ECMWF COPERNICUS NOTE

Copernicus Climate Change Service

# Documentation of the CERRA-Land system

Issued by: MF / P. Le Moigne

Date: 15/10/2021

Ref: C3S_D322_Lot1.1.1.12_202110_documentation_CERRA-Land

Official reference number service contract: 2017/C3S_322_Lot1_SMHI/SC4

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# Introduction

As part of the Copernicus Climate Change Service, a land regional reanalysis for Europe (CERRA-Land) is produced covering the period from 1984 to the present at 5.5km horizontal grid spacing.

Accurate spatial and temporal datasets of precipitation and surface variables are essential for water resources management and climate change studies. CERRA-Land is a regional land surface reanalysis dataset which describes the evolution of soil moisture, soil temperature and snowpack. This dataset is the result of a single standalone integration of the SURFEX V8.1 land surface model (LSM) driven by meteorological forcing from the CERRA atmospheric reanalysis system and a daily accumulated surface precipitation analysis produced with the MESCAN system (Soci et al., 2016), which performs an optimal interpolation between the CERRA forecast precipitation field and in situ rain gauges data.

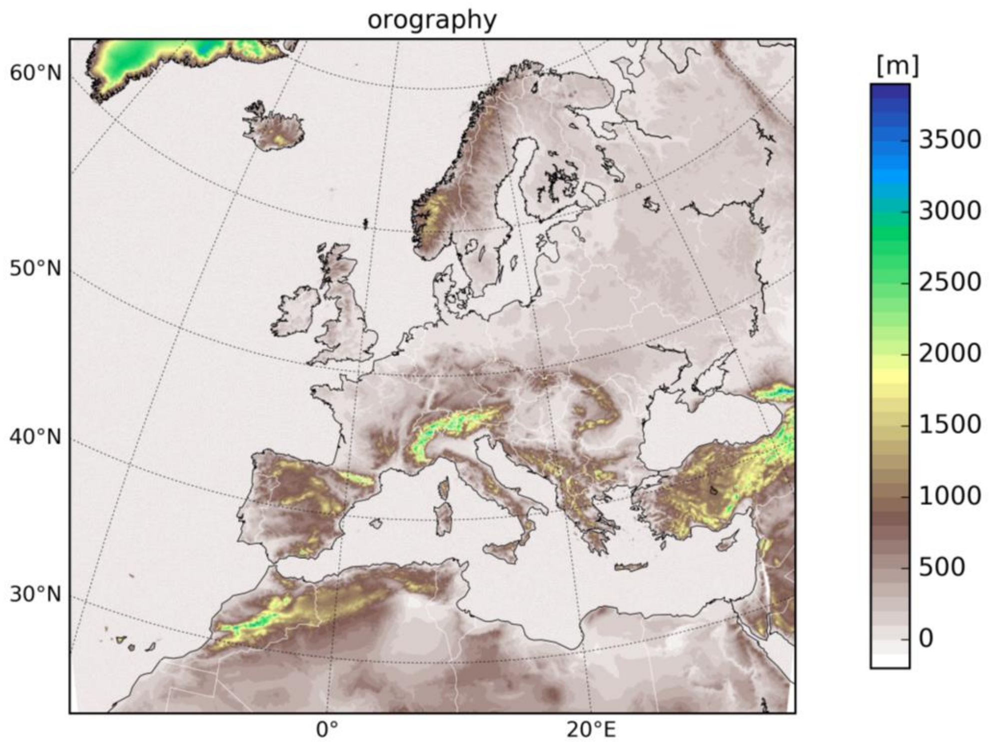



Figure 1.1.1: orography of the CERRA-Land system in meter (same as CERRA upper-air system)

# 1. The CERRA-Land system

The CERRA-Land system is composed of the SURFEX V8.1 land surface model driven by meteorological forcing (at 3 hourly time step) from the CERRA atmospheric reanalysis and a daily accumulated surface precipitation analysis over Europe. The outputs were archived at hourly time step and the precipitation analysis was archived at daily time step (Fig *1.2.1.1*).
The domain (Fig. 1.1.1) and the projection are the same as for the upper air-system, and the horizontal grid spacing is also 5.5 km. The system is integrated from the 1st of September 1984 to close to real-time.
SURFEX (Surface Externalisée, in French) is a surface modelling platform developed by Météo-France in cooperation with the scientific and ACCORD community. SURFEX is composed of various physical models for natural land surface, urbanized areas, ocean, and lakes.
A complete description of the SURFEX model can be found in the online documentation:
https://www.umr-cnrm.fr/surfex/IMG/pdf/surfex_scidoc_v8.1.pdf

## 1.1 Description of the SURFEX V8.1 land surface model setup

The LSM describes the evolution of soil moisture, soil temperature and snowpack. A grid point is composed of 3 different fractions (or tiles) of land cover: nature (frac_nature), lake (frac_lake) and town (frac_town). In the system, no sea fraction was used. The surface–atmosphere fluxes are then aggregated for each atmospheric grid cell, according to the fraction of the three types of surface in the cell. The averaged value (F) over the grid cell is thus given by:
$F = frac\_nature \times F_{nature} + frac\_town \times F_{town} + frac\_lake \times F_{lake}$
where the values $F_{nature}$, $F_{town}$, and $F_{lake}$ are calculated by specific physical parametrization.
For costal grid point, the positive values of sea fraction less than 1 were set to 0 and frac_nature was set to 1 - (frac_town + frac_lake). The sum of fractions must always equal 1. It means that the costal aggregated values can be biased because no sea fraction was considered.

The **nature fraction** (vegetation area) uses 12 separate vegetation types, each with its own set of parameters (Masson et al., 2003; Faroux et al., 2013). The classification distinguishes three non-vegetated types (rocks, bare soil, and permanent snow and ice) and nine vegetated types: temperate deciduous forest, boreal conifers, tropical conifers, C3 crops, C4 crops, irrigated crops, grasslands, tropical meadows, and peatlands, parks, and gardens. Over vegetated areas, SURFEX includes the Interactions between Soil, Biosphere, and Atmosphere (ISBA) scheme. The prognostic variables of soil temperature and soil moisture are represented in the model by a diffusive approach (Decharme et al. 2011). Such a method proposes a discretization of the soil into 14 layers, resulting in a total depth of 12 m, with a fine description of the subsurface layers to capture the diurnal cycle. The vertical discretization (bottom depth of each layer in metres) is as follows: 0.01, 0.04, 0.1, 0.2, 0.4, 0.6, 0.8, 1, 1.5, 2, 3, 5, 8, and 12 m, as described in Decharme et al. (2013). Heat transfer is resolved over the total depth, while moisture transfer is resolved only over the root depth, which depends on the type of vegetation and its geographical location. To better represent the permafrost active layer, the effect of soil organic carbon on hydraulic and thermal soil properties was taken into account in the northern part of the domain (Decharme et al. 2016). The snowpack is represented by a multilayer snow scheme of intermediate complexity developed by Boone and Etchevers (2001) and revised by Decharme et al. (2016). It uses 12 layers to represent snowpack processes. This scheme simulates all the macroscopic physical properties of the snowpack in each layer, such as absorption of solar energy, heat content, compaction and density, snowmelt, water percolation, and water refreezing.

The **lake fraction** is related to the FLake model (Mironov et al 2010). It is a bulk fresh-water lake model based on a two-layer parametric representation of the evolving temperature profile and on the integral budgets of heat and of kinetic energy.

The **town fraction** is parametrized with the TEB (Town Energy Balance, Masson 2000) single layer urban canopy model. It allows a better representation of energy budget over urban areas. Urban canopy is assumed to be an isotropic array of infinite street canyons. TEB simulates heat and water exchanges and climate of three generic surfaces (roof, wall, and road), where heat transfers by conduction are computed through several layers of materials.

## 1.2 Near-surface meteorological forcing data

The land surface model is driven by a set of near-surface meteorological forcing data (no coupling with the atmospheric model).

### 1.2.1 General overview of the meteorological forcing dataset

The figure *1.2.1.1* shows the general overview of the CERRA-Land system. The forcing data at 5.5km horizontal grid spacing is composed of 8 variables at a 3-hourly time step. The forecasting data such as the 10m wind speed (Wind), the 10m wind direction (Wind_dir), the surface pressure (Pres), the surface solar radiation downwards (SW) and the surface long wave radiation downwards (LW) are provided by the CERRA upper-air system dataset (see Fig. 1.2.1.1). A zenith angle correction factor was applied on the 3-hour accumulated surface downward short-wave radiation during the model integration. The two-meter temperature and two-meter humidity online surface analysis from the CERRA dataset were used as forcing data for the CERRA-Land system. No downscaling method was used to build up the forcing data because CERRA-Land has the same grid as the CERRA atmospheric reanalysis.

The daily surface accumulated precipitation analysis (see next paragraph) was temporally disaggregated to a 3-hour time step using the temporal distribution of 3-hour precipitation forecast. Then, the rain snow transition was parametrized with the formula proposed by Froidurot et al (2014).

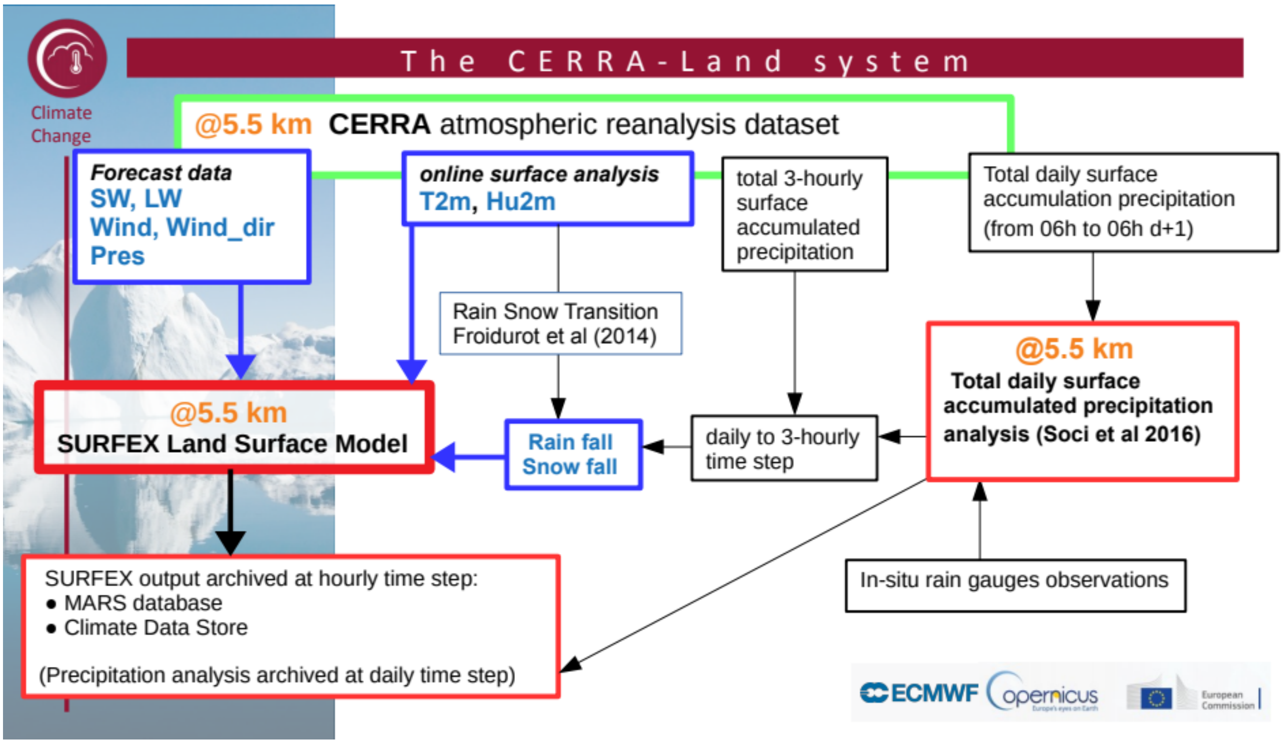



***Fig. 1.2.1.1: outline of the CERRA-Land system***

## 1.2.2 The daily surface accumulated precipitation analysis

The MESCAN daily surface accumulated precipitation analysis system (Soci et al., 2016) merges the daily aggregated gauge measurements from the surface synoptic network with a daily background surface precipitation field from the CERRA upper system. MESCAN is a version of the operational surface analysis (CANARI) used at Météo-France for the numerical weather prediction based on an Optimal Interpolation (OI) algorithm. The analyses were done from 06UTC to 06UTC next day (the analysis time refers to the end of the 24h period).

The accumulated background is the sum of 8 successive 3-hour forecasts starting from 06, 09, 12, 15, 18, 21, 00 and 03UTC. Alternative backgrounds that avoided the initial spin-up period were tested. Figure 1.2.2.1 shows a schematic describing the four composite types tested and Table 1.2.2.1 gives the RMSE results showing that in general “Composite 2”, the sum of 3-hour forecasts, gave the better (smaller) RMSE results.

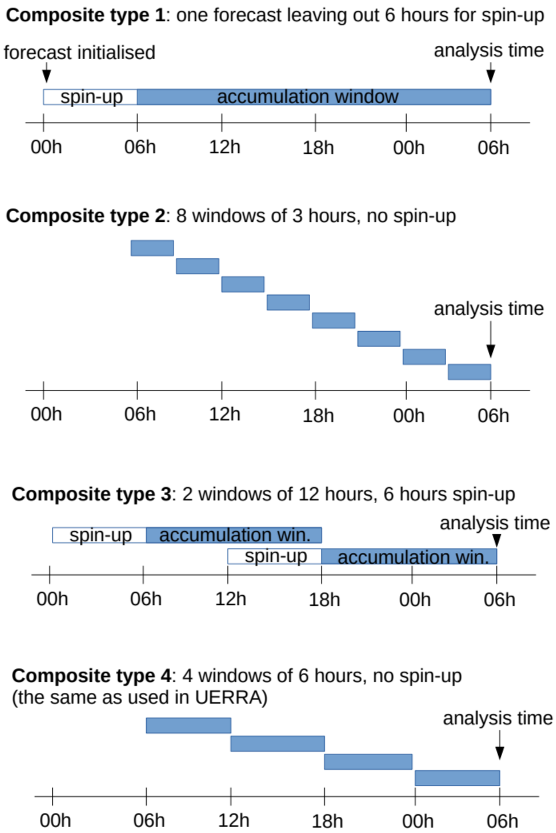



***Figure 1.2.2.1: Tested forecast-composite types for the RR24 first guess.***

| Season | Region | UERRA | Comp. 1 | Comp. 2 | Comp. 3 | Comp. 4 |
|---|---|---|---|---|---|---|
| **Winter** | Alps | 2.79 | 2.86 | 2.38 | 2.75 | 2.49 |
| | Atlas | 3.4 | 3.55 | 3.31 | 3.4 | 3.34 |
| | Easter Europe | 1.3 | 1.5 | 1.33 | 1.46 | 1.45 |
| | France | 2.76 | 2.88 | 2.57 | 2.7 | 2.66 |
| | Pyrenees | 5.9 | 6.03 | 5.4 | 6.61 | 5.98 |
| | Scandinavia | 2.44 | 2.38 | 2.32 | 2.34 | 2.31 |
| **Summer** | Alps | 7.5 | 6.69 | 6.71 | 6.51 | 7.27 |
| | Atlas | 2.28 | 1.69 | 1.4 | 1.67 | 1.5 |
| | Easter Europe | 4.73 | 4.89 | 4.15 | 4.64 | 4.22 |
| | France | 3.79 | 3.43 | 3.32 | 3.41 | 3.38 |
| | Pyrenees | 5.93 | 3.82 | 4.24 | 4.56 | 4.59 |
| | Scandinavia | 3.97 | 3.83 | 3.62 | 3.72 | 3.59 |

***Table 1.2.2.1: Root mean squared errors for the first guess departures (observation – guess) for designated regions for Winter (02/01/17 to 31/01/17) and Summer (02/07/17 to 31/10/17). The best (smallest) are highlighted in yellow. The composite numbers refer to those types described in Fig. 1.2.2.1.***

An ad-hoc spatial filter was added to the sum of 3-hour forecasts because it was found that precipitation accumulations were unrealistically high in the mountains. The spatial filter is defined as the minimum between either the original, or that with a Gaussian spline applied with a radius of 7 km.

The structure function for the MESCAN optimal interpolation is described in Soci et al. (2016). The background standard deviation error $\sigma_b$ is set to 13mm and the observation standard deviation error $\sigma_o$:

RR_obs=0.mm → $\sigma_o$=0.001 mm
RR_obs<50mm → $\sigma_o$=0.7+RR*0.1 mm
RR_obs ≥ 50mn → $\sigma_o$ =5.7 mm

The observation network consists of accumulations from synoptic rain gauges provided from the meteorological services of France, Sweden, Norway, Finland, Iceland and some from Denmark, from the meteorological global telecommunications system (GTS) stored in ECMWF's MARS database and from the European Climate Assessment and Dataset (ECAD). Figure 1.2.2.2 shows time series and an example map of the data sources.

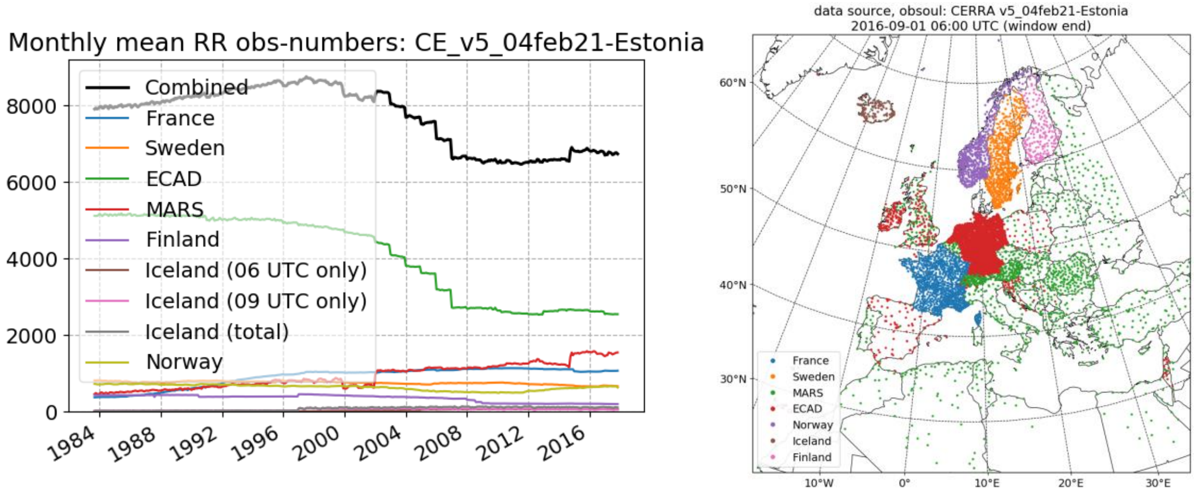



***Figure 1.2.2.2: Time series of obs-numbers by data source (left panel), and example map of the data sources (right panel.***

## 2. Main differences with the UERRA-MESCAN-SURFEX system

In 2018, the UERRA-MESCAN-SURFEX European land surface reanalysis system (Bazile et al. 2017) at 5.5km horizontal grid spacing and covering the period from January 1961 until July 2019 was released through the FP7 UERRA project (http://www.uerra.eu). This system was based on the standalone integration of the SURFEX land surface model driven by a set of near-surface meteorological forcing data from the UERRA-HARMONIE atmospheric reanalysis system (Ridal et al 2017) at 11km horizontal grid spacing downscaled to 5.5km. The boundary conditions of UERRA-HARMONIE system were provided by the ERA40 and ERA-Interim reanalysis, respectively. No downscaling was needed for the CERRA-Land system because it has exactly the same grid as the CERRA upper-air system.

For the UERRA-MESCAN-SURFEX system, the 2D surface analysis of two meter temperature and humidity was done in offline mode (online mode for CERRA-Land) every 6 h using the downscaled fields as a background whereas those surface analysis was directly taken from the CERRA upper air analysis system every 3h for the CERRA-Land system.
Both land surface reanalysis used the same surface precipitation analysis system, but the background is different and the number of in situ rain gauges observations is higher in CERRA.

# 3. Preliminary results

Among the various near surface meteorological variables, precipitation is one of significant interest, especially for hydrological studies. The snow depth (SD) simulated by land surface model may be used as an indirect validation of the precipitation forcing.

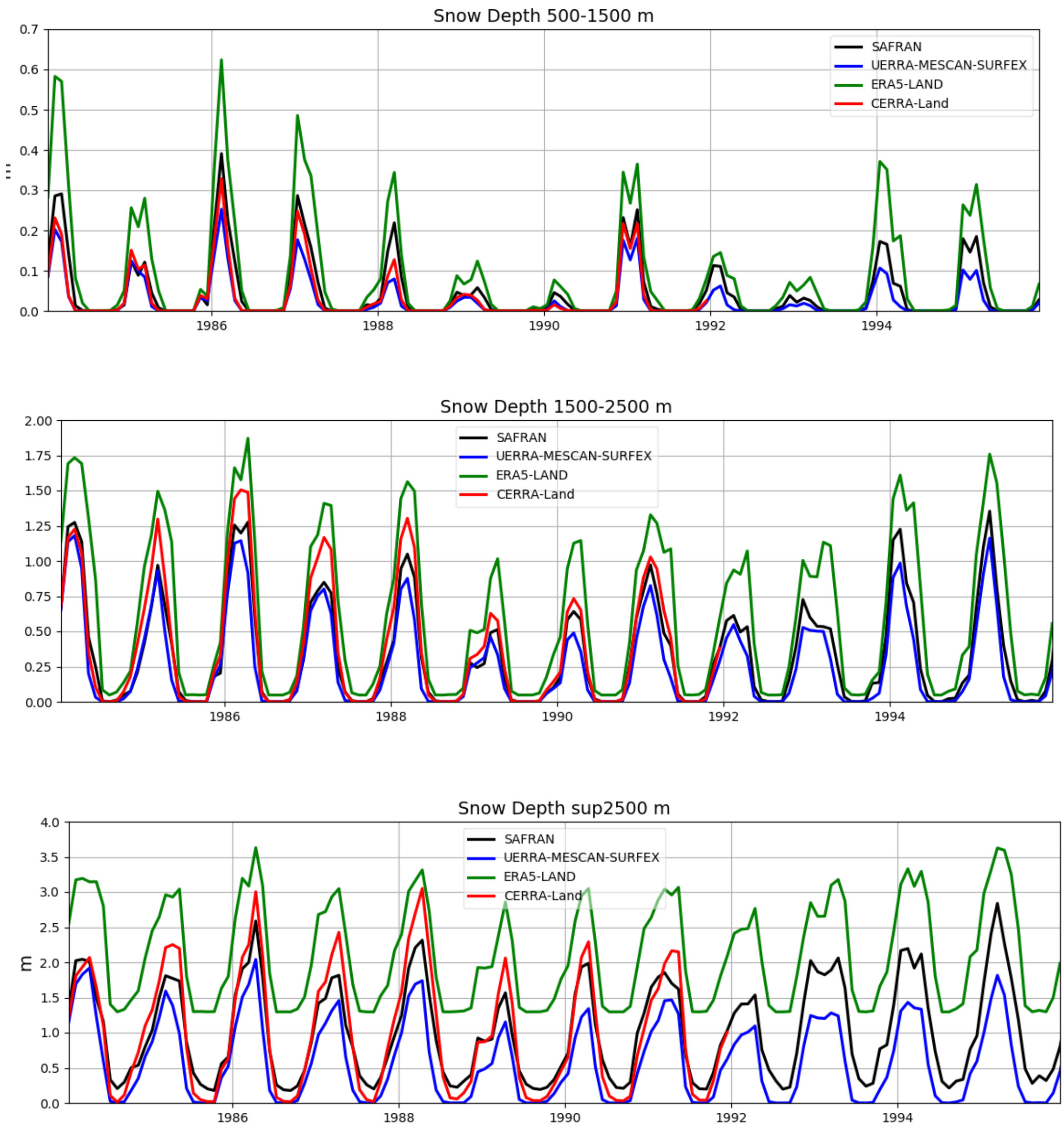



***Figure 3.1: Time series of snow depth monthly mean modelled over the French Alps by SIM (black), UERRA-MESCAN-SURFEX (blue), ERA5-Land (green) and CERRA-Land (red) for different elevation range, 500-1500m (upper), 1500m-2500m (middle) and higher than 2500m (lower). Only the period from September 1984 to December 1991 was available for the CERRA-Land system.***

The figure 3.1 shows the temporal evolution of the SD monthly mean over the French Alps simulated by CERRA-Land, ERA5-Land (Muñoz-Sabater et al. 2021), UERRA-MESCAN-SURFEX (Bazile et al 2017) and the SAFRAN–ISBA–MODCOU hydrometeorological operational model (SIM, Le Moigne et al. 2020) used at Météo-France. The SD modelled by the SIM system (black line) can be considered as a reference, even if this system tends to slightly underestimate the mean snow depth in mountainous area (not shown). The SD represented by CERRA-Land (red line) seems to be quite realistic over the French Alps in comparison with the reference. Nevertheless, it tends to simulate higher value of SD than SIM does at high altitude, whereas the UERRA-MESCAN-SURFEX underestimates it for the three class of elevation range. It might be due to a possible wet bias of the CERRA-Land precipitation analysis (see next paragraph) at high altitude. This should be addressed in more details. The plot shows also the added value of the regional land surface reanalysis against the global ERA5-Land surface reanalysis system for the representation of SD.

# 4. Known issues

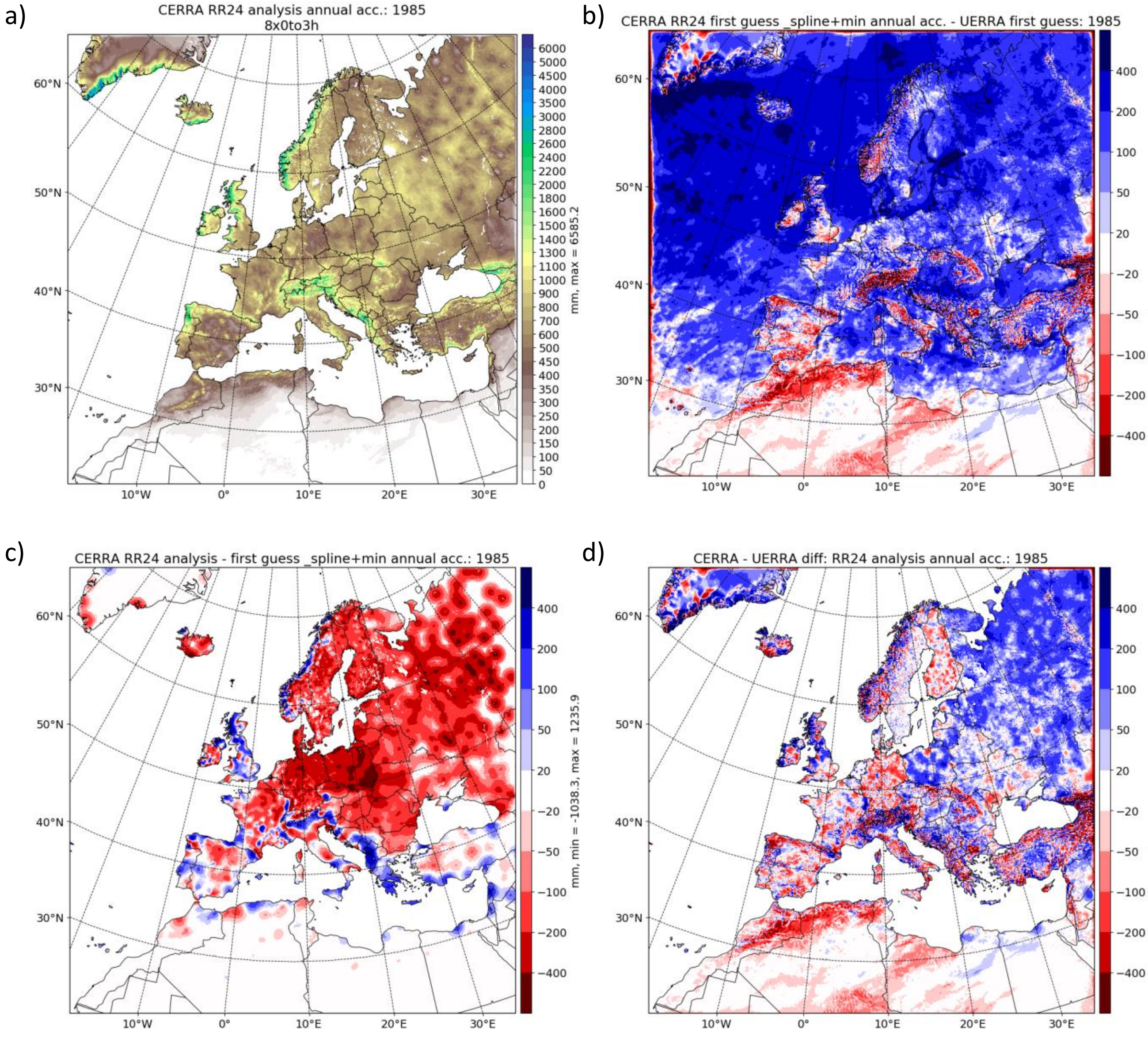
## 4.1 Suspected model wet bias (an impact on analyses with sparse/absent obs)

During production verification, some of the model biases have become apparent, which includes a model wet bias in north and eastern Europe which is impactful on the analyses since observations can be sparse there. This section offers a warning regarding the interpretation of the analyses in this region. Figure 4.1.1a shows the CERRA precipitation annual accumulation from analyses for e.g. 1985, which is what we are evaluating our confidence in.

Figure 4.1.1b shows the difference in background accumulations between CERRA and UERRA-HARMONIE. We see already that CERRA is wetter in the northern part of the domain, and particularly over the Atlantic, but we would warn that the surface analyses are not intended to be used over the ocean where there are no observations to constrain the model biases and that the focus should be over land with more observations. The differences in background can be substantial; E.g. over Hungary and Northern Serbia the CERRA background can have more than 200 mm more than the UERRA-HAMONIE equivalent where analysis accumulations give around 600 – 800 mm.

Figure 4.1.1c shows the annual accumulated increment of CERRA analyses against the background. It shows that the observations "dry" the background in a large part of the domain in the North East. In particular in north eastern Russia we see circles which represent the impact of single stations, so here the observations have become sparse. The observations over the Eastern part of Russia in the CERRA domain are also not present for the whole period, so here we would warn about the accuracy on the analyses in these regions of sparse observations.

Figure 4.1.1d shows the difference between CERRA-Land and UERRA-MESCAN-SURFEX, which supports this warning. We see white spots where observations have constrained CERRA-Land and UERRA-MESCAN-SURFEX to be the same, but blue regions where the lack of observations allow the differences in background to show through.




**F*igure 4.1.1: Annual precipitation accumulations (and differences of) for 1985: a) CERRA analyses, b) Increment between CERRA analysis and background, c) Increment between UERRA analyses and background and d) difference between CERRA and UERRA analyses. A-c have the land sea mask, but not d.***

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