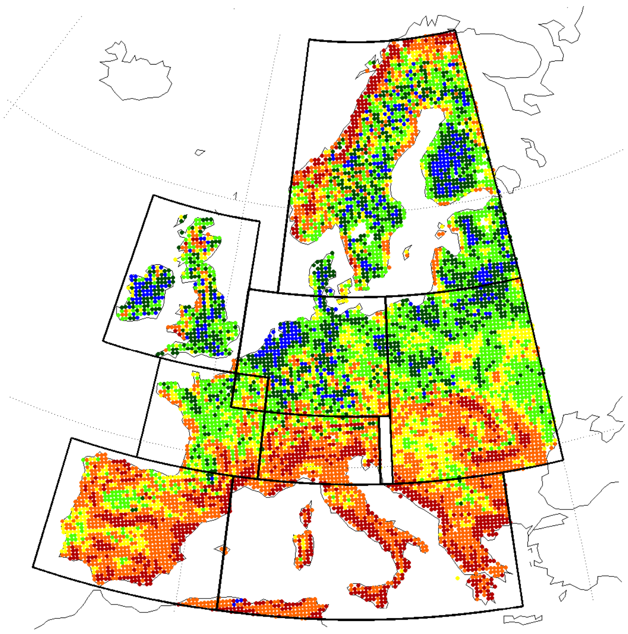
Danish Meteorological Institute

Ministry of Climate and Energy

Danish Climate Centre Report 09-04

Comparing regional climate models with gridded observations within the ENSEMBLES project using probability density functions

Fredrik Boberg, Peter Berg and Peter Thejll



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Serial title:
Danish Climate Centre Report 09-04

Title:
Comparing regional climate models with gridded observations within the ENSEMBLES project using probability density functions

Subtitle:

Authors:
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Other Contributers:

Responsible Institution:
Danish Meteorological Institute

Language:
English

Keywords:
Precipitation, temperature, ENSEMBLES, regional climate modelling, probability density function

Url:
http://ensemblesrt3.dmi.dk/

ISSN:
1399-1957

ISBN:
978-87-7478-579-8

Version:
1

Website:
www.dmi.dk

Contents

1. Dansk resumé

Fremtidens nedbør over Europa modelleres på grundlag af nuværende viden om nedbøren samt forventninger om fremtidens klima, på basis af regionale klimamodeller. De observerede data er centrale for afgørelsen af hvilke modeller der bedst beskriver den nuværende nedbør, men findes som to datasæt - det ene er stationsdata og det andet er et specielt fremstillet datasæt der i en jævn fordeling af grid-punkter beskriver nedbøren. Vi undersøger i denne rapport om de to repræsentationer for nedbør er lige gode.

Vi sammenligner i denne rapport et model-datasæt for temperaturer og nedbør med observationer. Vi sammenligner et gridded datasæt, fremstillet ved interpolation i stationsdata, med regionale klimamodeleksperimenter fra ENSEMBLES-projektet. Sammenligningen foretages for daglige værdier af nedbør og middeltemperaturer fra perioden 1961-1990 ved hjælp af fordelingssandsynligheder for ni europæiske underområder med forskellige klimakarakteristikker. Vi finder at de griddede observationsdata, for alle årstider og for de fleste geografiske underområder, afviger fra modellernes værdier i form af en overvurdering af moderat nedbør og en undervurdering af ekstrem nedbør. For daglige middeltemperaturer undervurderer de griddede observationer ofte antallet varme dage i de fleste underområder og de fleste årstider. Derimod svarer den kolde del af modelfordelingerne godt med de griddede observationsdata.

Vi inkluderer også et stationsdatasæt i studiet - altså et datasæt der ikke er placeret på et grid. Dette datasæt indeholder mange, men ikke alle, af de data der blev anvendt for at fremstille det tidligere griddede observationsdatasæt. På trods af stationsdatasættets inhomogene rumlige fordeling passer det ganske fint med modellerne i de fleste underregioner og i de fleste årstider. Men, set i forhold til de griddede observationer, passer de daglige middeltemperaturer fra stationsdata dårligt med modellernes værdier, specielt for kolde dage om sommeren.

2. Abstract

Future precipitation over Europe is being modelled on the basis of present knowledge of observed precipitation and expectations for the future based on regional climate models. The observational data are vital for determining which of the models best represent current precipitation, but the precipitation data are available in two versions - as raw station data and as a specially gridded set. We investigate here whether these two representations are similar or not.

A newly developed gridded data set, constructed using interpolations of station observations, is validated using regional climate model experiments within the ENSEMBLES project. The validation is made for daily precipitation and daily mean temperature during the period 1961-1990 using probability density functions for nine different European subregions with different climate characteristics. It is found that the gridded observations deviate from the models for precipitation, for all seasons and for most subregions, with an overestimation of days with moderate precipitation and an underestimation of days with more intense precipitation. For daily mean temperature, the gridded observations often underestimate the number of hot days, which is found for most subregions and most seasons. The cold day part of the model distribution is however relatively well matched by the gridded observations.

We also include a publicly available station based observational data set in the study. This data set constitutes a relatively large fraction of the observations used to produce the gridded observational data set and it is, despite of its inhomogeneous spatial distribution, found to match the daily model

precipitation distribution relatively well for most subregions and most seasons. However, compared with the gridded observations, the daily mean temperature distribution for the station observations is often poorly matching the model distributions, especially for colder days during summer.

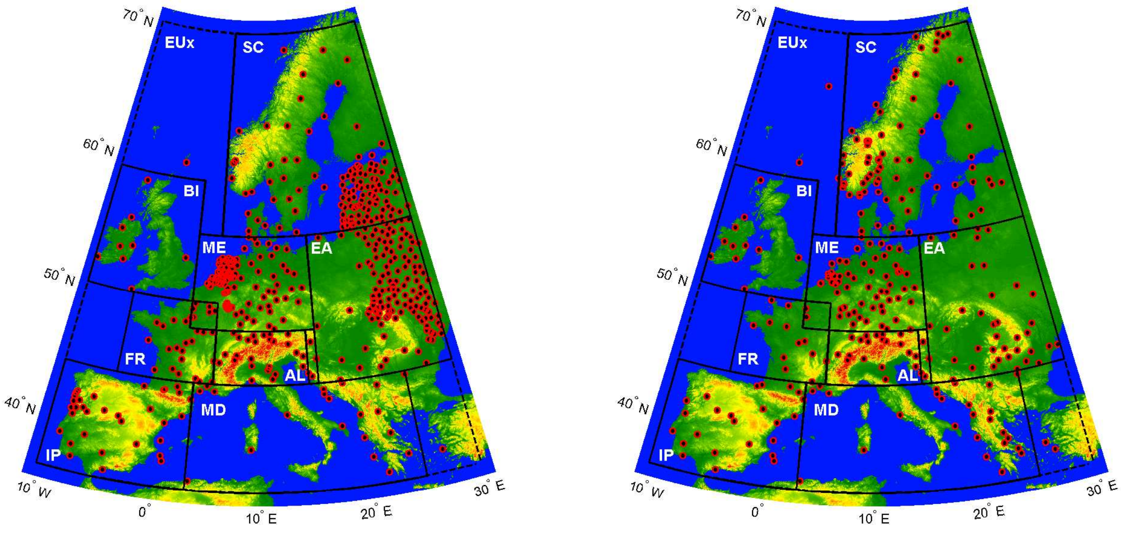

Figure 3.1: Geographical positions of ECA&D compiled stations (marked by dots) with more than 3000 daily measurements for the period 1961–1990 used in this study. The left panel shows locations for the 535 stations with precipitation records and the right panel shows locations for the 290 stations with temperature records. Also shown are the extent of eight predefined European PRUDENCE subregions marked by solid lines as defined by Christensen and Christensen (2007). These regions are: British Isles (BI), Iberian Peninsula (IP), France (FR), Mid-Europe (ME), Scandinavia (SC), the Alps (AL), the Mediterranean (MD), and Eastern Europe (EA). A ninth region termed 'EUx', marked by dashed lines enclosing all the predefined subregions, will also be used in this work. Note the more homogeneous distribution of temperature record stations relative the precipitation record stations.

3. Introduction

Station based measurements of precipitation and temperature are collected by the European Climate Assessment & Dataset (ECA&D) project (Klein Tank et al., 2002). This data set is publicly available and have records that in some cases extend back to the early 19$^{\text{th}}$ century. The spatial distribution of the stations represented is however not homogeneous and is a poor spatial representation for many regions in Europe, as seen in Figure 3.1.

A high-resolution gridded European data set has been developed (Haylock et al., 2008) to improve on the publicly available station based data set, with respect to spatial resolution and extent, and thereby facilitate a direct comparison with regional climate model (RCM) experiments within the ENSEMBLES project (Hewitt, 2005). This data set has been developed, using an interpolation procedure of station measurements, in an attempt to find the best estimates of grid box averages to enable a direct comparison with the RCMs. The final gridded data are currently available, at two spatial resolutions, for the variables precipitation and mean, maximum and minimum temperature with a daily resolution, for the period 1950-2006.

Hofstra et al. (2009) have recently reported that daily precipitation values in this gridded data set are over-smoothed, resulting in reduced interpolated daily values relative to the actual area-averages. This report will show a comparison between gridded observations and RCM data using probability density functions (PDFs) of daily precipitation and daily mean temperature. Although the focus in this study is on gridded data, we will also include PDFs calculated from the ECA&D station records in the comparison.

The PDF comparison presented here is made for different Europeans subregions with different climate characteristics for both annual and seasonal periods in an attempt to show under which conditions the gridded observations fail to match the model experiments.

4. Data

Three data sets are used in this comparative study. The first set is daily data from four RCMs within the ENSEMBLES project (Hewitt, 2005). The second data set is a daily gridded observational data set (Haylock et al., 2008) and the third data set consists of station based measurements of precipitation and temperature collected by the European Climate Assessment & Dataset (ECA&D) project (Klein Tank et al., 2002). We will exclusively use data during the period 1961–1990 due to the relatively large fraction of observations available during this period.

Model data

The model data set consists of RCM runs, with a 25 km resolution, within the ENSEMBLES project, an EU-funded integrated project aiming at developing an ensemble of prediction systems for climate change based on European climate models in an effort to estimate the uncertainty in future climate (Hewitt, 2005). RCM data within the ENSEMBLES project are collected at http://ensemblesrt3.dmi.dk/ and can be divided into two main categories, one with model runs driven by ERA40 reanalysis data for the control period 1961 to 2000, and one with model runs driven by different GCMs for the transient period 1951 to 2050 or 2100, depending on the model in question. With the aim of comparing observations with model data during the present time, we will here exclusively use the model runs driven by ERA40 reanalysis data. Furthermore we will only use RCMs sharing the same grid point coordinates as for the gridded observations. This selection criteria gives us four ERA40-driven models that will be used in this study: ETHZ CLM (Jaeger et al., 2008), HC HADRM3 (Collins et al., 2006), KNMI RACMO2 (Lenderink and van Meijgaard, 2008) and MPI REMO (Jacob et al., 2001).

Observational data

A data set consisting of daily gridded values of precipitation and mean, maximum and minimum temperature is now publicly available for the period 1950–2006 (Haylock et al., 2008). Daily data are provided on four spatial resolutions with best estimates of grid box averages to facilitate a direct comparison with the RCM experiments within the ENSEMBLES project. The grid box averages are found using a three-step process. First, monthly precipitation totals and monthly mean temperatures are interpolated using three dimensional splines. Secondly, daily anomalies are interpolated using kriging methods. Finally the monthly and daily values are combined together with daily standard errors of the interpolation.

The station data set consists of observations provided by the ECA&D project (Klein Tank et al., 2002). A total of 1084 blended station precipitation records and a total of 580 blended temperature records are currently publicly available at http://eca.knmi.nl, and out of those 535 precipitation records and 290 temperature records fulfill our requirements of having at least 3000 valid daily measurements during the control period 1961–1990 and laying within one or more of the nine subregions used in this study (see Figure 3.1). We will use this data set as it is, with no attempts to statistically optimize the station selection with regard to the stations' altitudes or inhomogeneous distributions of valid stations within the selected subregions.

5. European subregions

The data described in chapter 4 are divided into nine European subregions with different climatologies. The extent of these subregions are given in Figure 3.1. The climate of these subregions varies significantly (see e.g. Wallén (1970, 1977)) giving rise to different precipitation and temperature distributions. Regions BI, FR and the majority of ME have oceanic climate with lots of precipitation throughout the year with large variations in precipitation from day to day as well as prolonged periods of heavy rain. These regions often experience hot summers and cool winters but still in a relatively small temperature range.

IP and MD are subtropical regions with dry summers having annual precipitation concentrated to a small number of days with large inter-annual variation. The summers are very hot in these regions with a large number of heat spells and the winters are relatively mild, giving a rather narrow temperature distribution, especially during summer. In region AL, the complex mountain topography gives rise to extreme differences in climate with valleys with warm and dry conditions and the surrounding heights with a lot of precipitation. The extreme differences give rise to a wide temperature distribution for all seasons.

Region EA is basically characterized by a humid continental climate with high annual precipitation amounts. Region SC is a mixture of oceanic climate, humid continental climate, mountain climate as well as subarctic climate with short humid summers and long winters with somewhat less precipitation. This mixture of climates for these two regions result in a very wide temperature distribution. Finally, the enclosing EUx region contains the eight subregion climates discussed above.

6. PDF calculation

The observations and model data will be compared using probability density functions (PDFs). PDFs created separately for the nine individual subregions, for both the full annual period but also for all four seasons, for the period 1961–1990 will be used to compare models and observations over a range of climate types and thereby enabling to find out under what climate conditions the distributions match.

Precipitation PDFs are calculated for grid points and stations over land for wet days, defined as days with precipitation ≥ 1 mm, by binning the data into bins of 1 mm day^{-1} width and then multiplying the bin frequency by the bin average to get the precipitation amount. Finally the PDFs are normalized for the time period, subregion and model in question, so that the area of each individual PDF is equal to 1. This procedure is carried out for all three data sets for annual and seasonal periods.

Temperature PDFs are also calculated for grid points and stations over land. Here the data are binned into bins of 0.2°C width and then normalized for the subregion and season in question, so that the area of each individual PDF is equal to 1. This procedure is carried out for all three data sets.

7. Results

We will now show the results of comparing PDFs calculated for RCMs and for observations for the nine subregions for the period 1961–1990. First, we show the precipitation PDFs and then the temperature PDFs.

Precipitation PDFs

Figures 7.1 through 7.9 show precipitation PDFs for ECA&D observations, for gridded observations and for four ENSEMBLES RCM experiments for all nine European subregions. Each figure compare PDFs for the full annual period as well as for the four seasonal periods DJF, MAM, JJA and SON.

For Figure 7.1 we see a close match between model PDFs and PDFs for region BI for both observational data sets for all five time frames. The 95$^{\mathrm{th}}$ percentiles of accumulated observed precipitation also match the 95$^{\mathrm{th}}$ percentiles for the model runs, as indicated by the vertical lines and arrows in the top part of each panel. PDFs obtained from station measurements should show a wider distribution for more extreme precipitation compared to a gridded (observed or modelled) dataset for the same region. This is due to point measurements for station data and smoothed grid box averages for the gridded data. This is not the case for region BI.

For Figures 7.2 through 7.9 we see that the gridded observations underestimate days with extreme precipitation for all five time frames, with respect to the model PDFs. As given by the inserts in each panel, the gridded observations overestimate days with less intense precipitation for most subregions and most time frames. Moreover, the PDFs calculated using the station observation data set underestimate days with moderate precipitation for some subregions, especially during summer.

To measure the extent that the normalized model PDFs match the gridded observation PDFs, we construct a match metric based on the common overlap of the two precipitation PDFs. The match metric has a skill score of zero for no overlap between the two PDFs and a skill score of one for a perfect overlap (Perkins et al., 2007). Boberg et al. (2008) calculated the common overlap using the entire PDF for the model and region in question whereby the tail of the PDF, containing relatively few events with a small contribution to the total precipitation amount, did not influence the skill score much. We will here use the same method as used by Boberg et al. (2009), dividing the PDFs into two parts allowing the tail of the distribution with more extreme precipitation to influence the final skill score to a larger extent. The two parts are separated at the 90^{th} percentile of accumulated observed gridded precipitation, with one part characterizing relatively moderate precipitation conditions and the second part characterizing more extreme conditions. The two parts are then re-normalized separately and the final skill score metric for each model and each subregions is found by averaging the degree of PDF overlap for each part.

Figure 7.10 shows skill scores for each subregion for the full annual period 1961–1990. Given in the two top panels are the individual skill scores for the two separate parts of the PDF as described above. The bottom panel gives the combined skill scores. We see that the gridded observational PDF match the models well for bins with moderate precipitation (top panel) compared with the ECA&D PDFs. For more extreme precipitation (middle panel) we see that the ECA&D PDFs match the models better and the combined result (bottom panel) is that the ECA&D PDFs have on average a higher skill score with respect to model PDFs relative to the gridded observational PDFs.

Figure 7.11 shows skill score maps for the European subregions 1 through 8 for each of the four RCMs matched against gridded observations. The skill scores are calculated for each grid point by extracting PDFs for each grid point in the same manner as done for entire subregions shown in Figures 7.1 through Figure 7.9 but now only for the full annual period. We see that poor PDF overlaps are found in the subtropical regions IP and MD as well as the complex AL region and the Norwegian mountain region. It is also interesting to note that some of the areas with a relative high skill score in Figure 7.11, like the Netherlands and Ireland, are areas with a relative large number of precipitation stations contributing to the gridded observational dataset (cf. Figure 1a in Haylock et al. (2008)).

Temperature PDFs

Figures 7.12 through 7.20 show temperature PDFs for ECA&D observations, for gridded observations and for four ENSEMBLES RCM experiments for all nine European subregions. Note that the temperatures in this study have not been corrected for differences in height between stations, gridded data, or between models. Each figure compares PDFs for the full annual period as well as for the four seasonal periods DJF, MAM, JJA and SON. We see that there is no consistent bias valid for all regions or all seasons. For some regions during summer, the station temperature PDFs have a cold bias for the low temperature tail of the PDF compared with the models and with the gridded observations. In a few cases, both observational PDFs have a cold bias for the high temperature tail of the distribution. But overall, the gridded observational PDF match the models' PDFs better than the station temperature PDFs.

The zero degree problem is also evident in the model PDFs, especially for the MPI REMO model temperatures, where models have a misrepresentative number of days with temperatures close to 0°C. This is due to problems related to snow melt in the models.

Figure 7.21 shows skill scores for daily mean temperature for each subregion for the full annual period 1961–1990. We see that the gridded observational PDF match the models well for all regions compared with the ECA&D PDFs. Furthermore, we see that model KNMI RACMO has a top score for most subregions while model MPI REMO has an overall poor performance due to its pronounced zero degree problem.

Figure 7.22 shows skill score maps for the European subregions 1 through 8 for each of the four RCMs matched against gridded temperature observations. As for Figure 7.11, the skill scores are calculated for each grid point by extracting PDFs for each grid point in the same manner as done for entire subregions shown in Figures 7.12 through Figure 7.20 but now only for the full annual period. As with the comparison for precipitation PDFs in Figure 7.11, we see that poor PDF overlaps are found in the subtropical regions IP and MD as well as the complex AL region and the Norwegian mountain region. However, no clear correlation is seen between areas with a high skill score and areas with a high density of contributing stations to the gridded dataset (cf. Figure 1b in Haylock et al. (2008)).

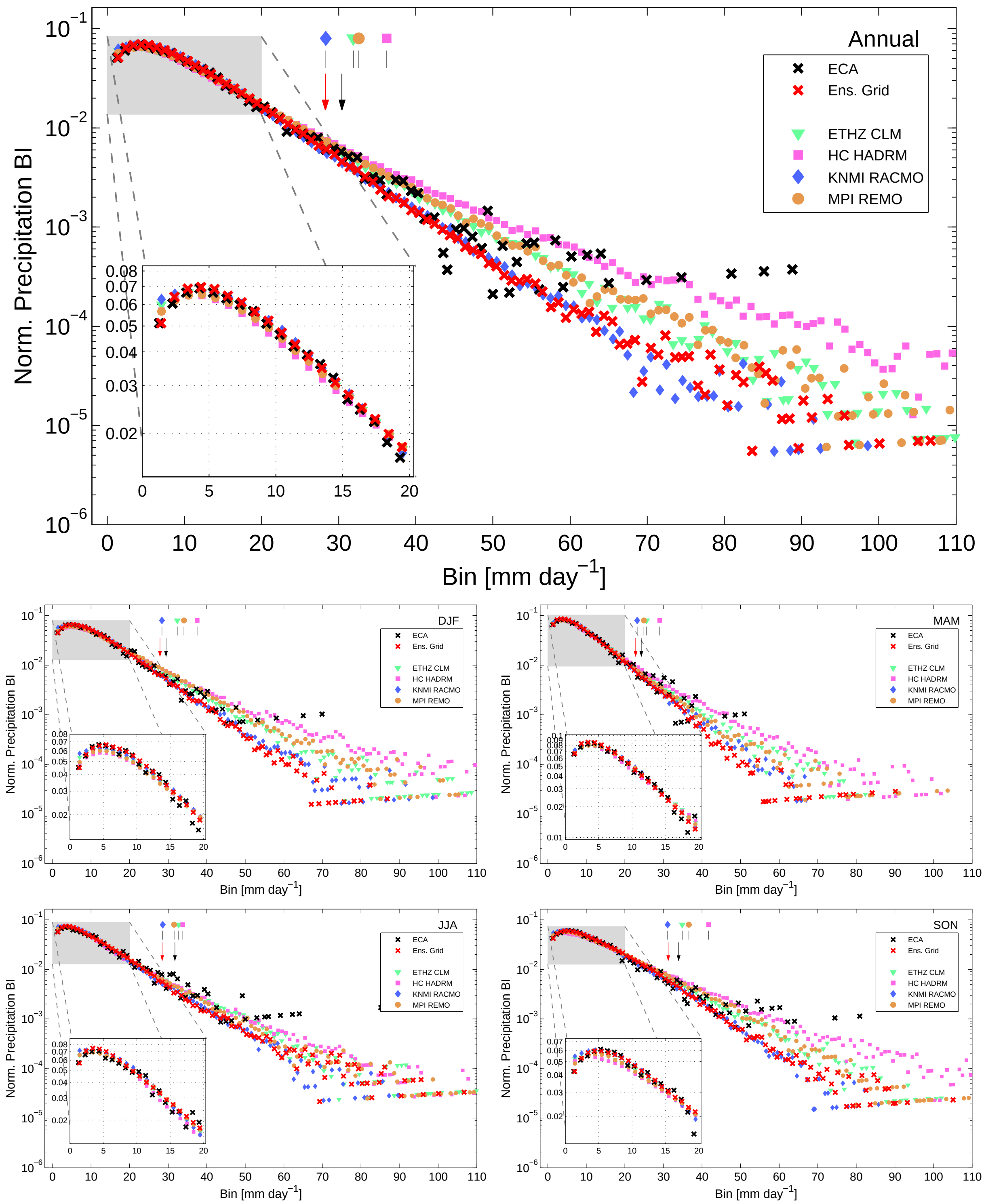

Figure 7.1: Comparison between observed daily ECA&D station precipitation PDFs (black crosses), gridded observations (red crosses) and daily precipitation PDFs from four ENSEMBLES models (colored symbols) for the period 1961–1990 for subregion BI. The top panel shows PDFs for the full annual period and the other panels show the results using seasonal data (DJF, MAM, JJA and SON). The insets are enlargements of the PDFs for the first 20 bins, as indicated by the dashed black lines. Arrows mark the 95th percentile of accumulated observed precipitation whereas vertical lines in the top part of each panel represent the 95th percentile of accumulated precipitation for the model runs.

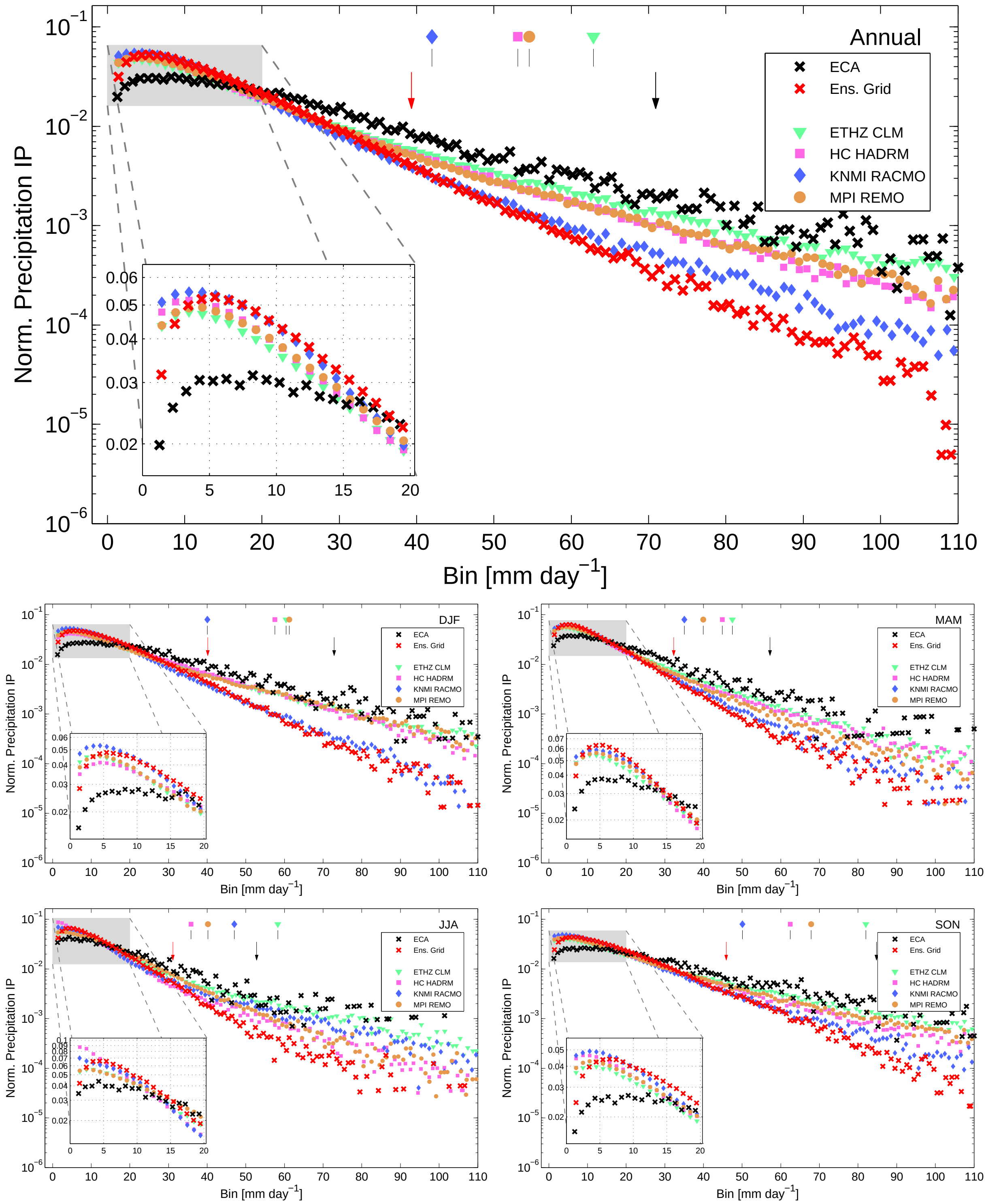

Figure 7.2: The same as for Figure 7.1 but for subregion IP.

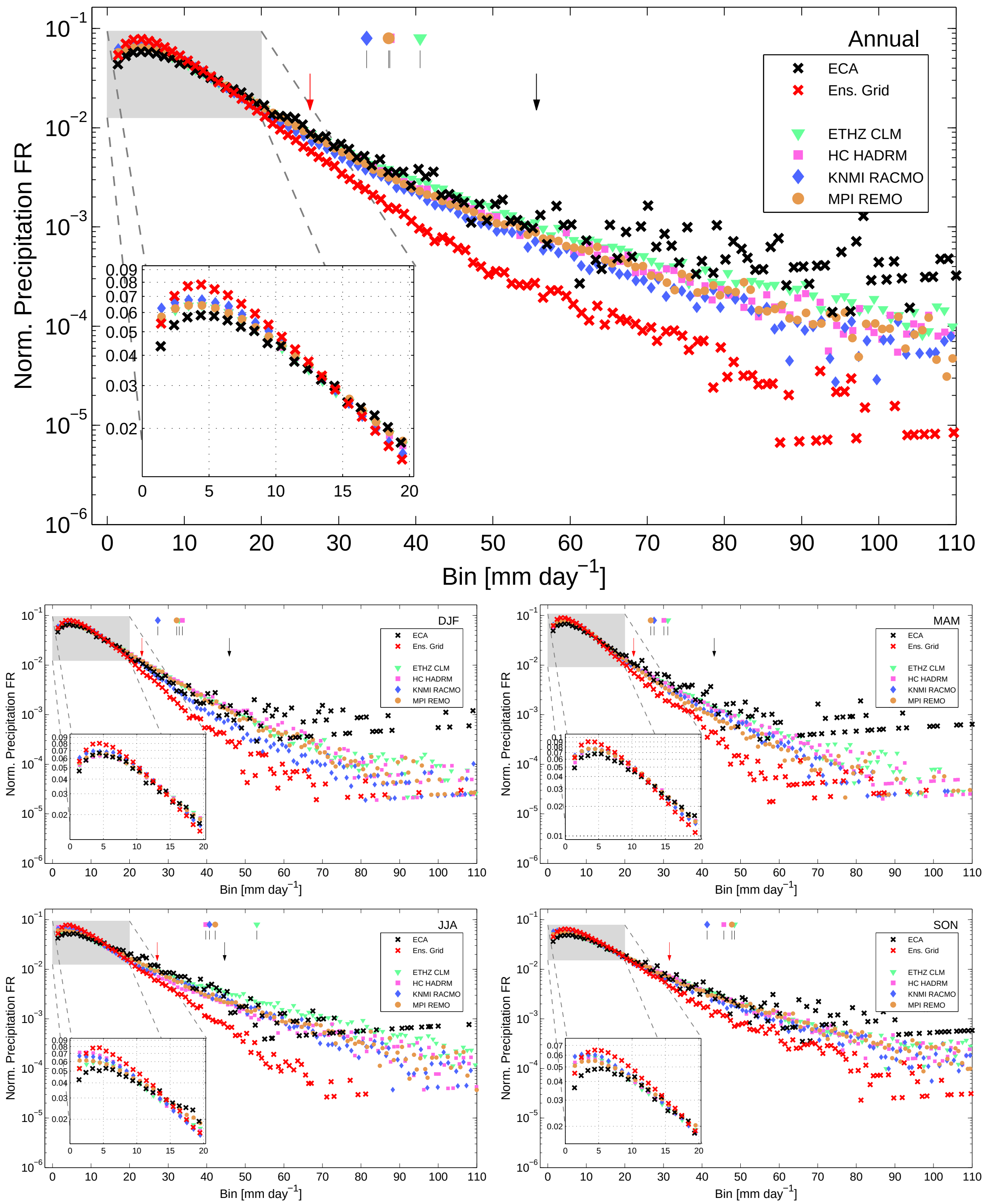

Figure 7.3: The same as for Figure 7.1 but for subregion FR.

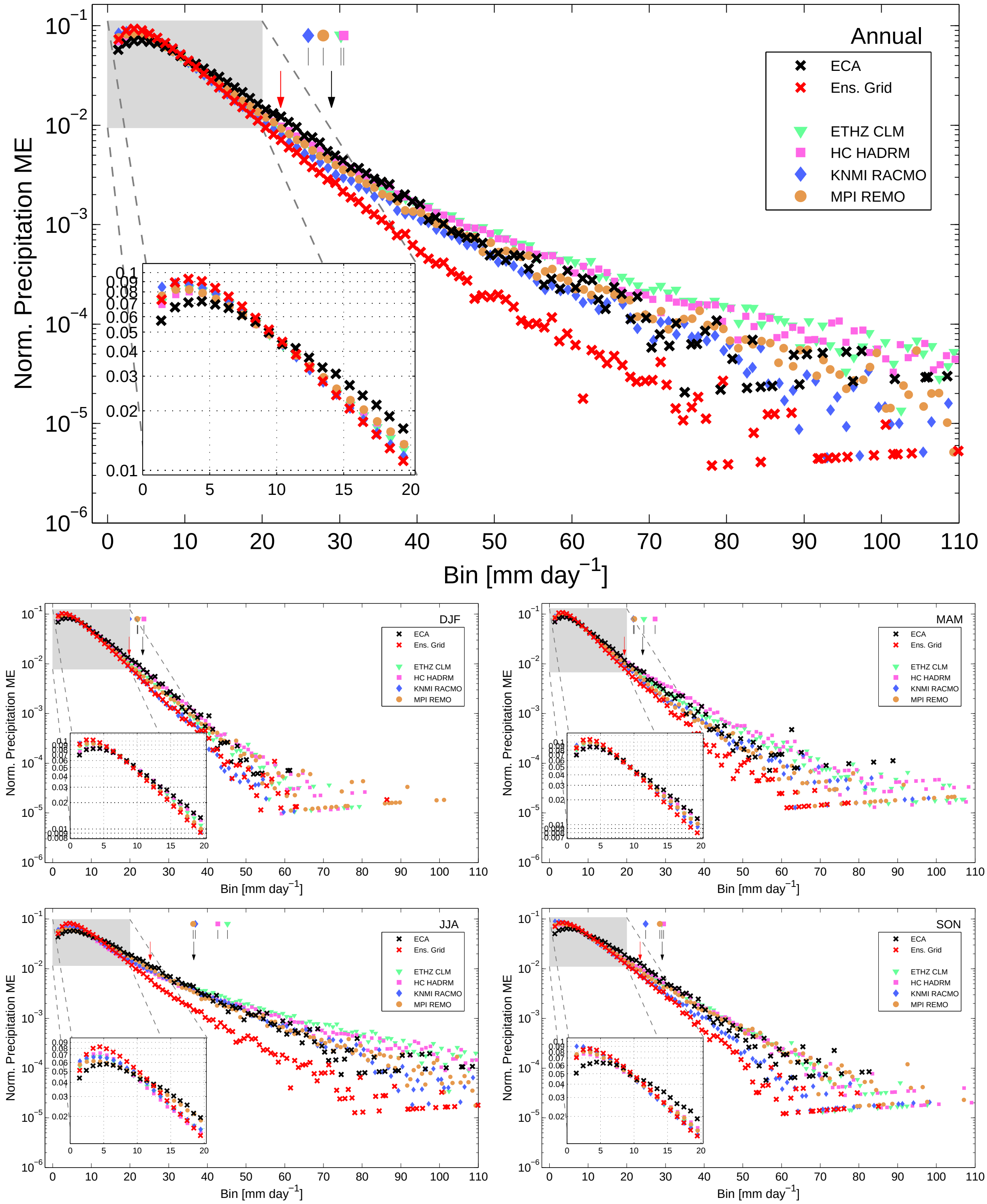

Figure 7.4: The same as for Figure 7.1 but for subregion ME.

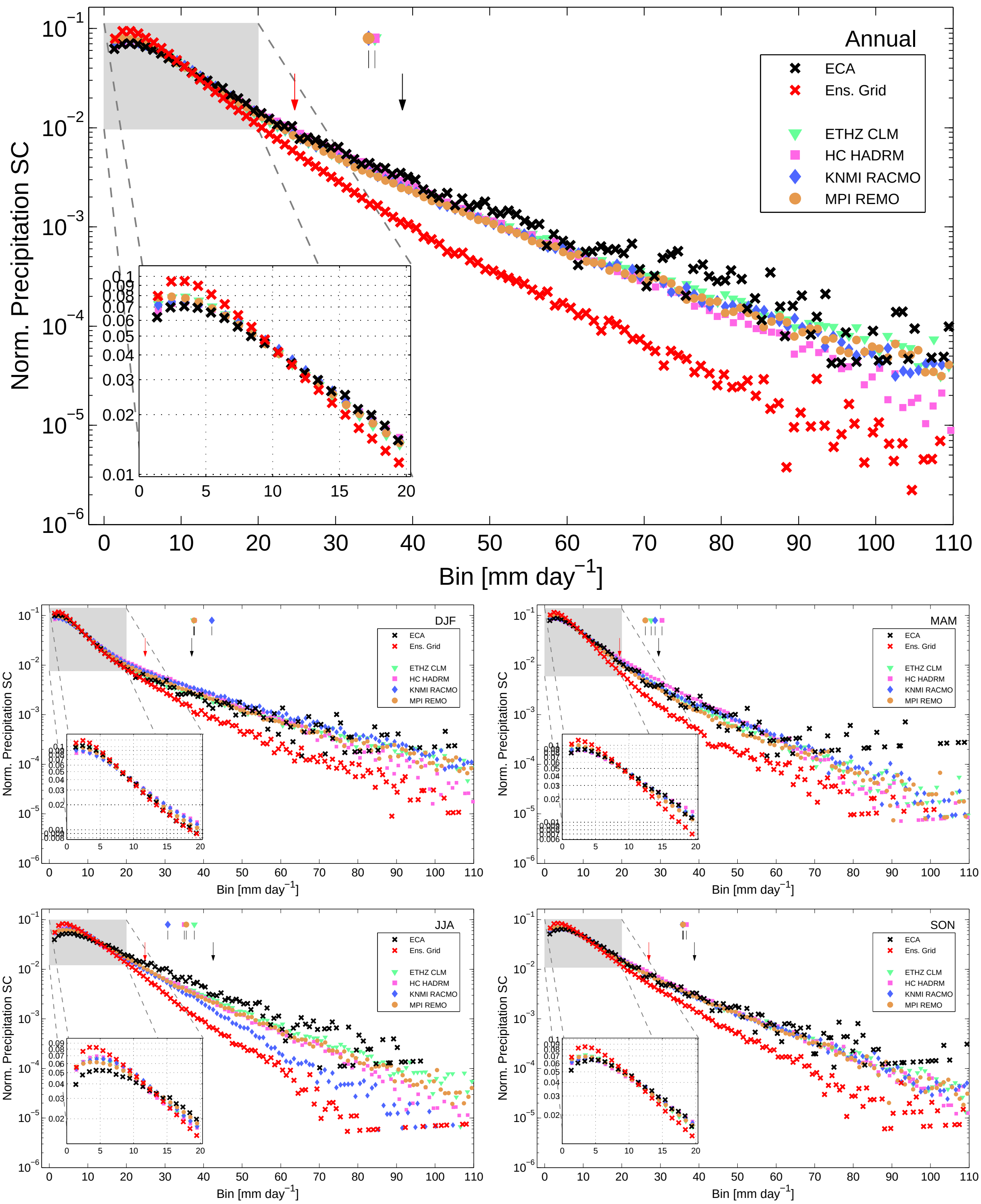

Figure 7.5: The same as for Figure 7.1 but for subregion SC.

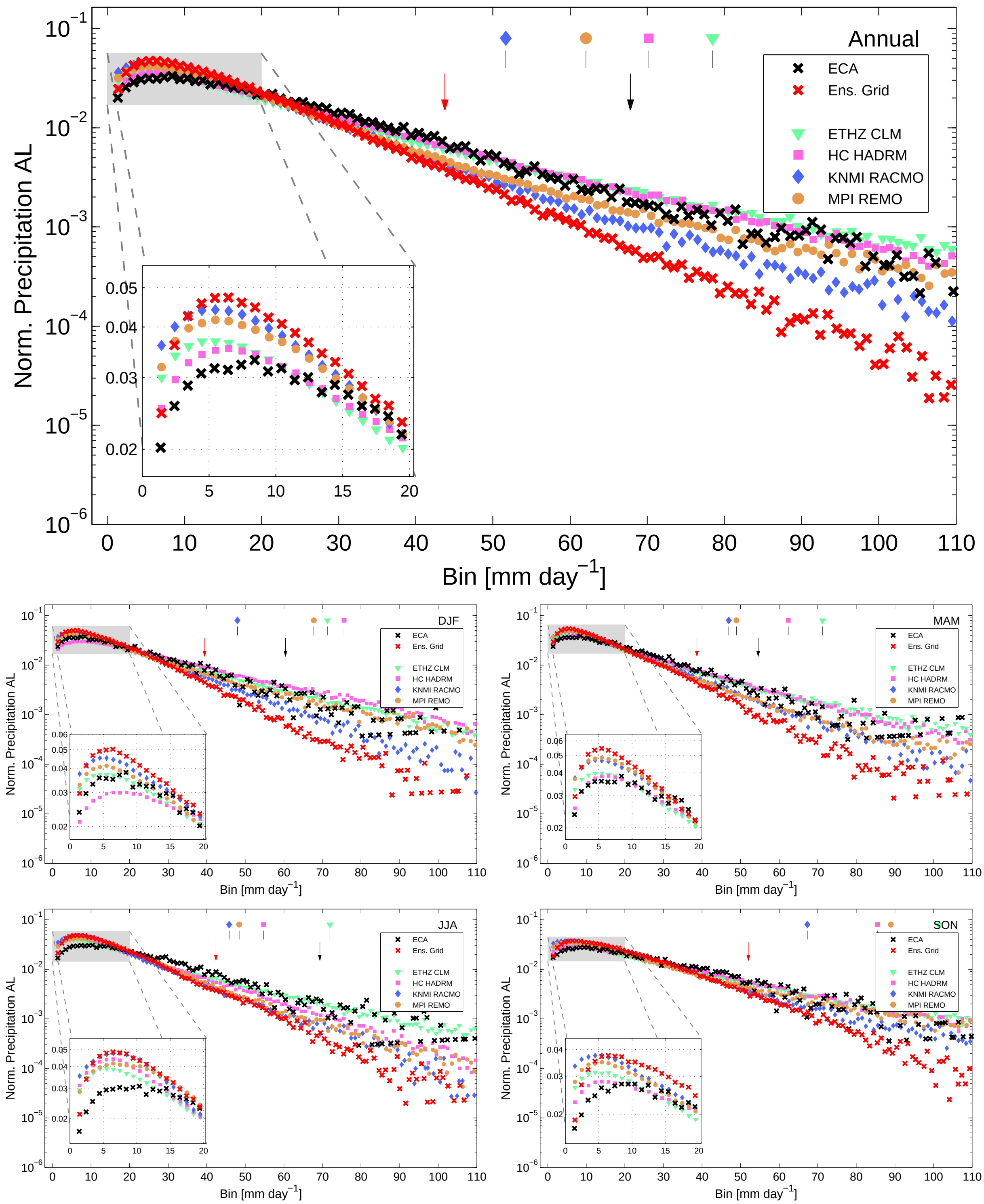

Figure 7.6: The same as for Figure 7.1 but for subregion AL.

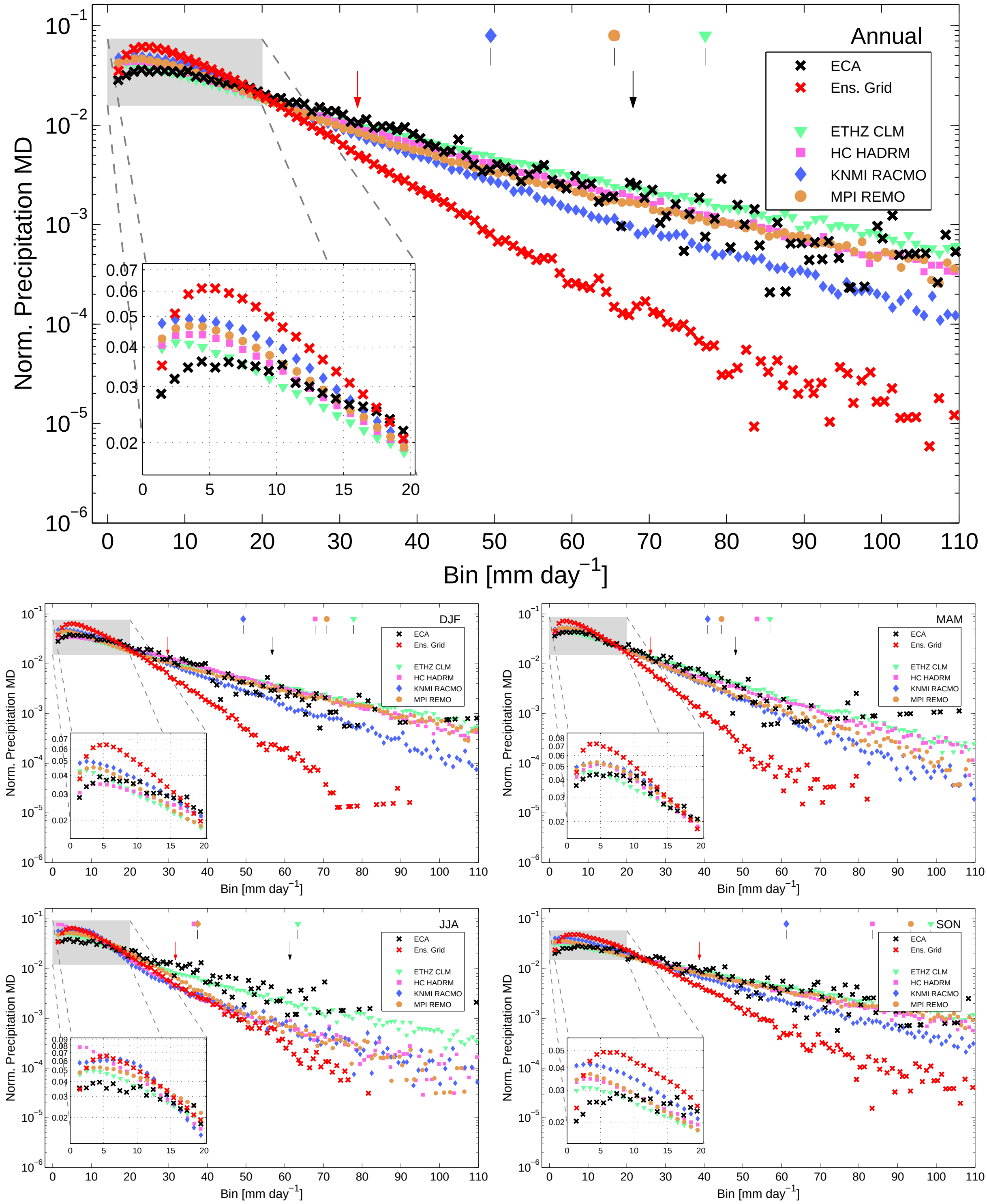

Figure 7.7: The same as for Figure 7.1 but for subregion MD.

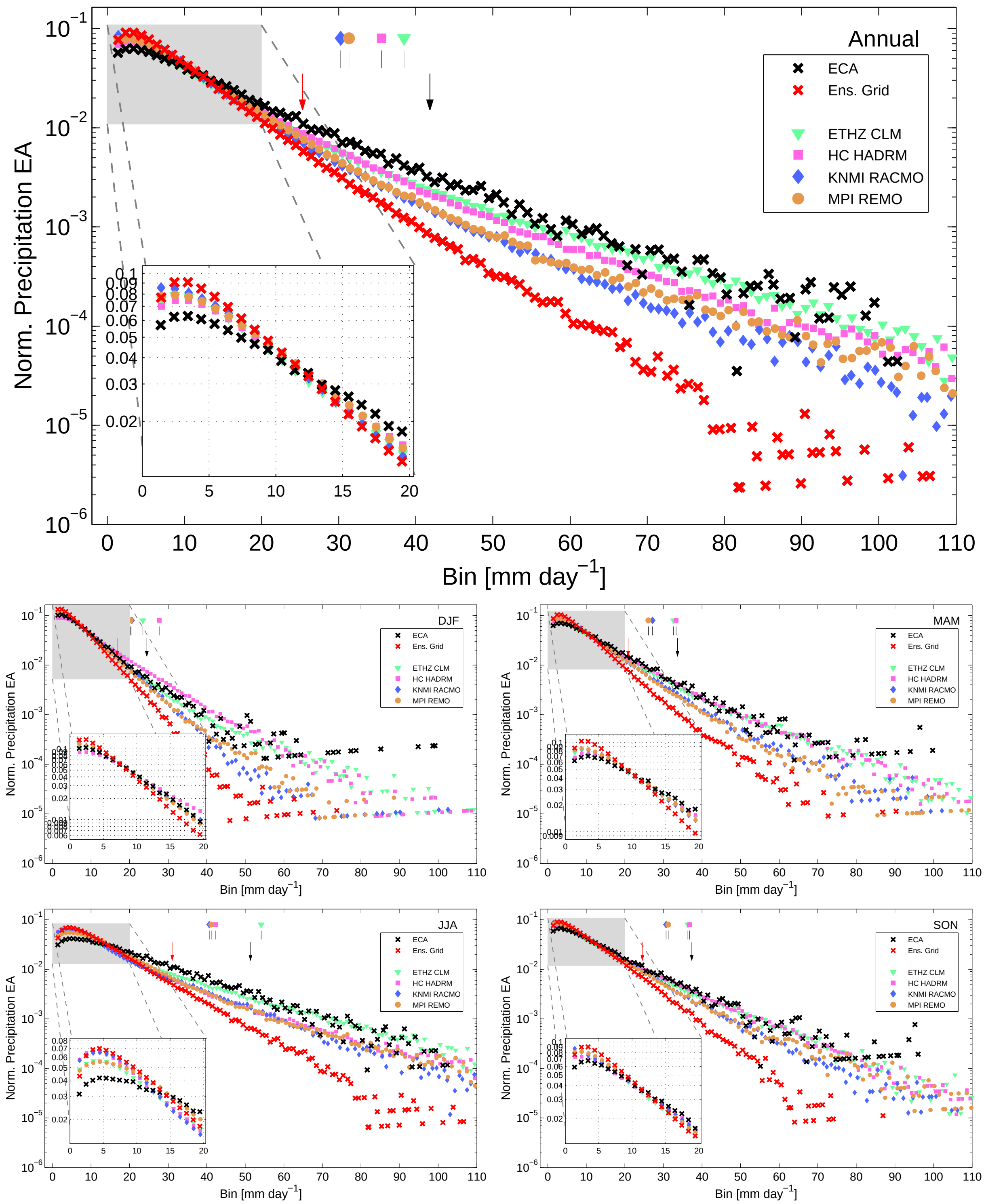

Figure 7.8: The same as for Figure 7.1 but for subregion EA.

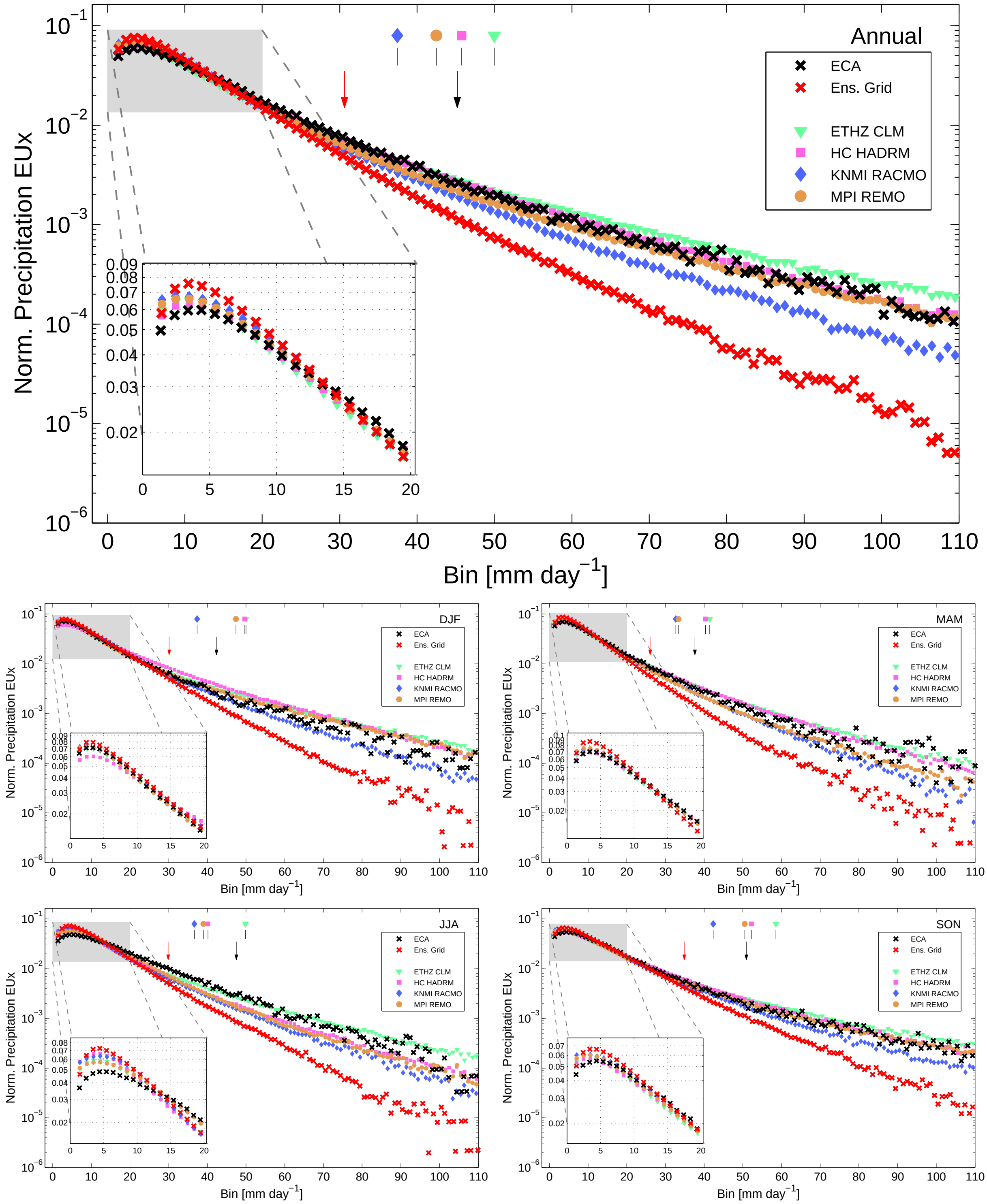

Figure 7.9: The same as for Figure 7.1 but for subregion EUx.

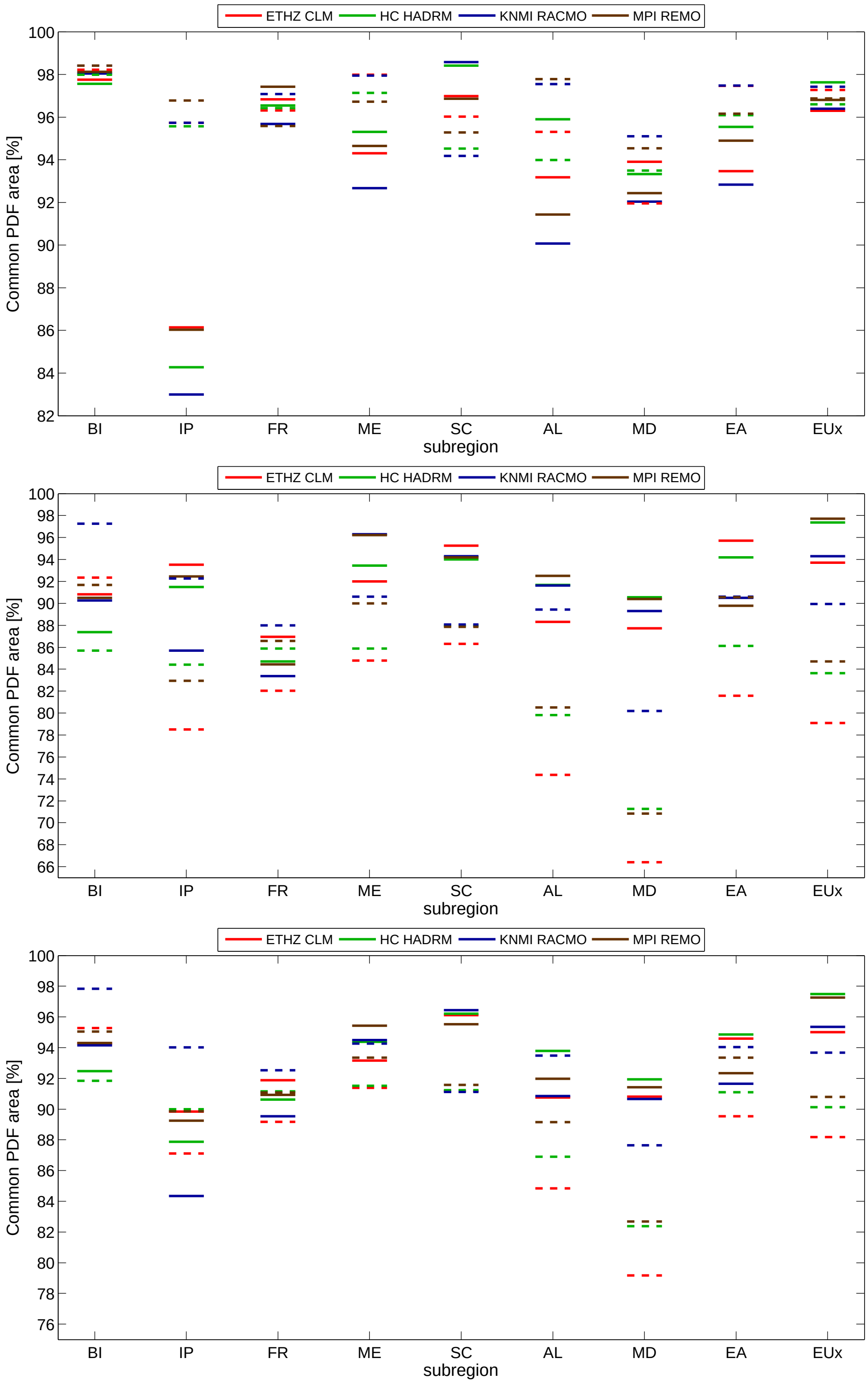

Figure 7.10: Results of comparing four ENSEMBLES runs for precipitation against observations, using daily values for the period 1961–1990. Solid lines represent skill scores for ECA&D observations while dashed lines give skill scores for the gridded observations. The top panel shows skill scores when comparing bins from 1 mm day^{-1} to the 90$^{\text{th}}$ percentile of gridded observations for the subregion in question. The middle panel shows skill scores when comparing bins above the 90$^{\text{th}}$ percentile of gridded observations for the subregion in question. The bottom panel is the average of the skill scores from the two divided parts.

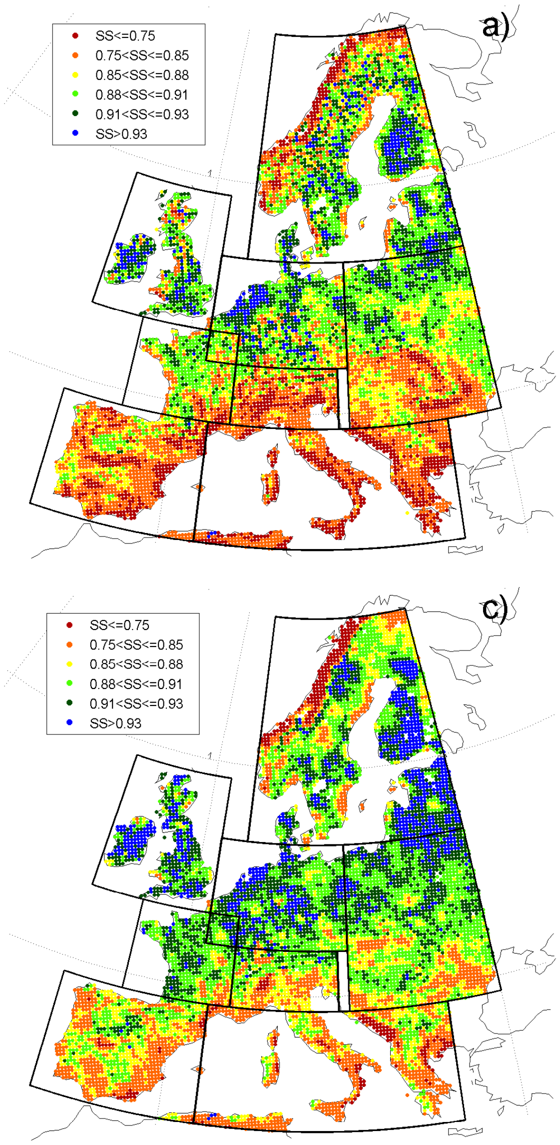

Figure 7.11: Map of grid point skill scores for gridded daily precipitation observations for 1961–1990 matched with the four RCMs used in the study. Top left panel is for model ETH CLM, top right panel is for HC HADRM3, bottom left panel is for KNMI RACMO2 and bottom right panel is for the MPI REMO model. The skill scores are based on the common overlap of the two precipitation PDFs in question with a skill score value of zero for no overlap between the two PDFs and a skill score of one for a perfect overlap. Blue/green colors represent grid points with a relative good match between model and observations while orange/red colors represent a poor overlap.

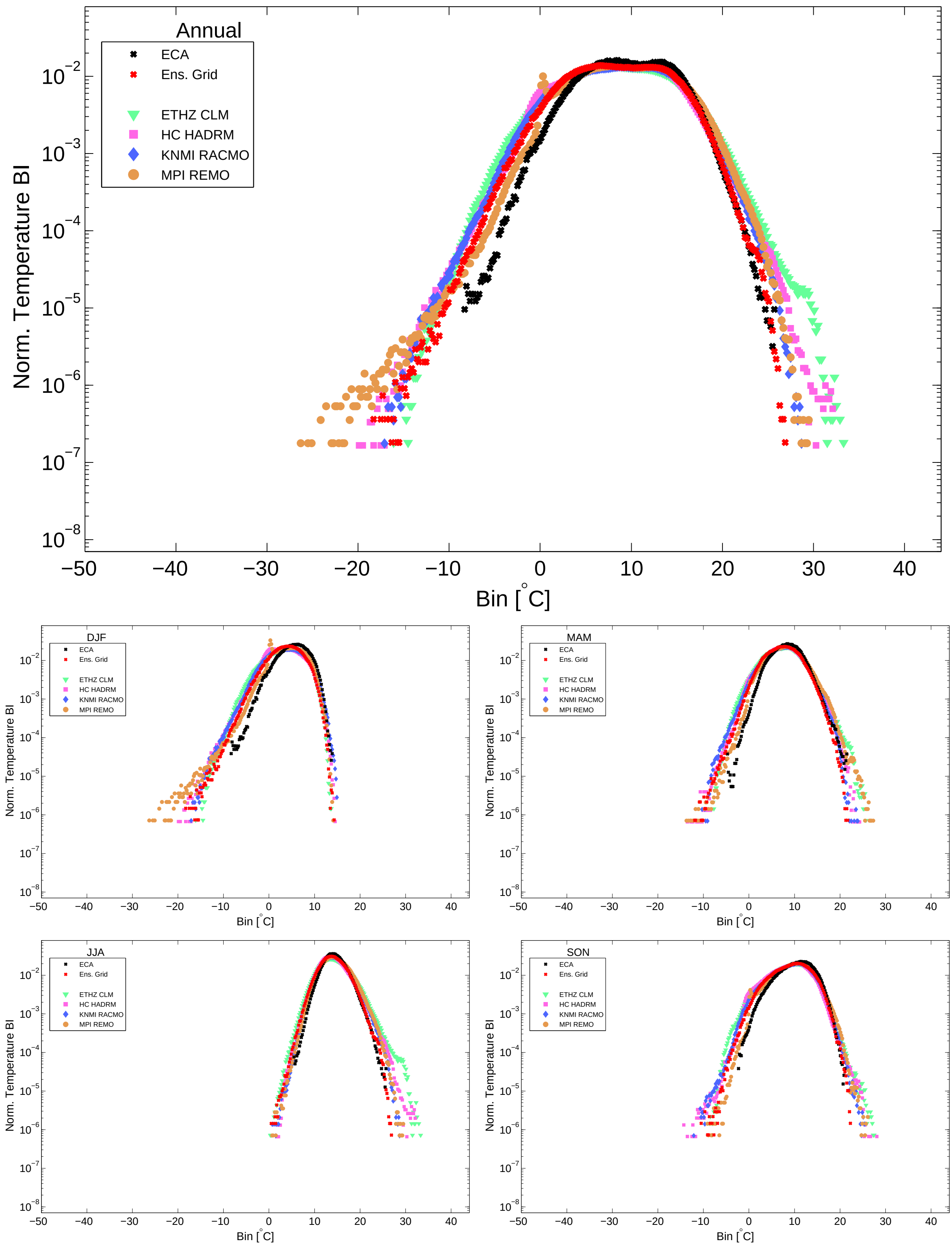

Figure 7.12: Comparison between observed daily ECA&D station temperature PDFs (black crosses), gridded observations (red crosses) and daily temperature PDFs from four ENSEMBLES models (colored symbols) for the period 1961–1990 for subregion BI. The top panel shows PDFs for the full annual period and the other panels show the results using seasonal data (DJF, MAM, JJA and SON).

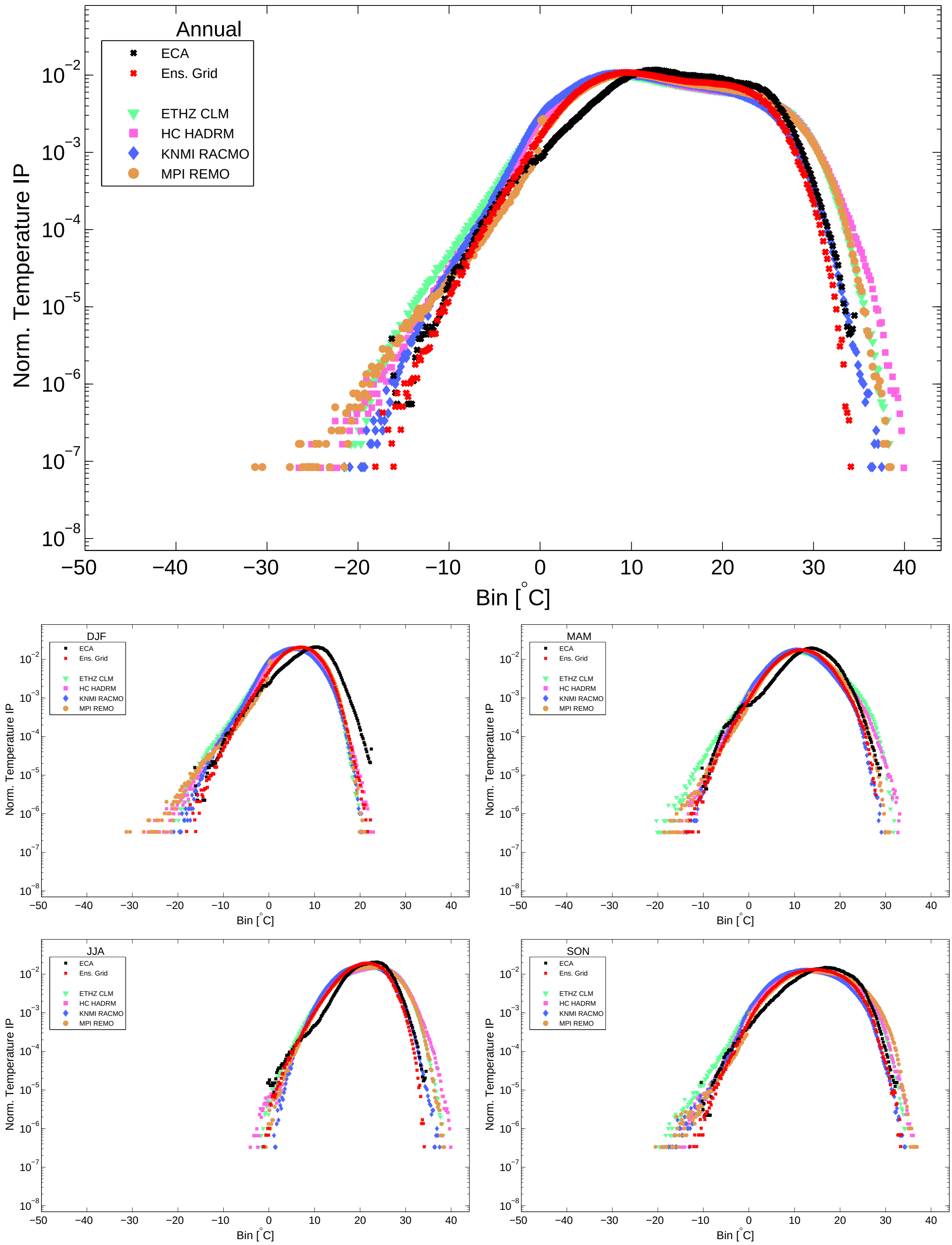

Figure 7.13: The same as for Figure 7.12 but for subregion IP.

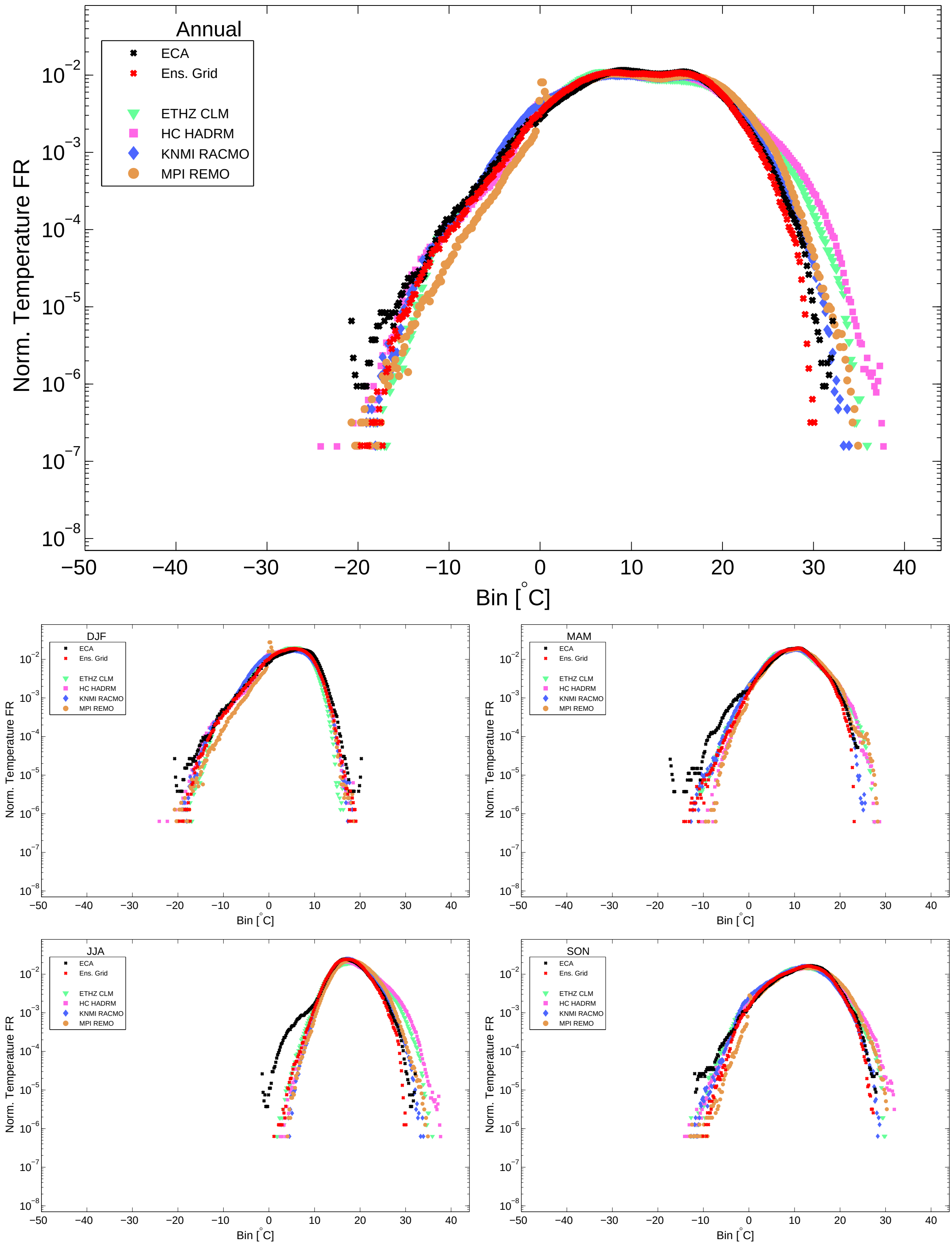

Figure 7.14: The same as for Figure 7.12 but for subregion FR.

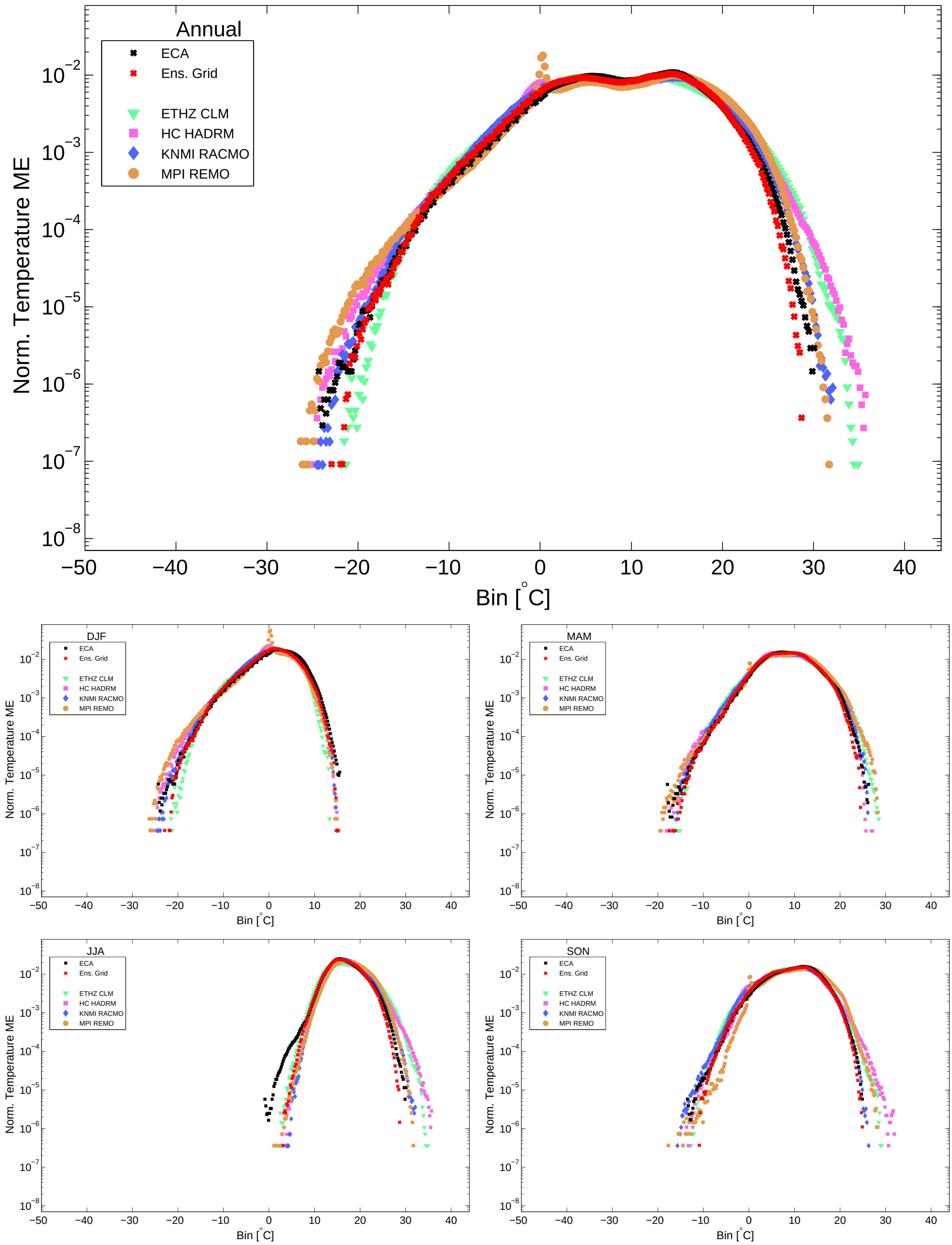

Figure 7.15: The same as for Figure 7.12 but for subregion ME.

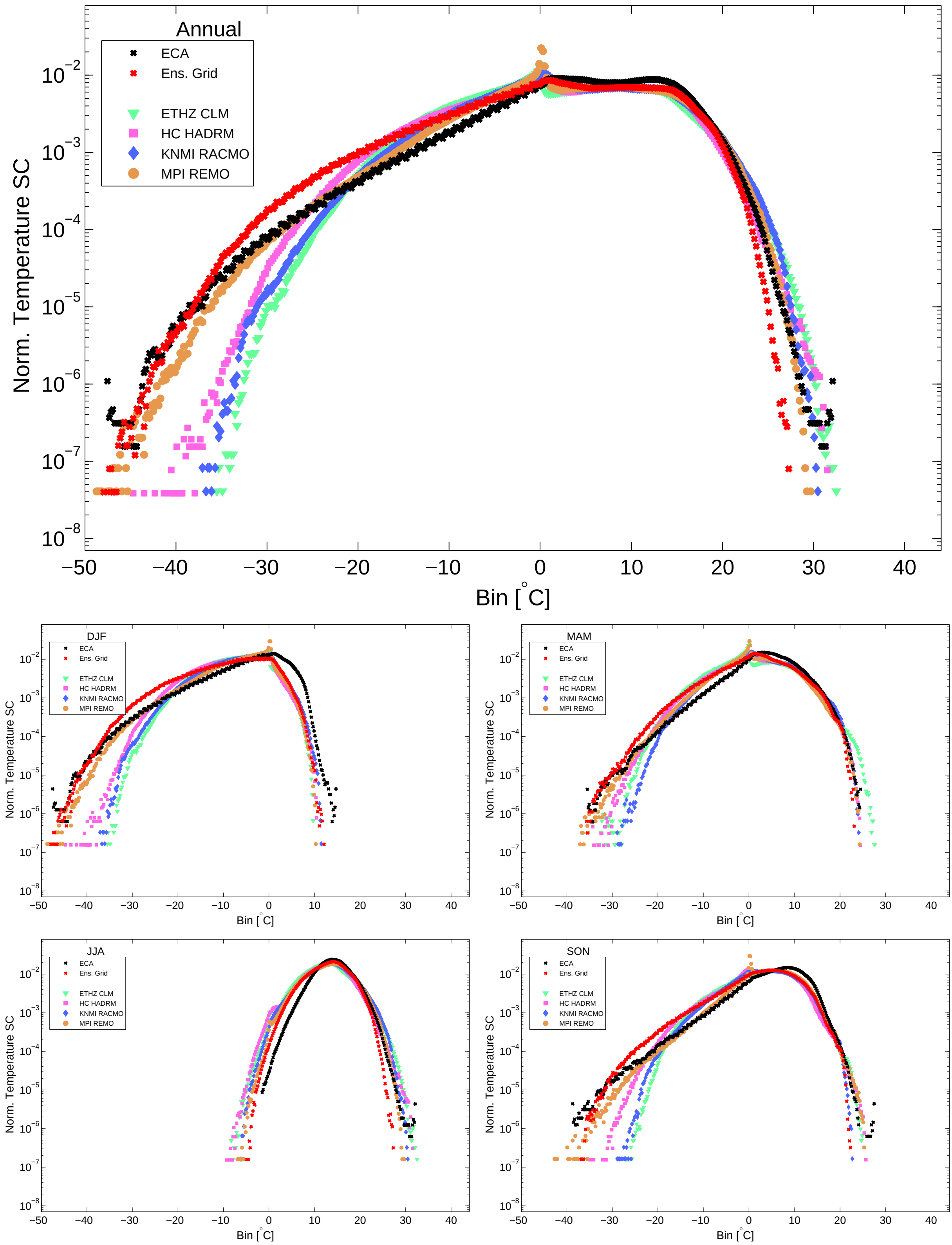

Figure 7.16: The same as for Figure 7.12 but for subregion SC.

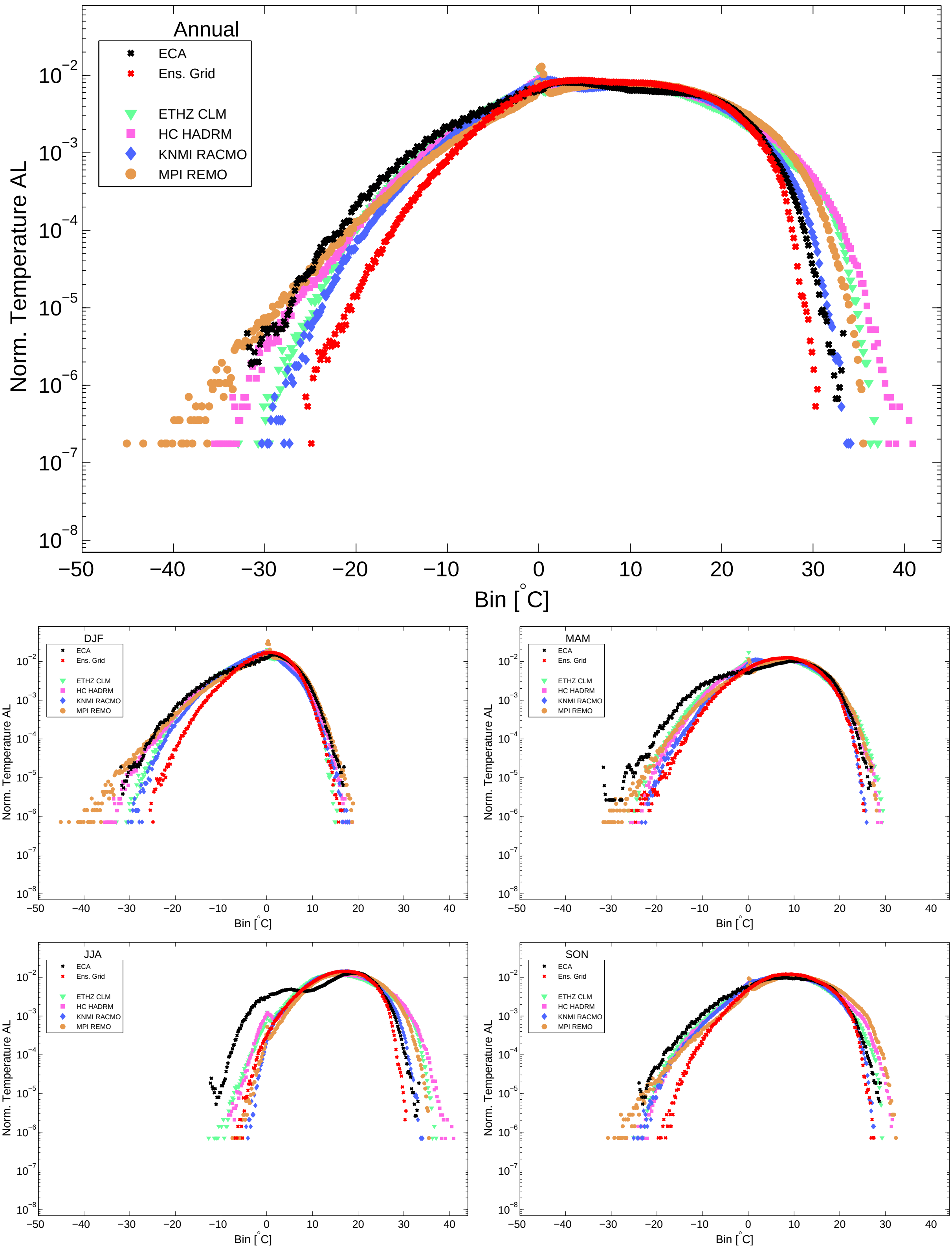

Figure 7.17: The same as for Figure 7.12 but for subregion AL.

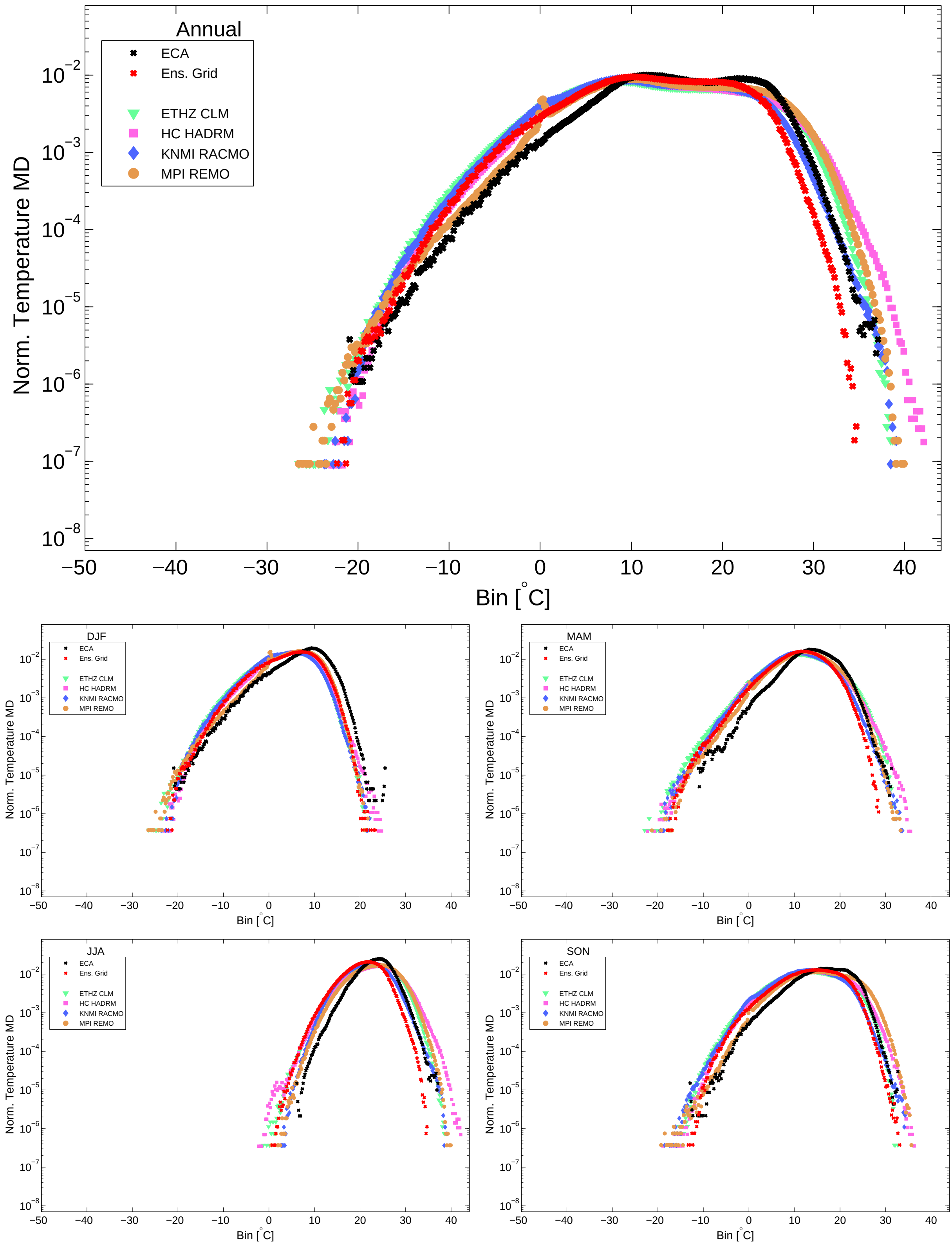

Figure 7.18: The same as for Figure 7.12 but for subregion MD.

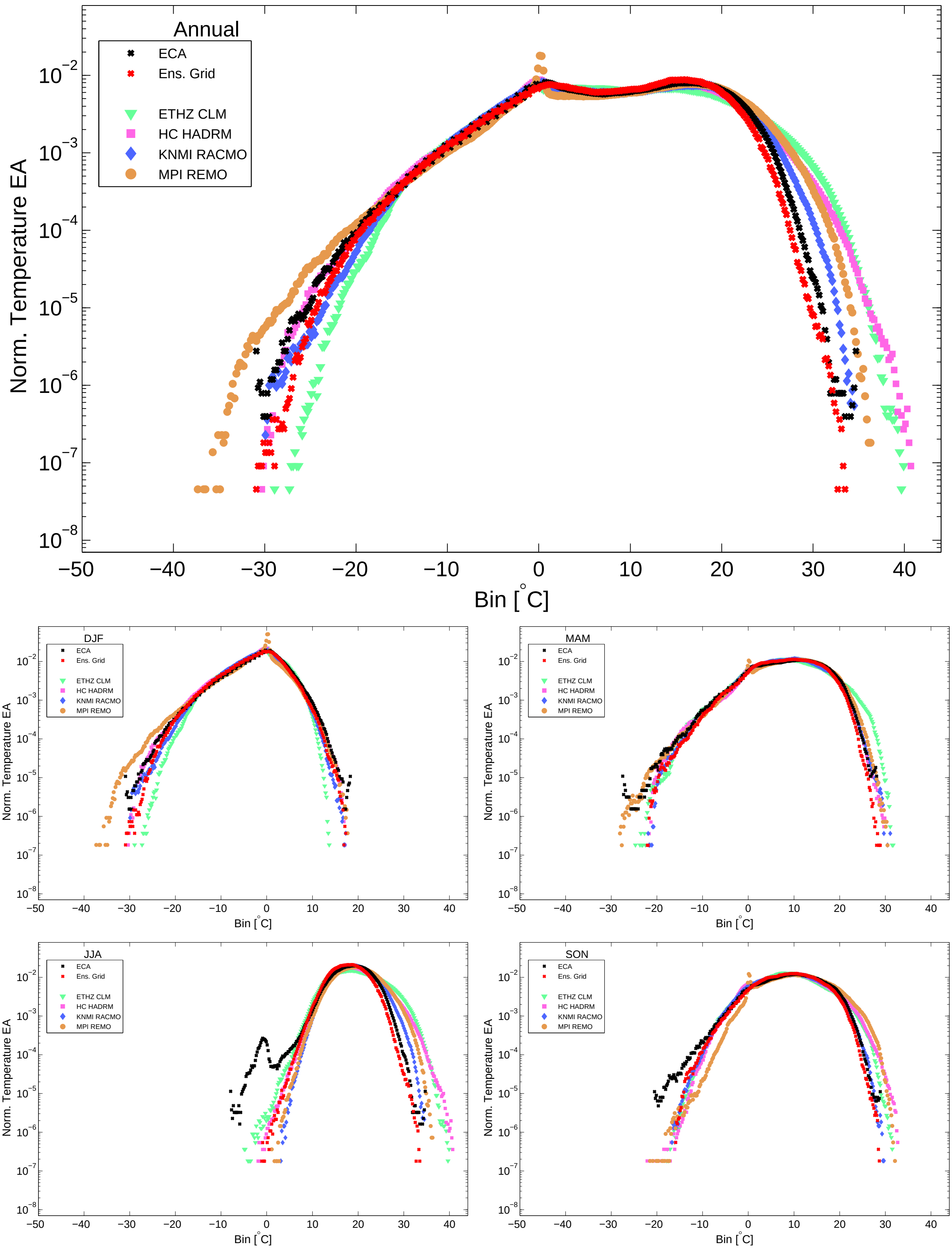

Figure 7.19: The same as for Figure 7.12 but for subregion EA.

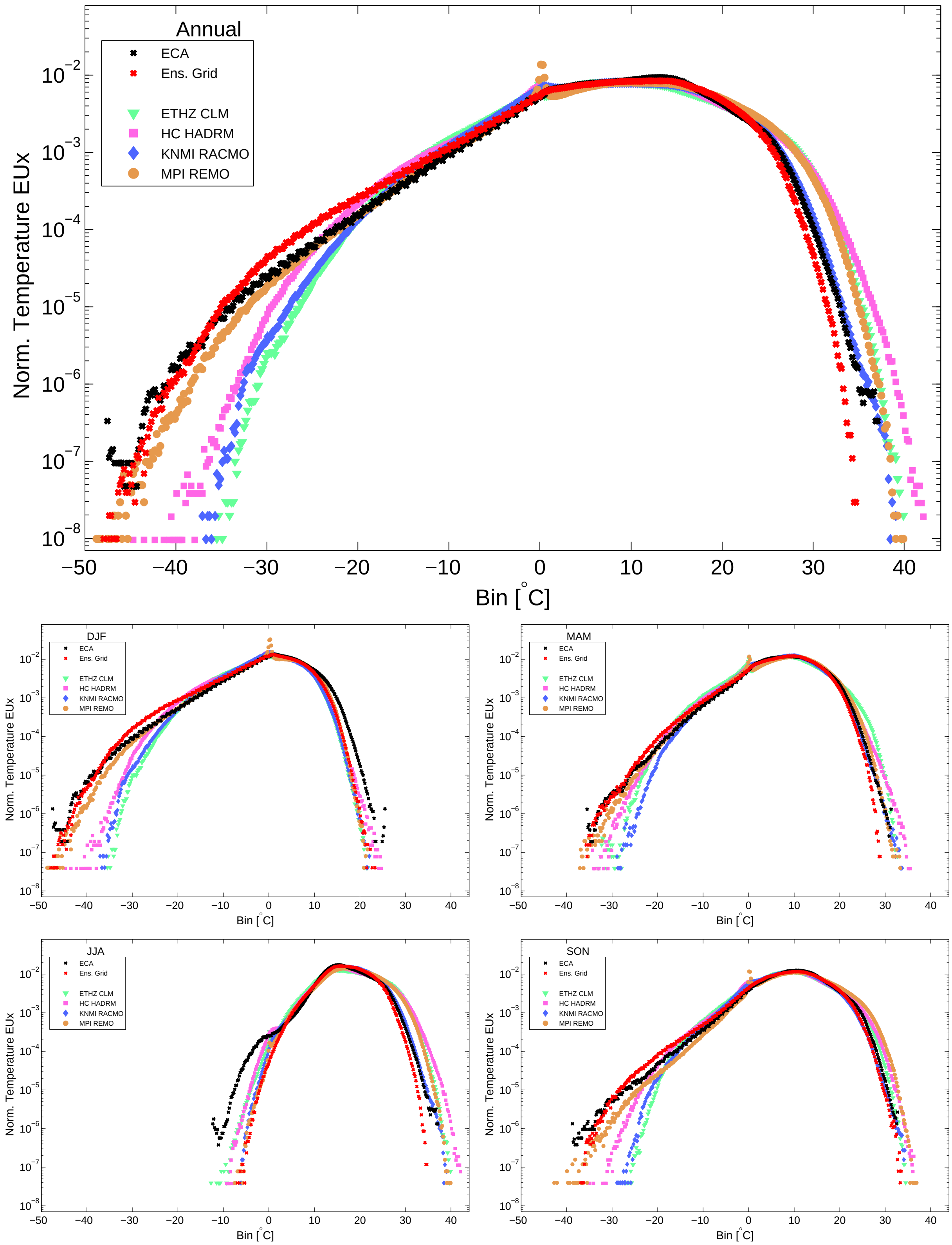

Figure 7.20: The same as for Figure 7.12 but for subregion EUx.

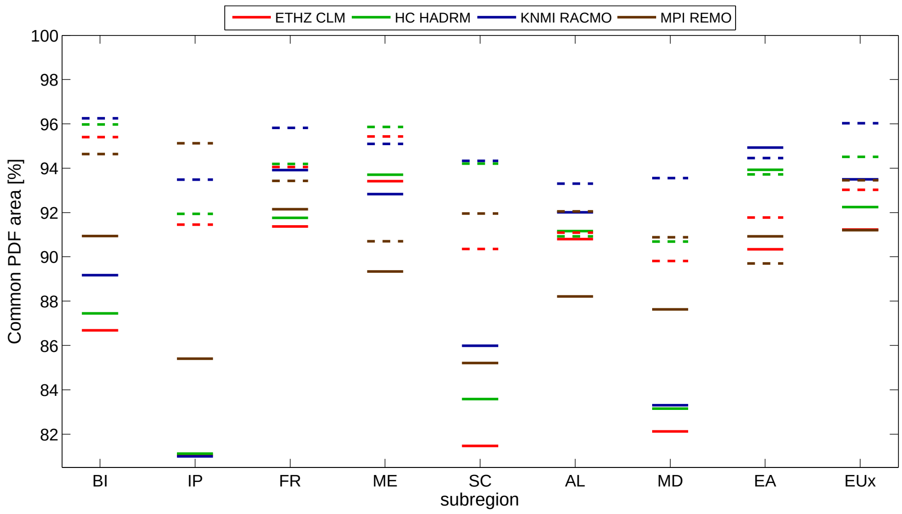

Figure 7.21: Results of comparing four ENSEMBLES runs for daily mean temperature against observations, using daily values for the period 1961–1990. Solid lines represent skill scores for ECA&D observations while dashed lines give skill scores for the gridded observations. The skill scores are based on the common overlap of the two temperature PDFs in question with a skill score value of zero for no overlap between the two PDFs and a skill score of one for a perfect overlap. Blue/green colors represent grid points with a relative good match between model and observations while orange/red colors represent a poor overlap.

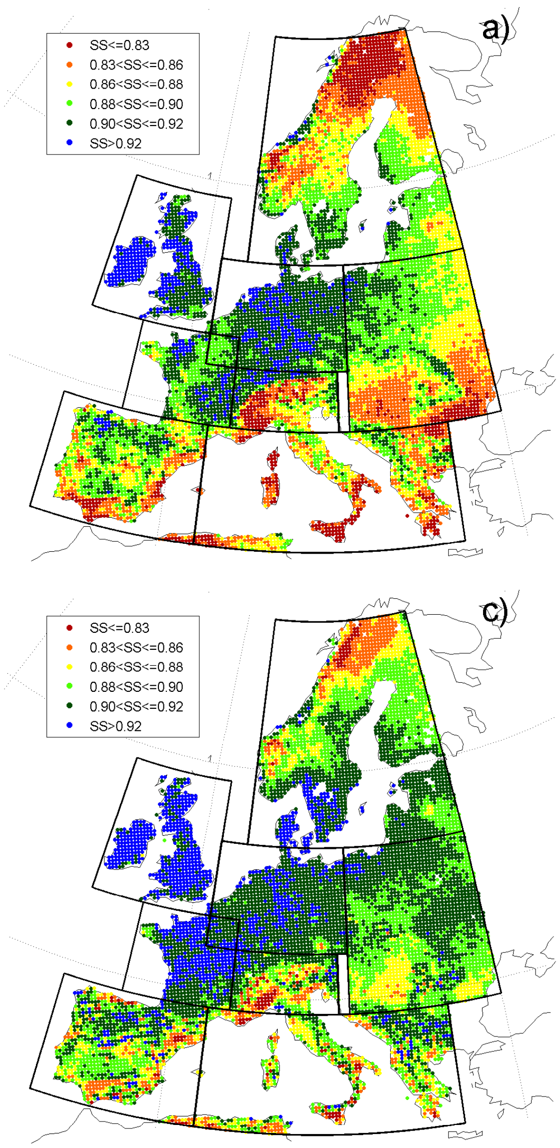

Figure 7.22: Map of grid point skill scores for gridded daily temperature observations for 1961–1990 matched with the four RCMs used in the study. Top left panel is for model ETH CLM, top right panel is for HC HADRM3, bottom left panel is for KNMI RACMO2 and bottom right panel is for the MPI REMO model. Note that the skill score value limits are not the same as those used in Figure 7.11.

8. Conclusions

We have compared daily precipitation and temperature PDFs for four ENSEMBLES RCMs with PDFs from two observational data sets. The first observational data set is the publicly available ECA&D station data and the second observational data set is a newly developed gridded dataset obtained using an extended set of station observations, including the publicly available data. It turns out that the gridded observational data set is over-smoothed, leading to reduced interpolated daily values relative to the actual area-averages. This is seen in the PDFs as an over-representation of days with moderate precipitation and an under-representation of days with more extreme precipitation, with respect to the model PDFs and with respect to the station observation PDFs. This pattern is seen for all nine sub-regions, except for region BI, and for all seasons. Overall, the station PDFs match the model PDFs well, relative to the gridded observation PDFs. When looking at daily mean temperature, we see a relatively close match between gridded observations and model PDFs. Here the station data are outperformed by the new gridded data set.

One should therefore use caution when using daily precipitation distributions from the gridded observational data set as a validation tool when studying other data sets.

Acknowledgements The present work has been carried out as part of the DMI's contribution to the EU 6th Framewok Programme projects ENSEMBLES (contract number GOCE-CT-2003-505539) and WATCH (contract number GOCE-2006-036946).

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