Land surface modelling in NWP at ECMWF

Gianpaolo Balsamo
European Centre for Medium-range Weather Forecasts (ECMWF)

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Pedro Viterbo, Anton Beljaars, Bart van den Hurk, Pedro Miranda, Emanuel Dutra, Viktor Stepanenko, Alan Betts, Florian Pappenberger, Souhail Boussetta, Anna Agusti-Panareda, Patricia de Rosnay, Joaquin Muňoz-Sabater, and others

OUTLINE

- Introduction
  - Land surface focus in NWP: from fluxes-only to fluxes&water storage?
  - Role of land surface in the ECMWF model
  - Where do we see land surface related errors in NWP?
- The land surface model:
  - The soil hydrology revision
  - The new snow scheme
- A quick look ahead
  - vegetation seasonality
  - water bodies (work in progress)
- Summary and conclusions
- Foreseen challenges

Atmospheric Fluxes vs. Water storage

- Land surface parameterisations entered in NWP models with a main target of providing <u>atmospheric turbulent fluxes</u> via a simple treatment of soil moisture and evaporation (Manabe, 1969 MWR). The main target was a representation of the Bowen ratio. $B = \frac{Q_h}{Q_e}$
- Snow cover was mentioned in the context of radiative effects (albedo) and snow mass was functional to this target…"snow water holding capacity was assumed to be zero for sake of simplicity"...
- In recent years much more attention is devoted to <u>fluxes & water storage</u> even in NWP. Motivations are given by:
  - **<u>PREDICTABILITY</u>**: caring about fluxes and not about absolute value of soil moisture/snow mass is limiting since it means that we can't sustain good quality fluxes for long-time in the forecast even under the assumption of unbiased precipitation. Land is an "integrator" of water and energy.
  - **<u>PURPOSE BENCHMARKING</u>**: Land surface model output can serve a wider scientific and user community (e.g. hydrology modelling, carbon modelling, climate change within EC-Earth) and feedback into model improvements.
  - **<u>MULTI-VARIATE LAND SURFACE DATA ASSIMILATION</u>**: Assimilating into NWP system satellite information which is sensitive to water channels (L-Band SMOS, C-Band AMSR-E) obliges the model to represent soil moisture in the observed range and water bodies.

Role of land surface at ECMWF

ECMWF model(s) and resolutions

	Length	Horizontal	Vertical	Remarks
- Deterministic	10 d	T799 (25 km)	L91	00+12 UTC
- Monthly/VarEPS (N=51)	0-10d 11-32d	T399(50 km) T255(80 km)	L62 L62	(SST tendency) (Ocean coupled)
- Seasonal forecast	6 m	T159 (125 km)	L62	(Ocean coupled)
- Assimilation physics	12 h	T255(80 km)/ T159(125 km)	L91	T95(200 km) inner
- ERA-40 Reanalysis	1958-2002	T159(125 km)	L60	3D-Var+surface OI
- ERA-Interim Reanalysis	1989-today	T255(80 km)	L91	4D-Var+surface OI

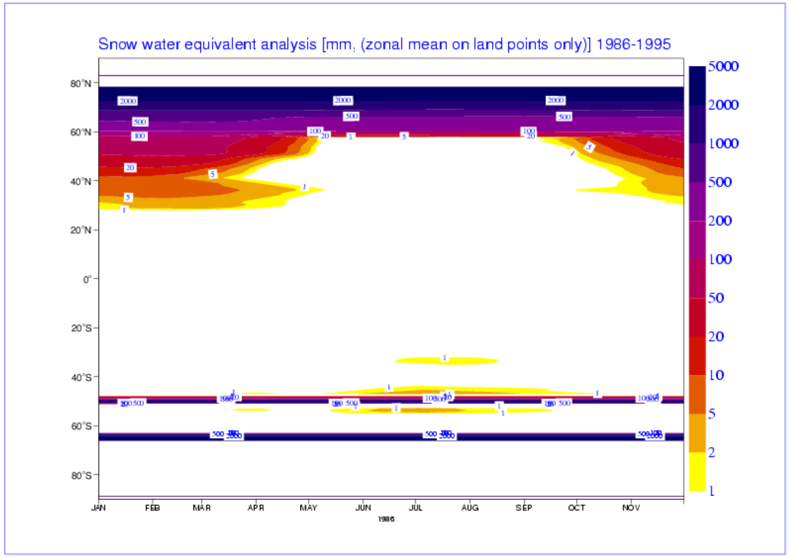
Land surface modelling (and LDAS systems) need flexibility & upscalability (conservation) properties to be used by at a wide range of spatial resolutions in spite of natural heterogeneity of land surfaces.

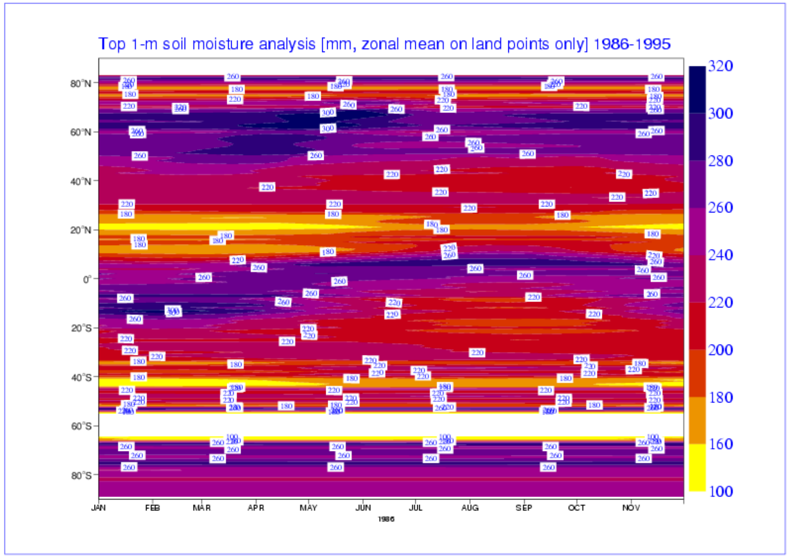
Errors in the treatment of land surface are likely to affect all forecasts products.

	Length	Horizontal	Vertical	Remarks
- Deterministic	10 d	T1279 (16 km)	L91	00+12 UTC
- Monthly/VarEPS (N=51)	0-10d 11-32d	T639(30 km) T399(60 km)	L62 L62	(SST tendency) (Ocean coupled)

Surface Water reservoirs (ERA-40 1986-95)

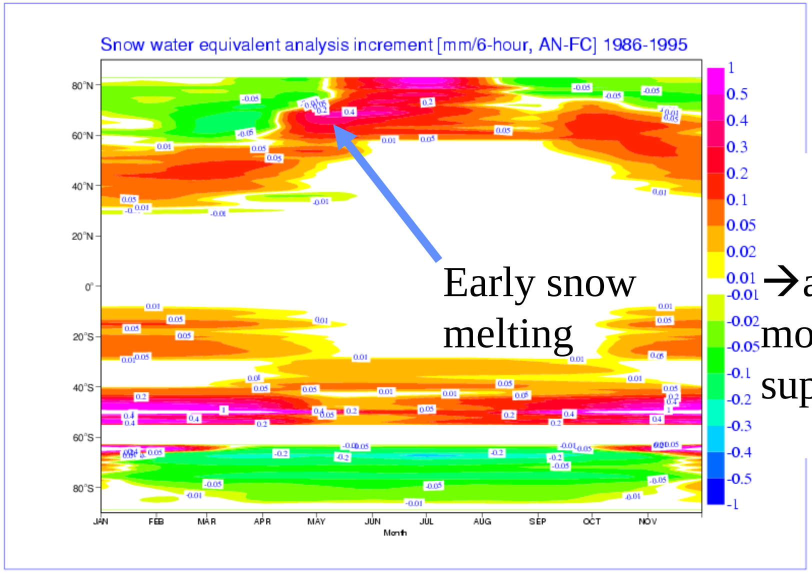
Snow



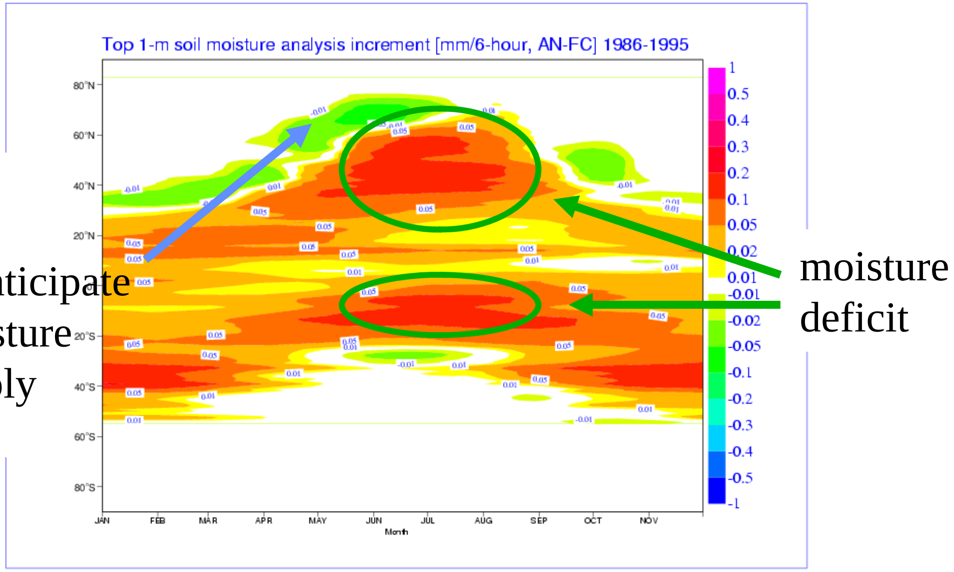


SM

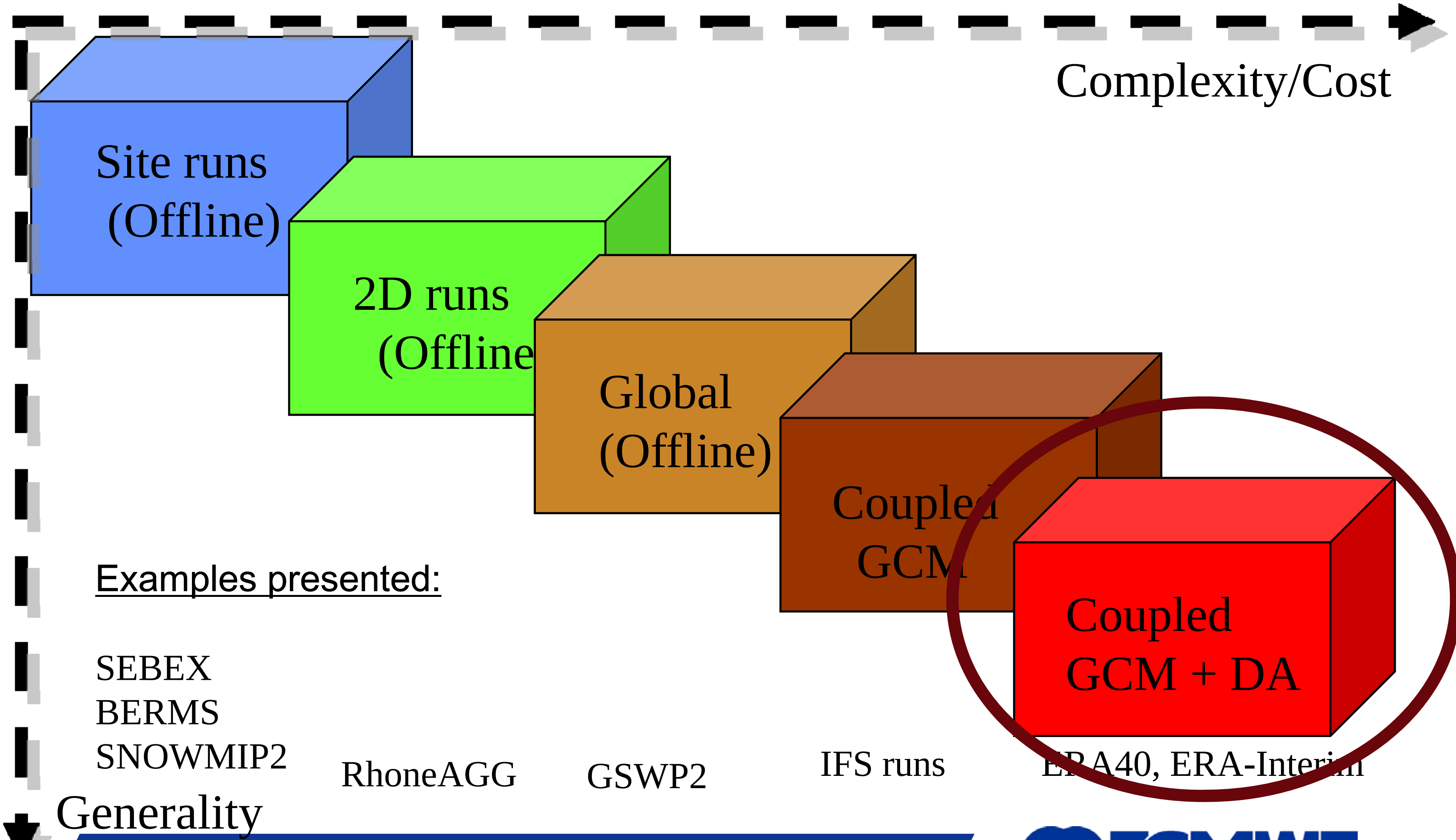
- **DA increments redistribute water and constraint near-surface errors**



→anticipate moisture supply



Land surface validation in global NWP



ECMWF

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Land surface model evolution

2000/06	2007/11	2009/03	2009/09		2010

- **TESSEL**

  Van den Hurk et al. (2000)
  Viterbo and Beljaars (1995),
  Viterbo et al (1999)

  Up to 8 tiles (binary Land-Sea mask)

  GLCC veg. (BATS-like)

  ERA-40 and ERA-I scheme

- **Hydrology-TESSEL**

  Balsamo et al. (2009)
  van den Hurk and Viterbo (2003)

  Global Soil Texture (FAO)

  New hydraulic properties

  Variable Infiltration capacity & surface runoff revision

- **NEW SNOW**

  Dutra et al. (2009)

  Revised snow density

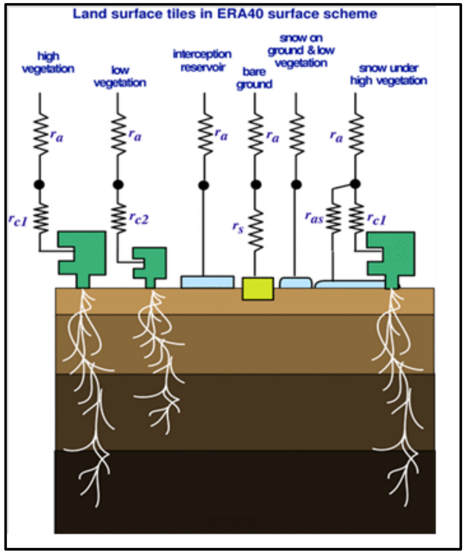
  Liquid water reservoir

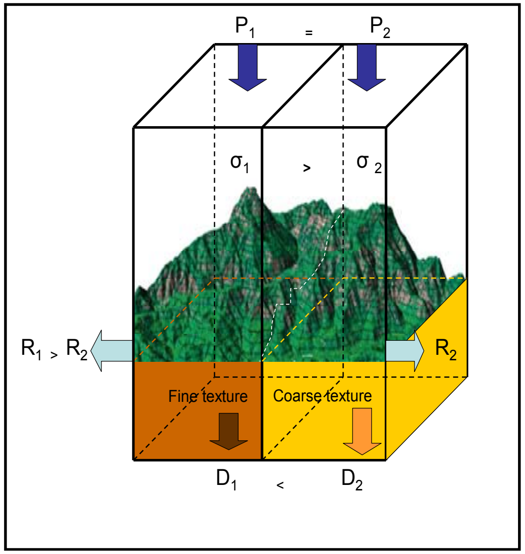
  Revision of Albedo and sub-grid snow cover

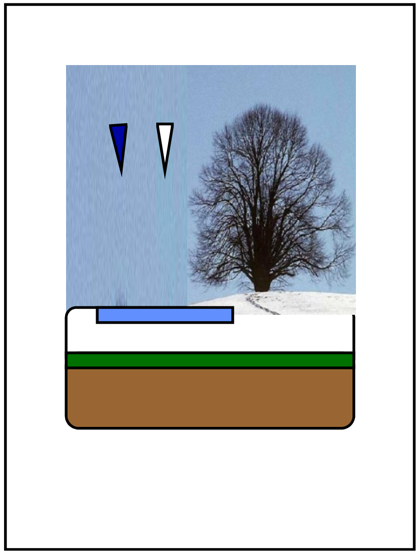
- **FLAKE**

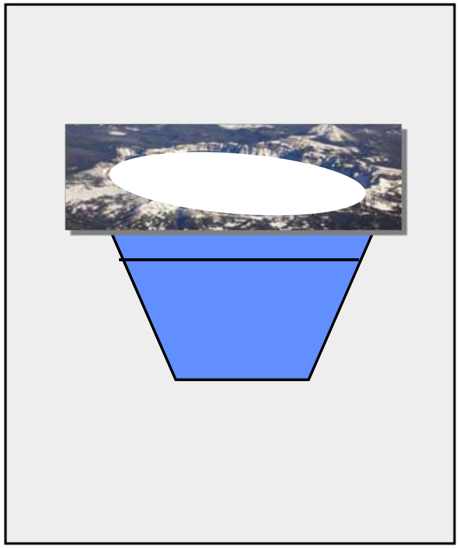
  Mironov et al (2009),
  Dutra et al. (2009),
  Balsamo et al. (2009)

  Extra tile (9) to account for sub-grid lakes



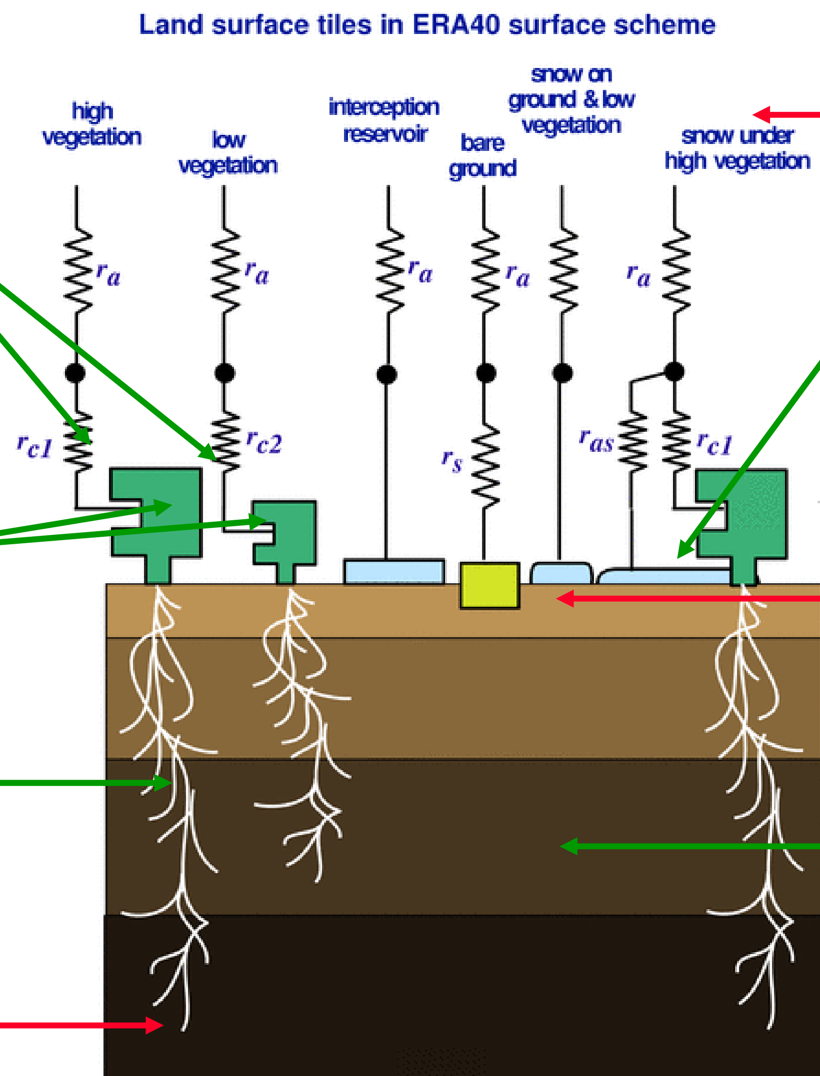






TESSEL land surface scheme

- **Tiled ECMWF Scheme for Surface Exchanges over Land**



Canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth

A single soil texture globally, excessive drainage

Too early snow melting

Separate treatment of snow under high vegetation

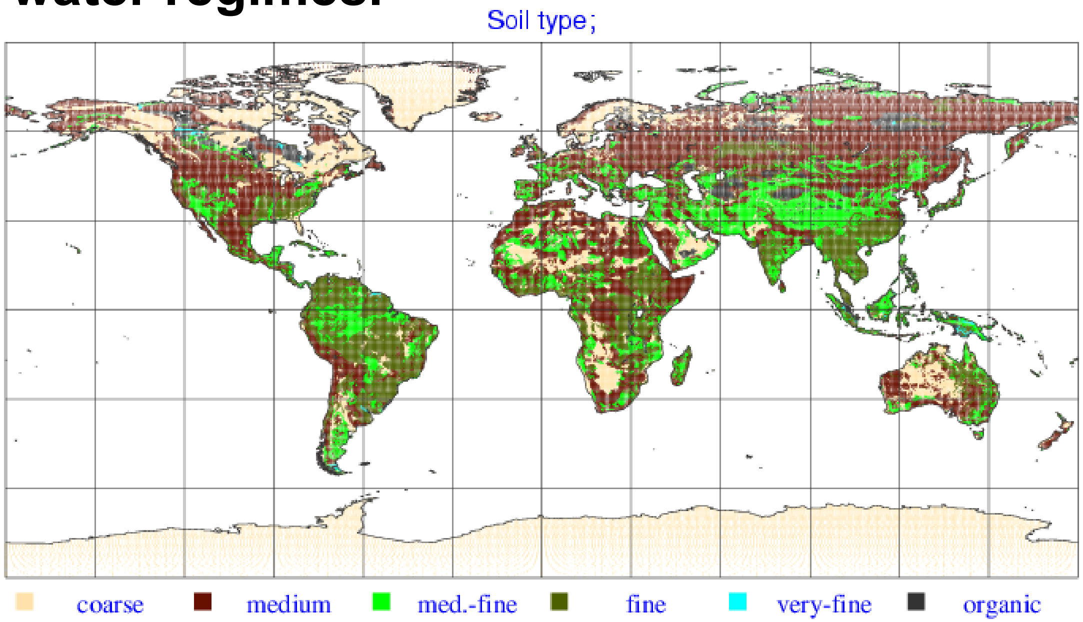
+ 2 tiles (ocean & sea-ice)

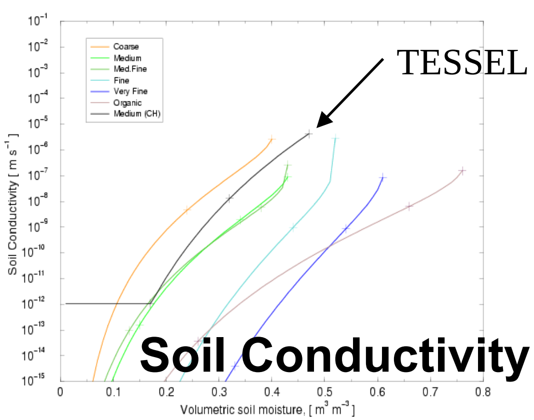
Too little surface runoff

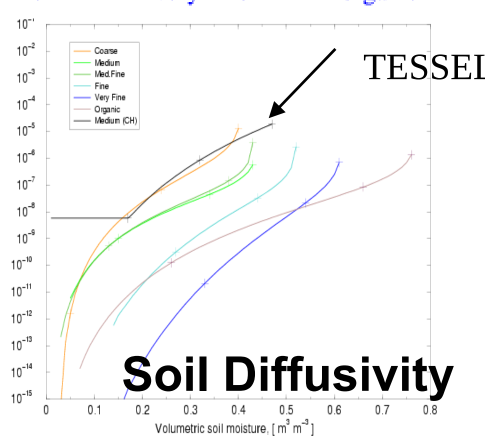
Inhibited root extraction, or drainage in frozen soils

HTESSEL a new soil hydrology (11/2007)

•6 Dominant soil texture from DSMW2003 are used to assign hydraulic properties (for drainage and surface runoff) characterizing different soil water regimes.



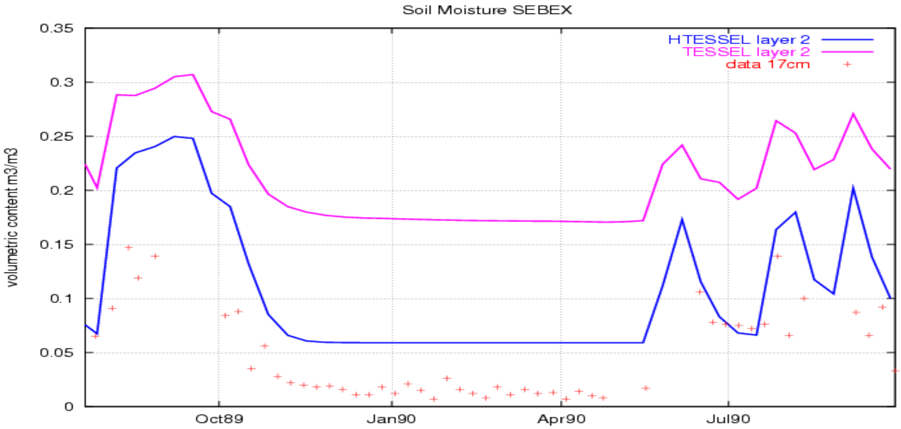


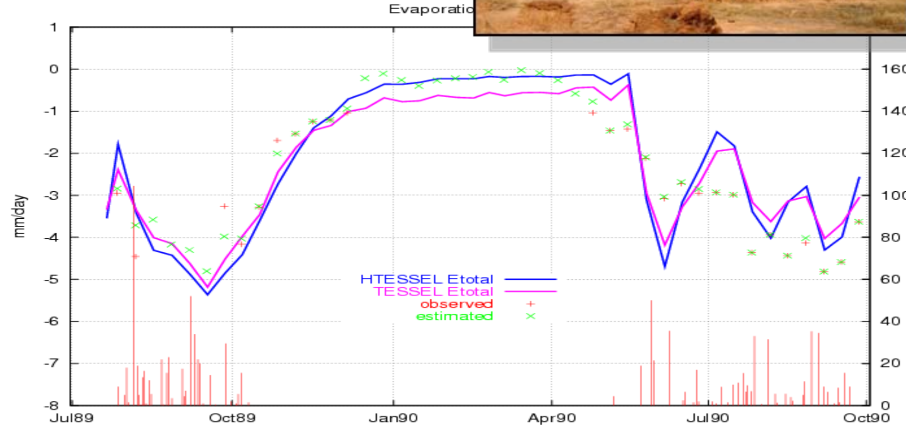


TESSEL	Soil	PWP [m³/m³]	FC [m³/m³]
1	Loamy	0.171	0.323
HTESSEL	**Soil**	**PWP [m³/m³]**	**FC [m³/m³]**
1	Coarse	0.059	0.242
2	Medium	0.151	0.346
3	Medium -fine	0.133	0.382
4	Fine	0.279	0.448
5	Very fine	0.335	0.541
6	Organic	0.267	0.662

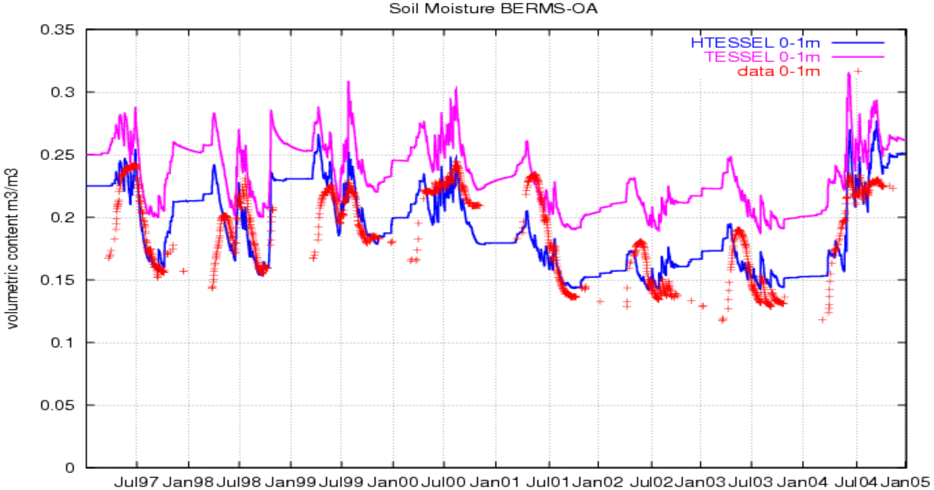
Improved match to soil moisture while preserving evaporation

SEBEX (Savannah, Sandy soil)





BERMS (Boreal Forest)

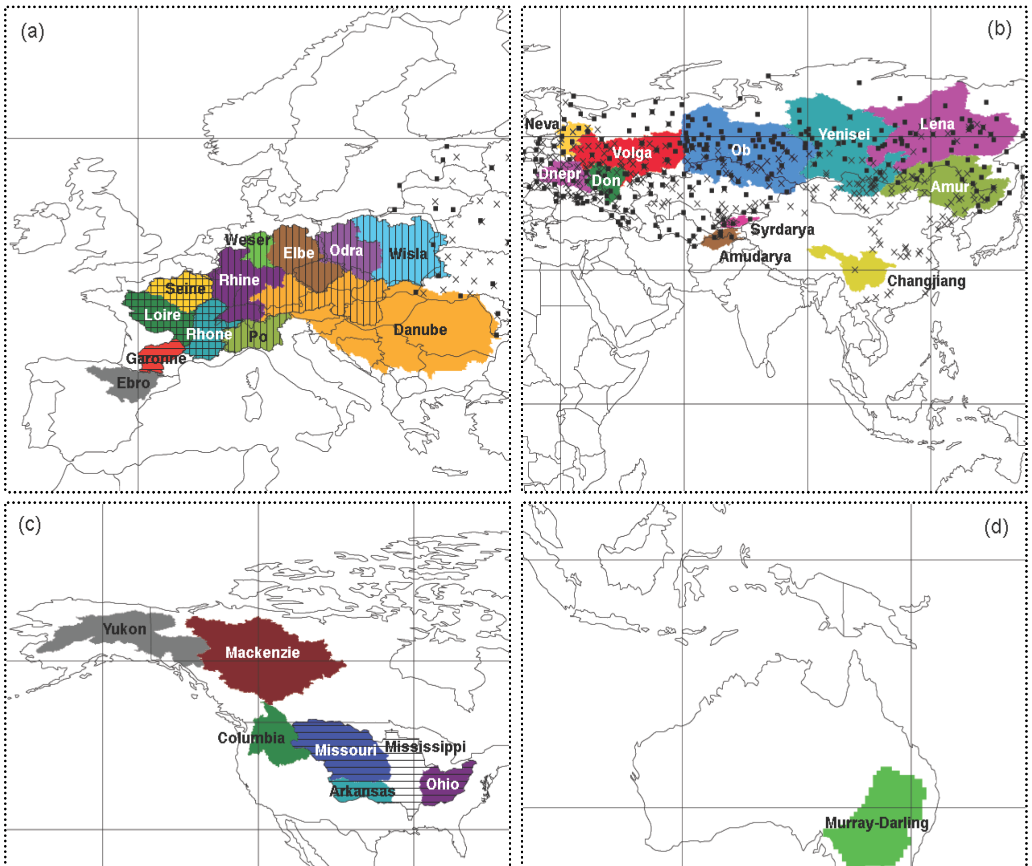


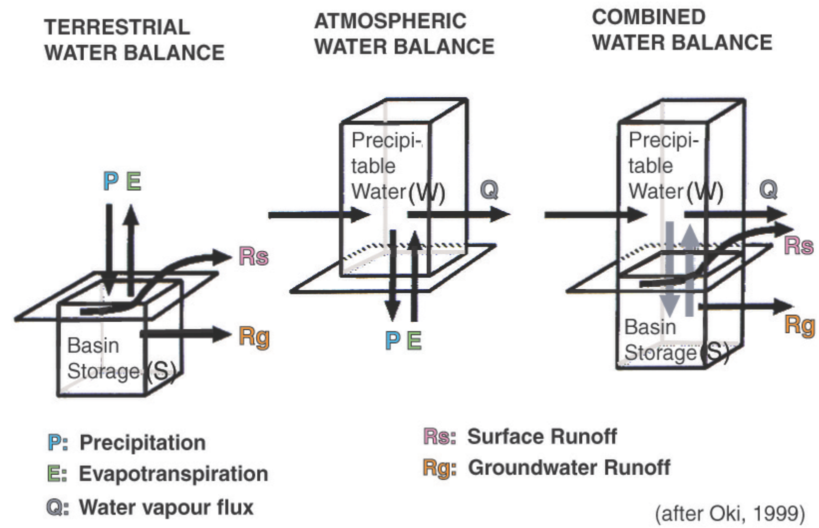
HTESSEL improves soil moisture and marginally evaporation with respect to TESSEL in dry climates and leads to a better represented soil moisture inter-annual variability in continental climate

Global Water budget: Re-analysis and Mid-latitude River discharges combined for land water storage

GSWP2 offline runs and ERA-40 can be informative about the large scale hydrology

“BSWB”





$$\frac{\partial S}{\partial t} = -\nabla_H \vec{Q} - \frac{\partial W}{\partial t} - R$$

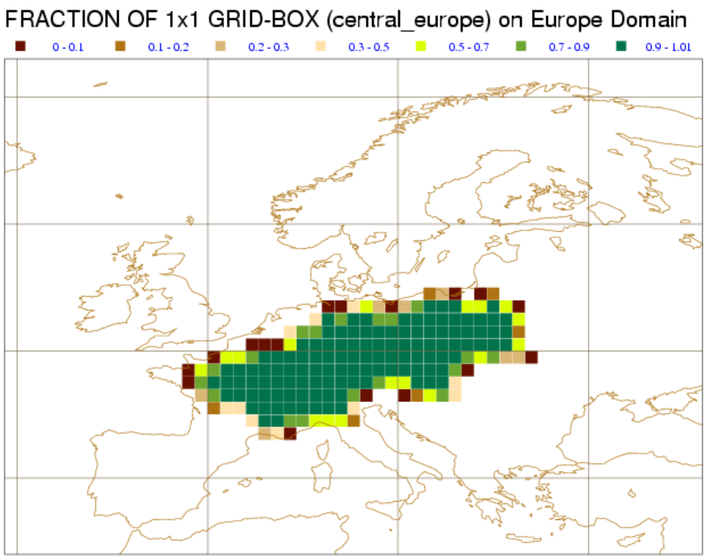
Courtesy of Sonia Seneviratne

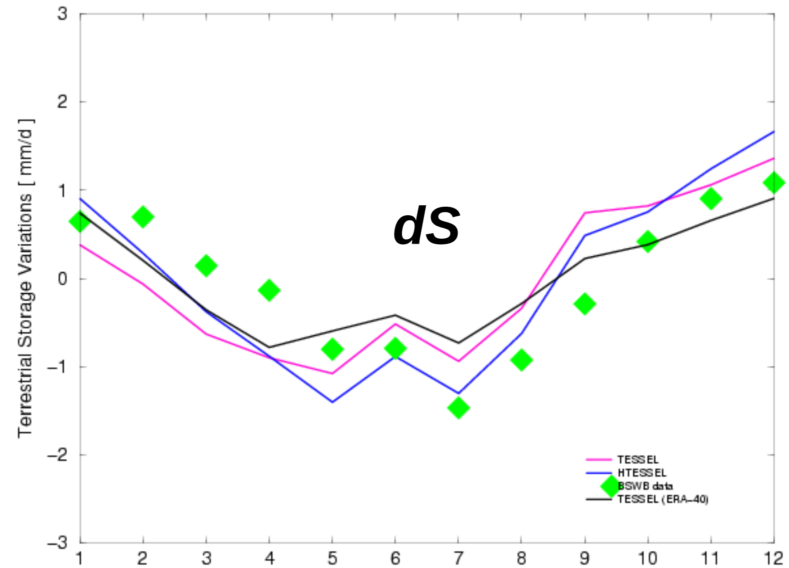
Seneviratne et al. 2004, J. Climate, 17 (11), 2039-2057
Hirschi et al. 2006, J. Hydrometeorol., 7(1), 39-60

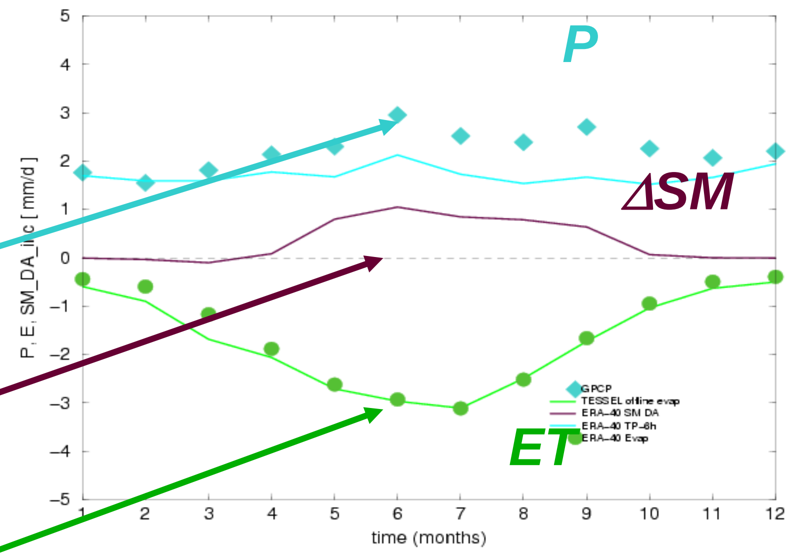
http://iacweb.ethz.ch/data/water_balance/

ECMWF

European catchments: Validation using ERA-40 derived BSWB (Basin Scale Water Budgets)

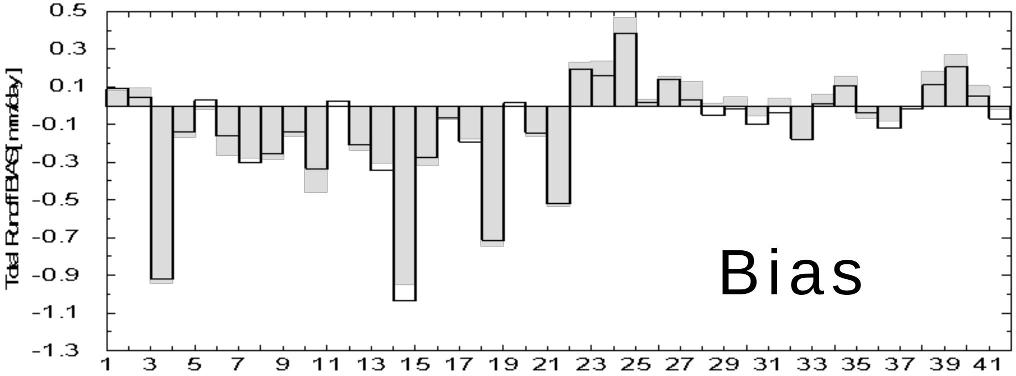


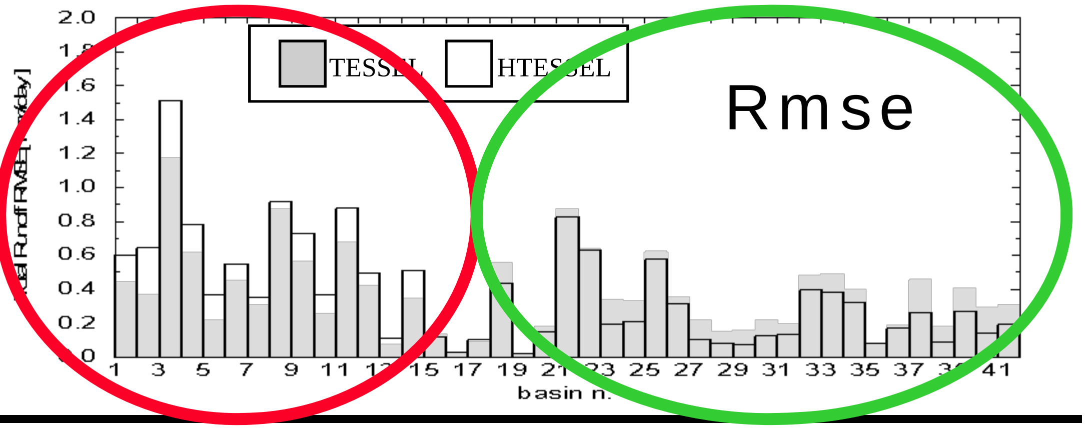


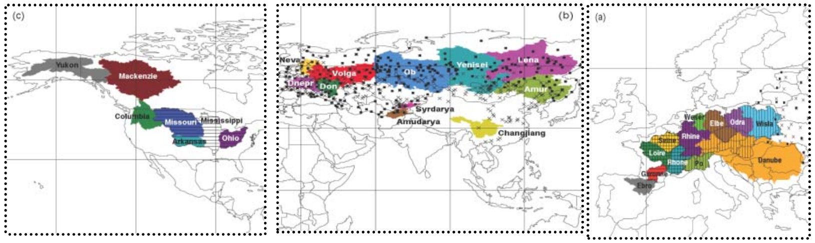


- ***HTESSEL* increases the storage w.r.t. *TESSEL*, closer to Annual variations estimated by the *BSWB* dataset**
- ***TESSEL is better in offline driven runs than in ERA-40 due to P6h bias (spinup) over Europe***
- ***DA works efficiently to correct soil moisture by adding water and preserving evaporation***

Monthly river runoff

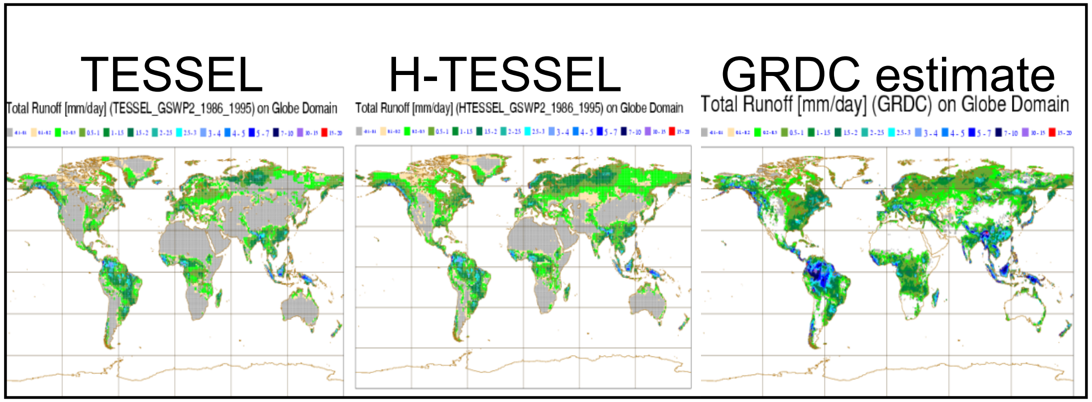






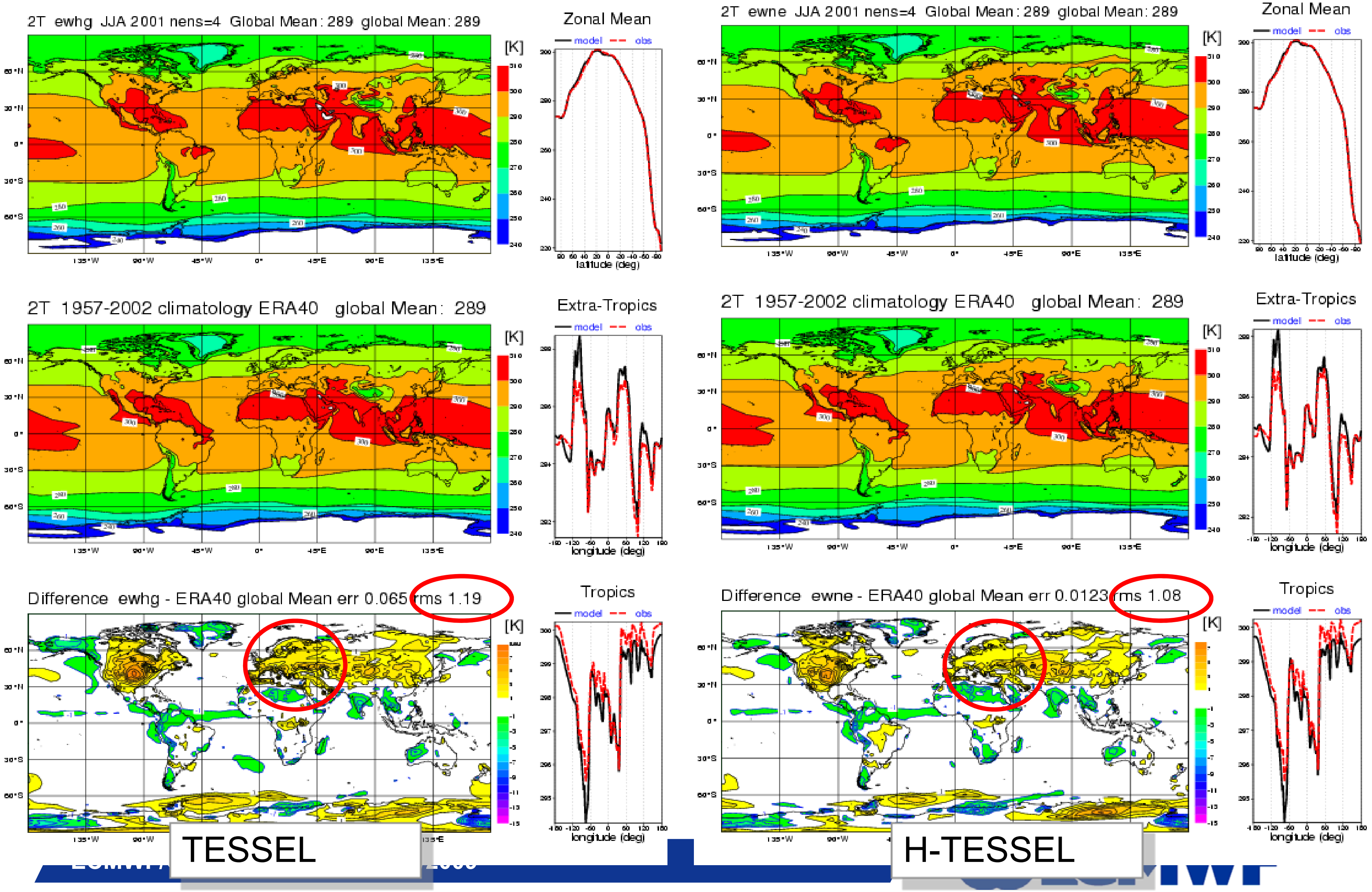
List of basins considered for the runoff verification

N. Basin		N. Basin
1 Ob	22 Volga	
2 Tura		23 Don
3 Tom		24 Dnepr
4 Podkamennaya-Tunguska		25 Neva
5 Irtish		26 Baltic
6 Amudarya		27 Elbe
7 Amur		28 Odra
8 Lena		29 Wisla
9 Yenisei		30 Danube
10 Syrdarya		31 Northeast-Europe
11 Yukon		32 Po
12 Mackenzie		33 Rhine
13 Mississippi		34 Weser
14 Ohio		35 Ebro
15 Columbia		36 Garonne
16 Missouri		37 Rhone
17 Arkansas		38 Loire
18 Xhangjiang		39 Seine
19 Murray-darling		40 France
20 Selenga		41 Central-Europe
21 Vitim		



HTESSEL improves river runoff (qualitatively and quantitatively) on major World river basins where the soil control is dominant. Snow errors still affect runoff at Northern latitudes.

“Climate run” (1-year AMIP-type run): surface T2m compared with analysis

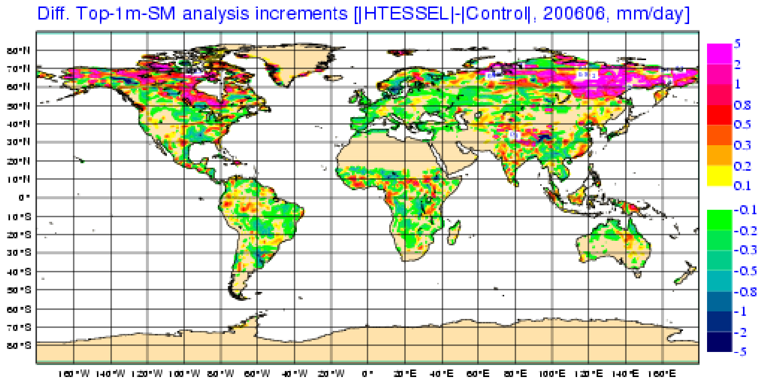


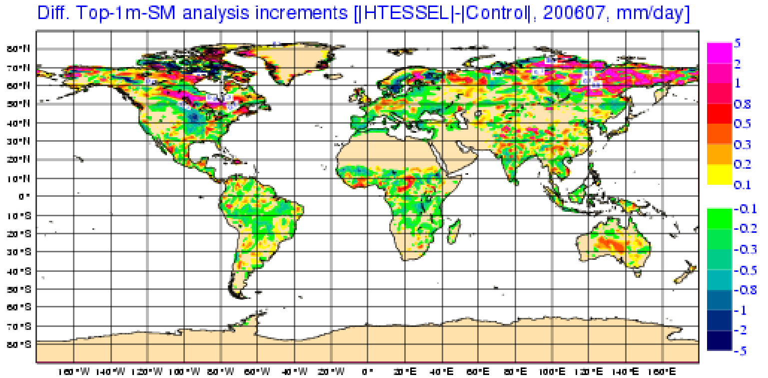
Long DA cycle with HTESSEL

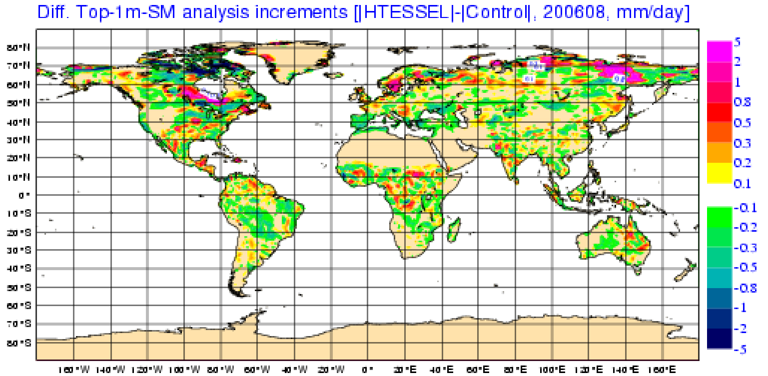
- ***A long DA experiment at T159L91 is done with TESSEL and HTESSEL (01/04-01/11/2006)***

- ***Differences in soil moisture analysis increments can be interpret as improvements of the slow model component***

  - **|ΔSM(HTESSEL)| > |ΔSM(TESSEL)|**
  - **|ΔSM(HTESSEL)| < |ΔSM(TESSEL)|**







Motivations for a snow scheme revision

- The operational snow scheme was originally based on the scheme proposed by Douville et al. (1995)
- Where did we see problems related to snow in ECMWF products?
  - In re-analyses systematic increments (both in ERA-40 and ERA-Interim)
  - In NWP, Albedo effect (associated to precipitation errors and to rapid spring melting)
  - Thermal insulation effects (soil too cold in Boreal regions, Beljaars et al. 2007)
  - “Piling effect” (isolated snow-fall e.g. UK Jan2009) melts too slowly
  - Water cycle (Snow/Soil moisture interplay for Northern latitudes)
- SNOW-MIP2 (Rutter et al. 2009, Essery et al. 2009) show some clear limitations of the operational snow scheme

A new snow model (09/2009)

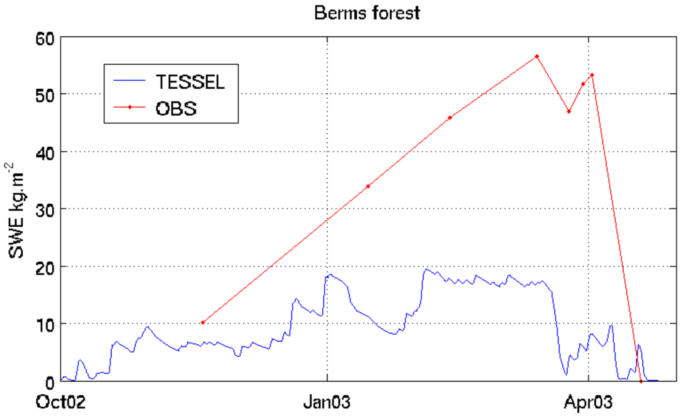
Dutra et al. (2009, in preparation) see the poster

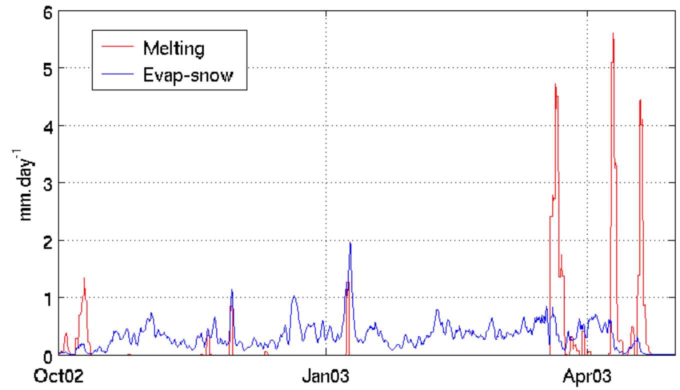
- **Between CY35R2 and CY35R3 the snow scheme has been fully revised according to Dutra et al. (2009 JHM)**
  - **Collaboration with Emanuel Dutra, Pedro Viterbo, Pedro Miranda and Christoph Schaer provided the framework. Tests were performed within EC-Earth and IFS (in parallel).**
- **Vegetation-dependent roughness (CY31R2)**
- **Permanent snow albedo retuning (CY35R1)**
- **Liquid water in the snow-pack (CY35R2)**
- **Snow density (CY35R2)**
- **Interception of rainfall (CY35R3)**
- **Forest-Snow albedo (CY35R3)**
- **Open-area snow albedo (CY35R3)**
- **Snow fraction (CY35R3)**

Operational at ECMWF since September 2009

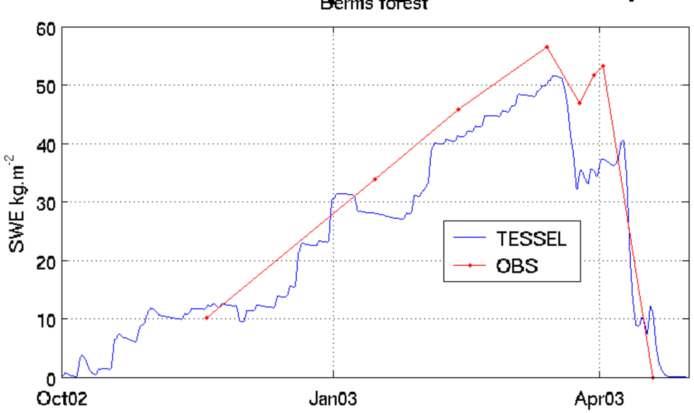
Impact of roughness changes: SnowMIP2

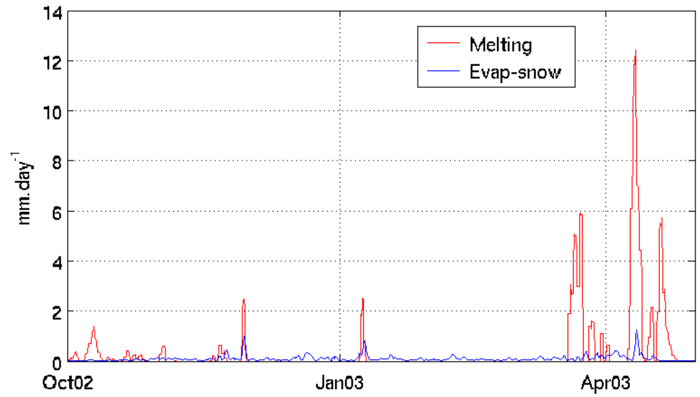
30R1 (5°x5° degree Z0m from Baumgartner et al. 1977**)**





32R1 (vegetation dependent Z0m, Z0h, Beljaars et al. 2007**)**





- Roughness length is key in forest+snow sites is effective on sublimation (via aerodynamic resistance

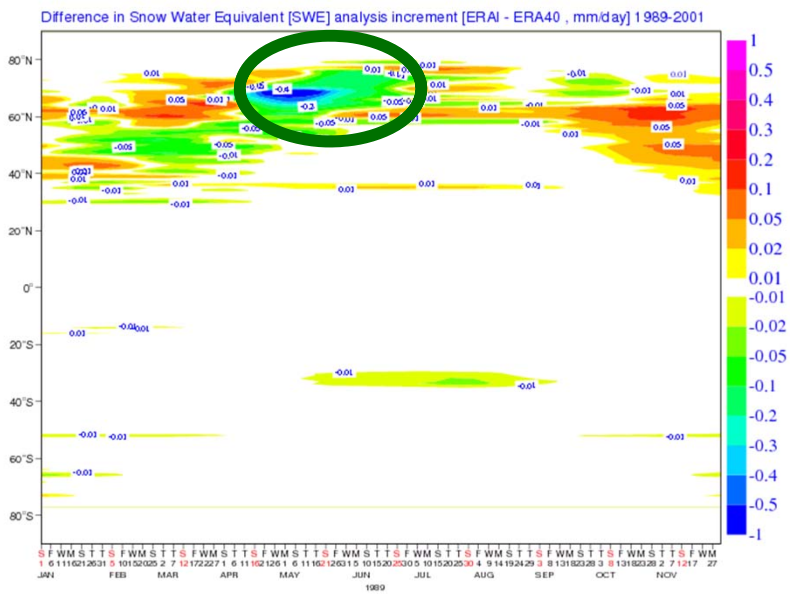
$z_{0m}\downarrow\ u^*\downarrow\ r_a\uparrow$

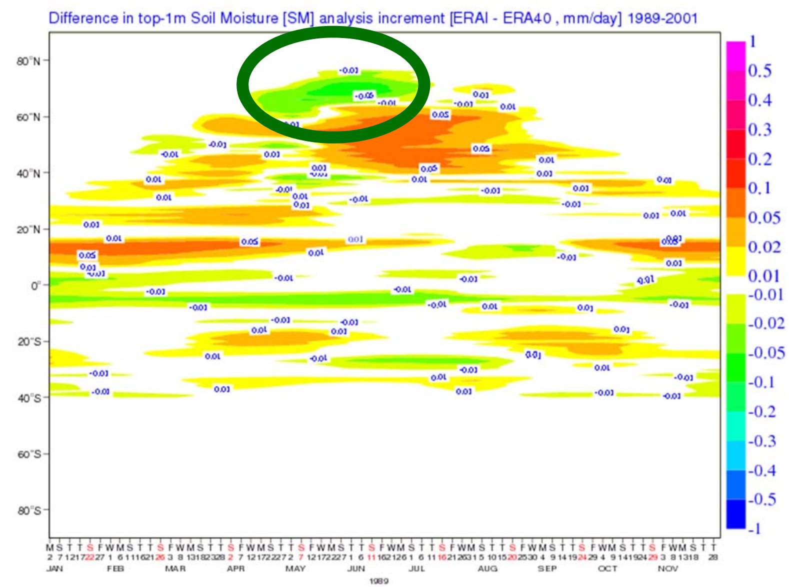
$z_{0h}\downarrow\ \ln(z/z_{0h})\uparrow\ r_a\uparrow$

Land SM/SWE errors: ERA-40 vs. ERA-I

- **Differences of ERA-Interim (vs. ERA-40) SWE analysis increments show an improvement in Spring.**

Snow



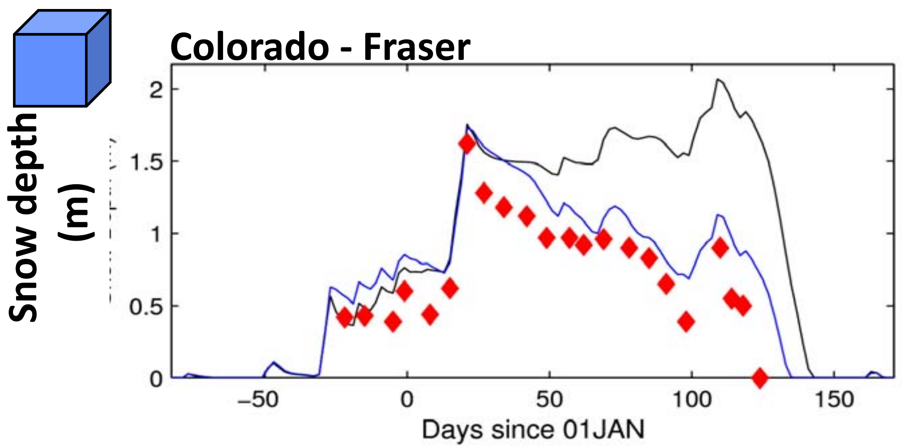


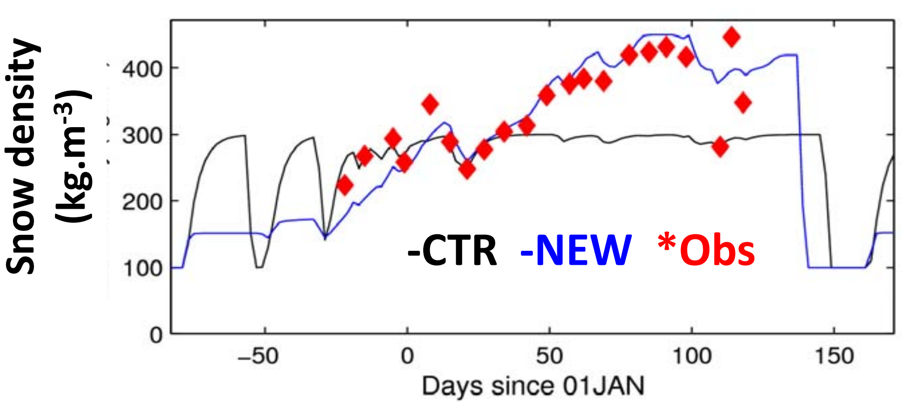
SM

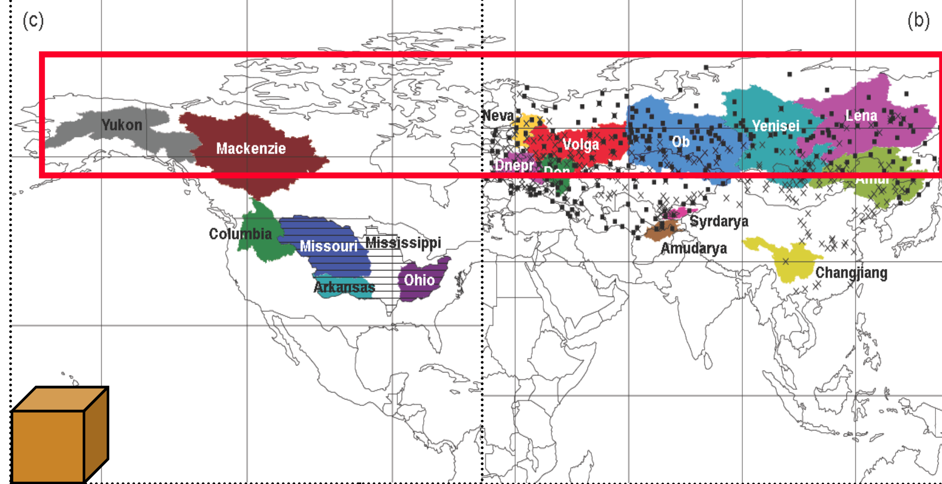
Impact of new snow (SnowMIP2/GSWP2)

Dutra et al. (2009 in preparation)

- **The snow-MIP2 runs showed improved snow depth/density**
- **GSWP2 runs an improved runoff**



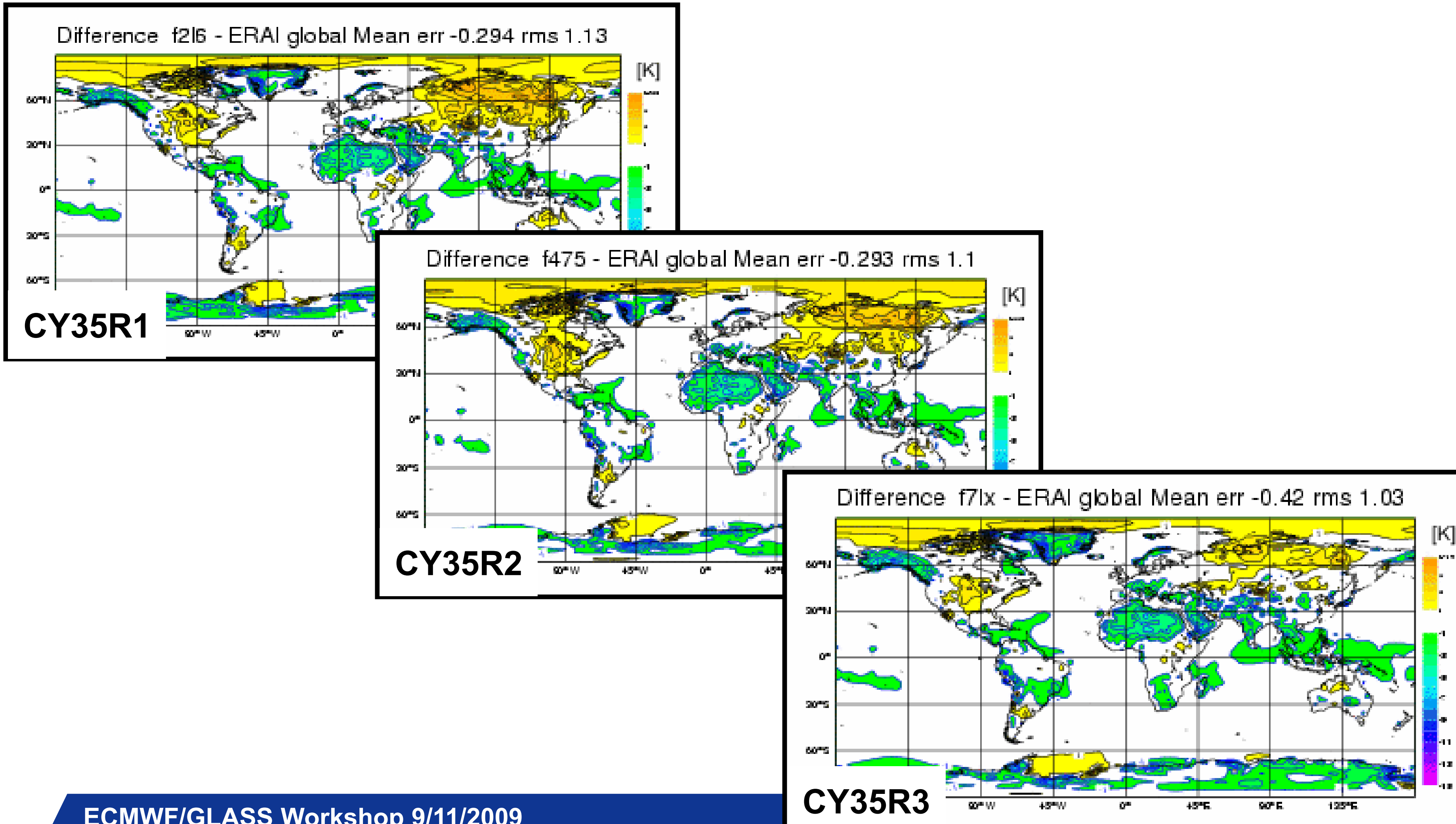




NH BASINs	Average of Yukon, Podka., Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtish, Neva
Area	12 334 161 km^2
Snow Days	157
Runoff	1.96 mm/day
CTR RMSE (GRDC)	0.75 mm/day
NEW RMSE (GRDC)	0.51 mm/day

“Climate runs” with the new snow

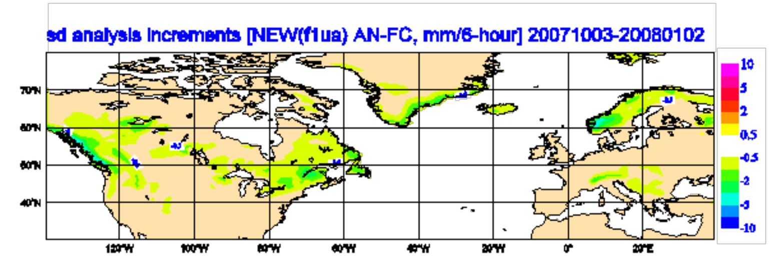
- **The annual mean T2m bias (13-month 4-member hindcasts) is reduced in snow-areas**

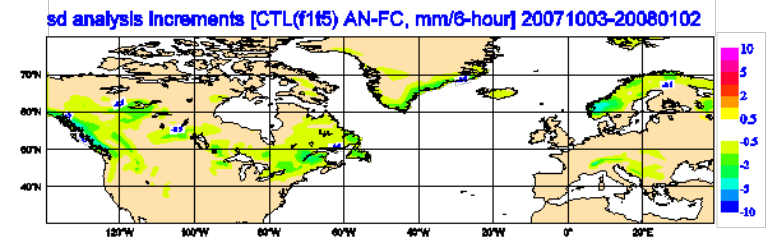


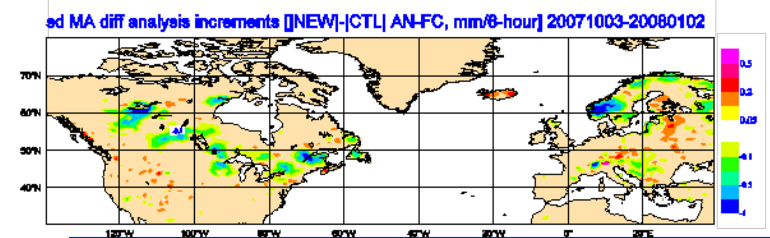
Long data assimilation experiment (ERA-Interim setup)

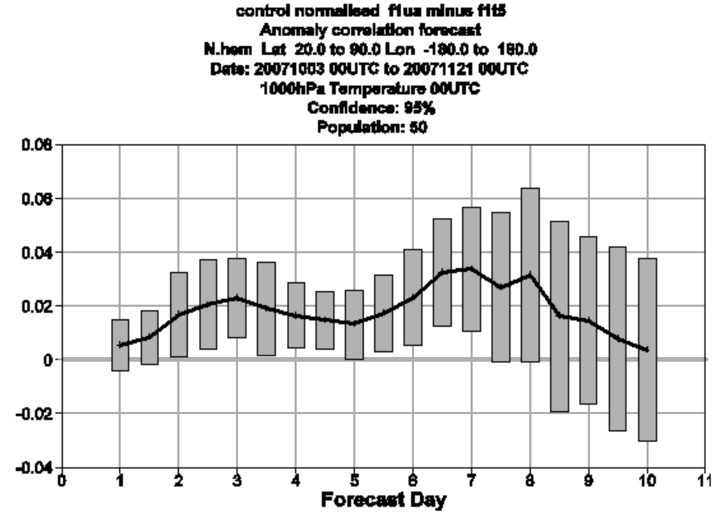
T255L91 4D-VAR 7-months (Oct'07-Apr'08)

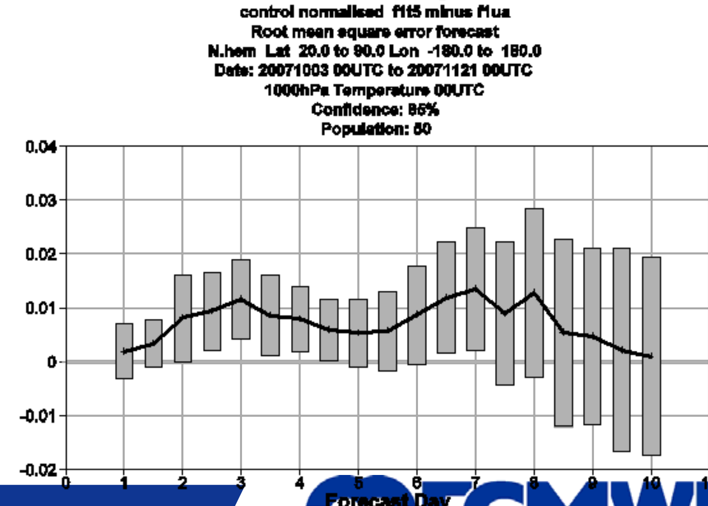
Snow Analysis increments and 10-day NH forecast issued (T1000 hPa)











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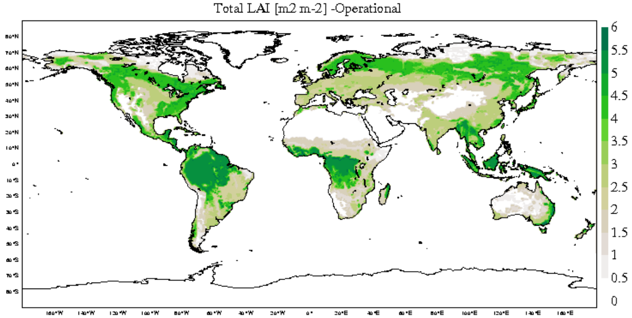
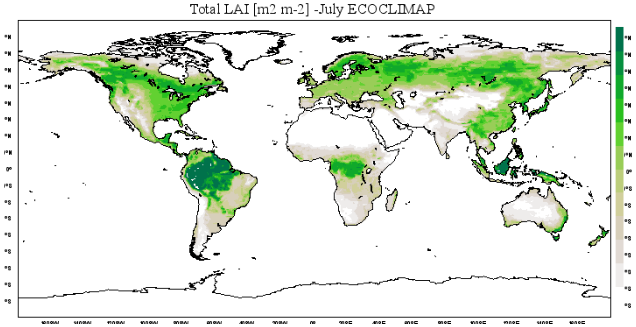
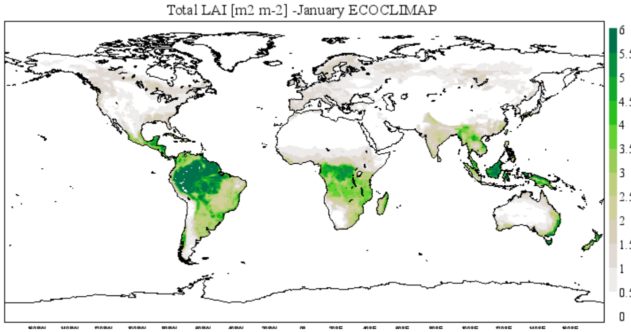
Vegetation Seasonality

OPER LAI (van den Hurk et al. 2000)



ECOCLIMAP LAI (Masson et al. 2003)



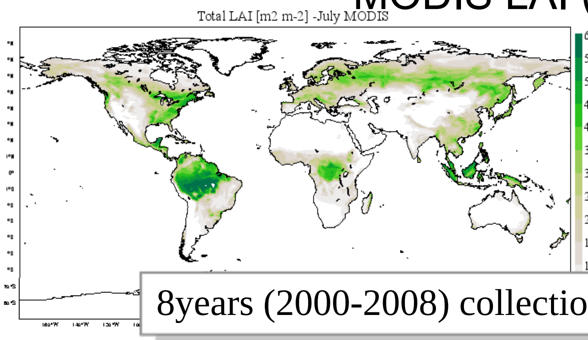


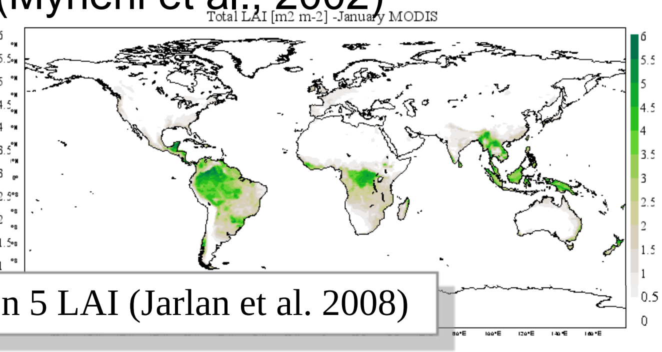
Study Started with the project GEOLAND 2004-2007 and ongoing within GEOLAND-2 2009-2012

Goal: Add the land surface carbon cycle to HTESSEL.

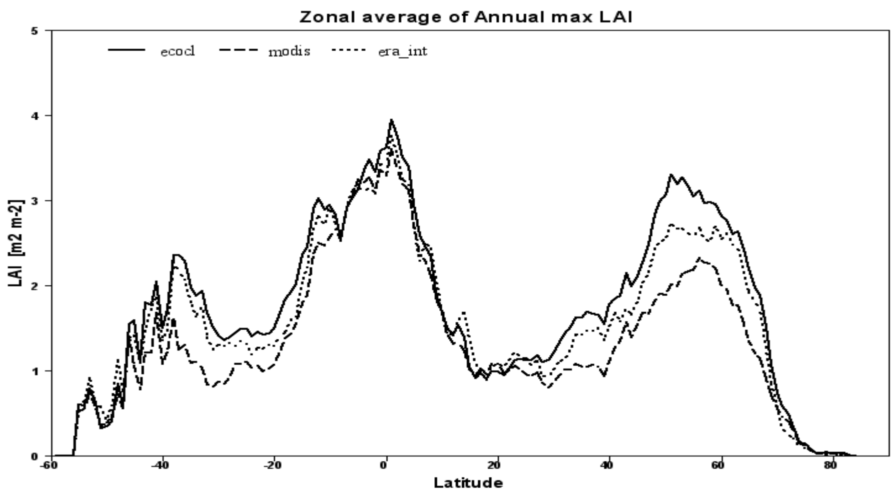
See poster by Calvet et al.

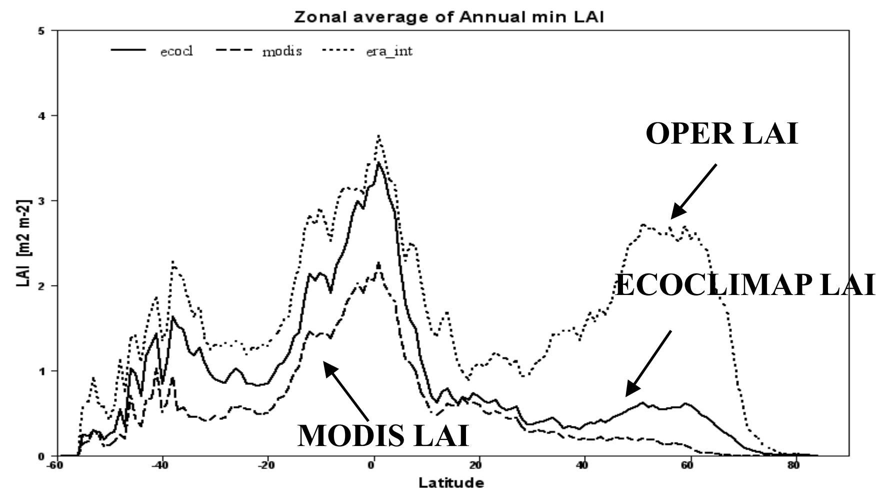
MODIS LAI (Myneni et al., 2002)





8years (2000-2008) collection 5 LAI (Jarlan et al. 2008)

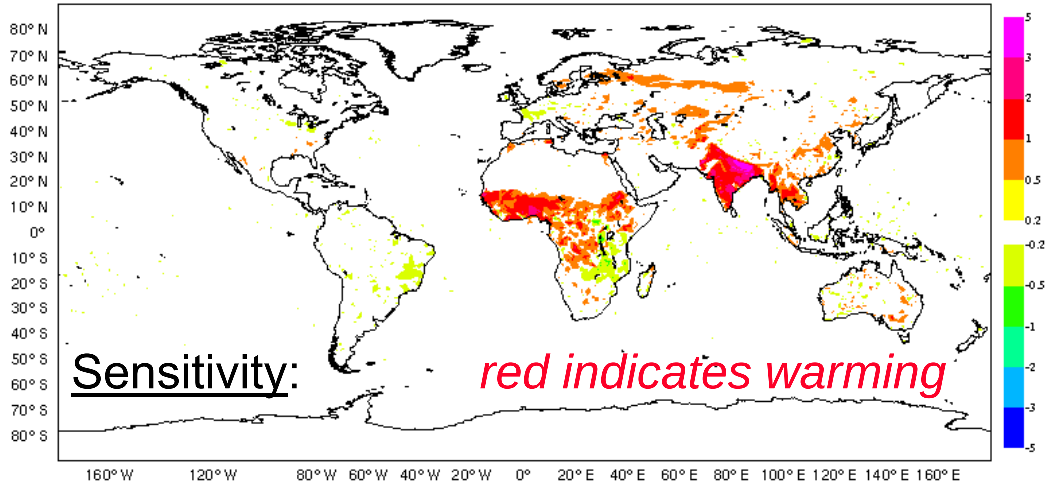




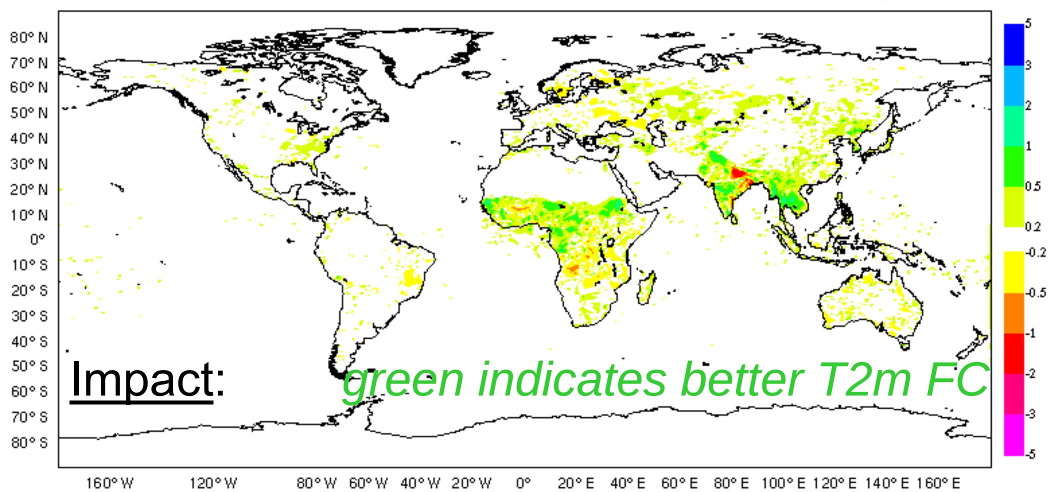
Vegetation Seasonality: sensitivity

Boussetta et al. (2009, in preparation), collaboration with EC-Earth

2T difference [CY35R2_LAI(f77h)-CY35R2_CTL(f75p), FC+36 valid 12 UTC, K]MAM 2008



2T error [abs(CY35R2_CTL(f75p)-analysis)-abs(CY35R2_LAI(f77h)-analysis), FC+36 valid 12 UTC, K]MAM 2008



GEOLAND-2 activities

- **ECOCLIMAP/MODIS LAI seems to introduce a consistent warming seen in FC36h (12UTC)**
- **This is due to reduction of LAI in spring, which increases the vegetation resistance to ET.**
- **Less LE and more H**

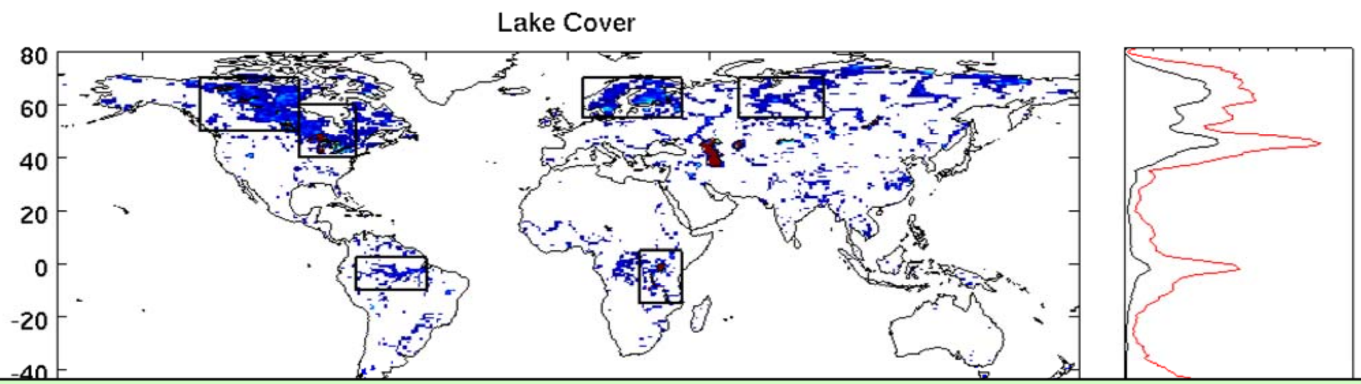
If *LAI* ↓ then r_c ↑ and *E* ↓ so *T2m* ↑
If *LAI* ↑ then r_c ↓ and *E* ↑ so *T2m* ↓

- **This has beneficial impact on near surface temperature forecast (green being positive impact in reducing t2m bias by ~0.5degree)**
- **A stepping stone to include carbon modelling (CTESSEL)**

ECMWF

Lake offline modelling

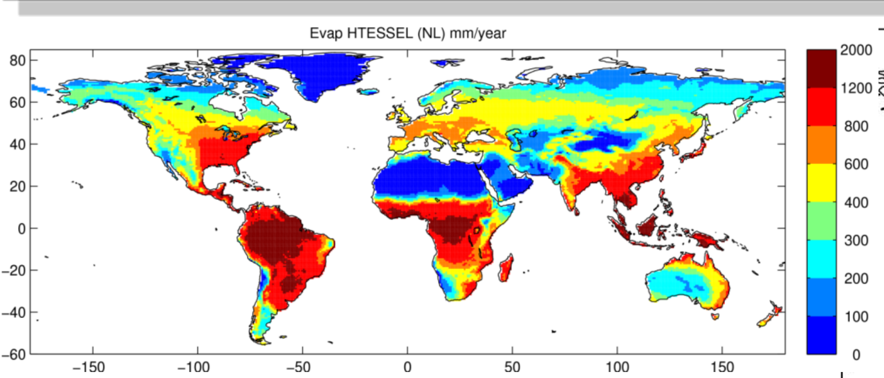
Dutra et al. (2009), Balsamo et al (2009), *Boreal Env. Res.*

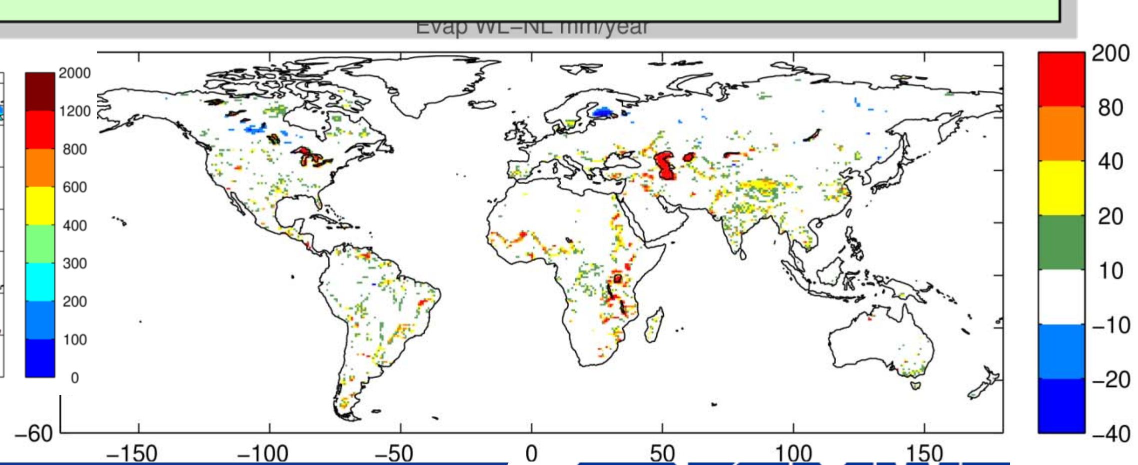


- FLAKE Lake model is implemented in CY35R3.
- Evaporation rates are greatly increased in temperate climate

This studies have been using ERA-Interim 1989-present as a 3-hourly forcing dataset to test the introduction of lakes in HTESSEL in offline mode (similarly to GSWP-type experiment).

This makes possible to compare land surface models output with recent satellite data in particular MODIS-based lake surface temperatures available from 2000.

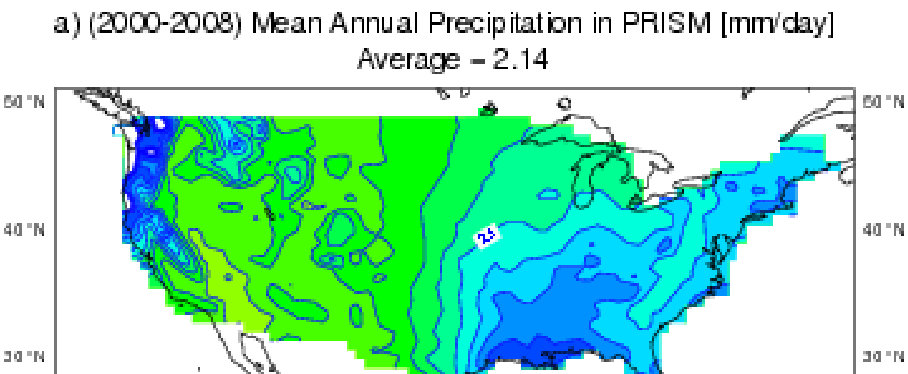


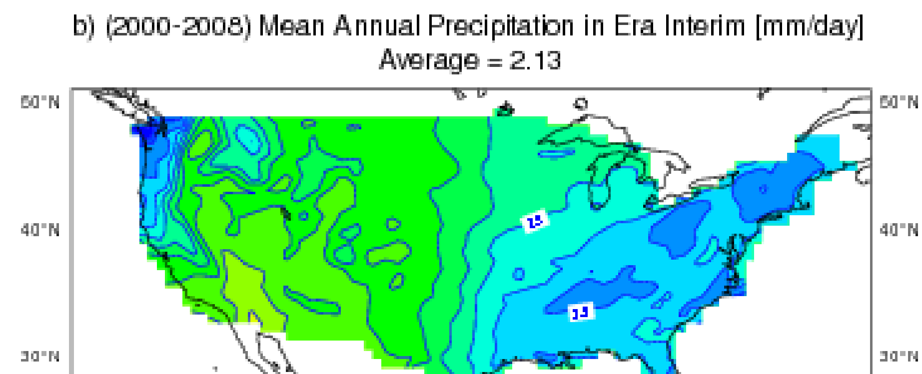


ECMWF

ERA-Interim in support of a GSWP-type model intercomparison?

- GSWP2 has been (and still is, e.g. GLACE2) a great initiative for modellers.
- What is the value of modern era re-analysis for this purpose?
- ERA-I covers 1989-present (3-hourly with 0.7^o resol.) and it is ongoing!
- Can we base reliably on precipitation by ERA-I for land surface applications?





ERA-Interim in the extra-tropics has comparable quality to GPCP products (here it is verified for the US where it is in between GPCP V2.0 & V2.1) and high temporal and spatial resolution that make it suitable for offline land surface modelling with the advantage to reach NRT.

	GPCP V2.1	ERA-I	GPCP V2.0
BIAS	0.081	-0.013	-0.068
RMSE	0.675	0.852	0.889
Correlation	0.899	0.853	0.816

Table: Average of 2000-2008 monthly BIAS, RMSE (mm/day) and correlation coefficient with respect to PRISM (USDA) precipitation dataset.

OUTLINE

- Introduction
  - Land surface focus in NWP: from fluxes-only to fluxes&water storage?
  - Role of land surface in the ECMWF model
  - Where do we see land surface related errors in NWP?
- The land surface model:
  - The soil hydrology revision
  - The new snow scheme
- A quick look ahead
  - vegetation seasonality
  - water bodies (work in progress)
- Summary and conclusions
- Foreseen challenges

Conclusions

- **Reanalyses are a fundamental source for modellers for improving the understanding of land-atmosphere interactions and for identifying problematic areas (that need RD).**
- **Soil & Snow hydrology have been revised in ECMWF model, validated at several spatial and temporal scales (thanks to collaborations with EC-Earth institutions) and confirmed by NWP impact!**
- **Soil water and snow reservoirs are linked and a correct representation in models is important for timing fresh-water recirculation and for governing the strength of land surface-atmosphere feedbacks.**
- **"Better" physics for land surface processes in global models can be achieved in a step-wise procedure where core RD is done on sites and regional-global experiments (e.g. WATCH, WaterMIP, SnowMIP, AMMA-ALMIP, RhoneAgg, GSWP2, PILPS, …)**
- **Generality of the results is obtained with higher computational cost involving atmospheric runs and DA exps. This is a necessary step!**
- **Land surface is characterized by long memory and that puts strong emphasis on the initial condition and on development of LDAS.**
- **Multi-variate land data assimilation of EO data will highlight further model shortcomings (will SMOS/ASCAT forgive our over-simplified treatment of Vegetation and Lakes?)**

Foreseen challenges (at ECMWF)

- **New higher resolution models will allow more detailed representation of the land surfaces to a level that present-day GCMs aren't considering.**
  - **Which model area suffers the most from "over-simplified" parameterizations?**
  - **How to balance complexity & technical feasibility?**
- **Cold versus warm processes:**
  - **where to put research efforts?**
- **Diurnal cycle issue: it is a delicate balance between radiation, clouds atmospheric vertical-diffusion and soil properties.**
  - **How many (soil/snow) layers should have ideally a land surface model?**
- **Can we do anything better than "tiling"?**
  - **Is "nesting" viable? Which land resolution is supported by today EO data?**
- **How can we integrate carbon and vegetation modules into NWP?**
  - **Is full-feedback a good strategy?**

…*we can expect that bigger challenges will come from the unforeseen***…**

THANK YOU FOR YOUR ATTENTION, QUESTIONS AND COMMENTS!