LDAS-Monde Sequential assimilation of satellite derived Vegetation and soil moisture products Applied to the Contiguous US

Clement Albergel [1] , Simon Munier [1] , Aymeric Bocher [1], Bertrand Bonan [1], Yongjun Zhang [1], Clara Draper [2], Delphine J. Leroux [1], Jean-Christophe Calvet [1]

[1] CNRM UMR 3589, Météo-France/CNRS, Toulouse, France
[2] CIRES/NOAA Earth System Research Laboratory, Boulder, CO 80309, USA

Copernicus Global Land User Conference
Toulouse, France, 23-25 October 2018

LDAS-Monde Sequential assimilation of satellite derived Vegetation and soil moisture products Applied to the Contiguous US

+ The summer 2018 heatwave impact on LSVs based on CGLS data

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Study 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]*

➔ Spatial and temporal gaps / Cannot observe all key LSVs

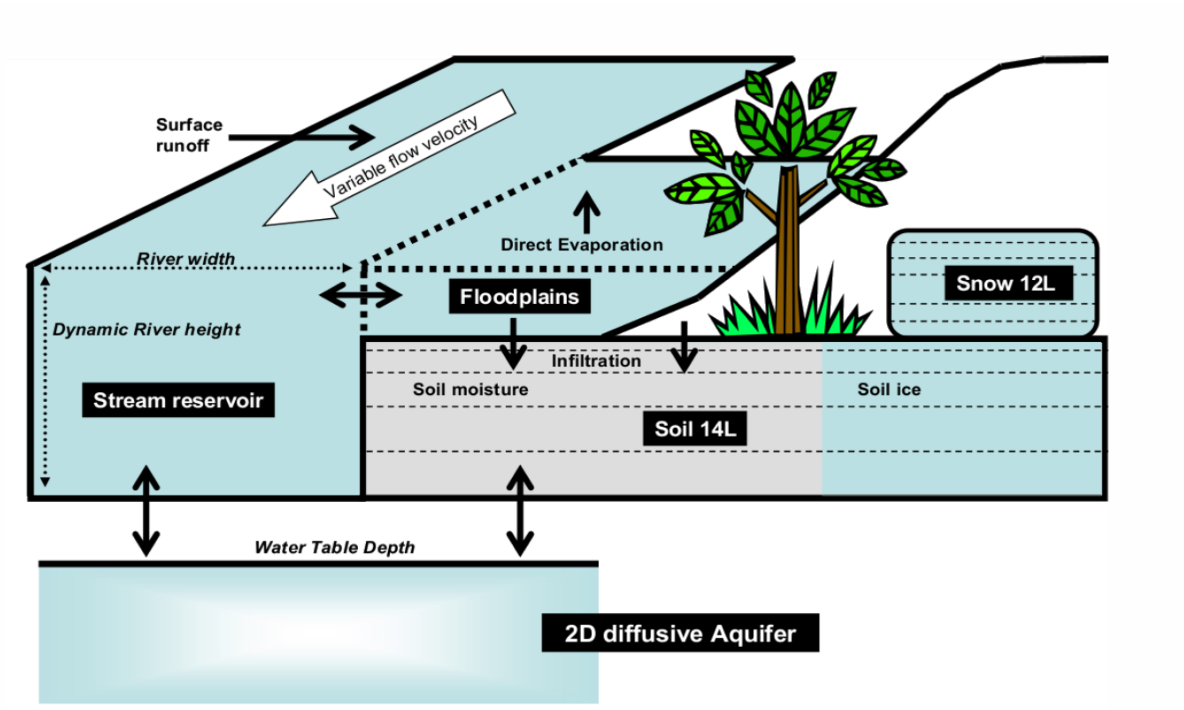
- **Land Surface Models (LSMs)** provide LSVs estimates at all time/location

- 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

Study the vegetation and terrestrial water cycles

LDAS-Monde : Global capacity (sequential) integration of satellite derived observations into the SURFEX modelling platform

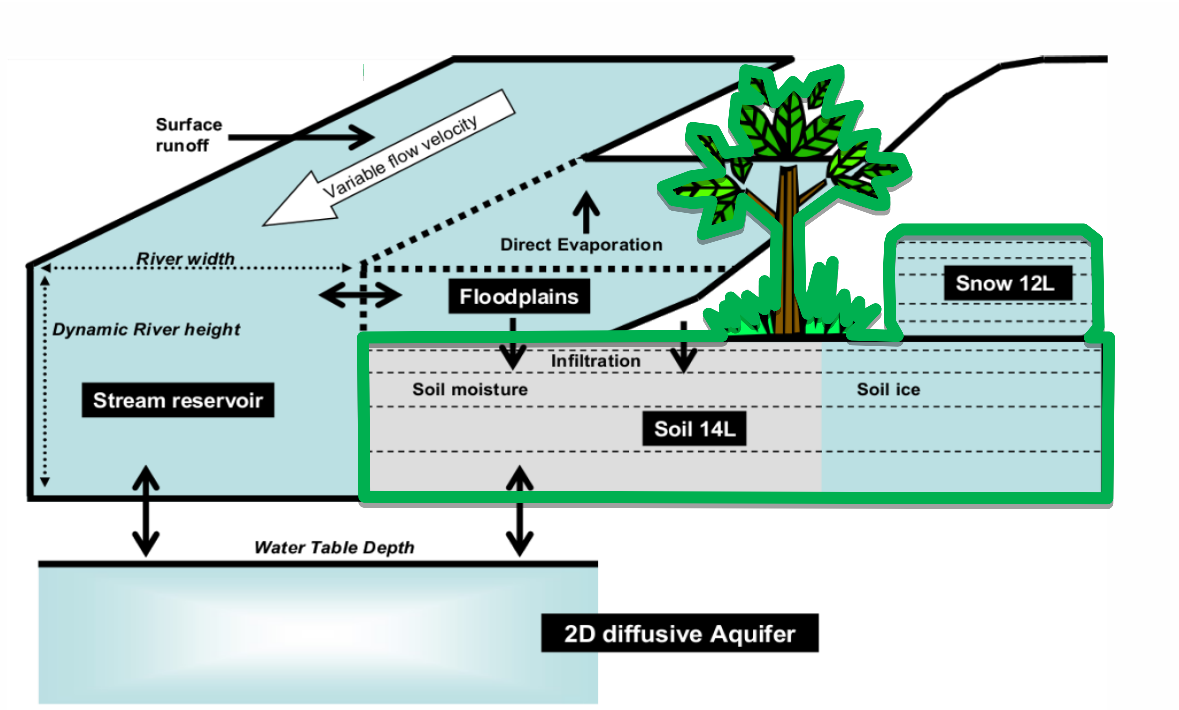


Copernicus Global Land User Conference, 23-25 October 2018, Toulouse, Fr.

Study the vegetation and terrestrial water cycles

LDAS-Monde : Global capacity (sequential) integration of satellite derived observations into the SURFEX modelling platform

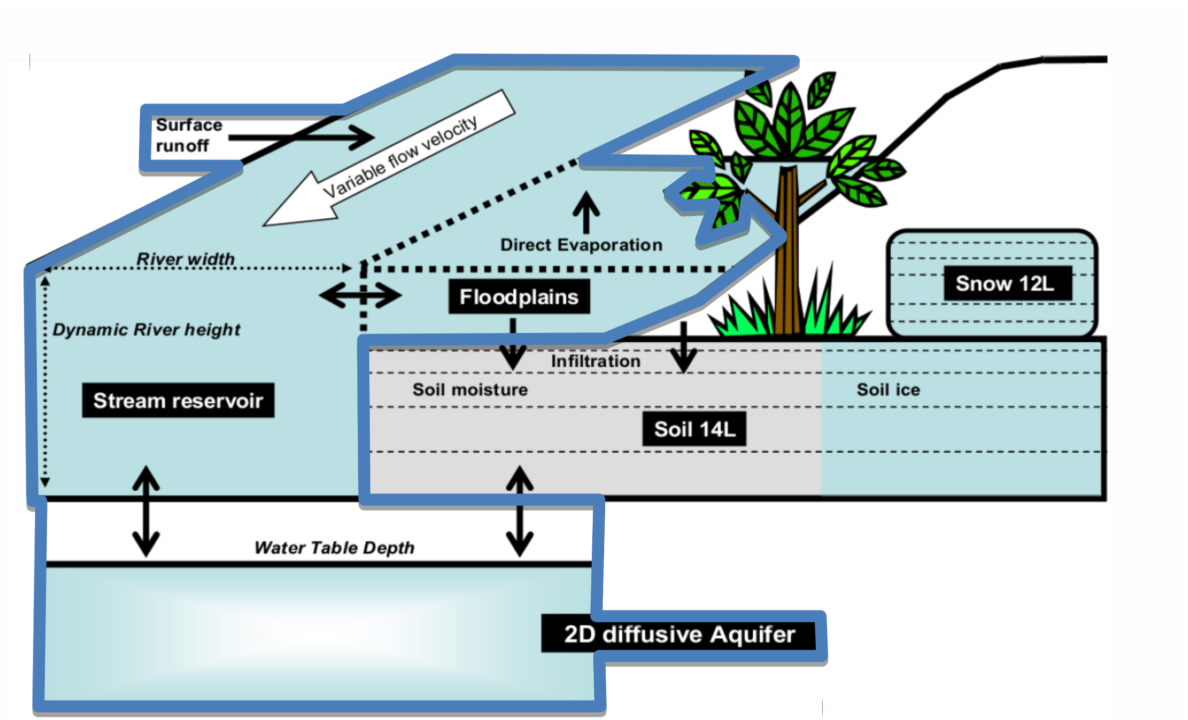
- ISBA-A-gs : simulates the diurnal cycle of water and carbon fluxes, plant growth and key vegetation variables on a daily basis
  [Calvet et al., 1998, 2007, Gibelin et al., 2006]



Study the vegetation and terrestrial water cycles

LDAS-Monde : Global capacity (sequential) integration of satellite derived observations into the SURFEX modelling platform

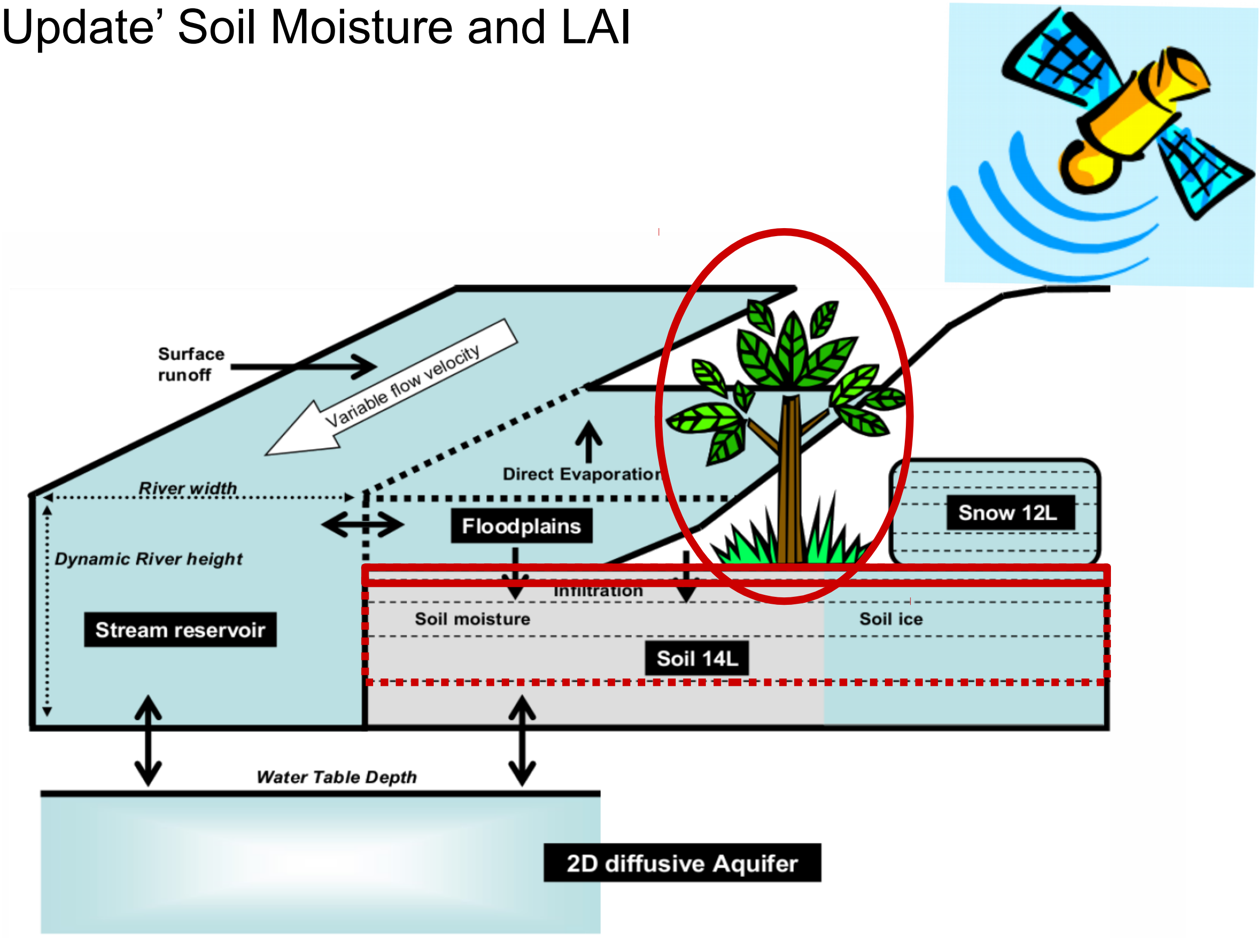
- CTRIP : TRIP based river routing system with CNRM developments for global hydrological applications
  [Oki and Sud, 1998, Decharme et al., 2008, 2010]



Study the vegetation and terrestrial water cycles

LDAS-Monde : Global capacity (sequential) integration of satellite derived observations into the SURFEX modelling platform

- 'Update' Soil Moisture and LAI



Study the vegetation and terrestrial water cycles

Model	Domaine	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
ISBA Multi-layer soil model CO_2-responsive version (Interactive veg.)			**SEKF** **EnSRF** **PF**	**SSM** (ESA-CCI, ASCAT SMOS SMAP Theia S1/S2) **LAI** (GEOV1/V2, 1km) **Sigma0**	**Second layer of soil (1-4cm)** **LAI**	**Layers of soil 2 to 8 (1-100cm)** **LAI**	

Study the vegetation and terrestrial water cycles

Model	Domaine	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
ISBA Multi-layer soil model CO_2-responsive version (Interactive veg.)	**Global (2000-2013, 1°)**	**EartH2Observe project (Schellekens et al., 2017)**	**SEKF** **EnSRF** **PF**	**SSM** (ESA-CCI, ASCAT SMOS SMAP Theia S1/S2) **LAI** (GEOV1/V2, 1km) **Sigma0**	**Second layer of soil (1-4cm)** **LAI**	**Layers of soil 2 to 8 (1-100cm)** **LAI**	**Coupling with CTRIP (0.5°)**
	Global (2000-[…], 0.5°)	**ERA-Interim (Dee et al., 2011)**					**Coupling with CTRIP (0.5°)**
	Meso-scale, Global (2000-[…], 0.25°)	**ERA-5 (Hersach, 2016, Albergel et al., 2018)**					**Coupling with CTRIP (0.5°)**
	Meso-scale (201604-NRT, 0.1°)	**IFS HRES**					**Coupling with CTRIP (0.5°)**
	France (2007-2017, 8kmx8km)	**SAFRAN (Quintena-Segui, et al., 2008)**					**Offline coupling with MODCOU**
	Spain (2008-07/2014 5kmx5km)	**SAFRAN-Spain (Quintena-Segui, et al., 2017**					**Offline coupling with RAPID**

Fairbairn et al., 2017, *HESS*, Albergel et al., 2017, *GMD*, Dewaele et al., 2017, *HESS*, Leroux et al., 2018, *RS*
Albergel et al., 2018, *HESS*, Albergel et al., 2018, *RS*

Study the vegetation and terrestrial water cycles

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	Meso-scale, Global (2000-[…], 0.25°)	**ERA-5 (Hersach, 2016, Albergel et al., 2018)**					**Coupling with CTRIP (0.5°)**
New	**Meso-scale (201604-NRT, 0.1°)**	**IFS HRES**					/
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Fairbairn et al., 2017, *HESS*, Albergel et al., 2017, *GMD*, Dewaele et al., 2017, *HESS*, Leroux et al., 2018, *RS* Albergel et al., 2018, *HESS*, Albergel et al., 2018, *RS*

Bonan et al., 2018, *in prep HESS,* Zheng et al., 2018*, in prep, GMD*

Next : use of ECMWF datasets (ERA5/HRES) to study resolution vs. System (Summer 2018)

Study the vegetation and terrestrial water cycles

LDAS-Monde sequential assimilation of satellite derived vegetation and soil moisture products

- Direct impact on model control variables (Soil moisture and LAI)
- Other variables benefit from the assimilation through biophysical processes and feedbacks in the model (e.g., Evap., GPP, river discharge, AGB)

➔ Powerful tool to monitor land surface variables

(Extreme events like agricultural drought, also)

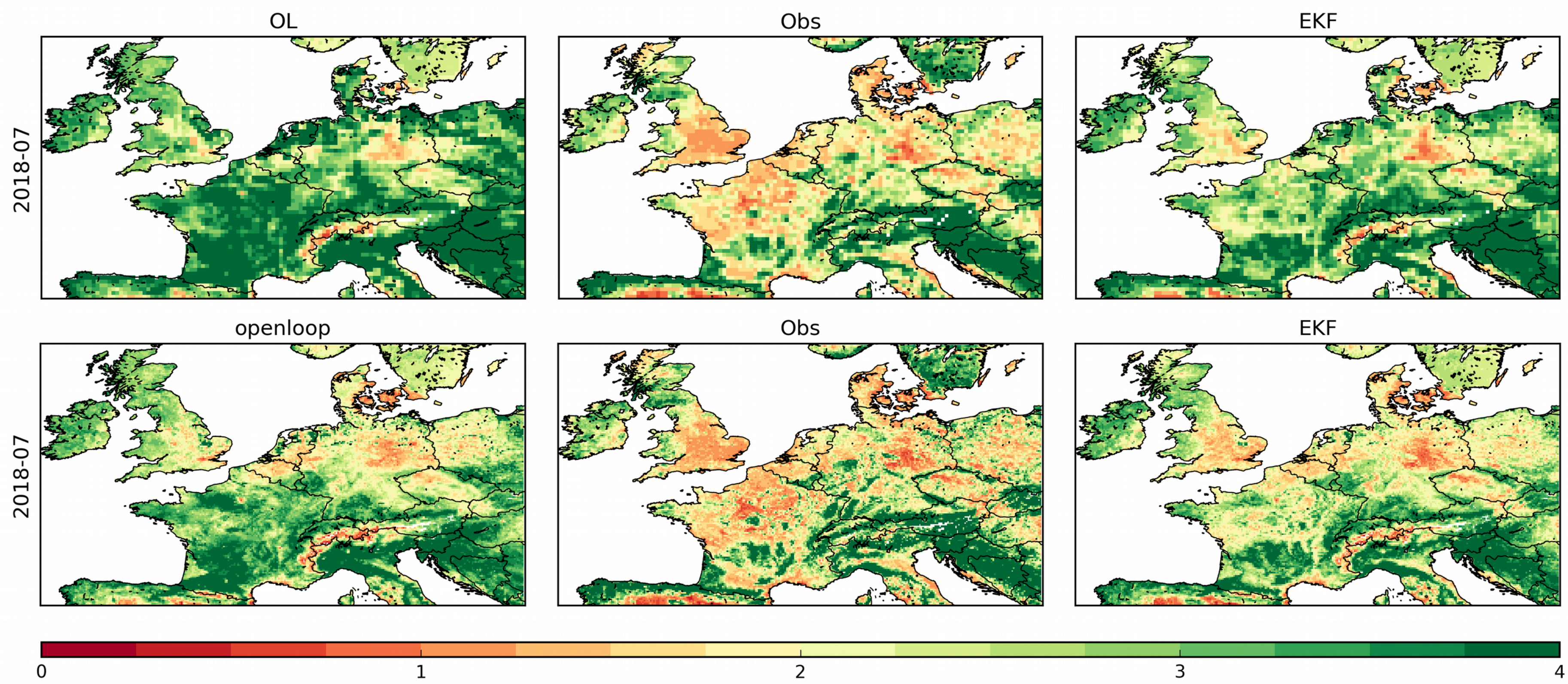
➔ High potential of the analysis for initialising forecasts

(Analysis provides better initial conditions than a model run)

- Towards higher spatial resolution LDAS-Monde using ECMWF IFS HRES (0.1°x0.1°)
- Combining ERA5 (0.25°x0.25°) and HRES (0.1°x0.1°) to force LDAS-Monde permits to have long Reanalysis with Real Time [and even forecast] capacities

The Summer 2018 heatwave over Europe

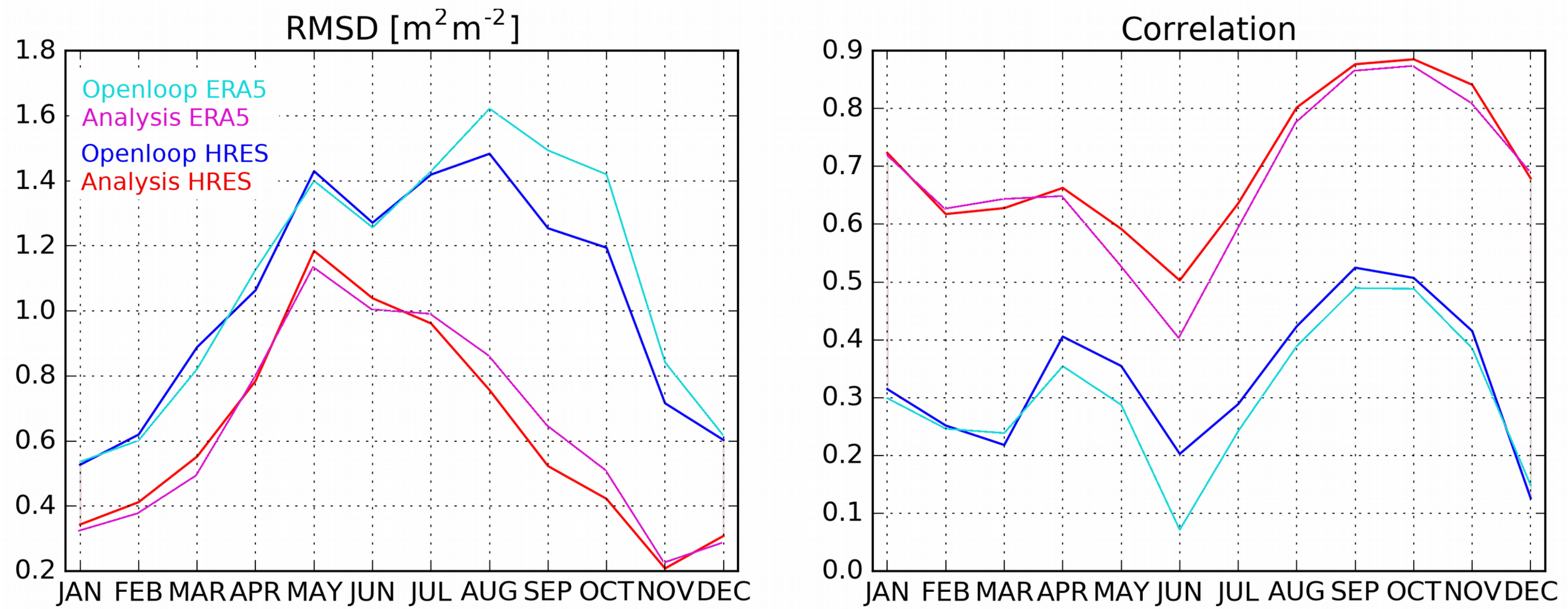
LDAS-Monde : ERA5 (0.25) Top, **HRES** (0.10) Bottom for 07/2018



- LDAS-Monde ERA5 & HRES share similar patterns, HRES better represents LAI states than ERA5 (in both open-loop & analysis) for this event

Study the vegetation and terrestrial water cycles

Higher spatial resolution : seasonal score for LAI (04/2016-07/2018)



- ERA5 and HRES LDAS open loop are quite comparable, HRES being slightly better
- LDAS Analysis add skill to both which is indication of healthy behaviour

➔ Long reanalysis of the LSVs with RT and FC capability

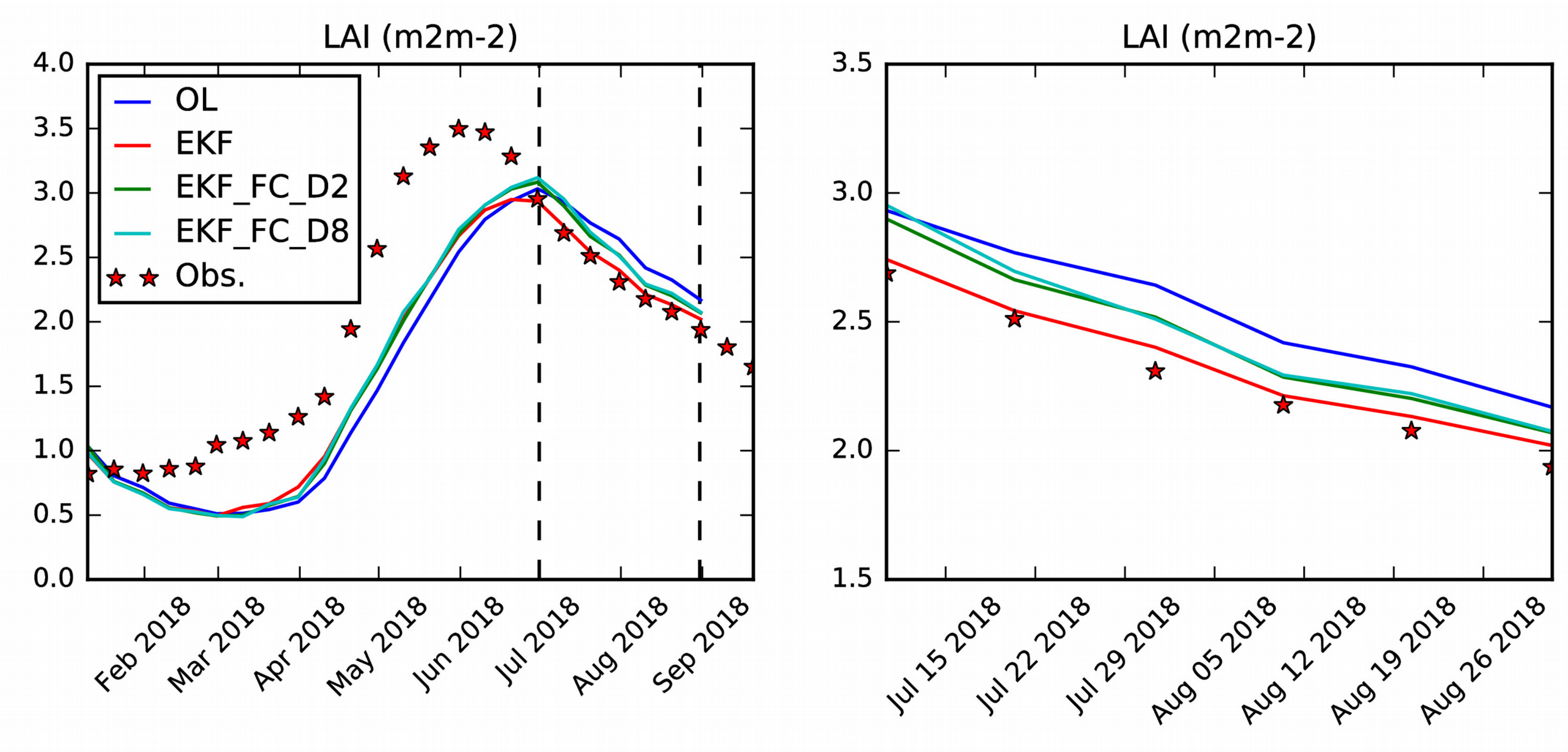
- Is the improvement due to the resolution only (e.g. better land cover?) or the forcing quality ? or both?

➔ Interesting opportunity to examine the impact of resolution independently from the system !

The Summer 2018 heatwave over Europe

LDAS-Monde : Study Forecast capacity (2018)

- LAI forecast from 2 to 8-days ahead initialised by LDAS-Monde vs. Openloop



➔ 2-day forecast experiment (and even 8-day) initialised by EKF better than an open-loop

The Summer 2018 heatwave over Europe

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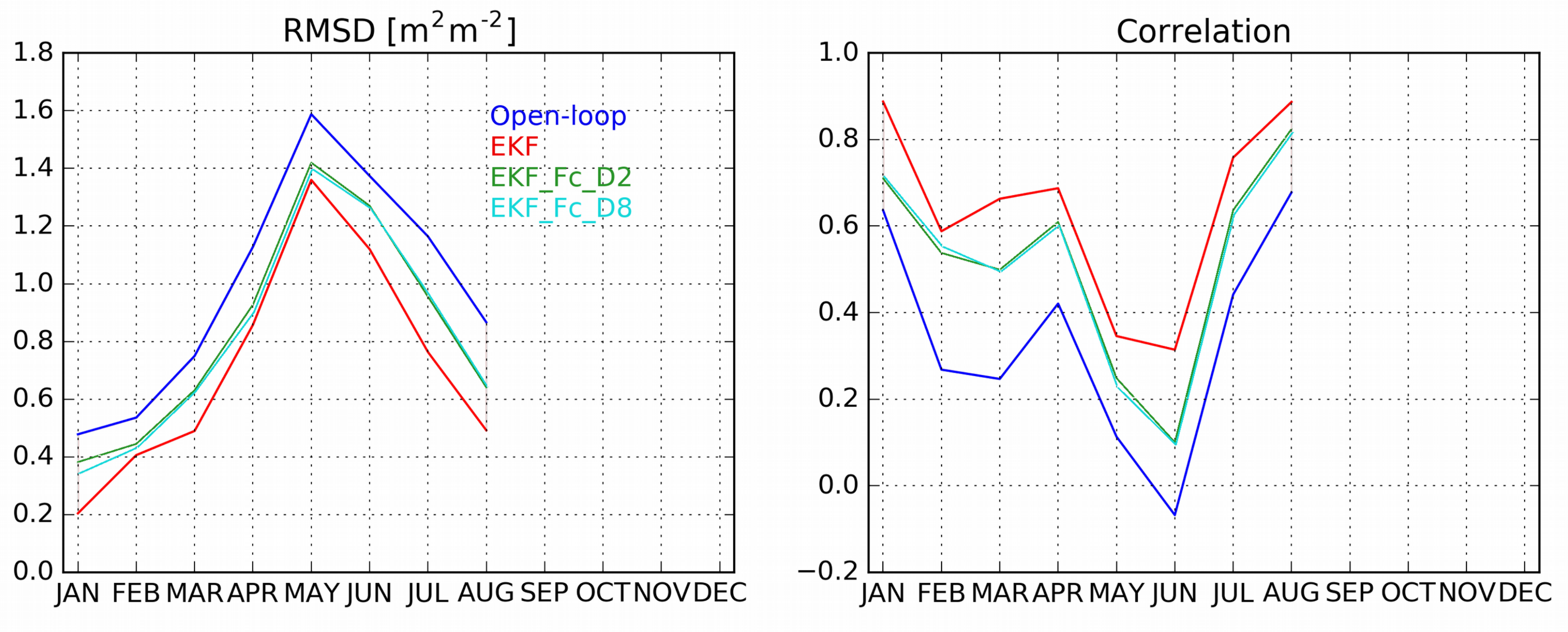


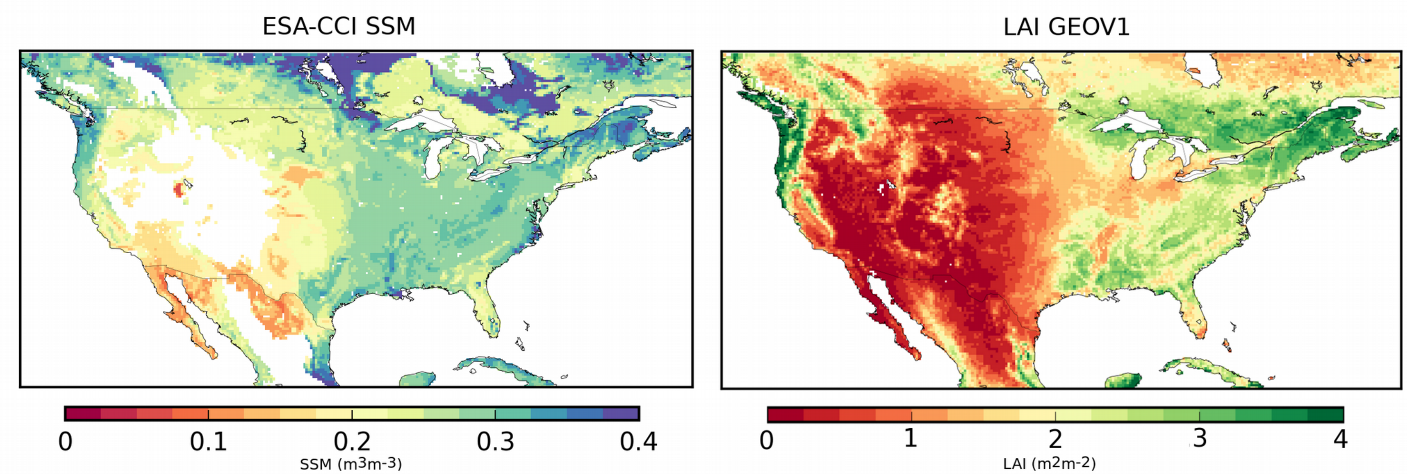
➔ 2-day forecast experiment (and even 8-day) initialised by EKF better than an open-loop

Study the vegetation and terrestrial water cycles

LDAS-Monde (*Albergel et al., 2017, GMD ; 2018 RS*)

Model	Domaine	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
ISBA Multi-layer soil model CO_2-responsive version (Interactive veg.)	**Continental US (2010-2016, 0.25°x0.25°)**	**ERA-5 (HersBach, 2016)**	**SEKF**	**SSM** (ESA CCI) **LAI** (GEOV1)	**Second layer of soil (1-4cm)** **LAI**	**Layers of soil 2 to 8 (1-100cm)** **LAI**	**Coupling with CTRIP (0.5°)**

Averaged over 2010-2016



(ESA CCI SSM)
(seasonal bias correction)
http://www.esa-soilmoisture-cci.org

(SPOT-VGT / PROBA-V, 1km)
http://land.copernicus.eu/global/

Study the vegetation and terrestrial water cycles

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Model	Domaine	Atm. Forcing	DA Method	Assimilated Obs.	Observation Operator	Control Variables	Additional Option
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- Direct impact of assimilating SSM on root-zone soil moisture as well as on LAI
- Direct impact of assimilating LAI on LAI and root-zone soil moisture
- Other variables benefit from the assimilation through biophysical processes and feedbacks in the model

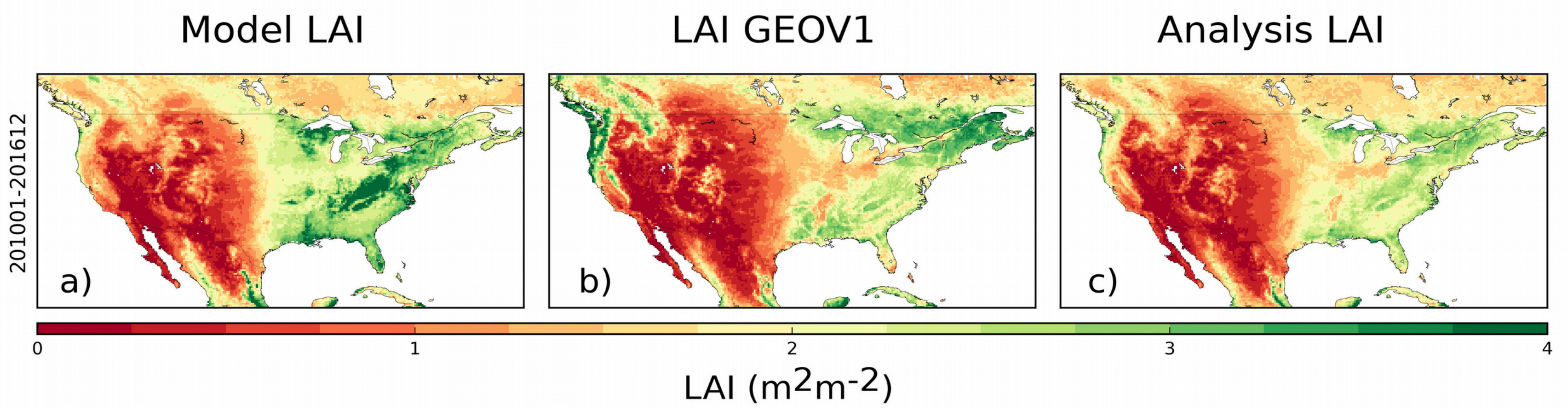
Study the vegetation and terrestrial water cycles

- **Analysis Impact is evaluated by comparing performance improvement relative to the open-loop**

Assimilated SSM & LAI (analysis has to be closer to them than the open-loop !)	http://www.esa-soilmoisture-cci.org https://land.copernicus.eu/
In situ measurements of soil moisture from USCRN network	https://www.ncdc.noaa.gov/crn
River discharge from USGS	https://waterdata.usgs.gov/nwis
Evapotranspiration from the GLEAM project	http://www.gleam.eu
Gross Primary Production from the FLUXCOM project	http://www.fluxcom.org

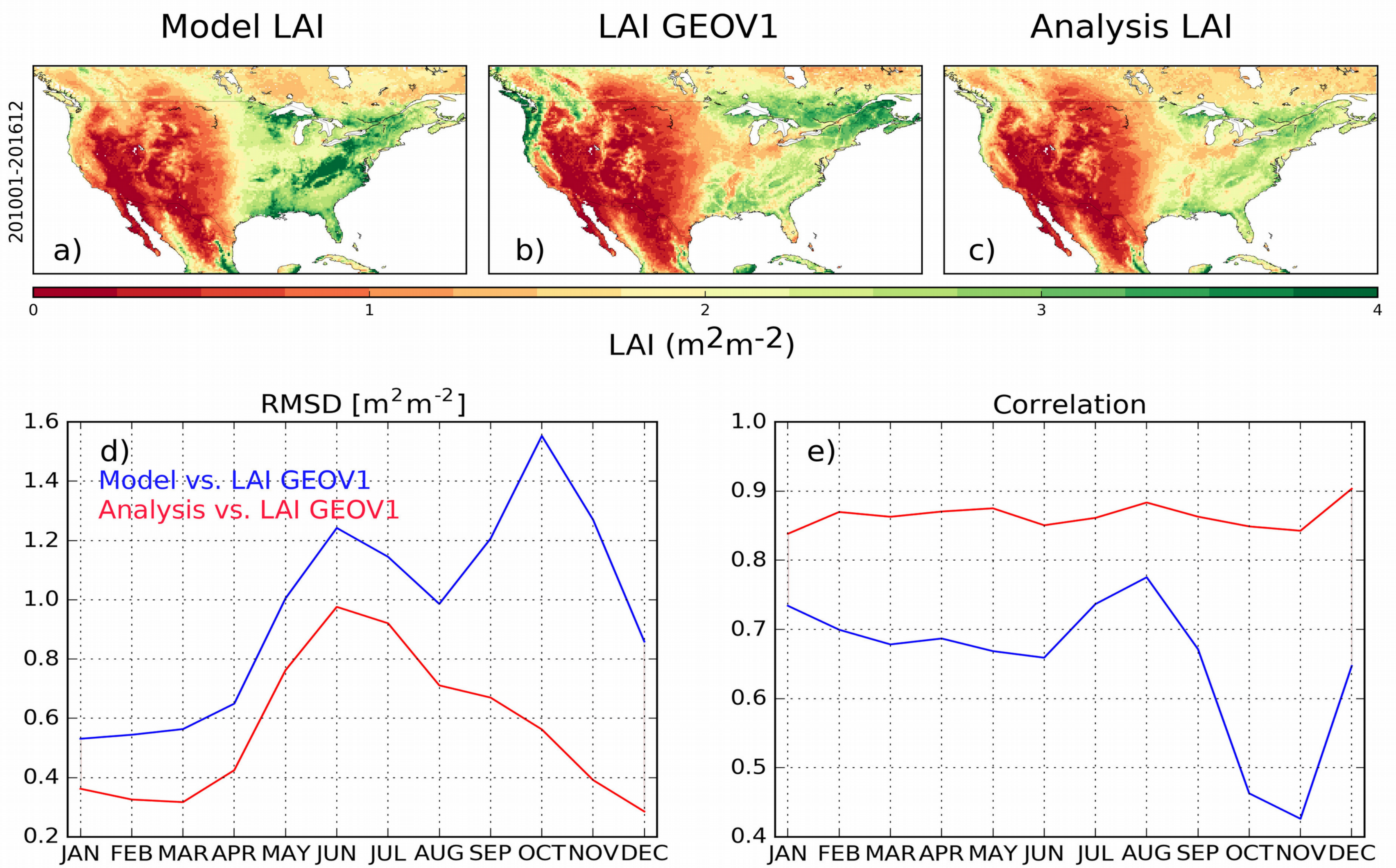
Study the vegetation and terrestrial water cycles

Analysis impact : LAI



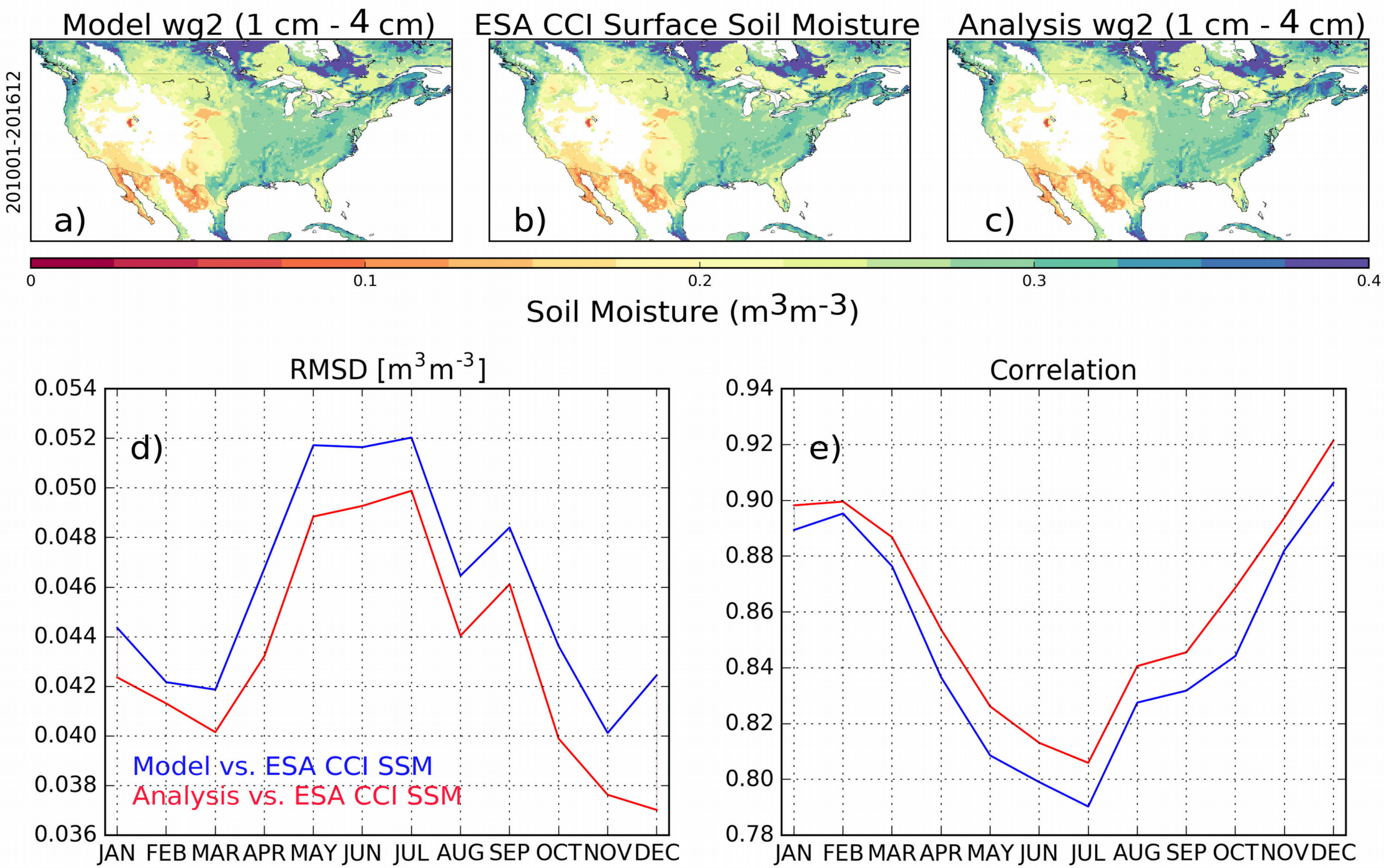
Study the vegetation and terrestrial water cycles

Analysis impact : LAI



Study the vegetation and terrestrial water cycles

Analysis impact : SSM

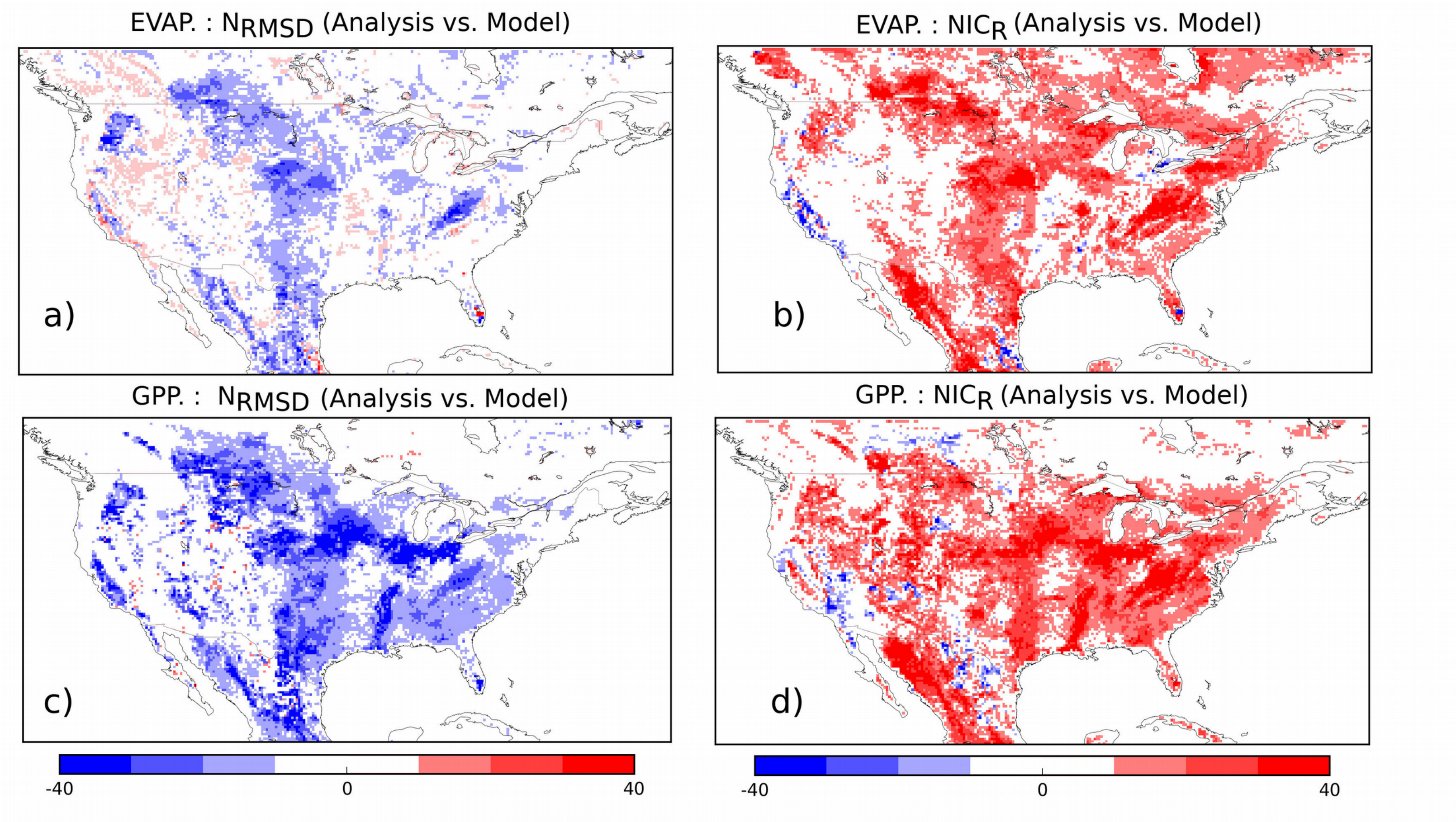


Study the vegetation and terrestrial water cycles

Analysis impact : Evapotranspiration & Gross Primary Production

- Normalised RMSDs and **NIC** (*100) on R values to quantify improvement/degradation

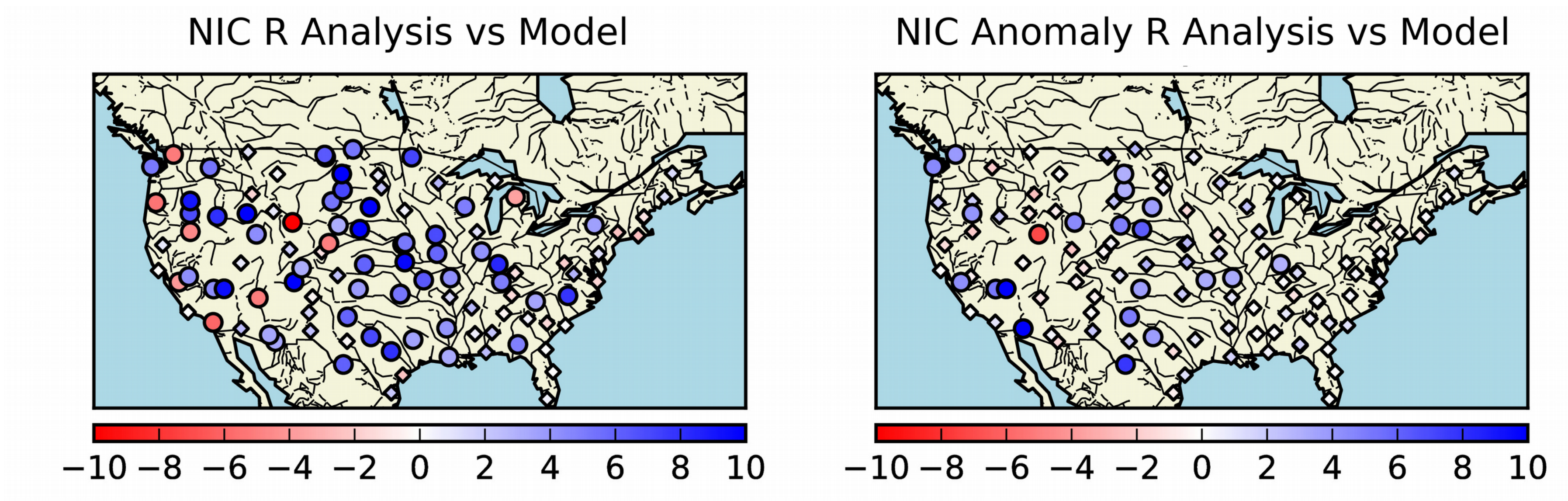
- Blue (negative) colours for RMSD suggest that analysis is better (a & c panels)
- Red (positive) colours for R suggest analysis is better (b & d panels)



Study the vegetation and terrestrial water cycles

Vs. in situ soil moisture from USCRN network

(in situ 5cm vs ISBA 4-10cm, April-September 2010-2016, daily data)

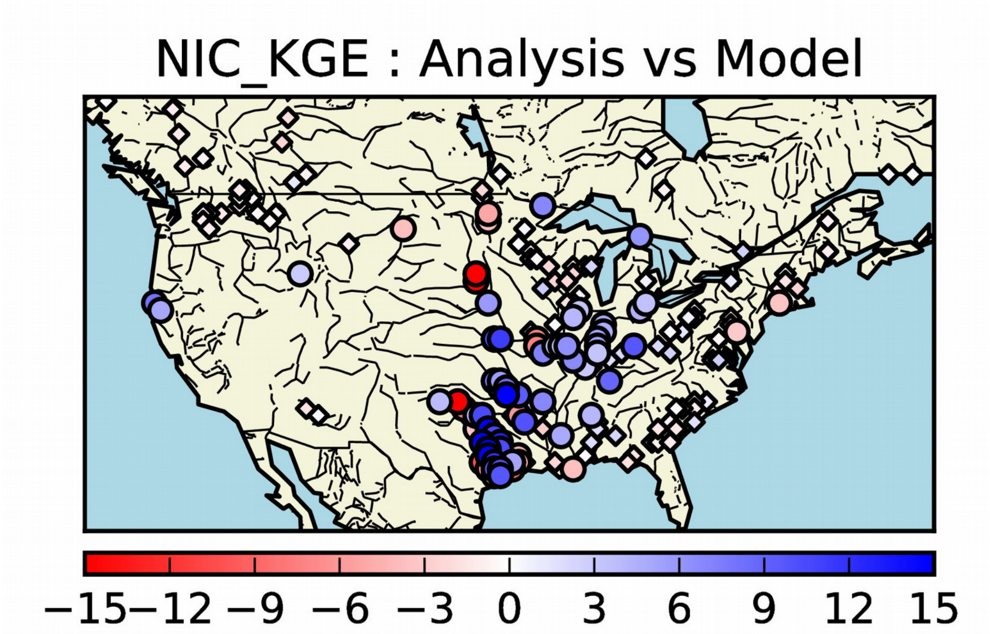


110 (110) stations with significant R (Anomaly R)	**Median R (Anomaly R)**	**Median ubRMSD**	**NIC_R (NIC_ANO_R) > +3 % Blue circles**	**NIC_R (NIC_ANO_R) < -3 % Red circles**	**NIC_NSE [-3,+3] Diamonds**
Model	0.72 (0.60)	0.049	/	/	/
Analysis	**0.74** (0.60)	**0.048**	**46 % (18 %)**	8 % (1 %)	46 % (81 %)
			Positive impact	Negative impact	Neutral impact

Study the vegetation and terrestrial water cycles

Vs. River discharge (USGS)

- Kling-Gupta efficiency (KGE) values are computed for each Exp. / stations
  (daily values scaled to the drainage area)
- NIC on KGE

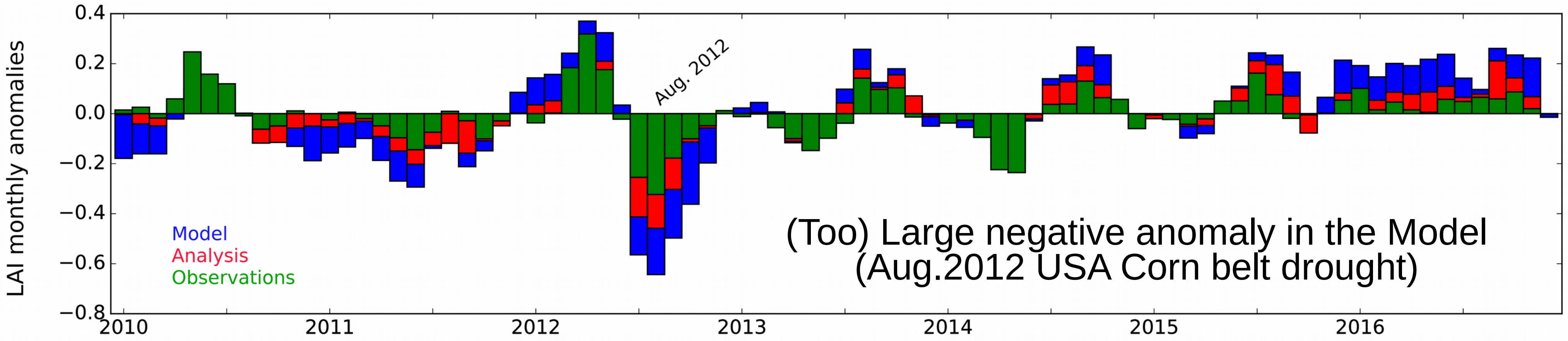


Diamonds : neutral impact
Red circles : negative impact
Blue circle : positive impact

258 out of 531 Stations with KGE Greater than 0	Positive Impact: >+3	Negative Impact: <−3	Neutral Impact [−3; +3]
NIC_{KGE}	26%	12%	62%
$N_{RE\sigma}$	22%	1%	77%
$N_{RE\mu}$	34%	1%	65%

Monitoring agricultural drought

- **Can LDAS-Monde provides a good monitoring of agricultural drought ?**



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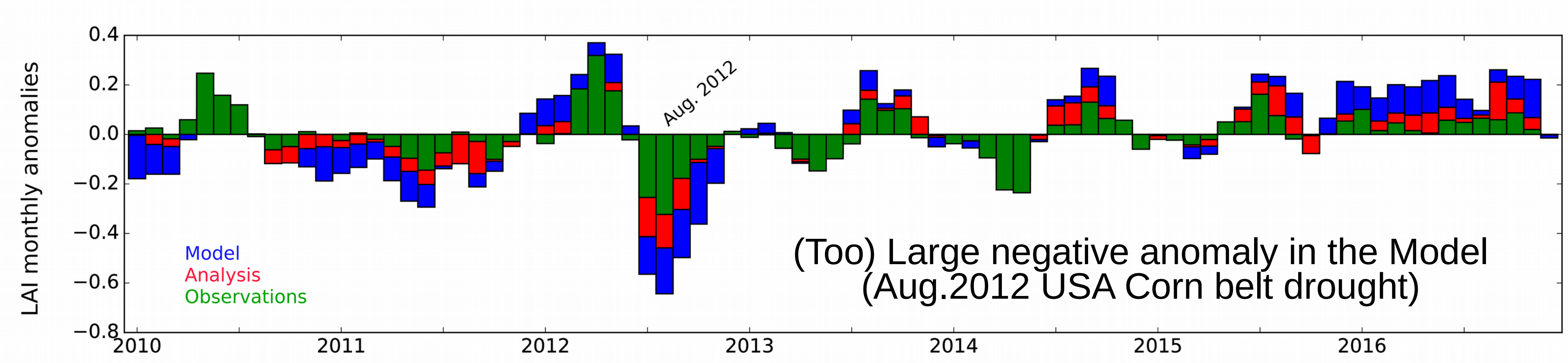
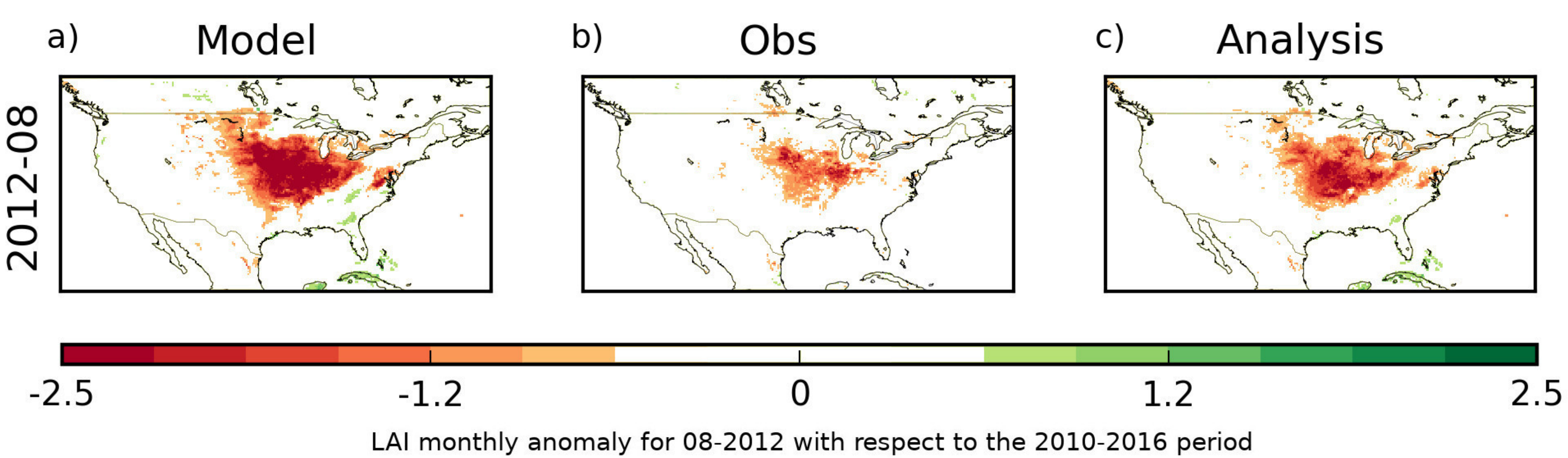
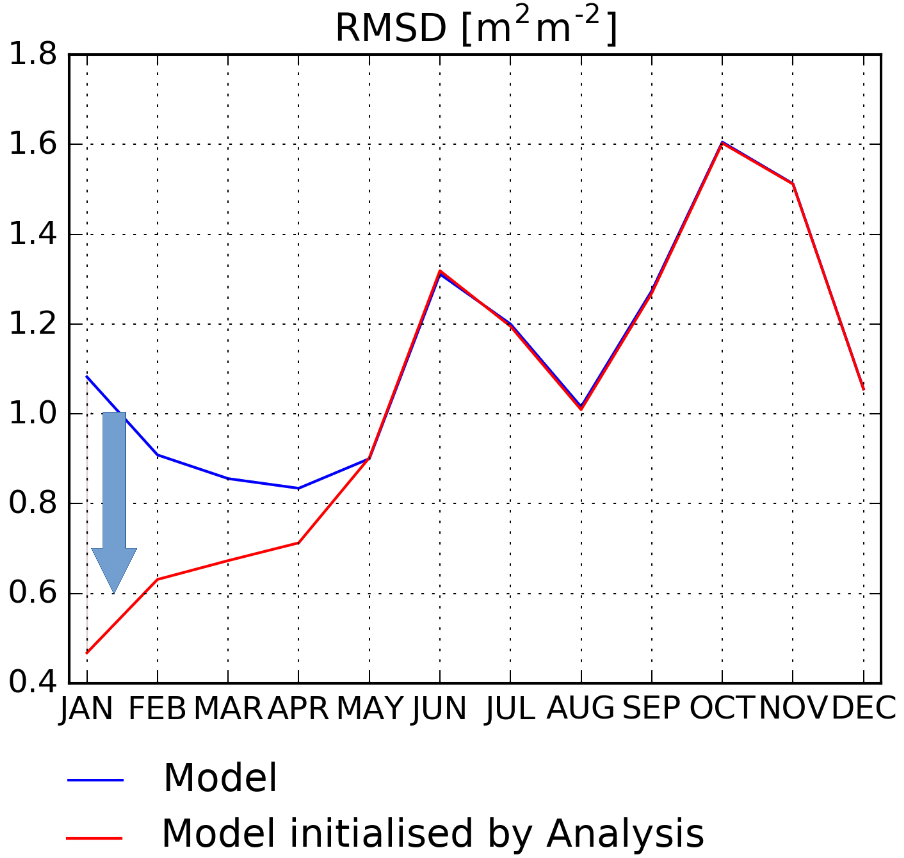


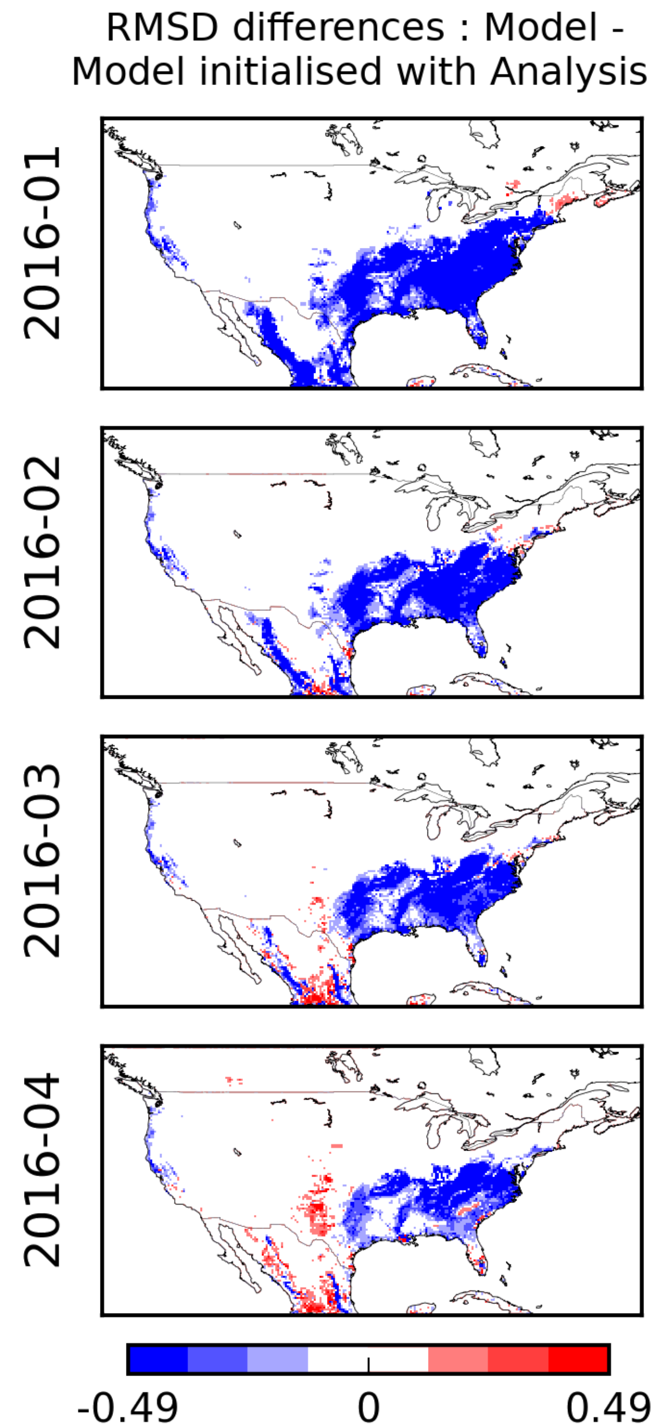


From monitoring to forecasting

- **Could analysis provide better initial conditions than model run ? Does the impact last in time ?**
  - Use analysis initial conditions at 01/01/2016 to start a 12-month Model run
  - Compare with a 'simple' model run
  - Evaluation against LAI observations over (2010-2016)

➔ ***Persistence for several weeks / months on LAI***





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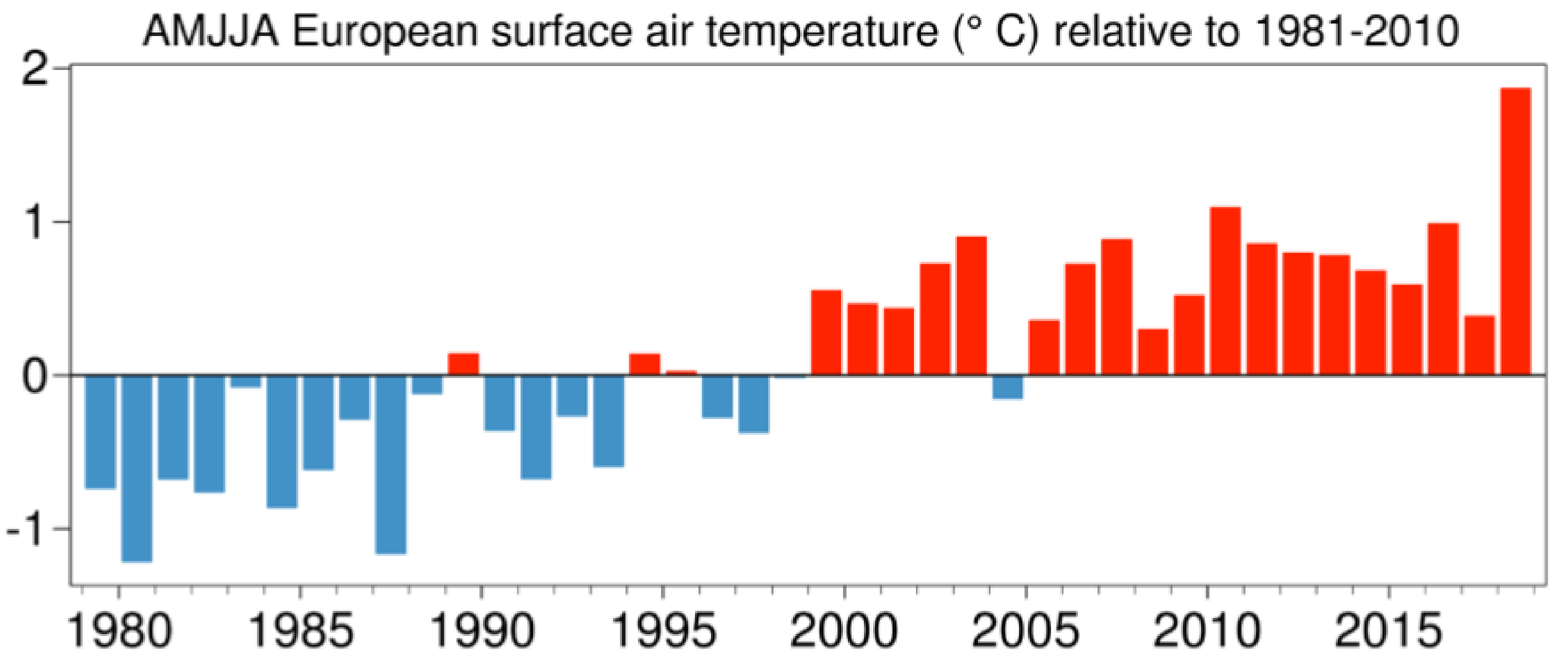
The Summer 2018 heatwave over Europe



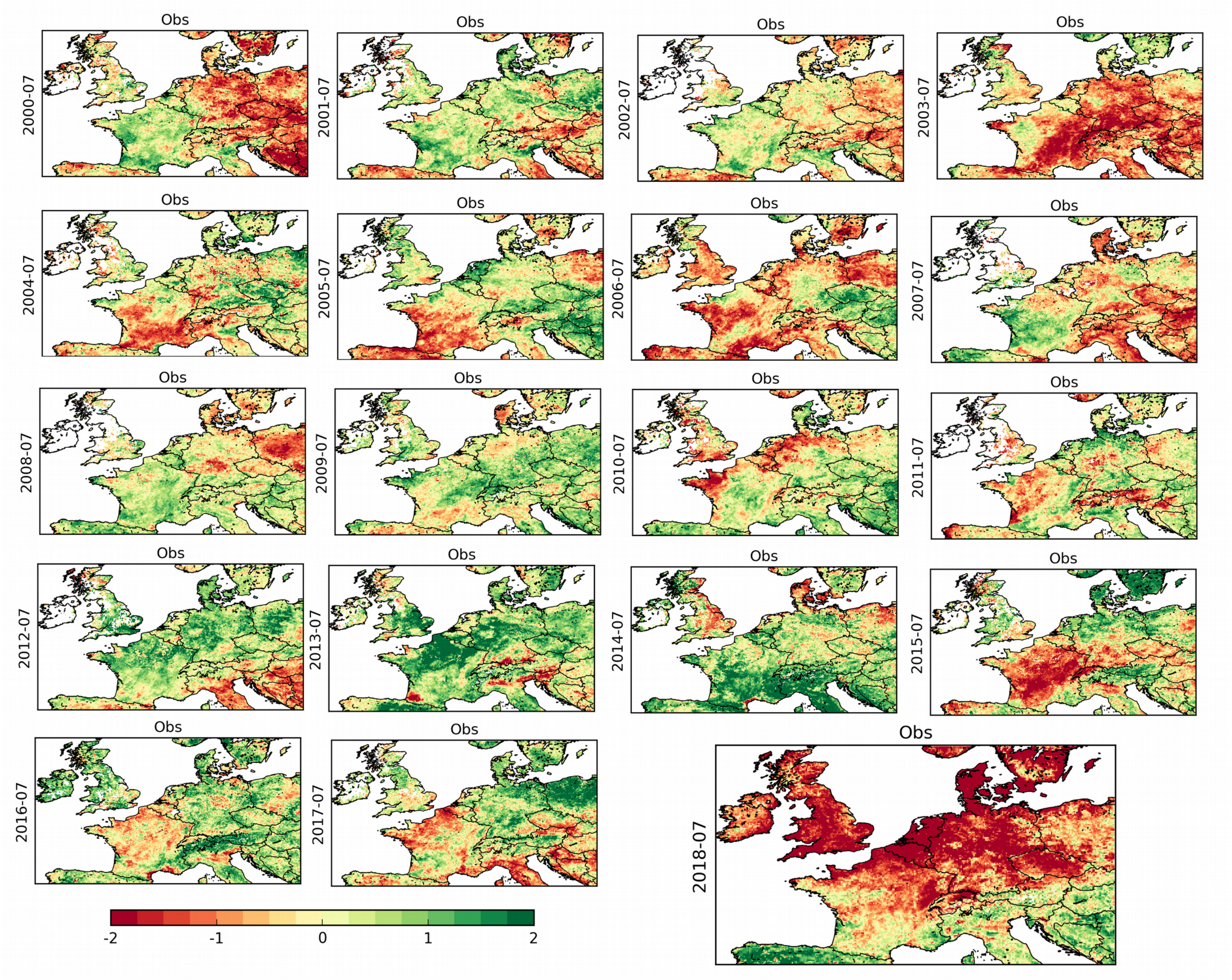
Evolution of near-surface air temperature anomalies. This chart produced by C3S shows that the near-surface air temperature anomaly in Europe in the period of April to August (AMJJA), calculated relative to the 1981–2010 average for those months, was much larger in 2018 than in any previous year since 1979.

From Magnusson et al., 2018, ECMWF newsletter #154

The Summer 2018 heatwave over Europe

The Earth Observations point of view : *CGLS GEOV2*

- Leaf Area Index monthly anomaly (scaled by stdv) over 2000-09/2018



The Summer 2018 heatwave over Europe

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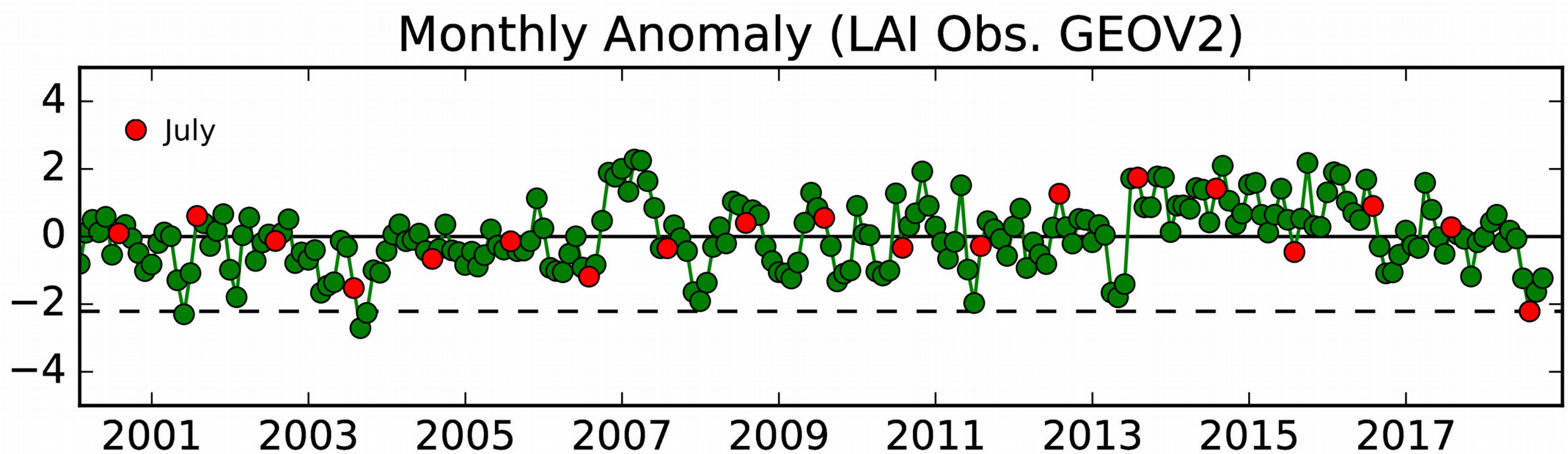


- Dashed line illustrates july 2018 values
- Summer 2018 : 4 months in a row with strong negative anomaly!

% of the domain with monthly anomalies greater than -2 stdv (July)

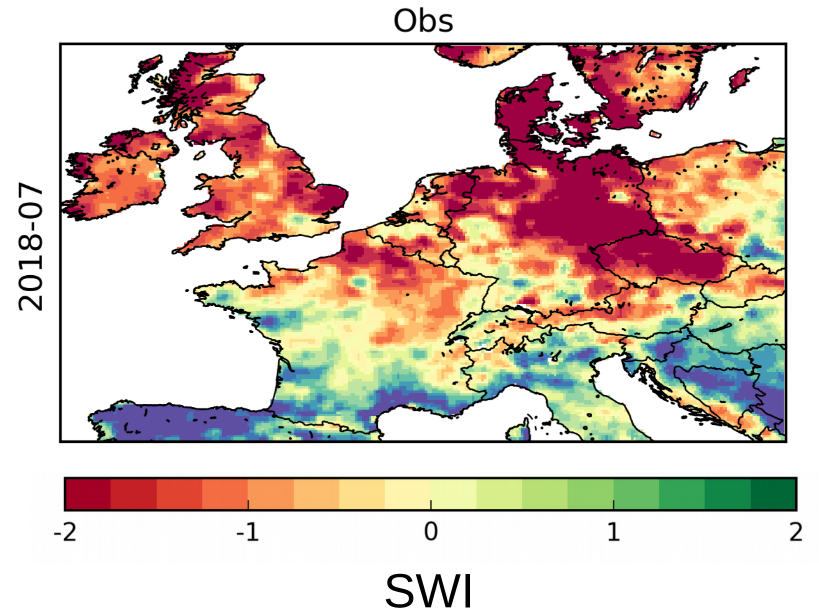
07/2000	07/2001	07/2002	***07/2003***	07/2004	07/2005	07/2006	07/2007	07/2008	07/2009	07/2010	07/2011	07/2012	07/2013	07/2014	***07/2015***	07/2016	07/2017	***07/2018***
5	0.4	0.25	***5***	0.6	0.8	1.84	1.14	0.22	0.03	0.67	0.70	0.28	0.7	0.25	***2***	0.10	0.6	***18.8***

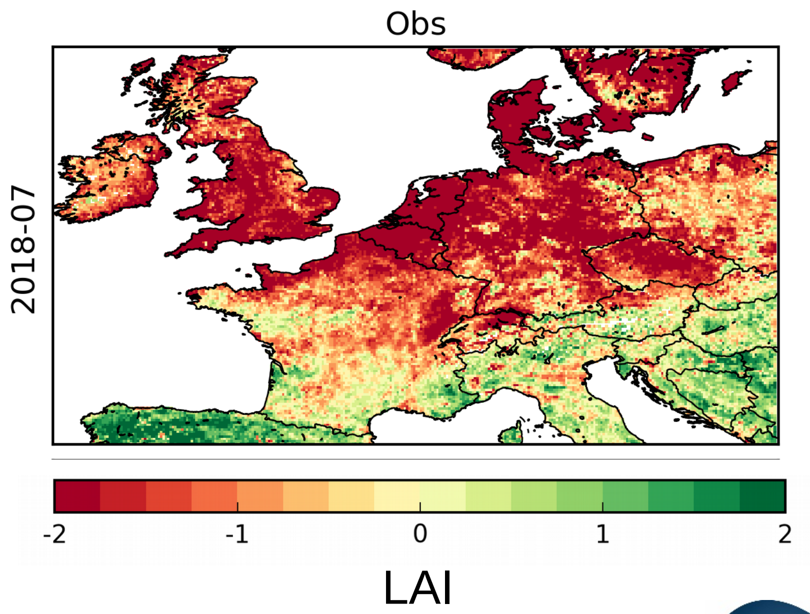
- Larger area affected in Jul. 2018 than Jul. 2003 (in 2003 Aug./Sept. where most affected)

The Summer 2018 heatwave over Europe

The Earth Observations point of view : *CGLS ASCAT SWI [0-100]*

- SWI monthly anomaly (scaled by stdv) over 2008-09/2018
- SWI patterns (top left) in agreement with LAI (bottom right) although time period differs





The Summer 2018 heatwave over Europe

The Earth Observations point of view : *CGLS ASCAT SWI [0-100]*

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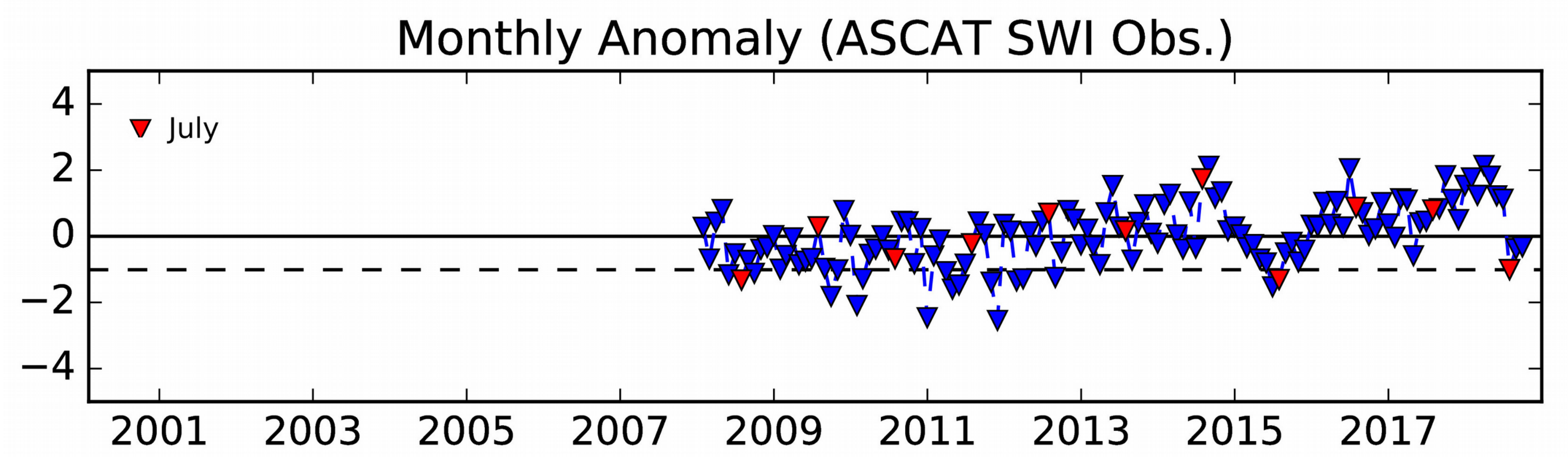

- Dashed line illustrates july 2018 values

% of the domain with monthly anomalies greater than -2 stdv (July)

07/2000	07/2001	07/2002	07/2003	07/2004	07/2005	07/2006	07/2007	07/2008	07/2009	07/2010	07/2011	07/2012	07/2013	07/2014	***07/2015***	07/2016	07/2017	***07/2018***
								2.2	0.04	1.75	0.17	1.5	0.5	0.06	***3.02***	0.01	0.01	***10.0***

LDAS-Monde to monitor (and forecast?) the summer 2018 heatwave impact on vegetation!