

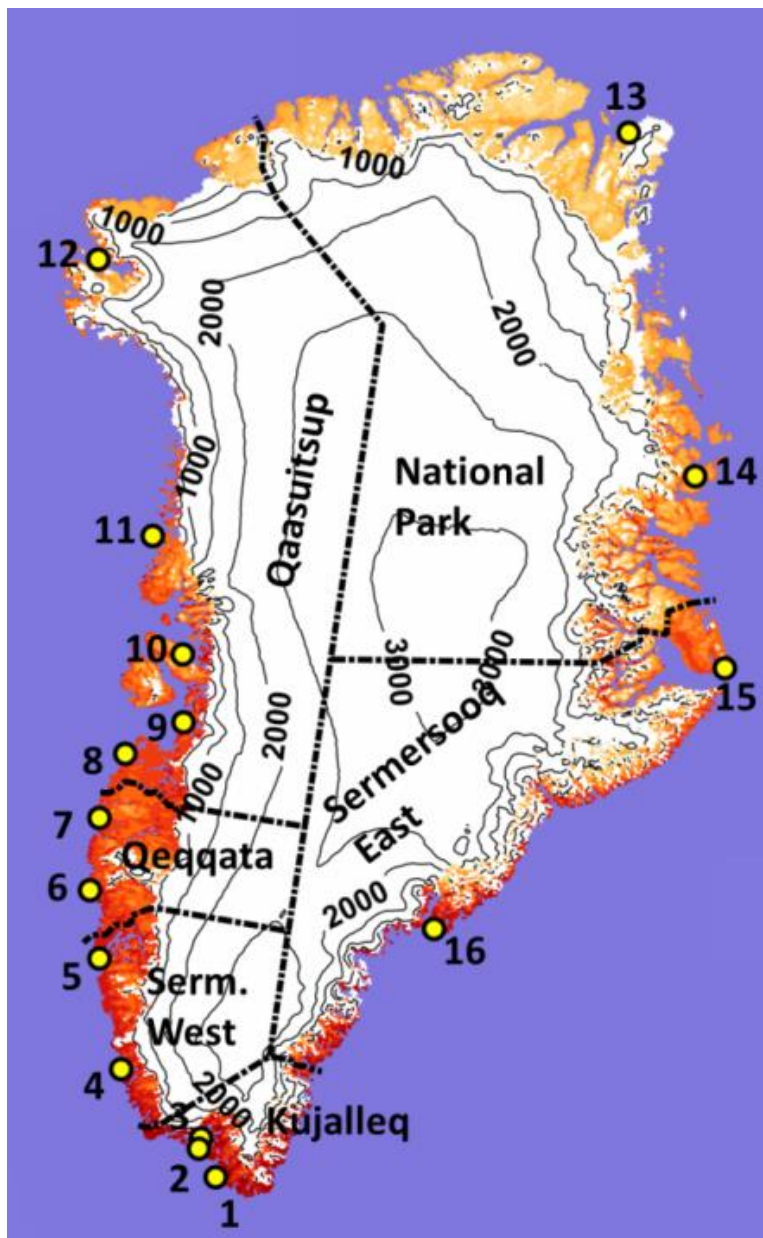


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Energi-, Forsynings- og Klimaministeriet

Scientific Report 15-04 (Index catalogue)

Climate indices for vulnerability assessments - Greenland



Copenhagen 2016



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Abstract

DMI has estimated the expected climate change in Greenland based on the latest Danish and international scenario calculations focusing on climate change within this century. The assessment of future climate change is based on the emission scenarios used by Intergovernmental Panel on Climate Change (IPCC) and climate changes are expected to increase towards 2100.

Climate simulations and understanding of associated uncertainties are constantly being improved. DMI here presents the latest results based on IPCC, European studies and the Danish project 'Datagrundlaget for klimatilpasningsindsatsen i Grønland' supported by the Danish Energy Agency where a number of climate simulations were performed with combinations of several global and regional climate models. Projections of future climate change based on an ensemble of climate models are more robust than estimates based on a single model. Here a statistical method to better frame results based on the DMI high resolution regional model is utilized to assess uncertainties of project climate change results.

For specific planning, assessment and risk analysis of climate adaptation, it is important to consider the full range of estimates as indicated by the uncertainty interval, instead of simply considering the best estimate.

Climate variability and change are expected to increase towards 2100 in terms of higher temperatures, more winter precipitation, more frequent and more extreme weather events and a continuing loss of sea ice.

Resumé

På baggrund af de nyeste scenarieberegninger med DMI's klimamodeller beskrives her mulige fremtidige klimaforandringer i Grønland med fokus på den fremtidige udvikling i dette århundrede. Vurderingen af fremtidige klimaforandringer er baseret på de scenarier, som også anvendes af FN's klimapanel, IPCC.

Klimascenarier og nøjagtigheden af dem bliver løbende forbedret. I denne rapport har DMI foretaget beregninger og udarbejdet grafik og tabeller baseret på de nyeste tal fra IPCC, EU-studier og det danske projekt 'Datagrundlaget for klimatilpasningsindsatsen i Grønland'. En række klimasimuleringer er gennemført med flere globale klimamodeller og ikke mindst DMI's regionale klimamodel HIRHAM, som er udviklet i samarbejde med Grønlands Klimaforskningscenter ved Naturinstituttet i Nuuk. Simuleringerne med den danske model er med statistiske metoder sammenholdt med resultaterne fra de globale modeller. Kun med den regionale model kan der laves egentlige klimascenarier, som er repræsentative for de beboede og kystnære områder af Grønland. Vurderingerne af fremtidige klimaforandringer bliver dermed væsentligt mere robuste, end hvis beregningerne kun baseres på en enkelt klimamodel.

Klimaforandringerne forventes at tiltage frem mod 2100. Det vil medføre højere temperaturer, mere vinternedbør, flere og mere intense ekstreme vejrhændelser samt ikke mindst en vigende mængde havis. En række afledte størrelser som fx perioden med snedække og vækstsæsonens længde påvirkes også. Men den præcise udvikling afhænger især af, hvor store mængder drivhusgasser, der slipper ud i atmosfæren i fremtiden.

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This document presents a wide range of climate indices for Greenland. The indices are based on 5 time slice runs done using the regional climate model HIRHAM, at a 0.04° horizontal resolution, forced by the global climate model EC-EARTH at the model boundary. The 5 time slice runs are 20 years long each and include a historical run for 1991-2010, two scenario runs for the RCP 4.5 greenhouse gas concentration scenario for 2031-2050 and 2081-2100 and finally two scenario runs for the RCP 8.5 scenario for 2031-2050 and 2081-2100. The climate indices are based on an SMHI report RMK (No. 111) by Persson et al., 2007, with a number of additional indices of interest for the Greenlandic community. The list currently contains 66 indices which are summarized in Table 1 below. Indices are shown, when suitable, as annual and seasonal (DJF and JJA) means for the 20-year period in question. Some indices are only given as annual means while others are only given as seasonal means.

Index 01	Daily mean temperature at 2m height, mean value
Index 02	Daily maximum temperature at 2m height, mean value
Index 03	Daily minimum temperature at 2m height, mean value
Index 04	Number of days when daily minimum temperature at 2m is below 0°C ("frost days")
Index 05	Number of days when daily maximum temperature at 2m is above 10°C
Index 06	Number of days when daily maximum temperature at 2m is below -7°C
Index 07	Longest continuous period with precipitation below 1mm ("dry period")
Index 08	Number of days with precipitation below 1mm ("number of dry days")
Index 09	Number of days with precipitation above 10mm ("heavy precipitation")
Index 10	Number of days with precipitation above 25mm ("extreme precipitation")
Index 11	Precipitation, summed up
Index 12	Maximum precipitation intensity (yearly maximum)
Index 13	Amount of rainfall, summed up
Index 14	Amount of snowfall, summed up
Index 15	Rainfall fraction of total precipitation
Index 16	Effective precipitation (i.e. precipitation minus evaporation), summed up
Index 17	Highest effective precipitation during a continuous 7-day period
Index 18	Highest effective precipitation during a continuous 14-day period
Index 19	Highest effective precipitation during a continuous 30-day period
Index 20	Highest effective precipitation during a continuous 60-day period
Index 21	Highest precipitation during a continuous 7-day period
Index 22	Evaporation, summed up
Index 23	Number of days during the year when daily maximum temperature at 2m is below 1°C and rainfall is above 0.5mm (model adjusted "days with freezing rain")
Index 24	Mean value of incoming longwave radiation (heat radiation)
Index 25	Number of days when the relative humidity (daily mean) is above 60% and daily mean temperature at 2m is above 10°C
Index 26	Net runoff, summed up
Index 27	Net runoff over glacier, summed up
Index 28	Number of days with snow cover (snow depth above 2 cm)
Index 29	Number of days with snow depth between 2 and 10 cm
Index 30	Number of days with snow depth between 10 and 20 cm
Index 31	Number of days with snow depth above 20 cm
Index 32	Mean value of incoming short wave radiation (global radiation)
Index 33	Number of degree days when daily maximum temperature at 2m is above 17°C
Index 34	Longest continuous period with daily maximum temperature at 2m above 15°C
Index 35	Daynumber for the end of the last continuous 4-day period with daily mean



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	temperature at 2m above 5°C ("end of growing season (5°C)")
Index 36	Daynumber for the end of the last continuous 4-day period with daily mean temperature at 2m above 2°C ("end of growing season (2°C)")
Index 37	Daynumber for the end of the first continuous 4-day period with daily mean temperature at 2m above 2°C ("start of growing season (2°C)")
Index 38	Daynumber for the end of the first continuous 4-day period with daily mean temperature at 2m above 5°C ("start of growing season (5°C)")
Index 39	Number of degree days for daily mean temperature at 2m above 10°C
Index 40	Number of degree days for daily mean temperature at 2m is above 8°C during the growing season (5°C)
Index 41	Number of degree days for daily mean temperature at 2m below 12°C ("heating degree days" HDD)
Index 42	Last daynumber (<240) when daily minimum temperature at 2m is below 0°C ("last spring frost")
Index 43	Number of days when daily minimum temperature at 2m is above 12°C (model adjusted "tropical nights")
Index 44	Number of days between the end of the first continuous 4-day period with daily mean temperature at 2m above 2°C and the end of the last continuous 4-day period with daily mean temperature at 2m above 2°C ("length of growing season (2°C)")
Index 45	Number of days between the end of the first continuous 4-day period with daily mean temperature at 2m above 5°C and the end of the last continuous 4-day period with daily mean temperature at 2m above 5°C ("length of growing season (5°C)")
Index 46	Number of days when daily mean temperature at 2m has been both above and below 0°C (daily maximum temperature at 2m above 0°C and daily minimum temperature at 2m below 0°C)
Index 47	Number of days when the daily mean surface temperature is below -7°C
Index 48	Daily mean wind speed at 10m, mean value
Index 49	Permafrost index ($\frac{\sqrt{DD\bar{F}}}{\sqrt{DD\bar{T}} + \sqrt{DD\bar{F}}}$, where DDF(DDT) = degree-days of freezing(thawing))
Index 50	Number of degree days when daily mean temperature at 2m is above 0°C ("thawing degree days")
Index 51	Number of days when 10m wind speed is below 20m/s ("fishing days (20m/s)")
Index 52	Number of days when 10m wind speed is below 15m/s ("fishing days (15m/s)")
Index 53	Number of degree days when daily mean temperature at 2m is below 0°C ("freezing degree days")
Index 54	Length of thawing season (from 0°C crossing dates using a 21-day moving average of daily mean temperature at 2m)
Index 55	Length of freezing season (from 0°C crossing dates using a 21-day moving average of daily mean temperature at 2m)
Index 56	Melt events during winter (number of days with daily maximum temperature at 2m above 0°C and 29-day running mean of daily mean temperature at 2m below -5°C)
Index 57	Daynumber, after day 220, of the first 5 consecutive days with snow cover above 2cm ("snow cover season – onset")
Index 58	Daynumber of the first 5 consecutive days with snow cover below 2cm ("snow cover season – end")
Index 59	Standard deviation of annual values of index 52 ("snow cover season – change in onset")



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Index 60	Standard deviation of annual values of index 53 ("snow cover season – change in end")
Index 61	Daynumber, after 10 continuous days with daily mean temperature at 2m above 0°C, when daily maximum temperature at 2m is above 10°C and the relative humidity is above 45% ("mosquito season – onset")
Index 62	Daynumber, after day 220, of the first 5 consecutive days with daily mean temperature at 2m below 0°C ("mosquito season – end")
Index 63	Difference between Indices 57 and 56 ("mosquito season – length")
Index 64	Longest continuous period with precipitation below 1mm ("dry period") during growing season (2°C)
Index 65	Longest continuous period with precipitation below 1mm ("dry period") during growing season (5°C)
Index 66	Daily mean sunshine hours, mean value

Table 1. List of 66 climate indices included in the Greenland study.



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Figure 1 below gives an example plot for Index 1. The dashed lines show the extent of the National Park and the 4 municipals where Sermersooq is divided into a west and an east part. Main villages/stations are shown with black/yellow dots. This document only contains map plots of the entire Greenland, but map plots for all the different regions are made and can be provided.

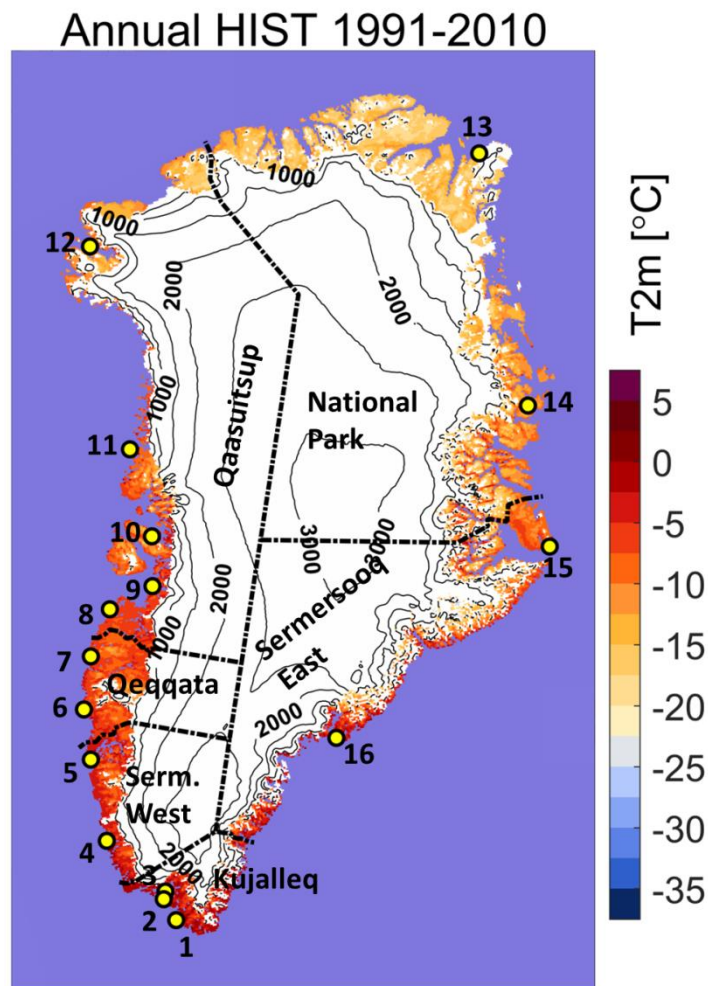


Figure 1. Index 1 with the 4 municipals together with the National Park. The villages/stations are: 1. Nanortalik, 2. Qaqortoq, 3. Narsaq, 4. Paamiut, 5. Nuuk, 6. Maniitsoq, 7. Sisimiut, 8. Kangaatsiaq, 9. Ilulissat, 10. Uummannaq, 11. Upernavik, 12. Qaanaq, 13. Station Nord, 14. Zackenberg, 15. Itloqqortoormiut and 16. Tasilaq.



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The climate index figures are given one for each page and arranged according to:

Historical 1991-2010 Annual	RCP 4.5 2031-2050 rel. Historical Annual	RCP 4.5 2081-2100 rel. Historical Annual	RCP 8.5 2031-2050 rel. Historical Annual	RCP 8.5 2081-2100 rel. Historical Annual
Historical 1991-2010 DJF	RCP 4.5 2031-2050 rel. Historical DJF	RCP 4.5 2081-2100 rel. Historical DJF	RCP 8.5 2031-2050 rel. Historical DJF	RCP 8.5 2081-2100 rel. Historical DJF
Historical 1991-2010 JJA	RCP 4.5 2031-2050 rel. Historical JJA	RCP 4.5 2081-2100 rel. Historical JJA	RCP 8.5 2031-2050 rel. Historical JJA	RCP 8.5 2081-2100 rel. Historical JJA

Scatter plot of annual index values, averaged for southern Greenland (including the ice sheet), as a function of annual mean temperature. The dots are fitted with a 2nd degree polynomial fit.

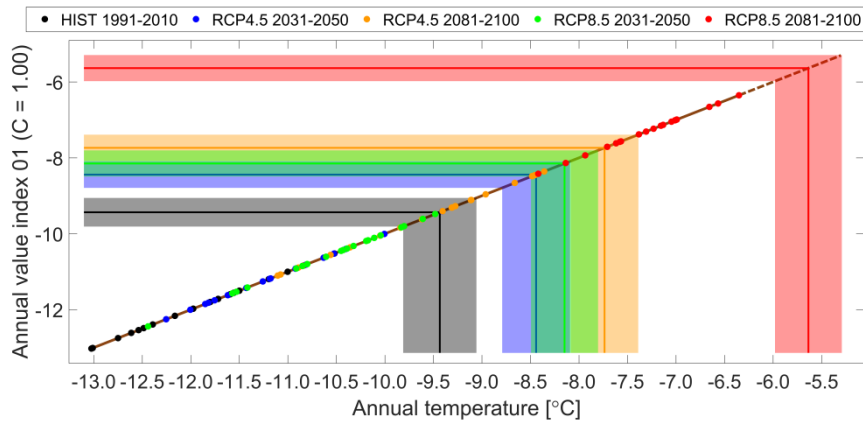
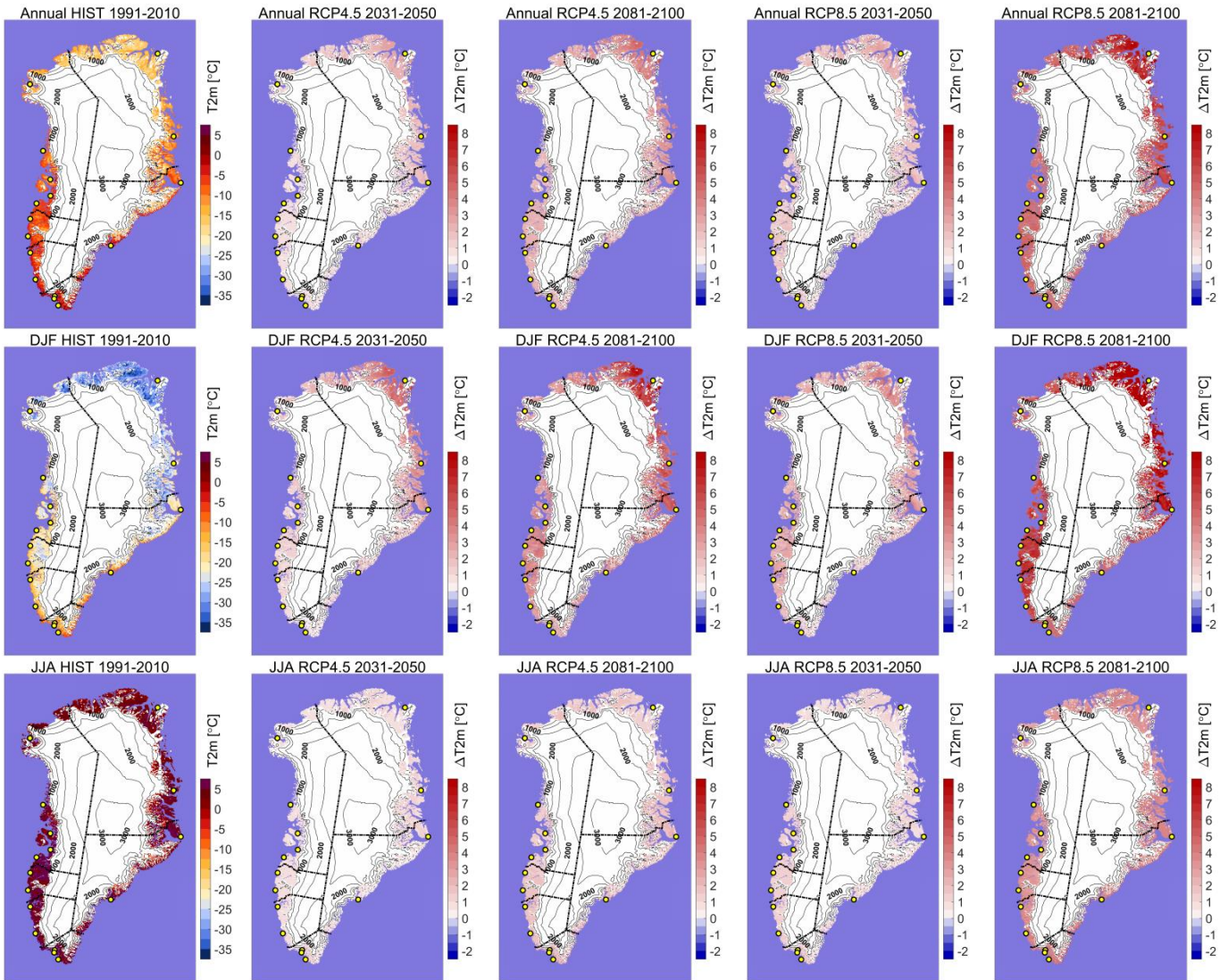
The vertical lines are CMIP5 20-year ensemble mean values of mean temperature for southern Greenland. The shadings represent one standard deviation of the mean and the intercepts with the polynomial fit can be used as an estimate of the uncertainty of the index value.



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Index 01 Daily mean temperature at 2m height, mean value

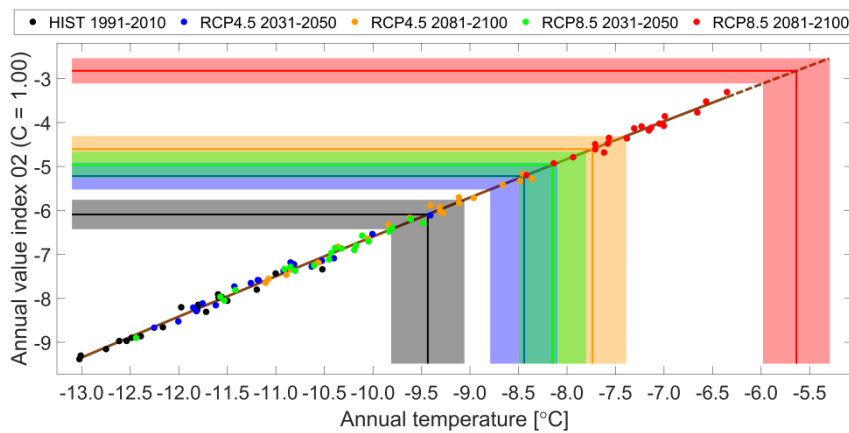
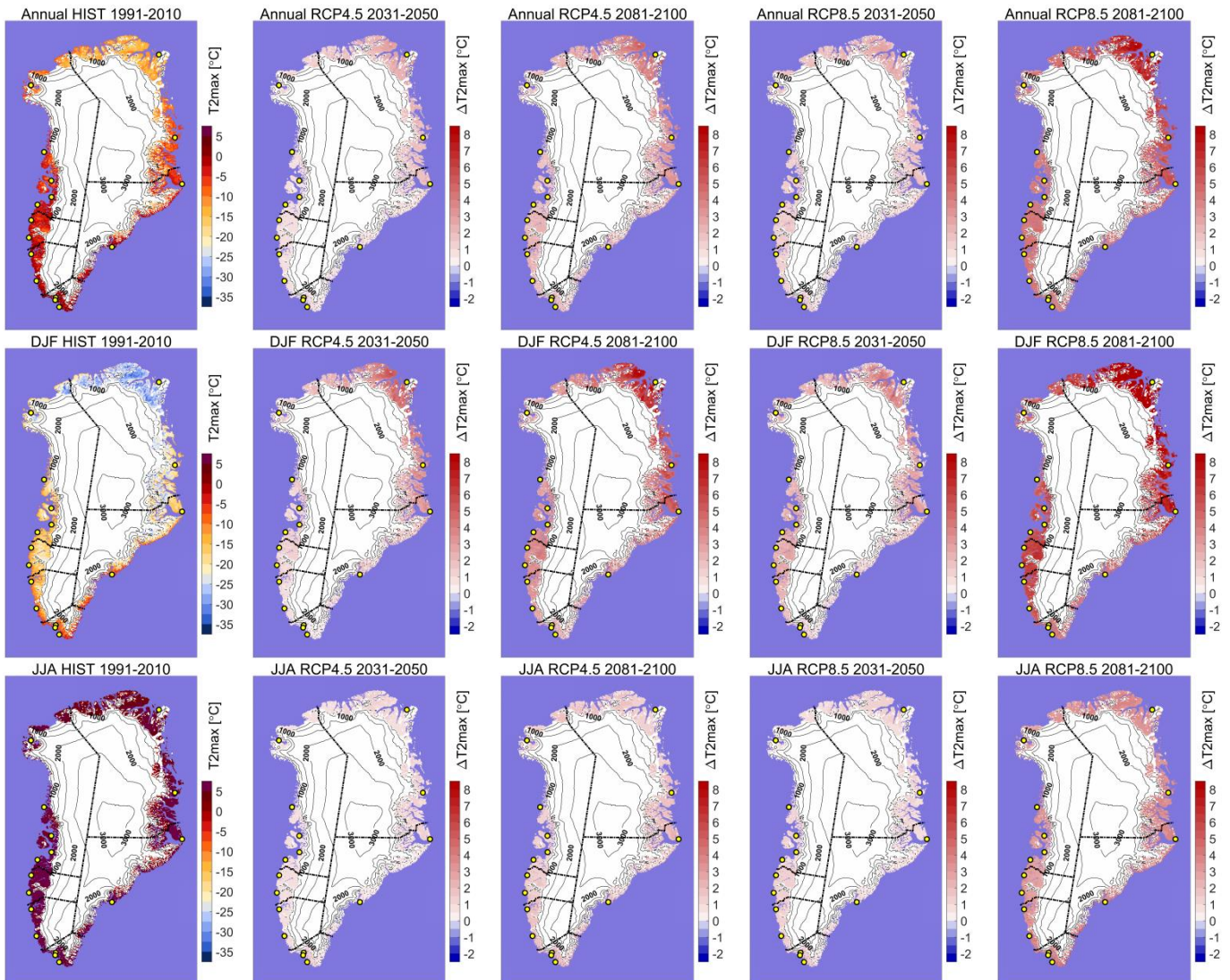




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Index 02 Daily maximum temperature at 2m height, mean value

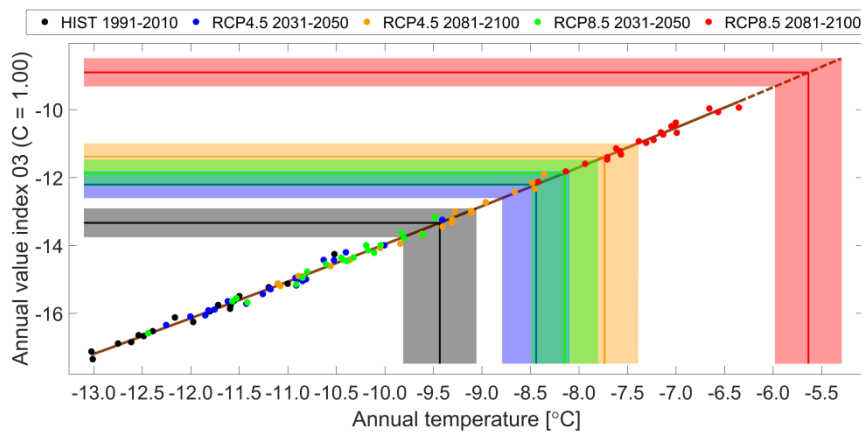
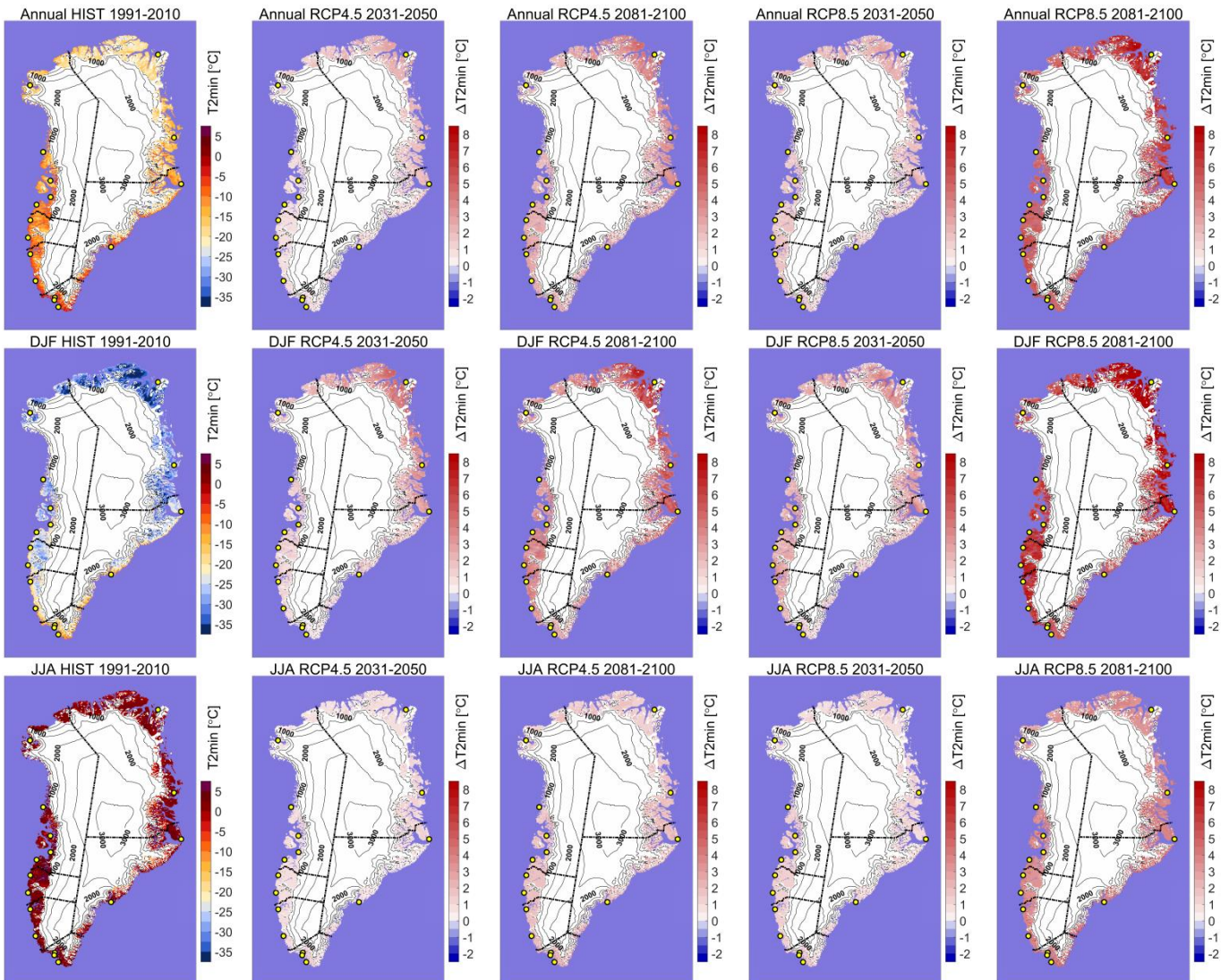




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Index 03 Daily minimum temperature at 2m height, mean value

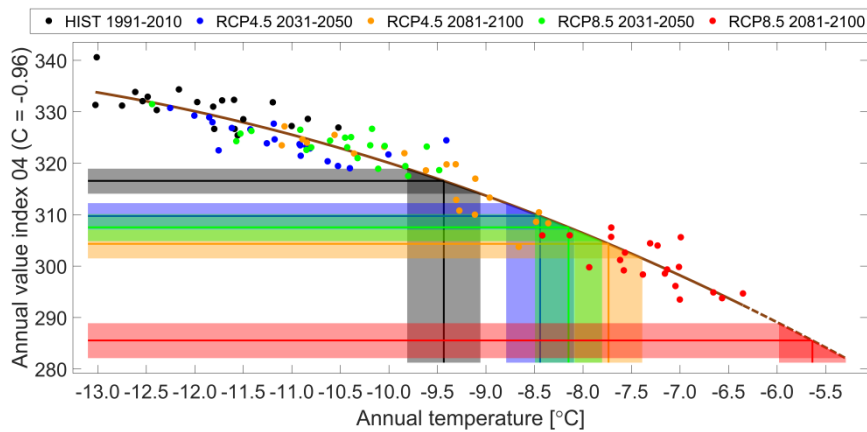
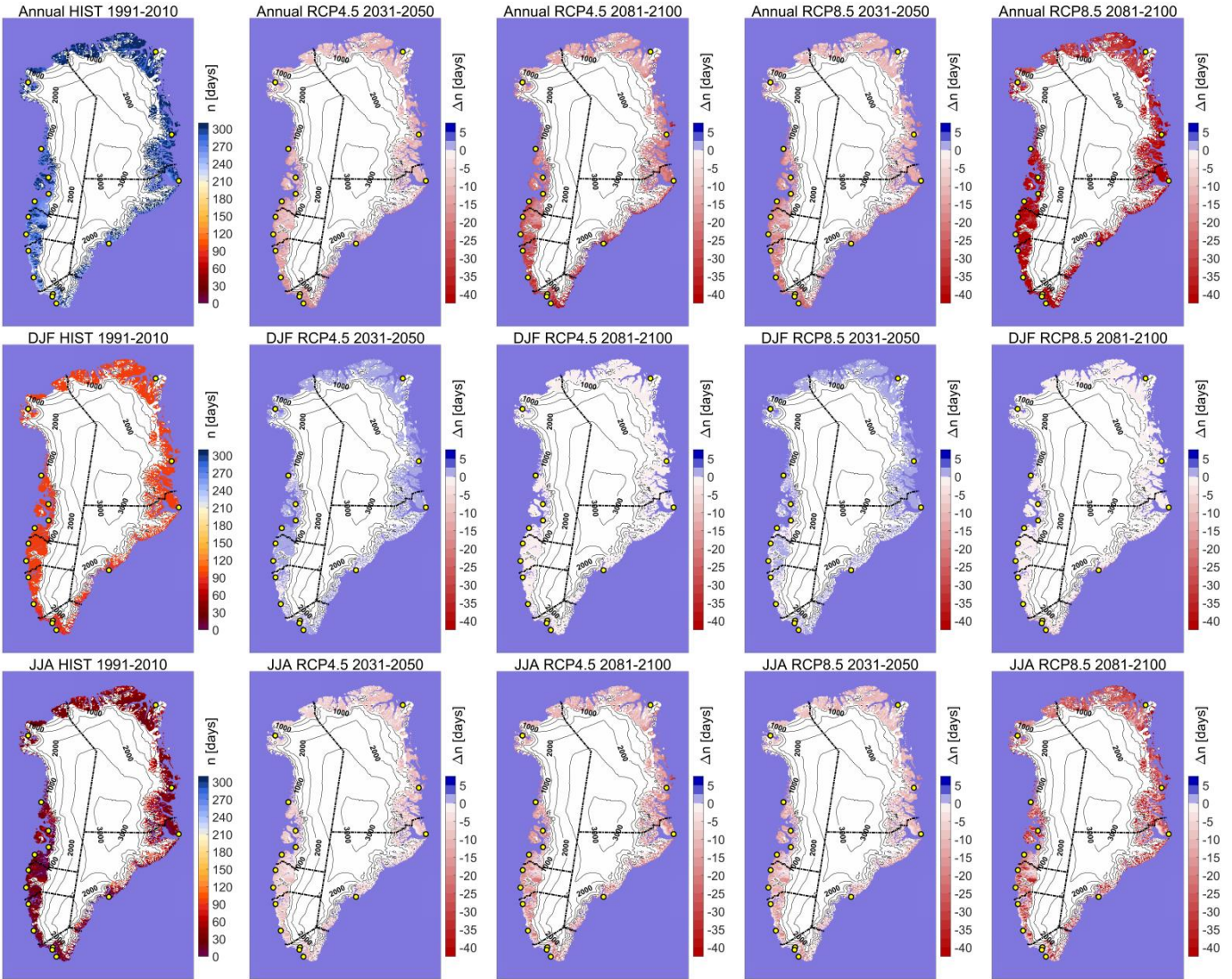




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Index 04 Number of days when daily minimum temperature at 2m is below 0°C ("frost days")

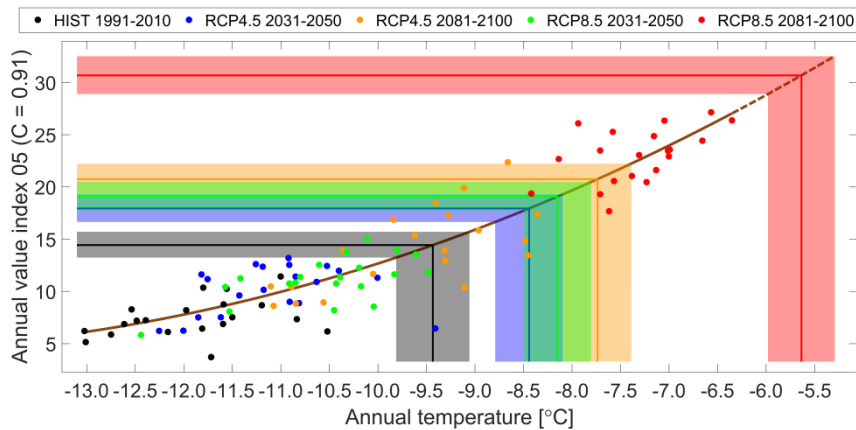
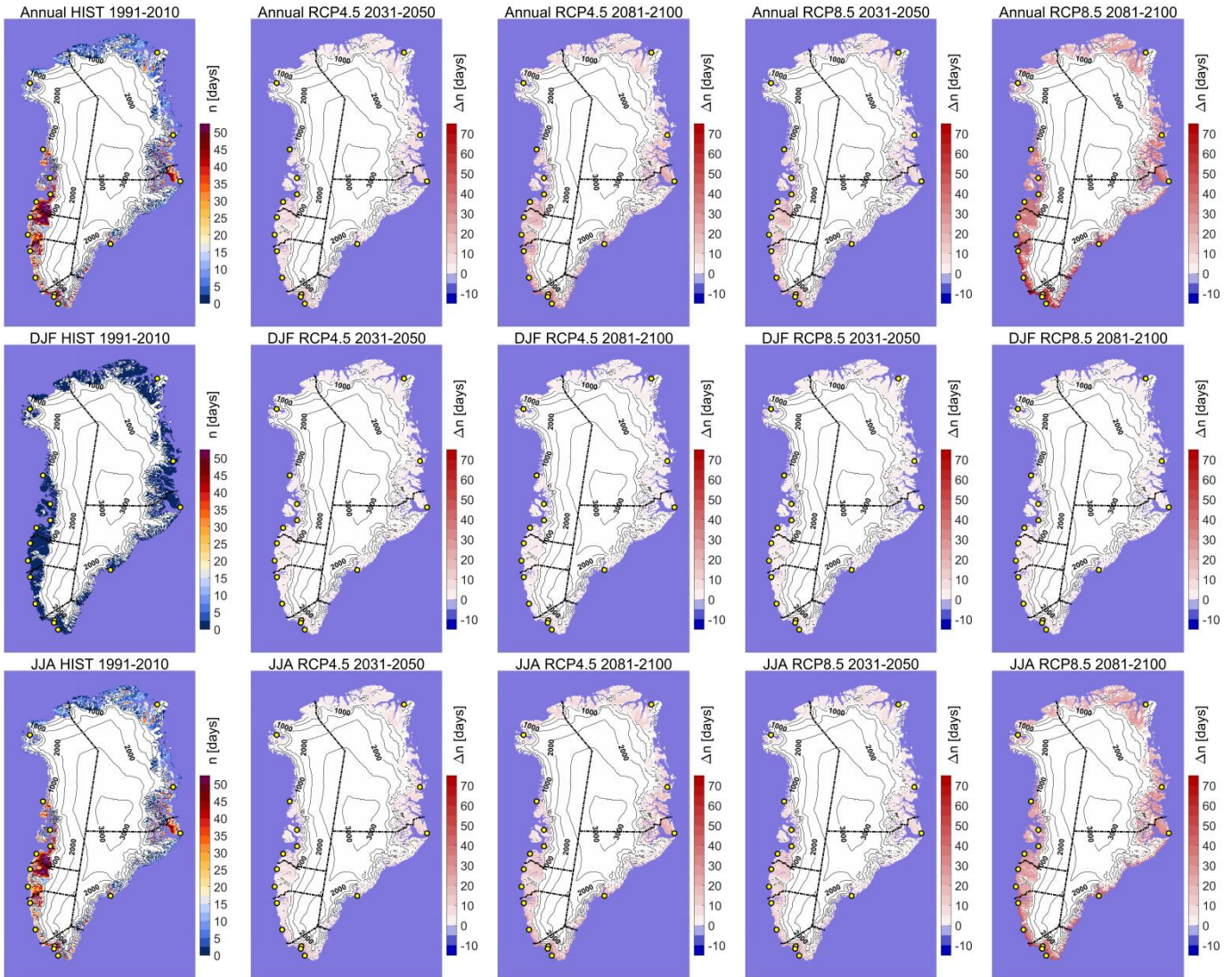




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Index 05 Number of days with daily maximum temperature at 2m is above 10°C

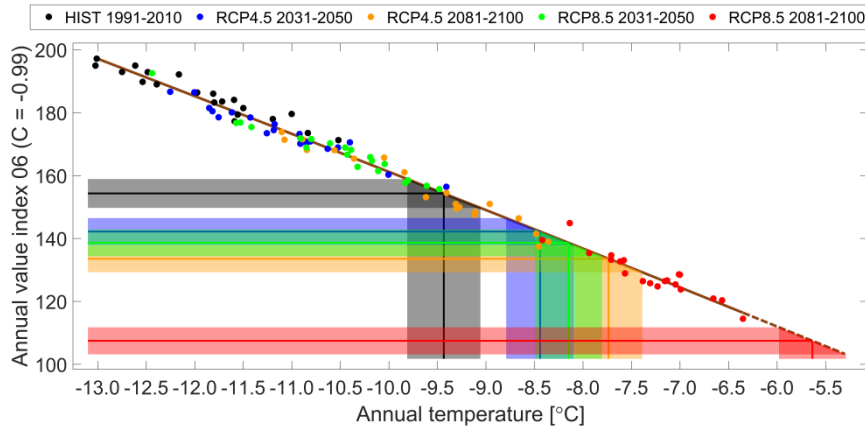
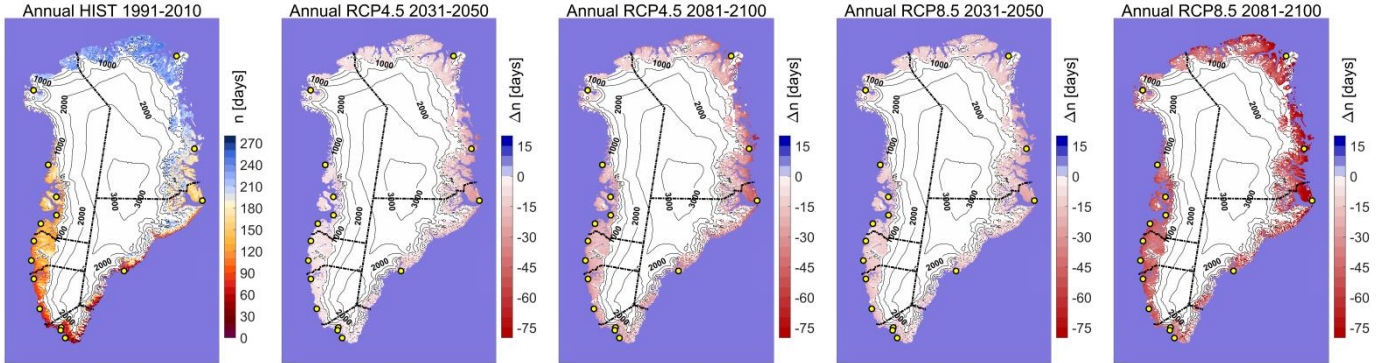




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Index 06 Number of days with daily maximum temperature at 2m is below -7°C

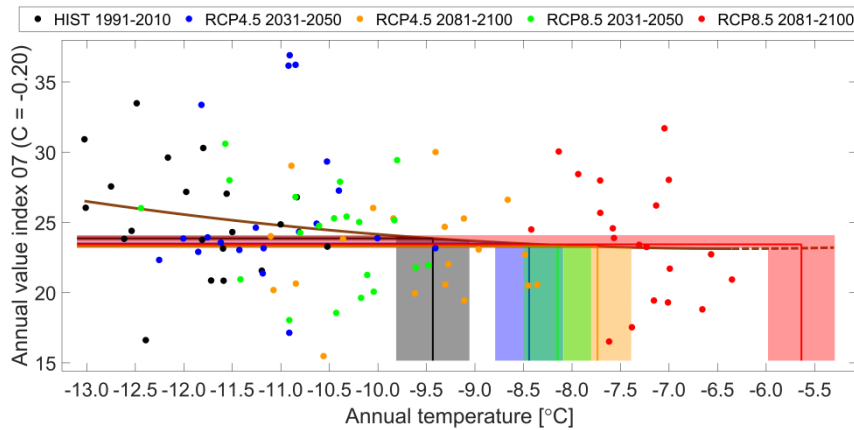
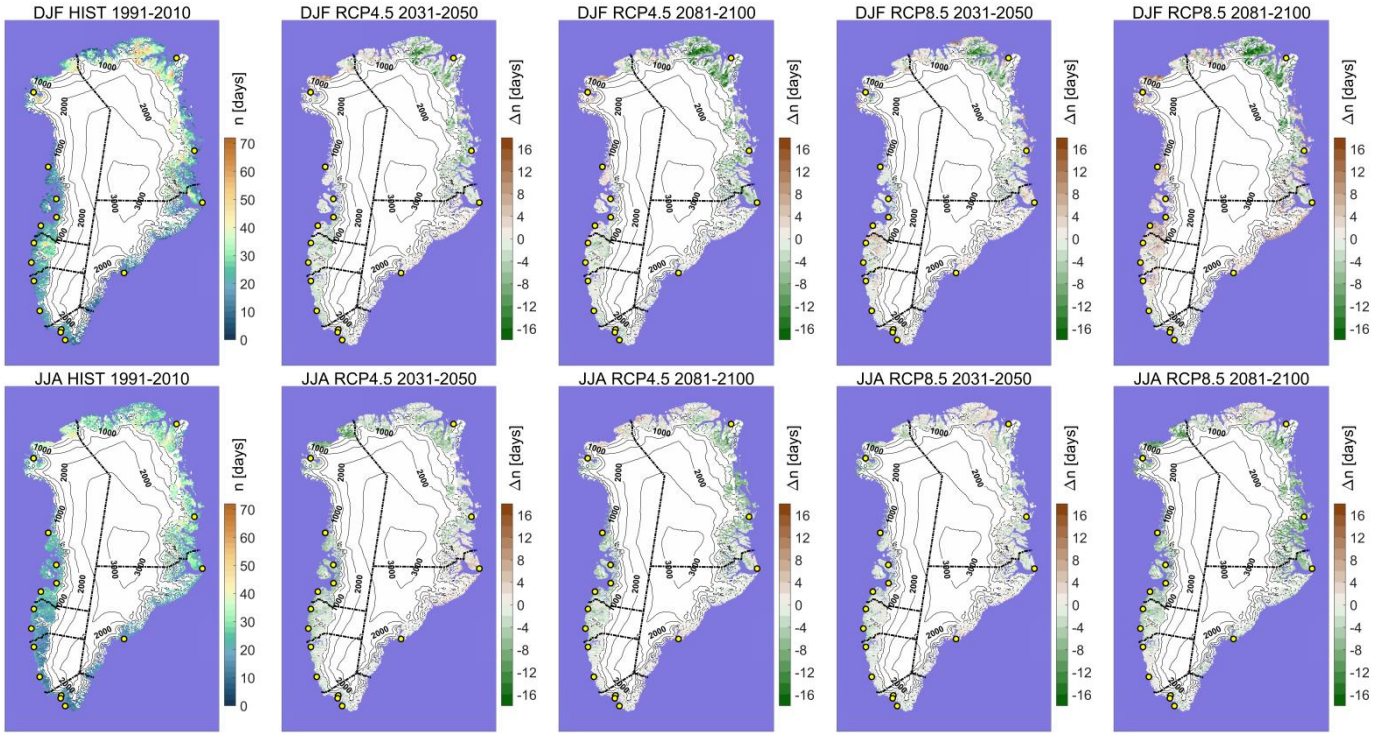




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Index 07 Longest continuous period with precipitation below 1mm ("dry period")

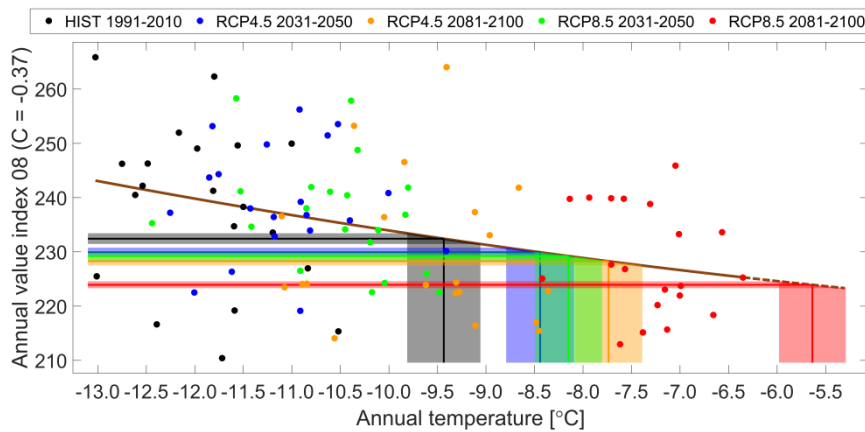
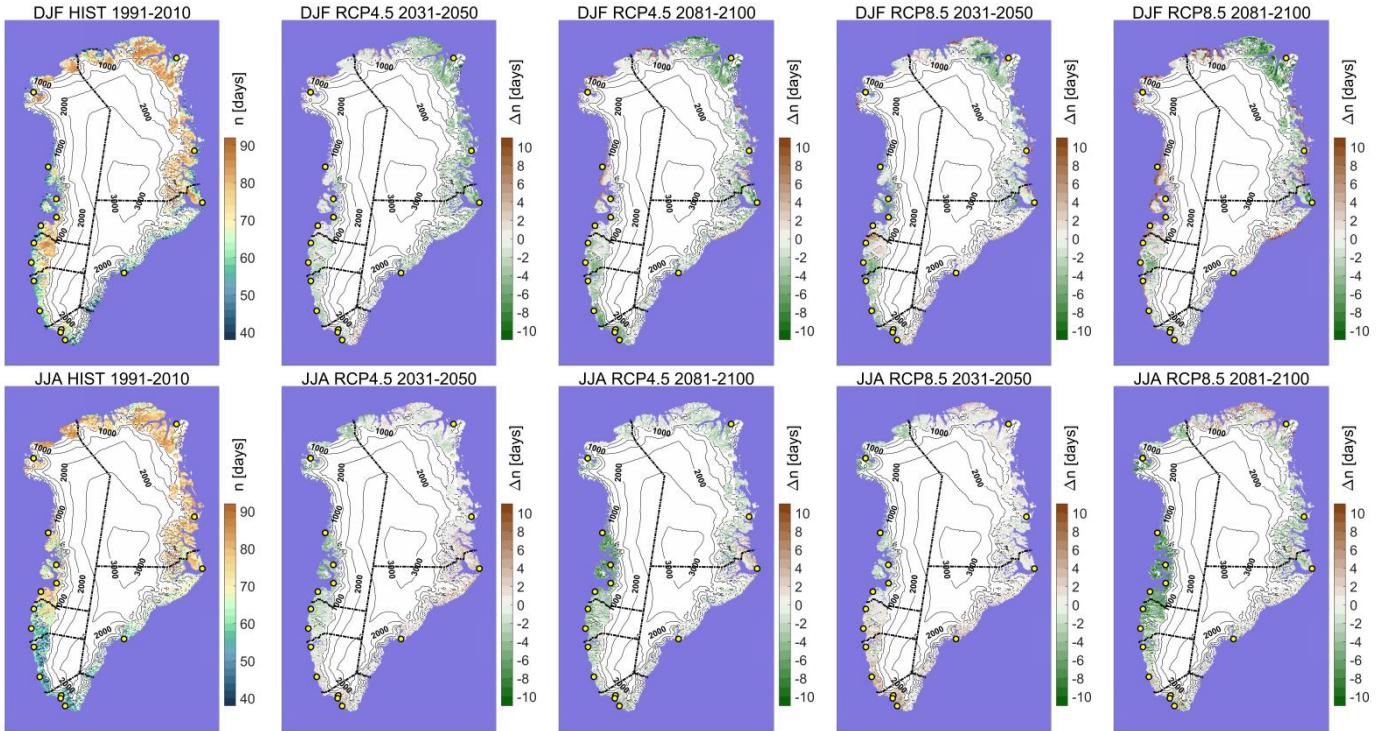




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Index 08 Number of days with precipitation below 1mm ("number of dry days")

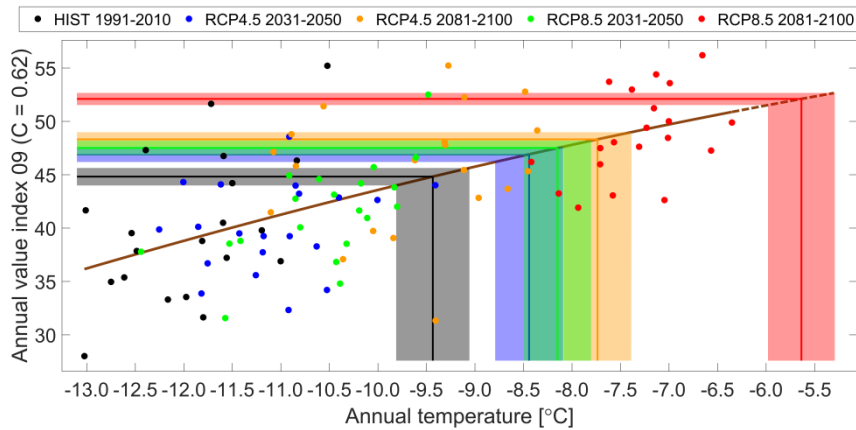
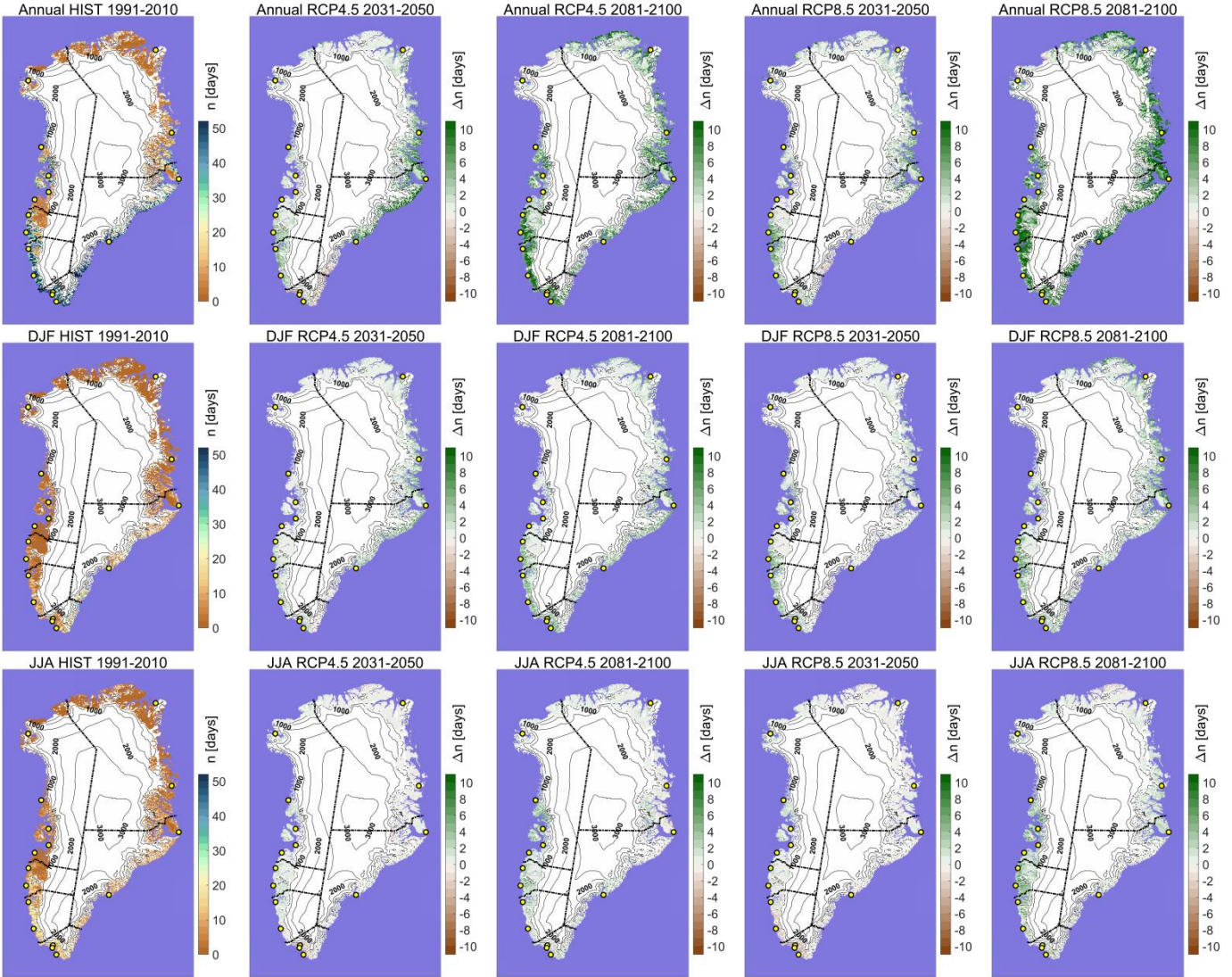




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Index 09 Number of days with precipitation above 10mm ("heavy precipitation")

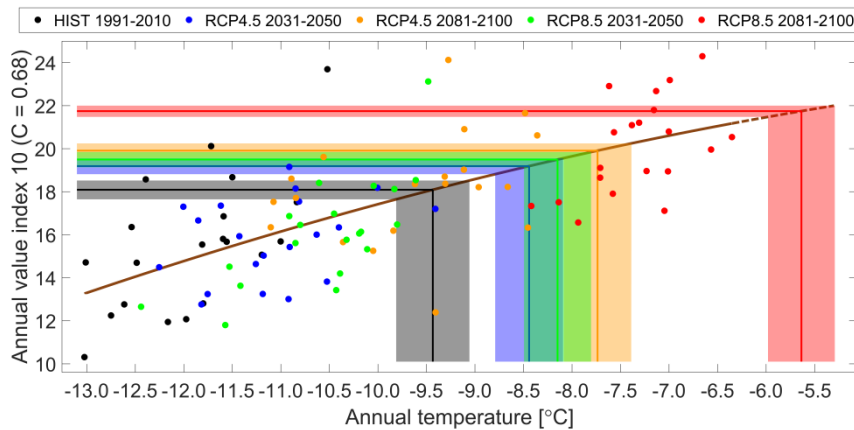
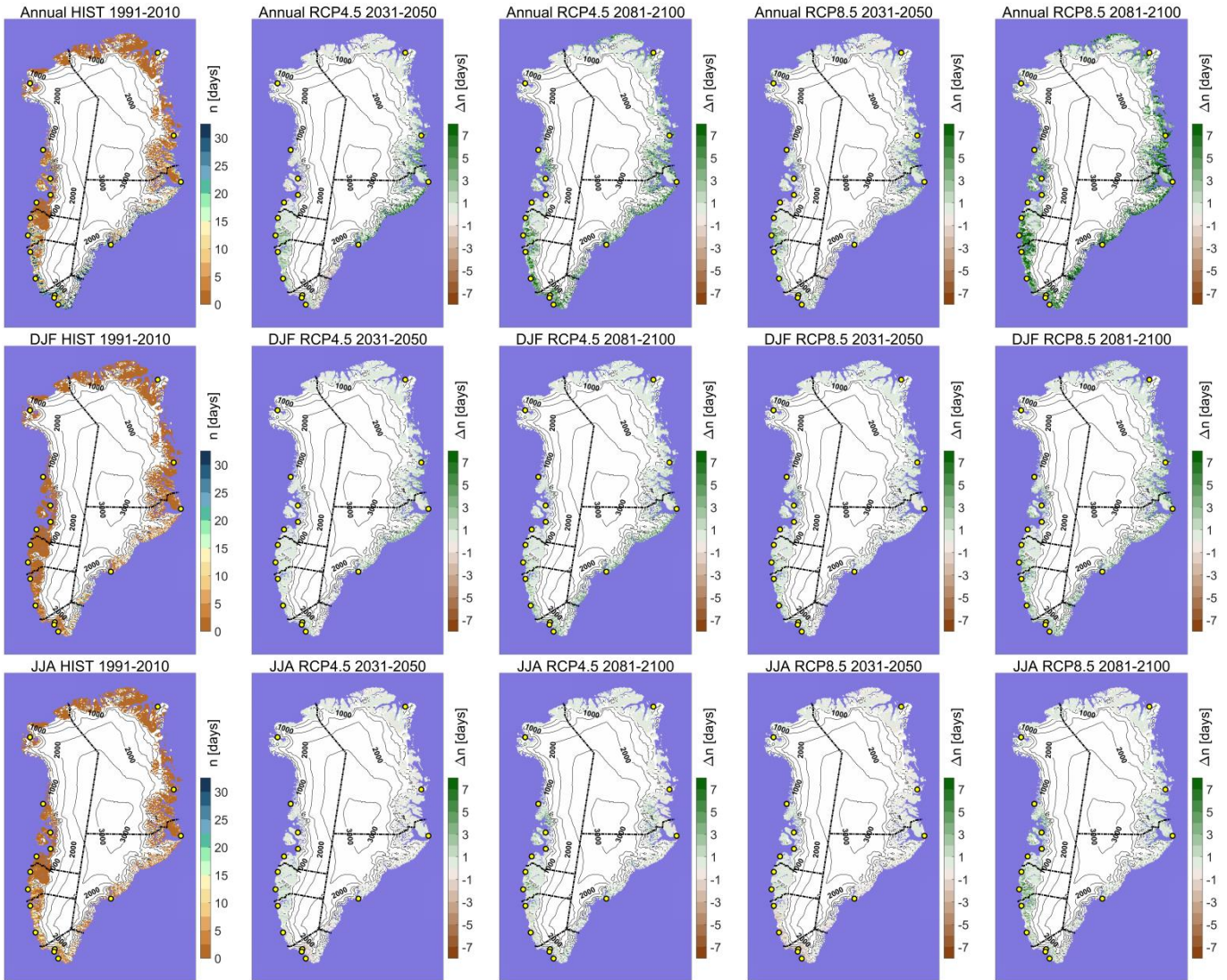




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Index 10 Number of days with precipitation above 25mm ("extreme precipitation")

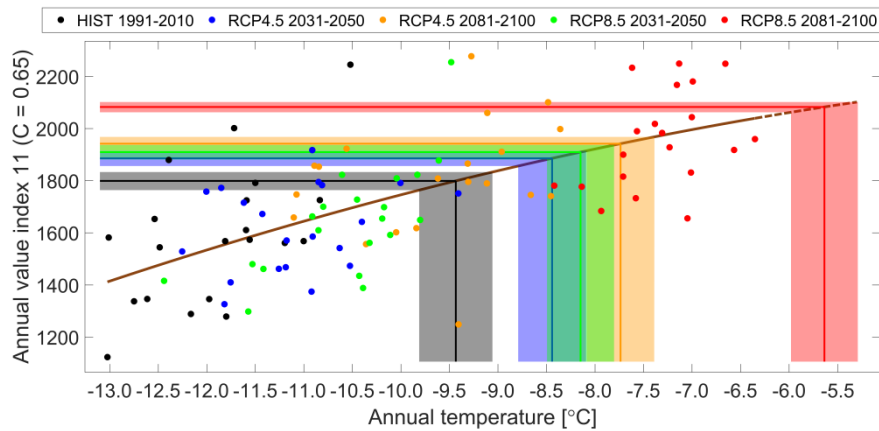
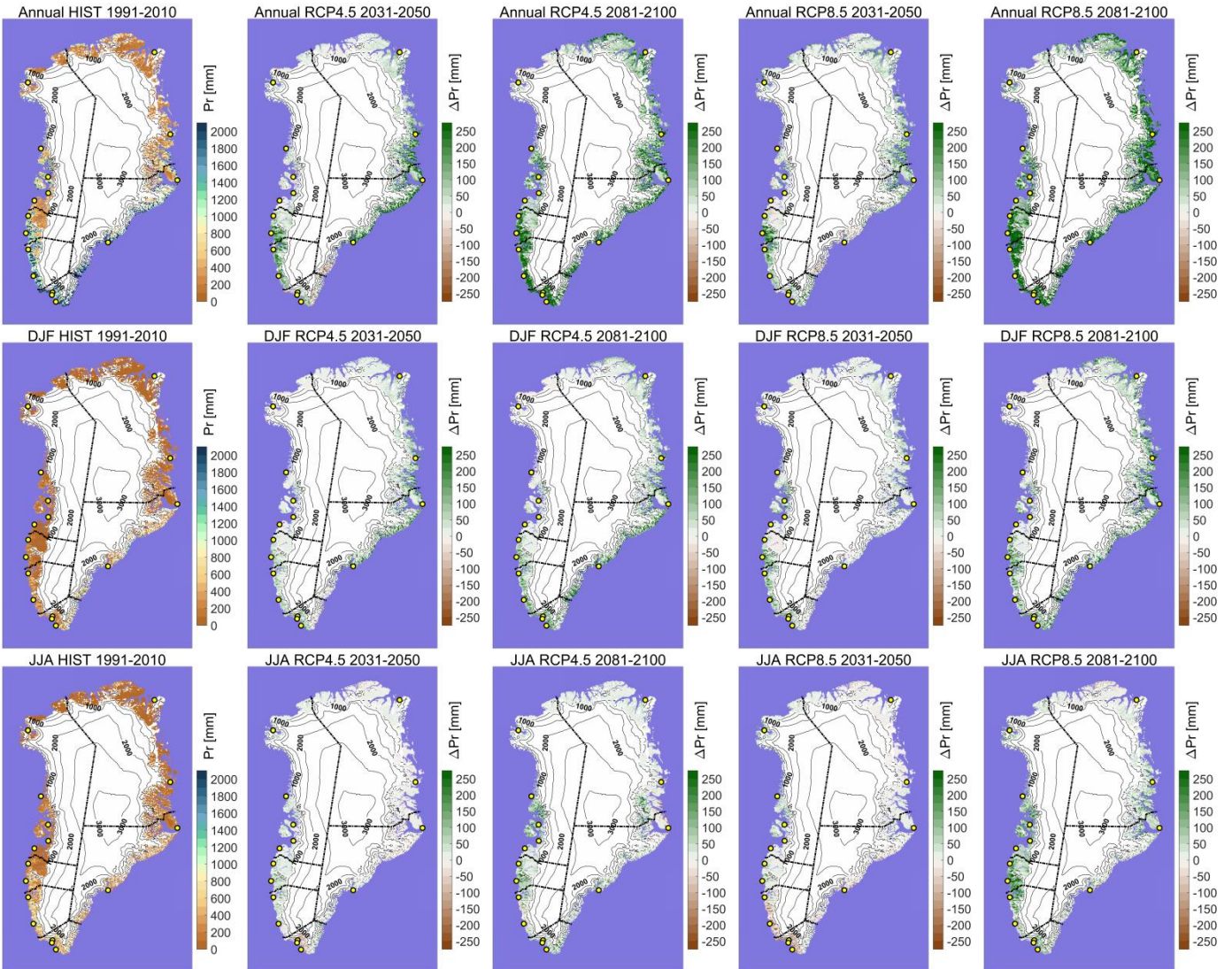




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Index 11 Precipitation, summed up

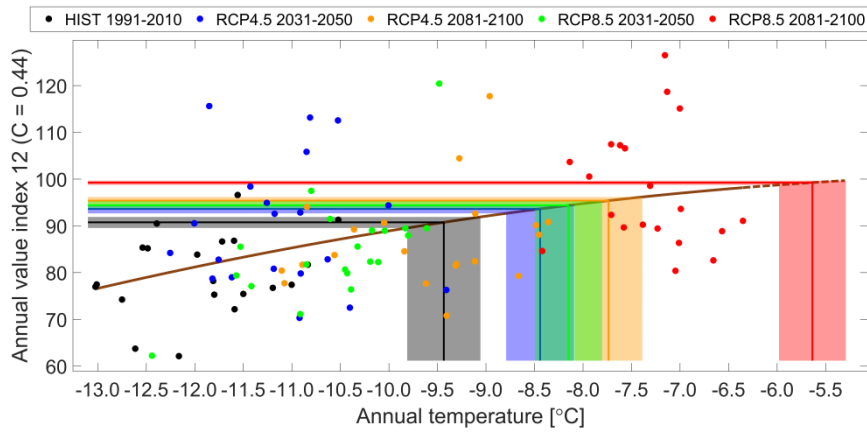
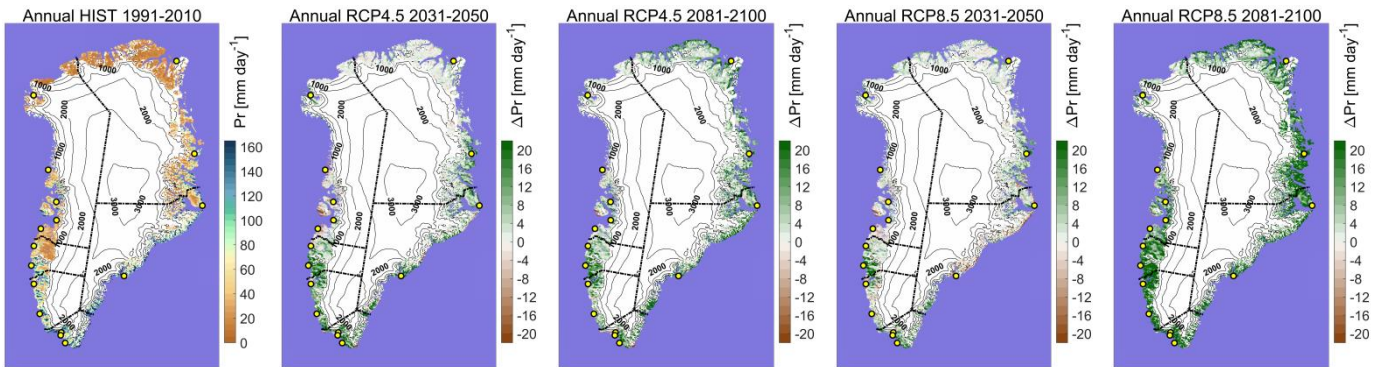




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Index 12 Maximum precipitation intensity (yearly maximum)

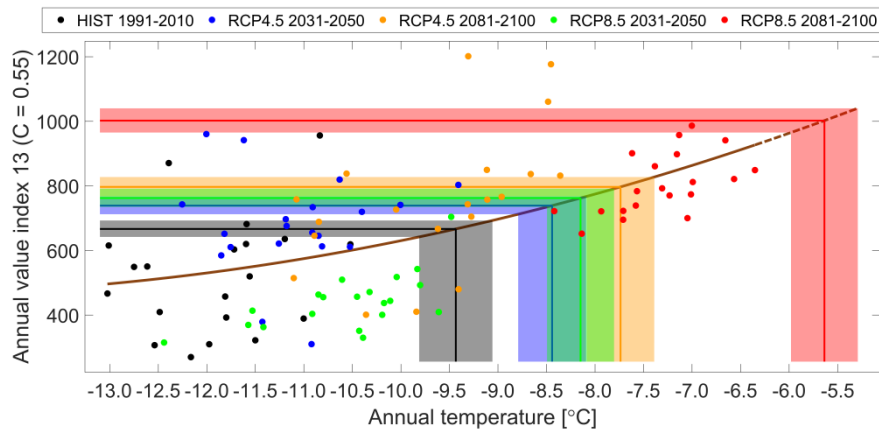
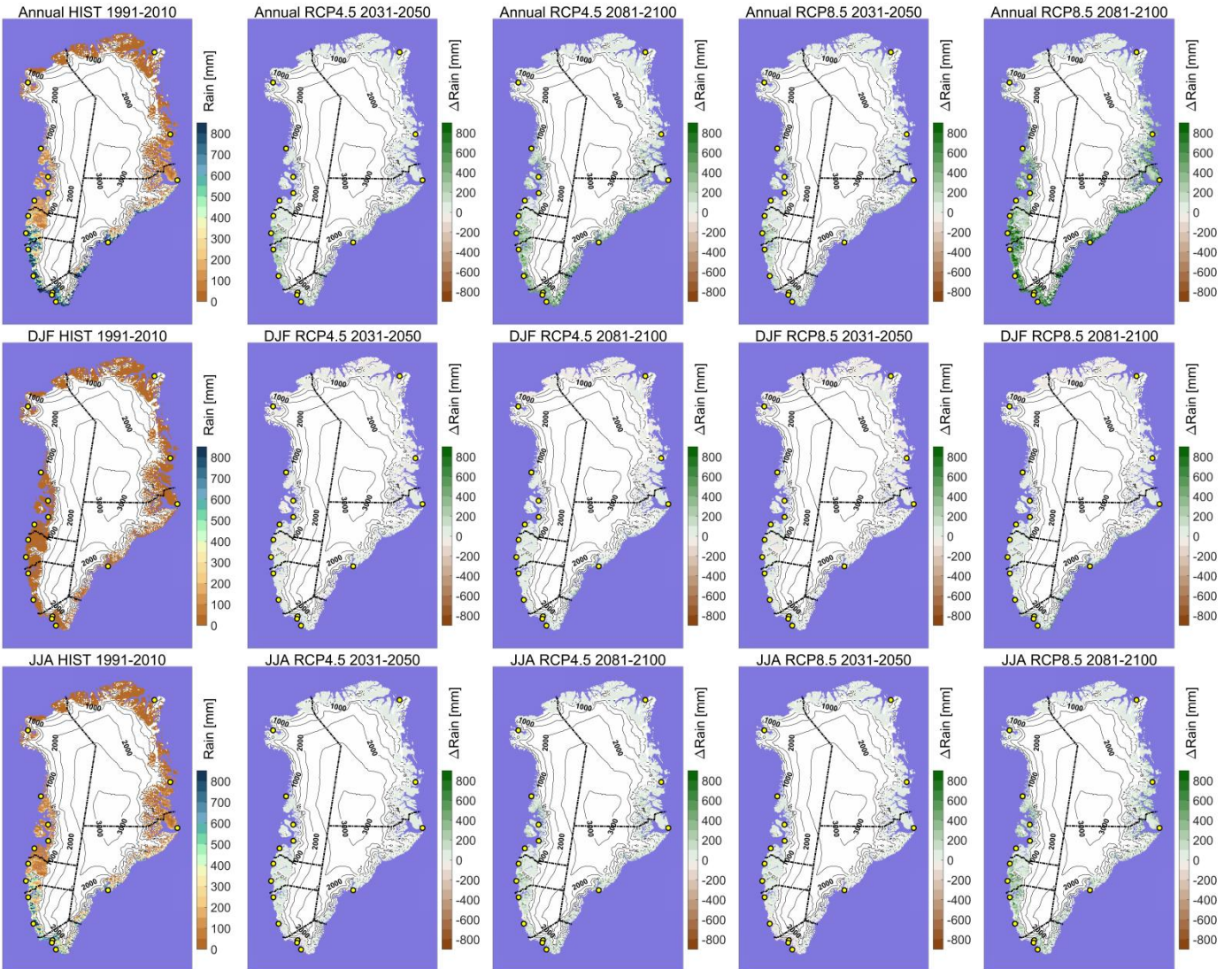




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Index 13 Amount of rainfall, summed up

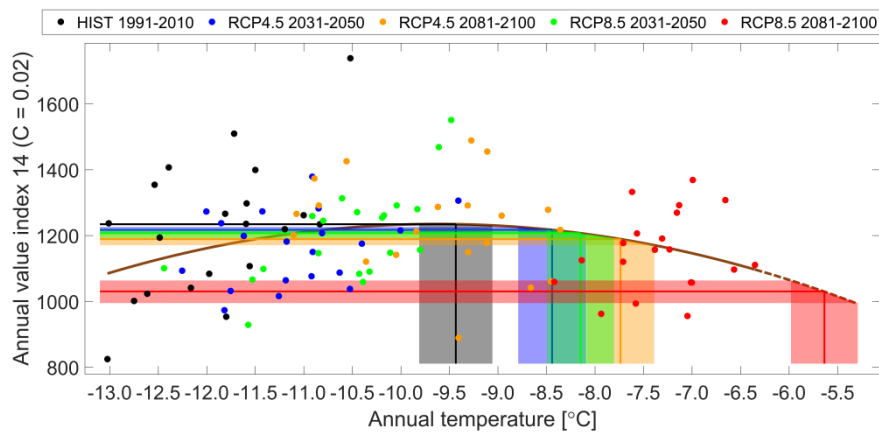
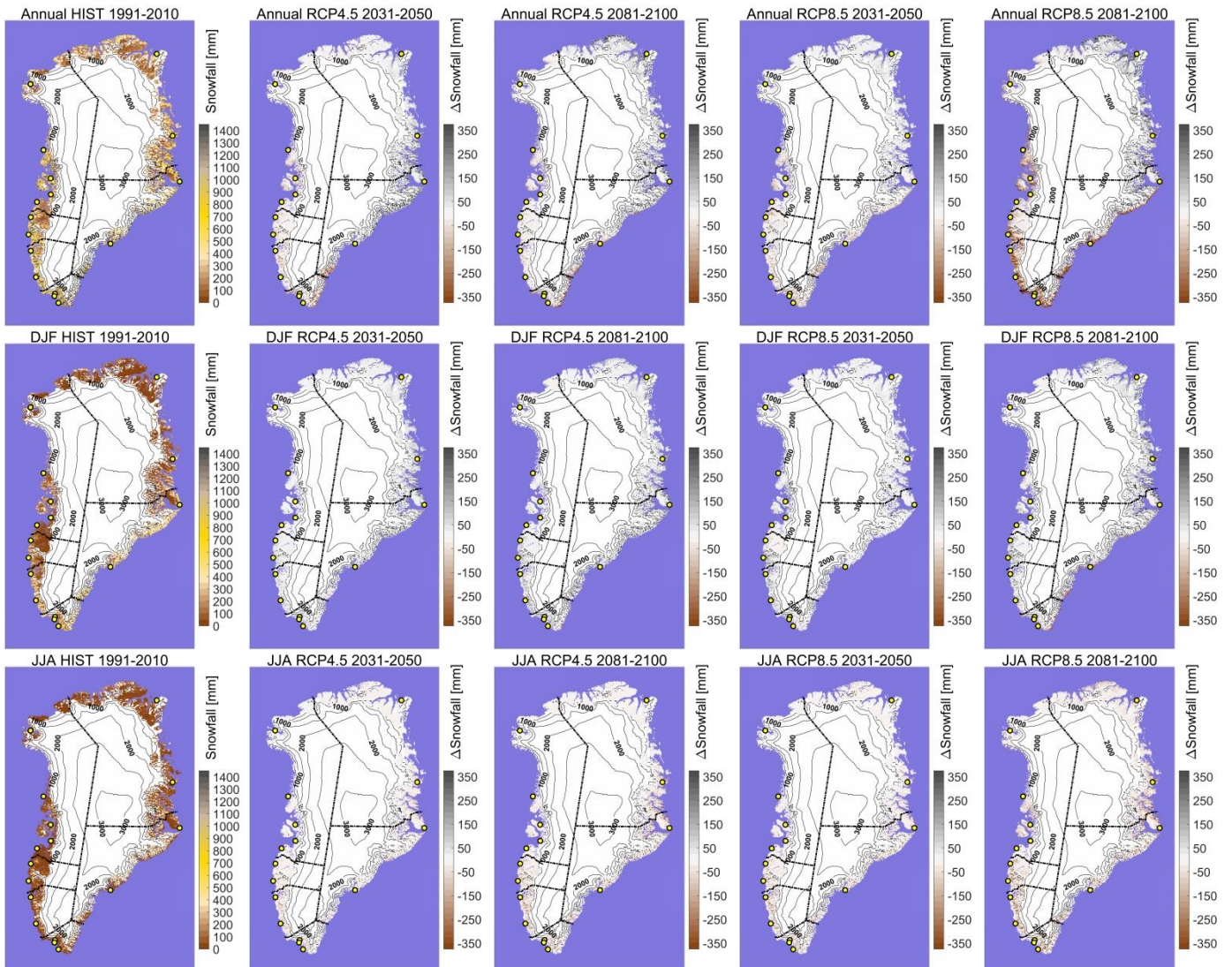




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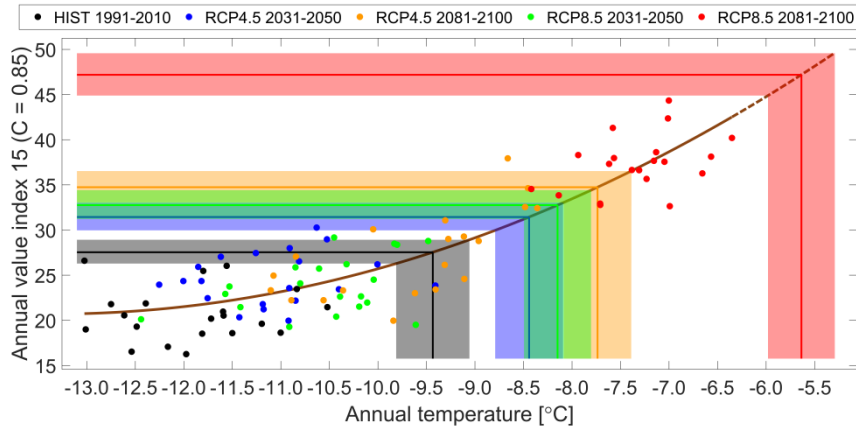
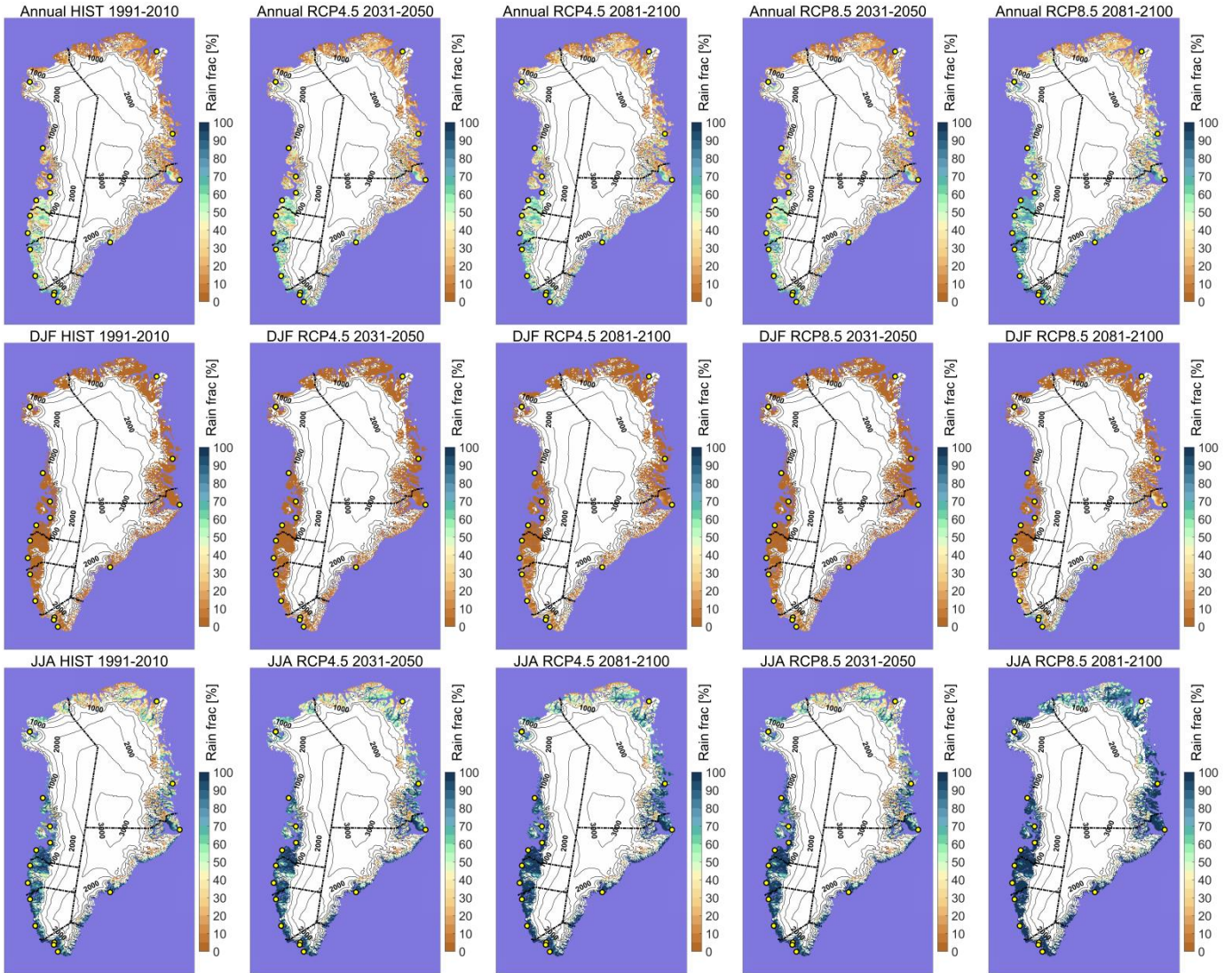
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Index 14 Amount of snowfall, summed up





Index 15 Rainfall fraction of total precipitation

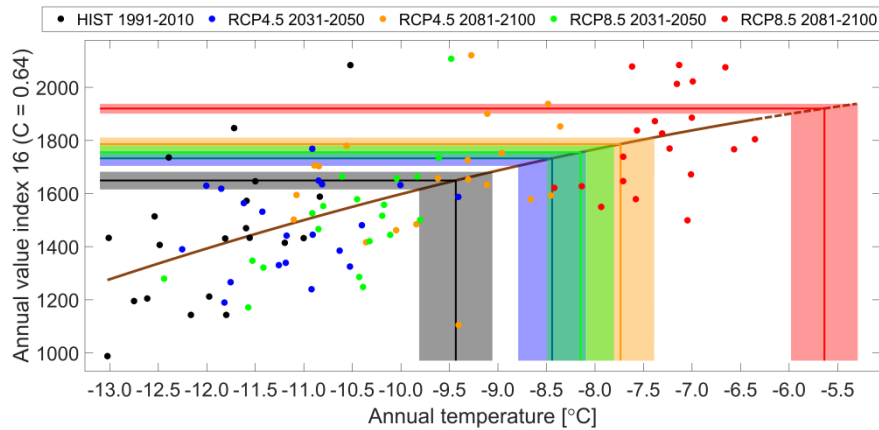
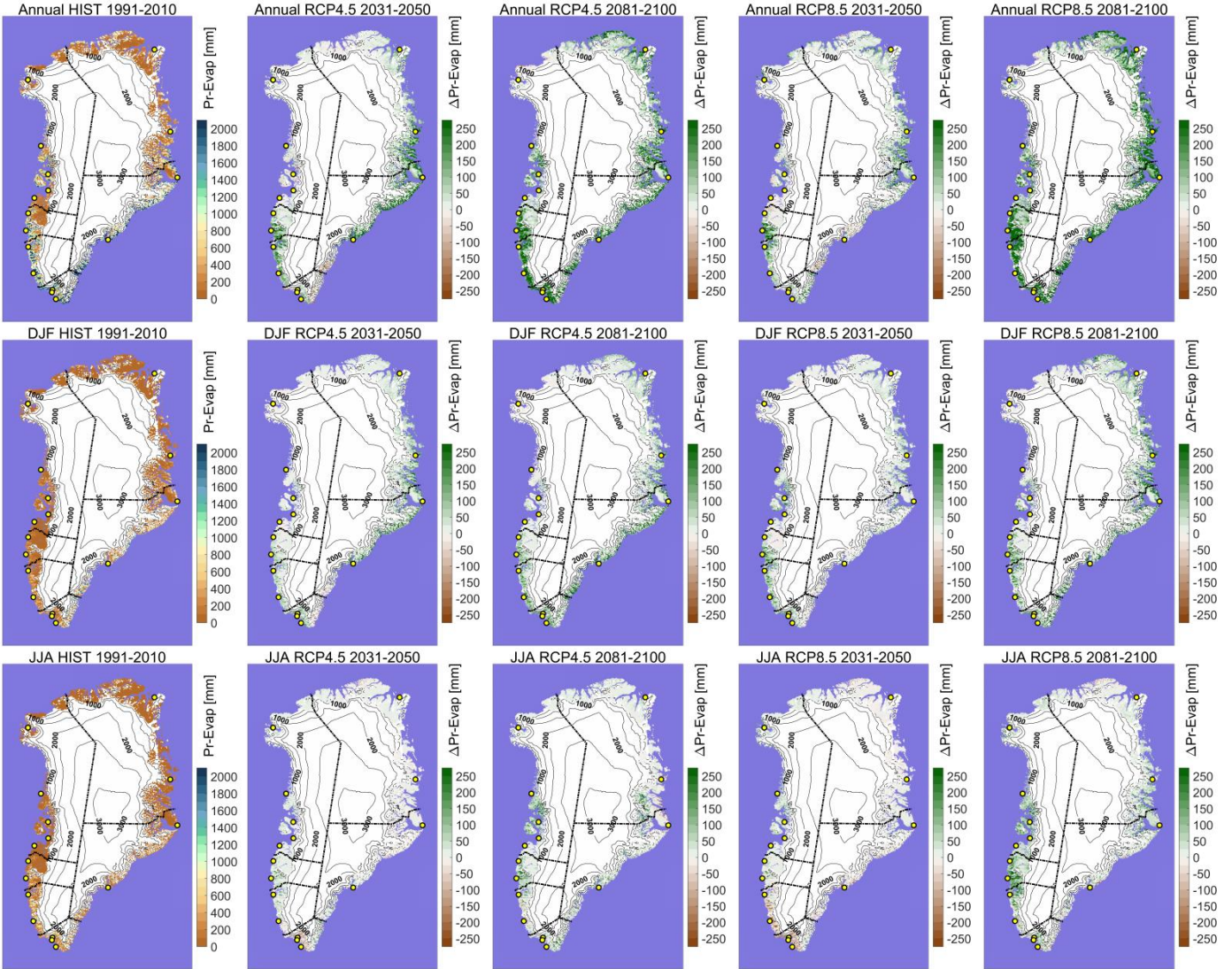




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Index 16 Effective precipitation (i.e. precipitation minus evaporation), summed up

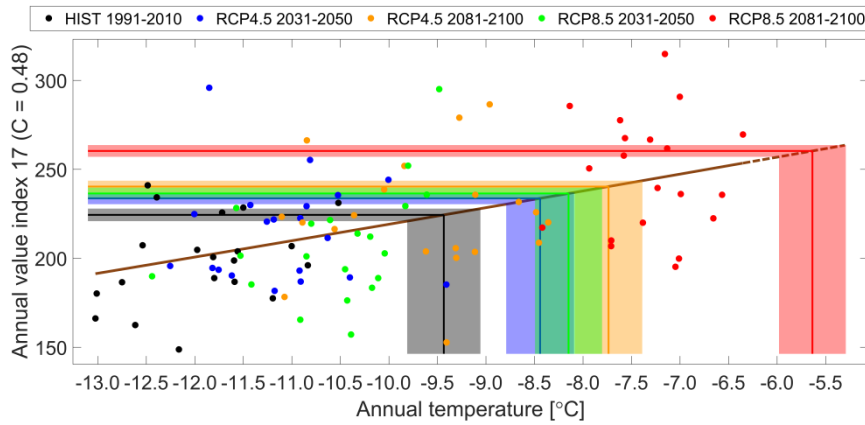
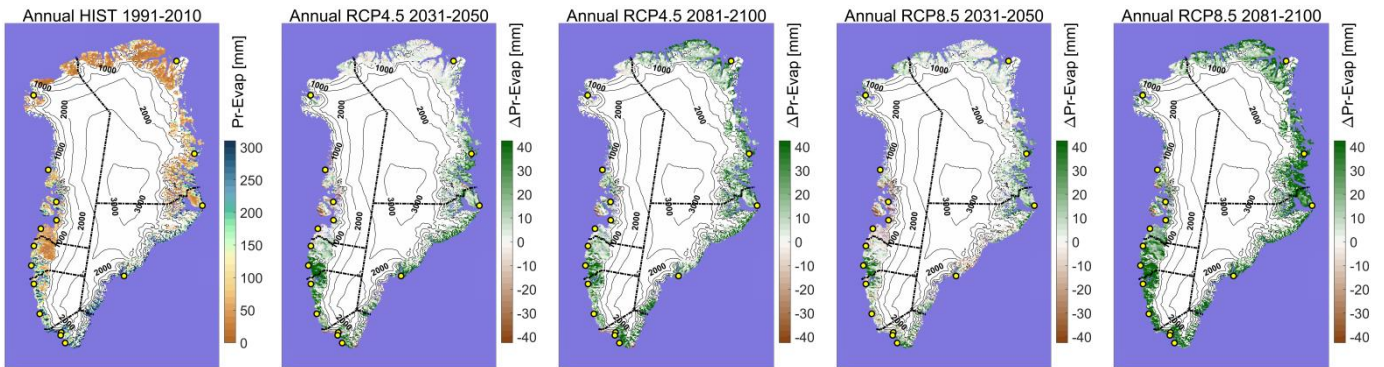




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Index 17 Highest effective precipitation during a continuous 7-day period

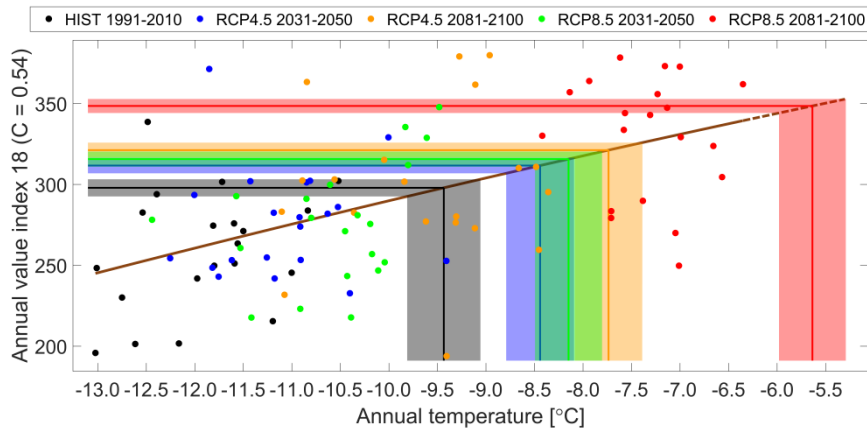
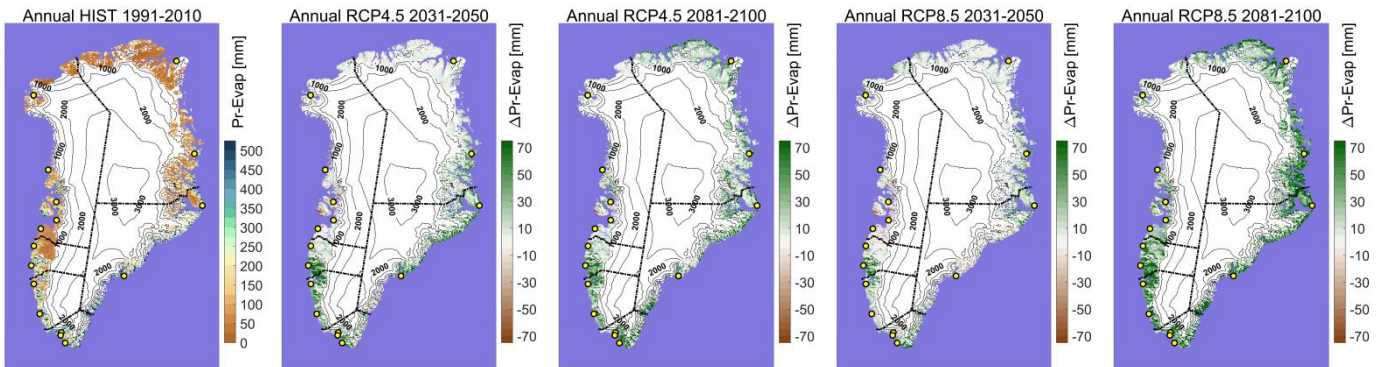




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Index 18 Highest effective precipitation during a continuous 14-day period

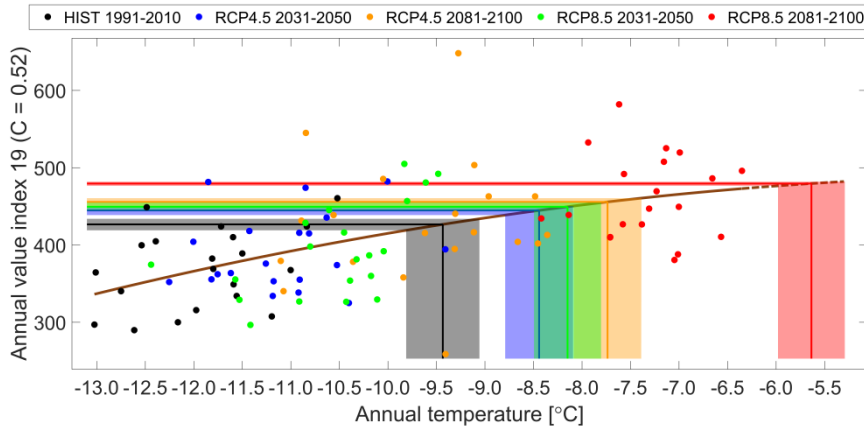
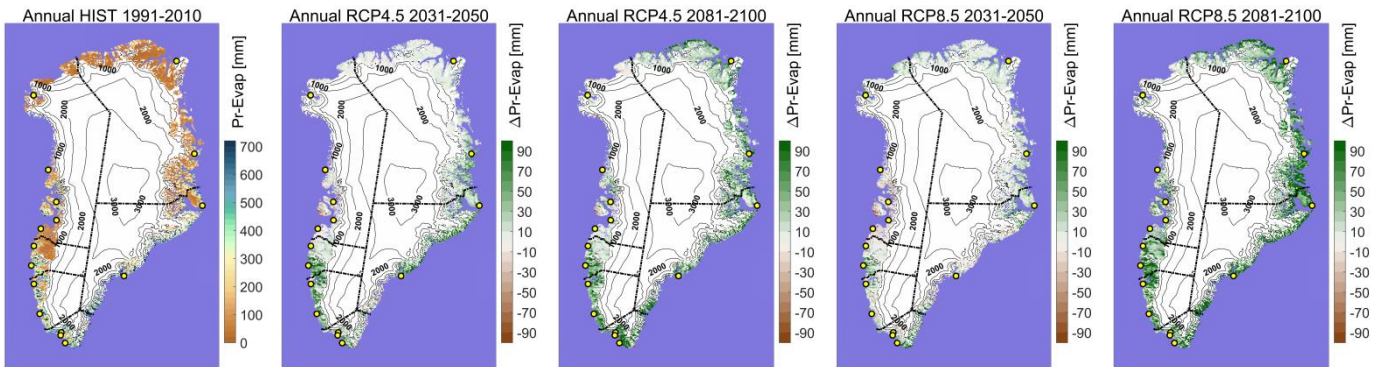




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Index 19 Highest effective precipitation during a continuous 30-day period

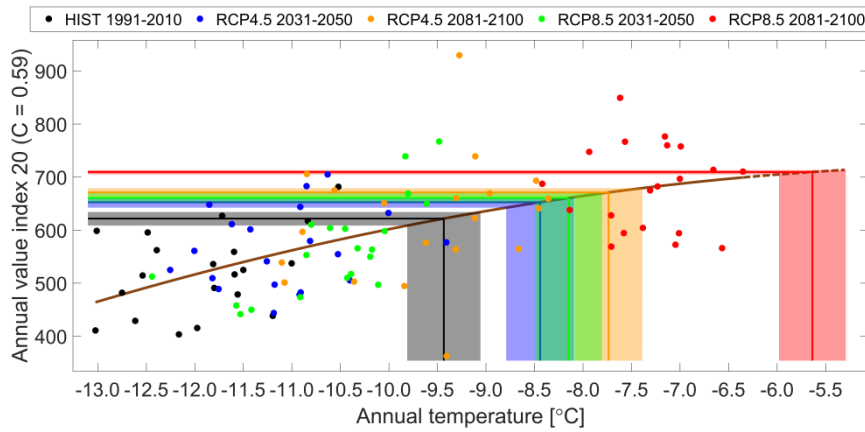
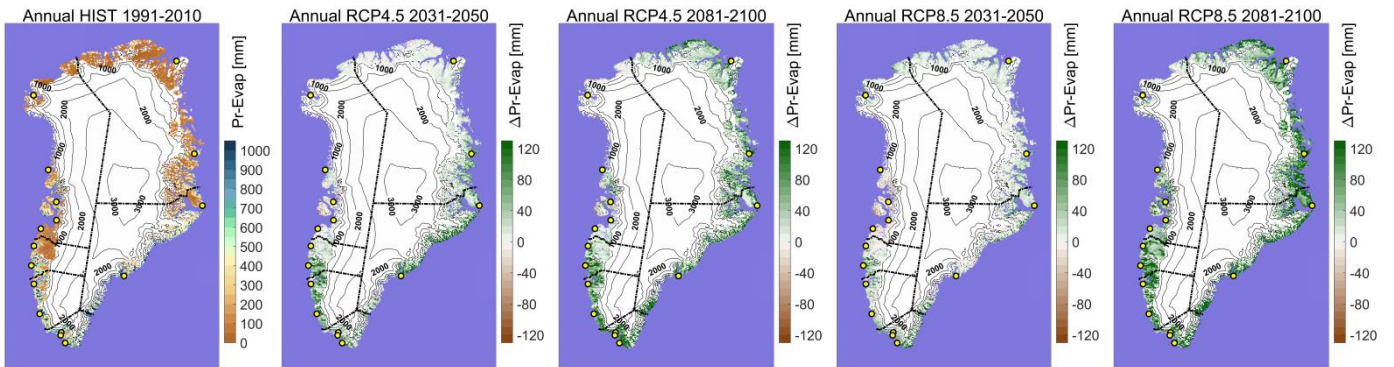




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Index 20 Highest effective precipitation during a continuous 60-day period

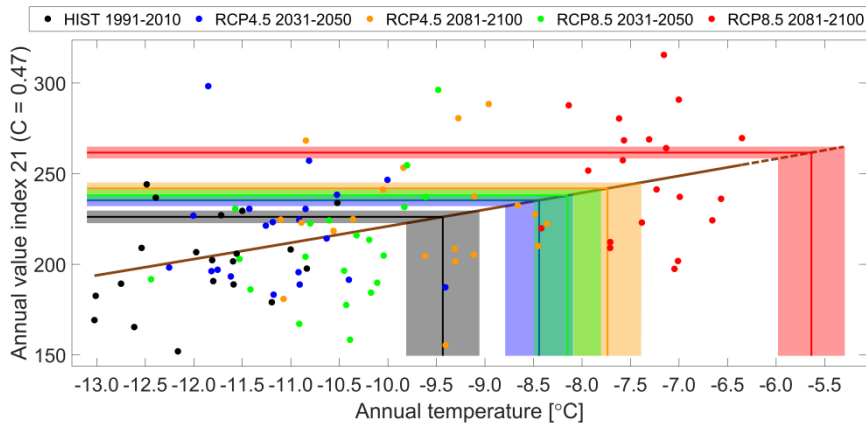
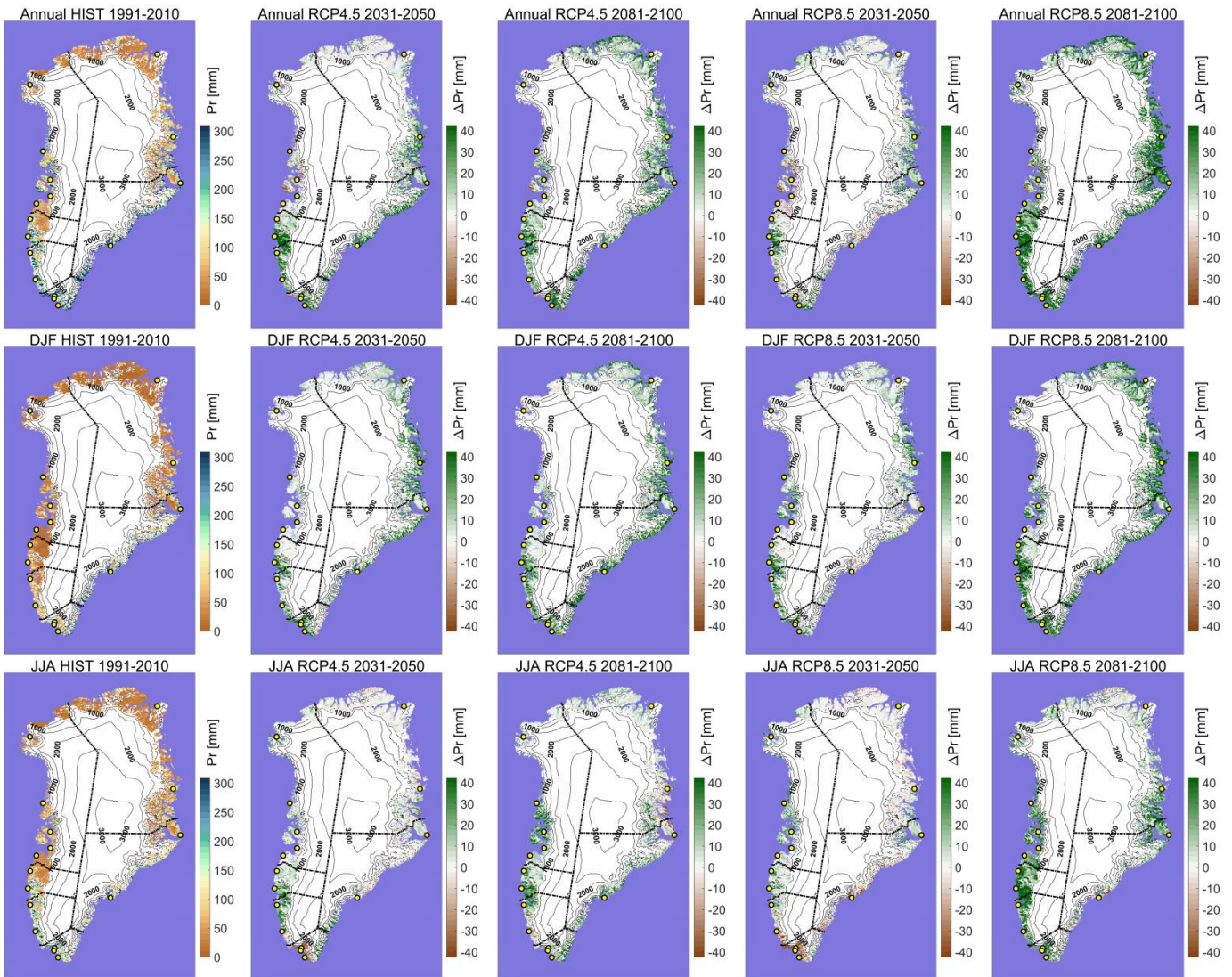




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Index 21 Highest precipitation during a continuous 7-day period

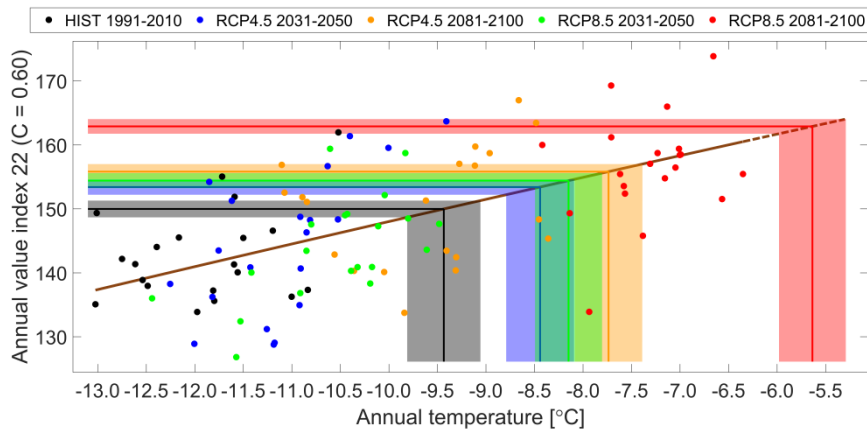
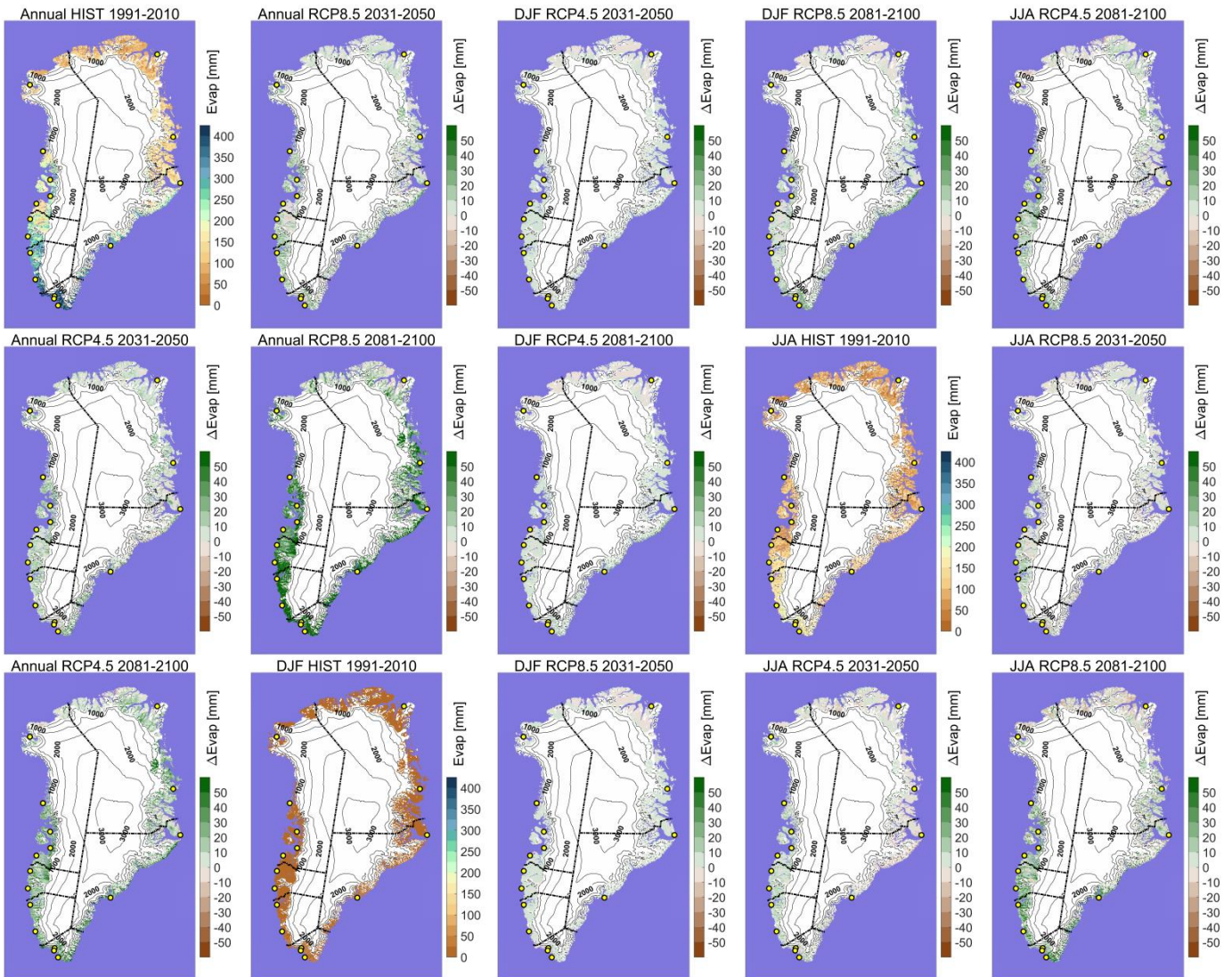




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Index 22 Evaporation, summed up

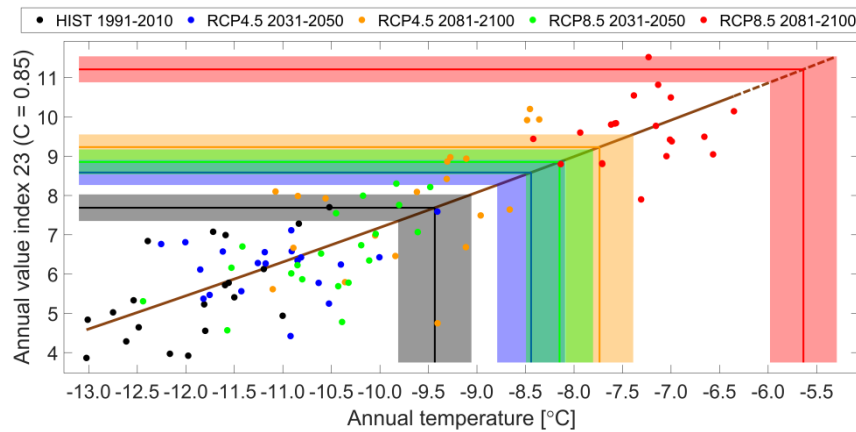
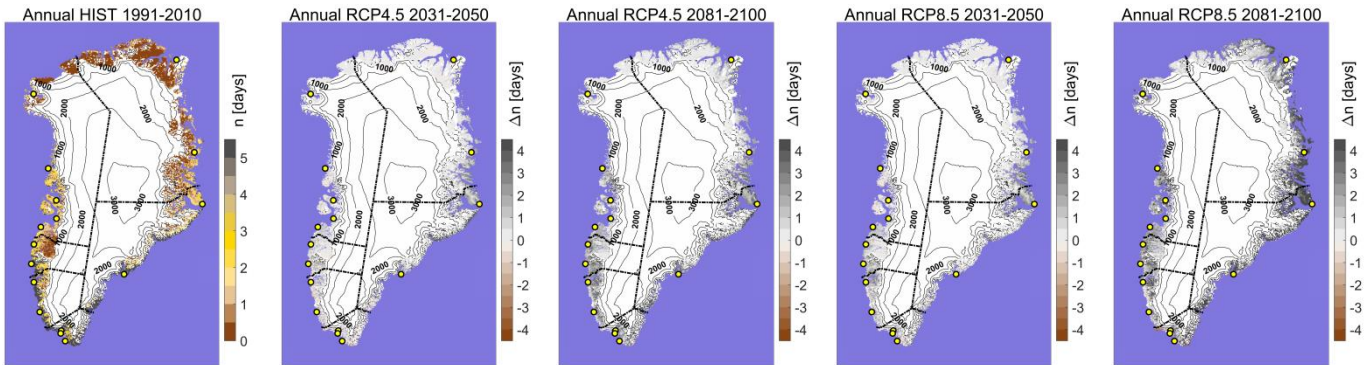




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 23 Number of days during the year when daily maximum temperature at 2m is below 1°C and rainfall is above 0.5mm (model adjusted "days with freezing rain")

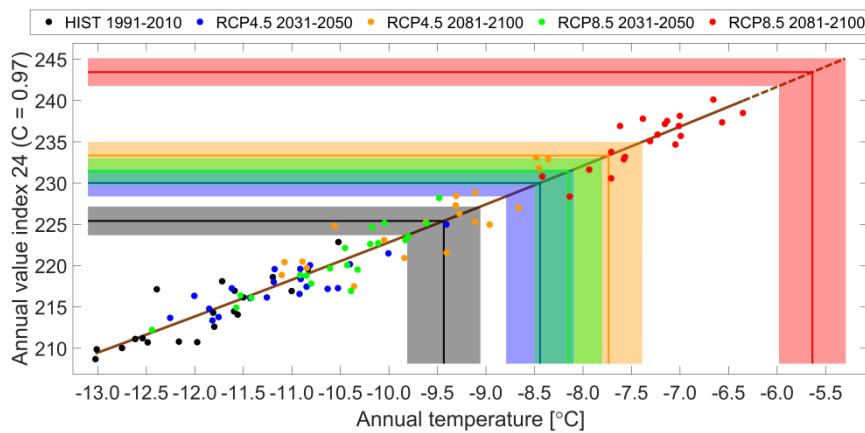
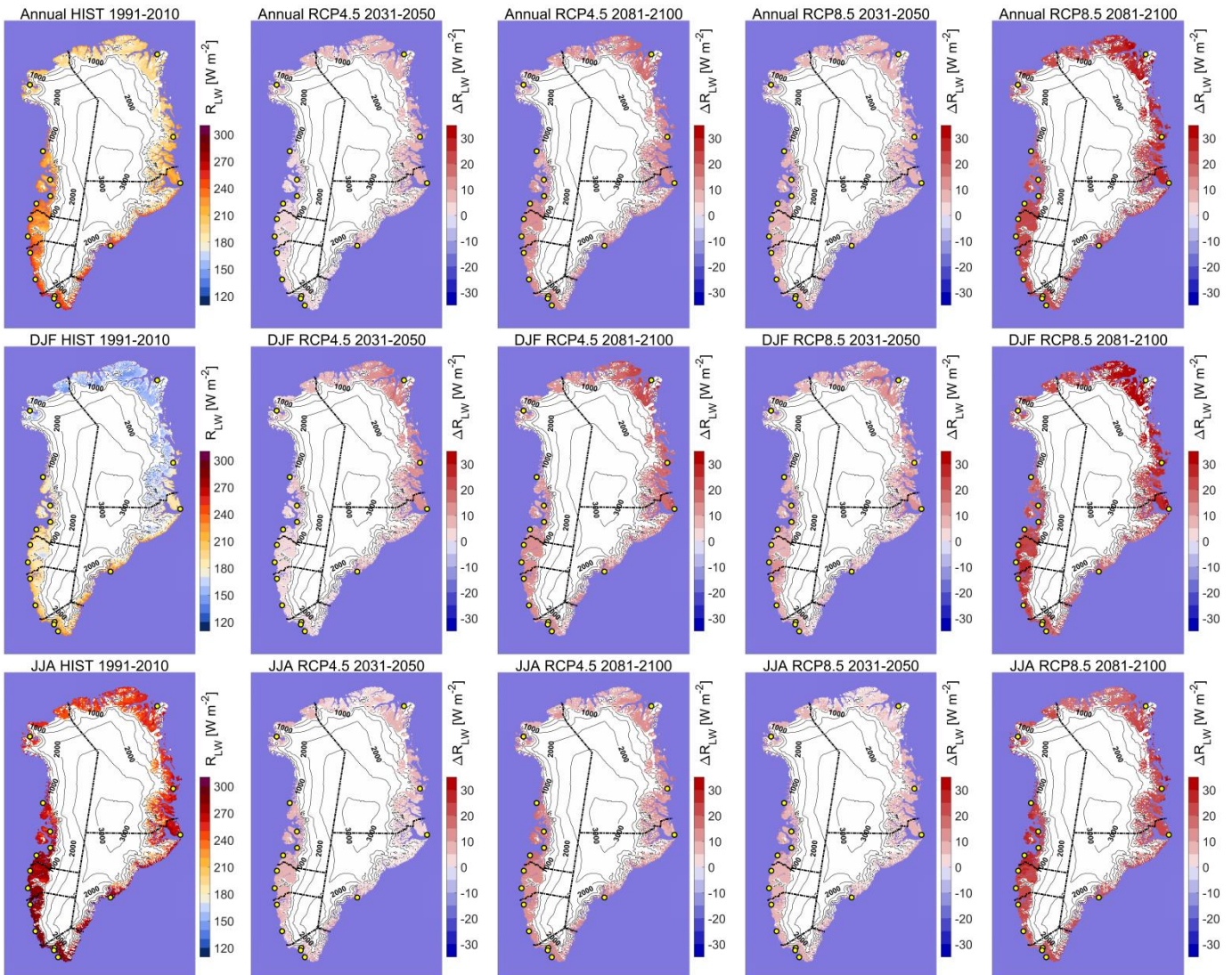




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 24 Mean value of incoming longwave radiation (heat radiation)

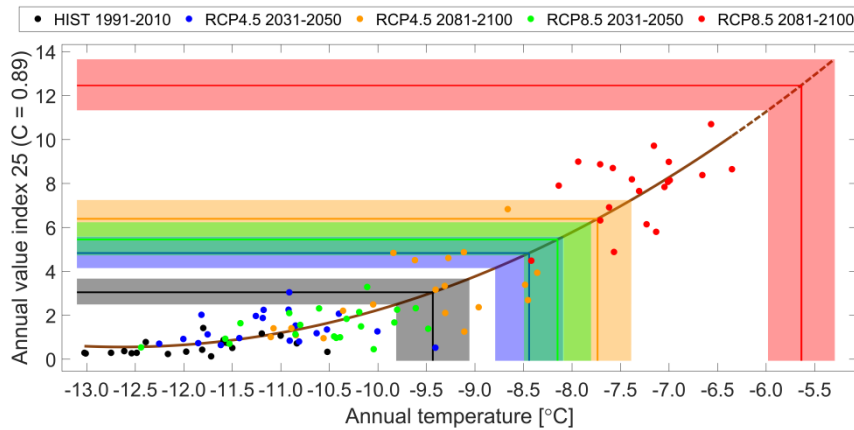
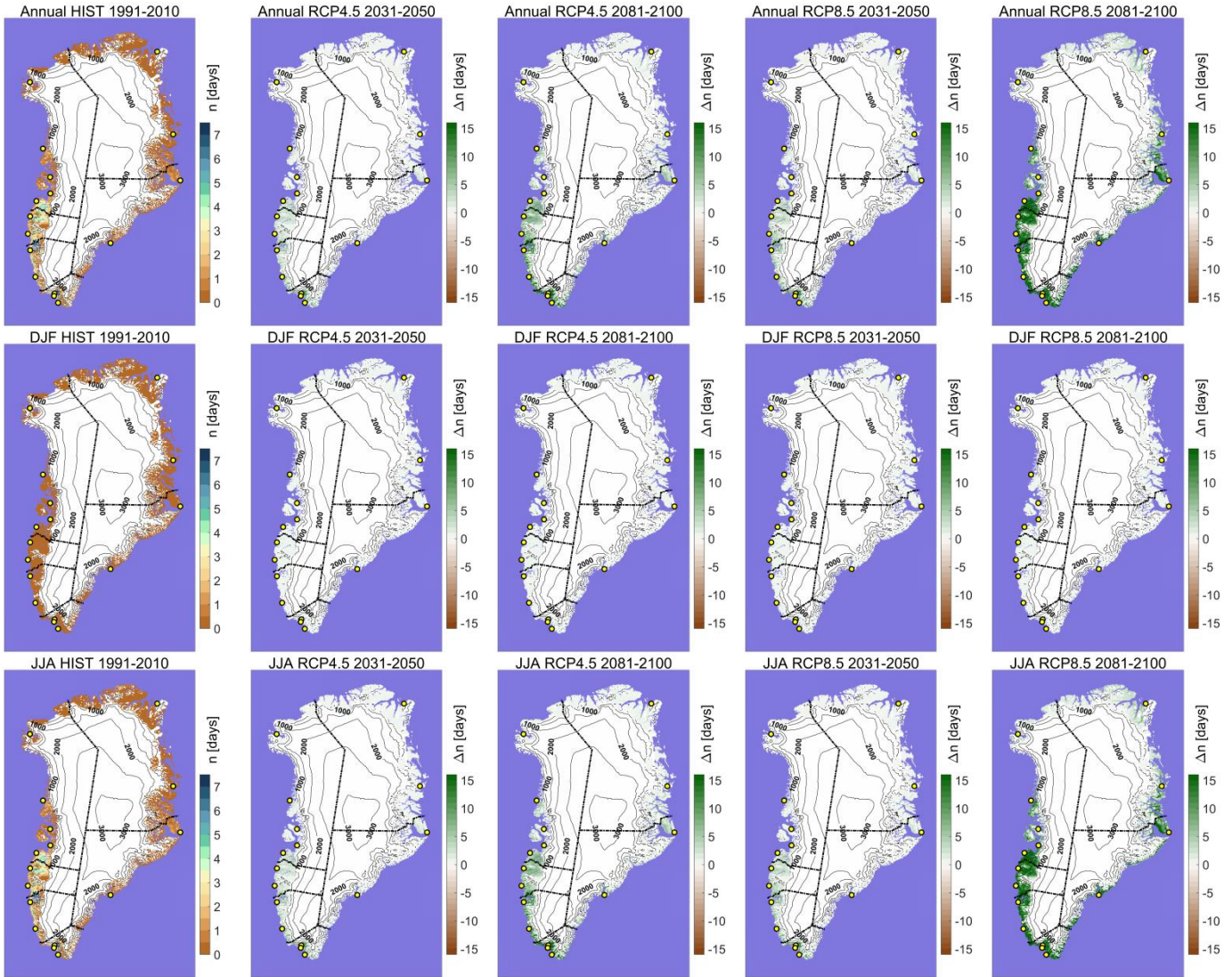




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 25 Number of days when the relative humidity (daily mean) is above 60% and the daily mean temperature at 2m is above 10°C

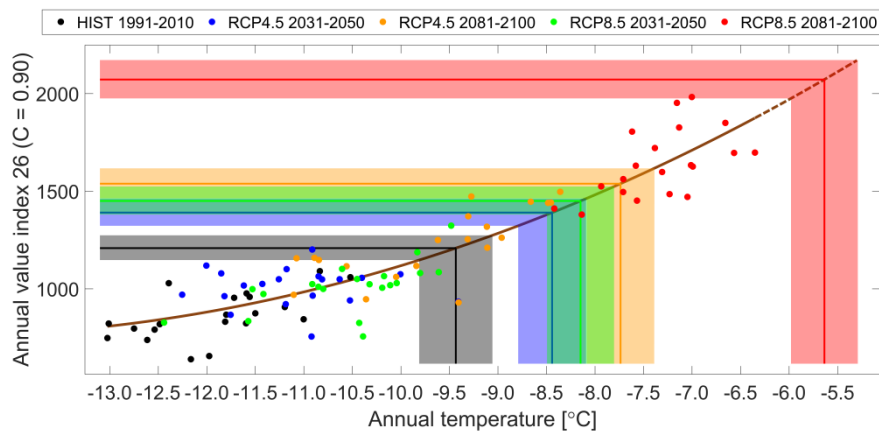
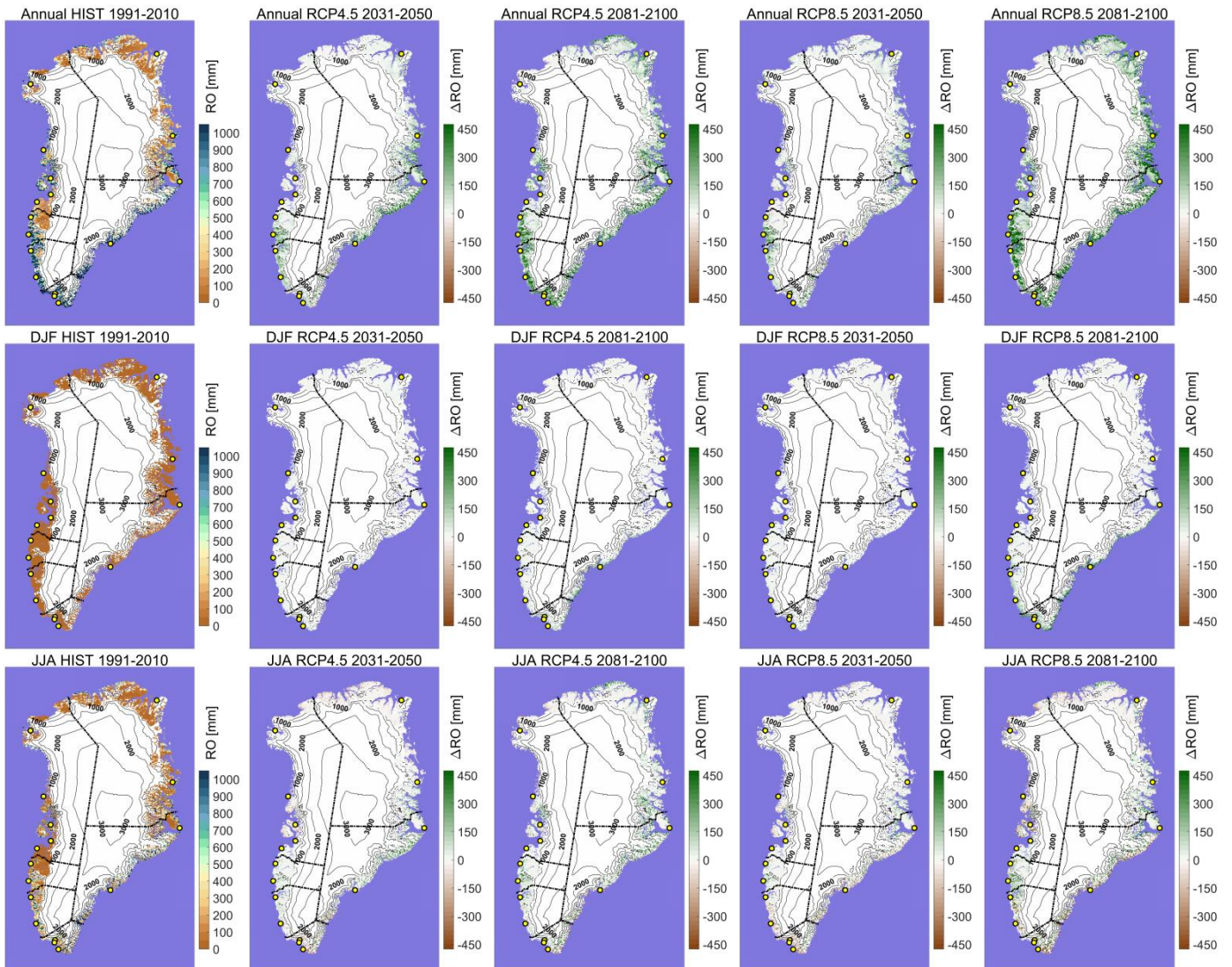




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 26 Net runoff, summed up

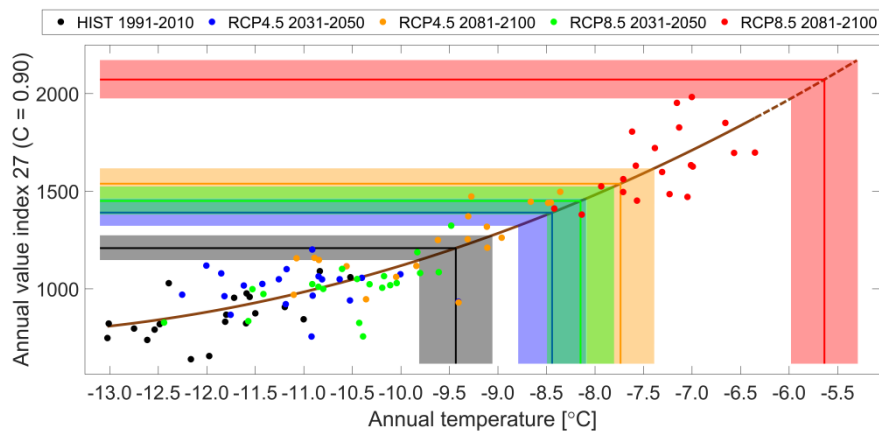
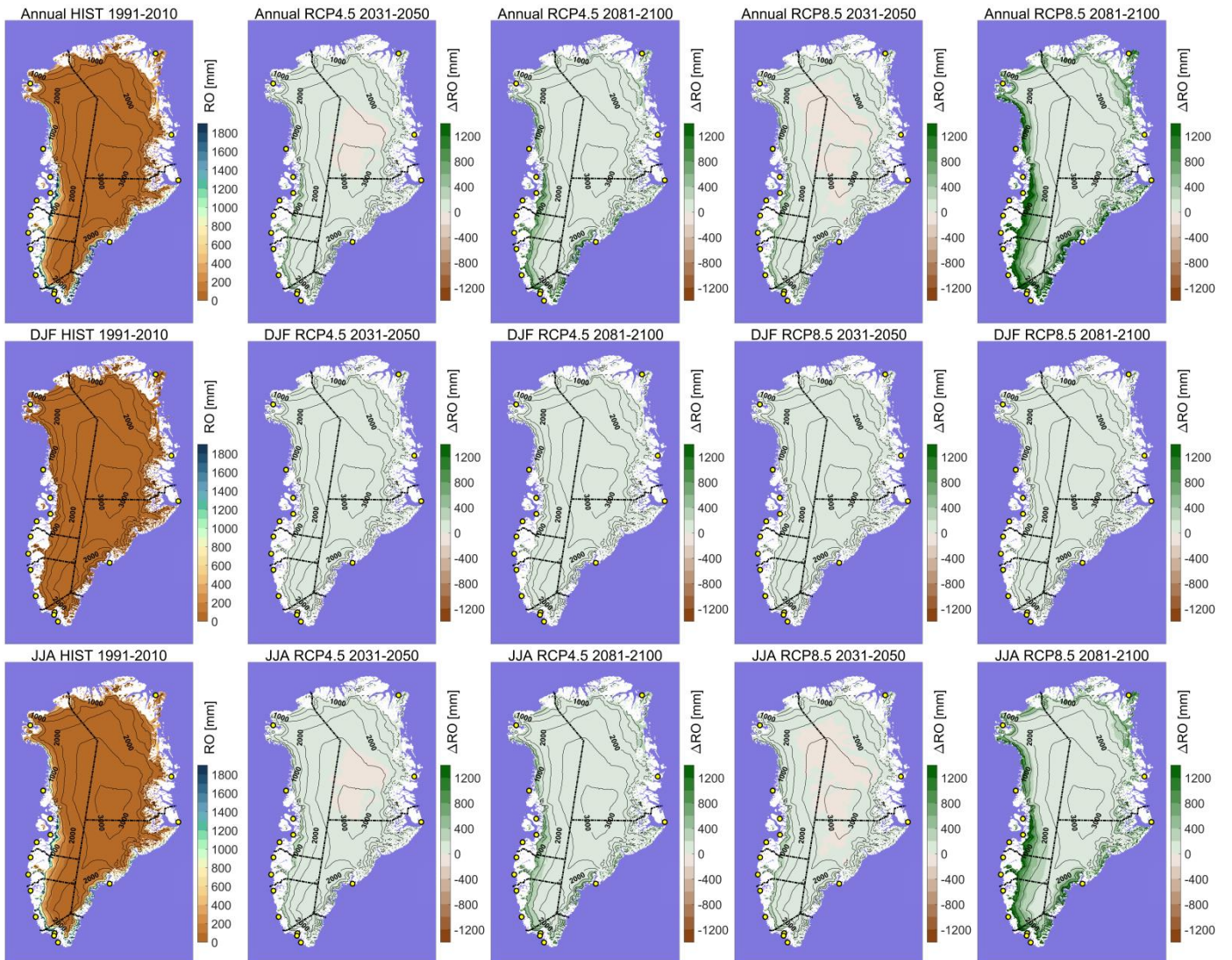




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 27 Net runoff over glacier, summed up

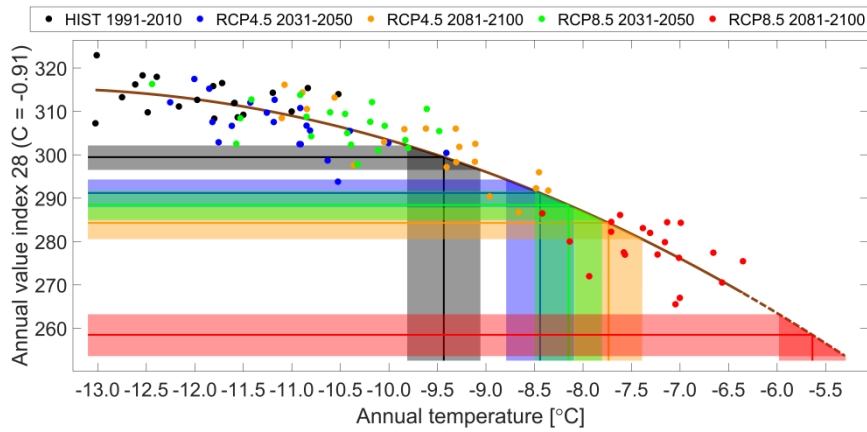
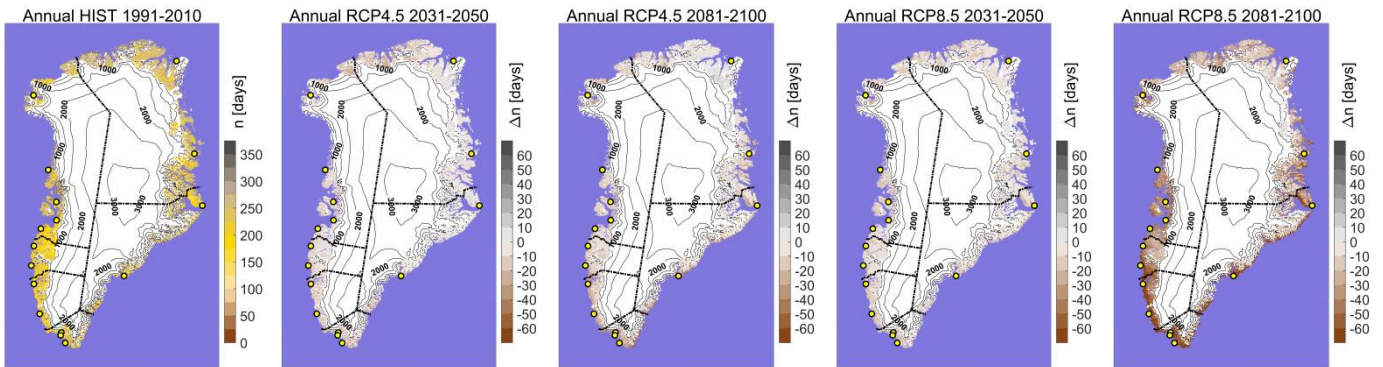




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 28 Number of days with snow cover (snow depth above 2 cm)

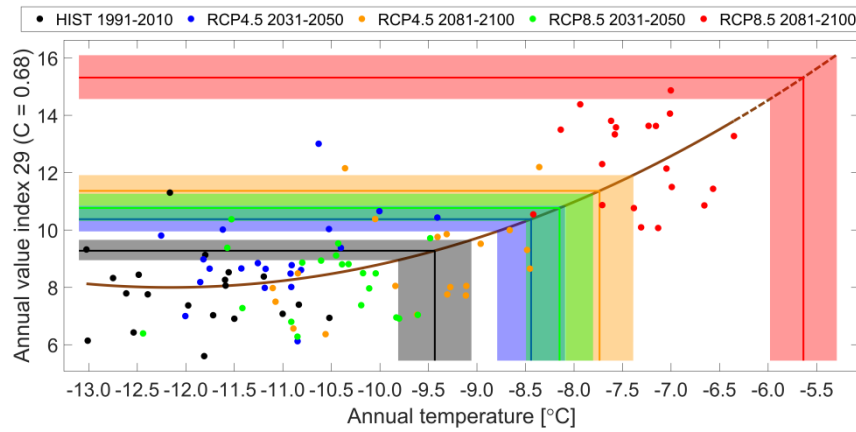
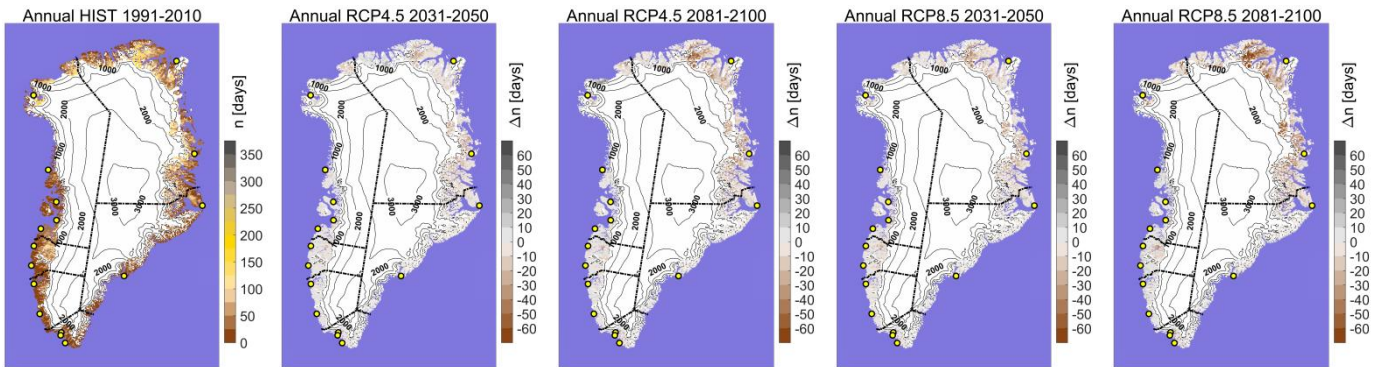




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 29 Number of days with snow depth between 2 and 10 cm

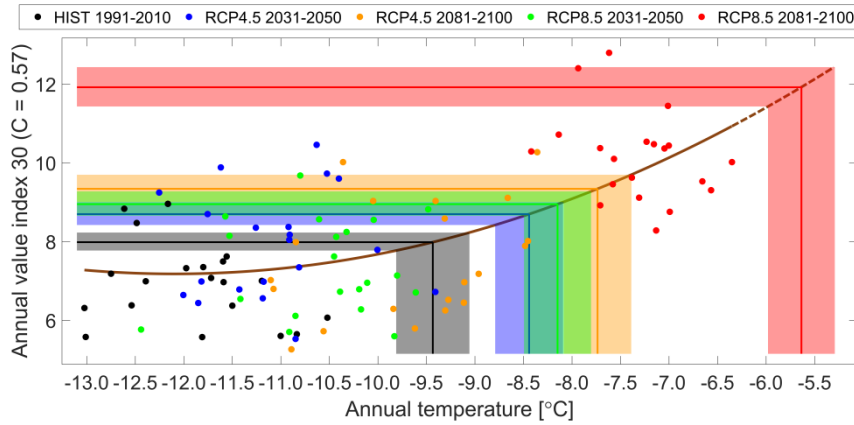
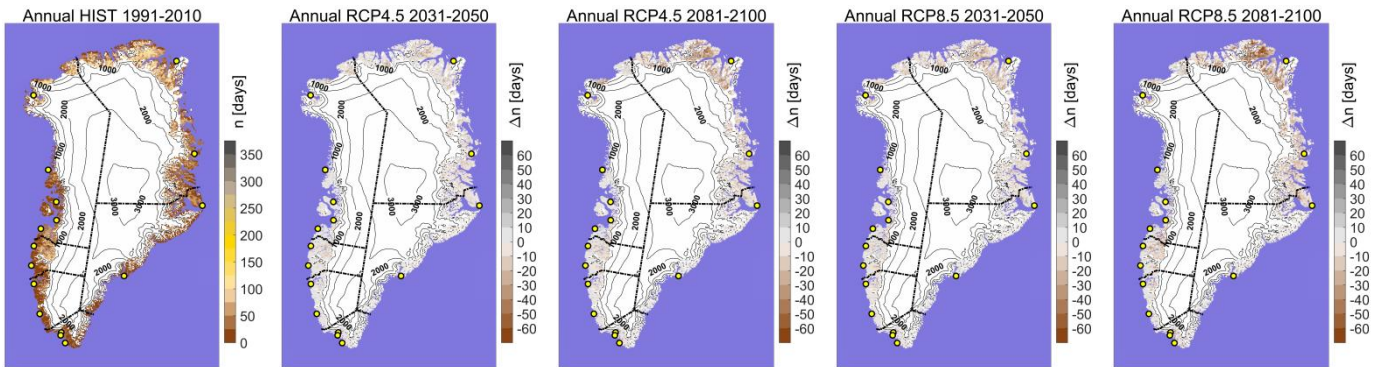




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 30 Number of days with snow depth between 10 and 20 cm

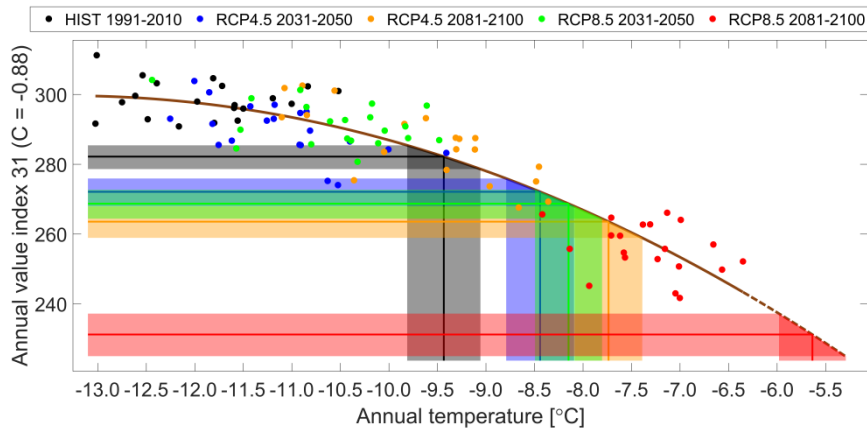
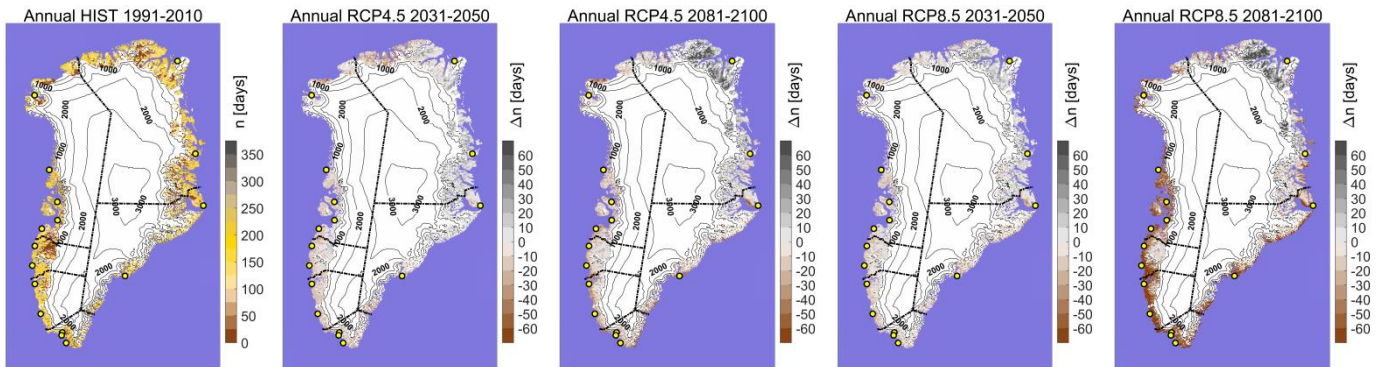




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 31 Number of days with snow depth above 20 cm

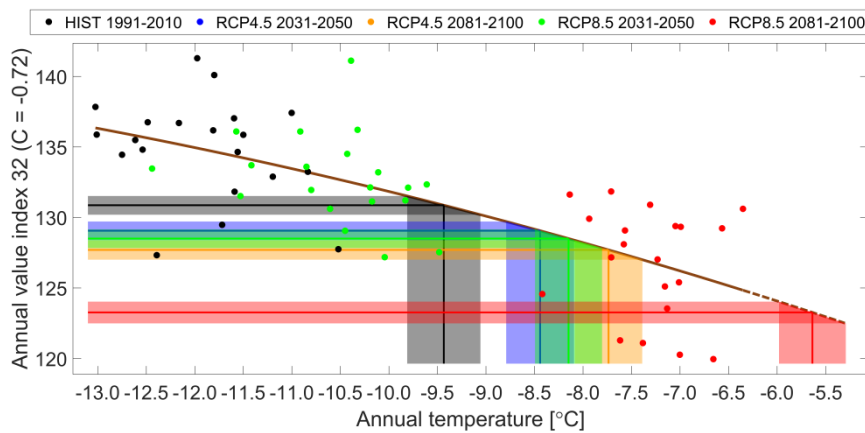
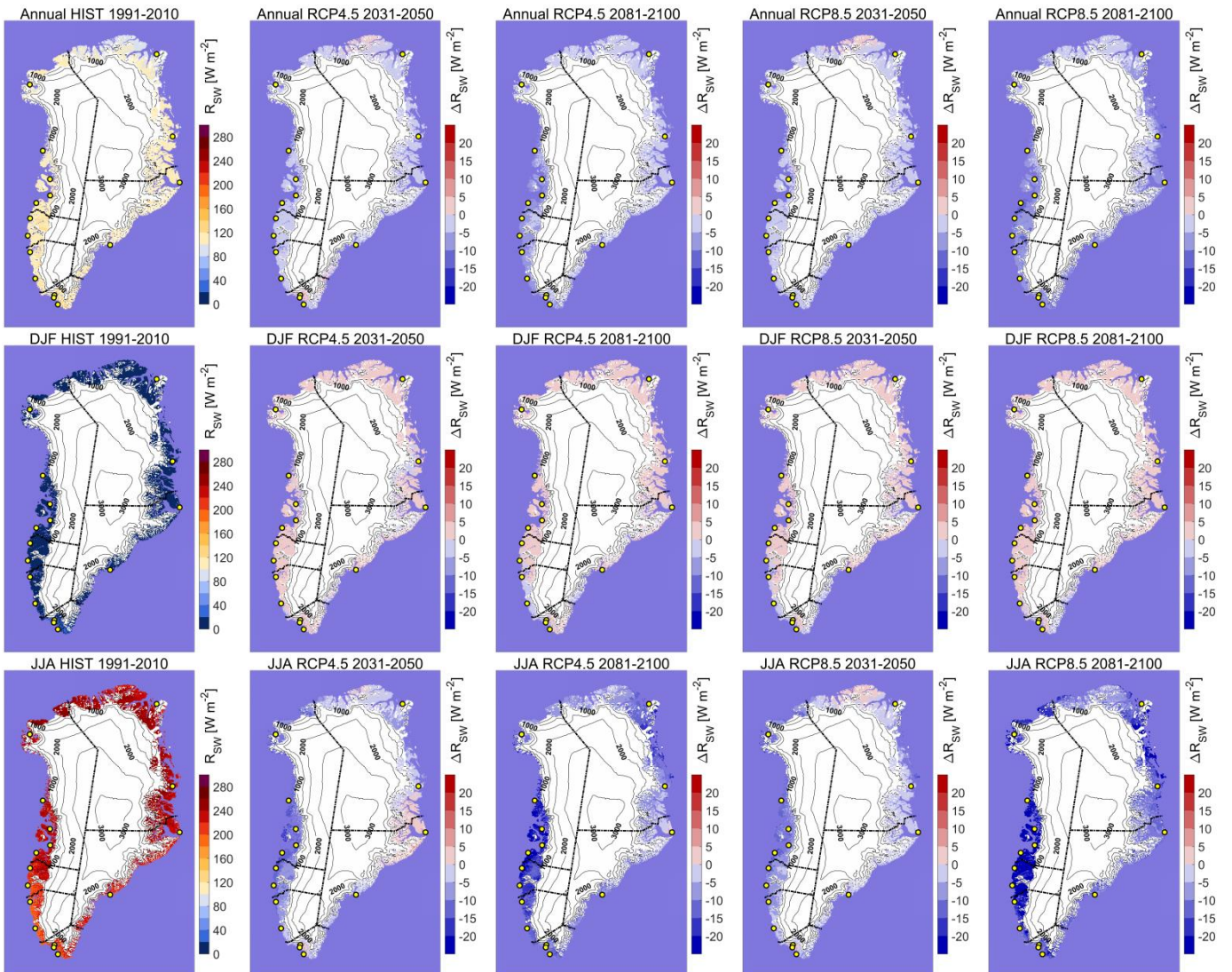




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 32 Mean value of incoming short wave radiation (global radiation)

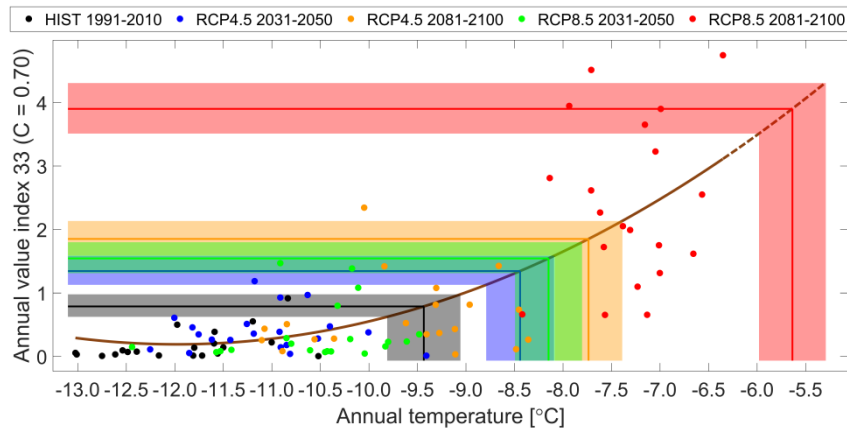
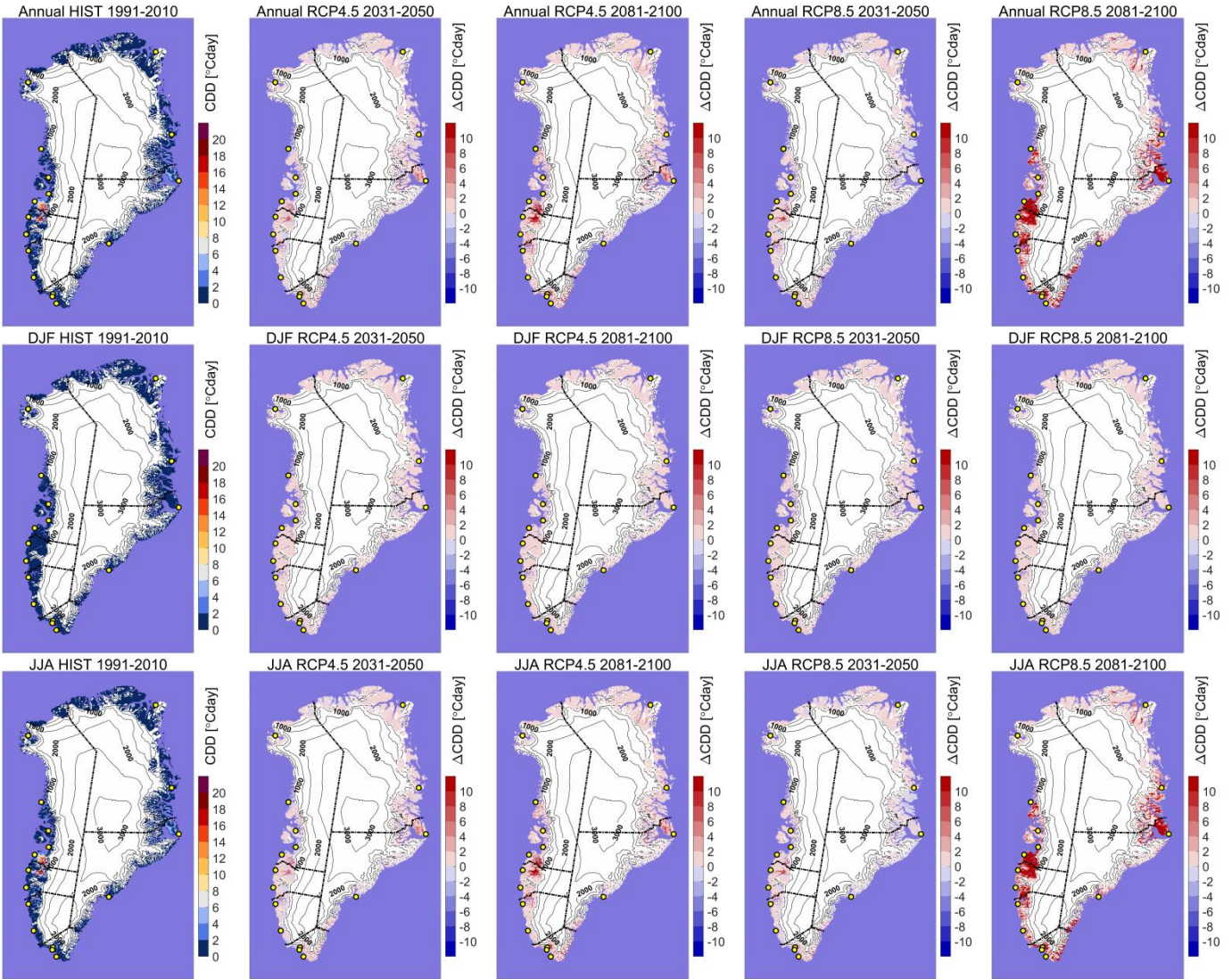




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 33 Number of degree days when daily maximum temperature at 2m is above 17°C

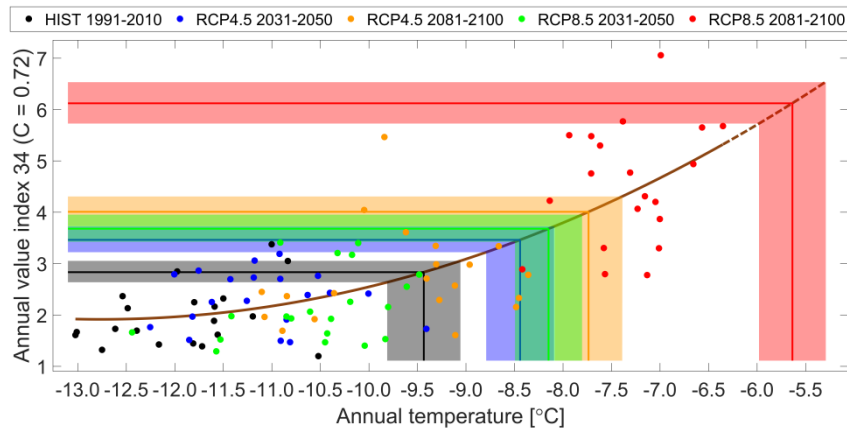
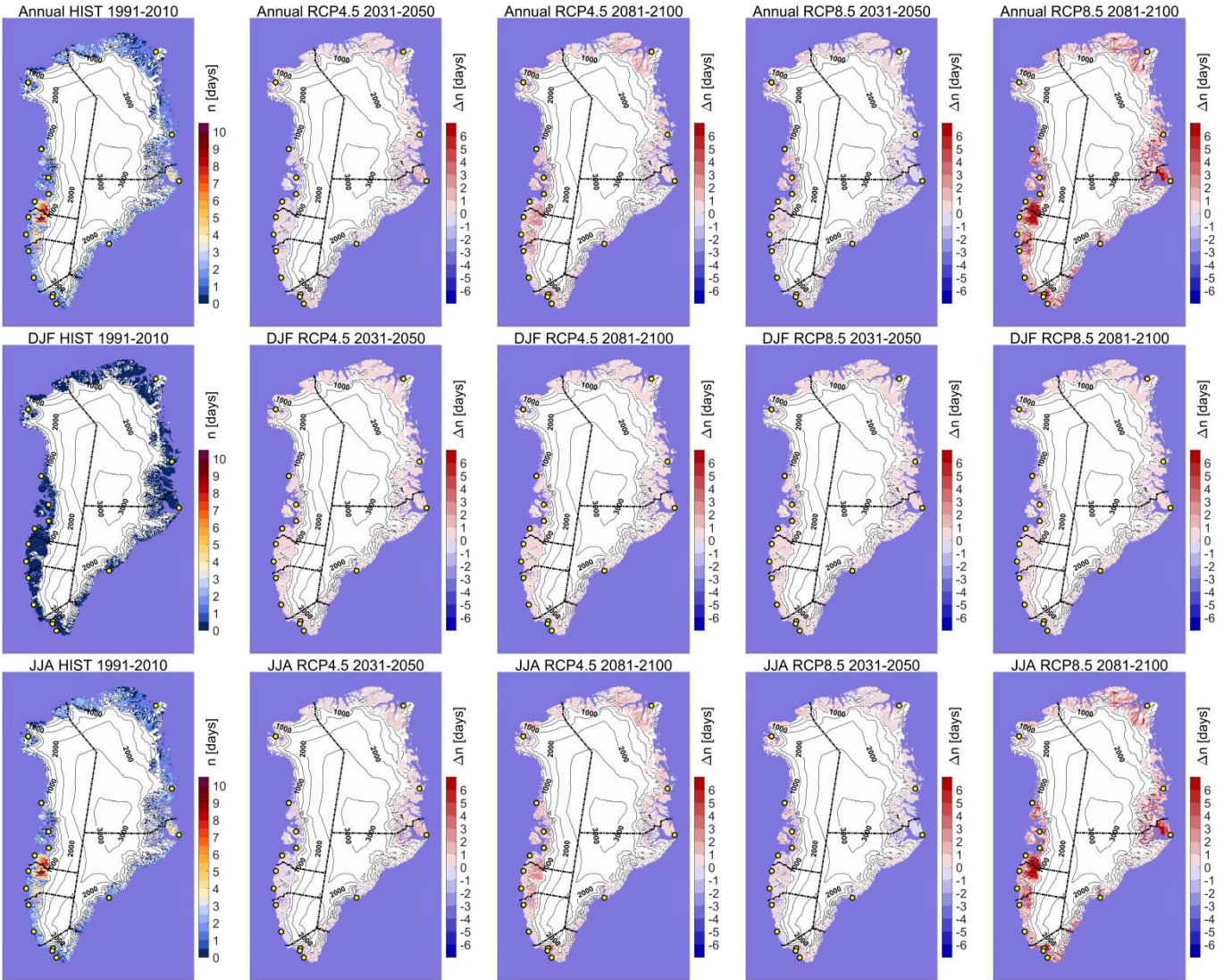




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 34 Longest continuous period with daily maximum temperature at 2m above 15°C

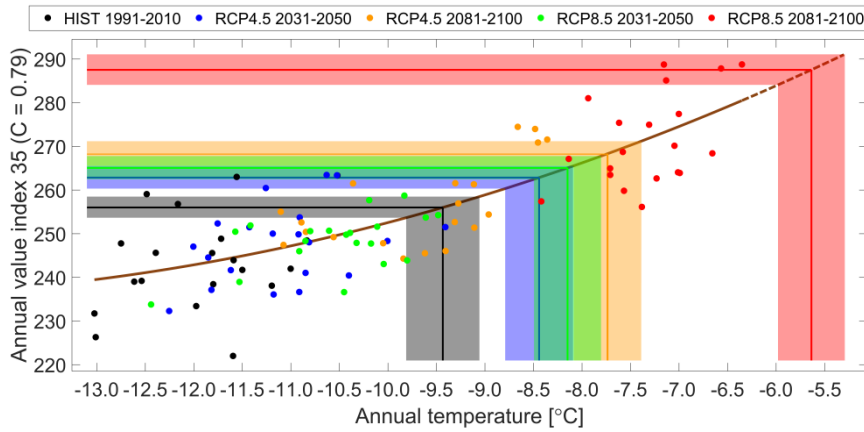
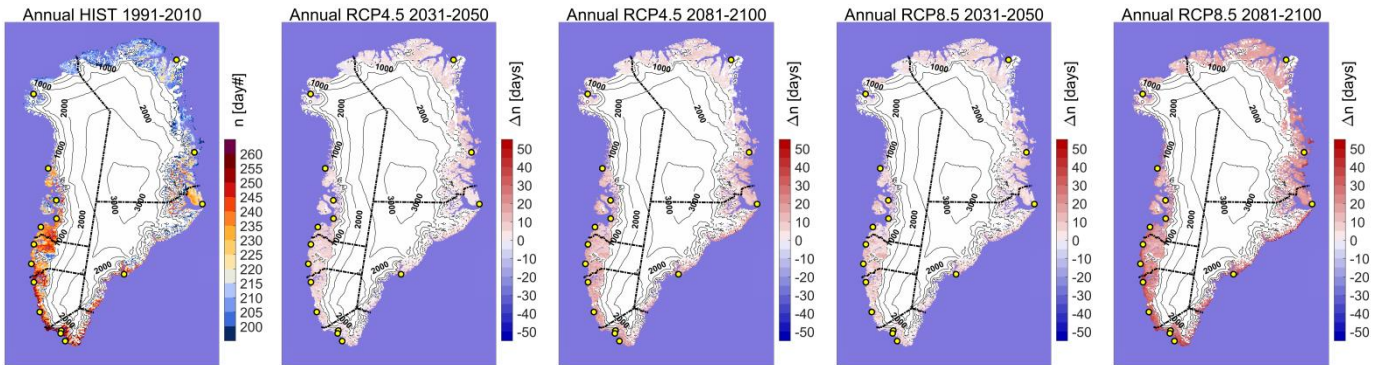




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 35 Daynumber for the end of the last continuous 4-day period with daily mean temperature at 2m above 5°C ("end of growing season (5°C)")

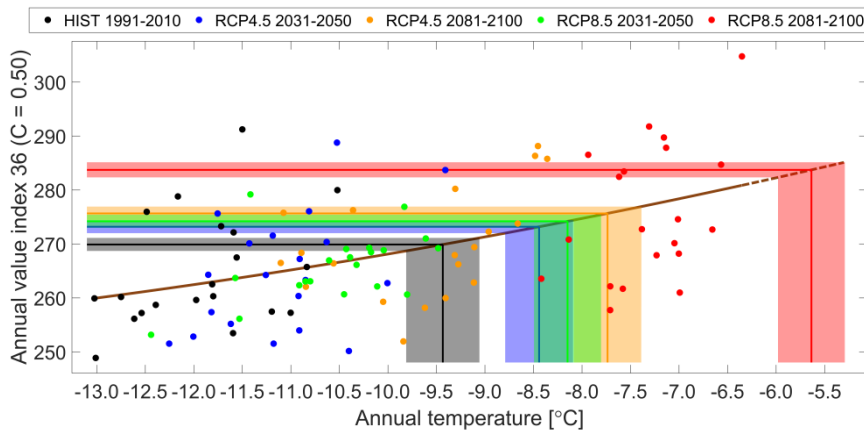
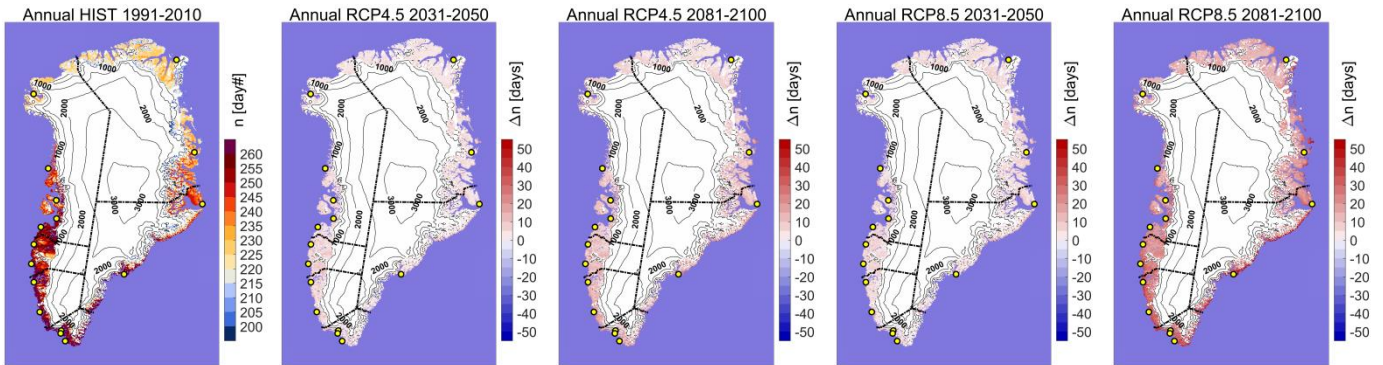




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 36 Daynumber for the end of the last continuous 4-day period with daily mean temperature at 2m above 2°C ("end of growing season (2°C)")

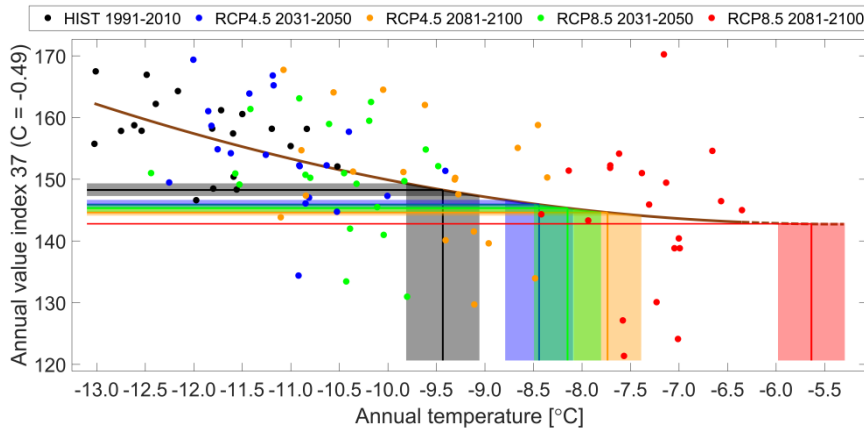
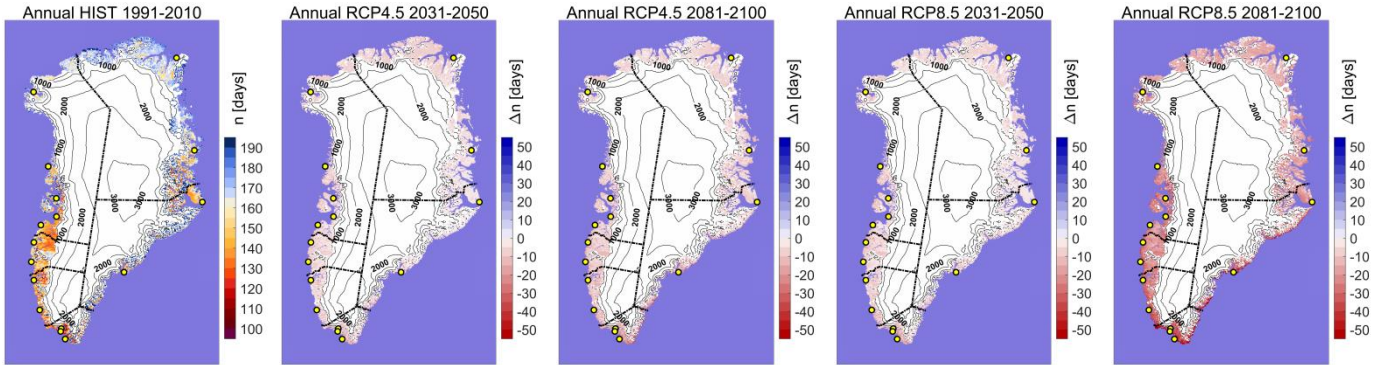




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 37 Daynumber for the end of the first continuous 4-day period with daily mean temperature at 2m above 2°C ("start of growing season (2°C)")

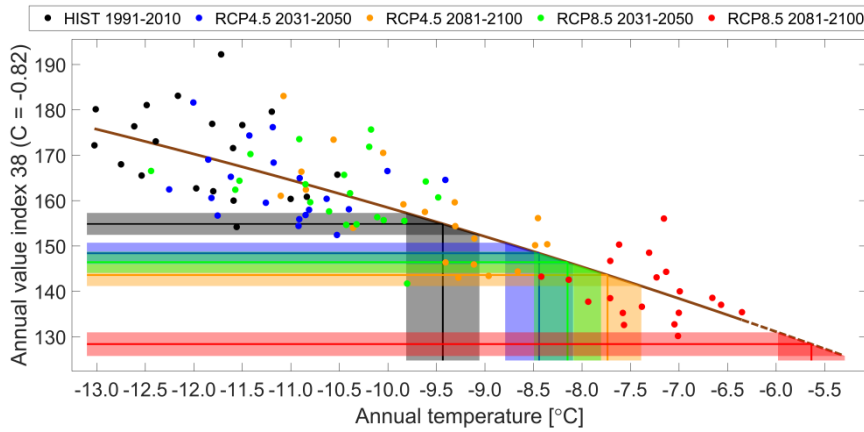
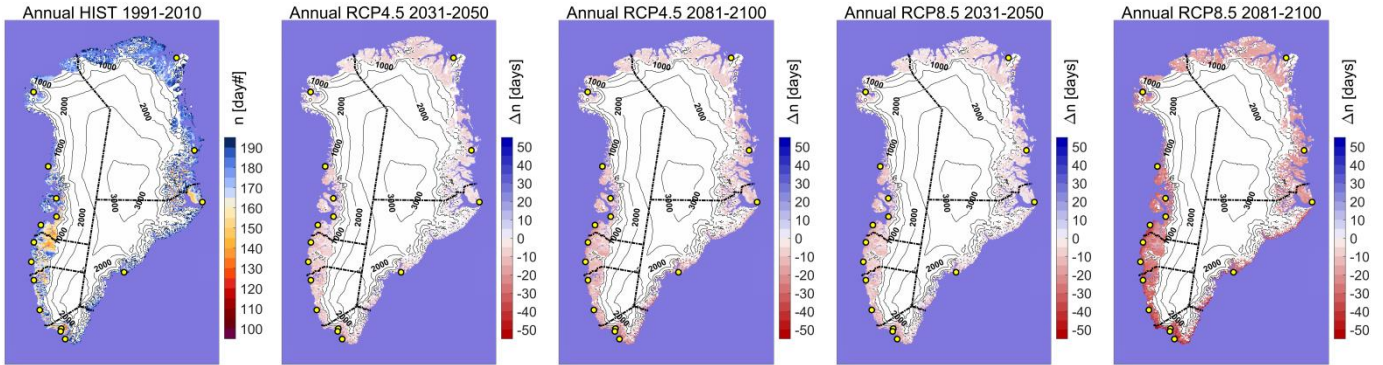




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 38 Daynumber for the end of the first continuous 4-day period with daily mean temperature at 2m above 5°C ("start of growing season (5°C)")

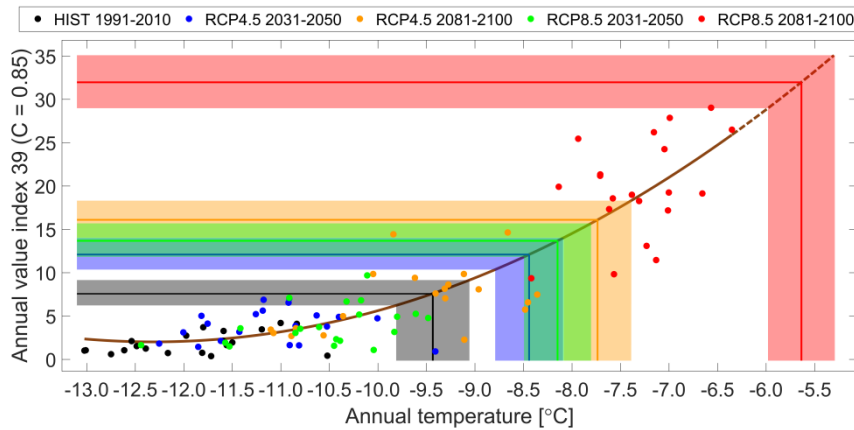
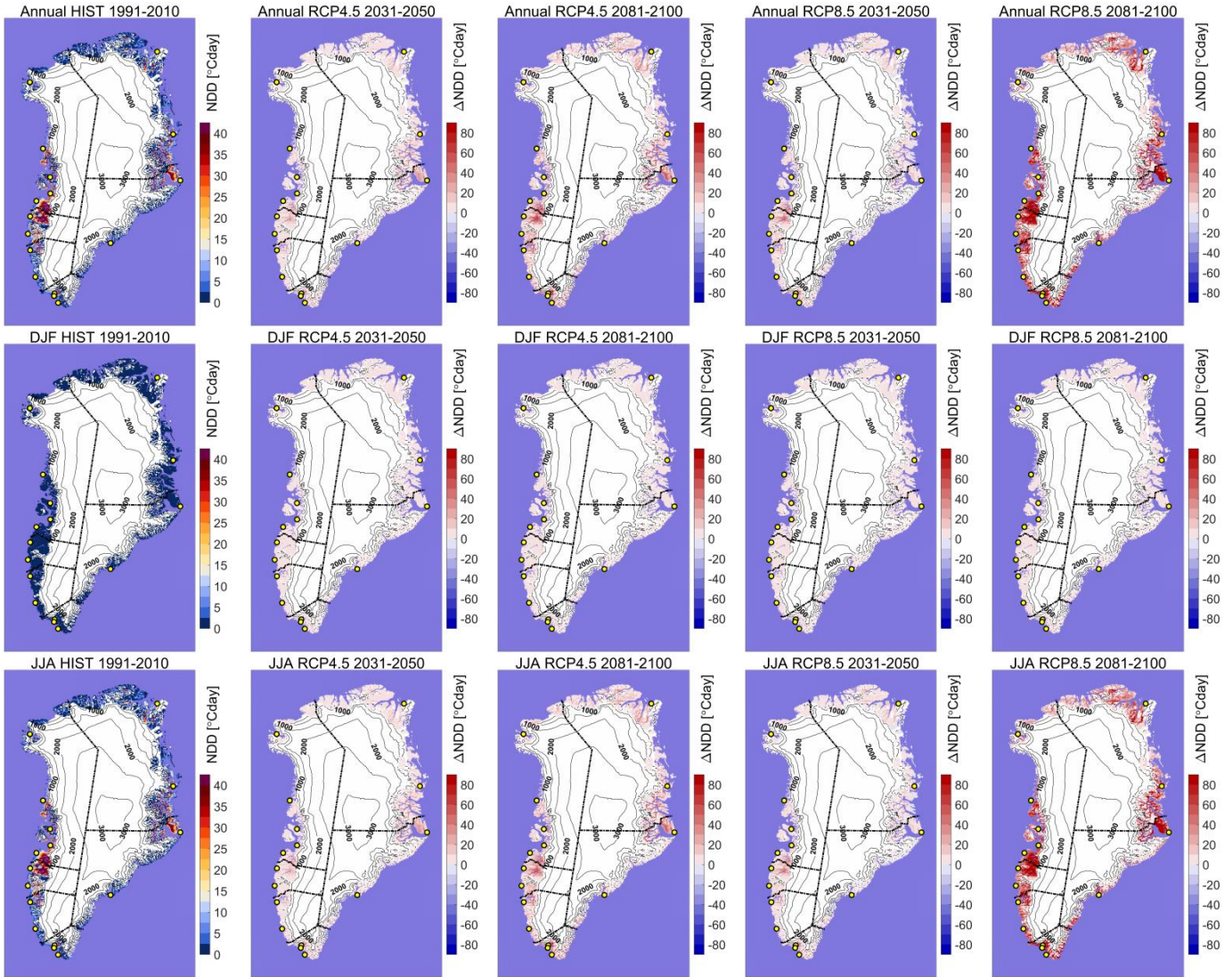




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 39 Number of degree days for daily mean temperature at 2m above 10°C

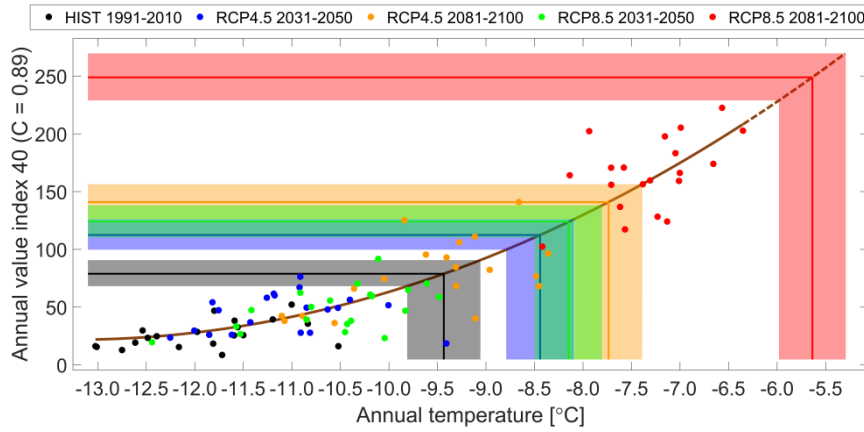
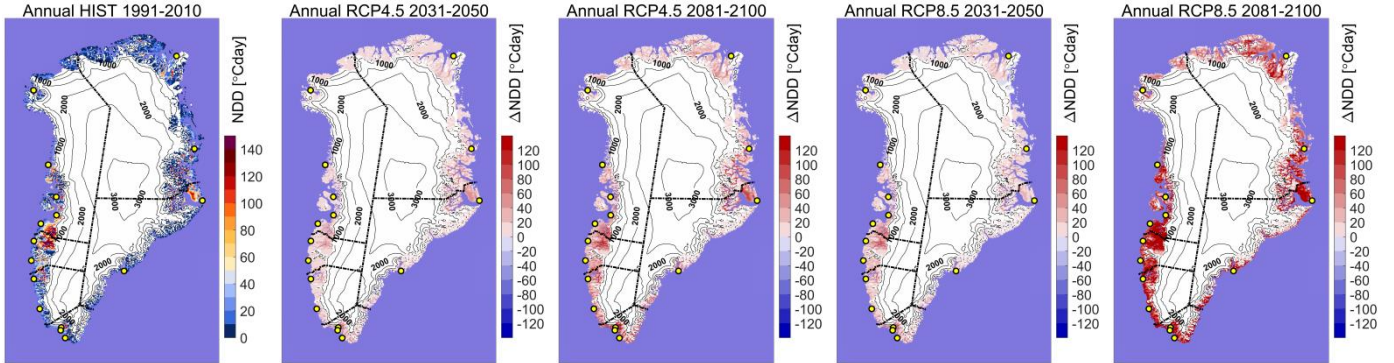




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 40 Number of degree days for daily mean temperature at 2m is above 8°C during the growing season (5°C)

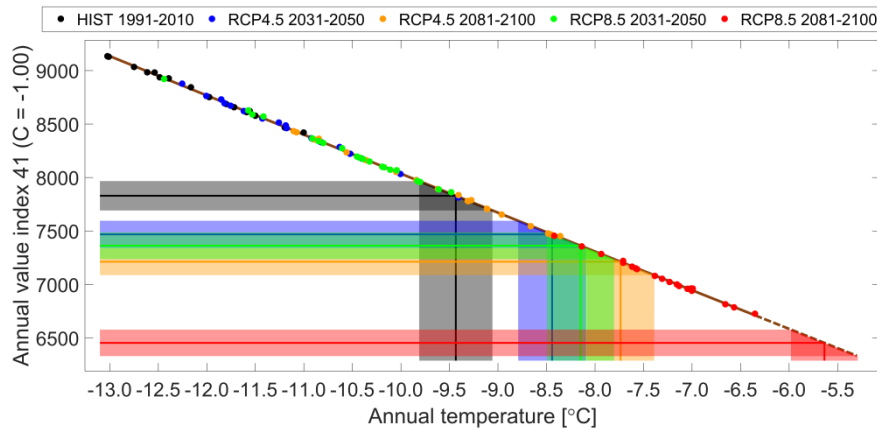
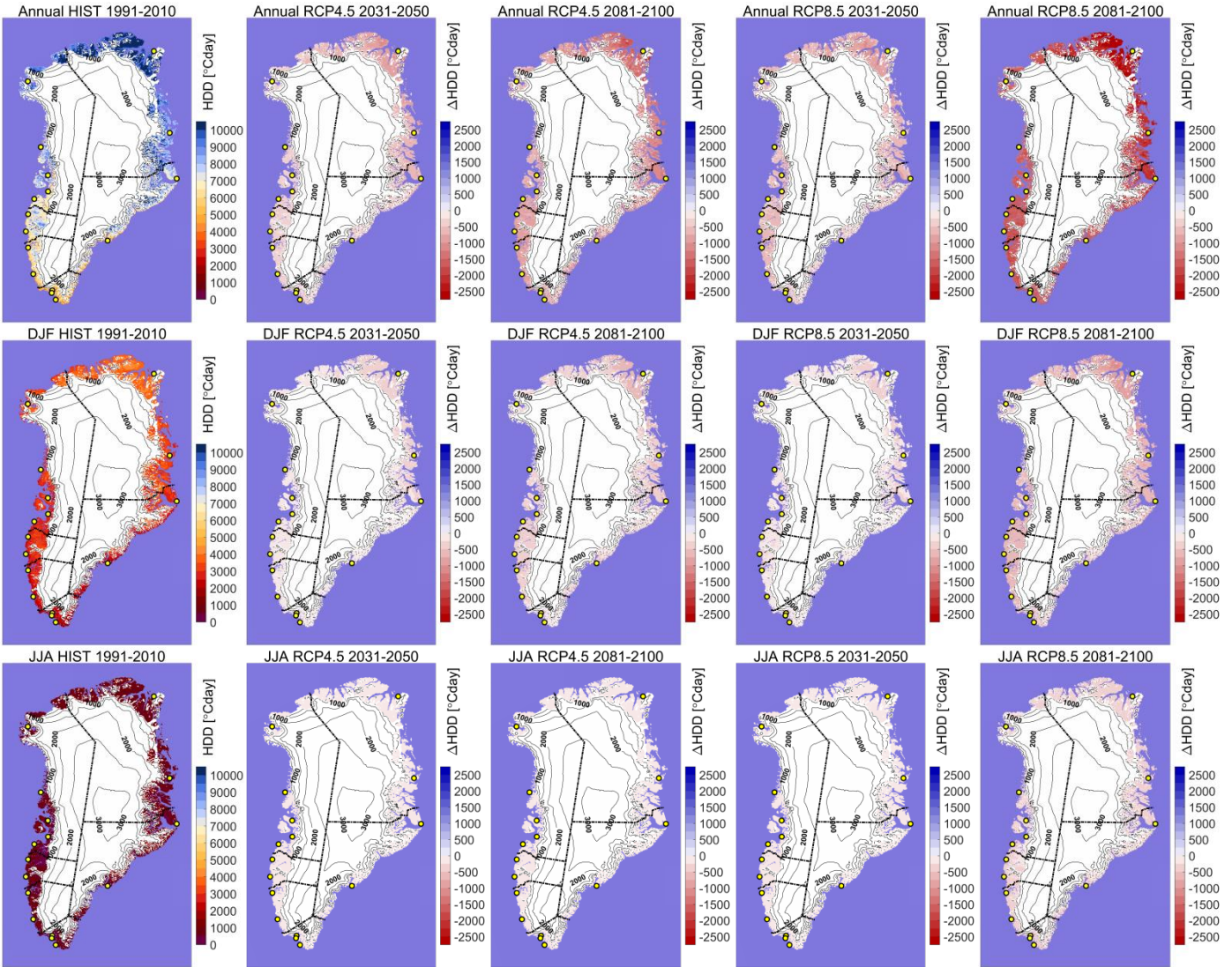




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 41 Number of degree days for daily mean temperature at 2m below 12°C (“heating degree days” HDD)

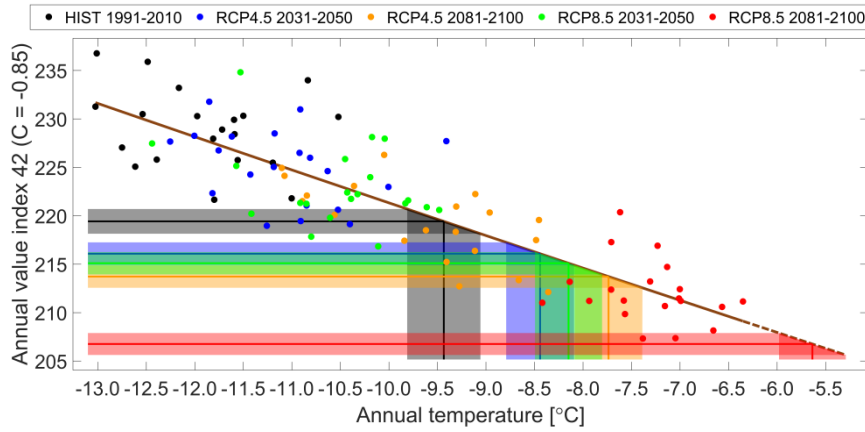
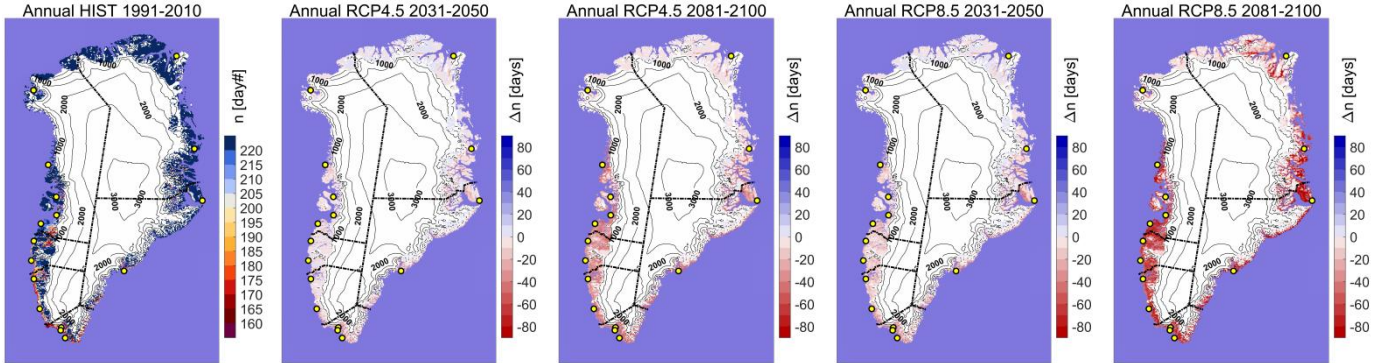




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 42 Last daynumber (<240) when daily minimum temperature at 2m is below 0°C (“last spring frost”)

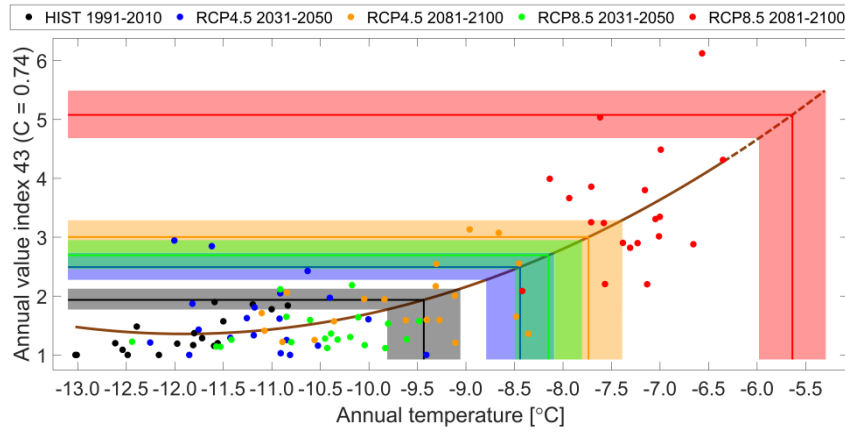
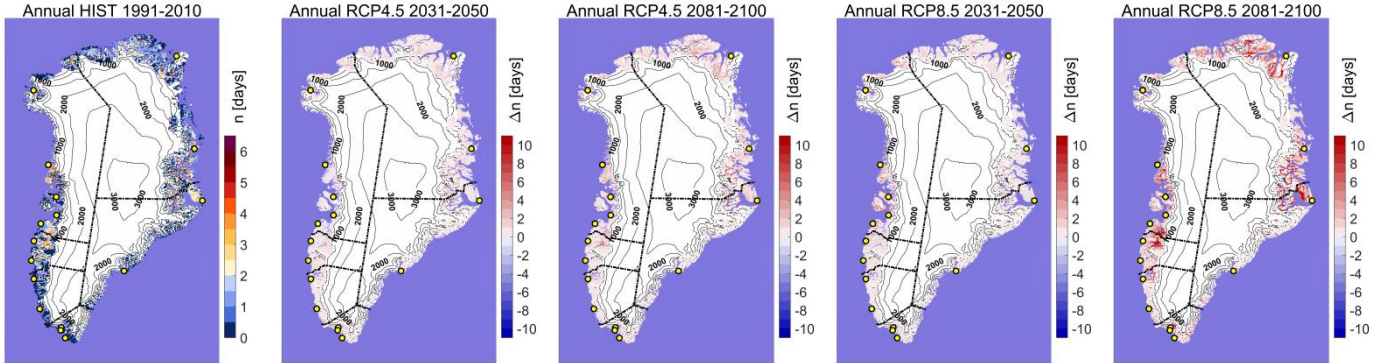




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 43 Number of days when daily minimum temperature at 2m is above 12°C (model adjusted "tropical nights")

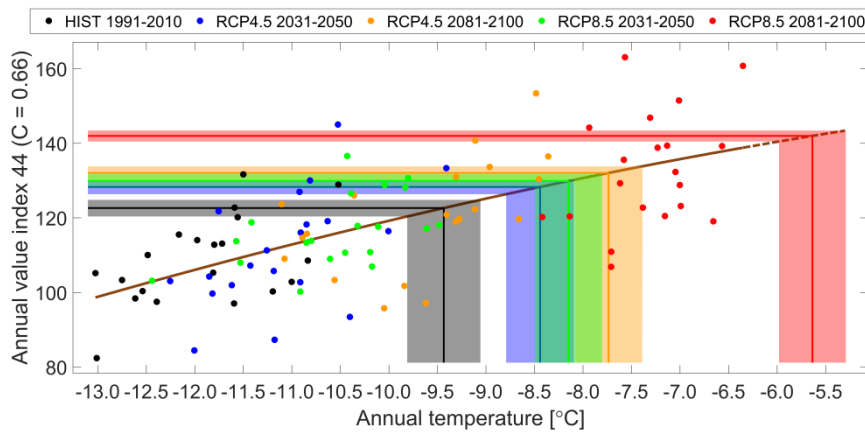
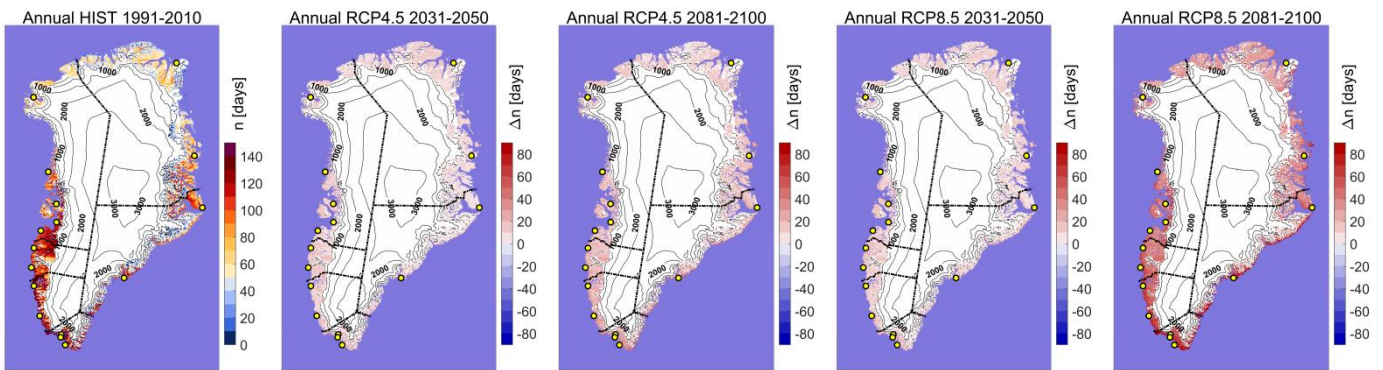




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 44 Number of days between the end of the first continuous 4-day period with daily mean temperature at 2m above 2°C and the end of the last continuous 4-day period with daily mean temperature at 2m above 2°C ("length of growing season (2°C)")

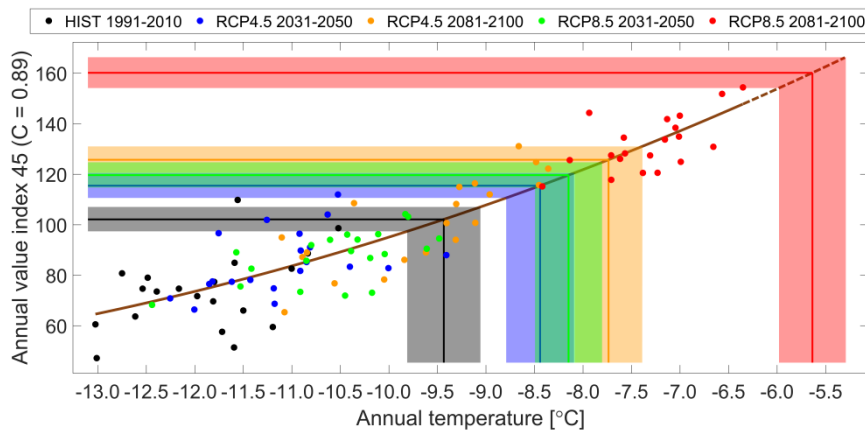
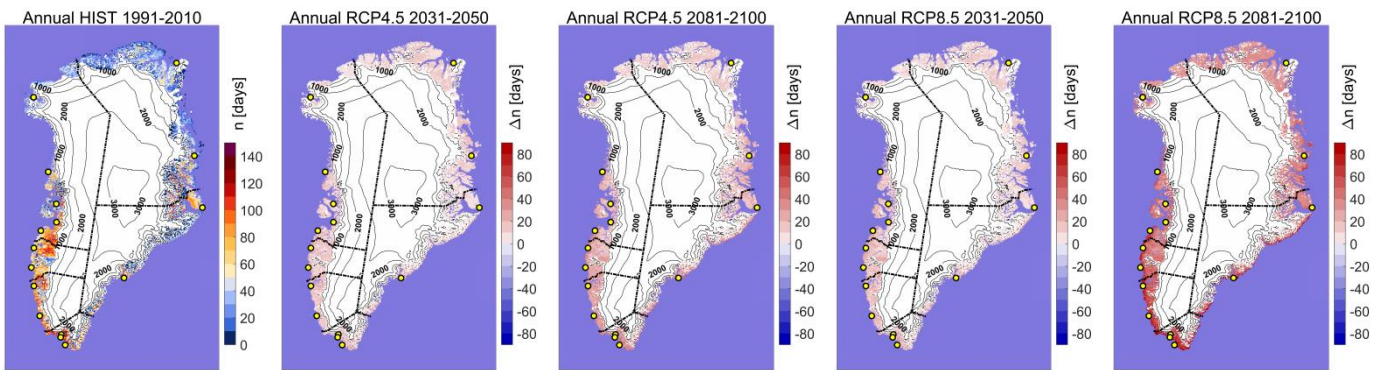




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 45 Number of days between the end of the first continuous 4-day period with daily mean temperature at 2m above 5°C and the end of the last continuous 4-day period with daily mean temperature at 2m above 5°C ("length of growing season (5°C)")

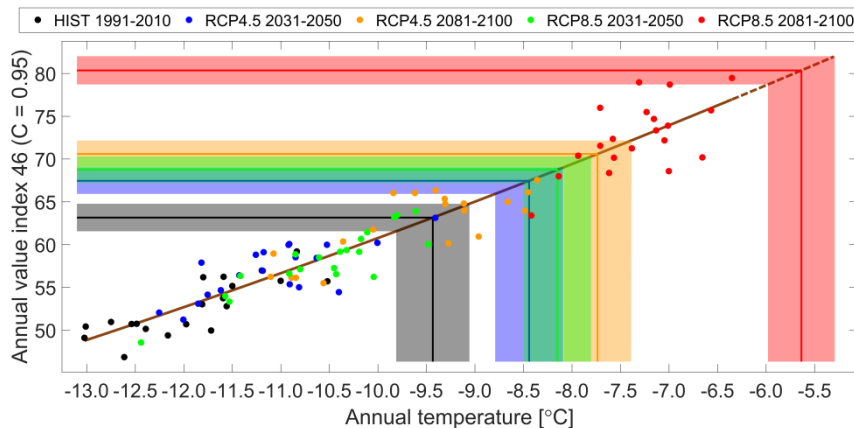
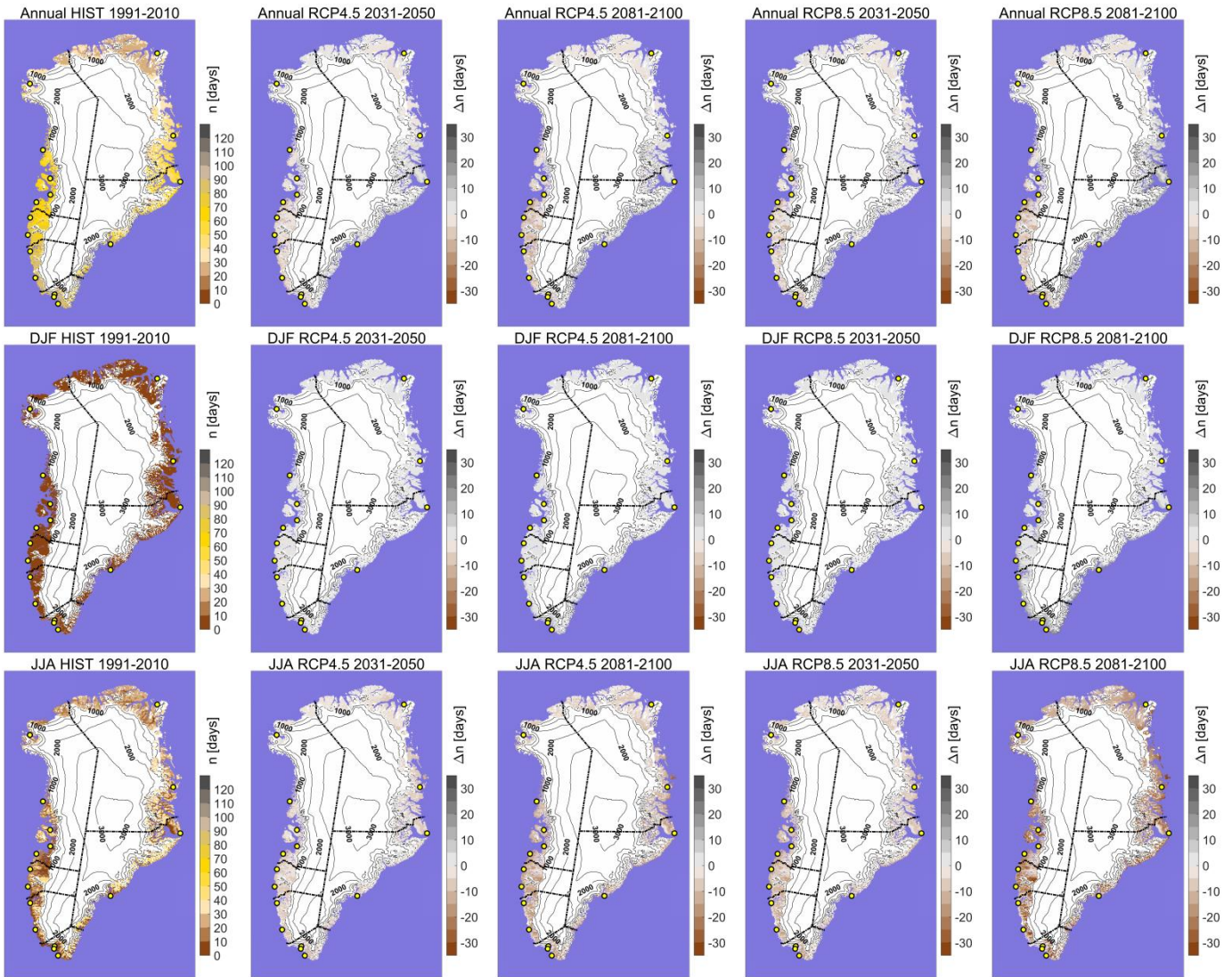




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 46 Number of of days when the temperature at 2m height has been both above and below 0°C (daily maximum temperature at 2m above 0°C and daily minimum temperature at 2m below 0°C)

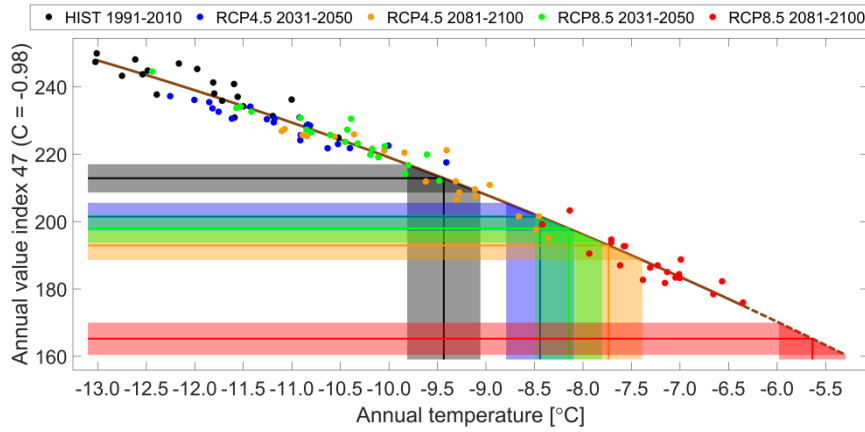
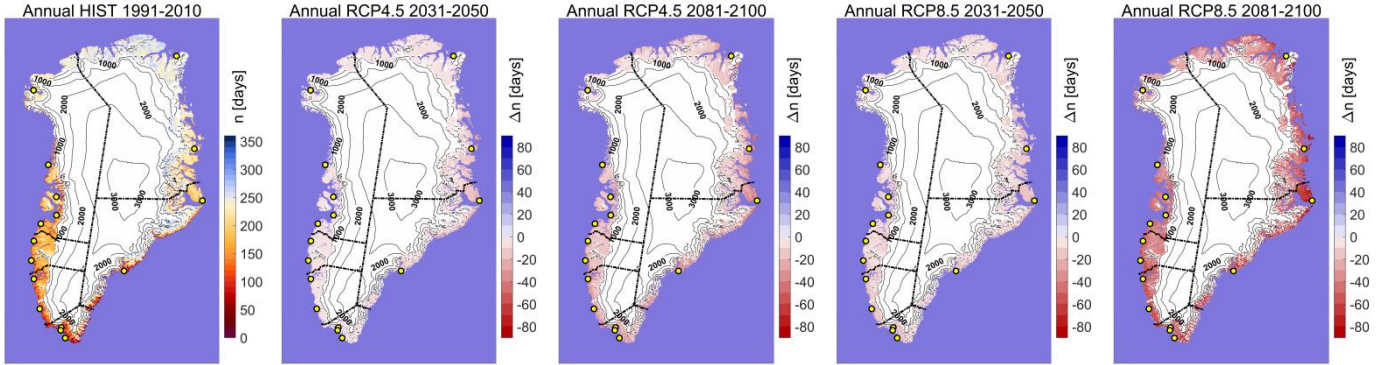




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 47 Number of days when the daily mean surface temperature is below -7°C

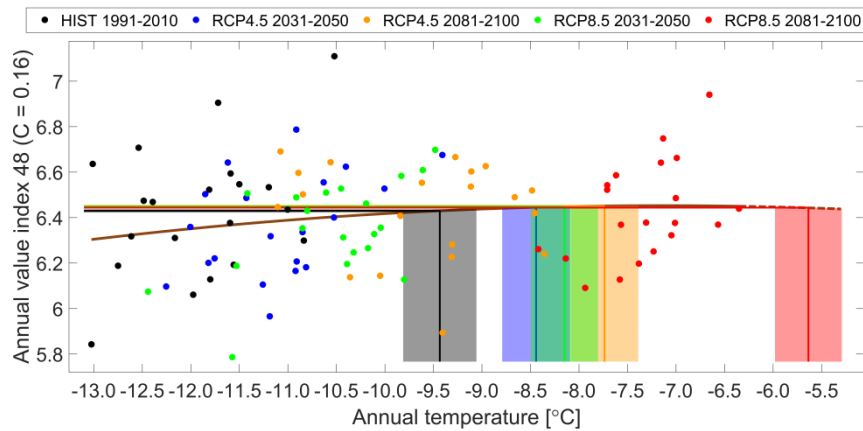
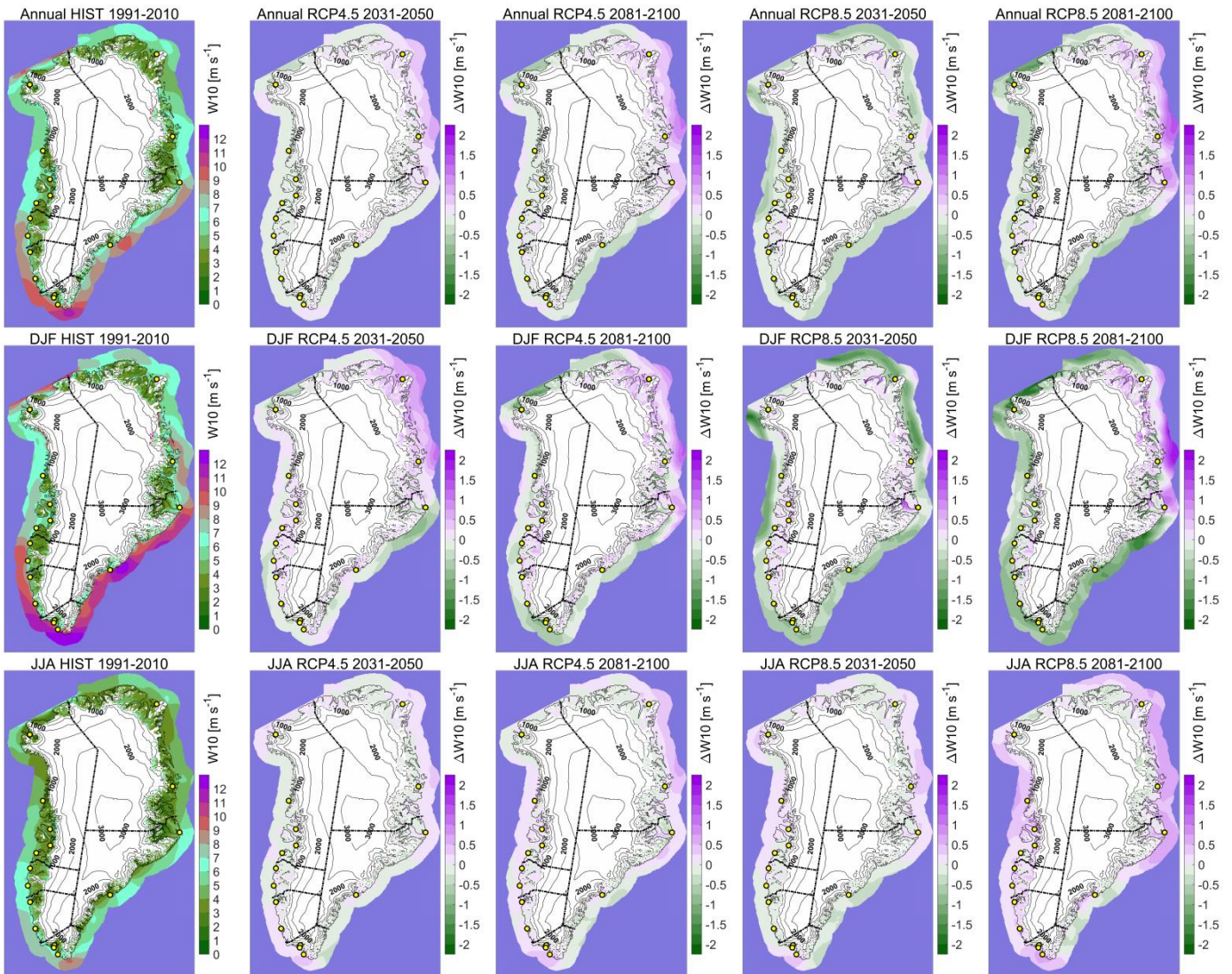




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 48 Daily mean wind speed at 10m, mean value



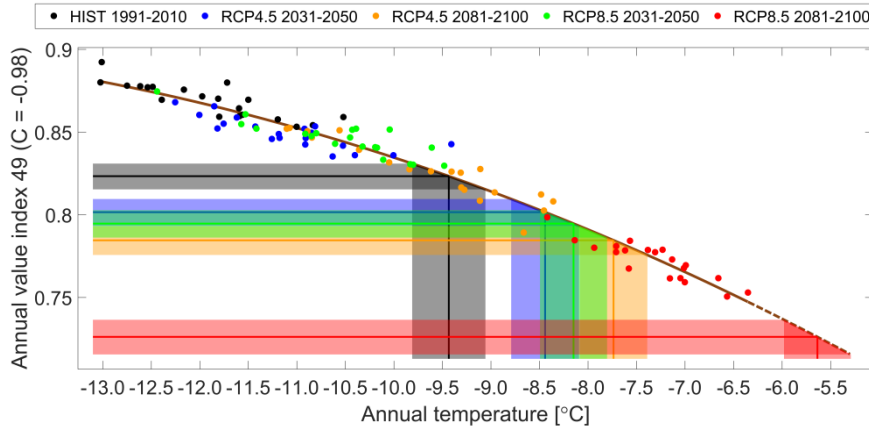
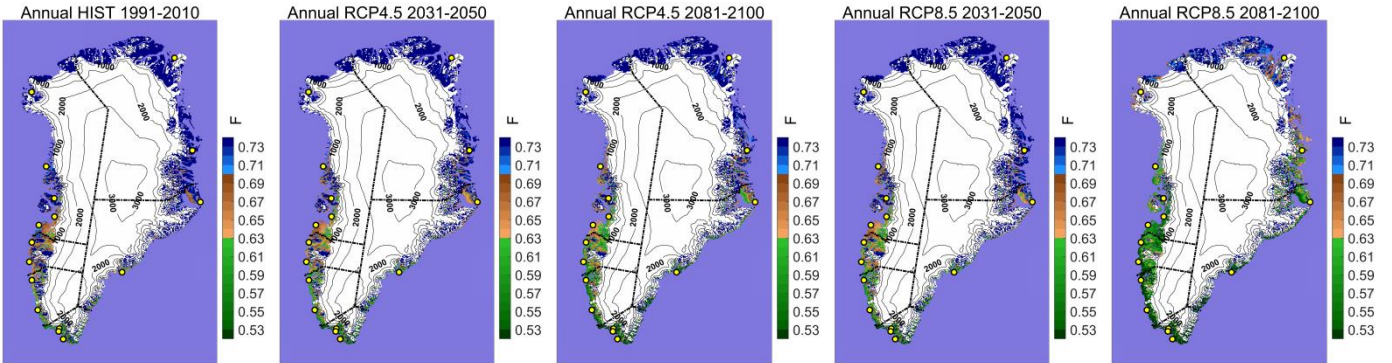


Dmi

Energi-, Forsynings- og Klimaministeriet

Index 49

Permafrost index ($\frac{\sqrt{DDF}}{\sqrt{DDT} + \sqrt{DDF}}$, where DDF(DDT) = degree-days of freezing(thawing))

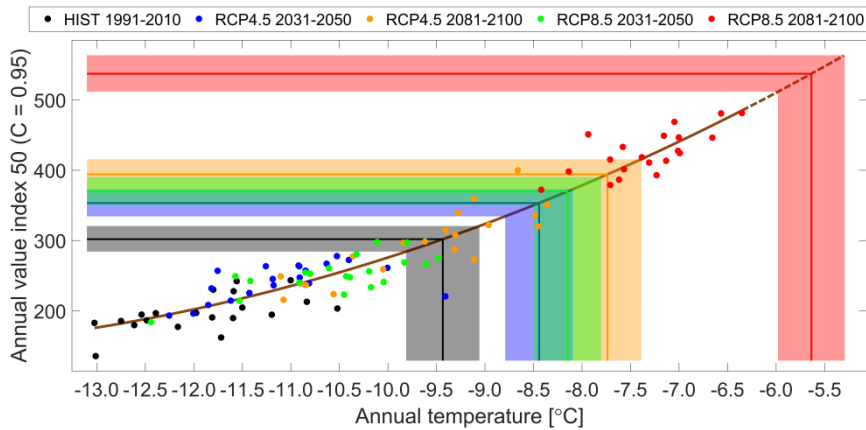
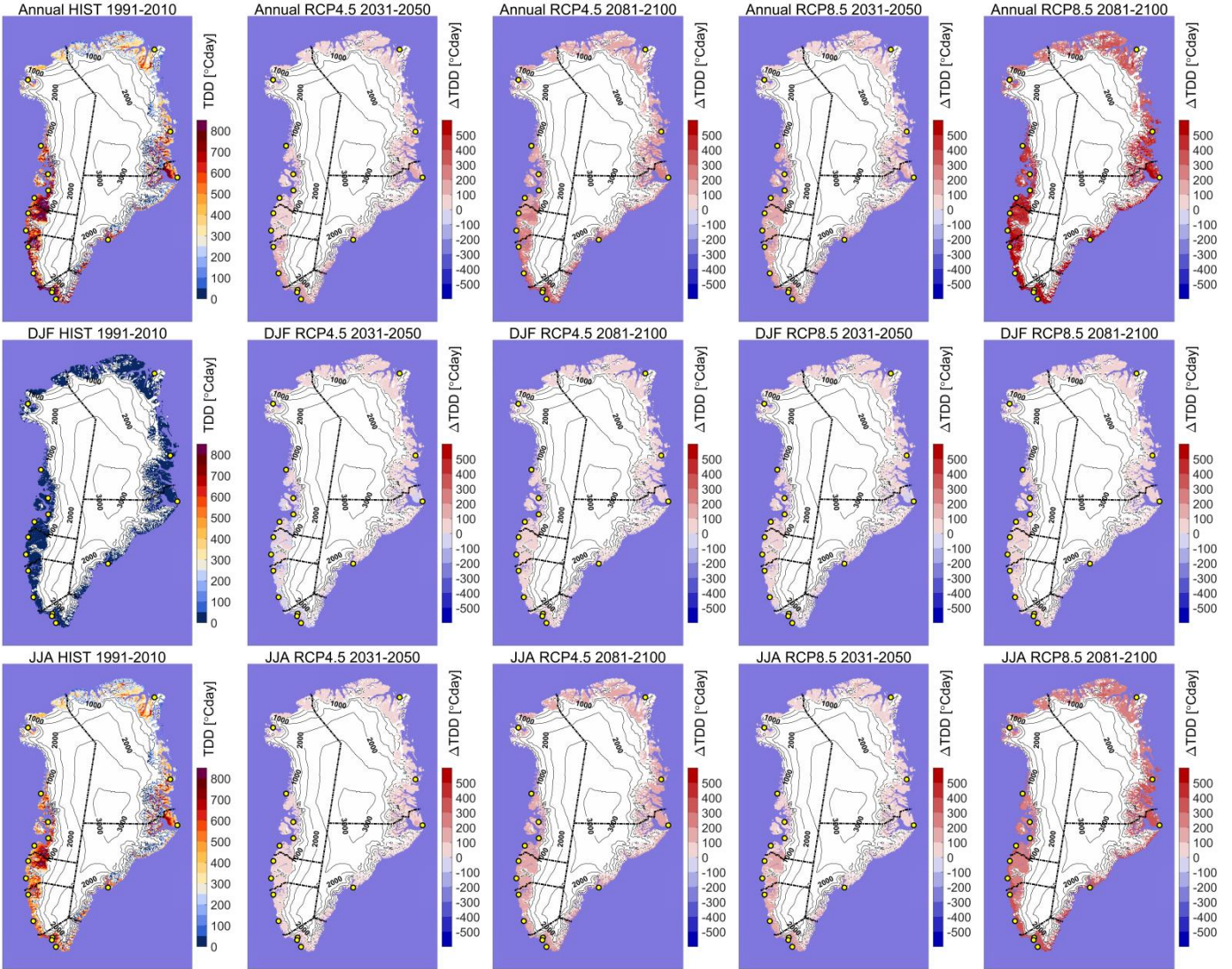




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 50 Number of degree days when daily mean temperature at 2m is above 0°C (“thawing degree days”)

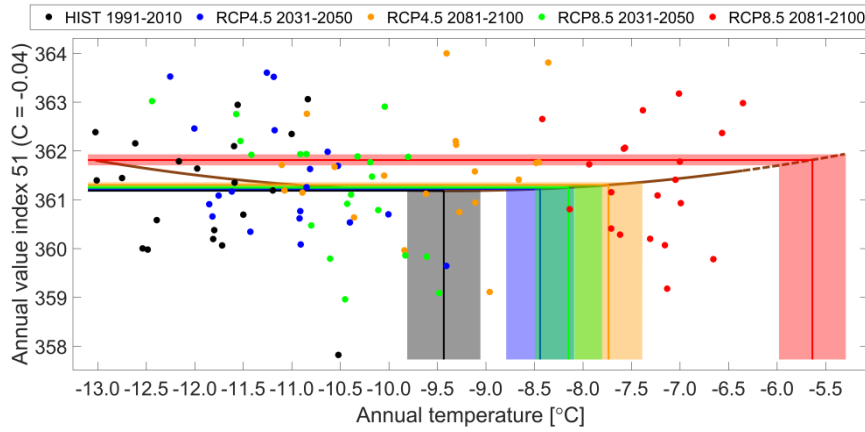
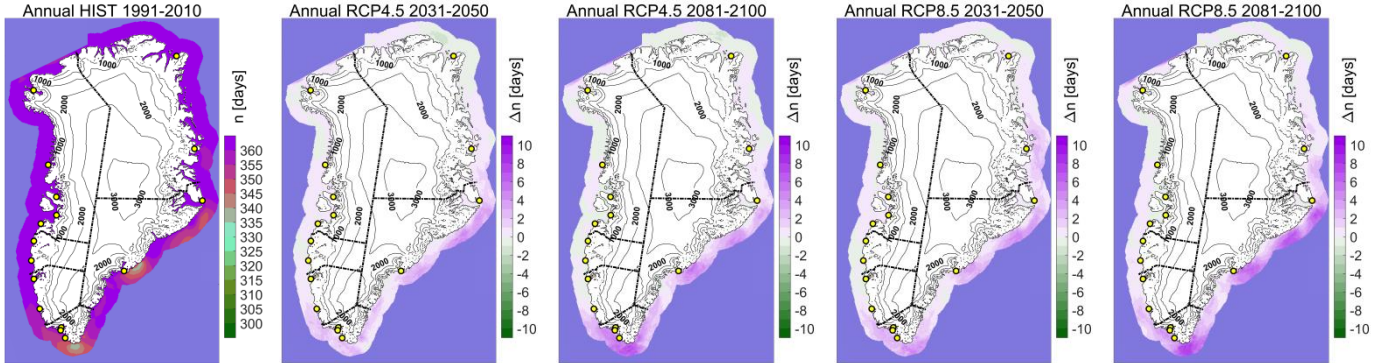




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 51 Number of days when 10m wind speed is below 20m/s (“fishing days (20m/s)”)

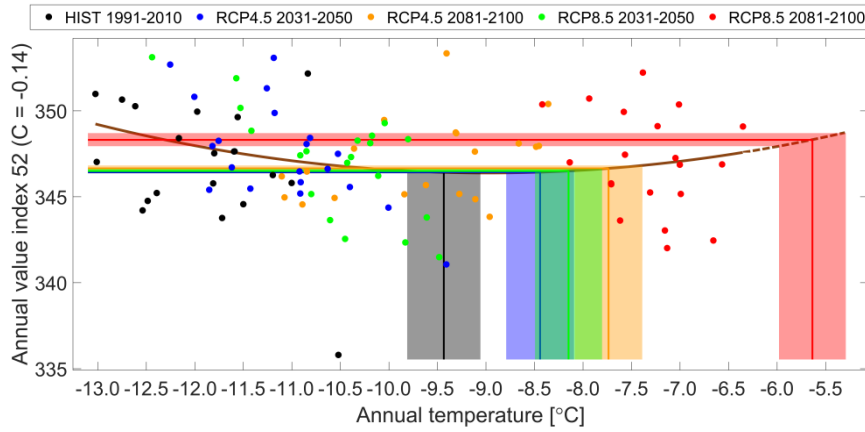
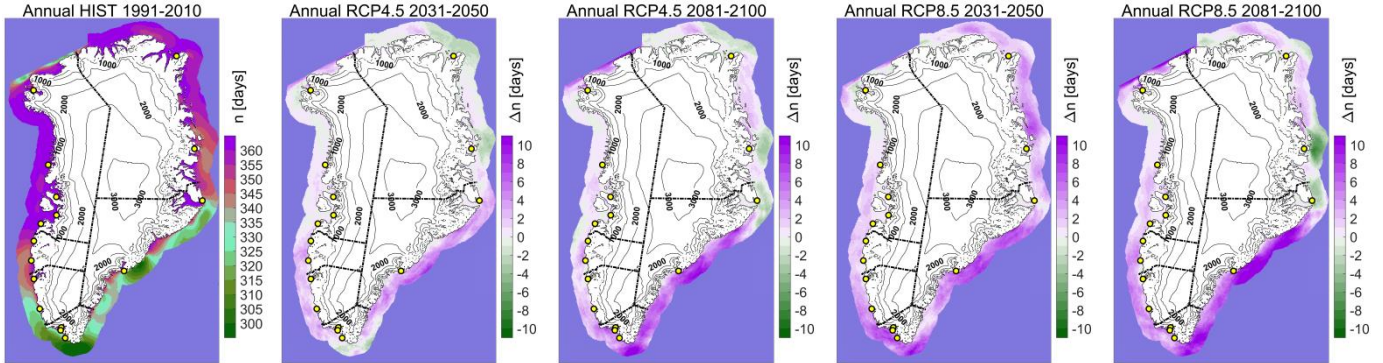




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 52 Number of days when 10m wind speed is below 15m/s (“fishing days (15m/s)”)

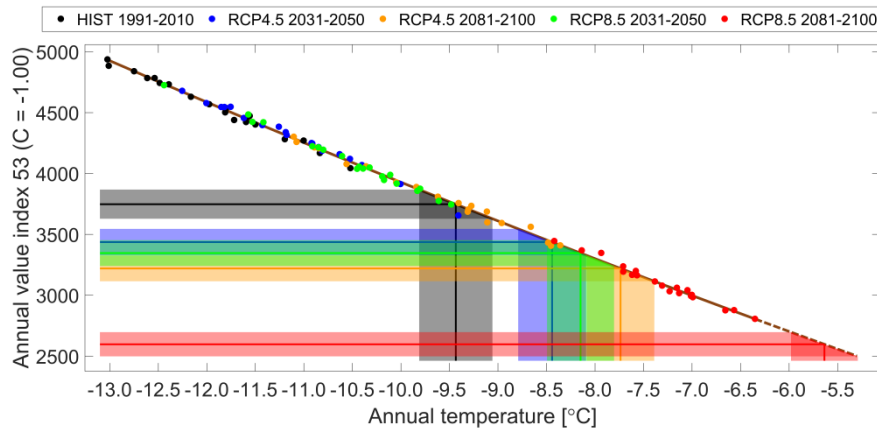
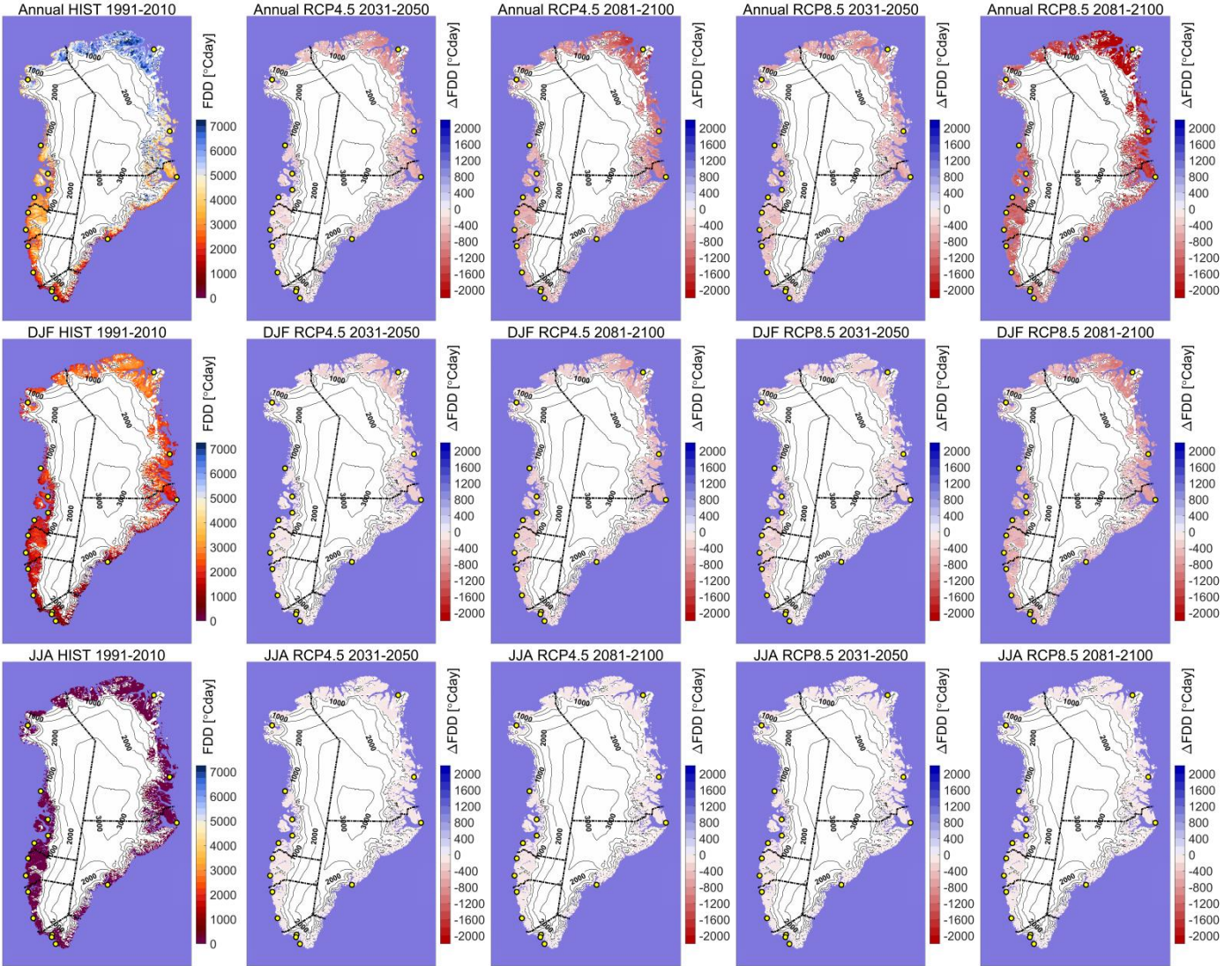




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 53 Number of degree days when daily mean temperature at 2m is below 0°C (“freezing degree days”)

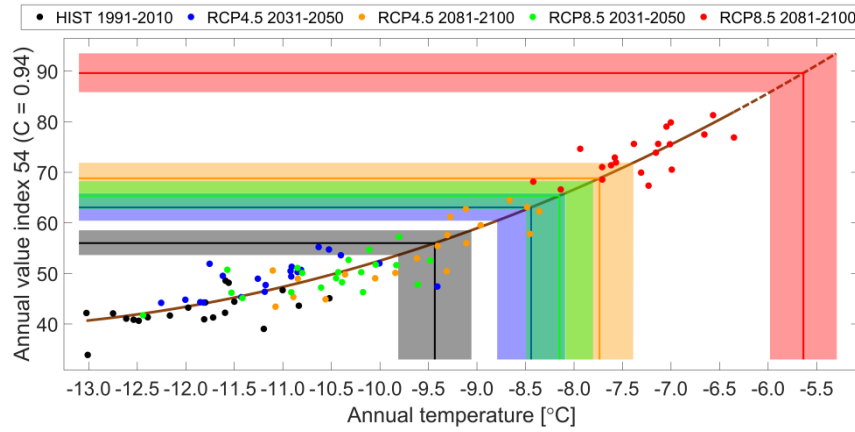
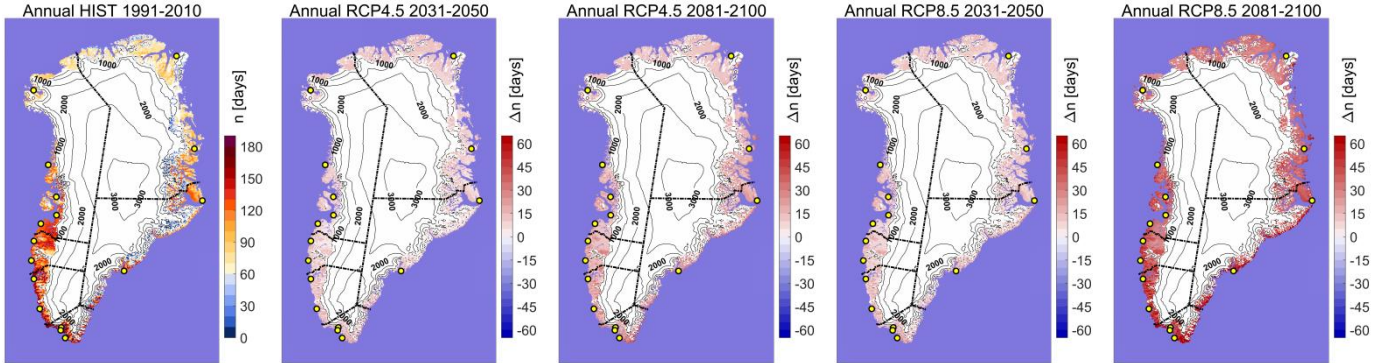




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 54 Length of thawing season (from 0°C crossing dates using a 21-day moving average of daily mean temperature at 2m)

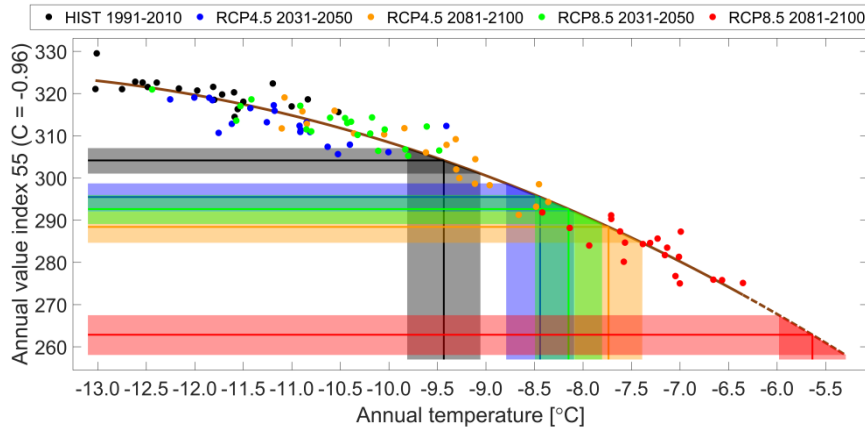
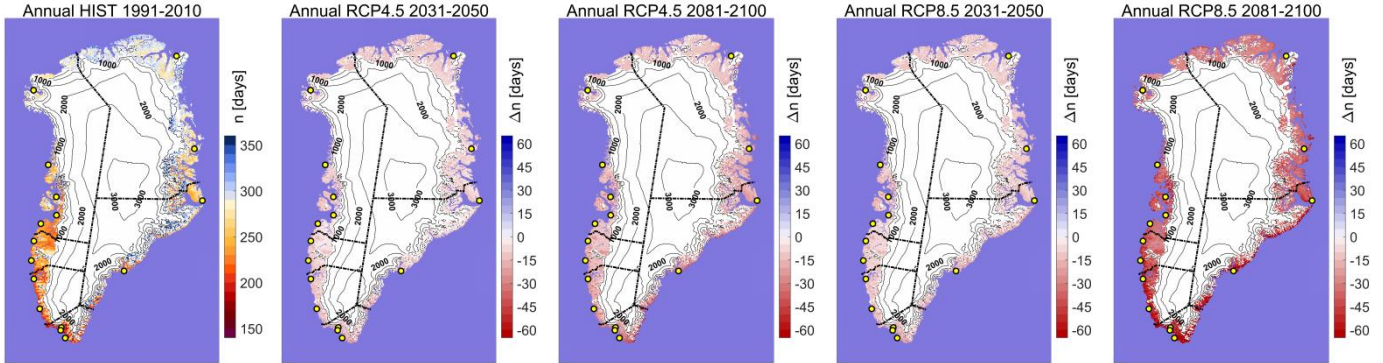




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 55 Length of freezing season (from 0°C crossing dates using a 21-day moving average of daily mean temperature at 2m)

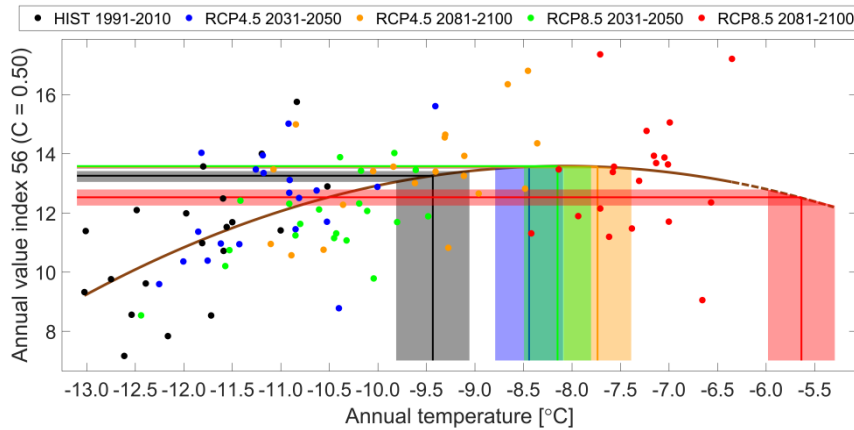
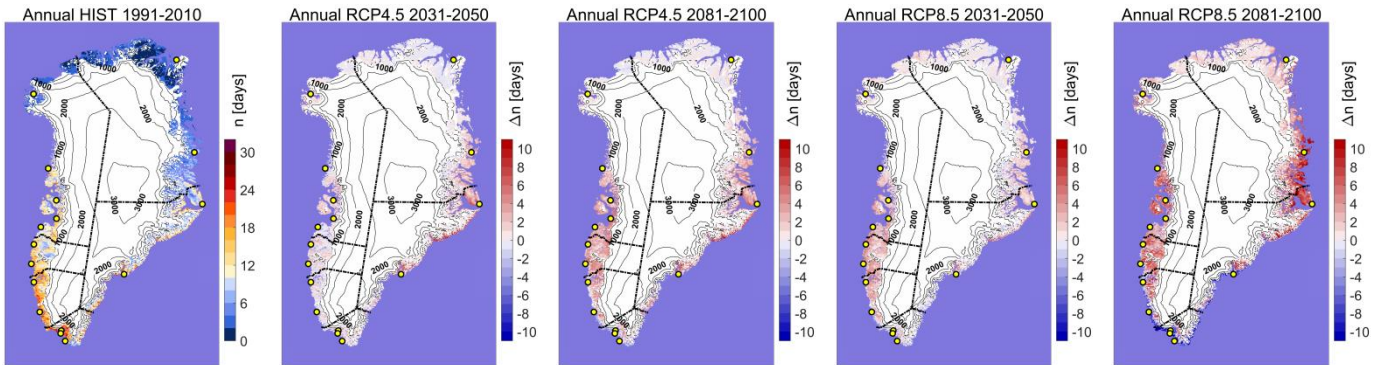




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 56 Melt events during winter (number of days with daily maximum temperature at 2m above 0°C and 29 day running mean of daily mean temperature at 2m below -5°C)

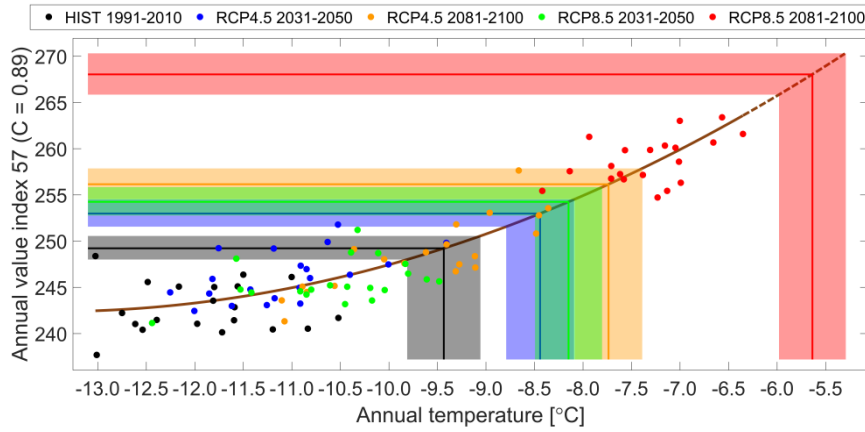
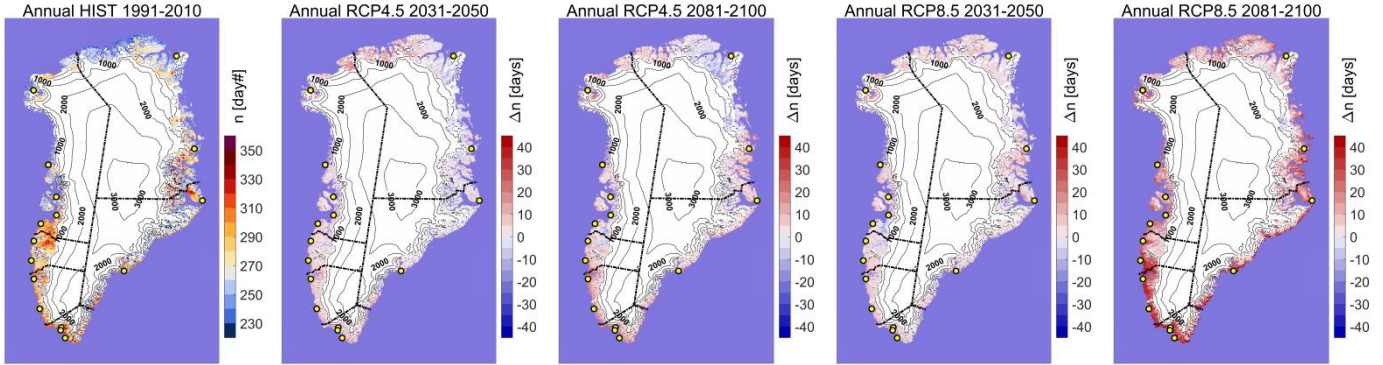




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 57 Daynumber, after day 220, of the first 5 consecutive days with snow cover above 2cm (“snow cover season – onset”)

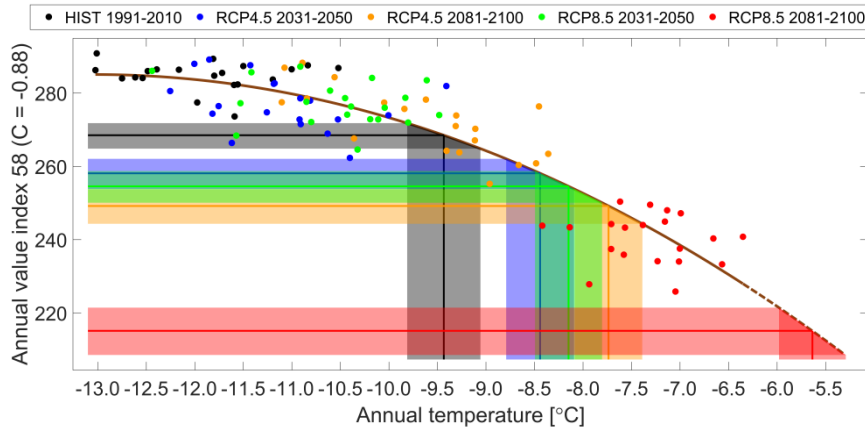
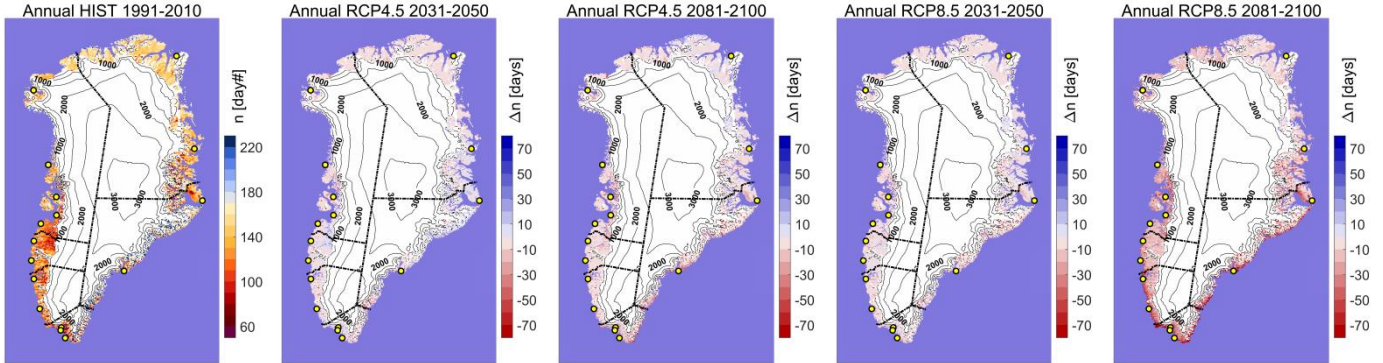




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 58 Daynumber of the first 5 consecutive days with snow cover below 2cm (“snow cover season – end”)

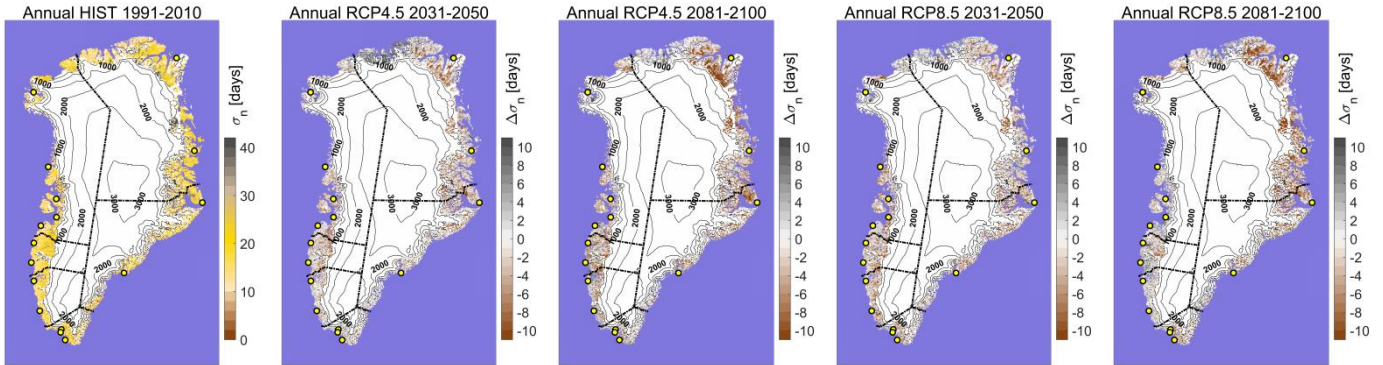




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 59 Standard deviation of annual values of index 52 (“snow cover season – change in onset”)

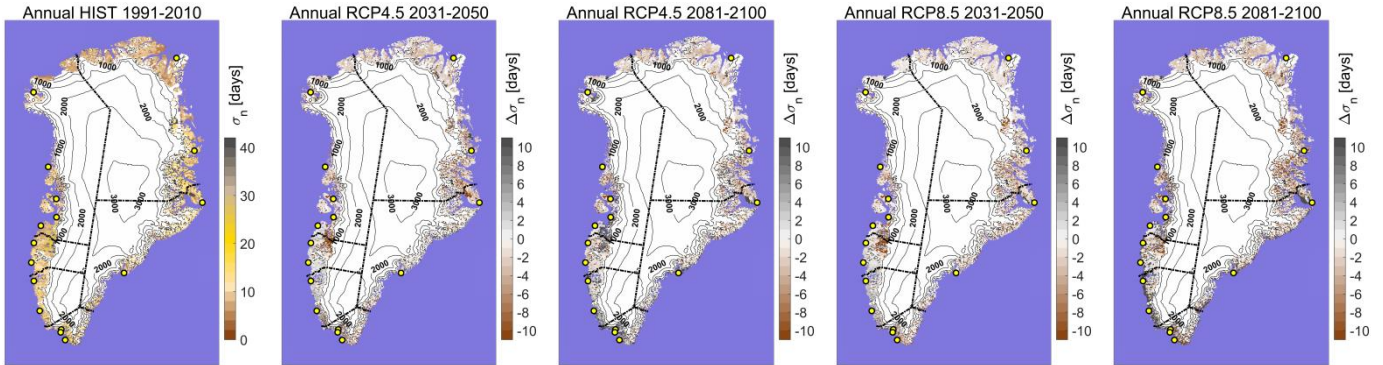




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 60 Standard deviation of annual values of index 53 (“snow cover season – change in end”)

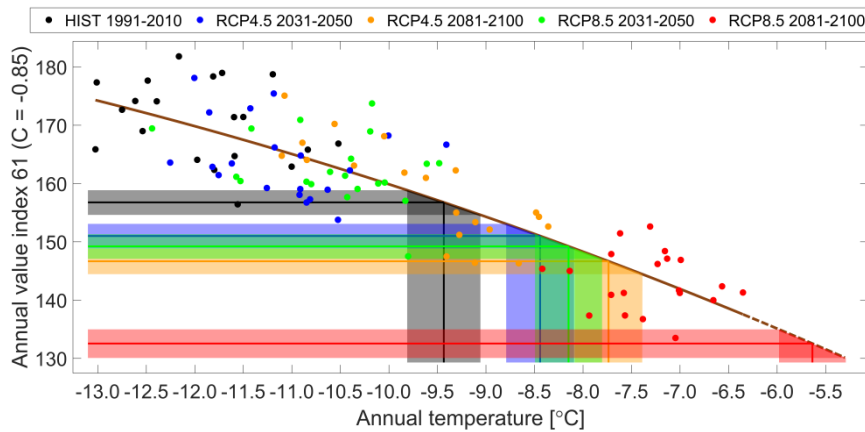
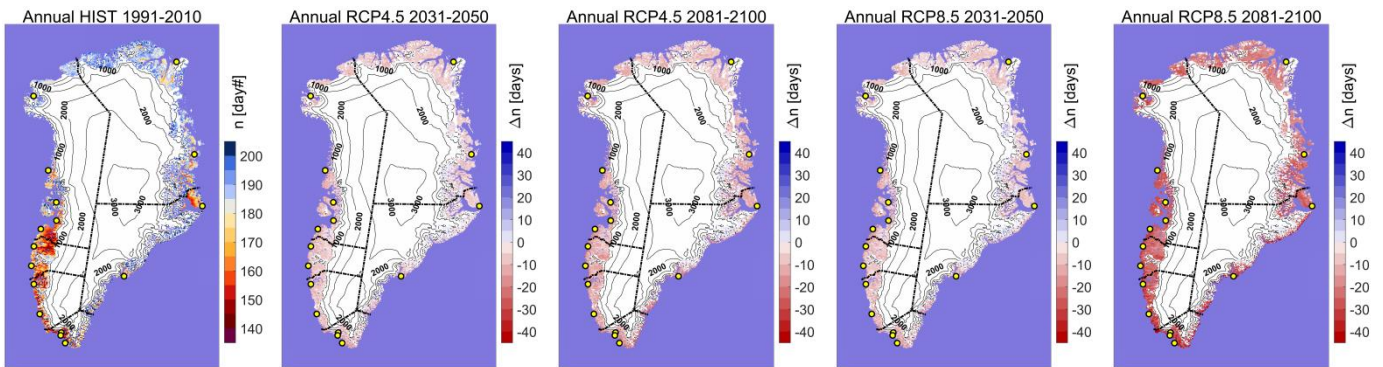




Dmi

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Index 61 Daynumber, after 10 continuous days with daily mean temperature at 2m above 0°C, when daily maximum temperature at 2m is above 10°C and the relative humidity is above 45% (“mosquito season – onset”)

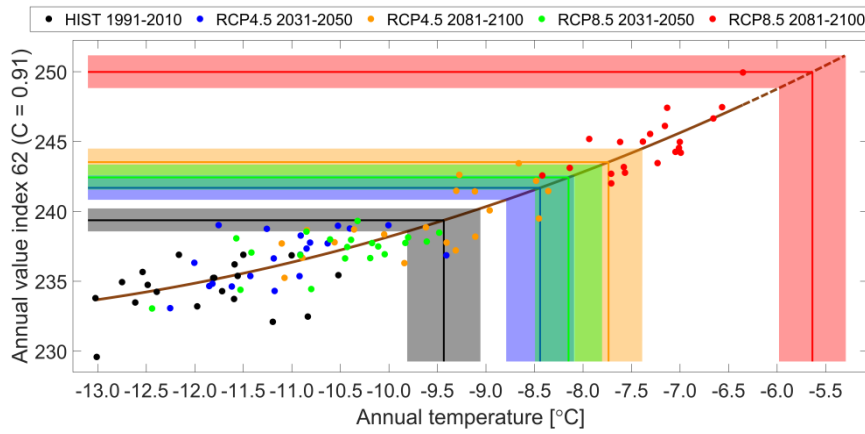
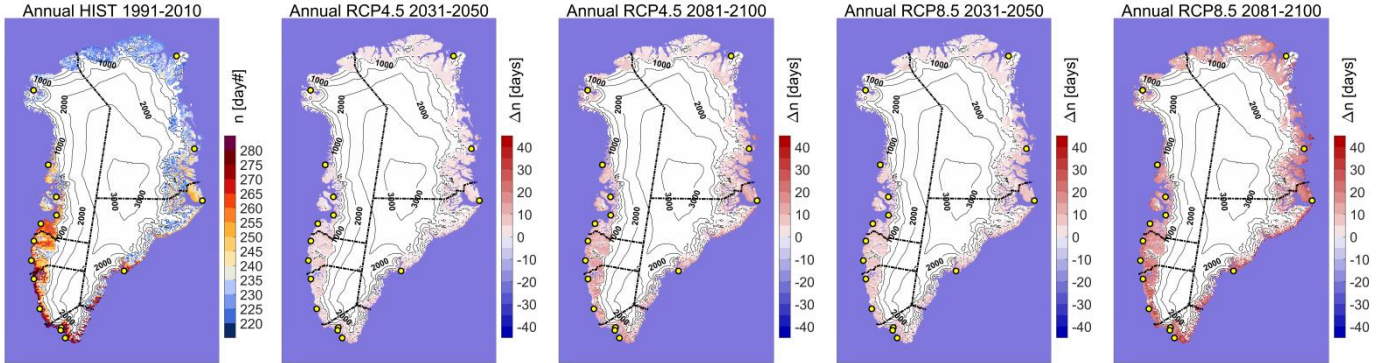




Dmi

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Index 62 Daynumber, after day 220, of the first 5 consecutive days with daily mean temperature at 2m below 0°C (“mosquito season – end”)

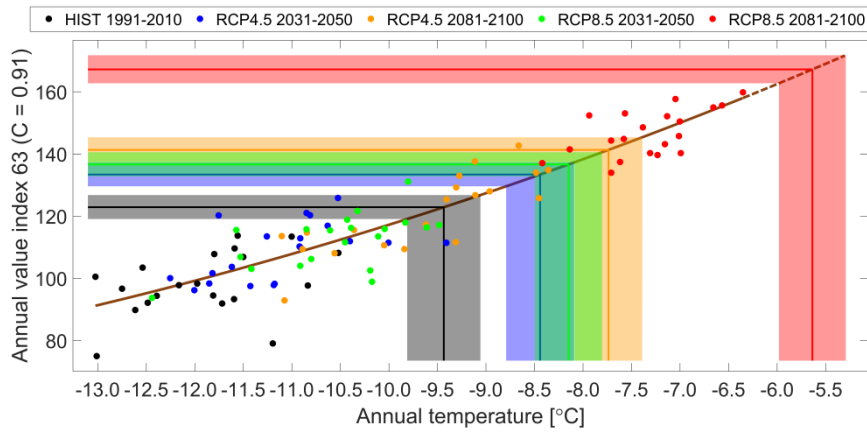
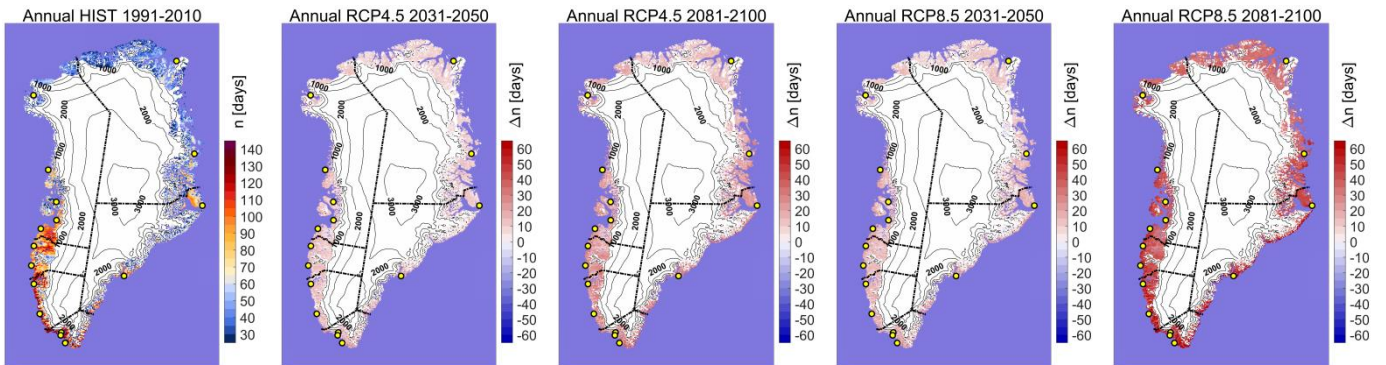




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Index 63 Difference between Indices 57 and 56 (“mosquito season – length”)

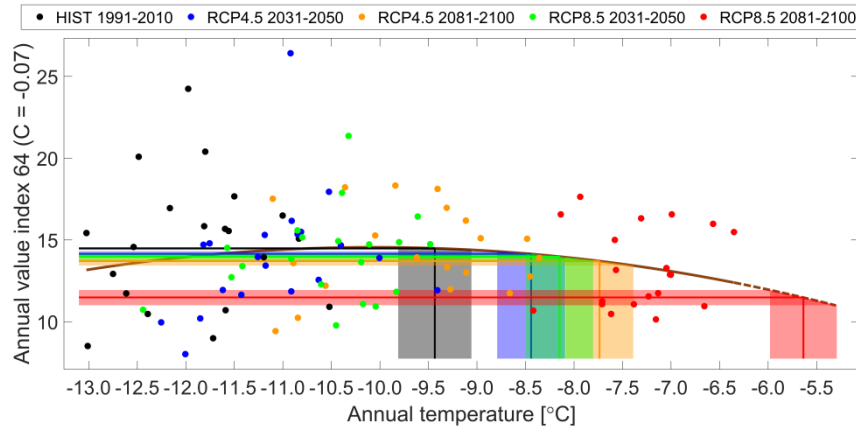
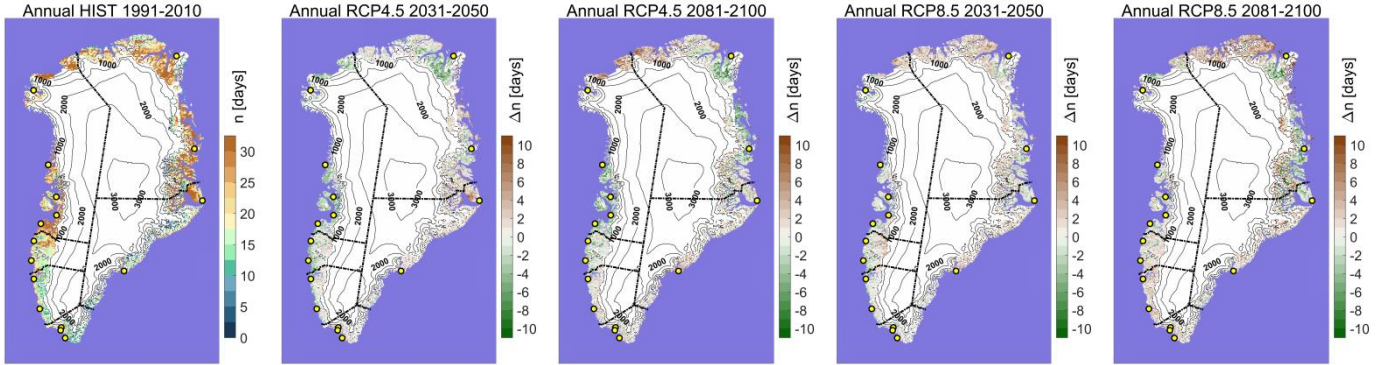




Dmi

Energi-, Forsynings- og Klimaministeriet

Index 64 Longest continuous period with precipitation below 1mm ("dry period") during growing season (2°C)

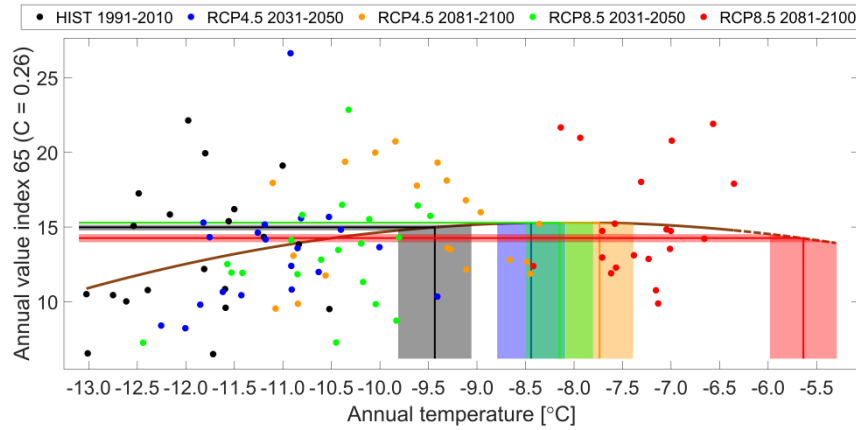
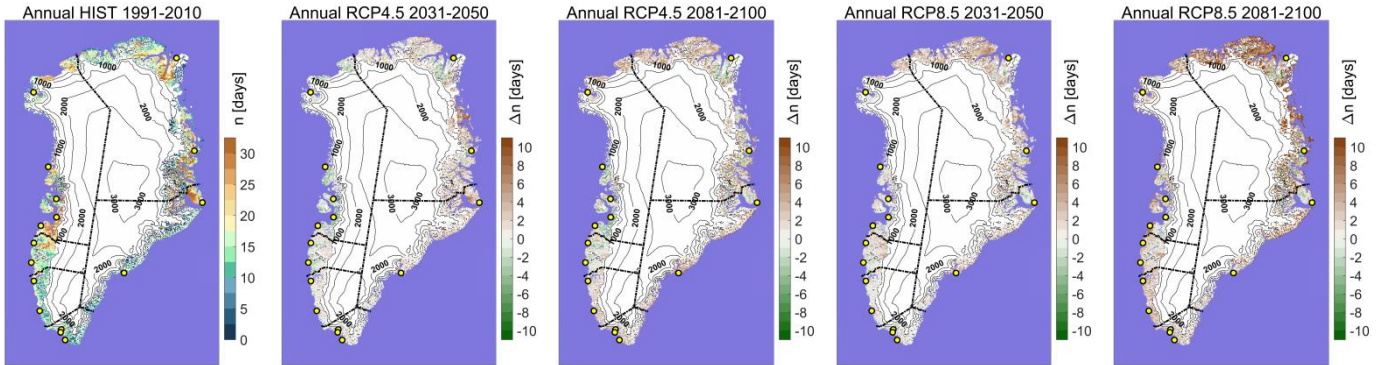




Dmi

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Index 65 Longest continuous period with precipitation below 1mm ("dry period") during growing season (5°C)





Dmi

Energi-, Forsynings- og Klimaministeriet

Index 66 Daily mean sunshine hours, mean value

