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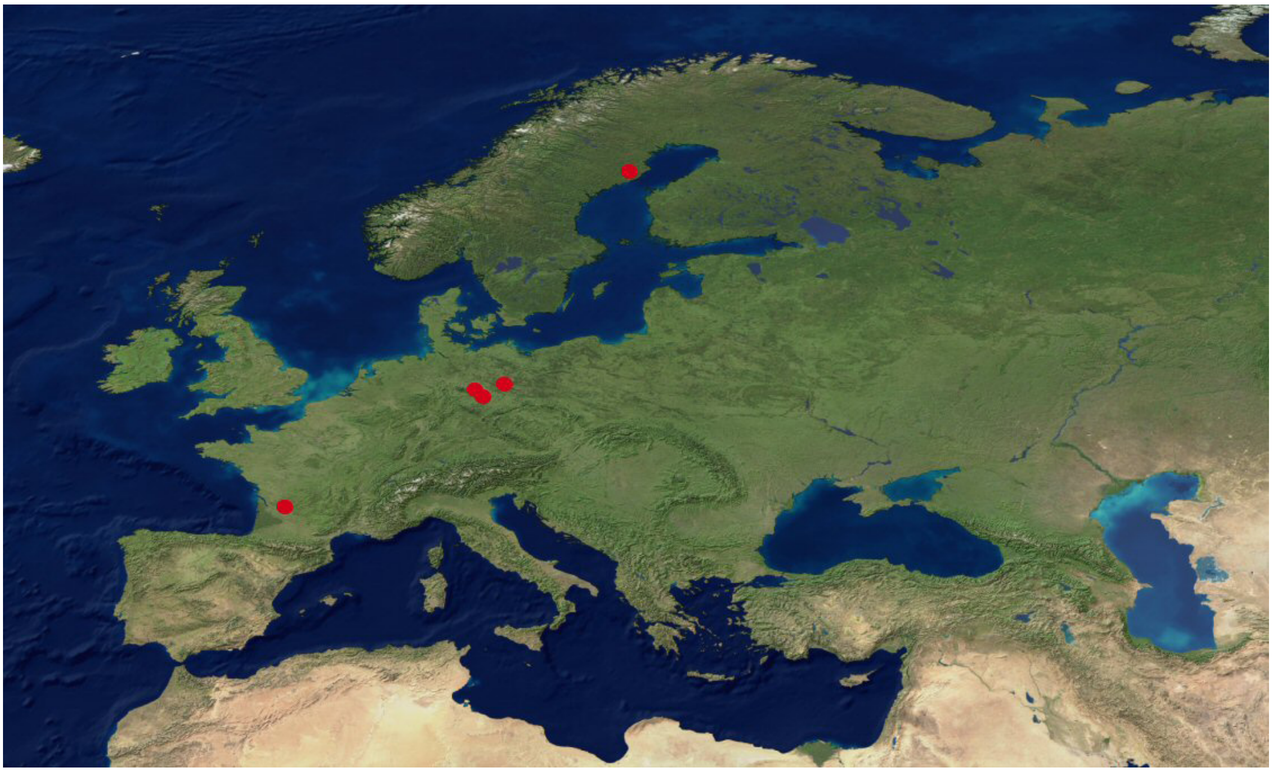

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A comparison of regional climate variables between various data sources

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Abstract

Climate parameters such as temperature, precipitation, radiation, etc. are important forcing factors for the ecosystem modeling. The reanalysis dataset, which is a result of data assimilation using a state-of-the-art weather analysis/forecast modeling system, provides these climate variables. Two well-known reanalysis datasets are from National Centers for Environmental Predictions (NCEP), USA and from European Centre for Medium-Range Weather Forecasts (ECMWF),UK. In addition, there are other climate datasets similar to reanalysis data such as the one from REgional MOdel (REMO), developed in Germany. Since there are several available climate datasets, we had compared these reanalysis data and attempted to find which one could be better for the ecosystem modeling or for investigation of uncertainty. We compared these reanalysis data with each other and against the available site observations at different temporal scales, such as the multiple year average, annual and diurnal variations. Statistical parameters such as standard deviation, frequency, intensity, skewness and kurtosis etc. were calculated for the comparison. Furthermore, we made the quantile-quantile plot (qq-plot) for comparing the daily data distribution.

We found that 20-year average spatial patterns were consistent between different climate datasets. At the site level, the data comparisons were not as satisfactory, especially for the annual values. The annual variations were similar between different reanalysis dataset, but not in comparison with the measured data. Some of it may be explained by location mismatch or by measurement error. The grid-points from these datasets did not have exactly the same locations, because datasets had different spatial resolutions. The daily data comparison showed more detailed differences between these datasets. The temperature variables were the most consistent of all the variables. The consistence of precipitation data was poorer than for temperature. The worst results of comparison were for the radiation variables. Our analysis showed that different reanalysis datasets had different advantages, but none of them could be identified as “the best”. We suggest however that for most variables (especially precipitation and radiation) ECMWF climate dataset manifested better quality than other datasets. Use of ECMWF dataset in ecosystem modeling is hindered by its coverage of time period limited to 1958 - 2001.

1. Introduction

The climate signal is not only one of the most important indicators of the climate change but also an important factor to influence ecosystem functioning. Therefore climate variables are used as forcings for ecosystem modeling. However, the observations of climate variables often have various problems, for instance, the observation errors, the problem with the spatial representatives and temporal continuity. Thus, generally the observation dataset cannot be directly applied to the ecosystem modeling. To keep the climate data consistent in spatial and temporal dimensions, the data assimilation is performed through the state-of-the-art analysis/forecast system. It results in various climate data sets, such as ECMWF, NCEP, REMO and CRU-PIK datasets, etc. The ecosystem modelers often use different climate datasets as their model forcing, which could make their modeling results different. Therefore, understanding the differences in various climate data sources would help to interpret the results of ecosystem modeling.

Though we use the measured data as the reference to justify the reanalysis data, we have no confidence that the observation is the absolute criteria to justify whether the reanalysis data is good or not. In essence there exists the difference between reanalysis data and the weather station observation. The observation data is only for the single point and there maybe exist difference from another point in a short distance away, especially in the season when small scale weather systems are popular. In contrast, the reanalysis data represent an area average, which depends on the data spatial resolution. In comparison with the single weather station observation, reanalysis data should have relatively small extreme value, which should be kept in mind when we explain the difference between the reanalysis data and observation.

There are many climate variables that could be used for ecosystem modeling, such as temperature, precipitation, radiation, relative humidity, vapor pressure deficit and so on. Since the temperature (at 2 meter), precipitation and radiation (surface solar radiation downwards) are three fundamental variables which could be used to induce other variables. These three variables have been focused for the data comparison in the respect of ECMWF, NCEP, REMO and CRU-PIK datasets at different spatial and temporal scales. These analysis datasets were also compared with corresponding variables measured at several ground stations. We would compare the annual average patterns, the area weighted average, annual variation and seasonal cycle, the daily variation in specific year, as well as the daily value probability distribution.

2. Description of climate data sets

Based on European area, the four datasets respectively named as ECMWF, NCEP, REMO and CRU-PIK datasets (table 1) were compared with each other and also against the weather station observation (OBS).

Metadata	**ECMWF**	**NCEP**	**REMO**	**CRU-PIK**
Data format	grib	netCDF	CDO	ASCII
Sorts of variables	analysis; forecast	analysis; forecast	analysis; forecast	observation with interpolation
Surface variables	82; 75	13; 41	as NCEP	temperature; precipitation
Pressure levels	23 levels, each 11 variables	17 levels, each 7 variables	as NCEP	NO
Time Range	1958-2001	1948-2004	1948-2005	1901-2003
Temporal resolution	6 hours	6 hours	1 hour	monthly
Spatial resolution	T159L60 or 1.125 lat/lon	T63; 2.5/2.5	0.5/0.5	0.5/0.5
Grids	0.25/0.25	Gaussian	0.25/0.25	0.167/0.167

Table 1: *Metadata of four climate datasets used for data comparison against the observation (OBS)*

ECMWF dataset (www.ecmwf.int) is the reanalysis data produced in European Center for Middle-Range Weather Forecast, which starts at September 1997 and end at August 2002, roughly 40-year time periods, therefore it is called ERA40. However, after the year 2001, we used the operational data in the ECMWF dataset as the extension to ERA40 data, together with ERA40 and the operational data we just call it ECMWF dataset.

NCEP dataset (ftp.cdc.noaa.gov) is the reanalysis data produced in NCEP/NOAA, which starts from 1948 up to the current time. There are reanalysis 1 (NCEP1) and reanalysis 2 (NCEP2) available with their Gaussian grids. A Gaussian grid is one where each grid point can be uniquely accessed by one-dimensional latitude and longitude arrays (i.e. the coordinates are orthogonal). The longitudes are equally spaced while the latitudes are unequally spaced according to the Gaussian quadrature. Gaussian grids do not have points at the poles. Typically, the number of longitudes is twice the number of latitudes (i.e. 128 longitudes and 64 latitudes). NCEP1 starts from 1948 and NCEP2 starts from 1979. Mostly the NCEP1 will be used for the data comparison, which is generally represented by NCEP. Both ECMWF and NCEP datasets have the global domain with 6-hours temporal resolution. NCEP spatial resolution is T63, roughly at 2/2 lat/lon; ECMWF has the spatial resolution of T159, at about 1.125/1.125 lat/lon. However, the ECMWF dataset can be easily set at different spatial grids.

REMO dataset only has European domain, which is derived using mesoscale climate model with NCEP data as its boundary condition. It was seen that REMO data is the improvement of NCEP dataset, the drawback of which in comparison with NCEP dataset is the smaller region, but the strength of which is its higher spatial resolution (0.25/0.25 lat/lon) and higher temporal resolution (hourly data). The radiation has two variables from REMO, respectively as net surface solar radiation (REMO1) and the calculated surface solar radiation downwards (REMO2) based on albedo and net surface solar radiation.

CRU-PIK dataset is one directly from the observations but using spatial interpolation of observations, produced in Potsdam Institute for Climate Impact Research (PIK) with the methods developed in Climate Research Unit (CRU) in UK. The CRU-PIK dataset used here just covers European continent with spatial grids being 0.167/0.167 lat/lon. There are only monthly temperature and precipitation available from CRU-PIK dataset.

As the verification against the observation, several weather stations were chosen based on availability of their observation data and the data quality. Not all the observed variables corresponding to these reanalysis datasets are available. For example, the high quality measured daily temperature and precipitation data are available for some stations but the corresponding radiation data may be not available (for instance in Jena).

3. Methodology

The data were compared in different time-space scale so that all the data characteristics could be involved in these comparisons. The multiple years average patterns, made from daily, monthly, annual and finally the 20-year average (1981-1999), are for displaying the fundamental spatial distribution, which could also be used to justify the possible data-processing errors.

When the spatial domains are the same, the spatial weighted average were made for comparing the temporal variation with all the domain as a whole. The area weighted average is calculated with the formula as:

$$\text{Area weighted average} = \frac{\sum_{i=1}^{n} x_i \cdot \cos(lat(x_i))}{\sum_{i=1}^{n} \cos(lat(x_i))} \qquad \text{where}$$

x_i is the i_{th} grid cell of total n grid cells, and $lat(x_i)$ is its corresponding latitude.

Since the data domains are not always the same so that the comparable area weighted averages are not always available for these data sets. Therefore, several single stations would be selected for further data comparison. The specific station is selected in tern of availability of measured data at the station. Since the reanalysis datasets have different grids and also the observation stations are not exactly at the grid point, we just chosen each of the grids which are the mostly nearby the in-situ station. Therefore, all the grid coordinates representing these reanalysis grid could be different. Finally five in-situ stations were selected (figure 1), and four of them are CarboEurope stations for European carbon cycle research. Another one is Jena, where the good quality of observation data is available. Nevertheless, there is still no radiation data available from both Fichtelberg and Jena stations. Table 2 shows the latitude and longitude of the selected grids from various datasets. The differences of the coordinate between the OBS and ECMWF (or REMO, or CRU-PIK) are small. Mostly it is smaller than 0.1 deg. However, the difference of grid coordinate between OBS and NCEP could amount to nearly 1 deg, which must be kept in mind when understanding the dataset difference.

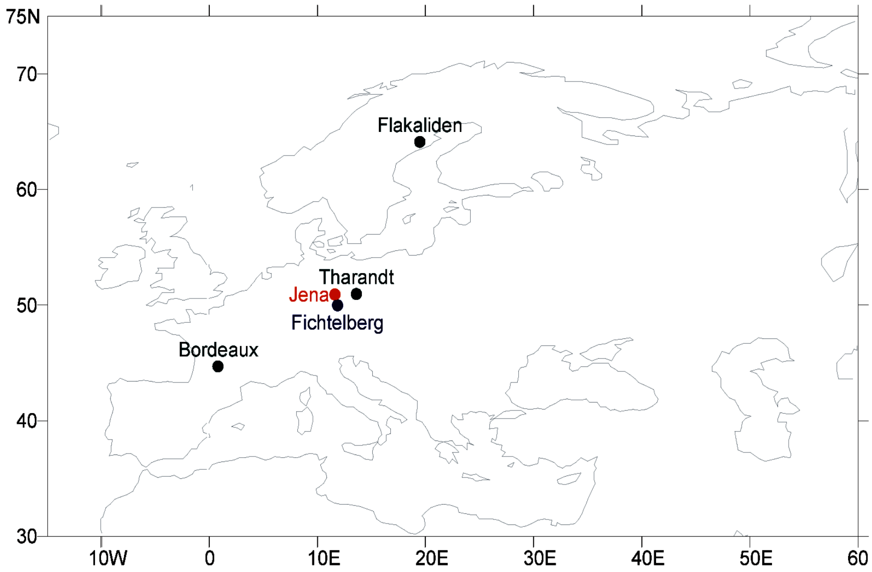

Figure 1: *Location of observation stations used for data comparison*

Dataset	OBS		ECMWF-REMO		NCEP		CRU-PIK	
Coordinate	long	lat	long	lat	long	lat	long	lat
Flakaliden	19.450	64.117	19.375	64.125	18.750	63.8079	19.417	64.083
Tharandt	13.567	50.967	13.625	50.875	13.125	50.4752	13.583	50.917
Bordeaux	0.767	44.700	0.875	44.625	0.000	44.7611	0.750	44.750
Fichtelberg	11.833	49.983	11.875	49.875	11.250	50.4752	11.750	49.917
Jena	11.584	50.925	11.625	50.875	11.250	50.4752	11.583	50.917

Table 2: *Geographic coordinates of observation stations and of the corresponding grid points from reanalysis datasets.*

Based on these selected grids, for temperature and radiation, the daily values, annual average, standard deviation, skewness and kurtosis were calculated and compared between each other; for precipitation, instead of using the standard deviation, skewness and kurtosis, the precipitation frequency and intensity were used for comparison.

In addition, we use the quantile-quantile plot (qq-plot) to compare the distribution of daily data. The purpose of the qq-plot is to determine whether the samples in X and Y come from the same distribution type (parameter values may be different.) If the samples do come from the same distribution, the plot will be linear. The generic function `quantile' produces sample quantiles corresponding to the given probabilities. The smallest observation corresponds to a probability of 0 and the largest to a probability of 1.

4. Data comparison for temperatures at 2m height

4.1 Average temperature patterns over 20 years (1980-1999)

Figure 2 depicts annual temperature patterns averaged over 20-years (1980-1999) for four datasets. Temperature for ECMWF and NCEP are calculated based on 6-hours forecast values. The overall pattern of the average temperature is qualitatively similar among the four datasets. A cold tongue along Scandinavia and warm tongue in the Atlantic are clearly shown. However, the ECMWF data shows relatively warmer temperature than other three datasets with its smaller cold tongue in Scandinavia and larger warm area around the Mediterranean Sea. The CRU-PIK dataset is most similar to REMO dataset. In contrast to other datasets, CRU-PIK resolves many spatial features in the Southern Europe.

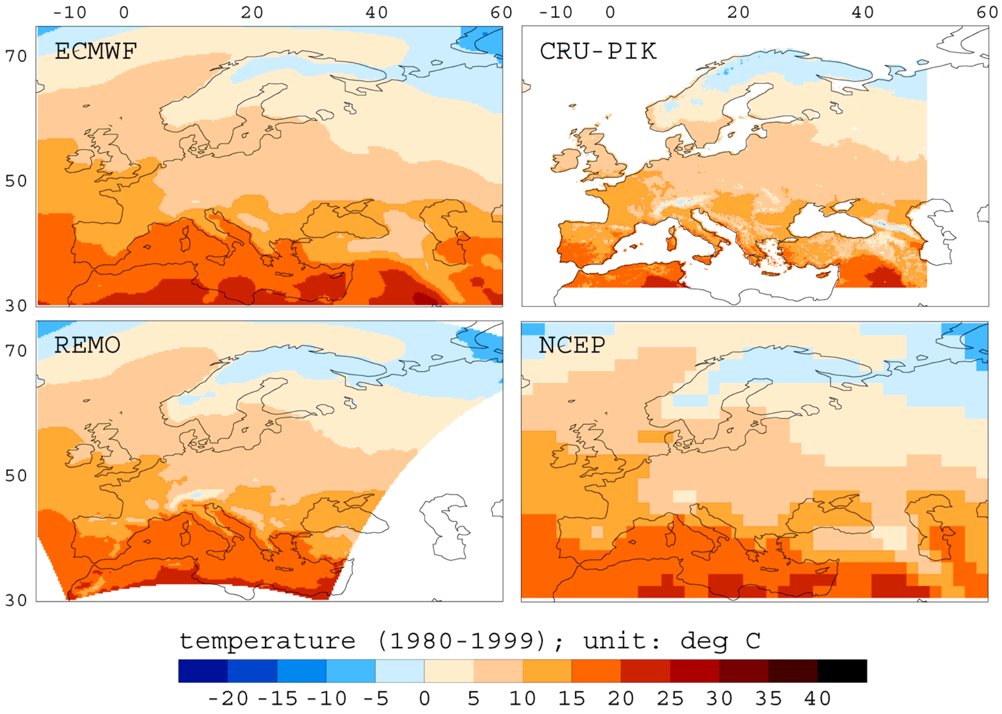

__Figure 2:__ Spatial patterns of annual mean temperatures for 1980-1999

4.2 Area weighted average temperature for ECMWF and NCEP datasets

The 20-year average patterns have given the first impression about various data sets. However, we are also curious to know how temperature patterns vary with time. The area weighted average was computed to look at the data time evolution. Direct comparison of four datasets was not possible because datasets have either different valid area or different grids, which make the weighted average incomparable to each other. Nevertheless, we still tried to compare the weighted average between ECMWF and NCEP datasets since they cover roughly the same region, though the data grids are different. The NCEP's Gaussian grid (2 lon/lat deg, total 941 grids) has fewer grid cells than ECMWF dataset (with spatial grid as 0.25 lon/lat deg, total 54000 grids). The REMO dataset has the same grid cells as ECMWF dataset but covers smaller valid area spatially; CRU-PIK dataset covers only European continent, so both of which were neglected in the comparison of area weighted average. The area weighted average was made for annual variation. The annual variations have good agreement between ECMWF and NCEP datasets, especially during late 1970s and early 1980s (Figure 3). At other time periods ECMWF has warmer temperatures than NCEP, in accordance with the result shown by the spatial average pattern (Figure 2).

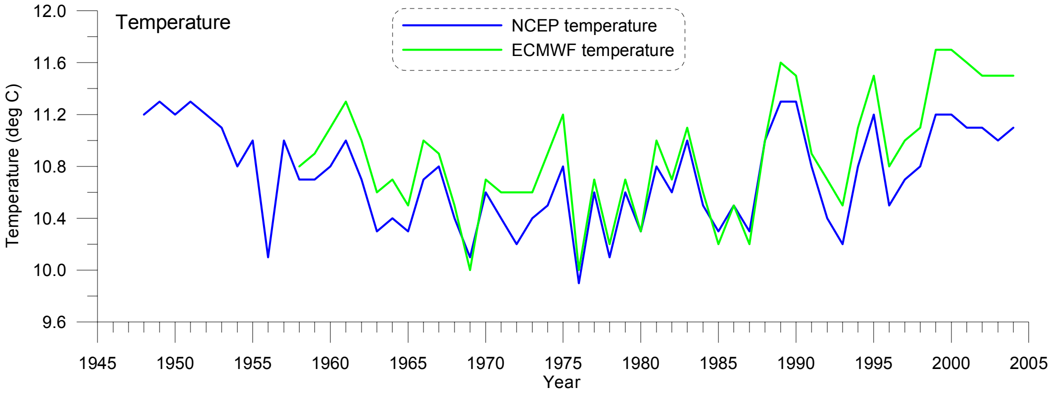

***Figure 3:** Annual variations of European mean temperature weighted by pixel area*

The seasonal cycle was made based on the time periods from 1980 to 1999 (Figure 4), in which the curves are respectively monthly mean value (bold curve), mean plus standard deviation (dash curve above), mean minus standard deviation (dash curve below) and monthly values in 2003 (black dots). Both ECMWF and NCEP show similar seasonal cycle. It is also seen that the temperature in 2003 shows negative anomaly in Spring but positive anomaly from summer to winter, especially in July and August when strong positive anomaly (more than two times of their standard deviation) suggest extreme weather situation in summer 2003.

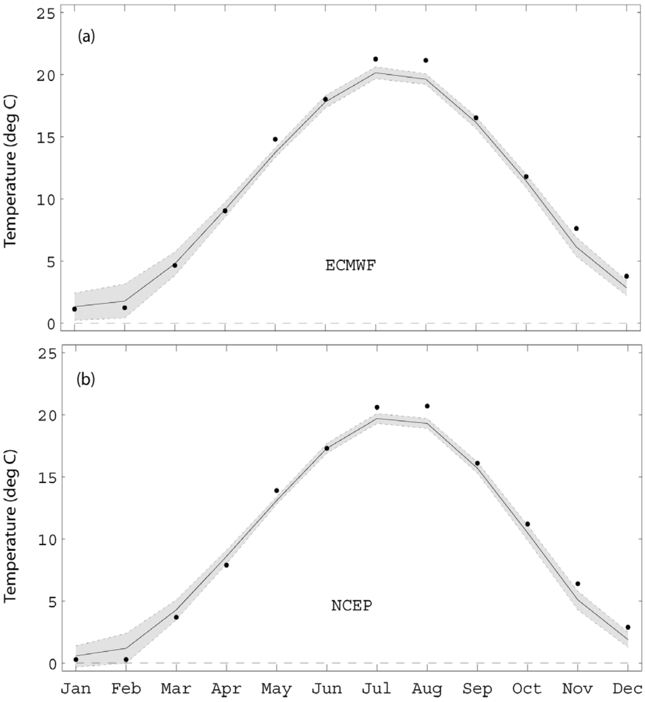

Figure 4: *Seasonal cycle of European mean temperature (bold curve) with one standard deviation bias (grey area) and 2003 temperature anomaly (black dot) from ECMWF (a) and NCEP (b) datasets*

4.3 Comparison of annual temperature for single stations

After the five in-situ stations were defined, the corresponding data from different datasets were extracted. Figure 5 shows inter-annnual variation of temperature respectively for these five stations. From these comparisons it is found that inter-annual variations are quite similar between these different datasets. REMO and CRU-PIK datasets are consistent very well for Flakaliden; ECMWF shows warmer temperature and observation has colder temperature. In Tharandt, all these four datasets have quite good consistence, and relatively ECMWF and observation have the best consistence. CRU-PIK dataset show a bit warmer and NCEP dataset shows colder. REMO and CRU-PIK datasets are consistent quite well for Bordeaux, both of which also have better relationship with OBS than ECMWF and NCEP dataset. For Fichtelberg the relation between REMO and ECMWF are better than other datasets, CRU-PIK show a bit warmer and the observation dataset is much colder. However, observation dataset is much warmer than all other datasets in Jena, where REMO, ECMWF and NCEP data are similar to each other. Overall, though the temperature annual variations are similar to each other for all these datasets, the differences are also obvious, and there is no stable relationship between these datasets. Therefore it is difficult to tell which dataset is relatively better than others with the respect of annual temperature.

In order to compare the seasonal variation, we made a 10-year average for daily temperature. The daily variation was made plots (figure 6), among them three stations (Tharandt, Fichtelberg and Jena) have quite good consistence with each other. However, another two stations (Flakaliden and Bordeaux) have rather larger bias, especially the station Flakaliden, its measured dataset show unrealistic drop, probably because the measured data has quality problem.

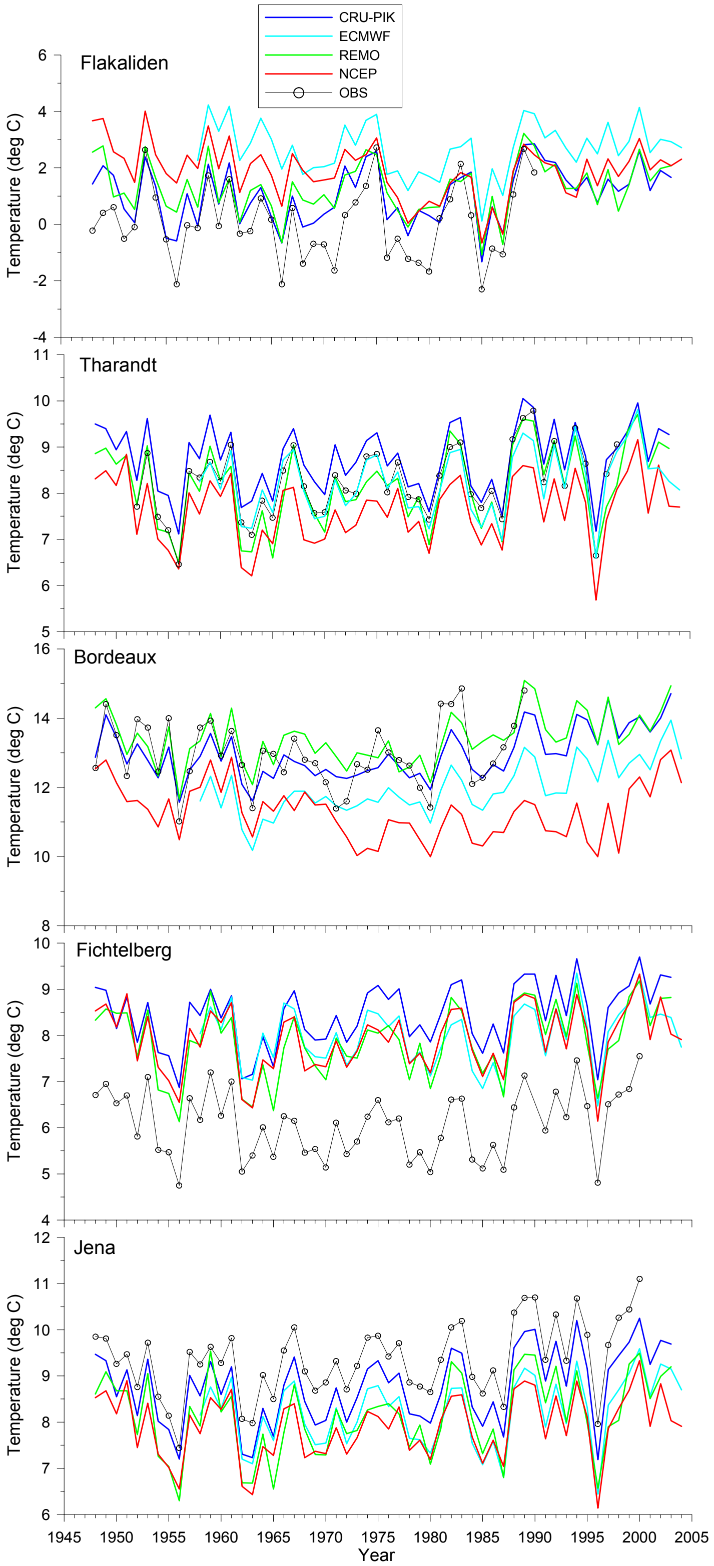

***Figure 5**: Comparison of mean annual temperatures from climate datasets to observations at five selected stations in Europe.*

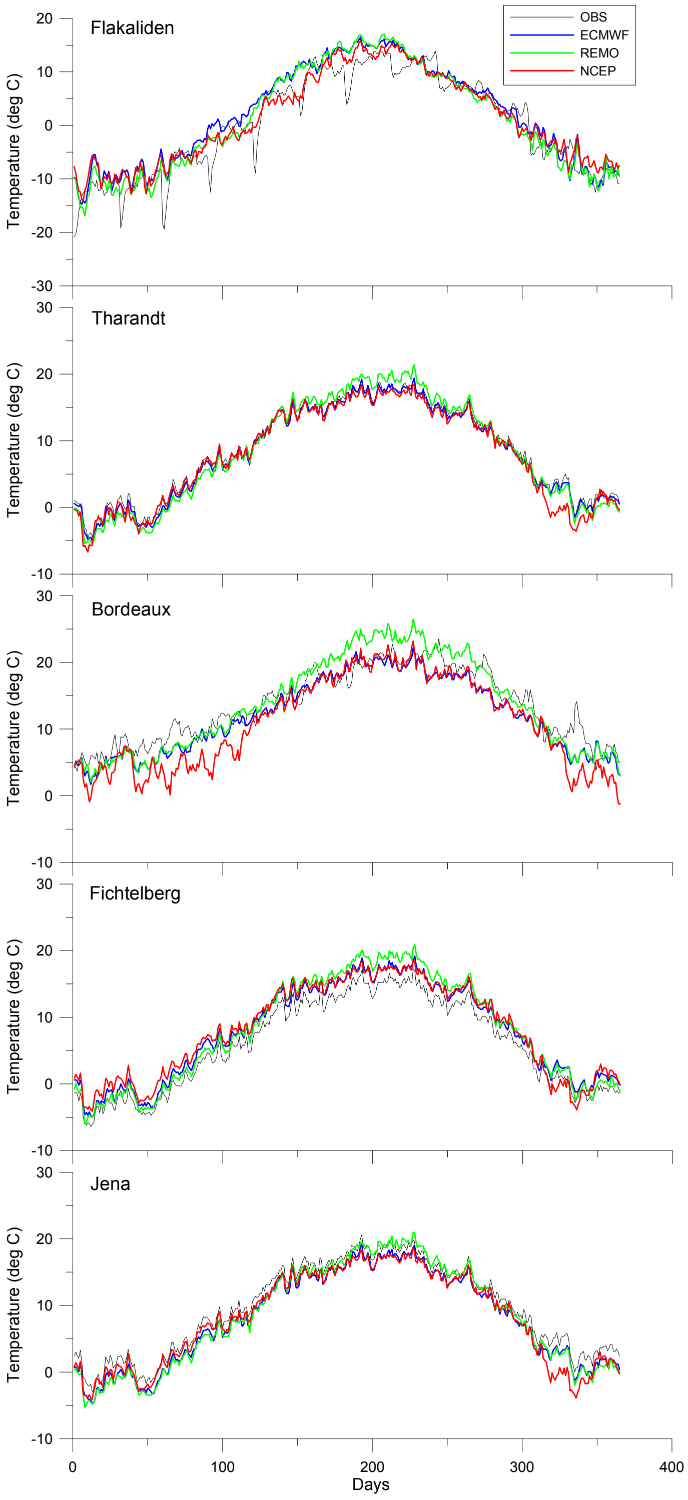

__Figure 6:__ Seasonal cycles of mean temperature from climate datasets and observations at five selected stations in Europe. Mean temperature was calculated from 10-years of data (1989-1990)

4.4 Comparison of daily temperature distribution with quantile-quantile plot

Here we use the 10-year (1980-1989) daily data to make the qq-plot. Although we have seen a lot differences between these datasets, relatively the differences of temperature are small, especially the 20-year average patterns from different datasets are quite similar to each other. With the qq-plot, we compared the ECMWF, REMO and NCEP datasets and their difference with observation, as in figure 7, in which both X and Y coordinates are temperature respectively for observation and analysis datasets. In term of distribution points of view three datasets manifest quite similar results. The qq-plots go along the diagonal line, which means that not only distribution type but also magnitude are quite consistent.

Statistical parameters based on 10-year temperature were calculated for further comparison (table 3). It is seen that the mean values has relatively larger difference between each other, especially the station Flakaliden, where the measured temperature is only 0.2 deg C, but the reanalysis data are from 1.1 to 2.1 deg C. Nevertheless, the standard deviations (STD) have no big difference. In addition, the parameter skewness and kurtosis are also quite similar between these datasets.

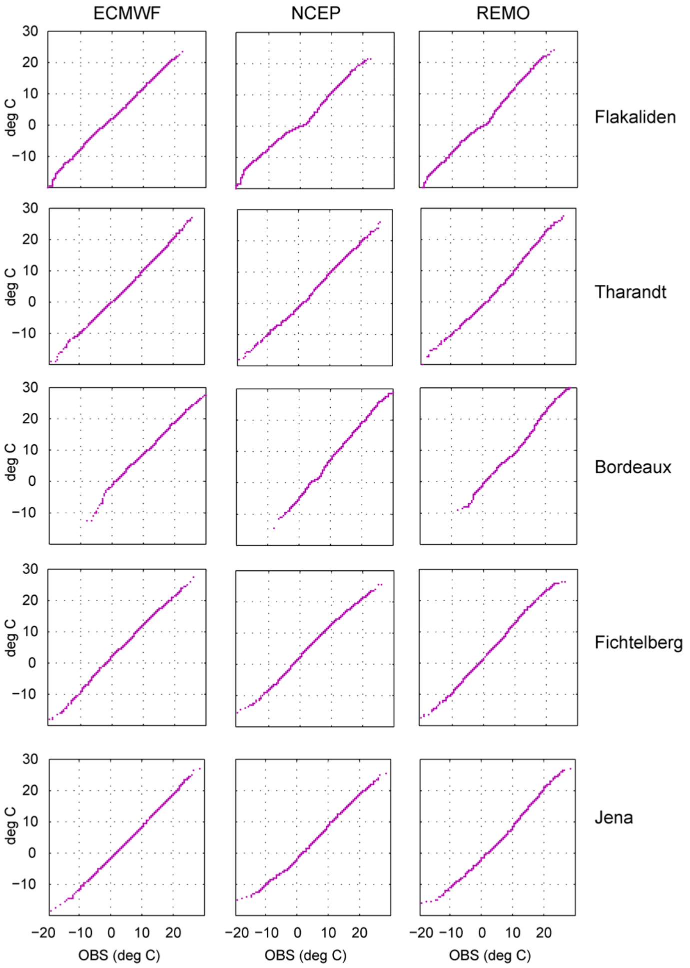

Figure 7: Comparison of daily temperature distributions (deg C) from reanalysis climate datasets and observations (OBS) at five selected stations in Europe with q-q plots. Horizontal axes represent OBS datasets and vertical axes represent reanalysis datasets with data sources' name on the top. Daily temperature data are from 1980 to 1989.

datasets	parameter	Flakaliden	Tharandt	Bordeaux	Fichtelberg	Jena
OBS	Mean	0.2	8.4	13.4	5.9	9.5
	STD	4.3	3.7	3.6	3.7	3.8
	Skewness	0.0	-0.3	0.0	-0.1	-0.2
	Kurtosis	0.2	0.7	-0.1	-0.1	0.5
ECMWF	Mean	2.0	8.1	12.0	7.7	7.9
	STD	4.3	3.7	3.2	3.6	3.7
	Skewness	-0.3	-0.2	-0.2	-0.2	-0.2
	Kurtosis	1.2	0.4	0.6	0.4	0.4
REMO	Mean	1.1	8.3	13.6	7.9	8.3
	STD	4.3	3.7	3.2	3.5	3.6
	Skewness	-0.3	-0.3	-0.2	-0.3	-0.2
	Kurtosis	1.0	0.1	0.1	0.1	0.0
NCEP	Mean	1.1	7.7	10.9	8.0	8.0
	STD	4.1	3.6	3.8	3.6	3.6
	Skewness	-0.6	-0.2	-0.1	-0.2	-0.2
	Kurtosis	2.1	0.2	0.3	0.1	0.1

Table 3: *Comparison of statistical parameters calculated for daily temperatures from climate datasets and observations at five selected stations in Europe. Statistical parameters are calculated based on daily temperatures over 10-year time period (1980-1989).*

4.5 Direct comparison of daily temperatures for year 1980

In order to have a direct impression how these datasets looks like, we choose the year 1980 for direct daily data comparison. From the figure 8 it is seen that Tharandt, Fichtelburg and Jena have good temperature datasets in term of the data consistence. Both Flakaliden and Bordeaux have rather big difference between OBS and the corresponding reanalysis data. The difference in Flakaliden is the most obvious, which confirms similar finding as the 10-year average daily variation (see figure 6) that the OBS shows unrealistic drop in its daily variation.

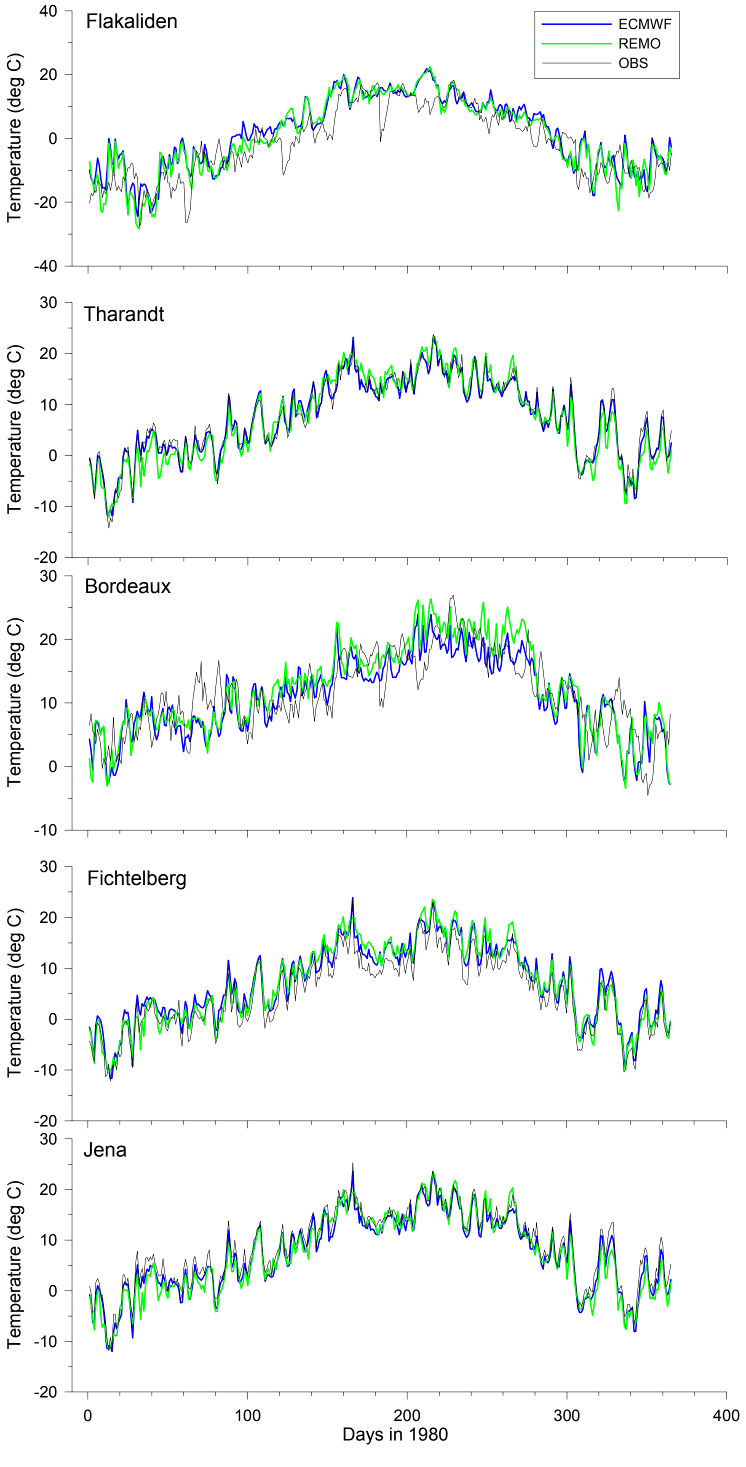

Figure 8: *Comparison of daily temperatures from climate datasets and observations at five selected stations in Europe for 1980.*

5. Data comparison for precipitation

5.1 Average patterns over 20 years (1980-1999)

Figure 9 shows patterns of annual precipitation averaged over 20-year (1980-1999) for four datasets (ECMWF, CRU-PIK, REMO, NCEP). It is seen that precipitation patterns resemble each other worse than temperature patterns. The REMO model is a regional mesoscale climate model and its precipitation pattern shows a clear artifact in the border area. Both REMO and NCEP data display a stronger precipitation in the north-eastern Europe which cannot be seen from ECMWF and CRU-PIK datasets. It seems the NCEP precipitation pattern manifests the worst case.

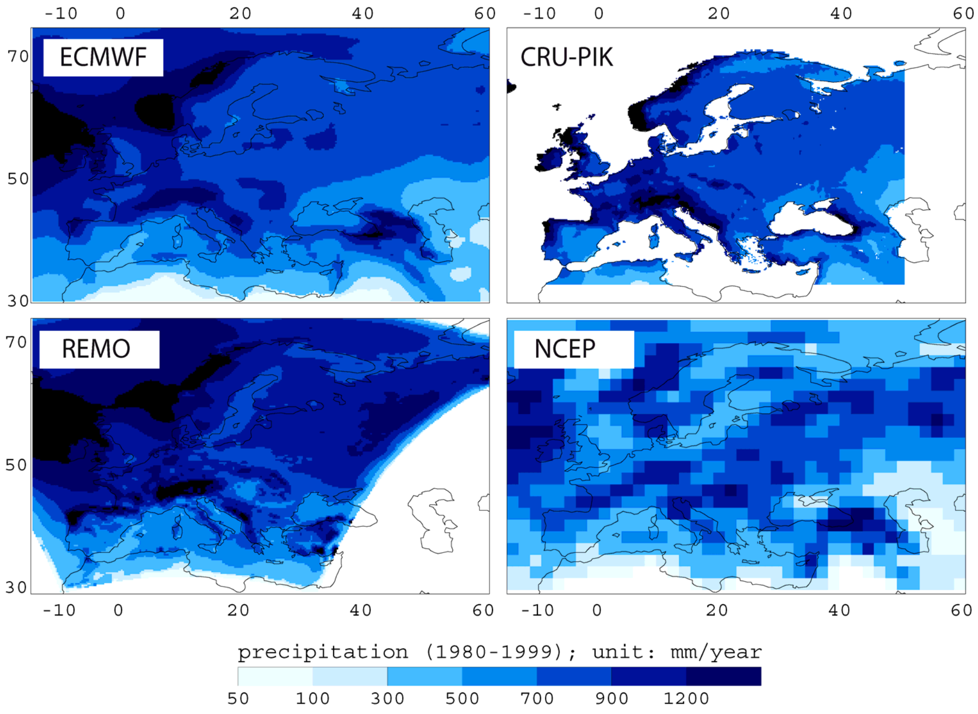

***Figure 9:** Spatial patterns of annual mean precipitation for 1980-1999*

5.2 Area weighted average precipitation for ECMWF and NCEP datasets

As we did for temperature, we also computed the area weighted average for ECMWF and NCEP precipitation datasets. The NCEP only has 6-hour forecast available, but ECMWF can have 6-hour and 36-hour forecast available, therefore there are one set of area weighted average for NCEP precipitation but two sets of ECMWF area weighted average of precipitation (figure 10). As we already explained before that the ECMWF data after the year 2001 is the operational data, and here the precipitation jumps can be seen from ECMWF datasets at the 2001. As we know that the reanalysis model and operational model from ECMWF are different, for instance, in the respect of spatial resolution. Because of the jump it is not suggested to extend the reanalysis data with operational model result for ECMWF dataset.

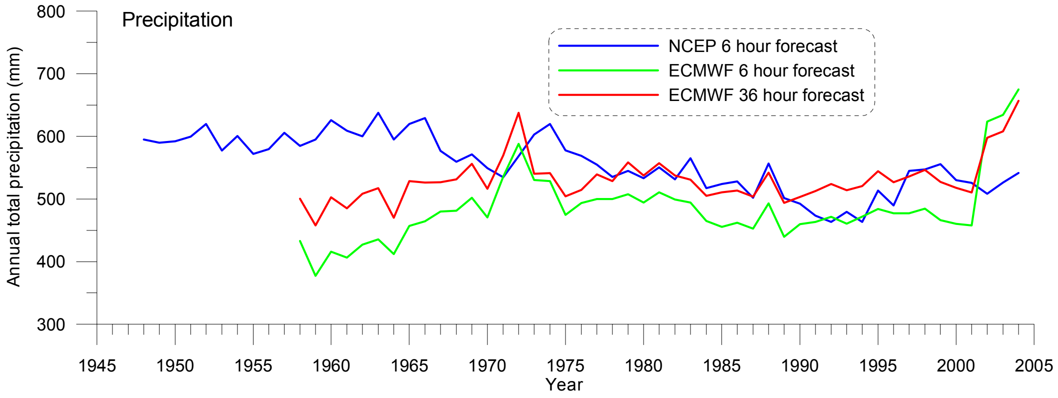

Figure 10*: Annual variations of European average precipitation weighted by pixel area*

From the figure 10 we can see that 36-hour forecast from ECMWF has relative larger precipitation than 6-hour forecast. The 36-hour value has better consistence with NCEP dataset, especially during time periods from 1978 to 1989. There is a significant difference before the year 1970, probably because input data for the reanalysis model at early time has poorer quality than later dataset.

Based on the area weighted precipitation, we made the seasonal cycle plot as in figure 11, in which bold curve is the average and the dash lines are the average plus standard deviation (mean + std) and average minus standard deviation (mean – std). It is seen that the mean seasonal cycle are obviously different between ECMWF and NCEP datasets. ECMWF shows smaller summer precipitation and stronger winter precipitation, while the NCEP data shows relatively less precipitation in

Spring and Autumn and stronger precipitation in winter and summer. Since the precipitation jump in 2001, the precipitation value in 2003 (black dots) are much stronger for ECMWF dataset, which of course, is unrealistic.

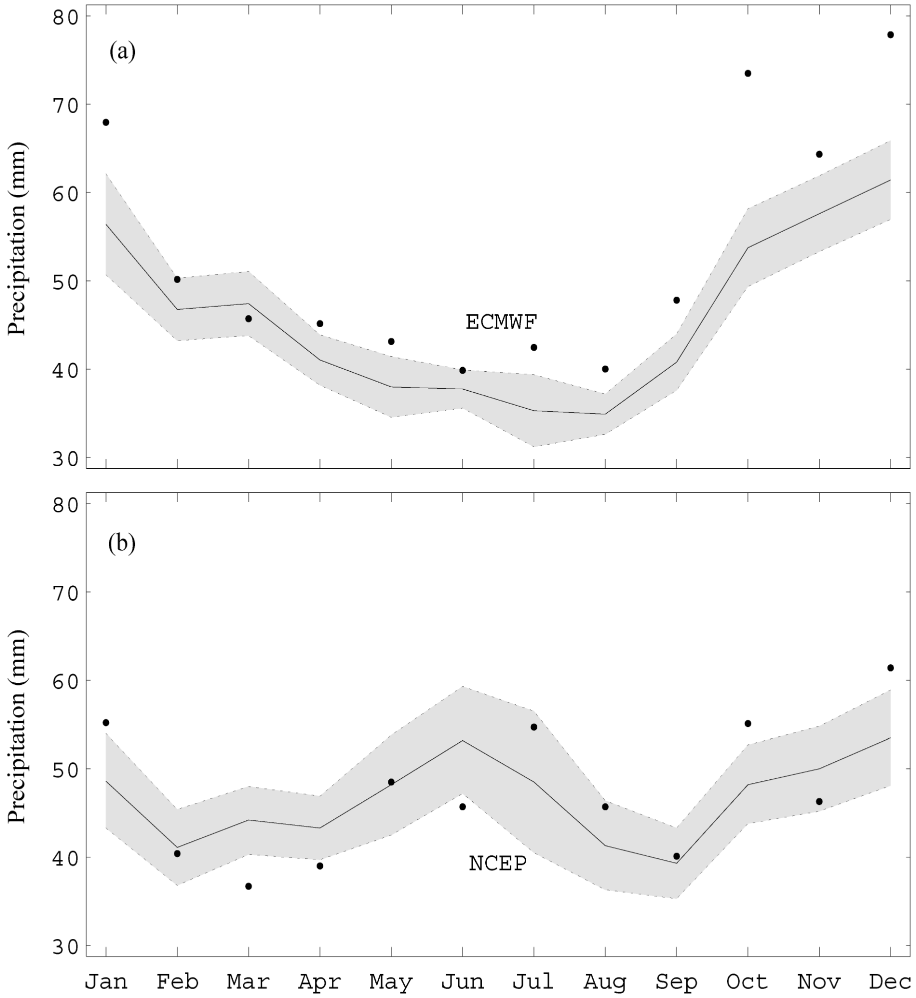

Figure 11: *Seasonal cycle of European mean precipitation (bold curve) with one standard deviation bias (grey area) and 2003 precipitation anomaly (black dot) from ECMWF (a) and NCEP (b) datasets*

How the notable precipitation jumps occur in ECMWF dataset? The figure 12 shows the mean difference between EAR40 and operational data. It is seen that the jump mainly occur in the area near the boundary between continent and ocean, though away from the boundary the jump could also happen. The inconsistency between the reanalysis data and operational data may result from the climate shift from their different models.

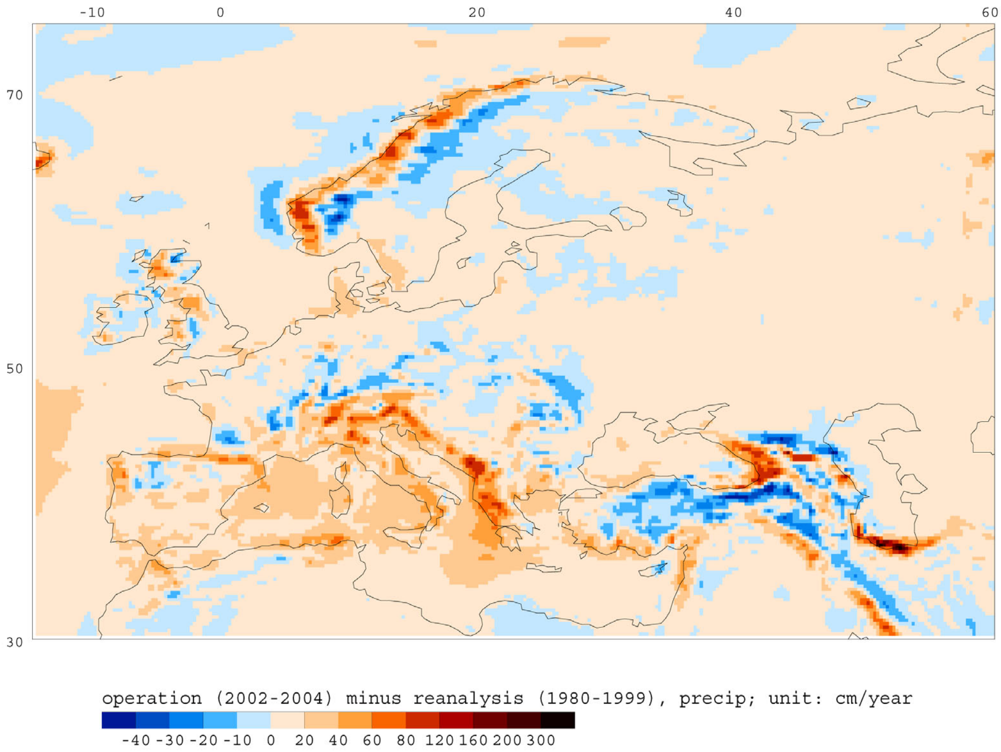

Figure 12: *Difference of precipitation between ECMWF reanalysis dataset and its operational dataset*

5.3 Comparison of annual precipitation for single stations

The annual precipitations were compared with observation respectively for five selected stations (figure 13). In station Flakaliden it seems that ECMWF and CRU-PIK precipitation datasets have better consistence than others. REMO and NCEP precipitation are relatively similar and show stronger precipitation than ECMWF and CRU-PIK datasets. The latter has better consistence with observation dataset. In station Tharandt NCEP precipitation has obvious stronger bias than all other datasets and relatively the ECMWF and CRU-PIK show consistence to each other better; and REMO and observation show consistence better to each other. Except for NCEP dataset, all other dataset have no big difference between them in Tharandt. In Bordeaux REMO and CRU-PIK are more consistent than others, both also have better relationship with observation. ECMWF has bigger bias to observation and NCEP have the biggest bias. However, in Fichtelburg, ECMWF and CRU-PIK and REMO are more consistent and also show much less precipitation than NCEP and observation datasets. The precipitation in Jena show better consistence except for NCEP dataset, which display much stronger precipitation. As above, it is seen that the consistence between these datasets for precipitation are weaker than for temperature, but the annual variation of precipitation show quite well similarity.

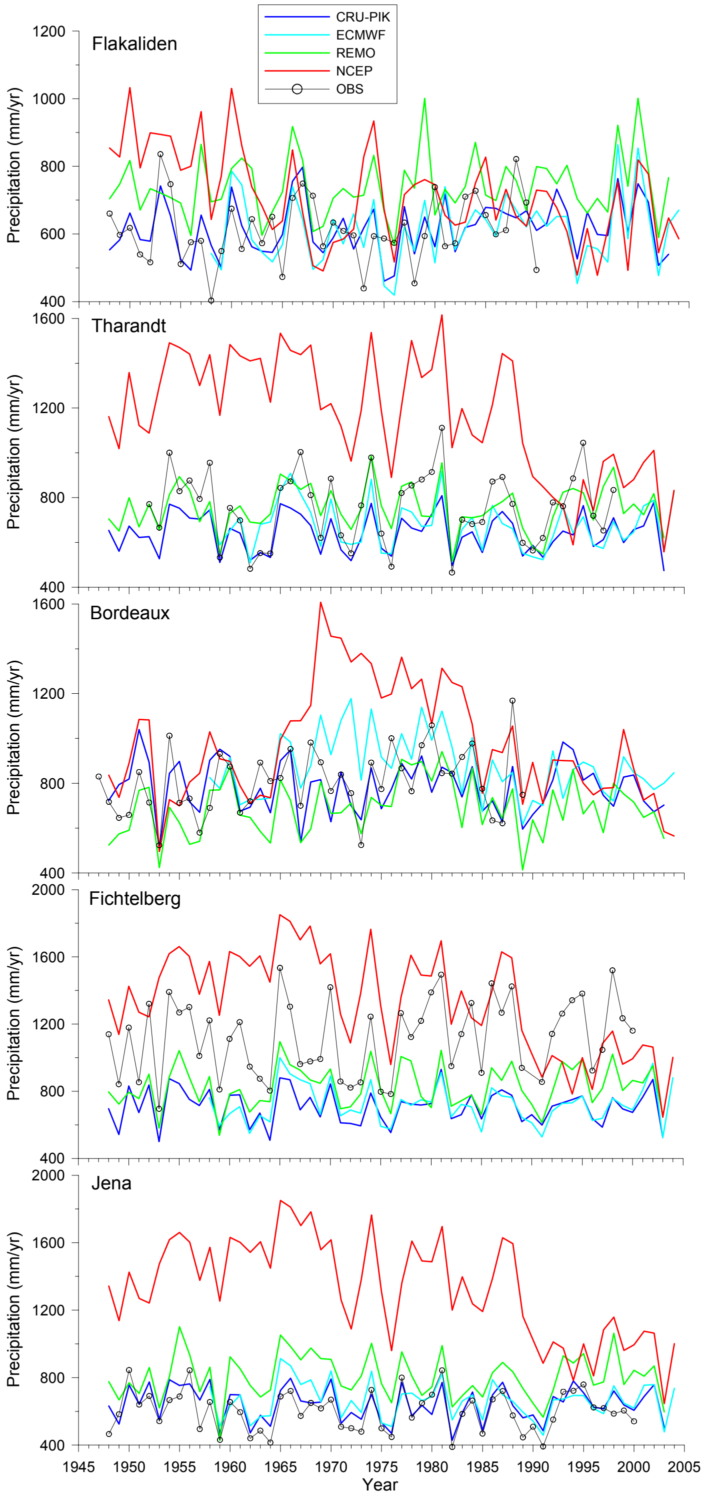

Figure 13: *Comparison of mean annual precipitation from climate datasets and observations at five selected stations in Europe.*

5.4 Comparison of daily precipitation distribution with quantile-quantile plot

The precipitation qq-plots (figure 14) for ECMWF dataset show that ECMWF reproduce more realistic precipitation for the daily precipitation with the amount less than 10 mm/day except for the station Fichtelberg, where ECMWF always show much weaker precipitation than the observation. As for the stronger precipitation than 10 mm/day, all these five stations show that ECMWF underestimate the precipitation. It is meant that ECMWF reproduce relatively less stronger precipitation. REMO precipitation has the similar result to ECMWF in term of daily value distribution. Relatively the NCEP reproduce a bit strange precipitation. For the precipitation less than 10 mm/day, precipitation was overestimated but NCEP underestimate the precipitation stronger than 10 mm/day. Therefore from the distribution point of view the NCEP and observation datasets are not even from the same distribution type. The underestimation of stronger precipitation is the common characteristics for all reanalysis dataset. It is reasonable since the measured data are for single point, instead, the reanalysis data represent the average of small area based on the spatial resolution, which will relatively have weaker peak than single station measured precipitation.

As in table 4, the precipitation parameters were also calculated for 10-year periods (1980-1989), for which we calculate the annual total precipitation, precipitation frequency and intensity, instead of calculating the STD, skewness and kurtosis as for temperature parameter. Precipitation frequency is the ratio of rainy days against total days; precipitation intensity is the mean daily total precipitation during the rainy days. Except for NCEP precipitation, which often show much larger precipitation than OBS, the ECMWF and REMO have quite similar total precipitation as OBS. However, the precipitation frequency and intensity are significantly distinct. OBS data show much less precipitation frequency but stronger intensity than the reanalysis data, in accordance with the result that the qq-plot shows. Feser et al also found that the reanalysis data take on too many wet events when in fact, the observation show no precipitation. It is likely that local convective precipitation might occur without being sampled by the observation. Overall, the precipitation reproduction in reanalysis data is much worse than temperature variable. In contrary to temperature, in which the measured data is used to produce the reanalysis data, the measured precipitation is not used to produce reanalysis precipitation variable. All the precipitation in reanalysis model is the forecast variables, which could be another error source for the reanalysis data.

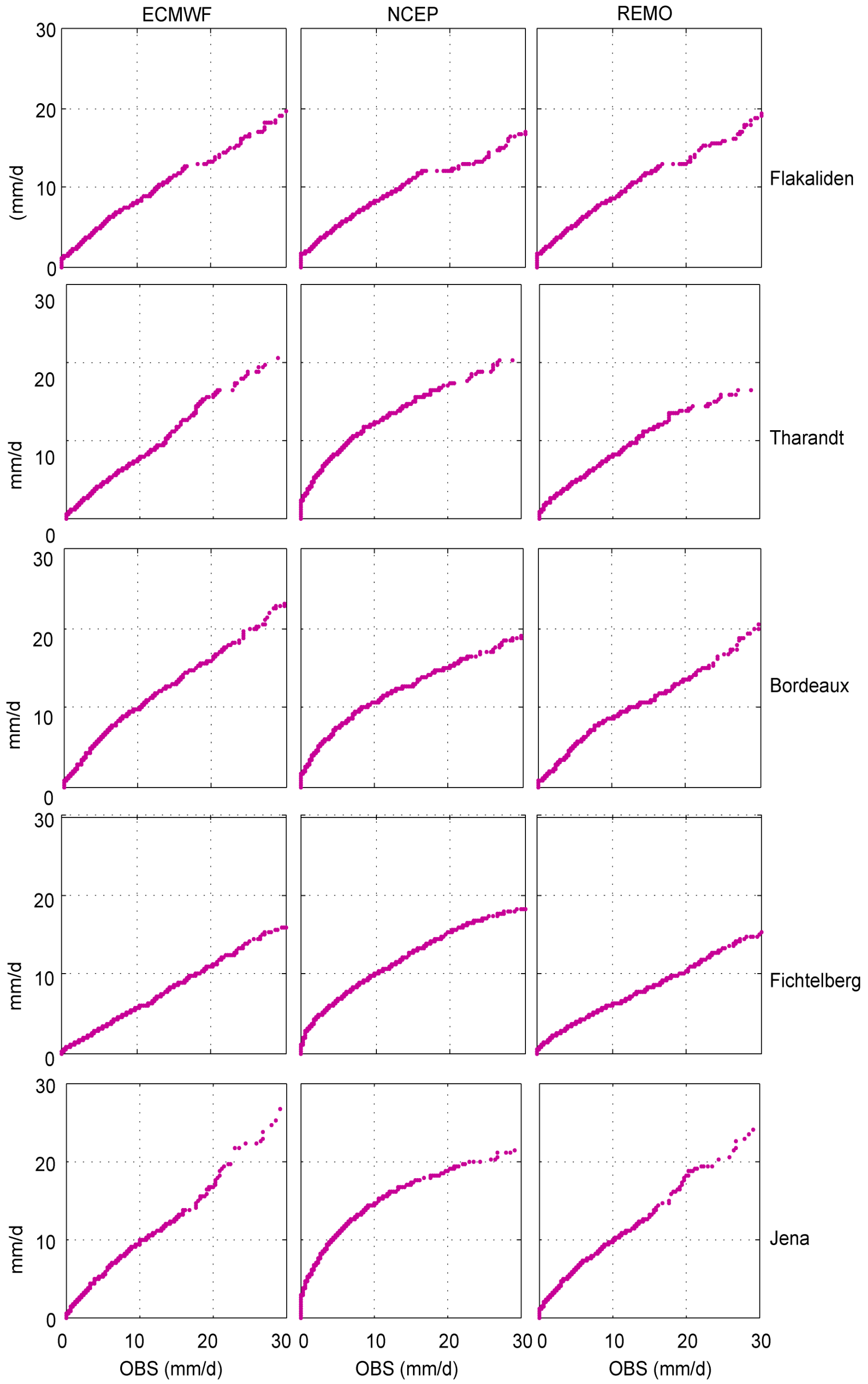

Figure 14: Comparison of daily precipitation distributions (mm/day) from reanalysis climate datasets and observations (OBS) at five selected stations in Europe with q-q plots. Horizontal axes represent OBS datasets and vertical axes represent reanalysis datasets with data sources' name on the top. Daily precipitation data are from 1980 to 1989.

stations	parameters	OBS	ECMWF	REMO	NCEP
Flakaliden	Frequency (%)	33.4	69.5	85.5	86.5
	Intencity (mm/d)	5.5	2.5	2.3	2.2
	Annual mean precip	669.4	634.0	732.6	688.6
Tharandt	Frequency (%)	51.5	70.2	79.4	86.7
	Intencity (mm/d)	4.1	2.6	2.5	3.9
	Annual mean precip	769.7	670.1	735.2	1243.9
Brodeaux	Frequency (%)	43.8	65.2	66.4	76.3
	Intencity (mm/d)	5.4	3.6	3	3.7
	Annual mean precip	859.1	868.1	722.4	1031.9
Fichtelberg	Frequency (%)	59.5	70.6	79.4	90.9
	Intencity (mm/d)	5.7	2.8	2.8	4.2
	Annual mean precip	1228.2	728.4	822.8	1398.1
Jena	Frequency (%)	49.2	71.9	79.6	90.9
	Intencity (mm/d)	3.4	2.6	2.7	4.2
	Annual mean precip	605.3	670.5	777.3	1398.1

Table 4: *Comparison of statistical parameters calculated for daily precipitation from climate datasets and observations at five selected stations in Europe. Calculations of statistical parameters are based on precipitation values over 10-year time period (1980-1989).*

5.5 Direct comparison of daily precipitations for year 1980

As we did for the temperature, here we also choose the year 1980 for the daily value comparison (figure 15). Obviously, the OBS data shows stronger extreme events than the reanalysis datasets show. Except for the station Bordeaux, where there is large difference between OBS and reanalysis data, all other stations have the precipitation consistent well to each other. Though the amount of precipitation is different, the rainy days occur at the similar time periods, i.e., the reanalysis data show similar precipitation cluster as the OBS.

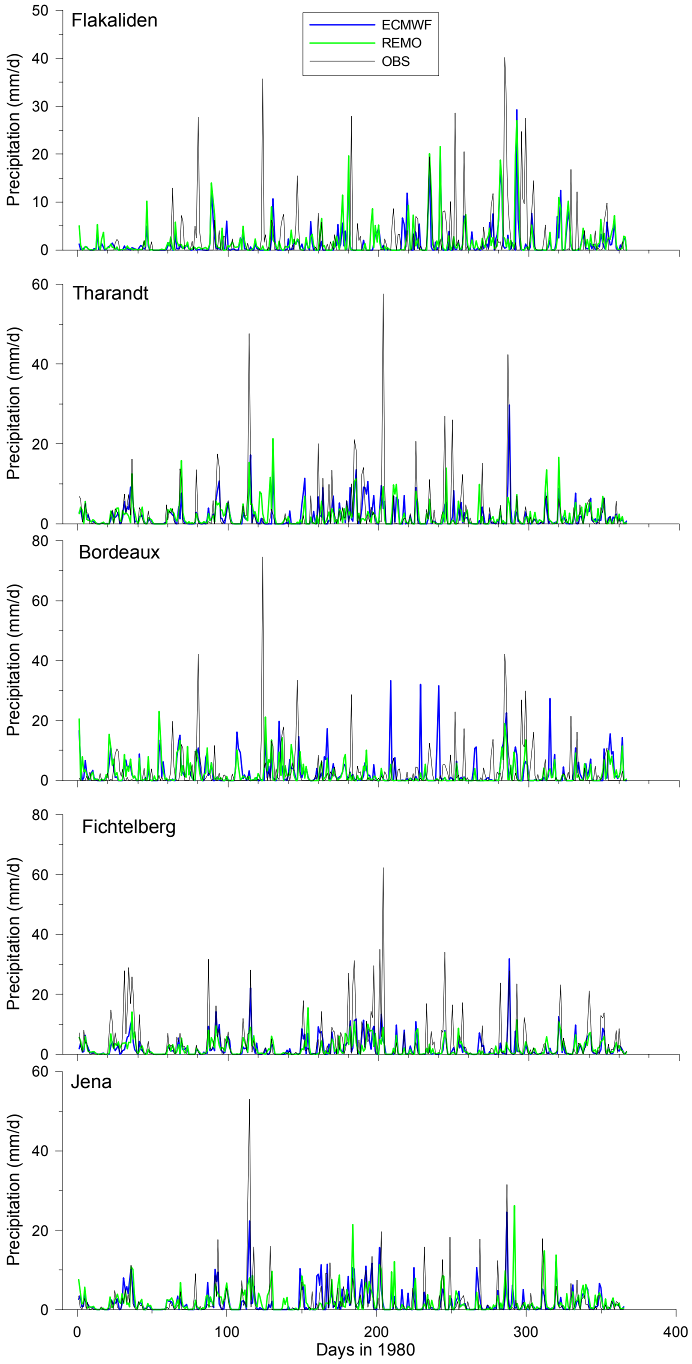

Figure 15: *Comparison of daily precipitation from climate datasets and observations at five selected stations in Europe for 1980.*

6. Data comparison for radiation

6.1 Average radiation patterns over 20 years (1980-1999)

We made the 20-year average radiation patterns respectively for ECMWF, REMO and NCEP datasets (figure 16). There are two radiation datasets available for REMO, one is the net surface solar radiation (REMO1) and another one is the surface solar radiation downwards (REMO2). REMO1 is directly available from REMO model archive, while REMO2 is the dataset that ecosystem modeler required, which have to be calculated based REMO1 and surface albedo with the formula as:

REMO2=REMO1/(1-albedo)

Here we will use both REMO1 and REMO2 to participate the data comparison. It is seen that REMO2 has larger values than REMO1, and also more regular structure along the longitude than REMO1, because REMO1 is more influenced by local underground environment. Except for the boundary artificial effect, REMO2 and ECMWF are quite consistent to each other, in contrast, NCEP radiation show much larger radiation value than REMO and ECMWF datasets.

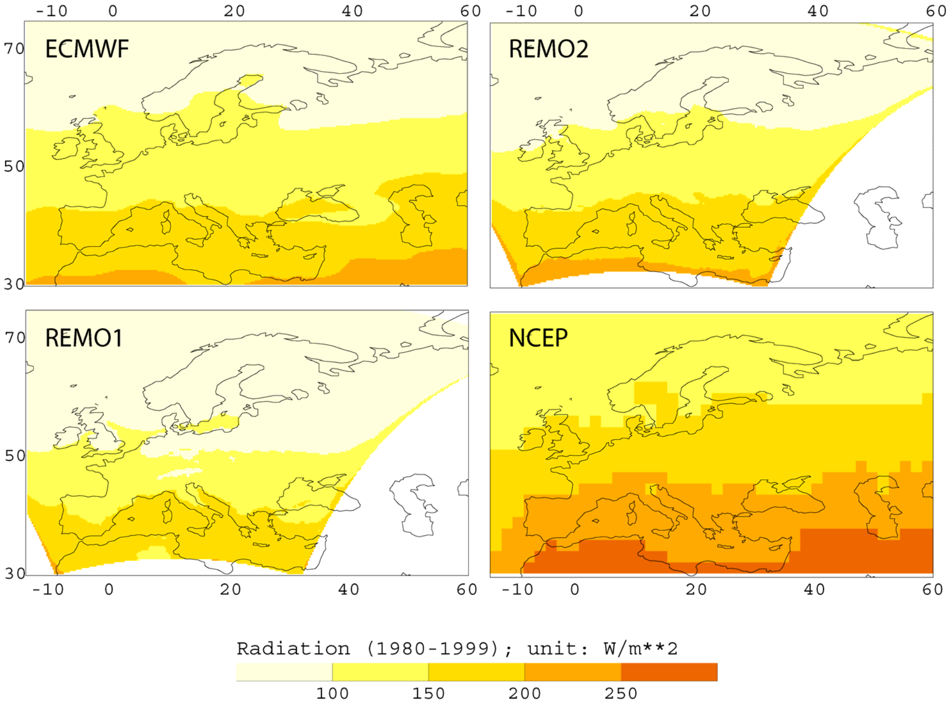

Figure 16: *Spatial patterns of annual mean radiation for 1980-1999*

6.2 Comparison of annual mean radiation for single stations

Based on three CarboEurope stations (Flakaliden, Tharandt and Bordeaux) where the measured radiation datasets are available, we compare the radiation data with the annual average value (figure 17). There are six datasets available here for these comparisons, i.e. OBS, ECMWF, REMO1, REMO2, NCEP1 and NCEP2, among which NCEP1 is the reanalysis-1 from NCEP and NCEP2 is for the reanalysis-2 from NCEP. NCEP's reanalysis-2 data is available from 1979 to 2005, which is assumed the improvement of earlier reanalysis-1 dataset. Of course, there are also reanalysis-2 datasets for temperature and precipitation which could be further compared with the corresponding reanalysis-1 datasets in the future.

From these three station data we found that the difference between REMO1 and REMO2 and between NCEP1 and NCEP2 are mostly in the magnitude, while their variations with time are quite similar. If we use OBS as the criteria, ECMWF data has better result for Flakaliden, while NCEP2 dataset is better for station Bordeaux. In station Tharandt both ECMWF and REMO2 dataset are quite similar to each other, which has relatively better consistence with OBS in some years, but in some other years OBS has better consistence with REMO1. On average, ECMWF has the best reproduction of OBS dataset and NCEP often overestimate the radiation and REMO underestimate the radiation.

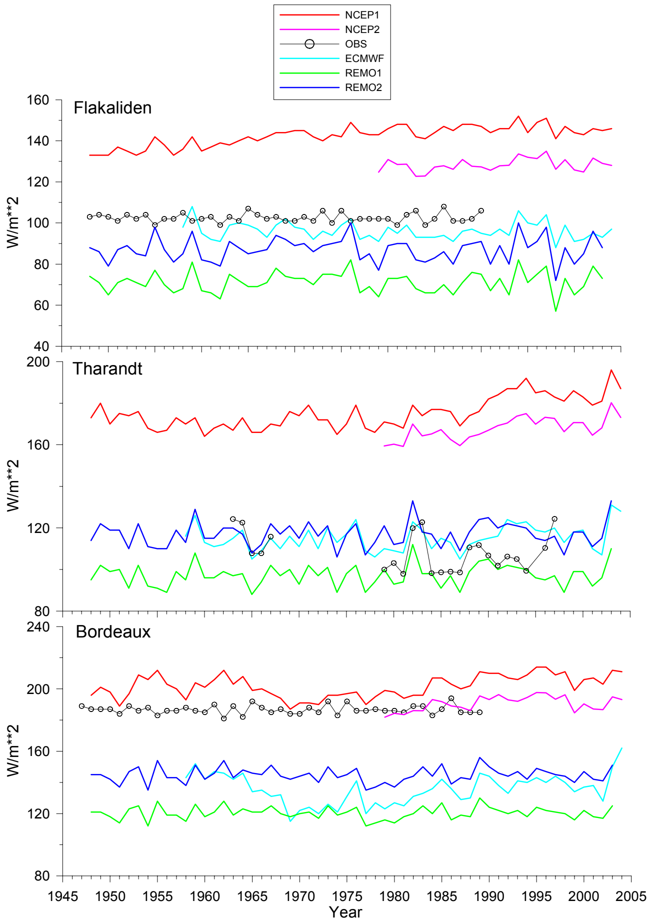

Figure 17: *Comparison of total annual radiation from climate datasets to observations at three selected stations in Europe.*

6.3 Comparison of daily radiation distribution with quantile-quantile plot

Figure 18 are the qq-plots with different datasets respectively for three CarboEurope stations. Both NCEP1 and NCEP2 strongly overestimate the radiation for Flakaliden and Tharandt, but for station Bordeaux both NCEP1 and NCEP2 give good estimation. Relatively NCEP2 has smaller values than NCEP1. ECMWF has quite good estimation for Flakaliden and Tharandt, but underestimate the radiation for Bordeaux. In term of the value REMO2 looks better than REMO1, especially for the station Flakaliden. REMO2 for station Bordeaux still underestimate the radiation as REMO1 does. The main problem for REMO radiation dataset is that the qq-plot is far from a straight line, which means that in term of distribution, REMO and OBS are different. We take the station Flakaliden as an example, REMO2 overestimate the smaller and larger values but underestimate the middle value radiation.

We made the daily average with 10-year data, and then seasonal cycle can be seen in these 10 year periods, which is considered as the common situations for radiation datasets (figure 19). For two stations Flakaliden and Tharandt, NCEP data is too strong and REMO1 is too weak, relatively ECMWF, REMO2 and OBS have good consistence. But for station Bordeaux, OBS and NCEP data are consistent and all other datasets show much smaller values than OBS. REMO2 and ECMWF are better consistent than others, but REMO2 has much larger variability than ECMWF data.

Based on the average and anomaly value, some statistical parameters were calculated for 10 years periods (1980-1989). The table 5 is about the statistical parameters based on 10-year daily radiation data. REMO1 underestimate the OBS average and NCEP overestimate the average. Both REMO2 and ECMWF have the average values comparable to OBS. However, based on standard deviation (STD), REMO1 and ECMWF can better represent the OBS than REMO2 and NCEP since REMO2 has much larger STD; and NCEP has much smaller STD than OBS. In comparison with REMO1, REMO2 significantly increase the STD, but did not change the skewness and kurtosis. All these datasets (their anomaly) have nearly asymmetric distribution (small values of skewness) but with a strong peak (large values of kurtosis), especially with the NCEP data for Flakaliden station (with kurtosis being 4.3).

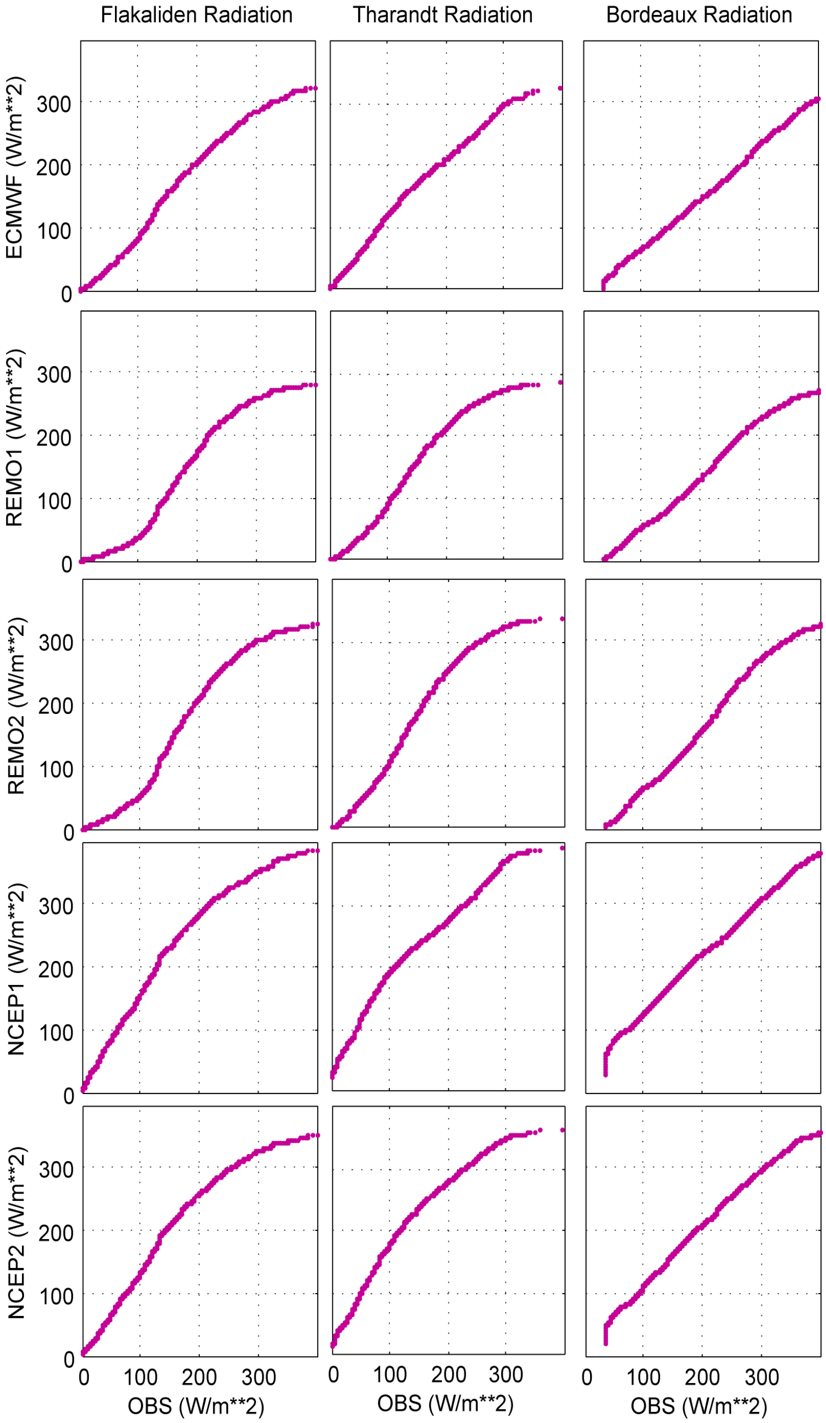

__Figure 18:__ Comparison of daily radiation distributions (W/m²) from climate datasets and observations at five selected stations in Europe with q-q plots. Daily radiation data are from 1980 to 1989.

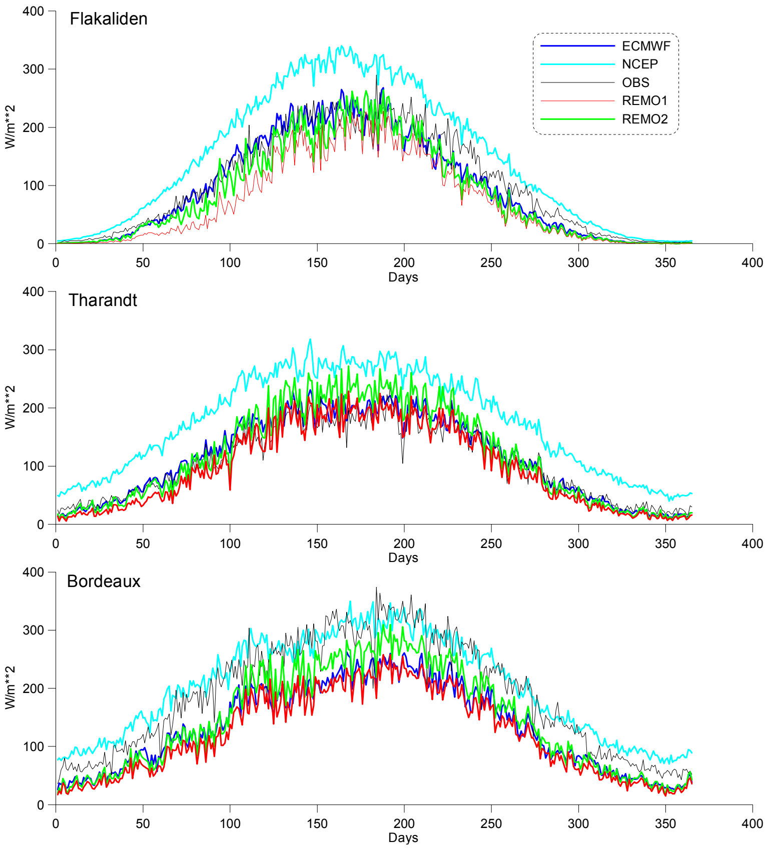

Figure 19: *Seasonal cycles of mean daily radiation from climate datasets and observations at three selected stations in Europe. Mean daily radiation was calculated from 10-years of data (1989-1989)*

	Mean values					Standard deviation				
	REMO2	REMO1	OBS	ECMWF	NCEP	REMO2	REMO1	OBS	ECMWF	NCEP
Flakaliden	86	70	103	95	146	54.6	45.3	40.2	37.2	25.1
Tharandt	118	98	106	113	174	57.2	47.9	47.8	38.1	33.4
Bordeaux	145	121	187	134	202	54.7	45.5	48.7	44.7	42.0
	Skewness					Kurtosis				
Flakaliden	-0.6	-0.7	0.6	-0.8	-0.9	1.5	2.0	2.8	3.1	4.3
Tharandt	-0.8	-0.8	-0.1	-0.4	0.2	1.3	1.4	0.9	1.9	0.9
Bordeaux	-1.0	-1.0	0.0	-0.3	-0.4	1.8	1.8	1.0	0.3	0.3

Table 5: *Comparison of statistical parameters calculated for daily radiation from climate datasets and observations at three selected stations in Europe. Statistical parameters are calculated from radiation values over 10-years (1989-1989)*

6.4 Direct comparison of daily radiations for year 1980

The daily variation of radiation is much larger than temperature, therefore we made a 11-day running average for 1980 in order that we can clearly compare the dataset. Figure 20 is about the comparison of daily radiation in 1980. From these plots it seems that the station Tharandt is the best case and the station Flakaliden is the worse case in term of data consistence. In station Tharandt, REMO2 is consistent with OBS better than REMO1 in the whole year except for the summer, when REMO1 is better than REMO2. For station Bordeaux, REMO1 and ECMWF are well consistent with each other though both are very different from OBS. REMO2 is more approximate to OBS than REMO1 in Bordeaux. As above, it could be said that REMO2 is not significantly better than REMO1 though theoretically REMO2 represent the realistic data better than REMO1. ECMWF radiation dataset is better than REMO dataset to represent OBS radiation.

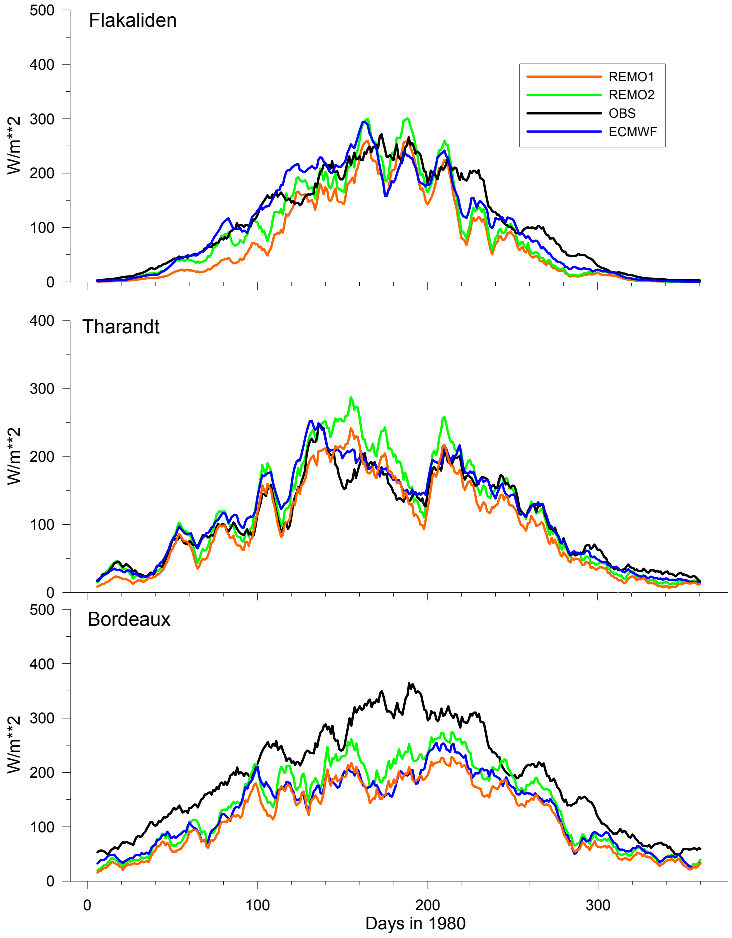

Figure 20: *Comparison of daily average radiation from climate datasets and observations at three selected stations in Europe for 1980. The radiation values are calculated as 11-day running averages.*

7. Discussion and conclusions

We have made the data comparison between several different datasets. It was found that the different datasets have different advantage and disadvantage. We tried to use the measured dataset in selected stations as the criteria to validate the reanalysis datasets (NCEP, REMO and ECMWF) and interpolated dataset (CRU-PIK). We do not think the measured dataset that we selected in this comparison are error-free, and moreover the comparison between reanalysis data and single point measured data may not be so reasonable since the reanalysis data represent the area average, not for a single point as the measured dataset does. Nevertheless, the data comparison were still carried out, which, at least is better than without any data comparison. It is desirable that much better quality measured dataset could be available for data comparison in the future.

The CRU-PIK dataset (1901-2003) is the "observational" data-set that has been produced using interpolations of meteorological data and the CRU approach, which could give the most correct results at the monthly scale. Availability of only monthly data limits its wider application, since many ecosystem models need daily data as input. The ECMWF dataset (1958-2001) or reanalysis data ‘REA40’ has a good spatial and temporal consistency. This global dataset has high temporal and spatial resolutions as well as easy grid setting, which provides the best possibility for global ecosystem modeling. Though the operational dataset could be used as the alternative after the year 2001, the existing jump in precipitation between its reanalysis model and the operational model limits its usefulness after 2001.

The NCEP dataset (1948-present) has fine temporal resolution (6 hours) but the coarsest spatial resolution (~2x2 deg, Gaussian grid), which may be too course for ecosystem modeling. Its precipitation is almost always the worst case (too high) among these four climate datasets. In addition, the NCEP radiation data is much over-estimated (as found by Zhao, et al).

The REMO dataset (1948-2003) was derived using mesoscale climate model with NCEP data as its boundary condition. In comparison with the NCEP dataset, REMO improved the spatial and temporal resolution, but impacted by the NCEP dataset. In addition, there exists a problem in the boundary area for the cumulated variables such as precipitation and radiation.

Relatively the temperature variable from different datasets has the best consistence over other variables; the precipitation datasets manifest the smaller extreme value compared to the observation; the consistence about radiation datasets is the worst. As above, ECMWF could be the ideal dataset for ecosystem modeling but the deficiency of its reanalysis dataset after the year 2001 could limit its usefulness.

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