Physics of Climate Change

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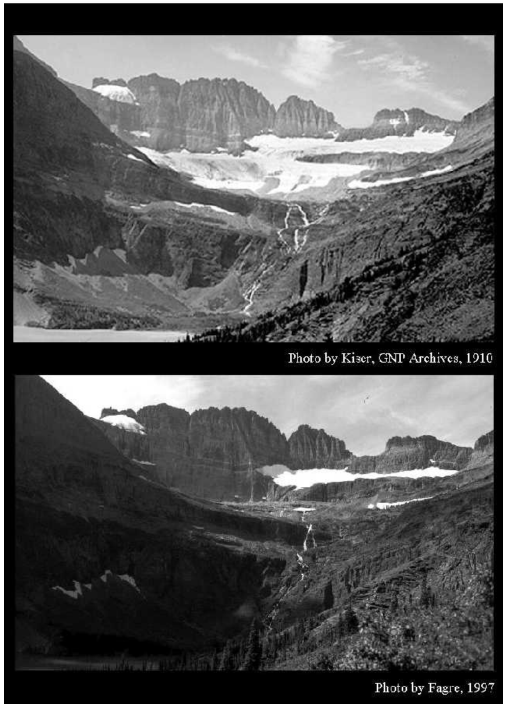
Physics 301 Physics Today – March 14, 2017

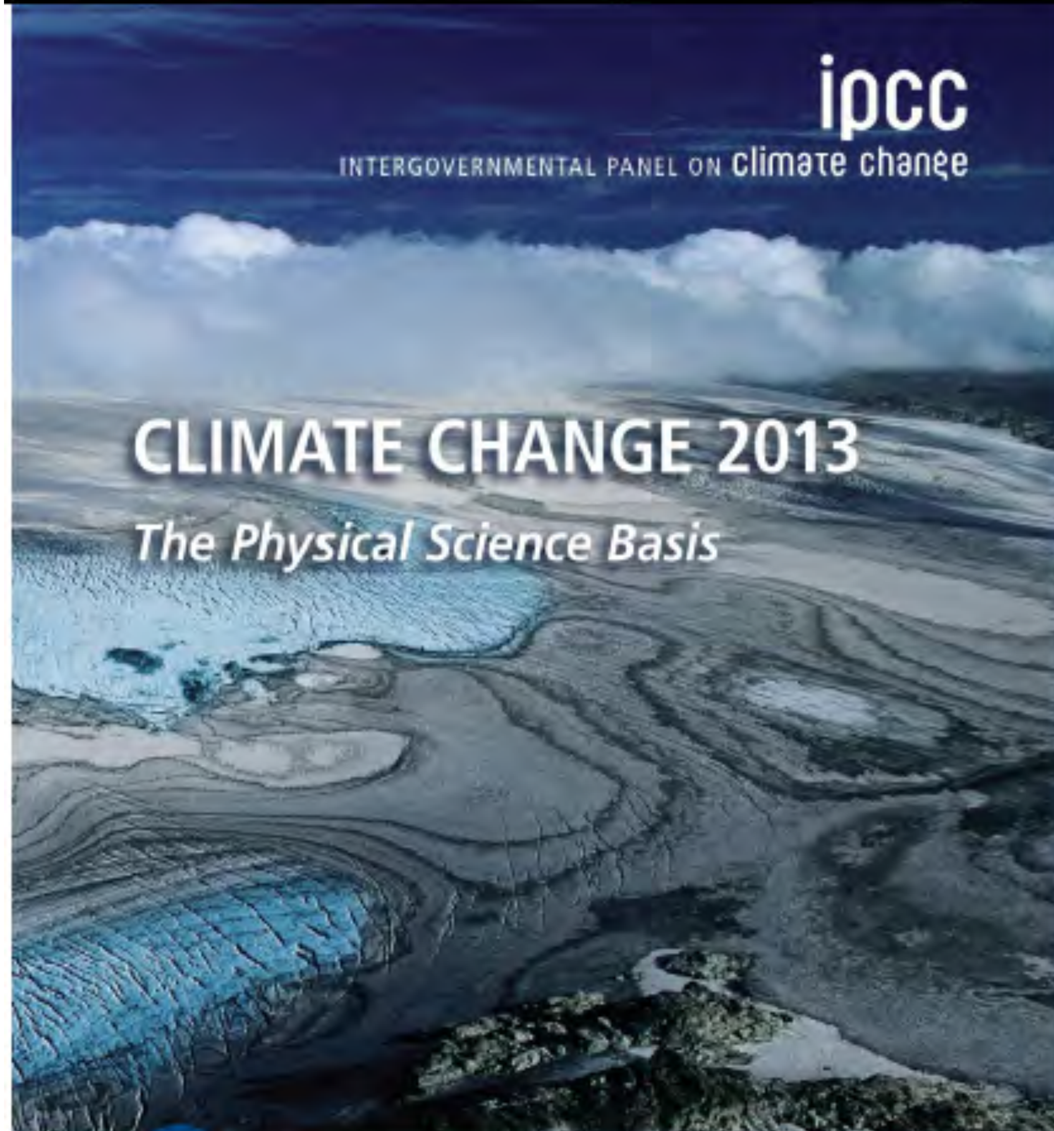
Grinnell Glacier and Grinnell Lake
Glacier National Park, 1910-1997

Overview

- Greenhouse effect
- Greenhouse gases
- Observations of climate change
- Climate change in the upper atmosphere
- IPCC conclusions
- Strategies for Reducing Warming Gases
- Conclusions

Grinnell Glacier and Grinnell Lake
Glacier National Park, 1910-1997





ipcc

INTERGOVERNMENTAL PANEL ON climate change

CLIMATE CHANGE 2013

The Physical Science Basis

WG I

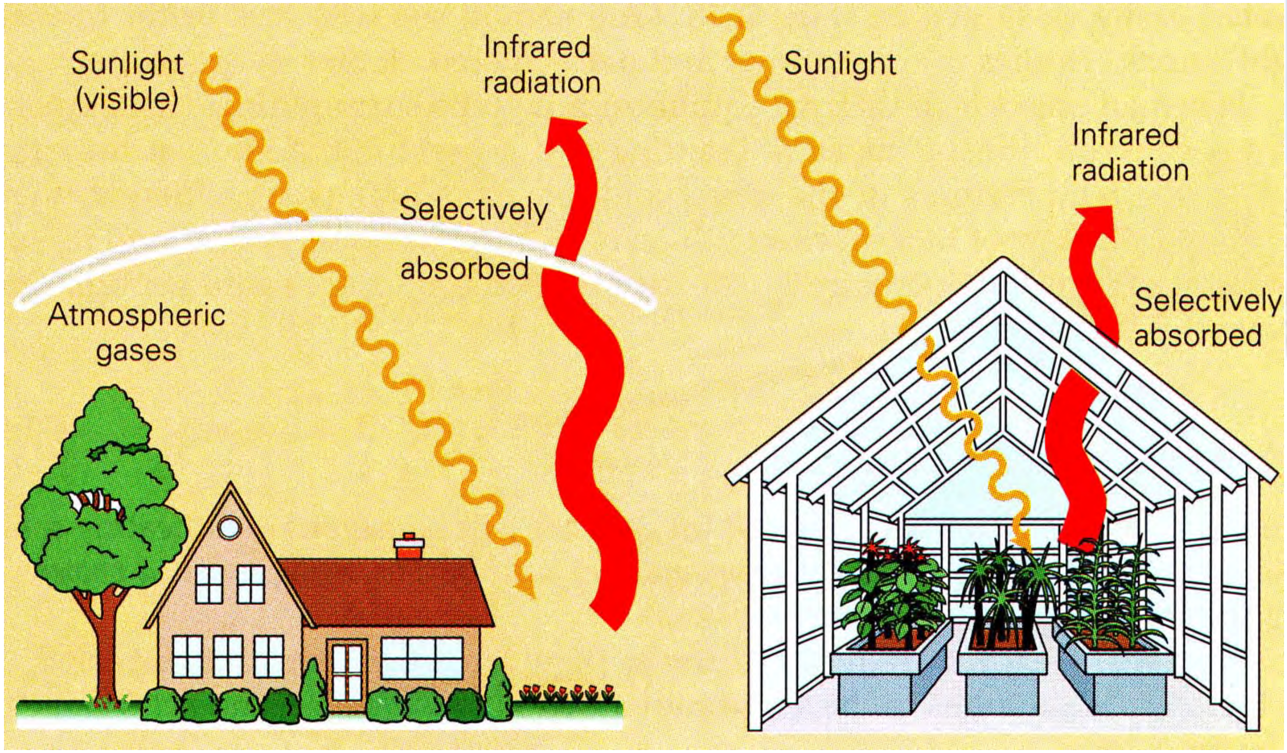
WORKING GROUP I CONTRIBUTION TO THE FIFTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE

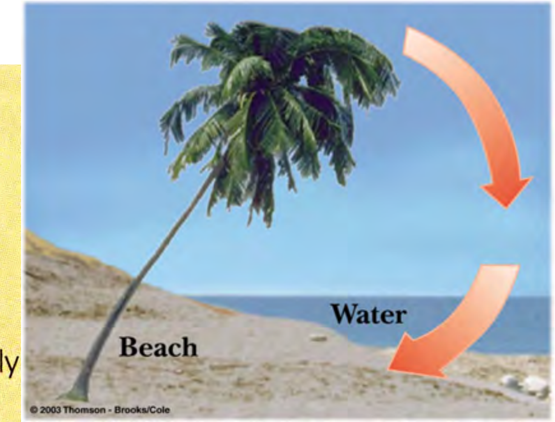
WMO UNEP

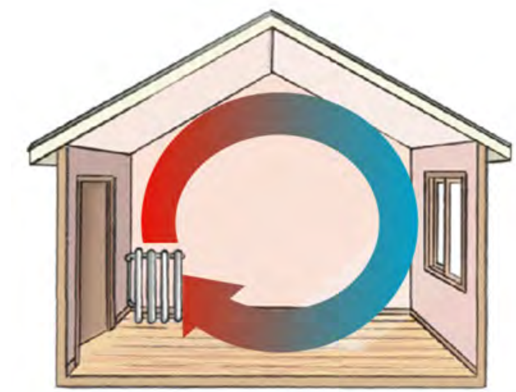
Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions

Human influence on the climate system is clear

Warming in the climate system is unequivocal



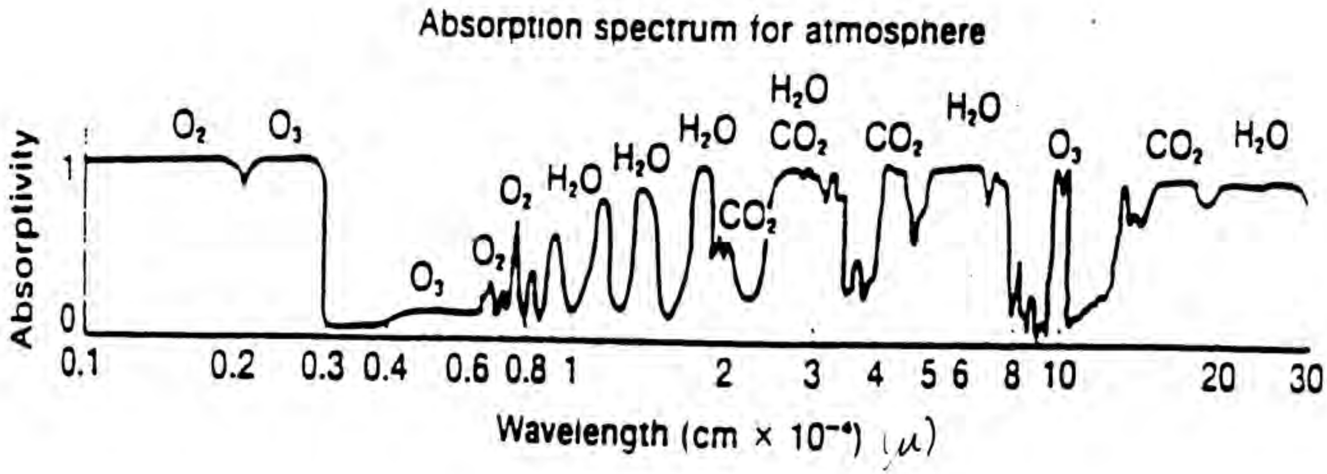


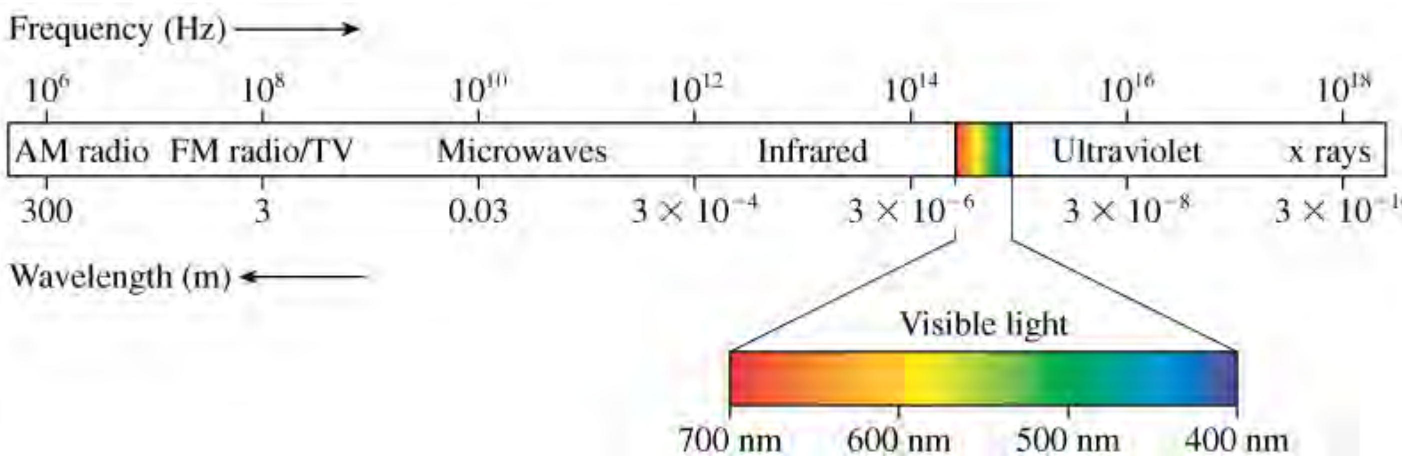


From Wilson and Buffa

From Serway & Faughn

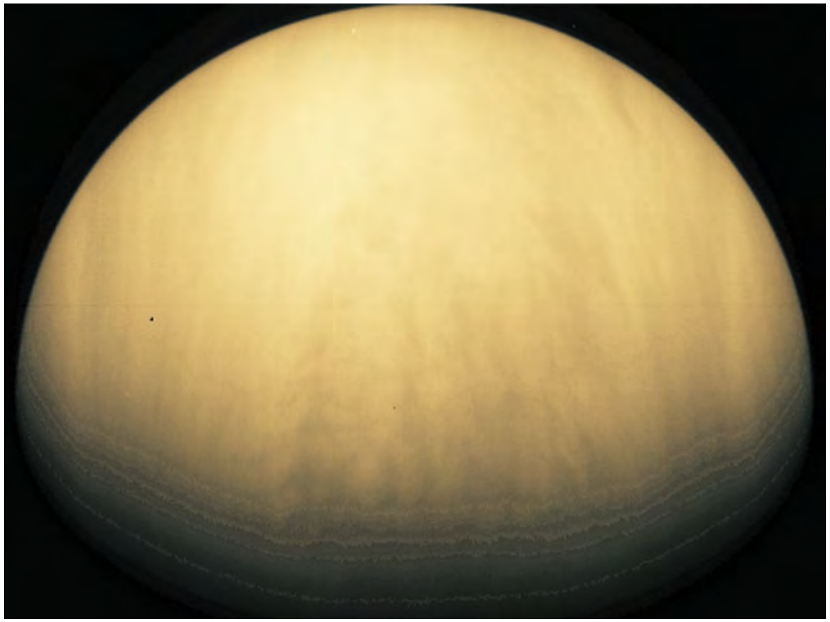
There is an analogy between the atmosphere and a greenhouse that has limitations due to convection





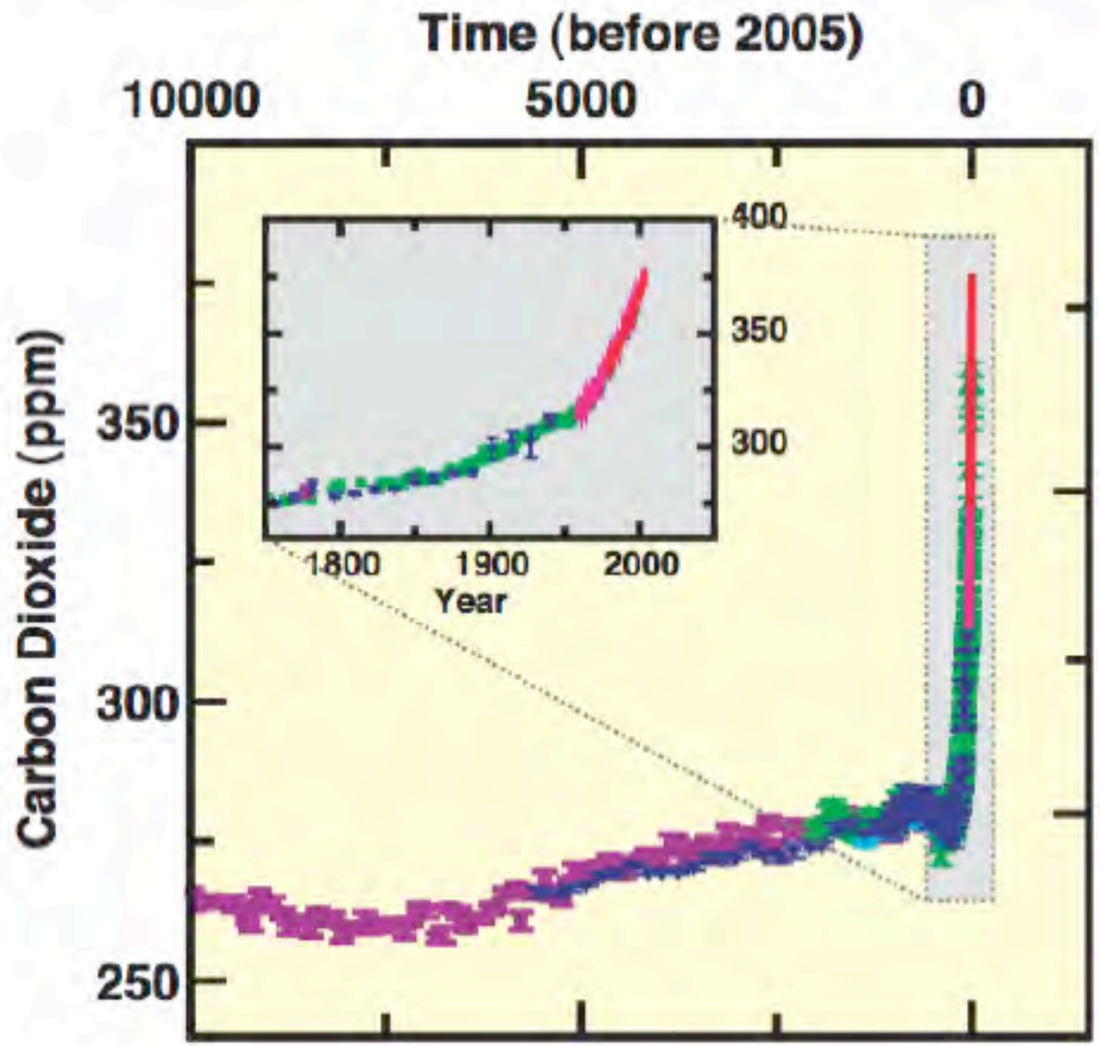
$c = f\lambda \quad E = hf$

VENUS

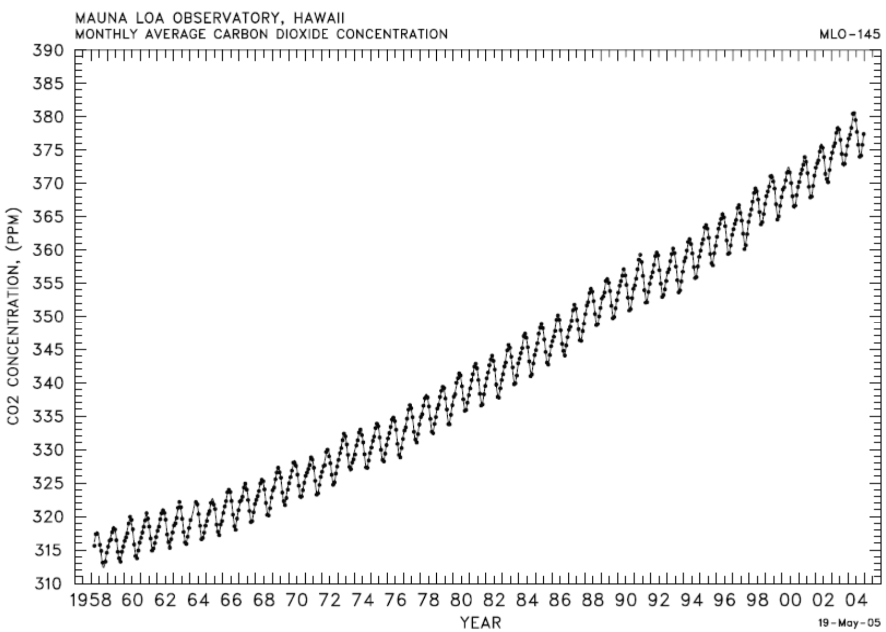


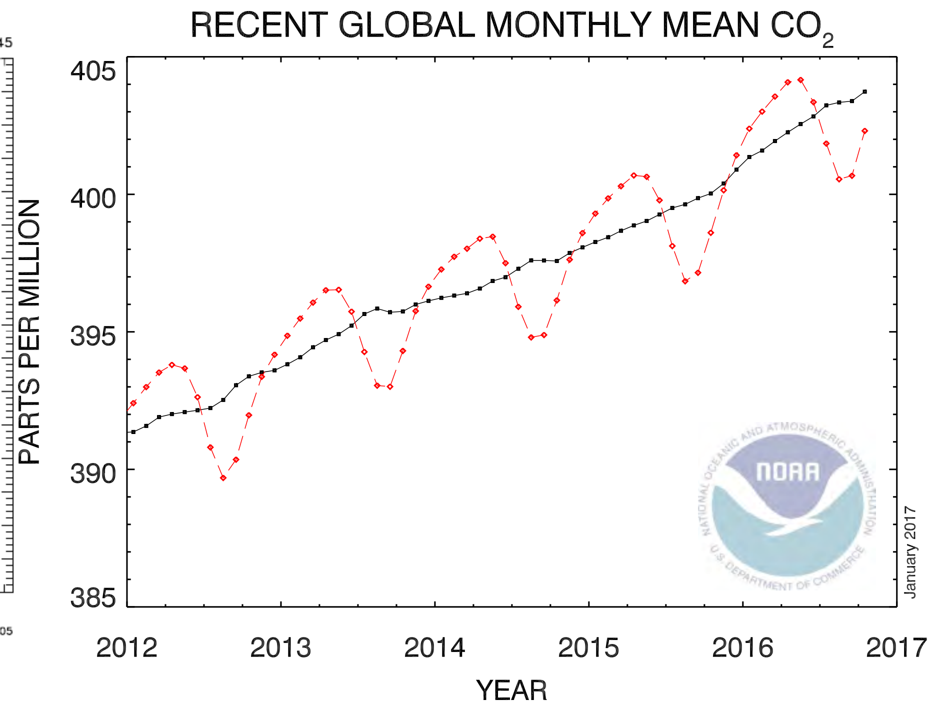
From Astronomy Picture of the Day and NASA

Changes in Heat-trapping Gases from Ice-Core and Modern Data

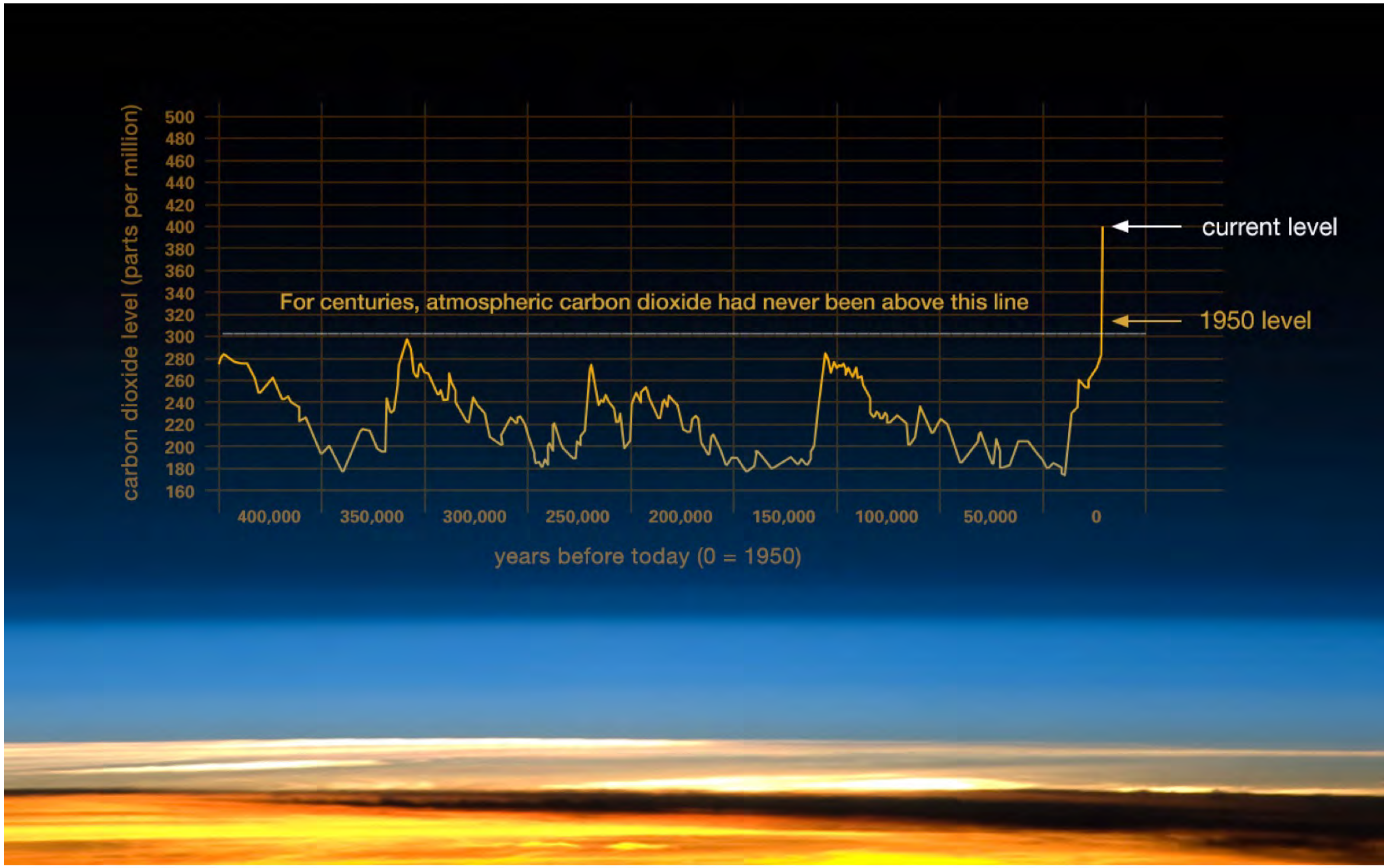


Source: IPCC *Climate Change 2007: The Physical Science Basis*—Summary for Policymakers.

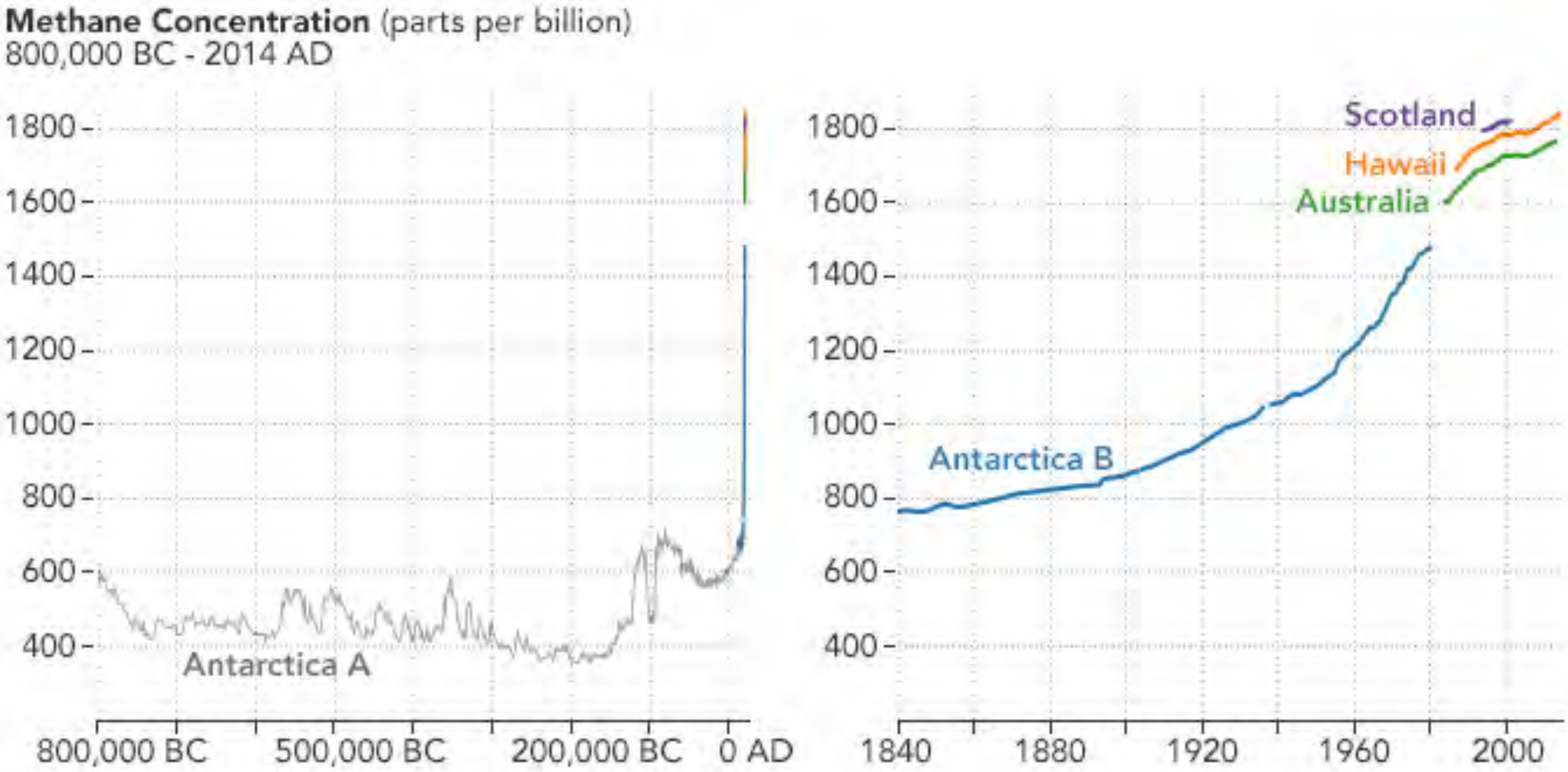

MAUNA LOA OBSERVATORY, HAWAII
MONTHLY AVERAGE CARBON DIOXIDE CONCENTRATION
MLO-145
CO2 CONCENTRATION, (PPM)
YEAR
19-May-05


RECENT GLOBAL MONTHLY MEAN CO_2
PARTS PER MILLION
YEAR
January 2017

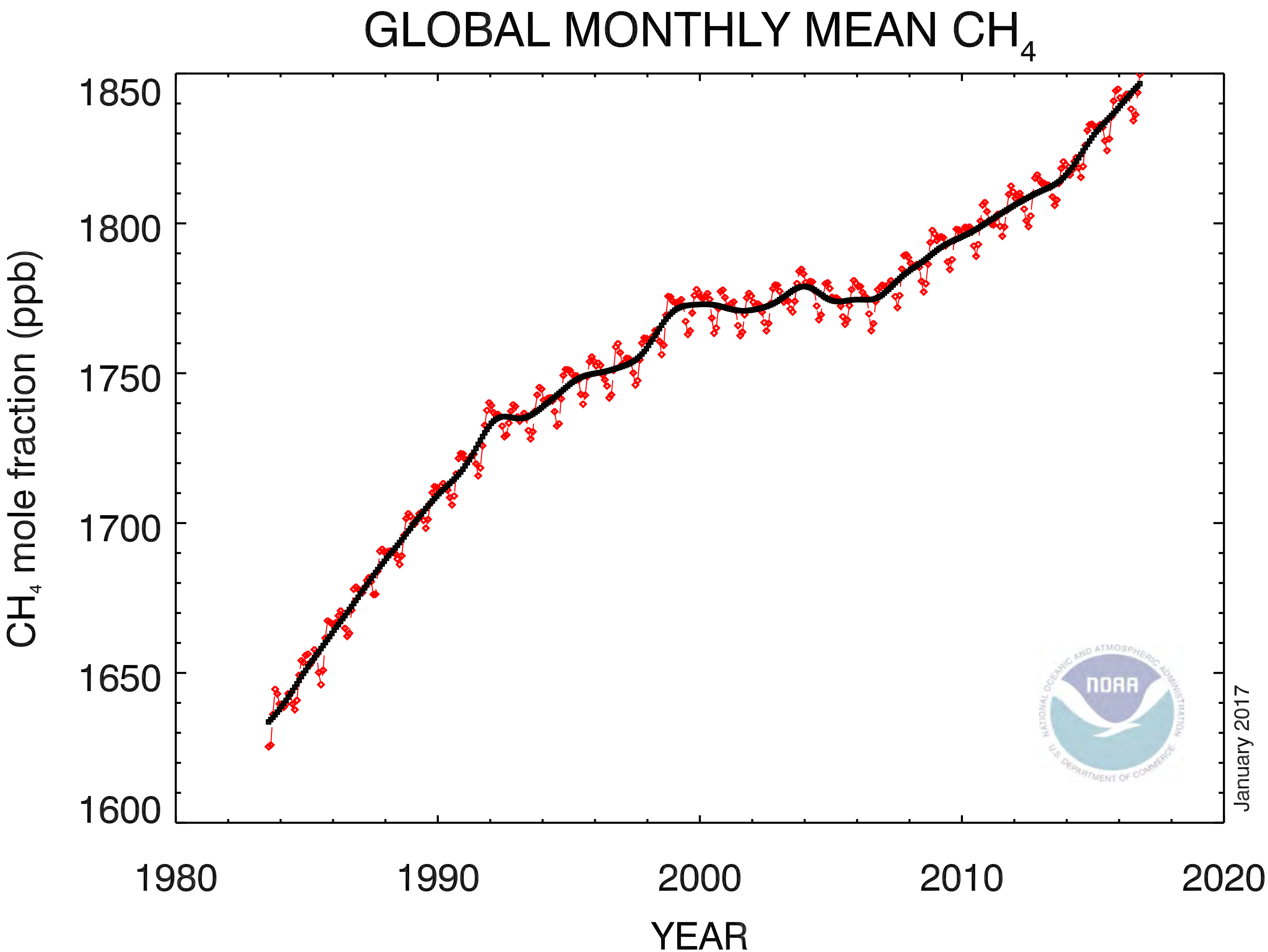
Historical Atmospheric Carbon Dioxide Concentrations



http://climate.nasa.gov/evidence/



http://earthobservatory.nasa.gov/IOTD/view.php?id=87681



GLOBAL MONTHLY MEAN CH_4
CH_4 mole fraction (ppb)
1850
1800
1750
1700
1650
1600
1980
1990
2000
2010
2020
YEAR
NOAA
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE
January 2017

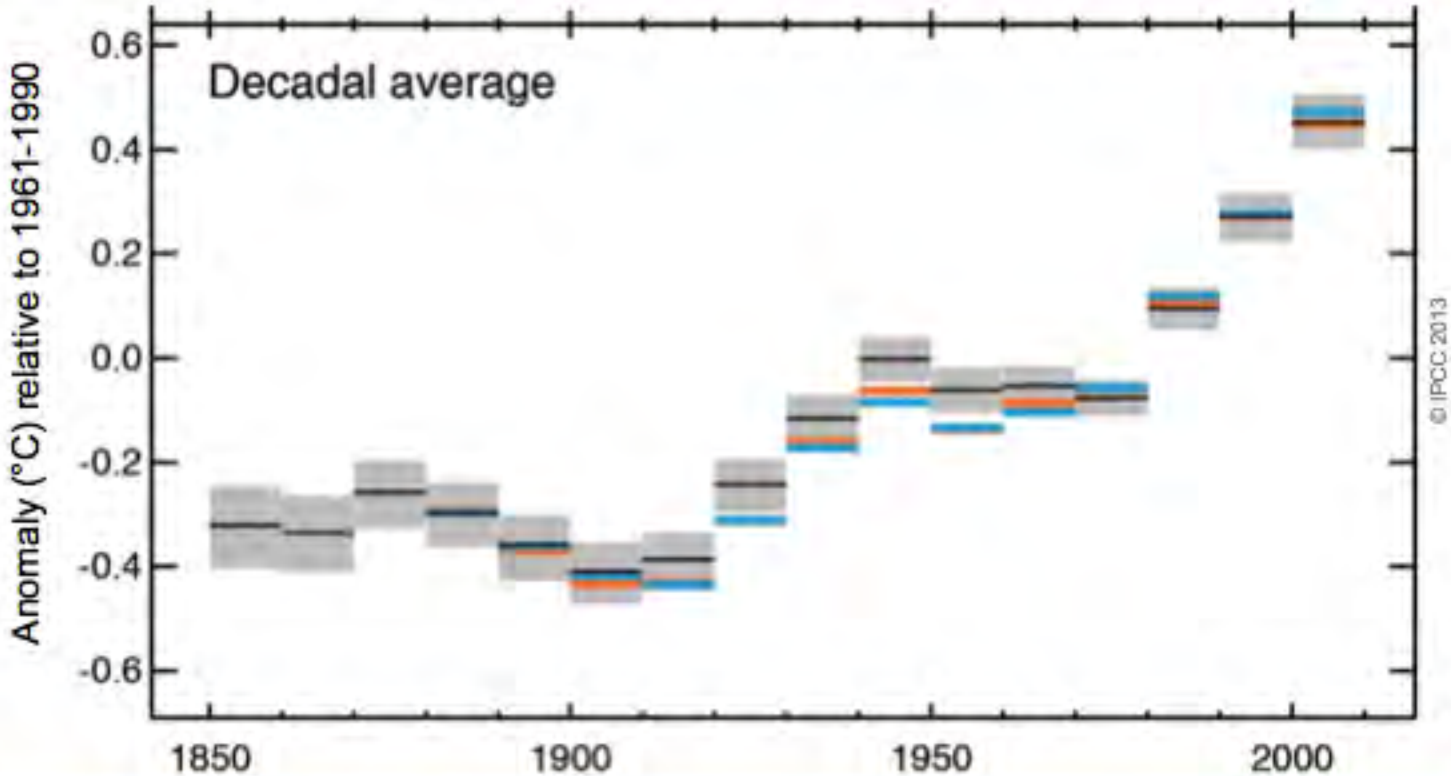


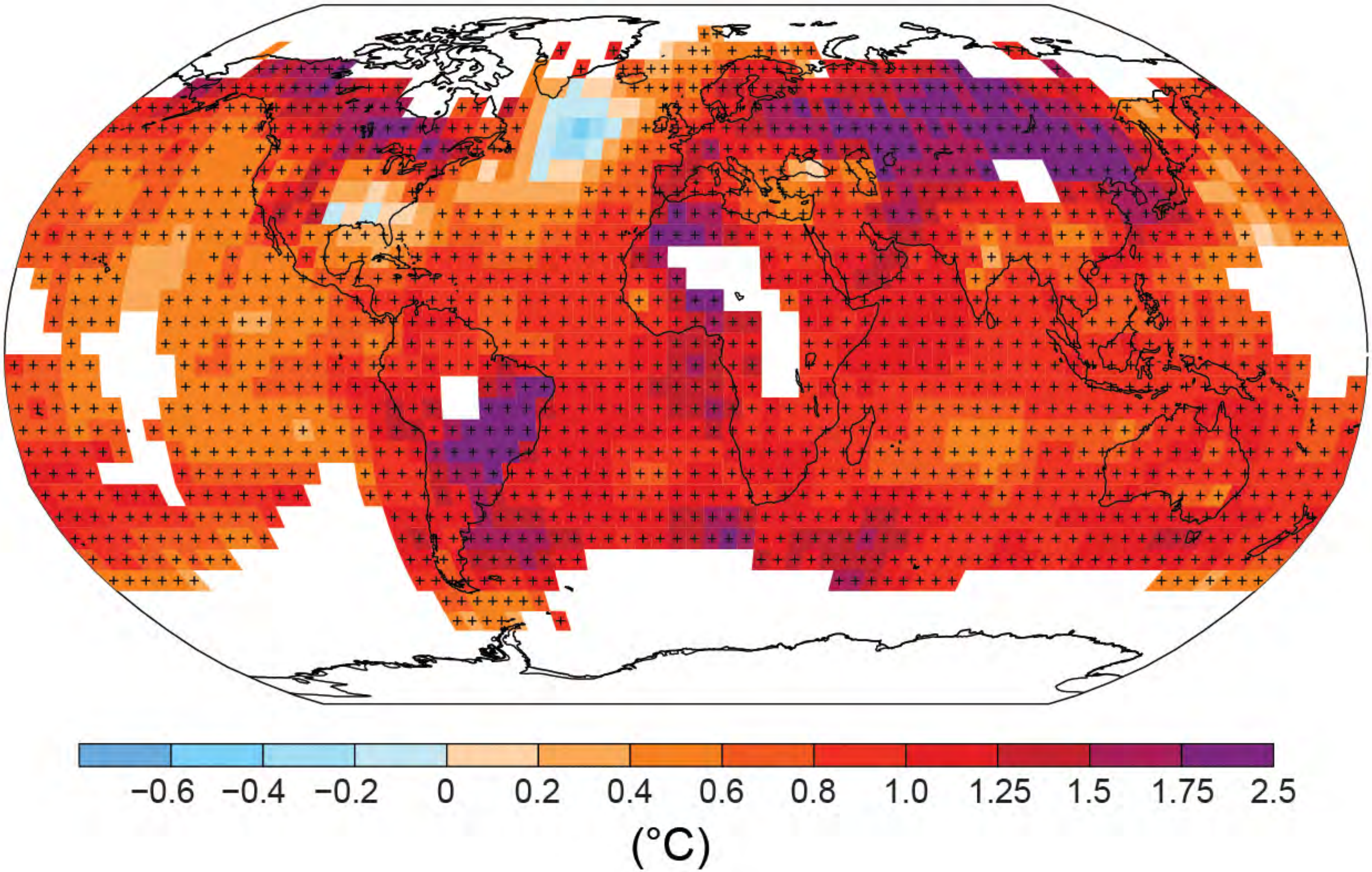
Fig. SPM.1a

Each of the last three decades has been successively warmer at the Earth's surface than any preceding decade since 1850.

In the Northern Hemisphere, 1983–2012 was *likely* the warmest 30-year period of the last 1400 years (*medium confidence*).

Figure SPM.1b

Observed change in surface temperature 1901-2012



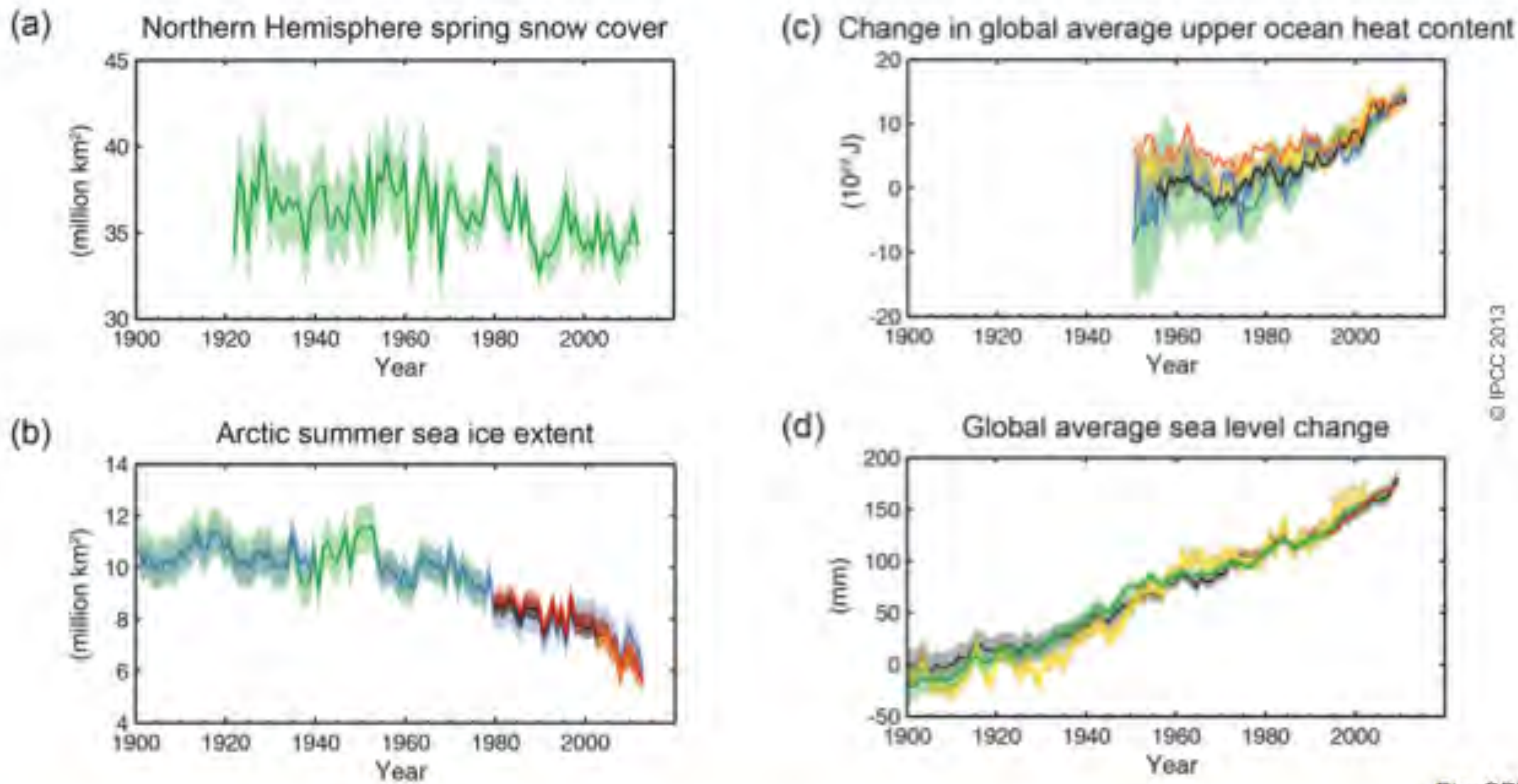


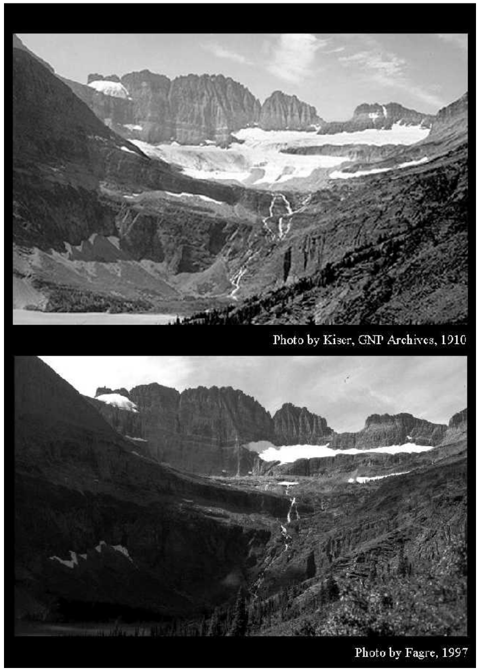
Fig. SPM.3

Warming of the climate system is unequivocal, [...]

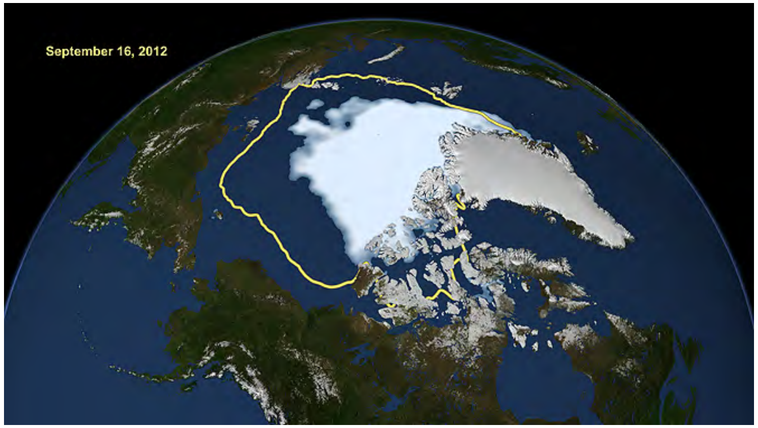
Signs of climate change

- January 2000 to December 2009 was the warmest decade on record
- Mountain glaciers and snow cover have declined on average in both hemispheres
- Global average sea level rise
- Increasing Arctic temperatures
- Shrinking of Arctic sea ice
- More intense and longer droughts
- Increased frequency of heavy precipitation events
- More extreme temperature events
- Decreased lake ice cover

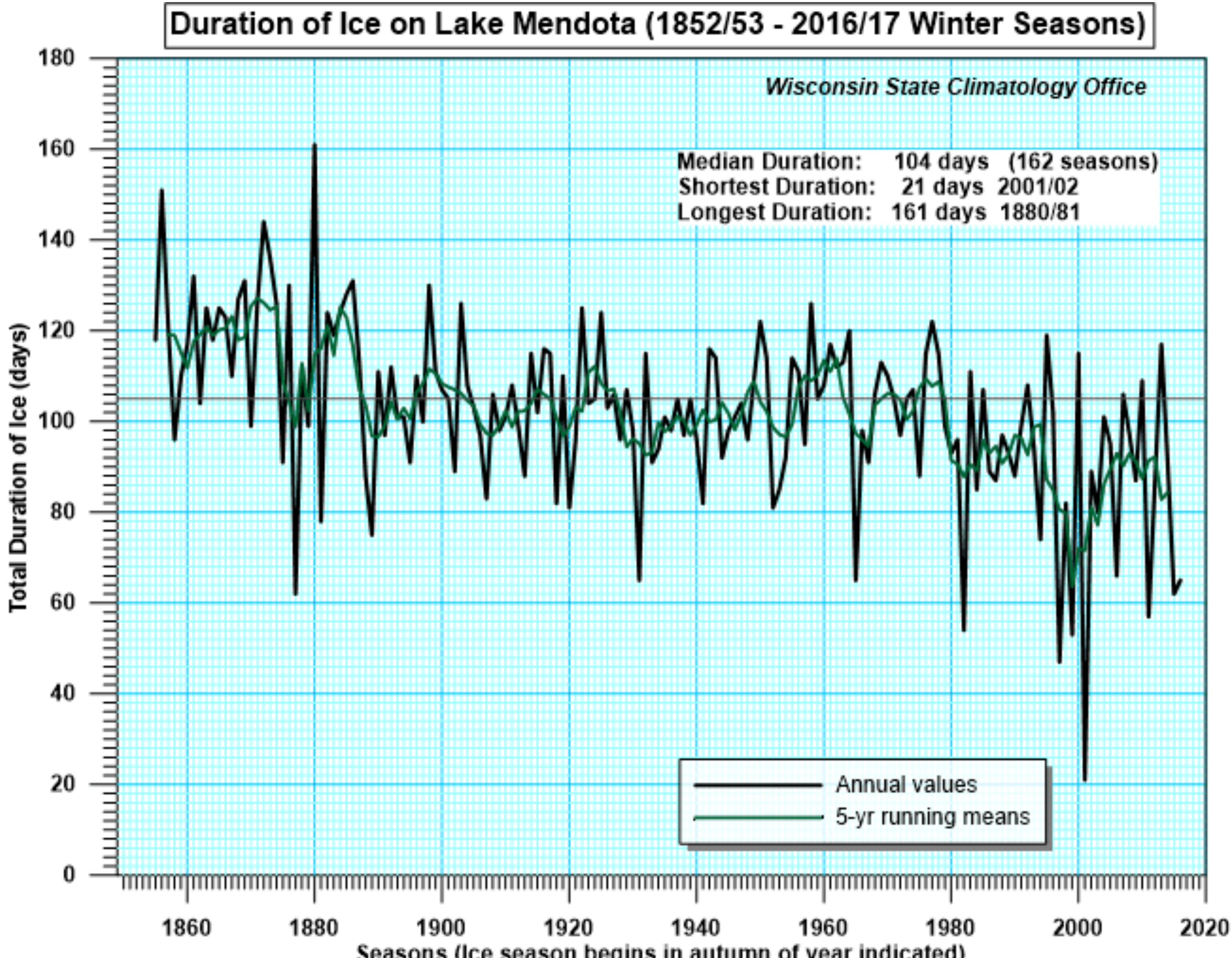
Grinnell Glacier and Grinnell Lake
Glacier National Park, 1910-1997



From the United States Geological Survey



From NASA


Duration of Ice on Lake Mendota (1852/53 - 2016/17 Winter Seasons)
Wisconsin State Climatology Office
Median Duration: 104 days (162 seasons)
Shortest Duration: 21 days 2001/02
Longest Duration: 161 days 1880/81
Total Duration of Ice (days)
0
20
40
60
80
100
120
140
160
180
1860
1880
1900
1920
1940
1960
1980
2000
2020
Seasons (Ice season begins in autumn of year indicated)
Annual values
5-yr running means

Projected Impacts in the Great Lakes Region

- More frequent, more severe, and longer-lasting heat waves
- Reduced air quality
- Increased incidence of insect and water-borne diseases
- Increased frequency of heavy rain storms leading to a greater incidence of flooding
- Increased health risks related to extreme heat
- Threats to water quality due to run-off
- Changes in species' populations such as trout, spruce, fir, and birds

Wisconsin Initiative on Climate Change Impacts

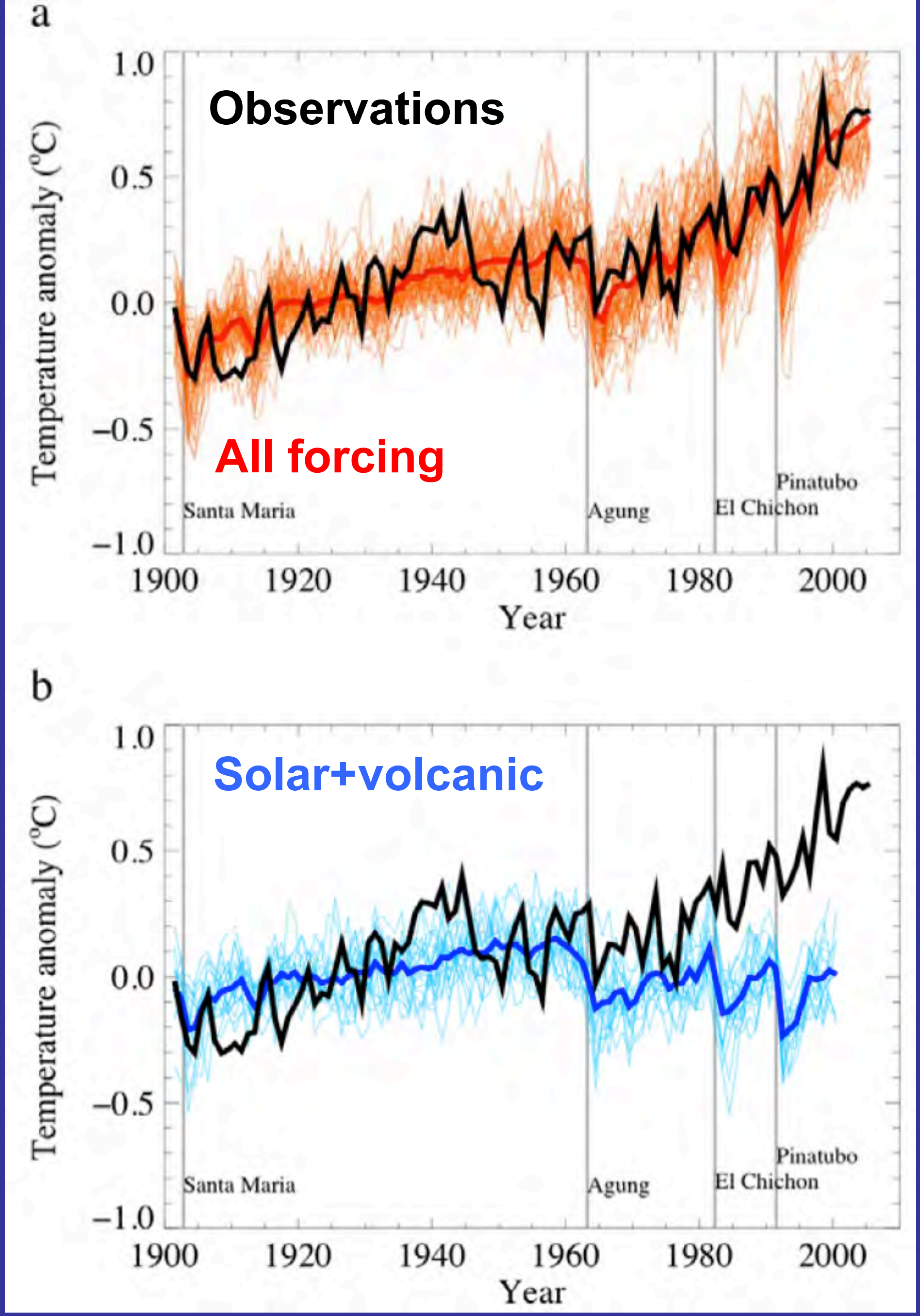
www.ssec.wisc.edu

Attribution

- are observed changes consistent with

☑expected responses to forcings

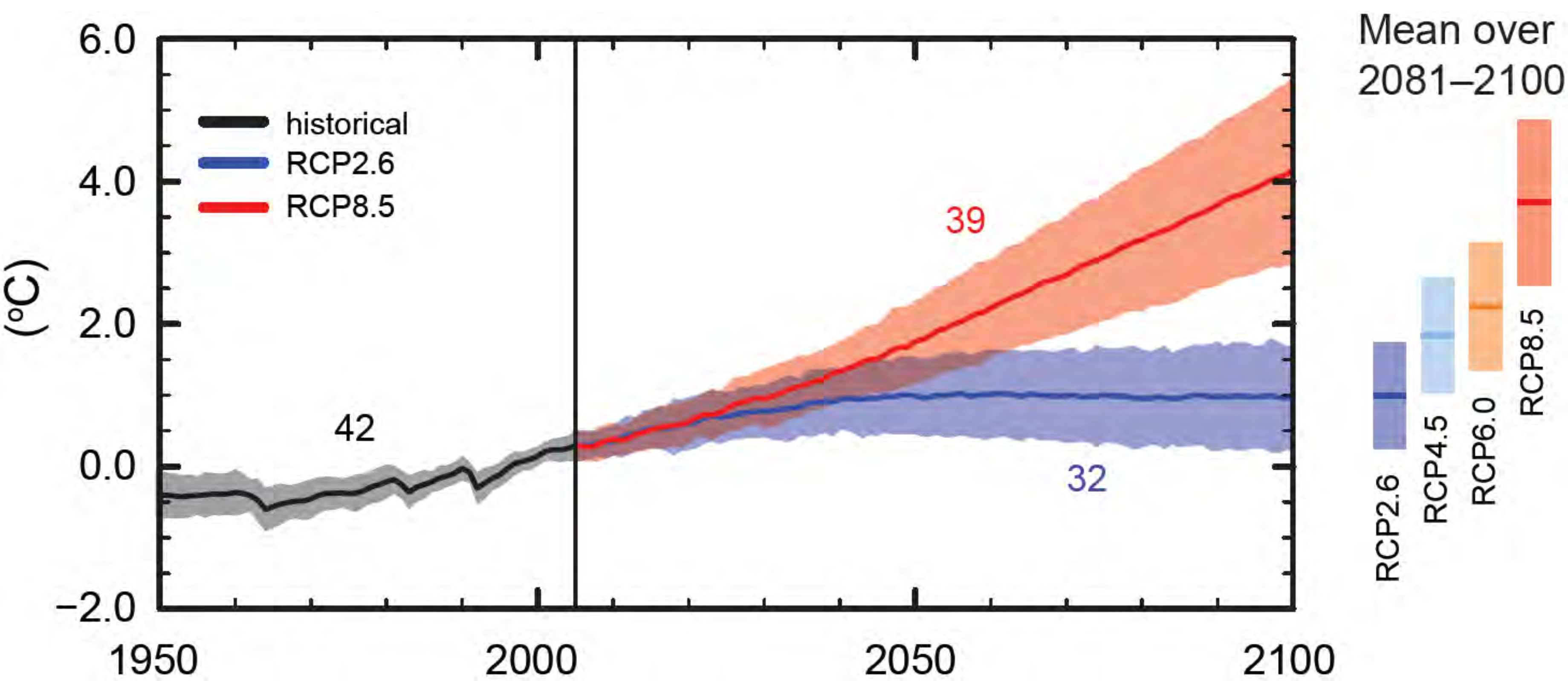
☒inconsistent with alternative explanations



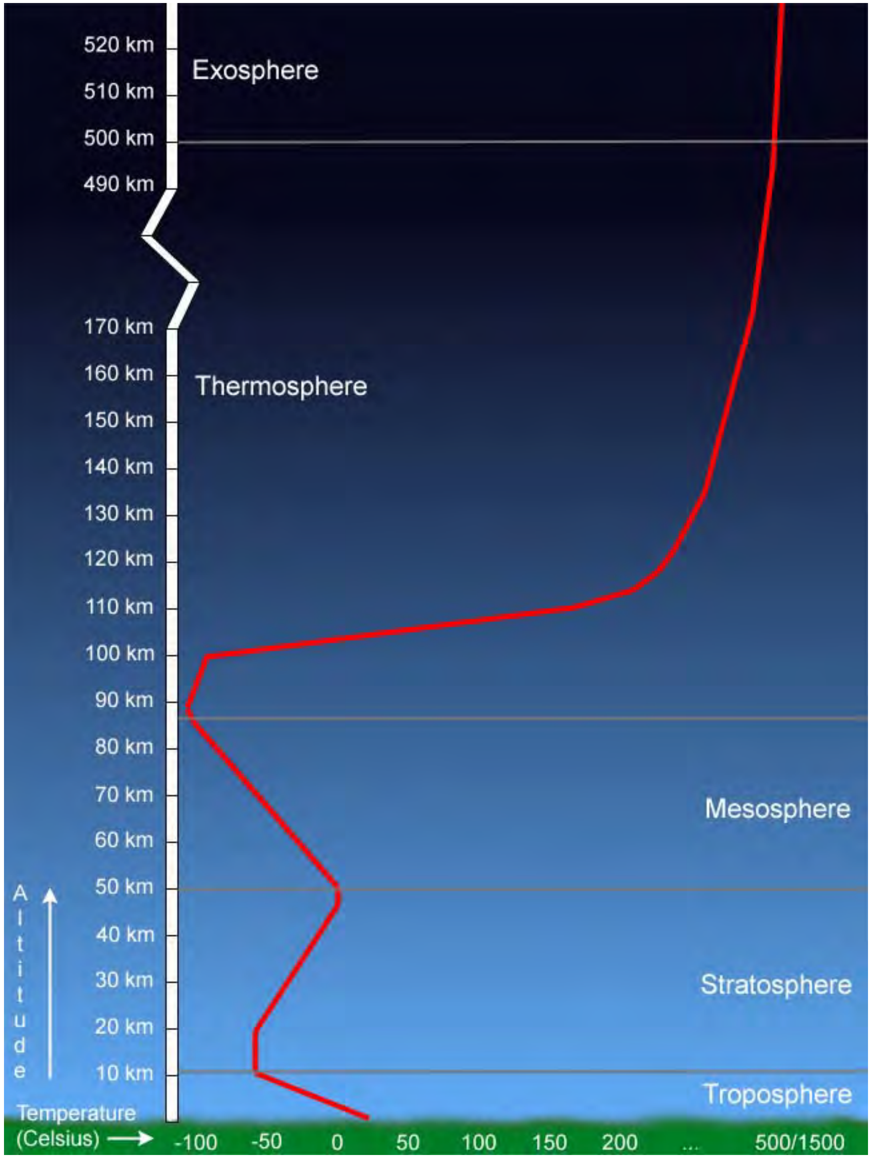
IPCC 2007

Figure SPM.7a

Global average surface temperature change



Regions of the Earth's Atmosphere

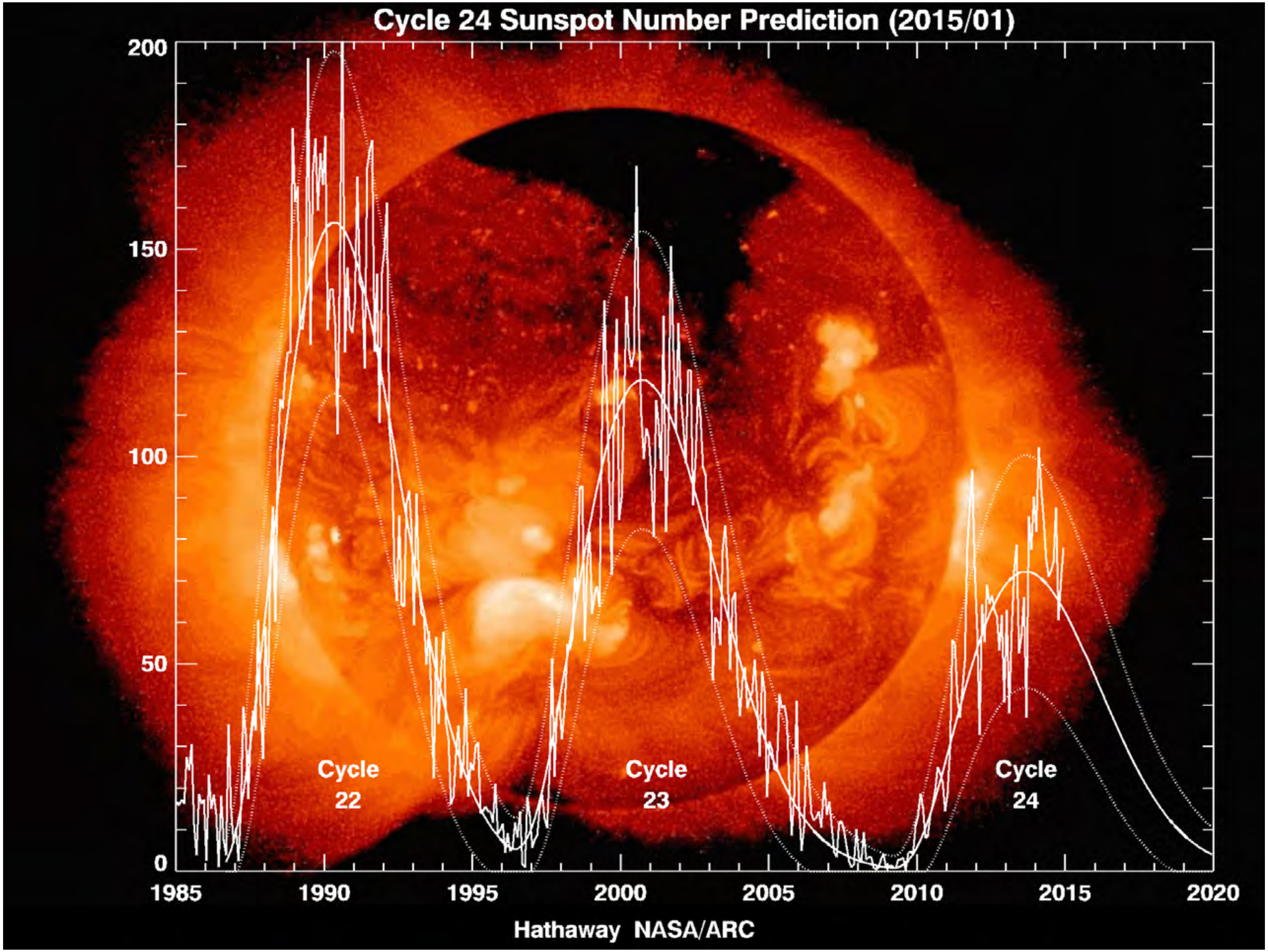


Predictions for Climate Change in the Upper Atmosphere

- Temperatures are expected to cool
- Changes in concentrations of many species

[*Roble and Dickinson*, 1989]

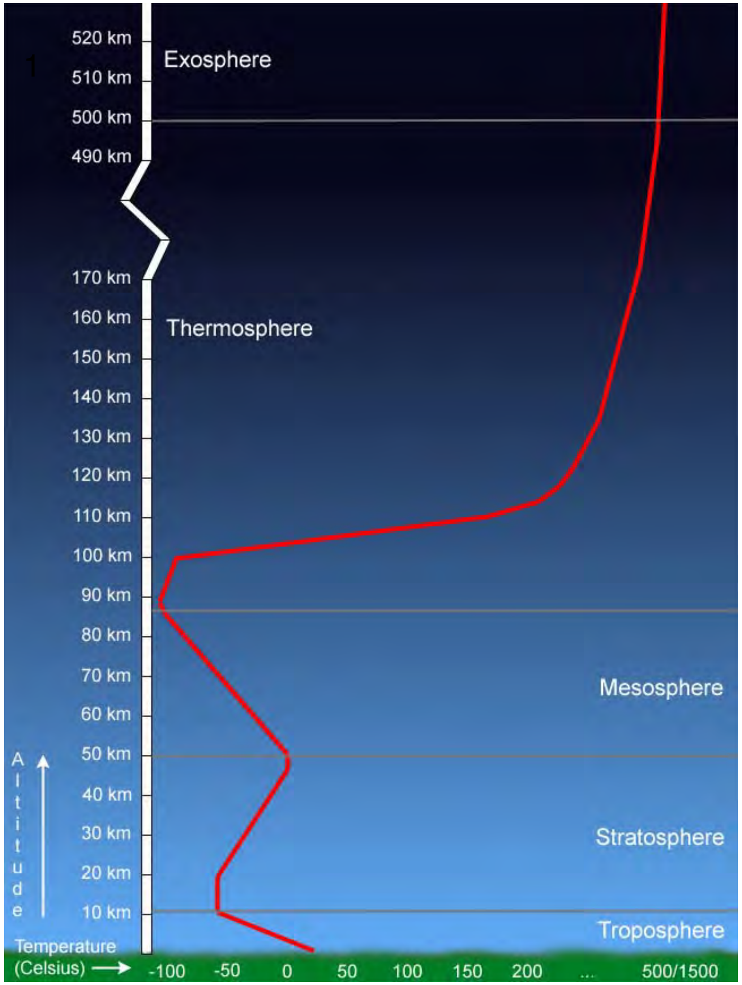
Courtesy of Windows to the Universe, http://www.windows.ucar.edu



https://www.nasa.gov/mission_pages/sunearth/news/gallery/april2013-ssn_predict_l.html

Coupling of hydrogen-containing species

1



4

Atomic hydrogen becomes increasingly dominant with altitude

3

CH_4, H_2O, H_2 chemistry & photolysis reactions

2

Sources of methane include: Agriculture, natural gas and petroleum systems, landfills, coal mining, wetlands, biomass burning

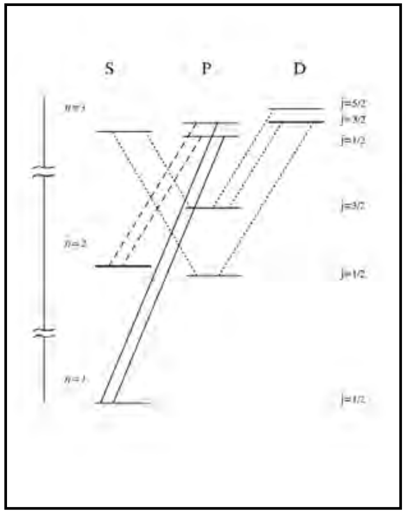
[1]Courtesy of Windows to the Universe, http://www.windows.ucar.edu

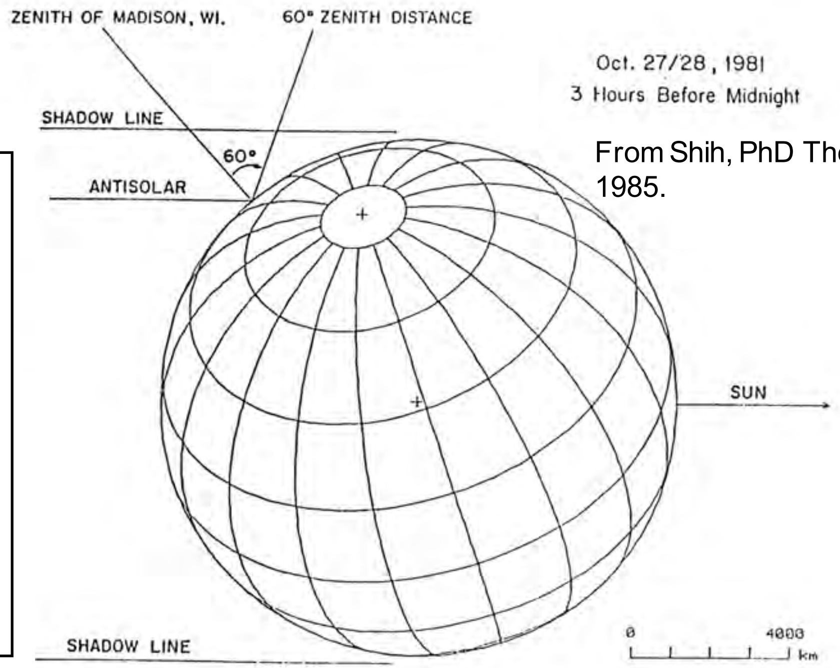
[2]from: http://earthobservatory.nasa.gov/Features/BiomassBurning/

Online: http://www.britannica.com/ebc/art-95671

[3]© Pekka Parviainen From http://lasp.colorado.edu/noctilucent_clouds/

[4]Source: Carruthers, Page, and Meier, Apollo 16 Lyman alpha imagery of the hydrogen geocorona, J. Geophys. Res., 81, 1664, 1976. and . pluto.space.swri.edu/.../apollo_geocorona2.gif



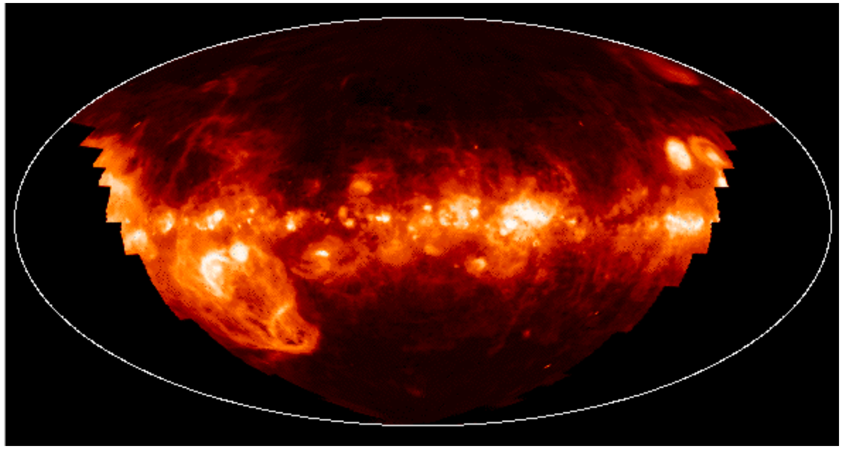


From Shih, PhD Thesis, 1985.

- Balmer-alpha is a solar excited emission
- Earth's shadow is used to determine the base of the emission column

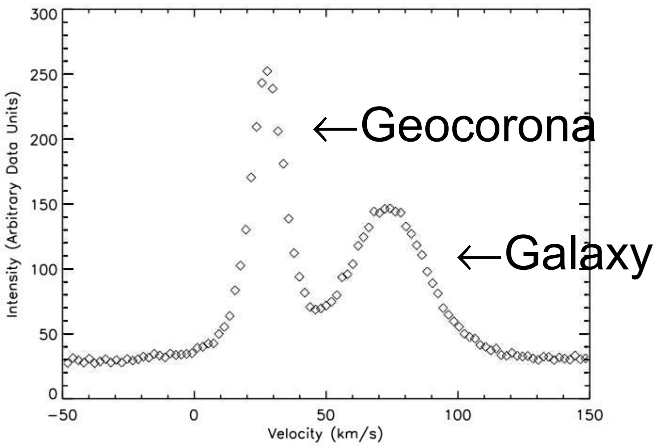
Wisconsin H-alpha Mapper Fabry-Perot

From www.astro.wisc.edu/wham



WHAM Hα Galactic Survey
From www.astro.wisc.edu/wham

From WHAM Survey

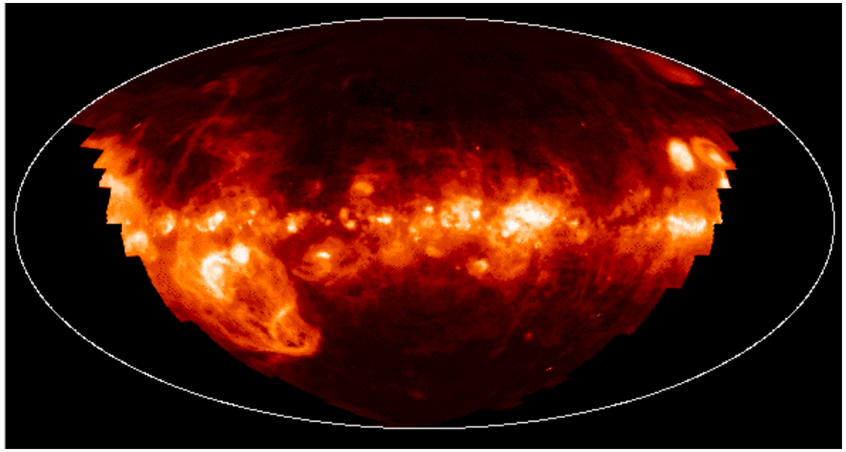


Haffner, L.M., Reynolds, et al., 2003, *ApJS*, **149**, 405.

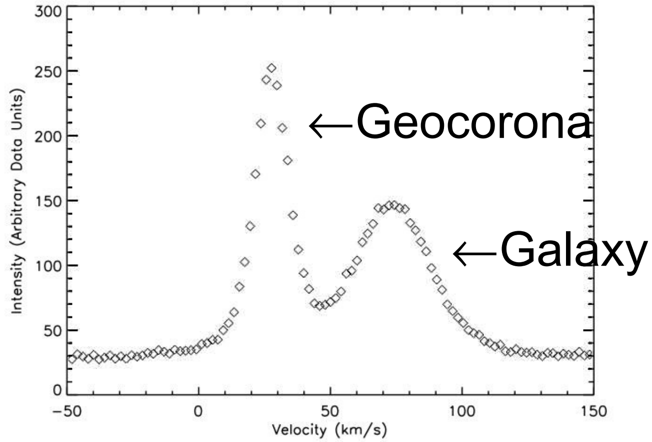
Galactic Hα Emission

WHAM Hα Galactic Survey
From www.astro.wisc.edu/wham

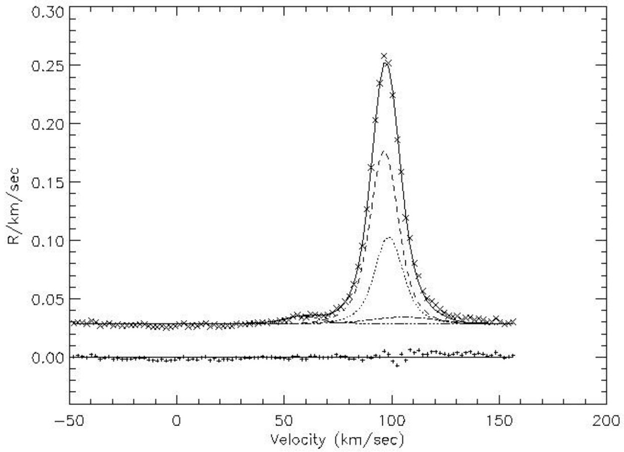
Haffner, L.M., Reynolds, et al., 2003, *ApJS*, **149**, 405.



From WHAM Survey

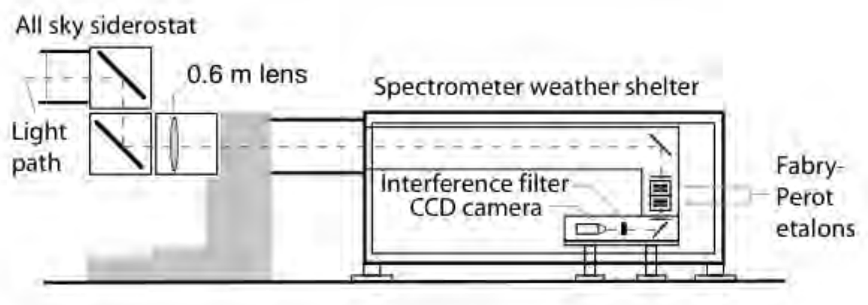


Region of Low Galactic Emission

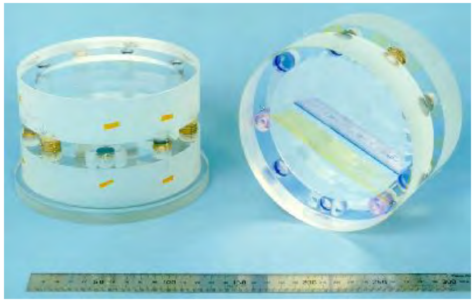


The magnitude and Doppler shift of the galactic Hα emission must be accounted for to accurately isolate the geocoronal emission line.

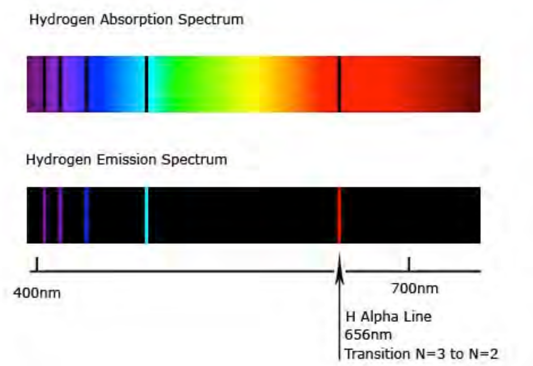
Observations of Upper Atmospheric Hydrogen



Wisconsin H-alpha Mapper Fabry-Perot [*Haffner et al.*, 2003]



[1]http://www.fabryperot.com/images/fixed_ets.jpg



• Hydrogen is a chemical byproduct of species below including methane and water vapor, two greenhouse gases.

• The solar cycle is a dominant source of natural variability in the upper atmosphere and must be accounted for when isolating potential signs of long-term change in the region.

Wisconsin H-alpha Mapper FPI (WHAM) Solar Cycle Observations

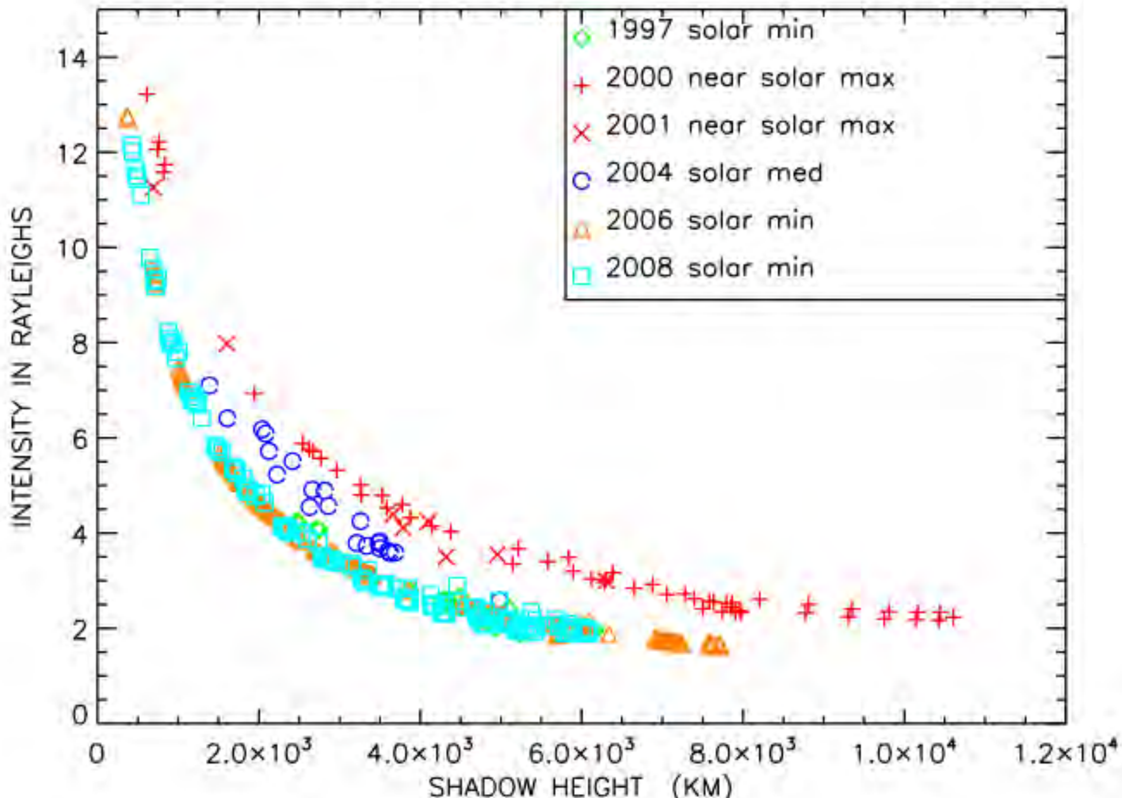


Figure 1

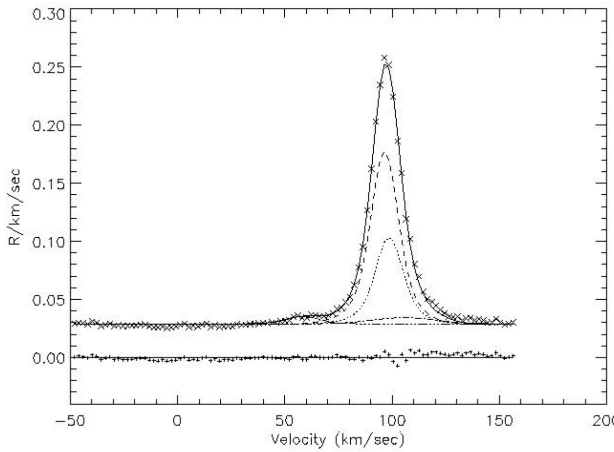


Figure 2

Figure 1: H-alpha observations by the Wisconsin H-alpha Mapper Fabry-Perot (WHAM) plotted vs.shadow altitude. The observations are those pointed toward very low Galactic emission regions, and were taken during winter, clear sky, moonless nights of exceptional viewing quality. They come from over 25 nights of observations. [Nossal et al., 2008, 2012]. There is an ~10% uncertainty in the relative intensity.

Figure 2: WHAM spectrum in region of low Galactic emission.

Wisconsin Long Timeline Hydrogen Balmer-alpha data set

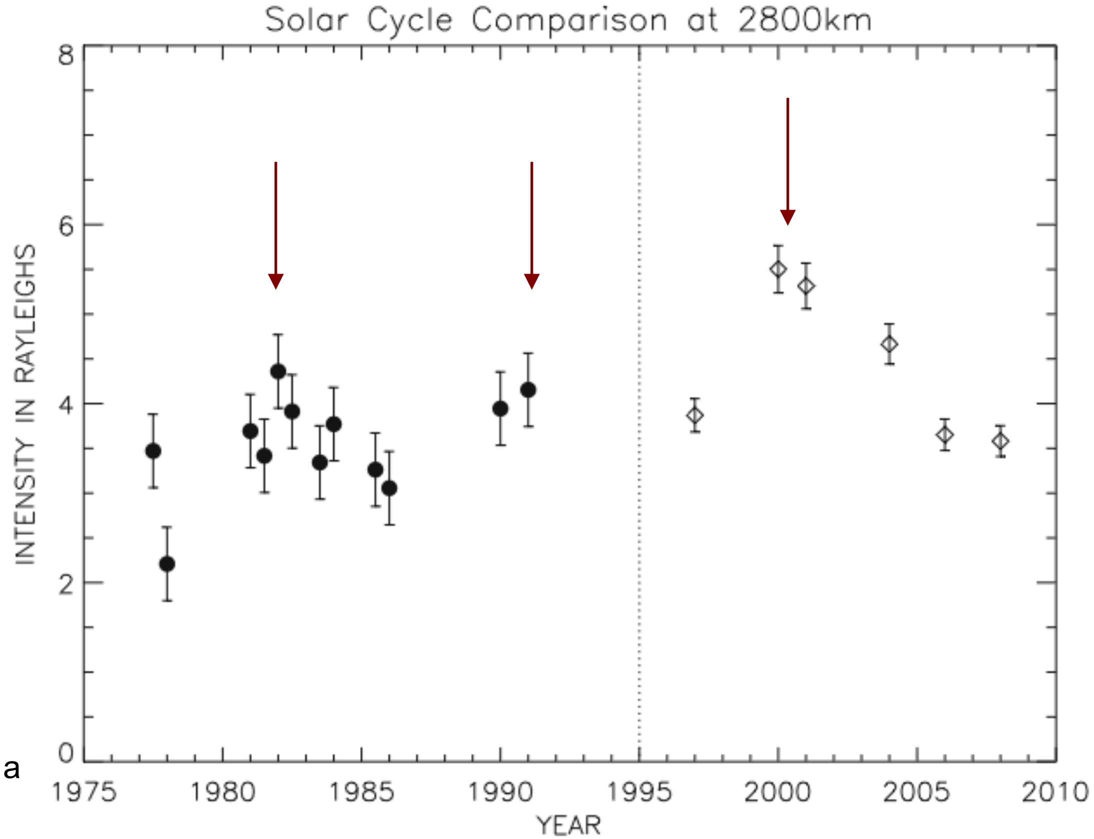


Fig. a

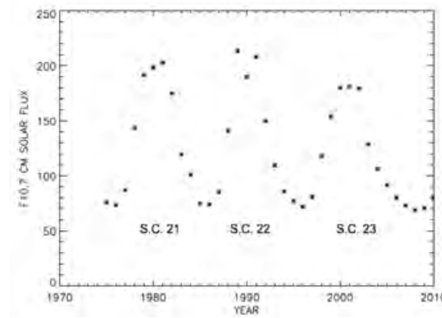
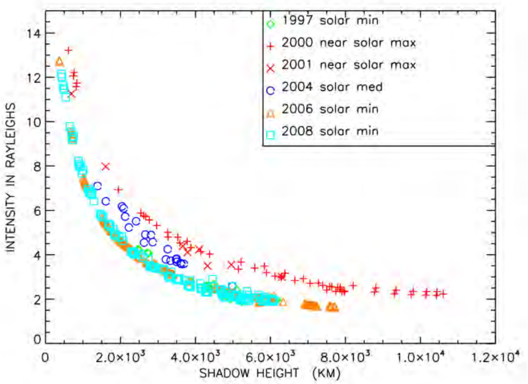


Fig. b

Yearly averaged F10.7 cm flux



- Figure a: Hα column emission intensity at a mid-range shadow altitude vs. year. Observations on the right were taken with WHAM and those on the left were taken with the scanning "pre-WHAM" Fabry-Perot. Error bars indicate uncertainty in the determination of the relative intensity. **Each point represents multiple nights and spectra.**

Is the increase between two solar maxima geophysical or artifact of experimental factors?

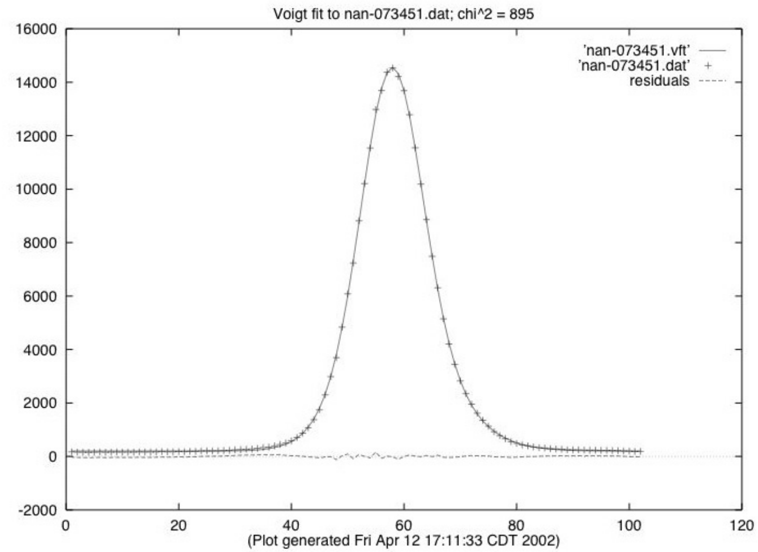
Considerations for long term data comparisons

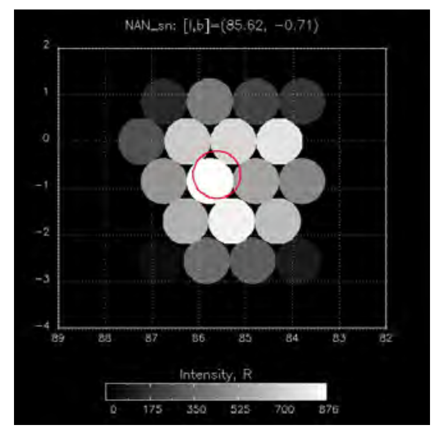
- Well understood, cross-calibrated, stable instrumentation
- Reproducible observing conditions
- Stable calibration source
- Consistent data analysis techniques accounting for correction factors

Corroboration of the Intensity Calibration

North American Nebula
Credit and Copyright: Dominique Dierick and Dirk De la Marche

From http://antwrp.gsfc.nasa.gov/apod/ap960606.html

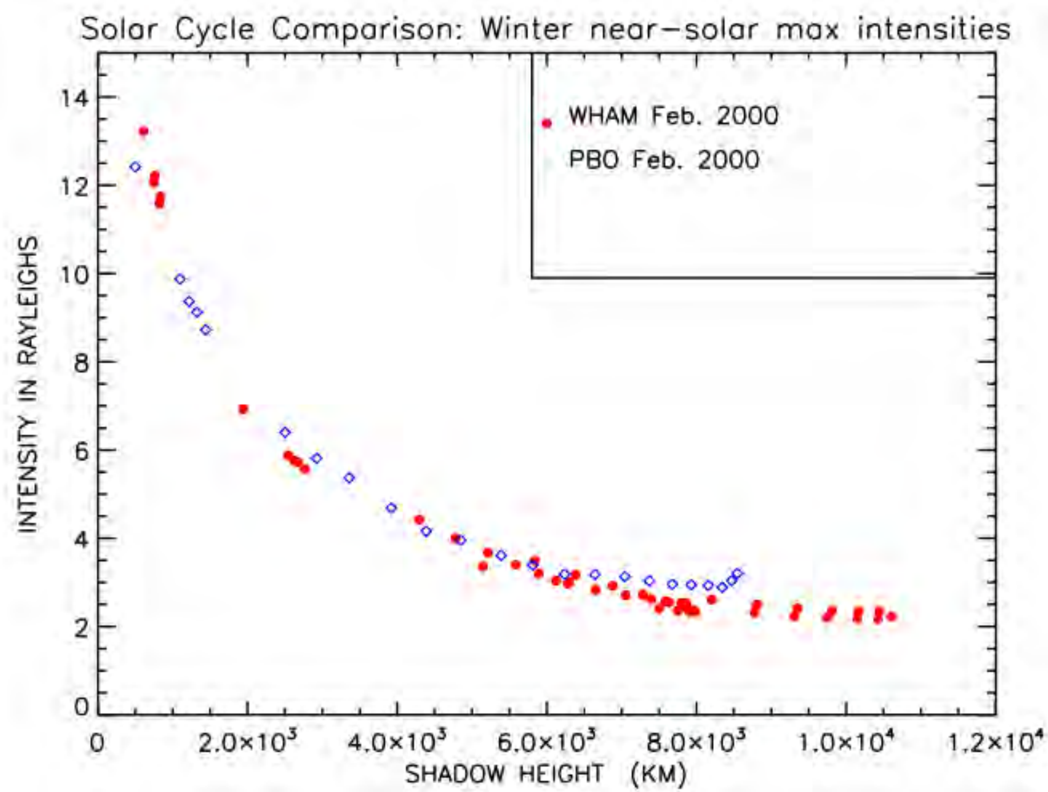




From Derek Gardner

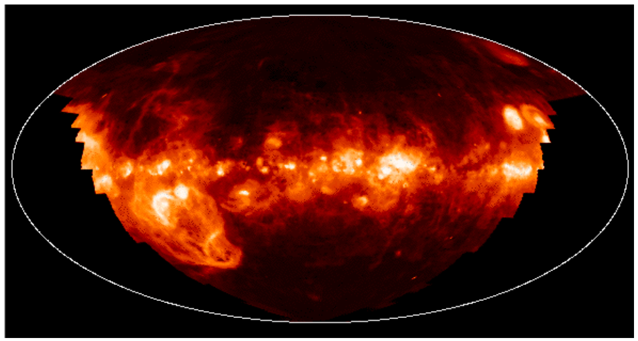
Intensity Calibration: Intensities of nebular sources used for calibrating the solar cycle 22 observations agree with WHAM Galactic Map within ~15%

Observatory Comparison



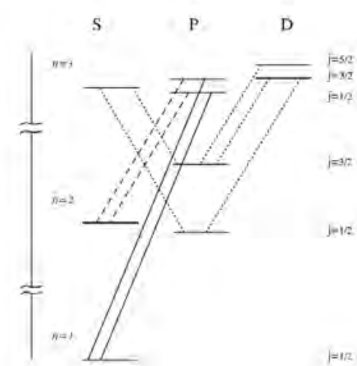
Location: Agreement between FPI observations from Kitt Peak, Arizona and Wisconsin during the same observing period

Analysis factors are unlikely to account for increase



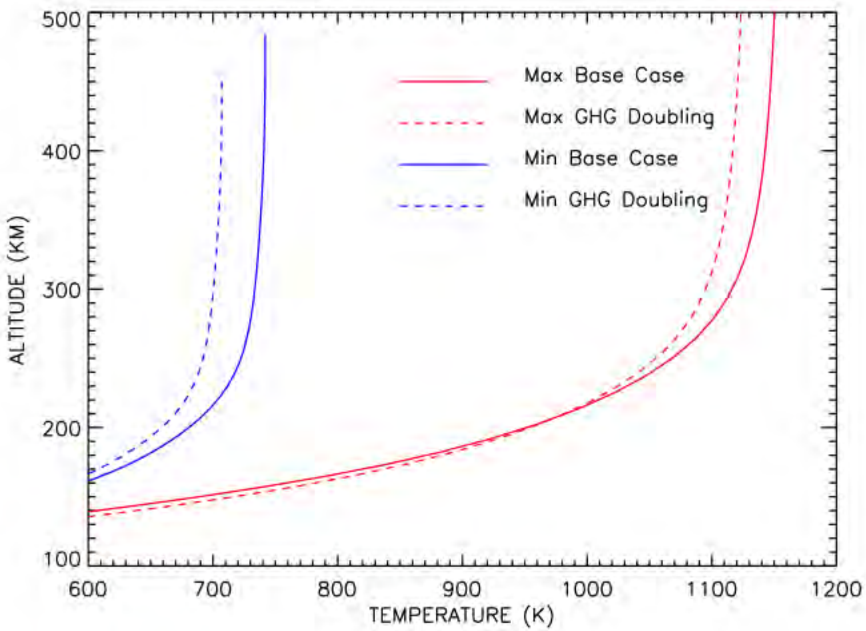
WHAM Hα Galactic Survey
From www.astro.wisc.edu/wham

Haffner, L.M., Reynolds, et al., 2003, *ApJS*, **149**, 405.

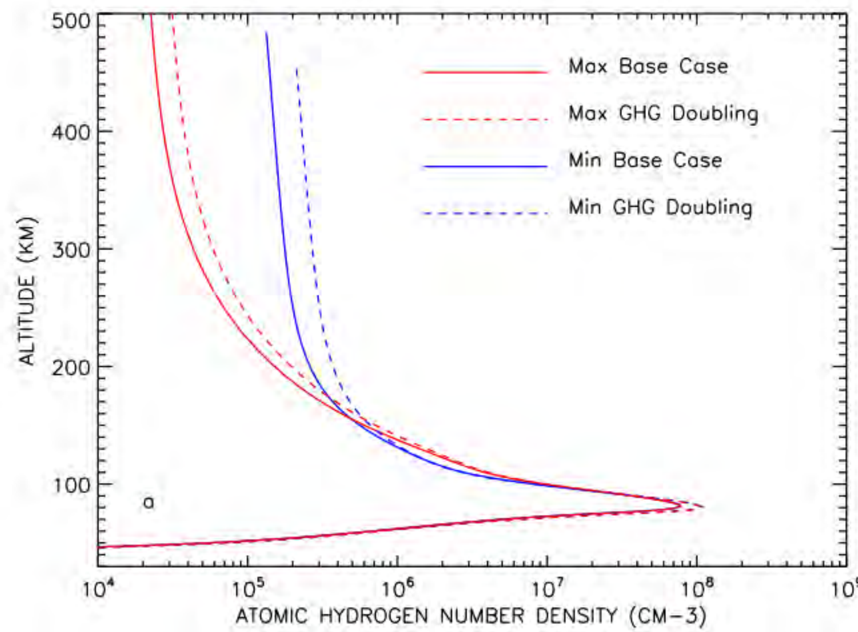


The WI Northern hemisphere data suggest an increase that has not been accounted for by uncertainties due to experimental factors, including calibration, tropospheric scattering, cascade fine structure excitation and Galactic emission.

Modeled Temperature and Atomic Hydrogen Density Profiles



Temperature

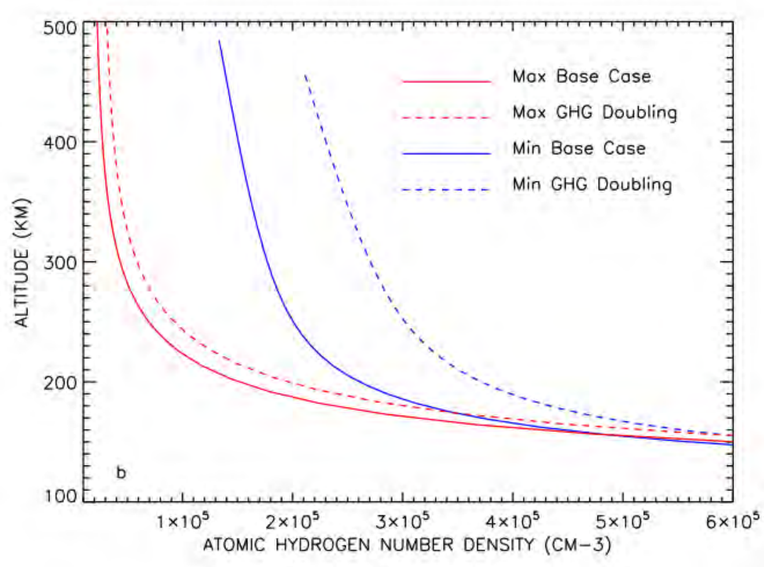


Atomic hydrogen

Nossal et al., 2016

In the thermosphere, the upper region of the Earth's atmosphere, solar cyclic changes in both temperature and hydrogen are greater than with greenhouse gas doubling. The 11-year solar cycle mainly effects the ultraviolet part of the Sun's spectrum which is mostly absorbed in the Earth's upper atmosphere and stratosphere. Thus, the solar cycle has little effect on the lower atmosphere.

Modeled Upper Thermospheric Atomic Hydrogen Density



Nossal et al., 2016

• H density (linear) for base case and GHG doubling scenarios for both solar min and max.

- **Carbon dioxide cooling & methane both lead to predicted increases in H**
- **Increase in H absolute density due to GHG doubling is greater at solar min.**
- **H response to GHGs depends on phase of solar cycle**

Wisconsin Long Timeline Hydrogen Balmer-alpha data set

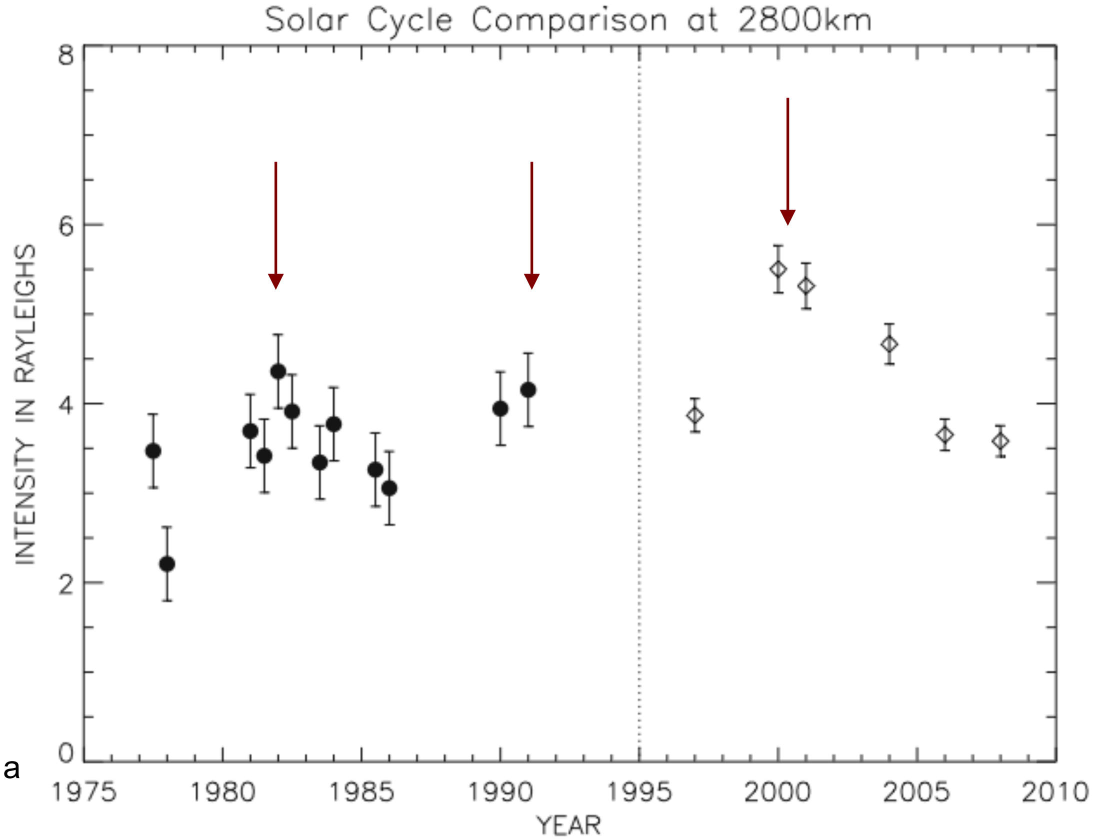


Fig. a

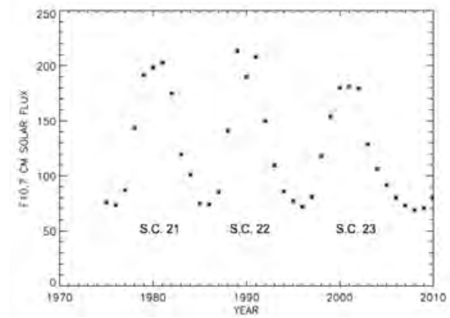


Fig. b

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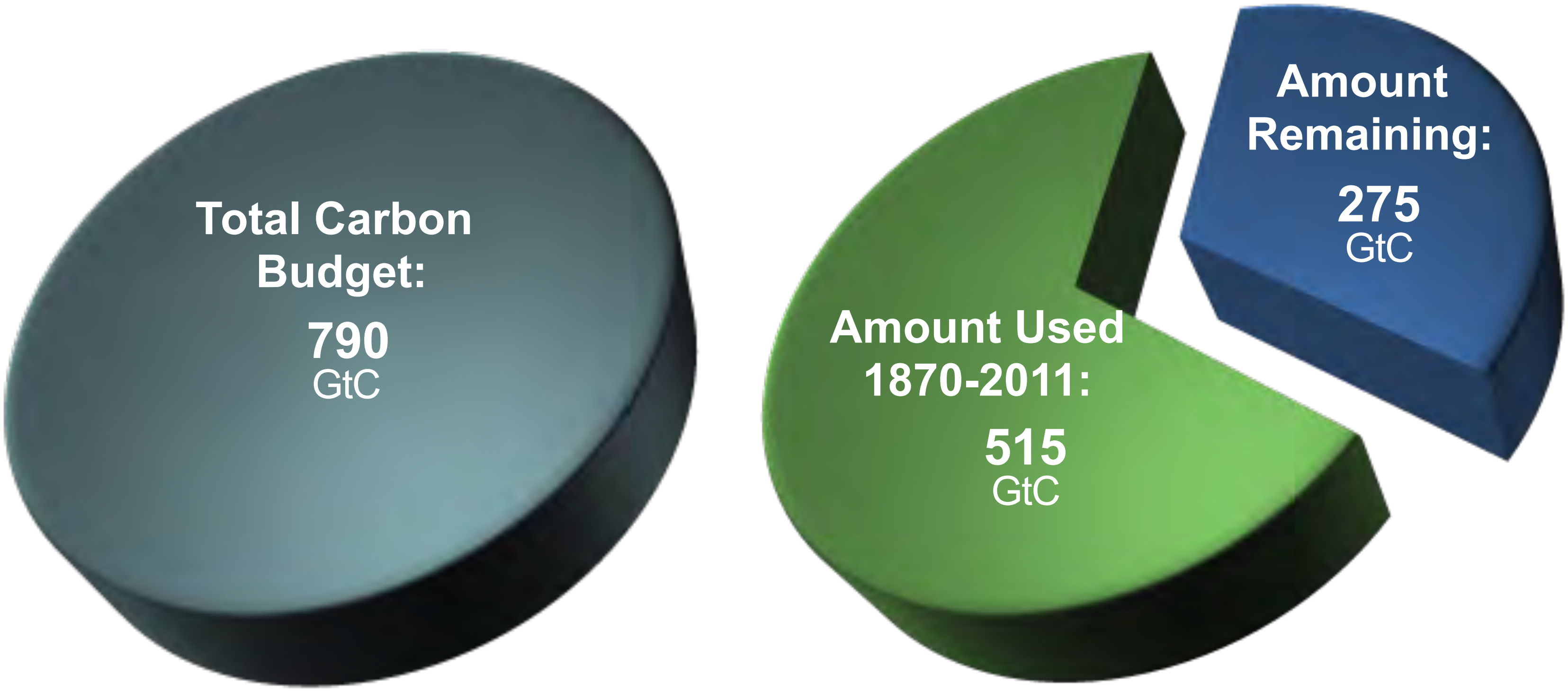
- Figure a: Hα column emission intensity at a mid-range shadow altitude vs. year. Observations on the right were taken with WHAM and those on the left were taken with the scanning "pre-WHAM" Fabry-Perot. Error bars indicate uncertainty in the determination of the relative intensity. Each point represents multiple nights and spectra.

The data suggest that there may be upper thermospheric H increases larger than would be accounted for by increases in greenhouse gases.

ExoCube

• In situ measurements of upper atmospheric neutral and ion species

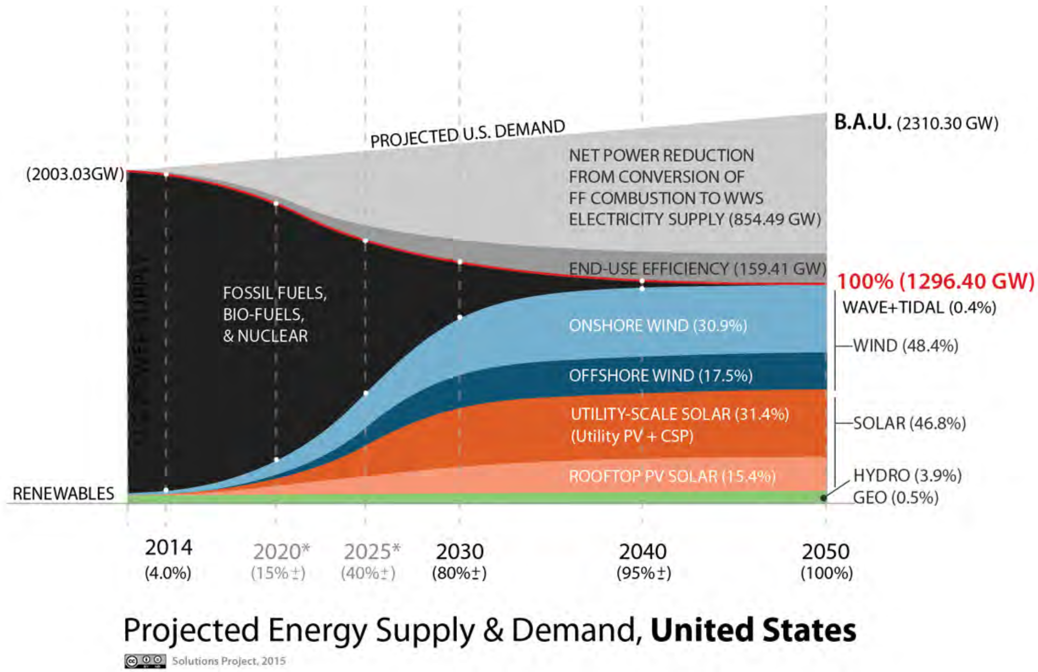
65% of our carbon budget compatible with a 2° C goal already used

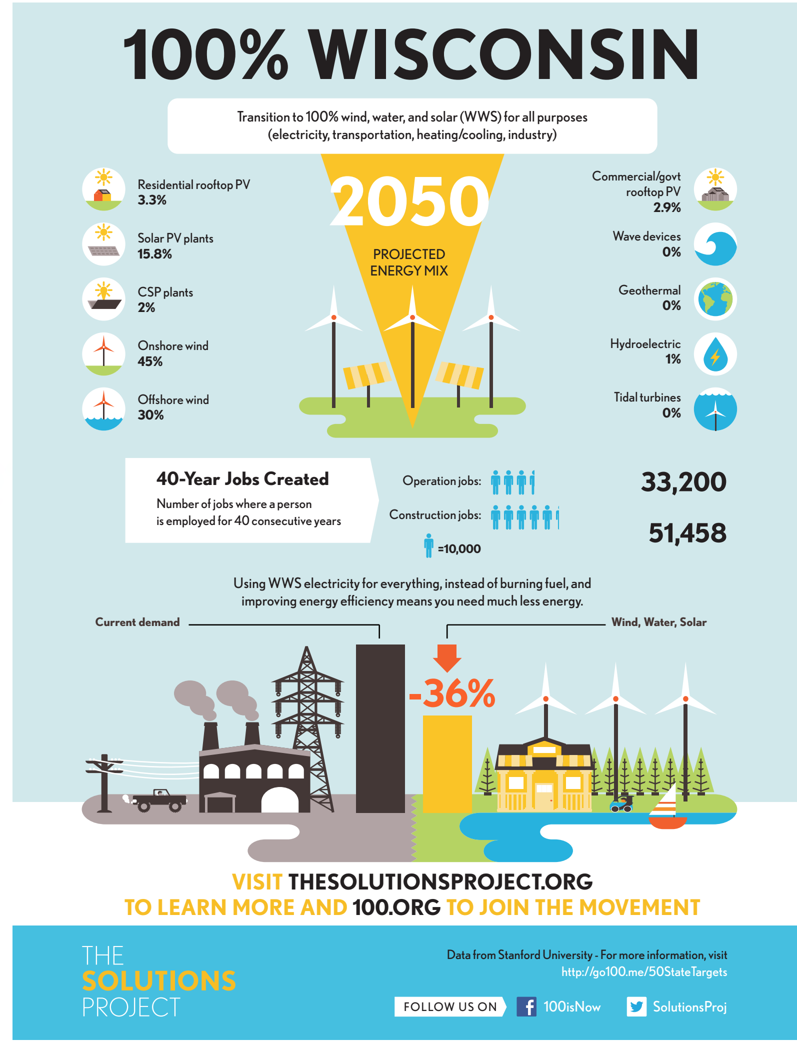


AR5 WGI SPM

Climate Change is an URGENT challenge

“There are multiple mitigation pathways that are likely to limit warming to below 2º C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of carbon dioxide and other long-lived greenhouse gases by the end of the century.” (IPCC 5th Assessment Synthesis Report)





[Mark Jacobson, Stanford University]

Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions

Human influence on the climate system is clear

Warming in the climate system is unequivocal

References:

Intergovernmental Panel on Climate Change: [www.ipcc.ch]

Wisconsin Initiative on Climate Change Impacts www.wicci.wisc.edu

Climate Wisconsin climatewisconsin.org

US Global Change Research Program www.globalchange.gov

Nelson Institute UW Madison www.nelson.wisc.edu

The Solutions Project, www.thesolutionsproject.org

Thank you!

Climate Change is an URGENT challenge

- “We are at risk of pushing our climate system towards abrupt, unpredictable, and potentially irreversible changes with highly damaging impacts.”

- “The sooner we act, the lower the risk and cost.”

- “Since the late 19th century, Earth’s global average temperature has risen by about 1.4º F. … The difference was about 9º F between the last Ice Age and today. … The Intergovernmental Panel on Climate Change states that continuing on a path of rapid increase in atmospheric CO_2 could cause another 4º F to 8º F warming before the year 2100.”

- “Given the high stakes, is is valuable to understand not just what is most likely to happen, but what might possibly happen to our climate. There is a possibility that temperatures will rise much higher and impacts will be much worse than expected. Moreover, as global temperature rises, the risk increases that one or more important parts of the Earth’s climate system will experience changes that may be abrupt, unpredictable, and potentially irreversible, causing large damages and high costs.”

What We Know Report from the American Association for the Advancement of Science: www.whatweknow.aaas.org