ERA5-Land: an improved version of the ERA5 reanalysis land component

Joaquin Muñoz Sabater,

E. Dutra, G. Balsamo, D. Schepers, C. Albergel, S. Boussetta, A. Agusti-Panareda, E. Zsoter, H. Hersbach, & collaboration of many others

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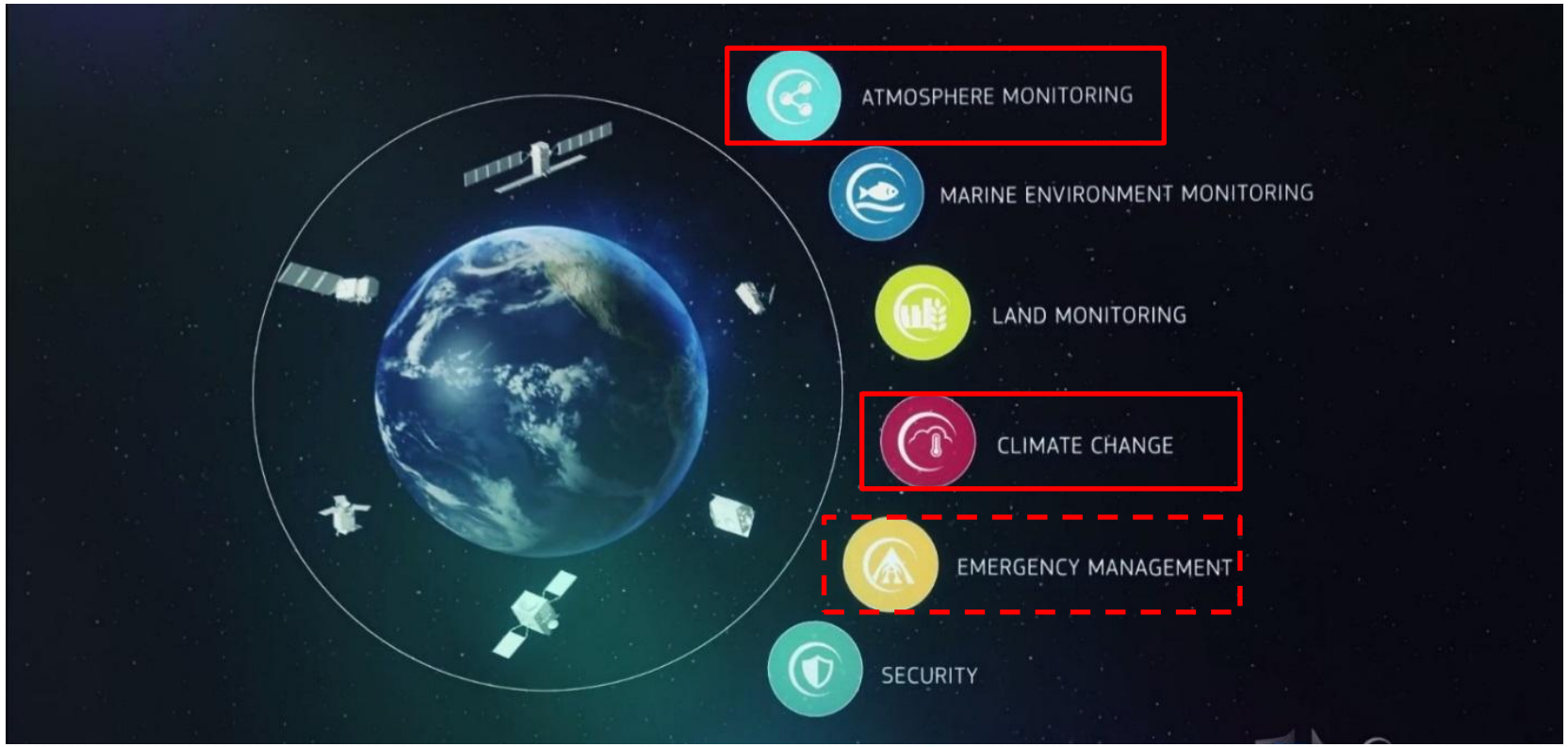
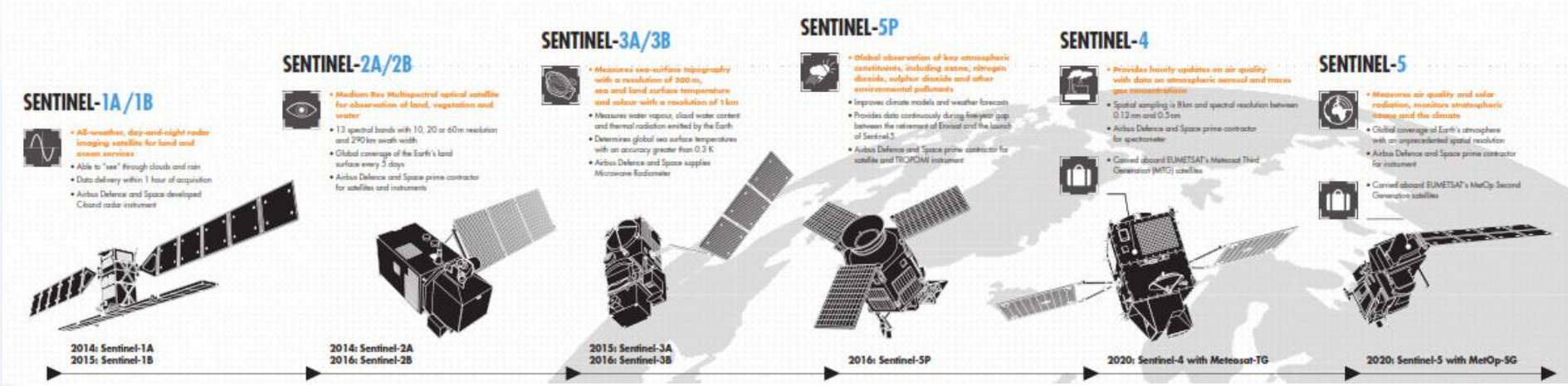
Context: Copernicus





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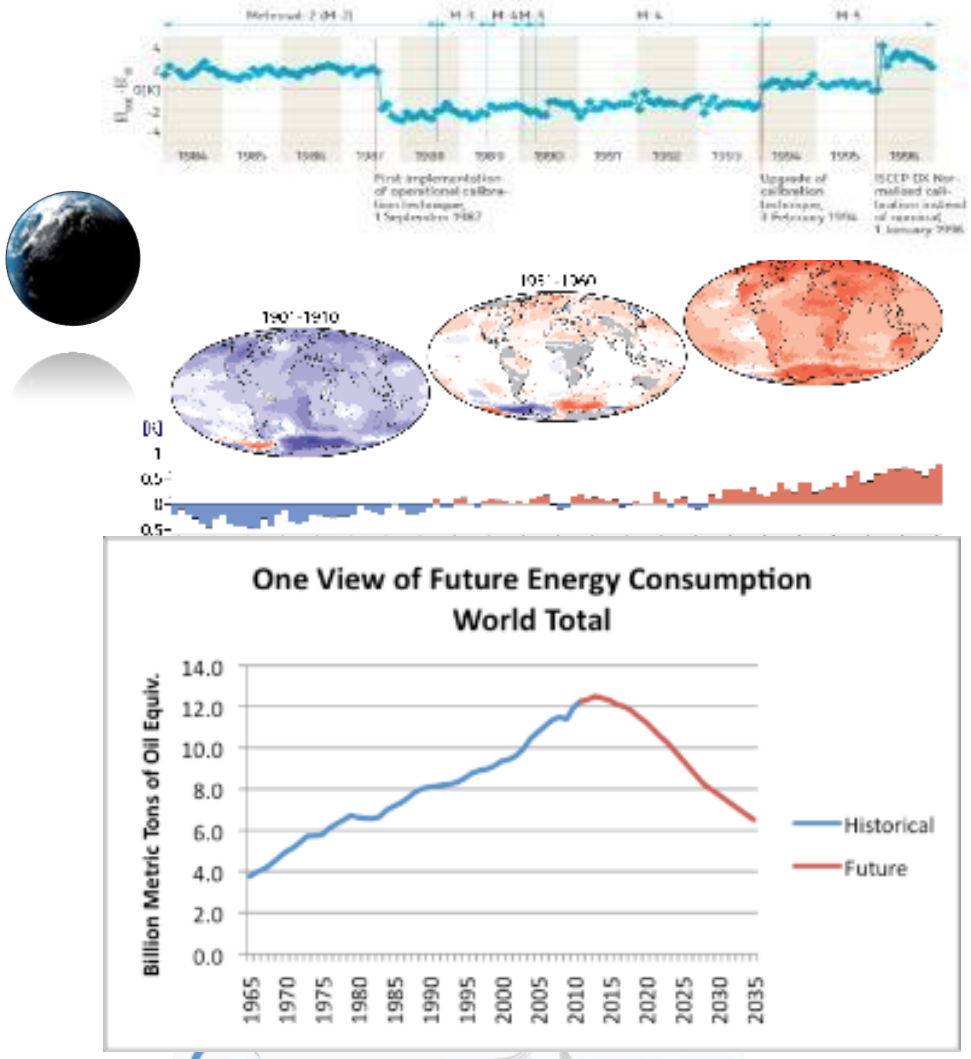
The Climate Change Service (C3S)

Questions addressed in the Service

- How is climate changing?
  - Earth observations
  - Reanalyses
- Will climate change continue/accelerate?
  - Predictions
  - Projections
- What are the societal impacts?
  - Climate indicators
  - Sectoral information



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- ERA5 global reanalysis
- European reanalysis (UERRA)
- Arctic reanalysis
- **ERA5-Land (global enhanced ERA5 surface fields at 9 km)**
- Coupled Climate reanalysis for 100-years (ERA6)

Reanalysis is now an operational service provided by ECMWF

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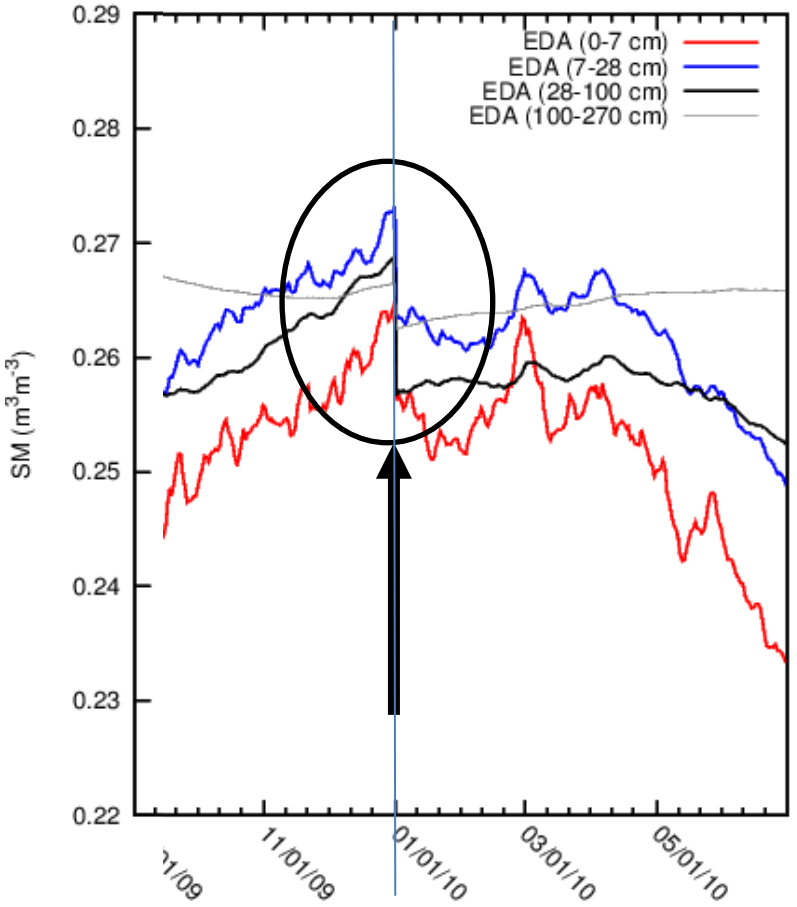
Dedicated land reanalysis - added value

Why do we need land-only reanalysis?

- Climate reanalysis does not occur very often.
- Need to bring rapid land model developments to long, consistent time series in a cost-effective way
  - Provide consistent land initial conditions to weather and climate models.
  - Support hydrological studies addressing global water resources
- Climate reanalysis often produce inconsistencies on land fields
- Provide dedicated datasets to support and encourage land applications



- **ERA-Interim/Land vs ERA-Interim**
  - **New soil hydrology**
  - **Snow hydrology**
  - **Vegetation seasonality**
  - **Bare soil evaporation**
  - **Precipitation readjustment based on GPCP v2.1**

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Dedicated land reanalysis – what's new?

ERA5-Land

- Rerun of a single stand-alone simulation of the land component
- No data assimilation
- Uncoupled run with the atmosphere

  - Physics of the IFS in cy45r1 (includes all modeling used in ERA-Interim/Land)
  - Surface dynamical downscaling (allows capturing details associated to processes as topographic forcing)
  - Daily lapse-rate correction
  - Revision of soil thermal conductivity and water balance,
  - Bug-fixes (rain over snow, infinitesimal fraction of convective rainfall, accumulation fluxes of CO2, etc.)
  - Potential evapotranspiration fluxes bugged in ERA5, corrected in ERA5-Land and added to the catalogue,

  - Uncertainty estimation based on a 10-member ensemble
  - More customized data set for users in different economic sectors

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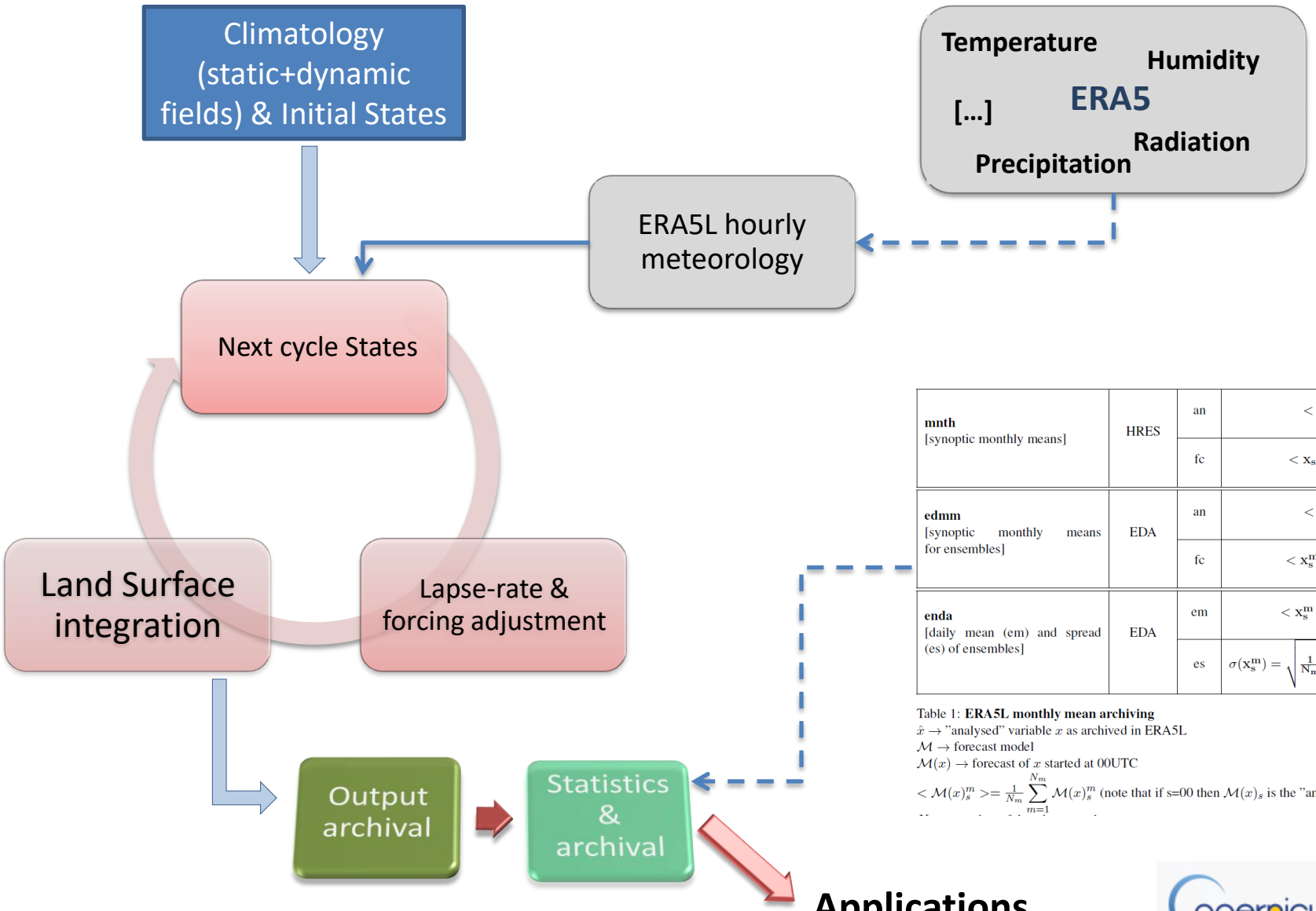
ERA5-Land in a simple diagram



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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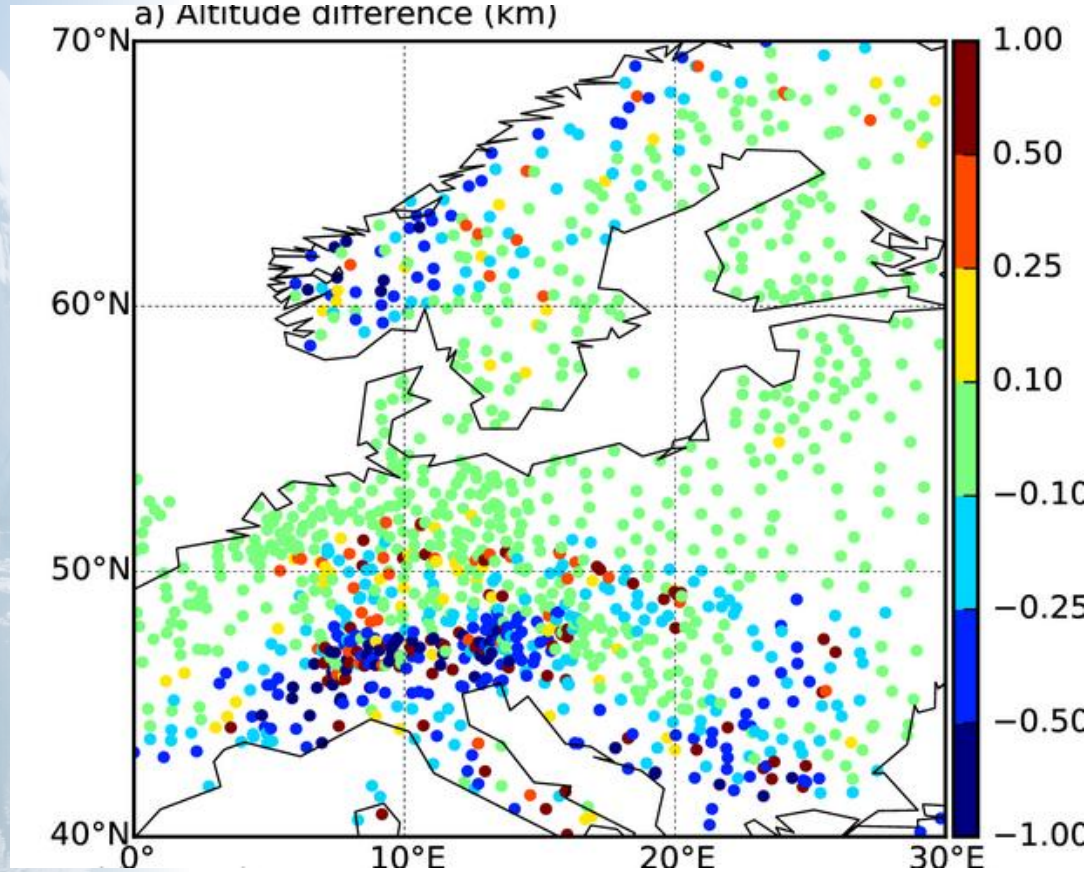
Lapse-rate adjustment

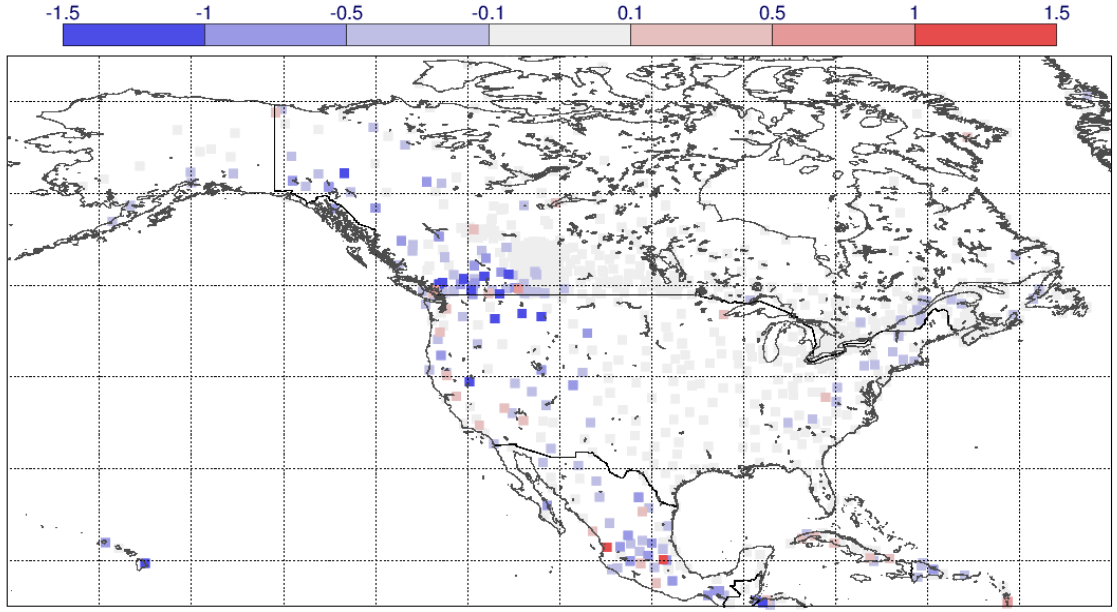
- **Correct for differences in orography due to different model resolutions.**



Δh (km)

T2m

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



See details in oral presentation: E. Dutra et al. (9.40am): "Land surface downscaling using a spatially and temporally varying lapse rate"

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ERA5-Land specs compared to…

	ERA-Int	Era-Int/Land	ERA5	ERA5-Land
Period covered	Jan 1979 – NRT(*)	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 atmospheric forcing at 31 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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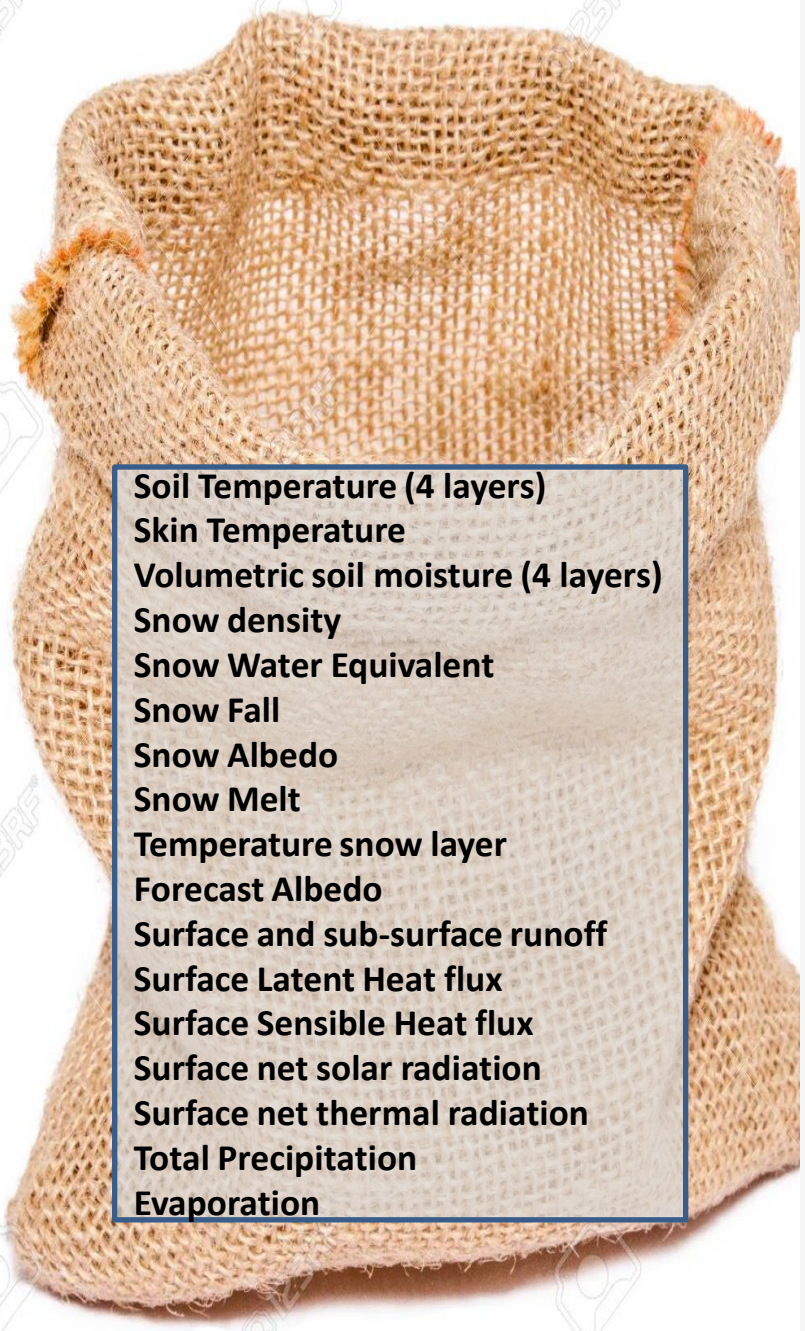
ERA-Int/Land vs ERA5-Land inventory of fields



- 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

ERA5-Land Roadmap

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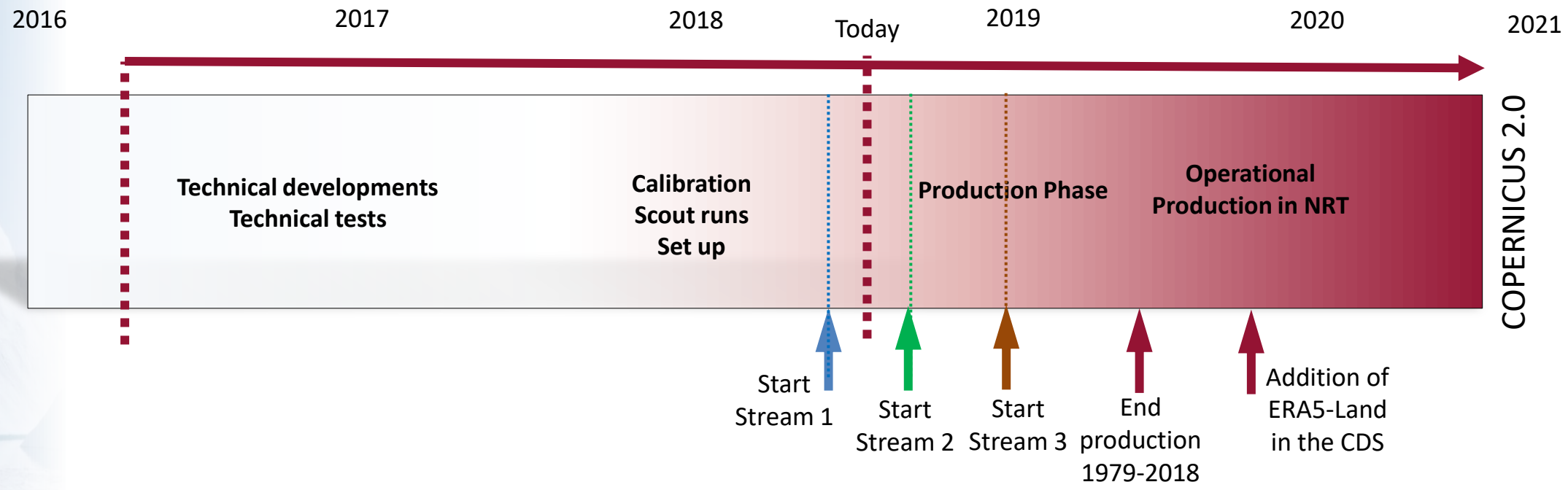

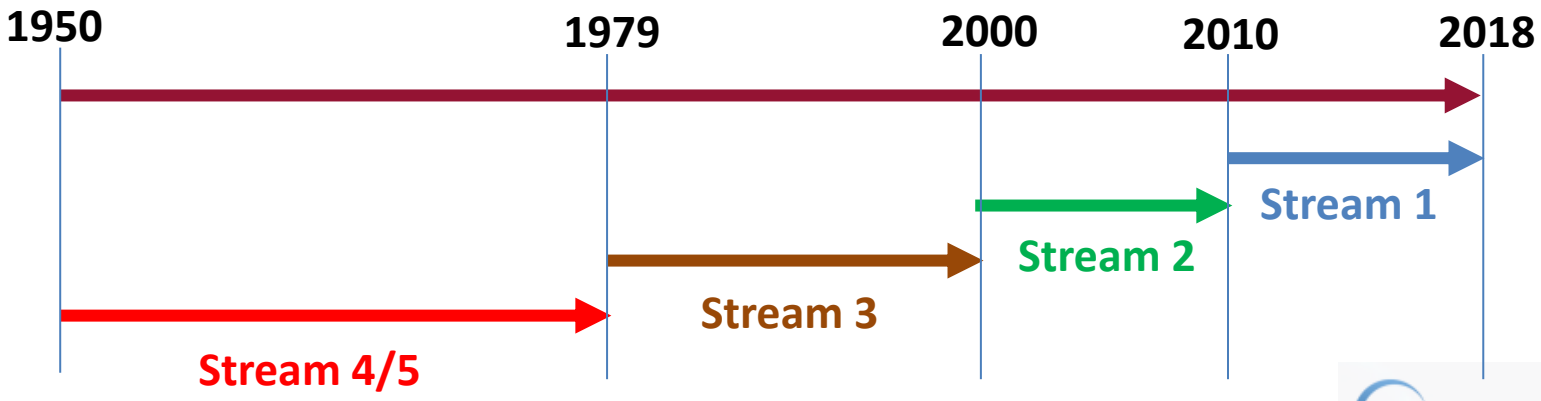

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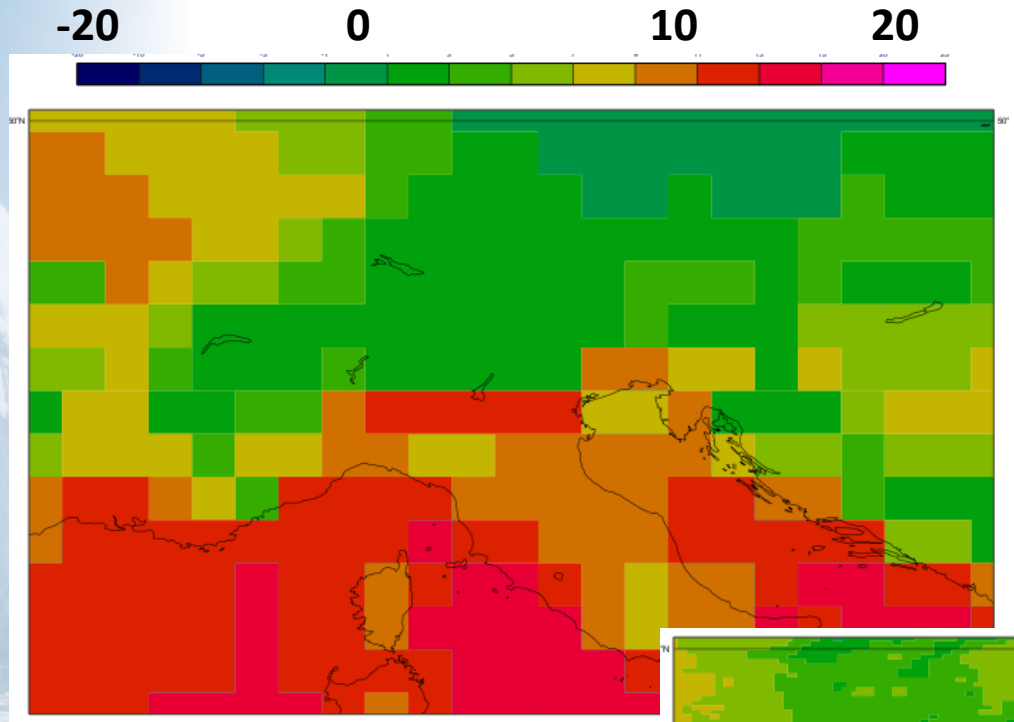
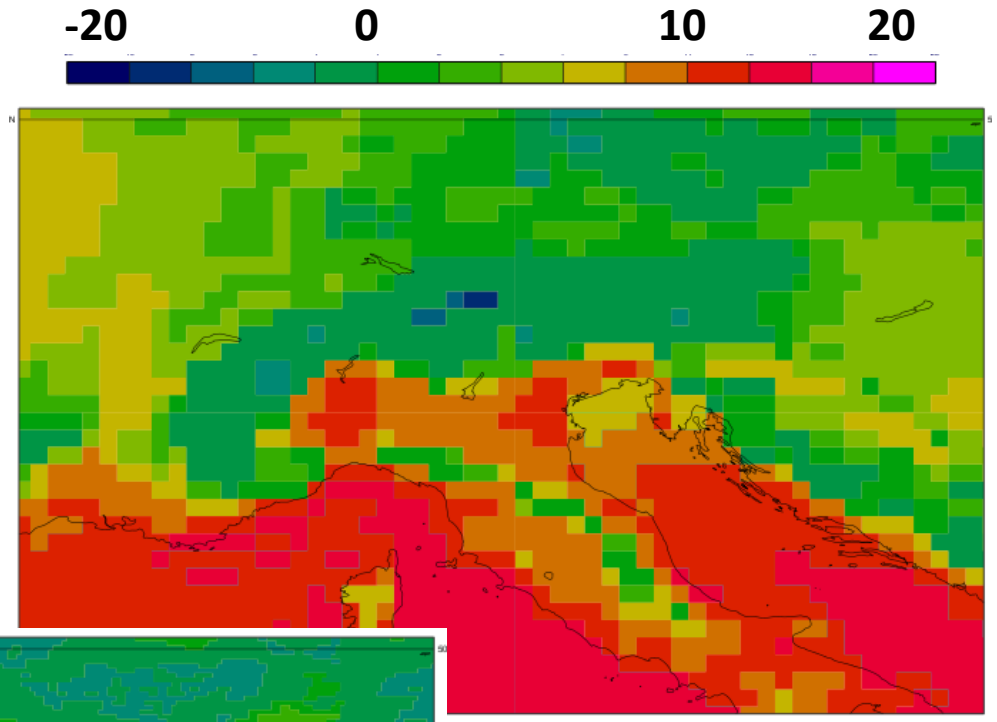
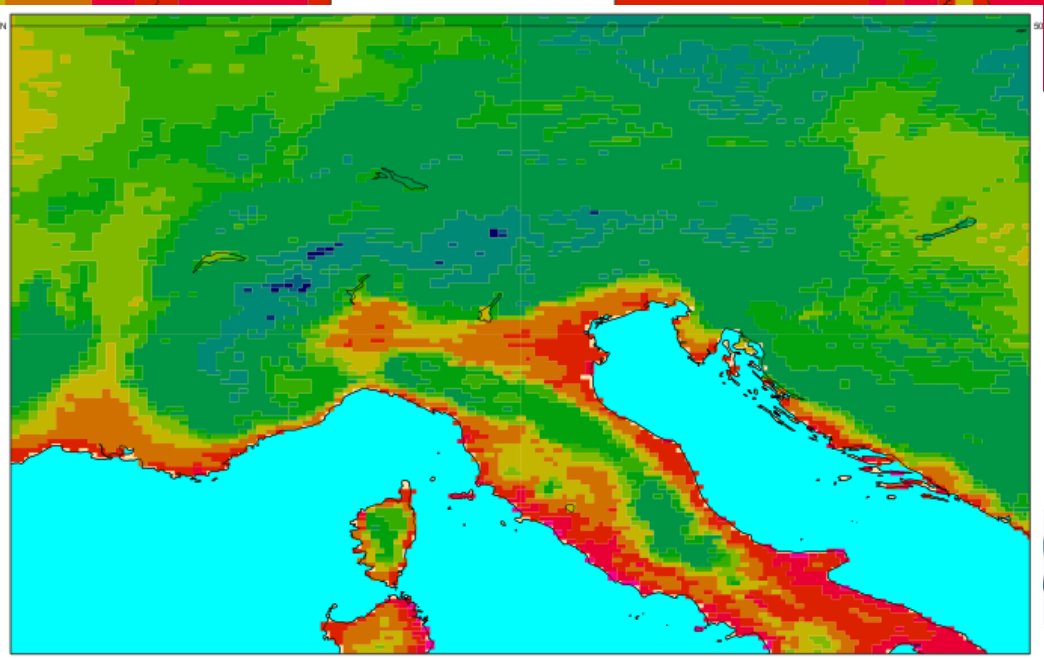
Add value of higher resolution; Soil Temperature (15 March 2010)



ERA-Interim (79 km)



ERA5 (31 km)



ERA5-Land (9 km)

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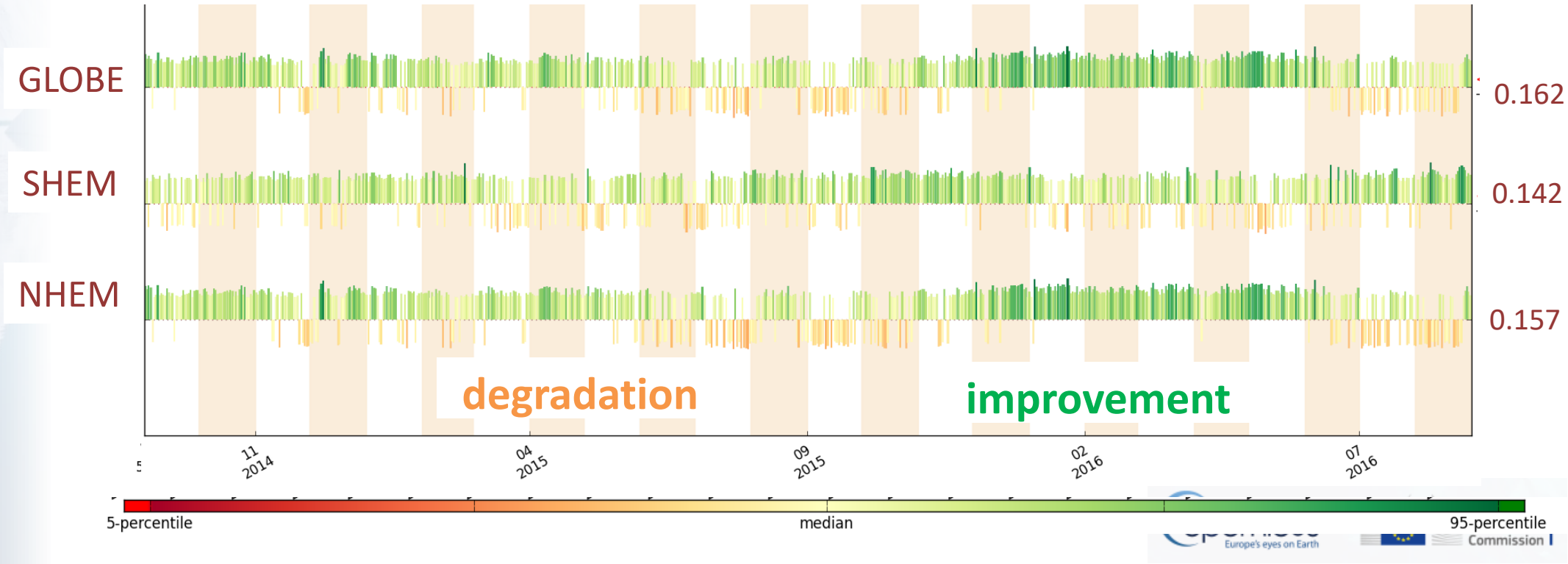
Preliminary results: 2 m temperature

- Observations from SYNOP network
- Period: Sept 2014 /to/ Sept 2016

$$abs[(OBS\text{-}FC^{24h})_{ERA5}] - abs[(OBS\text{-}FC^{24h})_{ERA5L}]$$

- In general ERA5-Land outperforms ERA5
- South-America, Tropics and Africa obtained the best results



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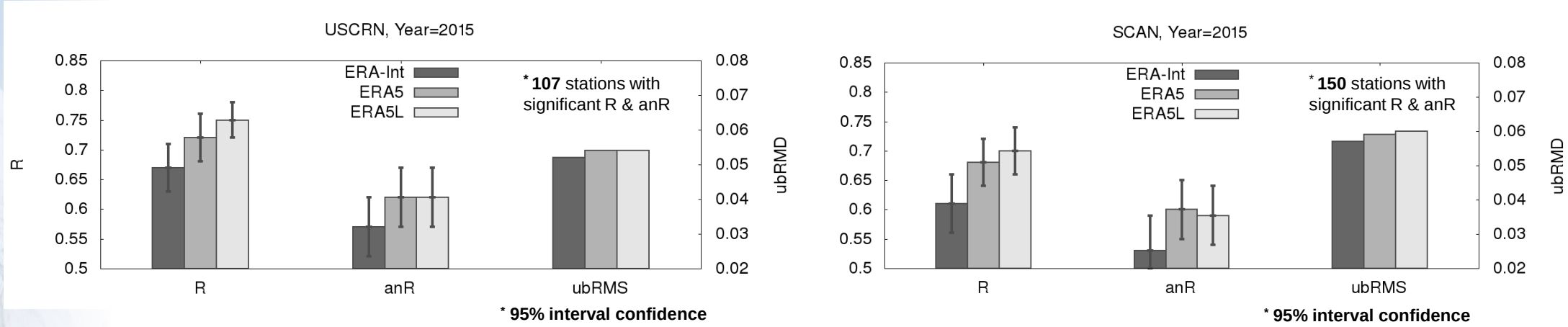
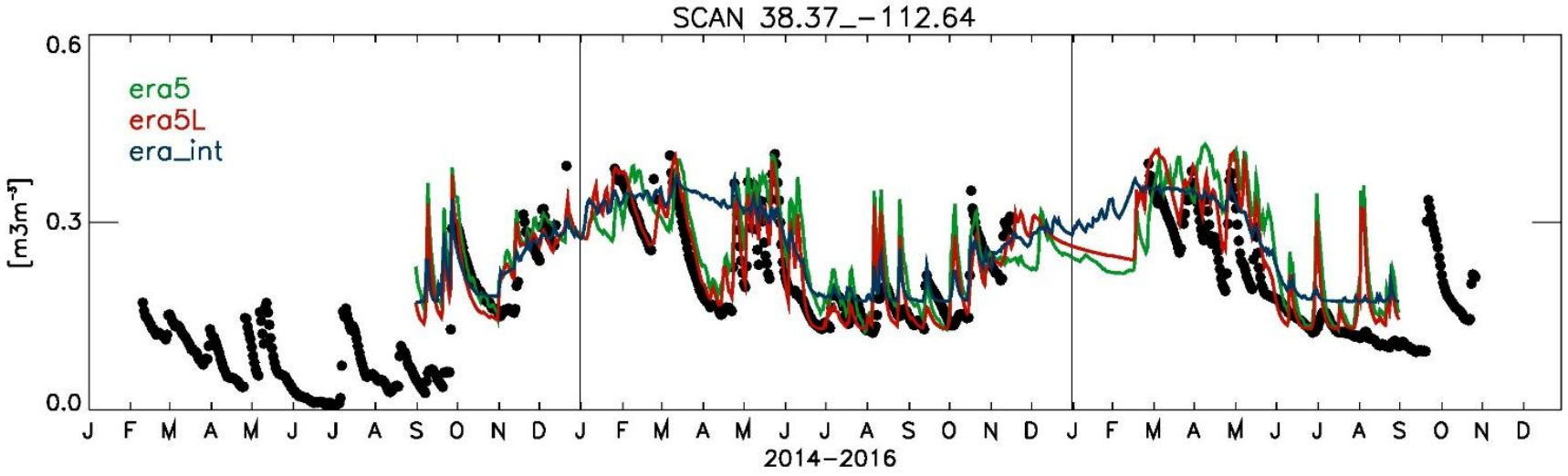
Preliminary results: Soil moisture

Evaluation against in-situ stations from SCAN and USCRN networks (year 2015)





- Provided by C. Albergel -

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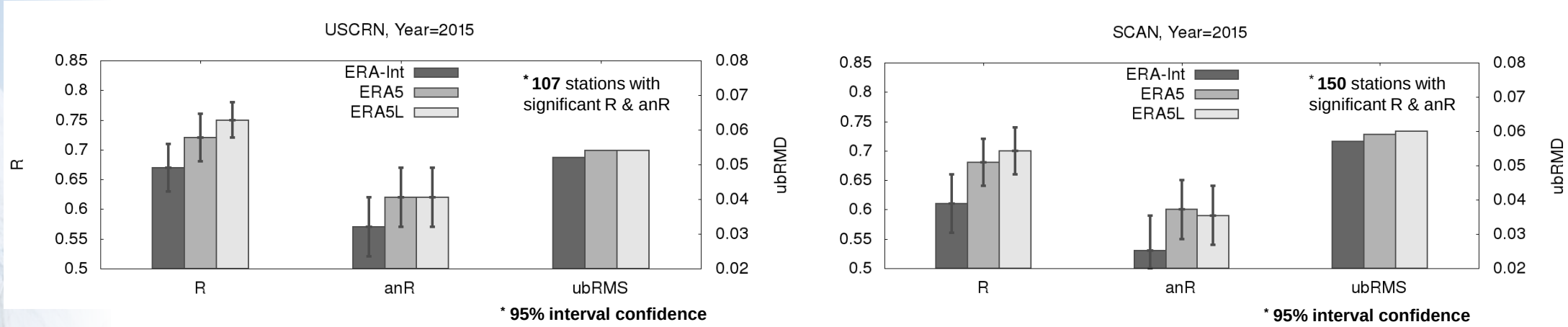

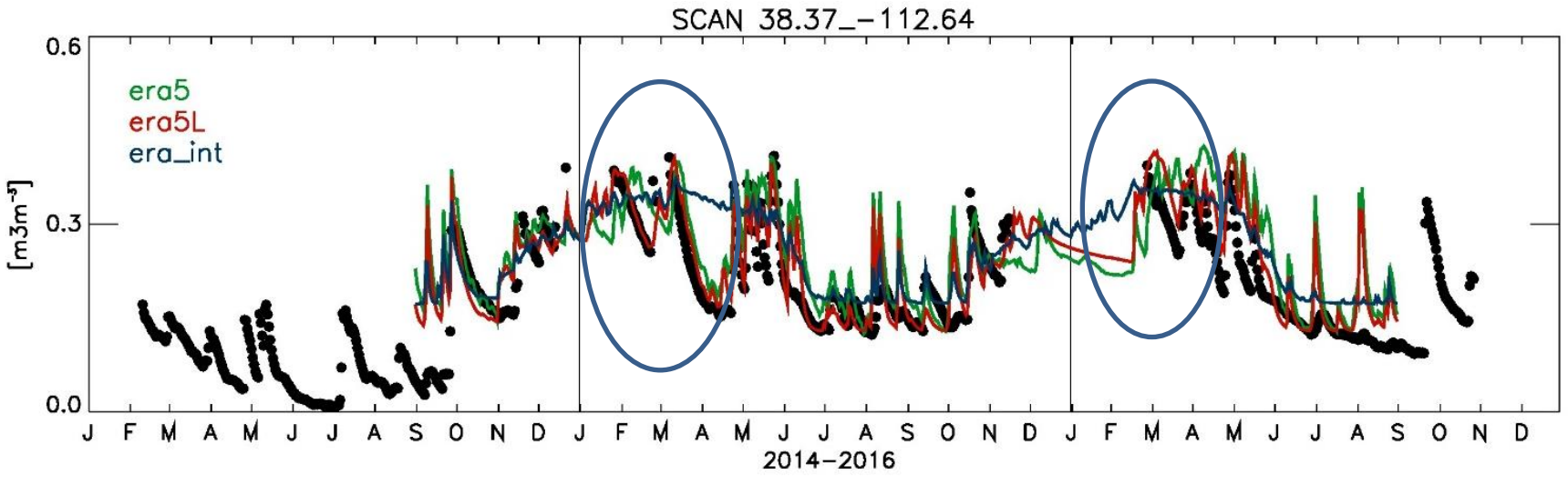

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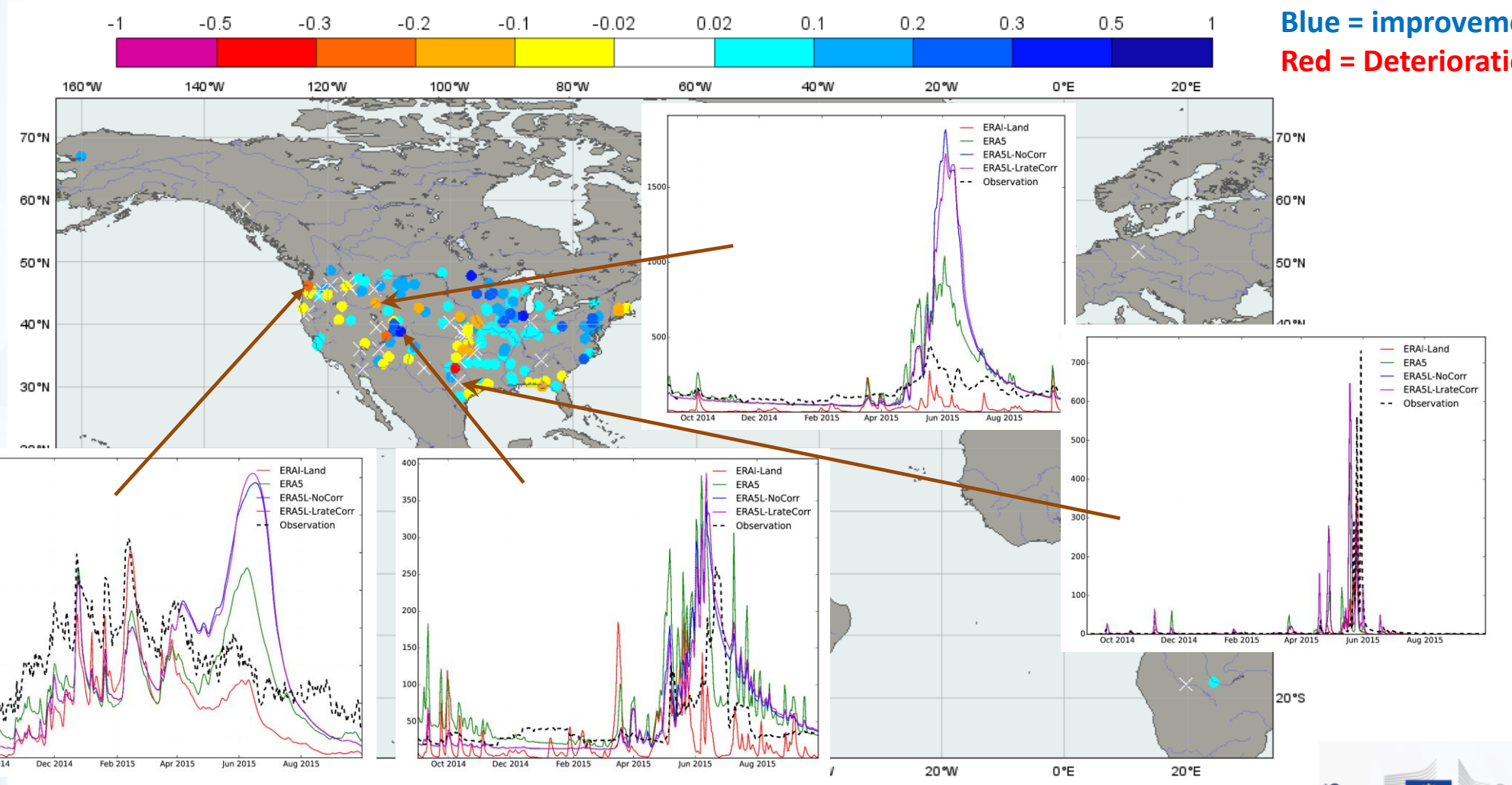
ERA5/ERA5-Land impact on river discharge

Discharge time series correlation difference ERA5-Land (no lapse rate) vrs. ERA5



Blue = improvement
Red = Deterioration

- Provided by E. Zsoter -

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River discharge forecasts

	ERA-Int	ERA5	ERA5L
Mean Err	-183.71	-116.07	-62.91
Mean Abs Err	235.20	209.11	191.37
CORR	0.466	0.534	0.581

- ERA5 is better than ERA-Int/Land in the correlation, with a more mixed picture of the absolute errors.
- ERA5-Land improves further over ERA5 in the correlation
- Small differences on the discharge by correcting the input forcing.

But…

- Too short period (only 13 months).
- The 30+year period will have a better area coverage (lot more stations with observation, better geographical coverage).

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Towards ERA6-Land

Future improvements:

- Post-processing of carbon fluxes with BFAS
- Enhanced ensemble spread through additional perturbations
- Increased vertical discretization to 10 layers
- Activation of A-gs formulation (C-TESSEL)
- And of course… integration of improved land processes or new ones. For ex. introduction of urban tile

Wish list:

- Use of real precipitation observations
- Integration of dynamical land cover
- NRT LAI
- Coupled to an offline data assimilation system
- Parallelised production
- User-defined area output

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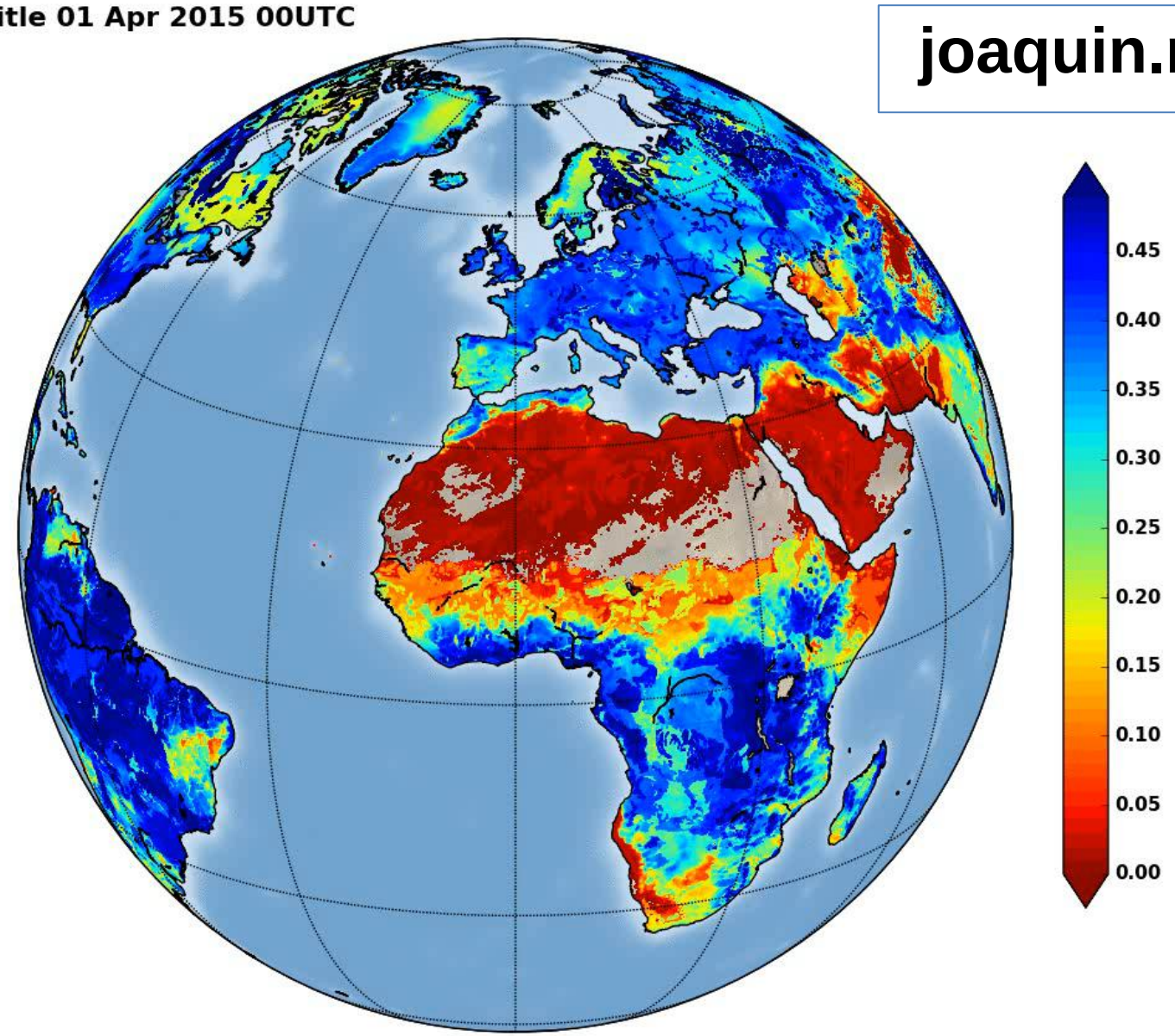

Thank you!

ERA5-Land (~9 km)

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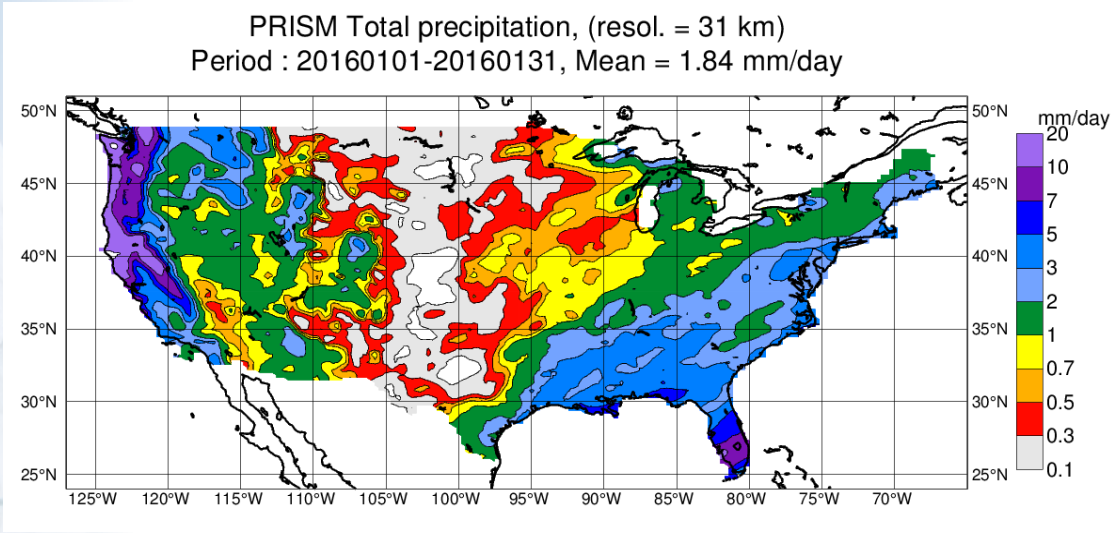
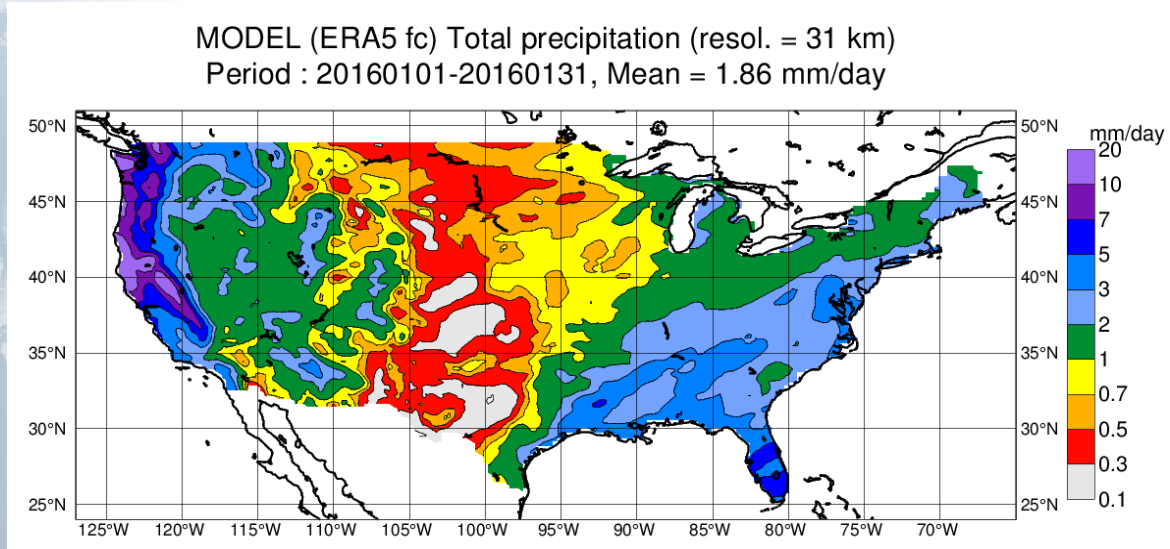
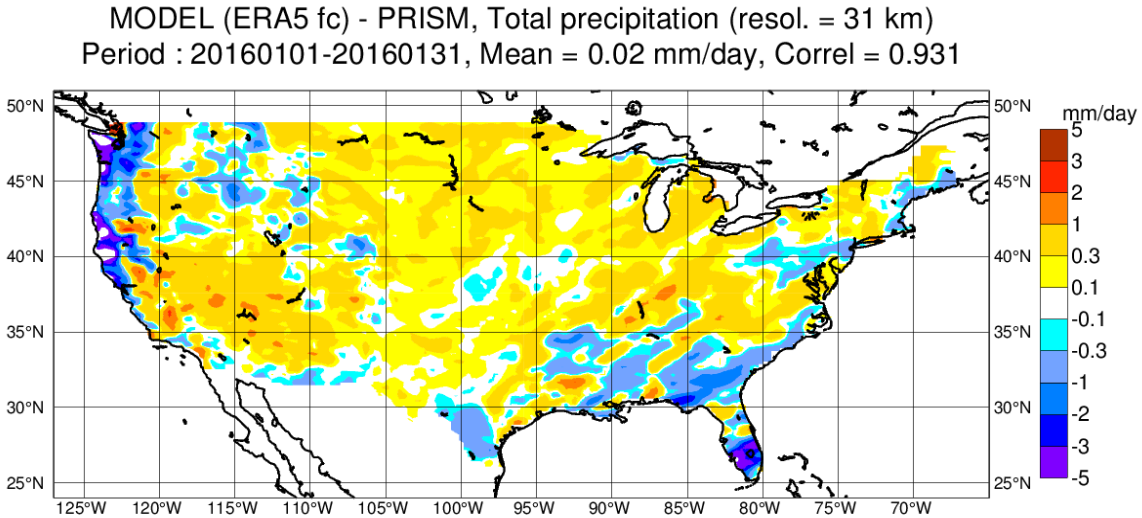
Precipitation

- Figures courtesy of Philippe Lopez -





- Bias correction of precipitation fields maintain consistency of the land hydrology
- ERA-Interim precipitation shows good synoptic variability but can be biased → monthly bias correction
- ERA-Int has large biases in tropics and areas with snow → large improvements in these areas, whereas extratropics is much better ERA-Int



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