An efficient and portable climate system model for studying past, present and future climate

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Tasmanian Partnership for Advanced Computing

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Acknowledgements

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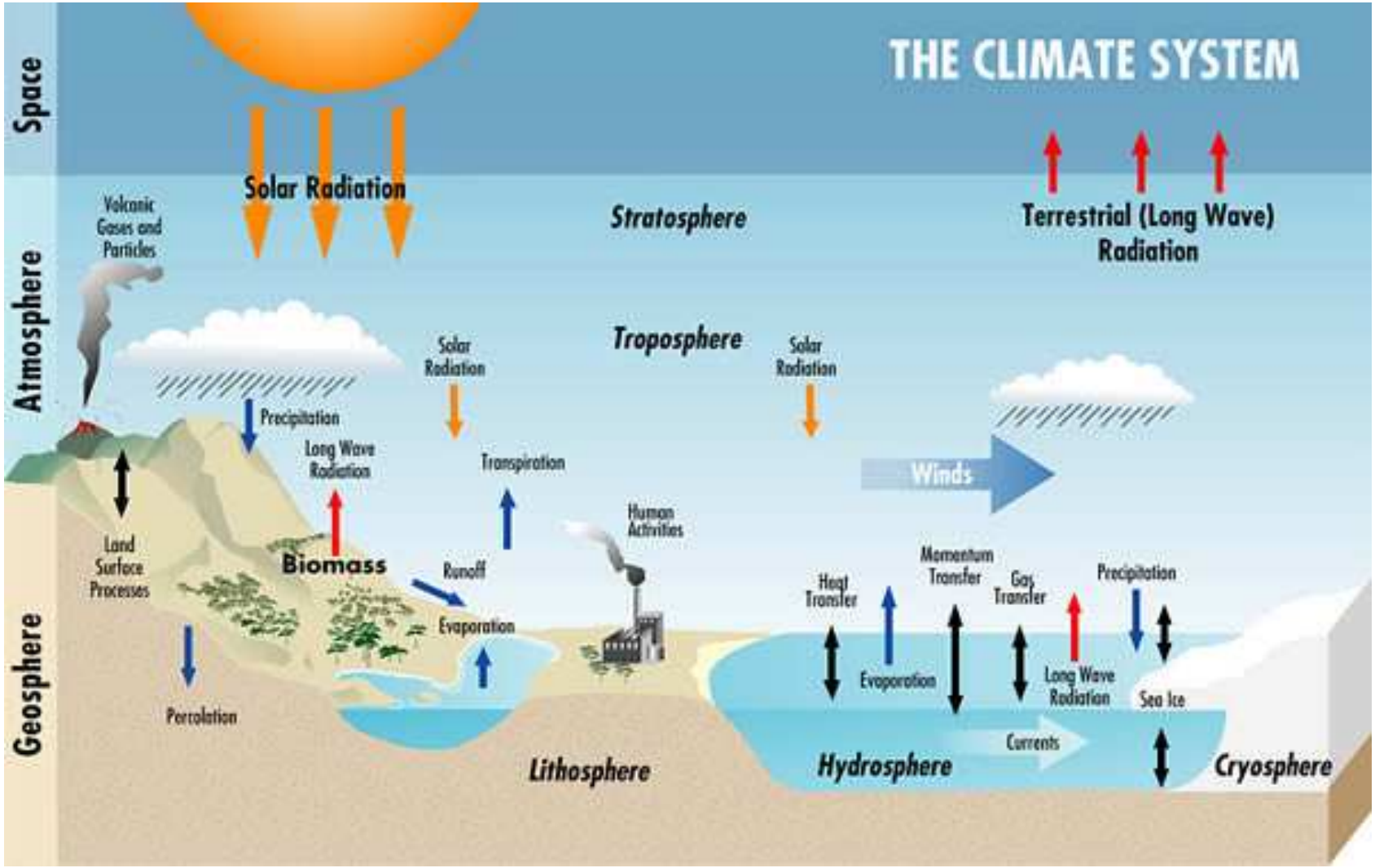
- CSIRO Marine and Atmospheric Research
- APAC
- iVEC

Overview

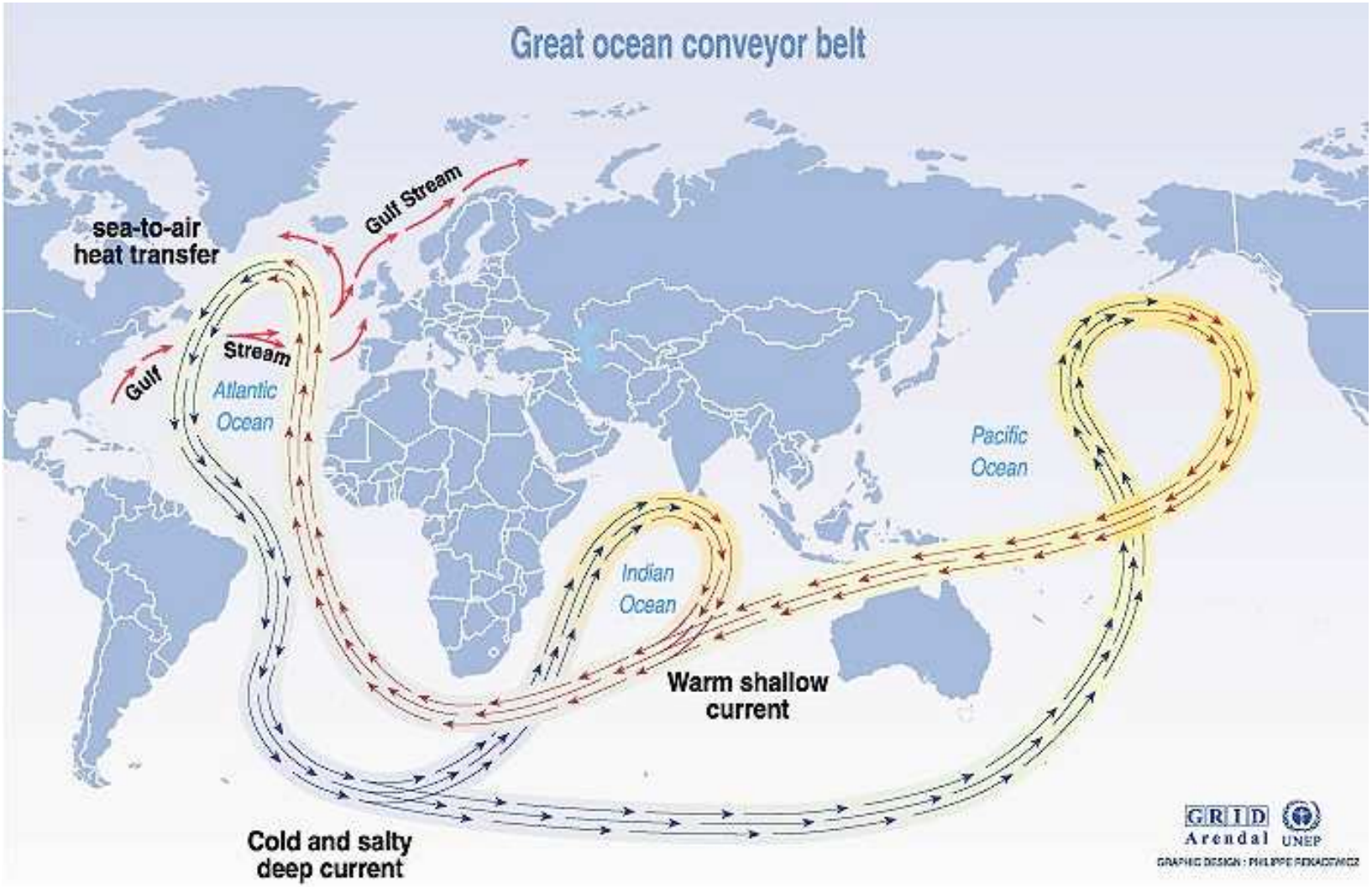
1. Climate variability and change
2. The CSIRO Mk3L climate system model
3. Present climate
4. Past climate
5. Future climate

Climate variability and change

1. Climate variability and change



1. Climate variability and change



Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

What is climate?

- mean state of the climate system ("average weather")

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- mean state of the climate system ("average weather")
- a measure of the variability within that state
- timescale?

Climate variability or climate change?

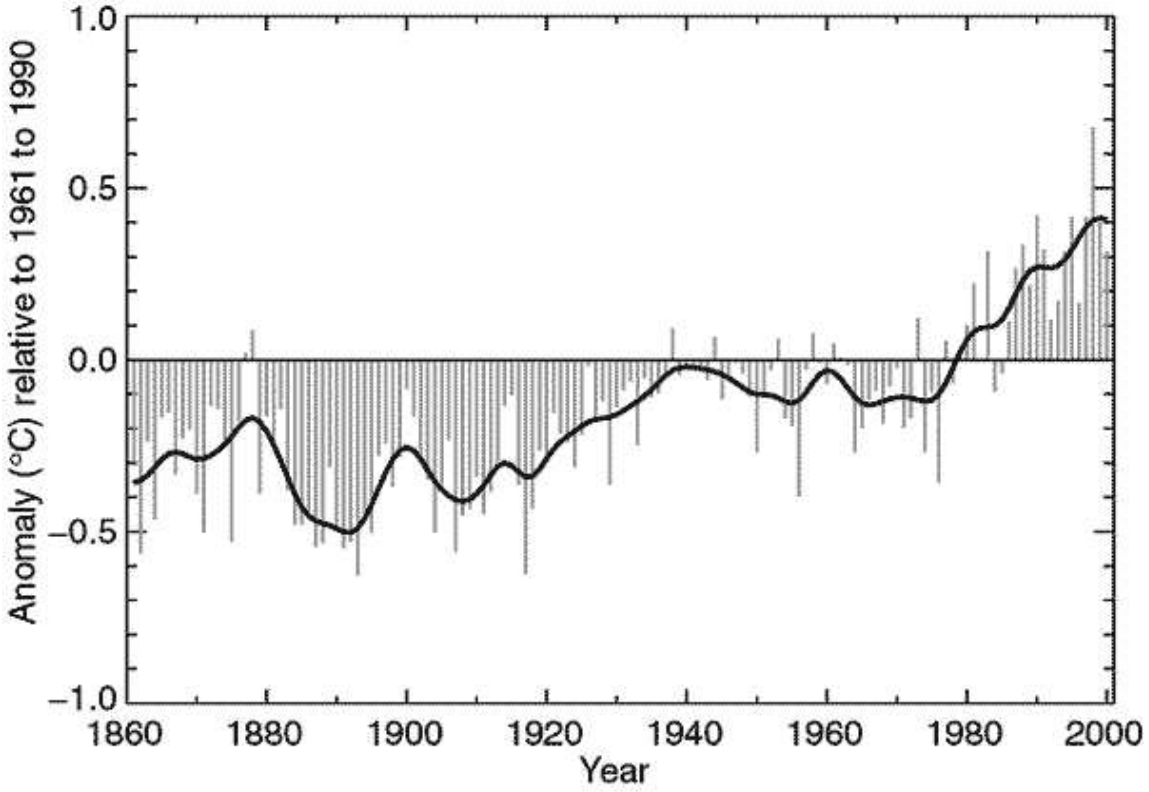
- climate *variability*
  - refers to natural variations around the mean state

Climate variability or climate change?

- climate *variability*
  - refers to natural variations around the mean state
- climate *change*
  - refers to a change in the underlying mean state
  - often used to refer to changes arising from human activity

1. Climate variability and change

The Earth's climate exhibits variability on all timescales...



Global land-surface air temperature 1861-2000

1. Climate variability and change

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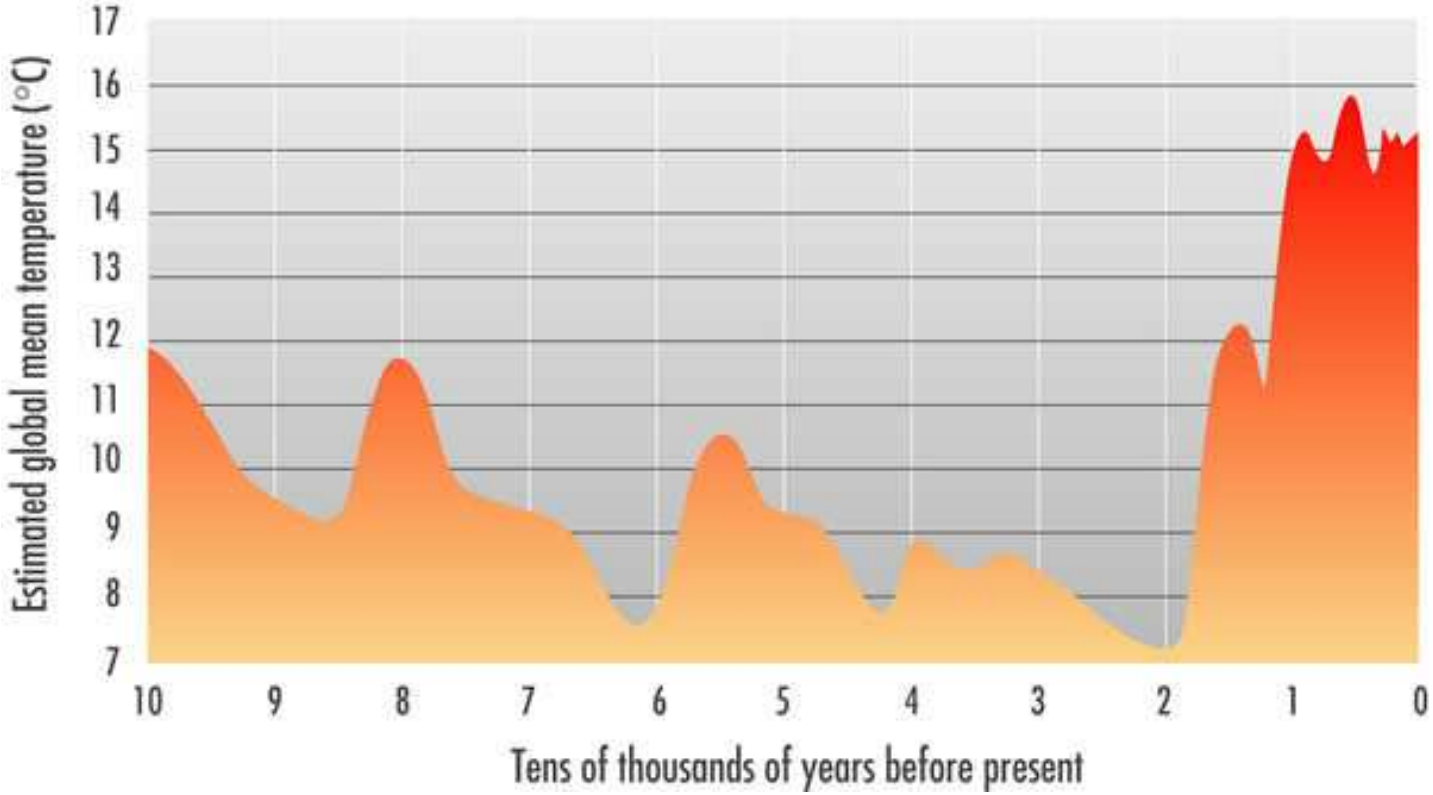
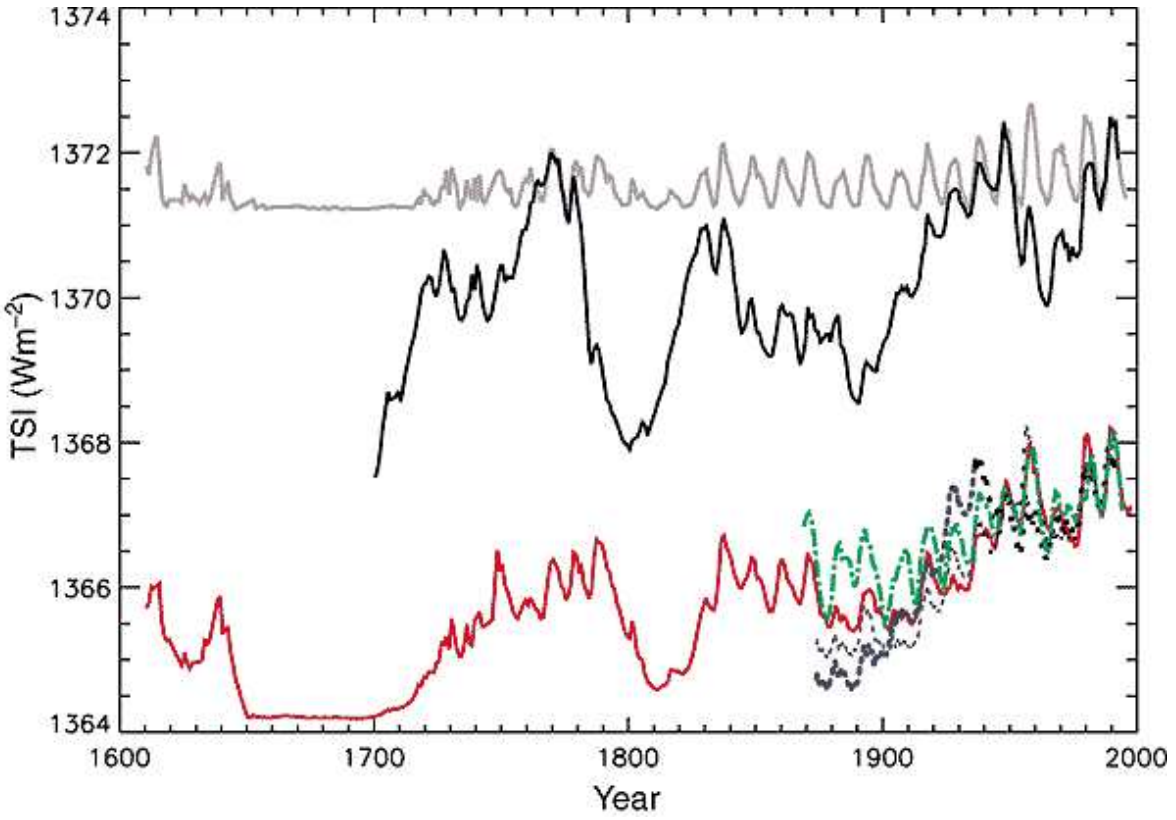


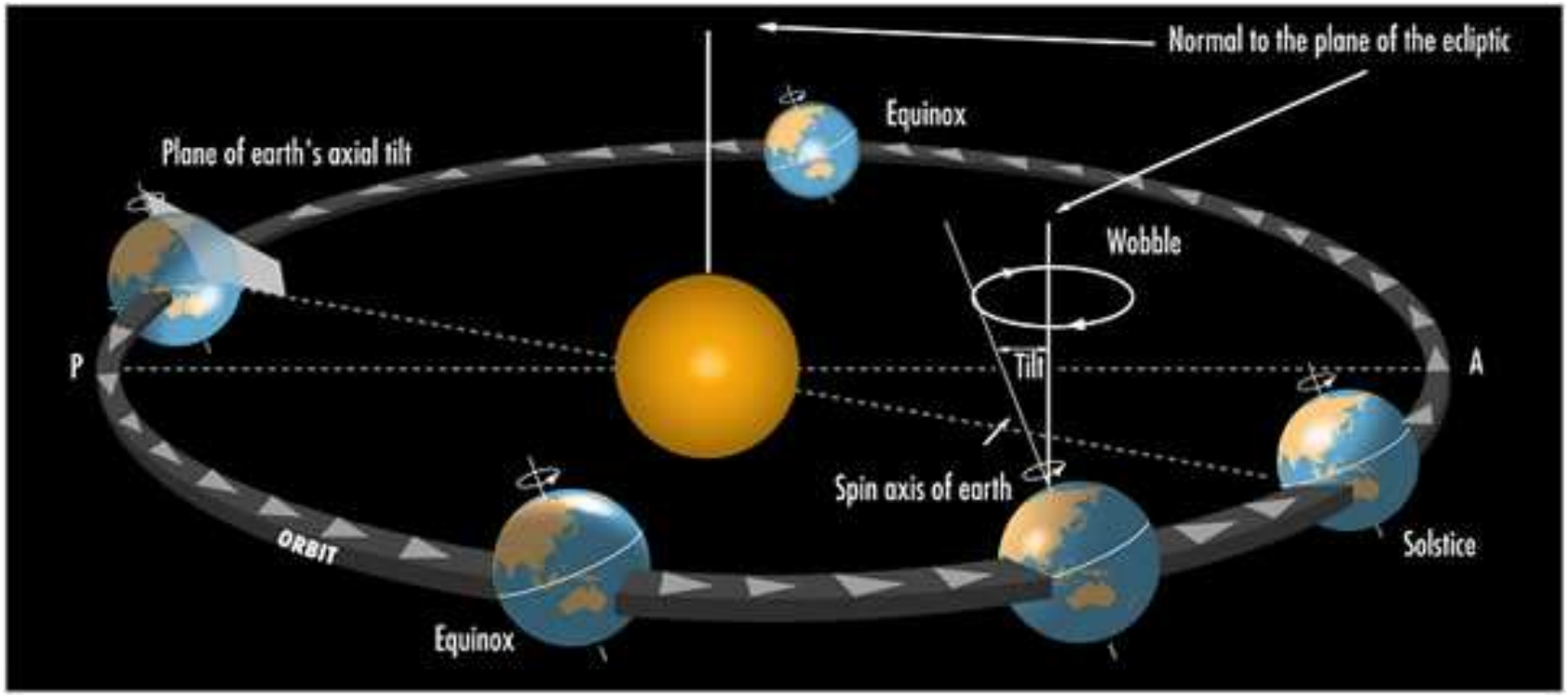
Global-mean surface air temperature over the past 100,000 years

External influences include the sun ...



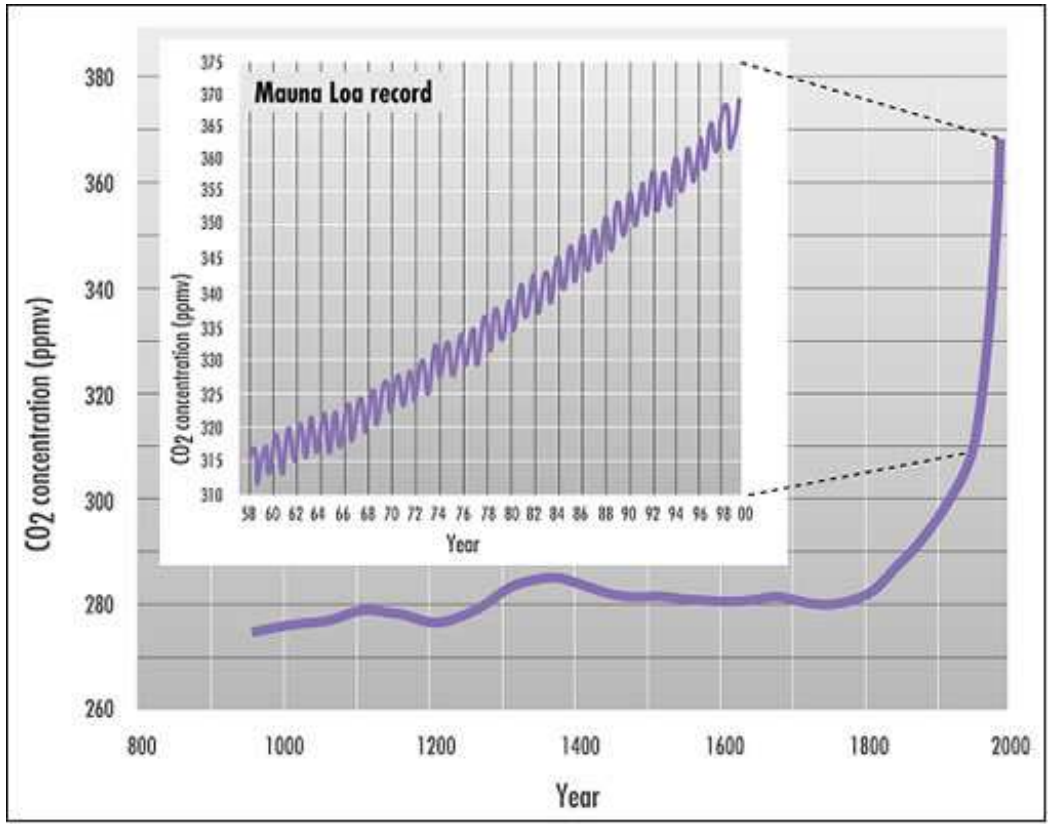
Total solar heat output 1600-2000

... the Earth's orbital geometry ...



1. Climate variability and change

... and us!



Atmospheric CO_2 concentration over the past 1000 years

Understanding climate variability and change

Fundamental questions include:

- What is the magnitude of natural climate variability?

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Understanding climate variability and change

Fundamental questions include:

- What is the magnitude of natural climate variability?
- To what extent are recent changes due to human influences?
- What can we expect in the future?

There are two ways that we can address these questions:

- Data
- Models

Data

Sources of data on past climates include:

- Direct measures
  - observations
- Indirect measures
  - ice cores
  - marine/lake sediments
  - tree rings
  - coral

Models

- based upon the physical laws describing the processes occurring within the climate system
- underlying equations are solved numerically
- enable direct simulation of past, present and future climate states
- can be used to study both the mean climate state, and the degree of climate variability
- can help to understand past climate change
- require large computer resources

Can we trust the models?

- models are limited by the representation of the underlying physical processes, which is restricted by:
  - the understanding of the processes
  - the comprehensiveness of the model
  - computational resources

Can we trust the models?

- models are limited by the representation of the underlying physical processes, which is restricted by:
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  - the comprehensiveness of the model
  - computational resources
- models require *validation* before we can trust the results

Model validation

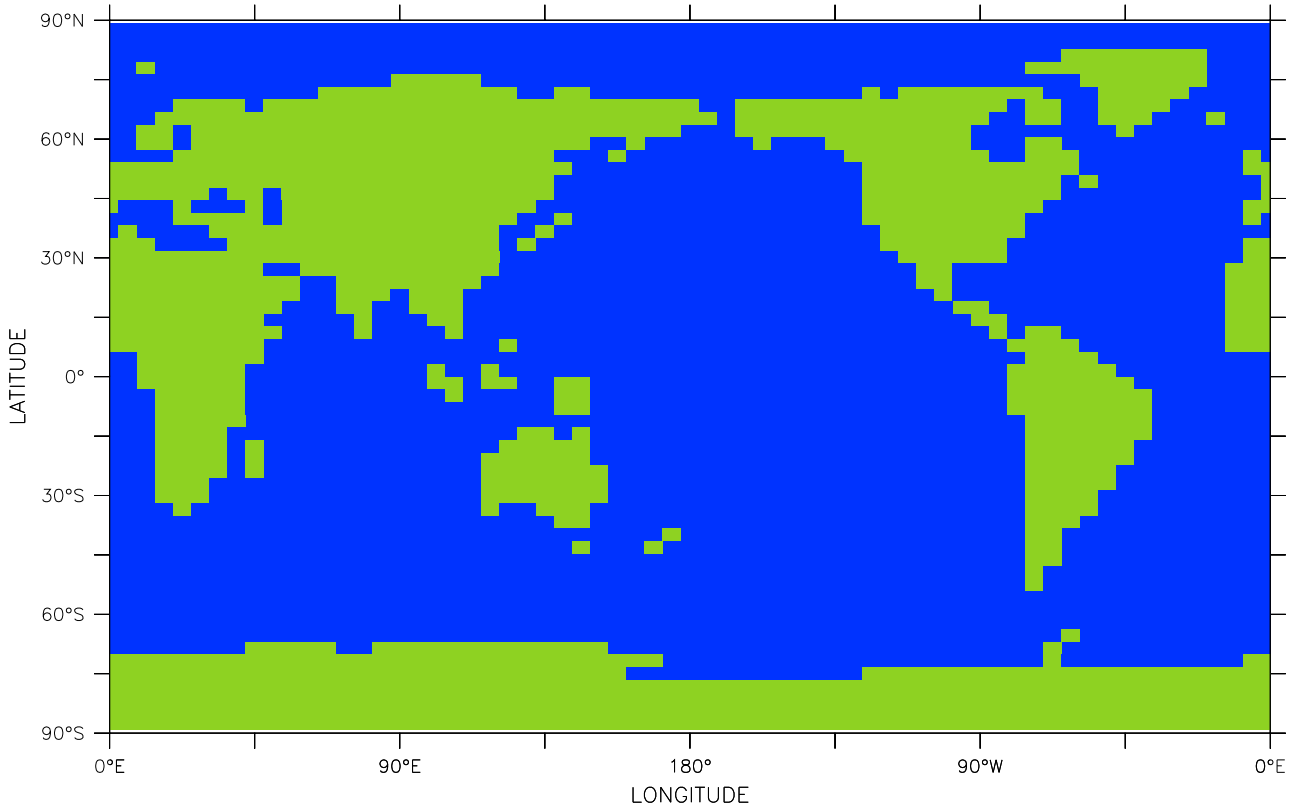
- compare simulated climate with observational or historical data
- the *maximum* extent to which we can have confidence in a model is the extent to which it can reliably simulate a range of climate states
- desirable to validate the model over as wide a range of climate states as possible
- the only feasible way of doing this is to simulate past climates

The CSIRO Mk3L climate system model

Model description

- Low-resolution version of the CSIRO Mk3 climate system model
- Includes:
  - Three-dimensional model of the atmosphere
  - Three-dimensional model of the ocean
  - Sea ice model
  - Land surface model
- 64 × 56 horizontal grid
- 18 vertical levels in the atmosphere
- 21 vertical levels in the ocean

Horizontal grid



Model source code

- Mostly Fortran 77 (plus some Fortran 90 and C)
- Over 85,000 lines of code
- Designed for maximum portability across computer architectures
- Should compile on any UNIX/Linux platform
- Shared-memory parallelism achieved using OpenMP
- Dependence on external libraries restricted to netCDF and FFTW
- Loop structure optimised for serial architectures

Benchmarks on APAC Facilities

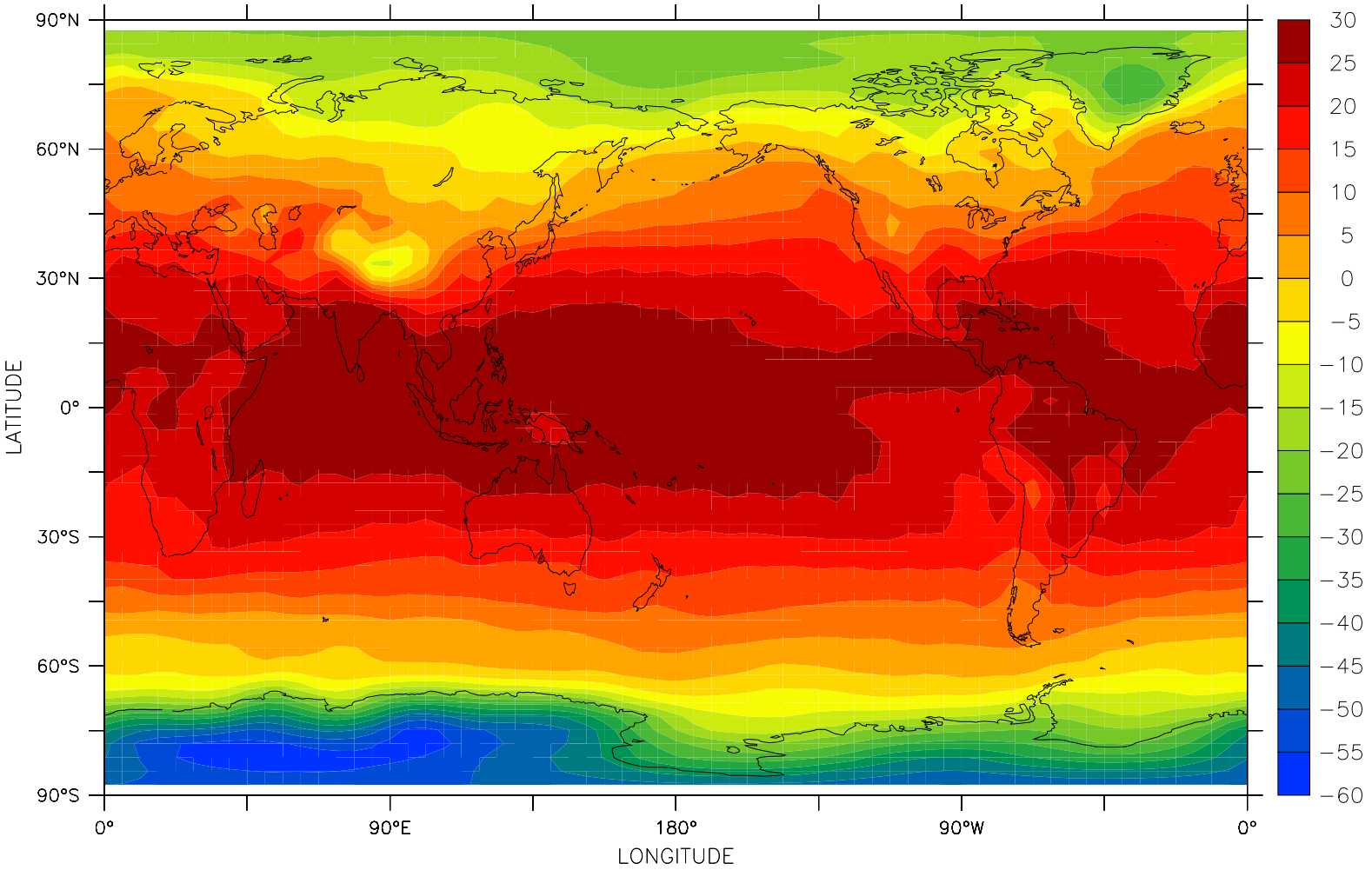
Facility	**Processor type**	**Number of processors**	**Speed (years/day)**
AlphaServer SC	1GHz EV68	1	4.0
		2	7.2
		4	11.7
Linux Cluster	2.66GHz Pentium 4	1	4.6

Present climate

Present climate

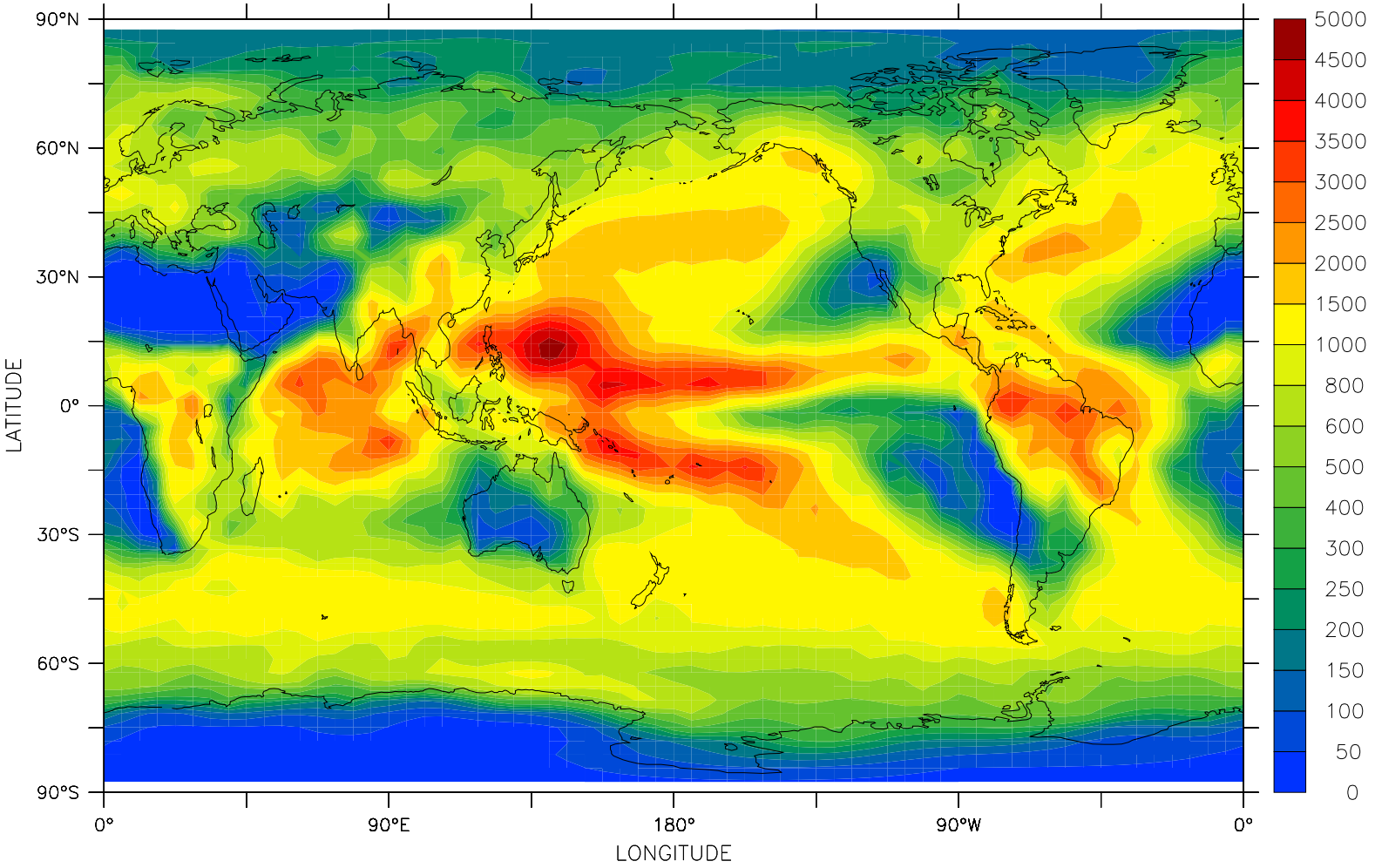
- Control simulation conducted for pre-industrial conditions
- Constant boundary conditions:
  - Atmospheric CO_2 concentration = 280ppm
  - Present-day orbital parameters
- Integrated for 2000+ years

3. Present climate



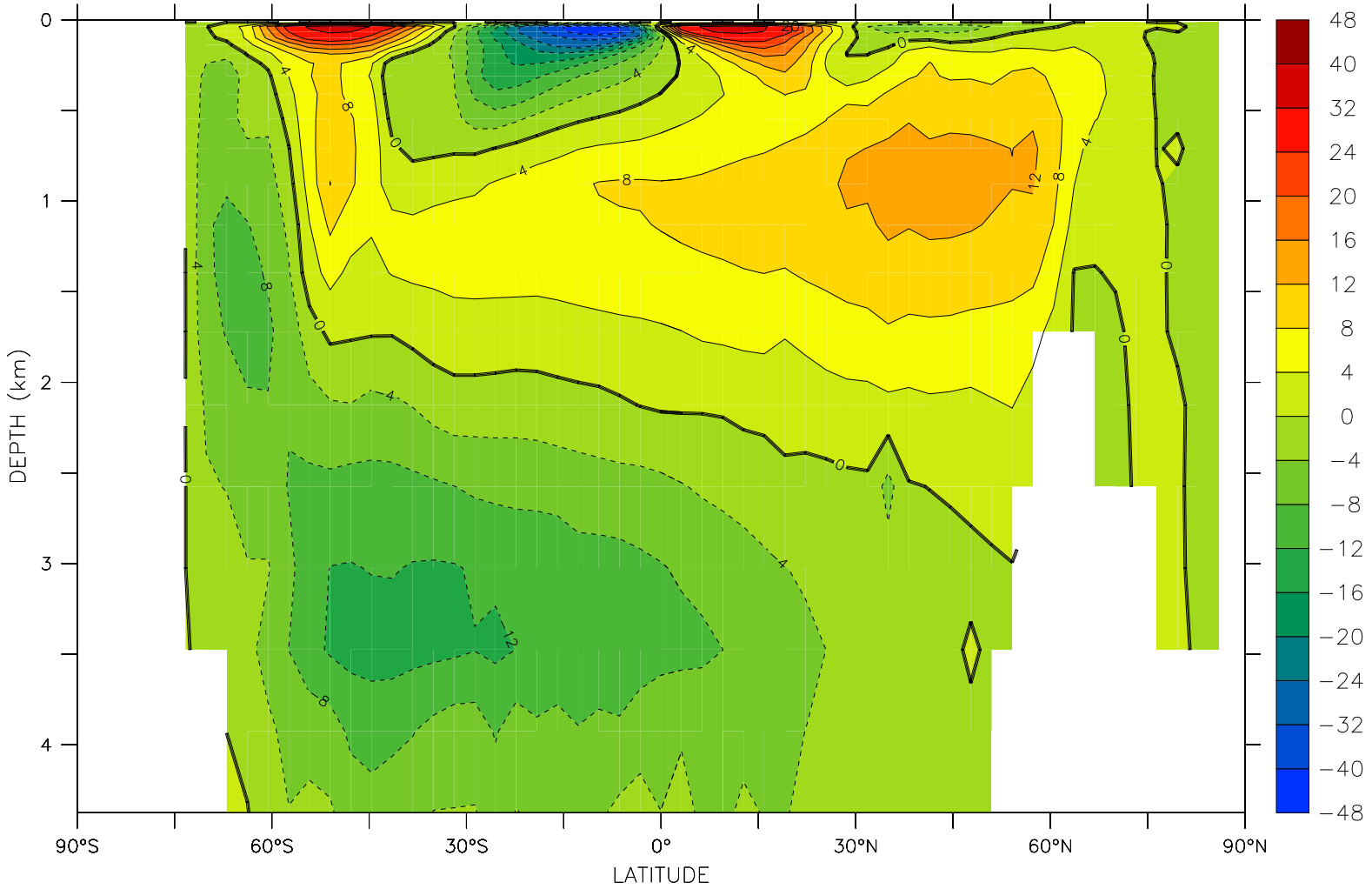
Annual−mean surface air temperature (°C)

3. Present climate



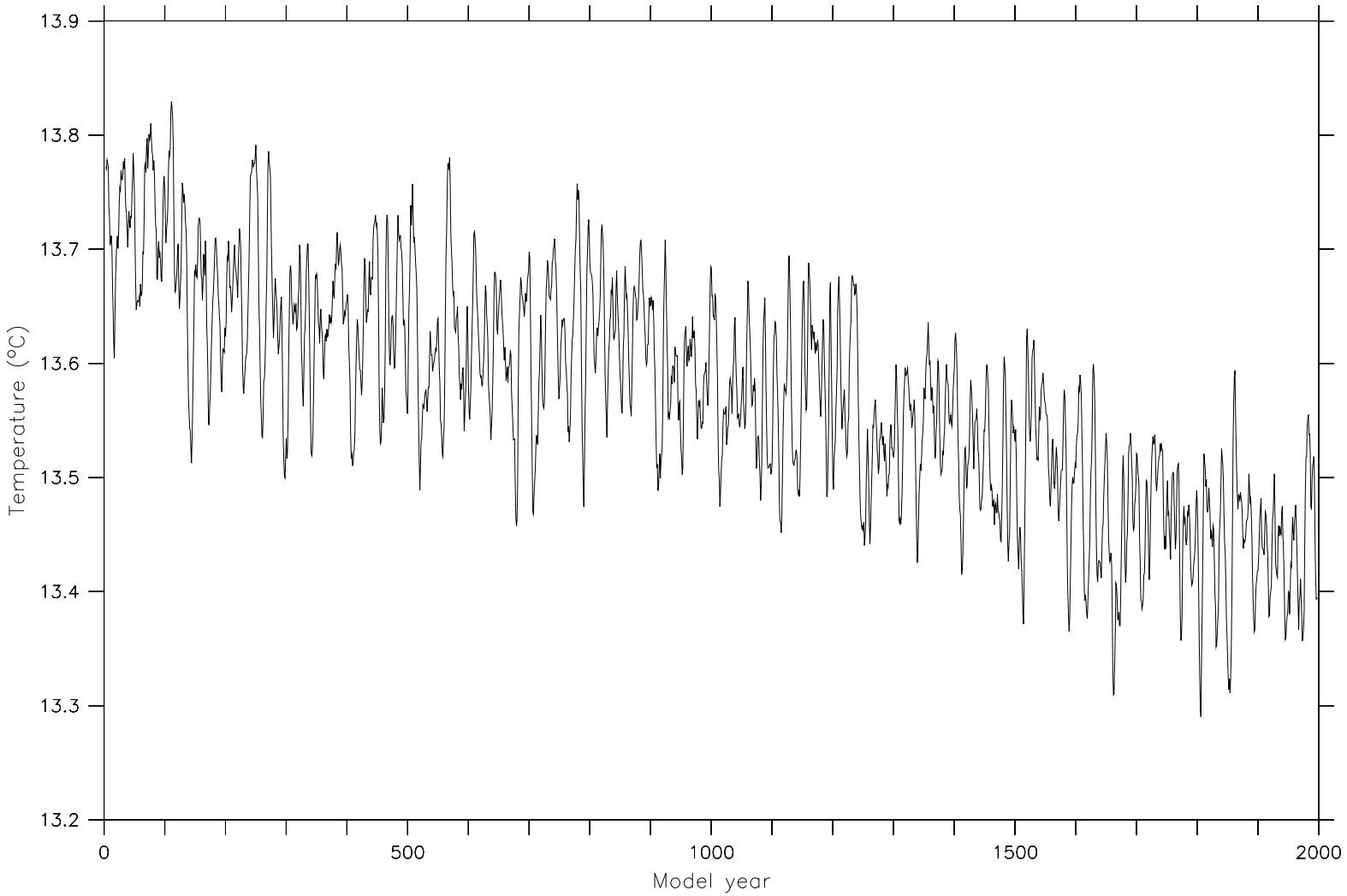
Annual precipitation (mm)

3. Present climate



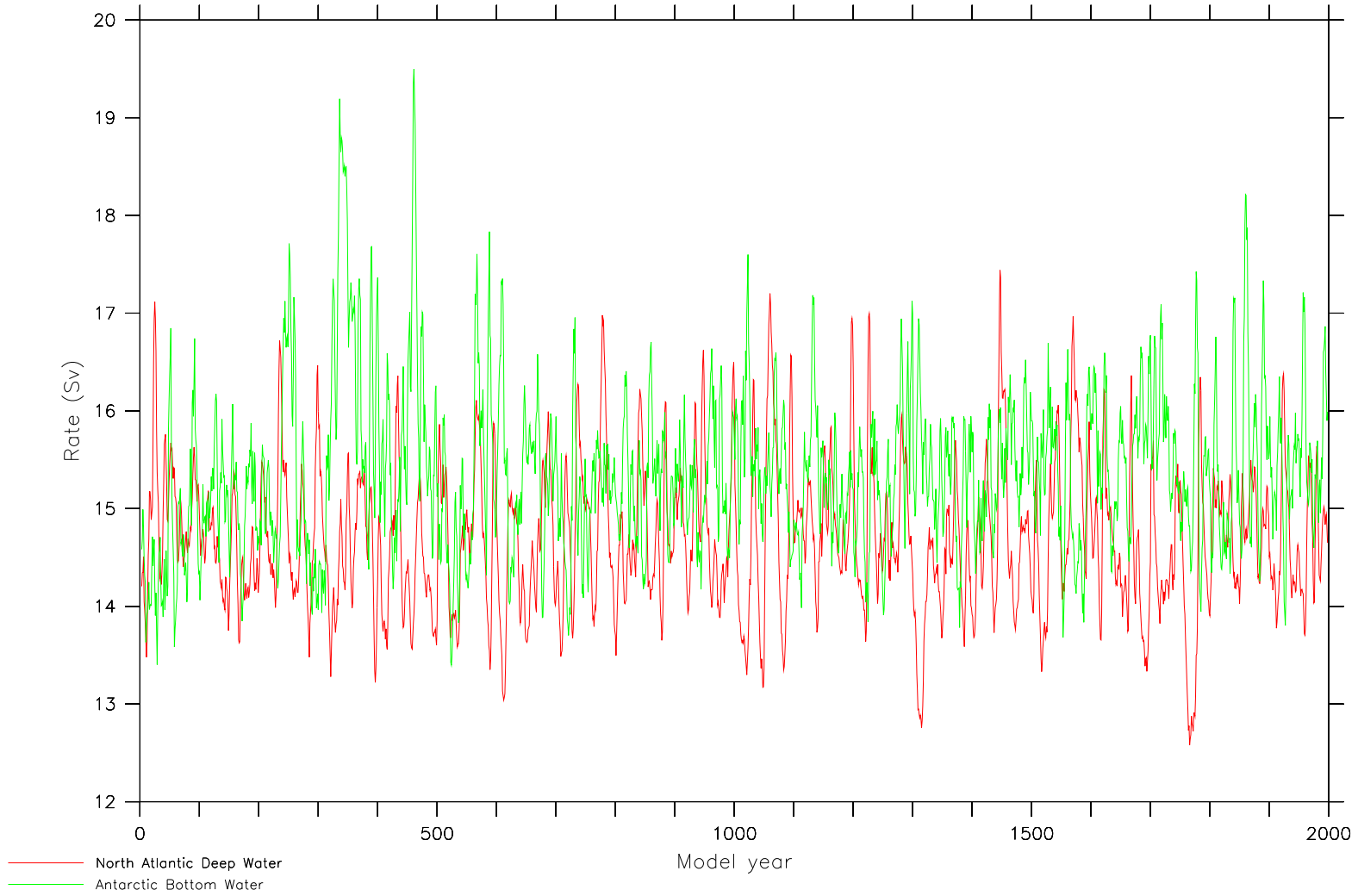
Global meridional overturning streamfunction (Sv)

3. Present climate



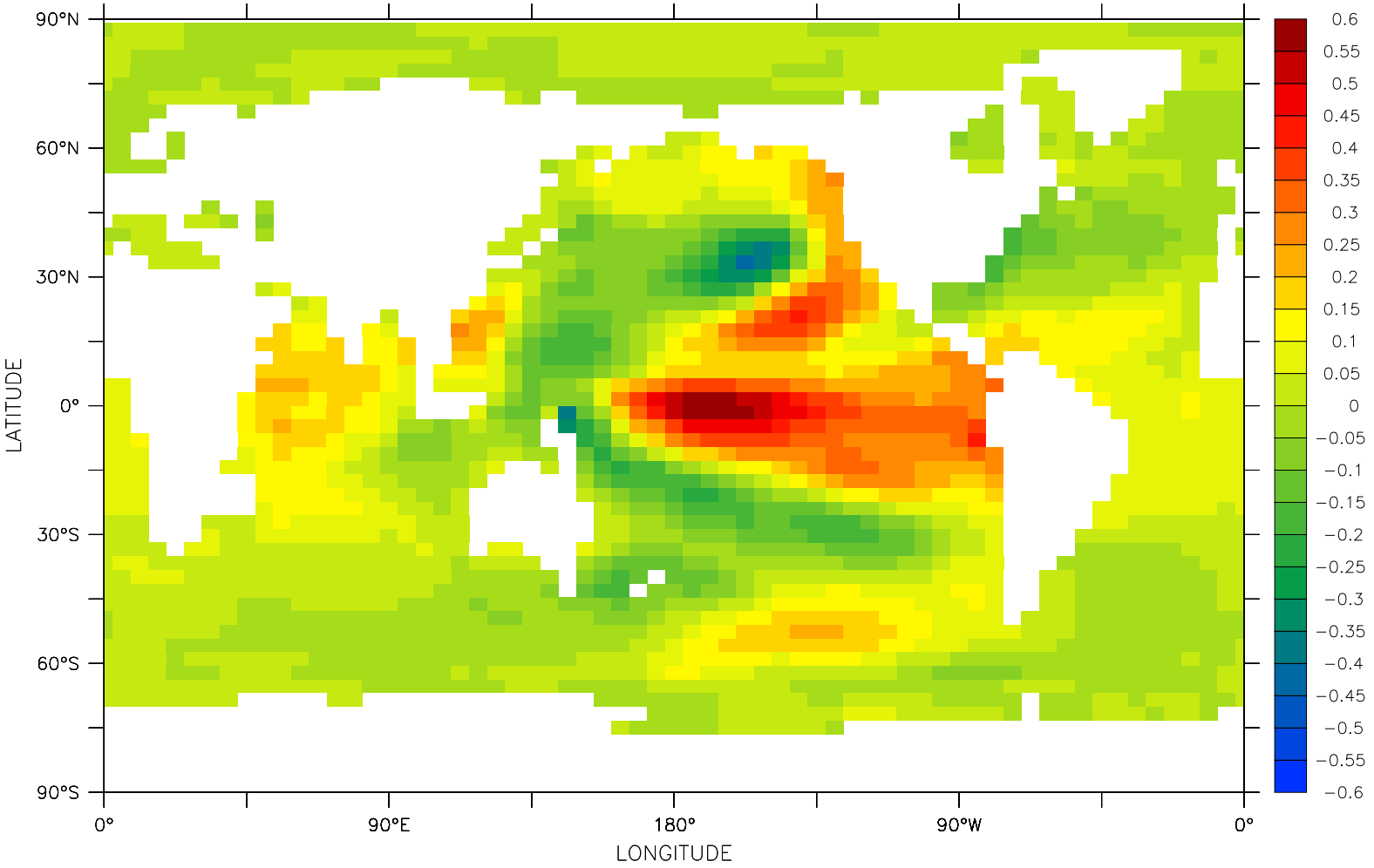
Global–mean surface air temperature

3. Present climate



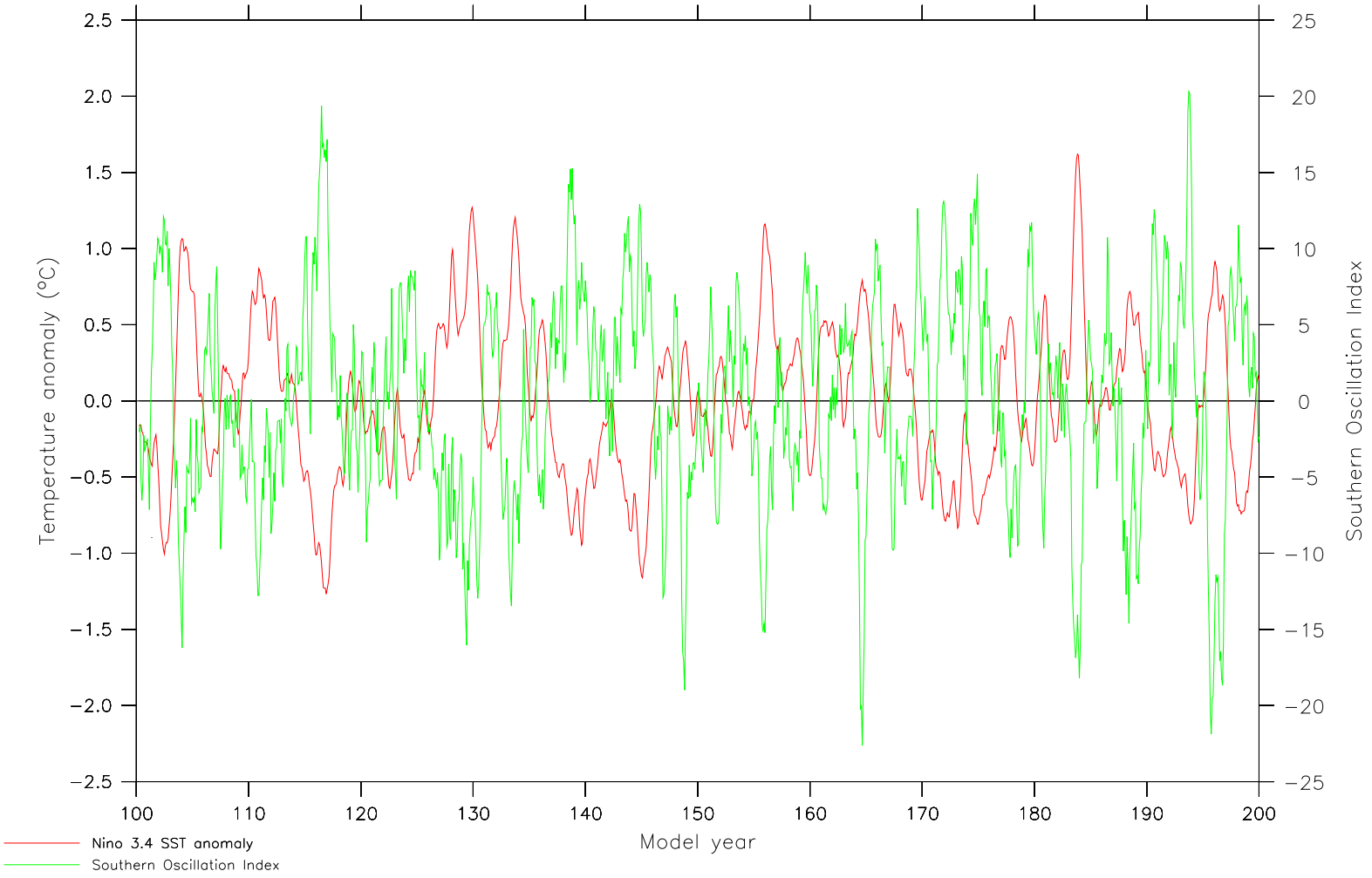
Deep water formation

3. Present climate



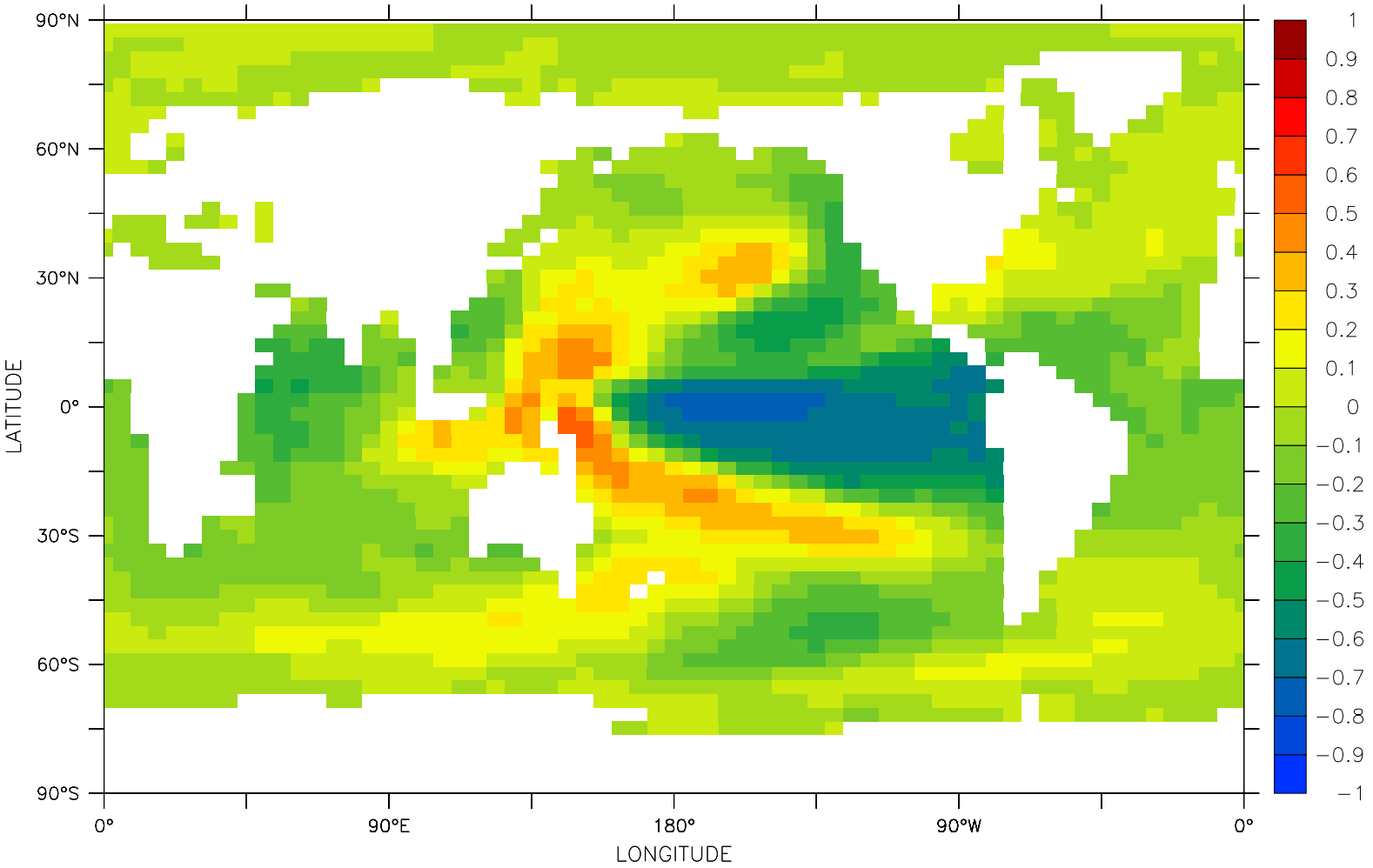
EOF1 of sea surface temperature (°C) – 22.3%

3. Present climate



Nino 3.4 SST anomaly and the Southern Oscillation Index

3. Present climate



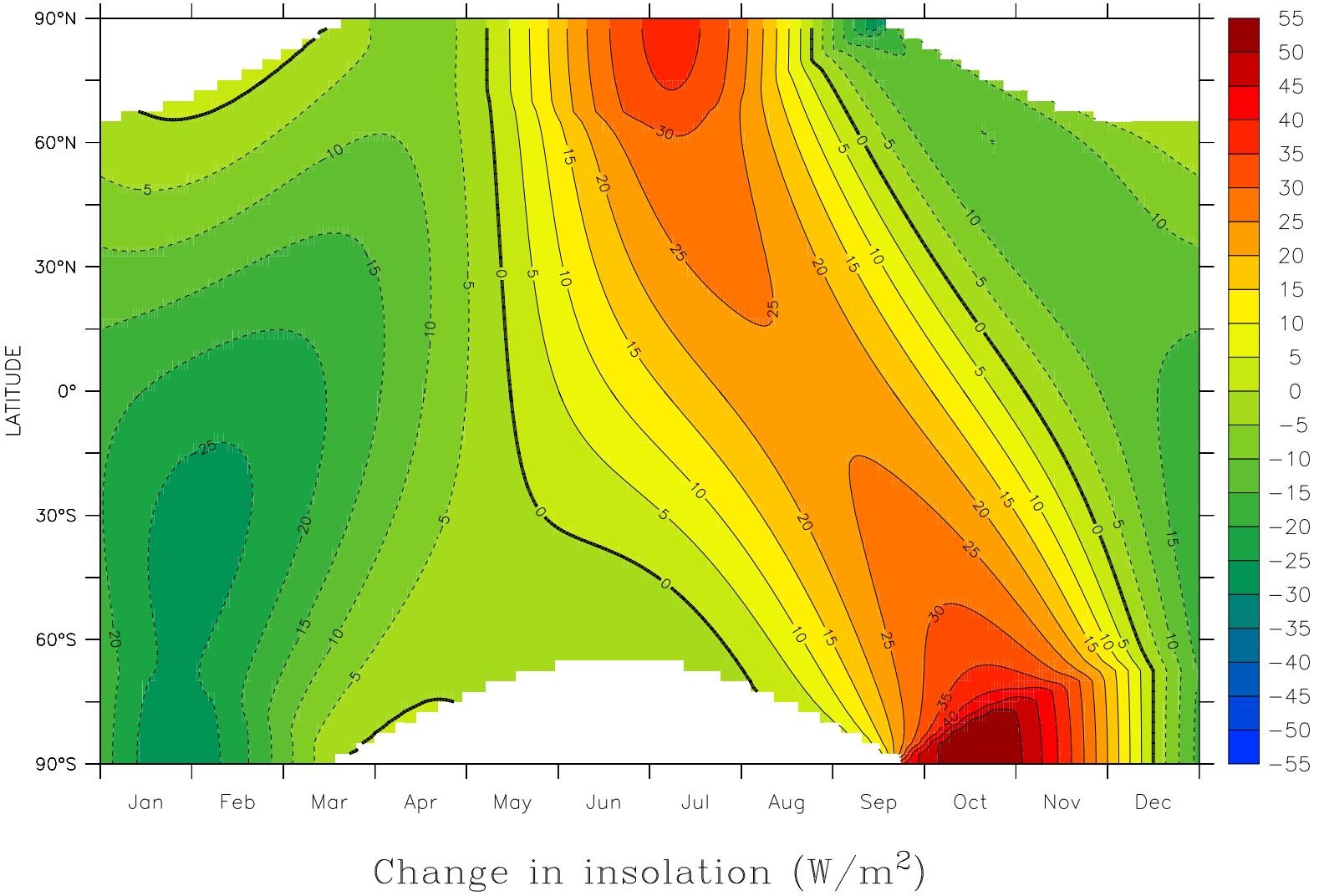
Correlation between SST and the Southern Oscillation Index

Past climate

Past climate

- Simulation conducted for the mid-Holocene (6,000 years ago)
- Constant boundary conditions
  - Orbital parameters for 6,000 years ago
- Integrated for 1200+ years

4. Past climate



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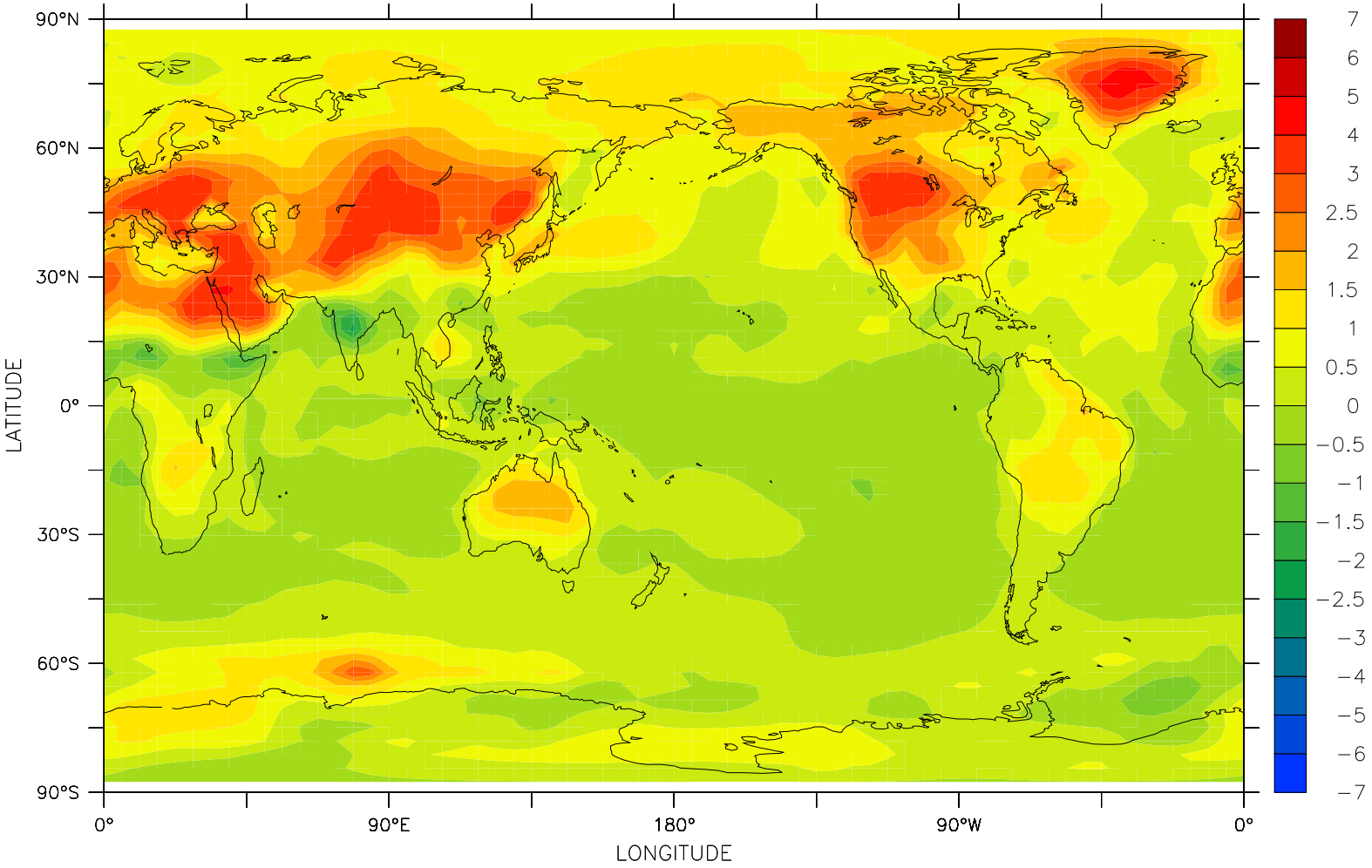
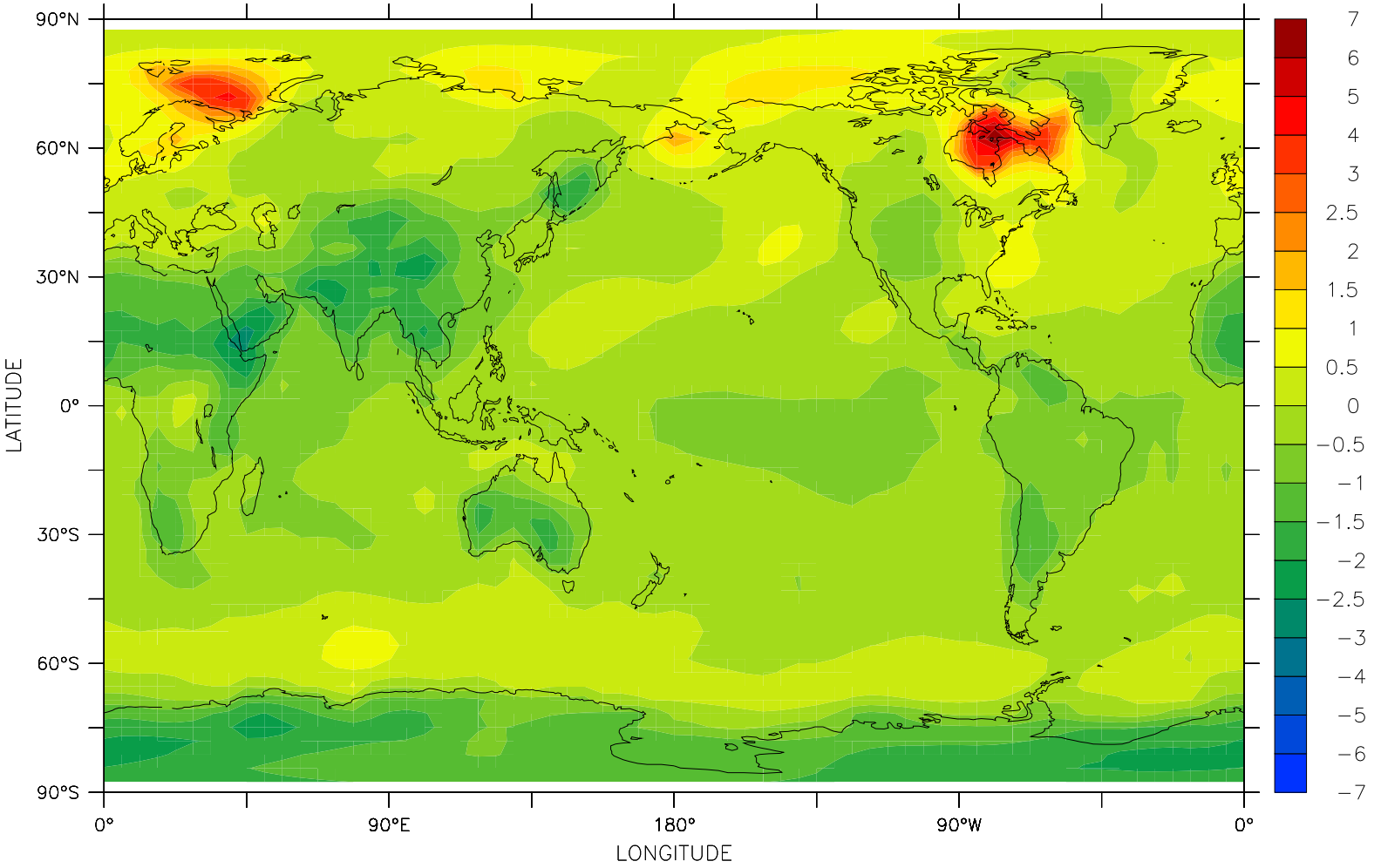


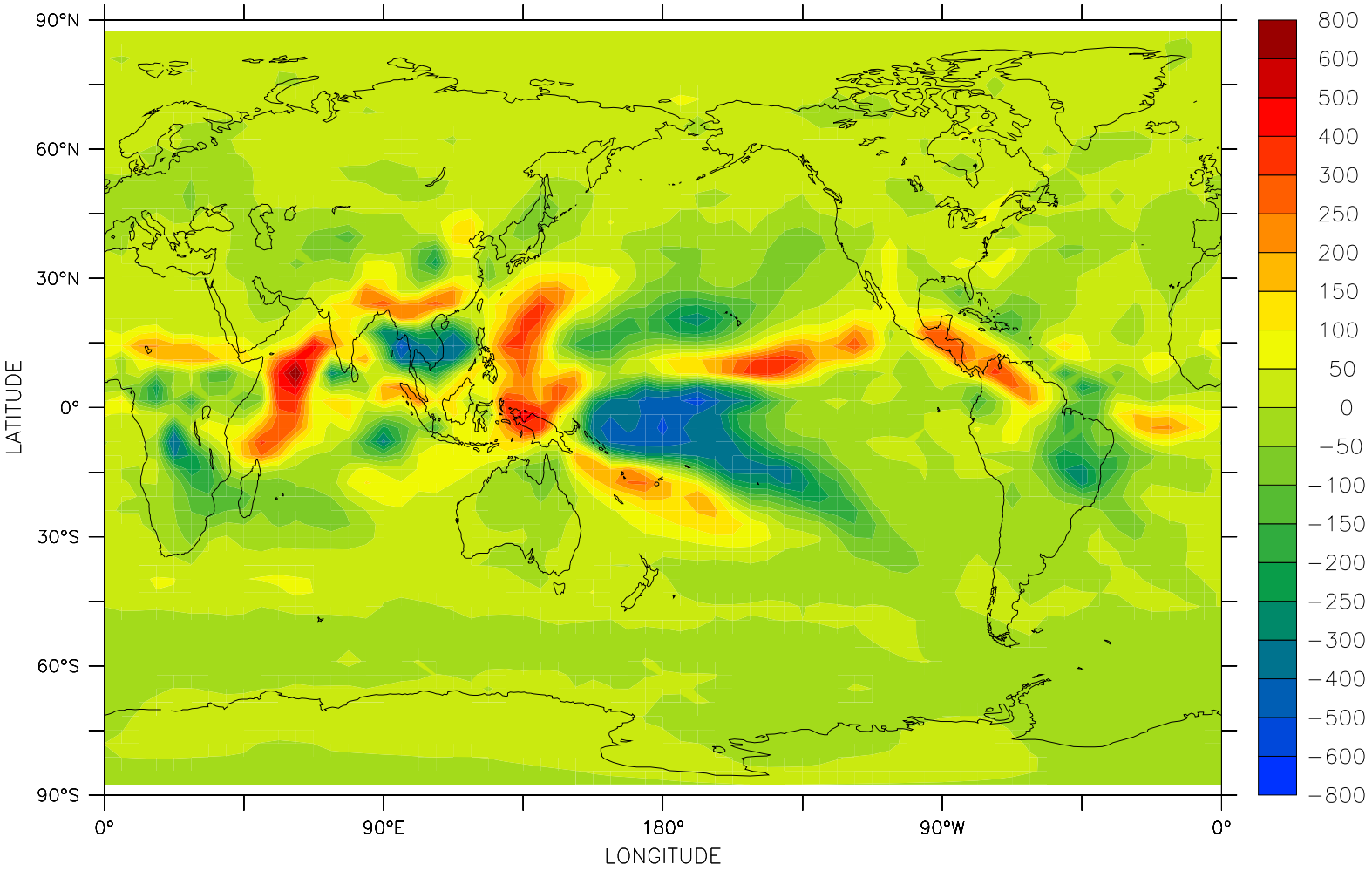
Difference in August surface air temperature (°C)

4. Past climate



Difference in February surface air temperature (°C)

4. Past climate



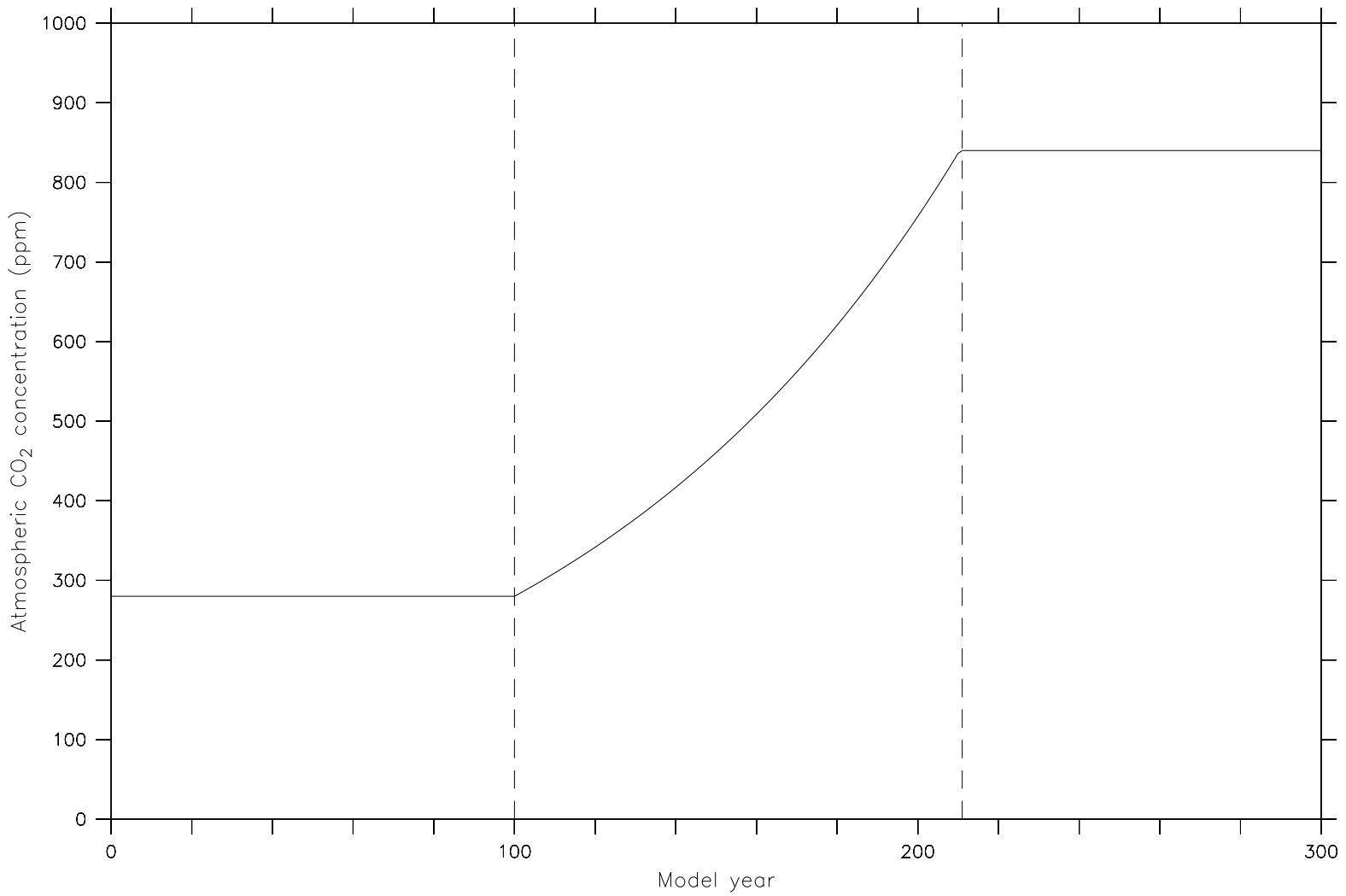
Difference in annual precipitation (mm)

Future climate

Future climate

- Stabilise the atmospheric CO_2 concentration at three times the pre-industrial value
- Variable boundary conditions:
  - Increase the CO_2 concentration at 1% per year
  - Once it reaches 840ppm, hold it constant thereafter
- Integrated for 2000+ years

5. Future climate



Atmospheric CO_2 concentration

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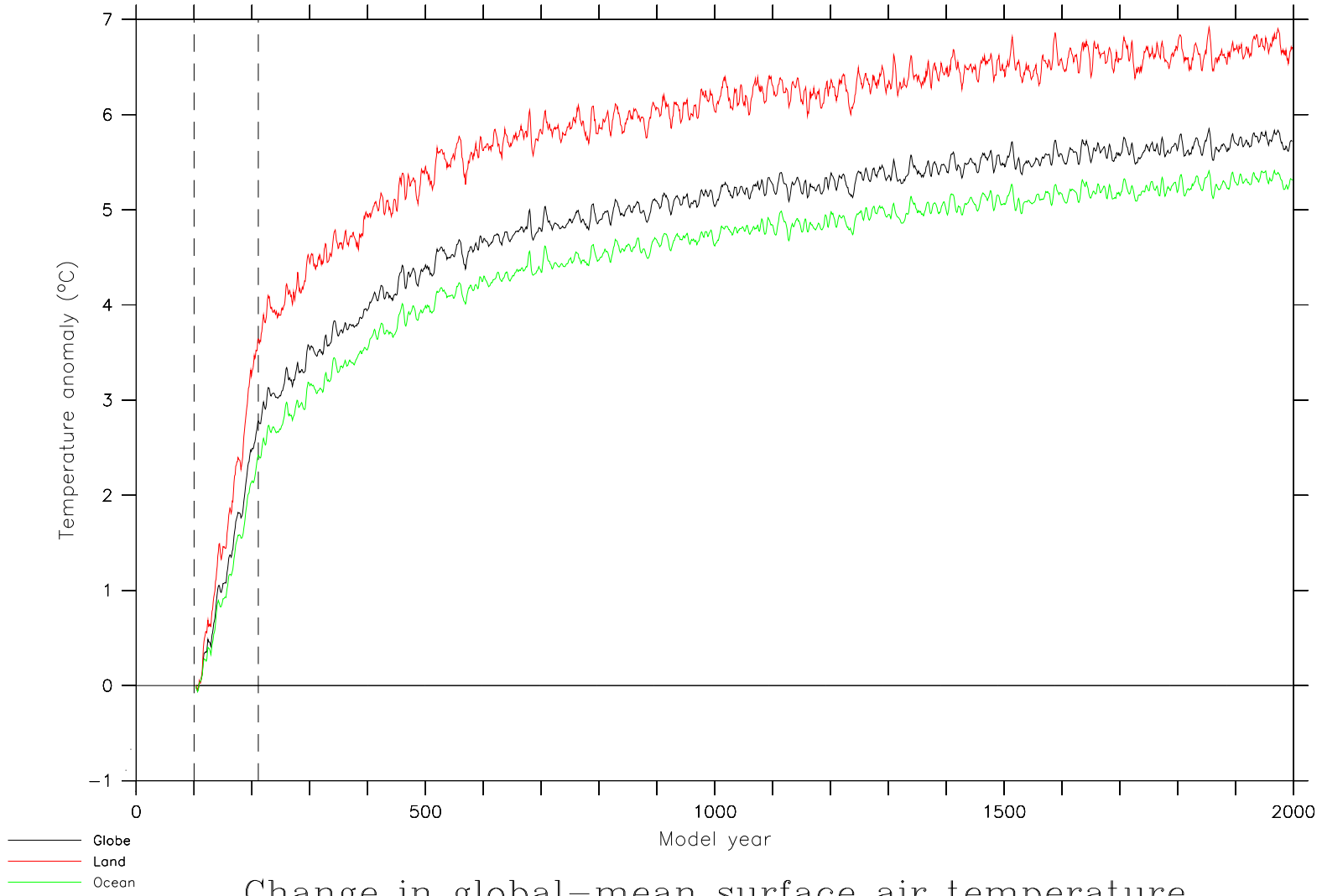
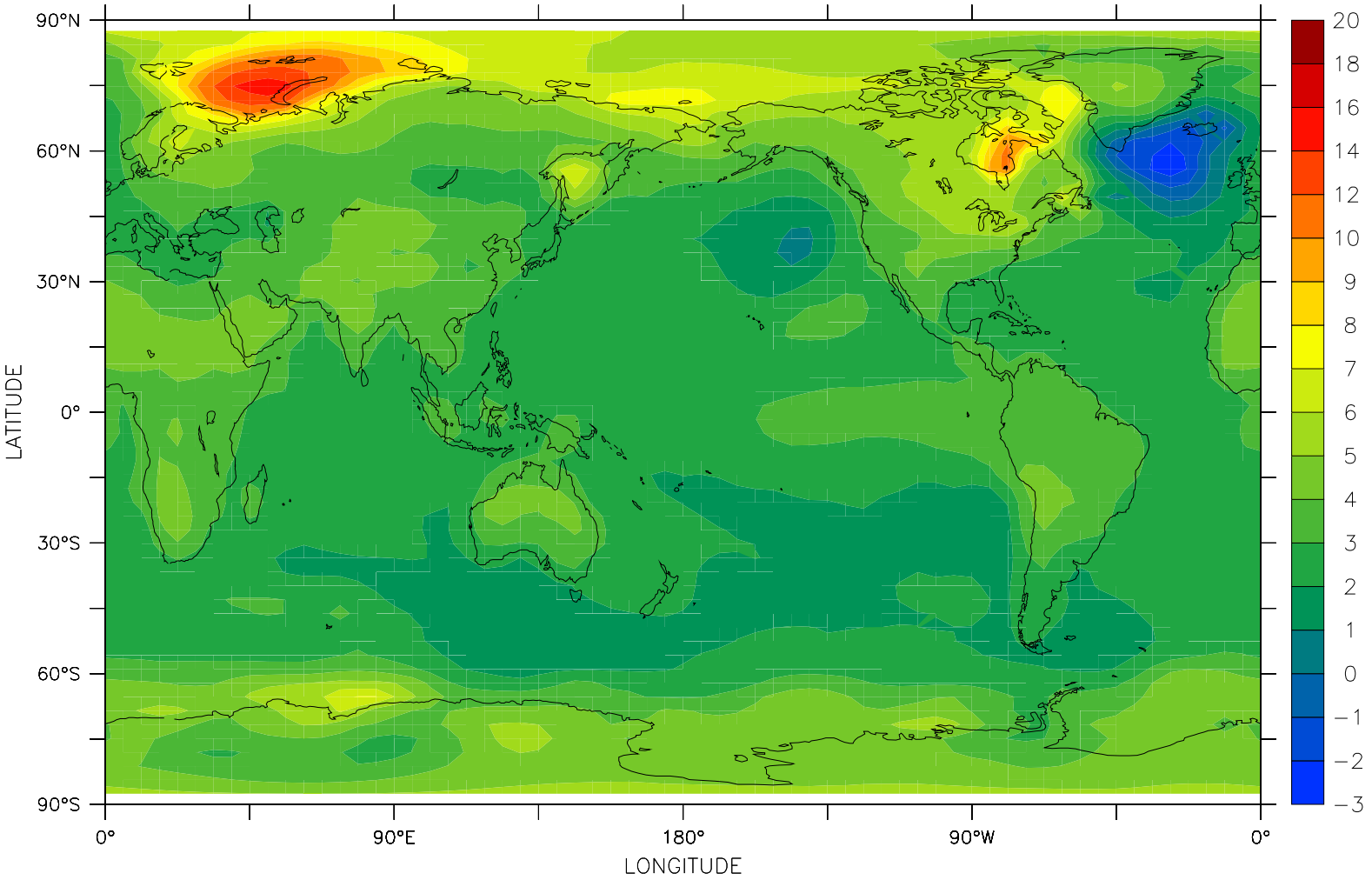


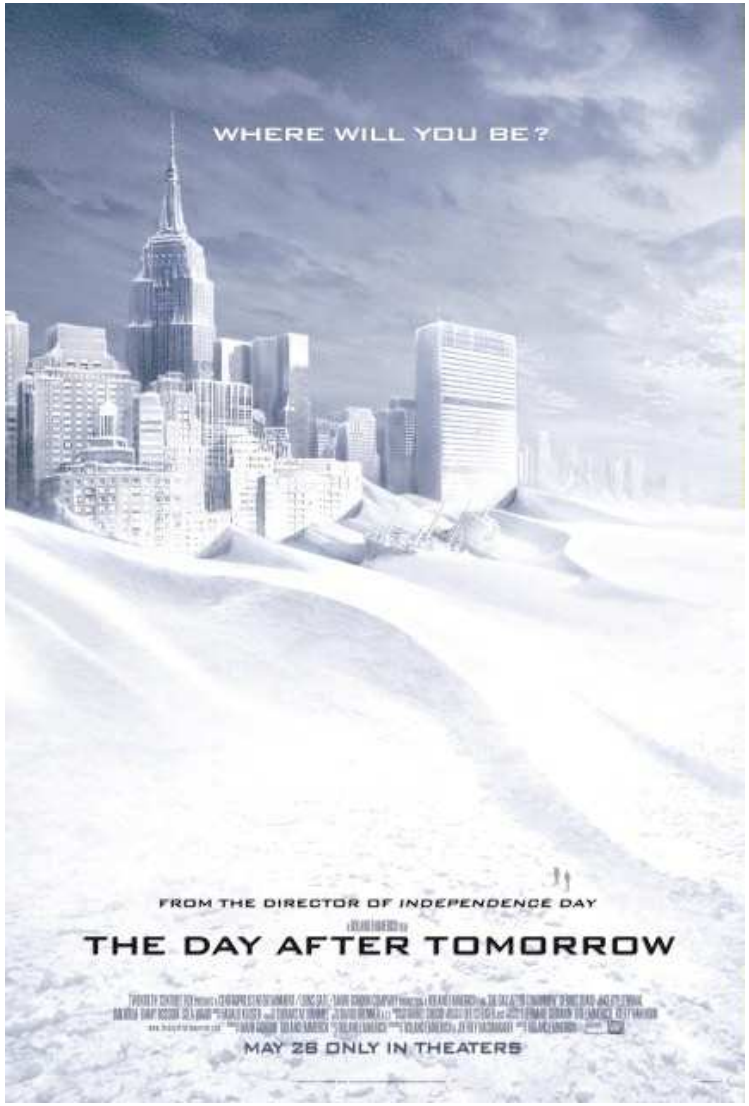
Change in global–mean surface air temperature

5. Future climate



Change in annual−mean SAT (°C) − years 211−260

5. Future climate



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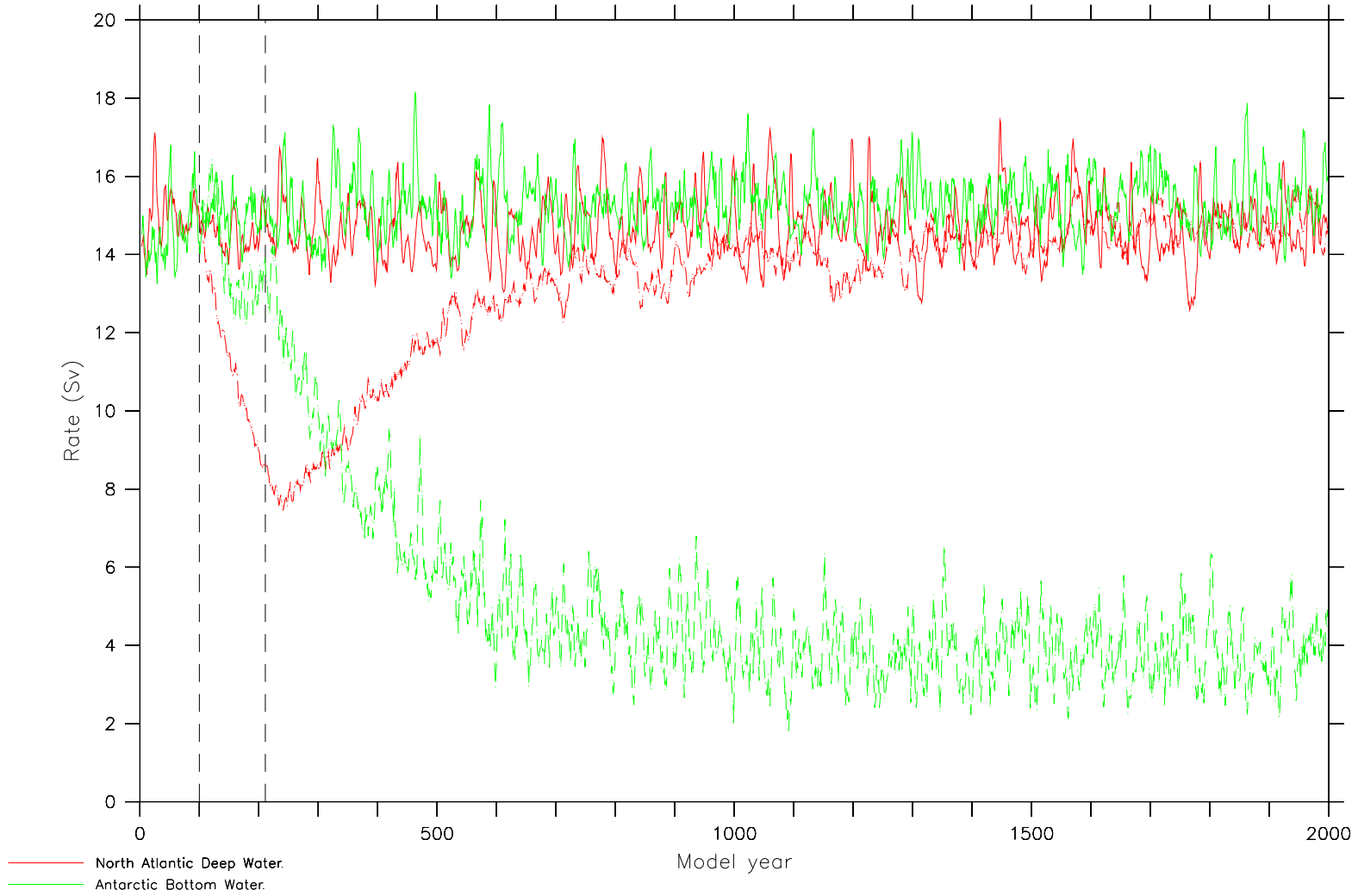
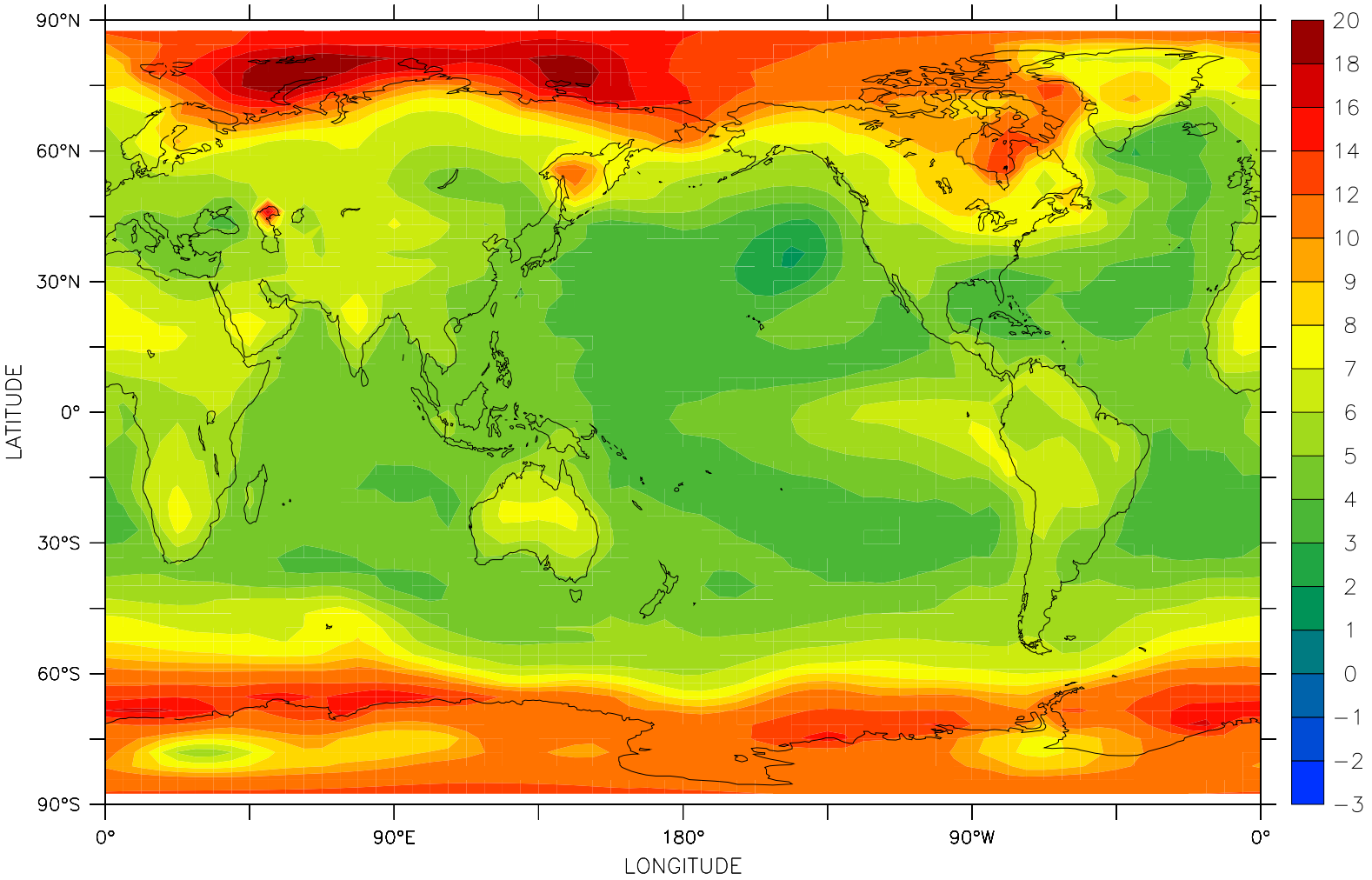


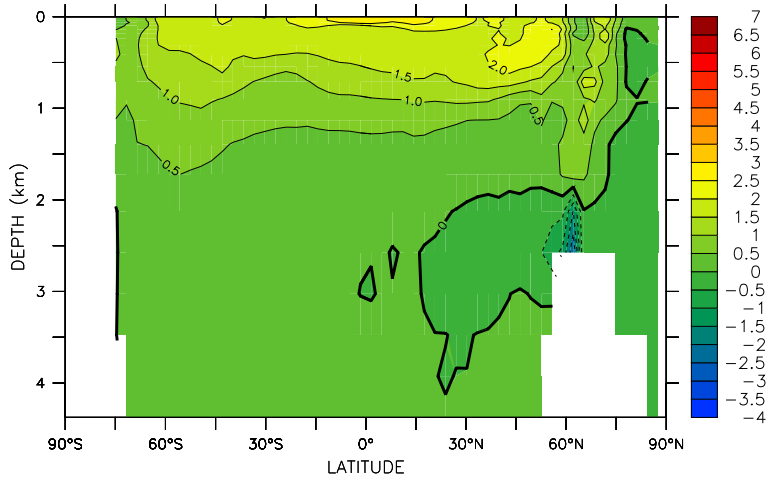
Deep water formation

5. Future climate

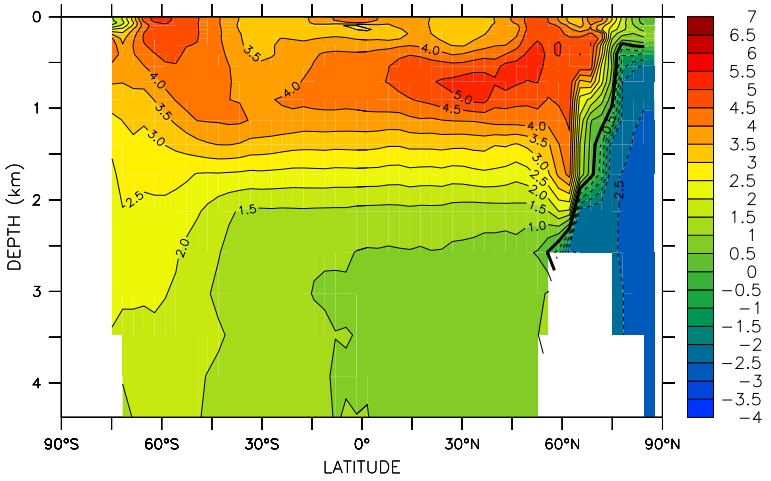


Change in annual−mean SAT (°C) − years 1951−2000

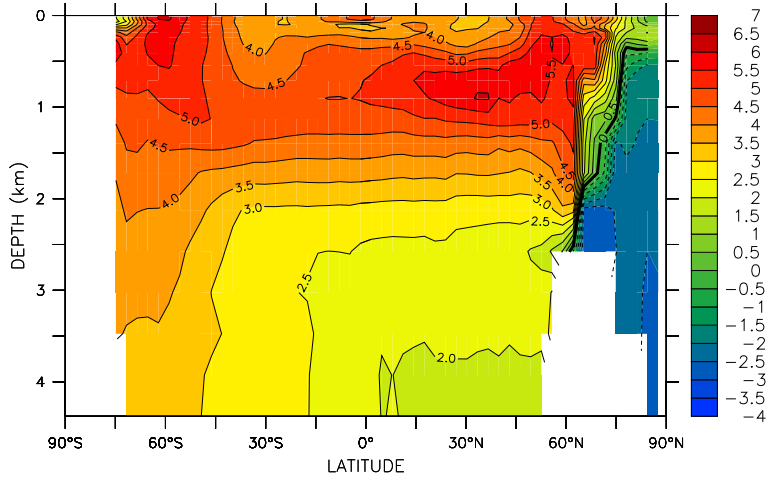
5. Future climate



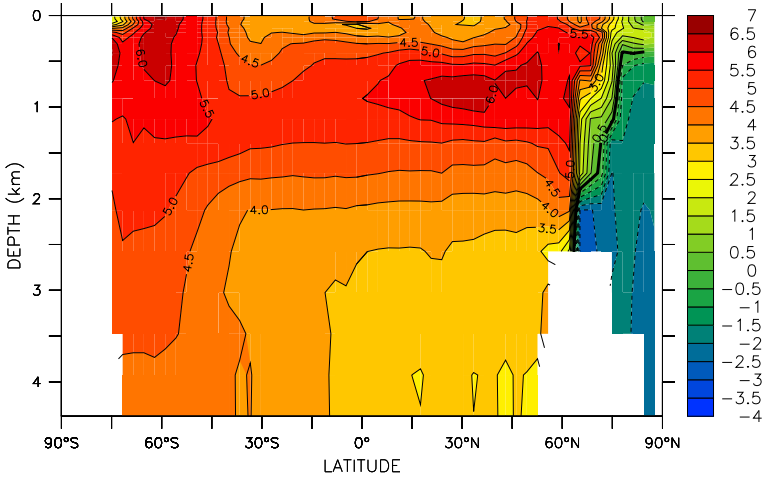
(a) Years 211–260



(b) Years 811–860

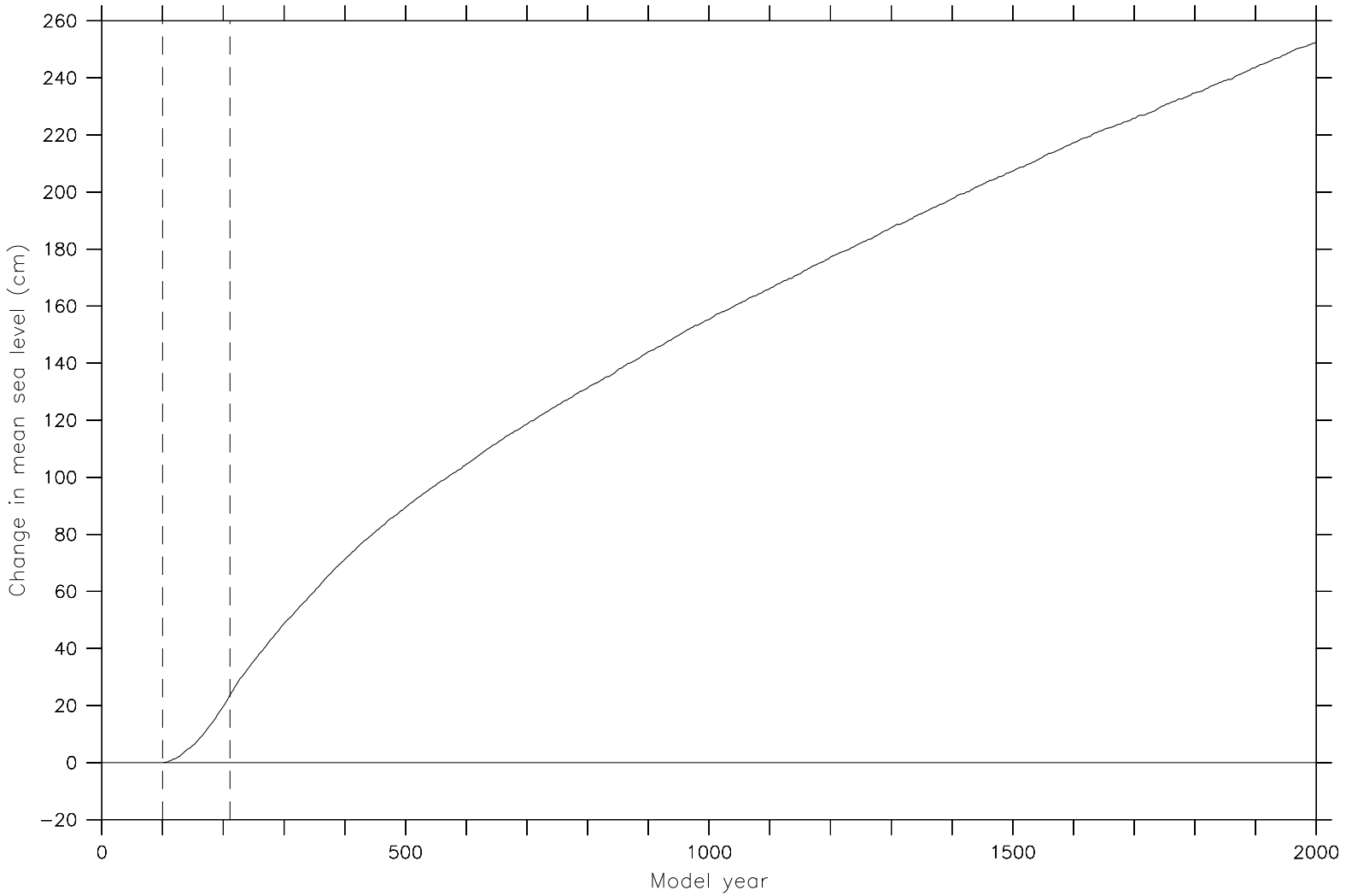


(c) Years 1411–1460



(d) Years 1951–2000

5. Future climate



Change in mean sea level

Thanks for coming!