Climate Change and Agriculture

The Road Ahead

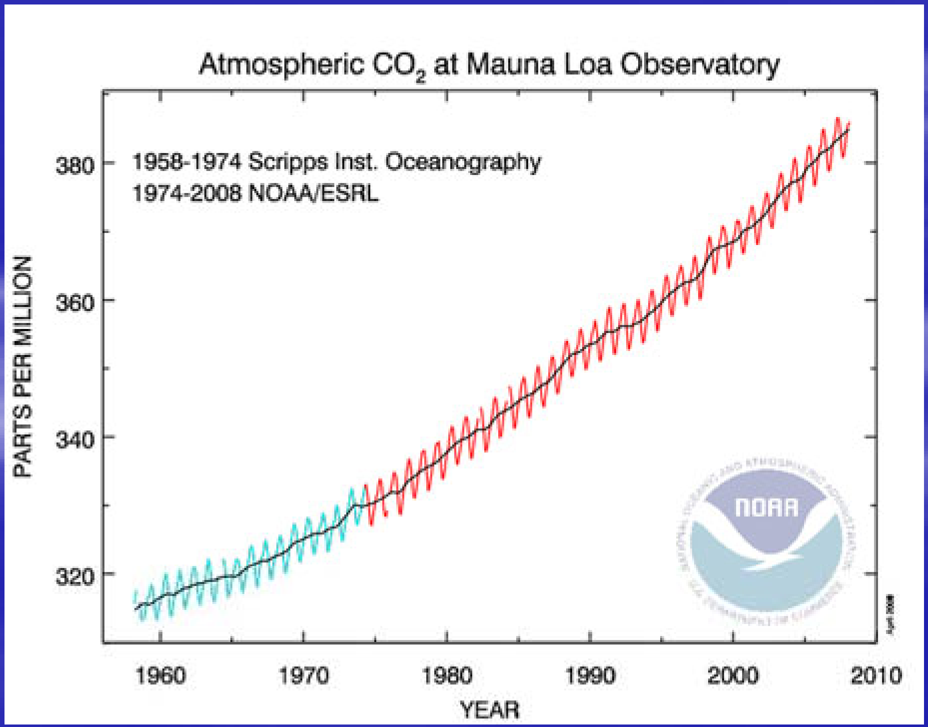
Photo by S Wood

The Bits

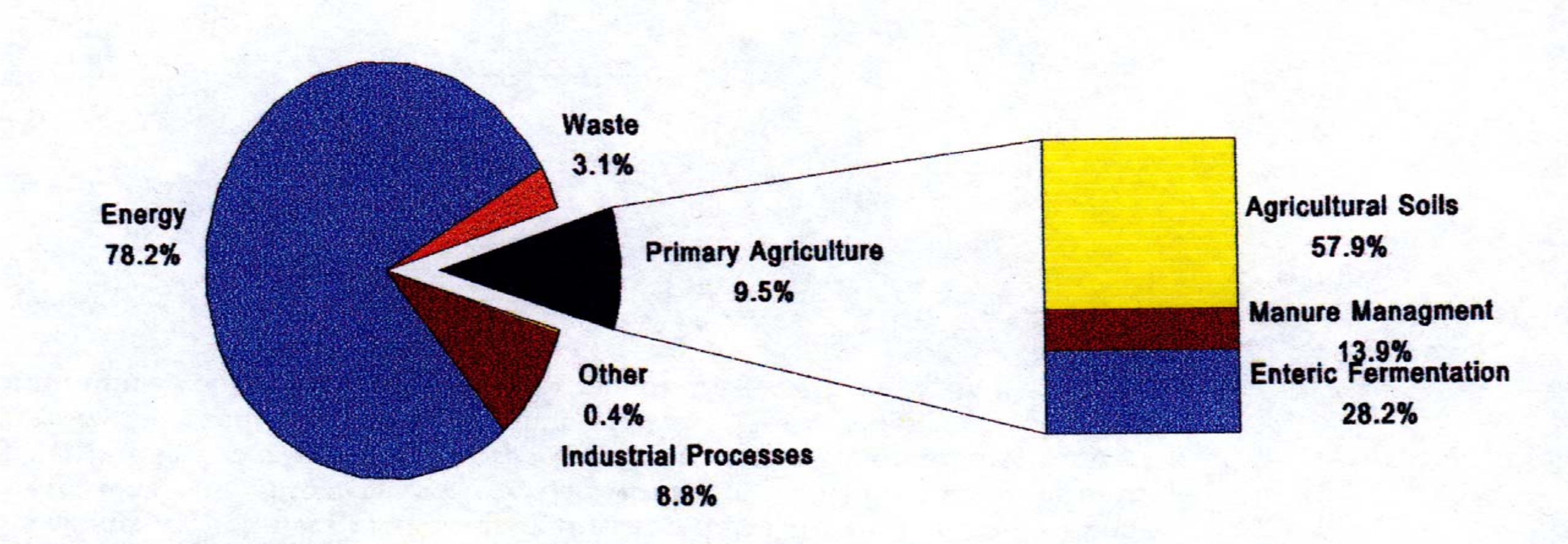
- Agriculture as a contributor
- Impacts on agriculture
- Adaptations
- Mitigation

1. Agriculture as a Contributor

We have changed things and things have changed



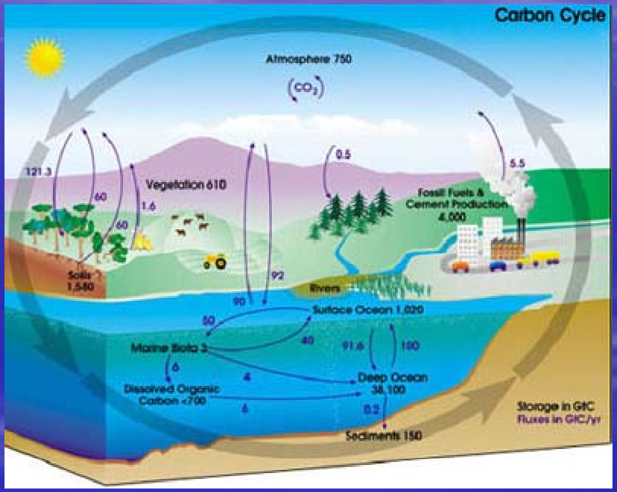
The Scale of It



- Globally, agriculture ranks third after energy consumption and chlorofluorocarbon production as a producer of greenhouse gases.

Greenhouse Gases from Agriculture

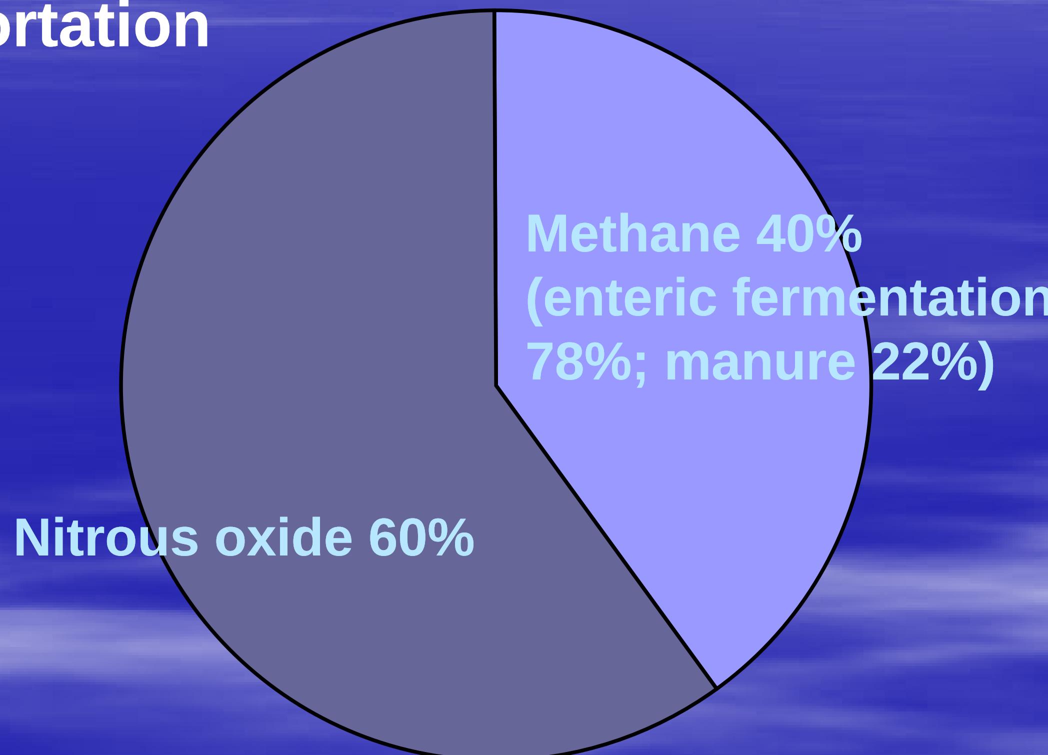
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)



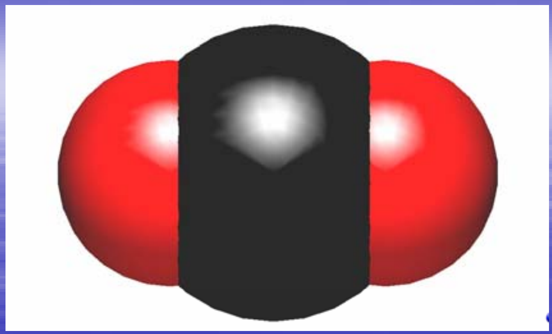
	CO_2	CH_4	N_2O
Relative effect	**1**	**21**	**310**

Agriculture Contributes

- 8.3% of Canada's total annual GHG production (EC 2004)
- 60 Mt of 726 Mt total
- Not including transportation fuel emissions



Canadian agriculture is a small net sink for CO_2 because of conversion to no-till.



Carbon Dioxide

Waiting to exhale

CO_2 Sources

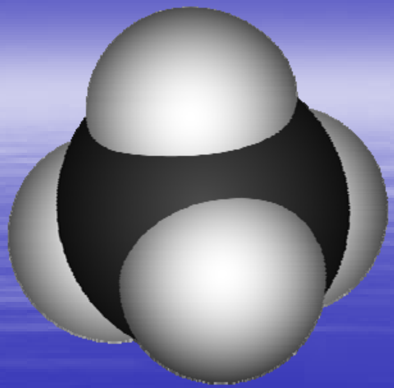
- Deforestation
- Declining soil organic matter

Deforestation

- During the last two millenia extensive areas of Europe and Asia have been deforested
- In North America most of this has occurred during the last 300 years
  - – From about 1700 to 1900, the clearing of northern hemisphere forests for agriculture was the largest agent of change in the carbon cycle.
- The process is ongoing is places such as the Amazon Basin
- Much of the deforestation is associated with creating land area for food production

Declining soil organic matter

- Tillage aerates soil and makes smaller particles enhancing oxidation of organic matter
- Unless organic matter inputs (crop residues) are increased under agriculture soil organic matter will decrease
- The organic matter is lost as CO_2
- Warmer soil temperatures will accelerate this



Methane

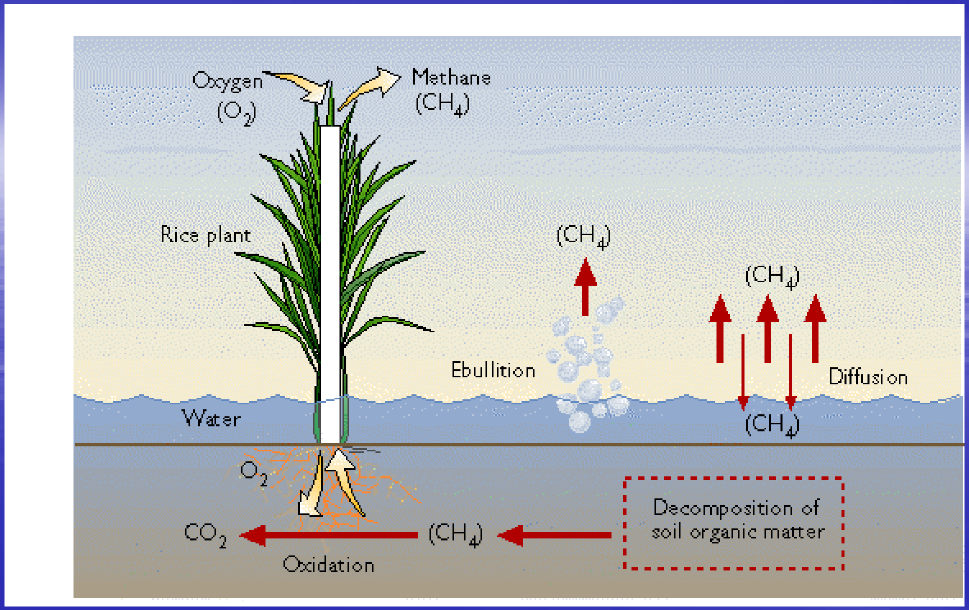
Excuse me!

CH_4 Sources

- Rice paddies
- Livestock

- Globally, agriculture is a very prominent source of CH_4, accounting for about a two thirds of human induced emissions.

Rice Paddies



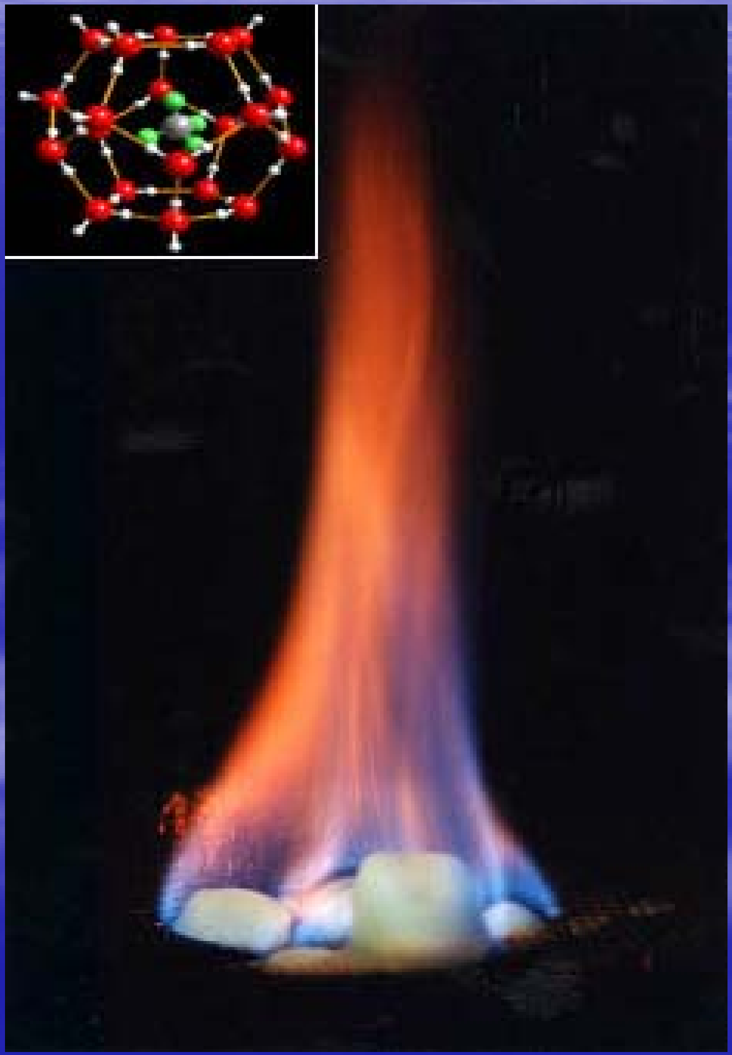
- Soils are anaerobic
- Organic matter break down leads to methane production
- Usually more than half of the methane escaping from the soil is oxidized to CO_2 in the upper few mm of soil and the water
- The methane diffuses out of the soil and also out through the plants via aerenchyma (major route to the atmosphere)
- Just over half of agricultural emissions

Livestock

- Ruminant livestock (sheep, goats, camel, cattle, buffalo, etc)
- Much is produced in the gut and is released by breathing, burping, flatulence (~80% of total)
- There are additional, and significant releases from decomposing manure (~20% of total)
- Just under half of current agricultural emissions

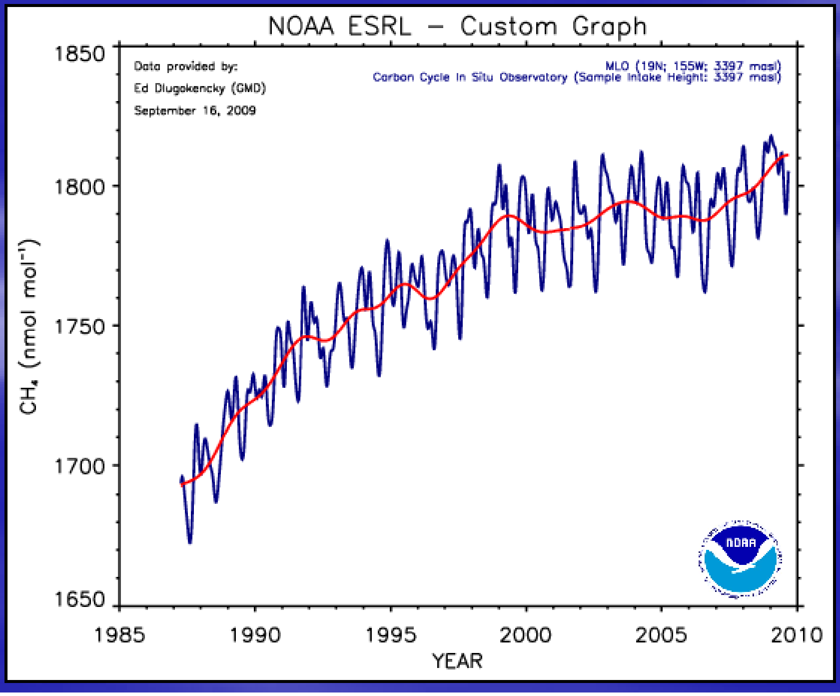
Methane Clathrates

- **Methane trapped in water ice**
  - **Fire ice**
- **Large amounts in the permafrost**
- **Clathrate melting may now be an issue**
- **Feed forward on climate change**



Methane Trends

- Its current atmospheric concentration of 1.7 ppm by volume, up from 0.7 ppm in preindustrial times
- Rate of increase has been in decline

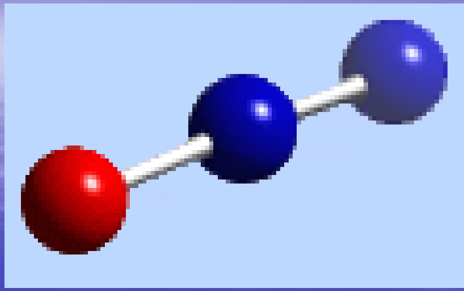


Nitrous Oxide

It’s no laughing matter

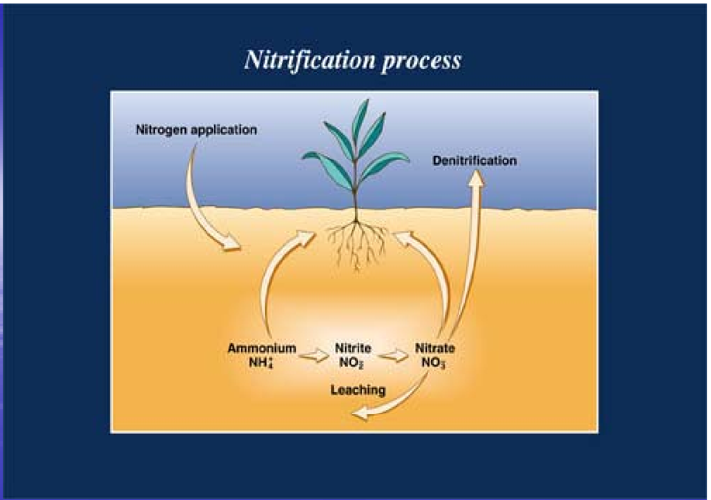
N_2O Sources

- Denitrification
- Nitrification (small amount)



- Concentration is now increasing at a rate of about 0.3% per year.
- Up to 70% of the anthropogenic N_2O emissions are agriculture.
- Also contributes to the destruction of ozone

Denitrification

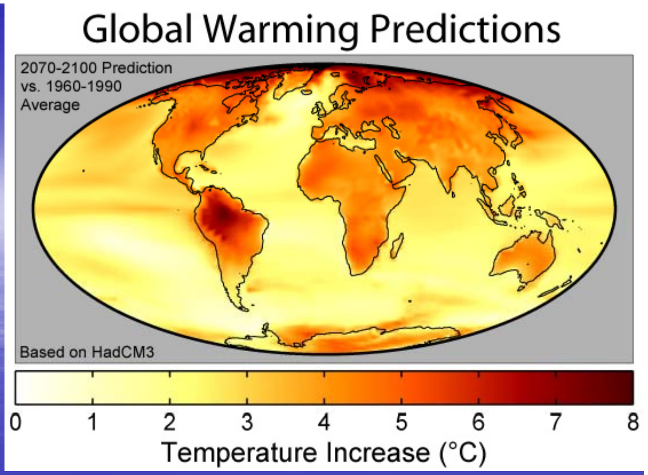


- The end products of this process are N_2 and N_2O
- Soil mineral N (from fertilizers or organic matter) can be denitrified when soils become anaerobic
  - eg. when there are periods of intense rain over several days or at snow melt in the spring
  - Can result in dentrification of up to several hundred kg ha^{-1} of N in only a few days
  - 1-2% of all added N fertilizer becomes N_2O
- Warmer soil temperatures will accelerate denitrification

2. Impacts

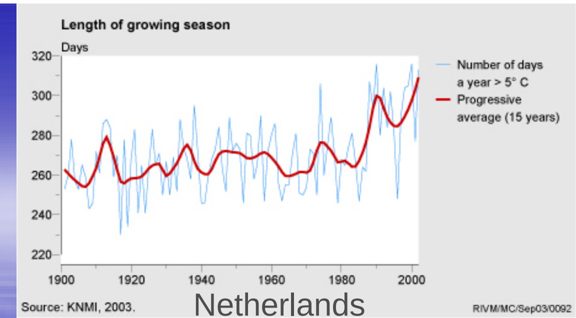
Those Chickens Come Home to Roost

It Will Get Warmer



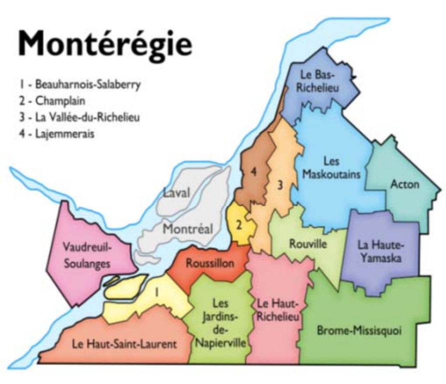
- Models indicate that global average surface temperatures will rise by 1.5-4.5 ºC over the next 100 years.
- Increases will be smallest at the equator and greatest at the poles
  – In Canada, on the order of 5 to 8 ºC
- Night temperatures have increased more than day temperatures

Seasons Will Get Longer

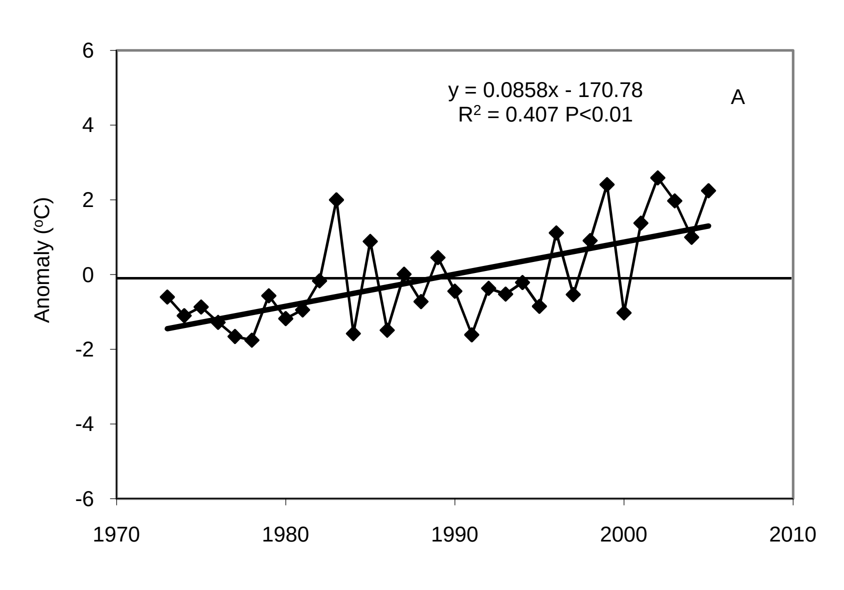


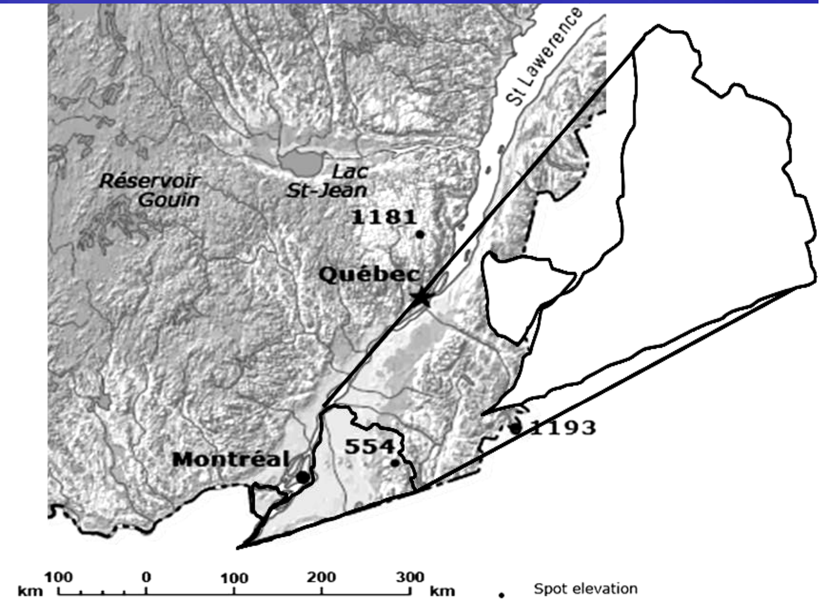
- At higher latitudes, where the length of the growing season is set by the time of last spring and first fall frosts the potential growing seasons will be longer
- Night temperatures are increased more than the day temperatures, and killing frosts occur at night, so the season lengths will increase faster than temperature means
- However, the higher night temperatures will increase the respiratory consumption of photosynthate disproportionately

Where I Live



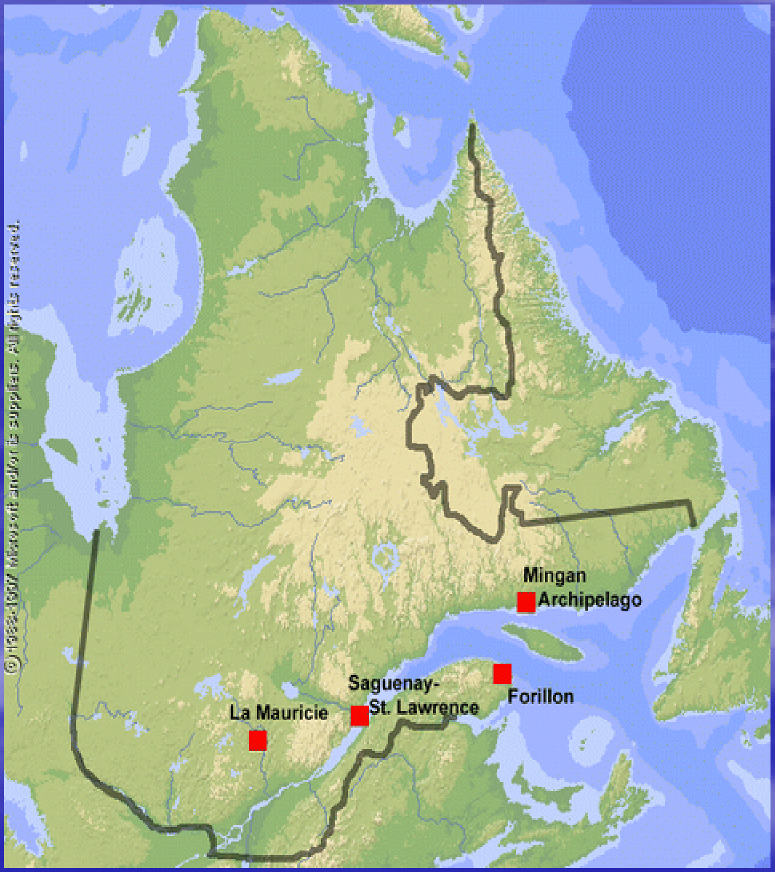
- In the Monteregie region of Quebec
  - Mid summer temperatures up only slightly
  - September temperatures up an average of 2.8 ºC over the 33 year period 1973 to 2005





More Quebec Effects

- Crops like fruit trees will be expand north as warmer winters will allow this.
- However, reduced snow cover in the winter may make it difficult for forage legumes to survive the winter.



Possible Cranberry Effects

- Changes in rainfall patterns leading to reduced water supply in some production areas
- Milder winters could result in a failure to meet the chilling requirement
  - cranberry plants in the northeastern United States need a minimum of about 1700 hours of exposure to temperatures below 7 ºC
  - Not likely to be a problem here for quite a long time
  - However, could remove more southern competition over the next few decades

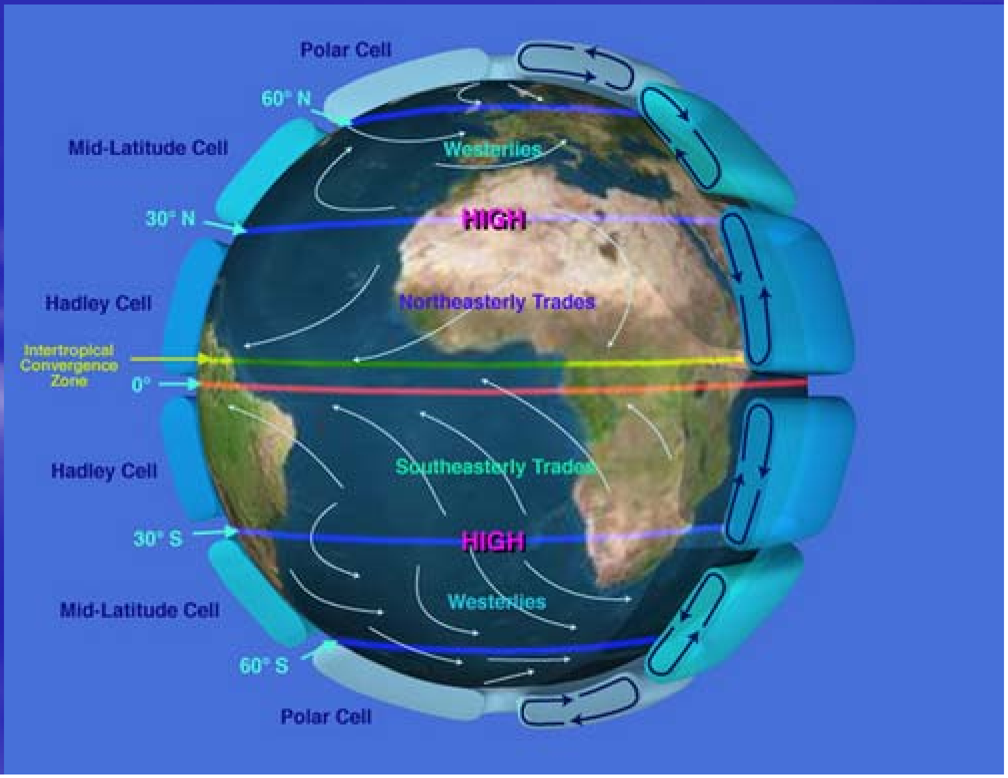
In General It Will Get Drier

- General circulation models predict decreased rainfall in some areas, and increases in others
- However, increased temperatures will lead to increased evaporation because of:

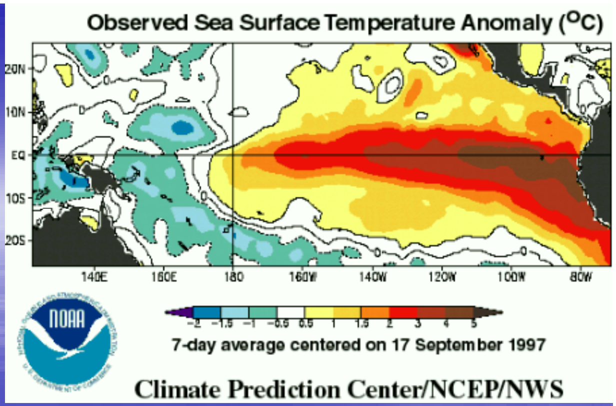
  – higher temperatures themselves
  – longer periods with unfrozen soil in northerly areas
- Evaporation increases by ~ 5 per cent for each ^{o}C of mean annual temperature.
- European wheat & maize: 1^{o}C warming (no change in precipitation) leads to a predicted 5% yield decrease.

Pressure Cell Effects

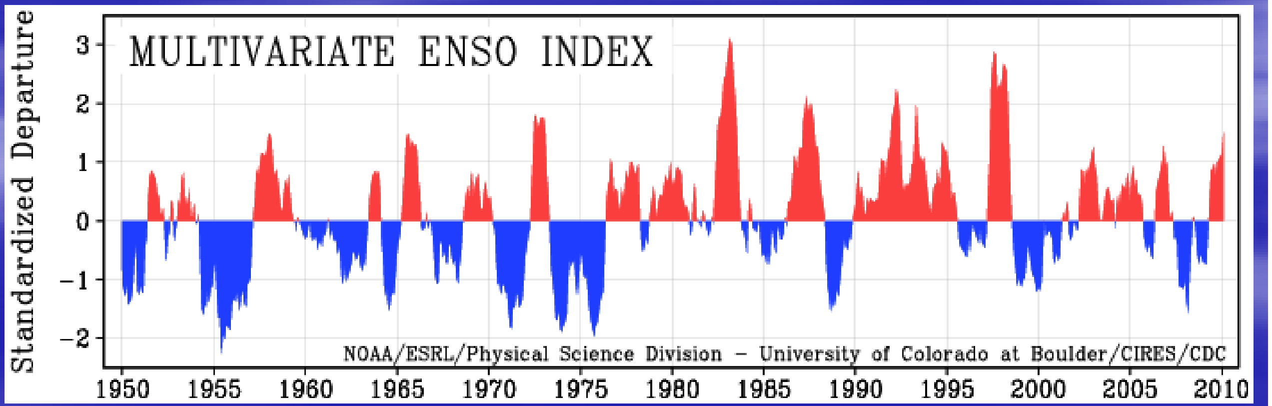
- Hadley Pressure cells have plumped out about 2º
- Regions of intense dryness have shifted to somewhat higher latitudes
- More severe fires in Southern Europe, California, Australia



More Frequent El Ninos



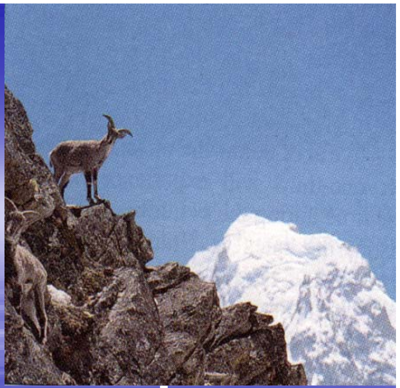
- In El Nino years monsoon rains in Asia start later so planting is later and less rice is produced
- Each 1 ºC decrease in surface water temperature in the lead up to the monsoon season means $1 billion reduction in rice production in Indonesia



Canadian Effects

- The Paliser triangle, in south central Saskatchewan, currently produces most of Canada's highest quality hard wheat
- The general circulation models predict that if global warming goes ahead this area will only be suitable for livestock grazing

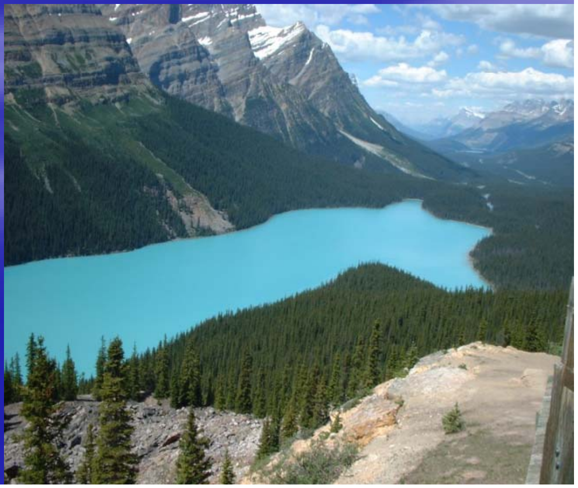
Glaciers and Rivers



- Glaciers around the world have retreated an average of about 30% during this century
- The 15,000 glaciers of the Himalayan mountains are retreating an average of 30 m per year, among them the Gangotri glacier that feeds the Ganges River
  - populations have developed based on this extra water availability for food production
- Many of these glaciers feed rivers whose waters are utilized for food production

In Canada Too

- A large amount of irrigated agriculture in Alberta is based on the many small rivers
- The Peyto glacier in Alberta has lost 70% of its mass during the last few decades.
- This is happening to many glaciers in these mountains
- Now less water flowing into the rivers they feed, and out onto the prairies where it is used for irrigation of crops

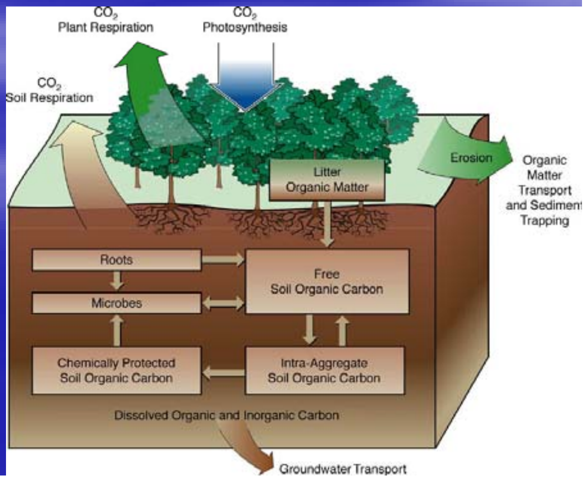


More Extreme Weather

- Drought and high temperature episodes will occur more often
  - rice could be pushed out of some parts of Asia
  - some semi-arid areas will become unable to support crop production
- We will probably have more extreme El Ninos and more often
- Tropical storms will be more frequent, stronger and more destructive

Changes in Soil Organic Matter

- Higher temperatures and, in some cases, higher rainfall levels, will accelerate soil organic matter break down
  - Low organic matter soils hold few nutrients and are more susceptible to drought
- Where elevated CO_2 levels and better precipitation patterns occur there will be greater inputs of crop residues, increasing soil organic matter

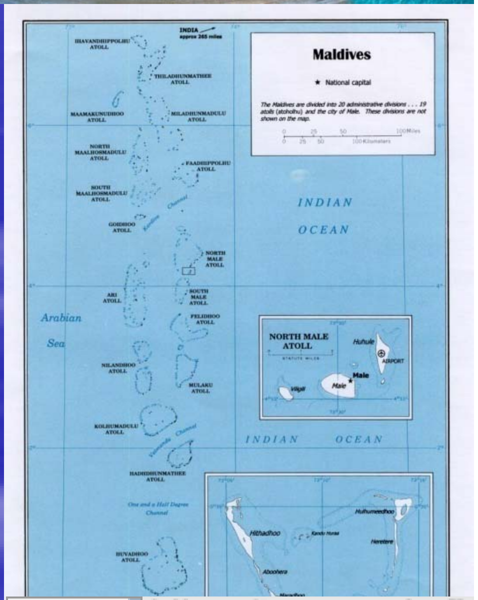


Soil Erosion

- In many areas soils will be drier
- Increased equator-to-pole heat flux will mean greater average wind speeds
- Soil organic matter will be lower
- This will increase the potential for wind driven erosion by an estimated 20 to 30%

Sea Level Rise

- Most models predict a sea level rise of about 50 - 100 cm by 2100
- This will lead to the loss of agricultural land due to flooding by sea water and salinization in areas that are newly coastal
- River deltas are some of the most productive agricultural lands
- Spring 2010 – New Moore Island disappeared



Plants and CO_2

- Photosynthesis is CO_2 limited, so more CO_2 increases the rate, and therefore plant growth
- Some plants partially close their stomata so that photosynthesis is not increased, but water use efficiency is.
- C_3 plants (more in the temperate zones) benefit more than C_4 plants (more in the tropics).
  - Photosynthesis ratios (555 ppm CO_2/330 ppm CO_2) for soybean, wheat and rice, and maize were 1.21, 1.17, and 1.06, respectively.

Changes in Crop Quality

- In general, the higher levels of carbon (CO_2) will lead to crops (seeds or, in the case of forages, leaves and stems) that are higher in carbon and lower in protein.
- On the other hand, material with higher sugar contents will make better silage.

Stimulation of Nitrogen Fixation

- Increased CO_2 levels will increase the amount of photosynthate available inside the plant for N_2 fixation.
- In areas where climate change conditions lead to increased growth of legumes, this will lead to increased N demand, and increased N fixation.

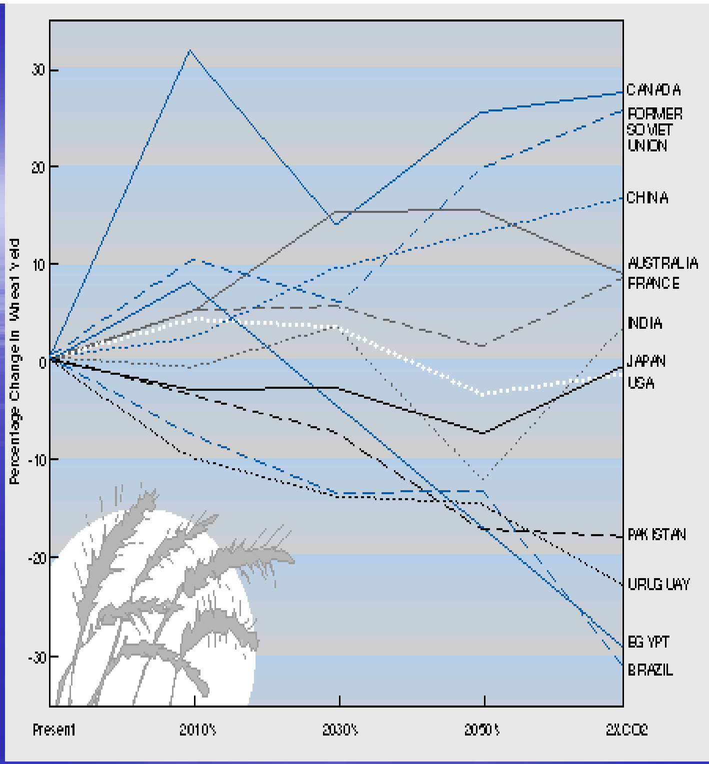
Pests Will Move

- Weeds, diseases, insects will spread from warmer areas into formerly cooler ones.
  - Warmer winters allow overwintering of larvae in areas where this was not possible.
  - Increased number of generations possible.
  - So, longer time for development and feeding and a wider range of pests
  - European Corn Borer 165 – 500 km northwards with a rise of 1^{o}C.
- Greater wind speeds will assist movement of spores.
- Similar effects for livestock pests.

Grassland species will change

- Where dry hot areas become more so there will be a shift from C_3 to C_4 species
  - Generally the grazing quality of C_4 species is lower.
- In temperate-moist areas increasing CO_2 will favour C_3 over C_4 species.

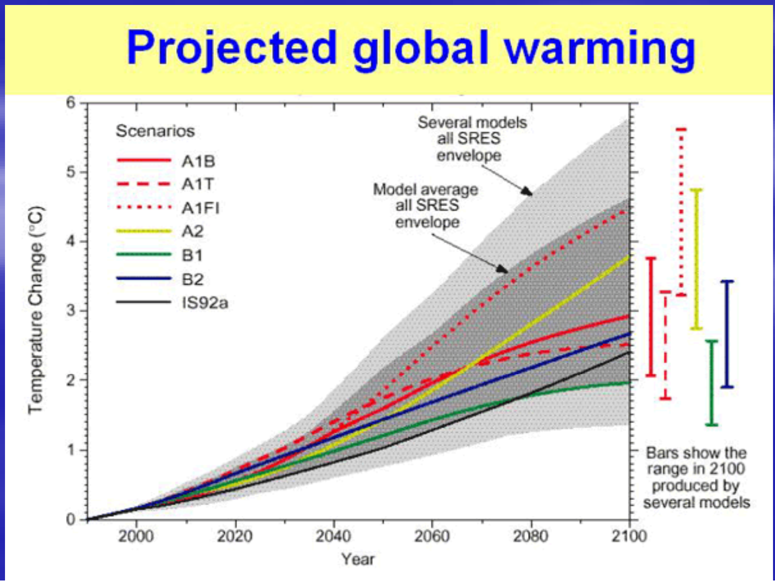
Estimates



- Most models show modest decreases in world food production due to climate change.
  - There will be increases in productivity in many temperate areas.
  - Tropical developing countries, those most directly dependant on agriculture, will suffer decreases of 10 to 20 %.

How Big A Temperature Effect?

- Lower temperature increases (on the order of 2ºC) have small overall effects, negative in some areas and and positive in others
- Larger temperature increases (on the order of 4ºC) tend to cause clear decreases

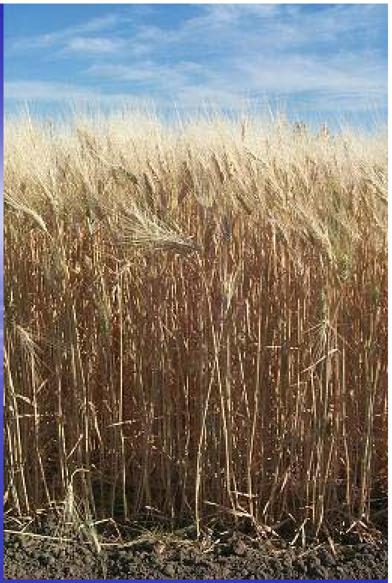


3. Adaptations

Living With It

Alternative Crops & Cropping Systems

- More C_4 crops can be grown in temperate areas
- Eg.: Although the current geographical boundary (with regards to temperature) for ripening maize excludes most of the UK, a temperature increase of 0.5 ^{o}C would allow maize cultivation across southern England.



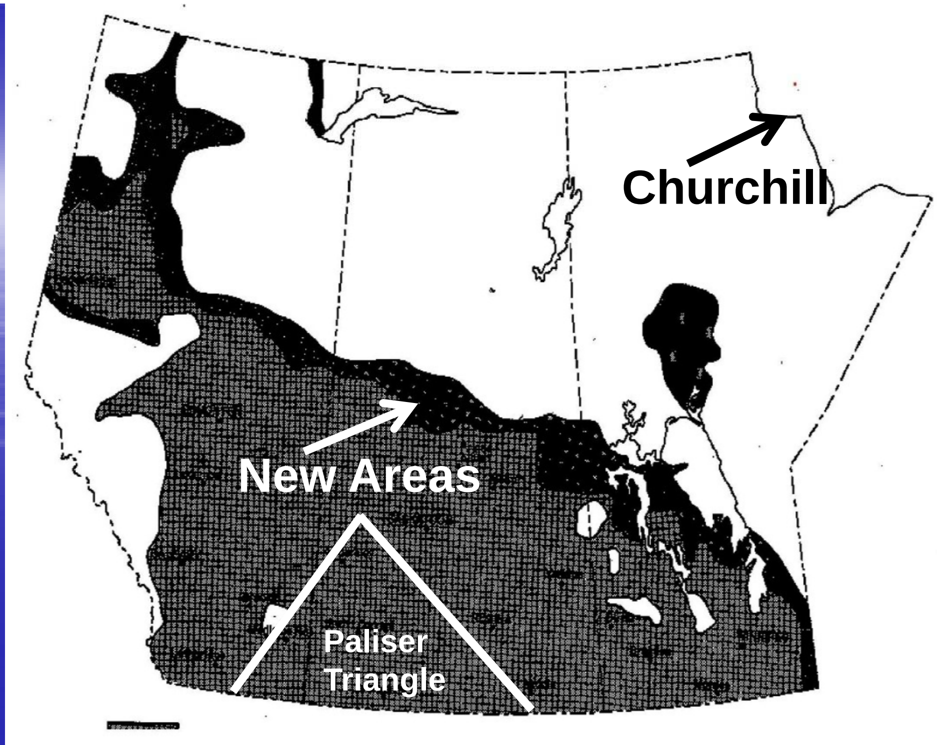
- Winter wheat, with its higher yield potential, could move into areas where spring wheat is now produced
- Cultivars with longer times to maturity (and therefore greater yield potentials) can be grown
  - This will bring management changes such as earlier seeding
- In the mid latitudes the increase in season lengths may be sufficient to allow the adoption of double cropping practices

Fertilizer Use Will Change

- In areas where crop production potential is increased higher levels of fertilizer application will be required to meet the potential
- The increases will be greatest for N

People Will Move

- Northward migration of crop production
- Will require the development of rail infrastructure in the north, and probably the ability to ship more grain out of the Port of Churchill
- The new area to the North is as large as the one going out of production, but the soils are younger and less fertile



Tillage Systems

- With warmer soils no-till and minimum-till systems will become more feasible
- These systems will store soil water better, and store soil carbon better, with the latter leading to less potential for soil erosion

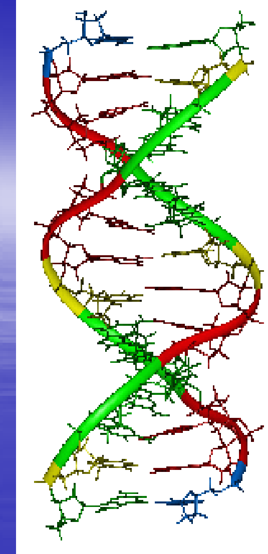
Pesticides

- There will be a greater need for applications of various pesticides (insecticides, fungicides, herbicides)
- Genetically modified crops may help out in this area

Irrigation

- In some areas there will be the potential to expand the use of irrigation
  – infrastructure costs
- However, in others, as river flows decrease, irrigation use will decrease
- The competition between urban and agricultural uses of water will be increased

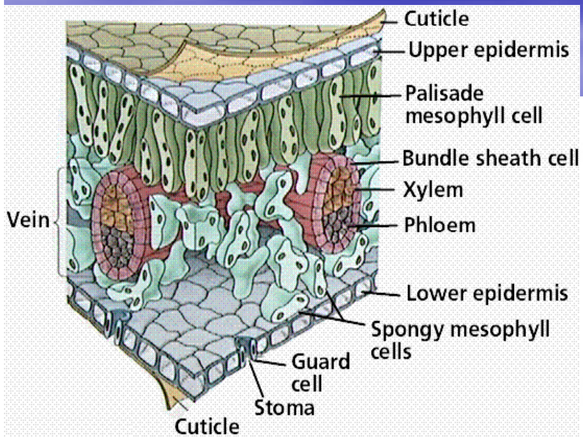
Genetics

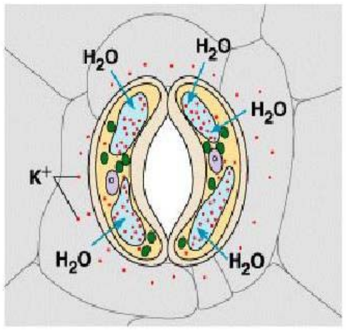


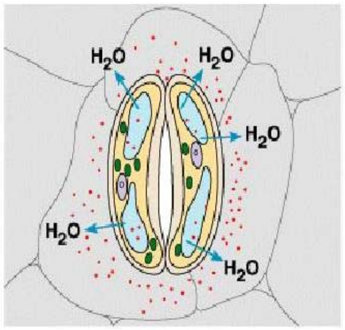
- Conventional breeding and genetic engineering can develop plants more tolerant of heat, drought and pests, and that take more advantage of elevated CO_2 levels
  - For crops, a drought tolerant genotype experiences less yield reduction in the presence of drought stress
- Plants better at sequestering carbon in soil and/or producing materials that substitute for fossil fuels could be developed

Potential Genetic Modification

- Roots – length, rate of development
- Osmotic adjustment
- Stomatal closure – reduced transpiration
- ABA mediated effects – stomata, desiccation tolerance, leaf senescence, accelerated maturity
- Reduced cuticular transpiration
- Water use efficiency
- Methane monoxygenase into rice







Some Others

Policy

- Policies that promote the production of established crops in a given area must be made flexible to allow the introduction of new crops and cropping practices

Inequities

- Developed countries in temperate zone areas will have more resources to aid in adaptation than developing countries
- These countries will also have greater negative effects to deal with

4. Mitigation

Crops to the Rescue

Carbon Sequestration

- 46 million ha resown each year
- If bulk density is 1 top 20 cm = 92 billion t
- 1% = 0.92 billion t (could be 2%)
- Carbon in soil somewhat reduced, assume about = to CH_2O, so add 14 to get to CO_2 so ~ 1.35 billion t
- Spread over 30 years – 45 million t per year, or about 6% per year
- Better yields too

Biochar

- Although there is still much to learn about this biochar may well off something very useful in this area

- Residence time for crop residues is on the order of decades
- For biochar it is millennia
- It also improves soil water and nutrient holding capacity

N_2O Emissions

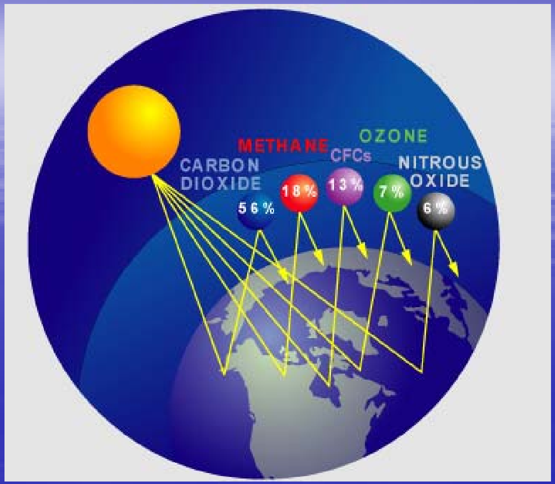
granular ammonium nitrate

- About 6% of the Canadian total emissions are N_2O
- There has been no previous effort to reduce this
- If good progress can be made, we might reduce total Canadian emissions by 5%

Bio-products

- Energy is about 80% of total GHG emissions, or 560 mT of CO_2
- If only 10% of this were replaced by biofuels this would amount to 56 mT, or about 8% of Canada's total emissions
  - Could eventually be greater than 10% replacement

In Total



- C sequestration – 6%
- N_2O – 5%
- Biofuels – 8%
- Approximately 20% of Canadian total emissions

At McGill

Green Crop Network

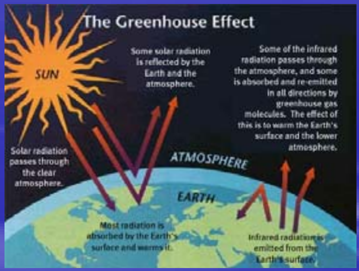
- Green Crop Network
- 14 Universities, 45 top researchers, almost 100 graduate students
- Reducing greenhouse gas emissions associated with crop production and, through biofuels, the energy sector
- Four themes
  1. N_2O
  2. Soil Carbon
  3. Photosynthesis
  4. Biofuel

Macdonald Campus of McGill University
Faculty of Agricultural & Environmental Sciences

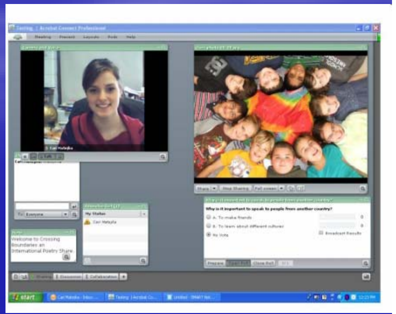
McGill

Plants, Ecosystems & Climate Change

- Green Crop Network course on climate change
- Developed in 2005 with B. Drake of the Smithsonian



- Given through internet video conferencing
  - Marratech then Adobe Connect
- Students from across Canada
- Speakers from across North America



- Next year input from California and Brazil

The  End!