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Assessment of the reliability of climate predictions based on comparisons with historical time series

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1. Abstract

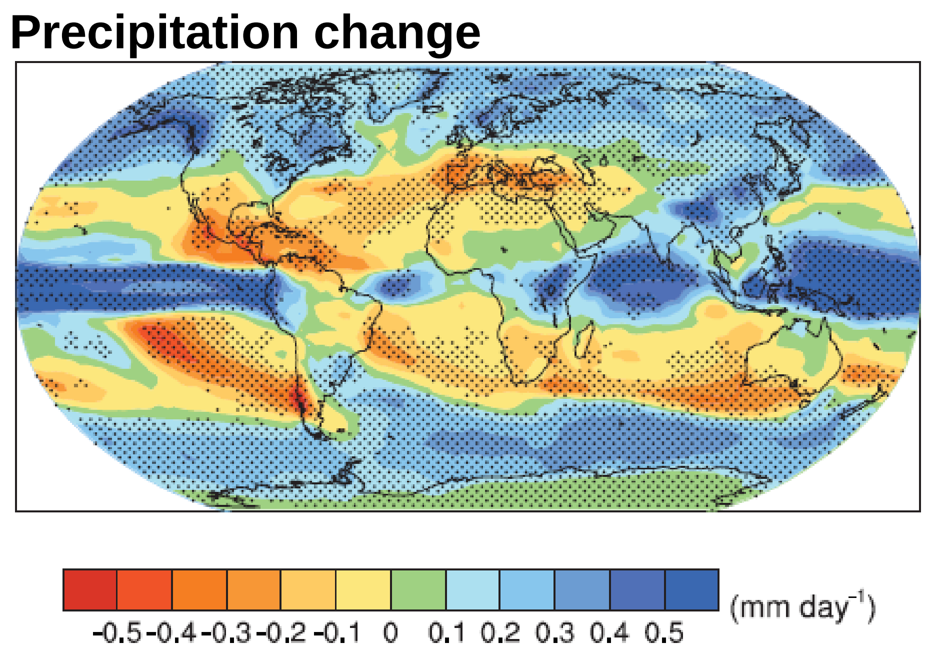
As falsifiability is an essential element of science (Karl Popper), many have disputed the scientific basis of climatic predictions on the grounds that they are not falsifiable or verifiable at present. This critique arises from the argument that we need to wait several decades before we may know how reliable the predictions will be. However, elements of falsifiability already exist, given that many of the climatic model outputs contain time series for past periods. In particular, the models of the IPCC Third Assessment Report have projected future climate starting from 1990; thus, there is an 18-year period for which comparison of model outputs and reality is possible. In practice, the climatic model outputs are downscaled to finer spatial scales, and conclusions are drawn for the evolution of regional climates and hydrological regimes; thus, it is essential to make such comparisons on regional scales and point basis rather than on global or hemispheric scales. In this study, we have retrieved temperature and precipitation records, at least 100-year long, from a number of stations worldwide. We have also retrieved a number of climatic model outputs, extracted the time series for the grid points closest to each examined station, and produced a time series for the station location based on best linear estimation. Finally, to assess the reliability of model predictions, we have compared the historical with the model time series using several statistical indicators including long-term variability, from monthly to overyear (climatic) time scales. Based on these analyses, we discuss the usefulness of climatic model future projections (with emphasis on precipitation) from a hydrological perspective, in relationship to a long-term uncertainty framework.

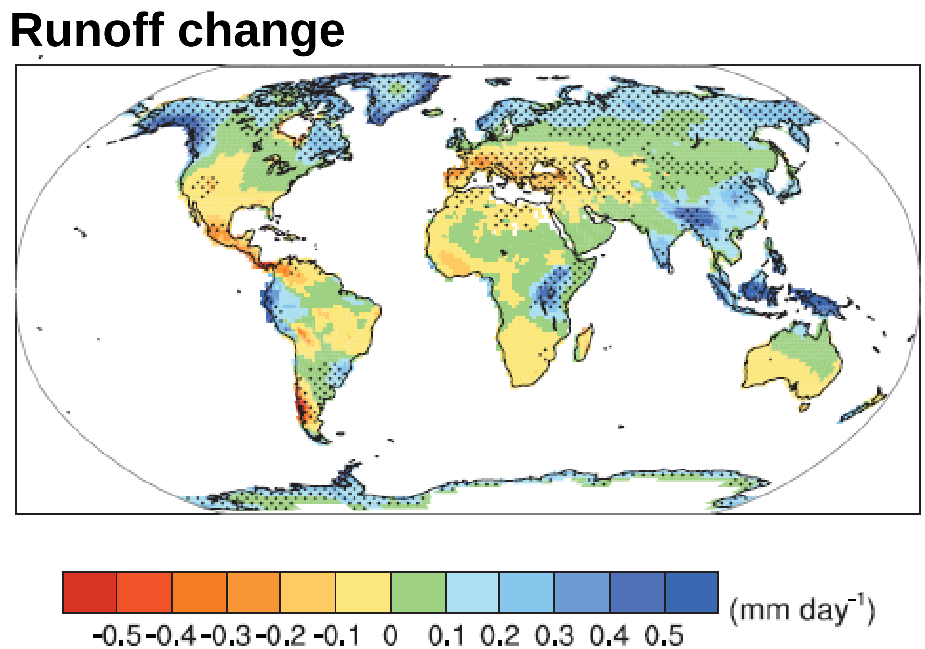
2. Rationale

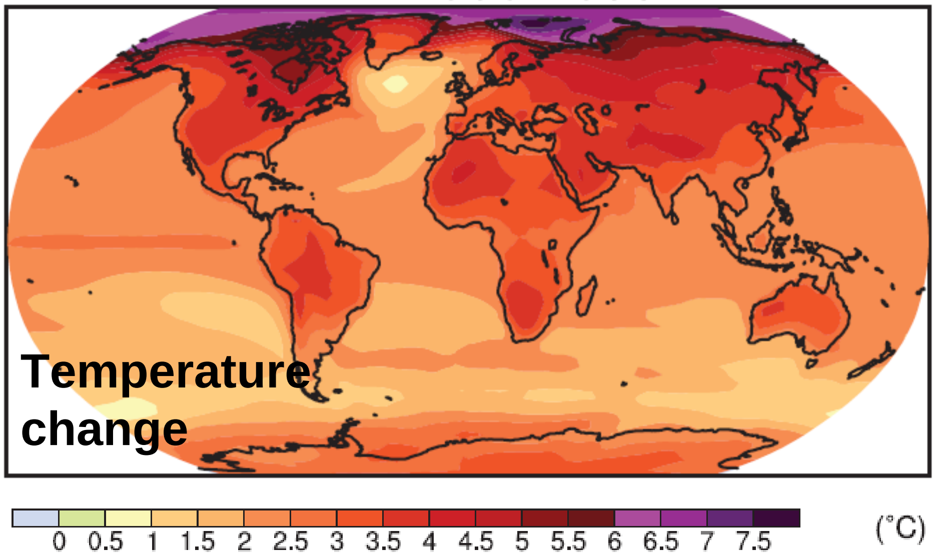
- Falsifiability is an essential element of science (Karl Popper).
- The hypothesis that climate is deterministically predictable and its implementation through the General Circulation Models (GCMs) are central on current scientific scene.
- However, as climatic predictions are cast for horizons of several decades (most typically on a hundred years) they may be not falsifiable or verifiable at present.
- Therefore elements of falsifiability for the present are urgently needed.
- These can be sought on existing long time series of the past and testing of GCM performance in reproducing past climatic behaviours.
- In particular, the models of the IPCC Third Assessment Report (TAR) have projected future climate starting from 1990; thus, there is an 18-year period for which comparison of model outputs and reality is possible.
- Besides several TAR model runs include longer past periods with historical inputs (the situation is more complicated with the IPCC Fourth Assessment Report (AR4)).
- In this study we present such comparisons for eight locations belonging to different climates worldwide that have temperature and rainfall records of 100 years or more.

3. Possible objections

- According to IPCC AR4 (Randall *et al.*, 2007) GCMs have better predictive capacity for *temperature* than for other climatic variables (e.g. *precipitation*) and their quantitative estimates of future climate are particularly credible at *continental scales and above*.
- However this did not prevent IPCC to give regional projections, not only of temperature but also of rainfall and even of runoff (Displayed: parts of Figs. 10.8 and 10.12 of Christensen *et al.*, 2007; projected changes for 2080-99 relative to 1980-99 for SRES scenario A1B).







4. Methodology

1. Collection of monthly temperature and precipitation records (preferably 100-year long or more and as complete as possible) from a number of representative stations worldwide (available on the Internet), with different climatic characteristics.
2. Filling-in of few missing values (with average monthly ones).
3. Retrieval of a number of climatic model outputs for historical periods (available on the Internet - not those merely referring to future periods under diverse hypothetical scenarios).
4. Extraction of the time series for the four grid points closest to each examined station (roughly following a technique by Georgakakos, 2003, for making inferences on small regional scales from coarser climate model scales).
5. Production of time series for the station location based on best linear estimation, i.e. optimizing the weight coefficients λ_1, λ_2, λ_3, λ_4 (with $\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 = 1$) in a linear relationship

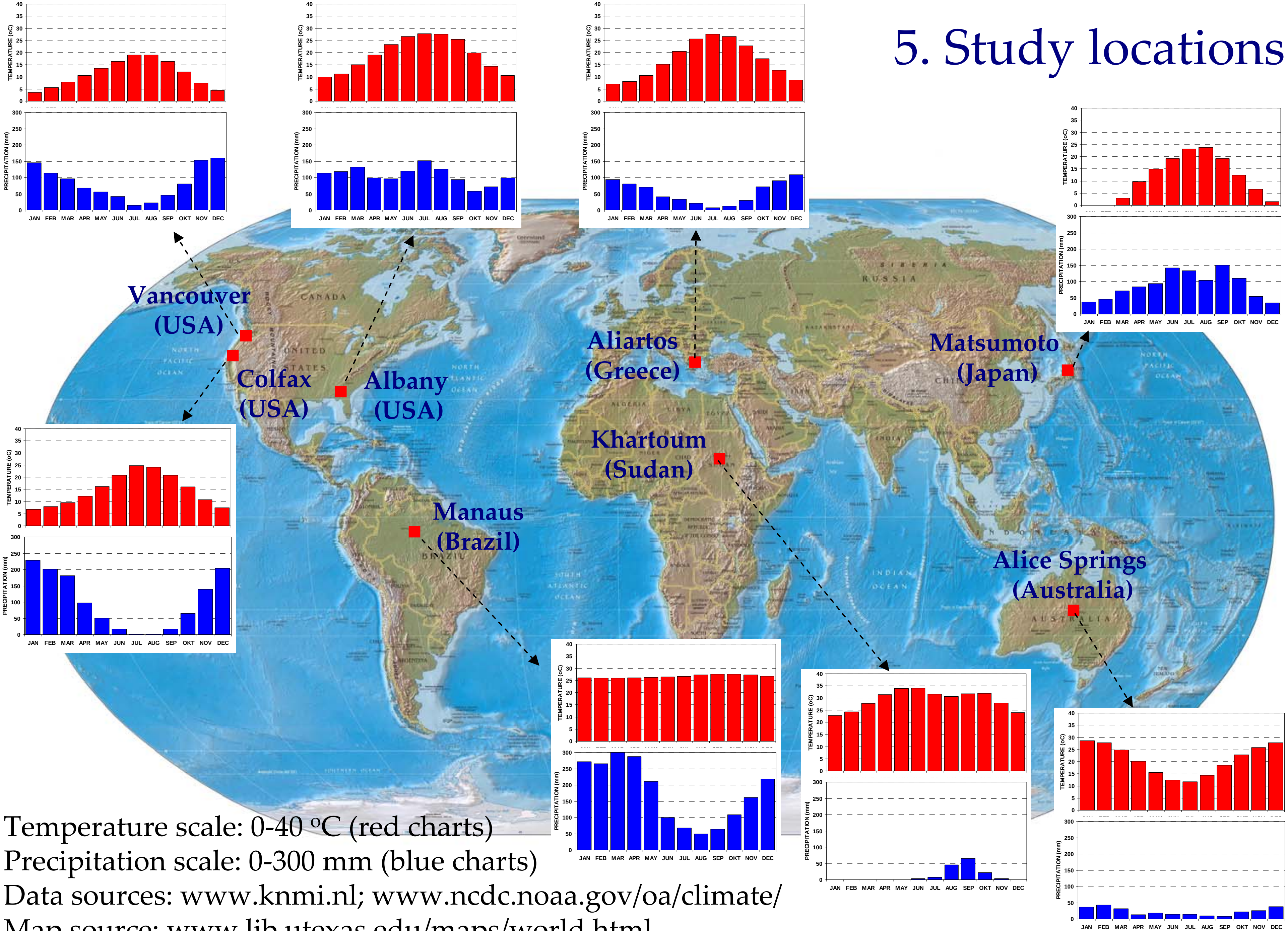
   $$\tilde{x} = \lambda_1 x_1 + \lambda_2 x_2 + \lambda_3 x_3 + \lambda_4 x_4$$

   where $\tilde{x}$ is the best linear estimate of the historical value x, and x_1, x_2, x_3, x_4 are the model outputs for the four closest grid points; optimization is done on the basis of the coefficient of efficiency, defined as

   Eff = 1 – (mean square error in prediction)/(variance of historical series)

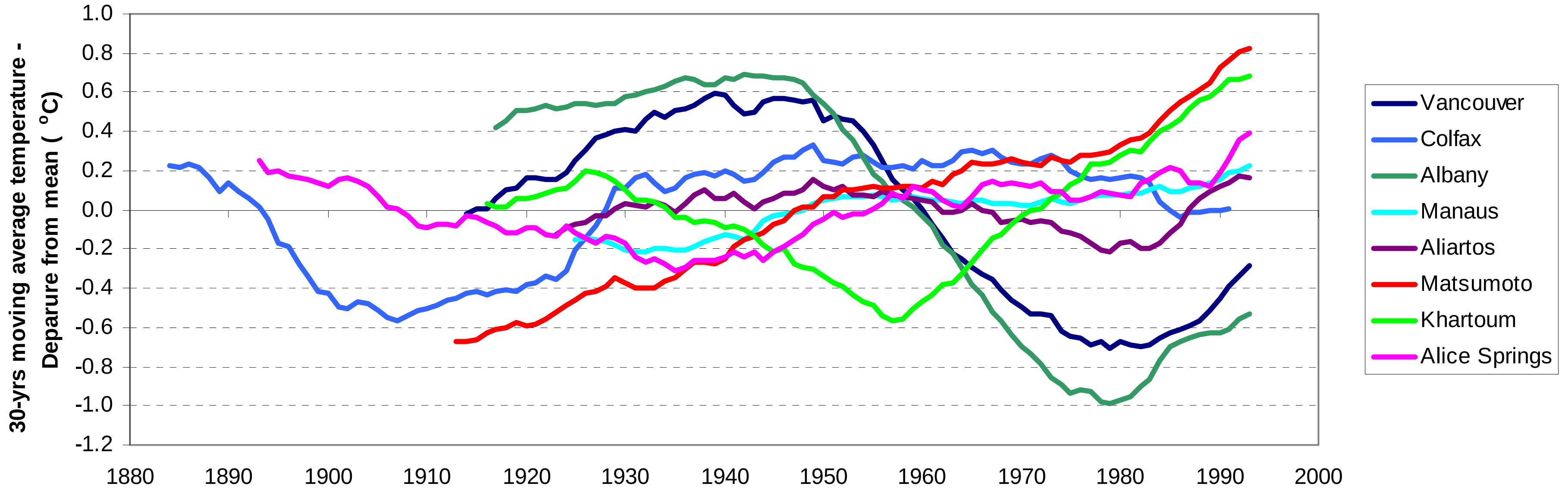
6. Graphical comparisons on a climatic (30-year moving average) time scale.
7. Calculation and comparison of historical and model statistical indicators from monthly to overyear (climatic) time scales, including long-term variability.

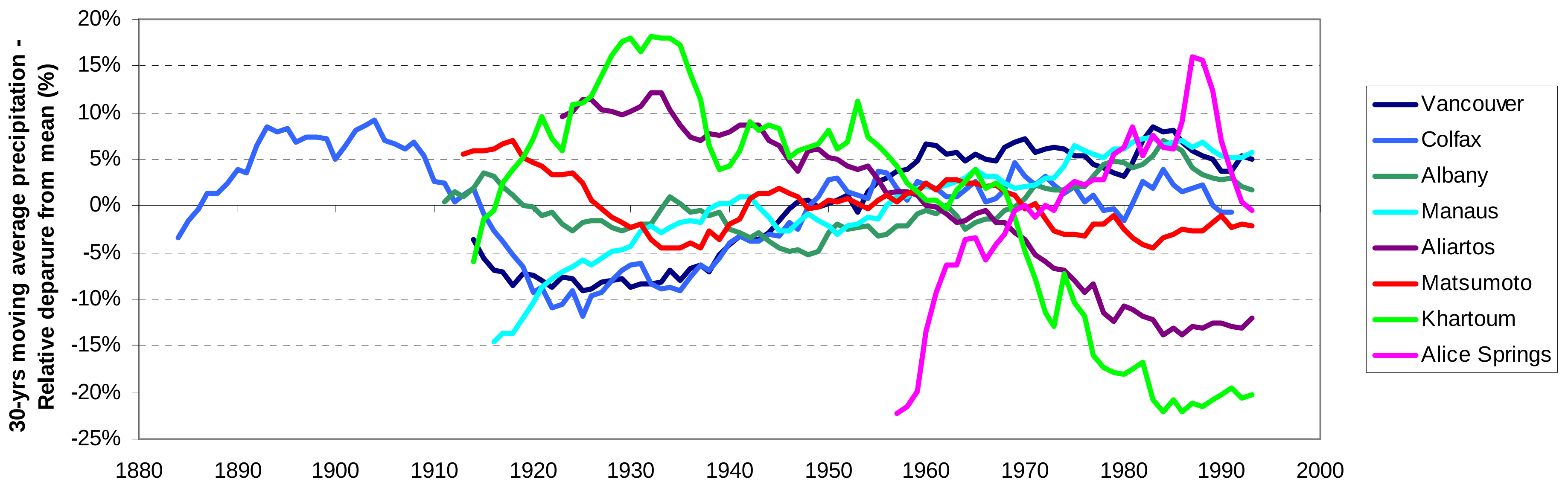
5. Study locations



Temperature scale: 0-40 ºC (red charts)
Precipitation scale: 0-300 mm (blue charts)
Data sources: www.knmi.nl; www.ncdc.noaa.gov/oa/climate/
Map source: www.lib.utexas.edu/maps/world.html

6. Long-term variability of historical time series





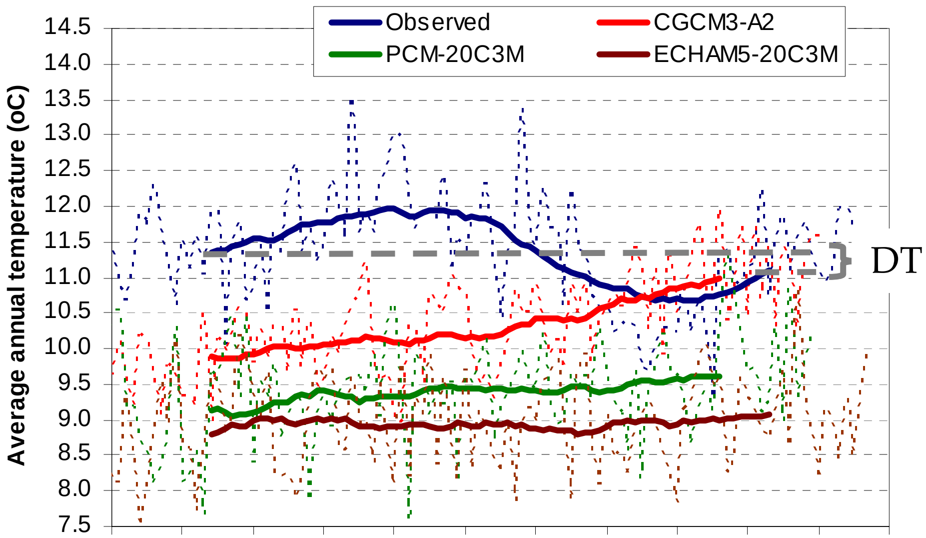
7. IPCC TAR models and data sets

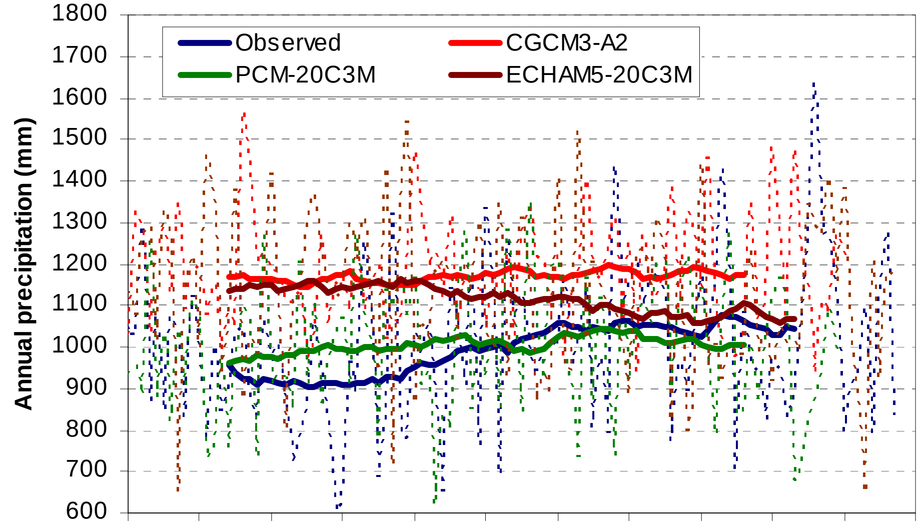
- **GCM coupled atmosphere-ocean global models**
  - ECHAM4/OPYC3: developed in co-operation between the Max-Planck-Institute for Meteorology and Deutsches Klimarechenzentrum in Hamburg, Germany
  - CGCM2: developed at the Canadian Centre for Climate Modeling and Analysis
  - HADCM3: developed at the Hadley Centre for Climate Prediction and Research
- **GCM output data sets** (from http://ipcc-ddc.cru.uea.ac.uk/ddc_gcmdata.html)
  - MP01GG01: output of ECHAM4/OPYC3 with historical inputs for 1860-1989 and inputs from IS92a beyond 1990
  - CCCma_A2: output of CGCM2 with historical inputs for 1900-1989 and inputs from scenario A2 beyond 1990
  - HADCM3_A2: output of CGCM2 with historical inputs for 1950-1989 and inputs from scenario A2 beyond 1990
- **Notes on the selection of IPCC scenarios for "future" (1990-2007) projections**
  - During the period 1990-today there is no significant difference between IPCC scenarios for the same model; two such scenarios were selected, namely:
    - SRES A2 (for models CGCM2 and HADCM3 : high population growth (15.1 billion in 2100), high energy and carbon intensity, and correspondingly high CO_2 emissions (concentration 834 cm^3/m^3 in 2100)
    - IS92a (older, for model ECHAM4/OPYC3): population 11.3 and CO_2 concentration 708 cm^3/m^3 in 2100

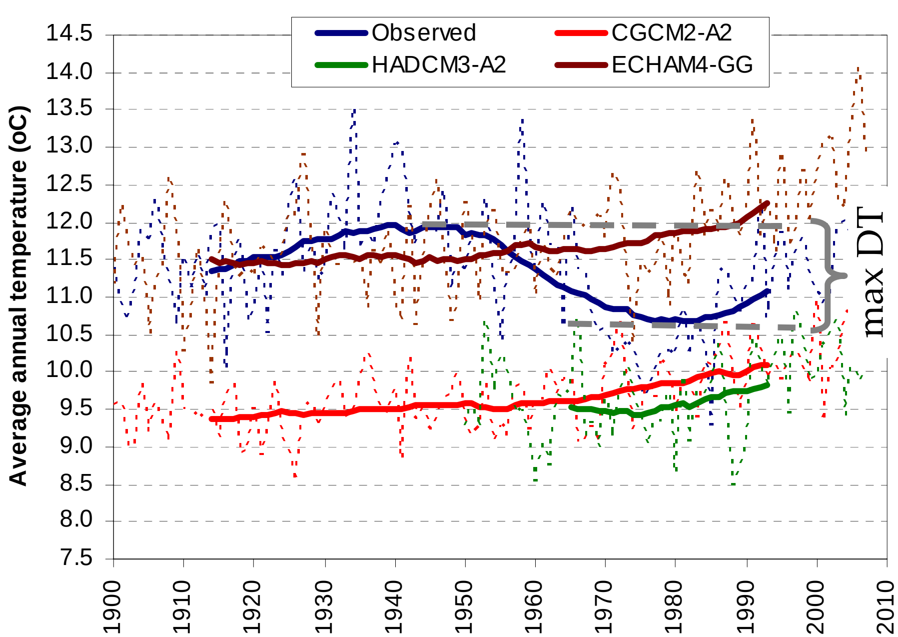
8. IPCC AR4 models and data sets

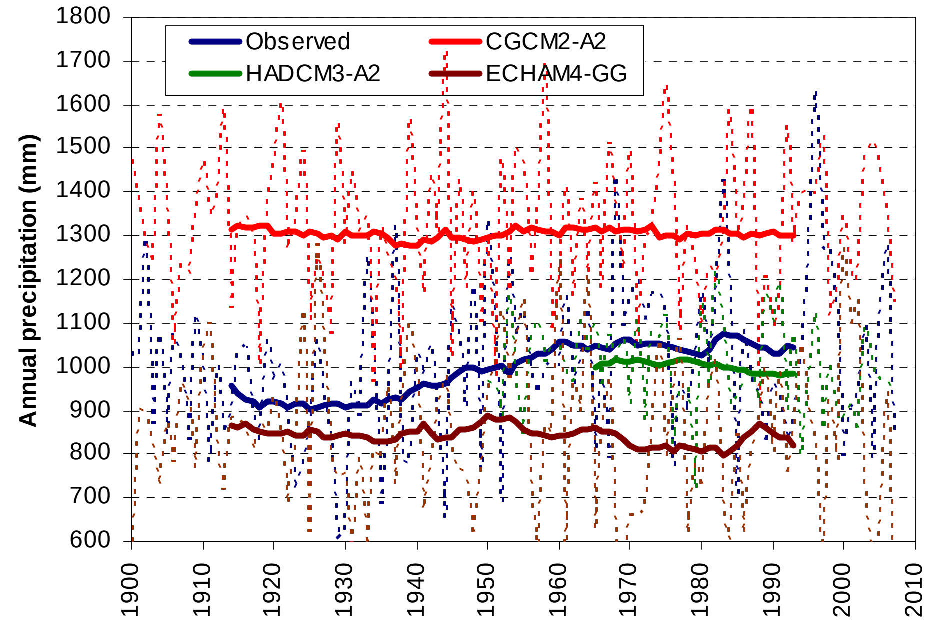
- **Models**
  - CGCM3: developed at the Canadian Centre for Climate Modeling and Analysis; run in two resolutions, T47 and T63 (we used T47).
  - ECHAM5-OM: developed at the Max-Planck-Institute for Meteorology, Germany.
  - PCM: developed at the National Centre for Atmospheric Research, USA
- **GCM output data sets**
  (from http://www.mad.zmaw.de/IPCC_DDC/html/SRES_AR4/index.html)
  - The output of each of the three above models run on scenario 20C3M
- **Notes on the scenario selected**
  - While in TAR all scenarios had been run for past periods with historical data, in AR4 only one scenario (20C3M) is supposed to have some connection with historical reality.
  - Specifically, scenario 20C3M was generated from the output of late 19^{th} and 20^{th} century simulations from many coupled ocean-atmosphere models, in order to help assess past climate change (Hegerl *et al.*, 2003).

9. Vancouver (Washington, USA; mild climate)

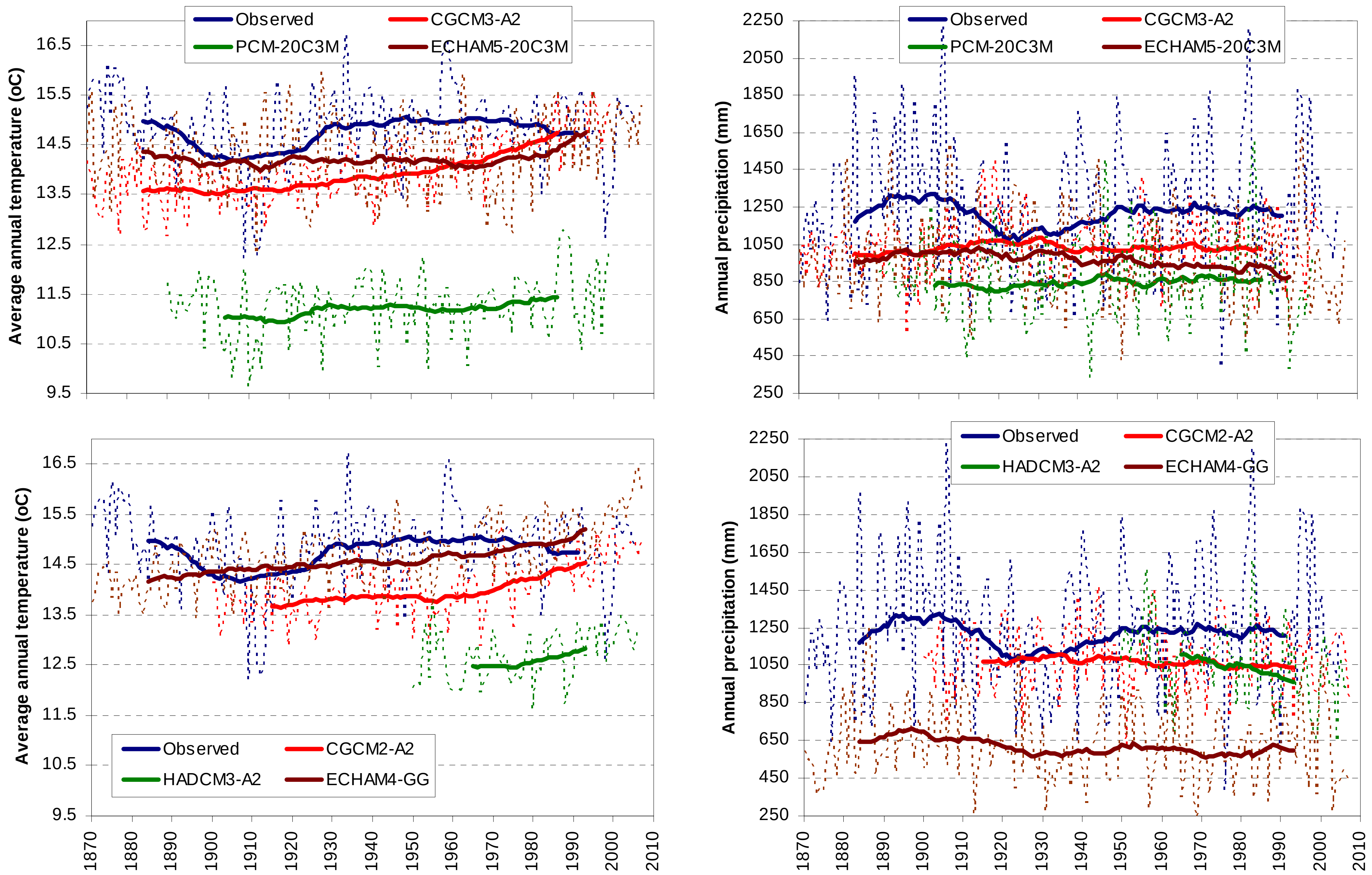




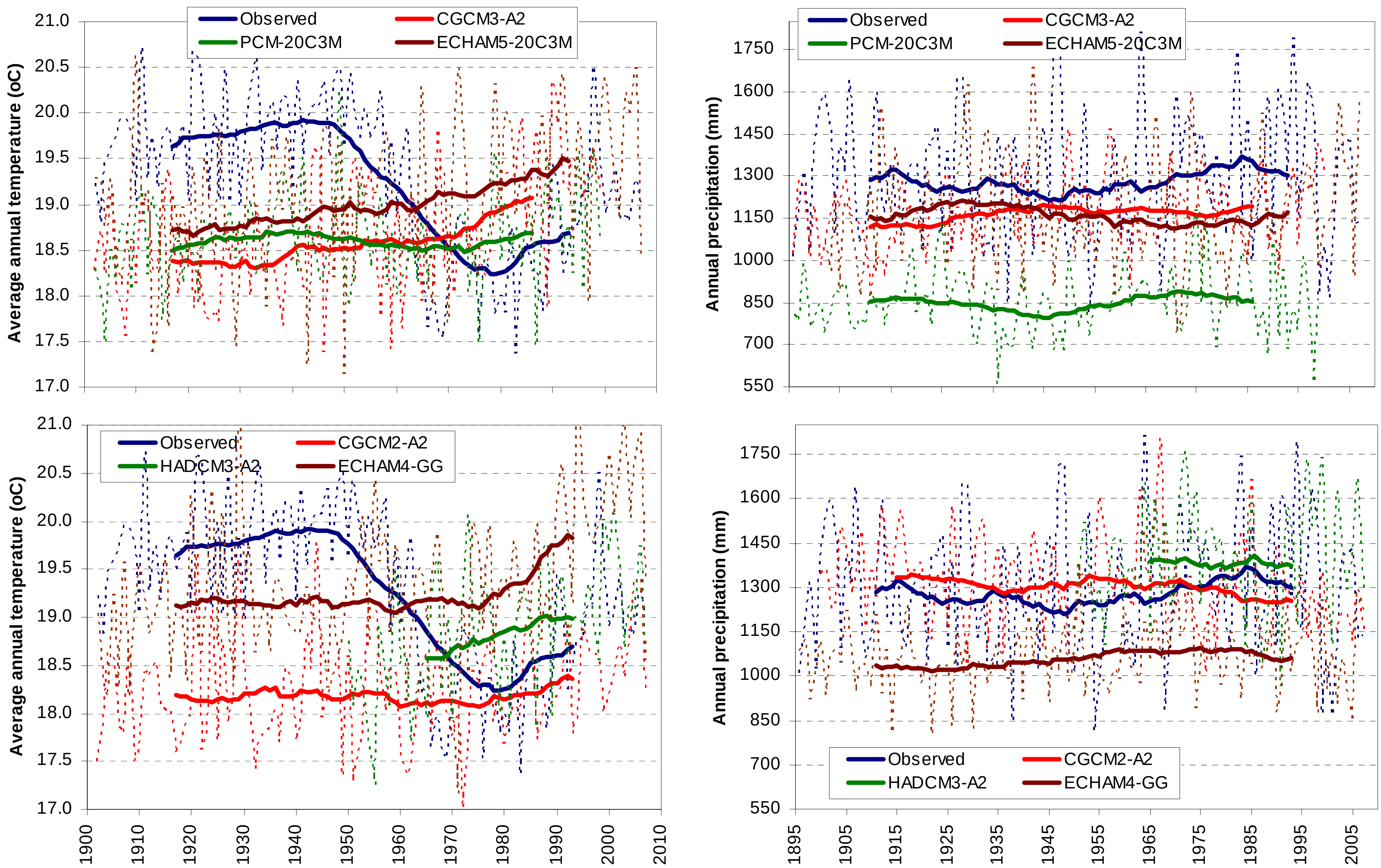




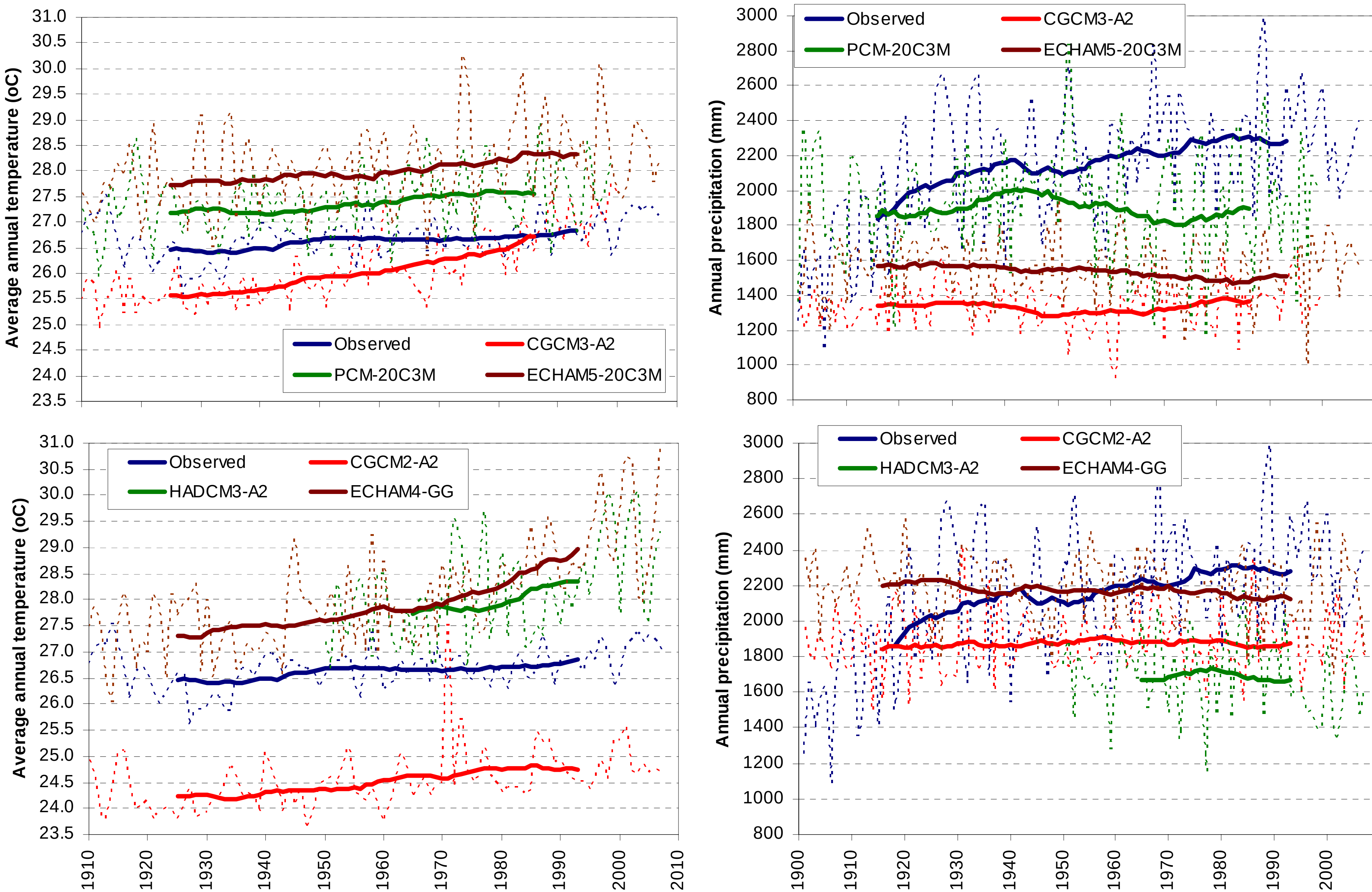
10. Colfax (California, USA; mountainous climate)



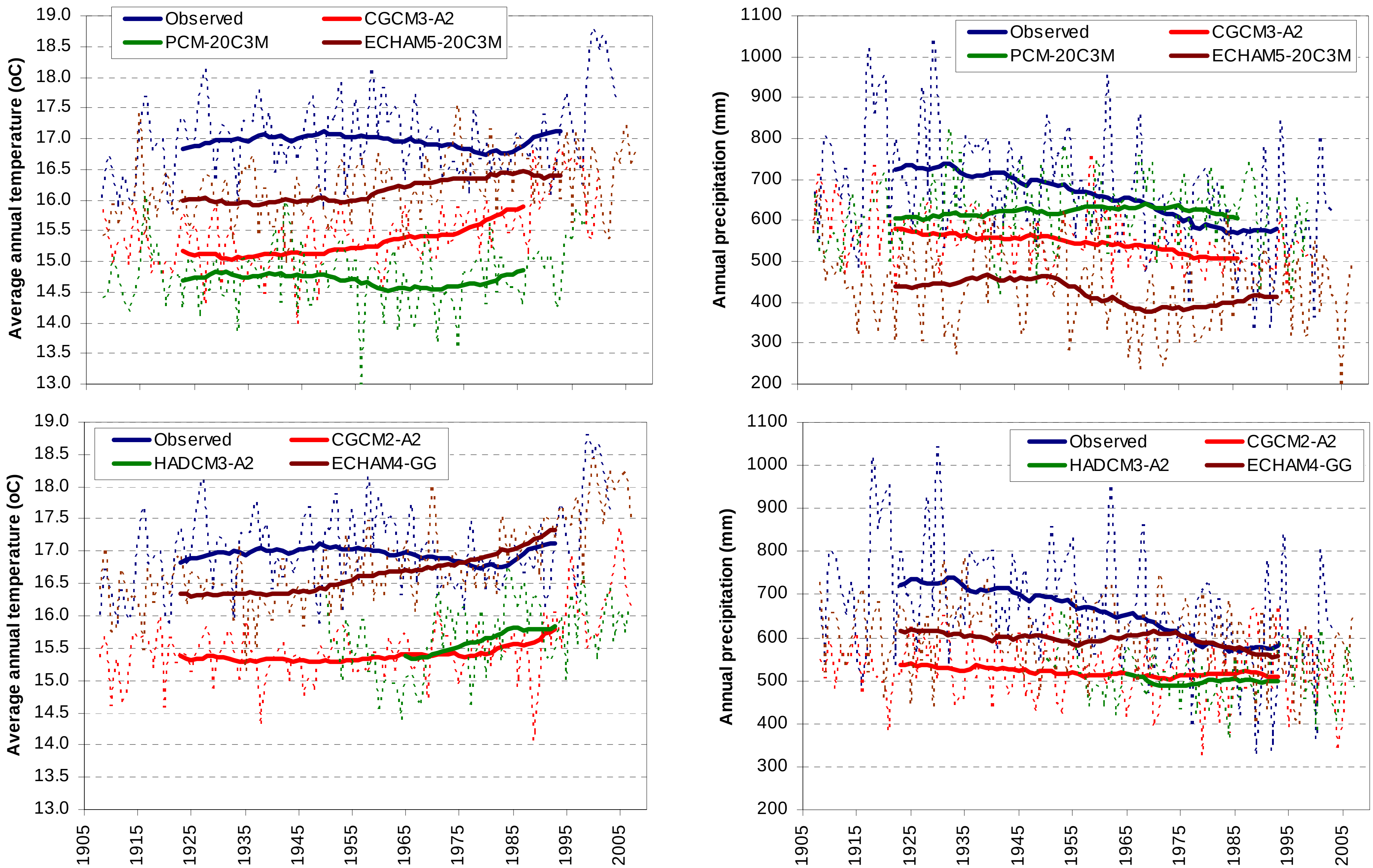
11. Albany (Florida, USA; sub-tropical climate)



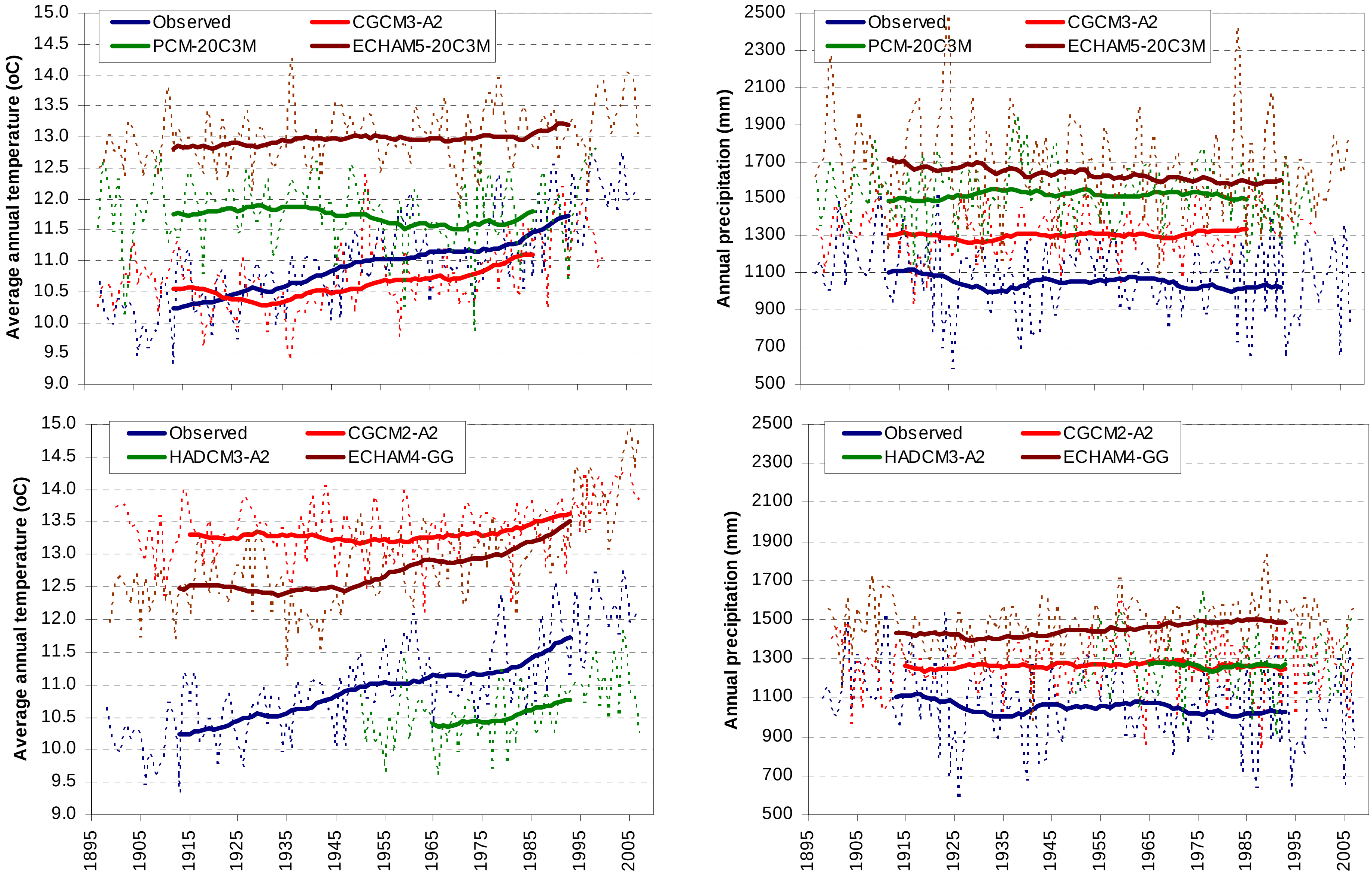
12. Manaus (Brazil; tropical climate)



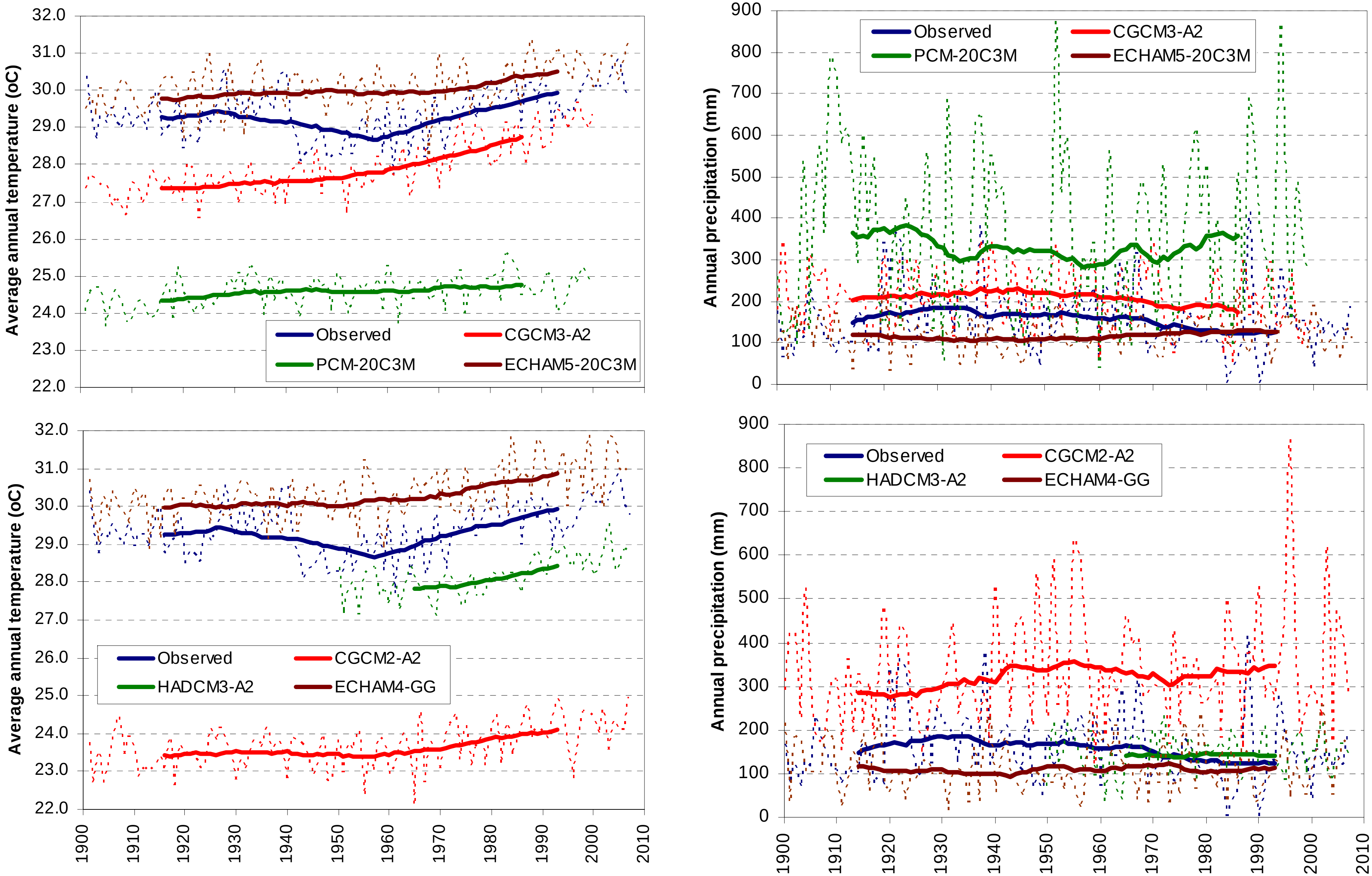
13. Aliartos (Greece; Mediterranean climate)



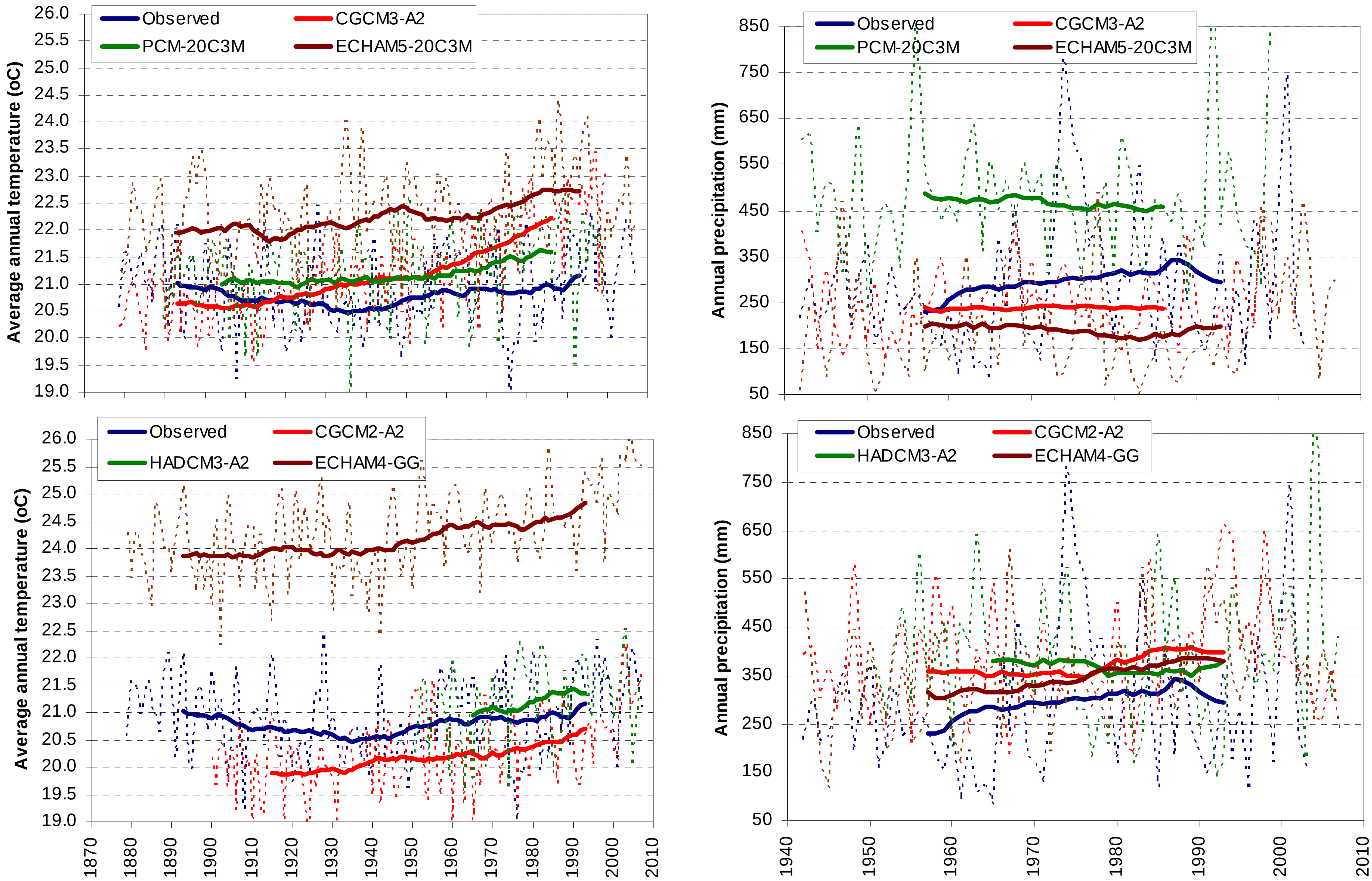
14. Matsumoto (Japan; marine climate)



15. Khartoum (Sudan; arid climate)



16. Alice Springs (Australia; semi-arid climate)



17. Detailed statistics of observed and model series

An example for the temperature of Vancouver

Monthly data	Period	Average	St. dev	Corellation	Efficiency
Observed	1899-2007	11.36	5.55		
CGCM3-A2	1899-2000	10.35	6.19	0.916	0.757
PCM-20C3M	1899-1999	9.40	6.06	0.882	0.610
ECHAM5-20C3M	1899-2007	8.93	5.00	0.906	0.633
CGCM2-A2	1900-2007	9.67	4.15	0.881	0.670
HADCM3-A2	1950-2007	9.67	6.12	0.925	0.748
ECHAM4-GG	1899-2007	11.74	5.94	0.916	0.813

Annual data	Period	Average	St. dev	Aurocorrel.	Corellation	Efficiency	Hurst coeff.
Observed	1899-2007	11.36	0.77	0.522			0.908
CGCM3-A2	1899-2000	10.34	0.70	0.474	-0.265	-2.894	0.881
PCM-20C3M	1899-1999	9.40	0.71	0.206	0.031	-6.861	0.629
ECHAM5-20C3M	1899-2007	8.94	0.65	0.168	0.019	-10.611	0.609
CGCM2-A2	1900-2007	9.67	0.48	0.416	-0.108	-5.356	0.828
CGCM2-A2	1900-1989	9.57	0.41	0.290	-0.194	-5.166	
CGCM2-A2	1989-2007	10.17	0.43	-0.069	0.243	-9.386	
HADCM3-A2	1950-2007	9.67	0.59	0.333	0.087	-3.836	0.706
HADCM3-A2	1950-1989	9.49	0.54	0.200	0.086	-3.481	
HADCM3-A2	1989-2007	10.02	0.56	0.114	0.197	-11.522	
ECHAM4-GG	1899-2007	11.74	0.70	0.373	0.166	-1.241	0.730
ECHAM4-GG	1899-1989	11.58	0.59	0.171	-0.137	-0.798	
ECHAM4-GG	1989-2007	12.50	0.69	0.136	-0.162	-10.180	

30yr moving avg.	Period	St. dev	Corellation	Efficiency	DT (common period)	DT (all period)	max DT
Observed	1899-2007	0.46			-0.60	-0.27	-1.30
CGCM3-A2	1899-2000	0.32	-0.836	-7.710	1.10	1.10	1.14
PCM-20C3M	1899-1999	0.14	-0.486	-20.406	0.48	0.48	0.56
ECHAM5-20C3M	1899-2007	0.06	-0.178	-28.464	0.20	0.27	0.27
CGCM2-A2	1900-2007	0.20	-0.766	-15.537	0.65	0.74	0.74
HADCM3-A2	1950-2007	0.12	0.297	-88.820		0.30	0.40
ECHAM4-GG	1899-2007	0.19	-0.722	-1.130	0.41	0.74	0.83

18. Synoptic statistical comparison of climatic model outputs and observations

Monthly time scale

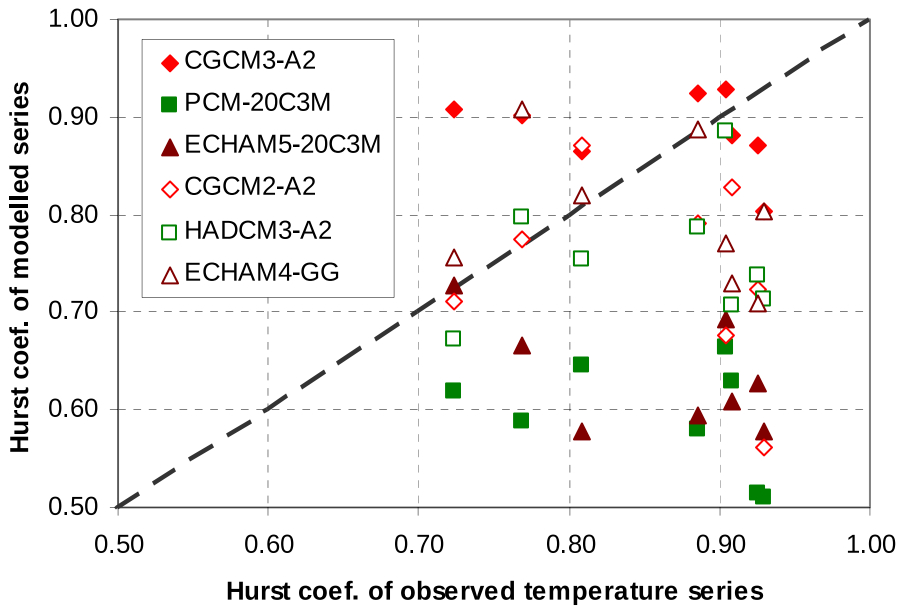
- Mean correlation/efficiency 0.849/-0.114 for temperature and 0.336/0.276 for precipitation.
- Satisfactory (>0.50) efficiency values in 77% of cases for temperature but in none for precipitation.

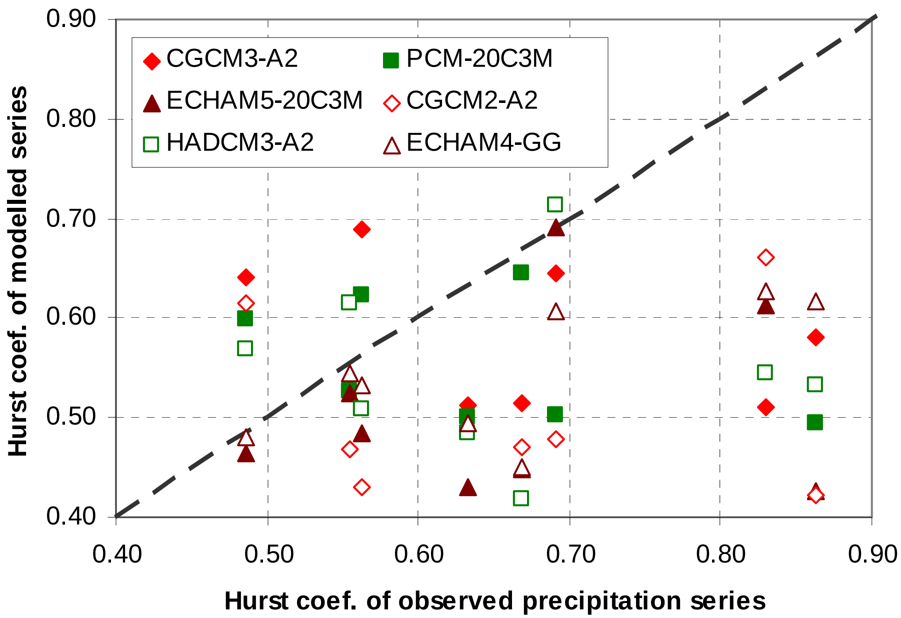
Annual time scale

- Mean correlation/efficiency 0.147/-8.649 for temperature and -0.010/-2.279 for precipitation.
- Underestimation of the observed Hurst coefficient (see figs.) in 73% of cases for temperature and 83% for precipitation.

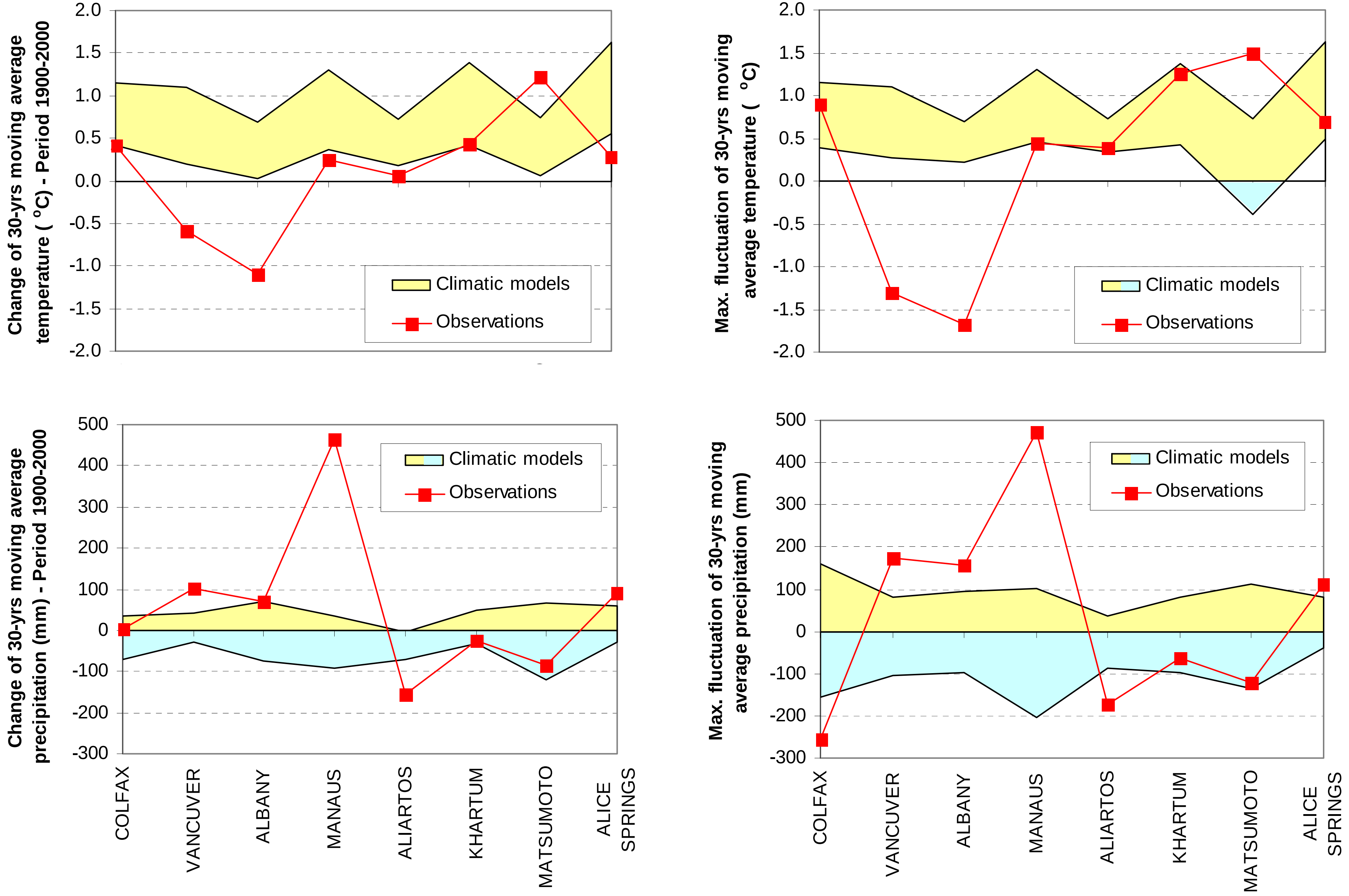
Climatic (30 year) time scale

- Mean correlation/efficiency 0.233/-101.1 for temperature and 0.010/-45.8 for precipitation.
- Climatic models generally fail to reproduce the long-term changes on temperature and precipitation.





19. Reproduction of observed long-term fluctuations



20. Conclusions

- All examined long records demonstrate large overyear variability (long-term fluctuations) with no systematic signatures across the different locations/climates.
- GCMs generally reproduce the broad climatic behaviours at different geographical locations and the sequence of wet/dry or warm/cold periods on a mean monthly scale.
- However, model outputs at annual and climatic (30-year) scales are irrelevant with reality; also, they do not reproduce the natural overyear fluctuation and, generally, underestimate the variance and the Hurst coefficient of the observed series; none of the models proves to be systematically better than the others.
- The huge negative values of coefficients of efficiency at those scales show that model predictions are much poorer that an elementary prediction based on the time average.
- This makes future climate projections not credible.
- The GCM outputs of AR4, as compared to those of TAR, are a regression in terms of the elements of falsifiability they provide, because most of the AR4 scenarios refer only to the future, whereas TAR scenarios also included historical periods.

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