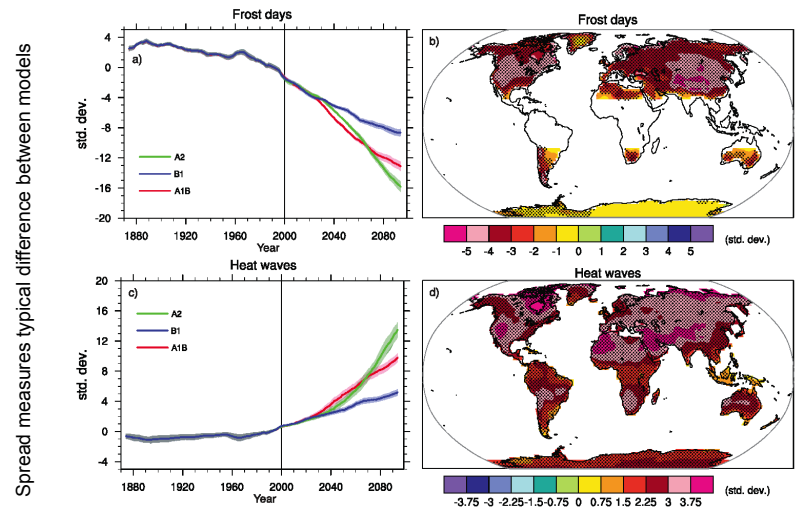


# Projected Extreme Events: Frosts and Heat Waves



Scenario A1B

IPCC AR4, Fig 10.19

heat waves = the longest period in one year of at least five consecutive days with maximum temperature at least 5C higher than the climatology of the same calendar day

# Climate changes due to human activity

Phenomenon* and direction of trend	Likelihood that trend occurred in late 20th century (typically post 1960)	Likelihood of a human contribution to observed trend*	Likelihood of future trends based on projections for 21st century using SRES scenarios
Warmer and fewer cold days and nights over most land areas	Very likely <sup>a</sup>	Likely <sup>d</sup>	Virtually certain <sup>d</sup>
Warmer and more frequent hot days and nights over most land areas	Very likely <sup>a</sup>	Likely (nights) <sup>d</sup>	Virtually certain <sup>d</sup>
Warm spells/heat waves. Frequency increases over most land areas	Likely	More likely than not <sup>f</sup>	Very likely
Heavy precipitation events. Frequency (or proportion of total rainfall from heavy falls) increases over most areas	Likely	More likely than not <sup>f</sup>	Very likely
Area affected by droughts increases	Likely in many regions since 1970s	More likely than not	Likely
Intense tropical cyclone activity increases	Likely in some regions since 1970	More likely than not <sup>f</sup>	Likely
Increased incidence of extreme high sea level (excludes tsunamis) <sup>g</sup>	Likely	More likely than not <sup>h</sup>	Likely <sup>i</sup>

IPCC 2007

Virtually certain > 99%    Very likely >90%    Likely >66%    More likely than not > 50%

# Changes in Regional Temperature Extremes: 2100 minus 2000 AD

Temperature-Related Phenomena	Projected changes
<b>Change in phenomenon</b>	<b>Projected changes</b>
Higher monthly absolute maximum of daily maximum temperatures (maxTmax) more hot / warm summer days	<b>VL (consistent across model projections)</b> maxTmax increases at same rate as the mean or median <sup>1</sup> over northern Europe, <sup>2</sup> Australia and New Zealand <sup>3</sup> <b>L (fairly consistent across models, but sensitivity to land surface treatment)</b> maxTmax increases more than the median over southern and central Europe, <sup>4</sup> and southwest USA <sup>5</sup> <b>L (consistent with projected large increase in mean temperature)</b> Large increase in probability of extreme warm seasons over most parts of the world <sup>6</sup>
Longer duration, more intense, more frequent heat waves / hot spells in summer	<b>VL (consistent across model projections)</b> Over almost all continents <sup>7</sup> , but particularly central Europe, <sup>8</sup> western USA, <sup>9</sup> East Asia <sup>10</sup> and Korea <sup>11</sup>
Higher monthly absolute maximum of daily minimum temperatures (maxTmin); more warm and fewer cold nights	<b>VL (consistent with higher mean temperatures)</b> Over most continents <sup>12</sup>
Higher monthly absolute minimum of daily minimum temperatures (minTmin)	<b>VL (consistent across model projections)</b> minTmin increases more than the mean in many mid- and high-latitude locations, <sup>13</sup> particularly in winter over most of Europe except the southwest <sup>14</sup>
Higher monthly absolute minimum of daily maximum temperatures (minTmax), fewer cold days	<b>L (consistent with warmer mean temperatures)</b> minTmin increases more than the mean in some areas <sup>15</sup>
Fewer frost days	<b>VL (consistent across model projections)</b> Decrease in number of days with below-freezing temperatures everywhere <sup>16</sup>
Fewer cold outbreaks; fewer, shorter, less intense cold spells / cold extremes in winter	<b>VL (consistent across model projections)</b> Northern Europe, South Asia, East Asia <sup>17</sup> <b>L (consistent with warmer mean temperatures)</b> Most other regions <sup>18</sup>
Reduced diurnal temperature range	<b>L (consistent across model projections)</b> Over most continental regions, night temperatures increase faster than the day temperatures <sup>19</sup>
Temperature variability on interannual and daily time scales	<b>L (general consensus across model projections)</b> Reduced in winter over most of Europe <sup>20</sup> Increase in central Europe in summer <sup>21</sup>

VL  
Very Likely  
> 90%

L  
Likely  
> 66%

IPCC 2007 Tab 11.2

# Changes in Regional Moisture Extremes: 2100 minus 2000 AD

Moisture-Related Phenomena	Projected changes
<b>Phenomenon</b>	<b>Projected changes</b>
Intense precipitation events	<b>VL (consistent across model projections; empirical evidence, generally higher precipitation extremes in warmer climates)</b> Much larger increase in the frequency than in the magnitude of precipitation extremes over most land areas in middle latitudes, <sup>22</sup> particularly over northern Europe, <sup>23</sup> Australia and New Zealand <sup>24</sup> Large increase during the Indian summer monsoon season over Arabian Sea, tropical Indian Ocean, South Asia <sup>25</sup> Increase in summer over south China, Korea and Japan <sup>26</sup> <b>L (some inconsistencies across model projections)</b> Increase over central Europe in winter <sup>27</sup> Increase associated with tropical cyclones over Southeast Asia, Japan <sup>28</sup> <b>Uncertain</b> Changes in summer over Mediterranean and central Europe <sup>29</sup> <b>L decrease (consistent across model projections)</b> Iberian Peninsula <sup>30</sup>
Intense precipitation events	<b>L (consistent across model projections)</b> Increase over central Europe in winter <sup>27</sup> Increase associated with tropical cyclones over Southeast Asia, Japan <sup>28</sup> <b>Uncertain</b> Changes in summer over Mediterranean and central Europe <sup>29</sup> <b>L decrease (consistent across model projections)</b> Iberian Peninsula <sup>30</sup>
Wet days	<b>L (consistent across model projections)</b> Increase in number of days at high latitudes in winter, and over northwest China <sup>31</sup> Increase over the Inter-Tropical Convergence Zone <sup>32</sup> Decrease in South Asia <sup>33</sup> and the Mediterranean area <sup>34</sup>
Dry spells (periods of consecutive dry days)	<b>VL (consistent across model projections)</b> Increase in length and frequency over the Mediterranean area <sup>35</sup> , southern areas of Australia, New Zealand <sup>36</sup> <b>L (consistent across model projections)</b> Increase in most subtropical areas <sup>37</sup> Little change over northern Europe <sup>38</sup>
Continental drying and associated risk of drought	<b>L (consistent across model projections; consistent change in precipitation minus evaporation, but sensitivity to formulation of land surface processes)</b> Increased in summer over many mid-latitude continental interiors, e.g., central <sup>39</sup> and southern Europe, Mediterranean area, <sup>40</sup> in boreal spring and dry periods of the annual cycle over Central America <sup>41</sup>

VL  
Very Likely  
> 90%

L  
Likely  
> 66%

IPCC 2007 Tab 11.2

## Changes in Regional Storminess Extremes: 2100 minus 2000 AD

Tropical Cyclones (typhoons and hurricanes)	
Change in phenomenon	Projected changes
Increase in peak wind intensities	L (high-resolution AGCM and embedded hurricane model projections) Over most tropical cyclone areas <sup>12</sup>
Increase in mean and peak precipitation intensities	L (high-resolution AGCM projections and embedded hurricane model projections) Over most tropical cyclone areas <sup>13</sup> South, <sup>14</sup> East <sup>15</sup> and southeast Asia <sup>16</sup>
Changes in frequency of occurrence	M (some high-resolution AGCM projections) Decrease in number of weak storms, increase in number of strong storms <sup>17</sup> M (several climate model projections) Globally averaged decrease in number, but specific regional changes dependent on sea surface temperature change <sup>18</sup> Possible increase over the North Atlantic <sup>19</sup>
Extratropical Cyclones	
Change in phenomenon	Projected changes
Changes in frequency and position	L (consistent in AOGCM projections) Decrease in the total number of extratropical cyclones <sup>20</sup> Slight poleward shift of storm track and associated precipitation, particularly in winter <sup>21</sup>
Change in storm intensity and winds	L (consistent in most AOGCM projections, but not explicitly analysed for all models) Increased number of intense cyclones <sup>22</sup> and associated strong winds, particularly in winter over the North Atlantic, <sup>23</sup> central Europe <sup>24</sup> and Southern Island of New Zealand <sup>25</sup> More likely than not
Increased wave height	L (based on projected changes in extratropical storms) Increased occurrence of high waves in most mid-latitude areas analysed, particularly the North Sea <sup>27</sup>

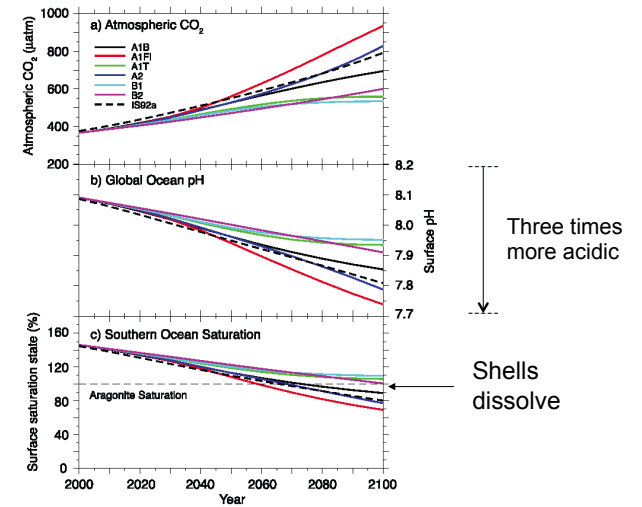
VL  
Very Likely  
> 90%

L  
Likely  
> 66%

M  
Medium  
Confidence

IPCC 2007 Tab 11.2

## Ocean Acidification



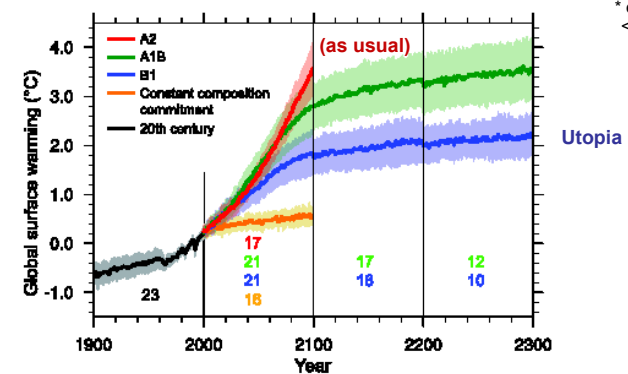
IPCC AR4, Fig 10.24

## 3. Projections of Climate Change: 2100 and beyond

- The projected forcings
- The projected climate change: 2000 to 2100
  - Global
  - Regional
  - Sea Level
  - Cryosphere
  - Extreme Events
- The long term outlook 2100 - 2300

## Global Annual Average Surface Temperature

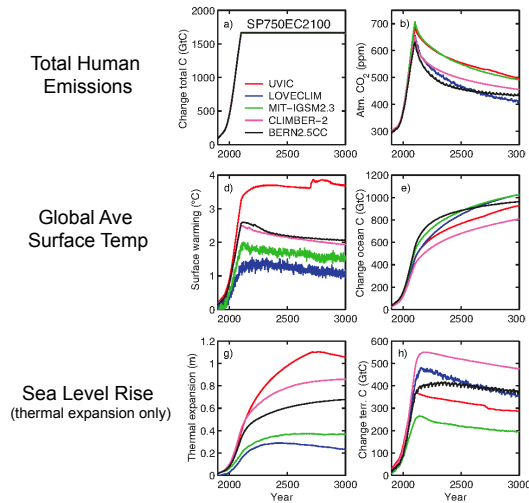
Values beyond 2100 assume stabilized GH gas concentrations\*



Referenced to the 1980-1999 Average Temperature  
Solid lines: average of all models used. The number of models used depends on the emission scenario; shaded area is the standard deviation of the models. Gold curve is for **Zero** emissions beyond 2100.

## The long term outlook: 2000-3000AD

If we stop *all* human CO<sub>2</sub> emissions in 2100, how long will it take to reach the pre-industrial climate\*?

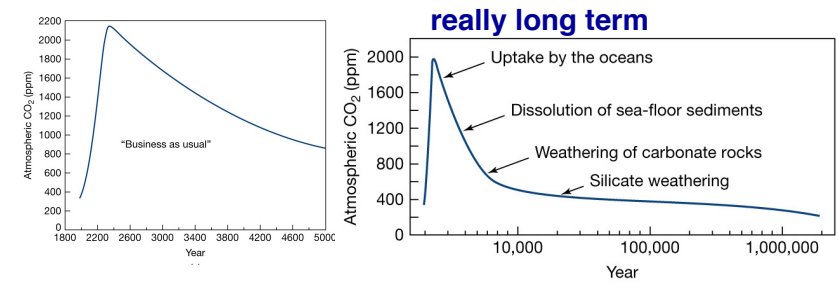


CO<sub>2</sub> in atmosphere peaks at 750 in 2100

CO<sub>2</sub> in ocean increases rapidly until ~2200, then slowly for 1000+ years

CO<sub>2</sub> in land biomass increases rapidly until ~2200, then slowly declines

## The VERY long term adjustment



The atmospheric CO<sub>2</sub> concentration - and hence climate - returns to near pre-industrial (PI) levels by 10,000 yrs

Almost all of the human emissions of CO<sub>2</sub> end up in the ocean

Kump et al. (2003), T Earth System, Box Fig 13-2

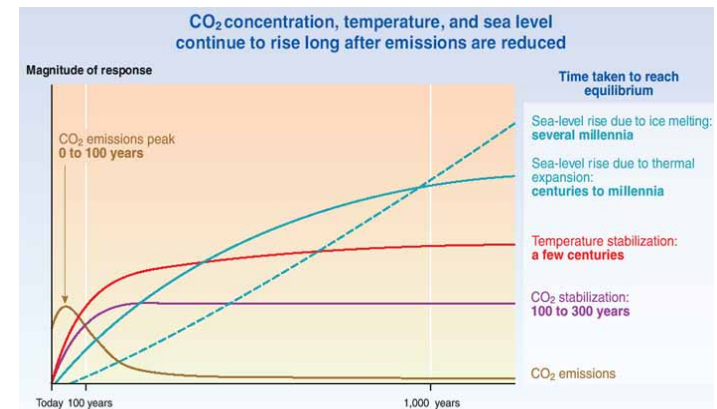
How long would forcing by humans last if we suddenly stopped emitting everything?

- Carbon Dioxide
  - About 1/2 removed in **1000 years** (absorbed in the deep ocean)
  - Most gone by 10,000 years
- Methane
  - About 70% removed in 10 years (absorbed into soil)
  - Most gone by 20 years
- CFCs
  - 50 to 20,000 years, depending on compound
- Aerosols
  - In troposphere, about 5 days
  - In stratosphere, about 2 years

**Editorial note:** Carbon credits for reducing methane will, at best, waste money. It will likely lead to *more* CO<sub>2</sub> in the atmosphere.

## The long term outlook: 2000-3000AD

If -- in the next 200-300yrs or so-- we reduce CO<sub>2</sub> emissions to a small constant rate (<10% of today's emission), the climate will eventually equilibrate. How long will it take to reach the new equilibrium?



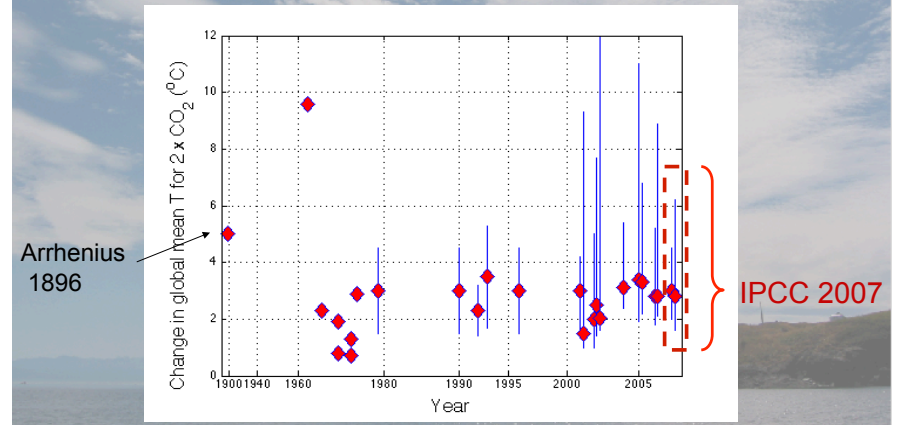
# Global Warming: Science, Projections and Uncertainties

An overview of the basic science

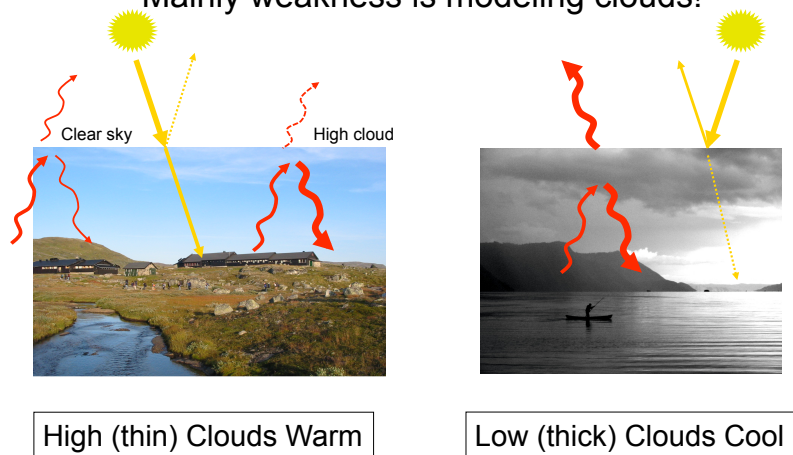
1. A Brief History of "Global Warming"
2. Climate Change: 1850-2007
3. Projections of Climate Change: 2100 and beyond
4. What's new in Climate Science?
5. Conclusions

## 4. What's new? A better quantification of the spread in the model response and reasons for the spread

*Climate Sensitivity*: the change in global temperature for a doubling of carbon dioxide



## Why is there uncertainty in the climate models? Mainly weakness is modeling clouds!



In today's climate, *the net effect of clouds is to cool the planet* (albedo effect wins over greenhouse effect)

## Clouds and Climate



## What happens when you double atmos CO<sub>2</sub>?

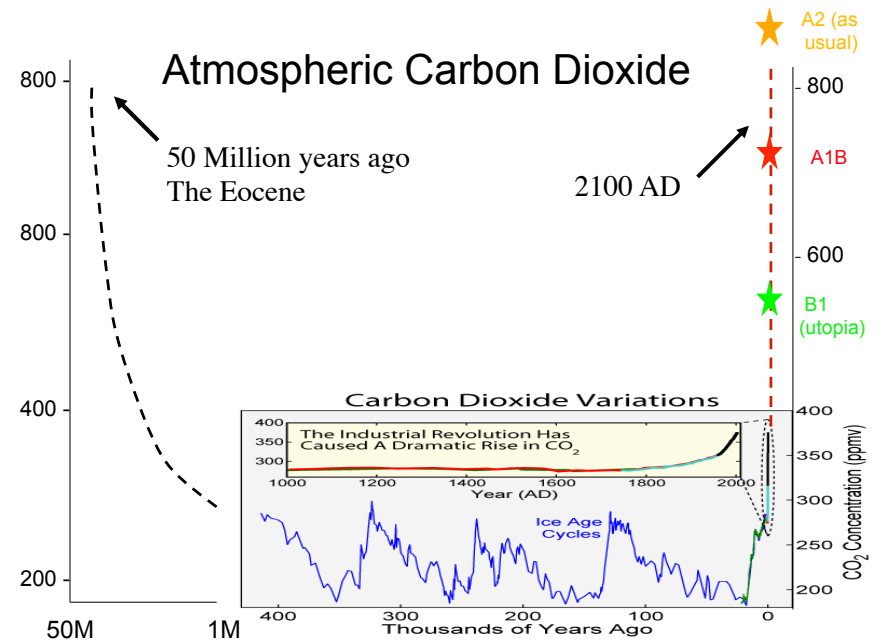
- With no feedbacks: increase temp by 1.2°C
- With all feedbacks (mainly water vapor) *except clouds*: increase by +1.9°C +/- 0.15°C
- With all feedbacks (*incl. clouds*): +3.2°C +/- 0.7°C

Clouds are a major positive feedback (ie, clouds cool less than today when CO<sub>2</sub> is doubled), but amplitude is uncertain.

More of these .... ...and/or... ... less of these.



Clouds are the major source of the differences between models (i.e., for the uncertainty in the projections of the climate response to increasing CO<sub>2</sub>).



In 100 years, the atmospheric CO<sub>2</sub> will reach 500-1000 ppm, which was last experienced during the EOCENE (55 to 36 million years ago)

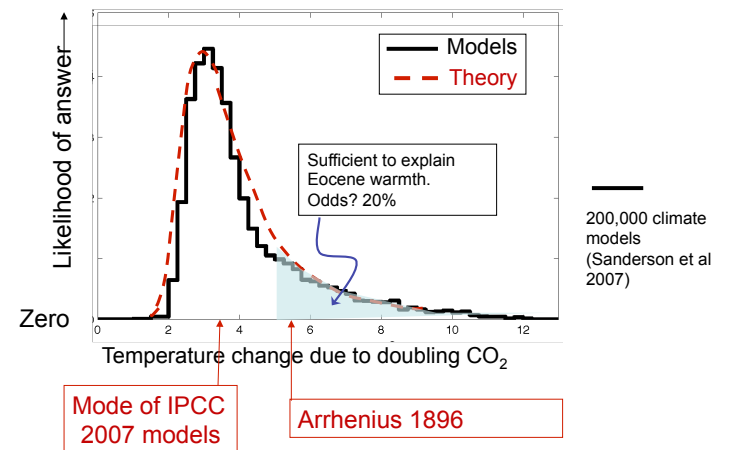


The Eocene climate was warm, even at high latitudes:

- palm trees flourished in Wyoming and Antarctica was a pine forest
- crocodiles lived in the Arctic
- deep ocean temperature was 55°F (today it is ~35°F)
- sea level was at least 300 feet higher than today

\* Climate models with mid-range climate sensitivity simulate an Eocene that is much too cold compared to the fossil records

## The Expected Distribution of Climate Sensitivity



Roe and Baker (2007) provide a simple theory for estimating the *expected* distribution of model responses due to model uncertainty.

*Implication of the fossils: true response is ~1.7x IPCC mean.*

## Summary: Climate in the 20<sup>st</sup> Century

- Greenhouse gases have increased over the past 100 years to do human activity, and this has caused the climate to change:
  - Warming -- more over continents than oceans; more in high latitudes than in tropics; more at night than day
  - fewer frost days per year; more extreme warm days, etc.
  - decreased sea ice extent and volume
  - higher sea levels; more acidic ocean
- The warming would have been much greater, if not for the increase in atmospheric aerosols due to burning of coal and atmospheric biomass

From IPCC 2007

## Summary: Climate in the 21<sup>st</sup> Century

- The climate is projected to change over this century because of human-induced changes in greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>, SO<sub>2</sub>, etc)
- The global, annual averaged temperature will likely increase by ~ +3°C [2.4 to 6.4°C]
  - Only the high-end estimate is consistent with the geological records
- The uncertainty in the climate projections is roughly equally due to
  - Uncertainty in emissions
  - Uncertainty in models

From IPCC 2007

## Summary: Climate in the 21<sup>st</sup> Century (cont)

• Warming will not be uniform in space or time. It is *very likely* that

- Warming -- more over continents than oceans; more in high latitudes than in tropics; more in winter than summer, more at night than day
- Fewer frost days per year
- More extreme warm days and nights

• Other climate changes that are *very likely*\* over the next 100 years include:

- the hydrologic cycle will speed up
- the area covered by snow and sea ice will decrease
- the subtropics will be drier (less precip/more evaporation)
- the sea level will rise
- The upper ocean will become twice as acidic.

(\* very likely: defined by the IPCC as greater than 90% chance) From IPCC 2007

## Summary: Climate in the 21<sup>st</sup> Century (cont)

- The changes over the next 100 years will be much, much greater than the changes seen over the past 150 years that have been attributed to increased greenhouse gases and aerosols.
- The rate of change is 100 - 1000 times faster than nature
- The changes in climate will have a significant and increasing effect on temperature, precipitation, snow pack, river flows (amount and timing), and soil moisture.

-> **agriculture**, fisheries, forestry, aquaculture ...  
-> ecosystems and biodiversity  
-> flood control policy, hydropower, vector borne diseases, ...

- We now understand the range in the warming projected for 2100 by the various models, and can better quantify the likelihood of a very large warming (compared to average warming, used by IPCC)

From IPCC 2007