Land Surface Data Assimilation at ECMWF

Patricia de Rosnay, Gianpaolo Balsamo, Clément Albergel, Joaquín Muñoz Sabater, Souhail Boussetta, Johannes Kaiser, Lars Isaksen, Anton Beljaars, Jean-Noël Thépaut, Peter Bauer
The ECMWF Integrated Forecasting System (IFS) data assimilation system

Data Assimilation System:
Provides best possible accuracy of initial conditions to the forecast model

Analysis:
- 4D-VAR for atmosphere
- Surface analysis

- Initialisation of soil variables ➔ significant impact on numerical weather forecast on both short and medium range
- Statistical techniques developed for atmospheric and oceanic analyses ➔ now applied to continental surfaces
ECMWF Land surface data assimilation

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SYNOP Data

NOAA/NESDIS IMS

Operational Research
Snow Analysis

- Simple snow analysis scheme in NWP centres:
  - Cressman at DWD, ECMWF ERA-Interim
  - OI at CMC, JMA, ECMWF Medium-Range (Nov. 2010)
- Use of SYNOP snow depth and snow cover data (NOAA/NESDIS/IMS)
- No current operational use of Snow Water Equivalent product in NWP
- Future developments: investigate the use of SWE and SCE in EKF analysis

Requirement:

- Advanced SWE data assimilation systems developments
- High quality SWE products for NWP
  - Short latency (NRT is within three hours)
  - Accurate location and variations of SWE and snow line (albedo effects)
  - Global coverage, frequent revisit time (ideally 1-day)
Soil moisture analysis

- Nov. 2010 Simplified Extended Kalman Filter (EKF) replaced the previous Optimum Interpolation (OI, 1999-2010)
- Possible to investigate the use of new generation of satellite data:
  - SM active microwave (MetOp/ASCAT, L-band SMAP)
  - SM passive microwave (L-band SMOS, SMAP)
- Possibility to combine different sources of information

- Dynamical estimates of the Jacobian Matrix that quantify accurately the physical relationship between observations and soil moisture
- Flexible to account for the land surface model evolution
Simplified EKF soil moisture analysis

For each grid point, analysed state vector $x_a$:

$$x_a = x_b + K (y - H[x_b])$$

$x_b$  background state vector,
$H$  non linear observation operator
$y$  observation vector
$K$  Kalman gain matrix, fn of
$H$  (linearisation of $H$), $B$ and $R$ (covariance matrices of background and observation errors).

Observations used:

- **Operational**: Conventional SYNOP observations (T2m, RH2m)
- **Research** (ECMWF, Météo-France, BoM, CMC): Satellite data from ASCAT, SMOS, AMSR-E
- **UKMO** uses ASCAT in operations in a nudging data assimilation scheme
SMOS Monitoring

- Soil Moisture and Ocean Salinity (launched in 2009)
- Earth Explorer Mission
- Passive microwave interferometric radiometer operating at L-band (1.4 GHz)
- Multi-angular measurements of Brightness Temperature (TB) (Kerr et al., 2010)
- Data access in NRT

SMOS NRT TB product

ECMWF SMOS L1c TB (K) NRT Monitoring (TBV 50°) Aug. 2011
SMOS Monitoring

- Routinely production of statistics with SMOS TB, model equivalents and background departures, in NRT
  - Global scale,
  - Land and ocean separately,
  - Several incidences angle [10, 20, 30, 40, 50, 60],
  - Two polarisations states [XX, YY],
  - Independently per continent and hemispheres
**ASCAT monitoring**

Advanced Scatterometer on MetOP (launched in 2006)

Active microwave instruments operating at C-band (5.6GHz) ~0.5-2 cm

Surface soil moisture index (ms) based on TUWien retrieval scheme (Wagner et al., 1999)

ASCAT operational SM product: NRT data and disseminated to Numerical Weather Prediction community via EUMETCAST

~50 km resampled 25km

ASCAT operational NRT

SSM Monitoring Aug. 2011
ASCAT monitoring

13 September:
Improved Bias Correction:
Good agreement between ECMWF and ASCAT (global)

18 August:
Improved ASCAT product
More data used
**Future plans and associated requirements**

Current Land Data Assimilation status: soil moisture and snow depth data assimilation for Medium-Range forecasts, Seasonal forecasts and Re-analysis

**SNOW:**
- SWE products: High quality, NRT (latency <3h), frequent revisit (daily)
- GlobSnow under investigation for validation activities
- Need to develop advanced Snow data assimilation to cope with satellite data and to combine with other land variables DA (Multivariate approach)
- Consistency SWE & SCE for the snow line (albedo effect)
- Model resolution: 2011; 16km, 2015; 10km Data needed at < 10km; in 2020, data at a resolution better than 5km required
Future plans and associated requirements

**SOIL MOISTURE**

- NRT (latency <3h), frequent revisit time (<3d), High resolution (<10km)

- Ongoing investigations to combine SYNOP, SMOS and ASCAT

- Multivariate approaches (→ LSM and LDAS developments)

- SMOS and ASCAT synergy and continuity

- NASA SMAP (Soil Moisture Active and Passive, 2014), concept → exploitation of the synergy between active and passive measurements to provide high resolution SSM (9km)

- Accuracy: For NWP, requirements in terms of correlation and anomaly correlation (time variations, not absolute magnitude)
**Future plans and associated requirements**

**Vegetation and Carbon cycle activities**

- **Today:** no operational data assimilation of vegetation data for NWP

- ECMWF investigates assimilation of vegetation parameters (Leaf Area Index) within Geoland-2

- **Continuity of the GEOLAND-2 project**
  - Adapt the existing LDAS to the assimilation of Sentinel data (including S1 biomass and SSM if available)
  - Investigate assimilation of new variables (e.g. albedo, FAPAR, burnt areas)

- Importance of the synergy between vegetation parameters data assimilation and hydrological cycle data assimilation (soil moisture, SWE)
Future plans and associated requirements
Some MACC(-II) land activities and requirements

- NRT assimilation of atmospheric composition observations
  - Analysis may be used for atmospheric correction of satellite data
- NRT assimilation of Fire Radiative Power observations
  - To calculate fire emission boundary conditions for the atmospheric systems
  - So far using MODIS, SEVIRI (GOES-E/W under development)
    - Need for continuation of LEO-based FRP
    - Need for better temporal sampling from LEOs: additional instrument would help
    - Need for correction of small fires below detection threshold: LEO with low detection threshold (through high spatial resolution) would help
- Need of consistent aerosol optical depth and FRP from S3
  (more details in presentation by Martin Wooster)
Future plans and associated requirements

Long term perspectives:
- Consistent evolution of Land surface Modelling and Data Assimilation Systems. ECMWF 10-year strategy ➔ high resolution LSM

- Synergies between Soil Moisture (ASCAT/Post-EPS, SMOS, SMAP), Snow Water Equivalent (CoreH2O, GlobSnow, GMES/SENTINEL), Vegetation parameters (LAI, fapar) (GMES/SENTINELS)

- Importance of horizontal processes (river routing) ➔ Use of integrated hydrological variables such as river discharges (e.g. Surface Water Ocean Topography (SWOT) mission)

More reading and references: ECMWF News Letter 127 (Spring 2011)

http://www.ecmwf.int/publications/newsletters/pdf/127.pdf
(de Rosnay et al., Balsamo et al., Muñoz Sabater et al.)
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New snow Analysis in Operations

Old: Cressman NESDIS 24km

New: OI NESDIS 4km

FC impact (East Asia):

Positive impact of new snow analysis on Z500 Hpa forecasts
Soil Moisture Analysis verification

Verification of ECMWF SM over the SMOSMANIA Network

→ SEKF improves Soil Moisture, improves screen level parameters and opens the possibility to use satellite data
Revised snow analysis from Nov.2010

- Optimum Interpolation Snow analysis:
  Optimal combination of the model background (SWE) and SYNOP (Snow Depth) data

- NESDIS: NOAA/NESDIS/IMS (Interactive Multisensor Snow and Ice Mapping System) 4km snow cover product (Northern Hemisphere daily product)

Information content: Snow/Snow free
http://nsidc.org/data/g02156.html
The observations are used to correct errors in the short forecast from the previous analysis time.

- Every 12 hours we assimilate 15,000,000 observations to correct the different variables that define the model’s virtual atmosphere.
- This is done by a careful 4-dimensional interpolation in space and time of the available observations; this operation takes as much computer power as the 10-day forecast.

Data Assimilation System:
Provides best possible accuracy of initial conditions to the forecast model

Analysis:
- 4D-VAR for atmosphere
- Surface analysis