The Recent Pause in Global Warming: A Temporary Blip or Something More Permanent?

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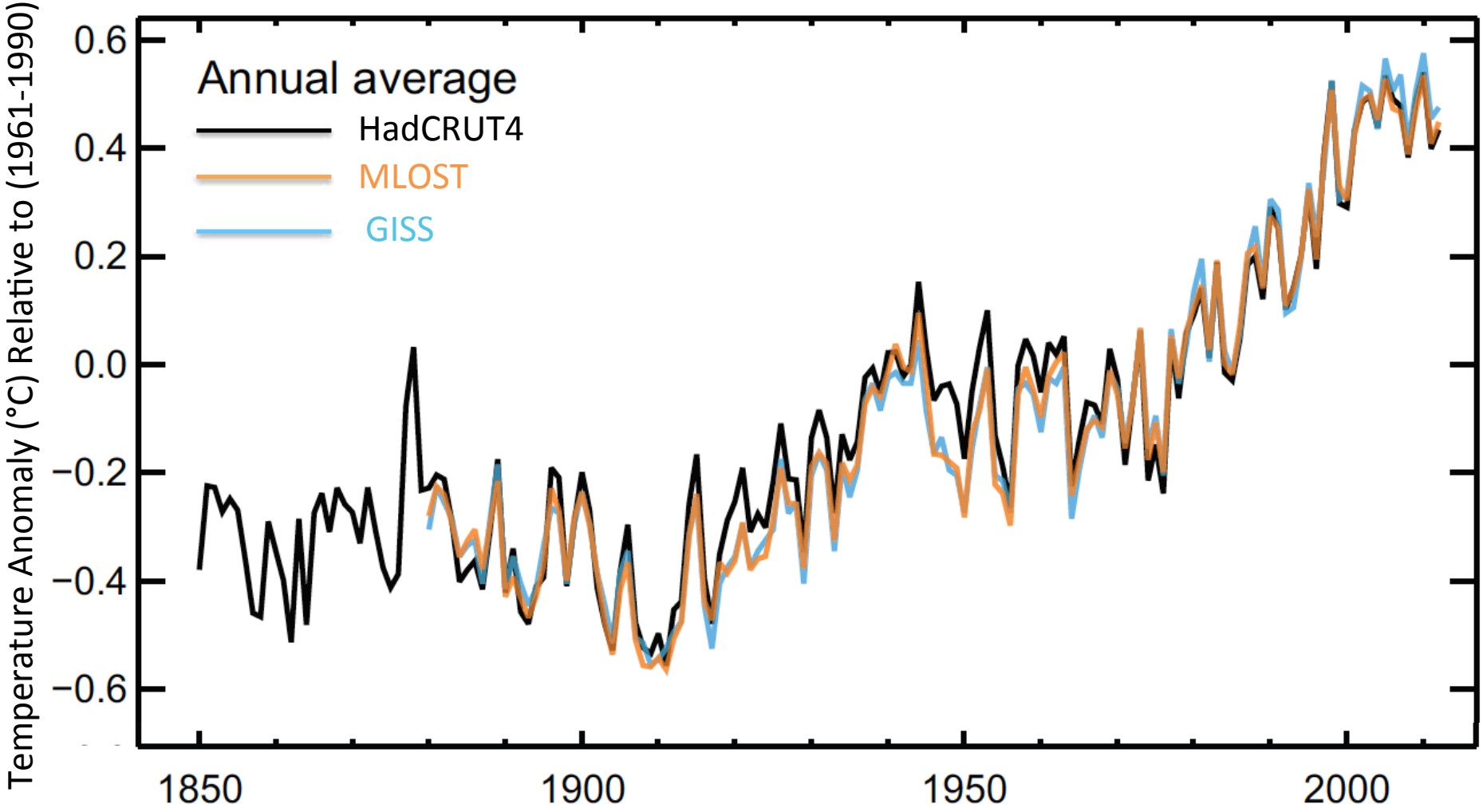
Outline

- Observed Indicators of a Changing Global Climate
- Earth's Energy Budget
- The Global Warming Hiatus
- Conclusions

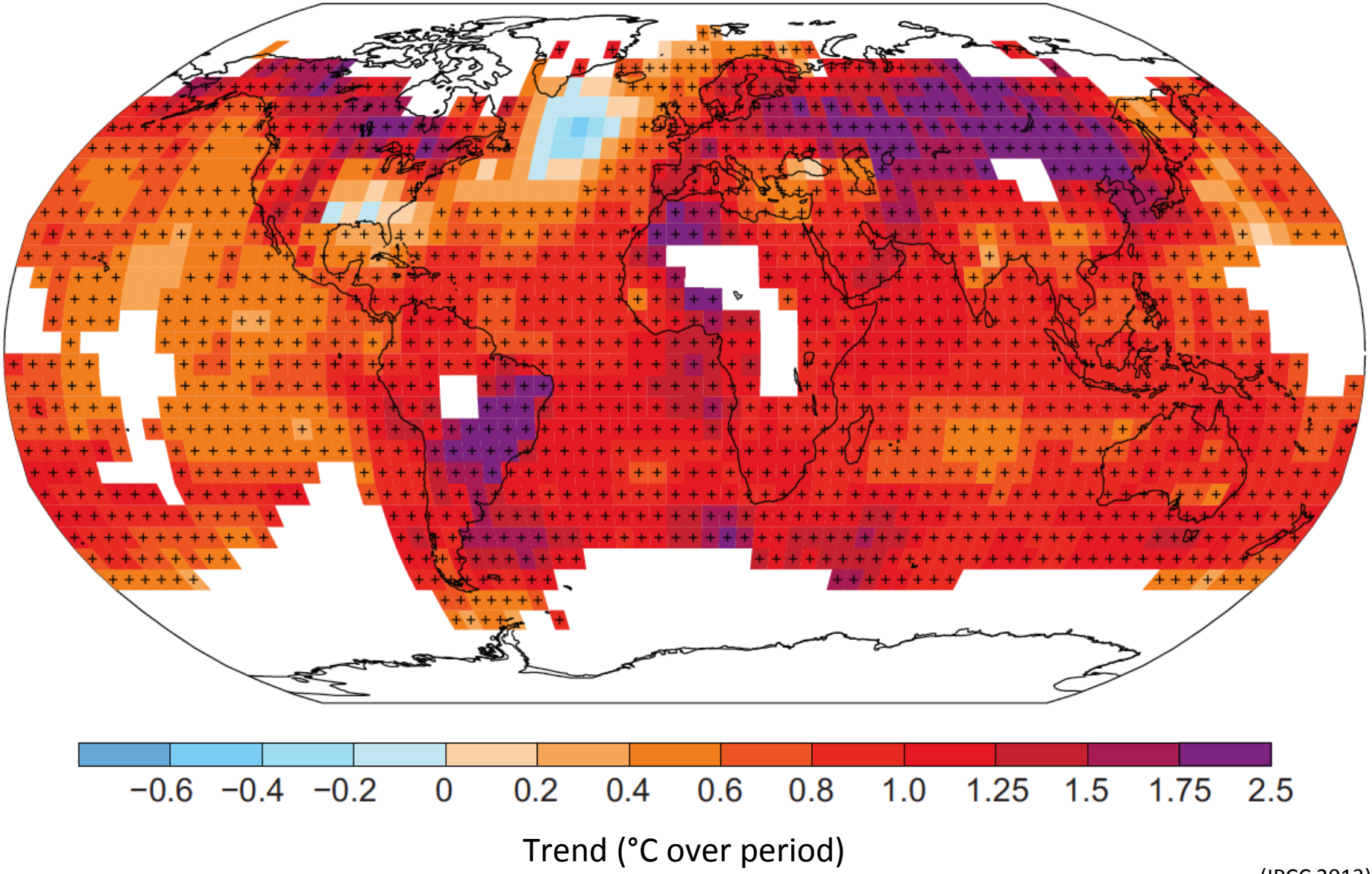
Observed Globally Averaged Combined Land And Ocean Surface Temperature Anomaly 1850–2012



- Observations show a warming of 0.85°C between 1880-2012.
- Last ice age: ~5°C cooler
- Climate model projections (2100): 1.5°C - 4.5°C warmer (90% Conf. Invl.)

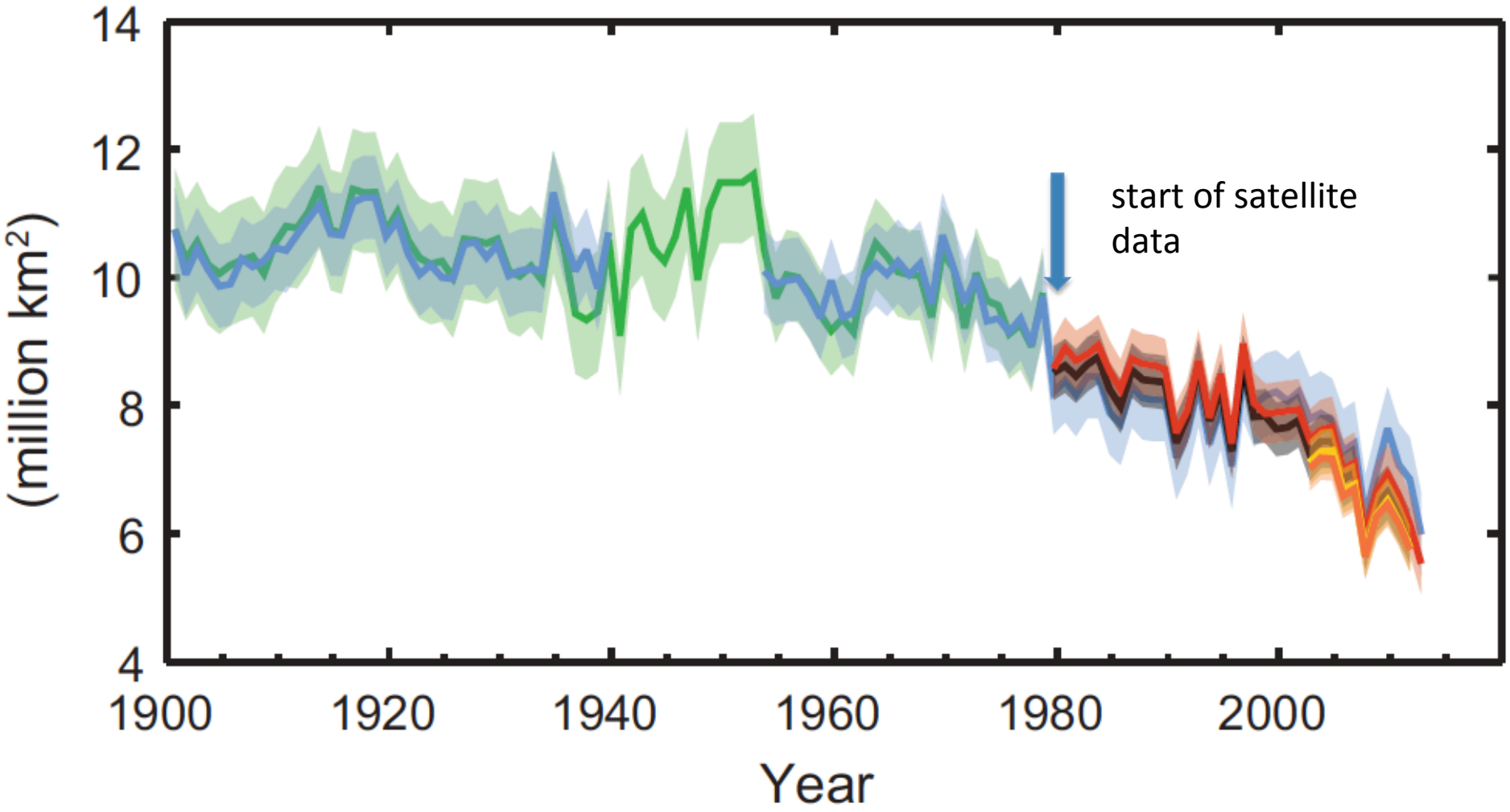
(IPCC 2013)

Observed change in surface temperature 1901–2012



(IPCC 2013)

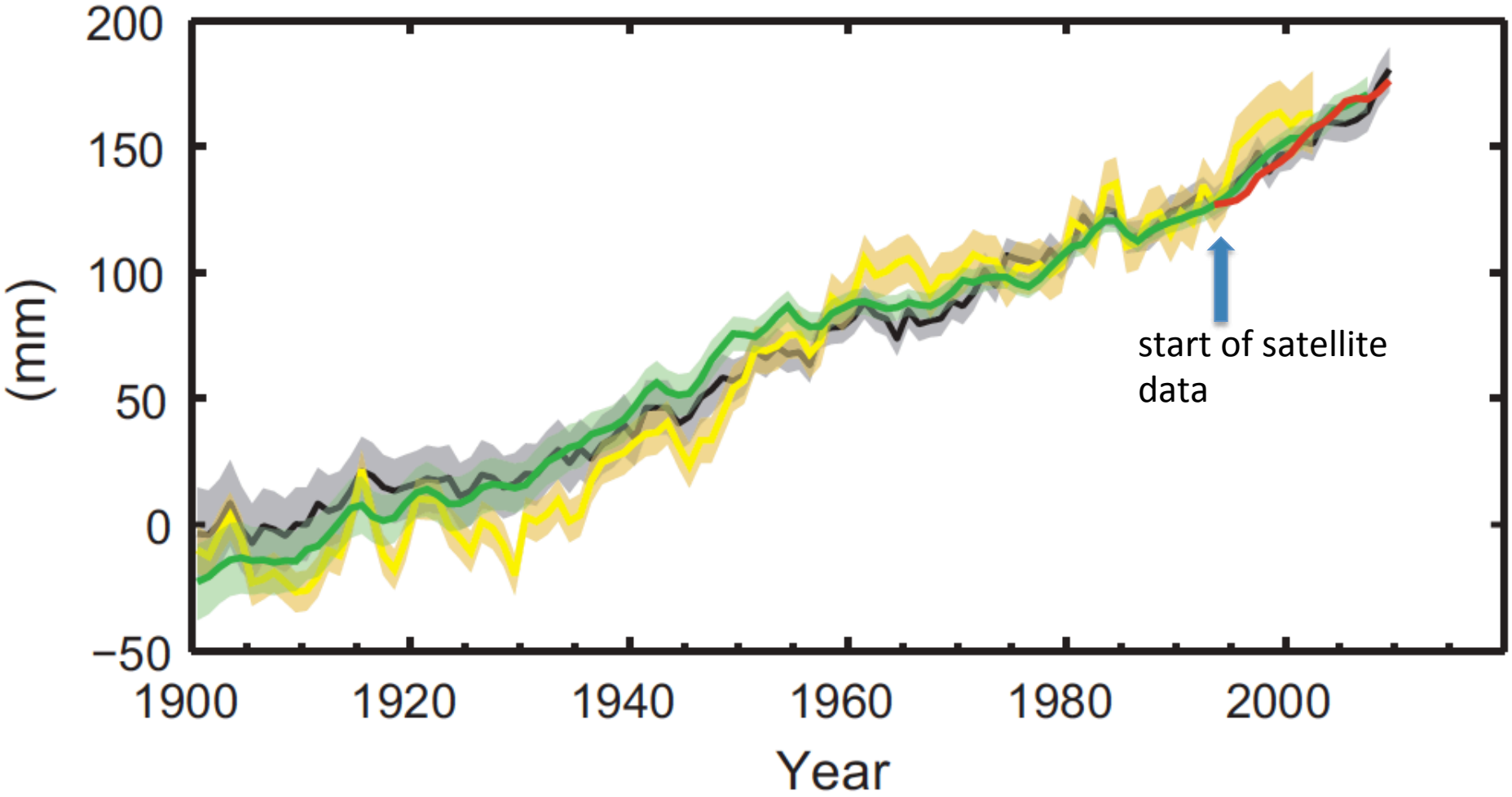
Extent of Arctic Sea Ice (July-August-September)



Summertime Arctic sea ice extent minimum decreased at a rate of 9.4%-13.6% per decade for 1979-2012 .

(IPCC 2013)

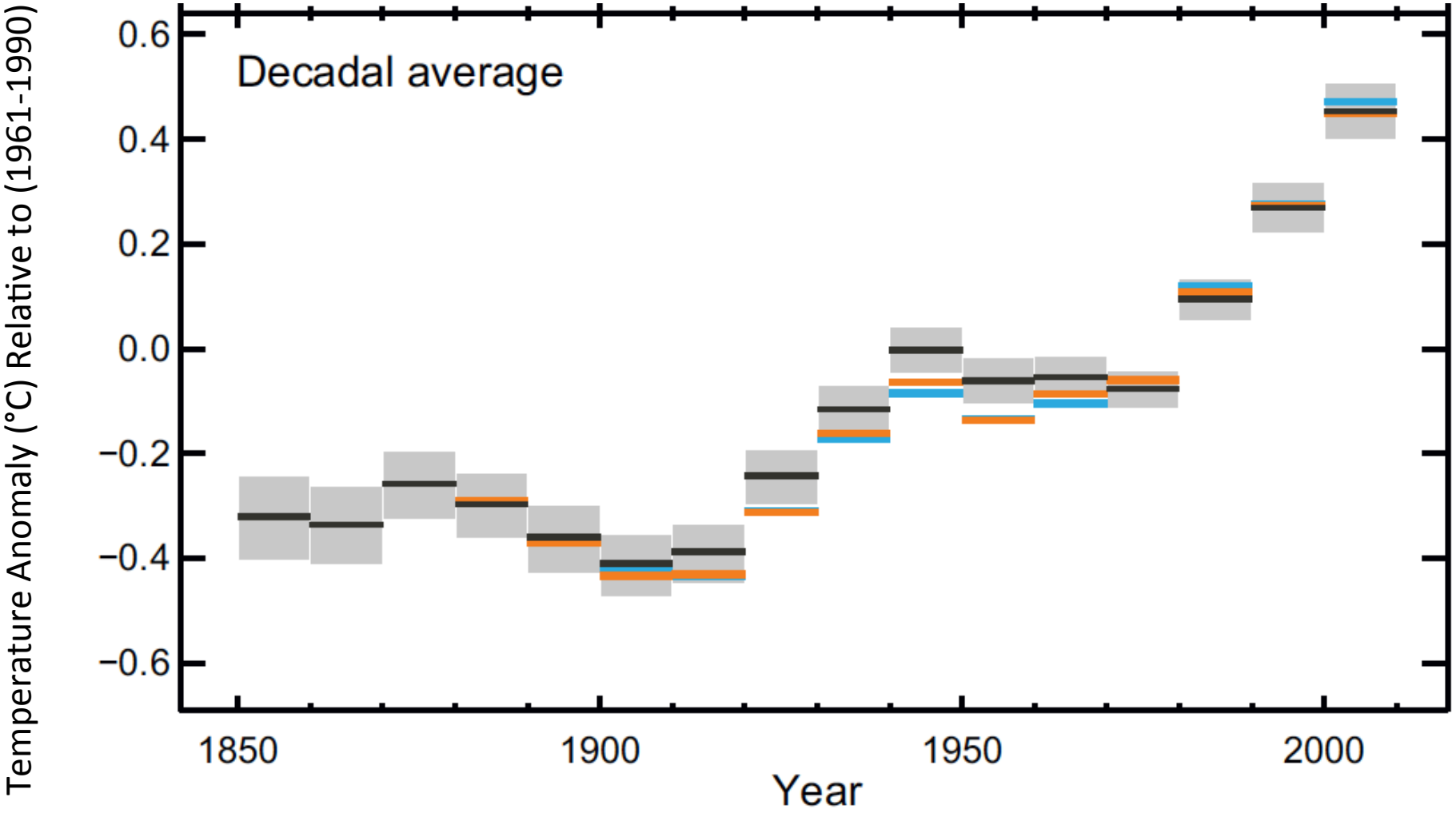
Global Mean Sea Level (Relative to the 1900–1905 Mean)



- Between 1901-2010, global mean sea level rose by 0.19 m (7.5”).
- Mean rate of global average sea level rise: 3.2 mm yr^{-1} (1993 and 2010) (0.13”/yr).
- In Norfolk, VA, sea level has risen 0.45 m (1.5 feet) since the 1920s. Land subsidence accounts for roughly half of the increase.

(IPCC 2013)

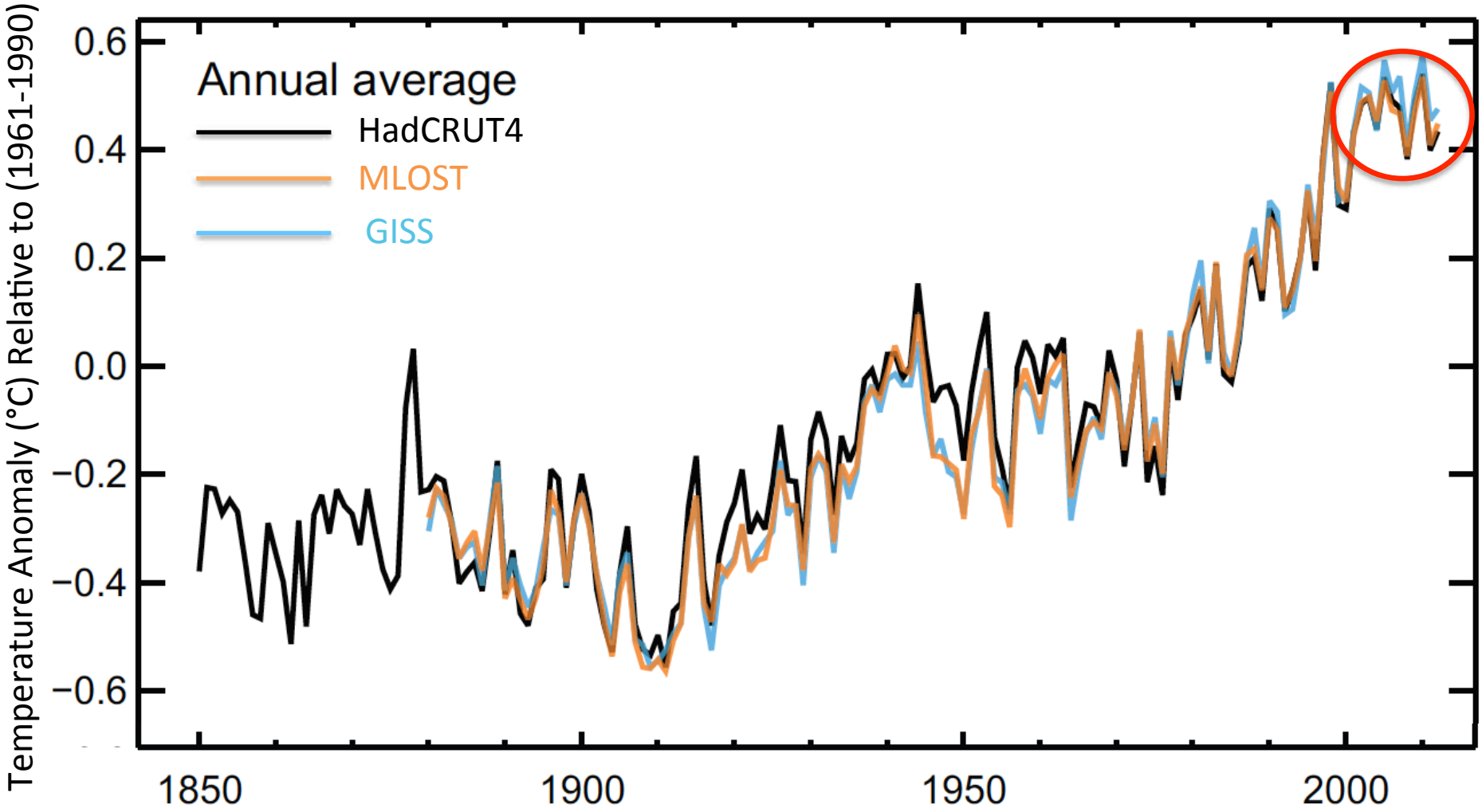
Observed Globally Averaged Land & Ocean Temperature Anomaly (1850-2012)



- Each of the last 3 decades has been successively warmer than any preceding decade since 1850.

(IPCC 2013)

Observed Globally Averaged Combined Land And Ocean Surface Temperature Anomaly 1850–2012

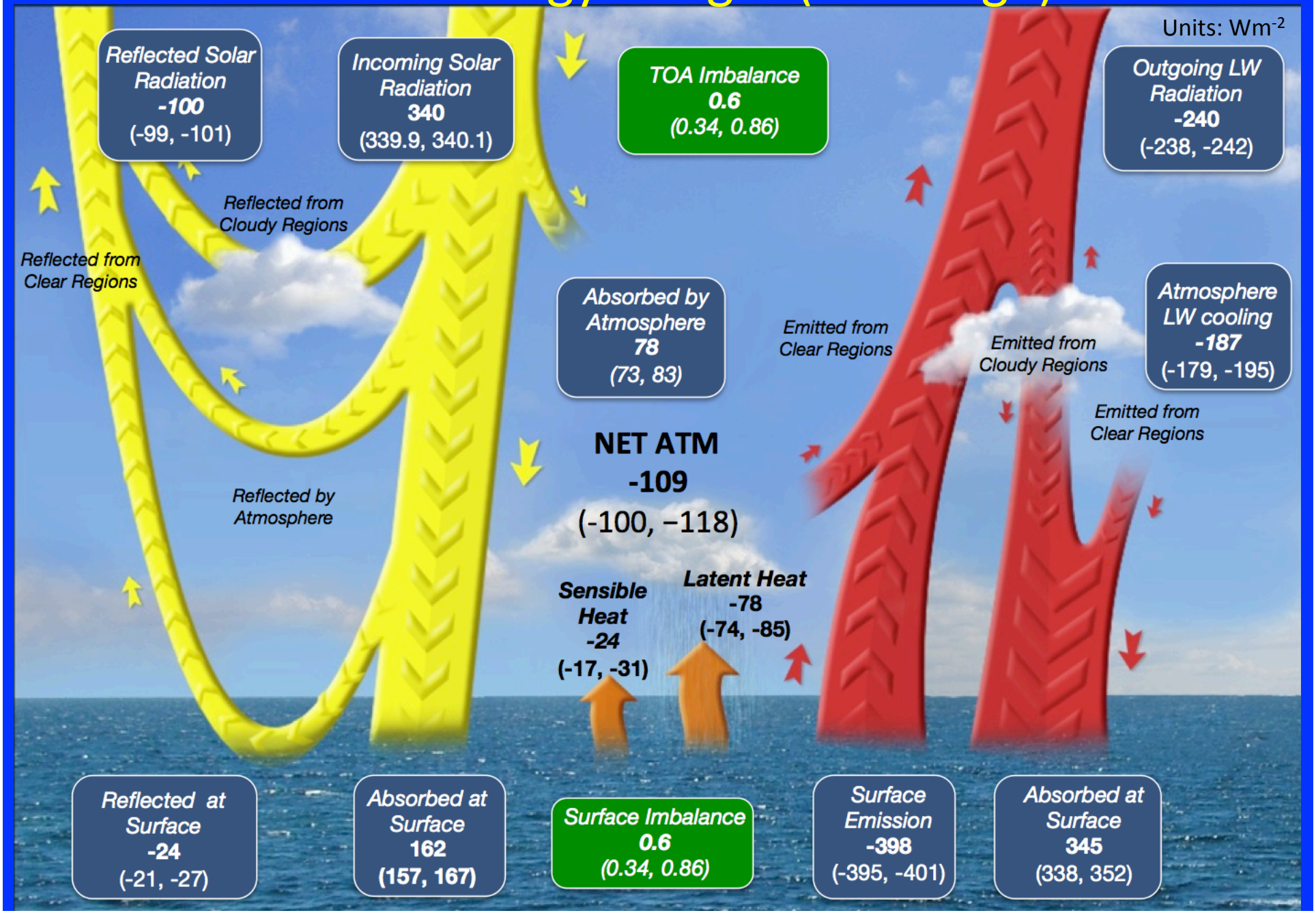


- The global mean surface temperature trend over 1998–2012 is roughly one third of the trend over 1951–2012.
- This is referred to as **"The Global Warming Hiatus"**.

(IPCC 2013)

Climate Forcing, Earth's Energy Budget & Global Mean Surface Temperature

Earth's Energy Budget (1σ Range)



Earth's Greenhouse Effect

- Solar radiation largely passes through the atmosphere to warm the planetary surface.
- Surface emits infrared thermal radiation, which is absorbed by greenhouse gases and re-radiated to the surface and lower atmosphere.
- Without greenhouse effect, surface temperature would be -18°C instead of +15°C.
- Main greenhouse gases: water vapor, carbon dioxide, methane, ozone, and nitrous oxide.

Atmospheric Composition

Dry Atmosphere

Gas	Volume
Nitrogen (N_2)	78%
Oxygen (O_2)	21%
Argon (Ar)	0.934%
Carbon Dioxide (CO_2)	0.0397%
Neon (Ne)	0.00182%
Helium (He)	0.000524%
Methane (CH_4)	0.000179%

Water Vapor in Atmosphere

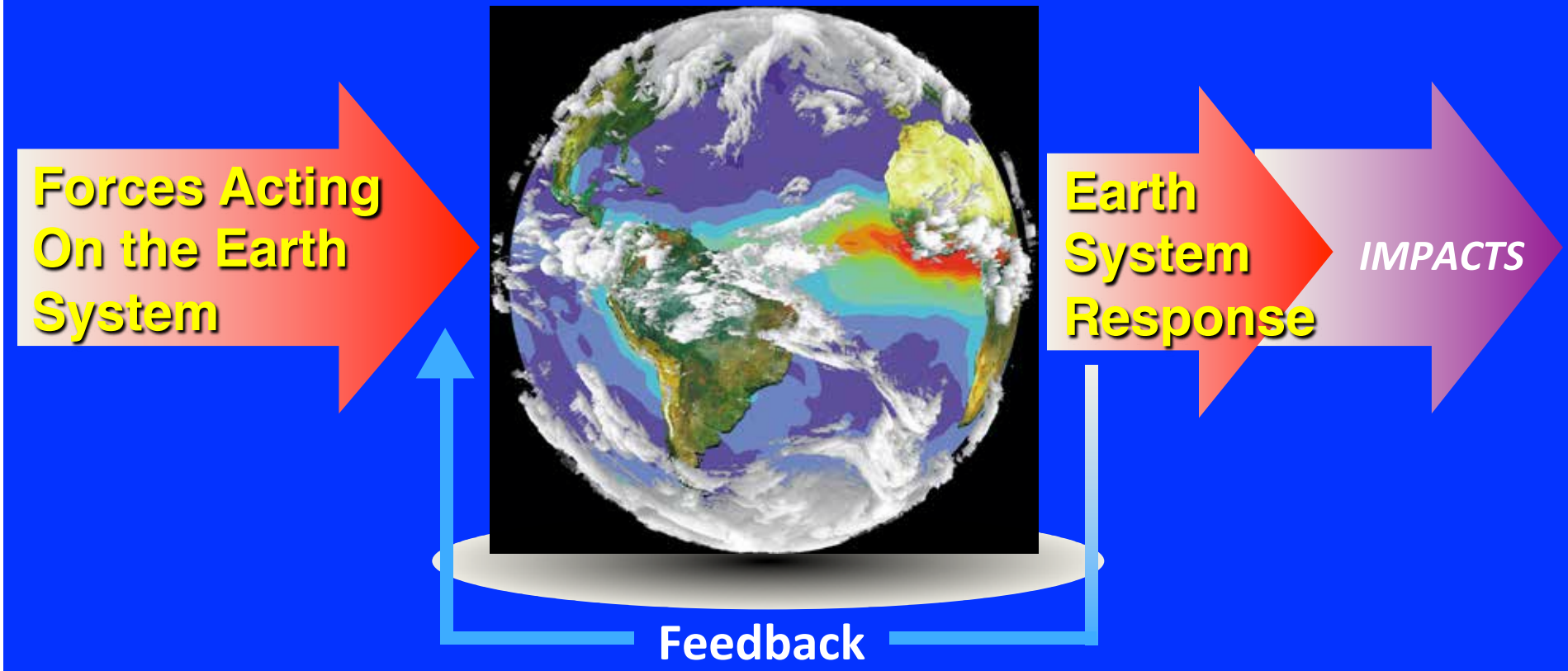
Gas	Volume
Water Vapor (H_2O)	0.001% - 5%

Dominant Contributors to Atmospheric Infrared Thermal Absorption (Present-Day Greenhouse Effect)

Contributor to GH Effect	Rel. Contrib.
Water Vapor	50%
Clouds	25%
Carbon Dioxide (CO_2)	20%
CH_4, O_3 and N_2O	5%

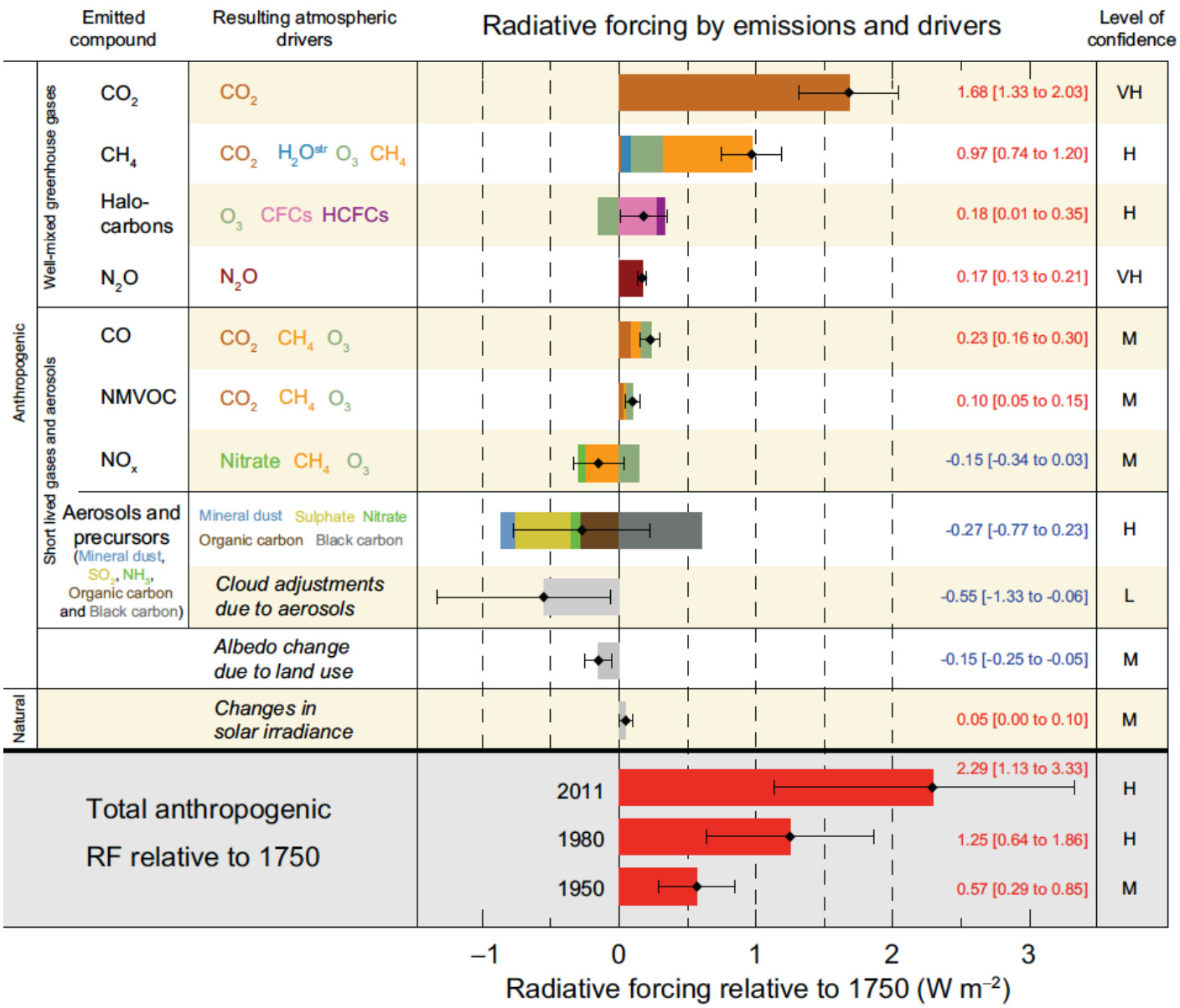
(Adapted from Schmidt et al., JGR 2010)

How does the Earth Respond?



- Forcings include natural (sun, volcanic eruptions) and man-made (CO_2 and other GHGs, aerosols, land cover changes, etc.).
- Feedbacks include those due to water vapor, temperature/lapse rate, surface albedo, clouds.

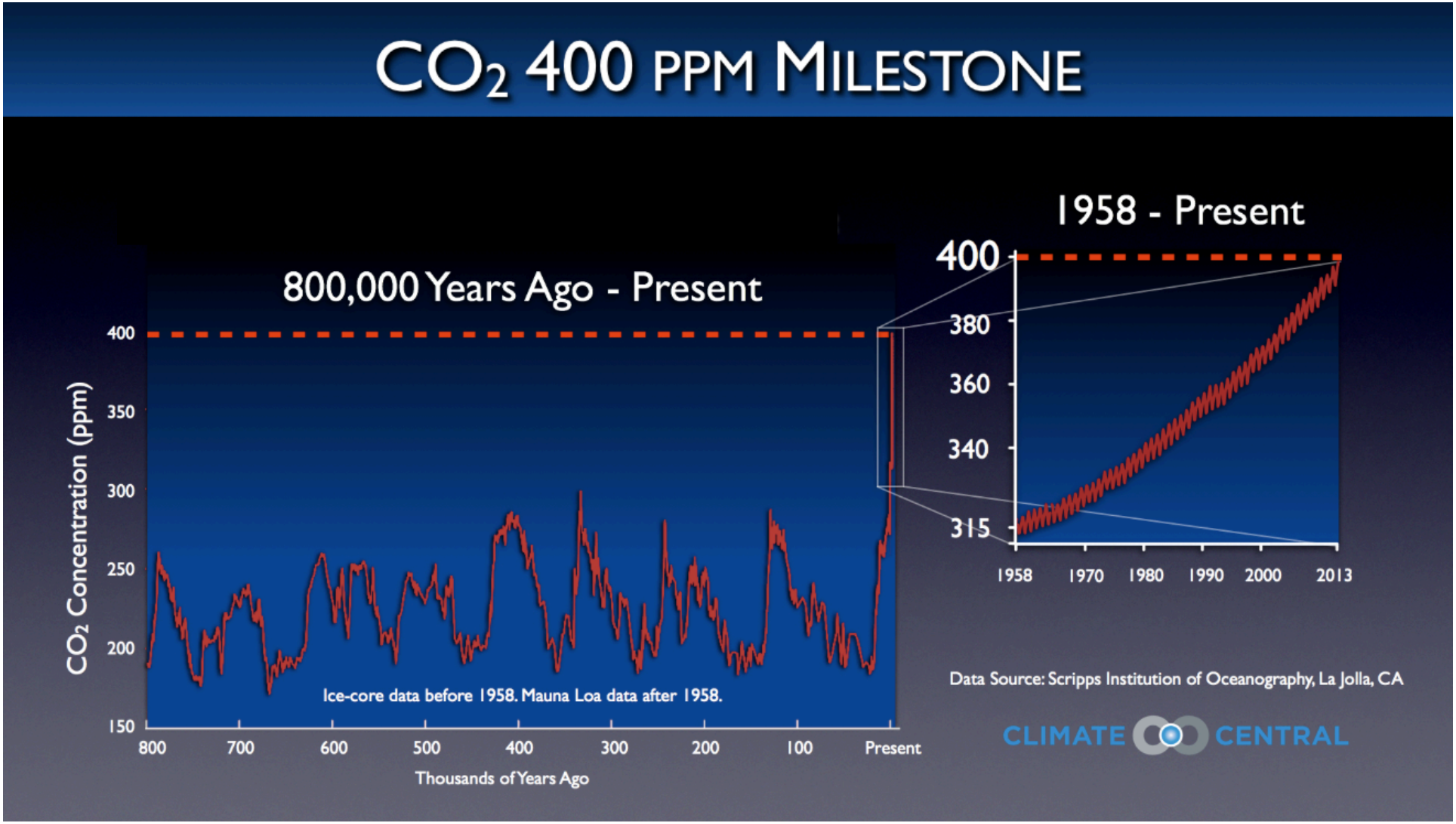
Radiative Forcing Estimates in 2011 relative to 1750



- Measure of the influence a factor has in altering the balance of incoming and outgoing energy in the Earth-atmosphere system.
- Total radiative forcing is positive. The largest contribution is from the increase in atmospheric CO_2.

(IPCC 2013)

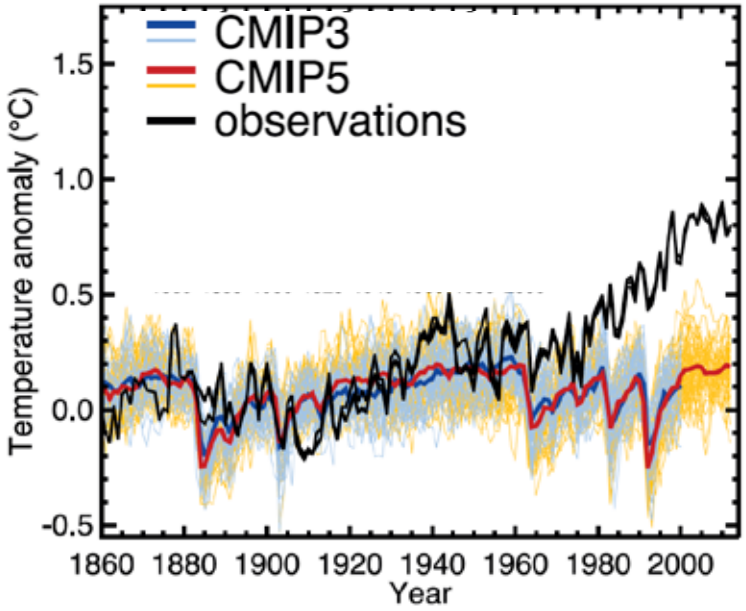
CO_2 400 PPM MILESTONE



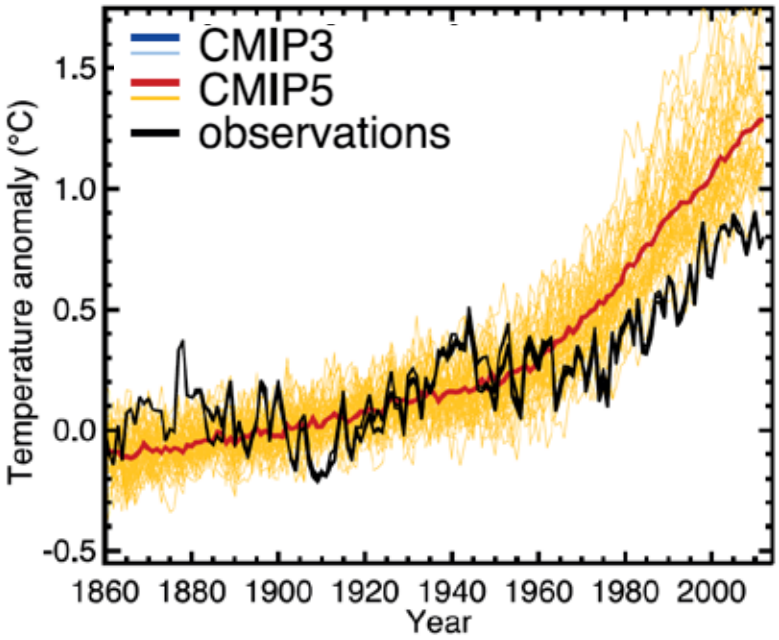
- Long-lived, heat-trapping gas
- Hit 400 ppm in May 9, 2013
- Growth of global CO_2 emissions from the burning of coal, oil, and natural gas

Climate Model Simulations vs Observations

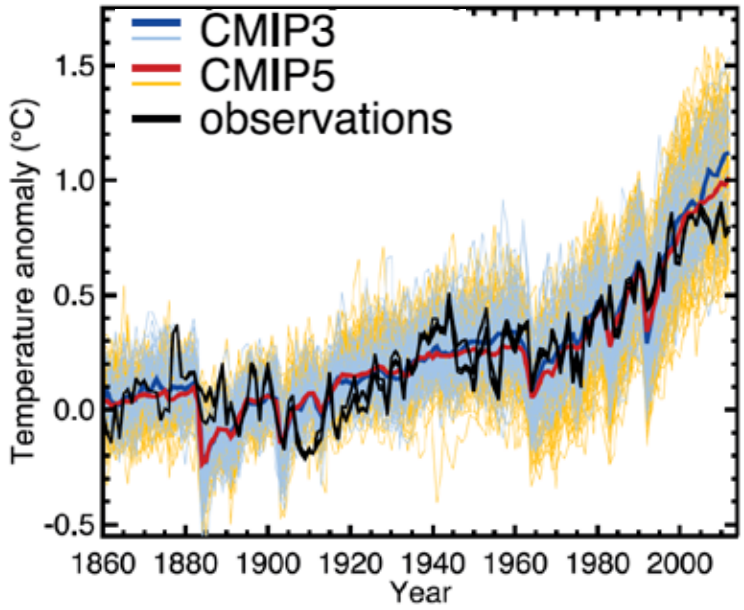
Natural Forcing Only

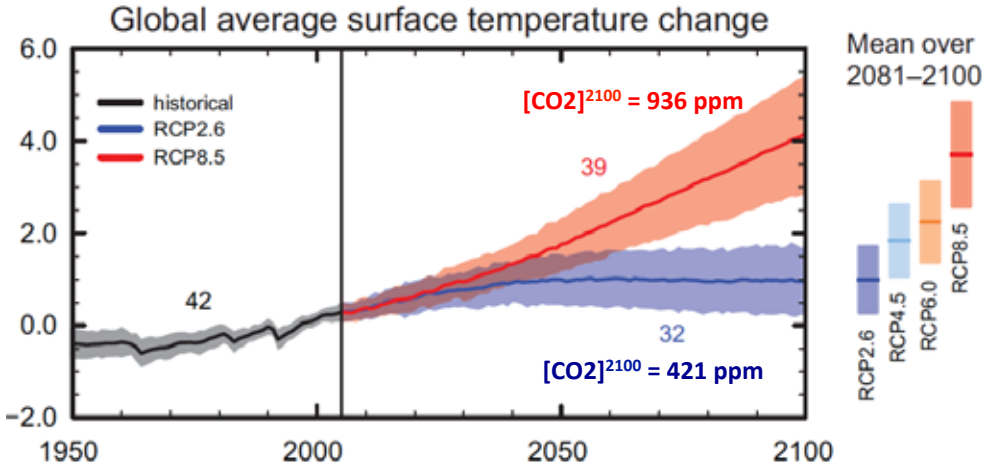


Anthropogenic Forcing Only



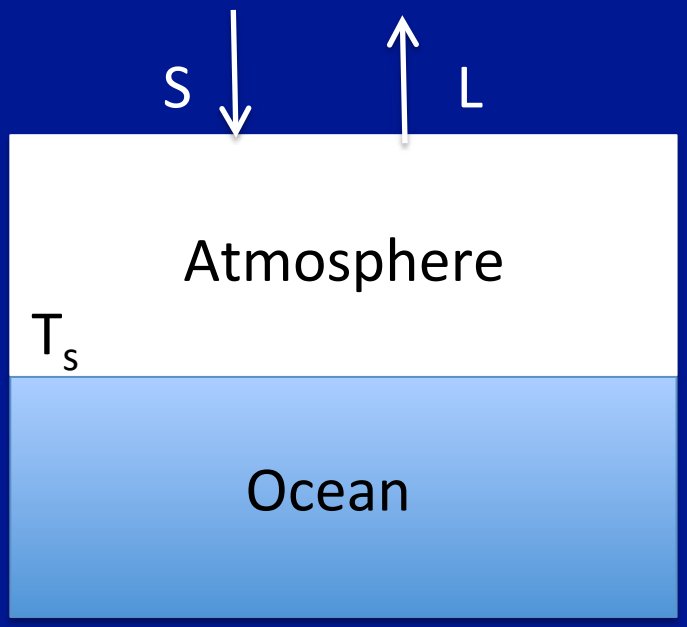
Natural + Anthropogenic Forcing



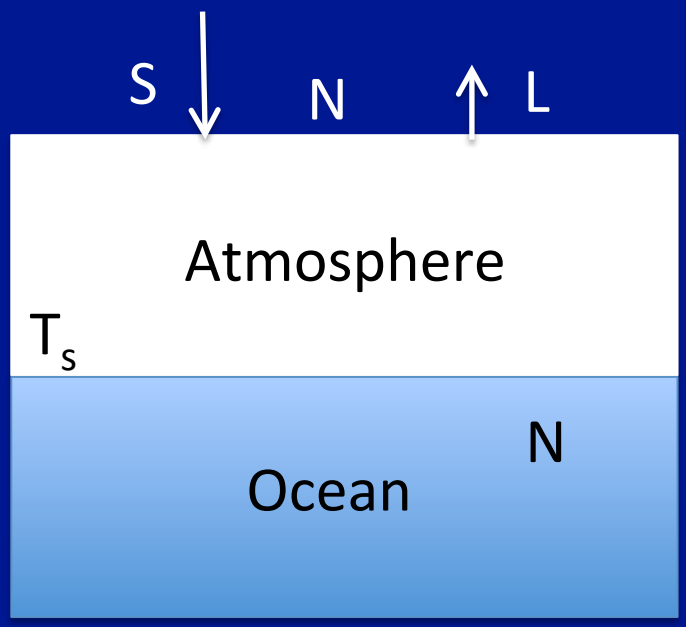


(IPCC 2013)

Temperature and Earth's Energy Imbalance



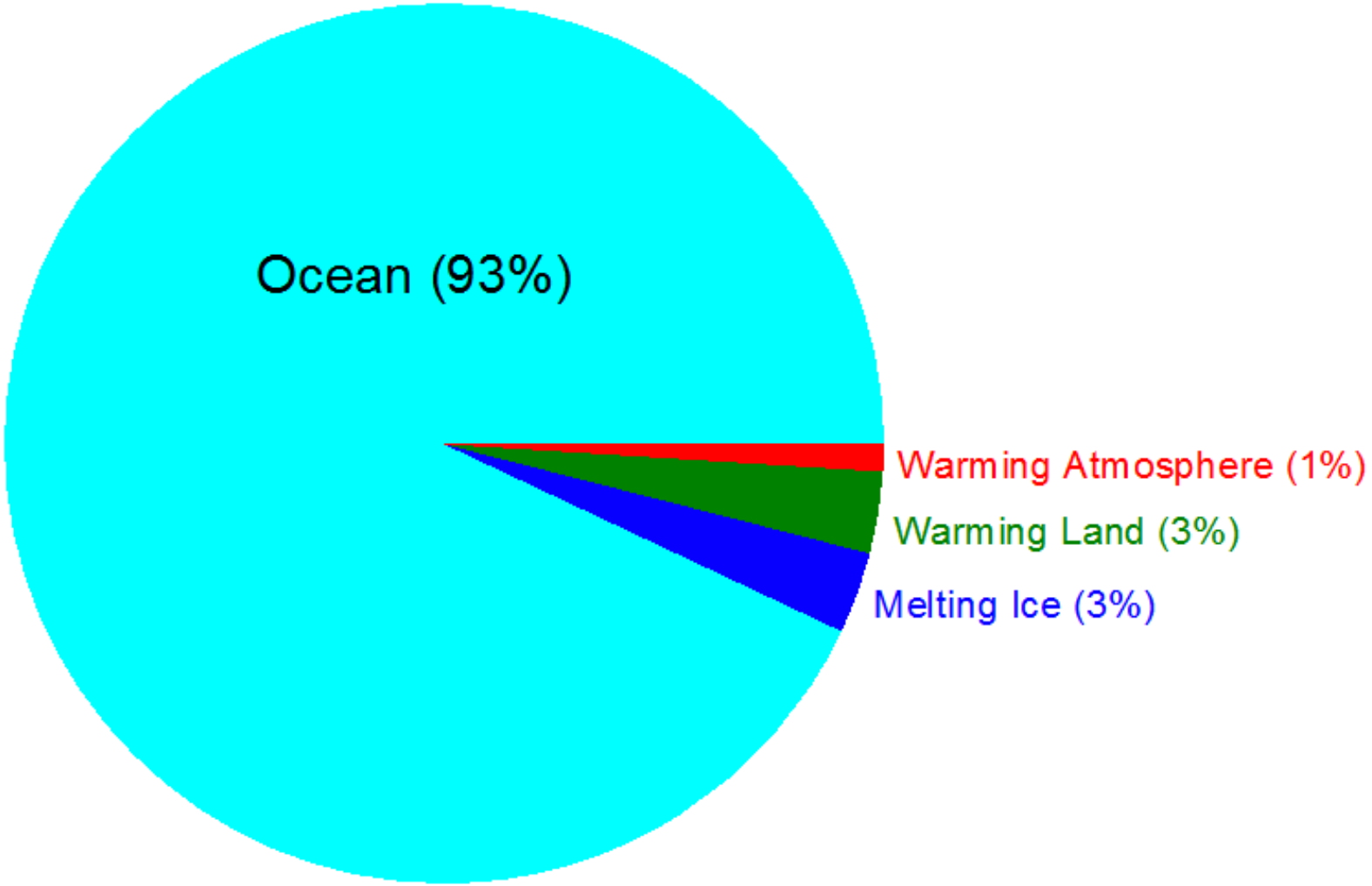
- No external forcing (S=L)
- T_s remains constant when averaged over a long time period.



- Imposed external forcing causes energy imbalance (S≠L) at the top-of-atmosphere (TOA).
- 90% of the excess energy is stored in the ocean.
- Over long time period, T_s increases to offset energy imbalance.

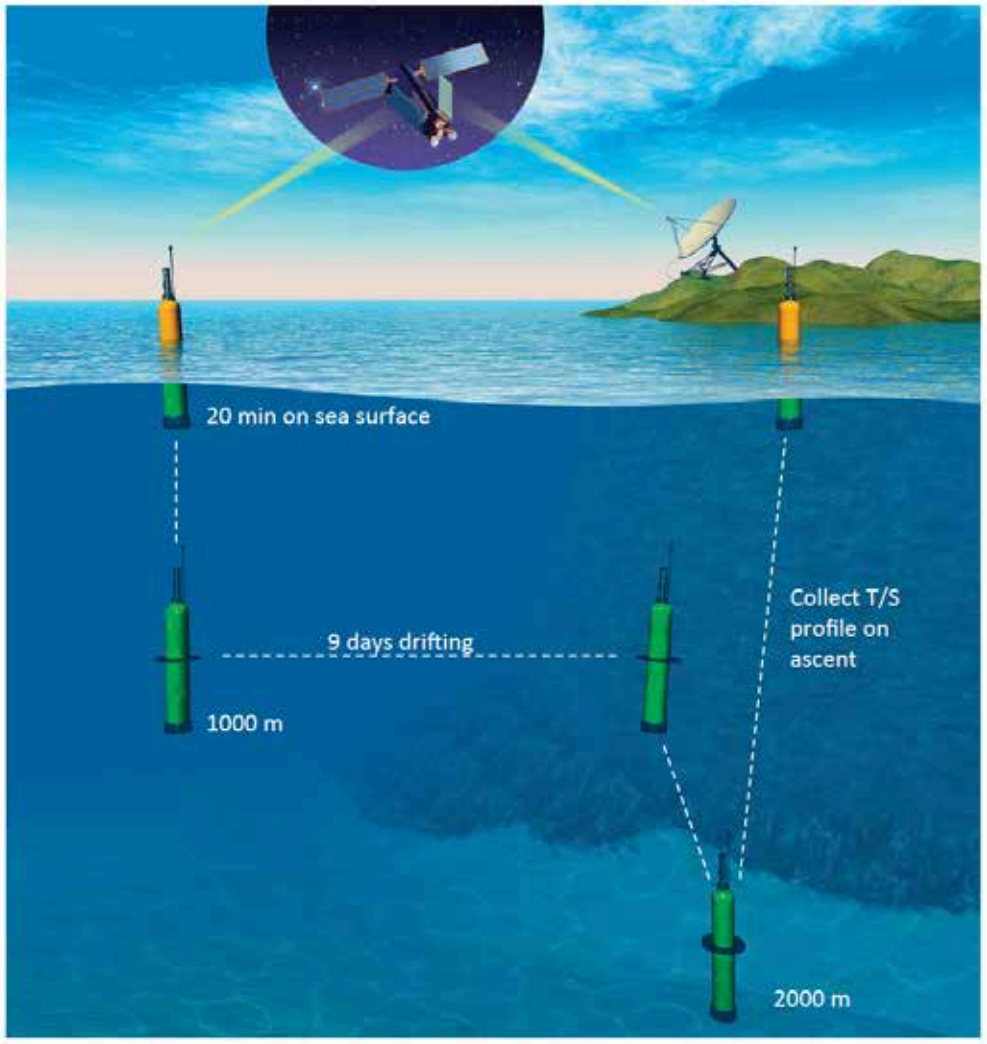
At timescales of up to a few decades, T_s can fluctuate naturally due to internal variability in the system, whether or not external forcings are applied.

Earth's Heat Budget



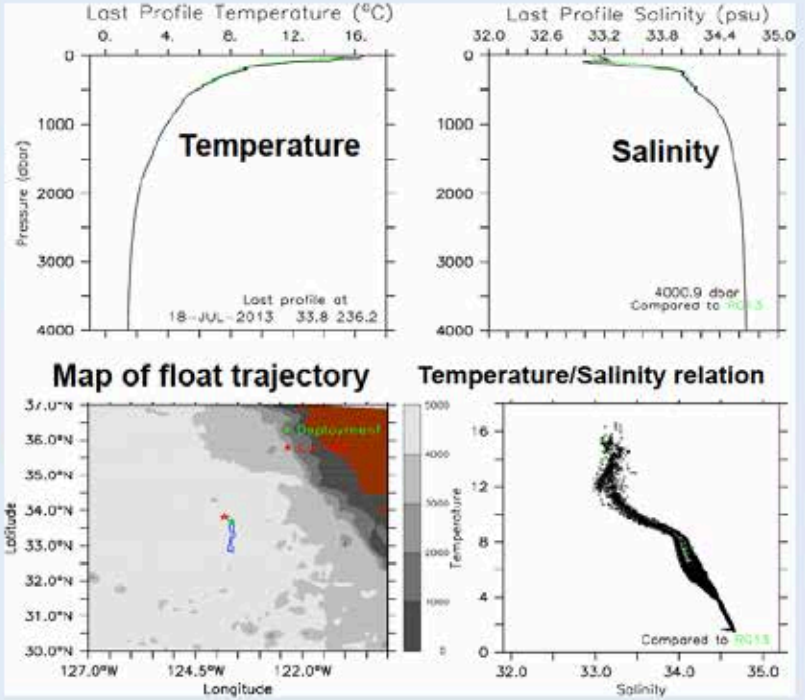
- Most of the excess heat in the climate system ends being stored in the ocean.
- Only 1% of the energy is used to change global mean surface temperature.

Observing Ocean Heat Uptake



How do Argo floats work?

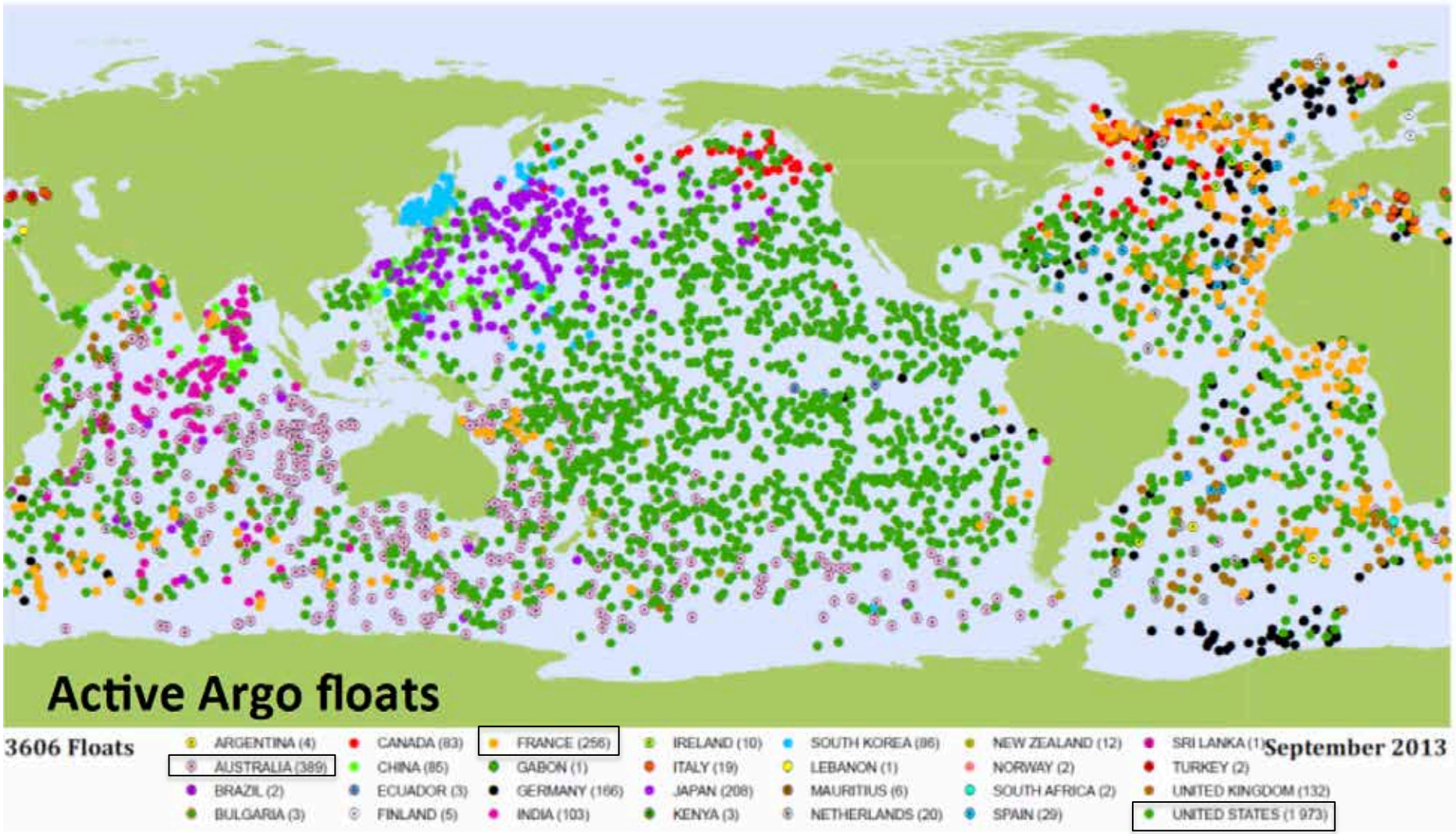
Argo floats collect a temperature and salinity profile and a trajectory every 10 days, with data returned by satellite and made available within 24 hours via the GTS and internet (http://www.argo.net) .



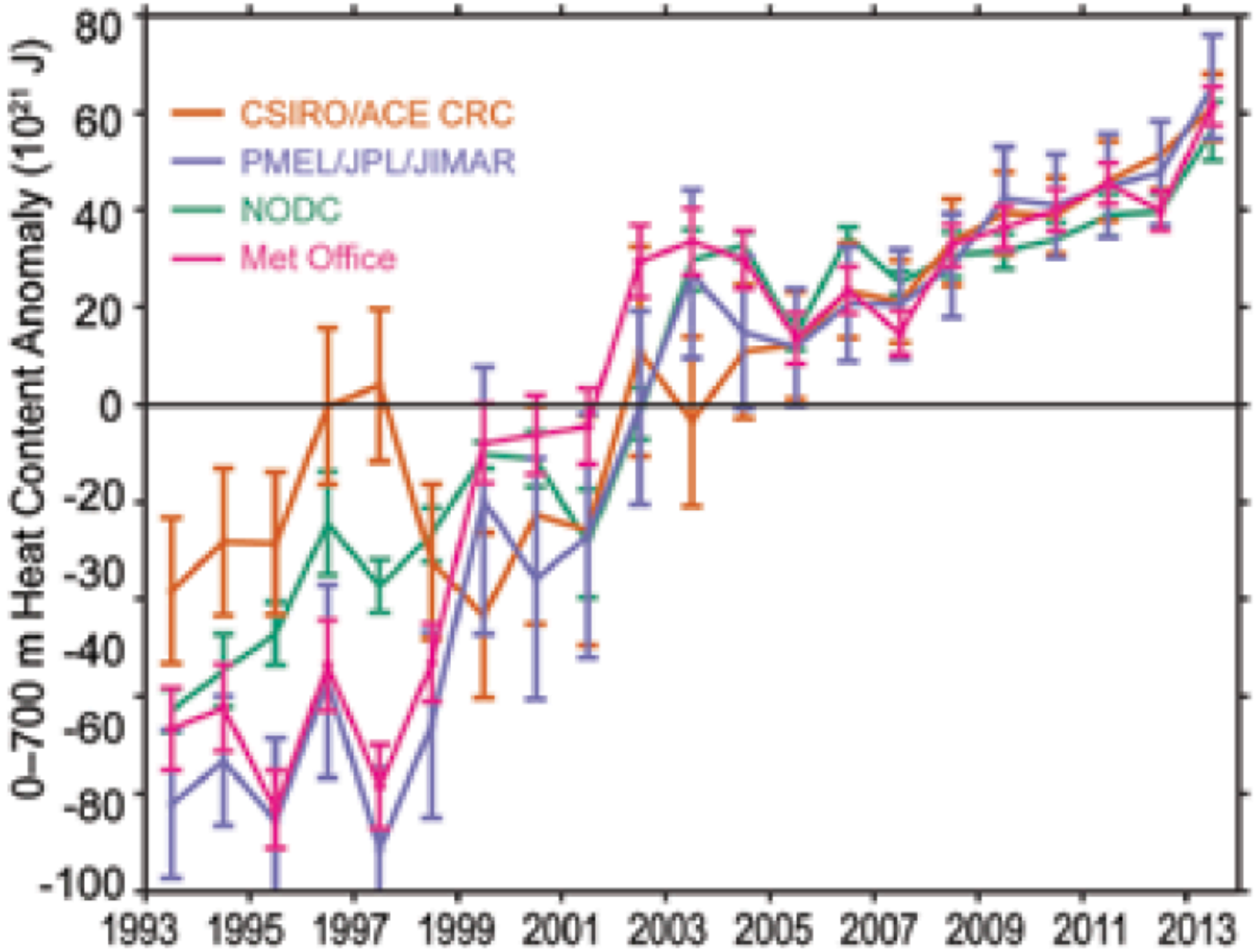
Cost of an Argo T,S profile is ~ $170.

Typical cost of a shipboard CTD profile ~$10,000.

Argo Float Regional Distribution



Change in global average upper ocean heat content (0-700 m)



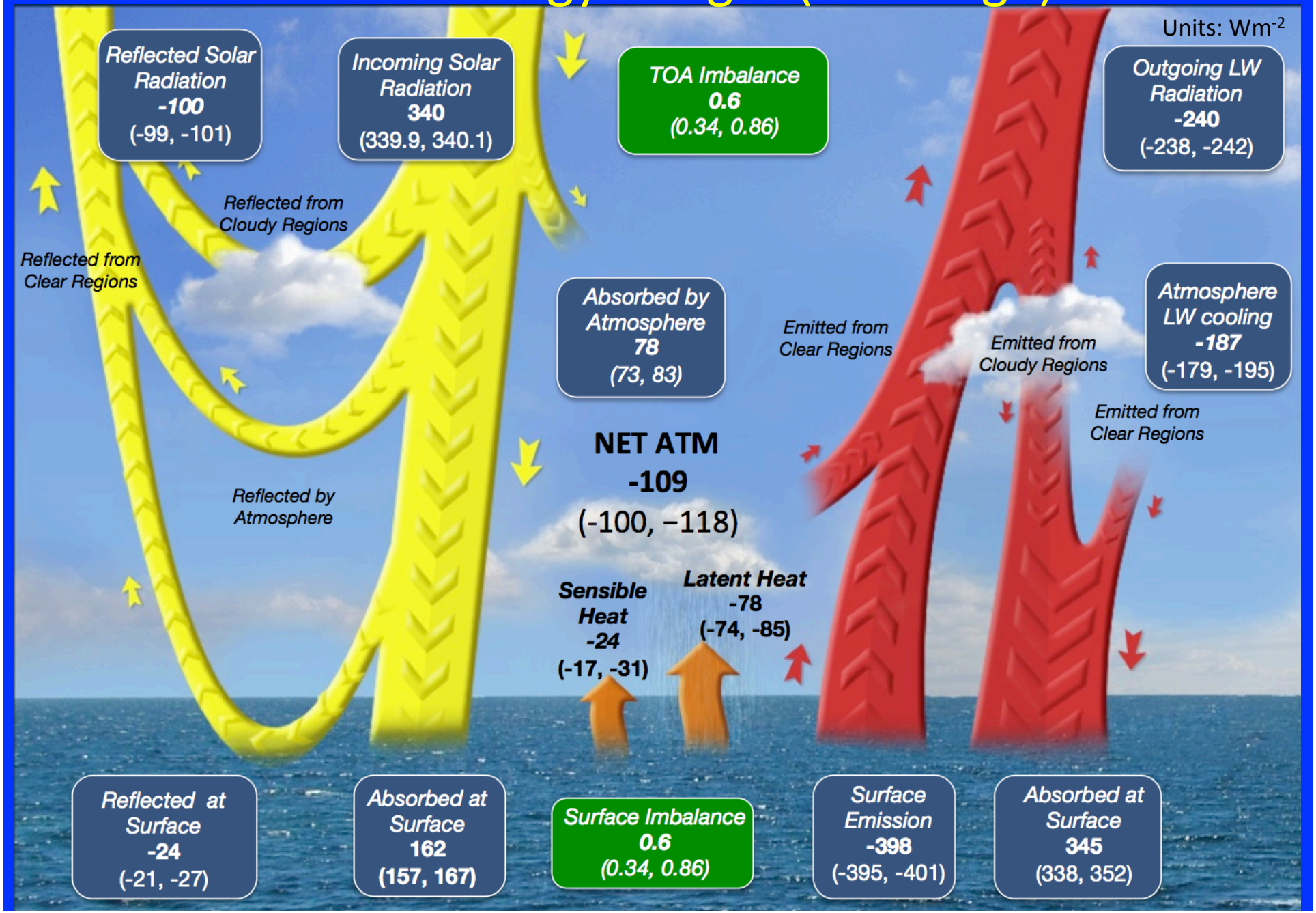
The globally averaged rate of upper ocean (0-700 m) heat gain for 1993-2013 is (Wm^{-2}):
0.29 (±0.12) CSIRO/ACE CRC, **0.48 (±0.13)** PMEL/JPL/JIMAR, **0.34** (±0.09) NODC, and
0.42 (±0.25) UK Met Office.

(Johnson et al., BAMS, 2014)

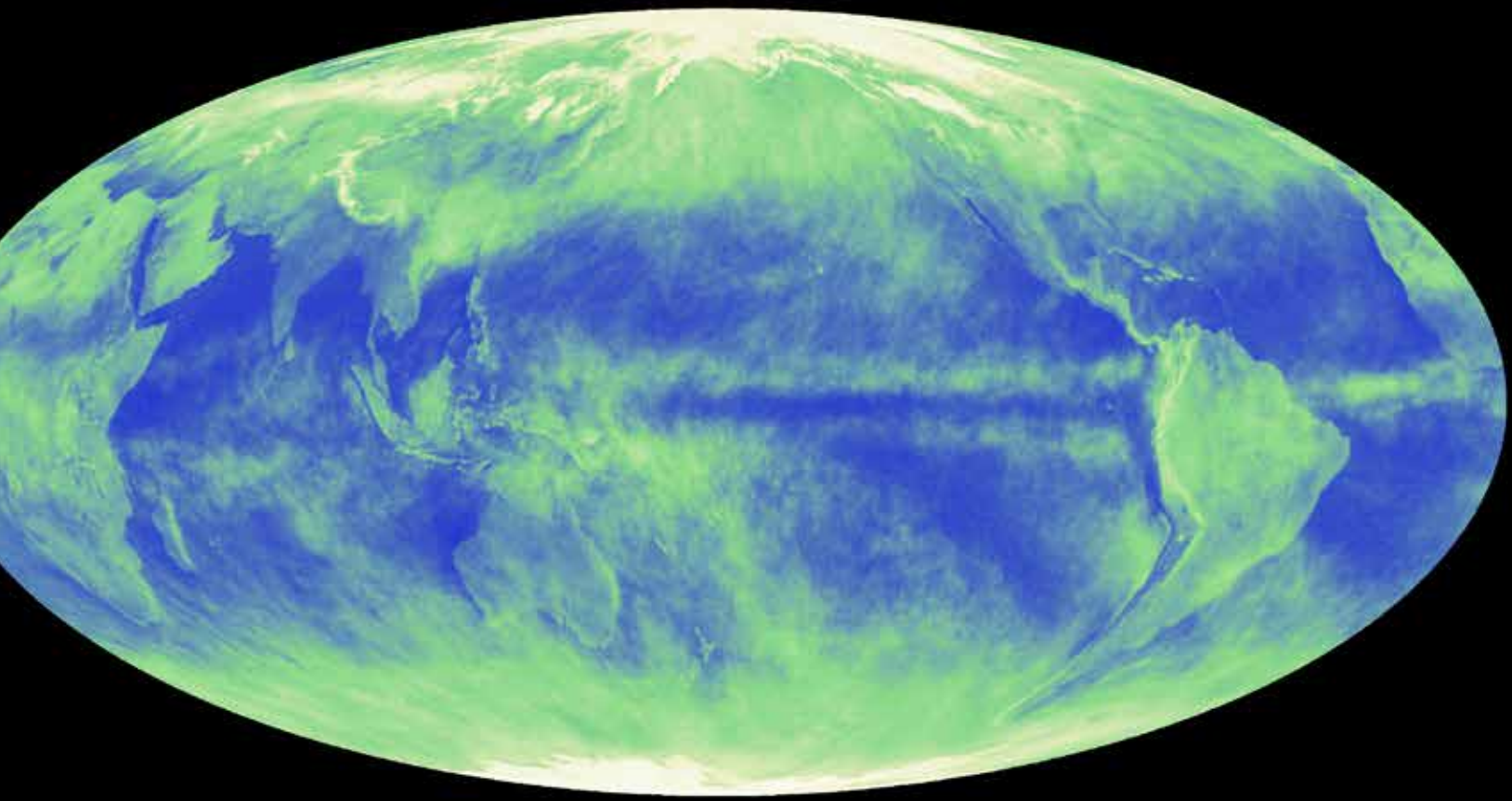
Tracking Changes in Earth's Energy Imbalance – NASA LaRC

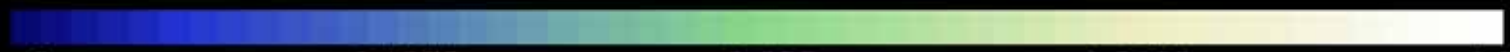
CERES

Earth's Energy Budget (1σ Range)



Planetary Albedo from CERES (March 2013)

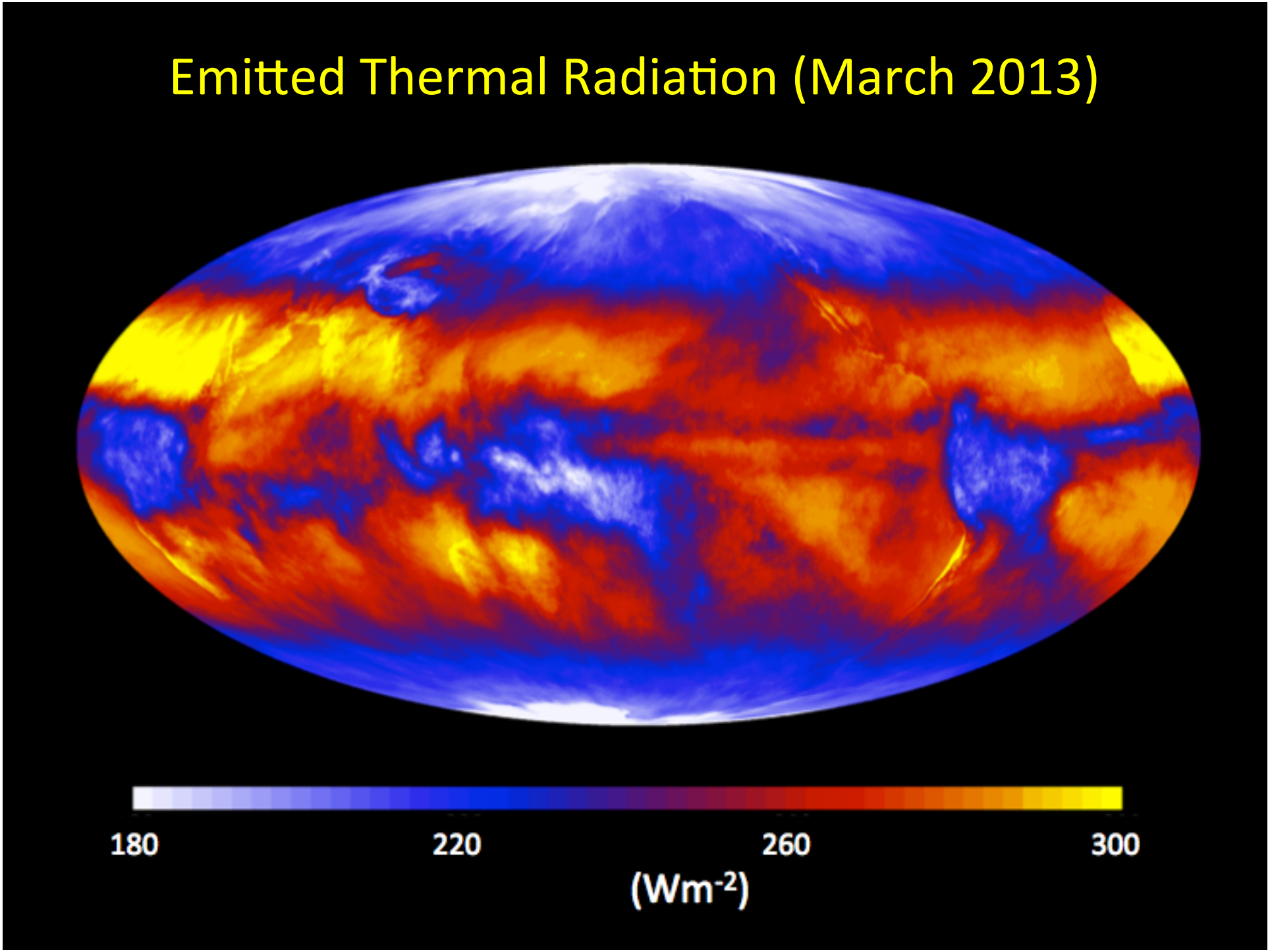




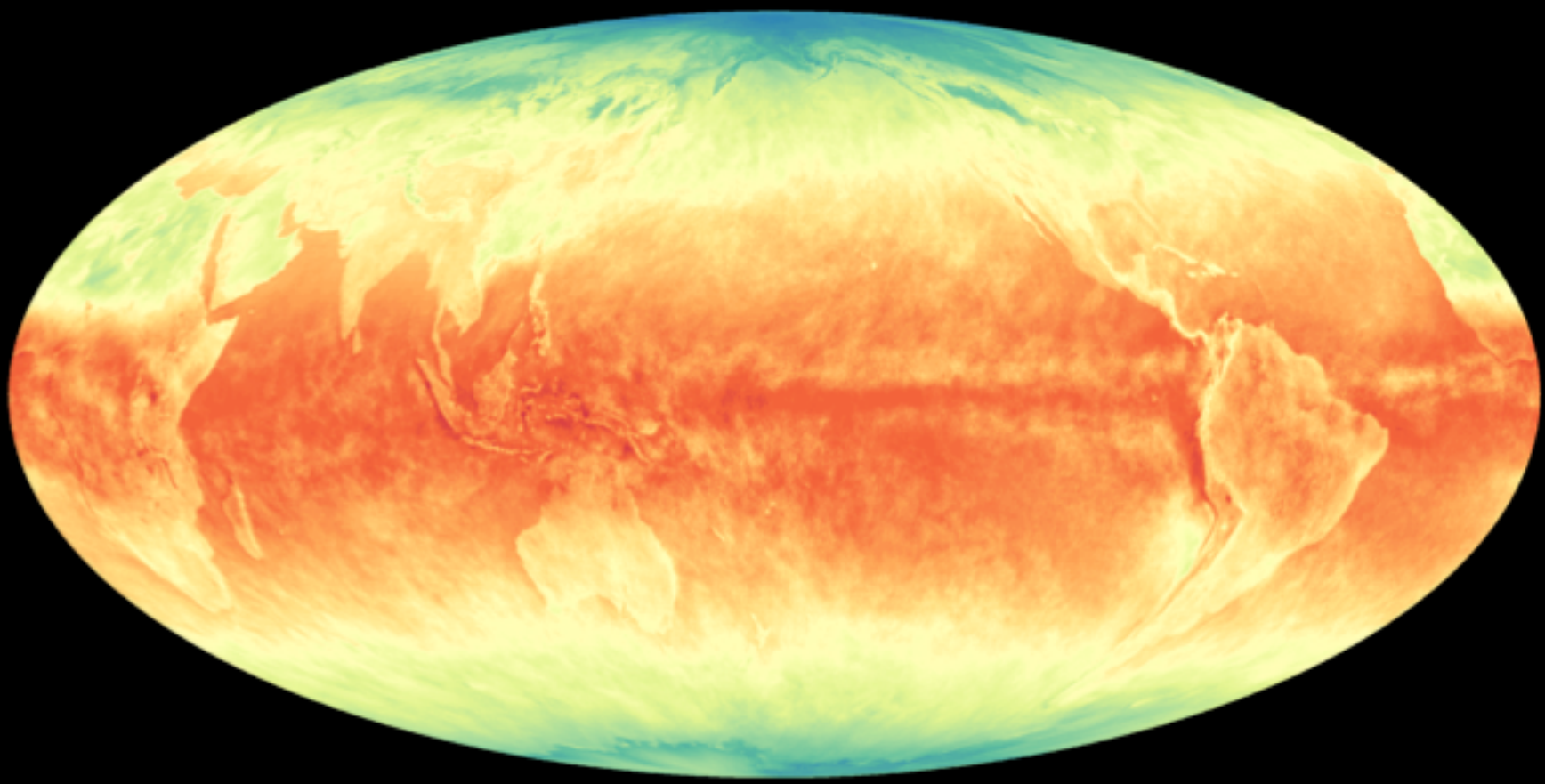
0 0.188 0.375 0.563 0.75

Albedo

Emitted Thermal Radiation (March 2013)



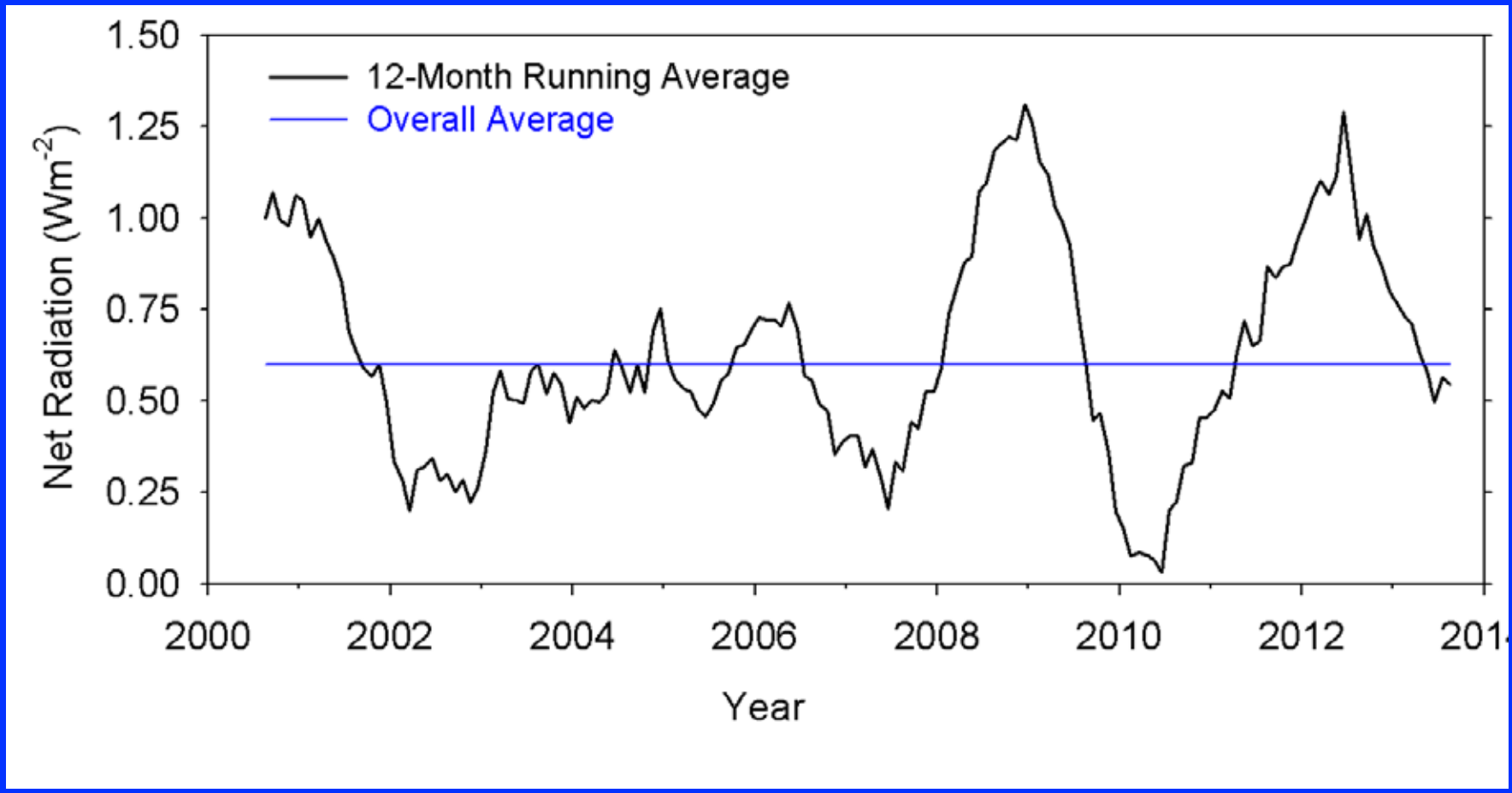
Net TOA Radiation (March 2013)



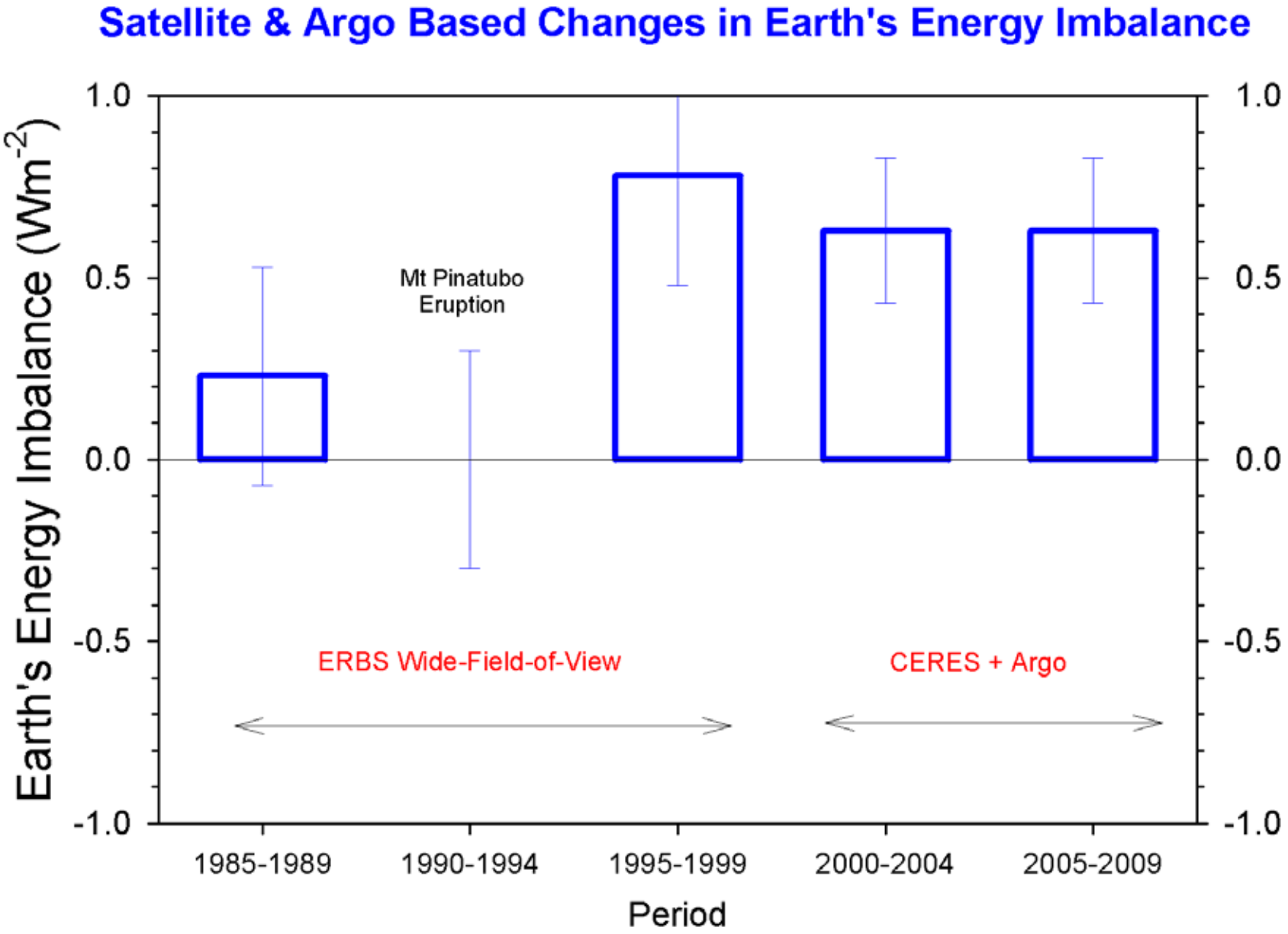
-150 -50 50 150

(Wm^{-2})

Earth's Energy Imbalance (CERES + Argo)



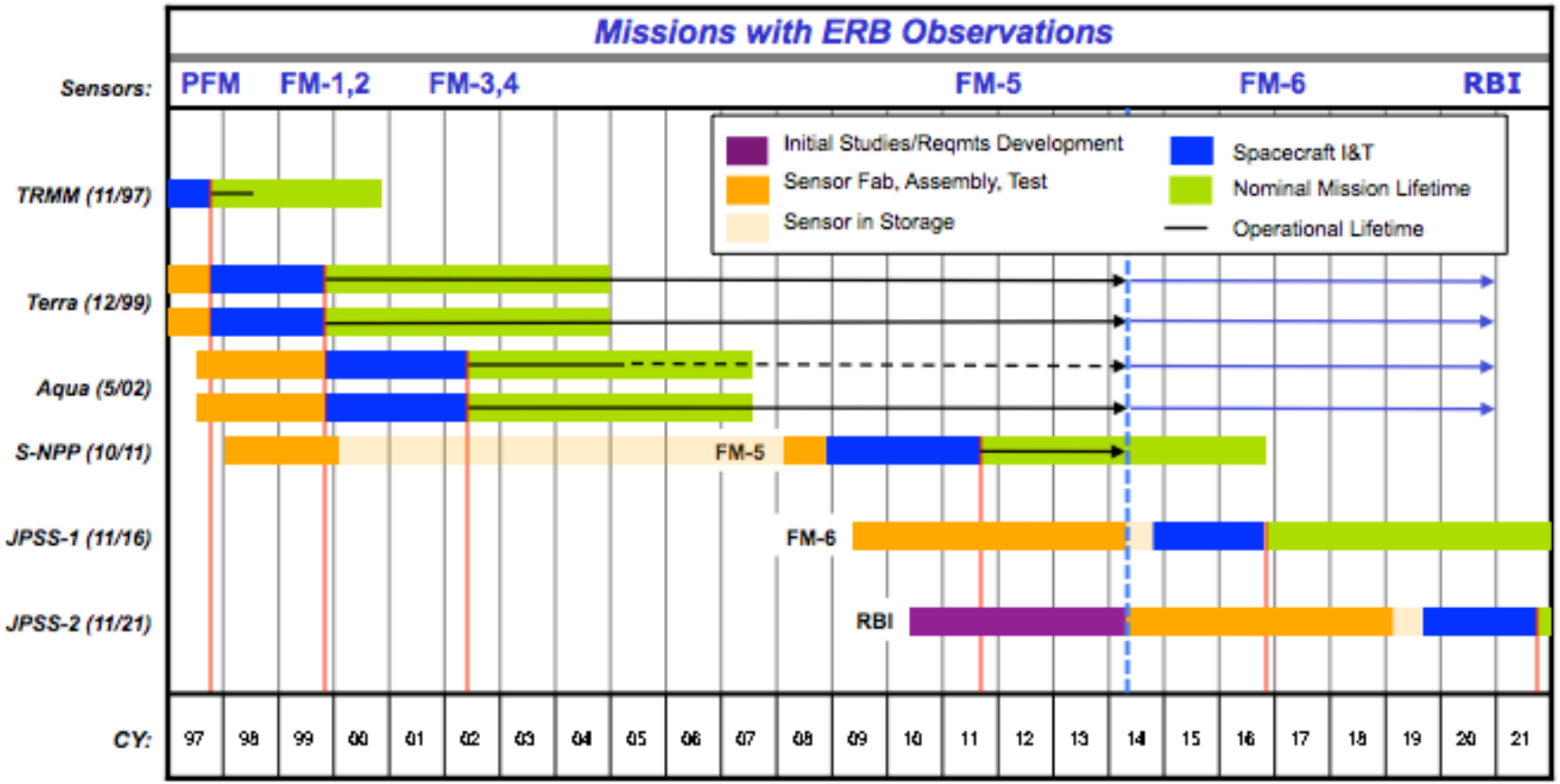
- The global mean net downward radiation exhibits substantial internal variability mainly associated with ENSO.



- The planet's EEI imbalance has been fairly stable since 1995.

(Adapted from Allan et al, JCLIM, 2014, Table 2)

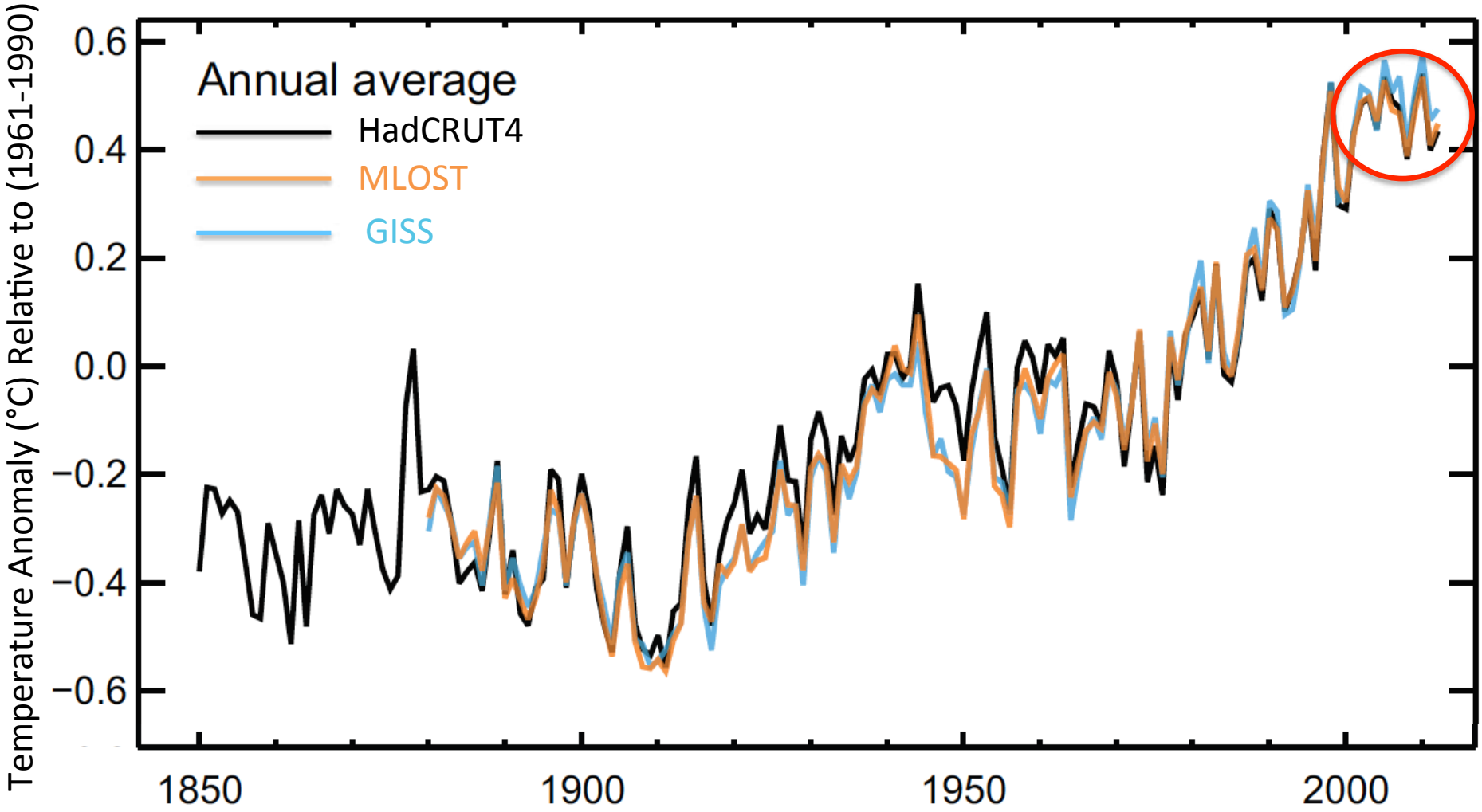
CERES & RBI Flight Schedules



- Five CERES instruments on 3 satellites (Terra, Aqua, SNPP) are flying.
- FM6 will be fly on JPSS-1 in 2017 and the CERES Follow-on (RBI) will fly on JPSS-2 in 2021.

Global Warming Hiatus

Observed Globally Averaged Combined Land And Ocean Surface Temperature Anomaly 1850–2012



- The global mean surface temperature trend over 1998–2012 is roughly one third of the trend over 1951–2012.
- This is referred to as **"The Global Warming Hiatus"**.

(Source: IPCC 2013)

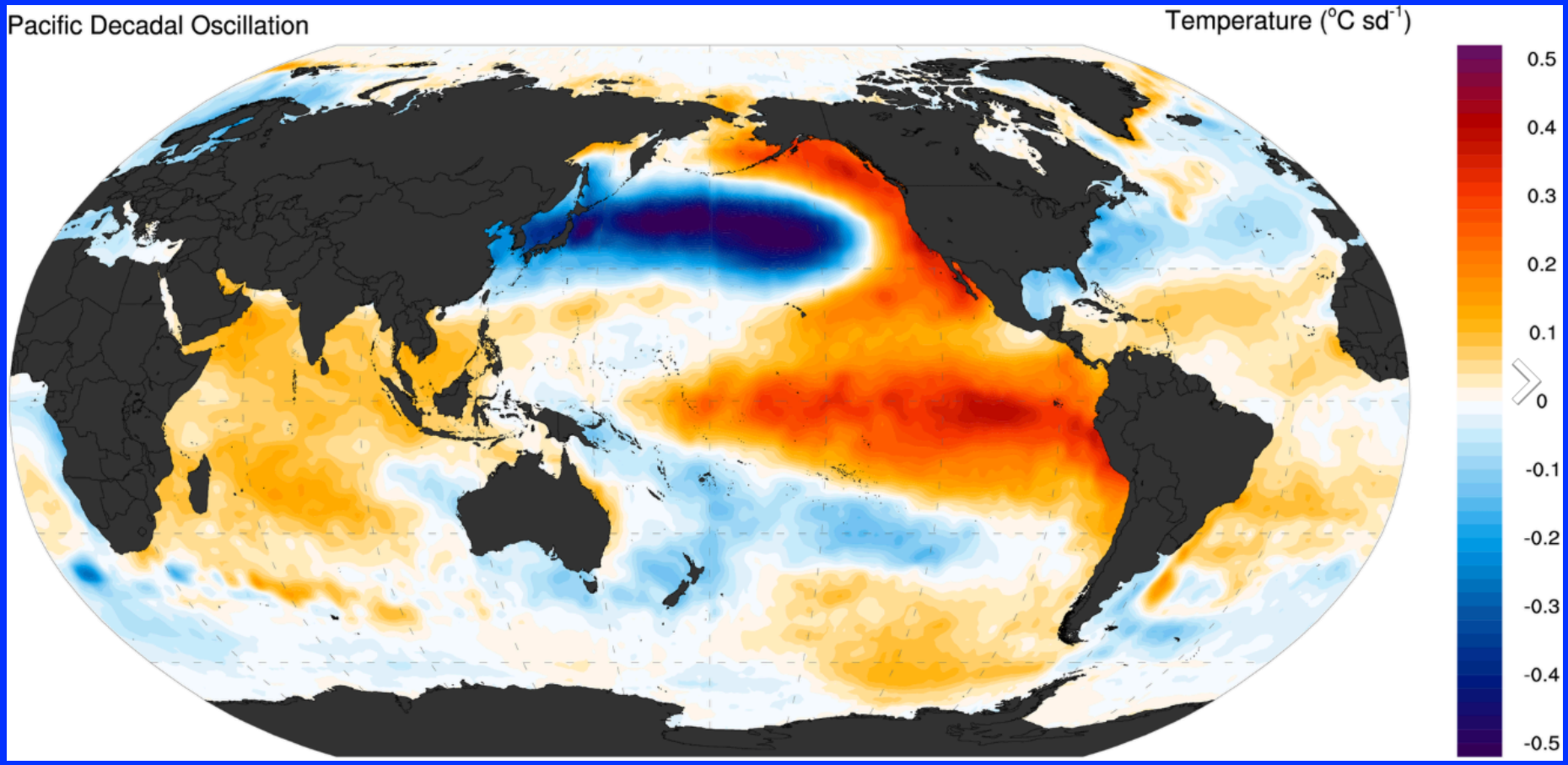
Hiatus & Earth's Energy Budget

$$N = F - \lambda \Delta T + \varepsilon$$

N = Earth's Energy Imbalance
F = Climate Forcing
λ = Climate Feedback Parameter
ΔT = Surface Temperature Change
ε = Internal variability of system not related to ΔT

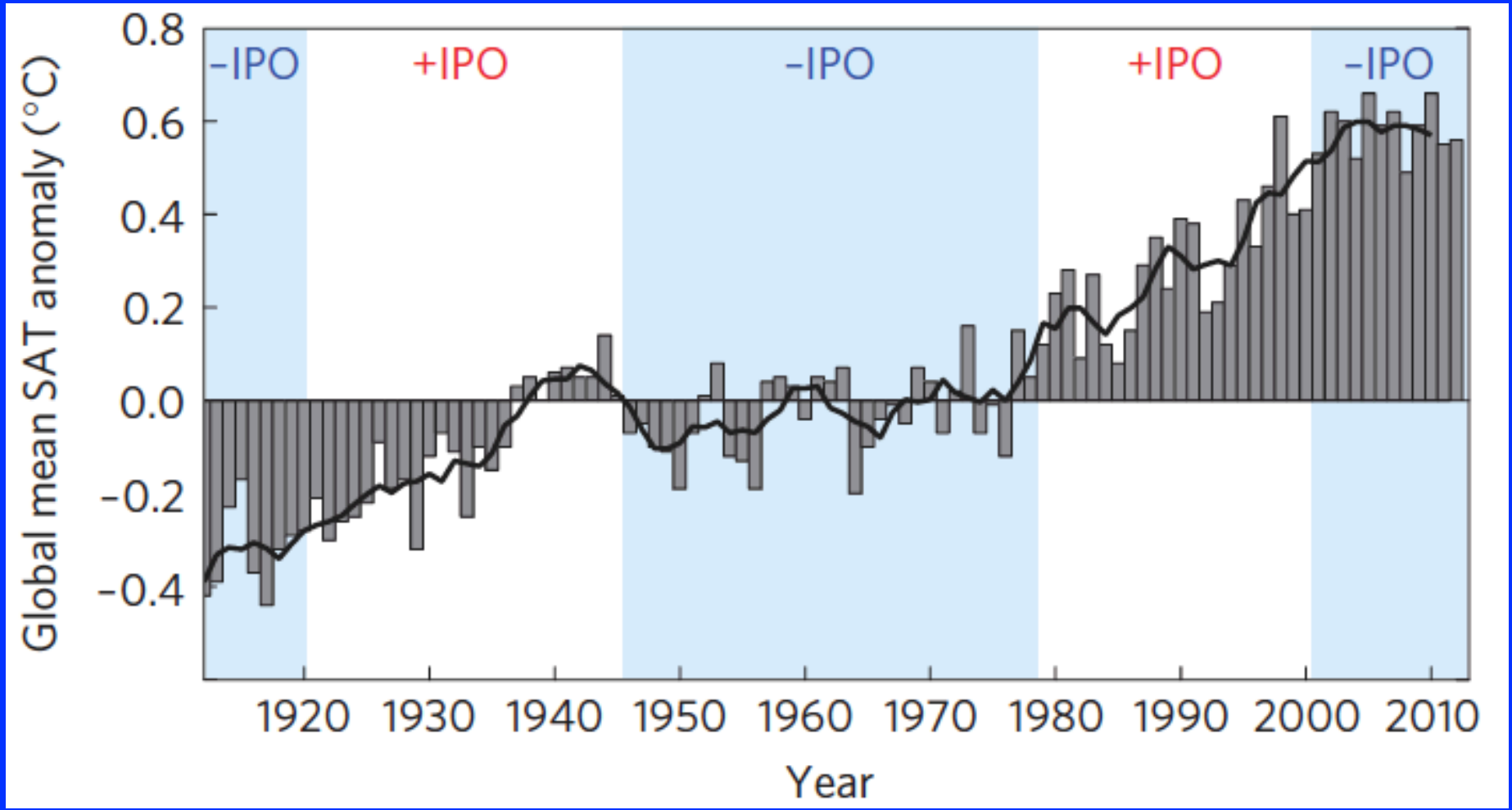
- If GHG forcing continued during 2000s, but climate system response ($\lambda \Delta T$) slowed, shouldn't N have increased?
- Or was forcing by greenhouse gases offset by increased aerosol forcing, decreased stratospheric water vapor concentration, a decrease in solar irradiance?
- Or was the temperature change (ΔT) underestimated? Note that the greatest temperature changes occurred at high latitudes where observations are sparse.
- Or was internal variability somehow playing a role?

Pacific Decadal Oscillation (PDO)/Interdecadal Pacific Oscillation (IPO)



- The PDO/IPO manifests as a low-frequency El Niño-like pattern of climate variability, with a warm tropical Pacific and weakened trade winds during its positive phase, and a cool tropical Pacific and strengthened winds during its negative phase.
- The IPO phase typically shifts about every 20 to 30 years.

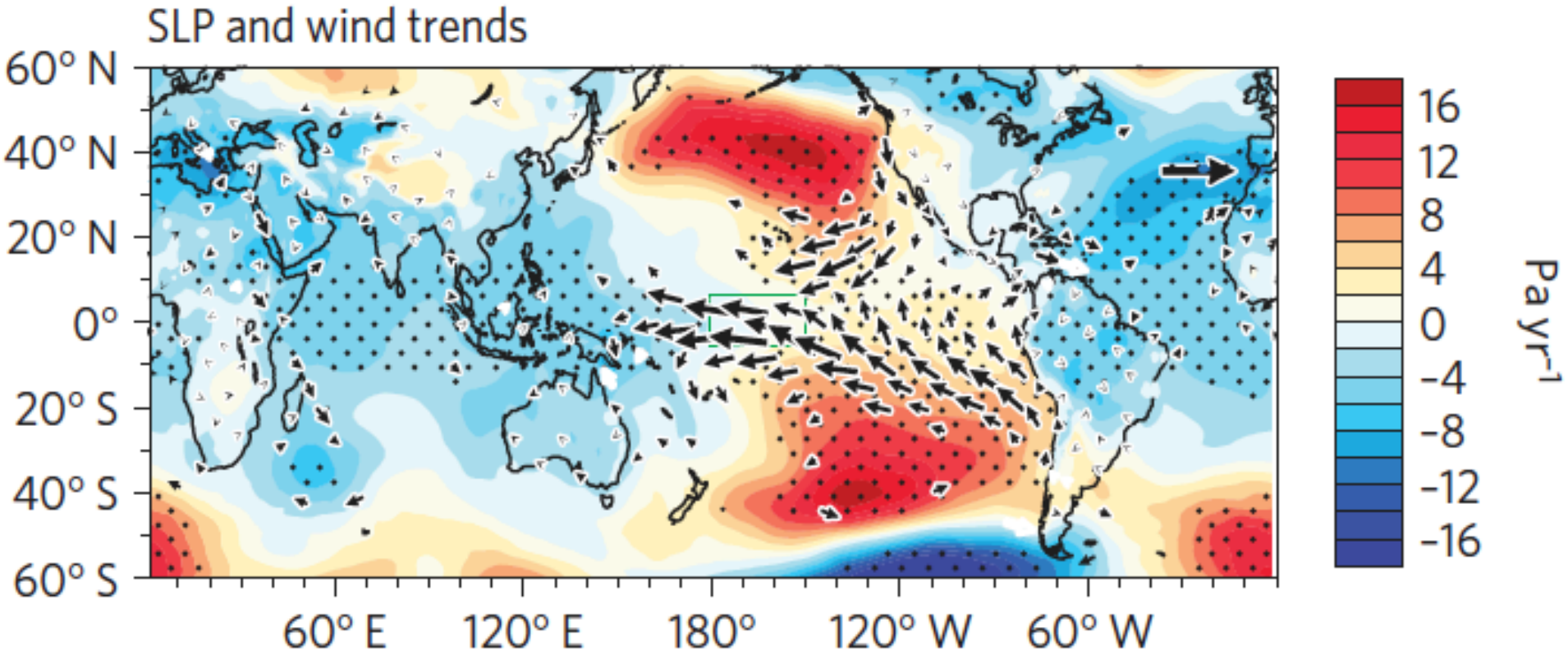
Global Mean Surface Temperature Anomalies (Relative to 1951–1980)



- The two most recent extended hiatus periods (1940-1975 and 2001-present) correspond closely to periods when the IPO has been primarily in a negative phase.
- Accelerated surface temperature warming decades (1920-1945 and 1976-2000) occurred during a positive IPO phase.

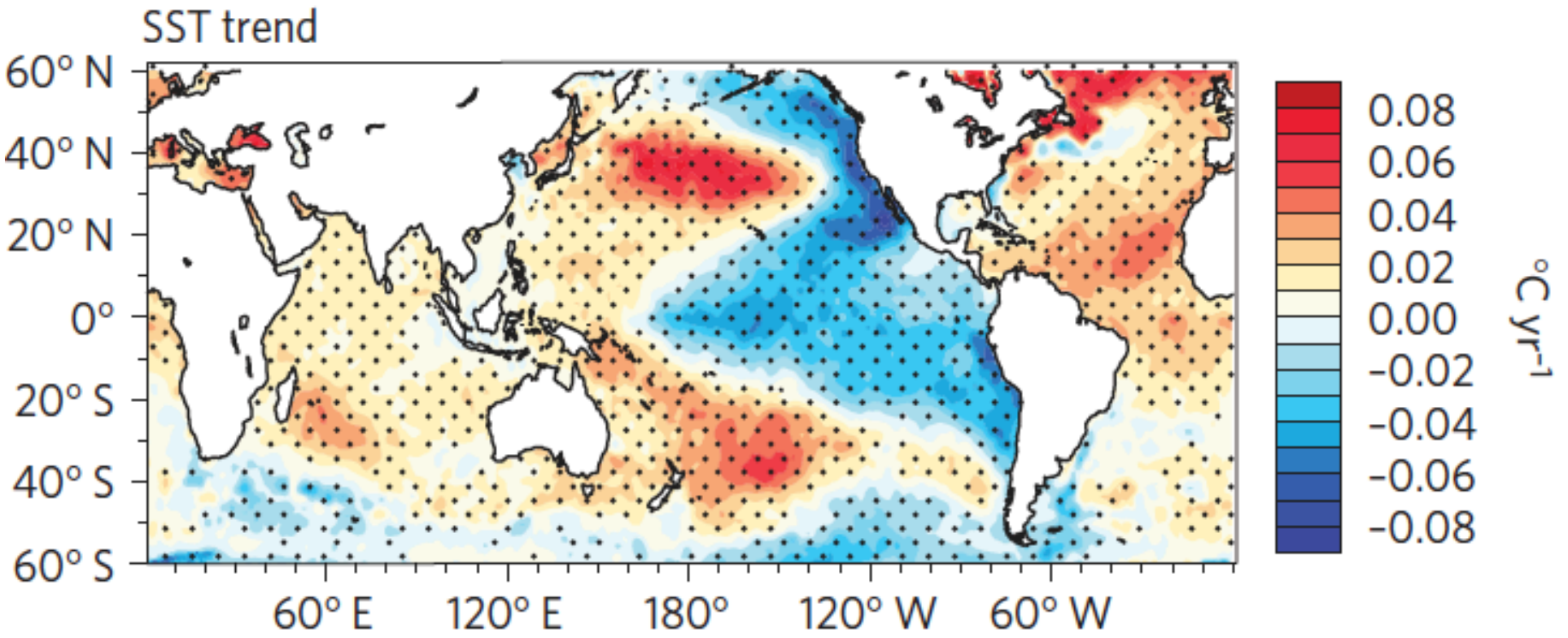
(Source: England et al, 2014, Nature Climate Change)

Observed Trends in Wind Speed and Surface Pressure During 1992-2011



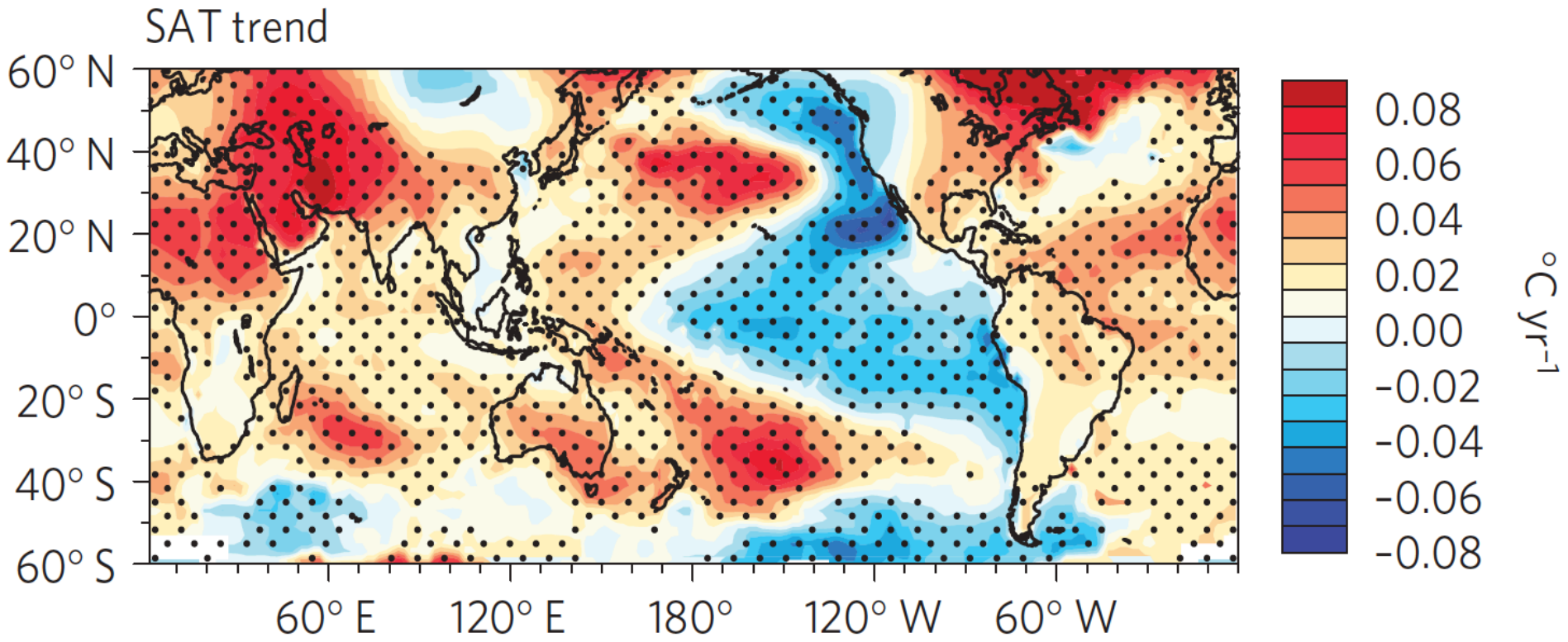
(Source: England et al, 2014, Nature Climate Change)

Observed Trends in Sea Surface Temperature During 1992-2011



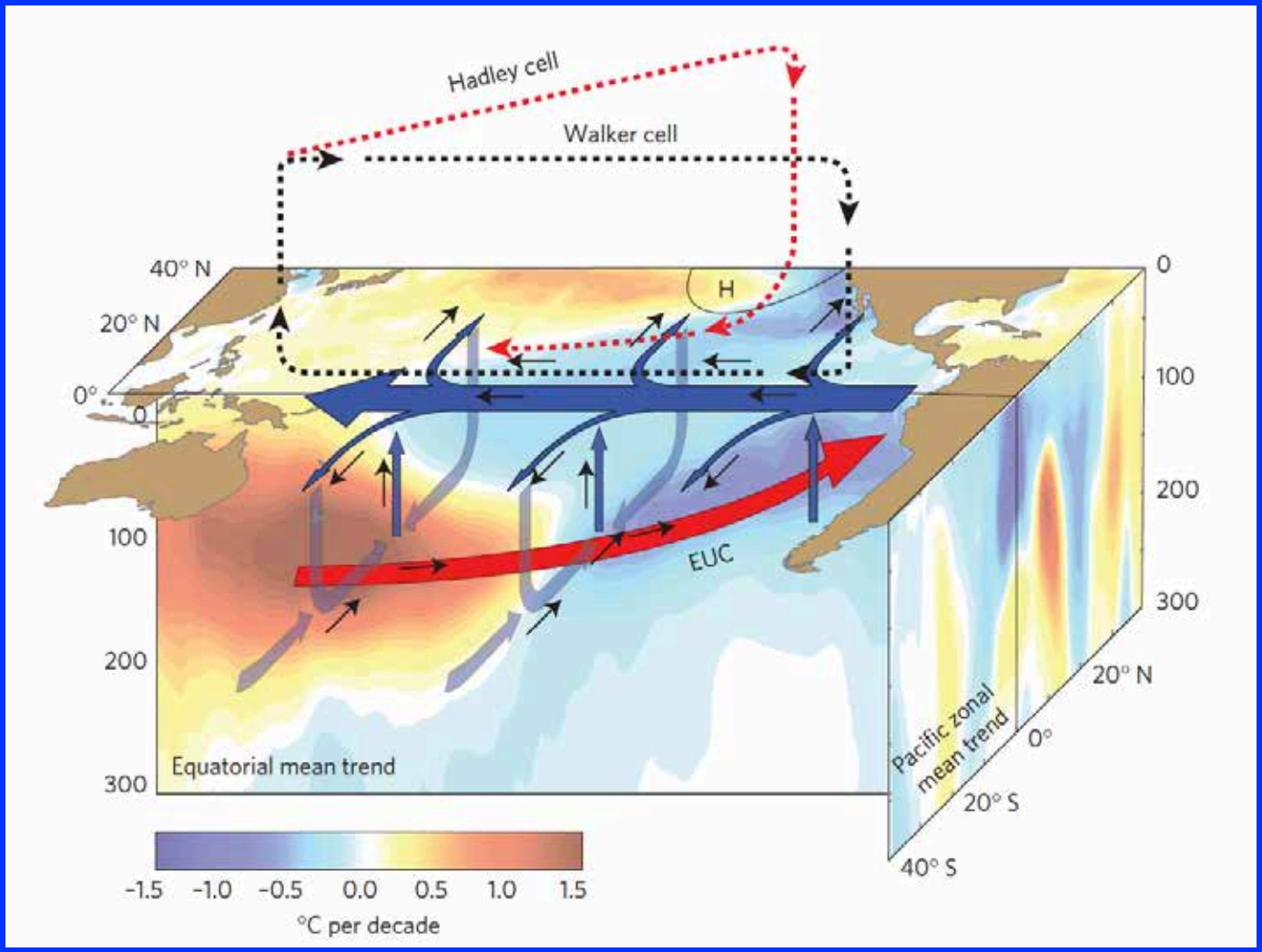
(Source: England et al, 2014, Nature Climate Change)

Observed Trends in Surface Air Temperature During 1992-2011



(Source: England et al, 2014, Nature Climate Change)

Trends in Pacific Temperature and Ocean–Atmosphere Circulation over Past Two Decades



- Changing surface wind pattern increases the subsurface uptake of heat in the Pacific, while cooling the surface layer that interacts with the atmosphere.
- The extra uptake has comes about through increased subduction in the Pacific shallow overturning cells, enhancing heat convergence in the equatorial thermocline.

(Source: England et al, 2014, Nature Climate Change)

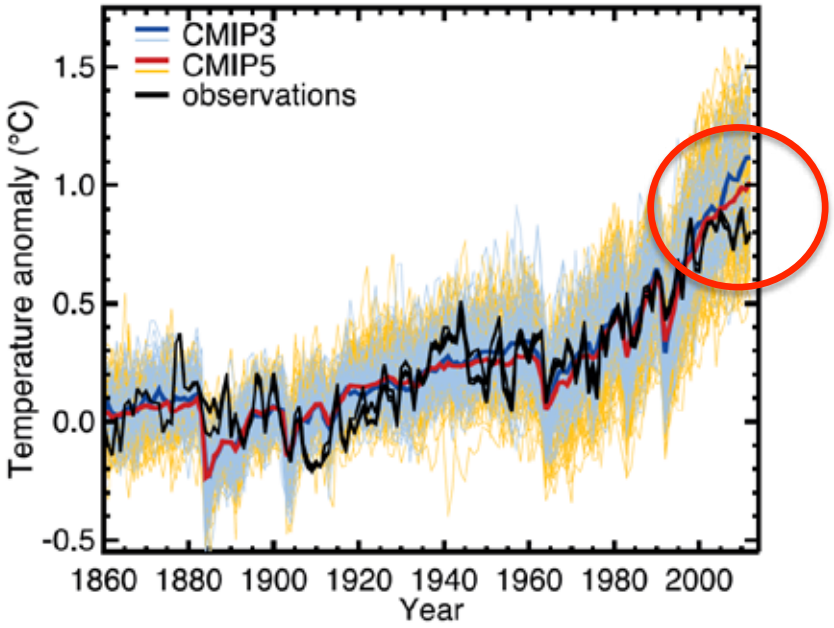
Perspective on Global Warming Hiatus

- The observations indicate that Earth is continuing to accumulate heat despite the recent slowdown in surface warming compared with the late 20th century.
- Decadal periods of minimal surface warming, or even cooling, interspersing decades of rapid surface warming, are not inconsistent with a long-term warming trend.
- Rather, it characterizes the interplay between steadily increasing greenhouse gas forcing and internally generated climate variability.
- Current Hiatus is associated with negative phase of Interdecadal Pacific Oscillation.
    - Sharp increase in easterly equatorial trade winds.
    - Cooling pattern over central and eastern Pacific Ocean.
    - Increased subsurface uptake of heat in the Pacific.
- Hiatus decades are expected to punctuate future warming trends.

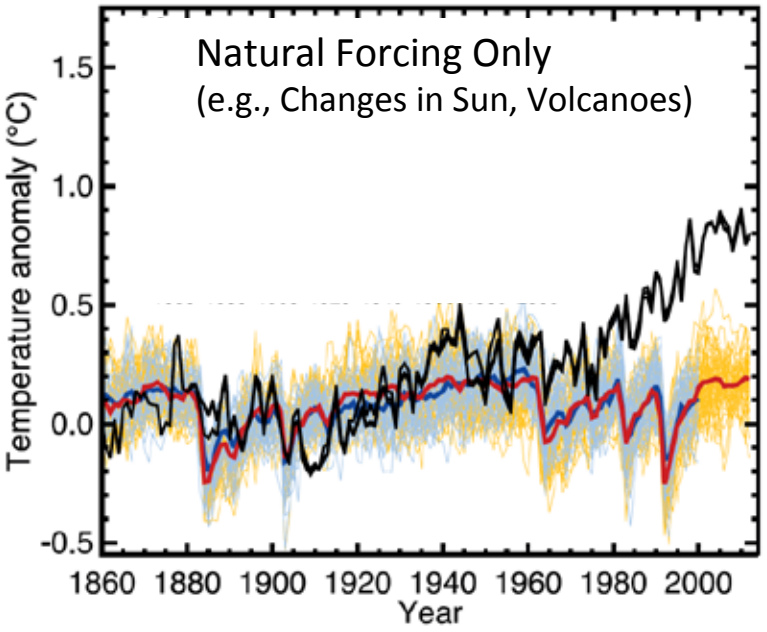
Thank You!

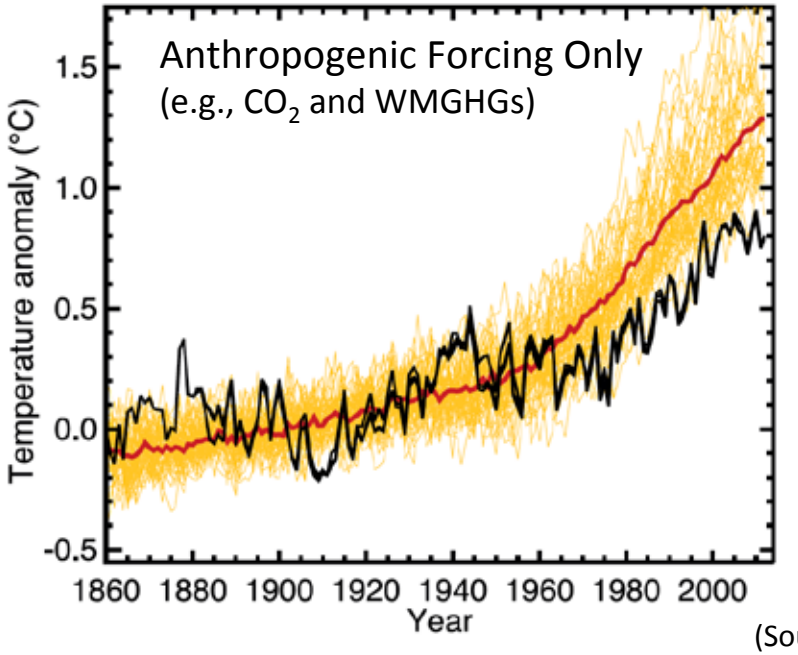
Climate Model Simulations vs Observations

Natural + Anthropogenic Forcing

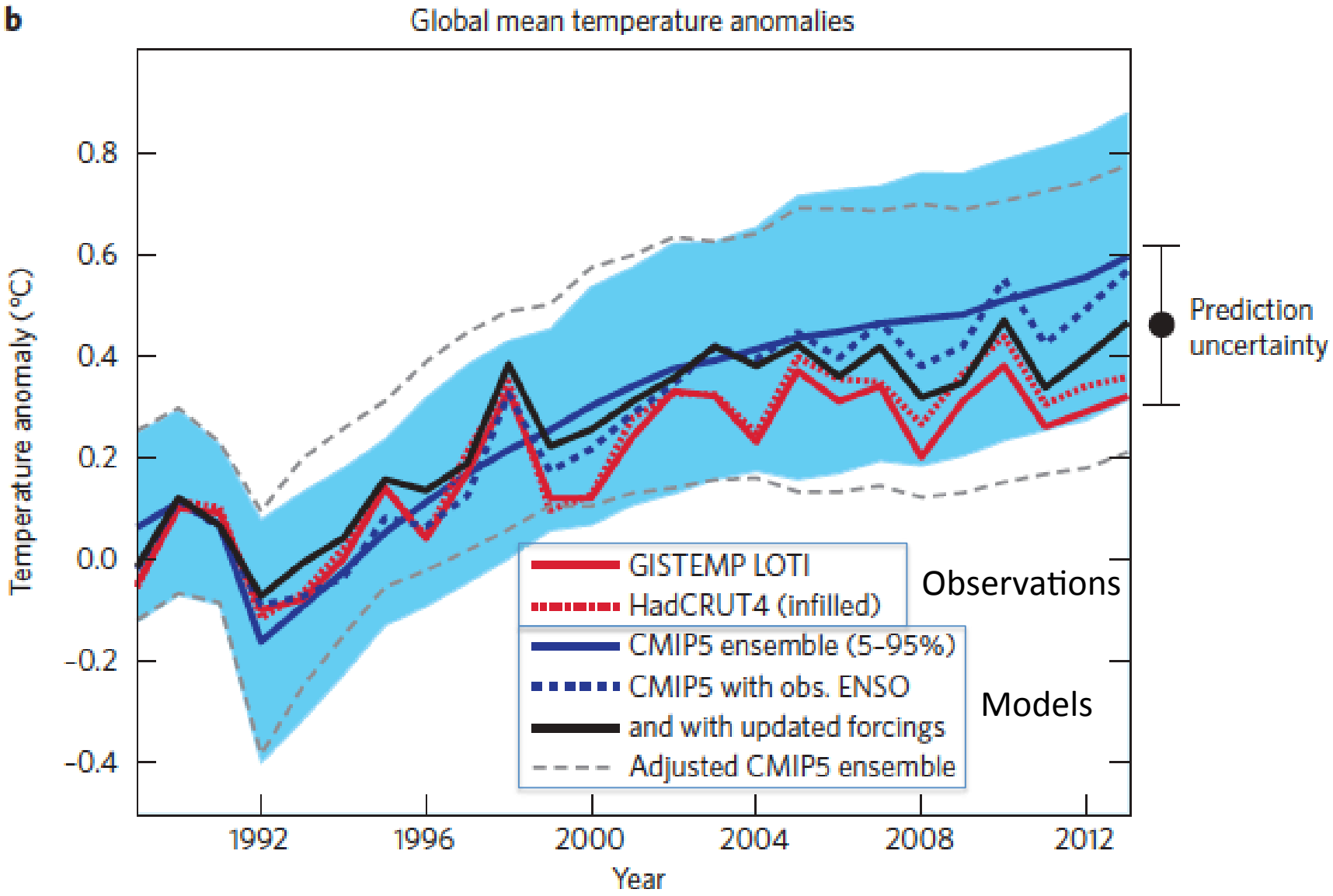


- Climate models did not anticipate pause in warming.
- Model simulations were run with historical estimates of external influences on climate and idealized scenarios thereafter.
- Exact phasing of any natural fluctuations will not be captured in any specific model.





(Source: IPCC 2013)



- When climate model ENSO is in phase with observations, and volcanic aerosol concentrations, solar activity and well-mixed greenhouse gases are specified, models and observations are more consistent.

(Source: Schmidt et al., 2014, Nature Climate Change)