Earth System
Dynamics

Supplement of

Comparison of land surface humidity between observations and CMIP5 models

Robert J. H. Dunn et al.

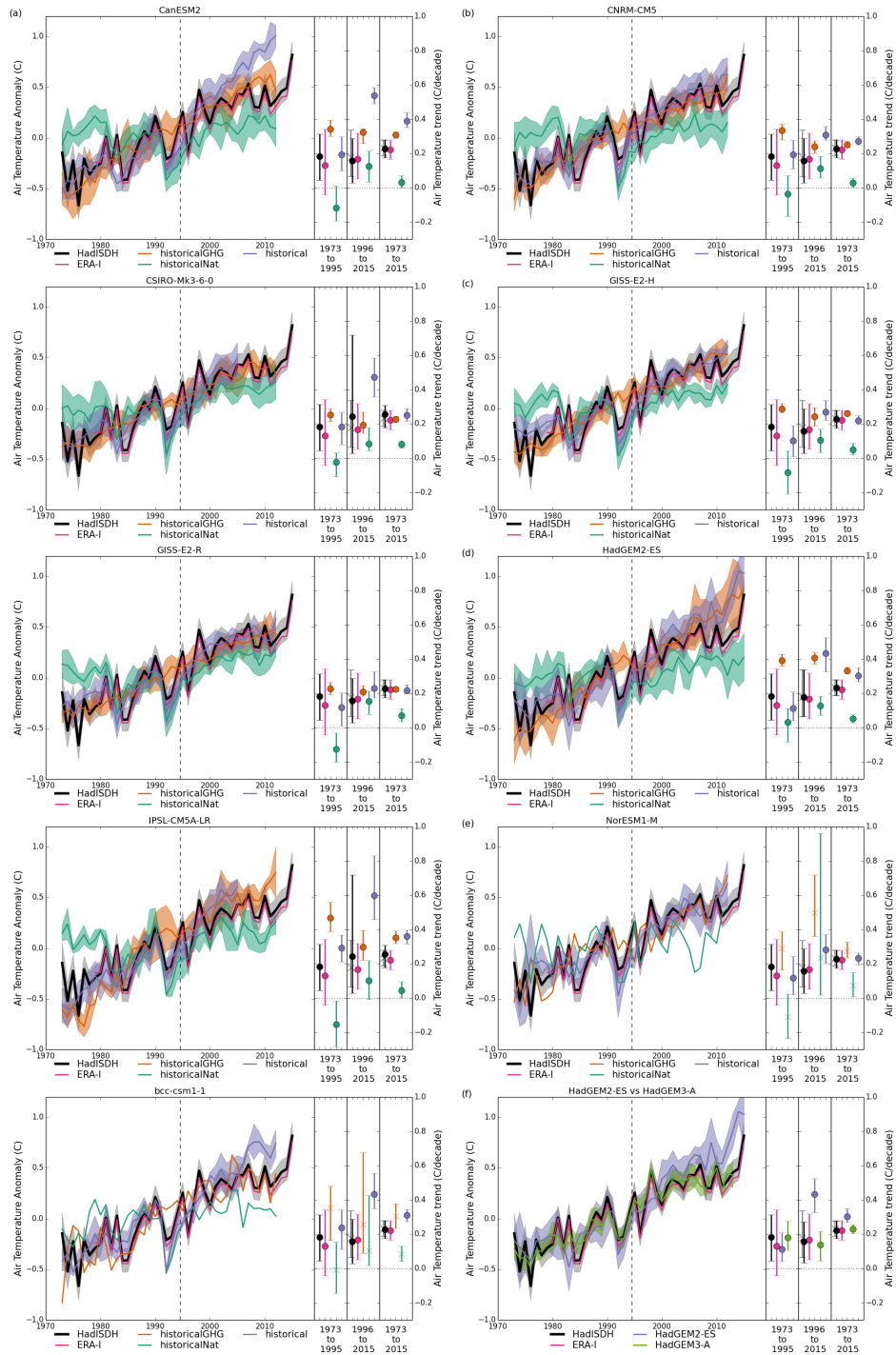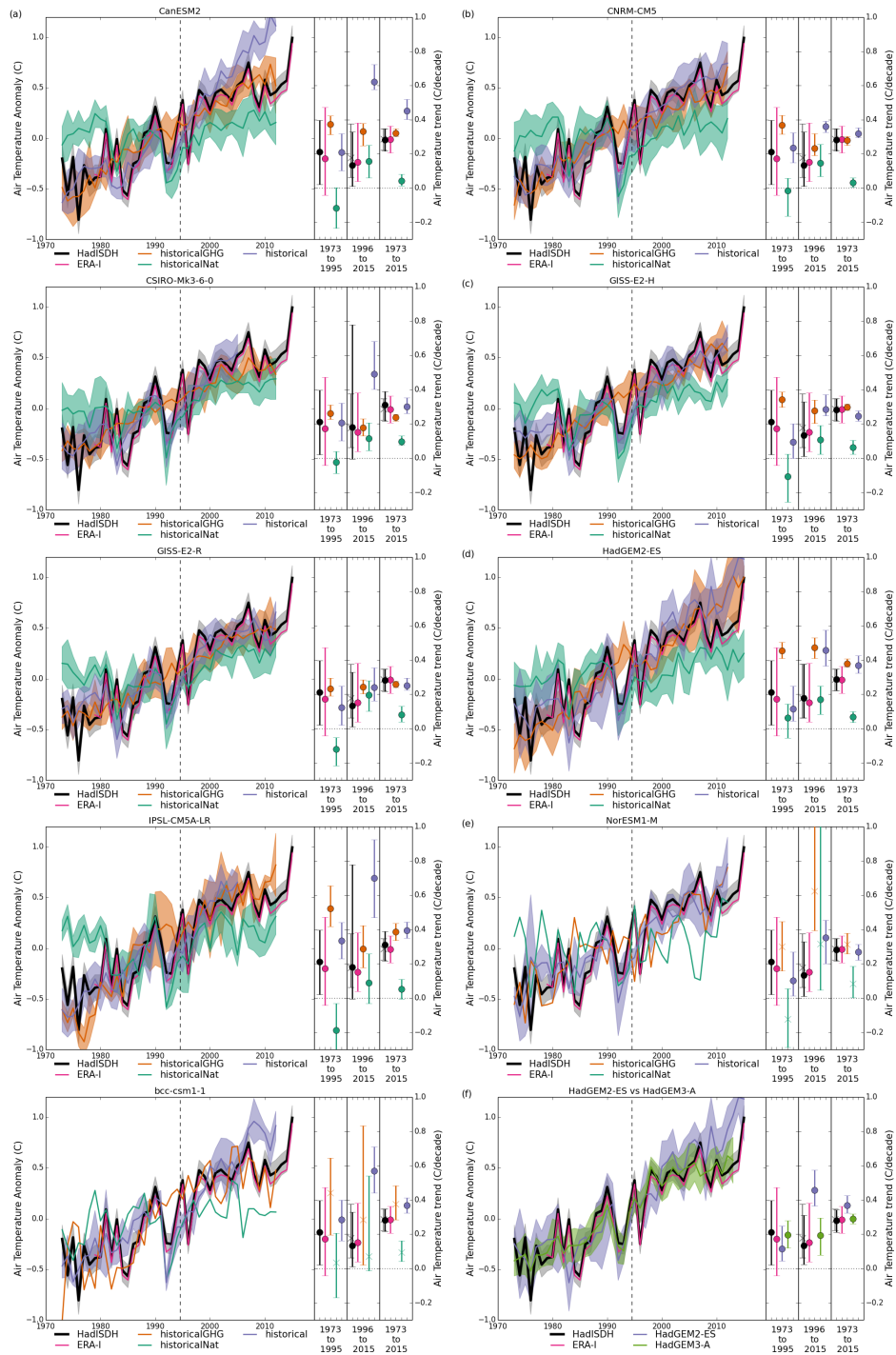*Correspondence to:* Robert J. H. Dunn (robert.dunn@metoffice.gov.uk)
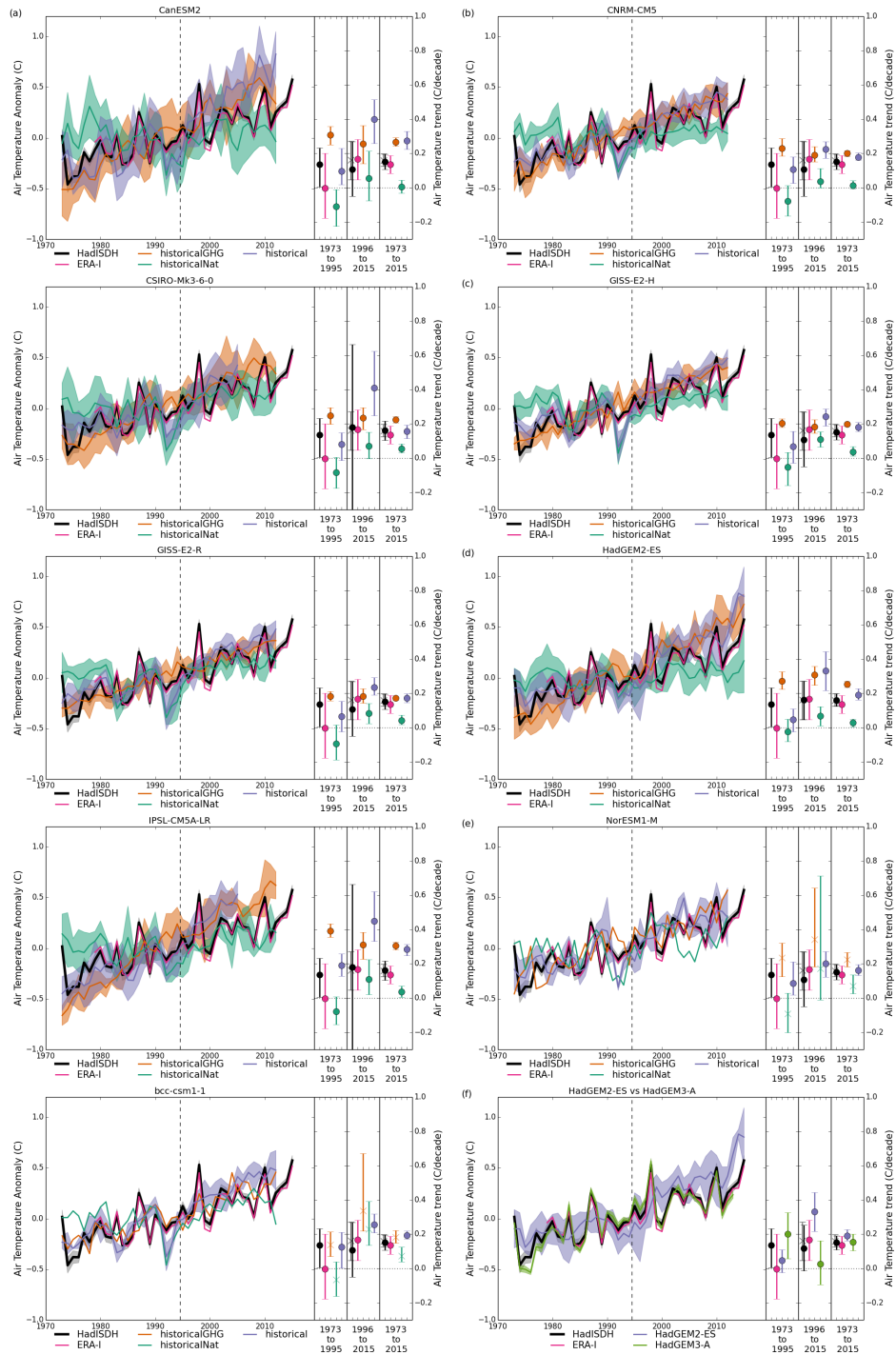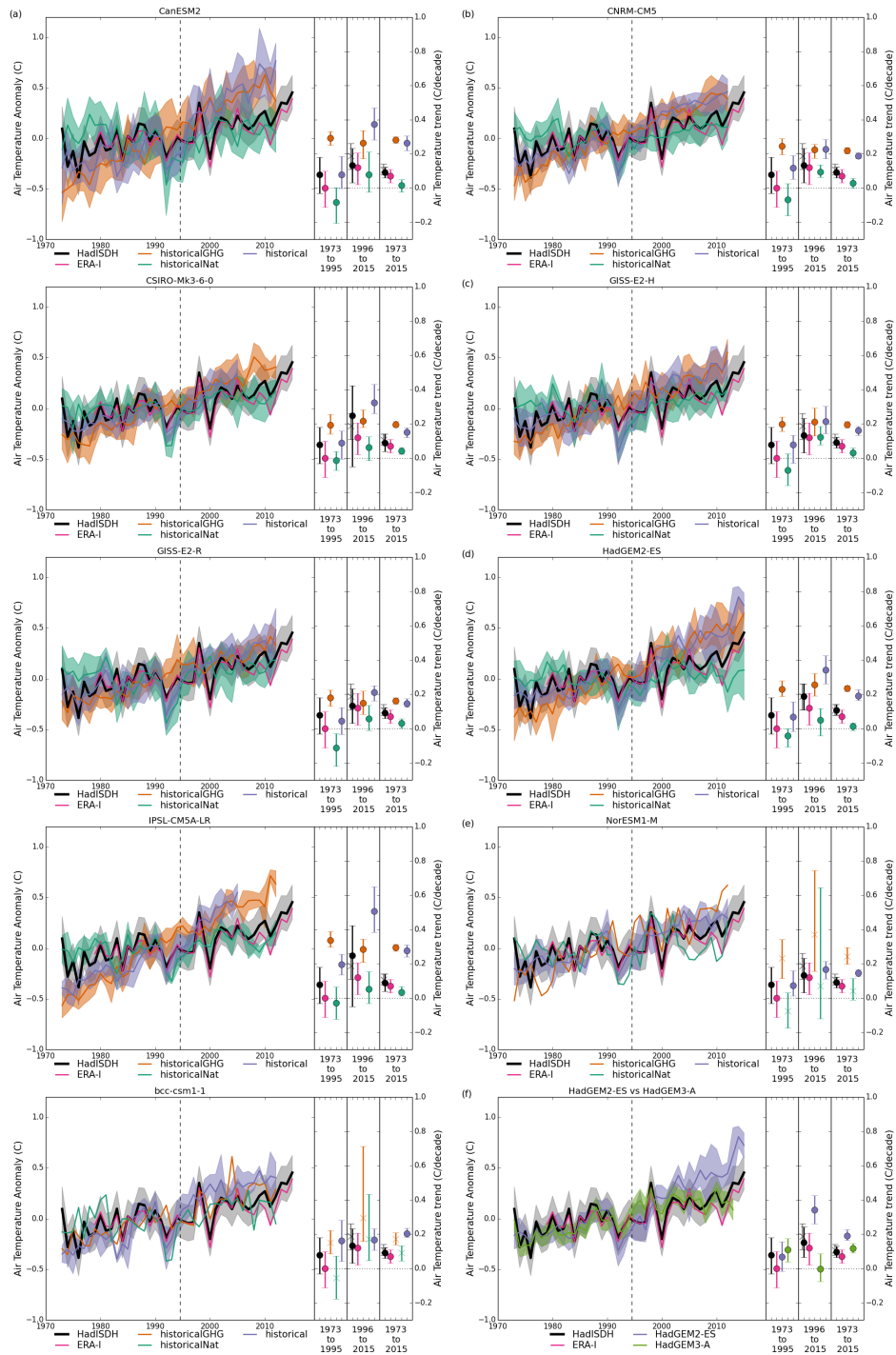
Supplementary Information

Temperature

Figure S1. Global annual timeseries for temperature for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S2. Northern Hemisphere annual timeseries for temperature for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
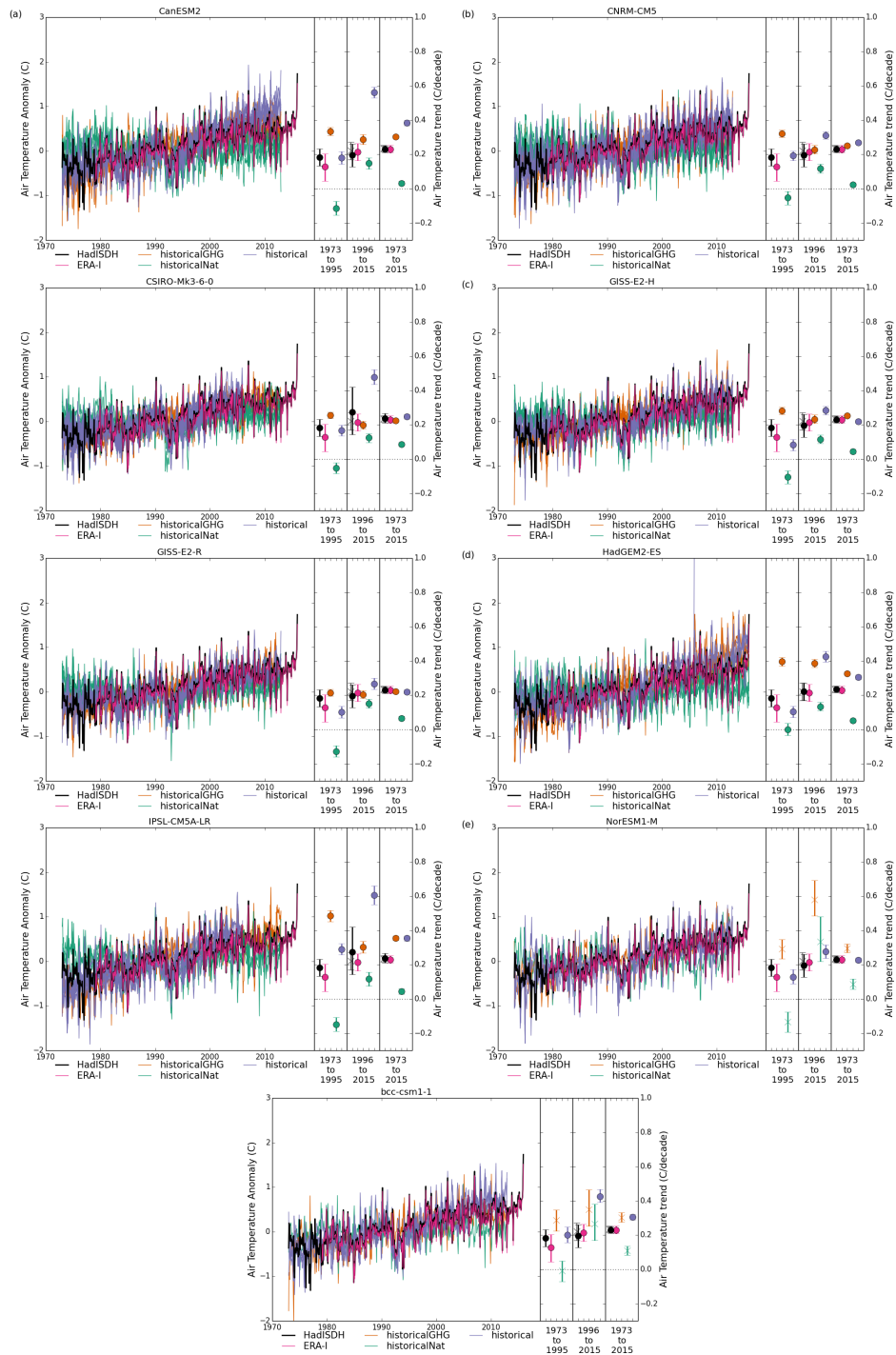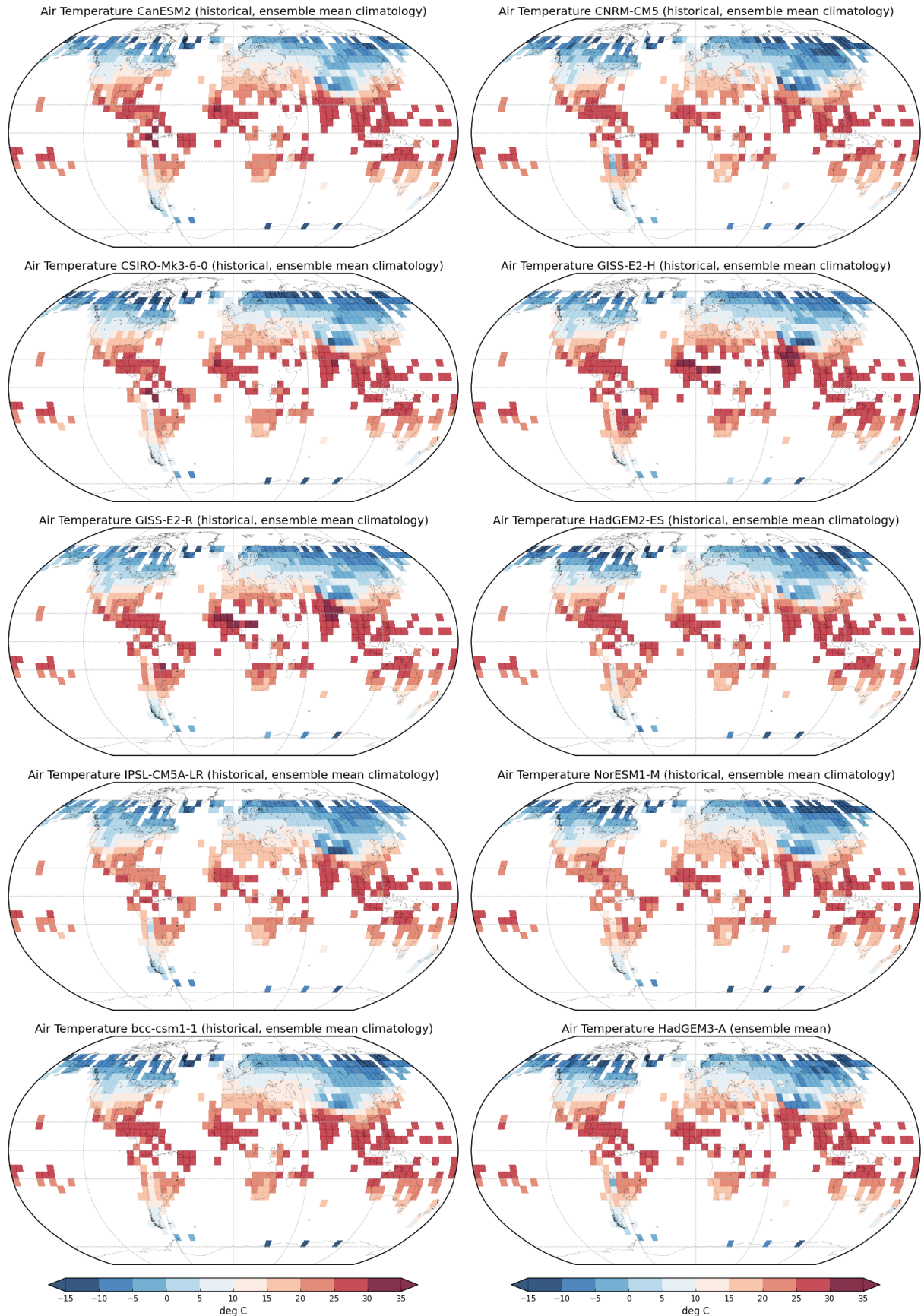
Figure S3. Tropical annual timeseries for temperature for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S4. Southern Hemisphere annual timeseries for temperature for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S5. Global monthly timeseries for temperature for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble members by the purple, green and orange lines respectively. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
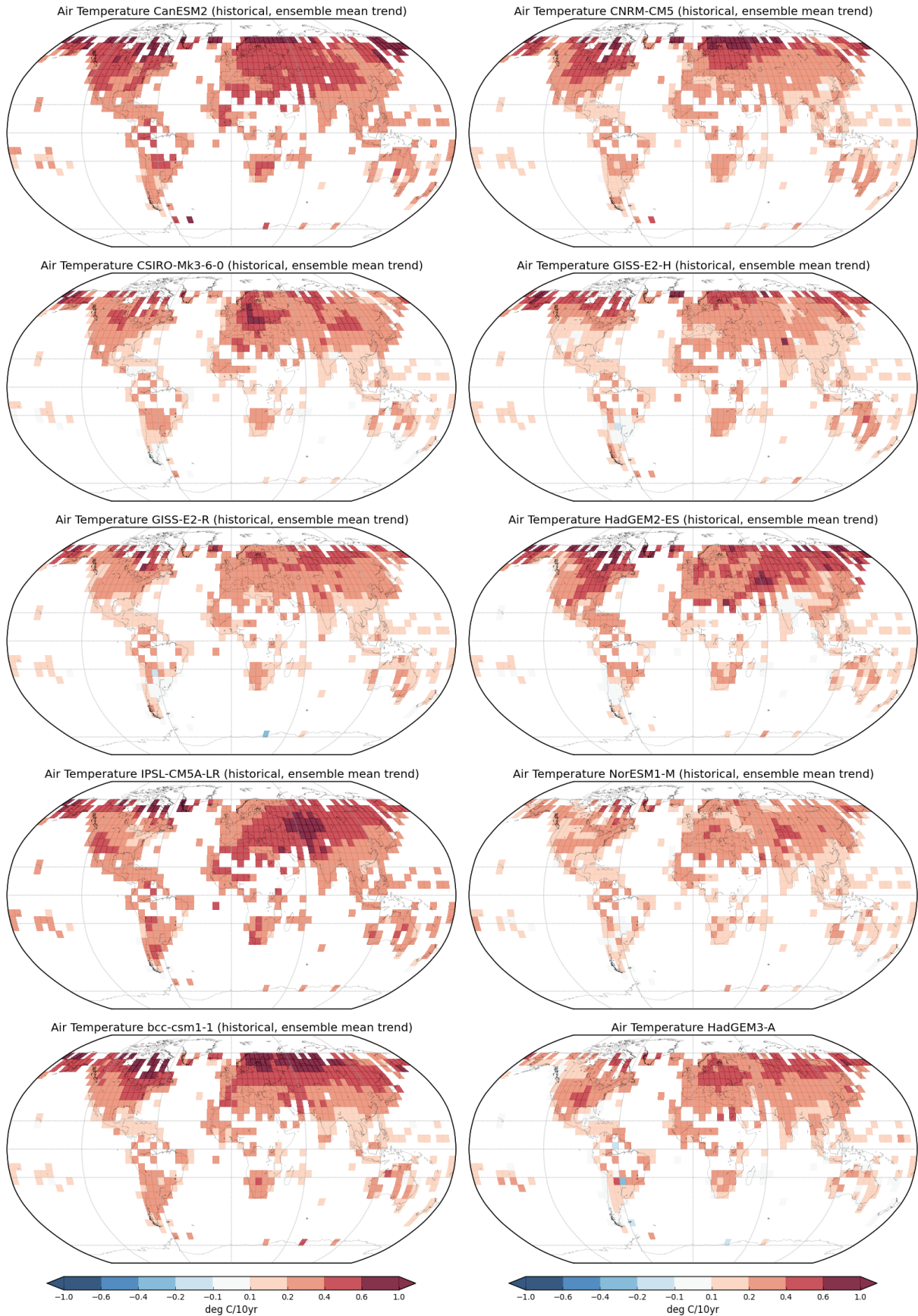
Figure S6. Temperature climatologies of the CMIP5 models at the gridbox scale. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.
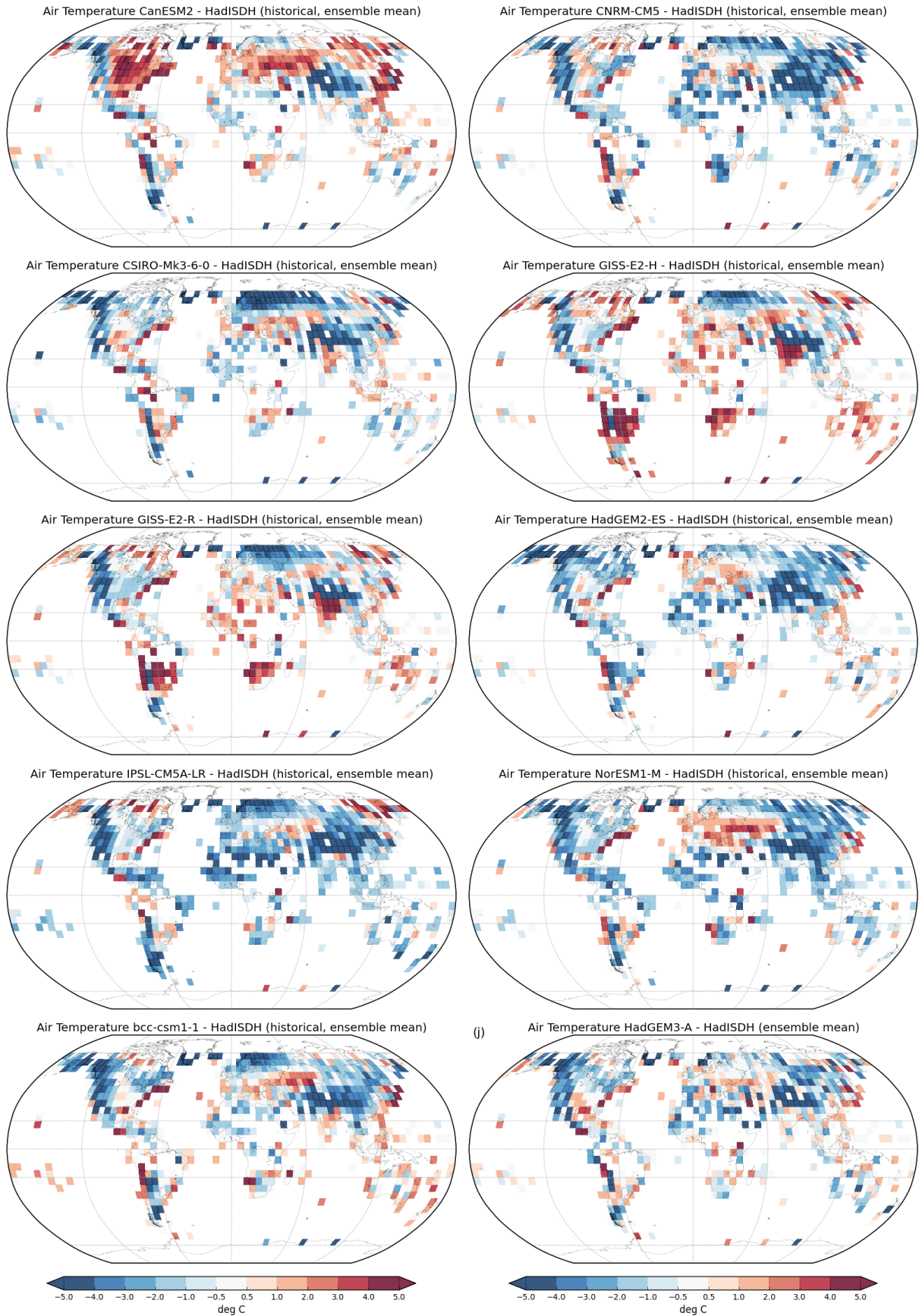
Figure S7. Climatological differences between models and observations at the gridbox scale for temperature. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.

Figure S8. Linear trends of the CMIP5 models at the gridbox scale for temperature. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
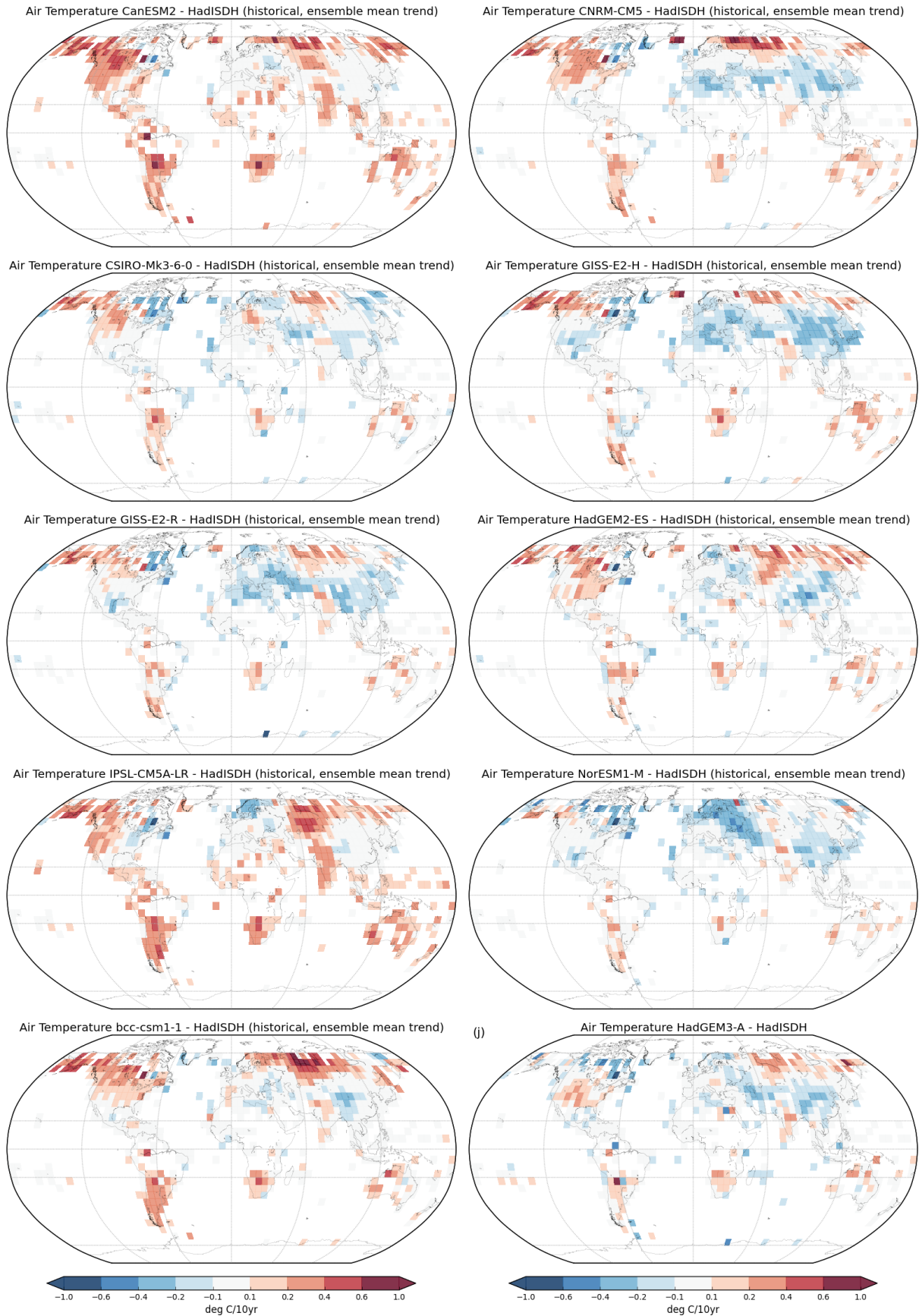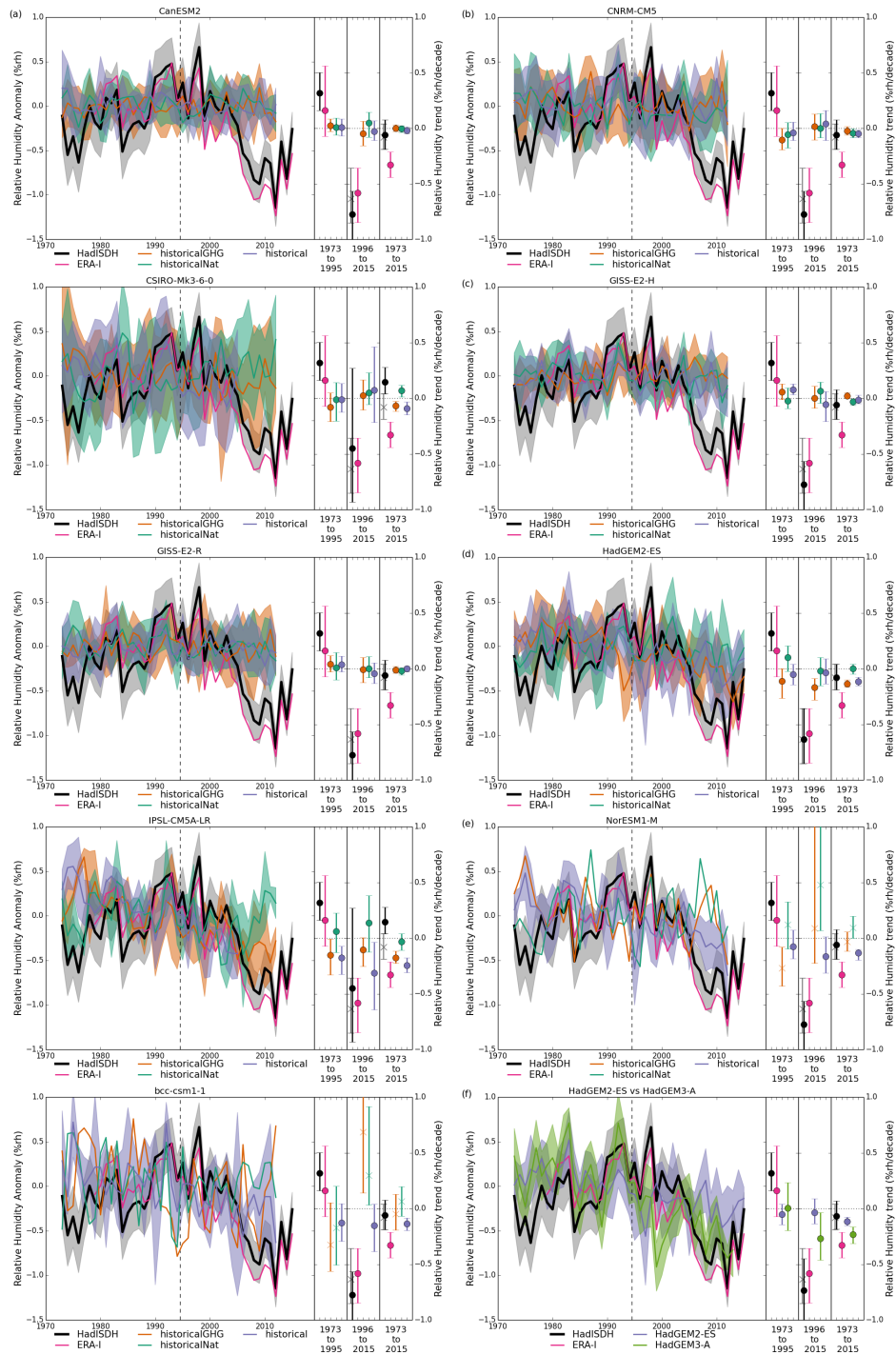
Figure S9. Linear trend differences of the CMIP5 models from the observations at the gridbox scale for temperature. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
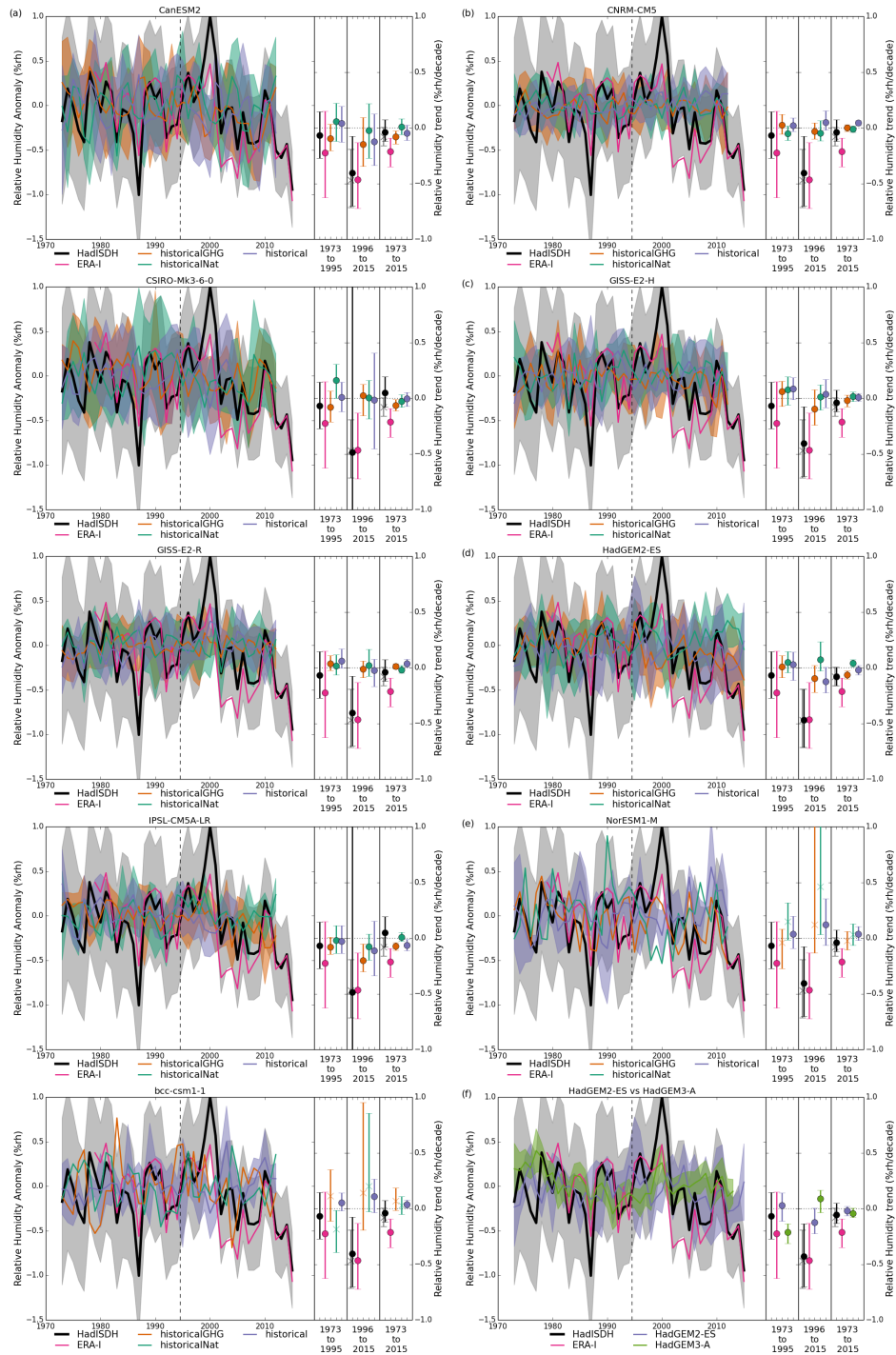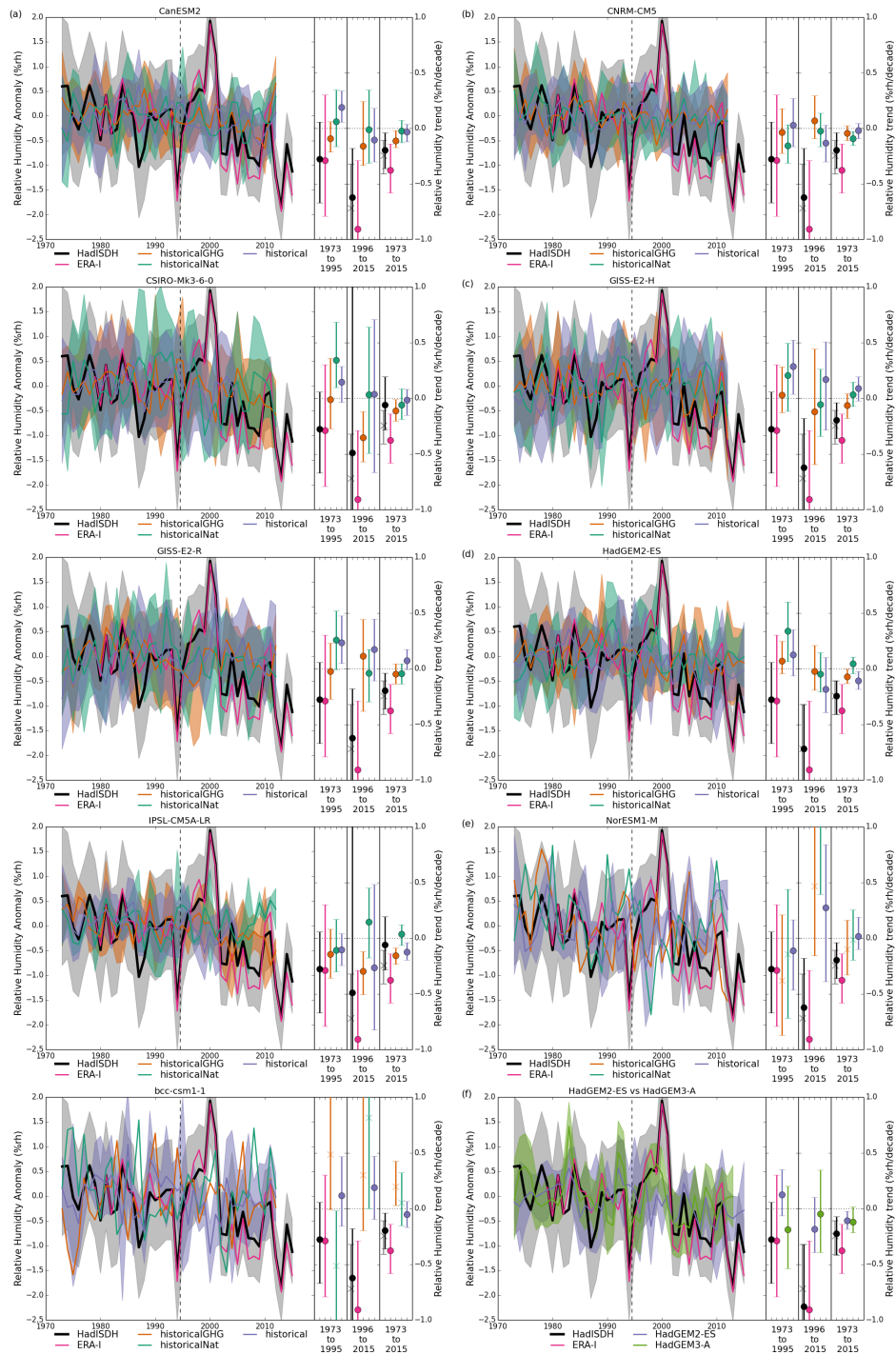
Relative Humidity
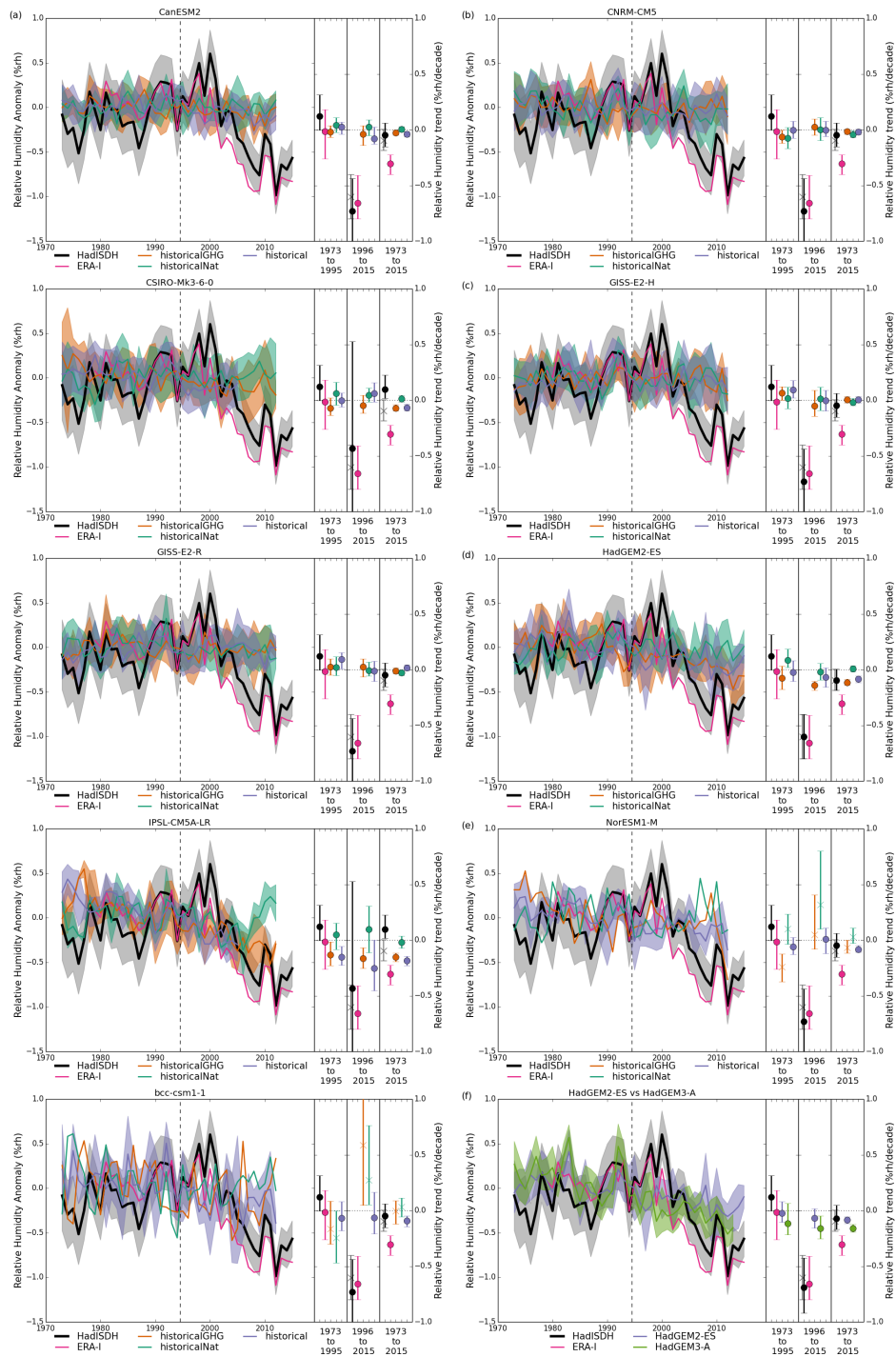
Figure S10. Global annual timeseries for relative humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S11. Northern Hemisphere annual timeseries for relative humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
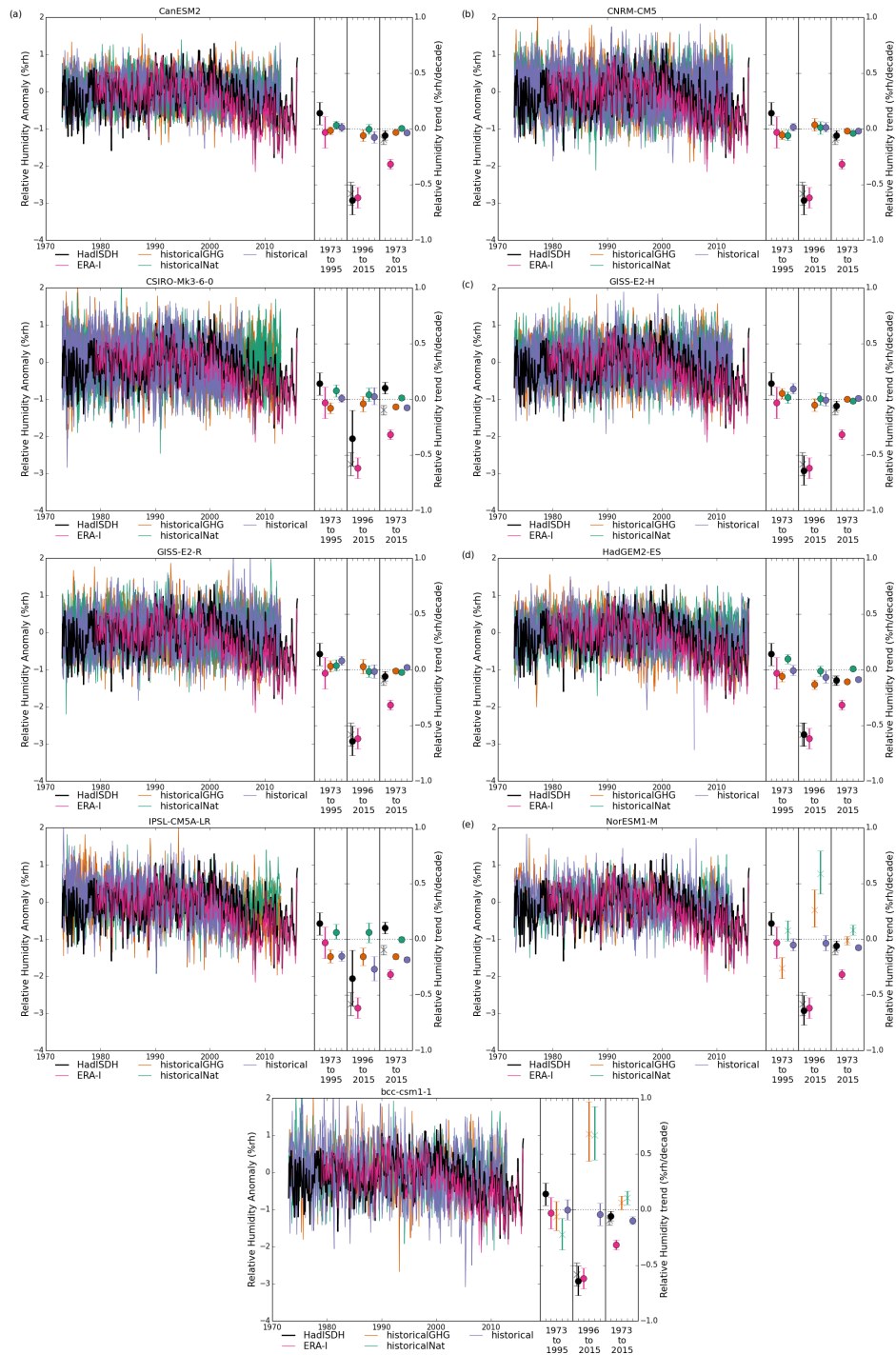
Figure S12. Tropical annual timeseries for relative humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
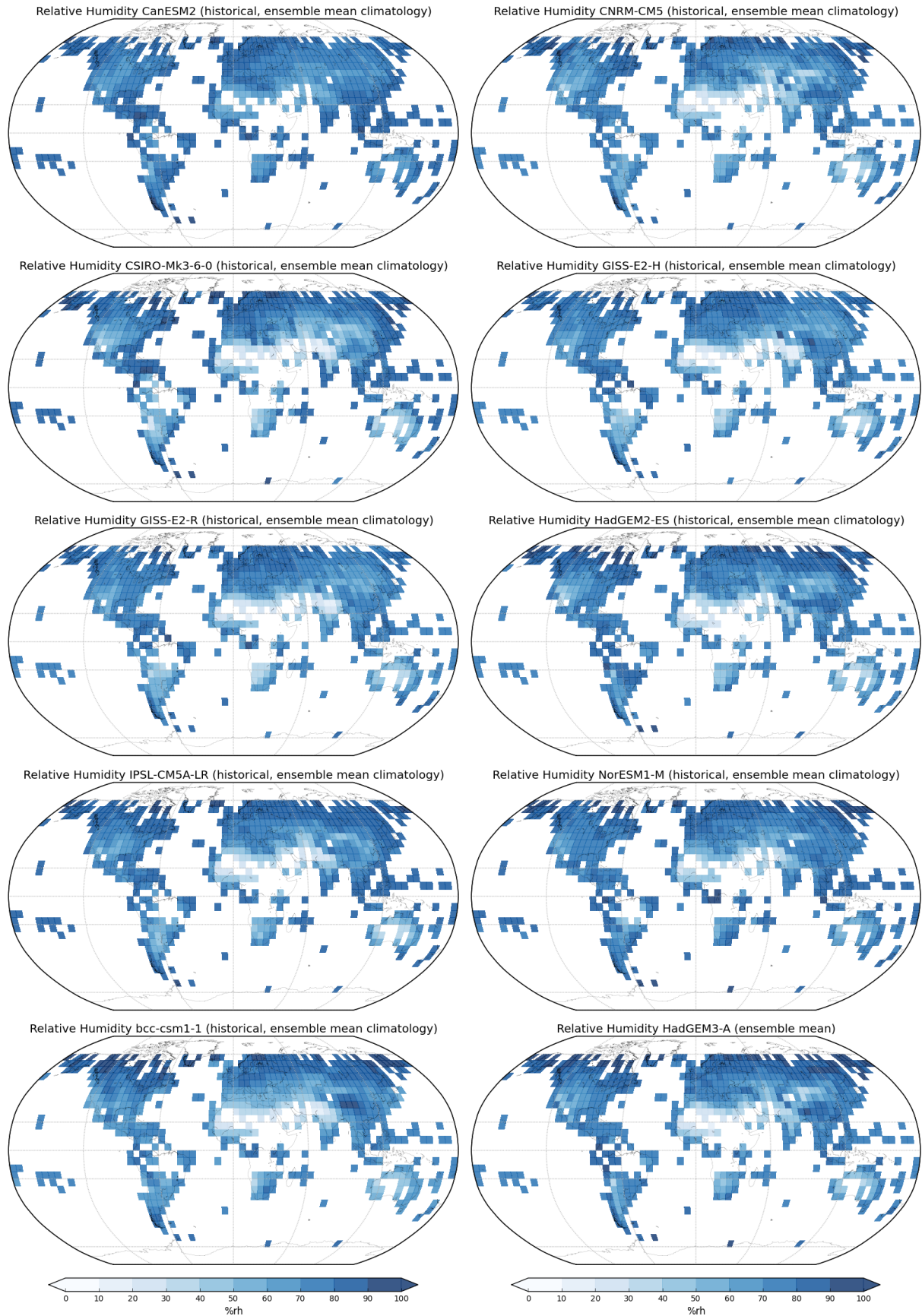
Figure S13. Southern Hemisphere annual timeseries for relative humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S14. Global annual timeseries for relative humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historical-GHG ensemble members by the purple, green and orange lines respectively. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S15. Relative humidity climatologies of the CMIP5 models at the gridbox scale. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.
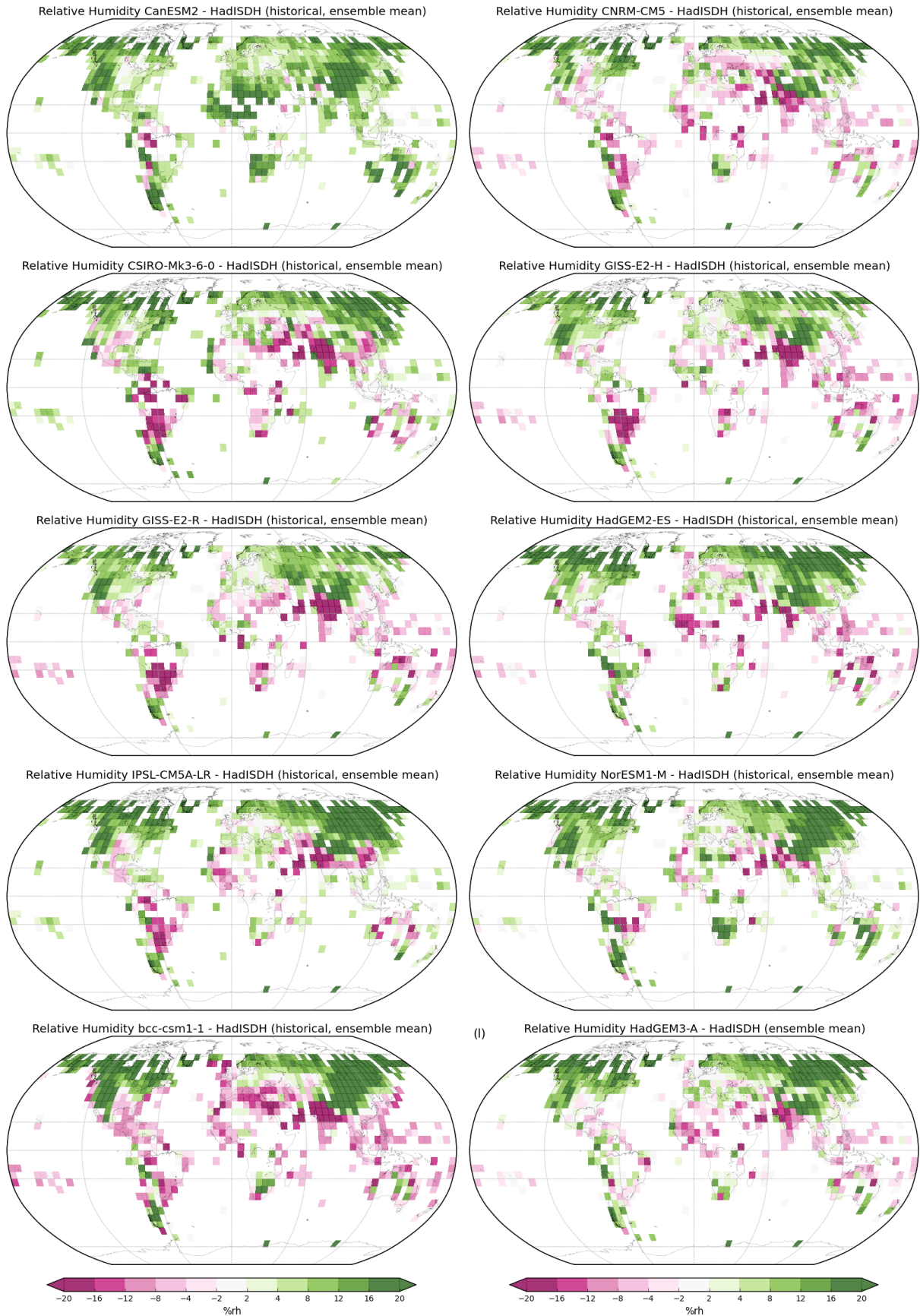
Figure S16. Climatological differences between models and observations at the gridbox scale for relative humidity. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.
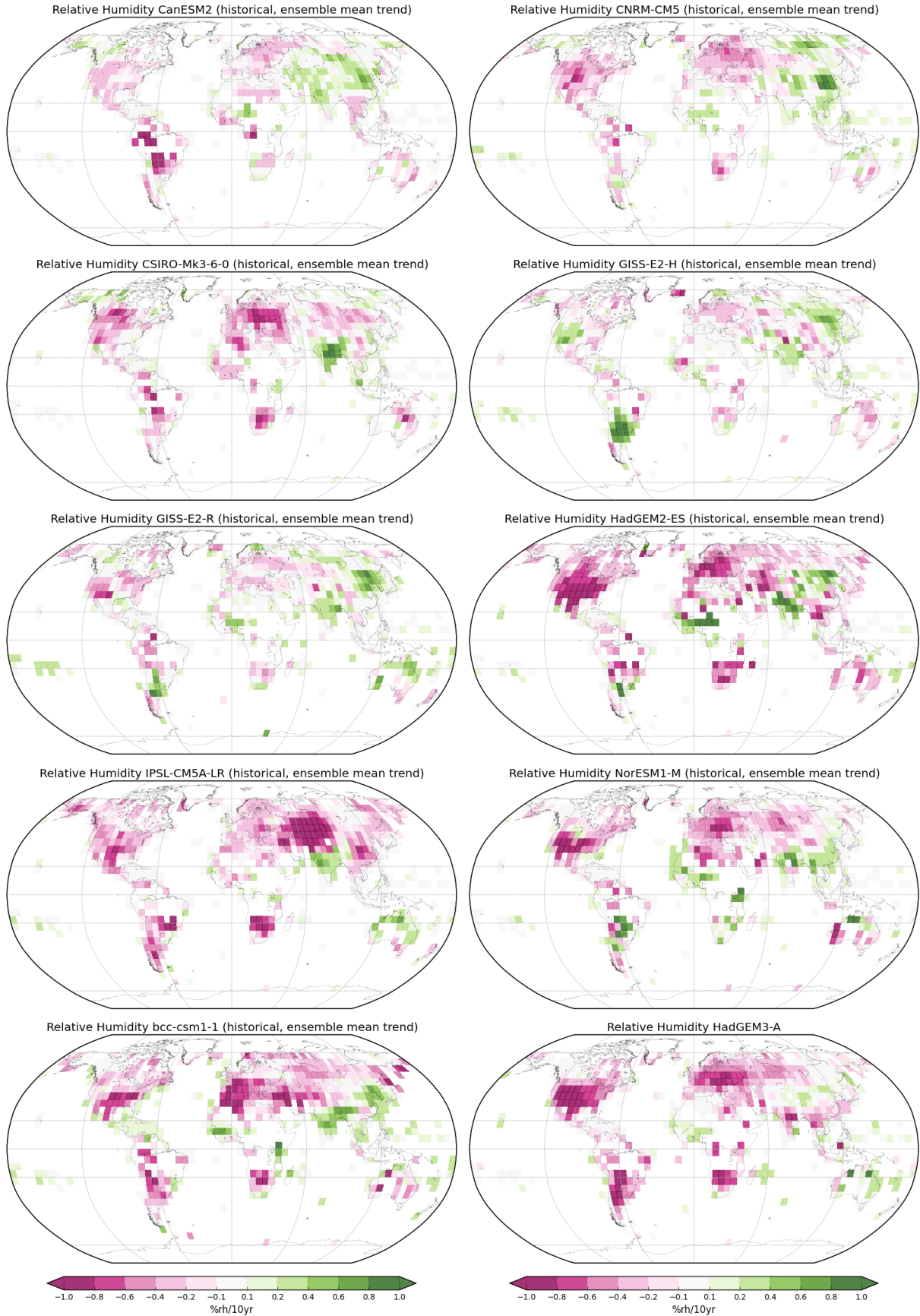
Figure S17. Linear trends of the CMIP5 models at the gridbox scale for relative humidity. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
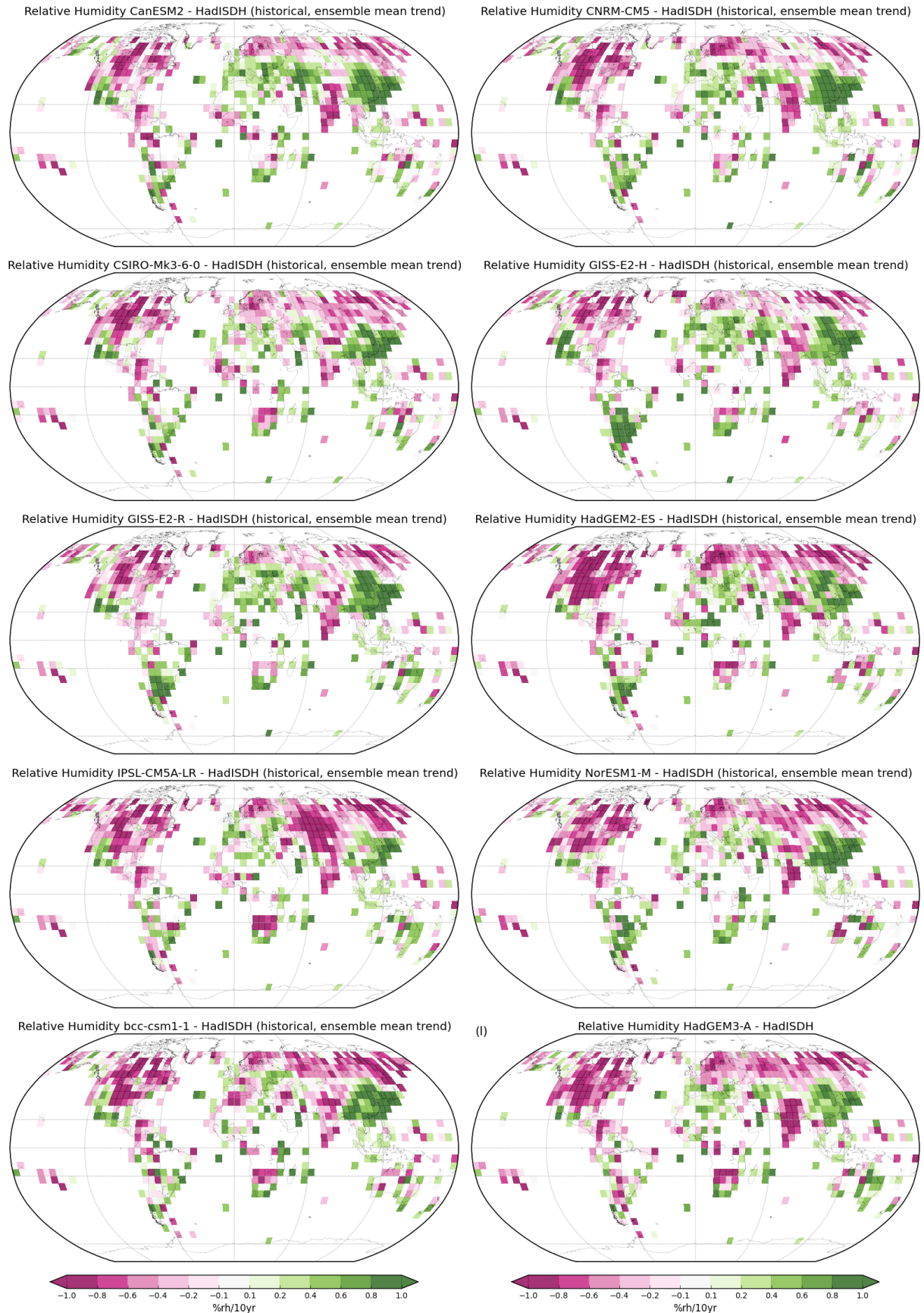
Figure S18. Linear trend differences of the CMIP5 models from the observations at the gridbox scale for relative humidity. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
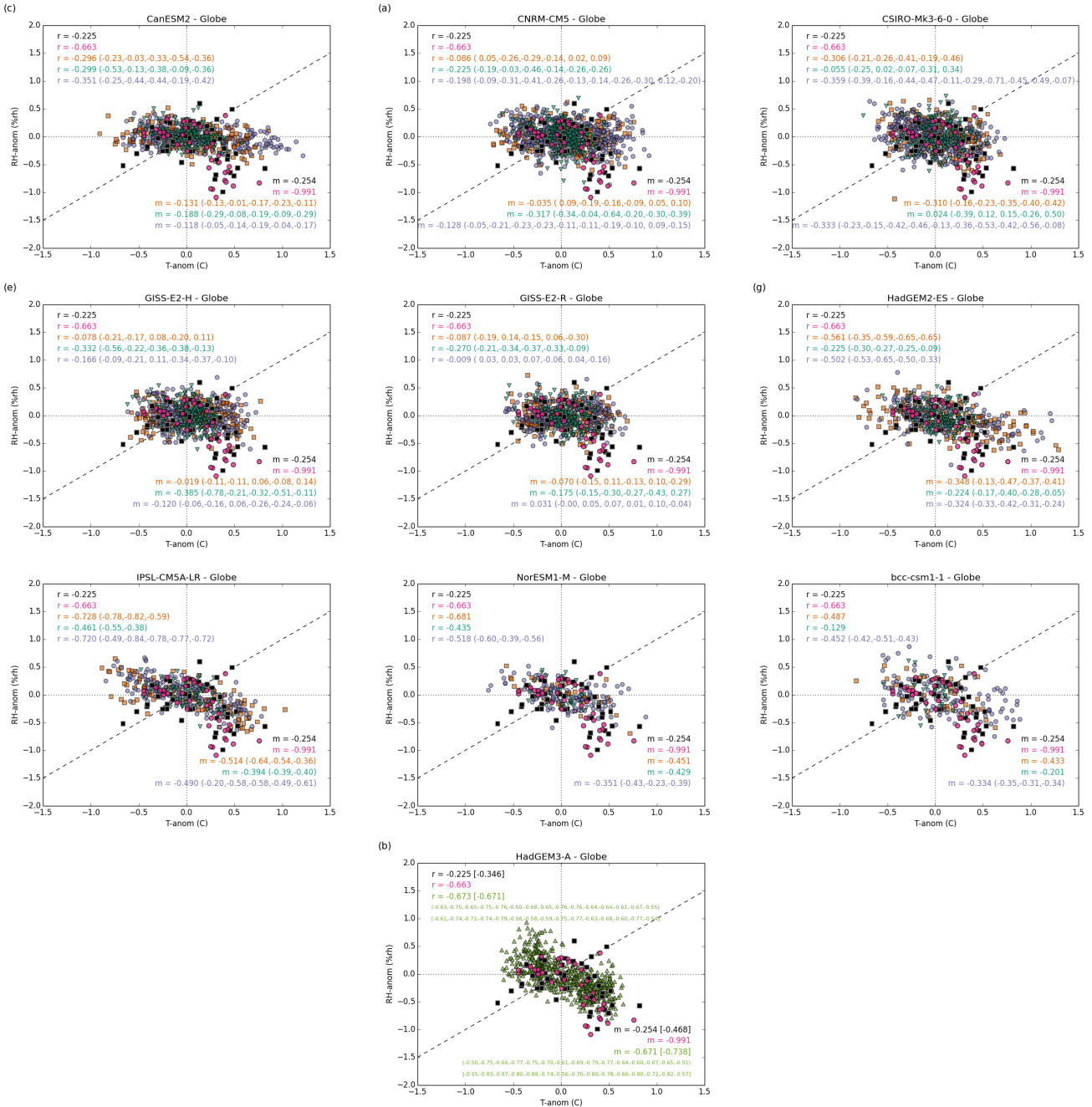
Figure S19. Relationships in global average temperature and relative humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
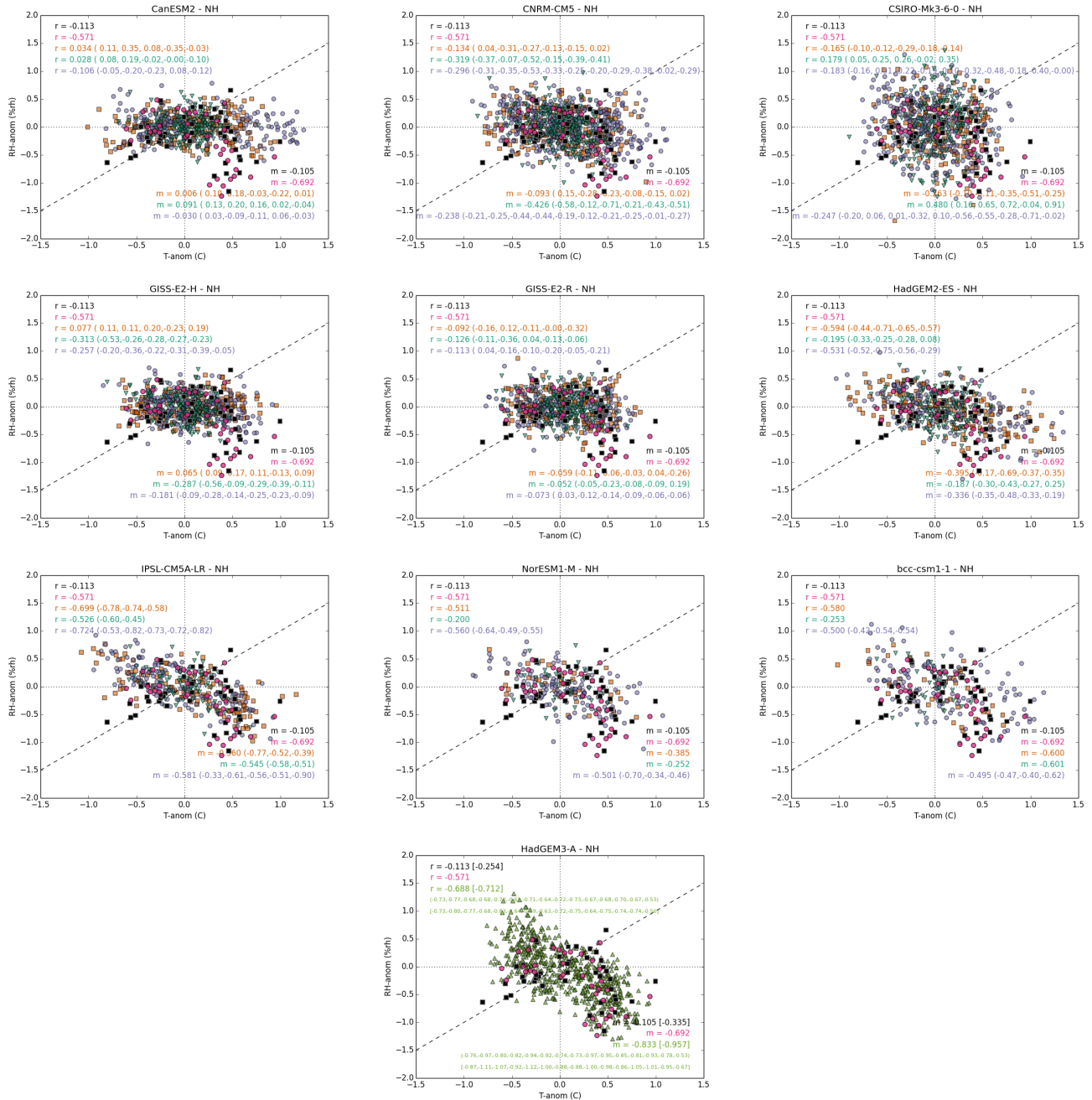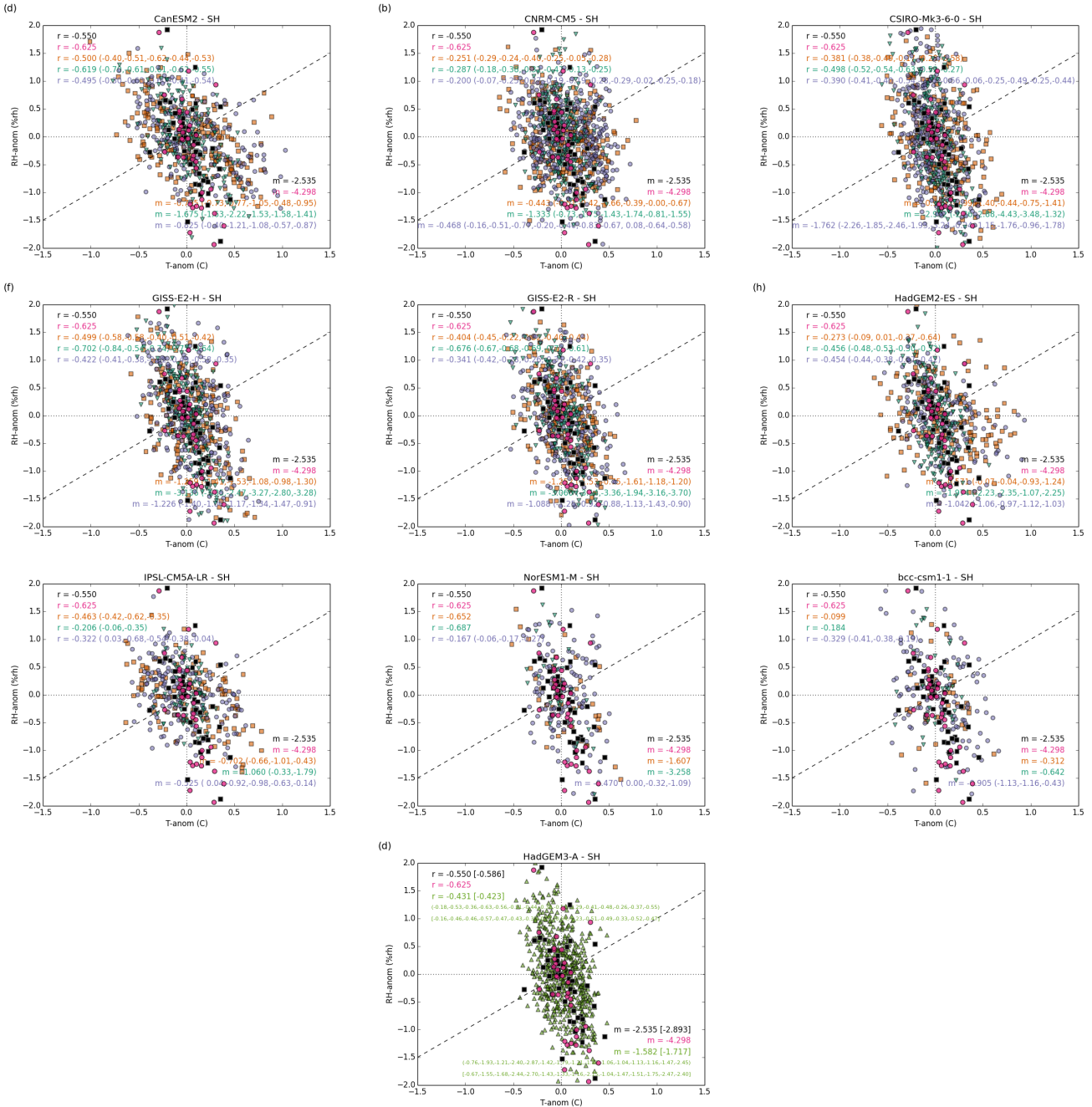
Figure S20. Relationships in Northern Hemisphere average temperature and relative humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
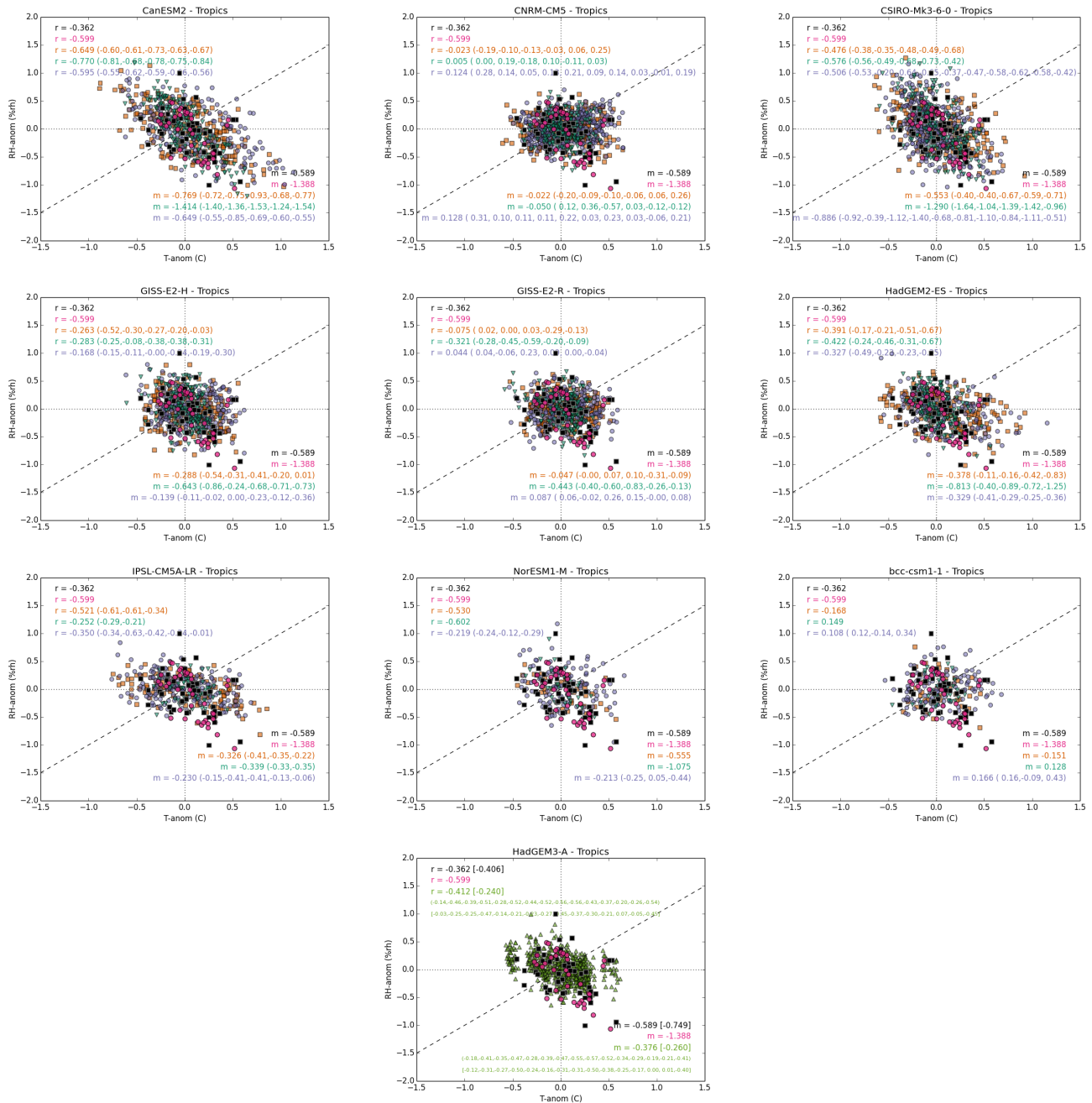
Figure S21. Relationships in tropical average temperature and relative humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.

Figure S22. Relationships in Southern Hemisphere average temperature and relative humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
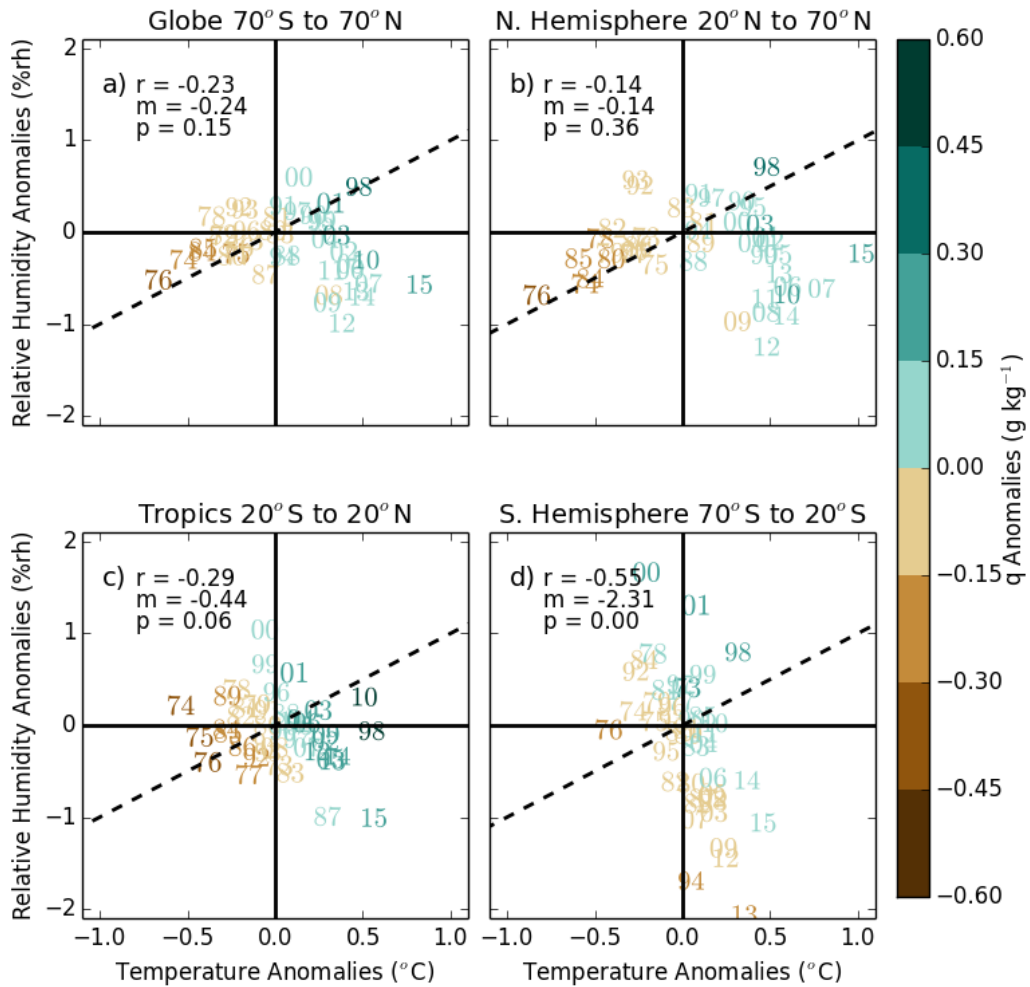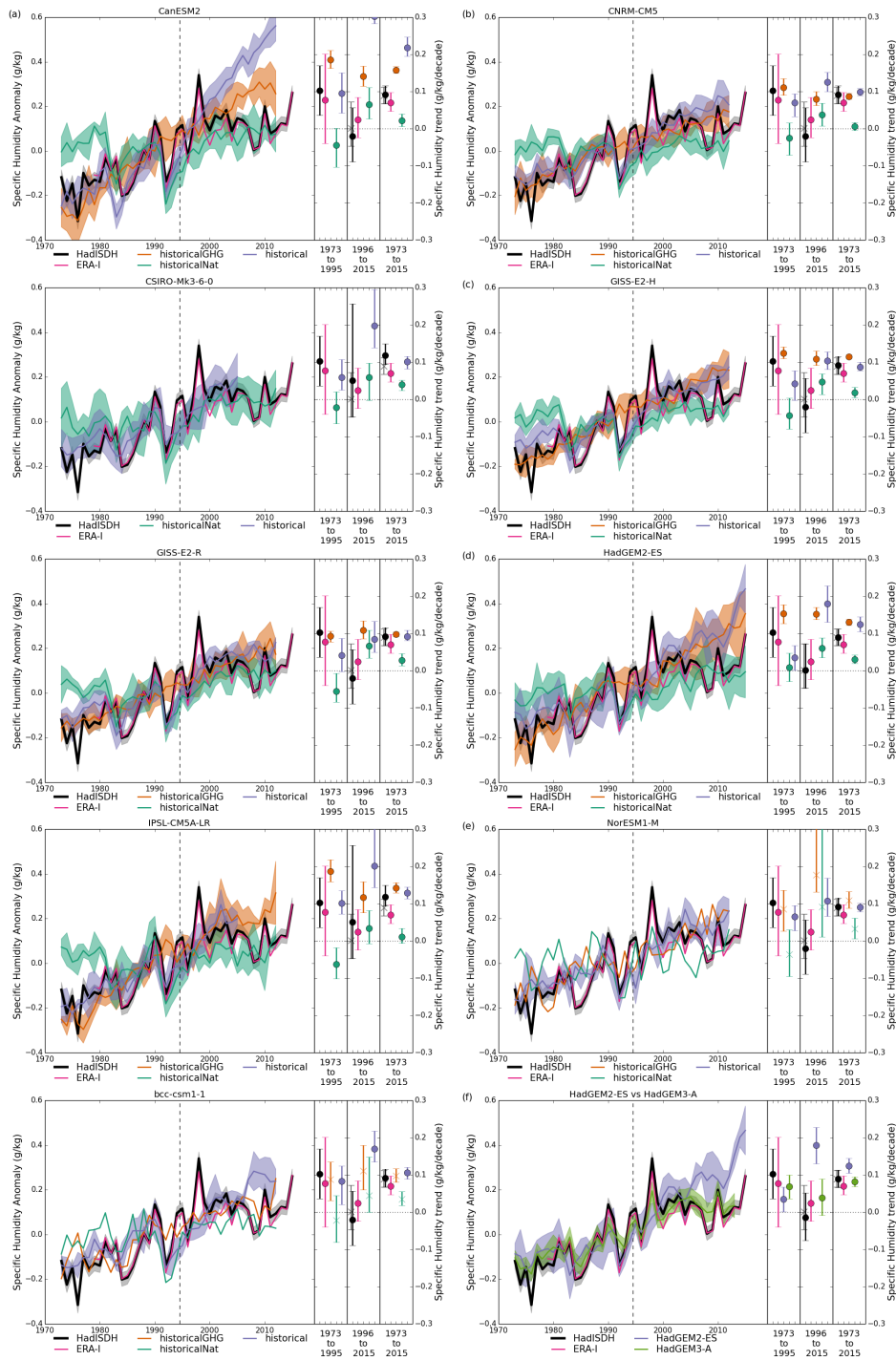
Figure S23. Temperature-relative humidity relationship, with the relative humidity anomaly as the colour scale, with the years as the points. The four zonal regions used in this analysis are shown in the four panels.
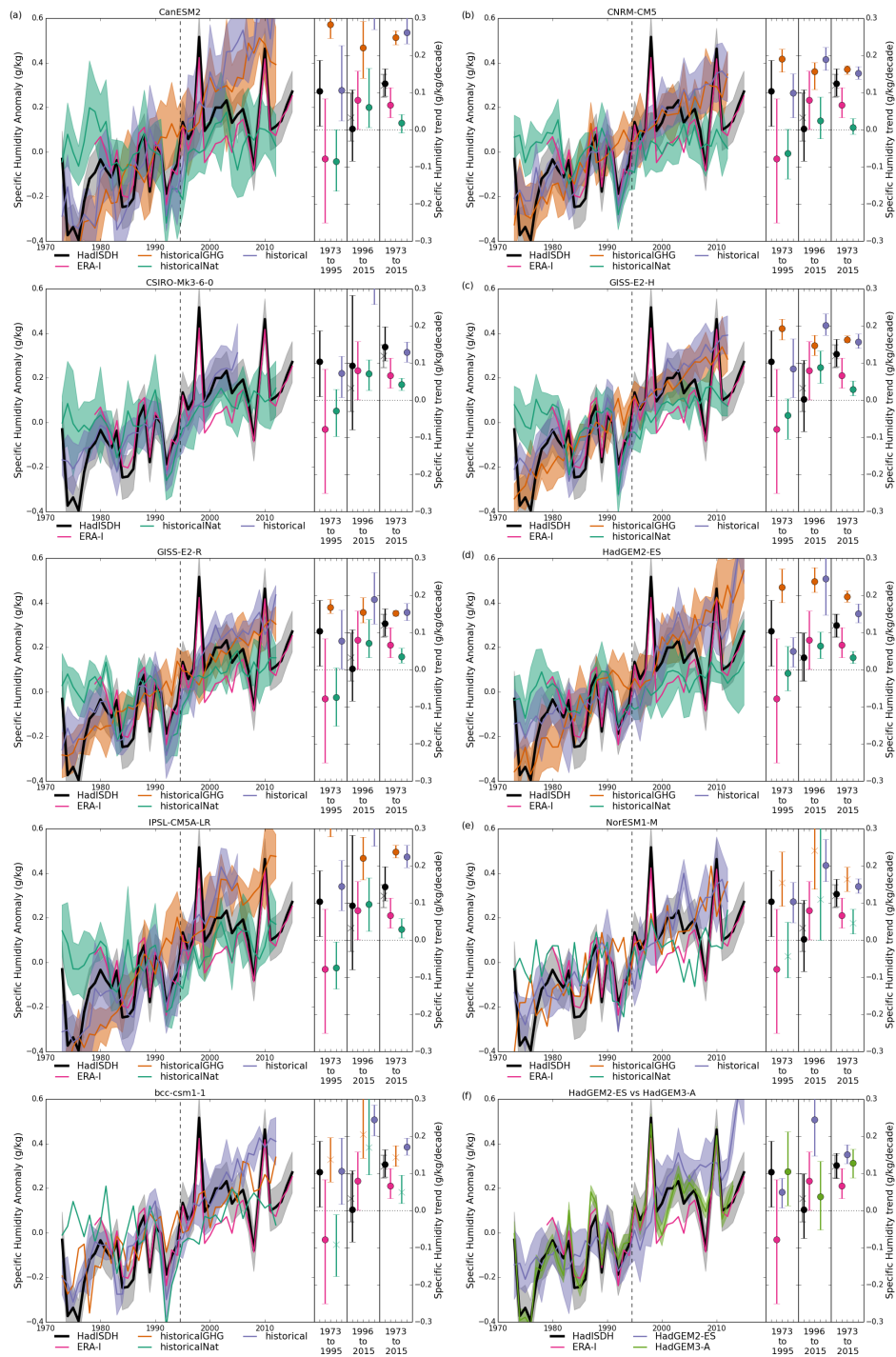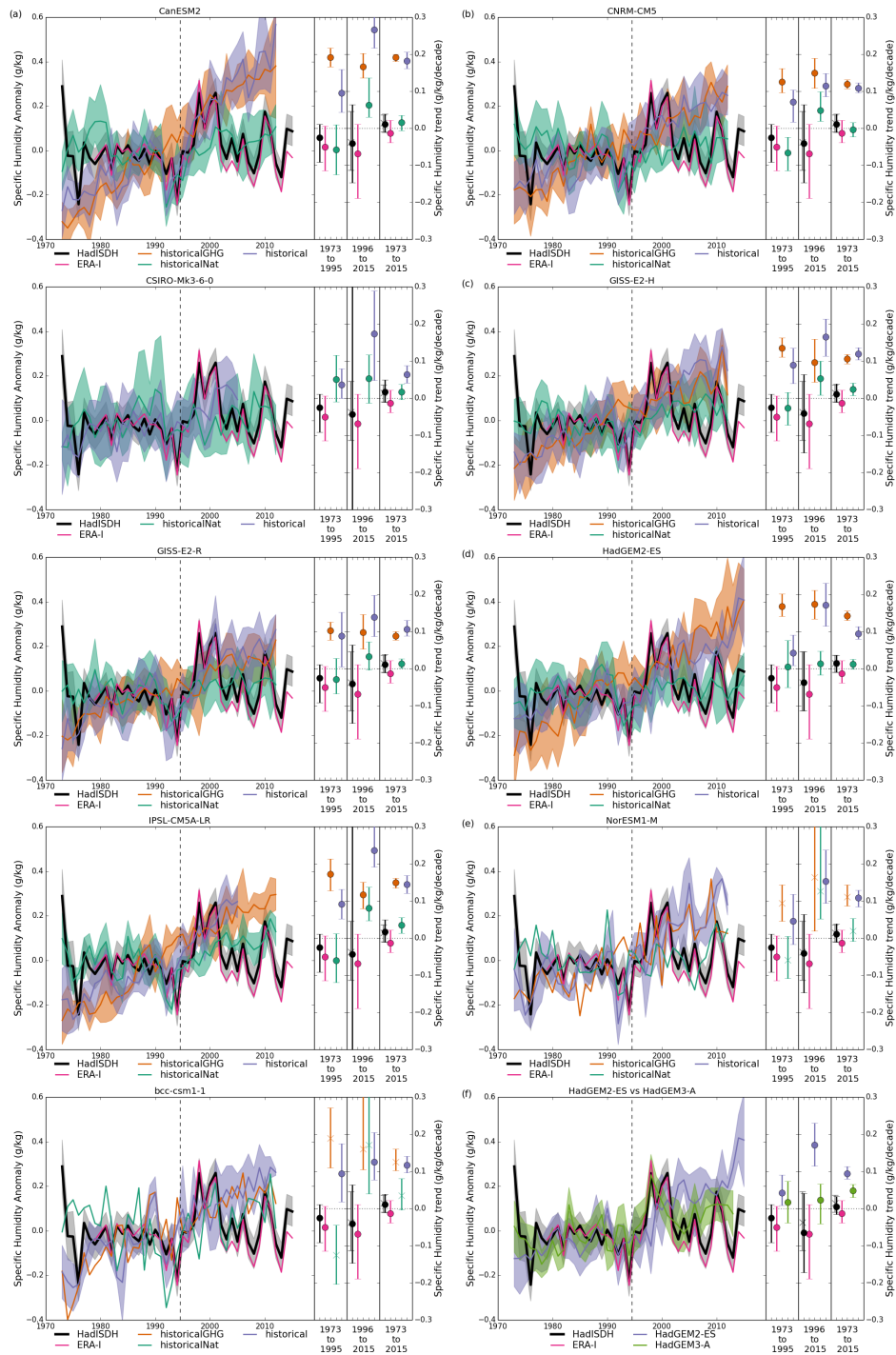
Specific Humidity
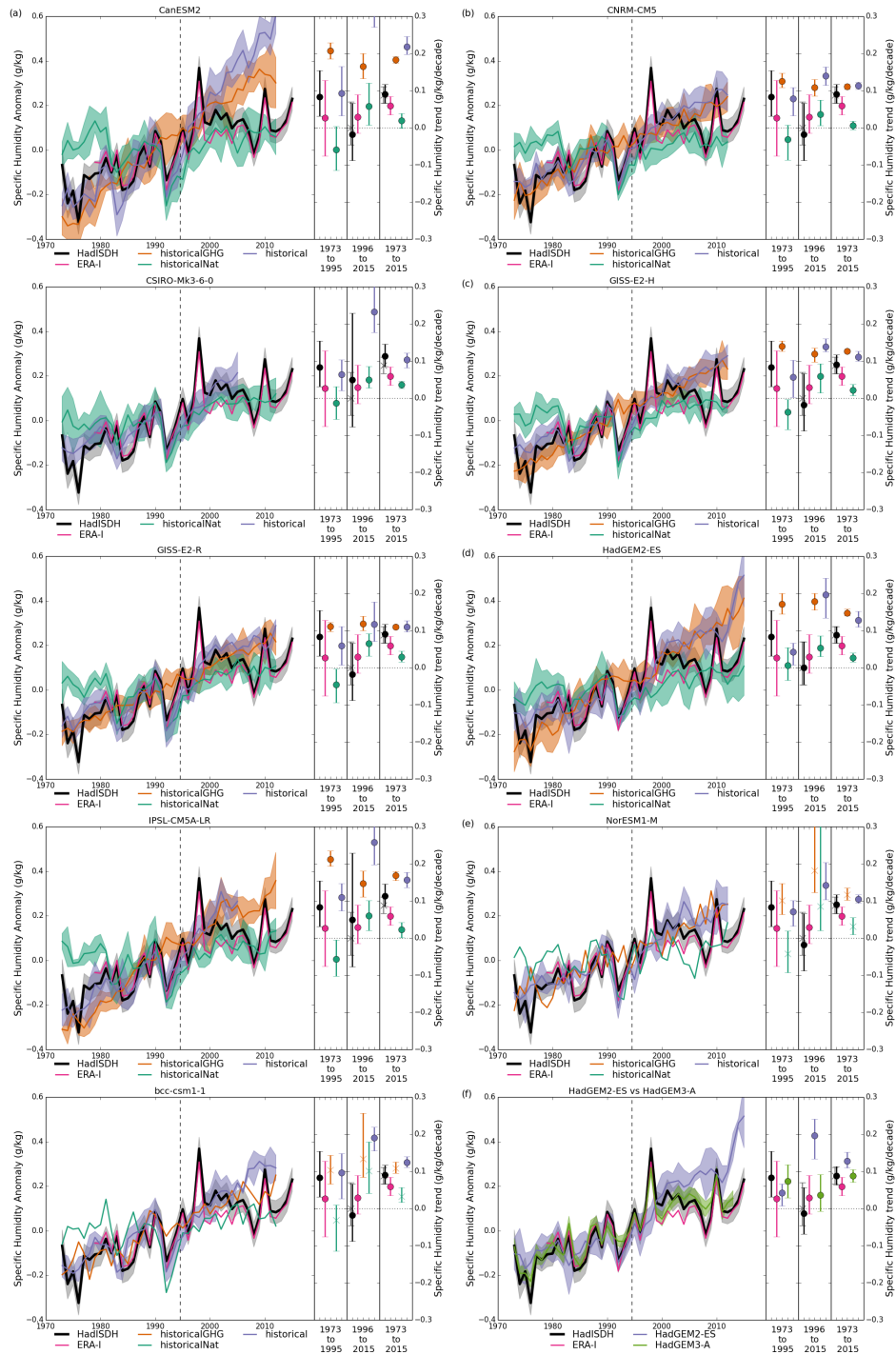
Figure S24. Global annual timeseries for specific humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
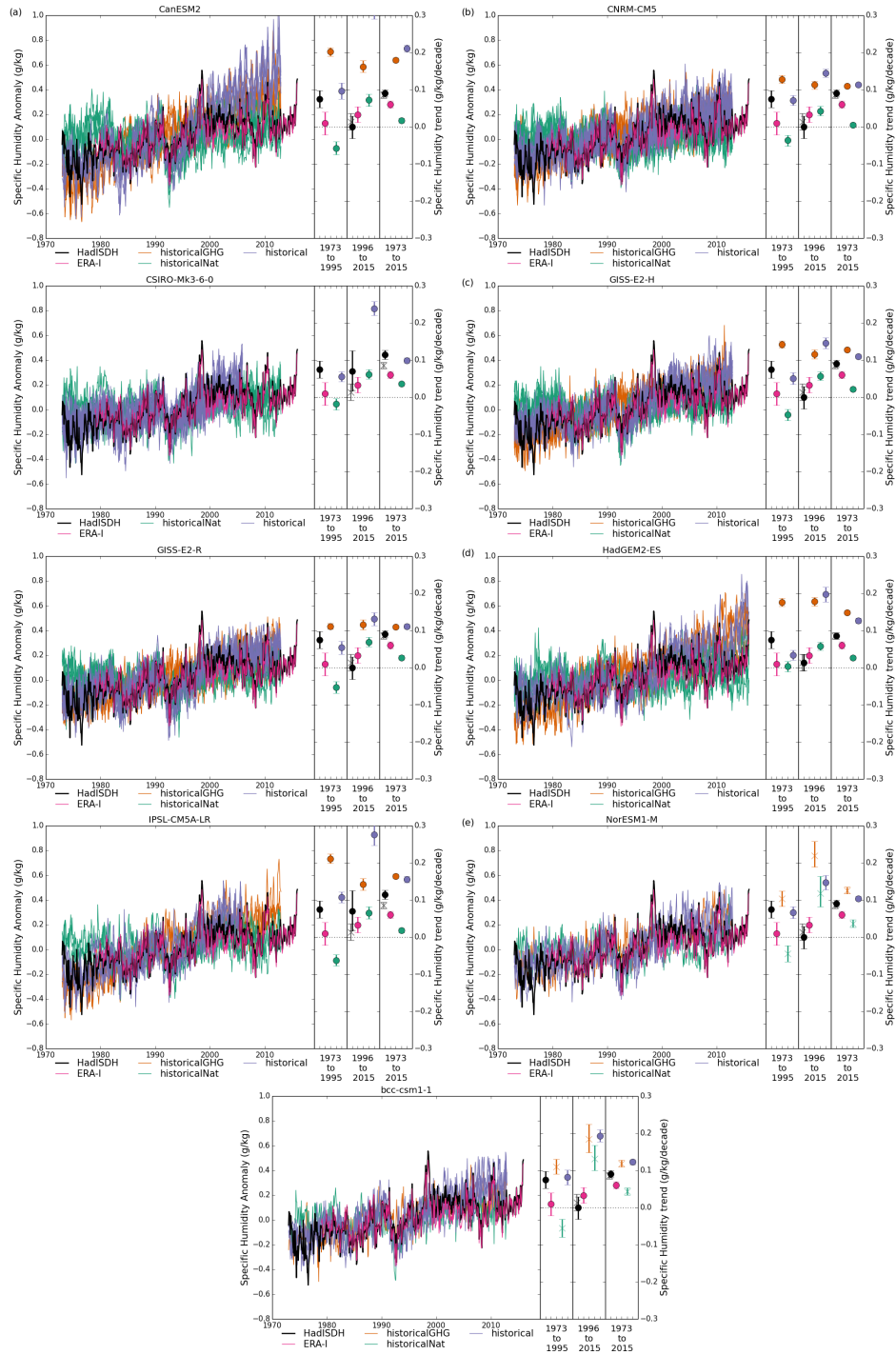
Figure S25. Northern Hemisphere annual timeseries for specific humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S26. Tropical annual timeseries for specific humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.
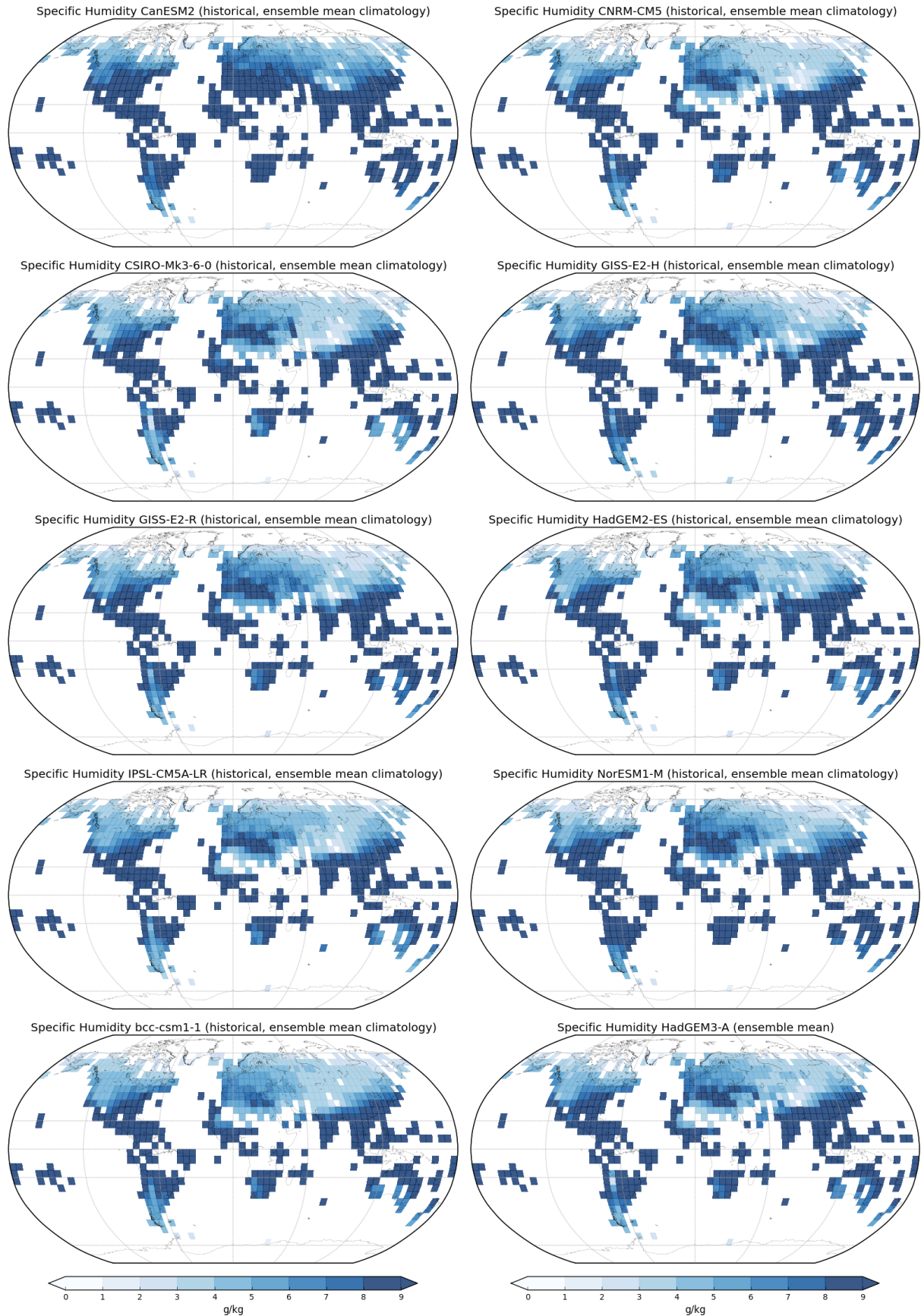
Figure S27. Southern Hemisphere annual timeseries for specific humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble averages by the purple, green and orange lines respectively. The uncertainty ranges are shown using the coloured shading. The right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S28. Global monthly timeseries for specific humidity for the nine CMIP5 models and HadGEM3-A, using a climatology period of 1976-2005. HadISDH is shown by the thick black line, ERA-Interim by the magenta line and the historical, historicalNat and historicalGHG ensemble members by the purple, green and orange lines respectively. he right-hand panels show the values of the linear trends for HadISDH, ERA-Interim and the ensemble averages of all three experiments for the early (1973-1994), late (1995-2015) and full periods. For the late and full period panels, the HadISDH trend is shown matching the temporal coverage of the *historical* model (circle) and its full coverage (cross). If there is only one ensemble member for the model, then the trend is marked with a cross rather than circle.

Figure S29. Specific humidity climatologies of the CMIP5 models at the gridbox scale. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.
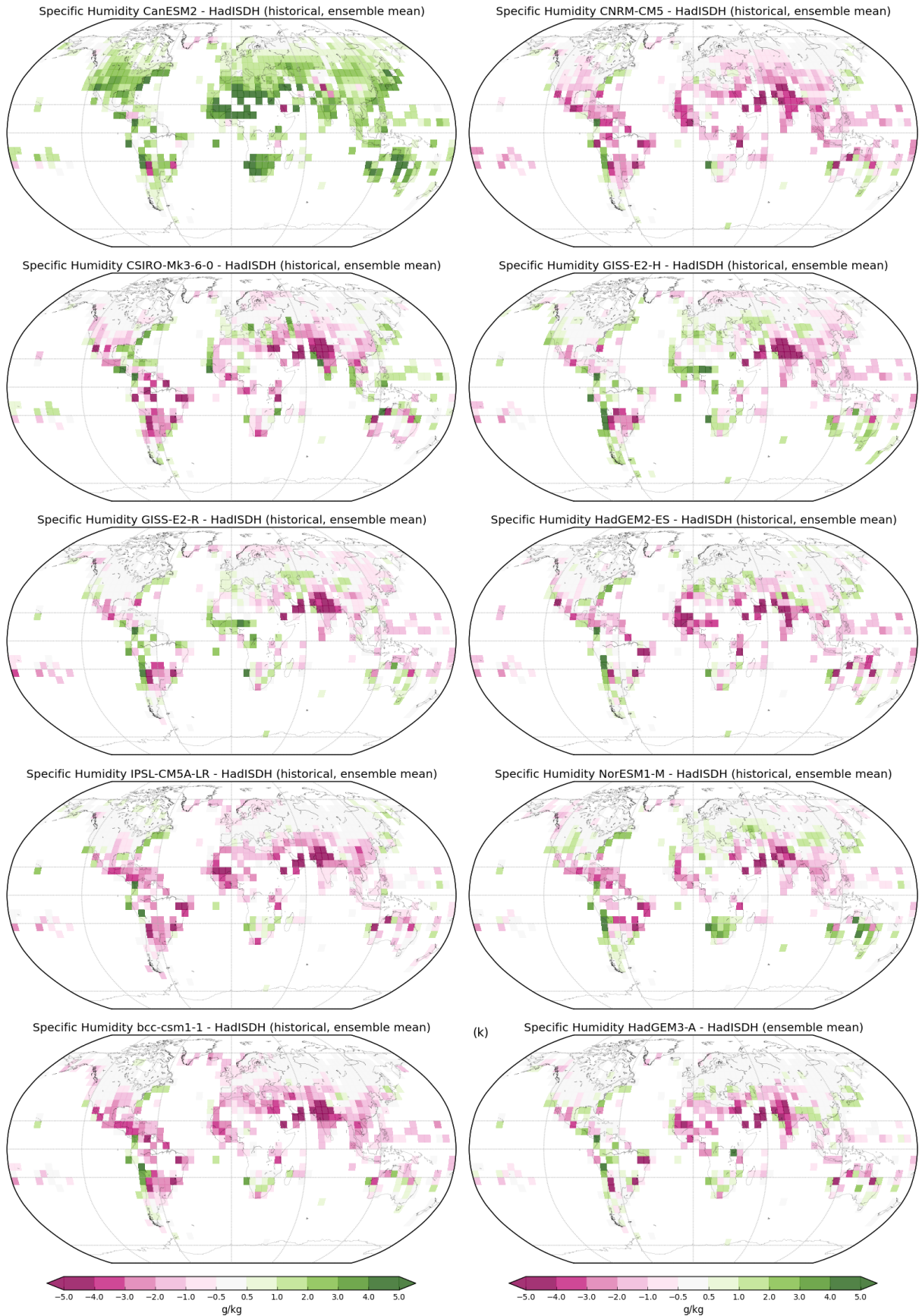
Figure S30. Climatological differences between models and observations at the gridbox scale for specific humidity. All climatologies have been calculated over the 1981 to 2010 period using identical spatio-temporal coverage to HadISDH.
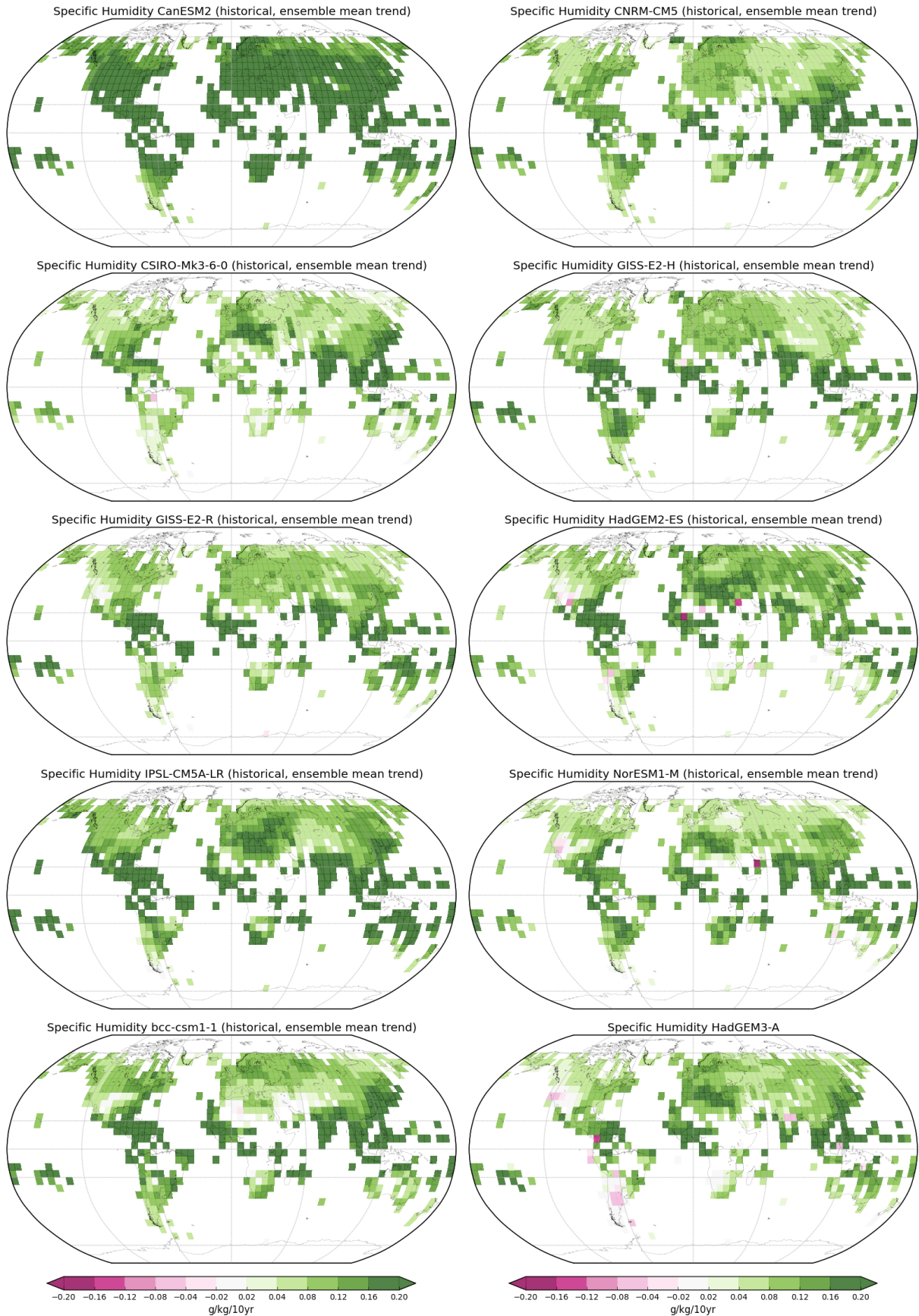
Figure S31. Linear trends of the CMIP5 models at the gridbox scale for specific humidity. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
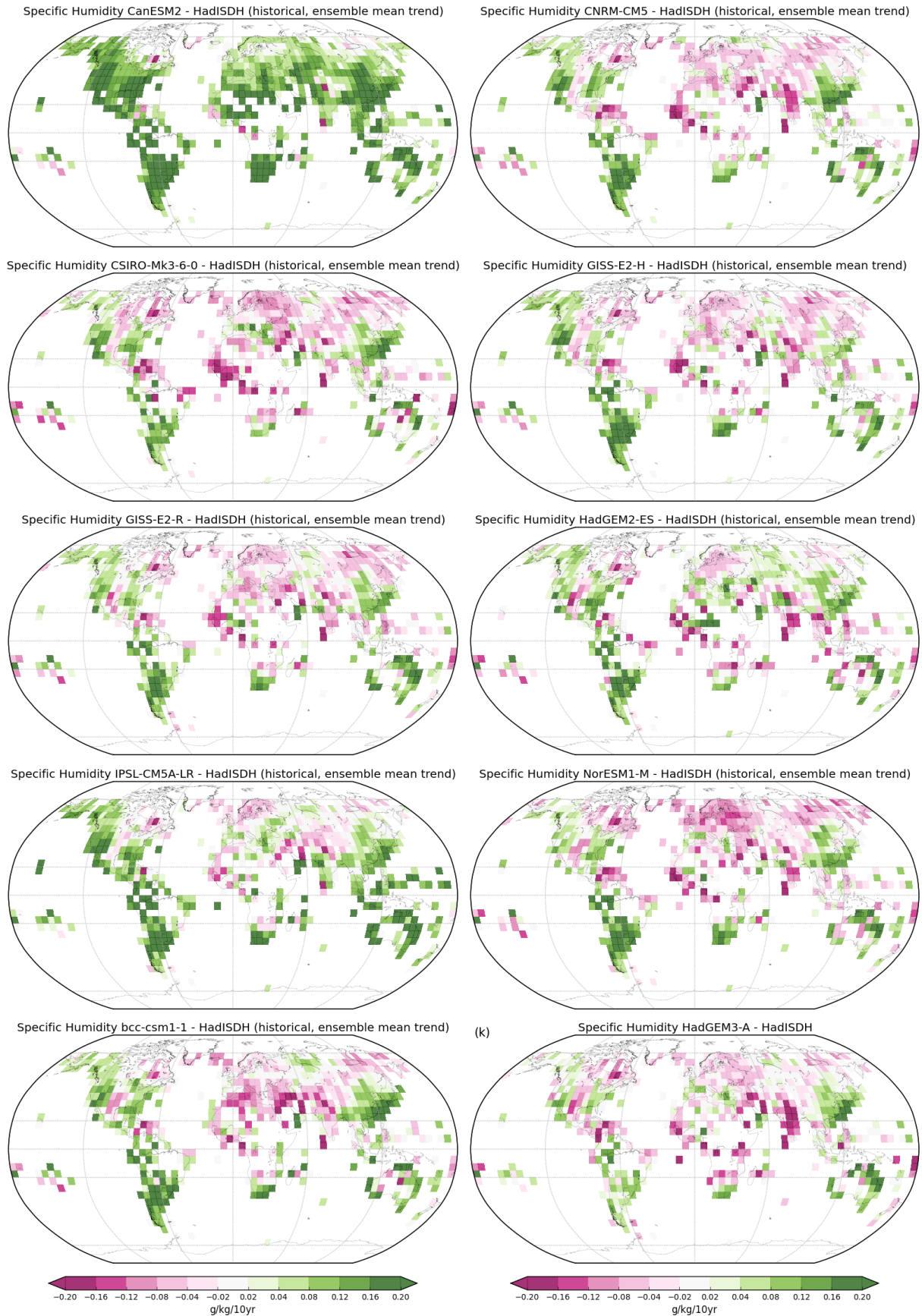
Figure S32. Linear trend differences of the CMIP5 models from the observations at the gridbox scale for specific humidity. All trends have been calculated using the median of pairwise slopes method, with identical spatio-temporal coverage to HadISDH.
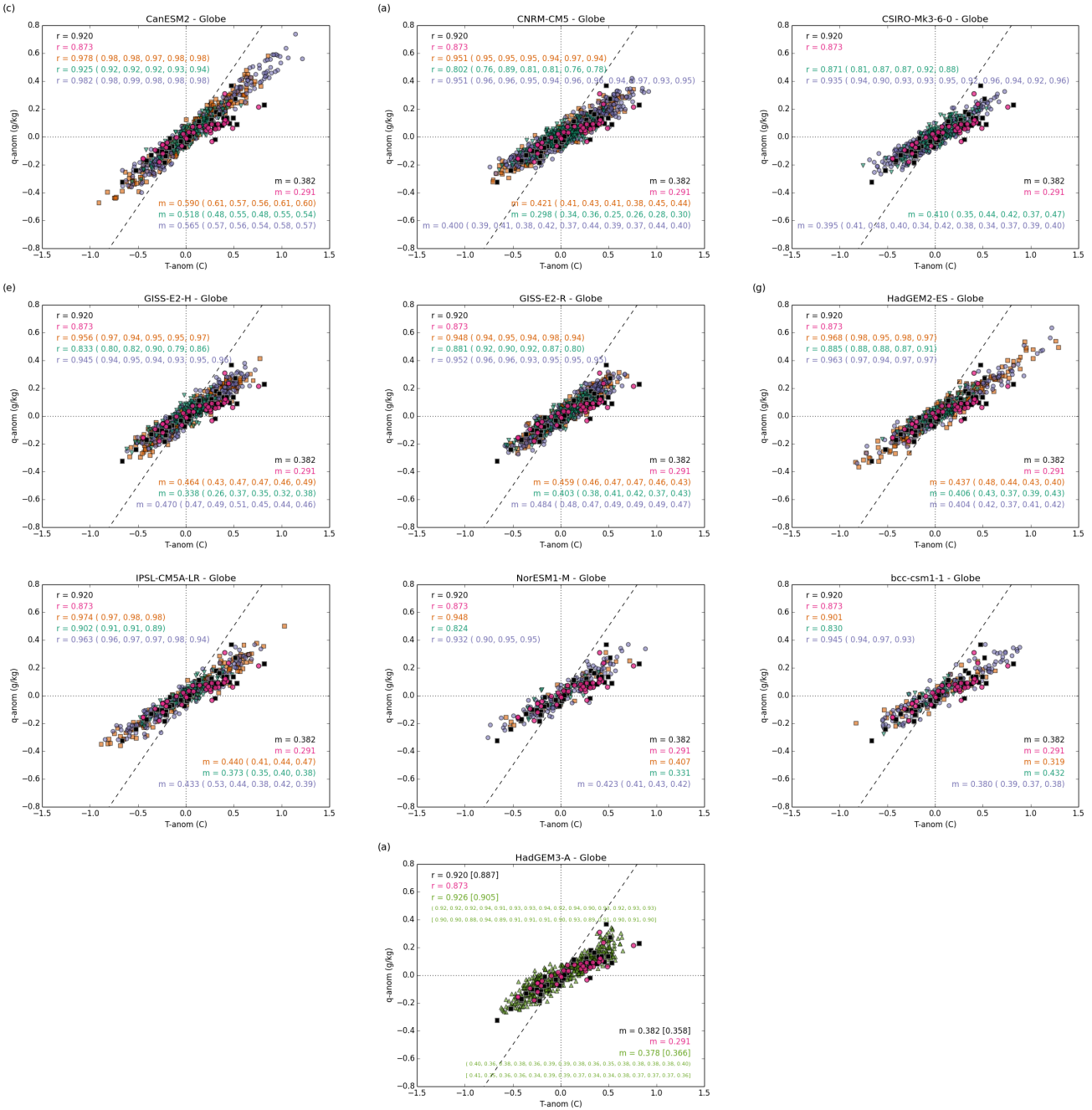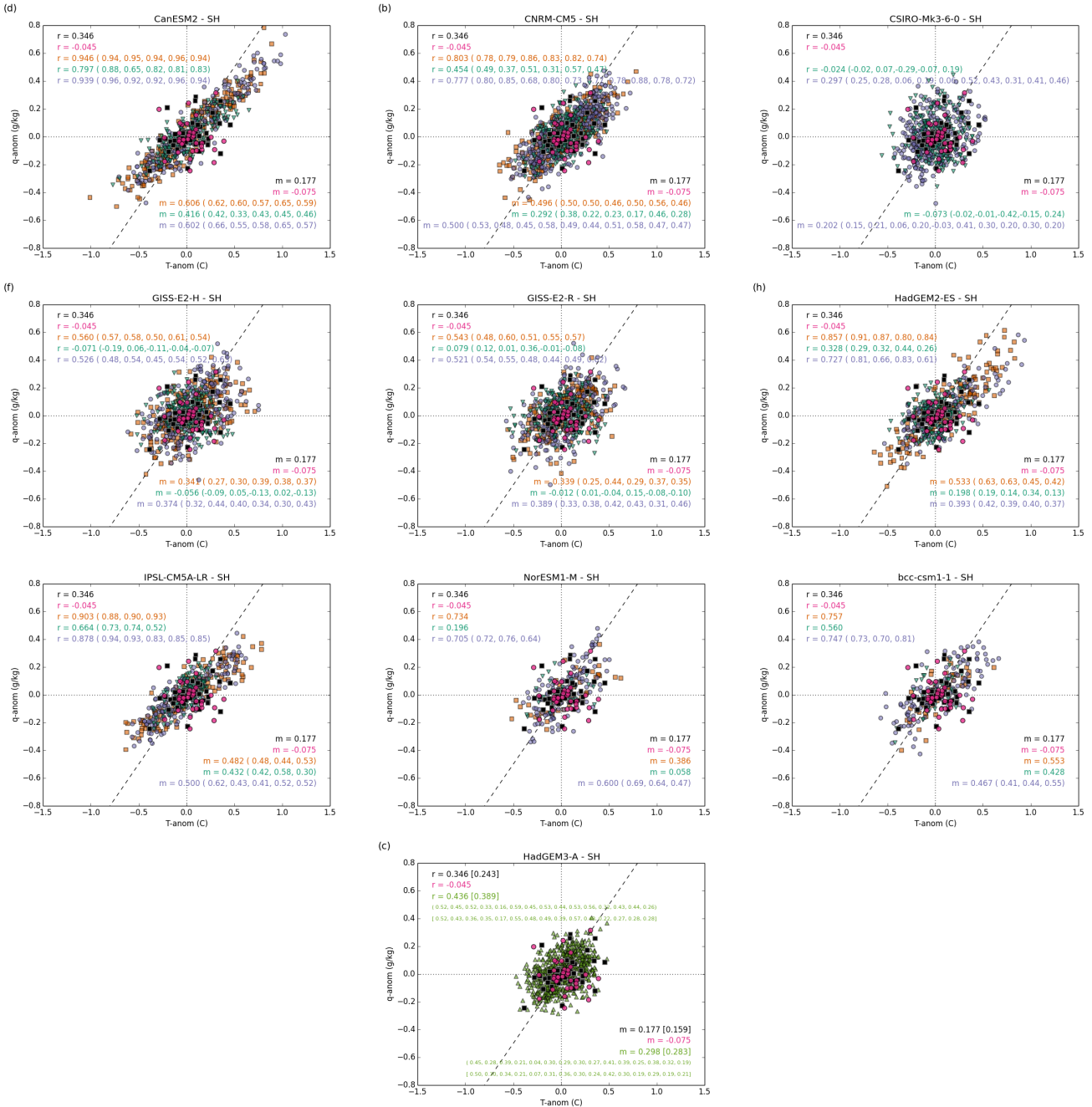
Figure S33. Relationships in global average temperature and specific humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
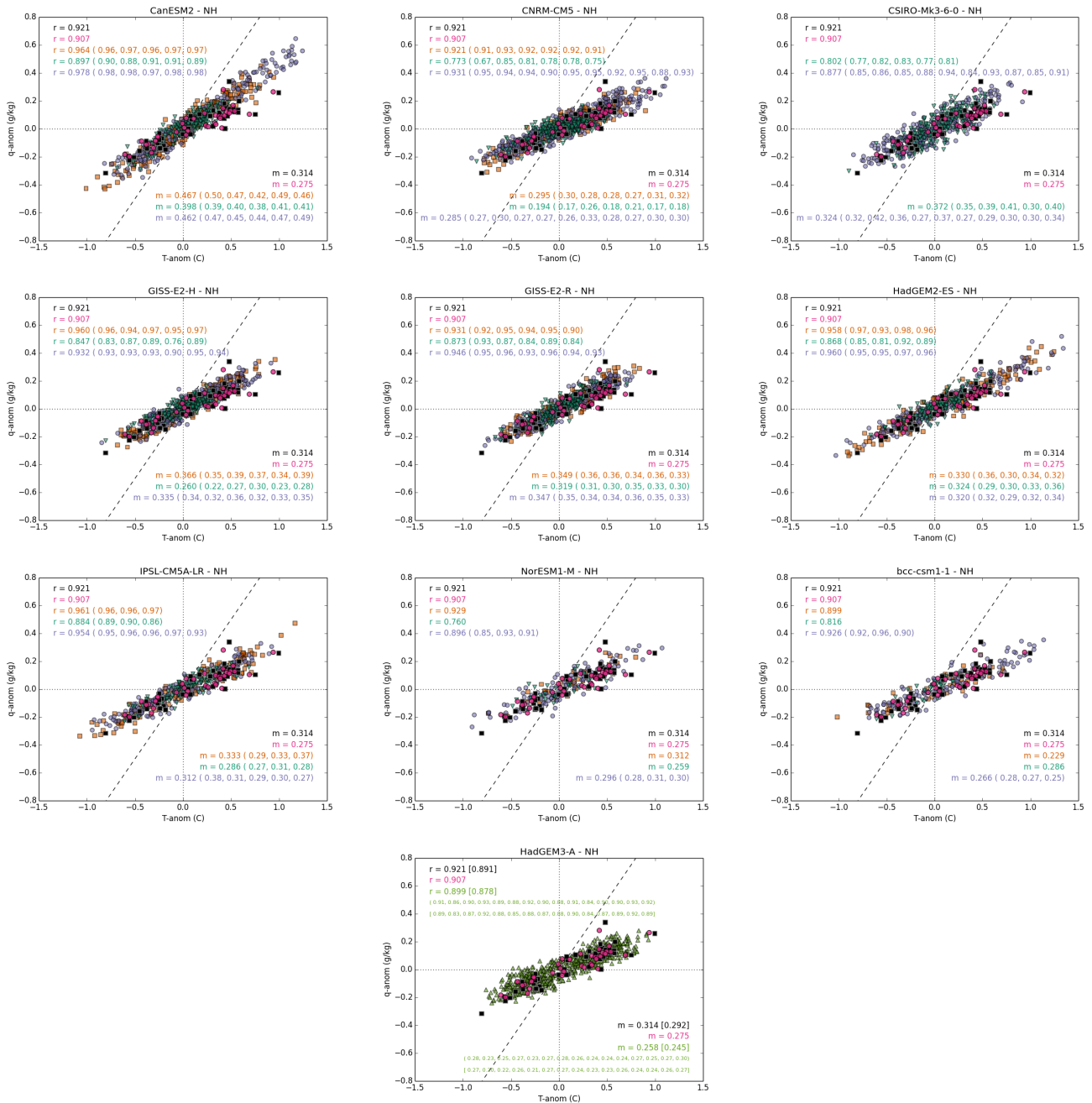
Figure S34. Relationships in Northern Hemisphere average temperature and specific humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
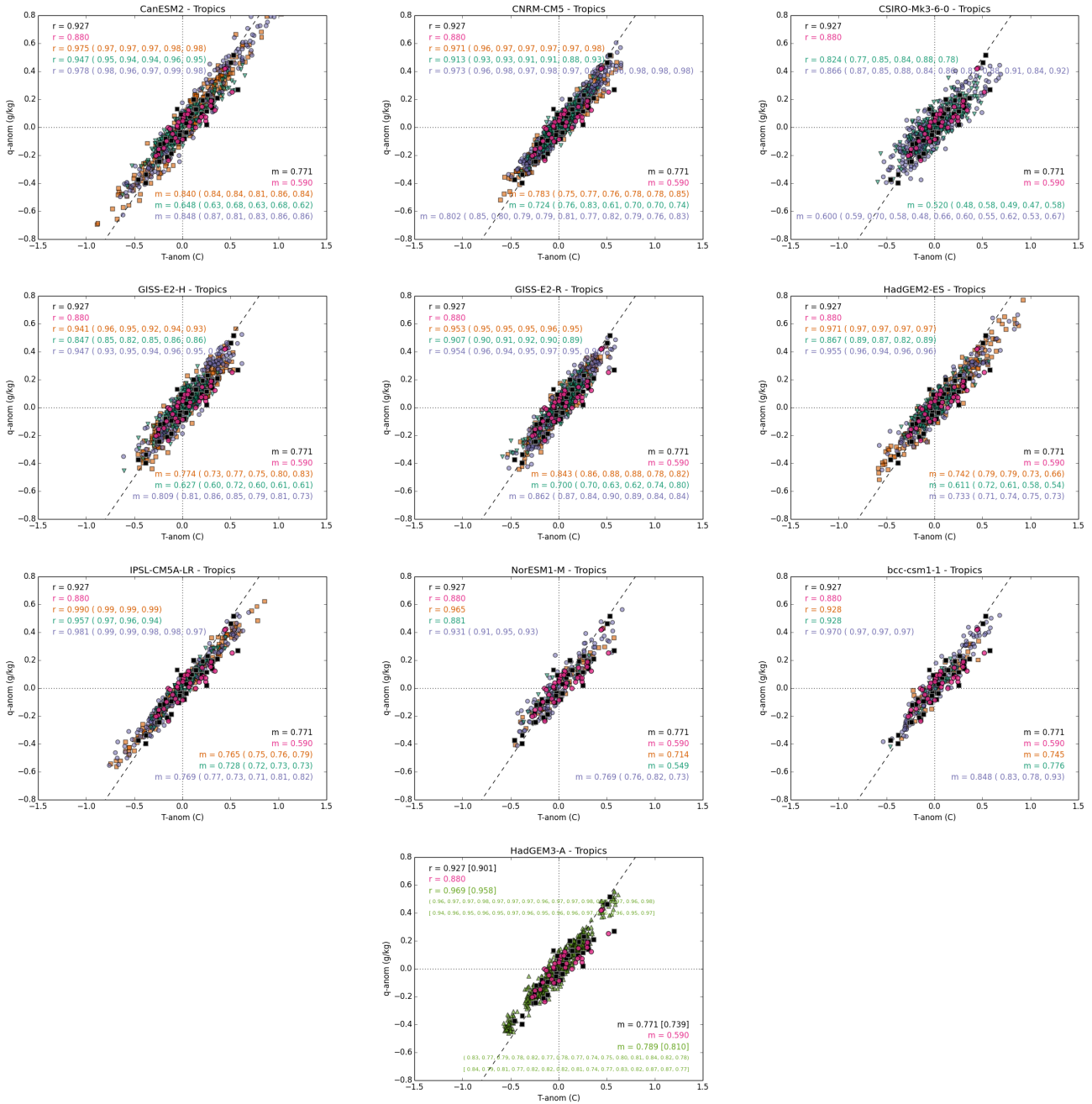
Figure S35. Relationships in tropical average temperature and specific humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.

Figure S36. Relationships in Southern Hemisphere average temperature and specific humidity for CMIP5 models compared to HadISDH and ERA-Interim. Correlations (r) are shown in the top left hand corner. The gradient of the line of best fit is given in the bottom right hand corner. HadISDH is shown in black. ERA-Interim is shown in magenta. *Historical*, *historicalNAT* and *historicalGHG* are shown in purple, green and orange respectively. The ensemble mean value is given for each model with individual member values in parentheses. Values in square brackets are calculated using data matched to the coverage of ERA-Interim, for both HadISDH and HadGEM3-A.
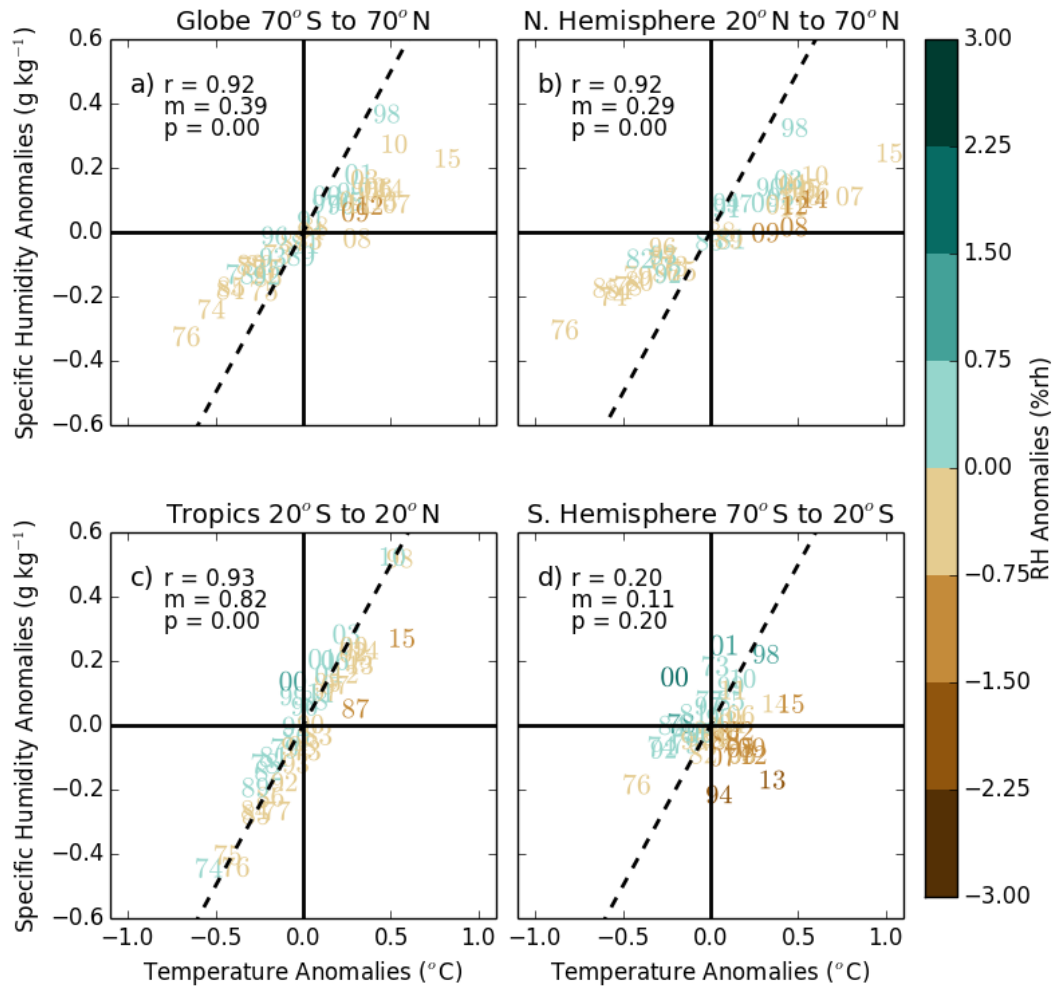
Figure S37. Temperature-specific humidity relationship, with the relative humidity anomaly as the colour scale, with the years as the points. The four zonal regions used in this analysis are shown in the four panels.