CMIP6-Based Convection-Permitting Future Climate Simulation over the Black Sea Basin

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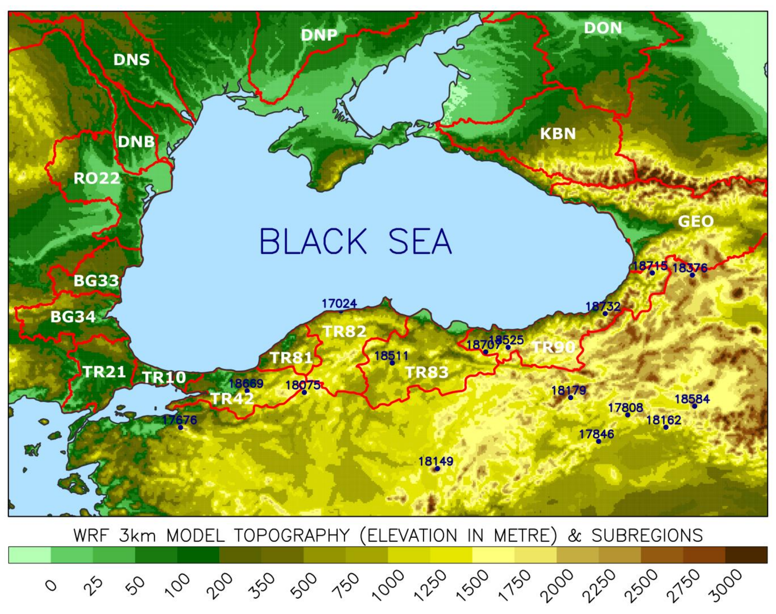
ABSTRACT

The Black Sea Basin is an area encompassing the coastal regions of the Black Sea and a broad part of the Anatolian Peninsula, which is highly vulnerable to the impacts of climate change. The region is characterized by complex topographical features and strong air-sea interactions, making it a climate change hot-spot. Previous studies have focused on regional climate modelling of this area, with horizontal resolutions on the order of 10 km. However, recent technological advances have enabled climate models to be run at 4 km or smaller grid spacings, known as the convection-permitting scale, over different regions worldwide. Such studies have highlighted the benefits of convection-permitting simulations, particularly in representing daily and sub-daily precipitation over complex terrain. In this study, we performed 10-years-long convection-permitting climate simulations at 3 km horizontal resolution for the reference and future periods (2005-2014 and 2061-2070) based on the SSP3-7.0 greenhouse gas emission scenario over the Black Sea Basin. To achieve this, we downscaled the CMIP6-based MPI-ESM1.2-HR outputs using the WRF model. The results indicate that the total precipitation decreases in spring and summer over the Black Sea Basin compared to the 2005-2014 reference period. On the other hand, it significantly increases by about 40% in winter over the Eastern Black Sea. The increase in the winter can be explained by the intensified low-level moisture flux, which increases by about 20%, enhanced by the increased evaporation due to higher SSTs. Regarding extreme precipitation, the maximum daily precipitation amount reaches 350 mm over the northeast of Türkiye and the Caucasus. The intensification of daily precipitation is most pronounced in the coastal subregions of the Black Sea Basin. Furthermore, the results highlight the intensification of sub-daily precipitation in these regions. In particular, afternoon precipitation intensifies in autumn over the coastal regions of Türkiye.

In terms of temperature, there is a significant increase in daily 2m maximum air temperatures in the spring, summer, and autumn, with an increase of about 3°C over the study area. Notably, the warming rates exceed 4.5°C in March and April. Analyses show that the northerly flow weakens around 1 m/s in March, resulting in warming. Moreover, the snow cover shrinks over the high-elevated regions of Eastern Anatolia in these months, and surface albedo decreases, further accelerating the temperature increase. This study emphasizes the urgent need for proactive measures to mitigate and adapt to the impacts of climate change in the Black Sea Basin, given its susceptibility to strong air-sea interactions and complex topographical features.

MODEL CONFIGURATION

- 3 km horizontal resolution (547x364 grids)
- 50 vertical levels
- Thompson microphysics scheme
- YSU Planetary Boundary Layer scheme
- RRTMG SW&LW radiation schemes
- Noah land-surface model



- CMIP6 MPI-ESM1.2-HR -> WRF (V3.9.1) -> 3km
- 2005 – 2014 (HIST) | 2061 – 2070 (SSP3-7.0)

SUMMARY

The Black Sea Basin -> Climate change hotspot

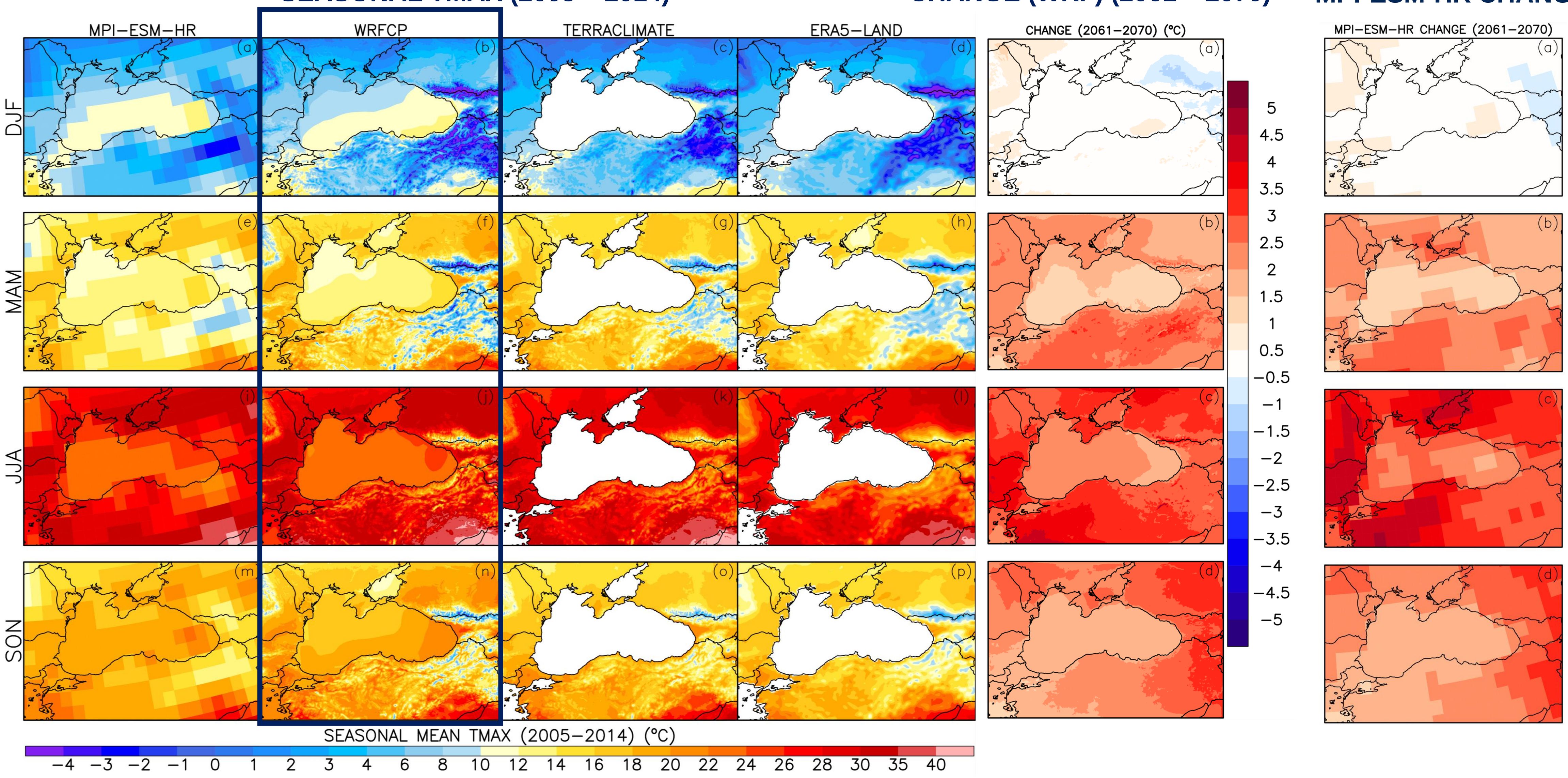
Warming SST over the Black Sea -> Increase in the precipitation extremes

Complex topography -> High-resolution climate information is required

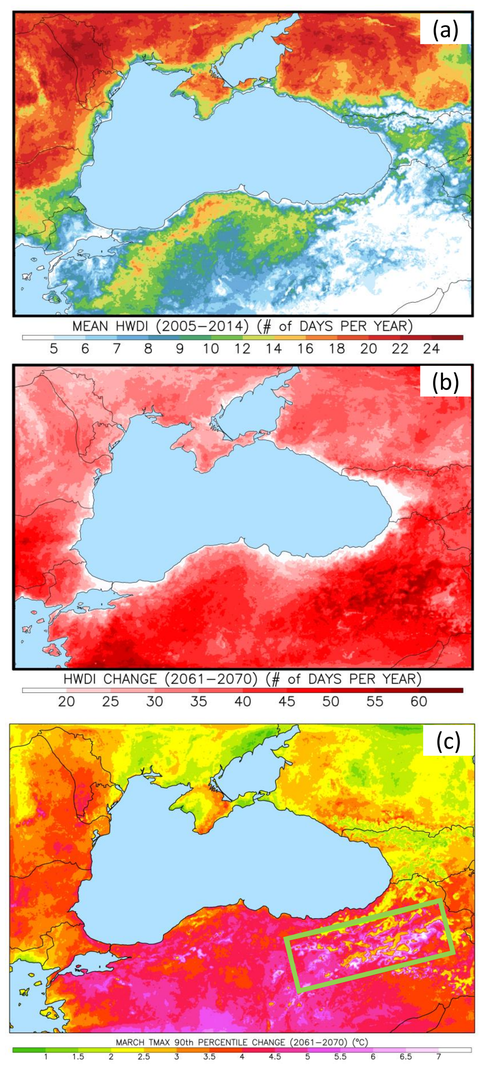
KEY FINDINGS

- WRF-CPM improves the daily and sub-daily precipitation representation
- The circulation change in the spring accelerates the warming and snow melt process in the future
- The daily and sub-daily precipitation intensify in the future

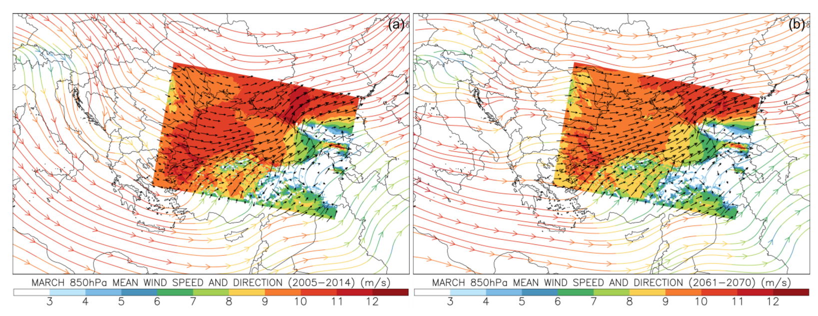
SEASONAL TMAX (2005 – 2014) | CHANGE (WRF) (2061 – 2070) | MPI-ESM-HR CHANGE



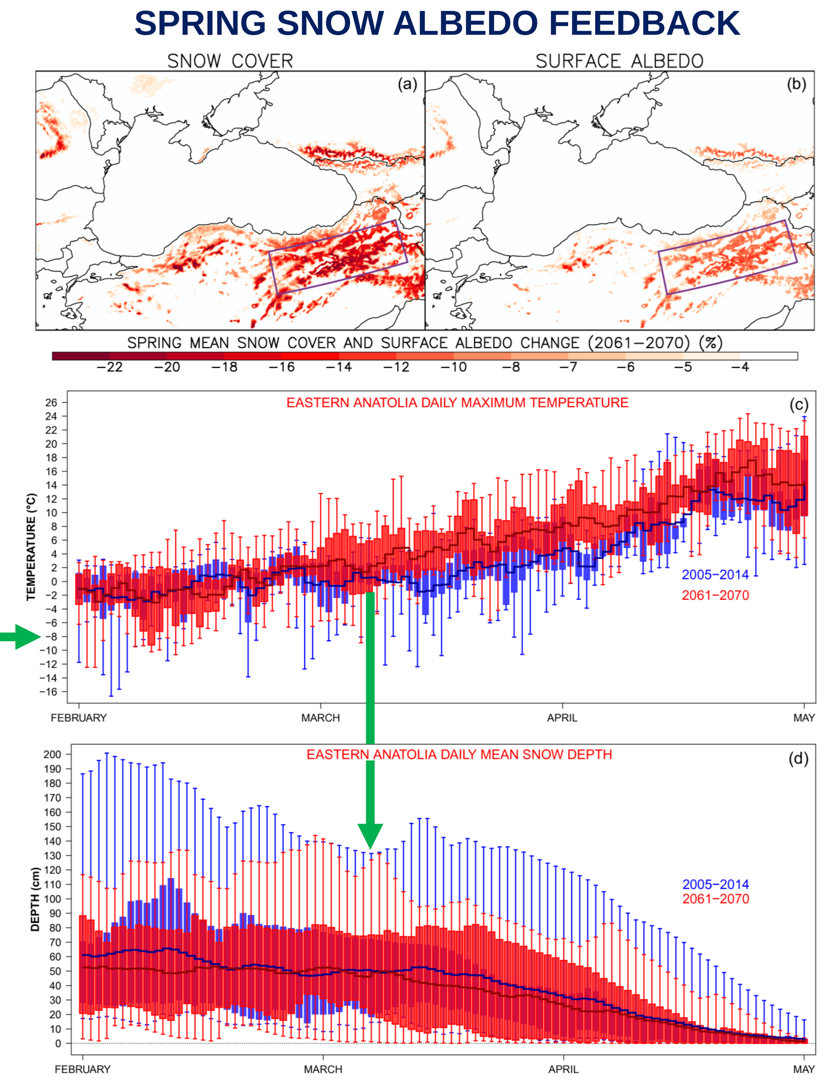
TEMPERATURE EXTREMES



MARCH 850 hPa CIRCULATION

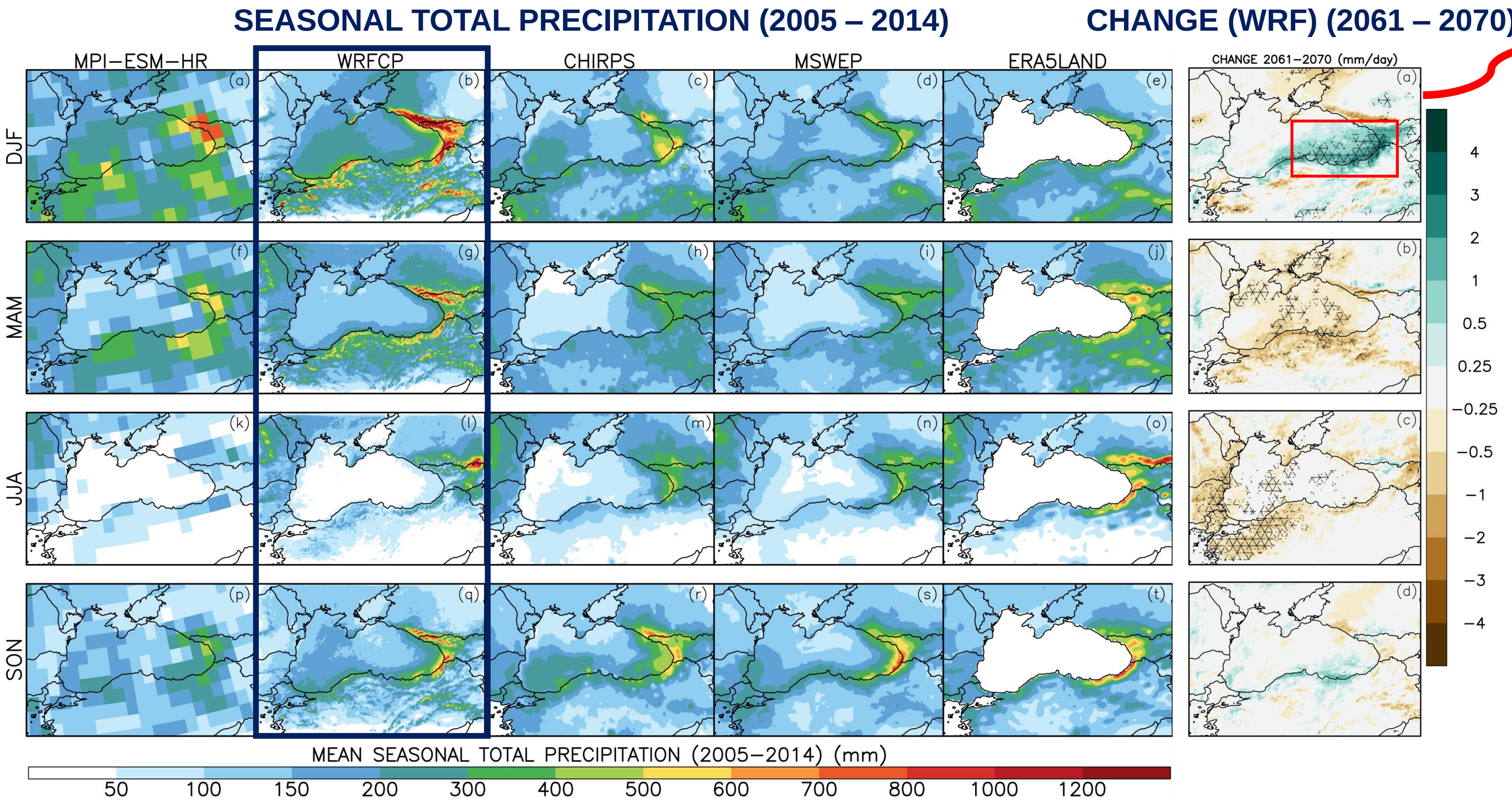


SPRING SNOW ALBEDO FEEDBACK

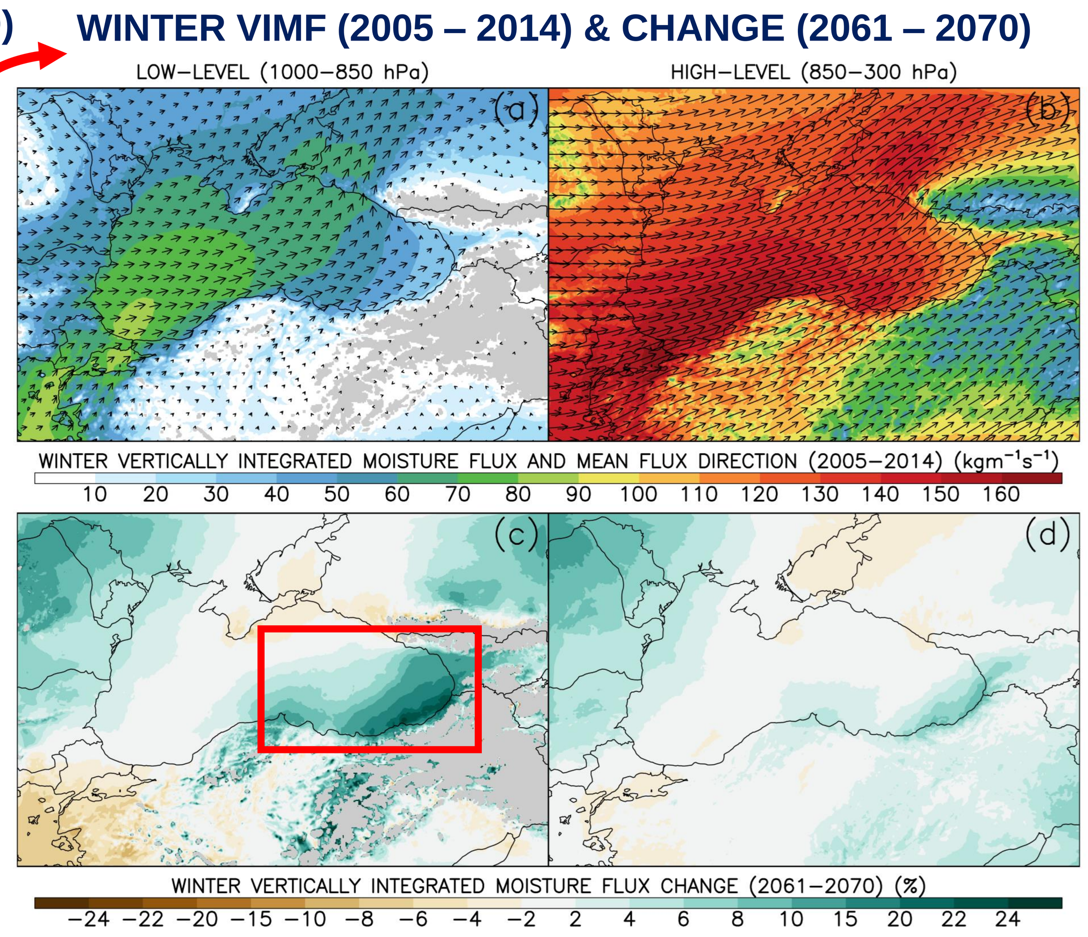


- The **maximum air temperature increases** in the spring, summer, and autumn by about 3°C. The suppressed warming in the winter is due to GCM forcing.
- **Temperature extremes** increase in the future. In particular, the HWDI increases by about 55 days per year over **the Eastern Anatolia**.
- There is a **significant warming** in March due to circulation change. The temperature increase reaches 3.5°C in the **spring** over the Eastern Anatolia is due to **the early snow melt** (snow–albedo feedback).

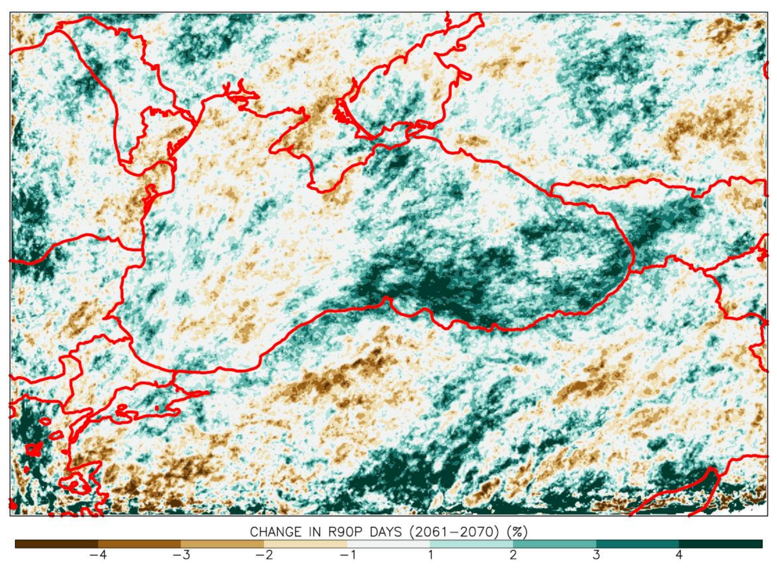
SEASONAL TOTAL PRECIPITATION (2005 – 2014) | CHANGE (WRF) (2061 – 2070)



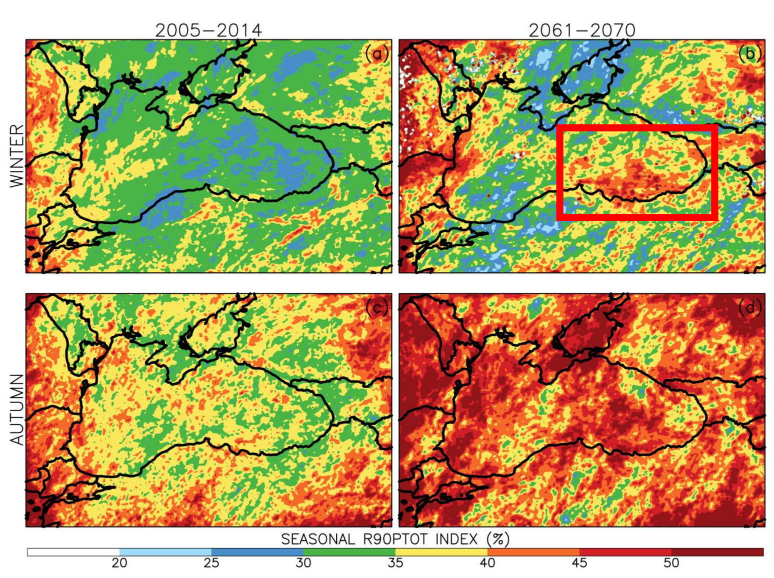
WINTER VIMF (2005 – 2014) & CHANGE (2061 – 2070)



R90PDAYS CHANGE (2061 – 2070)

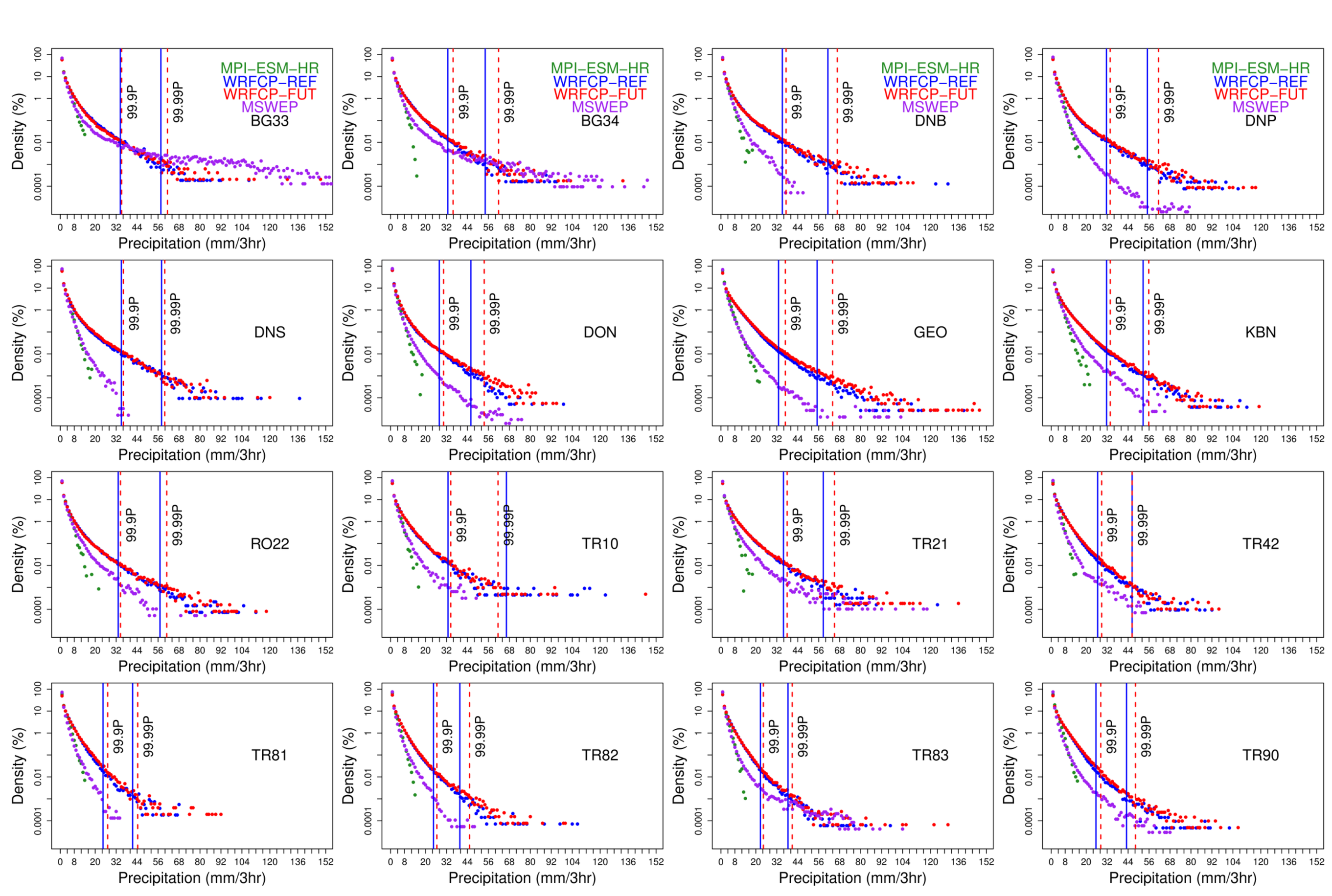


WINTER & AUTUMN R90PTOT INDEX



- The WRF model simulates seasonal total precipitation better compared to low-resolution MPI-ESM-HR.
- The **winter precipitation increases significantly** by about 3 mm/day over the Eastern Black Sea due to **intensified low-level moisture transport**.
- Daily **precipitation extremes** become more common in the future. The number of days with extreme precipitation (R90PDAYS) increases by about 4%.
- Extreme precipitation amount (R90PTOT) reaches ~50% in **winter and autumn** over the Black Sea region.

3-HOURLY PRECIPITATION



SUB-DAILY PRECIPITATION ANALYSES

MPI-ESM-HR (HIST)

WRF (2005 – 2014)

WRF (2061 – 2070)

MSWEP (OBS)

WRF model (3-km) **improves 3-hourly precipitation** of MPI-ESM-HR (100-km) within the subregions of the Black Sea Basin

Afternoon precipitation intensifies in the autumn over the Black Sea coast of Türkiye.

Sub-daily precipitation increases in the future (exceeds 120 mm/3hr)

AUTUMN PRECIPITATION CYCLE