Oluwakemi Izomo

Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

Class 7: Climate and Coastal Hazards

Questions and Conclusions:

- How well do we know past and current changes:
  - We have comprehensive observations that document the variability of the system
  - Detecting changes in dynamics and system state is nevertheless difficult due to large variability
  - knowledge about changes in variables and underlying processes is evolving rapidly
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?

Mitigation and Adaptation Studies

Mitigation and Adaptation Studies

MARI
MITIGATION & ADAPTATION RESEARCH INSTITUTE
OLD DOMINION UNIVERSITY

Class 8: Climate and Coastal Hazards, Public Health, Food Security

Mitigation and Adaptation Studies

Class 8: Climate and Coastal Hazards, Public Health, Food Security

Contents:

- Assignments
- Climate Change and Sea Level Hazards
  - (Detecting Changes)
  - Assessing Knowledge
  - Understanding the Processes and Causes
  - Predicting Future Changes
  - Having Foresight
- Public Health
- Food-Water-Energy Nexus

Understanding the Causes

Understanding the Causes

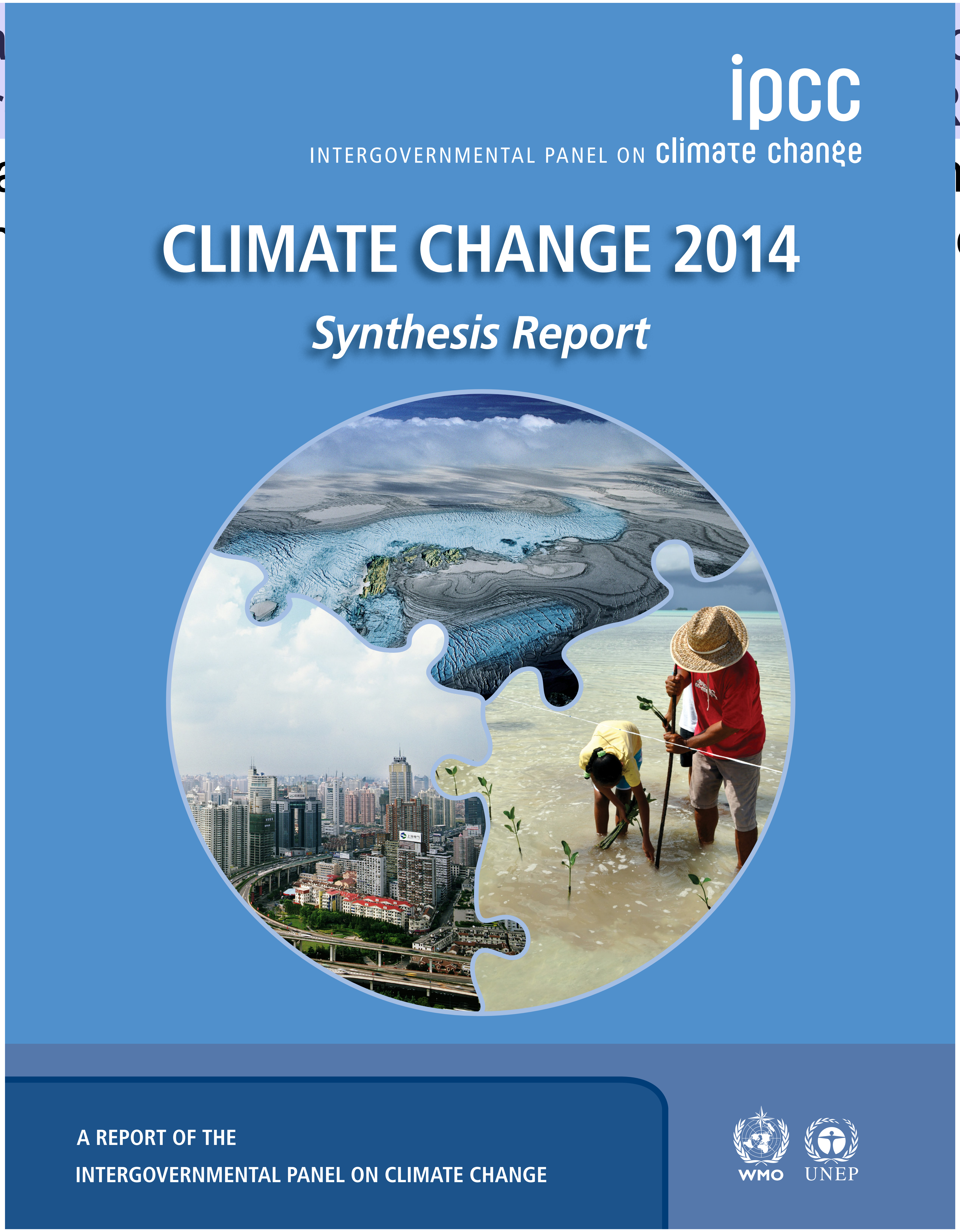
1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

Understanding the Causes

1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

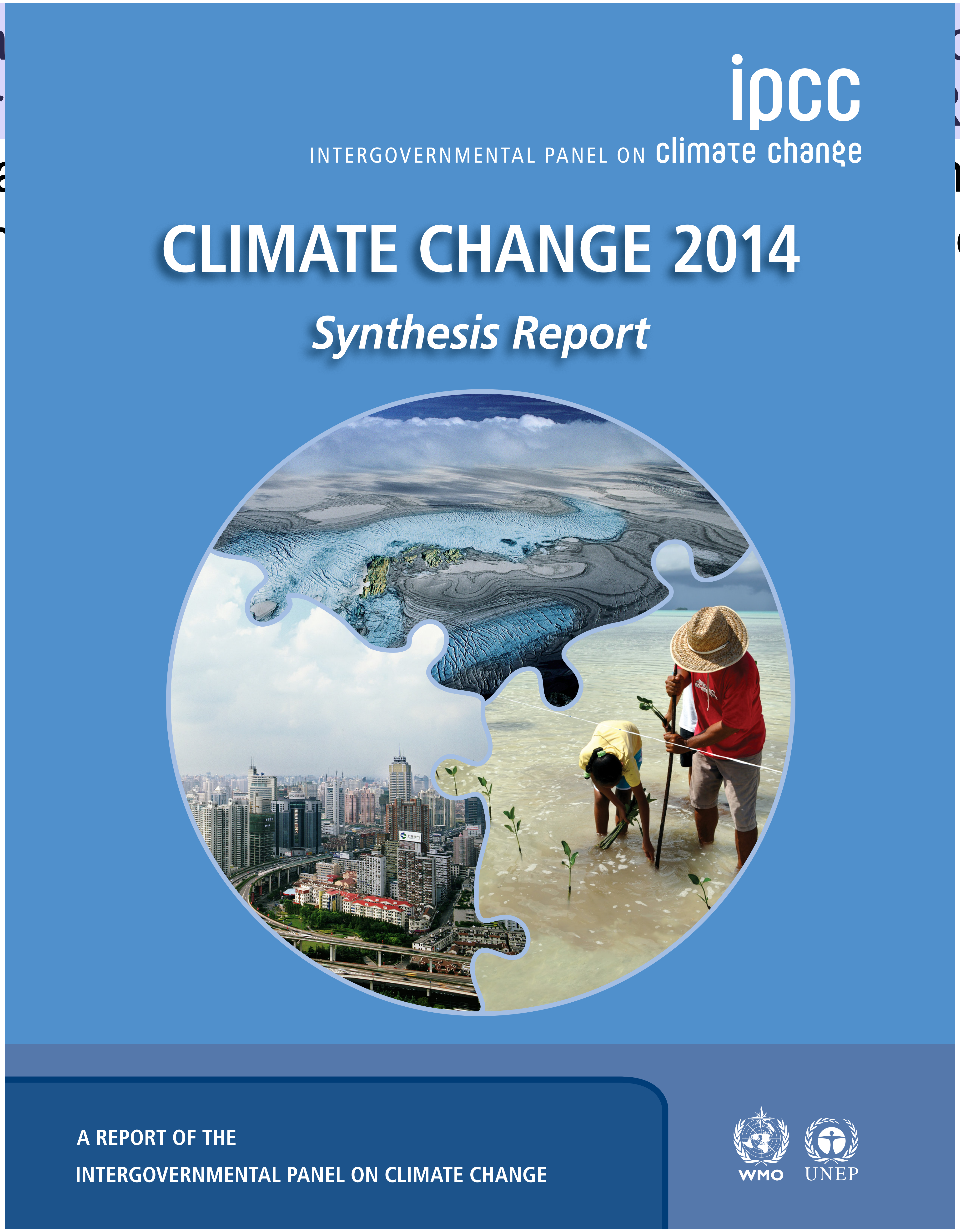
Understanding the Causes

1 To wha… …dress the drivers behind climate change, and how ar… …eport?
2 Summa… …ange and sea level rise for public health.
3 Explai… …ergy nexus.



Understanding the Causes

1 To wha… dress th… how ar… eport?
2 Summa… ange ar…
3 Explair… ergy ne…



SPM

Summary for Policymakers

Drafting Authors:
Lisa V. Alexander (Australia), Simon K. Allen (Switzerland/New Zealand), Nathaniel L. Bindoff (Australia), François-Marie Bréon (France), John A. Church (Australia), Ulrich Cubasch (Germany), Seita Emori (Japan), Piers Forster (UK), Pierre Friedlingstein (UK/Belgium), Nathan Gillett (Canada), Jonathan M. Gregory (UK), Dennis L. Hartmann (USA), Eystein Jansen (Norway), Ben Kirtman (USA), Reto Knutti (Switzerland), Krishna Kumar Kanikicharla (India), Peter Lemke (Germany), Jochem Marotzke (Germany), Valérie Masson-Delmotte (France), Gerald A. Meehl (USA), Igor I. Mokhov (Russian Federation), Shilong Piao (China), Gian-Kasper Plattner (Switzerland), Qin Dahe (China), Venkatachalam Ramaswamy (USA), David Randall (USA), Monika Rhein (Germany), Maisa Rojas (Chile), Christopher Sabine (USA), Drew Shindell (USA), Thomas F. Stocker (Switzerland), Lynne D. Talley (USA), David G. Vaughan (UK), Shang-Ping Xie (USA)

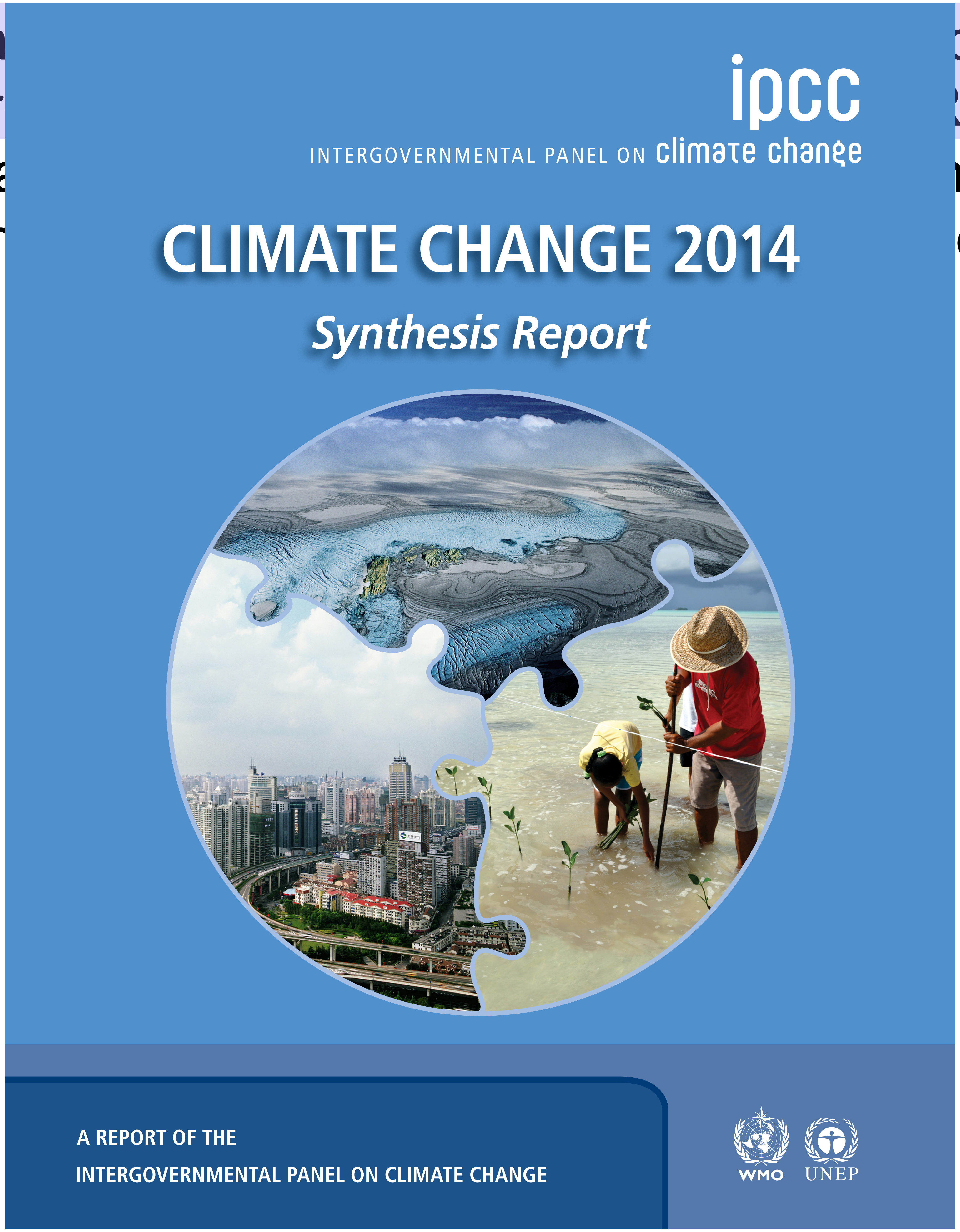
Draft Contributing Authors:
Myles R. Allen (UK), Olivier Boucher (France), Don Chambers (USA), Jens Hesselbjerg Christensen (Denmark), Philippe Ciais (France), Peter U. Clark (USA), Matthew Collins (UK), Josefino C. Comiso (USA), Viviane Vasconcellos de Menezes (Australia/Brazil), Richard A. Feely (USA), Thierry Fichefet (Belgium), Arlene M. Fiore (USA), Gregory Flato (Canada), Jan Fuglestvedt (Norway), Gabriele Hegerl (UK/Germany), Paul J. Hezel (Belgium/USA), Gregory C. Johnson (USA), Georg Kaser (Austria/Italy), Vladimir Kattsov (Russian Federation), John Kennedy (UK), Albert M. G. Klein Tank (Netherlands), Corinne Le Quéré (UK), Gunnar Myhre (Norway), Timothy Osborn (UK), Antony J. Payne (UK), Judith Perlwitz (USA), Scott Power (Australia), Michael Prather (USA), Stephen R. Rintoul (Australia), Joeri Rogelj (Switzerland/Belgium), Matilde Rusticucci (Argentina), Michael Schulz (Germany), Jan Sedláček (Switzerland), Peter A. Stott (UK), Rowan Sutton (UK), Peter W. Thorne (USA/Norway/UK), Donald Wuebbles (USA)

This Summary for Policymakers should be cited as:
IPCC, 2013: Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)). Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

3

Understanding the Causes

1 To wha d
how ar e
2 Summa a
3 Explai e



SPM

C. Drivers of Climate Change

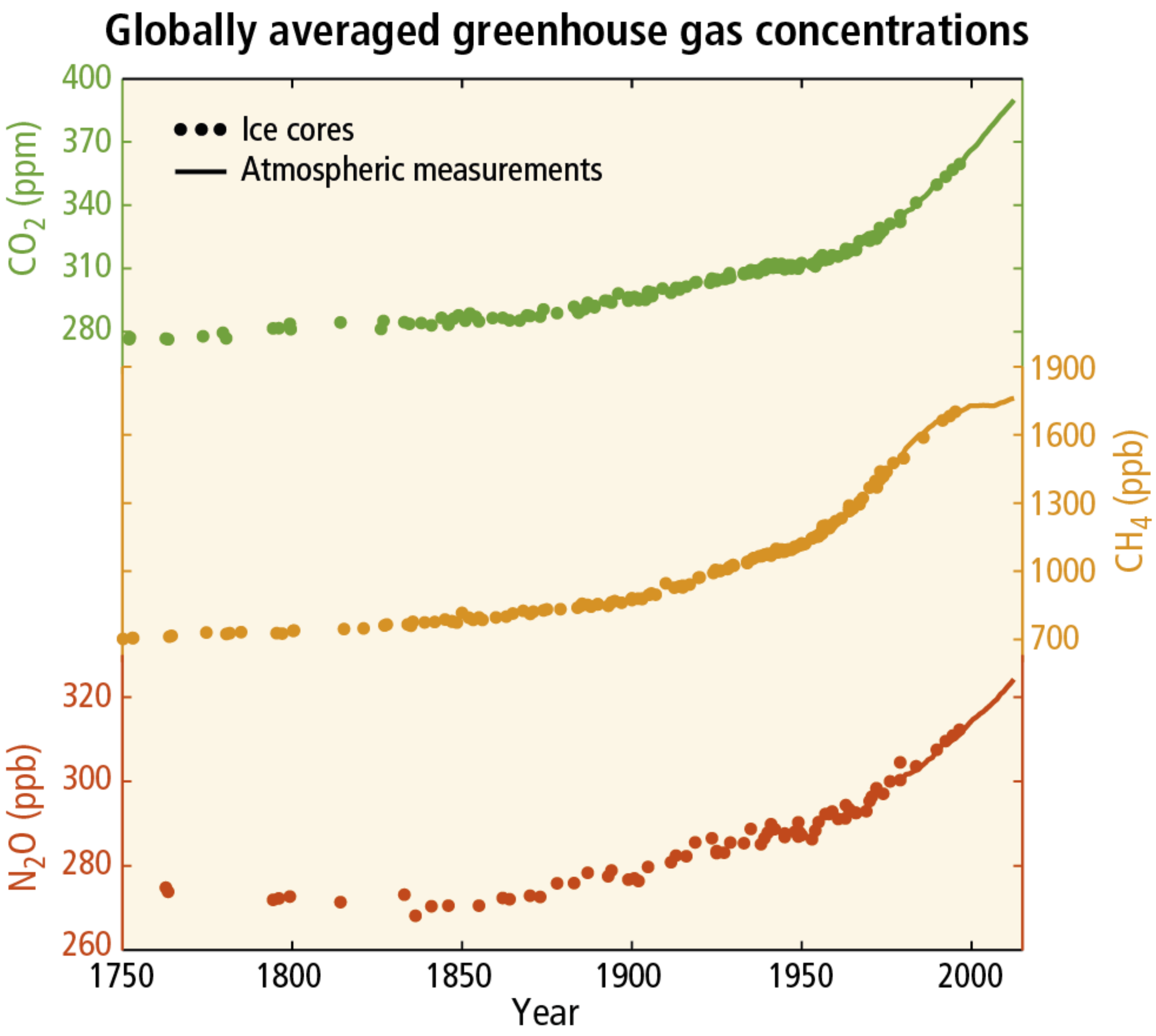
Natural and anthropogenic substances and processes that alter the Earth's energy budget are drivers of climate change. Radiative forcing[14] (RF) quantifies the change in energy fluxes caused by changes in these drivers for 2011 relative to 1750, unless otherwise indicated. Positive RF leads to surface warming, negative RF leads to surface cooling. RF is estimated based on in-situ and remote observations, properties of greenhouse gases and aerosols, and calculations using numerical models representing observed processes. Some emitted compounds affect the atmospheric concentration of other substances. The RF can be reported based on the concentration changes of each substance[15]. Alternatively, the emission-based RF of a compound can be reported, which provides a more direct link to human activities. It includes contributions from all substances affected by that emission. The total anthropogenic RF of the two approaches are identical when considering all drivers. Though both approaches are used in this Summary for Policymakers, emission-based RFs are emphasized.

Total radiative forcing is positive, and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO_2 since 1750 (see Figure SPM.5). {3.2, Box 3.1, 8.3, 8.5}

- The total anthropogenic RF for 2011 relative to 1750 is 2.29 [1.13 to 3.33] W m^{-2} (see Figure SPM.5), and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43% higher than that reported in AR4 for the year 2005. This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect (negative RF). {8.5}
- The RF from emissions of well-mixed greenhouse gases (CO_2, CH_4, N_2O, and Halocarbons) for 2011 relative to 1750 is 3.00 [2.22 to 3.78] W m^{-2} (see Figure SPM.5). The RF from changes in concentrations in these gases is 2.83 [2.26 to 3.40] W m^{-2}. {8.5}
- Emissions of CO_2 alone have caused an RF of 1.68 [1.33 to 2.03] W m^{-2} (see Figure SPM.5). Including emissions of other carbon-containing gases, which also contributed to the increase in CO_2 concentrations, the RF of CO_2 is 1.82 [1.46 to 2.18] W m^{-2}. {8.3, 8.5}
- Emissions of CH_4 alone have caused an RF of 0.97 [0.74 to 1.20] W m^{-2} (see Figure SPM.5). This is much larger than the concentration-based estimate of 0.48 [0.38 to 0.58] W m^{-2} (unchanged from AR4). This difference in estimates is caused by concentration changes in ozone and stratospheric water vapour due to CH_4 emissions and other emissions indirectly affecting CH_4. {8.3, 8.5}
- Emissions of stratospheric ozone-depleting halocarbons have caused a net positive RF of 0.18 [0.01 to 0.35] W m^{-2} (see Figure SPM.5). Their own positive RF has outweighed the negative RF from the ozone depletion that they have induced. The positive RF from all halocarbons is similar to the value in AR4, with a reduced RF from CFCs but increases from many of their substitutes. {8.3, 8.5}
- Emissions of short-lived gases contribute to the total anthropogenic RF. Emissions of carbon monoxide (CO) are *virtually certain* to have induced a positive RF, while emissions of nitrogen oxides (NO_x) are *likely* to have induced a net negative RF (see Figure SPM.5). {8.3, 8.5}

Understanding the Causes

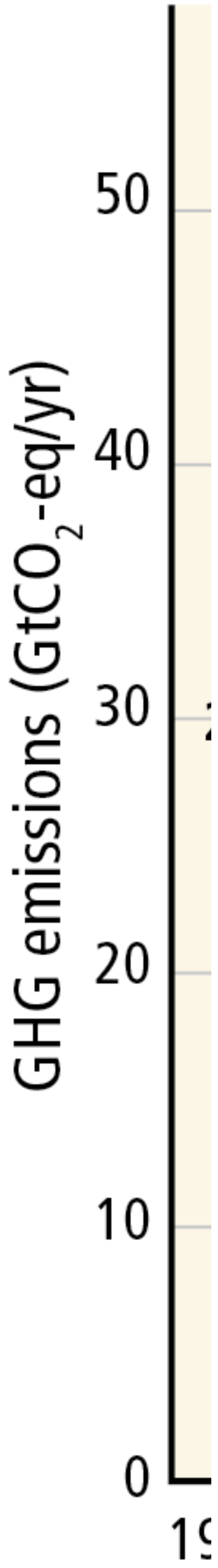
Understanding the Causes



Understanding the Causes

Understanding the Causes

Total annual anthropogenic GHG emissions by gases 1970–2010



F-gases and Radiative Forcing

Greenhouse gases have different strengths – some warm the globe more than others. To measure their net impact on the climate system, we use radiative forcing. The International Panel on Climate Change (IPCC) regularly measures the total net human contribution to radiative forcing. Their findings show two things:

1. A significant proportion of the global warming already happening is due to F-gases, including banned ozone-depleting substances, already in the atmosphere.

2. The effect of the legal gas HFC will grow massively if allowed to be produced in “business as usual” amounts.

Types of gases

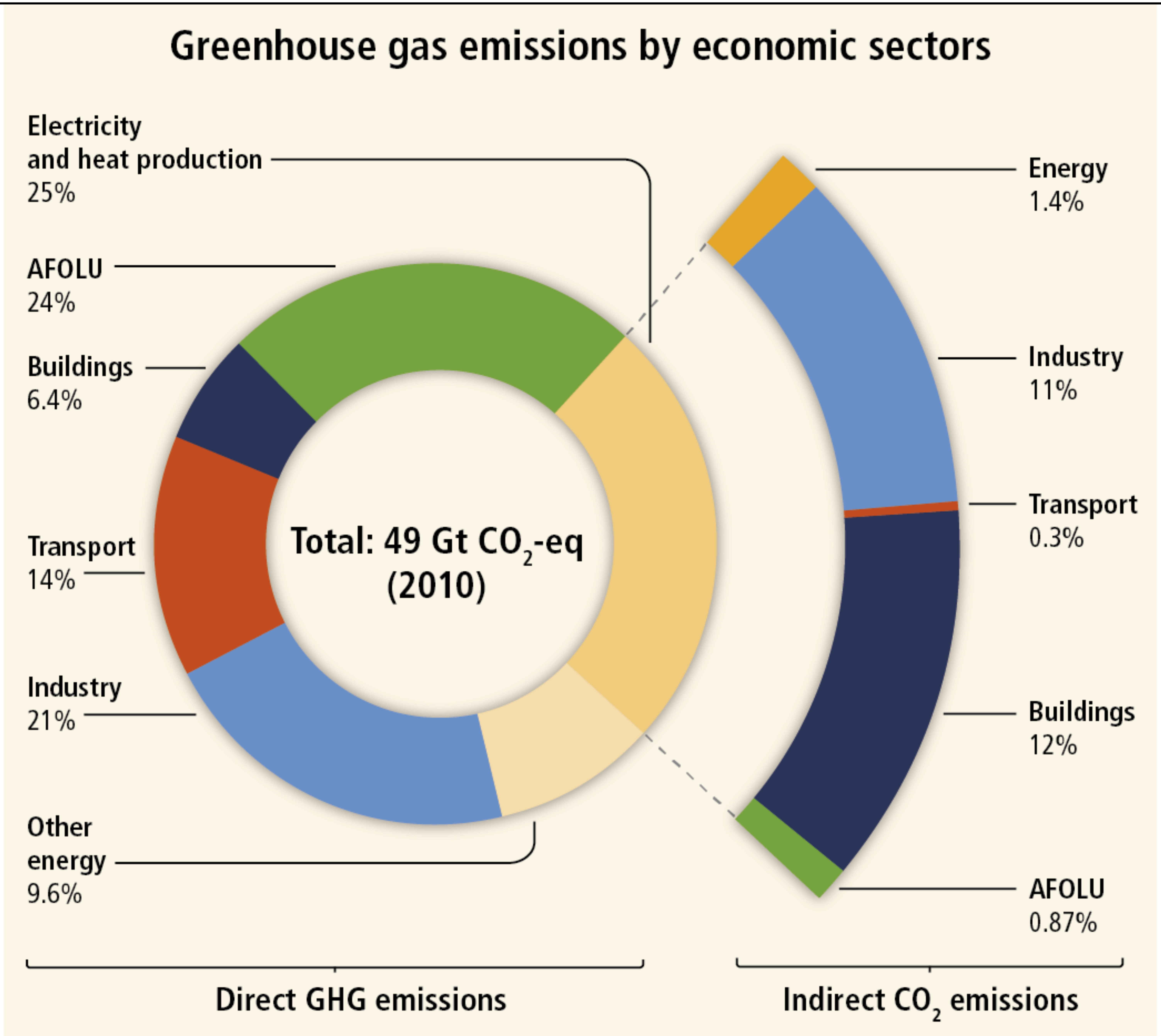
Ozone depleting substances: now banned under the Montreal Protocol of 1992
Chlorofluorocarbons (CFCs), Hydro-chlorofluorocarbons (HCFCs), Carbon Tetrachloride (CCL_4)

Kyoto F-gases: counted in Kyoto Protocol measurements for human-induced warming
Hydro-fluorocarbons (HFCs), Perfluorocarbons (PFCs), and Sulphur Hexafluoride (SF_6)

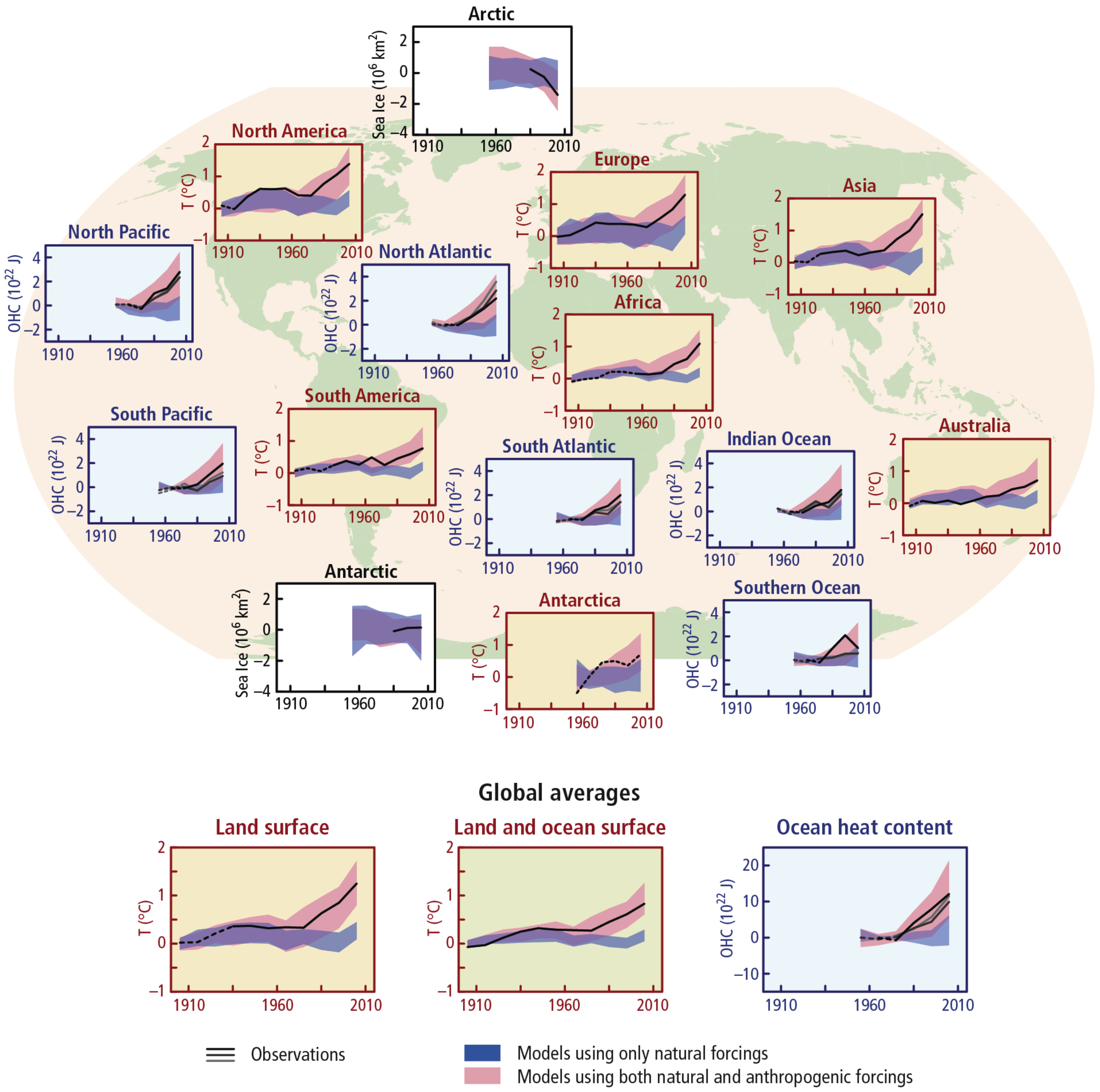
Understanding the Causes

Total annual anthropogenic GHG emissions by gases 1970–2010

Understanding the Causes



Understanding the Causes



Assignment

1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

Assignment

1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

Assignment

Table 1 Vulnerability to and impacts of LSLR

Hazard or impact	*Direct health impacts*	*Health infrastructure*
Catastrophic coastal flooding	Deaths through drowning and other causes, injuries, infectious diseases (respiratory, intestinal, skin), mental health disorders	Health services interruption, availability of health staff, transportation disruption, energy and other supplies
Flood-induced pollution	Infectious diseases, allergies	Long-lasting degradation of health service infrastructure
Reduced water quality and reduced access to potable water due to salinification and/or pollution	Diarrheal diseases (giardia, cholera), hepatitis, other water borne diseases	Reduced water supply for health services
Impairment of food quality (through pollution of farmland and fisheries) and reduction of food supply (e.g., loss of farmland and decreasing productivity of fisheries)	Malnutrition; shellfish poisoning, marine bacteria proliferation	Food safety
Change in transmission intensity, distribution of vector-borne disease, abundance of vectors	Changes in malaria and other mosquito-borne infectious diseases	
Population displacements, degradation of livelihoods	Less well defined; can include increased social conflicts; increased crime rate; prostitution to replace lost income	General stress on health services because of rapid changes in demands

Modified from Nicholls, R. J., P. P. Wong, V. R. Burkett, J. O. Codignotto, J. E. Hay, R. F. McLean, S. Ragoonaden, and C. D. Woodroffe, 2007b: Coastal systems and low-lying areas. *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. Hanson, Eds., Cambridge University Press, Cambridge, UK, 315–356.

Assignment

Table 1 Vulnerability to and imp

Hazard or impact	
Catastrophic coastal flooding	uption, availability of ortation disruption, supplies
Flood-induced pollution	tion of health service
Reduced water quality and reduced a to potable water due to salinificati and/or pollution	y for health services
Impairment of food quality (through of farmland and fisheries) and red food supply (e.g., loss of farmland decreasing productivity of fisheries	
Change in transmission intensity, dis vector-borne disease, abundance c	
Population displacements, degradatio livelihoods	alth services because of lemands

Modified from Nicholls, R. J., P. P. Wong, ... astal systems and low-lying areas. *Climate Change 2007: Impacts, Adapt* ... *tal Panel on Climate Change*, M. L. Parry, O. F. Canziani, J. P. Palutikof,

Executive summary

Climate change currently contributes to the global burden of disease and premature deaths (very high confidence).
Human beings are exposed to climate change through changing weather patterns (temperature, precipitation, sea-level rise and more frequent extreme events) and indirectly through changes in water, air and food quality and changes in ecosystems, agriculture, industry and settlements and the economy. At this early stage the effects are small but are projected to progressively increase in all countries and regions. [8.4.1]

Emerging evidence of climate change effects on human health shows that climate change has:

- altered the distribution of some infectious disease vectors (medium confidence) [8.2.8];
- altered the seasonal distribution of some allergenic pollen species (high confidence) [8.2.7];
- increased heatwave-related deaths (medium confidence) [8.2.1].

Projected trends in climate-change-related exposures of importance to human health will:

- increase malnutrition and consequent disorders, including those relating to child growth and development (high confidence) [8.2.3, 8.4.1];
- increase the number of people suffering from death, disease and injury from heatwaves, floods, storms, fires and droughts (high confidence) [8.2.2, 8.4.1];
- continue to change the range of some infectious disease vectors (high confidence) [8.2, 8.4];
- have mixed effects on malaria; in some places the geographical range will contract, elsewhere the geographical range will expand and the transmission season may be changed (very high confidence) [8.4.1.2];
- increase the burden of diarrhoeal diseases (medium confidence) [8.2, 8.4];
- increase cardio-respiratory morbidity and mortality associated with ground-level ozone (high confidence) [8.2.6, 8.4.1.4];
- increase the number of people at risk of dengue (low confidence) [8.2.8, 8.4.1];
- bring some benefits to health, including fewer deaths from cold, although it is expected that these will be outweighed by the negative effects of rising temperatures worldwide, especially in developing countries (high confidence) [8.2.1, 8.4.1].

Adaptive capacity needs to be improved everywhere; impacts of recent hurricanes and heatwaves show that even high-income countries are not well prepared to cope with extreme weather events (high confidence). [8.2.1, 8.2.2]

Adverse health impacts will be greatest in low-income countries. Those at greater risk include, in all countries, the urban poor, the elderly and children, traditional societies, subsistence farmers, and coastal populations (high confidence). [8.1.1, 8.4.2, 8.6.1.3, 8.7]

Economic development is an important component of adaptation, but on its own will not insulate the world's population from disease and injury due to climate change (very high confidence).
Critically important will be the manner in which economic growth occurs, the distribution of the benefits of growth, and factors that directly shape the health of populations, such as education, health care, and public-health infrastructure. [8.3.2]

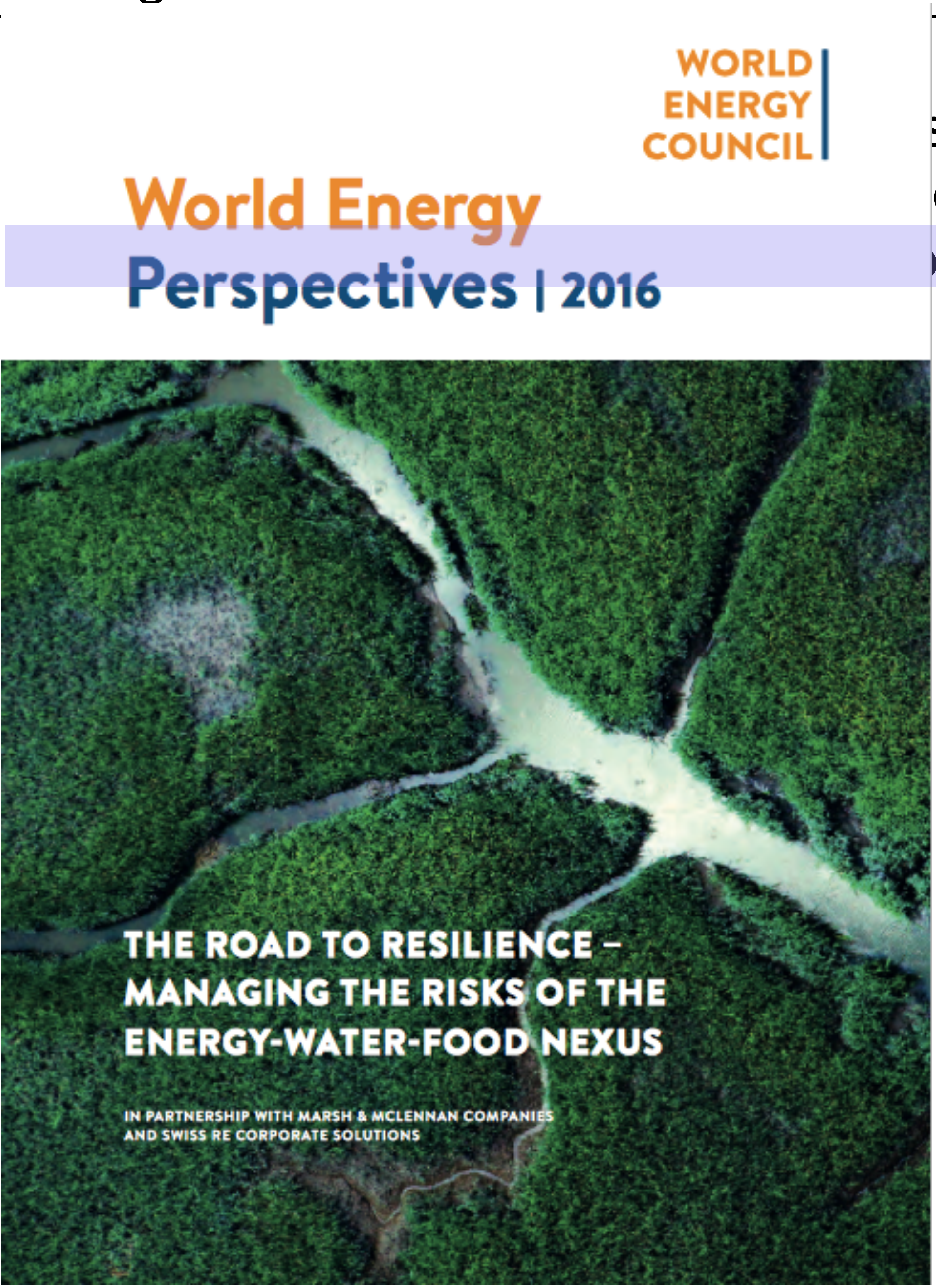
Assignment

1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

Assignment

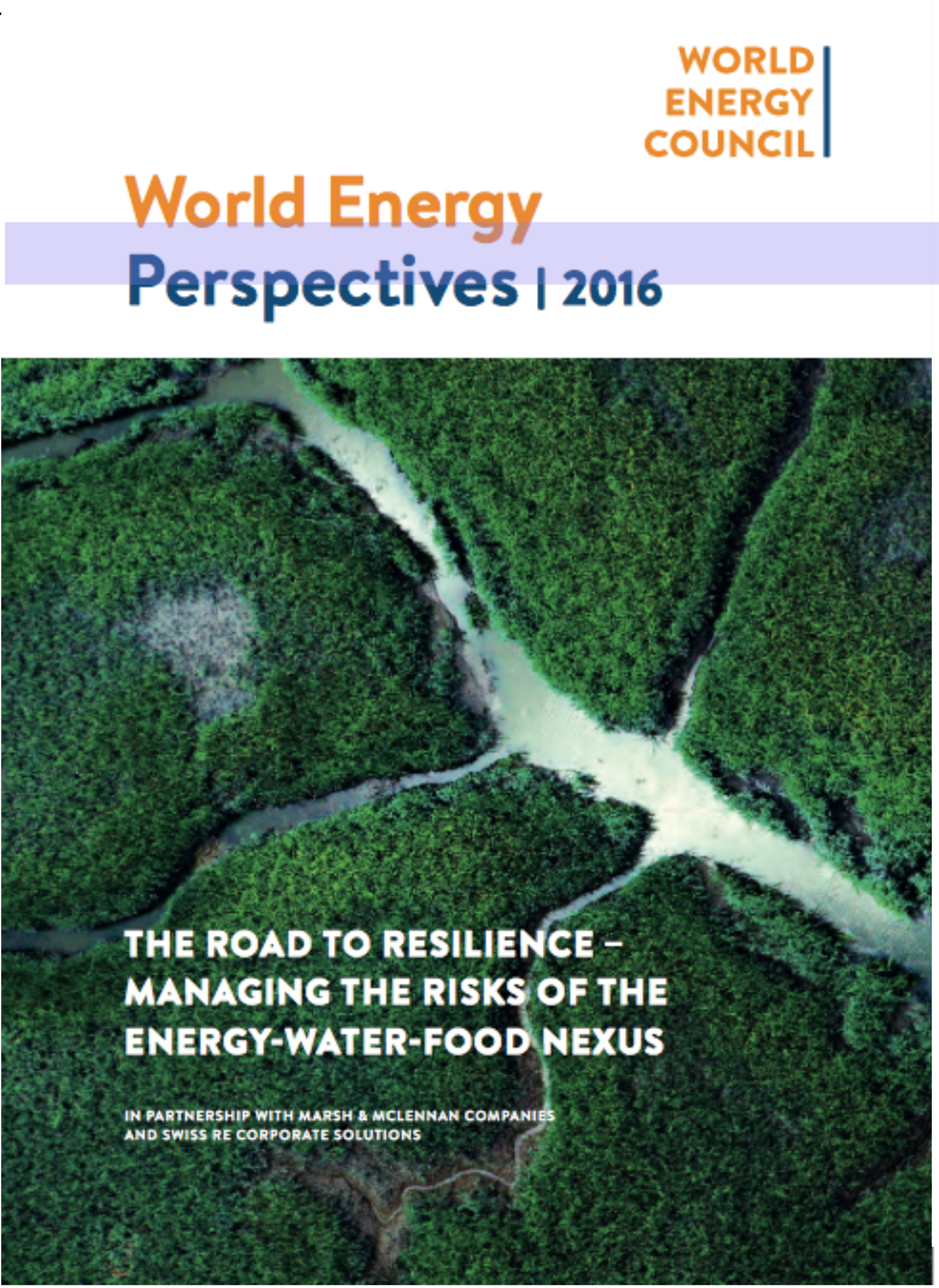
1. To what extent does the IPCC thoroughly address the drivers behind climate change, and how are these reflected in the Assessment Report?
2. Summarize the core challenges of climate change and sea level rise for public health.
3. Explain the main issues of the food-water-energy nexus.

Assignment



oroughly address the drivers behind climate change, and
ssessment Report?
of climate change and sea level rise for public health.
od-water-energy nexus.

Assignment



KEY FINDINGS

1 **ENERGY IS THE SECOND LARGEST FRESHWATER USER** after agriculture. Water is used all along the energy value chain in primary energy production (coal, oil, gas, biofuels) and in power generation (hydro, cooling). 98% of the power currently produced needs water.

2 **THE RISKS POSED BY THE ENERGY-WATER-FOOD NEXUS WILL BECOME MORE SIGNIFICANT** because of growing demand for energy, water and food. Moreover, some of the regions that are currently water stressed are also likely to see significant economic development, population growth and changing consumption patterns, and a higher concentration of people and assets in critical areas, intensifying the risks posed by the nexus.

3 **ALONGSIDE GROWING DEMAND, INCREASING UNCERTAINTY ABOUT WATER AVAILABILITY** and quality – driven by climate change impacts such as declining freshwater availability, increased ocean temperatures and more extreme weather – will further increase the significance of risks posed by the nexus.[1]

4 **ANALYSIS IN NATURE CLIMATE CHANGE**[2] highlights that from 2014 to 2069, reductions in usable water capacity could impact two-thirds of the 24,515 hydropower plants analysed and more than 80% of the 1,427 thermal electric power plants assessed.

5 **IN MANY CASES, THERE IS A LACK OF LOCATION-SPECIFIC KNOWLEDGE ON WATER ISSUES** and a lack of modelling tools to adequately reflect risks posed by the nexus in energy infrastructure investment decisions. Such risks can be associated with large economic stakes: in 2015, hydropower facilities in Brazil sustained economic losses of more than US$4.3 billion due to drought-related energy and water rationing measures.

6 **THE RISKS POSED BY THE NEXUS ARE OFTEN EXACERBATED** by the lack of sound water governance such as well-defined water rights for competing users, water pricing and trading arrangements.

7 **CROSS-BORDER COOPERATION IS A KEY ISSUE.** 261 international trans-boundary basins cover 45% of the earth's land surface, serve 40% of the world's population and provide 60% of the earth's entire freshwater volume. This affects the operation of planned and proposed energy infrastructures, and there is a need to ensure that adequate cross-border water management frameworks are in place.

imate change, and

r public health.

Climate Change and Sea Level Hazards

Hazards:

Changes in means:
- air temperature
- precipitation
- wind field/circulation
- evapotranspiration
- humidity
- soil moisture
- permafrost
- sea and lake levels
- inundation
- river runoff
- desertification
- ice and snow cover

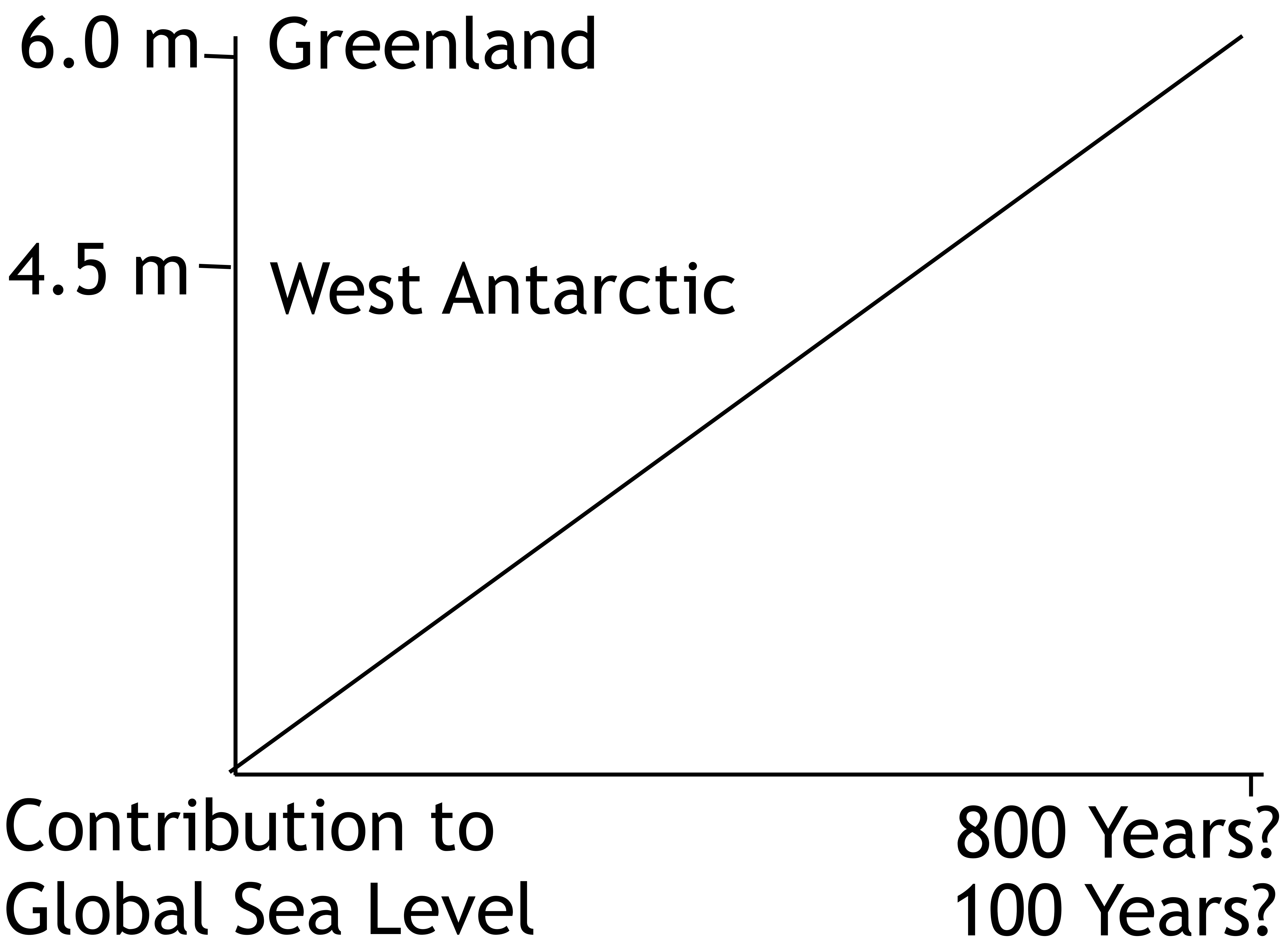
Changes in extremes:
- Storms (hurricanes, typhoons, tornados, thunderstorms)
- Floods
- Droughts
- Heat Waves
- Ice storms and snow fall

Changes in dynamics and chemistry:
- ocean circulation
- atmospheric circulation
- ocean temperature
- ocean acidification
- soil, air and water chemistry

Changes in biosphere:
- ecosystem health and services
- migration
- invasive species
- extinction

Questions:
- How well do we know the past and current changes?
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?

How solid is our knowledge?



Example sea level rise

Accepted knowledge in 2000:

Greenland: no significant contribution to sea level rise

Antarctica: minor contribution

Main contribution: steric changes

Knowledge in 2016:

Greenland: is contributing, is accelerating; increasing potential for a large contribution to sea level rise due to deep warm water around Greenland and impact of changes in atmospheric circulation.

Antarctica: West Antarctic ice sheet (WAIS) will contribute 4.5 m

How worried should we be?

What should we be worried about?

Assessing Knowledge

Assessing Knowledge

HOME SEARCH

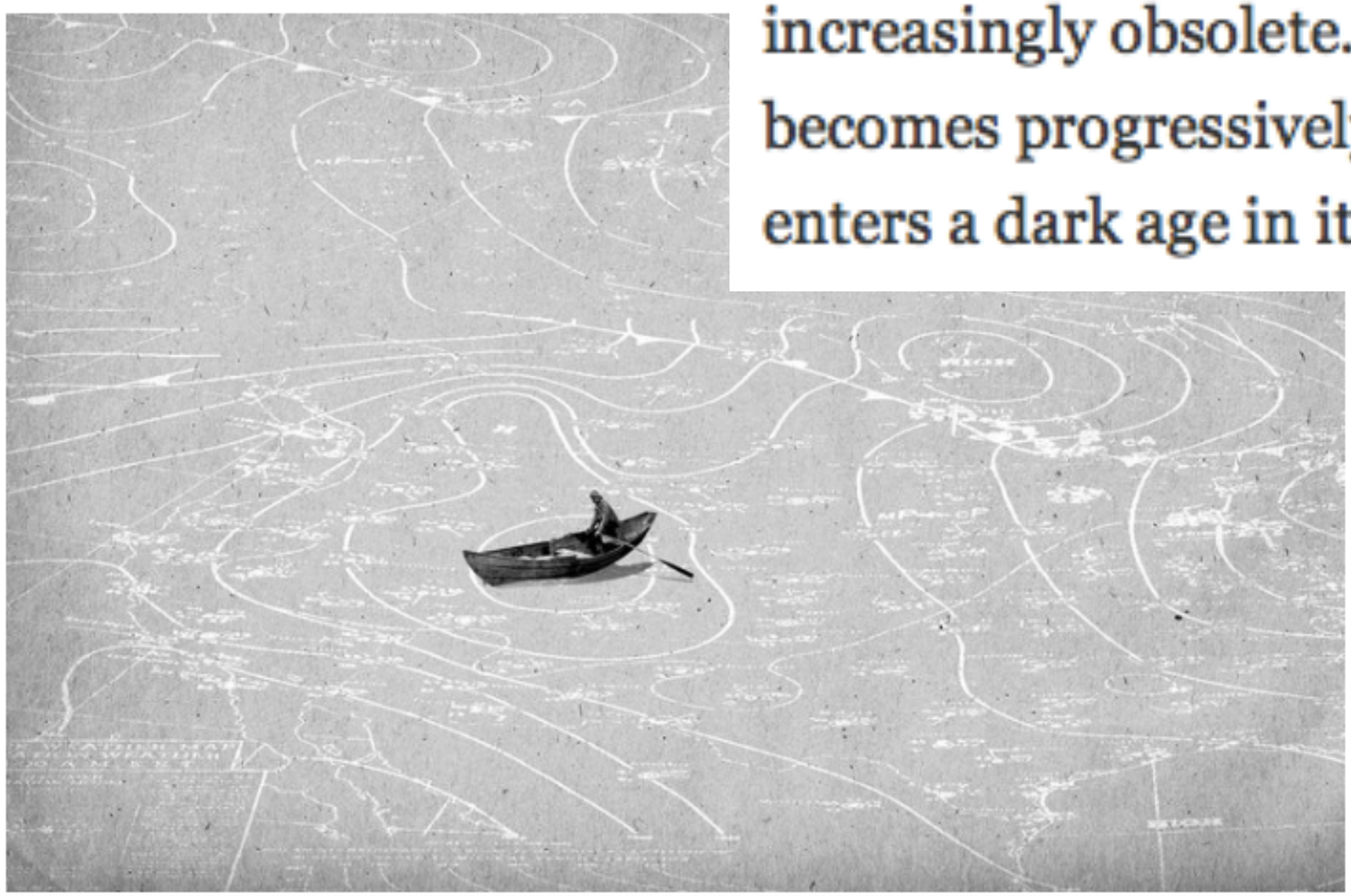
The New York Times

The Opinion Pages | OP-ED CONTRIBUTOR

A New Dark Age Looms

By WILLIAM B. GAIL APRIL 19, 2016

Boulder, Colo. — IMAGINE a future in which humanity's accumulated wisdom about Earth — our vast experience with weather trends, fish spawning and migration patterns, plant pollination and much more — turns increasingly obsolete. As each decade passes, knowledge of Earth's past becomes progressively less effective as a guide to the future. Civilization enters a dark age in its practical understanding of our planet.



Climate Change and Sea Level Hazards

Hazards:

Changes in means:
- air temperature
- precipitation
- wind field/circulation
- evapotranspiration
- humidity
- soil moisture
- permafrost
- sea and lake levels
- inundation
- river runoff
- desertification
- ice and snow cover

Changes in extremes:
- Storms (hurricanes, typhoons, tornados, thunderstorms)
- Floods
- Droughts
- Heat Waves
- Ice storms and snow fall

Changes in dynamics and chemistry:
- ocean circulation
- atmospheric circulation
- ocean temperature
- ocean acidification
- soil, air and water chemistry

Changes in biosphere:
- ecosystem health and services
- migration
- invasive species
- extinction

Questions:
- How well do we know the past and current changes?
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?

Climate Change and Sea Level Hazards

Hazards:

Changes in means:
- air temperature
- precipitation
- wind field/circulation
- evapotranspiration
- humidity
- soil moisture
- permafrost
- sea and lake levels
- inundation
- river runoff
- desertification
- ice and snow cover

Changes in extremes:
- Storms (hurricanes, typhoons, tornados, thunderstorms)
- Floods
- Droughts
- Heat Waves
- Ice storms and snow fall

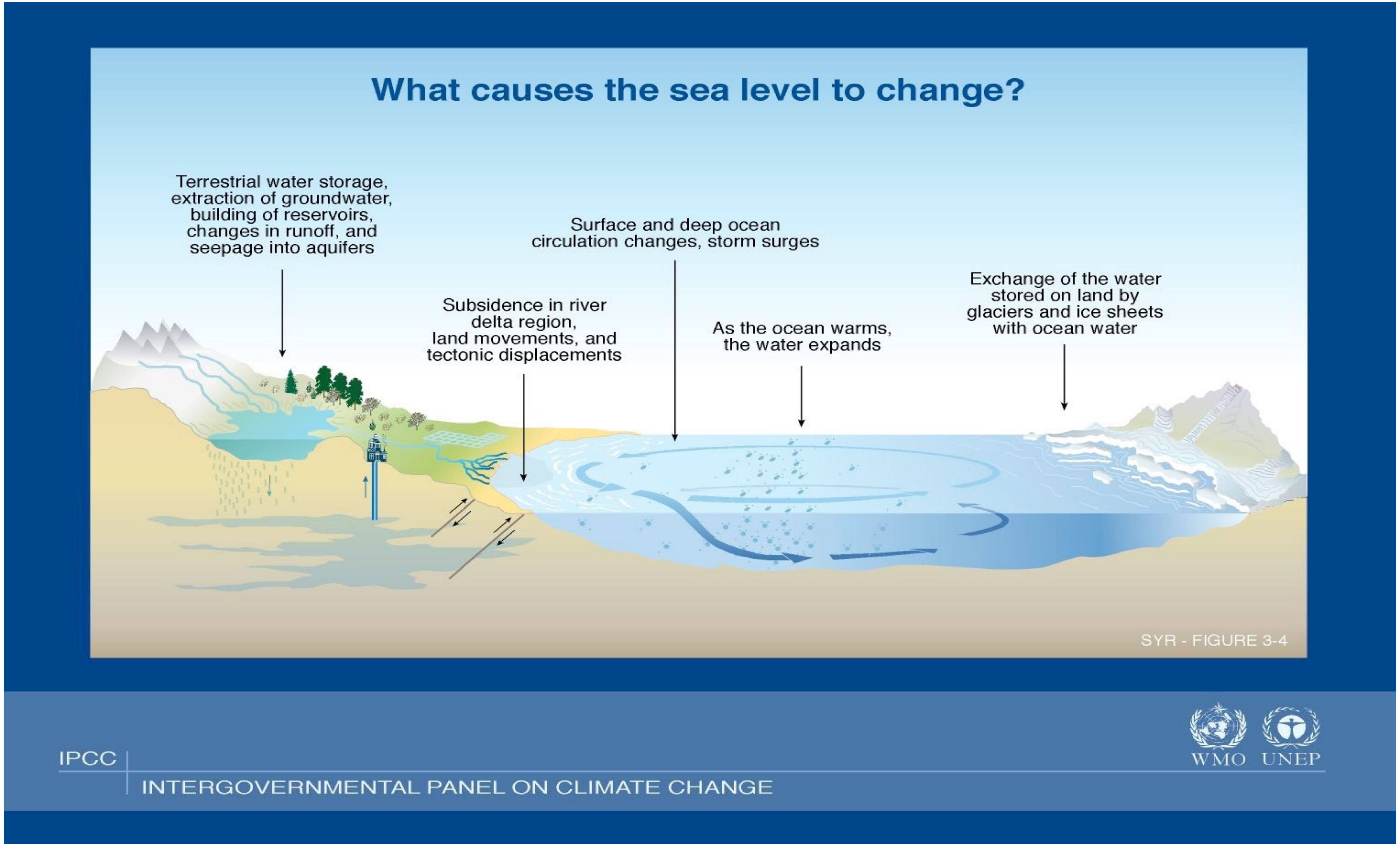
Changes in dynamics and chemistry:
- ocean circulation
- atmospheric circulation
- ocean temperature
- ocean acidification
- soil, air and water chemistry

Changes in biosphere:
- ecosystem health and services
- migration
- invasive species
- extinction

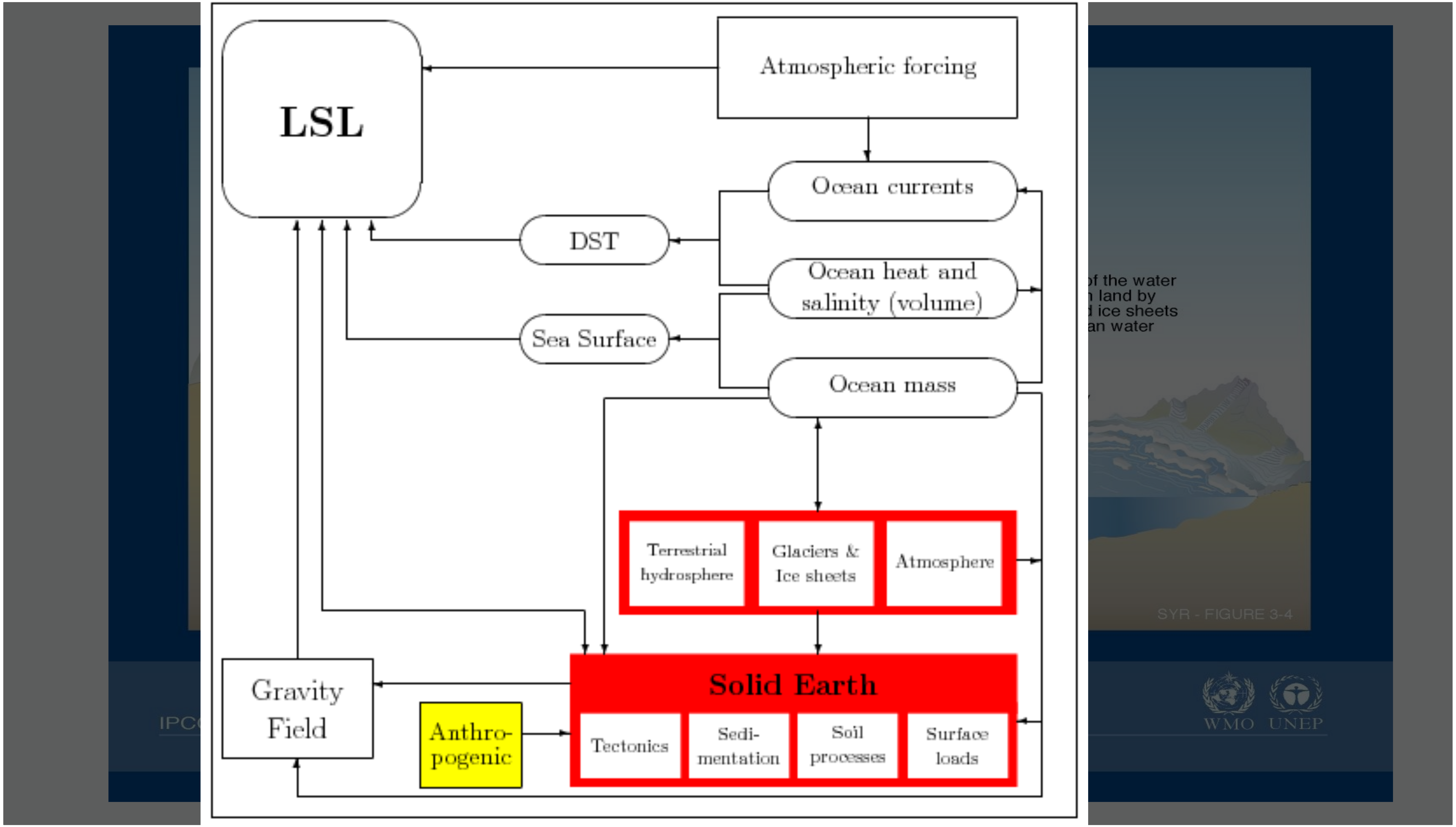
Questions:
- How well do we know the past and current changes?
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?

Understanding the Processes

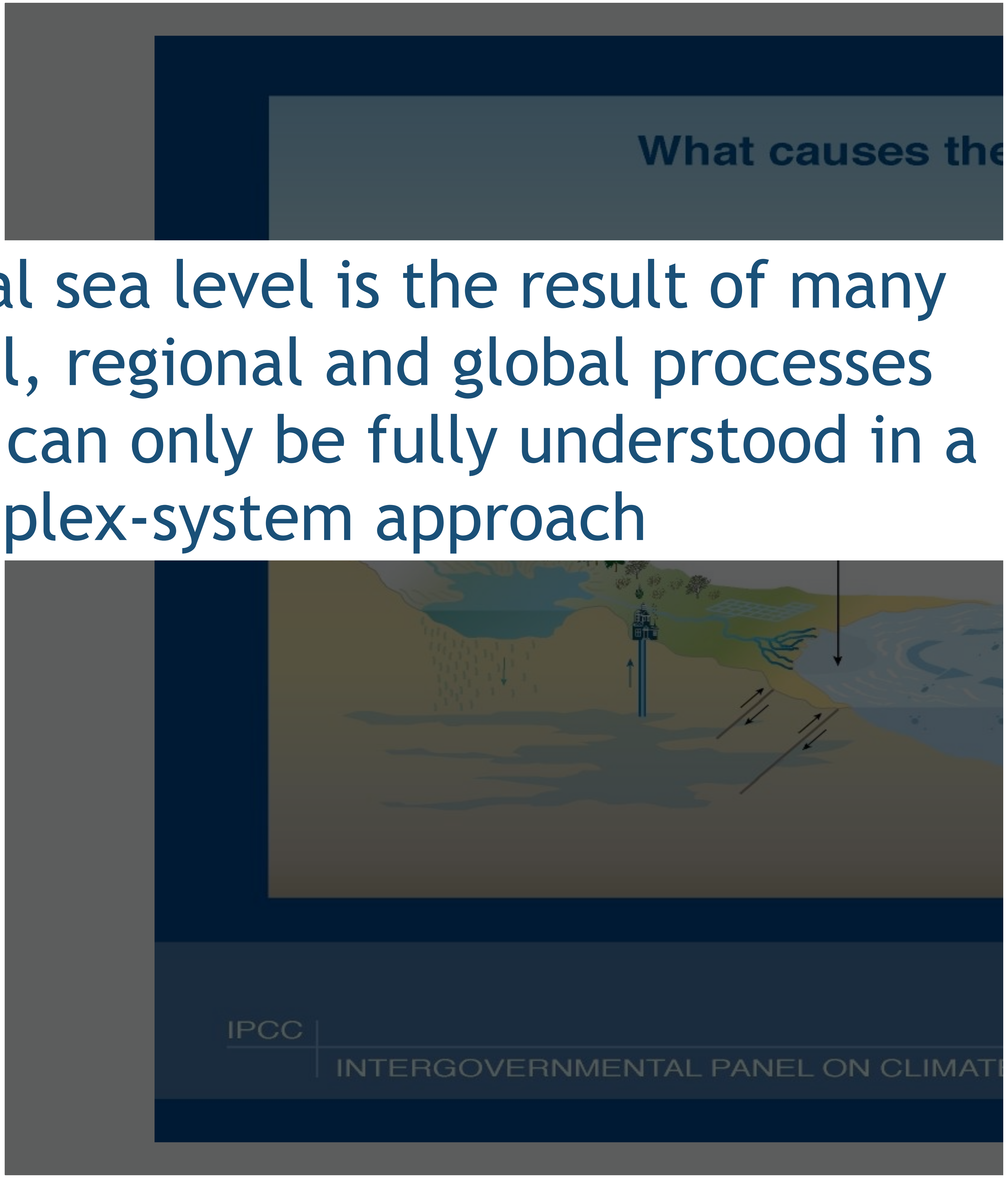
Understanding the Processes



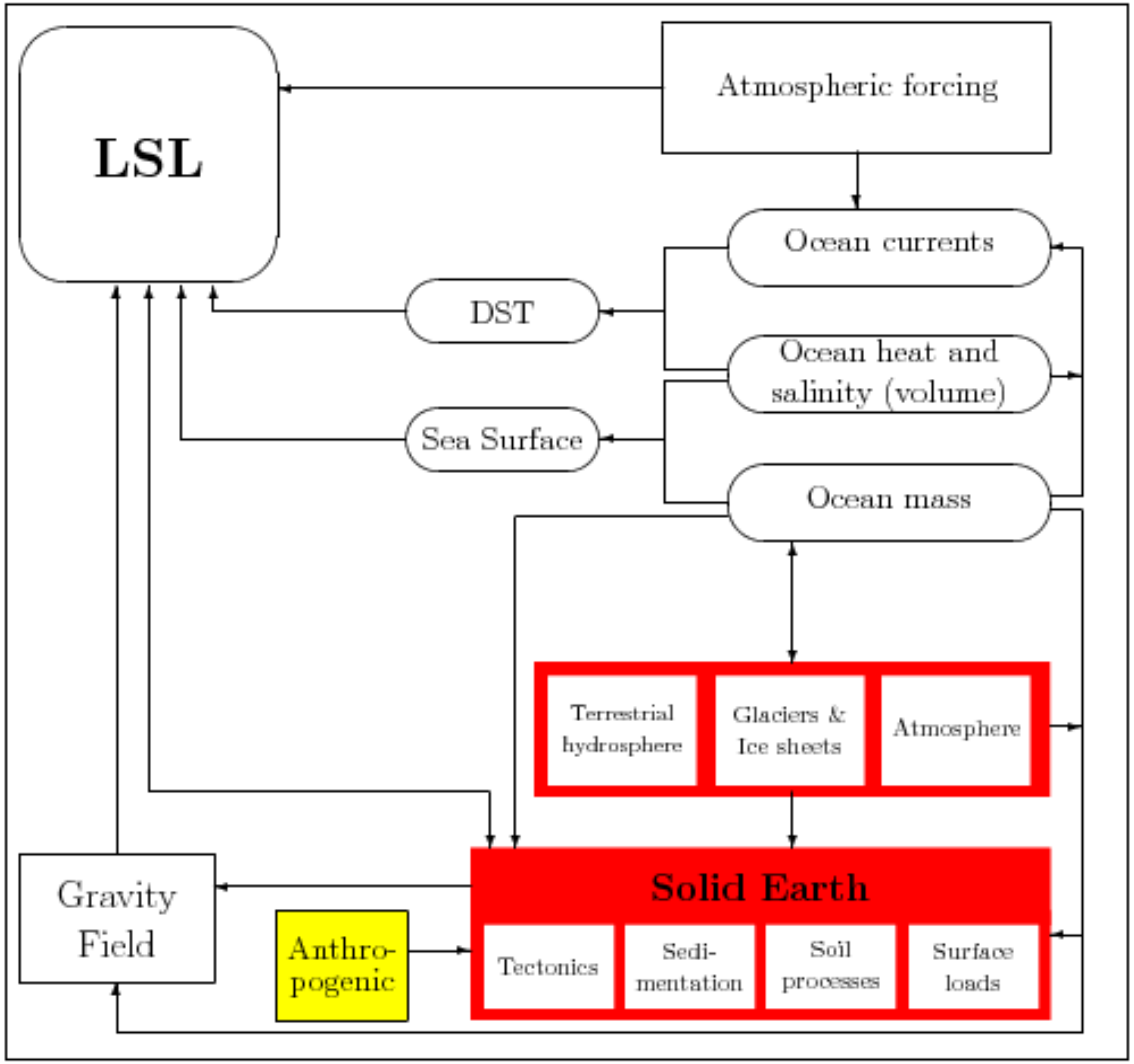
Understanding the Processes



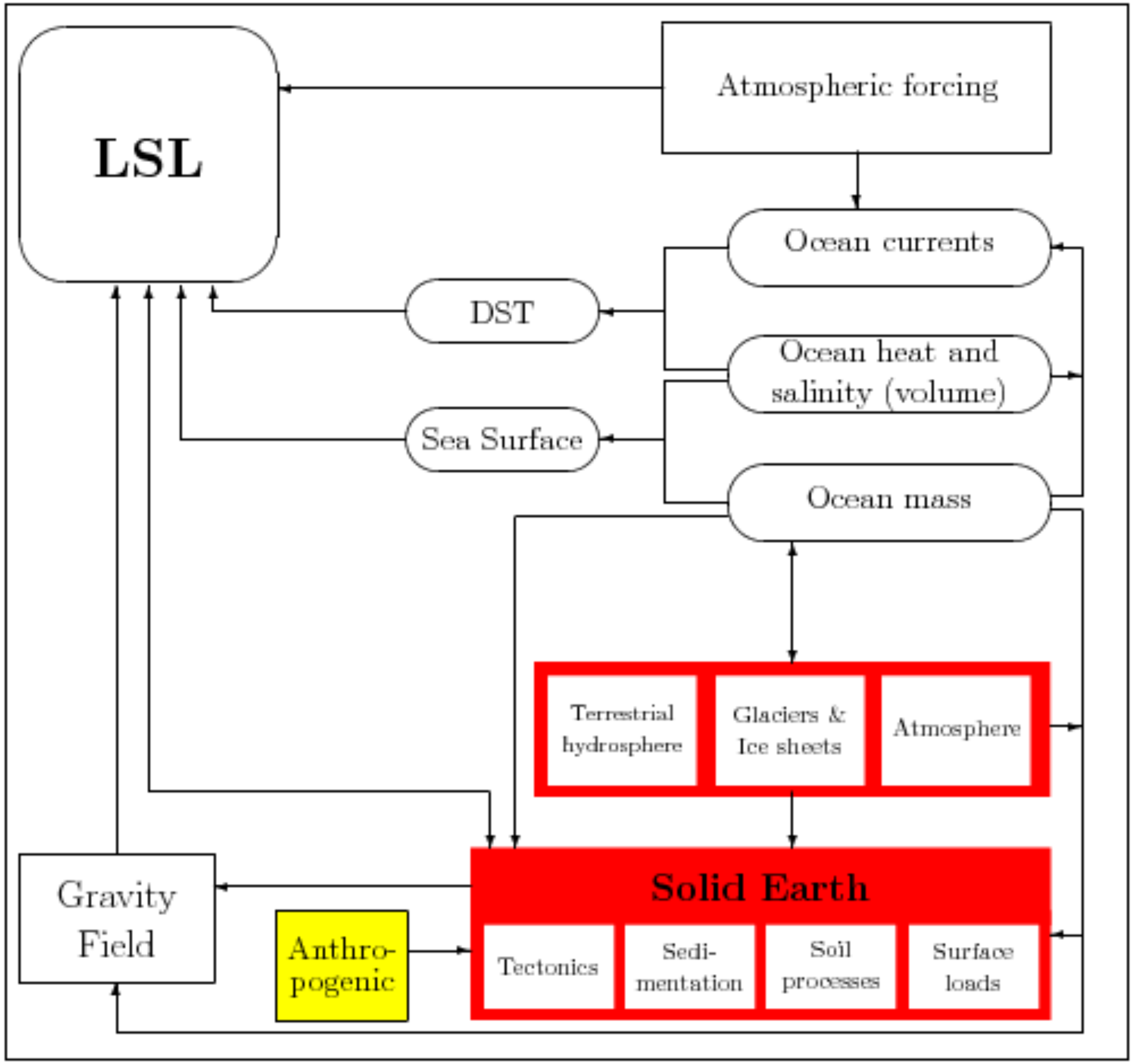
Understanding the Processes



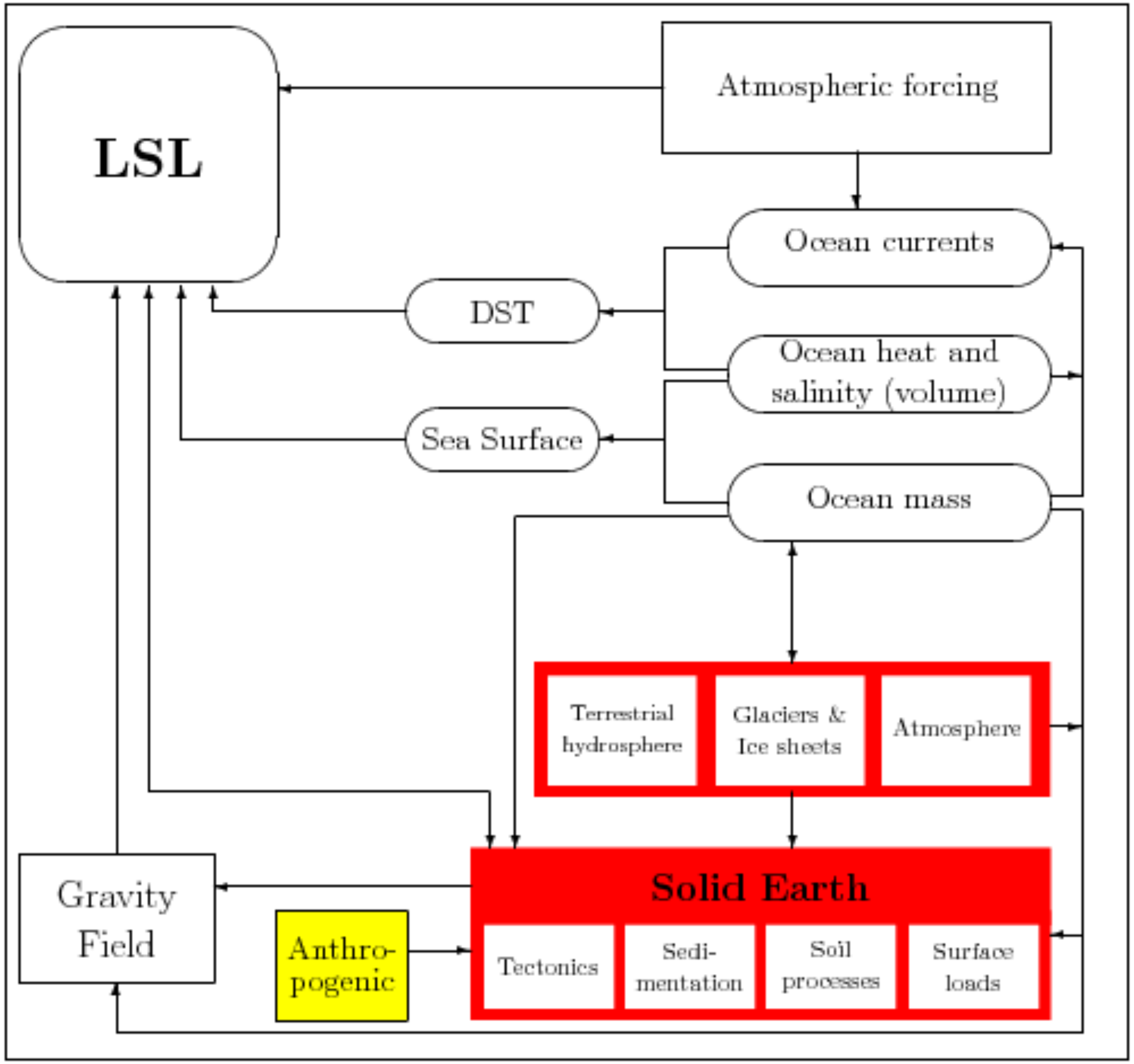
Local sea level is the result of many local, regional and global processes and can only be fully understood in a complex-system approach



Understanding the Processes

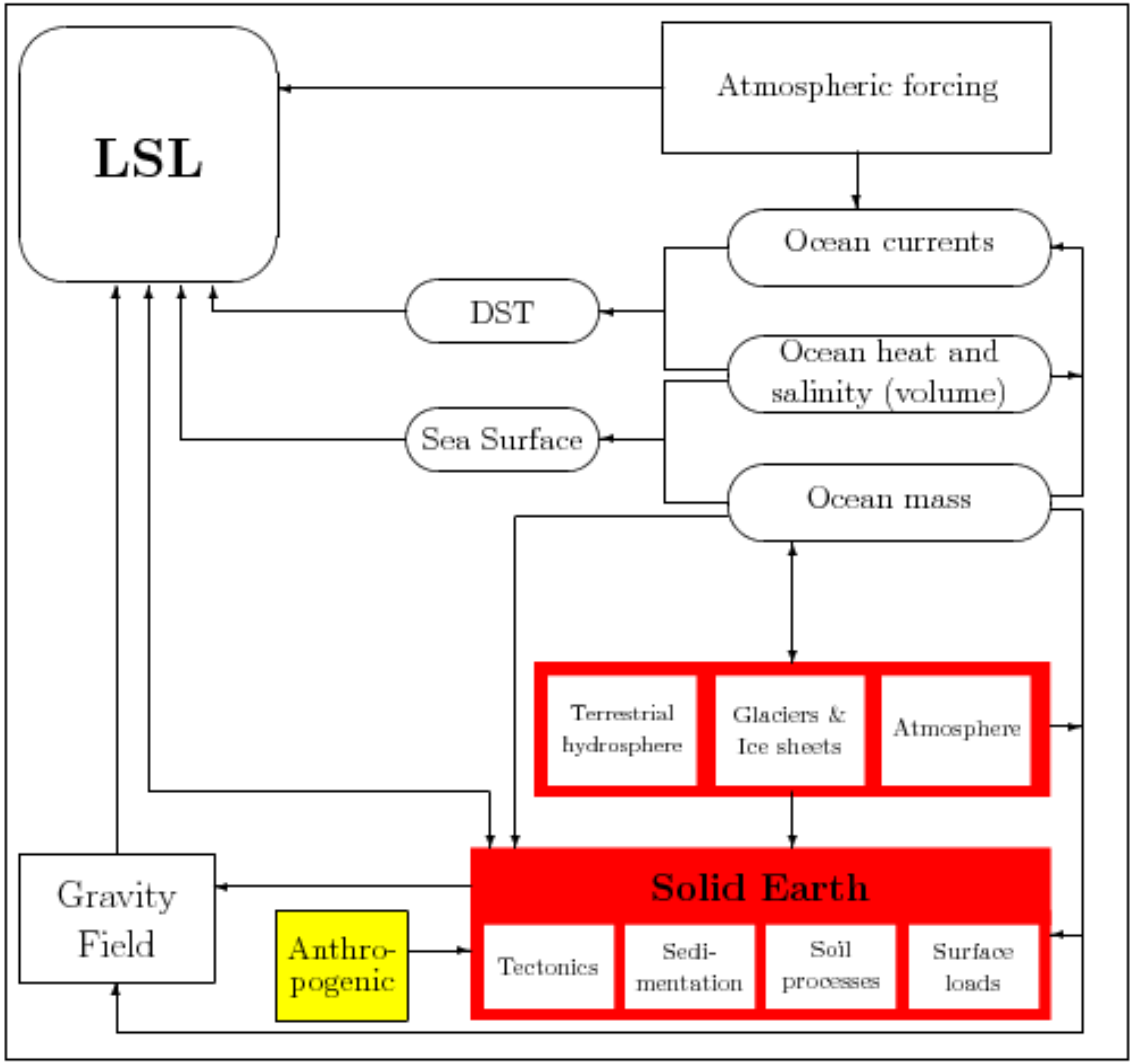


Local Sea Level:
vertical distance between sea surface and land surface



Local Sea Level:
vertical distance between sea surface and land surface

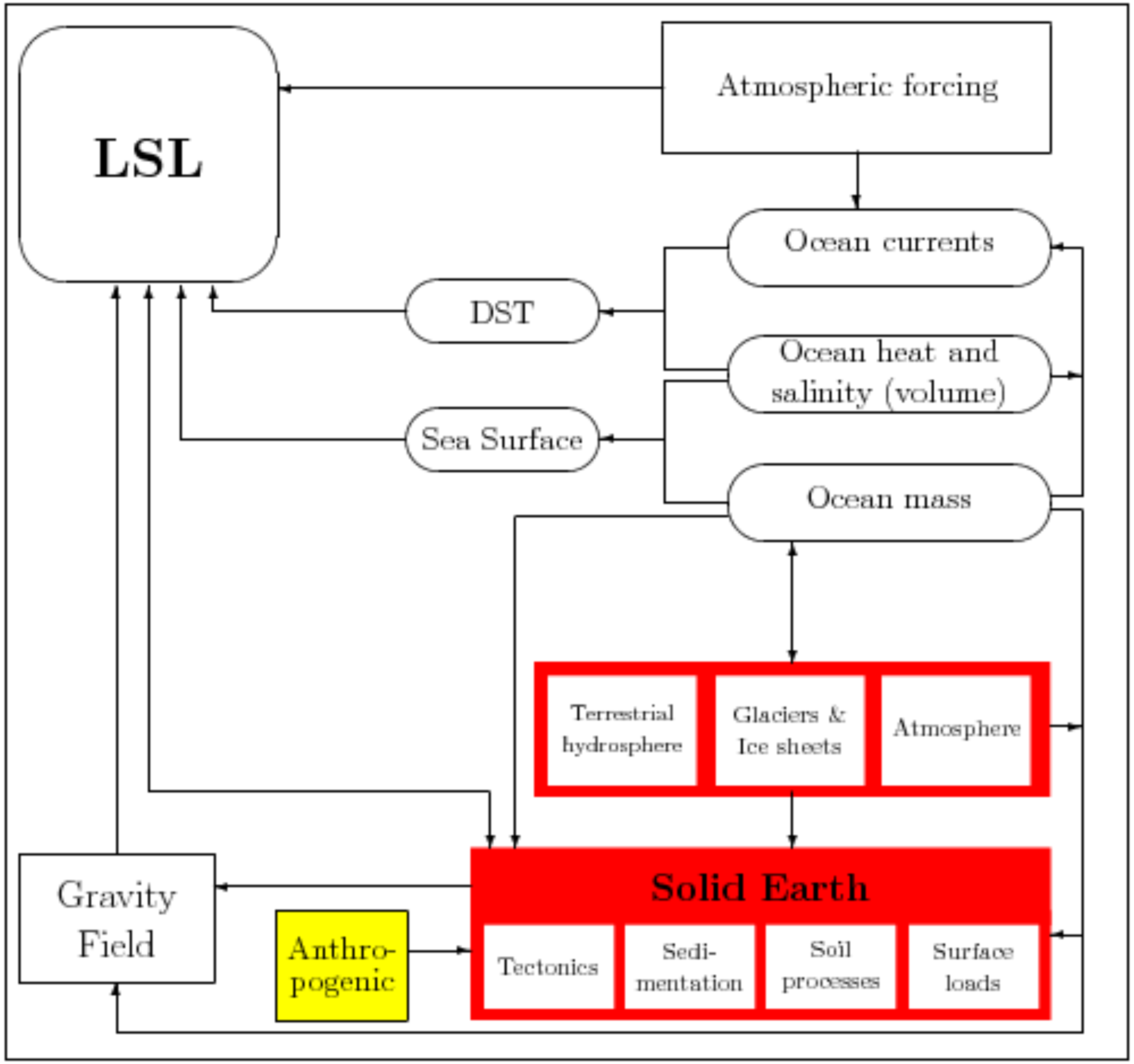
Local Sea Level (LSL) changes =
Sea Surface Height (SSH) changes -
Land surface height (LSH) changes.



Local Sea Level:
vertical distance between sea surface and land surface

Local Sea Level (LSL) changes =
Sea Surface Height (SSH) changes -
Land surface height (LSH) changes.

$$LSL(x,t) = SSH(x,t) - LSH(x,t)$$



Understanding the Processes

LSL = short-period part + long-period part

LSL = short-period part + long-period part

Separation at a period of about 2 months:

LSL = short-period part + long-period part

Separation at a period of about 2 months:

High-frequency part of LSL equation:

$$h_{\mathrm{hf}}t = w(t) + h_{\mathrm{tidal}}(t) + h_{\mathrm{atmos}}(t) + h_{\mathrm{seiches}}(t) + h_{\mathrm{tsunami}}(t).$$

Important for projection of maximum flood levels

LSL = short-period part + long-period part

Separation at a period of about 2 months:

High-frequency part of LSL equation:

$$h_{\mathrm{hf}}t = w(t) + h_{\mathrm{tidal}}(t) + h_{\mathrm{atmos}}(t) + h_{\mathrm{seiches}}(t) + h_{\mathrm{tsunami}}(t).$$

Important for projection of maximum flood levels

LSL = short-period part + long-period part

Separation at a period of about 2 months:

High-frequency part of LSL equation:

$$h_{\mathrm{hf}}t = w(t) + h_{\mathrm{tidal}}(t) + h_{\mathrm{atmos}}(t) + h_{\mathrm{seiches}}(t) + h_{\mathrm{tsunami}}(t).$$

Important for projection of maximum flood levels

Short-period variations are the result of local to regional processes

Understanding the Processes

LSL = short-period part + long-period part

$$\begin{aligned}\delta h_{\mathrm{M}}(\vec{x},t) = {} & N(\vec{x},t) + S(\vec{x},t) + C(\vec{x},t) + F(\vec{X},t) + A(\vec{x},t) + \\ & I(\vec{x},t) + G(\vec{x},t) + T(\vec{x},t) + P(\vec{x})(t-t_0) + \\ & V_0(\vec{x})(t-t_0) + \delta V(\vec{x},t) + B(\vec{x},t)\end{aligned}$$

N: nodal tide
S: steric changes
C: changes in ocean currents
A: changes in atmospheric circulation
F: freshening
I: changes in the mass of the large ice sheets
G: changes in continental glaciers
T: changes in terrestrial hydrosphere
P: postglacial rebound
V_0: secular vertical land motion
δV: non-linear vertical land motion
B: changes in shape and extent of ocean basins.

LSL = short-period part + long-period part

Low-Frequency part of the LSL equation:

$$\delta h_{\mathrm{M}}(\vec{x},t) = N(\vec{x},t) + S(\vec{x},t) + C(\vec{x},t) + F(\vec{X},t) + A(\vec{x},t) + I(\vec{x},t) + G(\vec{x},t) + T(\vec{x},t) + P(\vec{x})(t-t_0) + V_0(\vec{x})(t-t_0) + \delta V(\vec{x},t) + B(\vec{x},t)$$

N: nodal tide
S: steric changes
C: changes in ocean currents
A: changes in atmospheric circulation
F: freshening
I: changes in the mass of the large ice sheets
G: changes in continental glaciers
T: changes in terrestrial hydrosphere
P: postglacial rebound
V_0: secular vertical land motion
δV: non-linear vertical land motion
B: changes in shape and extent of ocean basins.

Important for projections of LSL

LSL = short-period part + long-period part

Low-Frequency part of the LSL equation:

$$\delta h_{\mathrm{M}}(\vec{x},t) = N(\vec{x},t) + S(\vec{x},t) + C(\vec{x},t) + F(\vec{X},t) + A(\vec{x},t) + I(\vec{x},t) + G(\vec{x},t) + T(\vec{x},t) + P(\vec{x})(t-t_0) + V_0(\vec{x})(t-t_0) + \delta V(\vec{x},t) + B(\vec{x},t)$$

N: nodal tide
S: steric changes
C: changes in ocean currents
A: changes in atmospheric circulation
F: freshening
I: changes in the mass of the large ice sheets
G: changes in continental glaciers
T: changes in terrestrial hydrosphere
P: postglacial rebound
V_0: secular vertical land motion
δV: non-linear vertical land motion
B: changes in shape and extent of ocean basins.

Important for projections of LSL

LSL = short-period part + long-period part

Low-Frequency part of the LSL equation:

$$\delta h_M(\vec{x},t) = N(\vec{x},t) + S(\vec{x},t) + C(\vec{x},t) + F(\vec{X},t) + A(\vec{x},t) + I(\vec{x},t) + G(\vec{x},t) + T(\vec{x},t) + P(\vec{x})(t-t_0) + V_0(\vec{x})(t-t_0) + \delta V(\vec{x},t) + B(\vec{x},t)$$

N: nodal tide
S: steric changes
C: changes in ocean currents
A: changes in atmospheric circulation
F: freshening
I: changes in the mass of the large ice sheets
G: changes in continental glaciers
T: changes in terrestrial hydrosphere
P: postglacial rebound
V_0: secular vertical land motion
δV: non-linear vertical land motion
B: changes in shape and extent of ocean basins.

Important for projections of LSL

Long-period variations are the result of local to global processes

LSL = short-period part + long-period part

Low-Frequency part of the LSL equation:

$$\delta h_{\mathrm{M}}(\vec{x},t) = N(\vec{x},t) + S(\vec{x},t) + C(\vec{x},t) + F(\vec{X},t) + A(\vec{x},t) + I(\vec{x},t) + G(\vec{x},t) + T(\vec{x},t) + P(\vec{x})(t-t_0) + V_0(\vec{x})(t-t_0) + \delta V(\vec{x},t) + B(\vec{x},t)$$

N: nodal tide
S: steric changes
C: changes in ocean currents
A: changes in atmospheric circulation
F: freshening
I: changes in the mass of the large ice sheets
G: changes in continental glaciers
T: changes in terrestrial hydrosphere
P: postglacial rebound
V_0: secular vertical land motion
δV: non-linear vertical land motion
B: changes in shape and extent of ocean basins.

Comments on the relation between mass changes (exchange and redistribution) and LSL

Important for projections of LSL

Long-period variations are the result of local to global processes

Understanding the Processes

Sea level equation (Farrell&Clark, 1976)

$$\xi(\vartheta,\lambda,t) = c(t) + O(\vartheta,\lambda,t)\int_{-\infty}^{t}\int_{0}^{\pi}\int_{0}^{2\pi} G(\vartheta,\lambda,\vartheta',\lambda',t-t')$$
$$\frac{\mathrm{d}}{\mathrm{d}t'}\left\{O(\vartheta',\lambda',t')\rho_{\mathrm{W}}\xi(\vartheta',\lambda',t') + [1-O(\vartheta',\lambda',t')]\,\rho_{\mathrm{L}}\eta(\vartheta',\lambda',t')\right\}\sin\vartheta'\mathrm{d}\lambda'\mathrm{d}\vartheta'\mathrm{d}t'.$$

ξ: local sea level change (distance to the deformable solid Earth surface),
G: Green's function for sea level,
O: ocean function,
η: cumulated water/ice load change due to mass added or removed from land,
ρ_{W} and ρ_{L}: densities of the ocean water and the load (water or ice), respectively,
$c(t)$: quantity to ensure mass conservation.

Understanding the Processes

Sea level equation (Farrell&Clark, 1976)

$$\xi(\vartheta,\lambda,t) = c(t) + O(\vartheta,\lambda,t)\int_{-\infty}^{t}\int_0^{\pi}\int_0^{2\pi} G(\vartheta,\lambda,\vartheta',\lambda',t-t') \frac{\mathrm{d}}{\mathrm{d}t'}\left\{O(\vartheta',\lambda',t')\rho_{\mathrm{W}}\xi(\vartheta',\lambda',t') + [1 - O(\vartheta',\lambda',t')]\,\rho_{\mathrm{L}}\eta(\vartheta',\lambda',t')\right\}\sin\vartheta'\mathrm{d}\lambda'\mathrm{d}\vartheta'\mathrm{d}t'.$$

ξ: local sea level change (distance to the deformable solid Earth surface),
G: Green's function for sea level,
O: ocean function,
η: cumulated water/ice load change due to mass added or removed from land,
ρ_{W} and ρ_{L}: densities of the ocean water and the load (water or ice), respectively,
$c(t)$: quantity to ensure mass conservation.

LSL change

Load on ocean areas

Load on land areas

Sea level equation (Farrell&Clark, 1976)

$$\xi(\vartheta,\lambda,t) = c(t) + O(\vartheta,\lambda,t)\int_{-\infty}^{t}\int_{0}^{\pi}\int_{0}^{2\pi} G(\vartheta,\lambda,\vartheta',\lambda',t-t') \frac{\mathrm{d}}{\mathrm{d}t'}\{O(\vartheta',\lambda',t')\rho_{\mathrm{W}}\xi(\vartheta',\lambda',t') + [1-O(\vartheta',\lambda',t')]\,\rho_{\mathrm{L}}\eta(\vartheta',\lambda',t')\}\sin\vartheta'\mathrm{d}\lambda'\mathrm{d}\vartheta'\mathrm{d}t'.$$

ξ: local sea level change (distance to the deformable solid Earth surface),
G: Green's function for sea level,
O: ocean function,
η: cumulated water/ice load change due to mass added or removed from land,
ρ_{W} and ρ_{L}: densities of the ocean water and the load (water or ice), respectively,
$c(t)$: quantity to ensure mass conservation.

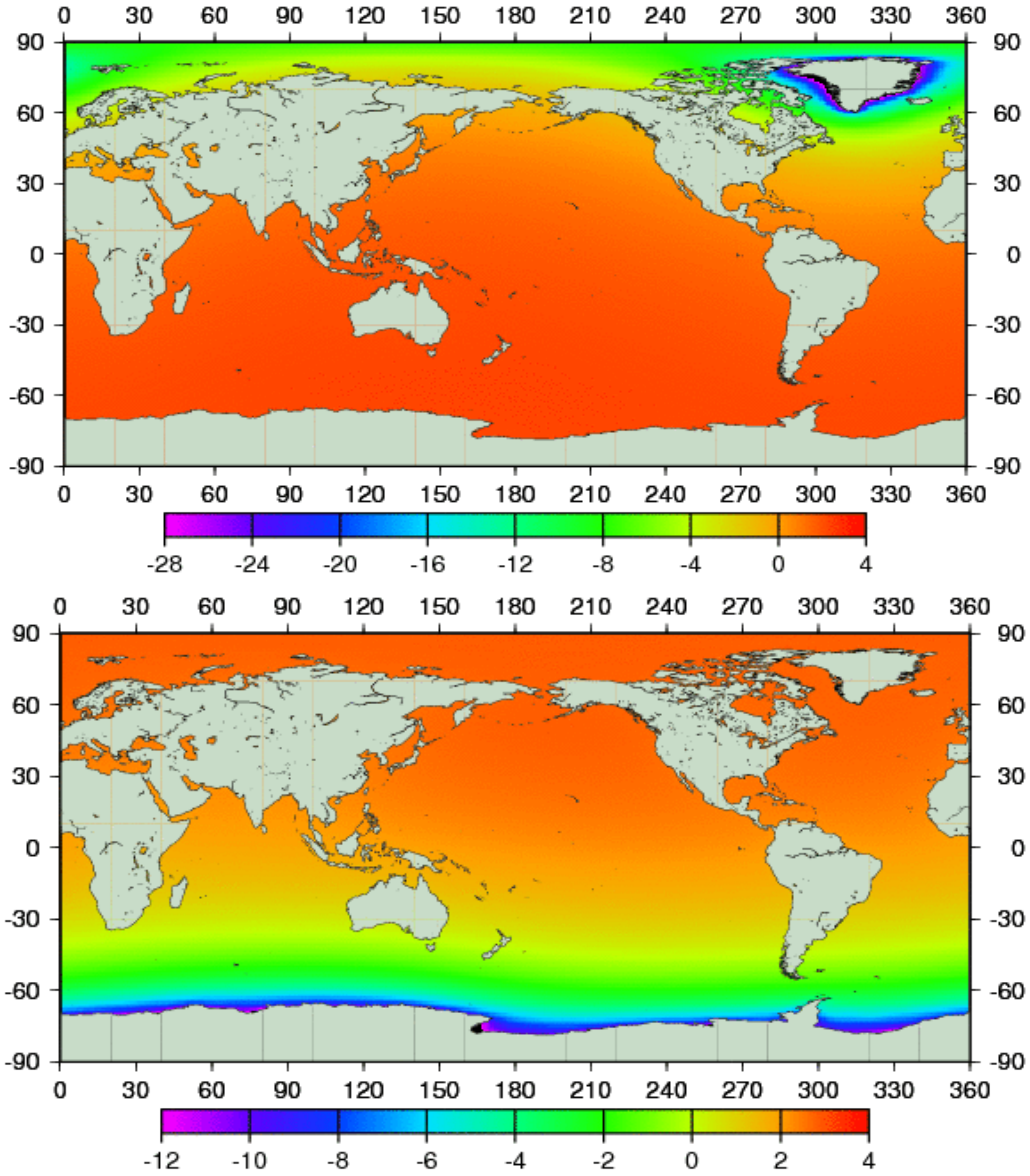
LSL change

All mass movements:
- change the geoid
- displace the ocean bottom vertically
- redistribute the water masses in the ocean

Load on ocean areas

Load on land areas

Understanding the Processes

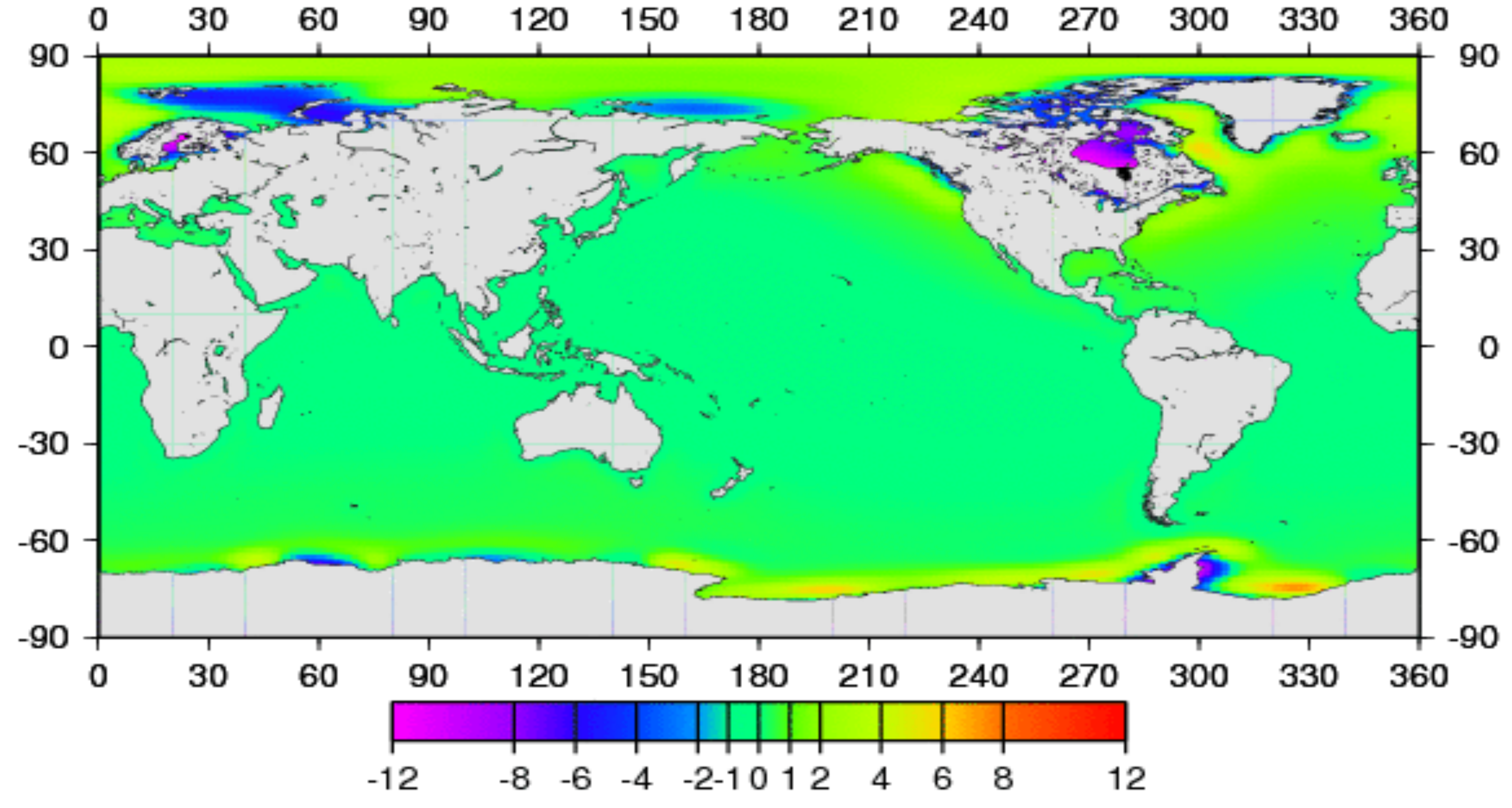


Fingerprints of the large ice sheets

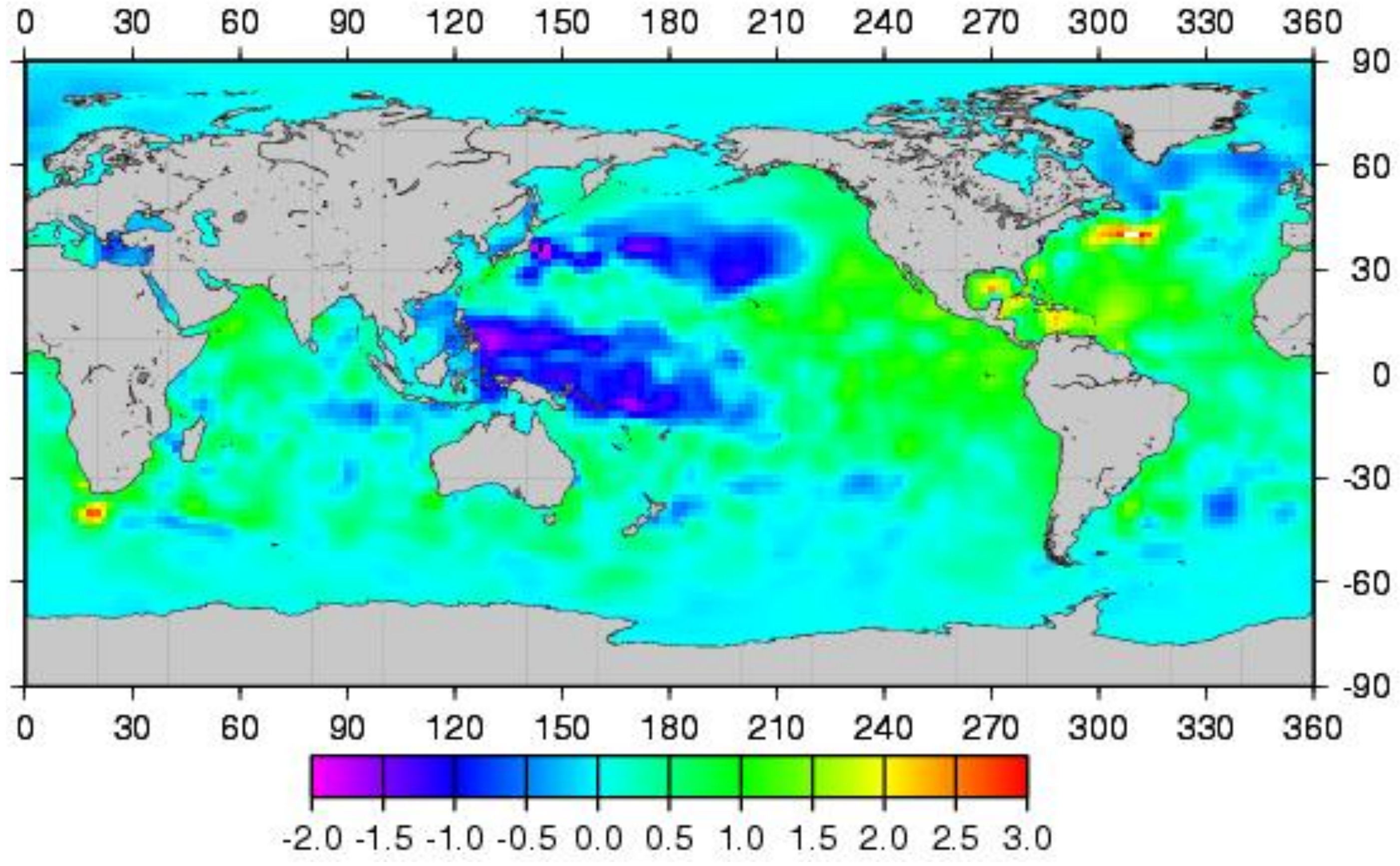
Plag and Juettner, 2001

Understanding the Processes

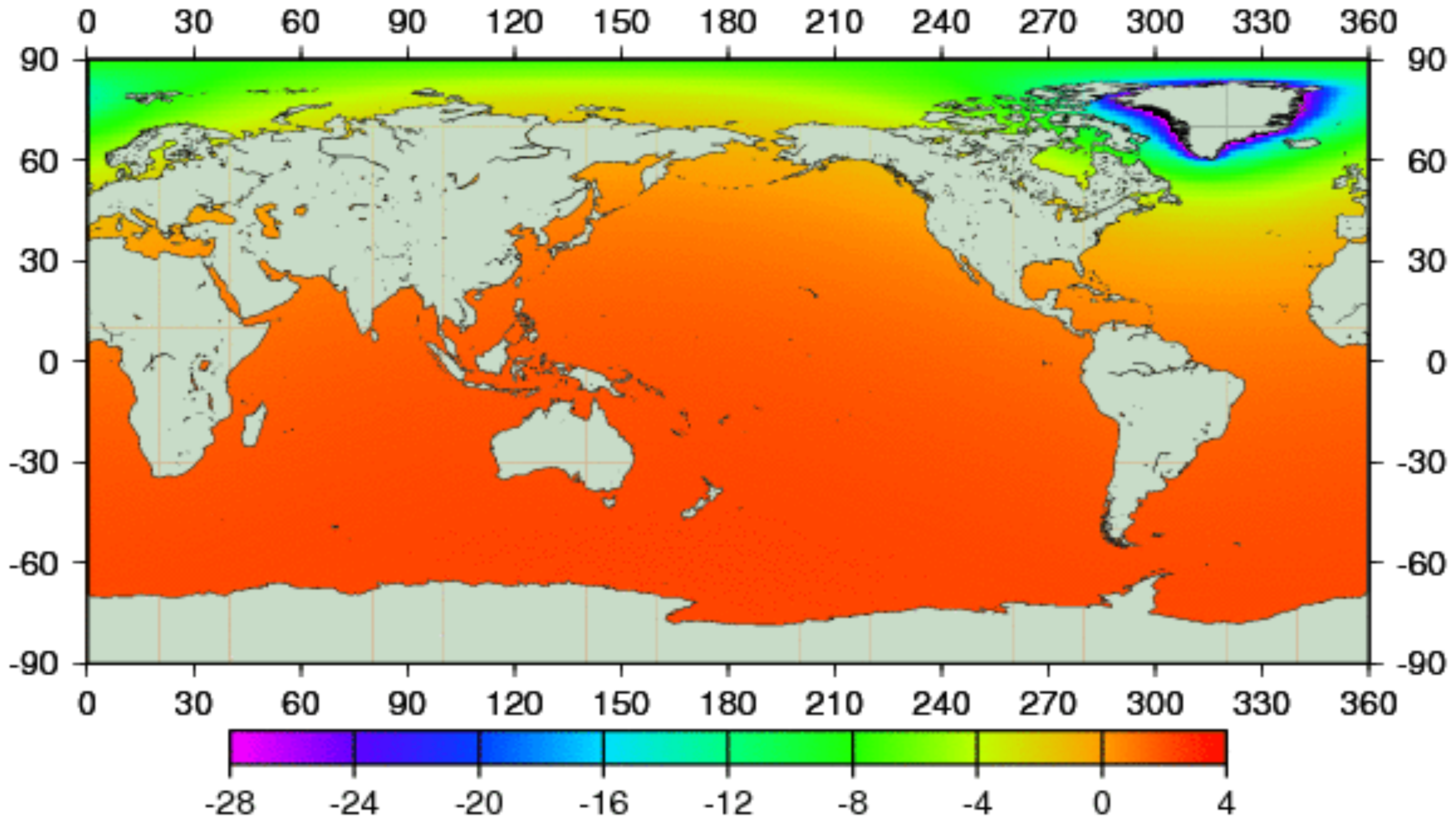
postglacial sea levels



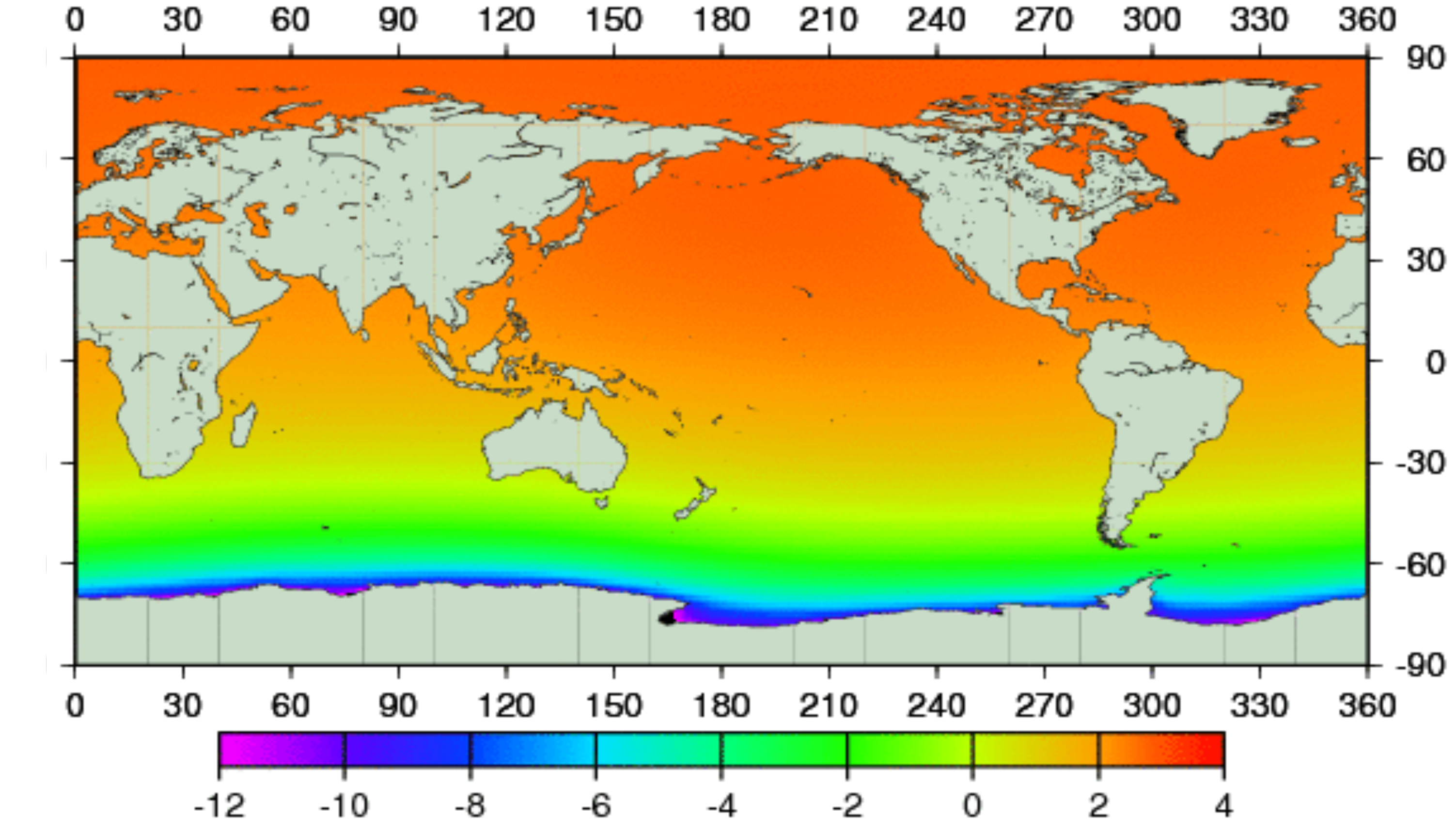
steric changes



Greenland

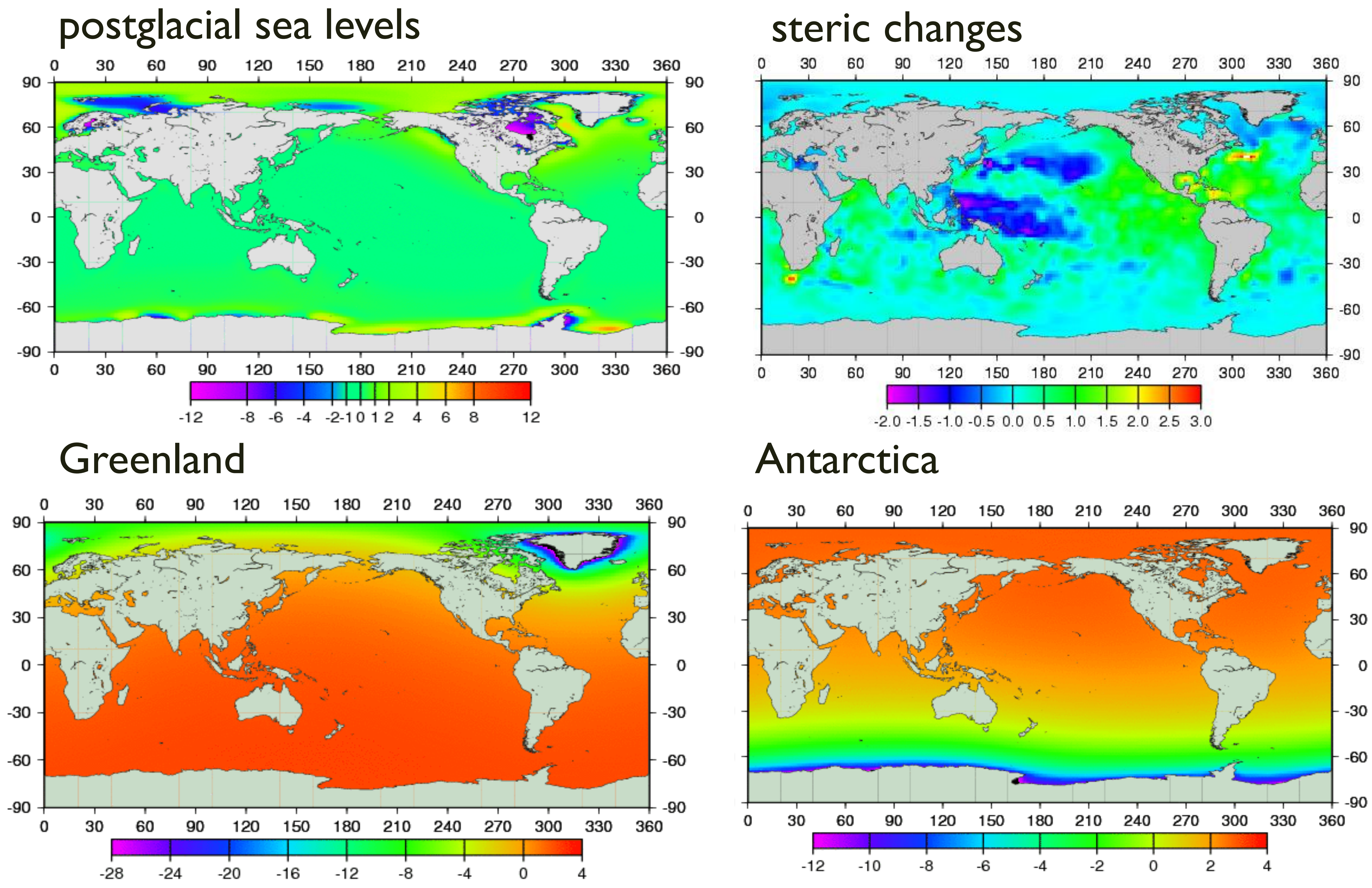


Antarctica



Plag, 2006

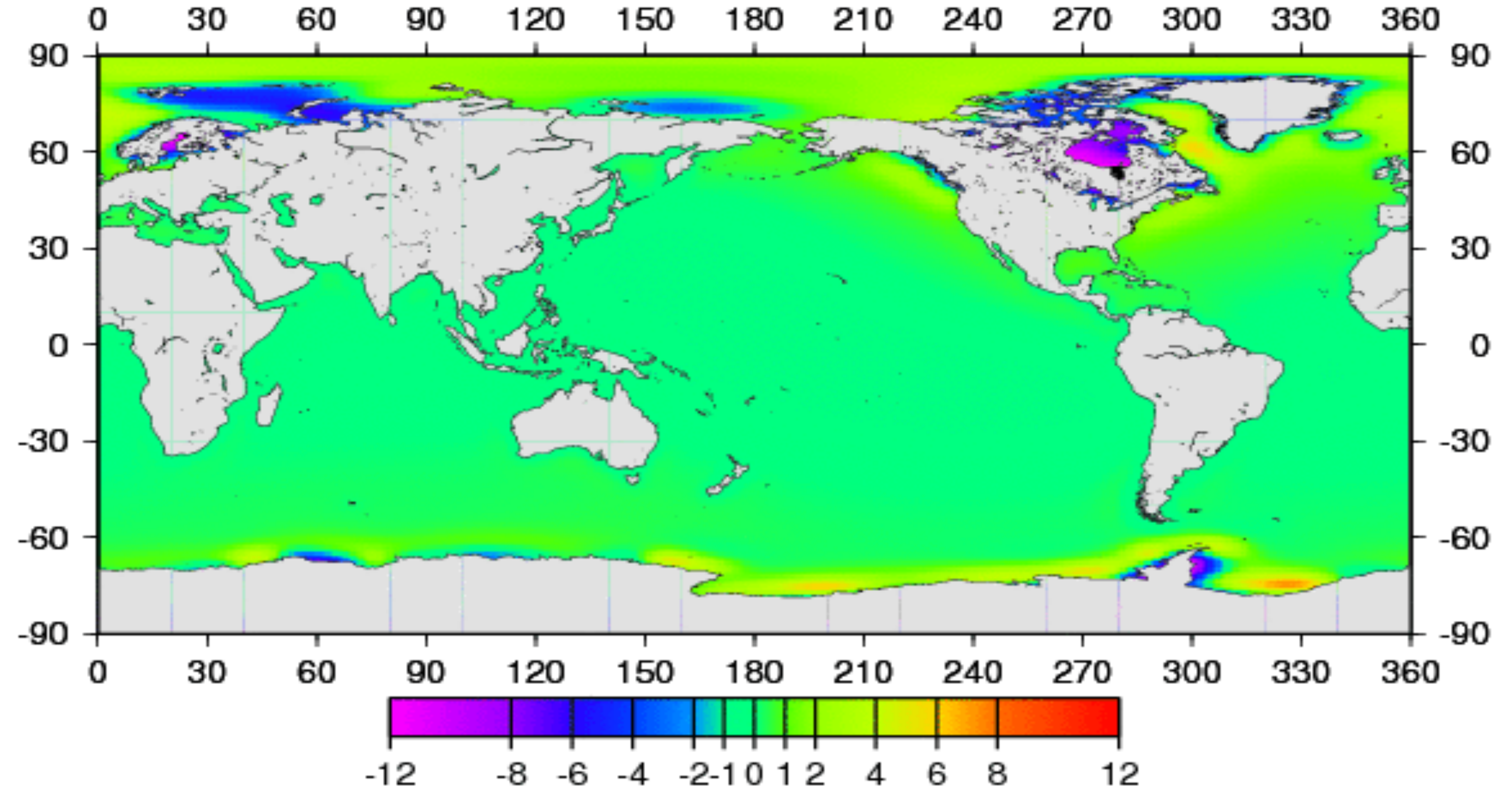
Understanding the Processes



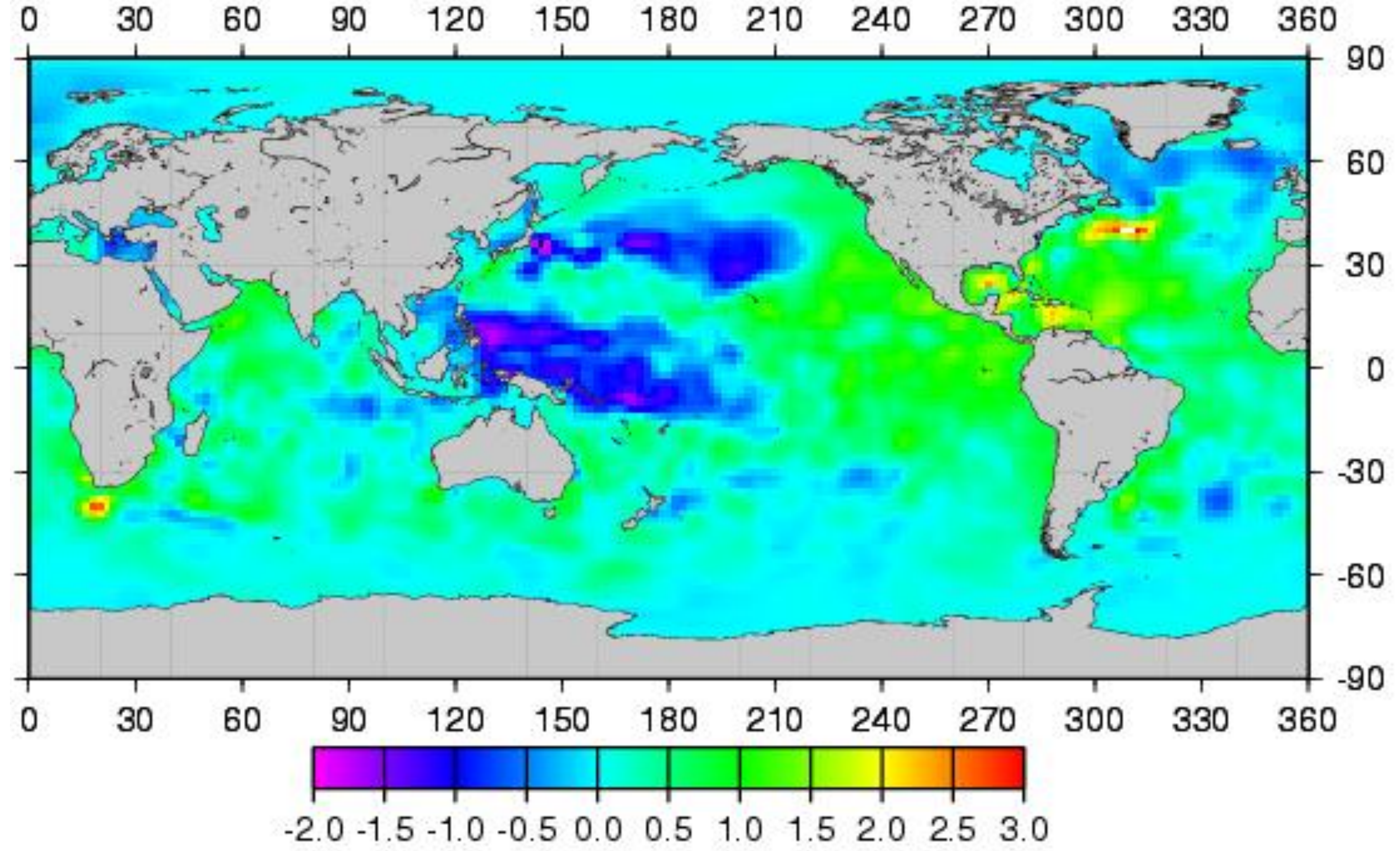
Plag, 2006

Understanding the Processes

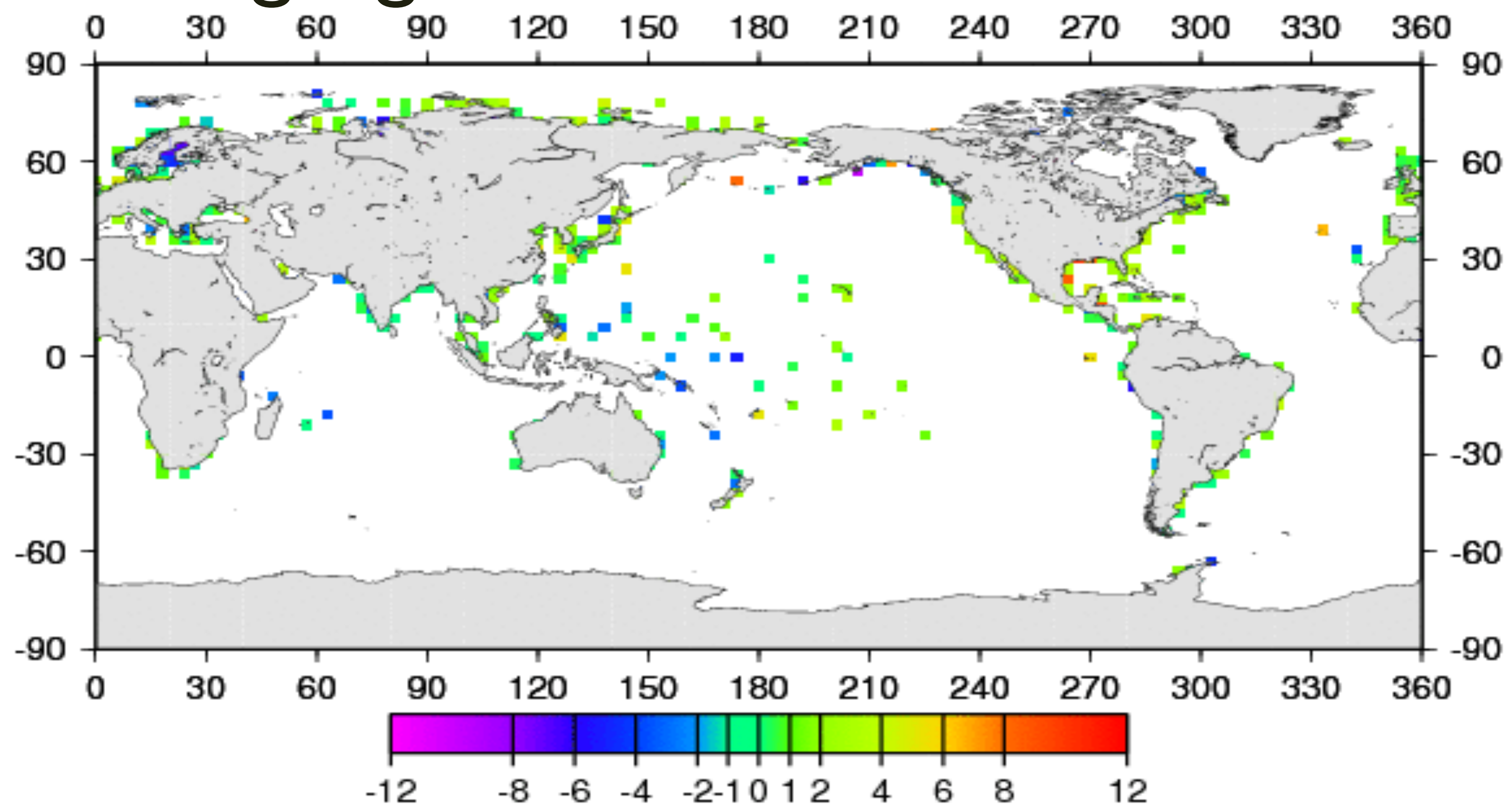
postglacial sea levels



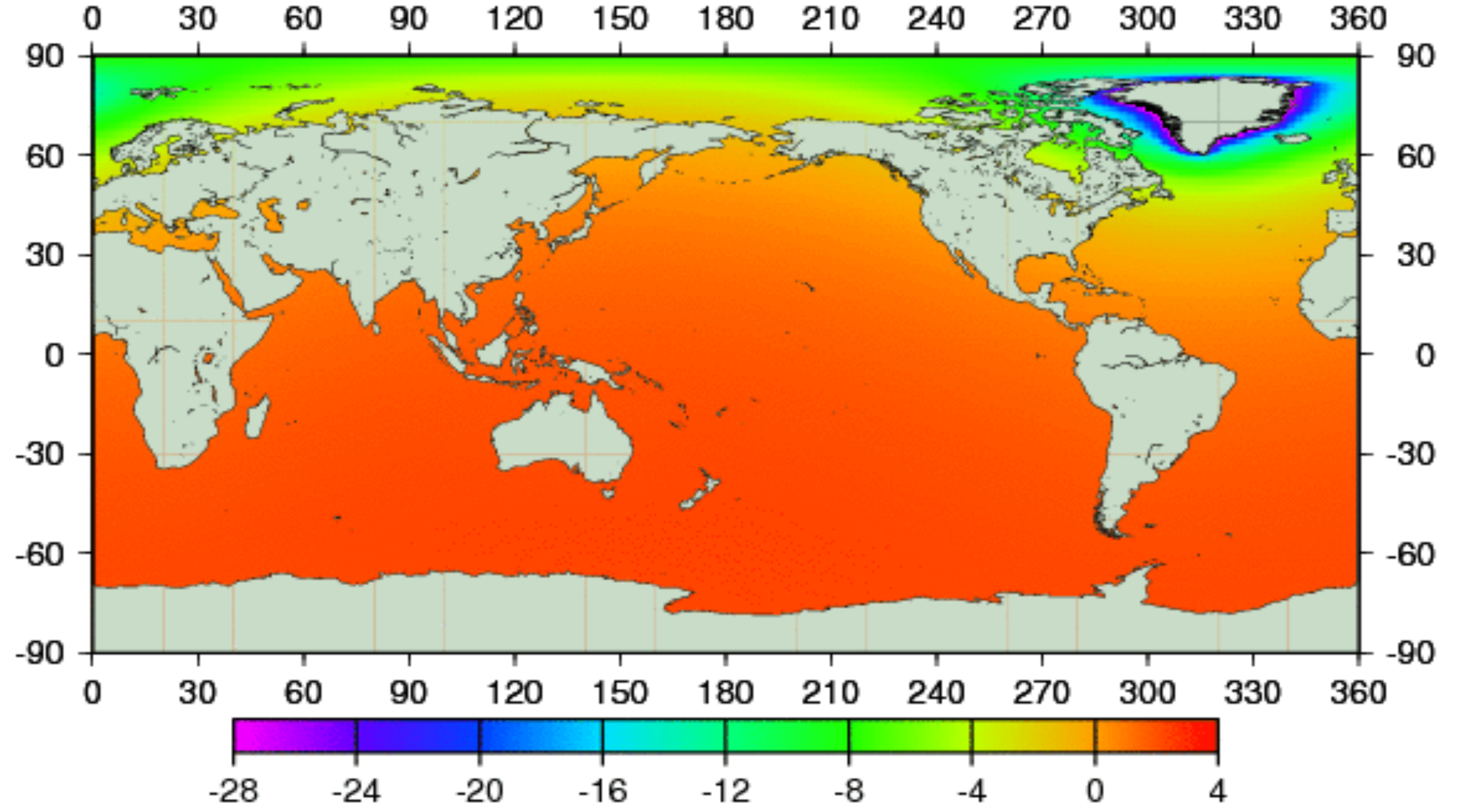
steric changes



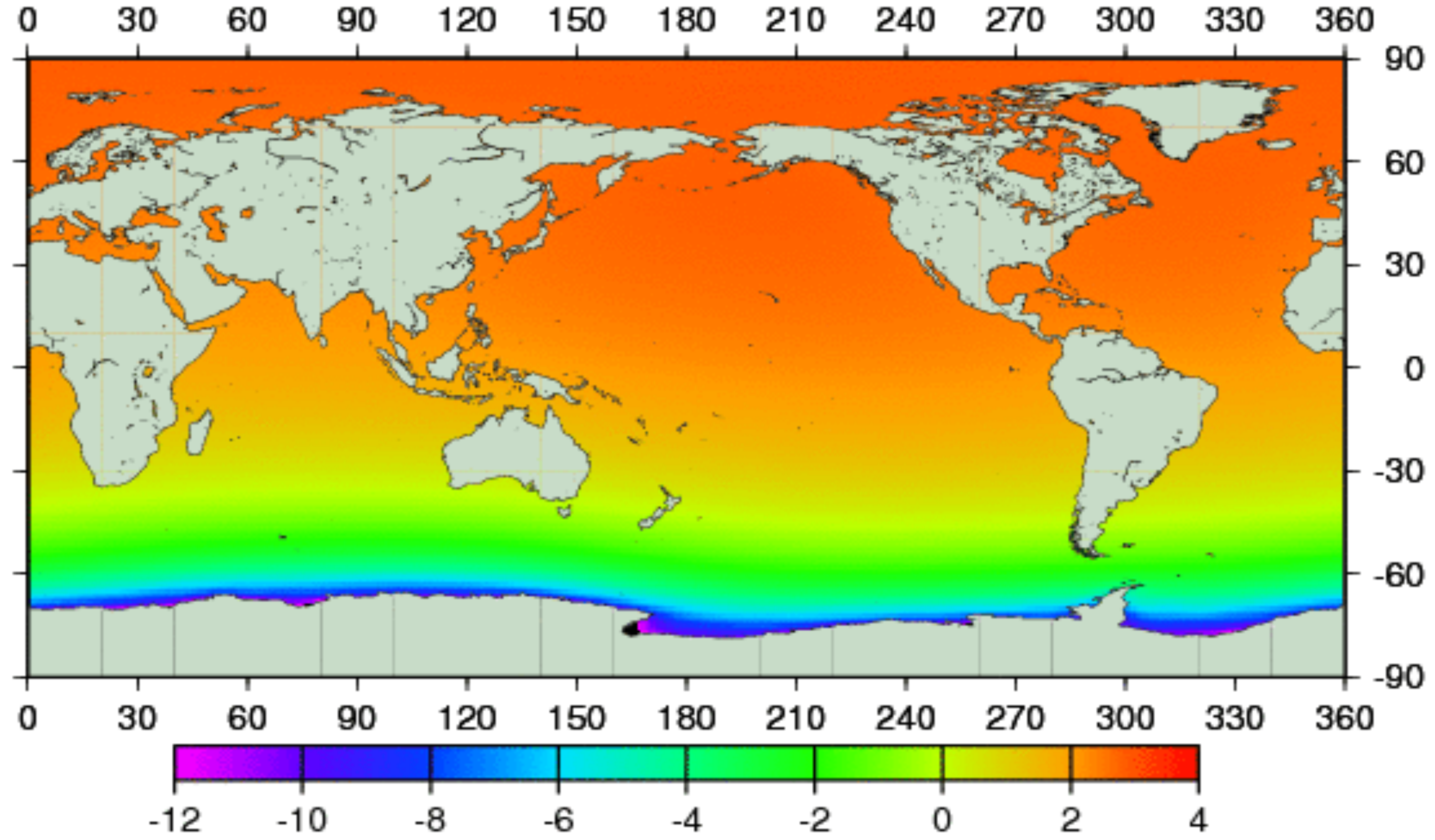
tide gauges



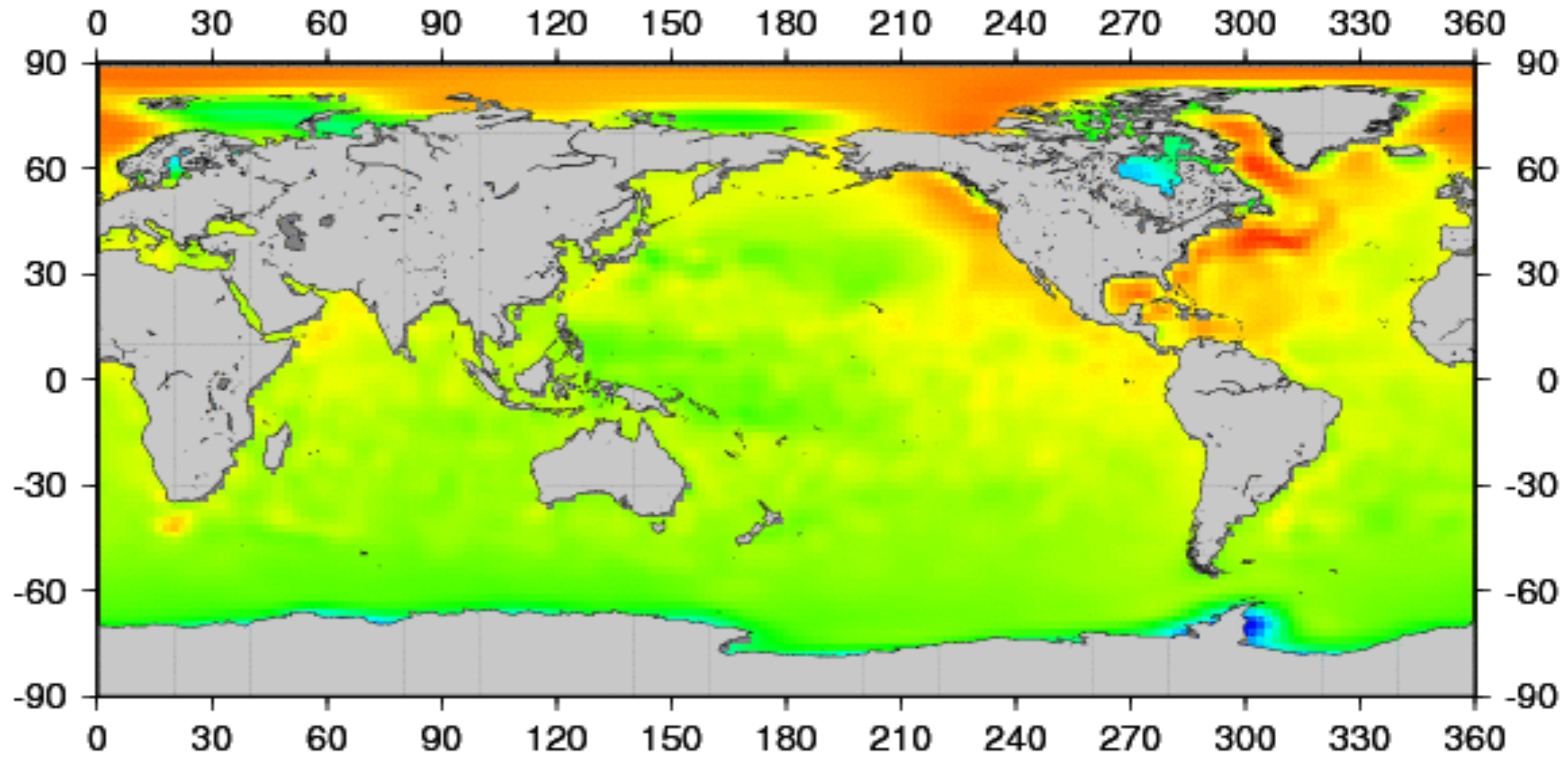
Greenland



Antarctica



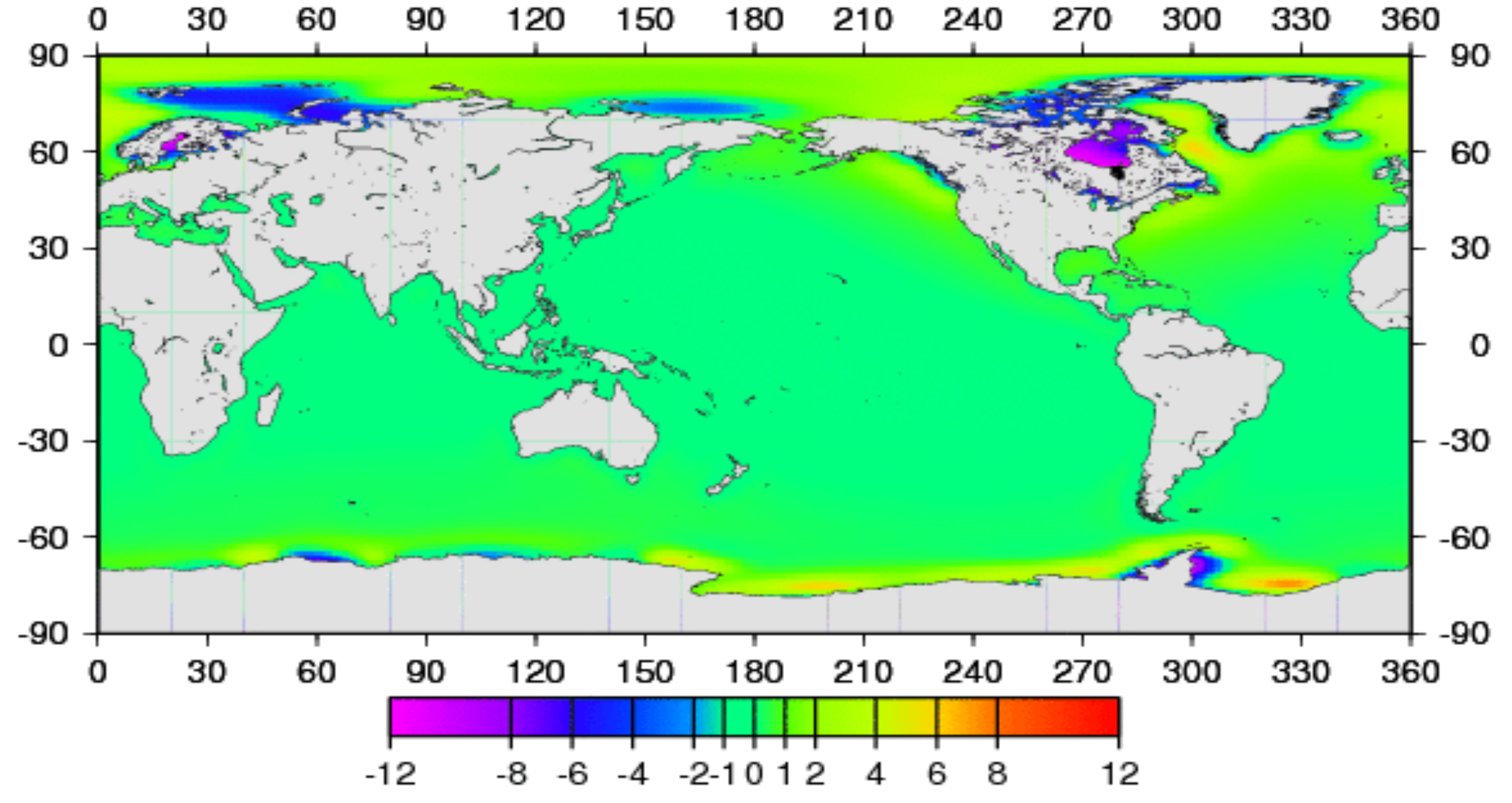
reconstructed LSL



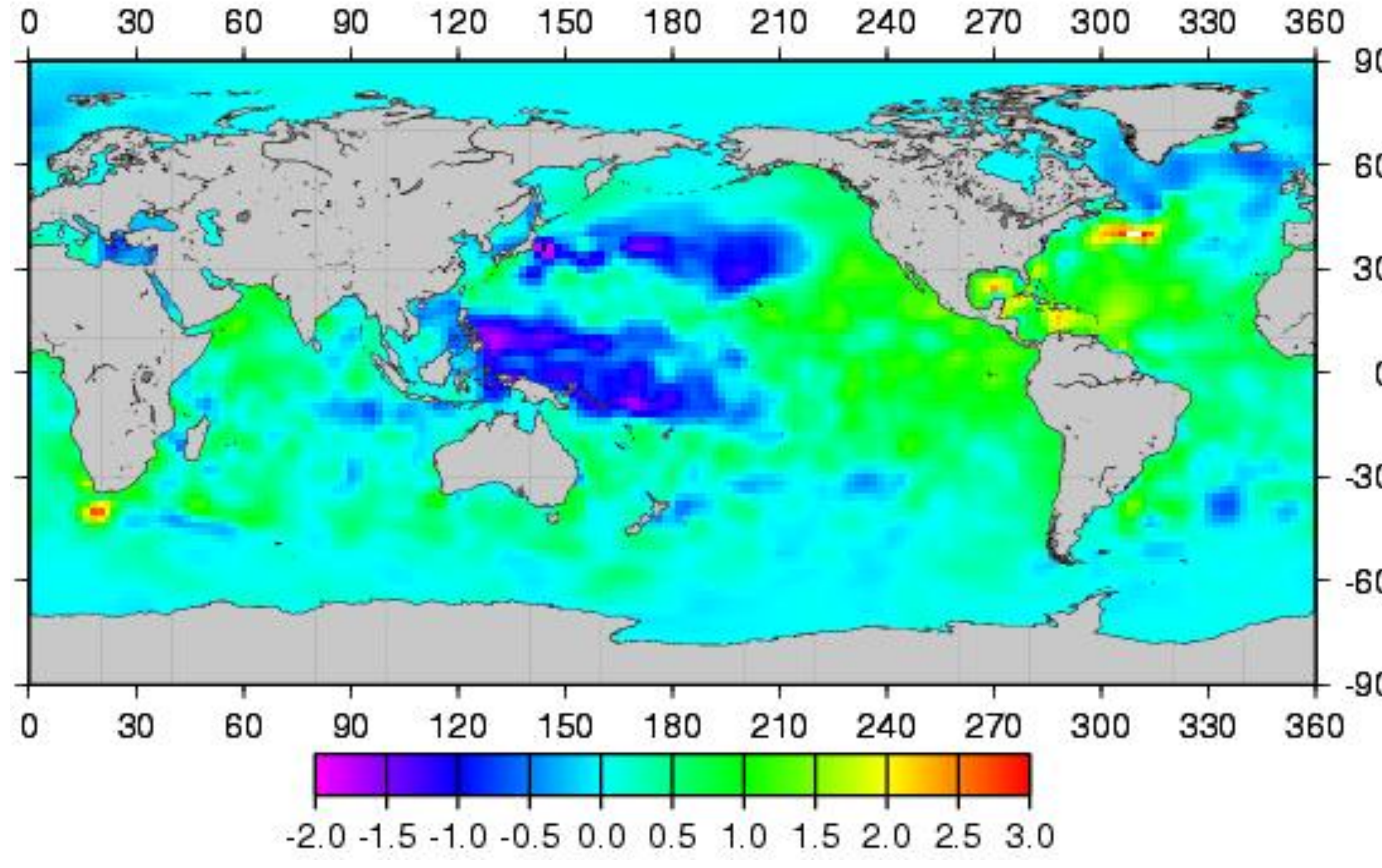
Plag, 2006

Understanding the Processes

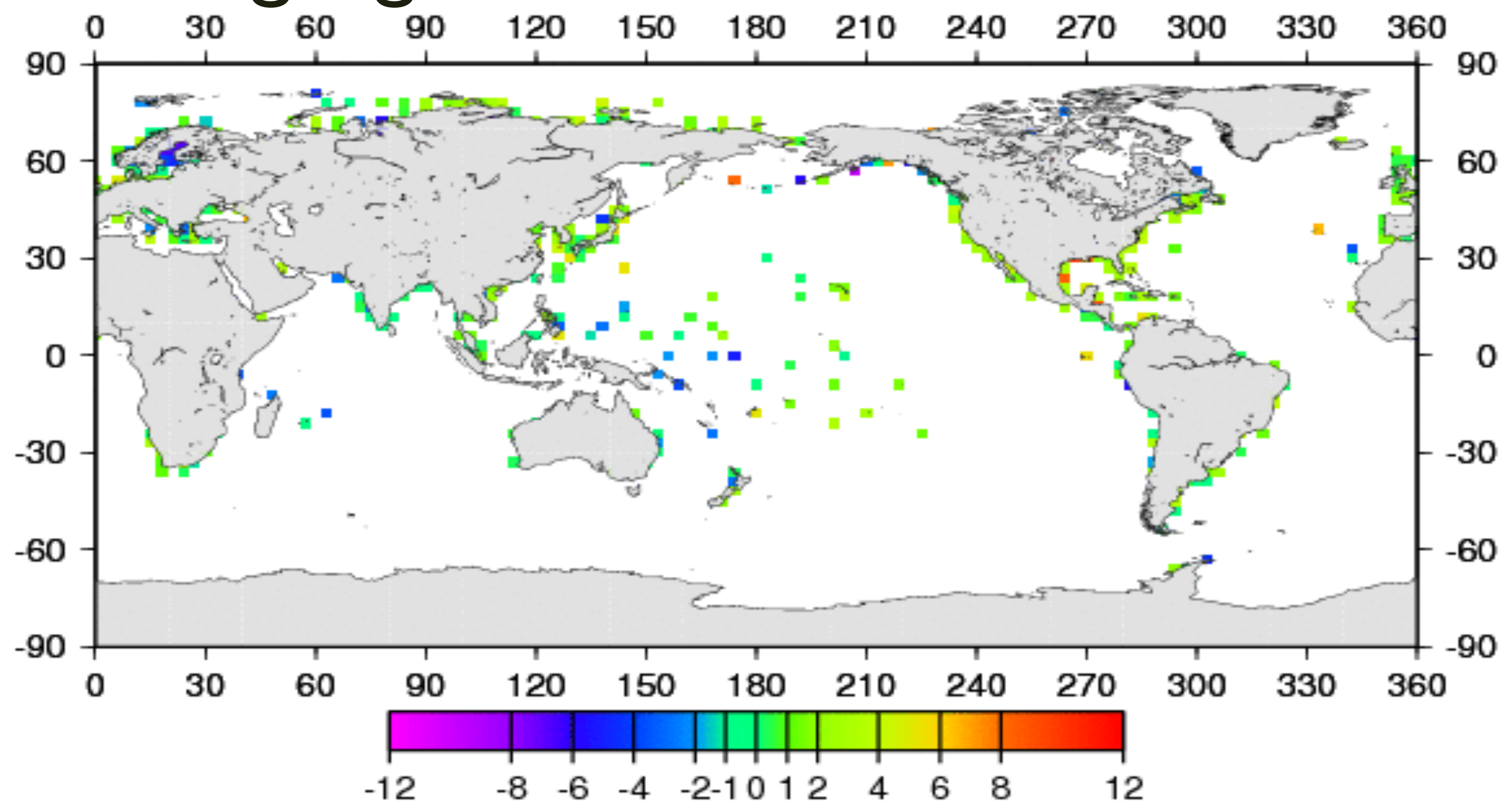
postglacial sea levels



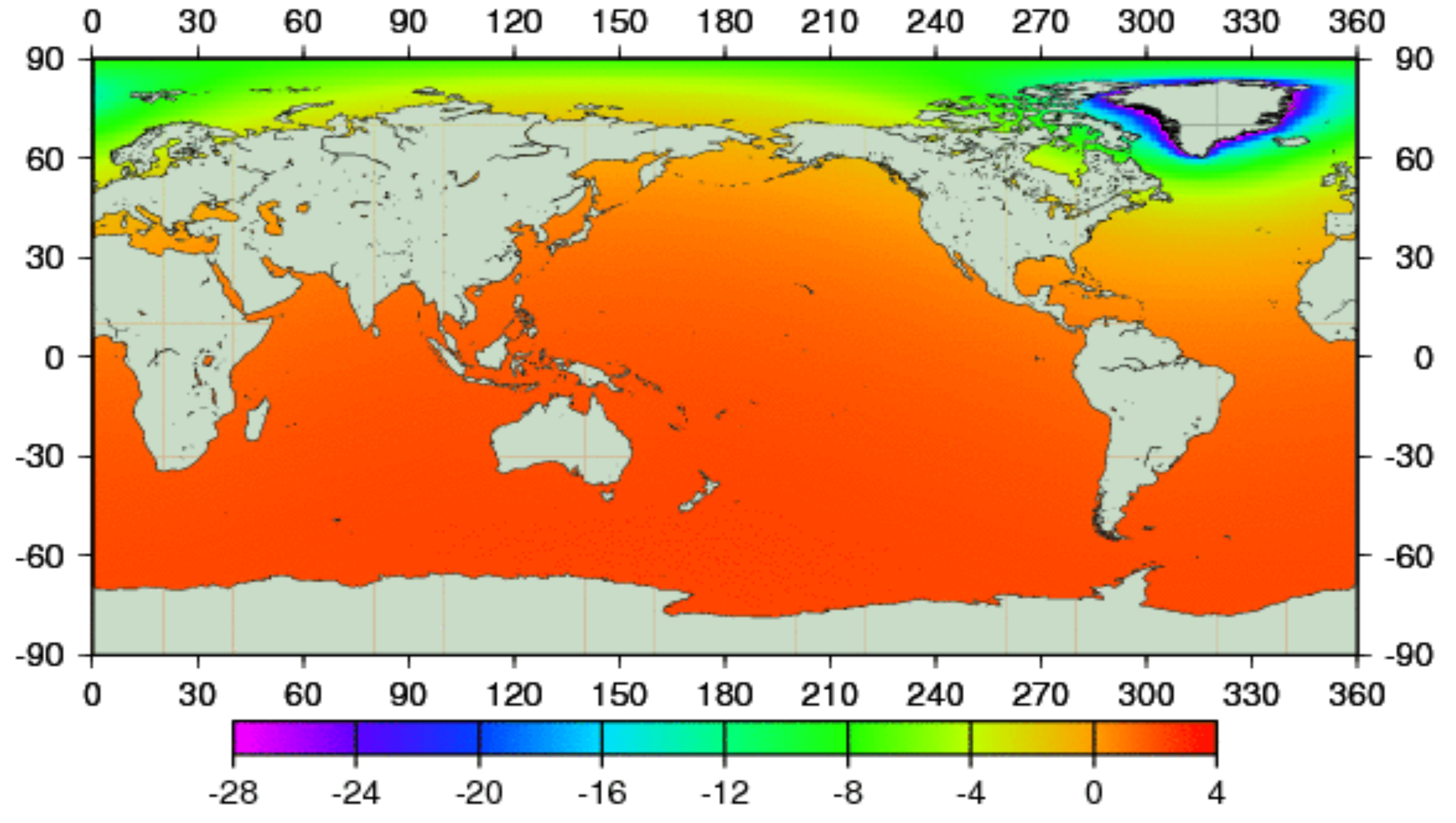
steric changes



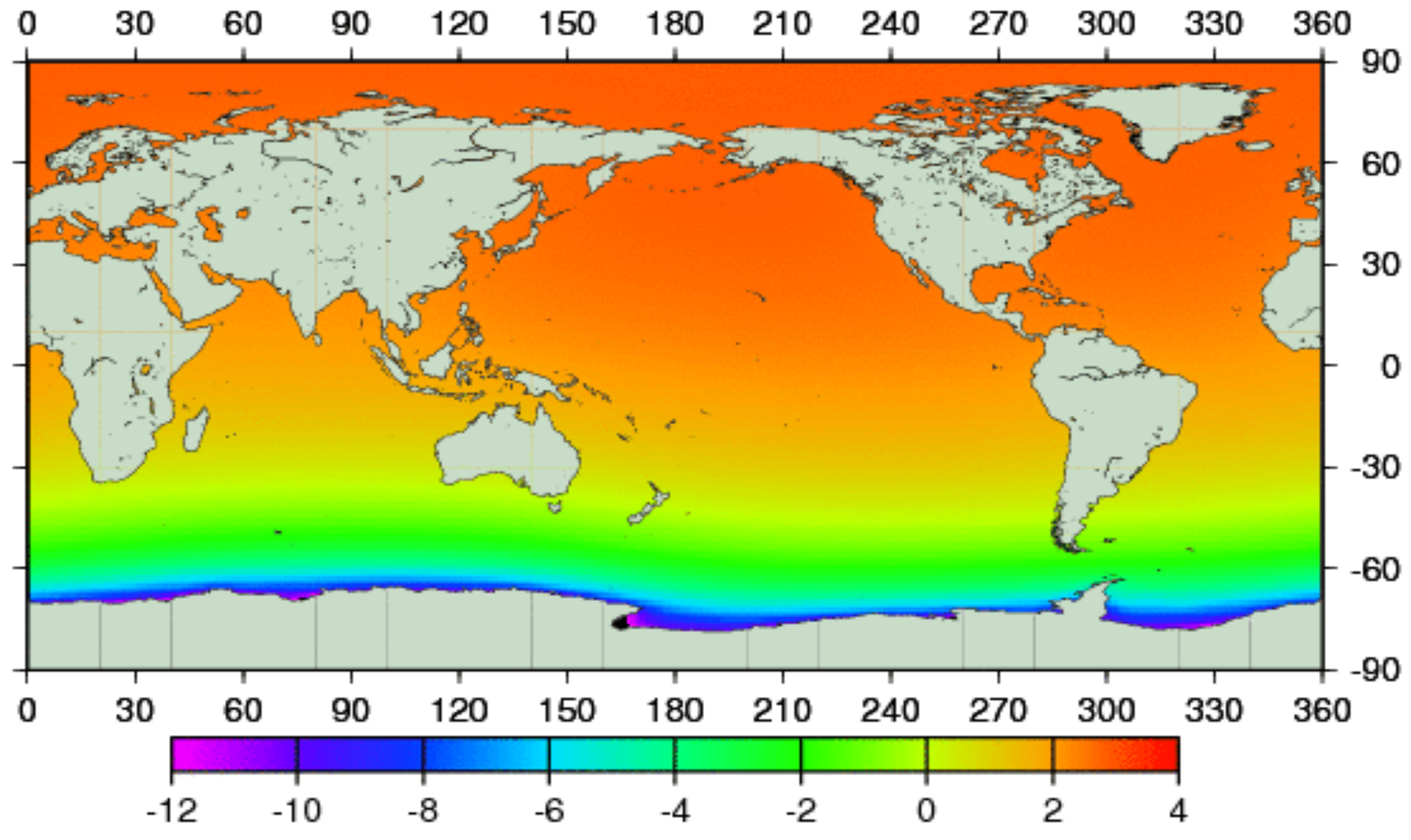
tide gauges



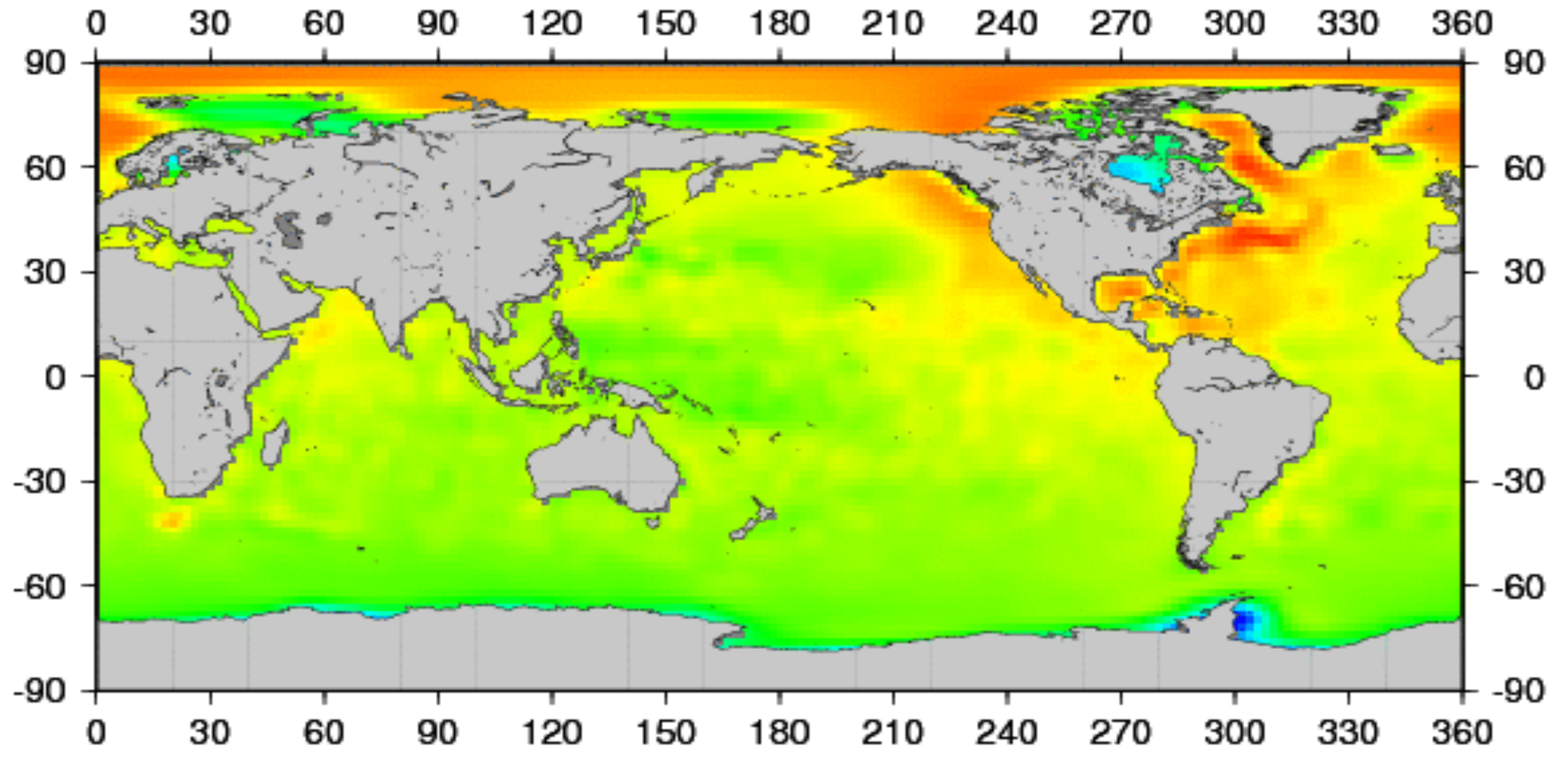
Greenland



Antarctica



reconstructed LSL

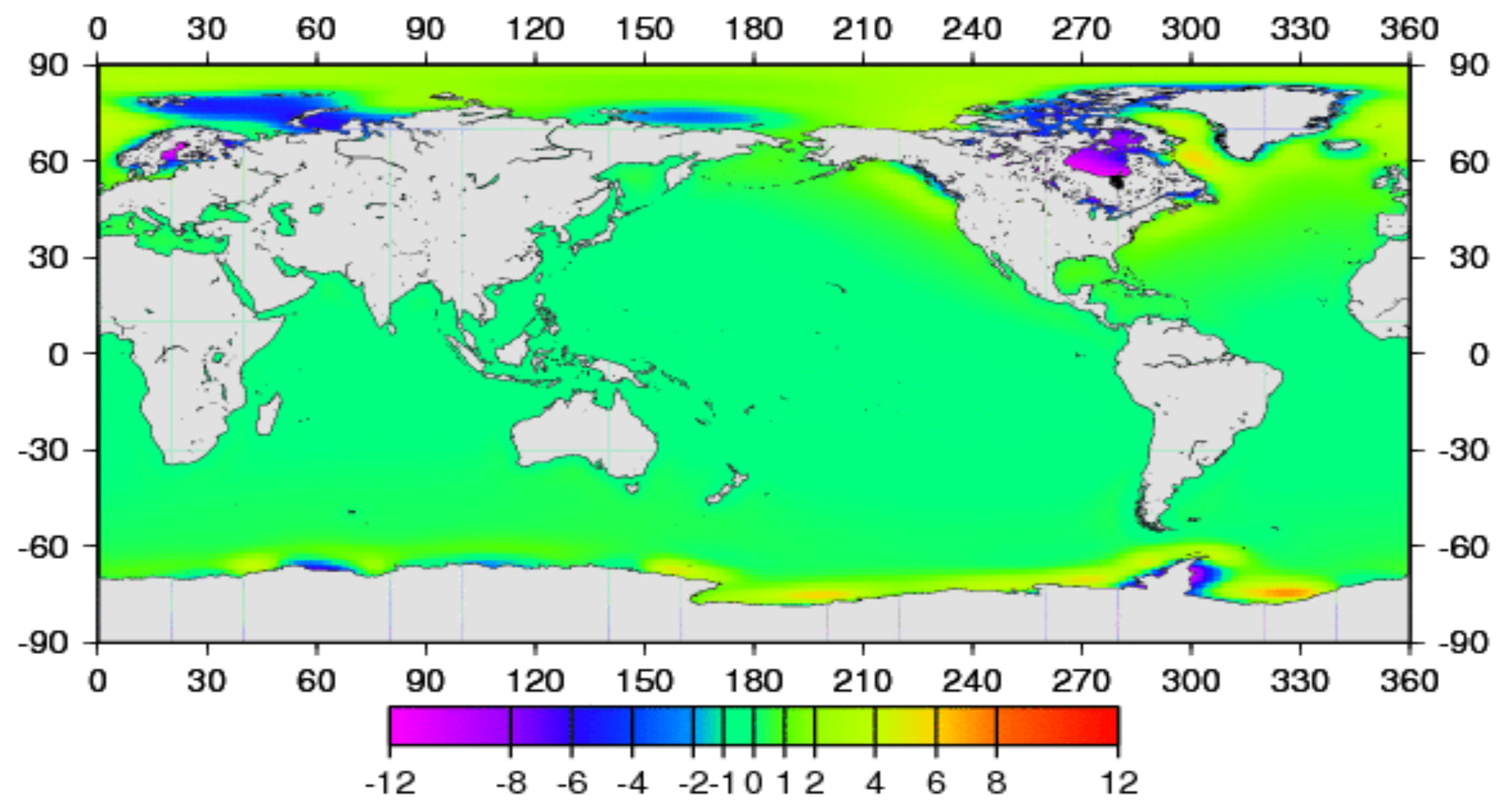


Example global average:
1.14 mm/yr at tide gauges
0.90 mm/yr global average

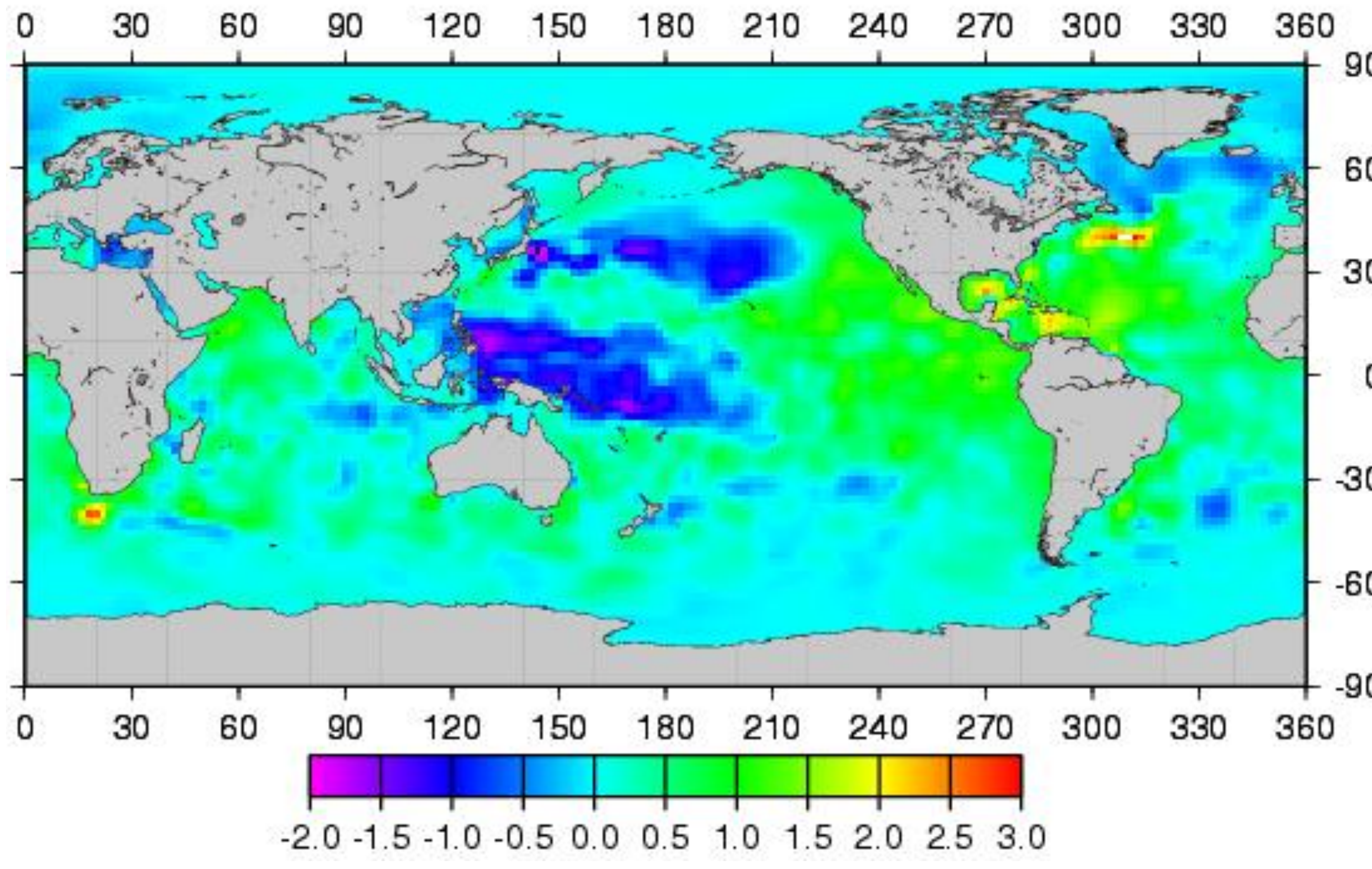
Plag, 2006

Understanding the Processes

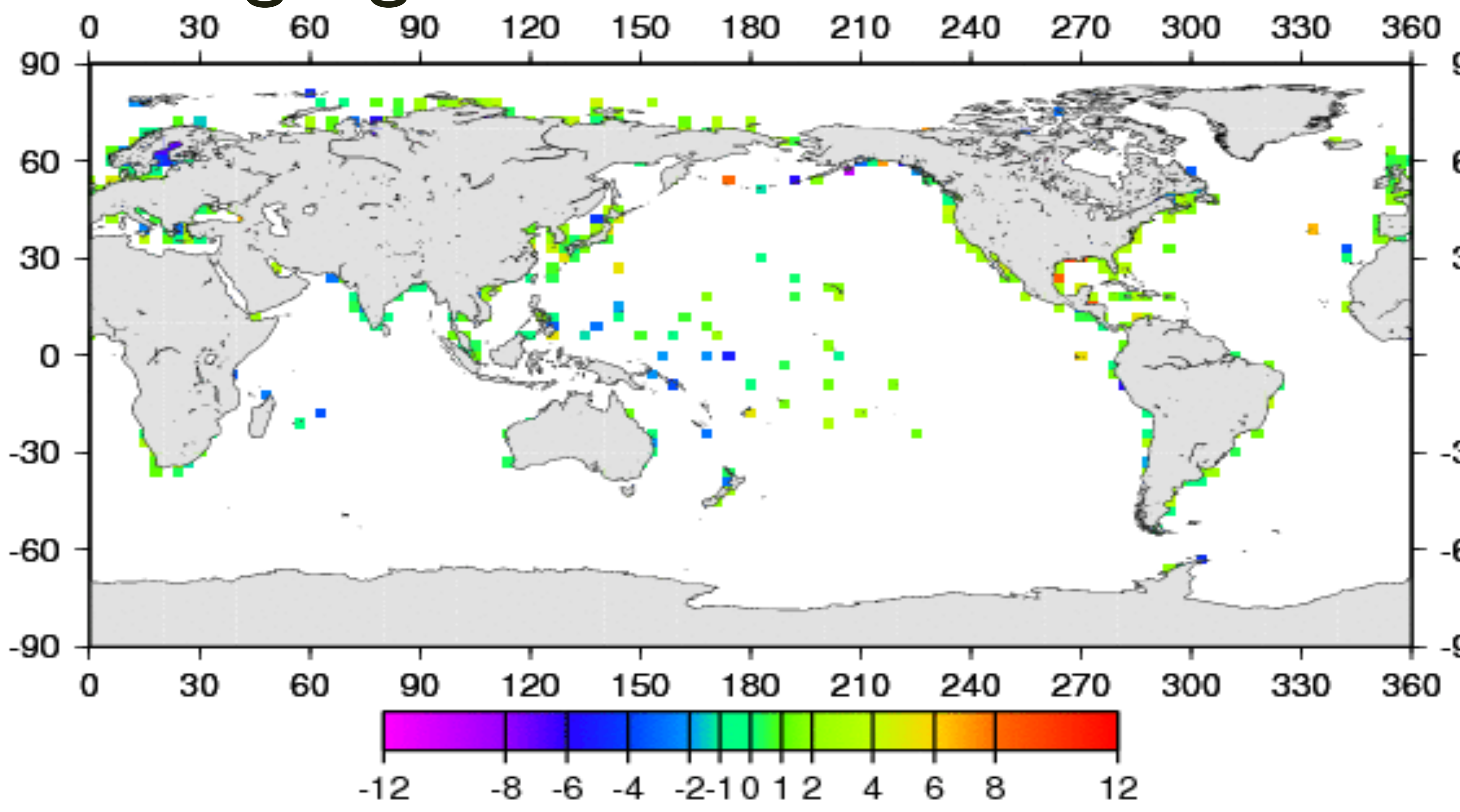
postglacial sea levels



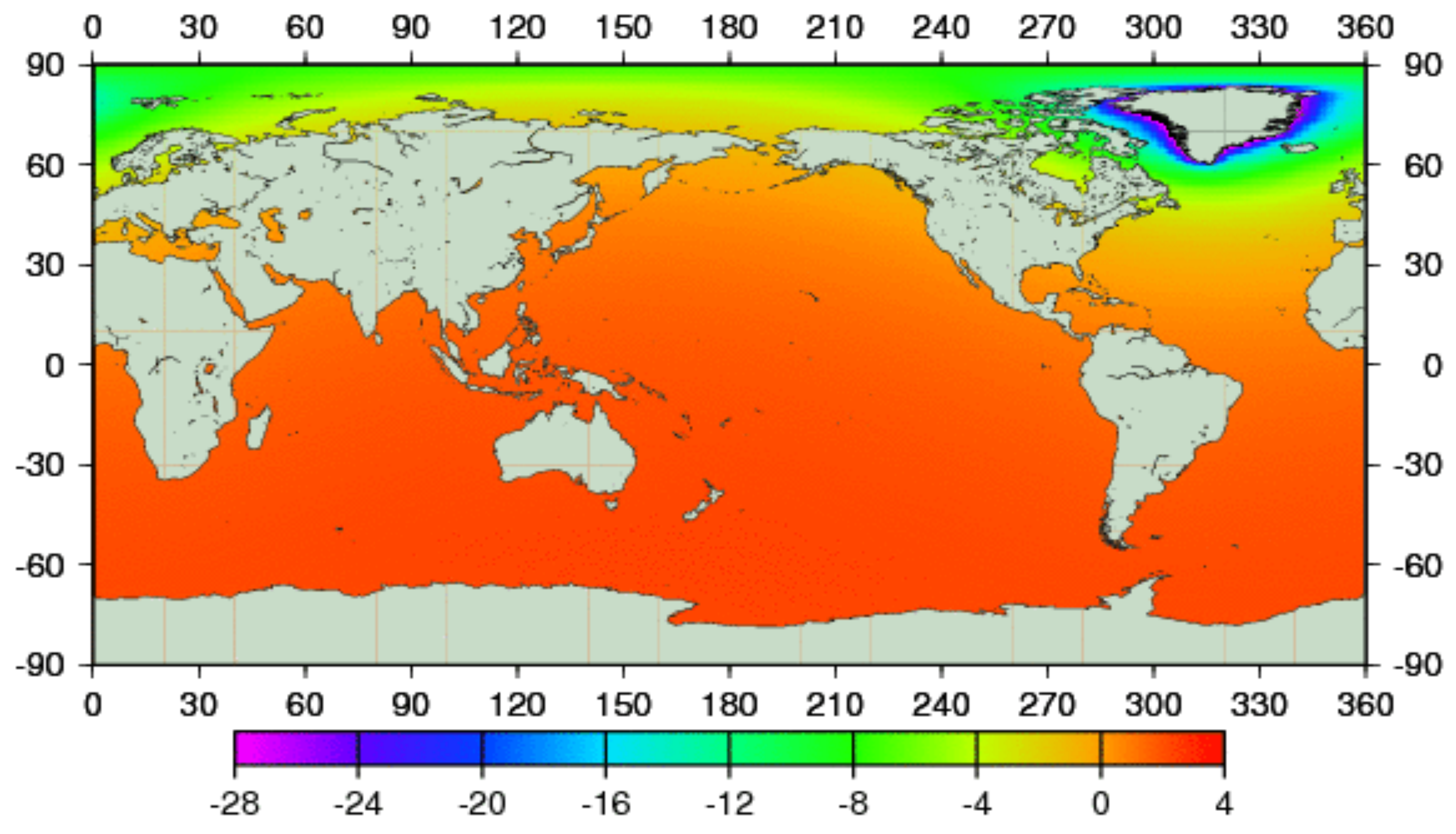
steric changes



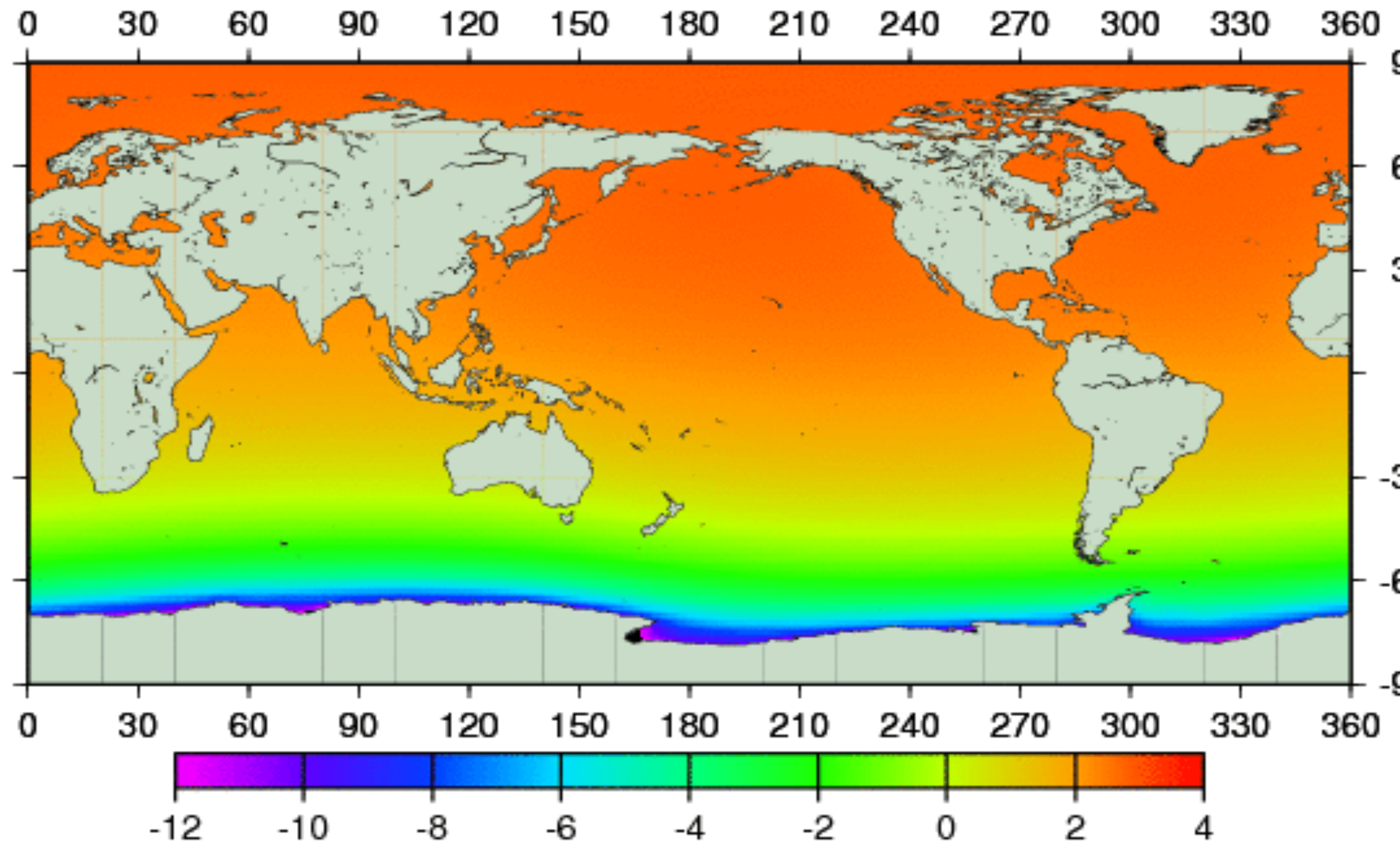
tide gauges



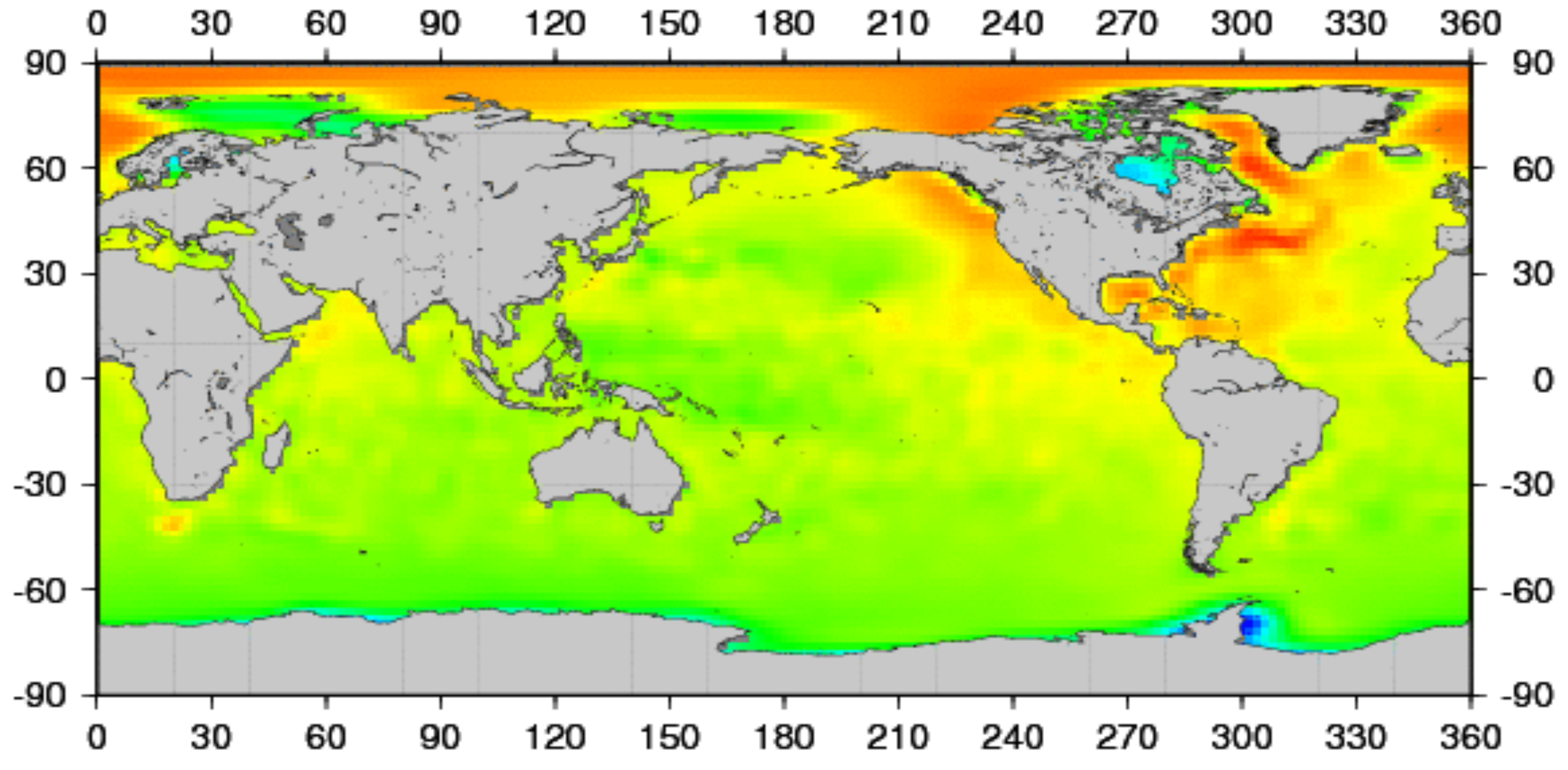
Greenland



Antarctica



reconstructed LSL



Greenland Ice sheet
contribution: 0.3 - 0.5 mm/yr

Antarctica Ice sheet
contribution: 0.1 - 0.3 mm/yr

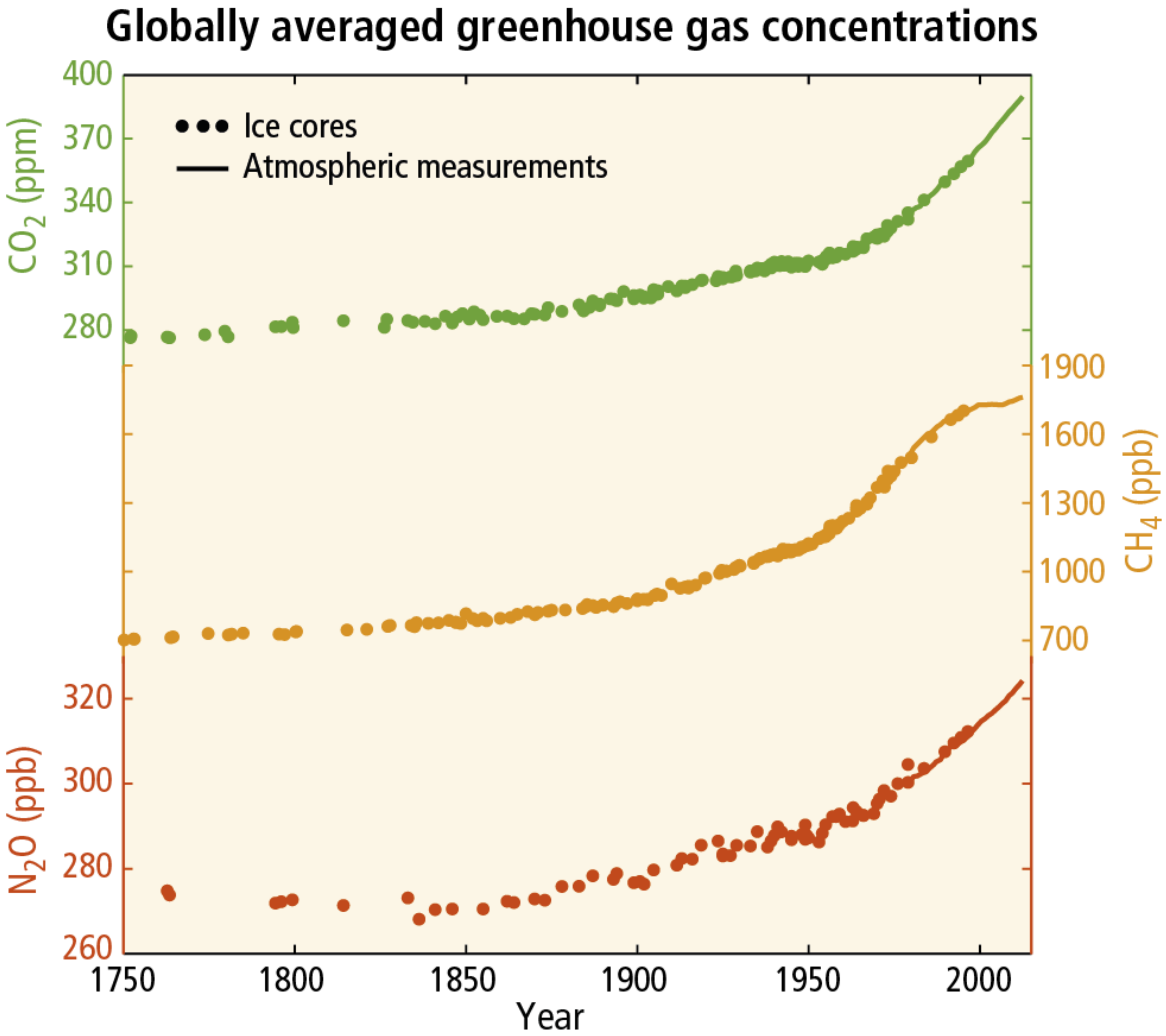
Example global average:
1.14 mm/yr at tide gauges
0.90 mm/yr global average

Plag, 2006

Understanding the Causes

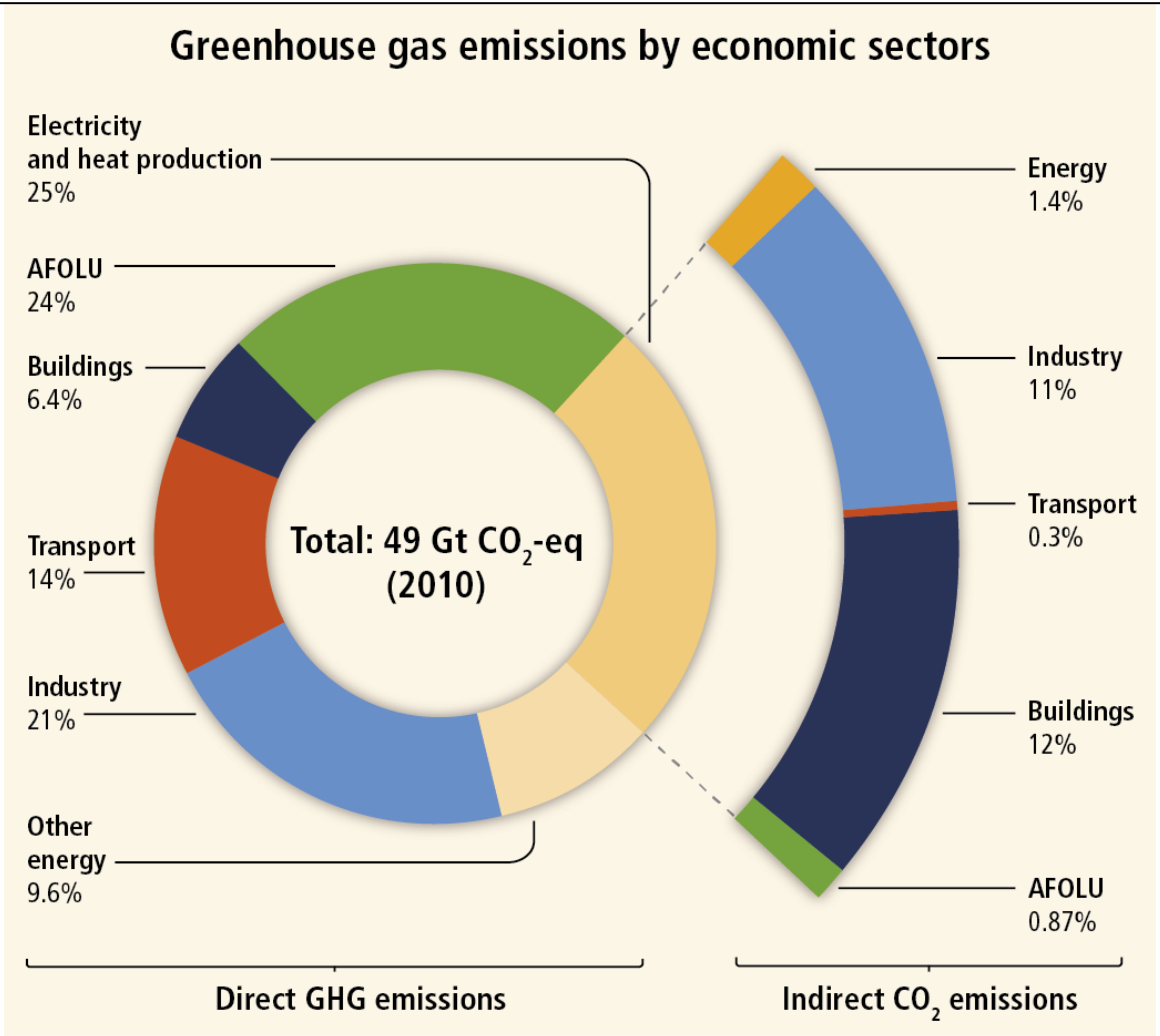
Understanding the Causes

Understanding the Causes

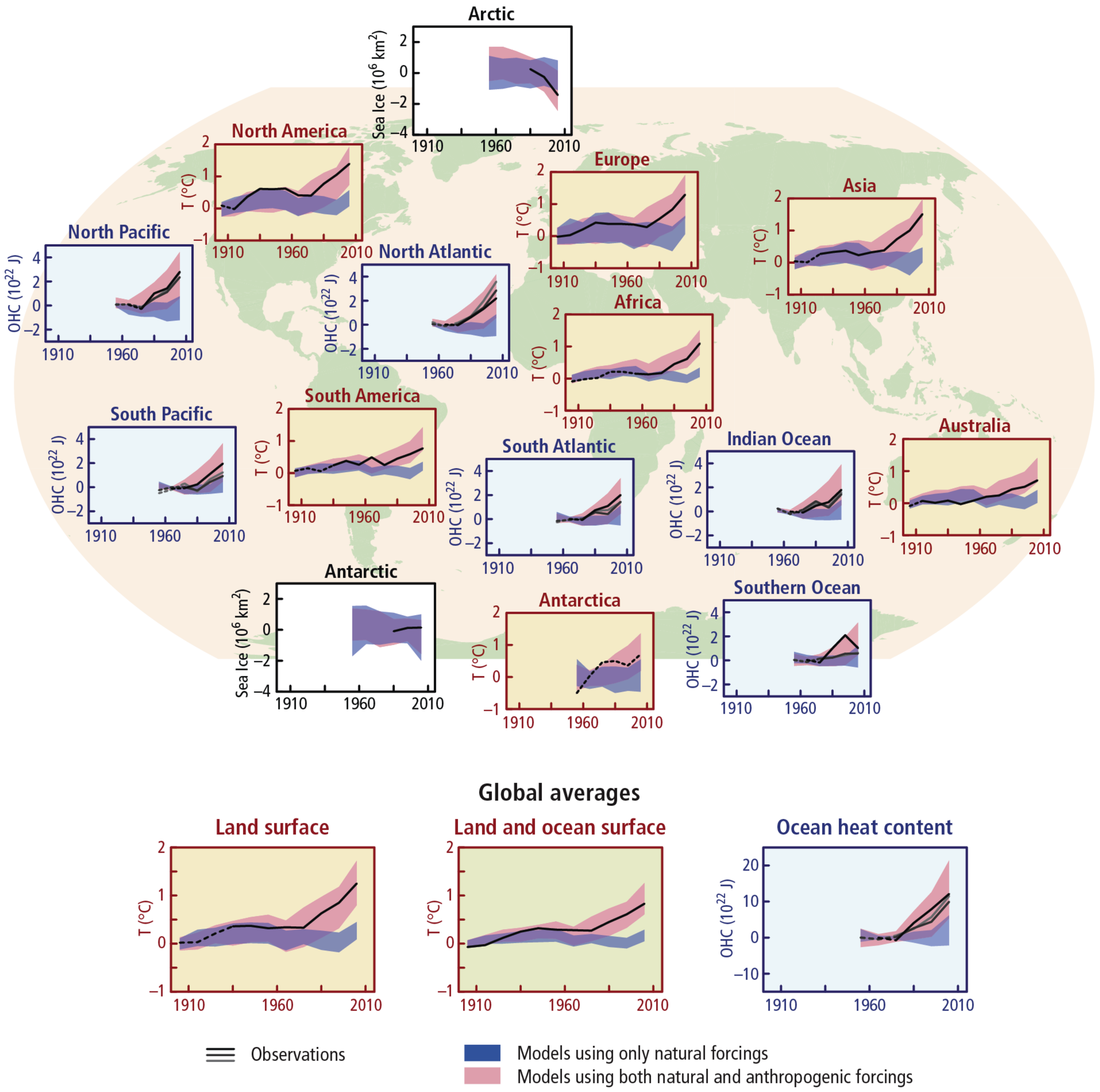



Global anthropogenic CO2 emissions
Quantitative information of CH4 and N2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
(GtCO2/yr)
0
5
10
15
20
25
30
35
40
1850
1900
1950
2000
Year
Cumulative CO2 emissions
(GtCO2)
0
500
1000
1500
2000
1750 – 1970
1750 – 2011

Understanding the Causes

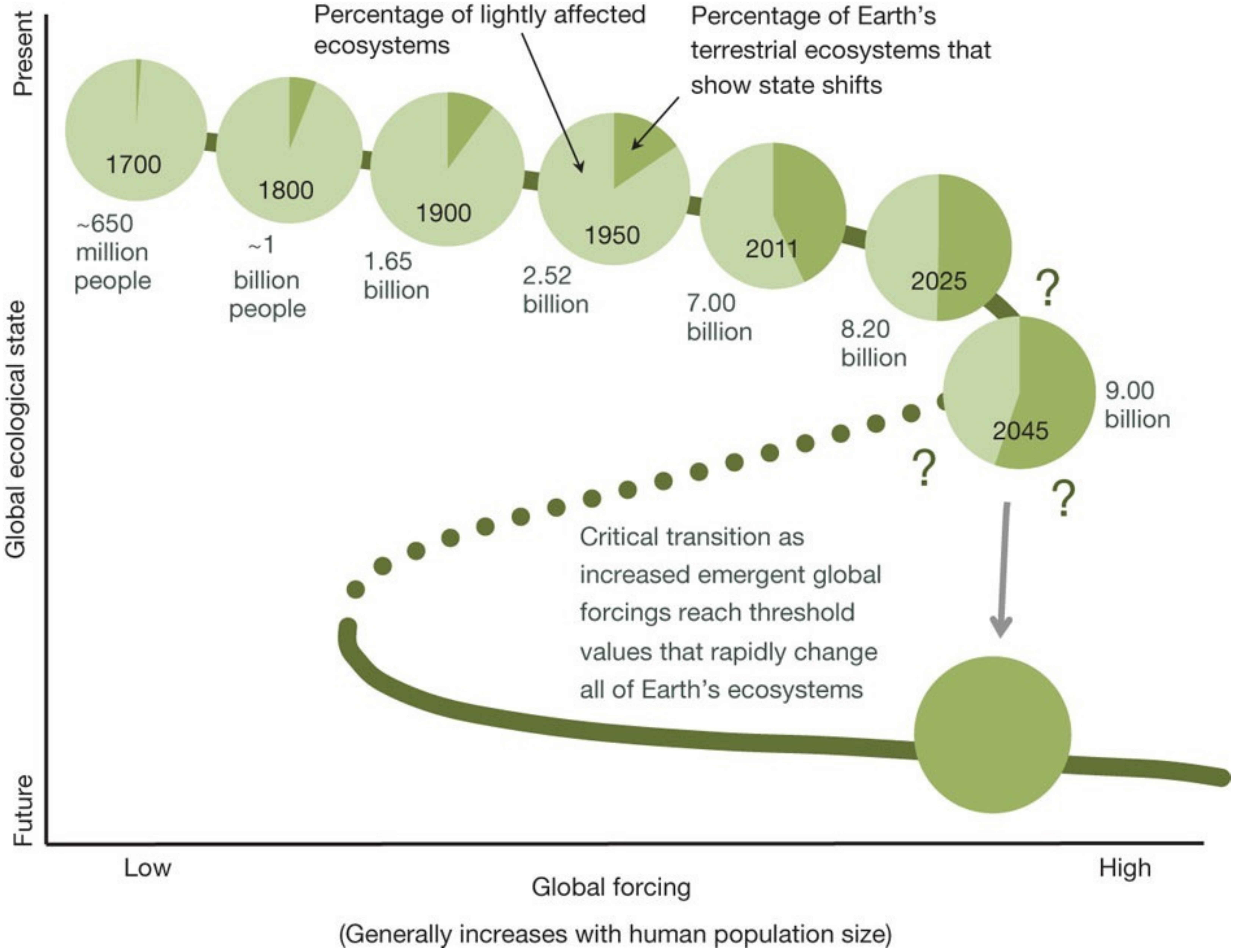

Greenhouse gas emissions by economic sectors
Electricity and heat production 25%
AFOLU 24%
Buildings 6.4%
Transport 14%
Industry 21%
Other energy 9.6%
Total: 49 Gt CO_2-eq (2010)
Energy 1.4%
Industry 11%
Transport 0.3%
Buildings 12%
AFOLU 0.87%
Direct GHG emissions
Indirect CO_2 emissions

Understanding the Causes



Understanding the Causes

Understanding the Causes



Climate Change and Sea Level Hazards

Hazards:

Changes in means:
- air temperature
- precipitation
- wind field/circulation
- evapotranspiration
- humidity
- soil moisture
- permafrost
- sea and lake levels
- inundation
- river runoff
- desertification
- ice and snow cover

Changes in extremes:
- Storms (hurricanes, typhoons, tornados, thunderstorms)
- Floods
- Droughts
- Heat Waves
- Ice storms and snow fall

Changes in dynamics and chemistry:
- ocean circulation
- atmospheric circulation
- ocean temperature
- ocean acidification
- soil, air and water chemistry

Changes in biosphere:
- ecosystem health and services
- migration
- invasive species
- extinction

Questions:
- How well do we know the past and current changes?
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?

Climate Change and Sea Level Hazards

Hazards:

Changes in means:
- air temperature
- precipitation
- wind field/circulation
- evapotranspiration
- humidity
- soil moisture
- permafrost
- sea and lake levels
- inundation
- river runoff
- desertification
- ice and snow cover

Changes in extremes:
- Storms (hurricanes, typhoons, tornados, thunderstorms)
- Floods
- Droughts
- Heat Waves
- Ice storms and snow fall

Changes in dynamics and chemistry:
- ocean circulation
- atmospheric circulation
- ocean temperature
- ocean acidification
- soil, air and water chemistry

Changes in biosphere:
- ecosystem health and services
- migration
- invasive species
- extinction

Questions:
- How well do we know the past and current changes?
- How well do we understand the processes?
- How well can we predict future changes
- Do we have foresight in terms of what might happen?