| | | |
|---|---|---|
| | **GEOSAF**<br>(Use of global earth observation data to support monitoring and forecasting of water and food security in Eastern Africa)<br>Funded by ESA<br>ESA Contract No 4000105983/12/NL/CBi | **Project Partners:**<br>**IIASA**<br>**ZAMG**<br>**TU Wien** |

| | | | |
|---|---|---|---|
| **WP Number/Name** | 5300 | **Lead Institution** | ZAMG |
| **Participants** | ZAMG, TU Wien | **Reporting Period** | 01.10.2012-31.07.2013 |
| **Synthetic activity report** | | | |

# Report on ASCAT soil moisture assimilation in ALADIN

## Introduction

Based on the work of WP 5200 (see report D17) where the model domain and testing period have been defined, WP 3300 (see report D15) with the preparation of the model input data and WP 3000 (see report D15) where ASCAT data have been defined as most useful soil moisture data set for the target region, WP 5300 is dealing with the forecasting runs providing short-range forecast to be included in the warning and information system (WP 6000).

## Satellite data preprocessing

Superficial satellite-measured soil moisture to be assimilated in the forecasting model is provided by TU Wien. These are reprocessed ASCAT data (version W54) available for the time period 2007 to 2012. Before applying them for assimilation, they are pre-processed in a three-step approach.
The first quality check is a check for unphysical values (below 0% or above 100% are rejected) in the original ASCAT data set. Besides some technical quality flags, there are mainly four flags which are relevant for application due to lower reliability of the measurements in the cases of: frozen soil, snow cover (both of them are of lower relevance for the IGAD region), complex topography and wetland. For all of these land cover categories, ASCAT measurements might not be as reliable as desired by the user, therefore, such data are usually withdrawn for the assimilation in NWP models (e.g. ALADIN (Mahfouf, 2010), IFS (Integrated Forecasting System; Scipal et al., 2008), UM (Unified Model; Dharrsi et al., 2011)). For the topographic flag, Mahfouf (2010) proposed to reject grid points with a topographic complexity of 15% or larger, while Draper et al. (2012) used a threshold of 10%. TU Wien is providing guidelines how to treat the topographic complexity quality flag in an optimal way to be used in the assimilation experiment. After eventually masking out data, the irregularly distributed ASCAT measurements are interpolated to the ALADIN-AUSTRIA grid with an inverse distance weighting function (Shepard, 1968), taking into account measurements within 25km of the model grid point. ALADIN resolves scales of a few grid points, therefore the scales of the modelled superficial soil moisture (mostly driven by the scales of the precipitation field) are between 20 and 40 km, thus corresponding to the ASCAT resolution. Only ASCAT measurements which passed the quality control are used for interpolation.
To apply a bias correction on satellite measurements, model data are used. The advantage of this correction over a (usually not possible) bias correction against accurate measurements is the fact that model assumptions (e.g. soil type and vegetation distribution) are included in the satellite measurements after the correction procedure. Differences in the soil moisture distribution are mainly due to model physics which is on the one hand avoiding very dry soil (below the wilting point defined for the grid point) and on the other hand is overestimating precipitation, thus producing too much saturated soils. In addition, discrepancies between the measuring depth of the satellite (1-2cm) and the model soil layers (defined as 1cm) have to be balanced by the bias correction. Hence, bias correction is

so far supposed to be crucial for assimilation of satellite data in NWP models. The approach for bias correction applied here is the cumulative distribution function (CDF) matching, proposed by Reichle and Koster (2004). CDF matching should be applied on a scale as localized as possible with a data set as long as possible to gain best results (Draper et al., 2009), so the bias correction is calculated for each ALADIN grid point separately. For the comparison, data from the whole year 2009 have been used. To obtain statistically significant results, only grid points with at least 100 available measurement-forecast data pairs were taken into account.
The CDF matching has been computed with 4th-order polynomial fits, considering the main statistical moments (expectation, variance, skewness and kurtosis). The components of the 4th-order polynomials are plotted in Fig. 1. Though there are significant spatial patterns, no clear correlation to model fields (e.g. sand/clay fraction of the soil) has been found so far. For the western part of the domain (DR Congo), CDF matching can be applied but should not be used to the problems of ASCAT data retrieval in tropical rain forests.

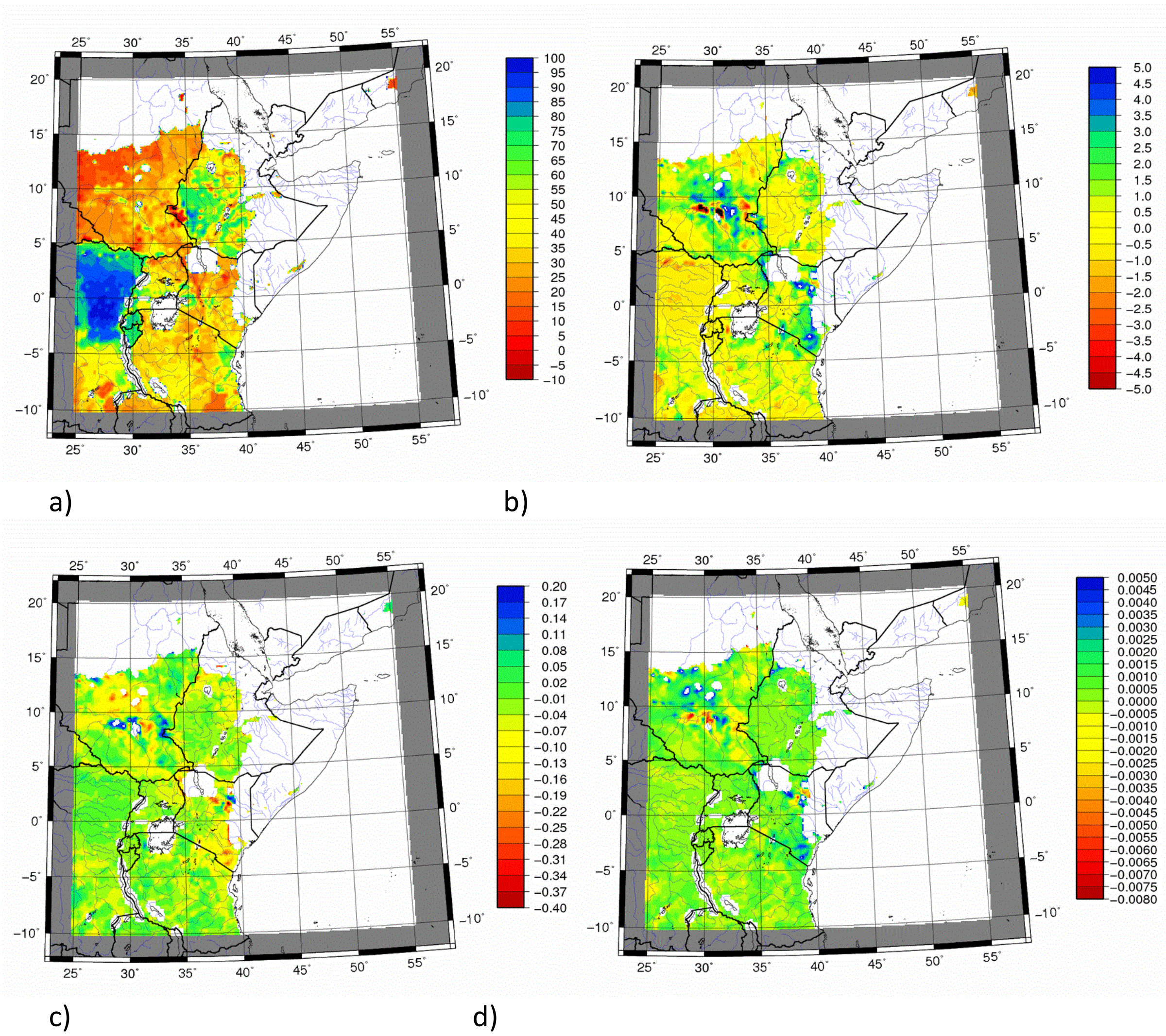



Figure 1: Terms of the 4th –order polynomials for a) expectation, b) variance, c) skewness and d) kurtosis. For white areas, either there were not enough data pairs or the ASCAT data range was too low for a useful comparison.

## Technical description

The main forecast model specifications are described in D17, the forecasting range was chosen to be 72hours. Forecasts are calculated for every day of the year 2009 at 00UTC.
To take soil-atmosphere-interaction into account, SURFEX (SURFace EXternalized; LeMoigne, 2009) has been used in combination with the forecasting model. SURFEX is a stand-alone model for the representation of surface processes in NWP modelling. SURFEX includes a soil vegetation atmosphere transfer scheme called ISBA (Interaction between Soil Biosphere and Atmosphere; Noilhan and Planton, 1989; Noilhan and Mahfouf, 1996) to simulate exchanges of water and energy between the surface and the atmosphere above and can be used offline (Mahfouf et al., 2009).
In the version used here, ISBA has two soil layers. The water transfers in the soil are described with two prognostic variables for the superficial soil layer water content wg [m3m-3] with a depth of 1cm and the deep reservoir water content w2 [m3m-3] (Mahfouf, 2010), which depth is depending on the local soil type. The prognostic equations for these soil variables are based on the force-restore method (Deardorff, 1977). For assimilating the ASCAT data, a simplified Extended Kalman Filter (Draper et al., 2009; Mahfouf, 2010) included in SURFEX is used. In a first step, atmospheric input data from ALADIN-AUSTRIA from the lowest model level for each time step are provided. To initialise the system, they are taken from REF. During the cycling experiment, the updated ALADIN atmospheric forecasts are used as input for the next assimilation. For each surface grid box, the near surface air temperature, specific humidity, horizontal wind components, surface pressure, total precipitation flux, long-wave and shortwave radiation fluxes from the NWP model are provided (Le Moigne, 2009). wg and w2 are forming the state variable for the sEKF. The observation operator is the 24hourly integration of ISBA, whereas it has to be run twice for each element of the state vector - once with the undisturbed prognostic soil variable and once with the perturbed one. This is necessary for the linearization of the observation operator. The amplitude of the perturbation is chosen as 1e-4*(wfc-wwilt). wfc is the volumetric field capacity and wwilt the wilting point at each grid point, depending on the soil type (Noilhan and Mahfouf, 1996). The static background error covariance matrix B is defined by model error standard deviation, 0.6*(wfc – wwilt) for wg and 0.3*(wfc – wwilt) for w2. Measurements from ASCAT are applied at the beginning of the assimilation window. For a more detailed description of the sEKF see Draper et al. (2009).

## Experimental set-up

To test the impact of the satellite soil moisture data assimilation, four model runs have been planned:

i) the reference run (REF) which is a dynamical downscaling of the IFS without data assimilation in ALADIN
ii) the open loop run (OL) which is using offline SURFEX including the sEKF without providing ASCAT data to be assimilated. Due to the differences in model physics between ISBA within ALADIN and offline SURFEX, the soil moisture distribution is evolving differently compared to REF.
iii) ASCAT data assimilation (EXP1) using offline SURFEX including the sEKF. For this experiment, all available ASCAT data are used.
iv) ASCAT data assimilation (EXP2) using offline SURFEX including the sEKF. For this run,

TU Wien is providing updated quality flag information (as was decided at the meeting at TU Wien on June 25th , 2013).

## Results

Output of the forecasting runs is available on an hourly basis up to +72hours for each day of the investigation period. As an example of the model output, Fig. 2 is displaying the 24hourly precipitation sum for April 1st, 2009 (00-24UTC) for REF, OL and EXP1. Fig. 2d) is displaying the difference field OL minus EXP1 for the 24hourly precipitation, showing differences up to plus/minus 15mm/24h.

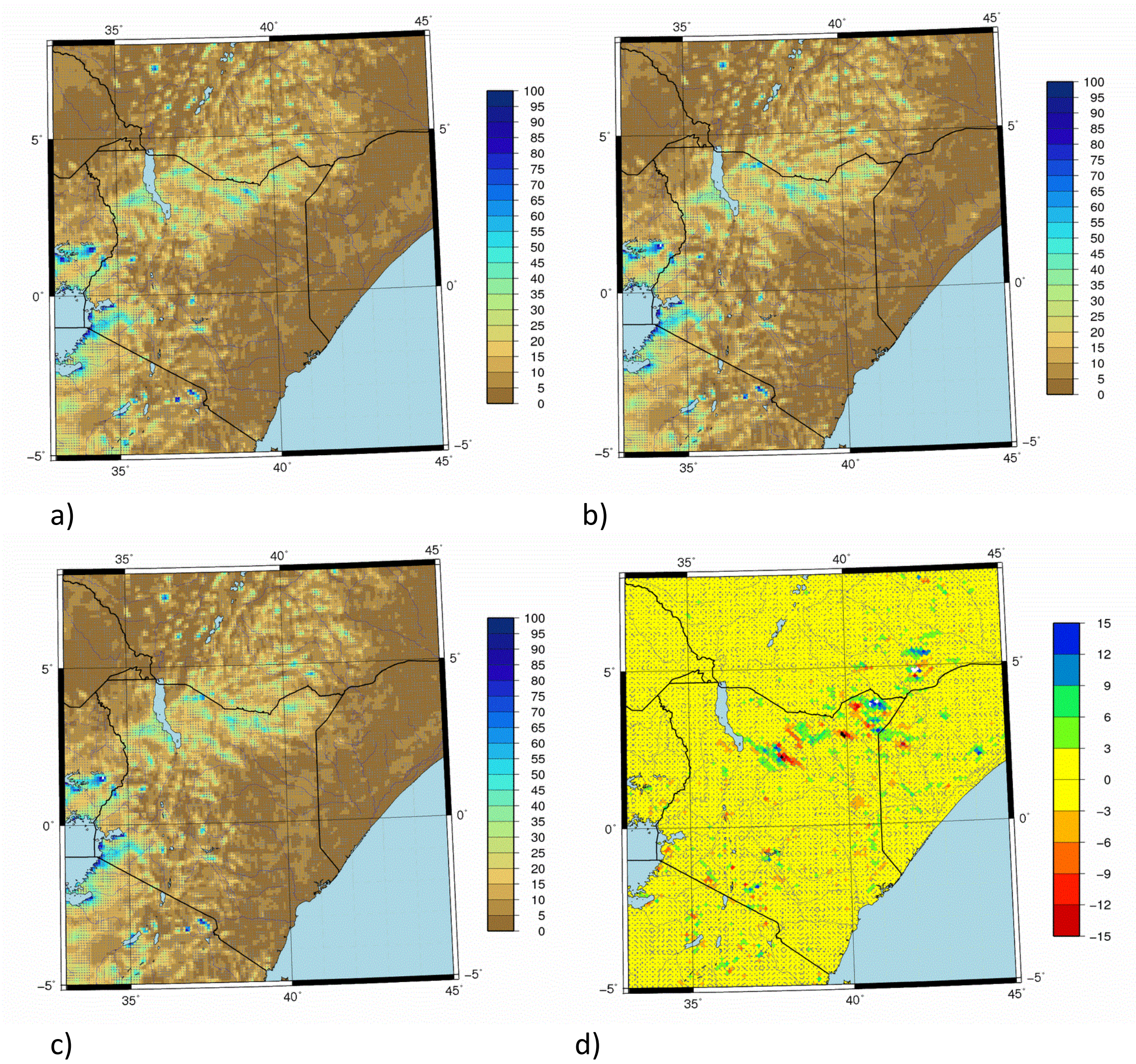



Figure 2: 24hourly precipitation sum for April 1st, 2009 (00-24UTC) for a) REF, b) OL and c) EXP1. d) is displaying the difference field OL minus EXP1 for the 24hourly precipitation.

The only difference between EXP1 and EXP2 is in the use of the quality flags. A description of the quality flags can be found in Scipal (2005). For EXP1, all available ASCAT data have been used, no matter if they are of questionable quality or not. Thus, high data coverage could be achieved. For EXP2, quality flags have been chosen accordingly to the advice of the data provider and recent scientific findings. For wetlands, frozen soils and snow covered areas, ASCAT data have been rejected completely. This means that even if small parts of the ASCAT grid cell is covered by wetlands, frozen soils and snow covered areas, data were not used. For topographic complexity, grid cells with a complexity of 30% or higher have been rejected. 10% (Draper et al., 2012) and 15% (Mahfouf, 2010) have been used as threshold in assimilation experiments, but newer investigations of Broccha et al. (2013) are suggesting that data quality of ASCAT is rather well over complex terrain, thus a higher threshold has been chosen here. Figure 3 is showing the impact of this quality control for one overflight (February 12th, 2009). Mainly grid points located next to lakes, but also several grid points in mountainous areas are rejected. Overall, the number of rejected grid points is relatively low.

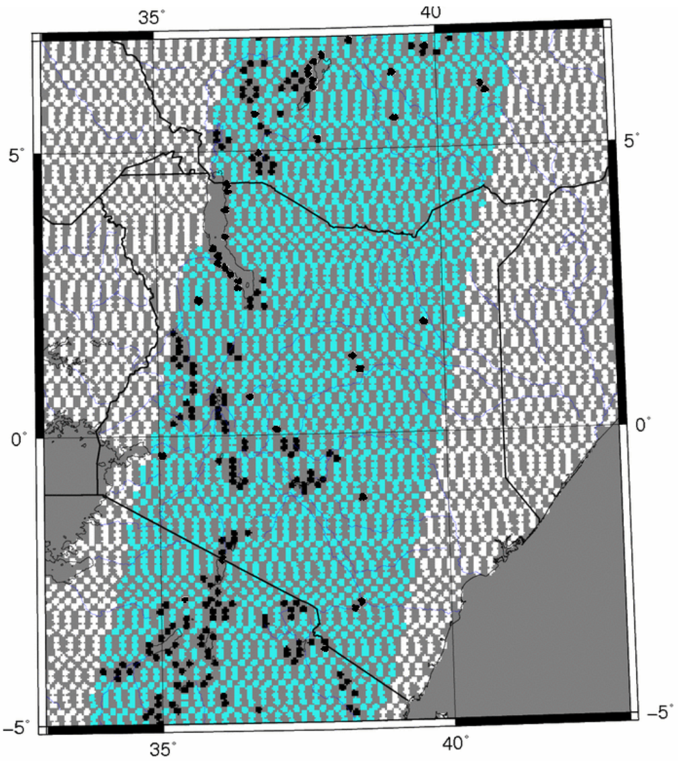



Figure 3: Grid points with ASCAT measurements used for assimilation (blue), sorted out due to the quality control (black) and without measurements during the overflight at February 12th, 2009 (white).

Forecast quality will be mainly validated by the precipitation forecast skill of the different model runs. Furthermore it is planned to investigate several case studies. This evaluation will be done in WP 7200.

## 2. WP 7200: Validation of short-range weather forecast products (ZAMG)

The aim of this work package is the evaluation of short-range forecast for 72h lead time of ECMWF-IFS and ALADIN for the region of Eastern Africa. The forecasts of ECMWF-IFS provide the initial and boundary conditions for ALADIN. It shall be tested if ALADIN can improve the forecasts of ECMWF by dynamical downscaling, i.e. if the higher resolution forecasts of ALADIN (~8km horizontal resolution) provide better results than the coarser driving model (~25km horizontal resolution). It is further investigated if the ALADIN forecasts can be improved by including soil moisture information of ASCAT by data assimilation. In doing so, two parameters are evaluated which are strongly dependent on soil moisture conditions: precipitation and clouds. The advantage of the chosen parameters is moreover, that two space-borne observation data sets are available as references: TRMM precipitation data and the cloud mask product of NWC-SAF.

## 2.1. Data sets

### 2.1.1. ECMWF

The short-range forecasts of ECMWF-IFS are extracted from the MARS archive (Meteorological Archival and Retrieval System, ECMWF 2013), the main repository of meteorological data at ECMWF. The forecasts are extracted using the highest (i.e. the original) resolution which was available at that time, T799 or 25km. Daily precipitation values are retrieved from 24h forecasts. For the evaluation, data are interpolated to the ALADIN grid. For the evaluation of clouds the parameter of total cloudiness is used which describes the degree of cloud coverage (between 0 and 1) for each grid box.

### 2.1.2. ALADIN

ALADIN (Bubnova et al., 1995) short-range forecasts (up to +72h) have been calculated for selected periods for the target region in Eastern Africa. Details about the model and assimilation system with the simplified Extended Kalman Filter (sEKF) are described in report D19 (Report on ASCAT soil moisture assimilation in ALADIN). Five experiments have been conducted:

- The reference run (REF), which is a dynamical downscaling of the ECMWF-IFS without data assimilation in ALADIN. This run is used as the basic reference for the verification.
- The open loop run (OLR) which is using offline SURFEX including the sEKF without providing ASCAT data to be assimilated. Due to the differences in model physics between ISBA within ALADIN and offline SURFEX, the soil moisture distribution is evolving differently compared to REF.
- ASCAT data assimilation experiment (EX1) using offline SURFEX including the sEKF. For this experiment, randomly distributed ASCAT data have been used. With this experiment it can be tested if it is the information provided by ASCAT or just the application of the sEKF which is responsible for improvements in the forecast.
- ASCAT data assimilation experiment (EX2) using offline SURFEX including the sEKF. All available ASCAT data have been used in this experiment.
- ASCAT data assimilation experiment (EX3) using offline SURFEX including the sEKF and quality control. Quality flags for wetlands, topographic complexity, snow and frozen soils are applied to the ASCAT data set to test the influence of these flags provided by TU Wien on forecasting quality.

### 2.1.3. TRMM

The reference data for the evaluation of precipitation are represented by TRMM (Tropical Rainfall Measuring Mission, Huffman et al., 2013) precipitation estimates. In its 3B42 product, NASA provides 3-hourly precipitation values on a 0.25° x 0.25° grid. On the TRMM satellite different instruments are used to measure precipitation: a precipitation radar operating at 13.8 GHz, a passive microwave radiometer and a visible and infrared radiometer. The 3B42 algorithm combines different independent precipitation estimates from the TRMM microwave image, Advanced Microwave Scanning Radiometer for Earth

Observing Systems (AMSR-E), Special Sensor Microwave Imager (SSMI), Special Sensor Microwave Imager/Sounder (SSMIS), Advanced Microwave Sounding Unit (AMSU), Microwave Humidity Sounder (MHS), and microwave-adjusted merged geo-infrared (IR). It is therefore a TRMM-adjusted merged-infrared precipitation rate.

### 2.1.4. NWC-SAF

NWC-SAF (EUMETSAT, 2013) is developed in the framework of the EUMETSAT SAF strategy to support the use of meteorological satellite data in nowcasting and very short range forecasting. The development of the product is based on a collaboration of the Spanish meteorological institute AEMET (leader), Météo France and the Swedish (SMHI) and Austrian (ZAMG) meteorological services.

For the evaluation of clouds we use the Cloud Type product of NWC-SAF, which provides a detailed analysis of the coverage, the height and type of prevailing cloudiness. The analysis is available every 15 minutes. For the purpose of cloud evaluation in GEOSAF, we could restrict ourselves to 6-hourly outputs. The algorithm of the cloud type product is based on a threshold approach. The thresholds refer to certain spectral band widths and are dependent on illumination conditions, viewing geometry, geographical location and the water vapour content and the vertical structure of the atmosphere. The two latter are retrieved from NWP data.

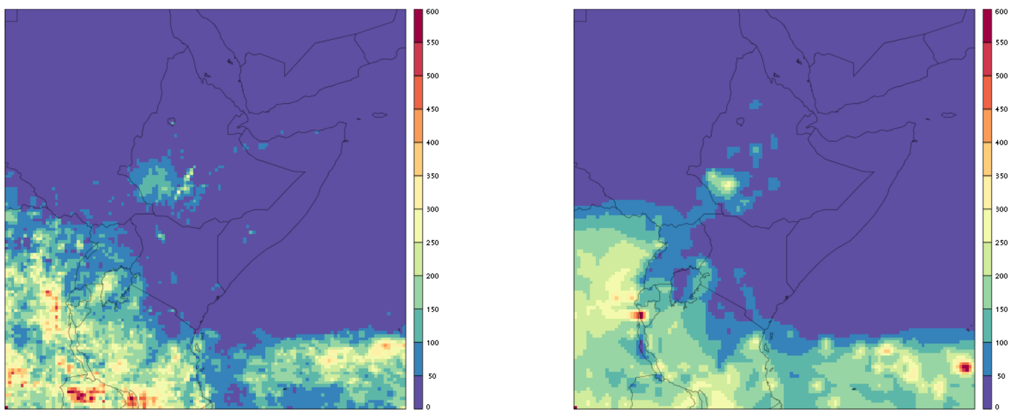
The cloud type product distinguishes 21 categories. Main categories are (very) low, medium and (very) high clouds, separated into stratiform and cumuliform clouds and further opaque, semi-transparent and fractional clouds (for high clouds only).

For the evaluation of the cloud coverage in ECMWF and ALARO all these categories are assigned with cloudiness = 1. All other categories, which describe cloud free conditions are assigned with cloudiness = 0. These are “cloud free land/sea”, “land/sea contaminated by snow/ice”, “undefined”, and “non-processed”.

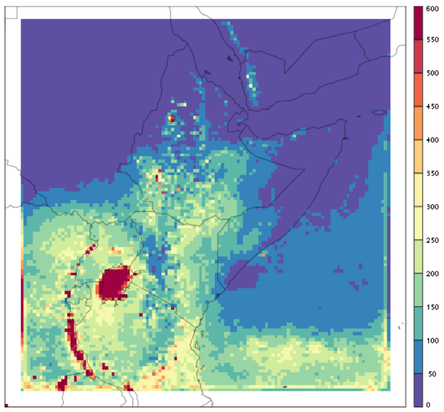
## 2.2. Results

### 2.2.1. Precipitation

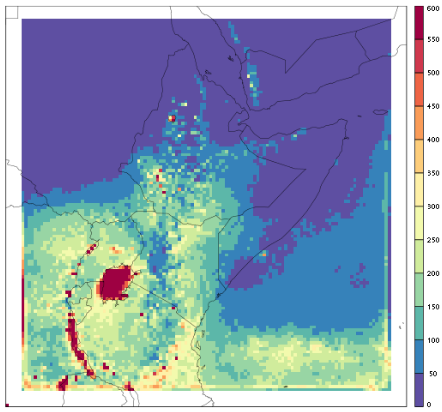
As a first step monthly precipitation sums are compared for the TRMM and the short-range forecasts of ECMWF and ALARO. An example of this comparison is shown in Figure 6 for March 2009.



a) b)




c)

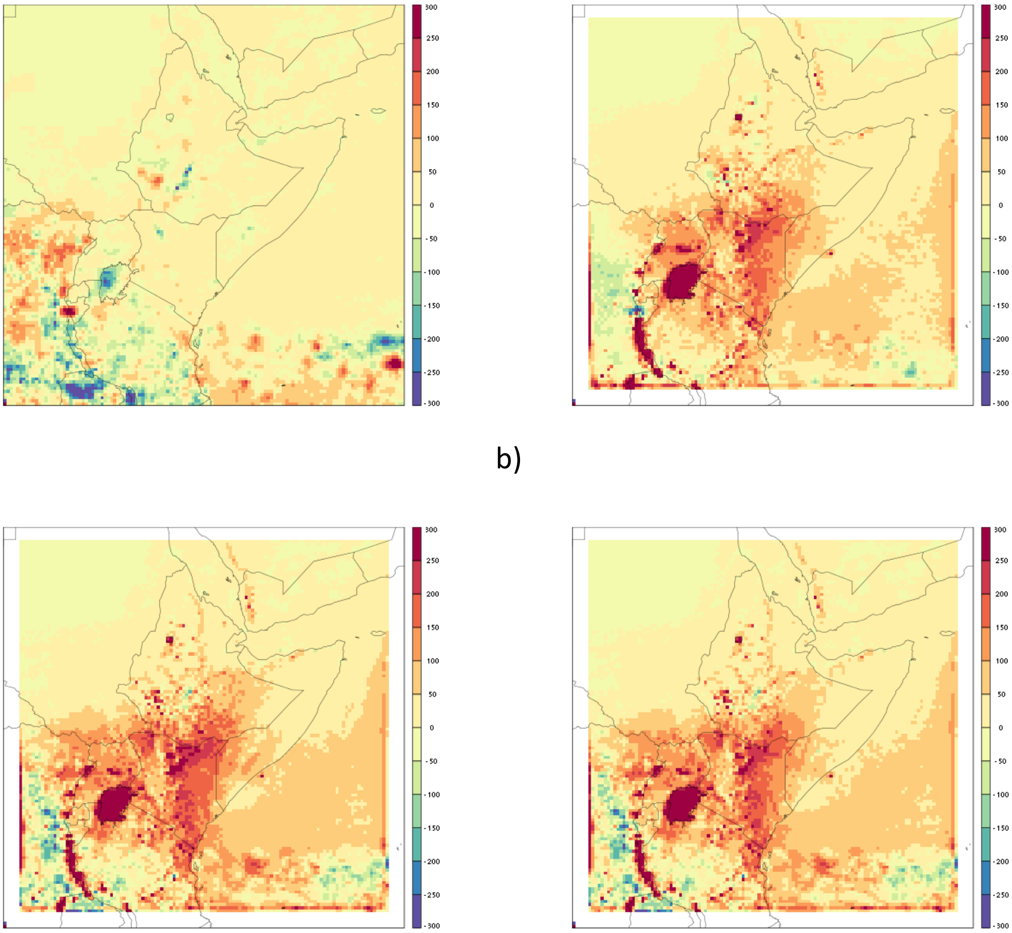



d)

Figure 4: Monthly precipitation sums [mm/month] for TRMM (a), ECMWF (b), ALADIN-REF (c) and ALADIN-EX3 (d)

The legends in the plot charts in Figure 4 range from 0 to 600mm/month. In TRMM and ECMWF plots this maximum value is only reached at a few locations. In both ALADIN versions shown, the maximum is reached and even exceeded over large lakes (Lake Victoria, Lake Tanganyika). This remarks one major problem, which arouse during the integration of ALADIN for Eastern Africa, namely that the convection is widely overestimated, especially over inland water surfaces and regions with complex topography. A detailed investigation for Kenya showed that convection is triggered too early and too intense over mountainous regions (which are covering mainly the south-western part of Kenya). This problematic feature of ALADIN in particular and limited area models in general is well known but still not solved (Wulfmeyer et al., 2008; Wittmann et al., 2010). As the problem could not be easily solved in the framework of GEOSAF, it was tried to document the impact of soil moisture assimilation despite this major drawback nevertheless.

Differences of monthly precipitation amounts are shown in Figure 5. Light yellow colours refer to balanced precipitation amounts in the verified and the reference data set. Balanced conditions can merely be found in the dry areas. The larger differences occur in the regions with large precipitation amounts. However, there is a large variability in the spatial distribution of the differences. ECMWF, for example, shows slightly drier conditions over the lakes than TRMM (green to blue colours). ALADIN, as already mentioned above, produces too heavy rains over the lakes (red colours). In the tropical regions in the south of the domain, ECMWF produces too dry conditions compared to TRMM. ALADIN, on the other hand, is balanced with TRMM in this region. A very problematic area, except for the lake areas, for ALADIN is located in Kenya. In the zone between the Indian Ocean and the first larger mountain ridge in Kenya seen from the seas side, precipitation is highly overestimated. In the ECMWF-forecasts the same area is slightly too dry, but shows not much spatial variation in the differences.



a) b)

c) d)

Figure 5: Differences of monthly precipitation sums [mm/month] between ECMWF and TRMM (a), ALADIN-EX3 and ECMWF (b), ALADIN-OLR and TRMM (c) and ALADIN-EX3 and TRMM (d)

In the monthly precipitation values hardly any difference can be seen between the different experiments which have been conducted for ALADIN. Therefore the monthly comparison is compared with a daily evaluation. The daily precipitation amounts are verified using the object based verification method SAL (Wernli et al., 2008, Wernli et al., 2009). The SAL method has the advantage that it investigates the structure “S”, the amplitude “A” and the location “L” of a number of defined precipitation objects. It is a spatial method and, as such, it avoids favouring the smoother forecasts of the coarser model, which is known as the “double penalty” problem (Nurmi, 2003).

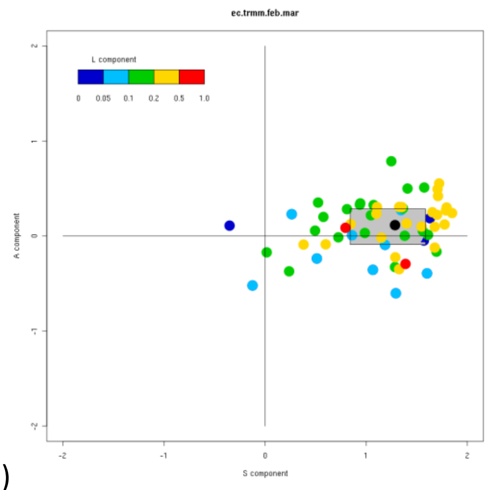
In Figure 6, SAL diagrams for daily precipitation of the period February to March 2009 are compared for ECMWF, ALADIN-OLR and ALADIN-EX3 evaluated by TRMM. The diagrams summarize three characteristics of the verified forecasts.

The vertical coordinate (component A) refers to the amplitude score. It describes an overall estimate of overestimation and underestimation of precipitation for the whole selected domain. As such, it can be interpreted as a normalized bias. The perfect value is zero. In Figure 6, ECMWF shows good estimates of daily precipitation amplitudes compared to TRMM. The median (black dot) is only slightly above the zero-line meaning that precipitation is slightly overestimated. For the two ALADIN versions, we see that the SAL results hardly differ and that we cannot conclude from the results if the assimilation of

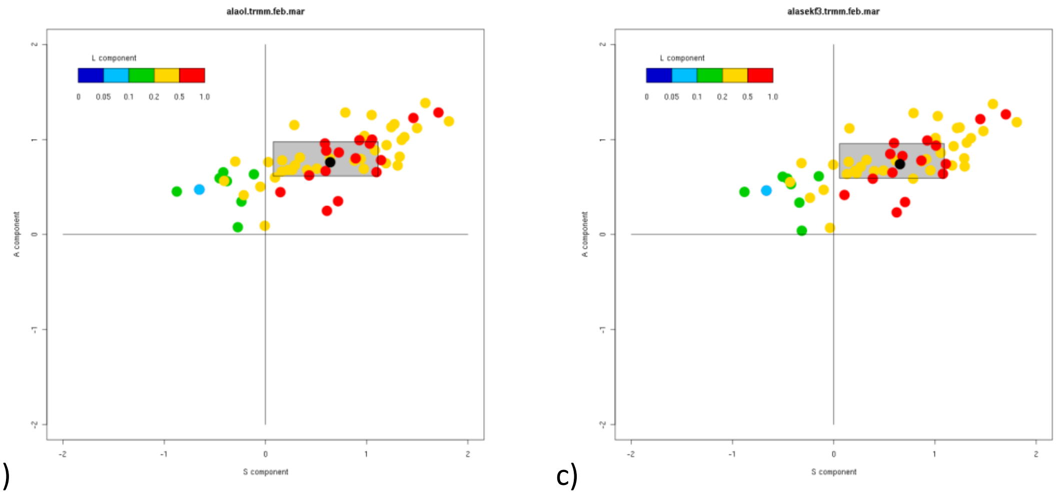
ASCAT in ALADIN-EX3 brings an improvement. Further, the precipitation amounts are highly overestimated. This corresponds to our evaluation of Figures 4 and 5.

The horizontal coordinate (component S) describes the structure of the forecasted precipitation object. A precipitation object is a coherent area with precipitation sum exceeding a certain threshold. In our evaluation the threshold is chosen according to the precipitation situation and is defined based on the reference of TRMM precipitation sums. The perfect value of the structure component is zero. If S is below zero, precipitation objects in the evaluated area are too small or too peaked. If S is above zero, objects are too large or too flat. For the structure component ALADIN achieves better median results than ECMWF. This is mainly due to the higher resolution of ALADIN. However, the variability of structure results is larger than in ECMWF, which means that ECMWF results are more stable in matters of spatial structure.

The third component described by the diagram (component L) provides information of the ability of the model to get the location of the precipitation objects right. As for the other components, zero is the perfect value. If L is above zero, either the centre of mass is different from the reference precipitation field or the location of the different precipitation objects relative to it. In the SAL diagrams the value of the location component is indicated by colours. Blue or green colours refer to more accurate location, yellow and red colours indicate that the model produces some spatial shift for the precipitation objects or that the spatial distribution of objects is wrong. The comparison of ECMWF and ALADIN results shows that ECMWF outperforms ALADIN for the evaluated period in regarding location. This can be partly described by the ALADIN problem of overestimating precipitation at the large lakes within the domain which is influencing the L component.




a)



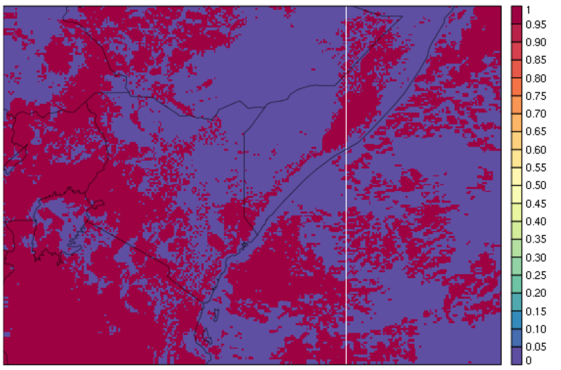

b) c)

Figure 6: SAL diagrams for daily precipitation values for the period February to March 2009. a) ECMWF compared to TRMM, b) ALADIN-OLR compared to TRMM, c) ALADIN-EX3 compared to TRMM.

### 2.2.2. Clouds

Additionally to precipitation also the cloud coverage has been evaluated, as there is a strong coherence between soil moisture, convection, clouds and precipitation (e.g. Ferranti and Viterbo, 2006). Cloud evaluation has the advantage that it can detect initiated convection, even if no rain is produced by the clouds.

For the investigation of cloud coverage also the SAL method has been used. The difficulty of the comparison of cloud forecasts and observations is, however, that the descriptions of cloud coverage in the datasets differ (see also Figure 7). The NWC-SAF product provides two values, 1 for a cloudy grid cell, 0 for a cloud-free grid cell. As a consequence, the cloud mask field of NWC-SAF appears more scattered than the model fields. The forecast models, ECMWF and ALADIN, provide values between 0 and 1. Hence, only if a grid cell is completely covered by clouds the value 1 is given, otherwise the value of “total cloud coverage” is below 1.




a)

b)

c)

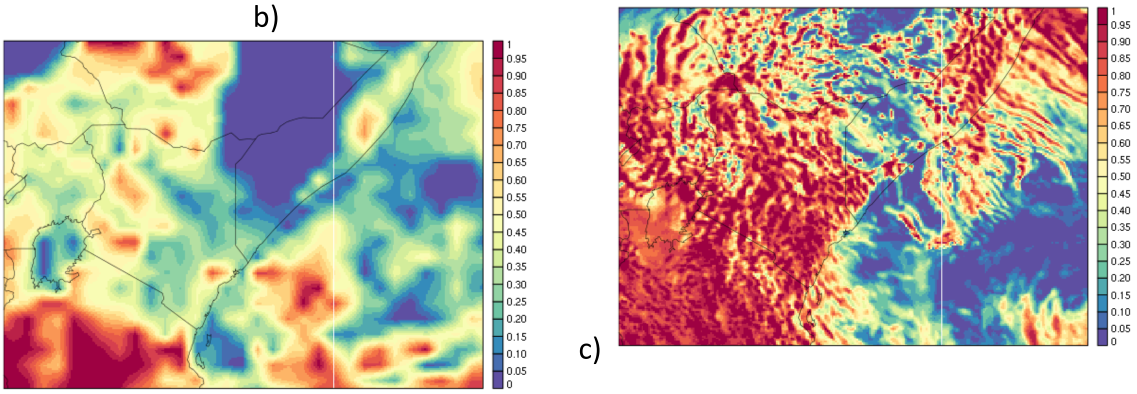



Figure 7: Examples of cloud data for March 31, 2009 at 18UTC: a) NWC-SAF, b) ECMWF, c) ALADIN

The SAL evaluation of clouds is shown in Figure 8. It has been performed for 6-hourly cloud forecasts and observations for the same period as for the precipitation, February and March which is the main sowing season. The left column of Figure 8 contains the results of 00 UTC, the right panel those of 12 UTC. Other than for precipitation, different experiments with ALADIN show different results.

The “open loop run” experiment, ALADIN-OLR which does not use ASCAT data in its data assimilation is overestimating cloud coverage both during night and during day. At 00 UTC overestimation is more intense. The cloud covered areas are larger than in ECMWF or ALADIN-EX3 (see S component). Further, only few dots refer to good results concerning the location of the cloud objects.

The results for ECMWF are slightly better than the ALADIN-OLR experiment. The amount of cloud coverage is more accurate during night, but slightly underestimated at 12 UTC. Also the structure and location components are slightly better. Despite the similarities in precipitation results, ALADIN-EX3 shows rather different results compared to the OLR experiment. Through the involvement of ASCAT data in the assimilation the simulation of cloudiness in the model is changed. Obviously it is important to rely on the quality flags provided by TU Wien for the ASCAT observations, because there is a major difference between ALADIN-EX3 which used flags and ALADIN-EX2 (not shown) which used the same approach only without considering the quality flags. Other than previous experiments ALADIN-EX3 is underestimating cloud coverage. This is most intense during night, where cloud objects are too small (see S component). Results for 12UTC are more accurate. Still cloud coverage is underestimated, but the size of cloud objects is better. Concerning the location component there is also a larger amount of good forecasts than in the other ALADIN experiments.

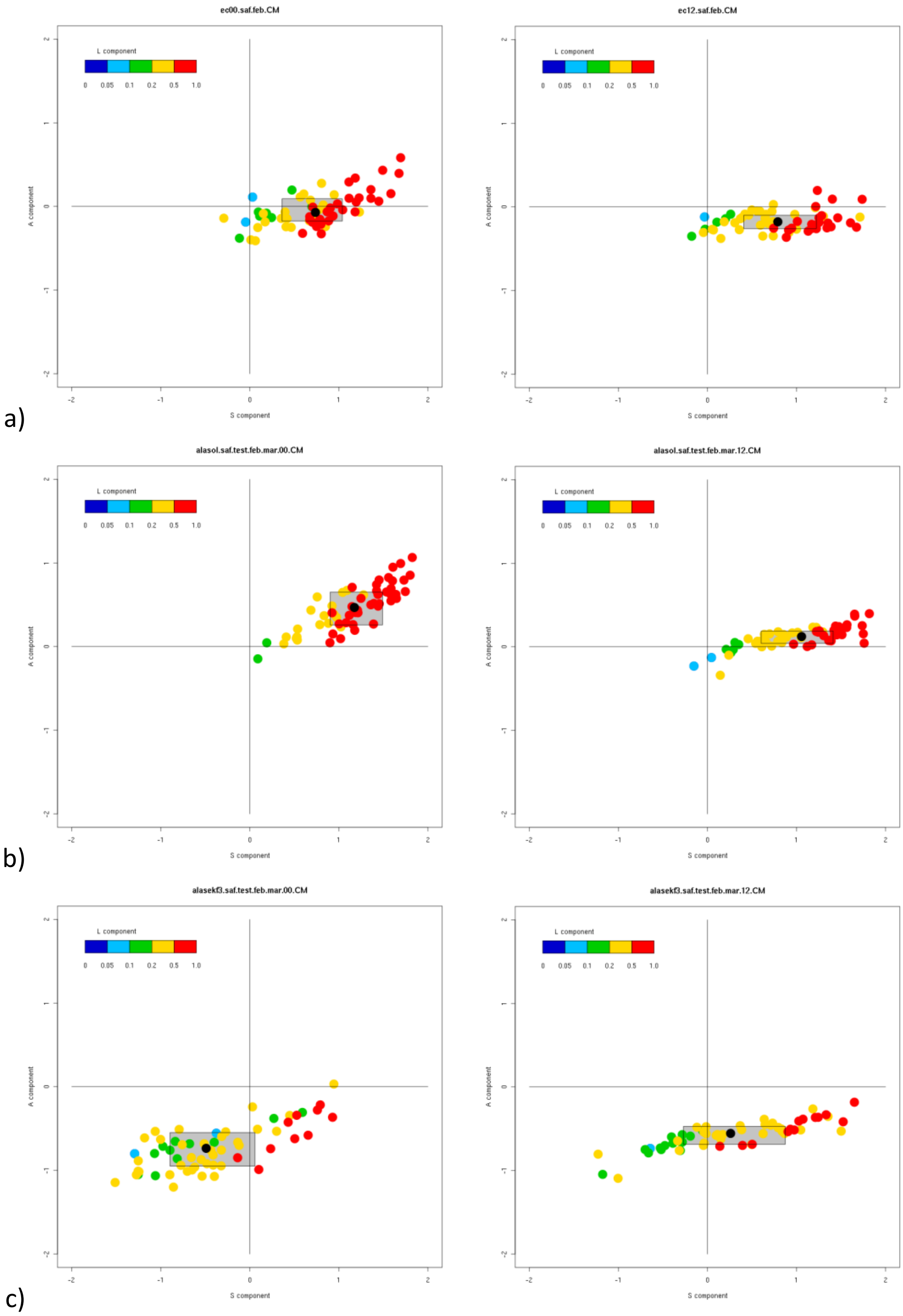



Figure 8: SAL diagrams for total cloud cover for the period of February to March 2009. a) ECMWF compared to NWC-SAF, b) ALADIN-OLR compared to NWC-SAF, c) ALADIN-EX3 compared to NWC-SAF. Left panels show results for 00UTC, right panels for 12UTC.

## 2.3. Conclusions

Within this work package, it was verified if short range forecasts will on the one hand benefit from satellite soil moisture data and on the other hand outperform global forecast performance. Improved weather forecasts would be a valuable tool for decision makers and

farmers especially during sowing and harvesting season.
Although there have been improvements in forecast quality due to the assimilation of ASCAT data with the simplified Extended Kalman Filter, they are unfortunately well covered by the problem of overestimated convection in ALADIN for most of the cases investigated. Project partner ZAMG was well aware of the fact that the use of ALADIN in tropical regions could lead to problems, mainly due to differences in the needed parameterization for convective processes, but the tuning of the model turned out to be more complex than expected. Nevertheless the validation pointed out the potential of the Kalman filter assimilation approach in the limited area model to improve forecasts for cloudiness and precipitation.

## References

Brocca, L., A. Tarpanelli, T. Moramarco, F. Melone, S.M. Ratto, M. Cauduro, S. Ferraris, N. Berni, F. Ponziani, W. Wagner, and T. Melzer, 2013: Soil moisture estimation in alpine catchments through modeling and satellite observations. Vadose Zone Journal, in press.

Deardorff, J.W., 1977: A parametrization of ground surface moisture for use in atmospheric prediction models. J. Appl. Meteorol., 16, 1182–1185.

Dharssi, I., K.J. Bovis, B. Macpherson, and C.P. Jones, 2011: Operational assimilation of ASCAT surface soil wetness at the Met Office. Hydrol. Earth Syst. Sci., 15, 2729–2746, DOI:10.5194/hess-15-2729-2011.

Draper, C.S., J.-F. Mahfouf, and J.P. Walker, 2009: An EKF assimilation of AMSR-E soil moisture into the ISBA land surface scheme. Journal of Geophysical Research, 114, D20104, DOI:10.1029/2008JD011650.

Draper. C.S., R.H. Reichle, G.J.M. DeLannoy, and Q. Liu, 2012: Assimilation of passive and active microwave soil moisture retrievals. Geophy. Res. Lett., 39 (4), DOI: 10.1029/2011GL050655.

Ferranti, L., and P. Viterbo, 2006: The European Summer of 2003: Sensitivity to Soil Water Initial Conditions. J Climate, 19, 3659-3680.

LeMoigne, P. (Ed), 2009: SURFEX scientific documentation. Note de Centre du Groupe de Météorologie à Moyenne Echelle, 87, CNRM, Météo France, Toulouse, France.

Mahfouf, J.-F., K. Bergaoui, C. Draper, C. Bouyssel, F. Taillefer, and L. Taseva, 2009: A comparison of two off-line soil analysis schemes for assimilation of screen-level observations. J. Geophys. Res., 114, D08105, DOI:10.1029/2008JD011077.

Mahfouf, J.-F., 2010: Assimilation of satellite-derived soil moisture from ASCAT in a limited-area NWP model. Q.J.R. Meteorol. Soc., 136, 784-798.

Noilhan, J., and S. Planton, 1989: A simple parameterization of land surface processes for meteorological models. Mon. Wea. Rev., 117, 536-549.

Noilhan, J., and J.-F. Mahfouf, 1996: The ISBA land surface parameterisation scheme. Global and Planetary Change, 13, 145-159.

Nurmi, 2003: Recommendations on the verification of local weather forecasts. ECMWF Technical Memoranda 430, 19pp. http://www.ecmwf.int/publications/library/ecpublications/_pdf/tm/401-500/tm430.pdf

Reichle, R.H., and R.D. Koster, 2004: Bias reduction in short records of satellite soil moisture. Geophys. Res. Lett., 31, L19501, DOI:10:1029/2004GL20938.

Scipal, K., 2005: Definition of Quality Flags. ASCAT Soil Moisture Report Series, 7, Institute of Photogrammetry and Remote Sensing, Vienna University of Technology, Austria.

Scipal, K., M. Drusch, and W. Wagner, 2008: Assimilation of a ERS scatterometer derived soil moisture index in the ECMWF numerical weather prediction system. Adv. Wat. Res., 31, 1101-1112.

Shepard, D., 1968: A two-dimensional interpolation function for irregularly spaced data. Proc. 23rd ACM Nat.Conf., Brandon/Systems Press, Princeton, NJ: 517-524.

Bubnová, R., G. Hello, P. Bénard, J.-F. Geleyn, 1995: Integration of the fully elastic equations cast in the hydrostatic pressure terrain-following coordinate in the framework of the ARPEGE/ALADIN NWP system. Mon. Wea. Rev., 123, 515-535.

Wernli H., M. Paulat, M. Hagen, C. Frei, 2008: SAL – A Novel Quality Measure for the Verification of Quantitative Precipitation Forecasts. Mon. Wea. Rev. 136, 4470-4487.

Wernli H., C. Hofmann, M. Zimmer, 2009: Spatial Forecast Validation Methods Intercomparison Project: Application of the SAL Technique. Wea. Forecasting 24, 1472-1484.

Wittmann, C., T. Haiden, A. Kann, 2010: Evaluating multi-scale precipitation forecasts using high resolution analysis. Adv. Sci. Res., 4, 89-98, DOI:10.5194/asr-4-89-2010.

Wulfmeyer, V., A. Behrendt, H.-S. Bauer, C. Kottmeier, U. Corsmeier, A. Blyth, G. Craig, U. Schumann, M. Hagen, S. Crewell, P. Di Girolamo, C. Flamant, M. Miller, A. Montani ,S. Mobbs, E. Richard, M.W. Rotach, M. Arpagaus, H. Russchenberg, P. Schlüssel, M. König, V. Gärtner, R. Steinacker, M. Dorninger, D.D. Turner, T. Weckwerth, A. Hense, C. Simmer, 2008: The Convective and Orographically Induced Precipitation Study. BAMS, 89 (10), 1477-1486, DOI:10.1175/2008BAMS2367.1.

**Issues and deviations from plans**

**Forward look**

| | |
|---|---|
| **Due deliverables delivered** | |
| **Due deliverables delayed (reason)** | |
| **Milestones (status)** | |