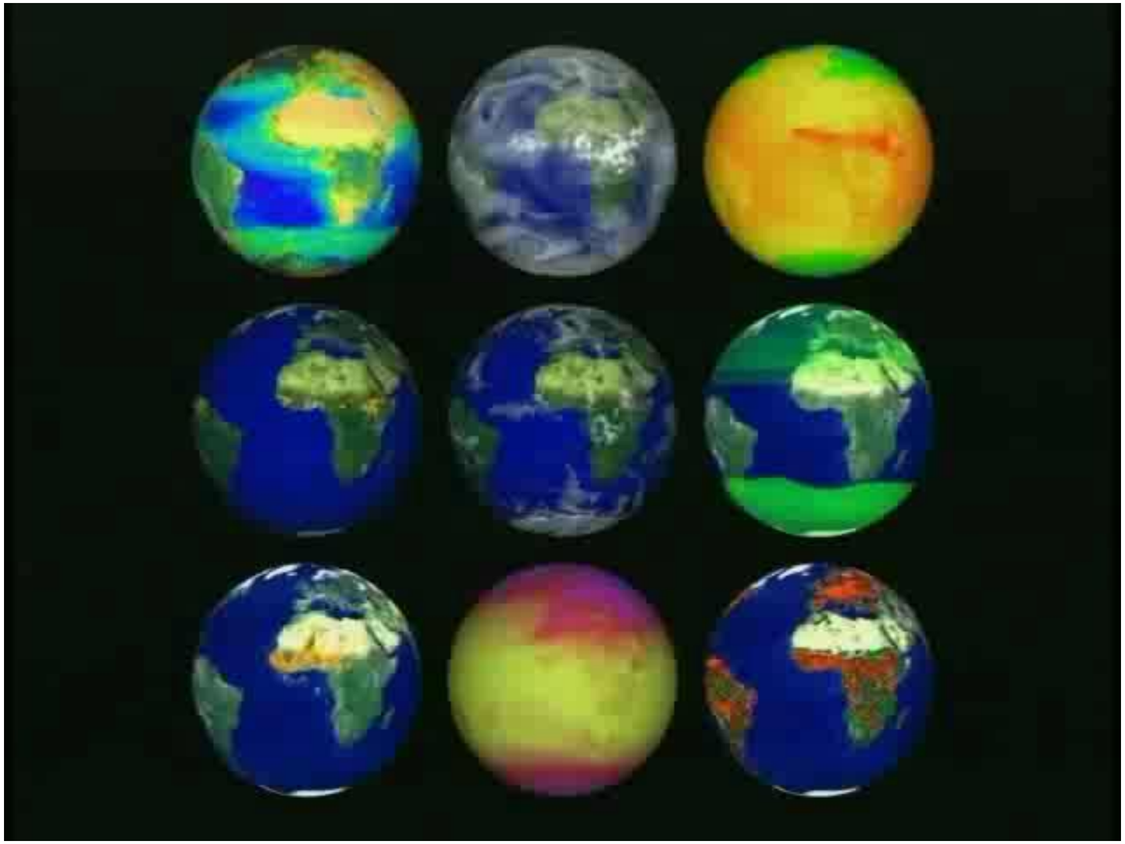
HOT ISSUES IN CLIMATE SCIENCE:
(a) RECENT TRENDS: WEATHER OR CLIMATE CHANGE, & WHY?
(b) PROBABILISTIC CLIMATE FORECASTS & POTENTIAL RISKS

Ronald G. Prinn, MIT



IMAGES From NASA's TERRA satellite

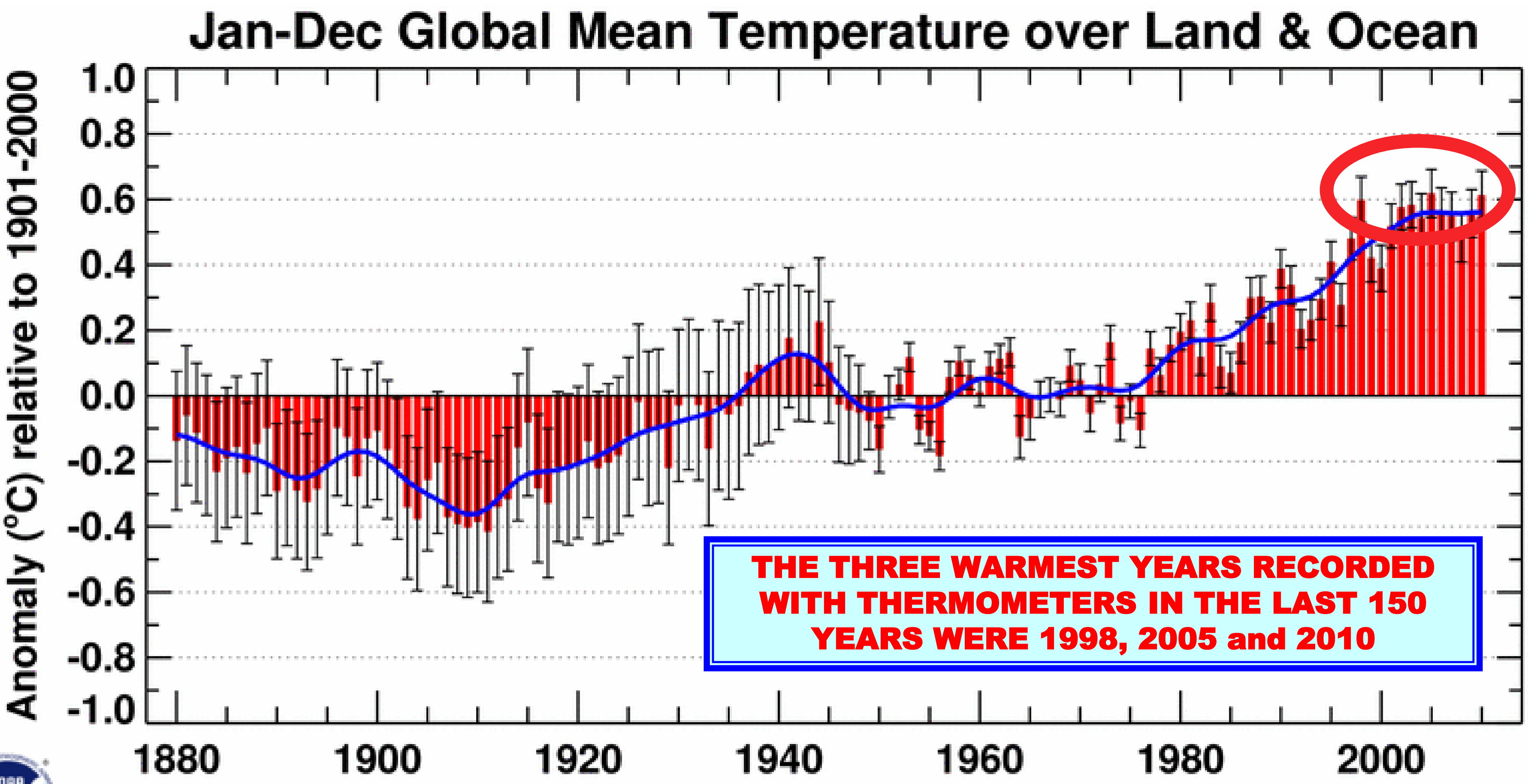
MIT JOINT PROGRAM SPONSOR'S WEBINAR SERIES #1

Massachusetts Institute of Technology

September 15, 2011

HOW DID TEMPERATURES EVOLVE OVER 1880-2010 & WHAT ARE THE WARMEST YEARS EVER RECORDED?

Global annual surface air temperature anomaly (relative to 1901-2000 average) as estimated from observations by NOAA-NCDC.

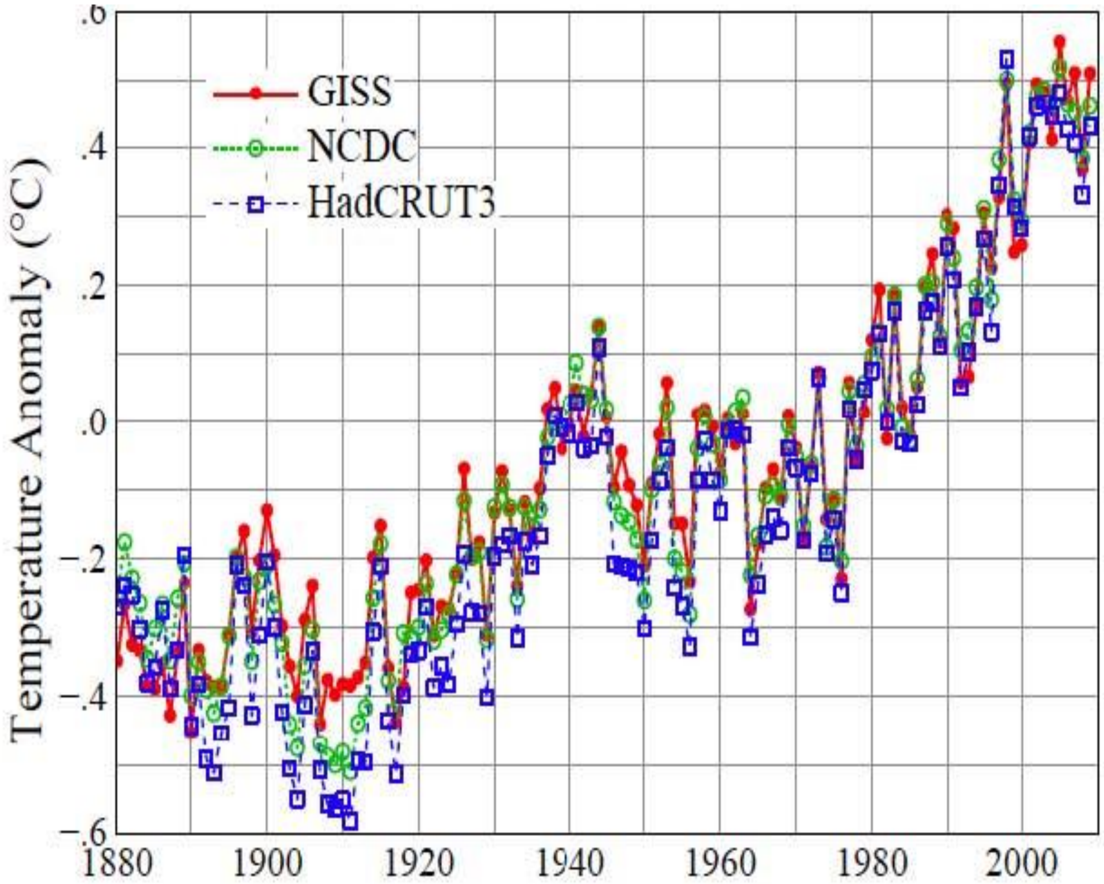


NCDC/NESDIS/NOAA

www.ncdc.noaa.gov/sotc

HOW WELL DO TEMPERATURE TRENDS AGREE AMONG ANALYSES BY DIFFERENT CENTERS?

Global annual surface air temperature anomaly (relative to 1961-1990 average) as estimated from observations by NASA-GISS, NOAA-NCDC, & UKMO-Hadley Center Climatic Research Unit (Hansen et al, 2010).

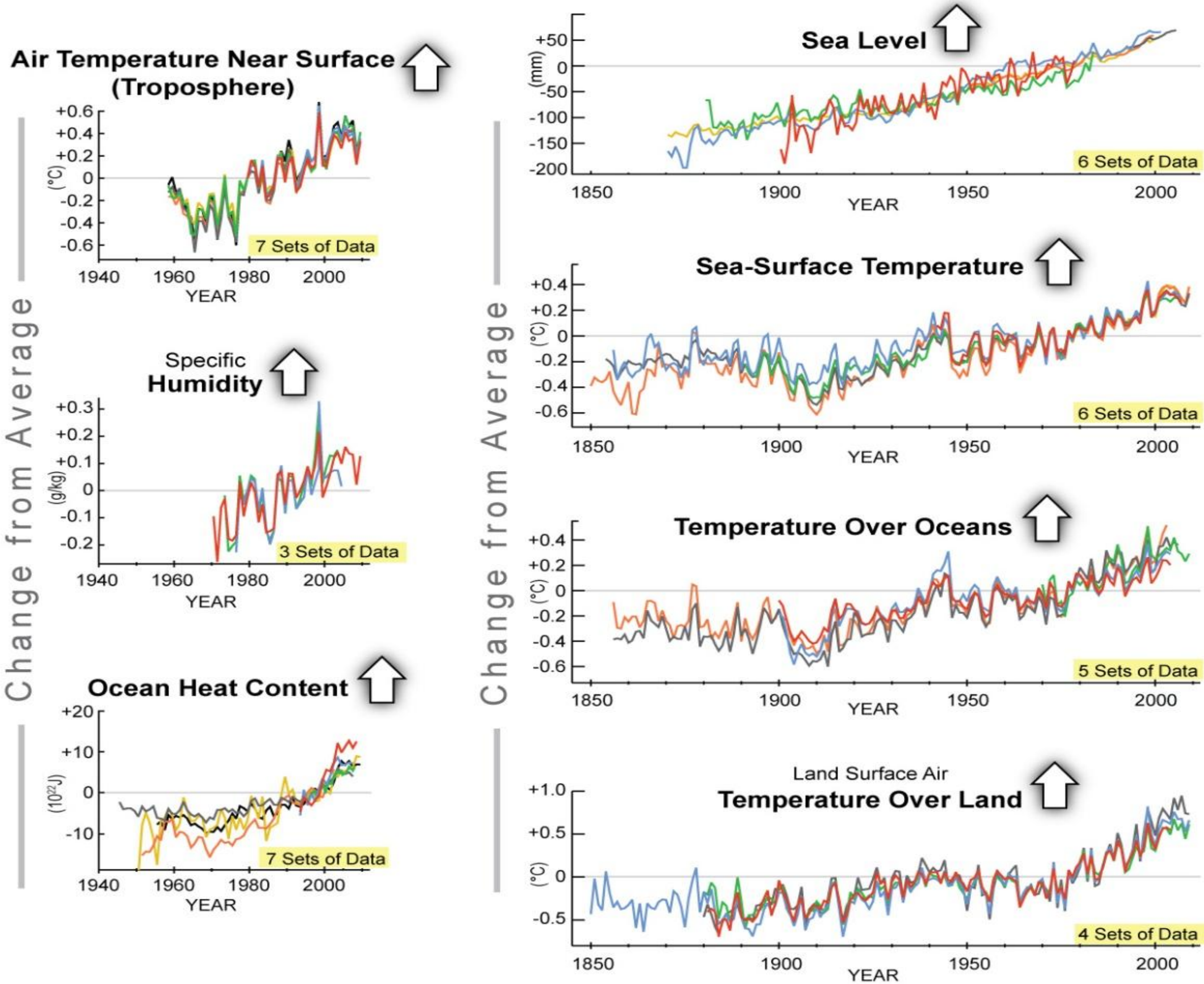


Agreement improves as more and better data becomes available.

Cloud cover changes induce year to year changes.

Ocean circulation changes and volcanic eruptions induce decade to decade changes.

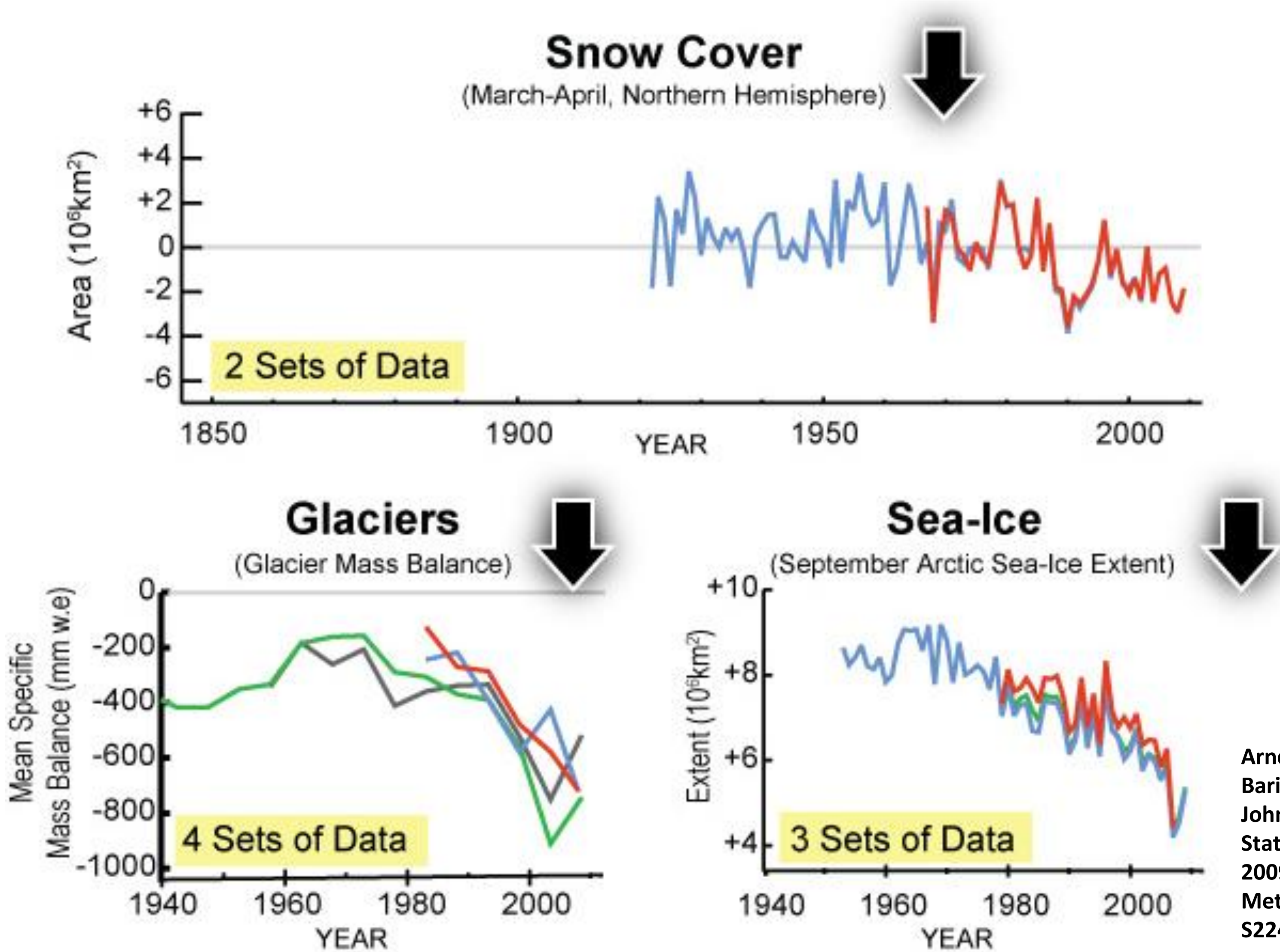
Indicators of Climate Change with Positive Trends*



Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., 2010: State of the Climate in 2009. Bull. Amer. Meteor. Soc., 91 (7), S1-S224

*Courtesy of Tom Karl, Director, National Climate Data Center, NOAA

Indicators of Climate Change with Negative Trends*

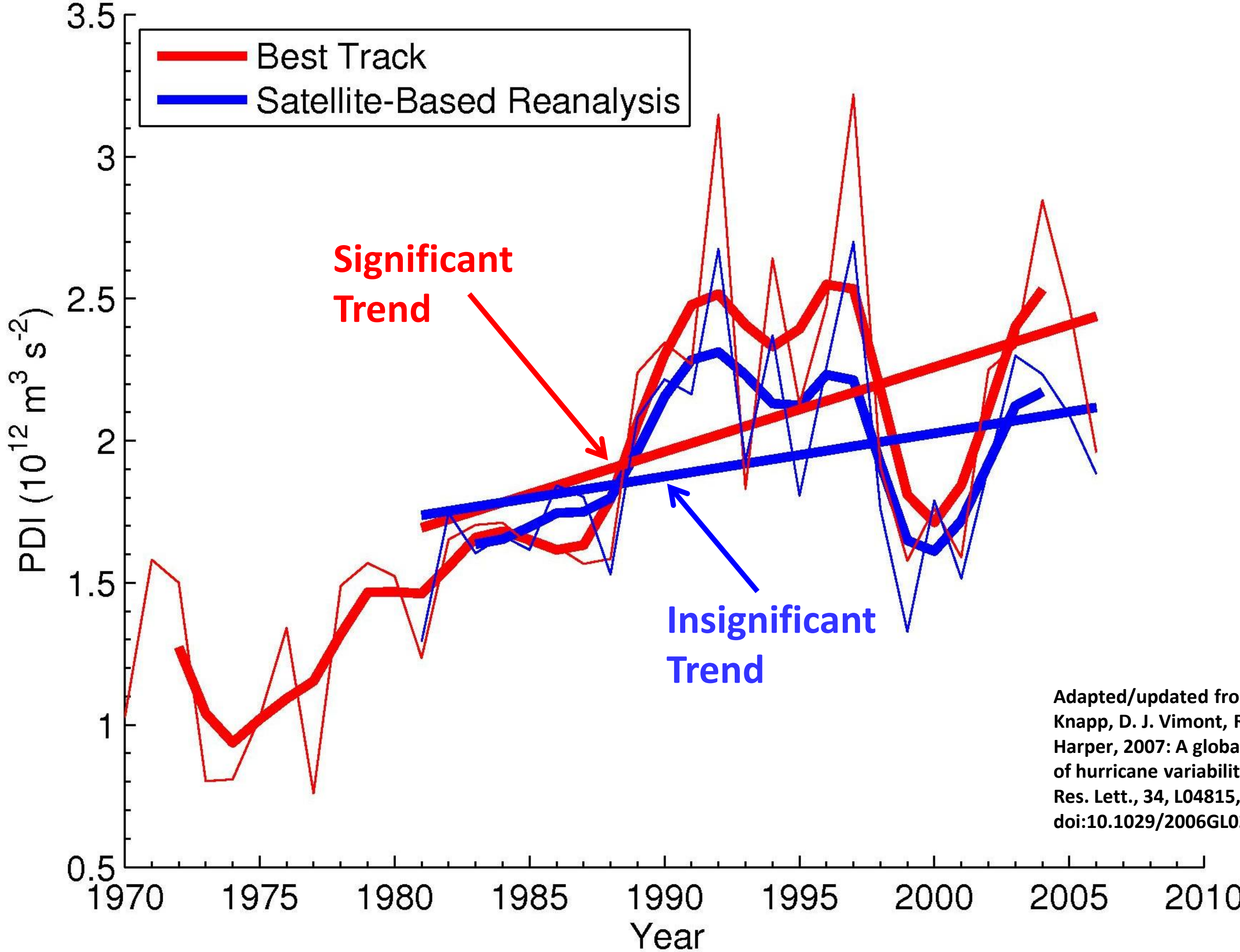


Arndt, D. S., M. O. Baringer, and M. R. Johnson, Eds., 2010: State of the Climate in 2009. Bull. Amer. Meteor. Soc., 91 (7), S1-S224

*Courtesy of Tom Karl, Director, National Climate Data Center, NOAA

Tropical Cyclone Global Power Dissipation Trend*

Thick wavy lines are smoothed versions of thin lines using a binomial filter.
Thick straight lines are linear trends.



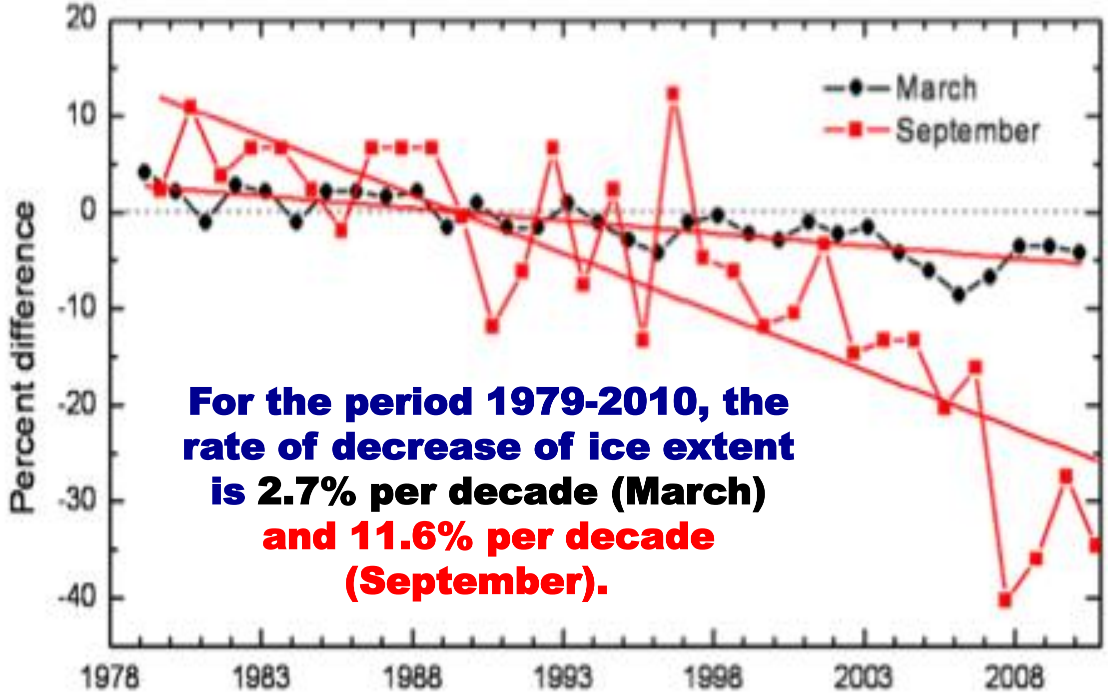
Adapted/updated from Kossin, J. P., K. R. Knapp, D. J. Vimont, R. J. Murnane, and B. A. Harper, 2007: A globally consistent reanalysis of hurricane variability and trends. Geophys. Res. Lett., 34, L04815, doi:10.1029/2006GL028836.

*Courtesy of Tom Karl, Director, National Climate Data Center, NOAA

IS ARCTIC SEA ICE AT THE END OF WINTER & SUMMER DECREASING?

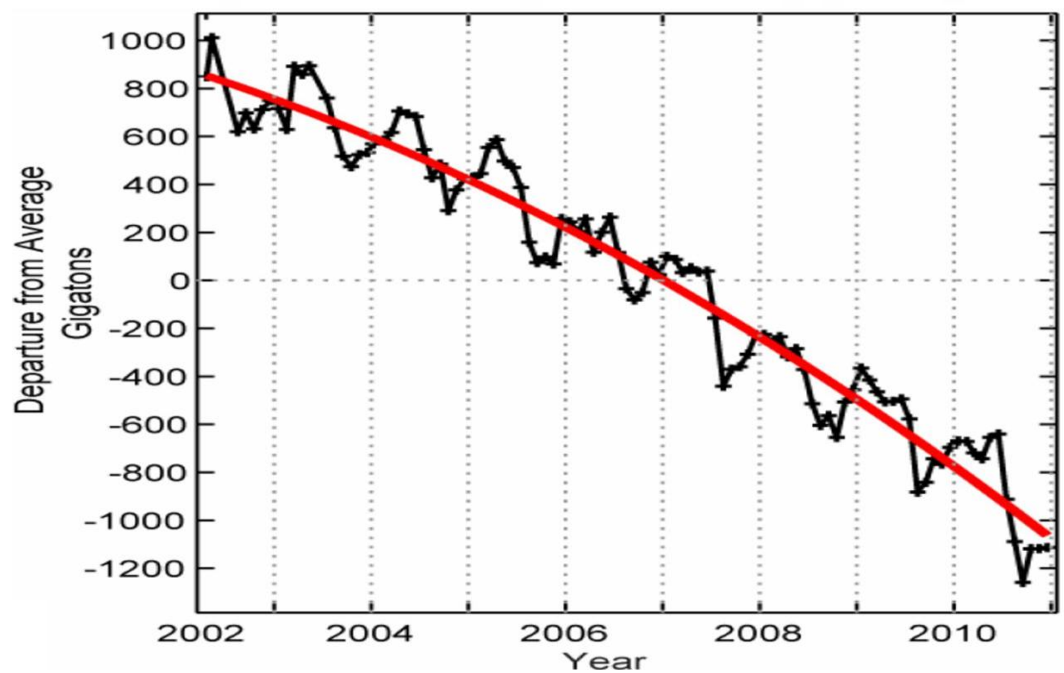
Time series of the percent difference in ice extent in March (the month of ice extent maximum) and September (the month of ice extent minimum) relative to the mean values for the period 1979–2000.

www.arctic.noaa.gov/reportcard/ArcticReportCard_full_report.pdf

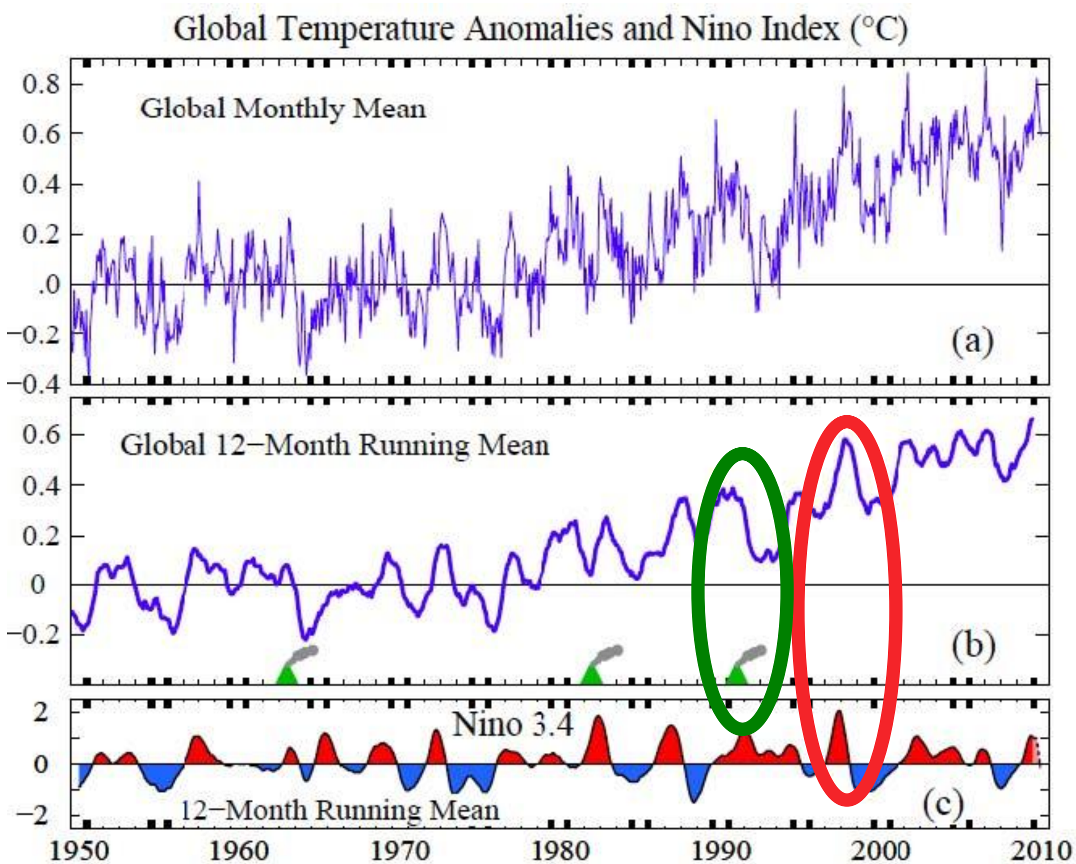


IS THE MASS OF THE GREENLAND ICE SHEET DECREASING?

Time series of Greenland total ice sheet mass (gigatons) relative to the 2002-2011 average mass. Deduced from the NASA/German Gravity Recovery and Climate Experiment (GRACE) satellite. Ref: Rodell et al, Bulletin AMS, 92, S50-S51, 2011



HOW HAS TEMPERATURE BEEN AFFECTED BY EL NINO & VOLCANOES?



Global monthly and 12-month running mean surface temperature anomalies relative to 1951-1980 base period, volcanic eruptions, and the El Nino 3.4 index. Data extend through June, 2010.

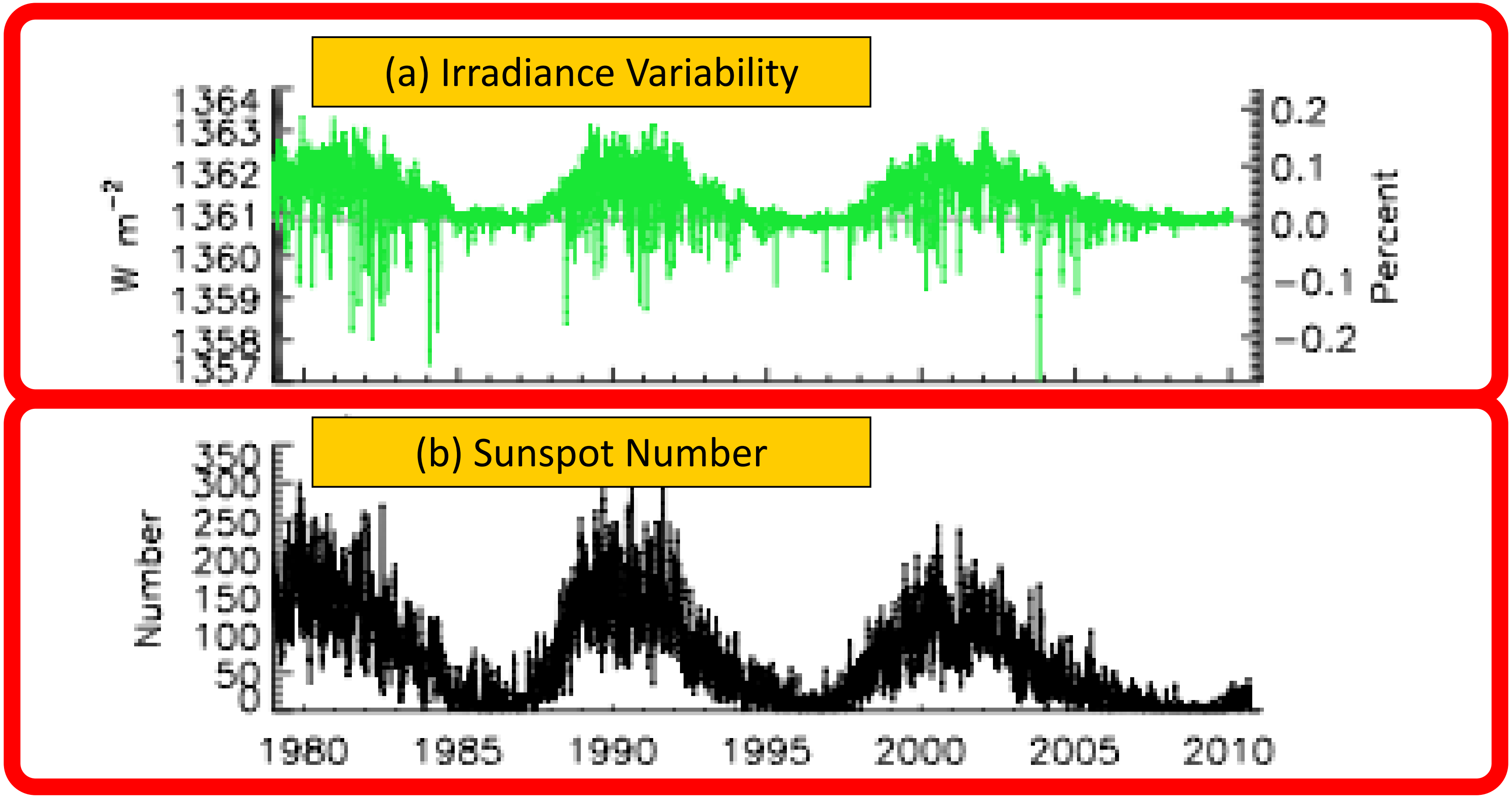
(Hansen et al, Reviews of Geophysics, 2010).

IS THE ENERGY OUTPUT OF THE SUN CHANGING?

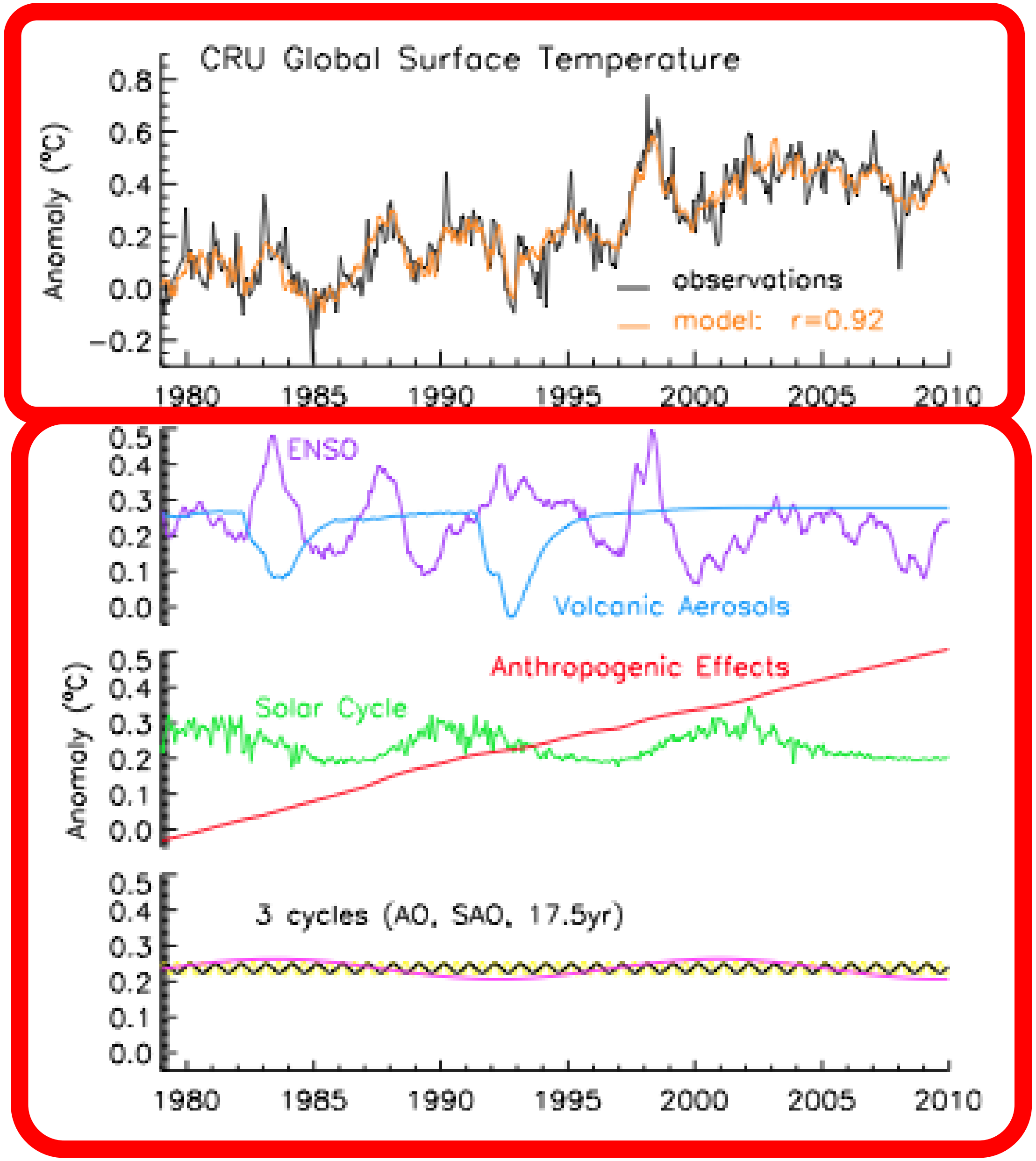
(a) Space-borne total solar irradiance estimated using the two primary influences of facular brightening and sunspot darkening with their relative proportions determined via regression from direct satellite observations made by SORCE/ TIM.

(b) The daily sunspot numbers indicate qualitatively the fluctuating levels of solar convective activity.

Ref: Kopp & Lean, GRL, 2011.



Solar Cycle Prediction by NASA Marshall Space Flight Center gives peak SSN of about 70 (+/-30) in June, 2013



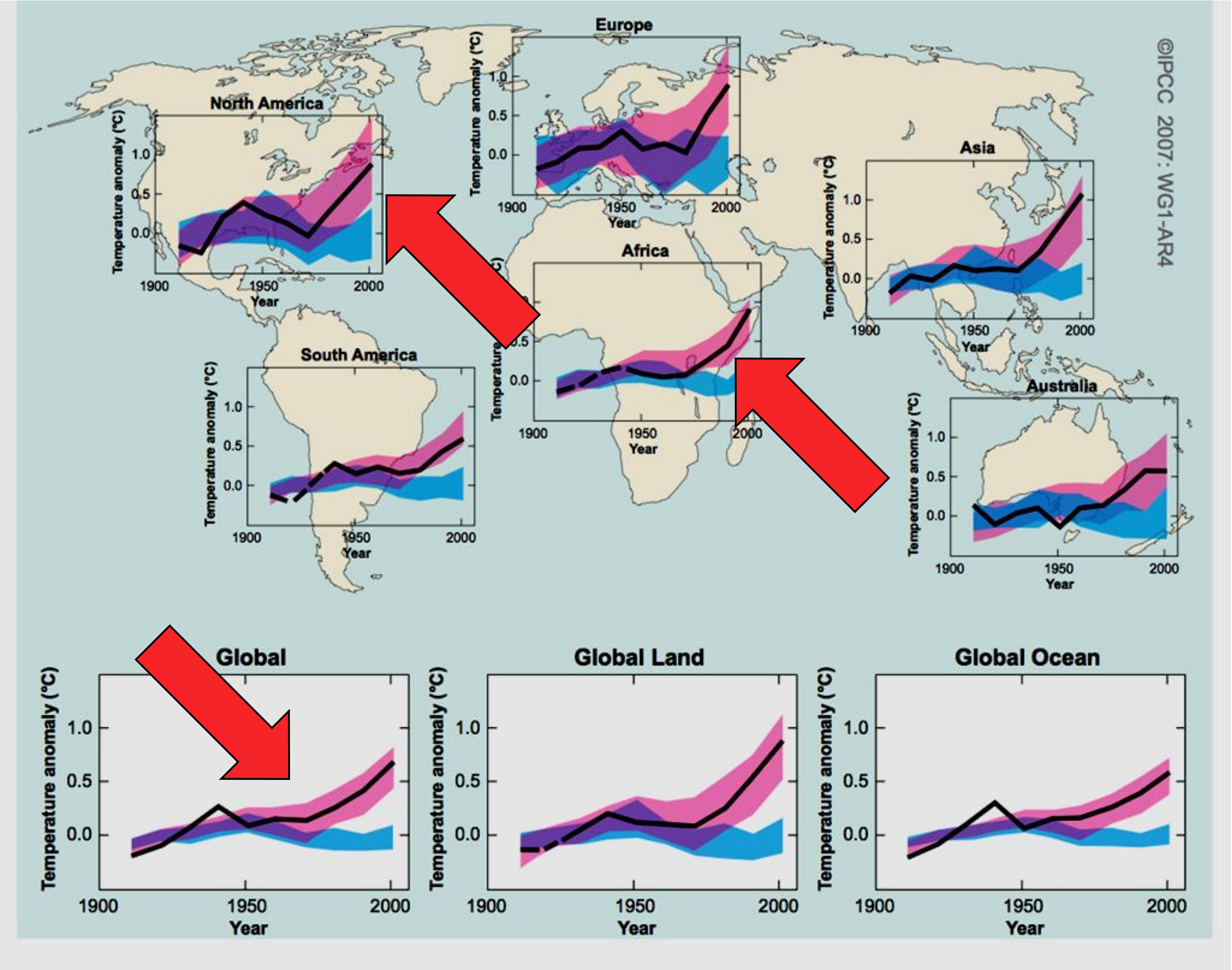
ATTRIBUTION PROBLEM: WHAT ARE THE RELATIVE CONTRIBUTIONS TO CLIMATE CHANGES OF VARIABILITY IN NATURAL PROCESSES & ANTHROPOGENIC EFFECTS?

Compared in the top panel are monthly mean variations in the global temperature of the Earth's surface, from the Climatic Research Unit (CRU, black) and an empirical model (orange, following Lean and Rind [2009]) that combines four primary influences and three minor cycles, whose variations are shown individually in the lower panels. The temperature record has sufficient fidelity that after removing the four primary effects, namely ENSO (purple) at three different lags, volcanic aerosols (blue) at two different lags, solar irradiance (green), and anthropogenic effects (red), minor cycles identifiable as annual (AO, black), semi-annual (SAO, yellow), and 17.5 year oscillations (pink) are evident in the residuals (bottom panel).

Ref: Kopp & Lean, GRL, 2011.

CLIMATE FORCING DUE TO INCREASES IN GREENHOUSE GASES AND AEROSOLS FROM 1850-2005 WAS:
1.6 W m^{-2} x 5.1 x 10^{14} m^2 = 816 TW (about 52 times current global energy consumption)

ATTRIBUTION PROBLEM: HOW HAVE GLOBAL & CONTINENTAL TEMPERATURES CHANGED OVER THE PAST CENTURY (1906-2005), AND WHY?



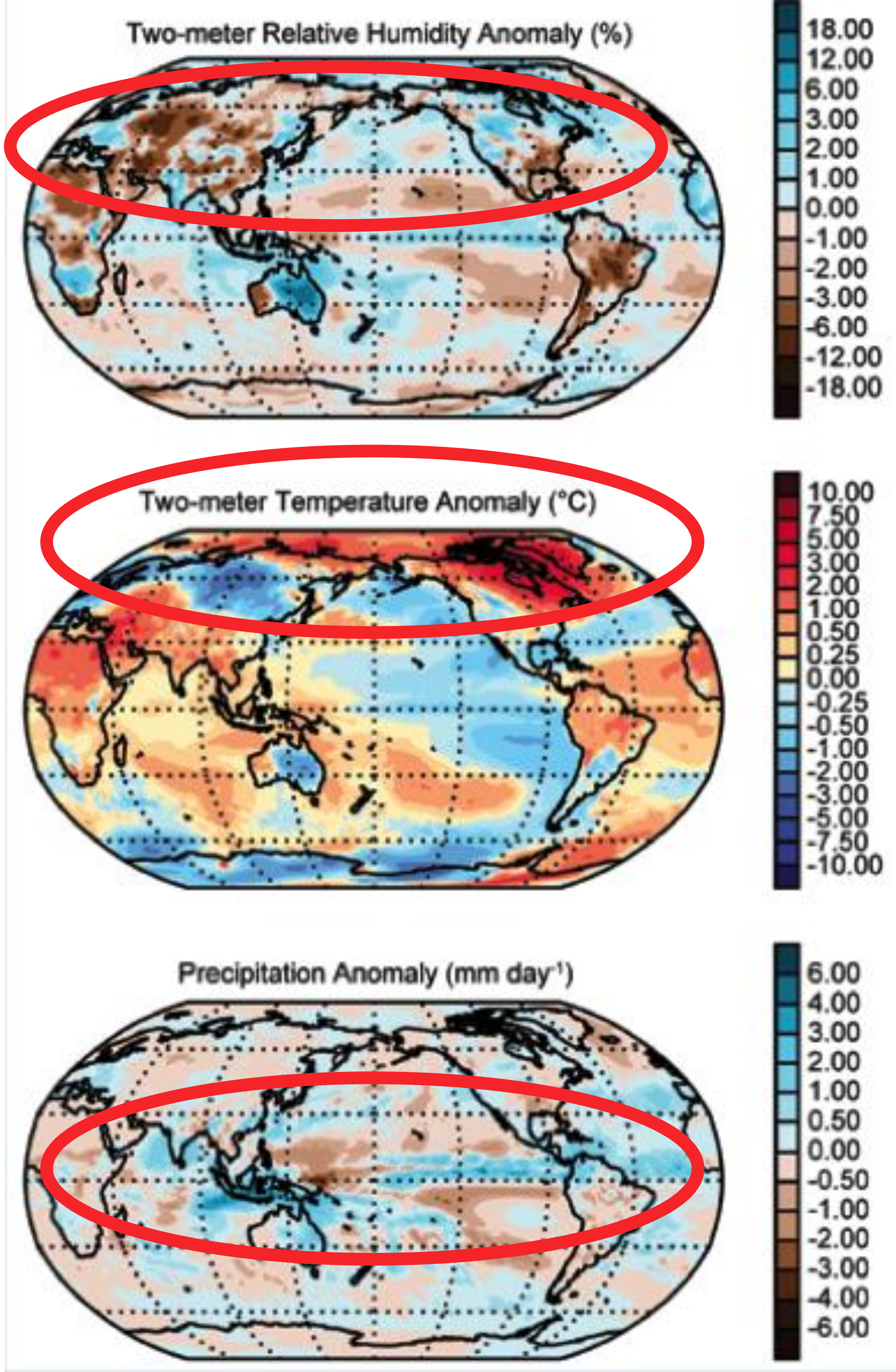
Black lines: observed changes. **Blue bands: range for 19 model simulations using natural forcings.** **Red bands: range for 51 model simulations using natural and human forcings.**

Ref: IPCC 4th Assessment, Summary for Policymakers, 2007

HOW SPATIALLY UNEVEN WERE THE EXTREME 2010 ANNUAL GLOBAL CLIMATE CHANGES?

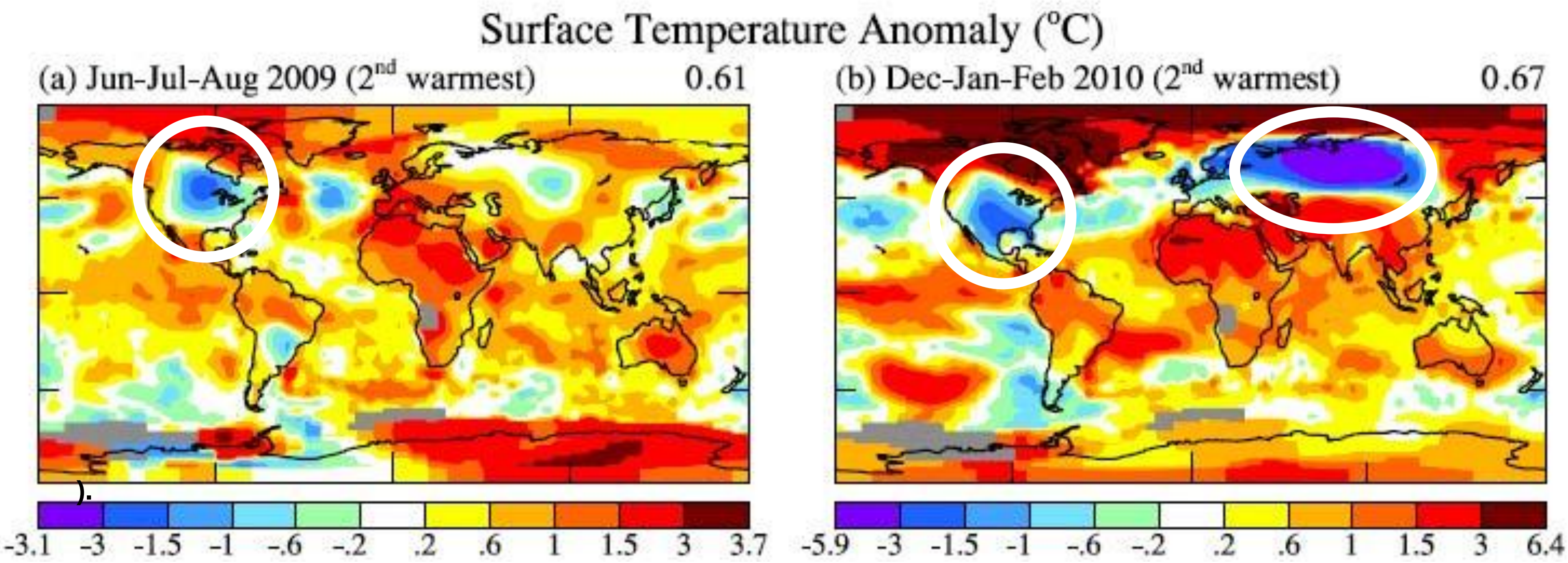
Relative humidity, temperature and Precipitation 2010 anomalies relative to 1989-2008 base period averages.

Ref: Dee et al, Bulletin AMS, v92, S34-35, 2011



HOW SPATIALLY UNEVEN WERE RECENT EXTREME SEASONAL GLOBAL TEMPERATURE CHANGES?

Global pattern of recent seasonal surface air temperature anomalies as estimated from observations by NASA-GISS.



Jun-Jul-Aug 2009 (globally the 2nd warmest ever) and Dec-Jan-Feb 2010 (globally the 2nd warmest ever) surface temperature anomalies (°C) relative to 1951-1980 base period, and the El Nino 3.4 index. Data extend through June, 2010. (Hansen et al, Reviews of Geophysics, 2010).

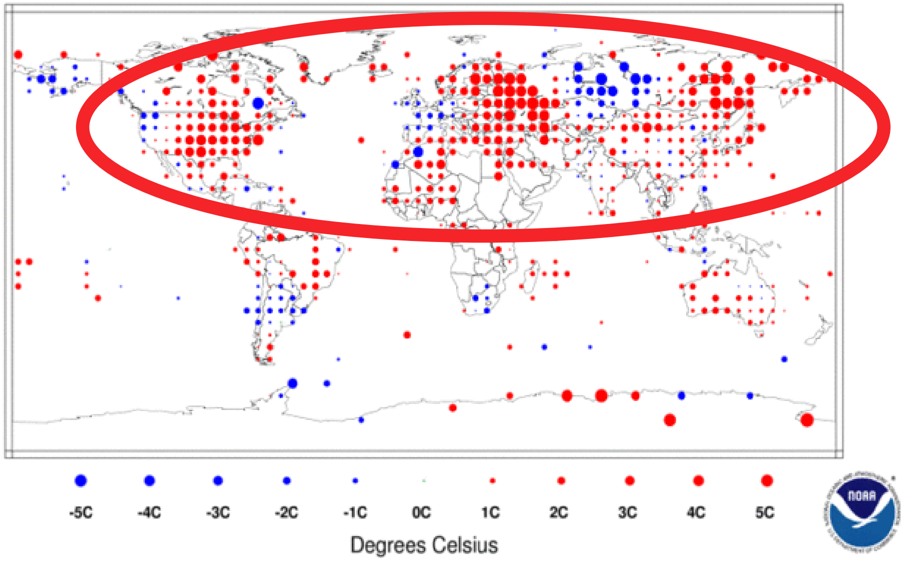
HOW UNUSUAL WAS JULY 2011 & WAS IT CLIMATE CHANGE OR WEATHER?

www.ncdc.noaa.gov/sotc/g#3877DE

Temperature Anomalies July 2011

(with respect to a 1961-1990 base period)

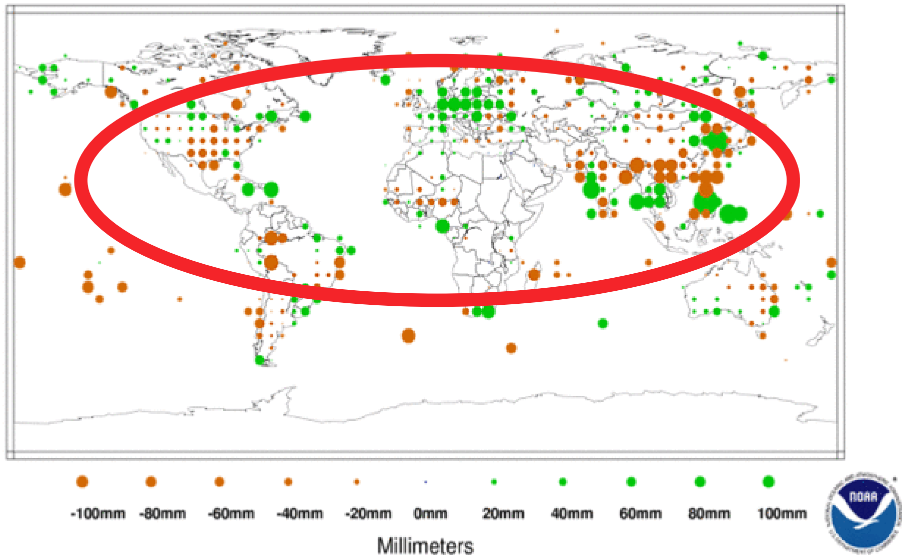
National Climatic Data Center/NESDIS/NOAA



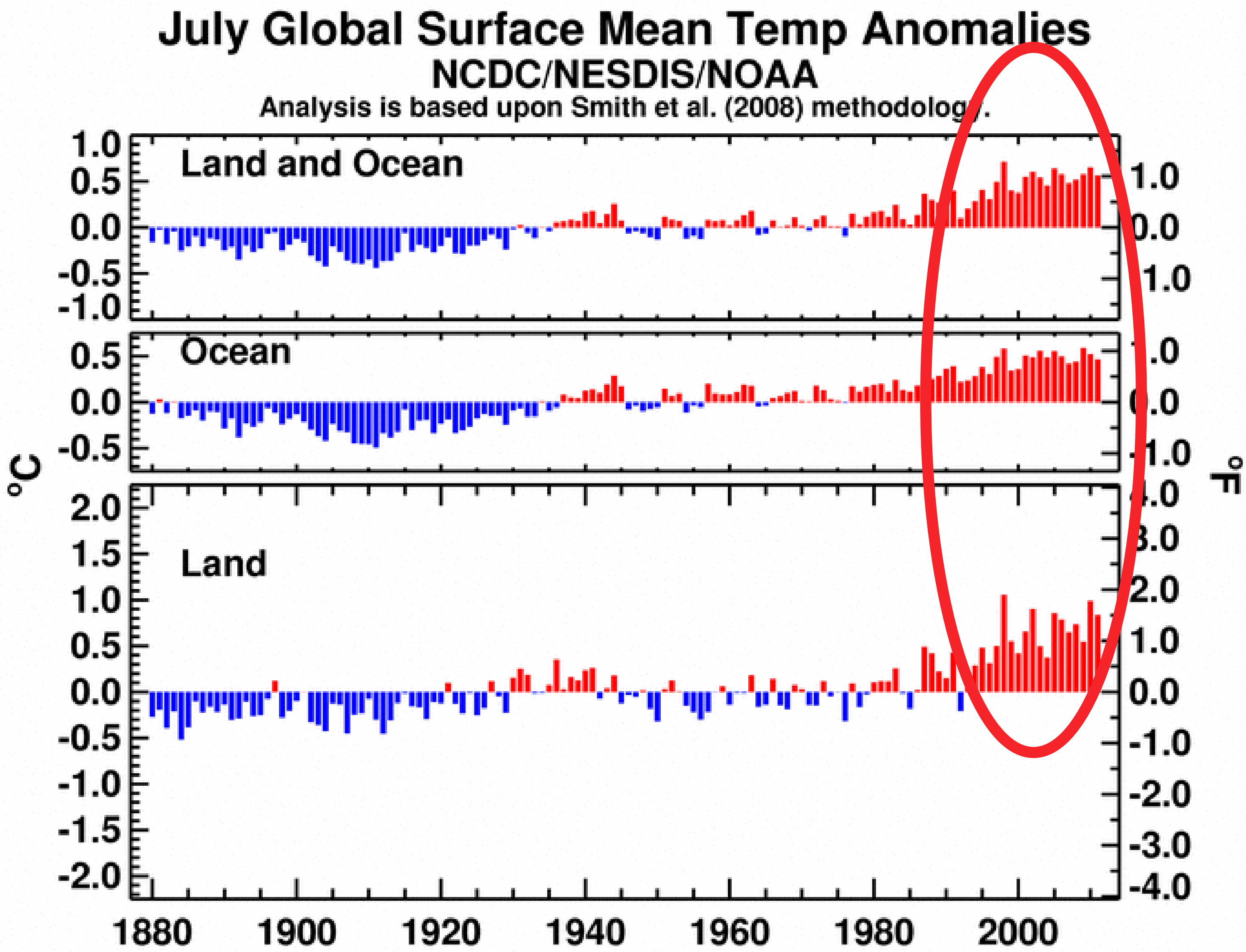
Precipitation Anomalies July 2011

(with respect to a 1961-1990 base period)

National Climatic Data Center/NESDIS/NOAA



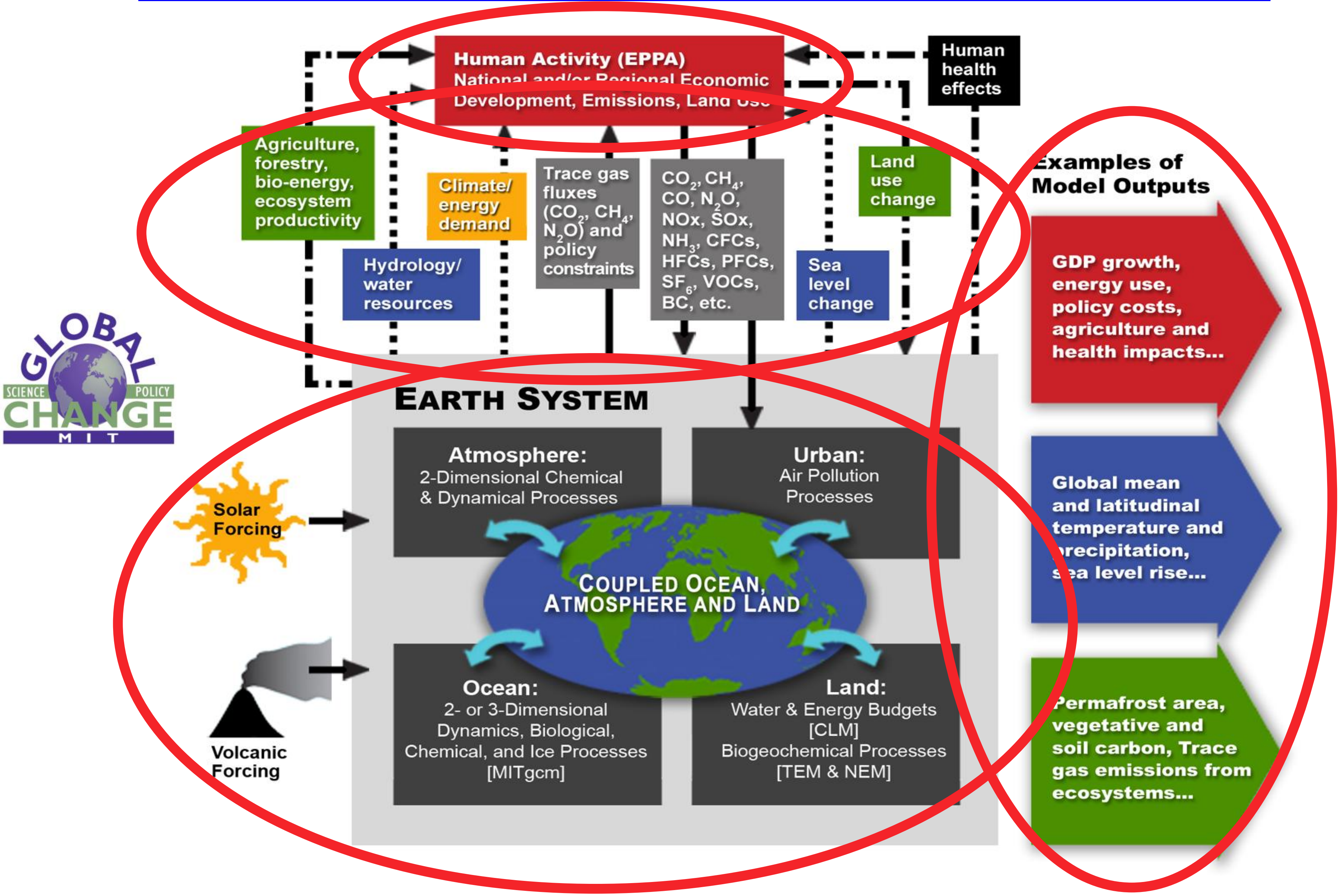
TO ANSWER THIS, WE NEED TO EXAMINE THE LONG TERM RECORDS FOR THE MONTH OF JULY



http://www.ncdc.noaa.gov/sotc/global/2011/7

PROBABILISTIC FORECASTS USING THE MIT INTEGRATED GLOBAL SYSTEM MODEL

http://globalchange.mit.edu



Cumulative PROBABILITY OF GLOBAL AVERAGE SURFACE AIR WARMING from 1981-2000 to 2091-2100, WITHOUT (median 1400 ppm-eq CO_2) & WITH A 550, 660, 790 or 900 median ppm-equivalent CO_2 GHG STABILIZATION POLICY

(400 IGSM forecasts per case)

Ref: Sokolov et al, Journal of Climate, 2009; Webster et al, Climatic Change, 2011

	ΔT > 2°C (values in red relative to 1860 or pre-industrial)	ΔT > 4°C	ΔT > 6°C
No Policy at 1400	100% (100%)	85%	25%
Stabilize at 900 (L4)	100% (100%)	25%	0.25%
Stabilize at 790 (L3)	97% (100%)	7%	< 0.25%
Stabilize at 660 (L2)	80% (97%)	0.25%	< 0.25%
Stabilize at 550 (L1)	25% (80%)	< 0.25%	< 0.25%

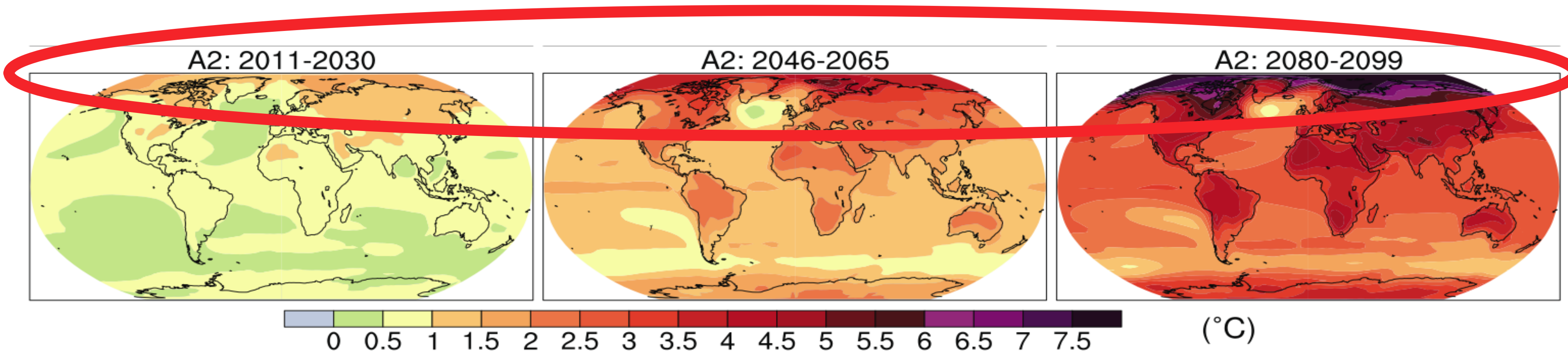
ADDRESSING REGIONAL CLIMATE CHANGE UNDER UNCERTAINTY

e.g. Cumulative PROBABILITY OF ARCTIC (60˚N to 90˚N) SURFACE AIR WARMING from 1981-2000 to 2091-2100, WITHOUT (1400 ppm-eq CO_2) & WITH A 550, 660, 790 or 900 ppm-eq CO_2 GHG STABILIZATION POLICY (400 IGSM forecasts per case)

Ref: Sokolov et al, J. Clim., 2009; Webster et al, Clim. Change, 2011

	ΔT > 4ºC	ΔT > 6ºC	ΔT > 8ºC
No Policy at 1400	100%	95%	70%
Stabilize at 900 (L4)	95%	30%	3%
Stabilize at 790 (L3)	80%	9%	0.25%
Stabilize at 660 (L2)	25%	0.25%	< 0.25%
Stabilize at 550 (L1)	0.5%	< 0.25%	< 0.25%

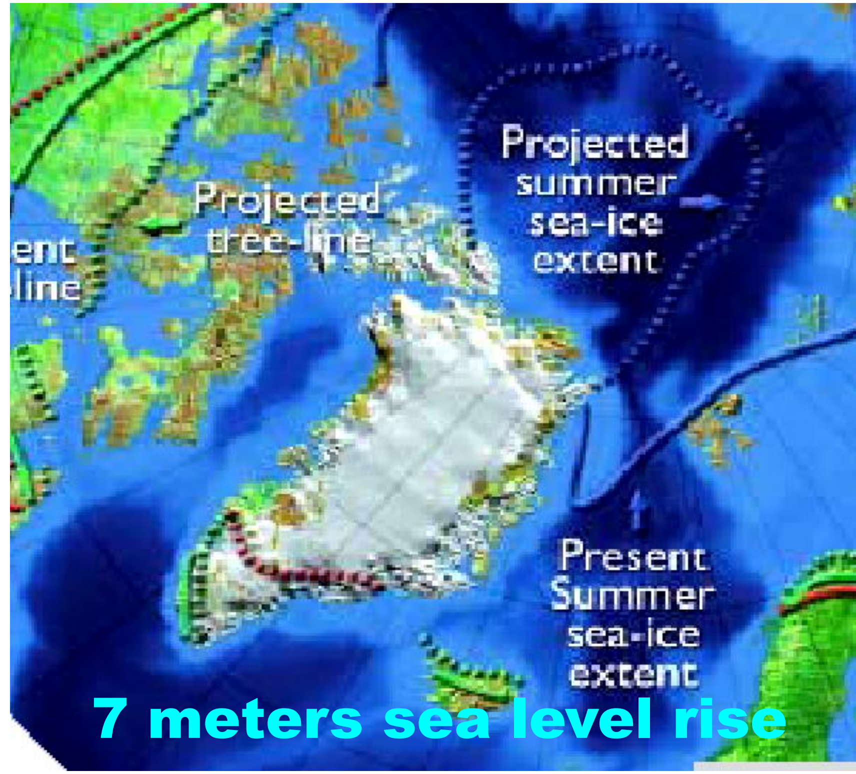
REGIONAL FORECASTS
TEMPERATURE CHANGES FOR THE HIGH EMISSION SCENARIO A2
(IPCC 4th Assessment, WG 1, CH. 10, 2007)



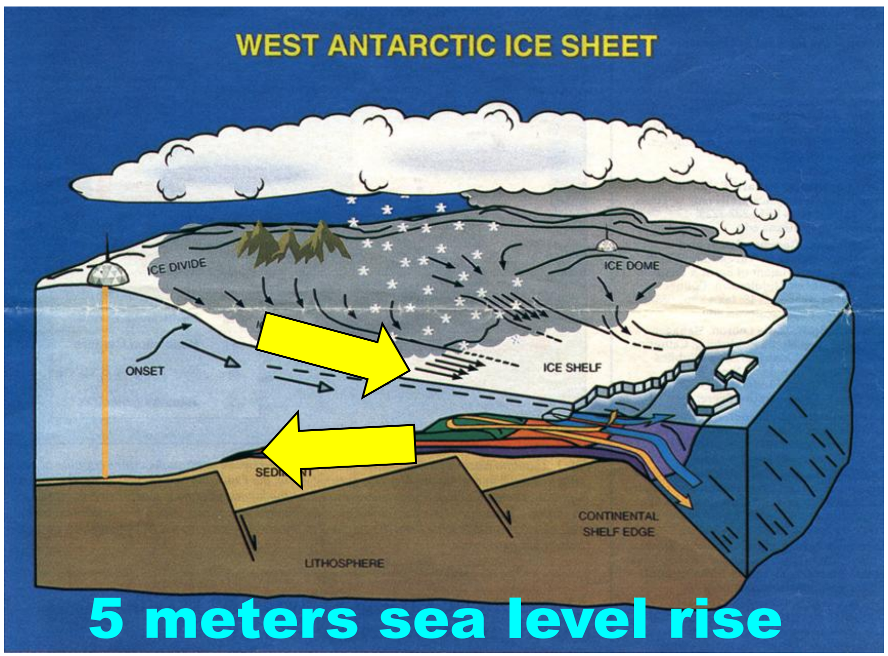
POLES (especially Arctic) warm much faster than tropics (similar to present-day trends)

Multi-model mean of annual mean surface warming (surface air temperature change, °C) for the emission scenario A2) at three time periods, 2011 to 2030 (left), 2046 to 2065 (middle) and 2080 to 2099 (right). Anomalies are relative to the average of the period 1980 to 1999.

POLES WARM MUCH FASTER THAN TROPICS; IF ICE SHEETS MELT, HOW MUCH SEA LEVEL RISE COULD OCCUR?



STABILITY OF GREENLAND ICE SHEET



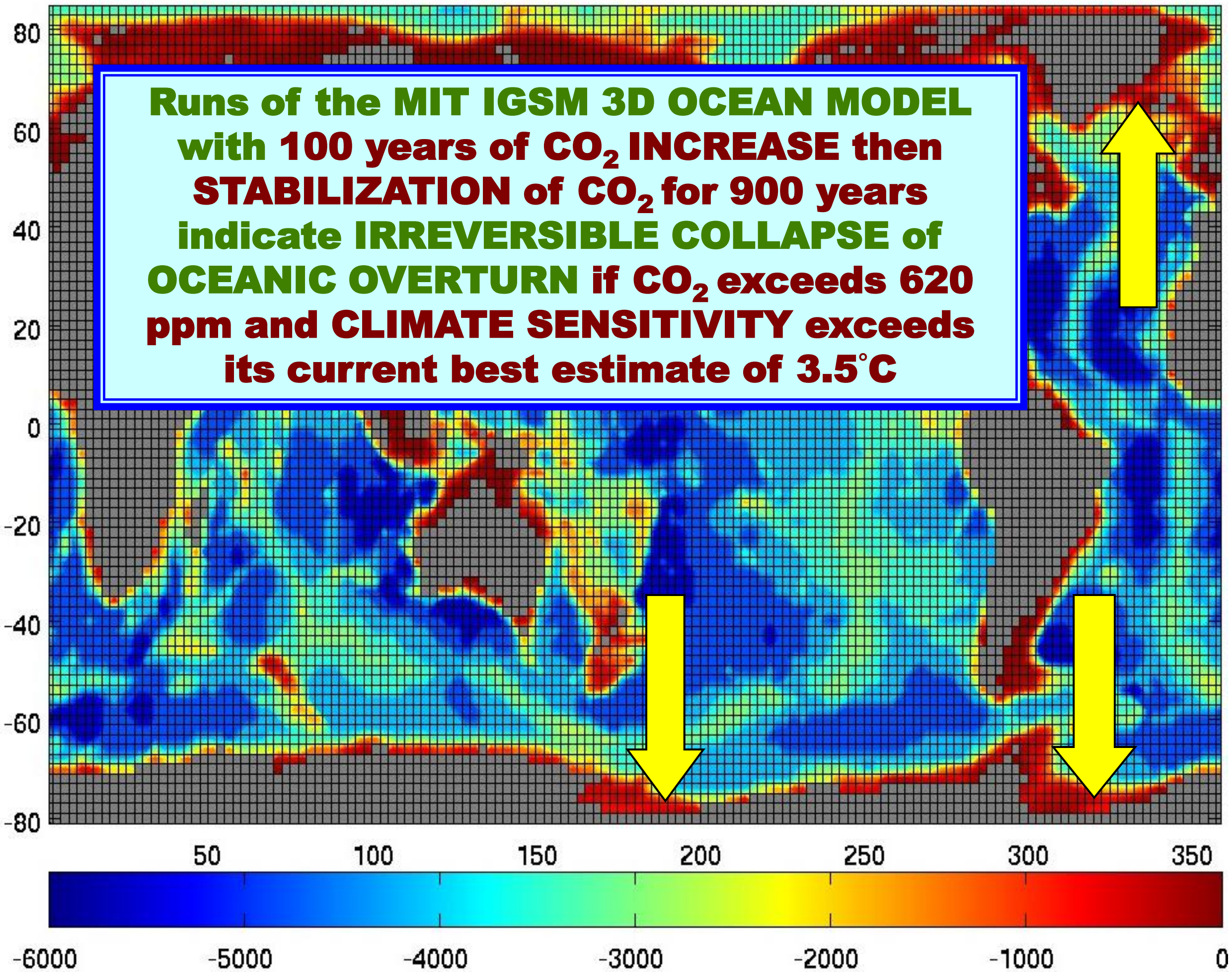
STABILITY OF WEST ANTARCTIC ICE SHEET

The last time the polar regions were significantly warmer (~4 ˚C) than present for an extended period (about 125,000 years ago), reductions in polar ice volume led to 4 to 8 meters of sea level rise.

REFs: Bindschadler et al; ACIA, Impacts of a Warming Arctic, Climate Impact Assessment Report, 2004

IF THE POLAR LATITUDES WARM TOO MUCH, COULD THE DEEP OCEAN CARBON & HEAT SINK COLLAPSE?

Runs of the MIT IGSM 3D OCEAN MODEL with 100 years of CO_2 INCREASE then STABILIZATION of CO_2 for 900 years indicate IRREVERSIBLE COLLAPSE of OCEANIC OVERTURN if CO_2 exceeds 620 ppm and CLIMATE SENSITIVITY exceeds its current best estimate of 3.5˚C



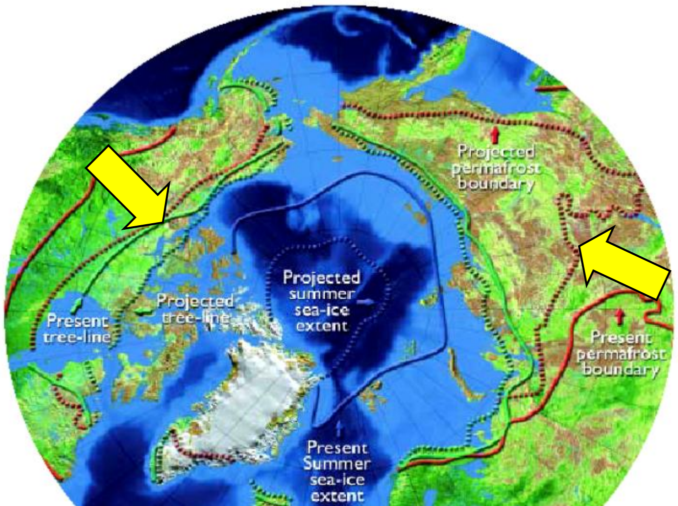
OCEAN BOTTOM DEPTHS (meters)
(MIT IGSM 3D OCEAN MODEL

OVERTURN DRIVEN BY SINKING WATER IN THE POLAR SEAS (Norwegian, Greenland, Labrador,Weddell, Ross)

SLOWED BY DECREASED SEA ICE & INCREASED FRESH WATER INPUTS INTO THESE SEAS

INCREASED RAINFALL, SNOWFALL & RIVER FLOWS, & DECREASED SEA ICE, EXPECTED WITH GLOBAL WARMING

Ref: Scott et al, MIT Joint Program Report 148, Climate Dynamics, v30, p441-454, 2008



WHAT WOULD HAPPEN IF ARCTIC TUNDRA & PERMAFROST THAWS?

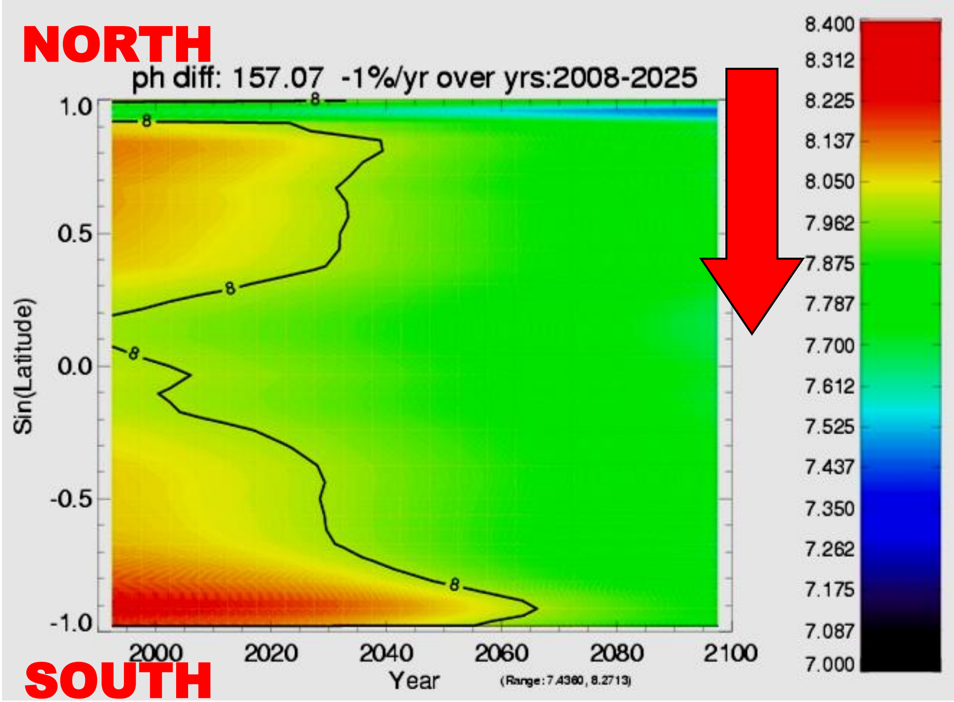
THIS WOULD INDUCE EMISSIONS OVER TIME OF THE 1670 BILLION TONS OF CARBON STORED IN ARCTIC TUNDRA & FROZEN SOILS (TARNOCAI ET AL, GBC, 2009). THIS IS ABOUT 200 TIMES CURRENT ANNUAL ANTHROPOGENIC CARBON EMISSIONS. THESE EMISSIONS WOULD INCLUDE METHANE FROM NEW & WARMER WETLANDS.

REF: ACIA, Impacts of a Warming Arctic, Climate Impact Assessment Report, 2004

WILL THERE BE DELETERIOUS INCREASES OF OCEANIC ACIDITY ($pH = -\log_{10}[H^+]$)?

e.g. IGSM forecast with NO EXPLICIT POLICY OVER NEXT 100 YEARS

DROP IN pH OF 0.5 or GREATER COULD LEAD TO DECIMATION OF CALCAREOUS PHYTOPLANKTON



WHAT ARE SOME LEADING ENVIRONMENTAL RISKS WHOSE ODDS OR AMPLITUDES COULD BE LOWERED BY MITIGATION?

DEPLETION OF ARCTIC SUMMER SEA ICE
Replacing reflecting with absorbing surface (2007 was 50% of 1979)

INSTABILITY OF GREENLAND & WEST ANTARCTIC ICE SHEETS
7+5=12 meters of potential sea-level rise (Eemian sea level rise = 4-8 meters)

DEEP OCEAN CARBON & HEAT SINK SLOWED BY DECREASED SEA ICE & INCREASED FRESH WATER INPUTS INTO POLAR SEAS
e.g. collapse if CO_2 >620 ppm and CLIMATE SENSITIVITY >3.5°C (Scott et al)

INSTABILITY OF ARCTIC TUNDRA & PERMAFROST
About 1670 billion tons of carbon stored in Arctic tundra & frozen soils; equivalent to >200 times current anthropogenic emissions (Tarnocai, GBC, 2009)

DELETERIOUS INCREASES OF OCEANIC ACIDITY
pH drop exceeding 0.5 (>875 ppm CO_2) could decimate calcareous phytoplankton

SHIFTING CLIMATE ZONES
Maximum warming & % precipitation increase in polar regions
More arid sub-tropics & lower mid-latitudes

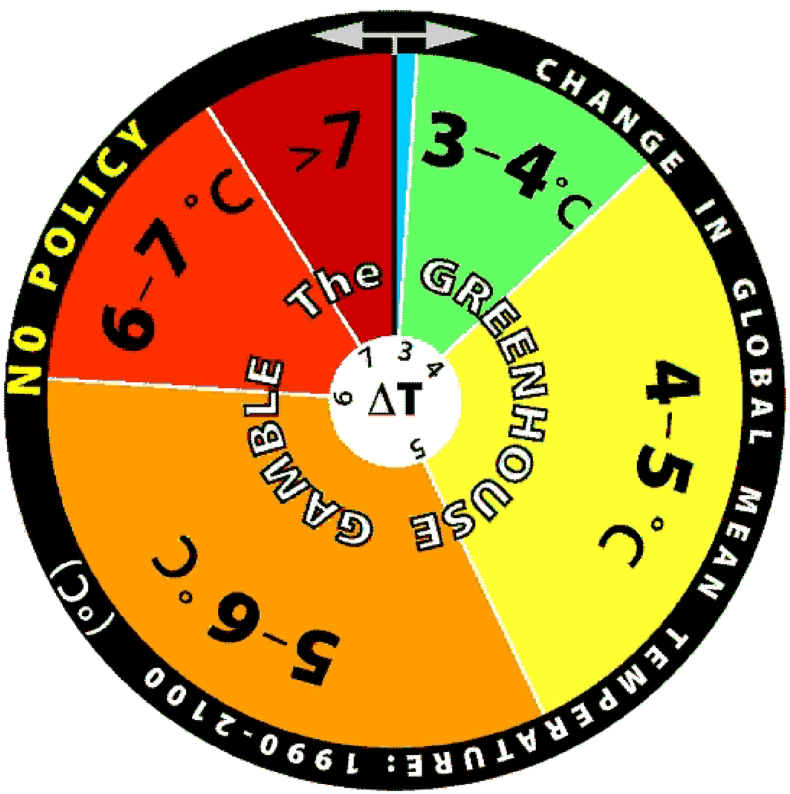
INCREASING DESTRUCTIVENESS OF HURRICANES
Increased 2-3 times post-1960 and correlated with sea-surface warming (Emanuel, Sci., 2005)

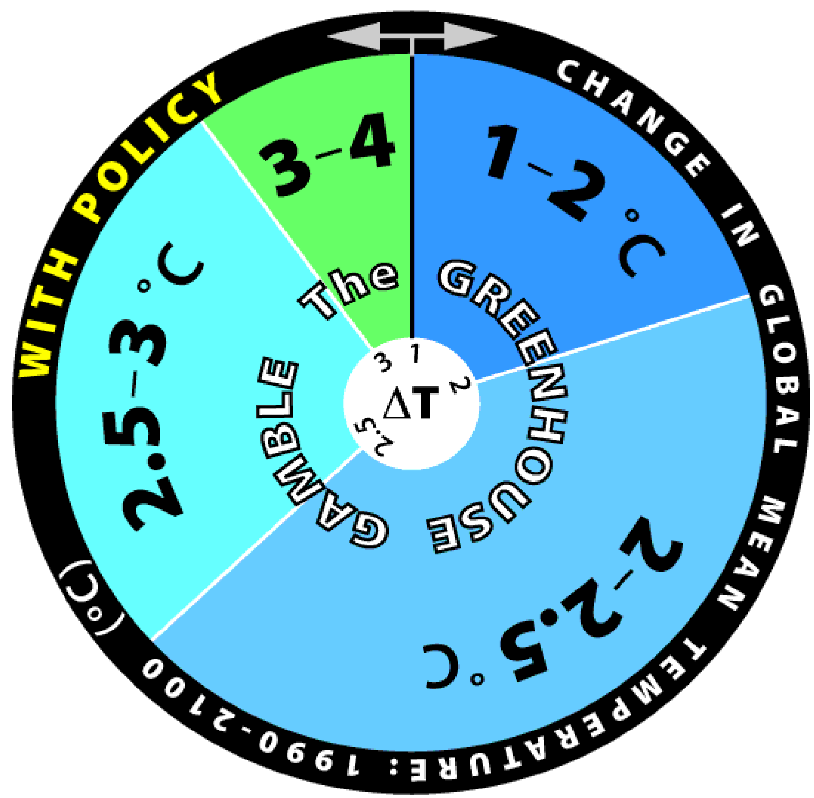
HOW CAN WE EXPRESS THE VALUE OF A CLIMATE POLICY UNDER UNCERTAINTY?

Compared with NO POLICY

What would we buy with STABILIZATION at 660 ppm-equivalent of CO_2?

A NEW WHEEL with lower odds of EXTREMES





http://globalchange.mit.edu

WE ARE CURRENTLY SPINNING THIS WHEEL