Probabilistic projections of climate system response to anthropogenic forcing, using hierarchy of climate models of different complexity.

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In collaboration with:
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Methodology of producing probabilistic climate change forecast.

Climate change projections for 21st century.

Relative contributions of economic and climate system uncertainties.

Climate changes in high latitudes of Northern Hemisphere

Conclusion.

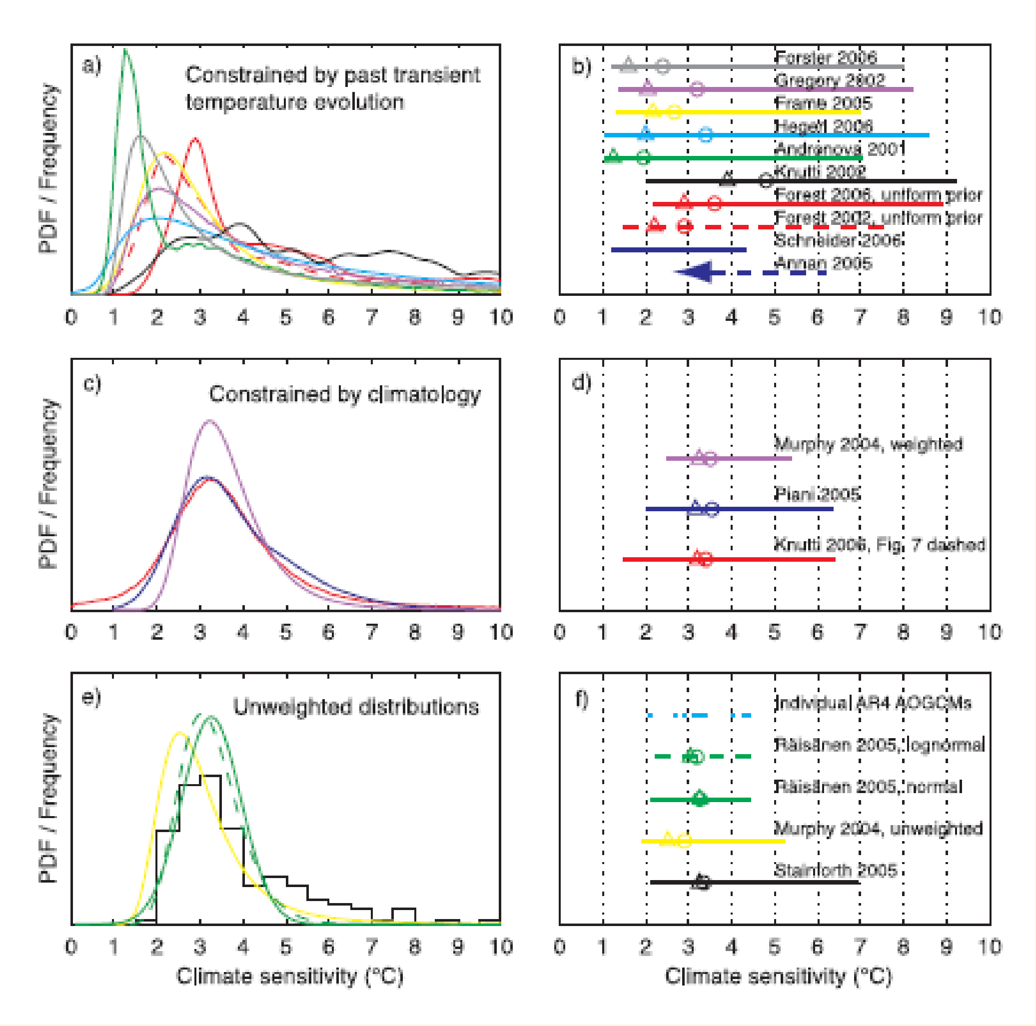
Main sources of uncertainties.

Economics.

Uncertainties in labor productivity, resource availability, population growth, and cost and availability of new technologies.

Climate.

Climate sensitivity, rate of the heat uptake by the deep ocean, strength of the sulfate aerosol forcing, and uncertainty in carbon uptake by the ocean and terrestrial ecosystem.



Box 10.2, Figure 1. *(a) PDFs or frequency distributions constrained by the transient evolution of the atmospheric temperature, radiative forcing and ocean heat uptake, (b) as in (a) and (b) but 5 to 95% ranges, medians (circles) and maximum probabilities (triangles), (c) and (d) as in (a) but using constraints from present-day climatology, and (e) and (f) unweighted or fitted distributions from different models or from perturbing parameters in a single model. Distributions in (e) and (f) should not be strictly interpreted as PDFs. See Chapter 9 text, Figure 9.20 and Table 9.3 for details. Note that Annan et al. (2005b) only provide an upper but no lower bound. All PDFs are truncated at 10°C for consistency, some are shown for different prior distributions than in the original studies, and ranges may differ from numbers reported in individual studies.*

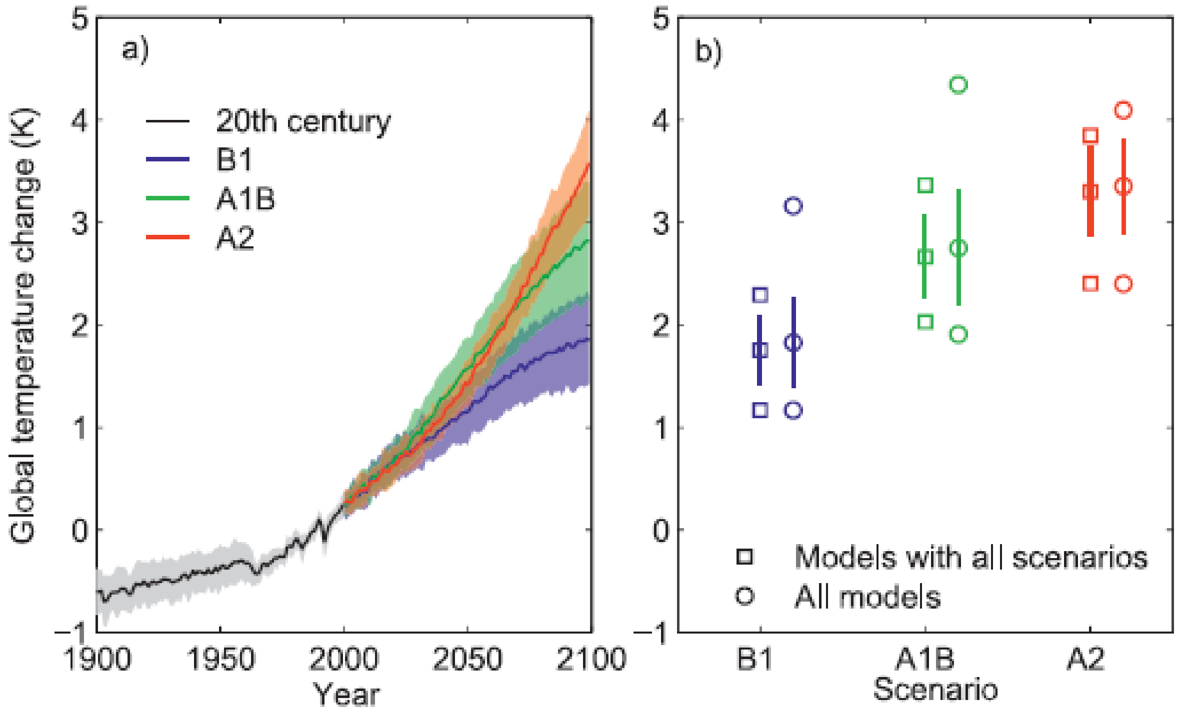
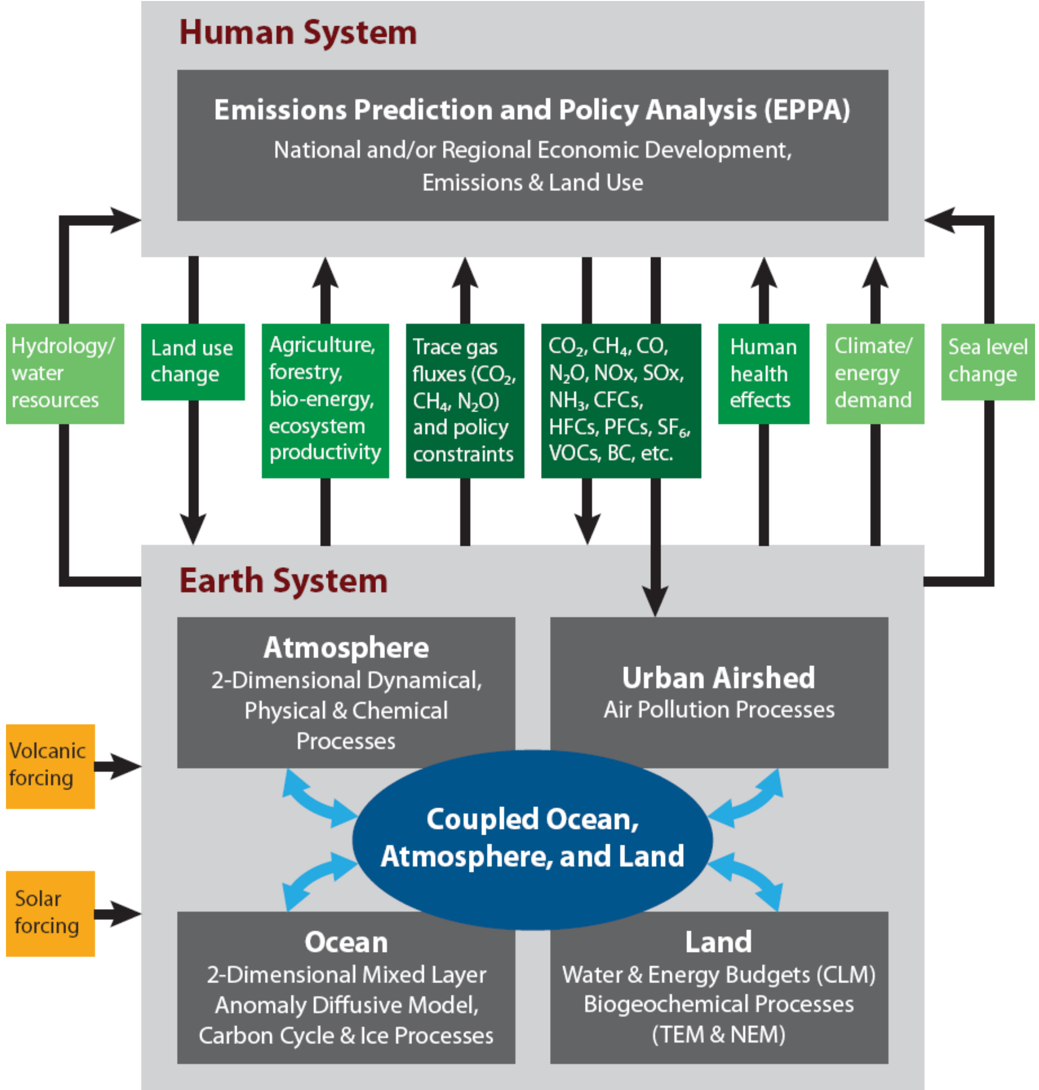


FIG. 1. (a) Multimodel mean and one std dev uncertainty ranges for global temperature (relative to the 1980–99 average for each model) for the historic simulation and projections for three IPCC SRES scenarios. (b) Mean and one std dev ranges (lines) plus minimum maximum ranges (symbols) for the subset of models that have run all three scenarios (squares) and for all models (circles). The model spread for the scenarios B1 and A1B depends strongly on what prior distribution of models is assumed.

From: Knutti et al. 2010: Challenges in combining projections from multiple climate models, J. Climate, 23, 2739-2758



MIT Integrated Global System Model

MIT Climate and Chemistry Model

Model Outputs:
Temperature
Cloudiness
Humidity
Precipitation
Nutrient Deposition
Greenhouse Gas and Air Pollutant Levels
Sea Level

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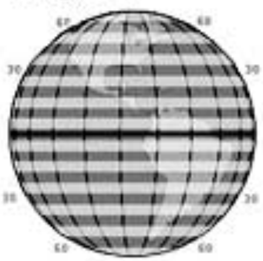
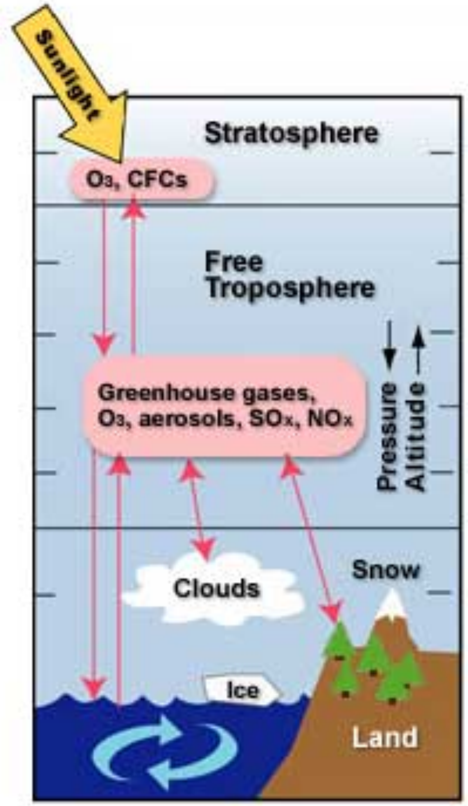
For research purposes, the model divides the globe into 46 regions of latitude each measuring 4 degrees.





Atmospheric Chemistry:
25 Chemical species,
53 Gas and Aerosol phase reactions,

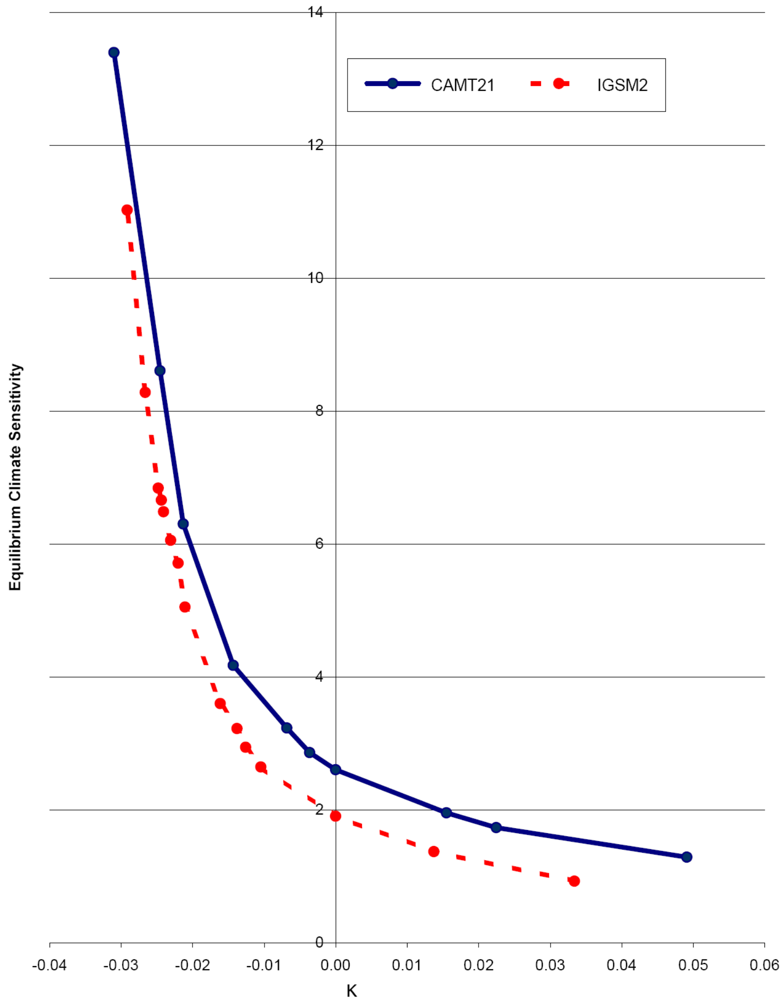
Time Steps:
Advection = 10 minutes,
Physics = 1 hour,
Photochemistry = 3 hours

....

Atmospheric Circulation:
Primitive equations,
Time Step = 10 minutes,
Sigma coordinates (vertical)
Spherical coordinates (horizontal)

....

Ocean Circulation:
Parameterized horizontal and vertical transport in simple version, predicted 3D transports in advanced version



$C = C^o \cdot (1.0 \pm \kappa \cdot \Delta Tsrf)$, where C^o is a cloud fraction simulated by the model and $\Delta Tsrf$ is a difference of the global-mean surface air temperature from is values in the control climate simulation.

This adjustment is applied, with different signs, to high and low clouds, - and + respectively.

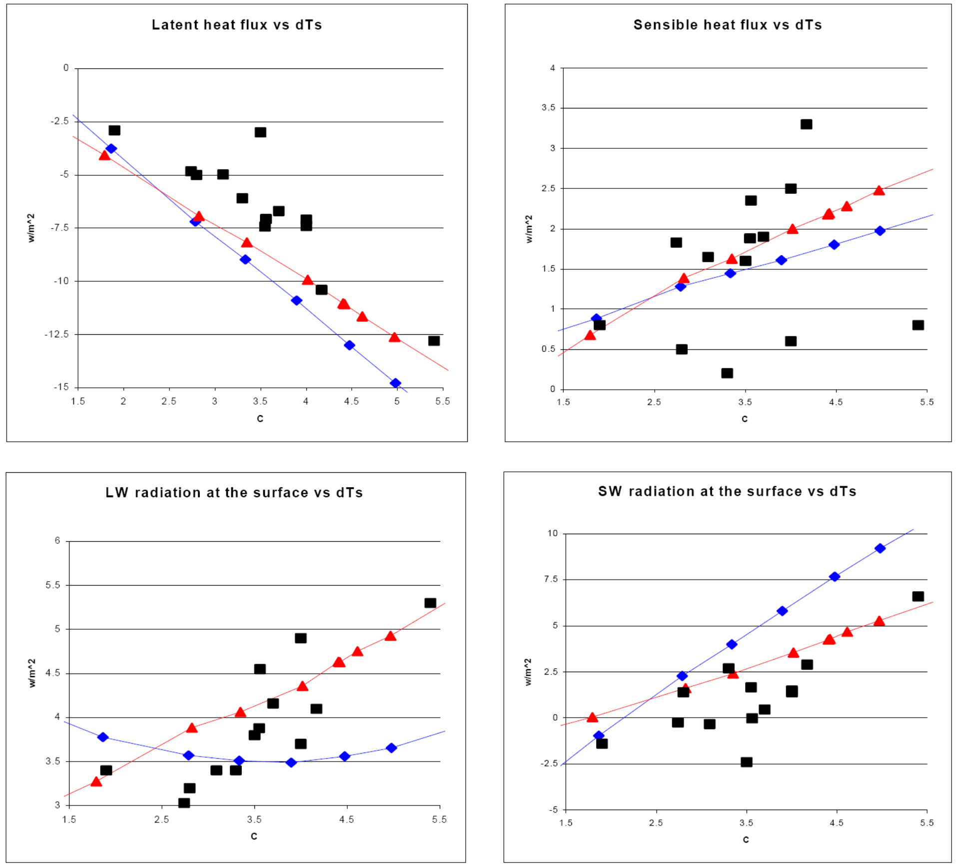


Figure 6. Changes in surface fluxes in equilibrium doubled CO_2 simulations with different GCMs (squares) and the versions of the MIT climate model with different sensitivities. Diamonds indicate results form the versions with the same k used for all clouds and triangles form the simulations with k of different signs used for high and low

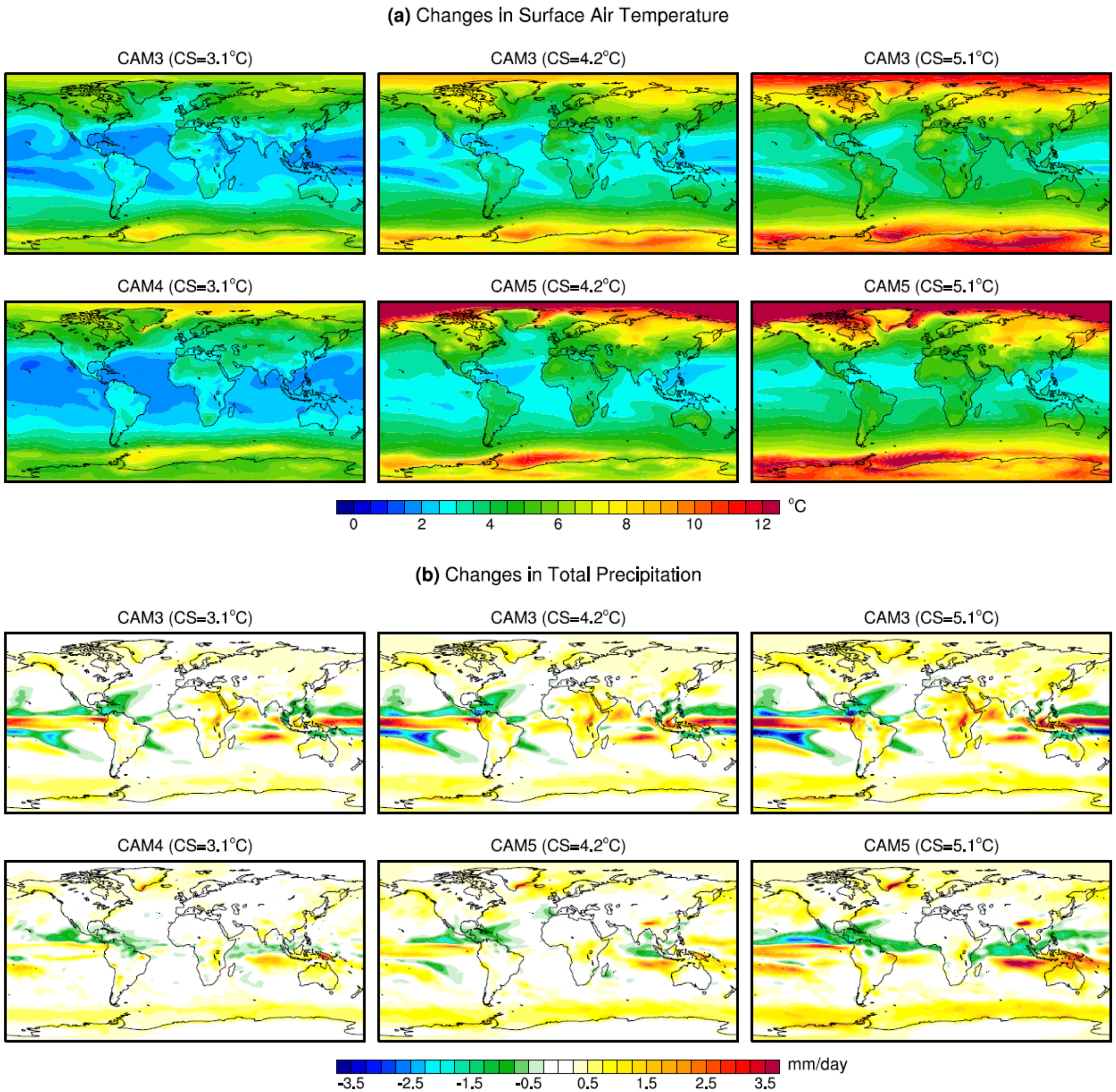
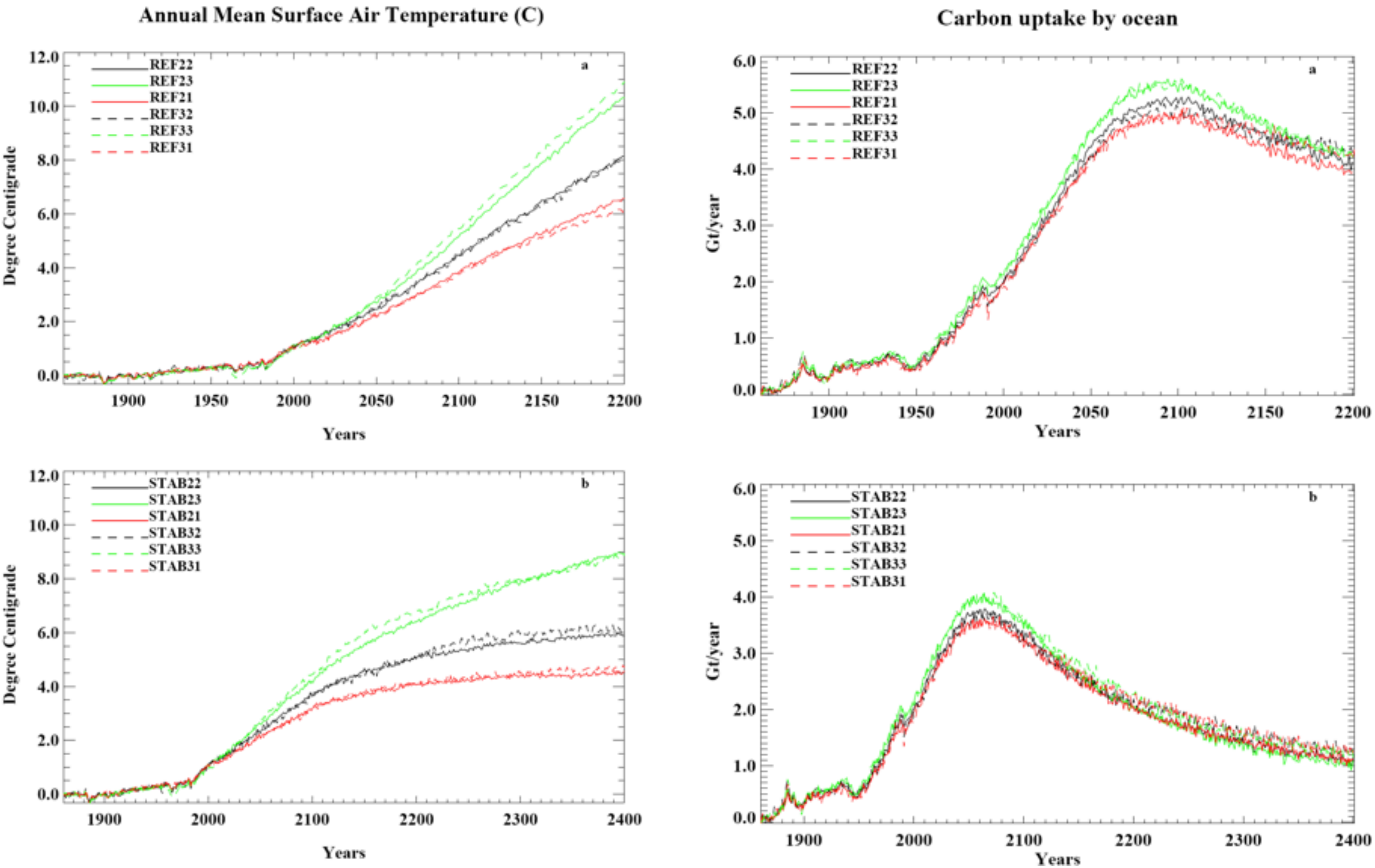


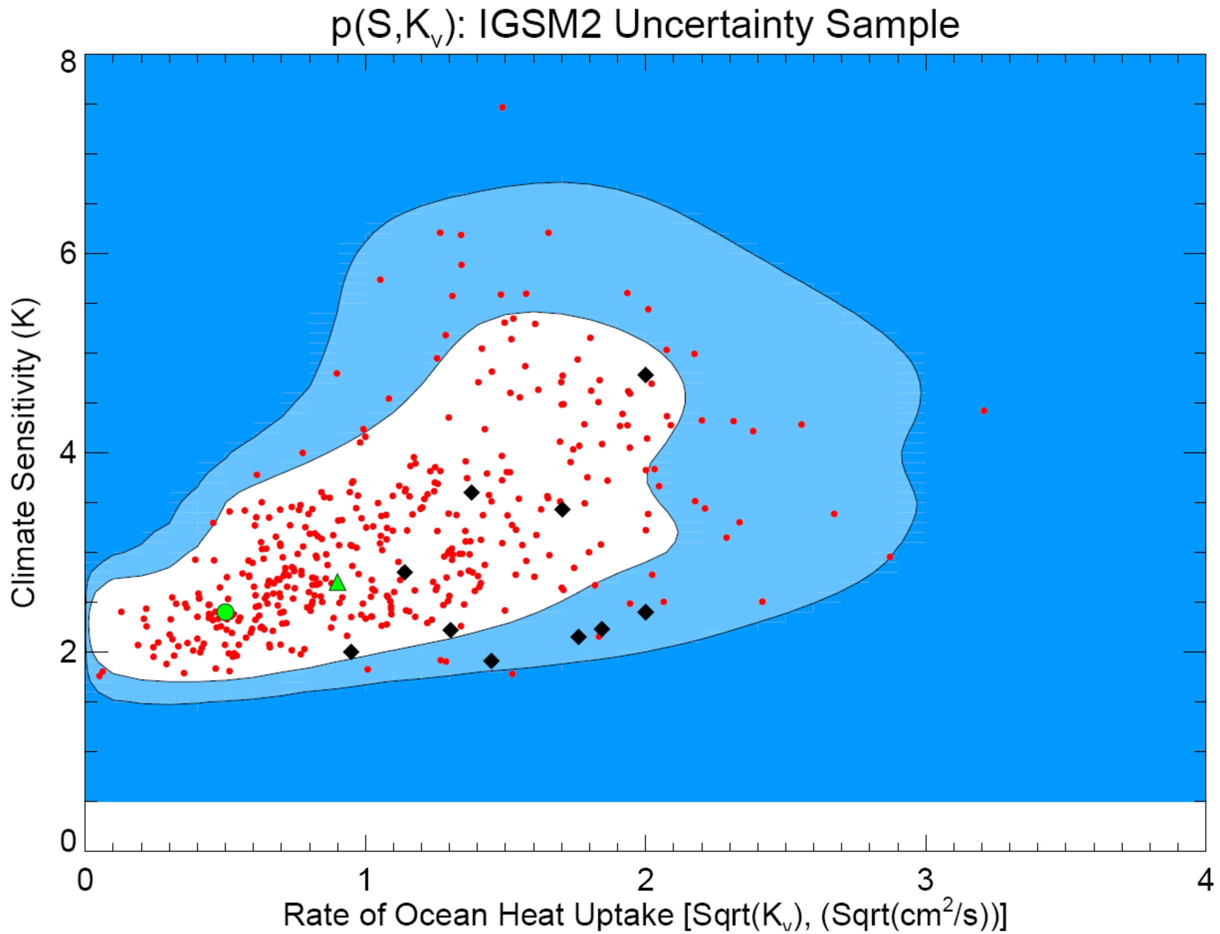
FIG. 9. Changes in **(a)** surface air temperature and **(b)** total precipitation in response to a doubling of CO_2 concentrations with CAM4 (CS=3.1°C) and CAM5 (CS=4.2°C and CS=5.1°C) and with versions of CAM3 with matching climate sensitivities.



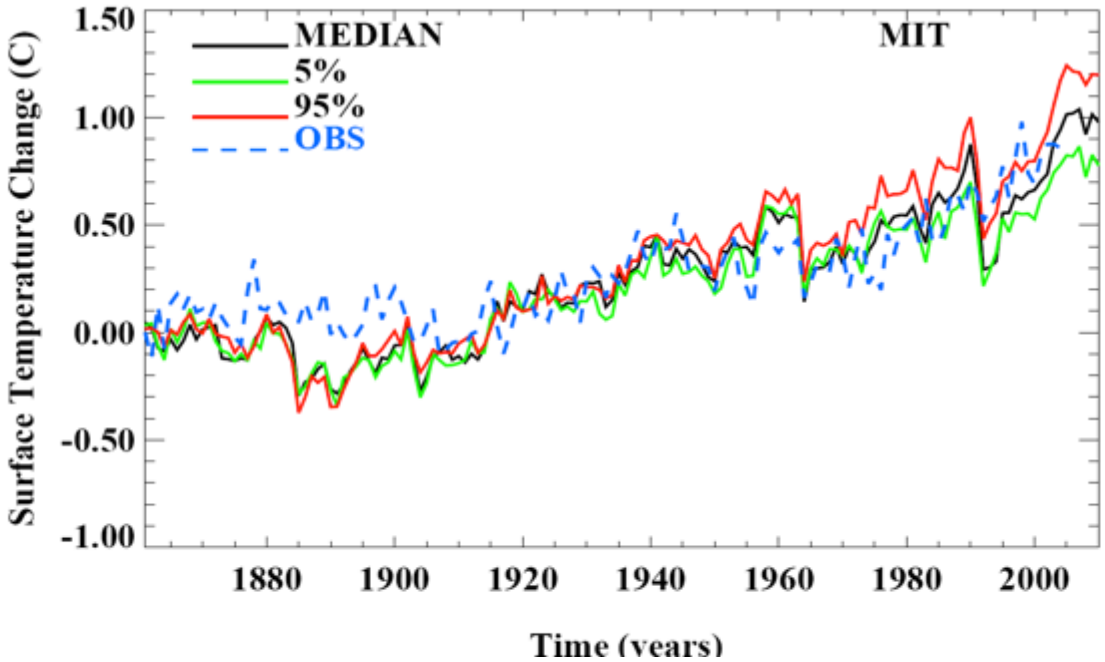
Global mean surface air temperature and carbon uptake by the ocean in simulations with the IGSM2.3 with different values of climate sensitivity and vertical diffusion coefficient (dashed lines) and with matching versions of the IGSM2.2 (solid lines) for reference (a) and stabilization (b) emission scenarios.

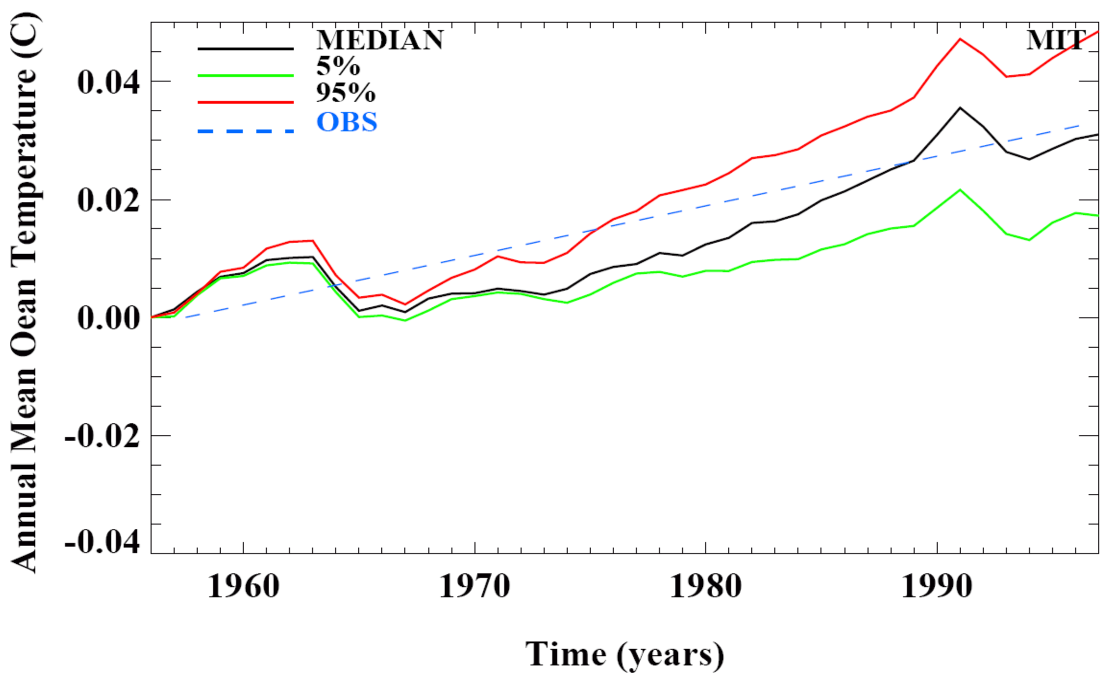
Large number of 19th - 20th centuries climate were carried out with climate model parameters (climate sensitivity, rate of heat uptake by the ocean and strength of aerosol forcing) varied over wide ranges. Probability distributions for climate parameters are defined based on comparing simulated and observed 20th century climate.

Probability distributions for economic model parameters are defined based on data for economic development over second half of 20th century

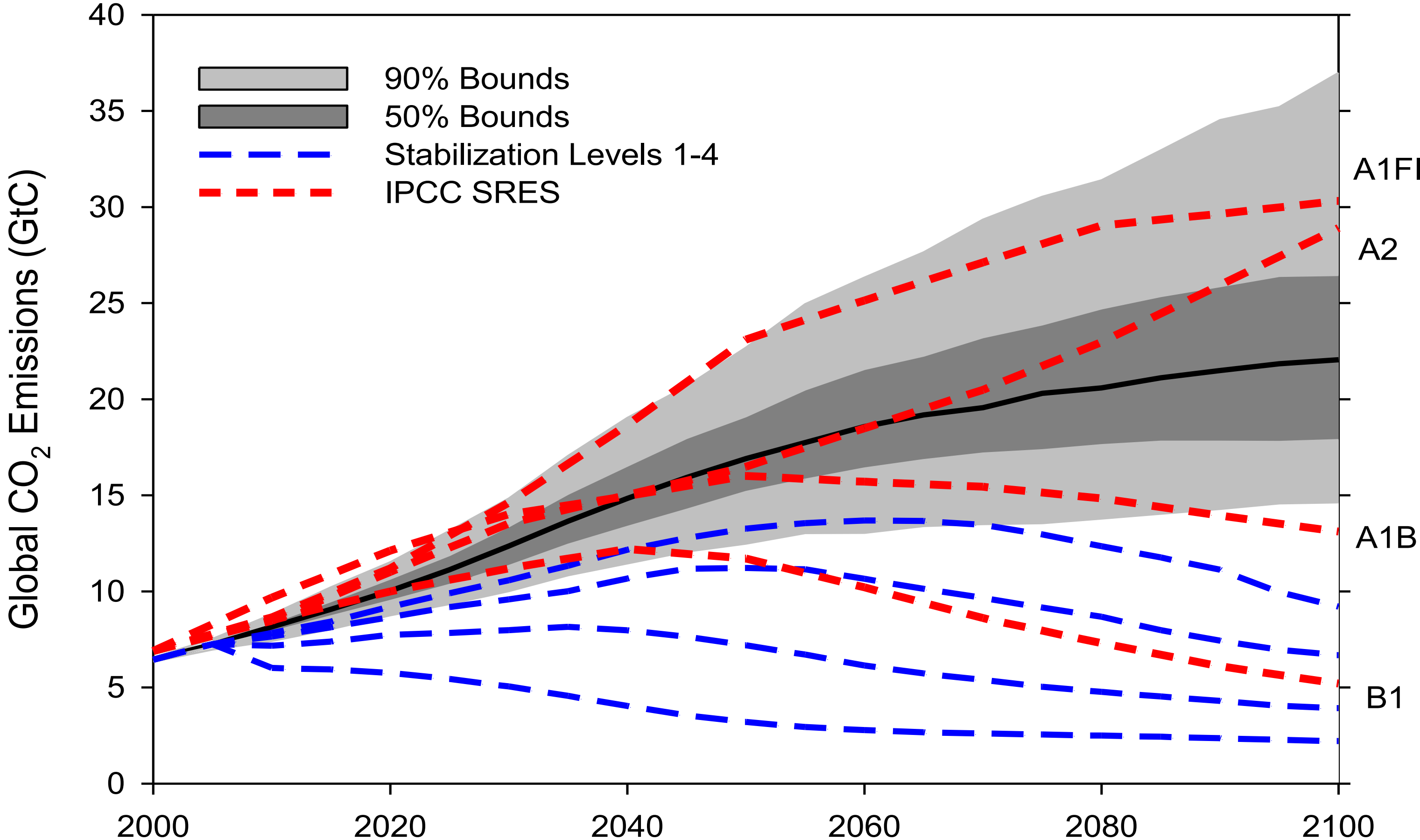


The marginal posterior probability density function for S-Kv parameter space. The shading and thick contours denote rejection regions for significance levels of 10% and 1% respectively. Green circle and triangle indicate mode and a median on the distribution respectively. Red dots show values for Kv and S from 400 samples.

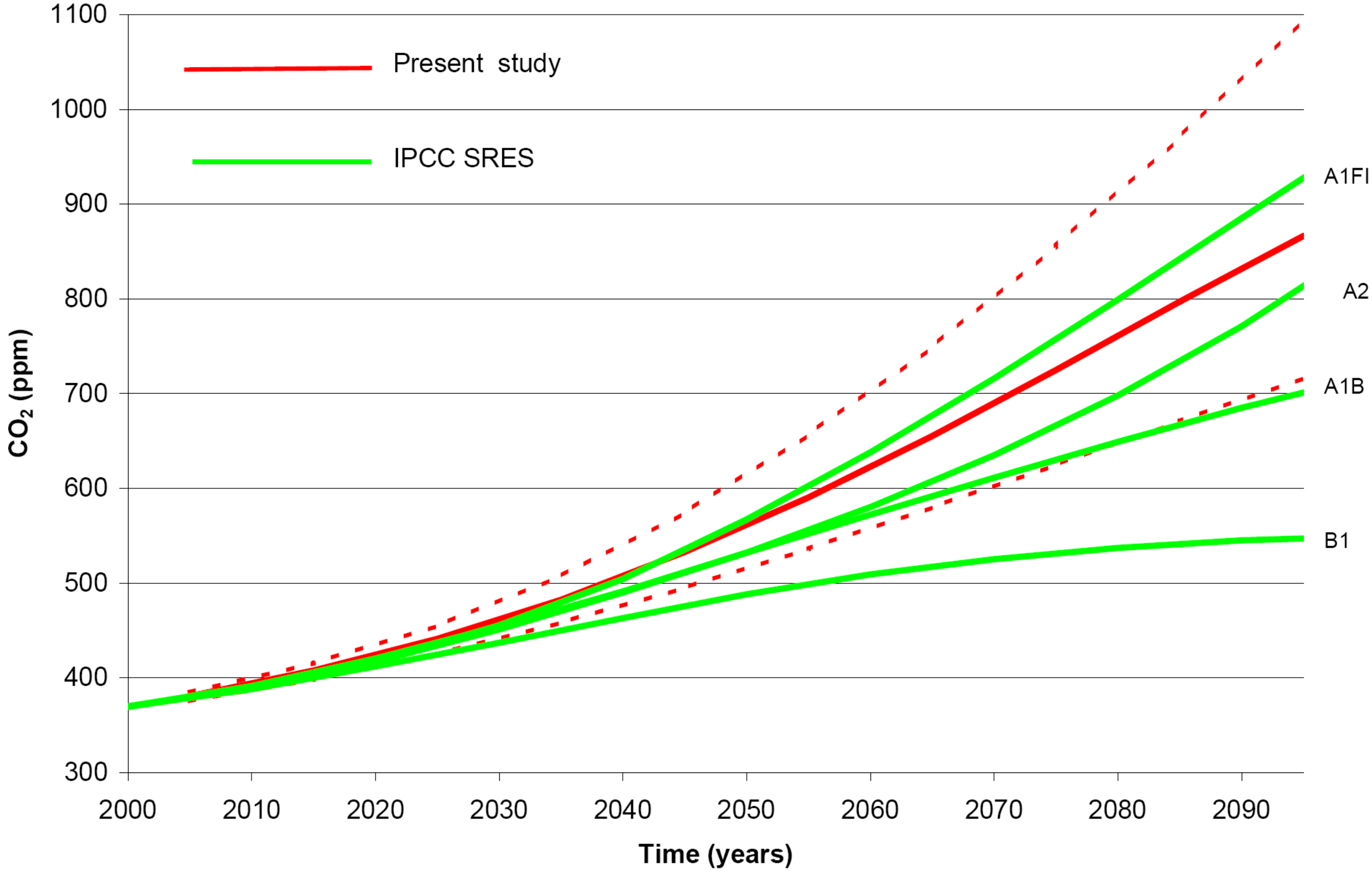




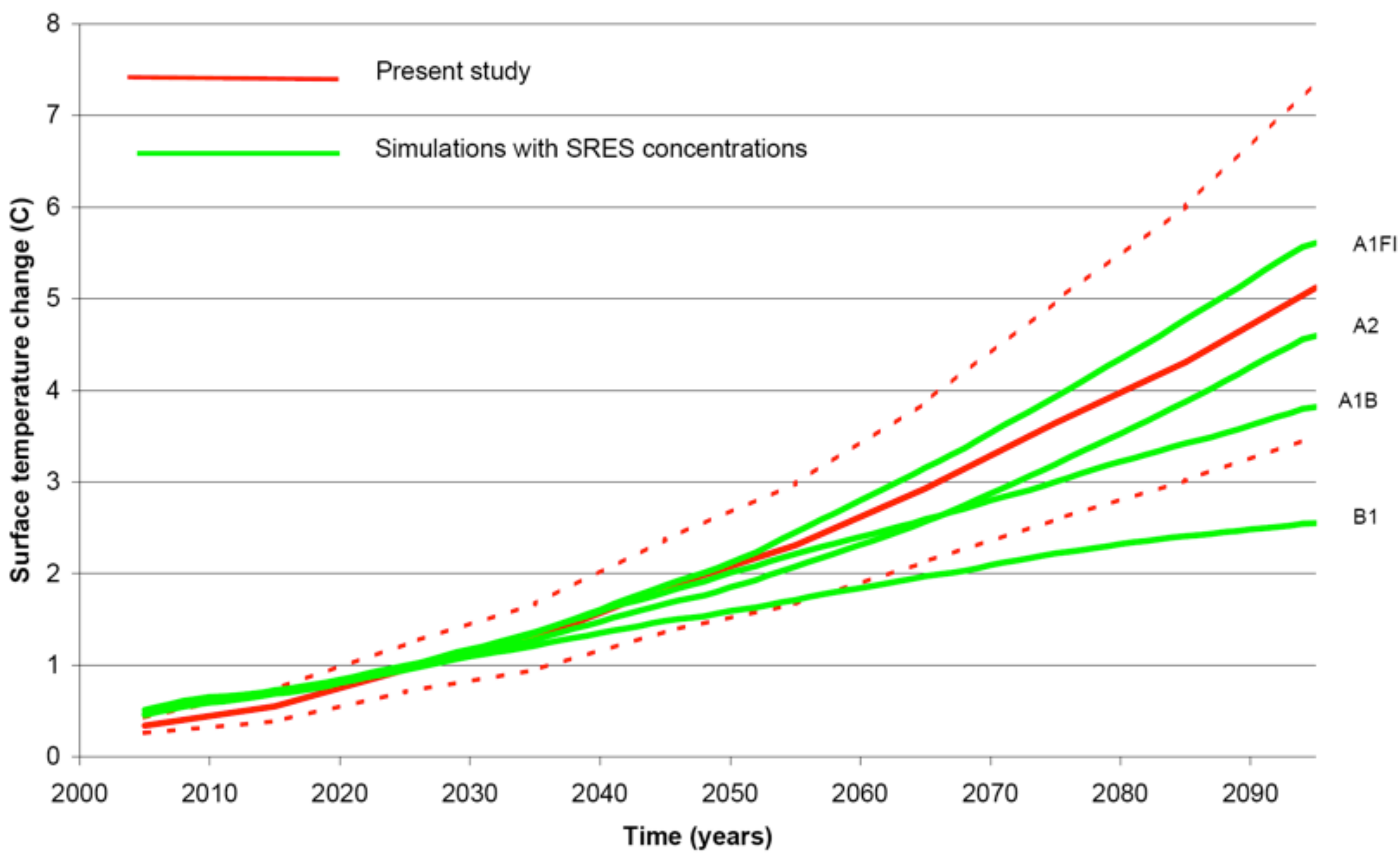
Changes in global mean annual mean surface air temperature (top) and in global mean annual mean ocean temperature for top 3000 meters. Observations are from Jones, 2003 and Levitus et al (2005), respectively .



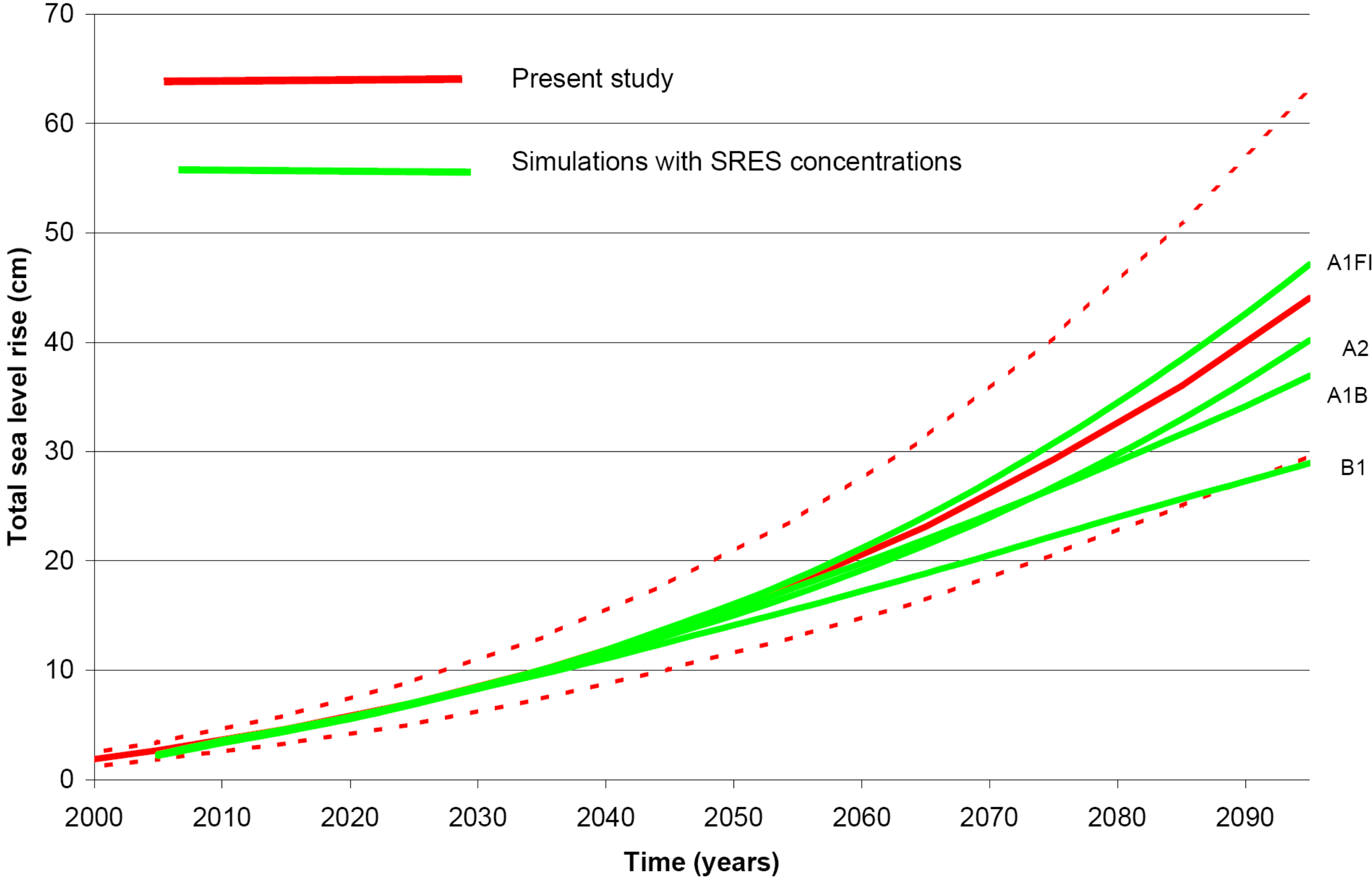
Global anthropogenic CO_2 emissions. Black line and shaded regions show median, 50% (light) and 90% (dark) probability bounds for business as usual emissions. Blue lines median emissions for different policies. Red lines IPCC SRES scenarios.



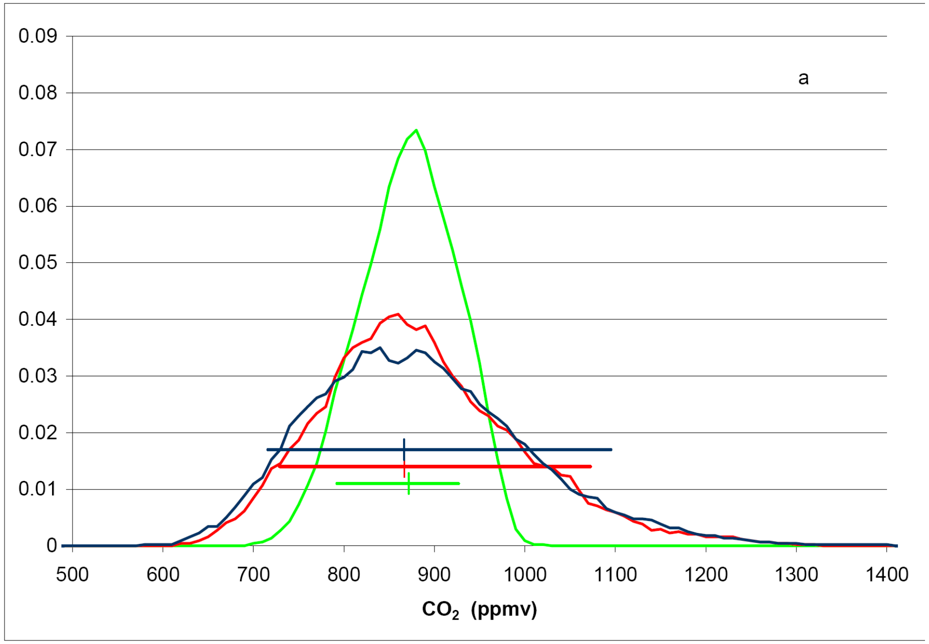
Global CO_2 concentrations.
Red lines show median, and 90% probability bounds from present study. Green lines indicate CO_2 concentration for IPCC SRES scenarios (ISAM reference).

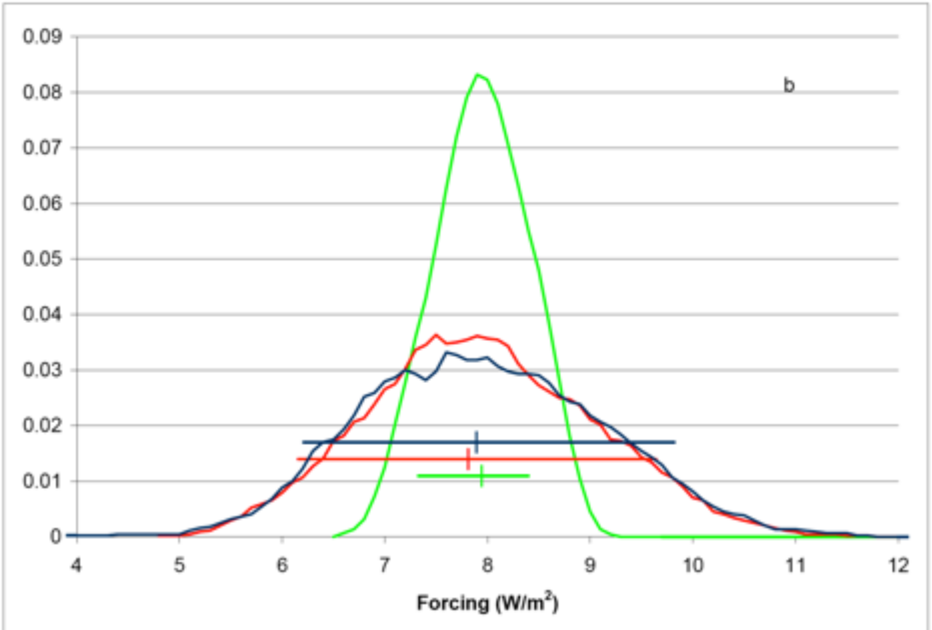


Change in surface air temperature.
Red lines show median, and 90% probability bounds from present study. Green lines indicate results of the simulations with version of the MIT IGSM with median values of climate parameters forced by GHG and aerosol concentrations from the IPCC SRES scenarios



Total sea level rise.
Red lines show median, and 90% probability bounds from present study. Green lines indicate results of the simulations with version of the MIT IGSM with median values of climate parameters forced by GHG and aerosol concentrations from the IPCC SRES scenarios

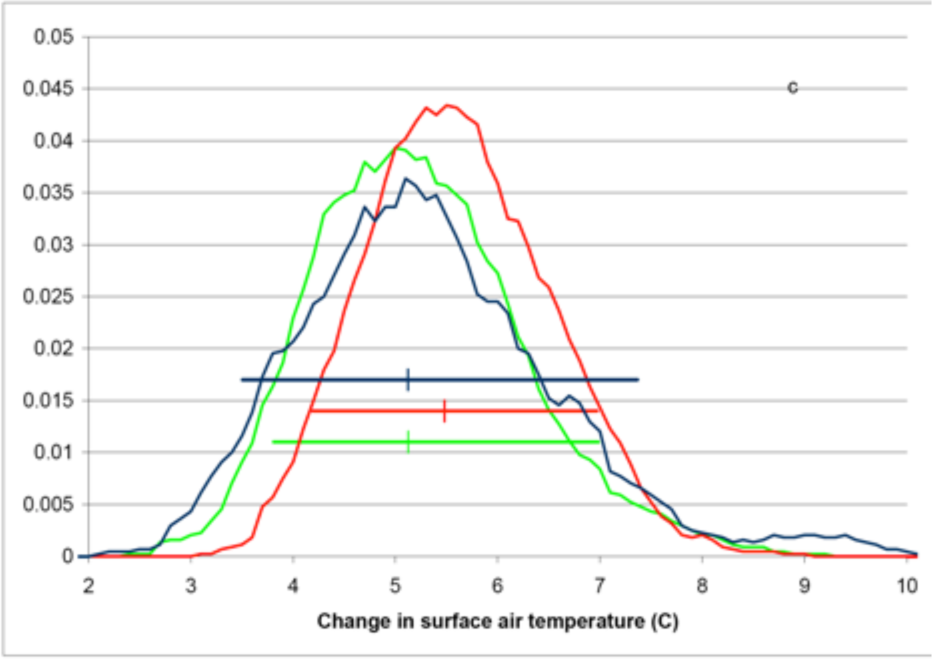


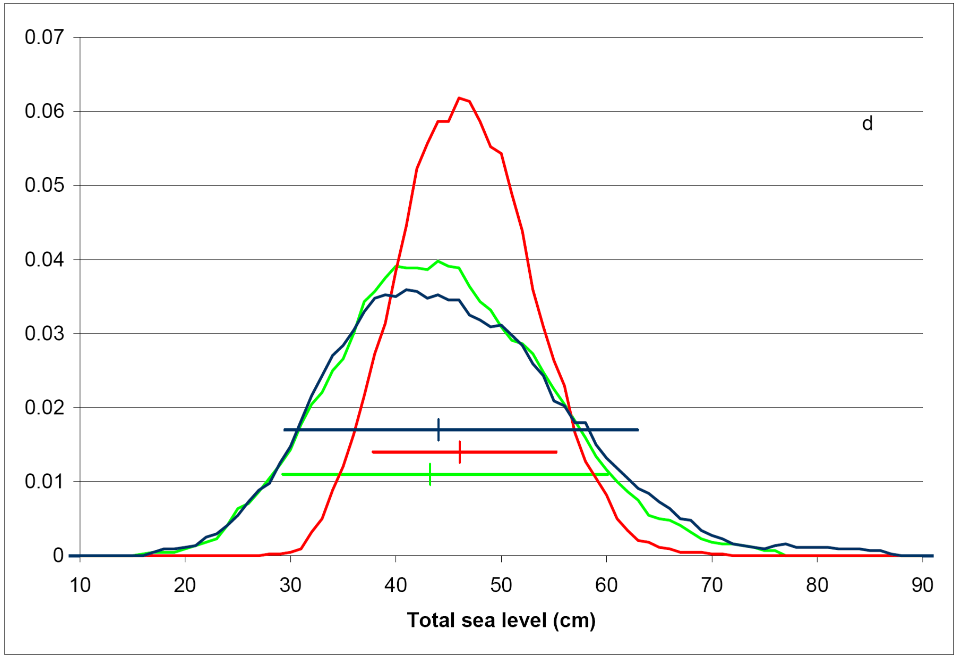


	5%	50%	95%
Full uncertainty	716	866	1095
Emission uncertainty	729	867	1072
Climate uncertainty	793	872	926
	5%	50%	95%
Full uncertainty	0.83	1.00	1.26
Emission uncertainty	0.84	1.00	1.24
Climate uncertainty	0.91	1.00	1.06

	5%	50%	95%
Full uncertainty	6.21	7.89	9.82
Emission uncertainty	6.16	7.81	9.64
Climate uncertainty	7.33	7.95	8.40
	5%	50%	95%
Full uncertainty	0.79	1.00	1.24
Emission uncertainty	0.79	1.00	1.23
Climate uncertainty	0.92	1.00	1.06

Frequency distributions for atmospheric CO_2 concentrations (a), radiative forcing in simulations with full uncertainty (blue), emissions uncertainty (red) and climate uncertainty (green) averaged over 2091-2100.





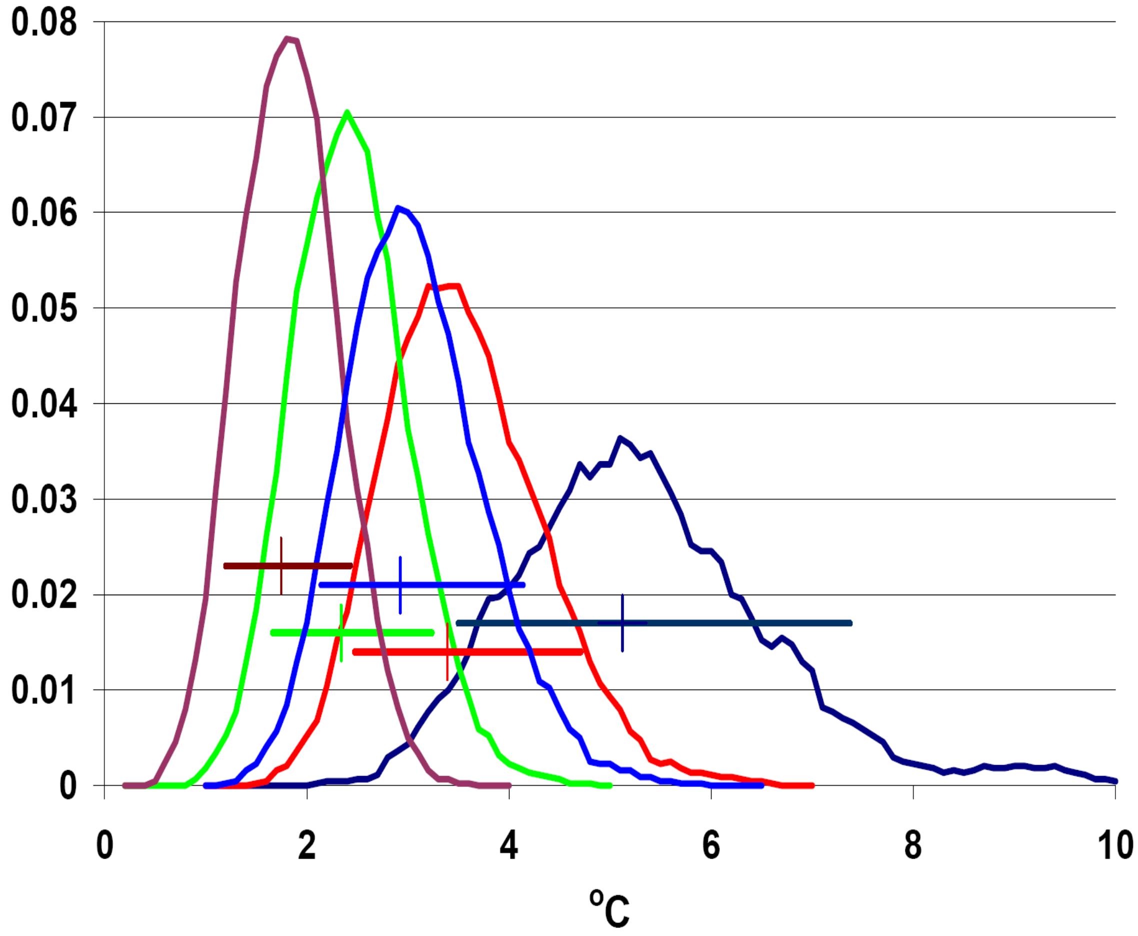
	5%	50%	95%
Full uncertainty	3.50	5.12	7.37
Emission uncertainty	4.19	5.48	6.97
Climate uncertainty	3.81	5.12	6.98
	5%	50%	95%
Full uncertainty	0.68	1.00	1.44
Emission uncertainty	0.76	1.00	1.27
Climate uncertainty	0.74	1.00	1.36

	5%	50%	95%
Full uncertainty	29.46	44.04	62.93
Emission uncertainty	37.87	46.06	55.21
Climate uncertainty	29.31	43.25	60.09
	5%	50%	95%
Full uncertainty	0.67	1.00	1.43
Emission uncertainty	0.82	1.00	1.20
Climate uncertainty	0.68	1.00	1.39

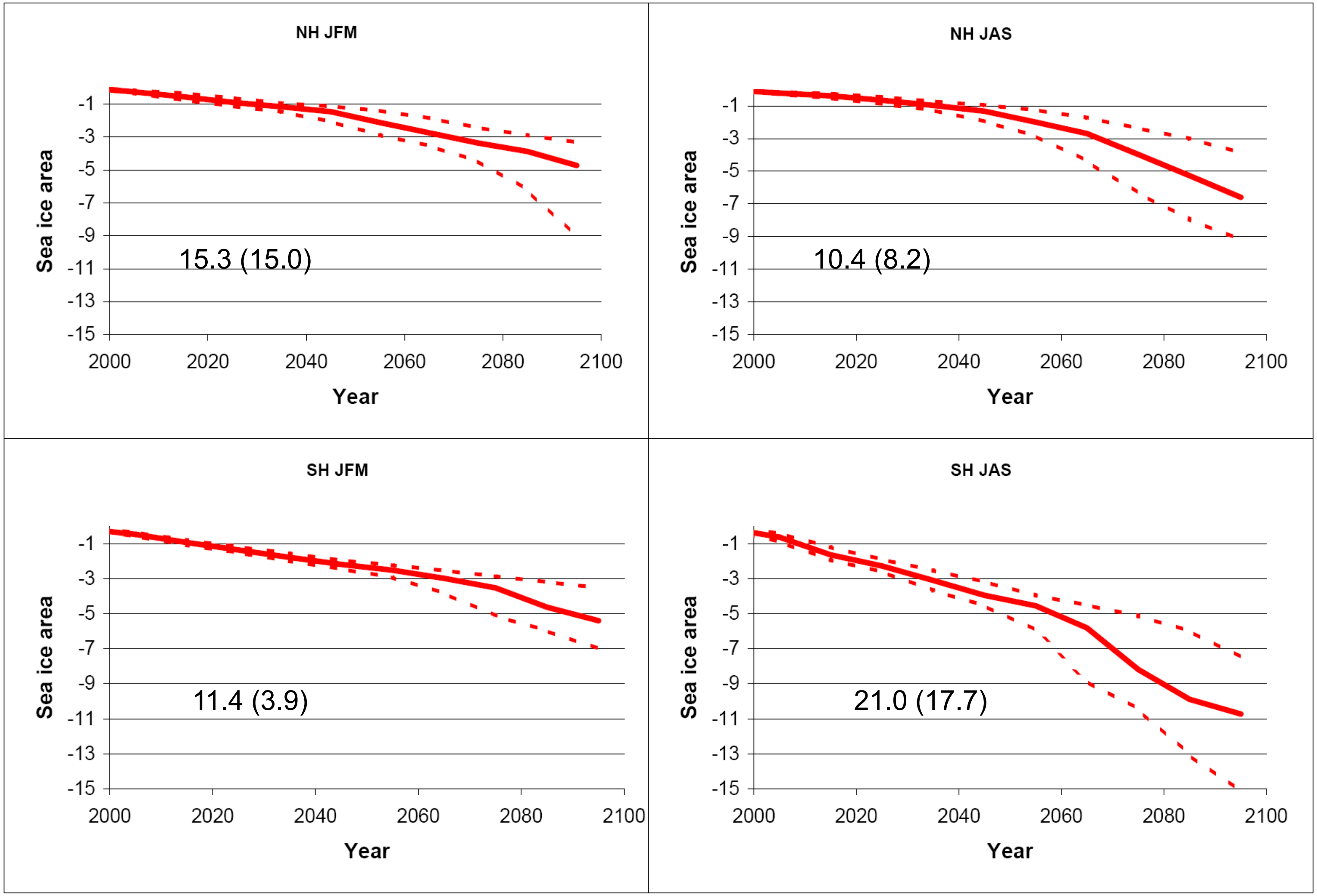
Frequency distributions for surface air temperature increase (c), and total sea level rise (d) in simulations with full uncertainty (blue), emissions uncertainty (red) and climate uncertainty (green) averaged 2091-2100

	CO_2 Concentrations (ppm)	CO_2–Equivalent Concentrations For all Long-lived Greenhouse Gases (ppm)	Total Radiative Forcing (W/m^2)	Change in Annual Mean Surface Temperature (Degrees C)
Level 1	477	552	4.22	1.75
Level 2	554	658	5.25	2.34
Level 3	643	787	6.30	2.93
Level 4	714	899	7.07	3.39
No Policy	866	1399	9.68	5.13

Median concentration, radiative forcing relative to 1860, and temperature change in last decade of 21st century relative to 1981-2000 average.



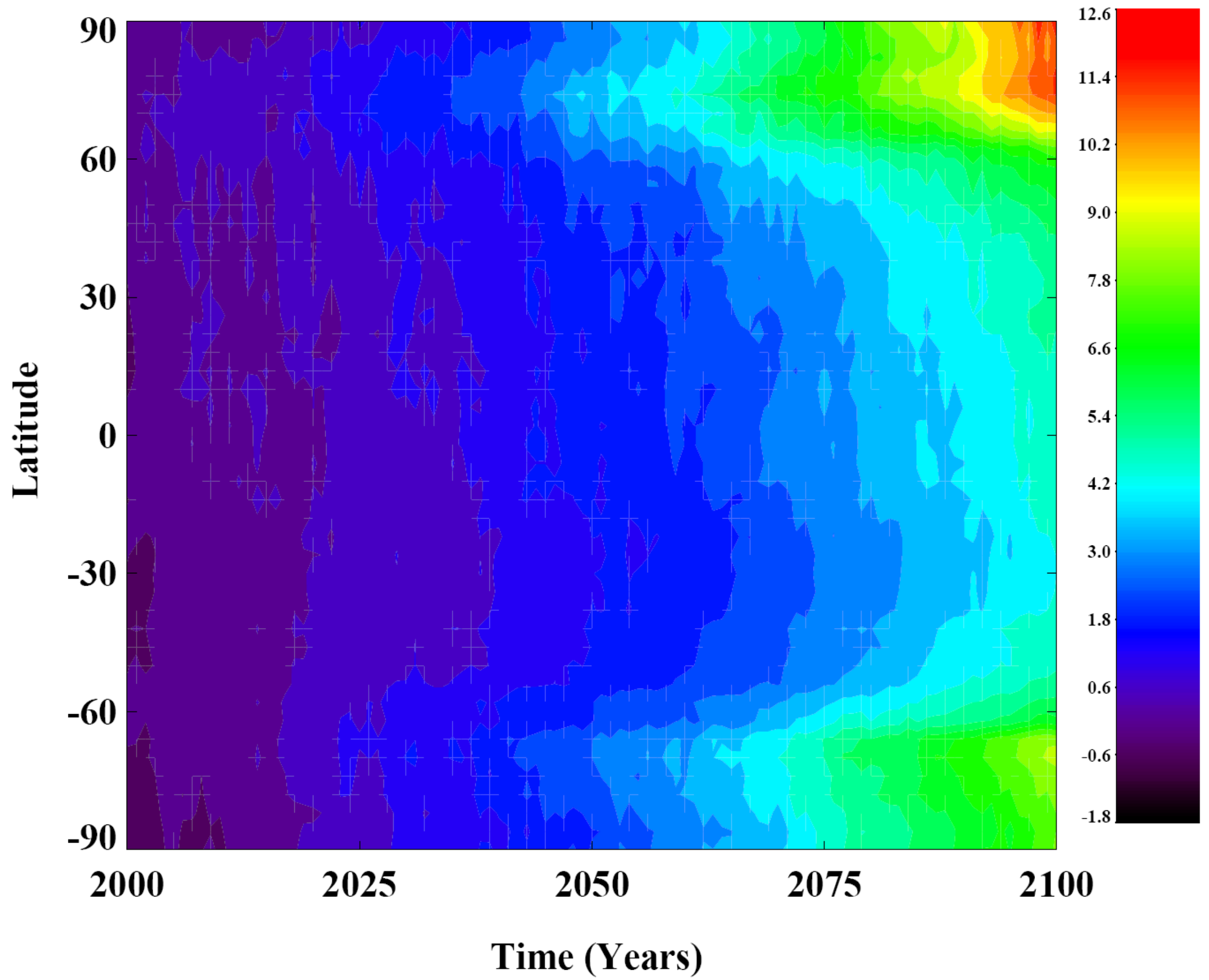
Probability Distributions for Global Mean Surface Temperature Change; average for 2091-2100 minus average for 1981-2000 for different policies.



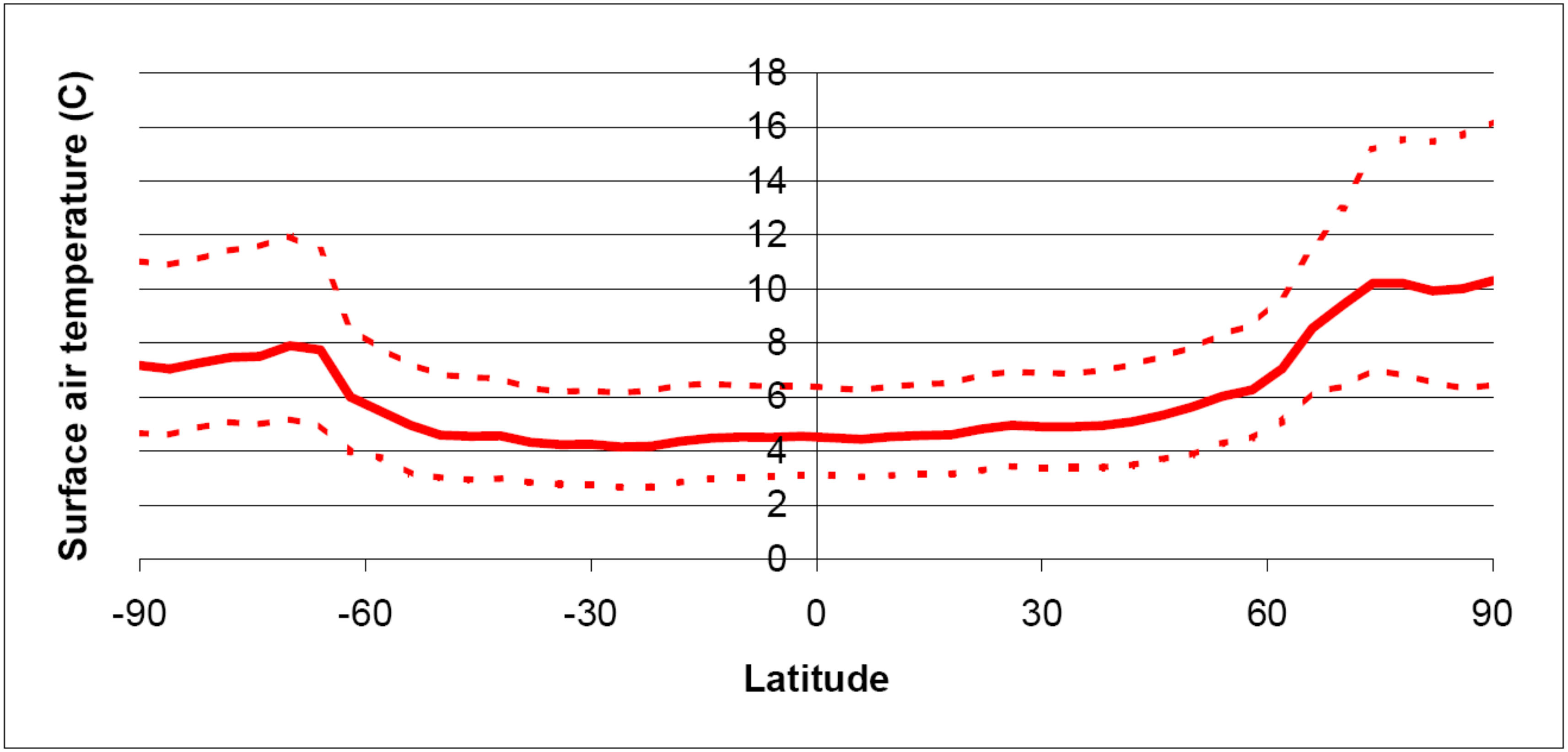
Changes in sea ice area (10^6 km^2) relative to 1981-2000 average.

Solid line median; dashed lines 5% and 95% probability bounds.

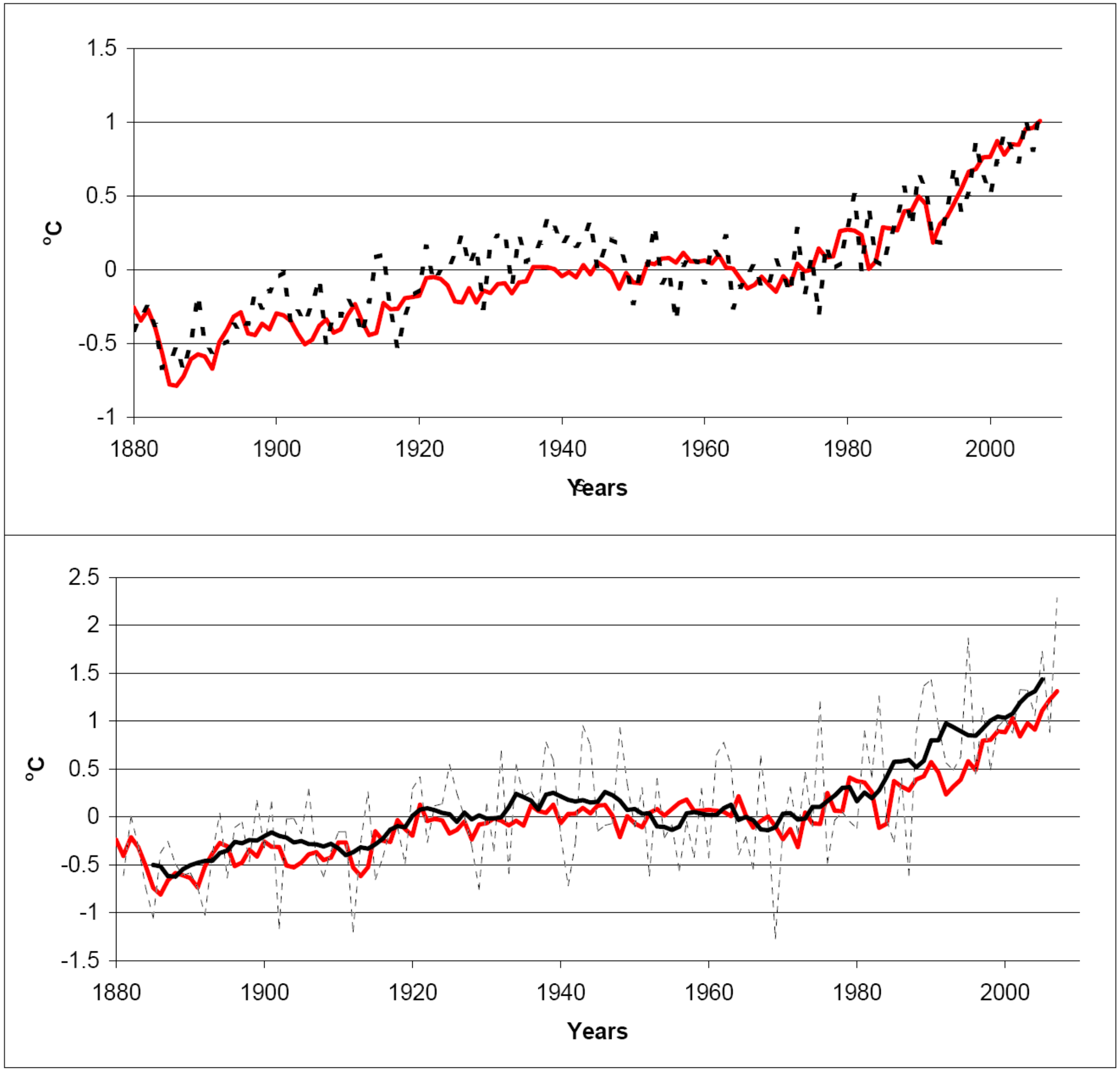
Numbers on each panel show sea ice coverage for reference period modeled (observed).



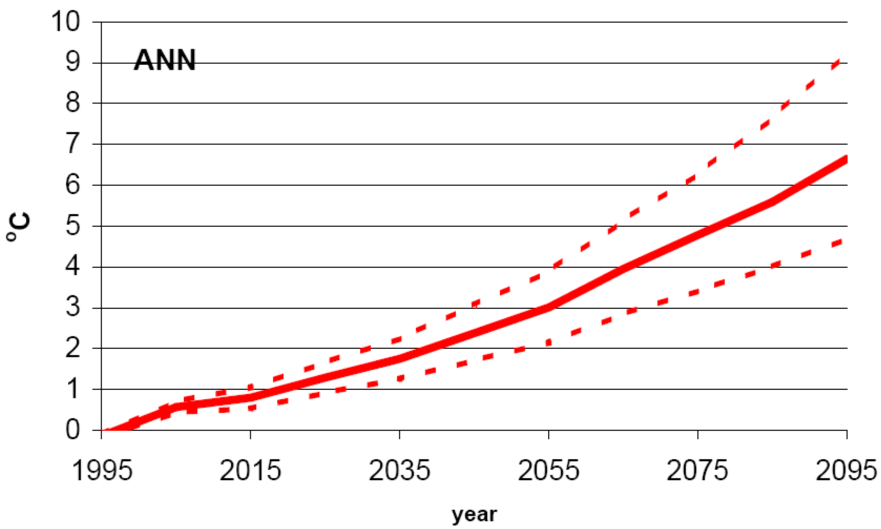
Transient change in surface air temperature in simulation with median values of parameters for both economics and climate model.



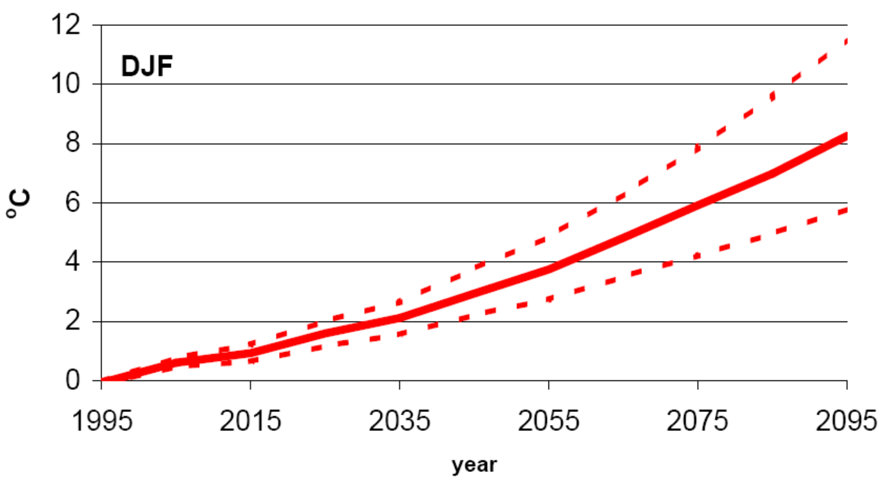
Latitudinal distribution of changes in SAT in the last decade of 21st century relative to 1981-2000 in simulations without climate policy.
Solid line is median, dashed lines are 5% and 95% percentiles.

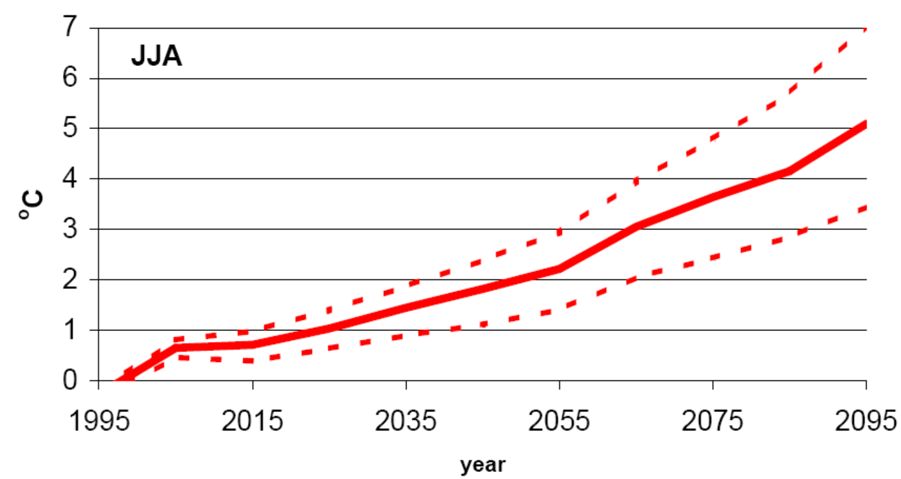


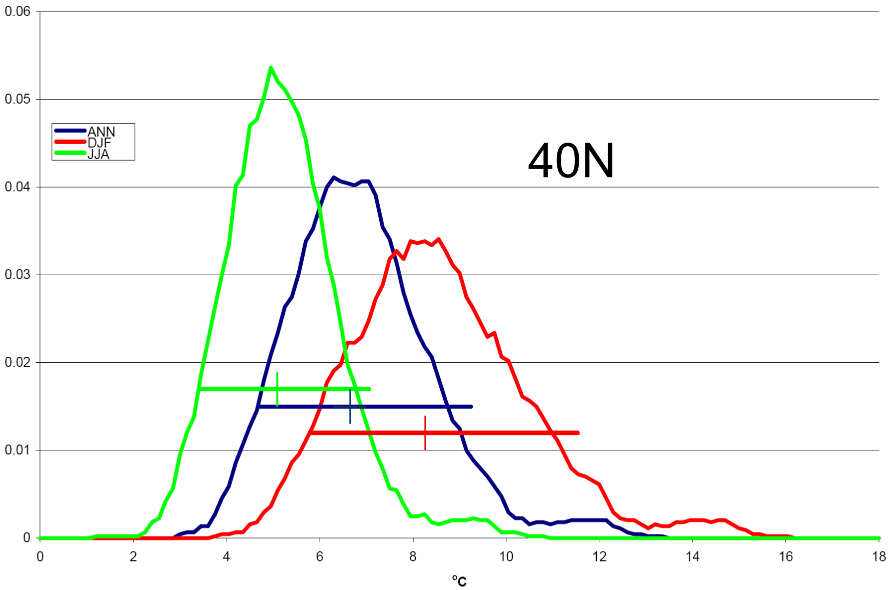
Surface air temperature over land area: global (top) and north from 40°N (bottom).
Black - observed: dashed line - annual data, solid line - 5 year running mean
Red - in simulation with median values of climate parameters and observed forcing

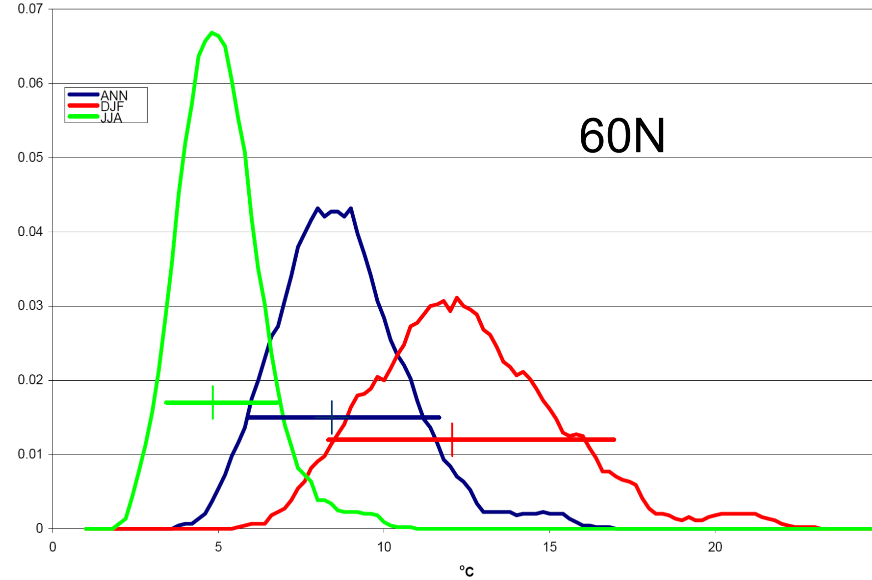


Projected changes in decadal mean surface air temperature over land area north from 40N Solid line - median, dashed lines - 5% and 95% percentiles







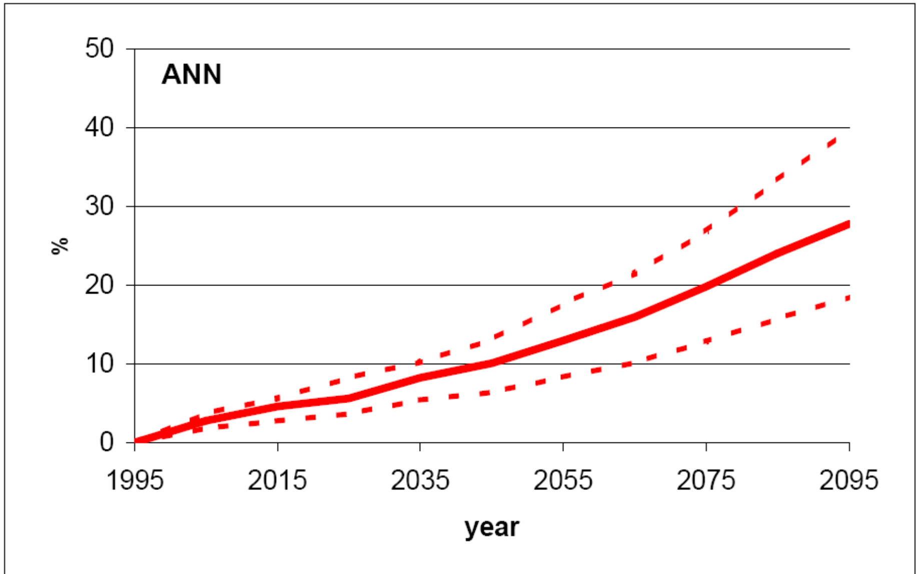


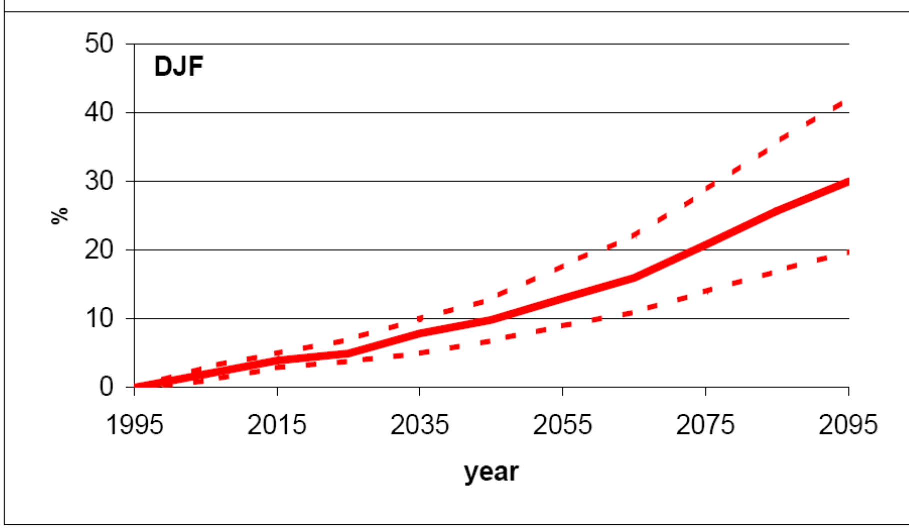
	5%	16.7%	50%	83.3%	95%
ANN	4.70	5.42	6.65	8.12	9.24
DJF	5.79	6.74	8.26	10.21	11.53
JJA	3.45	4.10	5.09	6.12	7.05

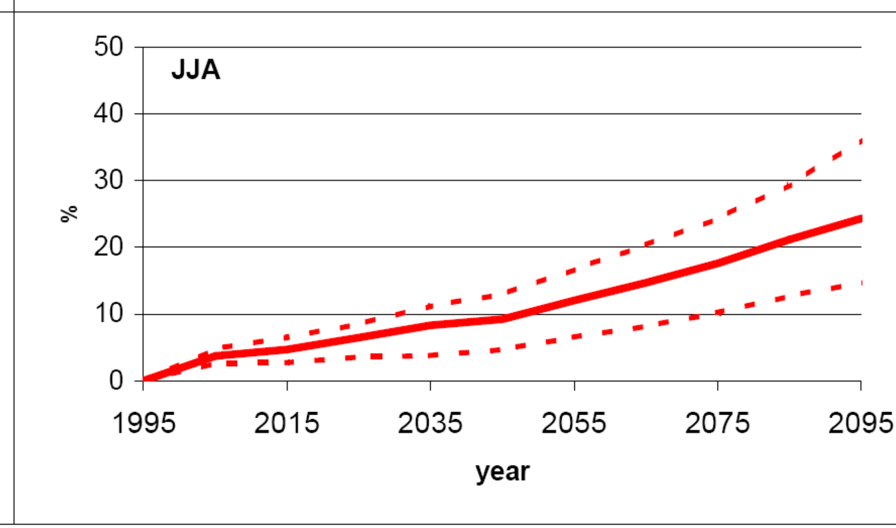
	5%	16.7%	50%	83.3%	95%
ANN	5.95	6.89	8.42	10.34	11.66
DJF	8.32	9.73	12.06	14.99	16.94
JJA	3.43	3.98	4.82	5.92	6.78

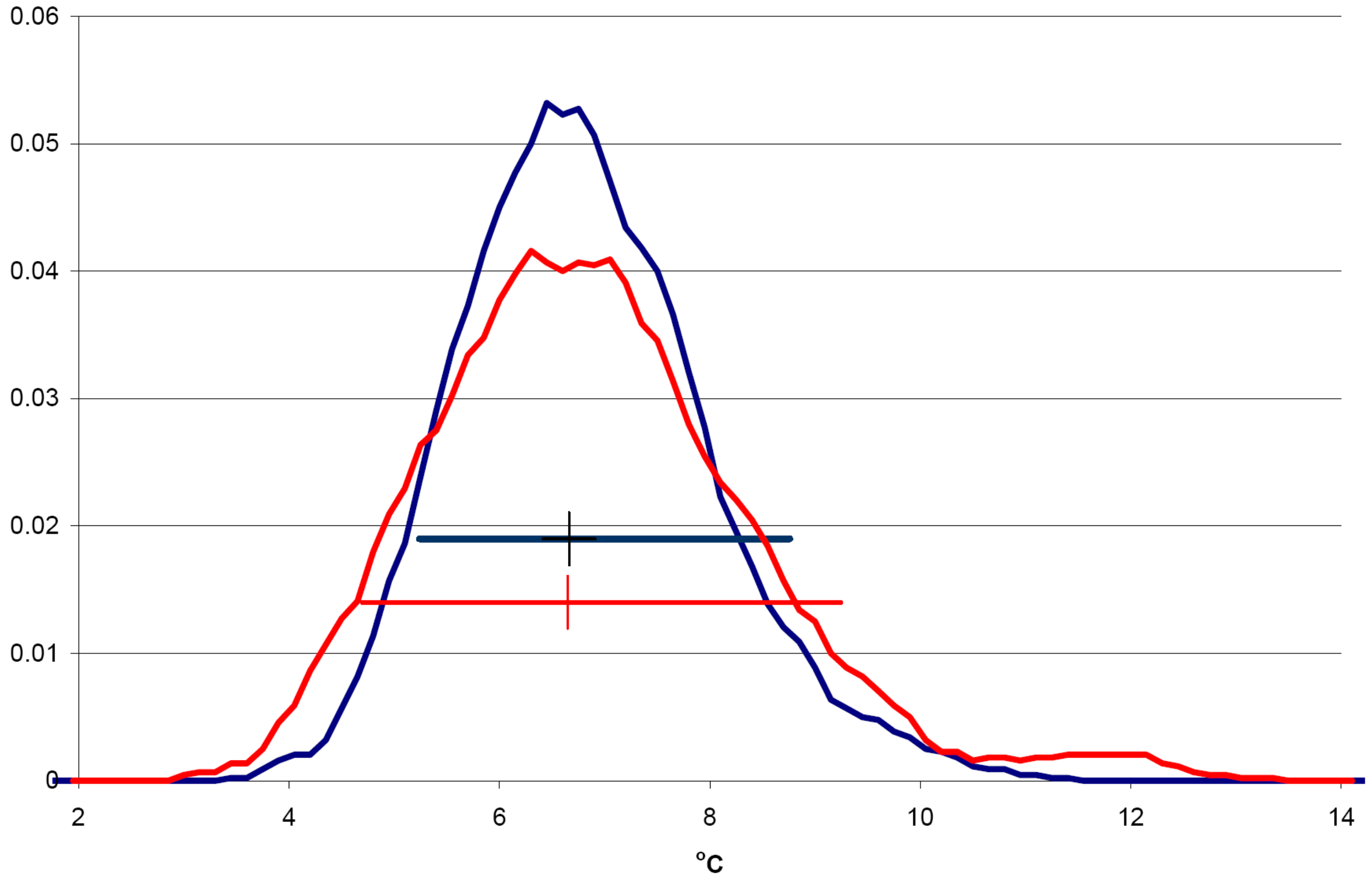
Frequency distributions for surface air temperature increase from 1981-200 to 2091-2100 over land north from 40N (left) and 60N (right). Annual mean -blue, summer mean - red and winter mean- green averaged 2091-2100

Projected changes in decadal mean precipitation (as % of 1981-2000 value) over land area north from 40N
Solid line - median, dashed lines - 5% and 95% percentiles

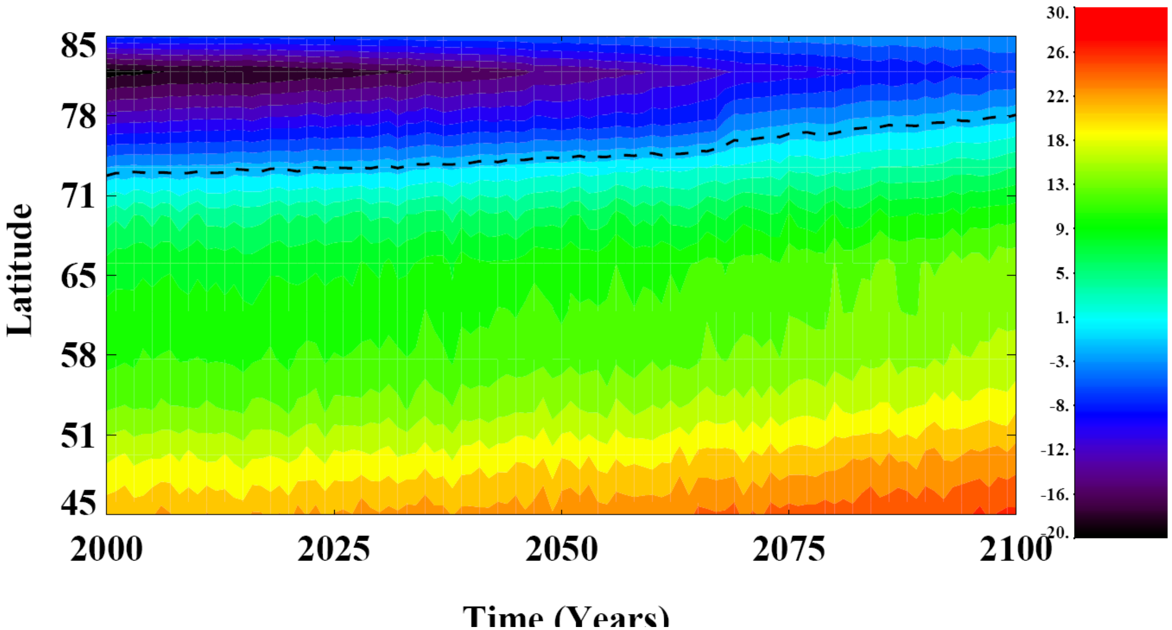




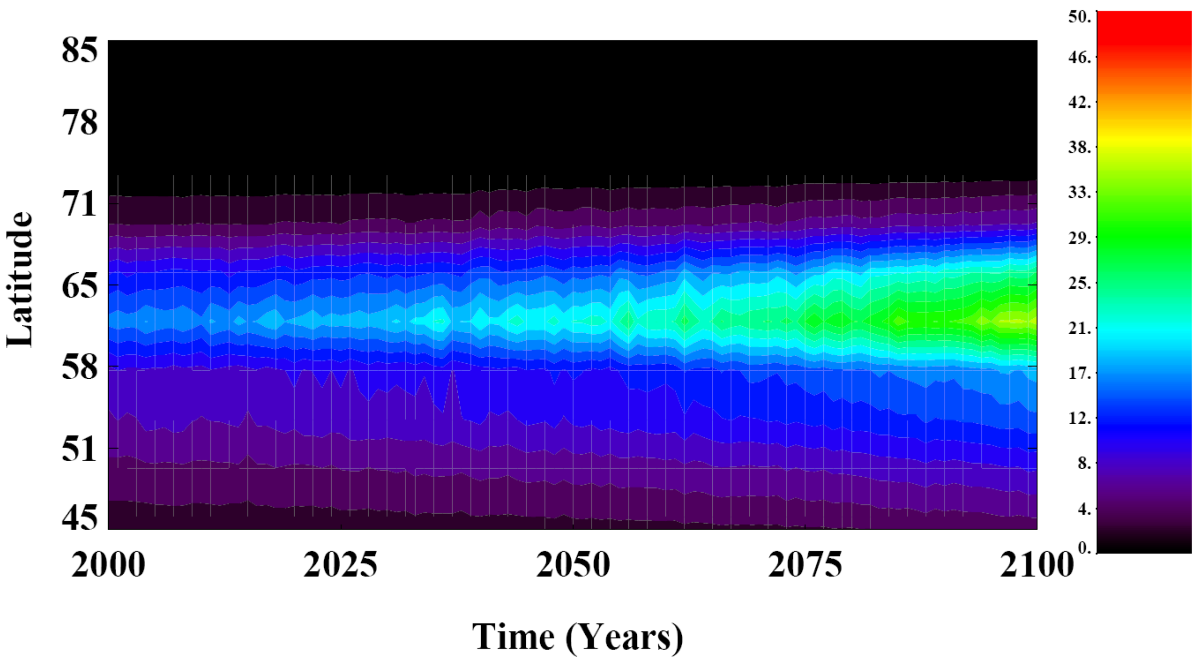




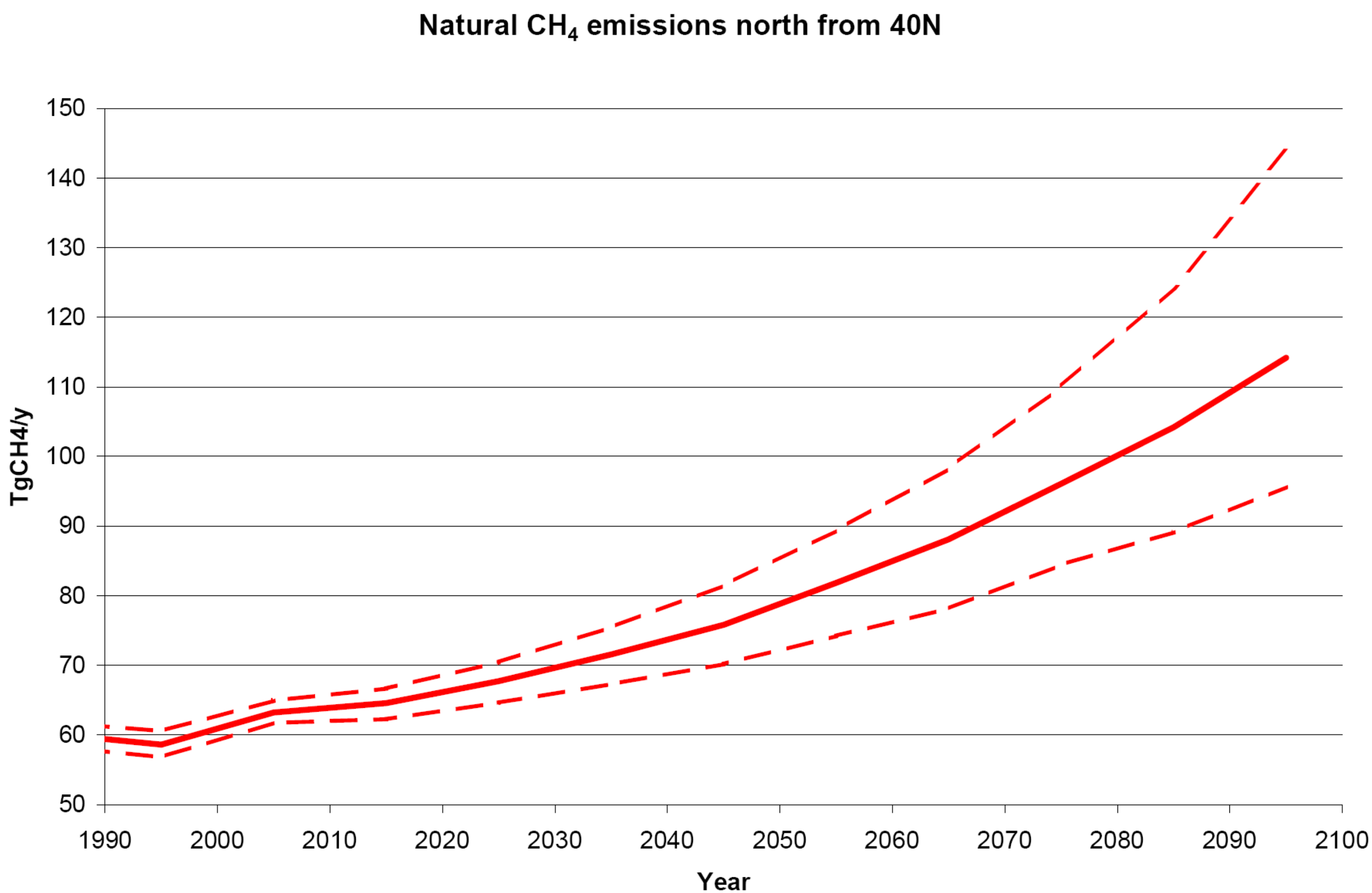
Frequency distributions for SAT increase over land north from 60N
in 2091 to 2100 relative to the 1981 to 2000 average.
Red – climate uncertainty only, black – full uncertainty.
Horizontal bars – 5%-90% ranges
Vertical bars - medians



Summer (JJA) soil temperature averaged from 0 to 1 m in simulation with median values of climate parameters and reference GHG emissions.
Dashed line - 0°C

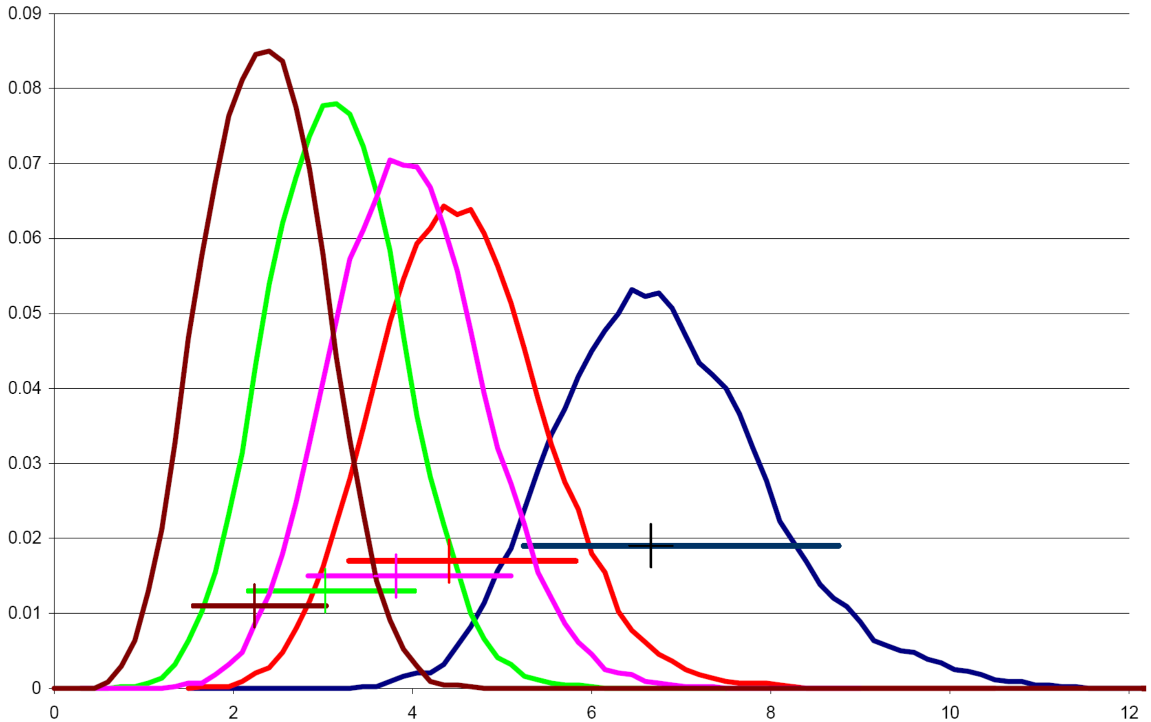


Natural methane emissions (Mt CH_4/year) in simulation with median values of climate parameters and reference GHG emissions.



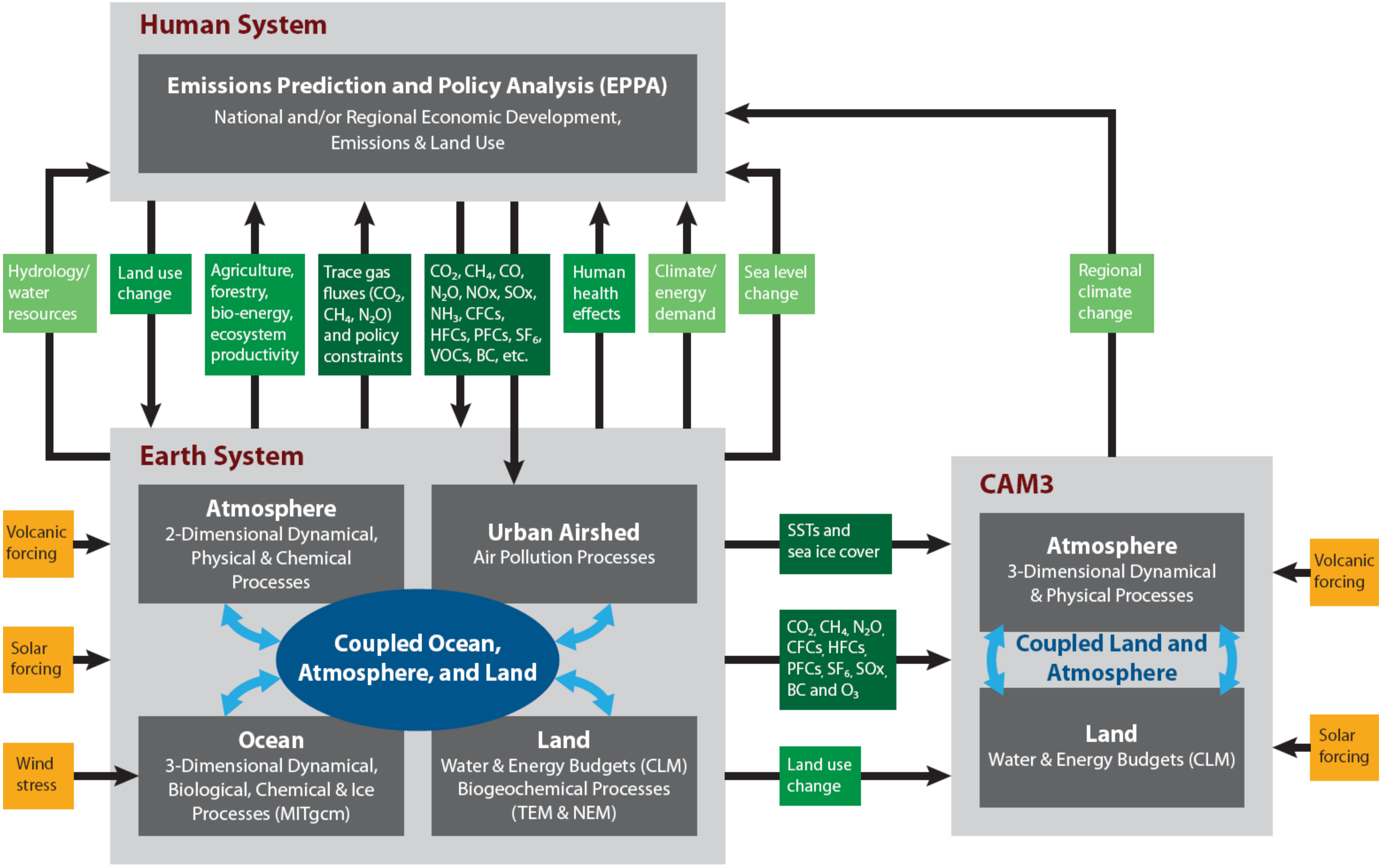
Projected changes in decadal mean natural CH_4 emissions north from 40N

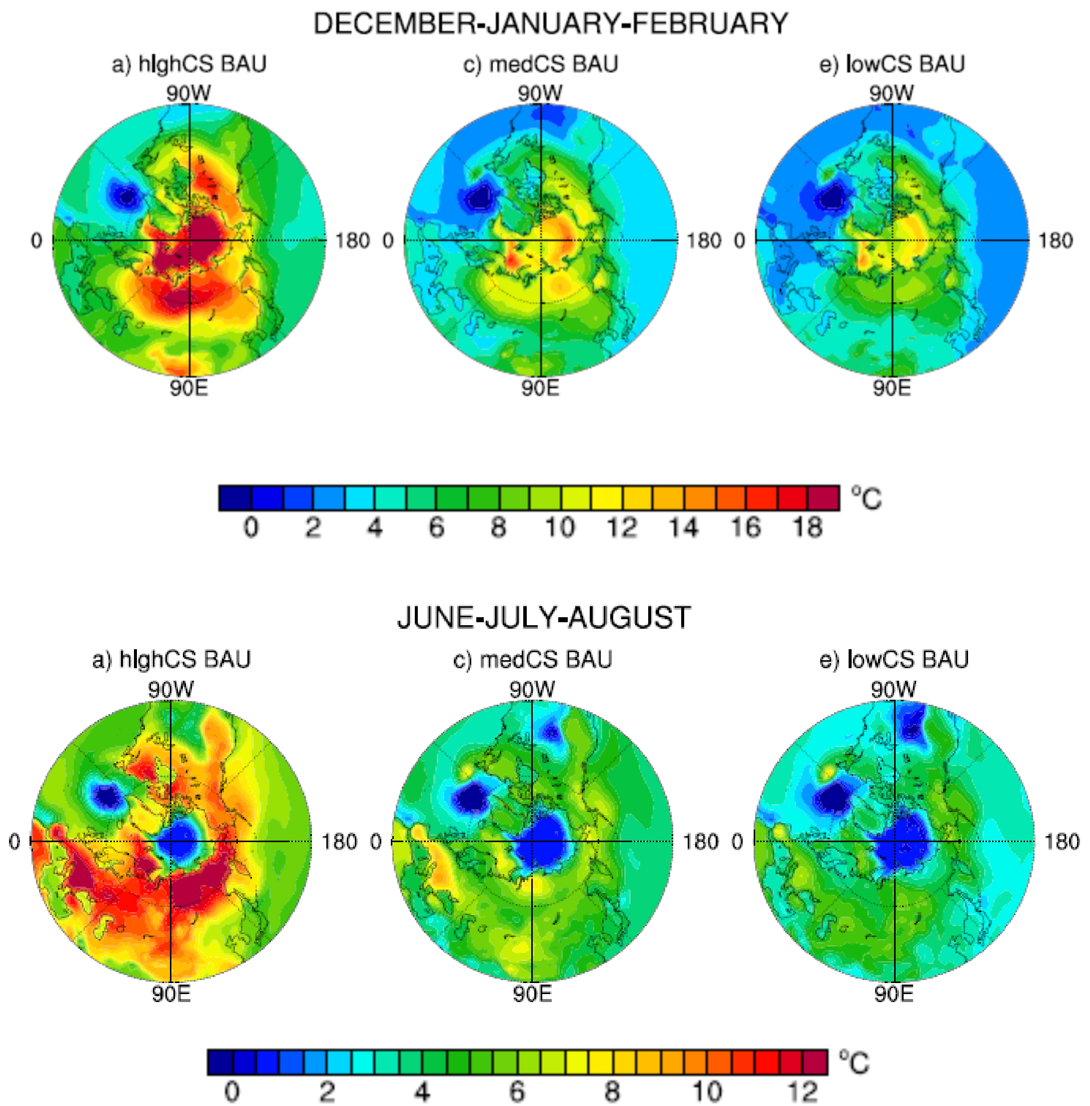
Solid line - median, dashed lines - 5% and 95% percentiles



Frequency distributions for SAT increase over land north from 40N in 2091 to 2100 relative to the 1981 to 2000 average.

Equivalent CO_2	5%	16.7%	50%	83.3%	95%
1400	5.24	5.68	6.66	7.72	8.76
900	3.29	3.73	4.41	5.26	5.82
790	2.83	3.23	3.82	4.53	5.10
660	2.17	2.54	3.03	3.61	4.02
550	1.56	1.85	2.24	2.69	3.03


Human System
Emissions Prediction and Policy Analysis (EPPA)
National and/or Regional Economic Development, Emissions & Land Use
Hydrology/ water resources
Land use change
Agriculture, forestry, bio-energy, ecosystem productivity
Trace gas fluxes (CO_2, CH_4, N_2O) and policy constraints
CO_2, CH_4, CO, N_2O, NOx, SOx, NH_3, CFCs, HFCs, PFCs, SF_6, VOCs, BC, etc.
Human health effects
Climate/ energy demand
Sea level change
Regional climate change
Earth System
Atmosphere
2-Dimensional Dynamical, Physical & Chemical Processes
Urban Airshed
Air Pollution Processes
Coupled Ocean, Atmosphere, and Land
Ocean
3-Dimensional Dynamical, Biological, Chemical & Ice Processes (MITgcm)
Land
Water & Energy Budgets (CLM) Biogeochemical Processes (TEM & NEM)
Volcanic forcing
Solar forcing
Wind stress
SSTs and sea ice cover
CO_2, CH_4, N_2O, CFCs, HFCs, PFCs, SF_6, SOx, BC and O_3
Land use change
CAM3
Atmosphere
3-Dimensional Dynamical & Physical Processes
Coupled Land and Atmosphere
Land
Water & Energy Budgets (CLM)
Volcanic forcing
Solar forcing



Changes in surface air temperature in simulations with BAU scenario.

Conclusions.

- Projections of climate changes show that in the absence of any climate policy by the end of the 21st century global averaged annual mean surface air temperature will be increase by 3.5^{o}C - 7.4^{o}C (90% probability range) relative to 1981-2000, with the median value of 5.2^{o}C.
- Uncertainties in projected surface warming associated with the uncertainties in GHG emissions are similar to the those associated with the uncertainties in climate system characteristics. While uncertainties in the sea level rise due to thermal expansion of the deep ocean are primarily associated with the uncertainties in the climate parameters.
- Over the same period temperature over land area north from 40^{o}N will rise between 4.7^{o}C and 9.2^{o}C, with warming being significantly larger during winter than during summer 5.8^{o}C to 11.5^{o}C compare to 3.5^{o}C to 7.0^{o}C. Corresponding median values are 6.7^{o}C, 8.3^{o}C and 5.1^{o}C, respectively.
- Natural methane emissions from wetlands north from 40^{o}N will increase by 38 to 83 (Mg CH4)/year or 1.7-2.4 times relative to present. However even in simulations with very high warming (near upper bound of 90% range) methane emission from northern wetland are only about 10-15% of anthropogenic emissions. As a result an effect of the increase in natural emissions on surface temperature is very small.
- Even under rather stringent climate policy there is about 75% probability of surface warming over land area north from 40^{o}N exceeding 2^{o}C relative to 1990s.