Introduction to Climate and Climate Change

Livio Fent
Metro Continuing Education

Course Outline

1. **Background**

    a) Climatology/Meteorology: definitions differences/similarities

    b) Is it getting warmer? A view of the past 60 years in Alberta and Canada.

    c) The evolving climate awareness: from academia to societal driver.

2. **Past Climates**

    a) Over four billion years of climate change: from the Archean Eon to the Holocene Epoch

Course Outline

3. Climate Mechanisms

a) Controls on the climate system and applications to Alberta

i. Solar input and distribution

ii. Latitude

iii. Earth-Sun Relationships

iv. Distance to Water (large)

v. Circulation

vi. Topography

Course Outline

3. **Climate Mechanisms cont'd**

    b) Atmospheric Interactions and teleconnection effects

    i. ENSO

    ii. Volcanism

    iii. Snow and Ice (Cryosphere)

4. **Present day climate and climate change: Global, Canada and Alberta**

    a) Affects to today's climate: natural and anthropogenic (albedo: deforestation /urbanization /agriculture)

    b)The situation with Greenhouse Gases (GHGs)

Course Outline

5. Future Climate: Canada and Alberta to 2050 and beyond

- Model basics
- Predictions and accuracies

6. The Climate Change Debate

- Mainstream views, the skeptics
- Coping strategies: Prevention, Mitigation, Adaptation
- Local impacts

Course References

Main reference text

- Climatology, Rohli and Vega (4^{th} edition, available from JBlearning)

Handout reference

- Climate Change, Scientific American

Secondary and historical references

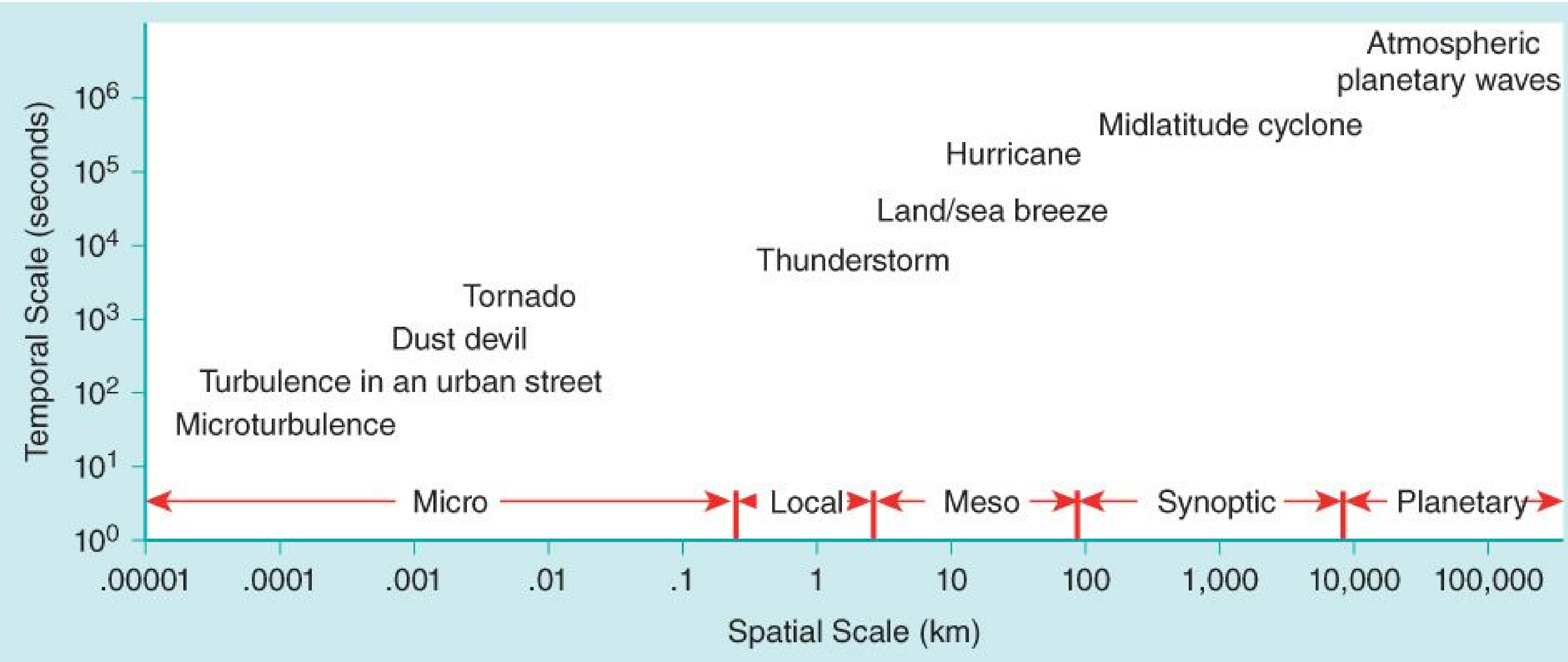
- IPCC Reports
- CCCR Full Report
- Physical Climatology, Sellers
- Climate Canada, Hare and Thomas
- FAQ about the science of climate change – Environment Canada
- Ages of Gaia, Lovelock
- The Long Summer, Fagan
- The Deniers, Solomon

Background
Meteorology - Climatology

- Study of ***current and near-future*** atmospheric variables – weather ex. temperature, precip, humidity, wind, etc.
- Understanding the physics and chemistry of the atmosphere is important in meteorology
- Meteorology is more singularly focused towards atmospheric variables and processes for its description of environmental state and prognostics

- Study of the same atmospheric variables but ***over much longer time***
- Understanding the statistical trends of atmospheric physics and chemistry is important in climatology
- Climatology is more wholistic; atmospheric processes are often considered in interaction with other environmental disciplines: hydrosphere, biosphere, lithosphere, cryosphere

Scales in Climatology and Meteorology

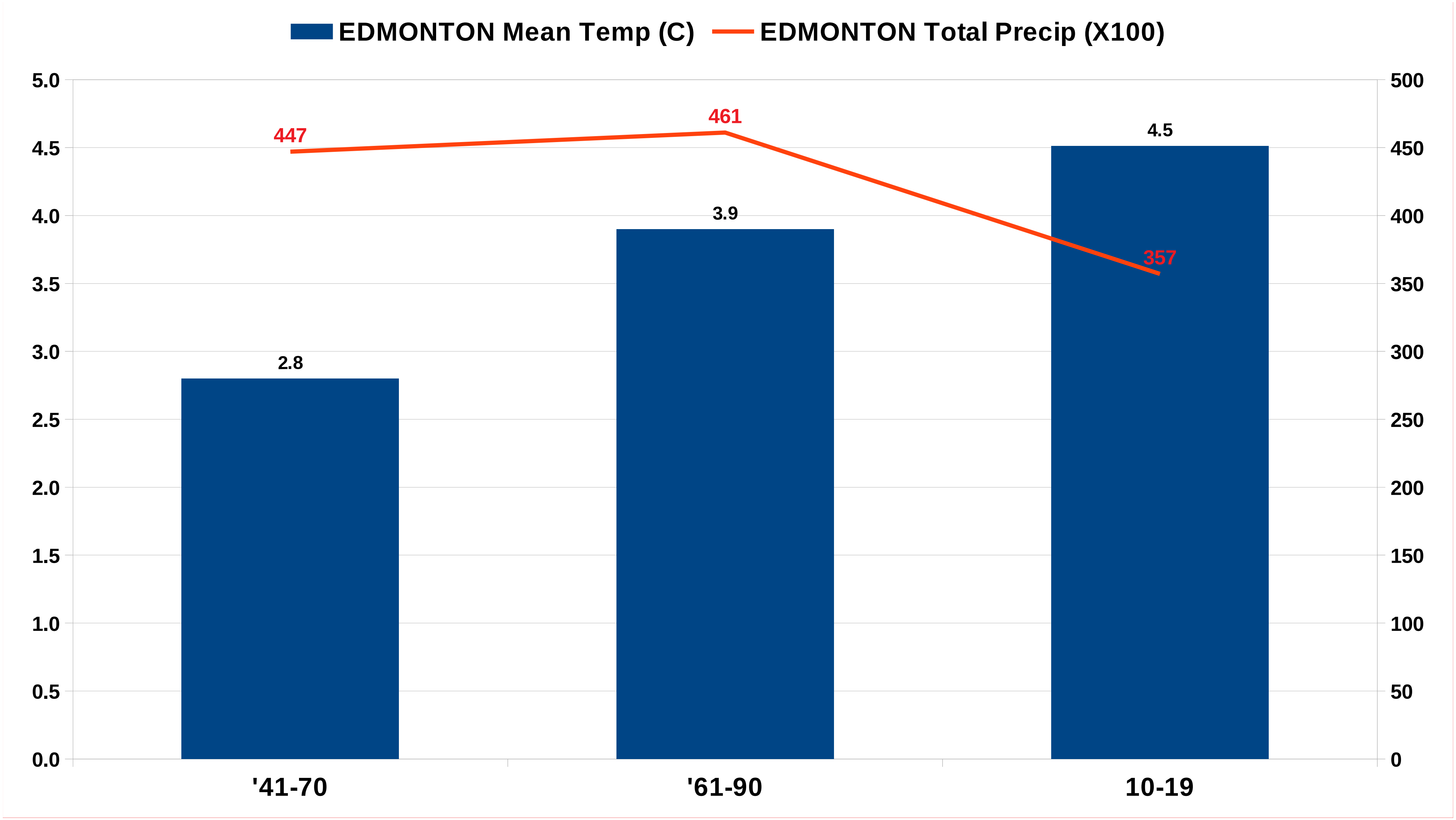


- Note that the same phenomena are of interest but climatology has a longer term temporal component, a statistical interest.
- Changes in the longer term lead to investigations beyond strictly the atmospheric system (the other ‘spheres’). This fact adds significant complexity in assessing climatological change.

Section 1.
Is the climate getting warmer?

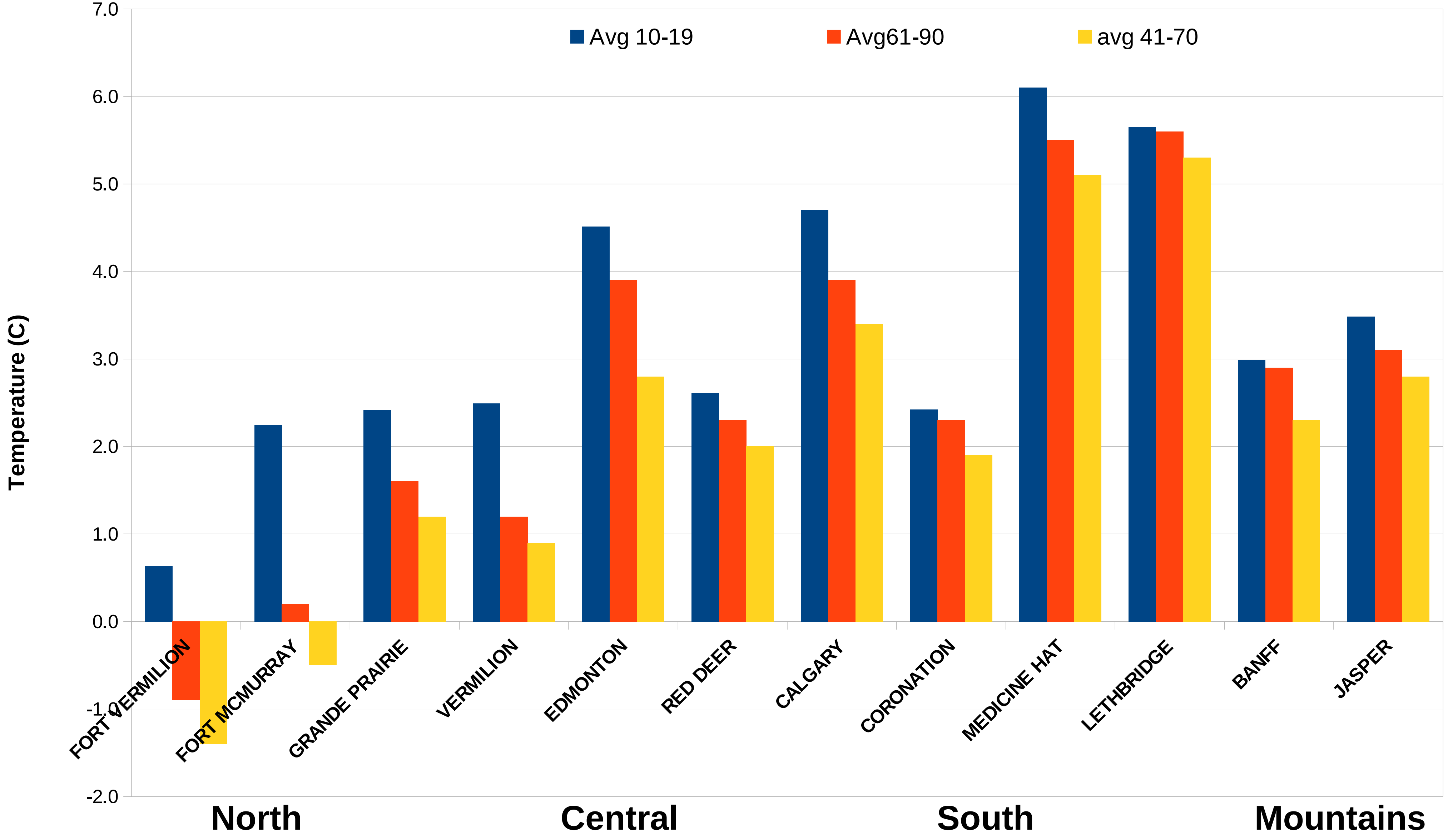
- The question needs further clarity:
  - Is it getting warmer from earth's beginnings (4.5 billion yrs)?
  - From the beginning of life (3.8 billion yrs)?
  - From the evolution of homo sapiens (about 100 thousand yrs)?
  - From the start of the Industrial Revolution (about 250 yrs)?
  - Within our lifetimes (25-90 yrs)?
- We will look at all these scales but let us first look at the local evidence over the past 80 years or so.

The Edmonton experience



Data: Environment Canada

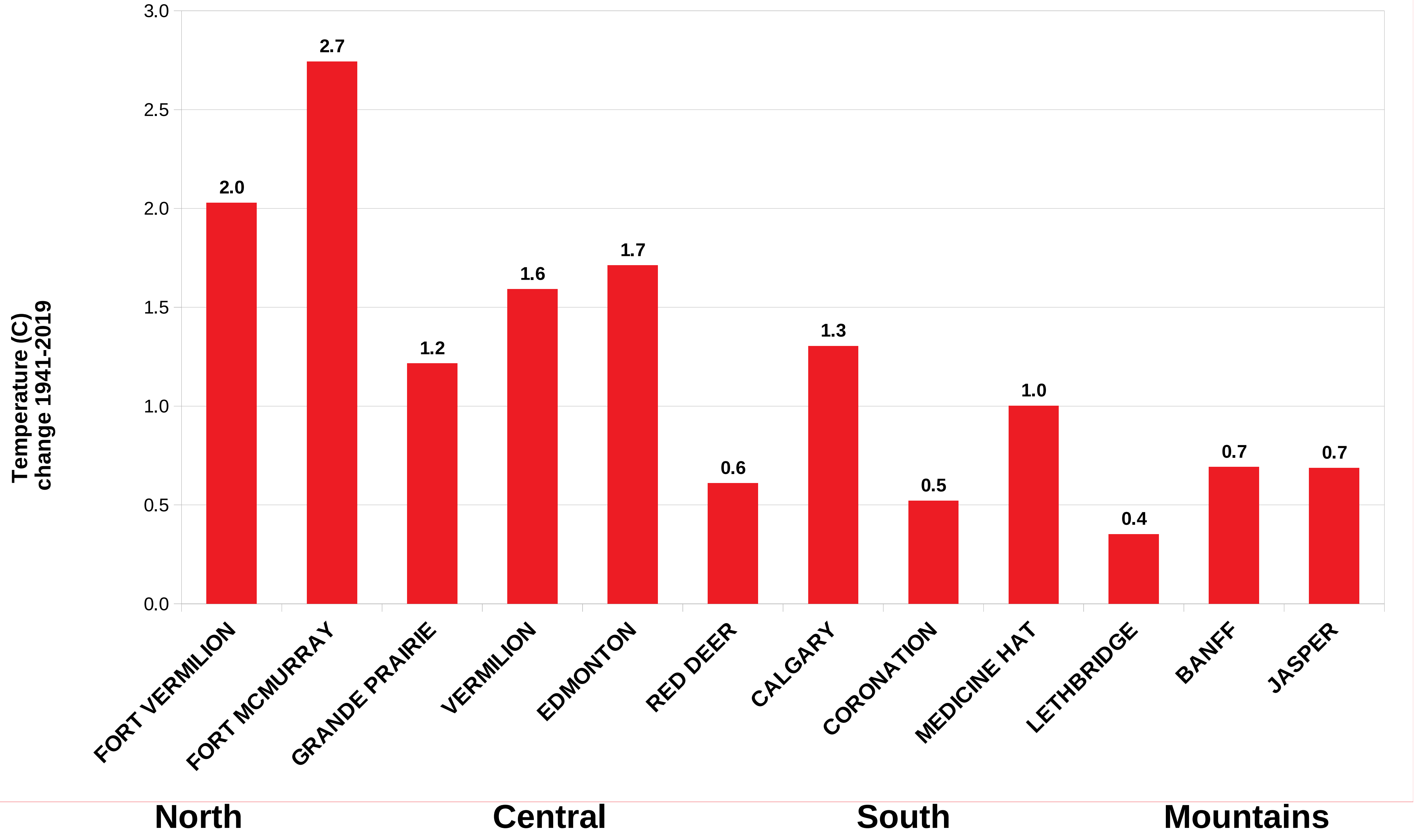
Other Alberta Locations (Temp.)



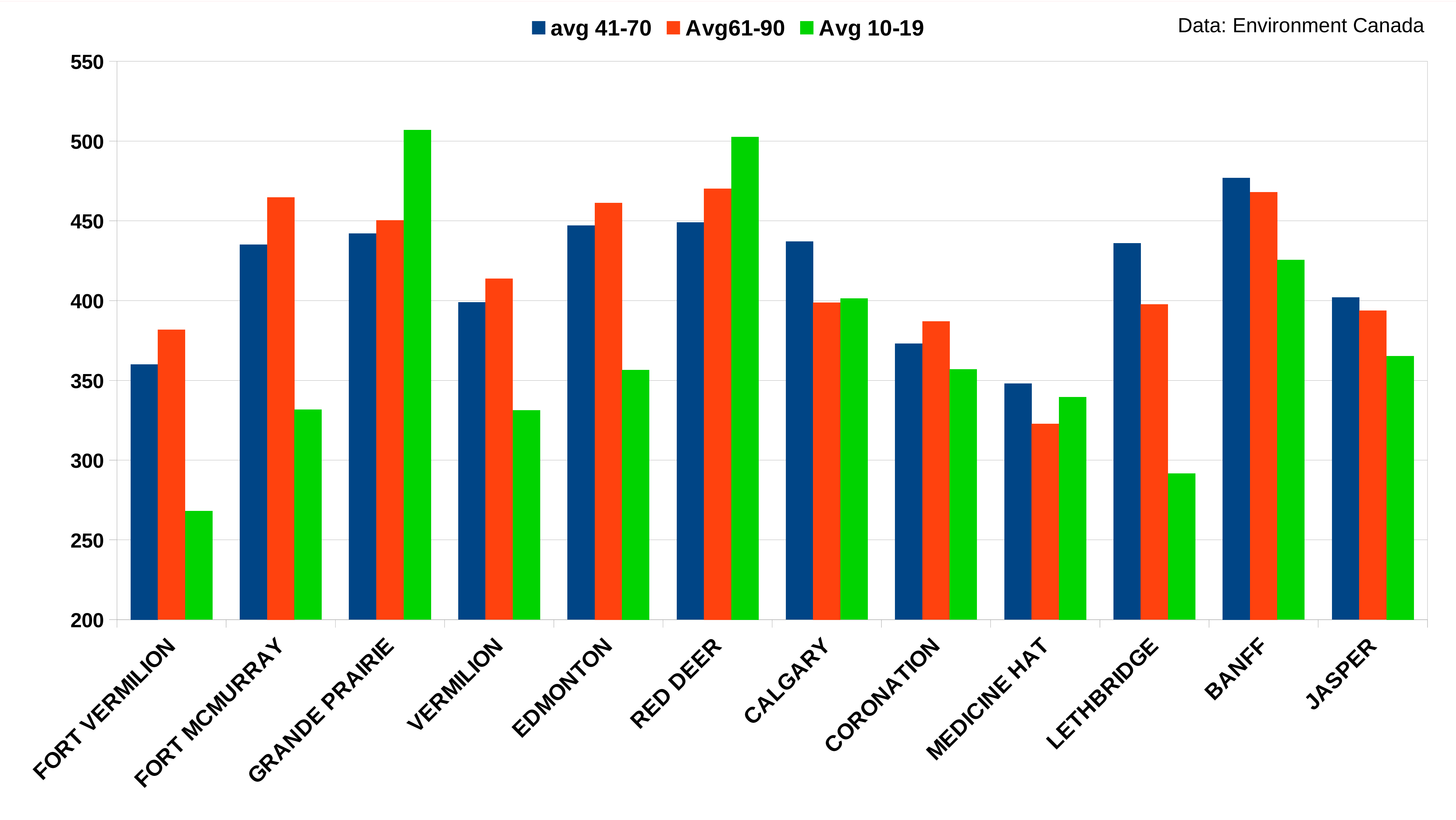
Data: Environment Canada

Alberta Locations: Temperature change from 1941 - 2019

Data: Environment Canada

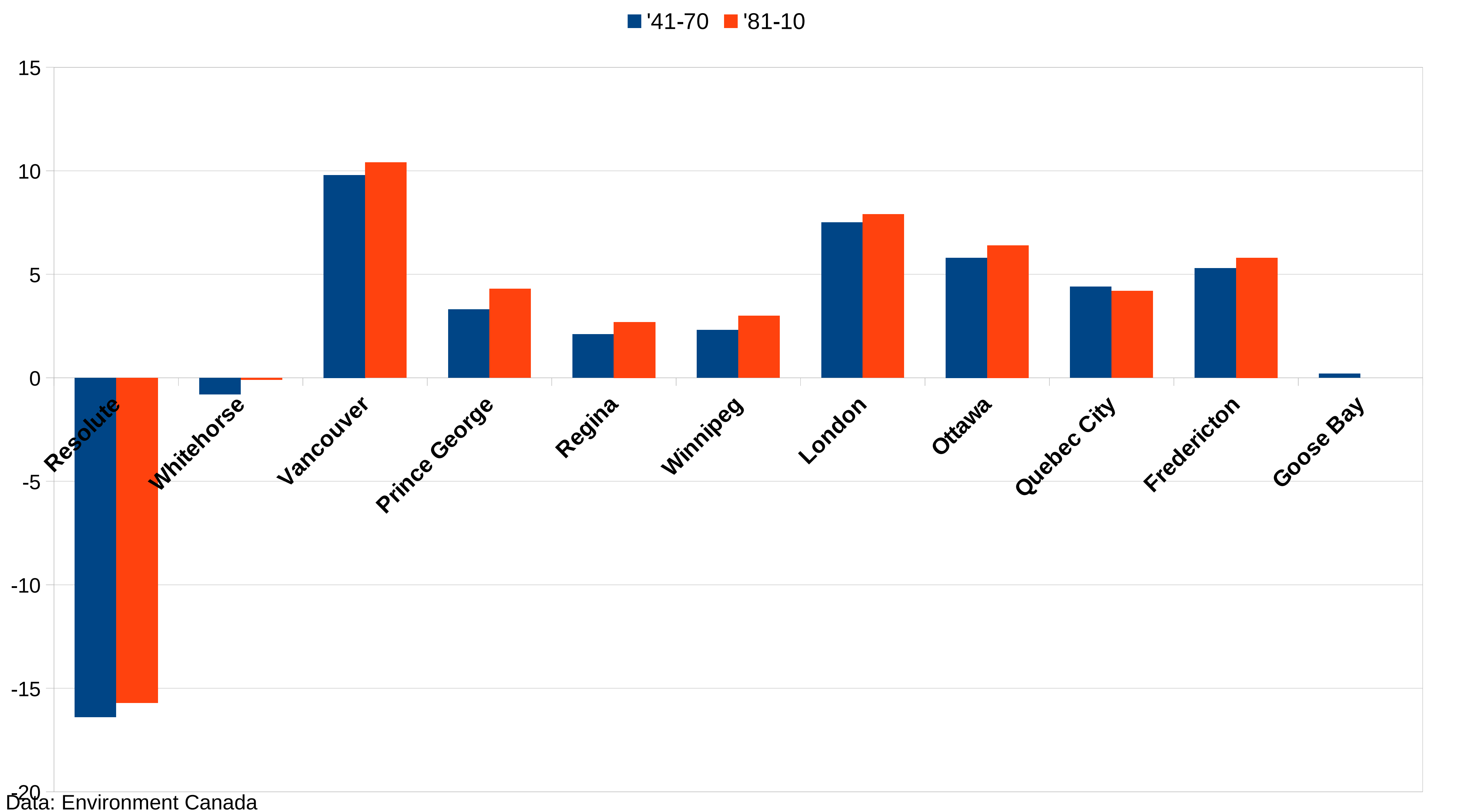


Alberta Locations: Precipitation 1941 - 2019



North Central South Mountains

Canada Locations: Temperature normals 1941 – 1970 and 1981 - 2010)



Data: Environment Canada

The evolution of the climate debate 1960s

- Climatology strictly within the domains of University academia in Geography and Meteorology.

- Climatologists are noting a global ***decrease*** in mean temperature:

  "Since 1942 the CO_2 has continued to rise at a rate of about 0.2% per year (Callender, 1958; Eichorn, 1963), while the world temperature has fallen slightly (Mitchell, 1961)

  Greatest warming was observed in Scandinavia, far from major industrial centres where carbon dioxide might be expected to accumulate" William Sellers, Physical Climatology, 1965

- However, Sellers speculates "*It is interesting to note, however, that if combustion of fossil fuels continues to increase at its current rate, by the middle of the next century (2050) the CO_2 content will be four to ten times the current amount and the temperature will have risen 7 to 12°F .*

The evolution of the climate debate
N. hemisphere temperature trends: 1960s

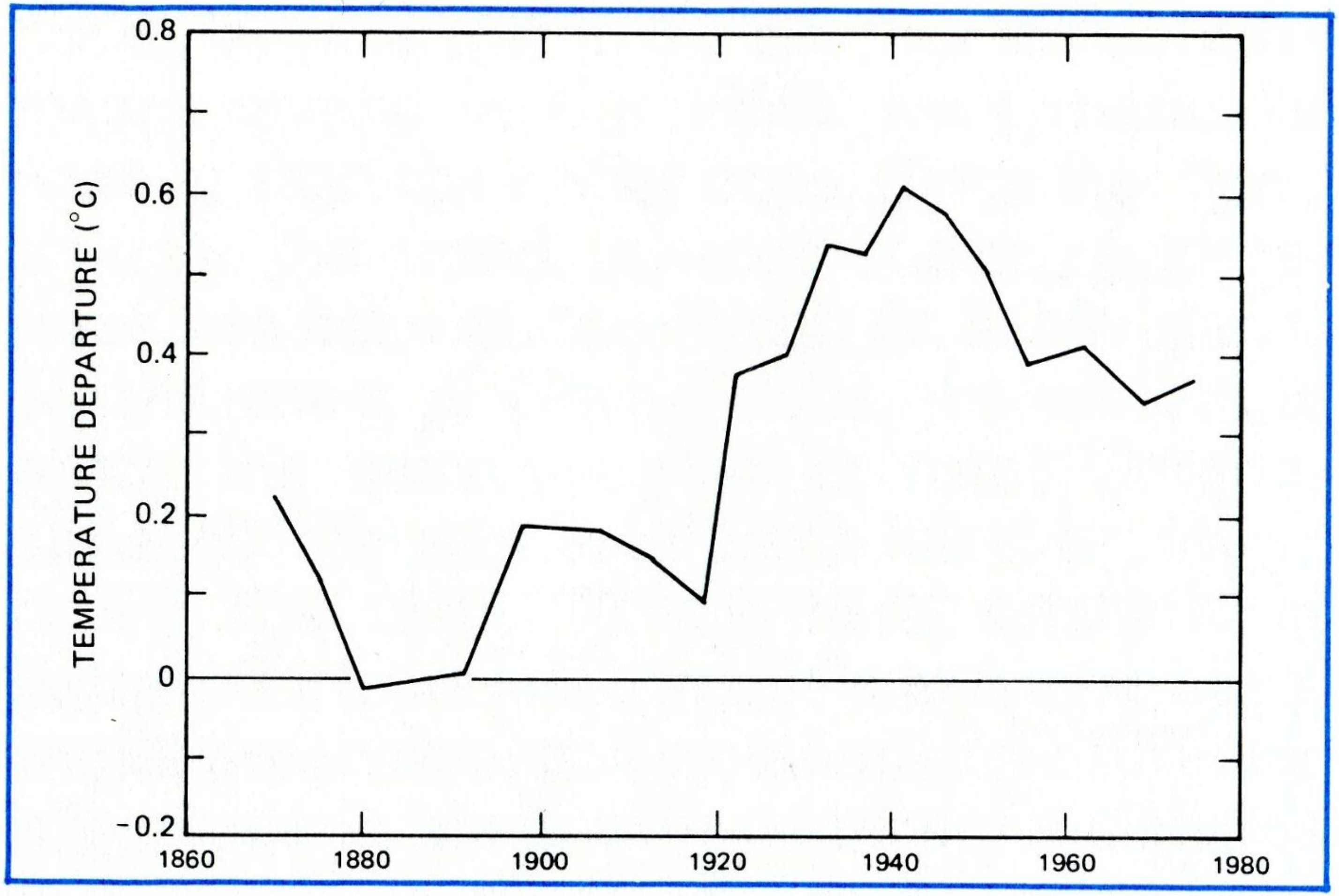


Figure 5.1 Deviation of northern hemisphere mean air temperature (°C) from mid-1880s values (after Willett, Mitchell, Reitan, and Brinkmann), showing the peak about 1940

The climate debates of the late 60s and early 70s

- The temperature is falling globally, concerns are of a triggering of an ice advance phase.
- Scientists are attributing this fall to increased aerosols in the atmosphere, mostly caused by air pollution. Smog and acid rain (from sulfur dioxide) are public hot button issues
- CFCs or chloroflourocarbons in the atmosphere are a major health concern, not for their intense greenhouse effects, but for their depletion of the stratospheric ozone layer.
  - Leads to the Montreal Protocol of 1987; the global phase out of Ozone Depleting Substances (ODS)
- Carbon dioxide is noted to be rising but its effect is seen as hypothetical.

The evolution of the climate debate: 1970s
The scientific community turns the corner

- Climate issues still within the domain of academia, the general public not aware of climate change but the CFC debate (ozone depletion and cancer) is at the same level as carbon issues today.

- The temperature decrease from the 1940s levels out

- Scientists speculating on future climate note that, at some point, temperature will start to rise because of increasing CO2.

- Carbon dioxide content of the atmosphere has risen from about 290 ppm in the 50s to about 320 ppm in the 70s

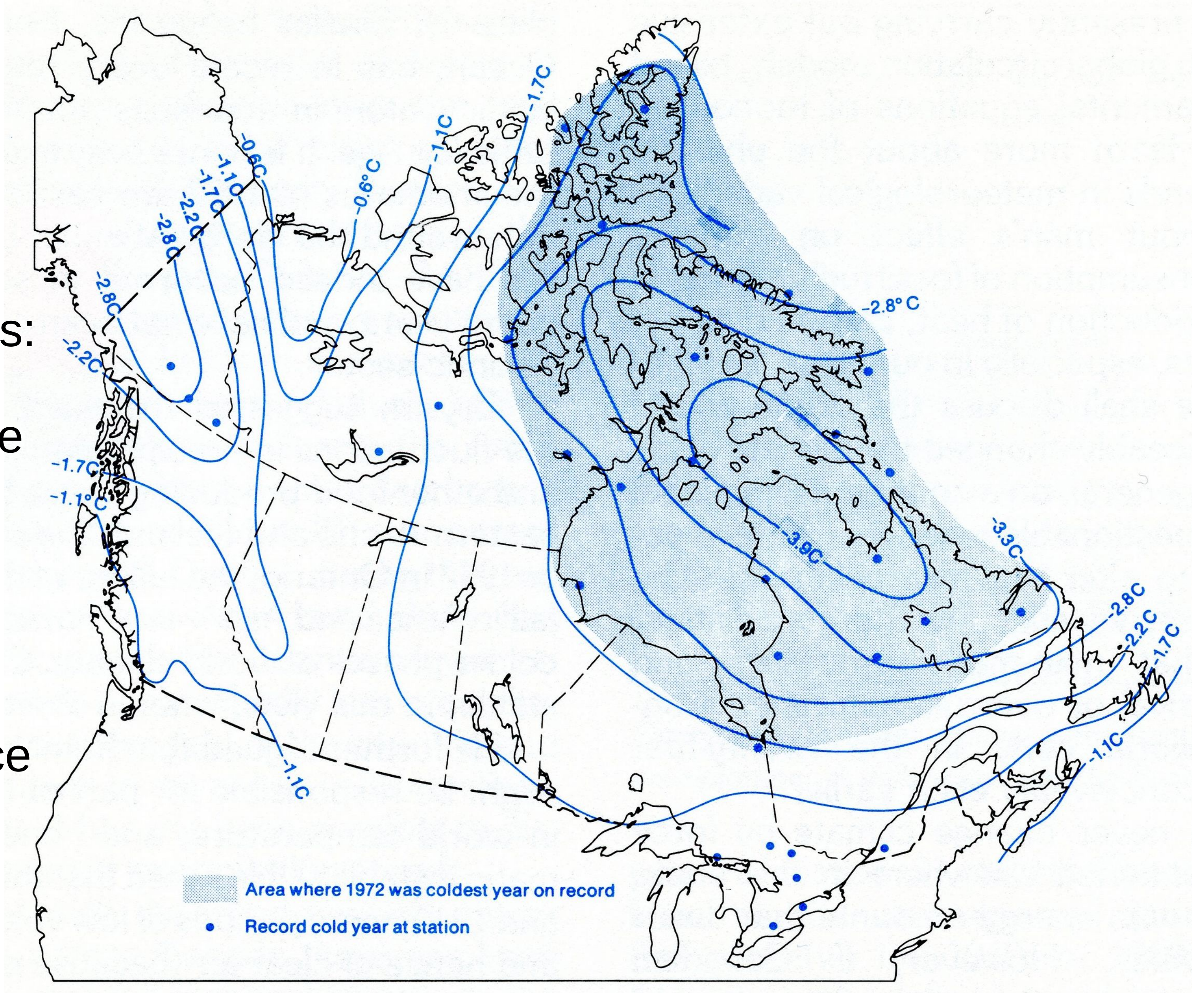
- Canada experiences the coldest year on record in 1972

The evolution of the climate debate
Deviation of temp from ‘31-60 normal in 1972

Often heard Anecdotal wisdom from our elders:

“Our winters used to be much colder”

They may have been correct. They certainly would have been correct if their reference year was 1972!



The evolution of the climate debate: the changing 1970s

- Towards the end of the decade climatologists start to realize that some profound changes will be incurred over the next century. Prominent Canadian climatologist F.K. Hare:

  "If current predictions of (carbon) consumption are confirmed, then a rise of world temperatures of two to four degrees C is very likely within the lifetime of some young Canadians now alive" ***Climate Canada, 1979***

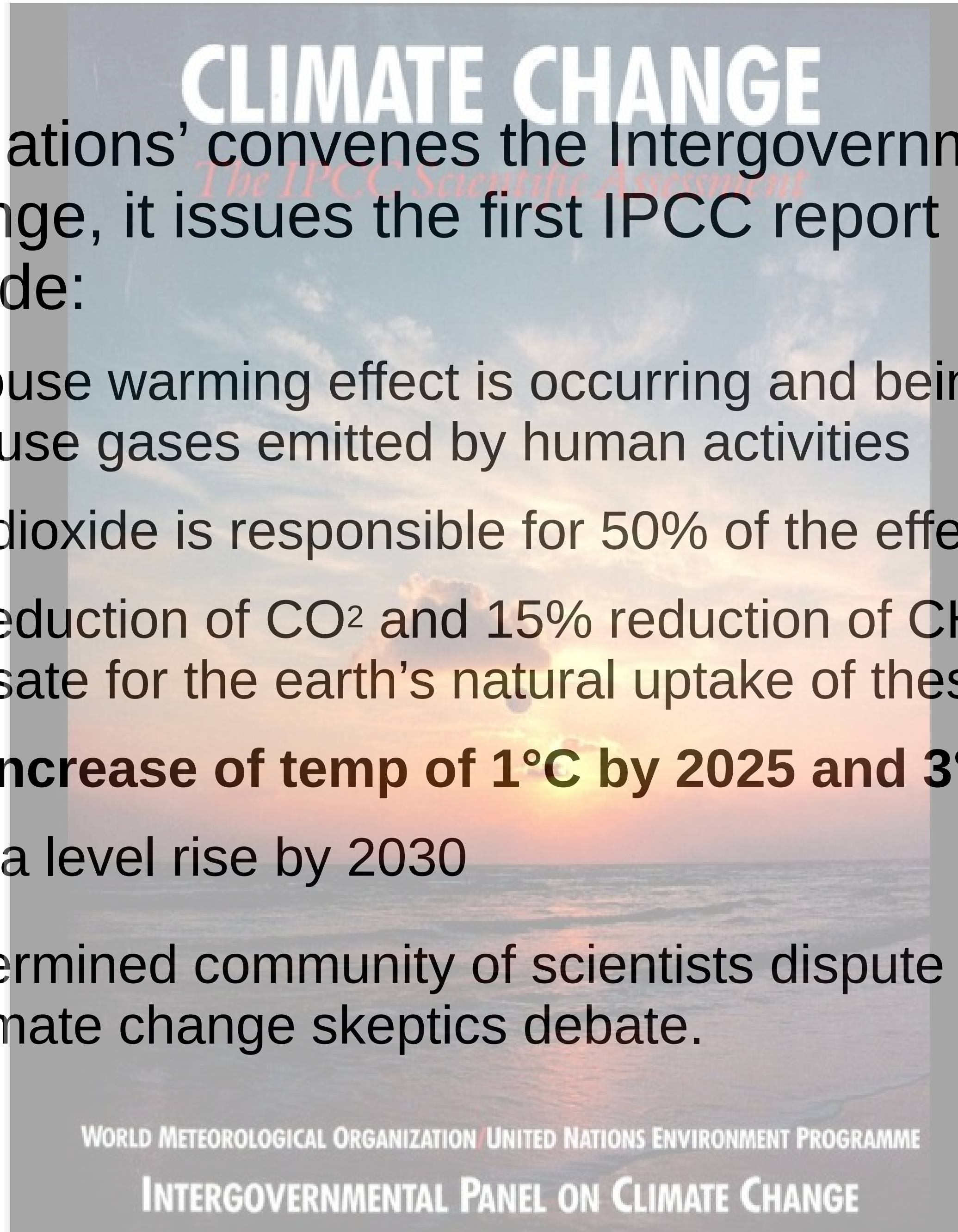
- And from a Maclean's magazine interview June 13, 1977:

  "***Macleans:*** *Could you forecast our climate for 2077?*
  Dr. Hare: *Yes, I think I could. I would visualize a world that was substantially warmer than it is today, and I think that there will be a lot of stress on trees, animals and fish upon which we depend for resources. I think that agriculture will be drastically changed. I would visualize a possibly open Arctic Ocean, a melting of the Arctic Ocean."*

The evolution of the climate debate
The 1980s: Acid rain and CFCs

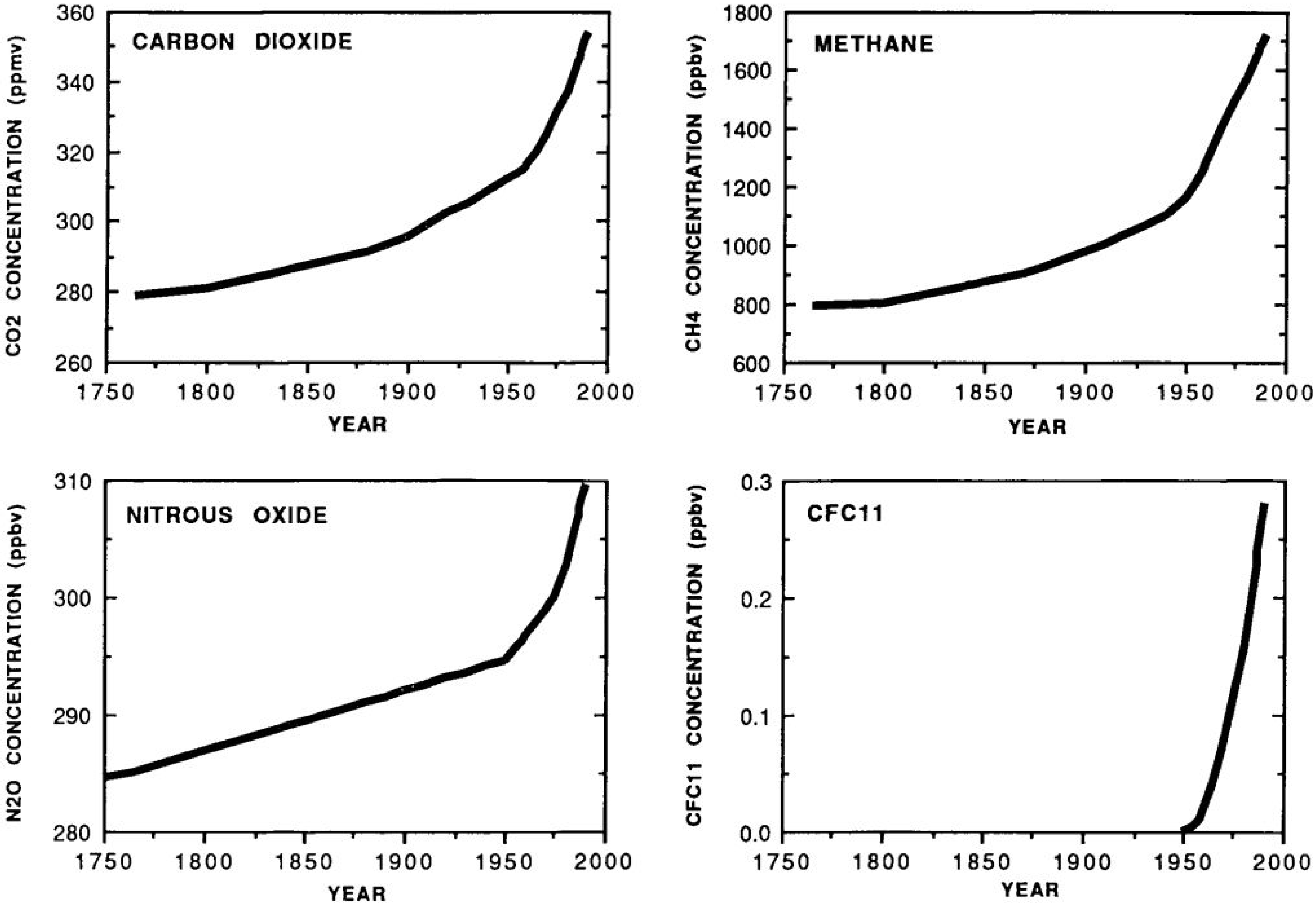
- The CFC debate ends with the Montreal Protocol (1987) banning the use of Ozone Depleting Substances
- The acid rain debate in the 80s ends with the U.S.-Canada Air Quality Agreement in 1991 (Acid Rain Treaty)
- Very large countries such as China and India start their progress towards significant industrialization.
- Carbon dioxide concentration is now at about 340 ppm
- Scientists start to raise the CO^2 alarm with the seminal publication of the **Carbon Dioxide Review 1982 by W.C. Clark**

The evolution of the climate debate
The 1990s

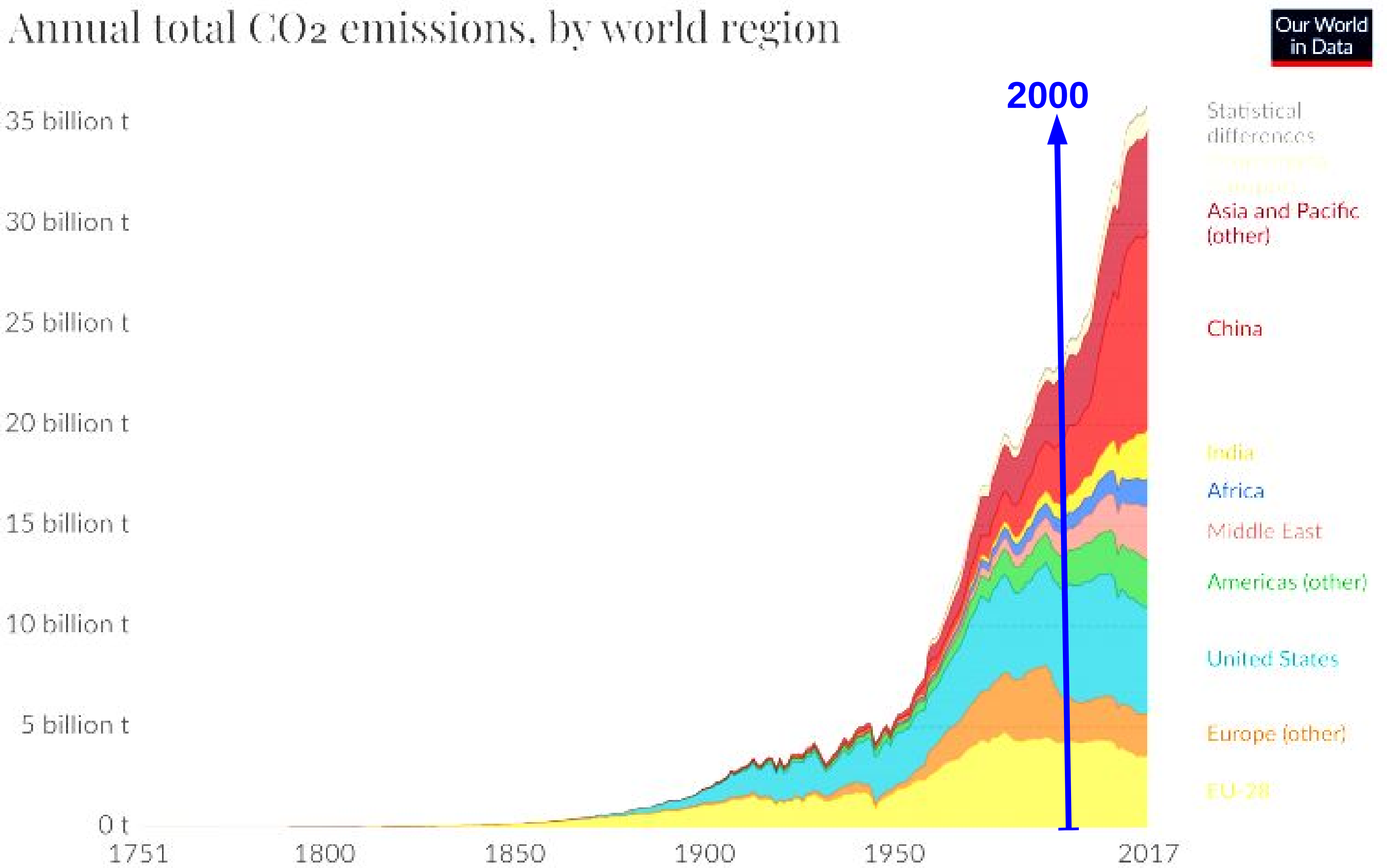


- The United Nations' convenes the Intergovernmental Panel on Climate Change, it issues the first IPCC report (1992). Its main findings include:
    - Greenhouse warming effect is occurring and being caused by greenhouse gases emitted by human activities
    - Carbon dioxide is responsible for 50% of the effect
    - A 60% reduction of CO^2 and 15% reduction of CH^4 is required to compensate for the earth's natural uptake of these gases.
    - **Global increase of temp of 1°C by 2025 and 3°C by 2100**.
    - 20cm sea level rise by 2030
- A small but determined community of scientists dispute the findings thus initiating the climate change skeptics debate.

The evolution of the climate debate GHGs status: IPCC 1990



The evolution of the climate debate
CO_2 status: 1990s into the new millenium



Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)
Note: The difference between the global estimate and the sum of national totals is labeled "Statistical differences".
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions • CC BY

The evolution of the climate debate 2000+: the public takes notice

- One event that takes the climate debate from the scientific realm to the public policy realm is the release of the film 'An Inconvenient Truth' narrated by former vice-president Al Gore (May 2006). How many (you) have seen this film?

The evolution of the climate debate 2000+: the Kyoto Protocol and Paris Agreement

- The Kyoto Protocol comes into effect in February 2005.
- Future global warming should be limited below 2°C relative to the pre-industrial temperature level.
- Hold atmospheric concentrations of GHGs (CO_2) at 450 parts per million (ppm). Today it is at 413 ppm
- Many of the signatories cannot hold the emissions reduction targets (ex. Japan, Russia), others withdraw (Canada) and most significantly, major emitters never sign on (China, India, USA).
- The Kyoto Protocol is less than effective.
- The Paris agreement (2015) limits temp. increase to no more that 1.5°C from 2016

The evolution of the climate debate: Canada today (CCCR, 2019)

temperature between 1948 and 2016 for six regions and for all Canadian land area[a]

REGION	CHANGE IN TEMPERATURE, °C				
	Annual	Winter	Spring	Summer	Autumn
British Columbia	1.9	3.7	1.9	1.4	0.7
Prairies	1.9	3.1	2.0	1.8	1.1
Ontario	1.3	2.0	1.5	1.1	1.0
Quebec	1.1	1.4	0.7	1.5	1.5
Atlantic	0.7	0.5	0.8	1.3	1.1
Northern Canada	2.3	4.3	2.0	1.6	2.3
Canada	1.7	3.3	1.7	1.5	1.7

The evolution of the climate debate: Today's facts

The last 5 years are the warmest years on record globally.

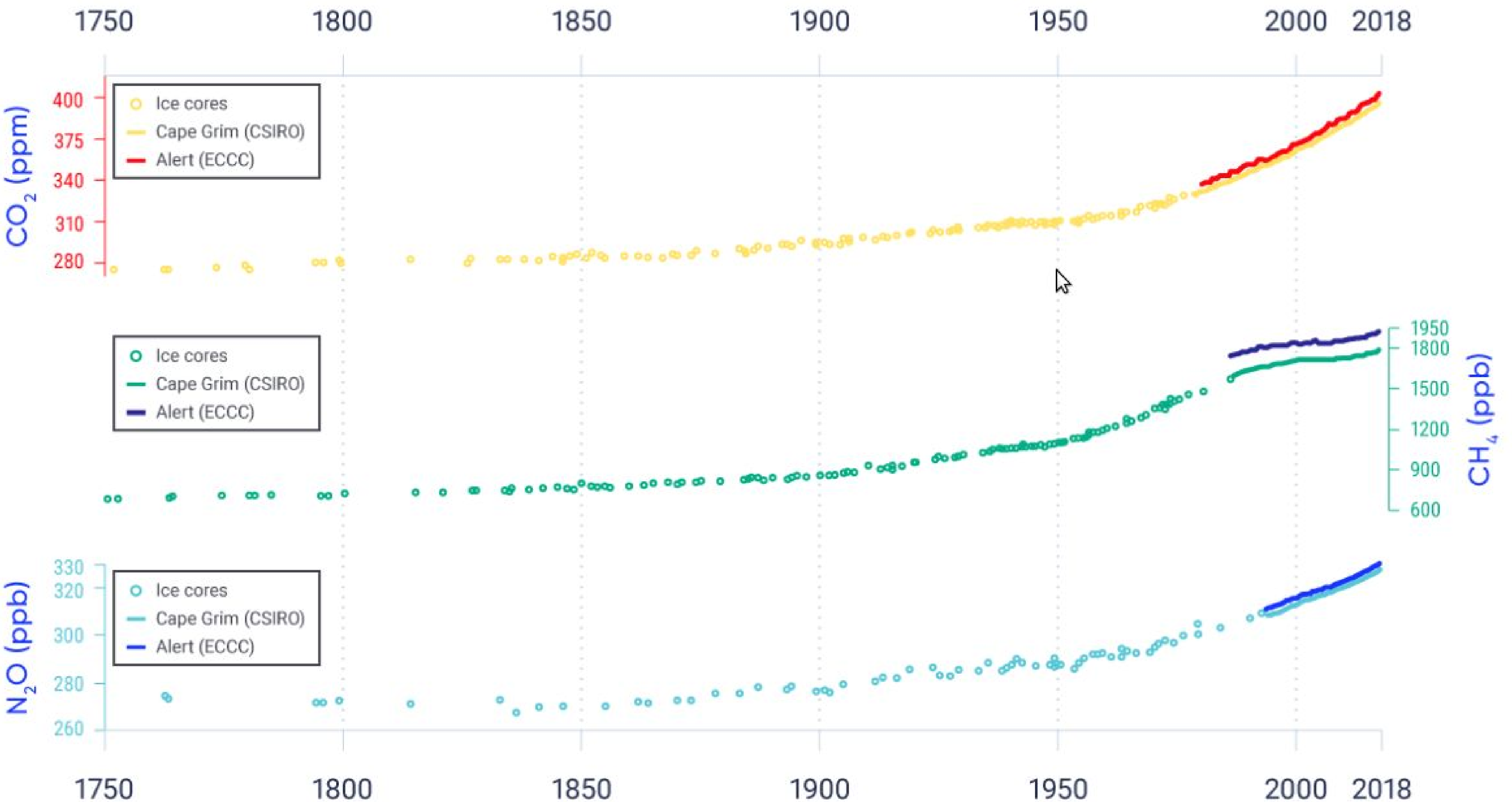
Hottest years on record

Rank	Year	°C over normal avg.
#1	2016	+0.99°
#2	2019	+0.95°
#3	2015	+0.93°
#4	2017	+0.91°
#5	2018	+0.83°
#6	2014	+0.74°
#7	2010	+0.72°
#8	2005	+0.67°
#8 (tied)	2013	+0.67°
#10	1998	+0.65°

CBC NEWS

Source: NOAA

The evolution of the climate debate: Today's facts - GHGs (CCCR, 2019)



The evolution of the climate debate: Canada today (CCCR, 2019)

- Canada’s climate has warmed and will warm further in the future, driven by human influence.
- Both past and future warming in Canada is, on average, about double the magnitude of global warming.
- Precipitation is projected to increase for most of Canada, on average, although summer rainfall may decrease in some areas.
- The seasonal availability of freshwater is changing, with an increased risk of water supply shortages in summer.
- Canadian areas of the Arctic and Atlantic Oceans have experienced longer and more widespread sea-ice-free conditions.
- Coastal flooding is expected to increase in many areas of Canada due to local sea level rise.
- A warmer climate will intensify some weather extremes in the future.

The evolution of the climate debate: Where do we stand today:

- Some societal drivers:
  - Social climate activism (eg. Greta Thunberg, David Suzuki),
  - Economic drivers (eg. Investment venture firms and insurance companies),
  - Political policy driver (eg. Issues re: Canadian federal election, Alberta election).
- Five more IPCC reports are produced since 1990, each more dire in their outlook.
- Climate change skepticism is part of the debate landscape particularly in conservative circles but also as part of a small minority in the scientific community.
- The middle-of-the-road view is that retooling of global economies to switch from or to trap carbon will be a longer term process. In 2020, we are still very much dependent on carbon based energy. All else being equal, temperature will continue to increase.

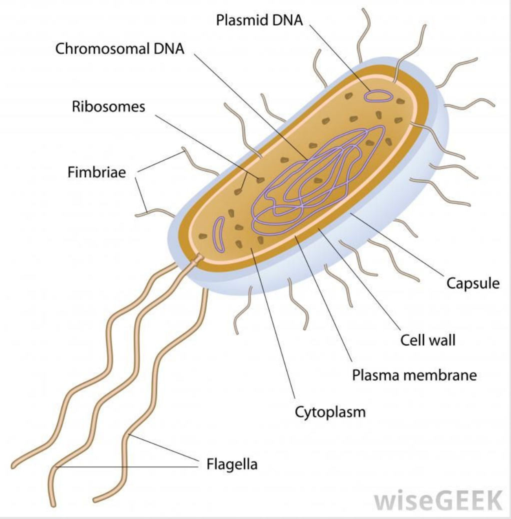
Section 2. Past Climate Changes: Geological Eons, Eras, Periods and Epochs

Era	Period		Epoch (start mya)	
Cenozoic	Quaternary		Holocene	0.01
			Pleistocene	2.6
	Tertiary	Neogene	Pliocene	5.3
			Miocene	23.0
		Paleogene	Oligocene	33.9
			Eocene	55.8
			Paleocene	65.5

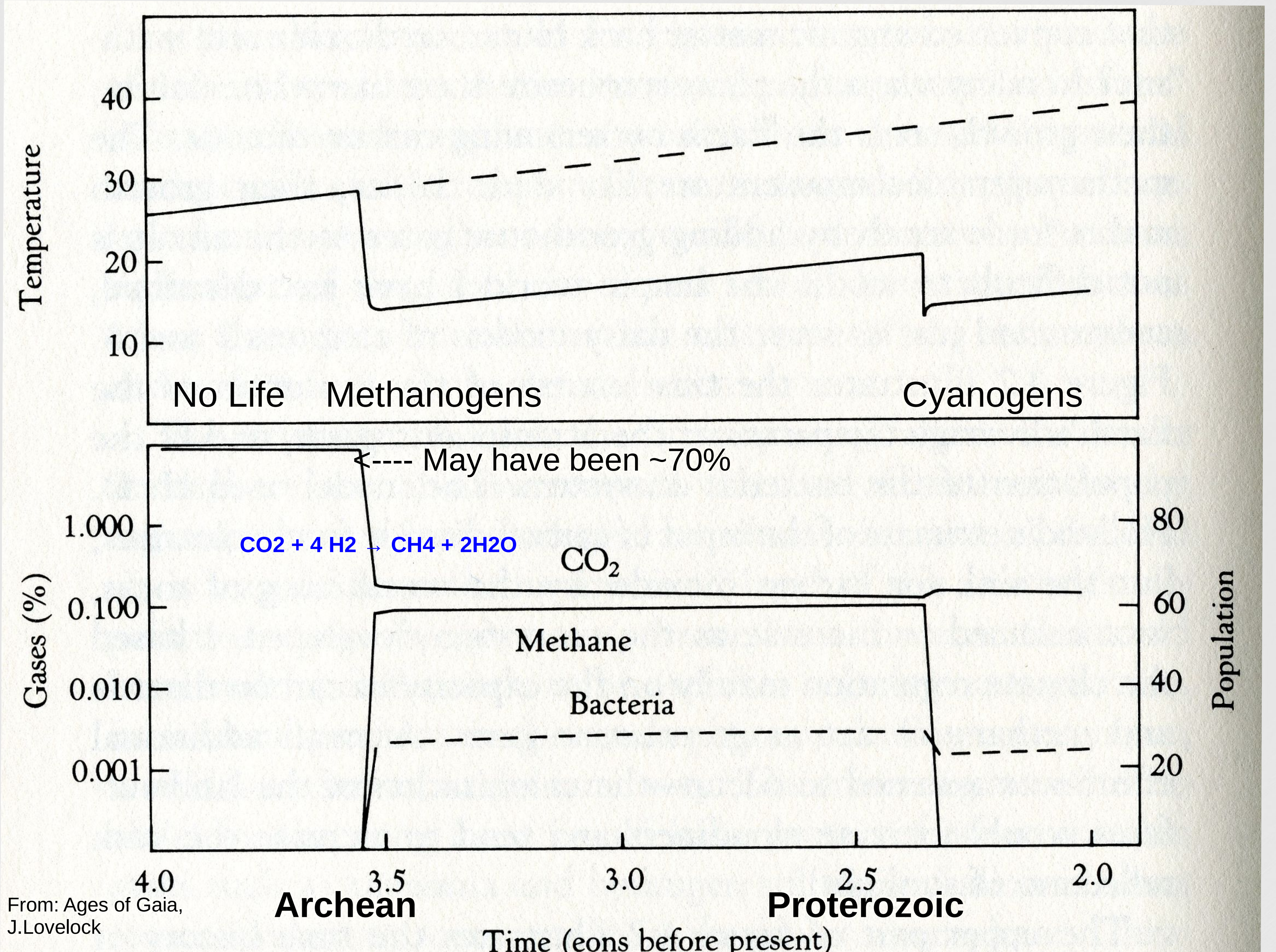
Eon	Era	Millions o years ago
Phanerozoic	Cenozoic	66.4
	Mesozoic	245
	Paleozoic	570
Proterozoic	This time interval generally known as the Precambrian	2500
Archean		3900
Hadean		4540

Climatic Changes in Geological History: Early Life on Earth

- Faint young Sun paradox in the **Archean** (cool sun - 30% less intensity, warm earth) Methanogens (3.5 by) supply CH_4
- Global demise of methanogens, the rise of the cyanogens, the beginning of the **Proterozoic** Eon and the onset of atmospheric oxygenation (2.5 by)*
- **Phanerozoic** Eon
  - Warmer period with high atmospheric CO_2
  - Led to the Cambrian Explosion, major biological species proliferation



Climatic Changes in Geological History: The Archean Eon



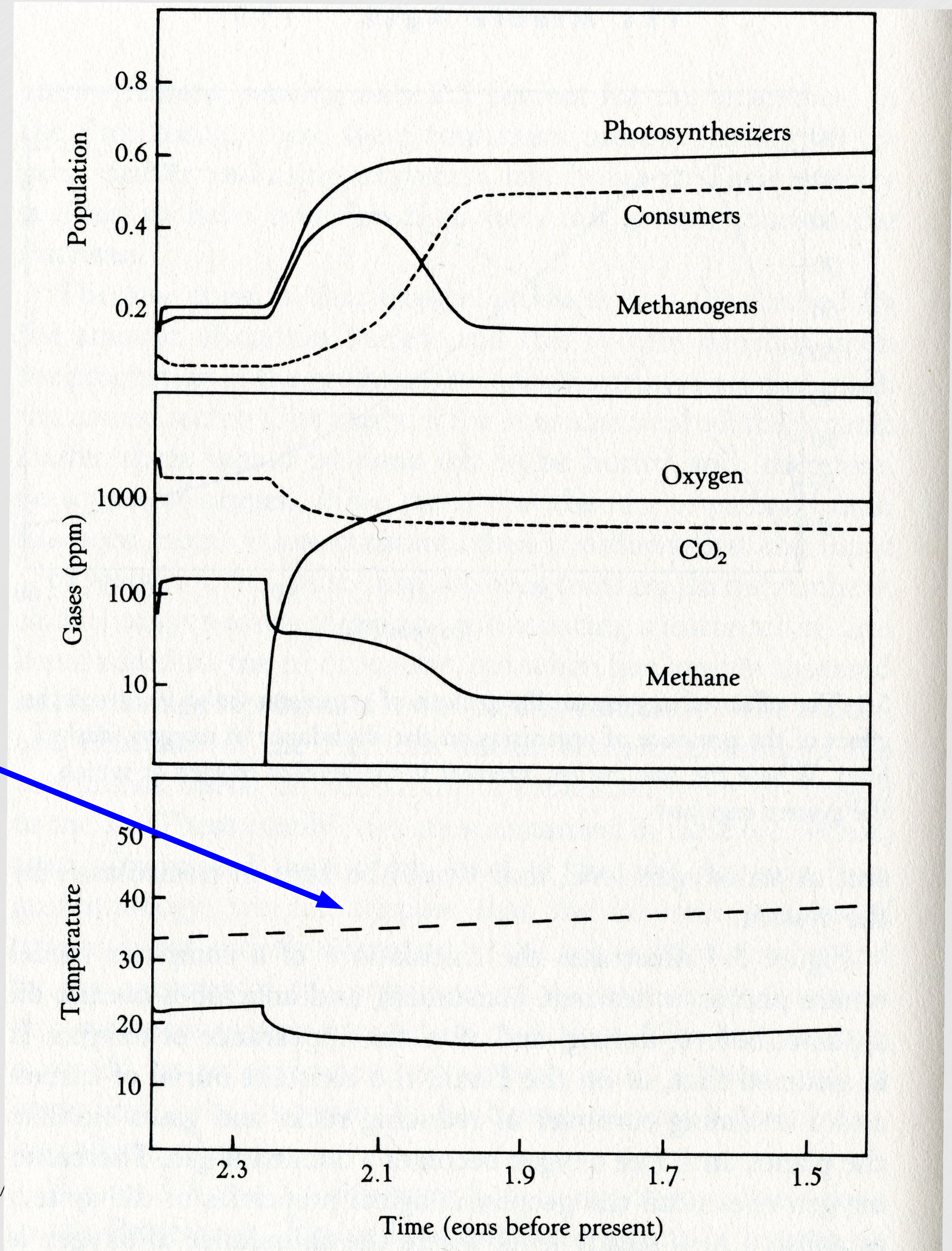
From: Ages of Gaia, J.Lovelock

Climatic Changes in Geological History: Proterozoic Eon

The dashed line in the temperature graph indicates temperature profile in the absence of life.

Key Events

- Infusion of Oxygen, why?
- Diminishing of Methane, why?
- Temperature is stable
- CO^2 is twice today's values



From Ages of Gaia, J.Lovelock

Climatic Changes in Geological History: The full picture: to the Phanerozoic Eon

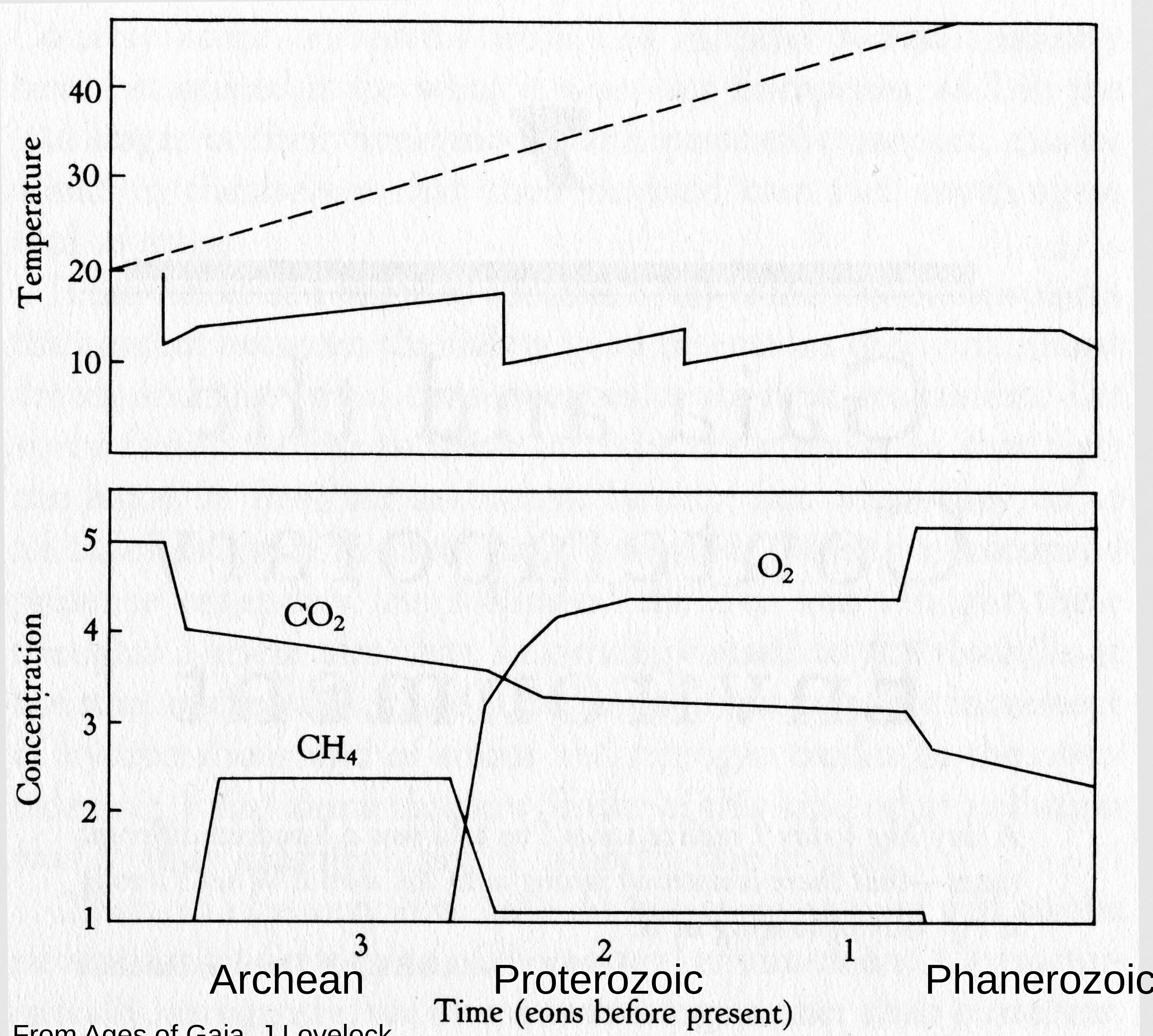
1. CO2 content shows a steady decrease throughout the geological record

2. CH4 content spikes, flattens out, and finally falls to a very low amount

3. O2 spikes and levels off to a relatively high concentration, Give 3 hypotheses

4. Temperature changes significantly with each major biological reconfiguration

5. The dashed curve is temperature with no biological regulation. The CO2 would likely also have risen resulting in a more Venus-like planet



From Ages of Gaia, J.Lovelock

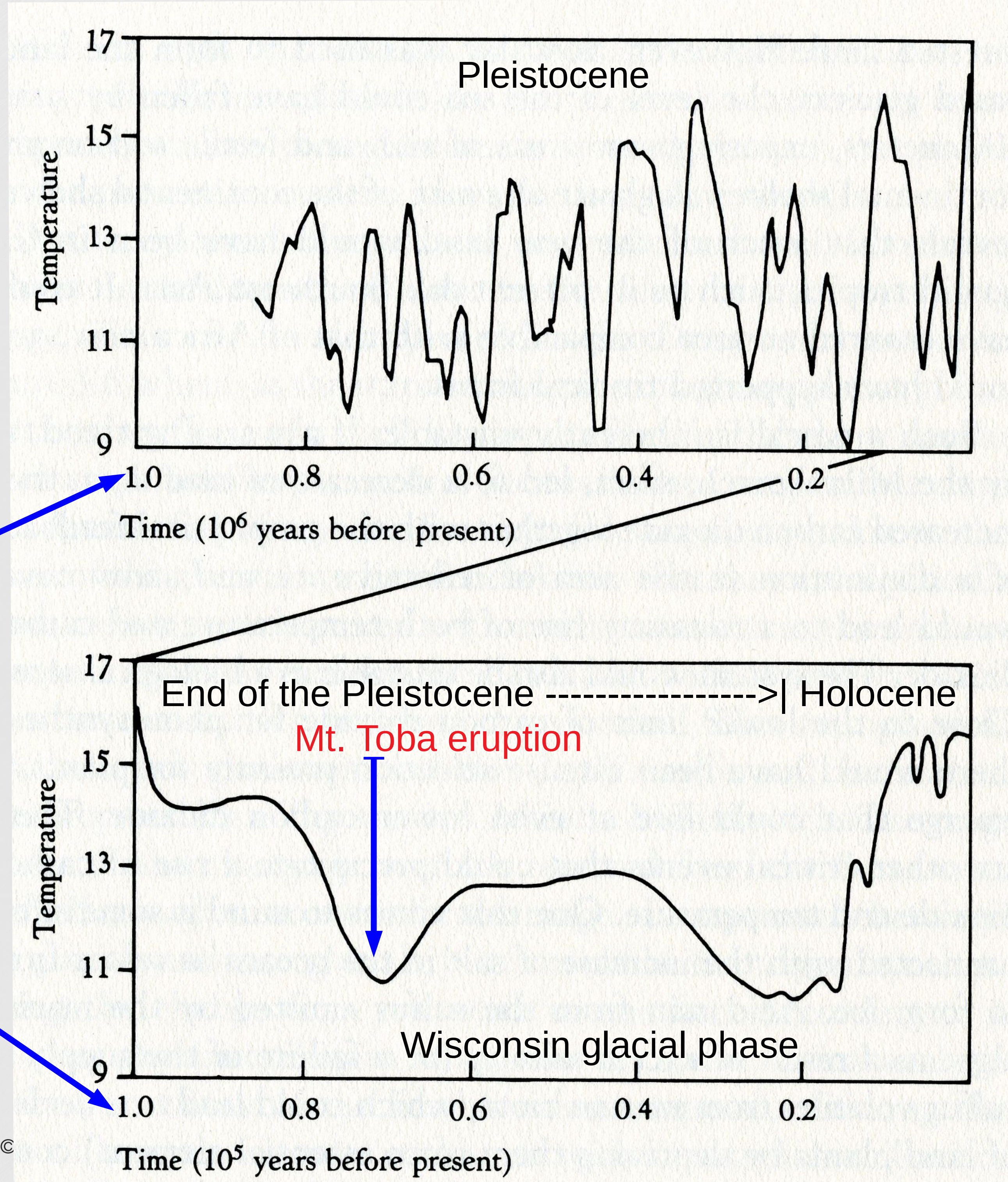
Climatic Changes in Geological History: Recent events - the Cenozoic Era - 65my

- K-T Extinction
  - Also known as the K-Pg (Cretaceous-Paleogene) extinction
  - Gulf of Mexico asteroid impact leads to ecosystem collapse
    - Atmospheric soot blocks sunlight, temp. drops some 6-9 degrees C
    - Most primary producers die off followed by the primary and secondary consumers – event lasts about 2 years
  - Commonly known as the dinosaur mass die-off
- Quaternary Period (2.6 my to present)
  - Current period
  - Marked by the latest ice age
  - Proliferation of large mammals

Climatic Changes in Geological History: The Cenozoic Era

1 million years

100,000 years



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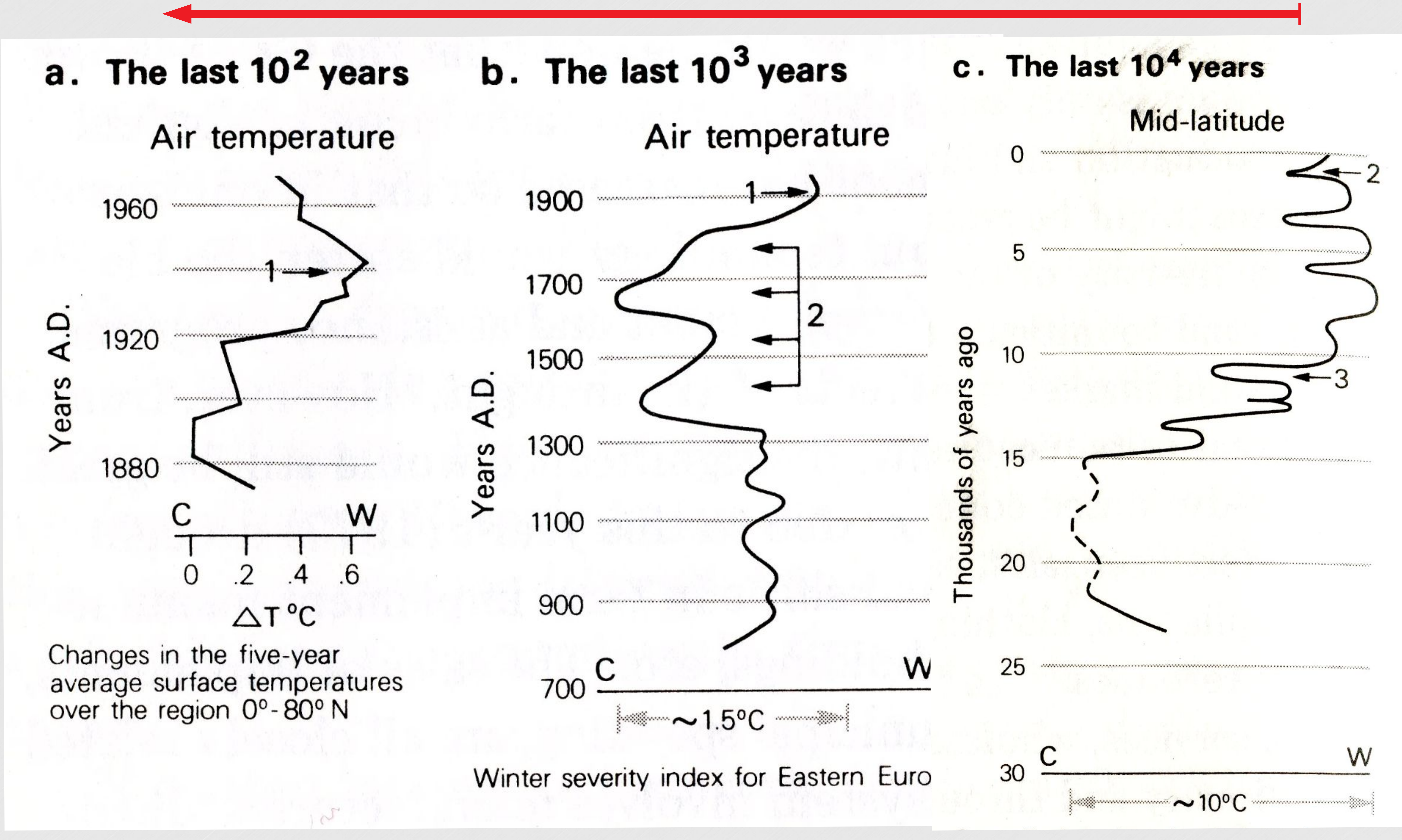
Climatic Changes in Geological History: The Current Epoch: Holocene/Anthropocene



Climatic Changes in Geological History: Today's Conditions

- Currently in an ice age because "permanent" ice exists on Earth today (ice sheets and mountain glaciers).
- Ice ages are subdivided into phases.
  - Glacial: "Permanent" ice is displaced equatorward
  - Interglacial: Intervals when ice retreats poleward
- Currently, we are in an interglacial phase.
  - The Holocene Interglacial Phase of the Pleistocene Epoch

Recommended Article: Climate's future written in rocks, Graham Lawton, New Scientist, 6 July, 2019

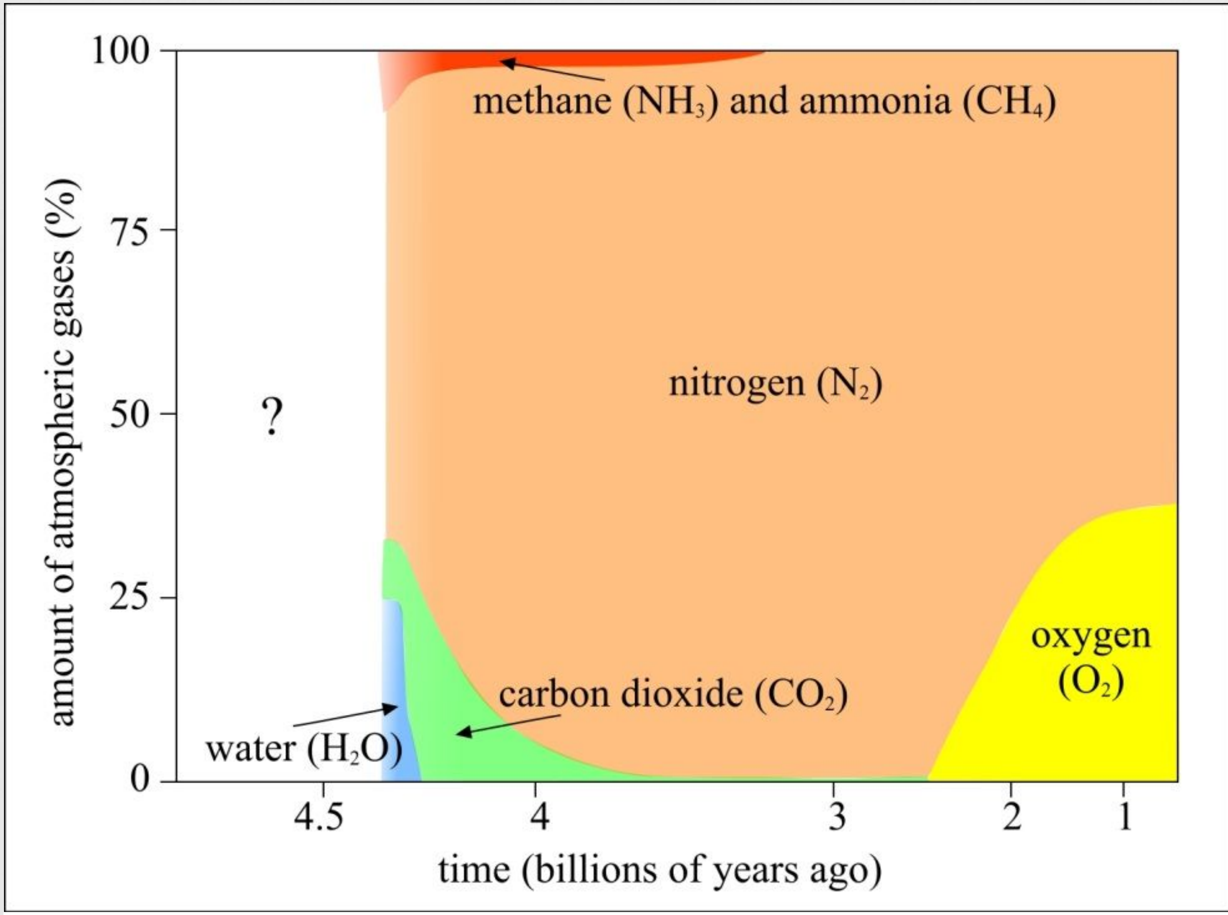
Climatic Changes in Geological History: A summary view

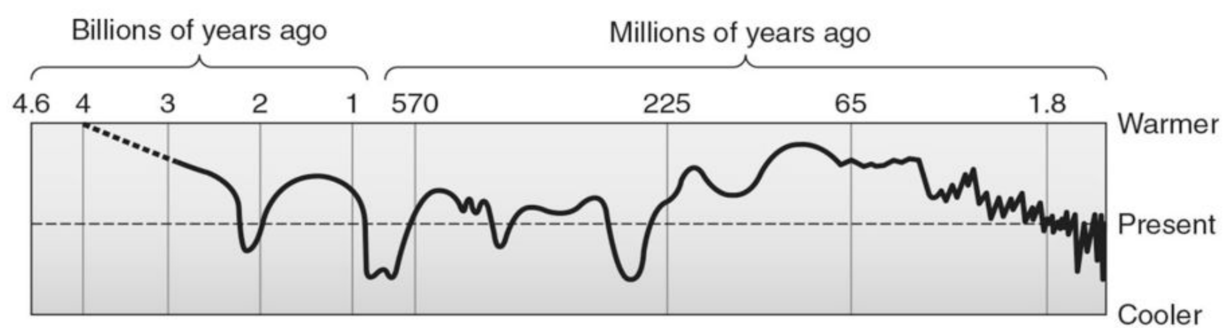
Key learnings from the paleontological climate Record:

1. The Biosphere is a key factor in determining the outcome of climate change and climate stabilization for most of earth's history

2. Major natural events affected climate (sun, plates, volcanism, bolides, etc.) but steady-state regulation is the norm.

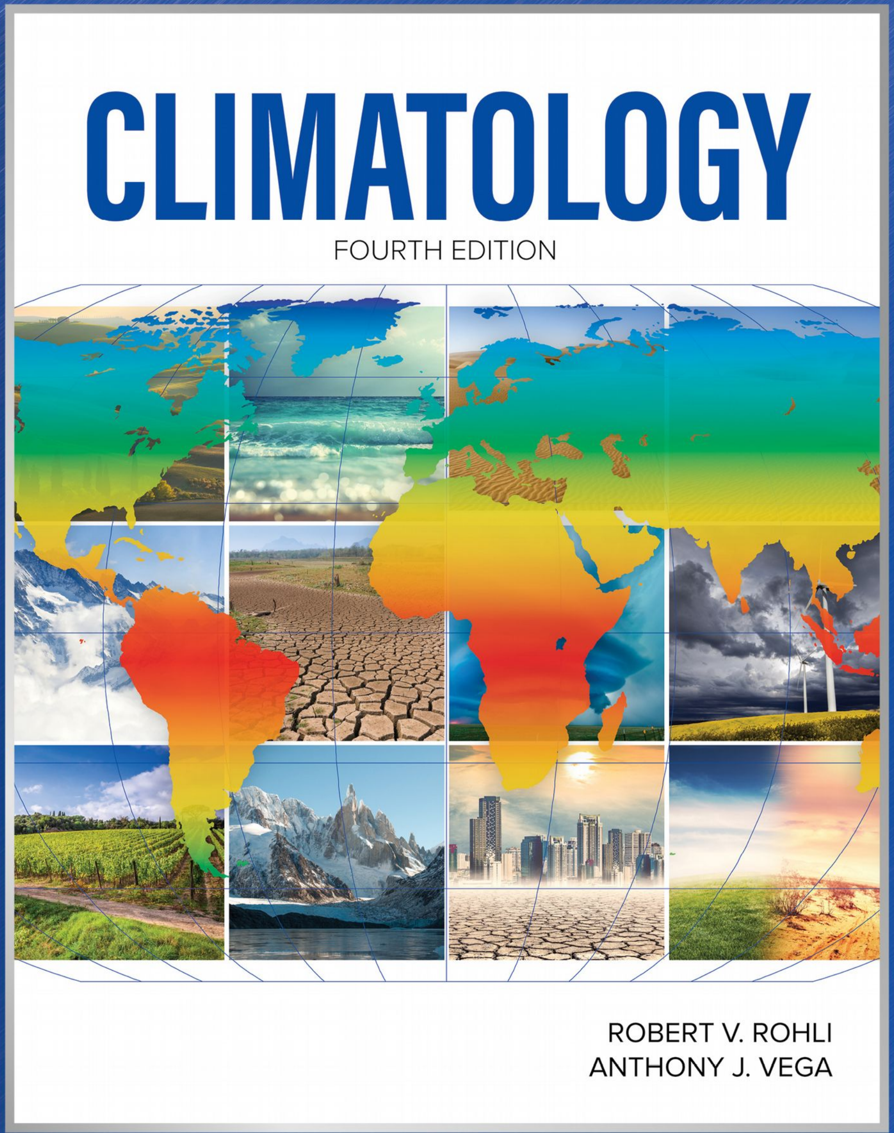
3. For 3.8 billion years Earth's temperature stays within 15°C





Section 3. Climate Mechanisms: Controls on the Climate System

- Latitude and radiation (angle)
- Earth–Sun relationships
- Distance to large bodies of water
- Circulation
- Topography
- Local features



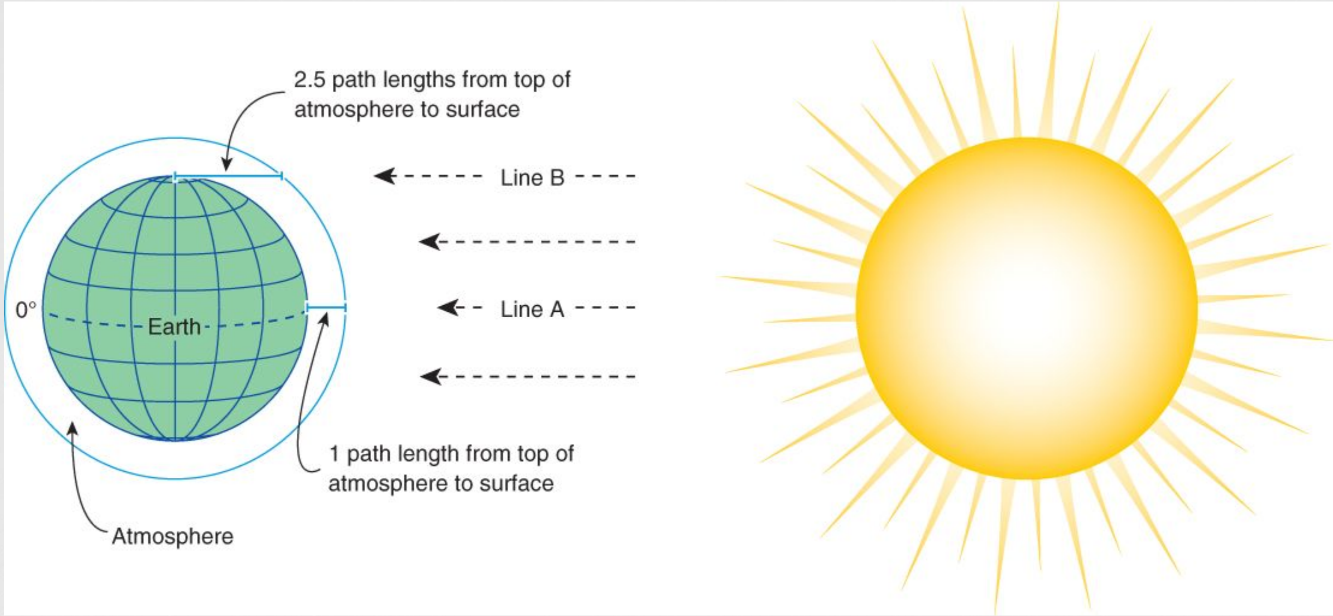
The Earth's Radiation Balance

Solar Energy Driving Climate

- The basic radiation climate equations:
  - **Earth's balance $R_E = (Q + q)(1 - a) - I$, R_E = 72kly/yr**
    - where Q + q is the sum of the direct and diffuse radiation on the earth (shortwave radiation = 124 kly/yr)
    - And 'a' is the surface albedo (reflectivity of the earth's surface)
    - And *I* is the outgoing radiation from the earth's surface (longwave radiation = 52 kly/yr)
  - **Atmosphere's balance $R_A = (Q + q)(1 - a) - I$, R_A = -72kly/yr**
    - where Q + q is the sum of the direct and diffuse radiation on the atmosphere (shortwave radiation = 45 kly/yr)
    - And 'a' is the surface albedo (reflectivity of the atmosphere)
    - And *I* is the outgoing radiation from the atmosphere (longwave radiation = 117 kly/yr)

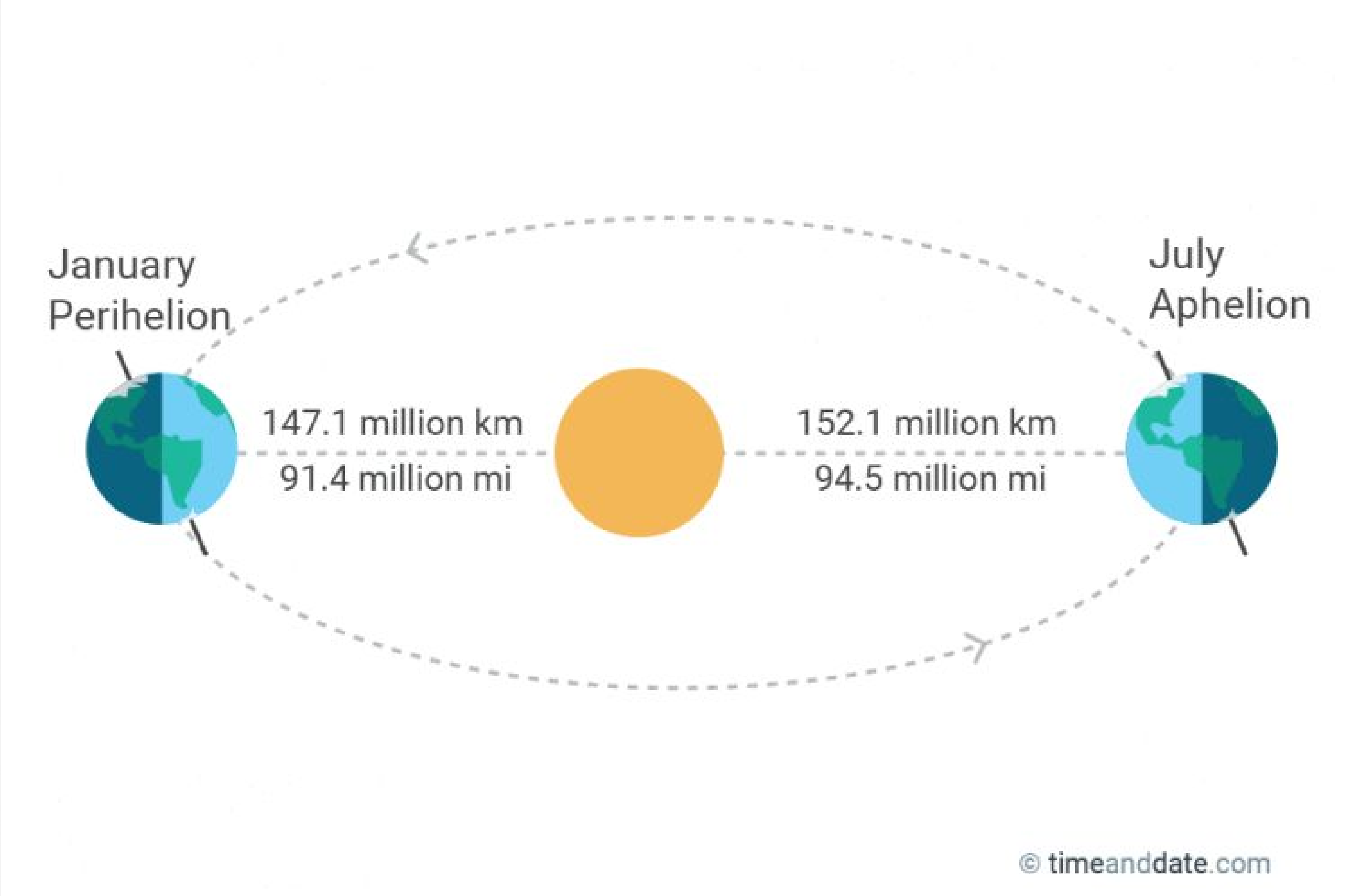
Latitude

- Lower Sun angles equate to less intense energy.
  - Passes through a larger and thicker atmosphere
  - Undergoes increased attenuation
    - Reflect and scatter radiation
    - Increases with particle concentrations and/or path length



Earth–Sun Relationships: Revolution

- Revolution: An elliptical orbit around the Sun
  - Distance varies
    - *Perihelion*
      - January 3
      - 147.09 million km (91.36 million mi)
    - *Aphelion*
      - July 4
      - 151.92 million km (94.36 million mi)



Earth–Sun Relationships: Axial Tilt

- The Earth's axis is tilted 23.5° from the plane of the ecliptic.
- Solar radiation (Langleys or W/m^2) over Alberta is more intense in summer and more diffused in winter
  - Edmonton Jan. = 87 W.. 13.0° on winter solstice
  - Edmonton Jul. = 523 W.. 59.9° on summer solstice

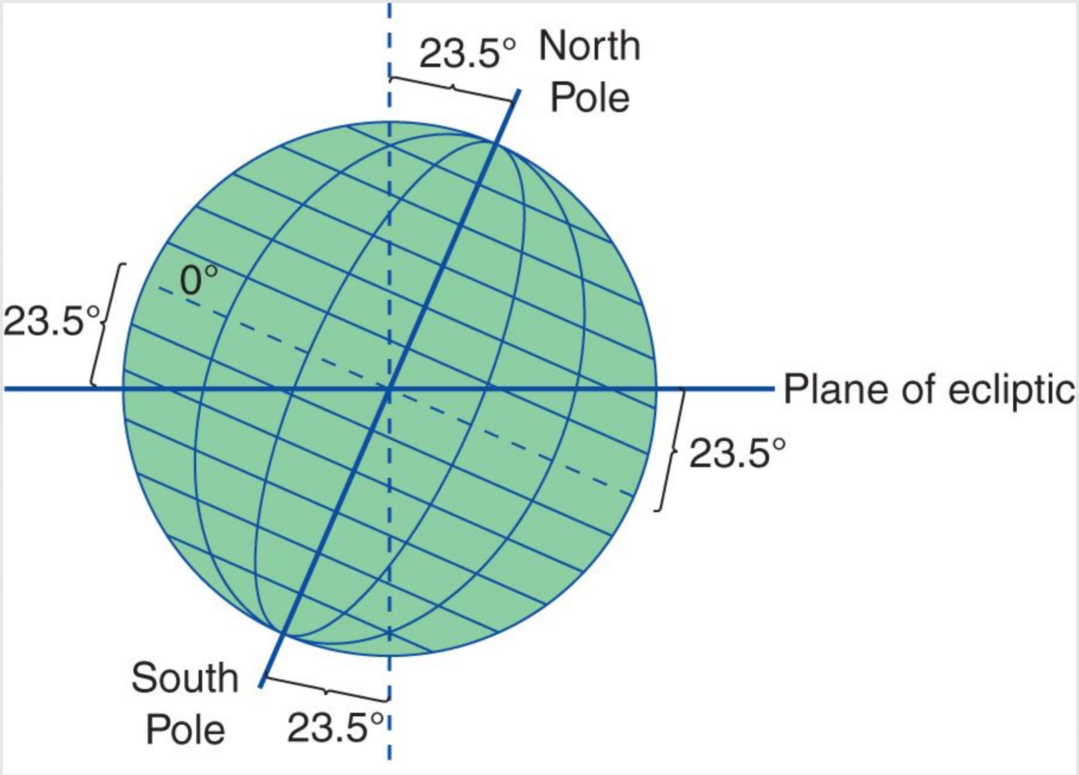


Figure 3.4 Earth's tilt is 23.5°from a perpendicular line through the plane of ecliptic.

Distance to Large Bodies of Water

- A situational climate control
- *Continentality* – Alberta highly affected
  - Location far from large bodies of water (North, South and East)
  - Seasonal temperature extremes occur
- *Maritime Effect* – Alberta minimally affected
  - Heat stored in the Pacific is blocked by the Rockies (West)

From Google Maps

Distance to Large Bodies of Water

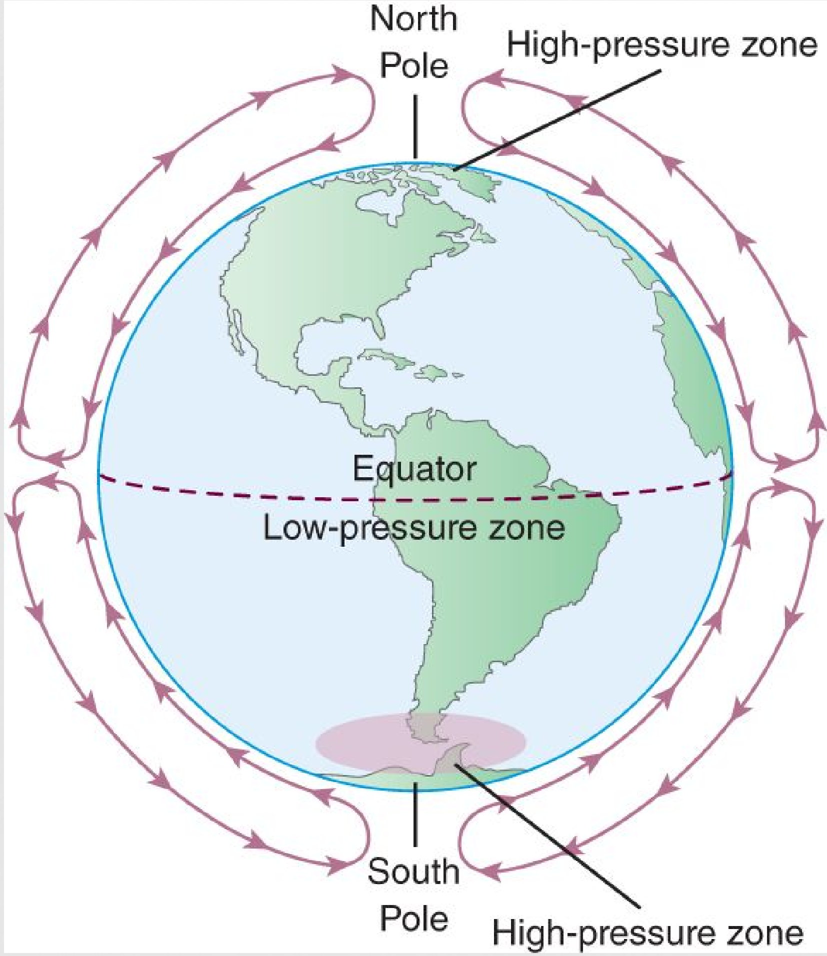
- Specific heat:
  - Energy required to raise 1 gram of water by 1°C
  - ~ 5 times greater for water than solids

TABLE 3.1 Specific Heat Values for Various Substances at 0°C

Substance	Specific Heat (Joules kg^{-1} K^{-1})
Mercury	139
Granite	190
Sand	835
Glass	840
Dry air	1005
Saturated air	1030
Water	4187

Atmospheric Circulation
A Non-rotating Earth: Hadley's model (late 1800s)

- Tropical air should warm and rise near the equator (become buoyant).
- Should travel aloft, cool, and sink near the poles.
- Then move equatorward across the surface to repeat.
- Two main complications with Hadley's model:
  - Topographic and land/water surface variations alter the formation of a single hemispheric convection cell in each hemisphere.
  - The rotation of the Earth (every 24 hrs) initiates trajectory changes in moving fluids through the Coriolis effect.



*Venus rotates once every 243 **Days** (very slow, very little Coriolis effect) the model above is more like Venus'*

General Circulation on a Rotating Planet: Three basic zones are induced

- Hadley cell is restricted to the tropics with warm air rising at the equator and subsiding at ~30° (creating high pressure)
- Polar cell forms with cold air subsiding at the pole and rising at ~60° (creating low pressure)
- At the mid latitudes winds increase in strength from the equator towards the mid-latitudes due to the conservation of angular momentum and are also deflected to the right or eastward (Coriolis effect)

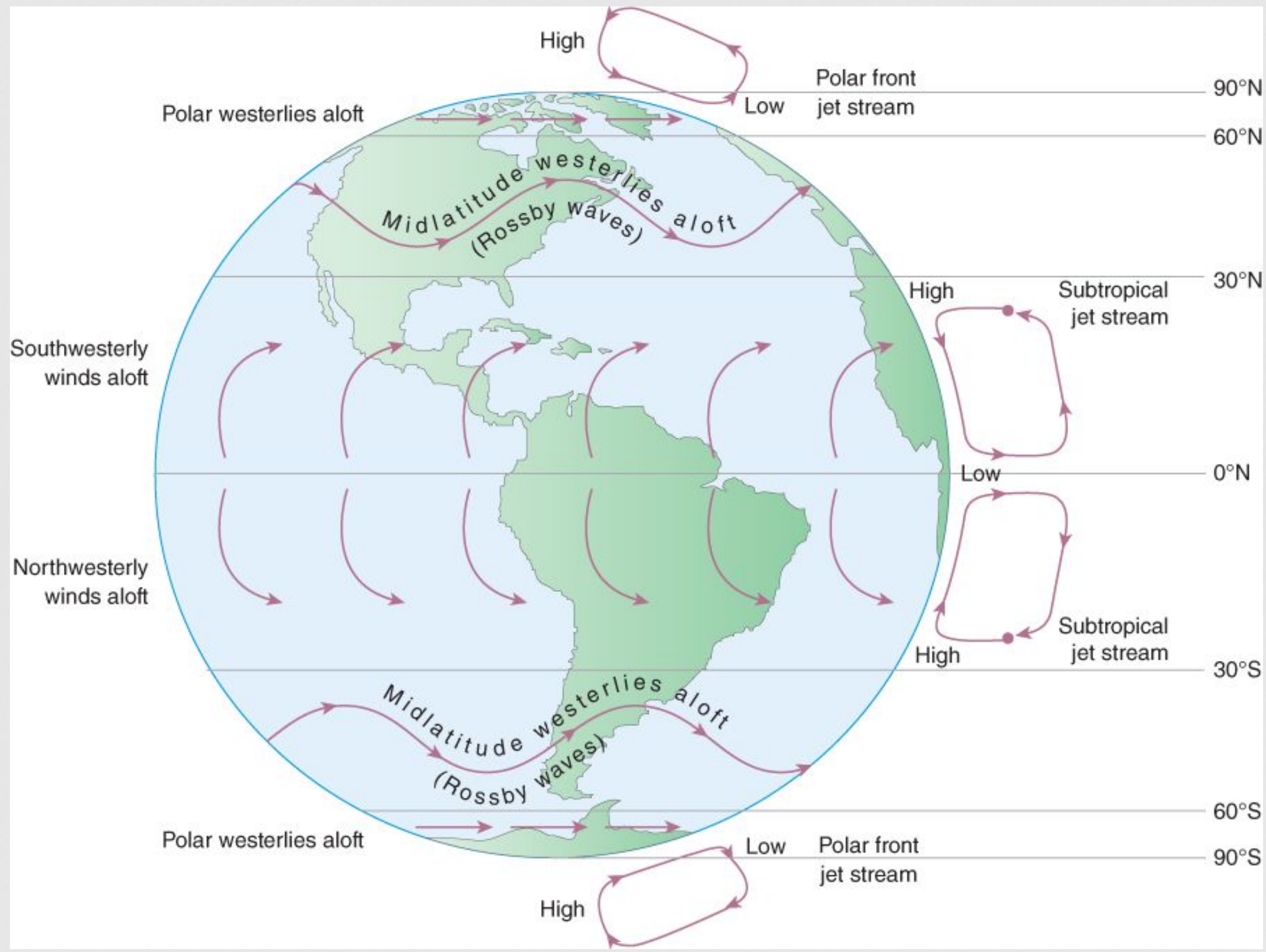
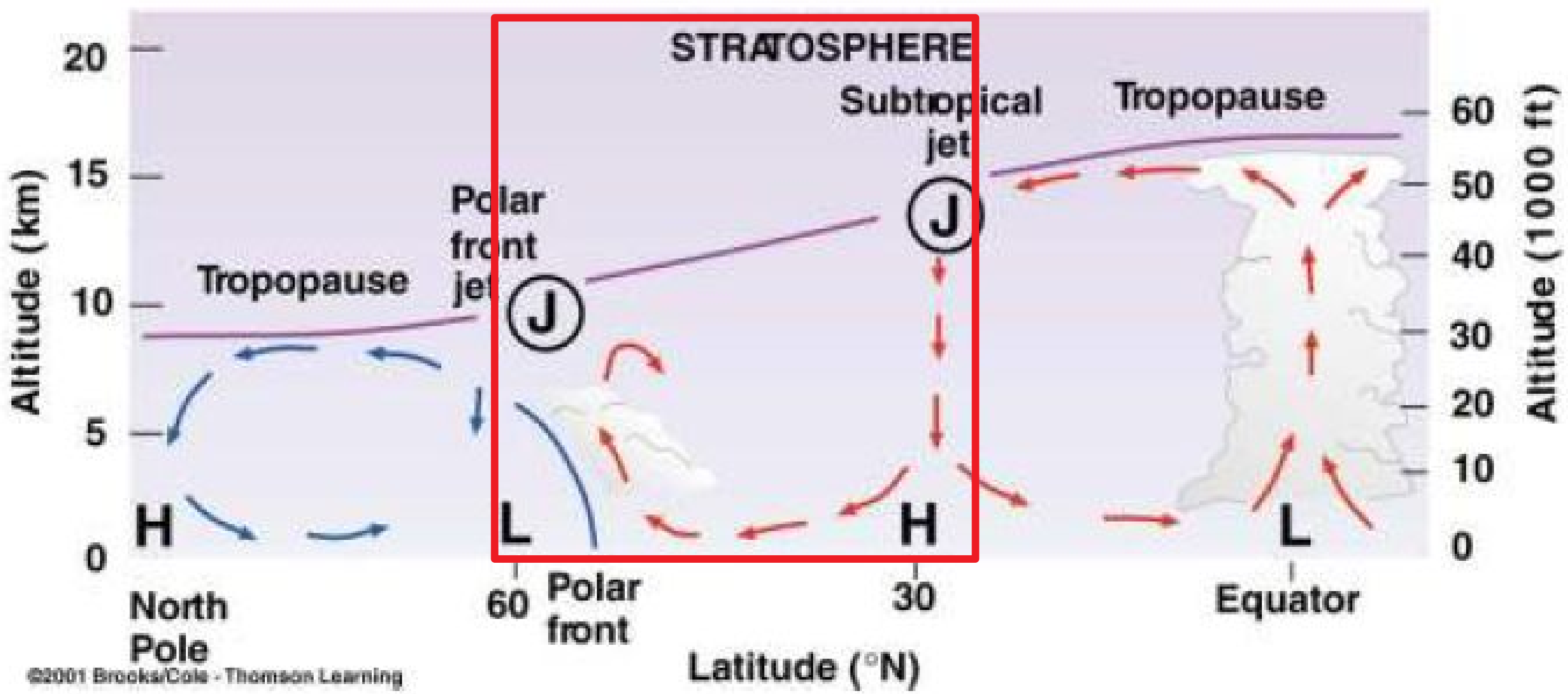


Figure 7.3 Global upper-level wind systems.

Three zones of exchange: the midlatitudes

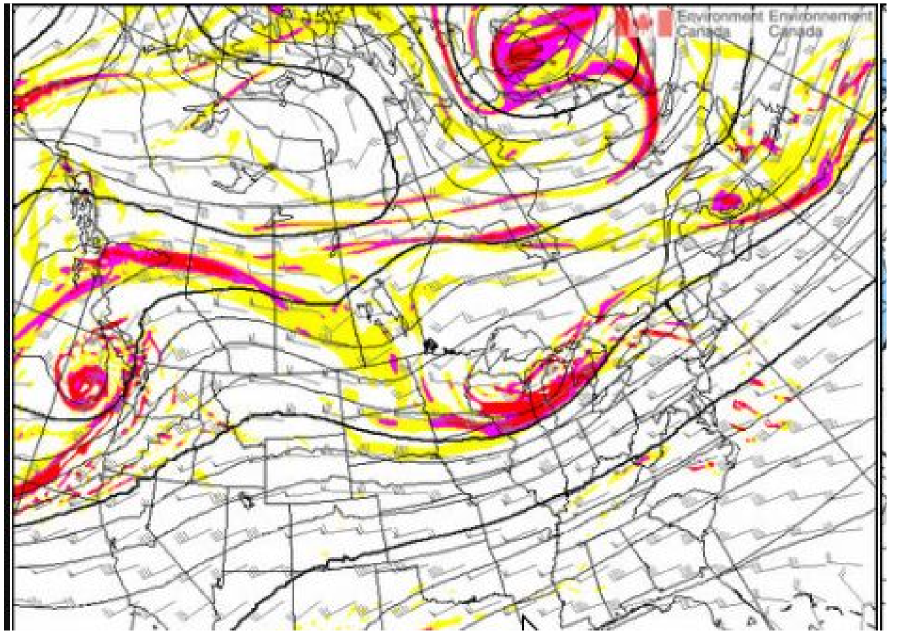


- Diverging air from the subtropical highs
- Converging air from the subpolar lows
- Maximum temp differences
- As noted subtropical air speed increases (conservation of angular momentum)

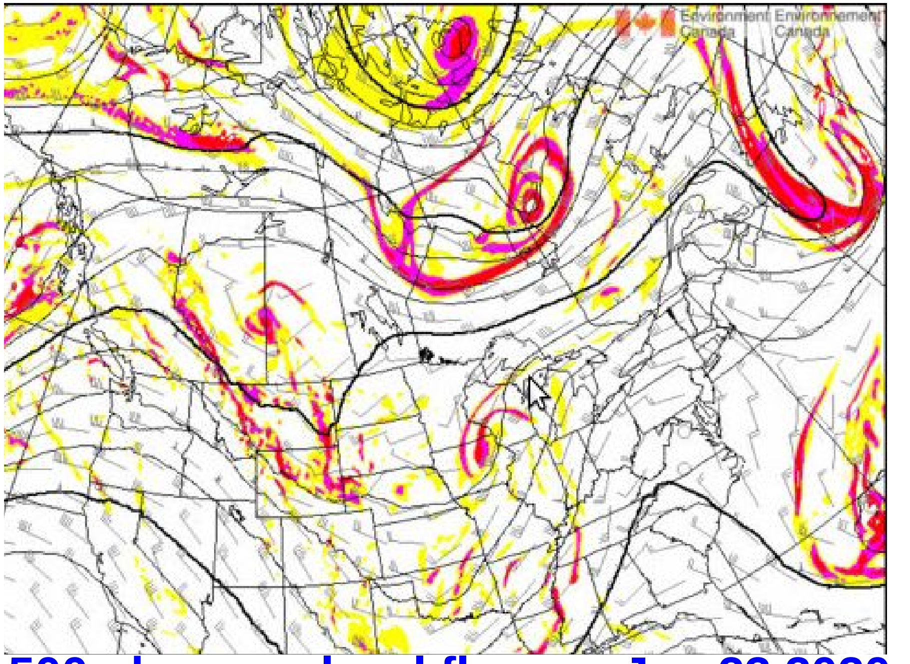
- Coriolis effect deflects air eastward (to the right) at higher latitudes
- Air flows along lines of equal pressure, tighter the pressure lines the faster the air flow
- All these factors lead to a **jet stream air flow**

North America: The mid-latitudes

- Typical pressure gradient isobars at mid-atmosphere (500 mb)
  - Air flows from west to east along lines of equal air pressure (geostrophic flow)
  - Air speed has increased from the tropics because of momentum conservation and temperature differences
  - Zone of maximum temperature differential usually associated with maximum wind flow. Generally referred to as the **Jet Stream**



500mb upper level flow on Jan.16 2020



500mb upper level flow on Jan.23 2020

Where is the jet stream on the maps?

Note the change within the week.

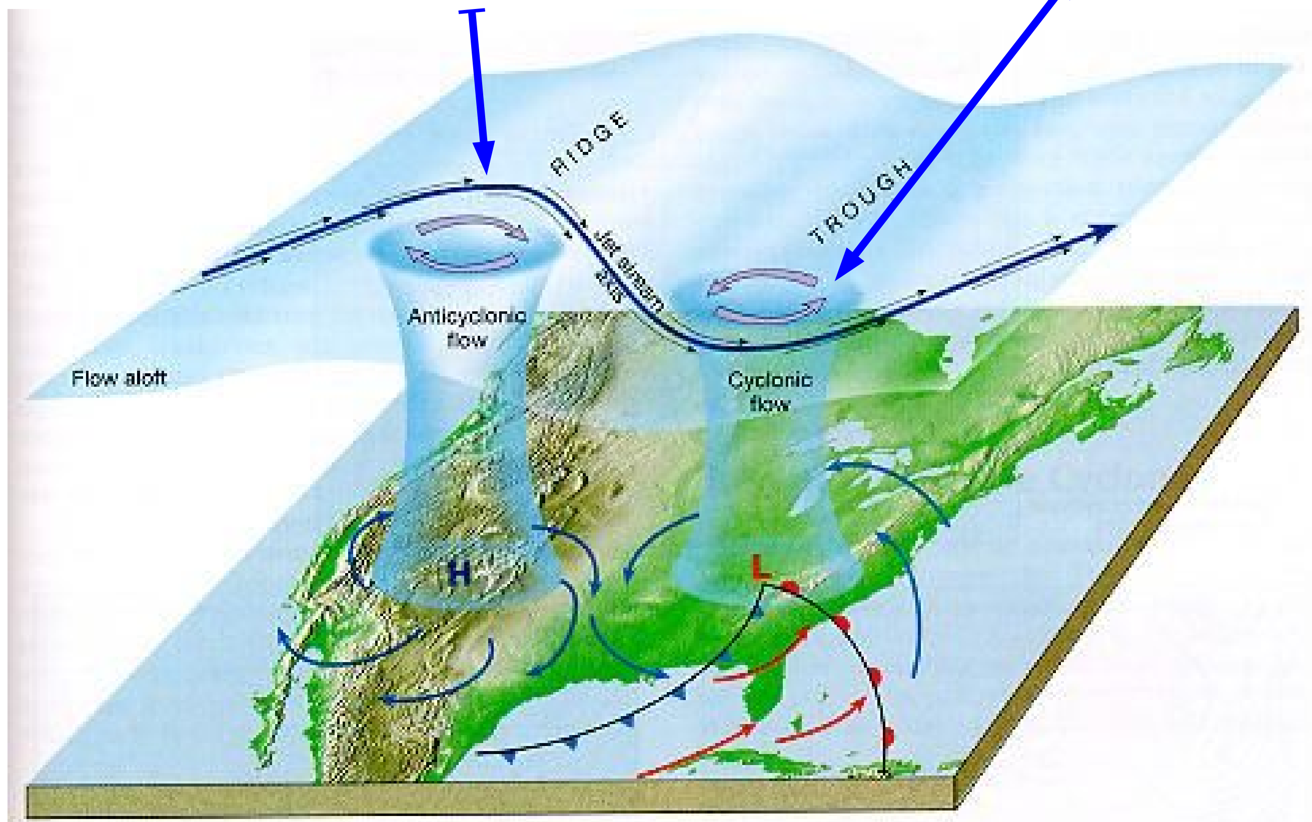
The mid-latitudes: basic dynamics

1. Air speed increases as it rotates with the larger Coriolis effect
2. Air converges or ‘piles up’ and descends
3. Anticyclone or ‘high’ results
4. The rotation or spin or Vorticity of the air is negative because it is spinning opposite the rotation of the earth

1. Air speed slows as it counters the Coriolis effect
2. Air diverges-spreads
3. Surface air rises to fill in the upper air ‘vacuum’. Low created
4. Cyclogenesis
5. The rotation or spin or Vorticity of the air is positive because it is spinning with the rotation of the earth

Negative Vorticity

Positive Vorticity

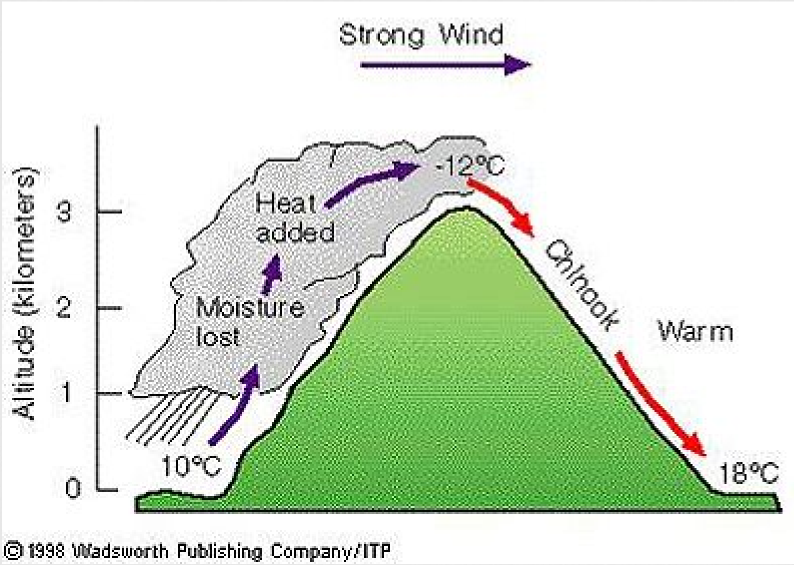


Go back to the previous slide
Where would you expect a surface low to form?

Topography

- Mountainous locations
  - Wide local climate variation across short distances due to changes in altitude
- The regional ‘Chinook’ effect also warms the Alberta plains
  - Caused by adiabatic warming of Pacific moist air streaming over the Rockies and drying over Alberta

Moist air cools at 0.6C/ 100m



Dry air warms at 1C/ 100m

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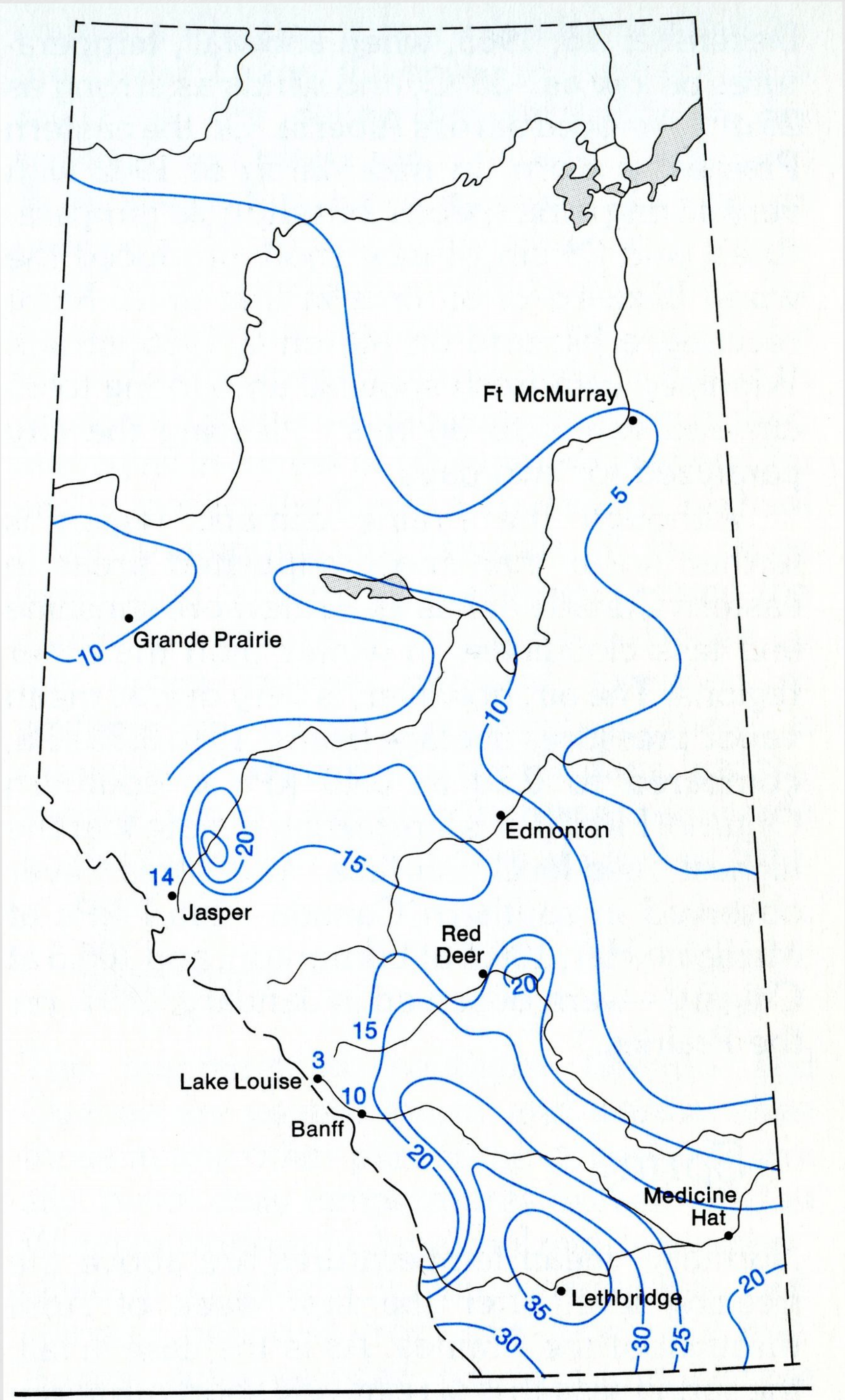


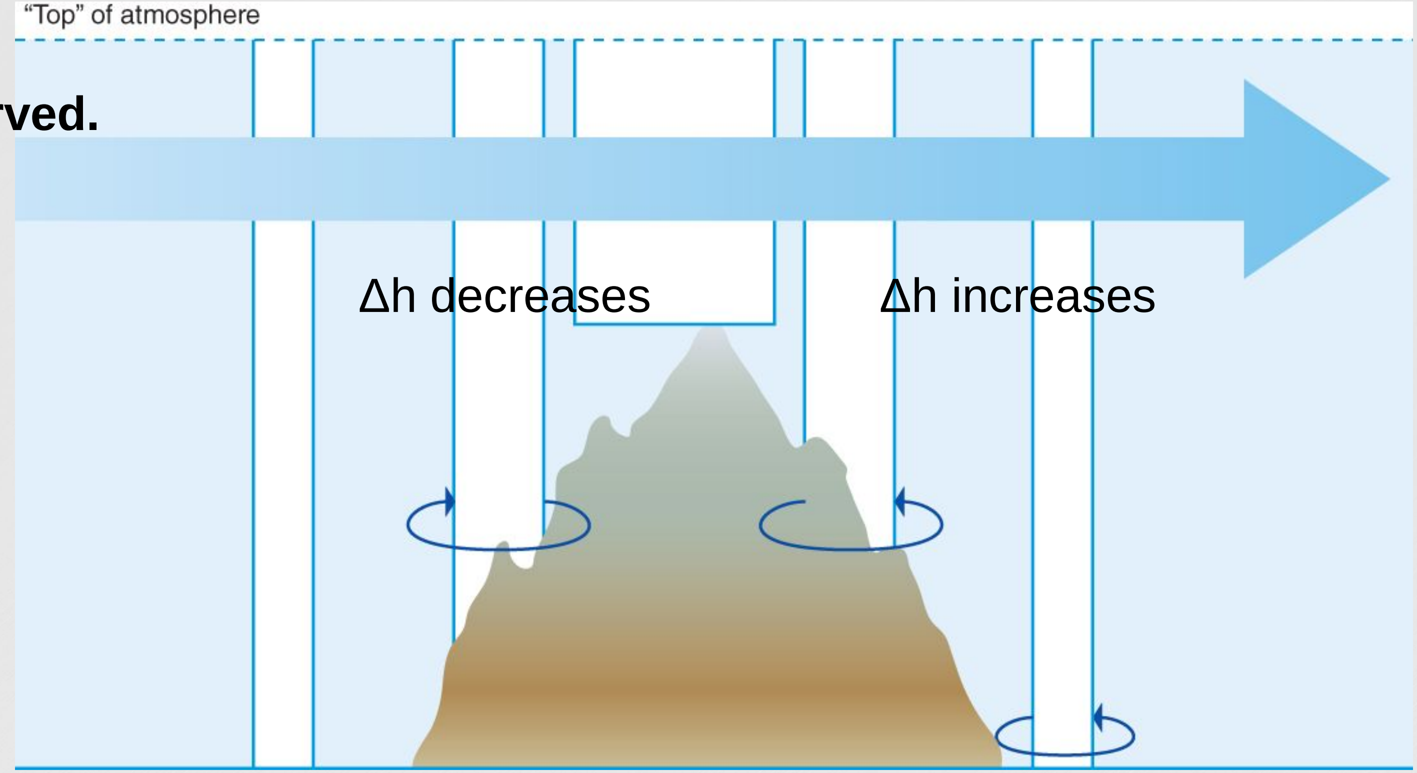
Figure 6.6 Frequency of chinook days in Alberta with maximum temperatures over 3.9°C (after Longley).

Topography: The Rockies and air flow

- North-South mountain ranges can affect upper air dynamics by creating ridges on the windward side (negative vorticity) and troughs on the lee side (positive vorticity)
- In Alberta (lee of the Rockies) the positive vorticity encourages cyclogenesis and produces the well-known 'Alberta Clipper' low pressure system. We get Chinooks, the east gets Arctic air

$PV = (\xi + f) / \Delta h$, where PV = Potential Vorticity, ξ = relative vorticity, f = Coriolis effect
Δh = height difference

Potential Vorticity is conserved.
Therefore if 'f' is constant (zonal flow), then if height difference lessens as air goes up a mountain then ξ must also lessen, ie. negative vorticity.
As air descends on the lee Δh, height difference increases as does ξ which leads to positive vorticity and favorable conditions for a low to form .



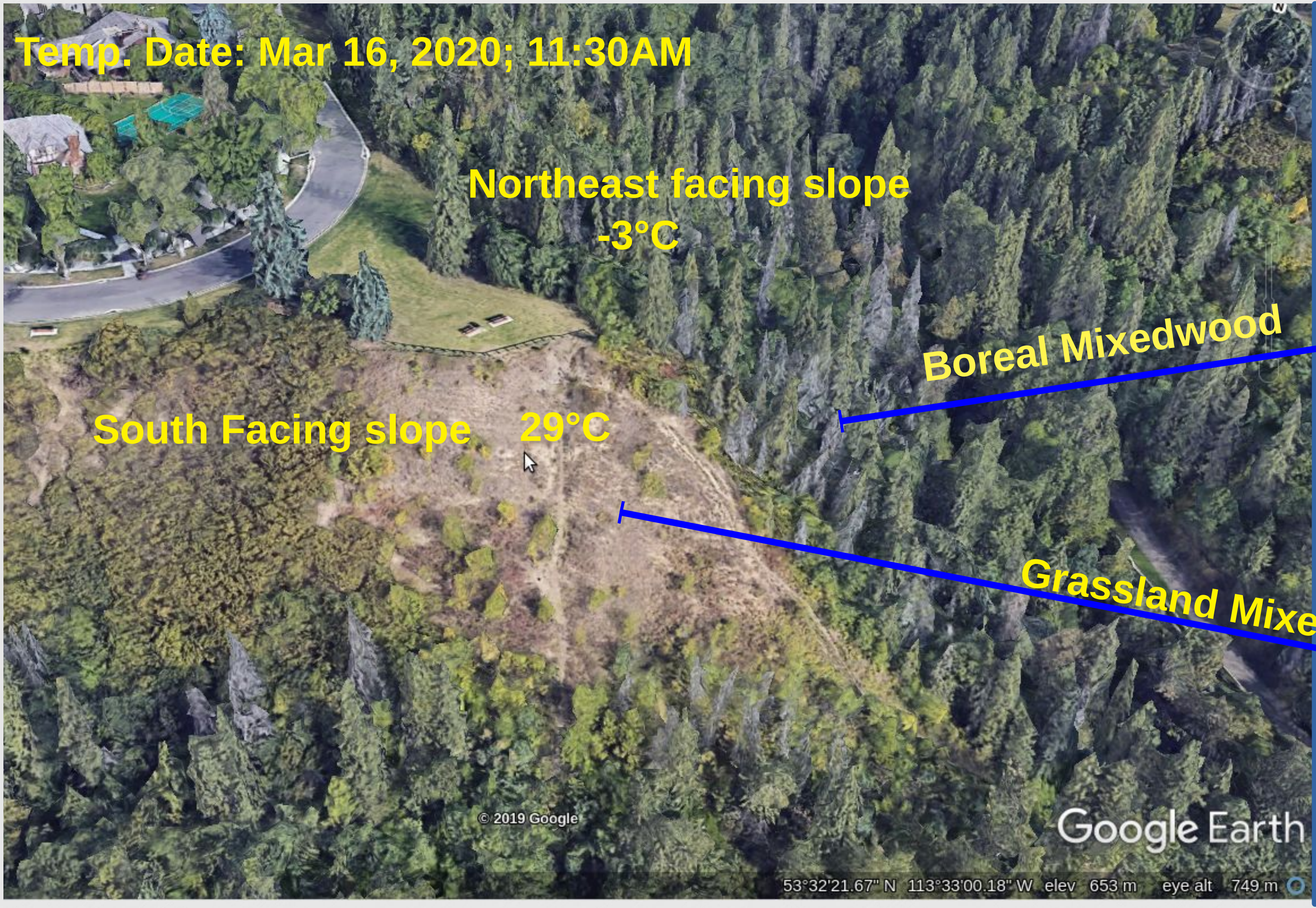
Local Features

Isolated influences on the climate of a small area

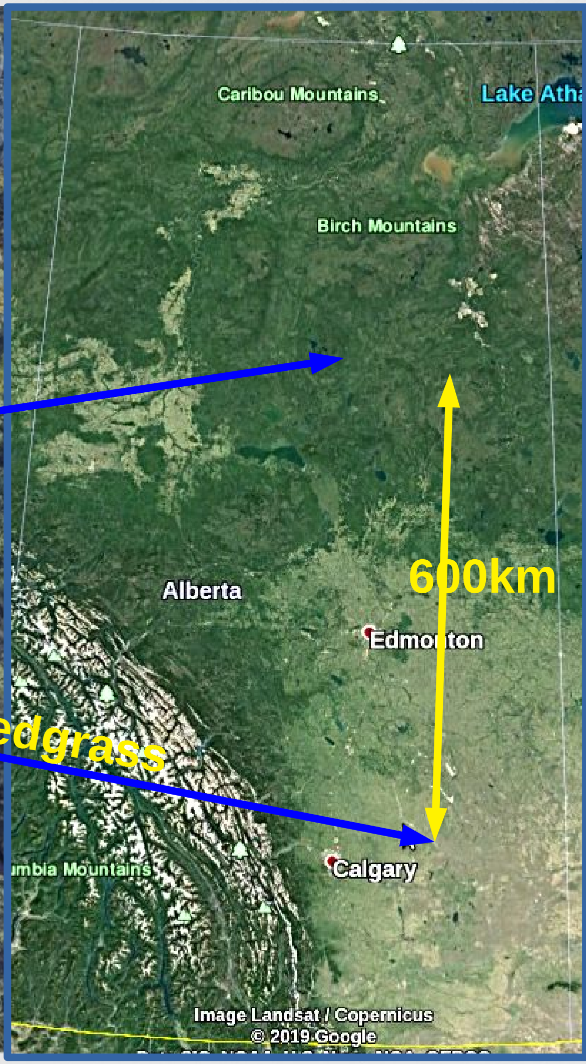
- Lake effect snows – minor effect in Alberta but major in the Great Lakes region of S.Ontario
- Urban heat island effect – significant for Edmonton and Calgary
- Air pollution – aerosols significant for Edmonton and Calgary
- Chinooks – significant for Lethbridge and Calgary
- Topographical effects
  - Cypress Hills – cooler and wetter than the surrounding prairie, maintain a lodgepole pine community on its slopes
  - Cariboo Mountains – colder and wetter than the surrounding boreal forest: subarctic permafrost widespread

Can you think of a local feature influencing temperature (microclimate) in Edmonton?

One of Edmonton's microclimates: Effect of Insolation/slope



Ramsey Ravine/River Valley



Alberta

Towards a general classification of climate

- Six factors cause the climate of a location to have its fundamental characteristics:
  - Latitude (angle)
  - Earth–Sun relationships
  - Distance to large bodies of water
  - Circulation
  - Topography
  - Local features
- They lead to climate classification systems, here are 4:
  - **Köppen-Geiger – A commonly used system based on vegetation**
  - Thornthwaite – A more precise system based on energy and moisture
  - Holdridge – Similar to the Thornthwaite system, used in the tropics
  - Budyko – A system based on evaporation and net radiation

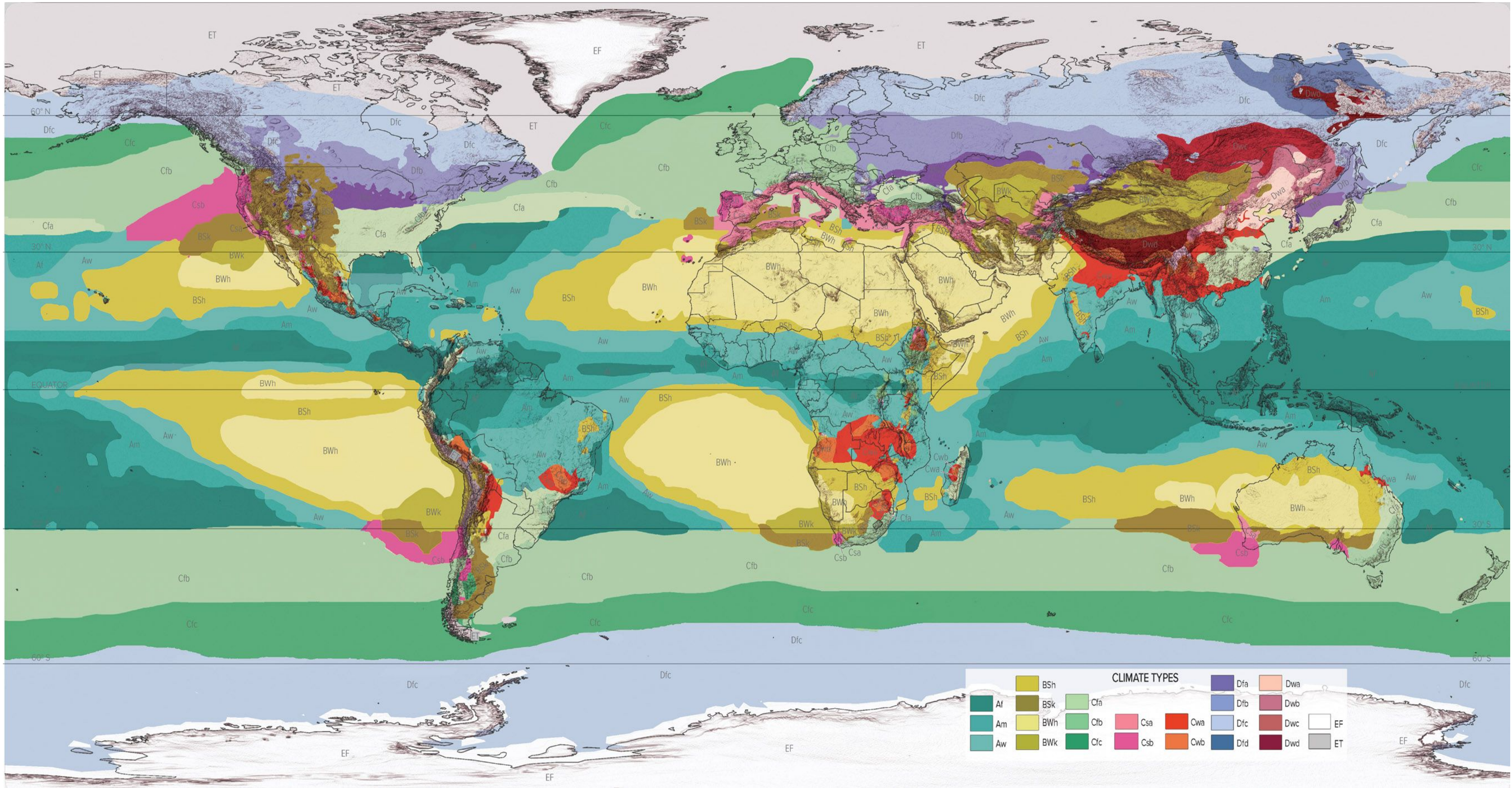
TABLE 8.1 First-Order Köppen-Geiger Climatic Classification Division

Subtype	Classification	Criteria Specifics
A	Tropical	Coolest month > 18°C (64°F)
B	Dry	See specifics bulleted in text
C	Mesothermal	Coldest month > 0°C (32°F) but < 18°C (64°F) Warmest month > 10°C (50°F)
D	Microthermal	Coldest month < 0°C (32°F) Warmest month > 10°C (50°F)
E	Polar	Warmest month < 10°C (50°F)
H	Highland	Undifferentiated highland climates

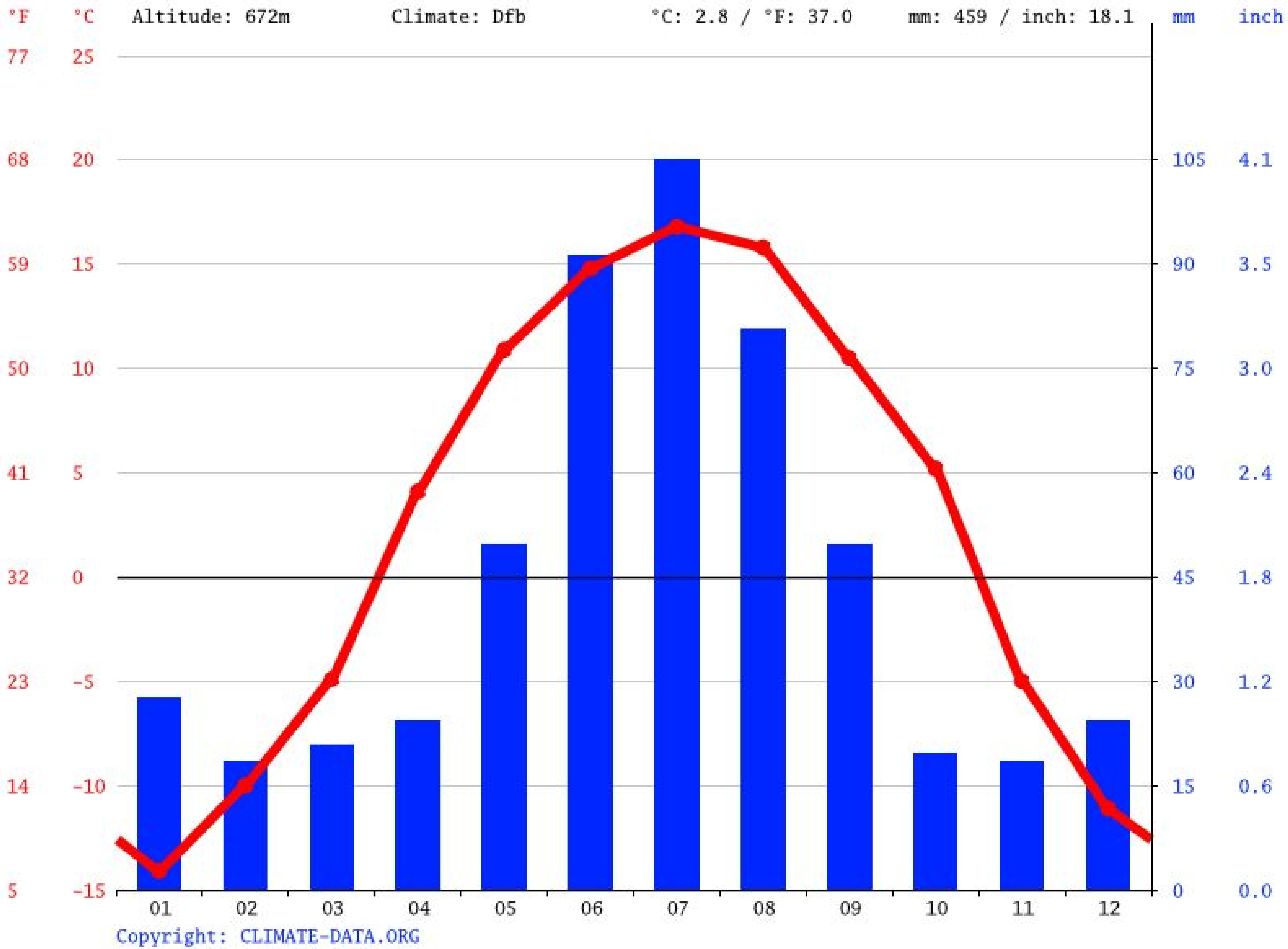
TABLE 8.3 Partial Listing of Köppen-Geiger Second- and Third-Order Subdivisions

Second Order	Third Order	Criteria Specifics
	a	Warmest month > 22°C (72°F)
	b	Warmest month < 22°C (72°F)
	c	Fewer than 4 months > 10°C (50°F)
	d	Same as c but coldest month < −38°C (−36°F)
f		Constantly moist. Rainfall through all months of year
m		Monsoon rain, short dry season. Total rainfall sufficient to support rain forest
s		Summer dry season
w		Winter dry season
W or S	h	Hot and dry year-round Average annual temperature >18°C (64°F)
W or S	k	Cold and dry year-round Average annual temperature >18°C (64°F)
	n	Frequent fog
	n′	Infrequent fog but high humidity and low rainfall

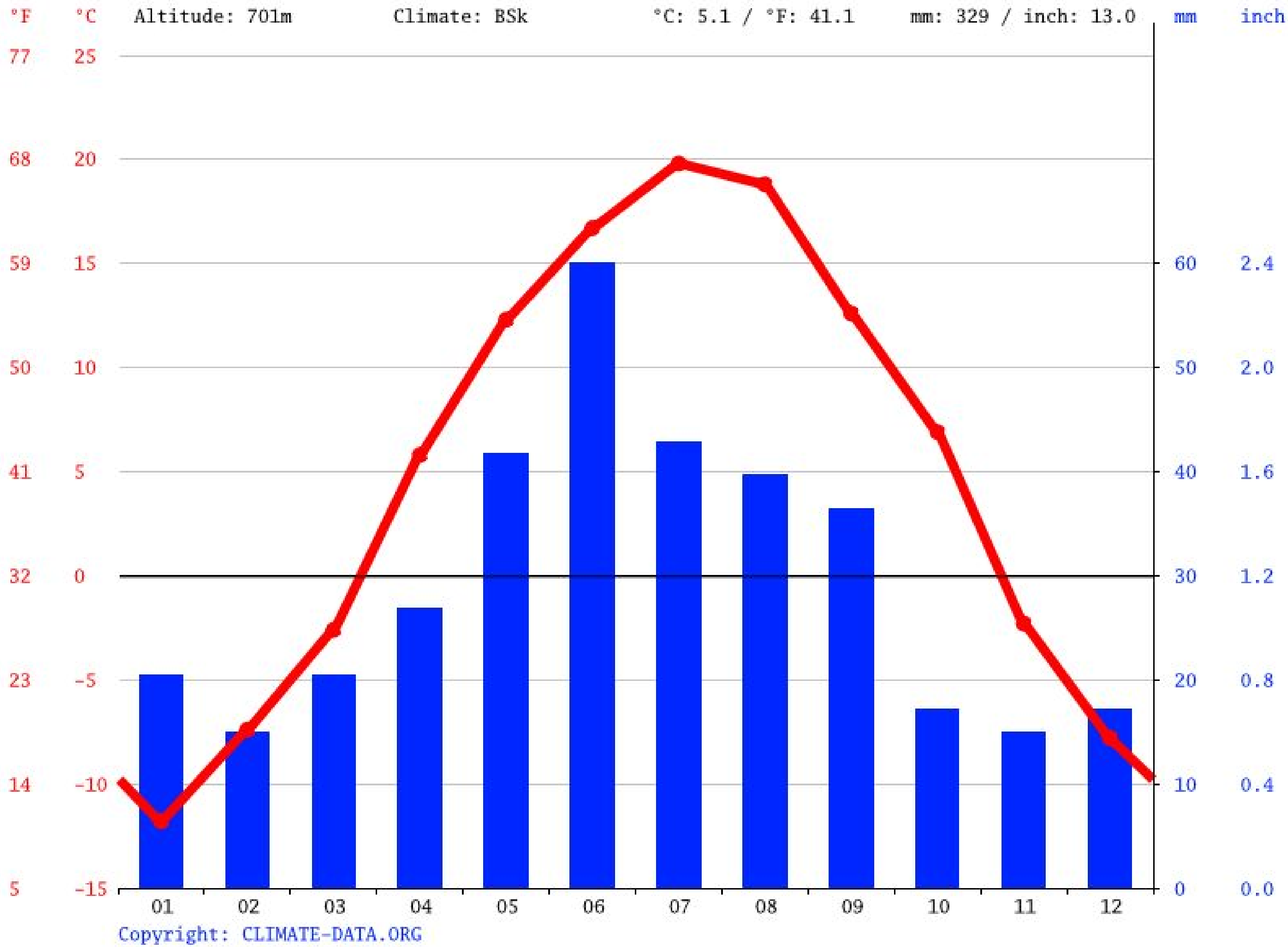
Köppen-Geiger Climate Zones



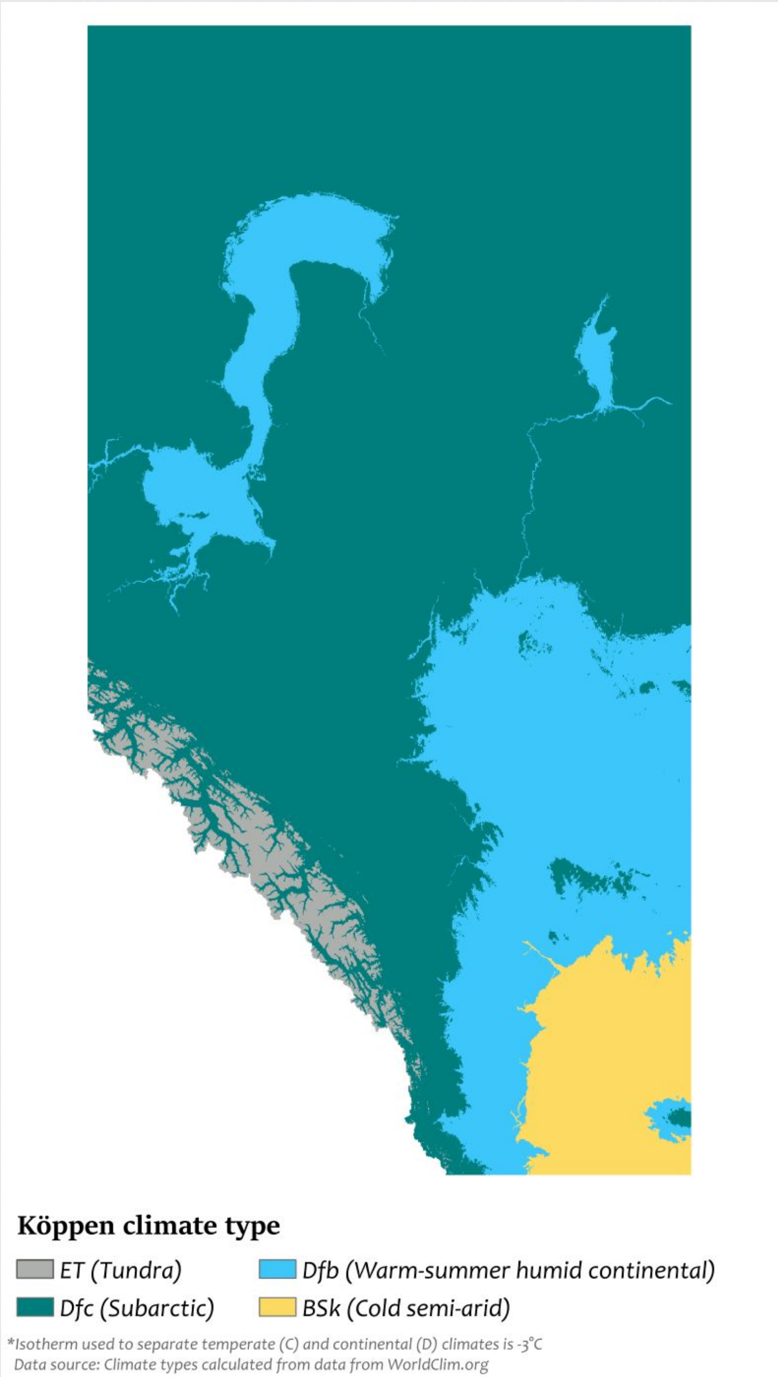
Edmonton Climate Graph: Dfb



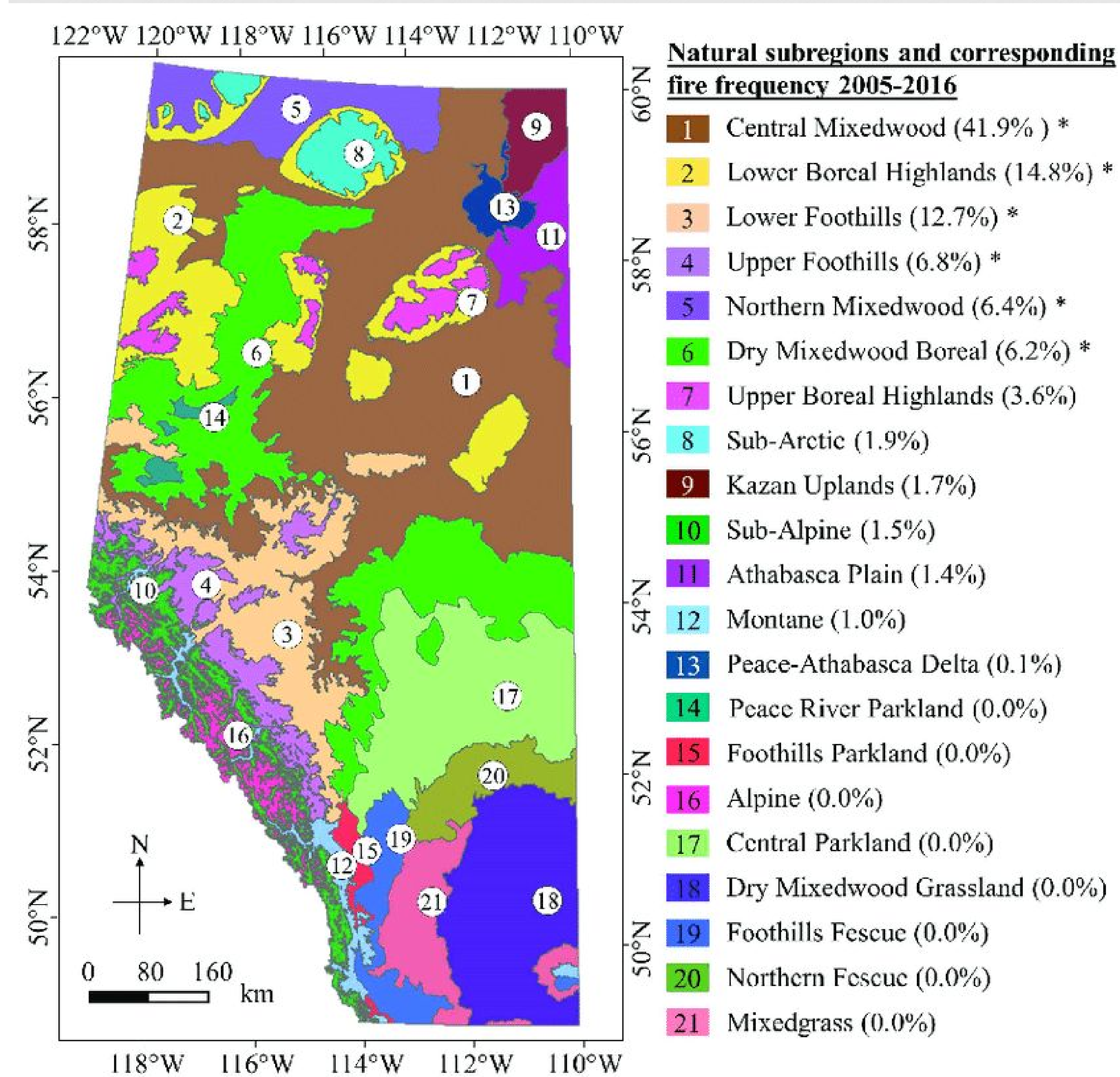
Medicine Hat Climate Graph: BSk



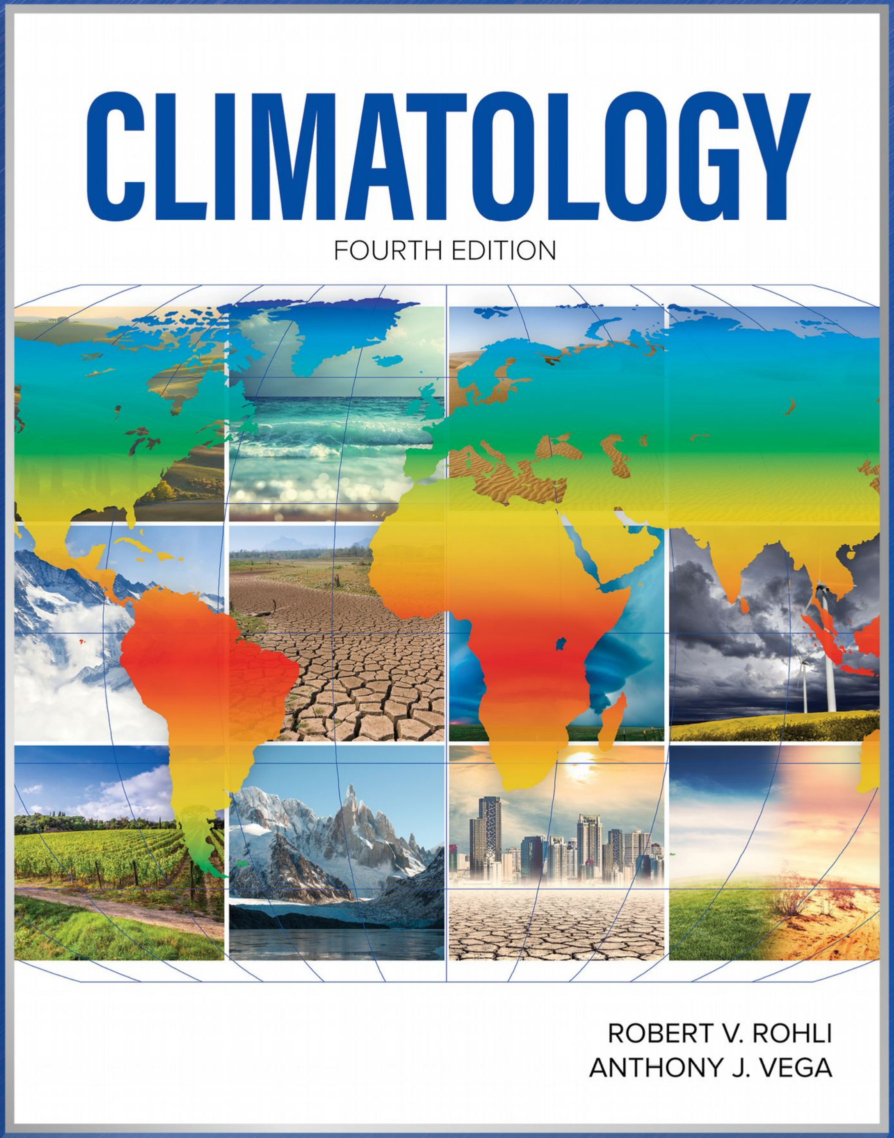
Climate/Natural Regions of Alberta



Alberta Natural Sub-regions

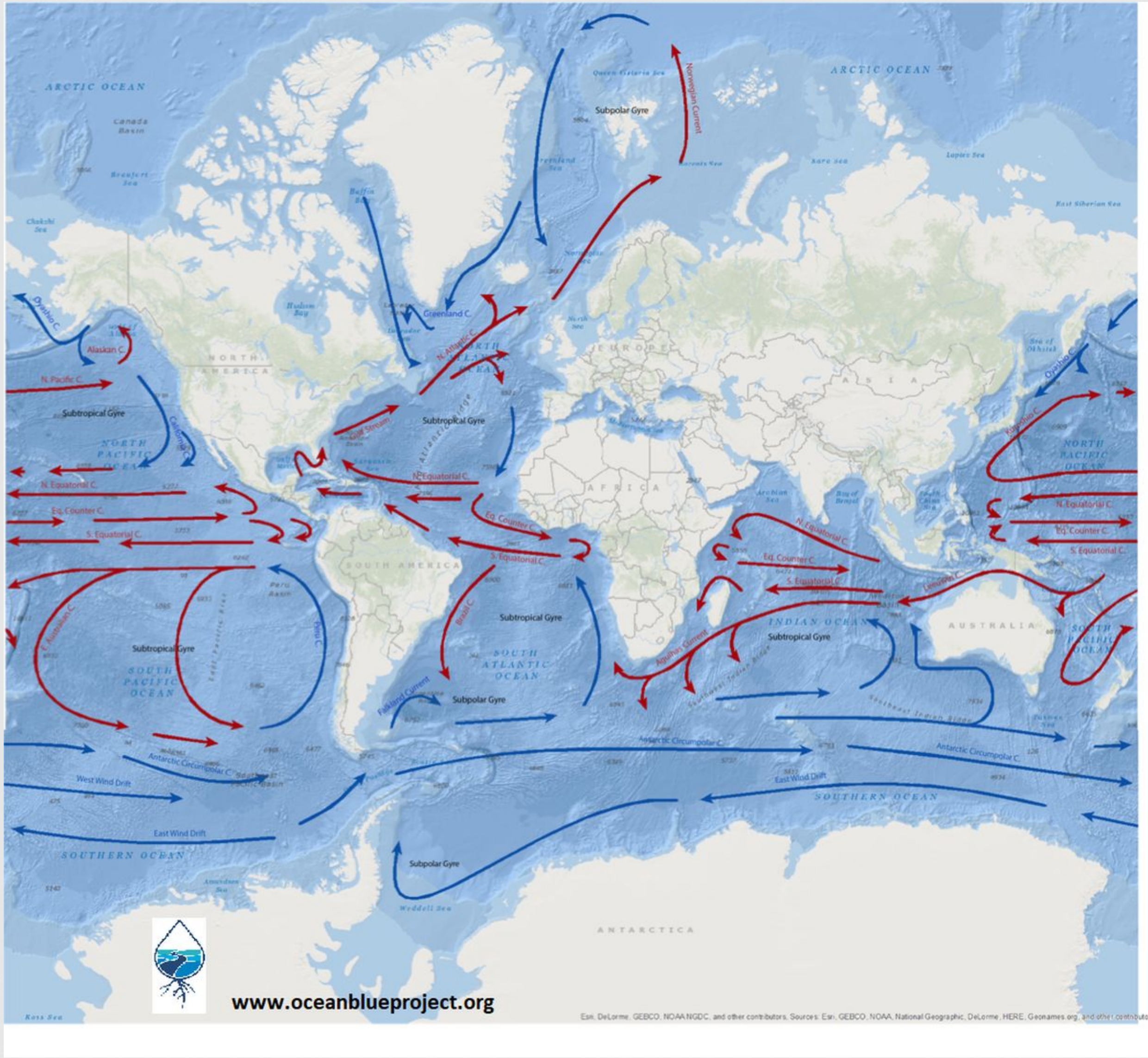


Section 3b. Atmospheric Interactions with Oceans, Volcanoes, and the Cryosphere

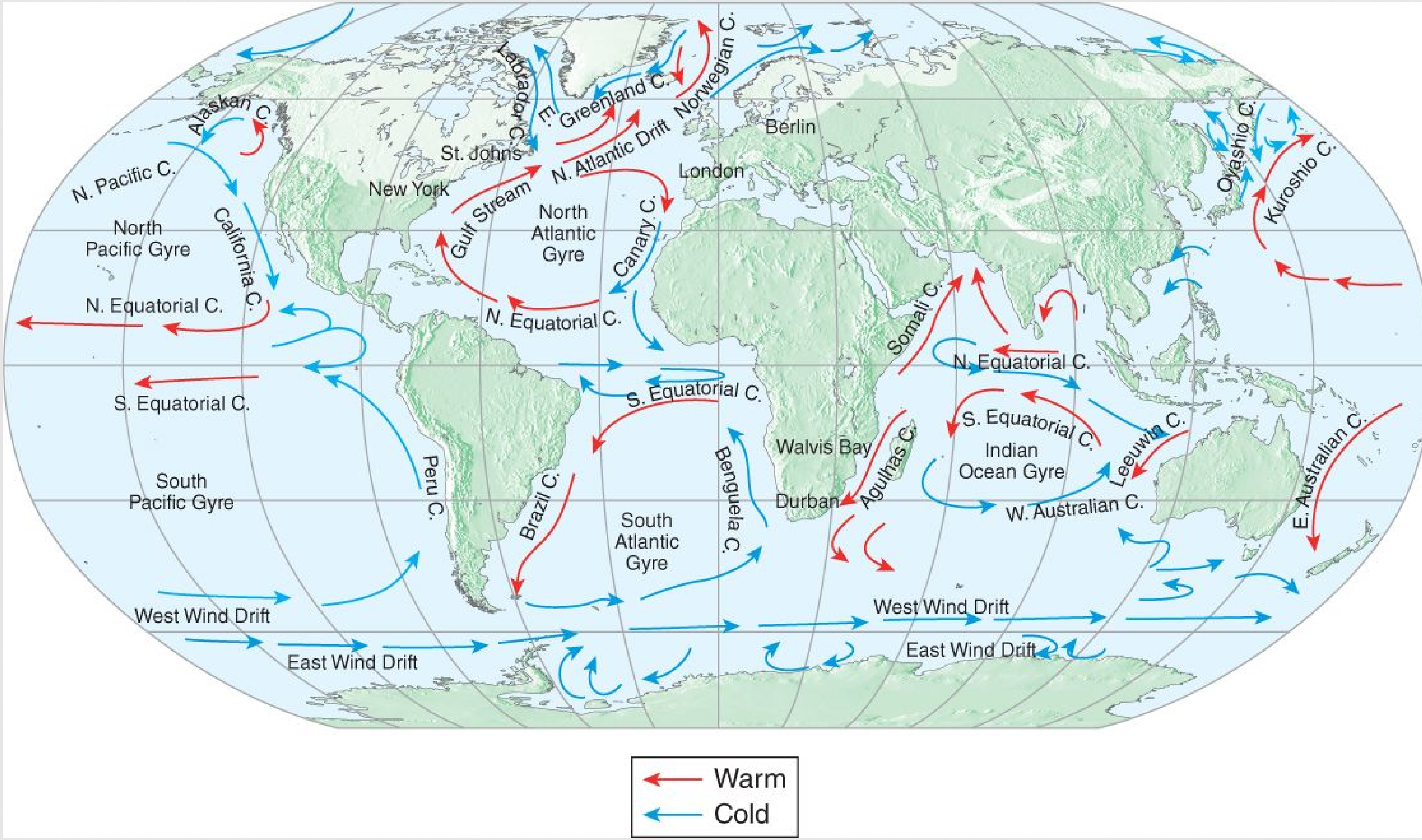


Circulation: Oceanic Circulation

- The mission of the oceans is the same as the atmosphere: exchange surplus equatorial heat with the polar zones via ocean currents
- Governed by the same laws of motion and the 2nd law of thermodynamics:
- Surface ocean currents extend to approximately 100 m (330 ft).
  - **Driven primarily by surface winds associated with the subtropical highs**

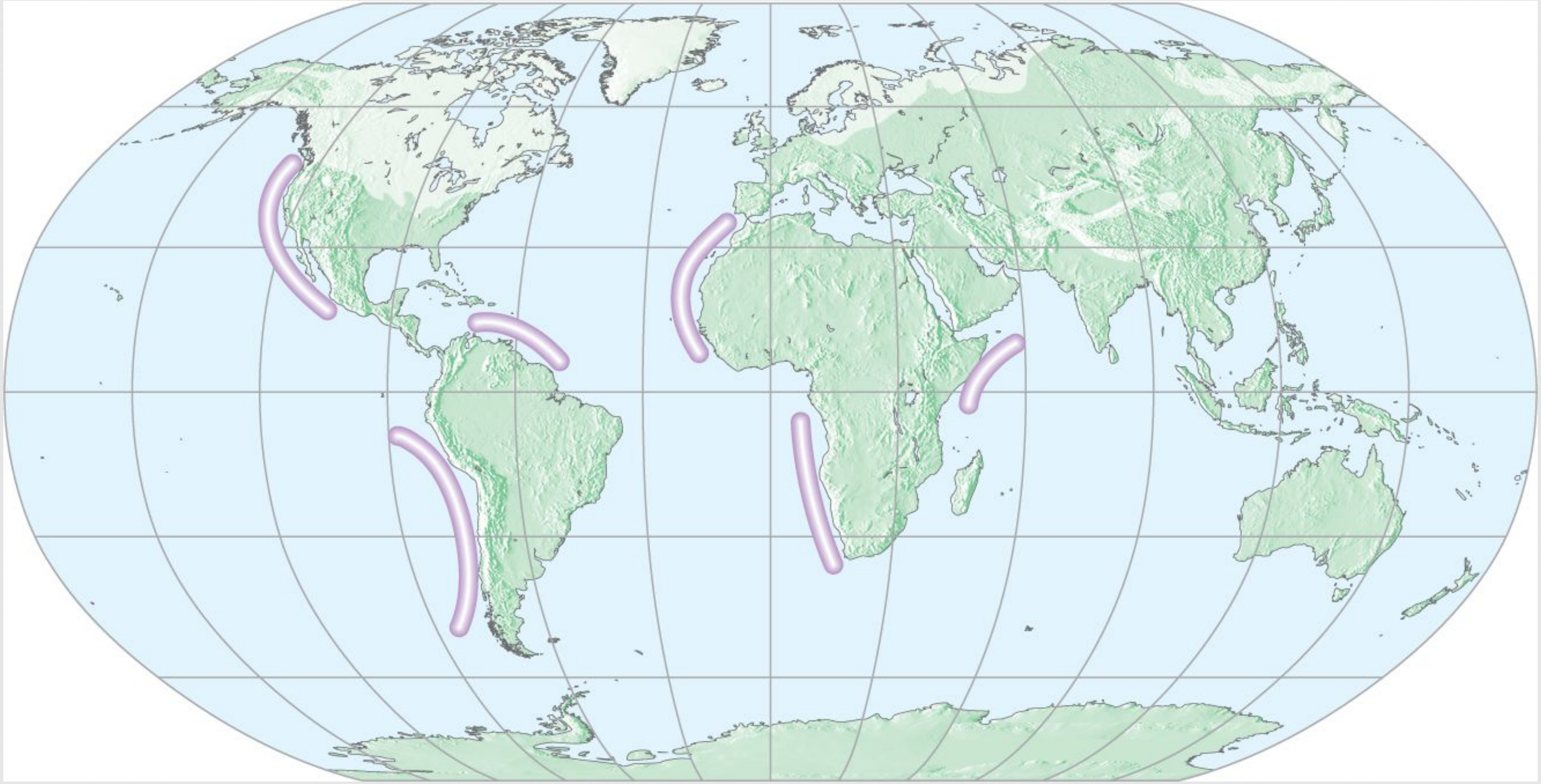


Ocean Circulation: Surface Currents



Gyres ensure cold currents on the east side of oceanic basins and warm currents on the west. Upwelling reinforces the cold ocean currents. Downwelling supports high ocean temperatures.

Ocean Circulation: Upwelling

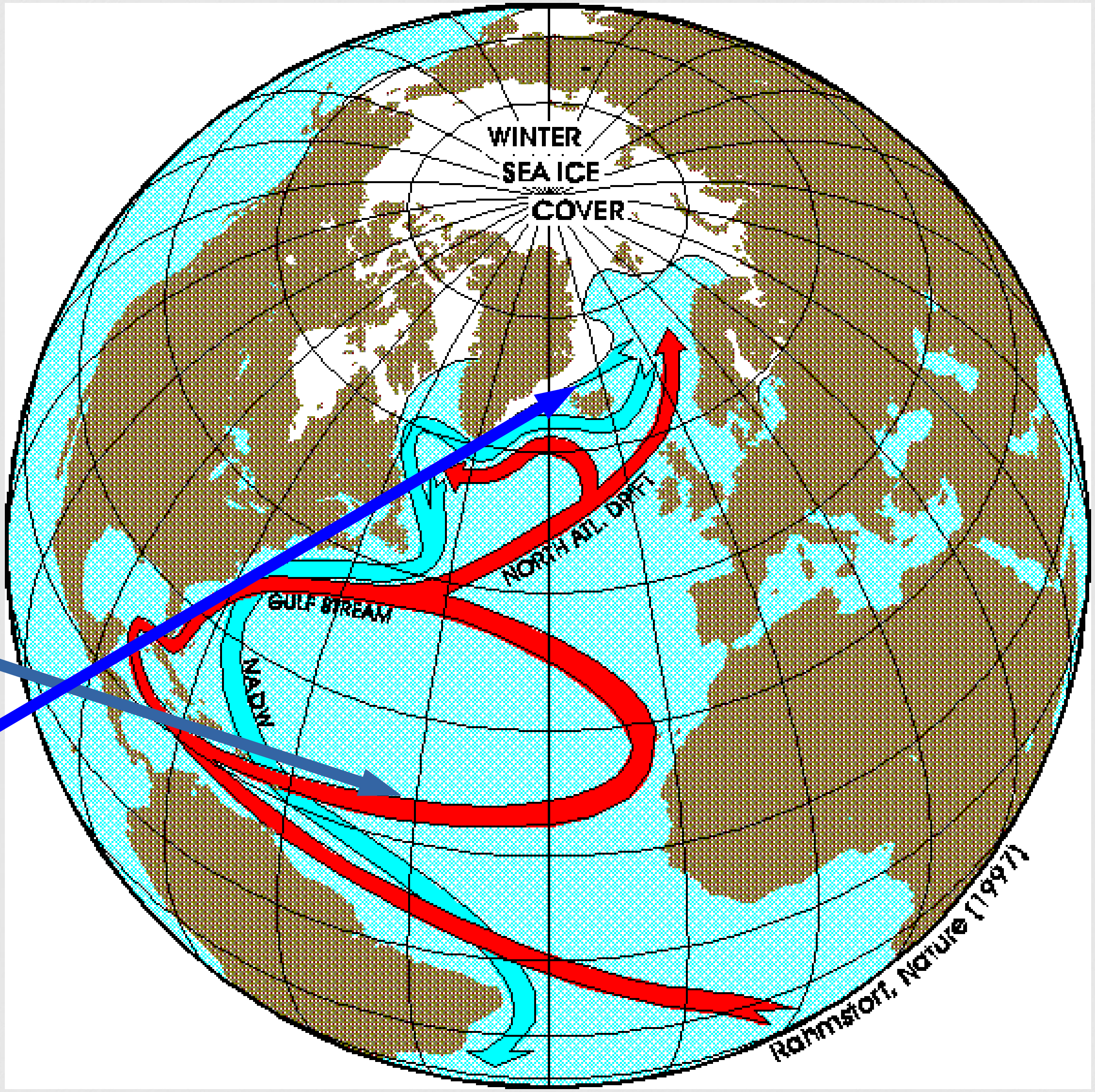


Upwelling brings deep cold water to the surface which stabilizes the atmosphere
ie. High pressure and dry conditions -

Deep Ocean Circulation: Thermohaline circulations

- Driven by temperature and/or salinity differences between the equatorial areas and polar areas

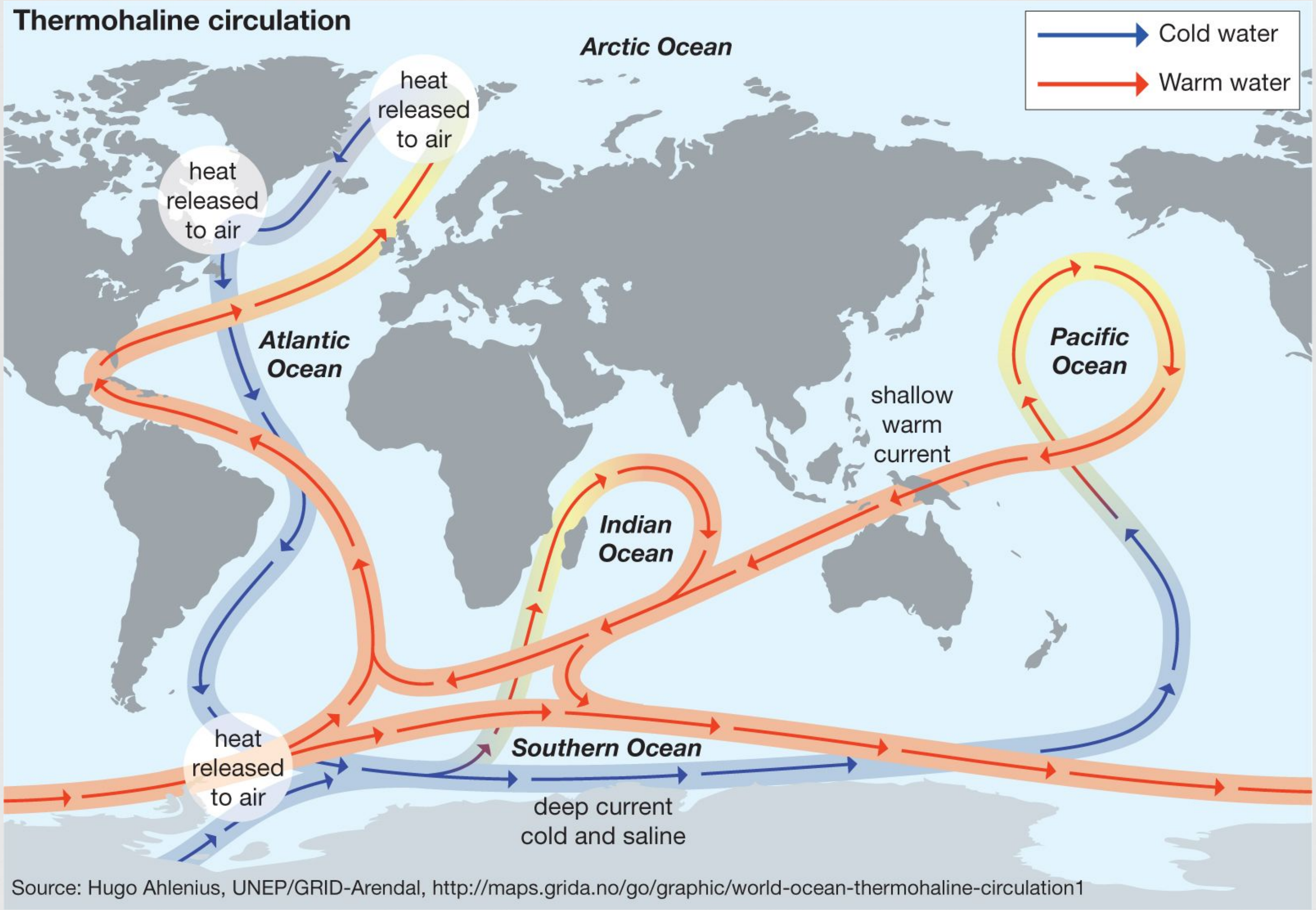
Higher temperatures and higher precip (fresh water)in the tropics are sources for lower density water. ex. the Gulf Stream



Colder temperatures and lower Precipitation (more saline water) in the polar areas cause Water to sink to the bottom of the Ocean and flow southward

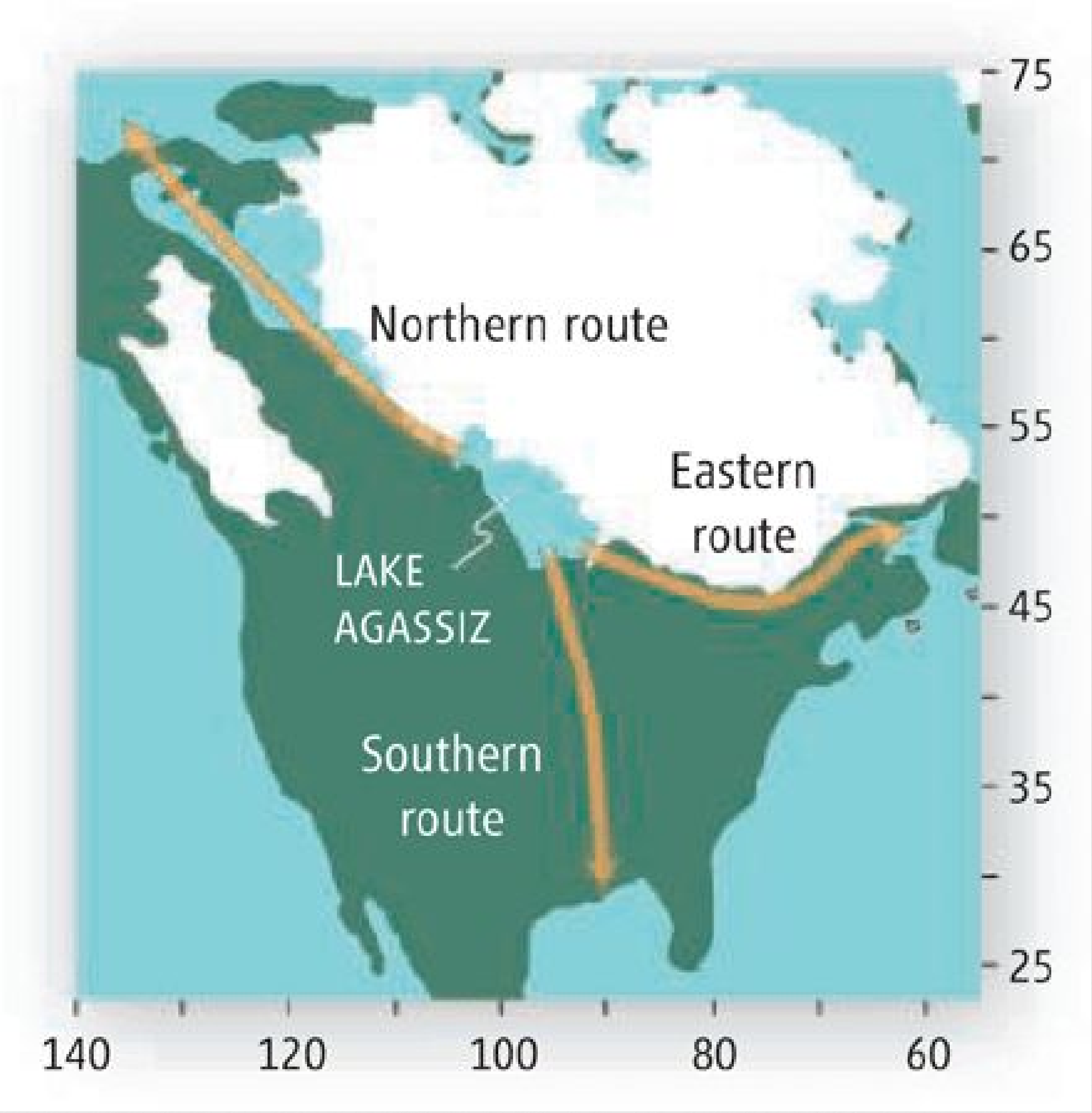
Circulation: Deep Ocean Conveyor Belt
The Stommel model

- Deep water ocean currents
  - Thermohaline induced.
- Globally connected deep ocean conveyor belt affects climatic conditions with global implications, ie. energy can be stored and released after hundreds of years



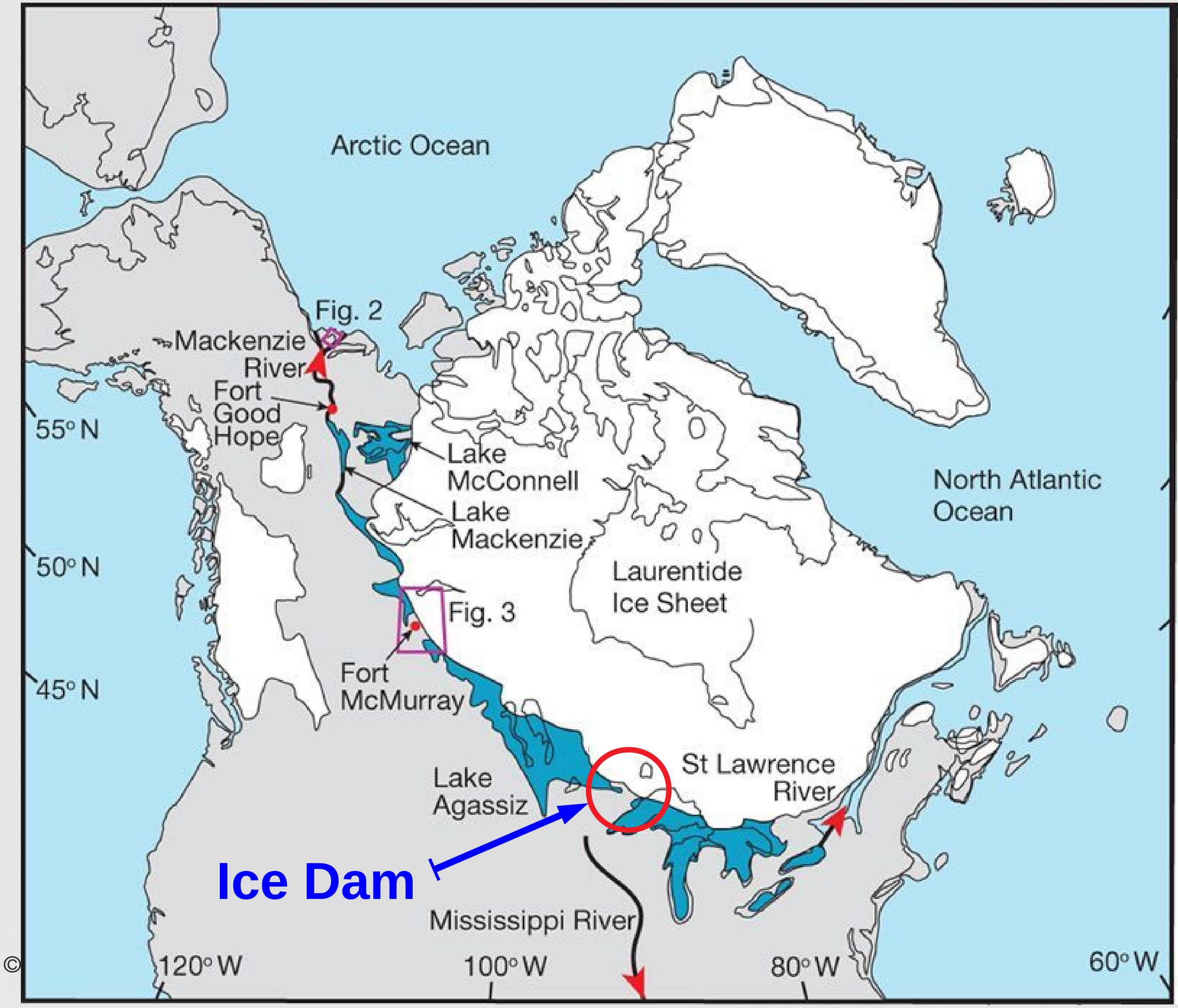
Circulation: Thermohaline Disturbance, The case of Lake Agassiz (1)

- 12,800 yrs ago
- Laurentide ice sheet is melting and creating glacial lakes along its SW west edge
- Lakes are draining north (Mackenzie) and south (Mississippi), east route via St. Lawrence is blocked.
- The biggest of the glacial lakes is Lake Agassiz.



Circulation: Thermohaline Disturbance, The case of Lake Agassiz (2)

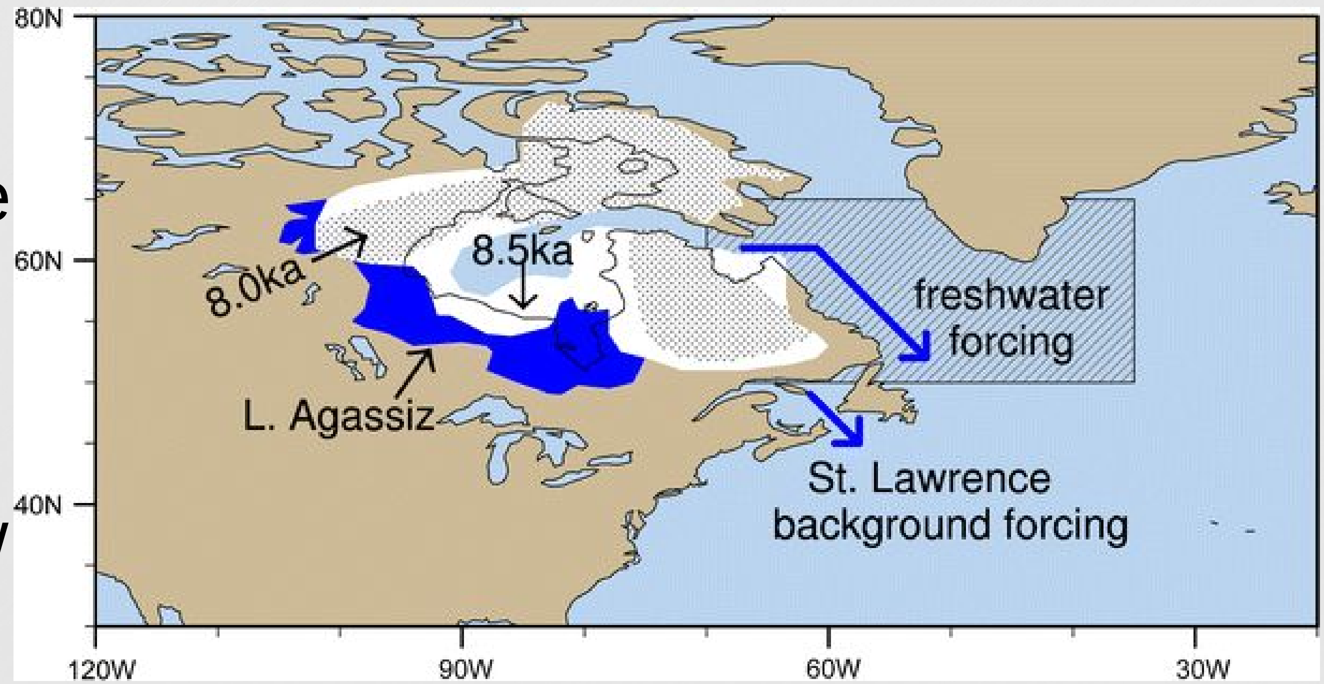
- The southern lobe of the Laurentide sheet eventually recedes and exposes the Great Lakes-St. Lawrence drainage (Eastern Route).
- As the ice dam creating Lake Agassiz breaks open the lake drains to the Atlantic, the duration may have been from days to years

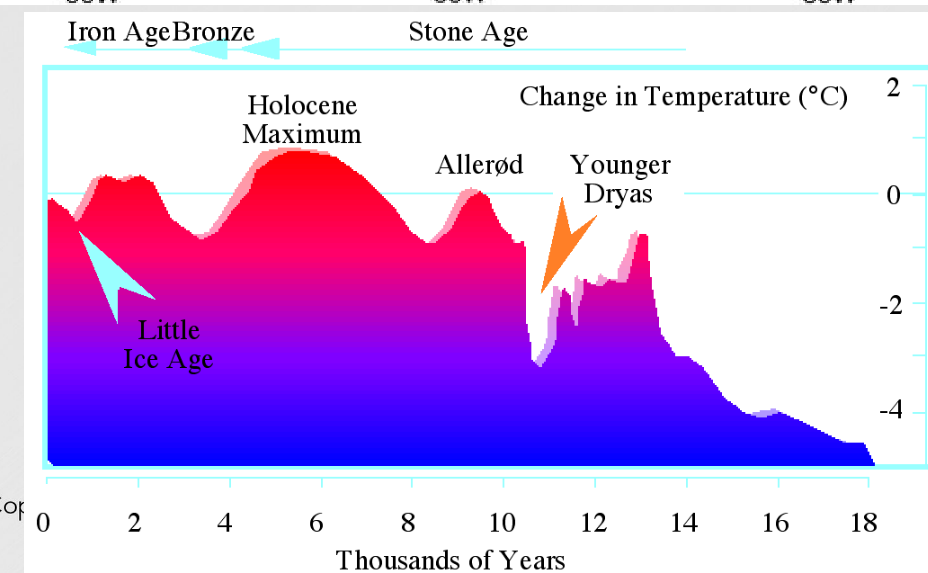


©

Circulation: Thermohaline Disturbance, The case of Lake Agassiz (3)

- The infusion of fresh water into the Atlantic (and Arctic) affects the both the surface Gulf Stream (via temperature) and the deep water return flow current (via salinity)
- The Gulf Stream halts and initiates a glacial period known as the Younger Dryas, most notable in Europe.
- Lasts ~1000 yrs

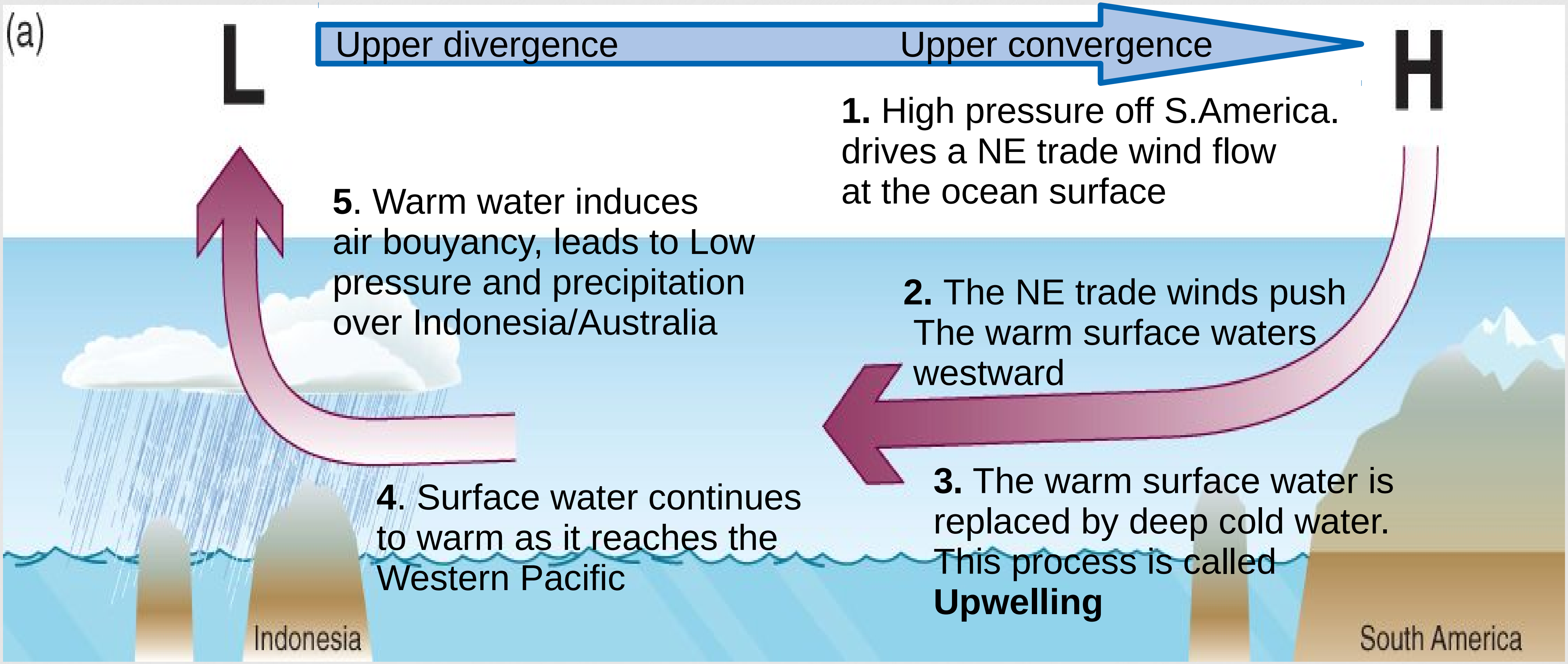




The El Niño–Southern Oscillation (ENSO): An atmosphere-ocean dynamic

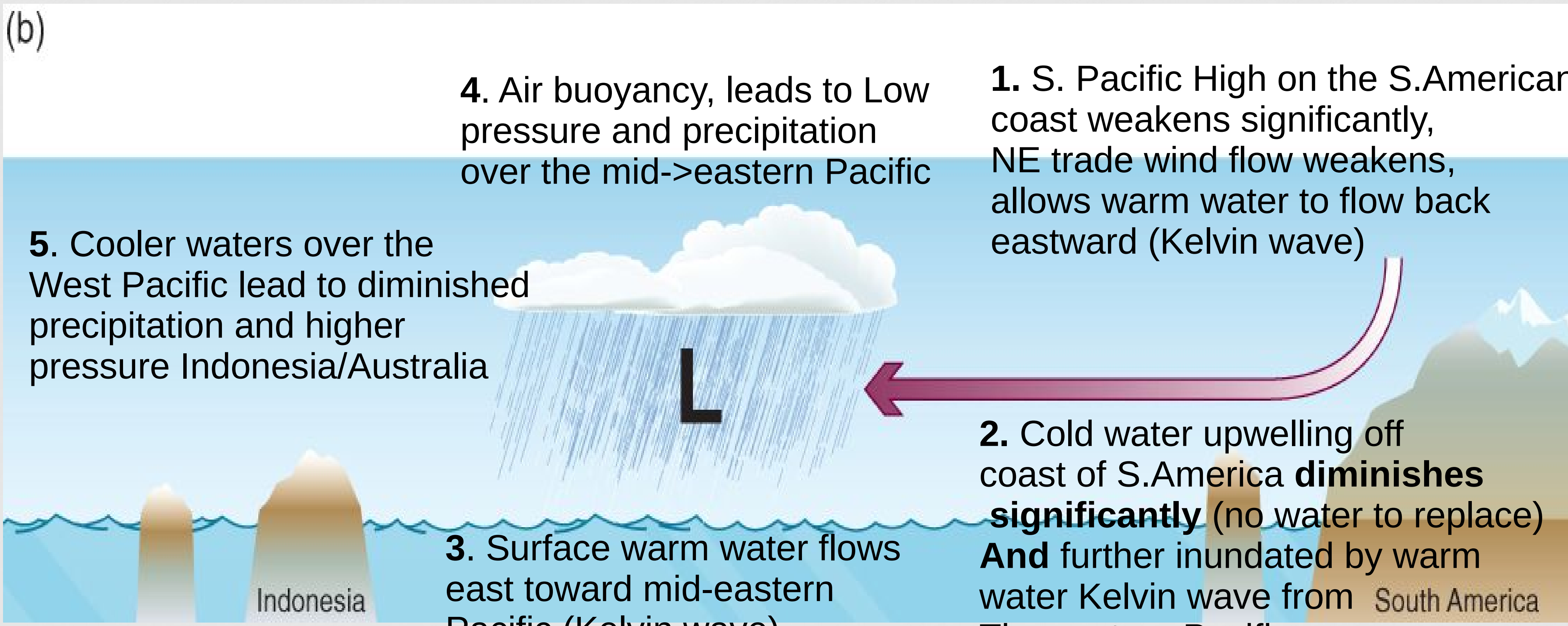
- Southern Oscillation: A seesaw of surface air pressure (High-Low to Low-High) between the eastern and western equatorial Pacific.
- In 1969 Jacob Bjerknes recognized that these pressure changes are a result of Sea Surface Temp (SST) variations, thus establishing a link between El Niño, La Niña, and the Southern Oscillation. He termed this **'The Walker Circulation'.** Today, it is called '**ENSO**'.
- Changes in air pressure associated with the extreme phases of ENSO cause unusual global atmospheric circulations.
- Indicators are: changes in SST, Sea level, and air pressure

The El Niño–Southern Oscillation: Walker Circulation or **ENSO Neutral**



Walker circulation: The connection between atmospheric pressure centers and SST in the equatorial Pacific that are associated with the Southern Oscillation.

El Niño–Southern Oscillation: ‘El Niño’ Event - **ENSO Warm**



1. S. Pacific High on the S.American coast weakens significantly, NE trade wind flow weakens, allows warm water to flow back eastward (Kelvin wave)

2. Cold water upwelling off coast of S.America **diminishes significantly** (no water to replace) **And** further inundated by warm water Kelvin wave from The eastern Pacific.

3. Surface warm water flows east toward mid-eastern Pacific (Kelvin wave)

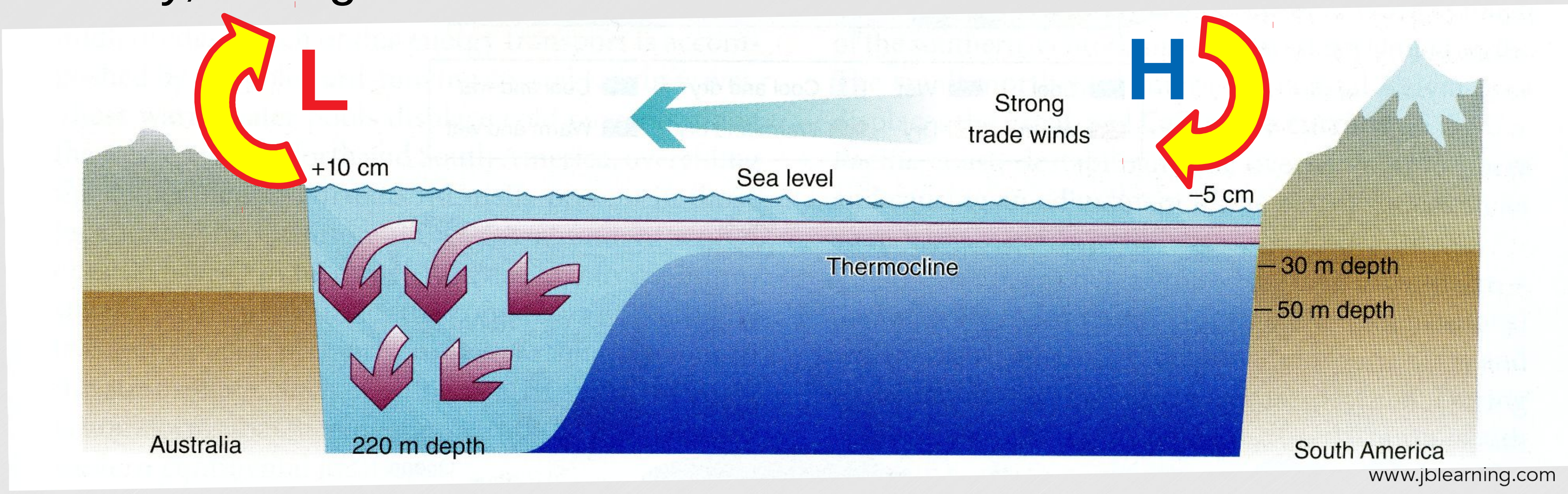
4. Air buoyancy, leads to Low pressure and precipitation over the mid->eastern Pacific

5. Cooler waters over the West Pacific lead to diminished precipitation and higher pressure Indonesia/Australia

- Coincides with a reversal of the normal Walker circulation.
- Occurs once every 3 to 7 years, and usually lasts 10 to 14 months.

El Niño–Southern Oscillation Events: La Niña – **ENSO Cold**

- Dynamics are the same as a ENSO Neutral but more extreme: strong high enhances trade wind flow along the equatorial Pacific Ocean, more warm water pushed westward, more cold water upwelling on S.America coast, atmospheric stability further strengths of the S.American coastal high.
- Increased warm water accumulation in the western equatorial Pacific (Australia, Indonesia), stronger buoyancy, more instability, stronger Low.



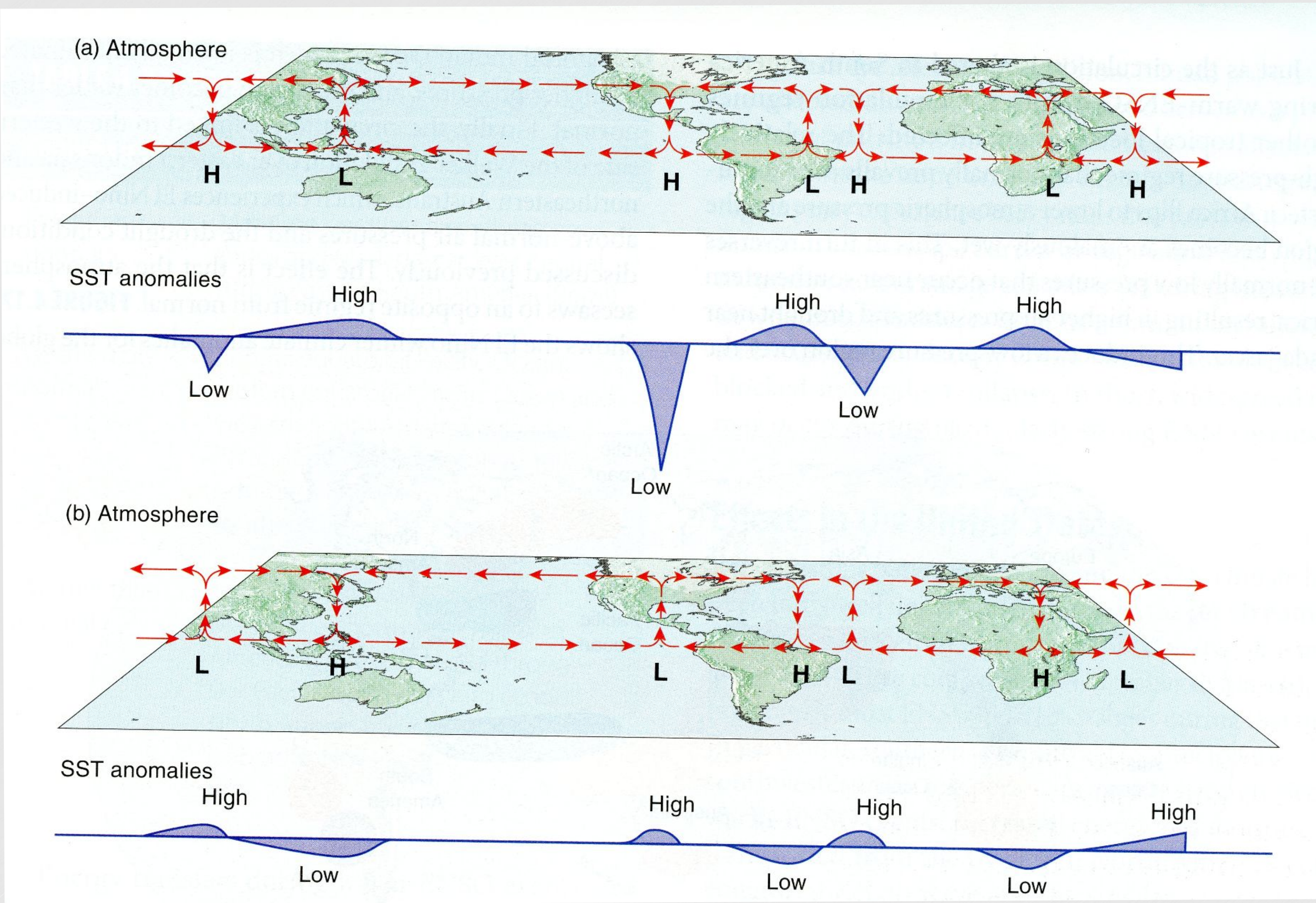
El Niño–Southern Oscillation Events: El Niño (Warm ENSO) Global Effects

- High rainfall and floods in western equatorial South America
- Drought over the western equatorial Pacific tropics
- Higher air pressure and subsiding airflow over tropical eastern South America, causing drought in rainforests
- Pressure flip from normally high to low over eastern equatorial Africa, causing region to become very wet
- Other effects elsewhere

El Niño–Southern Oscillation Events: Global Effects

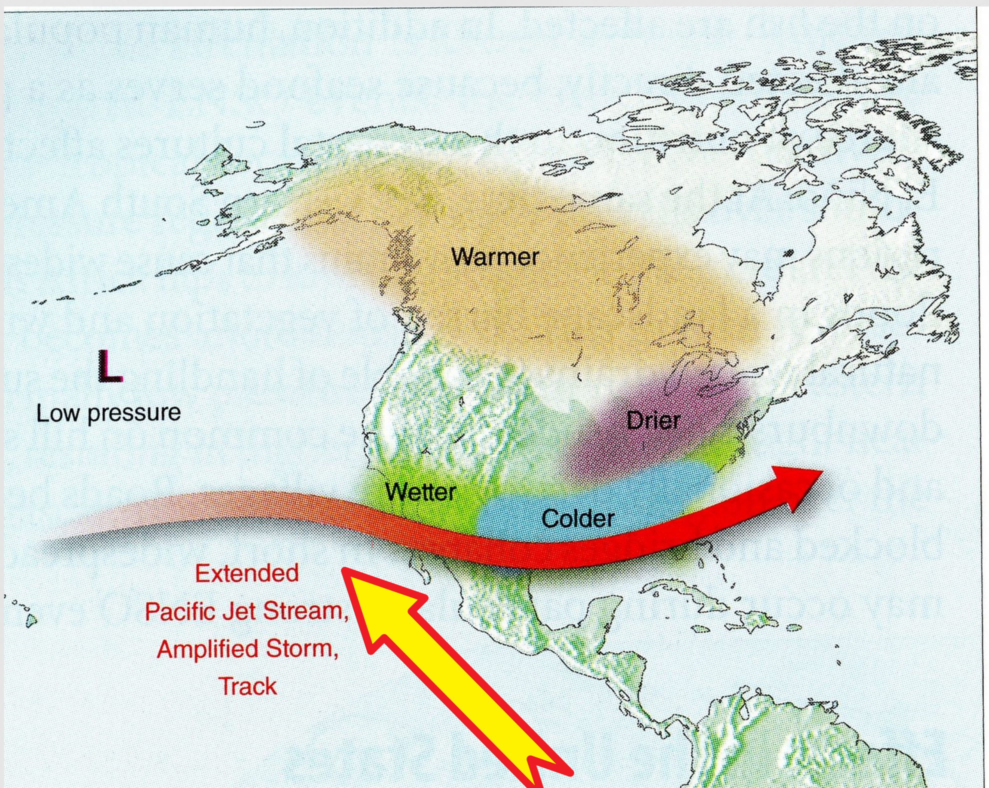
ENSO Neutral or ENSO Cold, La Nina

ENSO Warm or El Nino

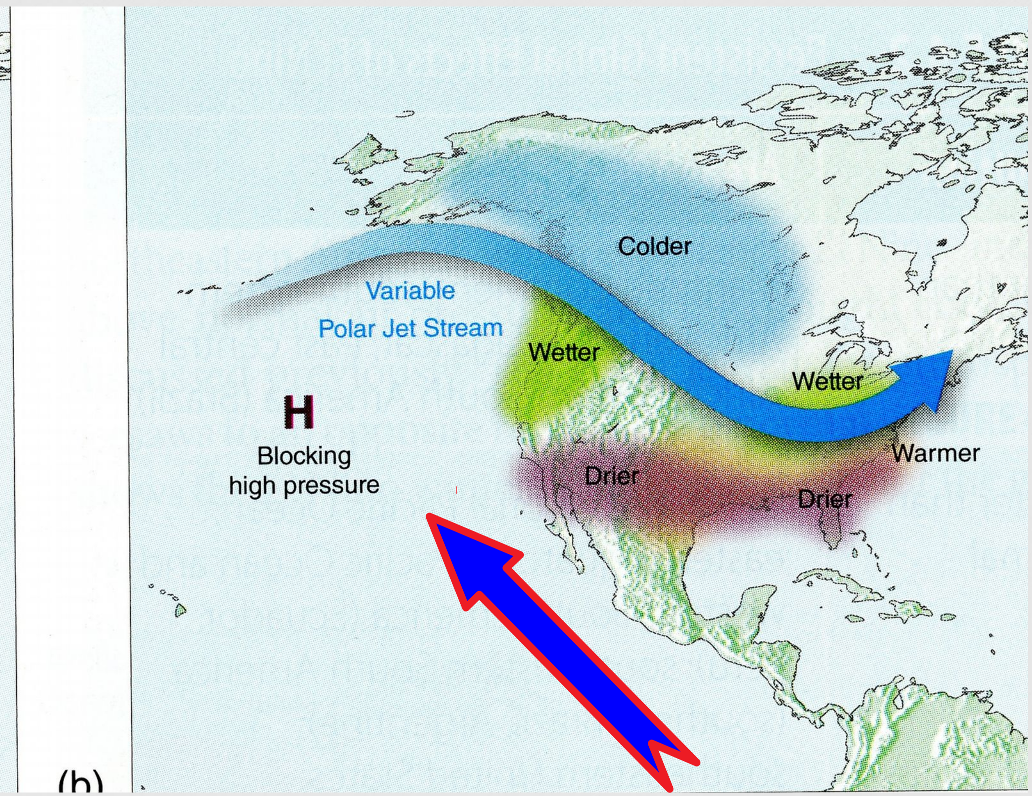


El Niño/La Niña –Southern Oscillation North America - Canada

https://www.severe-weather.eu/long-range-2/winter-forecast-season-2020-2021-lanina-early-look-fa/



El Niño with Kelvin warm water wave (yellow) moving northward: weakens the pacific high enhances low pressure (Aleutian Low)



La Niña with cold water (blue) moving northward: enhances high pressure (Pacific High)

El Niño–Southern Oscillation Events: A Relationship to Global Warming?

- It is widely assumed that global warming is caused by human emission of pollutants known as greenhouse gases.
- Some believe that global warming causes more extreme ENSO events.
  - Increased frequency of ENSO events could cause increased global temperatures through stored energy release.
  - May be periodic and associated with the Pacific Decadal Oscillation (PDO) which is similar to ENSO but phases are 20-30 years long, recent warm phase was 70s to 90s.

El Niño–Southern Oscillation Events

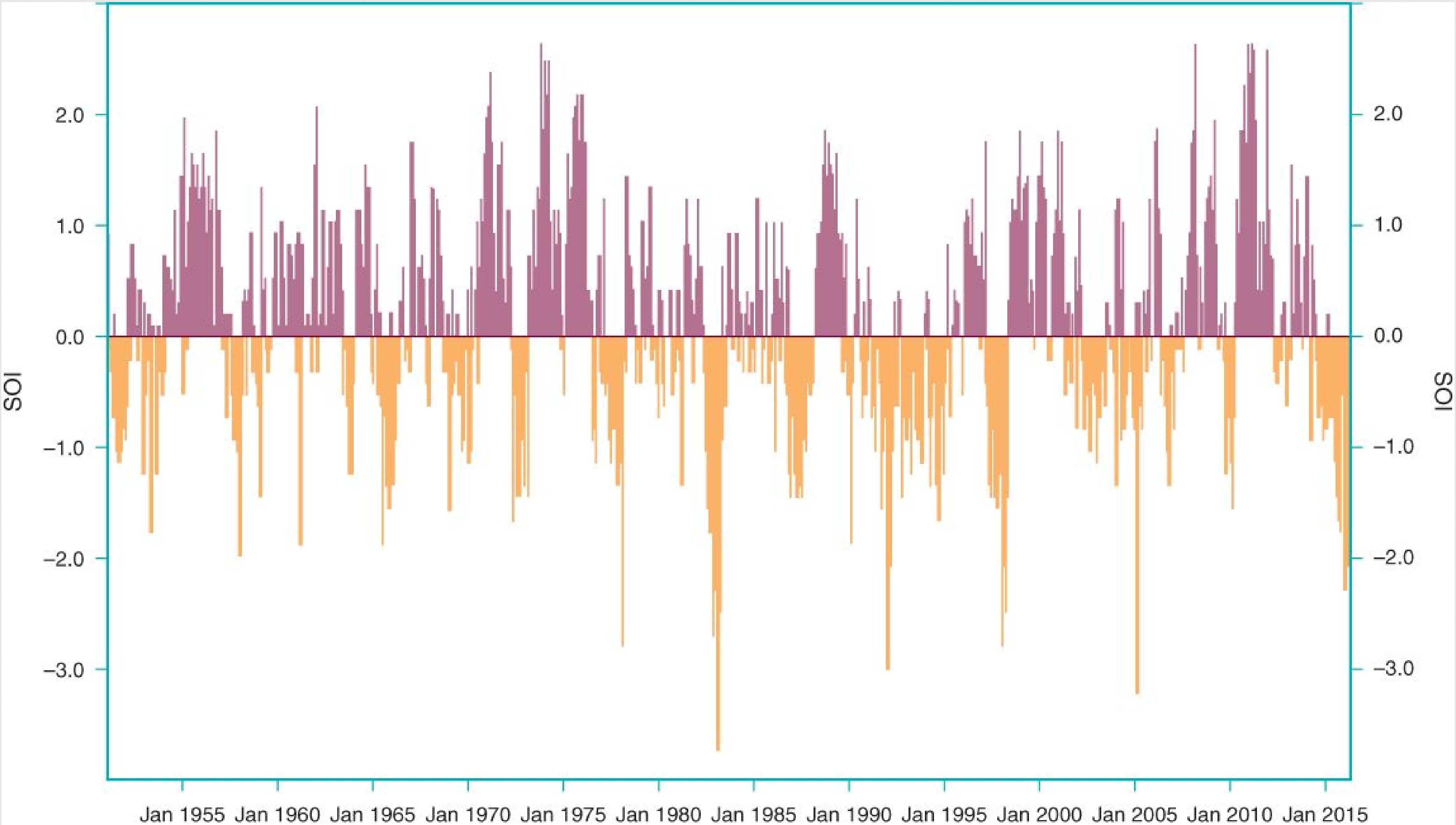


Figure 11.14 Southern Oscillation Index, 1950–2015.

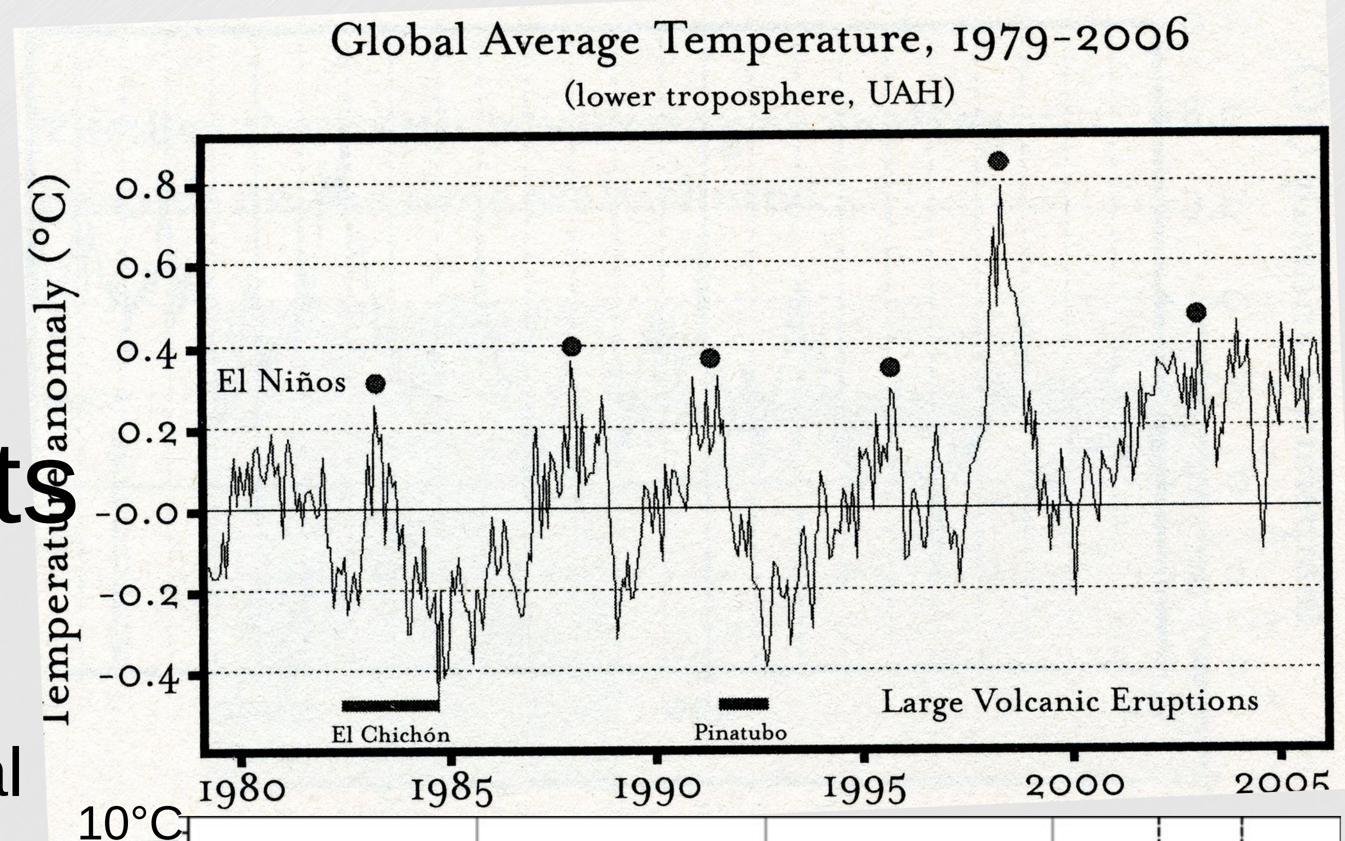
Data from NOAA/Earth System Research Laboratory/Climate Diagnostics Center/Climate Indices Plotting Page.

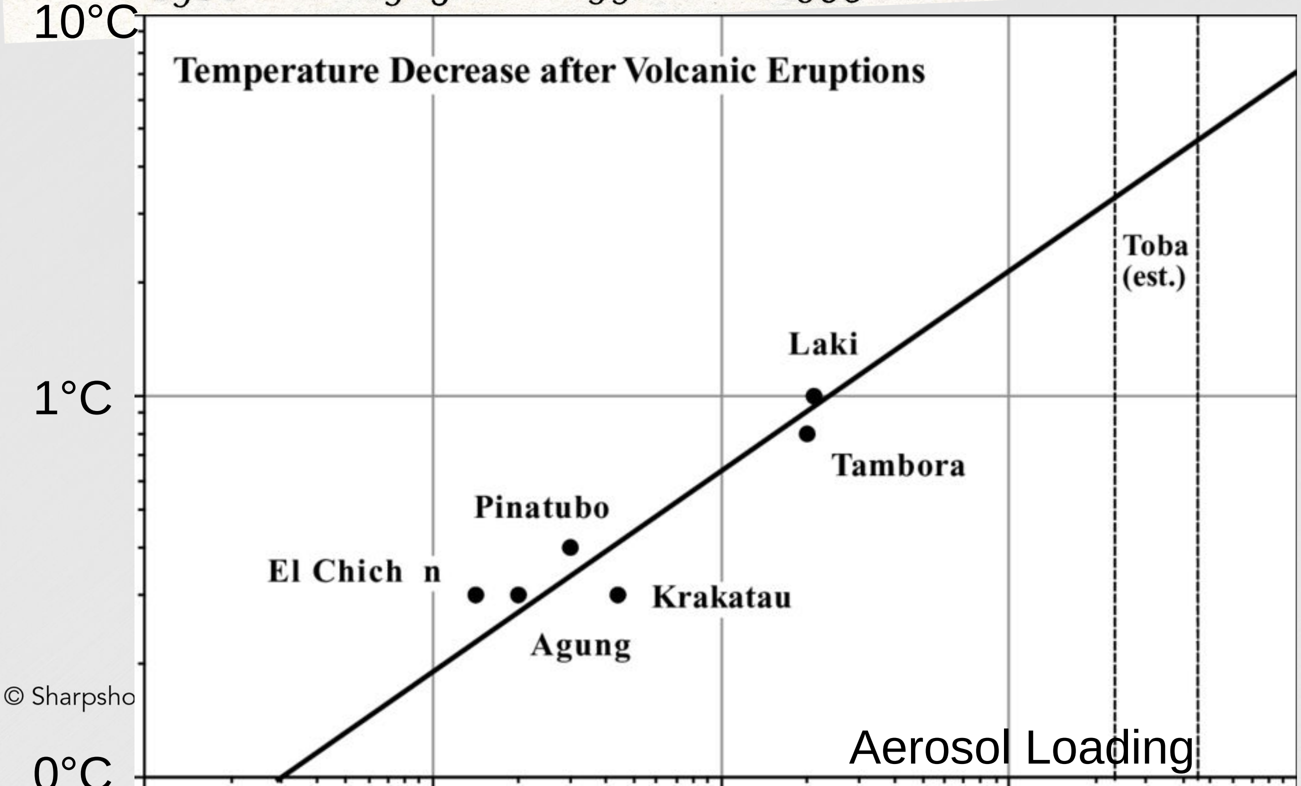
Optional: Onset of ENSO Warm: teleconnected events

- An ENSO warm event starts with weak trade wind flow along the equatorial Pacific Ocean, why?
- Trade winds are due to the North and South subtropical highs' descending return flow of the Hadley cell.
- Therefore, Hadley cell vertical/horizontal circulation weakens, why?
- Less buoyancy, cooler waters/land in the ITCZ. Why cooler water/land?
- Less cloud cover over water the water/land surface, why?

Volcanic Activity and Climate: General Effects

- Individual volcanic effects can alter global temperatures over short time periods.
- Long-term climatic changes will occur only during prolonged periods of above-normal volcanic activity.





Volcanic Activity and Climate: General Effects

- Mount Pinatubo in the Philippines: June 1991 eruption.
  - Surface global temperature decline of 0.5°C (0.9°F) for 2 years after the eruption
- The most catastrophic eruption known occurred on Mount Toba in Sumatra approximately 70,000 years ago.
  - Thought to have accelerated onset of last glacial advance
  - Caused evolutionary bottleneck in humans

TABLE 4.3 Major Volcanic Eruptions of the Past 200 Years

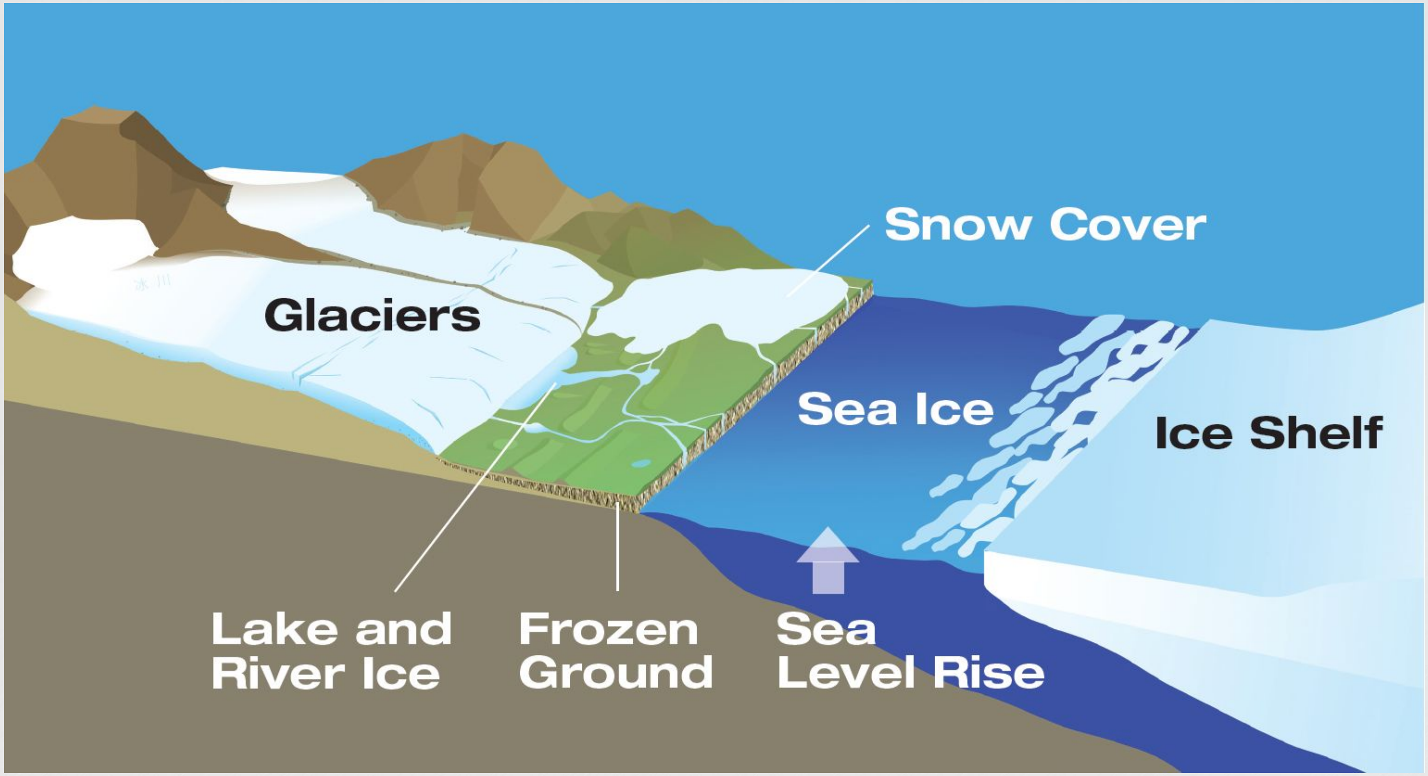
Volcano, Location	Year	Average Resulting Global Temperature Decline (C°)
Tambora, Indonesia	1815	0.4–0.7
Krakatau, Indonesia	1883	0.3
Santa Maria, Guatemala	1902	0.4
Katmai, Alaska	1912	0.2
Agung, Indonesia	1963	0.3
El Chichón, Mexico	1982	0.5
Mount Pinatubo, Philippines	1991	0.5
Eyjafjallajökull, Iceland	2010	believed to be negligible

Cryospheric Changes: Ice on the Earth's Surface

The cryosphere exists as:

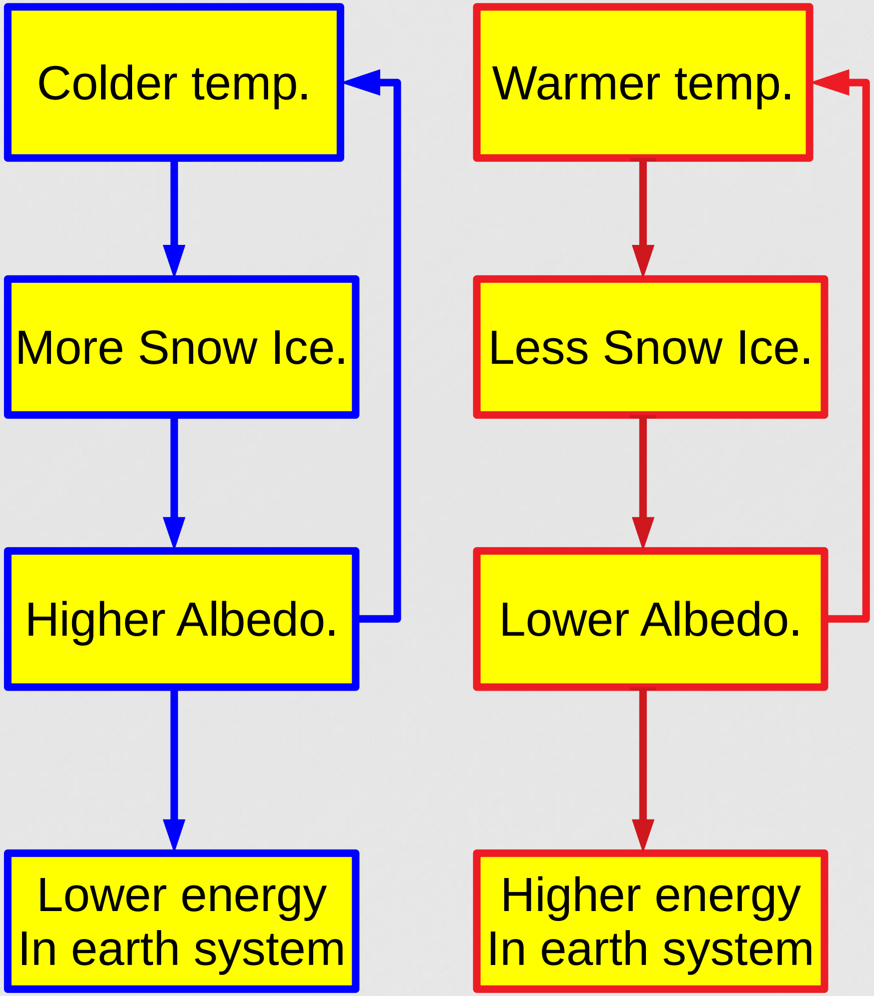
- Continental ice sheets – Antarctica and Greenland
- Semi-permanent alpine glaciers – Mountainous regions of the earth
- Seasonal sea ice – Arctic Ocean and winter lake/sea ice
- Seasonal snowpack – Winter snowfall

- The cryosphere is both a direct consequence of and an influence on the climate system through positive feedbacks



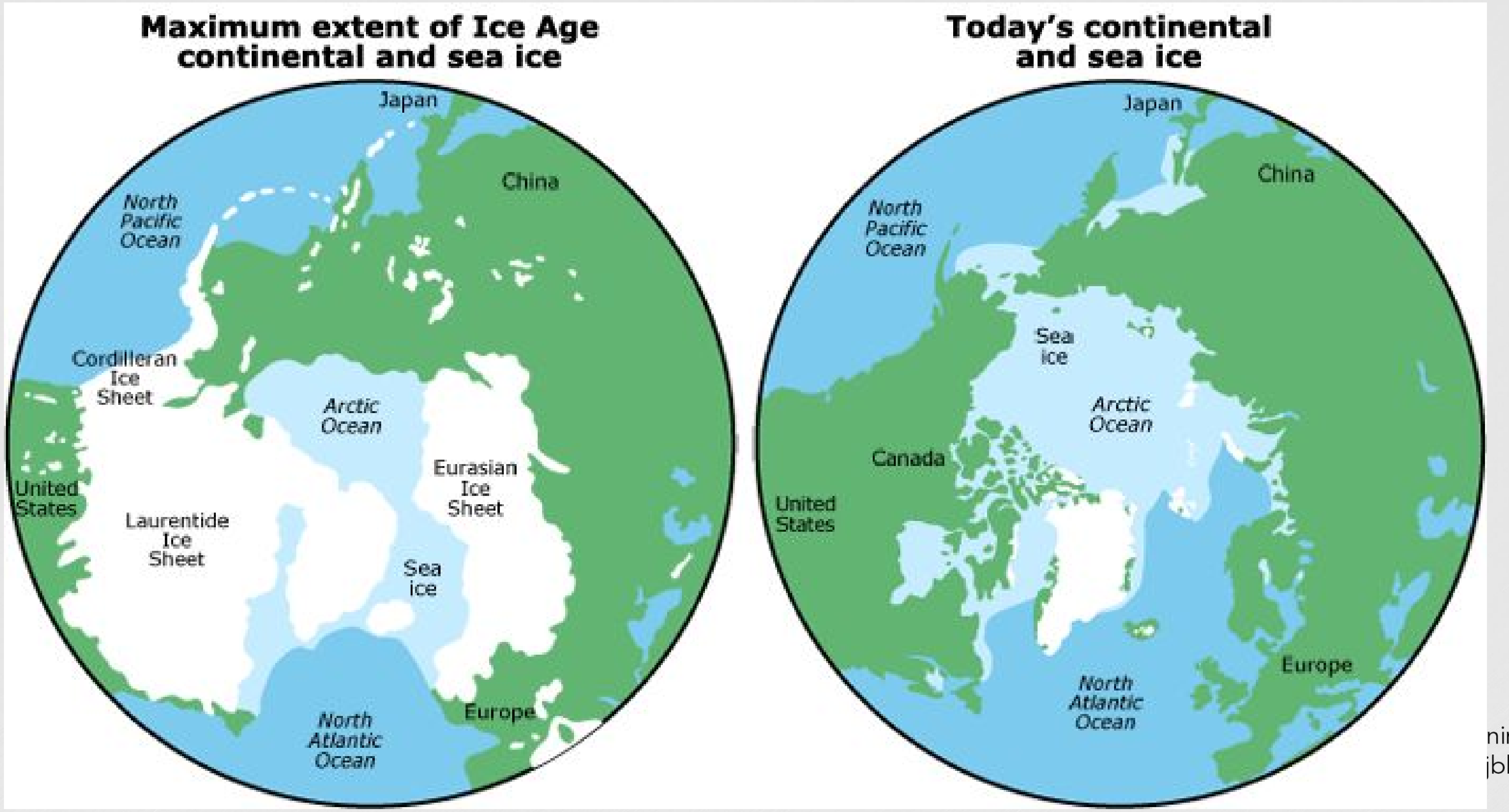
Cryospheric Changes: Feedbacks in the Cryosphere

- Addition of snow and ice increases albedo, causing:
  - Reduction in temperature
  - More extensive snow and ice
  - Positive feedback system
- Melting of snow and ice decreases albedo, causing:
  - Rise in temperature
  - Melting more snow and ice
  - Positive feedback system
  - This could be described as the current situation in Canada as alpine glaciers and ice caps are in retreat.
  - Also, less of the arctic sea ice remains frozen in summer



Cryospheric Changes: Ice on the Earth's Surface

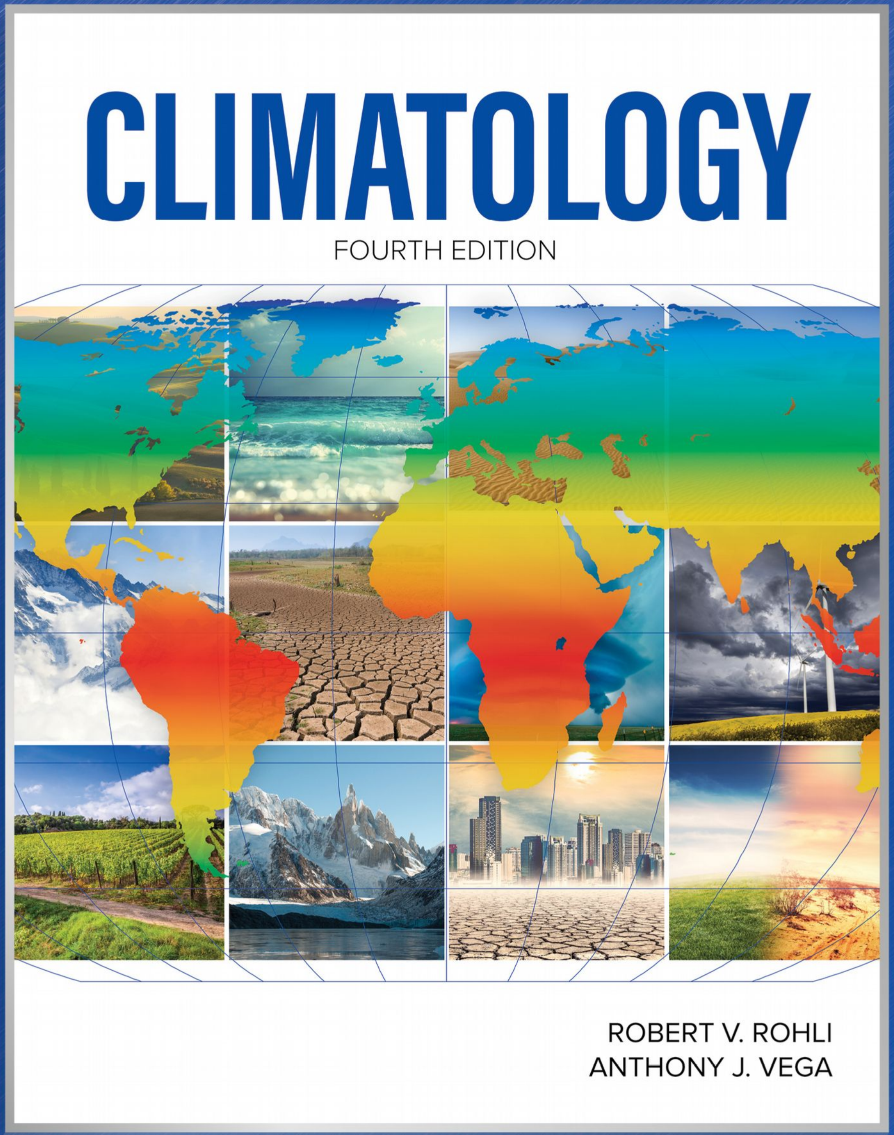
- Glacial advances are separated by interglacial phases, warmer periods of 8,000–12,000 years.
- We are in the Holocene Interglacial Phase (because glacial ice is receding)
- But, we are still in an ice age today because permanent ice exists on the planet.
- Last glacial advance in the present ice age was the Wisconsin Glacial Phase about 75K yrs ago.



Cryospheric Changes: Feedbacks in the Cryosphere

- Some researchers now estimate that the Greenland ice sheet could lose as much as one-half of its mass over the next thousand years, leading to an increase in global sea level of about 2.7 m (9 ft).
- If all permanent continental ice were to melt, sea levels would rise about 67 m (220 ft).

Section 4. Causes of Climatic Change Past, Present and Future



Natural Causes of Climatic Change: astronomical effects:Milankovitch cycles

- Serbian Milutin Milankovitch, mathematician and astronomer, calculated several cyclical changes in the Earth’s orbit around the Sun.
- Cycles operate on the order of tens of thousands of years and may be responsible for cycles in climate. Cycles may offset each other or coincide to produce change
  - Orbital Eccentricity (ellipse <--> circular)
  - Axial Tilt
  - Equinox Precession (wobble)

Natural Causes of Climatic Change: Milankovitch Cycles - Eccentricity

- Eccentricity
  - The Earth's orbit gradually changes from more circular to more elliptical with a **periodicity of approximately 95,000 years.**
  - Low eccentricity coincides with glacial periods (colder).
  - High eccentricity linked to interglacial phases (warmer).

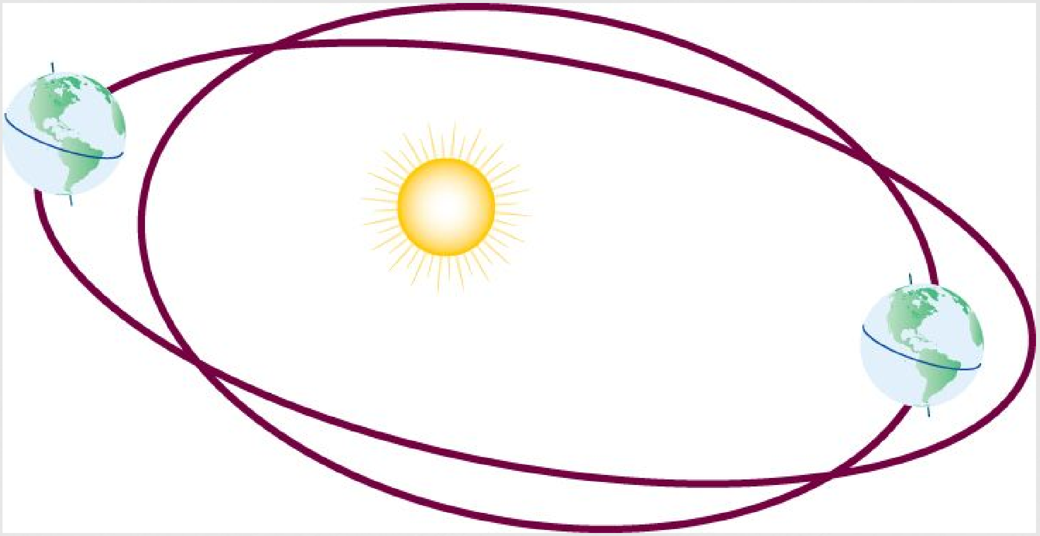


Figure 11.9 The eccentricity of Earth's orbit changes over time.

Natural Causes of Climatic Change: Milankovitch Cycles – Axial Tilt

- Tilt
  - Varies from 21.8° to 24.4° with a **periodicity of 44,000 yrs**
  - Affects summer to winter energy contrast (seasonality)
  - The smaller the tilt the less extreme the seasons.
  - Periods of high tilt allows greater seasonal extremes.

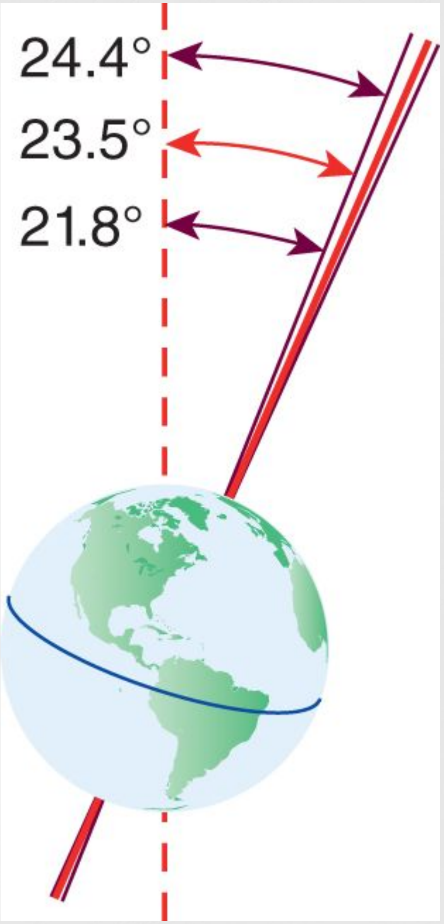


Figure 11.10 Variation in obliquity of the Earth's axis.

- **Would a high tilt (with greater seasonal extremes) produce warmer or colder temperatures?**

Think albedo!

Natural Causes of Climatic Change: Milankovitch Cycles - Precession

- Precession of the equinoxes
  - Earth's axis wobbles like a spinning top with a **periodicity of 23,000 yrs**
  - Invokes a progressive change in the dates of the solstices, equinoxes, perihelion, and aphelion

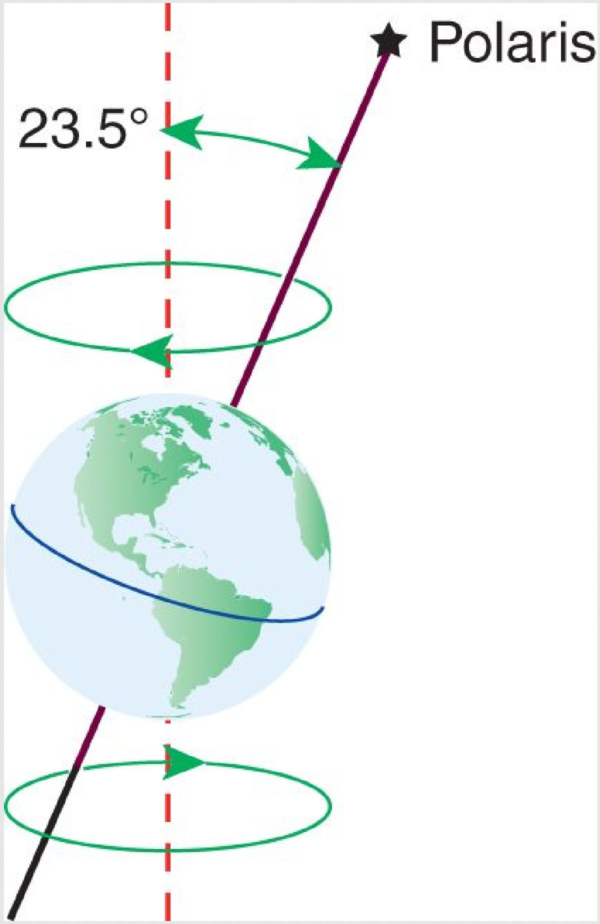
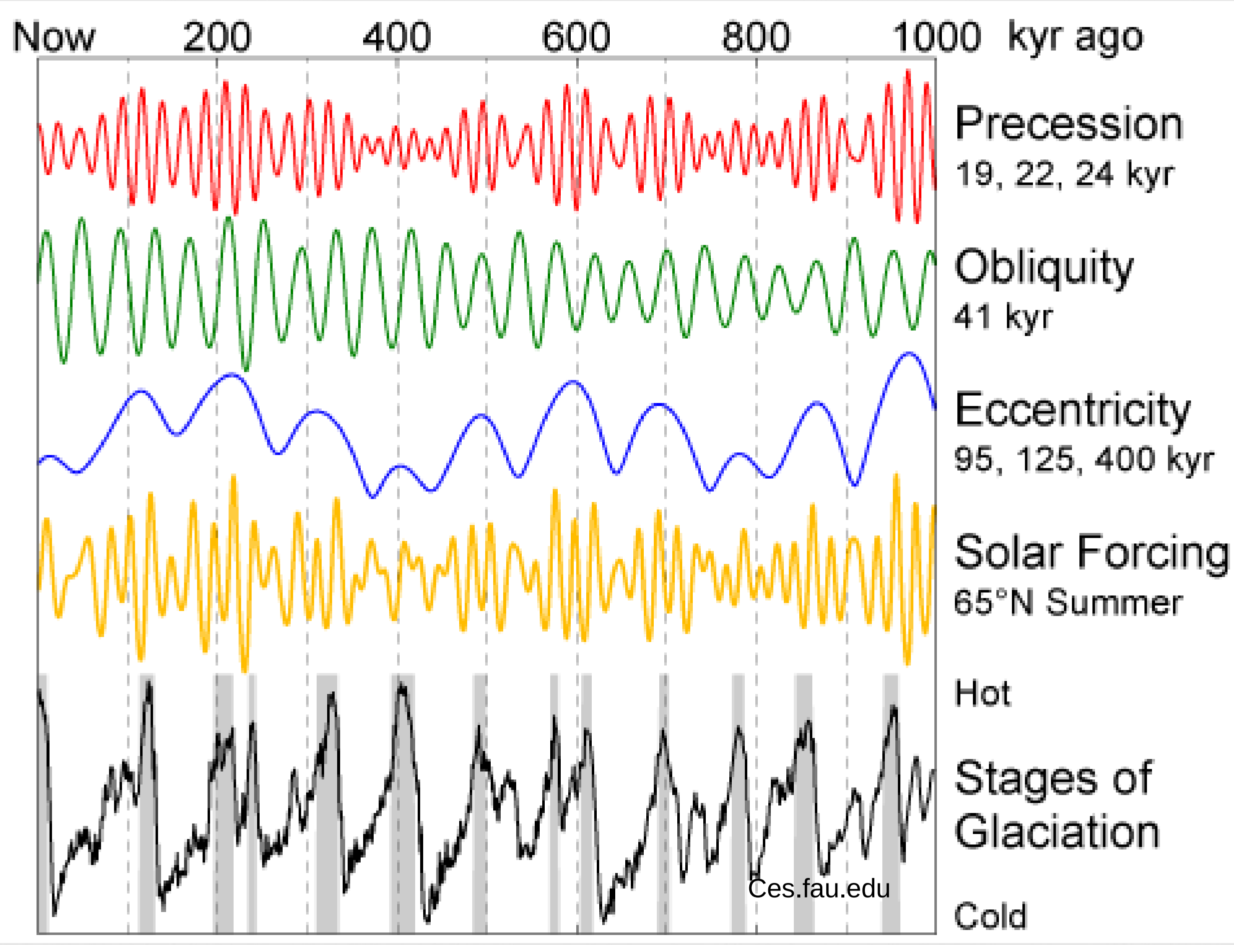


Figure 11.11 The precession, or wobble, of Earth on its axis.

- In about 11,500 years perihelion (closest to the sun) will be in July while aphelion (farthest from the sun) will be in January. **What would the temperature implications be for Alberta?**

Natural Causes of Climatic Change and Variability: Milankovitch Cycles

- Combined effects of the Milankovitch cycles
  - Climatic changes can result from overlapping changes in eccentricity, tilt, and/or precession.
  - A viable explanation for some types of long-term climatic changes and periodicities

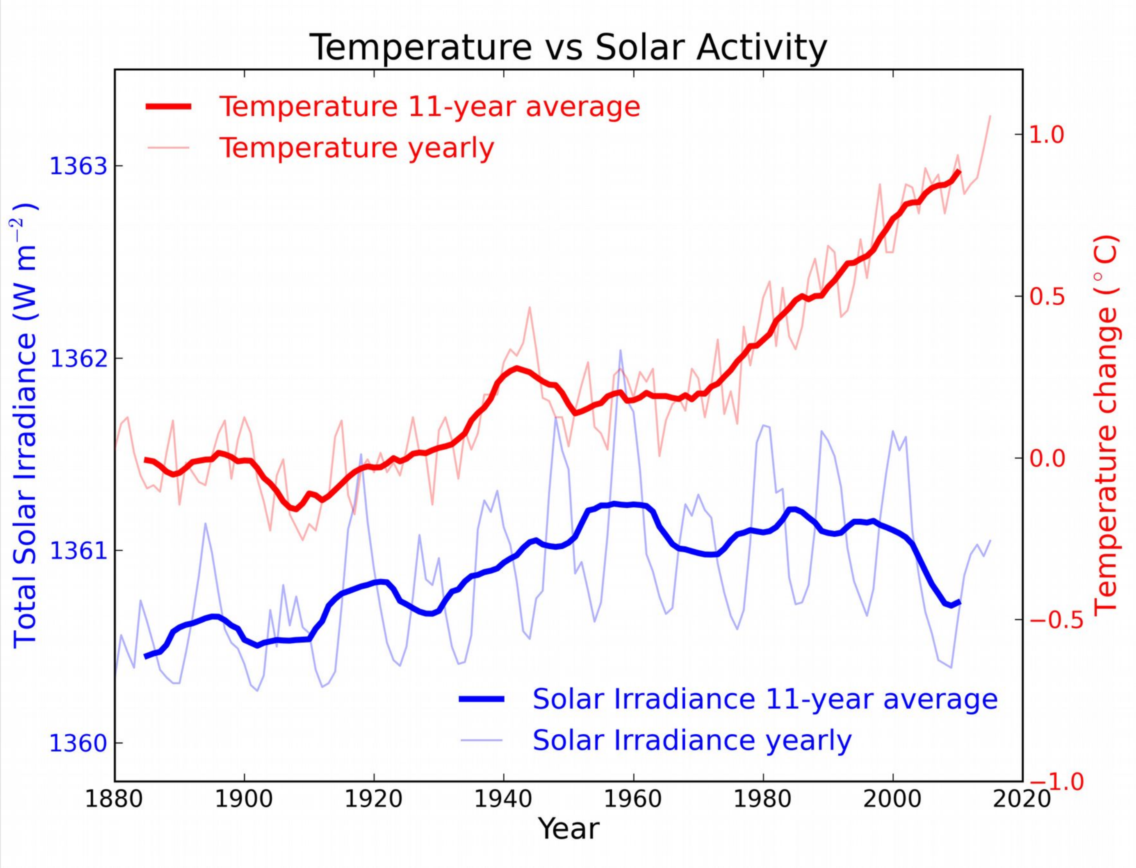


Natural Causes of Climatic Change Variability: Variations in Solar Output

- Assumption: increased solar output is associated with a warmer climate.
- An *inverse* relationship between solar output and temperature may exist.
  - Increased amounts of insolation lead to greater latitudinal temperature differences.
  - Stronger circulation results with more contrast between tropical and polar air masses.
  - Increased air mass contrast, along with the additional evaporation from a warmer tropical ocean, could create more precipitation.
  - This causes more snow and ice in the high latitudes.
  - This increases surface albedo, reflecting a greater percentage of solar energy.
  - This causes colder polar conditions even with greater input of solar energy.

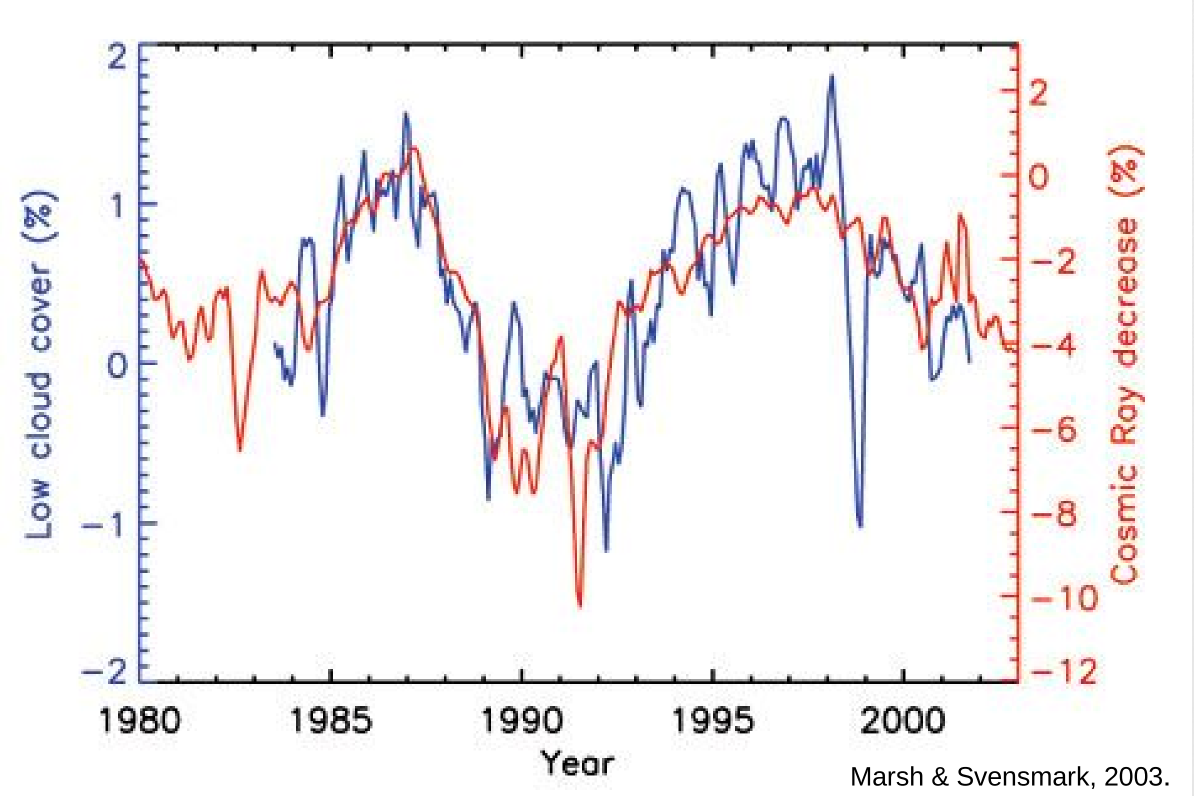
Natural Causes of Climatic Change and Variability: Sunspots

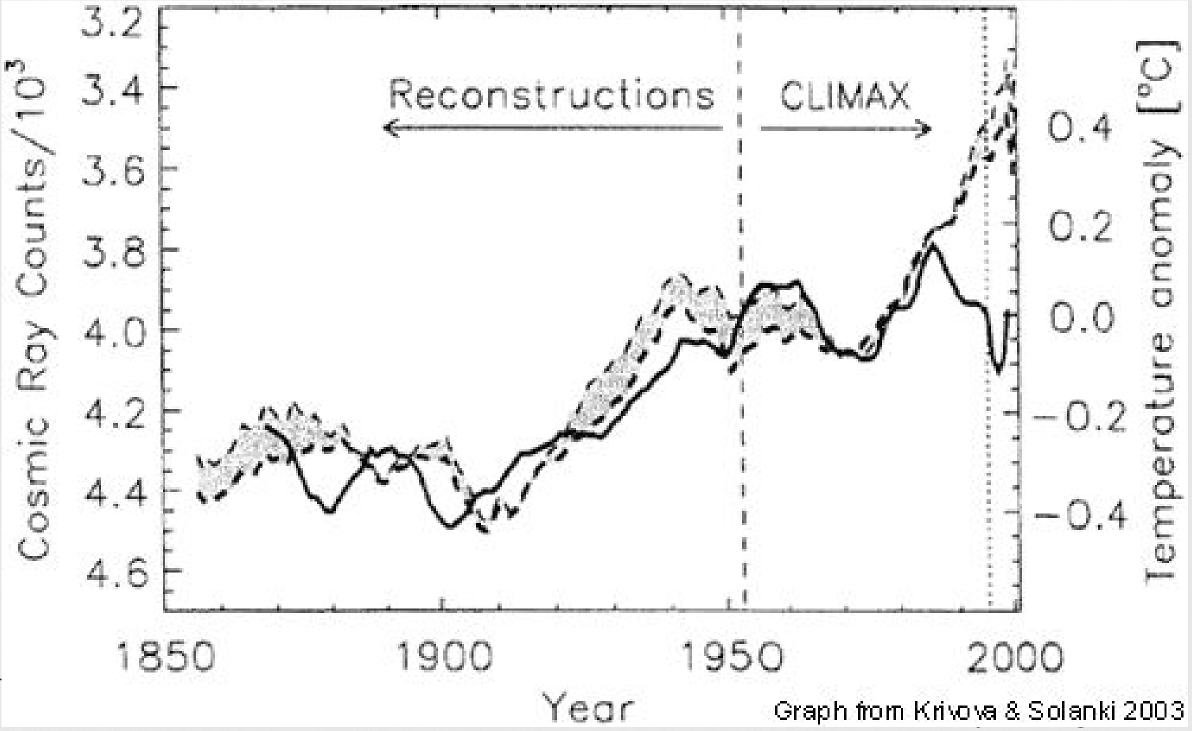
- Magnetic storms appearing as darker regions on the Sun's surface, varying in number and intensity over time.
- Great Plains drought seems to approximate the 22-year sun spot cycle (11 and 80 yr cycles)
- Correlations between sunspot cycles and climate are tenuous.
- Again, climate is rarely defined by any one factor



Natural Causes of Climatic Change: Cosmic Rays

- Controversial theory (Svensmark) that states:
  - More cosmic particle radiation (from supernovae)
  - = more atmospheric ions
  - = more stable condensation nuclei
  - = more low clouds
  - = less solar radiation
  - = colder temperatures.
- **What can be said of the two figures?**





Natural Causes of Climatic Change: Lunar/Solar Gravitational Forcing

Another controversial theory, distinguishing science from folklore is a challenge:

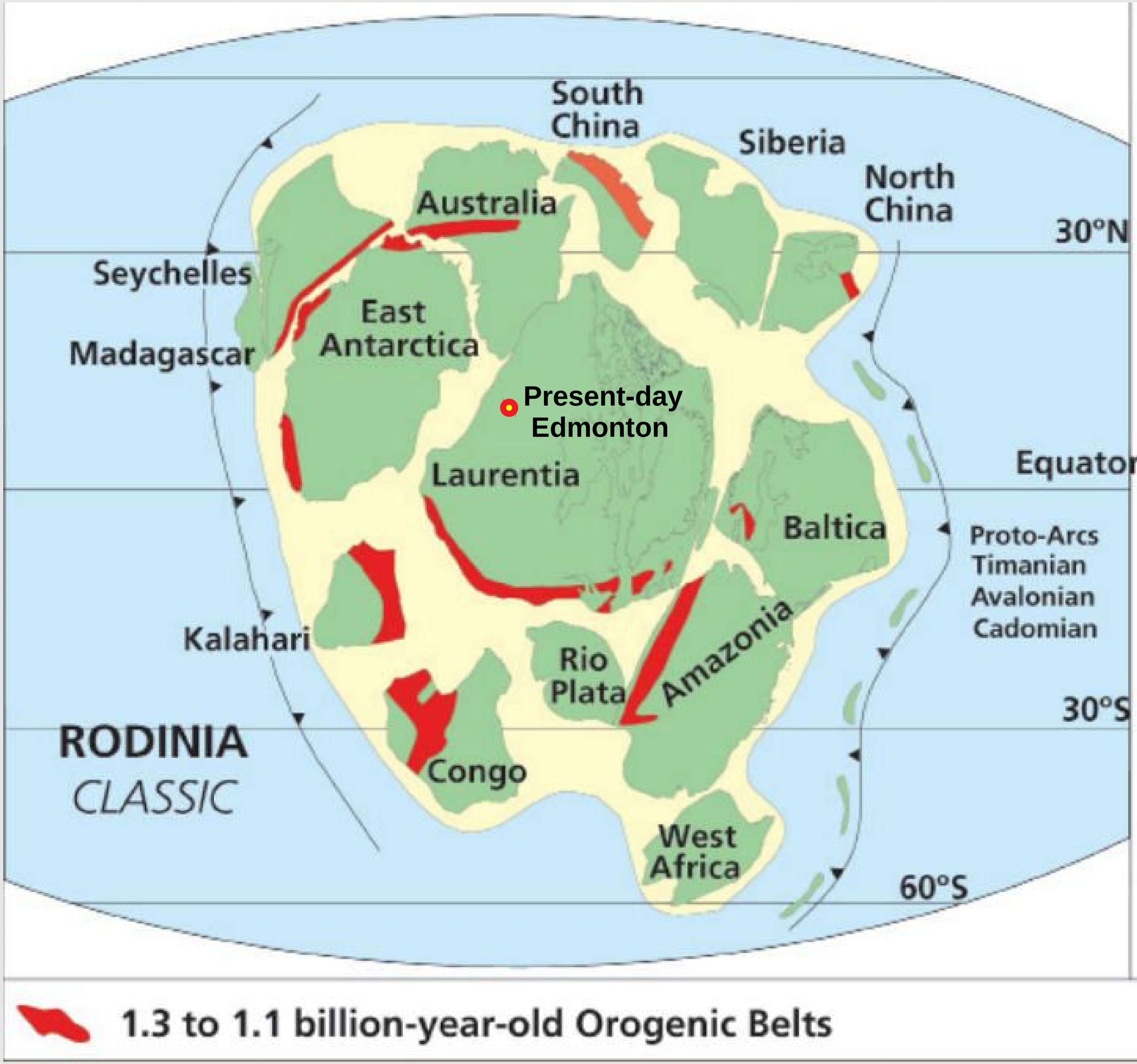
- Based on tidal effects of the sun and moon affect the atmosphere
- May affect the ENSO, Quasi Bienniel Oscillation (QBO, 26 month alternating East-West tropical stratospheric wind direction)
  - May affect the cyclical sinuosity of the jet stream flow and the pattern of storminess in the mid latitudes.
- Challenge is equating *correlational* evidence with *causal* processes

https://www.researchgate.net/publication/226454722_Lunar_Influences_On_Climate

http://contextearth.com/2015/11/07/more-refined-fit-of-qbo/

Natural Causes of Climatic Change: **Continental Drift:** The Archean-Proterozoic Eons

- Proto-continental cores and early mountain ranges
- **Can you speculate some of the climate dynamics of this earth period? Edmonton?**

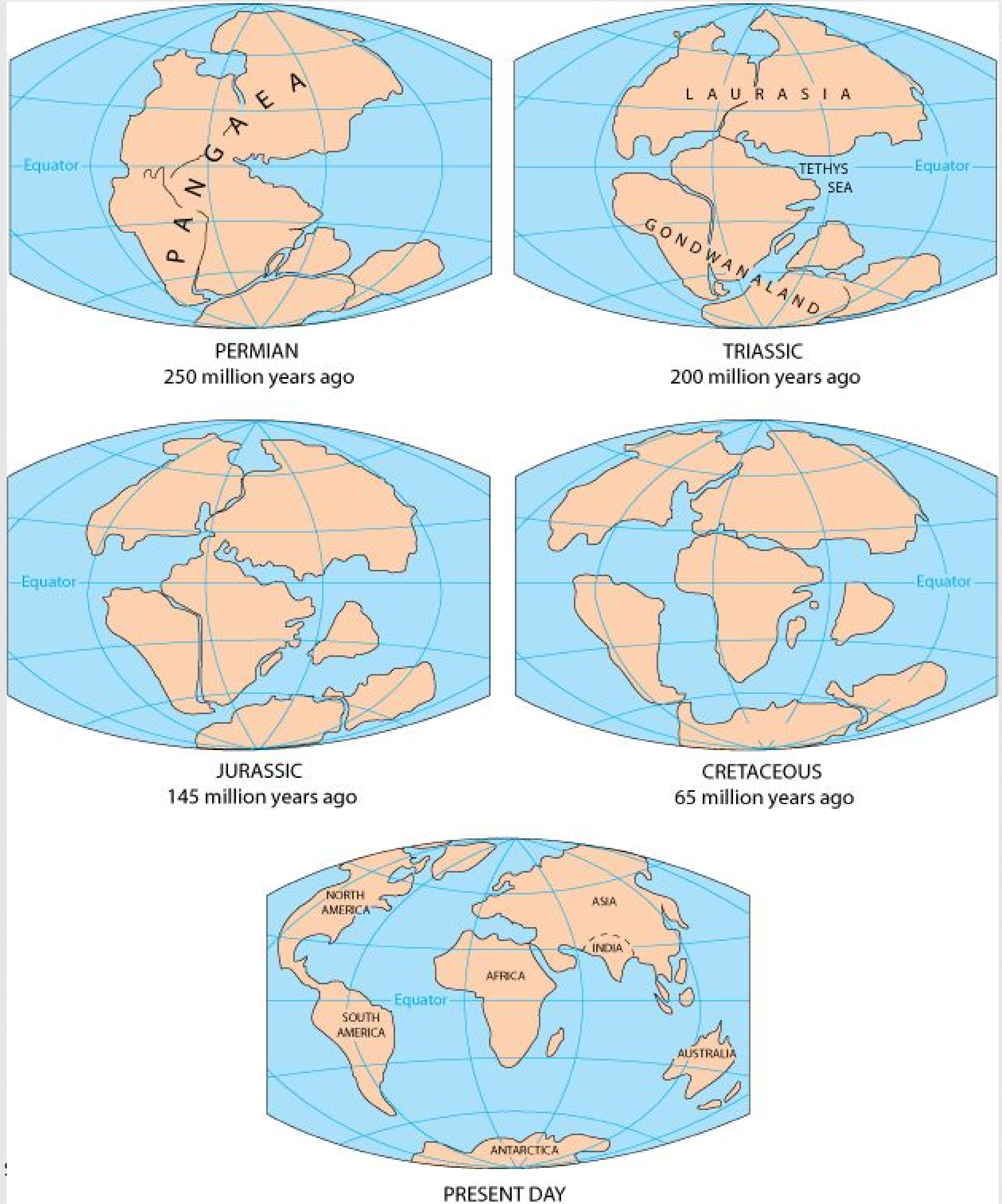


Natural Causes of Climatic Change

Continental Drift:

Phanerozoic Eon Mesozoic-Cenozoic Eras

- Positions of continents can affect ocean circulation, and therefore temperature.
- The positions of mountains can be important producers of climatic change.
- Mountain uplift affects the synoptic-scale atmospheric circulation.

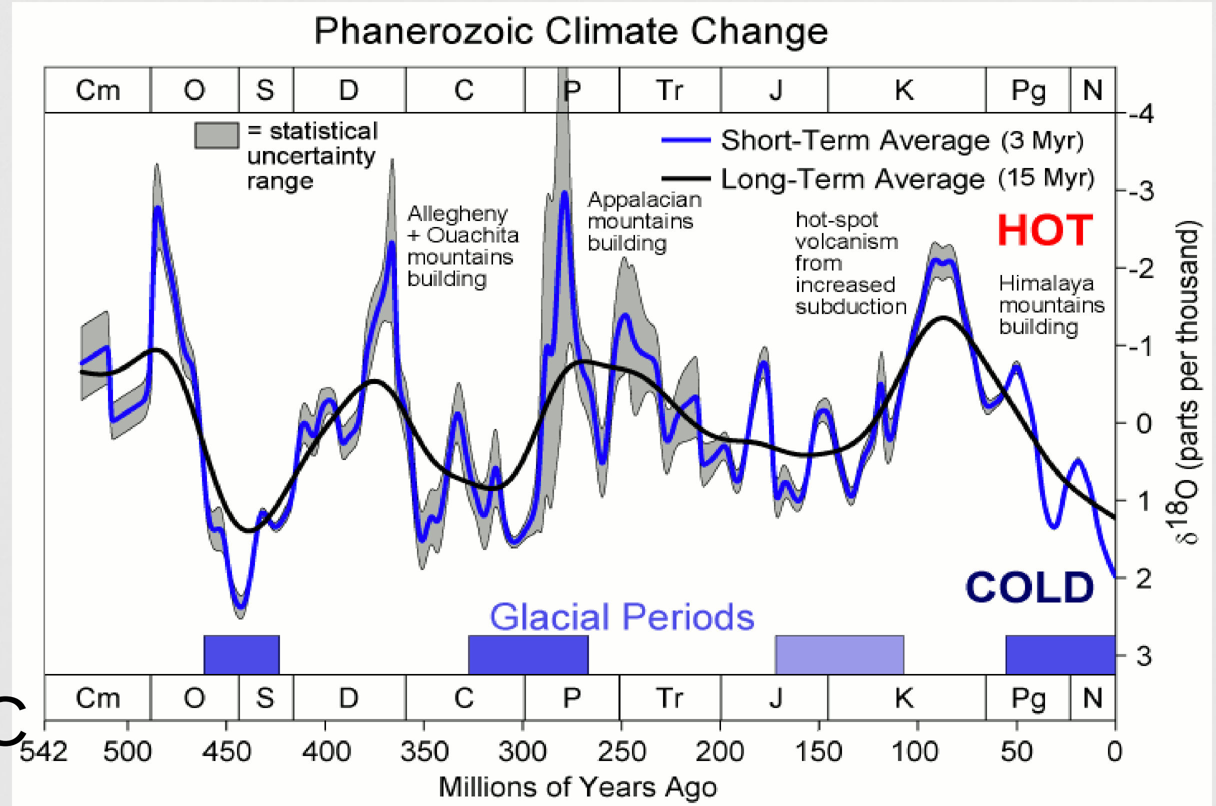


©

https://www.livescience.com/38218-facts-about-pangaea.html

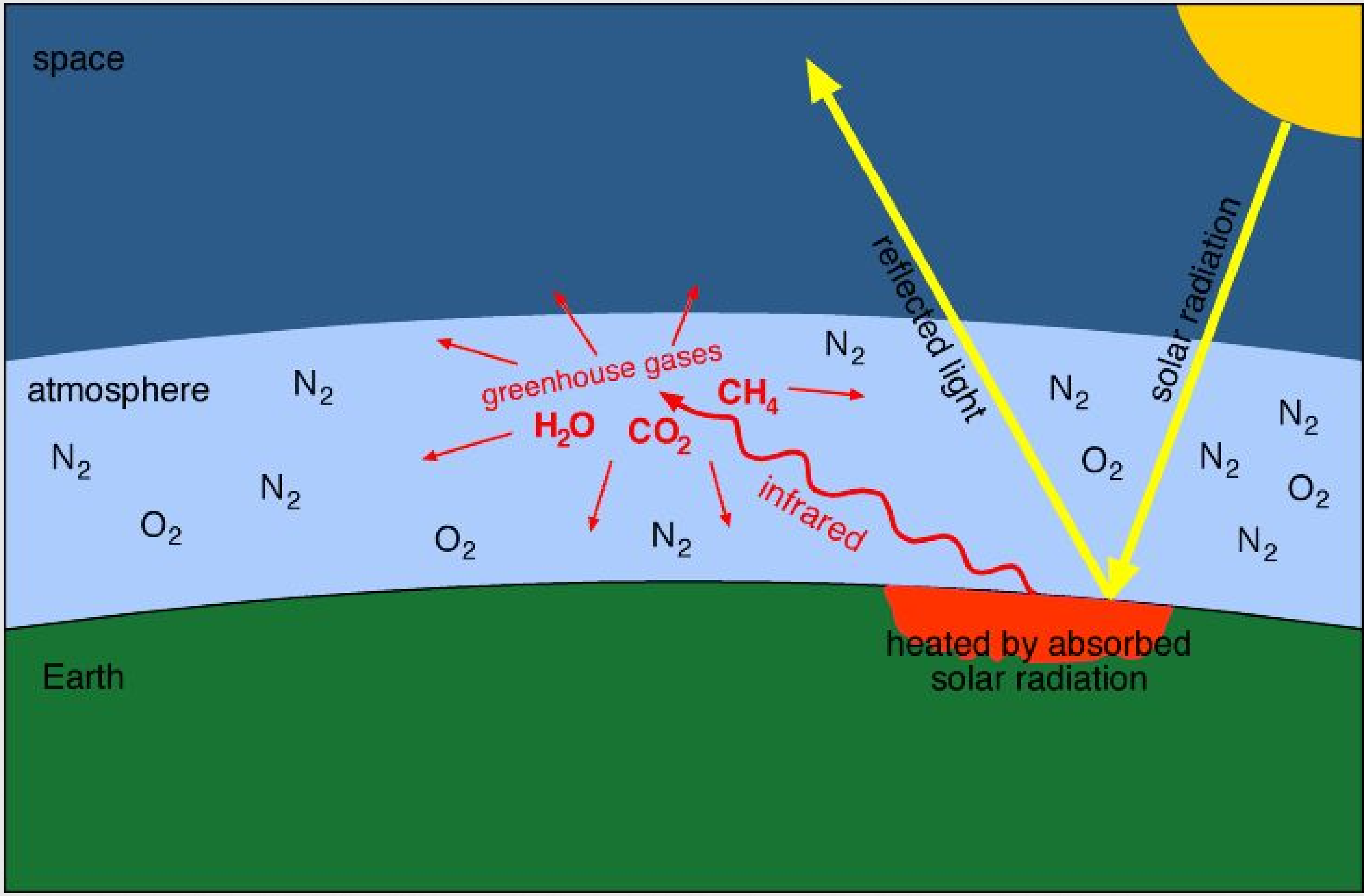
Climatic Change: Mountain Building

- Mountain building during the Phanerozoic induced higher temperatures
- As seen previously volcanoes can lower temperatures (via aerosols) but most eruptions decrease temperature about 0.5-1°C over 2 years or so. However, the CO_2 emitted remains significantly longer. Mt Toba was an exception.



Global Warming: The Greenhouse Effect

- A natural process that can be intensified by human activity
  - Certain atmospheric gases absorb longwave (terrestrial) radiation
  - Hinder its transmission from the surface to space
  - Counter-radiation emitted downward increases surface warming
  - Without the Greenhouse effect the earth's mean temp would be -19°C, instead of 14°C

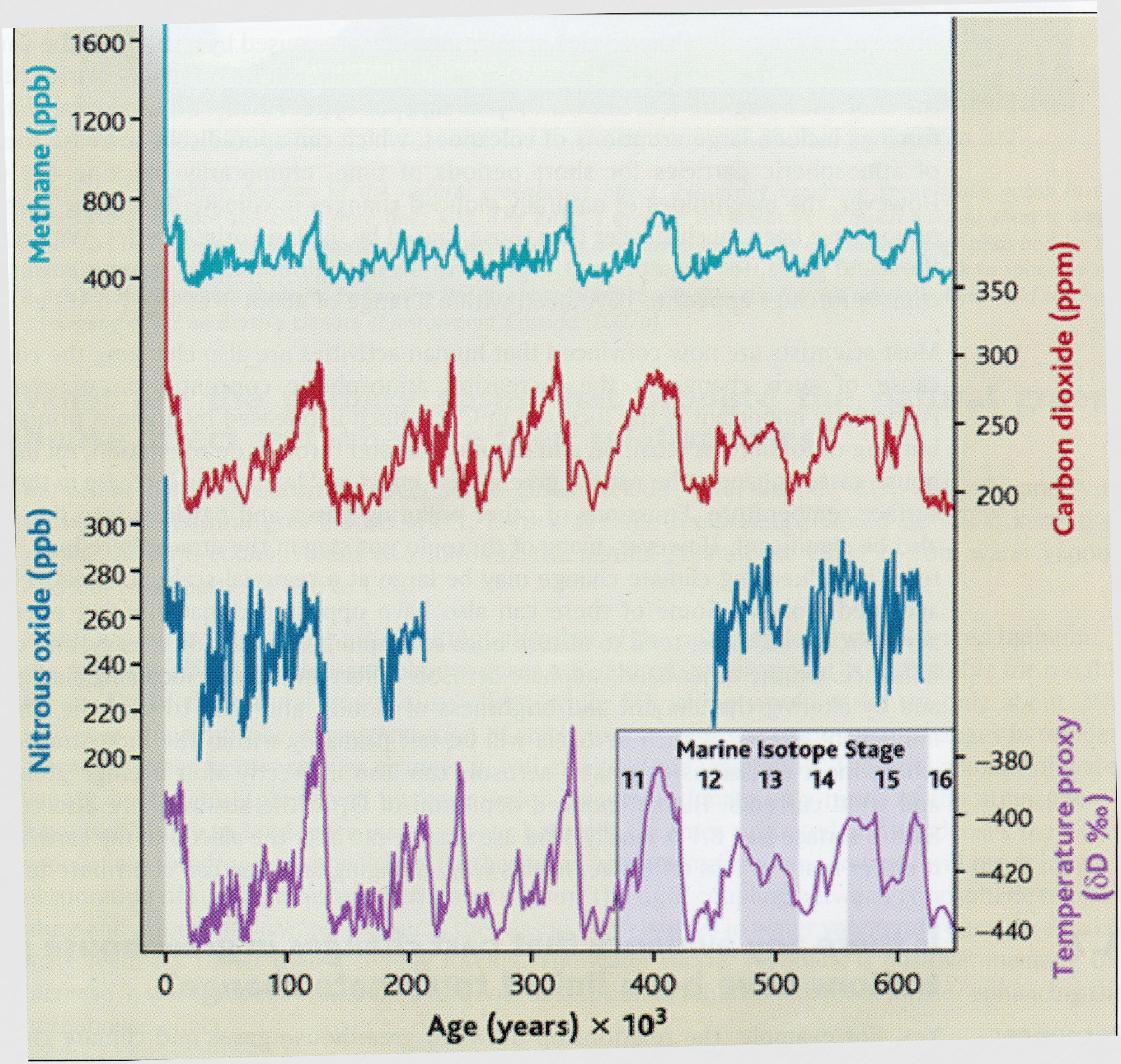


http://www.columbia.edu/~vjd1/greenhouse.htm

Global Warming: Greenhouse Gases

Fom the Middle Pleistocene to Present

- Major gases:
  - Water vapor
    - Most abundant and important GH gas
      - Atmosphere is efficient at getting rid of water vapor.
  - Carbon dioxide (CO_2)
    - Lingers around the atmosphere for 50 – 200 years
  - Methane (CH_4)
    - Atmospheric lifetime of 12 yrs.
  - Nitrous Oxide (N_2O)
    - Atmospheric lifetime is 114 yrs



Global Warming: Greenhouse Gases

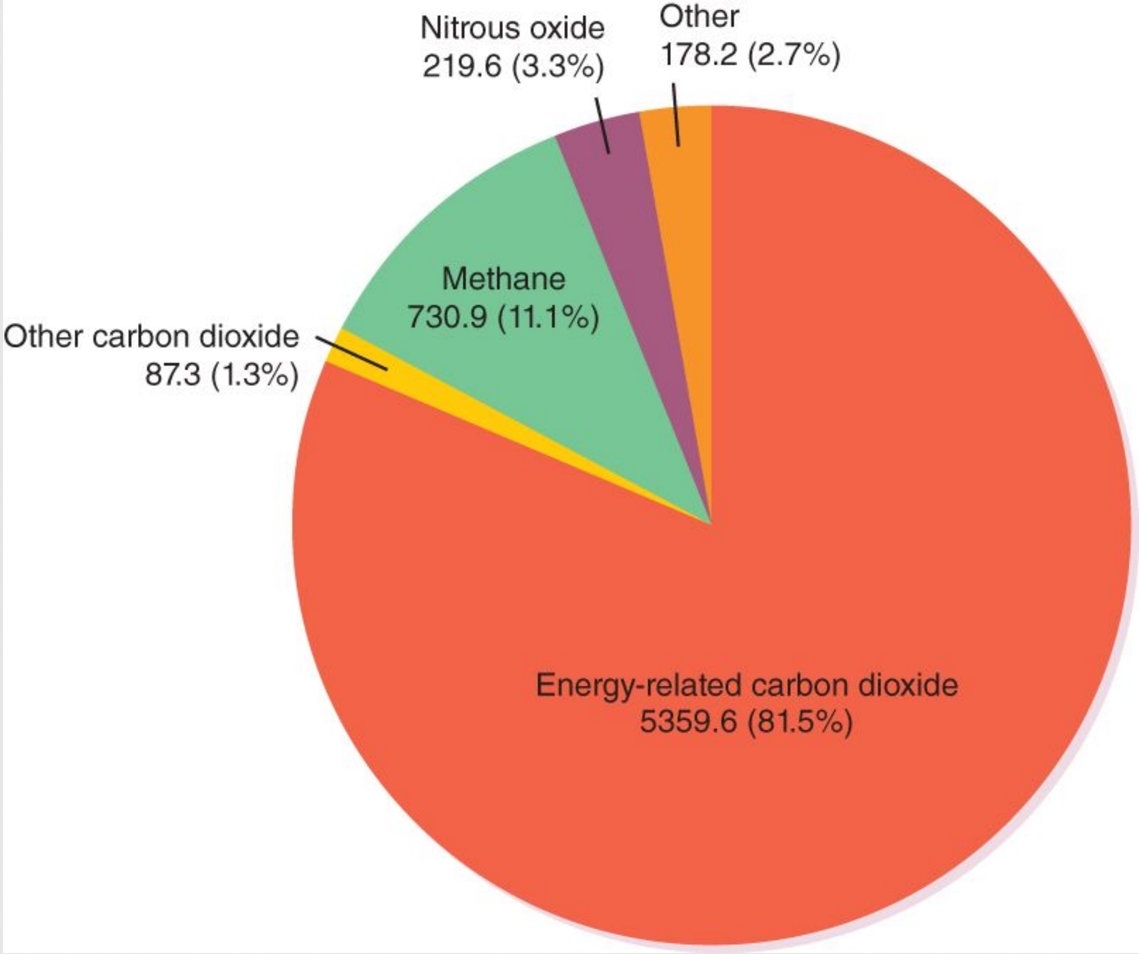
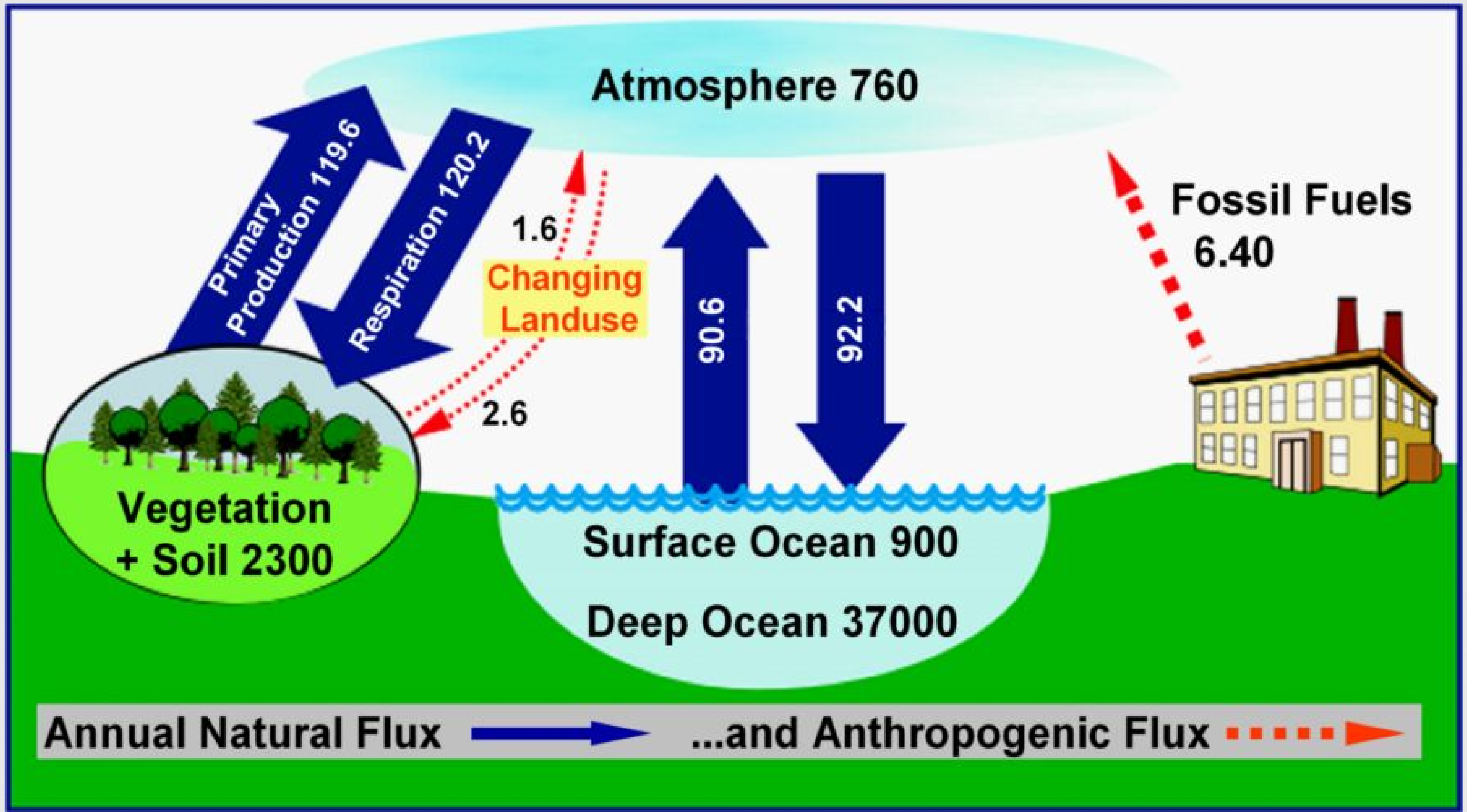


Figure 12.1. U.S. anthropogenic greenhouse gas emissions by gas, 2009 (million metric tons of carbon equivalent).

Global Warming: Greenhouse Gases

- Carbon dioxide (CO_2)
  - Current concentration = 413 ppm (https://www.co2.earth/daily-co2)
    - Projected to increase to 600 ppm by 2050
    - According to computer models, this concentration would produce a globally averaged temperature increase of 1.5 to 3.5^{o}C

Sources and sinks for Atmospheric CO_2



Global Warming: Greenhouse Gases

- Methane (CH_4)
  - Concentration in the atmosphere is only 1.85 parts per million
  - Recent research suggests that it is much more important than previously believed.
  - Acts as a far more effective absorber of terrestrial radiation (84x stronger) than CO_2.
- Other minor GHGs
  - Nitrous oxide (N_2O)
  - Various fluorocarbons
  - Carbon monoxide (CO)
  - Types of nitrogen oxides

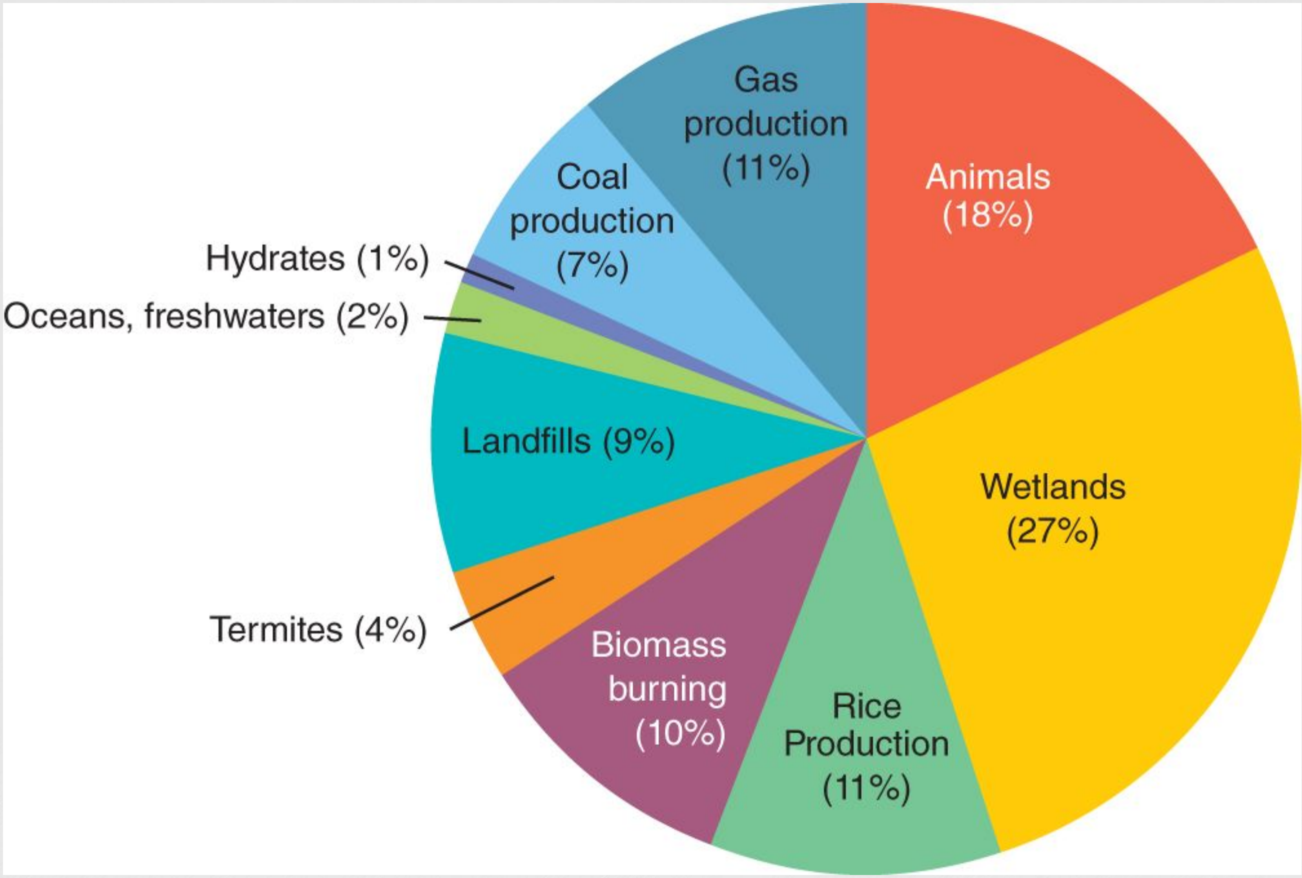
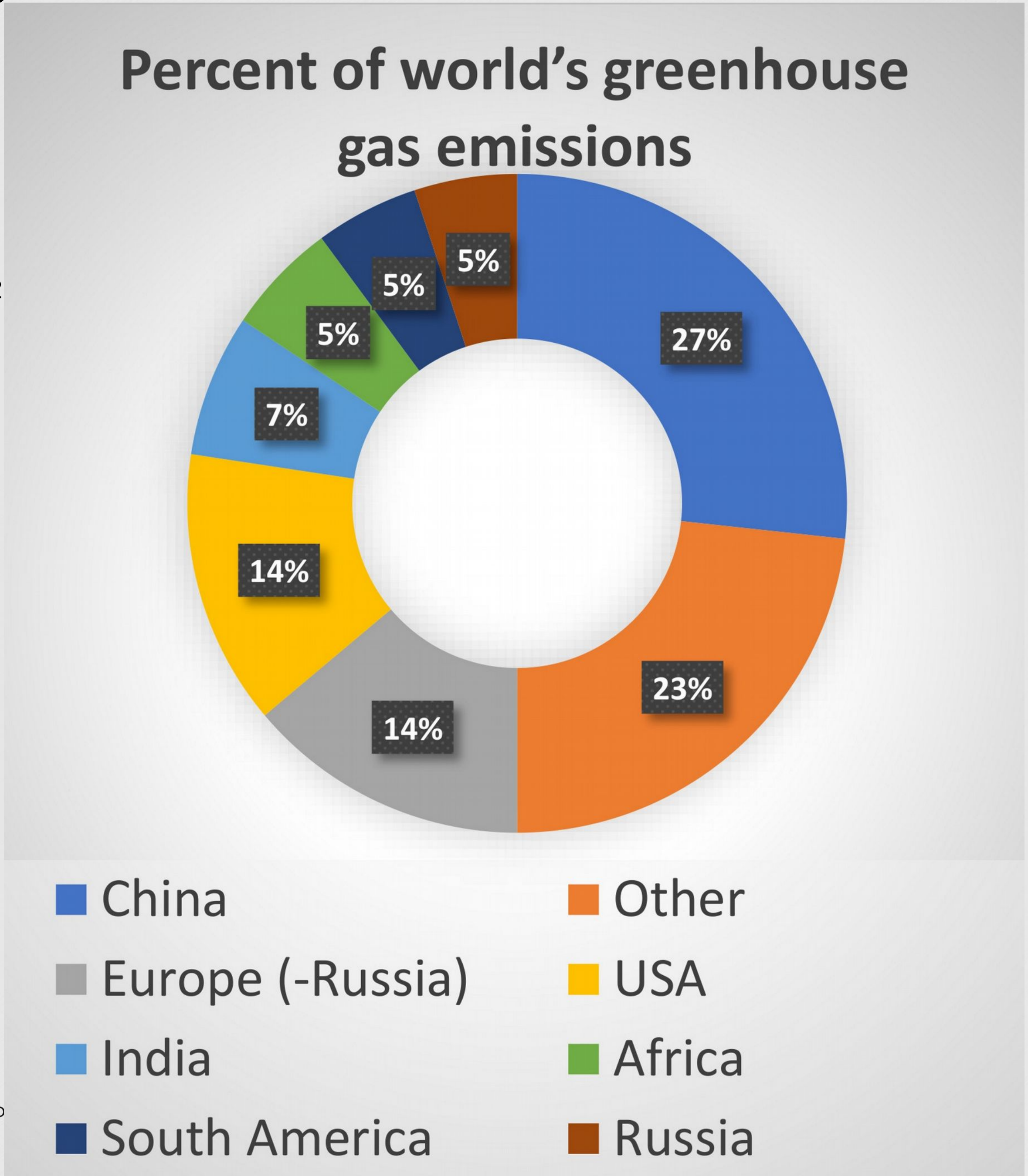


Figure 12.3 Sources of net global emission of atmospheric methane.

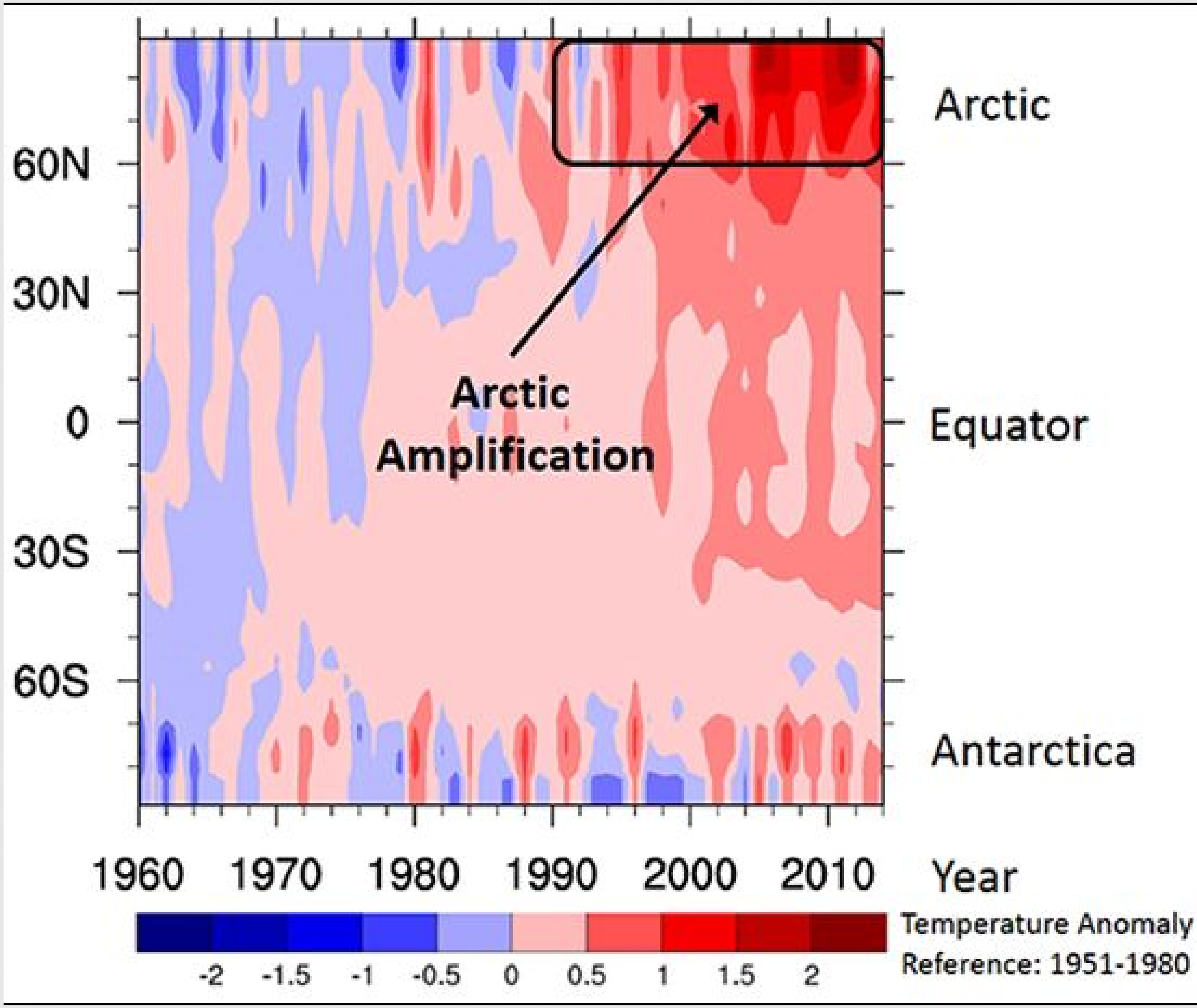
Global Warming: Greenhouse Gases

- Trends in greenhouse gas emissions
  - Increasing as sources of CO_2 CH_4, N_2O, and fluorocarbons continue to increase worldwide
  - Canada produces ~1.6%



Global Warming: Arctic Amplification

- The arctic is warming faster because of the diminished albedo due to less snow cover and ice.
- Average temperature increase of 2.3°C compared to 1.7°C in S. Canada



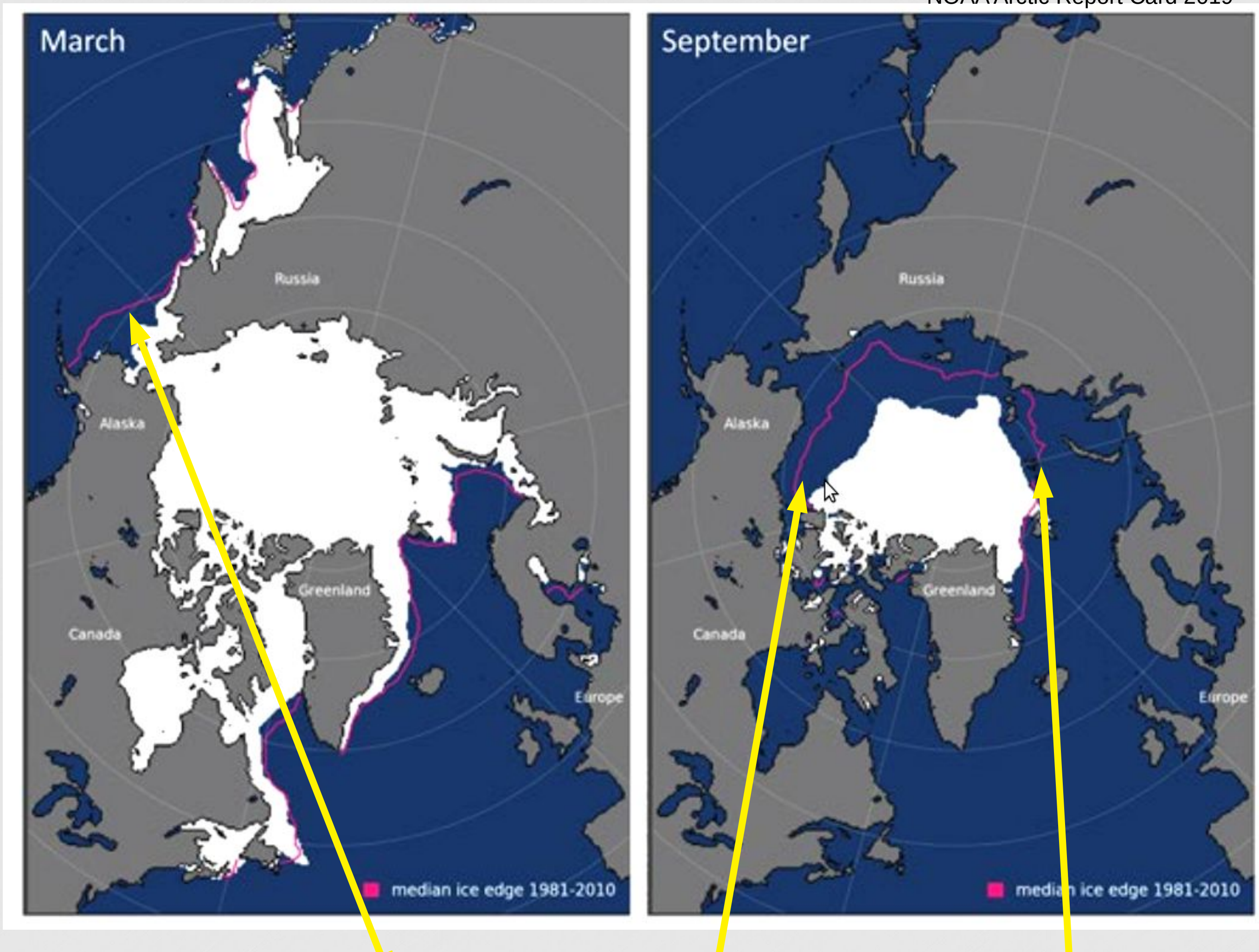
Global Warming: Arctic Amplification

Effects are:

- Less predictable sea ice conditions
- Infrastructure damage from permafrost thaw
- Shortened winter road seasons.
- Permafrost thaw will accelerate methane release and further impact the increase in GHGs
- Ecological change will be more pronounced, eg. loss of polar bear habitat

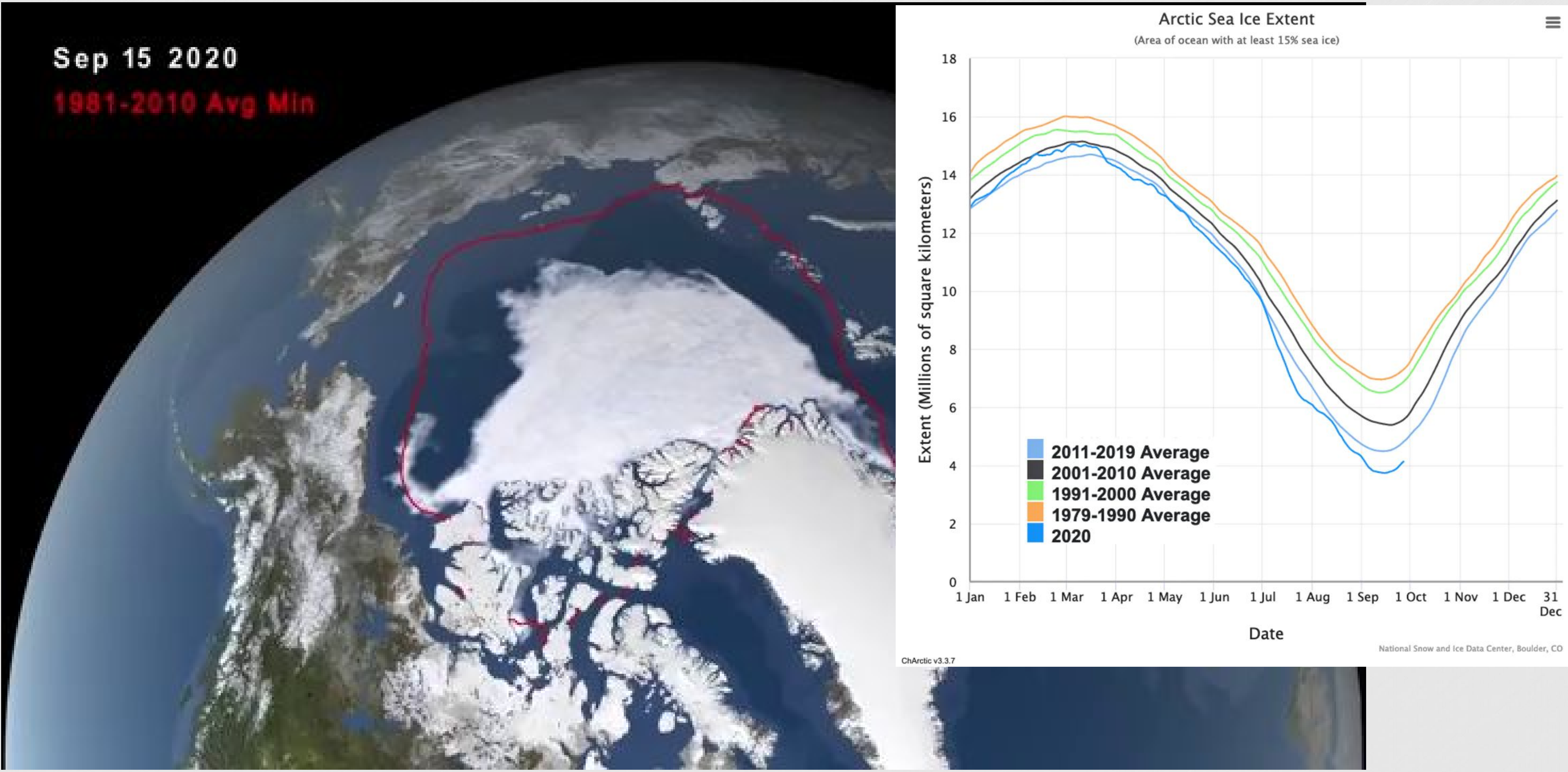
Year: 2019

NOAA Arctic Report Card 2019



Median Ice Edge: 1981-2010 (purple line)

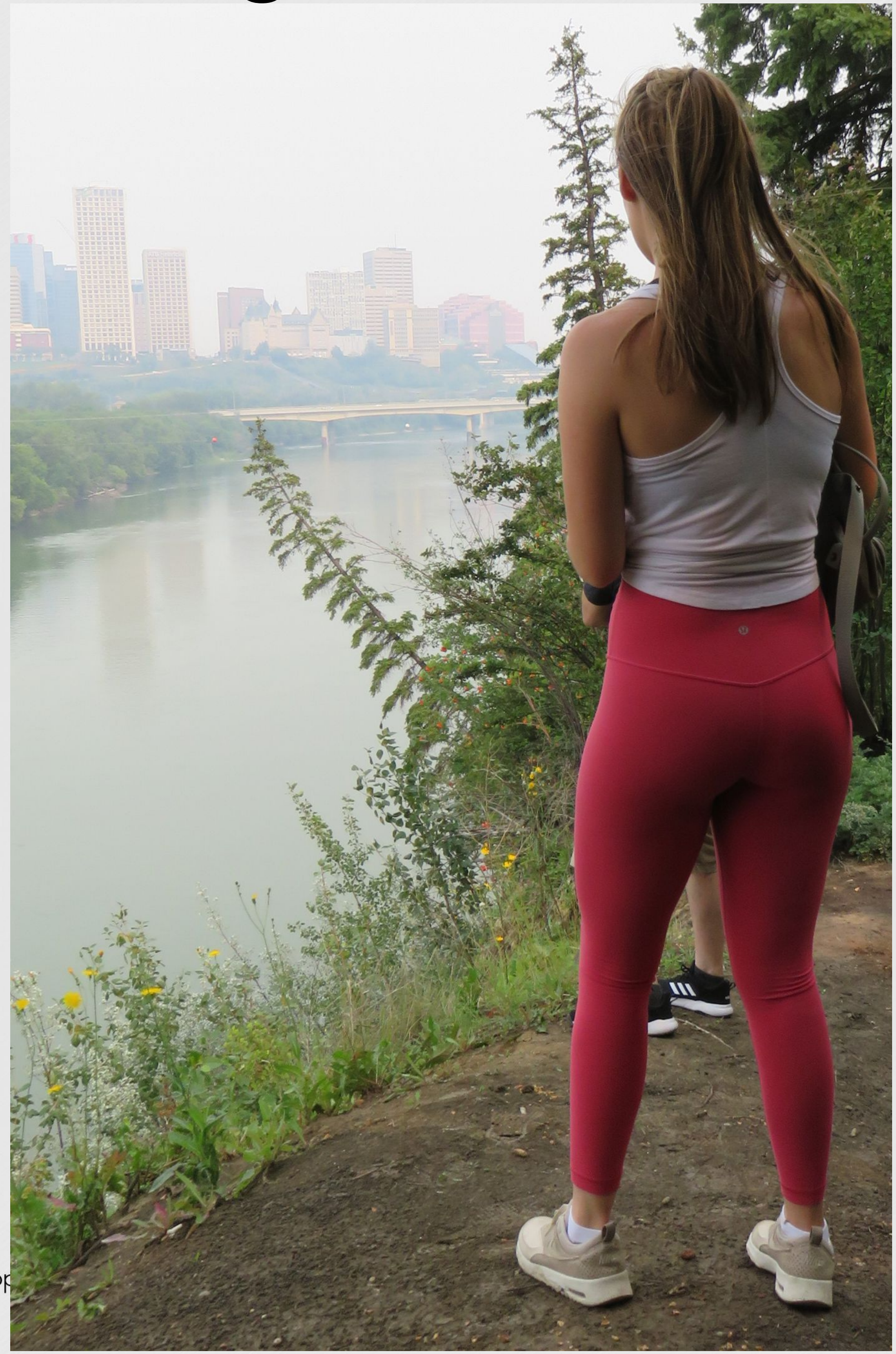
Global Warming: Arctic Amplification



https://theconversation.com/the-arctic-hasnt-been-this-warm-for-3-million-years-and-that-foreshadows-big-changes-for-the-rest-of-the-planet-14454

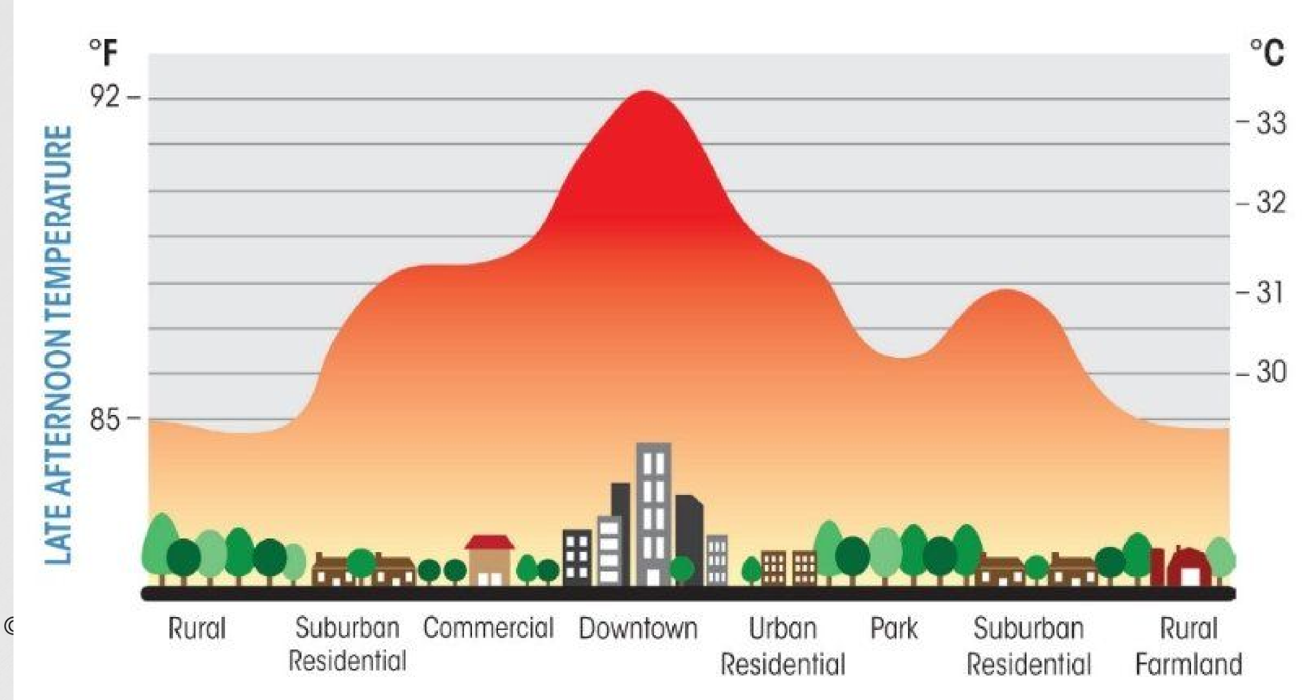
Global Dimming

- Pollution and smoke effects
  - The observed 2–3% rate of decrease in insolation in each decade from about 1961 to 1990
  - Increased atmospheric pollution and aerosols over this period
  - Additional cloud cover seems to have reflected more insolation
  - Daytime high temperatures suppressed
    - Offsetting warming effects of greenhouse gases and urban heat island
    - May explain the temporary temperature decrease from 1950 to 1975
    - Example: photo shows smoke over Edmonton Aug. 20 2018. Forecast high was 32°C, actual High was 26°C

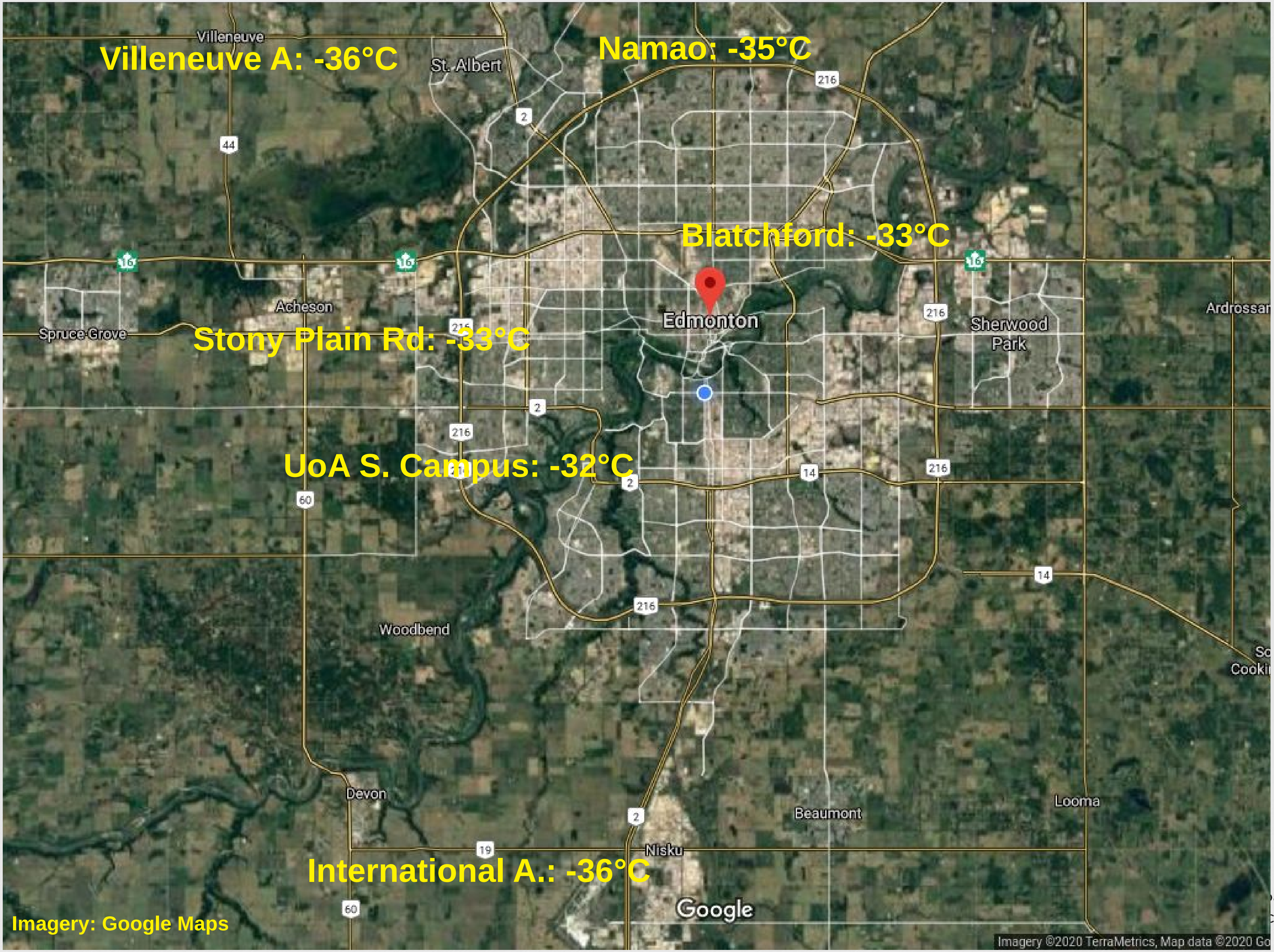


Global Warming: Urban Heat Island

- Cities are generally 1 to 5^{o}C warmer than the surrounding countryside.
  - Due to sparse vegetation, less evaporation and transpiration
  - Rainfall is more likely to become runoff immediately.
    - Less latent heating and more sensible heating
    - Buildings and surrounding materials have greater heat capacity than soil and vegetation.
- Intensified by clear skies with light to calm winds



Urban Heat Island: Edmonton 15/01/20



Landuse Effects – Class Think

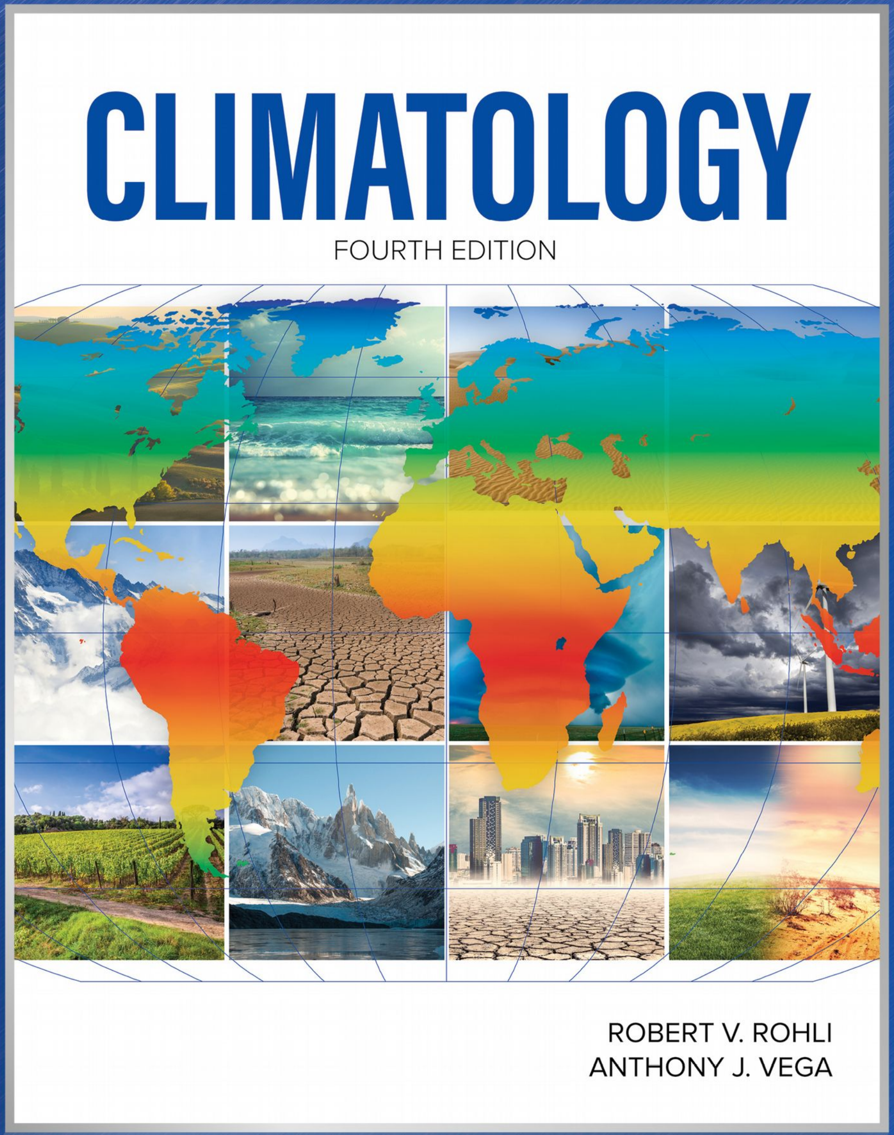
- Consider the removal of forest cover, not in the tropics but in the Alberta context, are climate variables affected?
  - Albedo, does it change, if so, how long does it last?
  - Forests are considered carbon sinks, does removing the forest (biomass) by clear cutting increase, decrease or not change carbon storage? How about forest removal by fire?
  - Forests are dynamic gas exchangers with the atmosphere, which gases increase and decrease? (think O^2, CO^2, H_2O)
  - How does deforestation conversion to agriculture affect the climate variables? (think albedo, permanency)
- (Instructor note: use Google Maps to get a visual context)
  - https://www.google.ca/maps/@55.9465157,-115.0104754,607773m/data=!3m1!1e3?hl=en
  - https://www.google.ca/maps/@53.5745952,-113.1505609,20140m/data=!3m1!1e3?hl=en

Landuse Effects: Deforestation

Global Warming:
Direct and Indirect Effects of Global Warming

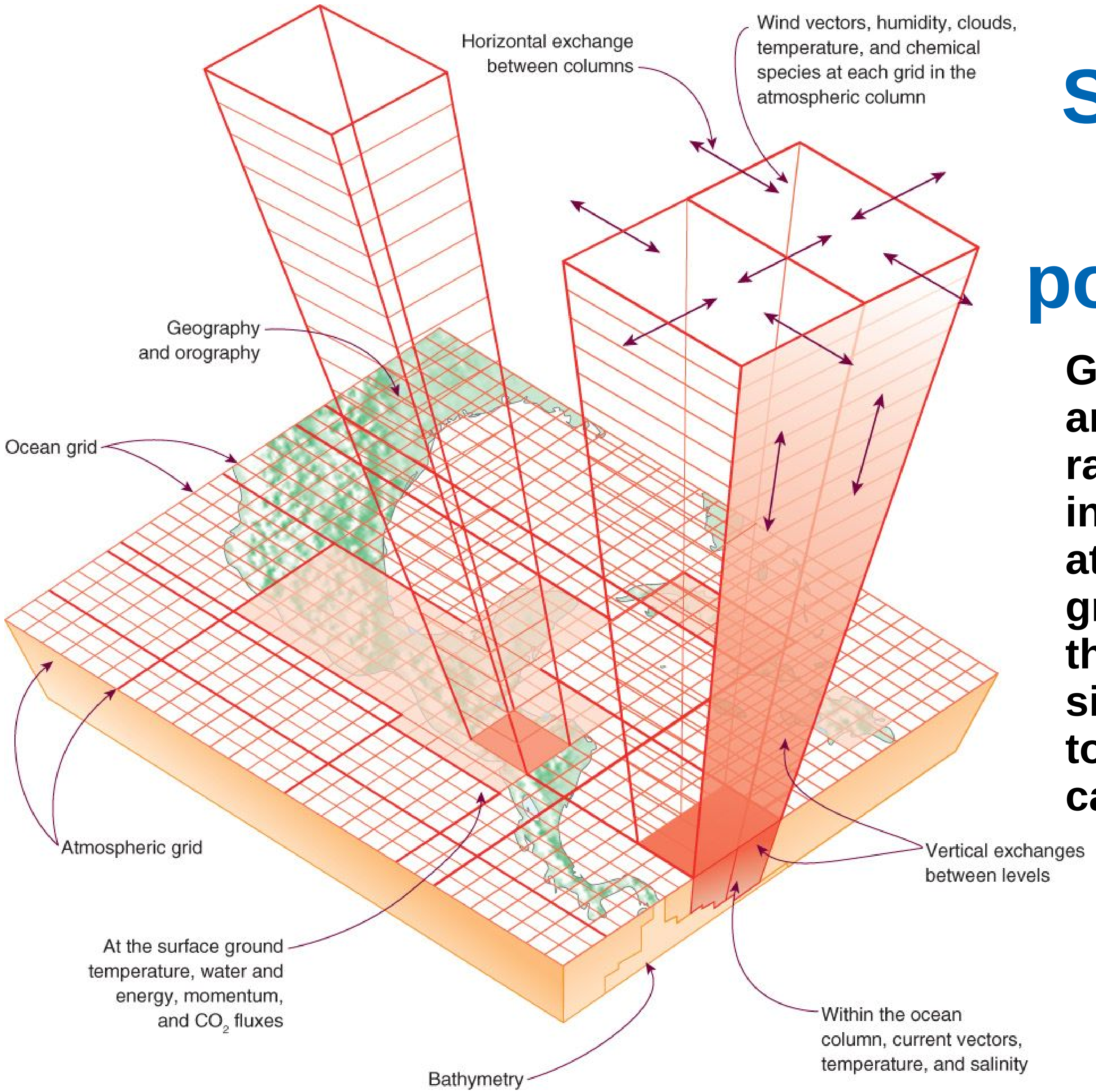
- The last three decades are the warmest on record over the last 1400 years. The rate of warming is unprecedented in the long-term proxy records: the evidence (other than Temperature)
  - Satellite records confirm surface observations.
  - Rapid ablation of ice over much of the planet.
  - Sea level rise due to meltwater input and thermal expansion.
    - Since 1990 a 1–2 mm/yr increase, double that of the century mean and > 10 times that of the mean from the Wisconsin Glacial
  - Ocean acidification from ocean absorption of atmospheric CO_2
    - Coral bleaching (dying) results.

Section 5. Computerized Climate Modeling



Climate/Weather Modeling Basics

- Future forecasts are made with computer models
- Simulate atmospheric processes
  - From very simple to very complex
- Complex models
  - General circulation models (GCMs)
    - Predict global atmospheric circulation based on dynamics
    - Regional Climate Models (RCMs) are used for Canada and Alberta
- Resolution
  - The coarseness, or precision of observations over space (spatial resolution - **gridpoint**) and time (temporal resolution)
- Time Step
  - The length of time into the future forecasted by each model “run”



Schematic of a grid point model.

Grid point models are also known as rasters or pixel data in GIS talk – atmospheric gridpoints are 3D therefore significantly adding to the amount of calculations required

Data from McGuffie, K., & Henderson-Sellers, A. A. (2005). Climate Modeling Primer. 3rd ed. New York: John Wiley & Sons.

Seven Basic Equations used in Atmospheric Modeling

- All weather and climate results from:
  - Horizontal and vertical motion
  - Energy
  - Moisture
  - Seven basic equations are solved simultaneously and iteratively:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \alpha\frac{\partial p}{\partial x} + fv + F_x$$

1st, 2nd and 3rd air motion equations for 'u' east-west, 'v' north-south and 'w' vertical air velocities

$$\frac{\partial T}{\partial t} = \frac{1}{C_p}\frac{dq}{dt} + \frac{\alpha}{C_p}\frac{\partial p}{\partial t} - u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - w\frac{\partial T}{\partial z}$$

4th is the thermodynamic equation (temperature)

$$\frac{\partial m}{\partial t} = -u\frac{\partial m}{\partial x} - v\frac{\partial m}{\partial y} - w\frac{\partial m}{\partial z} + S$$

5th is the moisture conservation equation

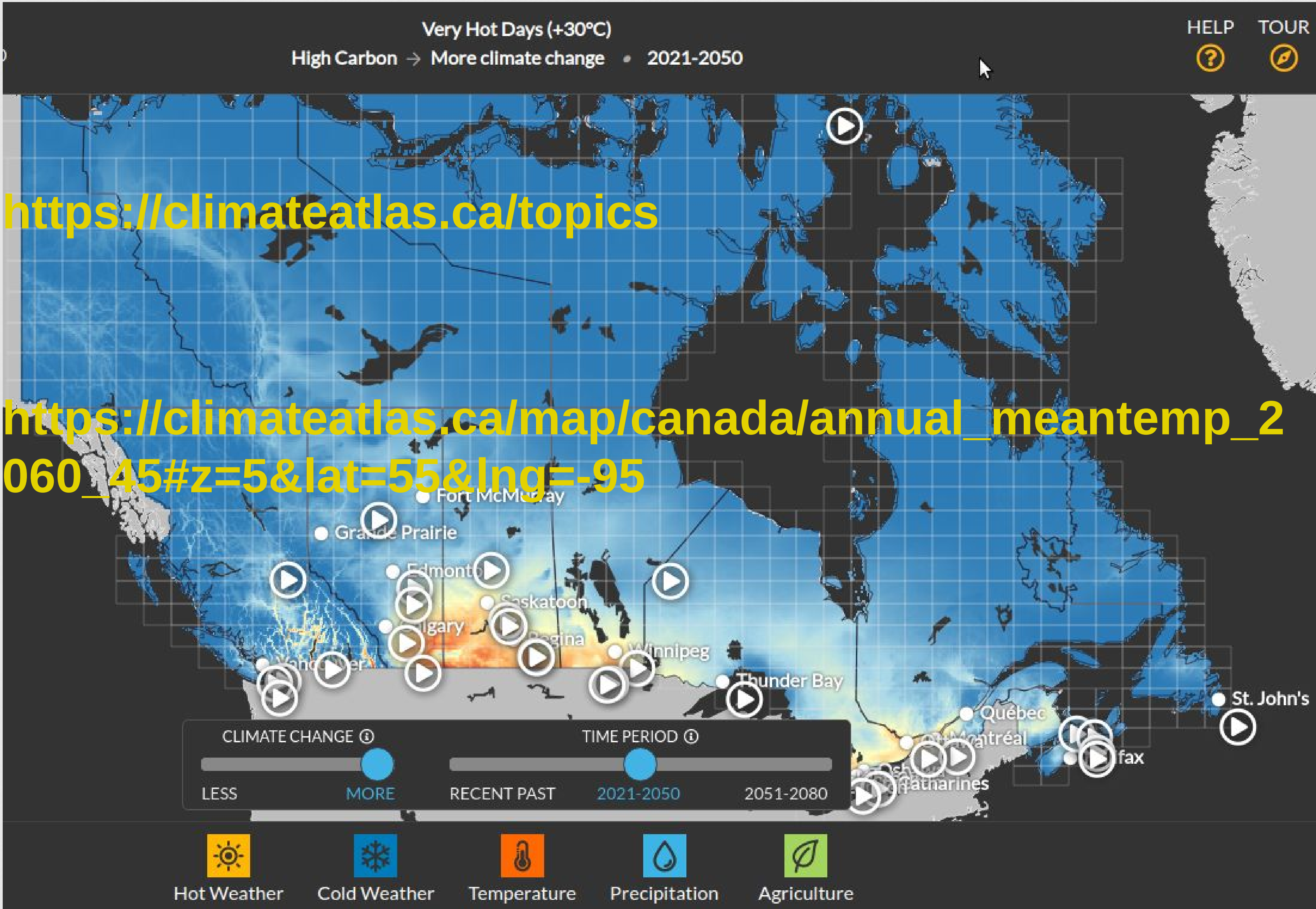
$$\frac{\partial p}{\partial t} = -u\frac{\partial p}{\partial x} - v\frac{\partial p}{\partial y} - w\frac{\partial p}{\partial z} - p\frac{\partial u}{\partial x} - p\frac{\partial v}{\partial y} - p\frac{\partial w}{\partial z}$$

6th is the continuity-density equation for air divergence and convergence

$$P\alpha = R_d T$$

7th Equation of State/Ideal Gas Law

Running the Canadian models



https://climateatlas.ca/topics

https://climateatlas.ca/map/canada/annual_meantemp_2060_45#z=5&lat=55&lng=-95

Some limitations of model results

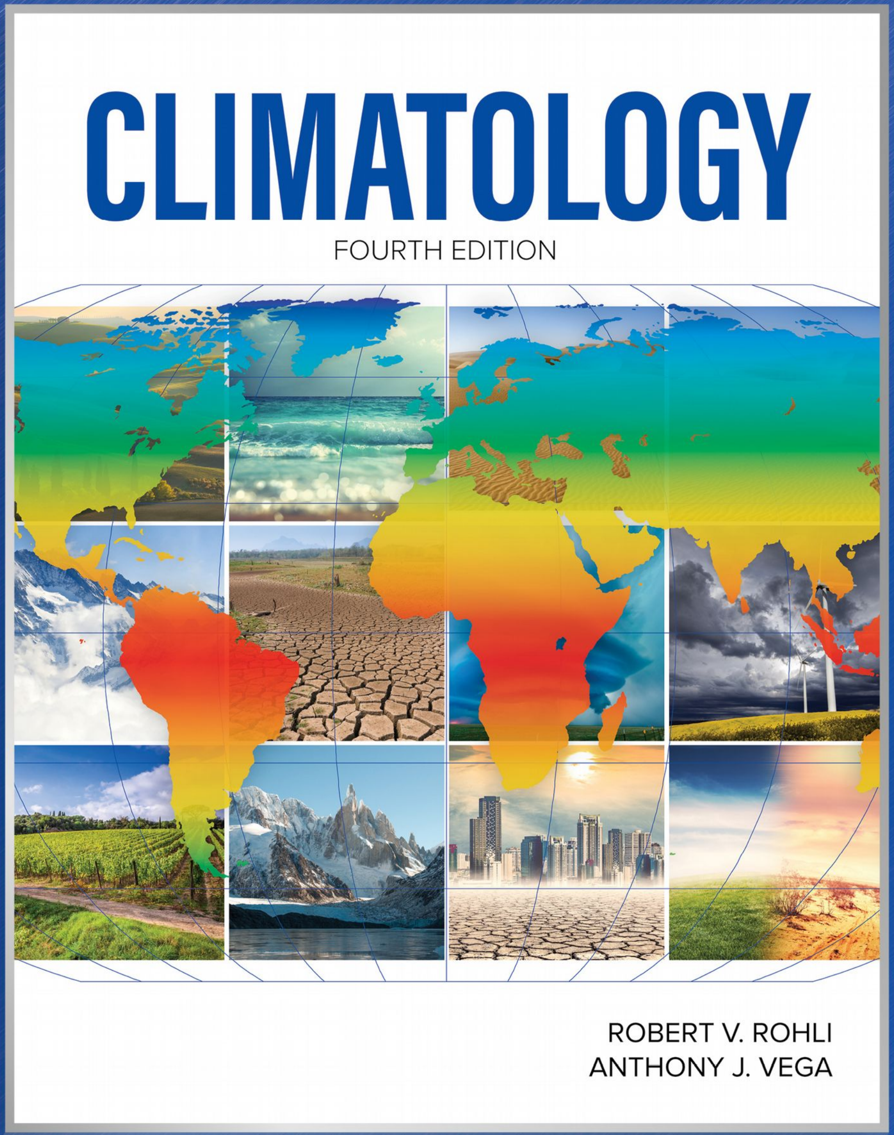
- Model output cannot be presumed to be accurate in all (or maybe even in most) cases.
  - Even if multiple models agree on some end result the inherent assumptions may be similar for the different models (such as the seven basic equations)
- Models can be inappropriately applied
  - If a model predicts a 3ºC rise in temperature, one should be cautious in extrapolating the temperature rise with an associated ecosystem change; ecosystems are much more complex than single variable changes.
- Models themselves may not incorporate all current environmental conditions.
  - Best example is the meteorological forecast model of September 18, 2020 – forecast high was 25ºC, actual temperature was 21ºC. Unaccounted condition? Attenuation of sunlight by smoke.

Wildfire smoke

September 19, 2020, S-SW upper air flow

September 20, 2020, NW upper air flow

Section 6. The Climate Debate: means of coping with a changing climate

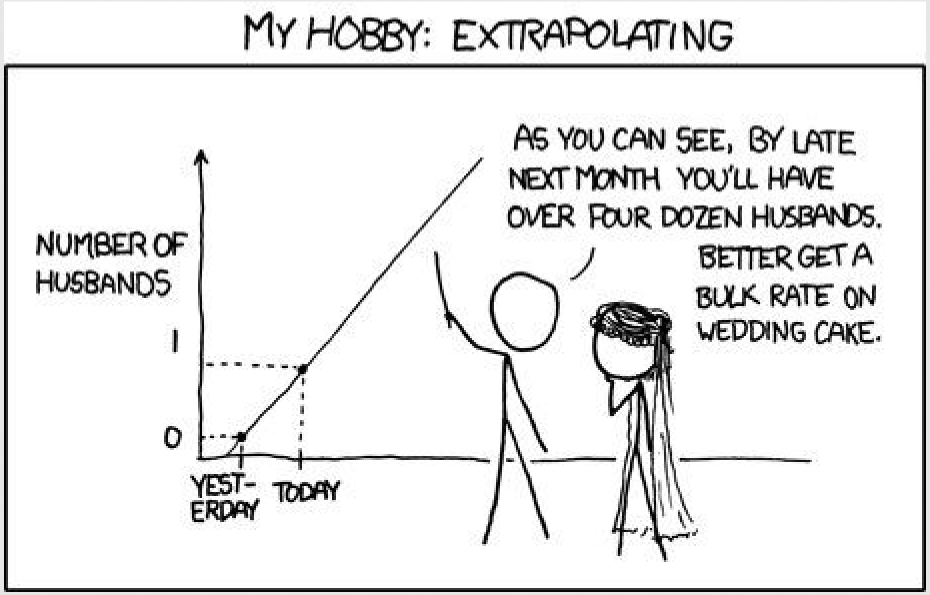


Global Warming: The Great Debate

- Mainstream perspective
  - Few climate scientists question that the Earth–ocean–atmosphere system has displayed a significant warming trend over the last century.
  - Because of the efficiency of gases as both absorbers and radiators of energy, from the evidence from ice cores, and the increased urbanization, the problem is real.
  - The temperature record is confirmed through glacial retreat, permafrost reduction, sea level rise, and other indirect streams of evidence such as animal migrations and disease spread.
  - Moving away from fossil fuels and toward more renewable sources of energy will lessen warming, pollution, and geopolitical issues.

Global Warming: The Great Debate

- The skeptical perspective
  - Some believe global warming is a less serious problem.
  - They believe there are too many uncertainties to establish drastic changes in policy.
  - The warming may be part of a larger natural cycle that will swing back toward cooling again in the future.
  - Higher temperatures may provide more benefits than costs.
  - Erroneous data may be providing a misleading impression of the amount of warming that has occurred.
  - Observed cooling from 1945 to 1980 should not have occurred if emission of greenhouse gases is to blame.



Global Warming: The bottom line regarding the Debate

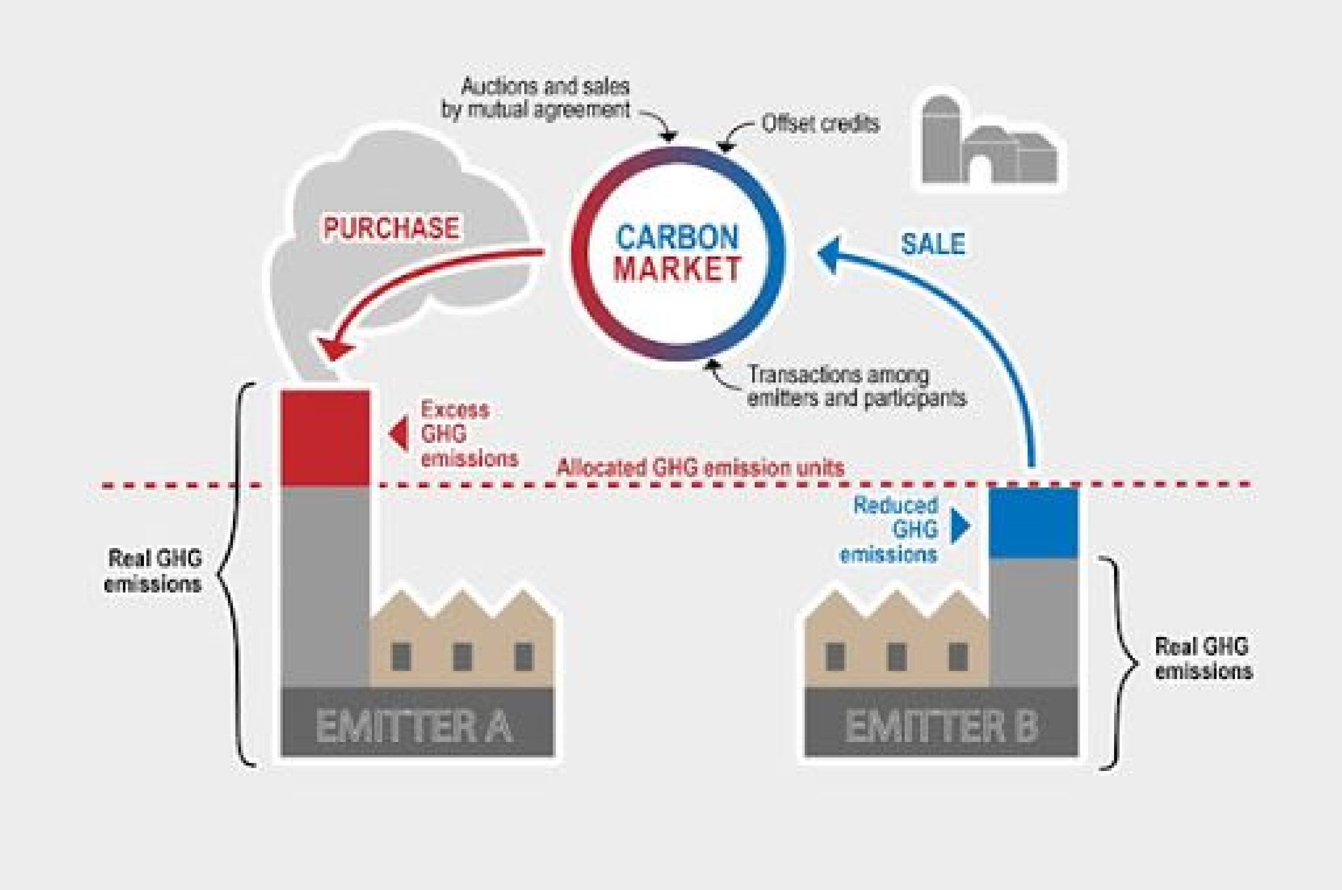
- Most (95%) atmospheric scientists support the notion of anthropogenic influences impacting the climate system.
- Scientists on each side have accused the other of propagating weak and faulty science and the expense of fairness and science.
- The 5th IPCC Report contains much stronger language than previous reports confirming human influences on the climate system.
- Still many unresolved anthropogenic global issues regarding <u>how</u> (as oppposed to if) societies should implement policy related to the issues. The global debate is slowly gravitating towards this reality.

Global Warming: Strategies for coping

- **Prevention**
  - Prevent/minimize the emission of greenhouse gases
  - Kyoto Accord, Paris Agreement
  - **"Cap and trade", Carbon taxes, 'green' energy, nuclear power (SMR), Carbon sequestration, Atmospheric carbon removal..**
- **Mitigation**
  - Decrease the risk associated with global warming effects
  - Build sea walls or prevent floodplain building to lower flood risk
  - Create firebreaks around towns to reduce forest fire impact
- **Adaptation**
  - Business as usual, prep cost is zero
  - Has been the default strategy until recently

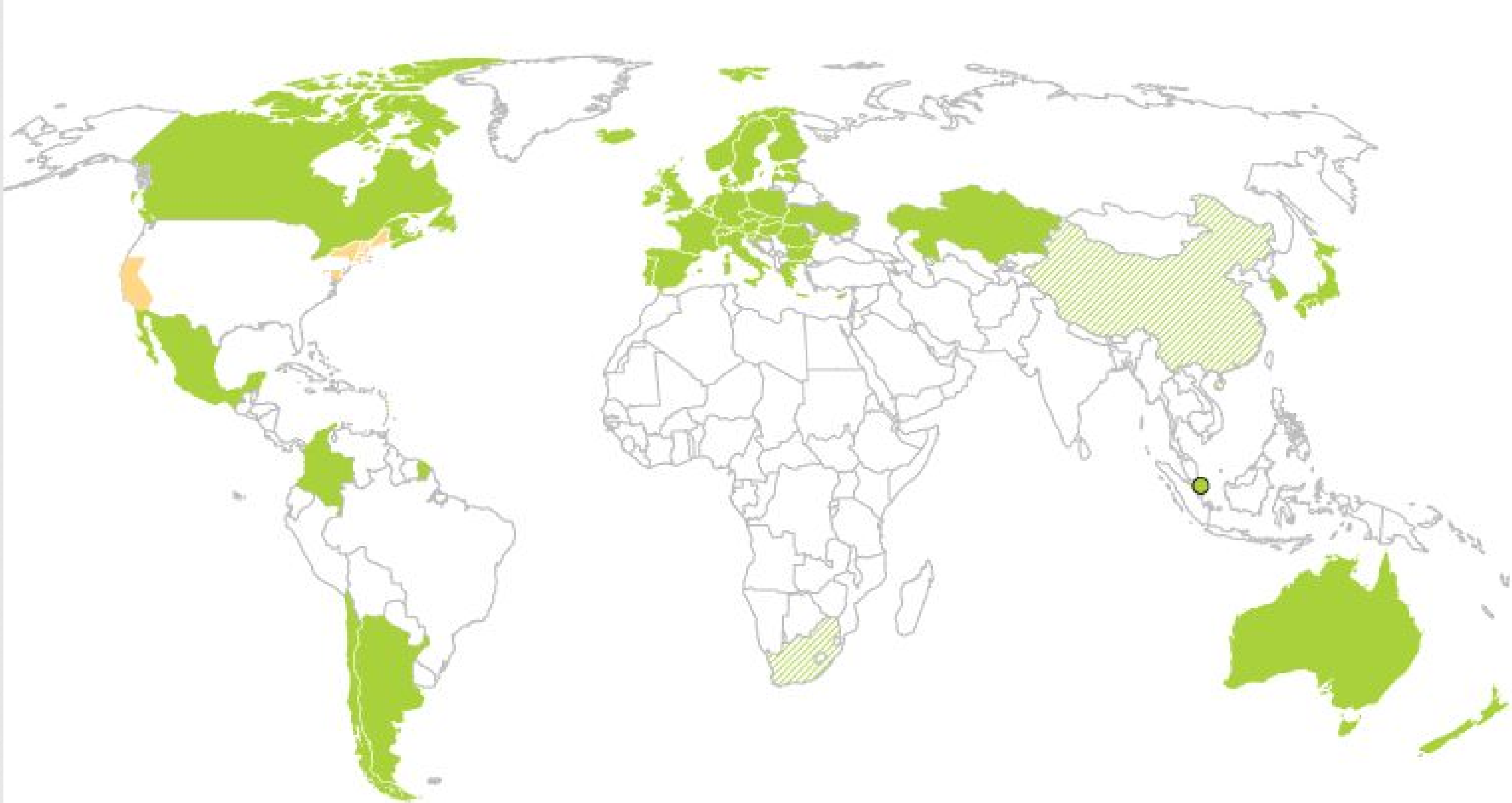
Global Warming: Prevention Strategies 'Cap and Trade'

- Set a cap on carbon emissions produced and trade with low emitters if the cap is surpassed. Market based system.
- Implemented in
  - Quebec
  - California
  - Ontario (withdrawn)
  - EU
- Level of cap?



Global Warming: Prevention Strategies Carbon Tax

- Set a tax on carbon based emissions, discourage carbon based use because of higher costs. Encourage non-carbon energy use. Current Canadian gov't preferred method.



Countries with either carbon tax or 'cap and trade'

Global Warming: Prevention Strategies
Carbon Sequestration

- Remove carbon dioxide at the point of production - this is an Alberta (current government) preferred method.
  - The Quest Project removes about 35% (1.08 m-tons) of CO_2 produced by the Shell Scotford Upgrader and stores it about 2km underground.
  - Allows for the fossil fuel industry to reduce its CO_2 footprint and continue with the economic benefits of fossil fuel production.
  - Does not address the consumptive side of CO_2 atmospheric forcing.

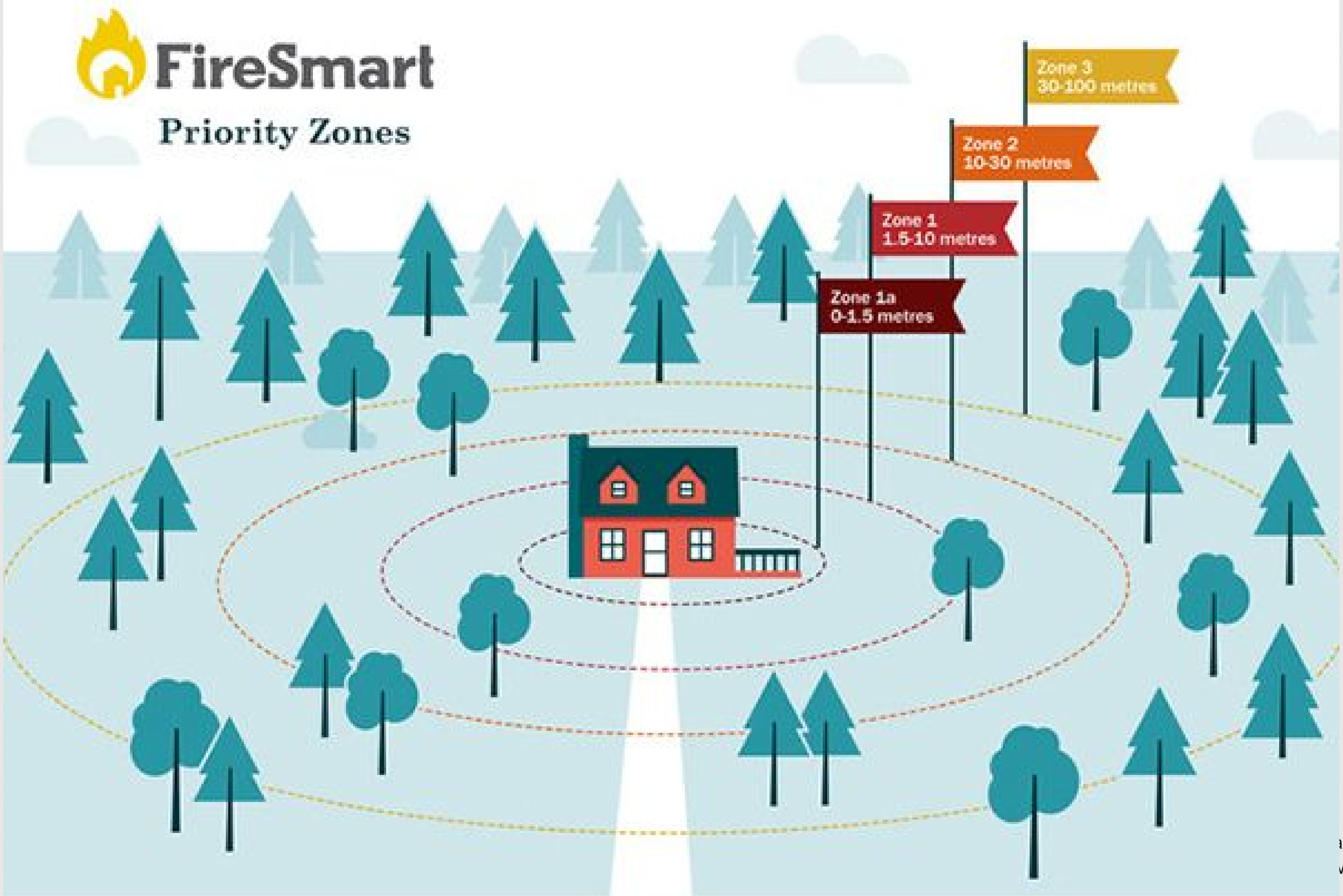
Direct Air Removal

- New technology uses chemical or physical processes to remove CO_2 from the air, also an Alberta preferred method
  - Work is in its infancy, pilot in BC is experimenting since 2015.
  - At the moment energy required to extract is significant.
  - If perfected and adapted to fossil fuel consumers, it may be prolong fossil fuel energy use

https://scitechdaily.com/mit-developed-a-controllable-membrane-to-pull-carbon-dioxide-out-of-exhaust-streams/

Global Warming: Mitigation Strategies ex. Forest Fires

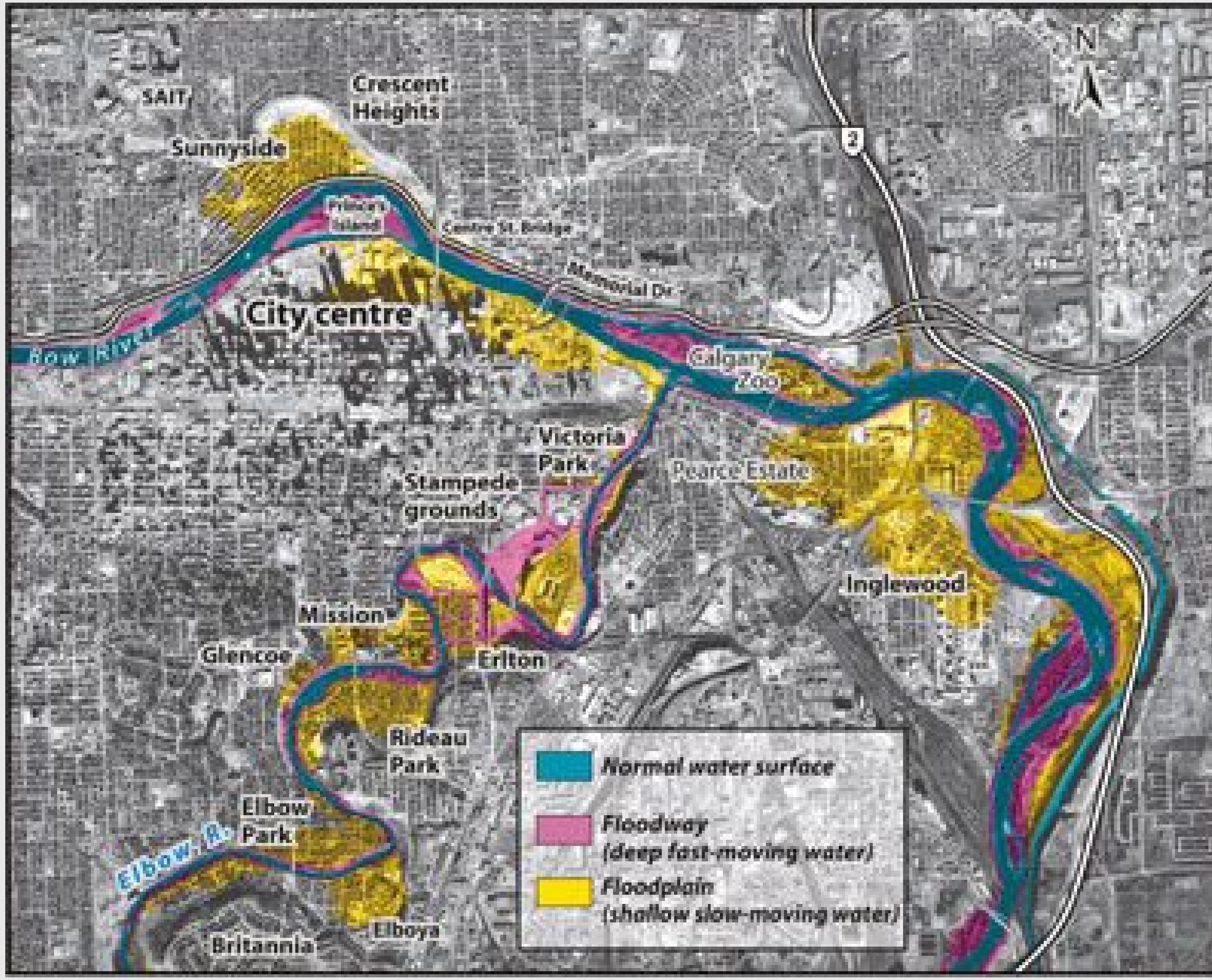
- Reduce the risk of a forest fire impacting populated areas such as occurred in Ft. McMurray and Slave Lake



Global Warming: Mitigation Strategies ex. Flooding

- Reduce the risk of property damaging floods such as the recent events in High River and Calgary

- Build dikes
- Floodplain building restrictions



Global Warming: Adaptation

- This strategy is controversial because it minimizes the impact of a warming climate, some even perceiving advantages (consider the unintentional UofA ads which ran in Edm.&Cal.)

- Other arguments for positive effects in Canada:
  - Lower heating costs
  - Longer and warmer growing seasons
  - Navigable Arctic

Some environmental impacts of global warming in the Edmonton region

- **Cryospheric –** Significant melting of the Rocky Mountain glaciers, https://www.cbc.ca/news/canada/calgary/alberta-water-supply-study-1.5680298
  - Decrease flow in the N.Sask. River, are the Abraham/Brazeau dams adequate to address water supply issues?
  - Major issue across south-central Alberta and for all towns and cities on the Oldman, Bow, N.Sask, and Athabasca rivers.
  - *How would an ice-free Arctic Ocean affect Edmonton?*
- **Hydrospheric –** Longer term models predict a decrease in precipitation, more evapotranspiration, dryer conditions
  - Agricultural practices change towards more dryland farming
  - Dryer forests north and west of Edmonton, more wildfires, more smoke

Some longer term economic impacts of global warming in the Edmonton region

- **Fossil fuel industry –** Diminishing importance over the next 50-100 yrs.
  - What gradually replaces this key industry? Green and nuclear energy?
- **Water supply security** – more glacial melt and lower precip. reducing water availability
  - How do we ensure that we have an adequate water supply for everyday living and work? Where do we get our water?
- **Agricultural/Forestry impacts –** Lower precip, longer growing season, more evapotranspiration.
  - What agricultural practices and products are more adapted to the above conditions?
  - Can the forest sector positively adapt to a warmer/dryer climate?
- **Transportation –** Does an ice-free Arctic provide opportunities?

Some other economic and societal impacts of global warming

- **Recreation –** Ski areas – Warmer and dryer conditions are generally not positive trends for this industry
- **Energy supply and demand –** More variability in climate affects the stability of longer term energy purchases and therefore price.
- **Insurance and Risk Management** - More extreme climate events lead to higher insurance premiums.
- **Human health -** Heat waves as evidenced in Europe last year kills people. More intense hurricanes as evidenced over the past few years kills people. Disease spread by insects (Nile fever, lyme disease, killer hornets etc.) kill people. And then there is Covid-19.. do these types of virusus become virulent in warmer weather?

What can we do as individuals?

Home

- Upgrade to a programmable thermostat or simply set your home's temperature to 16 Celsius when you leave the house or go to bed.
- Turn off the lights when you leave a room, or if you don't require lighting. Consider occupancy sensors that turn on and off automatically.
- Replace light bulbs with energy-efficient LEDs.
- Shorten your showers to less than five minutes.
- Purchase energy-efficient appliances, such as an ENERGY STAR® washing machine, which uses up to 50% less water and 50% less energy per load than average.
- Install new insulation and energy-efficient windows.
- Choose a push mower. Running an old gas lawn mower for an hour can create as much pollution as driving your car 500 kilometres.
- Buy local food and other goods whenever you can. Less travel distance means lower emissions.

Alberta Government:
https://www.alberta.ca/climate-change-alberta.aspx

Transportation

- Walk, bike or take public transit. Choose a more fuel efficient vehicle if you drive.
- If you have to drive to work, consider carpooling.
- Check your tire pressure. Tires that are underinflated by two pounds per square inch can cause a four per cent increase in fuel consumption.
- Use a block heater to warm your vehicle's engine in the winter. Buy a timer for it and set it for two to three hours before you need to start your car.
- Avoid idling your vehicle. Idling for longer than 10 seconds during cold weather isn't necessary, and wastes gas and money.


Thank you
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