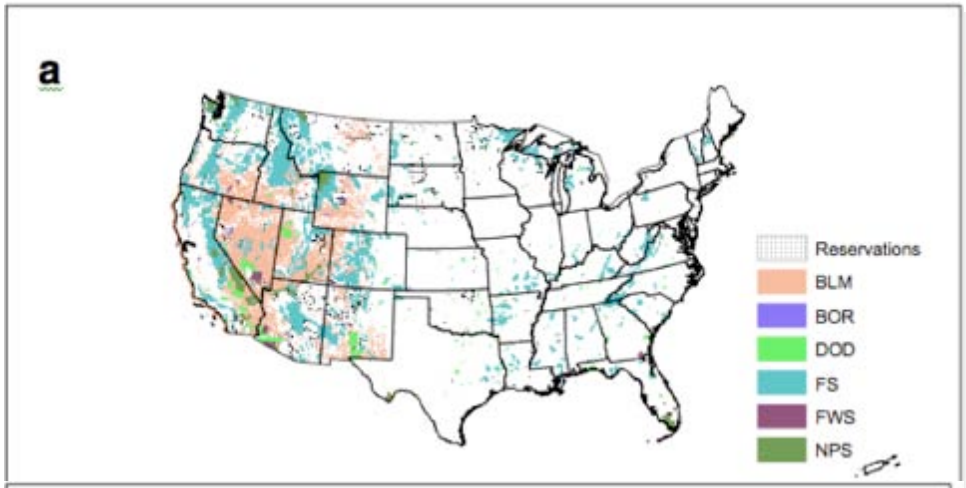
Heat, Drought and High Latitudes:
How the Arctic & Antarctic are Helping Arizona Keep its Cool

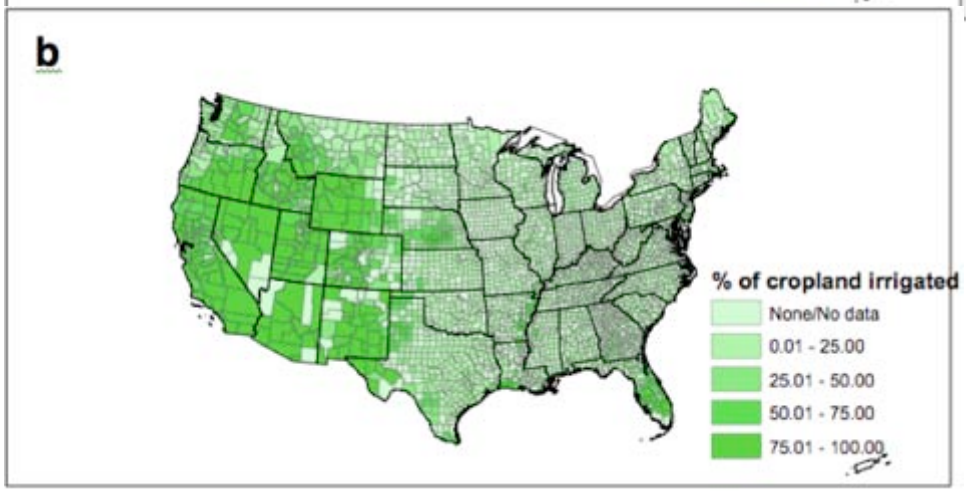
Photo by O. Schofield

Joellen L. Russell

Associate Professor, Geoscience and Planetary Science, University of Arizona

Growing rapidly …. And vulnerable to climate change





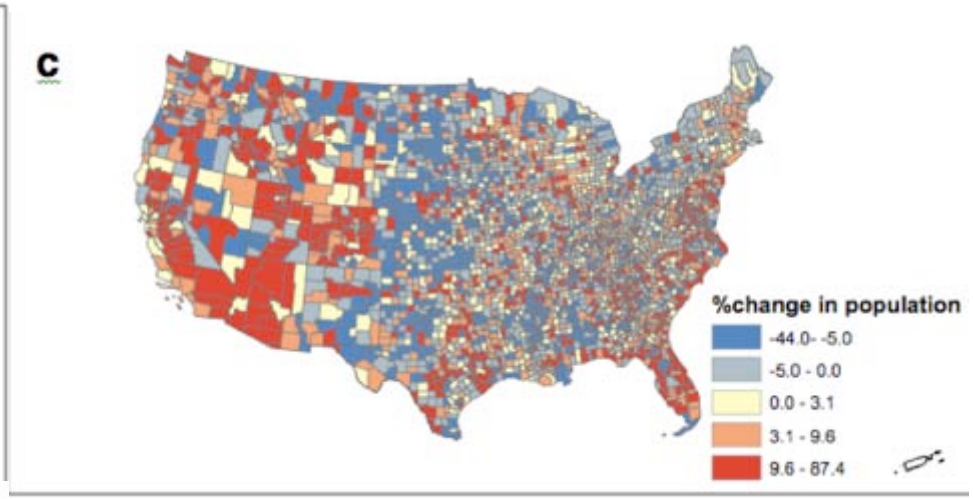
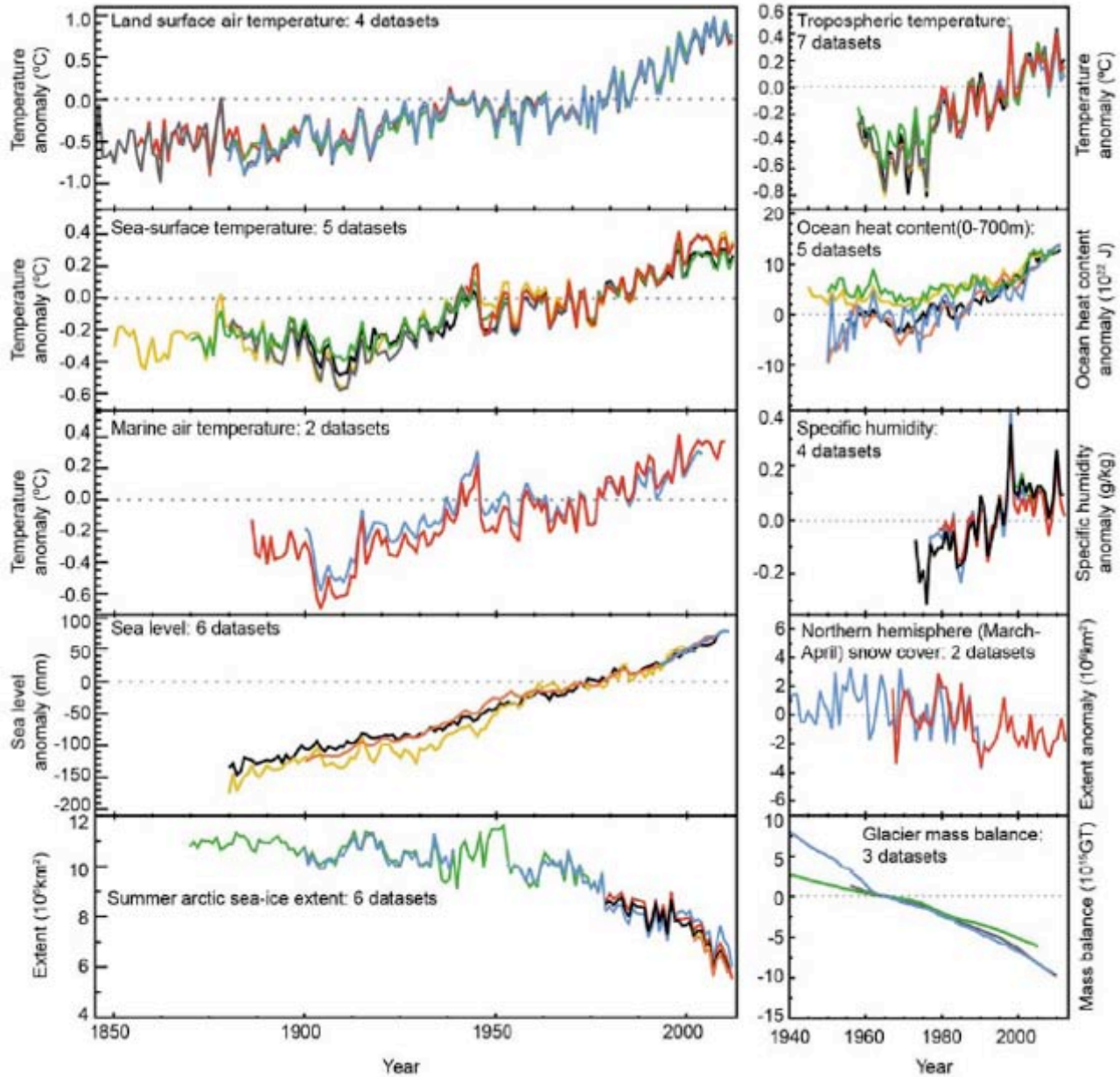


Figure F.2. Maps of federal lands and American Indian reservations (a), the percent of cropland irrigated (b), and the percent change in population from 2000 to 2008 (c). Data from the National Atlas and the U.S. Census Bureau.

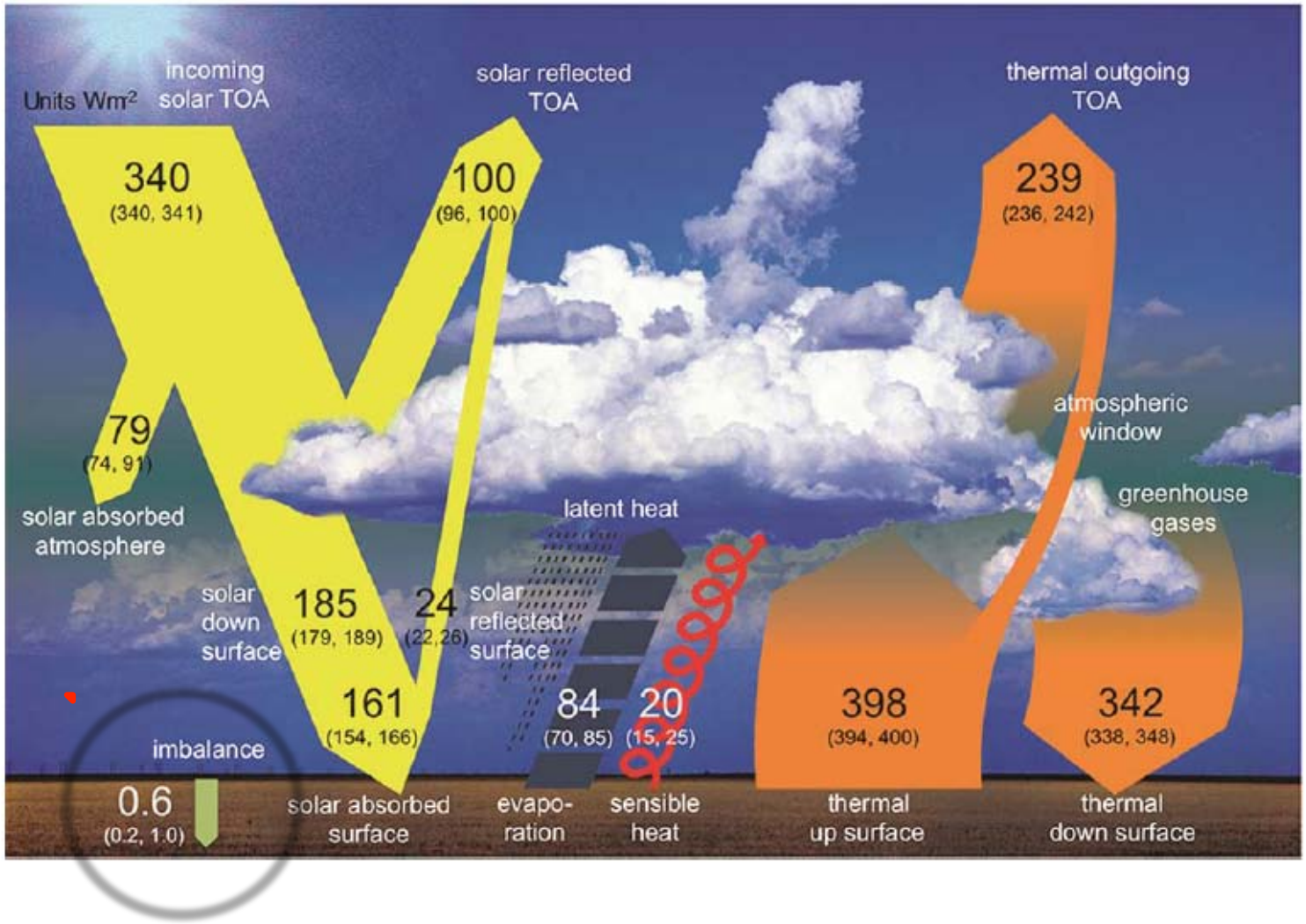
From S. McAfee

Climate Change Indicators



AR5 – TS.1

Global Energy Balance (W/m^2)



NET TOA/SURFACE IMBALANCE of ~0.6 W/m^2

AR5 – Figure 2.11

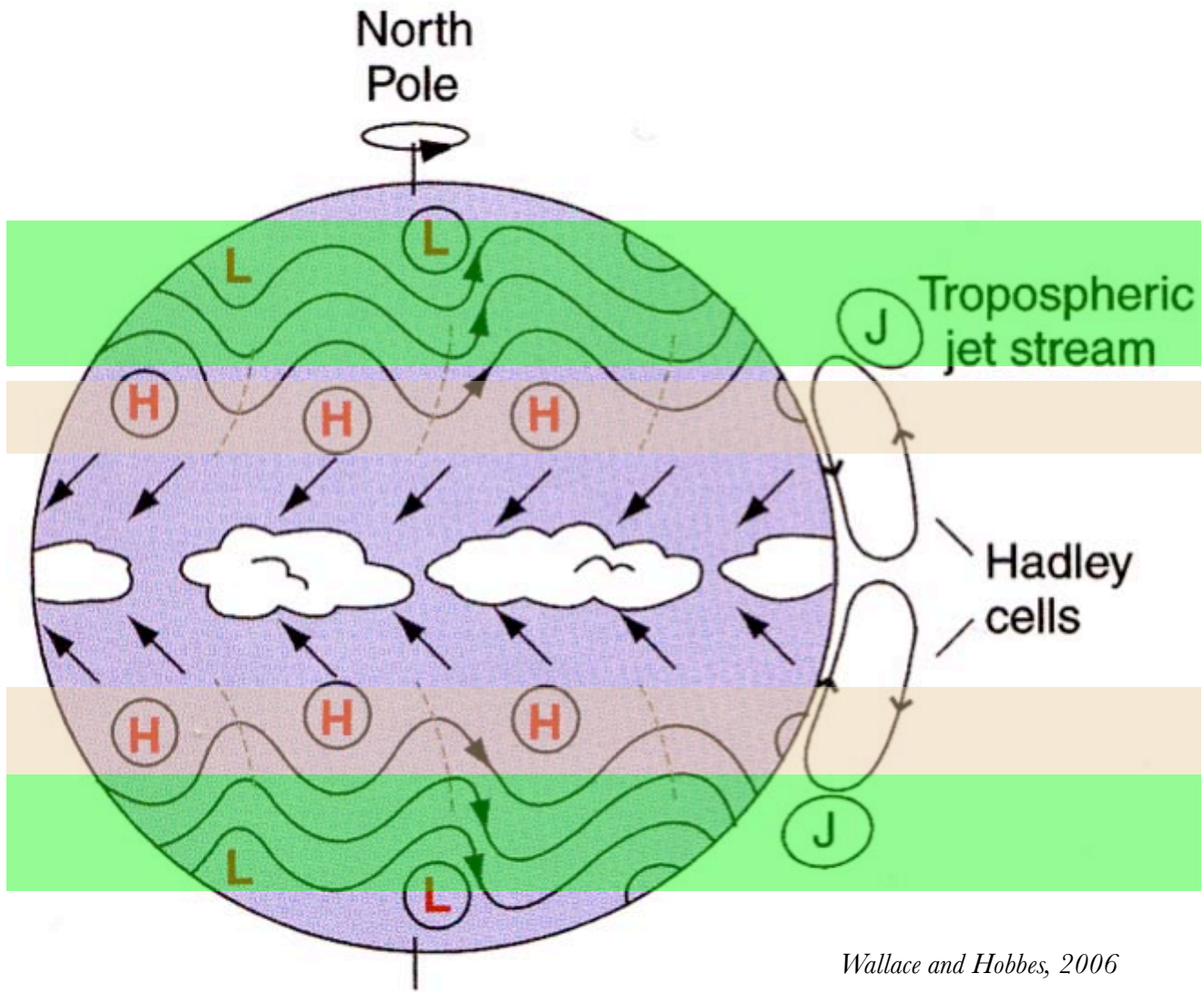
Westerlies

Dry Zone

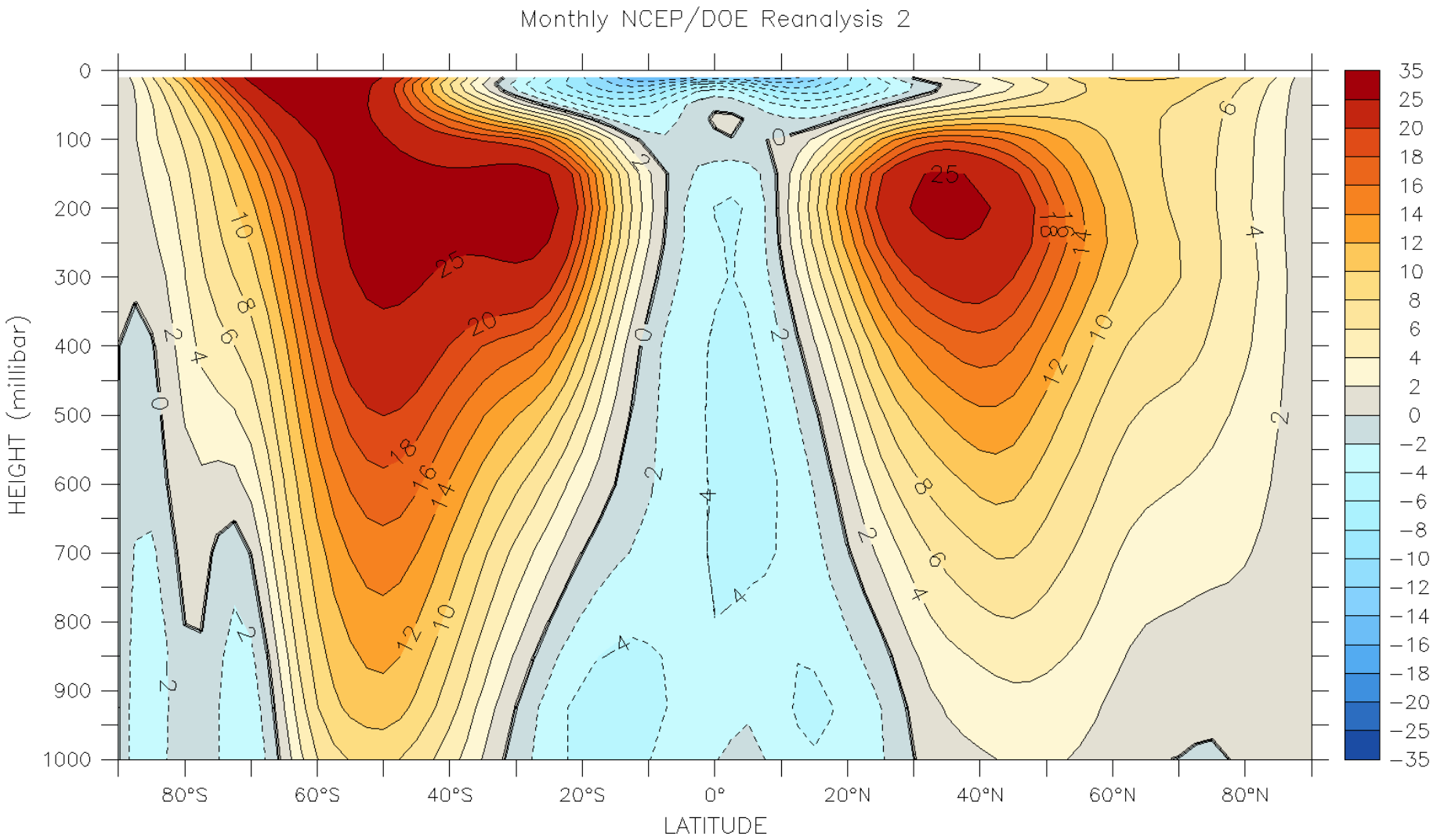
TROPICS

Dry Zone

Westerlies

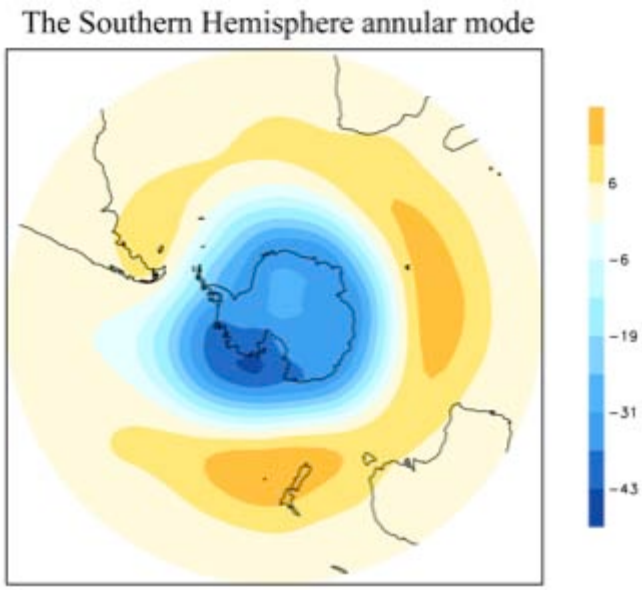


Wallace and Hobbes, 2006

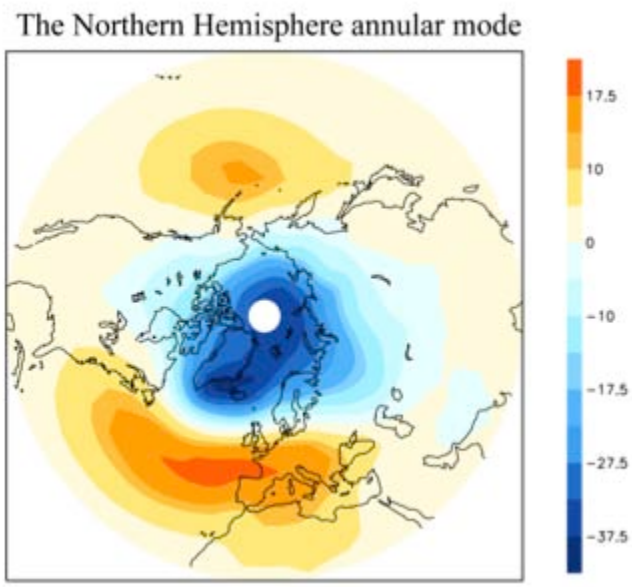


Observed Mean Zonal Wind (m/s)

- Poleward shift of the Southern Hemisphere Westerlies

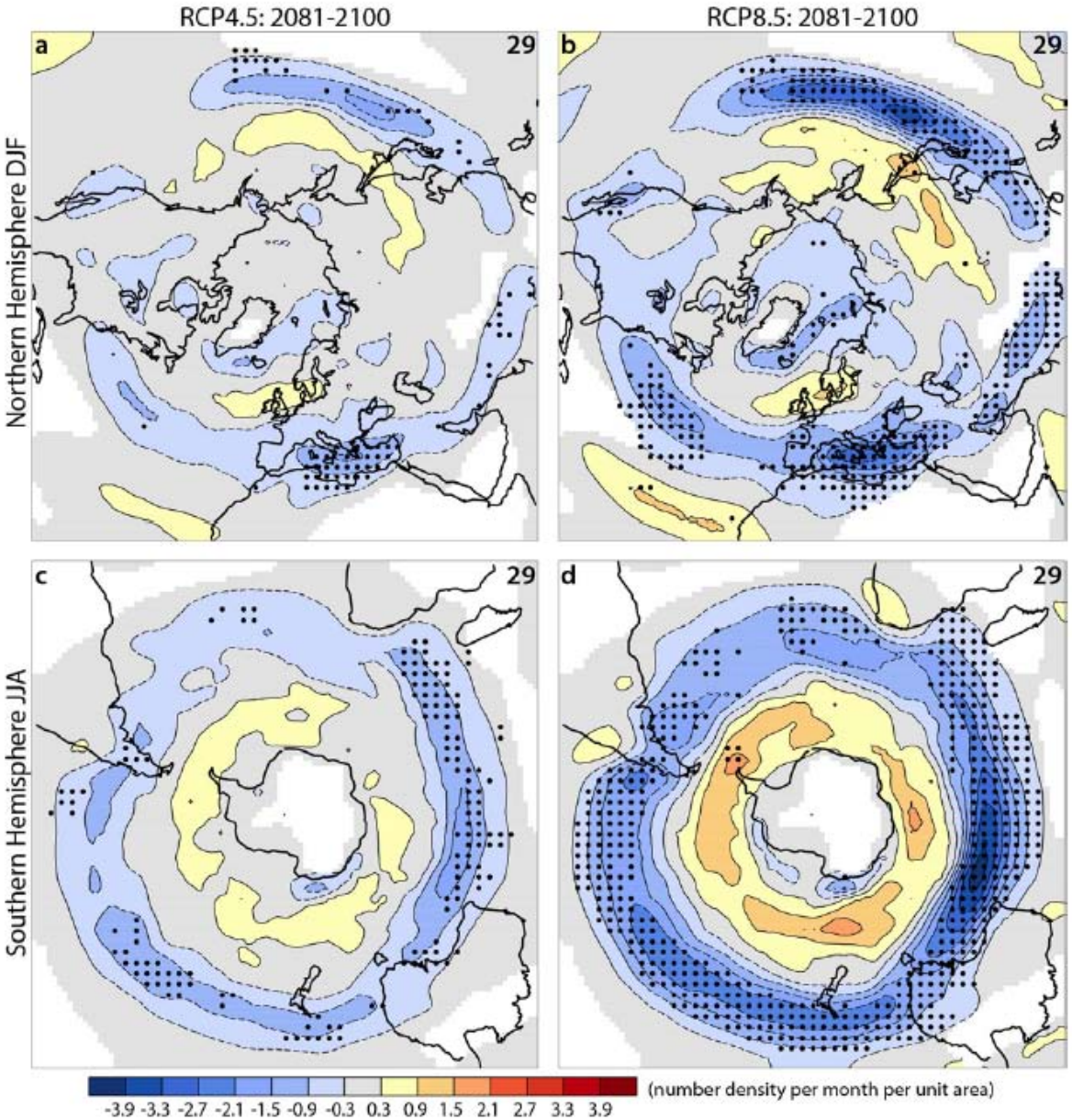


- Poleward shift of the Northern Hemisphere Westerlies



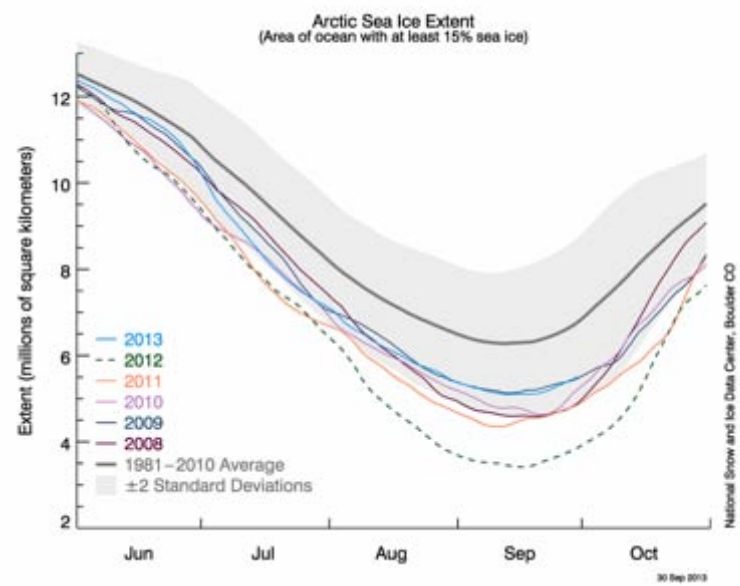
D. Thompson

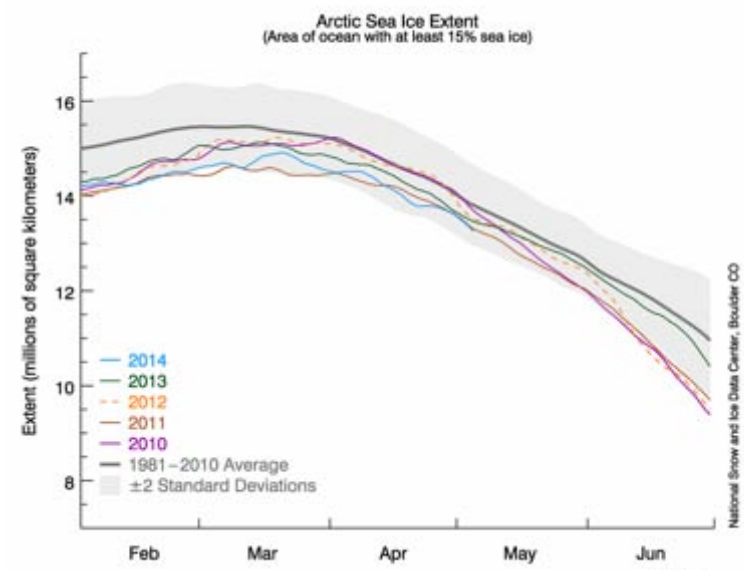
Winter Storm Track Changes

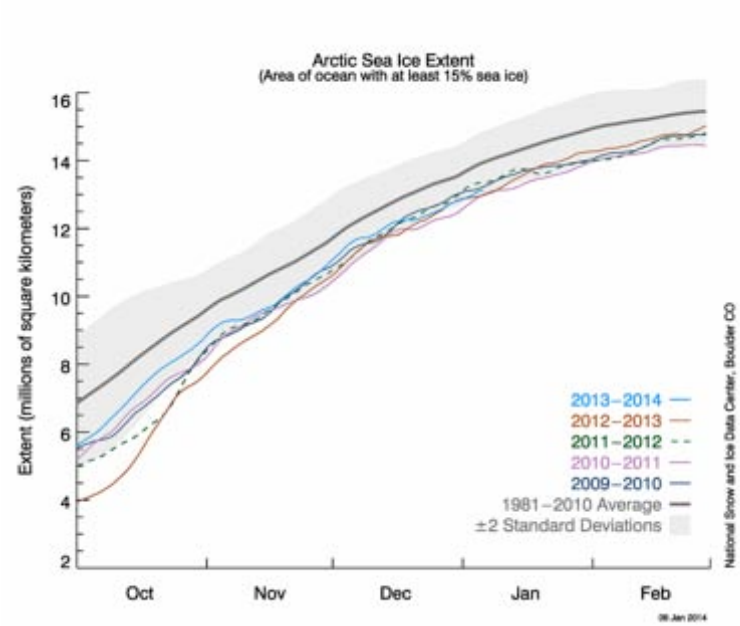


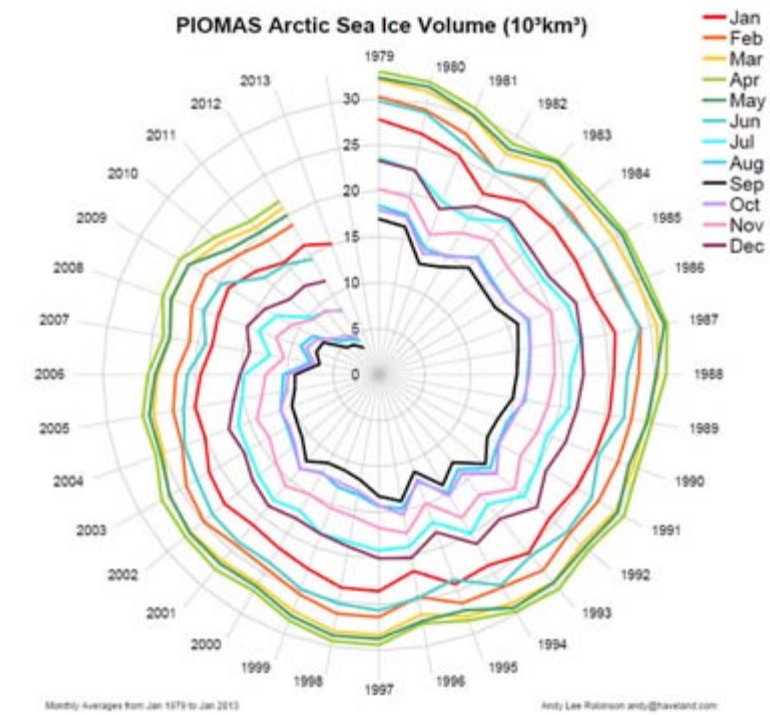
AR5 – Fig. 12.20

Arctic Sea Ice Extent





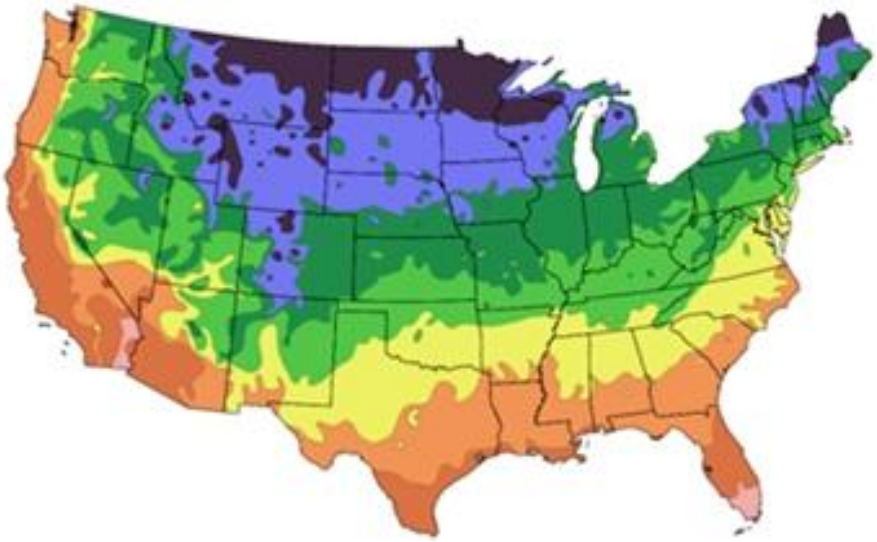




NSIDC

Planting Zone Shifts Already Observed

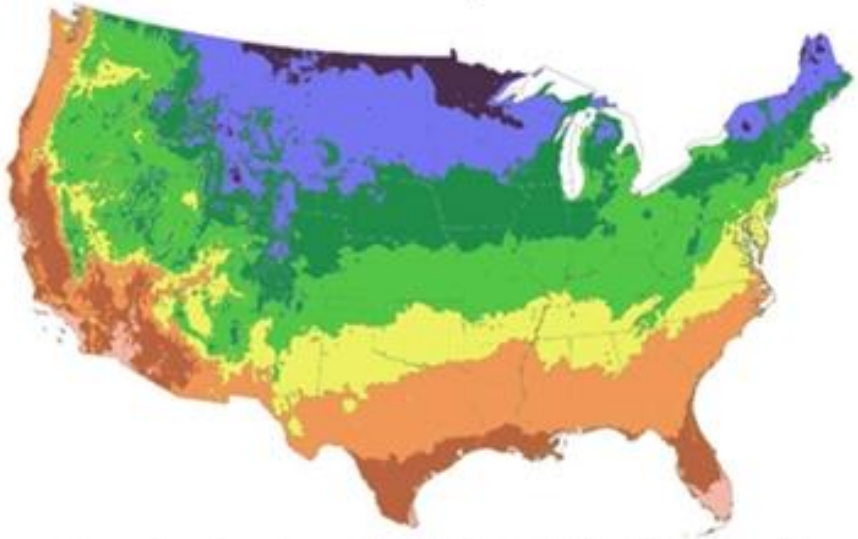
1990 Map



After USDA Plant Hardiness Zone Map, USDA Miscellaneous Publication No. 1475, Issued January 1990

© 2006 by The National Arbor Day Foundation

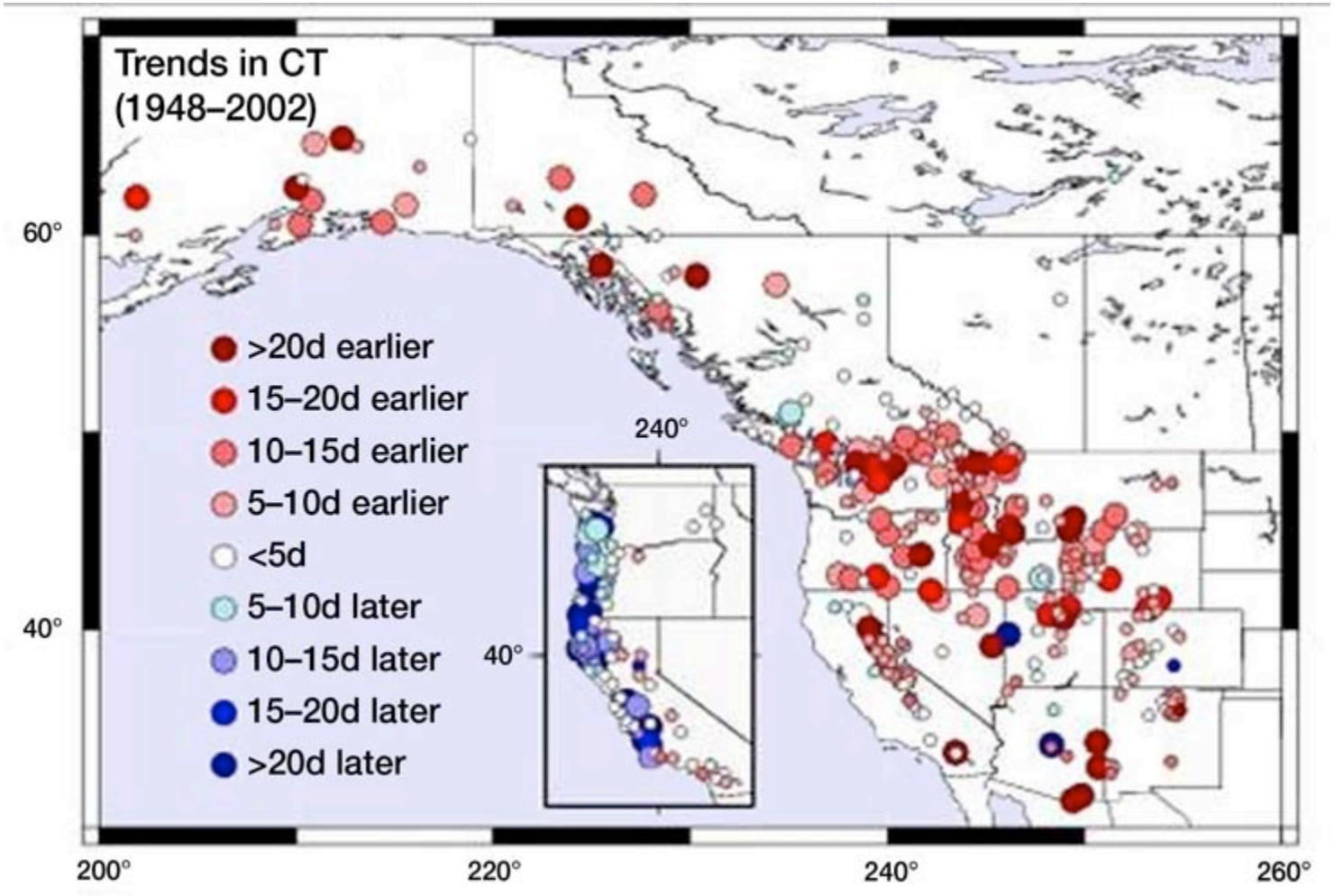
2012 Map



Re-colored version of the 2012 USDA Plant Hardiness Zone Map (available at: http://planthardiness.ars.usda.gov/PHZMWeb/)

© 2012 National Wildlife Federation

Zone



Changes in western U.S. snowmelt runoff timing, 1948-2002.
Source: Stewart et al. (2005).

Annual Surface Soil Moisture Trends

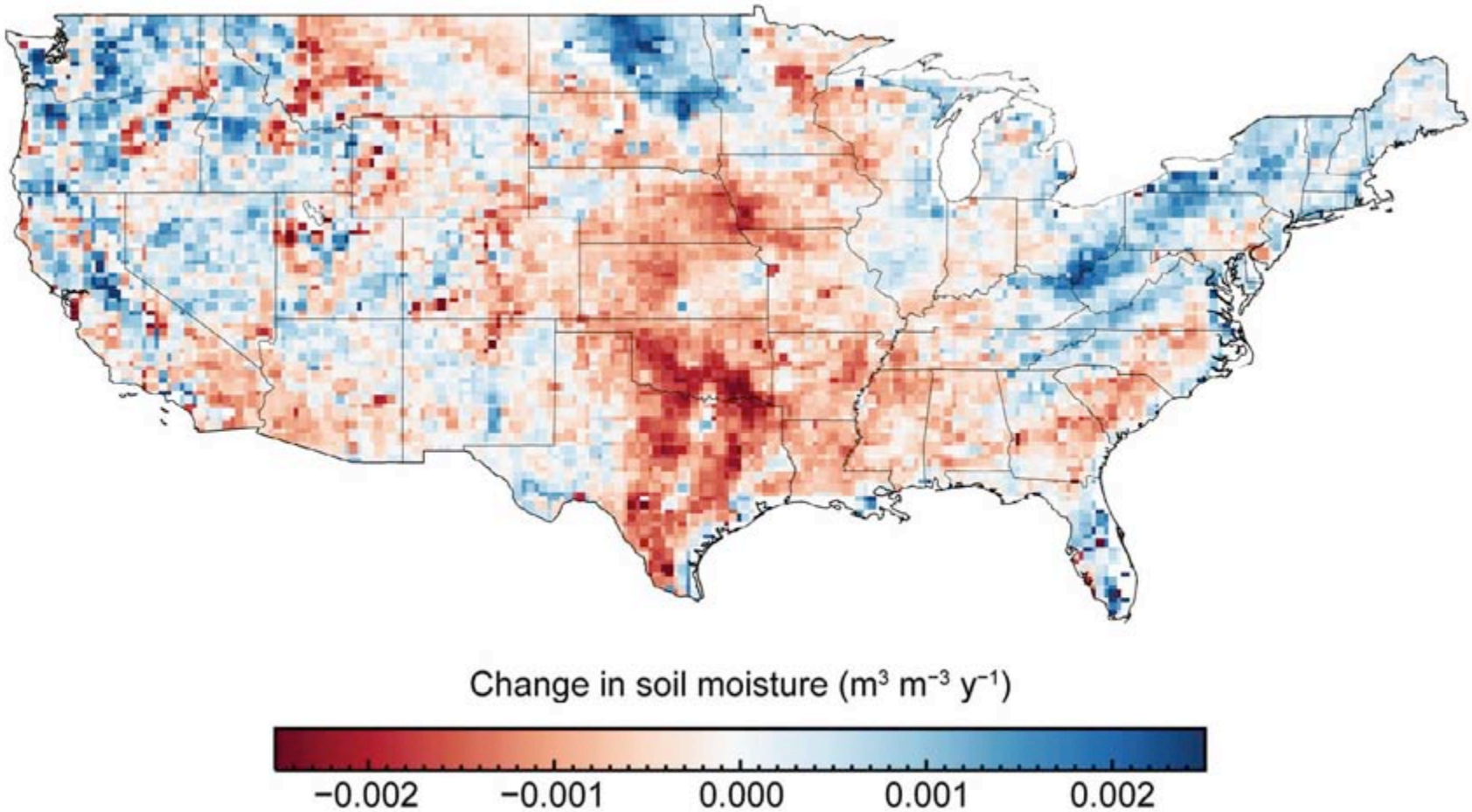


Figure 3.2. Changes in annual surface soil moisture per year over the period 1988 to 2010 based on multisatellite datasets. Surface soil moisture exhibits wetting trends in the Northeast, Florida, upper Midwest, and Northwest, and drying trends almost everywhere else. (Images provided by W. Dorigo).

From the "National Climate Assessment: Climate Change Impacts in the United States"

Trends in Flood Magnitude

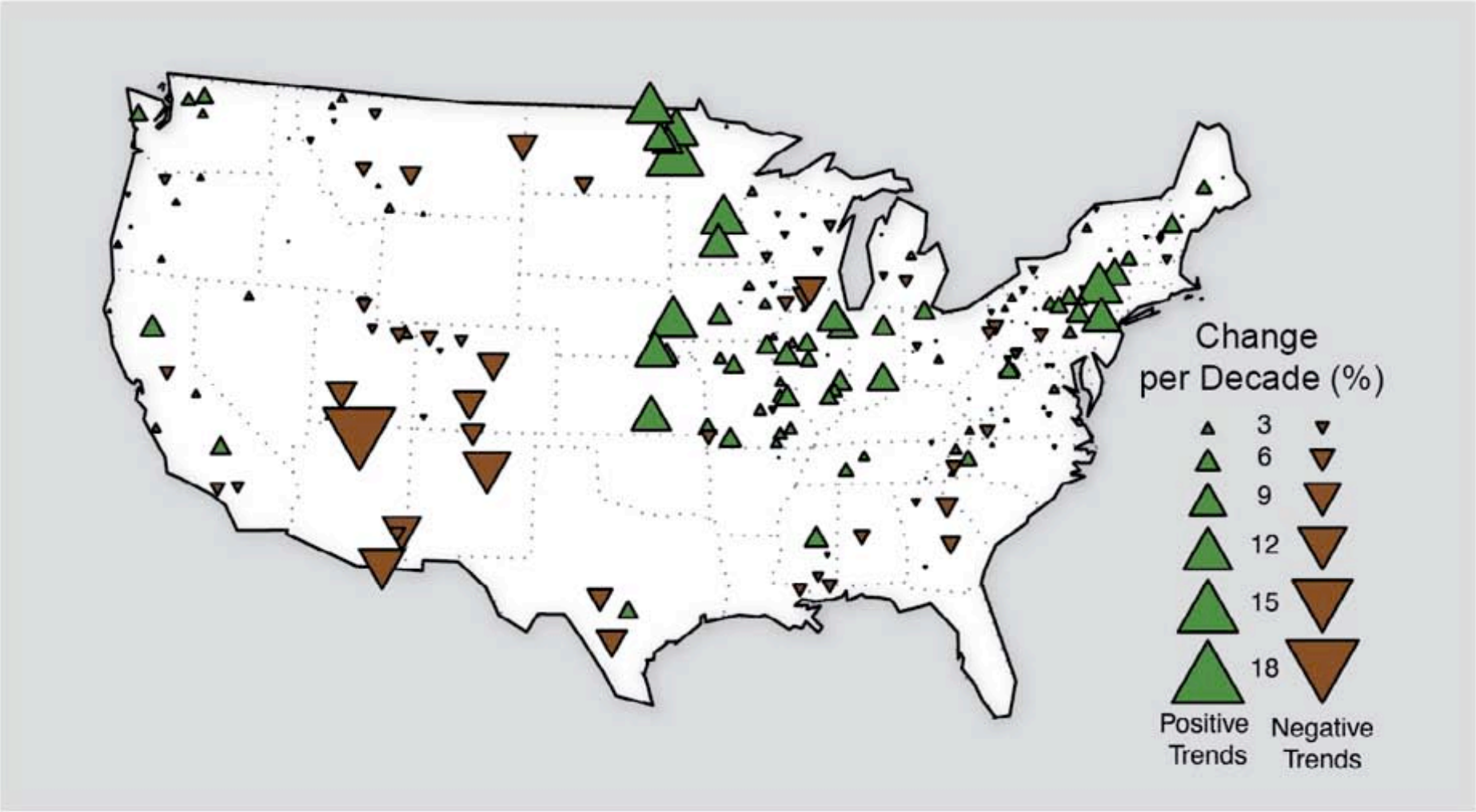
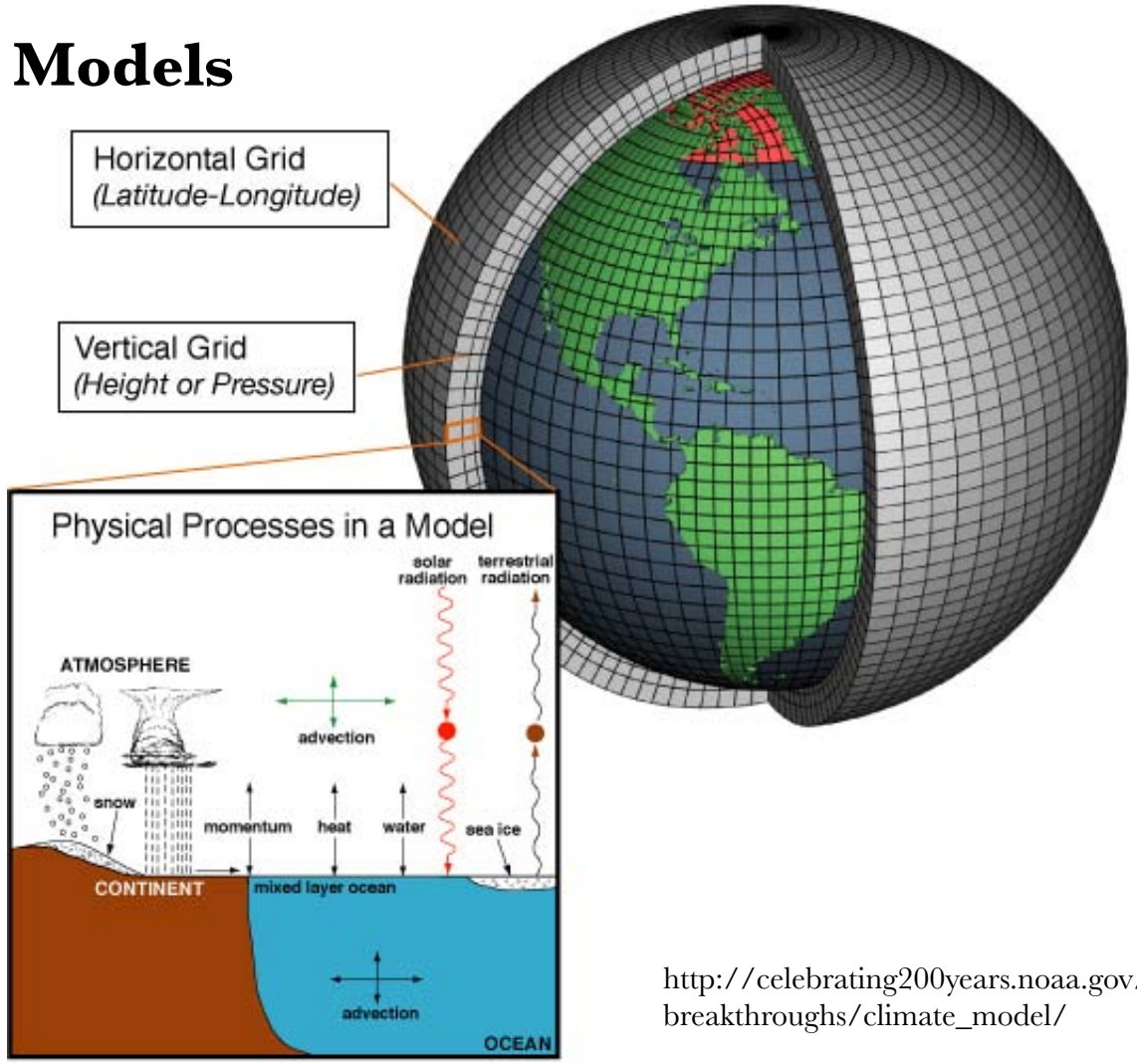


Figure 3.5. Trend magnitude (triangle size) and direction (green = increasing trend, brown = decreasing trend) of annual flood magnitude from the 1920s through 2008. Flooding in local areas can be affected by multiple factors, including land-use change, dams, and diversions of water for use. Most significant are increasing trends for floods in Midwest and Northeast, and a decreasing trend in the Southwest. (Figure source: Peterson et al. 2013).

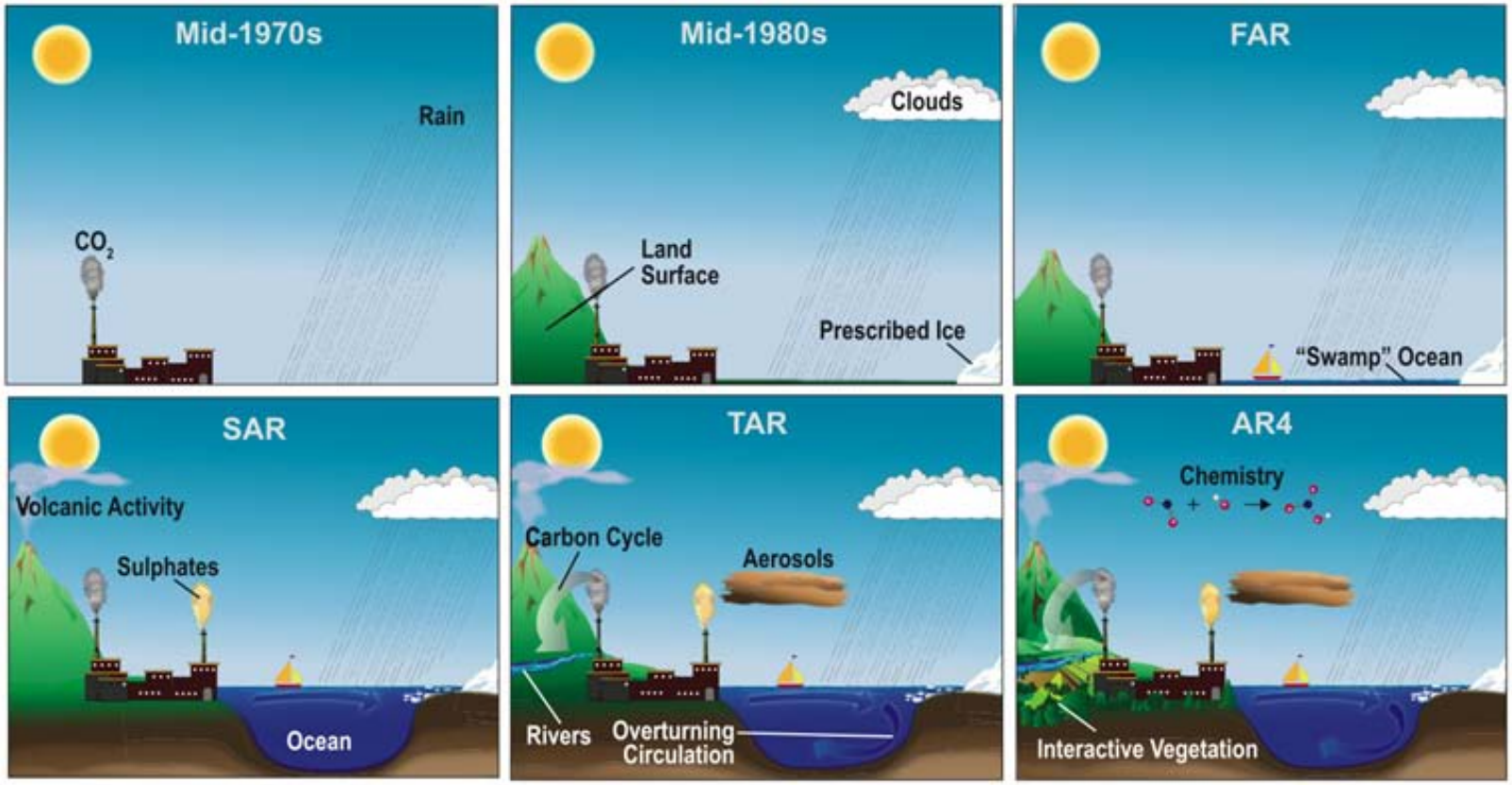
From the "National Climate Assessment: Climate Change Impacts in the United States"

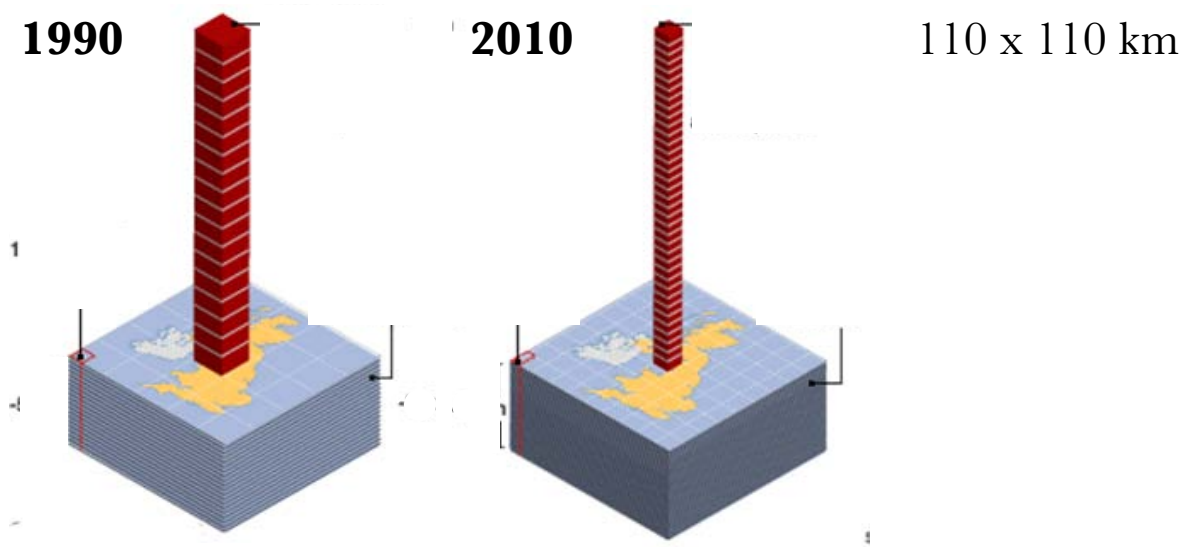
Atmospheric Models



http://celebrating200years.noaa.gov/breakthroughs/climate_model/

Computer code that solves differential equations of air motion and thermodynamics to obtain time and space dependent values for temperature, wind speed, moisture and pressure in the atmosphere.


Mid-1970s
Rain
CO_2
Mid-1980s
Clouds
Land Surface
Prescribed Ice
FAR
"Swamp" Ocean
SAR
Volcanic Activity
Sulphates
Ocean
TAR
Carbon Cycle
Aerosols
Rivers
Overturning Circulation
AR4
Chemistry
Interactive Vegetation


1990
2010
110 x 110 km

Cloud Responses to Warming

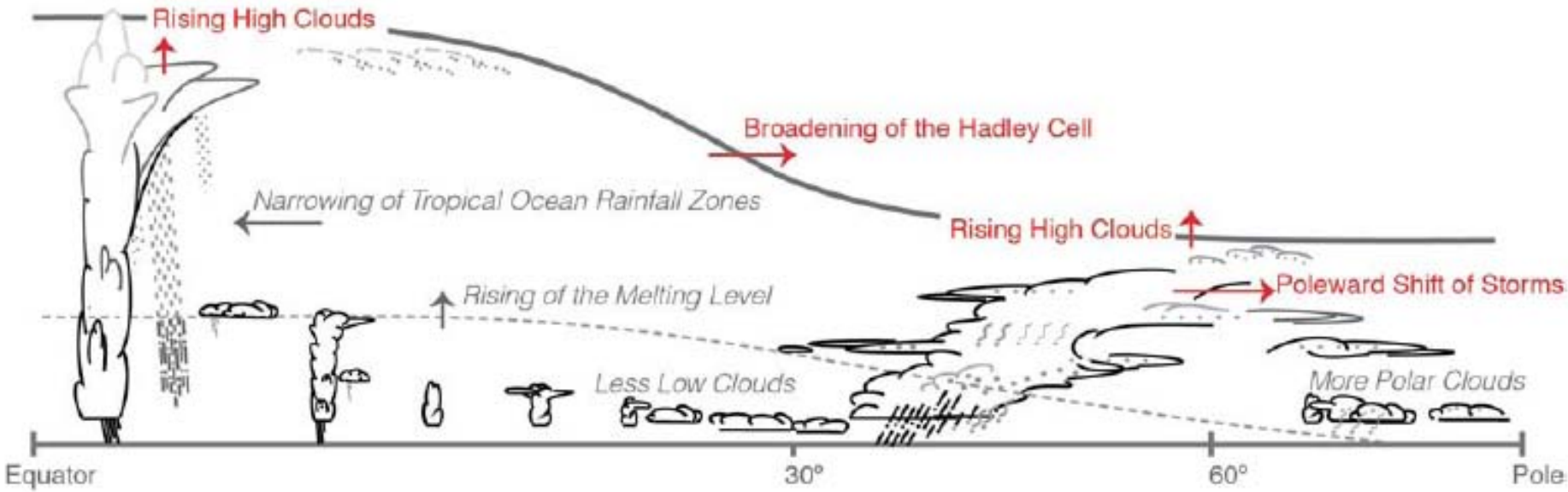
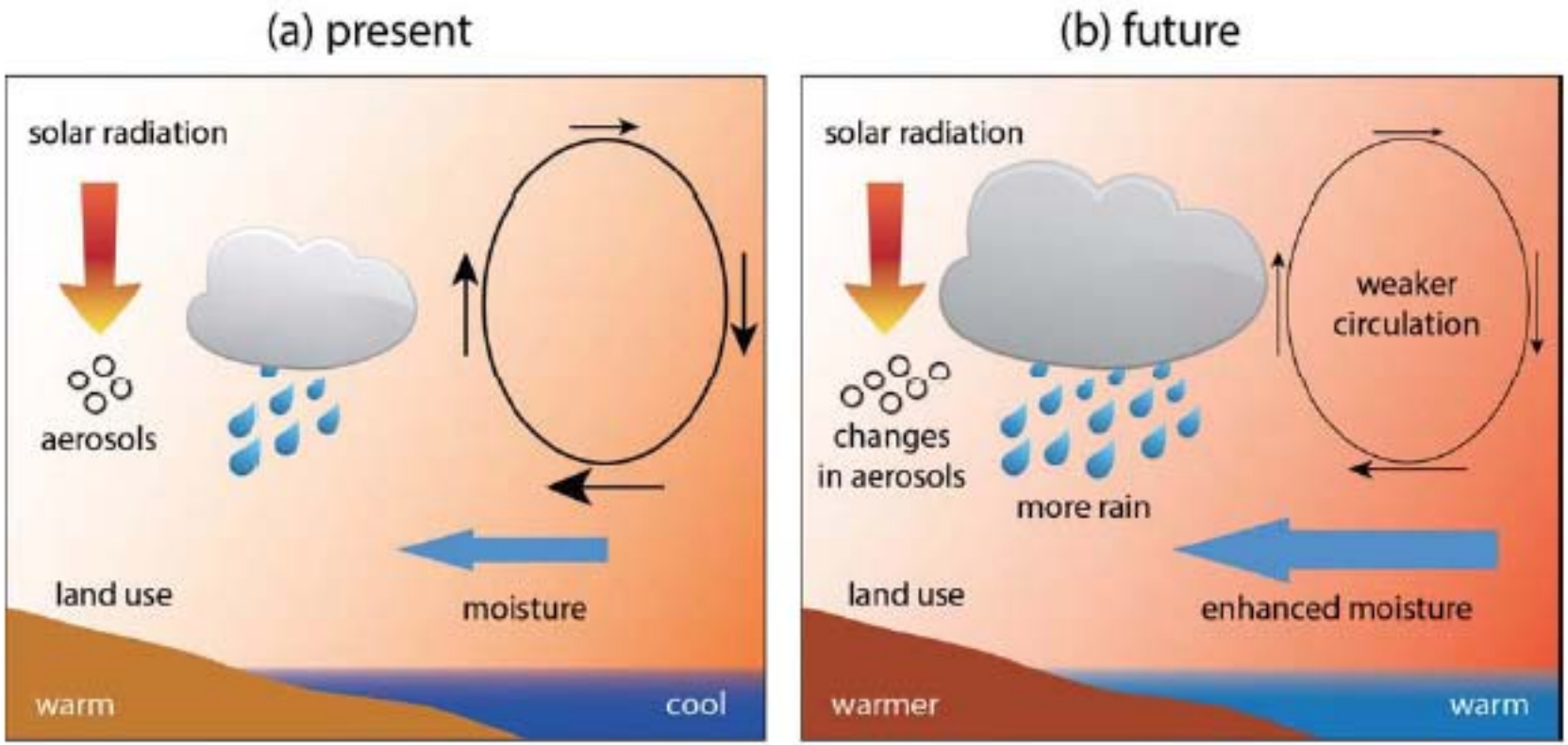


Figure 7.11: Robust cloud responses to greenhouse warming (those simulated by most models and possessing some kind of independent support or understanding). The tropopause and melting level are shown by the thick solid and thin grey dashed lines, respectively. Changes anticipated in a warmer climate are shown by arrows, with red colour indicating those making a robust positive feedback contribution and grey indicating those where the feedback contribution is small and/or highly uncertain. No robust mechanisms contribute negative feedback. Changes include rising high cloud tops and melting level, and increased polar cloud cover and/or optical thickness (*high confidence*); broadening of the Hadley Cell and/or poleward migration of storm tracks, and narrowing of rainfall zones such as the ITCZ (*medium confidence*); and reduced low-cloud amount and/or optical thickness (*low confidence*). Confidence assessments are based on degree of GCM consensus, strength of independent lines of evidence from observations or process models, and degree of basic understanding.

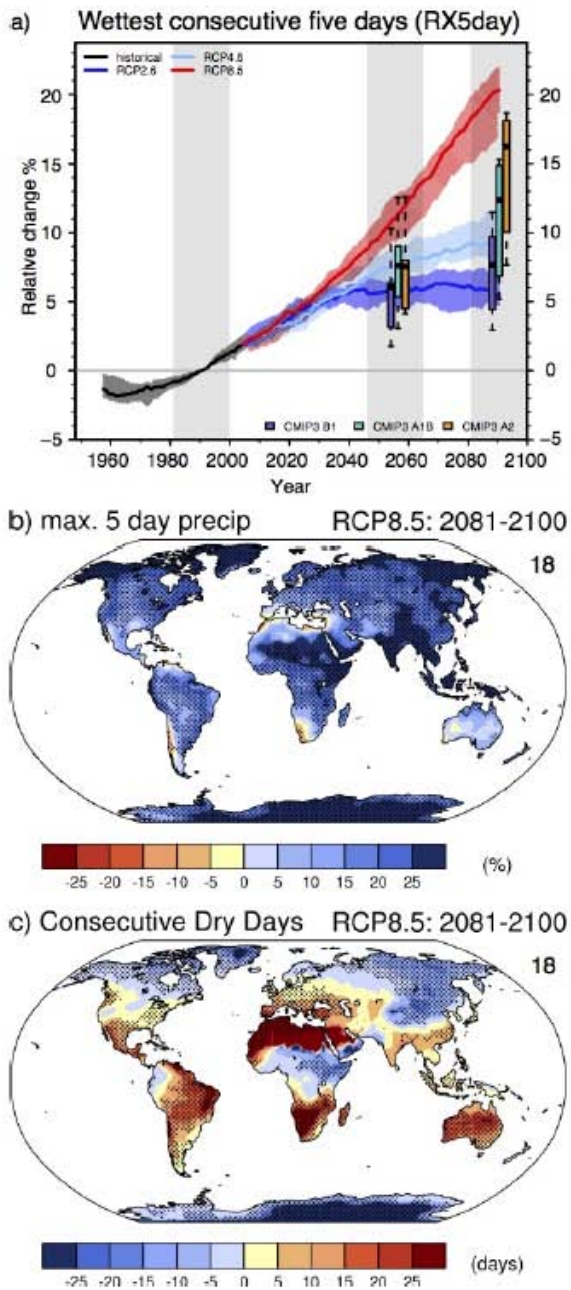
AR5 – Figure 7.1

Human Effects on Monsoons



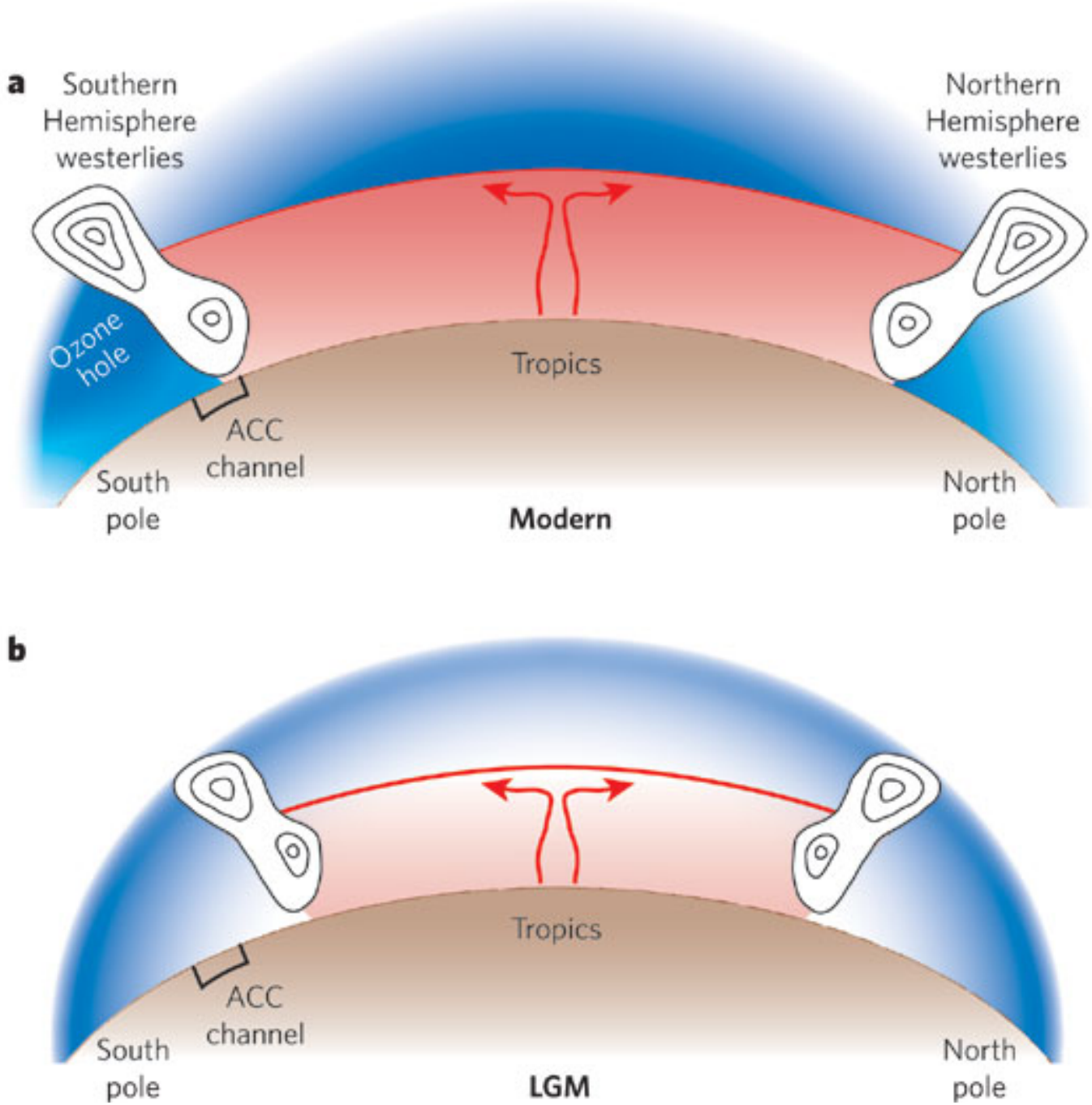
FAQ 14.2, Figure 1: Schematic diagram illustrating the main ways that human activity influences monsoon rainfall. As the climate warms, increasing water vapour transport from the ocean into land increases because warmer air contains more water vapour. This also increases the potential for heavy rainfalls. Warming-related changes in large-scale circulation influence the strength and extent of the overall monsoon circulation. Land use change and atmospheric aerosol loading can also affect the amount of solar radiation that is absorbed in the atmosphere and land, potentially moderating the land-sea temperature difference.

AR5 – FAQ. 14.2
Fig. 1



Precipitation Changes

AR5 – Fig. 12.26


a
Southern Hemisphere westerlies
Northern Hemisphere westerlies
Ozone hole
Tropics
ACC channel
South pole
North pole
Modern
b
Tropics
ACC channel
South pole
North pole
LGM

Projected Temperature Increases

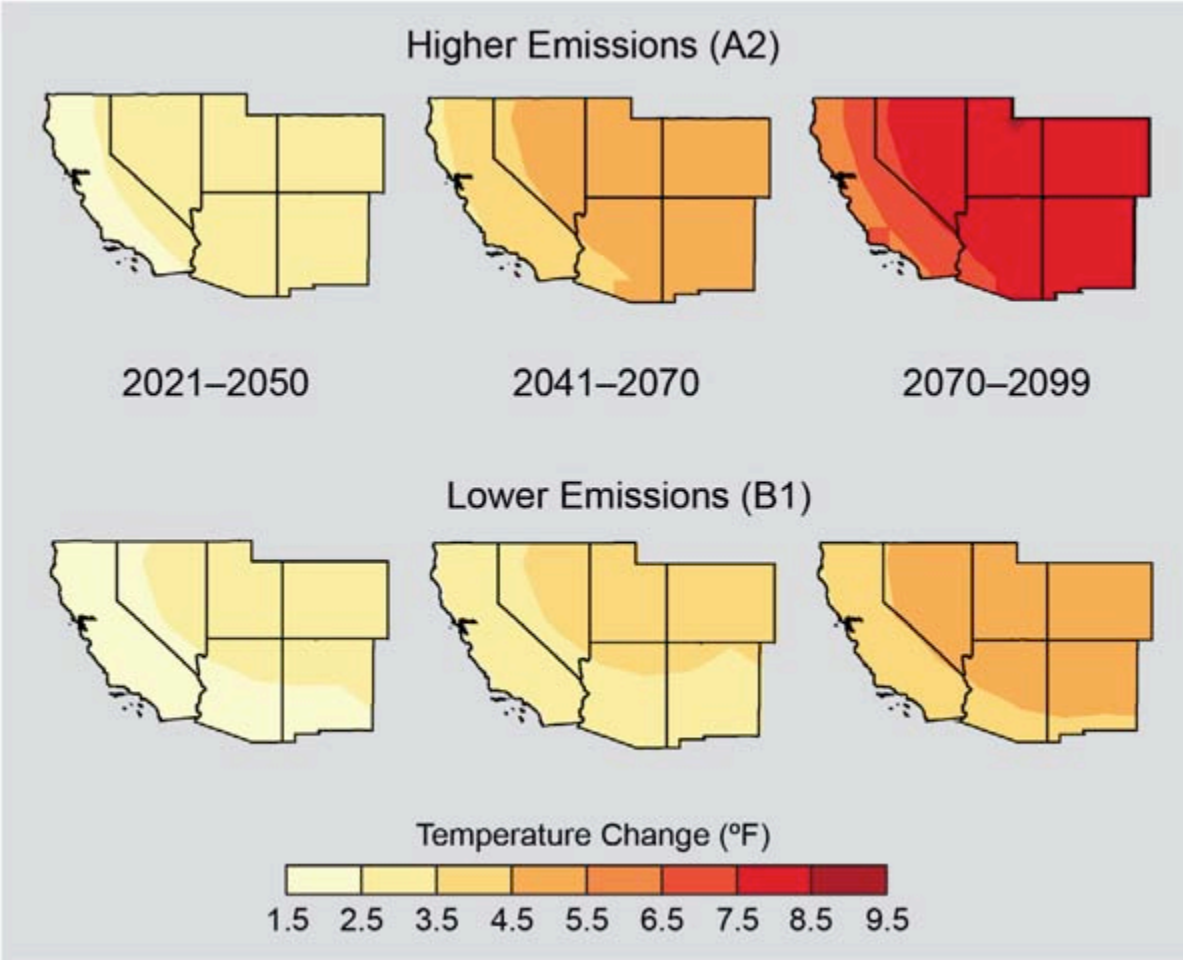


Figure 20.1. Maps show projected changes in average, as compared to 1971-1999. Top row shows projections assuming heat-trapping gas emissions continue to rise (A2). Bottom row shows projections assuming substantial reductions in emissions (B1). (Figure source: adapted from Kunkel et al. 2013).

From the "National Climate Assessment: Climate Change Impacts in the United States"

Projected Snow Water Equivalent

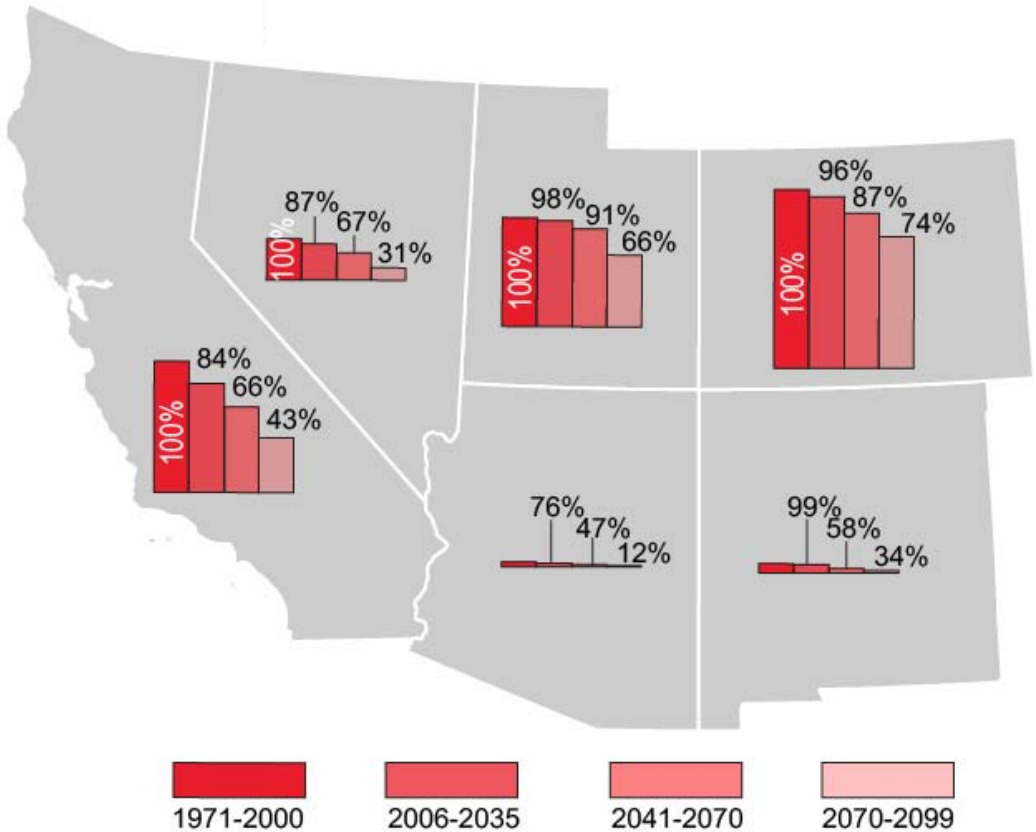
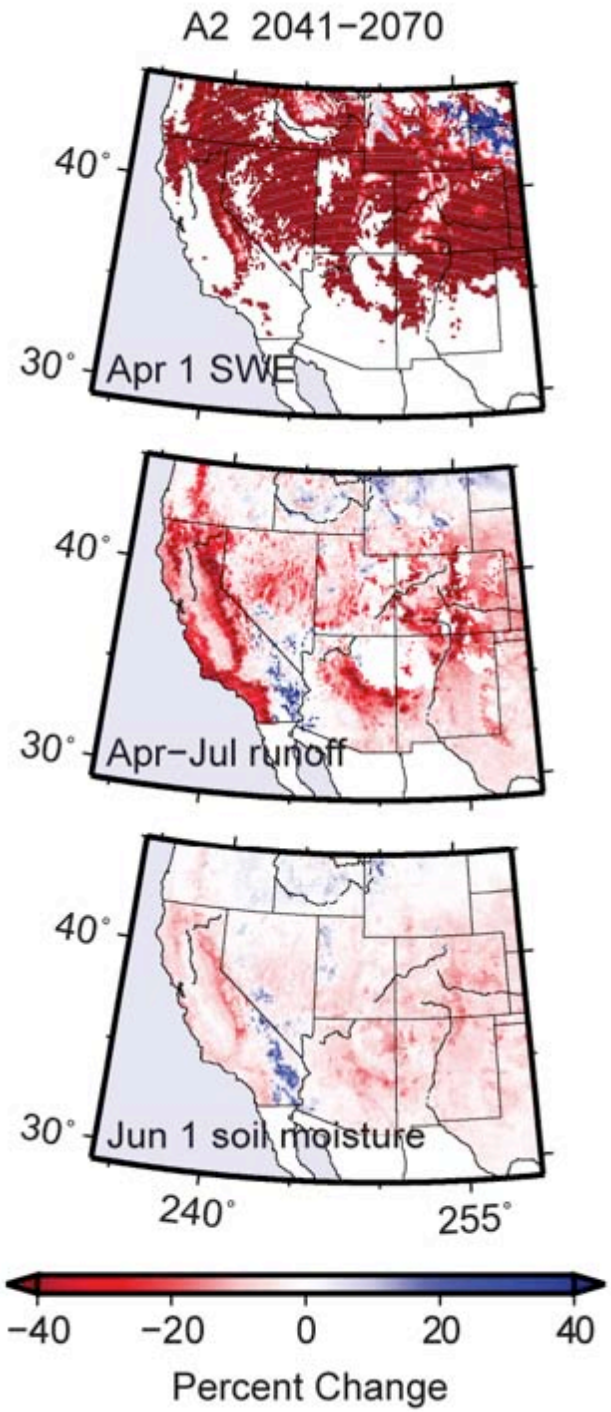


Figure 20.2. Snow water equivalent (SWE) refers to the amount of water held in a volume of snow, which depends on the density of the snow and other factors. Figure shows projected snow water equivalent for the Southwest, as a percentage of 1971-2000, assuming continued increases in global emissions (A2 scenario). The size of bars is in proportion to the amount of snow each state contributes to the regional total; thus, the bars for Arizona are much smaller than those for Colorado, which contributes the most to region-wide snowpack. Declines in peak SWE are strongly correlated with early timing of runoff and decreases in total runoff. For watersheds that depend on snowpack to provide the majority of the annual runoff, such as in the Sierra Nevada and in the Upper Colorado and Upper Rio Grande River Basins, lower SWE generally translates to reduced reservoir water storage. (Data from Scripps Institution of Oceanography).

From the "National Climate Assessment: Climate Change Impacts in the United States"



Projected Changes in Snow, Runoff, and Soil Moisture

Figure 3.1. These projections, assuming continued increases in heat-trapping gas emissions (A2 scenario; Ch. 2: Our Changing Climate), illustrate: a) major losses in the water content of the snowpack that fills western rivers (snow water equivalent, or SWE); b) significant reductions in runoff in California, Arizona, and the central Rocky Mountains; and c) reductions in soil moisture across the Southwest. The changes shown are for mid-century (2041-2070) as percentage changes from 1971- 2000 conditions (Figure source: Cayan et al. 2013).

From the "National Climate Assessment: Climate Change Impacts in the United States"

Streamflow Projections for River Basins in the Western U.S.

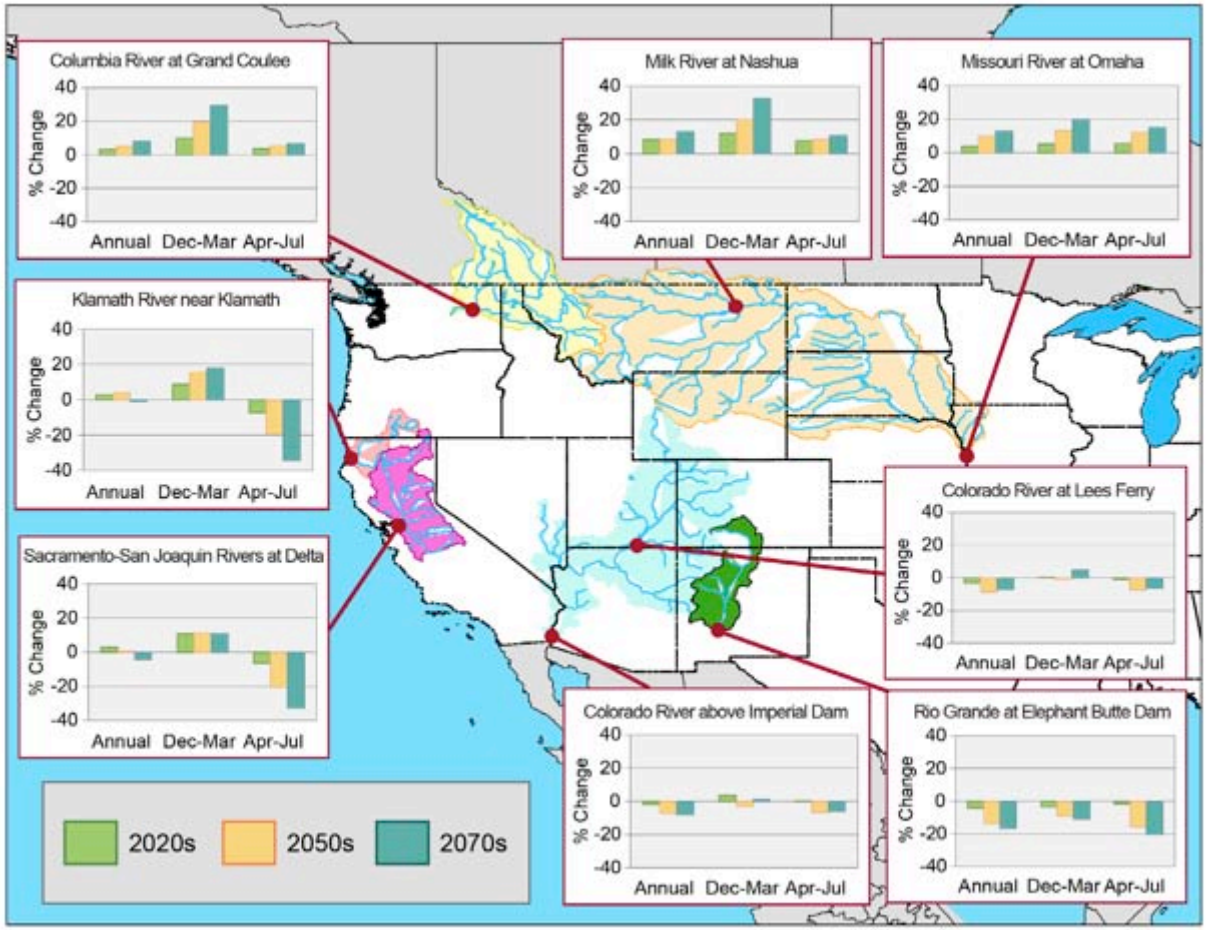


Figure 3.4. Annual and seasonal streamflow projections based on the B1 (with substantial emissions reductions), A1B (with gradual reductions from current emission trends beginning around mid-century), and A2 (with continuation of current rising emissions trends) CMIP3 scenarios for eight river basins in the western United States. The panels show percentage changes in average runoff, with projected increases above the zero line and decreases below. Projections are for annual, cool, and warm seasons, for three future decades (2020s, 2050s, and 2070s) relative to the 1990s.

From the "National Climate Assessment: Climate Change Impacts in the United States"

Projected Changes in Water Withdrawals

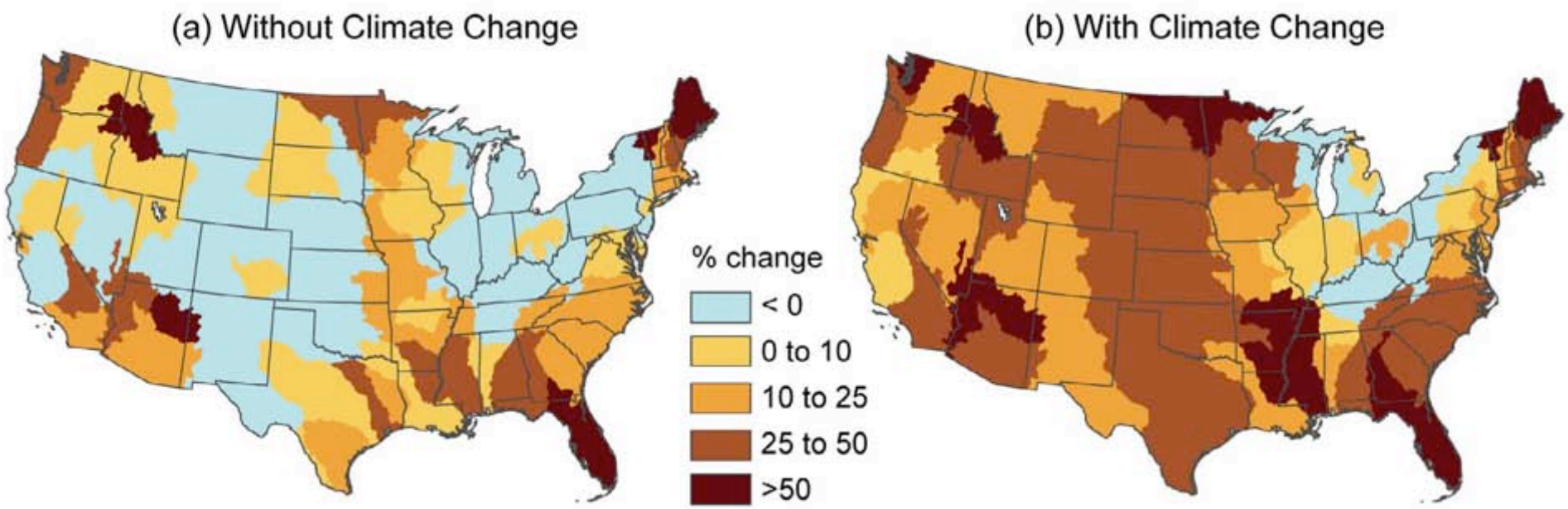
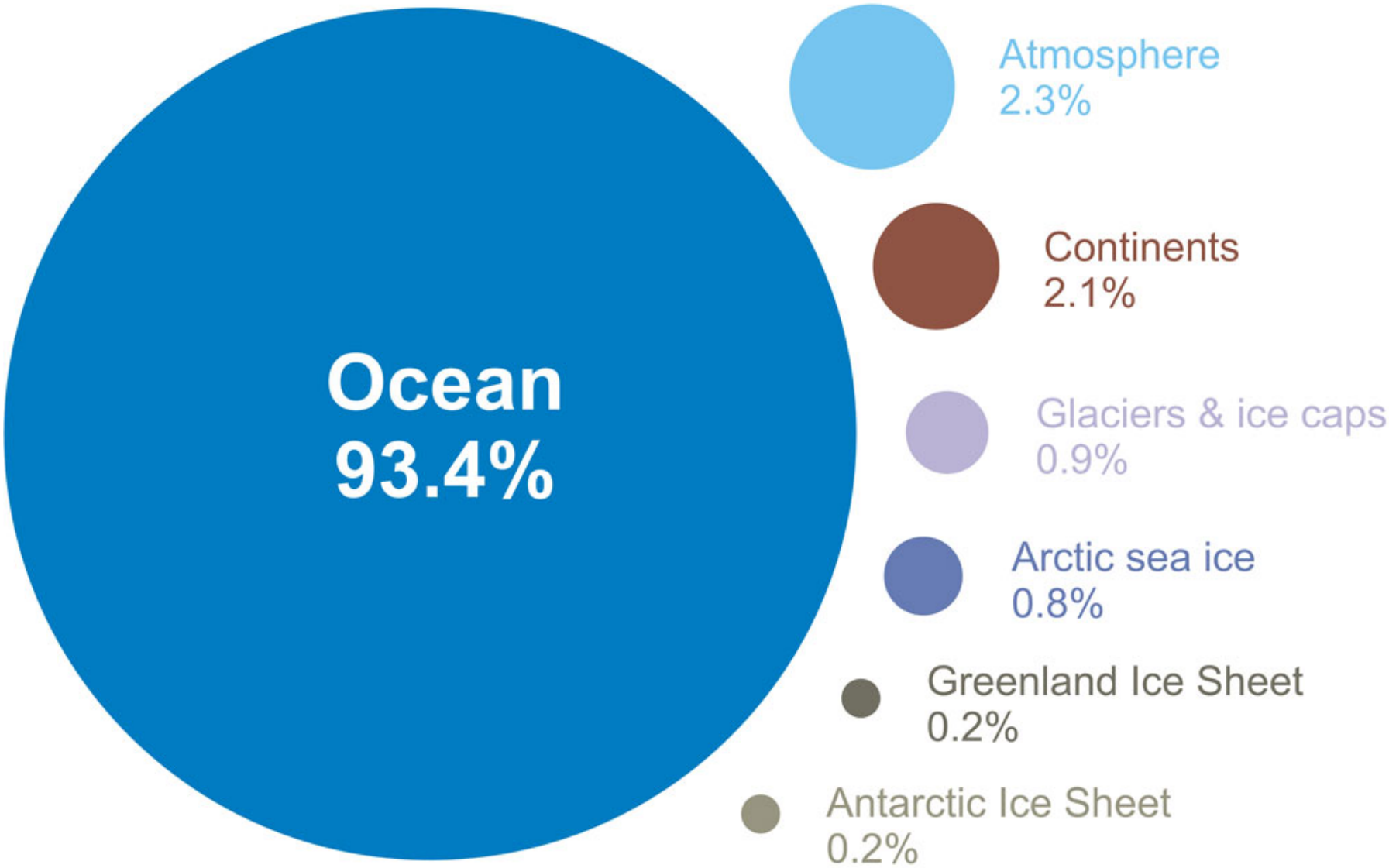


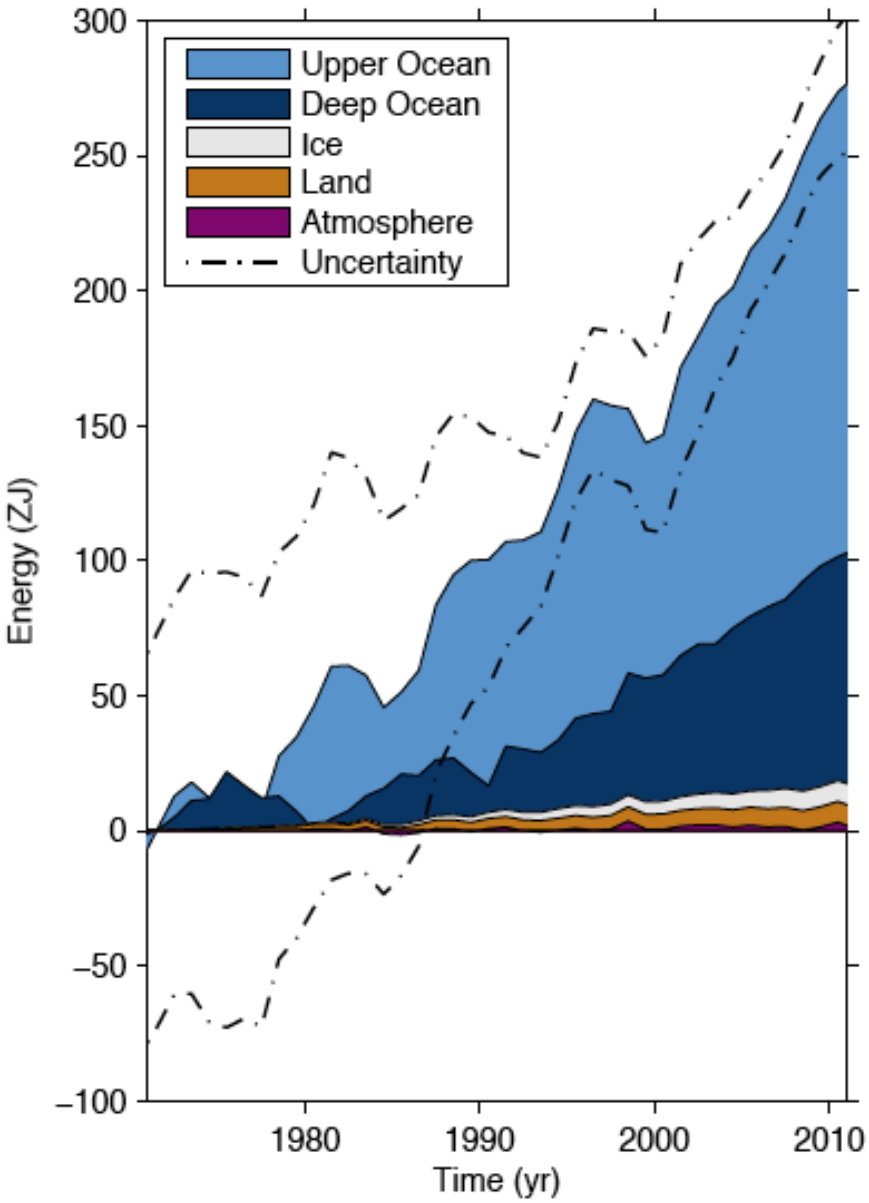
Figure 3.11. The effects of climate change, primarily associated with increasing temperatures and potential evapotranspiration, are projected to significantly increase water demand across most of the United States. Maps show percent change from 2005 to 2060 in projected demand for water assuming (a) change in population and socioeconomic conditions based on the underlying A1B emissions scenario, but with no change in climate, and (b) combined changes in population, socioeconomic conditions, and climate according to the A1B emissions scenario (gradual reductions from current emission trends beginning around mid-century). (Figure source: Brown et al. 2013).

From the "National Climate Assessment: Climate Change Impacts in the United States"

Where is global warming going?



The global energy imbalance goes into the ocean



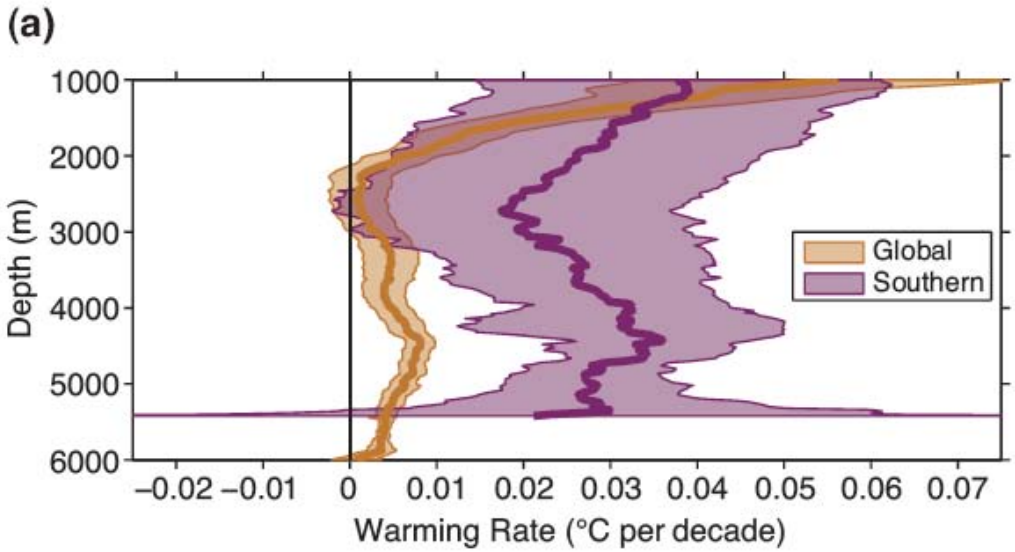
Box 3.1, Figure 1: Plot of energy accumulation within distinct components of Earth's climate system relative to 1971.

AR5

What is the role of the Southern Ocean in the global climate system?

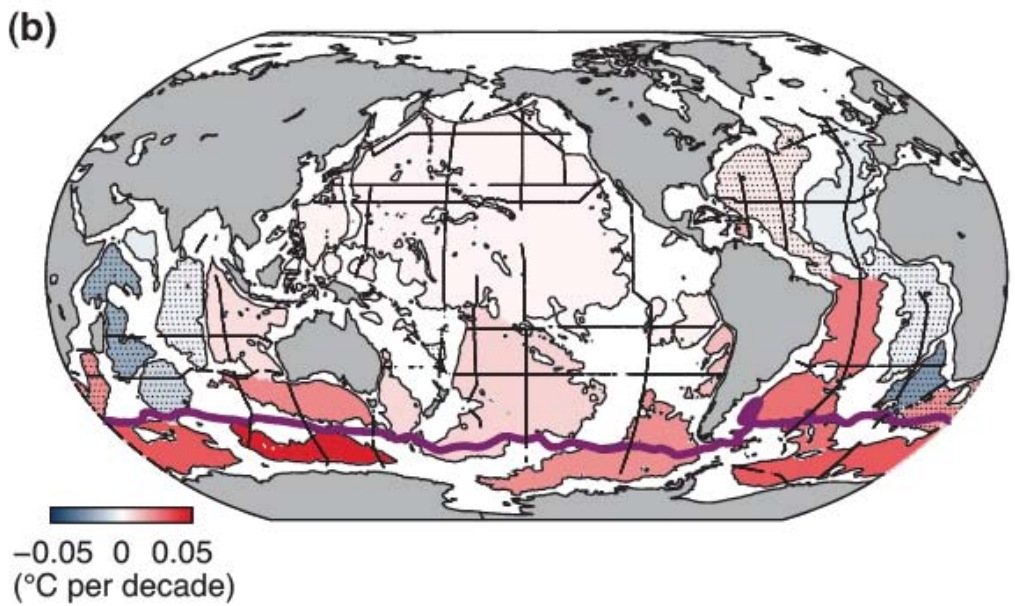
1. It may account for up to half of the annual oceanic uptake of anthropogenic carbon dioxide from the atmosphere (cf., Gruber et al., 2009)
2. Vertical exchange in the Southern Ocean is responsible for supplying nutrients that fertilize three-quarters of the biological production in the global ocean north of 30°S (Sarmiento et al., 2004)
3. It may account for up to 70 ± 30% of the excess heat that is transferred from the atmosphere into the ocean each year (see analysis of IPCC AR4 models)
4. Southern Ocean winds and buoyancy fluxes are the principal source of energy for driving the large scale deep meridional overturning circulation throughout the ocean (e.g., Toggweiler and Samuels, 1998; Marshall and Speer, 2012)

The Southern Ocean and the deep ocean are warming

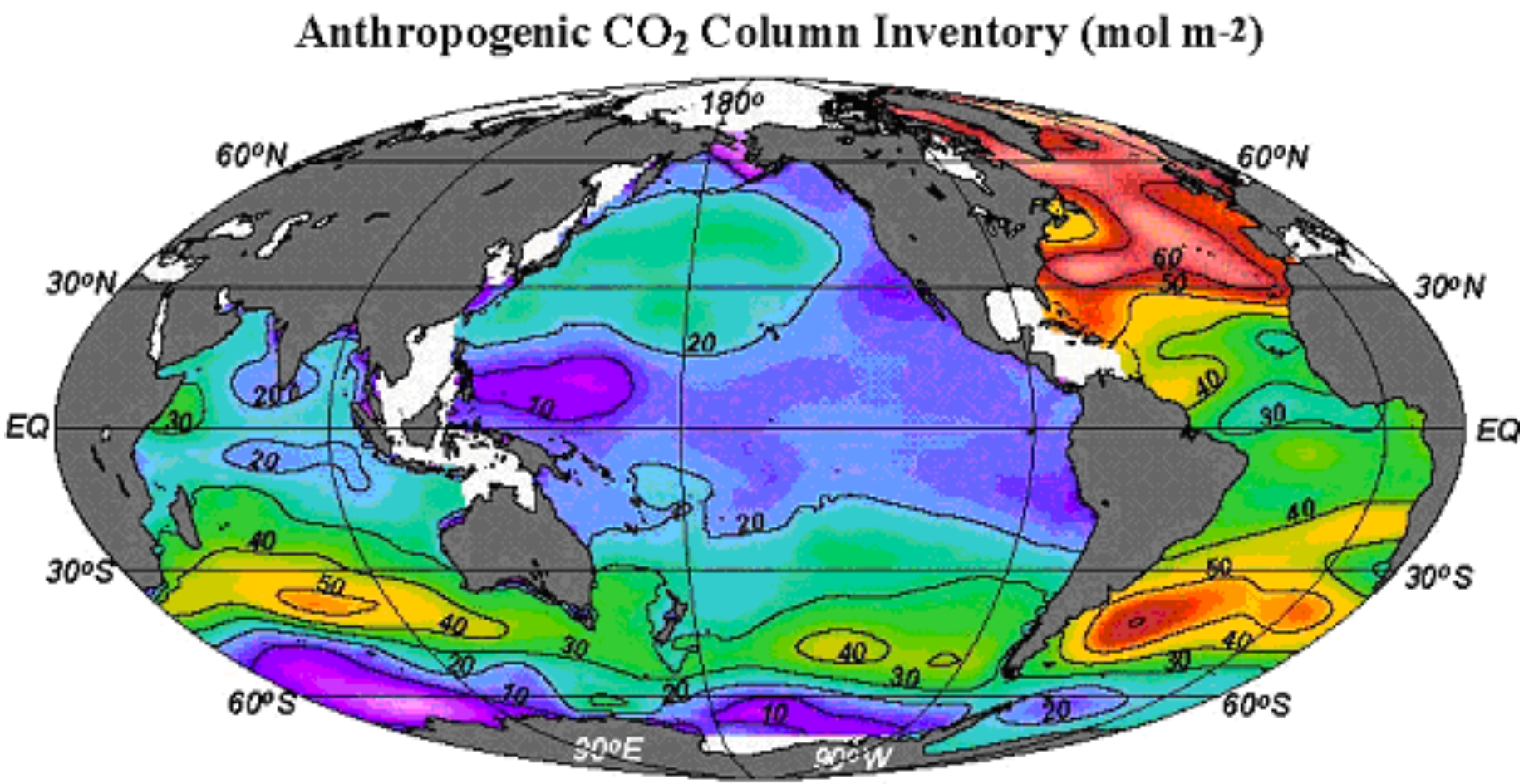


Warming Rate of Southern Ocean (purple) and global ocean (orange)

Figure 3.3: a) Areal mean warming rates (°C per decade) versus depth (thick lines) with 5 to 95% confidence limits (shading), both global (orange) and south of the Sub-Antarctic Front (purple), centred on 1992–2005. **b)** Mean warming rates (°C per decade) below 4000 m estimated for deep ocean basins (thin black outlines), centered on 1992–2005.



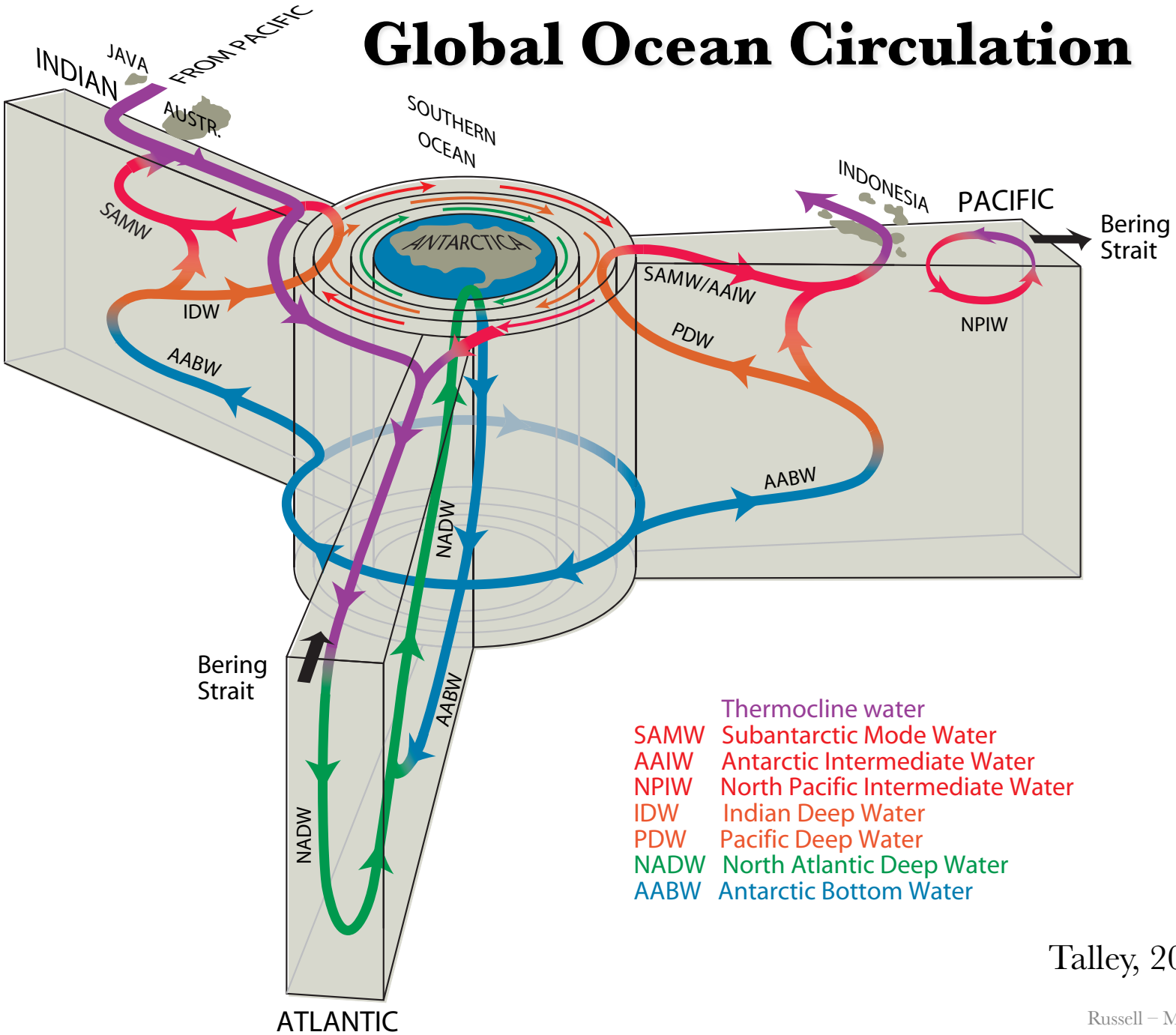
Warming Rate of deep ocean (>4000m)



Column inventory of anthropogenic CO_2 in the oceans (after Sabine et al. 2002). High inventories are associated with deep water formation in the North Atlantic and intermediate and mode water formation between 30°S and 50°S

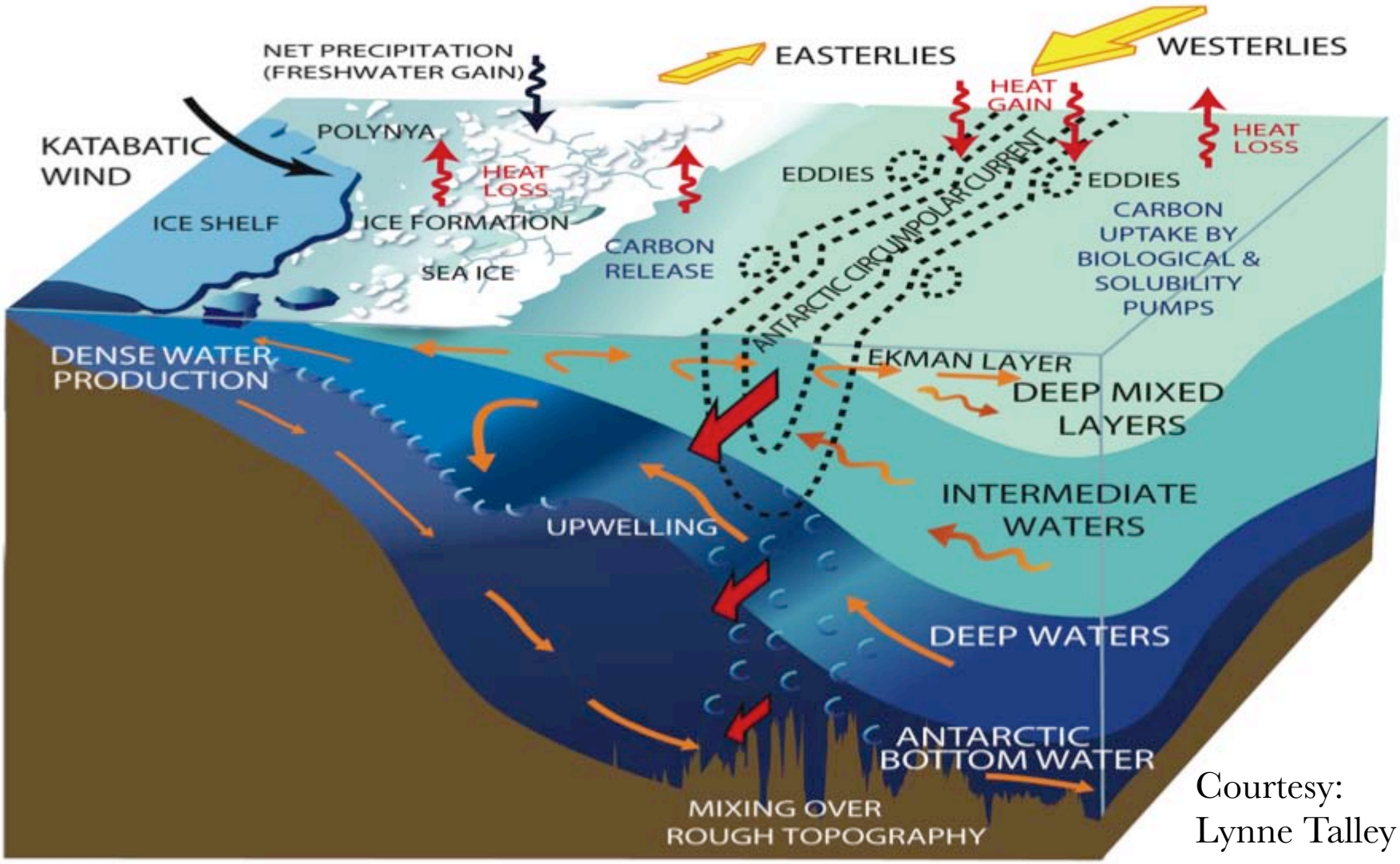
(Feely and Sabine, http://www.pmel.noaa.gov/co2/PressConference.html)

Global Ocean Circulation



Talley, 2013

The Antarctic Circumpolar Current System



Courtesy:
Lynne Talley

Simulations of the winds are getting better and are likely to continue their poleward shift over the near future.

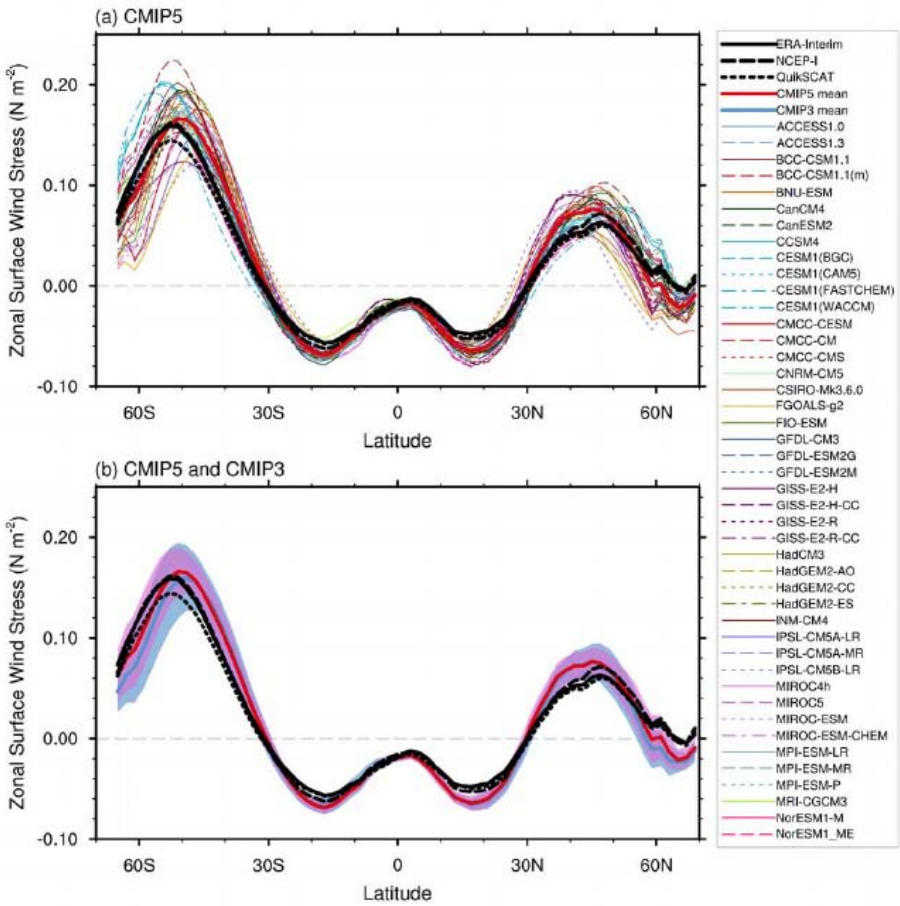


Figure 9.19: Zonal-mean zonal wind stress over the oceans in (a) CMIP5 models and (b) multi-model mean comparison with CMIP3.

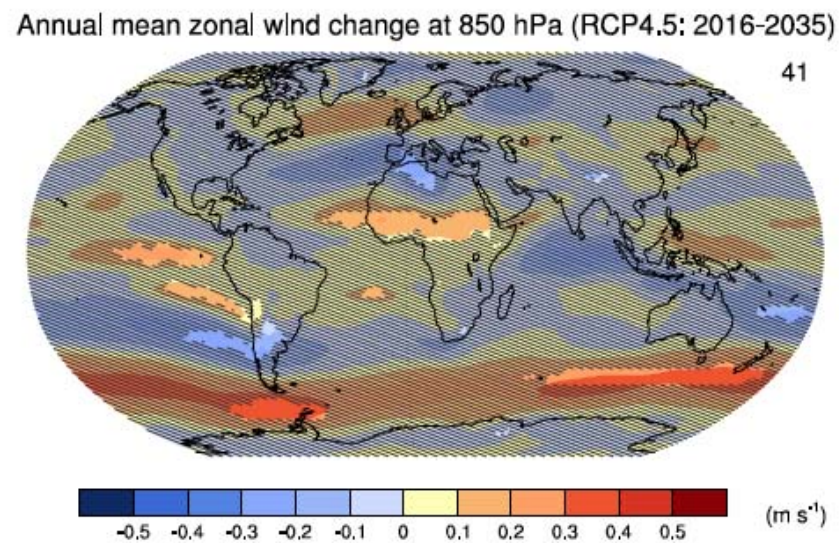


Figure 11.15: CMIP5 projected changes [m/s] in zonal (west-to-east) wind at 850hPa for 2016–2035 relative to 1986–2005 under RCP4.5.

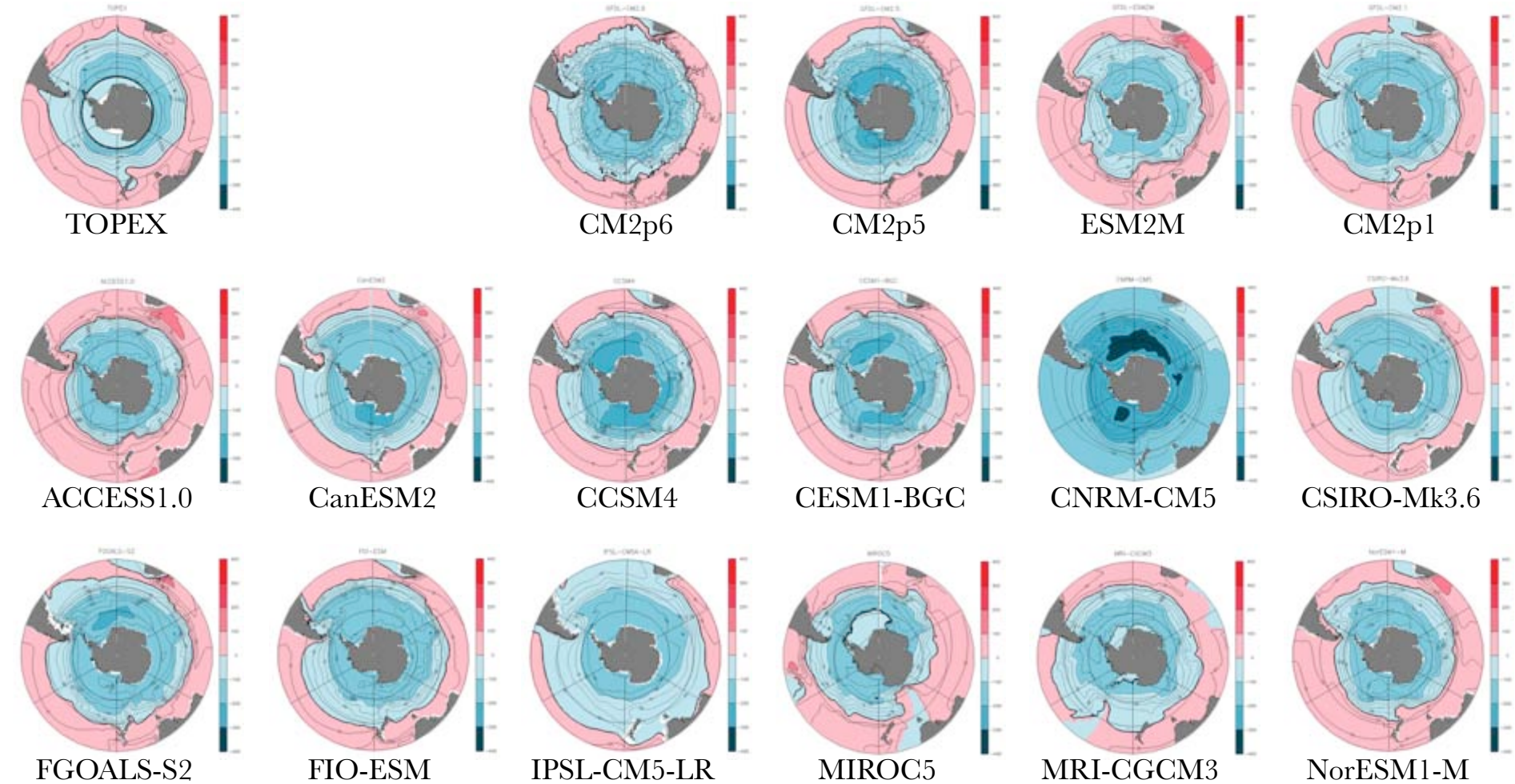
"The average 2016–2035 SH extra-tropical storm tracks and zonal winds are *likely* to shift poleward relative to 1986–2005."

Simulated Sea Surface Height (cm)

Annual mean, 2001-2005

Observed

GFDL

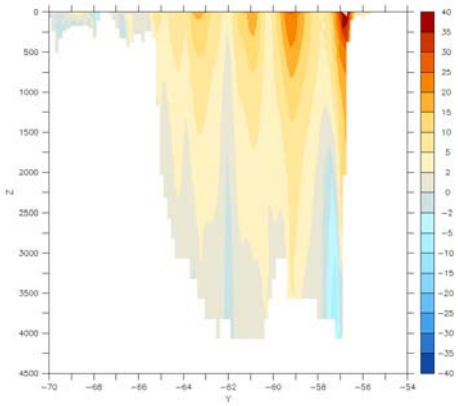


This is a different subset of CMIP5 models

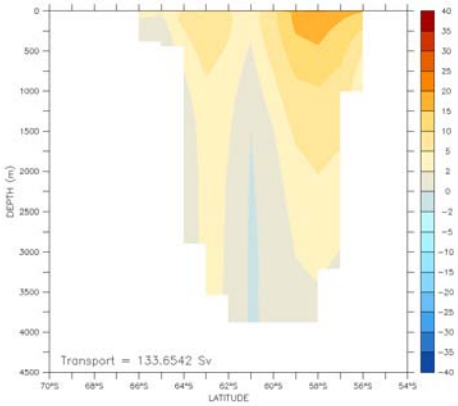
Drake Passage Transport: Zonal Velocity at 69°W

- Annual mean, 2001-2005
  Zonal Velocity
  Values are net transport through Drake Passage

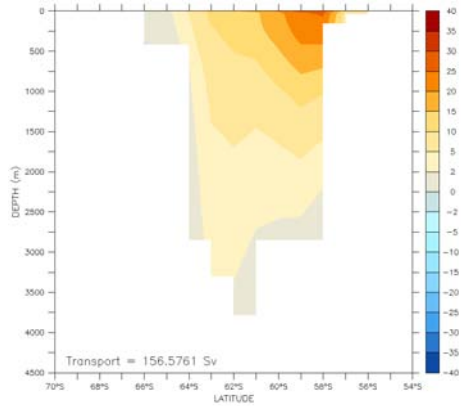
SOSE (2008)
148.1 Sv



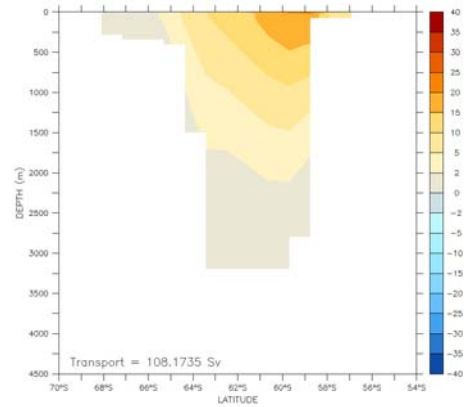
GFDL-ESM2M
133.7 Sv

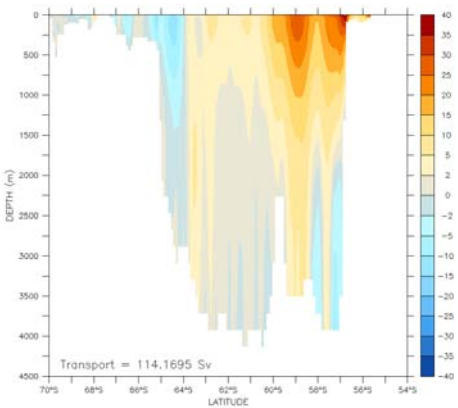


BCC-CSM2
156.6 Sv

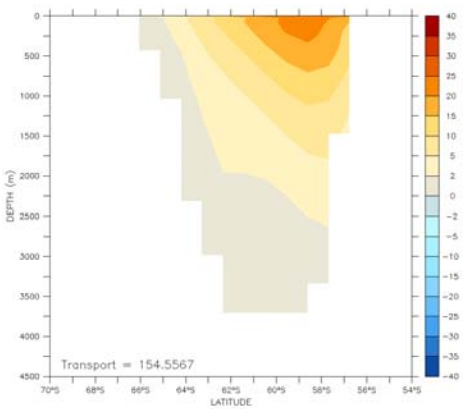


CSIRO-Mk3.6
108.2 Sv

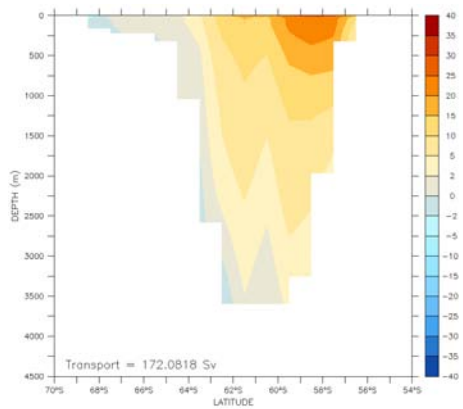




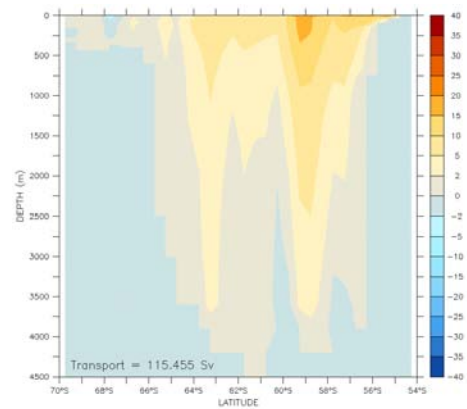
GFDL-CM2.5
114.2 Sv



CanESM2
154.6 Sv



HadGEM2-ES
172.1 Sv



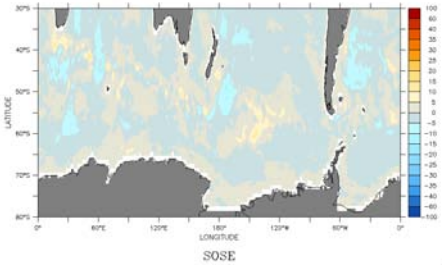
MRI
115.5 Sv

Frontal structure is not captured by lower resolution models

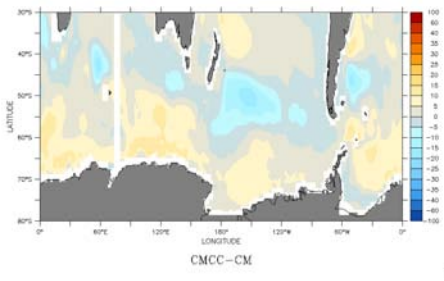
Ocean Heat Content "Error" (Modern)

(10^9 J/m^2, difference from WOA2009)

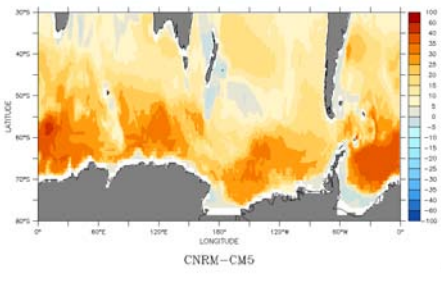
SOSE



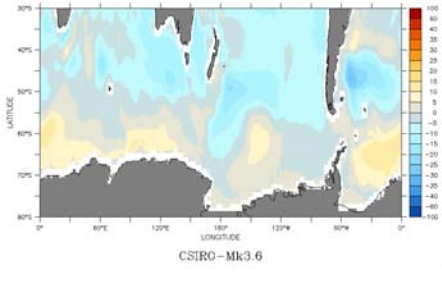
CMCC



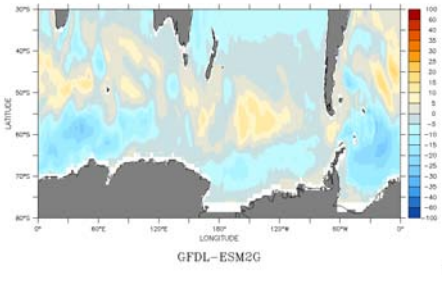
CNRM



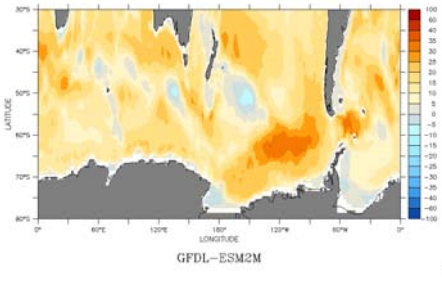
CSIRO



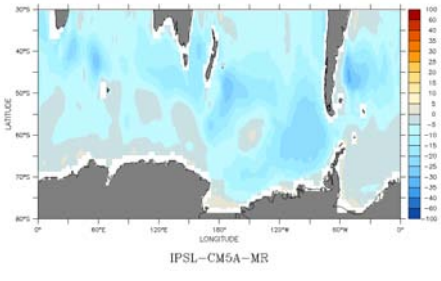
ESM2G



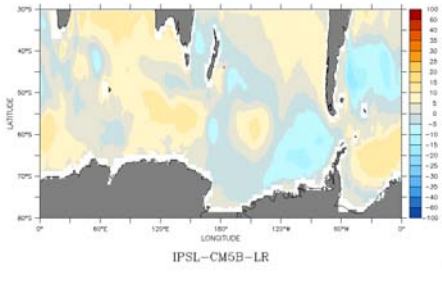
ESM2M



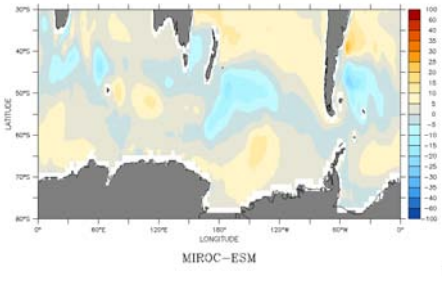
IPSL-MR



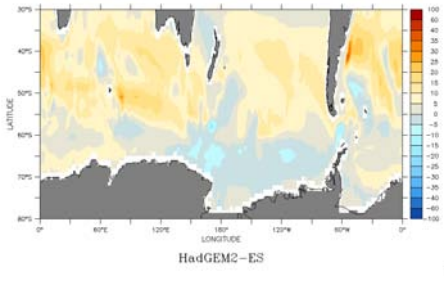
IPSL-LR



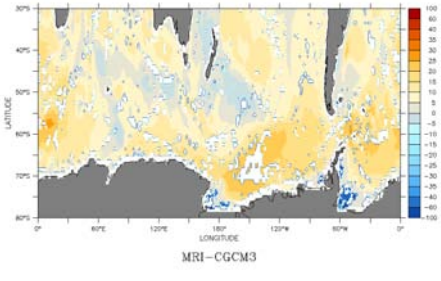
MIROC



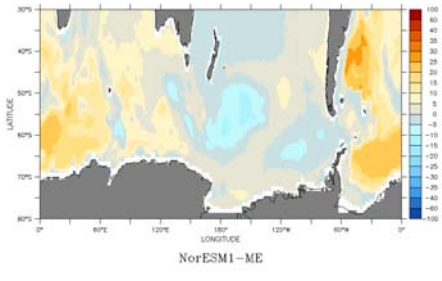
HadGEM2-ES



MRI



NorESM



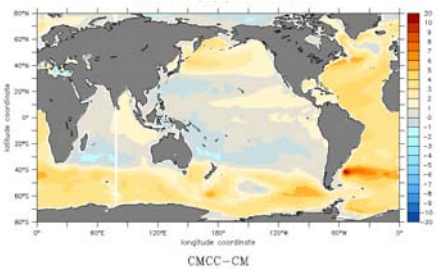
All averages are for model years 1986-2005, SOSE is annual average for 2008

Rate of Uptake of Heat by the Ocean (Future-Modern)

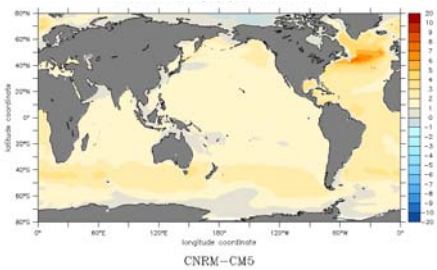
(W/m^2, over the next century [2081-2100 minus 1986-2005])

SOSE

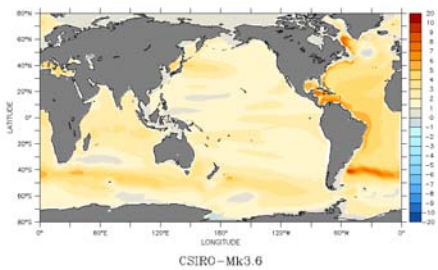
CMCC



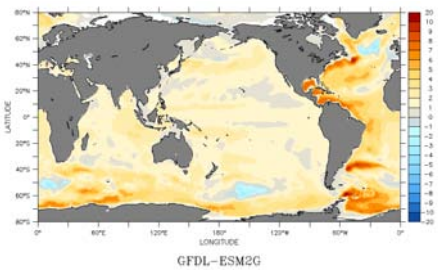
CNRM



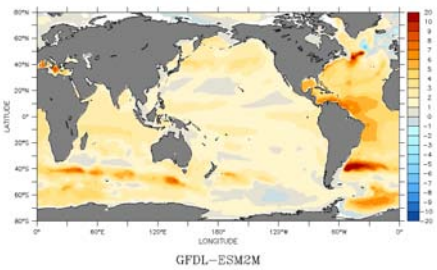
CSIRO



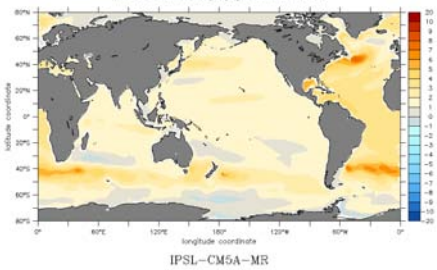
ESM2G



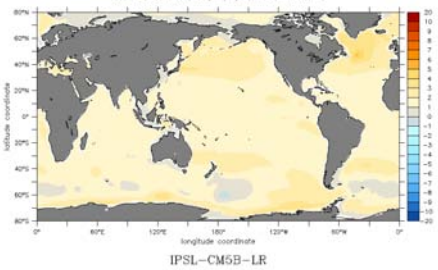
ESM2M



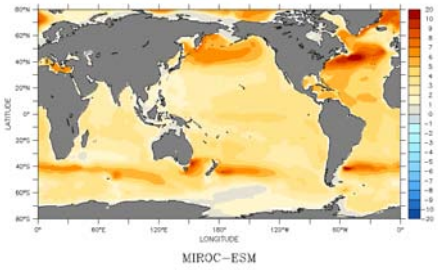
IPSL-MR



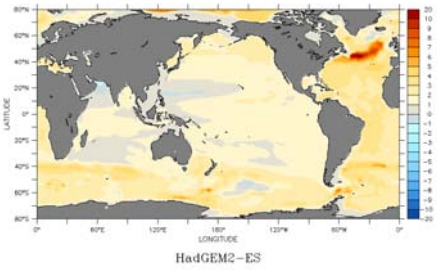
IPSL-LR



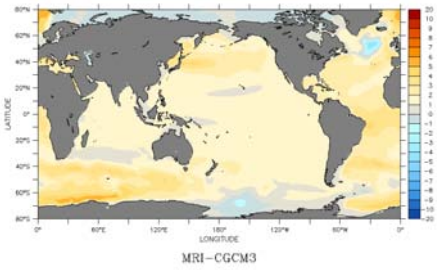
MIROC



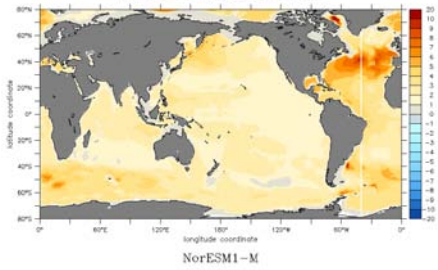
HadGEM2-ES



MRI



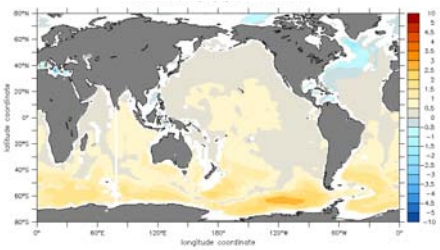
NorESM



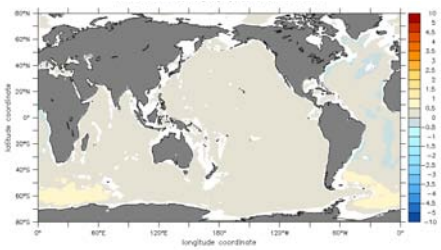
Rate of Uptake of Heat by the Lower Ocean (below 2000m)

(W/m^2, over the next century [2081-2100 minus 1986-2005])

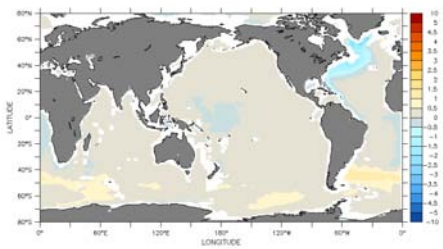
CMCC



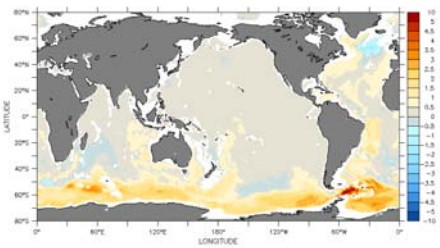
CNRM



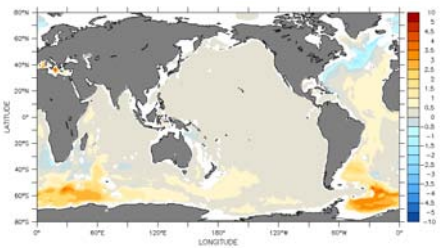
CSIRO



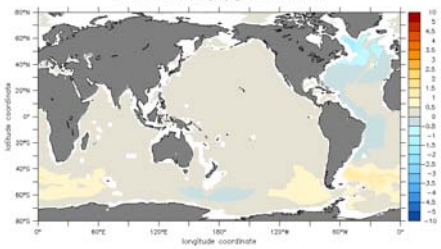
ESM2G



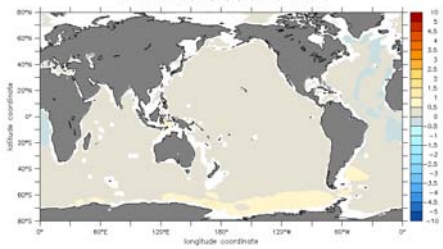
ESM2M



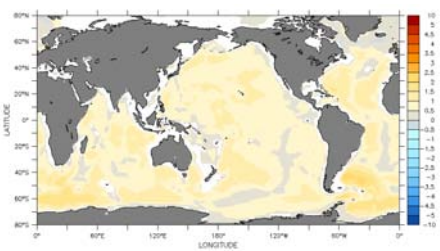
IPSL-MR



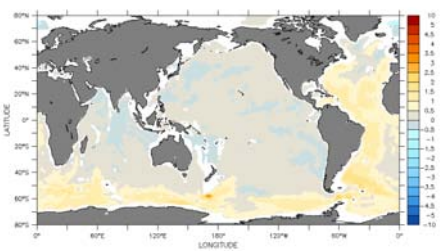
IPSL-LR



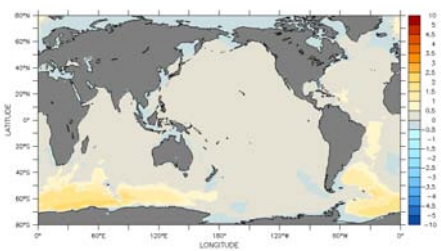
MIROC



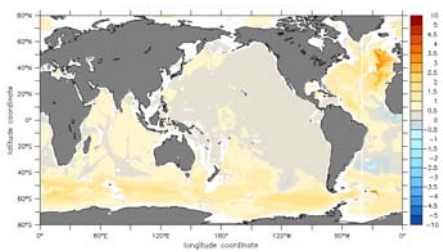
HadGEM2-ES



MRI



NorESM

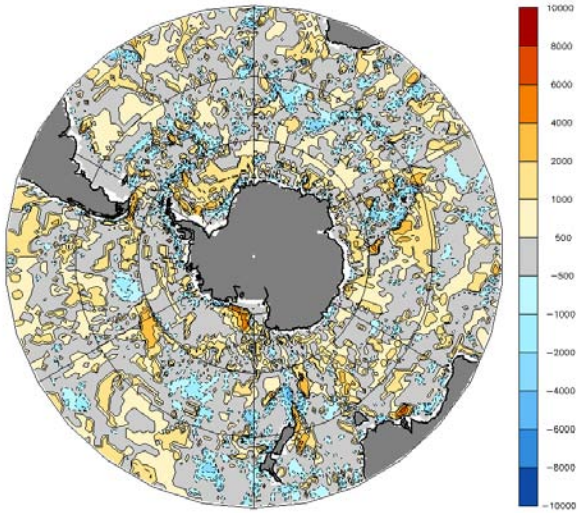


Colum Inventory DIC Difference

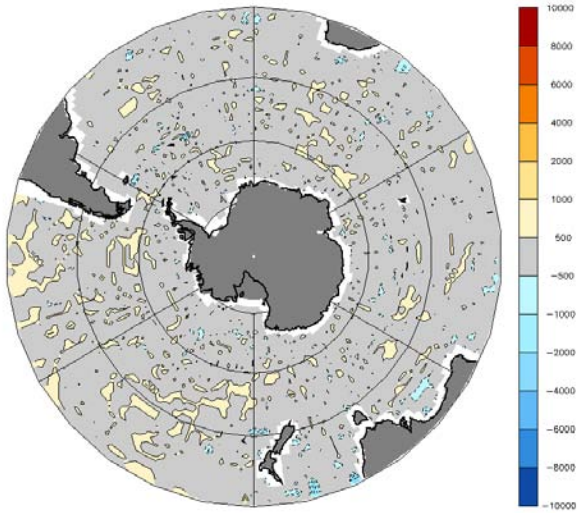
(mol/m^2; Difference From GLODAP)

- Annual mean (2001-2005)

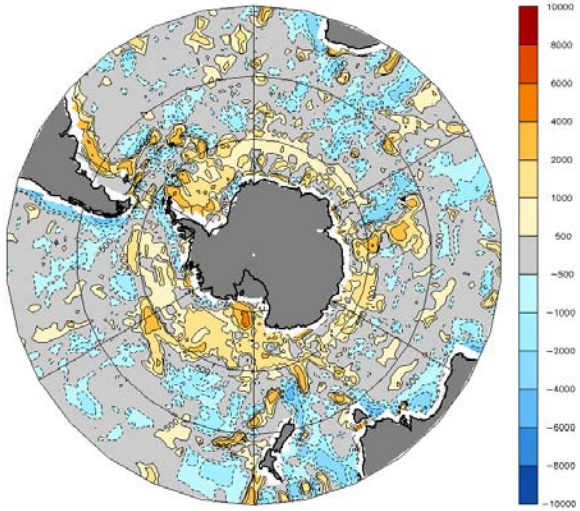
GFDL-ESM2M



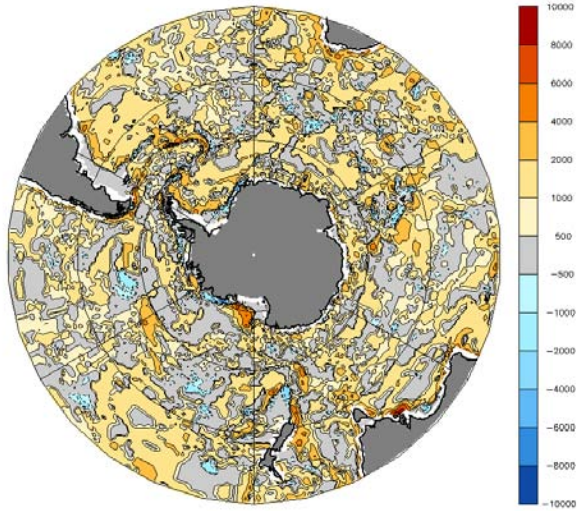
CanESM2



MIROC-ESM



MRI-ESM1



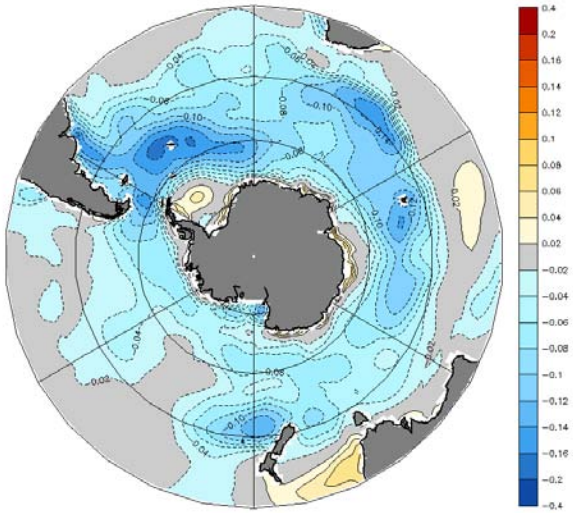
Some of the column inventory difference may reflect differences in the model bathymetry from observed

Surface Water pH Difference

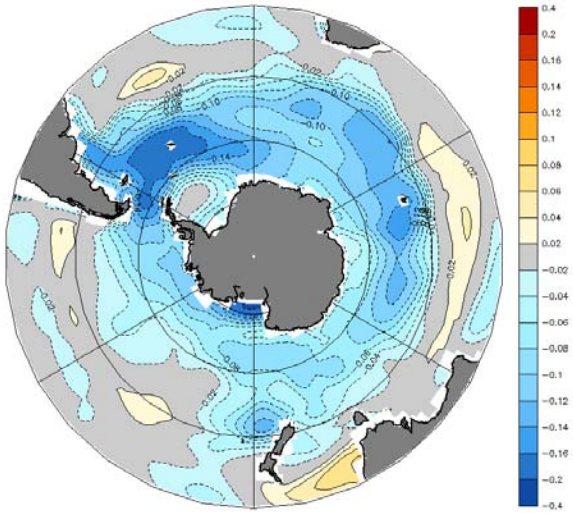
(From GLODAP/WOA2001)

- Annual mean (2001-2005)

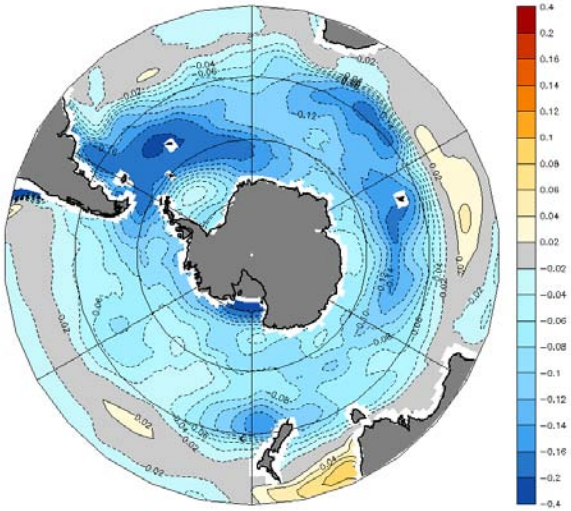
GFDL-ESM2M



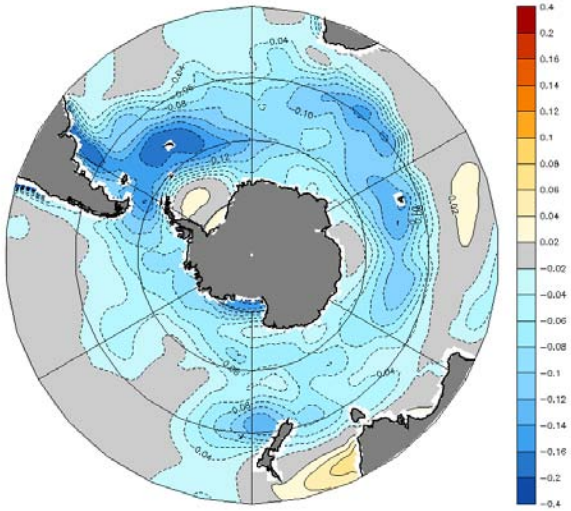
CanESM2



MIROC-ESM

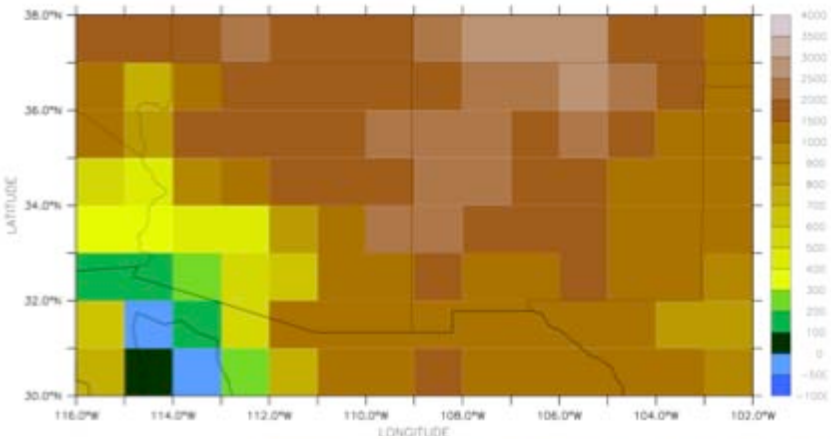


MRI-ESM1

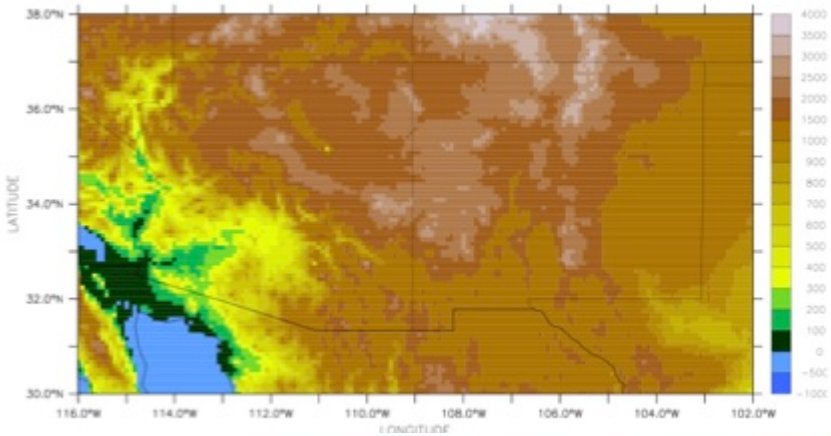


Observed pH was calculated from the GLODAP TCO_2 and Alkalinity and the World Ocean Atlas (2001) Temperature and Salinity using the formulas from Dickson (2007)

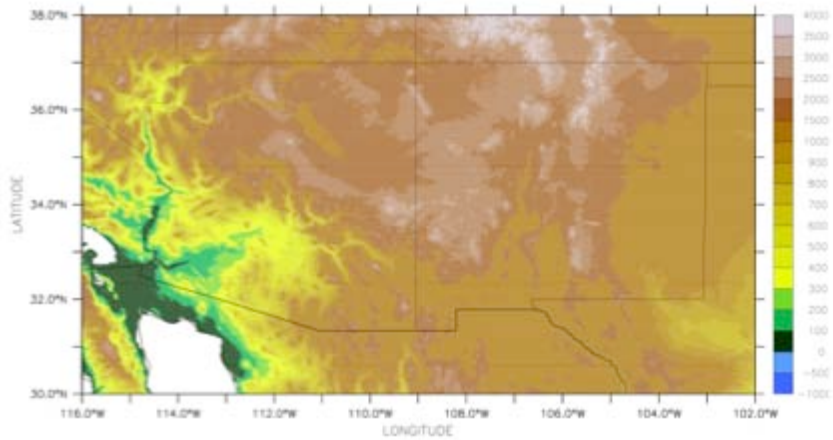
Resolution



1°x1°
(~111 km)



1/12°x1/12°
(~10 km)



1/120°x1/120°
(~1 km)

ABOUT | WCRP CMIP3 | PROJECTS | SOFTWARE | PUBLICATIONS | LINKS

PCMDI

Program for Climate Model Diagnosis and Intercomparison

11:18:15 - 9/20/2012

- About PCMDI
- CMIP3
- CMIP5
- Other CMIPs
- CAPT
- Software
- Publications
- Calendar
- Site Map

UCRL-WEB-152471

PCMDI | Printer Friendly Version

Welcome to PCMDI!

PCMDI was established in 1989 at the Lawrence Livermore National Laboratory (**LLNL**), located in the **San Francisco Bay area, in California**. Our **staff** includes research scientists, computer scientists, and diverse support personnel. We are primarily funded by the **Regional and Global Climate Modeling (RGCM)** Program and the **Atmospheric System Research (ASR)** Program of the **Climate and Environmental Sciences Division** of the U.S. Department of Energy's Office of Science, **Biological and Environmental Research (BER)** program.

The PCMDI mission is to develop improved methods and tools for the diagnosis and intercomparison of general circulation models (GCMs) that simulate the global climate. The need for innovative analysis of GCM climate simulations is apparent, as increasingly more complex models are developed, while the disagreements among these simulations and relative to climate observations remain significant and poorly understood. The nature and causes of these disagreements must be accounted for in a systematic fashion in order to confidently use GCMs for simulation of putative global climate change.

PCMDI's mission demands that we work on both scientific projects and infrastructural tasks. Our current scientific projects focus on supporting **model intercomparison,** on developing a **model parameterization testbed,** and on devising robust statistical methods for climate-change **detection/attribution.** Examples of ongoing infrastructural tasks include the development of **software** for data management, visualization, and computation ; the assembly/organization of observational data sets for model validation; and the consistent documentation of **climate model features.** Details of all this work are described in numerous **publications,** as well as on this website.

We now also are applying our collective expertise to support modeling studies initiated by the World Climate Research Programme (**WCRP**). Notably, we are currently providing leadership in managing the Coupled Model Intercomparison Project, Phase 5 (**CMIP5**). Among PCMDI's role in CMIP5 is responsibility for leading the Earth System Grid Federation (**ESGF**) which stores and distributes terrascale data sets from multiple coupled ocean-atmosphere global climate model simulations. Extensive analysis of these simulations by members of the international climate community will provide an important scientific basis for **the IPCC's Fifth Assessment Report on Climate Change,** which is scheduled for publication in 2013.

http://www-pcmdi.llnl.gov/

gfdl's home page > products and services > data portal

gfdl's data portal

CMIP3

- Official Site
- Available Data

CMIP5

- Official Site
- GFDL CMIP5 Overview
- Available Data
- ESGF Server

Ocean Data Assimilation Experiments (ODA)

- Related Info
- FTP Data
- LAS Access

North American Regional Climate Change Assessment Program (NARCCAP)

- Related Info
- CM2.1 experiments (6hr data)
- AM2.1 historical experiment
- AM2.1 sres experiment

Our Data Portal Services

Spotlight on NOMADS

NOMADS is being developed as a Unified Climate and Weather Archive to provide Web access to model information so that users can make decisions about their specific needs. This spans time scales from days (weather), to months (El Nino), to decades (global warming). For more, see NCDC's nomads page.

Spotlight on GO-ESSP

The Global Organization for Earth System Science Portal (GO-ESSP) is a collaboration designed to build the infrastructure needed to create

Public Data Files

- DecCen Coupled Climate Experiments
- Ocean Data Assimilation Experiments
- Flexible Modeling System

Public Source Code

- MOM4 registration
- MOM4 related data sets
- HIM registration
- HIM beta source code

Related Sites

- National Oceanic and Atmospheric Adminstration
- OAR
- Dept. of Commerce

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DATA CENTER

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UA Research Data Center

Overview

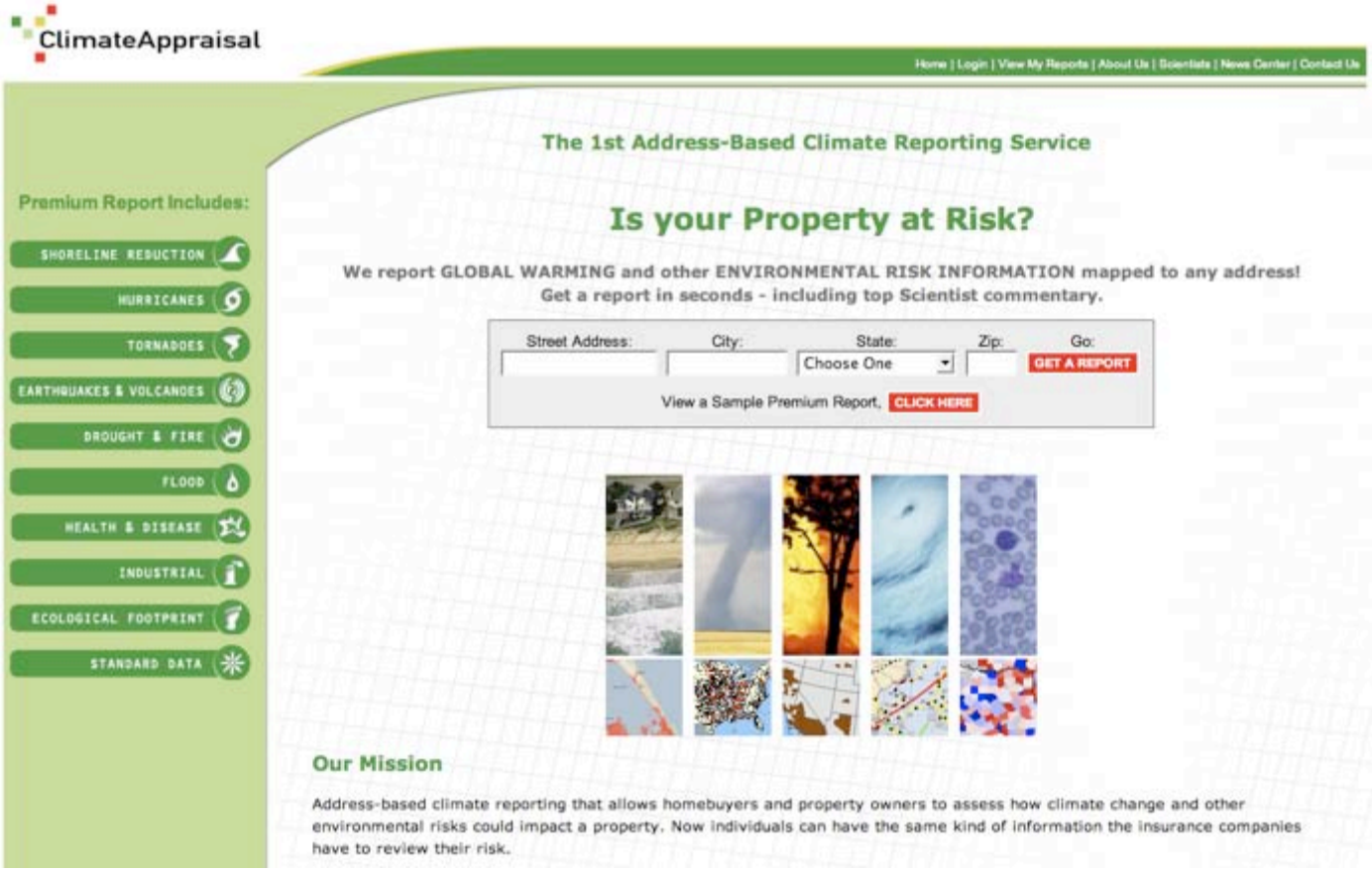
The new University of Arizona Research Data Center (RDC) is a state-of-the-art computer storage hub that triples the university's previous capacity to host centralized large computer clusters. Scientific research, particularly the kind done at the university, relies upon HPC/HTC capacity to hold and analyze the multitude of data collected during research. These services are open to any faculty, researcher or student who has a use for HPC/HTC systems.

Computer System Types

1. **Shared Memory** - High Performance Computing (HPC) systems enable users to run a single instance of parallel software over many processors.
2. **Distributed Memory** - Distributed memory refers to multiple-processor computer systems in which each processor has access to its own dedicated memory.
3. **High Throughput** - HighThroughput Computing (HTC) serial systems are more suited to running multiple independent instances of software on multiple processors at the same time.

UA Research Data Center Information/Specifications

So ….. Climate Change Info for your House?



We're not there yet ……

….. but we're working on it.