Land Surface Modelling and Data Assimilation at ECMWF

Gianpaolo Balsamo, Anton Beljaars, Sebastien Lafont, Matthias Drusch, Lionel Jarlan, Klaus Scipal

ECMWF

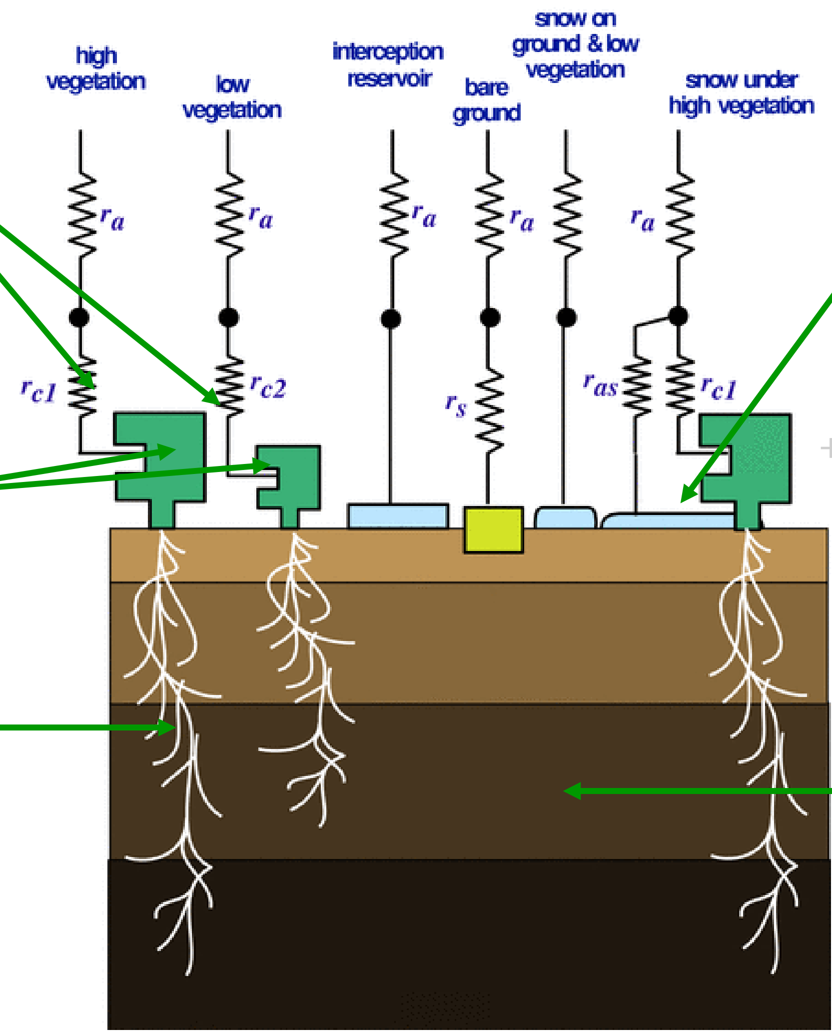
Outline

- **Modelling activities**
  - Current status
  - Improved hydrology (H-TESSEL)
  - Carbon cycle (C-TESSEL)
  - Offline Surface Model (OSM)
  - Validation of model changes (1-d, 2-d, 3-d, DA experiments)
- **Data assimilation activities**
  - Current status
  - Observation availability (screen-level T, RH, L-band, C-band, IR, SM and LAI products)
  - Observation operators (RTM, matching techniques)
  - ELDAS implementation (Soil moisture)
  - Offline data assimilation (LAI)
  - Cost considerations
- **Summary and conclusions**

TESSEL scheme

- Tiled ECMWF Scheme for Surface Exchanges over Land

Land surface tiles in ERA40 surface scheme



+ 2 tiles (ocean & sea-ice)

Revised canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

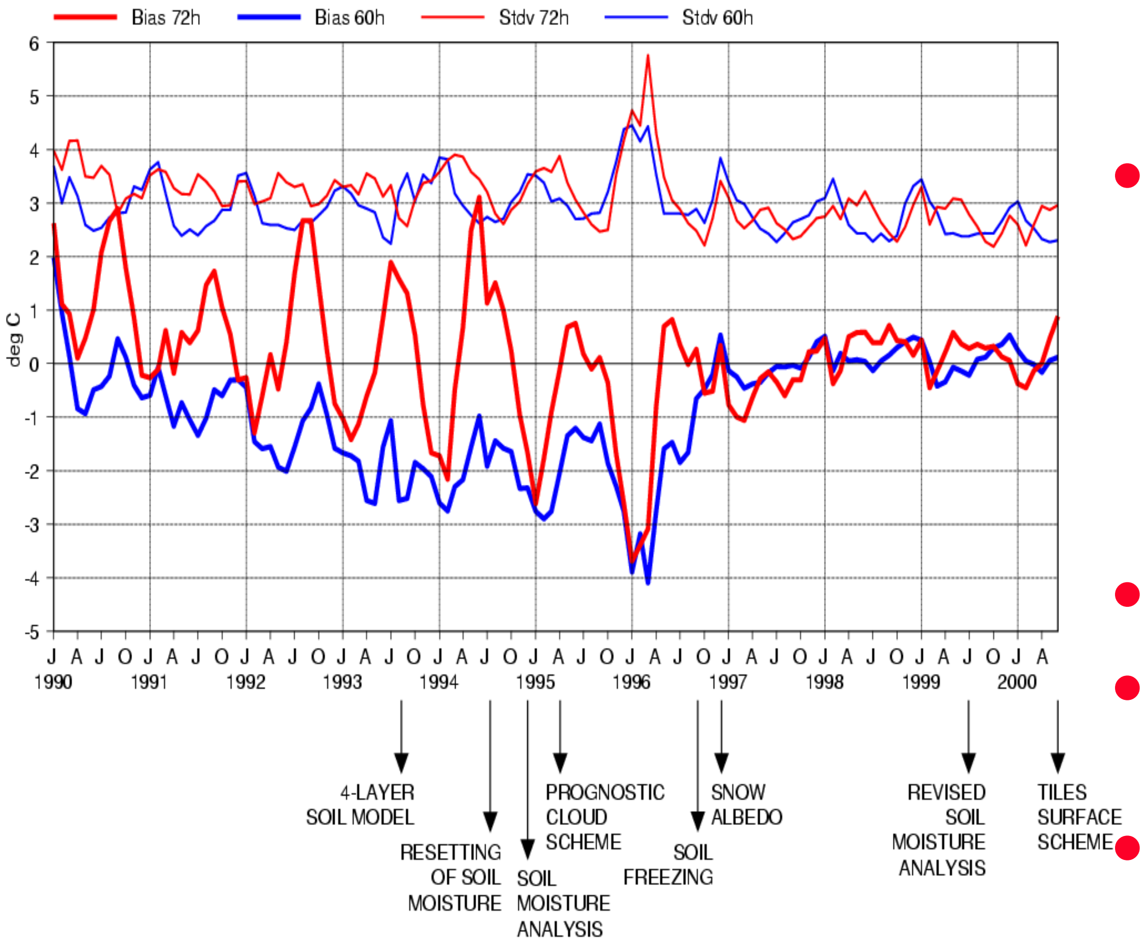
Variable root depth

New treatment of snow under high vegetation

Inhibited root extraction, or drainage in frozen soils

TESSEL scheme (II)

History of ECMWF 2m T errors



- **The set of parameterisations composing TESSEL allow to provide accurate surface fluxes**
- **Possible improvements are related to slow processes:**
  - -Simple hydrology with a single soil texture globally
  - -Little surface runoff and large drainage
  - -Fixed annual leaf area index (and no carbon cycle)
- **1d site run (e.g. sandy soils)**
- **NWP forecast are not affected also thanks to land surface DA.**
- **Errors show up as persistent DA increments (indicating a bias)**

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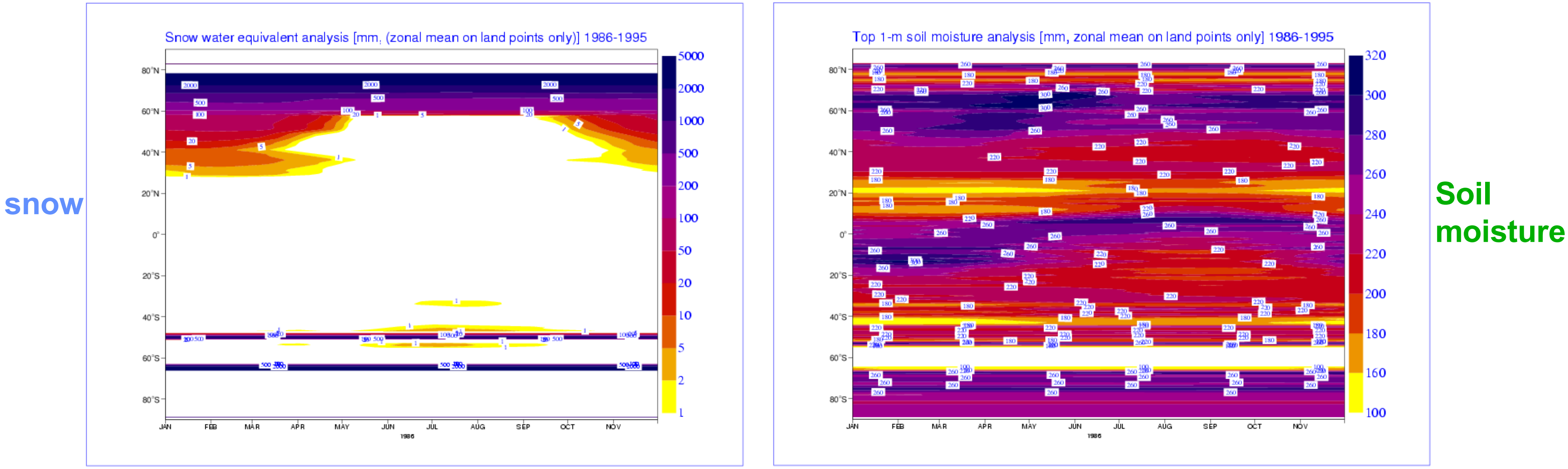
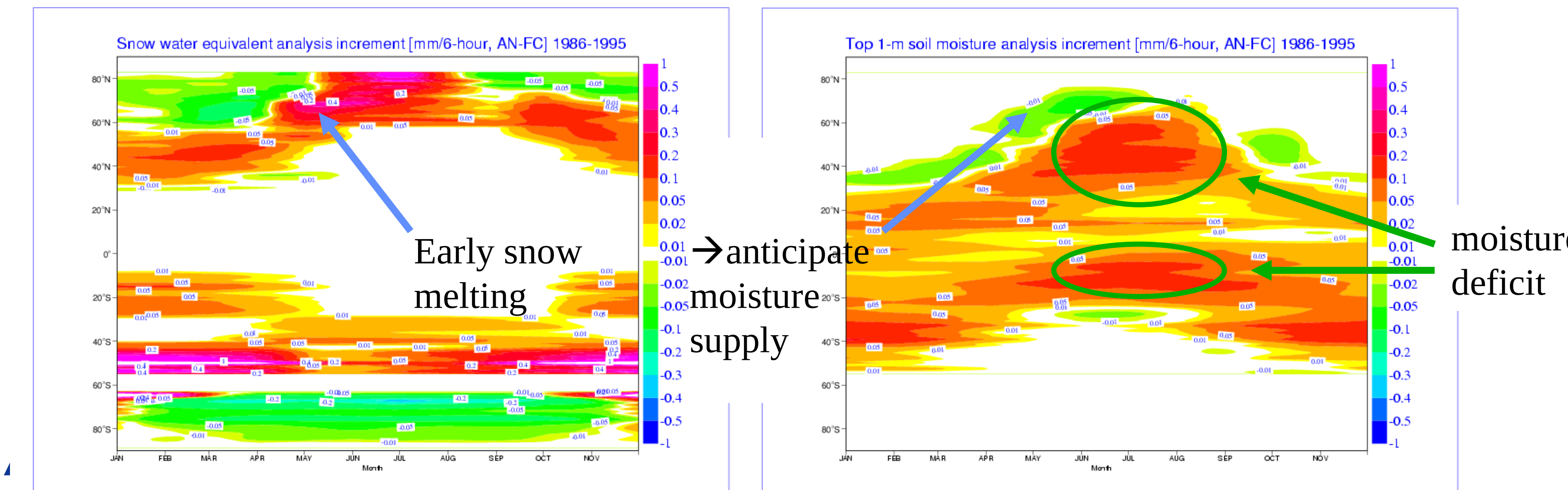
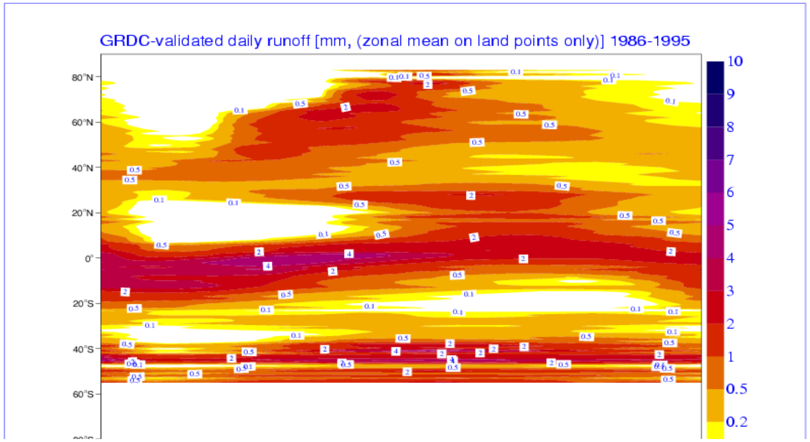
Surface Water reservoirs from ERA-40

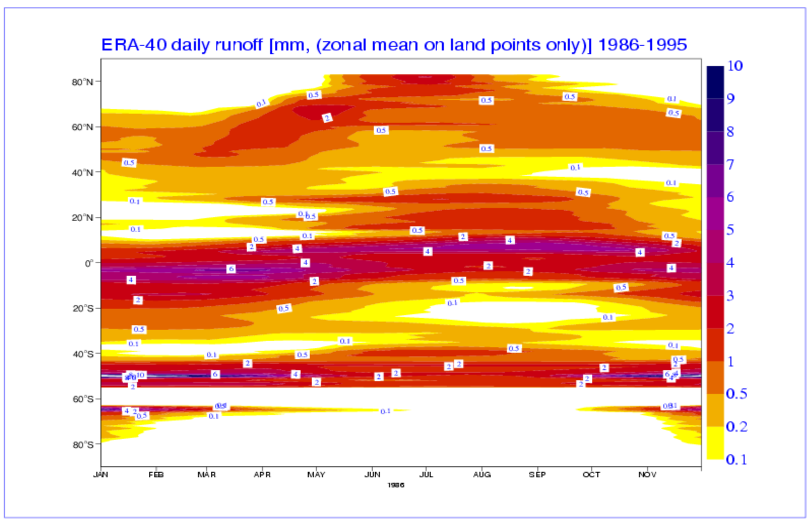


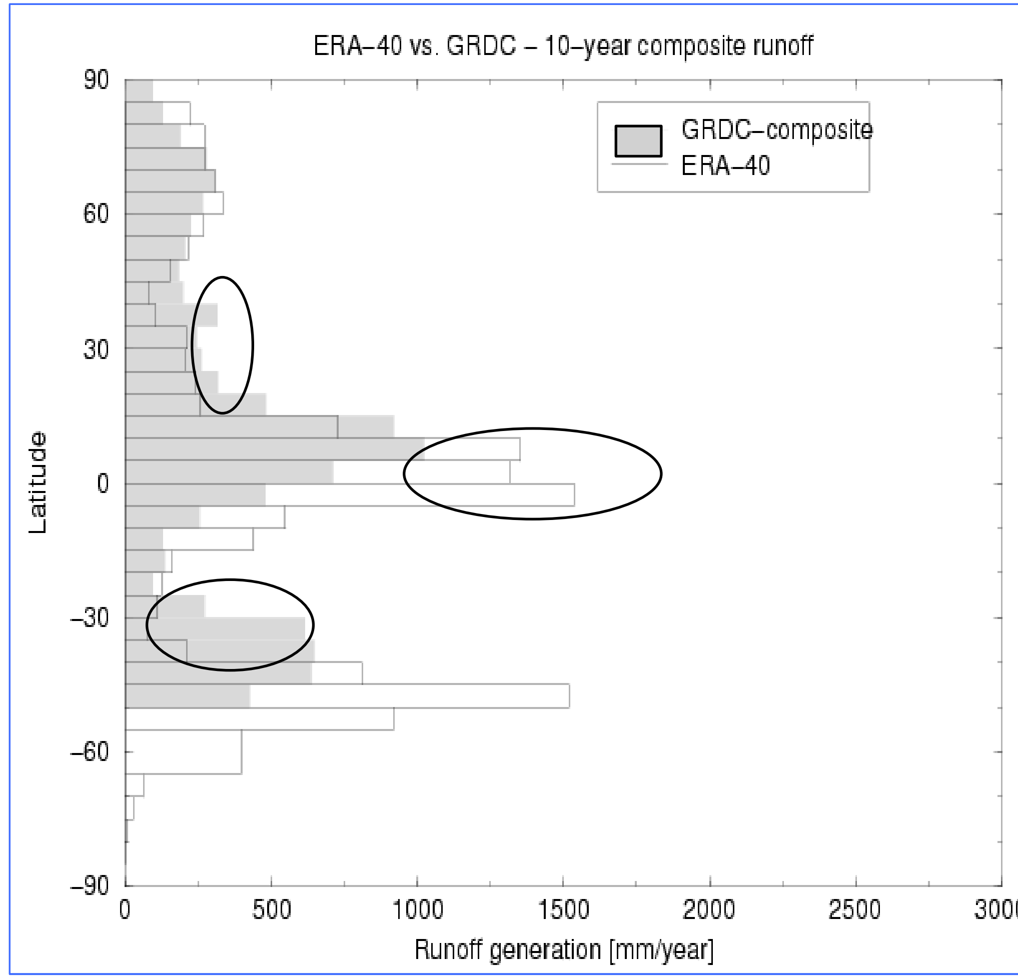
- DA increments redistribute water and constraint near-surface errors



Total Runoff : ERA-40 vs. GRDC







GRDC runoff is calibrated on 1347 discharge gauging station

A revised hydrology scheme (H-TESSEL)

- A spatially variable hydrology scheme is being tested following Van den Hurk and Viterbo 2003
- Use of a the Digital Soil Map of World (DSMW) 2003
- Infiltration based on Van Genuchten 1980 and Surface runoff generation based on Dümenil and Todini 1992

$$w(h) = w_r + \frac{w_{sat} - w_r}{(1+\alpha h)^{1-1/n}}$$

$$K(h) = K_{sat} \frac{\left[(1+\alpha h^n)^{1-1/n} - \alpha h^{n-1}\right]^2}{(1+\alpha h^n)^{(1-1/n)(\lambda+2)}}$$

Table 1: Soil type specific Van Genuchten coefficients

Parameter	Symbol	units	Texture class: Coarse	Medium	Medium -fine	Fine	Very fine
Saturation soil moisture content	w_{sat}	m^3/m^3	0.403	0.439	0.430	0.520	0.614
Residual soil moisture content	w_r	m^3/m^3	0.025	0.010	0.010	0.010	0.010
Fit parameter	α	m^{-1}	3.83	3.14	0.83	3.67	2.65
Fit parameter	λ	-	1.250	-2.342	-0.588	-1.977	2.500
Fit parameter	n	-	1.38	1.18	1.25	1.10	1.10
Saturated hydraulic conductivity	K_{sat}	10^{-6}m/s	6.94	1.16	0.26	2.87	1.74

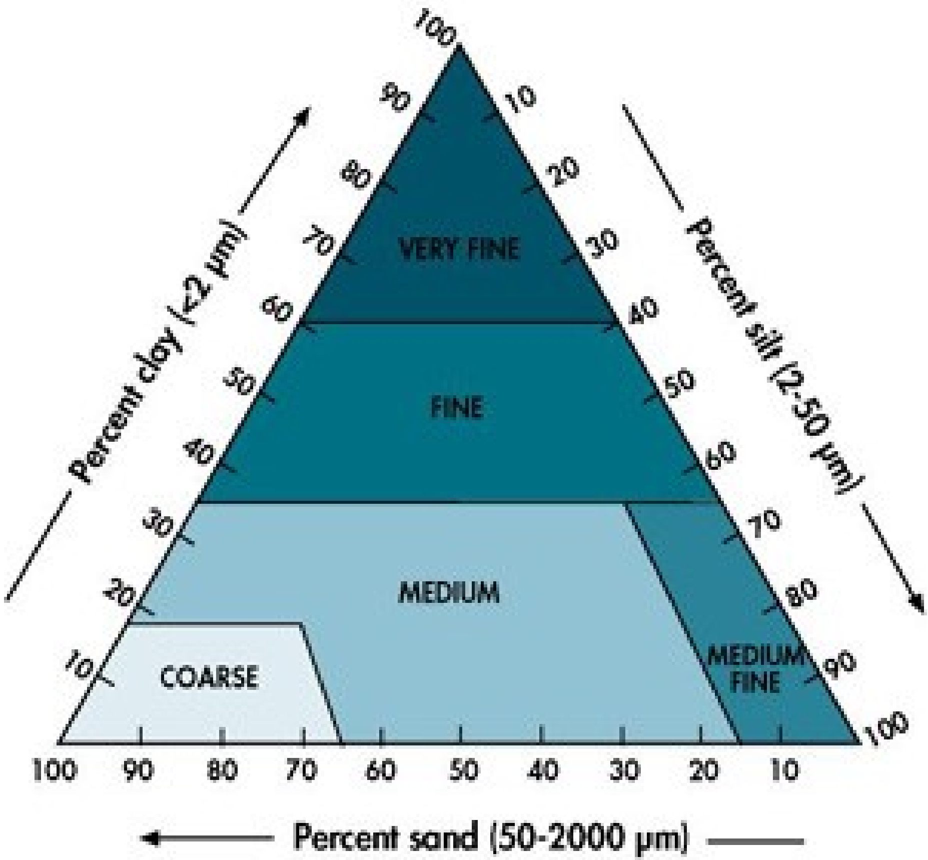
$$S = 1 - \left(1 - \frac{W}{W_{sat}}\right)^b$$

$$b = 0.01 \le \frac{\sigma_o - \sigma_{min}}{\sigma_o + \sigma_{max}} \le 0.5$$

$$R_s = T - (W_{sat} - W) + W_{sat}\left[\left(1 - \frac{W}{W_{sat}}\right)^{1/(b+1)} - \left(\frac{T}{(b+1)W_{sat}}\right)\right]^{b+1}$$

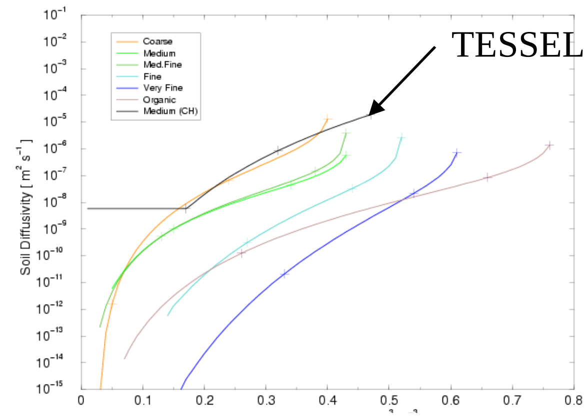
Van den Hurk and Viterbo 2003

The soil texture classification

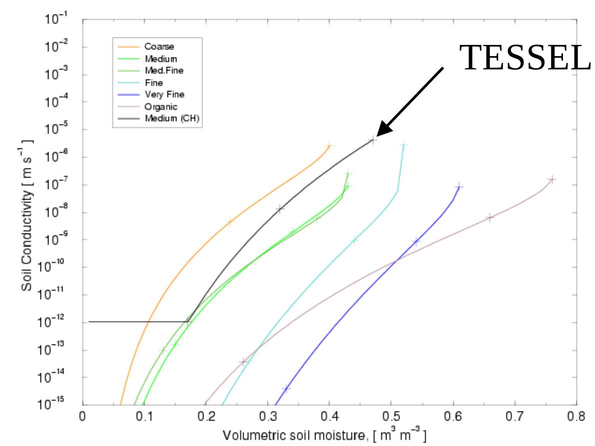


Soil textural triangle (from HYPRES: http://www.mluri.sari.ac.uk/hypres/).
A given soil type is a region in the triangle, and its textural description is found by the interception with the triangle border, of lines parallel to the sides, following the arrows.

Soil Diffusivity



Soil Conductivity



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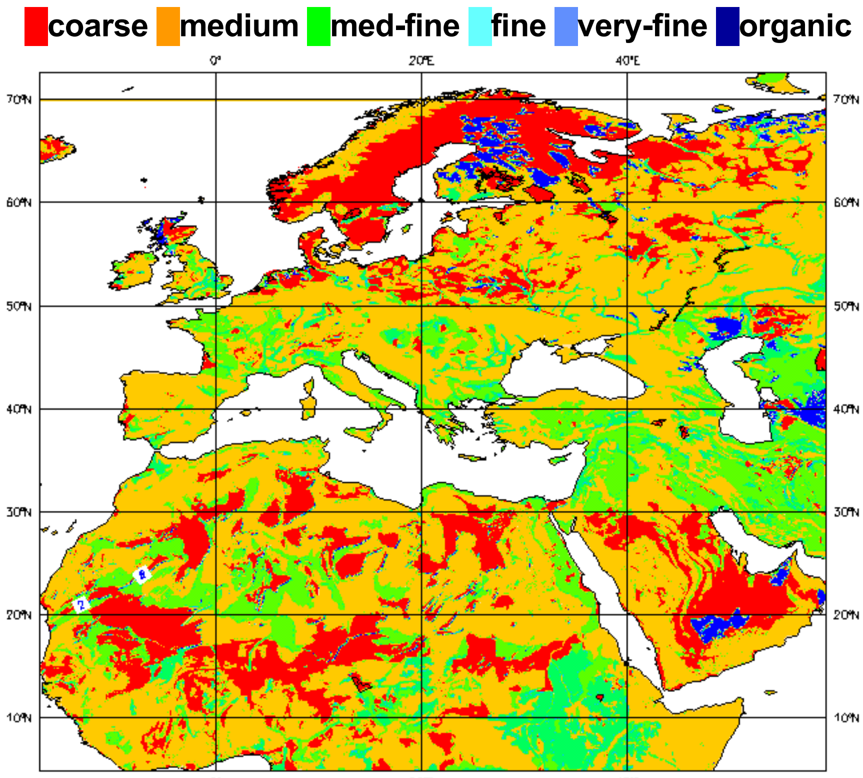
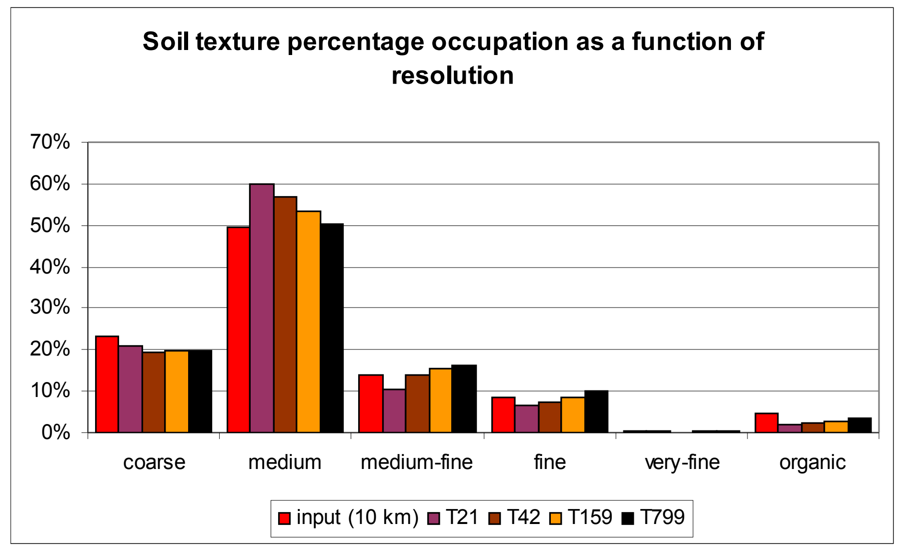
The soil texture classification database

FAO 2003 from Freddy.Nachtergaele, after a survey of the available datasets.



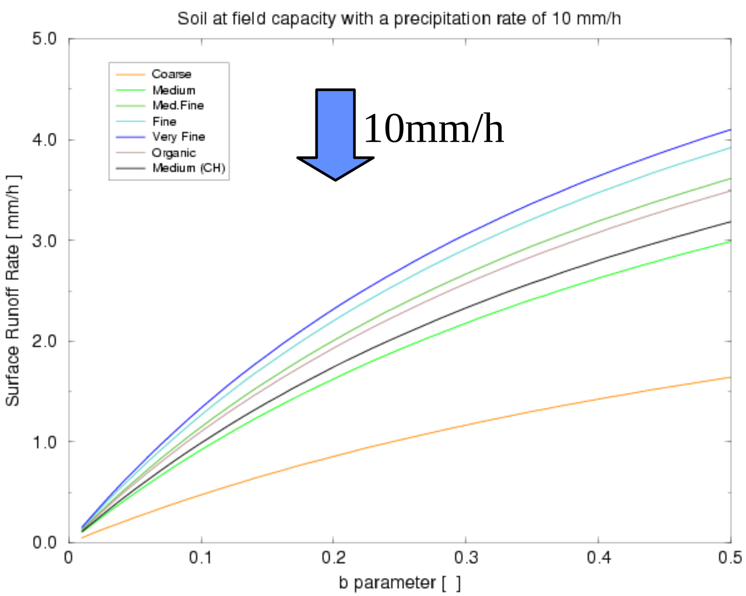
Dominant soil type from FAO2003 (at native resolution of ~ 10 km)

The interpolation to model grid is done within the IFS by the prepdata (interpo routine) preserving the dominant texture type at various resolution (T21-T799). Important for "upscalability"

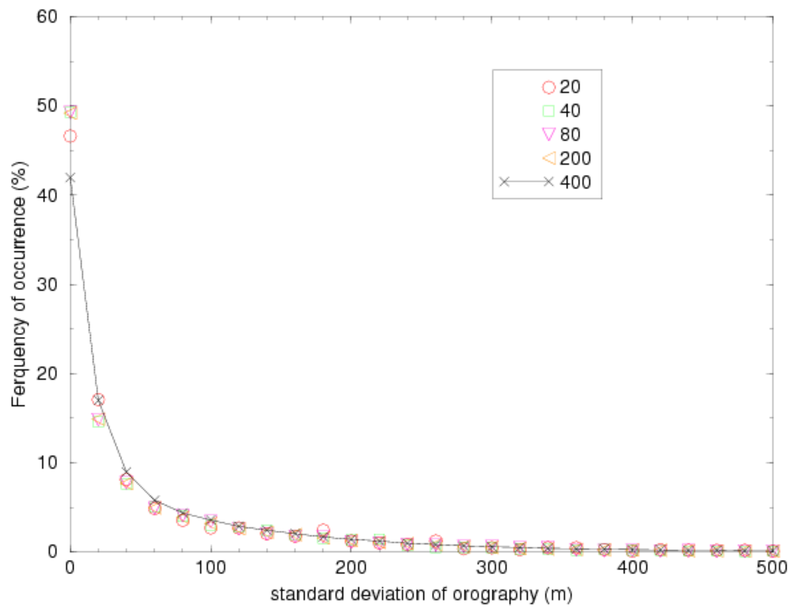


The orography runoff generation

Runoff as a function of orography (*b* is based on standard deviation of orography)



Up to ~30% Surface runoff in complex orography



fraction runoff *s* of the grid-point area *S*.

$$\frac{s}{S} = 1 - \left(1 - \frac{w_S}{w_{S\max}}\right)^b \; ; \; b = \frac{s - s_{\min}}{s_{\max} - s_{\min}}$$

Also the standard deviation of orography is scaling with resolution (especially T159-799).

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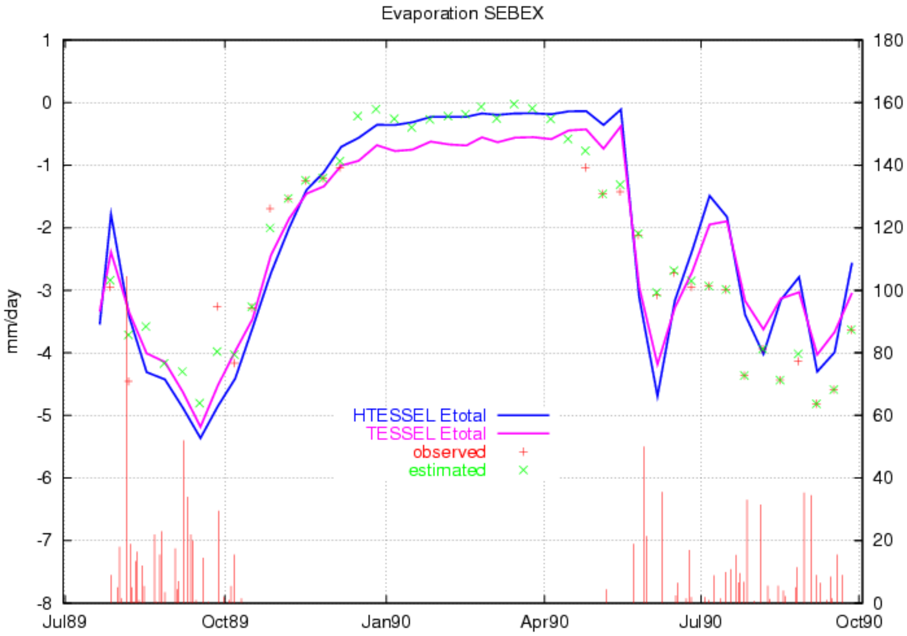
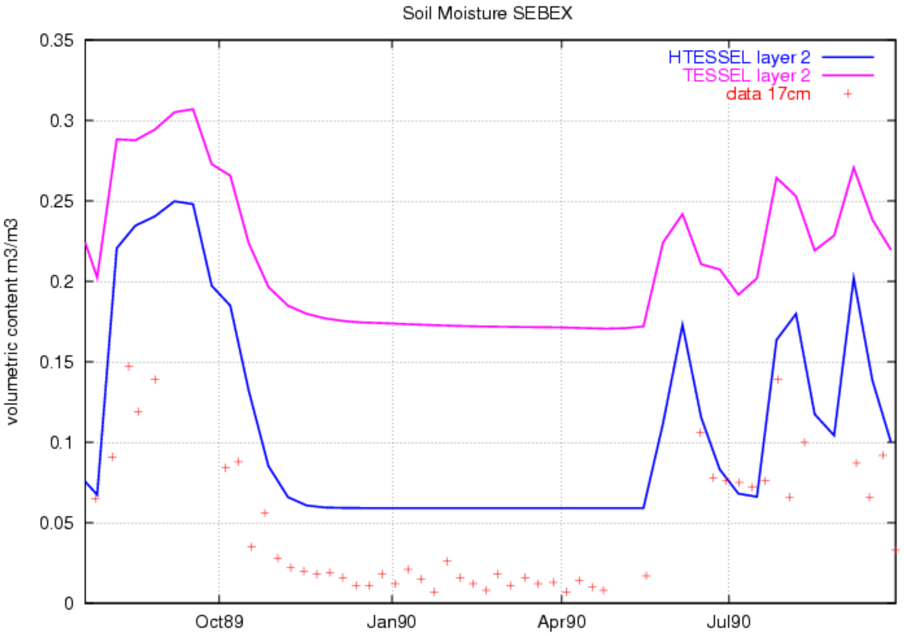
1D offline simulation with H-TESSEL

Site	Lat	Lon	Lat (FAO)	Lon (FAO)	Soil class (FAO)
Arme	-3.089000	-60.1870	-3.083560	-60.16655	1
Avignon	43.00000	0.000000	42.99977	0.000118	2
Boreas	55.87900	-98.4840	55.91644	-98.49988	6
Cabauw	51.94500	5.83300	51.91644	5.833452	3
Fife	39.02900	-96.6670	38.99977	-96.66655	2
Litfass	51.94500	14.16700	51.91644	14.16679	3
Loobos	52.16670	5.743900	52.16644	5.750119	1
Mobilhy	43.68300	-0.100000	43.66644	-0.0832144	3
Murex	43.38300	1.283000	43.41644	1.250119	4
Sahel	13.50000	2.500000	13.49977	2.500119	1
Sebex	13.50000	2.500000	13.49977	2.500119	1
Smosrex	43.38300	1.283000	43.41644	1.250119	4
Speuld	52.25000	5.683000	52.24977	5.666785	1

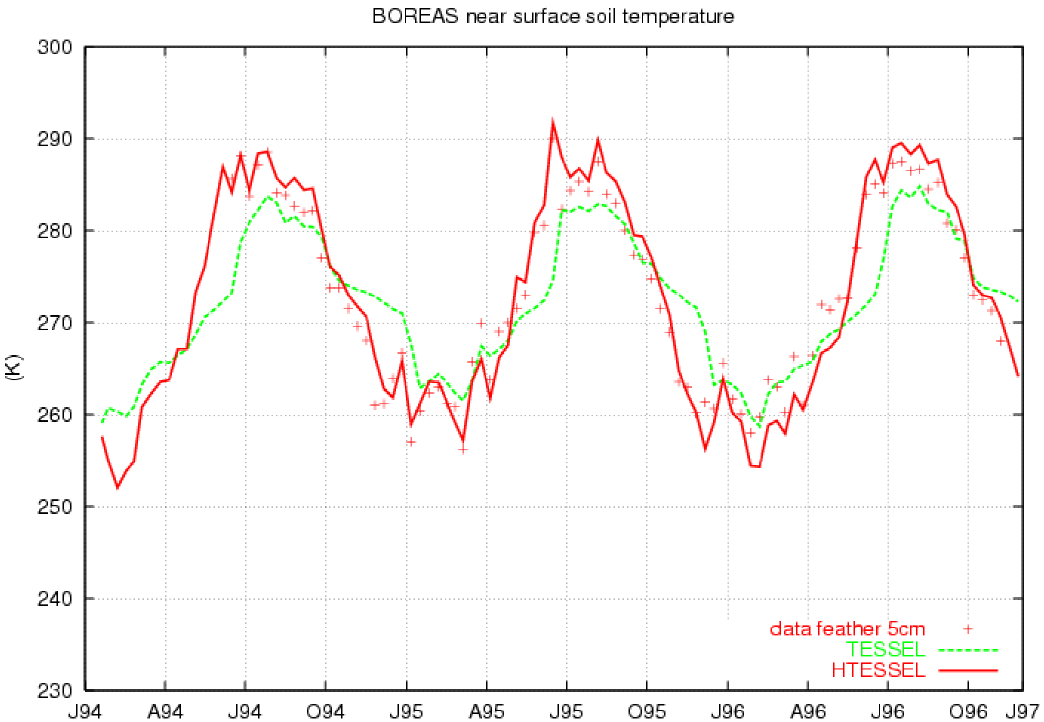
SEBEX (sandy soil)

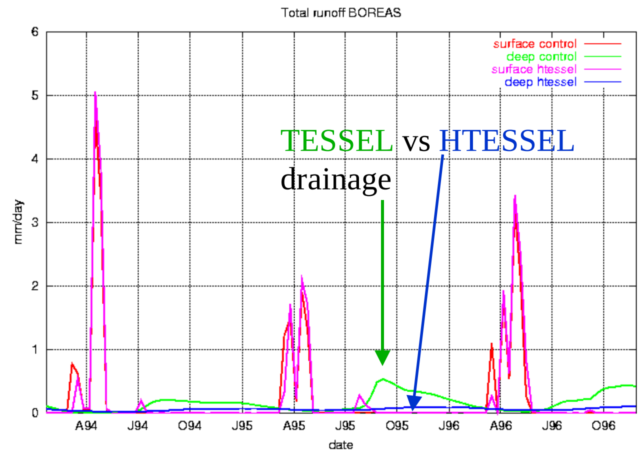


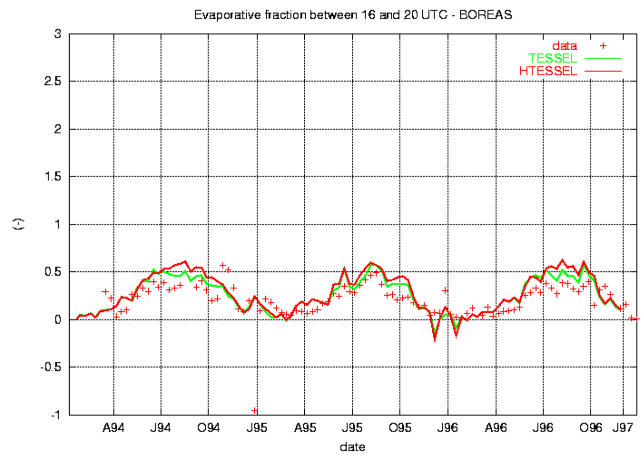


HTESSEL show a consistent improvement of soil moisture and evaporation with respect to TESSEL

BOREAS (organic soil)



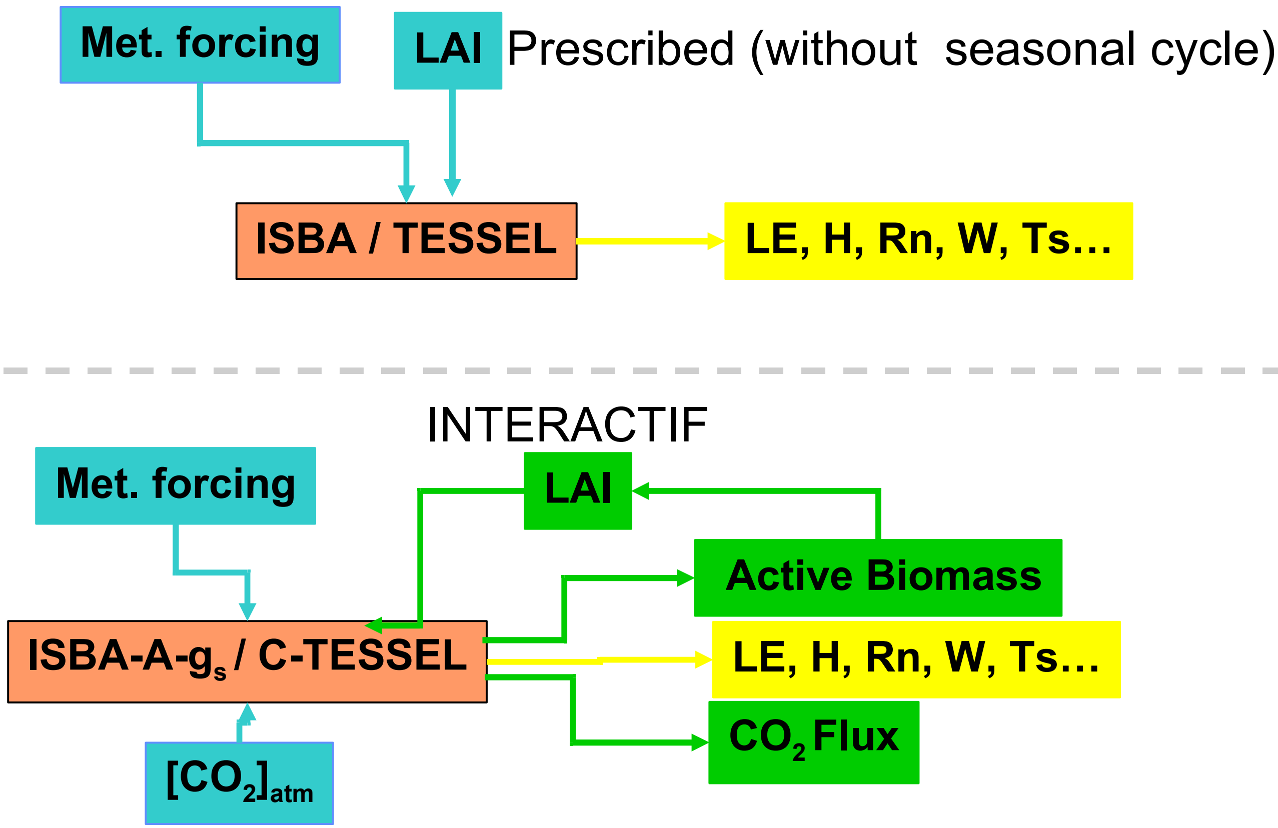




HTESSEL show a better match to soil temperature observations with respect to TESSEL. Water holding capacity is largely increased (and consequently deep drainage is reduced) while evaporative fraction remains comparable (good match with observations already in TESSEL).

Carbon cycle and Interactive vegetation C-TESSEL

Sebastien Lafont

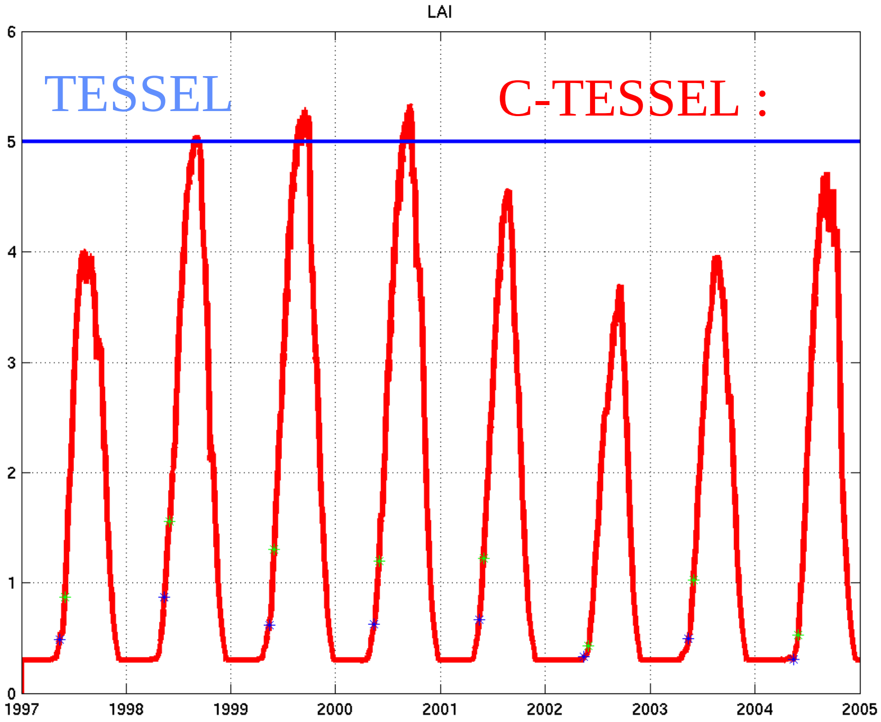


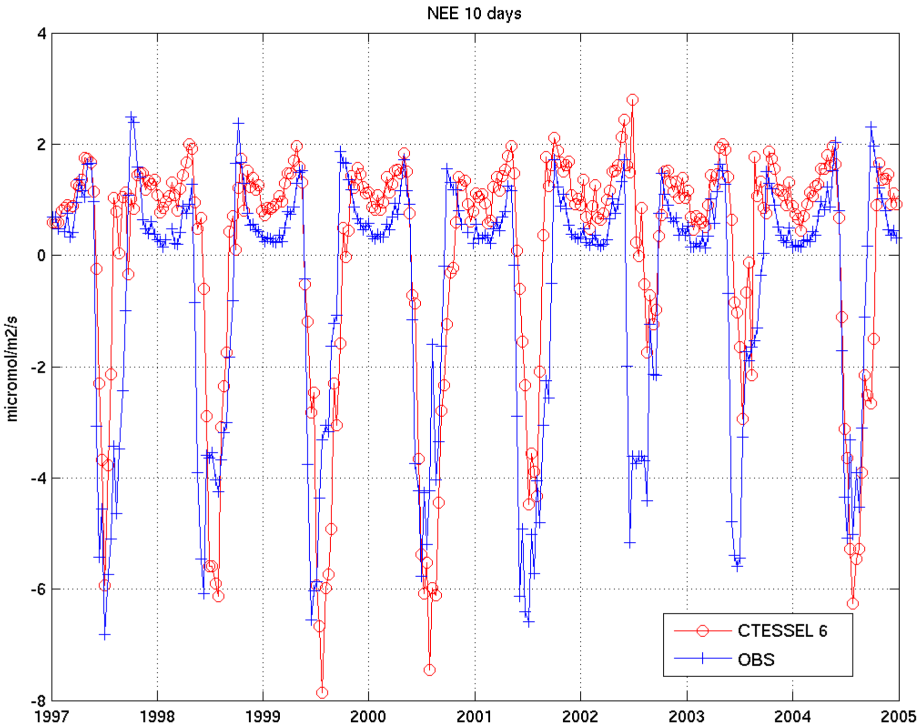
ISBA-A-g_s / C-TESSEL are CO_2-responsive land surface models, new versions of operational schemes used in atmospheric models

METEO FRANCE
ECMWF
KNMI
ALTERRA GREEN WORLD RESEARCH

ECMWF

Leaf area Index (LAI) & Net Ecosystem Exchange (NEE)



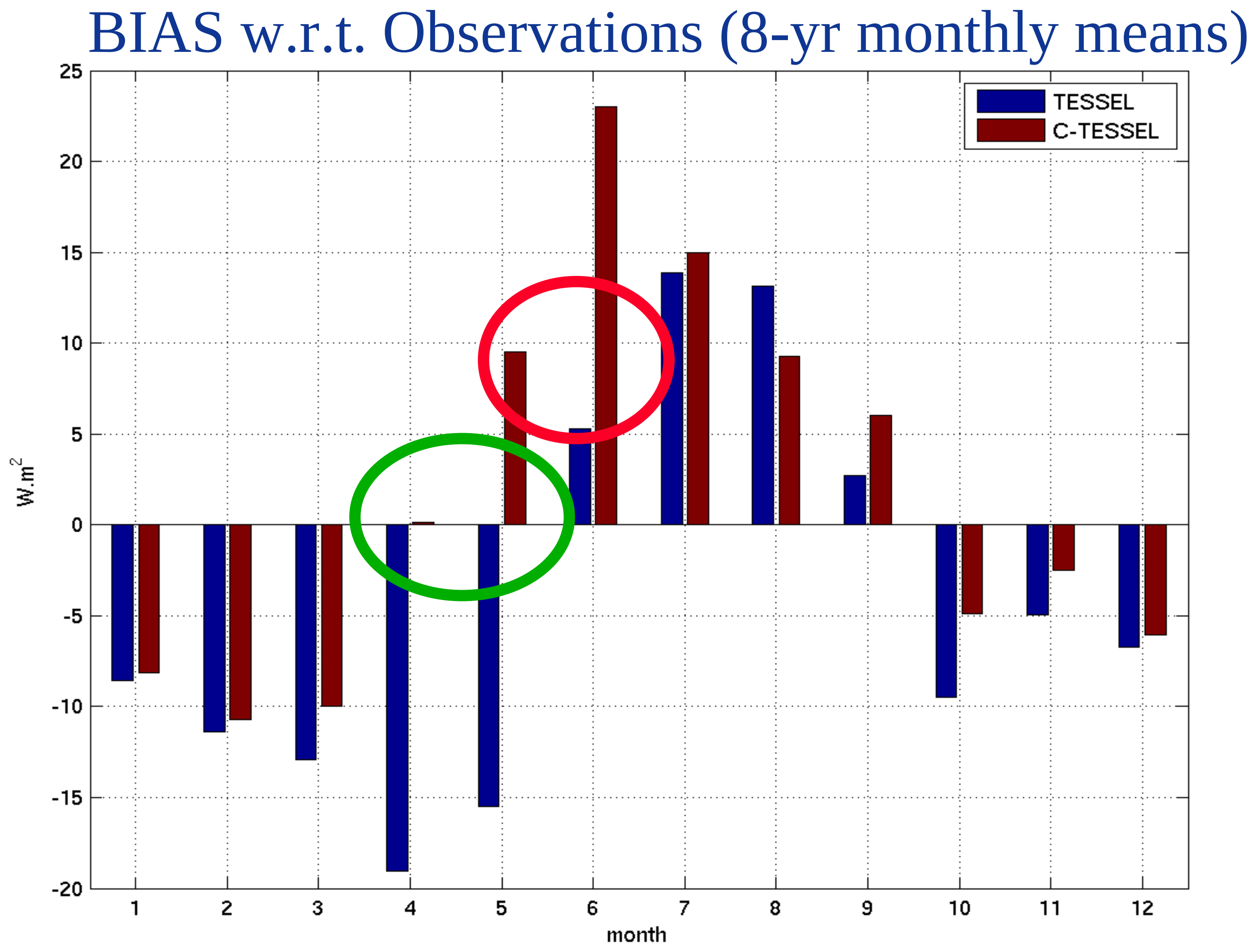


BERMS site Old Aspen.

8 years data set.

NOTE: NEE total flux conservation imposed

Impact on Latent Heat Flux



2D offline simulations

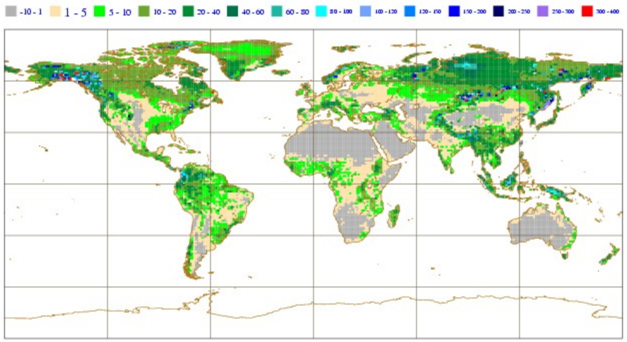
- The Offline Surface Model (OSM) driver has been integrated in the IFS code and run from IFS operational and ERA-40 archives (via MARS extractions).
- Offline 2D experiments are useful test-bed for LSS scheme:
  - Thorough test of scheme (stability, budget conservation)
  - Comparison of model versions (evaluate changes in LS state for a given set of forcing)
- Participation to International offline land surface project:
  - GSWP2: Global 1986-1995 near-surface atmospheric forcing (NCEP reanalysis+Observational datasets)
  - AMMA: West-African 2001-2005 (ECMWF oper. and AMMA satellite based forcing)
- The quality of the forcing is a pre-requisite!

Validation over large domains

- Global offline simulation can only be validated using proxy observations. Three proxy observation types can be used:
  - ERA-40 surface fluxes (constrained by OI land surface analysis which assimilate 2m T/RH. Significant only on SYNOP-dense areas)
  - GRDC runoff (validated against river discharge; questionable precipitation dataset)
  - Surface soil moisture climatology from ERS (1992-2000) by K. Scipal et al. This limits to the very shallow surface layer and sparsely vegetated areas (no signal over forests). Interesting for future METOP DA.
- Regional validation
  - with the aid of dense observation network (e.g. Ok-Mesonet) for area-average land surface variables/fluxes.

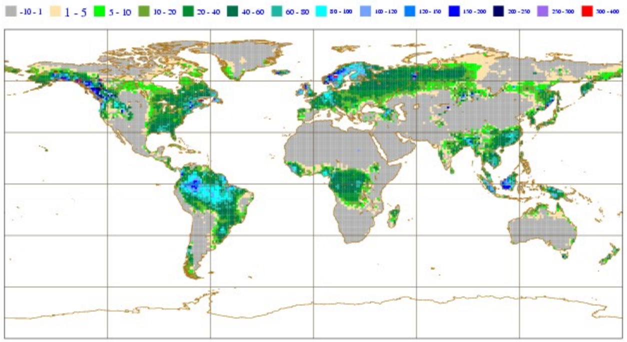
Surface runoff and Drainage

Surface runoff [kg/m2/month] (HTESSEL_GSWP2_1986_1995) on Globe Domain

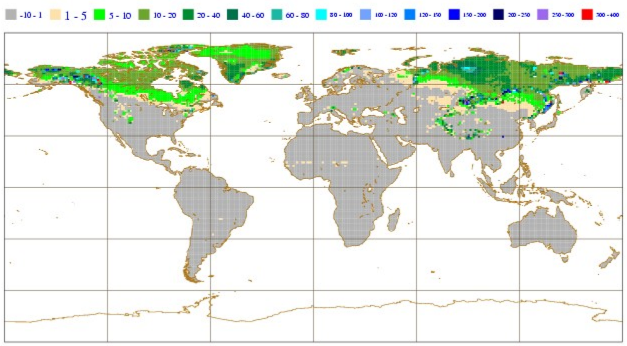


H-TESSEL

Subsurface runoff [kg/m2/month] (HTESSEL_GSWP2_1986_1995) on Globe Domain

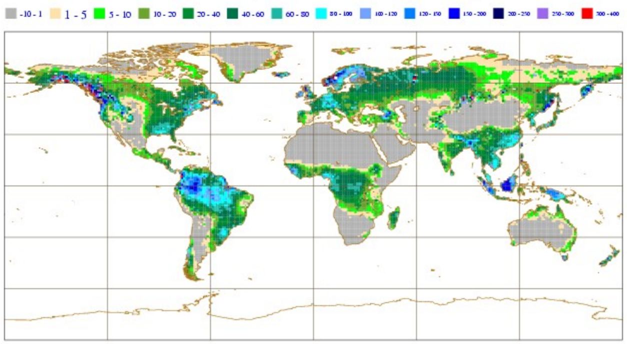


Surface runoff [kg/m2/month] (TESSEL_GSWP2_1986_1995) on Globe Domain

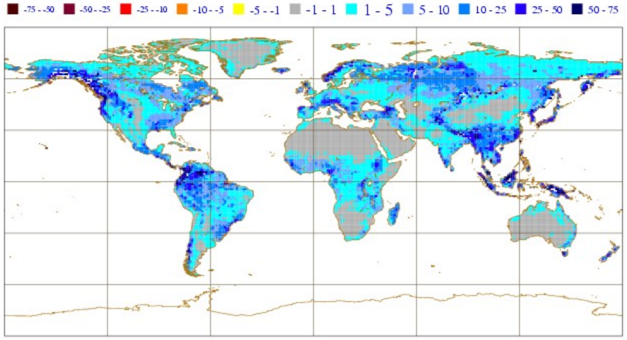


TESSEL

Subsurface runoff [kg/m2/month] (TESSEL_GSWP2_1986_1995) on Globe Domain

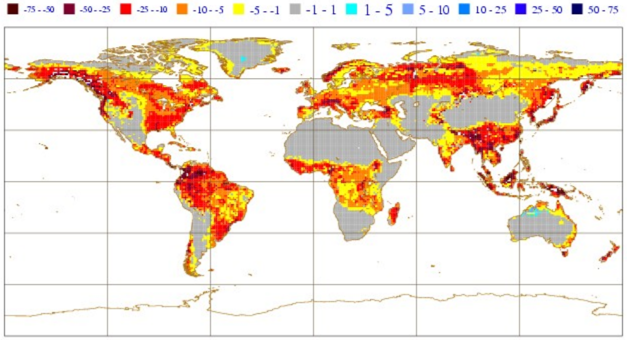


Surface runoff [kg/m2/month] (HTESSEL-TESSEL_GSWP2_1986_1995) on Globe Domain

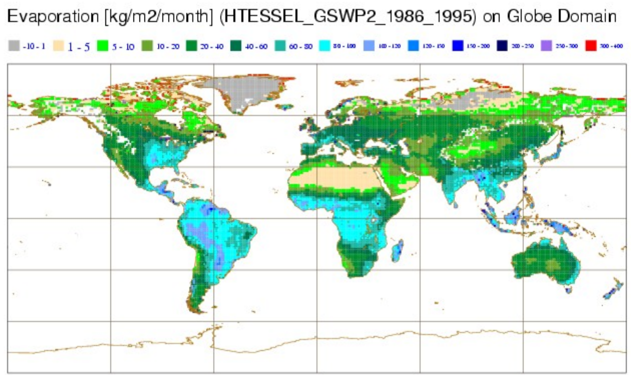


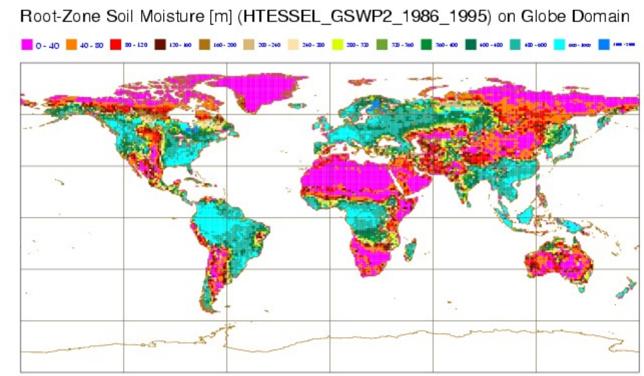
H-TESSEL
-TESSEL

Subsurface runoff [kg/m2/month] (HTESSEL-TESSEL_GSWP2_1986_1995) on Globe Domain

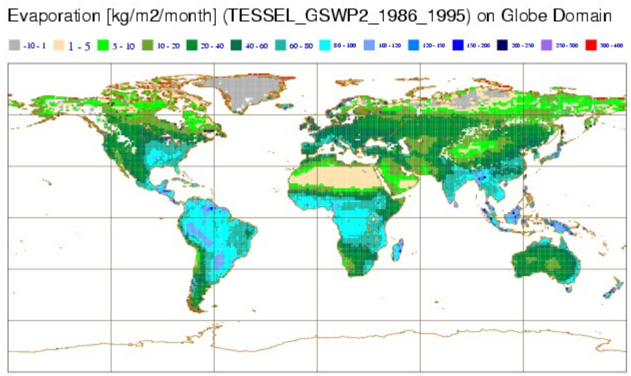


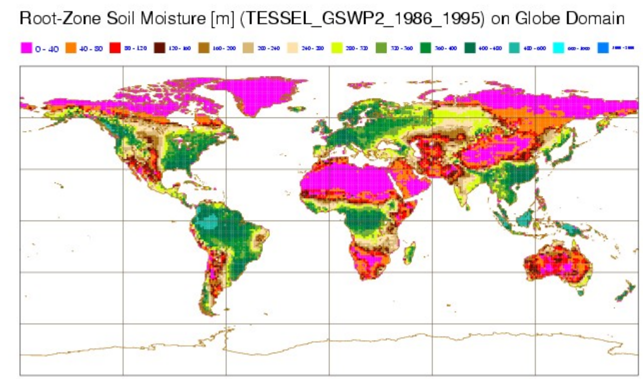
Evaporation and Soil water storage



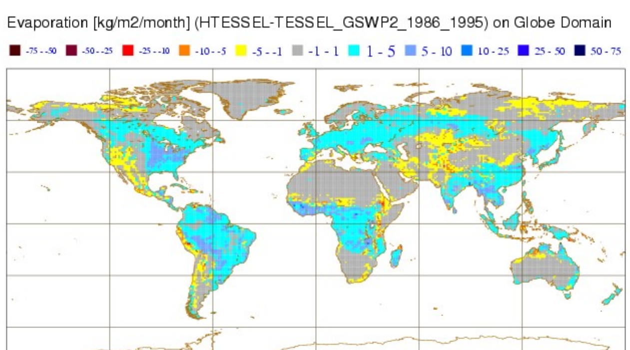


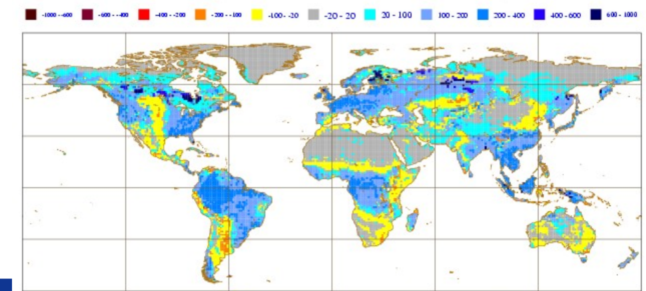
H-TESSEL





TESSEL





H-TESSEL
-TESSEL

slightly increased evaporation

100-400 mm more storage !

Climate run (13-month) with H-TESSEL

- IFS T156L91 + H-TESSEL compared to control
  4 members ensemble
- Neutral on scores
- Effective soil moisture recharge
  (need probably longer timescale for evaluation)
- DA experiments (at low resolution) may allow a more rapid adjustment to model changes (DA increments can be used to evaluate reduction of model bias)

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  - Carbon cycle (C-TESSEL)
  - Offline Surface Model (OSM)
  - Validation of model changes (1-d, 2-d, 3-d, DA experiments)
- **Data assimilation activities**
  - Current status
  - Observation availability (screen-level T, RH, L-band, C-band, IR, SM and LAI products)
  - Observation operators (RTM, matching techniques)
  - ELDAS implementation (Soil moisture)
  - Offline data assimilation (LAI)
  - Cost considerations
- Summary and conclusions

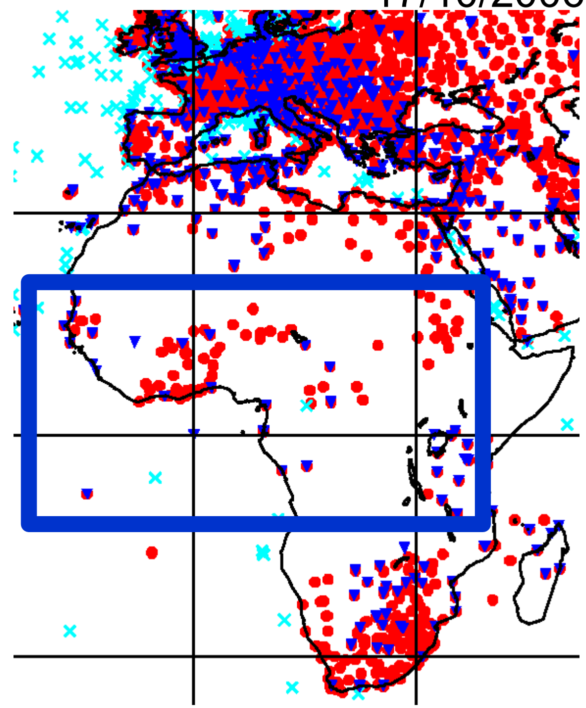
Operational OI soil analysis

Mahfouf (1991), Bouttier et al. 1993, Douville et al. (2000)

- The analysis increments from the screen level analysis are used to produce increments for the water content in the first three soil layers (root zone):

$$\Delta\Theta_i = a_i\left(T^a - T^b\right) + b_i\left(RH^a - RH^b\right)$$

synop/metar/ship
17/10/2006



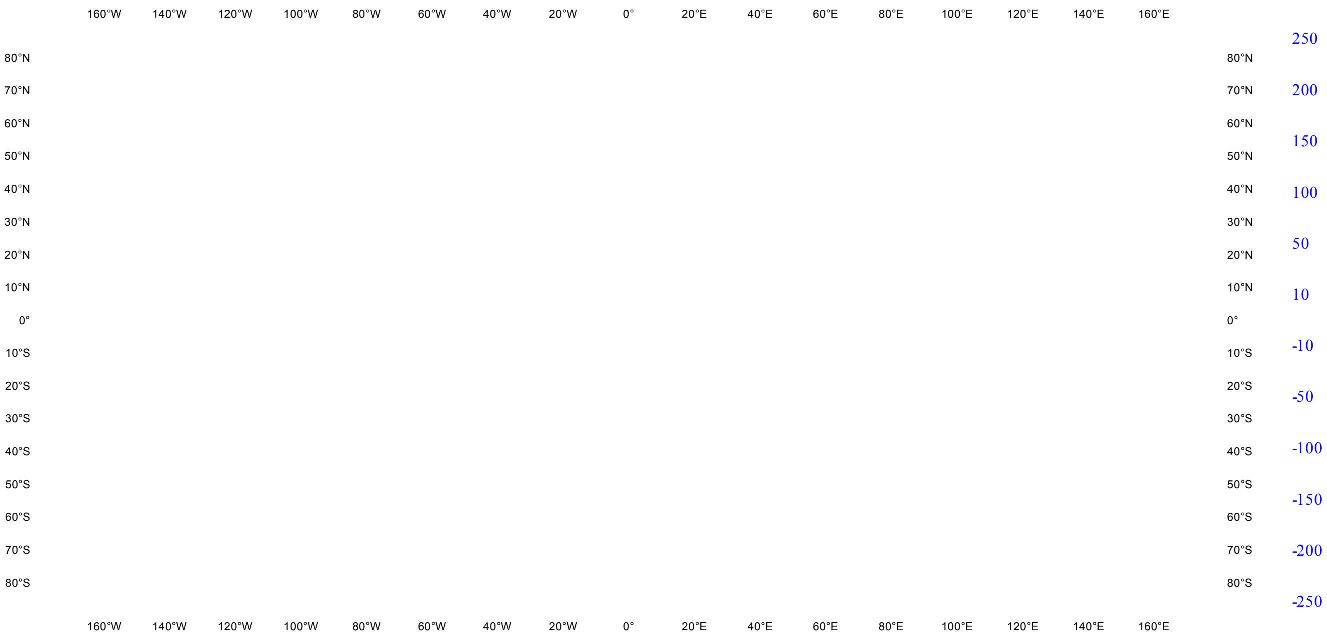
- and for the first soil temperature layer:

$$\Delta T = c \times \left(T^a - T^b\right)$$

- Key parameters are the a_i, b_i, c (optimum coefficients) which translate screen level errors into soil moisture/temperature adjustments.
- The method relies on the SYNOPs density which affects the quality of screenlevel analysis.

Operational OI soil analysis (II)

- **The soil moisture analysis is needed due to the feedback effects of soil moisture-evaporation-precipitation**



Example of accumulated root zone OI soil moisture increments (a – b) [mm] for the 2 June to 30 July 2005 (*Drusch et al. 2006*)

- **The Soil moisture analysis acts:**
  - **In the short term it improves LE and H fluxes (Bowen ratio)**
  - **In the long term it prevents model drifts!!!**

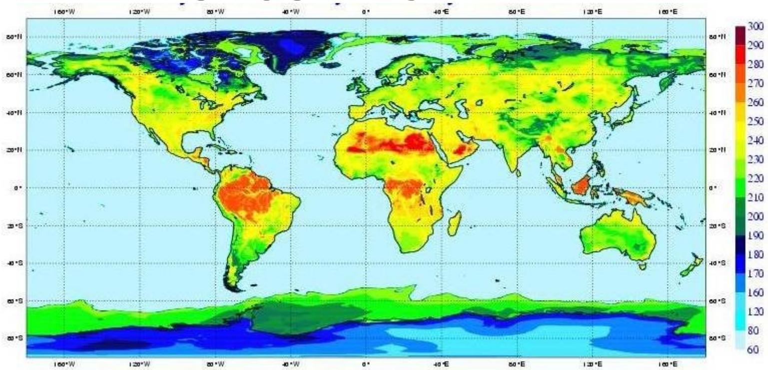
The new Land Surface Data Assimilation

Matthias Drusch

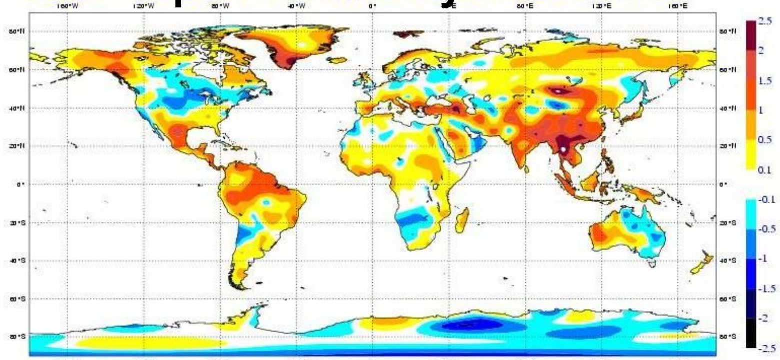
- Based on ELDAS concept (simplified Extended Kalman Filter)
- Integrated in IFS (accurate perturbation sensitivity)
- Flexible to accommodate present (screen-level) and near future (SMOS, ASCAT-SM, AMSR-E(-SM?)) observations within a defined assimilation window X-h (12 to 24)
- Include RTM for microwave (LSMEM+LMEB→ CMEM)
- Computation efficiency needs to be addressed (each control variable cost a forecast) by reducing the cost of perturbed runs.

ECMWF's future Surface Data Assimilation System (SDAS)

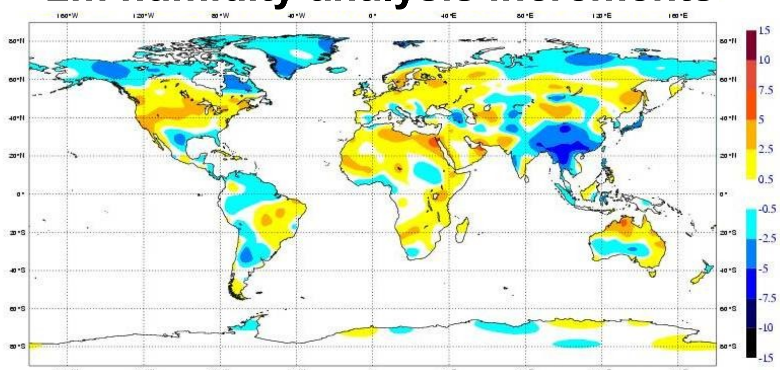
SMOS 1.4 GHz TB



2m temperature analysis increments



2m humidity analysis increments



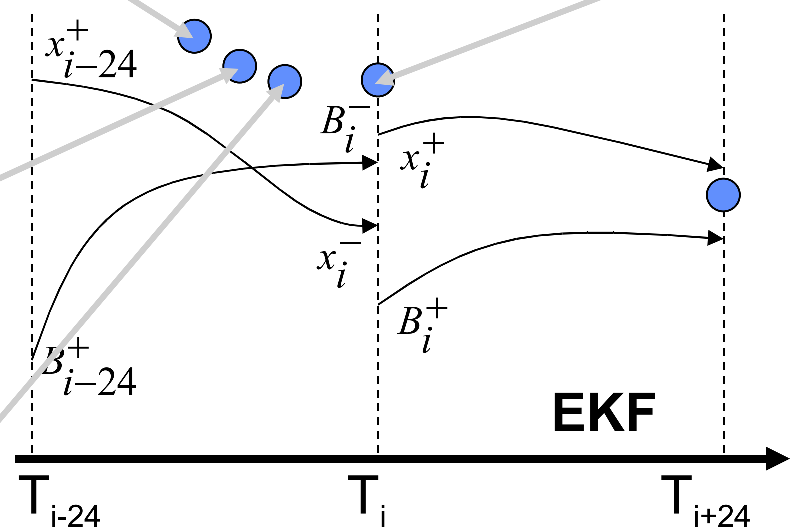
Update at T_i:

$$\mathbf{K}_i = \mathbf{B}_i^- \mathbf{H}_i^T \left[\mathbf{H}_i \mathbf{B}_i^- \mathbf{H}_i^T + \mathbf{R}_i\right]^{-1}$$

$$\mathbf{x}_i^+ = \mathbf{x}_i^- + \mathbf{K}_i \left[\mathbf{y}_i - \mathbf{H}_i \mathbf{x}_k^-\right]$$

$$\mathbf{B}_i^+ = \mathbf{B}_i^- - \mathbf{K}_i \mathbf{H}_i \mathbf{B}_i^-$$

ASCAT



Propagation T_{i-24} to T_i:

$$\mathbf{x}_i^- = \mathbf{f}_{i-24}(\mathbf{x}_{i-24}^+)$$

$$\mathbf{B}_i^- = \mathbf{F}_{i-24} \mathbf{B}_{i-24}^+ \mathbf{F}_{i-24}^T + \mathbf{Q}_{i-24}$$

$$\left[\mathbf{F}_{i-24}\right]_{mn} = \left.\frac{\partial f_m}{\partial x_n}\right|_{x_{i-24}}$$

Propagation T_i to T_{i+24}:

$$\mathbf{x}_{i+24}^- = \mathbf{f}_i(\mathbf{x}_i^+)$$

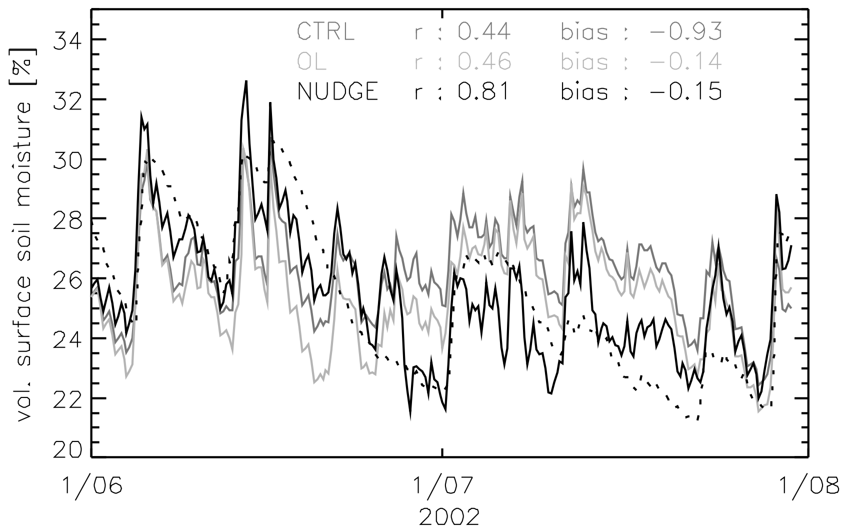
$$\mathbf{B}_{i+24}^- = \mathbf{F}_i \mathbf{B}_i^+ \mathbf{F}_i^T + \mathbf{Q}_i$$

$$\left[\mathbf{F}_i\right]_{mn} = \left.\frac{\partial f_m}{\partial x_n}\right|_{x_i}$$

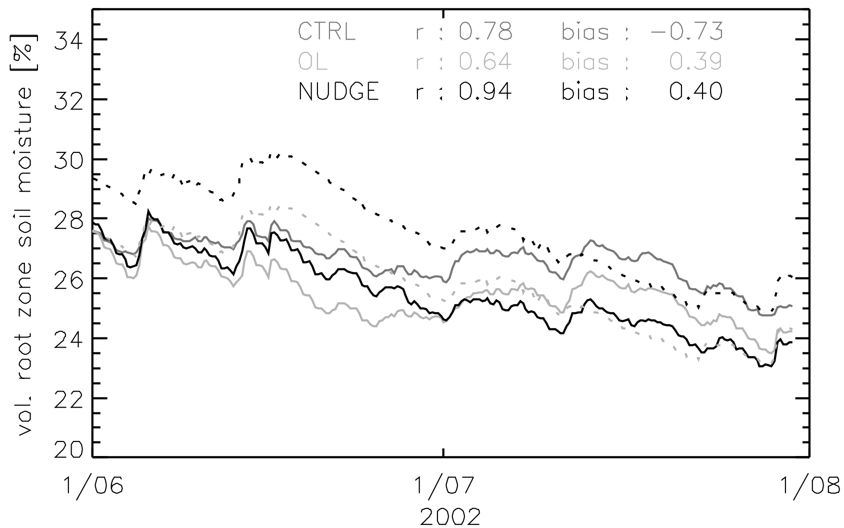
Impact study (nudging) using the IFS and TMI derived surface soil moisture

area averages for Oklahoma

surface soil moisture



root zone soil moisture



- Nudging / satellite data remove water effectively and produce a realistic dry down.
- Nudging the satellite results in the most accurate surface soil moisture estimate.

- The information introduced at the surface propagates to the root zone.
- The monthly trend is well reproduced using the nudging scheme.

Satellite derived soil moisture improves the soil moisture analysis and results in the most accurate estimate.

The METOP Scatterometer

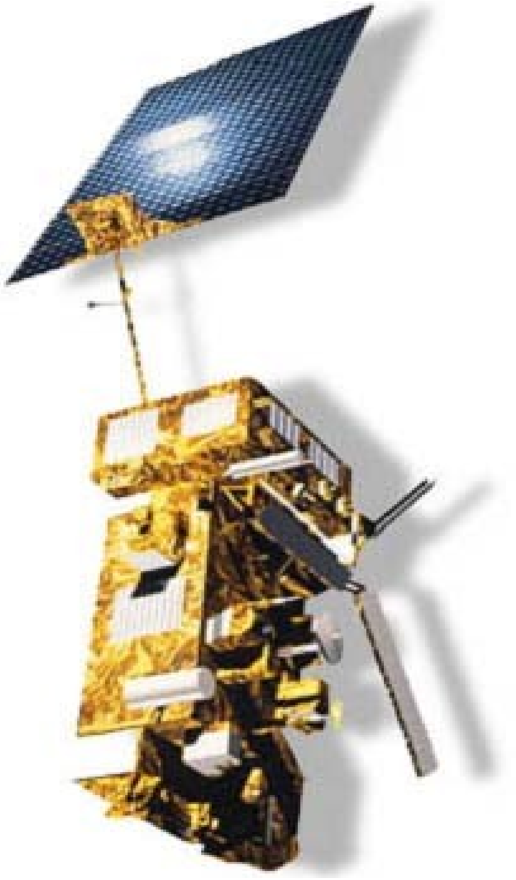
Klaus Scipal

Sensor Characteristics

- operated from 2006 until 2020
- Daily coverage 82 %
- 25 km spatial resolution
- C-Band (5.3 GHz) VV pol.
- ERS Heritage (since 1991)

Product Characteristics

- Relative surface soil moisture index
- Processed NRT at EUMETSAT
- Distributed via EUMETCAST



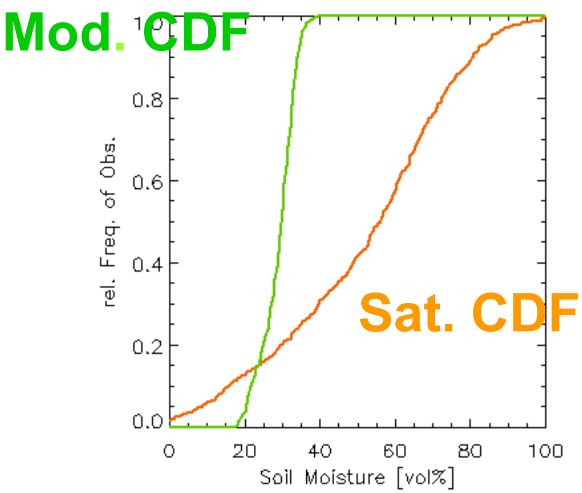
Bias correction / CDF matching

Bias correction to account for

- Relative nature of satellite observations
- Different climatology

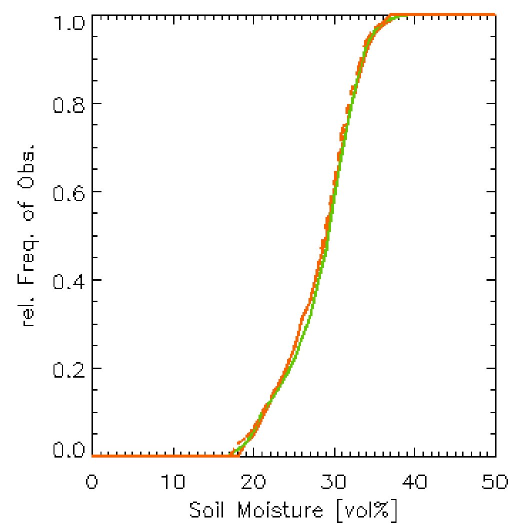
➡ CDF matching using linear model (based on mean and variance of model and satellite obs.)

CDF before fit



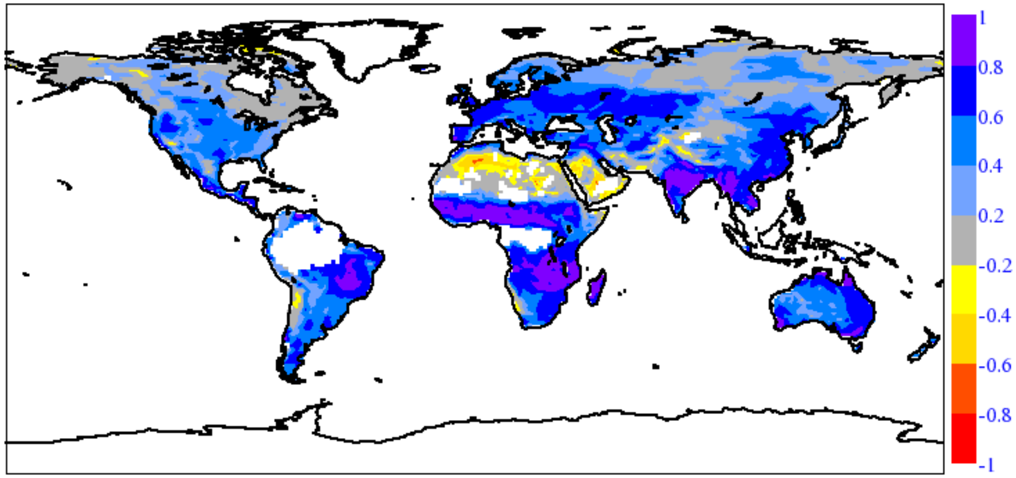
$$\theta_S' = \overline{\theta}_M + \frac{VAR(\theta_M)}{VAR(\theta_S)} \cdot \left(\theta_S - \overline{\theta}_S\right)$$

CDF after fit

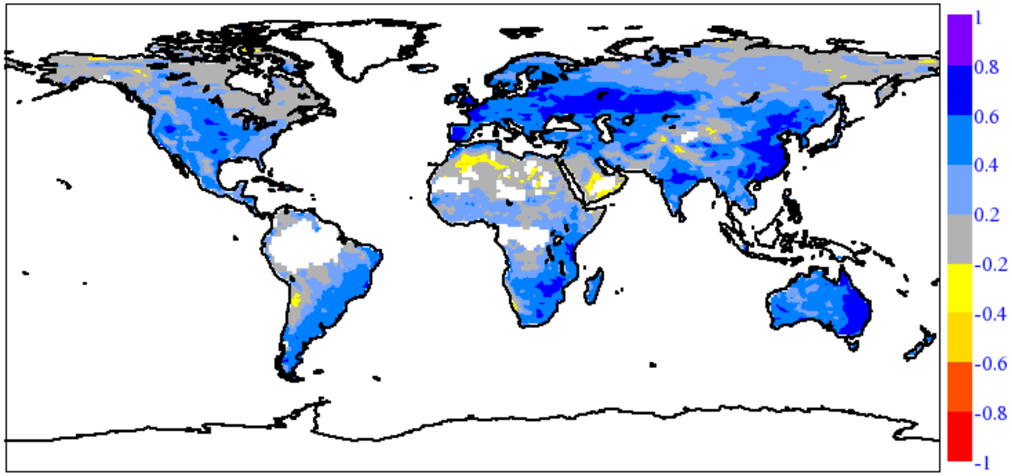


Comparison ERA-40 Scat soil moisture

Correlation ERA40 - ERSScat Soil Moisture (1992-2000)



Anomaly Correlation ERA40 - ERSScat Soil Moisture (1992-2000)

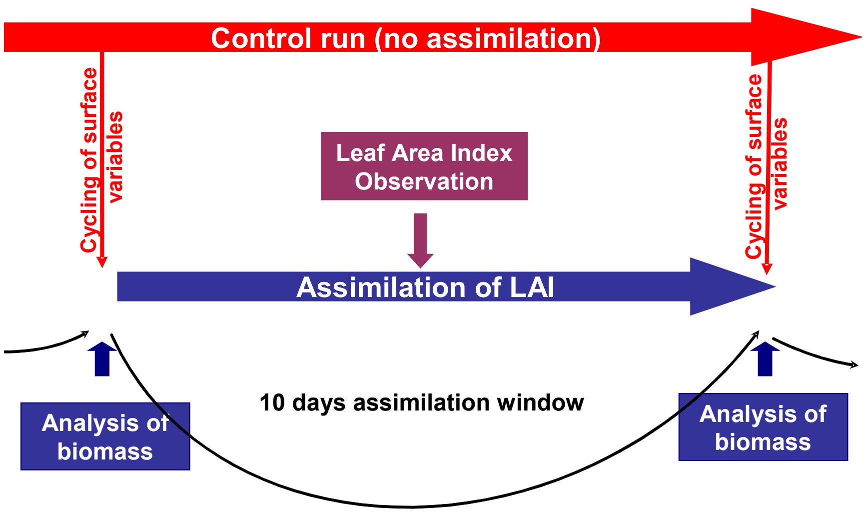


- Satellite and model soil moisture show good agreement
- High Agreement of absolute values and anomalies in tropics and mid latitudes
- Problems in desert (sensor related) and in cold climates

Assimilation of satellite LAI products in TESSEL. Application to West Africa.

Lionel Jarlan

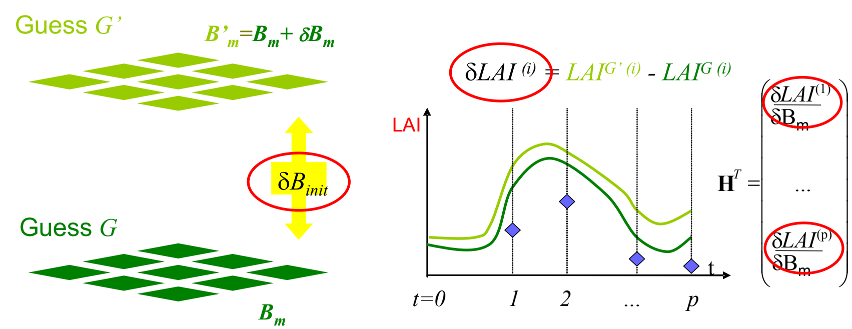
- Land surface DA system lay-out



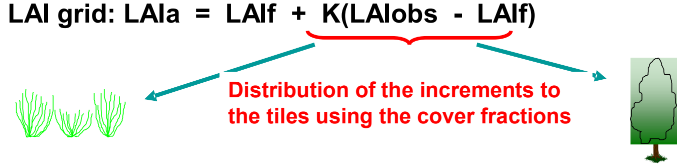
- DA scheme (simplified 2D-VAR)

Jarlan et al. (2006), Balsamo et al. (2004)

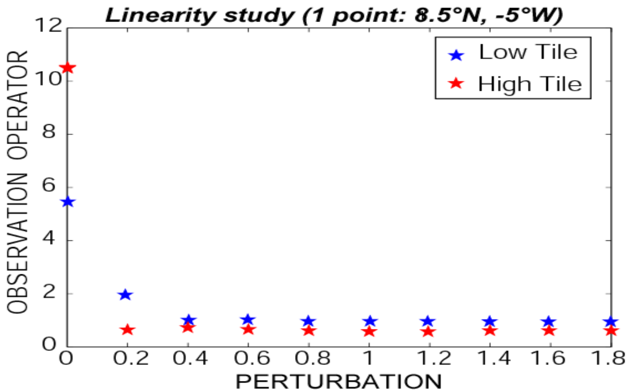
- **Numerical linearization of the observation operator**



- **Analysis on LAI grid: LAIa = LAIf + K(LAIobs - LAIf)**



Validation of the Linear hypothesis

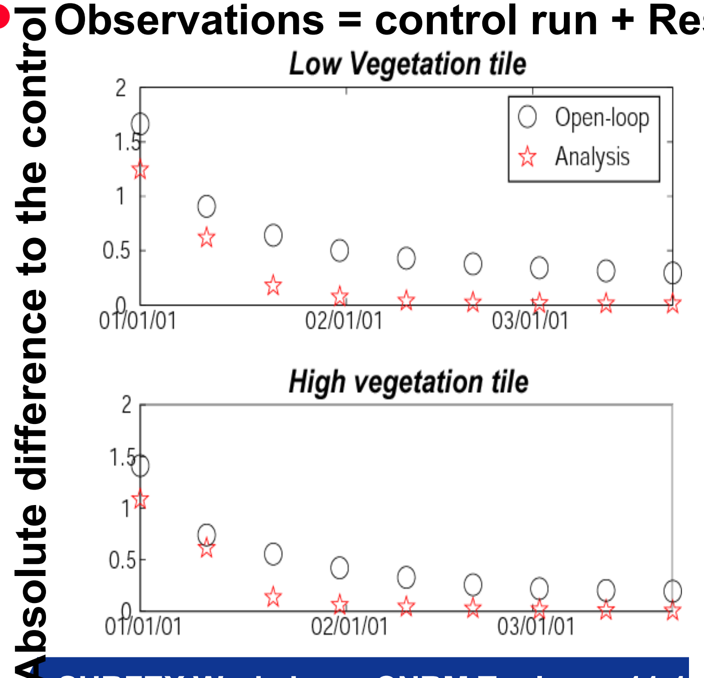


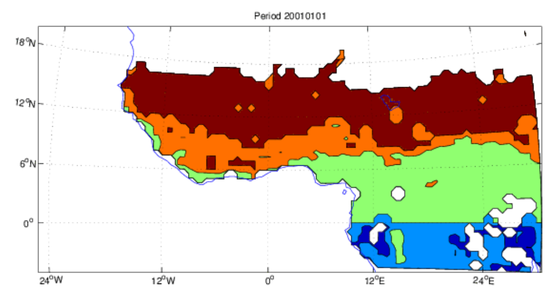
- Ensemble of 10 perturbations
  - Above 0.4 m²/m², very linear behaviour

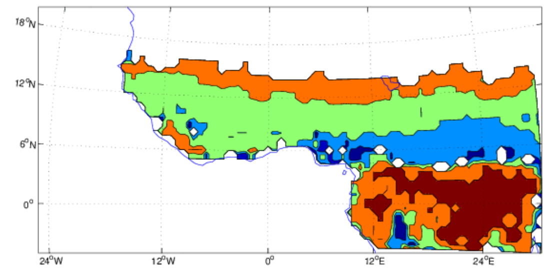
➡ Choice of the perturbation above 0.4 m²/m²

Analysis convergence test in twin exp.

- **Observations = control run + Reset of the guess at time 0 (LAIhigh=LAIlow=3.0)**



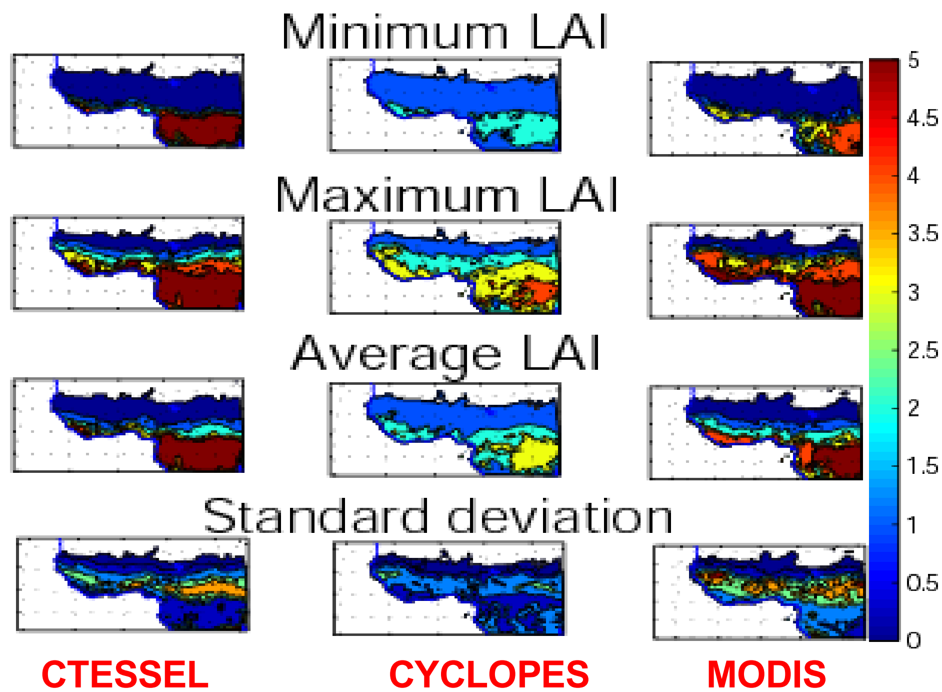




Two different data sets of LAI satellite products

- **« CYCLOPES » LAI (SPOT/VEGETATION sensor)**
  - -Retrieval: inversion of a 1D radiative transfer algorithm thanks to a neural network
  - -Characteristics: global, 1 km, 10 days time step, 1998-2003

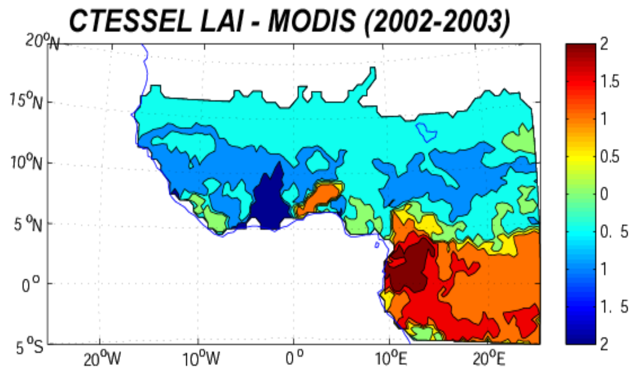
- **MODIS LAI**
  - -Retrieval: inversion of a 3D radiative transfer algorithm thanks to a look up table + backup algorithm
  - -Characteristics: global, 1 km, 8 days time step, 2001-present
  - -Unfortunately, the AMMASAT MODIS product is provide monthly

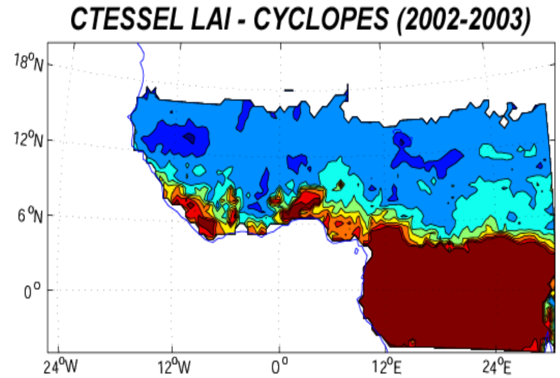


ECMWF

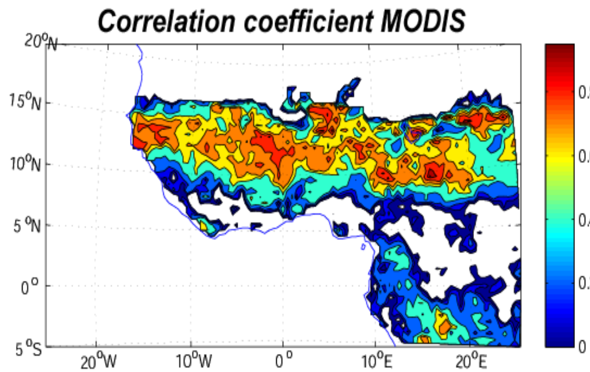
CTESSEL vs LAI satellite (2002-2003)

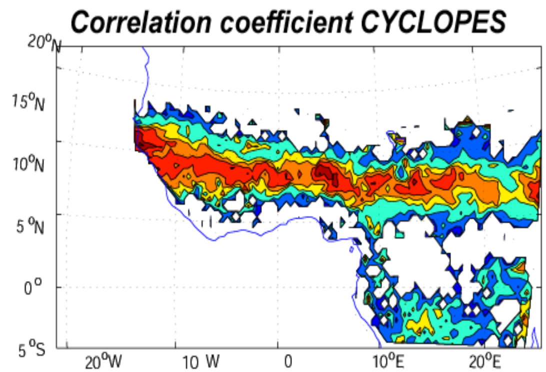
➔ **Estimate bias and correlation between the model and the data for data assimilation**





- **LAI products + biased over Sahel and Savannah and - over forest. MODIS: less biased**
- **correlation is better where (1) the seasonality is strong; (2) the cloud cover is low**



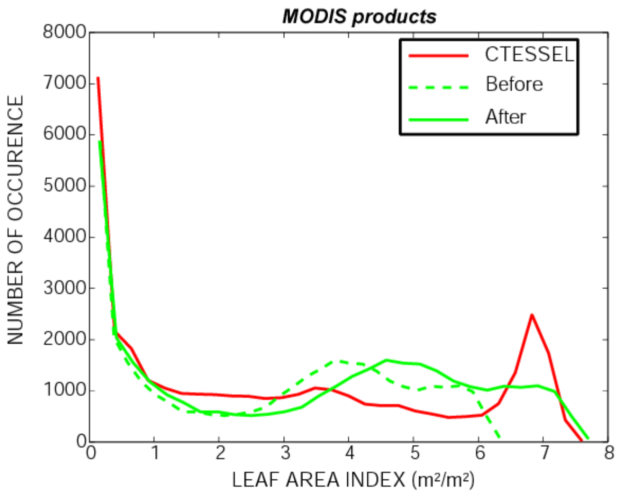


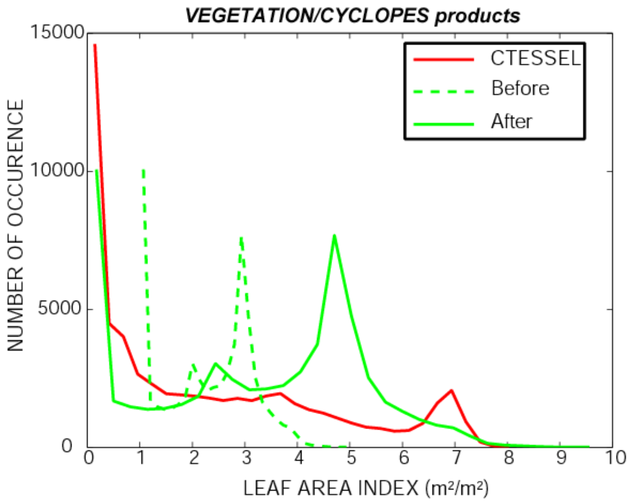
- **Higher correlation for MODIS, Less lacking data with MODIS**

ECMWF

Rescaling of satellite Data (2002-2003)

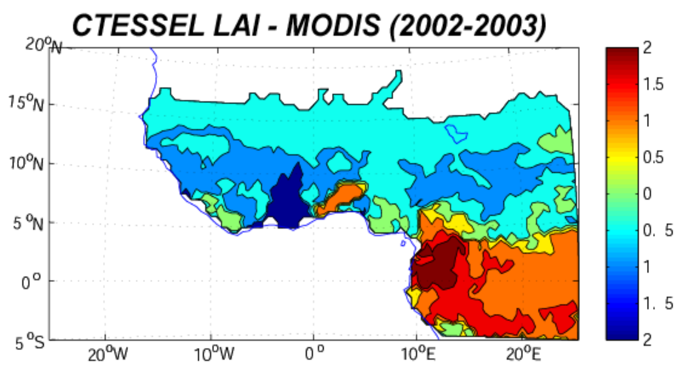
- Matching of 5% fractile and 95% fractile of the distributions

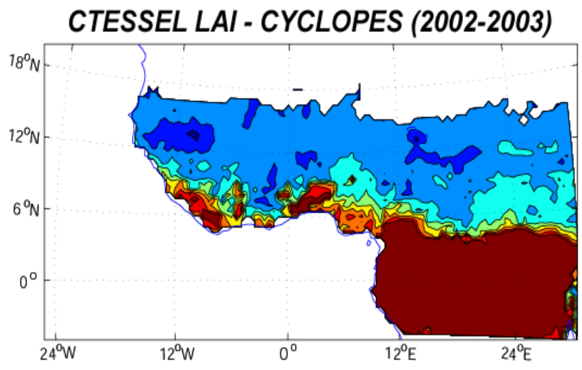




-

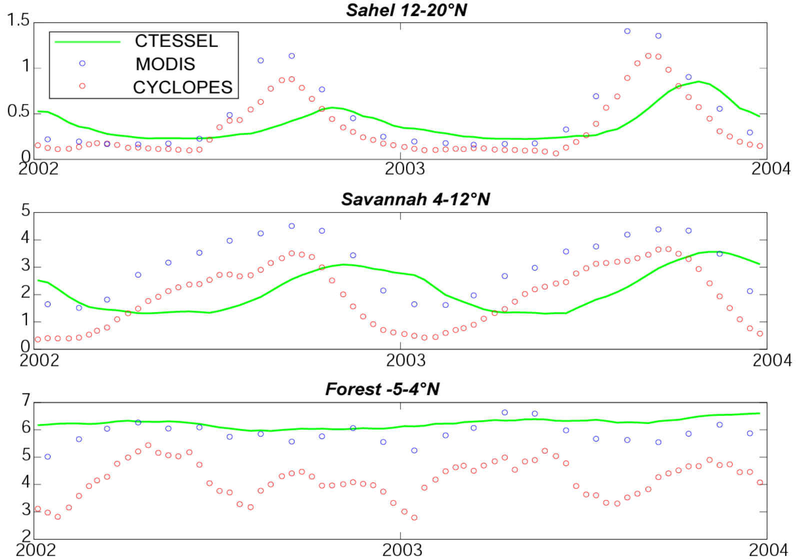
➔ Bias after rescaling (Better on MODIS)

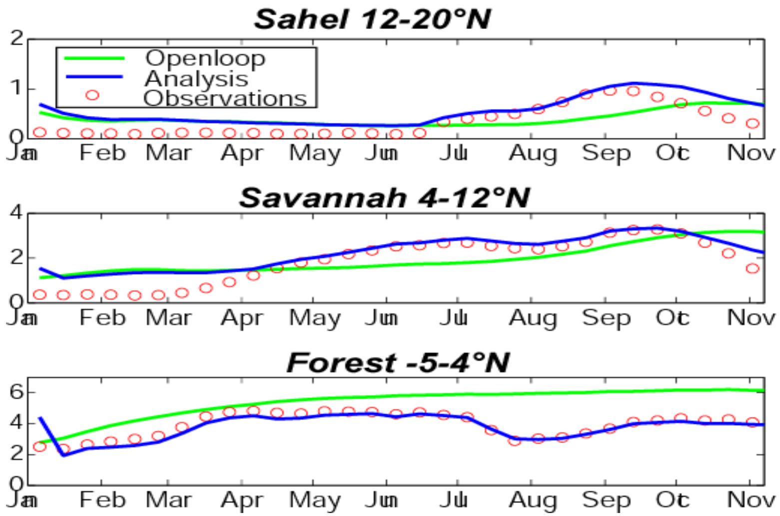




CTESSEL vs LAI satellite (2002-2003)

- **Time series over 2002-2003 (after rescaling)**





- ➢ Strong time shift of CTESSEL (# ISBA-A-gs)
- ➢ C-TESSEL – MODIS consistent over forest and Savanna (min value)

- The DA helps to correct the model delay in vegetation growth
- Low values of LAI in the observations are still difficult to achieve

Outline

- Modelling activities
  - Current status
  - Improved hydrology (H-TESSEL)
  - Carbon cycle (C-TESSEL)
  - Offline Surface Model (OSM)
  - Validation of model changes (1-d, 2-d, 3-d, DA experiments)
- Data assimilation activities
  - Current status
  - Observation availability (screen-level T, RH, L-band, C-band, IR, SM and LAI products)
  - Observation operators (RTM, matching techniques)
  - ELDAS implementation (Soil moisture)
  - Offline data assimilation (LAI)
  - Cost considerations
- **Summary and conclusions**

Summary and conclusions (I)

- **Model developments are advanced:**
  - **H-TESSEL implemented in cycle 30r1**
    - Soil type characterisation (FAO 2003)
    - 1d validation show improved match over sites departing from TESSEL "loamy" soil
    - Desired features shows in 2d runs (Enhanced soil moisture storage and surface runoff)
    - Preliminary 3D validation in progress
    - Foreseen implementation in 2007
  - **C-TESSEL implemented in cycle 30r1 (offline)**
    - Interactive Carbon and Water cycles
    - Comparables 1d results
    - Enhanced evaporation in 2d runs
    - Foreseen implementation by the end of 2007

Summary and conclusions (II)

- **validation of model developments:**
  - **1D sites are useful although limited (can not cover all the climate regimes)**
    - Quality control of forcing is essential (reducing further the datasets)
  - **2D runs are essential to test the stability of the scheme**
    - Rely also on QC dataset (biases forcing can cause model drifts also in offline integrations!)
    - 2D runs do not account for feedback (by conception)
  - **3D runs (atmospheric coupled) allow a proper validation**
    - At full resolution, FC only. Need rescaling (in case of H-TESSEL). Problematic in case of major LSS modifications
    - At low resolution, CLIMATE runs. The length of integration is an issue (13-months is too little for H-TESSEL)
  - **3D runs + DA are the promise**
    - 6-month cycle at low H/V res (need a control and a experiment)
    - DA increments act as “scores”

Summary and conclusions (III)

- **Land surface data assimilation follow closely**
  - **The ELDAS DA scheme (simplified EKF within IFS) is under development**
    - T21 OSSE available (phasing to current IFS cycle in progress).
    - Advanced RTM developments (LSMEM, L-band, C-band) in preparation for SMOS
    - ERS scat (SM products) could also be assimilated
  - **The CaLDAS DA scheme (simplified 2D-VAR offline) used in research mode:**
    - LAI OSSE (2001) at 0.5x0.5 over AMMA (C-TESSEL simulated LAI)
    - LAI OSE (2001) with over AMMA SPOT/VEGETATION LAI product
- **Offline vs. Atmospheric coupled land surface DA schemes**
  - **Cost is a clear advantage of offline DA allowing to preserve high resolution**
    - Equivalence at moderate resolution (with GEM-15km, MSC)
    - Preliminary tests within IFS in progress (research issue)

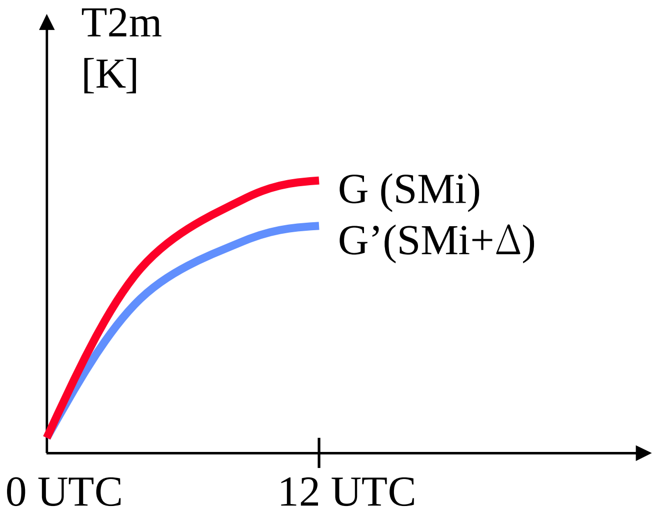
Thanks for attention!

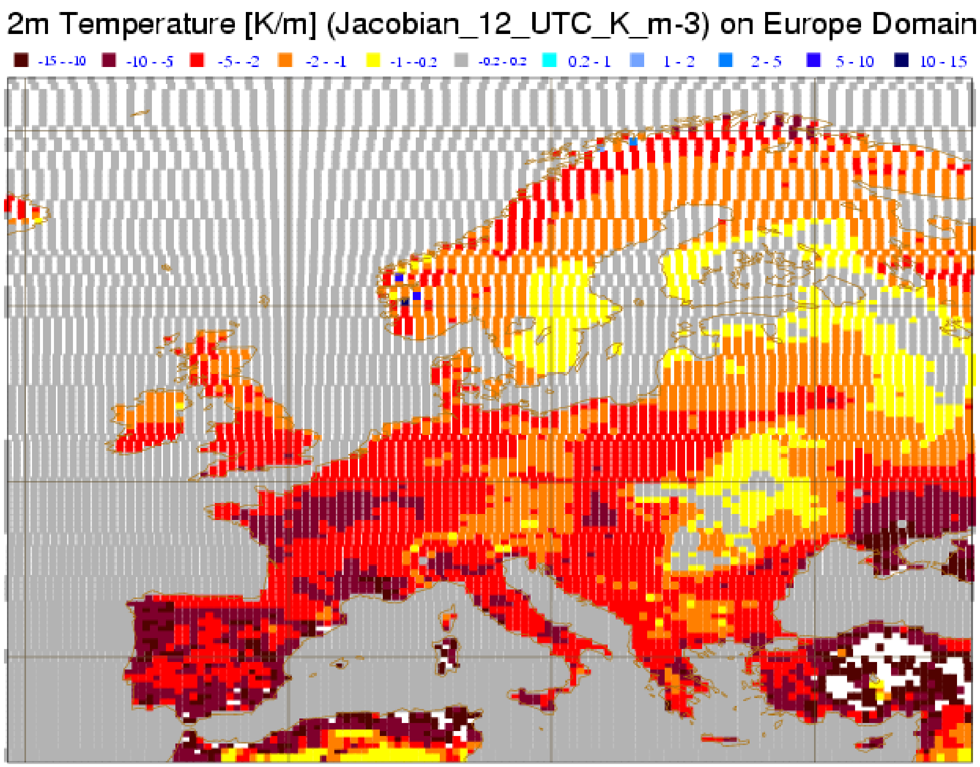
Acknowledgements

- Thanks also to Pedro Viterbo, Bart van den Hurk, Alan Betts and others

Preliminary test of the offline Jacobian for T2m/soil moisture in IFS (forcing at 10m).

- Similarly to LAI DA the SM DA could be implemented offline
- A first test is performed



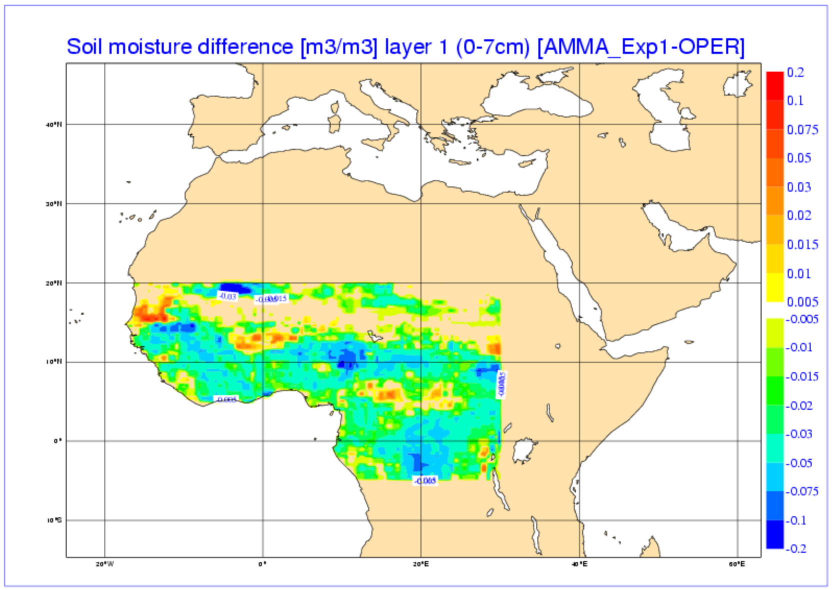


ECMWF

2D offline simulations: AMMA

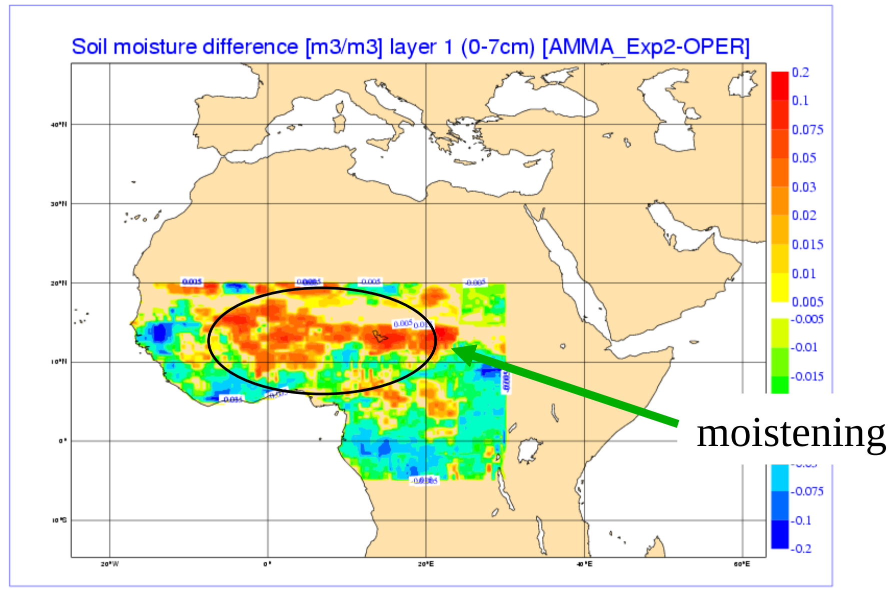
- **AMMA 2001-2005 (**2004-2005 “observed forcing” by A. Boone at Météo-France**)**
- **Soil moisture (SM) sensitivity to precipitation**

Offline TESSEL (open loop)



Exp1 - Control

Offline TESSEL + AMMA prec. forcing



Exp2 - Control

Exp1 allows to explore the impact of OI on AMMA region while Exp2 the precipitation impact