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Report for the 55years MESCAN-SURFEX re-analysis

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1) Introduction

Within the UERRA project a 2D surface re-analysis have been performed at 5.5km grid space over Europe, aiming to provide added value for Essential Climate Variables (ECV) such as accumulated precipitation and 2m temperature and humidity, compared to the global atmospheric re-analysis. In this report, the observations used in the MESCAN-SURFEX analysis system is described in Section 2. Section 3 describes the MESCAN-SURFEX system following by section 4 with some statistics of the surface analysis along the 55 years. Section 5 shows some results with some examples of application such as surface fluxes, snow depth and river discharge. Discussions and some limitations will be discussed in Section 6.

2) Observations

The observations used in the surface analysis system MESCAN-SURFEX are: (i) the 2 meters temperature and relative humidity, (ii) the 24h accumulated precipitation from 6h to 6h (day+1). The surface analysis is done 4 times per day for the 2 m temperature (T2m) and relative humidity (RH2m) and once a day for 24h-precipitation (RR24). Several databases were merged to increase the number of observations used in the fine scale (5.5km) surface analysis. Additional national data from the Swedish, Norwegian and French Meterological services have been added to the observations available at ECMWF on the MARS archive coming mainly through the GTS system. The Worck Package 1 (WP1) of the UERRA project provides also some T2m observations mainly in the Southern part of Europe and the observed RR24 from ECA&D database were used. Fig. 1 shows the number of observations used in the MESCAN-SURFEX re-analysis from the WP1 for the T2m, the data rescue from WP1 has been beneficial before the 80’s and after 1989 with additional data from Catalonia.

The total number of the observed 2m temperature (Fig: 2) and relative humidity observations increases almost regularly along the period as shown in Fig 2 for T2m. A first increase of ~1000 observations occurred in 1967 and a second jump in 2002. In between the number of observed T2m used in the analysis was almost constant.

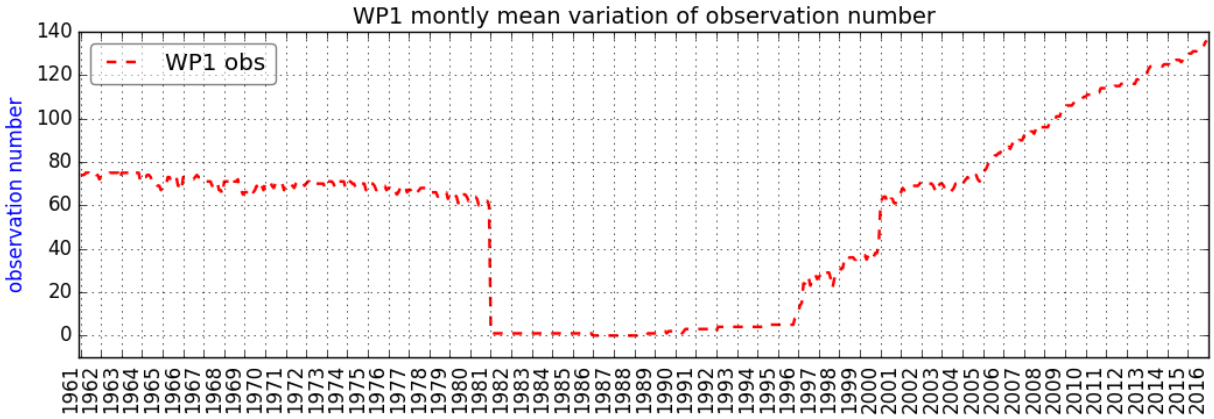

Fig 1: Number of T2m observations provided by WP1 and used in the re-analysis

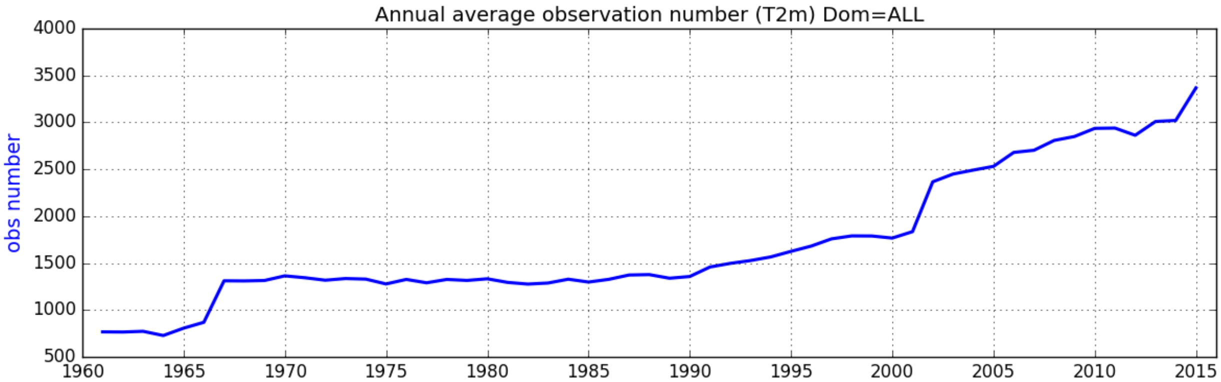

Fig 2: Number of T2m observation used in the surface analysis

For the precipitation observations, the period chosen is between 6UTC and 6UTC the day after. Several databases were used: ECA&D, ECMWF and national database (Norway, Sweden) or partial database from France. Unfortunately, it was not possible to use all the precipitation observations available in ECA&D due to some missing informations for the observation period or an incorrect time duration (from 6UTC to 6UTC). In addition, from the MARS database no 24h accumulated precipitation observations were available, however some observations with a 12h accumulated precipitation have been used by adding two successive observations. Finally, the number of the precipitation observations (Fig 3) varies from 2200 in the 1960 up to 4000 in 2010. Nevertheless, the evolution of the number depends strongly on the area in Europe as shown in (Fig: 4) for the Eastern part of Europe ([20W; 48.5] [30W;54.2N]) with no data available before 1978 compared to the Scandinavian area ([5W; 55N] [25W;72N]) where the number of observation is almost constant.

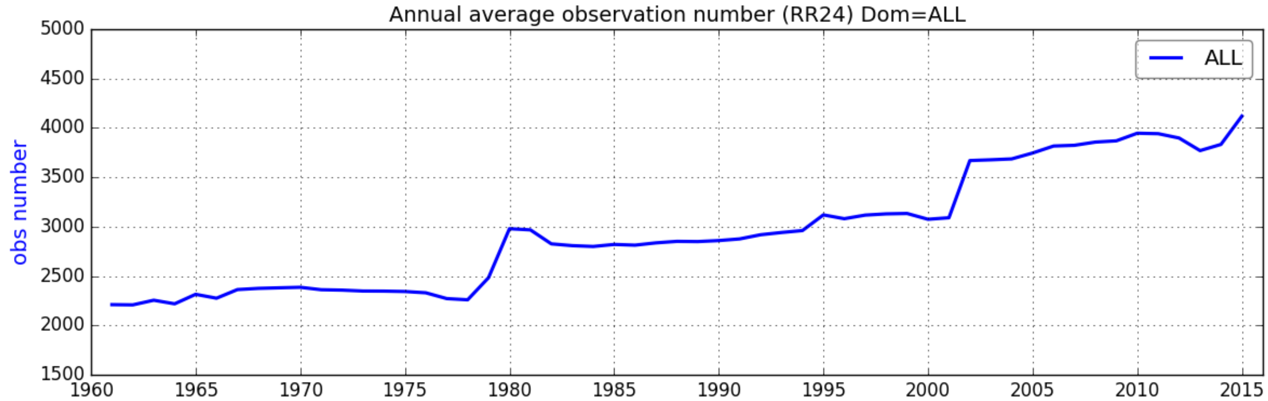

Fig 3: Number of the 24h accumulated precipitation observation used in the re-analysis

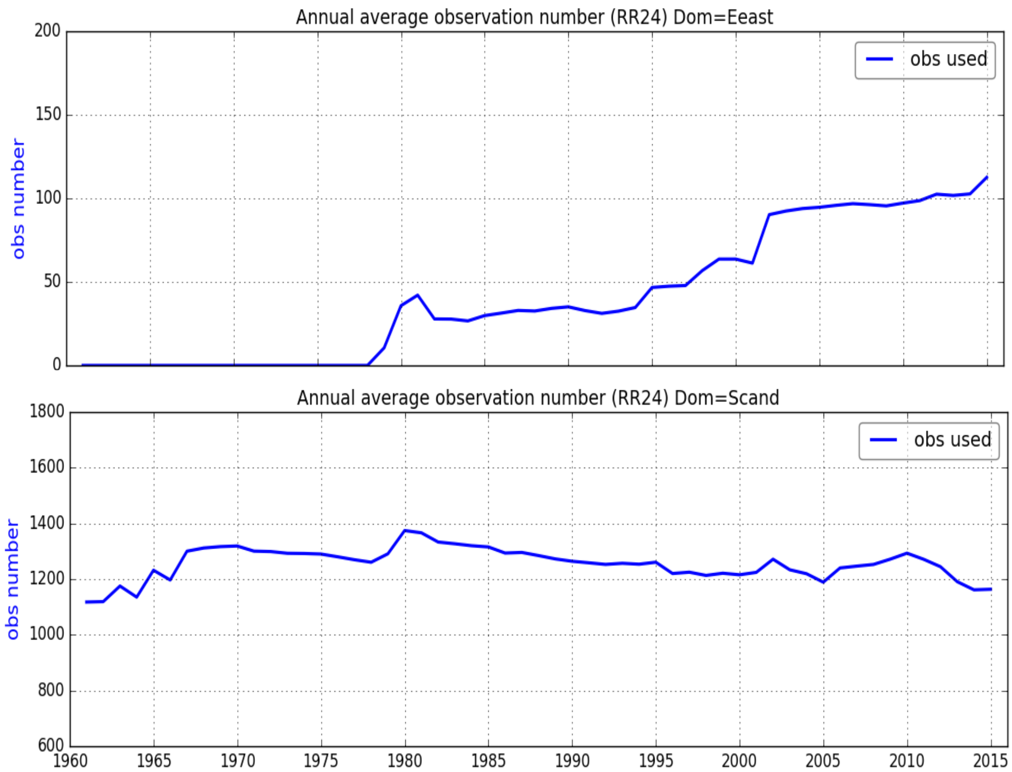

Fig 4: Number of the 24h-accumulated precipitation observation. Top Eastern part of Europe. Bottom Scandinavian area

A re-analysis on a long period has at least two main challenges or objectives:

- an homogeneous quality in space and in time, especially to avoid spurious effect on trends due to a change of the observation network
- a fine scale analysis “must” use all the observations available and very close to the observed value.

The quality of the surface analysis is strongly dependent in time and space on the observations network density and on the background field especially where observations are sparse. For climate studies, 2m-temperature or precipitation trends are often used to characterize the climate change. In this respect, an estimate of the impact of the density network on the re-analysis has been estimated for the short period 2006-2010 and described in the UERRA report D2.9. The figures 3a and 3b from the UERRA report D2.9 show clearly the areas where observations are not available for some periods.

3) MESCAN-SURFEX description

The MESCAN-SURFEX system is based on two separate tools :

- 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 MESCAN’s version have been described in details by Soci et al. (2013, EURO4M report D2.6) for the screen level analysis 2m temperature (T2m) and relative humidity (RH2m). The 24h-total accumulated precipitation analysis used in the UERRA project has been developed and implemented in the MESCAN system during the EURO4M project by Soci et al. (2016).

- SURFEX (Masson et al, 2013) is a land and ocean surface platform (Fig. 5) that describes the surface processes, computes surface fluxes, soil heat transfer etc … The diffusive approach is used to compute the heat and water transfer in the snow and in the soil with 14 layers. SURFEX is driven by atmospheric forcing at 5.5km of T2m, RH2m and 24h-precipitation analyzed by MESCAN and by the radiative fluxes and wind. The radiative fluxes and wind are downscaled at 5.5km from the 3DVar re-analysis done at 11km with the HARMONIE system and the ALADIN model (Ridal et al. 2017, UERRA report D2.7). More details can be found in (P. Le Moigne et al., 2017, UERRA report D4.8)

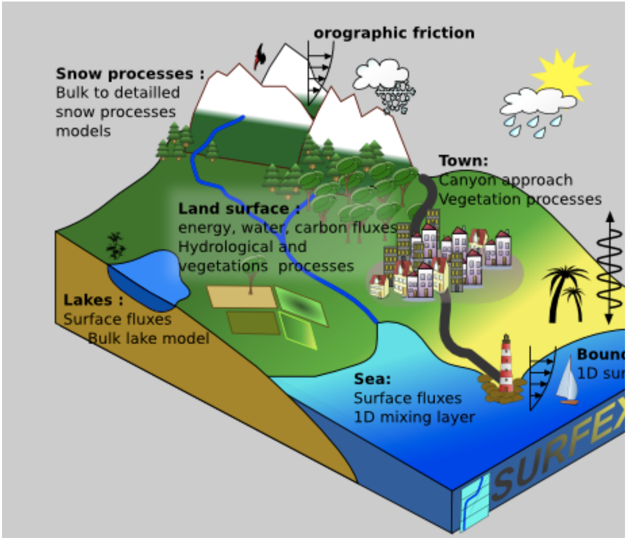

Fig 5: Schematic of SURFEX (from Masson et al., 2013).

a) MESCAN characteristics for the 2m-temperature and relative humidity analysis:

The structure function used in MESCAN for the near surface variables (Fig: 6), 2m-temperature (T2m) and relative humidity RH2m has the following expression :

$$Cor_{Surf}(r,d_p,d_z)=0.5\left[e^{-\frac{r}{L}}+\left(1+\frac{2r}{L}\right)e^{-2\frac{r}{L}}\right]F_p(d_p)F_z(d_z)$$

r is the distance between two points on the same horizontal surface, $F_p(d_p)$, and $F_z(d_z)$ are empirical linear functions to take into account respectively the land-sea mask difference d_p and the difference of height, d_z, between two locations. These functions vary from 1, for $d_p= d_z=0$, to 0.5 for $d_p=1$ and $d_z \geq 500$m, respectively (Häggmark et al. (2002)). L is the characteristic horizontal scale set at 190Km.

The observation standard deviation error, σ_o, is set to 0.2 for RH2m and for T2m a dependency to the measured temperature is used, as it is in MESAN (Häggmark et al. (2002)) with T_{ref}=270K. It is a way to take into account the lower accuracy of the instrument with cold temperature.

$$\sigma_o=\begin{cases} 1.5+0.1\cdot(T_{ref}-T_{2m})+0.15\cdot\left[(T_{ref}-10)-T_{2m}\right], & T_{2m}<260 \\ 1.5+0.1\cdot(T_{ref}-T_{2m}), & (T_{ref}-10)\leq T_{2m}<T_{ref} \\ 1.5, & T_{2m}\geq T_{ref} \end{cases}$$

The background standard deviation error, σ_b, is set to 0.3 for RH2m and for T2m the value is higher during winter Nov, Dec, Jan, Feb with 8K and lower for June and July with 5K, the rest of the year the value is set to 7K, this season dependency of σ_b could be justified by the fact that model errors are higher during winter due to the stable boundary layer, fog and/or snow cover.

b) MESCAN 24h-precipitation analysis:

For the 24h-precipitation analysis the background is computed with 4 successive 6hours forecast from 6,12,18 and 00UC instead of a 24h forecast from 6UTC or 2 successive 12h forecast from 6UTC and 18UTC. The main reason of this choice was to save time for the downscaling method (11km to 5.5km) with less downscaling computation. Nevertheless, an objective evaluation done for 1 year shows similar results in term of analysis of precipitation between the different options.

The background error spatial correlation function (Fig: 6) is expressed as follow with L=35km :

$$Corr_{RR}(r)=\left(1+\frac{r}{L}\right)\cdot\exp\left(\frac{-r}{L}\right)$$

The background standard deviation error σ_b is set to 13mm but the observation standard deviation error, $\sigma_{o,}$ previously set to 5mm for the MESCAN-ENS described in the UERRA report D2.9 has been modified with a variable $\sigma_{o,}$ function of the rainfall intensity to reduce the number of wet days in the analysis :

- RR_obs=0.mm → σ_o=0.001 mm
- RR_obs<50mm → σ_o=0.7+RR*0.1 mm
- RR_obs ≥ 50mn → σ_o=5.7 mm

4) Statistics from the analysis

The monitoring of the analysis is a necessary tool to verify if the system is working properly especially without any drift or jump for the incoming observations due to unexpected reasons. An other aspect of the monitoring is to compare the 6h forecast used as the background and the observations (first guess departure) and then the analysis departure. A monthly mean first guess departure (red) and analyse departure (blue) are shown in Fig. 7 and Fig. 8 for the temperature. As usual and expected, an annual cycle exists for the first guess departure with more bias during winter. However, the analysis departure (blue) is very close to zero for all the period. Fig 8 shows the same diagnostics but with a 12 months moving mean. We can notice a slight increase of the first guess departure after 1992 (from 0.2°C up to 0.8°C) due probably to an increase of the number of observation in some “cold” regions (Alps and Eastern part of Europe), where the models have higher errors due to the stable boundary layers and snow cover. Nevertheless the analysis departure (Blue line) is around -0.01°C for all the period except for the first 25 years.

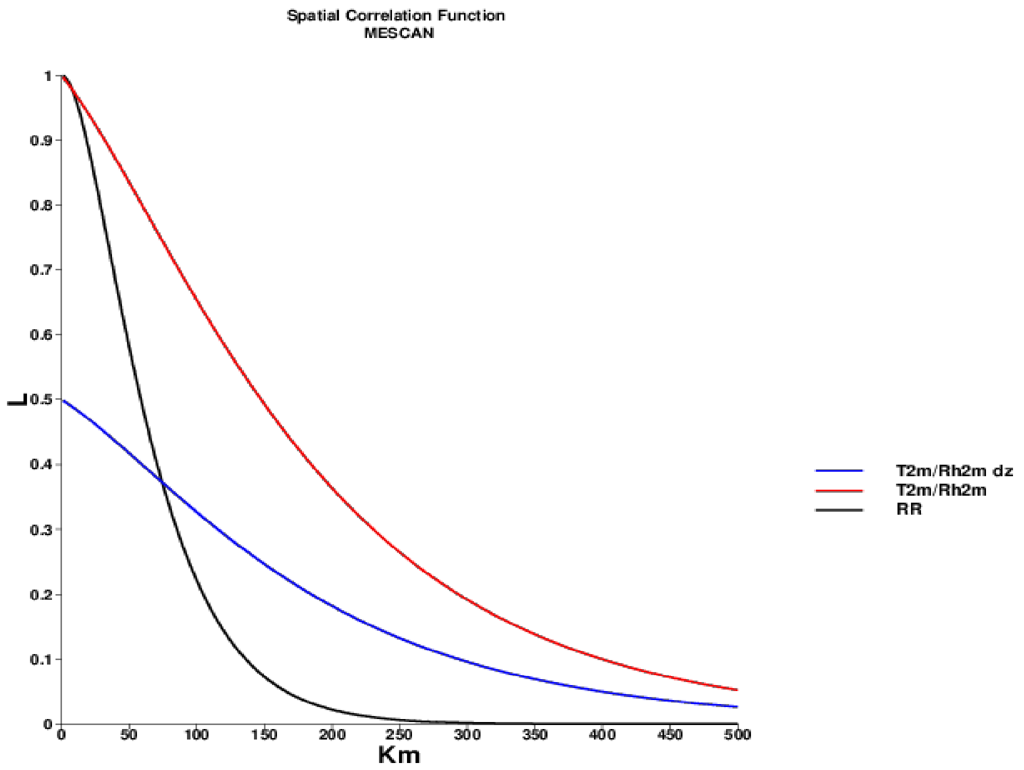

Fig 6: Horizontal background error spatial correlation function used in MESCAN: for (i) precipitation (black line), (ii) T2m and RH2m if the difference of elevation between the model and the observation is zero (red line), (iii) T2m and RH2m if the difference of elevation between the model and the observation is 500m (blue line).

In Fig. 10, the monitoring of the 24h-precipitation does not show drifts or high value for the first guess departure at the monthly scale. Nevertheless, at the daily scale (not shown), those diagnostics were very useful to detect erroneous observations (finally corrected manually) and re-run the analysis. For a first use, of the MESCAN precipitation analysis on a long period (55years), the results are very encouraging with an analysis departure around 0.1mm for all the period.

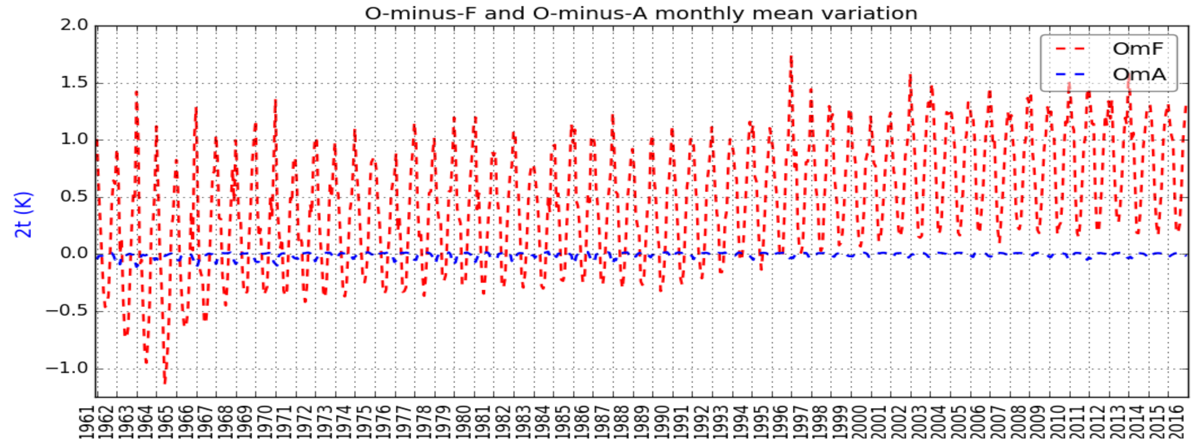

Fig 7: Monthly first guess departure (O-F) and analysis departure (O-A)for T2m

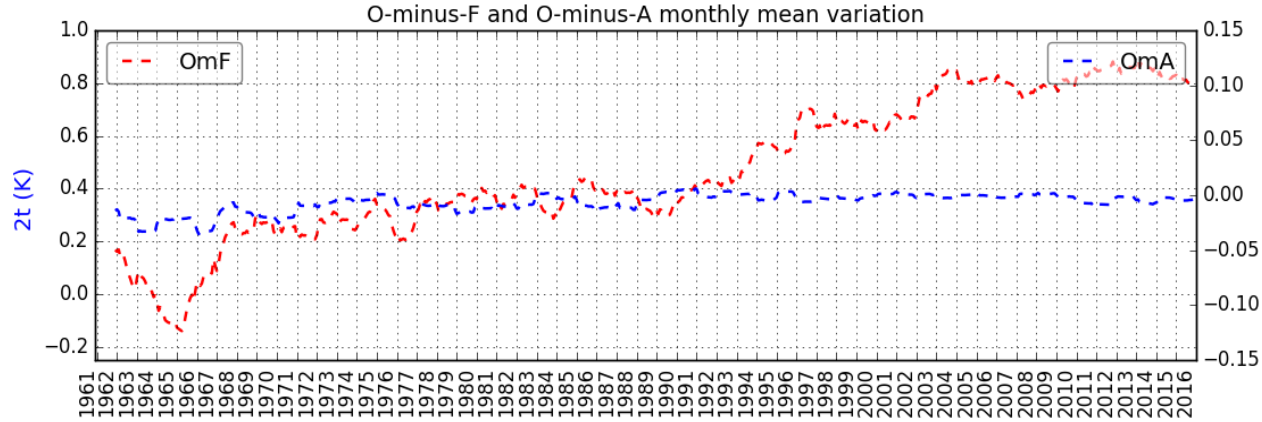

Fig 8: 12 months moving mean for (O-F) and (O-A) for T2m

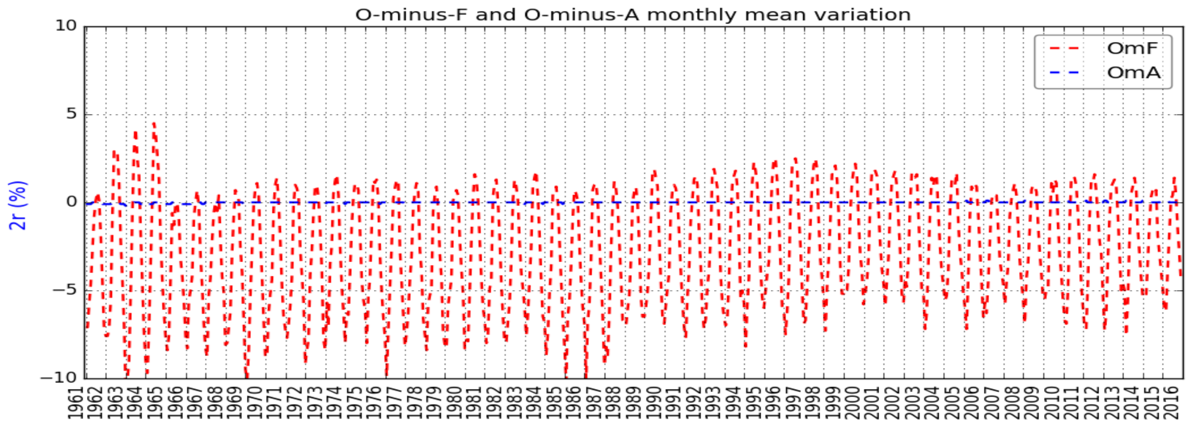

Fig 9: Monthly first guess departure (O-F) and analysis departure (O-A)for RH2m

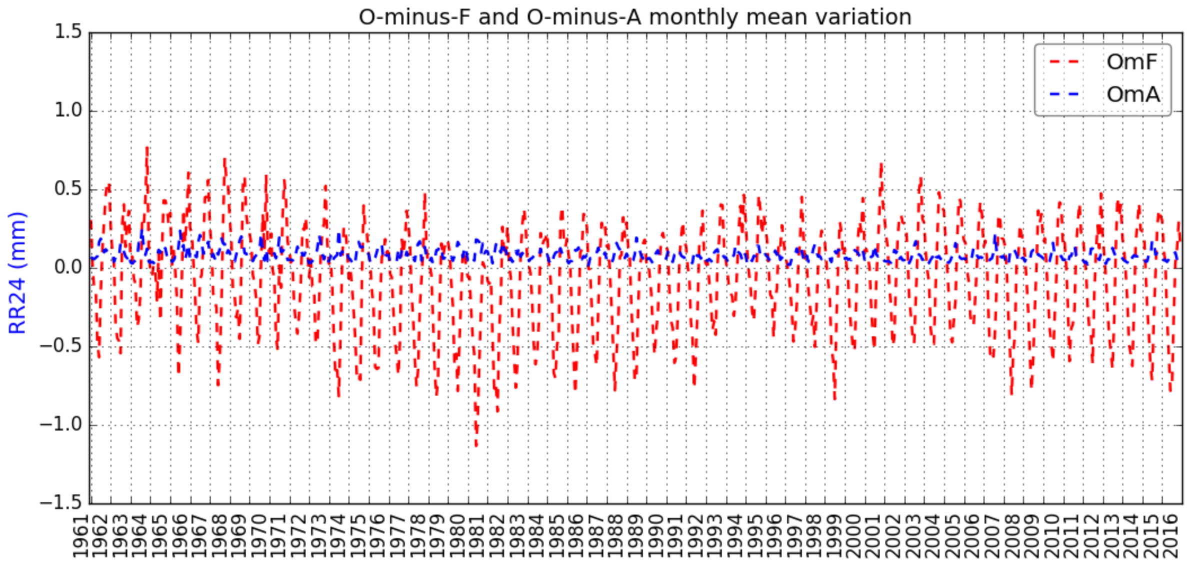

Fig 10: Monthly first guess departure (O-F) and analysis departure (O-A) for 24h rainfall

5) Some results of the MESCAN-SURFEX analysis

In this section, some preliminary results are shown for several Essential Climate Variables (ECV) such as T2m, precipitation, snow cover, snow depth and some surface fluxes with maps or time series for 6 domains (see Appendix A). For the time series the number of observations available and used in the analysis is always plotted with the variable. It is highly recommended for the user to have an idea of the evolution of the observation number along the 55 years. In some regions, over mountains or depending of the horizontal scale, the observations number can change significantly and could some times explain some part of the trends. In parallel, it is highly recommended to use the MESCAN-SURFEX-ENS output even if the ensemble is available on a short period (2006-2010) (UERRA report D2.9)

- **55 years time series for annual mean 2m temperature:**

Fig. 12-15 show time series of T2m annual mean from 1961 to 2015 for 4 different domains Alps, Atlas, Scandinavia and East Europe. An increase of the temperature is clearly seen for the 4 domains with may be a more pronounced warming for the Alps and the Scandinavian area. However, due to the significant increase of the number of observations for the Alps (Fig 11) and the Scandinavian area (Fig. 12) after the year 2000, the user can ask: “ how this increase of the observations number impacts the intensity of the warming ? “One possible option to address this question is to use the MESCAN-SURFEX-ENS (UERRA report D2.9). Fig. 16 shows an example of how to use the ensemble for the Scandinavian area to have an idea of the uncertainties. Some members of the ensemble use a low density network for observations, but none of the 8 green lines are below the reference re-analysis it means that the additional observations, used in the reference re-analysis, corrects in a more efficient way a warm bais of the background.

However, for the Pyrénées (Fig. 17), a smaller domain, where the UERRA fine scale re-analysis at 5.5km improves significantly the monthly mean T2m compared to the global re-analysis done at lower resolution, the uncertainties (green lines) or the spread is more important. The user can easily noticed that before 1995 less than 3 observations were used in the system for this domain.

Nevertheless, for all the domains shown in this report, an increase of the T2m about 1 or 2°c is observed in the MESCAN re-analysis during the 55 years period. For the winter (December, January and February) the increase of the T2m can be greater than 1°C/10years in mountain regions in Europe : Alps and Norway (Fig. 11)

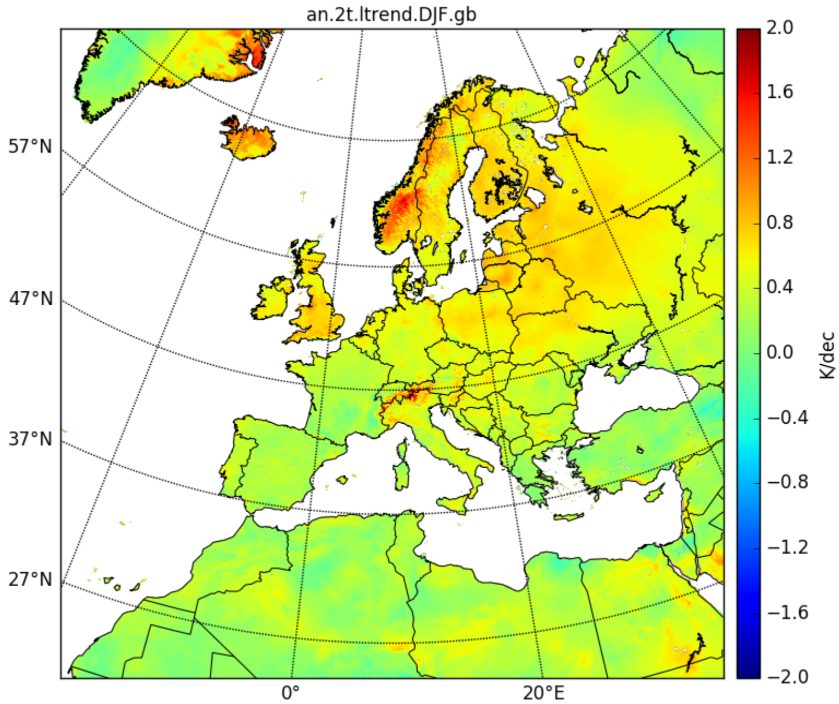

Fig 11: T2m trends in Kelvin/10years for the period December/January/February

- **<u>55 years time series for annual precipitation:</u>**

Figures 18-21 do not show a clear tendency for the annual accumulated rainfall. However, a slight decrease of the accumulated rainfall can be seen especially over the Alps and the Pyrénées. The uncertainties estimated for the period 2006-2010 (UERRA report D2.9), show a very large spread (Fig 20-21). Moreover, the number of observations increased significantly for the Alps and the Pyrénées after 2000. Those additional observations, used in the analysis, could explain partially the decrease of the annual accumulated rainfall due to a more efficient correction of the overestimation model rainfall (background) over mountain, which is a very well known and old problem in Numerical Weather Prediction (Wang and Bazile (2003)) but still valid even at the kilometer scale (Vionnet et al. (2016)).

- **<u>Other examples for output variables</u>** :

In Fig. 22, the annual mean Snow Water Equivalent (SWE) is shown for 3 domains: Scandinavia, East Europe and Alps. As expected and in agreement with a warmer temperature, the SWE decreases for the 3 domains and may be more rapidly over the Alps. However, the “user” should keep in mind the uncertainties in the precipitation analysis (discussed above) and compared to the SWE computed with the MESCAN-SURFEX-ENS. Fig. 23 shows an example of the MESCAN-SURFEX 2d fields such as the snow depth for several years, the spatial variability of the snow extend can change significantly especially over the eastern part of Europe with almost no snow cover over eastern Europe in 2015. The MESCAN-SURFEX snow depth product can be evaluated against the independent snow depth observations (not used in the system) and against super sites observations such as Sodankÿla shown in Fig 18-20 in the UERRA report D2.9.

Fig. 24 shows a comparison at the Col de Porte site in the Alps, the snow depth is underestimated by MESCAN-SURFEX for almost all the periods but the inter annual variability follows well the observation variability. Nevertheless, after 1980, the underestimation is reduced especially after the year 2000. It is probably an effect of a denser observation network available for the precipitation analysis.

All the components of the surface energy budget and water budget such as surface fluxes, evaporation, soil heat flux, soil wetness index (SWI) etc .. have been produced. Fig 25 shows a climatology for the period 1962-2010 for the surface sensible and latent heat flux and SWI.

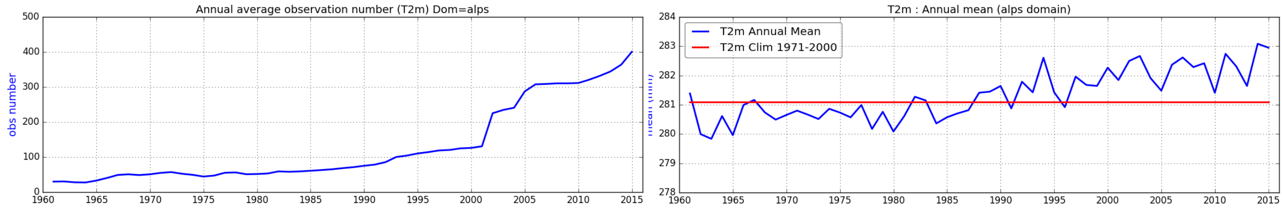

Fig 12: Alps: Left : Number of T2 observations used in the re-analysis. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000)

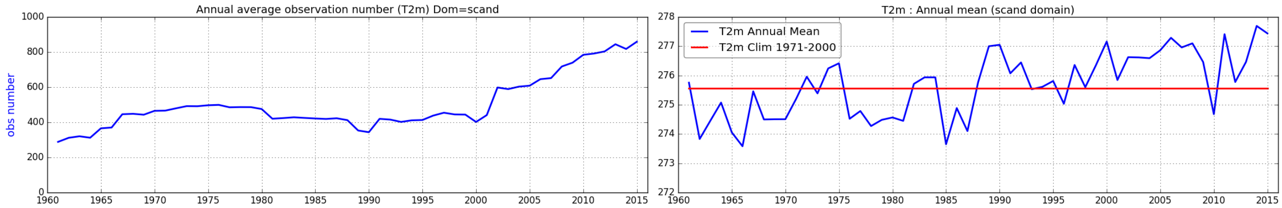

Fig 13: Scandinavia: Left : Number of T2 observations used in the re-analysis. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000)

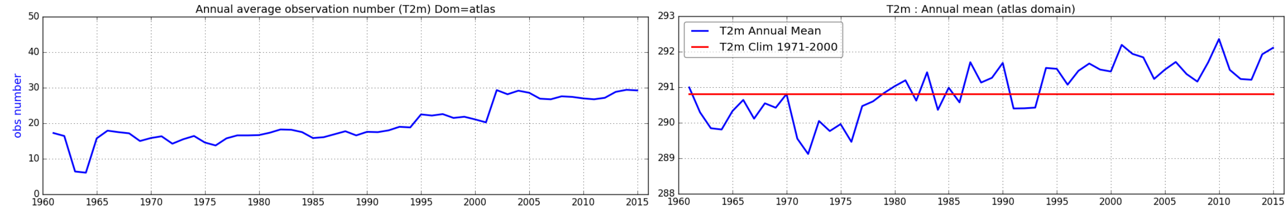

Fig 14: Atlas: Left : Number of T2 observations used in the re-analysis. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000)

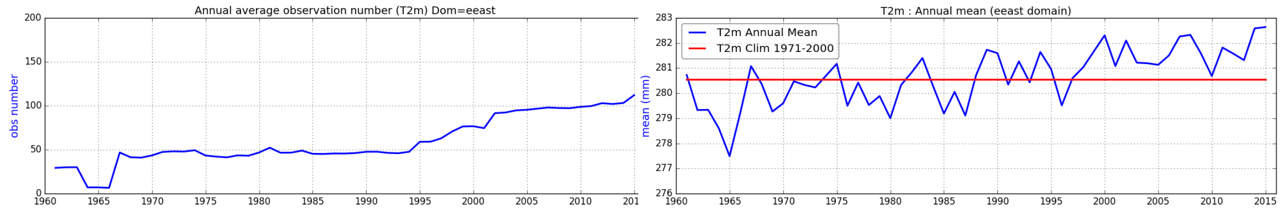

Fig 15: East Europe: Left : Number of T2 observations used in the re-analysis. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000)

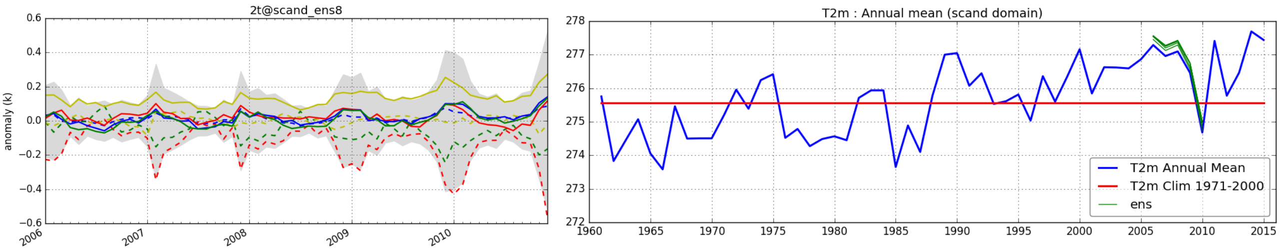

Fig 16: Scandinavia: Left : Anomaly or uncertainties of T2m monthly mean around the ensemble mean. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000). Green line 8 members of the ensemble

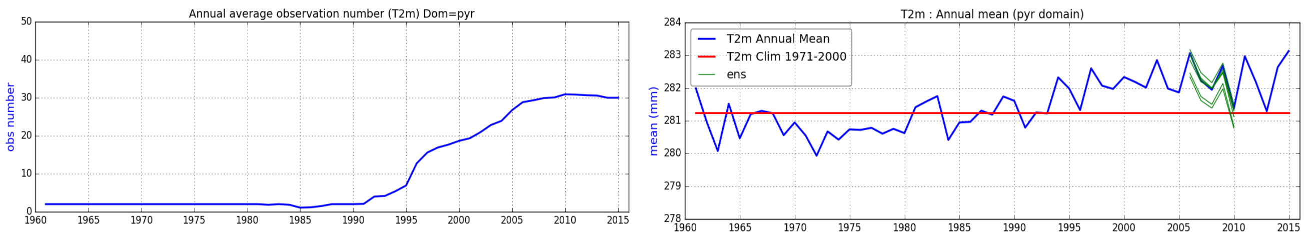

Fig 17:Pyrénées Left : Number of T2 observations used in the re-analysis. Right: Annual mean T2m (blue). Climatological T2m from the re-analysis (1971-2000) Green line 8 members of the ensemble

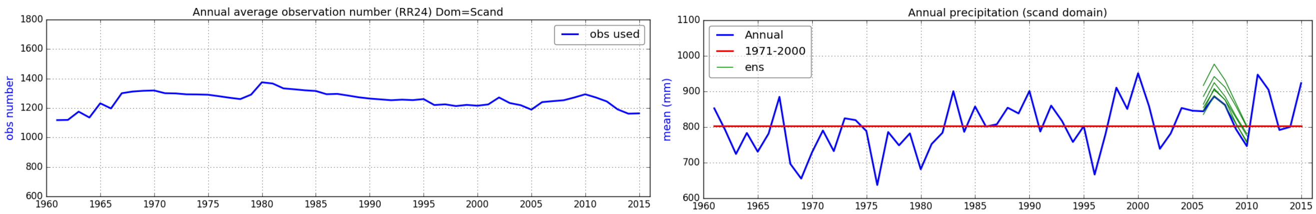

Fig 18: Scandinavia Left : Number of 24h rainfall observations used in the re-analysis. Right: 24h rainfall annual mean (blue). Climatological of 24h rainfall from the re-analysis (1971-2000) Green line 8 members of the ensemble

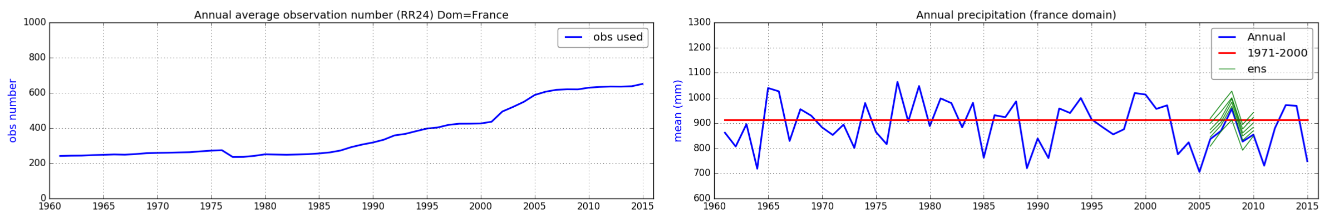

Fig 19: France Left : Number of 24h rainfall observations used in the re-analysis. Right: 24h rainfall annual mean (blue). Climatological of 24h-rainfall from the re-analysis (1971-2000) Green line 8 members of the ensemble

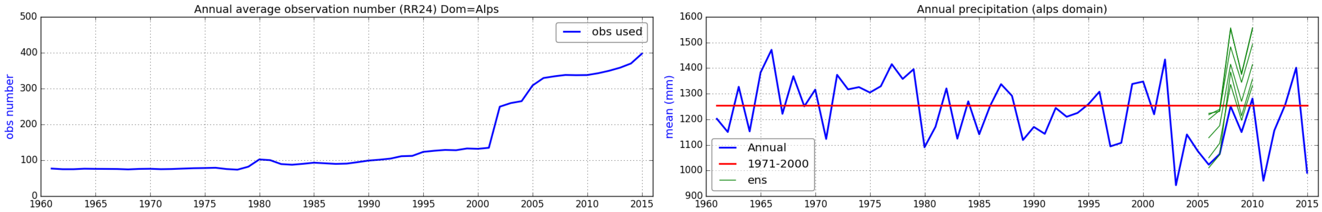

Fig 20: Alps Left : Number of 24h rainfall observations used in the re-analysis. Right: 24h rainfall annual mean (blue). Climatological of 24h-rainfall from the re-analysis (1971-2000) Green line 8 members of the ensemble

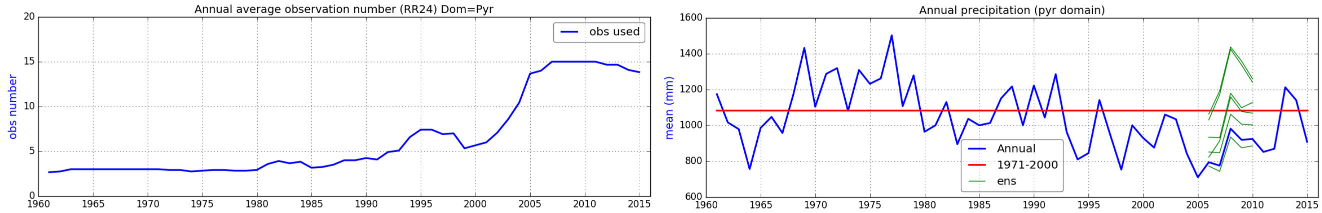

Fig 21: Pyrénées Left : Number of 24h rainfall observations used in the re-analysis. Right: 24h rainfall annual mean (blue). Climatological of 24h-rainfall from the re-analysis (1971-2000) Green line 8 members of the ensemble

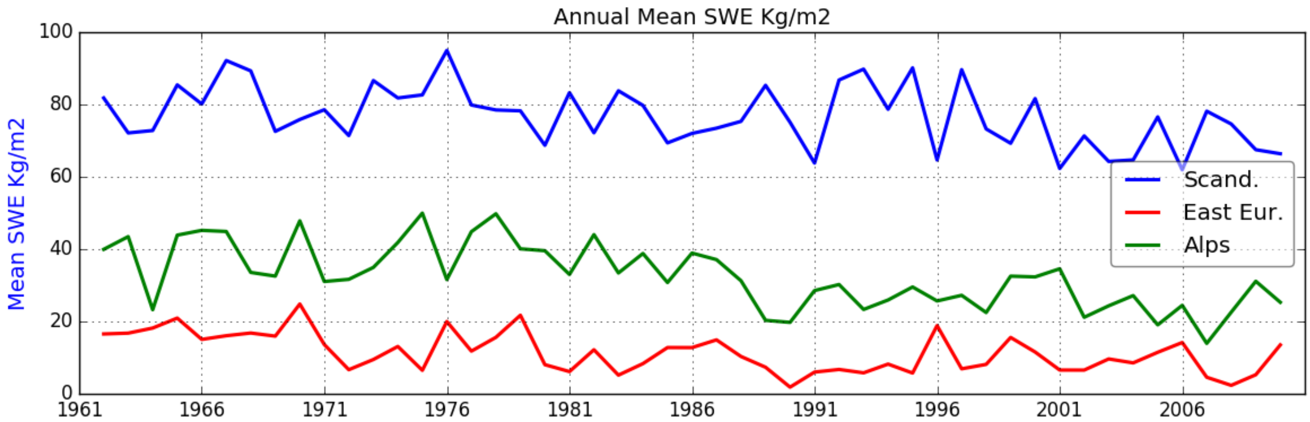

Fig 22: Annual mean of the Snow Water Equivalent SWE (Kg/m2)

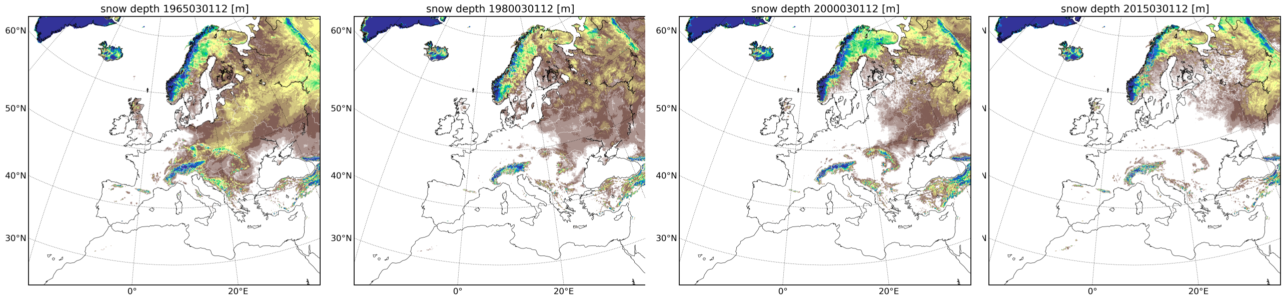

Fig 23: Snow depth (m) for the 1st March 1965, 1980, 2000, 2015

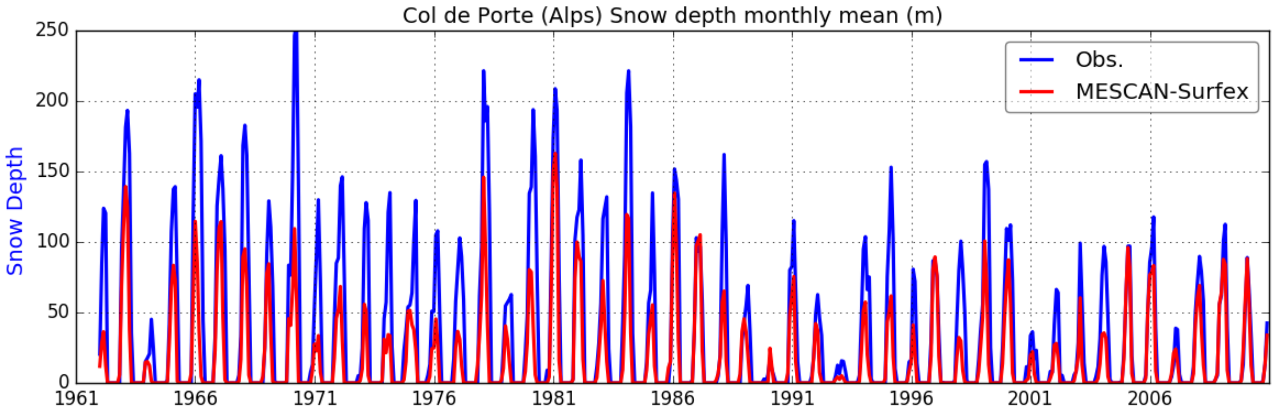

Fig 24: Snow depth monthly mean Col de Porte (Alps)

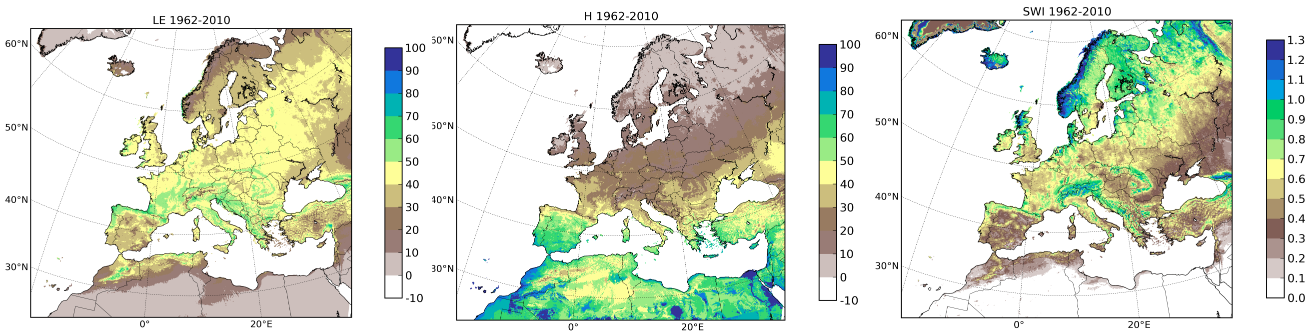

Fig 25: Climatology of surface Latent heat (Left), surface Sensible heat (Middle) and Soil Wetness Index

An other way to use and validate the MESCAN-SURFEX analysis is to couple the hydrological model CTRIP (Decharme et al. 2012) and to compare river discharge computed by MESCAN-SURFEX-CTRIP against measurements from the Global Runoff Data Center (GRDC). Fig. 26 shows the river discharge for the Danube river, the river discharge computed with MESCAN-SURFEX-CTRIP is in a good agreement with the observed value. More details and results can be found in Le Moigne et al (2017).

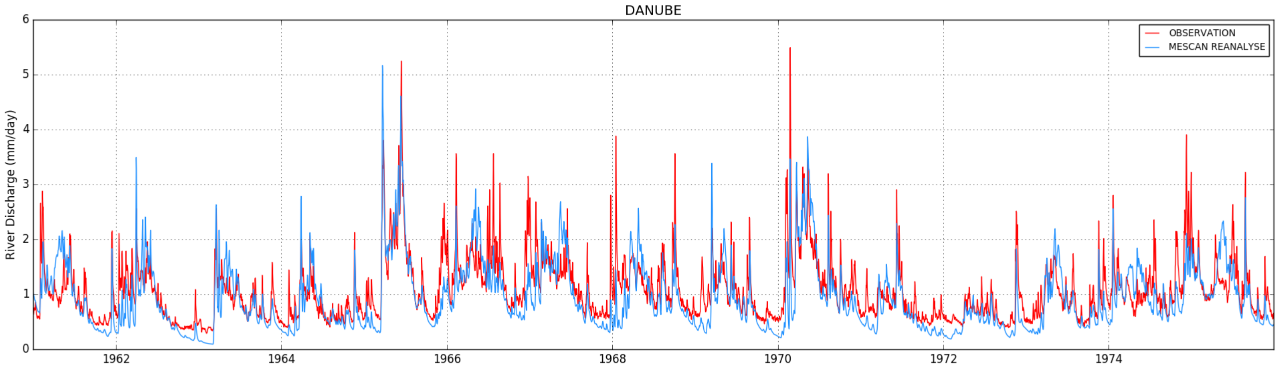

Fig 26: Danube River discharge

6) Conclusions and remarks

This report describes the configuration of the MESCAN-SURFEX re-analysis system used to provide 55 years of surface and soil variables over Europe at 5.5km. The diagnostics of the re-analysis statistics errors (analysis departure) are almost constant for all the period and preliminary results (long time series, maps, etc ..) are encouraging and do not show important deficiencies.

In addition to the classical ECV (T2M, Wind, RH2m, Rainfall), the first evaluation for the surface MESCAN-SURFEX output such as snow cover, snow depth, river discharge or surface fluxes are improved compared to ERA-I/SURFEX and very promising due probably to a higher horizontal resolution used in the surface analysis and the first precipitation analysis done over Europe.

Uncertainties computed on a short period (2006-2010) are necessary and should be the “users” with the observation statistics.

However, for the next version or generation of surface analysis with a higher resolution, especially for the precipitation analysis, an effort should be done to create a better database especially for precipitation observations to avoid areas with sparse observations.

A better automatic quality control for the precipitation analysis must be developed in order to reject the erroneous observation without rejection of extreme rainfall events occured the South East of France or in Italy.

The list of the surface variables and surface fluxes available on the MARS archive provied by the the MESCAN-SURFEX system is described in appendix B.

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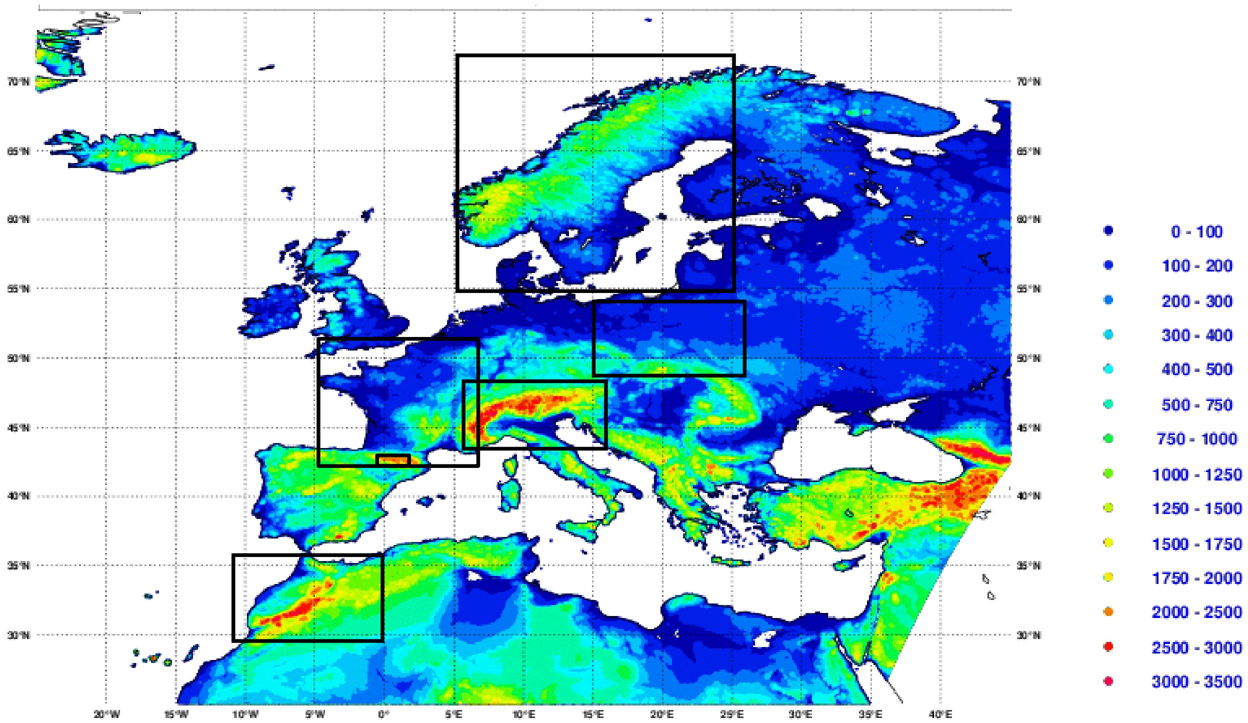
Appendix A :



Atlas [-11.7E; 29N] [-0.3E;36N]. Alps [5.35W; 42.82N] [16.W;48N].

Scandinavia [5W; 55N] [25W;72N]. East Europe [20W; 48.5] [30W;54.2N].

France [-5W; 42] [7W;51.4N], Pyrénées [-1W; 42] [2.5W;43.10N]

Appendix B : Parameter list for MESCAN-SURFEX available on MARS (ECMWF)

MESCAN-SURFEX: (lfpw, oper) for type=an

UERRA GRIB2				
Parameter	Unit	paramId	shortName	Time
Accumulated total precipitation	kg m-2	228228	tp	Only available at 6h (24h accumulated from 6 to 6)
2m relative humidity	%	260242	2r	0, 6, 12, 18
10m wind speed	m s-1	207	10si	0, 6, 12, 18
10m wind direction	degree true	260260	10wdir	0, 6, 12, 18
2m temperature	K	167	2t	0, 6, 12, 18
Land cover (1=land,0=sea)	(0-1)	172	lsm	constant
Orography (surface geopotential height)	m	228002	orog	constant

MESCAN-SURFEX: (lfpw, oper) for type=fc

UERRA GRIB2				
Parameter	Unit	paramId	shortName	Time
Surface pressure	Pa	134	Sp	av. at 6h step
Accumulated total precipitation	kg m-2	228228	tp	av. at 6h step
2m relative humidity	%	260242	2r	av. at 6h step
2m temperature	K	167	2t	av. at 6h step
10m wind speed	m s^{-1}	207	10si	av. at 6h step
10m wind direction	degree true	260260	10wdir	av. at 6h step
Direct short-wave radiation flux at the surface	J m^{-2}	260264	tidirswrf	av. at 6h step
Net long-wave radiation flux at the surface	J m^{-2}	177	str	av .at 1h step
Net short-wave radiation flux at the surface	J m^{-2}	176	ssr	av. at 1h step
Surface solar radiation downwards	J m^{-2}	169	ssrd	av. at 1h step
Surface thermal radiation downwards	J m^{-2}	175	strd	av. at 1h step

Surface runoff	kg m^{-2}	174008	sro	av. at 1h step
Albedo	%	260509	al	av. at 1h step
Surface latent heat flux	J m^{-2}	147	slhf	av. at 1h step
Surface sensible heat flux	J m^{-2}	146	sshf	av. at 1h step
Skin temperature	K	235	skt	av. at 1h step
Water equ. of acc. snow depth	kg m^{-2}	228141	sd	av. at 1h step
Acc. total snowfall	kg m^{-2}	228144	sf	av. at 1h step
Snow density	kg m^{-3}	33	rsn	av. at 1h step
Snow depth	m	3066	sde	av. at 1h step
Soil temperature on 14 levels	K	260360	sot	av.at 1h step
Volumetric total soil water on 14 levels	m3 m^{-3}	260199	vsw	av.at 1h step
Liquid non-frozen volumetric soil moisture on 14 levels	m3 m^{-3}	260210	liqvsm	av.at 1h step
Soil heat flux	J m^{-2}	260364	sohf	av.at 1h step
surface roughness	m	173	sr	av.at 1h step
Volumetric wilting point	m3 m^{-3}	260200	vwiltm	constant
Volumetric field capacity	m3 m^{-3}	260211	voltso	constant