Indus: Climate and Water Budget

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Study Area

- Geographical range of IRB- Lat: 23–37°N; Lon: 66–82°E.
- The basin hosts (i) western Himalaya at lower latitudes of the basin, (ii) Karakoram Range in further north (Trans-Himalayas), and (iii) Hindu Kush Range in the west of Karakoram-Himalaya ranges.
- Upper basin is mainly dominated with rugged and high mountains including the cold desert regions of Tibet and Ladakh.
- Lower basin is dominated by the alluvial plains of Punjab and Sindh.

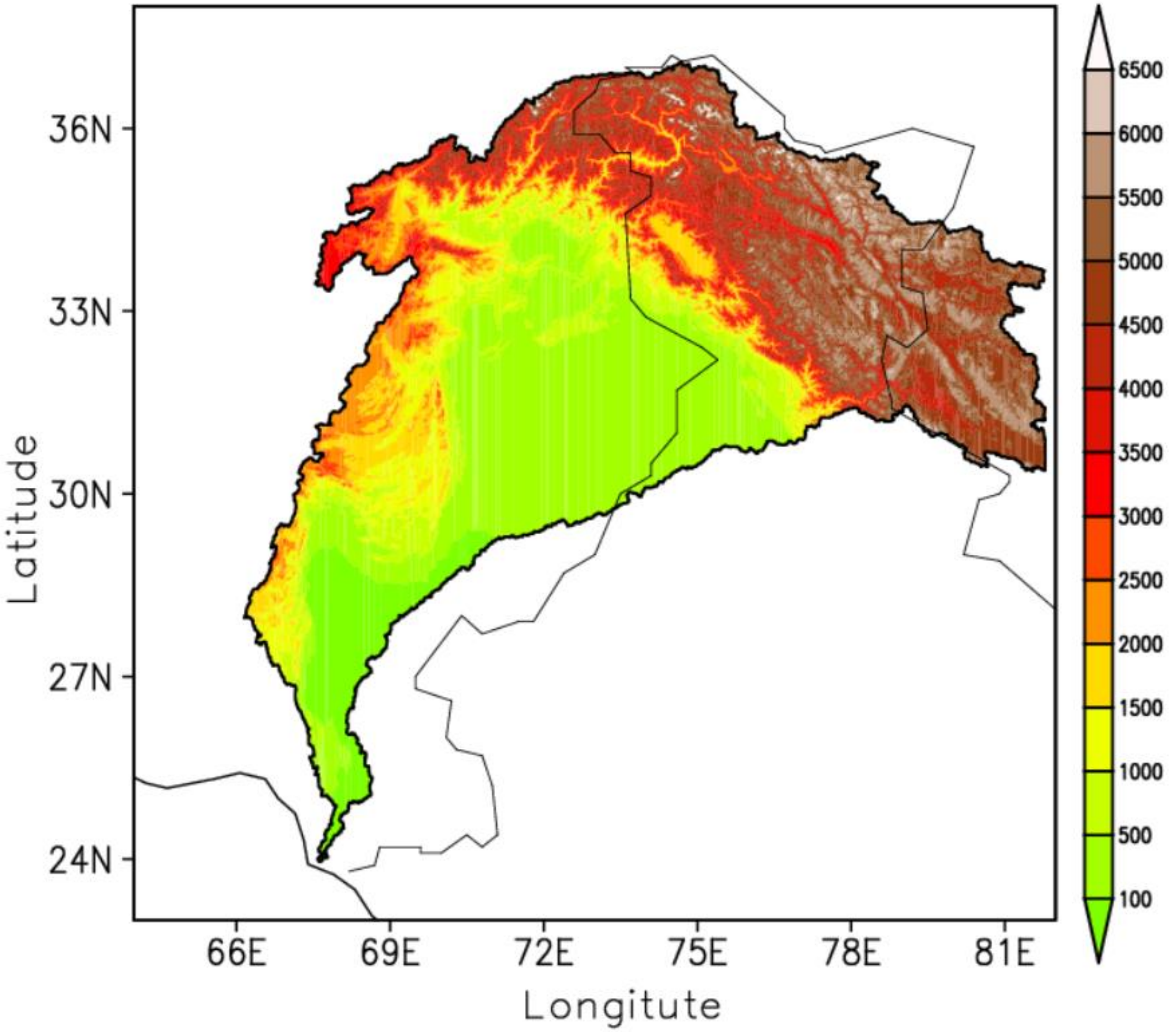


Fig 1. Surface elevation (m) over Indus River Basin (IRB). Red/brown/white- higher elevation areas and green/yellow- lower elevation areas.

Data and Methodology

- Coordinated Regional Downscaling Experiment (CORDEX)
- REMO regional model
- Validation for the period 1970-2005 through observation data obtained from:

    - APHRODITE

    - APHROTEMP

- Horizontal resolution- 50 km (0.44°)
- Time period for the study - Present (1970-2005)

  - Future (2006-2099)

  - Long term (1970-2099)
- Representative Concentration Pathways (RCP) chosen for the study are RCP2.6 and RCP8.5
- Variables considered include precipitation (pr), near-surface air temperature (tas), evapotranspiration (evspsbl), snowmelt (snm) and runoff (mrro).

Calculations

- Climatology of all variables for present climate (1970-2005).
- Calculation of bias for precipitation and temperature.
- Long term trend (1970-2099) of all variables for four different seasons including DJF, MAM, JJAS and ON, under RCP2.6 and RCP8.5 .
- Time series of all variables for Present, RCP2.6 and RCP8.5 climate scenarios.
- Climatology of total water storage (precipitation minus evaporation minus runoff) (1970-2005).
- Long term trend (1970-2099) of total water storage for four different seasons including DJF, MAM, JJAS and ON, under RCP2.6 and RCP8.5.
- Time series of total water storage for Present, RCP2.6 and RCP8.5 climate scenarios.

RESULTS

PRECIPITATION

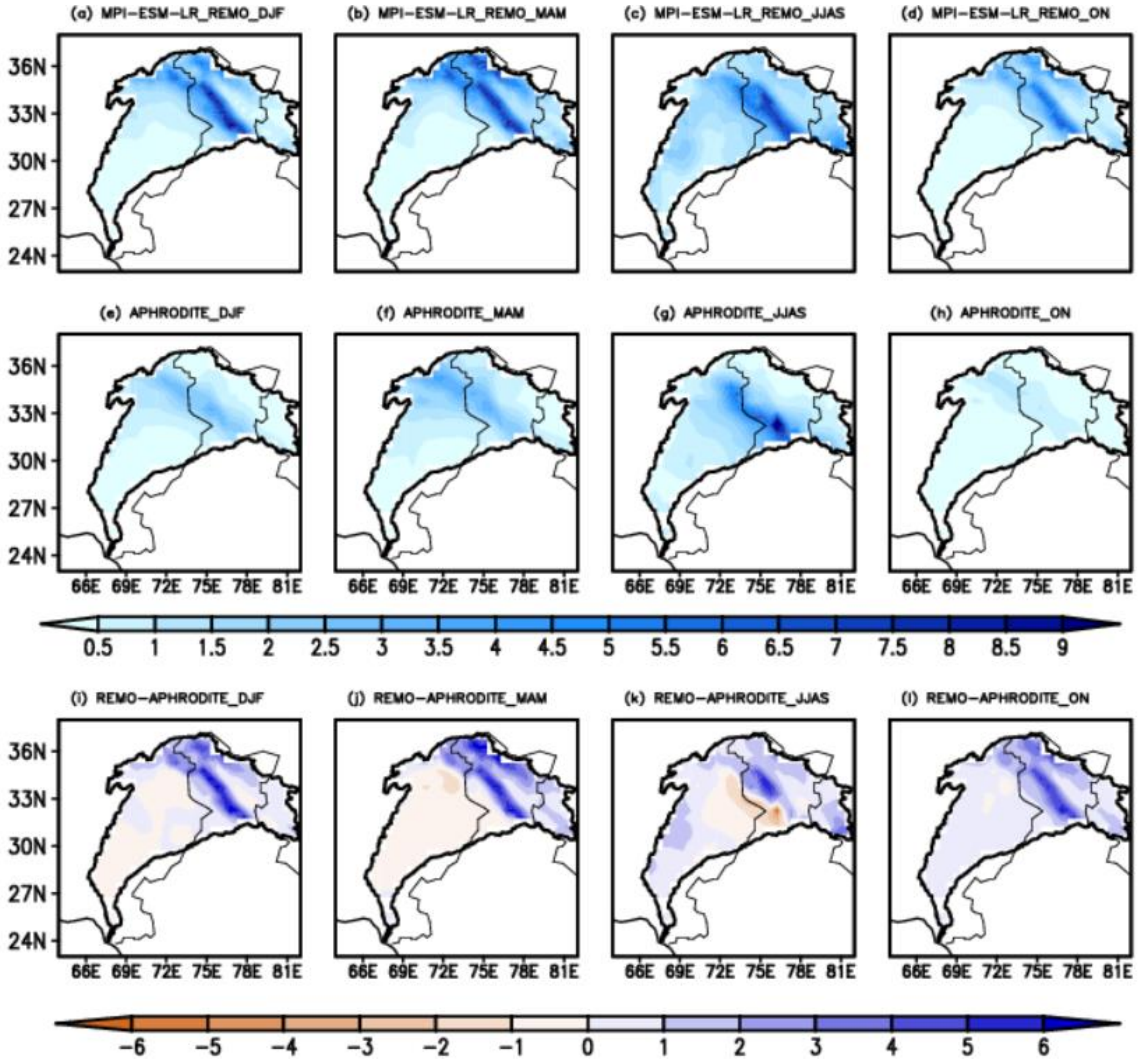


Fig 2. Daily mean precipitation climatology (mm/day) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA, observation (e-h), and the corresponding bias (i-l) for DJF (December, January, February), MAM (March, April, May), JJAS (June, July, August, September) and ON (October, November) seasons.

- The model is well able to simulate the spatial precipitation.
- It is mostly dry in the foothills in the DJF and MAM seasons, while wet in the JJAS and ON seasons.
- Spatial pattern in the northern part simulated by REMO for JJAS season agrees with the pattern simulated by PRECIS model (Rajbhandari *et al*., 2015)
- The model is wettest in the northern part of the basin which could be due to mountain or topography influences.

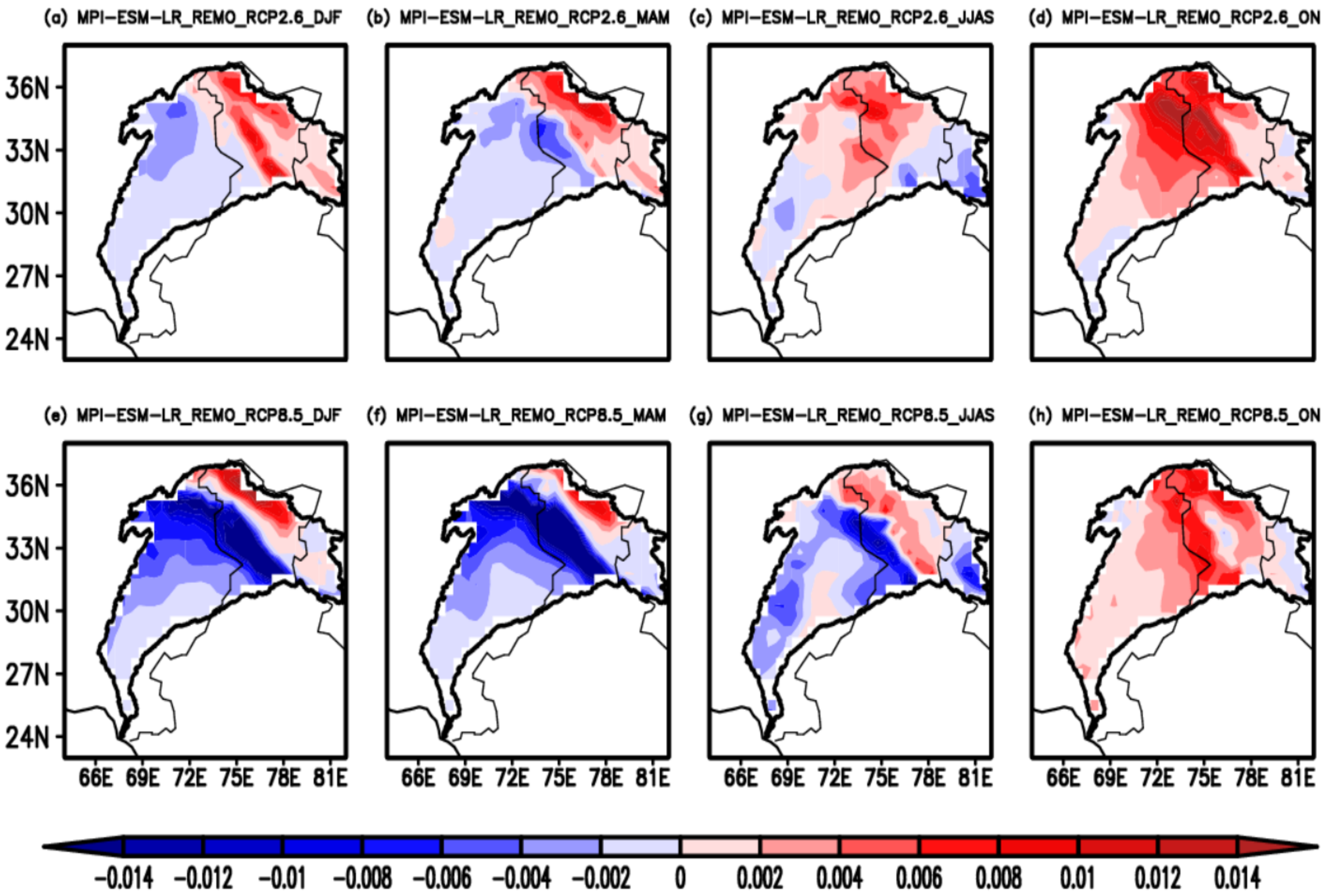


Fig 3. Trend of seasonal mean precipitation (mm/day/year) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

- Decreasing precipitation amount for RCP2.6 and RCP8.5 in all seasons except ON wherein the precipitation amount is increasing in almost the whole basin.
- The increase is within the range 0 to 0.014 mm/day/year.
- The decrease is stronger in RCP8.5 climate scenario with the precipitation amount decreasing by more than 0.014 mm/day/year mainly in the northern part.
- However, for RCP2.6 the decrease is within the range 0 to 0.006 mm/day/year.
- Indus basin is prone to flash floods and floods. Changes in precipitation are likely to change the magnitude and frequency of these floods (Rajbhandari *et al.*, 2015). ON season might have chances of floods as compared to other seasons due to the trend shown.

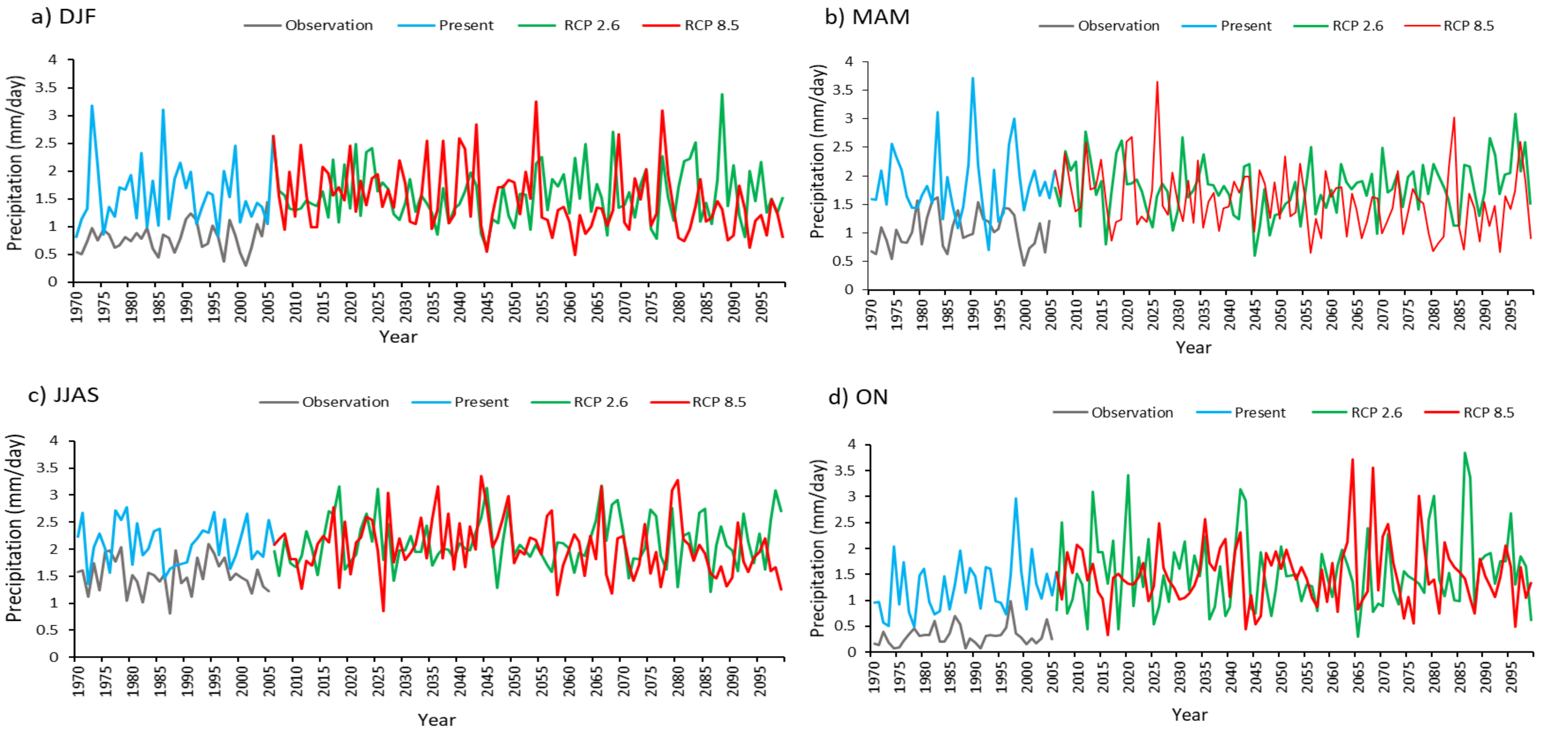


Fig 4. Time series of precipitation (mm/day) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in grey corresponds to observation data (APHRODITE) for the period 1970-2005. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

- The time series of precipitation doesn’t show any significant trend between the RCPs.

- The precipitation amount averaged over the IRB lies within the range 0.5 to 4 mm/day for present, RCP2.6 and RCP8.5 climate scenarios in all the four seasons.

TEMPERATURE

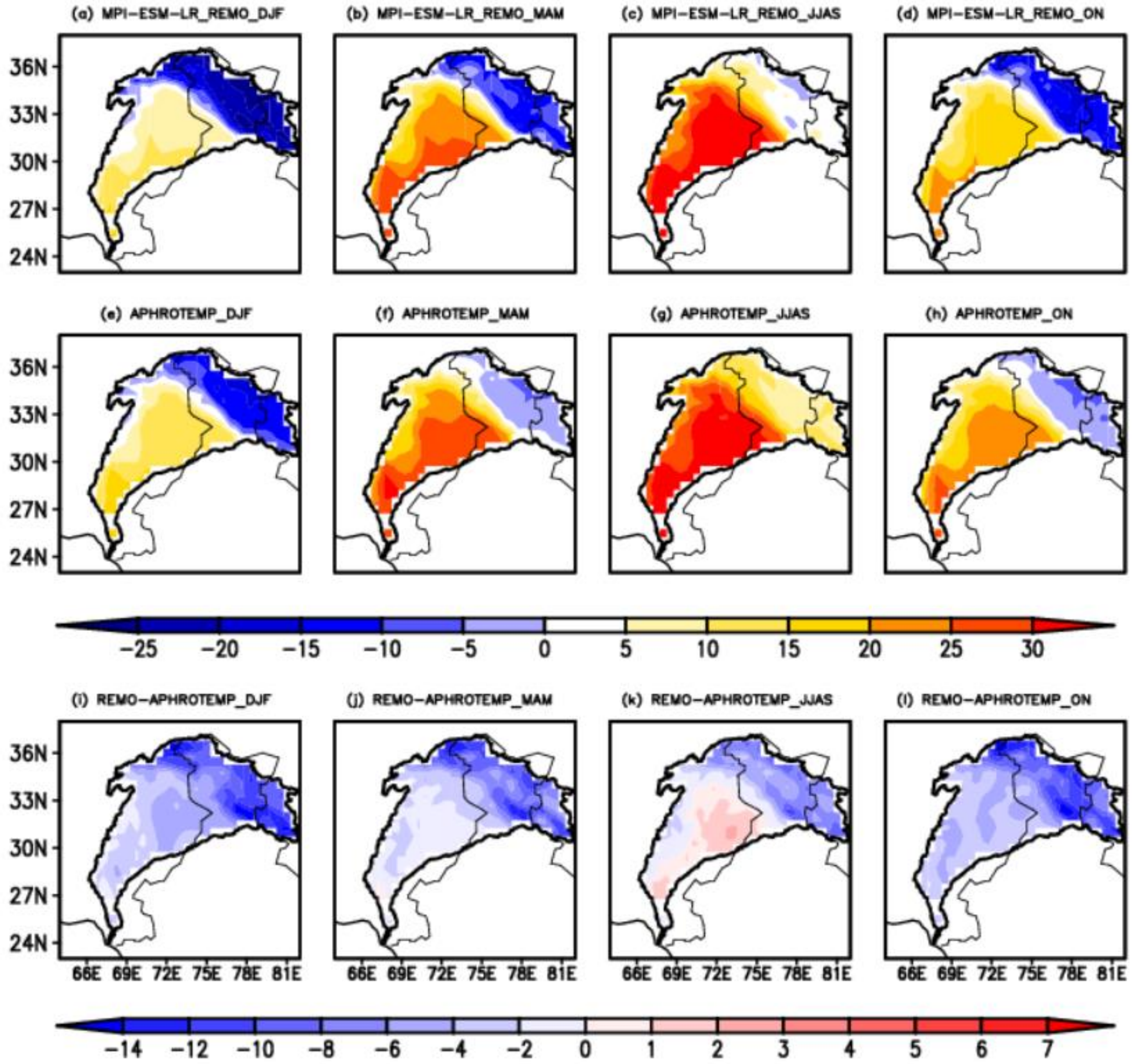


Fig 5. Near-surface Air Temperature seasonal climatology (°C) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA, observation (e-h), and the corresponding bias (i-l) for DJF (December, January February), MAM (March, April, May), JJAS (June, July, August, September) and ON (October, November) seasons.

- The dominant features of the observed geographical spatial distribution are well captured by the REMO model simulation.
- The model is overall showing a cold bias in all the seasons, however shows some warm bias in the foothills in JJAS within the range 0 to 4 °C.
- The cold bias is less than -6 °C with extreme bias of less than -12 °C mainly in the northern IRB in DJF, MAM and JJAS seasons.
- The cold bias has been reported in other studies (Rajbhandari et al., 2015; Xue et al., 1996; Suh and Lee 2004; Dimri 2012). This has been attributed to the prescribed land-use distribution in Biosphere Atmosphere Transfer Scheme (BATS).

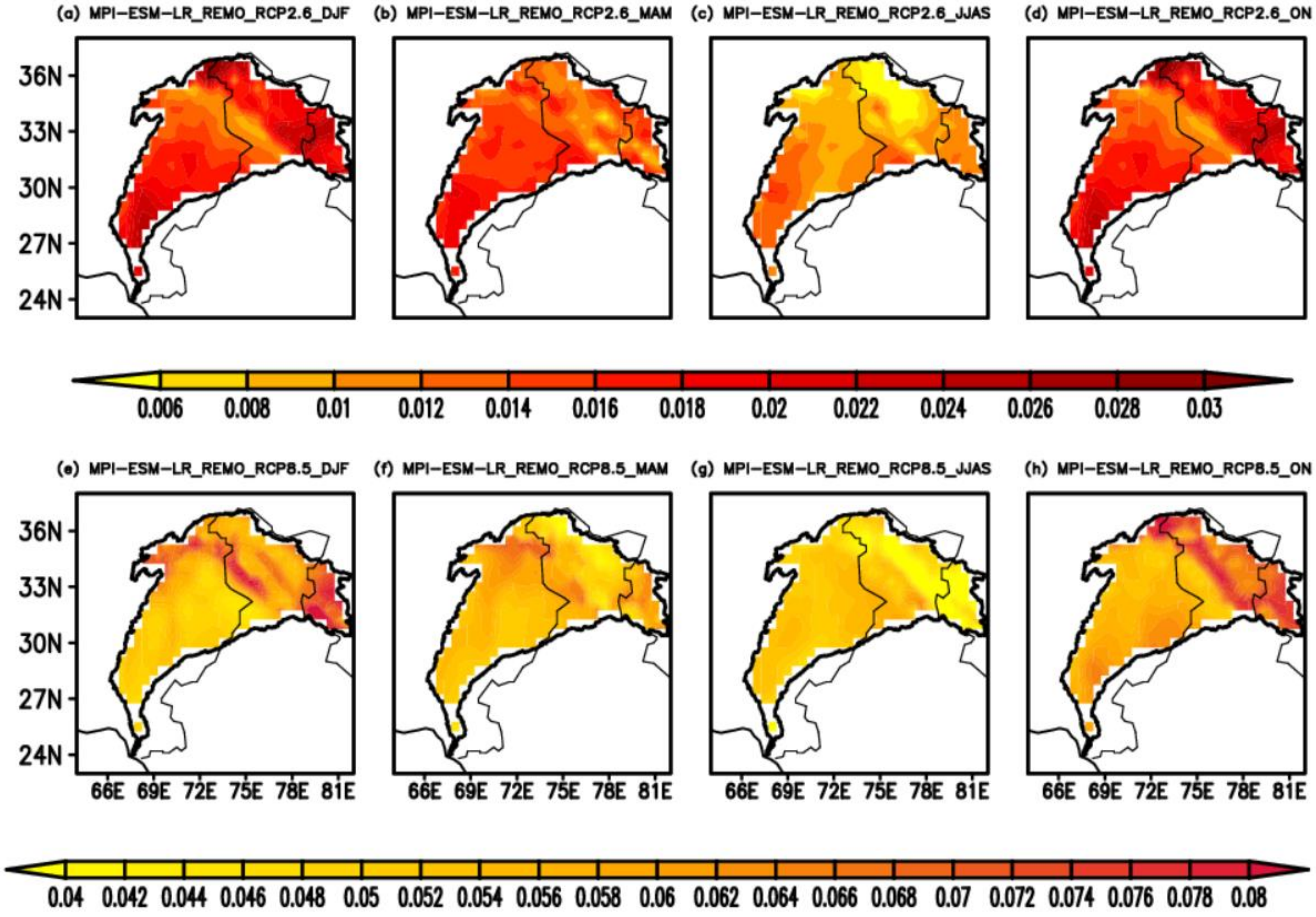


Fig 6. Trend of seasonal mean Near-surface Air Temperature (°C/year) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

- For RCP2.6, there has been an increasing trend of temperature ranging from 0.006 to about 0.03 °C/year.
- However, for RCP8.5, the increment is more lying within the range 0.04 to 0.08 °C/year. The highest increase is in the upper part of the basin in DJF and ON seasons. This partially agrees with the results simulated by regional climate model COSMO-CLM (Huang *et al.*, 2017). This also shows that IRB may experience warmer winters in the future.
- This shows that the temperature increase is over the entire basin and, in situations of higher emissions rate the increases will be stronger. This goes along with the results simulated by CCLM (Huang *et al.*, 2017).
- Other RCMs and downscaled GCMs have also produced similar results of warming in the upper IRB (Kazmi *et al.*, 2014; Rajbhandari *et al.*, 2015; Su *et al.*,2016; Huang *et al.*, 2017)

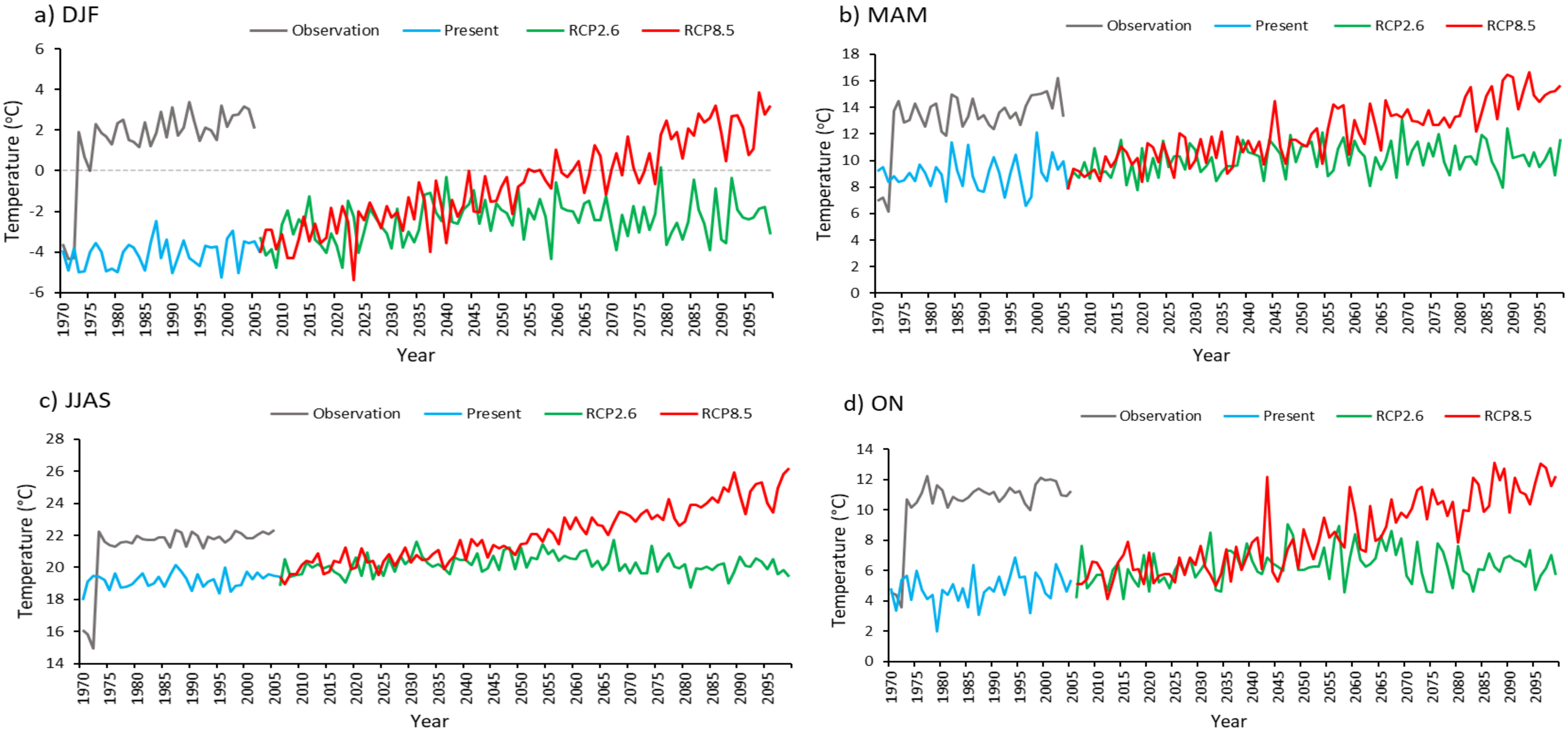


Fig 7. Time series of Near-surface Air Temperature (°C) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in grey corresponds to observation data (APHROTEMP) for the period 1970-2005. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

- The temporal distribution verifies the spatial distribution of temperature.
- In time series, it is more clear that till the mid 21st century, temperature is increasing in the both the RCPs.
- In the late 21st century a divergence indicates stronger increase in temperature in the higher concentration pathway (RCP8.5), while the rate of increase being almost the same for RCP2.6.

Evapotranspiration

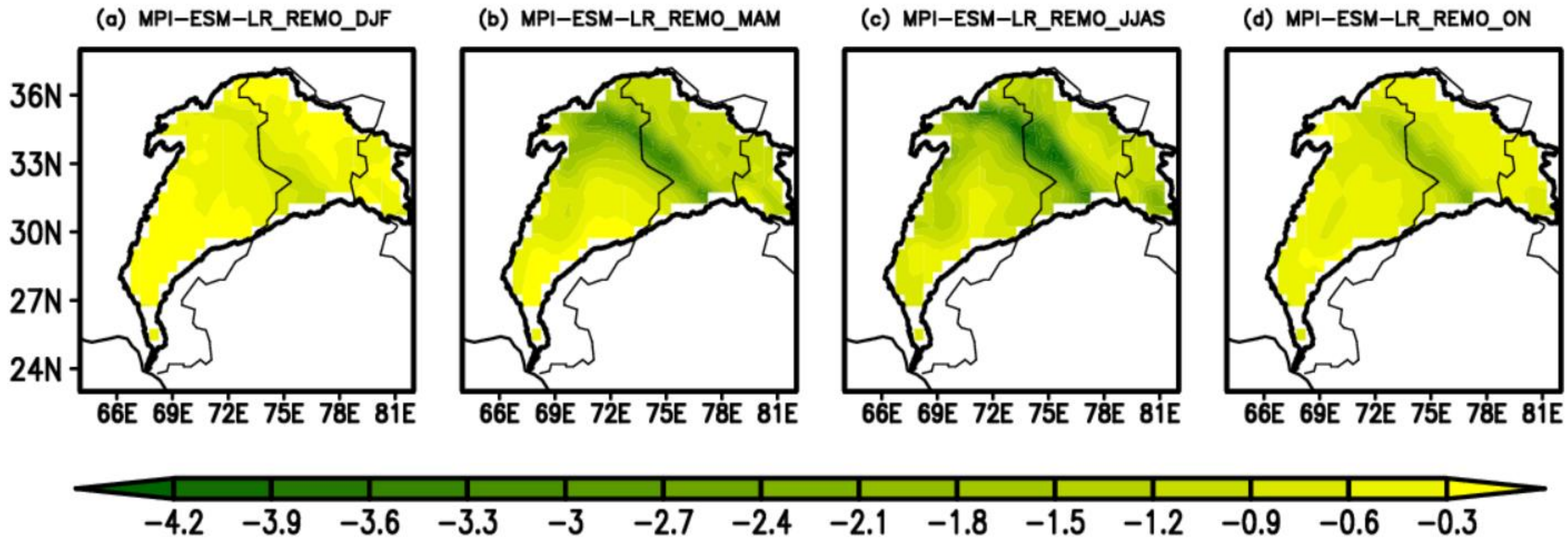
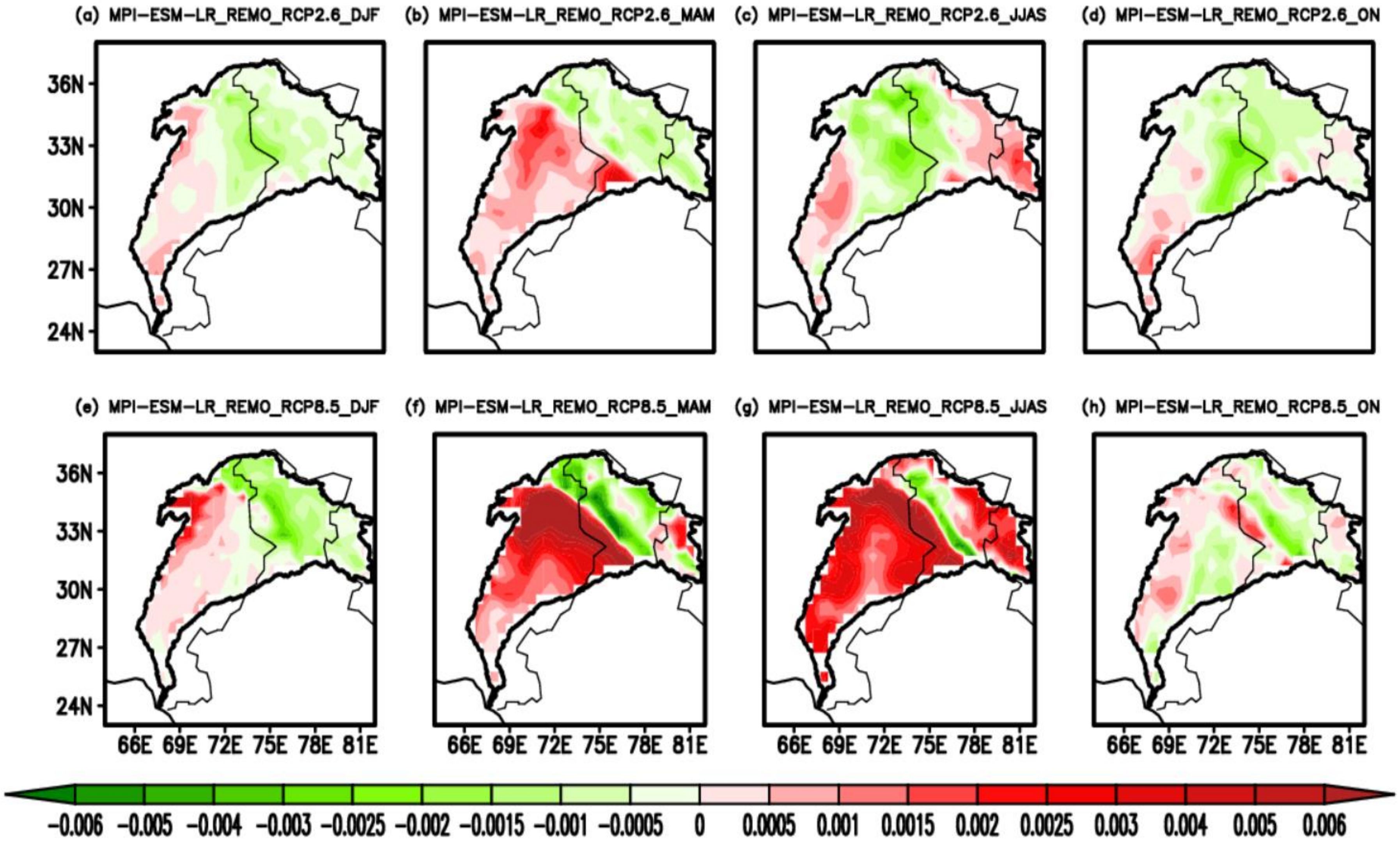


Fig 8. Total evapotranspiration climatology (mm/day) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA for DJF (December, January February), MAM (March, April, May), JJAS (June, July, August, September) and ON (October, November) seasons.

- More negative value means more evapotranspiration from the surface into the atmosphere, ranging from -4.2 to -0.3 mm/day.
- Evapotranspiration is occurring the most in the mountainous region of the upper part of the basin in MAM and JJAS seasons.



- In RCP2.6, the seasonal mean evapotranspiration has a non uniform trend in the basin with both increases and decreases in the amount within the range 0 to 0.003 mm/year.
- For RCP8.5, the amount is strongly increasing being more than 0.006 mm/year in most of the basin for MAM and JJAS seasons.

Fig 9. Trend of seasonal mean evapotranspiration (mm/year) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

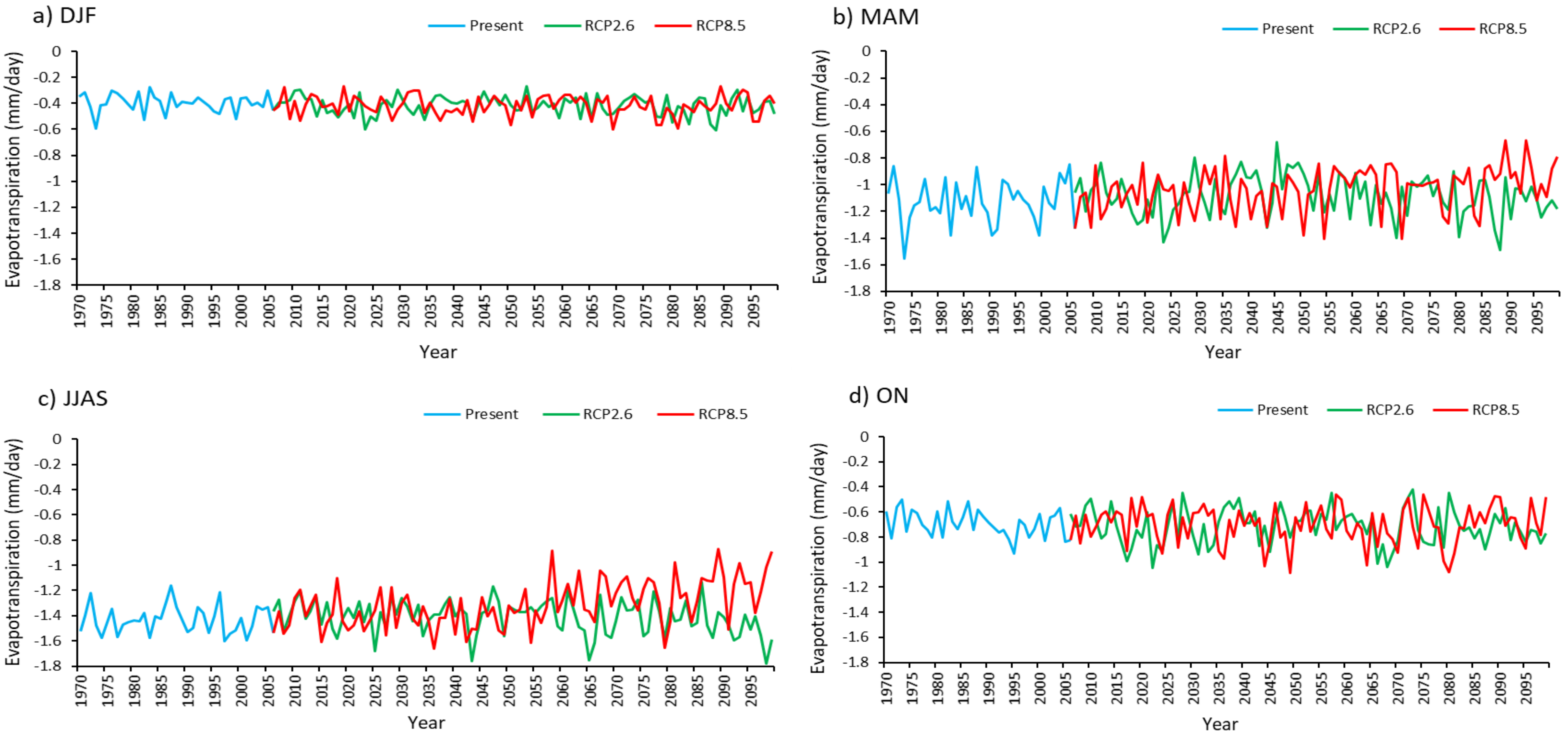


Fig 10. Time series of Evapotranspiration (mm/day) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

Snowmelt

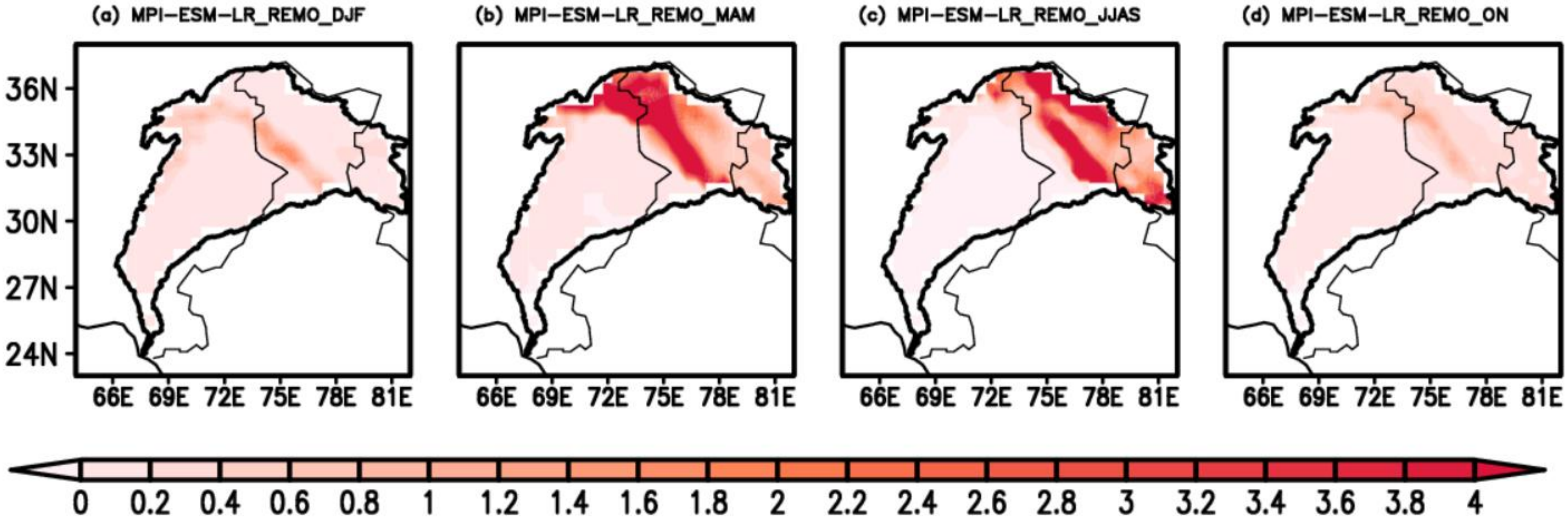


Fig 11. Snowmelt climatology (mm/day) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA for DJF (December, January February), MAM (March, April, May), JJAS (June, July, August, September) and for ON (October, November) seasons.

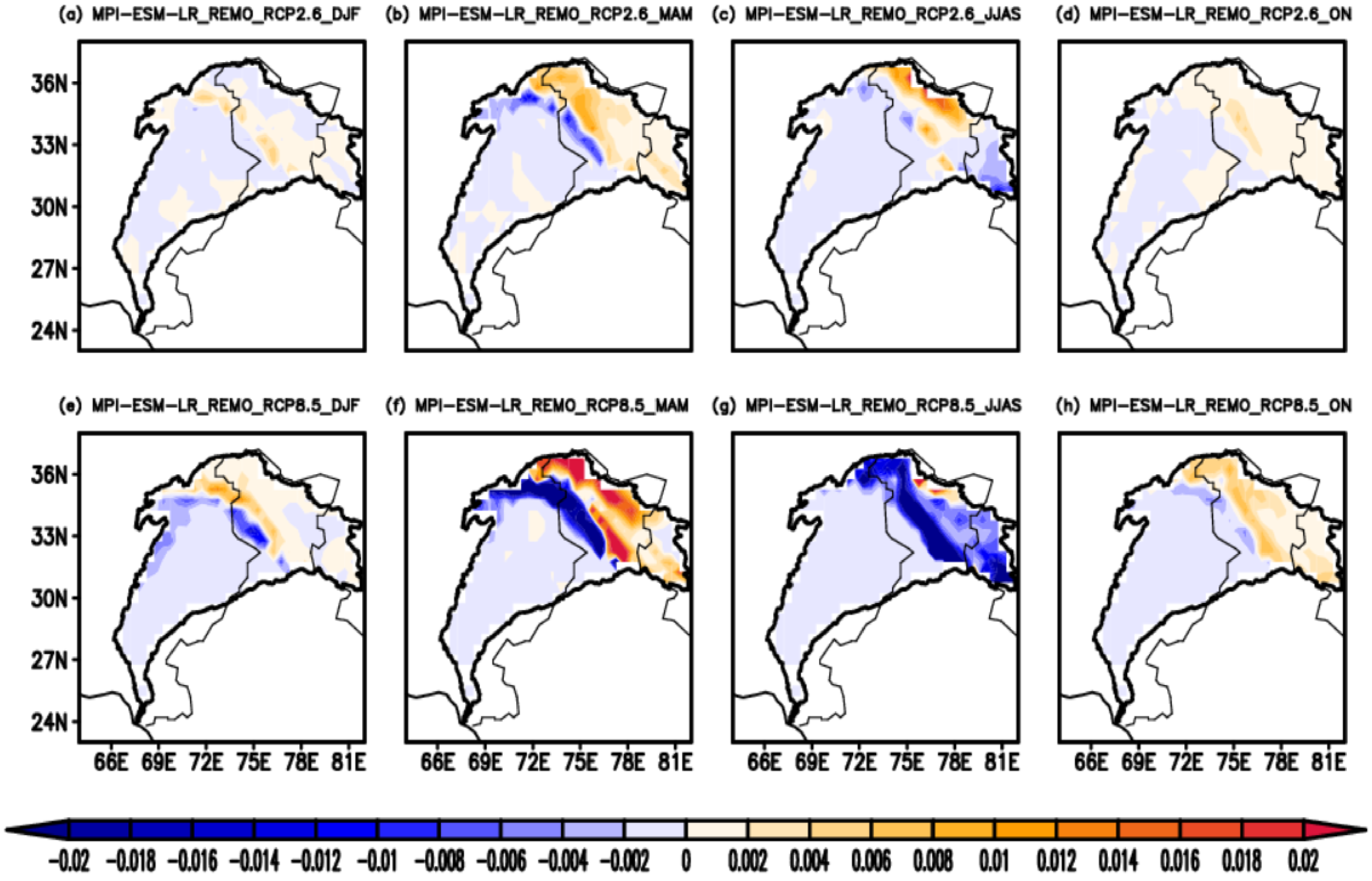


Fig 12. Trend of snowmelt (mm/day) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

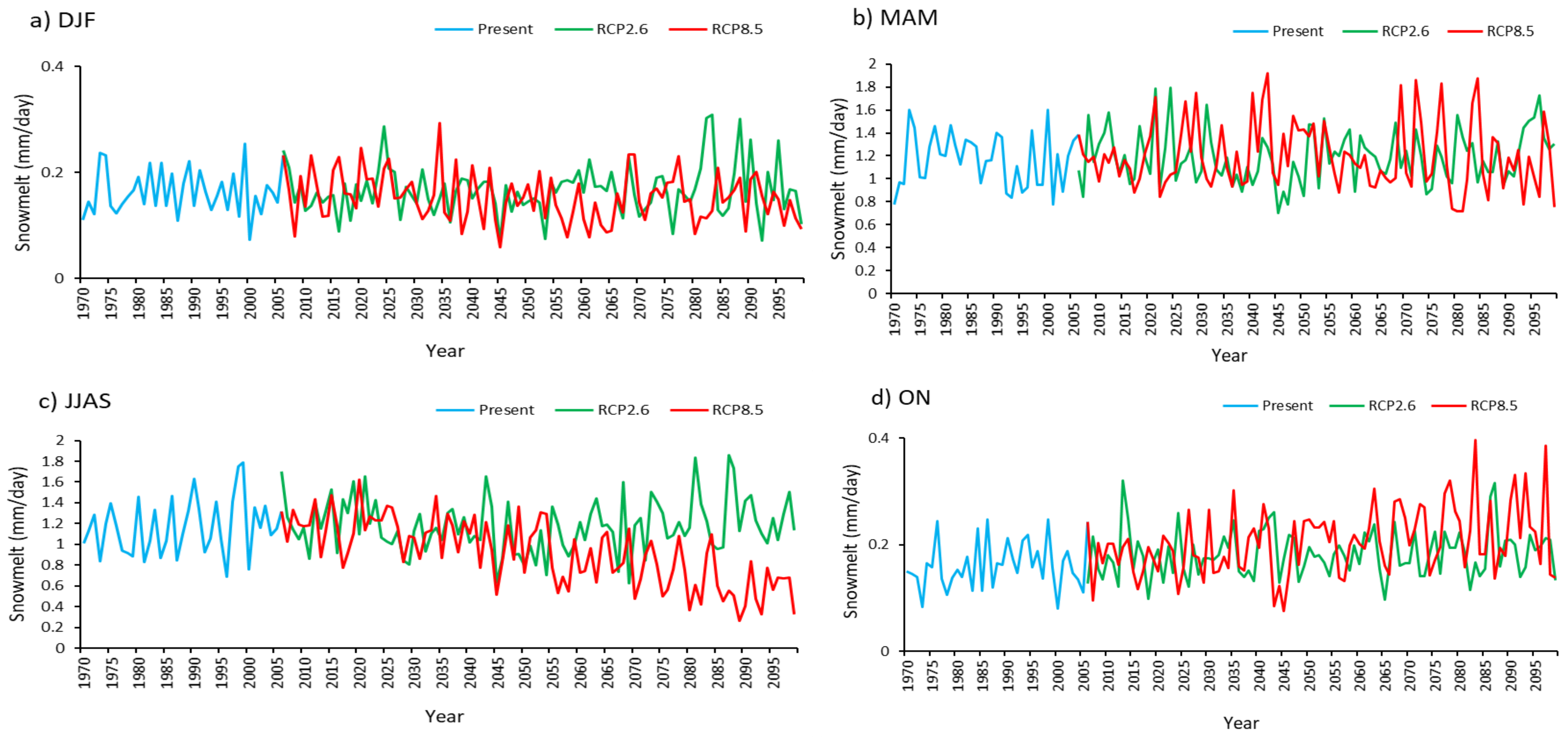


Fig 13. Time series of Snowmelt (mm/day) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

Runoff

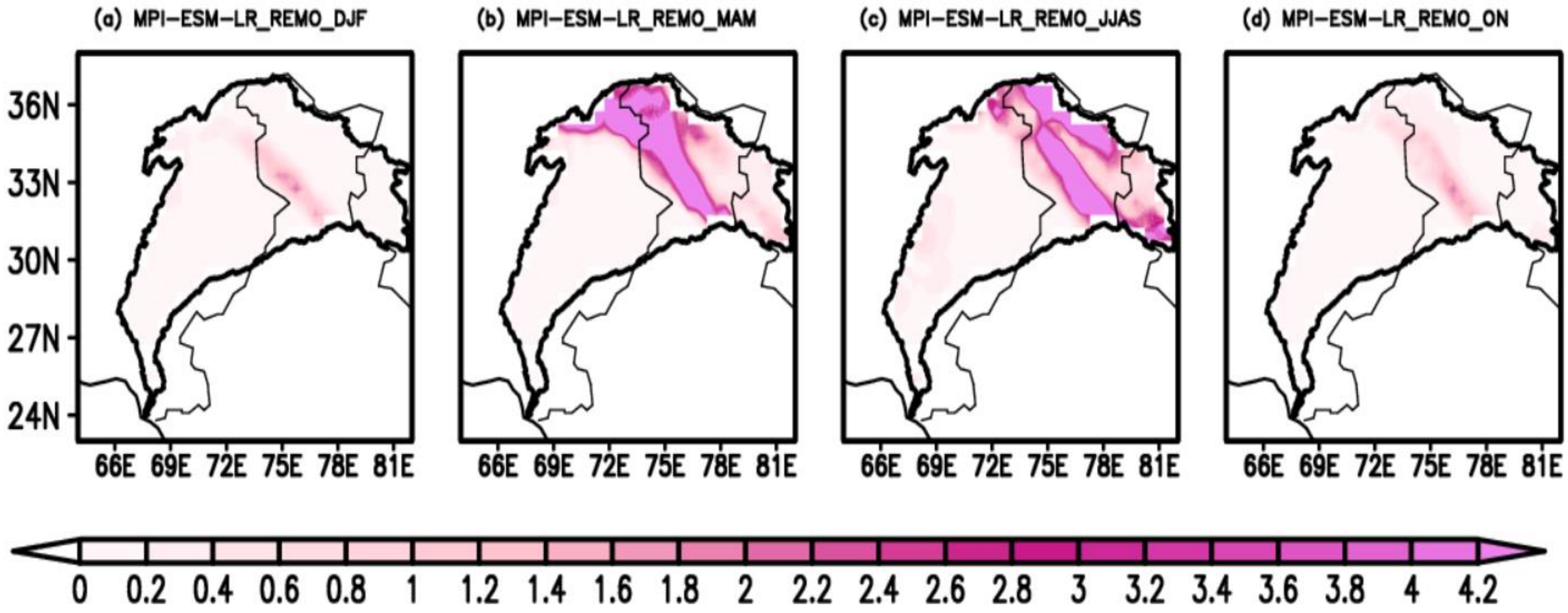


Fig 14. Total runoff flux climatology (mm/day) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA for DJF (December, January February), MAM (March, April, May), JJAS (June, July, August, September) and for ON (October, November) seasons.

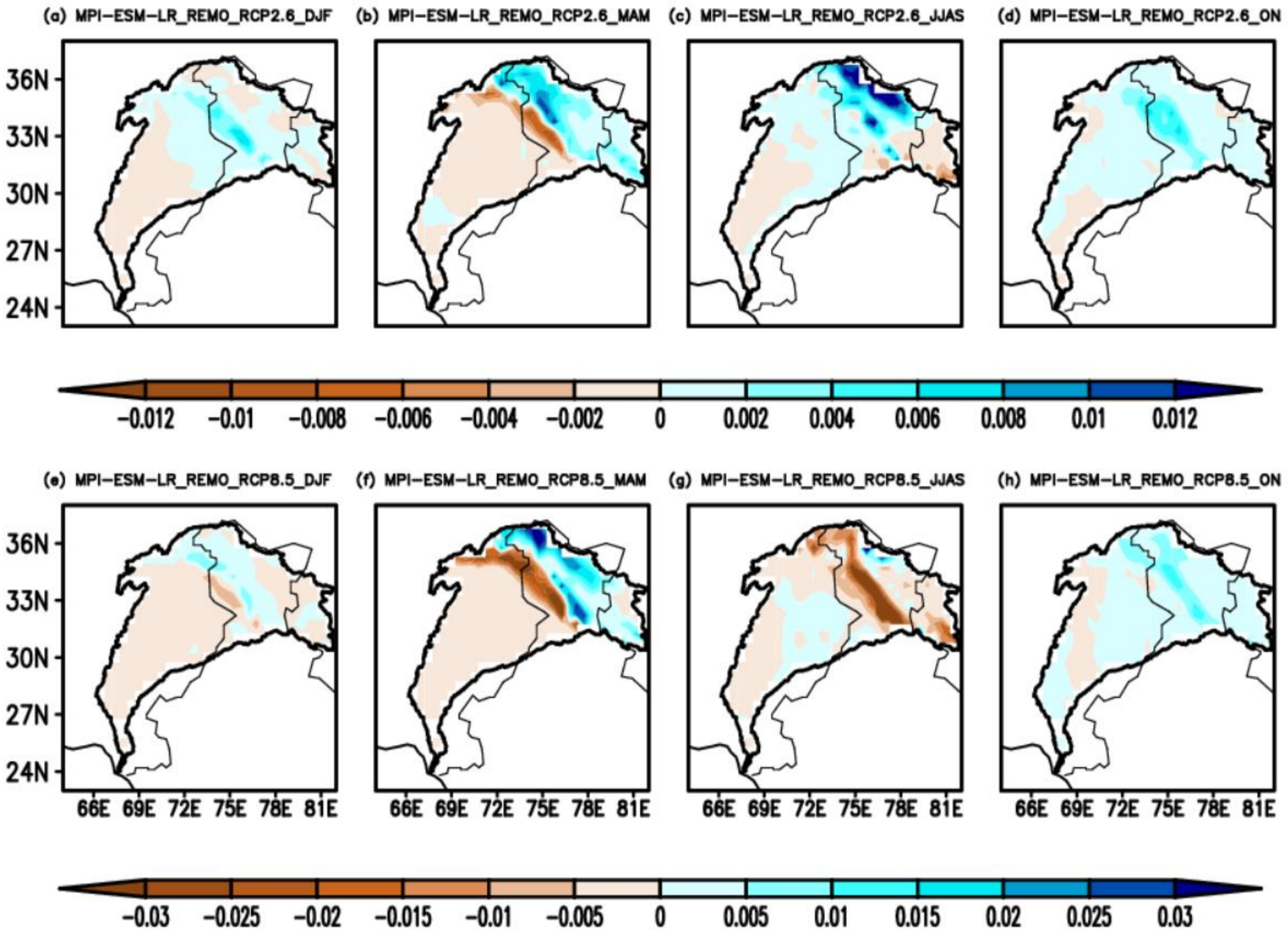


Fig 15. Trend of seasonal mean runoff flux (mm/year) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

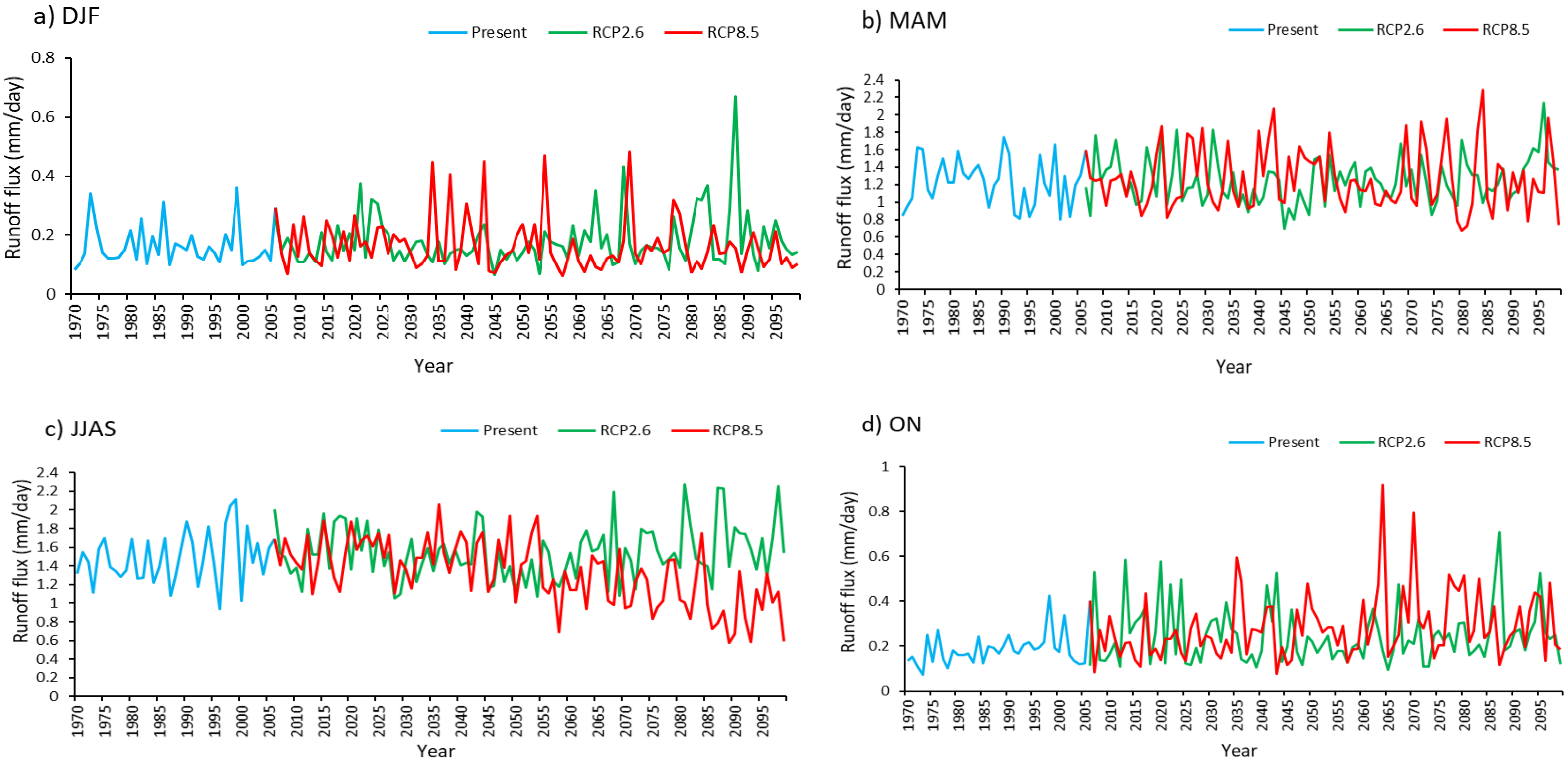


Fig 16. Time series of Runoff flux (mm/day) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

Total water storage

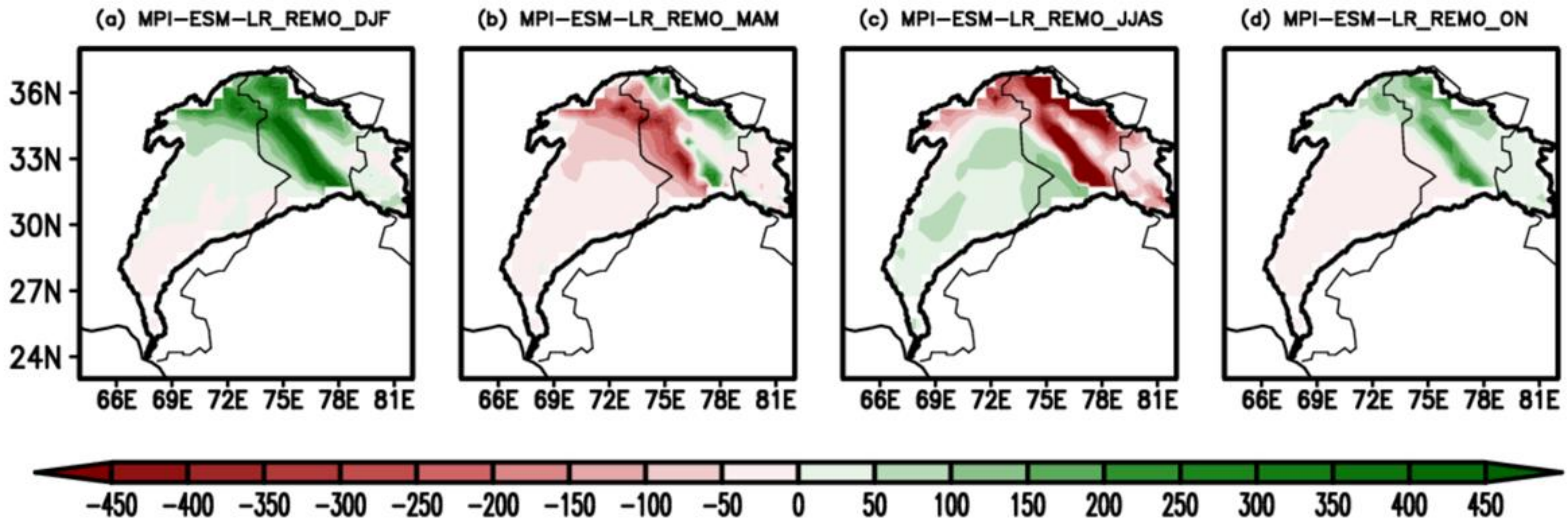


Fig 17. Total water storage (calculated as total precipitation (pr) minus evaporation (evspsbl) minus runoff (mrro)) (pr-evspsbl-mrro) climatology (mm/year) during 1970-2005 over Indus River Basin (IRB) from REMO regional model (a-d) driven by MPI-ESM-LR global model under CORDEX-SA for DJF (December, January February), MAM (March, April, May), JJAS (June, July, August, September) and for ON (October, November) seasons.

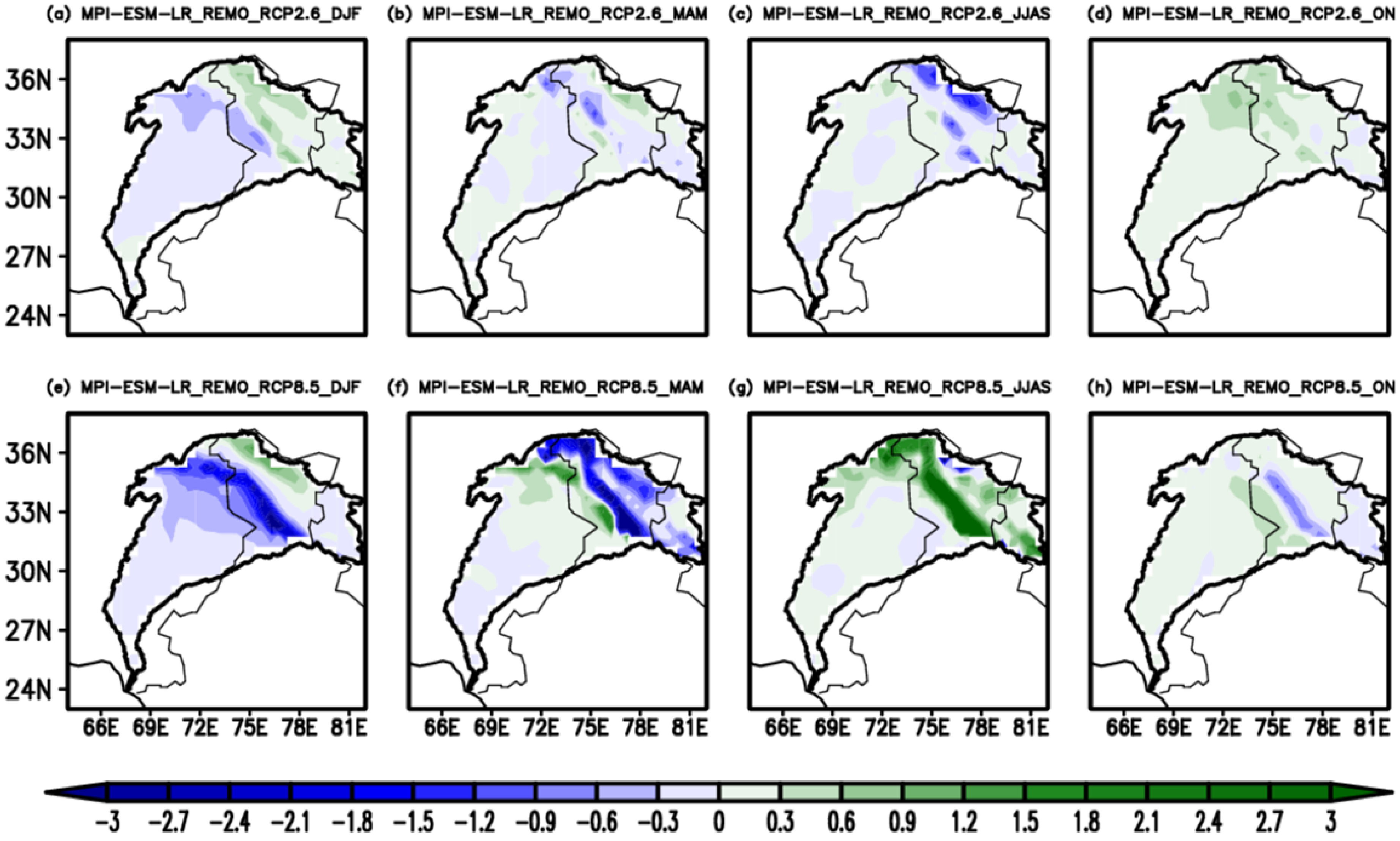


Fig 18. Trend of total water storage (mm/year) during 1970-2099 over Indus River Basin (IRB) from REMO regional model driven by MPI-ESM-LR global model under CORDEX-SA, under RCP 2.6 (a-d) and RCP 8.5 (e-h) for DJF, MAM, JJAS and ON seasons.

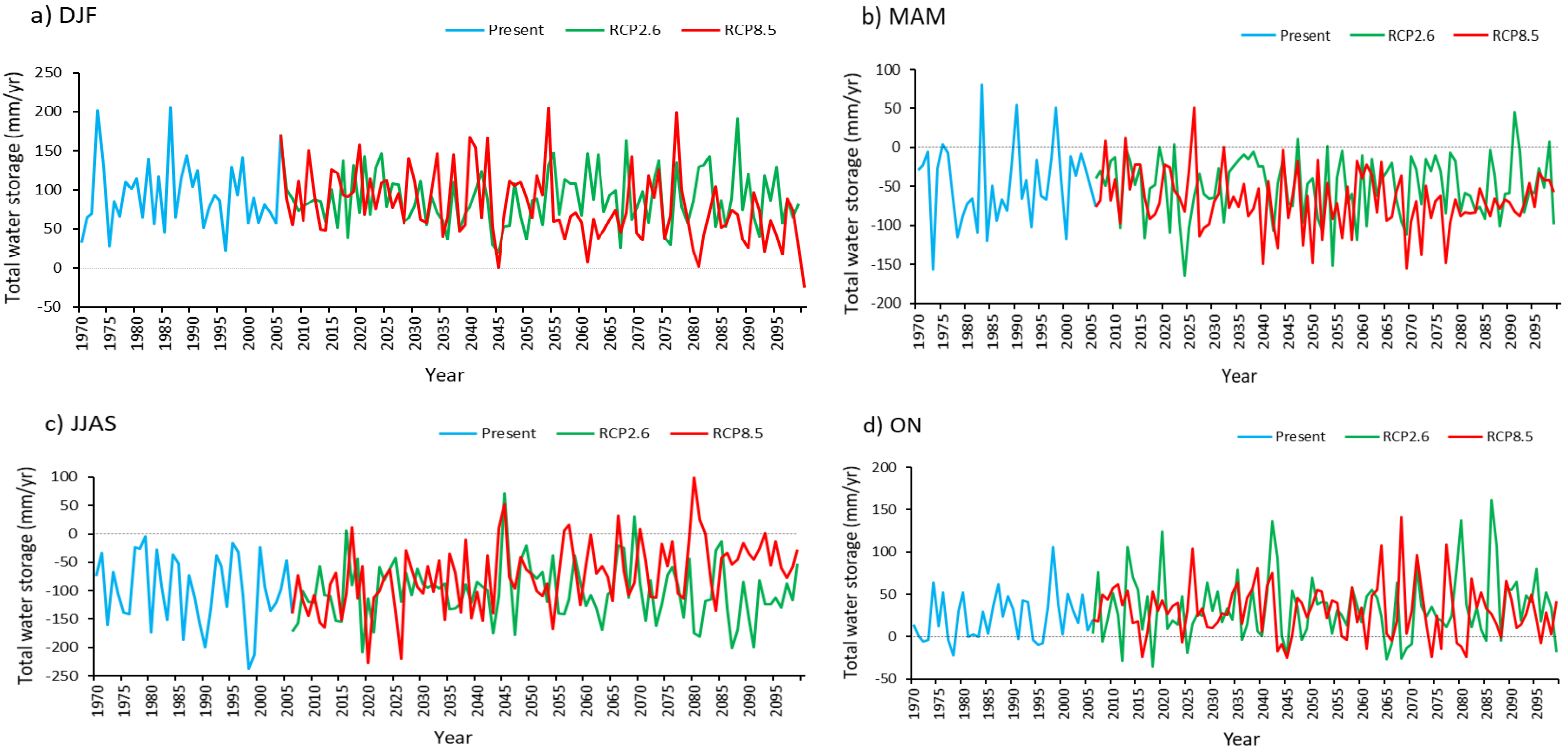


Fig 19. Time series of Total water storage (mm/year) averaged over the Indus basin for the period 1970-2099 for (a) DJF, (b) MAM, (c) JJAS and (d) ON seasons. The series in blue, green and red correspond to Present (1970-2005), RCP2.6 and RCP8.5 warming scenarios respectively from REMO regional model forced with MPI-ESM-LR global model.

Future work

- To consider snowmelt as well and its trend under the different RCPs to be able to overall compare different variables involved in the hydrological cycle.
- To consider P minus E minus R (P-E-R) relationship.
- To detect changes in the hydrological cycle under future climate scenarios.

Thank you