Climate Variability

Natural and Anthropogenic

Jim Renwick

NIWA Climate Research

j.renwick@niwa.co.nz

NIWA

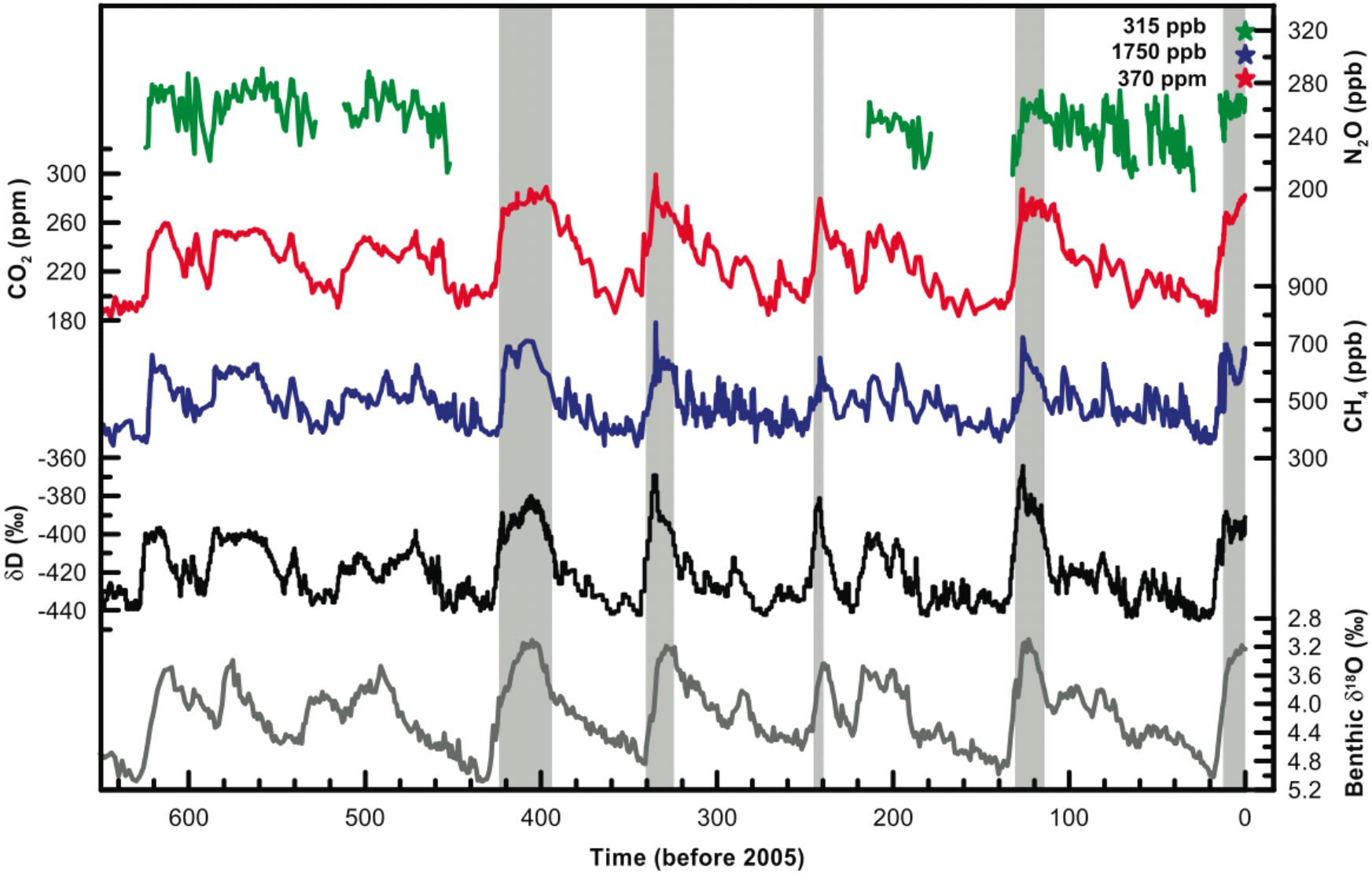
Taihoro Nukurangi

- Climate equilibrium and climate forcings
- Natural forcings
- Anthropogenic forcings
- Feedbacks
- Natural variability
- Interactions between variability and change

Climate Equilibrium

- A balance of energy
  - Many inputs and outputs, in balance
  - Constant over time (how long?)
- Solar energy in = infrared energy out
  - A stable equilibrium, in simple terms
  - Regional imbalances make it interesting
- Many components, dynamic equilibrium
  - Cloud cover, storm tracks, rainfall patterns,…

Equilibrium and natural variability



Climate Forcings

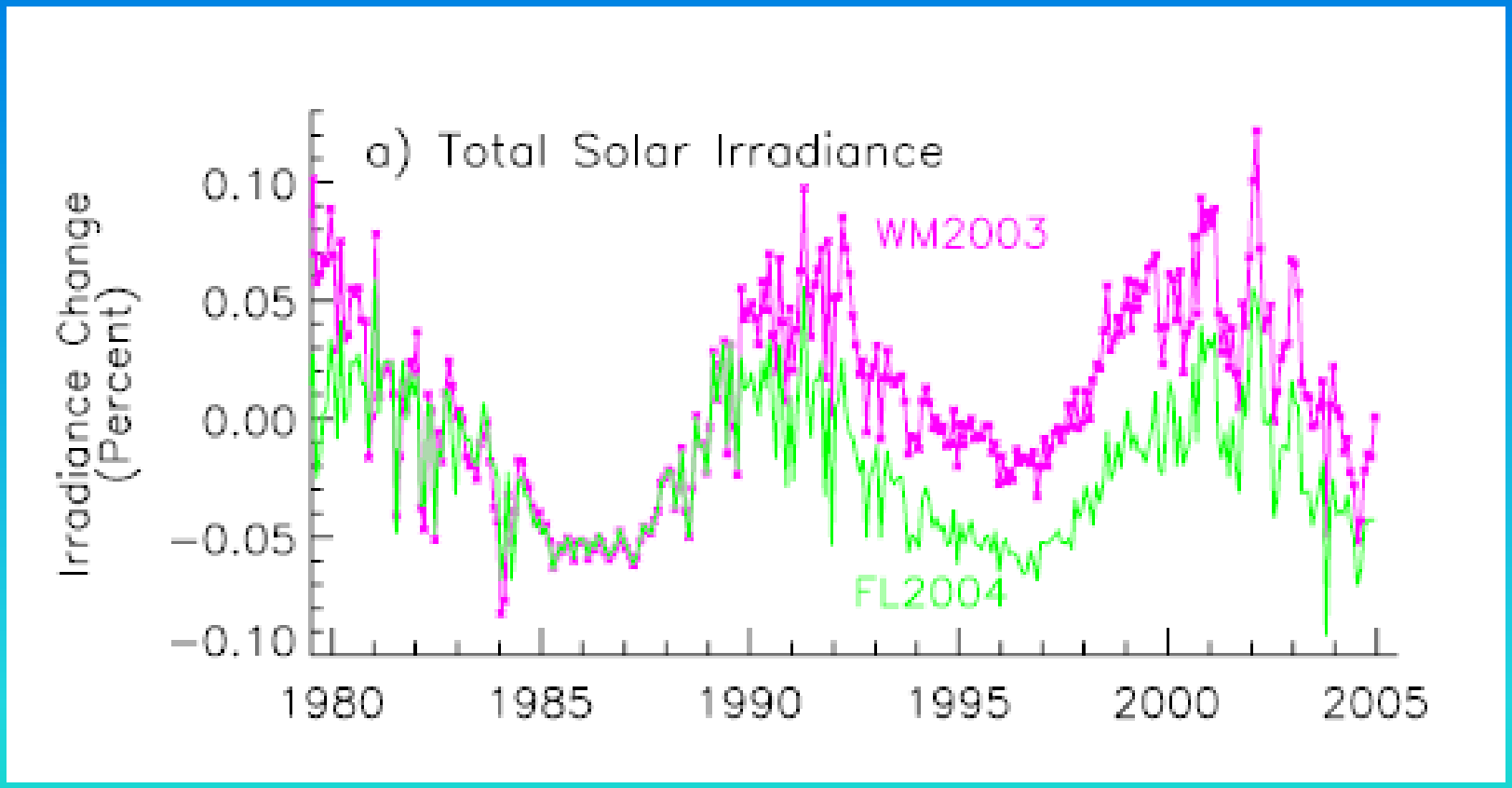
- Disturbances
  - Change an input or an output = a climate ***forcing***
  - System moves towards a new equilibrium

- Volcanic eruption: Mt Pinatubo
  - Less solar input ➔ less terrestrial output ➔ cooler

Natural Forcings

- Solar
  - Variations in solar output
  - Related to sunspot cycle and longer-term modulation
  - Estimated at +0.12 Wm^{-2} since 1750 (IPCC)
    - Was estimated at +0.3 Wm^{-2} with poorer data
  - Effect is to turn the whole climate system up or down, warming (or cooling) the Earth
- The Sun has been brightening lately (0.1%)

Solar Variability



Source: Willson and Mordvinov (2003), Fröhlich and Lean (2004)

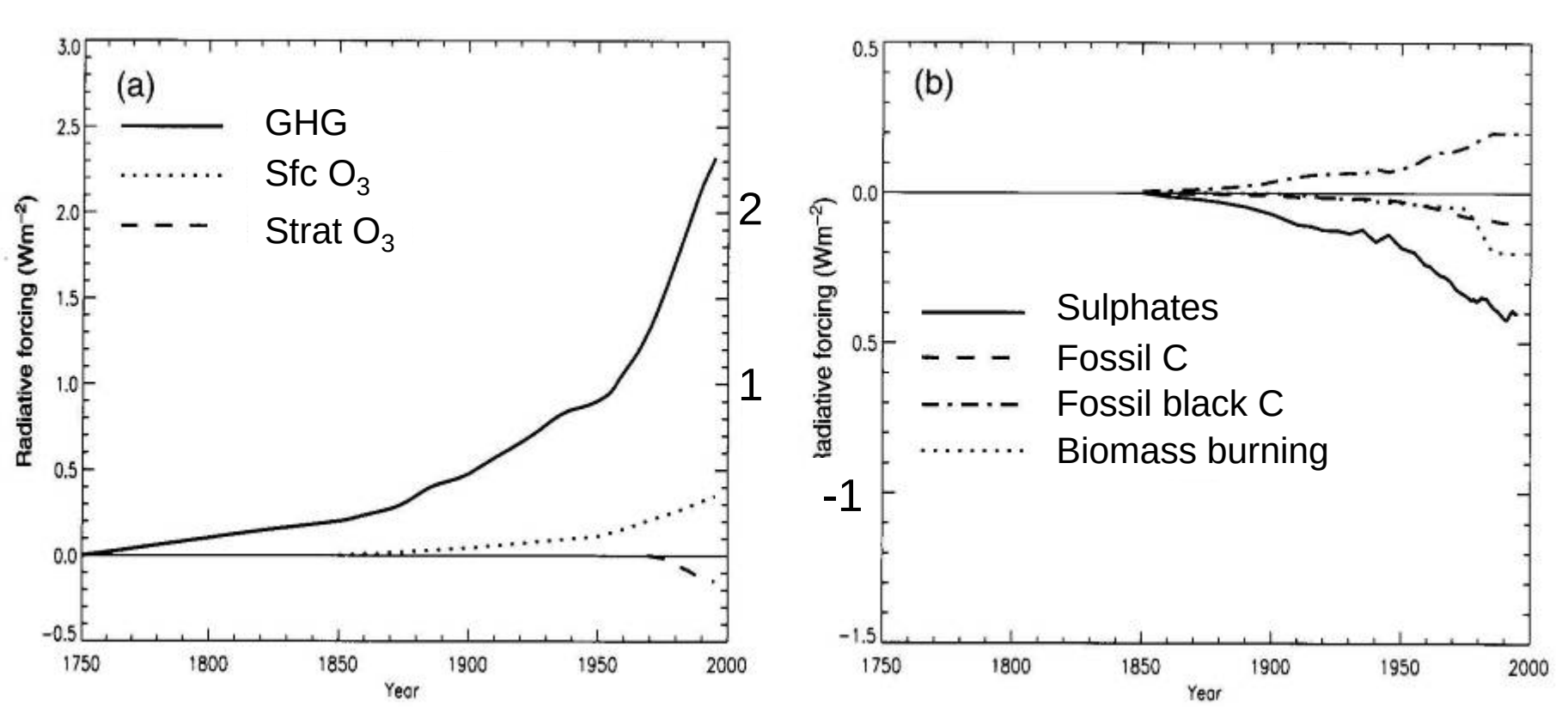
Natural Forcings

- Volcanic
  - Injection of sulphate aerosols etc into the upper atmosphere
  - Episodic, usually short-lived
  - Most efficient for large tropical volcanoes
  - Effect is to cool the surface/troposphere and warm the stratosphere
- Pinatubo peaked at –3 ±0.6Wm^{-2} (1%)
  - Largest volcanic forcing for 100 years
  - Cooled Earth's surface ~½° for 2-3 yr

Anthropogenic Forcings

- Greenhouse Gases
  - Carbon dioxide, methane, ozone, CFCs, Nitrous oxide
  - Positive forcing on radiation balance (warming)
- Aerosols
  - Sulphates, soot, …
  - Negative (generally) forcing on radiation balance
- Clouds
  - Poorly understood, negative forcing (cloudier)
- Land use
  - Albedo change, e.g deforestation
  - Generally negative forcing (increased albedo)

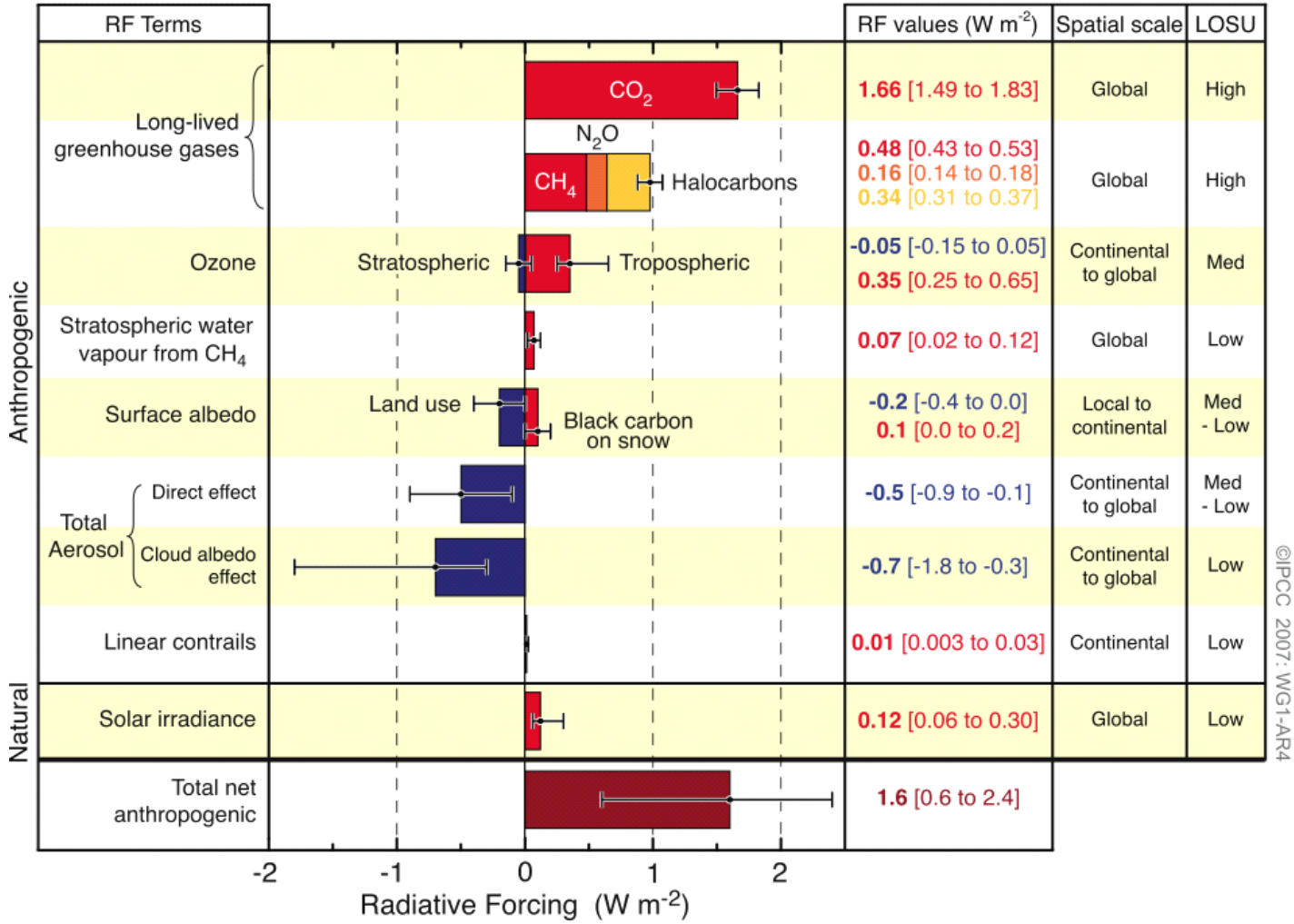
Anthropogenic Forcings



Source: IPCC

- GHG forcing now roughly equal (& opposite) to a continuous large volcanic eruption, in terms of forcing
- GHG forcing increasing, climate system constantly adjusting
- GHG lifetime much longer than aerosol lifetime

Anthropogenic Forcings



Source: IPCC

Figure SPM.2

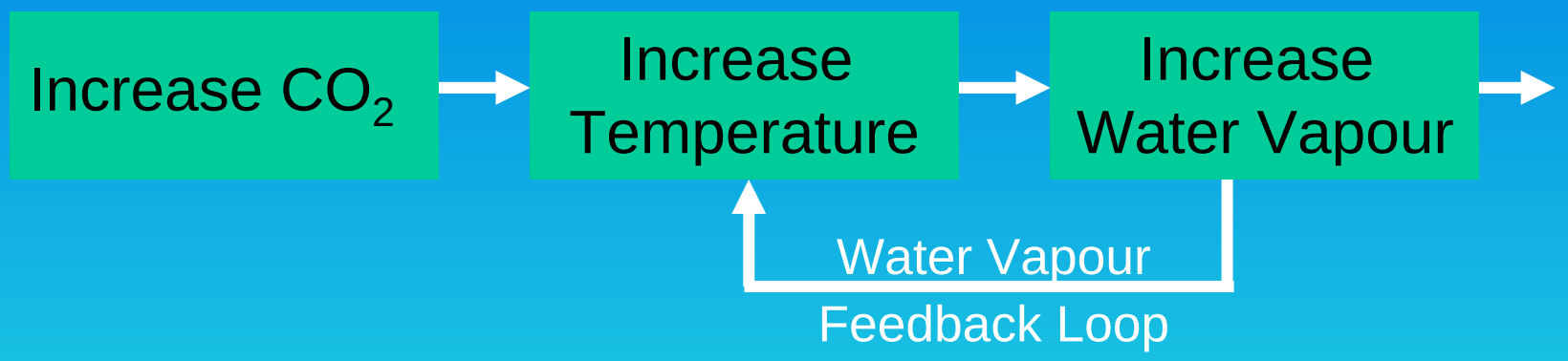
Forcings summary

- Solar input drives the climate system
  - Solar energy variation a small forcing
- Volcanic eruptions ➔ large forcings for short periods
- Greenhouse gases now the dominant positive forcing
  - Comparable with volcanoes, but continuous
- Aerosol pollution a negative forcing
  - Short time scale compared to GHGs
- Much uncertainty about cloud and aerosol effects

Feedbacks

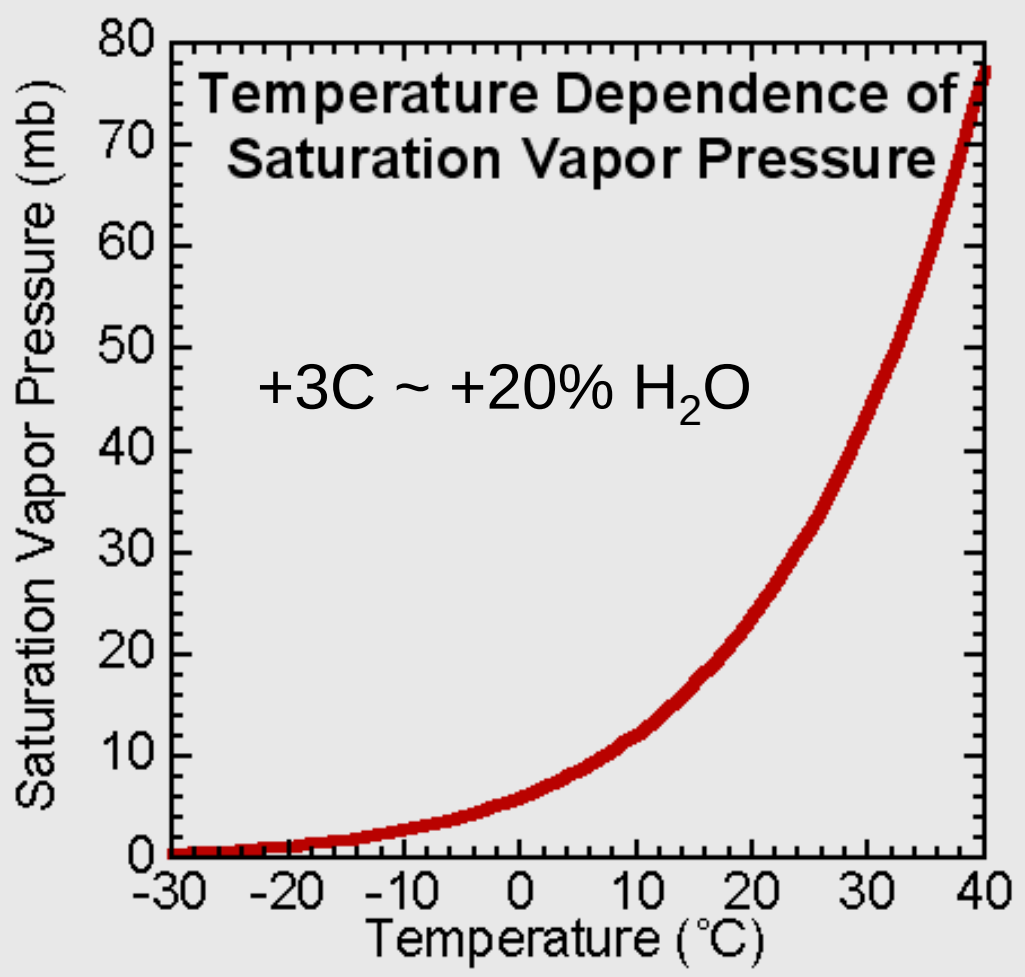
- A natural effect, amplifying or damping a forcing
  - Apparent in many physical systems
  - Stable or unstable equilibrium?
- Many important climate feedback effects
  - Water vapour, ice-albedo, clouds, biosphere
  - Other dynamical feedbacks (ocean/atmosphere etc)

Water Vapour Feedback

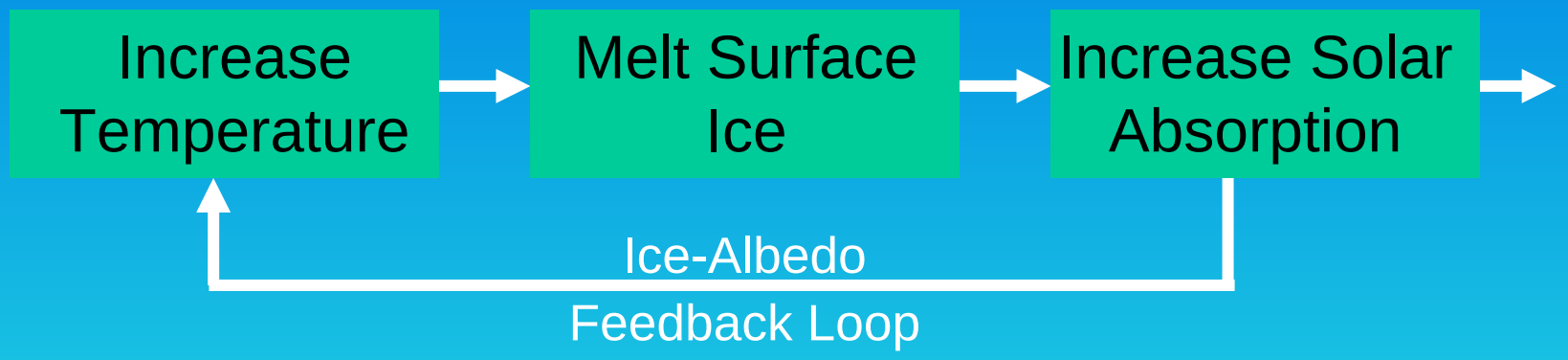


Roughly doubles climate sensitivity.
Water vapour changes in response to temperature, not the other way around.
Vertical distribution important: more complicated in upper air.

Water Vapour Feedback

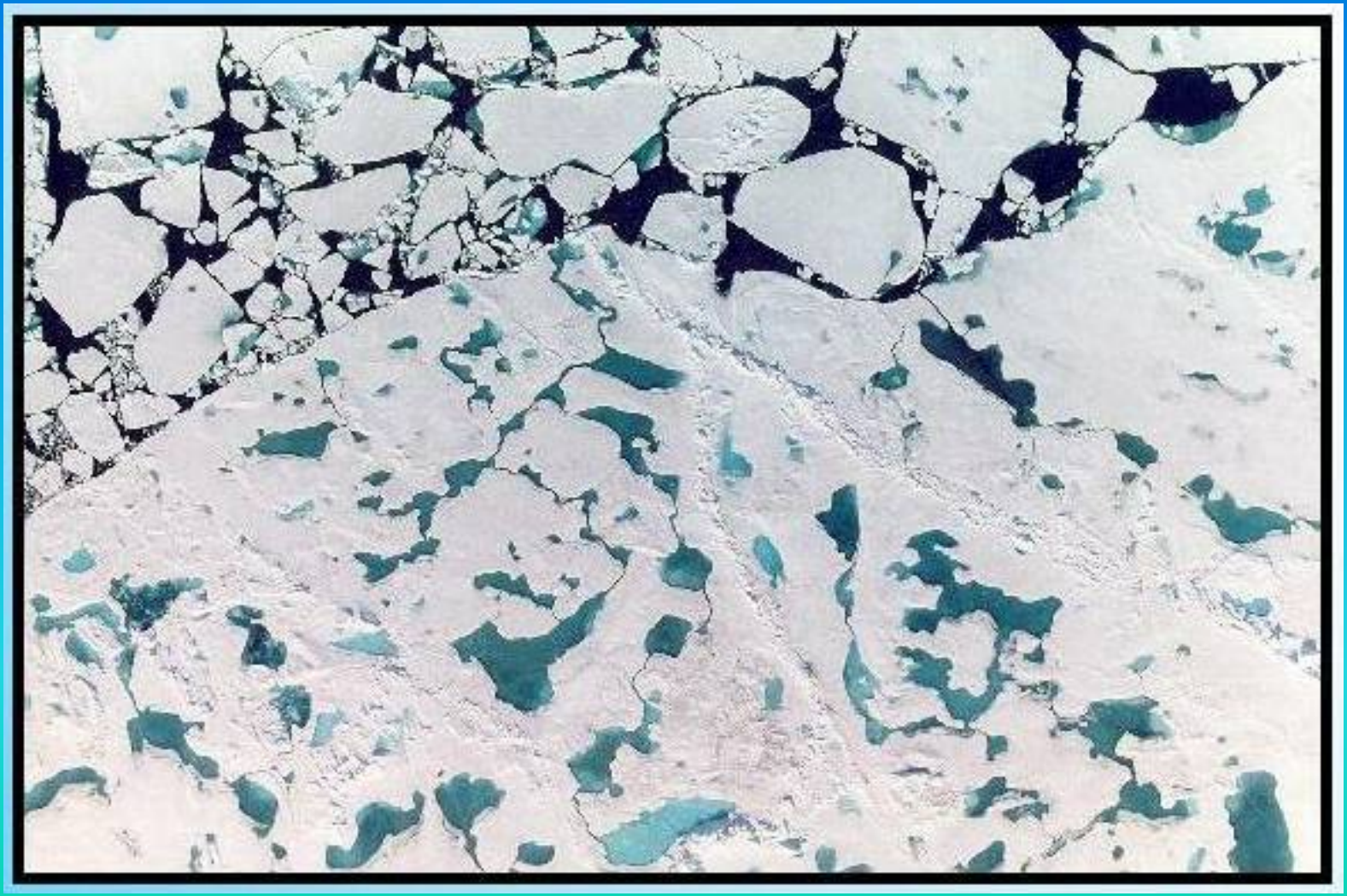


Ice-albedo Feedback



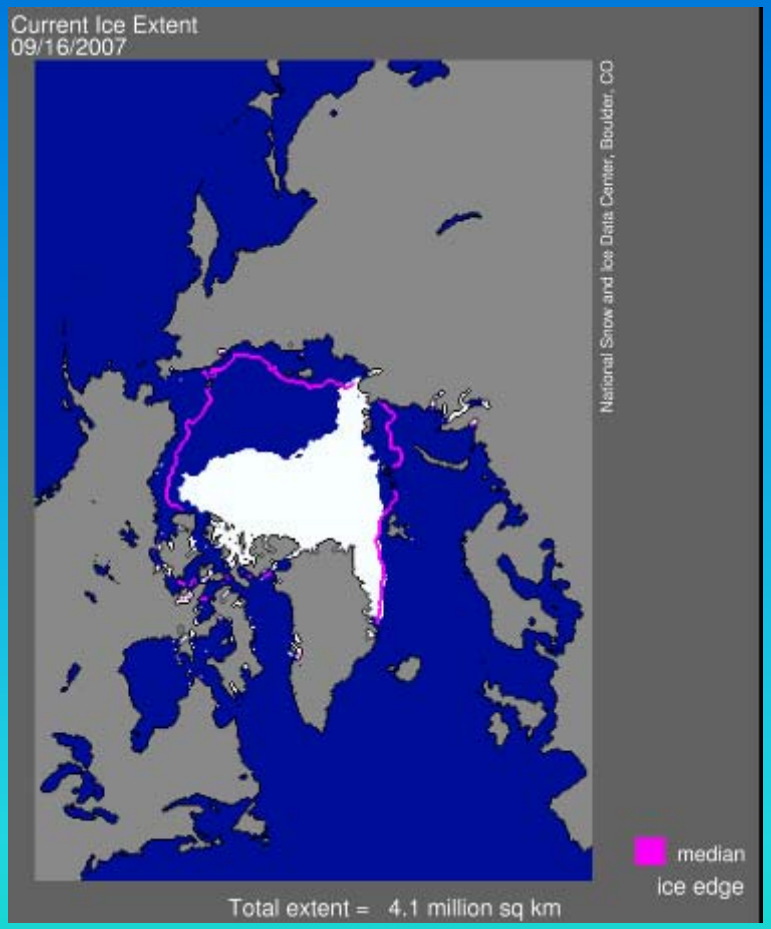
- Increases climate sensitivity by ~30%
- May be jumps: melting ice sheets?

Ice-albedo Feedback

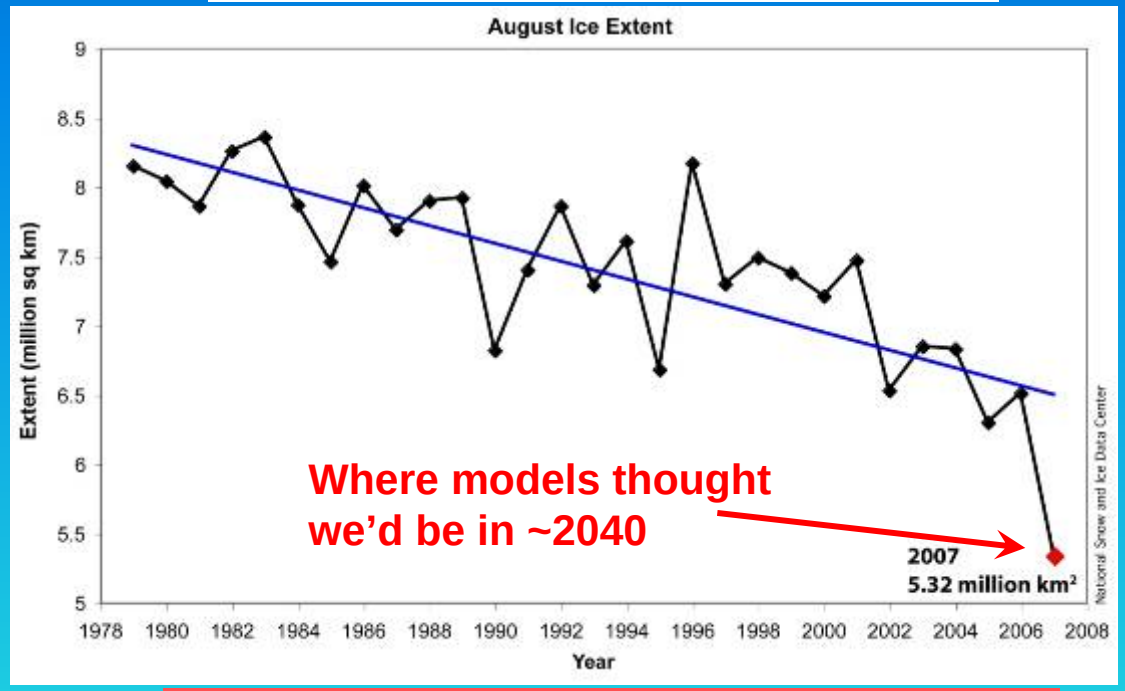


Source: Hartmann, U. Washington

Arctic Sea Ice



Sea Ice extent (millions sq km)



At the present rate of change, a summer ice-free Arctic Ocean within a century is a real possibility, a state not witnessed for at least a million years

Overpeck et al, EOS, Aug2005

Cloud Feedback

Increase Temperature → Change Cloud Properties → Change Earth's Energy Balance

Cloud Feedback Loop

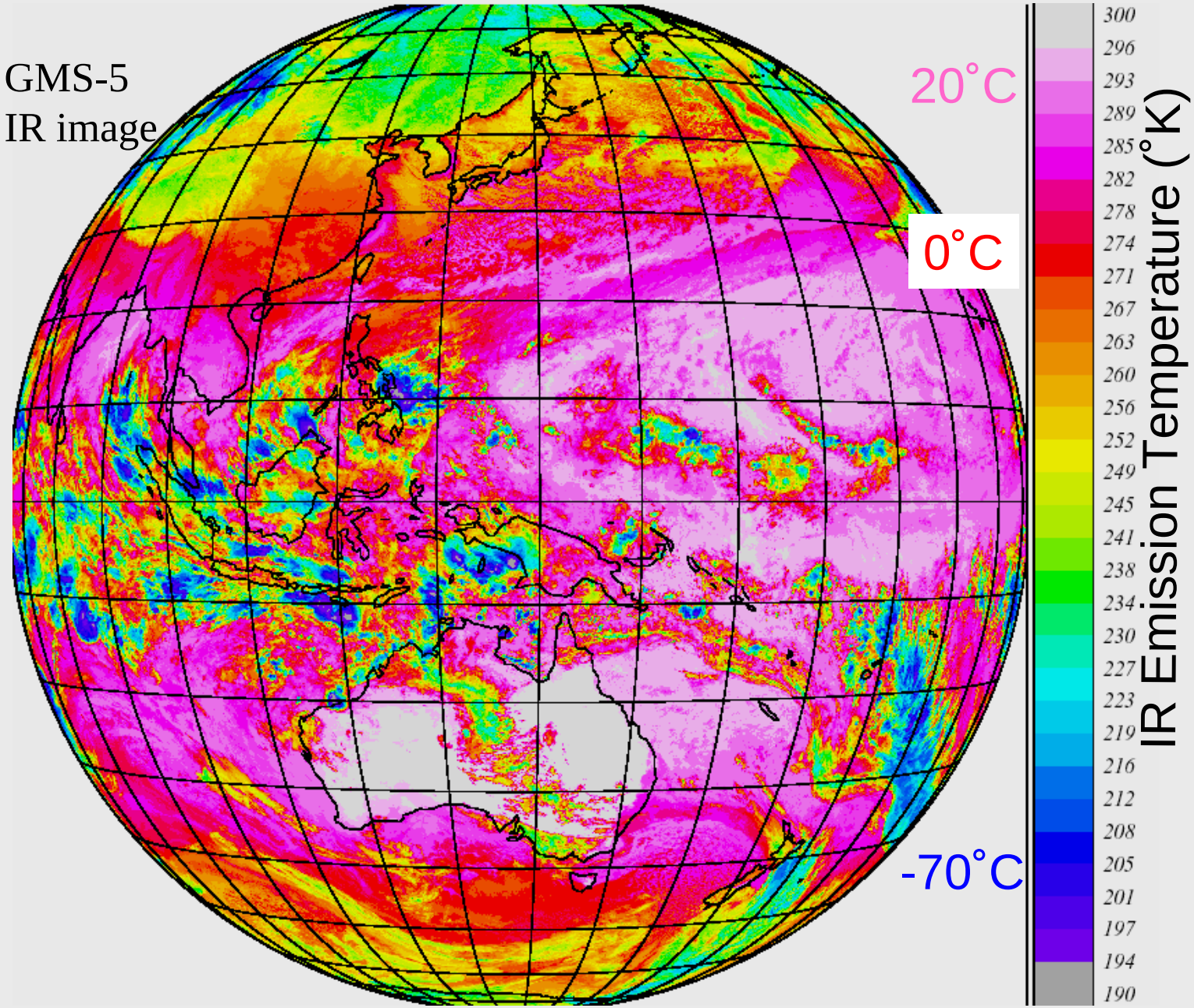
? Magnitude potentially large, but neither magnitude nor sign known (probably negative).

Radiative Effects of Clouds

1. Clouds reflect solar radiation - a cooling effect

2. Clouds emit less energy to space than clear skies – a warming effect

- Opaque to infrared radiation
- Colder than surface because air temperature decreases with altitude.


GMS-5
IR image
20°C
0°C
-70°C
IR Emission Temperature (°K)
300
296
293
289
285
282
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190

Radiative Effects of Clouds

Clouds double the Earth's albedo from 15% to 30%

This results in a net loss of energy of 50 Wm^{-2}

But cloud reduce emitted infrared radiation by 30 Wm^{-2}

The net result of today's clouds on the energy balance is thus a loss of 20 Wm^{-2}

Doubling CO_2 changes the energy balance by +4 Wm^{-2}

Biosphere Feedback

- Ocean productivity linked to carbon uptake, and cloudiness
- Reduction of forest
  - increases albedo: negative feedback
  - Decreases CO_2 uptake: positive feedback
- Gaia?

Feedbacks summary

- Several natural feedbacks that amplify or damp the sensitivity of the climate system
  - Water vapour a key player
  - Ice-albedo feedback
  - Cloud feedbacks still being researched
    - Role of low marine clouds very important
- Biosphere feedbacks undoubtedly operating
  - e.g., Southern Ocean productivity
  - Not well quantified

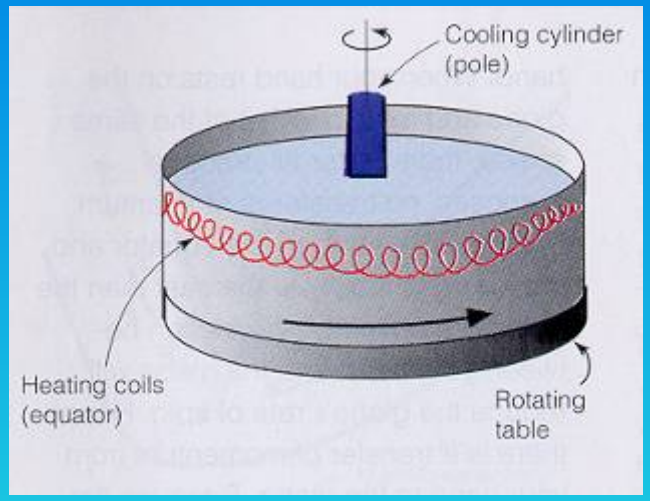
Half-time break

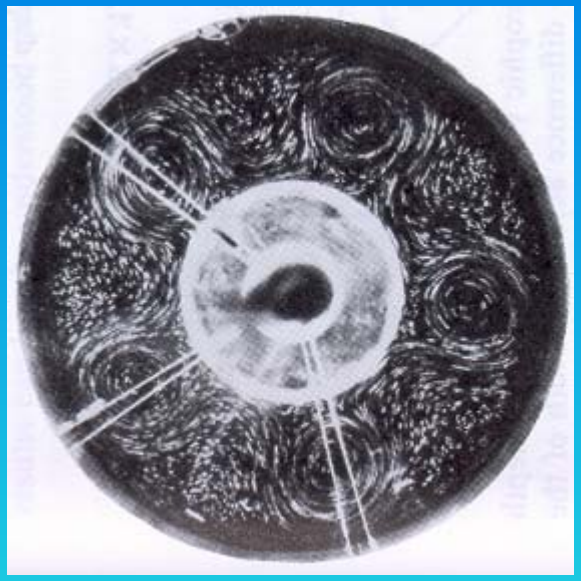
Natural Variability

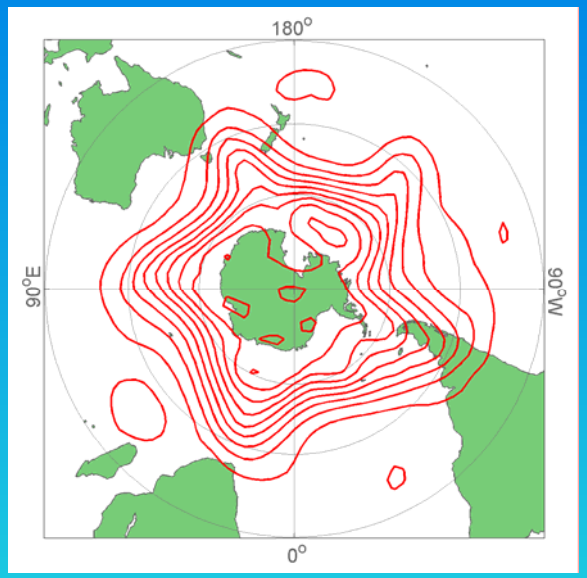
Natural Variability

- Mean climate, seasonal change
  - Solar radiation
  - Rotation, orbit, axial tilt
  - Land/sea distribution
  - Climate the “sum of the weather”
- Year-to-year variability
  - A cold summer, wet winter, windy spring
  - Why?

The Dishpan Climate



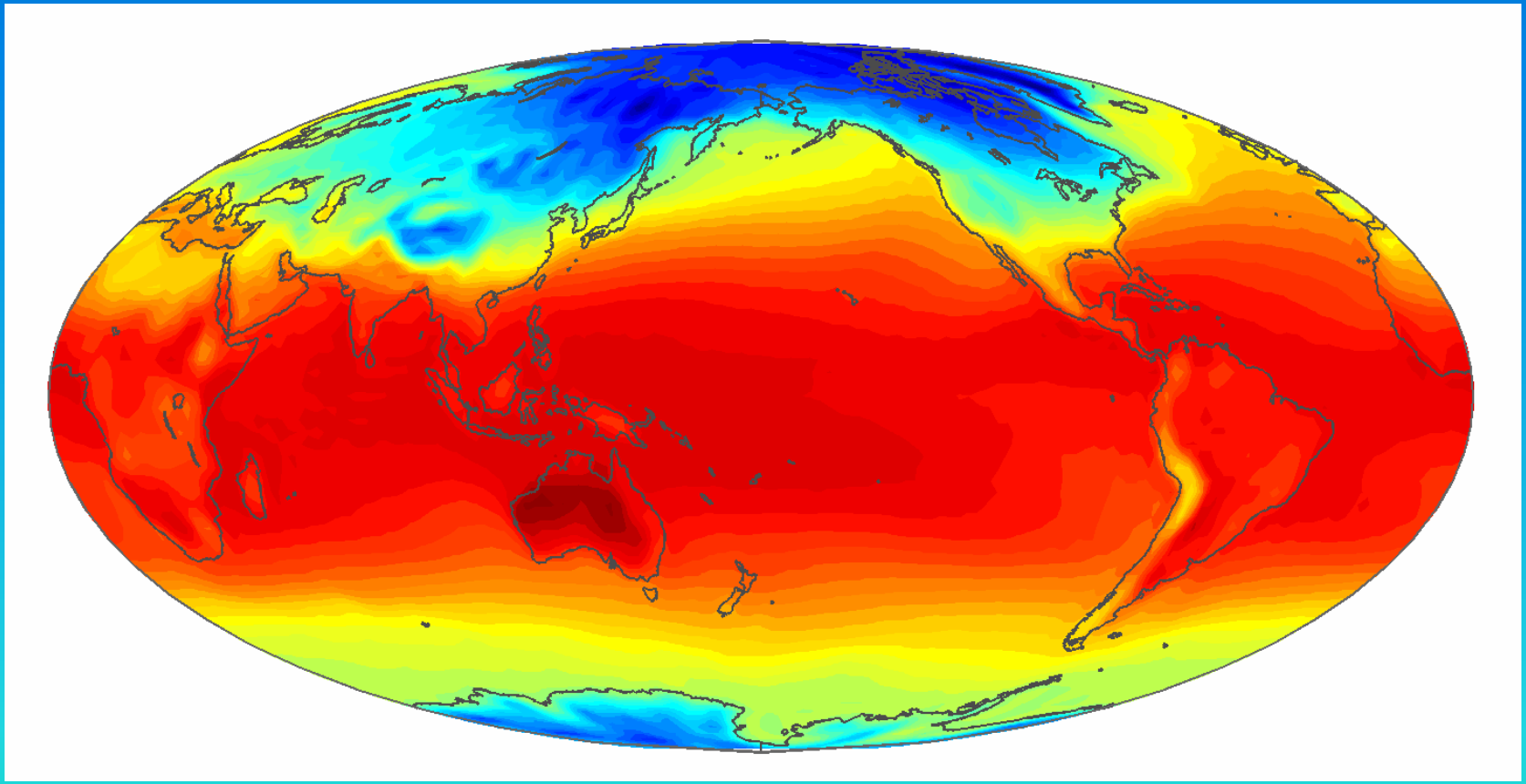




Fultz, 1951 **Feb 2000**

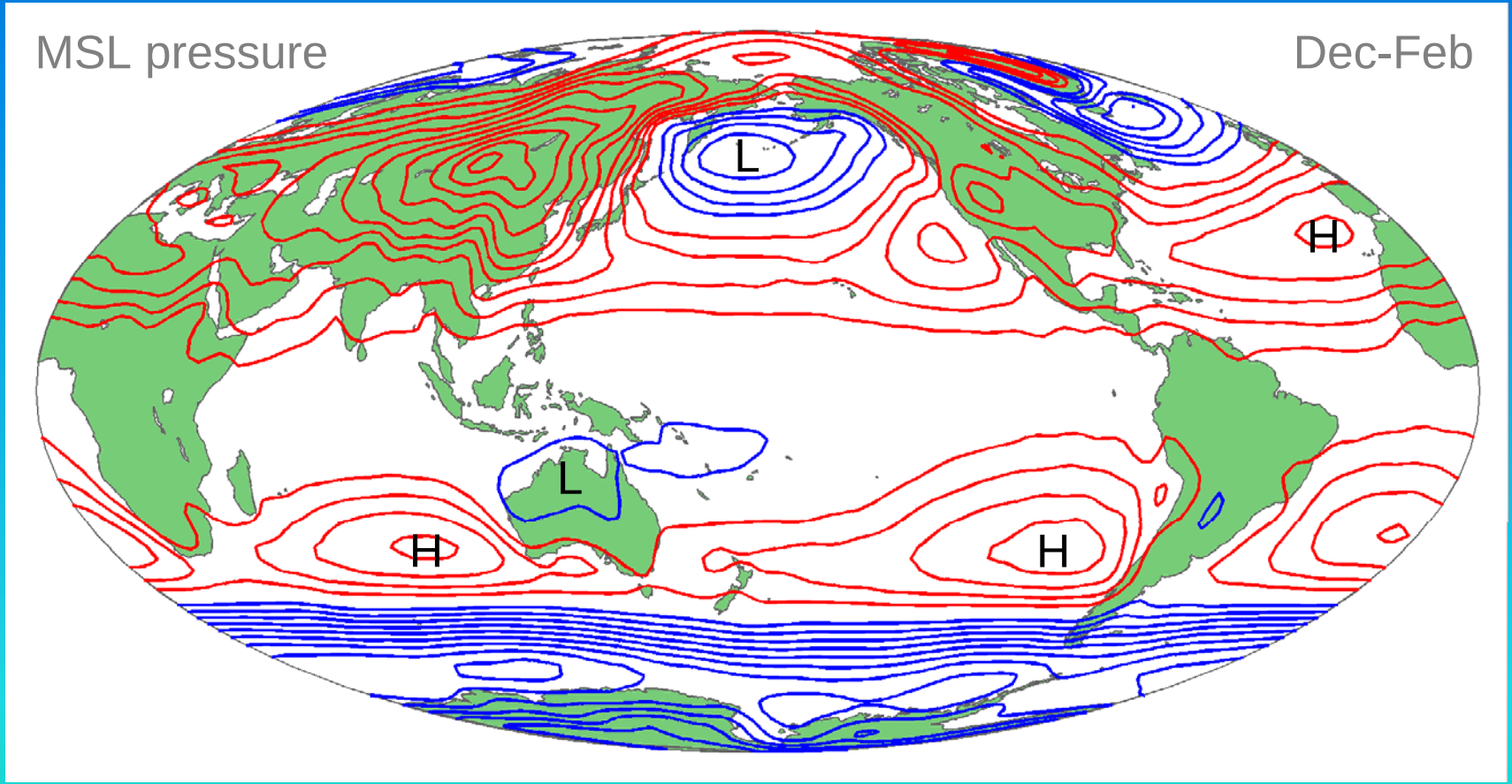
- Heating contrast and rotation = climate

Land and Water



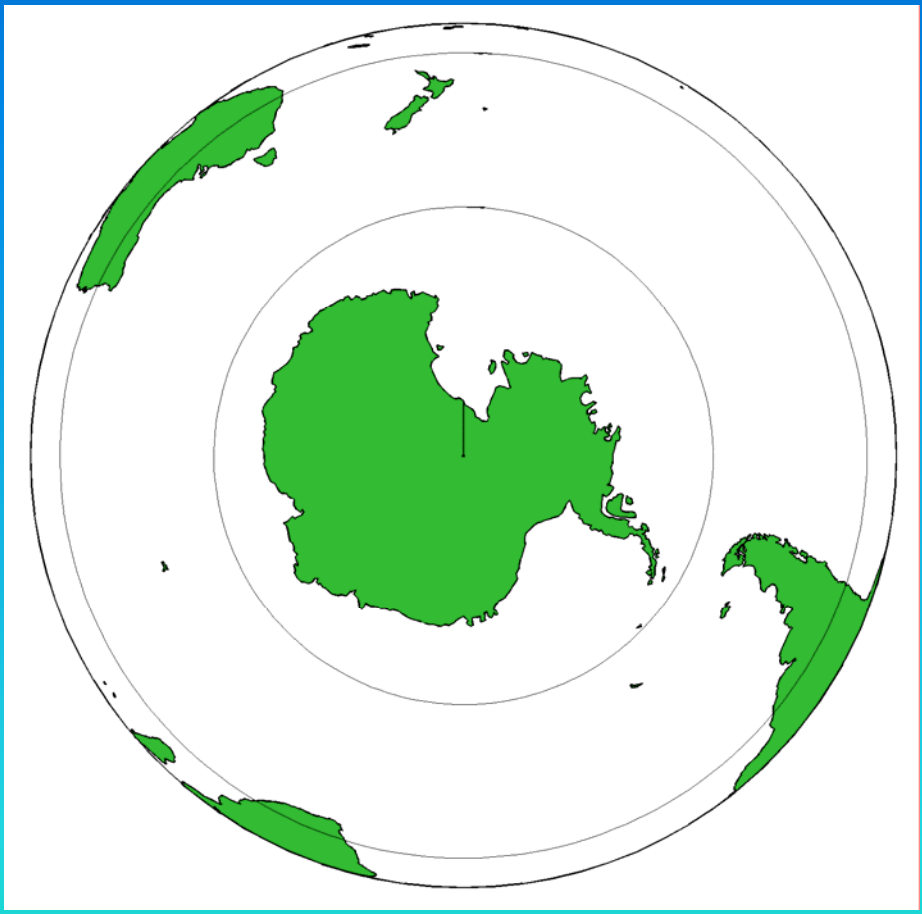
- Land/ocean heating rate differ
- Temperature extremes far from the ocean

Global climate



- Controlled by heating, rotation, land

The Hemispheres

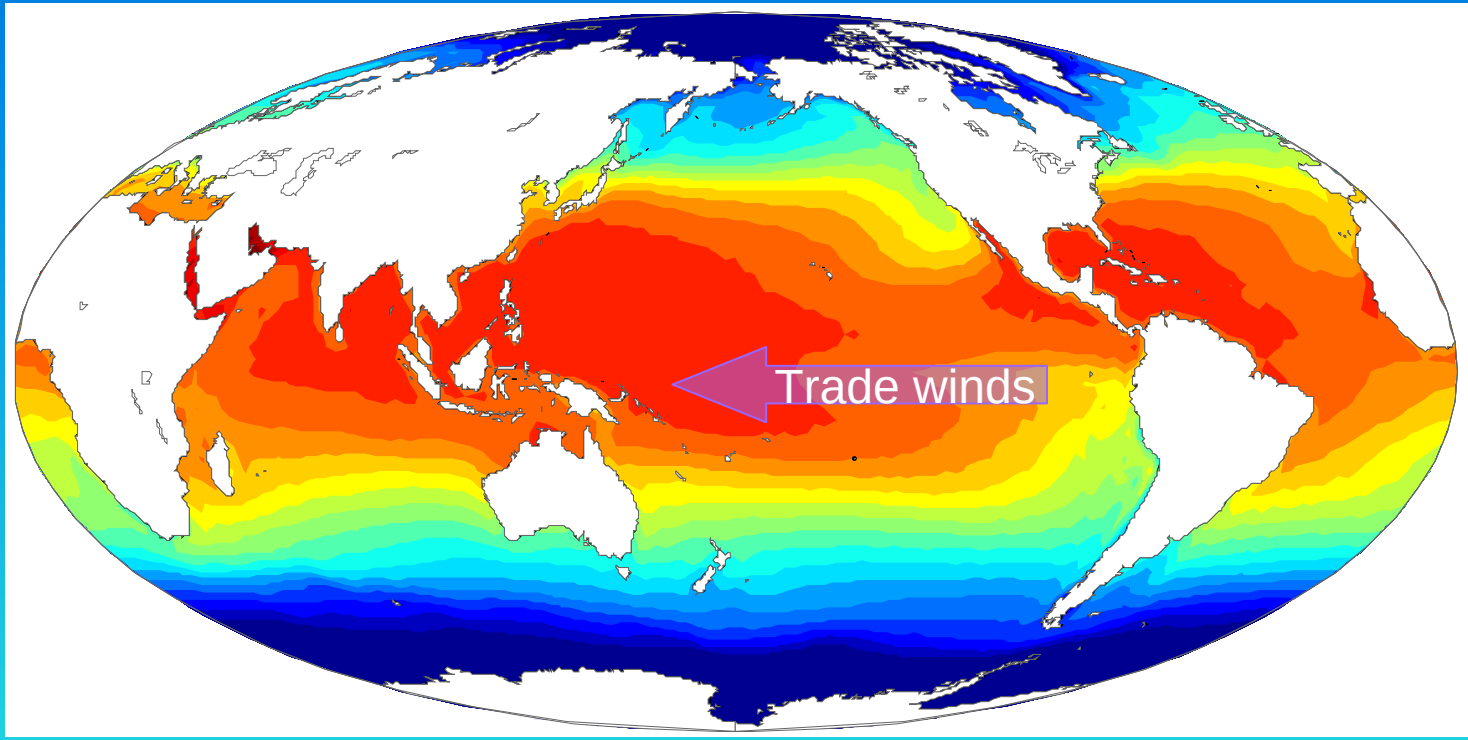


- Very different land distribution, climates
- Instructive to compare & contrast

Natural Variability

- Large scale modes of climate variability
  - Changing the canvas on which the weather is painted
  - Redistribution of heat regionally
    - Local seasonal variability
- Main natural modes
  - El Niño/Southern Oscillation (ENSO)
  - Pacific Decadal Variability (IPO/PDO, AMO)
  - Annular modes (SAM & NAM)
- Large-scale changes, regional differences

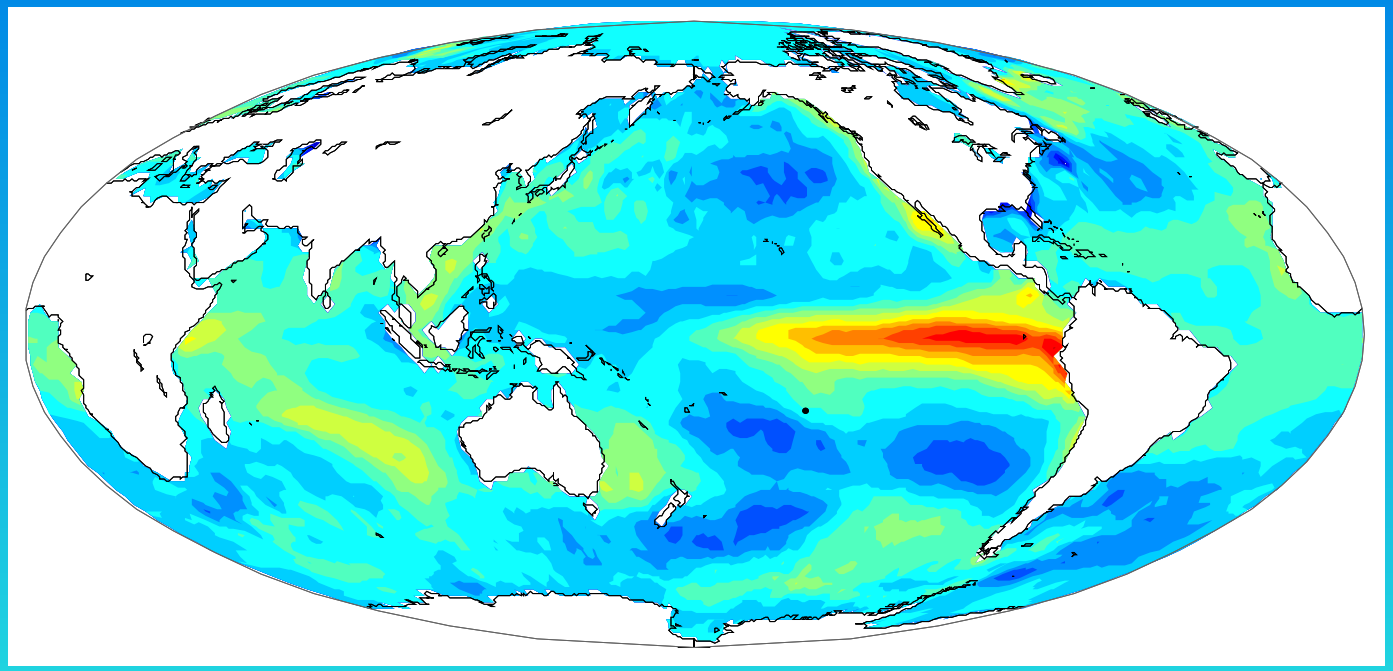
El Niño and La Niña (ENSO)



- Global sea surface temperatures
  - Western tropical Pacific warmest, east relatively cool
  - Supported and maintained by the Trade winds (unstable equilibrium)

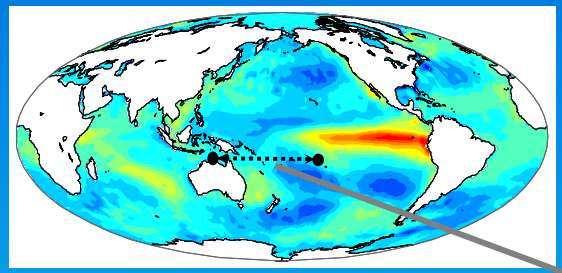
El Niño

Sea temperature difference from average

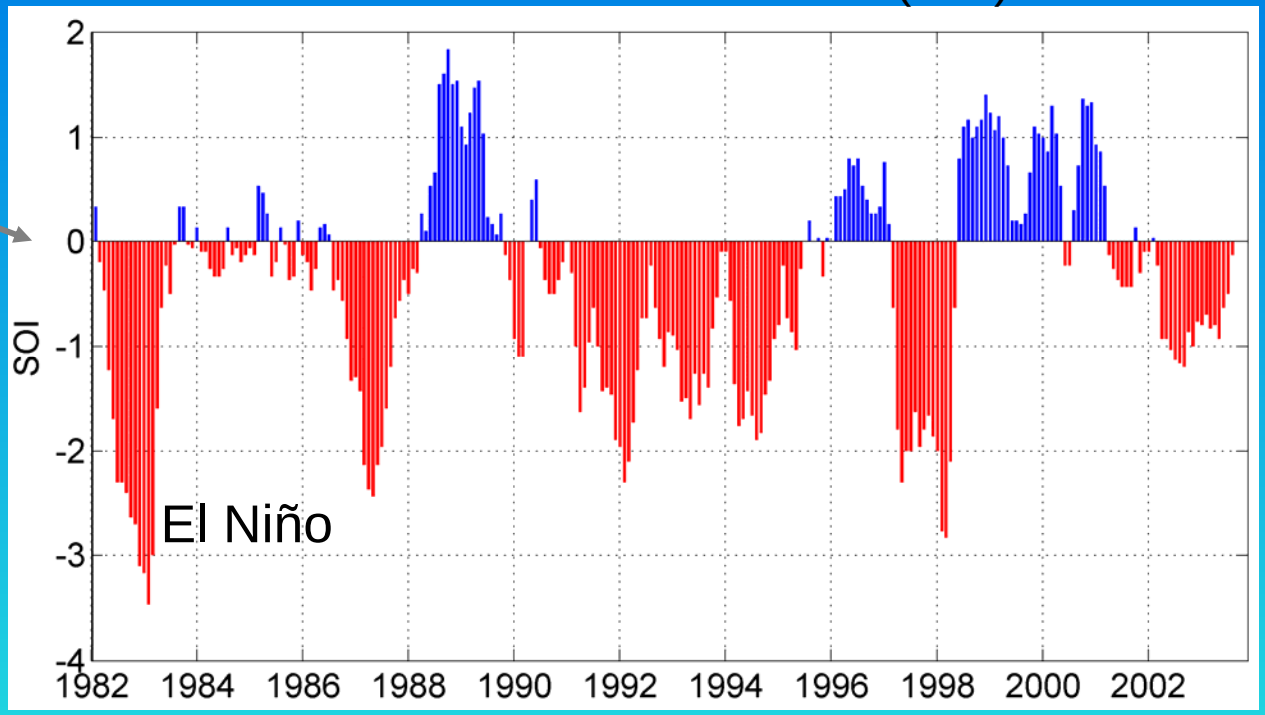


- Eastern Equatorial Pacific warms
  - Trade winds weaken
  - More warming ➔ positive feedback

Southern Oscillation



Southern Oscillation Index (SOI)



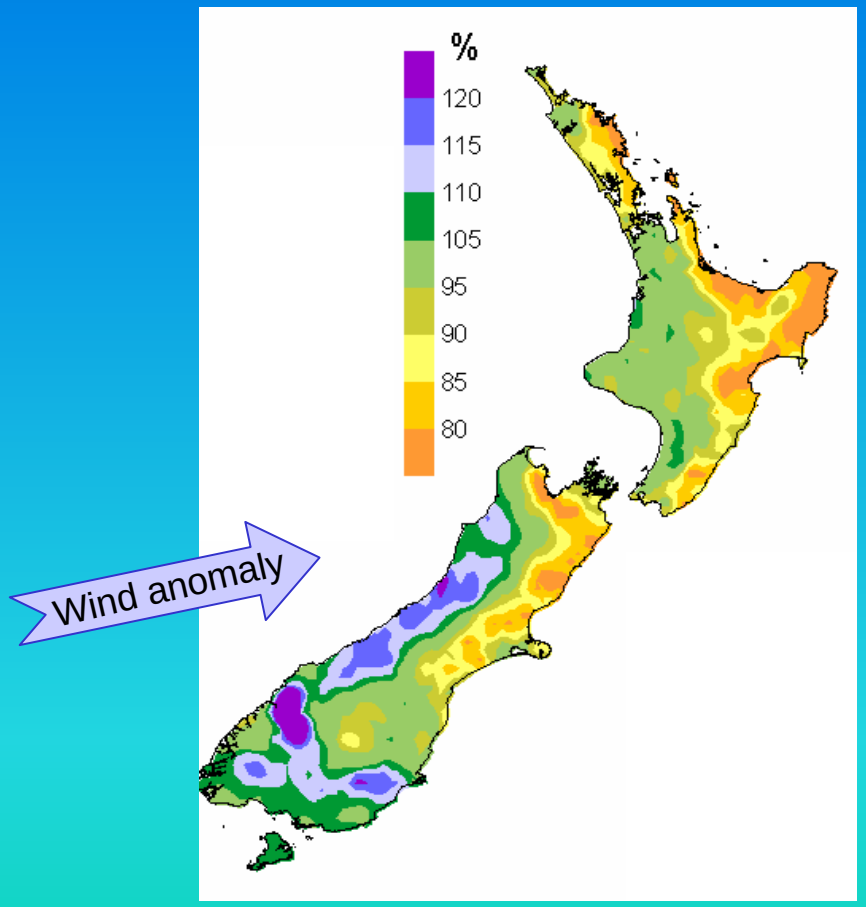
- Pressure seesaw across the Pacific
  - Measures strength of the Trade winds
  - Negative: weak winds, El Niño
  - Positive: strong winds, La Niña

ENSO

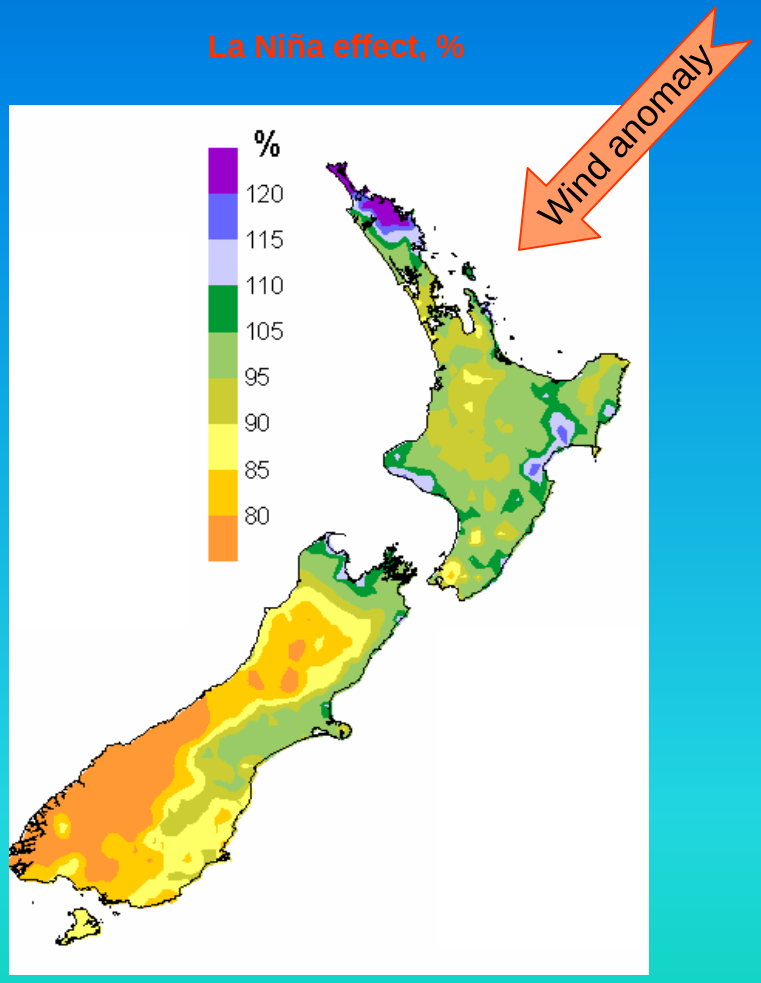
- A coupled feedback between tropical ocean and atmosphere
- El Niño warms the Tropics, and the Globe
  - Ocean gives up heat to the atmosphere
  - Pumps up the circulation
  - Westerly winds stronger
  - Windier over N.Z., cooler
    - Different effects in different locations
- Interplay between ENSO and climate change?
  - Changing background conditions

ENSO: N.Z. summer rainfall

El Niño effect, %



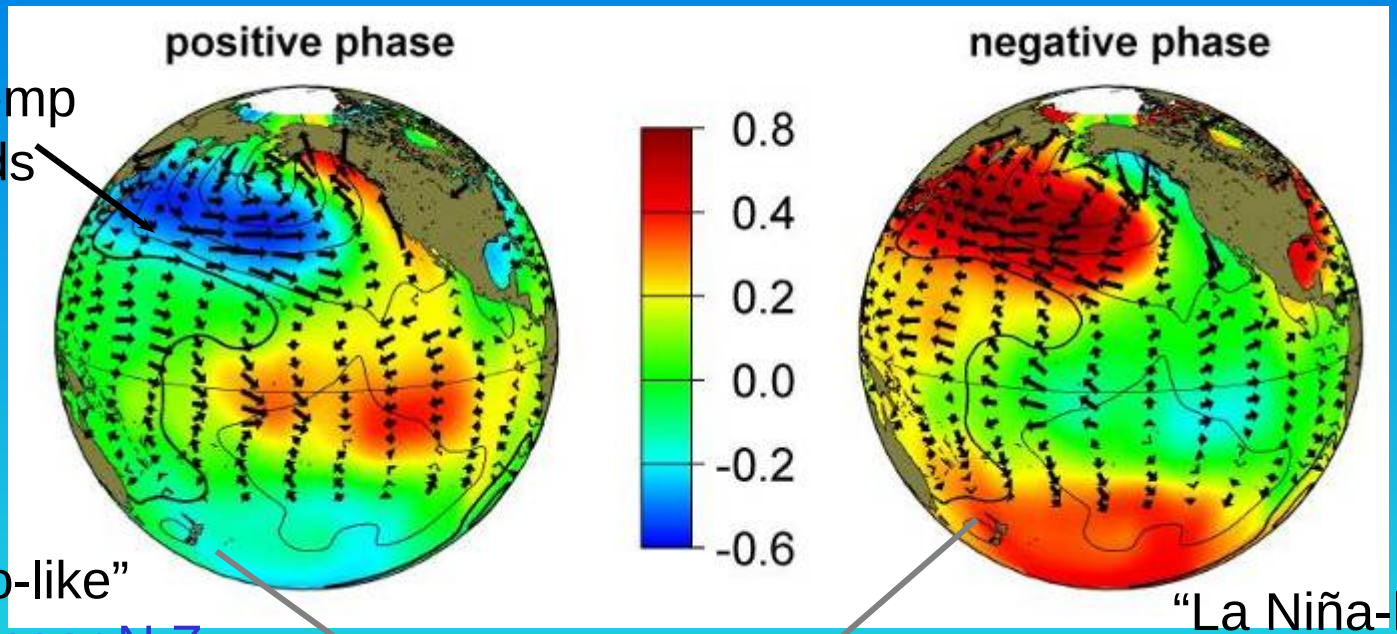
La Niña effect, %



Pacific Decadal Variability

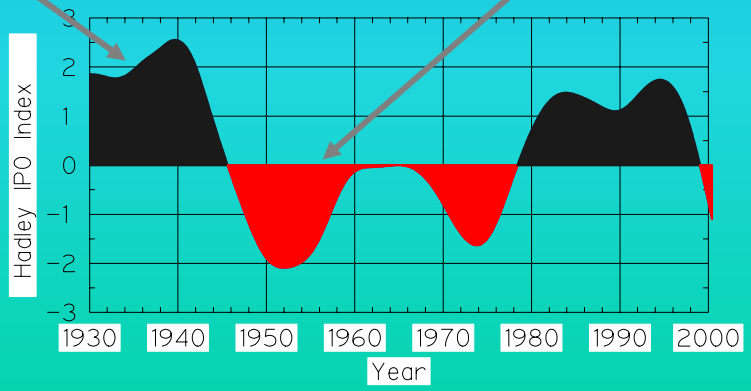
The PDO, or IPO

Sea temp
& winds



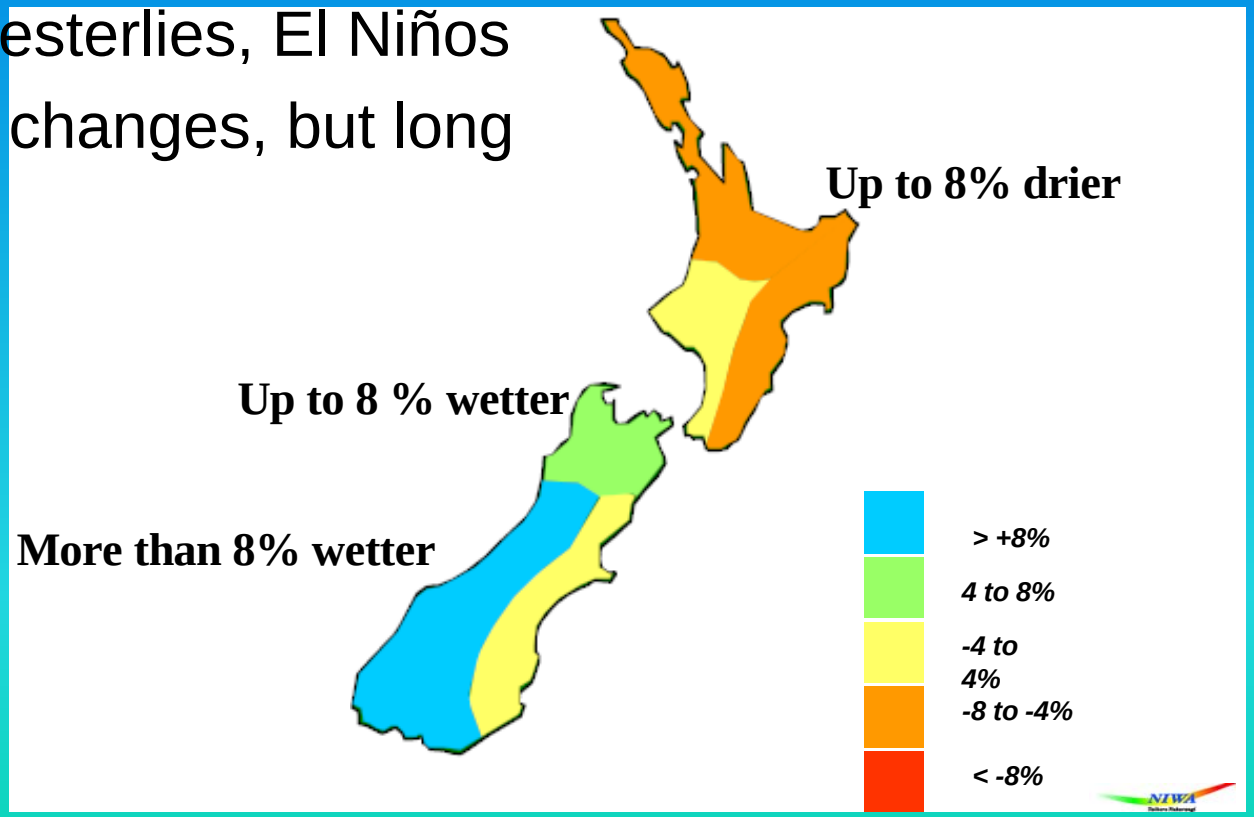
"El Niño-like"
Cooler near N.Z.
Stronger westerlies

"La Niña-like"
Warmer near N.Z.
Weaker westerlies

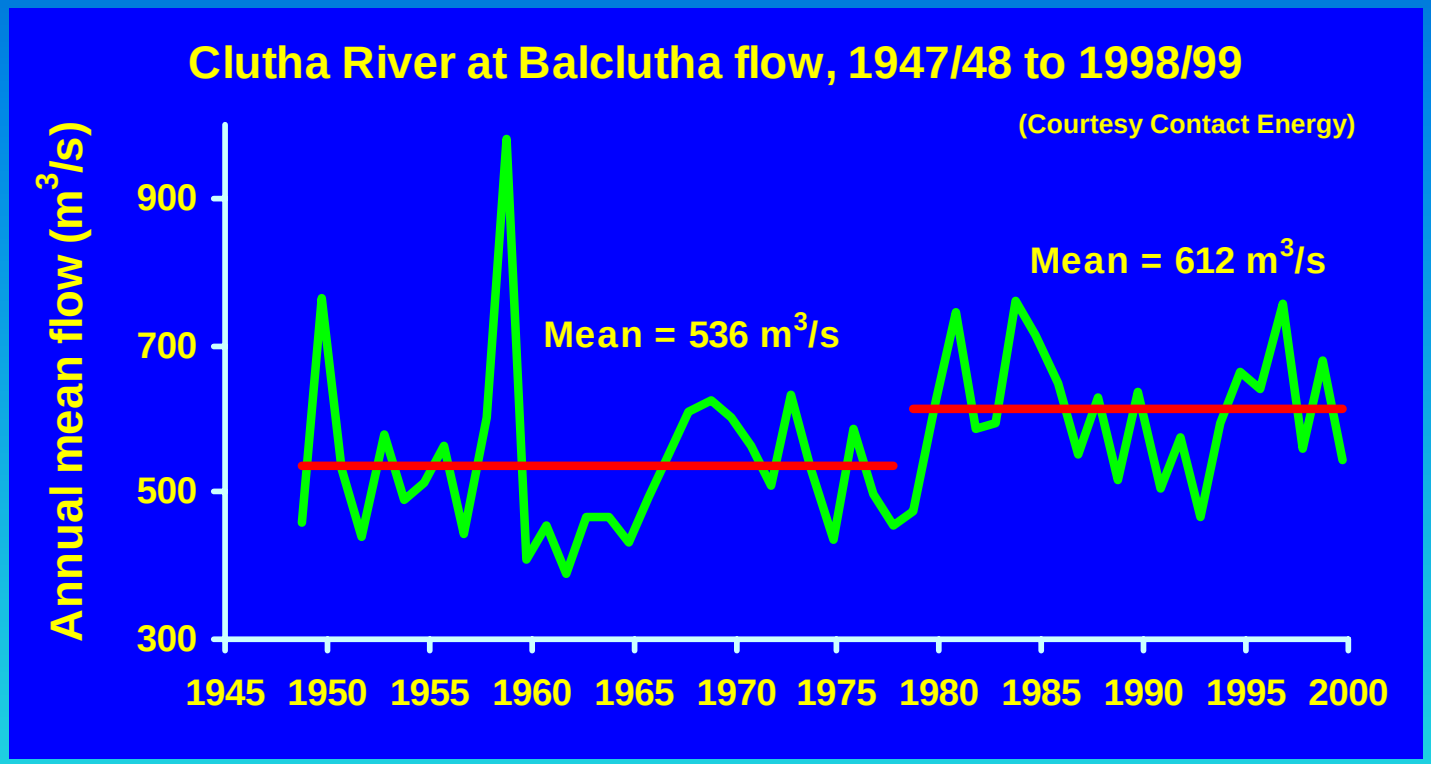


IPO: Local effects

- New Zealand rainfall
  - 1978-99 minus 1947-77
  - Increased westerlies, El Niños
  - Small mean changes, but long time scales



IPO: river flows

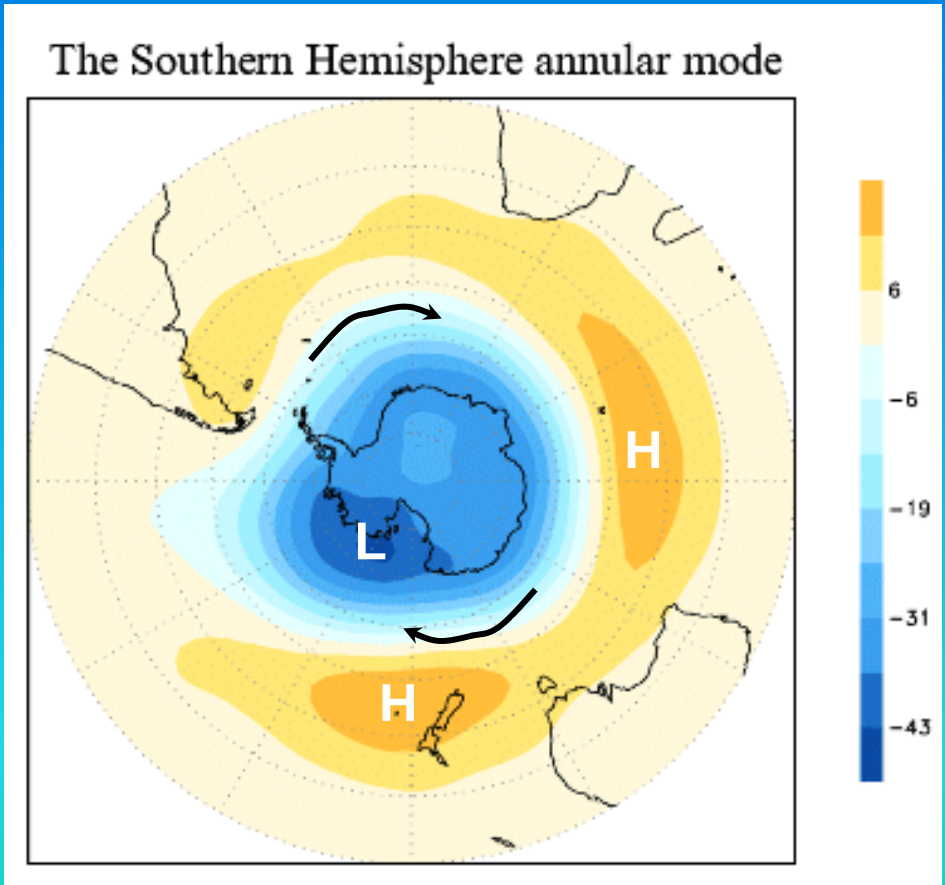


- Volume change (14%) comparable with rainfall change
  - Shorter term (ENSO etc) variability around these level changes

Annular modes

- Changes in the hemispheric westerly circulation
  - Exchange of air between middle and high latitudes
  - Analogous modes in both hemispheres

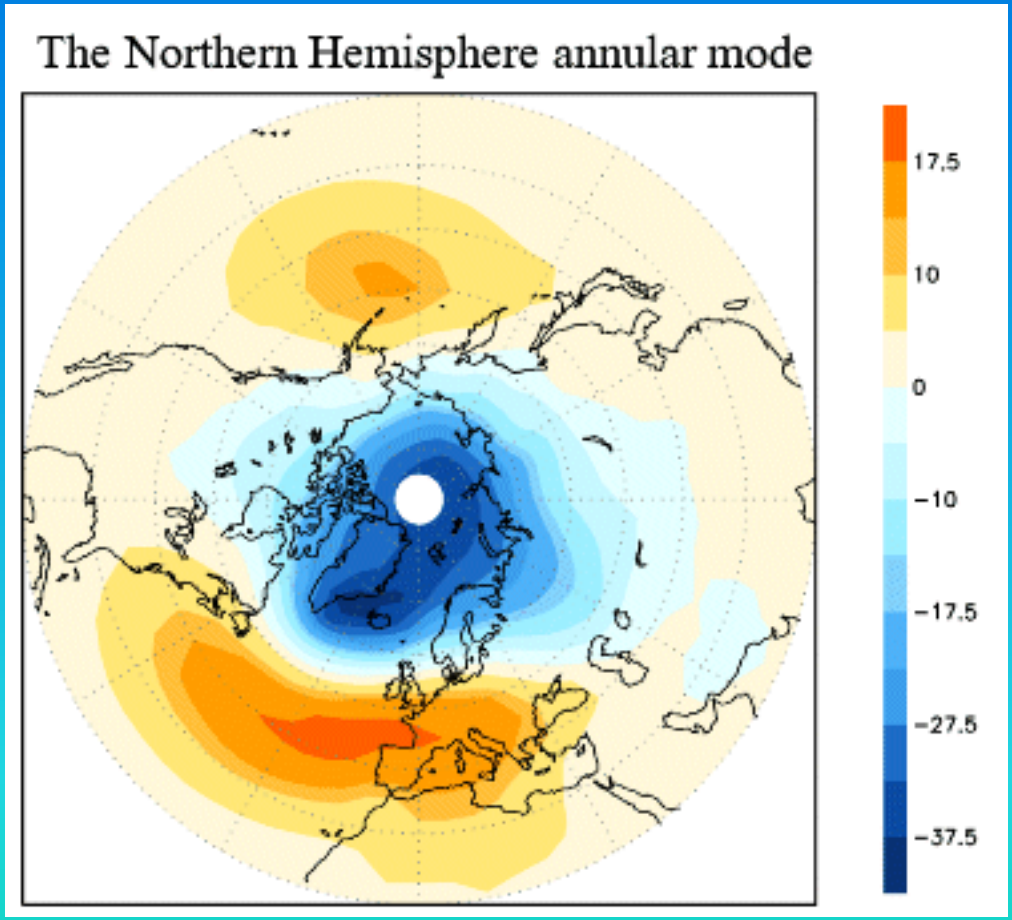
SAM: Southern Annular Mode



Source: Thompson & Wallace (2000)

- Key feature of monthly variability
  - a.k.a. High Latitude Mode, Polar Vortex, Antarctic Oscillation
  - Westerly winds, 50°-65°S
  - Modulates the “storm track”
- No clear time scale
  - Can quickly flip
  - Stays in one phase for several weeks
    - Feb-Mar 2004 a good example (negative phase)

NAM: Northern Annular Mode



- Not as symmetric as SAM
  - continental effect
- Otherwise similar in the vertical etc.

Source: Thompson & Wallace (2000)

Southern Annular Mode

- Changes wind patterns over the southern oceans
- Modulates the location of the storm track
  - Strong influence on weather patterns in mid-latitudes
    - Positive SAM more settled over N.Z.
    - Negative SAM stormier over N.Z. (Feb 2004)
- No net effect on hemispheric or global balance

Annular Modes

- Trending upwards (stronger westerlies) the last few decades
  - Related to ozone depletion?
    - Colder polar stratosphere, stronger stratospheric winds
    - “Spins down” to the lower atmosphere
  - Related to “global warming”?
    - Warms the tropics faster than the Antarctic
    - Increases the N-S temperature gradient, winds
  - May mean a slower recovery of the ozone hole
    - A more windy future…?

Natural variability summary

- Main features related to ENSO, annular modes
- Redistribute energy around the climate system
- Provide a lot of noise to mask long term signals
- Probably sensitive to radiative forcings
  - Changing background state may encourage a change in behaviour
  - Linear trends, or regime shifts?

Natural variability & climate change

- Evidence that long-term trends are changing the occurrence of natural modes
  - Move towards the “positive” SAM
- Natural variability also modulates background trends
  - An IPO change can enhance or damp temperature change in New Zealand
  - ENSO events will continue to have big year-to-year impacts, against a changing background
  - For the future, we must consider a mix of trends and shorter-term variability

Future climates

- …next time