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# Report on land surface data assimilation activities in Europe and the Americas in the context of NWP SAF objectives

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## Introduction

Regional and global weather and climate are subject to the land surface influence through the exchange of water and energy with the atmosphere. Along with the need for a realistic characterization of the land surface characteristics for controlling the storage of water and energy, data assimilation is key for a deterministic model accuracy. Within the framework of the NWP-SAF, a EUMETSAT-funded activity for improvement of the interface between satellite data and NWP, this report intends to summarize the state-of-the-art of land surface data assimilation in five operational centers of Europe and Americas (i.e. UK Met. Office, ECMWF, Météo-France, NASA and CPTEC/INPE) which were visited during 2011. The report is intended to inform the use of satellite data in land surface activities and vice-versa but is not intended to be a complete review of the subject.

The methods for estimating land surface conditions (e.g. soil moisture, snow, near surface air temperature and relative humidity) at the meteorological operational centers visited are presented in this report. Each centre employs a different methodology to estimate such surface states from conventional observations, satellite data and numerical modeling results.

### Land Surface DA at ECMWF

The *European Centre for Medium-Range Weather Forecasts* (ECMWF) provides daily estimates for snow depth from SYNOP stations and NESDIS datasets. In the early years, the snow depth was estimated using a Cressman analysis. However in regions with very few observations "Bulls eyes" occurred, compromising the analysis. Starting on November 2010 this methodology was replaced by the Optimal

Interpolation scheme making a better use of the model background. During the same period, a new version of NESDIS datasets was made available with increased resolution from 25Km to 4Km with superior quality of the analysis, in particular over the coastal areas.

The soil moisture states in the ECMWF are estimated by using air temperature and relative humidity forecast errors near the ground. Since November 2010 soil moisture conditions have been produced using a Simplified Extended Kalman Filter (SEKF).

**Land Surface DA at Météo-France**

Météo-France uses an Optimal Interpolation scheme to estimate soil moisture states assimilating 2 metre relative humidity and temperature observations. In this scheme temperature and relative humidity increments at 2 metres are correlated to soil moisture increments in each of the land surface model soil layers. A univariate 2 meter temperature and relative humidity analysis is first produced and then the soil moisture increments calculated. This type of scheme used at Météo-France does not allow introduction of new types of observations, relying only on the SYNOP network.

Currently an offline data assimilation system called SURFEX (SURFace Externalized) is under development at Météo-France. This system can be coupled with any atmospheric model used at that centre allowing validation studies in the offline mode. Data assimilation schemes such as the *Extended Kalman Filter (EKF), Ensemble Kalman Filter (EnKF)* and Particle Filters are currently being added to SURFEX.

Snow depth estimates from the SYNOP network are made using CANARI (Code for the Analysis Necessary to ARPEGE for its Rejections and its Initialization). This system uses the same Optimal Interpolation approach to produce its univariate analysis of the near surface variable at 2 metres. It also includes 10 metre wind speed and multivariate analysis of surface pressure, wind and temperature at various levels in the atmosphere.

**Land Surface DA at the Met Office**

The Met Office uses a nudging scheme for its soil moisture analysis. In this scheme temperature and humidity errors near the surface are used to infer the errors in the soil moisture fields and consequently estimate the appropriated corrections for that variable. This analysis is combined with the assimilation of ASCAT-derived soil moisture fields. This procedure became operational at the Met Office in July 2010.

The snow depth analysis combines information from fractional snow cover products and model background fields. The snow cover fraction is derived from NESDIS at 4Km spatial resolution. There is a simplified operator relating snow cover to snow depth. This information is quality controlled, mostly over coastal areas.

**Land Surface DA at NASA**

Land surface data assimilation at NASA is mostly conducted at the Global Modeling and Assimilation Office (GMAO) located at the Goddard Space Flight Center, in Maryland, US. There is also land surface DA research being carried on at the Hydrological Sciences Lab, in the same centre. The four main land surface assimilation areas are soil moisture, skin temperature, snow and terrestrial water storage DA. The DA is mostly based upon the Ensemble Kalman Filter (EnKF) scheme for both offline and coupled instances. The terrestrial water storage DA is based on the Gravity Recovery and Climate Experiment (GRACE) satellite mission observations. Despite its low spatial and temporal resolutions it provides an account of the total water storage over large basin regions (Zaitchik et al., 2008). GRACE-derived terrestrial water storage anomalies are combined with land surface model storage estimates to improve water balance over land.

**Land Surface DA at CPTEC/INPE**

The Center for Weather Forecast and Climate Studies (CPTEC) part of the National Institute for Space Research (INPE) uses an offline Land Data Assimilation System (LDAS) based upon the NASA´s Land Information System (LIS) framework. LIS is a land surface modeling and data assimilation framework developed to facilitate the integration of satellite information with conventional observations and ancillary data from various sources. The South American LDAS provides consistent and balanced land surface fields (e.g. soil moisture and temperature) for CPTEC´s NWP models.

**Discussion**

The lack of conventional observations of soil moisture led the major operational and research centres to develop methodologies that take into account screen-level observations of temperature and relative humidity. Generally, the first guess depatures from these variables are used to estimate increments in soil moisture using data assimilation techniques such as Optimal Interpolation (OI) or Nudging. However, various types of information are available currently through remote sensing of the atmosphere, and can be used to estimate the states of the surface more accurately. As a result, new methods of data assimilation capable of combining the conventional and satellite information are being investigated.

Since November 2010, the ECMWF**,** has been producing estimates of soil moisture using the SEKF. This is an innovative and dynamic data assimilation scheme that takes in account non-linearities of the soil moisture observation operators and can prevent undesirable increments. Furthermore, this system allows a wide range of satellite products to be combined with conventional observations. There is also the possibility of simultaneously assimilating screen-level observations and satellite data such as ASCAT surface soil moisture or SMOS brightness temperature products.

Météo-France and the Met Office are working in the same direction, although still using conventional systems ( *OI* and *Nudging* ). Currently an offline data assimilation system called SURFEX (SURFace

Externalized) is under development at Météo-France. This system can be coupled with any atmospheric model used at that centre allowing validation studies in the offline mode. Data assimilation schemes such as the *Extended Kalman Filter (EKF), Ensemble Kalman Filter (EnKF)* and Particle Filters are currently being added to SURFEX. Various types of observation used for EKF soil moisture data assimilation are under development and testing including ASMR-E/Aqua, SCAT/ERS and ASCAT/MetOp.

The Met Office uses a nudging scheme for its soil moisture analysis, but a new procedure became operational in July 2010 where this analysis is combined with the assimilation of ASCAT-derived soil moisture fields.

The importance of good quality satellite observations is recognized by all centres (e.g. ASCAT soil moisture) for land surface DA. ECMWF uses a more advanced scheme of soil moisture data assimilation, which already uses ASCAT information. Furthermore, the use of SMOS data is under development within the same framework. On the other hand, the development of SURFEX by Météo-France will increase the ability to perform new types of tests with different soil moisture data assimilation systems, as well as enable the inter-comparison between these systems and between different types of information. A similar approach is in use at CPTEC and NASA (*Land Information System - LIS*). This framework enables the run of different land surface models and data forcing, and employs an Ensemble Kalman Filter to assimilate soil moisture derived from AMSU information. We strongly recommend a collaborative work between CPTEC, NASA and Météo-France aiming at the development of a unique tool that can aggregate all capabilities resulting in improvement of land data assimilation. The Met Office is in a less advanced stage in the use of satellite information for soil moisture data assimilation, using a less robust methodology for ASCAT DA (i.e. *nudging*). Nonetheless, they are conducting research on several new types of information, including the Kalman Filter as a future surface data assimilation system.

There is also a general consensus that there should be more investment towards the improvement of land surface temperature and emissivity estimates, which remains a major source of uncertainty in the forward model for observations sensitive to surface information. Passive microwave observations, in particular, are also sensitive to the atmosphere, in particular humidity and clouds. Where there is sensitivity to both surface and atmosphere a data assimilation approach coupling land surface and atmospheric data assimilation may be necessary,

The NWP SAF has already supported collaboration between European centers aiming the improvement of land surface temperature and emissivity estimates. However the problem remains far from solved. Many researches are already working on SEVIRI radiances assimilation over land in the mesoscale models at Metéo-France, where land surface emissivity is described using climatologies from the EUMETSAT Land-SAF. The forecast impact when assimilating this climatological data is generally neutral to positive and the assimilation of many more SEVIRI data improves the quality of analyses, particularly total column water vapor.

The Met Office, Météo-France and ECMWF perform assimilation of lower tropospheric sounding channels over land using AMSU and an emissivity atlas created by Karbou *et al. (*2006). ECMWF additional derive a dynamic emissivity from the observations. In this case, the assimilation of sounding channel

radiances is very sensitive to the accuracy of the skin temperature estimates and the specification of skin temperature errors in the analysis system. There is on-going work to validate the skin temperatures analysed, and whether these skin temperatures are themselves useful for land surface analysis.

**Summary, Final Remarks and Recommendations**

Five centres actively aiming to improve land surface data assimilation have been visited, 3 in Europe (and 2 through previous collaboration with other centers in the Americas) during 2011 to provide a compilation of the land surface activities relevant to NWP SAF objectives. There are existing strong links between the different groups, but different approaches have been employed by each centre. It is, nonetheless, recognized by all centers that more satellite observations of good quality are needed for land surface DA. Moreover, there is a general consensus that more should be invested in the improvement of land surface temperature and emissivity estimates, and other sources of uncertainties to satellite estimates. Due to the non negligible influence of land surface states in NWP more research should be done in land surface modeling and data assimilation in collaboration between the different centers visited.

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