Land surface Modelling and Data Assimilation at ECMWF

Gianpaolo Balsamo and Patricia de Rosnay

Thanks to: Peter Bechtold, Anton Beljaars, Souhail Boussetta, Emanuel Dutra, Jean-Jacques Morcrette, Joaquin Munoz-Sabater, Florian Pappenberger, Bart van den Hurk (KNMI), Pedro Viterbo (IM), Clement Albergel (MF), Jean-Christophe Calvet (MF), Matthias Drusch (ESA), Klaus Scipal (ESA), Camille Szczypta (MF), Dick Dee, Antje Weisheimer, Francisco Doblas-Reyes (IC3)

OUTLINE

- Introduction
  - Land surface evolution at ECMWF: a roadmap from a Boundary Condition provider towards Ecosystem modelling and data assimilation
- The land surface model update:
  - A revised soil and snow hydrology
  - A satellite-based vegetation seasonality
- The land surface data assimilation update:
  - An Extended Kalman Filter for Soil moisture
  - A New Snow Analysis
- Summary and Conclusions

Role of land surface at ECMWF

ECMWF model(s) and resolutions

	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)
- 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.

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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)

  <u>ERA-40 and ERA-I scheme</u>

- **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. (2010)

  Revised snow density

  Liquid water reservoir

  Revision of Albedo and sub-grid snow cover

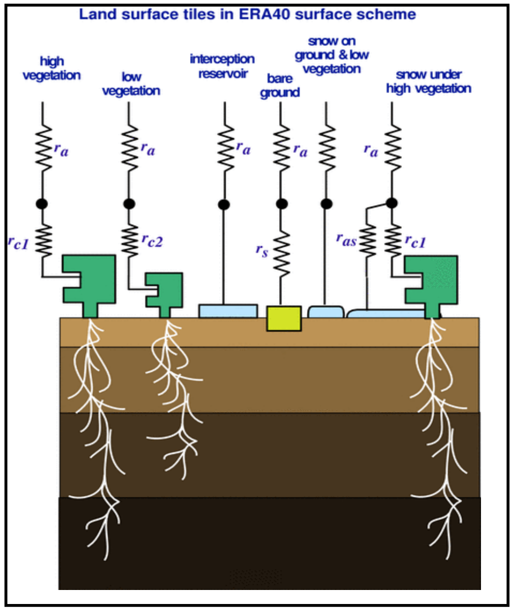
- **NEW LAI**

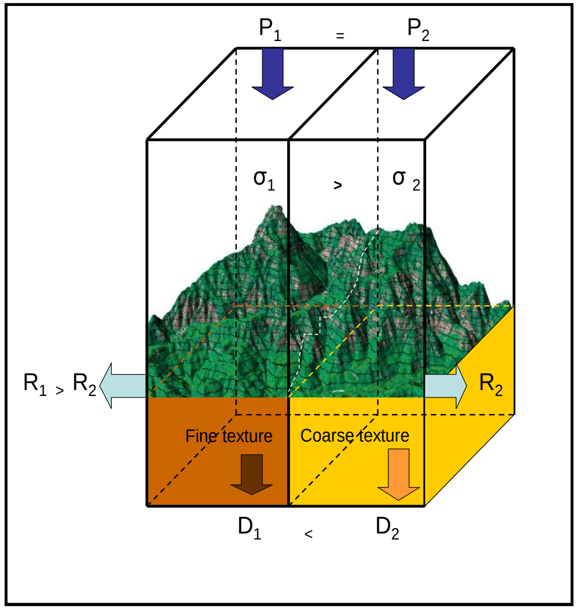
  Boussetta et al. (2010)

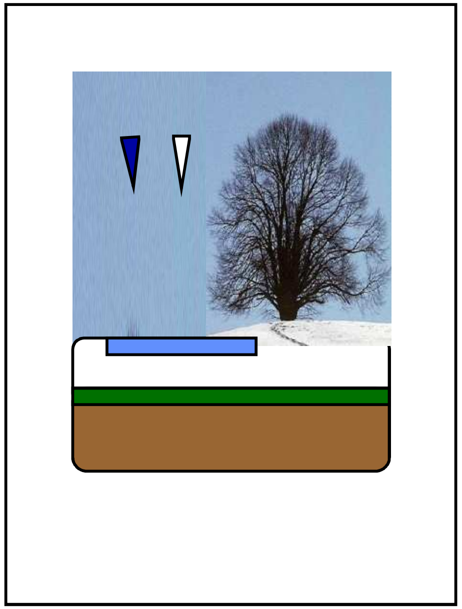
- **FLAKE**

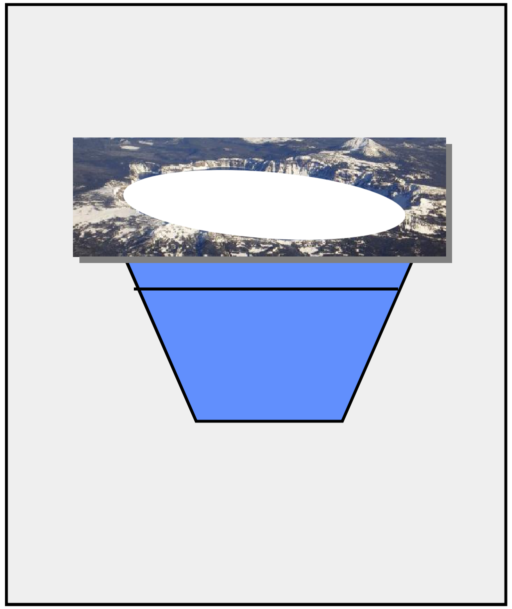
  Mironov et al (2010),
  Dutra et al. (2010),
  Balsamo et al. (2010)

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





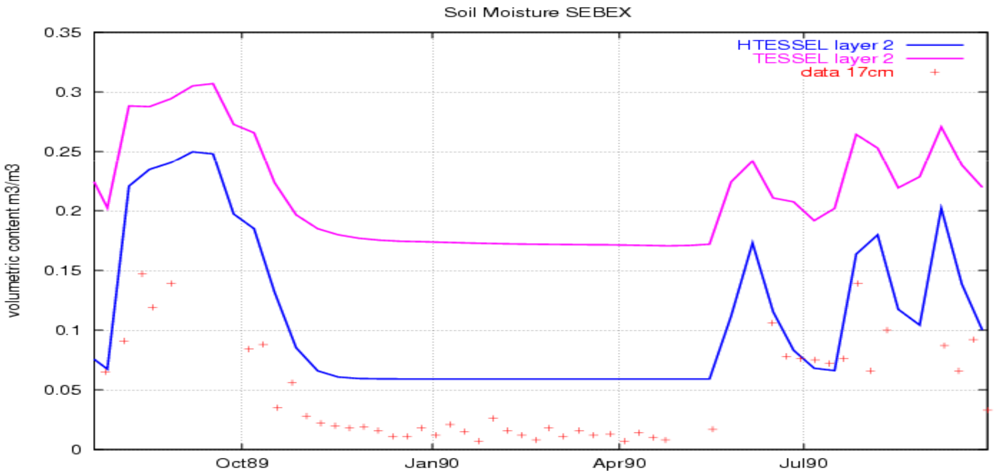


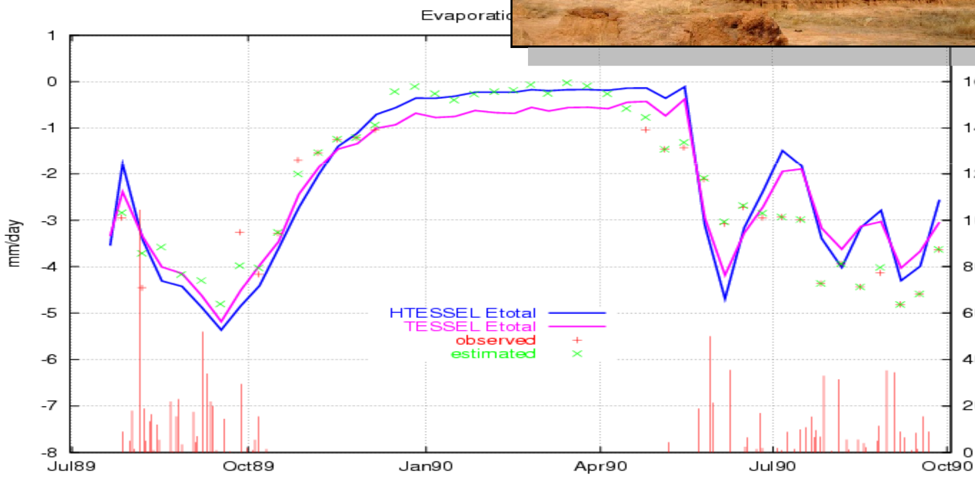


ECMWF

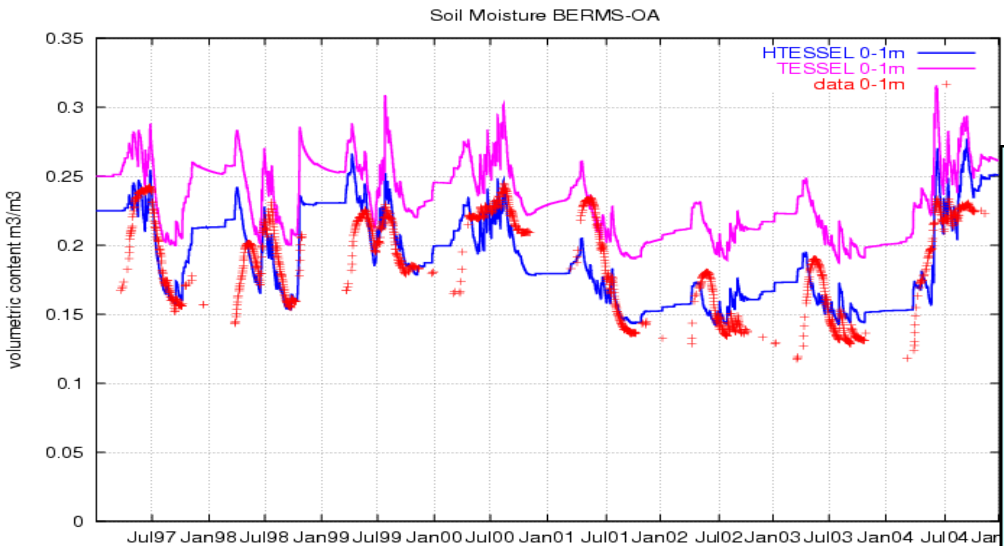
HTESSEL soil hydrology: Improved match to soil moisture while preserving evaporation

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

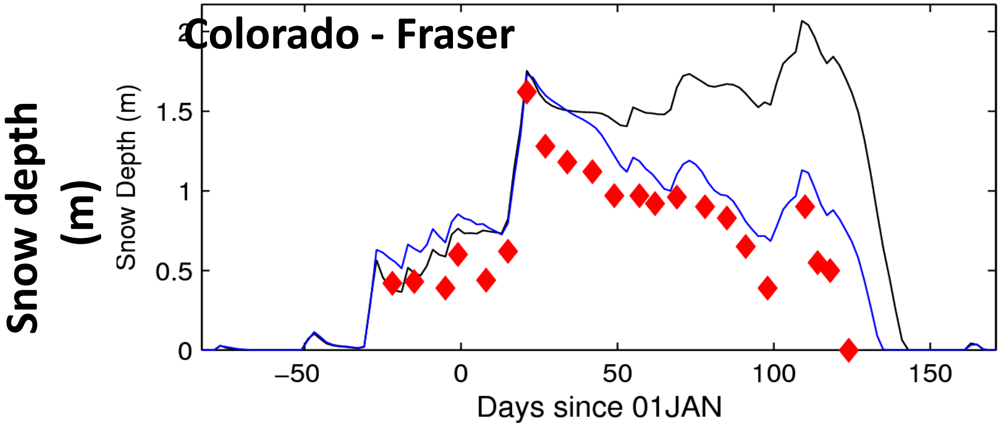
A new snow model (09/2009)

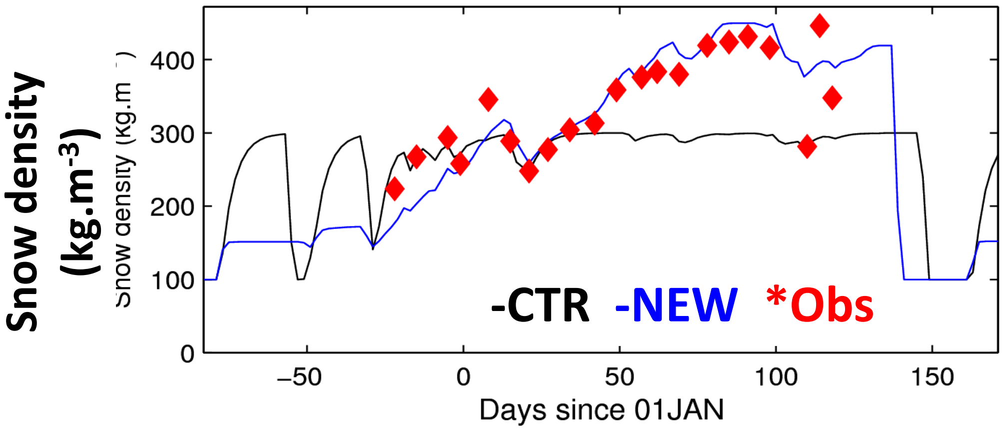
- The snow scheme from Douville et al. (1995) had few shortcomings shown on SNOW-MIP2 (Rutter et al. 2009) and highlighted by the ERA-40 analysis increments
- A revised snow scheme has been developed by Dutra et al. (2009) in collaboration with IM (P. Viterbo), Univ. of Lisbon (P. Miranda), ETH (C. Shär)
- The revised snow scheme has been tested in cycle 33R1 and implemented in cycle 31R2(ERA-Interim) / 35R2 / 35R3(operational on the 10^{th} of September 2009).
  - Vegetation-dependent roughness (CY31R2)
  - Liquid water in the snow-pack (CY35R2)
  - Snow density (CY35R2)
  - Interception of rainfall (CY35R3)
  - Forest-Snow albedo revision
  - Open-area snow albedo revision
  - Snow fraction (depth dependent)

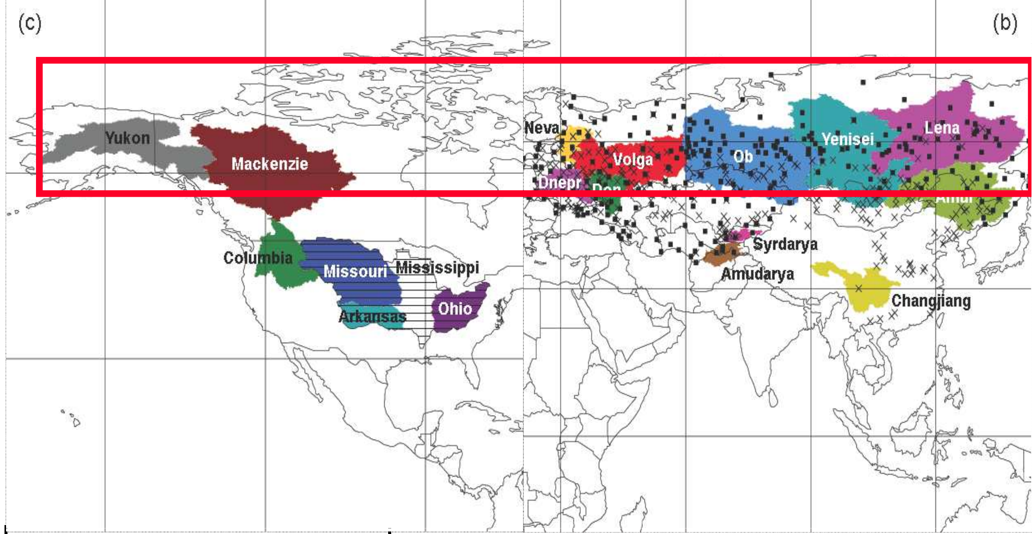
Impact of new snow (SnowMIP2/GSWP2)

Dutra et al. (2009 JHM)

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



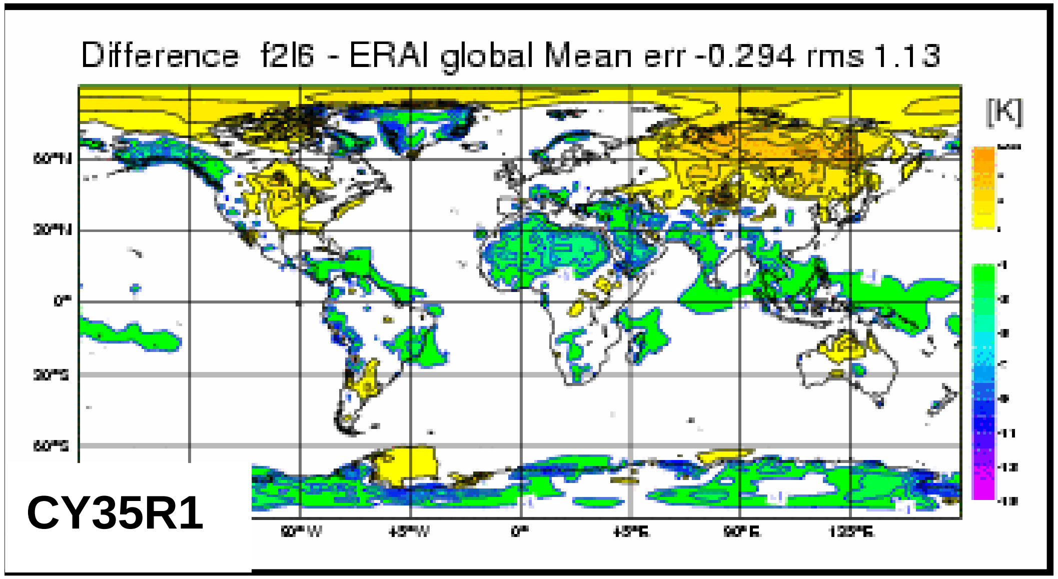


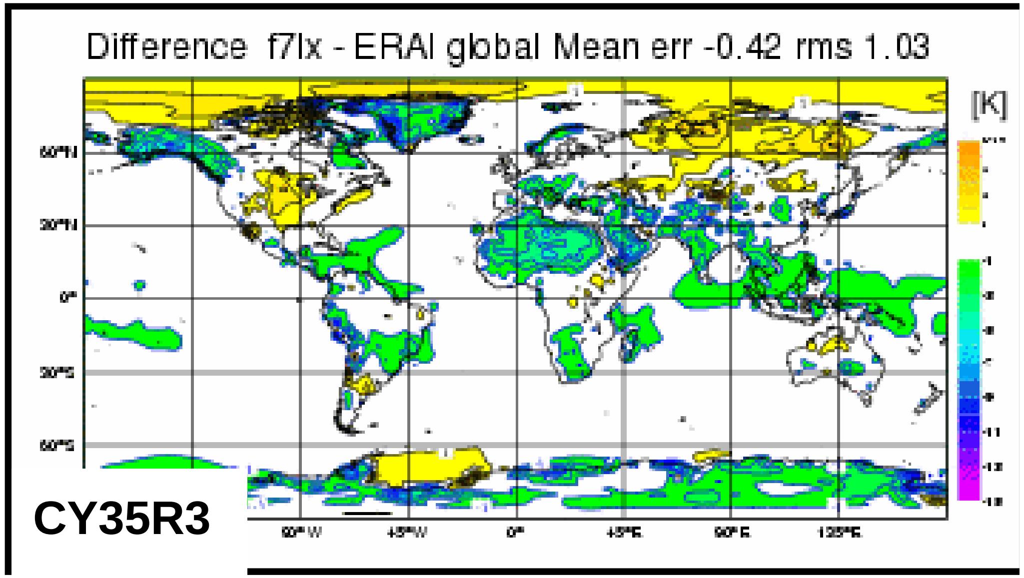


NH BASINs	Average of Yukon, Podka., Lena, Tom, Ob, Yenisei, Mackenzie, Volga, Irtish, Neva
Area	12 334 161 km^2
Snow Days	157
Runoff	1.96 mm/day
CTR RMSE (GRDC)	0.75 mm/day
NEW RMSE (GRDC)	0.51 mm/day

“Climate runs” with the new snow

- **The annual mean T2m bias (13-month 4-member hindcasts with prescribed SSTs) is reduced in snow-areas as a consequence of the snow model improvements**

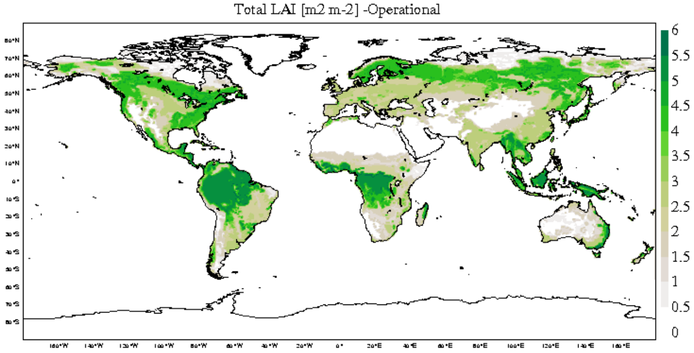




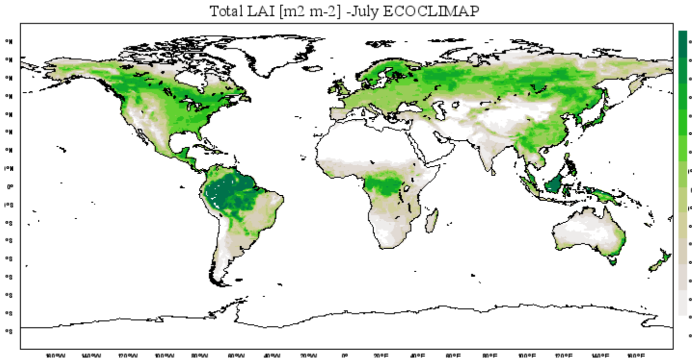
ECMWF

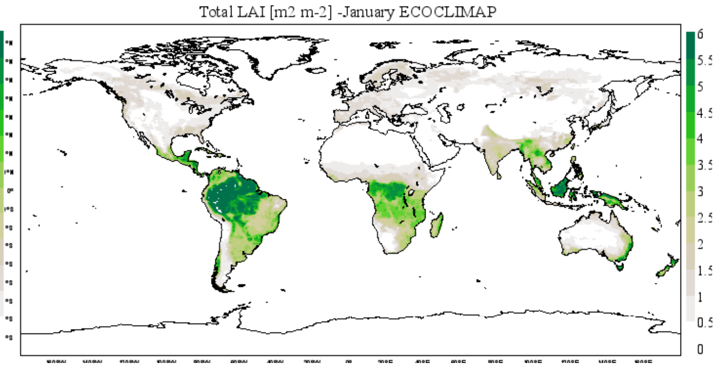
Vegetation Seasonality

OPER LAI (van den Hurk et al. 2000)



ECOCLIMAP LAI (Masson et al. 2003)

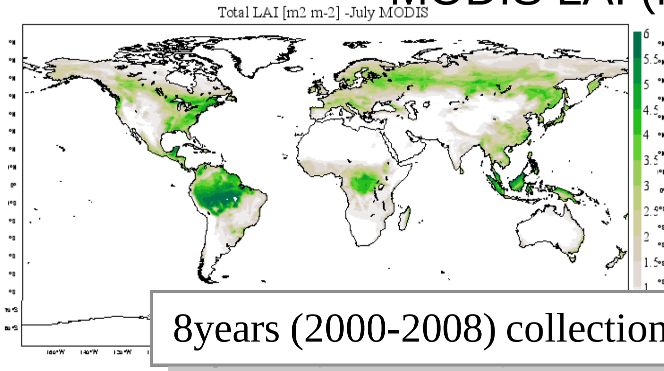


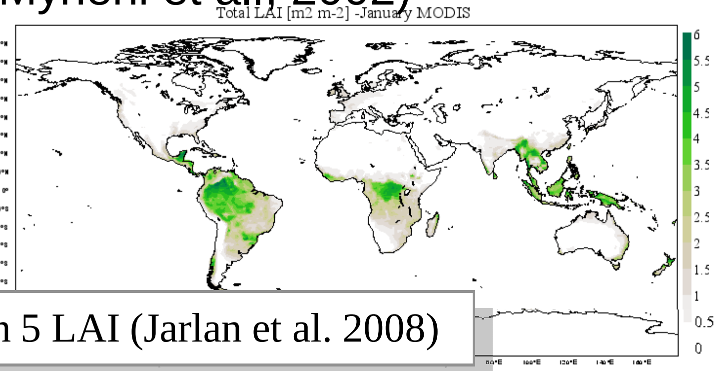


Study Started with the project GEOLAND 2004-2007 and ongoing within GEOLAND-2 2009-2012

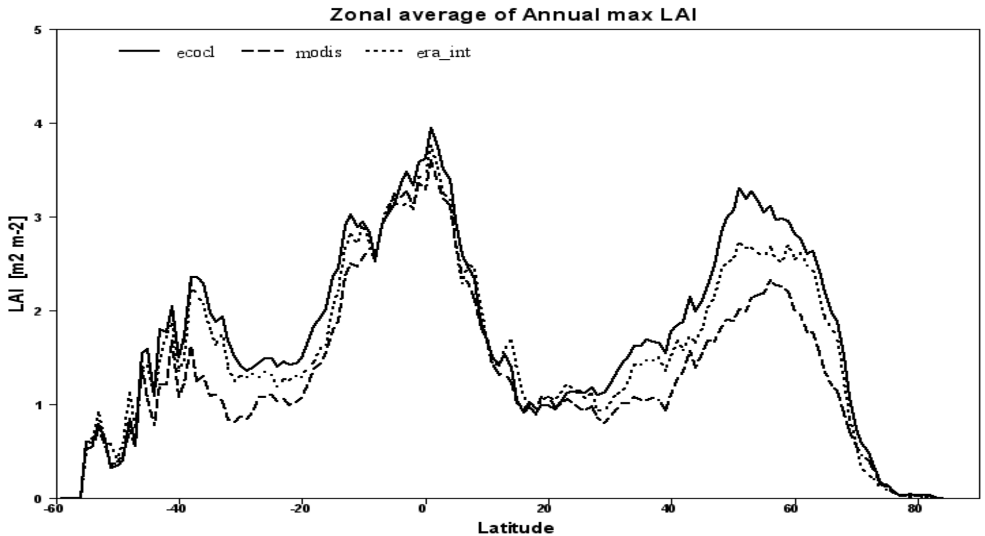
Goal: Add the land surface carbon cycle to HTESSEL.

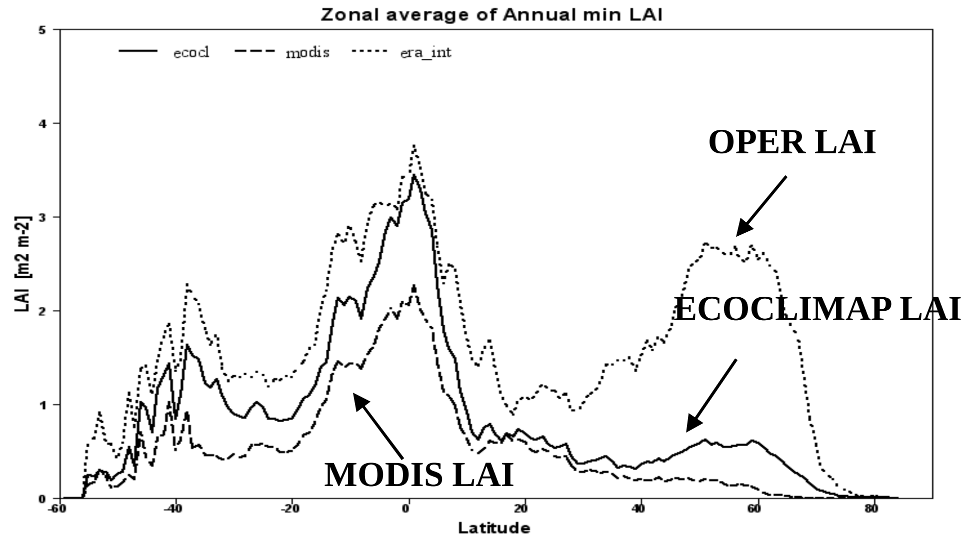
MODIS LAI (Myneni et al., 2002)





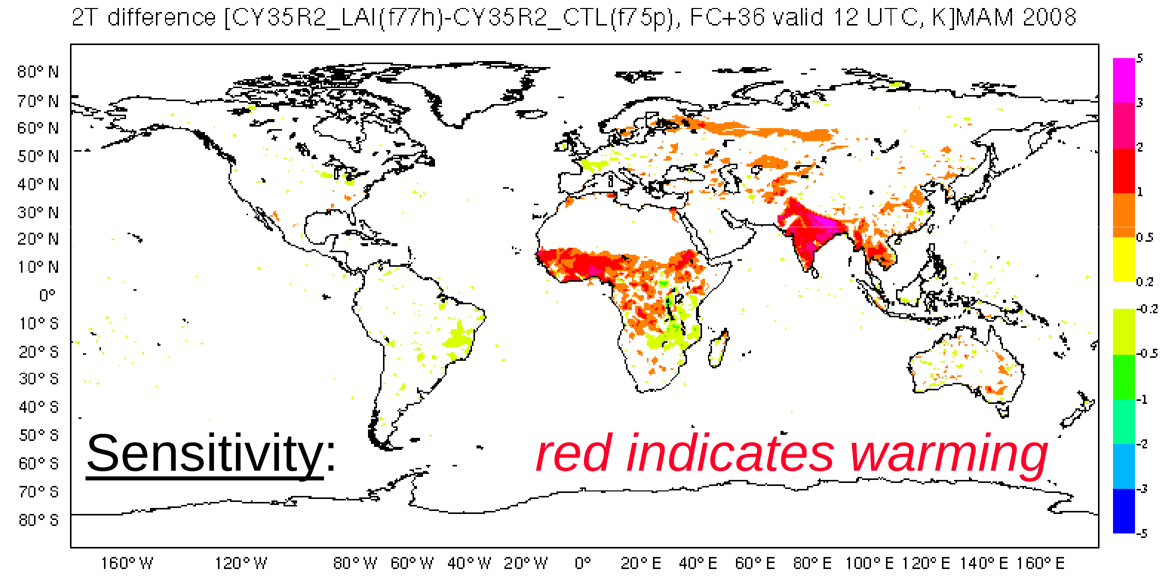
8years (2000-2008) collection 5 LAI (Jarlan et al. 2008)

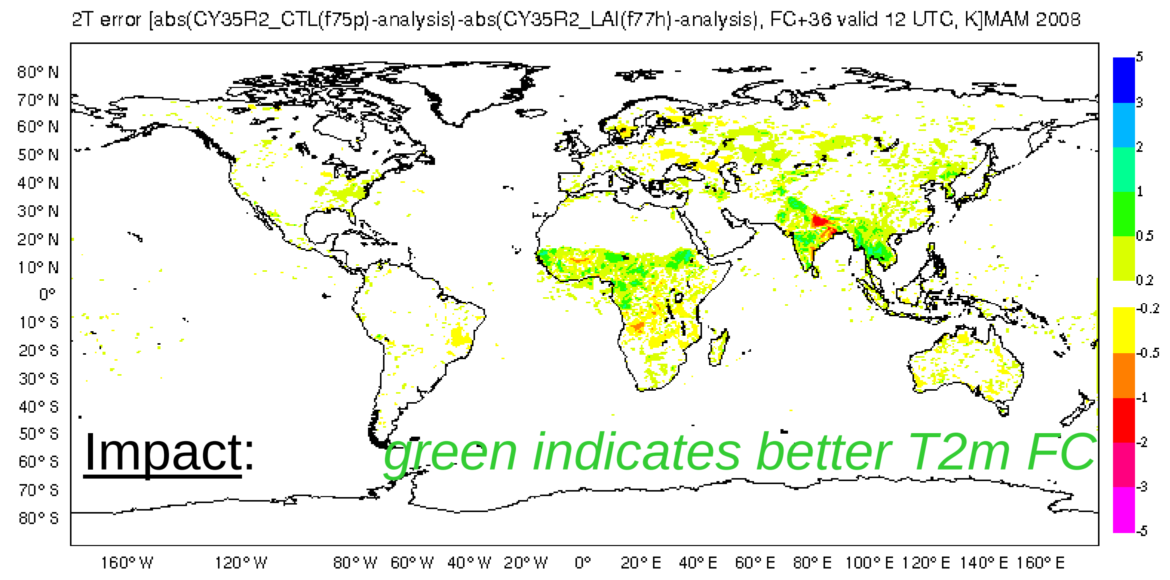




Vegetation Seasonality: sensitivity

Boussetta et al. (2010, submitted), collaboration with EC-Earth





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 $LAI \downarrow$ then $r_c \uparrow$ and $E \downarrow$ so $T2m \uparrow$

If $LAI \uparrow$ then $r_c \downarrow$ and $E \uparrow$ so $T2m \downarrow$

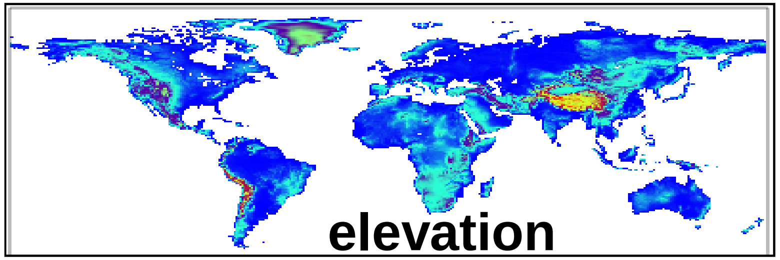
- **This has beneficial impact on near surface temperature forecast (green being positive impact in reducing t2m bias by ~0.5degree)**
- **A stepping stone to include carbon modelling (CTESSEL)**

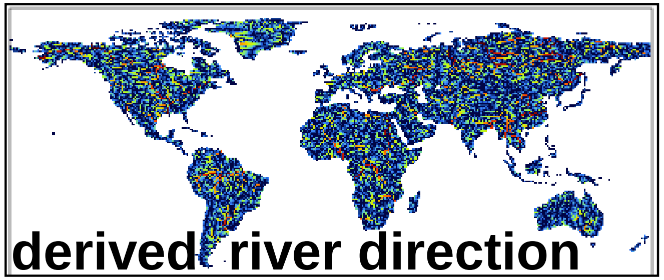
ECMWF

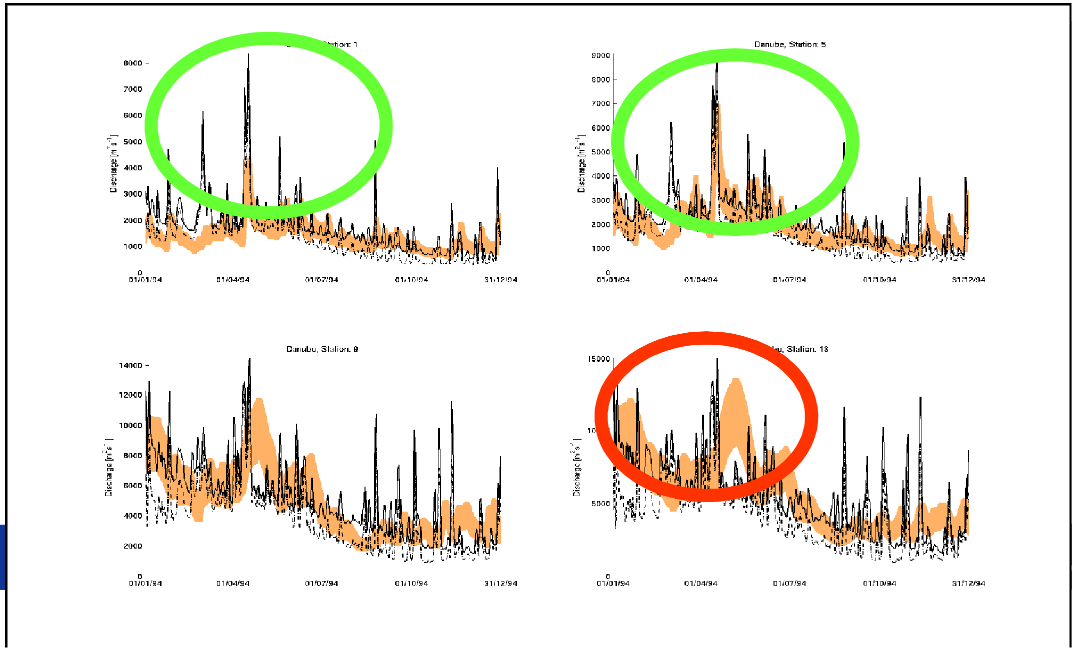
HTESSEL and river hydrology

F. Pappenberger, H. Cloke, G. Balsamo, N.D. Thanh, T. Oki
(*Int. J. of climatol., in press*)

- **A routing scheme [TRIP2 evolution of TRIP , Oki and Sud, 1998)] is coupled to HTESSEL to account water path into rivers.**
- **The aim is to assess skill of the land surface models water output (Runoff) for river discharge modelling**







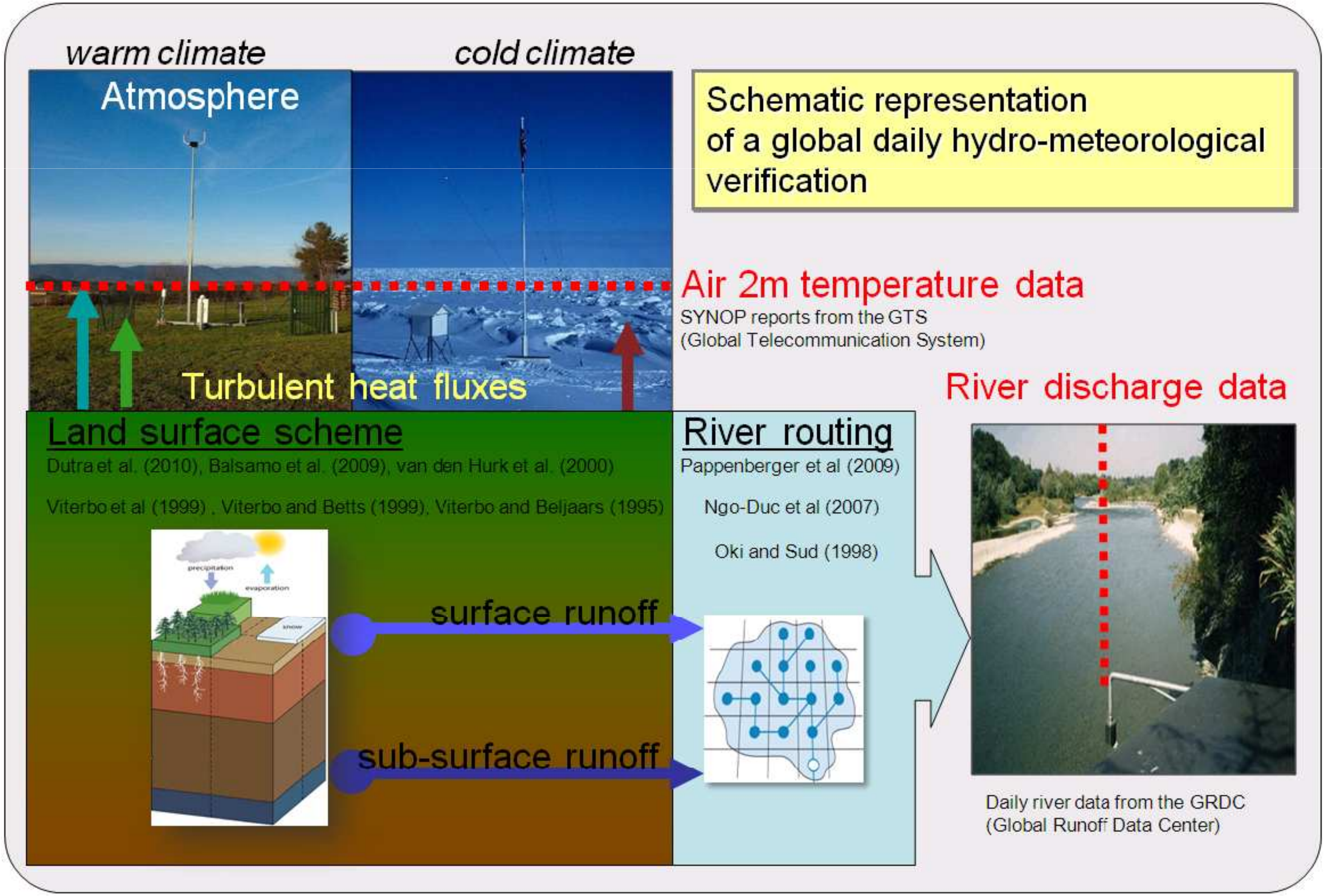
GSWP2+HTESSEL+TRIP2

Figure 10: Observed and modelled hydrographs (using HTessel) for four stations on the Danube river for the year 1994. The orange area indicates the observed data with its uncertainties. The dotted black line represents the 5th and 95th percentiles of the modelled flow.

HTESSEL and daily fluxes verification (river & screen level)

G. Balsamo, F. Pappenberger, E. Dutra, P. Viterbo, B. van den Hurk.

(*Hydrol. Proc., accepted*)



If we consider 3 model versions:

- SNOWHTESSEL
- HTESSEL
- TESSEL

River verification: can it show model improvements?

G. Balsamo, F. Pappenberger, E. Dutra, P. Viterbo, B. van den Hurk.

(*Hydrol. Proc., accepted*)

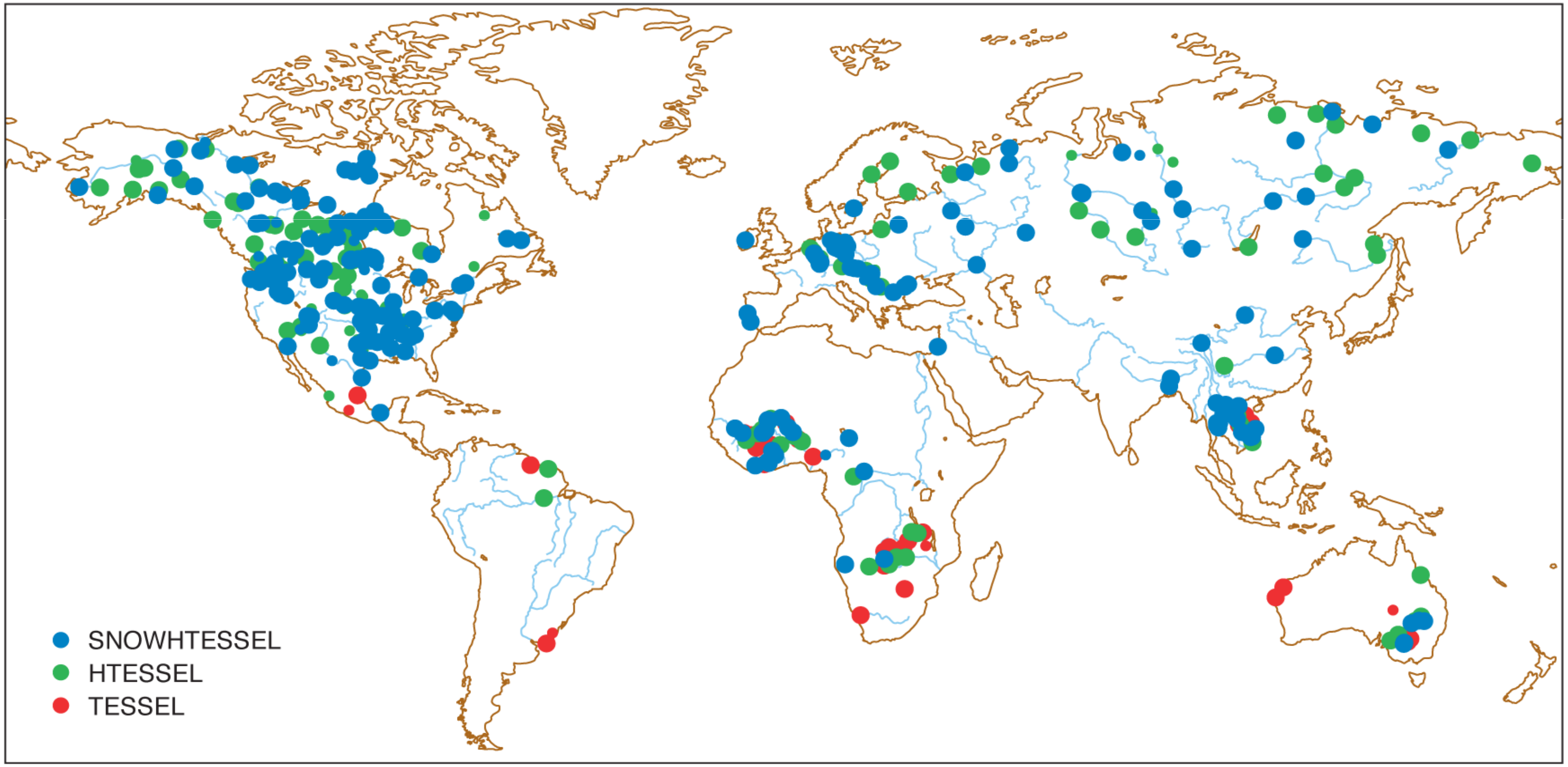
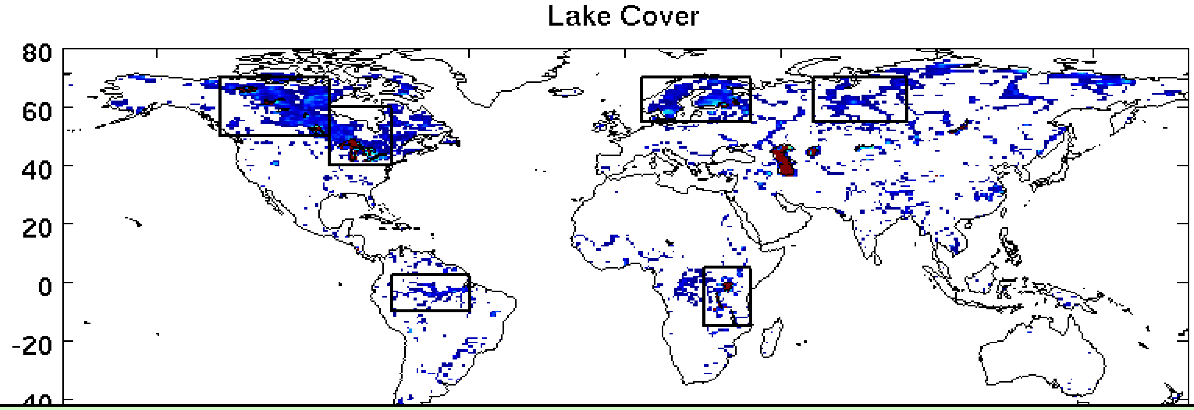


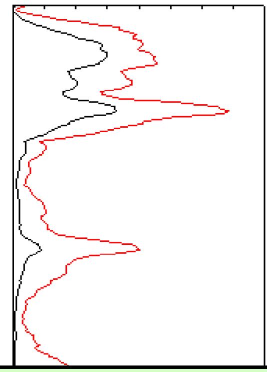
Figure 7: Indication of best correlated modelled and observed river discharges. Models include SNOWHTESSEL (blue), HTESSEL (green), and TESSEL (red). Large circles indicate the best performing scheme is significantly better than the others at a 5% significance level, while small circle indicate non-significant improvements. All river discharges plotted have positive correlation significantly different from zero.

	Correlation of daily river discharges	Number of river gauges (out of 211)
SNOWHTESSEL	**0.33**	**116 best correlate rivers**
HTESSEL	**0.25**	**81**
TESSEL	**0.09**	**14**

Lake modelling

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

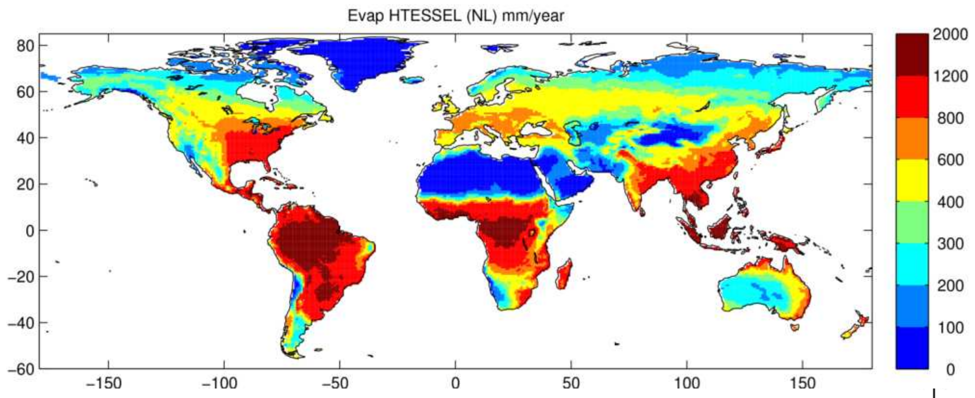


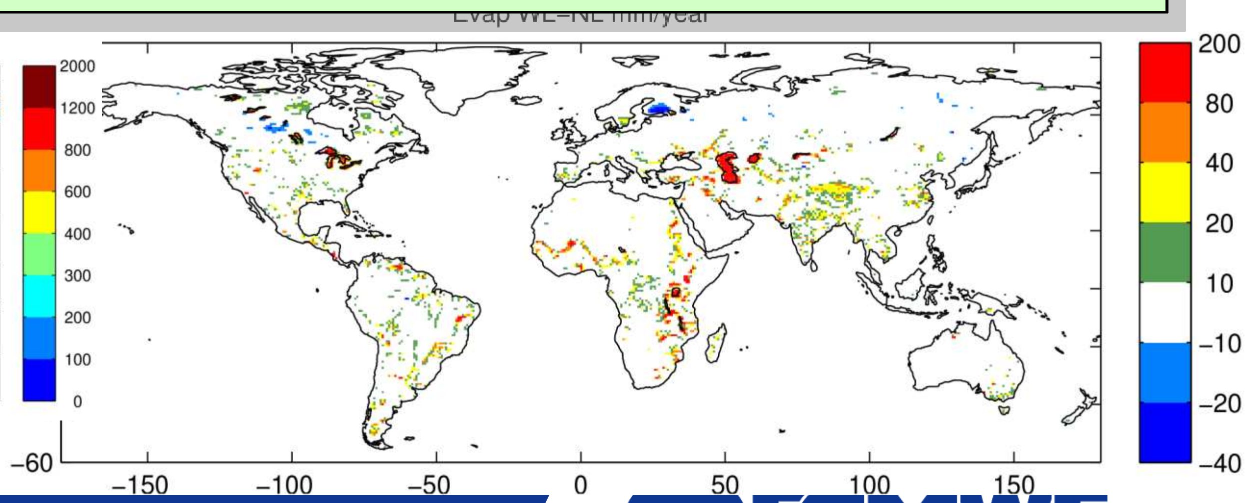


- FLAKE Lake model is implemented in CY35R3.
- Evaporation rates are greatly increased in temperate climate

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

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Land surface data assimilation evolution

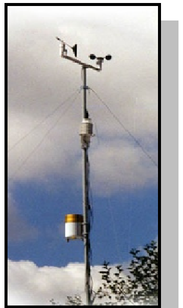
1999/07	2004/03	2008/09 2010

- **OI screen level analysis**

  Douville et et al. (2000)

  Mahfouf et al. (2000)

  Soil moisture analysis based on Temperature and relative humidity analysis

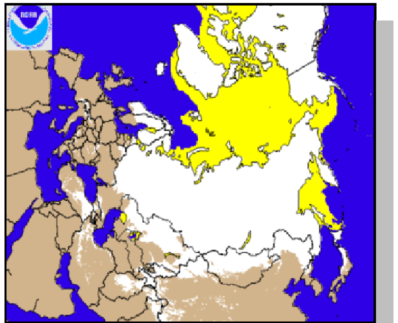


- **Revised snow analysis**

  Drusch et al. (2004)

  Cressman snow depth analysis using SYNOP data

  Improved by using NOAA / NSEDIS Snow cover extend data

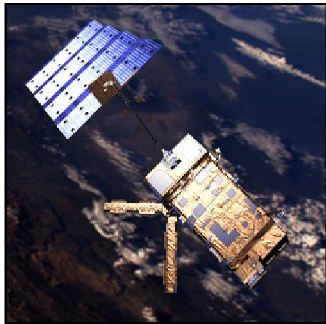


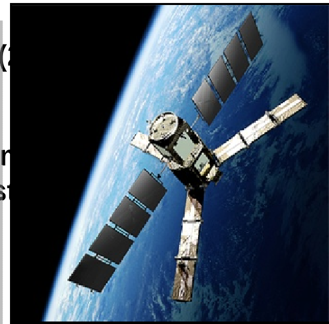
- **NEW EKF Soil Moisture analysis**

  Drusch et al. (2009) De Rosnay et al. (2010)

  Extended Kalman Filter developed for soil moisture analysis

- **NEW OI Snow analysis**





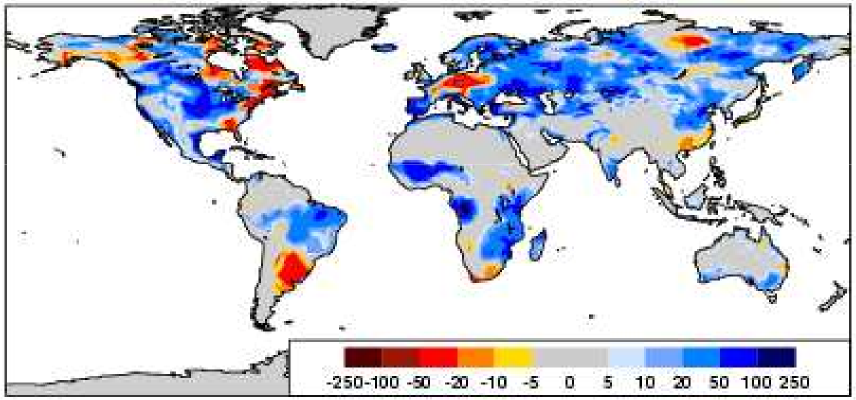
METOP-ASCAT SMOS

- Potential for re-analysis to exploit land surface satellite data, such as long time series of soil moisture data (e.g. ASCAT).
- Potential to extend the surface analysis to use vegetation parameters from satellite data (e.g. AVHRR).
- Stand alone surface analysis: opens the possibility to run re-analysis at high resolution for land surfaces.

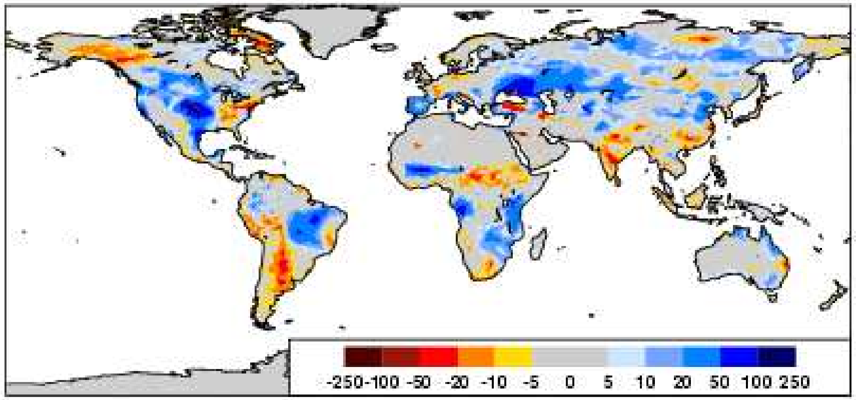
A new EKF soil moisture analysis

de Rosnay et al (2010 in prep.), Drusch et al (2009)
Implementation in IFS cycle 36r4 (currently in the e-suite)

Soil moisture increments (mm) July 2009



OI

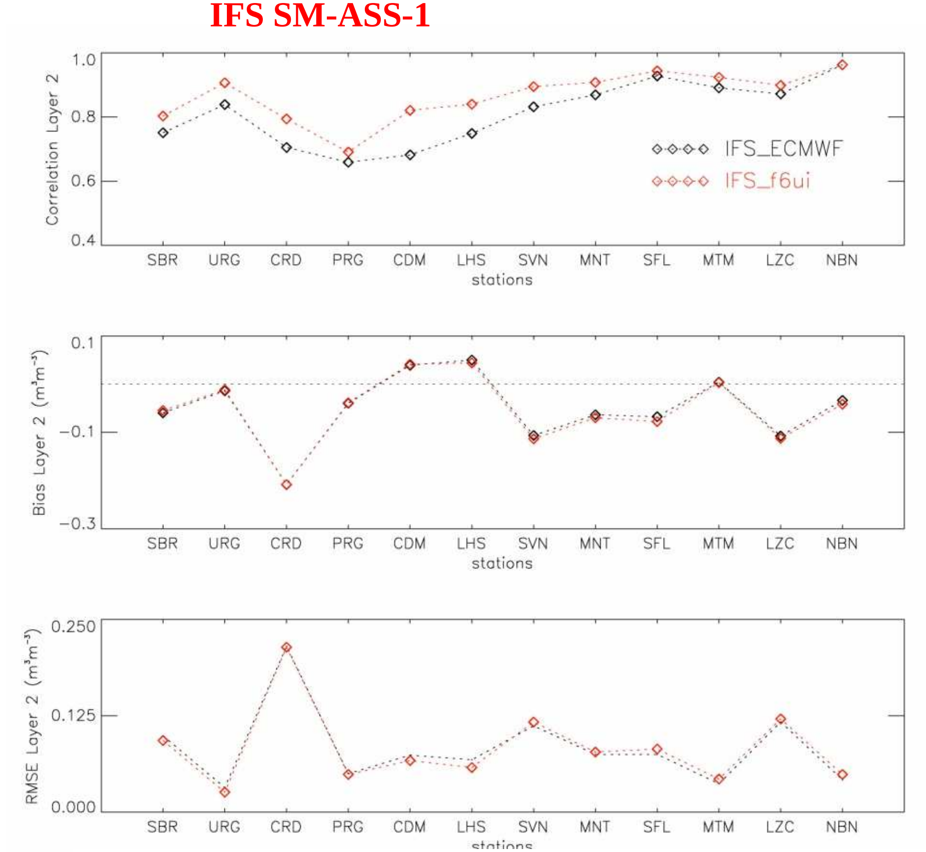


SEKF

r	
IFS oper	IFS SM-ASS-1
0.812	0.866

ECMWF layer 2 soil moisture (7-21cm) against 10 in-situ datasets –20c

IFS Oper
IFS SM-ASS-1



Albergel et al. (2010)
SMOSMANIA validation of EKF

ECMWF Root zone soil moisture product based on ASCAT data assimilation

- July 2008-August 2010 daily data

-H-SAF area – also available at global scale

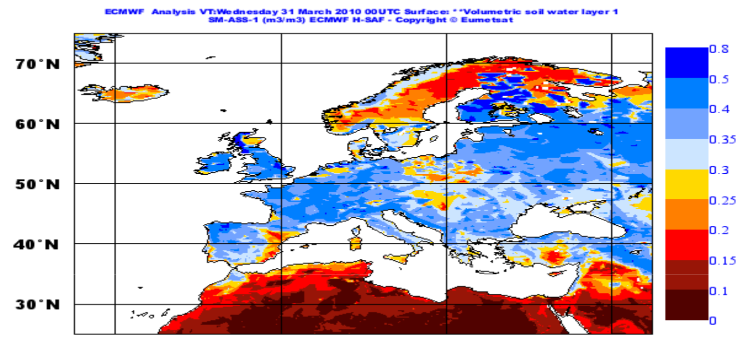
- Based on ASCAT surface soil moisture data assimilation in the IFS, using the EKF soil moisture analysis.

Link with:
- SAF-CAF: Use of the global soil moisture product in the SM-ASS-1 production chain
-Inter-SAF:
- LSA-SAF: SM-ASS-1 highly relevant input for ETR estimation.
- NWP-SAF RTTOVS: use of the code in the IFS to assimilate radiances
- OSI-SAF: use sea ice in the surface analysis

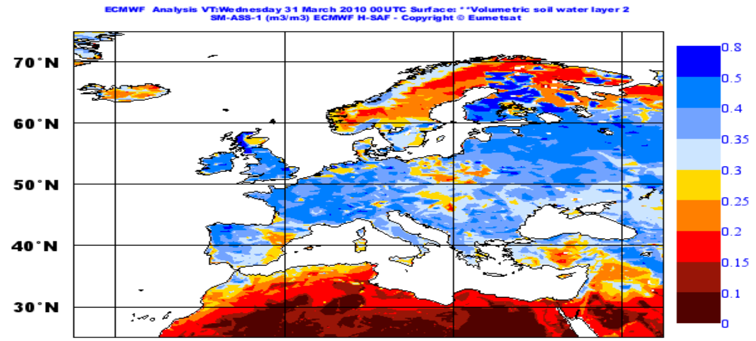
- Other projects: GEOLAND (vegetation), SMOS (ESA project, use of TB).

3-layer daily product

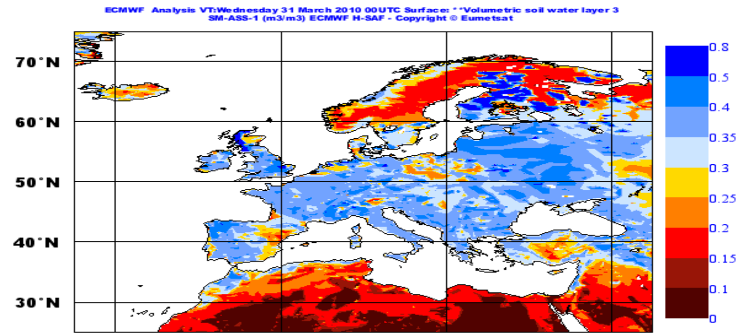
Layer 1: 0-7 cm



Layer 2: 7-28 cm

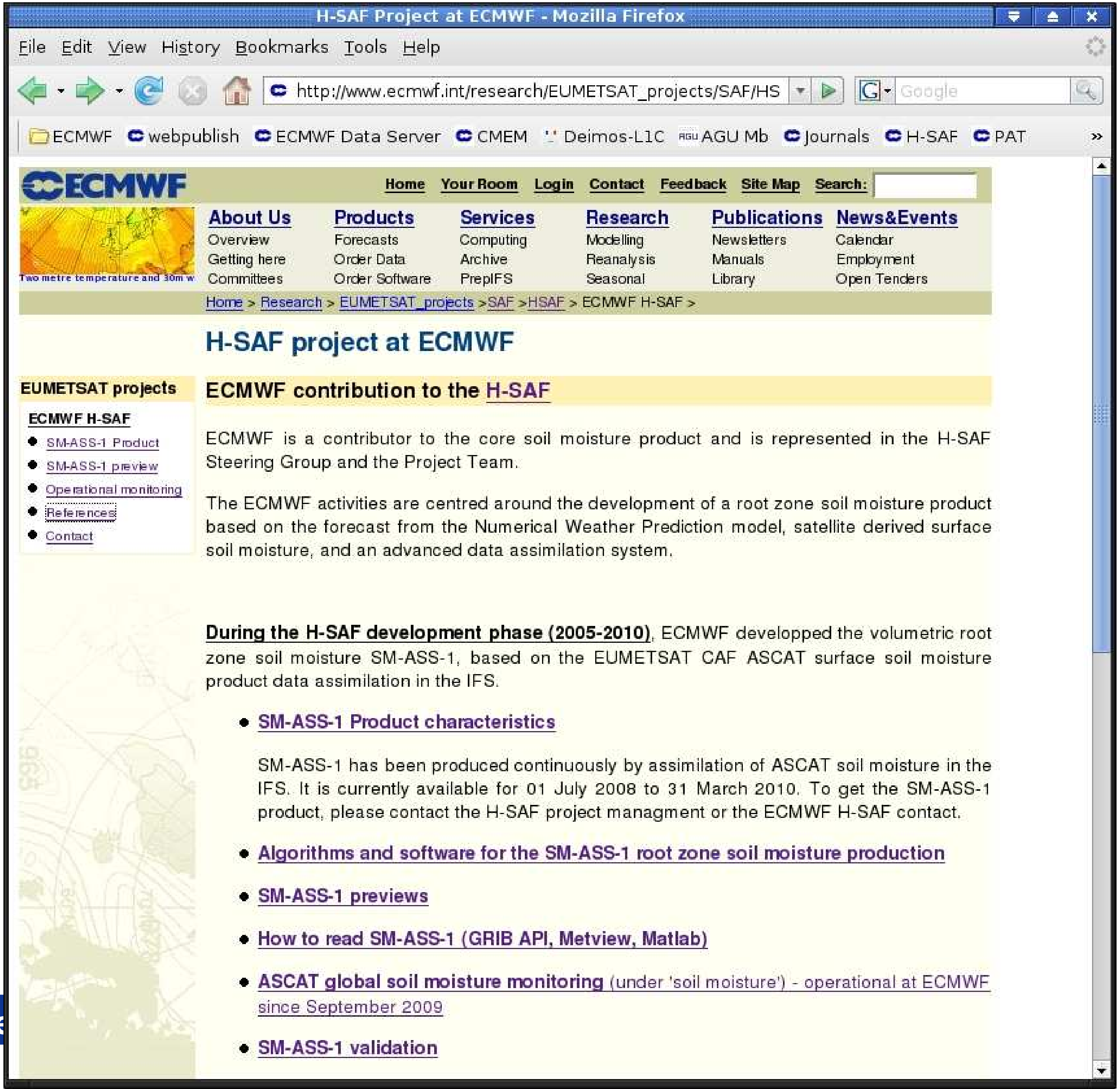


Layer 3: 28-100 cm



ECMWF Root zone soil moisture product based on ASCAT data assimilation

SM-ASS-1 Web page
And product information



SMOS Near-Real-Time monitoring

Munoz-Sabater et al. (2010)

20-Nov-09

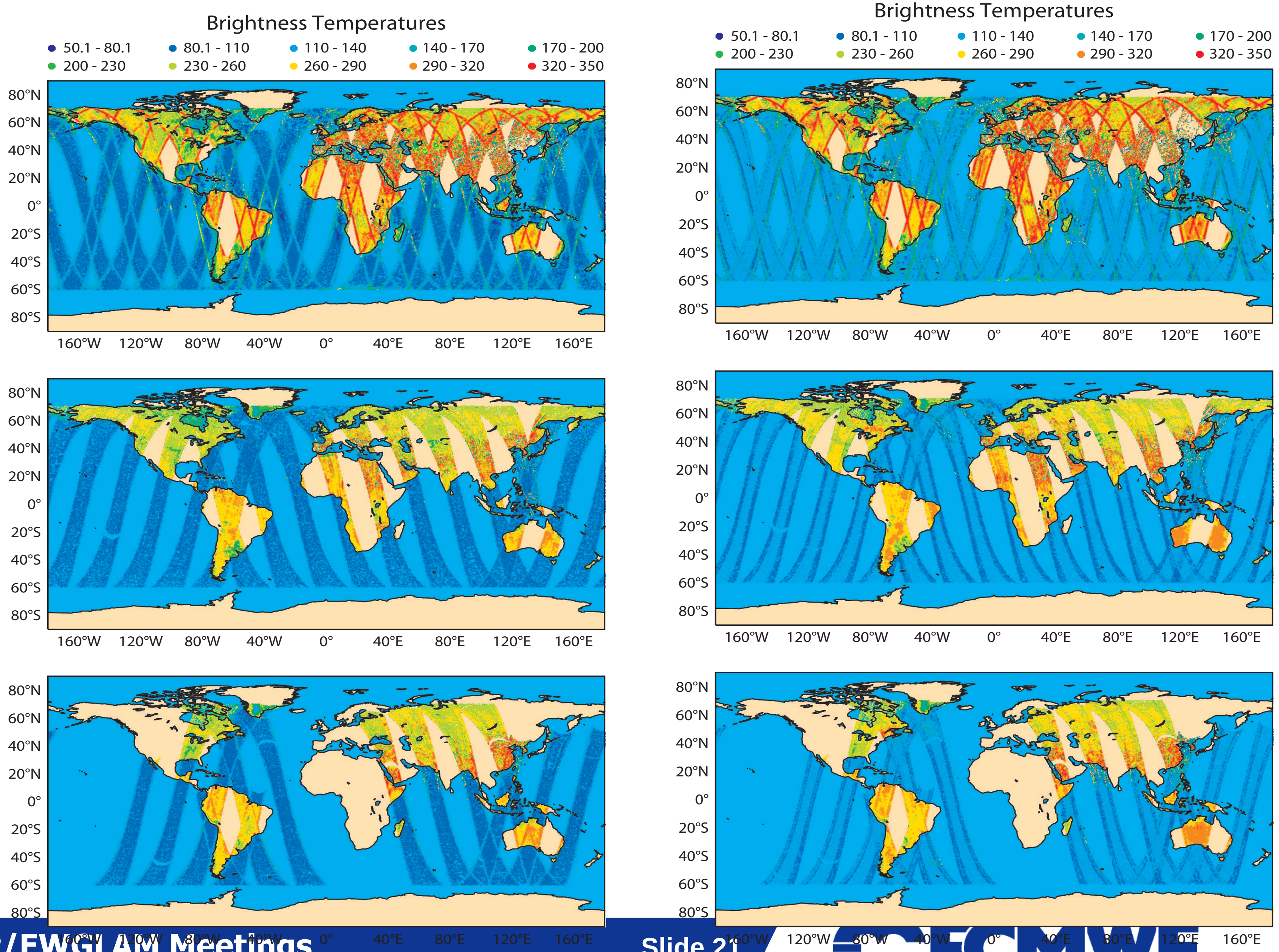
20-Dec-09

NRT

16-Jan-10

NRT

Θ = 40°



TBH

TBV

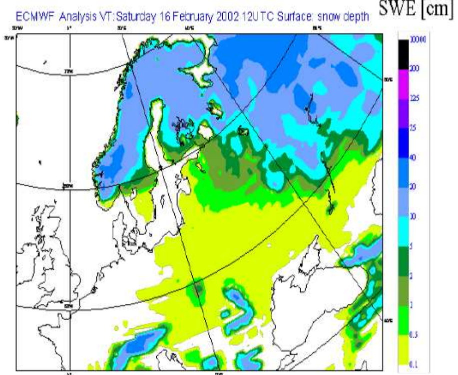
A new snow analysis (I)

For snow SYNOP reports an satellite based snow cover are assimilated

Analyses vs Satellite Data

MODIS 16/02/2002

Analysis based on SYNOP



Snow extent is overestimated in the analysis when it is based on SYNOP data only

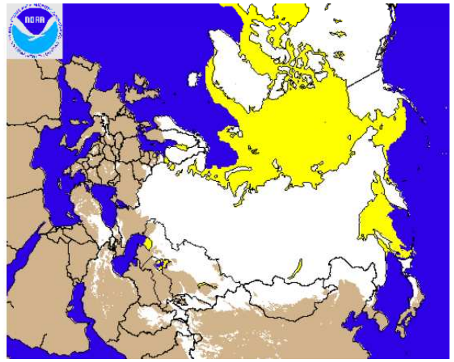
NOAA/NESDIS Snow extent

Interactive Multisensor Snow and Ice Mapping System:

- time sequenced imagery from geostationary satellites,
- AVHRR,
- SSM/I,
- station data,
- previous day's analysis

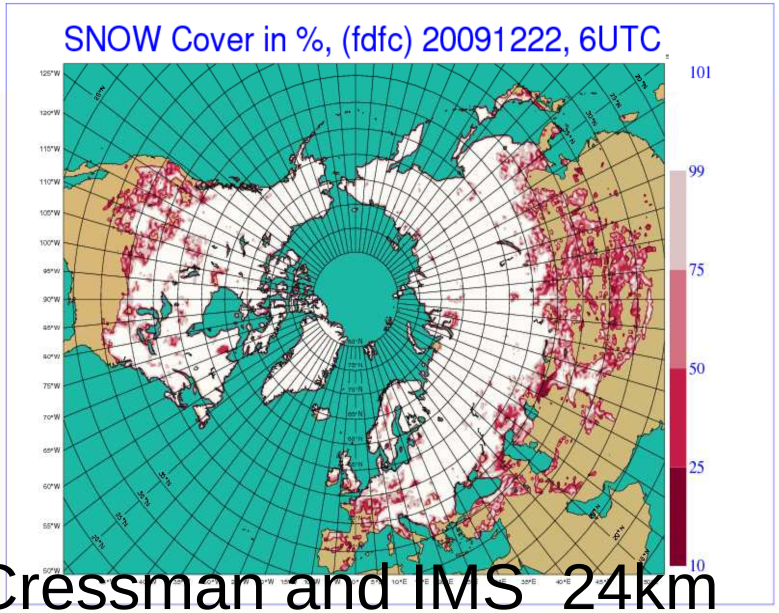
Northern Hemisphere product

- real time
- polar stereographic projection
- 1024 × 1024 elements

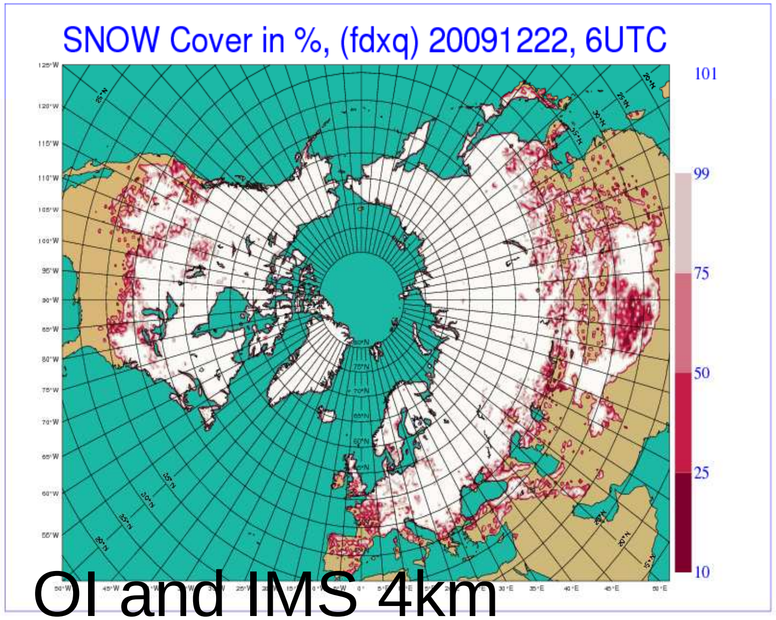


A new 4 km IMS snow cover is assimilated into a new OI analysis replacing Cressman interpolation

Here shown is the analysed snow cover

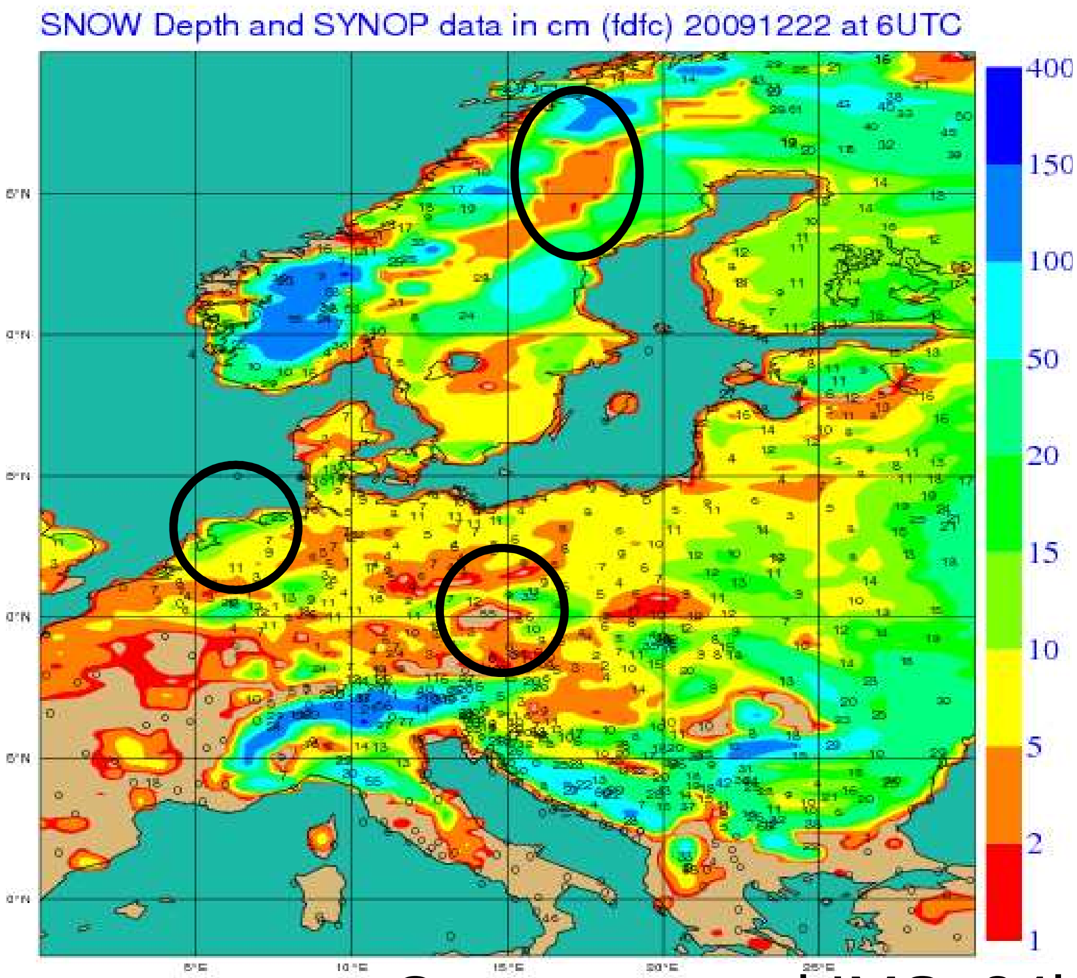


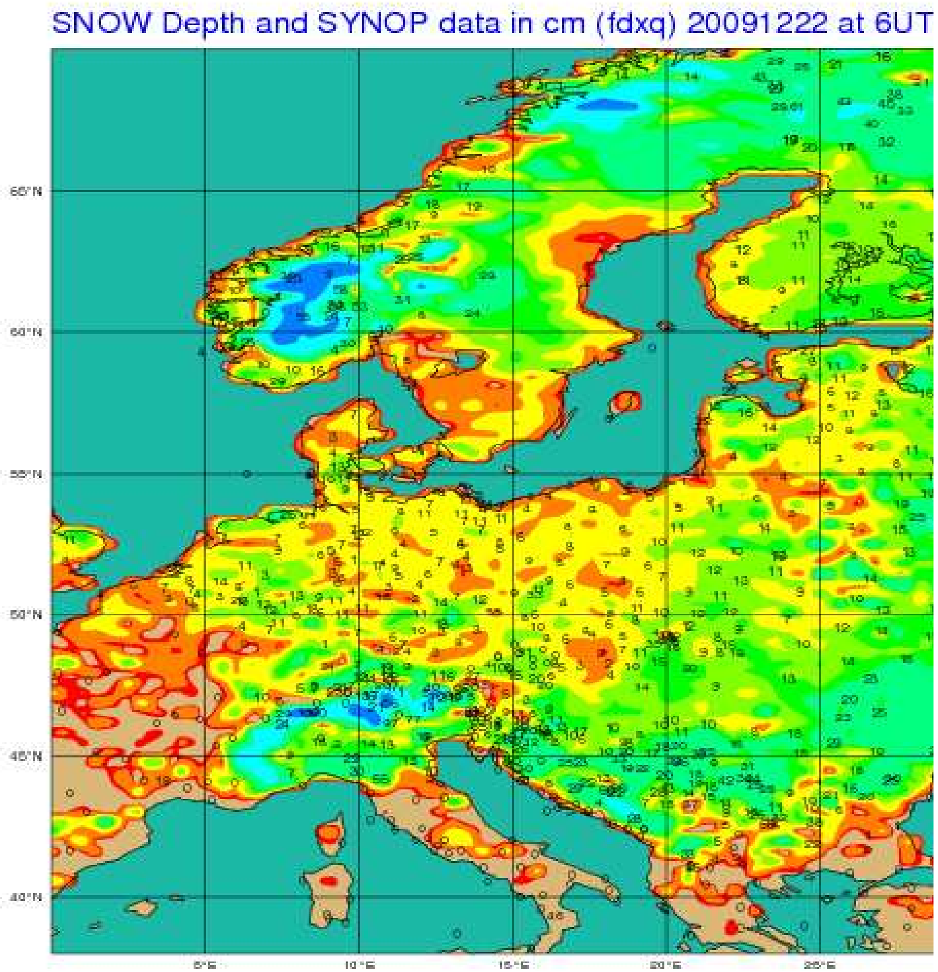
Cressman and IMS_24km



OI and IMS 4km

A new snow analysis (II)



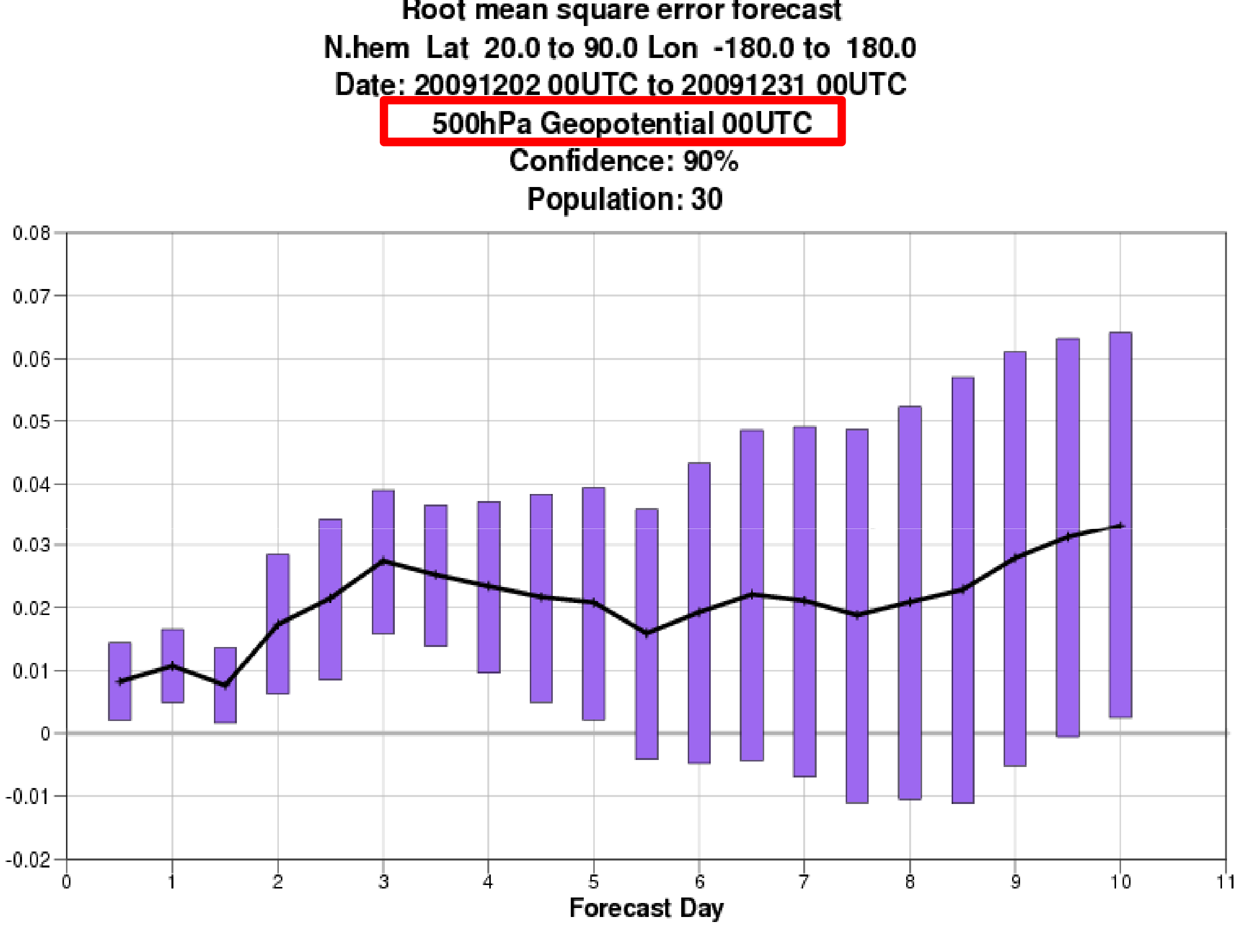


Cressman and IMS_24km

OI and IMS 4km

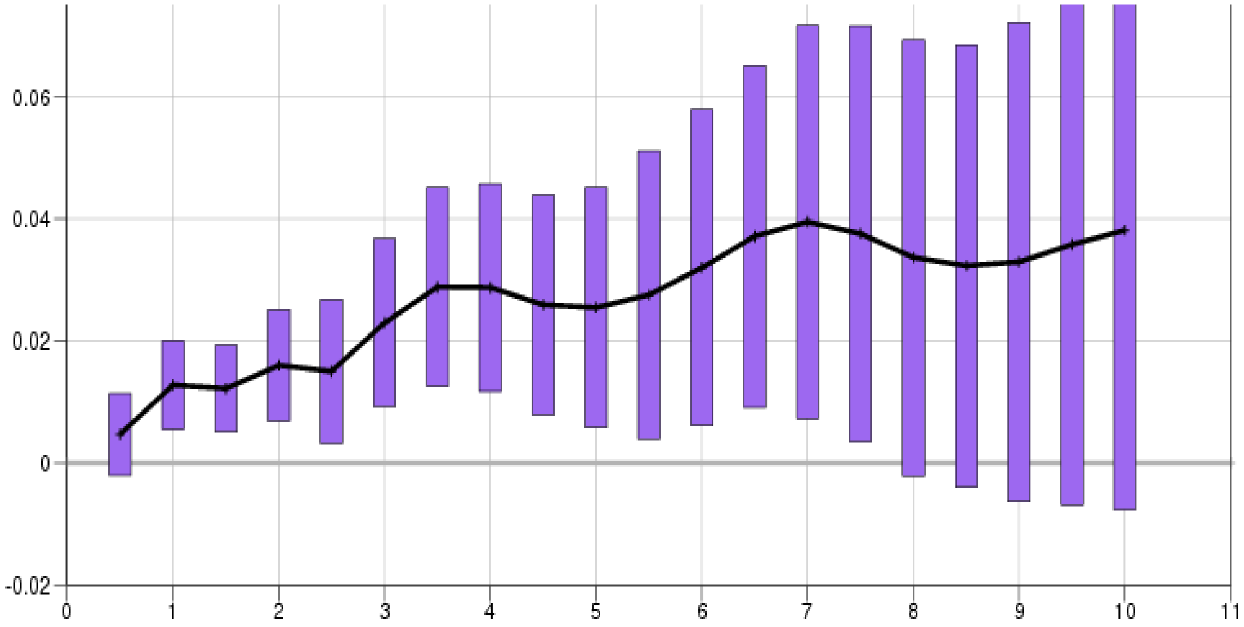
Case study: 22 december 2009 – first major snow fall event

- Removes snow free patches and overestimated snow patches
- Better agreement with SYNOP data and NESDIS data



Northern Hemisphere

OI impact



OI+new IMS 4km impact

Significant improvement of circulation until FC day +7

ECMWF

Summary and Conclusions

- 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!

- Land surface analysis has been revised for soil moisture (EKF implementation in Winter 2010-11) and snow analysis (OI and new high resolution NESDIS product)

- Participation to Geoland-2, GSWP-3, H-SAF, SMOS

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?
- Which variables can be treated by 1D assimilation techniques
  - Soil moisture&temperature (2D+1D), can Snow be also (2D+1D)?