Uncertainty in representation of land surface processes: soil hydrology & river runoff

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ECMWF

With thanks to Gianpaolo Balsamo, Tim Stockdale & others, ECMWF

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Outline

1. Uncertainty in Hydrological modelling
2. Soil hydrology & land surface schemes
3. A soil parameterisation experiment with ECMWF seasonal forecasts

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Land surface uncertainty

- The land surface is extremely heterogeneous and difficult to parameterise.
- Land surface hydrology:
  - lack of knowledge about input and boundary conditions;
  - non-linearity, complexity and spatio-temporal variability in process representation;
  - uncertainty in the representation of process;
  - inadequate observational data at the river catchment scale
  - **representation of uncertainty is fundamental**

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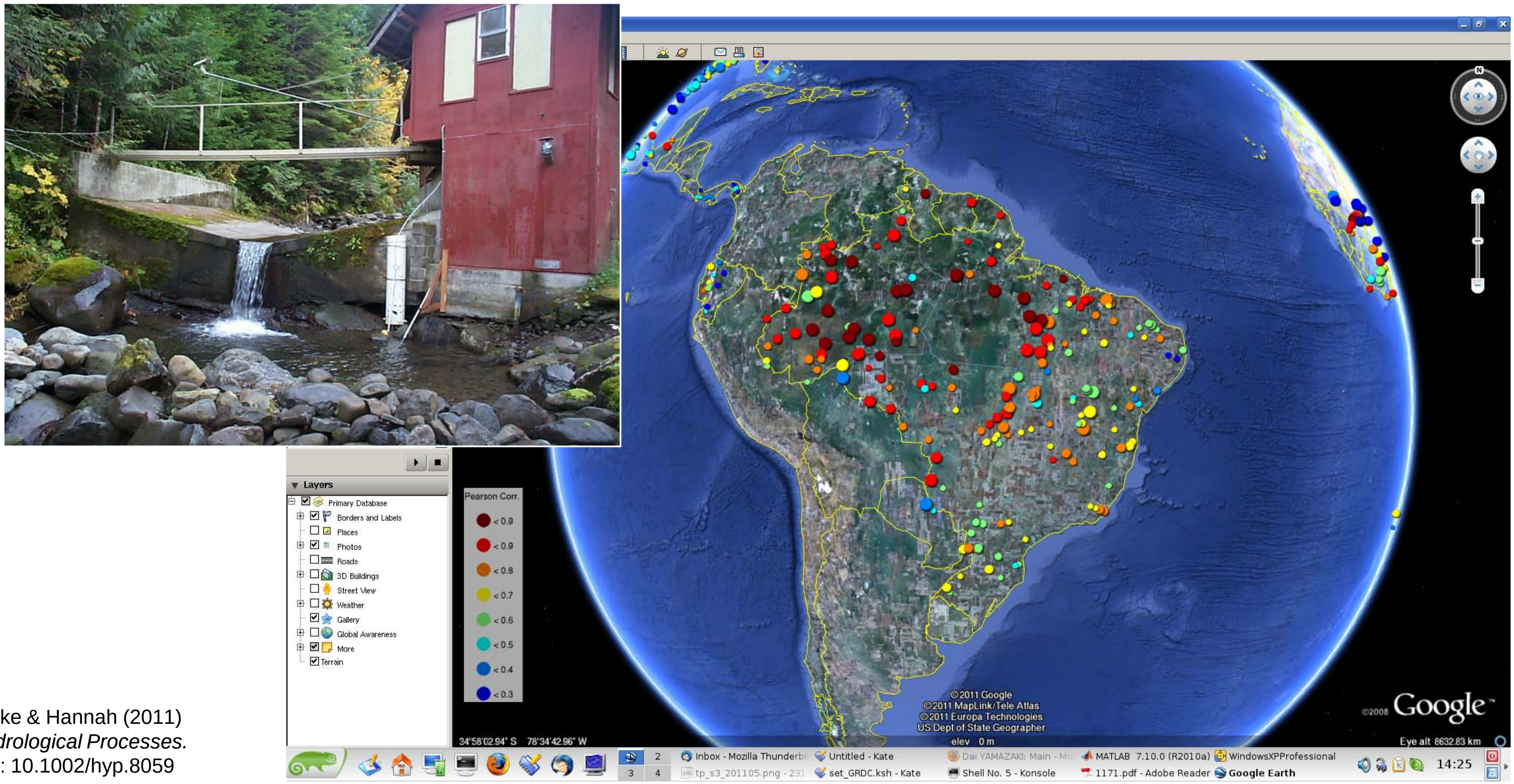
Convergence of two communities

- Spatial resolution of land surface schemes - now coinciding with the scales commonly used in river catchment modelling

http://www.stormrm.info/



Cloke & Hannah (2011)
Hydrological Processes.
Doi: 10.1002/hyp.8059

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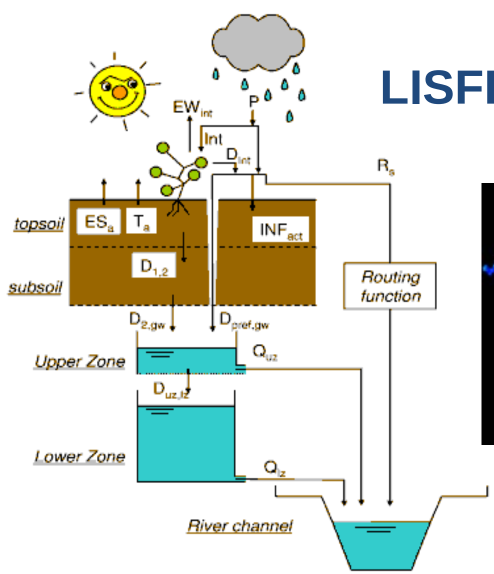
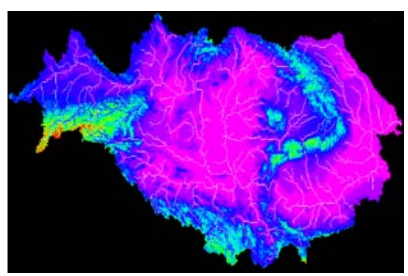
Uncertainty in hydrological modelling

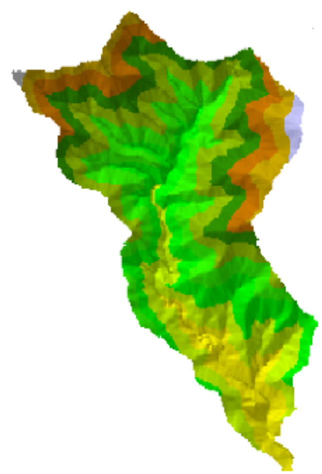
- Hydrological models predict river discharge (m^3s^{-1}) and related hydrological variables such as soil moisture. Often focused on the catchment scale.
- Can be 'lumped' across river catchments, distributed on a grid or broken into representative hydrologically active areas (REW approach).
- Known that adding explanatory depth (more physics processes) or higher spatial resolution to a hydrological model is not always good (over-parameterisation). Beven 1989 – Changing Ideas in Hydrology: the case of physically based models

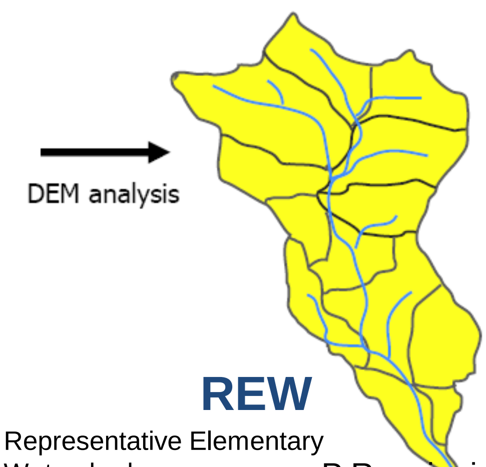


LISFLOOD



J Thielen





REW

Representative Elementary Watershed

P Reggiani

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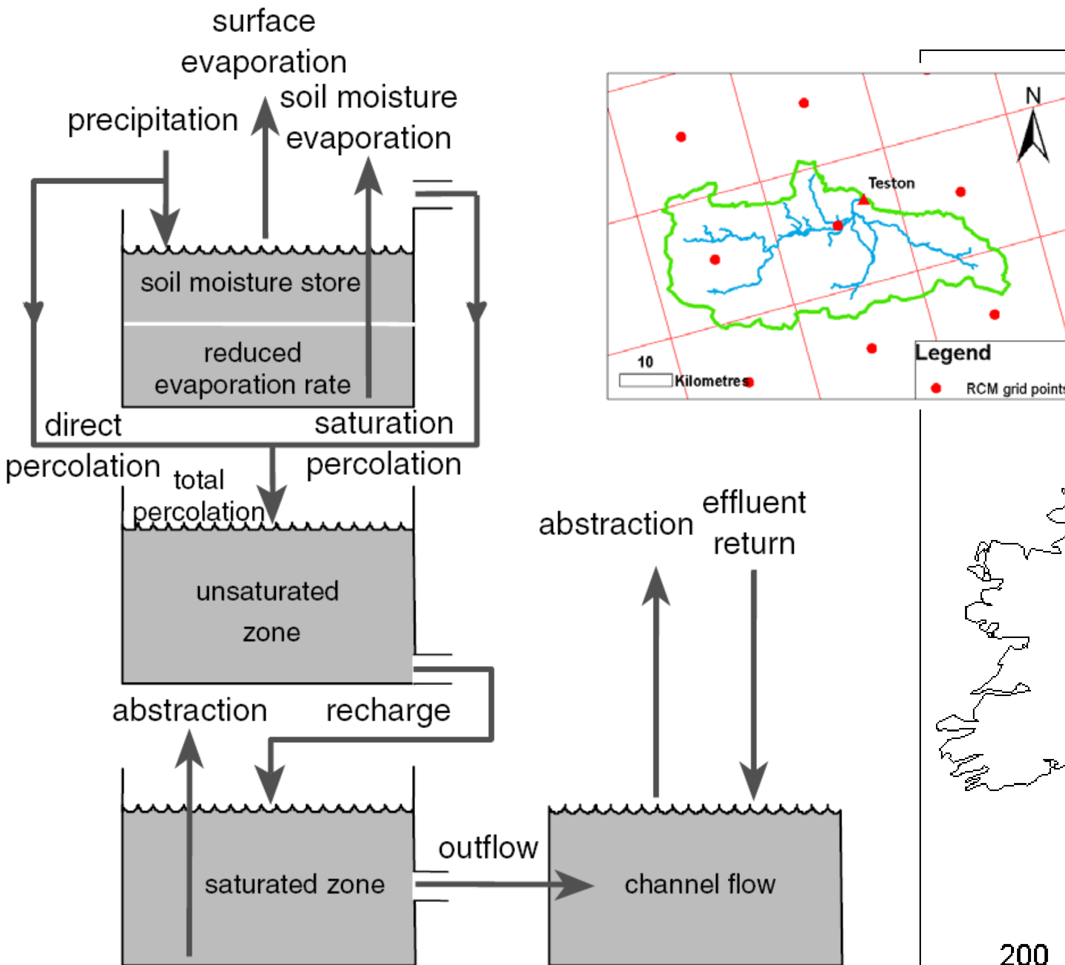
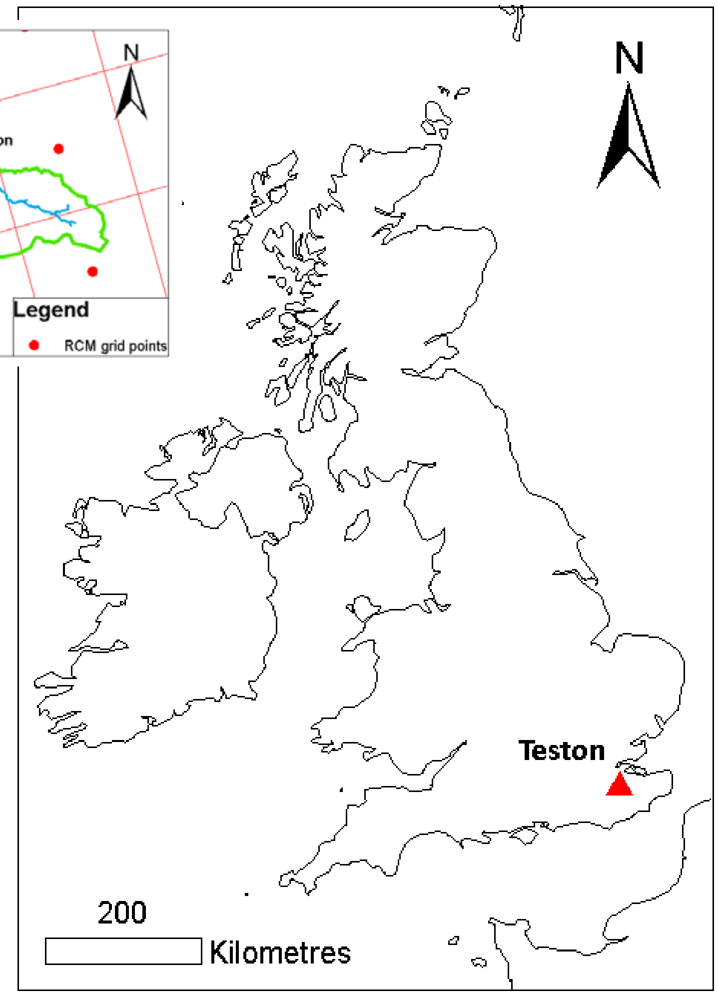
Cloke et al, 2010
10.1002/hyp.7769

Parameter uncertainty & climate impact modelling



CATCHMOD



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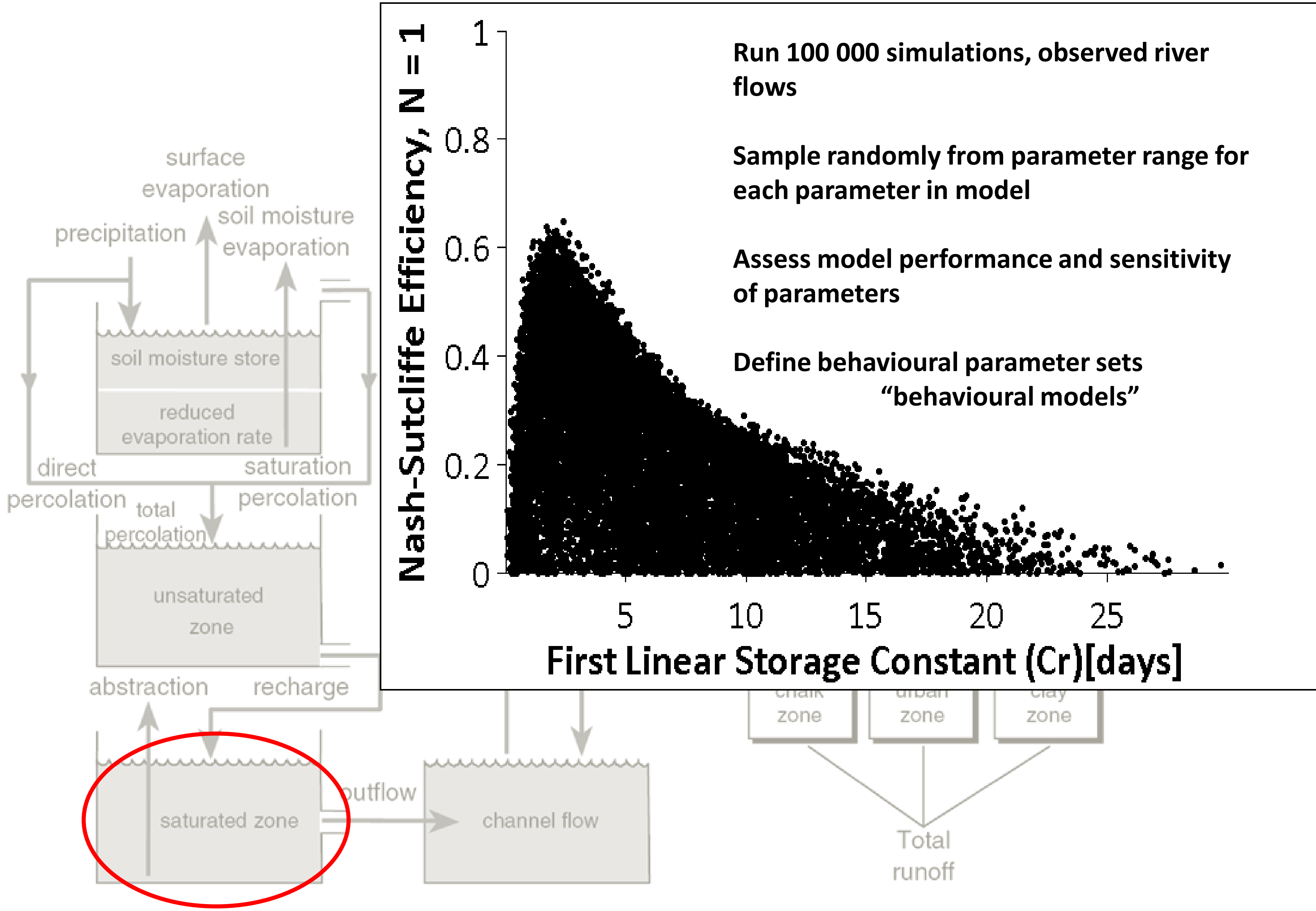

1st storage constant

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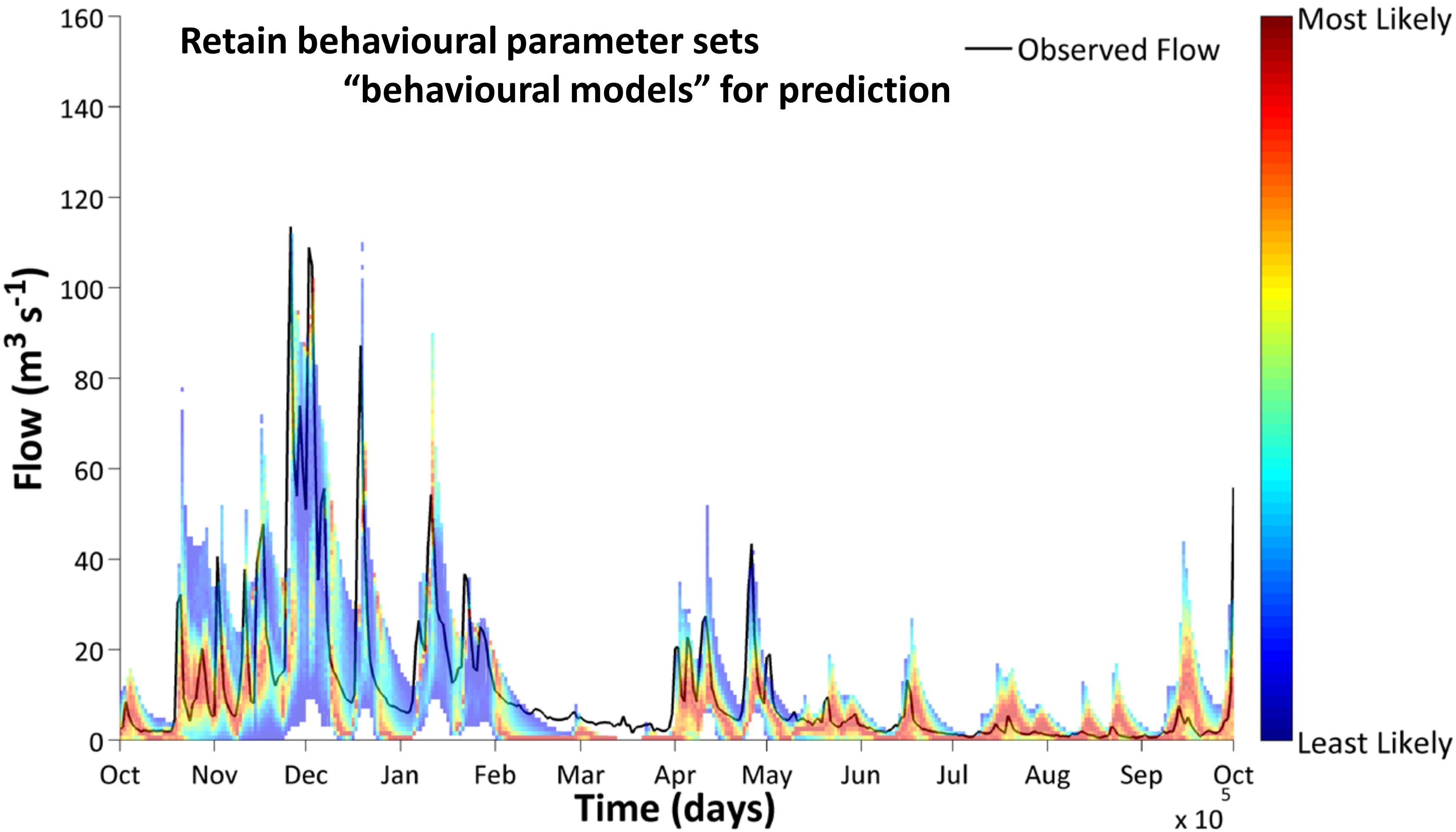

Generalised Likelihood Uncertainty Estimation (GLUE), Beven

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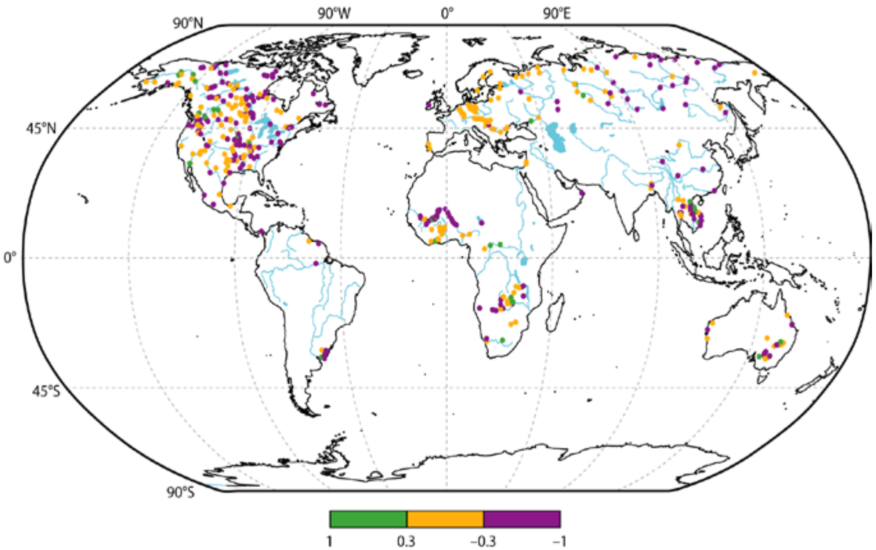
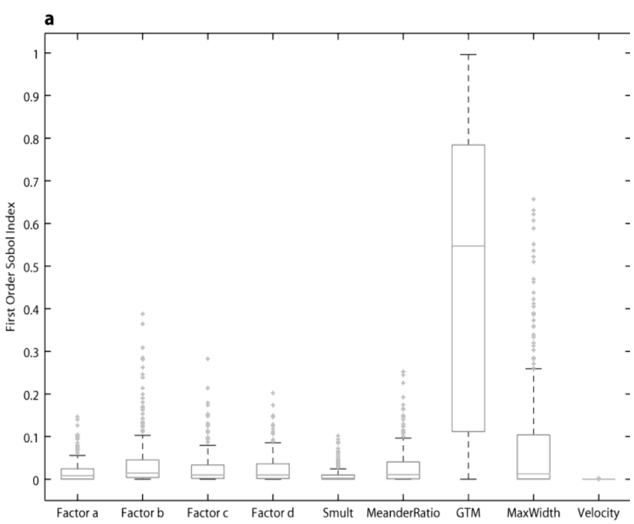
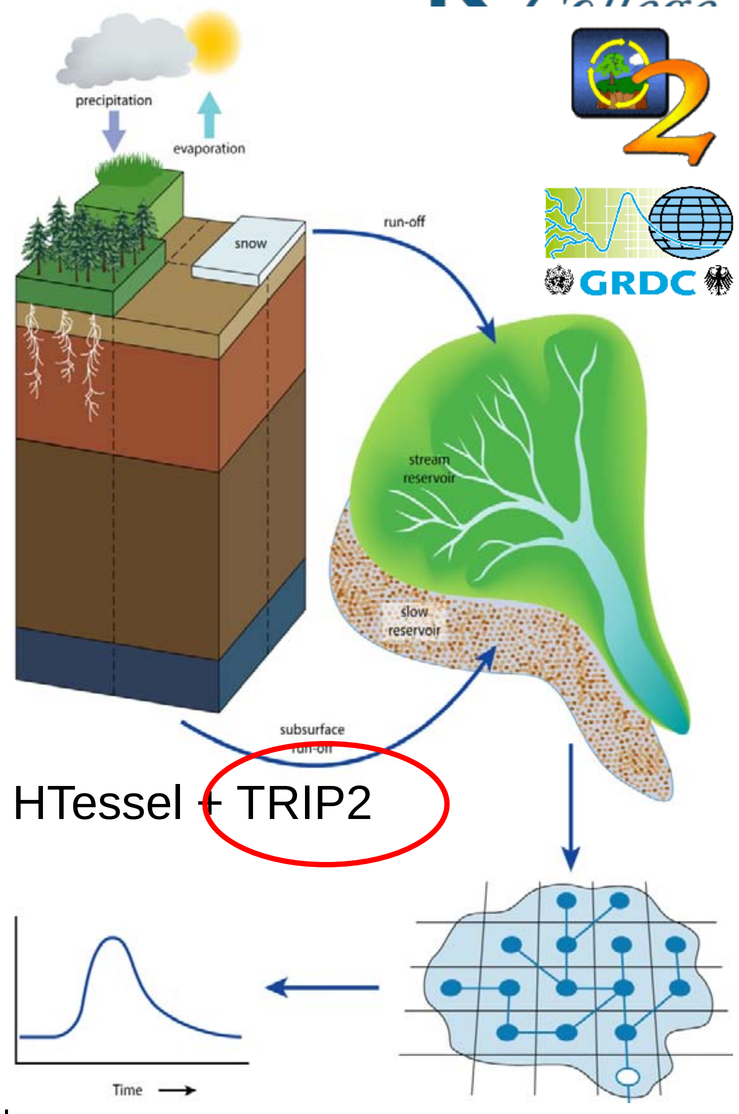
Global river routing



Stations from GRDC



Sensitivity river flow predictions to parameters!



HTessel + TRIP2

Pappenberger et al., 2010, DOI: 10.1002/joc.2028

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Soil moisture & land surface schemes

- soil moisture can influence the variability of precipitation & air temperature

- higher soil moisture = higher evaporation and greater cooling of surface and overlying air BUT soil moisture effects on precipitation more complex

Shao and Henderson-Sellers (1996): Modelling soil moisture, PILPS phase2, (the Intercomparison of Land-surface Parameterization Schemes) http://www.pilps.mq.edu.au/ (GLASS)

Global Land-Atmosphere Coupling Experiment –Phase 2 (GLACE2)

- quantifying, for boreal summer, the subseasonal (out to two months) forecast skill for precipitation and air temperature that can be derived from the realistic initialization of land surface states, notably soil moisture.
- **Land initialization** impacts on skill increase dramatically when conditioned on the size of the initial local soil moisture anomaly.
- Koster et al, GRL, JHM etc.
- http://gmao.gsfc.nasa.gov/research/GLACE-2/

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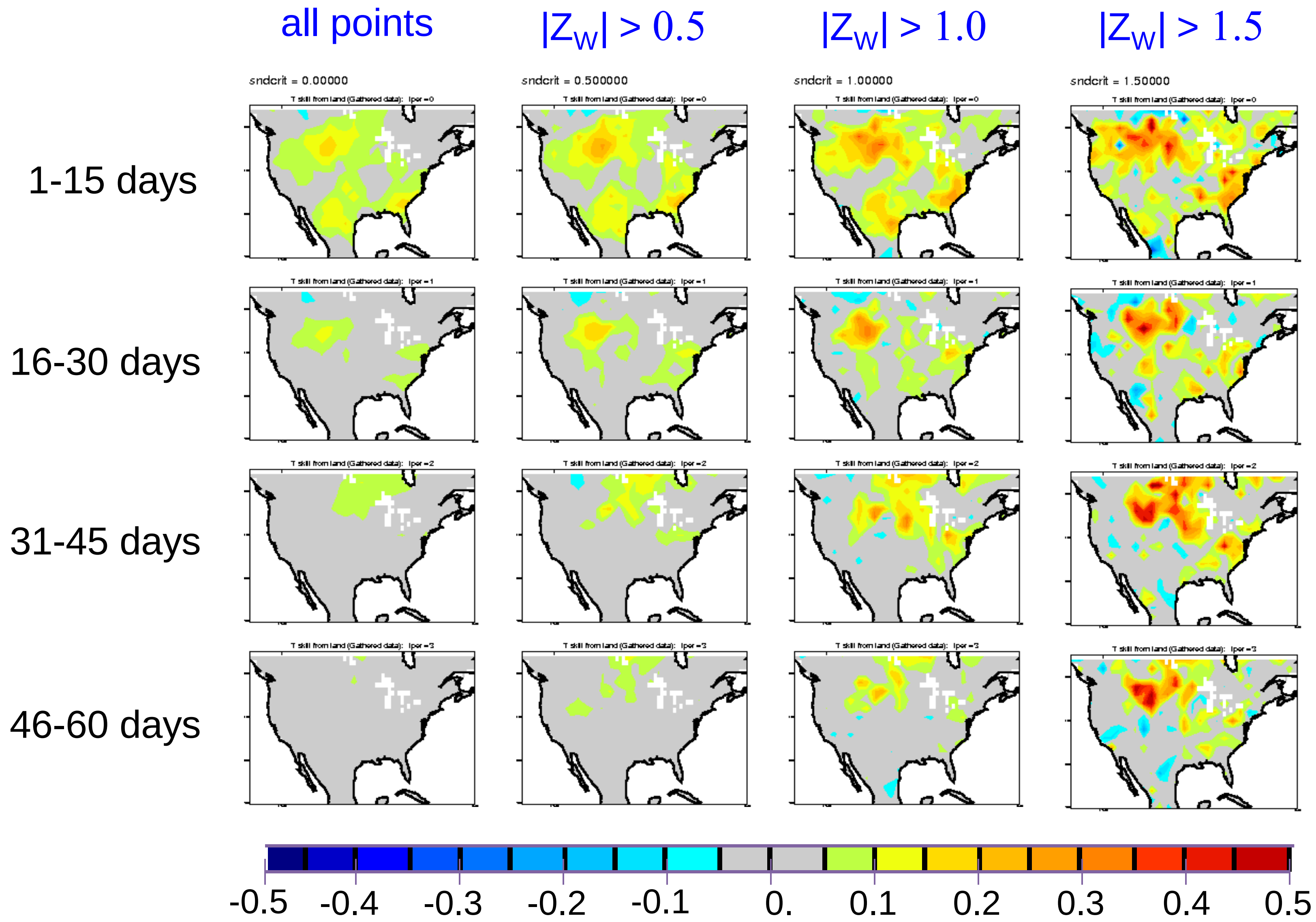
Temperature forecasts: Increase in skill due to land initialization (JJA) (conditioned on Z-score of initial soil moisture anomaly)

http://gmao.gsfc.nasa.gov/research/GLACE-2/



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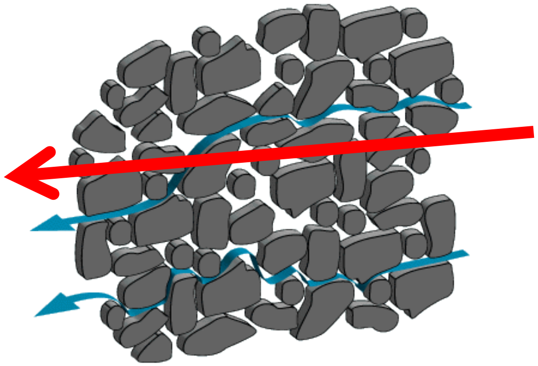
Land Surface Schemes often use Richards equation - Flow in the subsurface

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[K(\theta)\left(\frac{\partial \psi}{\partial z} + 1\right)\right]$$

K is the hydraulic conductivity,
ψ is the pressure head,
z is the elevation above a vertical datum,
θ is the water content, and
t is time.

K –describes the ease with which water can move through pore spaces



Non-linear relationship between *θ* and *ψ* described with soil moisture release curve - e.g. **van Genuchten** (1980)

α, n and l are soil-texture dependent parameters.

$$\theta(h) = \theta_r + \frac{\theta_{sat} - \theta_r}{(1 + \alpha h)^{1-1/n}}$$

Table 1: Van Genuchten soil parameters.

Texture	α	l	n	γ_{sat}
Units	m^{-1}	-	-	$10^{-6} m/s$
Coarse	3.83	1.250	1.38	6.94
Medium	3.14	-2.342	1.28	1.16
Medium-Fine	0.83	-0.588	1.25	0.26
Fine	3.67	-1.977	1.10	2.87
Very Fine	2.65	2.500	1.10	1.74
Organic	1.30	0.400	1.20	0.93

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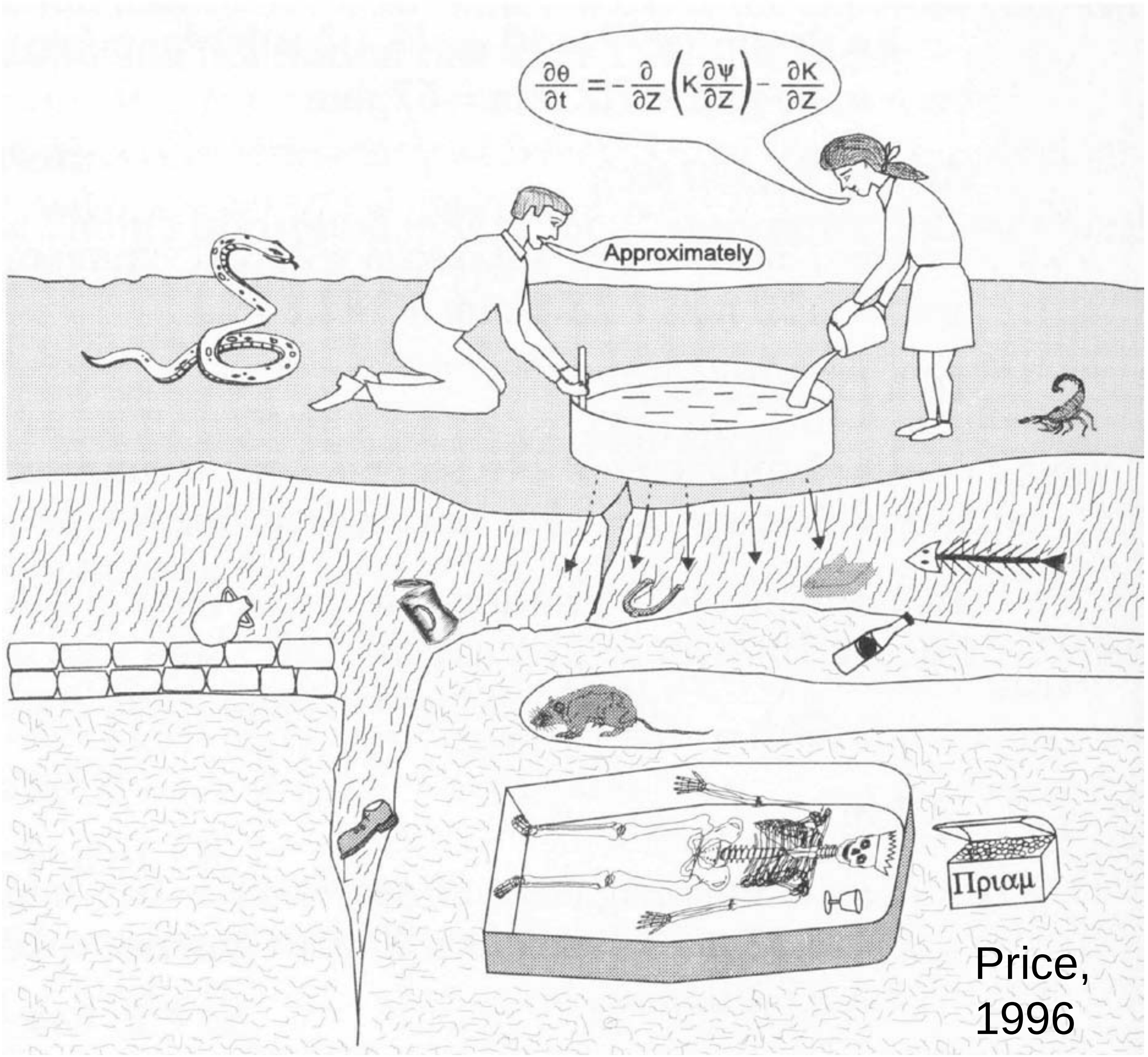
The uncertain subsurface



Price, 1996

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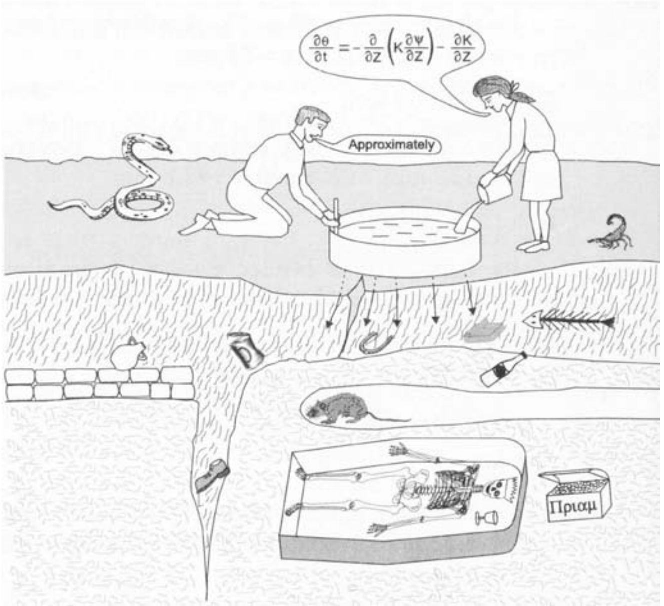
- A heterogeneous unsaturated zone will **not** average linearly in its parameters.
- Darcy-Richards equation **not** representative of processes - preferential flows of some type will have an important effect on the flux of water to deeper layers and therefore on the water balance partitioning (Beven and Germann, 1982; Uhlenbrook, 2006)

- Richards equation can be useful BUT only if used understanding that parameters are EFFECTIVE – not directly comparable to measurements
- Neglect of sub-grid variations in soil moisture – NOT incorporating the full suite of processes and variability
- Lead to alternative approaches e.g. JULES and TOPMODEL



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Soil physics uncertainty experiment: ECMWF seasonal forecasts

- Generated 25 member control forecast - **CONTROL**
- 25 Member perturbed soil physics in HTESSEL (Richards equation / van Genuchten soil representation)
- 25 Member perturbed soil physics WITH atmospheric stochastic physics turned off

- Comparison to ERA40/interim
- 2 sensitive parameters (Cloke et al., 2008, DOI: 10.1002/hyp.6734) :
  - K Hydraulic Conductivity
  - α van Genuchten parameter
  - Soil becomes more hydrologically active as these increase
  - Select from known distributions

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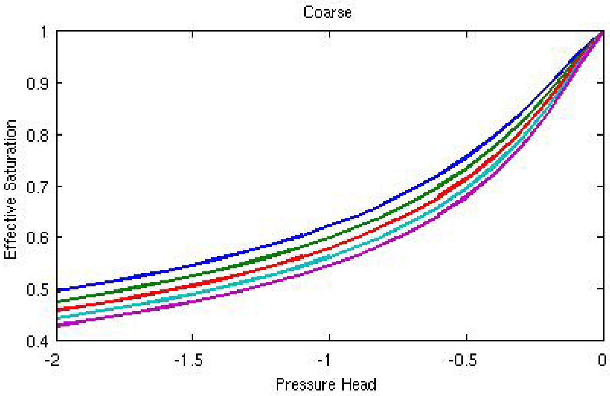
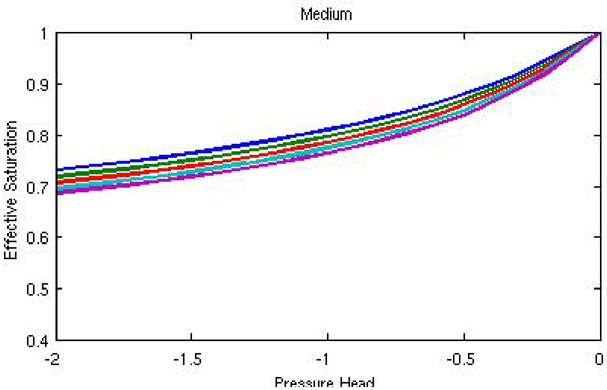
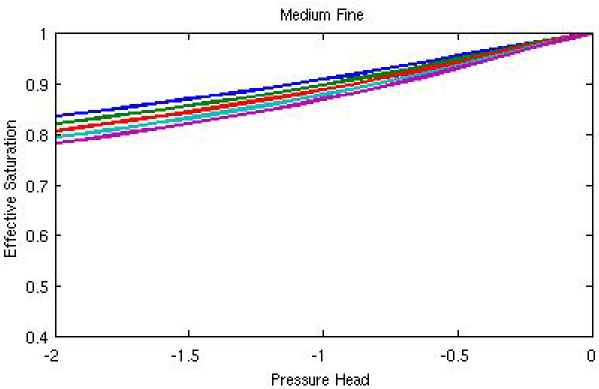
Van Genuchten α

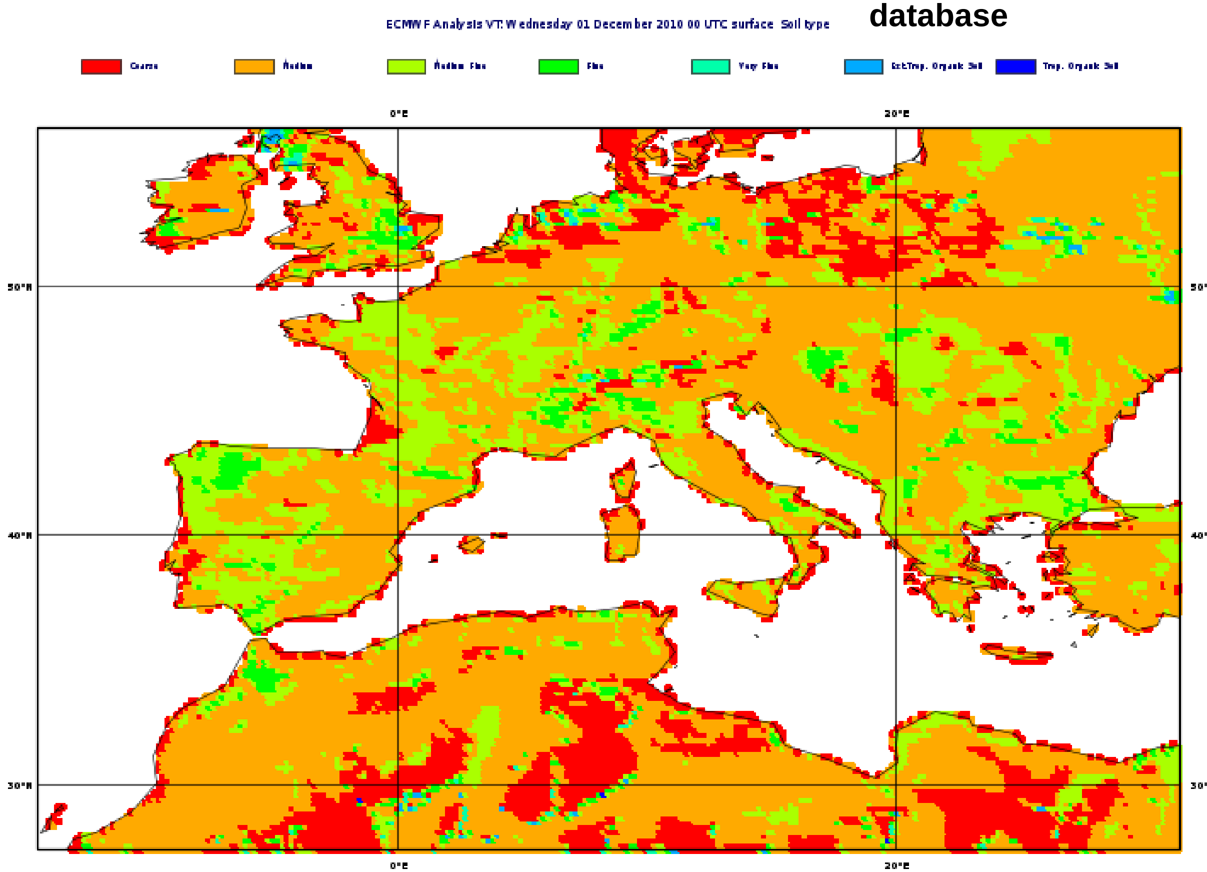
Shape of soil moisture release curve







ECMWF soils from FAO database



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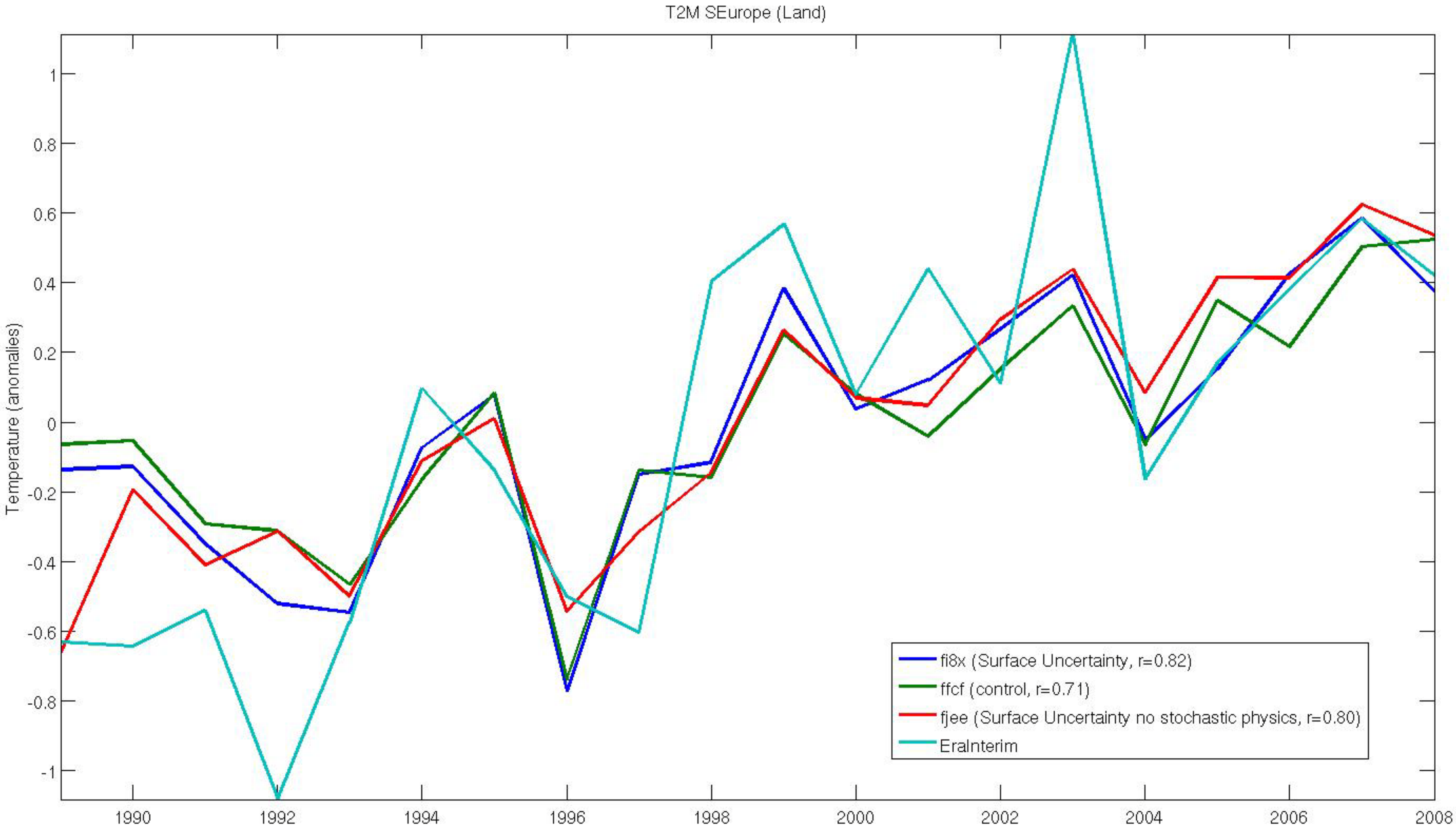

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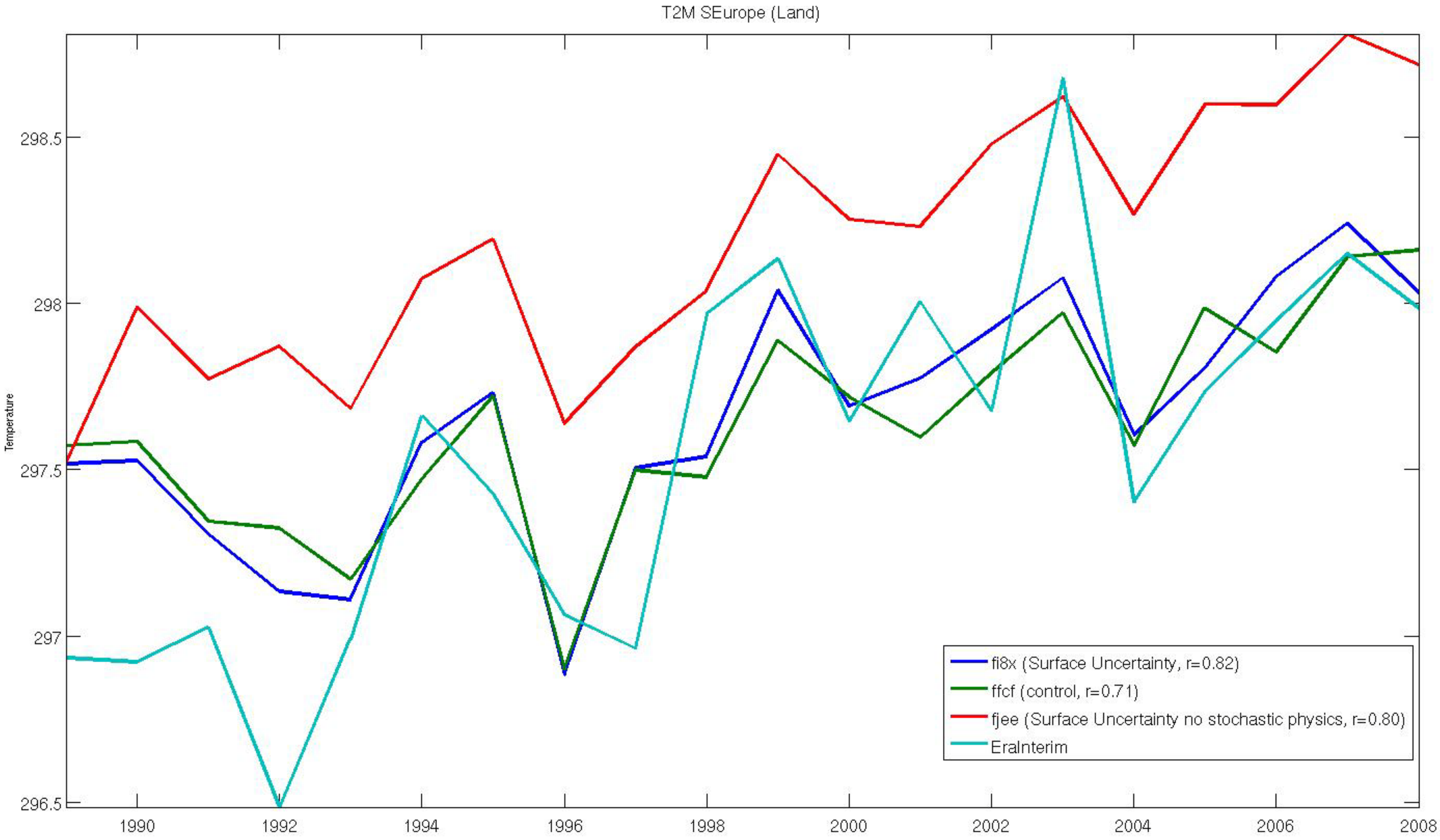

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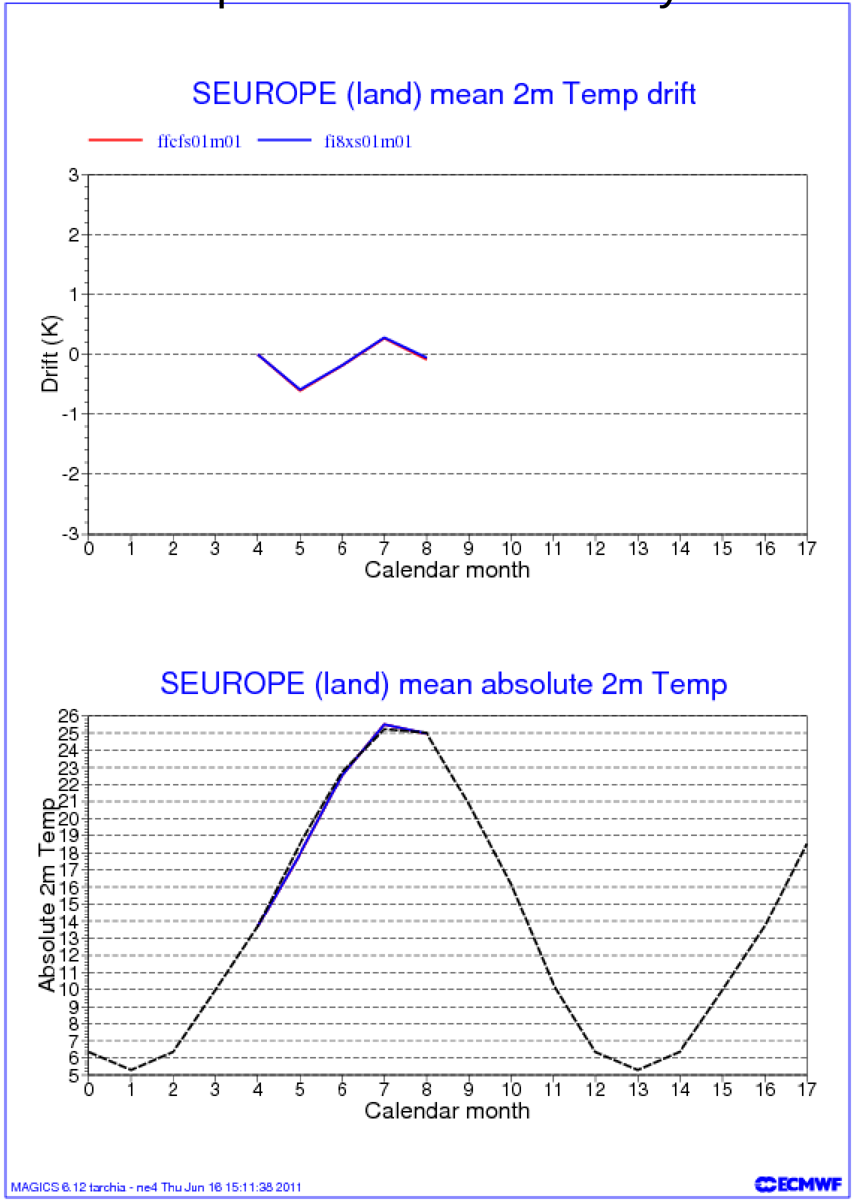
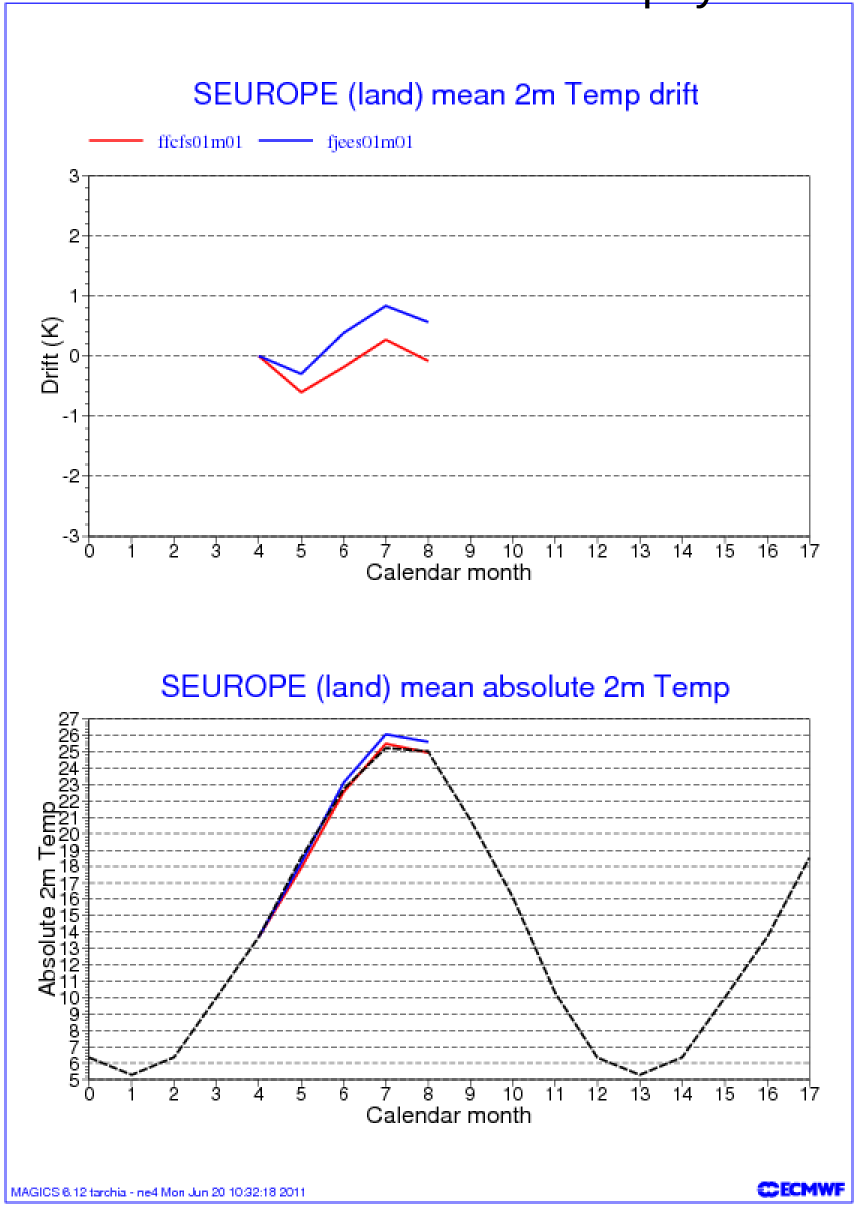
Soil parameter uncertainty



Without Atmos stochastic physics



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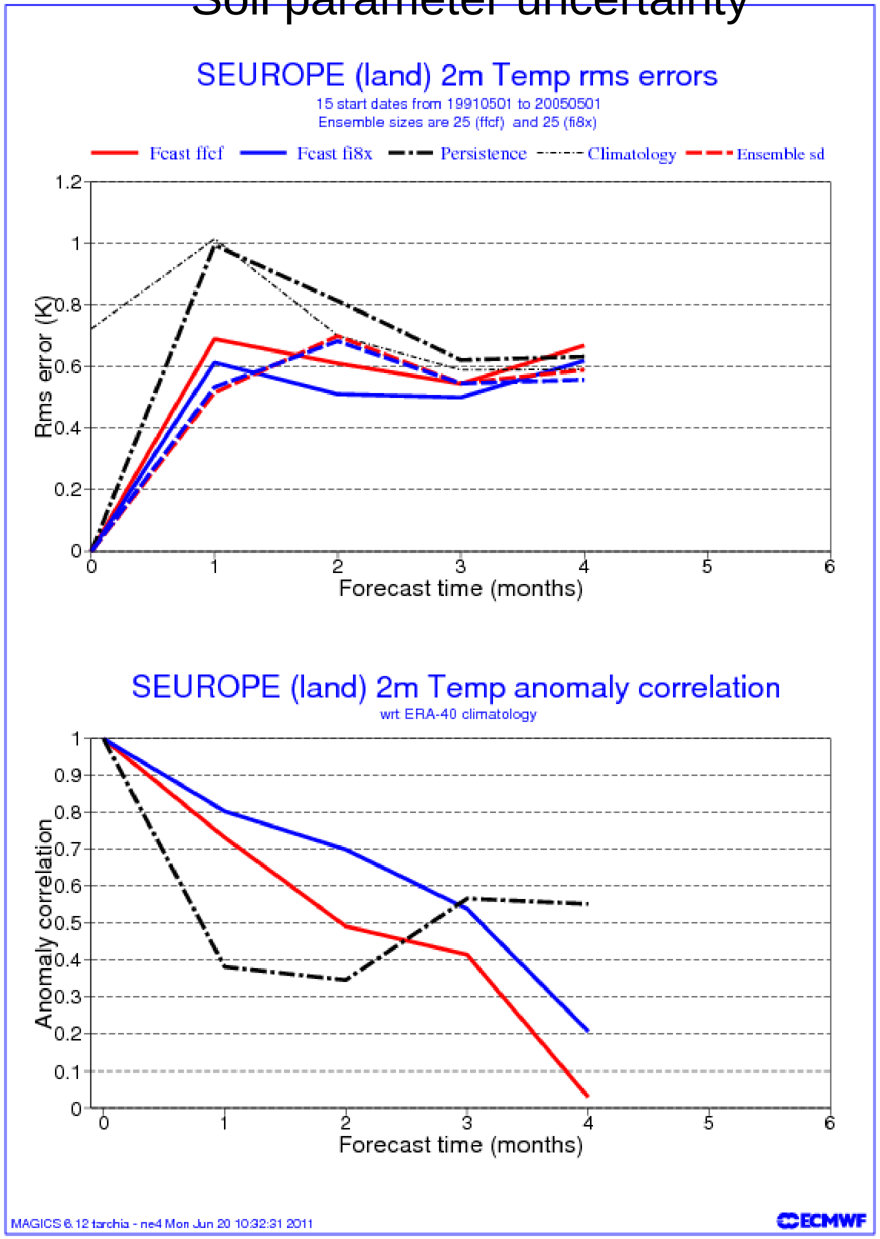
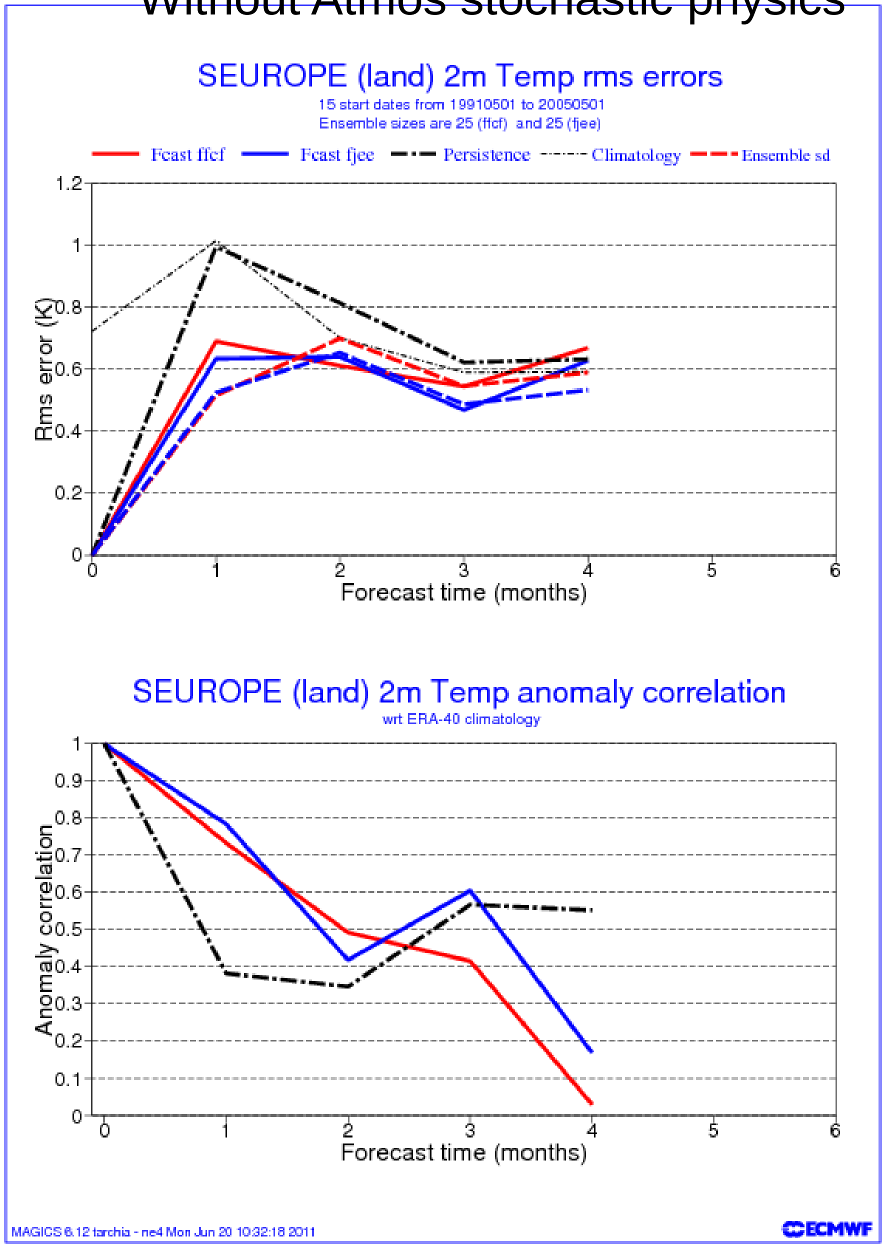
Soil parameter uncertainty



Without Atmos stochastic physics



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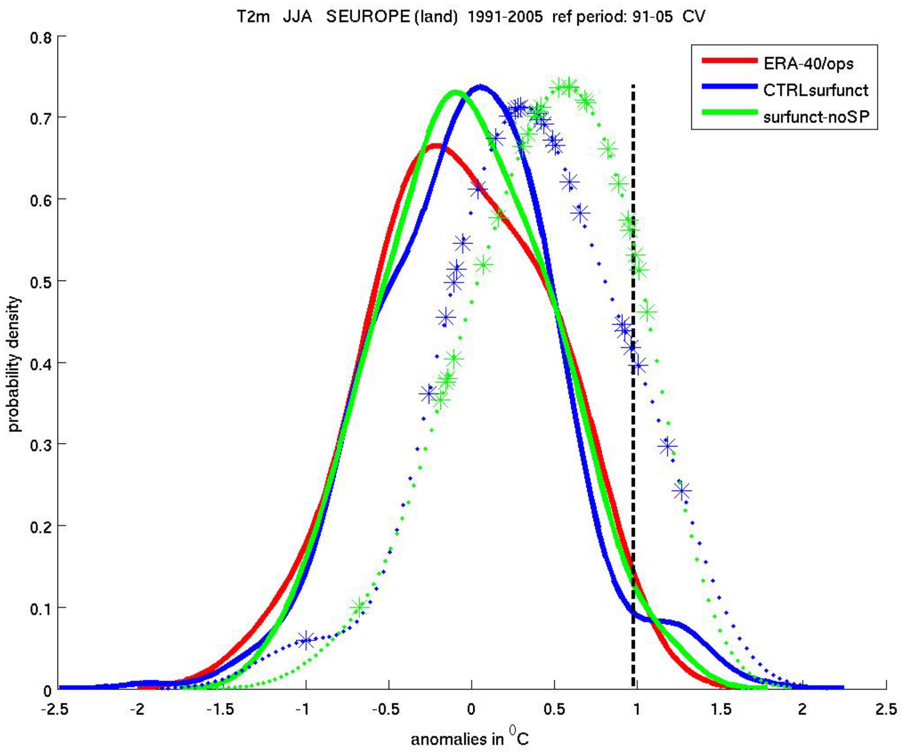

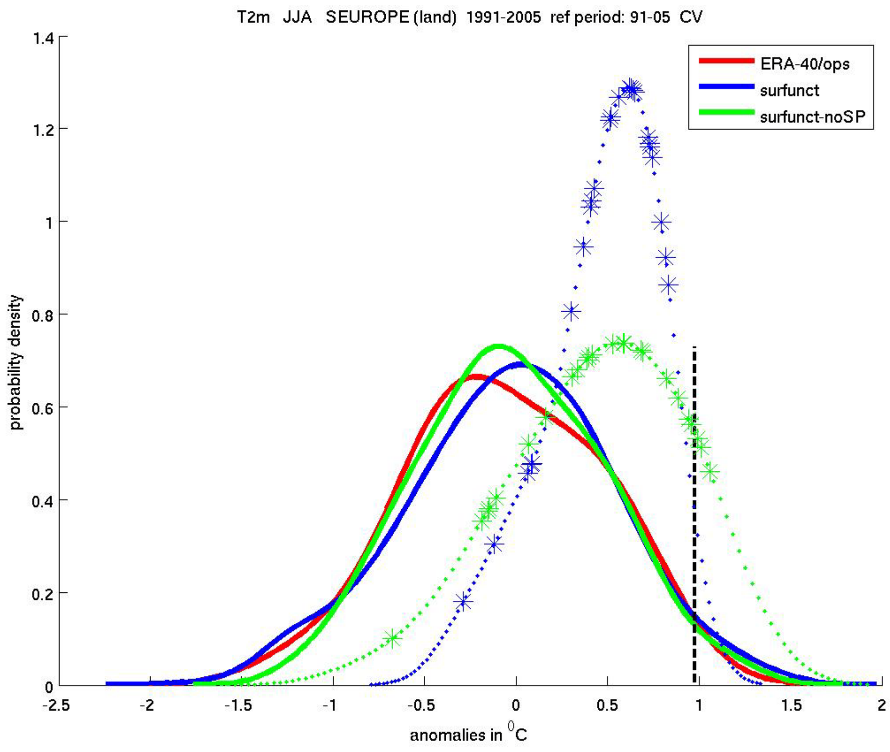

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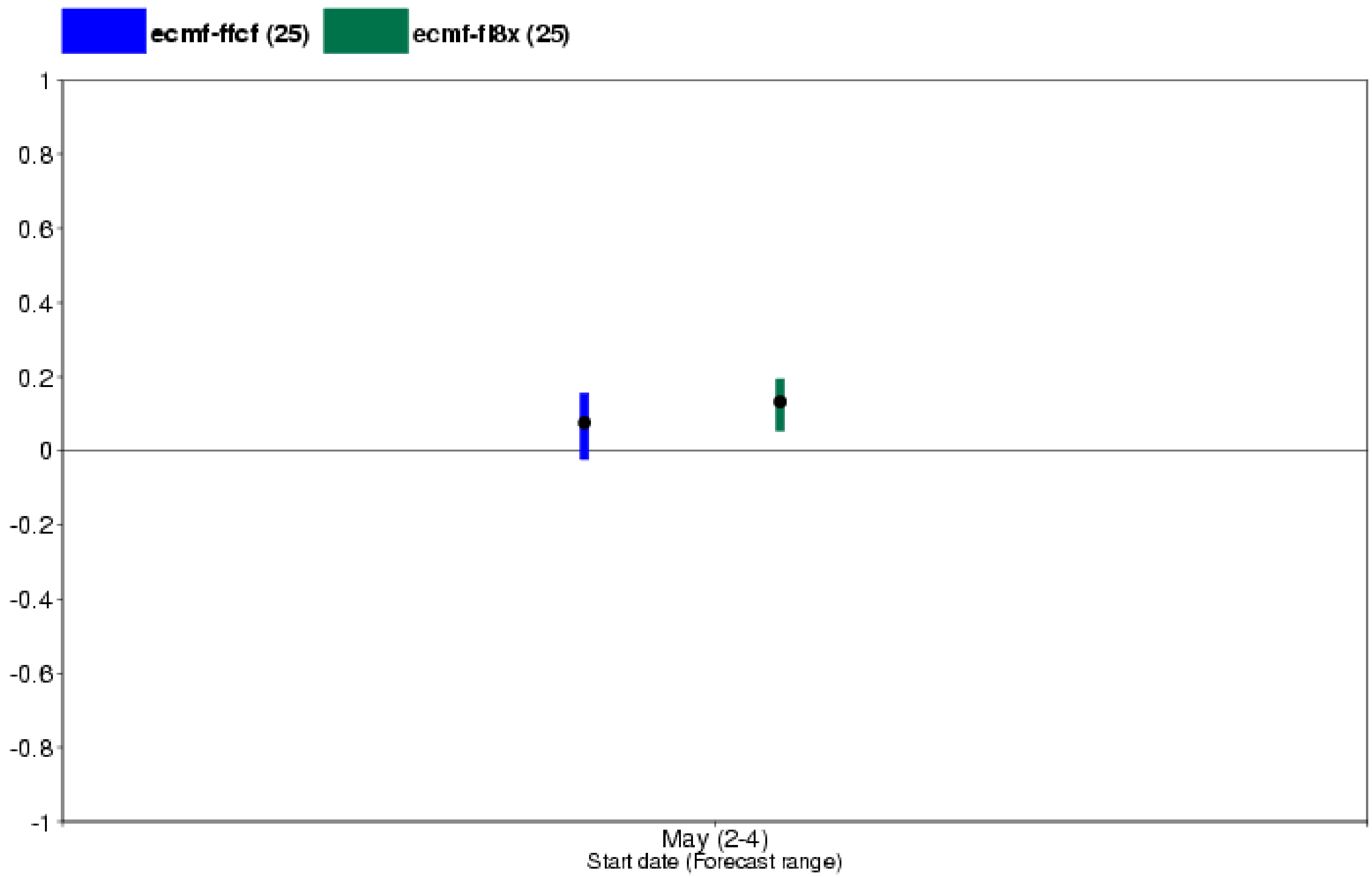
Brier Skill Score for Mediterranean Basin, G&F (land points only)
Near-surface air temperature anomalies above the upper tercile
Hindcast period 1989-2008

Threshold estimated with a kernel method for the PDF
Bars are 95% conf. intervals computed with 1000 samples



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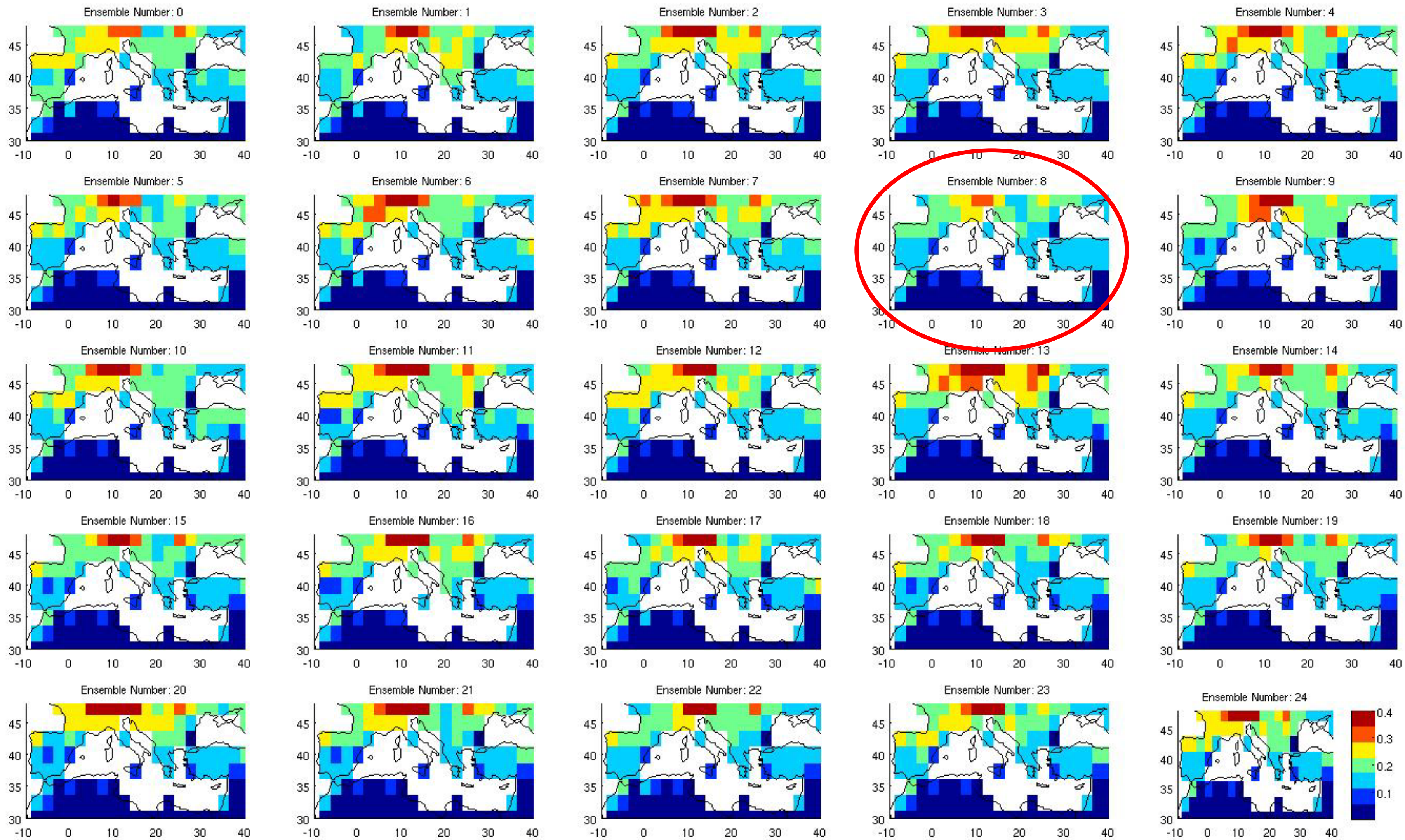

Volumetric soil moisture, S Europe, Summer 2003

relationship with hydrological activity of parameter sets

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Conclusions

- Parameterisation of soil hydraulic properties in land surface schemes (LSS) is not straightforward. The land surface is extremely heterogeneous and difficult to parameterise. Many realistic parameter sets.
- *Initial results* show that taking account of some of the uncertainty in two of the most sensitive soil parameters can improve 2m Temp skill in seasonal forecasts for S Europe in ECMWF seasonal forecasts.

- Next steps:
  - other regions and time periods. Check tendencies found above.
  - Derive formal sensitivity between soil hydraulic parameters and forecast skill
  - Strategy for **stochastic selection of parameters.**

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