



Walter Orr Roberts Memorial Public Lecture

Has global warming stopped?

Understanding the ups and downs of climate
in a changing world

Gerald A. Meehl

With contributions from Haiyan Teng, Julie Arblaster, Aixue Hu,
Grant Branstator, John Fasullo, Kevin Trenberth
Matt England (UNSW), Cecilia Bitz (UW), Gokhan Danabasoglu, Andy Mai

National Center for Atmospheric Research
Boulder, CO, U.S.A.



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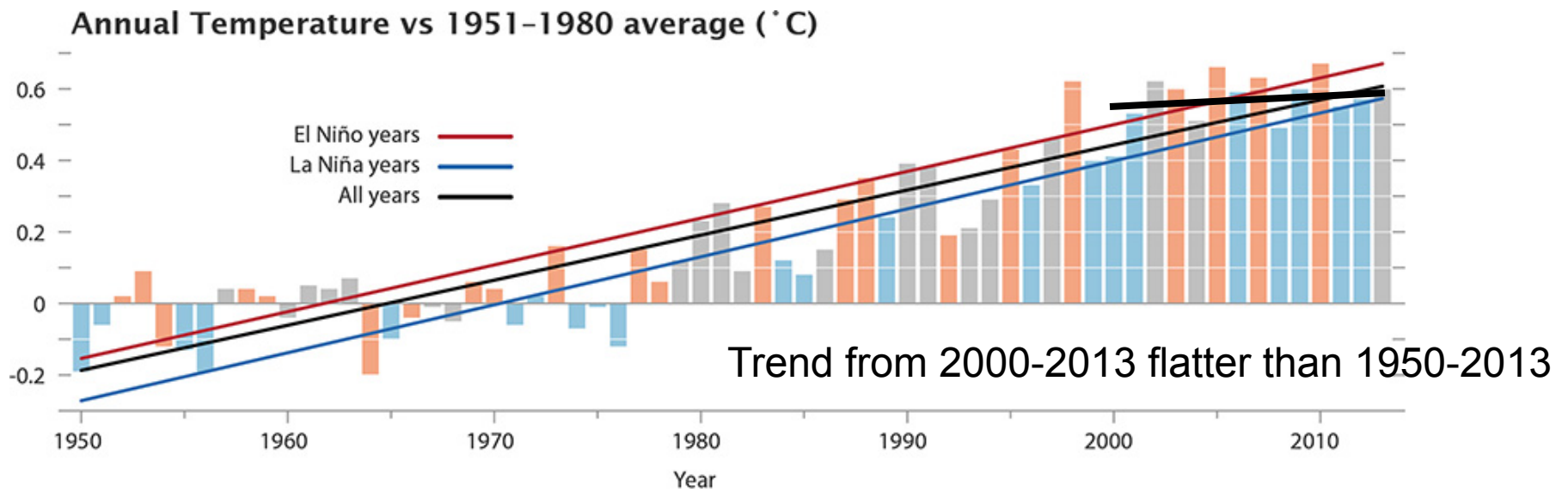
Regional and Global Climate Modeling Program



NCAR

Global warming has slowed to a near-zero trend since 2000 (+0.04 °C/decade)

This phenomenon is referred to as “the pause”, “the early-2000s hiatus”, or just “the hiatus”



The hiatus has spurred one of the most intense and focused periods of research in the history of climate science

Why? It's a great mystery story:
“The case of the missing heat”

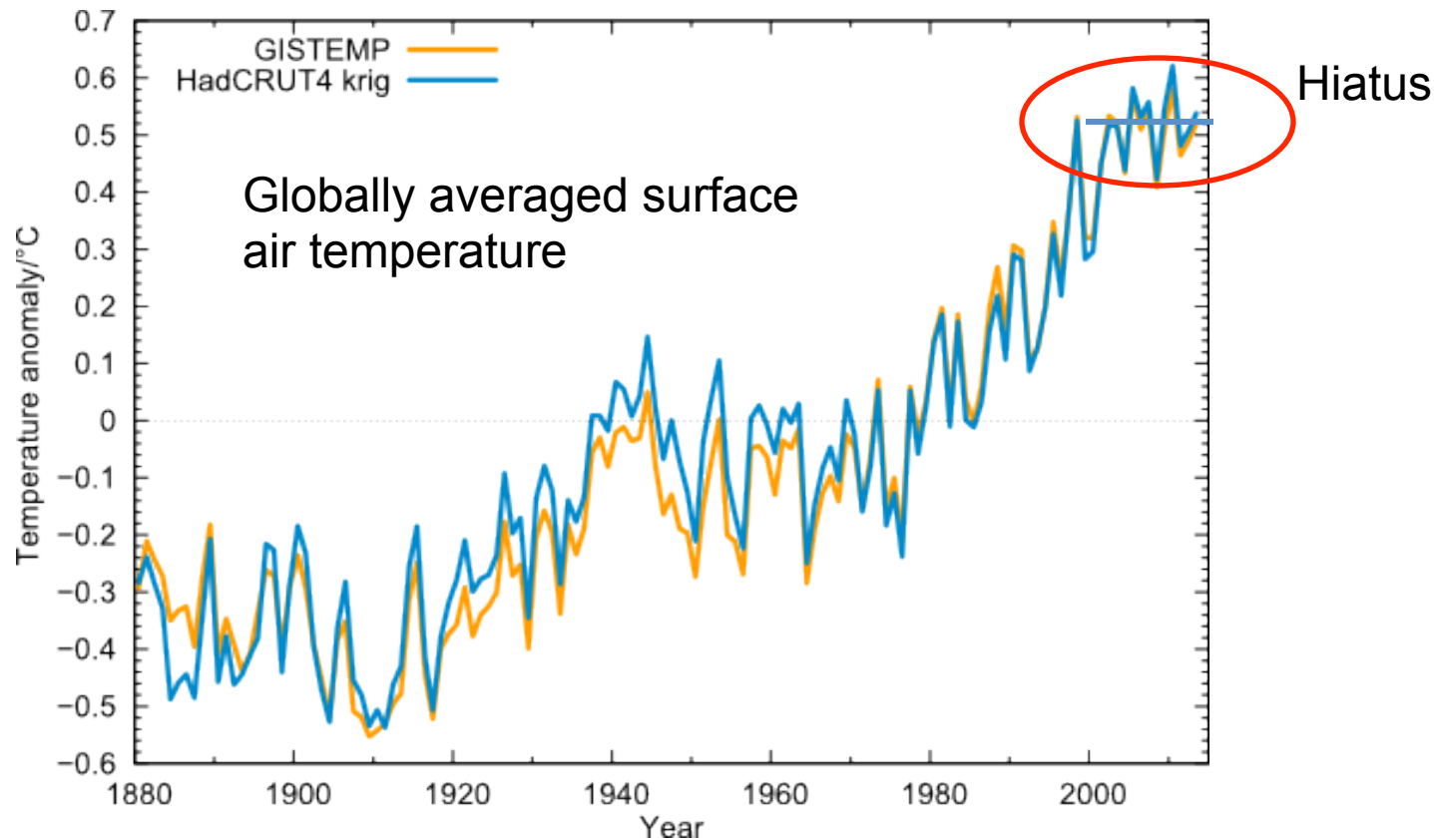
It involves a compelling science question
(what is the relationship between naturally-occurring climate variability and the climate system response to increasing human-produced greenhouse gases?),
and there is interest from the public, the media, and decision-makers

“The pause in warming has raised doubts in the public mind about climate change. A few sceptics say flatly that global warming has stopped. Others argue that scientists’ understanding of the climate is so flawed that their judgments about it cannot be accepted with any confidence. A convincing explanation of the pause therefore matters both to a proper understanding of the climate and to the credibility of climate science.”

-- article in *The Economist*, 2014

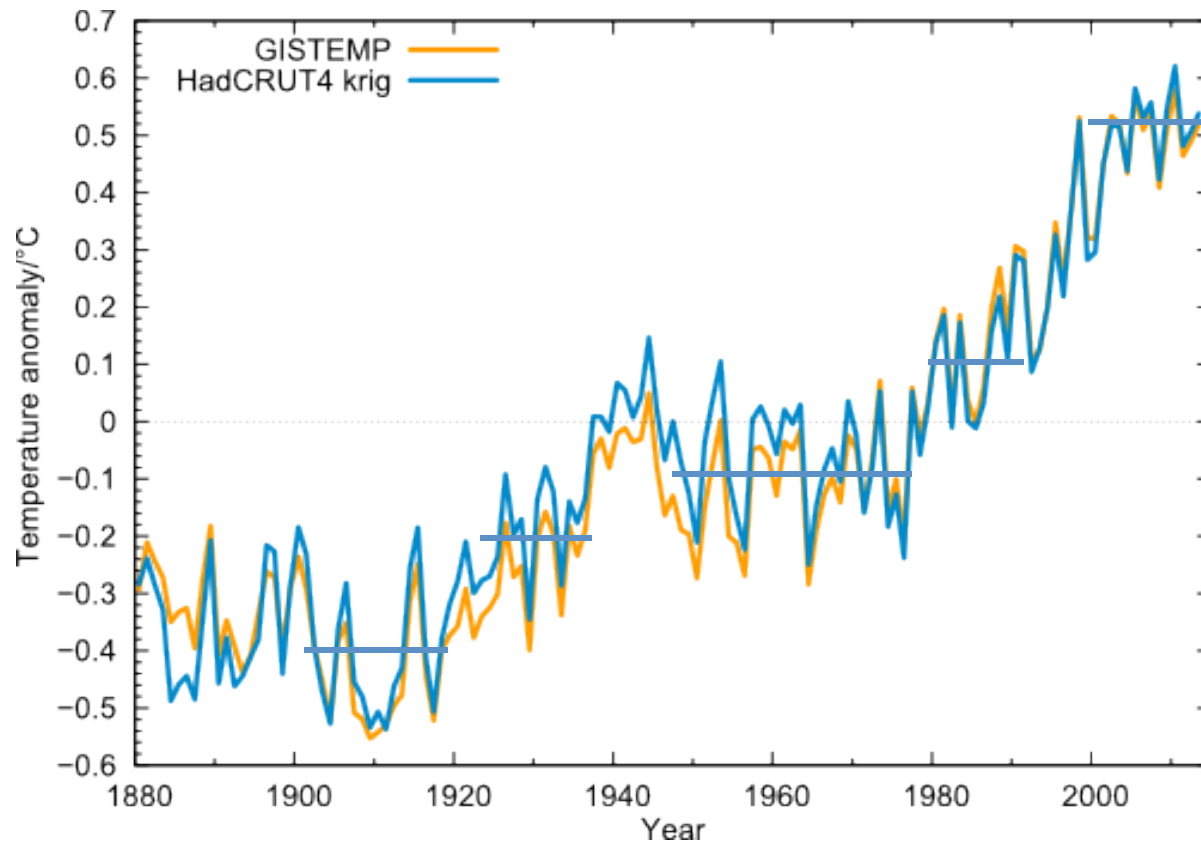
“Temperatures have ‘flatlined’ over the past 15 years...and to my knowledge, not a single climate model ever predicted that a pause in global warming would ever occur.”

--Senator James Inhofe (R-Okla.) in U.S. Senate hearing on the Obama Climate Action Plan on January 16, 2014 (quoted in Eos, January 28, 2014)



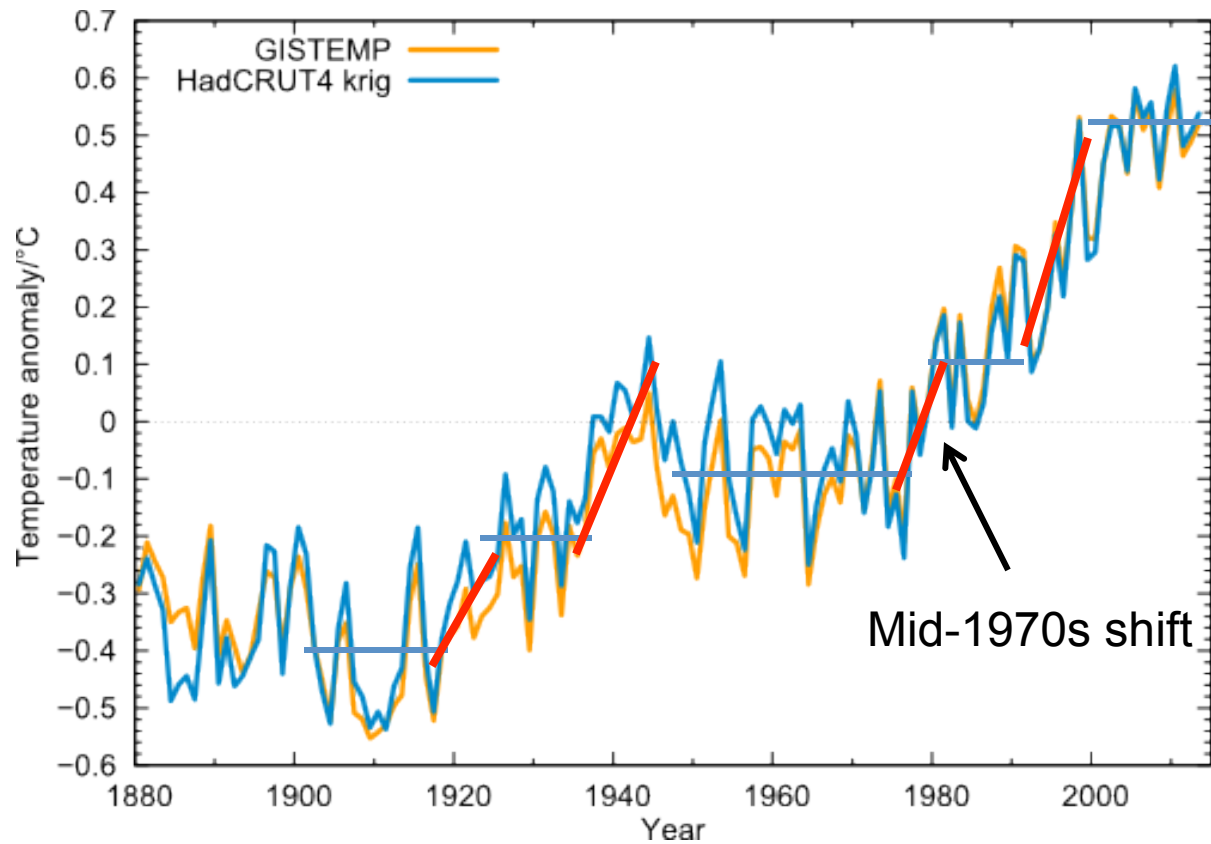
**The “case of the missing heat” crime scene: Global warming seems to have stopped since 2000
(linear trend of only +0.04 °C/decade)**

What or who is responsible?



Start collecting evidence:

Hiatus periods have occurred before and appear to be a naturally-occurring part of climate variability



And the flip side of hiatus periods are accelerated warming periods

(e.g. the “mid-1970s climate shift”)

Logical deduction phase (reviewing the facts of the case):

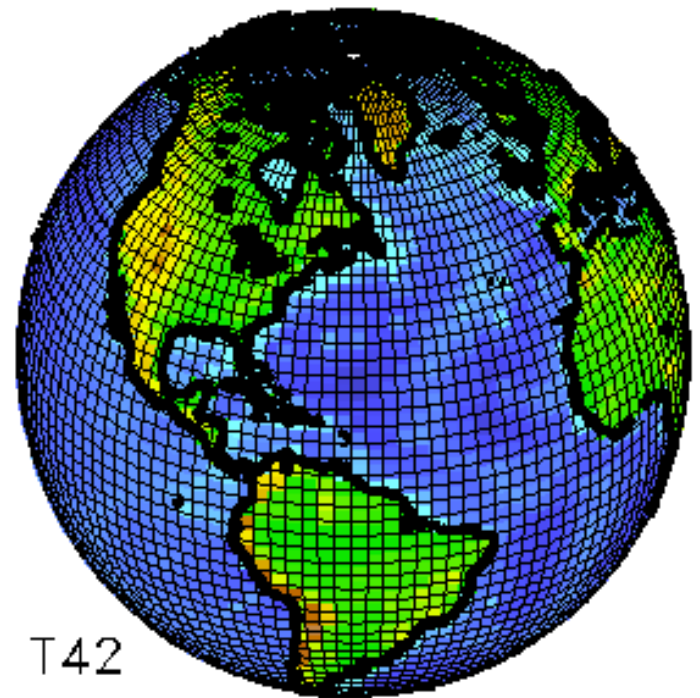
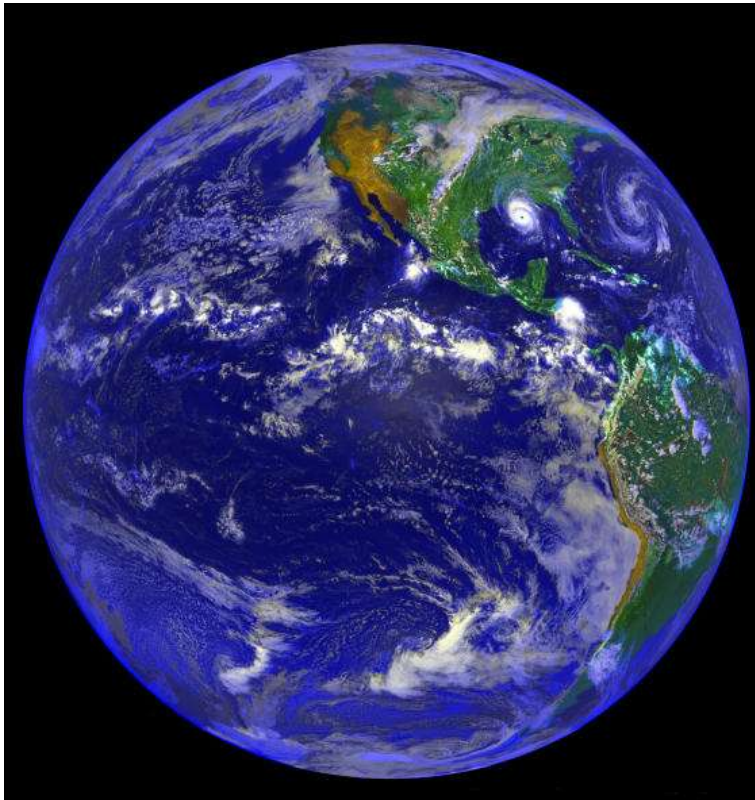
1. Measurements show that CO₂ has continued to increase throughout the hiatus
2. Satellite measurements show that the increase of CO₂ has continued to trap heat in the climate system
3. Measurements of globally averaged surface air temperature show little warming trend
4. Measurements of globally averaged upper ocean temperatures show little warming trend
5. So where can the heat be going? It has to be going into the deeper layers of the ocean
6. But we have few measurements of deep ocean temperatures to pin this down

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We need a diagnostic tool: a climate model

The challenge of simulating the earth's climate with equations



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Resolution of climate models is improving:

1995: about 500 km

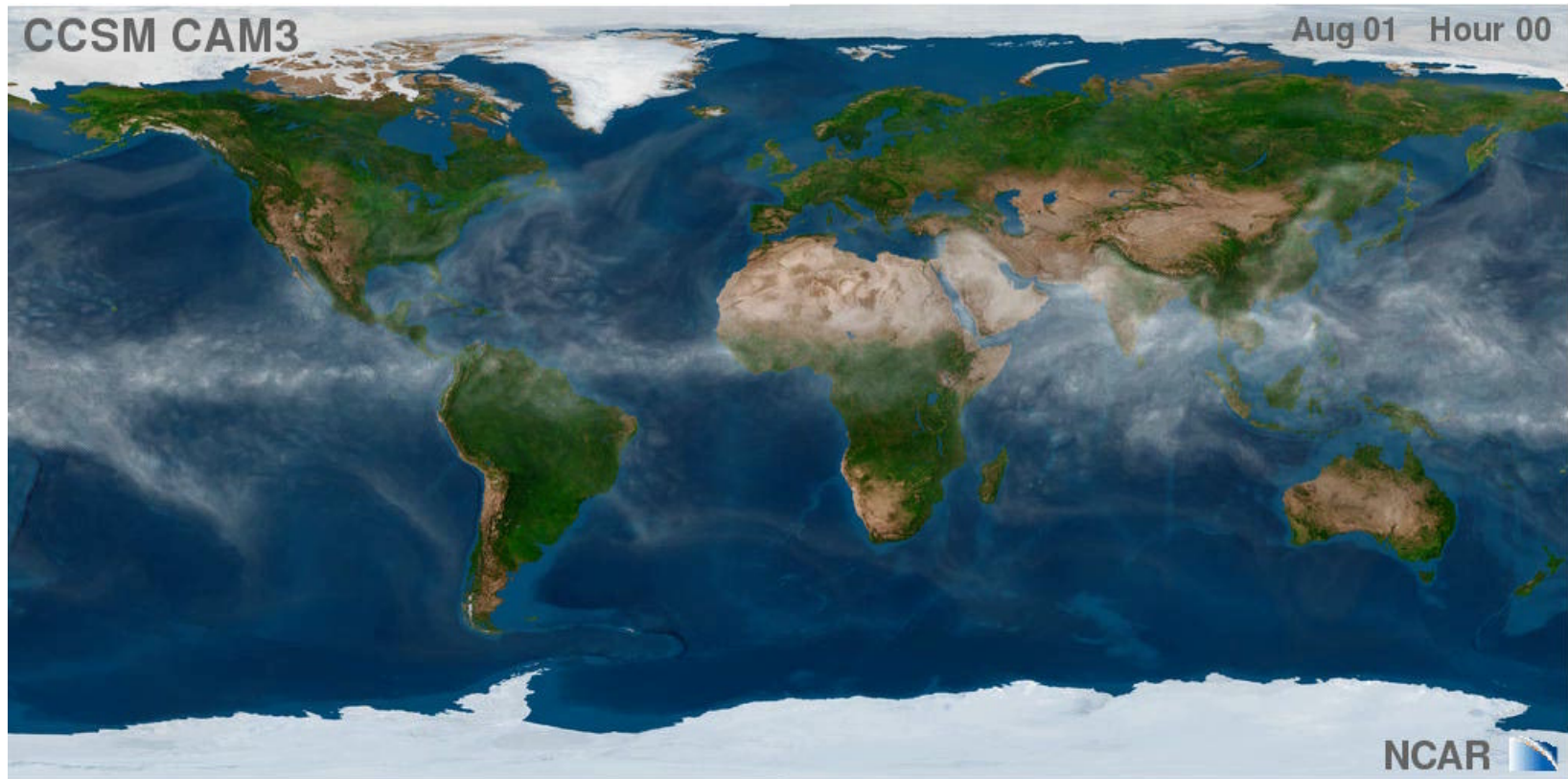
2000: about 250 km

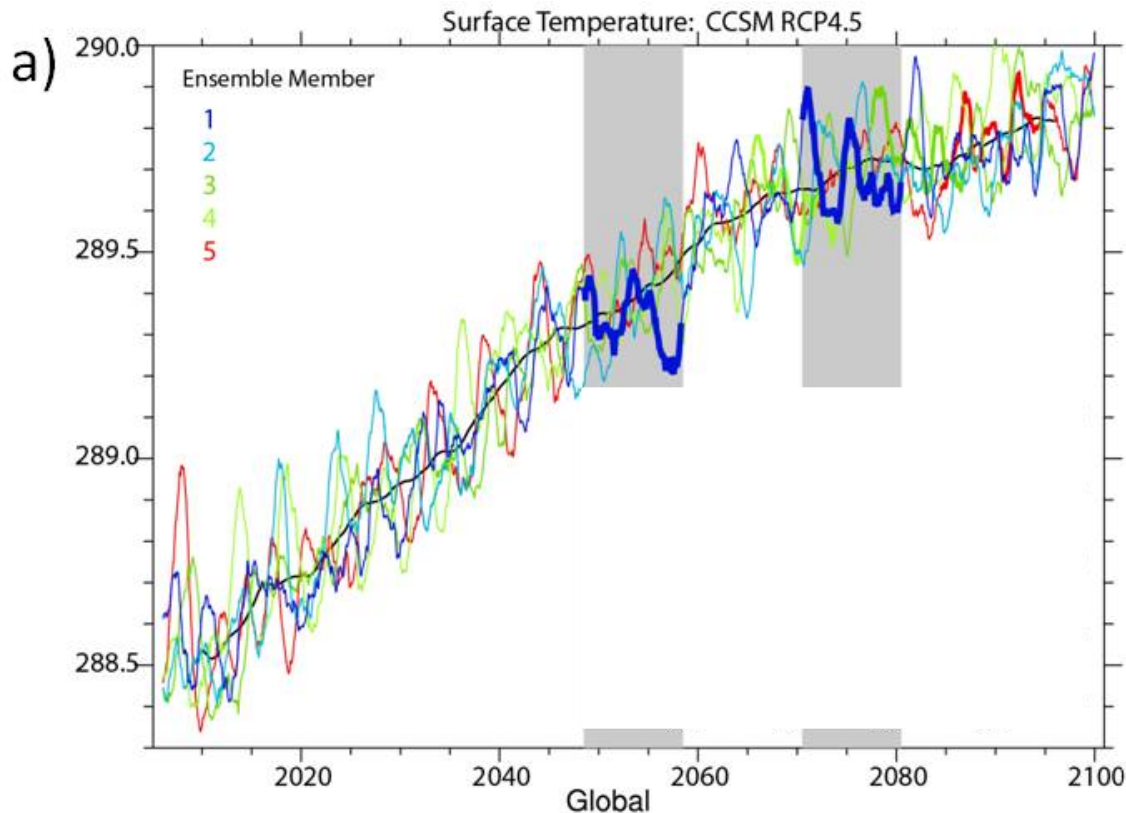
2005: about 150 km

2011: about 100 km

2014: about 25 km

Climate Model Simulation





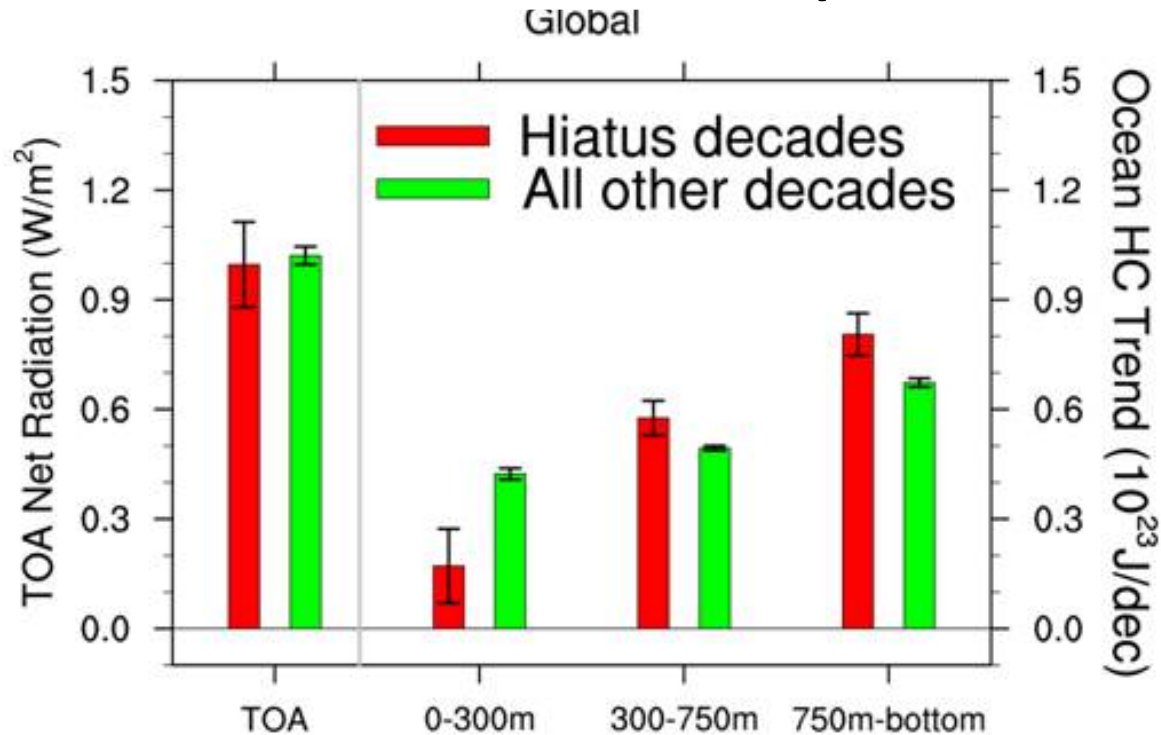
If individual climate model simulations are plotted, there are hiatus decades that occur even as CO₂ is increasing

We can use the climate model as a diagnostic tool to collect evidence as to where the heat goes when the surface temperature trend is flat

Two examples of hiatus decades are highlighted (in these five model simulations, there are 8 hiatus decades)

Q: Where does the heat go when the surface temperature trend is flat for a decade or so?

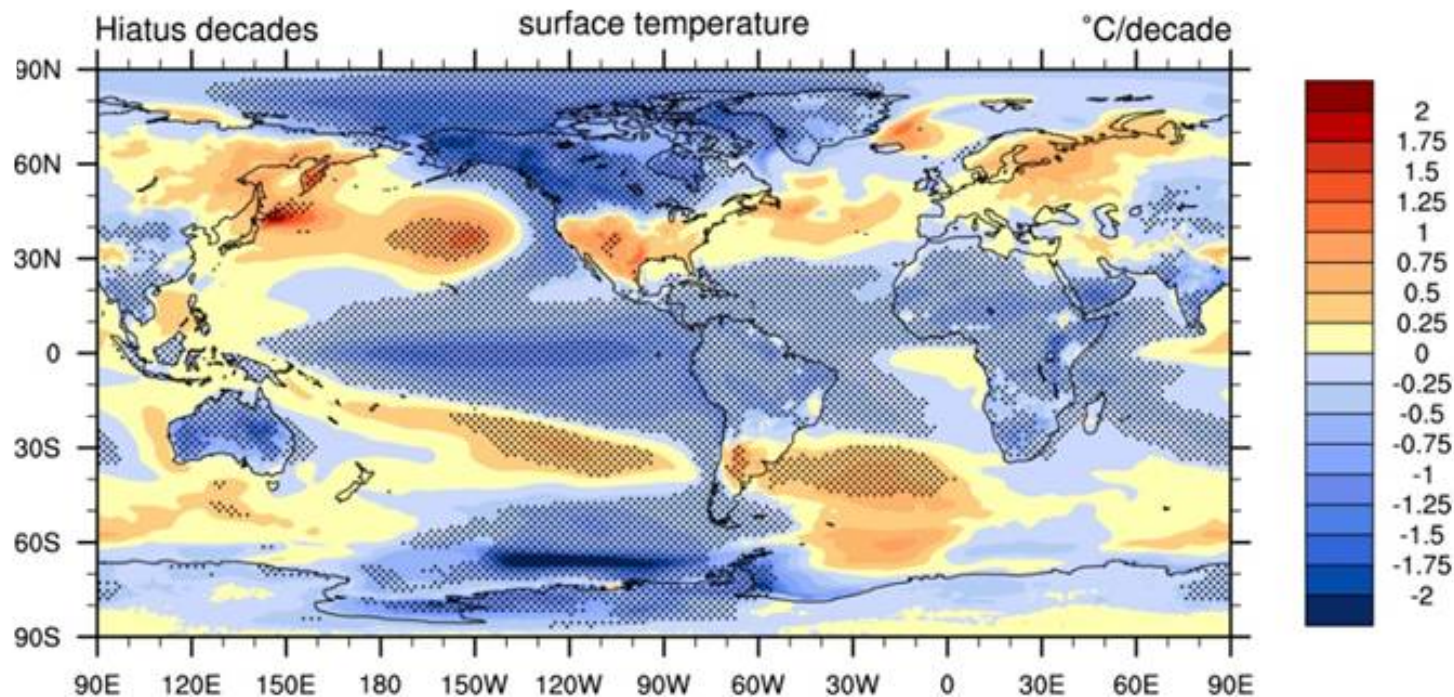
A: The model results: The deep ocean



(Meehl et al., 2011, Nature Climate Change)

**An important clue from the model:
During hiatus decades in the model, there are cooler
sea surface temperatures (SSTs) in the tropical Pacific**

**Resembles the negative phase of the Interdecadal
Pacific Oscillation (IPO)**

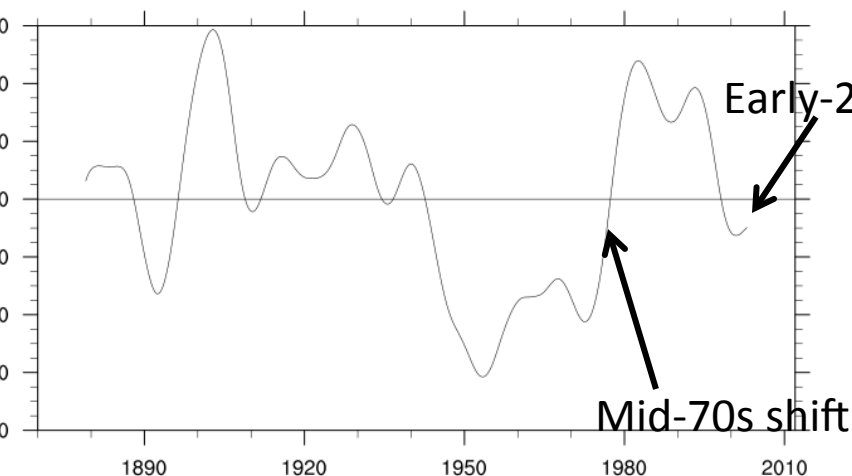
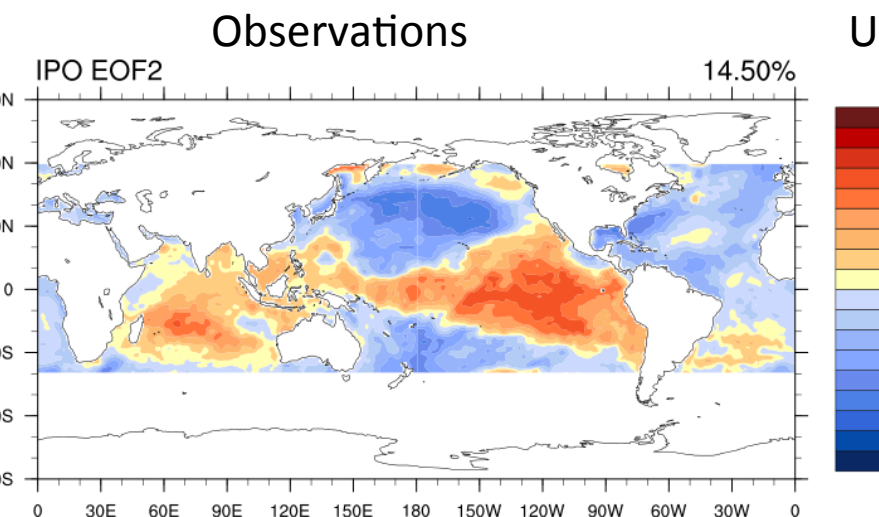


(Meehl et al., 2011, Nature Climate Change)

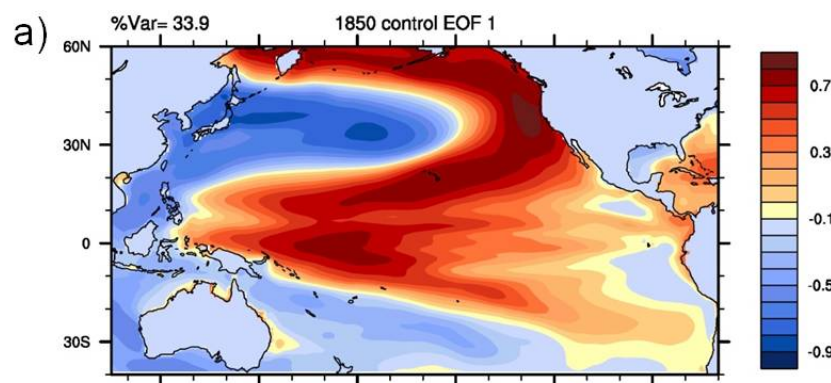
What is the IPO?

the Interdecadal Pacific Oscillation (IPO, Power et al., 1999) defined for entire Pacific (the Pacific Decadal Oscillation PDO is defined for the North Pacific but patterns are comparable)

Climate model simulations indicate IPO is internally generated



Unforced model control run (CCSM4)

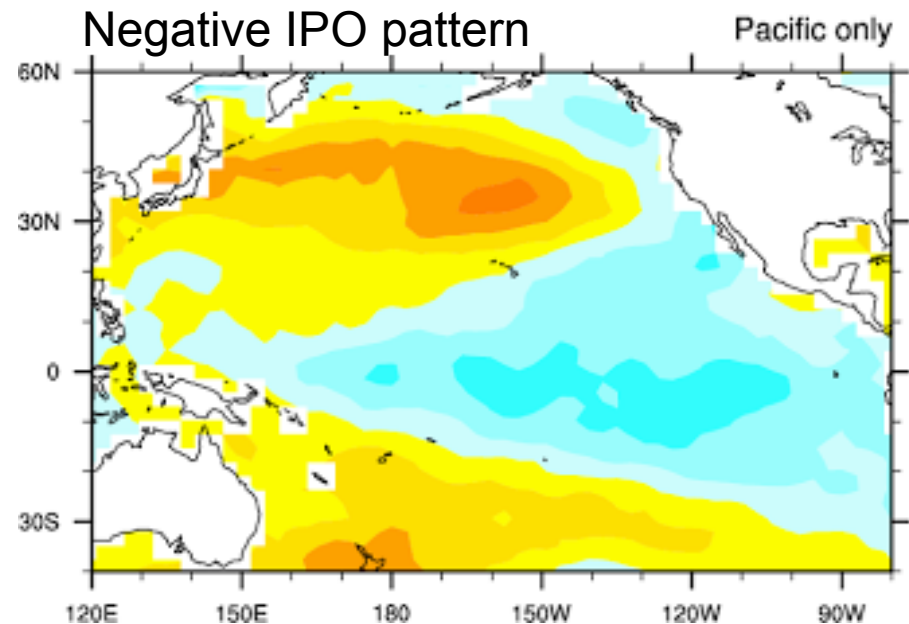
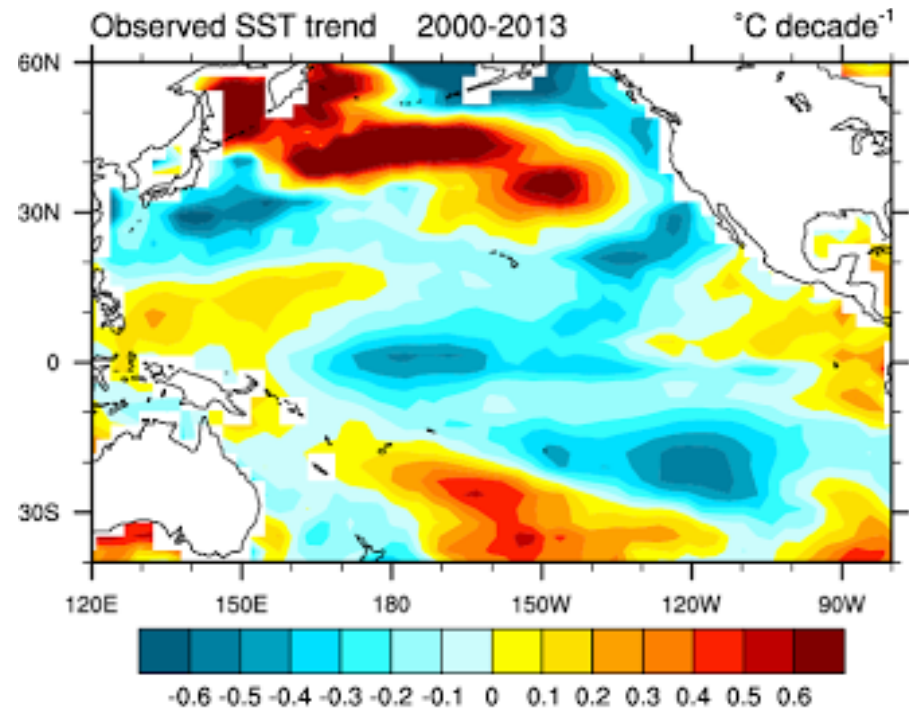


The observed IPO pattern resembles internally-generated decadal pattern from an unforced model control run (pattern correlation= +0.63)

(Meehl et al., 2009, J. Climate; Meehl and Arblaster, 2011, J. Climate)

A crucial clue:

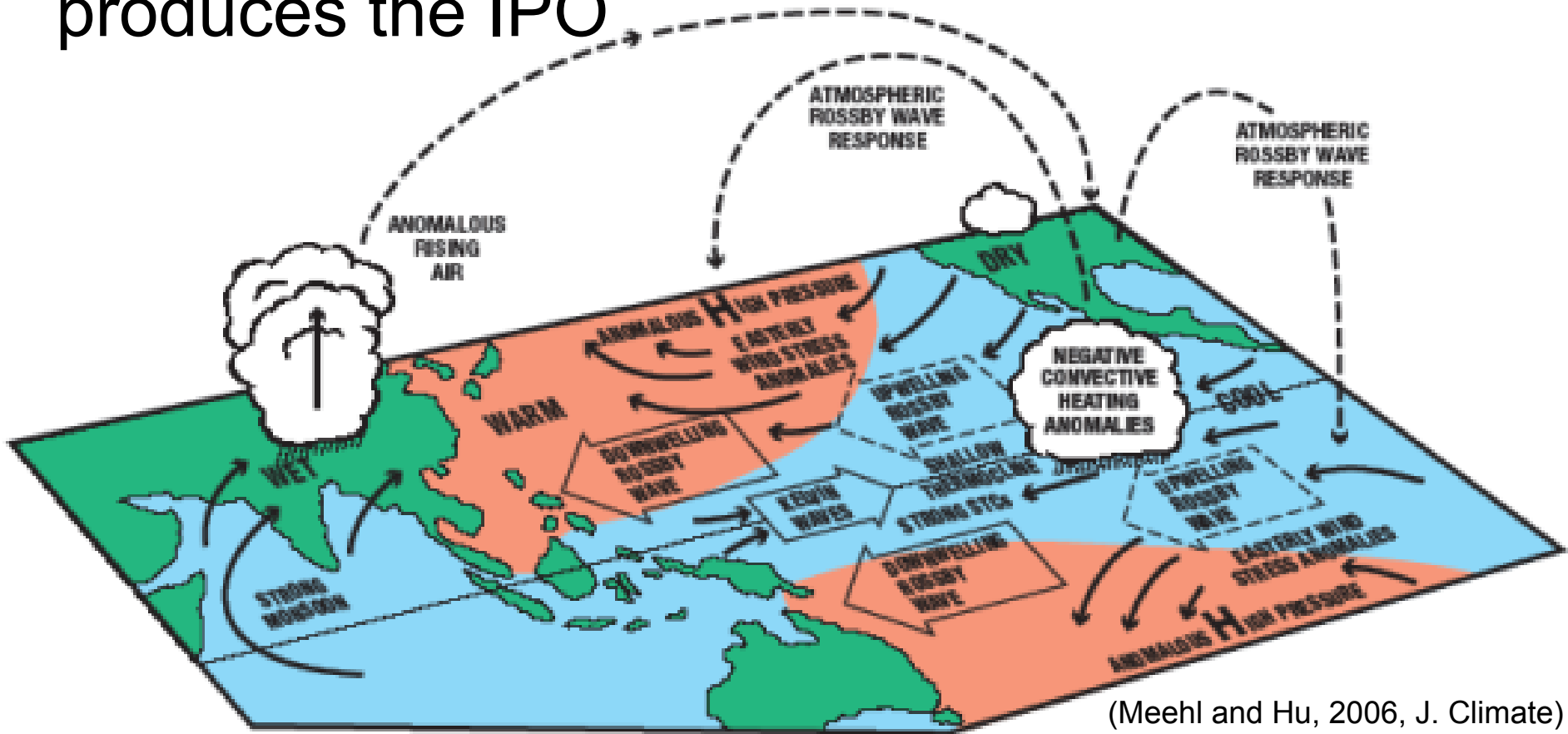
Measurements of sea surface temperatures since 2000 show a negative IPO pattern during the early-2000s hiatus



The evidence so far:

1. Measurements show that CO₂ has continued to increase throughout the hiatus
2. Satellite measurements show that the increase of CO₂ has continued to trap heat in the climate system
3. Measurements of globally averaged surface air temperature show little warming trend
4. Measurements of globally averaged upper ocean temperatures show little warming trend
5. Longer term observations show that hiatus and accelerated warming periods have occurred before
6. Using the climate model as a diagnostic tool, during hiatus decades the heat is going into the deeper layers of the ocean
7. The model indicates that hiatus periods are characterized by the negative phase of the IPO; the IPO is a naturally-occurring element of decadal timescale variability; and positive IPO decades are associated with accelerated global warming
8. Observations show the current hiatus has negative a IPO

We have evidence for the mechanism that produces the IPO

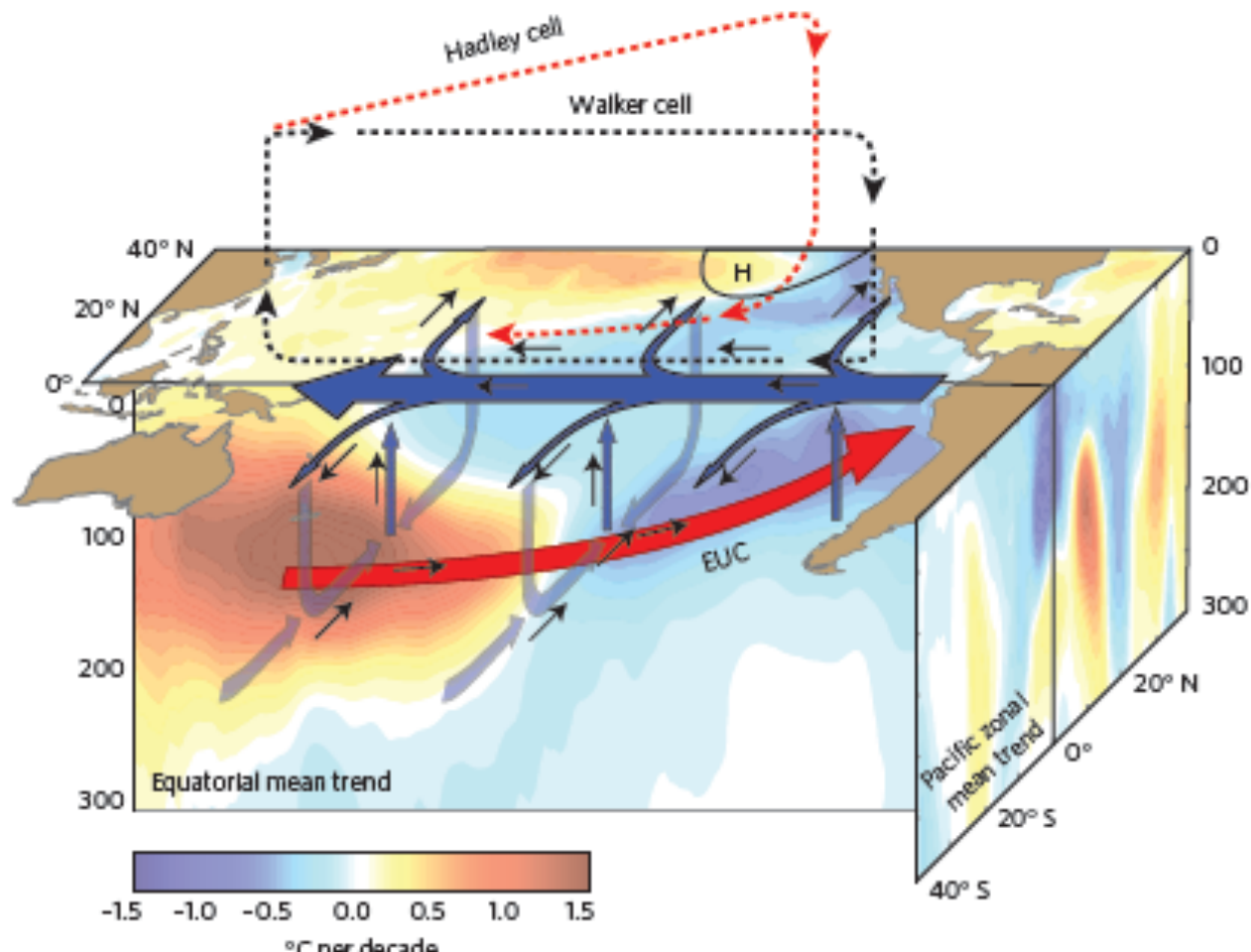


There is evidence that the IPO is internally generated naturally-occurring climate variability involving coupled air-sea tropical-midlatitude processes that produce transitions from negative to positive to negative IPO every 10 to 30 years; **year-to-year El Niño and La Niña events still occur superimposed on these slower fluctuations of the climate system**

More clues from modeling studies:

By specifying the observed time evolution of tropical Pacific sea surface temperatures, the early-2000s hiatus is simulated, thus implicating the IPO's role in producing the hiatus (Kosaka and Xie, 2013, Nature)

During the negative phase of the IPO, stronger trade winds mix more heat into the subsurface ocean (England et al., 2014, Nature Climate Change)



More pieces to the puzzle:

- The climate model result of more heat being mixed to the deeper ocean during the hiatus has been confirmed by data sets that include the limited deep ocean observations (Balmaseda et al., 2013, GRL; Chen and Tung, 2014, Science)**
- Another climate model confirms the previous model results (and more recent ocean observations) for the early-2000s hiatus in terms of the heat being mixed into the deeper ocean (Guemas et al., 2013, Nature Climate Change)**

--A new analysis of observations confirms earlier studies showing there has indeed been a recent net energy imbalance at the top of atmosphere, indicating this extra heat trapped in the system must be mixed into the subsurface ocean in association with the negative phase of the IPO (Trenberth et al, 2014, J. Climate)

But is something other than internal variability contributing to the hiatus?

--Cumulative effects from a series of small volcanoes in the early 21st century could have contributed perhaps about 15% of the hiatus (Santer et al., 2014, Nature Geoscience)

But maybe the hiatus doesn't exist at all and is an artifact of incomplete observed data coverage over the Arctic

--Not likely—two surface temperature data sets that include temperature information over the Arctic still show the hiatus

Have we solved the “case of the missing heat”?

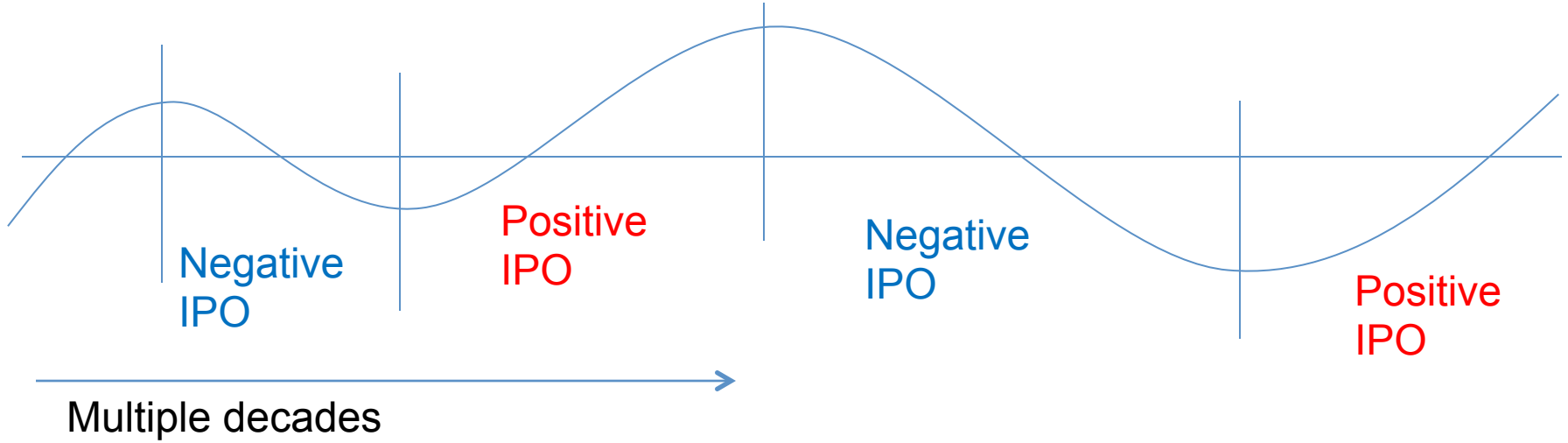
(a.k.a. the early-2000s hiatus)

There is strong evidence that as CO₂ continues to increase and trap heat in the atmosphere, and when globally averaged surface temperatures aren't increasing, the heat goes into the subsurface ocean; **global warming hasn't stopped, it's just shifted temporarily below the ocean surface**

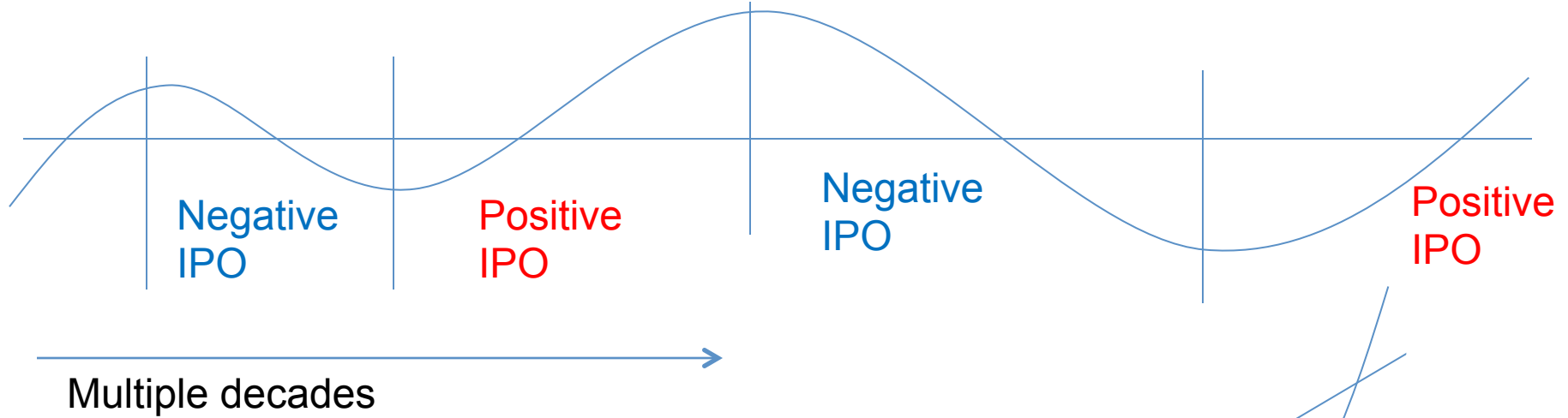
The hiatus is characterized by the negative phase of the IPO in the Pacific associated with subsurface ocean mixing; the IPO is a dominant source of naturally-occurring decadal timescale variability in the climate system

In its negative phase, the IPO can temporarily stop the surface warming from increasing greenhouse gases as it puts that heat into the subsurface ocean, but in the past (and in models) when it shifts to its positive phase there is more rapid global warming

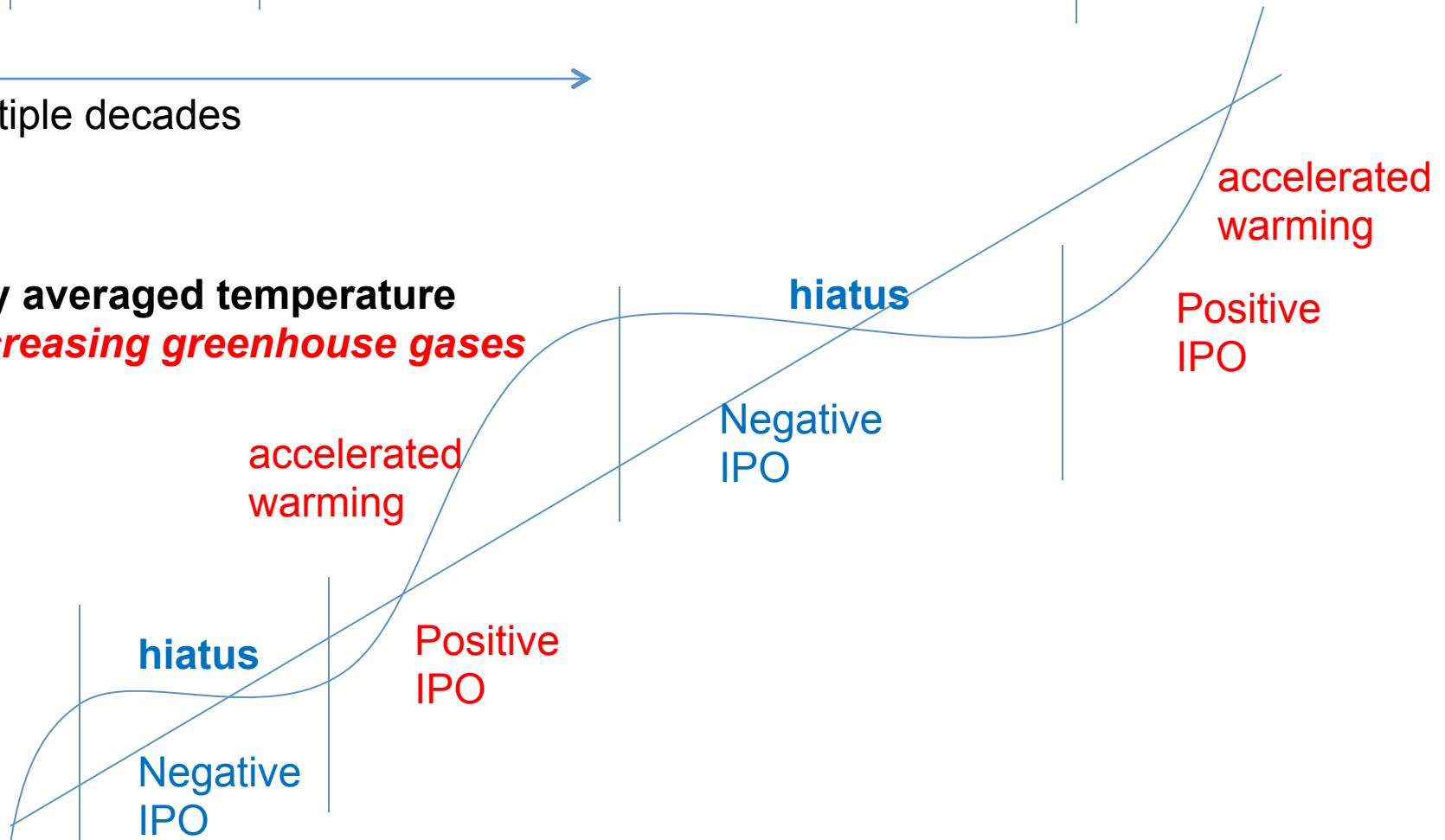
Globally averaged temperature
without increasing greenhouse gases



Globally averaged temperature
without increasing greenhouse gases



Globally averaged temperature
with increasing greenhouse gases



Case closed?

(not quite—when will the hiatus end?)

“Temperatures have ‘flatlined’ over the past 15 years...and to my knowledge, not a single climate model ever predicted that a pause in global warming would ever occur.”

--Senator James Inhofe (R-Okla.) in U.S. Senate hearing on the Obama Climate Action Plan on January 16, 2014 (quoted in Eos, January 28, 2014)

It turns out that ten climate model simulations actually reproduced the hiatus

Hiatus from 2000-2013: 10 members

And those ten simulations, by chance, had a **negative phase of the IPO**

(internal variability is random in observations and models, so it is only by chance that a model simulation that started in the late-1800s happened to simulate the observed hiatus at the right time)

internally generated variability in those model simulations happened to sync with observed internally generated variability

Total: 262 possible simulations

2000-2014 hiatus: 9

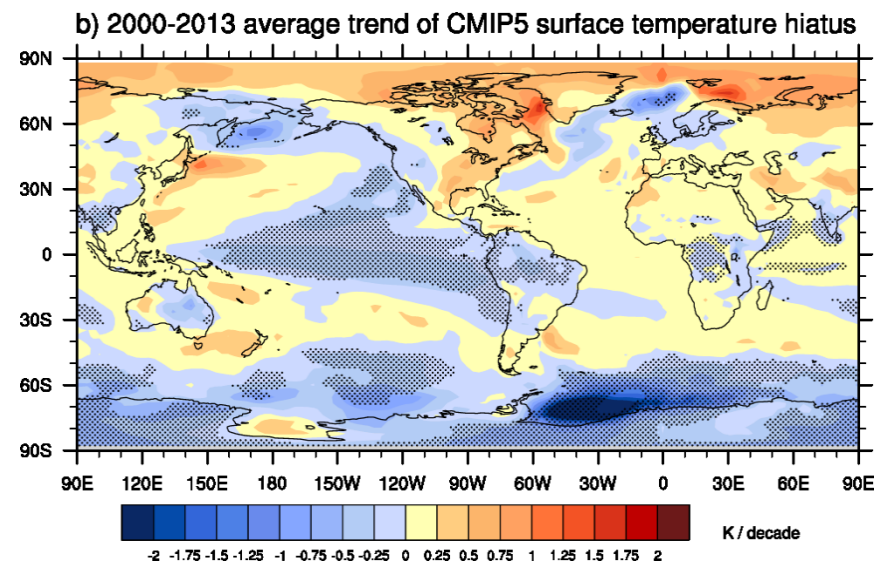
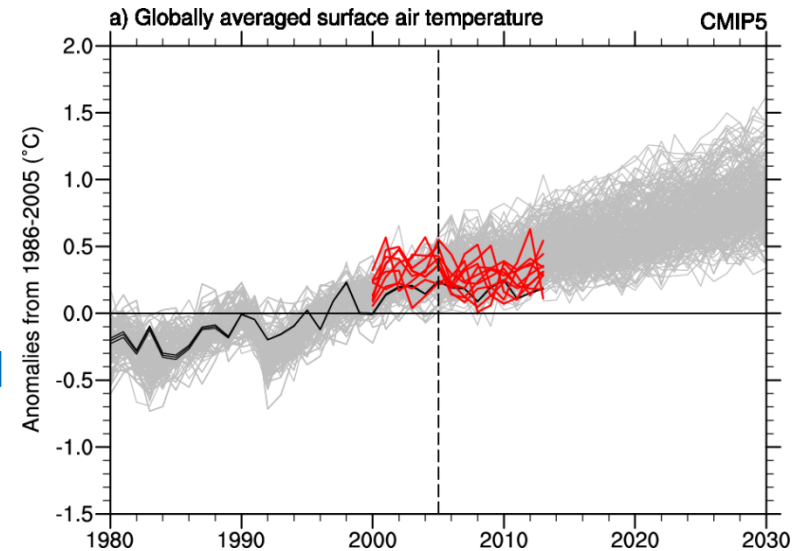
2000-2015 hiatus: 6

2000-2016 hiatus: 6

2000-2017 hiatus: 1

2000-2018 hiatus: 1

(Meehl et al., 2014, Nature Climate Change)

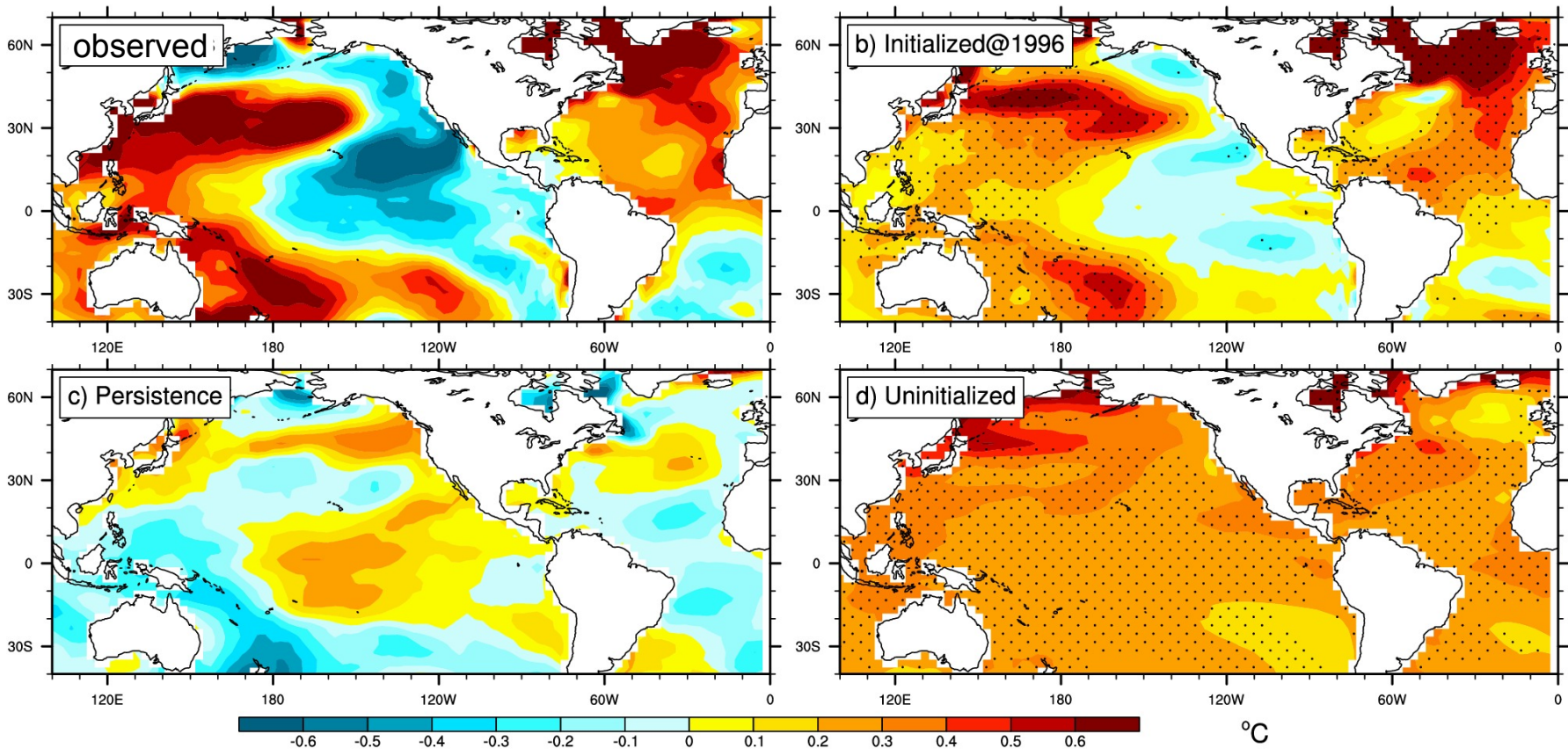


Random alignment of model-produced variability with observations has no predictive information—could we somehow have anticipated the “crime scene” of the early-2000s hiatus?

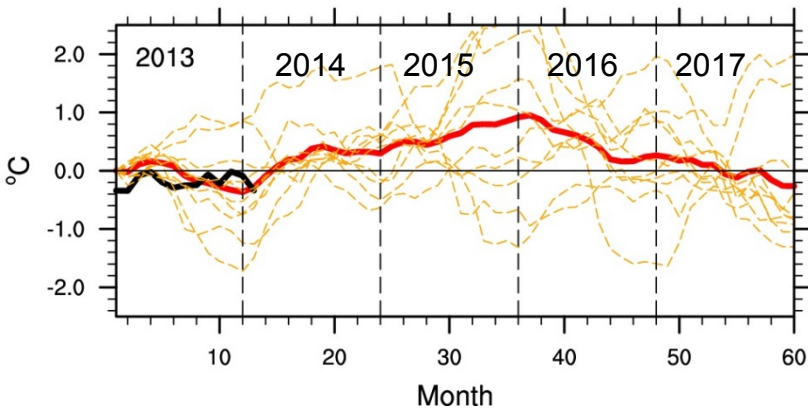
Beginning about five years ago, we now have a new methodology to predict near-term climate on decadal timescales, called “decadal climate prediction”

Climate models are started out (or initialized) with observations at a specific time to simulate the next ten years of climate, combining internally-generated variability and response to increasing greenhouse gases.

a prediction with models initialized with observations in 1996 for the five year average 1998-2002 shows the onset of the negative phase of the IPO
Sea surface temperature 1998-2002 minus 1981-1995

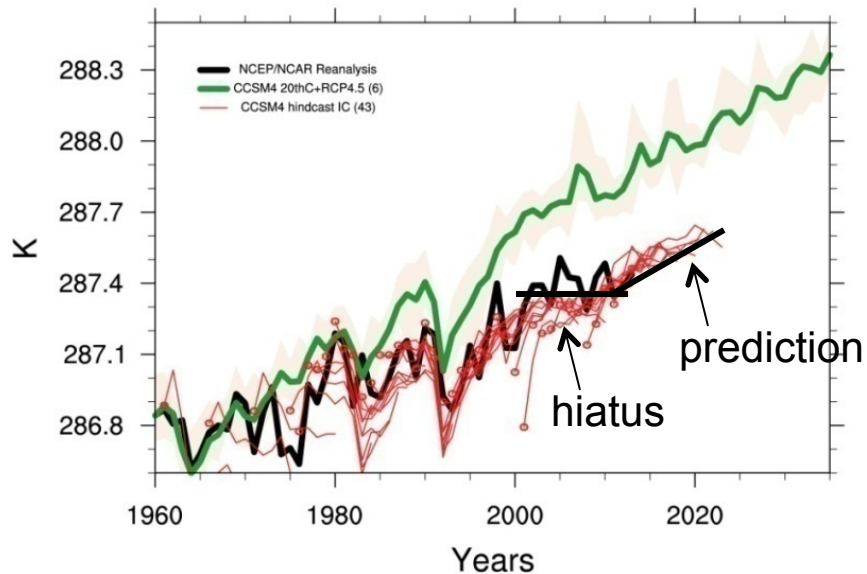


(Meehl et al., 2014, Nature Climate Change)



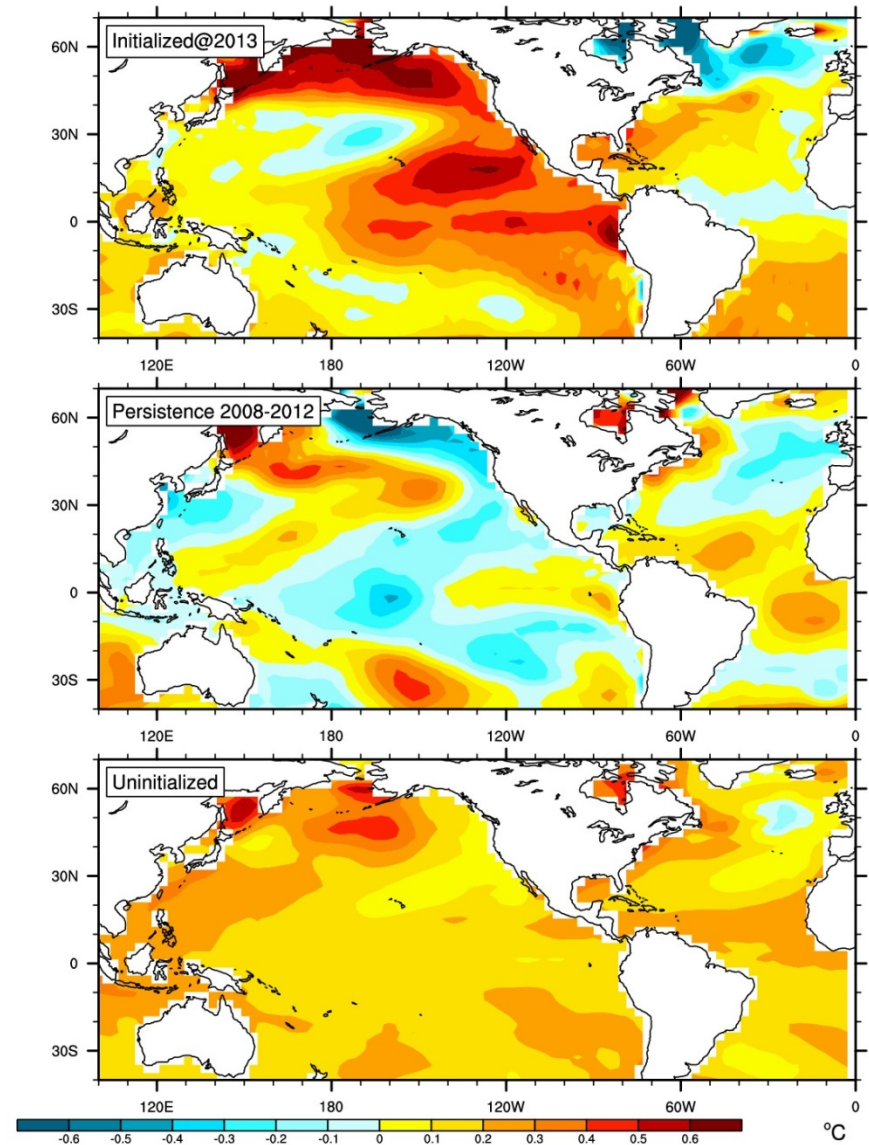
A climate model (CCSM4) initialized with observations in 2013 predicts a weak El Niño in 2014 and transition to the positive phase of the IPO with greater global warming

Global Annual Mean Surface Air Temperature



Sea surface temperature prediction

2015-2019 minus 1998-2012



Case closed?

not quite...

Stay tuned over the next few years to see if the model prediction or this media prediction verifies:

“Like the Terminator, global warming will be back” --article in *The Economist*, 2014

