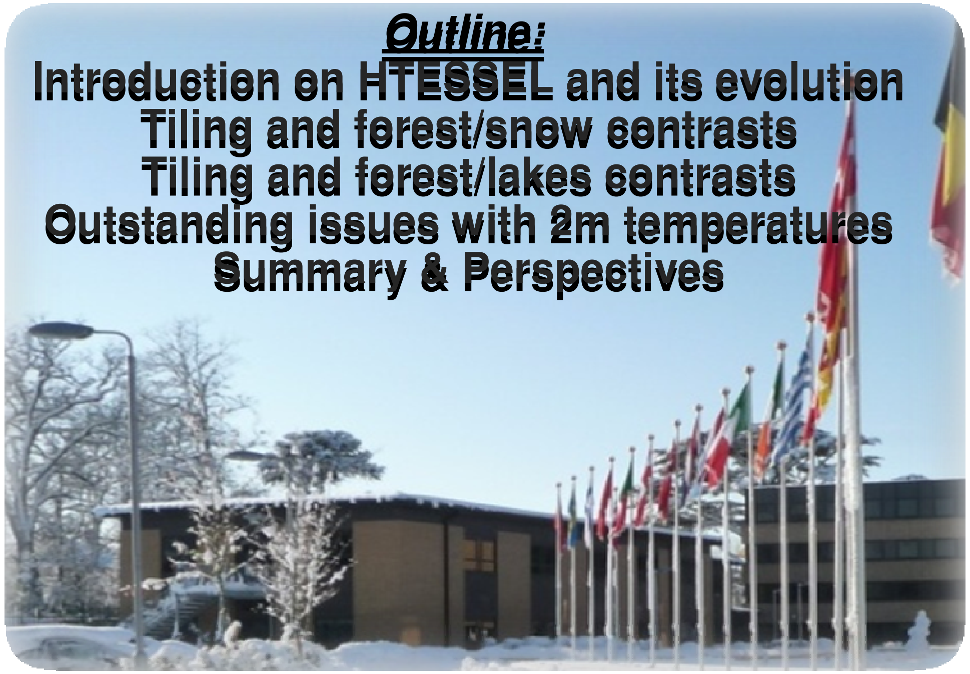
Forest Processes and Land Surface Tiling In the ECMWF model

presented by
Gianpaolo Balsamo



Outline:

Introduction on HTESSEL and its evolution
Tiling and forest/snow contrasts
Tiling and forest/lakes contrasts
Outstanding issues with 2m temperatures
Summary & Perspectives

Photo :ECMWF January 2010

Acknowledgements:
Andrea Manrique-Sunen, Patricia de Rosnay, Anna Agusti-Panareda
Anton Beljaars, Thomas Haiden, Souhail Boussetta, Emanuel Dutra, Clement Albergel

The ECMWF land surface model

- **T**iled **E**CMWF **S**cheme for **S**urface **E**xchanges over **L**and

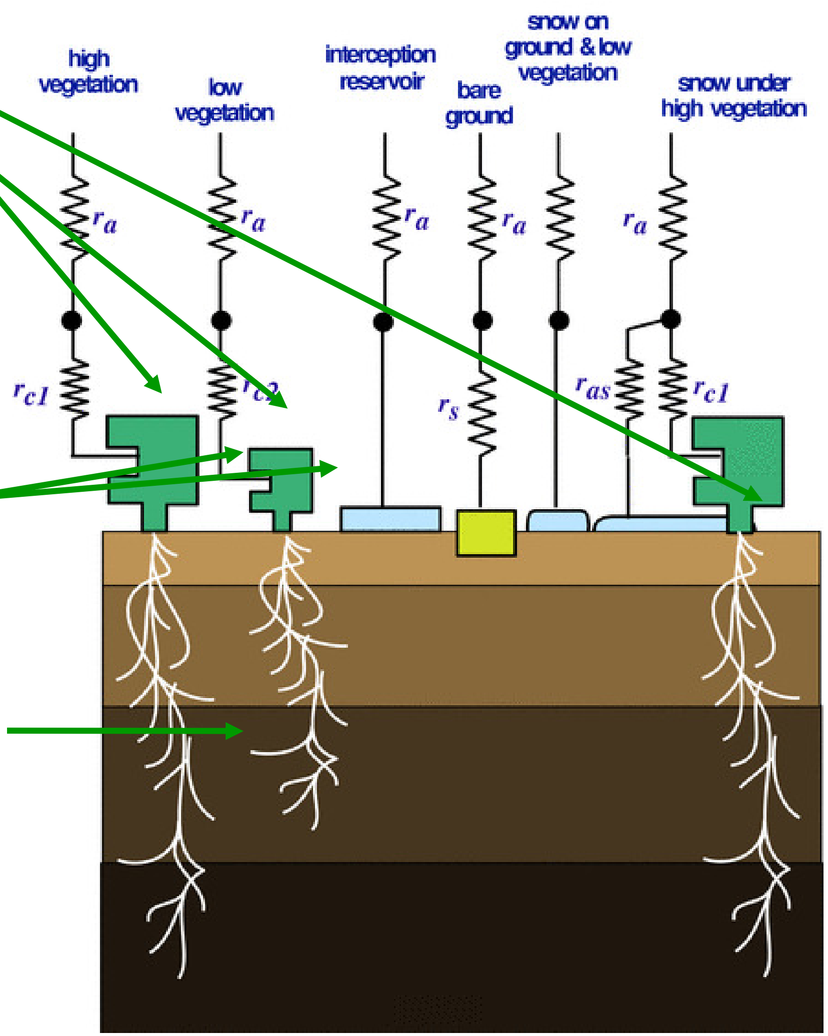
Treatment of snow under high vegetation

Canopy resistances, including air humidity stress on forest

High and low vegetation treated separately

Variable root depth

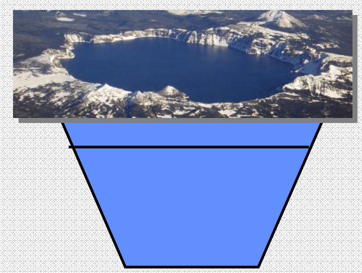
Land surface tiles in ERA40 surface scheme



- **Lake tile (in progress)**

Mironov et al (2010),
Dutra et al. (2010),
Balsamo et al. (2010)
Balsamo et al. (2011)

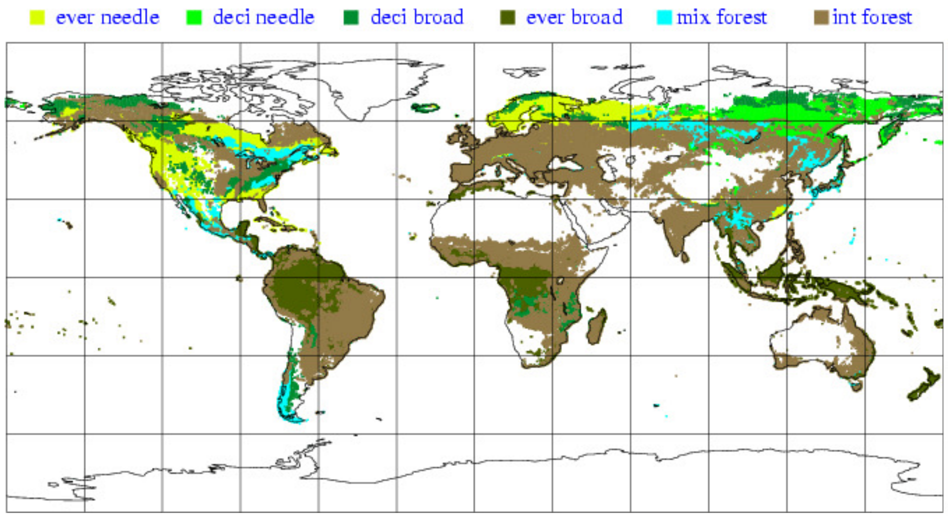
Extra tile (9) to account for sub-grid lakes



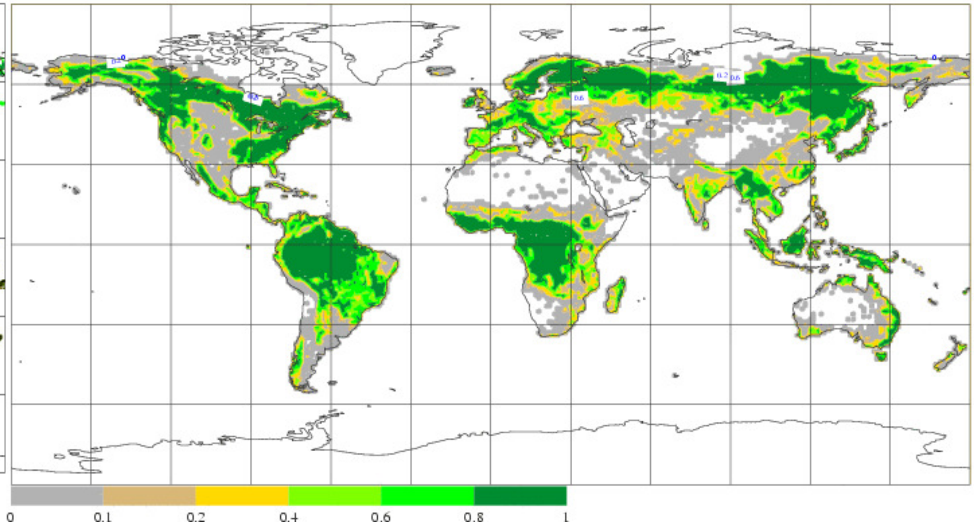
Forests description

The dominant forest type and its cover are prescribed by a global static map (Loveland et al. 1998)

FOREST TYPE



FOREST COVER FRACTION

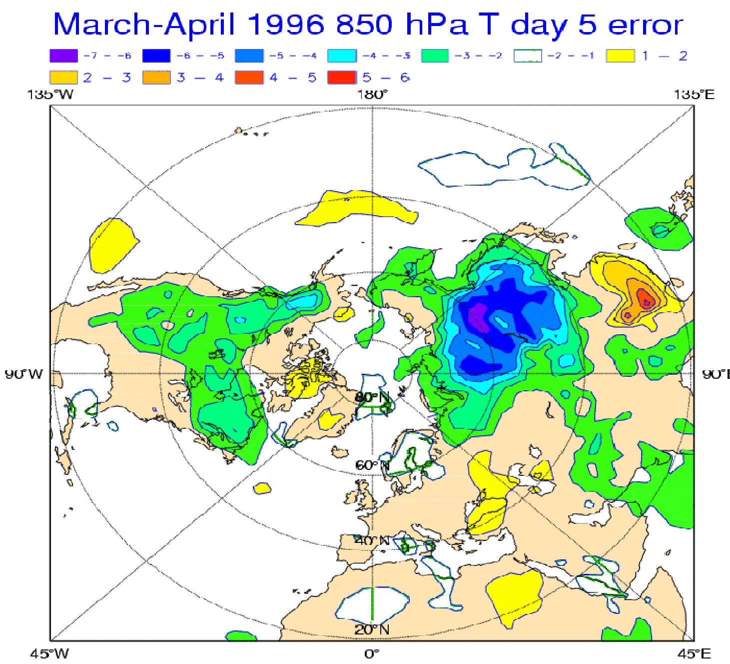


Aggregated from GLCC 1km

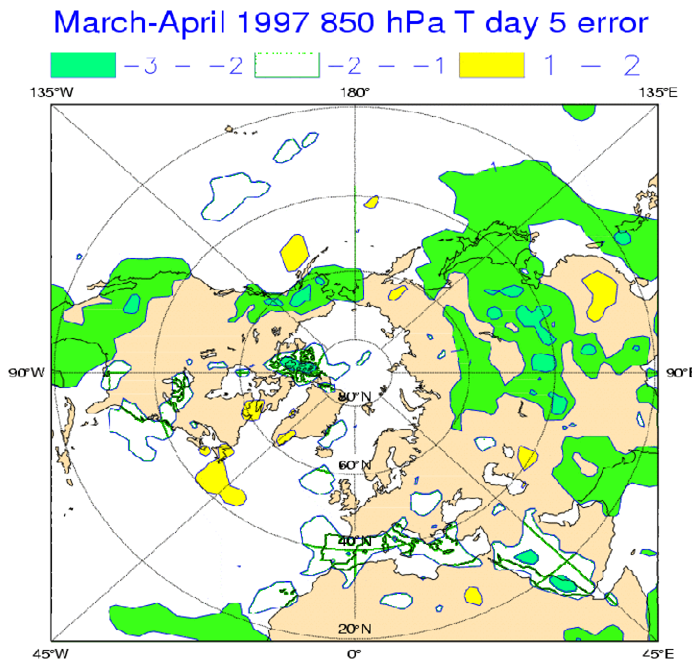
Impact of Forest+Snow Albedo

A lower albedo of snow+forest tile in the boreal forests (1997) reduced dramatically the spring (March-April) error in day 5 temperature at 850 hPa

1996 operational bias



1997 operational bias



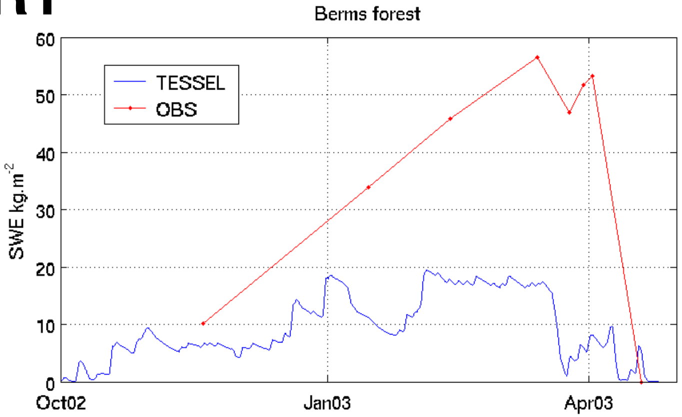
Viterbo and Betts, 1999

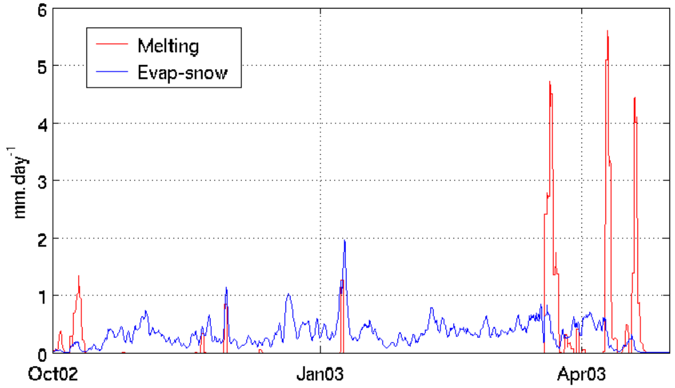
Impact of Forest+Snow Roughness Length

Dutra et al. 2009

The introduction of a vegetation dependent roughness length affecting the aerodynamic resistance show sensitivity on snow accumulation (less sublimation)

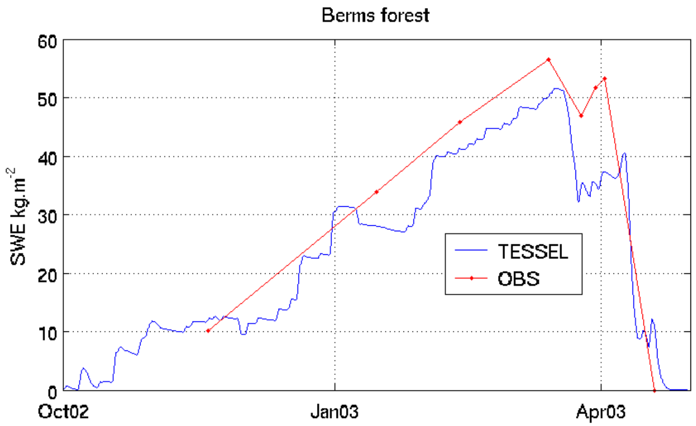
30R1

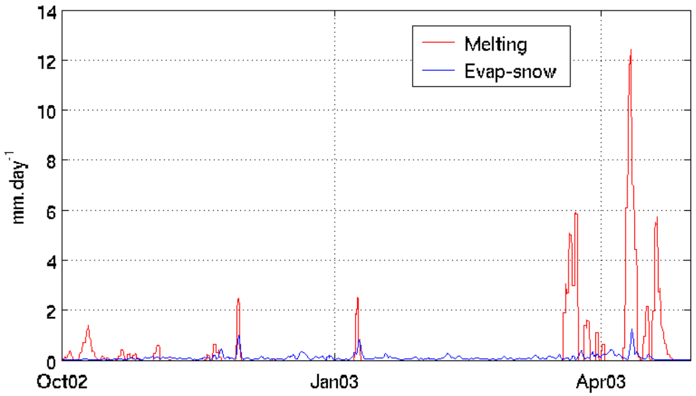




31R2, snow water equivalent

melting & sublimation





SnowMIP2: BERMS forest site simulations

ECMWF

Land surface model current status

2007/11	2009/03	2009/09		2010/11	2011/11 2012/06

- **H**ydrology-**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. (2011)

  New satellite-based

  Leaf-Area-Index

- **SOIL Evaporation**

  Balsamo et al. (2011),

  Albergel et al. (2012)

- **H_2O / E / CO_2**

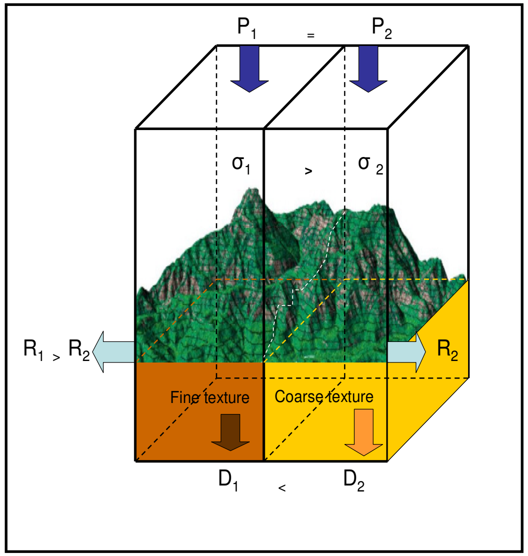
  Integration of Carbon /

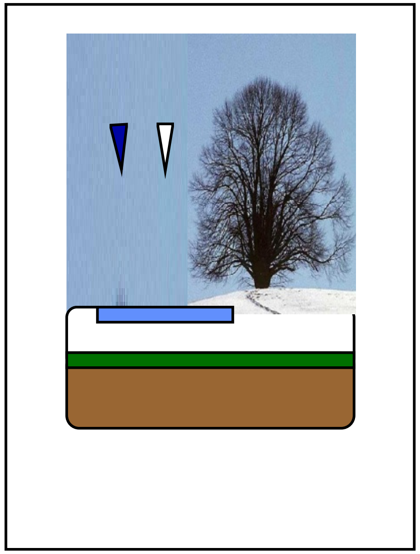
  Energy / Water cycles

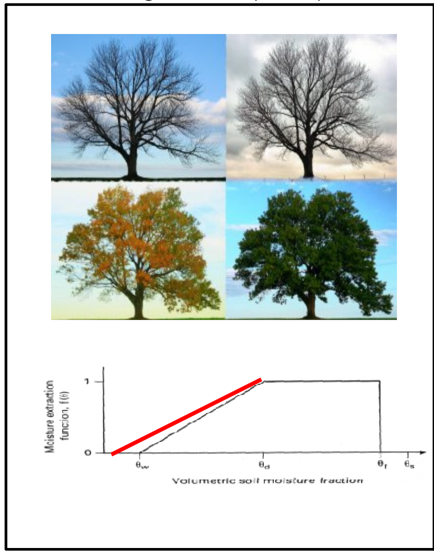
  at the surface (GEOLAND-2

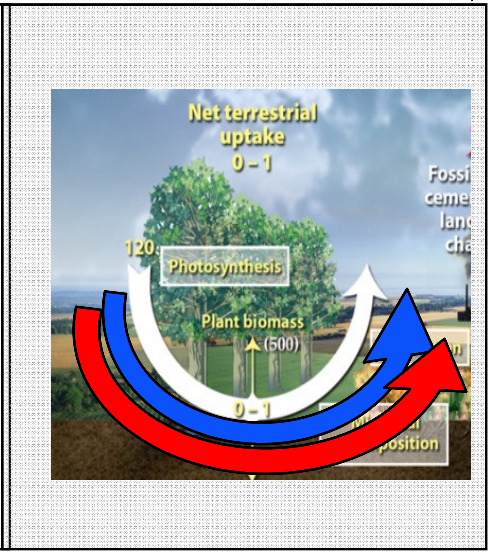
  based & GMES funded)

  Calvet et al. (1998)
  Jarlan et al (2007)
  Boussetta et al. (2010,
  Boussetta et al. 2012)









Land surface data assimilation status

1999	2004	2010/2011

OI screen level analysis

Douville et al. (2000)
Mahfouf et al. (2000)

Soil moisture 1D OI analysis

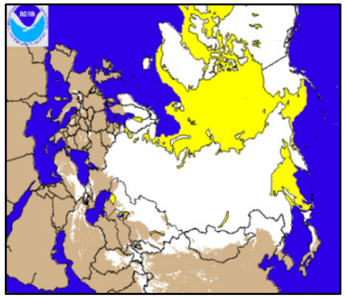
based on Temperature and relative humidity analysis

SYNOP Data

Revised snow analysis

Drusch et al. (2004)

Cressman snow depth analysis using SYNOP data improved by using NOAA / NSEDIS Snow cover extend data (24km)



NOAA/NESDIS IMS

Optimum Interpolation (OI) snow analysis

Pre-processing NESDIS data

High resolution NESDIS data (4km)

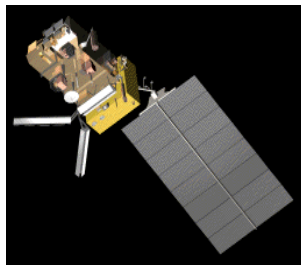
de Rosnay et al., 2012

SEKF Soil Moisture analysis

Simplified Extended Kalman Filter

Drusch et al. GRL (2009)
de Rosnay et al (2012)

Use of satellite data



METOP-ASCAT
de Rosnay et al., 2011

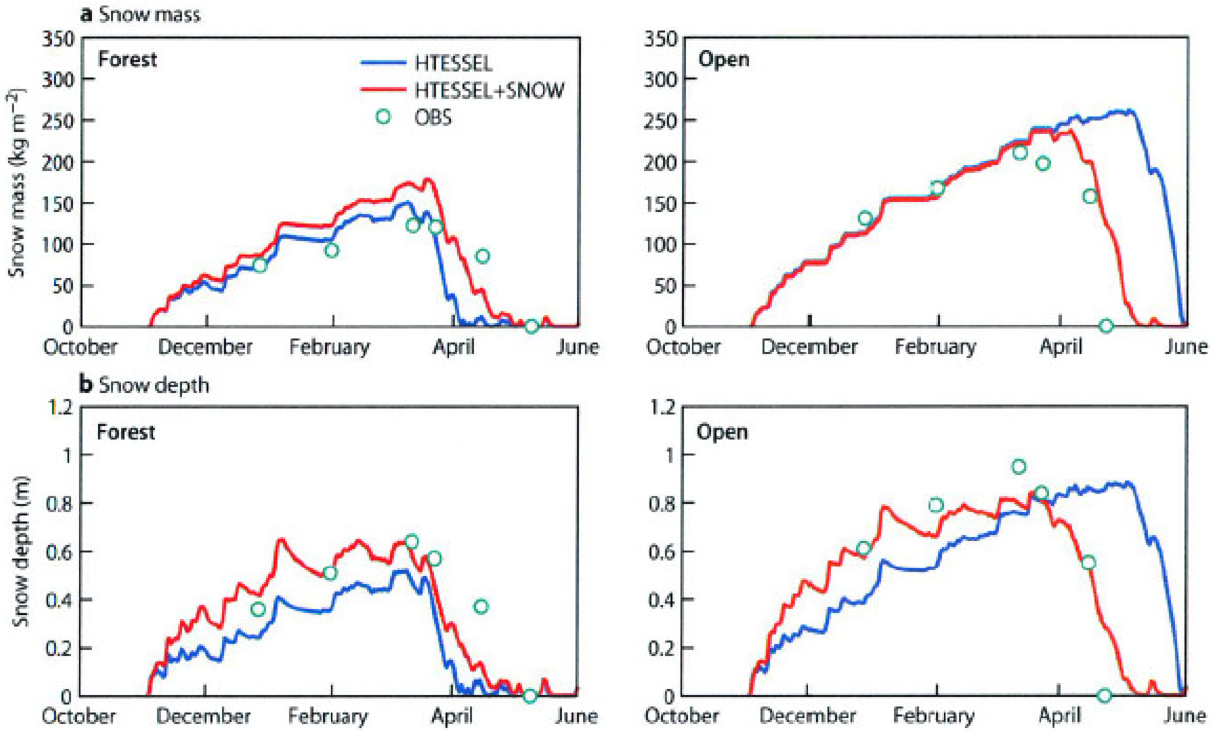
SMOS
Sabater et al., 2011

Validation activities

Albergel et al. 2011, 2012, 2013

A revised snow scheme: simulation of forest and open area snow

(Dutra et al. 2010, JHM)



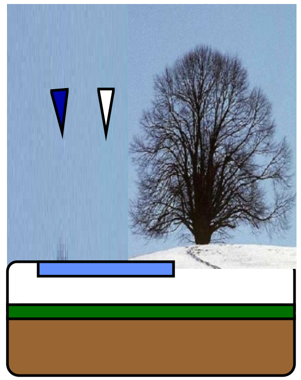
- **NEW SNOW**

Dutra et al. (2010)

Revised snow density

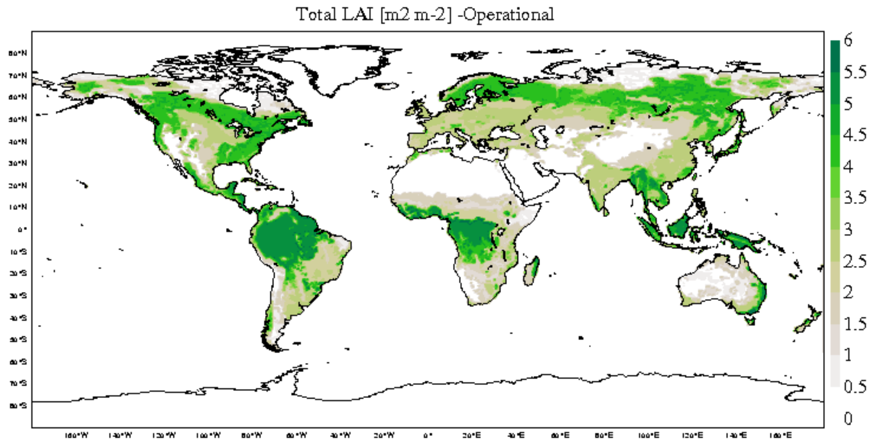
Liquid water reservoir

Revision of Albedo and sub-grid snow cover



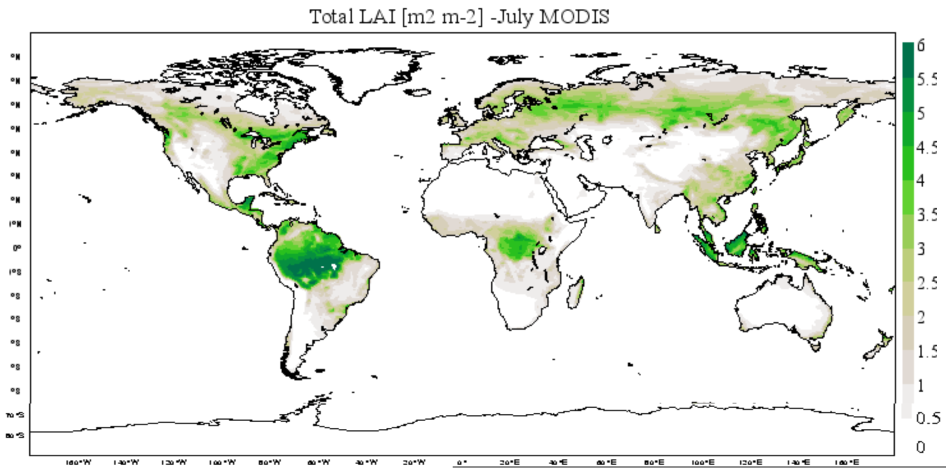
The key elements of the new snow schemes are in the treatment of snow density (including the capacity to hold liquid water content in the snowpack). The SNOWMIP 1&2 projects with their observational sites have been essential for the calibration/validation of the new scheme.

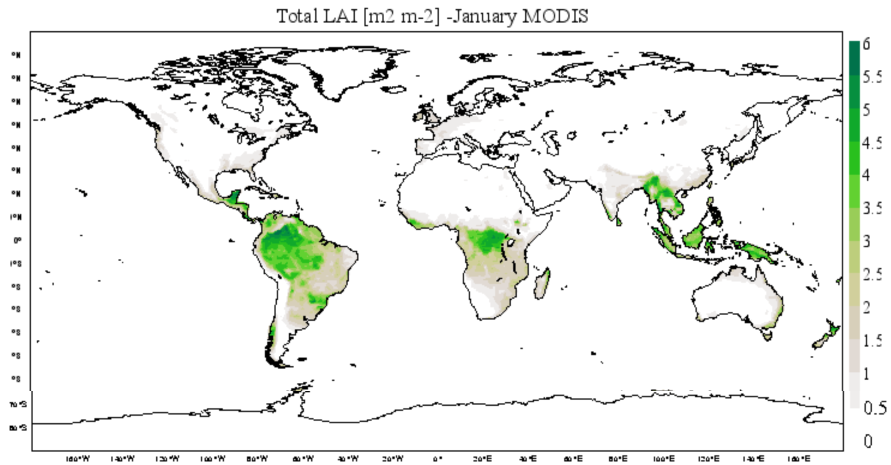
Satellite-based LAI monthly climatology



OPER LAI (van den Hurk et al. 2000, ECMWF TM)

MODIS LAI (Boussetta et al., 2011, IJRS, Myneni et al., 2002)

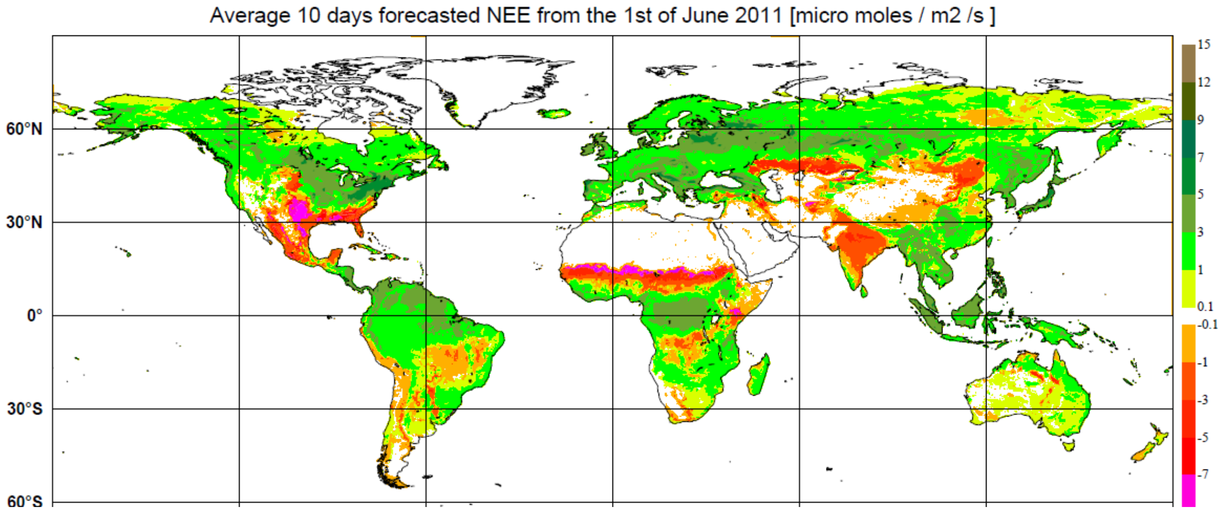




9years (2000-2008) collection 5 LAI (Jarlan et al. 2008)

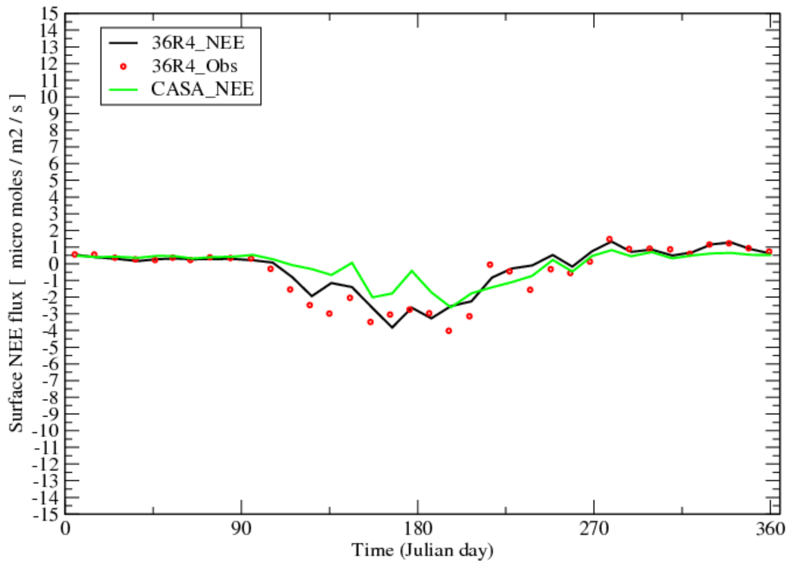
Land Carbon & Forest uptake (CTESSEL)

Boussetta et al. (2013, JGR) and ECMWF TM 675



Example of Average 10 days forecast NEE (natural CO2 exchange) from the 1st of June 2011 extracted from the pre operational run (e-suites) [micromoles/m2/s] – Operational from November 2011

GEOLAND-2 R&D support



Example of NEE (micro moles /m^2/s) predicted over the site **Fi-Hyy** by **CTESSEL** (black line) and **CASA** (green-line)

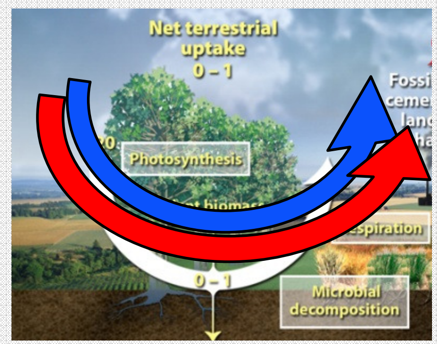
- **Land Natural CO_2**

land carbon uptake

Calvet et al. (1998)

Jarlan et al (2007)

Boussetta et al. (2013)



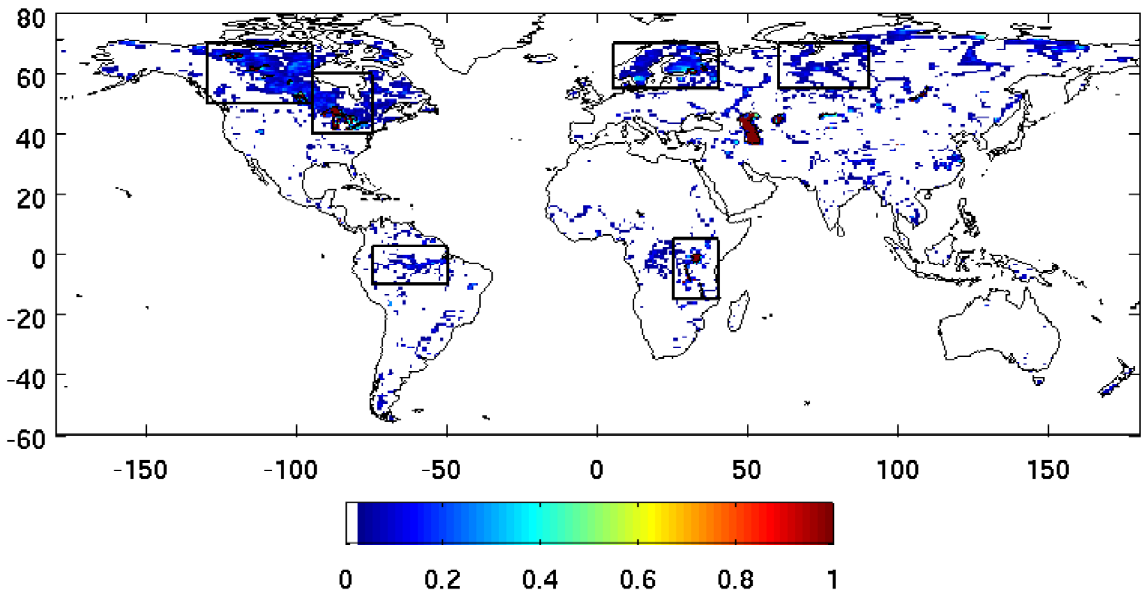
ECMWF

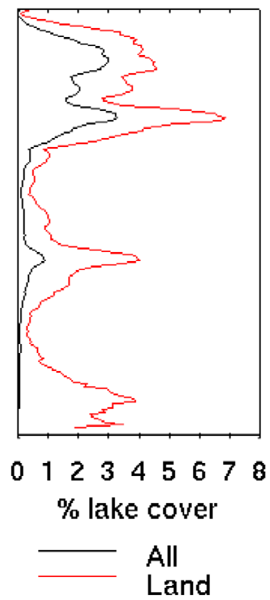
Lake modelling activity (FLAKE)

E. Dutra, V. Stepaneko, P. Viterbo, P. Miranda, G. Balsamo, 2010 BER

Motivation: a sizeable fraction of land surface has sub-grid lakes

LAKE COVER FRACTION



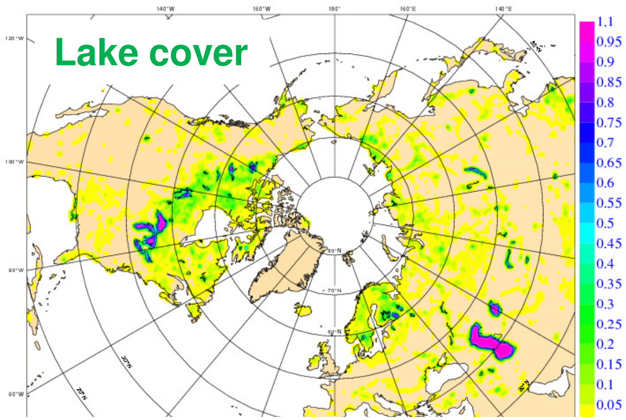


Nº Points 0.05< Clake<0.5

Canada	309/754 **41%**
USA	175/482 **36%**
Europe	170/385 **44%**
Siberia	104/467 **22%**
Amazon	81/629 **13%**
Africa	74/584 **13%**

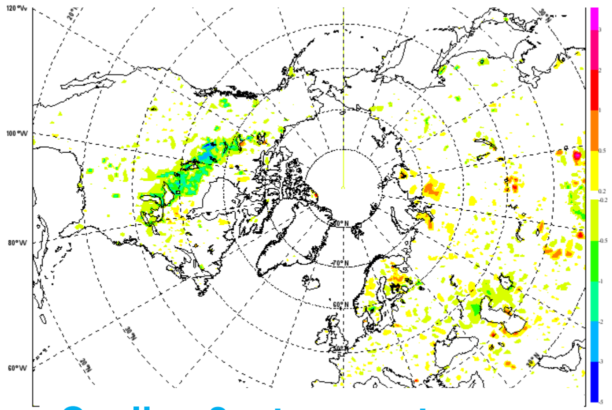
Impact of lakes in NWP

Balsamo et al. (2012, TELLUS-A) and ECMWF TM 648



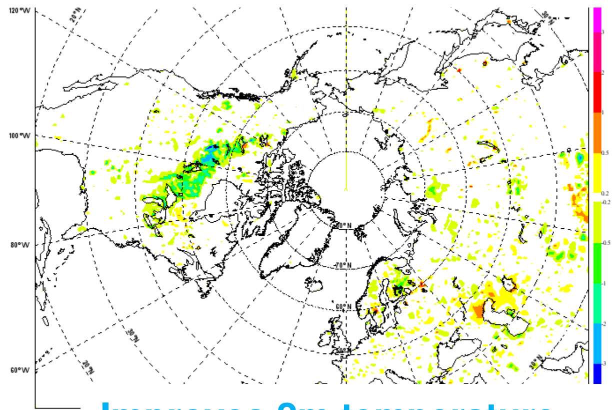
- **Forecasts sensitivity and impact is shown to produce a spring-cooling on lake areas with benefit on the temperatures forecasts (day) at 2m.**

Forecast sensitivity



Cooling 2m temperature
Warming 2m temperature

Forecast impact

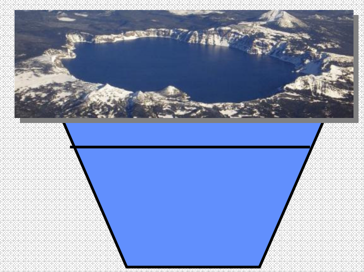


Improves 2m temperature
Degrades 2m temperature

- **FLake**

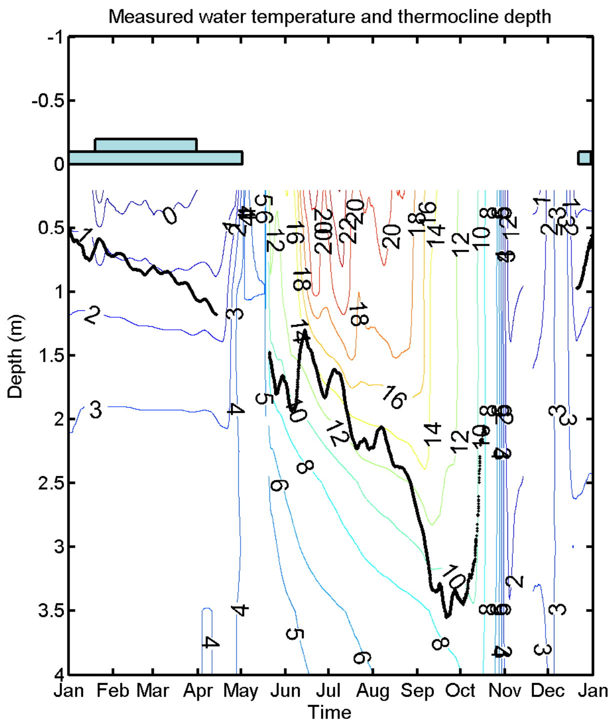
Mironov et al (2010),
Dutra et al. (2010),
Balsamo et al. (2010)
Balsamo et al. (2011)

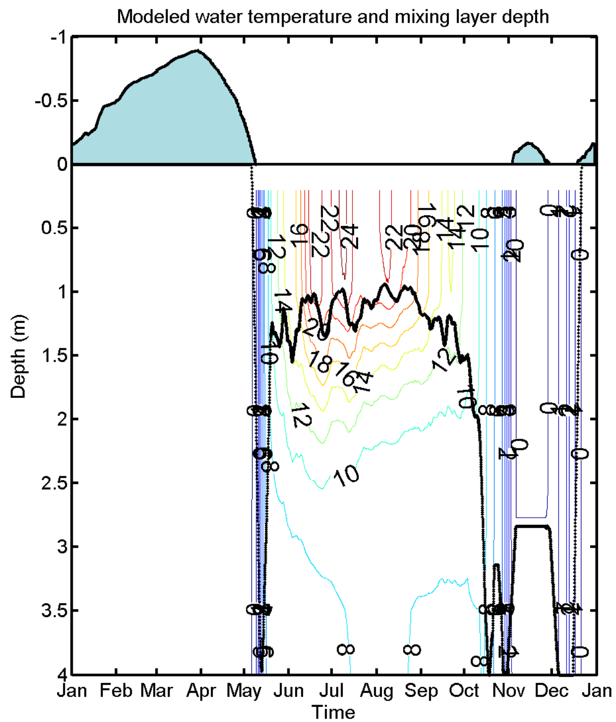
Extra tile (9) to account for sub-grid lakes



ERA-Interim forced runs of the FLAKE model are used to generate a lake model climatology which serves as IC in forecasts experiments (Here it is shown spring sensitivity and error impact on temperature when activating the lake model).

Realism of lake simulations (site validation)

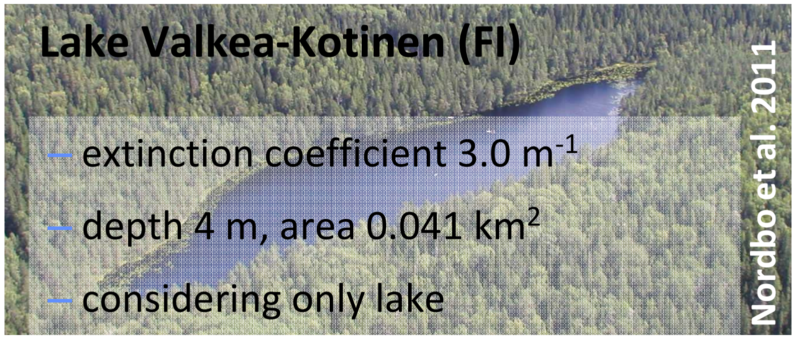




- Over a lake specialized site observations can be compared with FLake (Mironov et al. 2010) model output as provided by the LAKEHTESSEL model version (foreseen for 2012).
- Collaboration with Annika Nordbo (U. Helsinki), Ivan Mammarella (U. Helsinki)

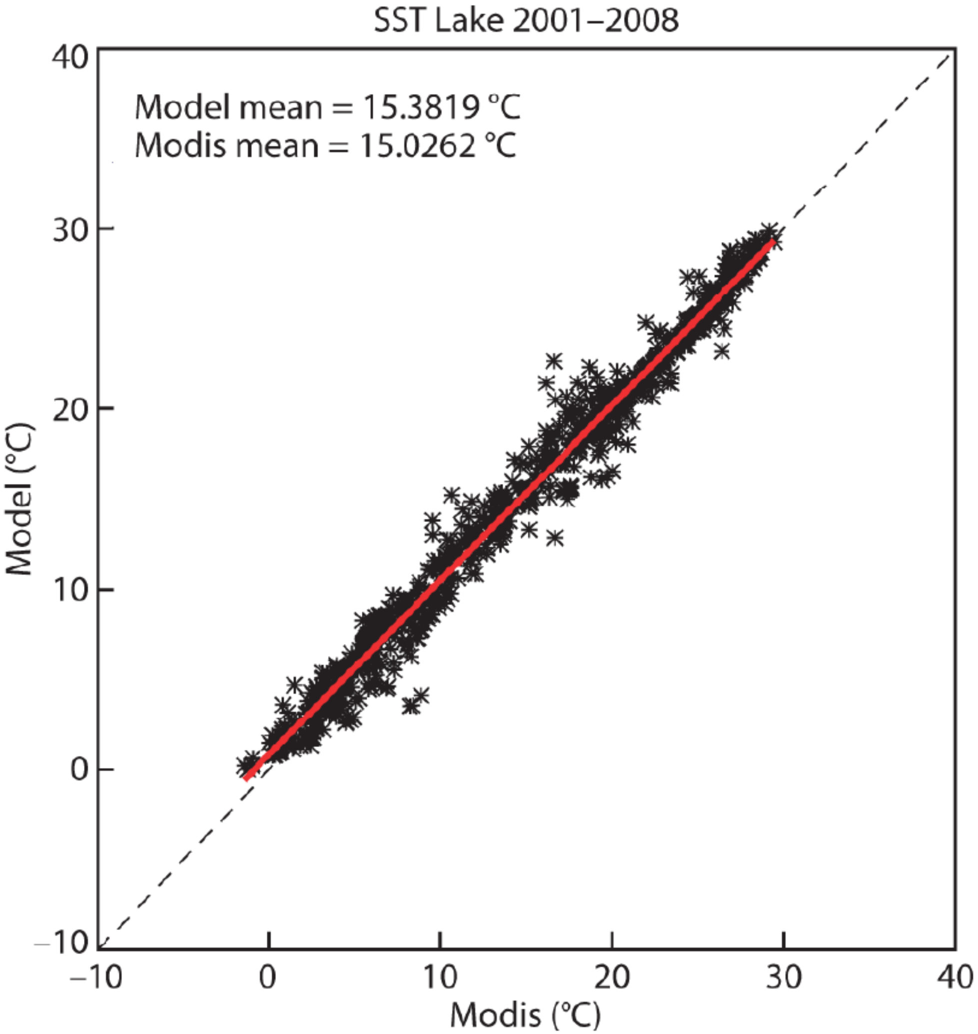
Courtesy of Annika Nordbo et al.

The Finnish observing sites have been very important to evaluate the possibility of simulating subgrid-lakes and were made available in a scientific collaboration (FMI/U Helsinki)



Lakes surface temperature (global validation)

Balsamo et al. (2012, TELLUS-A) and TM 648



- FLAKE Lake surface temperature is verified against the MODIS LST product (from GSFC/NASA)
- Good correlation

  R=0.98
- Reduced bias

  BIAS (Mod-Obs) < 0.3 K

ECMWF

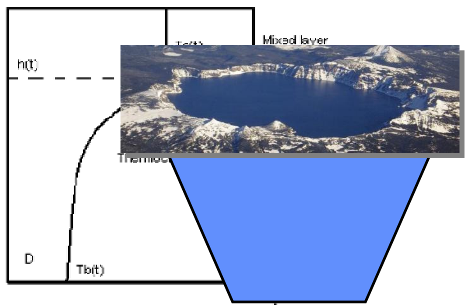
Can we simulate Forest and Lakes contrasts?

Andrea Manrique-Sunen et al (2013, JHM)

Meteorological forcing: ERA-Interim reanalysis

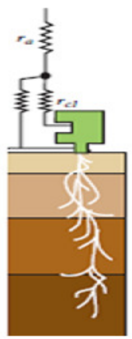
Model was run for the year 2006, doing 3 iterations

LAKEHTESSEL



Lake: Full coverage of inland water
Lake depth = 4 m
Water extinction coefficient = 3 m^{-1}

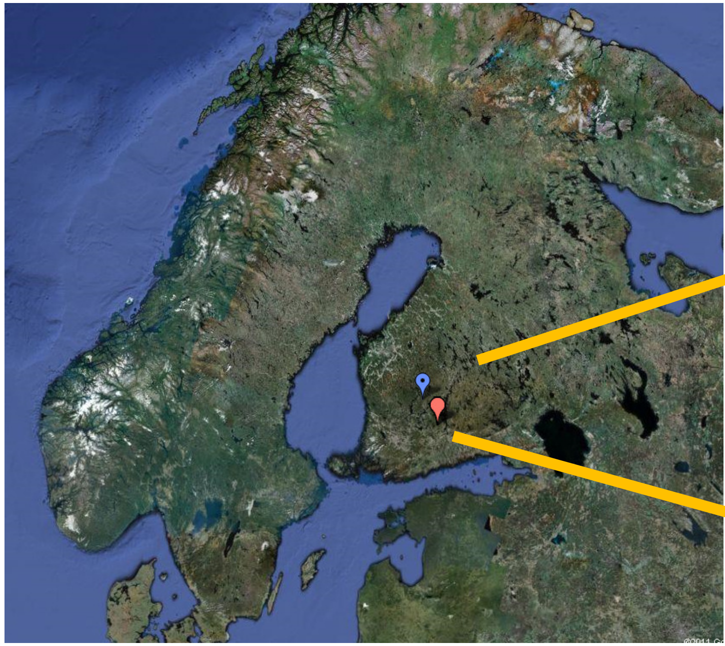
HTESSEL



Forest: Full coverage of high vegetation
Vegetation type: Evergreen needleleaf trees
Soil type: Medium texture

Energy balance in the surface $R_n + SH + LE = G$

Observational sites (forest/lake) in Finland



Observational data available:

Validation data:

•SH, LE (Eddy covariance technique)

•Net radiation

• Ground heat flux/lake heat storage

Forest: soil T, soil moisture, snow depth...

Lake: Water T at 13 depths, ice cover duration...

Forcing data:

•SW/LW downward radiation

•Surface pressure

•Specific humidity

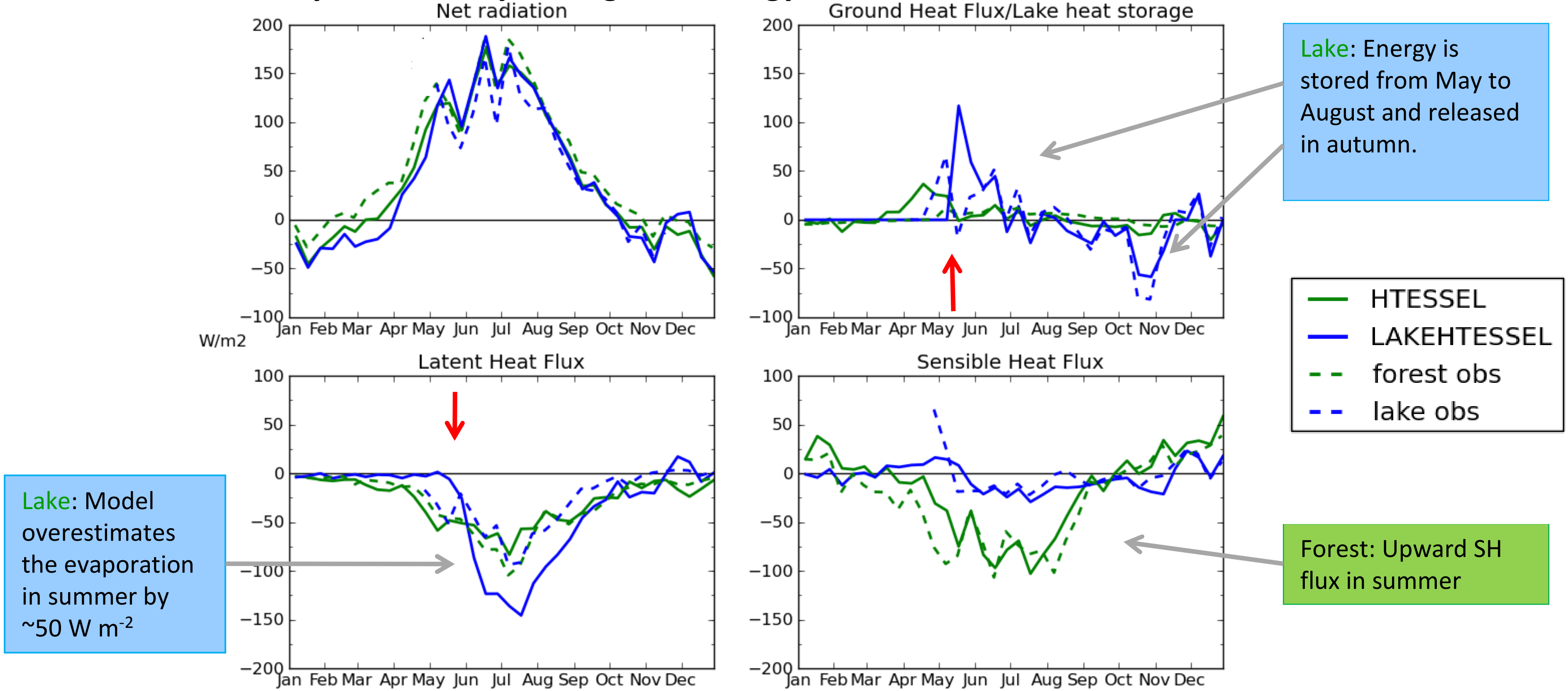
•Wind speed

•Rainfall, snowfall,

•T, wind ...

Energy fluxes: Seasonal cycles

Seasonal cycle of 10 day averages of energy fluxes



Sign convention: Positive downwards

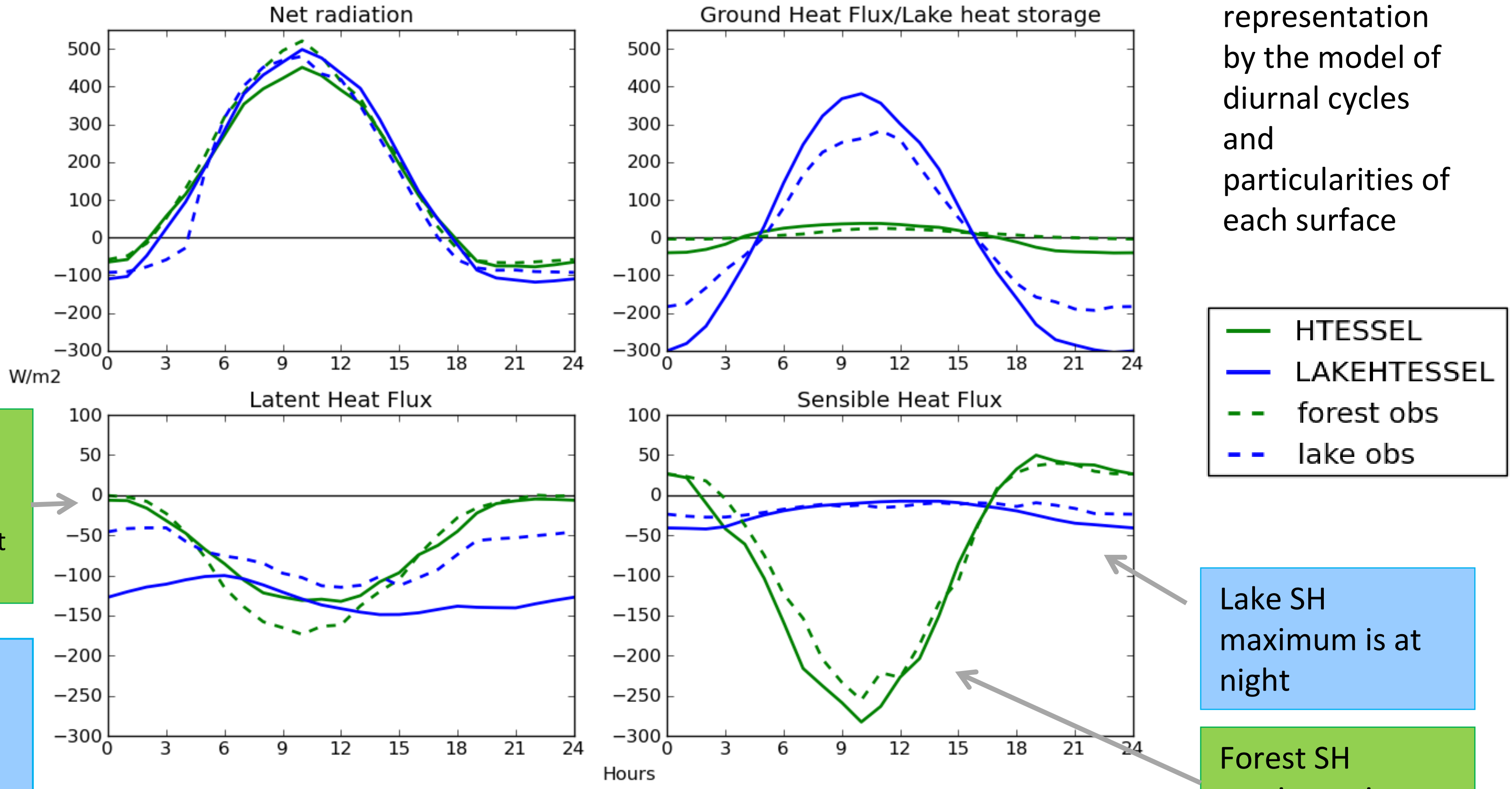
The timing of the lake's energy cycles is influenced by the ice cover break up, and it is delayed by 14 days in the model

Main difference between both sites is found in the energy partitioning into SH and G

ECMWF

Energy fluxes: Diurnal cycles

Monthly diurnal cycle of energy fluxes for July



Very good representation by the model of diurnal cycles and particularities of each surface

Forest evaporation is driven by vegetation, so it is zero at night

Lake LH diurnal cycle: overestimation in evaporation

Lake SH maximum is at night

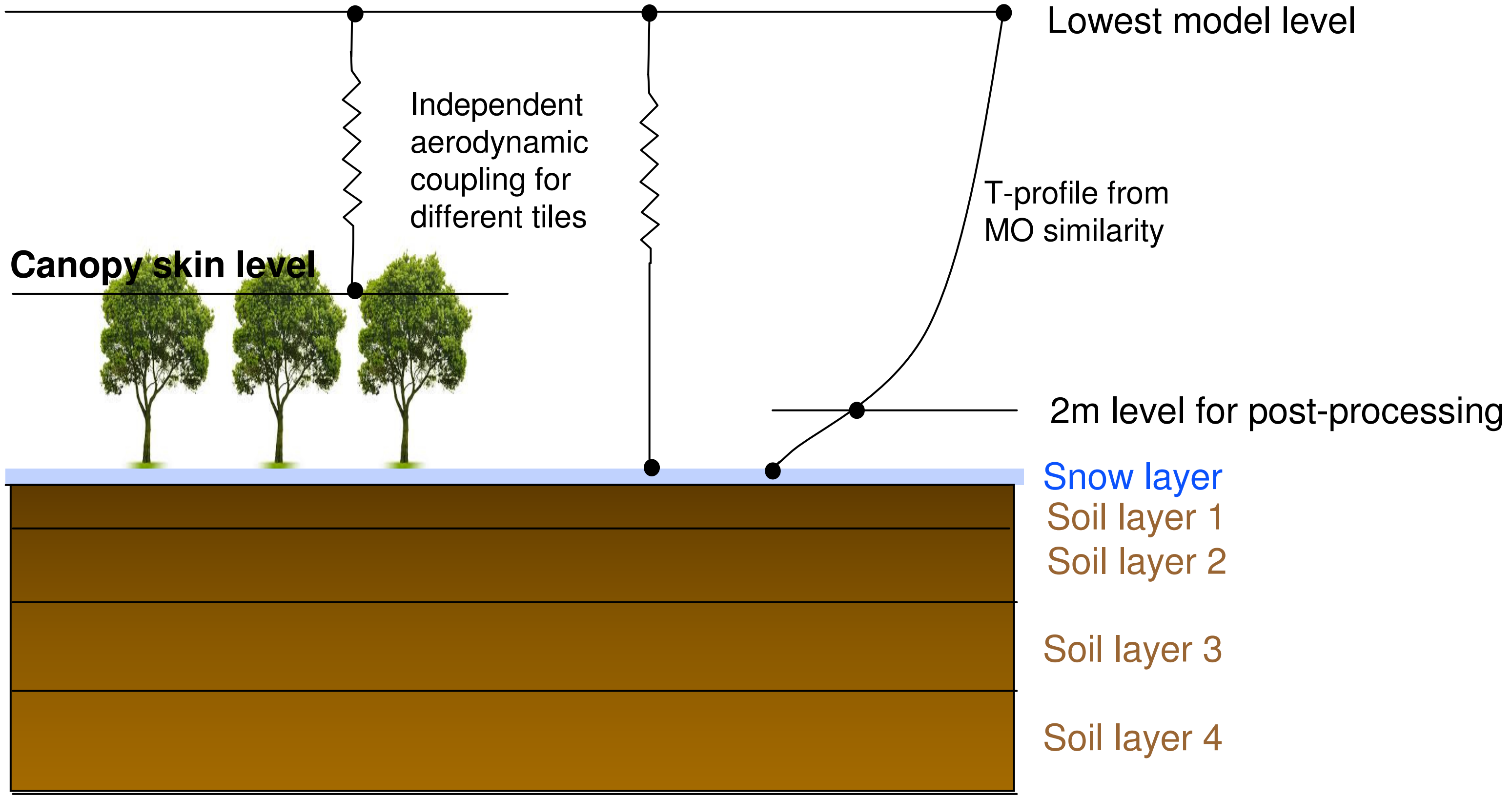
Forest SH maximum is at midday

Main difference between both sites is found in the energy partitioning into SH and G

ECMWF

Outstanding issues with forests and T2m

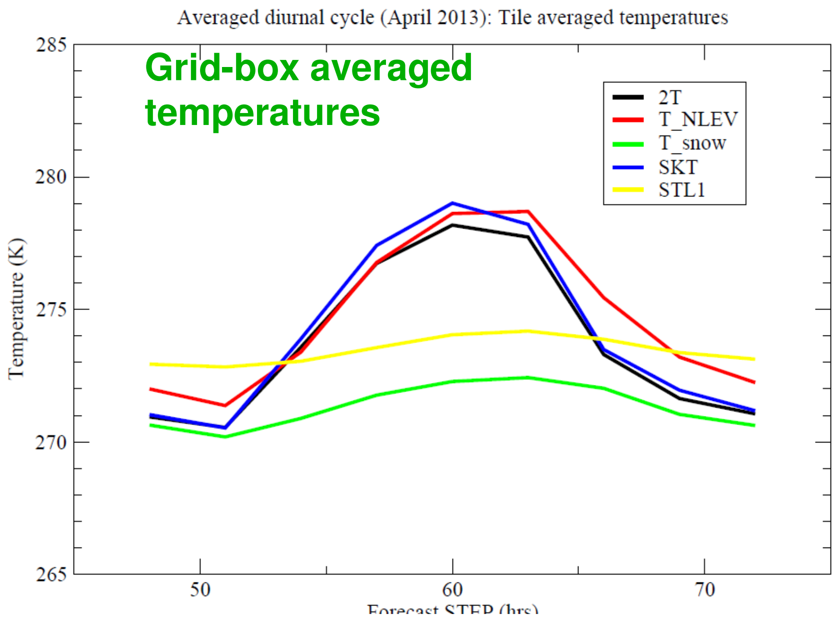
(i) tile with snow under vegetation and (ii) tile with exposed snow

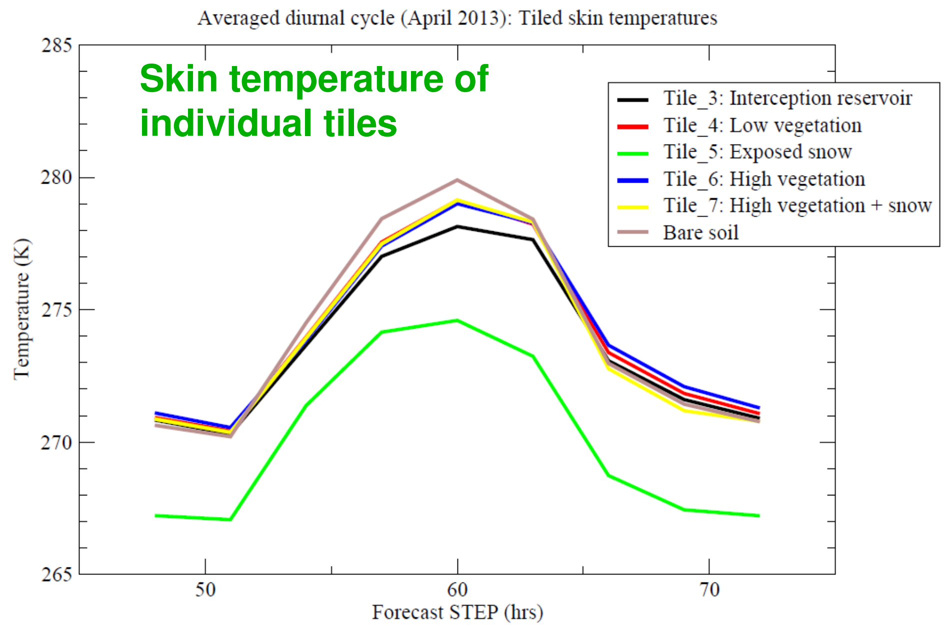


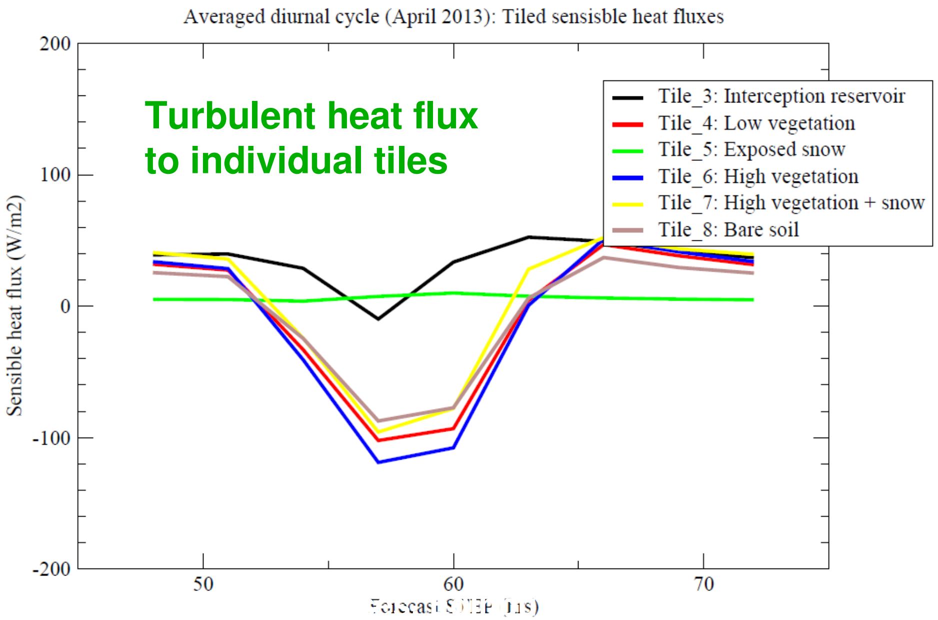
Even if the forest is dominant, the vertical interpolation to the 2m level is done for the exposed snow tile (SYNOP stations are always in a clearing).

During day time, the forest heats the atmosphere. At sunset exposed snow tile becomes very stable cutting off turbulent exchange. Therefore snow temperature and T2 drop too much. In reality forest generated turbulence will maintain turbulent exchange over the clearing and prevent extreme cooling.

Tiles temperature split in HTESSEL



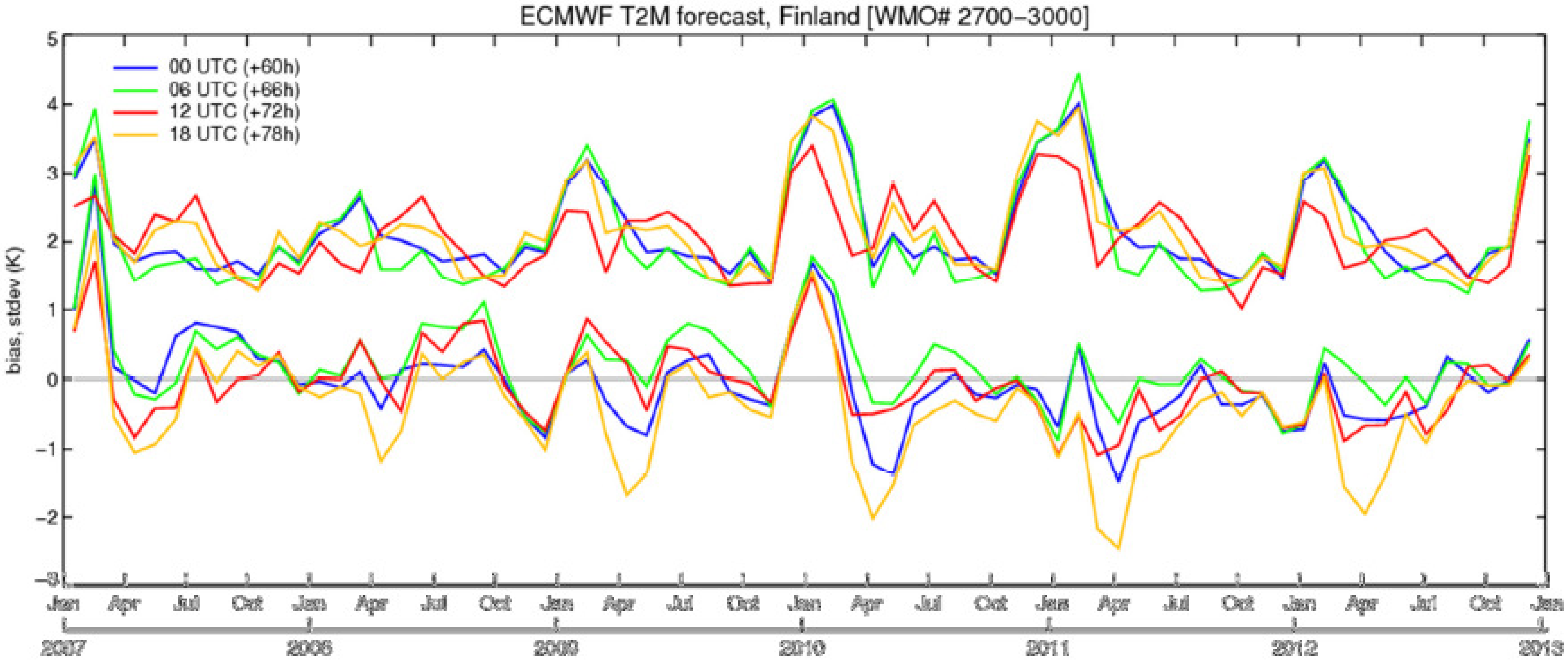




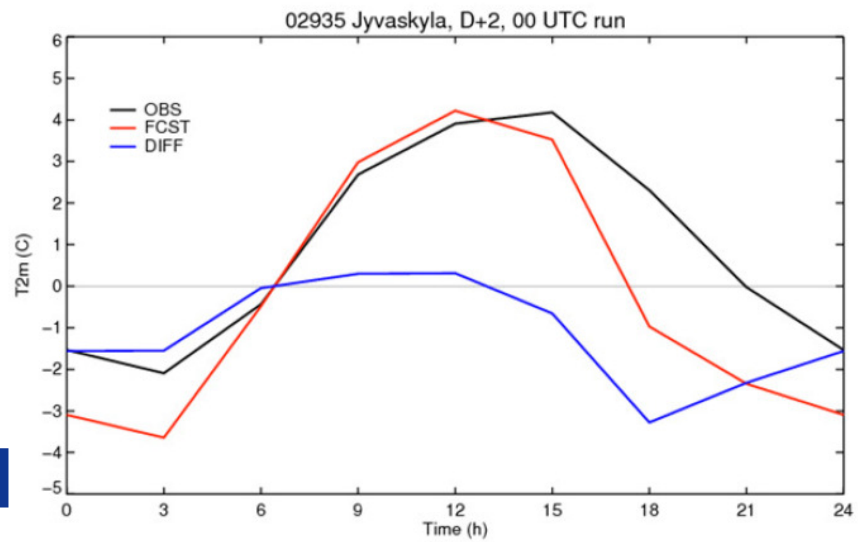
The heat flux towards the exposed snow is nearly zero!

ECMWF

Spring temperature biases over Scandinavia



Scandinavian countries show a spring time cold bias mainly at 18 UTC related to snow melt in forested areas. The bias has a distinct diurnal cycle.



Figures: Thomas Haiden

Summary & Outlook

- **The ECMWF land surface scheme**
  - Uses the tiling concept to represent sub-grid land variability including forest and forest+snow tiles, and a lake dedicated tile (cy40r1)
- **Benefits of the tiling**
  - Each tile has its process description (no ad-hoc or effective parameters)
- **Shortcomings of the tiling**
  - No surface boundary layer mixing (blending height hypothesis)
  - Too strong decoupling of snow surface (2m temperature forest bias)
  - Single soil layer underneath
- **Outlook**
  - The enhanced representation of surface tiles (more tiles and better vertical discretisation in the canopy-soil & lakes) + introduction of a SBL scheme are foreseeable developments with NWP relevance

References

Available at: http://www.ecmwf.int/staff/gianpaolo_balsamo/

Land surface model status in 36R4 (as in S4)

An ECMWF Newsletter article in Spring 2011 issue (N127) documents Operational developments since the ERA-Interim land surface scheme

Evolution of land-surface processes in the IFS

GIANPAOLO BALSAMO, SOUHAIL BOUSSETTA, EMANUEL DUTRA, ANTON BELJAARS, PEDRO VITERBO, BART VAN DEN HURK

MAJOR UPGRADES have been implemented over the last few years in the soil hydrology, snow and vegetation components of the ECMWF land-surface parametrization. Compared to the scheme used in ERA-Interim and ERA-40 reanalyses, the current model has an improved match to soil moisture and snow field-site observations with a beneficial impact on the forecasts of surface energy and water fluxes and near-surface temperature and humidity. This is verified by conventional synoptic observations and by dedicated flux-tower sites for forecasts ranging from daily to seasonal. The gain in hydrological consistency is also of crucial importance for data assimilation of land-surface satellite observations in water sensitive channels. The scheme described here, currently used for daily medium-range forecasts, will be adopted by the new Seasonal Forecasting System and included in future reanalyses.

A brief description of the main hydrological components of the land-surface model with selected validation results will now be presented followed by an outlook for future research activities.

Development of the land-surface model

In recent years the land-surface modelling at ECMWF has been extensively revised. An improved soil hydrology (*Balsamo et al.*, 2009), a new snow scheme (*Dutra et al.*, 2010) and a multi-year satellite-based vegetation climatology (*Boussetta et al.*, 2011) have been included in the operational Integrated Forecasting System (IFS). These have had a positive impact on both the global hydrological water cycle and near-surface temperatures compared to the TESSEL (Tiled ECMWF Scheme for Surface Exchanges over Land) scheme which was used in the ECMWF's ERA-40 and ERA-Interim reanalyses.

In particular the soil hydrology affected the quality of seasonal predictions during extreme events associated with soil moisture-precipitation feedback as in the European summer heat-wave in 2003 (*Weisheimer et al.*, 2011). The new snow scheme improved the thermal energy exchange at the surface with a substantial reduction of near-surface temperature errors in snow-dominated areas (i.e. northern territories of Eurasia and Canada).

More recently, the introduction of a monthly climatology for vegetation Leaf Area Index (LAI) to replace the fixed maximum LAI has shown a reduction of near-surface temperature errors in the tropical and mid-latitude areas, particularly evident in spring and summer. At the same time the bare ground evaporation has been enhanced over deserts by adopting a lower stress threshold than for vegetation. This is in agreement with experimental findings (e.g. *Mahfouf & Noilhan*, 1991) and results in a more realistic soil moisture for dry-lands.

The participation in international projects such as GLACE2 (Global Land-Atmosphere Coupling Experiment-2) and AMMA (African Monsoon Multidisciplinary Analysis), in which the ECMWF model was coupled with a realistic set of soil moisture fields, have improved the understanding of the mechanisms and areas of strong coupling between the land surface and the atmosphere.

The land-surface components

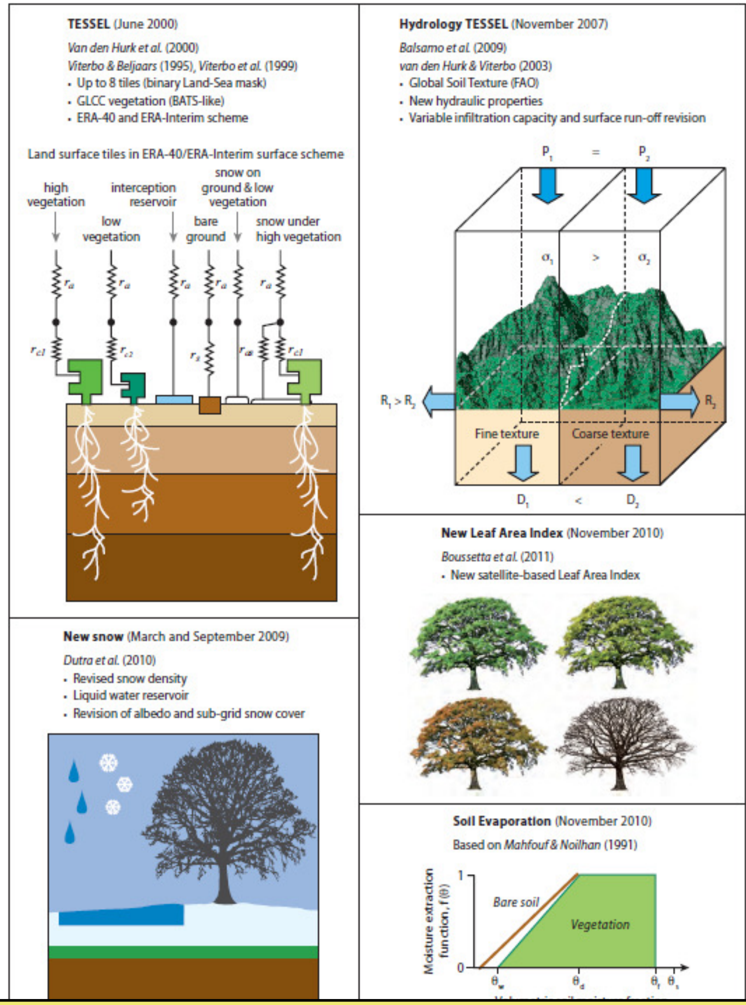
TESSEL as documented by van den *Hurk et al.* (2000) and *Viterbo & Beljaars* (1995) is the backbone of the current operational land-surface scheme at ECMWF. It includes up to six land-surface tiles (bare ground, low and high vegetation, intercepted water, and shaded and exposed snow) which can co-exist under the same atmospheric grid-box. Recent revisions of the soil and snow hydrology as well as vegetation characteristics are illustrated in Figure 1.

Soil hydrology

A revised soil hydrology in TESSEL was investigated by van den *Hurk & Viterbo* (2003) for the Baltic basin. These model developments were a response to known weaknesses of the TESSEL hydrology: specifically the choice of a single global soil texture, which does not characterize different soil moisture regimes, and an infiltration-excess runoff scheme which produces hardly any surface runoff. Therefore, a revised formulation of the soil hydrological conductivity and diffusivity (spatially variable according to a global soil texture map) and surface runoff (based on the variable infiltration capacity approach) were introduced in IFS Cy32r3 in November 2007. *Balsamo et al.* (2009) verified the impact of HTESSEL from field site to global atmospheric coupled experiments and in data assimilation.

Snow hydrology

A fully revised snow scheme has been introduced in 2009 to improve the existing scheme based on *Douville et al.* (1995). The snow density formulation was changed and a liquid water storage in the snow-pack was introduced, which also allows the interception of rainfall. On the radiative side, the snow albedo and the snow cover fraction have been revised and the forest albedo in presence of snow has been retuned based on MODIS satellite estimates. A detailed description of the new snow scheme and a verification from field site experiments to global offline simulations is presented in *Dutra et al.* (2010). The results showed an improved evolution of the simulated snow-pack with positive effects on the timing of runoff and terrestrial water storage variation and a better match of the albedo to satellite products.



Revised soil, snow, and vegetation components of the IFS model are summarized (based on 3-supporting publications) in a ECMWF news item. This model version is adopted by the new seasonal forecasting system (System-4)

ECMWF

Soil Moisture Analysis Status

An ECMWF Newsletter article in the Spring 2011 issue (N127) documents Operational developments on the Soil Moisture Analysis at ECMWF

Extended Kalman Filter soil-moisture analysis in the IFS

PATRICIA DE ROSNAY, MATTHIAS DRUSCH, GIANPAOLO BALSAMO, CLÉMENT ALBERGEL, LARS ISAKSEN

A NEW soil moisture analysis scheme based on a point-wise Extended Kalman Filter (EKF) was implemented at ECMWF with cycle 36r4 of the Integrated Forecasting System (IFS) in November 2010. The EKF soil moisture analysis replaces the previous Optimum Interpolation (OI) scheme, which was used in operations from July 1999 (IFS cycle 21r2) to November 2010. In continuity with the previous system it uses 2-metre air temperature and relative humidity observations to analyse soil moisture. The computing cost of the EKF soil moisture analysis is significantly higher than that of the OI scheme. So, as part of the EKF soil moisture analysis implementation, a new surface analysis structure was implemented in September 2009 (cycle 35r3) to move the surface analysis out of the time critical path.

The main justifications for implementing the EKF soil moisture analysis are as follows.

- In contrast to the OI scheme, which uses fixed calibrated coefficients to describe the relationship between an observation and model soil moisture, the EKF soil moisture increments result from dynamical estimates that quantify accurately the physical relationship between an observation and soil moisture.
- The EKF scheme is flexible to cope with the current increase in model complexity. In particular, changes in the IFS and in the land-surface model H-TESSEL (Hydrology Tiled ECMWF Scheme for Surface Exchanges over Land) are accounted for in the analysis increments computation.
- The EKF soil moisture analysis makes it possible to use soil moisture data from satellites and to combine different sources of information (i.e. active and passive microwave satellite data, and conventional observations).
- It considers the observation and model errors during the analysis in a statistically optimal way and allows assimilation of observations at their correct observation times.

The implementation and evaluation of the EKF soil moisture analysis is described in this article. An overview is given of a set of one-year analysis experiments conducted to assess the performance of the EKF. These experiments led to the implementation of the EKF in November 2010 using screen-level parameters to analyse soil moisture. The impact of ASCAT (Advanced SCATterometer) data assimilation is also briefly presented to investigate the possibility to combine conventional observations and satellite data for the soil moisture analysis.

Sources of data

The ECMWF operational soil moisture analysis system is based on analysed screen-level variables (2-metre temperature and relative humidity). In the absence of a near-real time global network for providing soil moisture information, using screen-level data is the only source of information that has been continuously available for NWP soil moisture analysis systems. It provides indirect, but relevant information to analyse soil moisture.

In the past few years several new space-borne microwave sensors have been developed that measure soil moisture. They provide spatially integrated information on surface soil moisture at a scale relevant for NWP models.

- The active sensor ASCAT on MetOp was launched in 2006. The EUMETSAT ASCAT surface soil moisture product is the first operational soil moisture product. It is available in near-real time on EUMETCAST and it has been monitored operationally at ECMWF since September 2009.
- ESA's SMOS (Soil Moisture and Ocean Salinity) mission was launched in 2009. Based on L-band passive microwave measurements, SMOS is the first mission dedicated to providing information about soil moisture.
- The future NASA SMAP (Soil Moisture Active and Passive) mission, planed to be launched in 2015, will be a soil moisture mission that combines active and passive microwave measurements to provide global soil moisture and freeze/thaw state.

ECMWF plays a major role in developing and investigating the use of new satellite data for soil moisture analysis. For example, the EUMETSAT ASCAT soil moisture product has been monitored operationally at ECMWF since September 2009 and SMOS brightness temperature product has been monitored in near-real time since November 2010:

- http://www.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/slmoist/ascat/
- http://mwmstest.ecmwf.int/products/forecasts/d/charts/monitoring/satellite/smos

Implementation of SMOS data monitoring at ECMWF is described in an accompanying paper by *Muñoz Sabater et al.* in this edition of the *ECMWF Newsletter* (pages 23–27).

The ECMWF land-surface analysis system

The ECMWF land-surface analysis system includes the analysis of snow depth, screen-level parameters (2-metre temperature and relative humidity) as well as soil moisture and soil temperature. It is performed independently from the 4D-Var atmospheric analysis. The upper-air analysis and the land-surface analysis are used together as initial conditions for the forecast. In turn, the model-predicted fields provide the first guess and initial conditions of the next land-surface and upper-air analysis cycle.

Tests of the EKF soil moisture analysis

Experimental set up

In preparation for implementing the EKF soil moisture analysis three analysis experiments were conducted at T255 resolution over a one-year period (December 2008 to 30 November 2009).

- ***'OI' experiment***. The OI soil moisture analysis uses the increments of the screen-level parameters analysis as input. It represents the operational soil moisture analysis configuration that was used in operations at ECMWF from July 1999 to November 2010.
- ***'EKF' experiment***. This uses the dynamical EKF soil moisture analysis, in which the analysis of screen-level parameters is used as proxy information for soil moisture.
- ***'EKF+ASCAT' experiment***. This was conducted for the same one-year period using the EKF in which the analysis of screen-level parameters is used together with the ASCAT soil moisture data.

In this 'EKF+ASCAT' experiment, ASCAT soil moisture data is matched to the ECMWF IFS model soil moisture using a Cumulative Distribution Function (CDF) matching as described in *Scipal et al.* (2008). A first demonstration of the impact of using a nudging scheme has already been performed by *Scipal et al.* (2008). They showed, however, that compared to the OI system, using scatterometer data slightly degraded the forecast scores. They recommended using ASCAT data in an EKF analysis to account for observation errors and to combine ASCAT data with screen-level proxy information. This is investigated in the 'EKF+ASCAT' experiment.

Note that:

- The 'OI' and 'EKF' experiments only differ in the method used for the soil moisture analysis. Observations used for the analysis are identical.
- The 'EKF' and 'EKF+ASCAT' experiments use the same EKF scheme, but satellite data is used in addition to conventional data in the 'EKF+ASCAT' experiment.

One month of spin-up is considered for the first month of the experiment, so results presented here focus on the period January to November 2009.

Comparing the 'OI' and 'EKF' experiments

Figure 1 shows monthly accumulated soil moisture increments for the first metre of soil for July 2009 for the OI and EKF experiments, and their difference . Spatial patterns of soil moisture increments are quite similar for the OI and EKF schemes. For both the OI and the EKF the soil moisture increments are generally positive in most areas. However, negative increments are found in Argentina, Alaska and North East of America. These results mainly show that the EKF soil moisture analysis generally reduces the soil moisture analysis increments compared to the OI scheme.

Figure 2 shows the annual cycle of the global mean soil moisture increments for the OI and EKF experiments. It can be seen that the soil moisture increments of the OI scheme systematically add water to the soil. The global monthly mean value of the OI analysis increments is 5.5 mm, which represents a substantial and unrealistic contribution to the global water

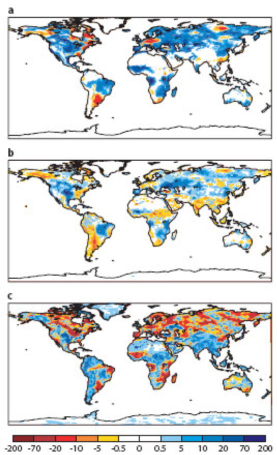


Figure 1 Monthly soil moisture increments (mm) within the top soil metre root zone (in mm) during July 2009 produced by (a) OI scheme and (b) EKF scheme. (c) Difference between EKF and OI schemes.

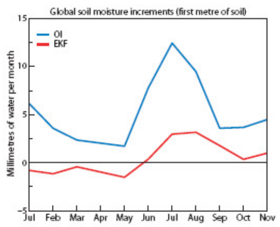


Figure 2 Temporal evolution of soil moisture increments in the first metre of soil (global mean value) in mm of water per month from January to November 2009, produced by the OI and EKF schemes.

cycle. In contrast the EKF global mean soil moisture analysis increments are much smaller, representing global monthly mean increments of 0.5 mm. The reduction of increments between the EKF and the OI is mainly due to the reduction in increments below the first layer. The OI increments computed for the first layer are amplified for deeper layers in proportion to the layer thickness, explaining the overestimation of OI increments. In contrast the EKF dynamical estimates, based on perturbed simulations, allow the optimizing of soil moisture increments at different depths to match screen-level observations according to the strength of the local and current soil-vegetation-atmosphere coupling. The EKF accounts for additional controls due to meteorological forcing and soil moisture conditions. Thereby it prevents undesirable and excessive soil moisture corrections.

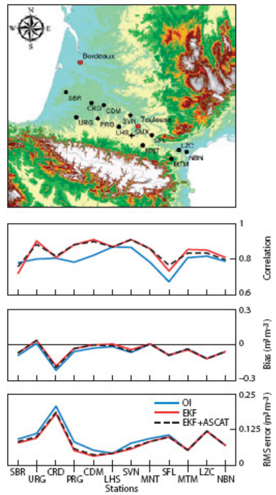


Figure 3 Correlation, bias (observation minus model) and root-mean-square (RMS) error of ECMWF surface soil moisture analysis of layer 1 for the 12 soil moisture stations in the SMOSMANIA (soil moisture observing system – meteorological automatic network integrated application) network in Southwest France in 2009, for the OI, EKF and EFF+ASCAT configurations of the soil moisture analysis.

Comparing 'OI', 'EKF' and EKF+ASCAT' experiments

Figure 3 shows the impact of the soil moisture analysis scheme on analysed soil moisture of the first soil layer (0–7cm) for all three experiments. Evaluation is conducted for 2009 against the 12 SMOSMANIA ground stations of the operational soil moisture network of Météo-France (*Calvet et al.*, 2007). It shows that ECMWF soil moisture is generally in good agreement with ground observations, with mean correlations higher than 0.78.

Using the EKF instead of the OI scheme improves significantly the soil moisture analysis, leading to a remarkable agreement between ECMWF soil moisture and ground truth (mean correlation higher than 0.84 for EKF and EKF+ASCAT). The bias and root-mean-square error are also improved with the EKF compared to the OI scheme. One may note that a strong negative bias is indicated for all schemes for one station, indicating that the analysis overestimates soil moisture content. This systematic difference in terms of volumetric soil moisture content is related to soil texture issues in this area for which the local ground data is not representative of the ECMWF model soil texture.

Results obtained from the EKF+ASCAT experiment show that using ASCAT does not improve the performance of the soil moisture analysis. In the experiment where ASCAT data is assimilated, soil moisture data has been re-scaled to the model soil moisture using a CDF matching, as described in *Scipal et al.* (2008). The matching corrects observation bias and variance. So, in the data assimilation scheme only the observed ASCAT soil moisture variability is assimilated.

In Figure 3, the impact of ASCAT data assimilation might be limited by both the quality of the current ASCAT product and the CDF-matching approach used in the assimilation scheme. EUMETSAT recently revised the processing of the ASCAT soil moisture product to reduce the ASCAT product noise level. Test conducted with the new product prototype (not shown) considerably improved the usage of the ASCAT soil moisture data. Future experiments using an improved CDF-matching, with H-TESSEL corrected from precipitation errors, and improved data quality are expected to improve the impact of using ASCAT soil moisture in the data assimilation.

Impact on first guess and forecasts

Figure 4 shows the global impact of the EKF on the 2-metre temperature first guess that enters the analysis. The EKF soil moisture analysis scheme slightly improves the 2-metre temperature scores by consistently reducing the bias of the first-guess.

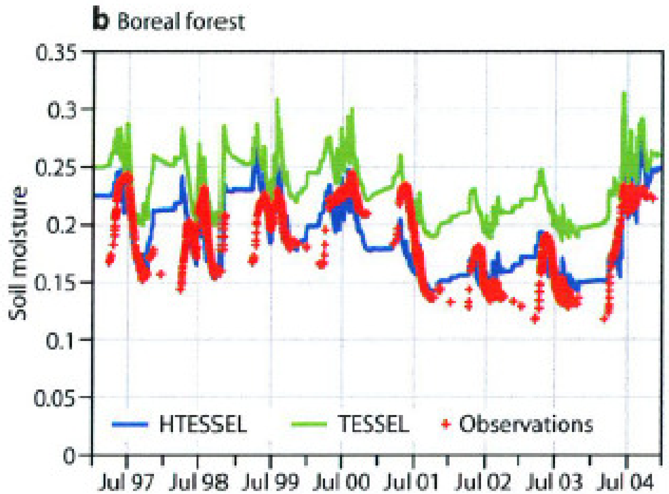
Figure 5 is an evaluation of the 48-hour forecast of 2-metre temperature (at 0000 UTC) for the African continent. It shows that the EKF reduces the night time cold bias compared to the OI scheme. Also the specific humidity (not shown) generally indicates drier conditions with the EKF than the OI scheme. Note that the ASCAT soil moisture data does not impact on screen-level variables and it has only a slight impact on soil moisture analysis as shown in Figure 3.

Figure 6 shows the monthly mean impact of the EKF soil moisture analysis on the 48-hour forecast of 2-metre

The Extended Kalman Filter Soil Moisture Analysis greatly improves the hydrological consistency across assimilation cycles reducing soil moisture increments and is improving the Day-2 weather forecasts for 2m temperature in summer.

A revised soil hydrology

(Balsamo et al. 2009, JHM)



Long record observations at BERMS-Canadian site have crucial to assess the hydrological performance of the new scheme

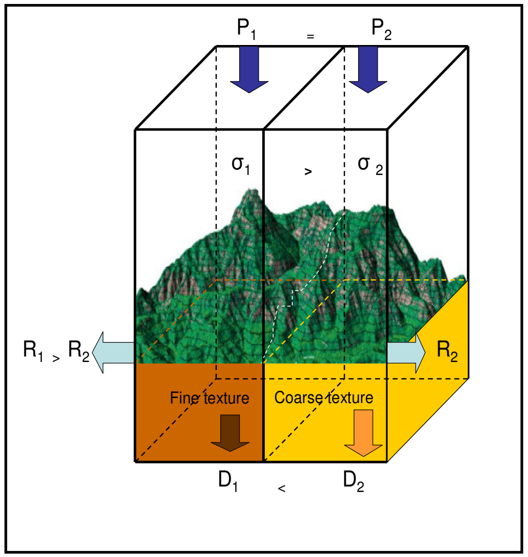
- **Hydrology-TESSEL**

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

  Global Soil Texture (FAO)

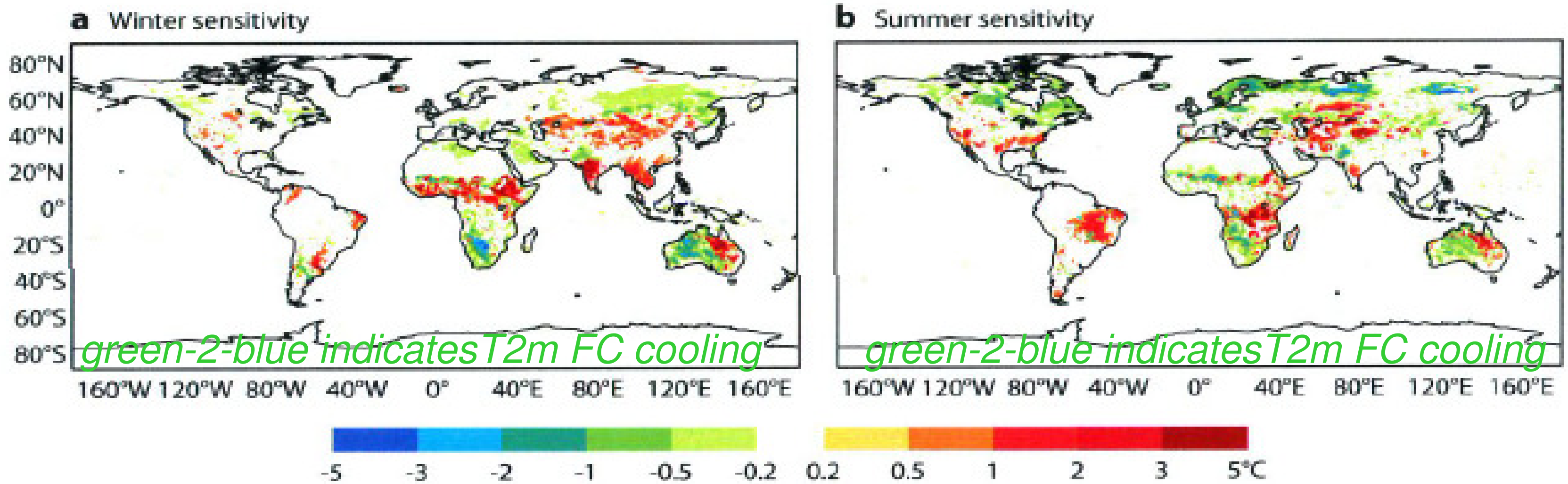
  Van Genuchten hydraulic properties

  Variable Infiltration capacity & surface runoff revision

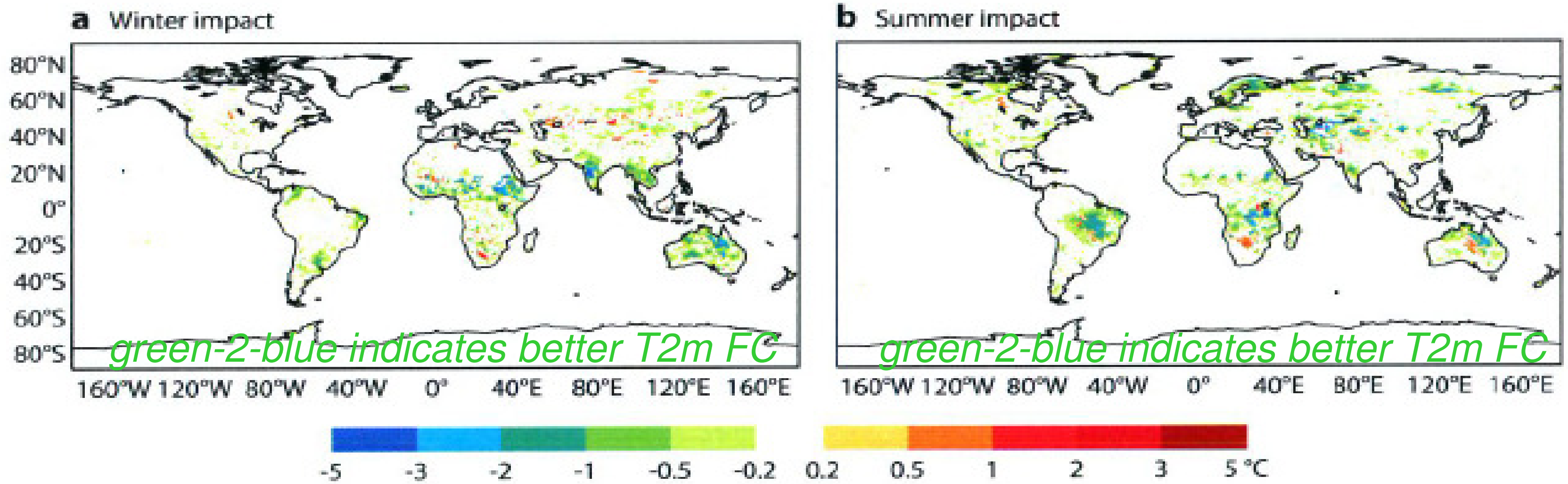


ECMWF

Forecasts sensitivity and impact

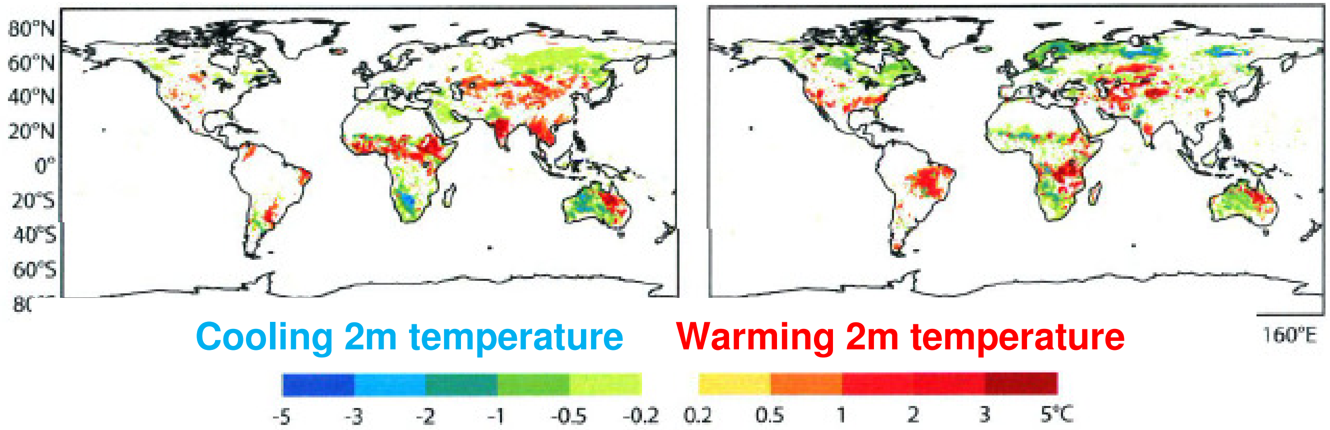


- The revised soil/snow scheme introduce additive improvements respectively in summer/winter seasons forecasts of 2m temperatures

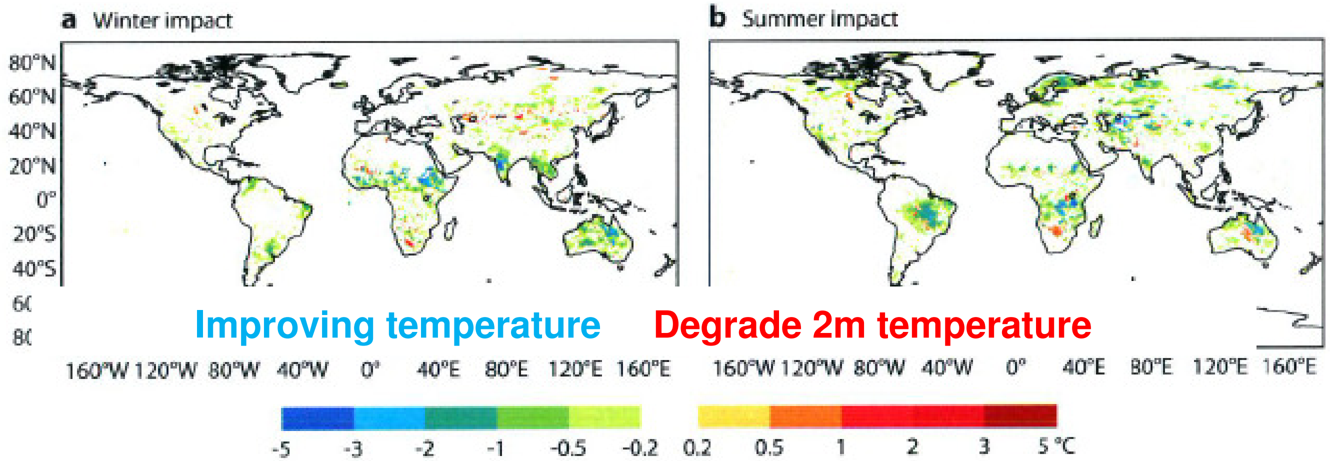


Forecasts sensitivity and impact to land

Sensitivity of a set of T2m Day-2 forecasts in winter 2008 (DJF) and Summer 2008 (JJA)



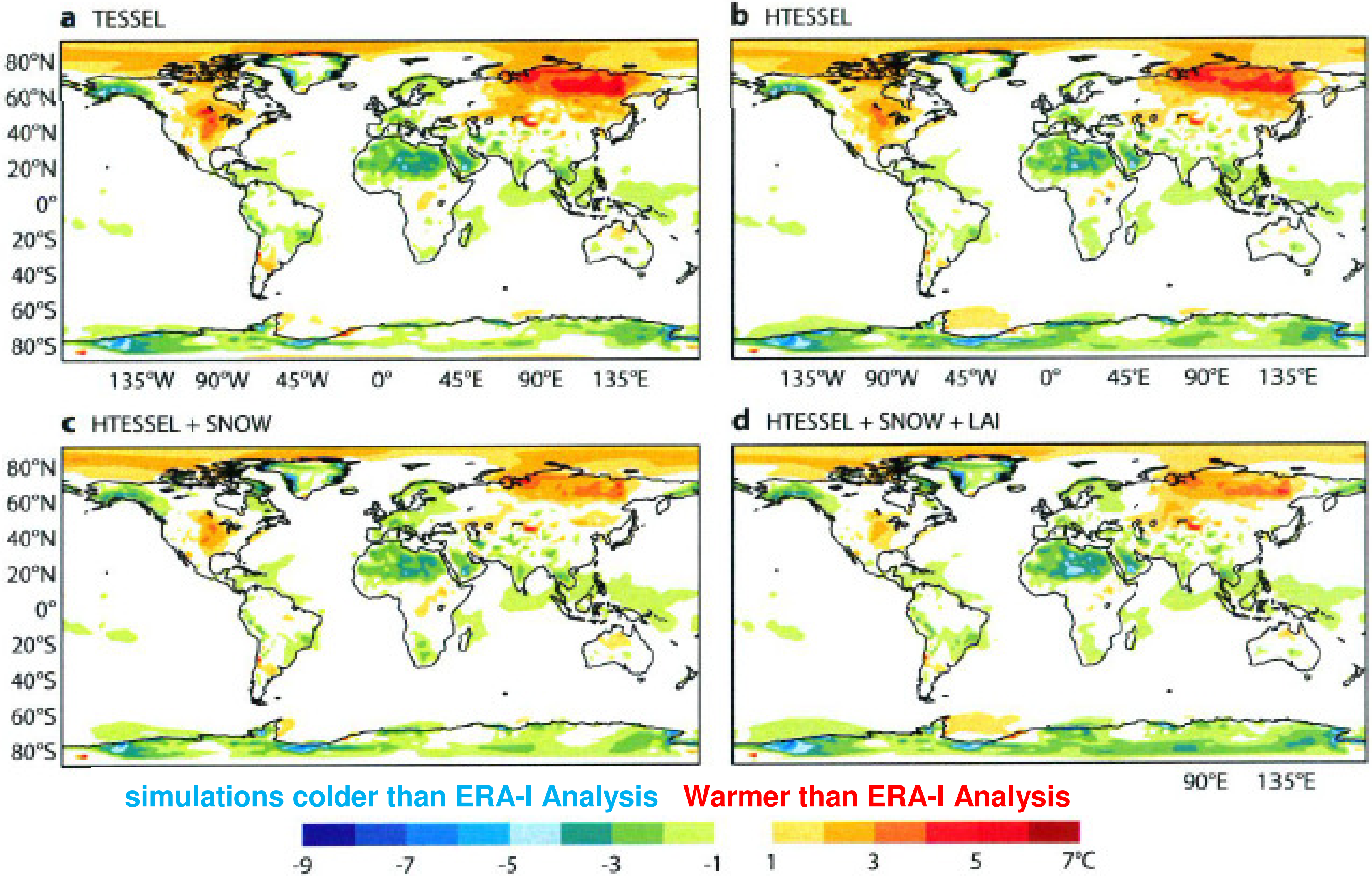
Forecast Impact (Mean Absolute Error reduction of the T2m Day-2 forecast error)



The revised land surface scheme in CY36R1 is compared to the land surface model version (CY31R2 LSM used in ERA-Interim) for its sensitivity and impact on the short-term weather forecasts of 2m temperature showing an improvement also in Day-2 range

Land-related improvements in climate runs

Hindcast (13-months integrations with specified daily SSTs). Here shown the evolution of the annual mean T2m errors compared to analysis



The revised land surface scheme in CY36R4 (d) is compared to the land surface model version (a, CY31R2 LSM used in ERA-Interim) for its impact on long-range forecasts of 2m temperature showing an improvement on annual mean 2m temperature