Development and evaluation of new Van Genuchten soil-properties ancillary files for JULES and the Unified Model

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Introduction

- Soil physical properties affect the flow and drainage of heat and water between the surface and the entire soil column. The soil state, in turn, influences weather/climate, through controls on evapotranspiration and the Bowen ratio, affecting cloud formation and the hydrological and energy cycles. Downstream effects also impact our estimates of floods/droughts, forestry/agriculture, and the water supply.

- **The usage of Van Genuchten (1976) model parameters instead of Brooks & Corey (1964) model parameters may more accurately reflect the actual soil hydraulics. With this end, we explored the usage of Van Genuchten model parameters in the JULES (offline) land-surface model as well as with the (coupled) Unified Model.**

- We have been using new soil minerals maps, SoilGrids (Hengl *et al.*, 2014), which are suitable for high resolution, with 1-5 km horizontal gridding. Previously, using IGBP/HWSD soil mineral maps was more common.

- **We have code working now for comparing different Pedotransfer Functions (PTFs) used to estimate the Van Genuchten soil-hydraulics physical parameters from the soil mineral information in the SoilGrids maps. We have been exploring the use of the PTFs defined by Toth *et al.* (2014), Weynants *et al.* (2009), and Zhang & Schaap (2017).**

- This is being done for HadGEM3 (JULES) and CESM (CLM).
  - JULES can be run in standalone mode using for example the WFDEI driving data (1979-2012 or 1979-2018, Weedon *et al.* 2018) instead of coupling to the atmosphere and ocean models.
  - **The HadGEM3 coupled model uses JULES as its land model. And the CESM coupled model uses CLM as its land model.**

Brooks & Corey model and Van Genuchten model

Brooks and Corey:

Soil Water Retention Relationship

It has been shown that the Brooks and Corey equation (1964) provides a reasonably accurate representation of the water retention-matric potential relationship for tensions greater than 50 cm (Brakensiek et al., 1981). This equation is written as

$S_e = (\psi_b/\psi)^\lambda$

where:

S_e = Effective saturation = $(\theta - \theta_r)/(\theta_s - \theta_r)$
θ = Soil water content, cm^3/cm^3
θ_r = Residual soil water content, cm^3/cm^3
θ_s = Saturated soil water content, cm^3/cm^3
ψ_b = Bubbling pressure, cm of water
ψ = Capillary pressure, cm of water = Capillary head = Matric potential
λ = Pore size distribution index = 1/b

From: Rawls, Brakensiek, & Saxton (USDA), 1982, *Trans. Amer. Soc. Agric. Engineers*

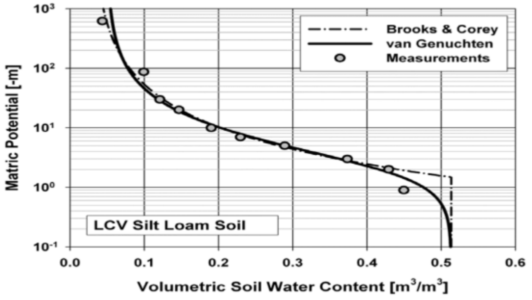


Figure 5: van Genuchten (VG) and Brooks and Corey (BC) parametric models fitted to measured data for silt loam soil.

From: Tuller, M., & Or, D. 2004, *Encyclopedia of Soils in the Environment.*

van Genuchten:

The *van Genuchten* [1976] model is widely used for predicting soil water content as a function of pressure head. This model is generally expressed as

$$S_e = \frac{1}{[1 + (\alpha\psi)^n]^m}$$

where:
α, n, m are empirical constants,
and where m is [normally] related to n as follows:

$$m = 1 - \frac{1}{n}$$

Hydraulic conductivity can be represented by:

$$K(S_e) = K_s \cdot S_e^{1/2} \cdot \left[1 - (1 - S_e^{1/m})^m\right]^2$$

where :
$K_s = K_{sat} = K(S_e = 1)$ is an empirical constant.

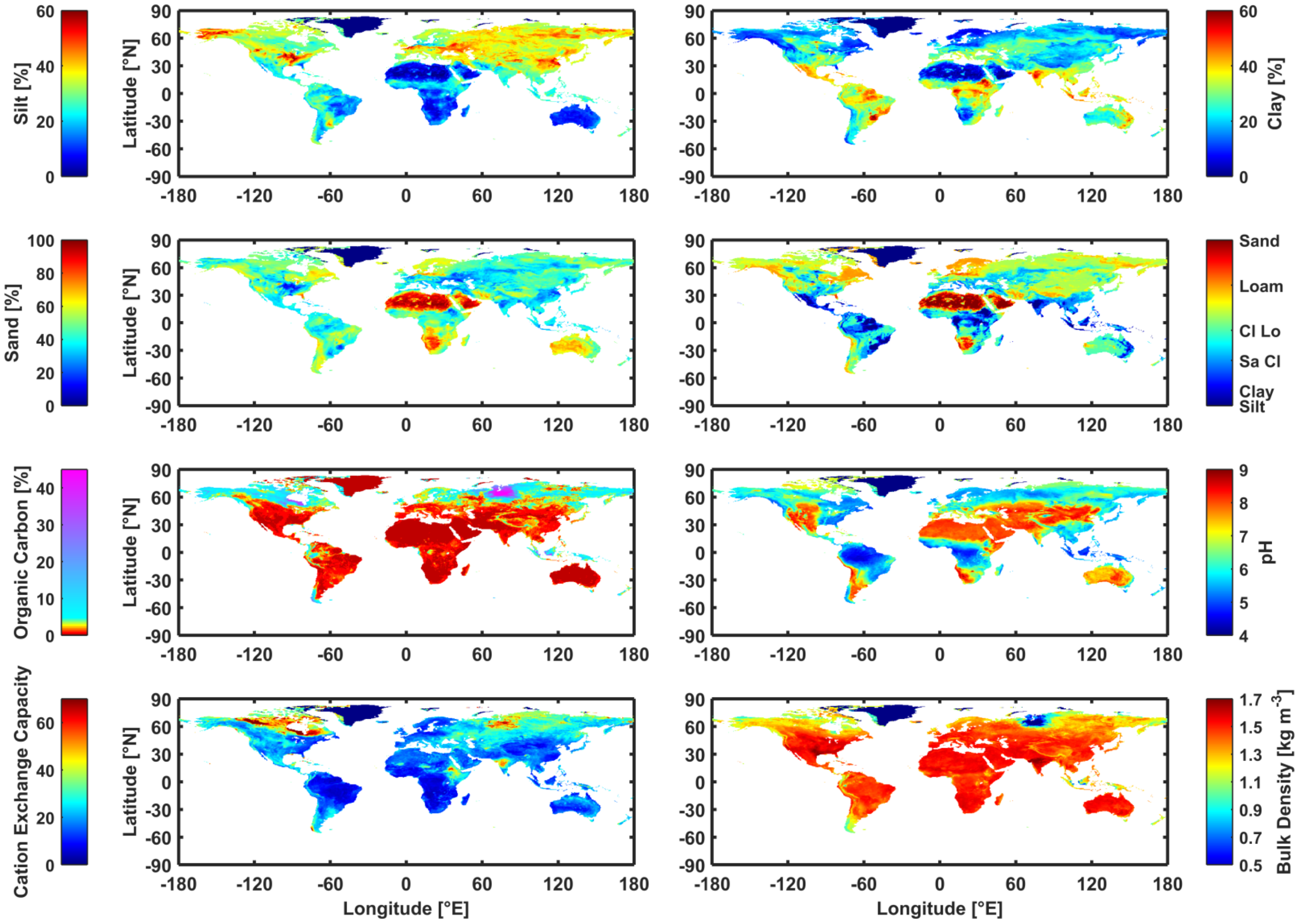
From: Carsel & Parrish (US EPA), 1988, *Water Resources Research*

At high values of ψ, the models are equivalent if
b $\equiv 1/\lambda$ is set
= 1/(n-1)

This approximation breaks down at low values of ψ.

Soilgrids 5km global maps (60-100cm depth):

These are the input parameters we use for the Tóth et al. pedotransfer functions



The Soilgrids Dataset is from Hengl *et al.* (2014), and is also available at 1km resolution

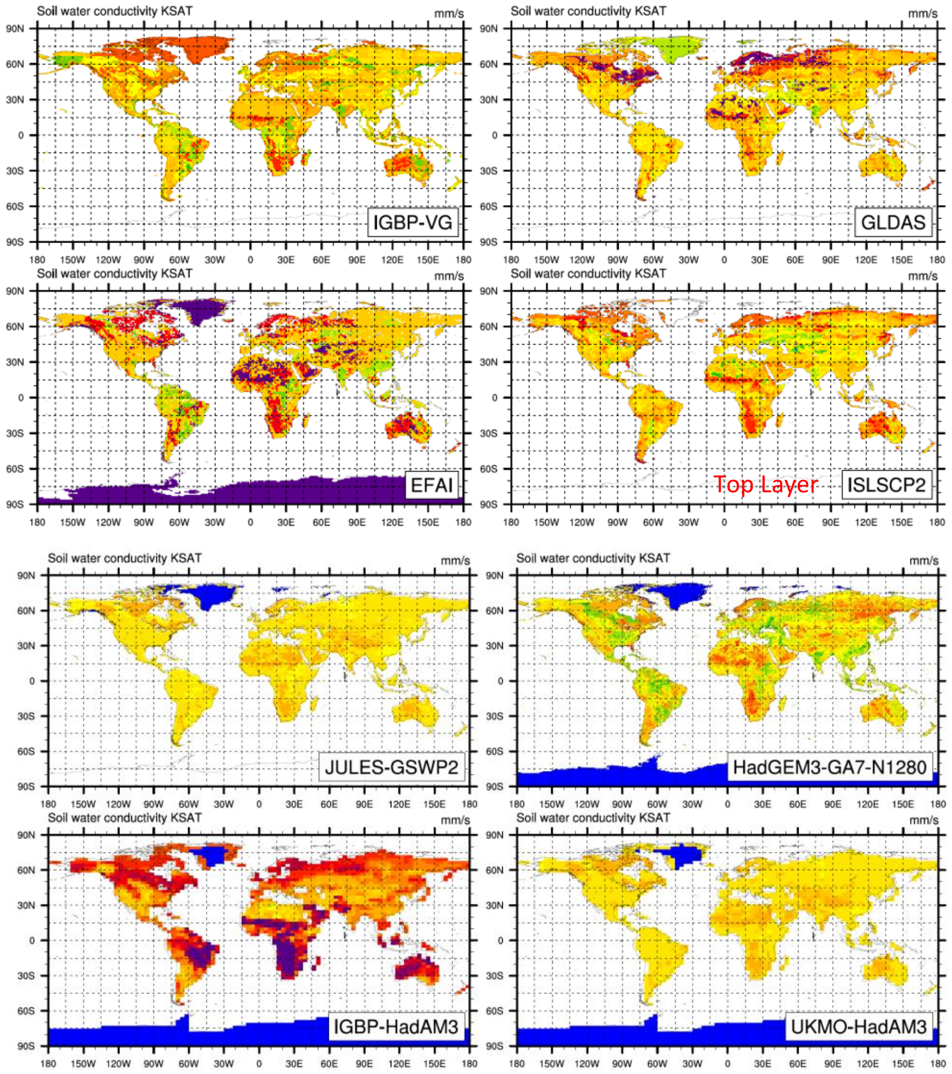
We use these Soilgrids maps instead of the UM/HWSD maps as inputs to the PTFs.

Plots from Markus Todt

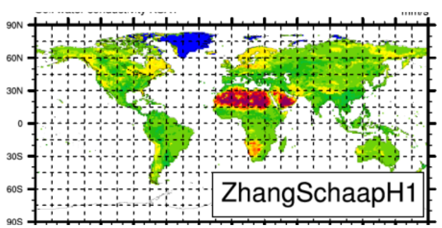
Ksat is one of the physical properties derived using the PTFs

Units = mm/s

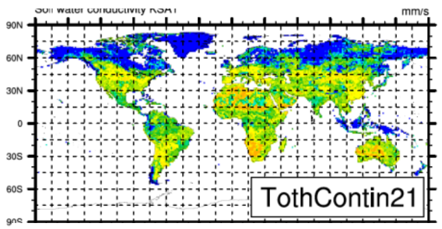
Hydraulic Conductivity at saturation (K_{sat})



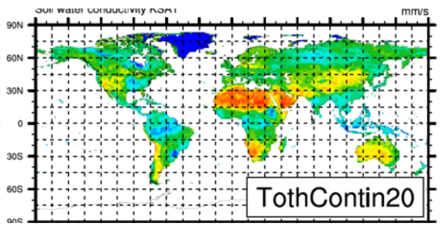
VG, Zhang Discrete PTFH1, soilgrids 5km



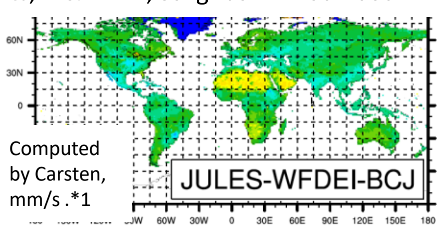
VG, Toth Continuous PTF16+21



VG, Toth Continuous PTF17+20

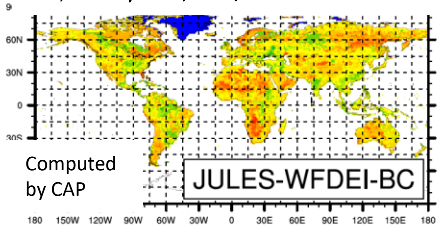


BCJ, R & B PTF, soilgrids 1km 60-100cm



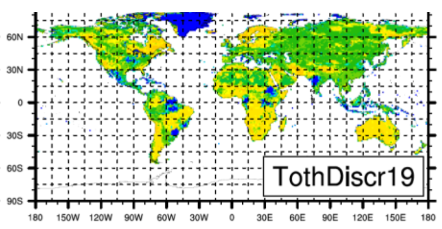
Computed by Carsten, mm/s .*1

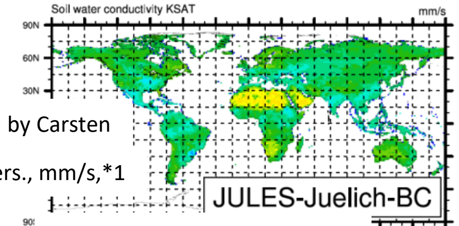
BC, Cosby PTF, UM/HWSD soils



Computed by CAP

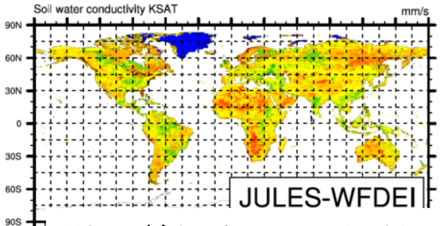
VG, Toth Discrete PTF19

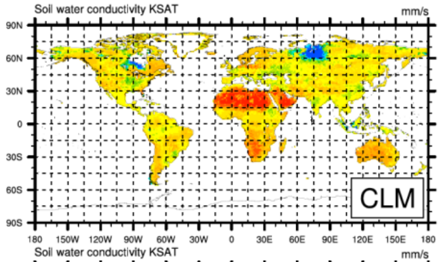




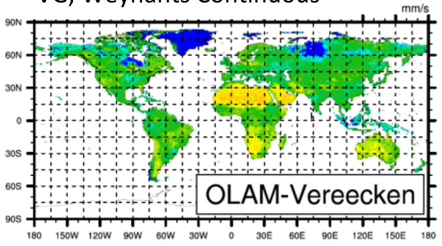
Computed by Carsten

Jun'17 vers., mm/s,*1

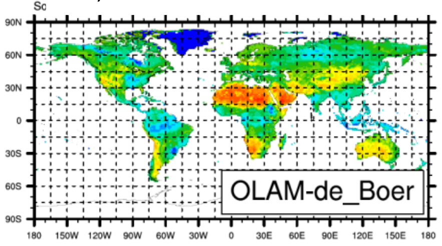


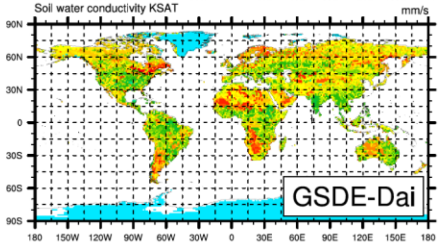


VG, Weynants Continuous



VG, Toth' Continuous PTF17+21

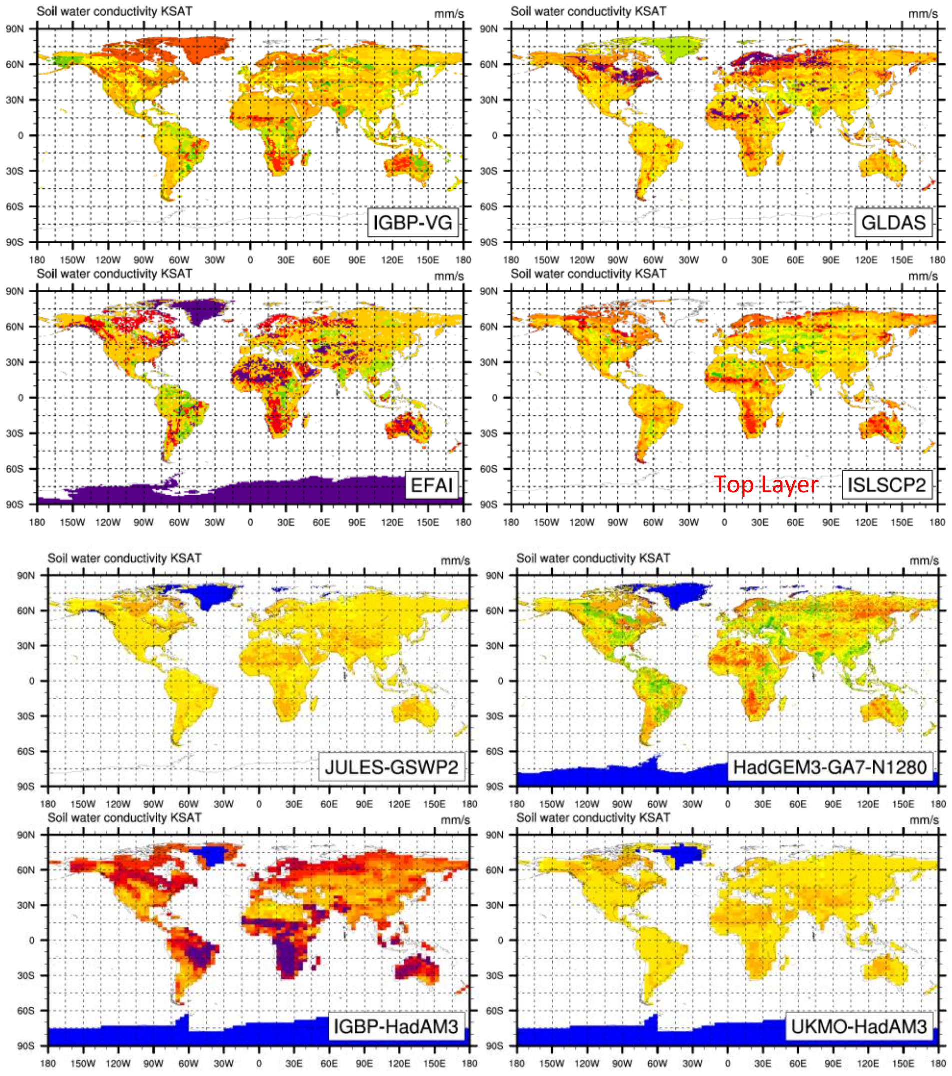


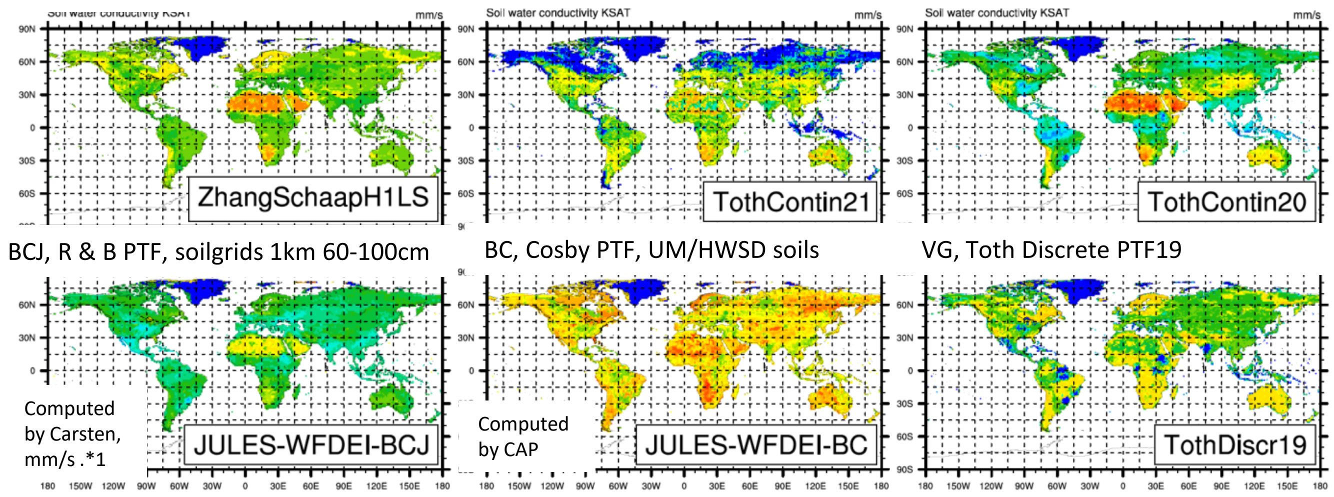


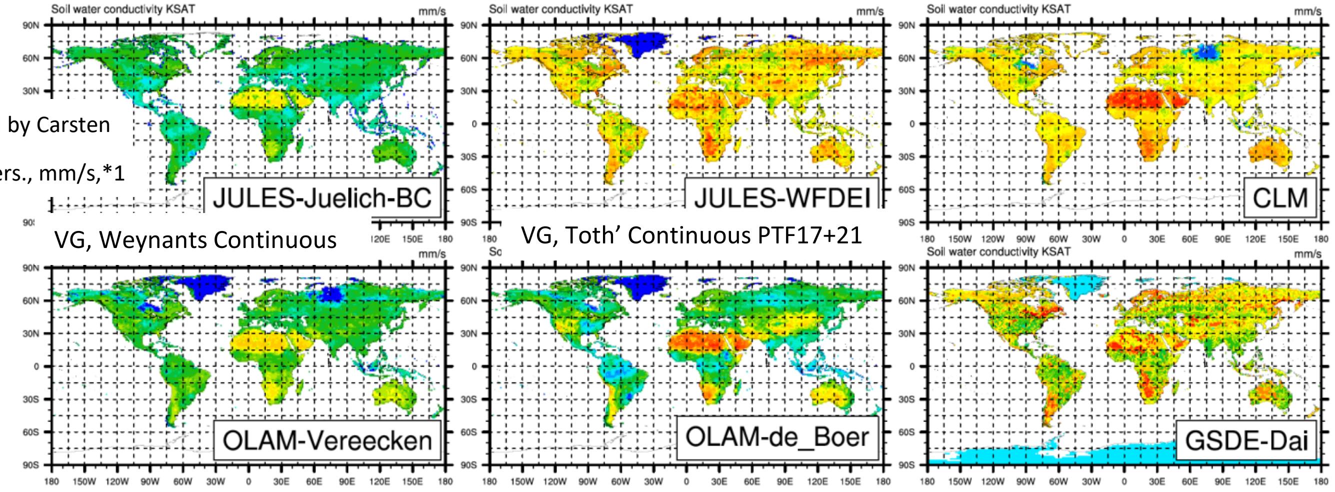
Zhang+Schaap H1LS=H1LoamySand instead of H1:
Using Loamy Sand values from H1 PTF instead of Sand values

Units = mm/s

Hydraulic Conductivity at saturation (K_{sat})







Zhang & Schaap ROSETTA3 H1 LS VG PTF

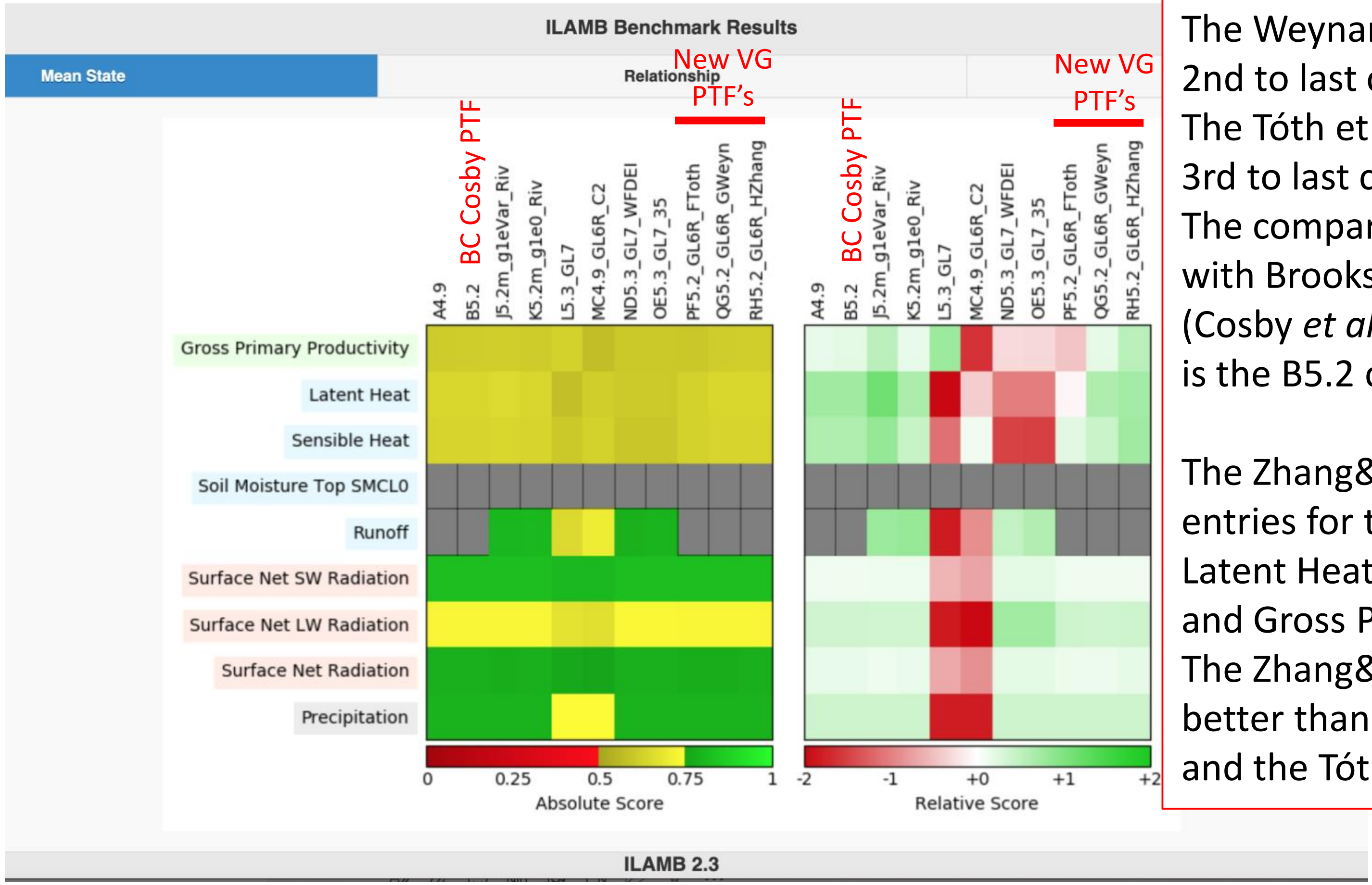
USDA Texture-class	θ(res)	θ(sat)	alpha (cm^{-1})	n exp.	m =1-1/n	K0 (cm/day)	L tortuosity
~~Sa~~	~~0.055~~	~~0.363~~	~~0.0328~~	~~2.895~~	~~0.655~~	~~643.0~~	~~0.5~~
Sa=Lo Sa	0.058	0.383	0.0246	1.697	0.411	108.2	0.5
Lo Sa	0.058	0.383	0.0246	1.697	0.411	108.2	0.5
Sa Lo	0.061	0.381	0.0164	1.457	0.314	37.45	0.5
Lo	0.090	0.402	0.00636	1.421	0.297	13.34	0.5
Si Lo	0.083	0.427	0.00343	1.552	0.356	18.47	0.5
Si	0.065	0.472	0.00604	1.577	0.366	43.75	0.5
Sa Cl Lo	0.093	0.380	0.0124	1.305	0.234	13.23	0.5
Cl Lo	0.107	0.428	0.00995	1.391	0.281	7.06	0.5
Si Cl Lo	0.120	0.470	0.00556	1.434	0.303	11.11	0.5
Sa Cl	0.147	0.382	0.0250	1.237	0.191	11.35	0.5
Si Cl	0.123	0.473	0.0101	1.273	0.215	9.61	0.5
Cl	0.131	0.457	0.00857	1.255	0.203	14.75	0.5
Org	0.000	1.000	0.00690	1.500	0.333	1.00	0.5

Our current choice/decision:
The K0 & n-exponent values for Sa=Sand are too extreme for JULES to handle
(causing gridded JULES to hang without crashing),
so we replaced the Sa values with the Lo Sa values.
That’s why this PTF has LS in its name.

Zhang & Schaap (2017)
Zhang (private communication)
Rounded here to a few significant figures.

Sa=Sand, Lo=Loam, Si=Silt, Cl=Clay

ILAMB summary chart,
comparing various offline JULES global runs
including new run with the Zhang&Schaap H1LS Pedotransfer Function (PTF)



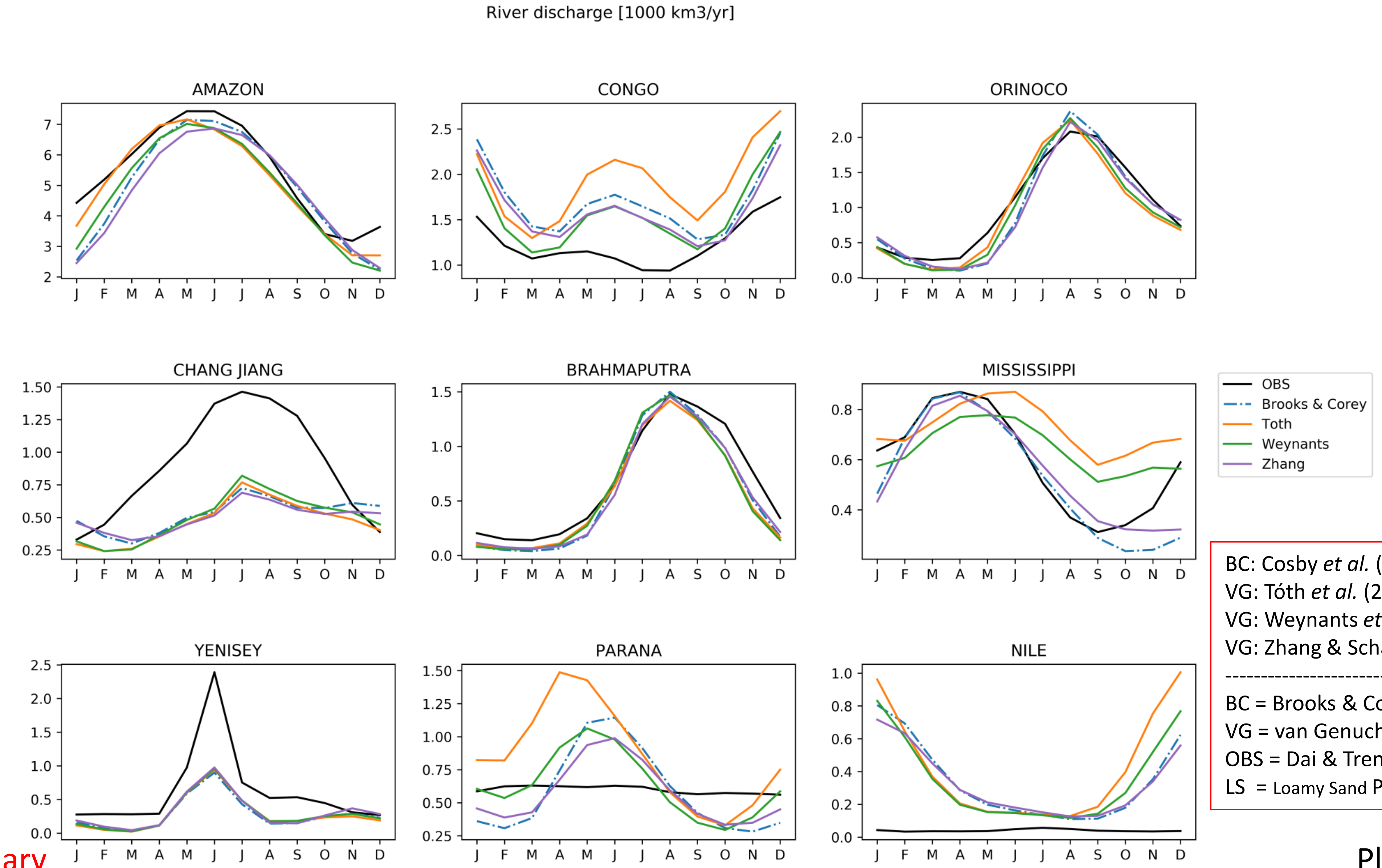
The Zhang&Schaap H1LS VG PTF is the last column.
The Weynants et al. VG PTF is the 2nd to last column.
The Tóth et al. VG PTF is the 3rd to last column.
The comparison control with Brooks & Corey (Cosby *et al.* PTF) is the B5.2 column.

The Zhang&Schaap PTF has greenish entries for the relative score for Latent Heat Flux, Sensible Heat Flux, and Gross Primary Product.
The Zhang&Schaap PTF is apparently better than the Weynants et al. PTF and the Tóth et al. PTF!

preliminary

The H1LS PTF uses Loamy Sand H1 PTF values instead of the Sand H1 PTF values

Monthly river-discharges for different basins, comparing various offline JULES global runs, including new run with the VG Zhang&Schaap H1LS Pedotransfer Function (PTF)



BC: Cosby *et al.* (1984) PTF
VG: Tóth *et al.* (2015) PTF
VG: Weynants *et al.* (2013) PTF
VG: Zhang & Schaap (2017) ROSETTA3 H1LS PTF

BC = Brooks & Corey (1964) model;
VG = van Genuchten *et al.* (1976) model
OBS = Dai & Trenberth (2017) river-gauge dataset
LS = Loamy Sand PTF values replacing Sand PTF values

preliminary

Plots from Omar Müller

AutoAssess of 1989-2008 JJA 1.5m air-temperature for UM run with new soil ancillary (part 1/3)

Both control & experiment
used the same standard start-dump,
without extra spinup.

We are now doing 35-year continuation runs
(1979-2014) using these runs as spinups.

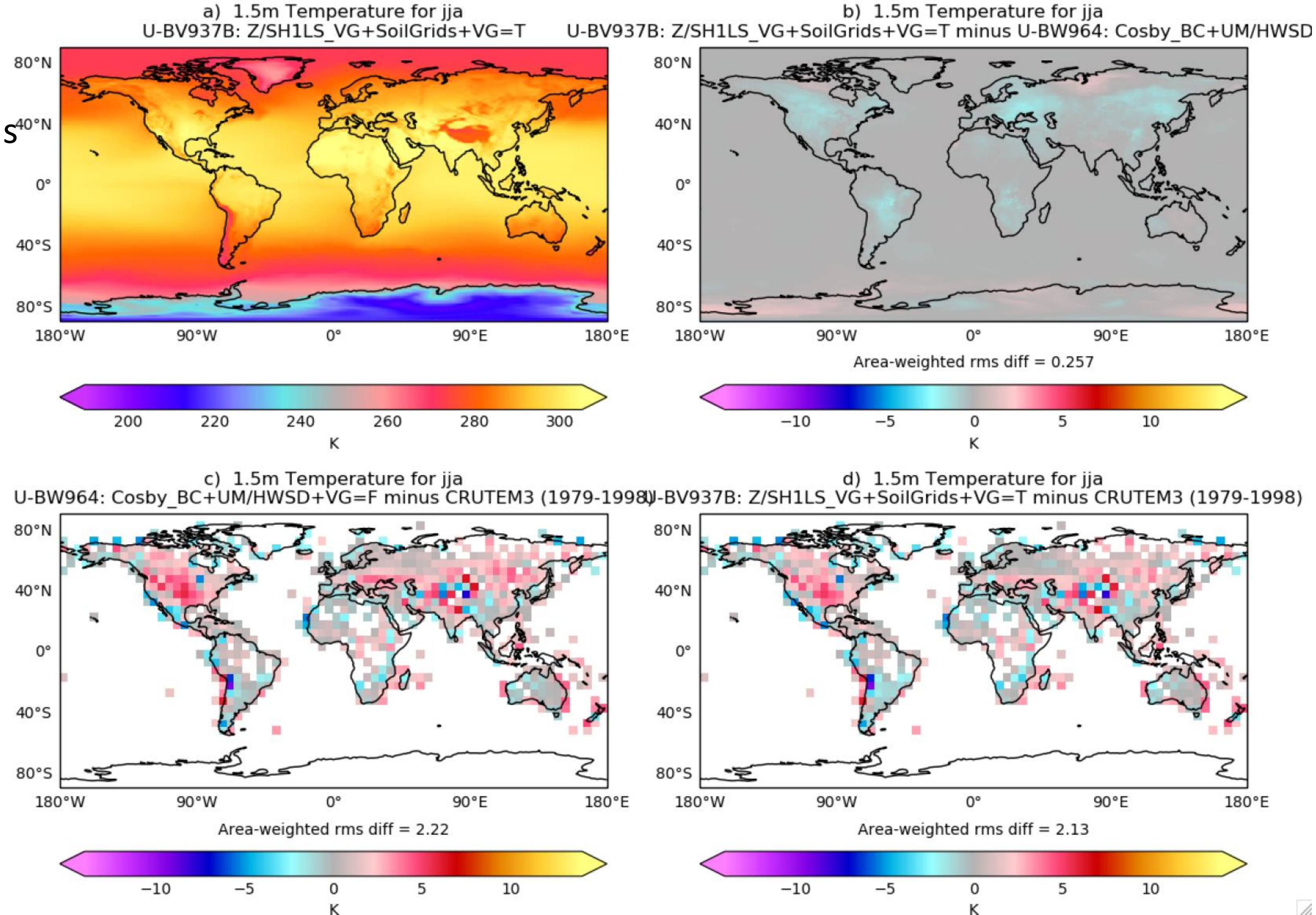
Both control & experiment used
same constant-in-time&space
atmospheric CO_2 (348.5ppm = 1988 level)

Control =
CosbyEtAl. BC PTF
UM/HWSD soil mineral maps
JULES flag: l_vg_soil = FALSE

Experiment =
Zhang&Schaap H1 LS ROSETTA3 VG PTF
SoilGrids (0.6-1.0m) soil mineral maps
JULES flag: l_vg_soil = TRUE

Much of the model<->model variance is due to l_vg_soil, but some is due to choice of PTF and mineral maps.

preliminary



AutoAssess of 1989-2008 JJA 1.5m air-temperature for UM run with new soil ancillary (part 2/3)

Both control & experiment
used the same standard start-dump,
without extra spinup.
We are now doing 35-year continuation runs
(1979-2014) using these runs as spinups.
Both control & experiment used
same constant-in-time&space
atmospheric CO_2 (348.5ppm = 1988 level)

Control =
CosbyEtAl. BC PTF
UM/HWSD soil mineral maps
JULES flag: l_vg_soil = TRUE

Experiment =
Zhang&Schaap H1 LS ROSETTA3 VG PTF
SoilGrids (0.6-1.0m) soil mineral maps
JULES flag: l_vg_soil = TRUE

Much of the model<->model variance is due to l_vg_soil,
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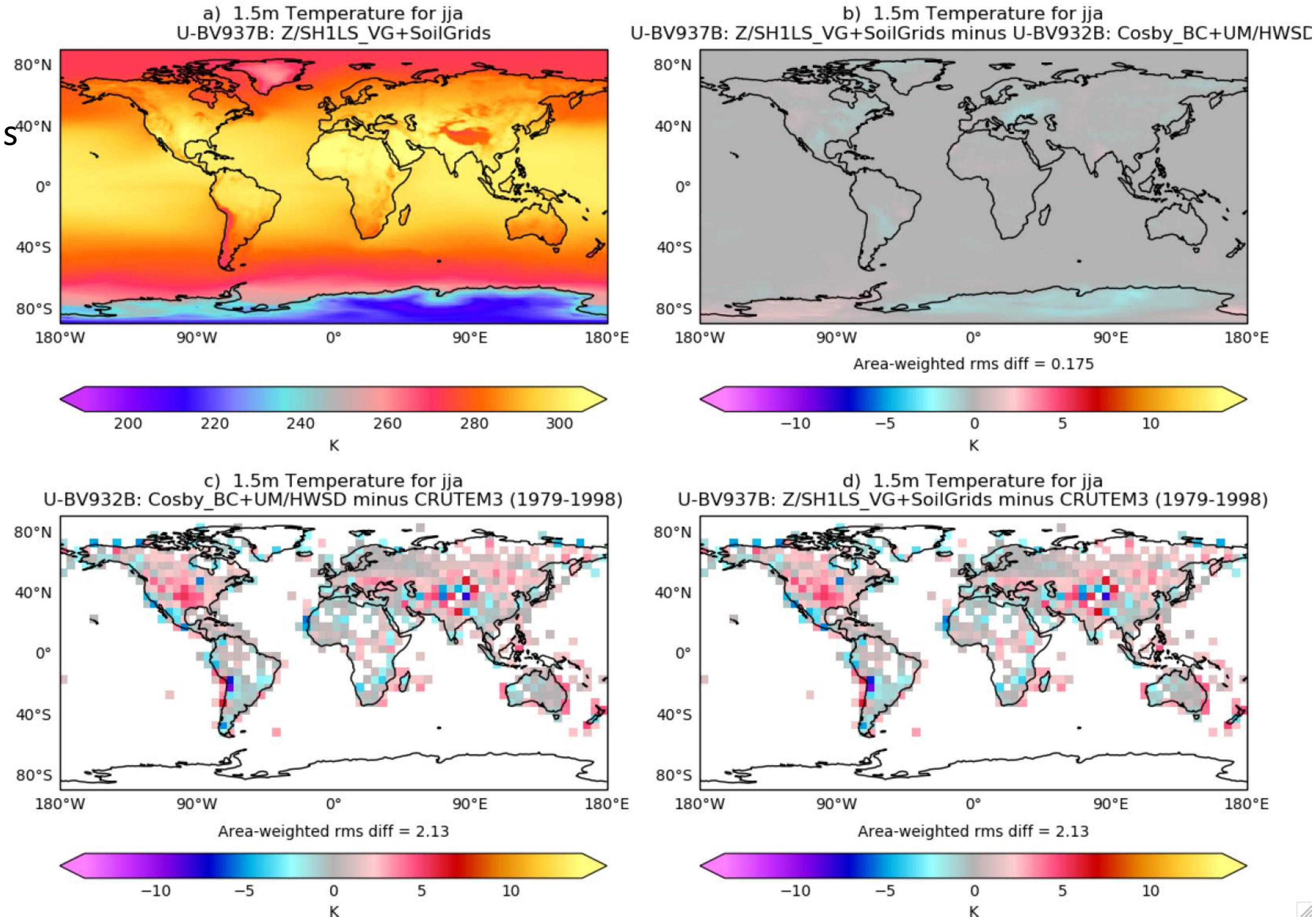
preliminary



AutoAssess of 1989-2008 JJA 1.5m air-temperature for UM run with new soil ancillary (part 3/3)

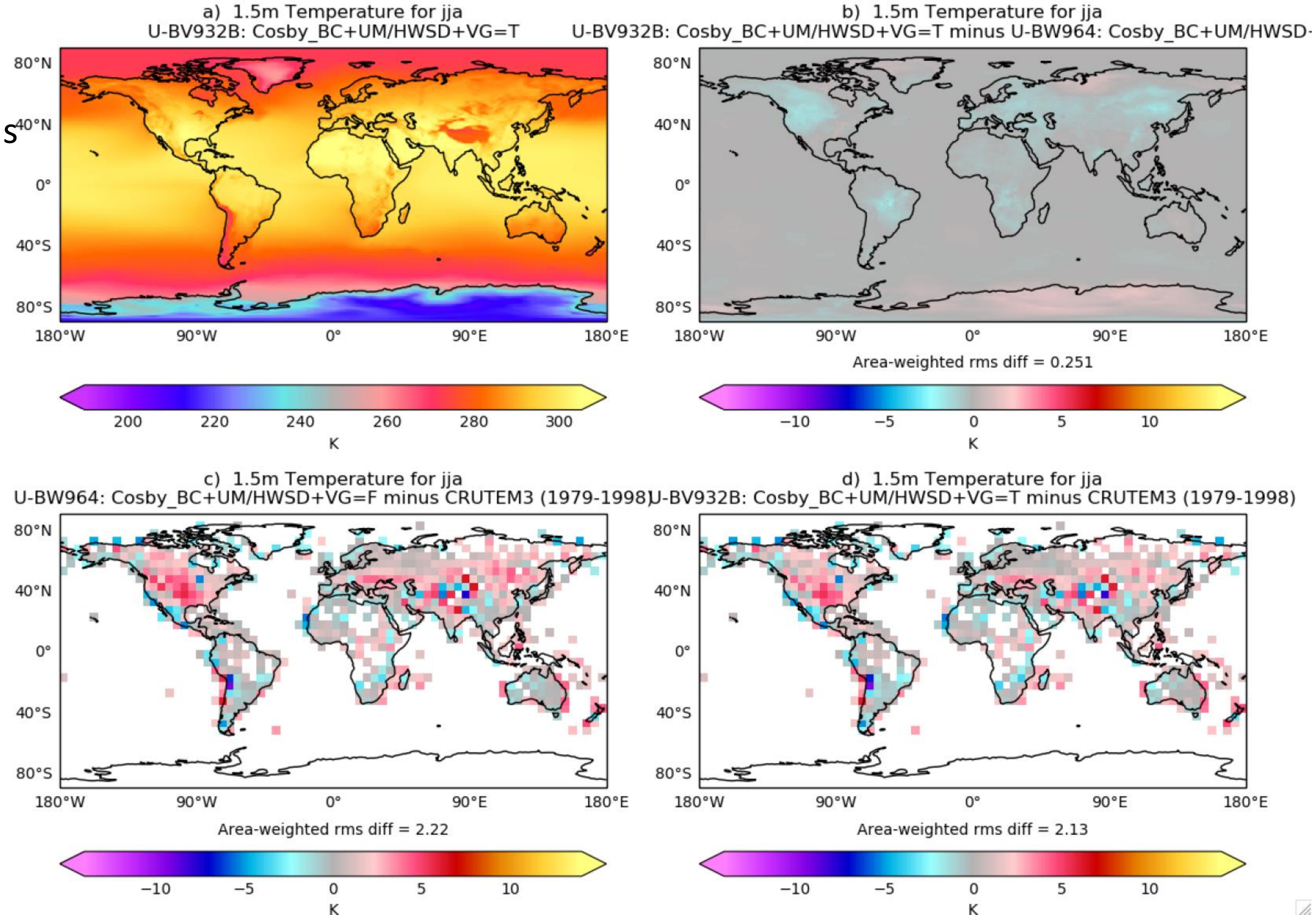
Both control & experiment used the same standard start-dump, without extra spinup.
We are now doing 35-year continuation runs (1979-2014) using these runs as spinups.
Both control & experiment used same constant-in-time&space atmospheric CO_2 (348.5ppm = 1988 level)

Control =
CosbyEtAl. BC PTF
UM/HWSD soil mineral maps
JULES flag: l_vg_soil = FALSE

Experiment =
CosbyEtAl. BC PTF
UM/HWSD soil mineral maps
JULES flag: l_vg_soil = TRUE

Much of the model<->model variance is due to l_vg_soil, but some is due to choice of PTF and mineral maps.

preliminary



Overall Progress Report and Conclusions

- We did a comparison of a number of different pedotransfer functions (PTFs) for Van Genuchten soil properties.
- From this comparison of soil properties, we decided in November 2019 that the Tóth *et al.* 17+20 PTFs were our best option for initial global (offline) runs of JULES and that the Weynants/Vereecken PTF were our 2nd best option.
- We did these JULES global runs on JASMIN with the VG Tóth *et al.* 17+20 PTFs replacing the B & C Rawls & Brakensiek PTF in the soil ancillary files.
- We compared them to our prior runs with ILAMB and with Markus Todt's new bias-ratio technique:
  - We decided that the Tóth *et al.* 17+20 PTFs for soil properties may not be the best option.
- We looked into alternative sources of global Van Genuchten soil properties:
  - We tried the 2nd best option: the Weynants/Vereecken PTF for Van Genuchten soils.
  - JULES models for this PTF run to completion for E+S Asia and the UK region, as well as for the whole globe.
  - The Weynants/Vereecken PTF has somewhat better ILAMB scores globally than does the Tóth et al. PTF, and better regional bias maps in the tropics.
  - We also tried a 3rd option in global runs of JULES, the Zhang&Schaap (2017) ROSETTA3 H1LS PTF. We needed to use Loamy Sand values from the PTF instead of the Sand values of the PTF in order to run in JULES.
  - The derived VG soil parameters for this PTF are substantially different than for Weynants/Vereecken (2014) PTF or the Tóth et al. (2017) PTF.
  - But the ILAMB scores for the Zhang&Schaap ROSETTA3 H1LS PTF are an improvement over the Weynants/Vereecken PTF and the Tóth *et al.* 17+20 PTF.
  - And the river-discharge annual profiles for different river basins in the offline JULES simulations match the Dai & Trenberth (2017) river-gauge measurements much better with the Zhang&Schaap ROSETTA3 H1LS PTF, particularly for the Mississippi.
- We have produced Zhang & Schaap H1LS soil ancillaries in N216 format (with both UM/HWSD soil inputs and SoilGrids soil inputs), and we have run the (coupled) Unified Model (UM) with this ancillary. Autoassess has been run, comparing the Zhang & Schaap run with a control experiment. Further runs and analysis are forthcoming.