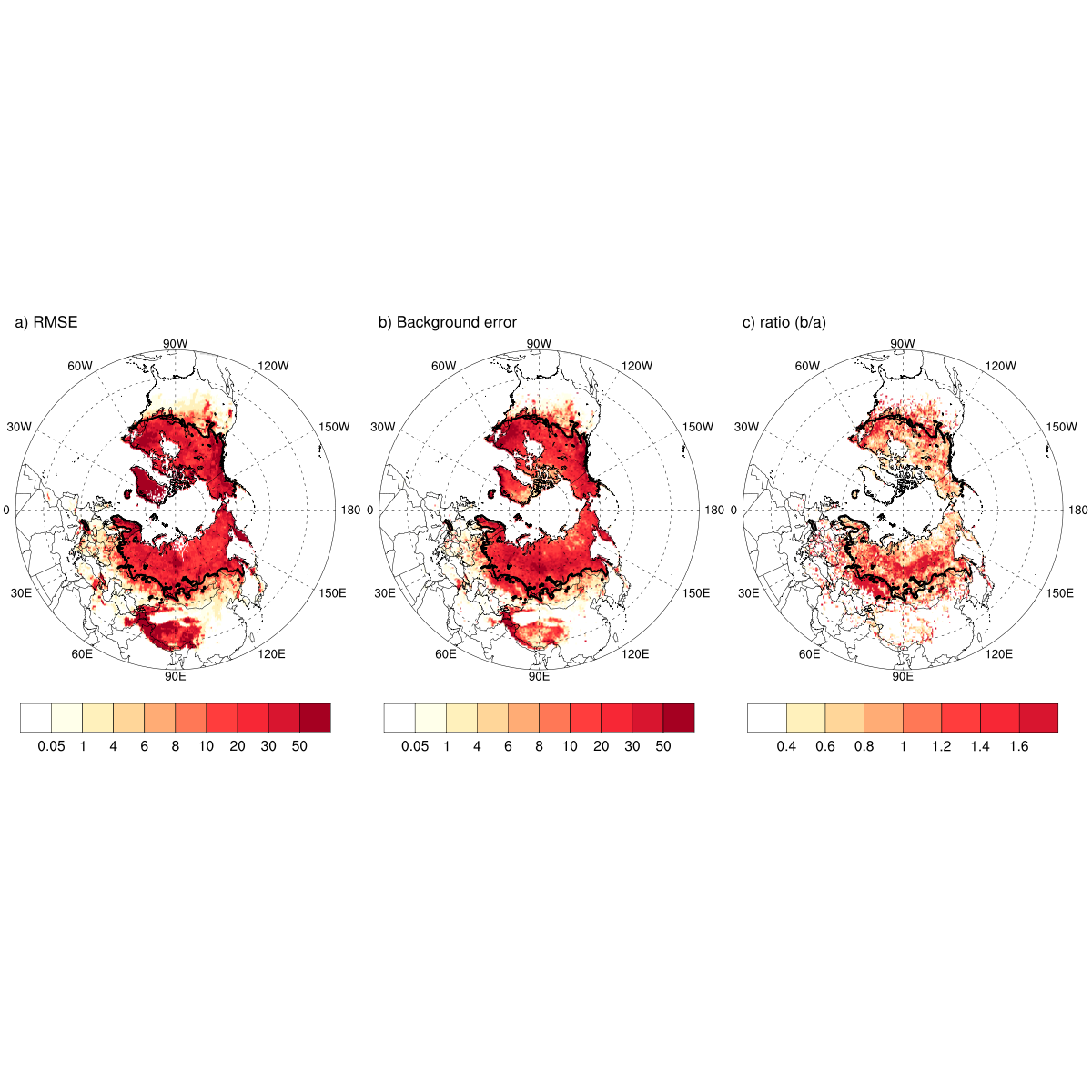
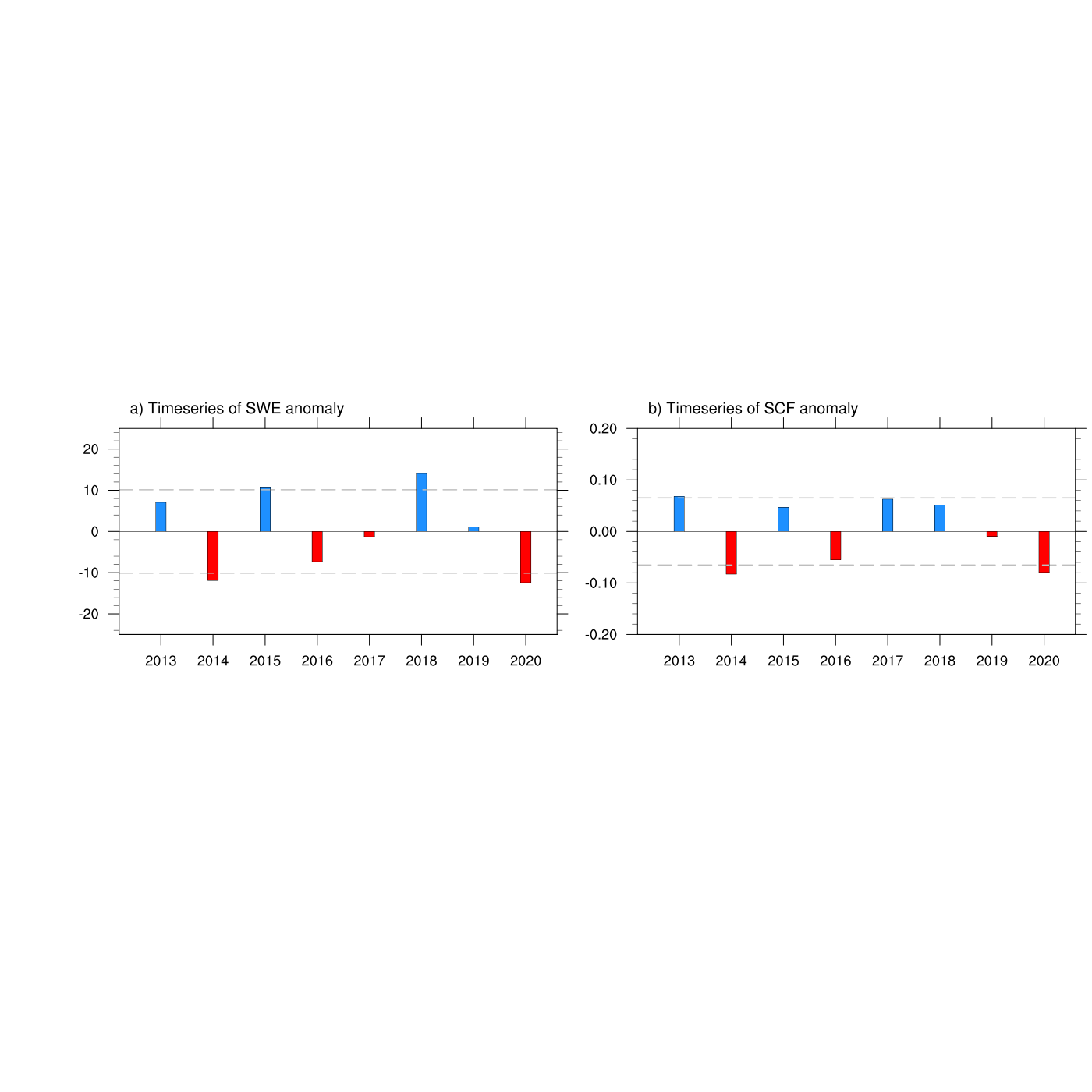
**Supplementary Information**

**Supplementary Table 1** Confusion matrices for the experiment products (e.g., AMSR2, Openloop, JRA55, and the DA) against IMS data. Overall accuracy = (A+D) / (A+B+C+D)

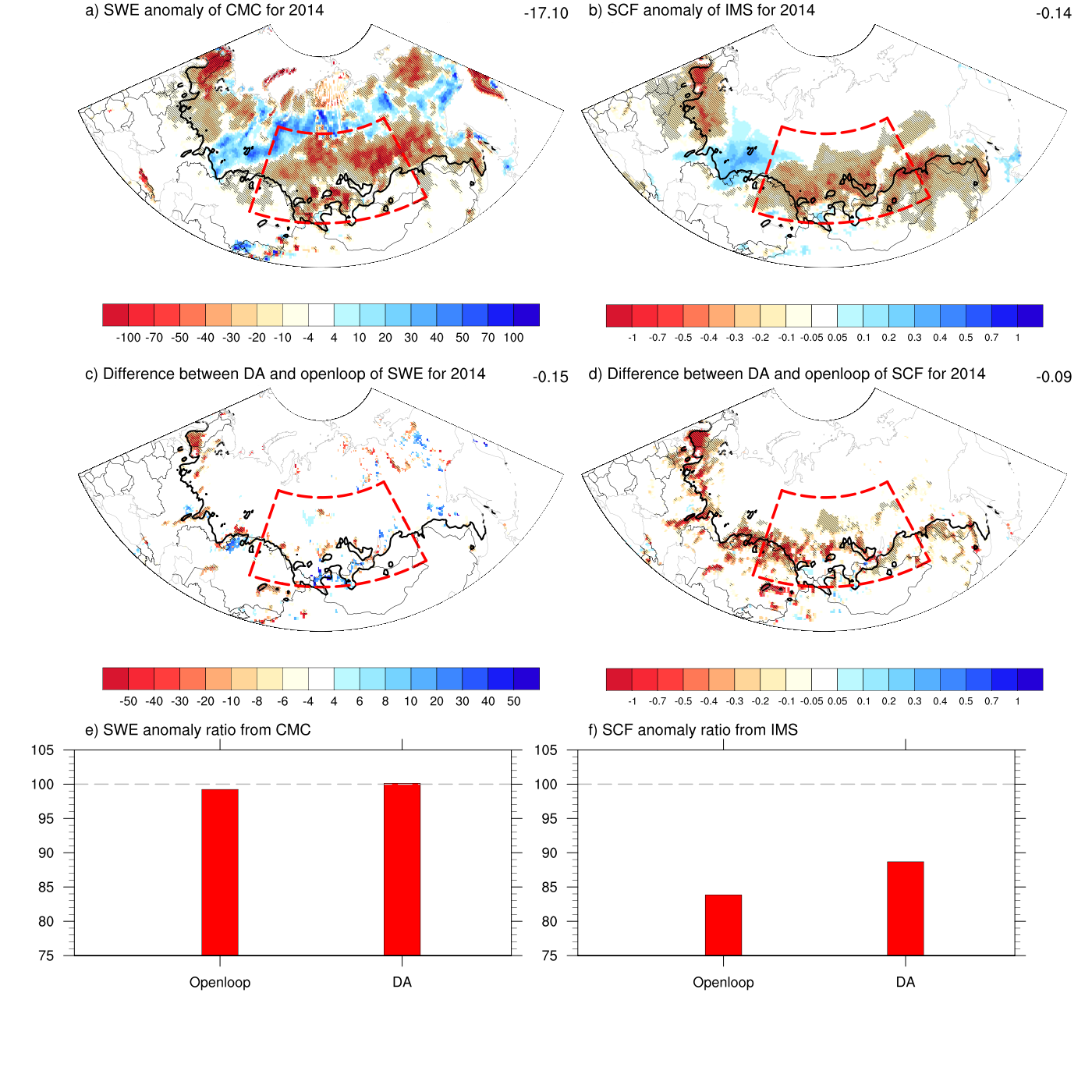
|  |  |  |
| --- | --- | --- |
|  | IMS snow | IMS no snow |
| EXPERIMENT SNOW | A | B |
| EXPERIMENT NO SNOW | C | D |



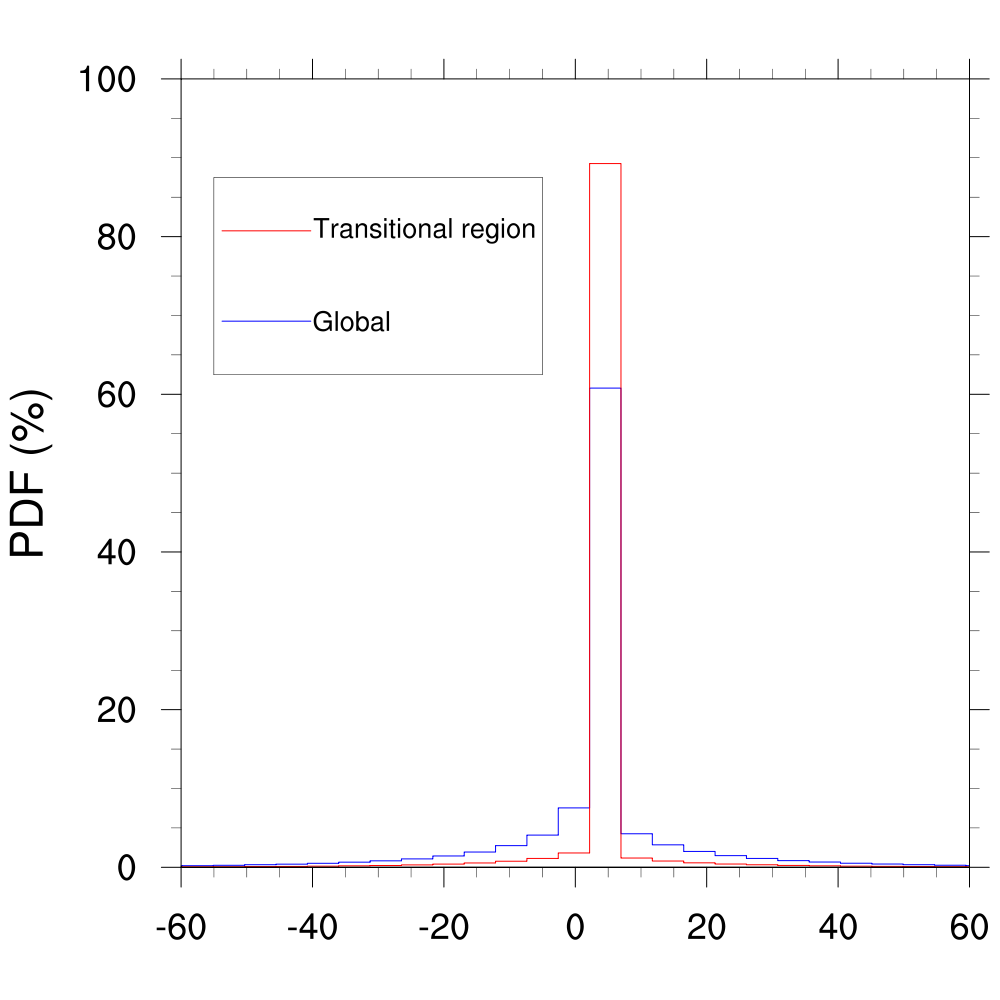
**Supplementary Fig. 1** Spatial distribution of root mean square error (RMSE) with CMC, model ensemble spread, and ratio. The black line represents the boundary of the transition region, defined as the climatological-mean SWE of less than 16mm.



**Supplementary Fig. 2** Time series of the area-averaged SWE and SCF anomaly of CMC and IMS, respectively, in Eurasian bounded by 48–65 oN and 55–120 oE, as shown by the red box in Figure 10. The dotted lines represent the one standard deviations of each variable.



**Supplementary Fig. 3** Anomalies of a) SWE from CMC and b) SCF from IMS as well as the difference (c, d) of variables between DA and Openloop in April 2014. Bar chart (e, f) indicates the ratio of DA and Openloop to verification data such as CMC and IMS in the red box (48–65oN and 70–120 oE), which is the region associated with extreme high-temperature events, focused on this study. Negative values are indicated with a diagonal line.



Supplementary Fig. 4 Probability Density Function (PDF) of ensemble distribution for Snow Water Equivalent (SWE) over Global (red line) and Transitional Region (red line) for April during 2013-2020.