Integrating satellite-derived LAI into the ISBA model: A sequential data assimilation approach

J.-C. Calvet[1], C. Albergel[1], Y. Zheng[1], B. Bonan[1], E. Dutra[2], N. Rodríguez-Fernández[3], S. Munier[1], C. Draper[4], P. de Rosnay[5], J. Muñoz-Sabater[5], G. Balsamo[5], D. Fairbairn[5], and C. Meurey[1]

1 CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France
2 Instituto Dom Luiz, IDL, Faculty of Sciences, University of Lisbon, Portugal
3 CESBIO, Université de Toulouse, CNRS, CNES, IRD, Toulouse, France
4 CIRES/NOAA Earth System Research Laboratory, Boulder, CO 80309, USA
5 European Centre for Medium-Range Weather Forecasts, Shinfield Road, Reading RG2 9AX, UK

Monitor the vegetation and terrestrial water cycles

- **Current fleet of Earth Satellite missions holds an unprecedent potential to quantify Land Surface Variables (LSVs)**
  [Lettenmaier et al., 2015, Balsamo et al., 2018]

➔ Spatial and temporal gaps & cannot observe all key LSVs (e.g. RZSM)

- **Land Surface Models (LSMs)** provide LSV estimates at all time/location

➔ LSMs have uncertainties

- Through a weighted combination of both, LSVs can be better estimated than by either source of information alone *[Reichle et al., 2007]*

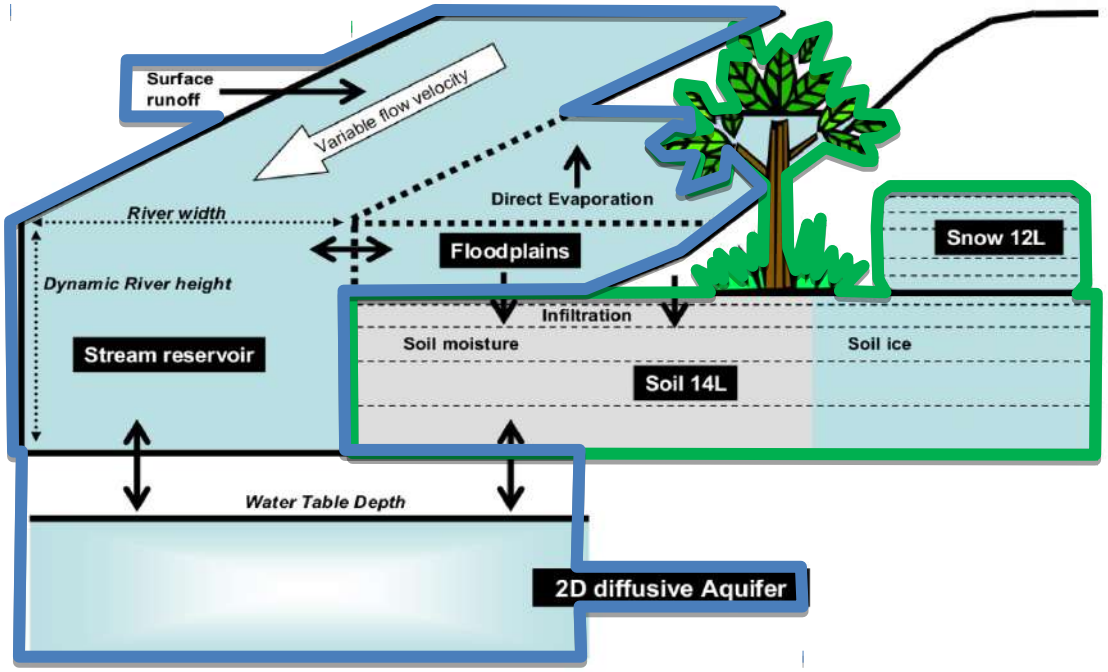
➔ **Data assimilation**
Spatially and temporally integrates the observed information into LSMs in a consistent way to unobserved locations, time steps and variables

Monitor the vegetation and terrestrial water cycles

LDAS-Monde: global capacity offline integration of satellite observations into a land surface model fully coupled to hydrology

LDAS-Monde involves

- **Land surface model: ISBA-A-gs** *[Calvet et al., 1998, Gibelin et al., 2008]*
- **River routing system: CTRIP** *[Decharme et al., 2019]*
- **Data assimilation routines** (SEKF, EnSRF) *[Barbu et al., 2014, Bonan et al., 2019]*
- **Satellite derived observations - Copernicus Global Land Service** (SSM, LAI)



The ISBA Land Surface Model

ISBA solves the energy and water budgets at the surface level and describes the exchanges between the land surface and the atmosphere (on a sub-hourly basis)

- ISBA-A-gs (CO_2-responsive version) simulates the diurnal cycle of water and carbon fluxes, plant growth and key vegetation variables
- Phenology driven by photosynthesis

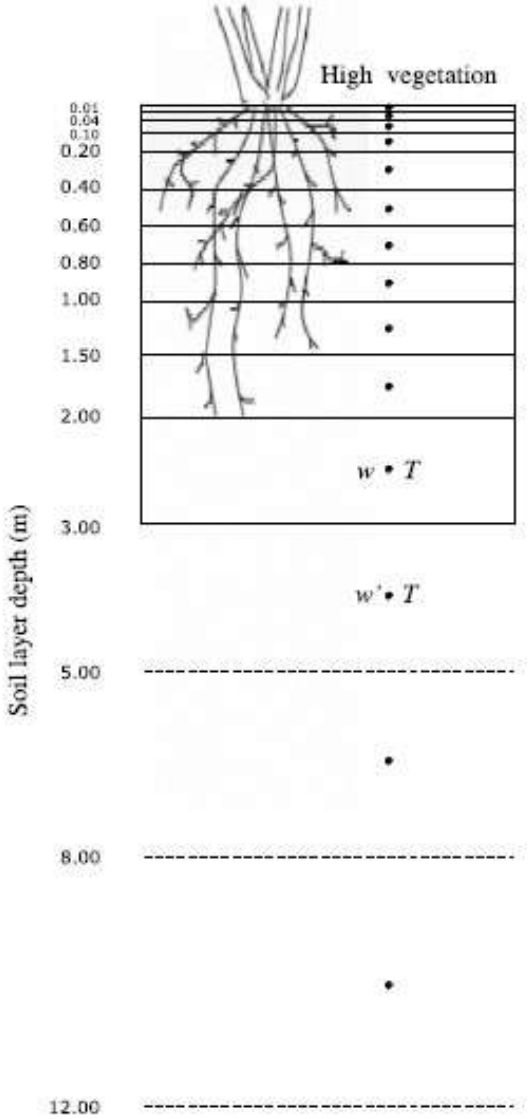
➔ *LAI is very flexible and can be updated when observations are available*

- ISBA-Dif multilayer soil diffusion scheme (14 layers, 12 m)

- ISBA land surface model needs:
  - Parameters for the vegetation and soil texture

    Derived from the ECOCLIMAP-II landcover database*
  - Atmospheric forcing

    Longwave & shortwave radiation, 2-metre air temperature & humidity, precipitations (liquid and solid), surface pressure and near surface wind speed

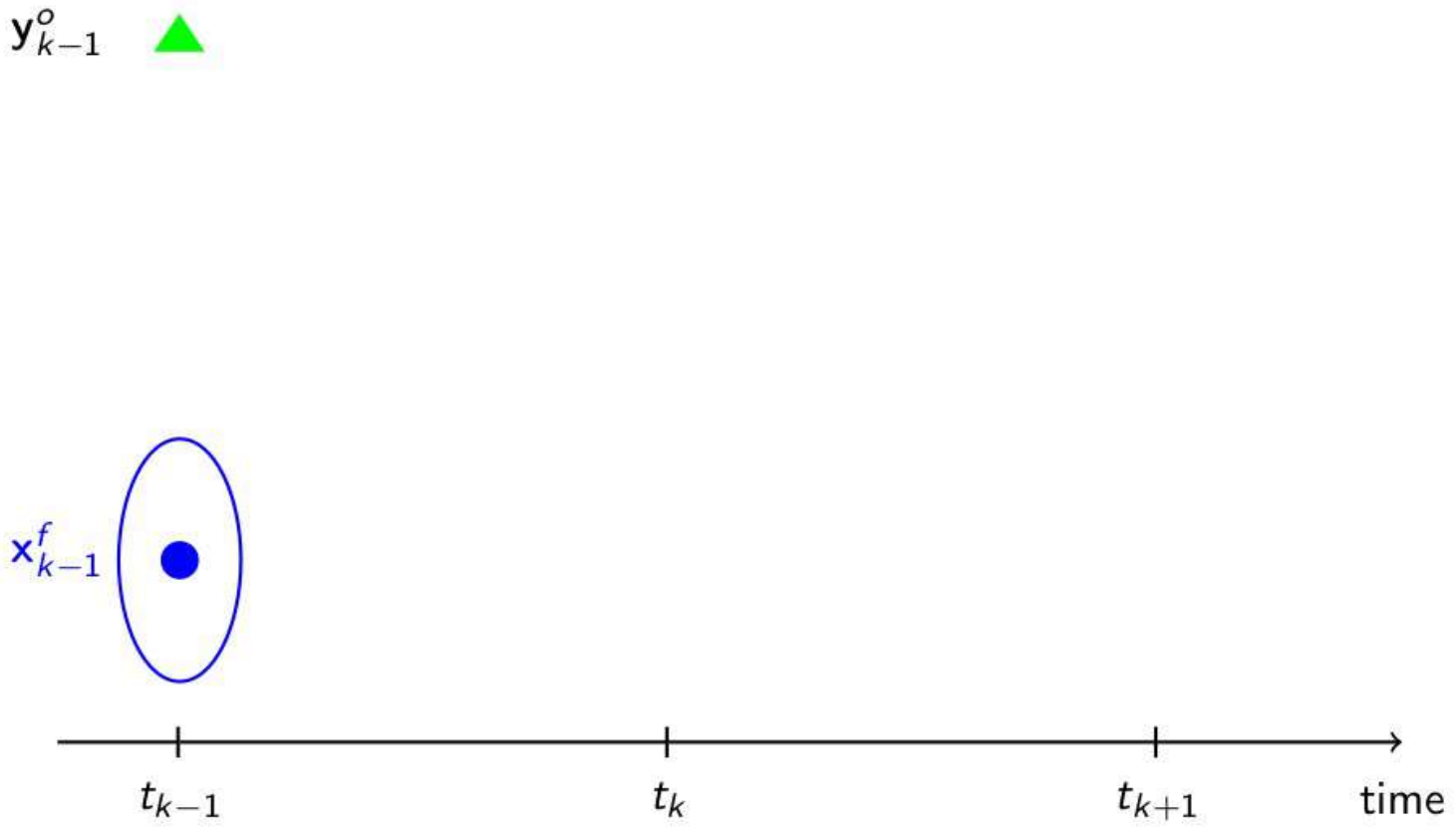


** 1km spatial resolution, ECOCLIMAP-SG already available, 300m resolution*

Sequential Data Assimilation

Two step approach:

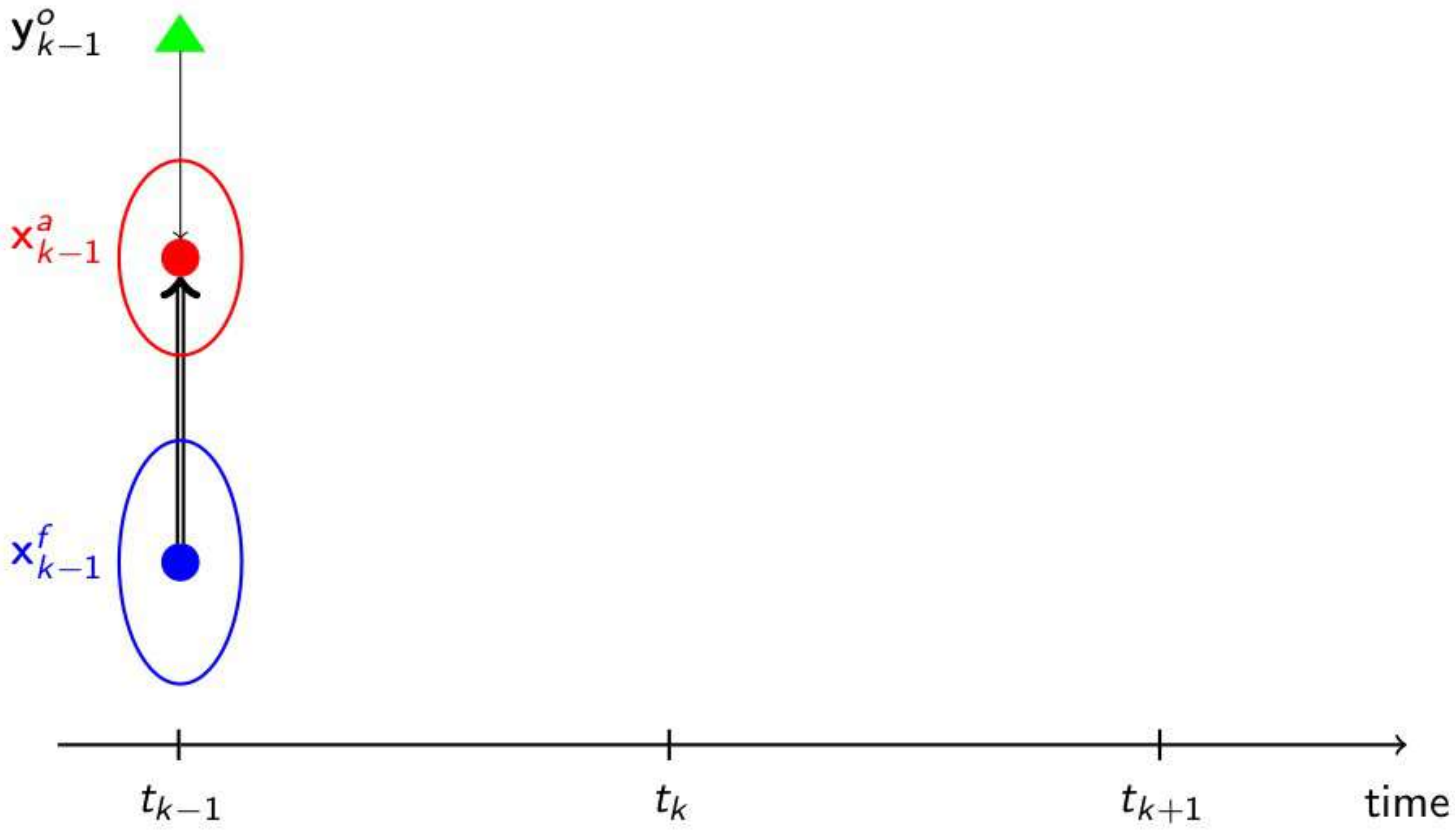
- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



Sequential Data Assimilation

Two step approach:

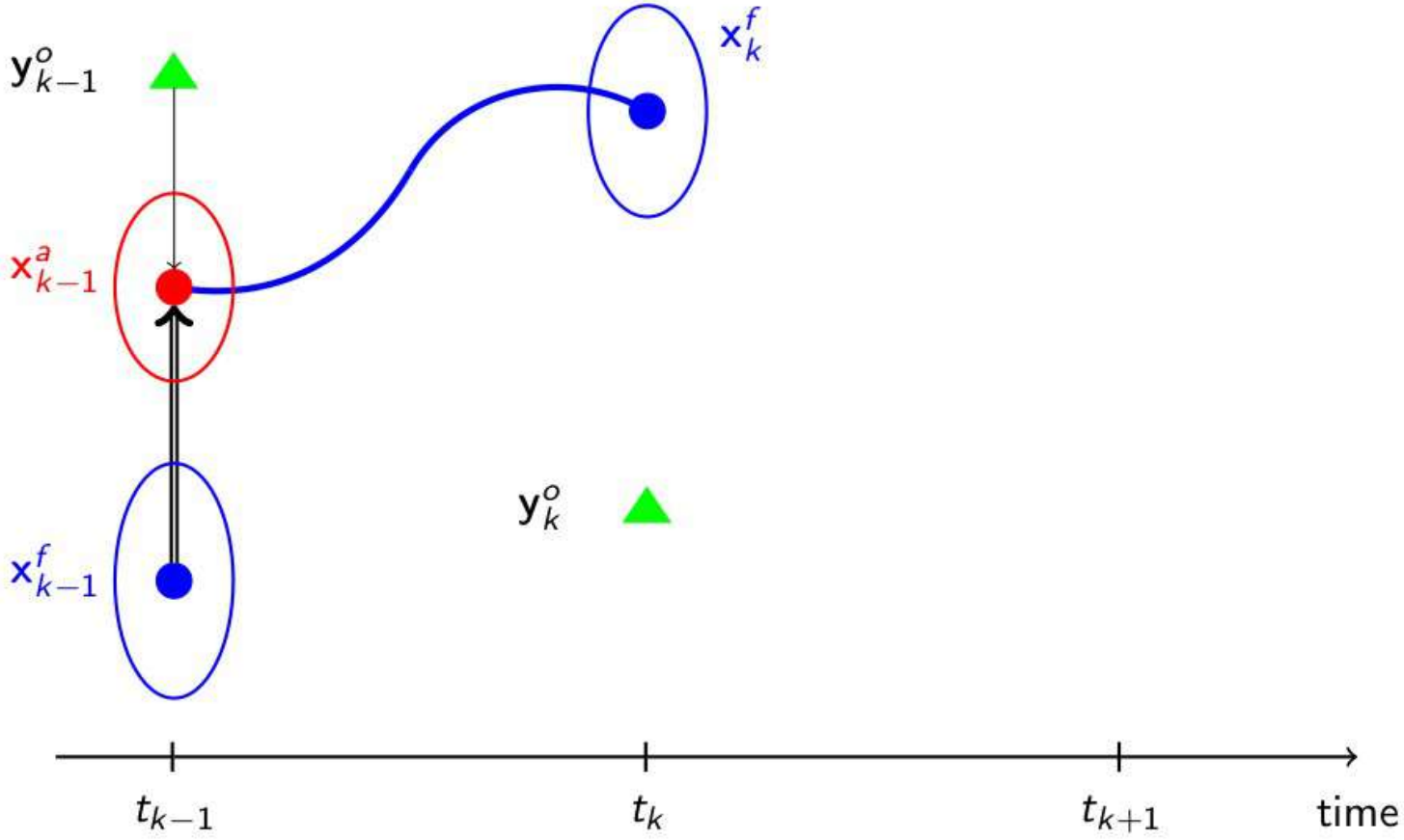
- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



Sequential Data Assimilation

Two step approach:

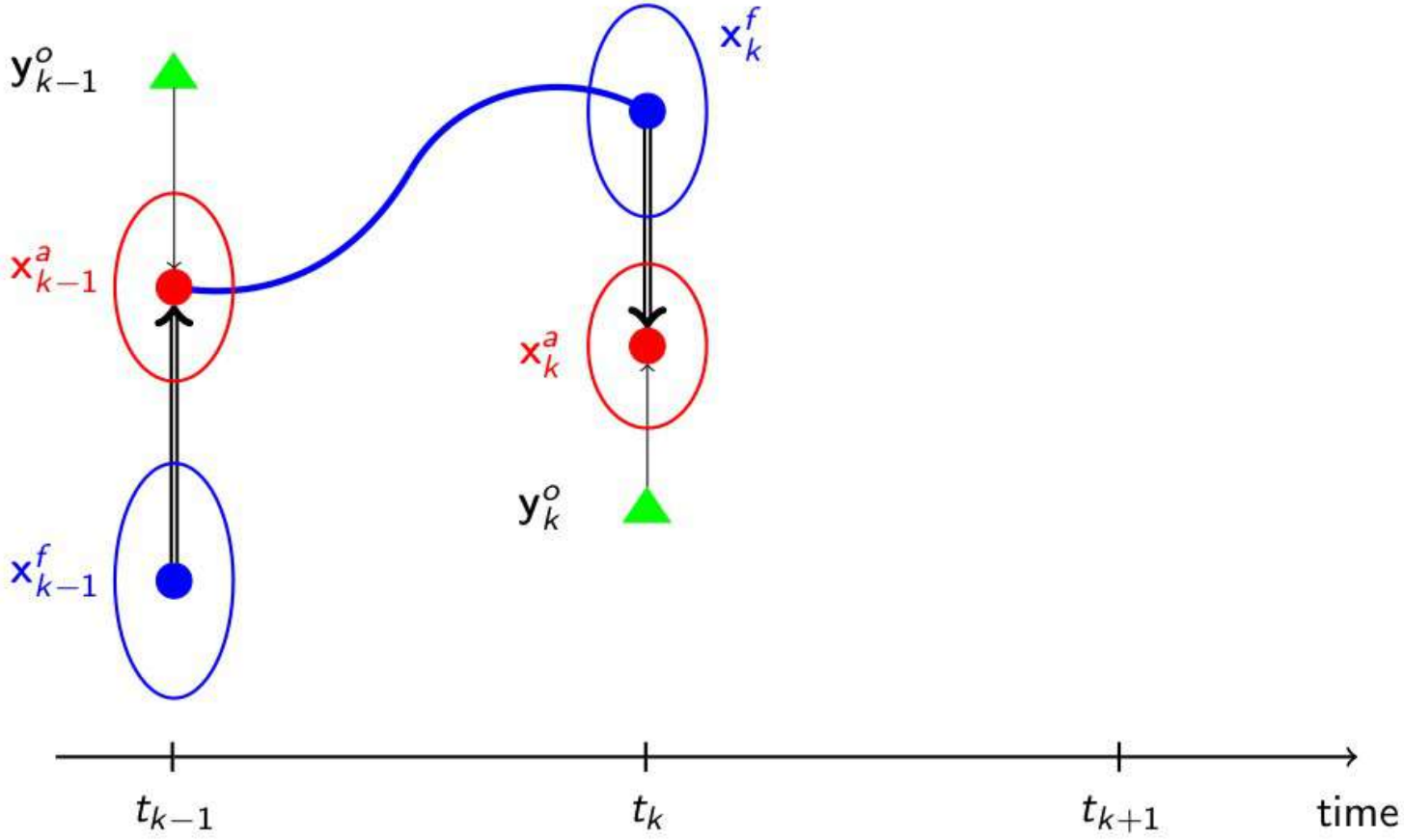
- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



Sequential Data Assimilation

Two step approach:

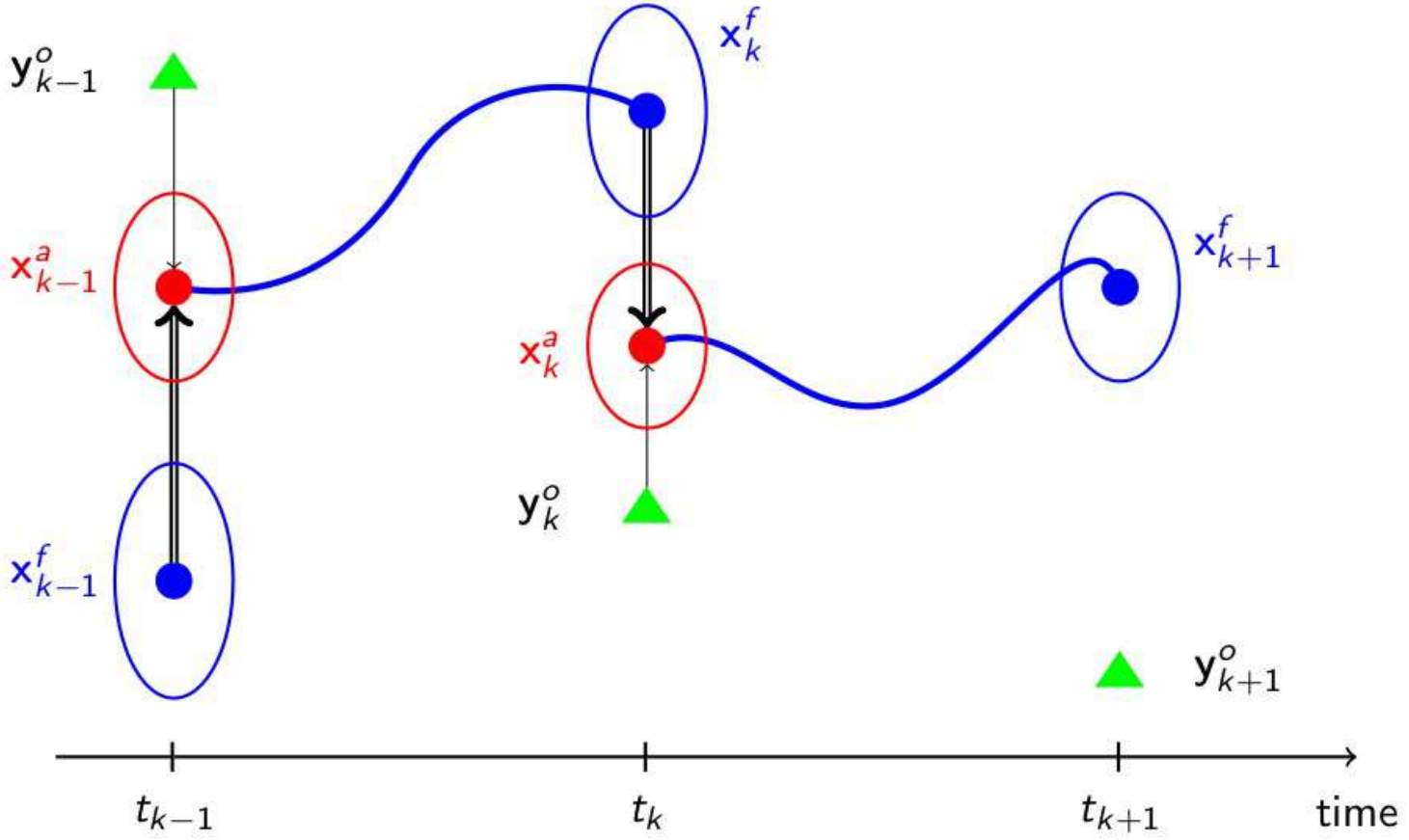
- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



Sequential Data Assimilation

Two step approach:

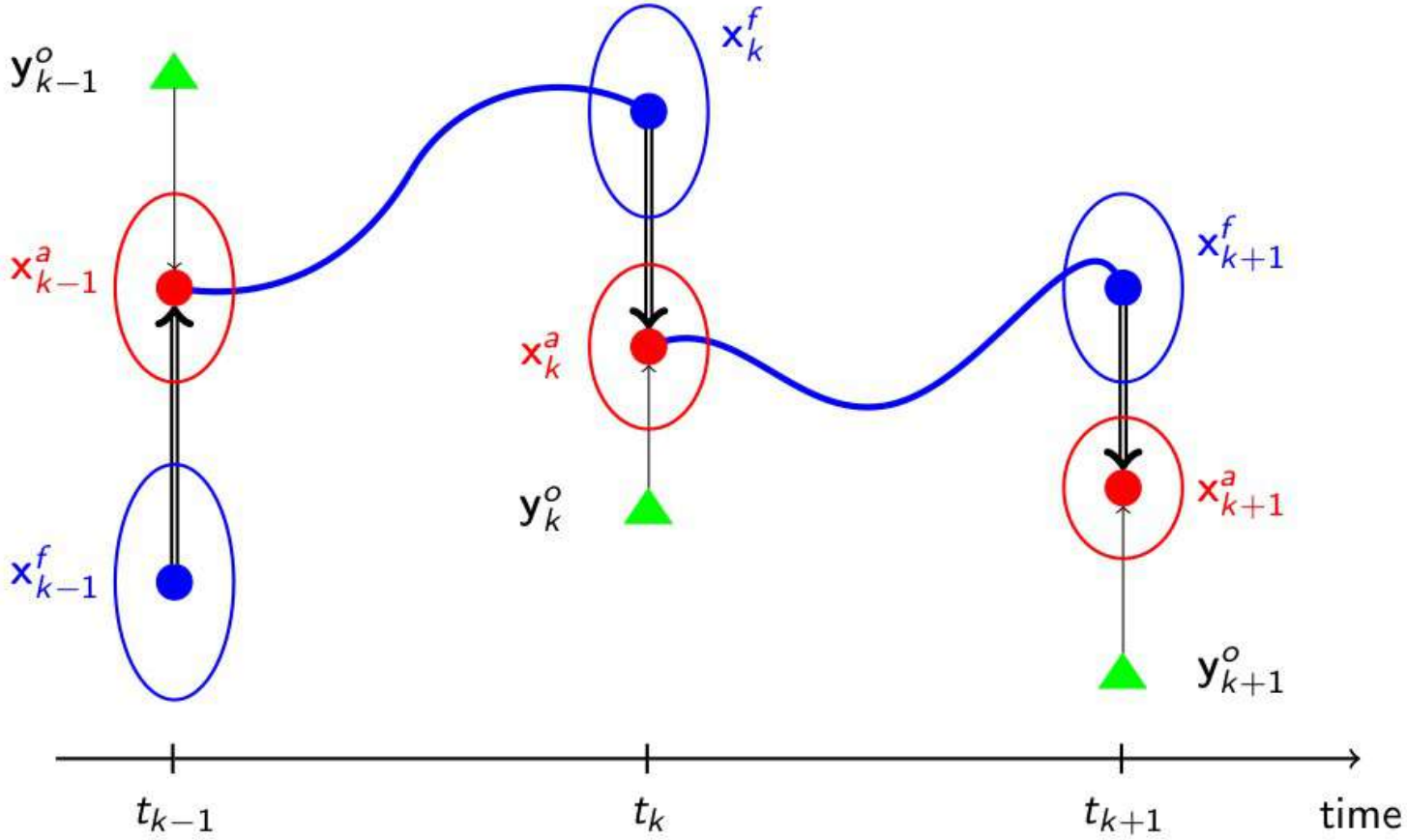
- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



Sequential Data Assimilation

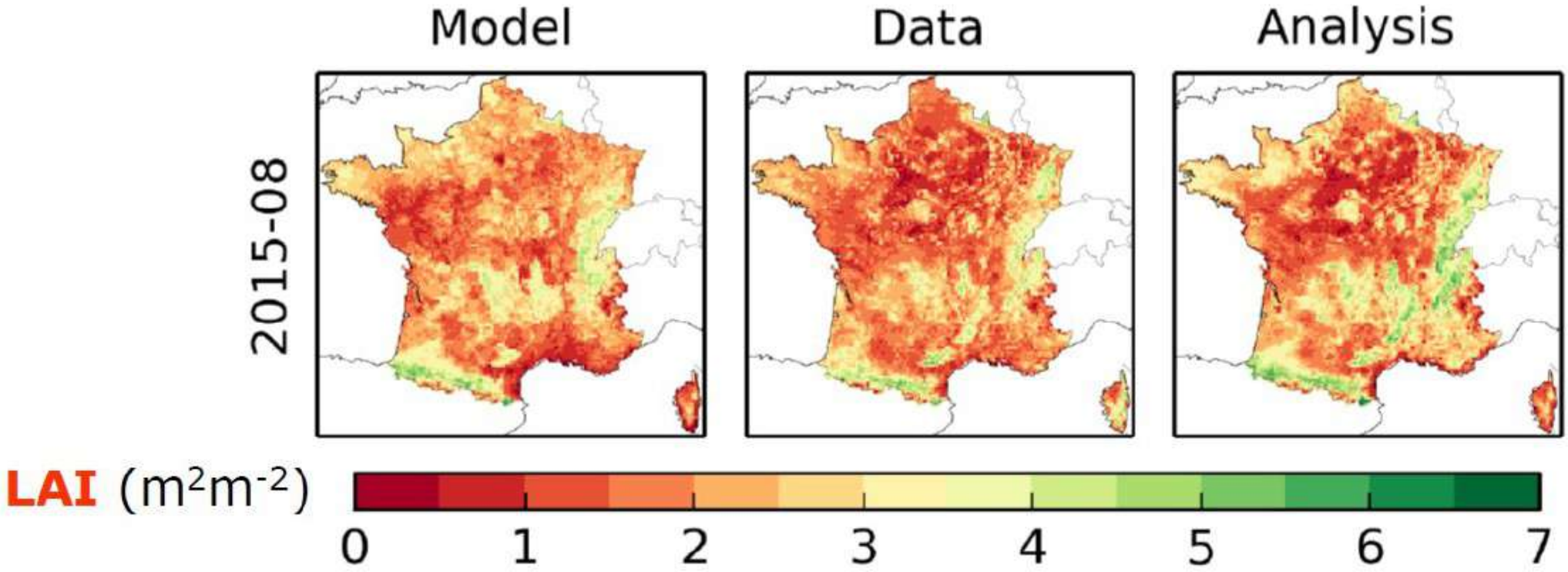
Two step approach:

- Forecast – predict the state of the system $\mathbf{x}_k^f$ at time t_k from previous time step $\mathbf{x}_{k-1}^a$
- Analysis – correct the predicted state $\mathbf{x}_k^f$ with observations $\mathbf{y}_k^o$ to give $\mathbf{x}_k^a$



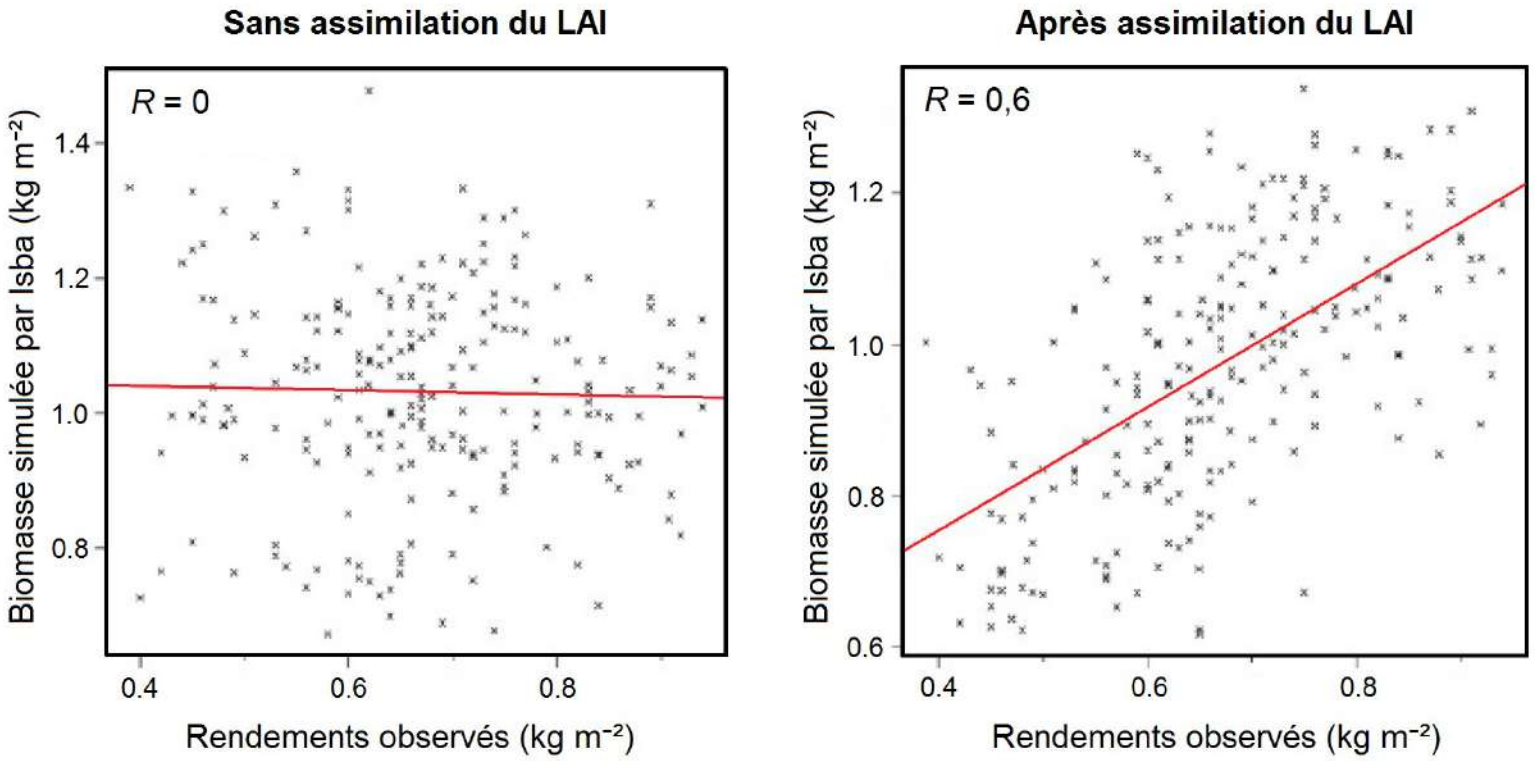
Monitor the vegetation and terrestrial water cycles

- **Incorporation of geographic information into land surface models**
  - Example: France



Monitor the vegetation and terrestrial water cycles

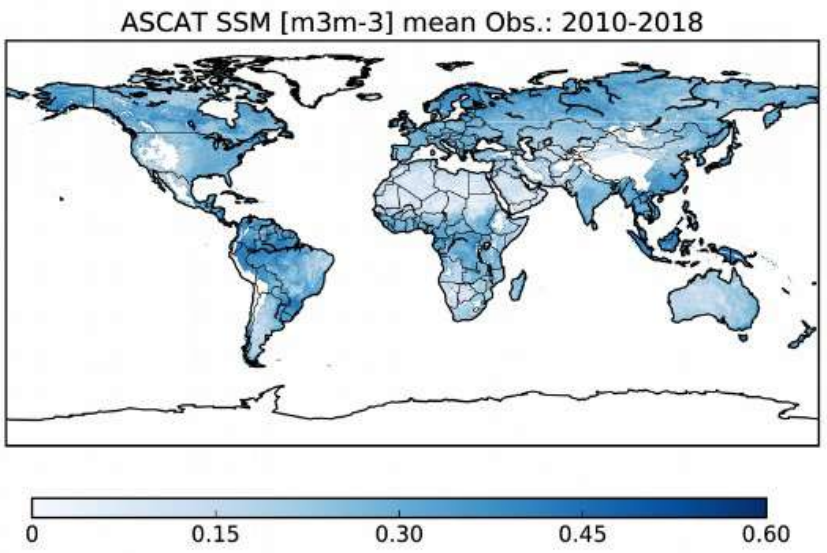
Validation: **using wheat grain yield estimates over France**

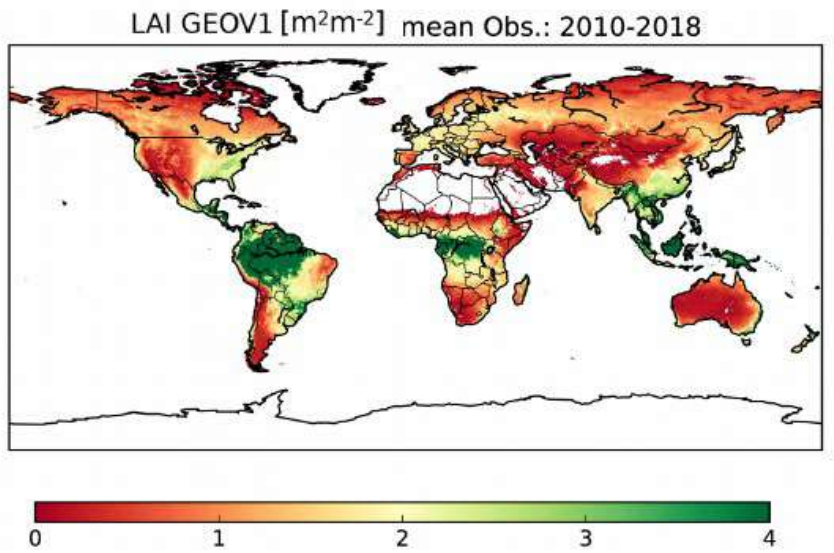


[Dewaele, 2017]

LDAS-Monde goes global

Model	Domain	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
ISBA Multi-layer soil model CO_2-responsive version (Interactive vegetation)	**Global (2010 – 2018)**	**ERA-5 Res.: 0.25°x0.25° (LDAS-ERA5)**	**SEKF**	**SSM** (CGLS ASCAT SWI* + cdf matching) **LAI** (CGLS GEOV1*)	**Second layer of soil (1-4cm) LAI**	**Layers of soil 2 to 8 (1-100cm) LAI**	**Coupling with CTRIP (0.5°)**



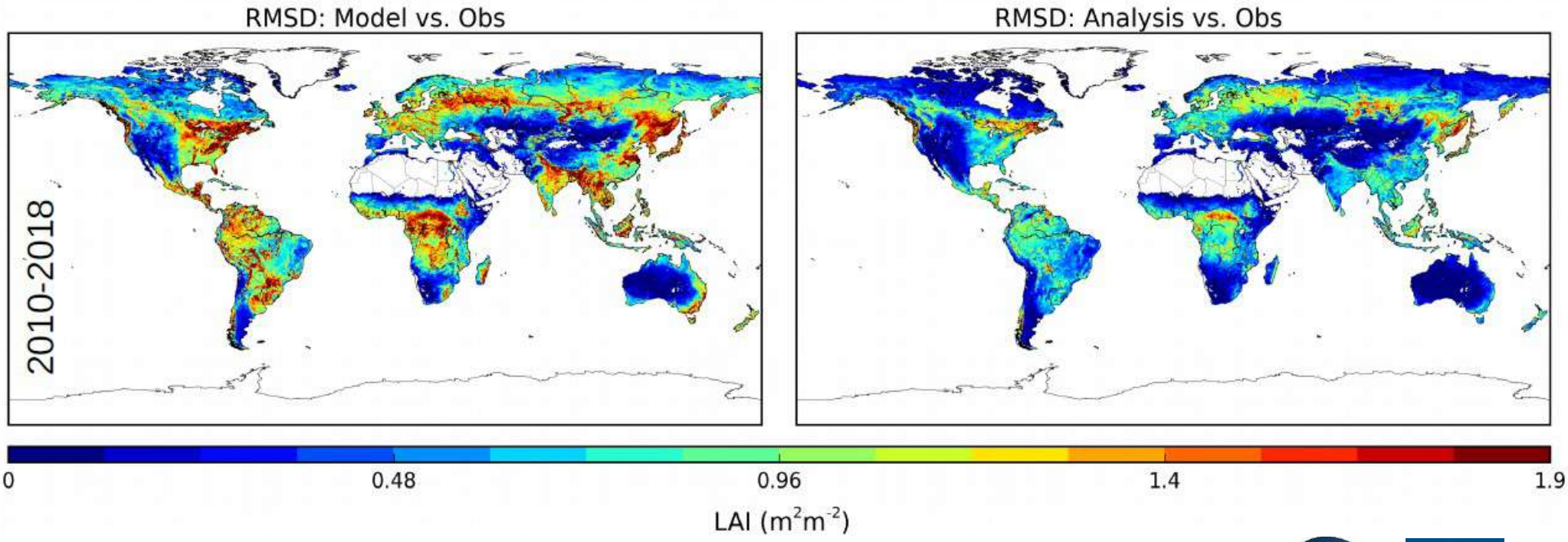


- Control variables (CVs) are directly updated thanks to their sensitivity to the observed variables
- Other variables are indirectly modified through biophysical processes and feedbacks in the model

LDAS-Monde goes global

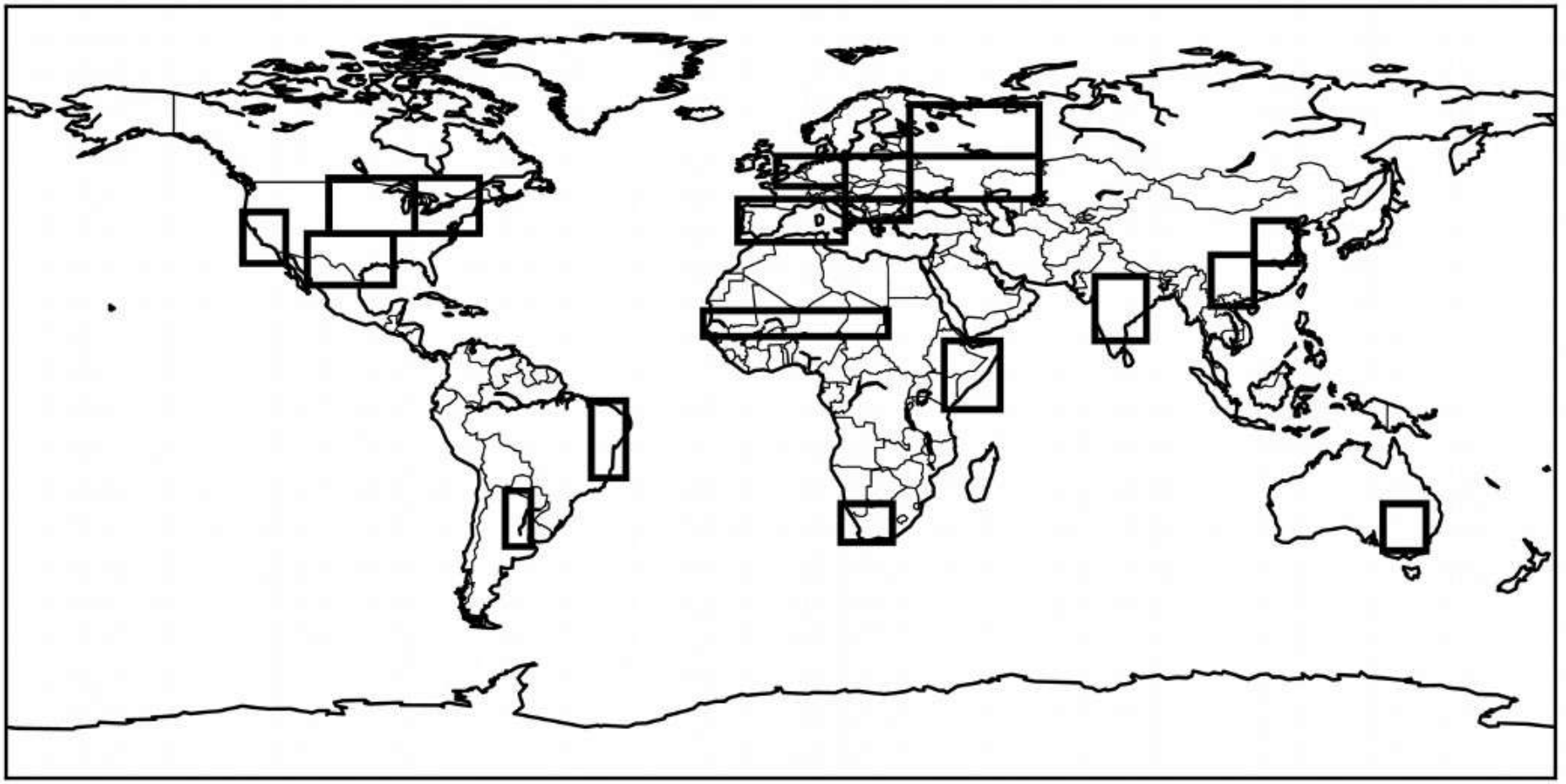
Model	Domain	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
ISBA Multi-layer soil model CO_2-responsive version (Interactive vegetation)	**Global (2010 – 2018)**	**ERA-5 Res.: 0.25°x0.25° (LDAS-ERA5)**	**SEKF**	**SSM** (CGLS ASCAT SWI* + cdf matching) **LAI** (CGLS GEOV1*)	**Second layer of soil (1-4cm) LAI**	**Layers of soil 2 to 8 (1-100cm) LAI**	**Coupling with CTRIP (0.5°)**

2 LDAS-ERA5 experiments : Model/Open-loop (no assimilation) and Analysis (assimilation)



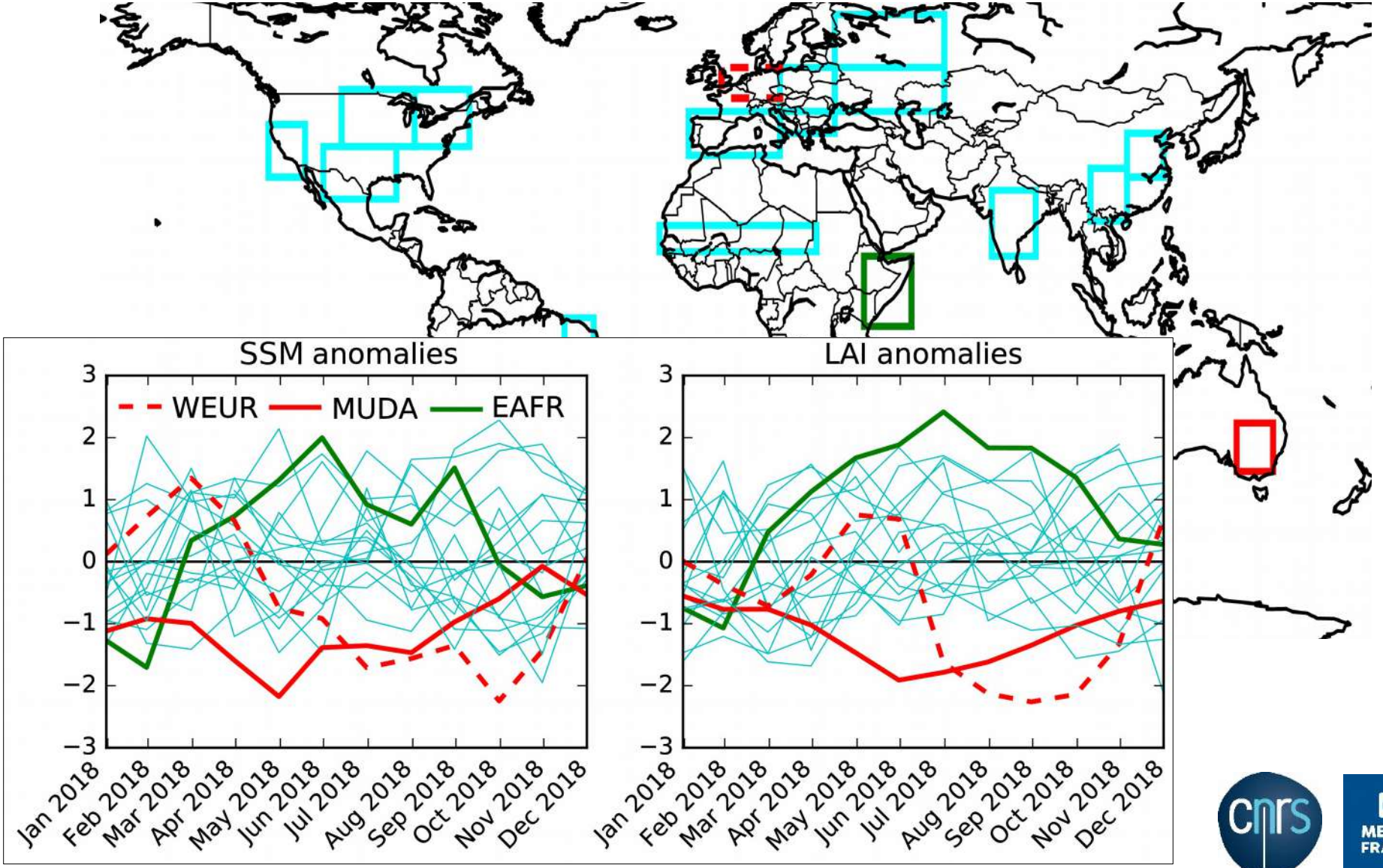
LDAS-Monde goes global

Selection of 19 regions known for being potential hot spots for droughts and heat waves



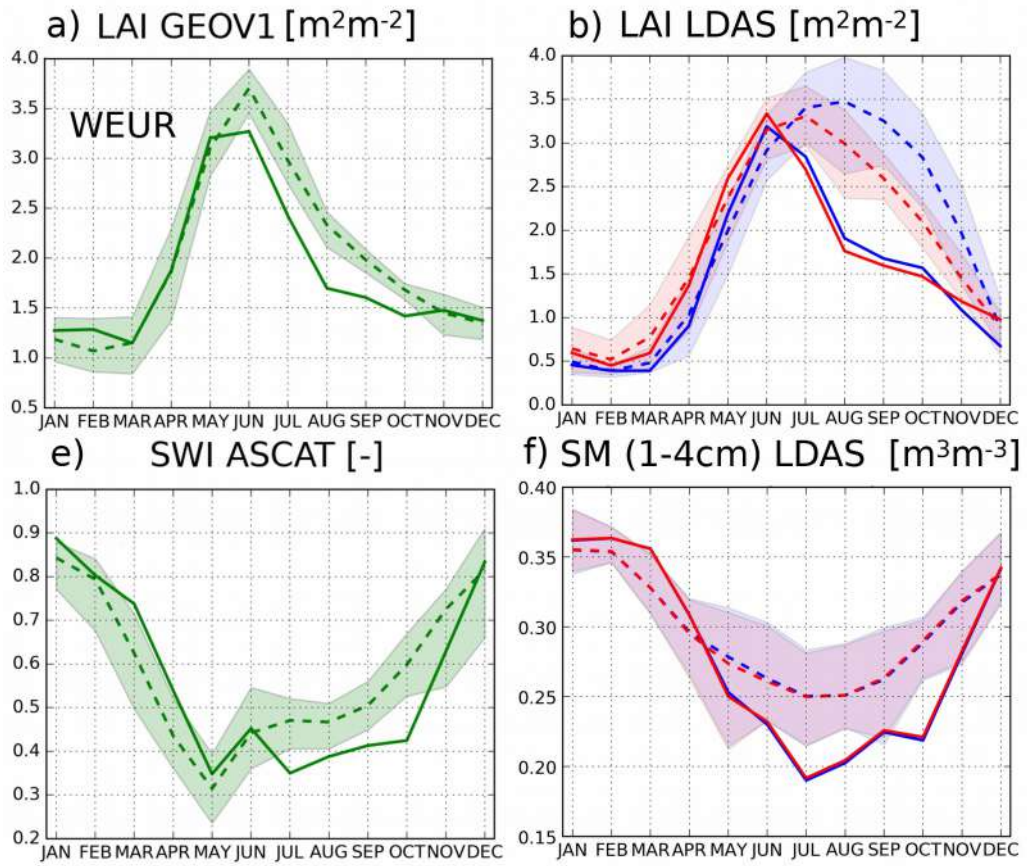
LDAS-Monde goes global

Monthly anomalies for 2018 with respect to 2010-2018



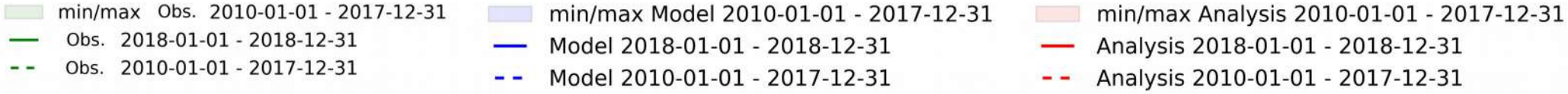
Impact of the 2018 heatwave on LSVs: Europe

LDAS-Monde : Leaf Area Index (top) and soil Moisture (bottom)



Seasonal cycles:

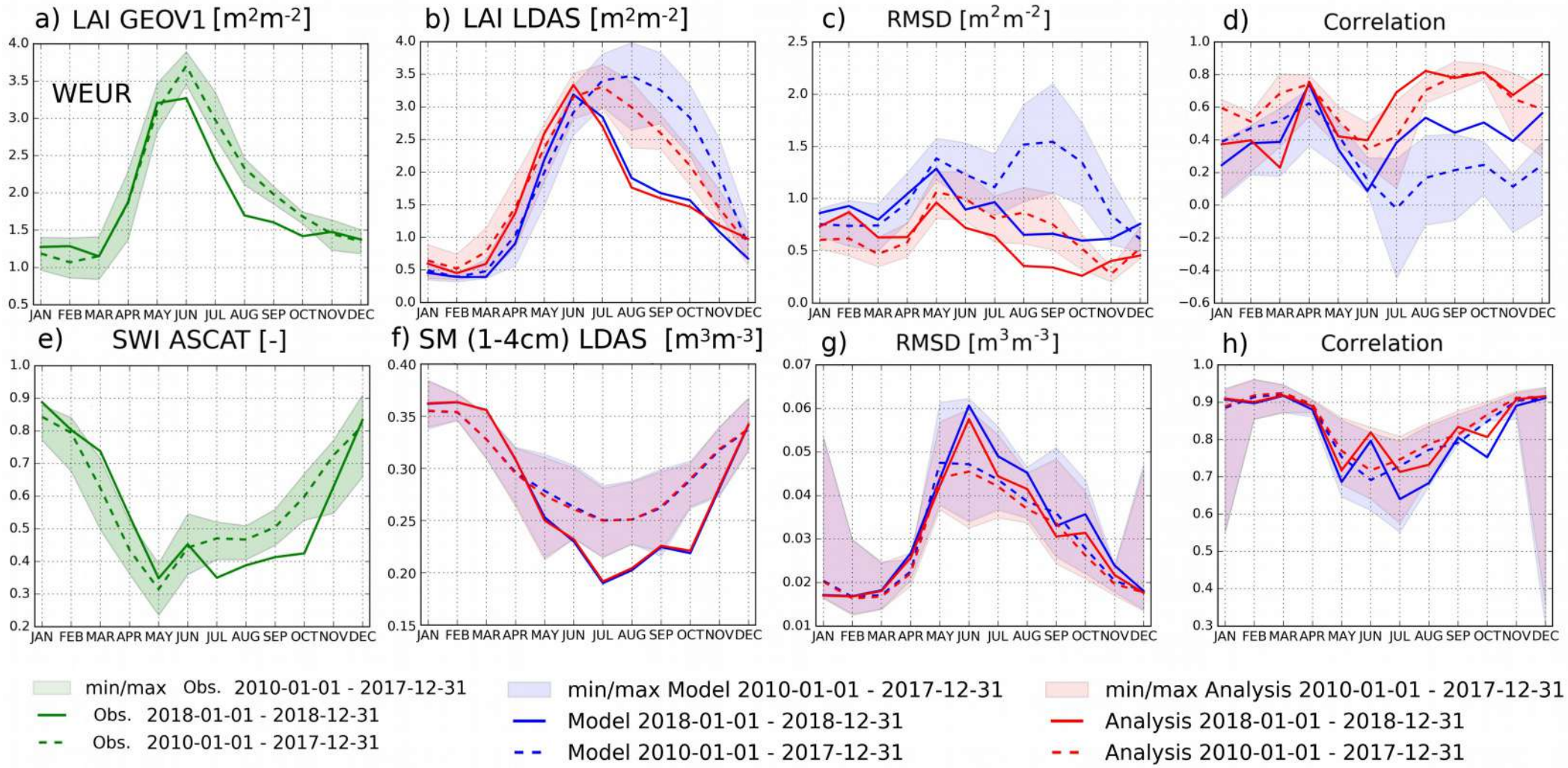
- Obs., Model, Analysis : 2018 quite different from 2010-2017
- smaller differences between Model and Analysis for 2018 than for 2010-2017



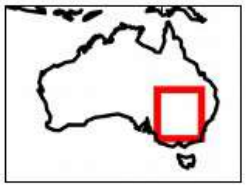
Impact of the 2018 heatwave on LSVs: Europe

LDAS-Monde : Leaf Area Index (top) and soil Moisture (bottom)

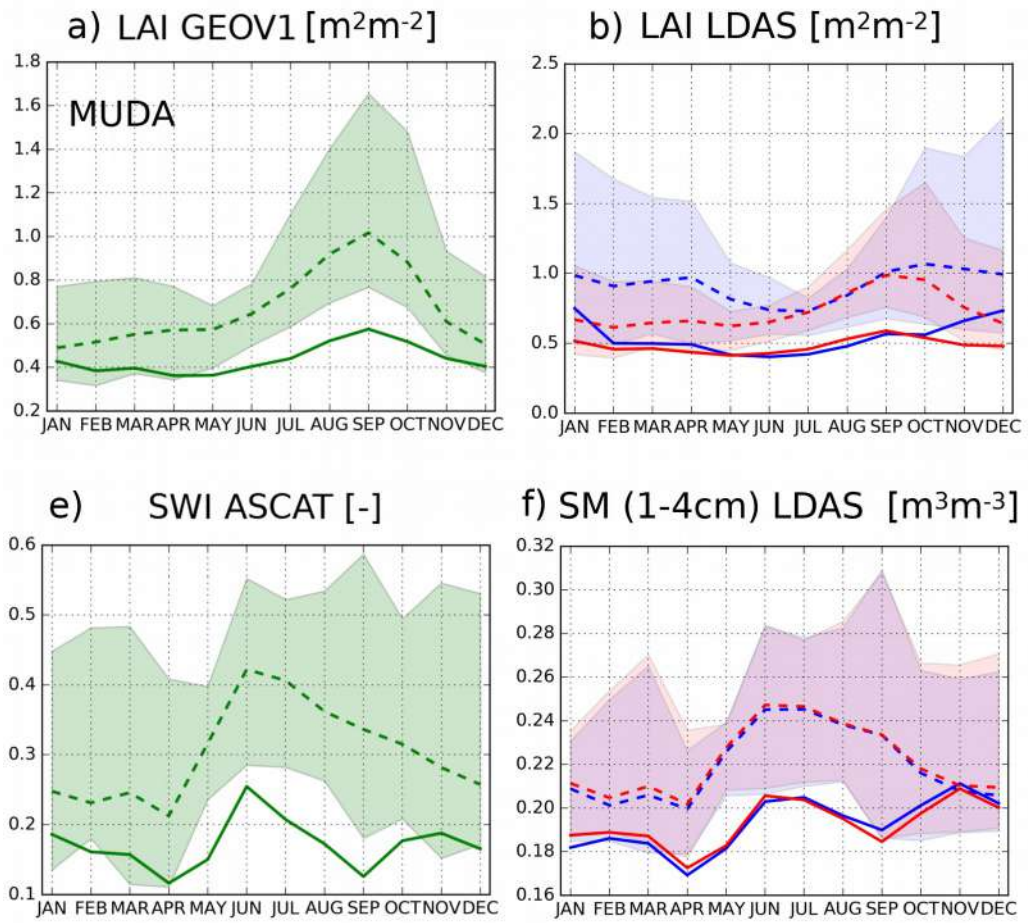
Analysis improvements over Model simulation



Impact of the 2018 heatwave on LSVs: Murray-Darling



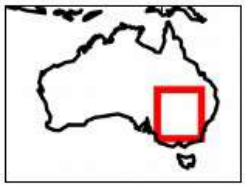
LDAS-Monde : Leaf Area Index (top) and soil Moisture (bottom)



Seasonal cycles:

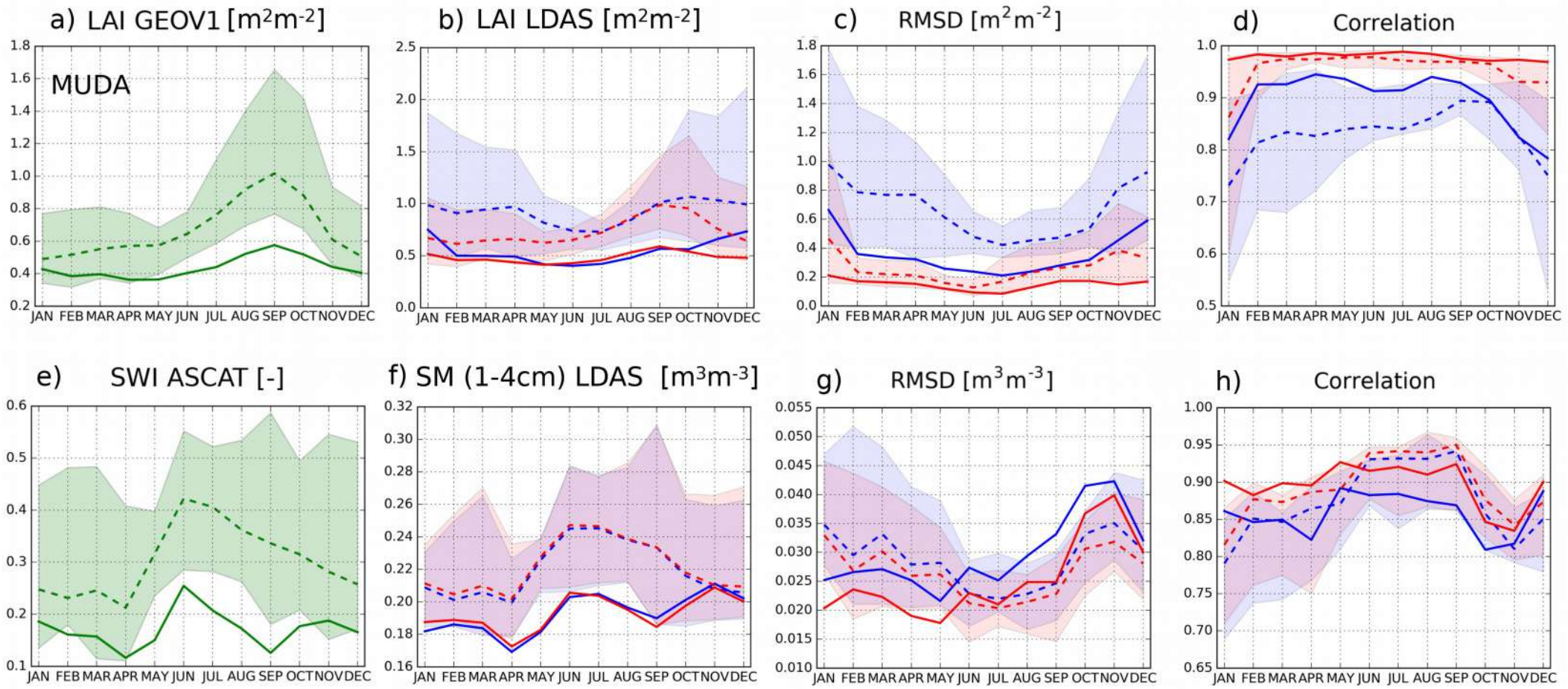
- Obs., Model, Analysis : 2018 quite different from 2010-2017
- smaller differences between Model and Analysis for 2018 than for 2010-2017

Impact of the 2018 heatwave on LSVs: Murray-Darling

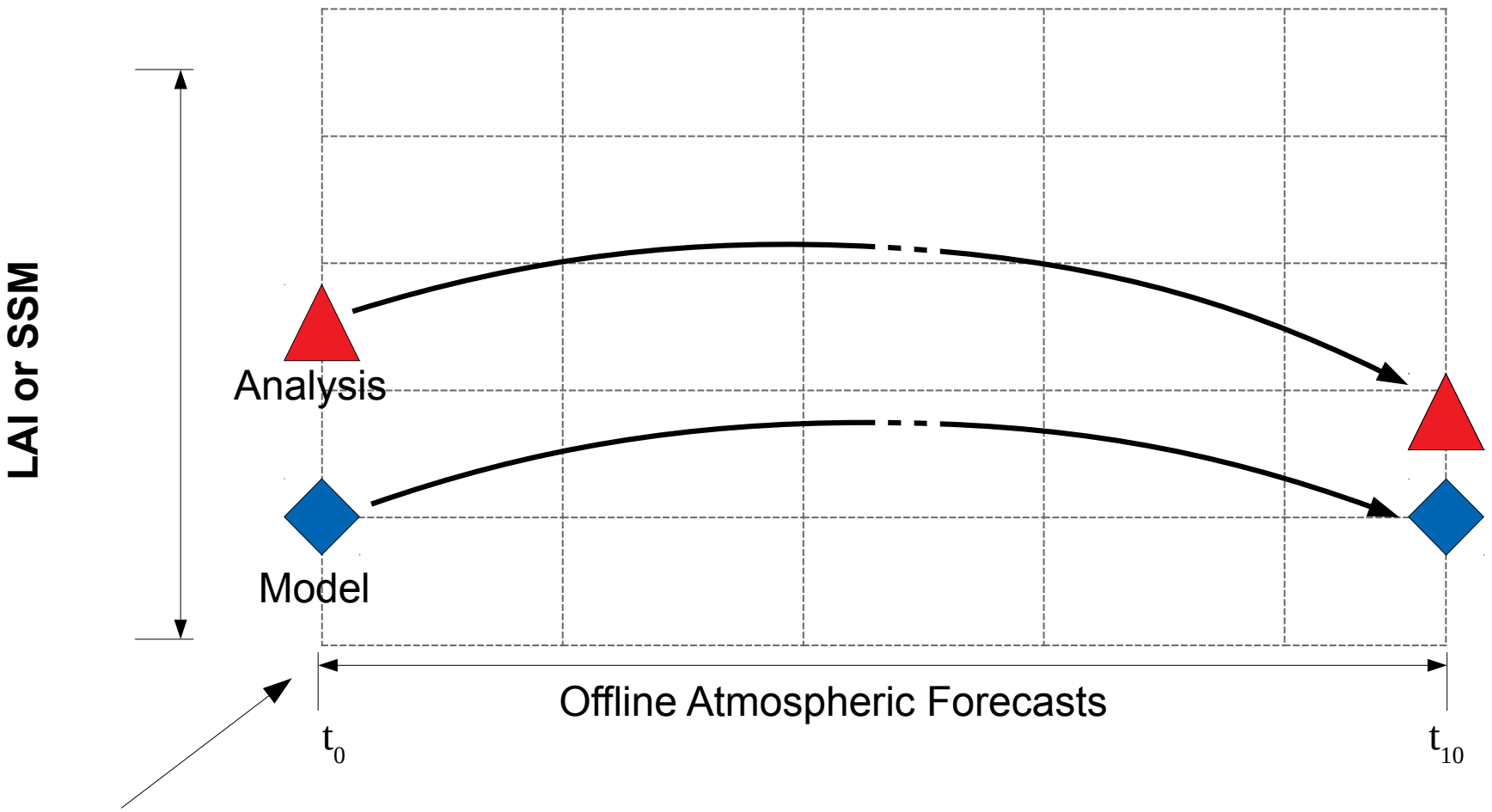


LDAS-Monde : Leaf Area Index (top) and soil Moisture (bottom)

Analysis improvements over Model simulation

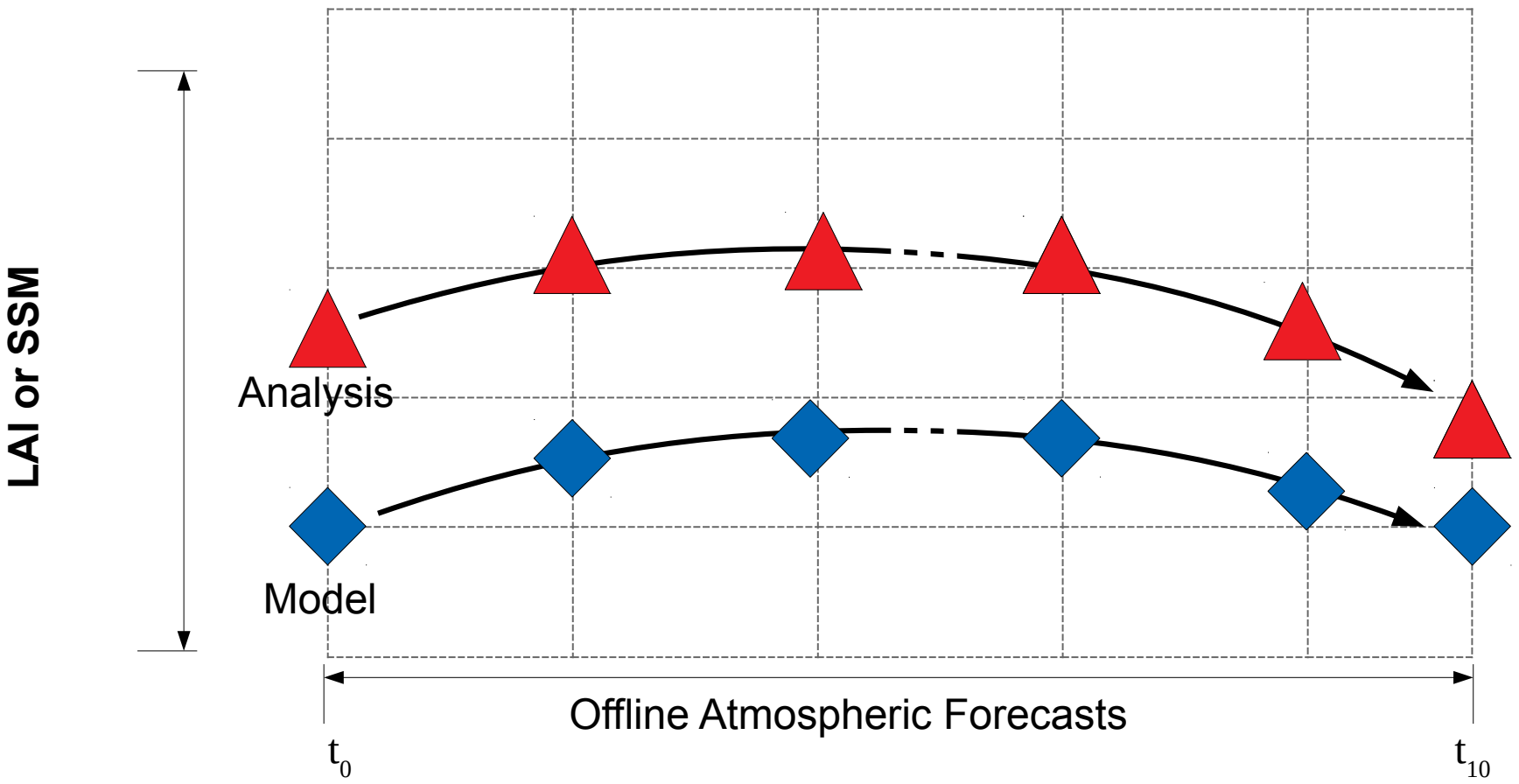


LDAS-Monde Forecast Implementation



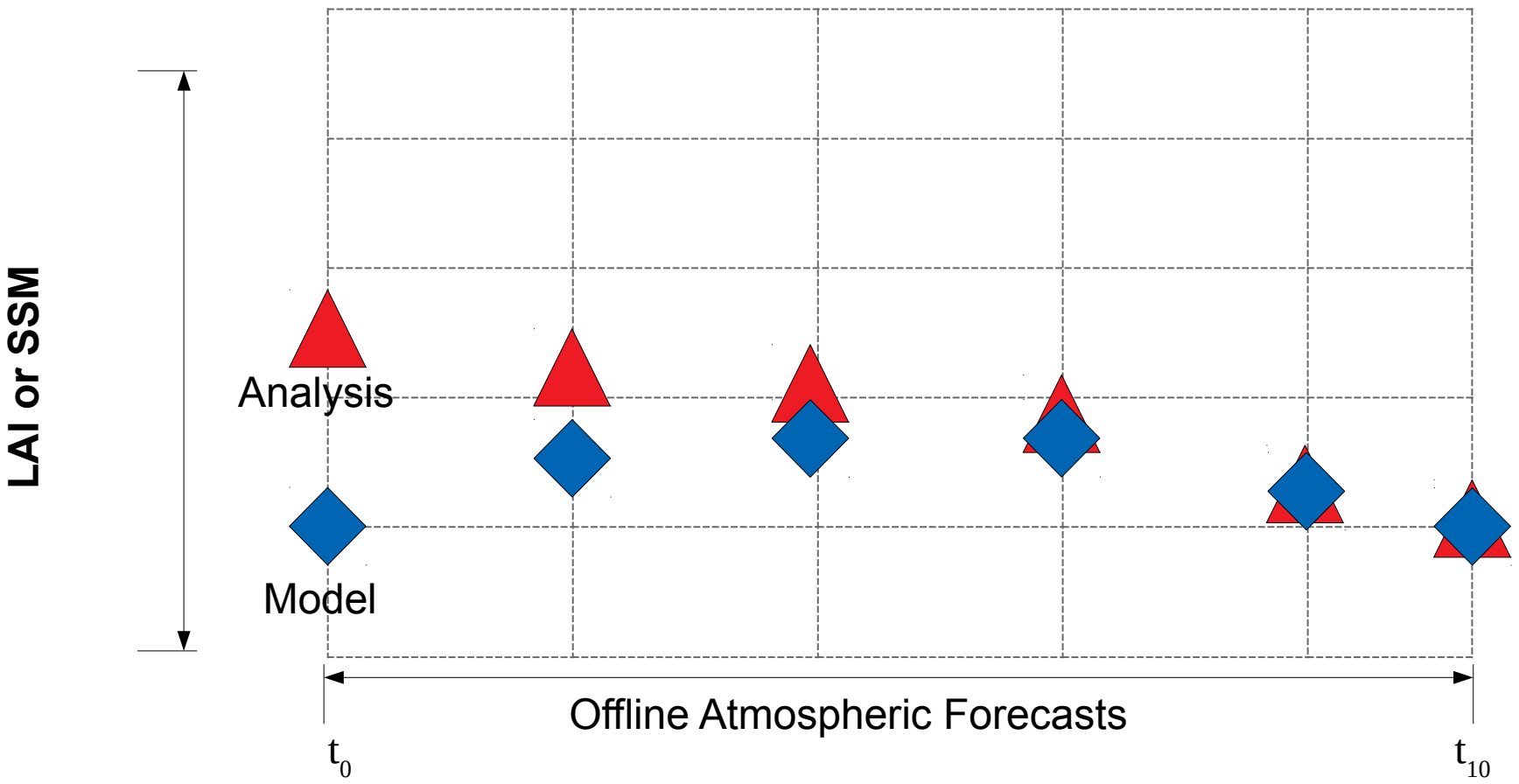
Up to **10 day** Forecasts

LDAS-Monde Forecast Implementation



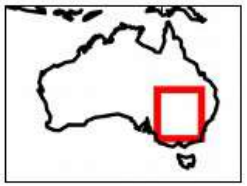
Up to **10 day** Forecasts
Strong impact of initial conditions

LDAS-Monde Forecast Implementation



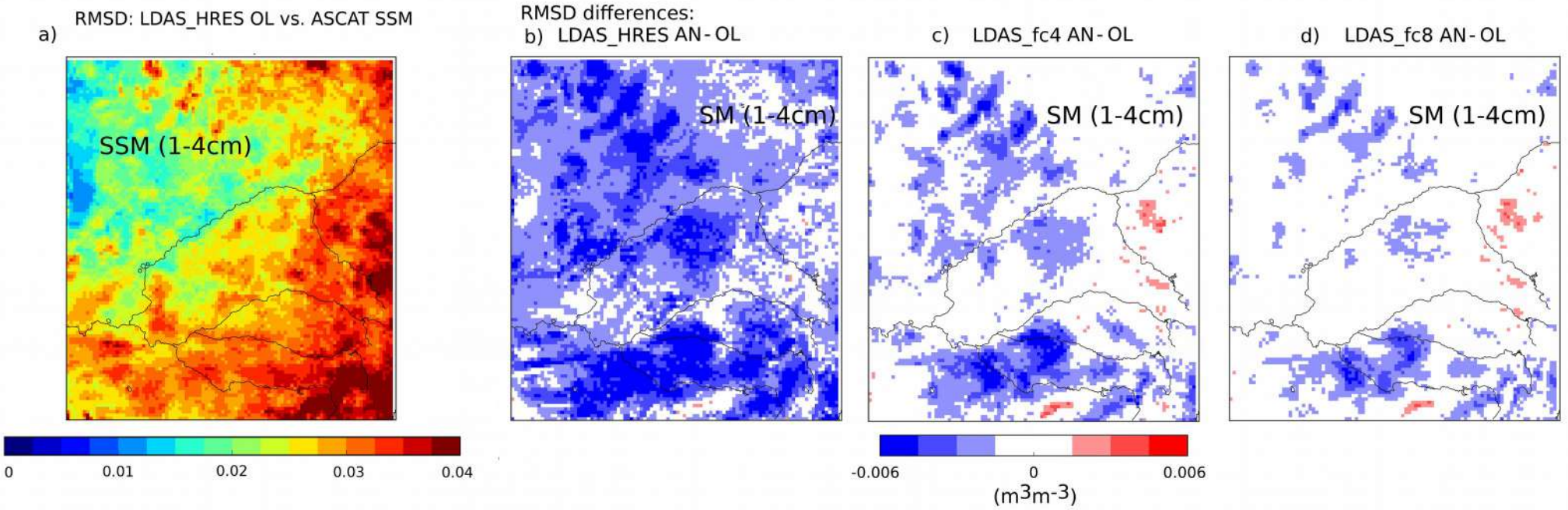
Up to **10 day** Forecasts
Small impact from the initial conditions, model goes back quickly to its climatology

Impact of the 2018 heatwave on LSVs: Murray-Darling



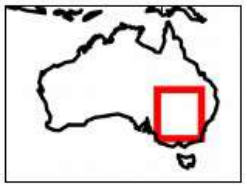
Such an extreme event needs more attention!

- Using ECMWF high resolution operational analysis to force LDAS-Monde (LDAS-HRES, 0.10°x0.10°) and complement the use of ERA5 (LDAS-ERA5, 0.25°x0.25°)
- Forecast up to 8-days ahead : assess the impact of the initial conditions on the Fc



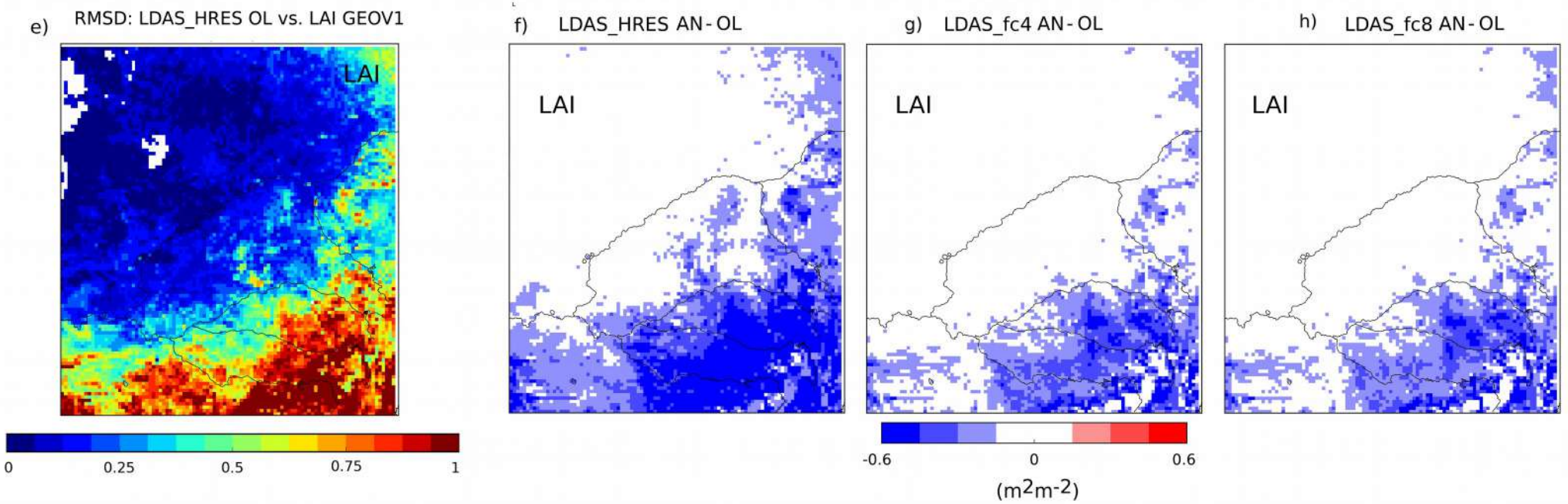
- SSM: strong positive impact from the analysis, impact of initialisation seems to vanish quickly

Impact of the 2018 heatwave on LSVs: Murray-Darling



Such an extreme event needs more attention!

- Using ECMWF high resolution operational analysis to force LDAS-Monde (LDAS-HRES, 0.10°x0.10°) and complement the use of ERA5 (LDAS-ERA5, 0.25°x0.25°)
- Forecast up to 8-days ahead initialised by either LDAS-HRES Openloop or Analysis

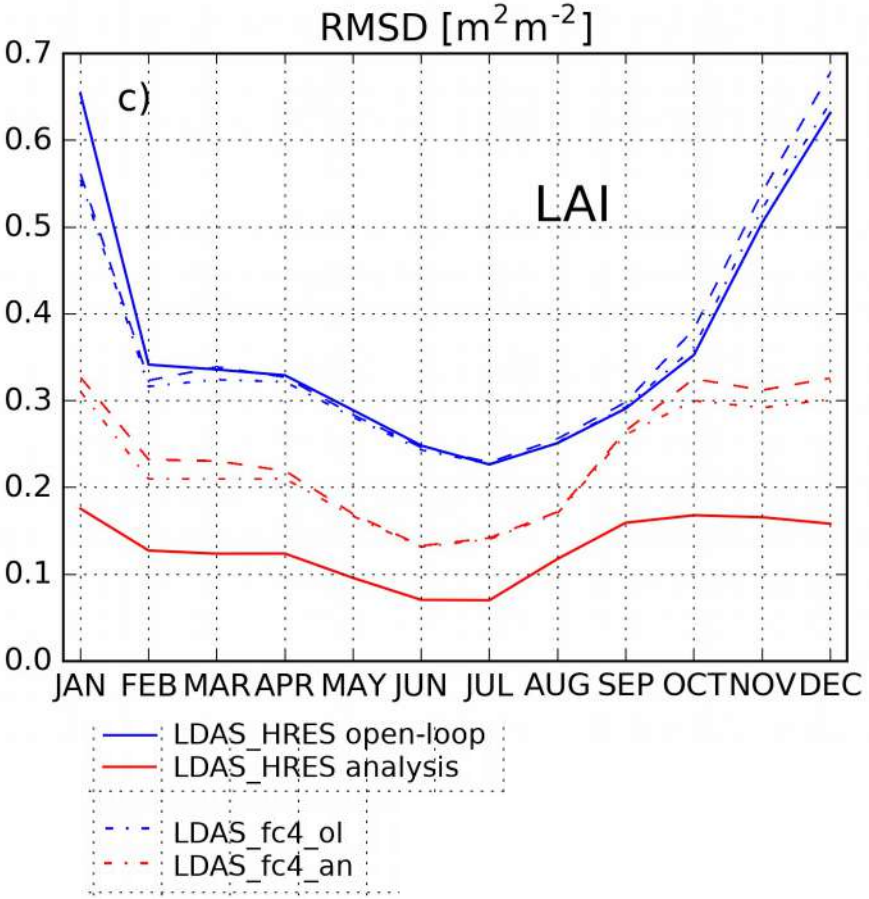


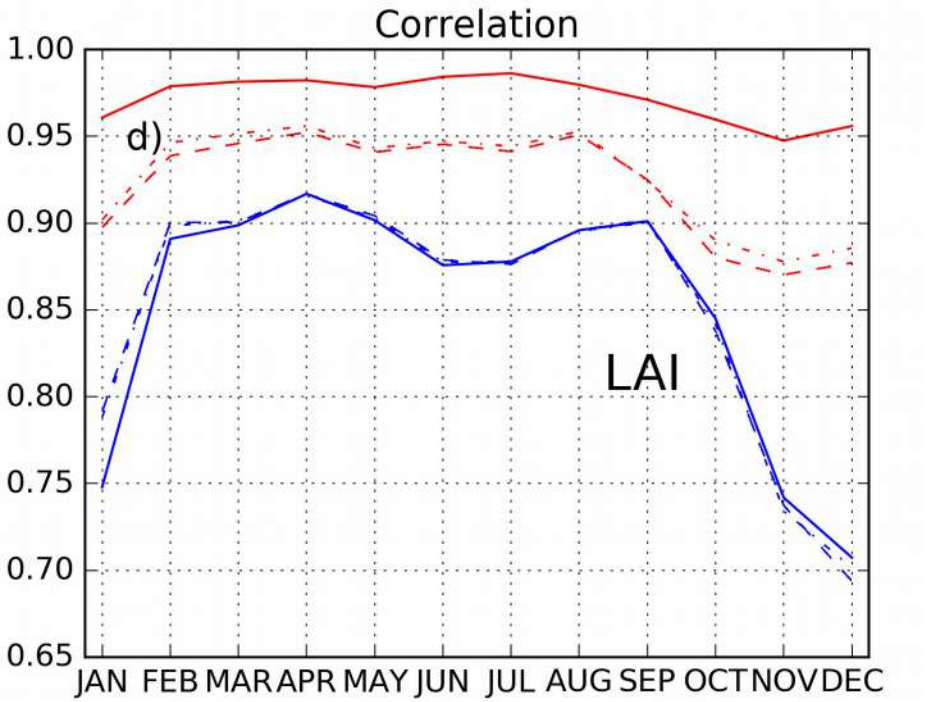
- LAI: strong positive impact from the analysis, strong positive impact from the initialisation

Impact of the 2018 heatwave on LSVs: Murray-Darling

Such an extreme event needs more attention!

- Using ECMWF high resolution operational analysis to force LDAS-Monde (LDAS-HRES, 0.10°x0.10°) and complement the use of ERA5 (LDAS-ERA5, 0.25°x0.25°)
- Forecast up to 8-days ahead initialised by either LDAS-HRES Openloop or Analysis

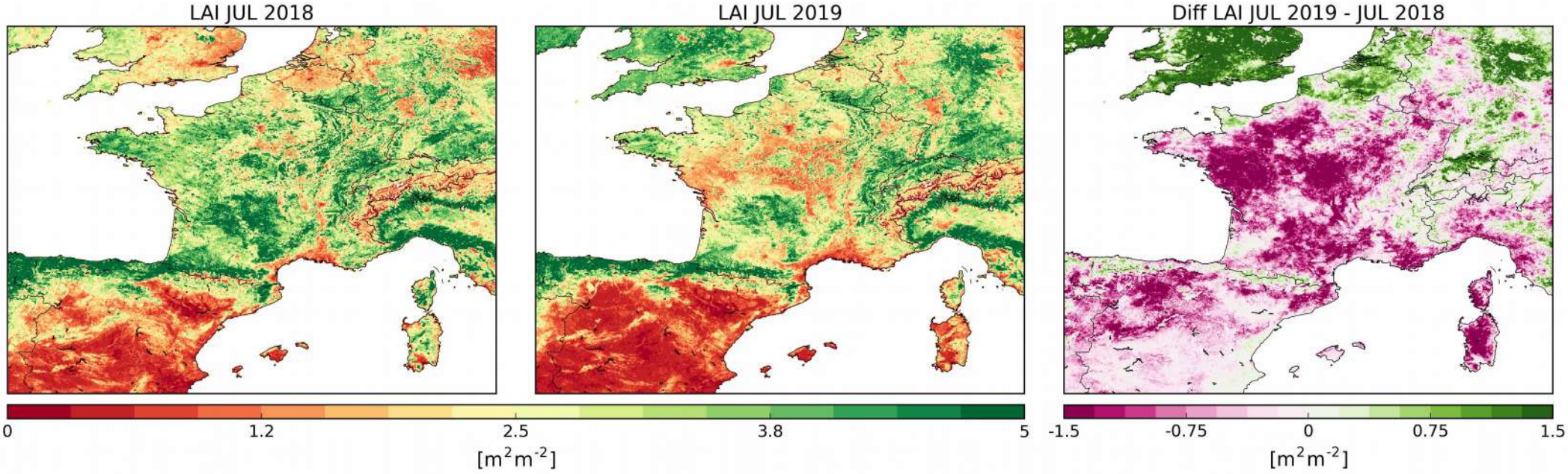




Towards better spatial resolution

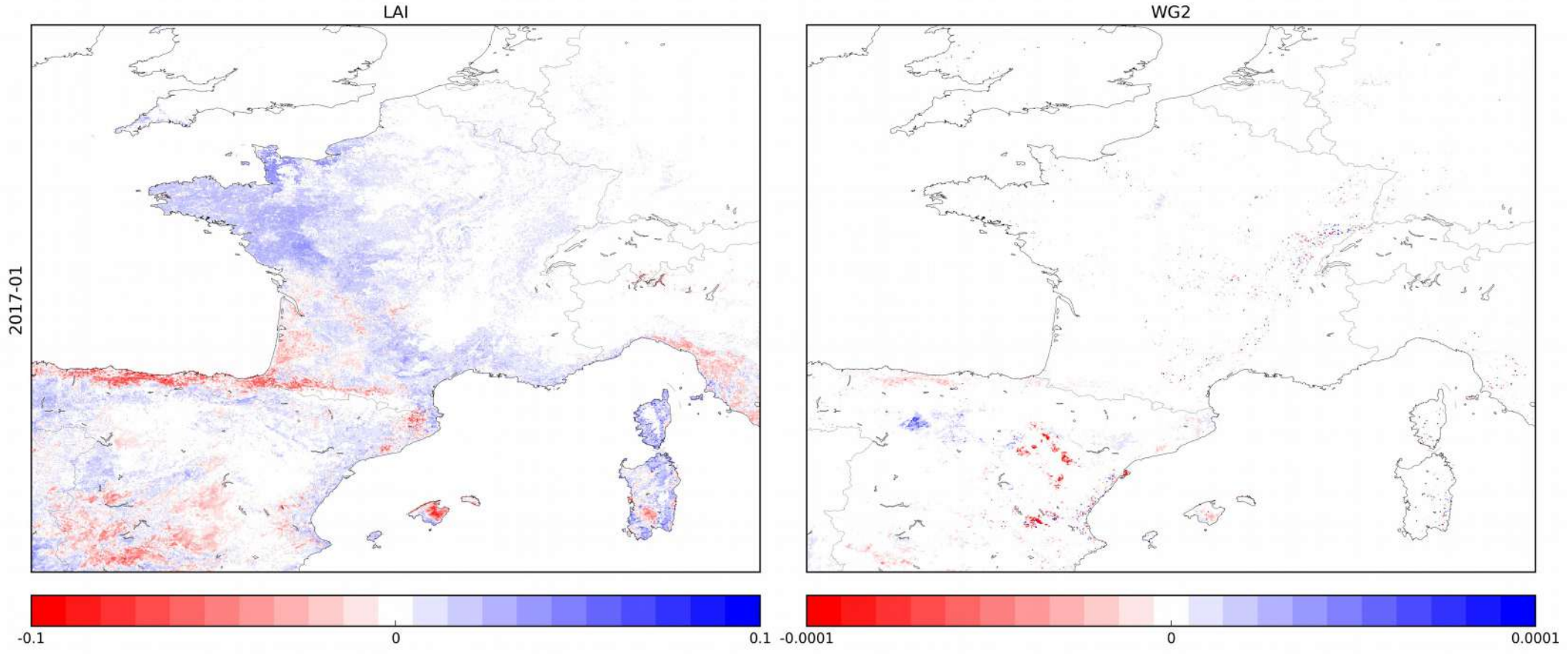
- **LDAS-Monde** forced by **AROME** atmospheric fields from Météo-France at 2.5km x 2.5km spatial resolution (aggregated from 1.3km x 1.3km spatial resolution),
- **Assimilation of LAI CGLS 300 m x 300 m**

➔ Impact of the July 2019 heatwave



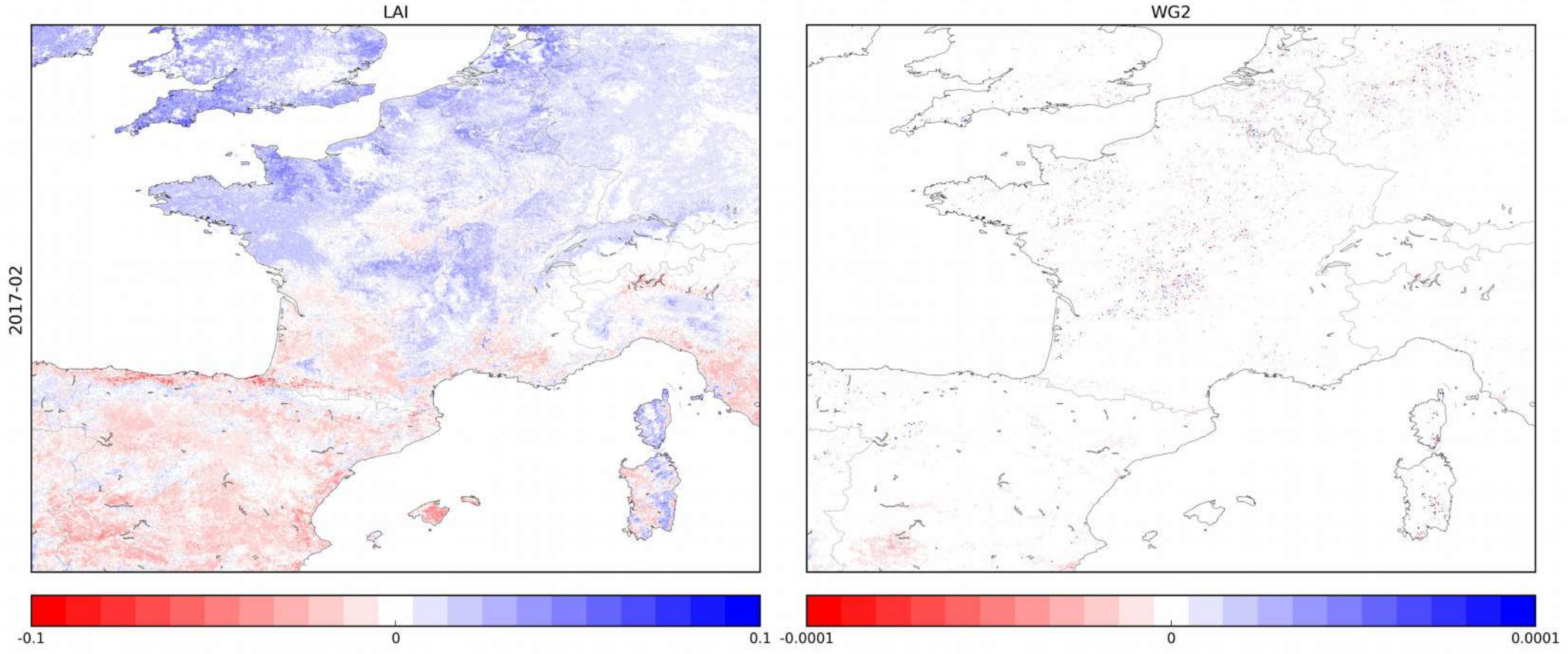
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



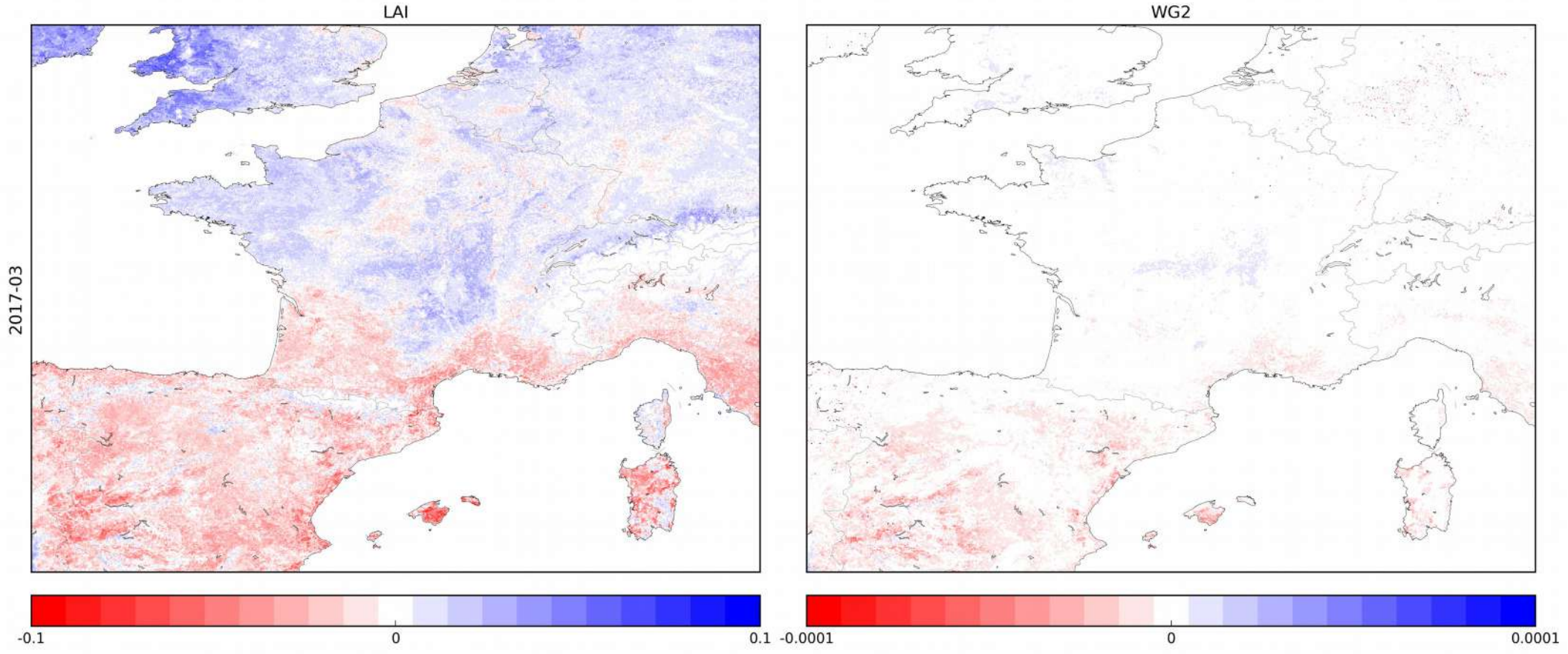
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



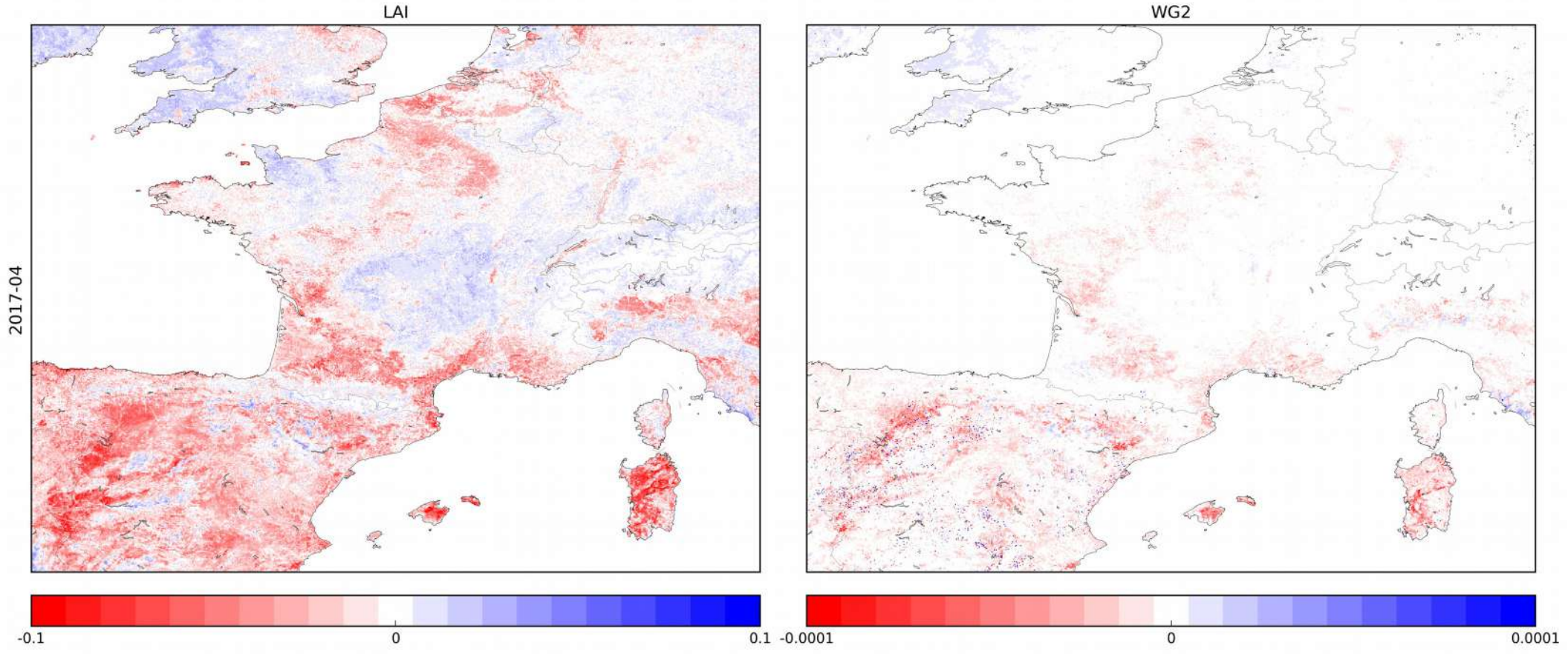
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



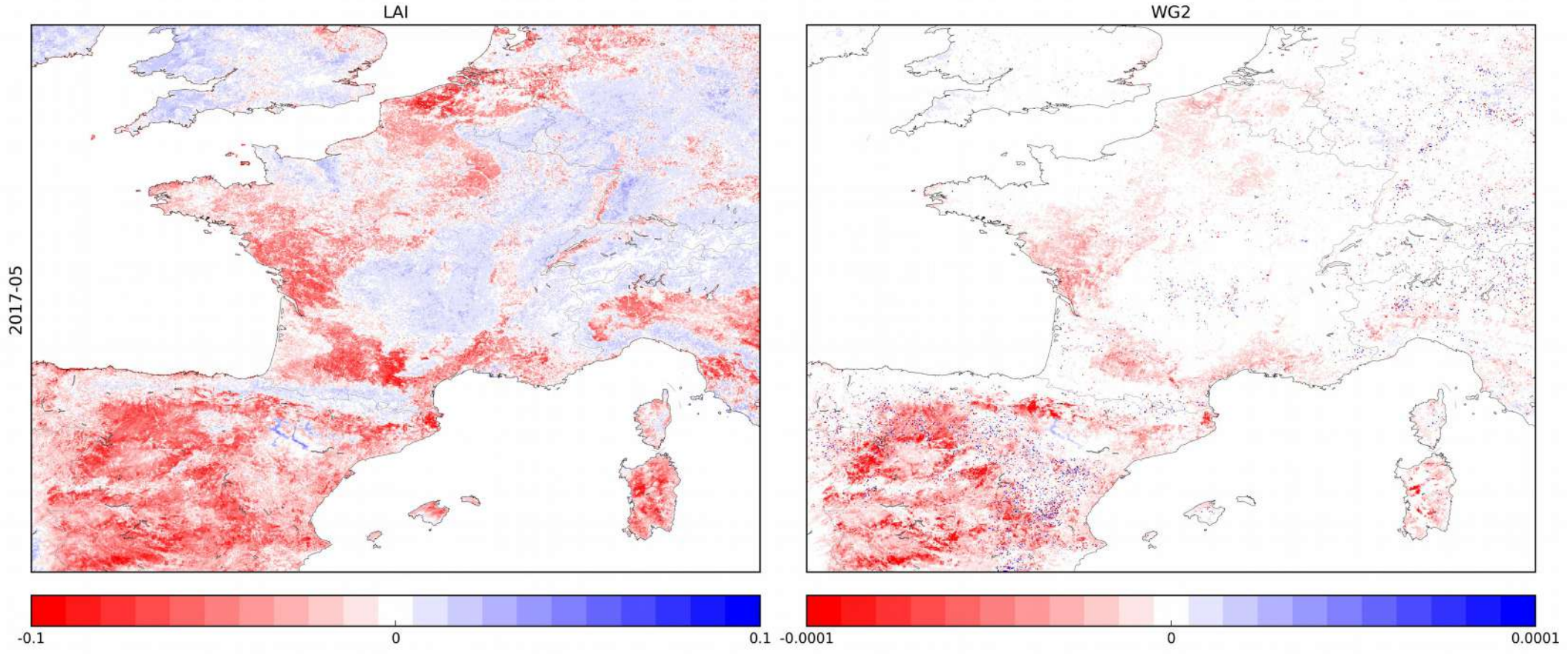
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



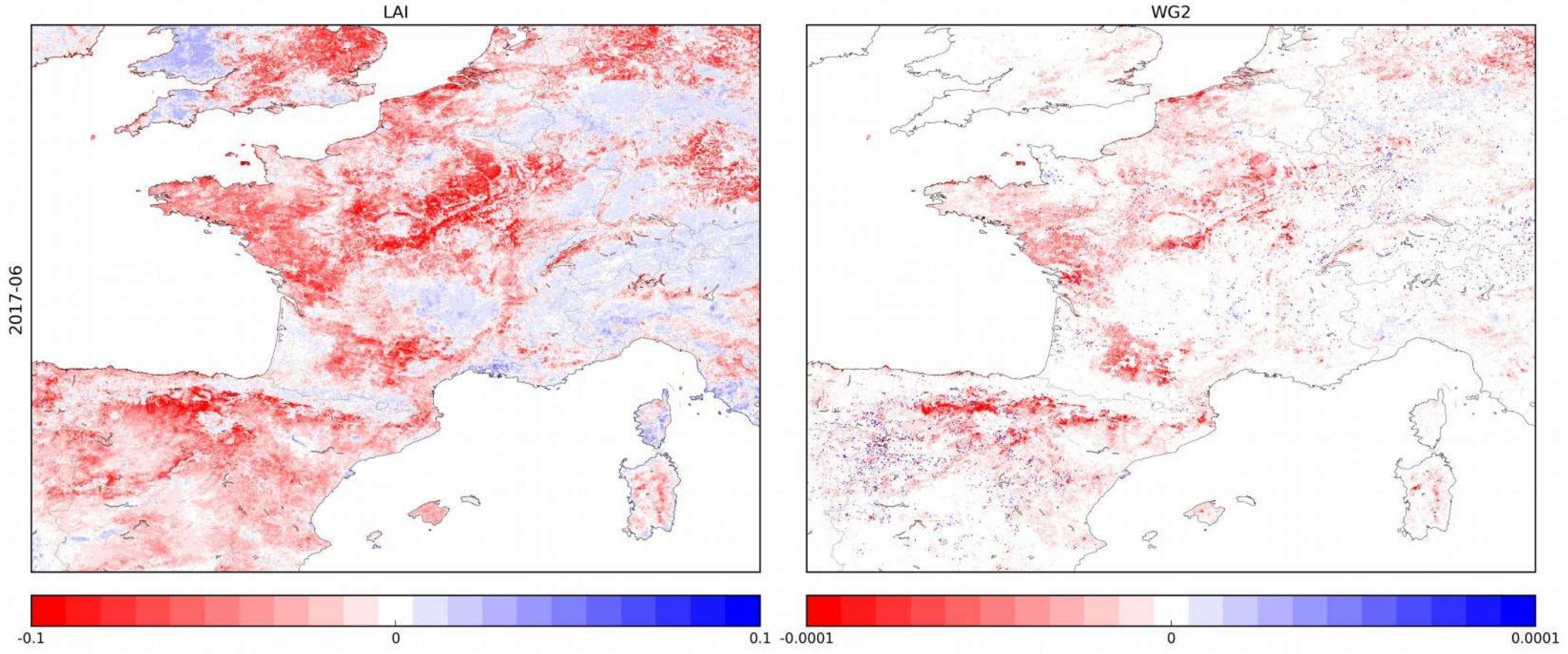
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



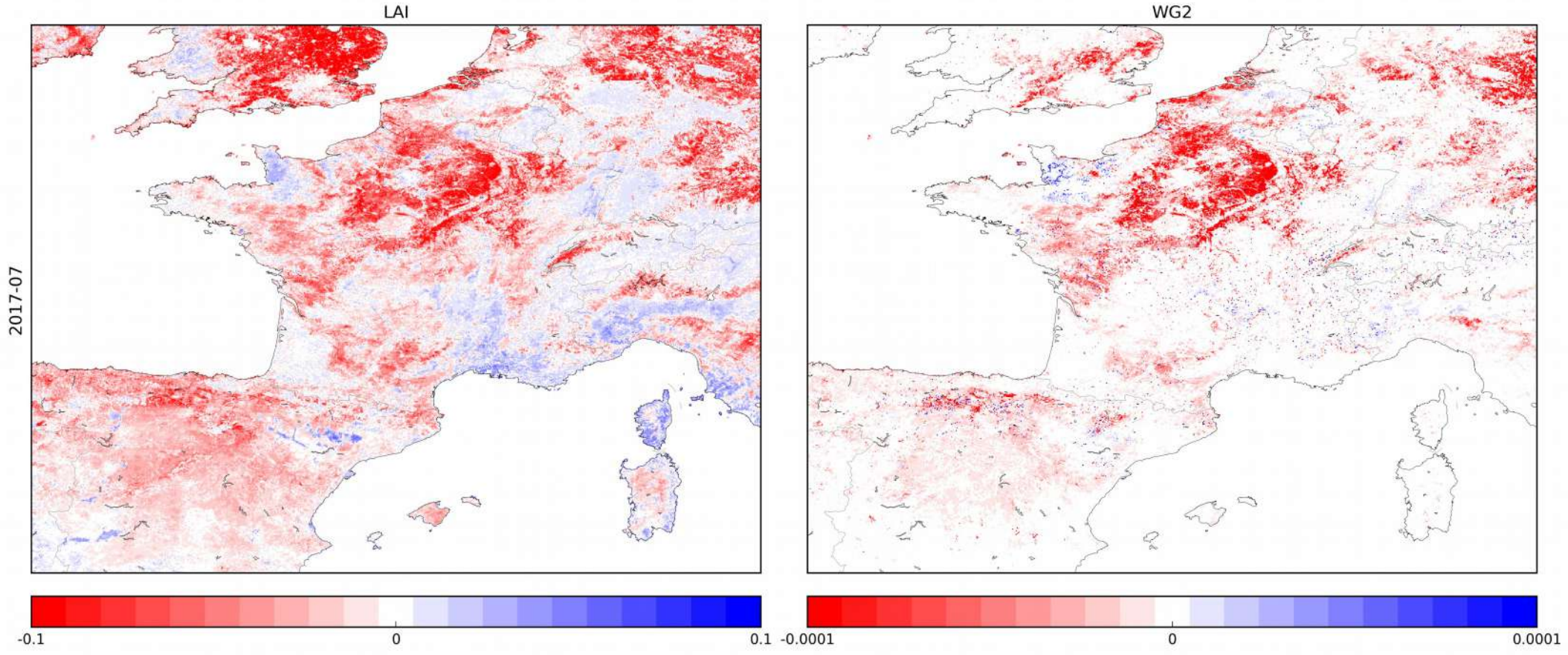
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



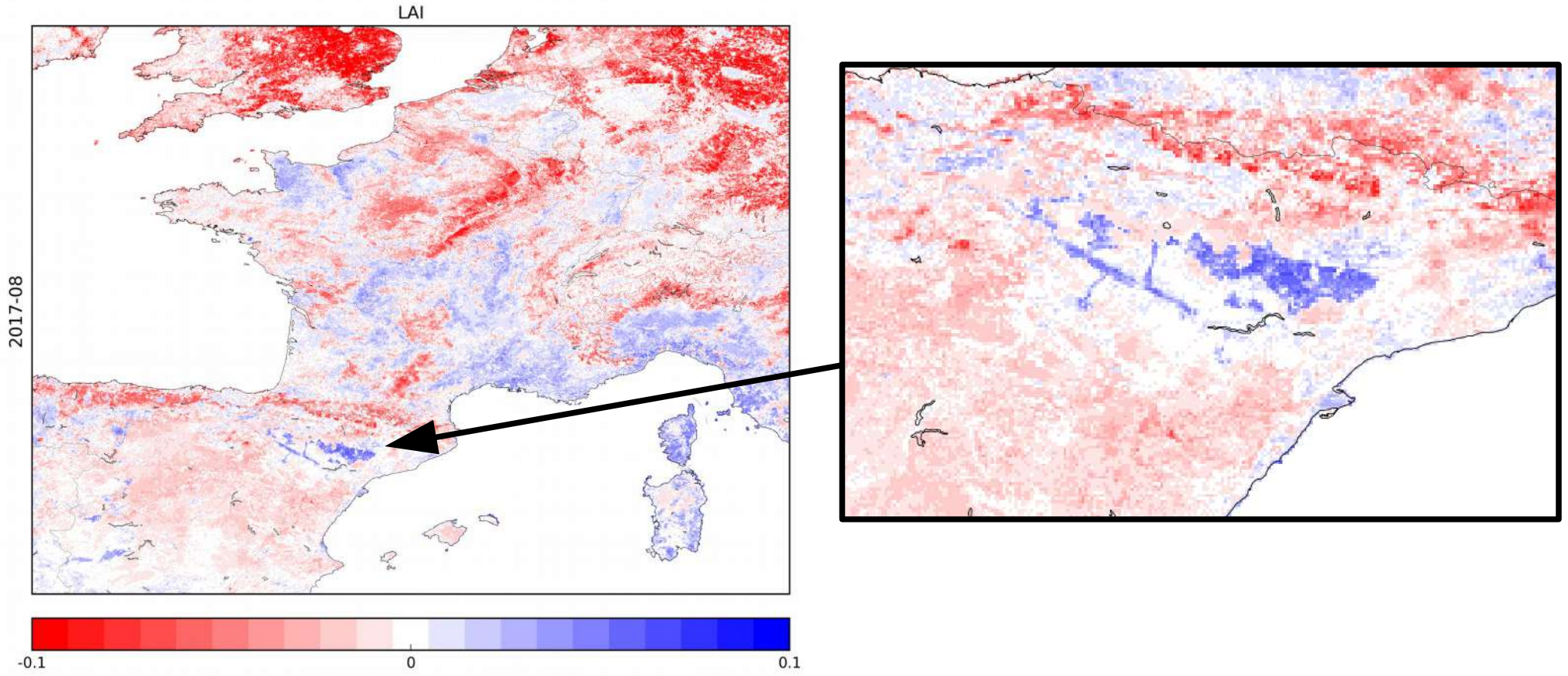
Towards better spatial resolution

- **Analysis increments** (mean monthly values)



Towards better spatial resolution

- **Analysis increments** (mean monthly values)



- **Data assimilation compensates for missing process: irrigation** (available from SURFEX V.9)

Conclusions and prospects

LDAS-Monde combines LSM, satellite data and atmospheric variables

➔ Great potential to monitor and forecast the impact of extreme weather on LSVs

LDAS-Monde provides a global climatology as a reference for LSV anomalies

➔ Significant anomalies used to initiate more detailed monitoring and forecasting at a better spatial resolution

LDAS-Monde ready for use in various applications

➔ Reanalyses of land ECVs
➔ Water resource / drought / vegetation monitoring
➔ Early-warning of severe conditions over land and initialisation of LSVs forecast

On-going developments

➔ **Assimilation of snow data**
➔ **Assimilation of Level 1 data (e.g. sigma0 instead of SSM)**
➔ **AI in support to data assimilation (observation operators)**

Open LDAS-Monde freely available:
https://opensource.umr-cnrm.fr/projects/openldasmonde
contact: clement.albergel@meteo.fr @CAlbergel