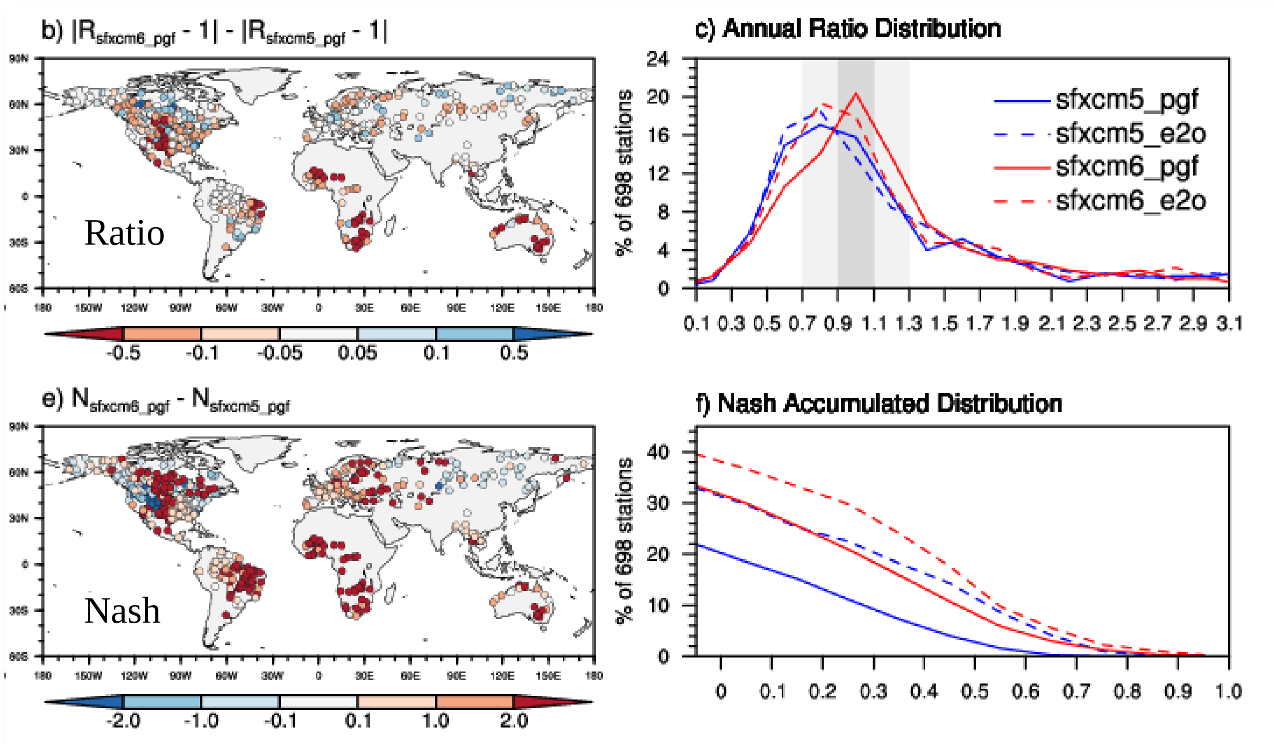
Impacts of flooded water re-infiltration

➢Impacts are globally low but can be regionally significant.

Impact of upward capillarity fluxes and floodplain processes

River discharges: daily measurements over 1979 – 2010

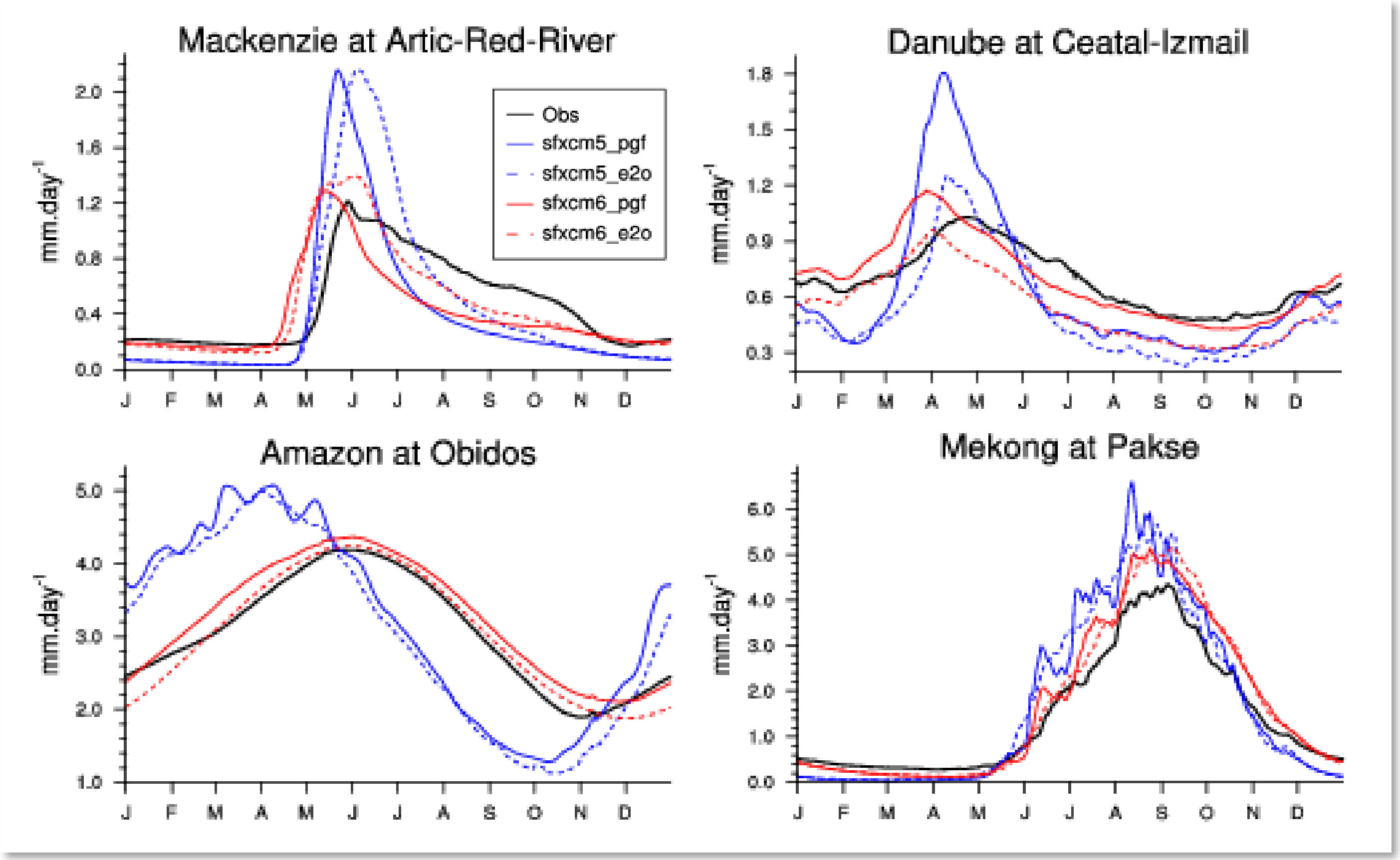
- Comparison (annual Ratio and Nash criteria) at 668 stations selected over 1979-2010 (only large basins) from a datasets of 20164 stations from 1900 to present:
  - *GRDC : global*
  - *Hybam : Amazonia*
  - *French Hydro database (as SIM) : France*
  - *Antico et al. (2018) for Parana river at Rosario*



- *sfxcm6* generally simulates better discharges than *sfxcm5*

- ERA-I forcing with MSWEP precipitation allows better simulated discharges but annual Ratio are slightly underestimated (larger evaporation than PGF)

Discharges: daily measurements over 1979 – 2010



Climatological seasonal cycles of daily discharges near the mouths of some rivers

- Improved baseflow : (1) better drainage dynamics and no limitation under w_{fc} with ISBA$_{DF}$; (2) aquifers restitute the water stored during rainy or snowmelt season to the river throughout the low flow season.
- Improved peak of discharges : floodplain reservoir induces a buffer effect on river discharge by storing a large part of the springtime snowmelt runoff; but because springtime snowmelt is too fast, peak of discharges is too early
- Over Tropical or Monsoon basins, all changes (diffusive soil scheme, floodplains and groundwater) contribute equally to river flow improvements

Terrestrial Water Storage Variation over 2002-2010

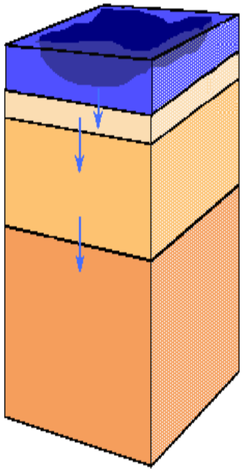
Gravity Recovery and Climate Experiment (GRACE)

- Monthly terrestrial water storage (TWS) variation estimates based on earth's gravity field (spatial scale about 300-400 km resolution)
- 3 products over the 2002 – 2014 period :
  - GeoForschungZentrum (**GFZ**)
  - Center for Space Research (**CSR**)
  - Jet Propulsory Laboratory (**JPL**)

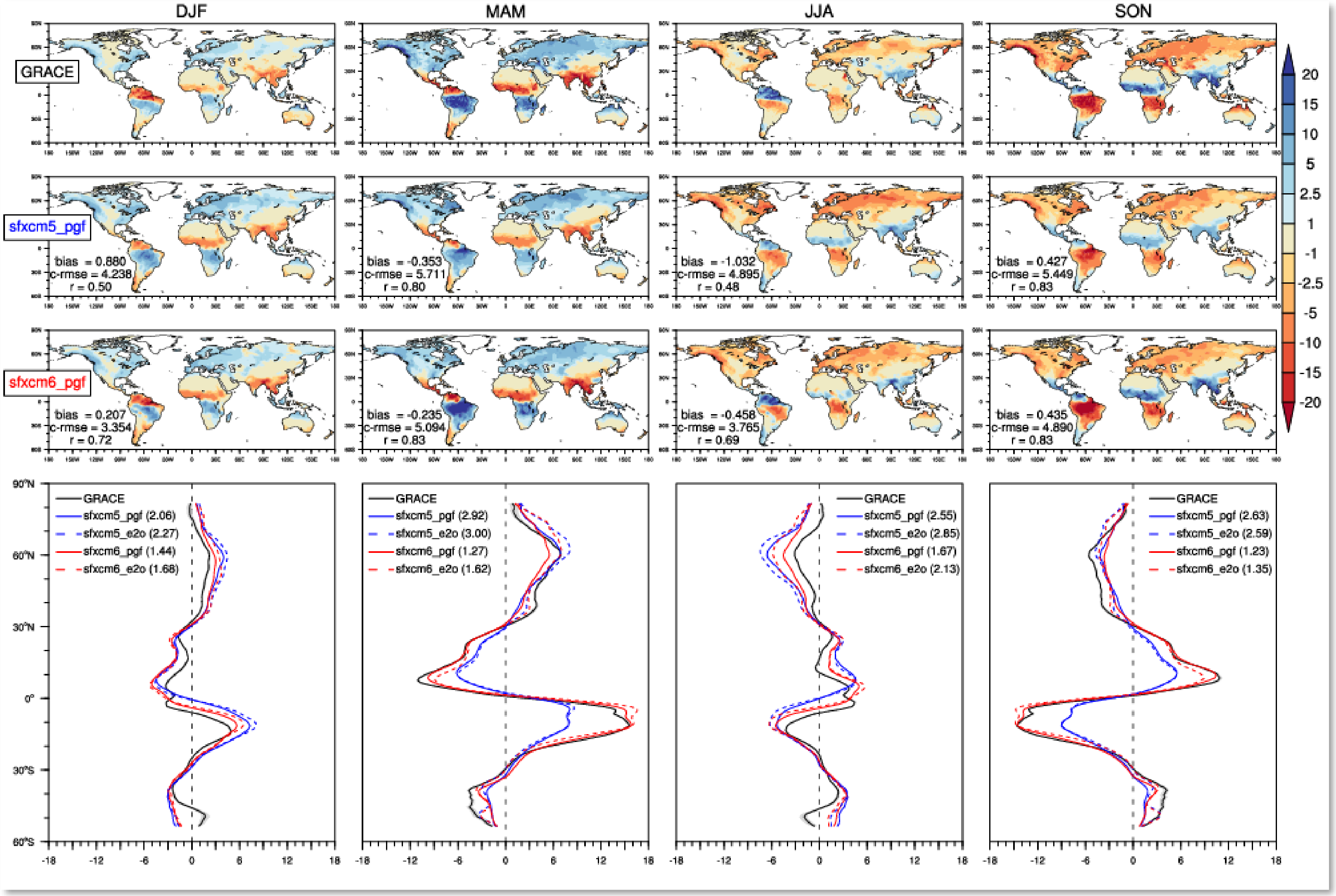
→ TWS model variations are compared to the standard deviation and **mean of the 3 GRACE products**

Terrestrial water storage
TWS

surface water (storage reservoir)
snow + vegetation
+
soil moisture
+
groundwater



Terrestrial Water Storage Variations over 2002-2010



- ➢Significant improvements, especially over the tropics.
- ➢Main contributors are ISBA_{DF} and the groundwater scheme that increase the memory of the system

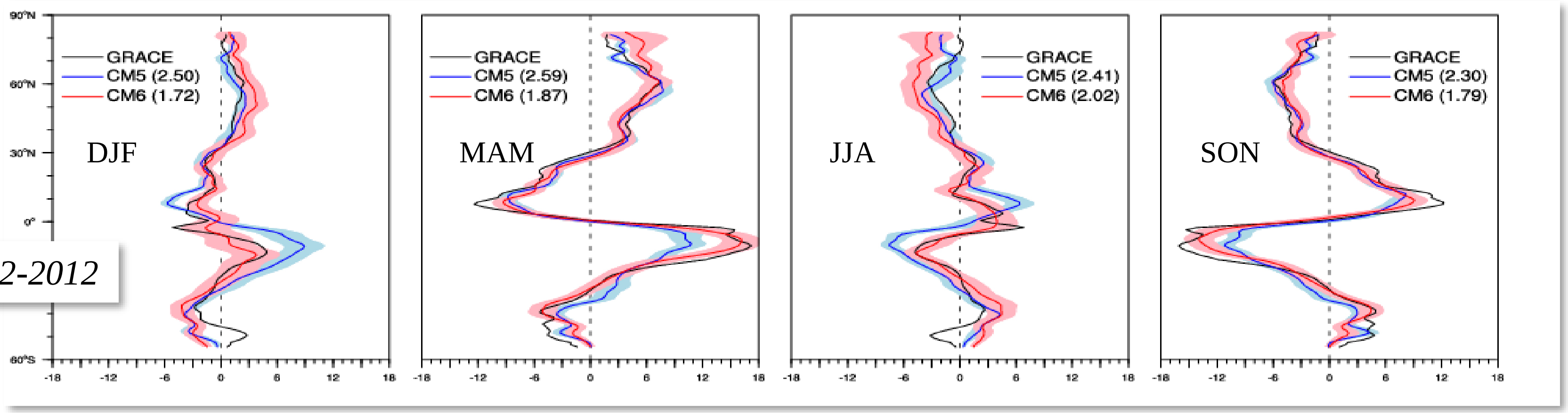
Conclusions & Perspectives

- ISBA$_{DF}$-CTRIP represents a significant advance compared to the previous ISBA$_{FR}$-TRIP :
    - *Snow season and permafrost characteristics are appreciably reproduce*
    - *Soil moisture is significantly increased and more in agreement with GLEAM and ERA-I/land*
    - *Evapotranspiration is reasonably simulated*
    - *Significant improvements in simulating river discharge and terrestrial water storage variations*

Conclusions & Perspectives

- ISBA$_{DF}$-CTRIP represents a significant advance compared to the previous ISBA$_{FR}$-TRIP :
    - *Snow season and permafrost characteristics are appreciably reproduce*
    - *Soil moisture is significantly increased and more in agreement with GLEAM and ERA-I/land*
    - *Evapotranspiration is reasonably simulated*
    - *Significant improvements in simulating river discharge and terrestrial water storage variations*

- Same results can be found “in-line” when we compare CNRM-CM6 to CNRM-CM5

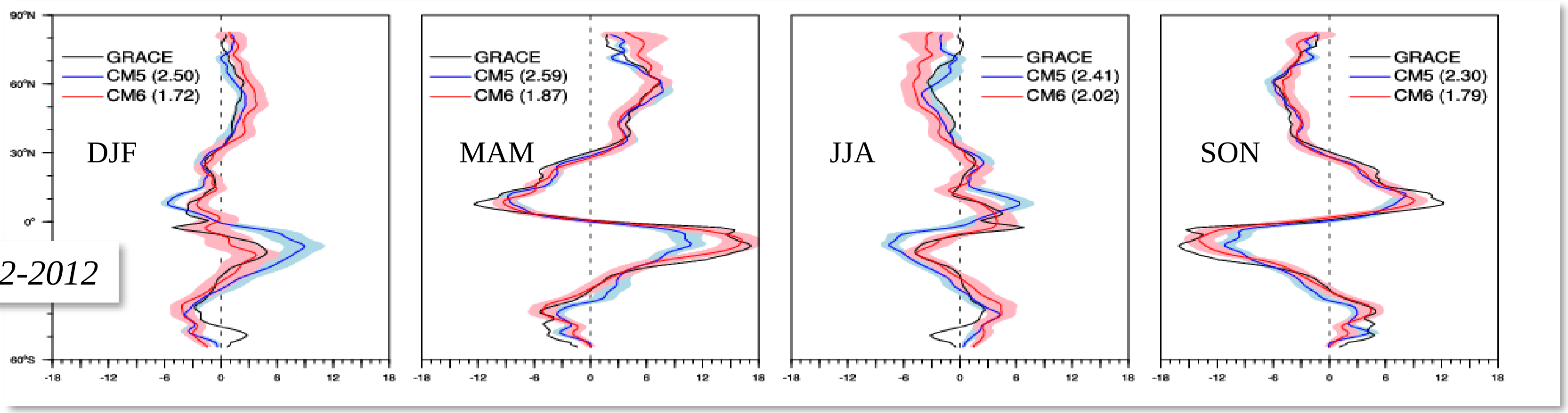


ΔTWS 2002-2012

Conclusions & Perspectives

- ISBA$_{DF}$-CTRIP represents a significant advance compared to the previous ISBA$_{FR}$-TRIP :
  - *Snow season and permafrost characteristics are appreciably reproduced*
  - *Soil moisture is significantly increased and more in agreement with GLEAM and ERA-I/land*
  - *Evapotranspiration is reasonably simulated*
  - *Significant improvements in simulating river discharge and terrestrial water storage variations*

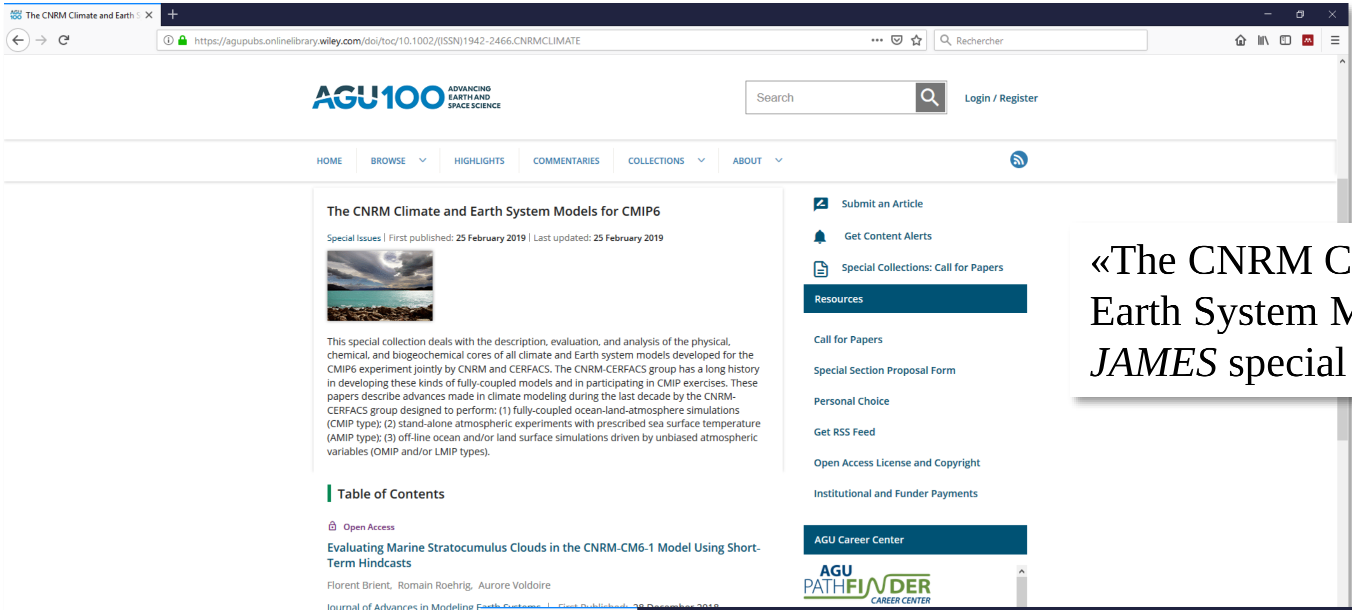
- Same results can be found "in-line" when we compare CNRM-CM6 to CNRM-CM5



ΔTWS 2002-2012

- But :
  - *Springtime snowmelt is too faster, too early peak of discharge and permafrost limits too south.*
  - *Some other weaknesses not explained here*

- Future plans :
  - *Use future SURFEXv9.0 with MEB-Litter to improve snowmelt timing*
  - *Improve artic region processes: snow with Crocus ? ; lateral subsurface runoff in the active layer*
  - *Specific work on tropical forest (offline and inline)*
  - *CTRIP resolution at 1/12° (~9km) accounting for lakes and dams water budgets (Simon Munier)*
  - *River enthalpy and temperature to simulate ice breakup, upward energy and carbon fluxes to atmosphere*
  - *Anthropic water use: irrigation (Arsène Druel), aquifer pumping, paddy fields, etc.*



The CNRM Climate and Earth System Models for CMIP6

Special Issues | First published: **25 February 2019** | Last updated: **25 February 2019**

This special collection deals with the description, evaluation, and analysis of the physical, chemical, and biogeochemical cores of all climate and Earth system models developed for the CMIP6 experiment jointly by CNRM and CERFACS. The CNRM-CERFACS group has a long history in developing these kinds of fully-coupled models and in participating in CMIP exercises. These papers describe advances made in climate modeling during the last decade by the CNRM-CERFACS group designed to perform: (1) fully-coupled ocean-land-atmosphere simulations (CMIP type); (2) stand-alone atmospheric experiments with prescribed sea surface temperature (AMIP type); (3) off-line ocean and/or land surface simulations driven by unbiased atmospheric variables (OMIP and/or LMIP types).

Table of Contents

Open Access

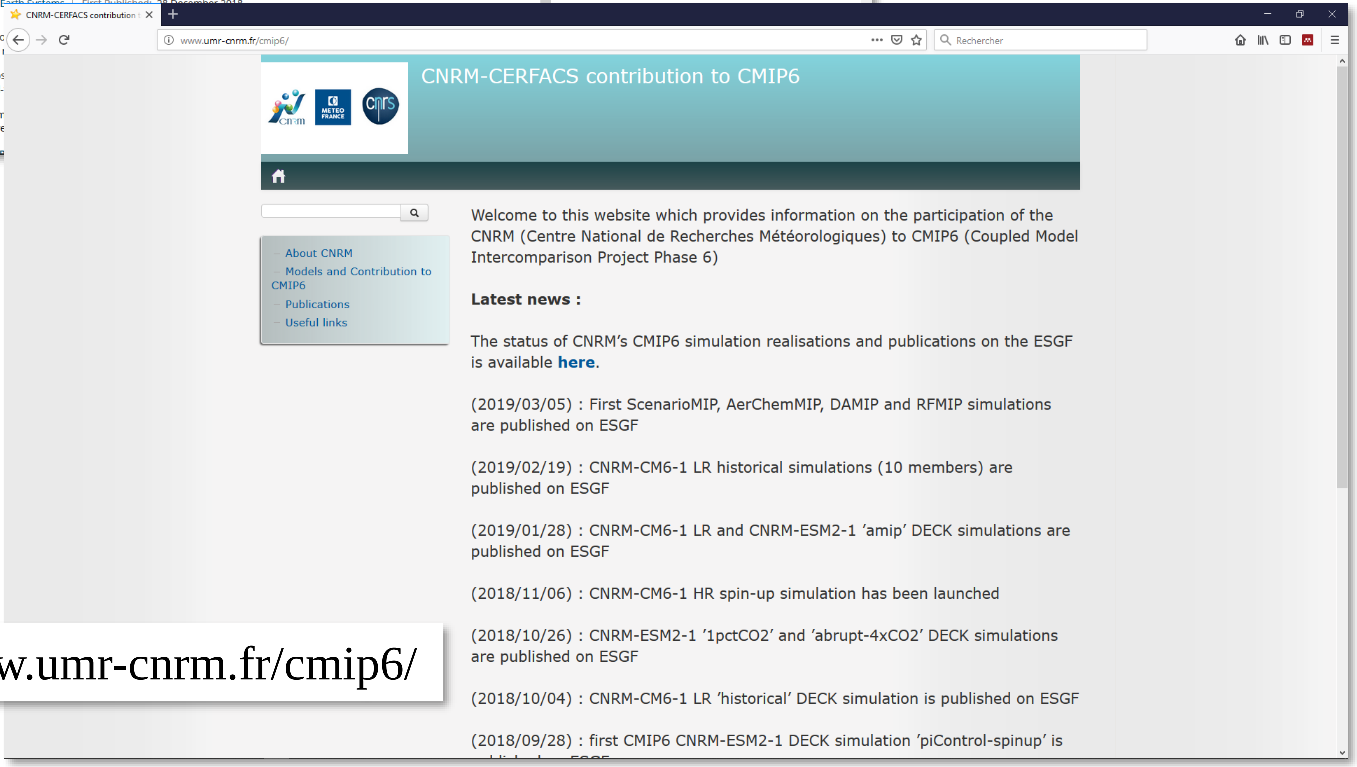
Evaluating Marine Stratocumulus Clouds in the CNRM-CM6-1 Model Using Short-Term Hindcasts

Florent Brient, Romain Roehrig, Aurore Voldoire

Journal of Advances in Modeling

- Short-term hindcasts help to growth in the CNRM-CM6-1
- Biases in low clouds are mos and humidity and the cloud-
- Along with single-columns m cloud parameterization deve

«The CNRM Climate and Earth System Models for CMIP6 »
JAMES special issue



CNRM-CERFACS contribution to CMIP6

Welcome to this website which provides information on the participation of the CNRM (Centre National de Recherches Météorologiques) to CMIP6 (Coupled Model Intercomparison Project Phase 6)

Latest news :

The status of CNRM's CMIP6 simulation realisations and publications on the ESGF is available **here**.

(2019/03/05) : First ScenarioMIP, AerChemMIP, DAMIP and RFMIP simulations are published on ESGF

(2019/02/19) : CNRM-CM6-1 LR historical simulations (10 members) are published on ESGF

(2019/01/28) : CNRM-CM6-1 LR and CNRM-ESM2-1 'amip' DECK simulations are published on ESGF

(2018/11/06) : CNRM-CM6-1 HR spin-up simulation has been launched

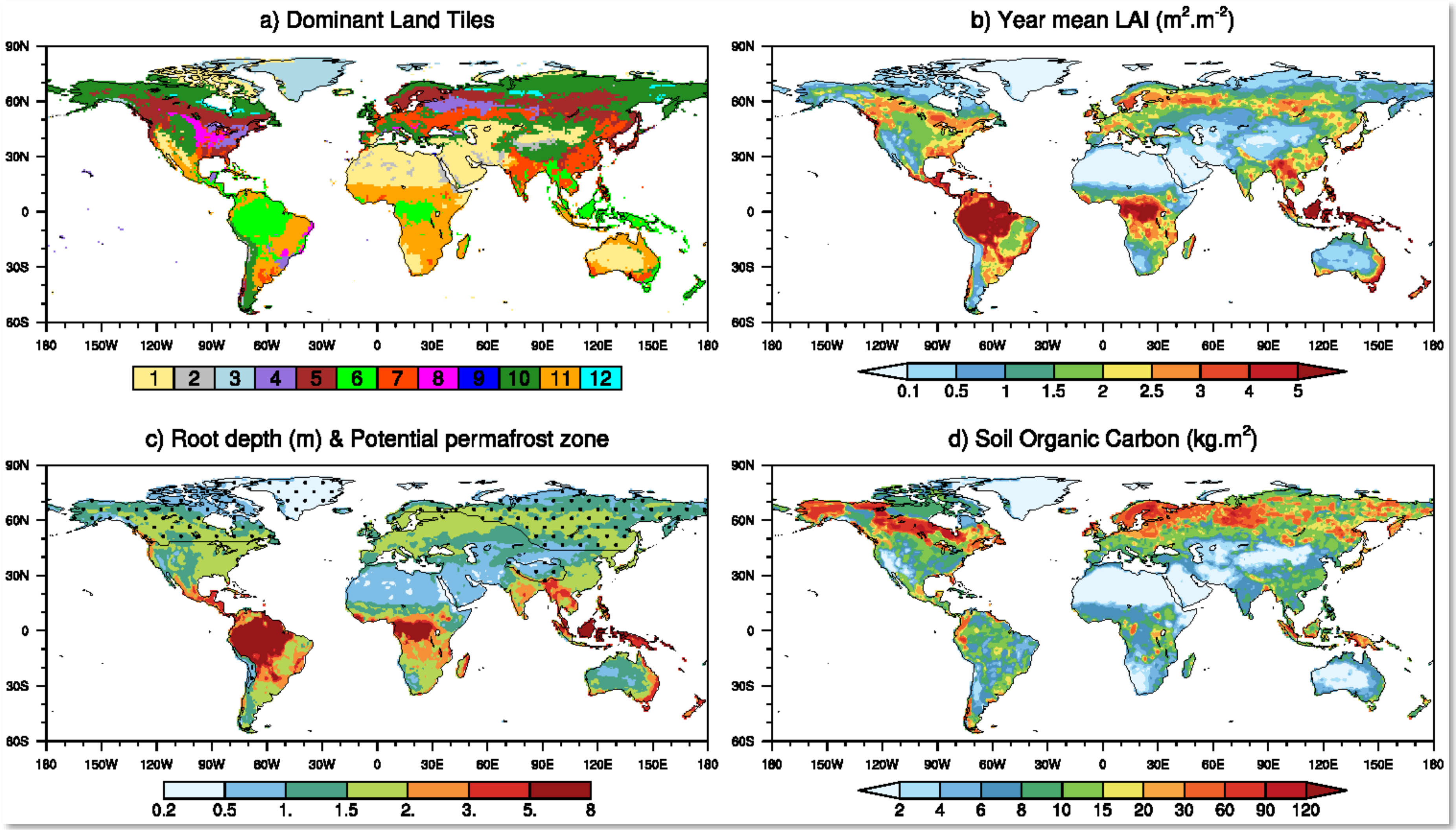
(2018/10/26) : CNRM-ESM2-1 '1pctCO2' and 'abrupt-4xCO2' DECK simulations are published on ESGF

(2018/10/04) : CNRM-CM6-1 LR 'historical' DECK simulation is published on ESGF

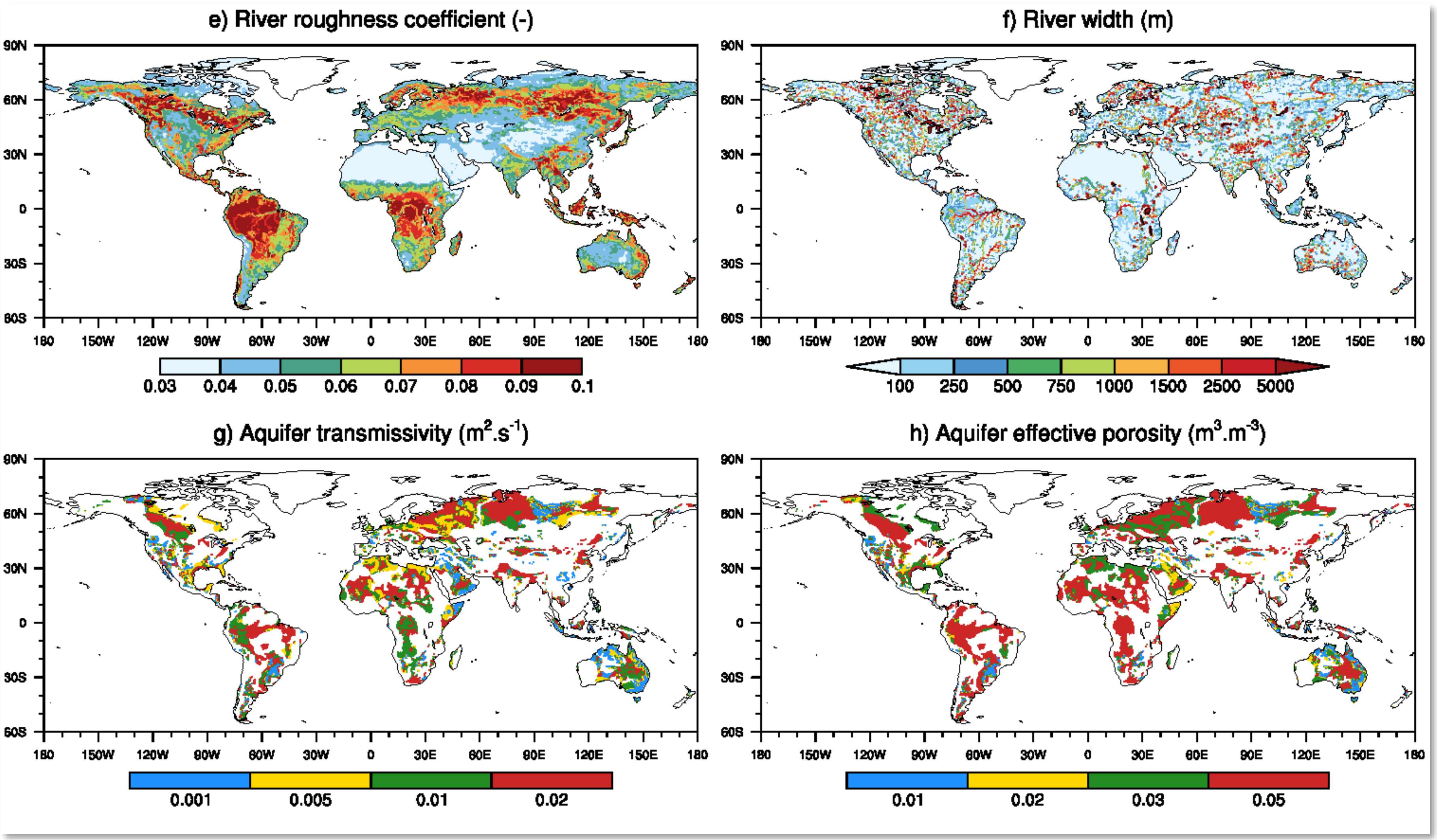
(2018/09/28) : first CMIP6 CNRM-ESM2-1 DECK simulation 'piControl-spinup' is

http://www.umr-cnrm.fr/cmip6/

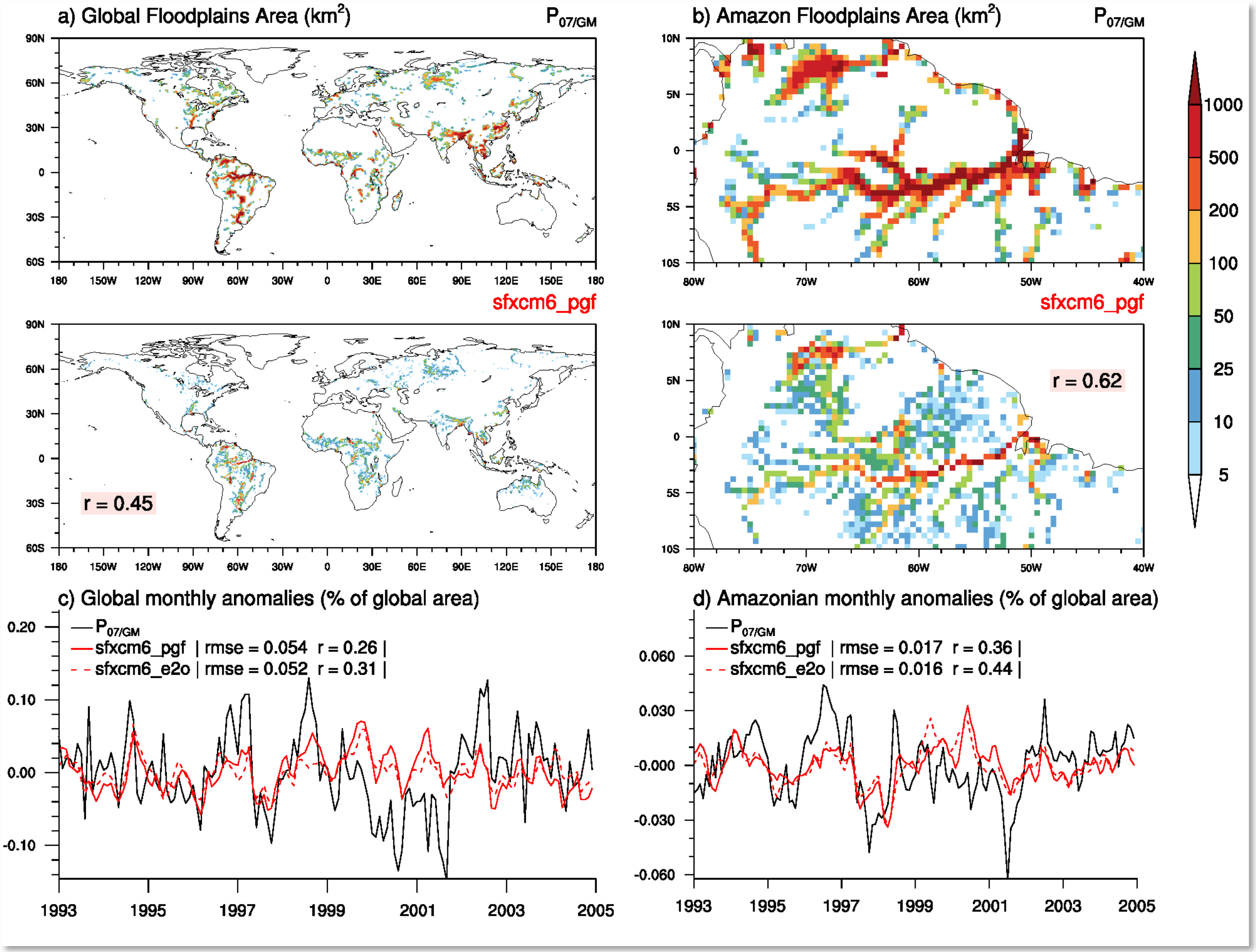
Parameters


a) Dominant Land Tiles
b) Year mean LAI ($m^2.m^{-2}$)
c) Root depth (m) & Potential permafrost zone
d) Soil Organic Carbon ($kg.m^2$)
90N
60N
30N
0
30S
60S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
1 2 3 4 5 6 7 8 9 10 11 12
0.1 0.5 1 1.5 2 2.5 3 4 5
0.2 0.5 1. 1.5 2. 3. 5. 8
2 4 6 8 10 15 20 30 60 90 120

Parameters


e) River roughness coefficient (-)
f) River width (m)
g) Aquifer transmissivity (m².s⁻¹)
h) Aquifer effective porosity (m³.m⁻³)
90N
60N
30N
0
30S
60S
180
150W
120W
90W
60W
30W
0
30E
60E
90E
120E
150E
180
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
100
250
500
750
1000
1500
2500
5000
0.001
0.005
0.01
0.02
0.01
0.02
0.03
0.05

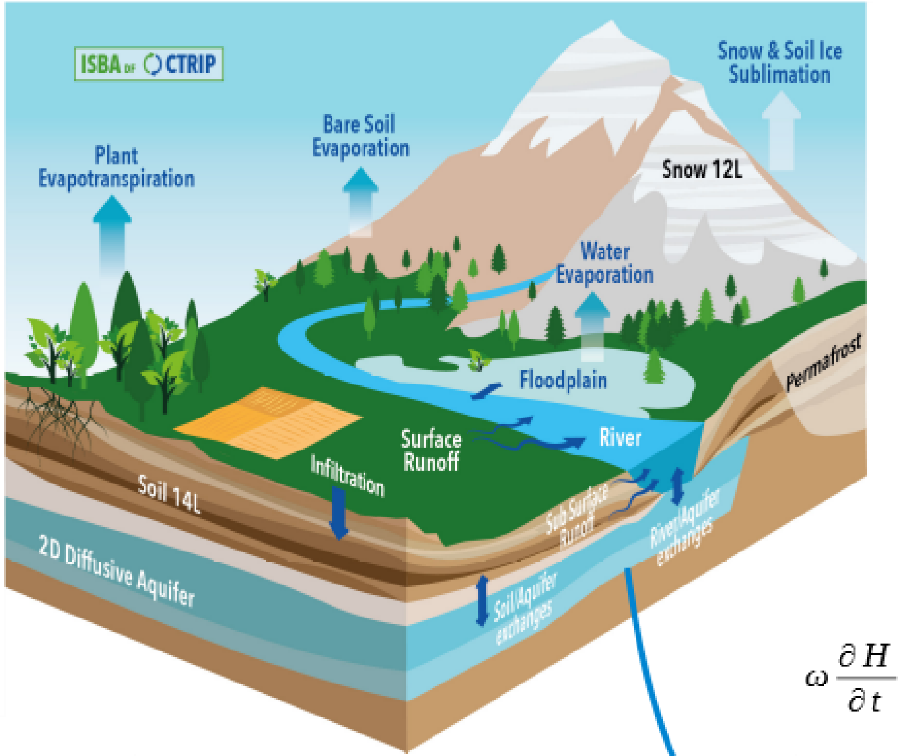
Inundations



Aquifers

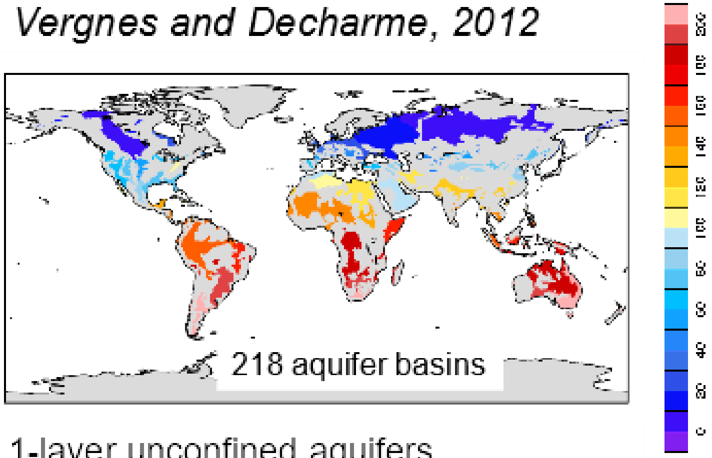
ISBA-CTRIP (within Surfex)

Decharme et al. 2019 (under review)



Aquifer scheme

Vergnes et al. 2012,
Vergnes and Decharme, 2012

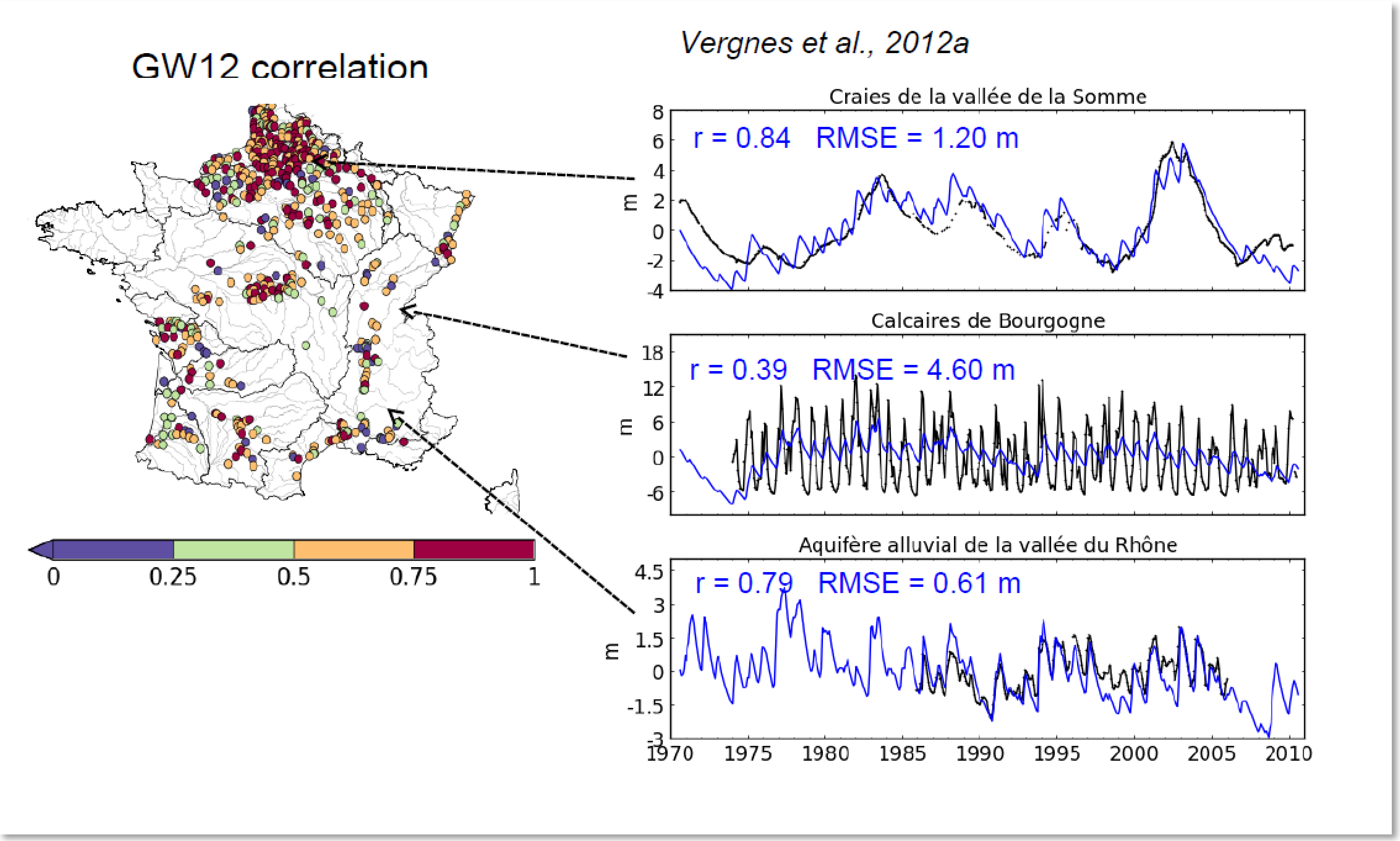


- 1-layer unconfined aquifers
- 2D diffusive (lateral fluxes)
- Groundwater-river exchanges
- Coupling with ISBA Soil

$$\omega\frac{\partial H}{\partial t}=\frac{1}{r^2\cos(\phi)}\left[\frac{\partial}{\partial\theta}\left(\frac{T_\theta}{\cos(\phi)}\frac{\partial H}{\partial\theta}\right)+\frac{\partial}{\partial\phi}\left(T_\phi\cos(\phi)\frac{\partial H}{\partial t}\right)\right]+Q_{sb}-Q_{riv}$$

H : water table head (m)
ω : effective porosity
T : transmissivity (m²/s)

Aquifers



Vergnes et al., 2012a

GW12 correlation

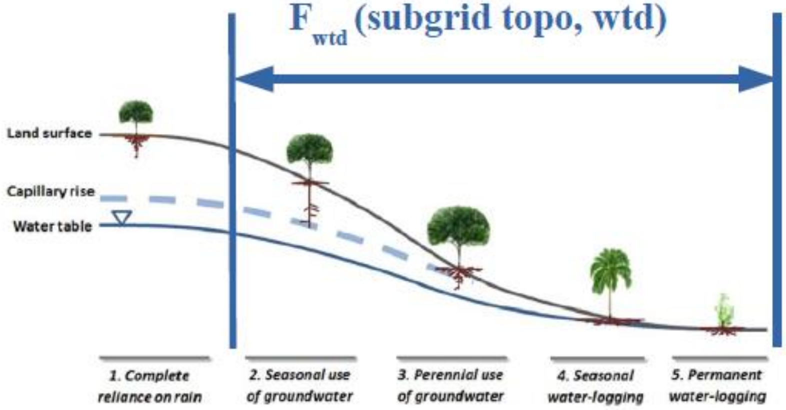
Craies de la vallée de la Somme

Calcaires de Bourgogne

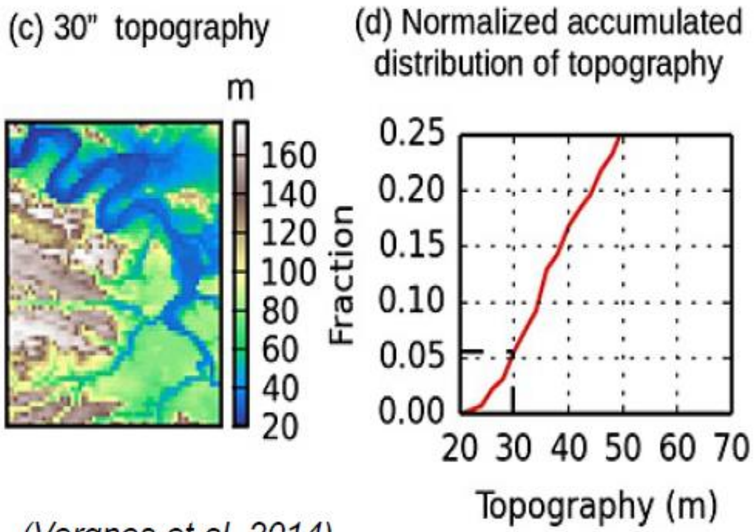
Aquifère alluvial de la vallée du Rhône

Aquifers

Soil → Aquifer : possible drainage recharge everywhere
Aquifer → Soil : capillary rises only over a **fraction f_{wtd}** of the grid mesh



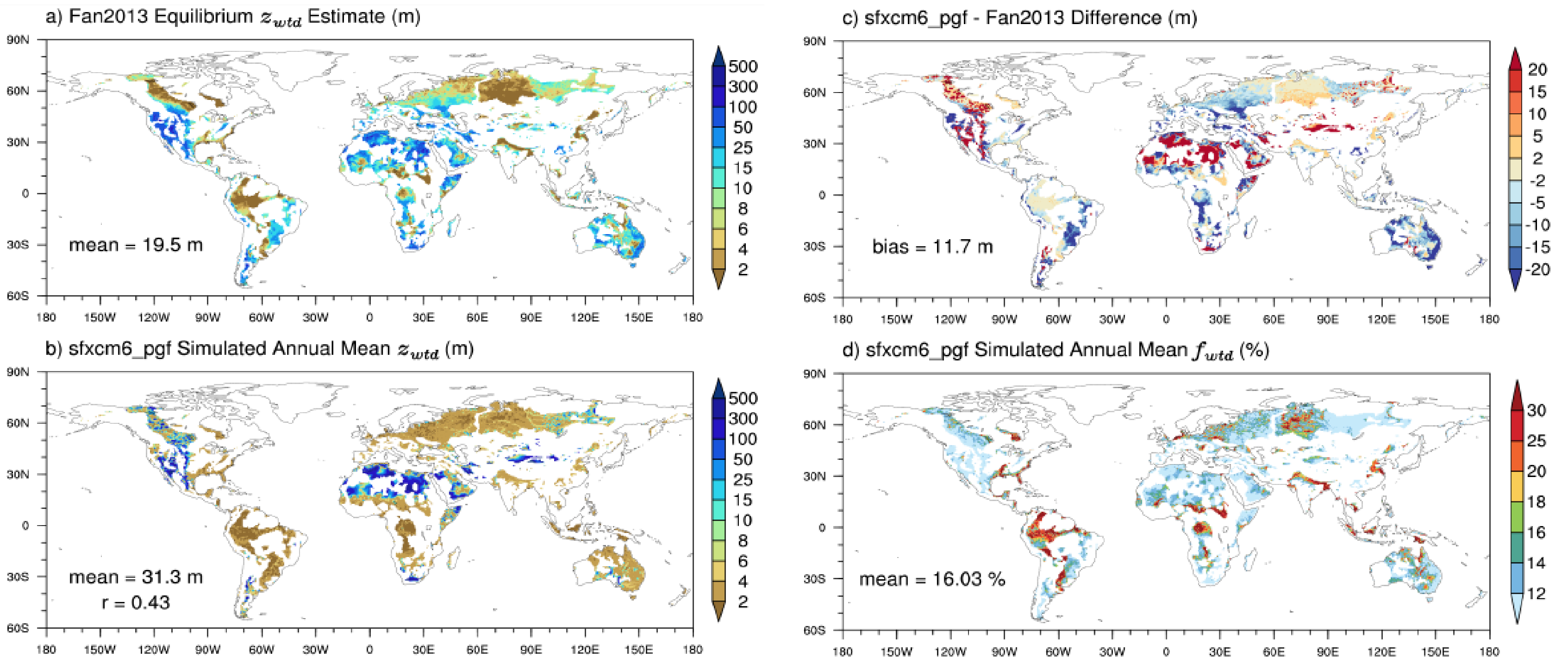
(From Fan, 2015)



(Vergnes et al. 2014)

Our large scale aquifer scheme is meant to represent the river-aquifer-soil interactions in rather flat areas with shallow water table depths

Aquifers



a) Fan2013 Equilibrium z_{wtd} Estimate (m)

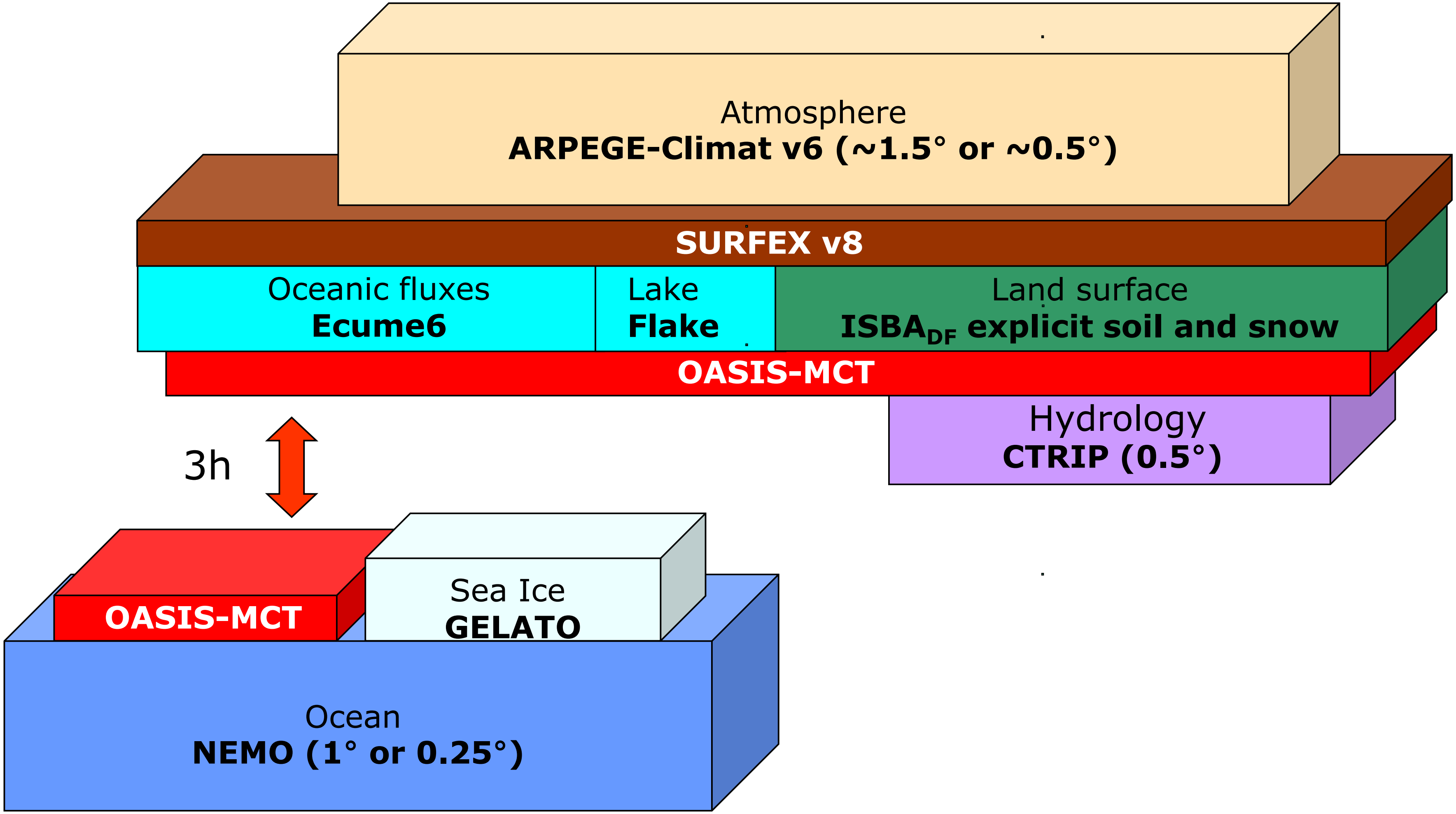
b) sfxcm6_pgf Simulated Annual Mean z_{wtd} (m)

c) sfxcm6_pgf - Fan2013 Difference (m)

d) sfxcm6_pgf Simulated Annual Mean f_{wtd} (%)

=> Good agreement for shallow water table depths in flat areas, where f_{wtd} is maximum

CNRM-CM6 & CNRM-ESM2



Atmosphere
ARPEGE-Climat v6 (~1.5° or ~0.5°)

SURFEX v8

Oceanic fluxes
Ecume6

Lake
Flake

Land surface
ISBA$_{DF}$ explicit soil and snow

OASIS-MCT

Hydrology
CTRIP (0.5°)

3h

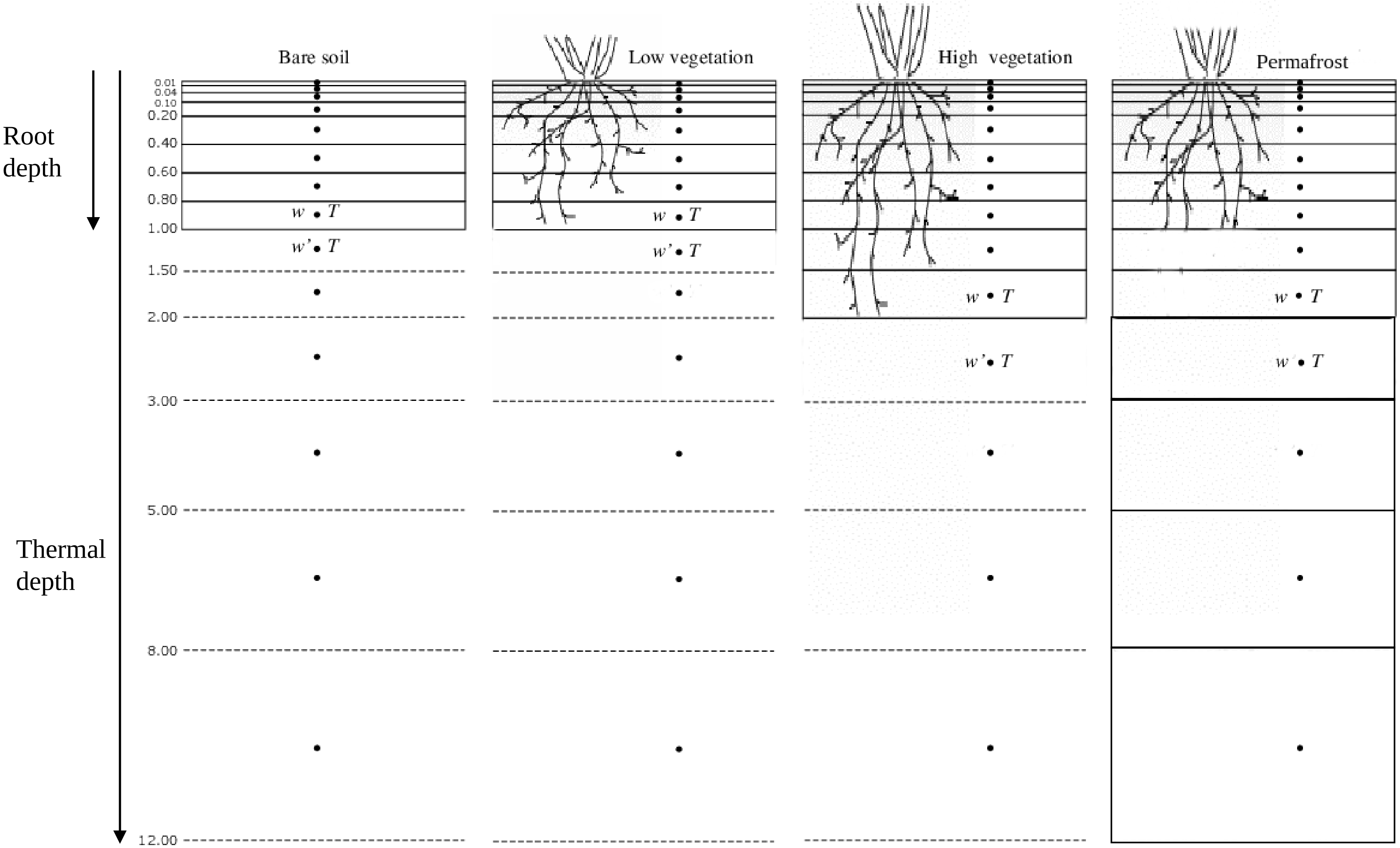
OASIS-MCT

Sea Ice
GELATO

Ocean
NEMO (1° or 0.25°)

(Voldoire et al., JAMES, 2019)

ISBA Explicit Soil Configuration



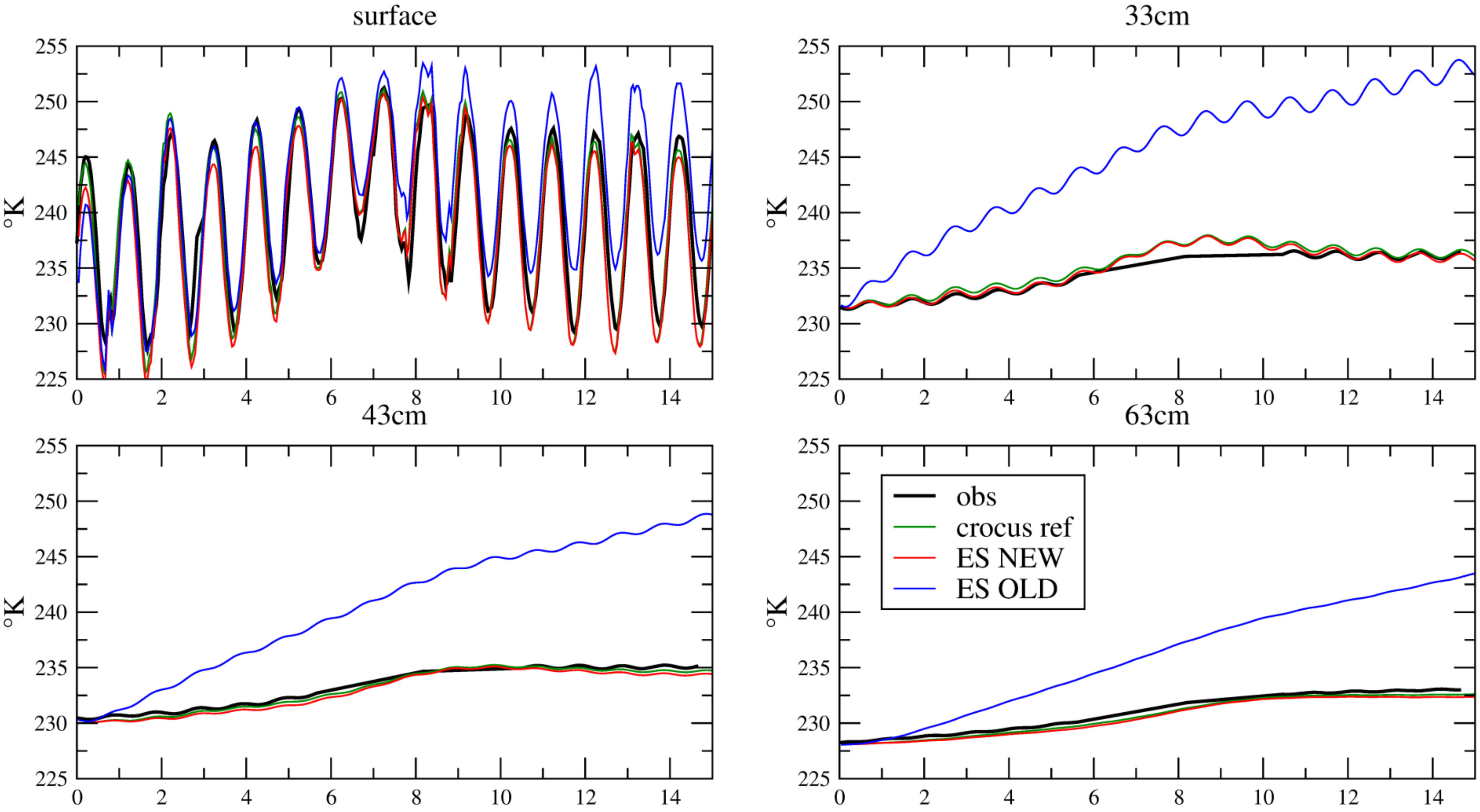
(Decharme et al. 2013, JGR)

ISBA Explicit Snow improvements

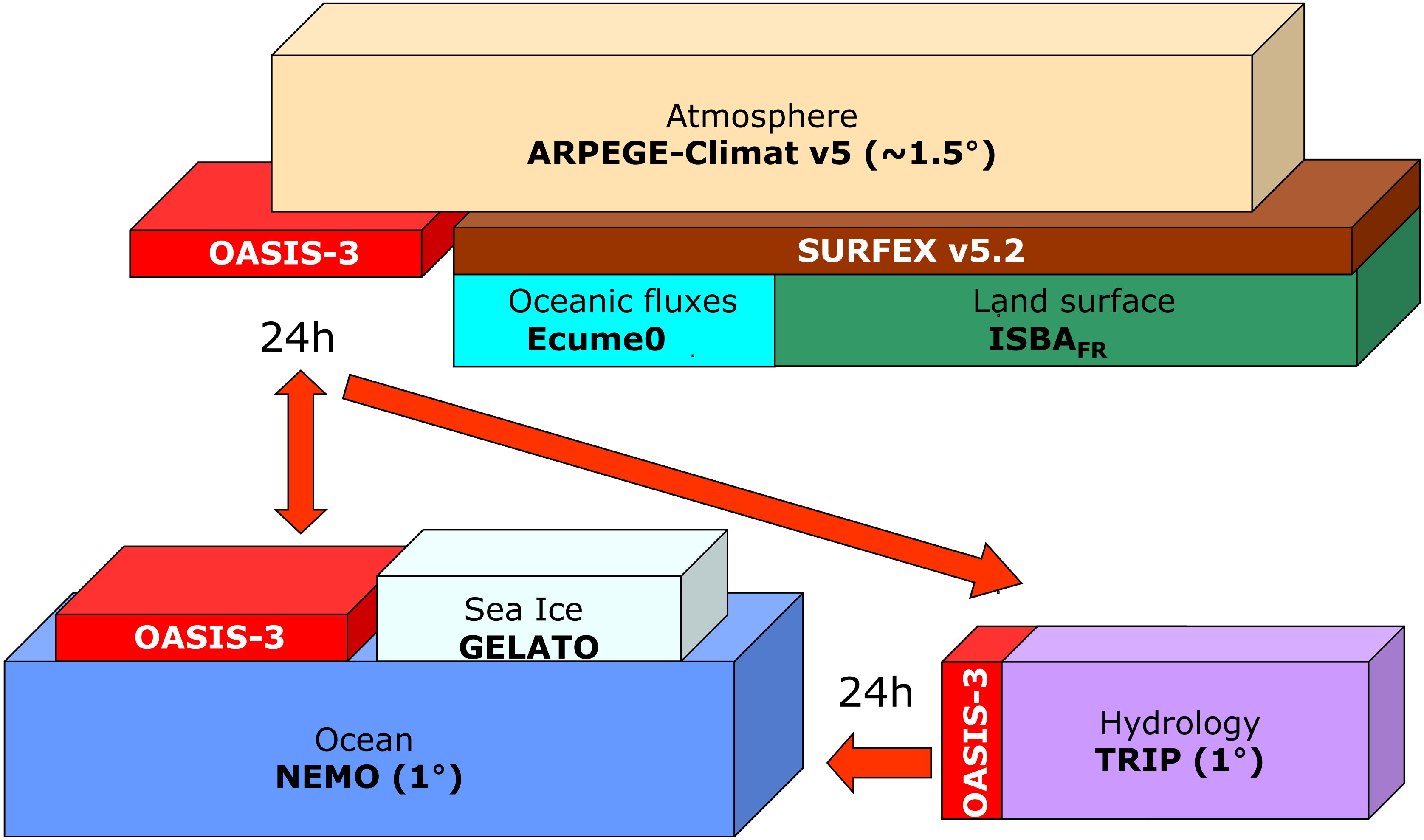
	Old Version **Boone et al. (2001)**	**SURFEXv8 version** **Decharme et al. (2016)** **(based on Crocus)**
Layers	3 (adjusted at each time step)	12 (adjusted only if thickness of layer 1, 2 or 12 become too large)
Albedo	Decrease form 0.85 to 0.50 with time only (Douville et al 1995)	3-bands: 1 visible + 2 nir accounting for snow grain size (Brun et al. 1992)
Compaction/Settling	Viscosity and fresh snow settling from Anderson (1976)	Viscosity from Brun et al. (1992) (accounting for liquid water) Surface compaction during wind drift (Brun et al. 1997)
Thermal conductivity	Anderson (1976) Interfacial arithmetic average	Yen et al. (1981) Interfacial harmonic average

Snowpack Temperature validation at DOMEC (Antarctica)

For all scheme, 19 layers are used with the same initialization



CNRM-CM5 & CNRM-ESM1



(Voldoire et al., Clim. Dyn. 2013)