EGU General Assembly, 23-28 April 2023

ERA5-Land: More than 7 decades of land surface consistency with timely updates

Climate Change

Motivation

Methodology

Evaluation

Conclusions & data access

- Joaquín Muñoz Sabater -

with contributions from many colleagues

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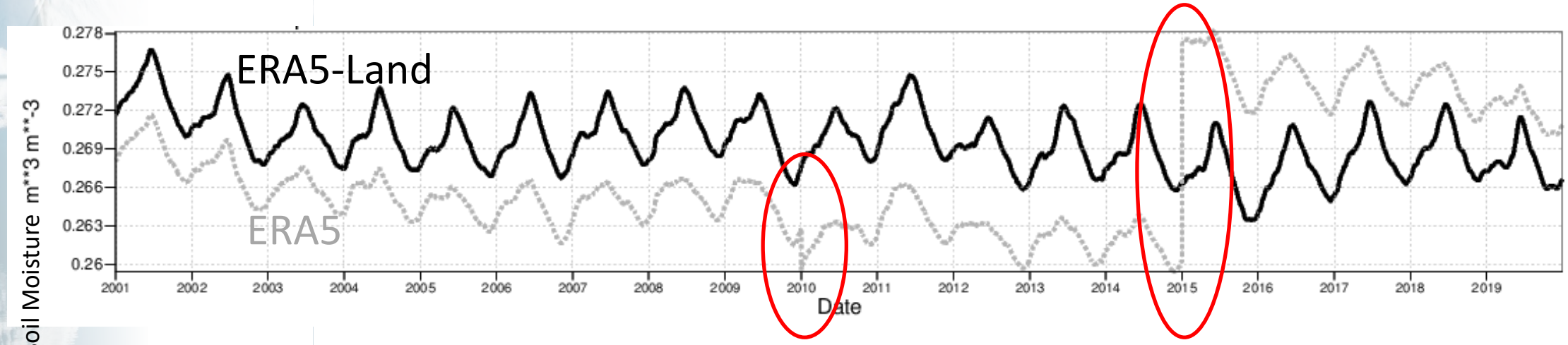
Motivation

- Climate reanalysis does not occur very often (ERA-Interim, ERA5)
- Need to bring rapid land model developments to long, consistent time series in a cost-effective way (ERA-Interim/Land)
  - Provide consistent land initial conditions to weather and climate models.
- Climate reanalysis often produce inconsistencies on land fields
- Provide dedicated datasets to support and encourage land applications



→ First operational land European reanalysis: daily updates (5-days delay wrt real-time), documentation, user support, independent quality control, etc.

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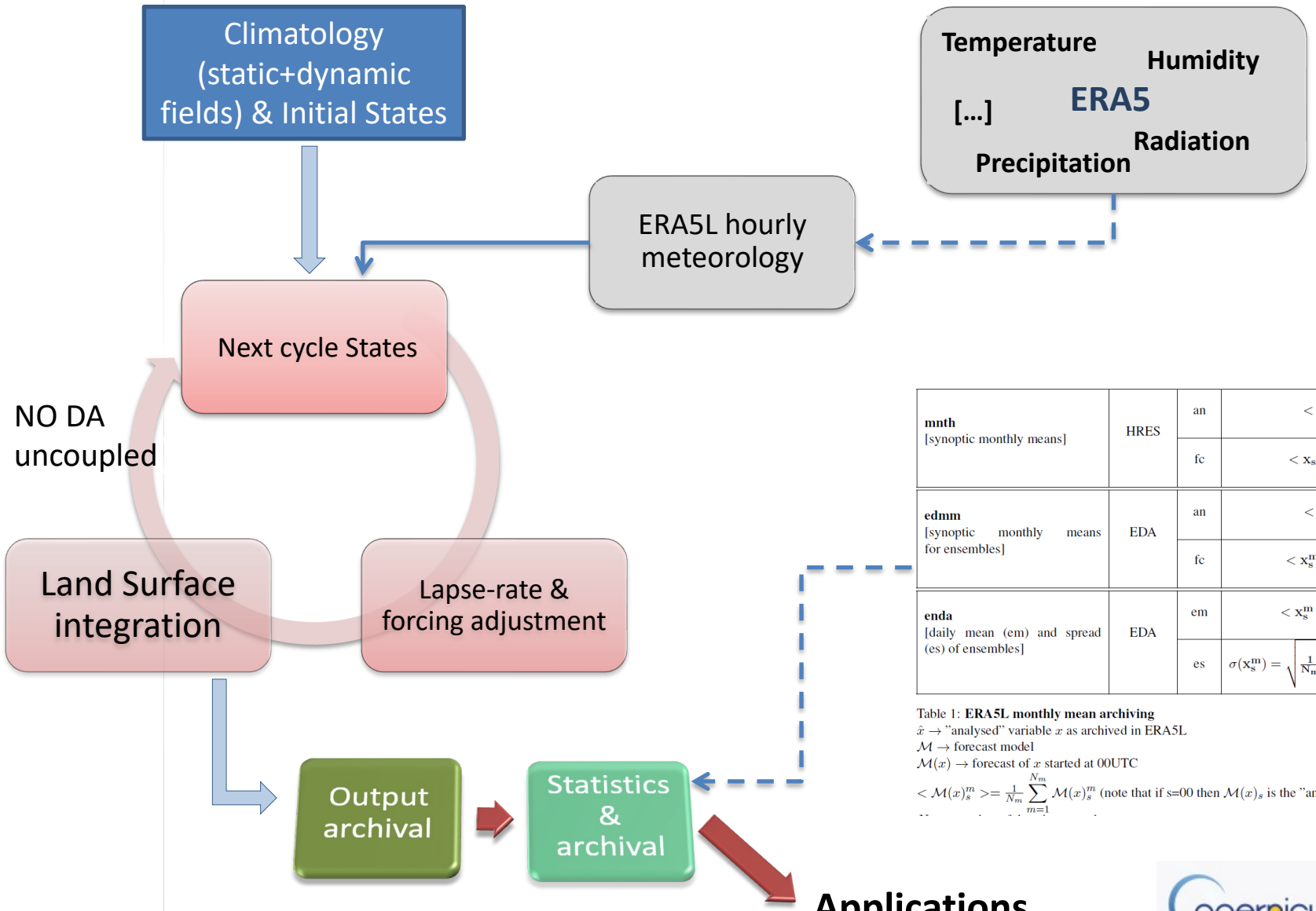
ERA5-Land in a simple diagram



mnth [synoptic monthly means]	HRES	an	$< \hat{x}_h >= \frac{1}{N_d} \sum_{d=1}^{N_d} \hat{x}_{d,h}$
		fc	$< x_s >= \frac{1}{N_d} \sum_{d=1}^{N_d} \mathcal{M}(x)_{d,s}$
edmm [synoptic monthly means for ensembles]	EDA	an	$< \hat{x}_h^m >= \frac{1}{N_d} \sum_{d=1}^{N_d} \hat{x}_d^m$
		fc	$< x_s^m >= \frac{1}{N_d} \sum_{d=1}^{N_d} \mathcal{M}(x)_{d,s}^m$
enda [daily mean (em) and spread (es) of ensembles]	EDA	em	$< x_s^m >= \frac{1}{N_m} \sum_{m=1}^{N_m} < x_s >^m$
		es	$\sigma(x_s^m) = \sqrt{\frac{1}{N_m} \sum_{m=1}^{N_m} [\mathcal{M}(x)_s^m - < \mathcal{M}(x)_s^m >]^2}$

Table 1: **ERA5L monthly mean archiving**
$\hat{x} \rightarrow$ "analysed" variable x as archived in ERA5L
$\mathcal{M} \rightarrow$ forecast model
$\mathcal{M}(x) \rightarrow$ forecast of x started at 00UTC
$< \mathcal{M}(x)_s^m >= \frac{1}{N_m} \sum_{m=1}^{N_m} \mathcal{M}(x)_s^m$ (note that if s=00 then $\mathcal{M}(x)_s$ is the "analysis")

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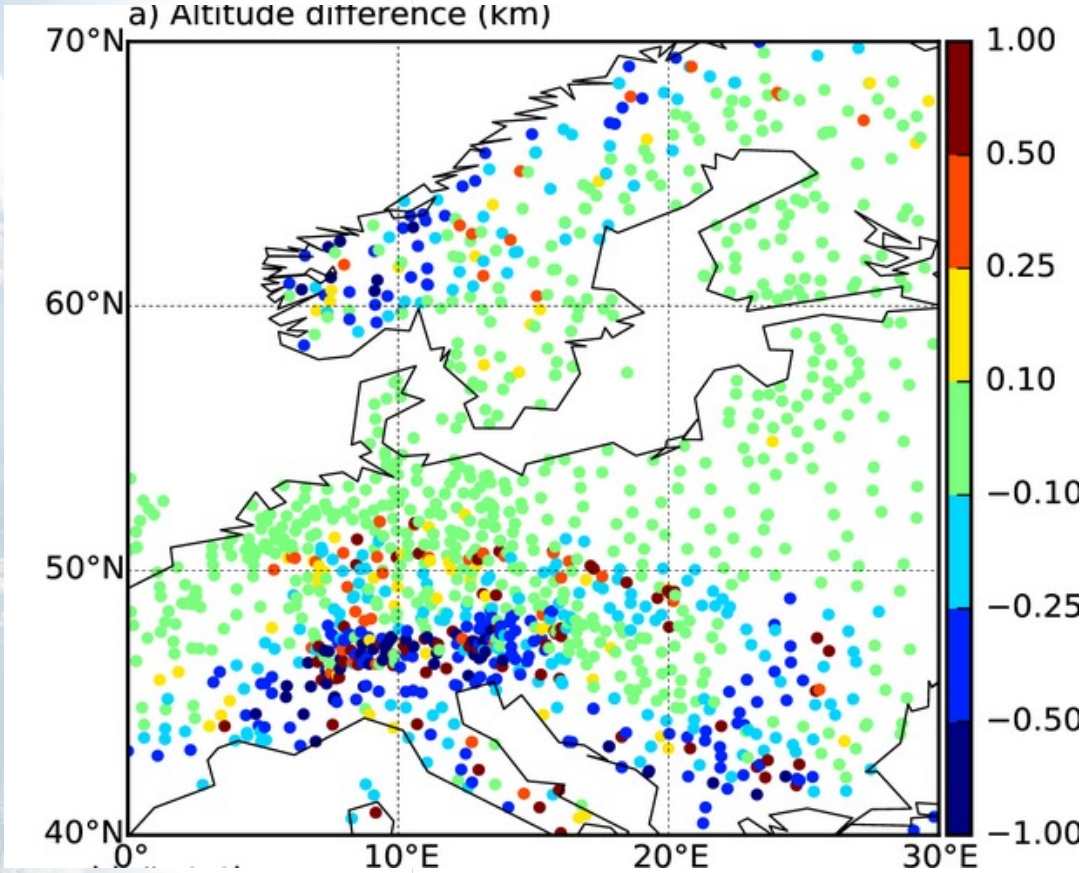
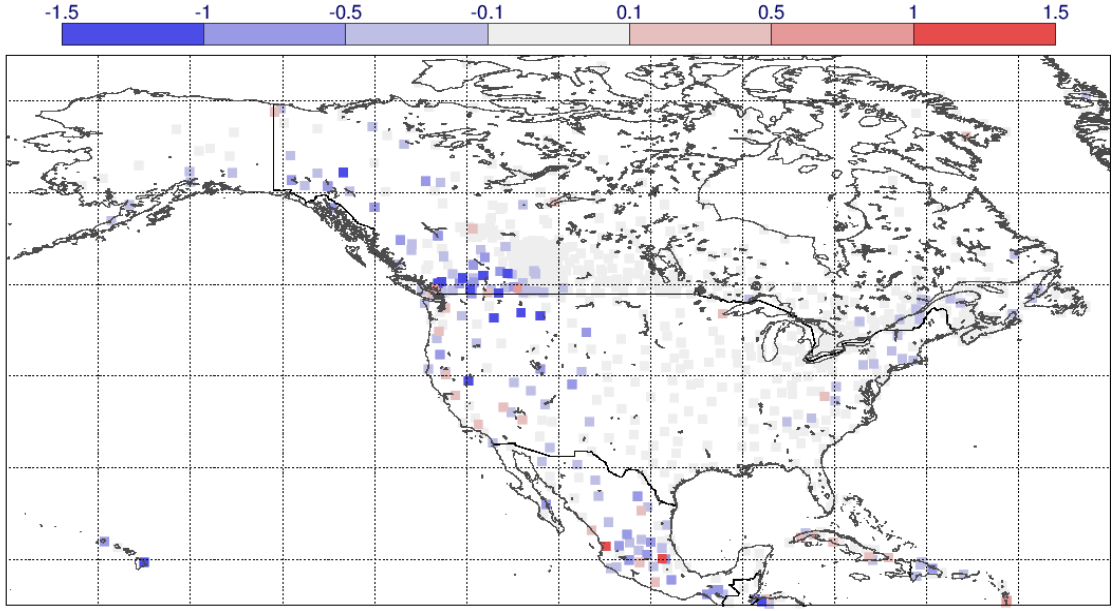
Lapse-rate adjustment

- **Correct for differences in orography due to different model resolutions.**



Δh (km)

T2m RMSE(corrected)- RMSE(no corrected) (K)



E. Dutra, J. Muñoz-Sabater, S. Boussetta, T. Komori, S. Hirahara and G. Balsamo, 2020: "Land surface downscaling of ERA5 and the role of the lapse rate correction: An application to ERA5." Earth and Space Science, https://doi.org/10.1029/2019EA000984.

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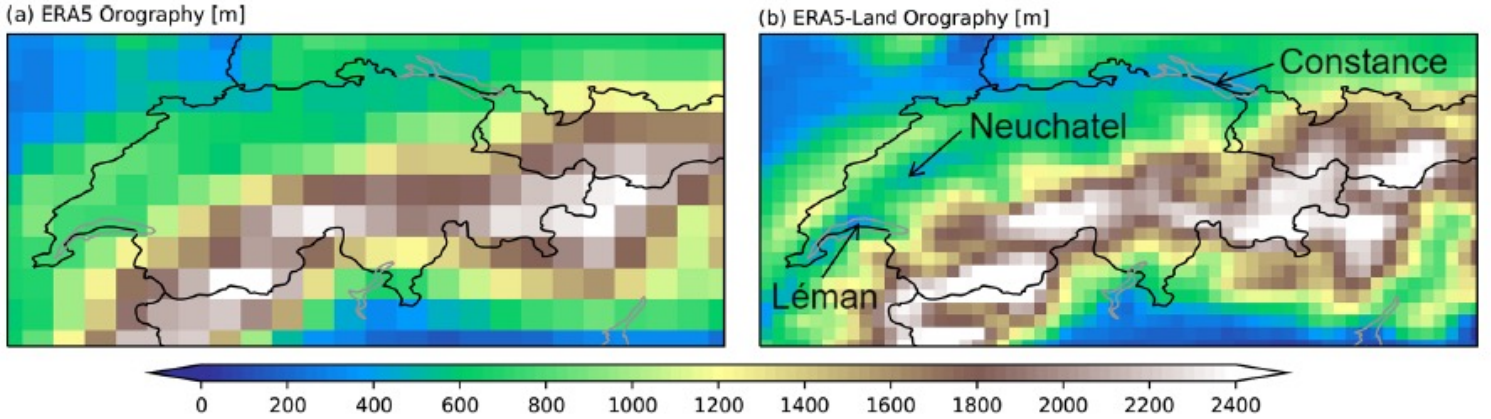
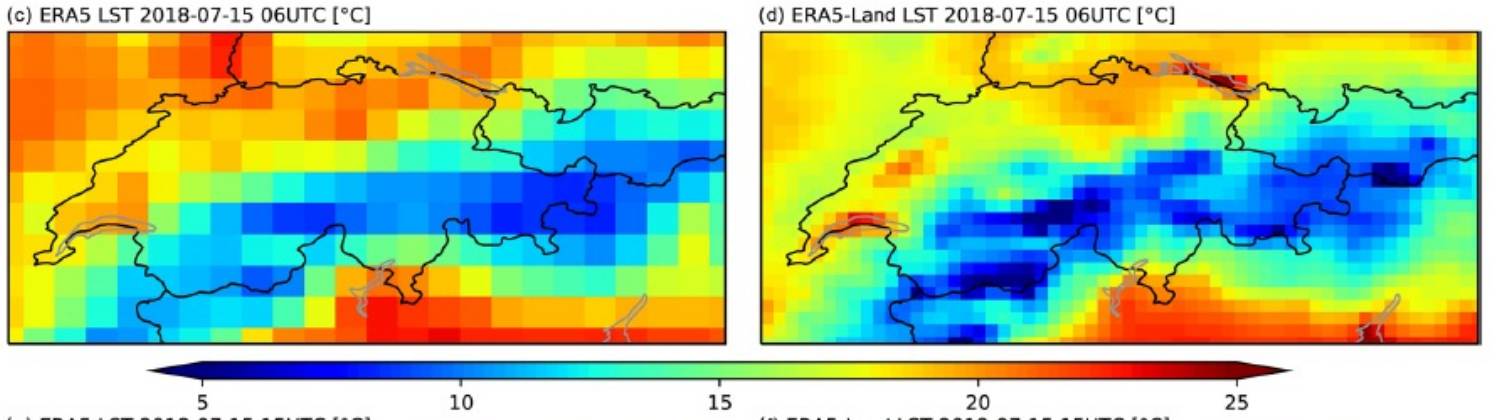
Add value of higher resolution and lapse-rate correction

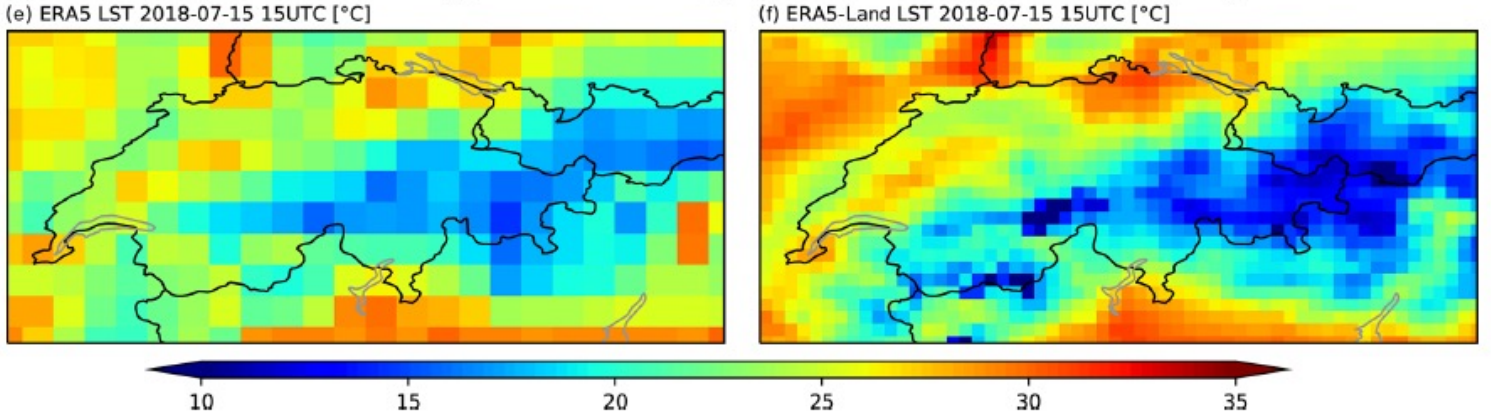
orography



Soil Temperature (15 July 2018 06UTC)



Soil Temperature (15 July 2018 15UTC)



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ERA5-Land specs compared to…

	ERA-Int	Era-Int/Land	ERA5	ERA5-Land
Period covered	Jan 1979 – Jul 2019	Jan 1979 – Dec 2010	Jan 1950 - NRT	Jan 1950 - NRT
Spatial resolution	~79km / 60 levels	79 km	~32 km / 137 levels	~9 km
Model version	IFS (+TESSEL)	HTESSEL cy36r4	IFS (+HTESSEL)	HTESSEL cy45r1
LDAS	cy31r1	NO	cy41r2	NO
Uncertainty estimate	-	-	Based on a 10-member 4D-Var ensemble at 62 km	Based a 10-member 4D-Var ensemble at 62 km
Output frequency	6-hourly Analysis fields	6-hourly Analysis fields	Hourly (three-hourly for the ensemble)	Hourly (three-hourly for the ensemble)

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ERA-Int/Land vs ERA5-Land inventory of fields

Soil Temperature (4 layers)
Skin Temperature
Volumetric soil moisture (4 layers)
Snow density
Snow Water Equivalent
Snow Fall
Snow Albedo
Snow Melt
Temperature snow layer
Forecast Albedo
Surface and sub-surface runoff
Surface Latent Heat flux
Surface Sensible Heat flux
Surface net solar radiation
Surface net thermal radiation
Total Precipitation
Evaporation

2m temperature & dew point
Accumulated CO2 (Reco, GPP, NEE)
Lakes (Bottom Temperature, Ice depth, ice Temperature, mix-layer depth, mix-layer temperature, shape factor, total layer temperature)
LAI (low/high vegetation)
Runoff
Skin reservoir content
U,V surface wind components
Surface Pressure
Snow Depth
Snow cover fraction
Snow evaporation
Canopy evaporation
Soil evaporation
Vegetation transpiration
Surface solar radiation downwards
Surface Thermal radiation downw

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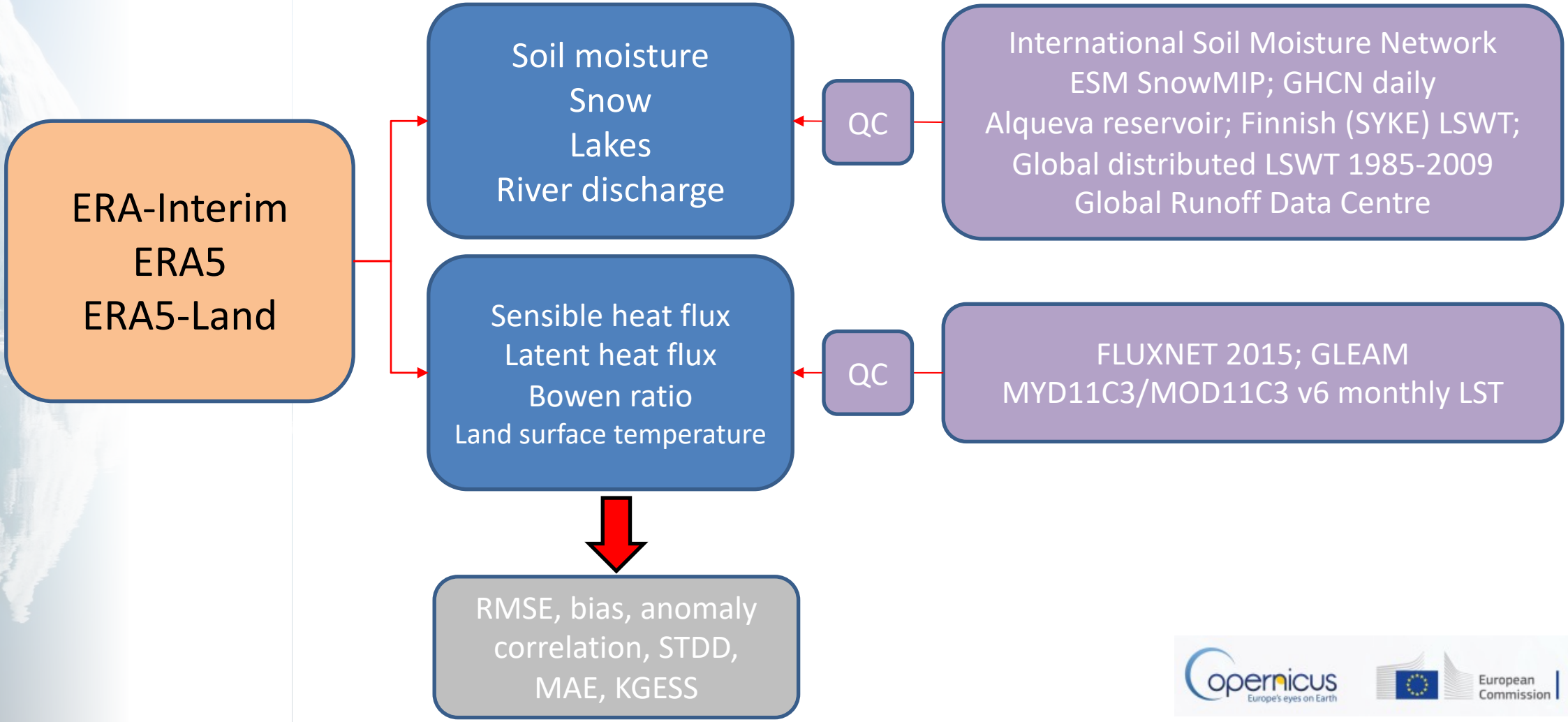
Evaluation

The quality of ERA5-Land was evaluated comparing reanalysis estimates with in-situ observations and remote sensing products.



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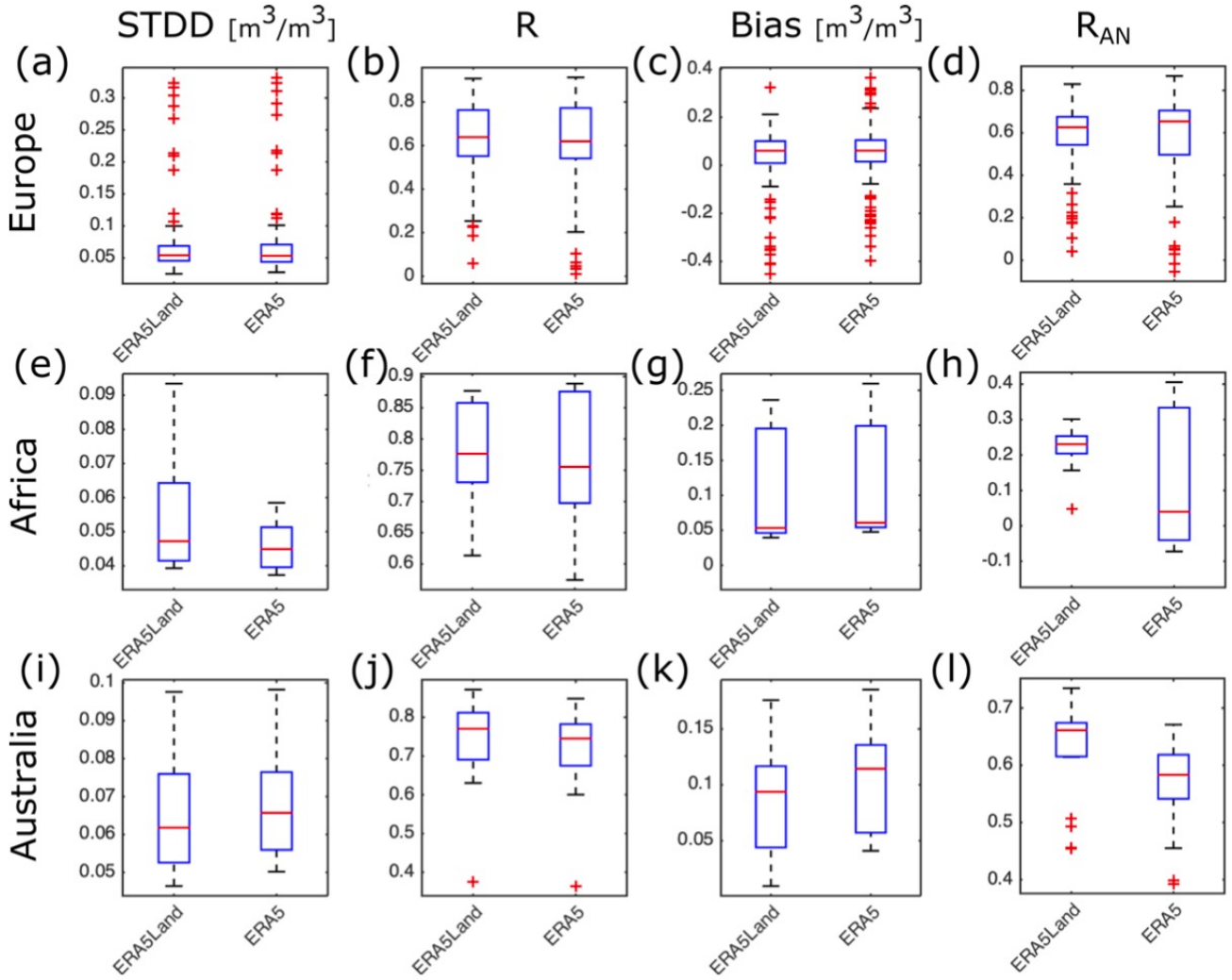
Evaluation – Soil Moisture



Box plots showing the evaluation of ERA5-Land and ERA5 top layer soil moisture against in situ measurements at 5 cm for sites in Europe (a–d), Africa (e–h), and Australia (i–l). Panels (a), (e), and (i) show the standard deviation of the difference (STDD), (b), (f), and (j) the Pearson correlation coefficient (R), (c), (g), and (k) the bias, and (d), (h), and (l) the Pearson correlation of the anomaly time series (RAN). On each box, the central mark indicates the median, and the bottom and top edges of the box indicate the 25th (q25) and 75th (q75) percentiles, respectively. The whiskers extend to the most extreme data points not considered outliers.

Evaluation – Snow depth

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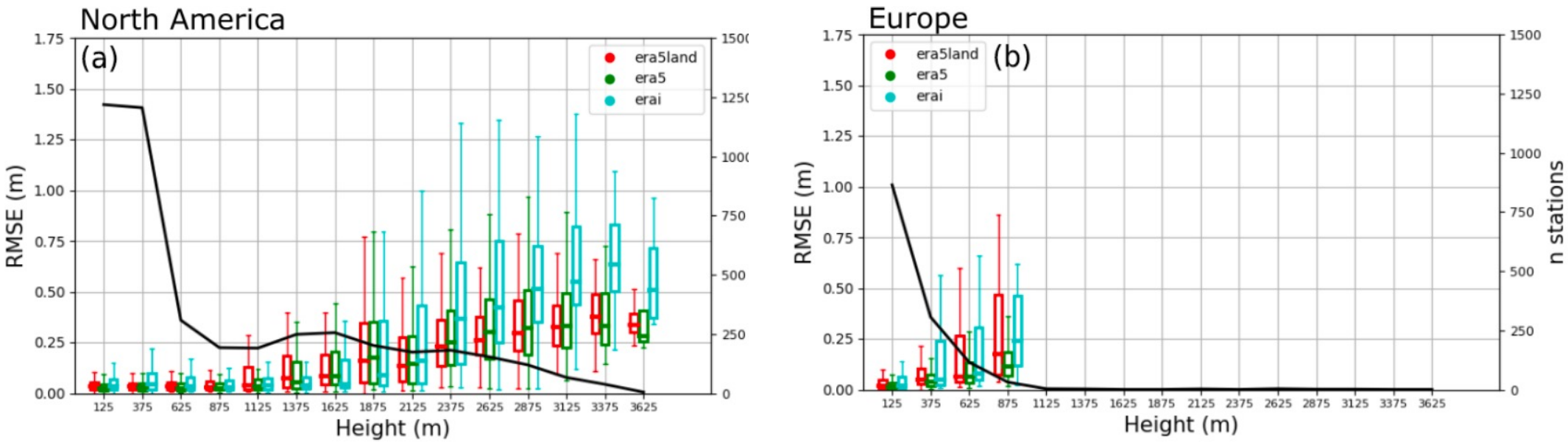

Box plot of the snow depth RMSE distribution as func- tion of the site altitude, for North America (30–80◦ N, 60–160◦ W, a) and Europe (25–80◦ N, 10◦ W–40◦ E, b), for ERA5-Land (red), ERA5 (green), and ERA-Interim (cyan). Boxes extend between the lower (25 %) and upper quartiles (75 %), and the horizontal lines within each box represent the median value of the distribution. The black line represents the number of stations grouped at each bin.

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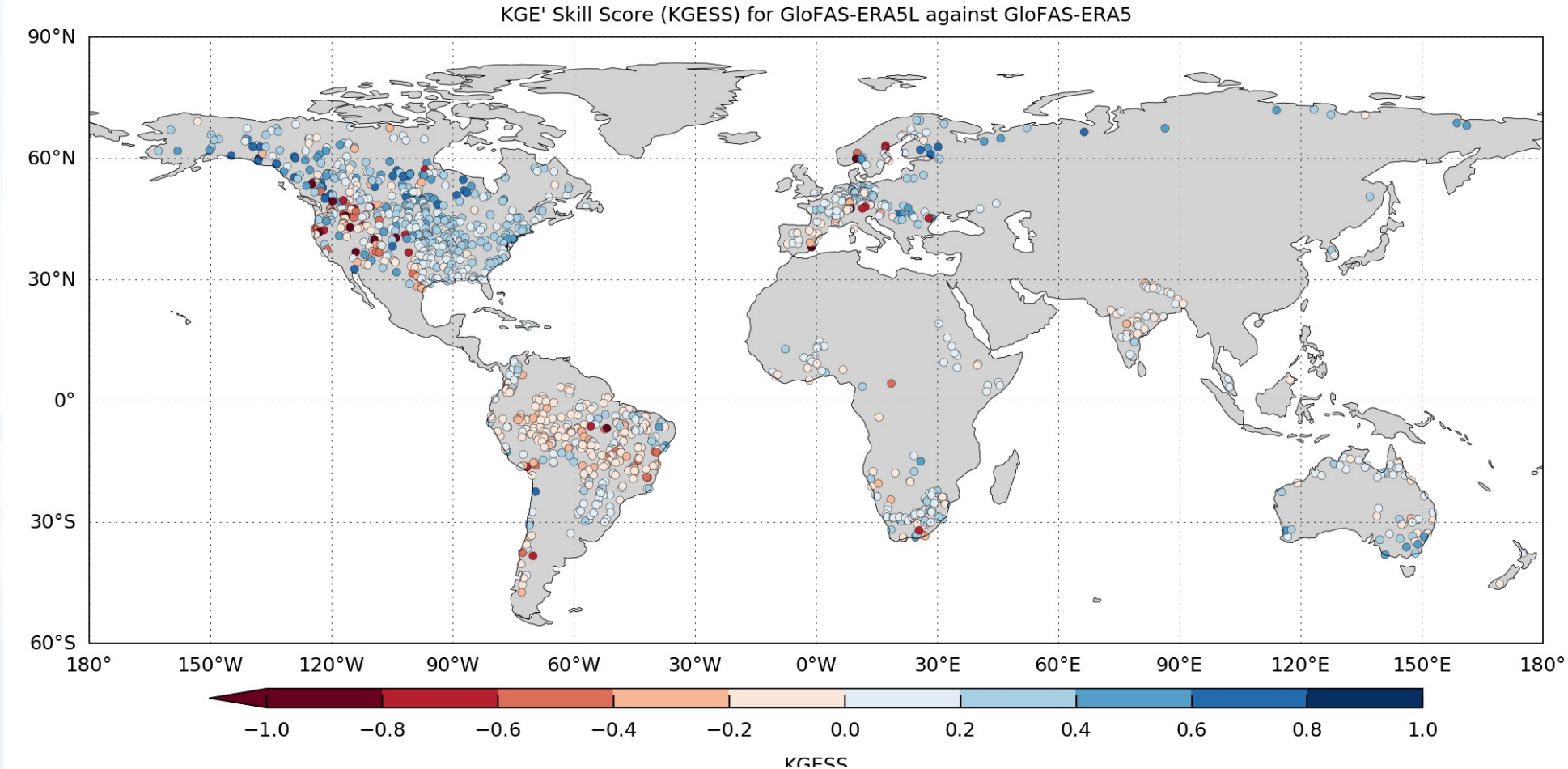
Evaluation – River discharge

Runoff from ERA5/ERA5-Land + channel routing model LISFLOOD → **GloFAS-ERA5/ERA5-Land**
More than 2000 stations from the Global Runoff Data Centre



Modified Kling-Gupta Efficiency Skill Score (KGESS) for GloFAS-ERA5L river discharge reanalysis against the GloFAS-ERA5 benchmark across 1285 observation stations. Optimum value of KGESS is 1. Blue (red) dots show catchments with positive (negative) skill.

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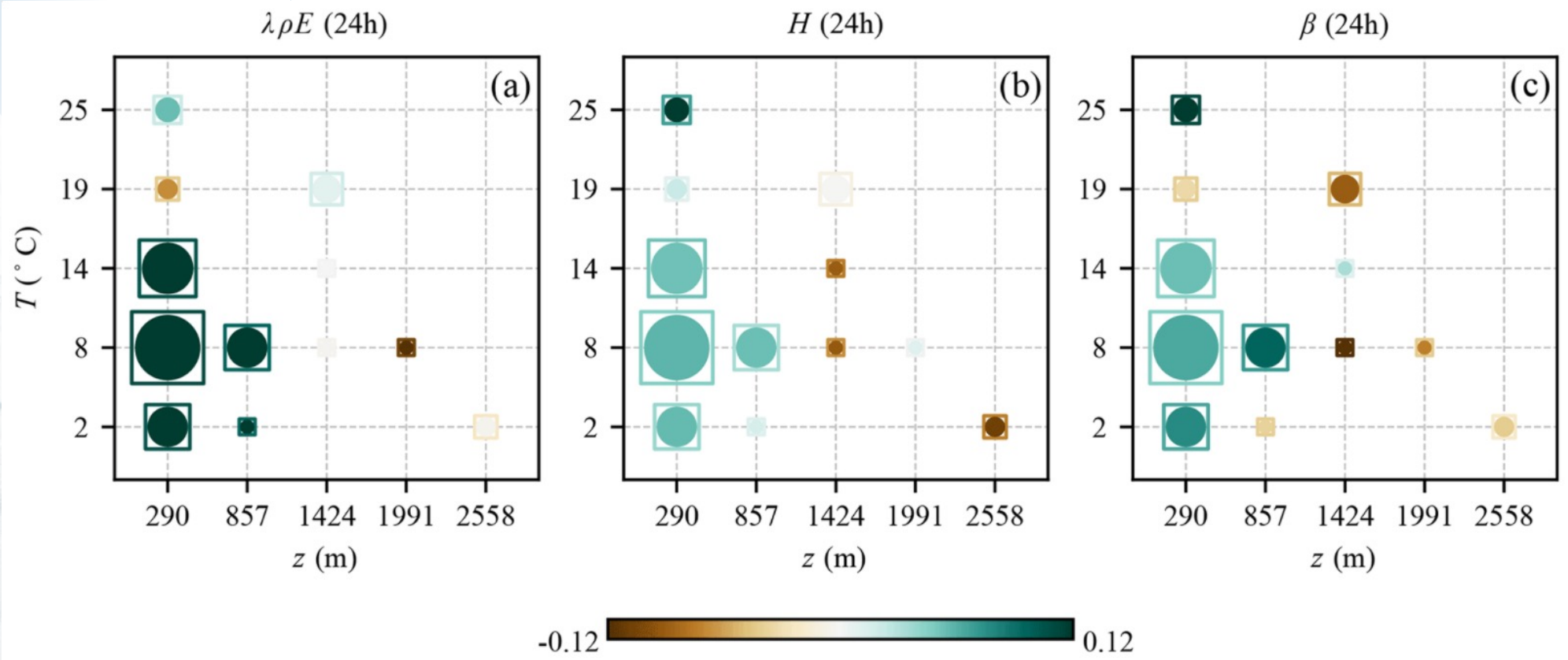
Evaluation – Heat fluxes

Heat fluxes from ERA5-Land vs GLEAM+ERA5-Land.



Standardized anomaly correlation difference (circles) and standardized mean absolute differences (squares) between ERA5-Land and GLEAM-ERA5-Land latent heat flux (a), sensible heat flux (b), and Bowen ratio (c), grouped as a function of stations' temperature and altitude. The size of circles and squares is proportional to the number of eddy-covariance towers. Green values denote better matching of ERA5-Land with in situ data.

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Conclusions

- ERA5-Land provides a view of the land surface from 1950 to present (5-days delay w.r.t real time), i.e., more than 7 decades of land surface evolution;
  - Consistently,
  - Globally,
  - Hourly,
  - 9 km horizontal resolution,
  - Reduced computational cost
  - Operational services (update documentation, user support, quality assurance, etc.)
- Horizontal resolution matters
- Clear signs of improvements in all components of the hydrological cycle compared to previous reanalysis
- Evaluation of the energy cycle comparable to ERA5, but the devil is in the detail…

Data availability & way forward

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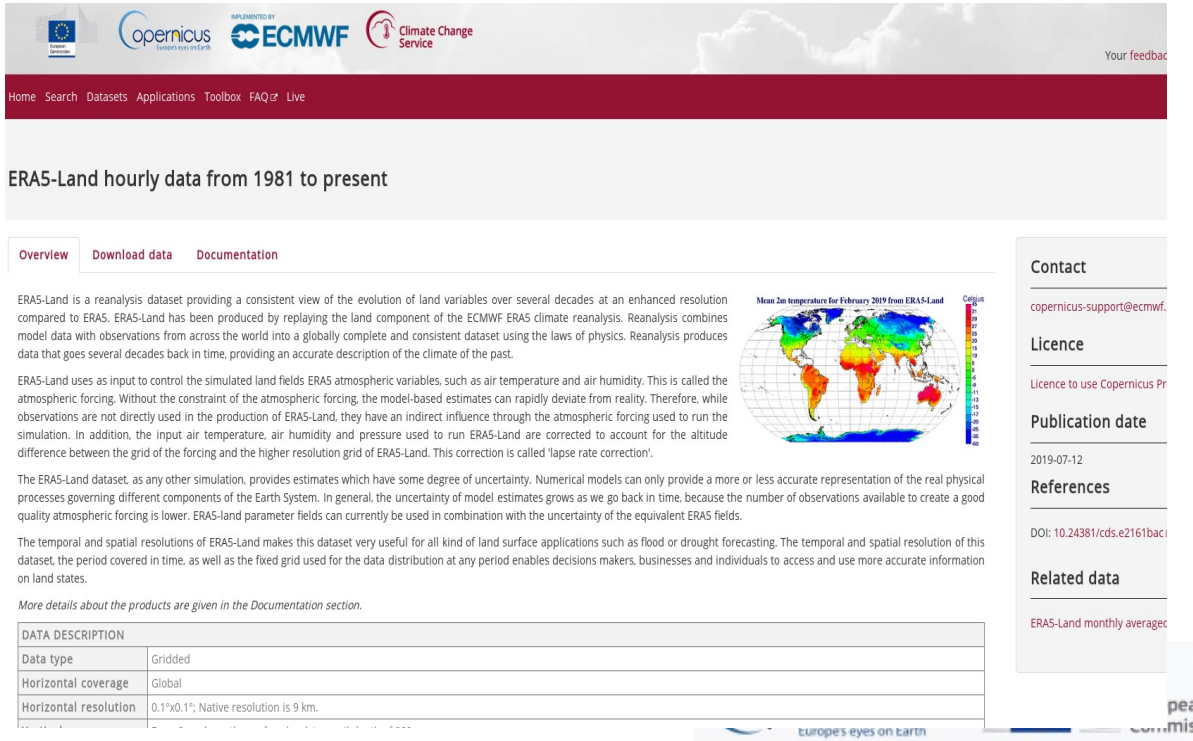
- Data is open and available in the Climate Data Store (doi: 10.24381/cds.e2161bac)
  - Hourly and monthly averaged fields
  - Interpolated to 0.1° x 0.1° (grid and netCDF formats)
  - The CDS provides a tool to build daily aggregates

  - From 1950 to present (validated data with 2-3 months delay w.r.t real time)
  - ERA5-Land-T: preliminary (non-validated) data with 5-days delay w.r.t real time

- Improvements under research for potential future versions:
  - Dynamic land use maps
  - LAI measured from satellites
  - Bias corrected precipitation
  - Offline data assimilation
  - …



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https://doi.org/10.5194/essd-13-4349-2021

Open Access Earth System Science Data

ERA5-Land: a state-of-the-art global reanalysis dataset for land applications

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Abstract. Framed within the Copernicus Climate Change Service (C3S) of the European Commission, the European Centre for Medium-Range Weather Forecasts (ECMWF) is producing an enhanced global dataset for the land component of the fifth generation of European ReAnalysis (ERA5), hereafter referred to as ERA5-Land. Once completed, the period covered will span from 1950 to the present, with continuous updates to support land monitoring applications. ERA5-Land describes the evolution of the water and energy cycles over land in a consistent manner over the production period, which, among others, could be used to analyse trends and anomalies. This is achieved through global high-resolution numerical integrations of the ECMWF land surface model driven by the downscaled meteorological forcing from the ERA5 climate reanalysis, including an elevation correction for the thermodynamic near-surface state. ERA5-Land shares with ERA5 most of the parameterizations that guarantees the use of the state-of-the-art land surface modelling applied to numerical weather prediction (NWP) models. A main advantage of ERA5-Land compared to ERA5 and the older ERA-Interim is the horizontal resolution, which is enhanced globally to 9 km compared to 31 km (ERA5) or 80 km (ERA-Interim), whereas the temporal resolution is hourly as in ERA5. Evaluation against independent in situ observations and global model or satellite-based reference datasets shows the added value of ERA5-Land in the description of the hydrological cycle, in particular with enhanced soil moisture and lake description, and an overall better agreement of river discharge estimations with available observations. However, ERA5-Land snow depth fields present a mixed performance when compared to those of ERA5, depending on geographical location and altitude. The description of the energy cycle shows comparable results with ERA5. Nevertheless, ERA5-Land reduces the global averaged root mean square error of the skin temperature, taking as reference MODIS data, mainly due to the contribution of coastal points where spatial resolution is important. Since January 2020, the ERA5-Land period available has extended from January 1981 to the near present, with a 2- to 3-month delay with respect to real time. The segment prior to 1981 is in production, aiming for a release of the whole dataset in summer/autumn 2021. The high spatial and temporal resolution of ERA5-Land, its extended period, and the consistency of the fields produced makes it a valuable dataset to support hydrological studies, to initialize NWP and climate models, and to support diverse applications dealing with water resource, land, and environmental management.

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Thank you!

@j_munoz_sabater

C3S: https://climate.copernicus.eu/

Climate Data Store: https://cds.climate.copernicus.eu/

ERA5-Land: https://www.ecmwf.int/en/era5-land

Muñoz-Sabater et al., 2021
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