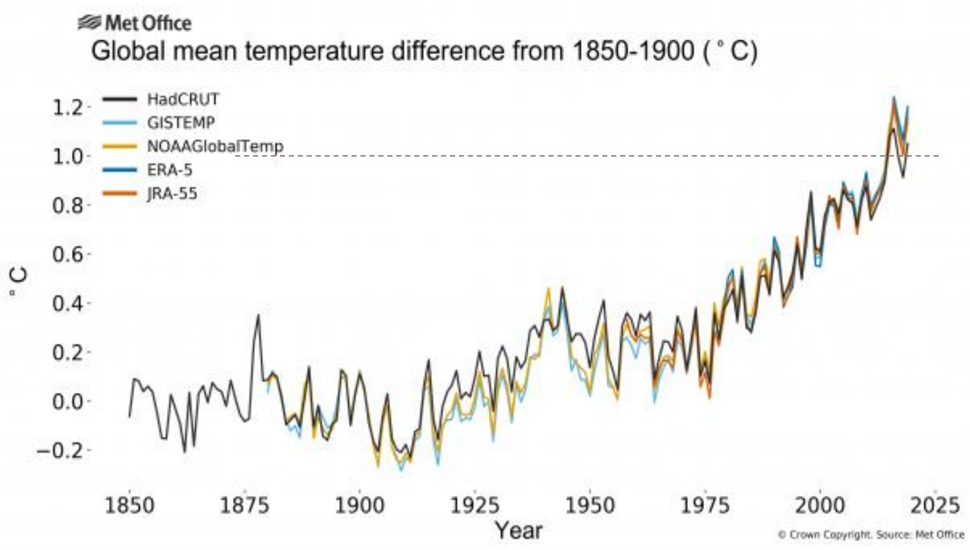
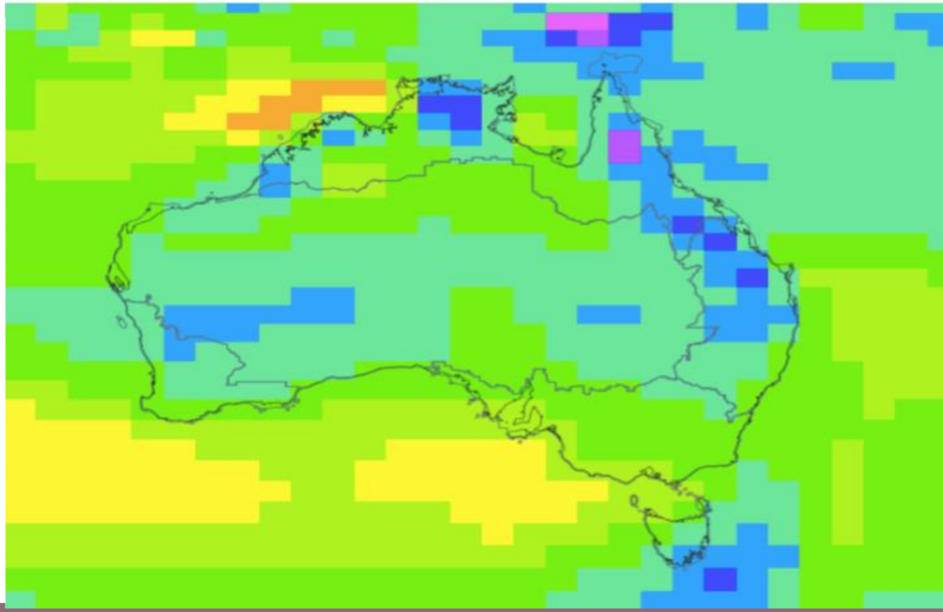
Earth Systems and Climate Change Hub

National Environmental Science Programme



# Modelling the climate system to understand the human role in recent climate change


Professor David Karoly, Earth Systems and Climate Change Hub

National Environmental Science Program, CSIRO

# Why do we need climate models?

- Climate models are able to realistically simulate past and current global and regional climate conditions
- They are the best tools to project future climate change
- Climate models enable us to understand the causes of climate variability and change, including climate extremes

**Outline:**

- Overview of climate models, their development & evaluation
- Evaluating the causes of recent observed climate change
- Human role in the record Australian temperature in 2019

**Acknowledgements**: Harun Rashid, ACCESS modelling team,

Francis Zwiers and other D&A colleagues

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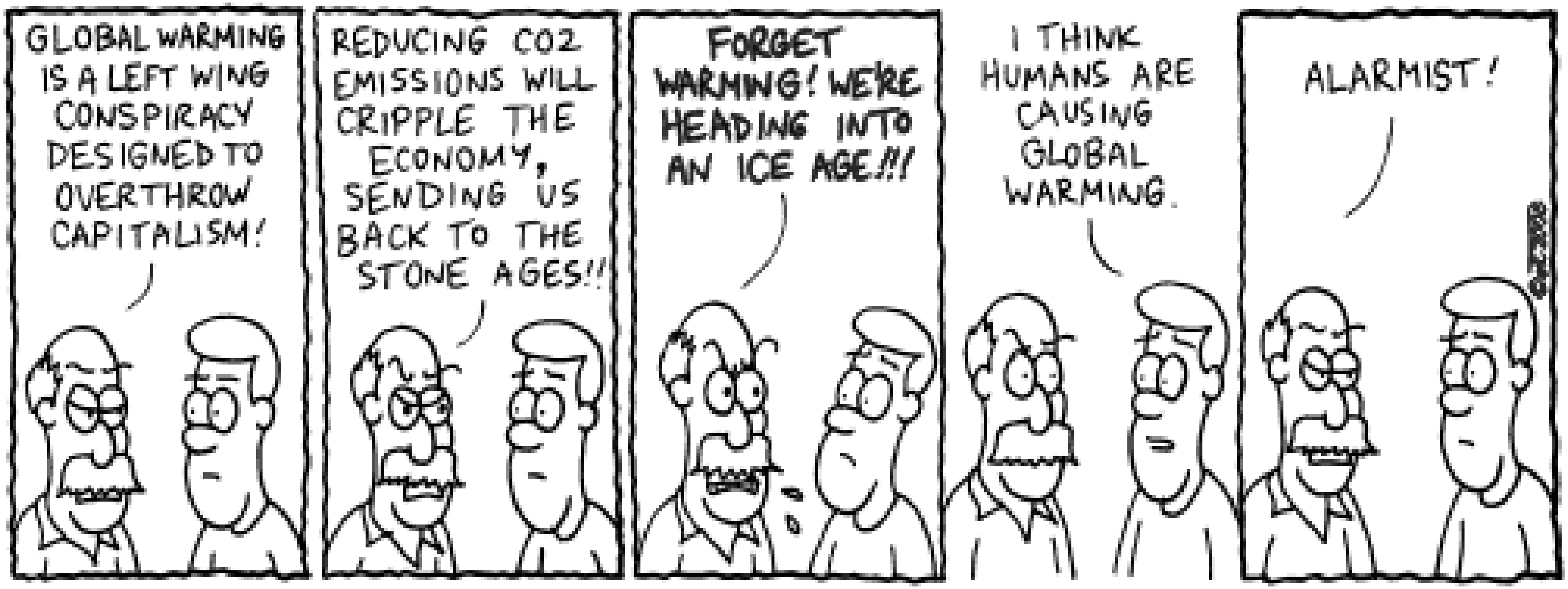
# Different perspectives




Global climate change research tools

- Observational data
- Theoretical analysis
- Climate models

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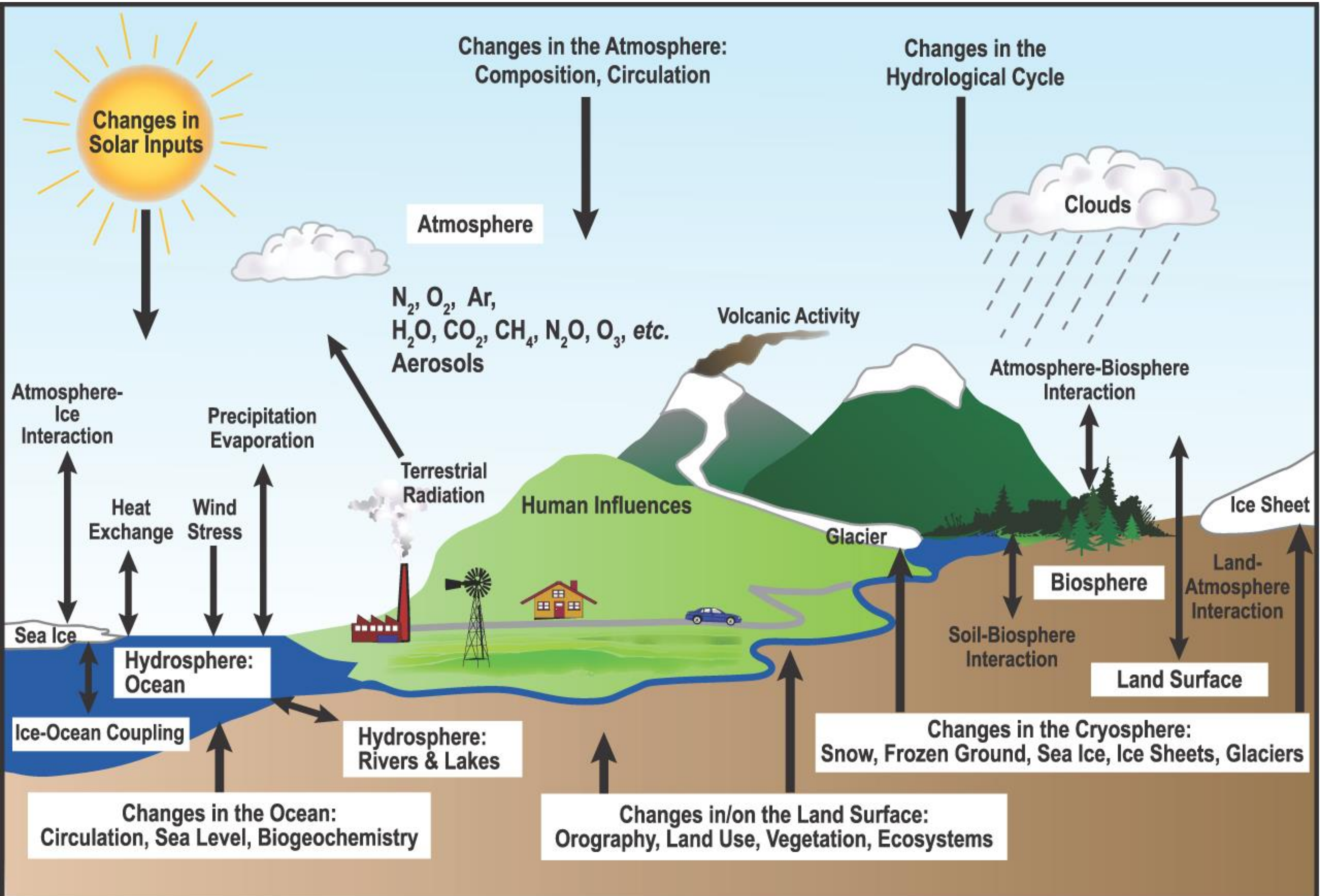
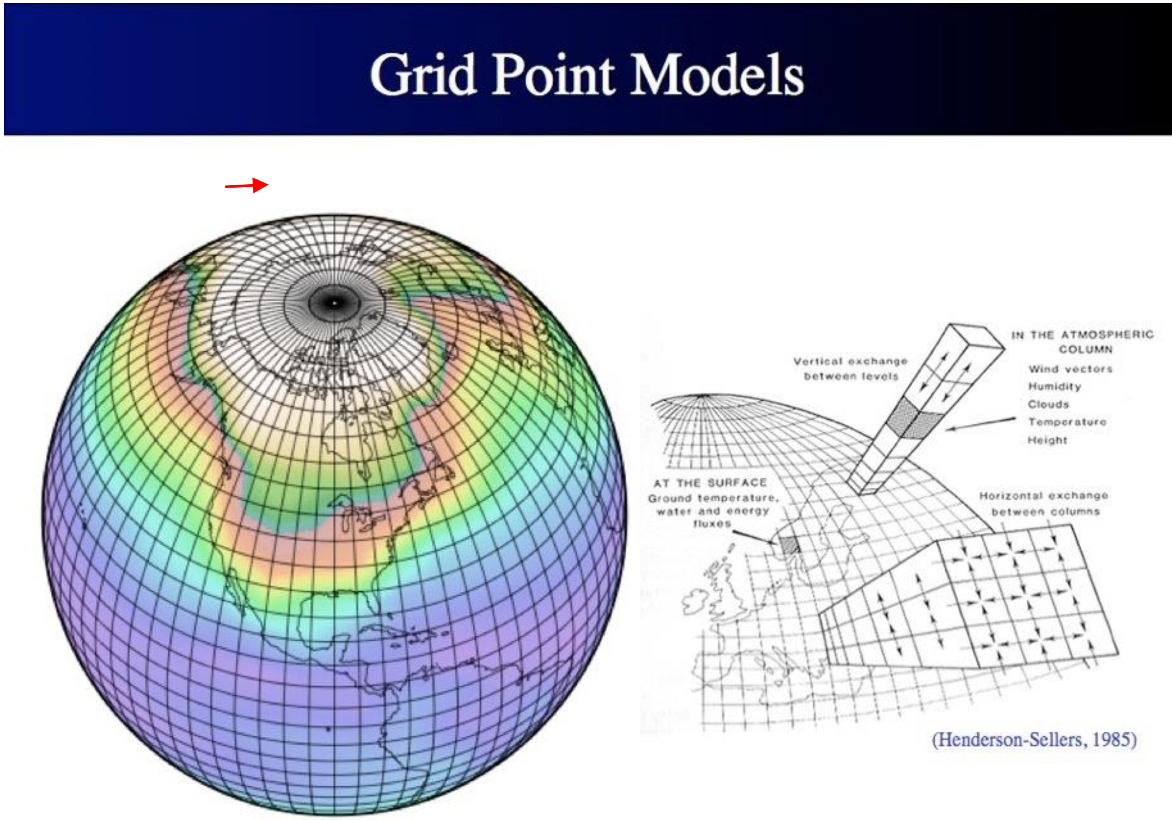



IPCC AR4 WGI FAQ1.2 Fig 1

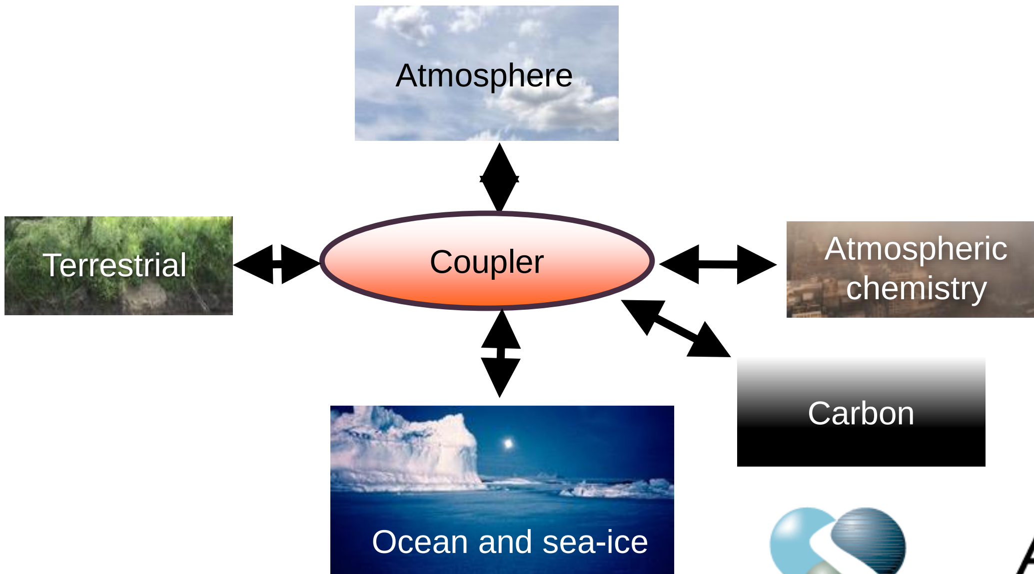
# Building a climate model

- Climate system processes and their mutual interactions are modelled using mathematical equations
- Many of these equations are derived from the first principles of physics, others are empirically derived from observations
- A model (of the atmosphere, for example ) is constructed by representing the equations numerically on a grid (latitude, longitude and height)
- More than 40 different global climate models developed around the world



# ACCESS: the Australian Community Climate and Earth System simulator:

A weather, climate and Earth System model for Australia built by the Australian research community in partnership with the UK MetOffice




ACCESS
The Australian Community Climate and Earth-System Simulator

## The model:

- Earth system components (atmosphere, land surface, ocean, cryosphere, chemistry) interact with each other
- Each component is governed by its own dynamical, physical, and chemical processes

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# Computer code

- The model predicts the climate snapshot a short time (~20 minutes) later using an earlier snapshot. The predicted snapshot is then used to predict the next snapshot, and so on.
- The complex set of numerical partial differential equations must be converted into a computer program (huge , more than 1 million lines long)

## Sample

```
!------------------------------------------------------------------------
! 3.1  Calculate layer dependent constants (pressure,
!      layer thickness, entrainment coefficients, detrainment
!      coefficients)
!------------------------------------------------------------------------

! DEPENDS ON: layer_cn
       Call LAYER_CN(k,n_dp,nlev                                        &
     ,                    mdet_on, ent_on                               &
     ,                    ntml,ntpar                                    &
     ,                    .false.,.false.,.true.                        &
     ,                    bconv,bwk,bwkp1                               &
     ,                    exner_layer_boundaries                        &
     ,                    exner_layer_centres                           &
     ,                    p_layer_boundaries,p_layer_centres            &
     ,                    recip_pstar,rhum, zk, zkp12, zkp1             &
     ,                    thek, qek,qsek, thekp1,qekp1,qsekp1           &
     ,                    thpk,qpk ,ekm14                               &
     ,                    pkp1,delpkp1,exkp1                            &
     ,                    pk,delpk,delpkp12,exk,delexkp1                &
     ,                    delp_uv_k, delp_uv_kp1                        &
     ,                    ekp14,ekp34,amdetk)

! Set ekm14 for next pass through loop
        Do i = 1, n_dp
          ekm14(i) = ekp14(i)
        End Do

!
! Calculate dqs/dth for layers k and k+1 (subroutine DQS_DTH)
!

       If (k == 2) then
! DEPENDS ON: dqs_dth
         Call DQS_DTH(dqsthk,k,th(1,k),qse(1,k),exk,n_dp)
       else
         Do i = 1,n_dp
           dqsthk(i) = dqsthkp1(i)
         End Do
       End If

! DEPENDS ON: dqs_dth
       Call DQS_DTH(dqsthkp1,k+1,th(1,k+1),qse(1,k+1),exkp1,n_dp)
```

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# National Computational Infrastructure (NCI) supercomputer:  Raijin

- 84,656 cores in 4416 compute nodes
- 300 Terabytes of main memory
- 8 Petabytes of high-performance operational storage capacity
- 37 Petabytes of supporting storage space for big data
- Replaced in Dec 2019 by bigger, faster system *Gadi*


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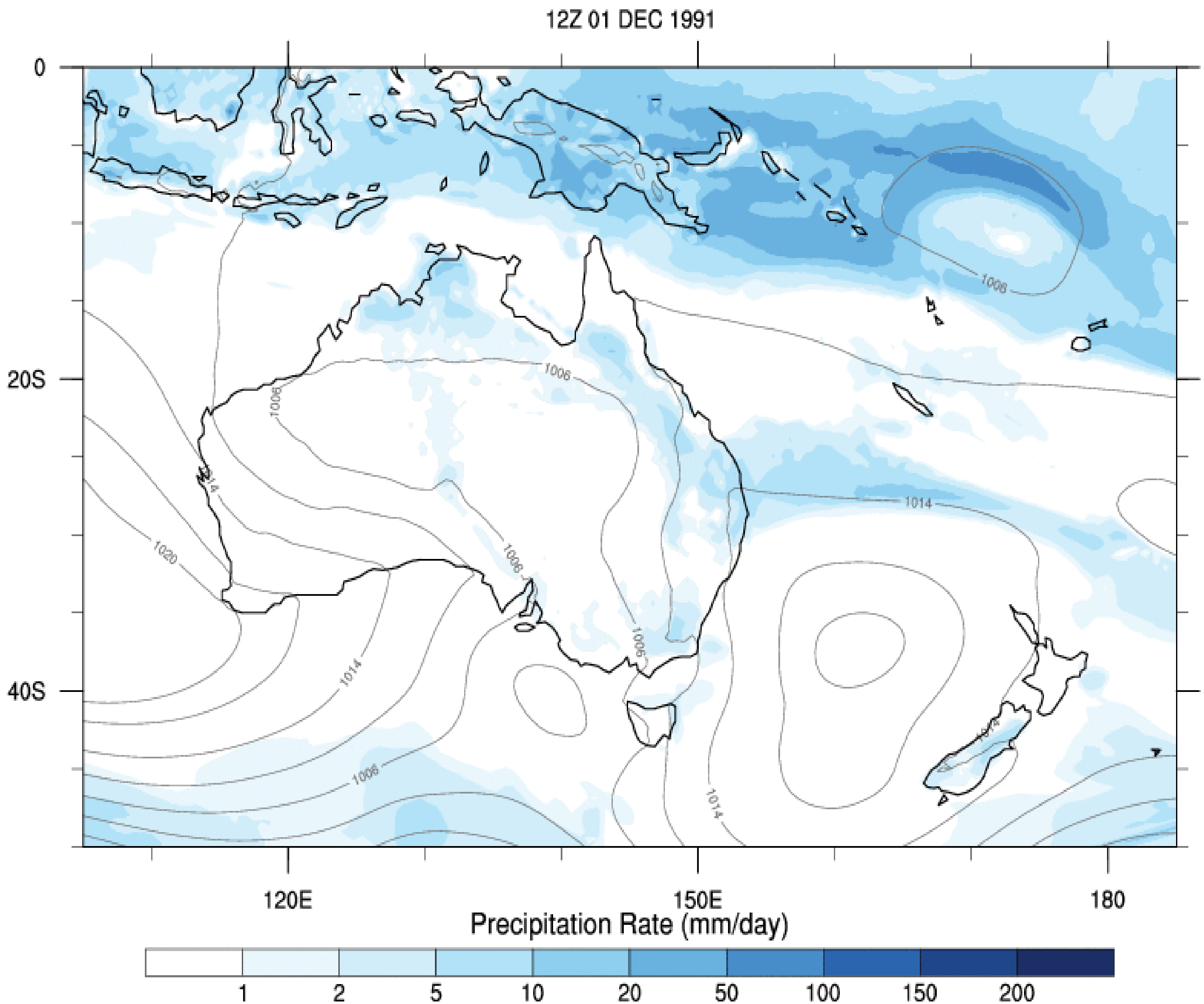
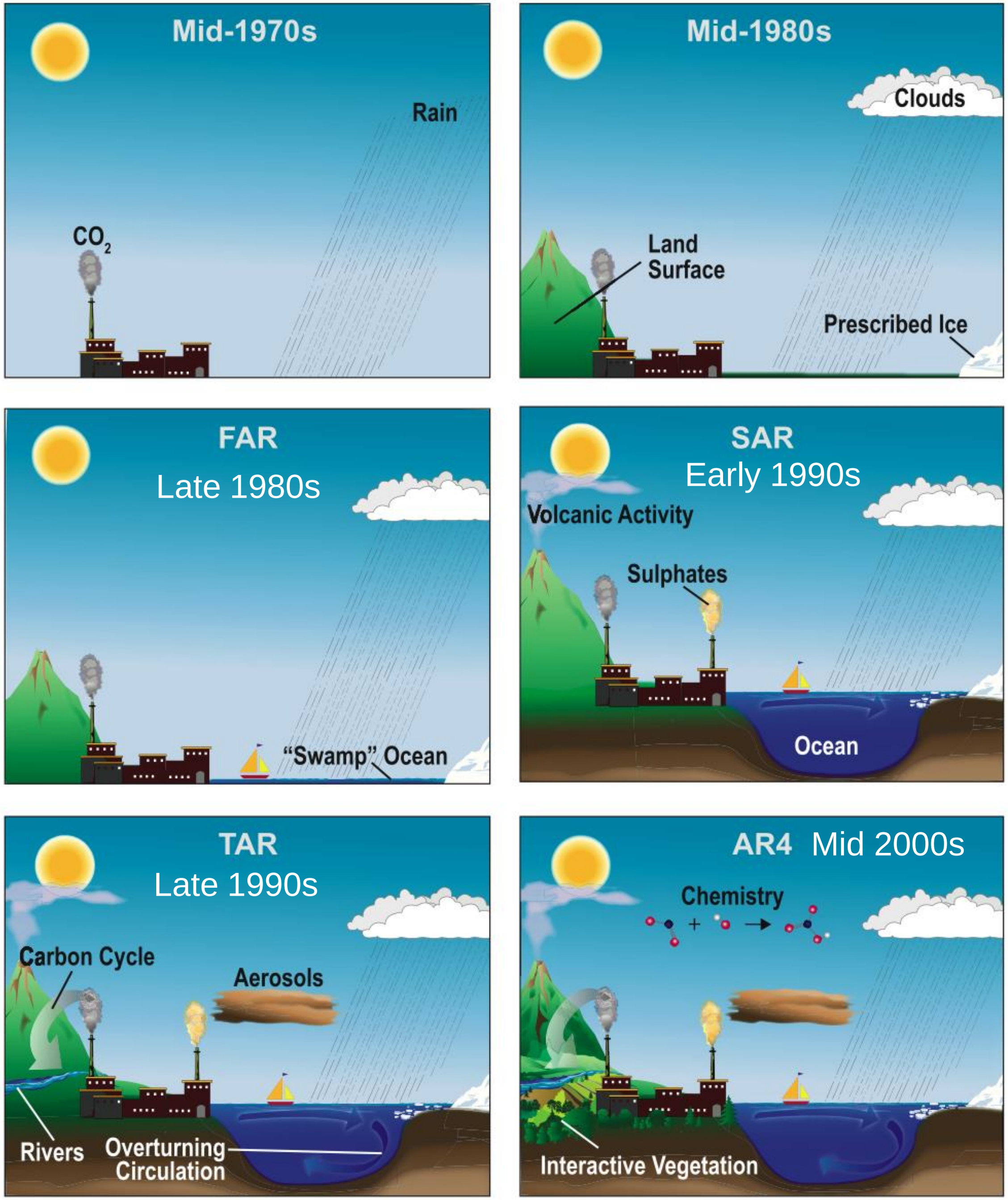
# Australia-New Zealand Regional Climate Model

Extract of daily sea-level pressure and rain from regional simulation for Dec 1991- Feb 1992



# The World in Global Climate Models




IPCC AR4 WGI Fig 1.2

The complexity of climate models has increased over the last few decades. The additional processes incorporated in the models are shown pictorially by the different features of the modelled world.

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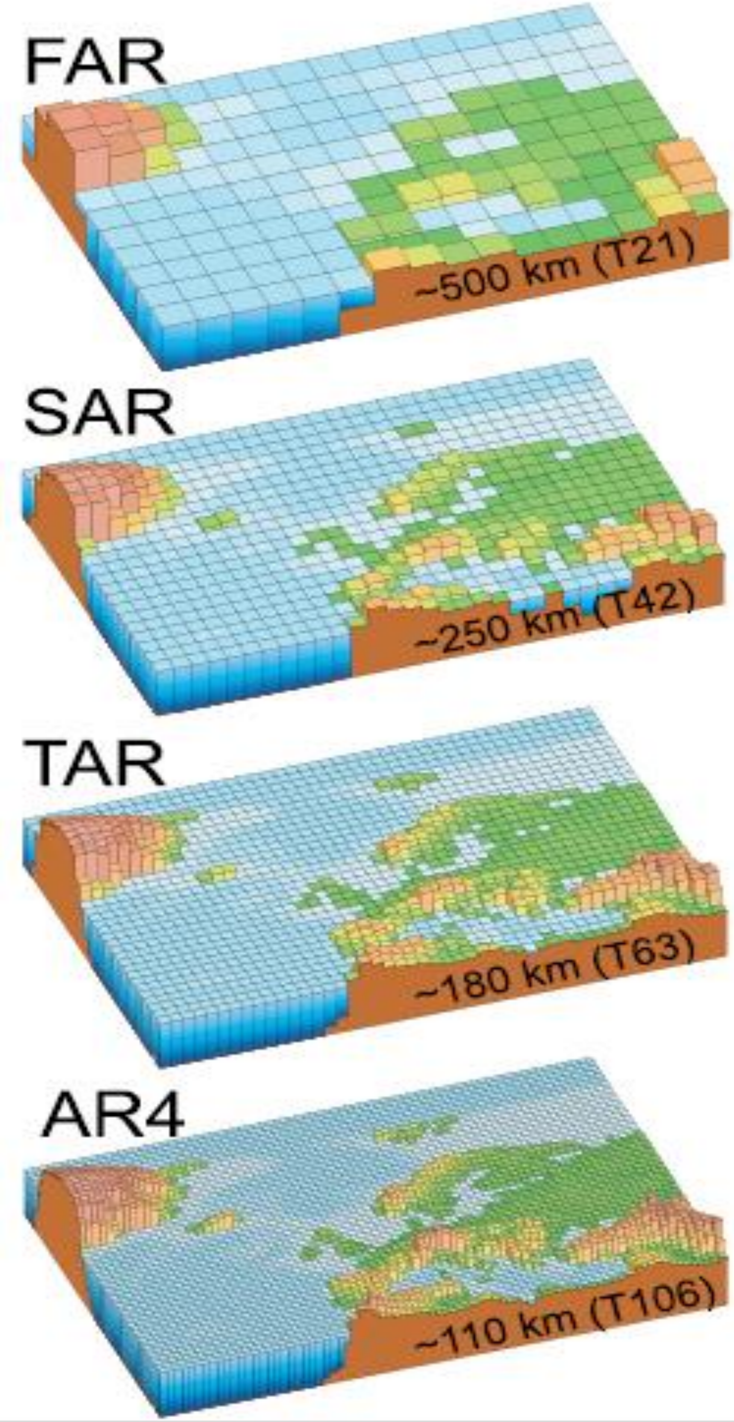
# Model Limitations

- Resolution
- Computer power
  - length of simulation
  - number of points
  - speed of processors
- Parameterization schemes
  - representation of unresolved processes
- Insufficient observations
  - for evaluating simulations of some variables

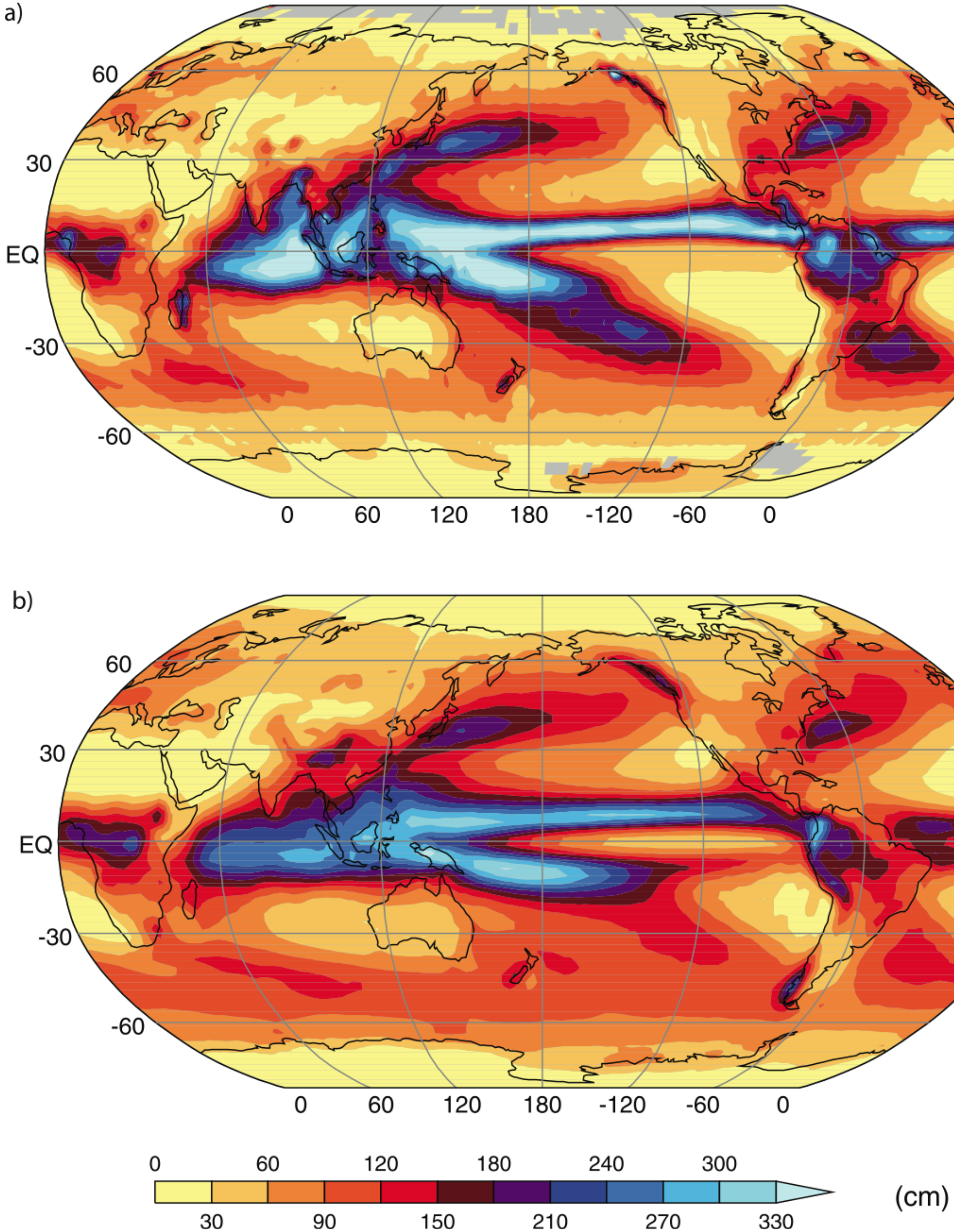


# Climate models

- A climate model can be used to predict the climate response due to:
  - Changes in boundary conditions, such as changes in sea surface temperature (SST) or land surface properties
  - Changes in radiative forcing factors, such as changes in solar radiation, volcanic aerosols or greenhouse gas concentrations
- The major difference between a climate model and a weather forecast model is that the climate model is used to predict the longer term behavior of the global climate system
- The chaotic nature of the atmosphere means that deterministic predictions for a specific time are not possible

# Annual mean precipitation

Observations 1980-99




Multi-model ensemble mean for 1980-99, from simulations of the 20th century

IPCC WGI Fig 8.5

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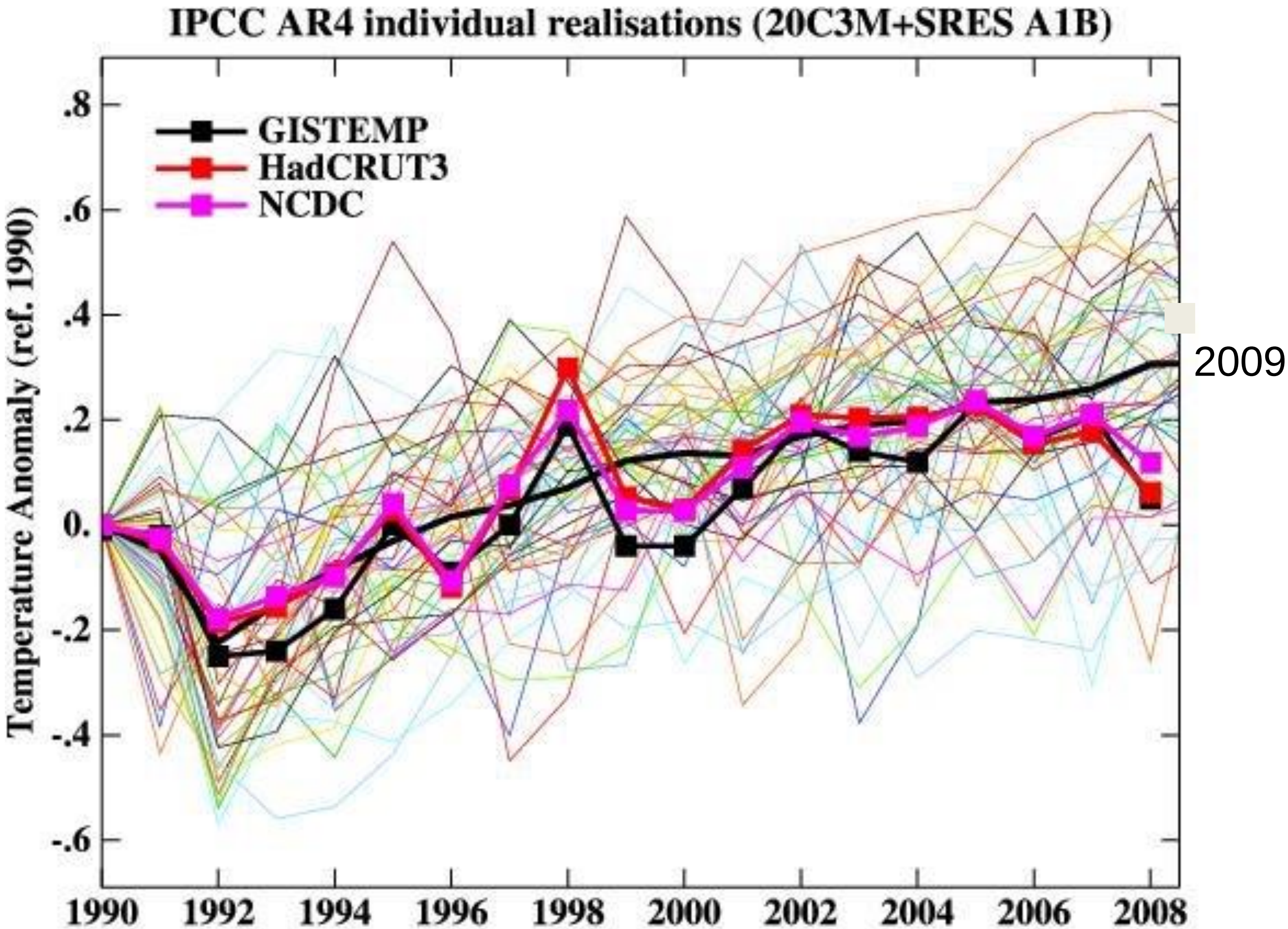
Comparison of observed global mean temperature with climate model simulations

Models started in 1880, with data extracted for 1990-2009

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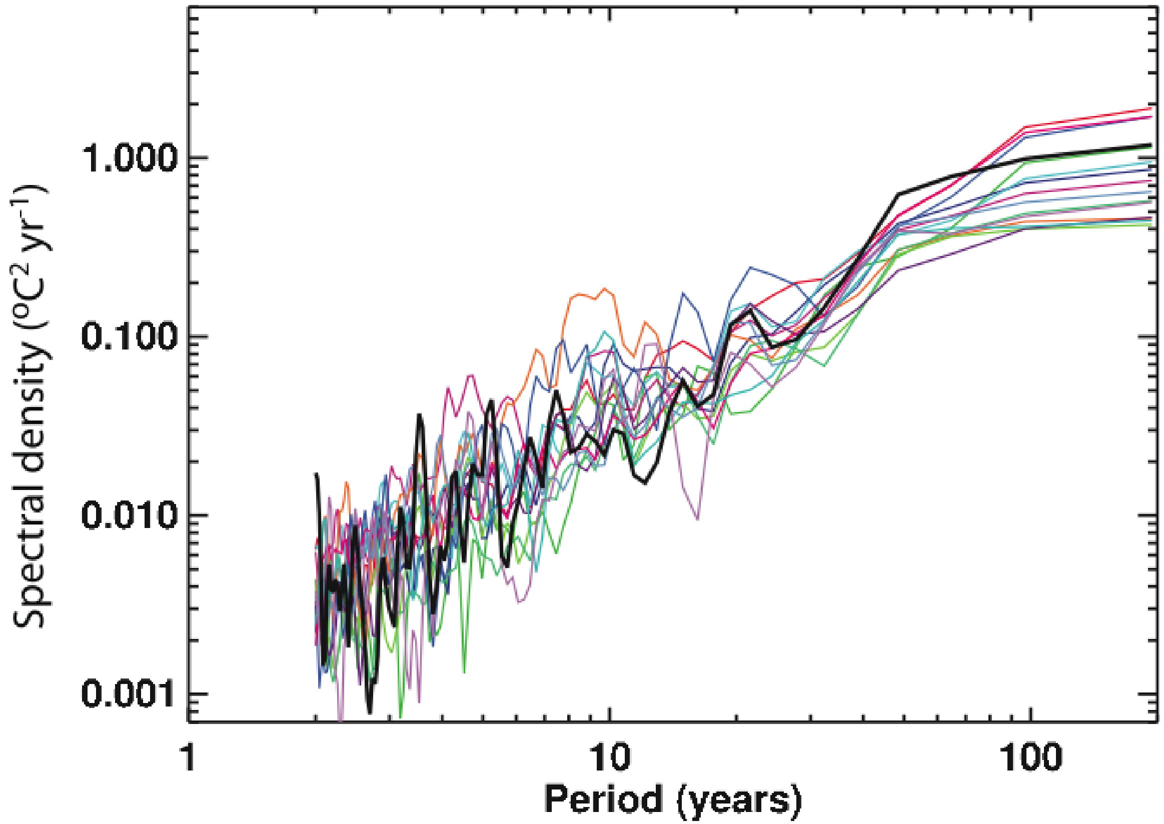
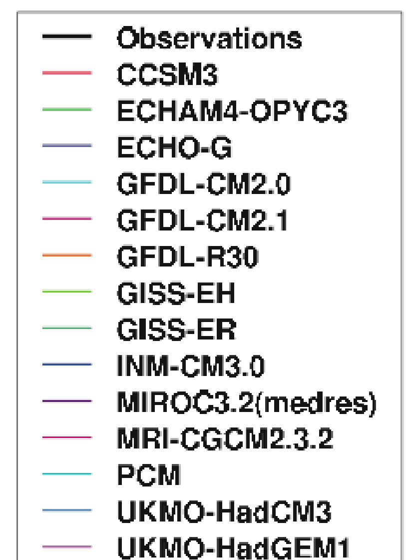
Climate models adequately represent internal surface temperature variability on global scales …

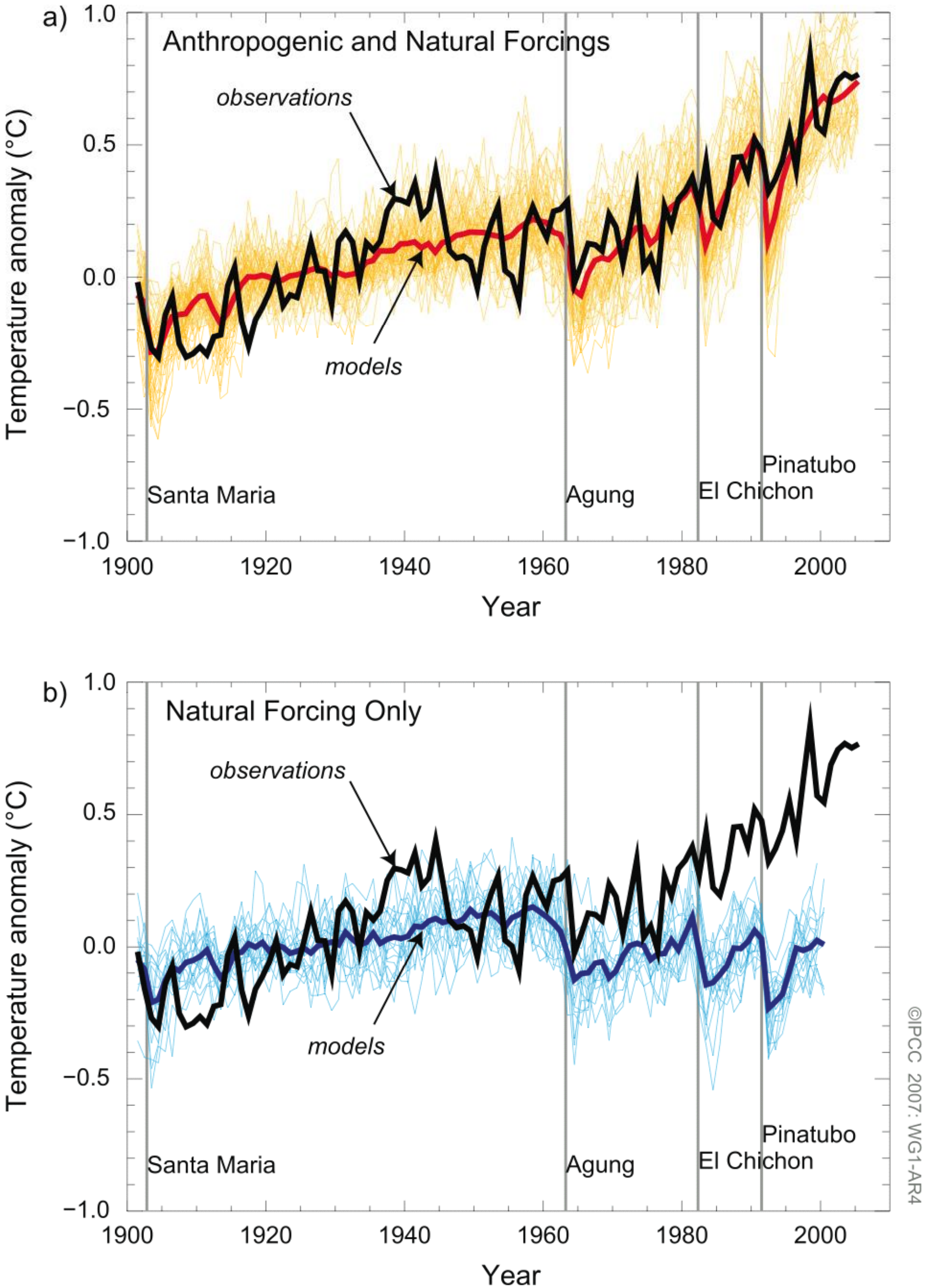



Variability of observed and simulated annual global mean surface temperature (1901-2005)


ALL forcings
58 simulations
14 models

IPCC TAR WG1 Fig. 9.7




# Global mean temperature variations from models and observations

'Most of the observed increase in global average temperatures since the mid-20th century is *very likely (more than 90% certain)* due to the observed increase in anthropogenic greenhouse gas concentrations.' IPCC(2007)

IPCC AR4 WGI
Fig TS.23

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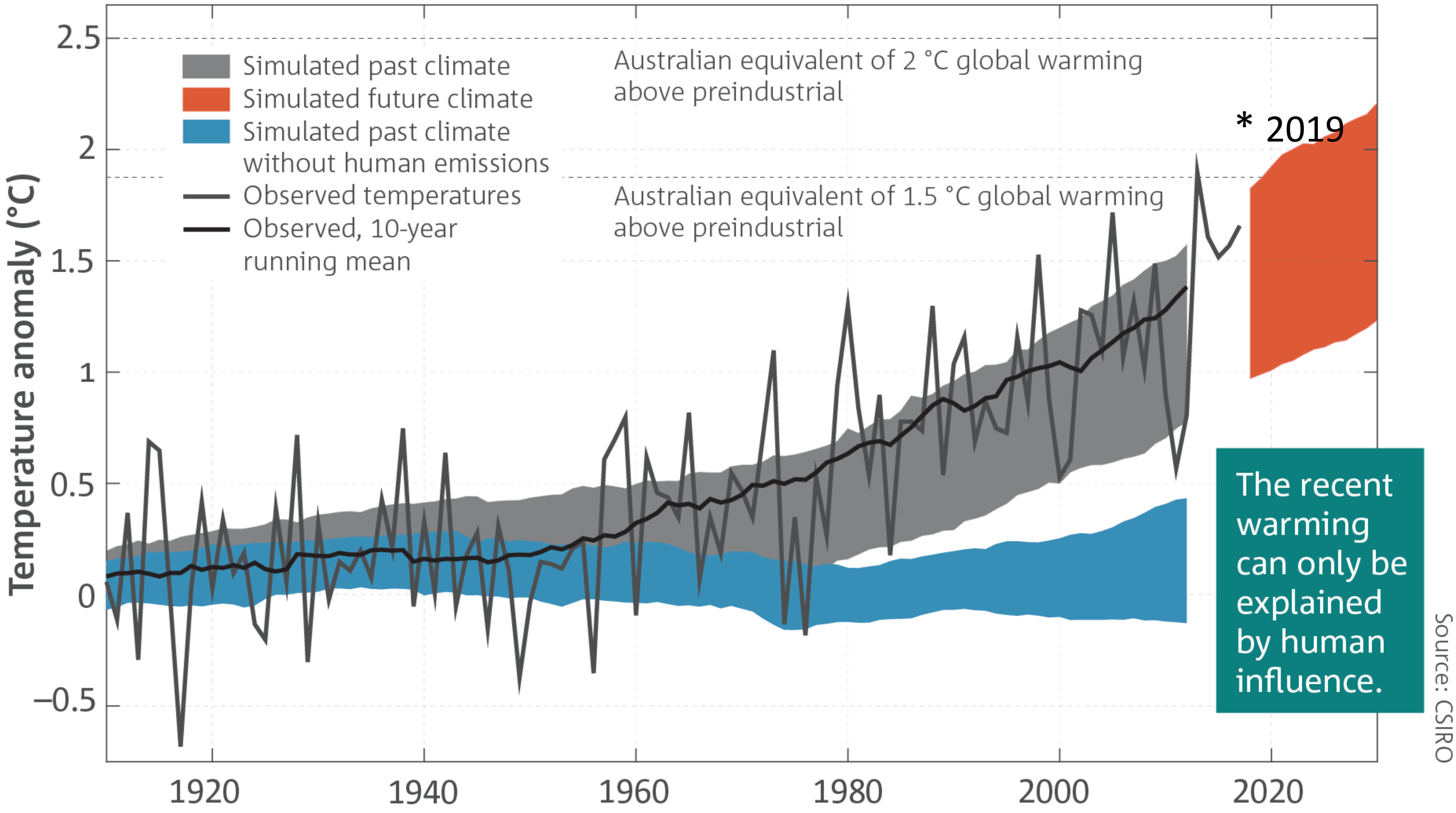
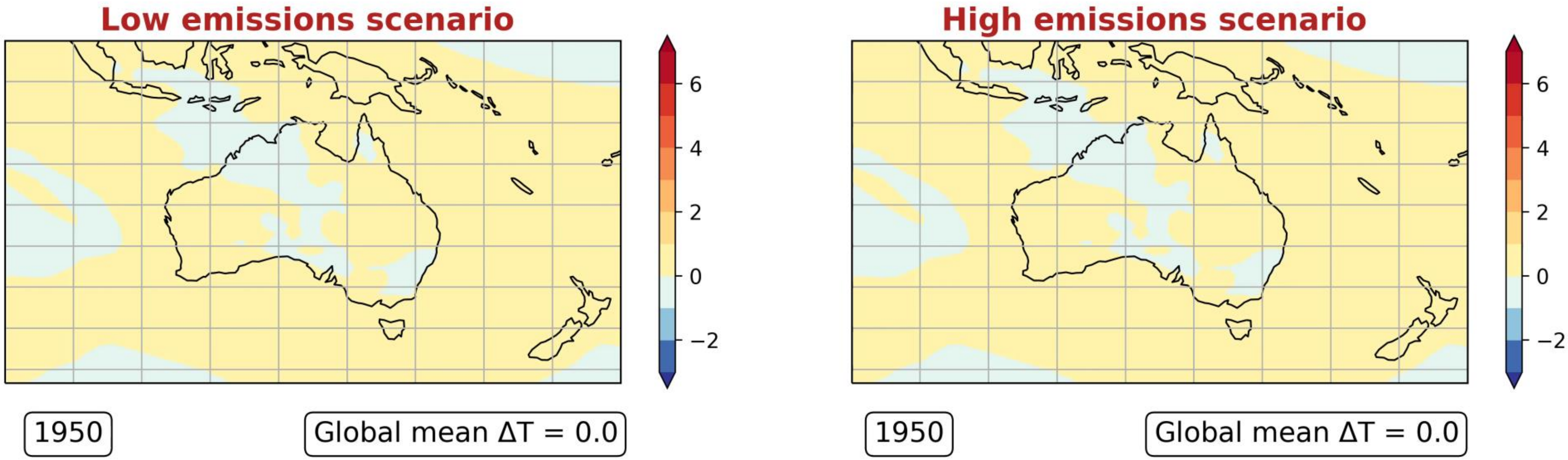
# Simulated temperature changes in Australia

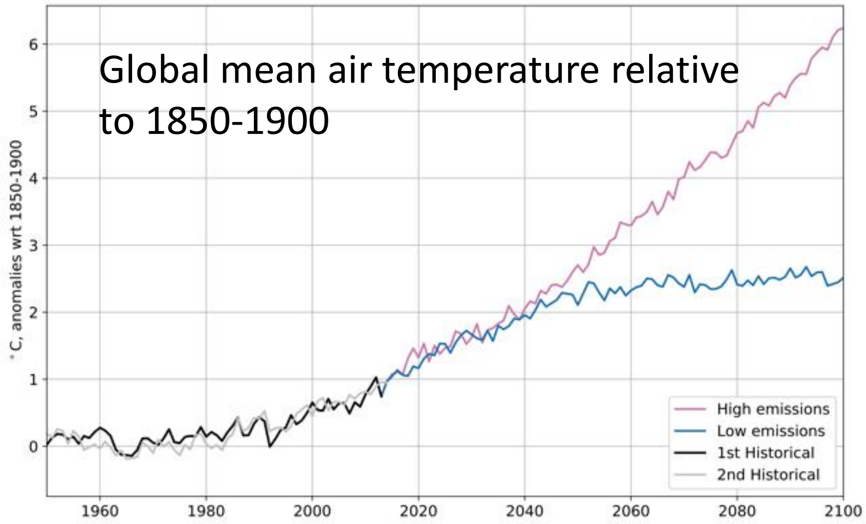



SoC, 2018

# Simulated temperature changes in Australia with new ACCESS-CM2 model

**Temperature change relative to 1850-1900**

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# Identifying the causes of observed climate change: Detection and attribution

Detection of significant observed climate change and attributing this observed change to one or more causes is a signal-in-noise problem: identifying possible signals in the noise of natural internal climate variations in the chaotic climate system.

***Attribution*** of climate change to specific causes involves statistical analysis and the careful assessment of multiple lines of evidence to demonstrate that the observed changes are:

- unlikely to be due entirely to internal climate variability;
- consistent with the estimated responses to a given combination of anthropogenic and natural forcing; and
- not consistent with alternative, physically plausible explanations of recent climate change

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# Fingerprint detection and attribution

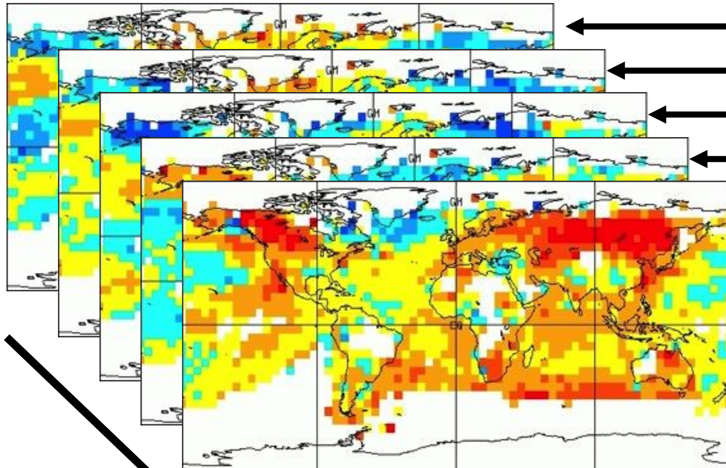
Greater confidence when

- We are able to separate the contributions to observed change from individual sources

  - Decompose the observed change into space-time patterns from different factors; GHG, aerosols, solar, ozone, internal variability

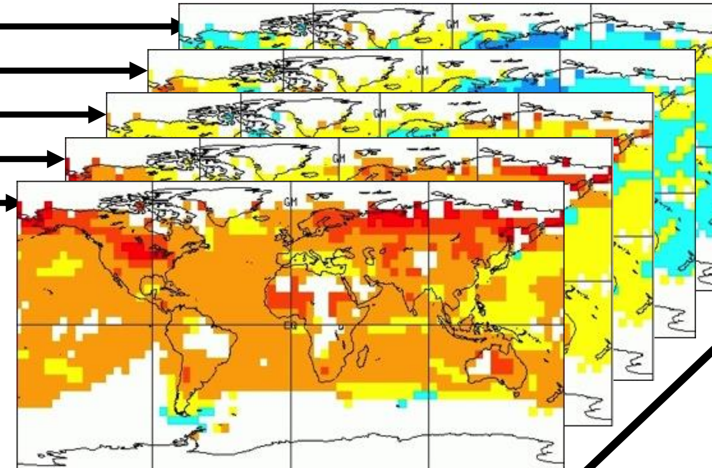
- Account for multiple known sources of uncertainty
- Models and observations agree on the amplitude of the contributions
- Able to demonstrate that competing explanations are not viable
- Models simulate similar levels of internal variability to observed

**Observations** **Model**



1951-60

2001-2010



Filtering and projection onto reduced dimension space

$\mathbf{Y}$ $\mathbf{X}$

$$\mathbf{Y} = b\mathbf{X} + e$$

Total least squares regression in reduced dimension space

$\hat{b}$ $\hat{e}$

**Evaluate amplitude estimates**

**Evaluate goodness of fit**

Weaver and Zwiers, 2000

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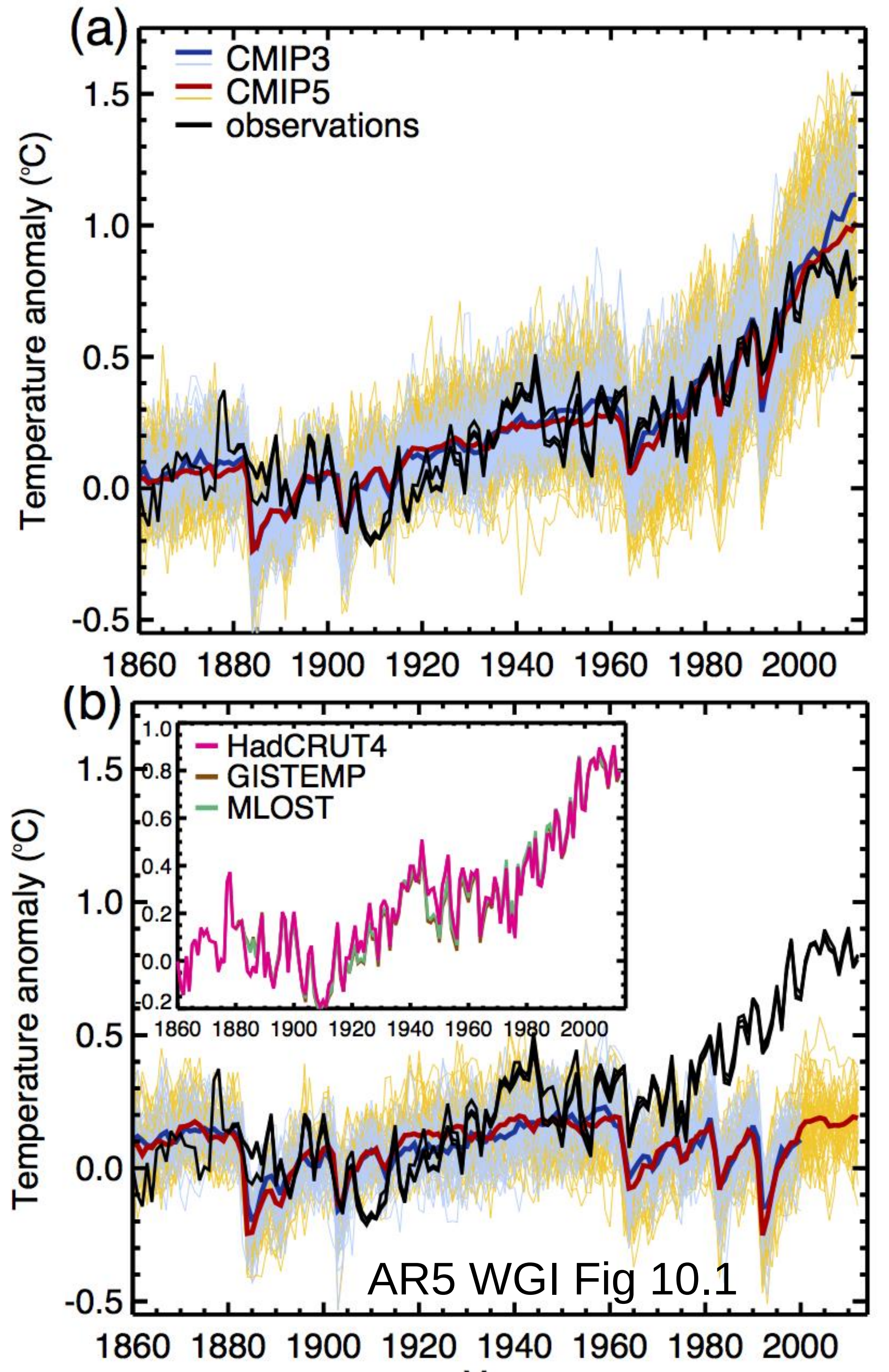
**Y = (X- î)â + å**

- **Observations** represented in a dimension-reduced space
  - Typically filtered
    - Spatially (to retain large scales)
    - Temporally (to retain decadal variability - 5-10 decades)
    - Projected onto low-order space-time EOFs

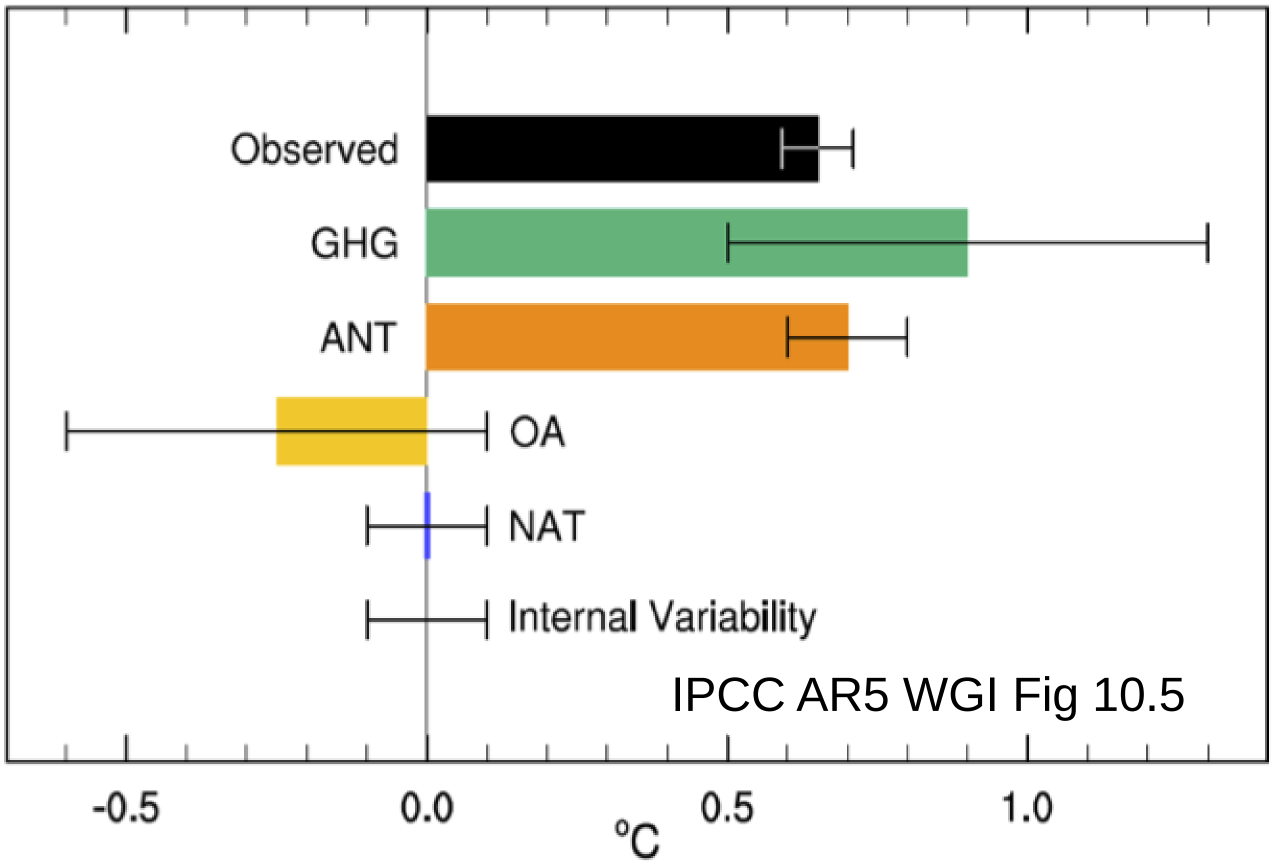
- **Signals** estimated from
  - Multi-model ensembles of 20th century simulations
    - With different combinations of external forcings
  - Anthropogenic (GHG, aerosols, etc)
  - Natural (Volcanic, solar)
    - Multiple models, ensemble sizes from 1-9 runs
    - Assume linearity of response




AR5 WGI Fig 10.1

‘It is *extremely likely (>95%)* that human activities caused more than half of the observed increase in global mean surface temperature from 1951–2010.’ IPCC(2013)

Estimated contribution from different forcings to observed global mean temperature change 1951-2010



IPCC AR5 WGI Fig 10.5

**Different forcing factors**

GHG – greenhouse gases

ANT – combined human-related factors

OA – Other human-related, mainly aerosols

NAT – natural factors, solar, volcanoes

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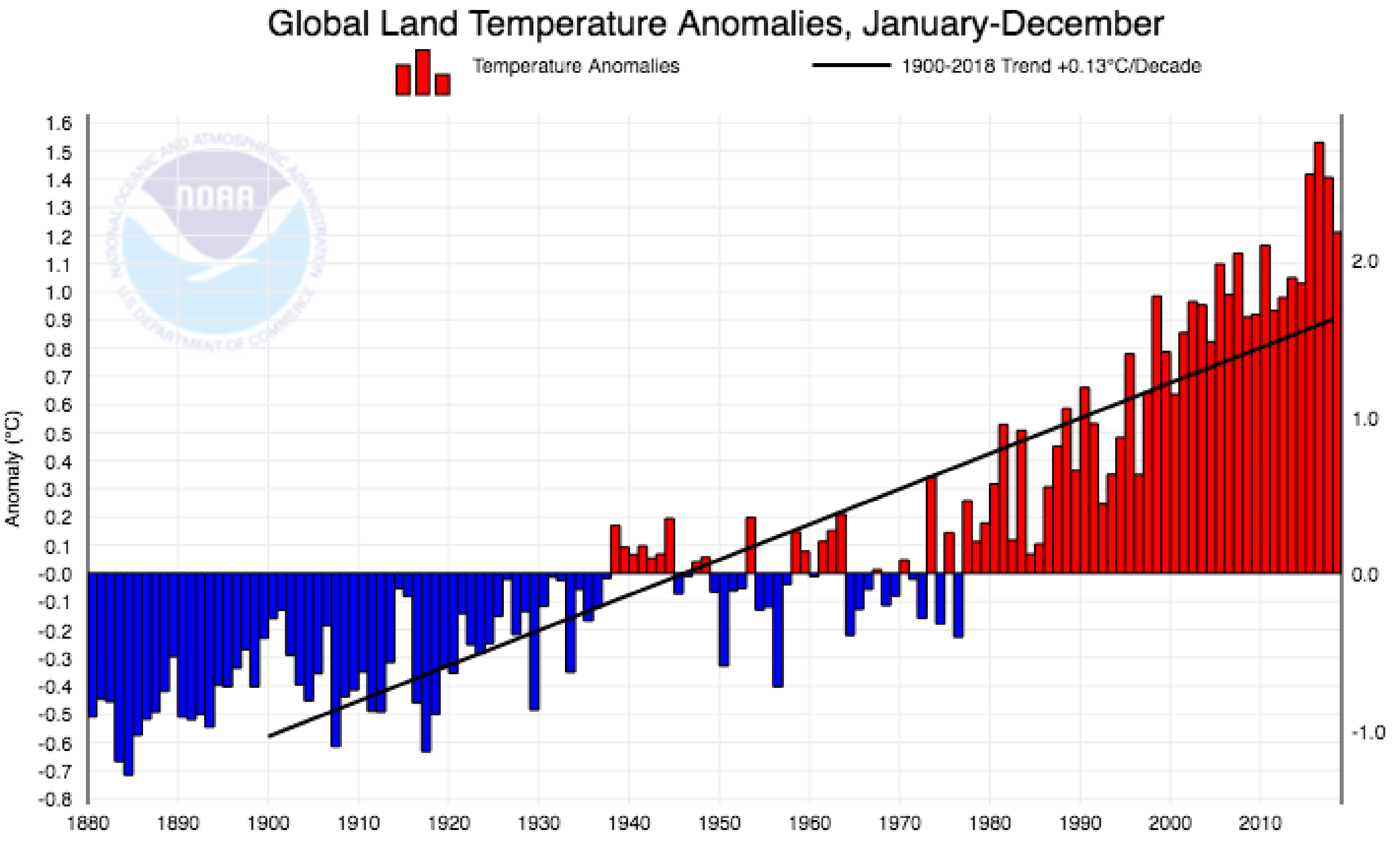
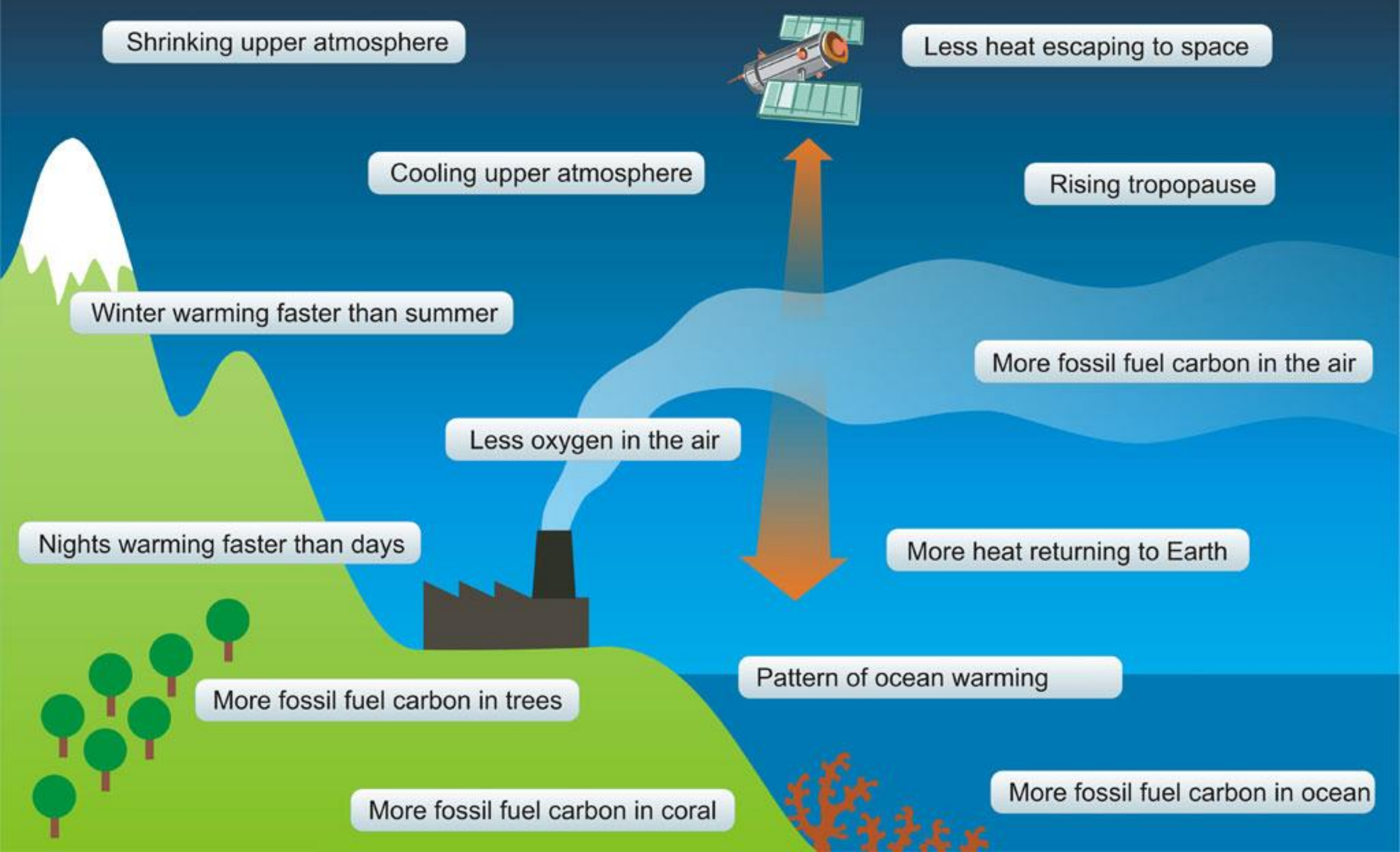
# IPCC Special Report *Climate Change and Land*

"…, land surface air temperature has risen nearly twice as much as the global average temperature"

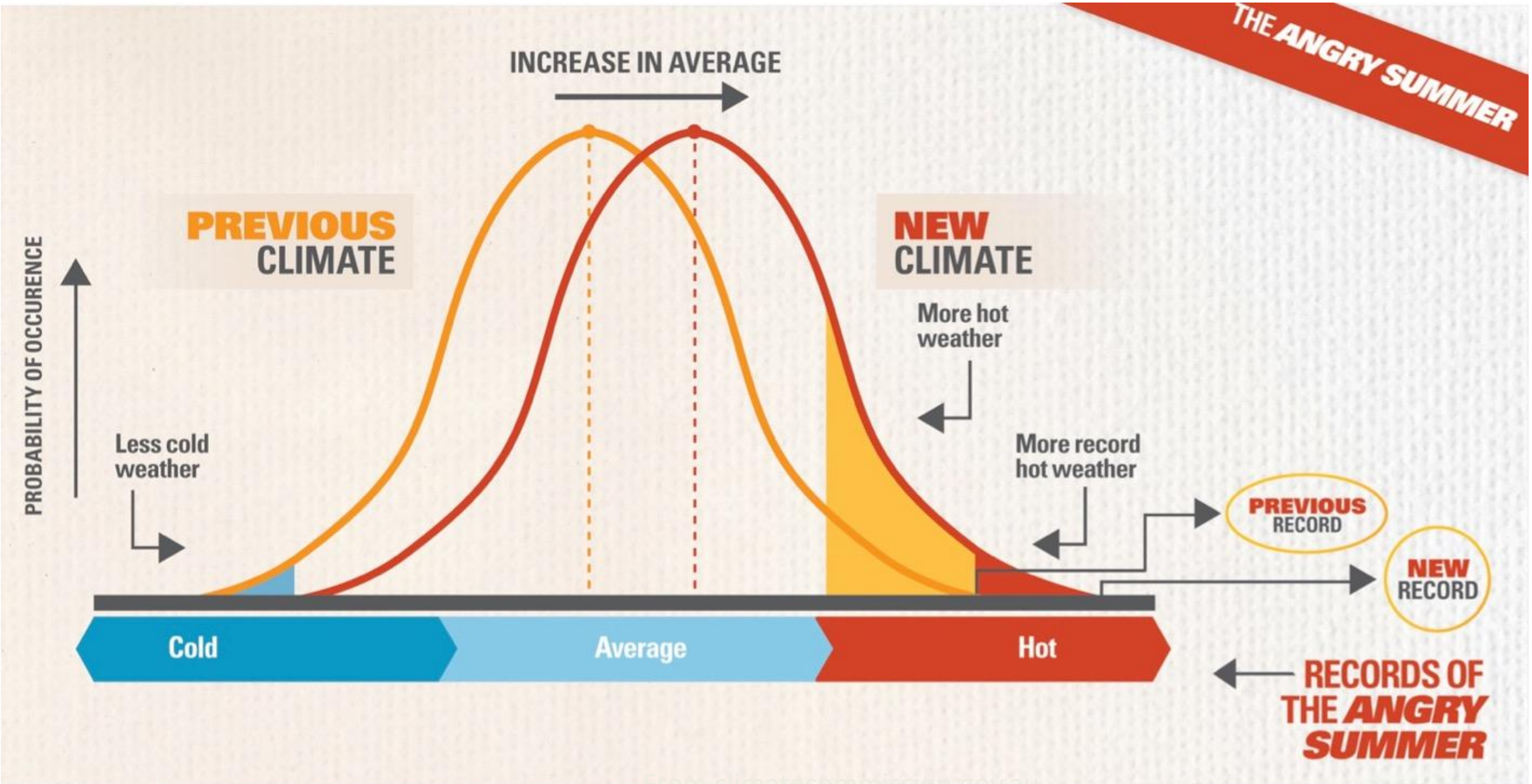


# How we know we're causing global warming

From http://www.skepticalscience.com/



# Global warming increases the likelihood of extreme temperatures




SOURCE: Modified from: Intergovernmental Panel on Climate Change (IPCC). (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K., Tignor, M.M.B., Miller, H.L. Jr and Chen, Z. (eds). Cambridge, UK and New York, NY, USA: Cambridge University Press.

From climatecommission.gov.au

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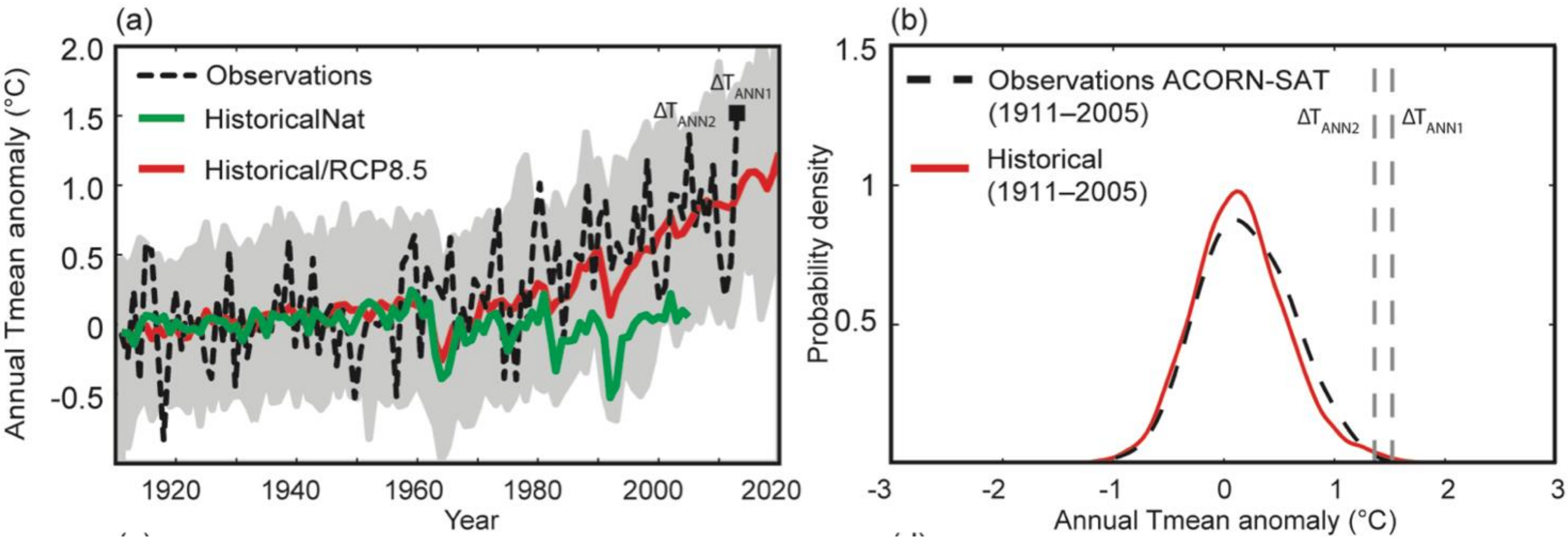
# The record hot year across Australia in 2013




Compare Australian average annual temperatures from climate model simulations with observations for 1911-2005

Lewis & Karoly (2014) BAMS

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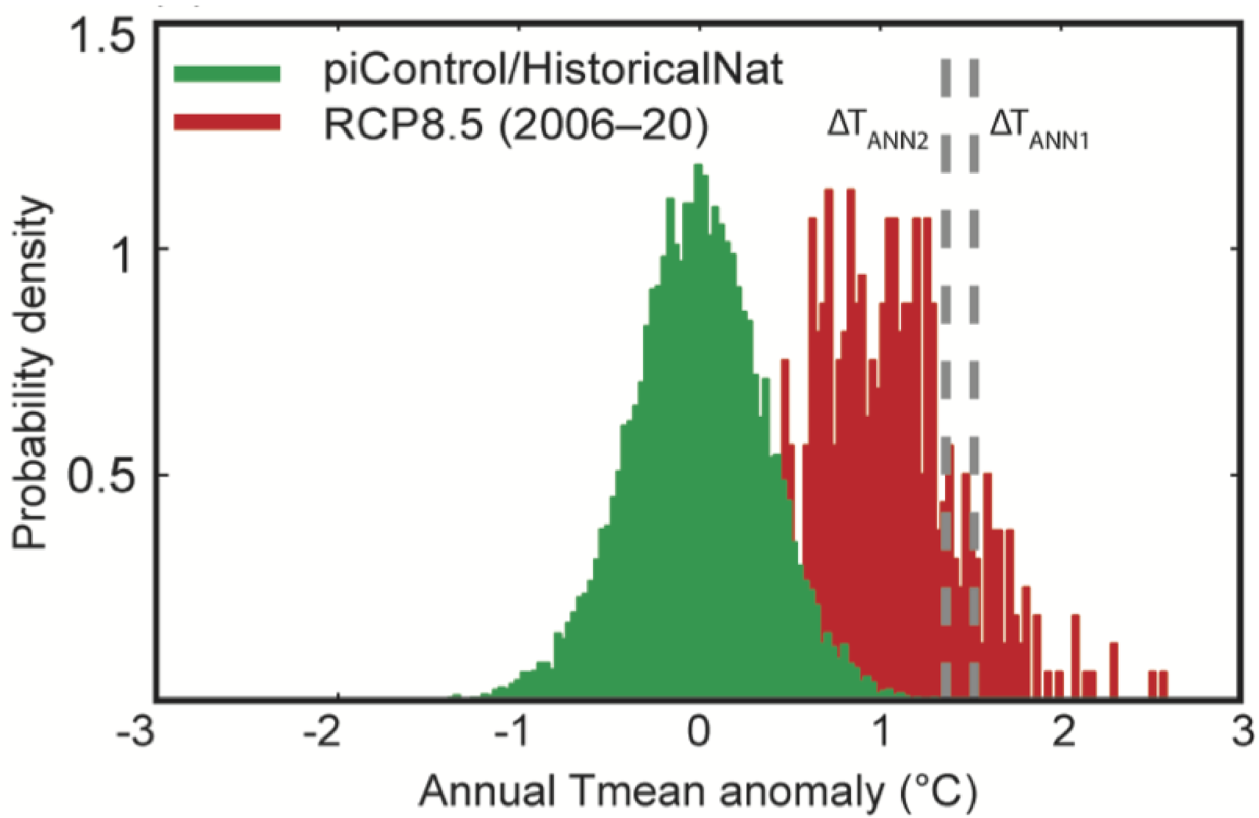
# The record hot year across Australia in 2013

Change in probability of extreme Australia average annual temperatures for a warming climate

Virtually impossible for annual temps hotter than in 2005 **without** human influences on climate (only 1 in 12,000 in model simulations)




Lewis & Karoly (2014) BAMS

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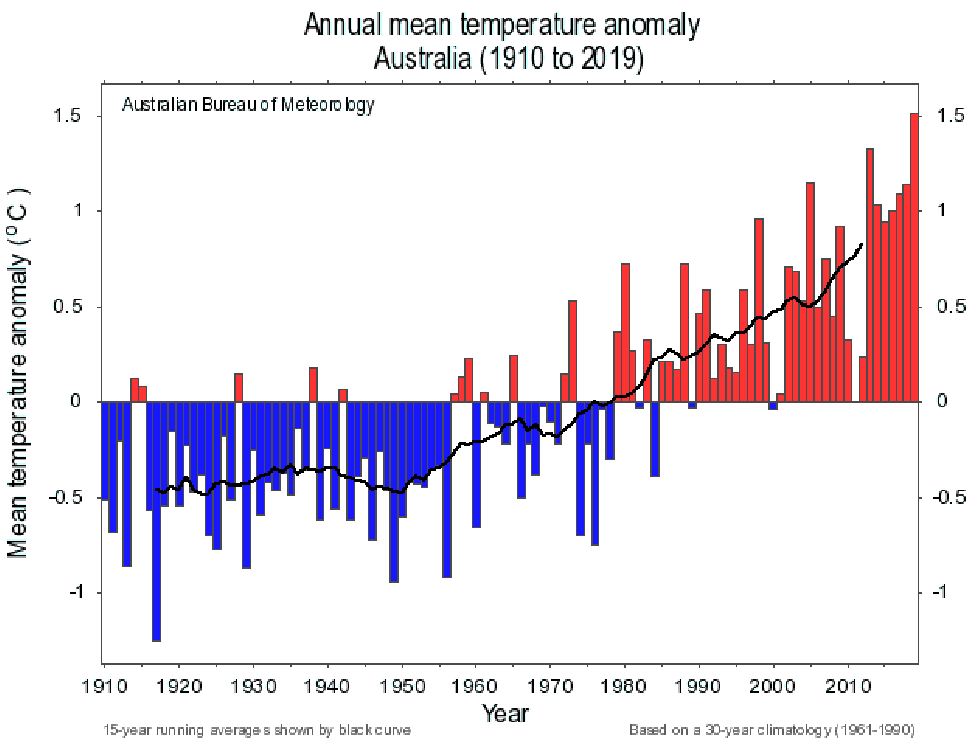
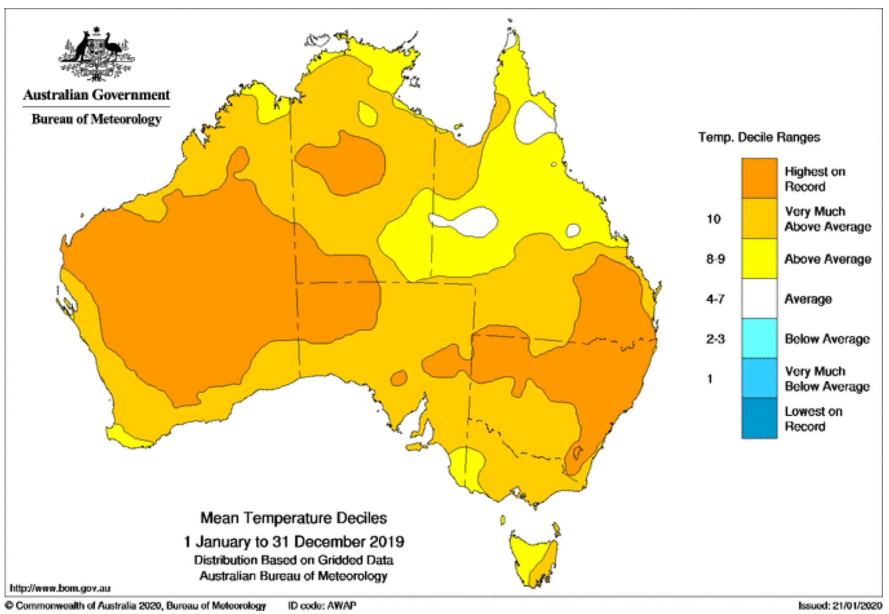
# The record hot year across Australia in 2019

Australia in 2019 set a new record for the hottest annual average temperature across the country.
Model simulations with human influences on climate indicate one year in seven is likely to beat the 2013 record hot year.

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# Summary

- Climate models are physically-based mathematical models of the complex non-linear coupled climate system
- Climate model simulations represent both forced and chaotic variations of the climate system
- Agreement between climate model simulations and observations requires that the observed variations lie within the range of simulated variations from a large ensemble of model simulations
- There is better agreement between the pattern and magnitude of simulated and observed large-scale temperature changes over the last 50 years than for other variables, like rainfall
- Human activities have been the major cause of the observed increase in global and Australian mean surface temperature since 1950
- “All models are wrong! but some are useful” (G E Box)

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# Key Messages

- **Human influence on the climate system is clear**
- **The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts**
- **We have the means to limit climate change and build a more prosperous, sustainable future**

AR5 WGI SPM, AR5 WGII SPM, AR5 WGIII SPM



INTERGOVERNMENTAL PANEL ON climate change

# References


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**www.nespclimate.com.au**


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