# The ERA5-Land global land surface reanalysis

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*Joaquín Muñoz Sabater*

*with contributions from many colleagues*

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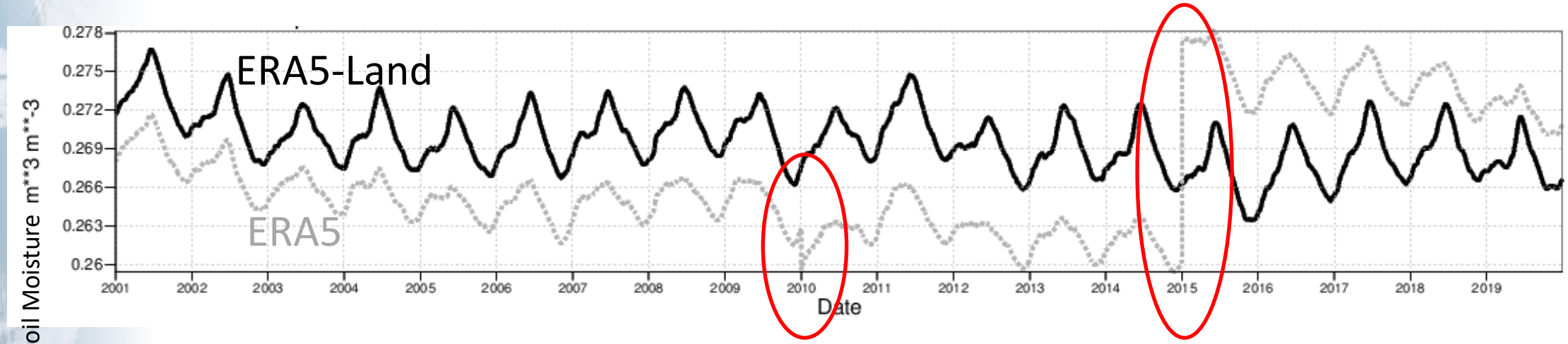
# Motivation

- 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: timely updates (2-3 months delay wrt real-time), documentation, user support, independent EQC, etc.

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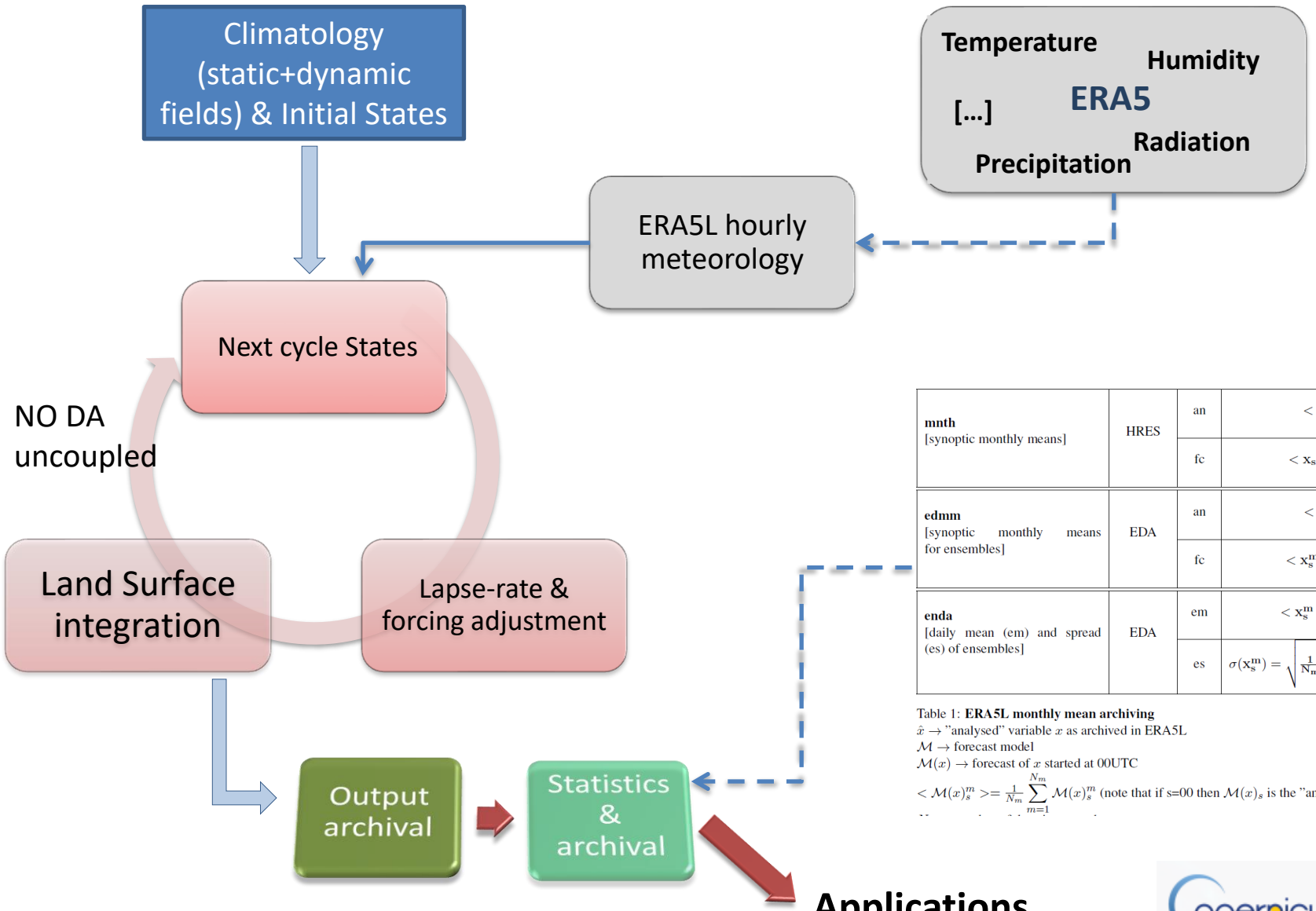
# ERA5-Land in a simple diagram




| | | | |
|---|---|---|---|
| **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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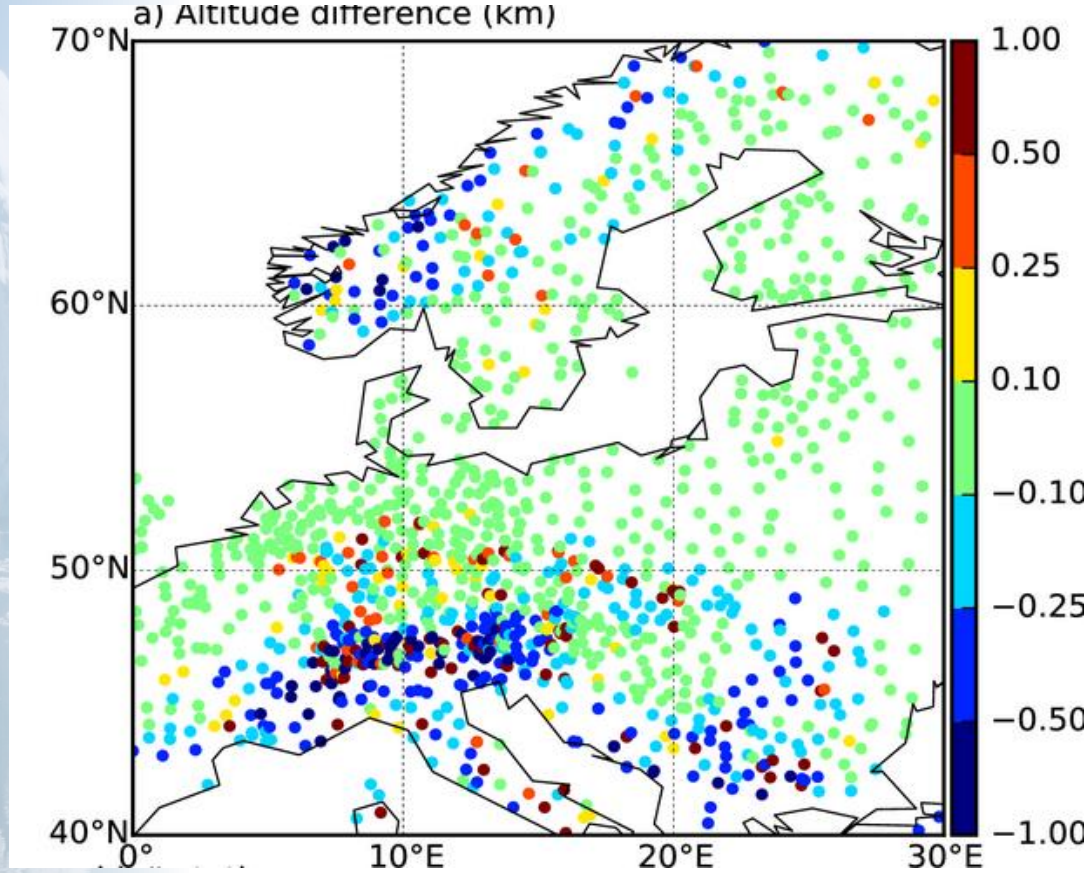
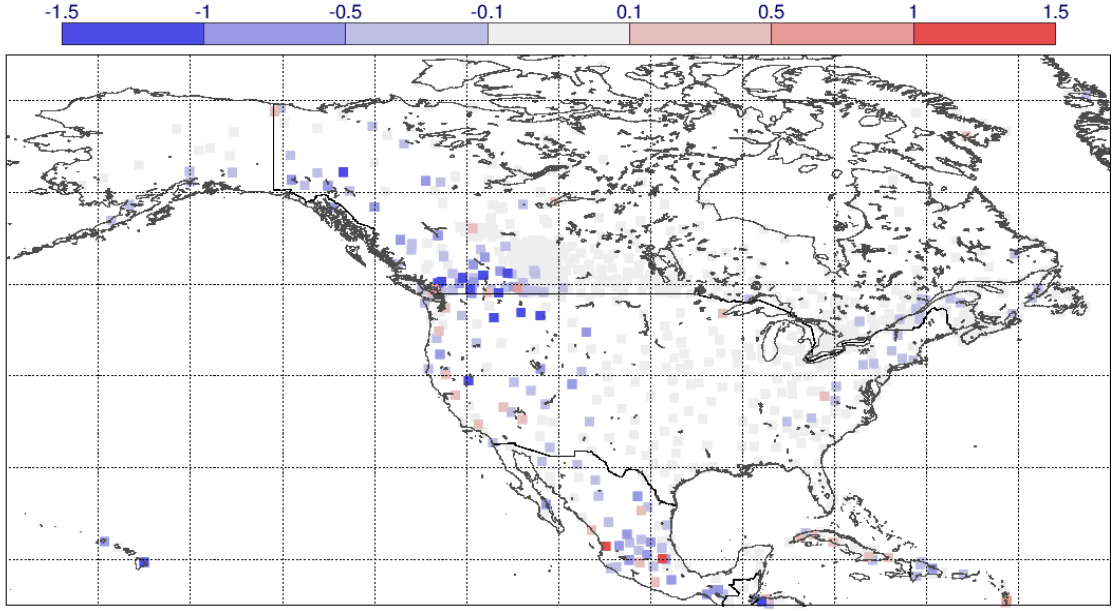
# Lapse-rate adjustment

- **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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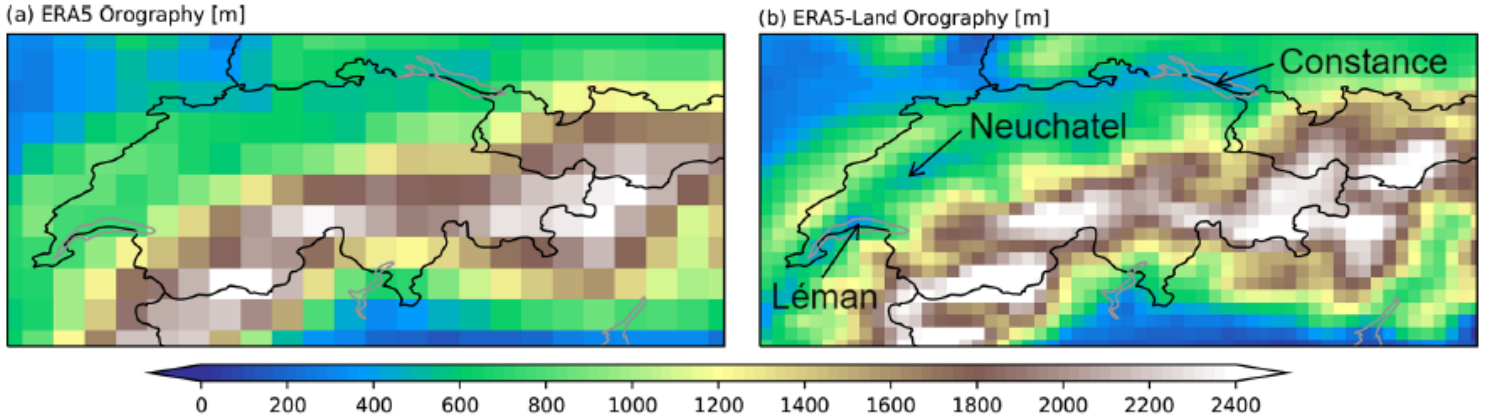
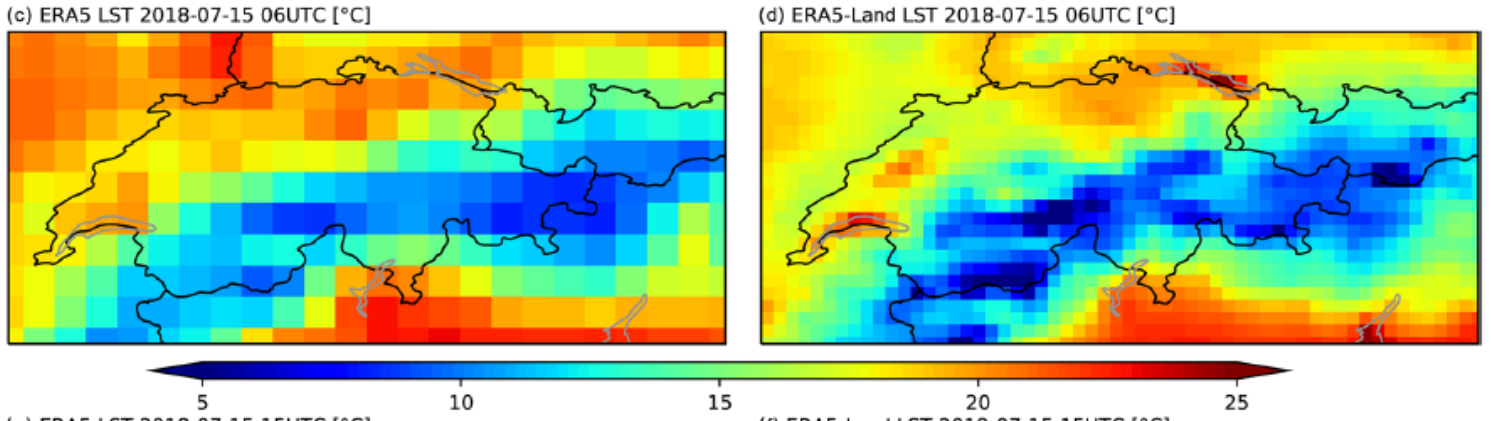
# Add value of higher resolution and lapse-rate correction

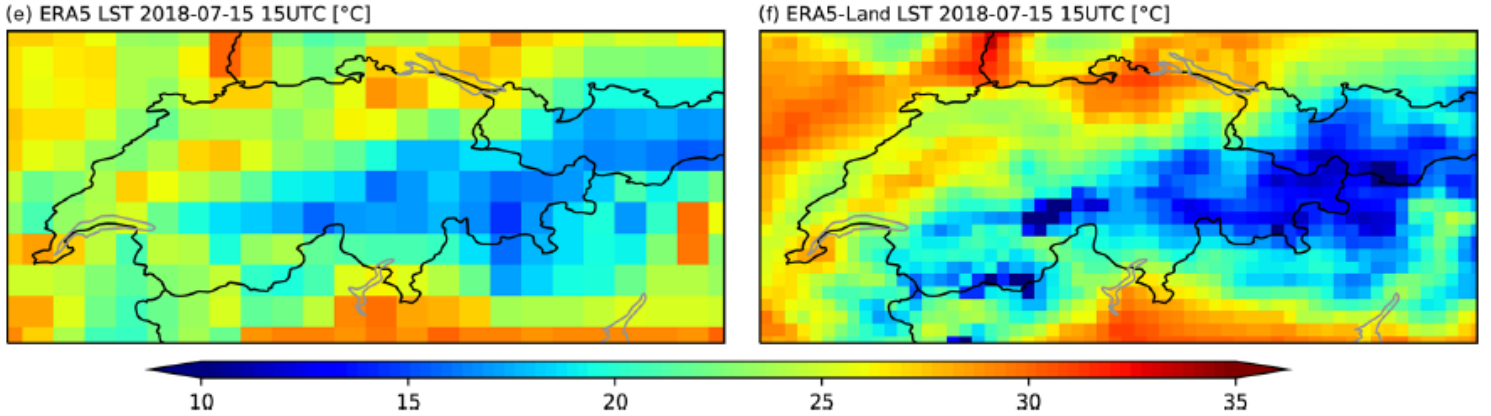
**orography**




**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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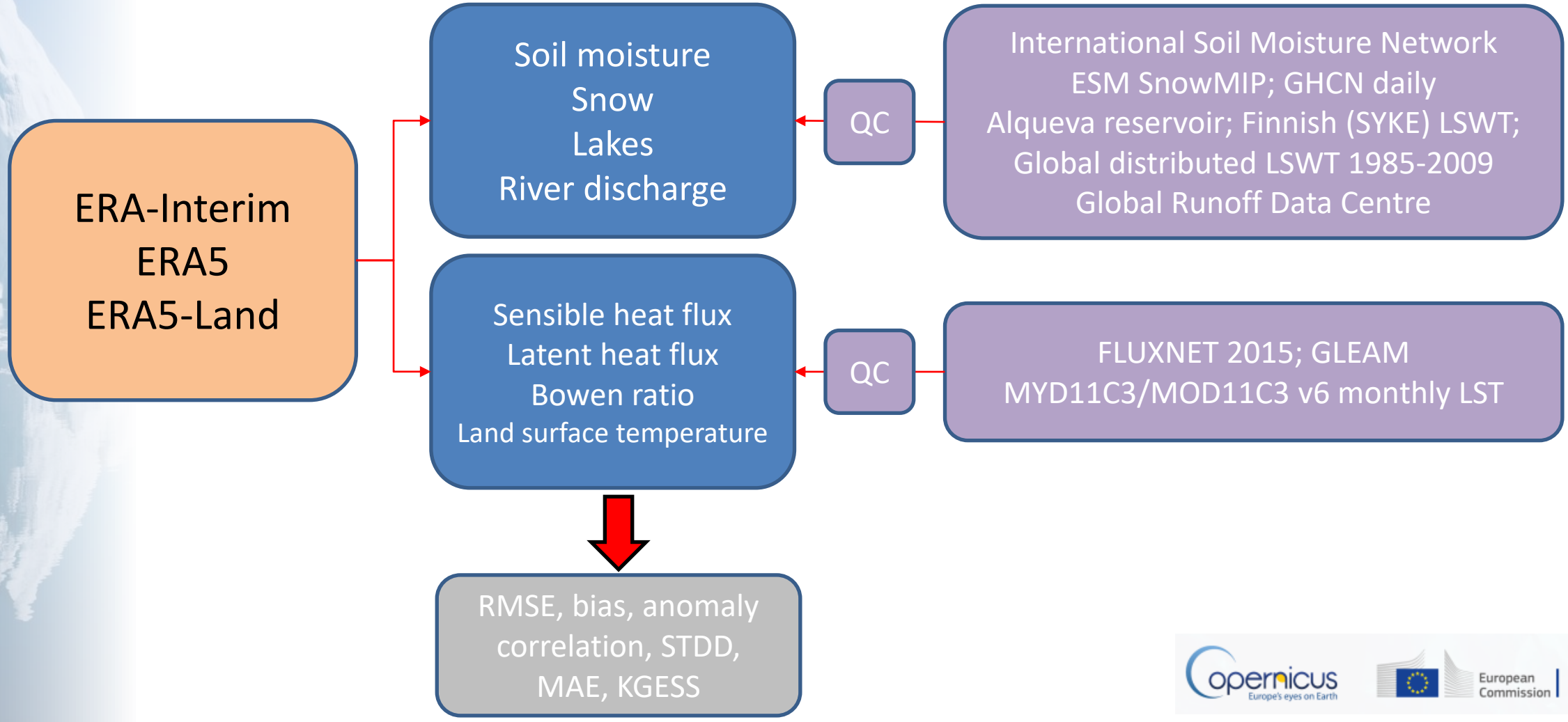
# Evaluation

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

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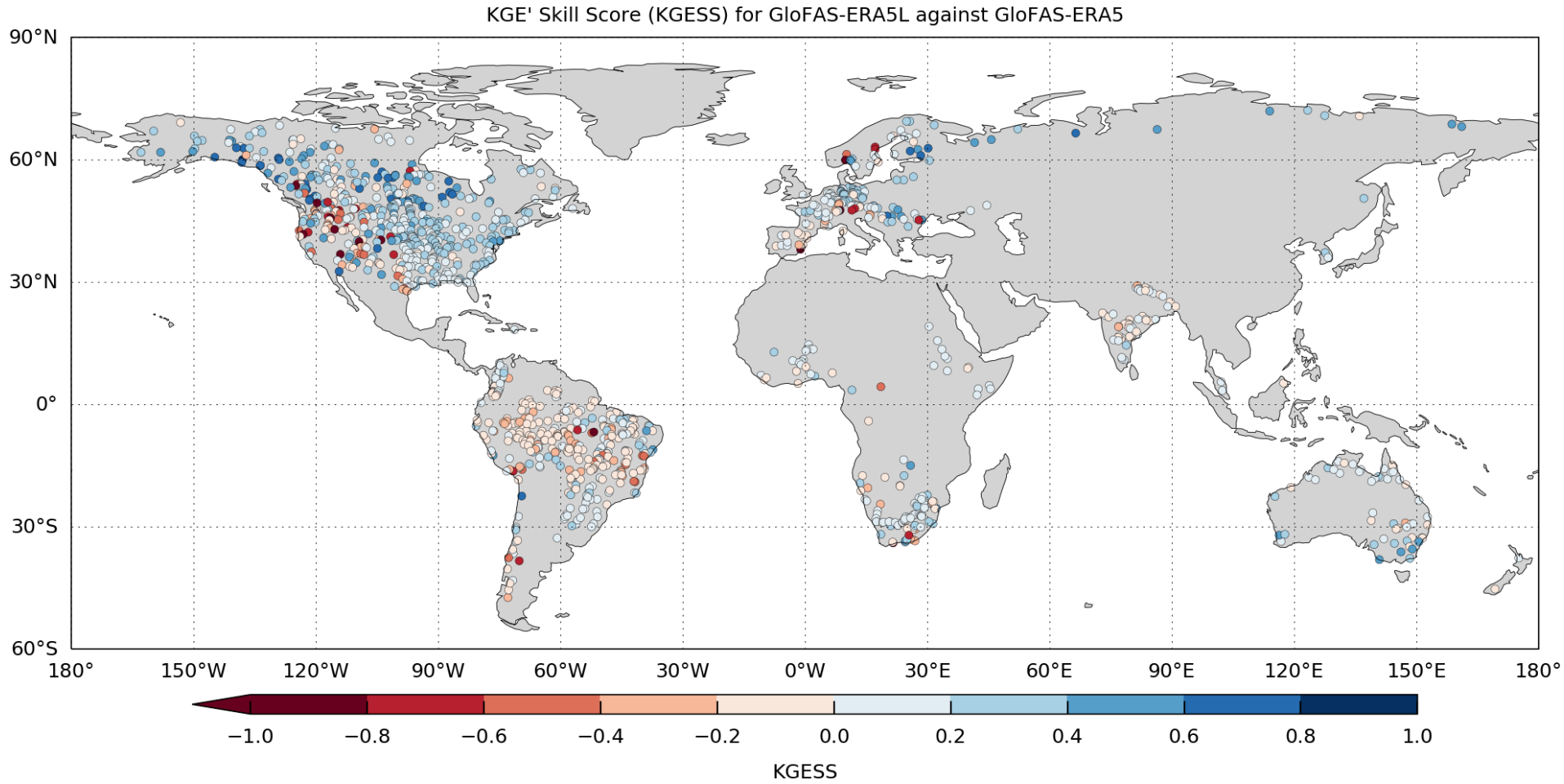
# Evaluation – River discharge

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.

- Figure produced by S. Harrigan -

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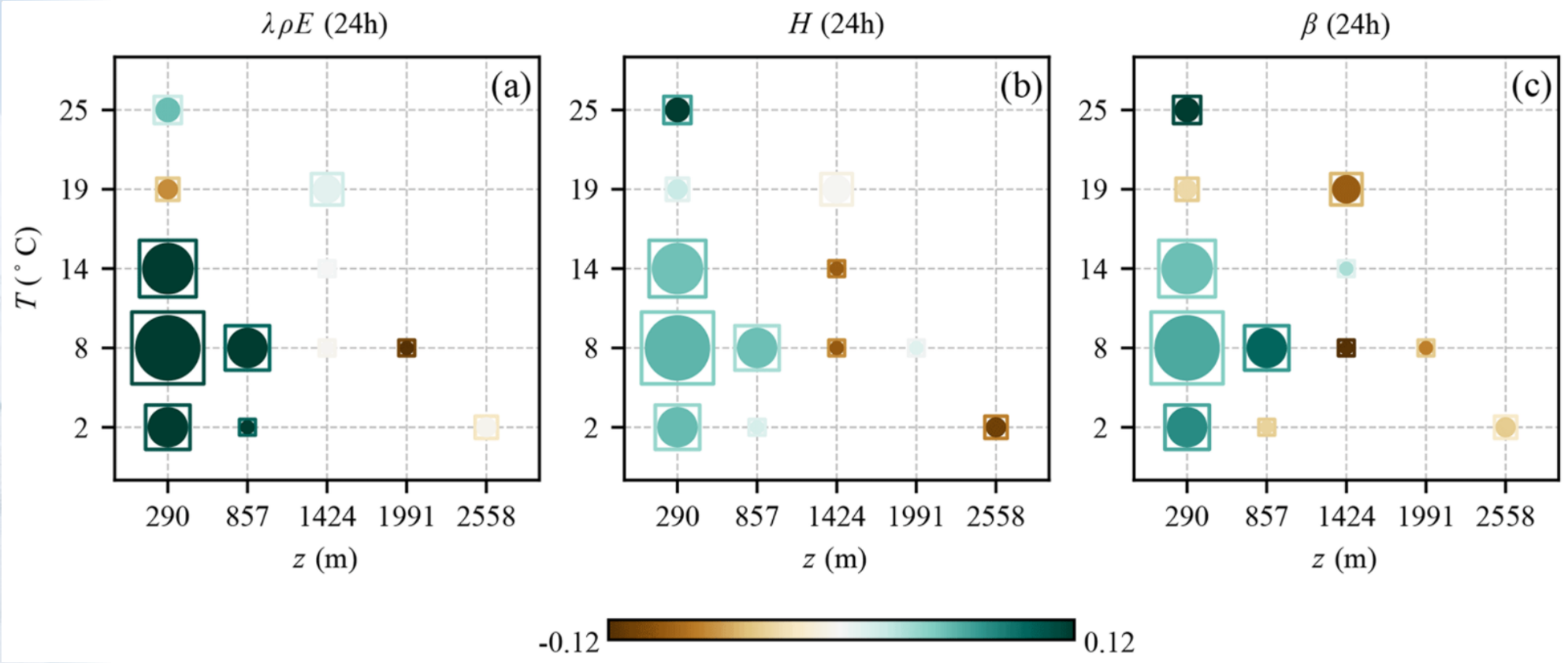
# Evaluation – Heat fluxes

## 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.

- Figure produced by B. Martens -

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# Conclusions

- Horizontal resolution matters
- ERA5-Land provides a consistent view of the land surface from 1950 to present, i.e., more than 7 decades of land surface evolution
  - Consistently,
  - Globally,
  - Hourly,
  - 9 km horizontal resolution,
  - At much reduced computational cost
- Clear signs of improvements in all components of the hydrological cycle
- Evaluation of the energy cycle comparable to ERA5, but the devil is in the detail…

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# Data availability & way forward

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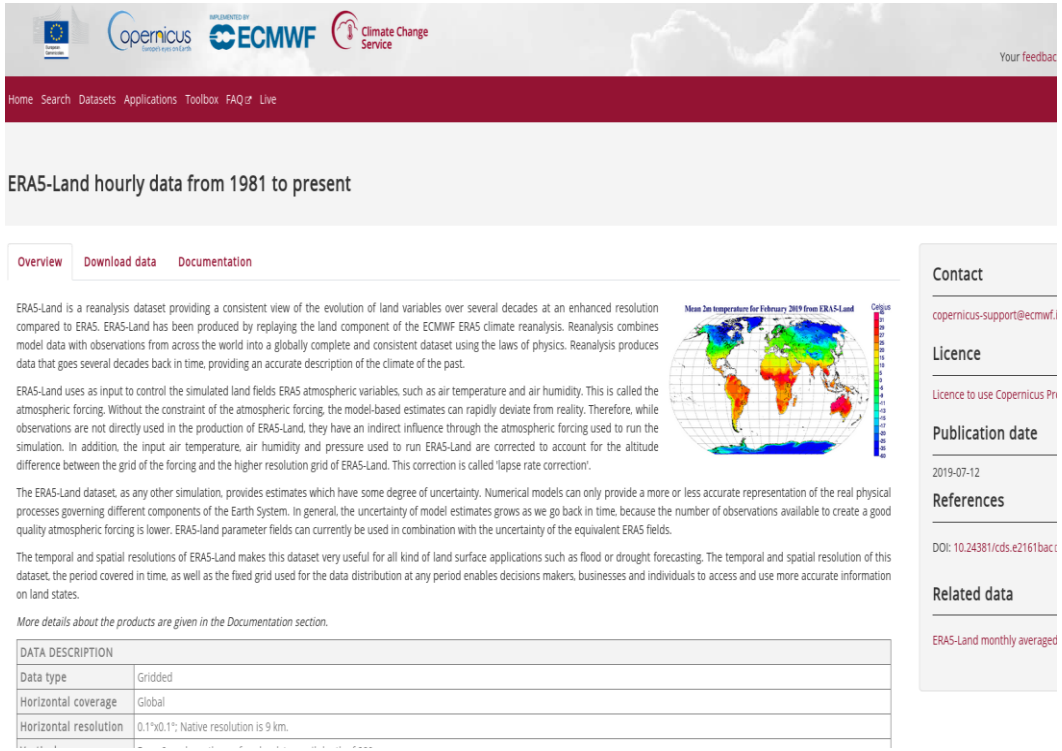
- Data is open and available in the Climate Data Store (doi: 10.24381/cds.e2161bac)
- From 1981 to present (2-3 months delay wrt real-time)
- Hourly and monthly fields
- Interpolated to 0.1° x 0.1°




Coming up:

- ERA5-Land Back-Extension (1950-1980) is complete and it'll be published very shortly.
- ERA5T-Land by 2022

Improvements under research:

- Dynamic land cover maps
- LAI measured from satellites
- Bias corrected precipitation
- Offline efficient data assimilation
- …

→ Preparation for ERA6-Land

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Open Access Earth System Science Data

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

**Joaquín Muñoz-Sabater[1], Emanuel Dutra[2,3], Anna Agustí-Panareda[1], Clément Albergel[4,5], Gabriele Arduini[1], Gianpaolo Balsamo[1], Souhail Boussetta[1], Margarita Choulga[1], Shaun Harrigan[1], Hans Hersbach[1], Brecht Martens[6], Diego G. Miralles[6], María Piles[7], Nemesio J. Rodríguez-Fernández[8], Ervin Zsoter[1], Carlo Buontempo[1], and Jean-Noël Thépaut[1]**

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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

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