A global Land Data Assimilation System for sequential assimilation of vegetation products:

Towards cross-cutting land ECV consistency assessment through data assimilation

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LPVE workshop
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« Sequential assimilation »

- **Model trajectory is driven by observations**
  - e.g. Kalman Filtering approach

- **Better than model calibration**
  - all kinds of errors can be accounted for
  - near real-time operation is possible
  - key parameters can be efficiently tuned by minimizing analysis increments
LDAS-Monde: a European global LDAS

- Based on the open-source SURFEX modeling platform
  - http://www.umr-cnrm.fr/surfex/
  - SURFEX is used in operational applications:
    - Weather forecast, hydrology, IPCC simulations (CNRM-ARPEGE)
    - Used by many meteorological services in Europe and North Africa

- Heritage
  - ISBA land surface model (in SURFEX)
  - Numerical Weather Prediction:
    - 1990’s: Meteo-France implements sequential assimilation of in situ T2m, HU2m observations to analyze root-zone soil moisture in weather forecast models
  - SMOSREX field experiment: LAI and soil moisture
  - Research Copernicus service demonstrators
    - FP7 GEOLAND2, IMAGINES, EARTH2OBSERVE
LDAS-Monde: addresses key issues

- Sequential assimilation of vegetation products
  - Unique!
    - Thanks to flexible LAI simulated by the ISBA model (photosynthesis-driven phenology, no GDD phenology sub-model)
    - Permits a better monitoring of unusual / extreme / poorly modeled events
  - Joint assimilation of LAI (or FAPAR) and surface soil moisture
- Satellite-derived LAI (5km x 5km) disaggregation
  - Disaggregation method developed by Carrer et al. RSE 2014 for surface albedo
    - Kalman filter based on SURFEX static proxy (ECOCLIMAP, Faroux et al. GMD 2013)

\[
\begin{align*}
X^a &= X^b + K(Y -HX) \\
\begin{pmatrix}
\text{LAI}_1^a \\
\vdots \\
\text{LAI}_N^a
\end{pmatrix} &= \begin{pmatrix}
\text{LAI}_1^b \\
\vdots \\
\text{LAI}_N^b
\end{pmatrix} + K \begin{pmatrix}
\text{LAI}_1^{eco} & \cdots & 0 & \vdots \\
\vdots & \ddots & \vdots & \vdots \\
0 & \cdots & 1 & \vdots \\
\text{LAI}_N^{eco} & \cdots & \vdots & \text{LAI}_N^b
\end{pmatrix}
\end{align*}
\]

\[
K = PH^T(HPH^T + R)^{-1}
\]
\[
P^a = (I_n - KH) P^b
\]

\[
R = \begin{pmatrix}
r_{eco} & \cdots & 0 & 0 \\
\vdots & \ddots & \vdots & \vdots \\
0 & \cdots & r_{eco} & 0 \\
0 & \cdots & 0 & r_{soil} \ll r_{eco}
\end{pmatrix}
\]
LDAS-Monde: addresses key issues

- Satellite-derived LAI (5km x 5km) disaggregation
  - Needed for LAI ECV trend analyses (Munier et al., under review 2018)

1999-2015
Copernicus Global Land Service GEOV1 LAI
(SPOT-VGT and PROBA-V)
LDAS-Monde: addresses key issues

- Assimilating LAI or FAPAR?

\[ \sigma_{\text{LAI}}^b = 0.2, \sigma_{\text{LAI}}^o = 0.2, \sigma_{\text{FAPAR}}^o = 0.02 \]

Explicit FAPAR (Carrer et al. 2013, JGR-B)
LDAS-Monde: addresses key issues

- Incorporation of geographic information into land surface models
  - Example: France
LDAS-Monde: addresses key issues

- Enhanced representation of agricultural droughts: spring 2011
- Soil moisture and photosynthesis 10-day changes

![SOIL MOISTURE](image)

Assimilation reinforces the drought signal

![GPP](image)

Barbu et al. 2014, HESS
LDAS-Monde: addresses key issues

- Enhanced representation of agricultural droughts: spring 2011
  - Agricultural drought indicators, example of Puy-de-Dôme (France)

LAI and biomass anomalies are less erratic than SWI anomalies
Complementary information content

10-day scaled anomalies:

![Graphs showing SWI, LAI, and Above-ground biomass anomalies](image)
LDAS-Monde: cross-cutting quality evaluation

- An operational component of the Copernicus Global Land Service using:
  - **LDAS-France** *(Barbu et al. HESS 2014)*
    - ISBA model forced by SAFRAN
    - 8 km x 8 km
  - **LDAS-Monde** *(Albergel et al. GMD 2017)*
    - ISBA model forced by ERA-Interim / ERA5
    - 0.5° x 0.5°
  - Assimilation (active monitoring) of
    - Copernicus GLS LAI
    - Copernicus GLS surface soil moisture
  - Passive monitoring of
    - FAPAR
    - SA
    - LST

LDAS-Monde: cross-cutting quality evaluation

- Example: LAI and soil moisture over France during late Summer of 2016
  - Extreme drought event!
  - LAI analysis departs from the observations

![Graph showing LAI over time]
LDAS-Monde: cross-cutting quality evaluation

- Example: LAI and soil moisture over France during late Summer of 2016
  - Extreme drought event!
  - Root-zone soil moisture analysis departs from the model
LDAS-Monde: cross-cutting quality evaluation

- Example: LAI and soil moisture over France during late Summer of 2016
  - Extreme drought event!
  - Surface soil moisture analysis scores depart more from model scores
LDAS-Monde: cross-cutting quality evaluation

- Example: LAI and soil moisture over France during late Summer of 2016
  - Extreme drought event!
  - LAI and root-zone soil moisture increments: LAI assimilation
LDAS-Monde: cross-cutting quality evaluation

- Example: LAI and soil moisture over France during late Summer of 2016
  - Extreme drought event!
  - LAI and root-zone soil moisture increments: LAI and SWI assimilation
LDAS-Monde: cross-cutting quality evaluation

- Example: Euro-Mediterranean area in September 2016 w.r.t. 2007-2015
  - Root-zone soil moisture increments (m$^3$m$^{-3}$)

![Maps showing soil moisture increments for 2007:2015 and 2016.]
LDAS-Monde: cross-cutting quality evaluation

  - LAI accuracy assessment (low LAI values)

![Graph showing RMSD for LAI <= 2.5 m².m⁻² over 2007-2015]

GCOS accuracy requirement
LDAS-Monde: cross-cutting quality evaluation

  - LAI accuracy assessment (high LAI values)

![MAY](image)

![AUG](image)

Relative RMSD for LAI > 2.5 m².m⁻²

GCOS accuracy requirement
Validation: hydrology

- Example: Impact of vegetation and soil moisture analysis on river discharge

Mean analysis impact on river discharge over the 2000-2012 period
Validation: natural CO$_2$ fluxes

- Example: GPP vs. FLUXNET-MTE (2010-2011)

- SWI assimilation
Validation: natural CO$_2$ fluxes

- **Example: GPP vs. FLUXNET-MTE (2010-2011)**
  - SWI *and* LAI assimilation
Validation: natural CO$_2$ fluxes

  - SWI and LAI assimilation

Correlation (Analysis, Obs)

Corr(Analysis, Obs) - Corr(Model, Obs)

Leroux et al. in prep 2018
Validation: crop yields

- Example: wheat yields in France (1999-2013)
  - Disaggregated Copernicus GLS LAI correlates with wheat yields

Dewaele et al. HESS 2017

\[ R^2 = 0.84 \]
Validation: crop yields

- Example: wheat yields in France (1999-2013)

ISBA MODEL WITHOUT ASSIMILATION
Validation: crop yields

- Example: wheat yields in France (1999-2013)

ISBA MODEL WITH ASSIMILATION

Dewaele et al. PhD 2017
Applications: estimation of key land parameters

- Example: soil maximum available water content (MaxAWC, in mm)
  - LDAS tuning (minimize LAI increments) is better than inverse modeling (minimize LAI RMSE)

![Graphs showing inverse modeling and LDAS tuning with RMSE and LAI increments vs. MaxAWC](image)

Dewaele et al. HESS 2017

Growth
Peak
Senescence
Applications: estimation of key land parameters

- Example: soil maximum available water content (MaxAWC, in mm)
  - LDAS tuning (minimize LAI increments) is better than inverse modeling (minimize LAI RMSE)

<table>
<thead>
<tr>
<th></th>
<th>Inverse modeling</th>
<th>LDAS tuning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction of administrative units with significant correlation (p-value &lt; 0.01)</td>
<td>36 %</td>
<td>53 %</td>
</tr>
<tr>
<td>LAI RMSE</td>
<td>1.2 m²m⁻²</td>
<td>1.1 m²m⁻²</td>
</tr>
<tr>
<td>Median MawAWC</td>
<td>111 mm</td>
<td>129 mm</td>
</tr>
</tbody>
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More realistic!

Dewaele et al. HESS 2017
LDAS-Monde: conclusions

- Integration of satellite observations into SURFEX, fully coupled to hydrology
  - Now the only system able to sequentially assimilate vegetation products (together with soil moisture observations).
    - A powerful tool to monitor droughts!
    - A powerful tool for cross-cutting evaluation of land ECV products!

- Issues:
  - Assimilation of LAI is often more beneficial than assimilation of SSM
  - LAI can be used to analyze root-zone soil moisture but sampling time is affected by clouds
  - ASCAT-derived soil moisture product is affected by vegetation effects (seasonal CDF-matching needed)

- Prospects:
  - Observation operator for
    - ASCAT sigma0 using a multi-layer soil model
    - Surface albedo
  - Foster link to applications
    - Climate reanalisys, drought monitoring, seasonal weather forecast, agrometeorology, ...
    - Go near-real-time
    - Forest biomass data assimilation?
Thank you for your attention

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