Climatology and Climate Change

John C. Bean

Outline

Inconvenient truths about An Inconvenient Truth?

Paleoclimatology: Gathering climate data spanning millions of years

- Ten thousand years: Dendrochronology (tree rings), radiocarbon dating . . .
- Hundred thousand years: Glacial ice cores . . .
- Million years: Geology, fossils and their isotopic ratios . . .

The recent stark increases in atmospheric gases such as CO2

- vs. a less stark upward trend in temperature

Climate Models: The long, long list of effects & mechanisms that must be included

- Their surprisingly slow incorporation during the 1970's to 1990's
- The 2000's: Supercomputers finally allow for high-resolution worldwide modeling
- The ongoing transition from fitting past data toward accurately predicting future data

(Written / Revised: February 2021)

Climatology and Climate Change

At least in the US, climate change is **extremely** controversial

So rather than just adding to the high ambient noise level

I am going to share my own personal exploration of this subject

Which began by learning how NOT to judge climate change

And then progressed to "Paleoclimatology" & its tools

Which yield more complete data on atmospheric gases and temperature

To the elements (and difficulties) of climate forecasting

Which took me (as described in the following note set) to the topics of:

The "carbon footprints" of alternative energy technologies

And to the possibly wishful proposals for "carbon sequestration"

I am in no way involved in climate research – But I am a scientist!

As a scientist I know that the ultimate test of any theory is **successful prediction**

So I'd noted poor forecasting of upcoming winters or hurricane seasons

Which certainly **suggested** that climate modeling **was** still in its infancy

I thus sought 3rd party (~uninvolved) scientific sources and came across the book:

"Physics for Future Presidents" by U.C. Berkeley's Richard Muller

As in our textbook, Muller reduces important technical topics to basic science

With the goal of estimating basic limits and/or ultimate possibilities

And also as in our textbook, Muller brings with him a scientist's skepticism

Not in the "denier's" sense, but in the sense of "Show me the evidence!"

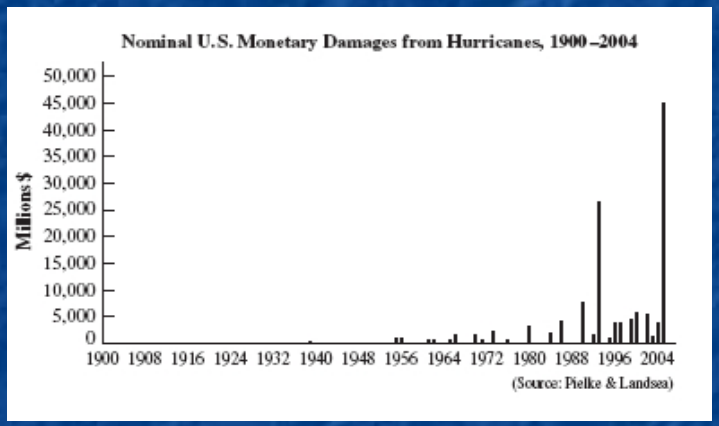
(Which ultimately pushed him to center stage in the climate change controversy)

*So, as a skeptical scientist, what **is** the evidence?*

Well, on climate, Muller first taught me not to jump to premature conclusions

Such as those he identified in Al Gore's movie "An Inconvenient Truth"

Example #1) U.S. Monetary Damage from Hurricanes, 1900-2004

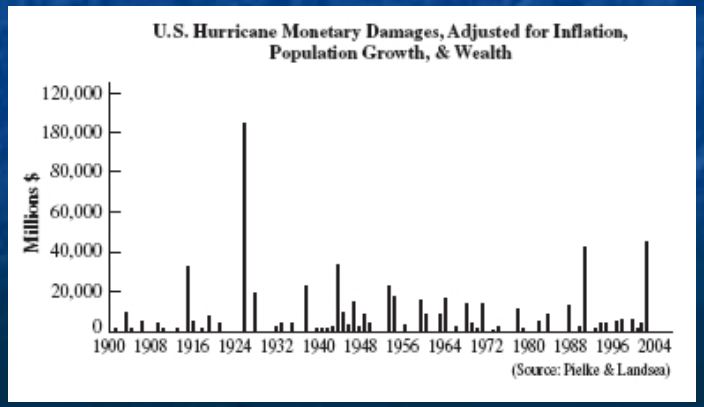


Wow!

Damage costs have skyrocketed indicating hurricanes have gotten **much** worse

Except for a few problems

But when a **century of inflation** is taken into account, the figure becomes:



And what first looked like a **strong** trend becomes **NO** trend!

Black and white figures here and to follow are from Richard Muller's "Physics for Future Presidents"

And it's actually a bit worse than that:

Because, in that century, we have built hugely more homes/cities on the coast

So **similar** storms should have produced **more** (adjusted dollar) damage

The lack of rise in the corrected figure thus suggests **lowered** damage per building

Which could be taken as evidence of **weakening** hurricanes

But what about the **increase in Category 4/5 hurricanes in last 20 years?**

Indeed: 2005 set a record with **five** such storms recorded

Well, here the key word is “recorded” because:

In the past we only noticed intense hurricanes when they hit us onshore

Or when they crossed heavily trafficked ocean shipping lanes

But we then began sending **hurricane-spotting planes** out over the ocean

And now **weather satellites** continuously photograph the **entire** ocean

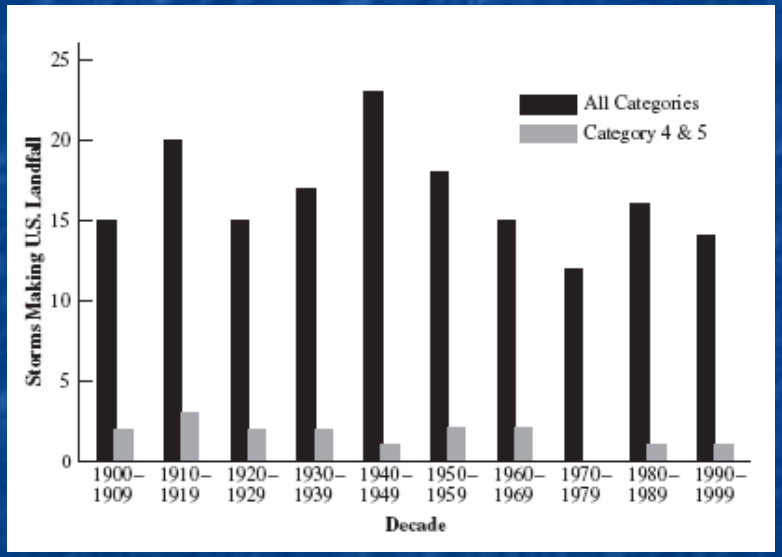
So you have to carefully avoid apple and orange comparisons

Our old data were almost entirely for hurricanes when they came ashore

So, for true historical trends, we must filter our much richer modern data

Taking from it **only** data for hurricanes **AT LANDFALL**

A century of tropical storm **landfall** data:



Thus earlier numbers ignored the fact that we now **spot** more hurricanes!

And thus, including mid-ocean data, also spot more Cat 4/5 hurricanes

*We can **also** identify increased tornado damage:*

At left, a newspaper photo of my daughter's home:

Many saw a tie between this "freak" Suffolk Virginia tornado and global warming

But are we sure of that? Take a look at the larger area photograph on the right

That photo reveals that her neighborhood was built in a grassy tidal marsh

And **I know** the neighborhood was built in only ~ the last decade

So if an identical storm touched down in the same place two decades ago

We might not have even noticed (with only a tree or two knocked down)!

This reveals a fundamental flaw in weather reporting:

We don't monitor weather with the goal of compiling scientific data

We instead search for anomalous weather that might harm us or our property

And we now search harder and harder, with ever improving technology

Making special use of recent, widespread, deployment of Doppler radars

For which I now carry near-instant monitoring apps on my phone!

With this goal, weather data has a **built-in bias** toward finding irregularities

So weather data must be **very carefully filtered** to eliminate biases

Here I'm not just talking about human bias. It can be more subtle, for instance:

We (logically) keep **building more** Doppler radars in tornado-prone areas

And (surprise!), as a result, we **detect more** tornados!

So consider a non-weather reporting phenomenon: ***Ice sheet thickness***

There is very strong data, worldwide, on the recent (alarming) retreat of glaciers

And because glaciers **do** incorporate the snowfall of decades and centuries

They **would** seem to offer an excellent way of spotting long term trends

In the mountains of the middle latitudes (e.g. the Alps and Rockies)

Summer temperatures **can** rise above 0°C, thus:

Glacial retreat is an indication of warmer summers => melting

Given its vastness, we are particularly alarmed by the thinning of the **Antarctic Ice**

However, Antarctica remains well below freezing all year round

But warming of adjacent seas should **enhance** water evaporation,

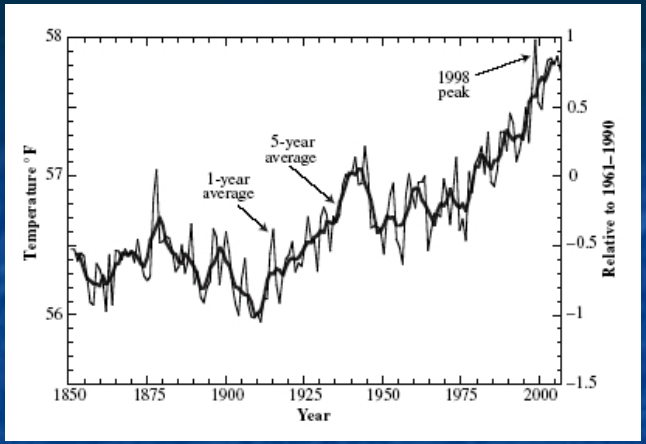
Which should increase snowfall => **Increase** in Antarctic ice thickness

So present thinning of Antarctic ice sheet **contradicts** some warming models!

OK, then what about simple, direct, temperature data?

The type of data we had

in the 80's and 90's:



Recorded temperature **does** seem to be trending upward. **However:**

- It is awfully noisy (with the upward trend only about twice the variation)

- We KNOW that the earth's climate has regular (non-global warming) variations

  For example, mega ice ages (and even mini ice ages)

- Historical data come primarily from a handful of **big cities** (e.g., London)

  But we know that cities are WARMER than the surrounding countryside

  And we know these cities GREW hugely during this same period

  So we'd **expect** their (local only) temperatures to have increased!

So even for simple, direct, temperature data:

To accurately evaluate **global climate trends**, we really need to:

Acquire a much **larger** data set

Acquire a much more geographically **diverse/representative** data set

Including, for balance, much more data from the southern hemisphere

Which **could** be different based on lower land to sea ratio

Rely much less heavily on data from large growing cities

And/or develop models that can reliably separate the effects of localized urban heat bubbles from underlying large area temperature changes

Acquire temperature data covering 10X, 100X, or 1000X longer time spans

Where am I going with this?

Am I a closet "denier?"

NO, to me a denier is someone who refuses to listen to **any** evidence

But in the preceding I **do** see misuse of evidence on the other side of the table

As, at least in the political/popular arena and in news reporting,

advocates have grabbed at selective seemingly supportive data

that could not withstand more careful examination

Whether deliberate or non-deliberate, such selective use of data can mislead

And Gore and others **do** seem to have succumbed to such "Cherry Picking"

My conclusions from all of the above?

On climate, it can be **extremely hard** to find unambiguous evidence

So better data are absolutely essential, bringing me to the topic of:

"Paleoclimatology"

Where, as the strange name sort of suggests, this is:

The study of the earth's climate over the earth's whole history

Covering ~ 4.5 billion years, including periods in which earth's surface was:

Largely/entirely molten lava

Or 100% frozen

Or enveloped by suffocating (Venus-like?) atmosphere

For our purposes, more relevant is the last ~ half billion years

When the biosphere (as we know it and need it) came into existence

Data on climate over THAT time span would make it **much easier** to decide

if something truly strange (and possibly man-made) is **now** altering climate!

*Source of data for last **ten thousand** years: Dendrochronology*

Known more commonly as **tree ring dating:**

Trees grow more vigorously in certain seasons => thicker accumulations of tissue

Leading to growth rings in trunk and branches

Sections of which can be easily extracted using core drills:

http://en.wikipedia.org/wiki/Dendrochronology

Better growth conditions => Thicker annual rings

Sequence of ring thickness + knowledge of tree's preferences => Climate history

Albeit a history that combines effects of **both** temperature and rainfall

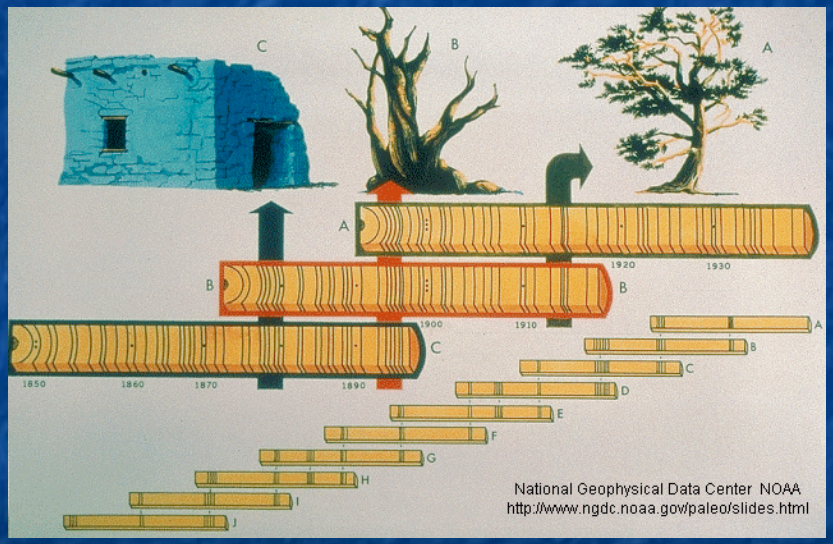
But the oldest trees are only about 2000 years old!

We can extend climate history by using cores from multiple trees (dead or alive):

Trees of **different ages** that experienced the **same climate patterns**

Corresponding parts of tree ring pattern allow alignment of cores to one another:

Line up older core with a still older core, and so on and so on:



In certain locations, histories have thus been compiled going back ~ 10,000 years

What if we can't find wood from some periods?

We can date disconnected tree ring samples via radiocarbon dating

Which we've all heard of – but probably never had completely explained:

The atmosphere contains both: ^{12}C (=stable) & radioactive ^{14}C (half-life 5730 years)

But, despite **^{14}C** decay, the **^{12}C / ^{14}C** ratio remains constant because (KEY POINT!):

Cosmic rays striking the **upper atmosphere** continuously create **new ^{14}C**:

^{1}n (neutron as a cosmic ray) + **^{14}N** => **^{14}C** + **^{1}p** (proton)

This new (replacement) **^{14}C** then diffuses through the **entire** atmosphere

Thus maintaining an atmospheric **^{12}C / ^{14}C** ratio of about 10^{12} to 1.5

However, most cosmic rays don't reach the ground, so C **inside** plants is **not** altered

But their incorporated **^{14}C** does continue to radioactively decay away

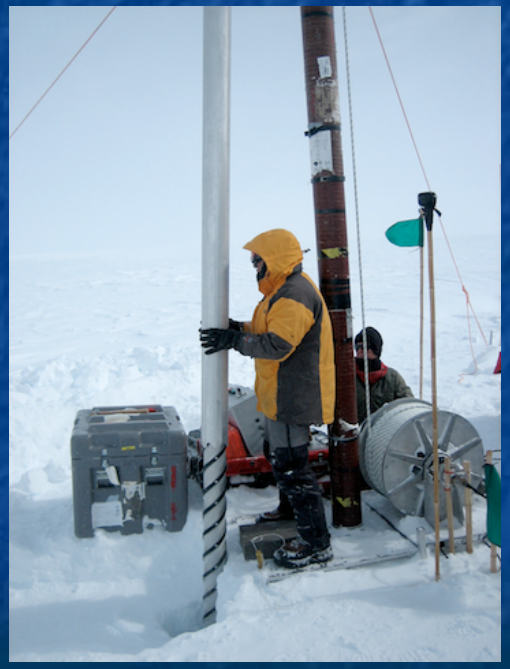
Thus: Changing **^{12}C / ^{14}C ratio inside a plant => Age of that plant**

Source of data for last **hundred thousand** *years: Glacial Cores*

Water vapor freezes => Snow flakes => Which are compressed into ice

Some glaciers, such as those on Greenland, are over 100,000 years old

And cores can be (relatively) easily drilled from such ancient glaciers:



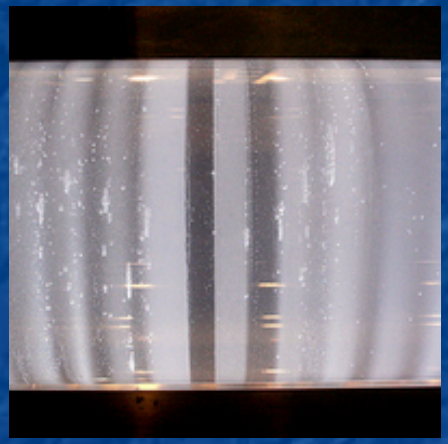
www.washington.edu/news/2014/04/11/greenland-ice-cores-show-industrial-record-of-acid-rain-success-of-u-s-clean-air-act/

www.colorado.edu/news/releases/2013/01/23/deep-ice-cores-show-past-greenland-warm-period-may-be-%E2%80%98road-map%E2%80%99-continued

Information extractable from such glacial cores:

Snowfall has annual variations including cycles in snowflake size and compaction

Which can sometimes be seen in the detailed structure of ice cores:



www.methanenet.org/news/clathrate-gun-shot-down

Thicker / broader annual bands

indicate higher annual snow fall

Suggesting colder surface temperatures

(OR more moisture from warmer local seas?)

Whiter bands also (correctly) suggest that **gas has been trapped** in the cores

I.E., not all of the air between snowflakes escaped as it compacted into ice

By cutting out thin slices and melting in vacuum (or under controlled inert gas)

These trapped bubbles of ancient atmospheres can be reclaimed

More subtly:

Plant pollens can blow over long distances

To eventually fall upon the surfaces of such glaciers

Where they can not only provide another seasonal marker

But, by identifying the plant responsible and its preferred habitat,

they can also indicate climates in surrounding regions

Volcanic dust can circle the world – and then get similarly trapped in glaciers

Offering opportunity to correlate **atmospheric opacity** with climate

Oxygen has two atomic isotopes, ^{16}**O** and ^{18}**O**, so seawater has two masses

Relative evaporation of lighter vs. heavier water changes with temperature

So ratio in glacier hints at the nearby **ocean surface temperature**

"Hints" because factors such as salinity **also** affect evaporation

Sources of data spanning millions of years:

Morphology/Shape of Sedimentary Deposits:

E.G., Sand dunes, lake shores, glacial scars . . . => indications of climate

Content of Sediment Deposits:

Remnants of animals, plants, pollens => indications of climate

Chemical Analysis of Fossils:

^{18}O to ^{16}O ratio in foraminifera fossils (~ amoeba like water dwellers)

Different heavy/light water evaporation rates =>
Different **^{18}O / ^{16}O** ratio in water dwellers =>
Temperature of body from which water evaporated
(as with glaciers)

Mg/Ca ratio in shells varies with temperature at which shell was formed

Sr/Ca ratio in corals varies with temperature at which coral grew

(continuing)

Organic Residues in marine sediments reflect ambient temperature

Leaf shape ("physiognomy") is different for leaves from different climates

Tropical Rain forests: Larger leaves or many "drip tips"

Cooler climates: Smaller leaves, toothed edges more common

Heavy Isotope Bonds (e.g. ^{13}**C** to ^{18}**O**) more probable at low temps

Plus quite a few additional techniques

Most of which **are** also indirect and **do** require subtle/complex analysis

But which, together, can be used to build up an extremely long climate record

What does resulting much more extensive data set look like?

Above, first call was for more globally representative recent data:

Data from the **IPCC** (Intergovernmental Panel on Climate Change)

- Chartered by United Nations in 1988

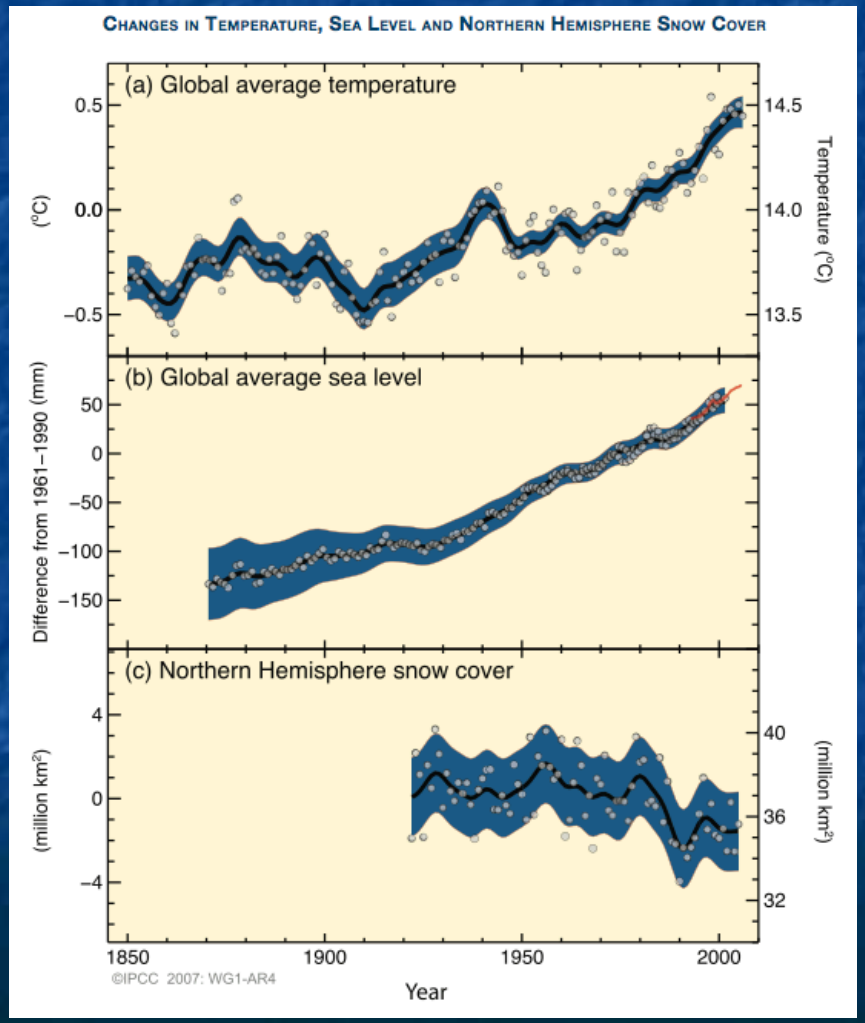
- Goal: Collect/analyze **all available data**

- 2007 => Nobel Peace Prize (w/ Al Gore)

More data => Higher confidence level

Less scatter

Clearer recent trends

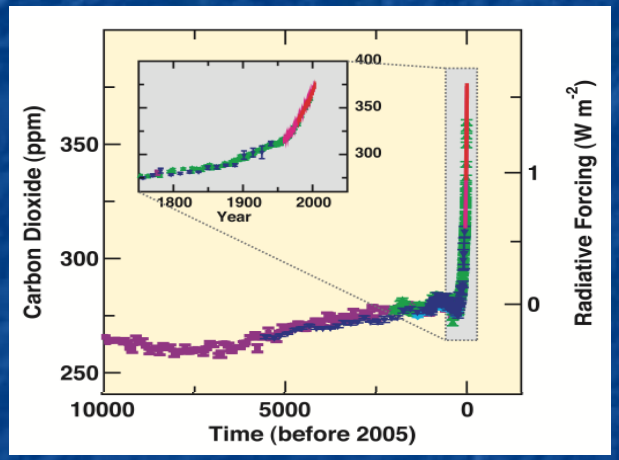


IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 6):

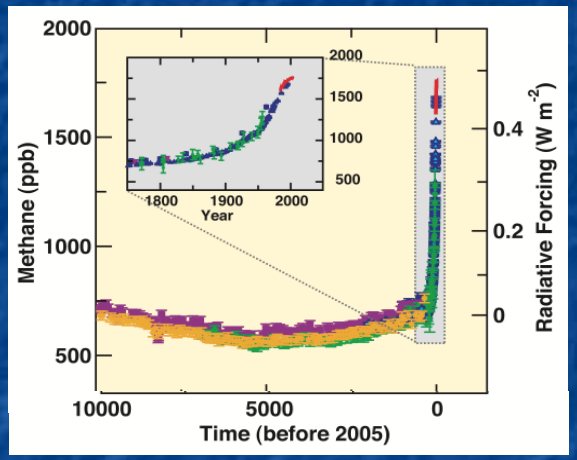
Long term data on three atmospheric greenhouse gases:

Main figures: 8000 BC to 2005 AD Inset figures: 1750-2005 AD

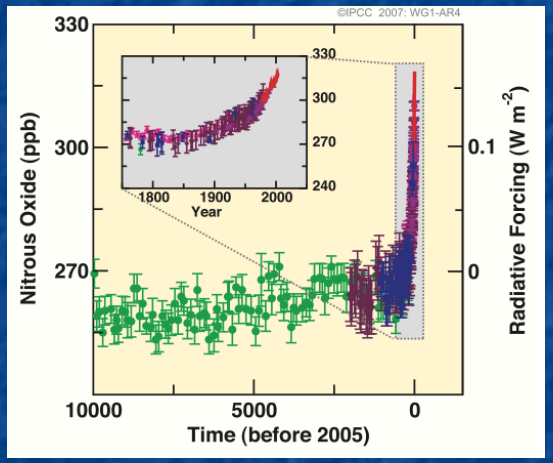
CO_2:



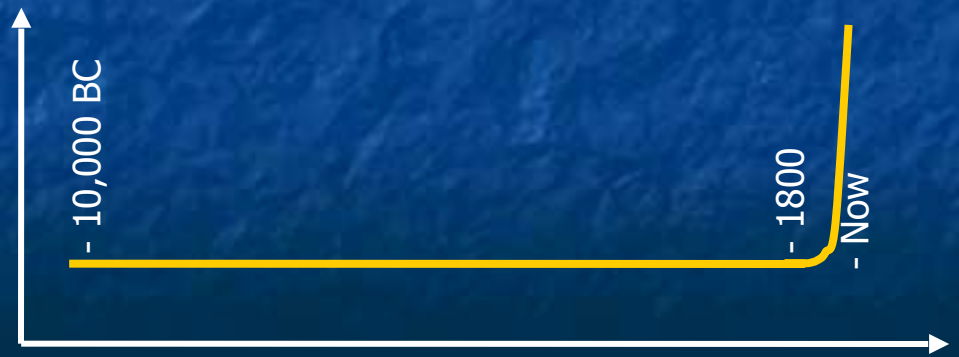
CH_4:



NO_2:



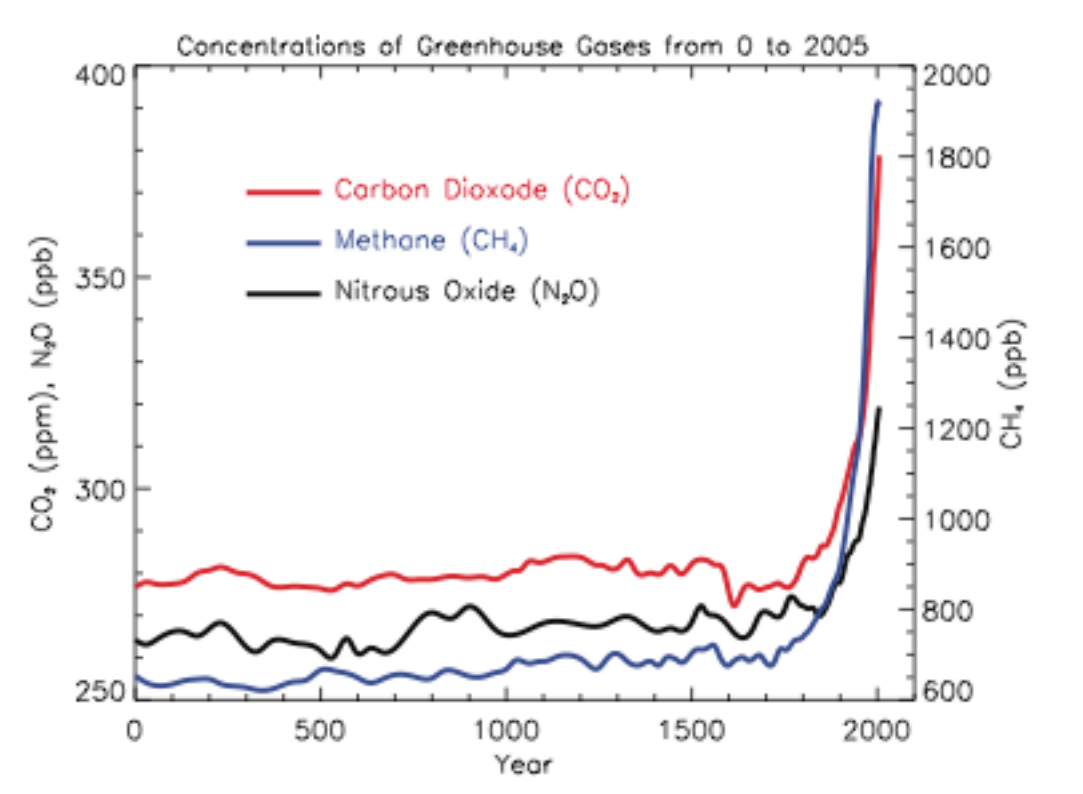
Note recurring pattern:



Source: IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 3)

Or, expanding greenhouse gas data for last two millennia:

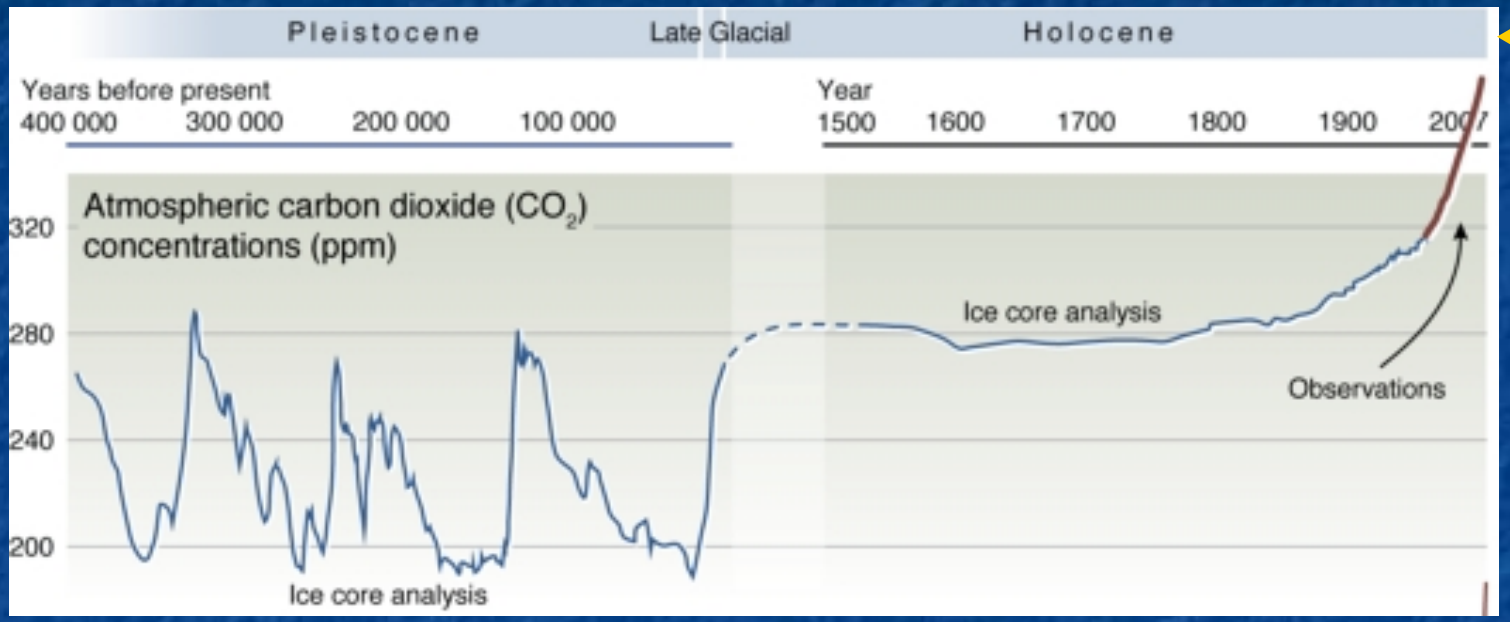
From the IPCC Fourth Assessment Report (2007):



Source: IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 135)

Or CO_2 back to a half million years ago:

From the United Nations Environmental Project / GRID Arendal:



Clearly indicating (at least to me) that:

Although atmospheric CO_2 concentration **has** indeed varied a lot

Especially during ice age cycles at left

Rise in last ~100 years is unprecedented

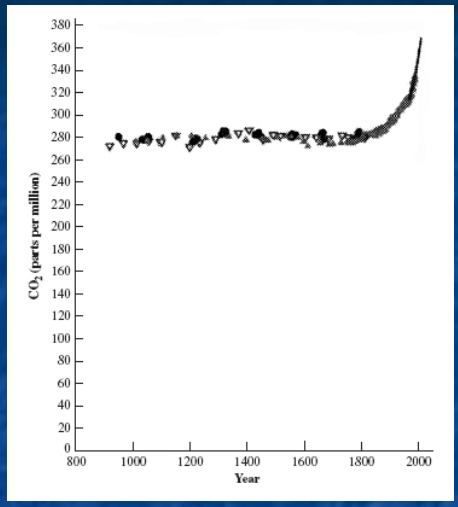
http://www.grida.no/graphicslib/detail/historical-trends-in-carbon-dioxide-concentrations-and-temperature-on-a-geological-and-recent-time-scale_a210

CO_2 data's "signal to noise ratio" and causality:

Raw CO_2 data for last 1200 years:

Upward trend is huge and >> data variation

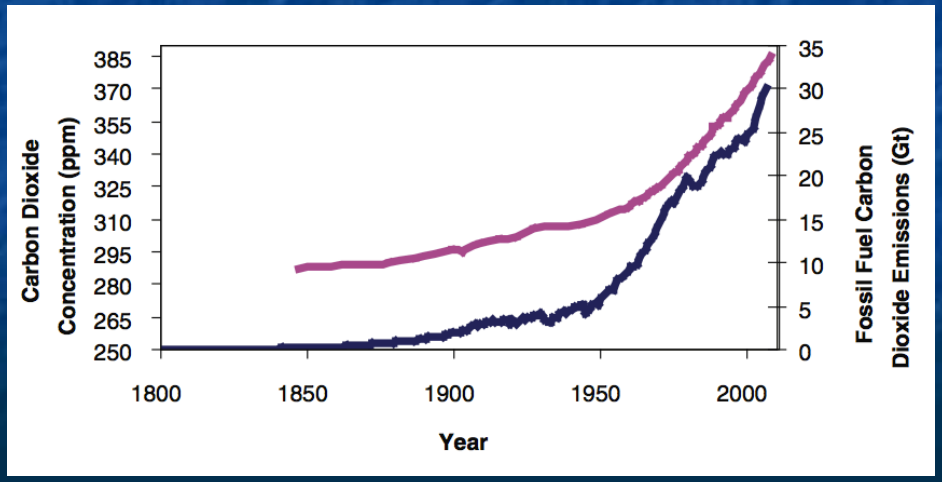
(**much** less ambiguous than temperature data)



"Physics for Future Presidents"

Sharp modern rise has no historical precedent

But possible correlation with industrial revolution (and fossil fuels) is clear



US National Research Council

(National Academy of Science &

National Academy of Engineering)

"America's Climate Choices" – Figure 2.2 - National Academies Press (2011)

CO_2 bottom lines:

Data above are so clear and so unprecedented

that I know of no group of reputable scientists

who, however skeptical, do not now accept:

- Reality of recent CO_2 atmospheric gas spike

- Uniqueness of this CO_2 atmospheric gas spike

- **Human role** in driving CO_2 atmospheric gas spike

HOWEVER don't confuse this **CO_2 data** with (noisier) **temperature data**

Also, while we know that greenhouse CO_2 should have a warming effect

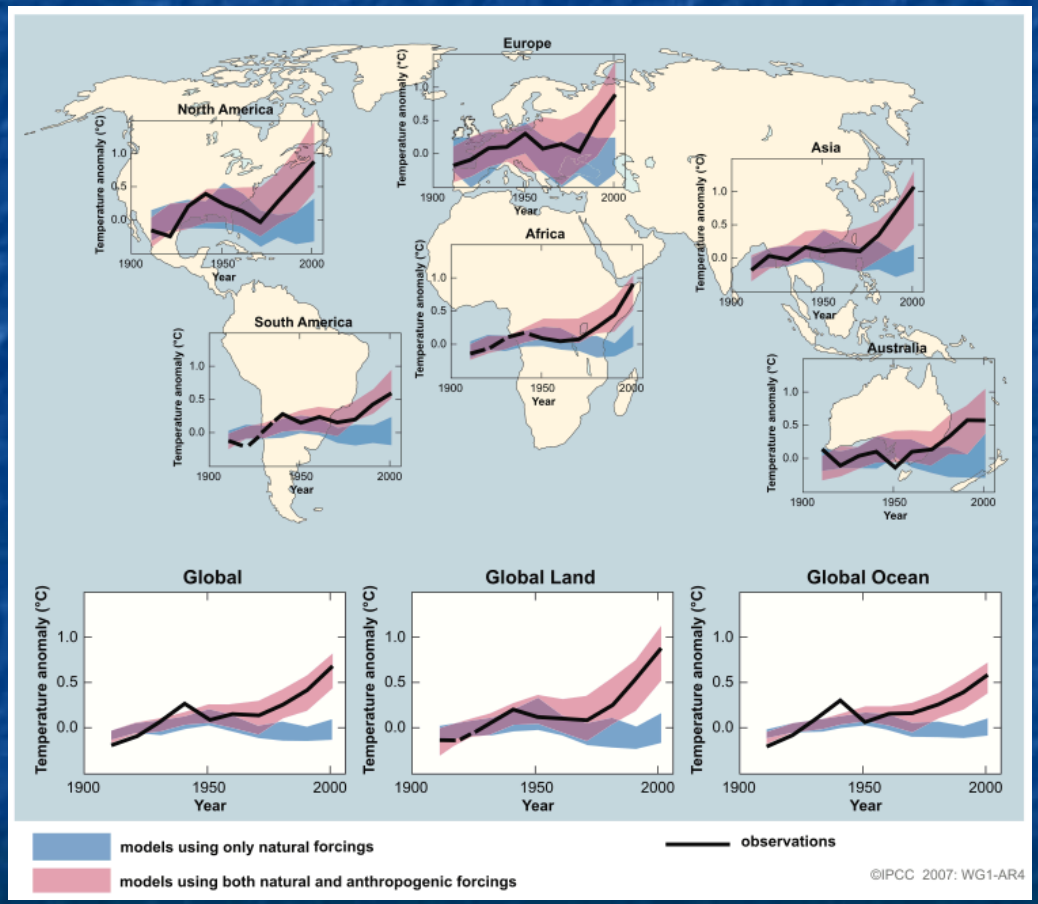
Above (alone) does not prove CO_2 **drives** global warming

(We need still **more** evidence!)

*But now returning to more ambiguous **temperature** data:*

2007 IPCC data for last 200 years = Black lines

(for the moment, disregard colored bands = models)

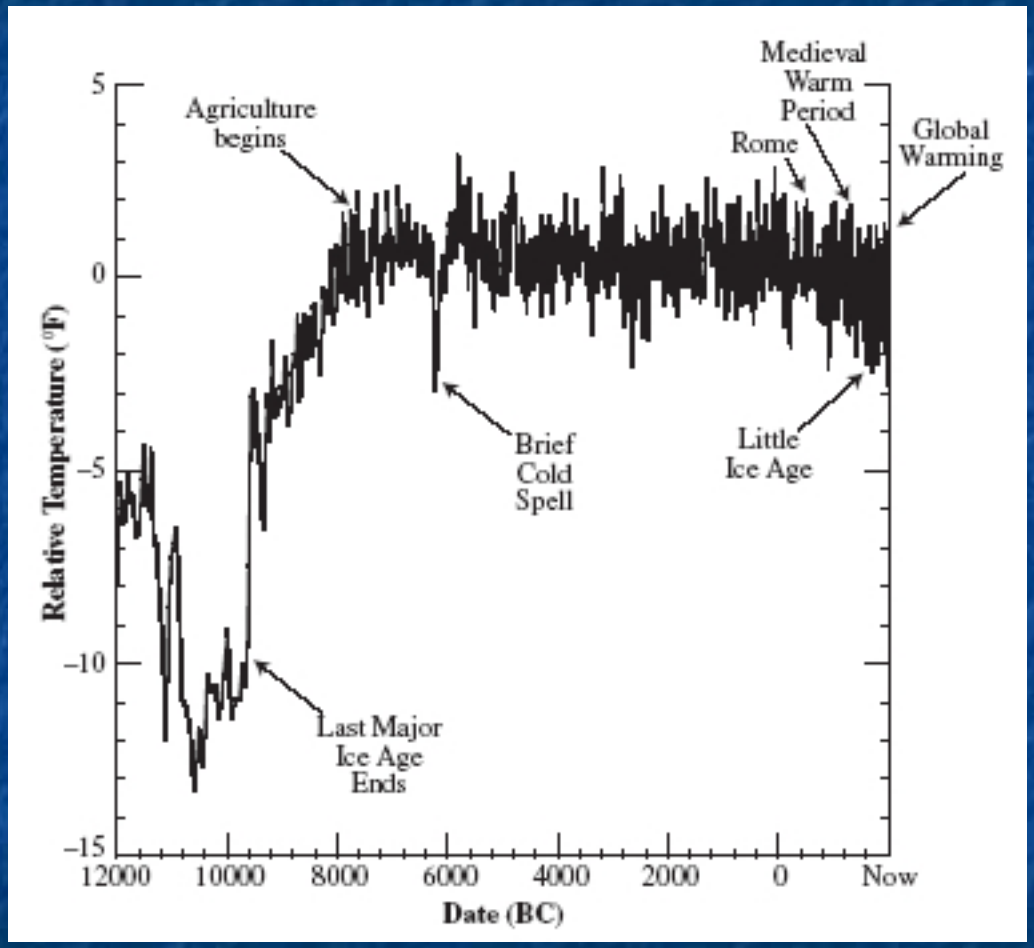


Now documented **worldwide:** Strong upward trends over the last 200 years

IPCC Fourth Assessment Report – WG1 – 2007 (p. 11)

Or, temperature data looking back 12,000 years:

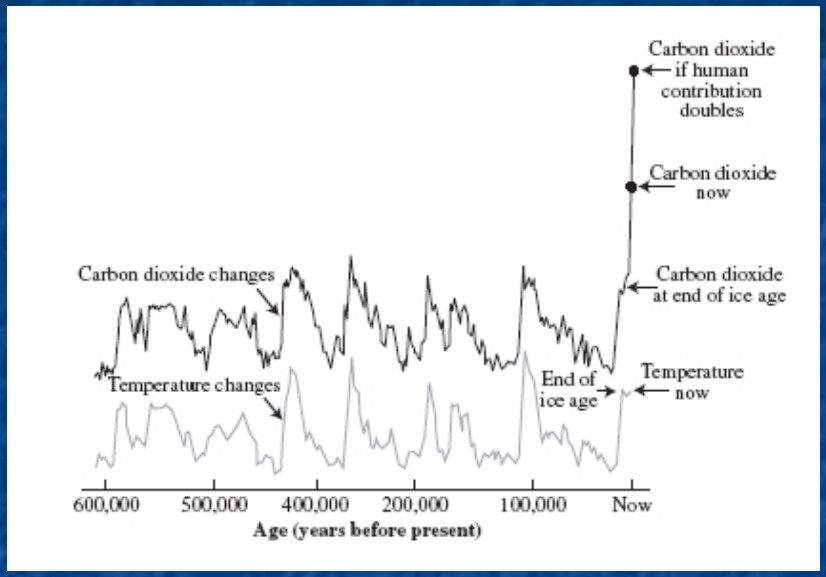
From Muller's "Physics for Future Presidents:"



Last full ice age at left, mini-ice ages / oscillations later

Or, temperature data looking back 600,000 years:

This plot, from Muller's book and Gore's movie, adds in CO_2 data:



Source: Richard Muller's "Physics for Future Presidents"

Gore and others point out this correlation of CO_2 with temperature

But Muller reminds us that correlation does NOT tell which one causes which

Or if something else could be causing **both** of these to change

Wait a second! CO_2 is a greenhouse gas

Doesn't that, by definition, mean that **it** causes warming?

CO_2 as a cause AND effect of warming:

Yes, CO2 is a strongly infrared-radiation-absorbing gas

Which means that it will absorb incoming IR light from the sun

AND absorb heat that earth would have re-released to space

So atmospheric CO_2 is a CAUSE of warming

But microbial activity also releases CO_2 from earth surface soils

and warming of soils increases their activity:

"Soils store about four times as much carbon as plant biomass, and soil microbial respiration releases about 60 petagrams of carbon per year to the atmosphere as carbon dioxide. Short-term experiments have shown that soil microbial respiration increases exponentially with temperature[1]"

So atmospheric CO_2 is an EFFECT of warming

[1]Source: Temperature sensitivity of soil respiration rates enhanced by microbial community response, Karhu et al., Nature 513, pp. 81-84 (September 2014)

Raising a very scary possibility:

Warming and CO_2 each cause the other = Positive feedback

That is, scenarios like this are then fed:

little more CO_2 => little warmer => lot more CO_2 => lot warmer . . .

Action => Reaction => Stronger Action => Stronger reaction . . .

This leads to fears about a possible "TIPPING POINT"

Where, at some point, this feedback loop might become so self-reinforcing

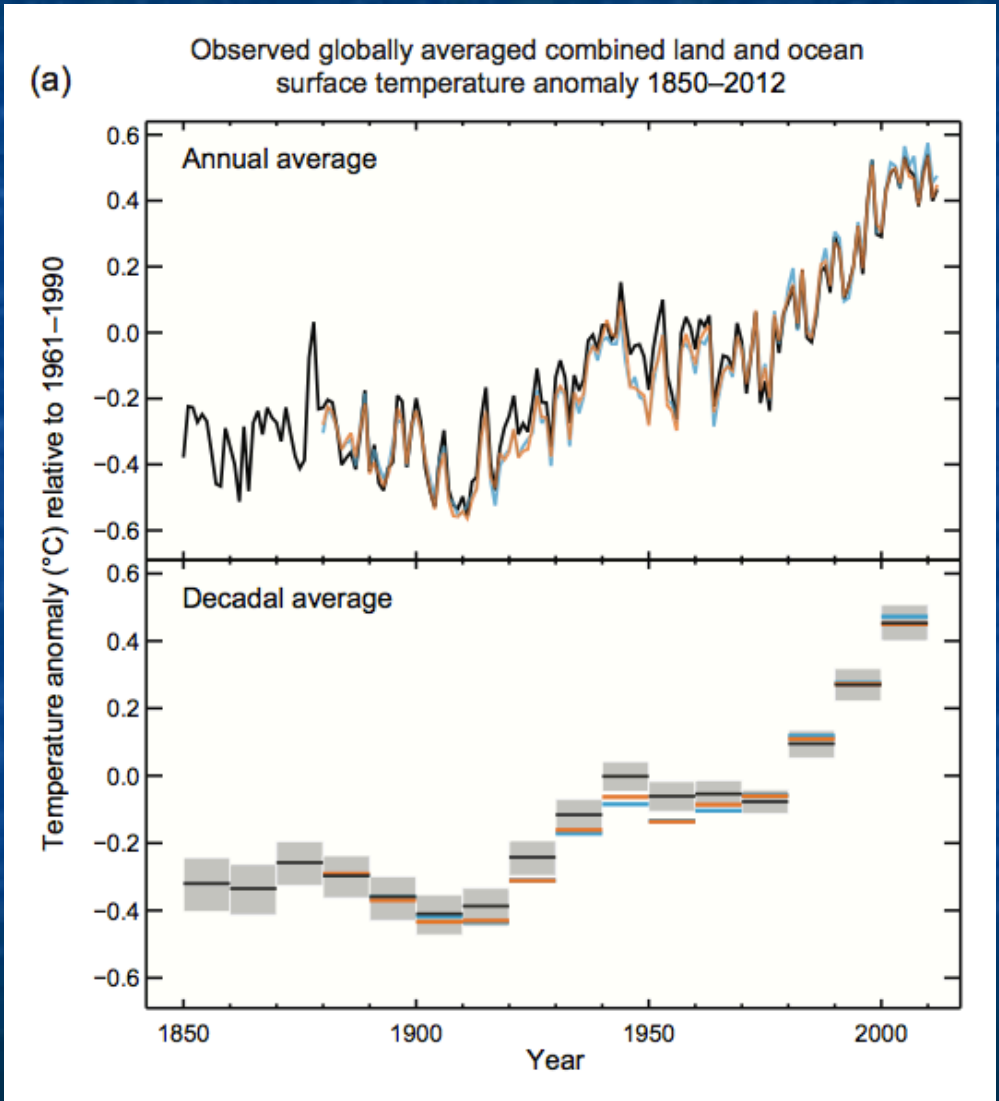
That, even if we drastically cut OUR CO2 emissions,

its growth might become unstoppable

Suggesting we'd better learn more about this phenomenon NOW!

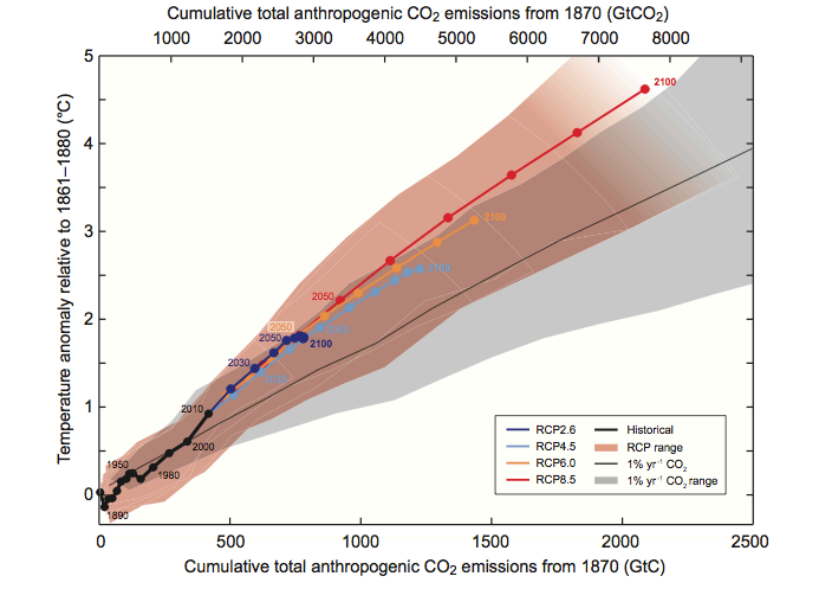
So here is IPCC's much more careful look at a possible correlation

200 years of worldwide TEMPERATURE data:



IPCC Fifth Assessment Report – WG1 – 2013 (p. 6)

*Correlation of that temperature "anomaly" with **man-made** CO_2*



IPCC Fifth Assessment Report – WG1 - 2013 (p. 128)

Note that this is a plot of ΔT vs ΔCO_2 (and not, as earlier, one or other vs. time)

But the data set does include values 1870 to present

More thorough correlation, here with only man-made CO_2, looks excellent

"OK, what if temperature and CO_2 DO track? Are things really getting out of hand?

For instance, I've read about a recent (unexpected) PAUSE in global warming"

"Global Warming Pause"

Below, expanded, is earth surface temperature data from last 65 years

"BerkeleyEarth.org" has fitted this, over 10-15 years spans, by straight lines

Six segments show increases, three segments show decrease

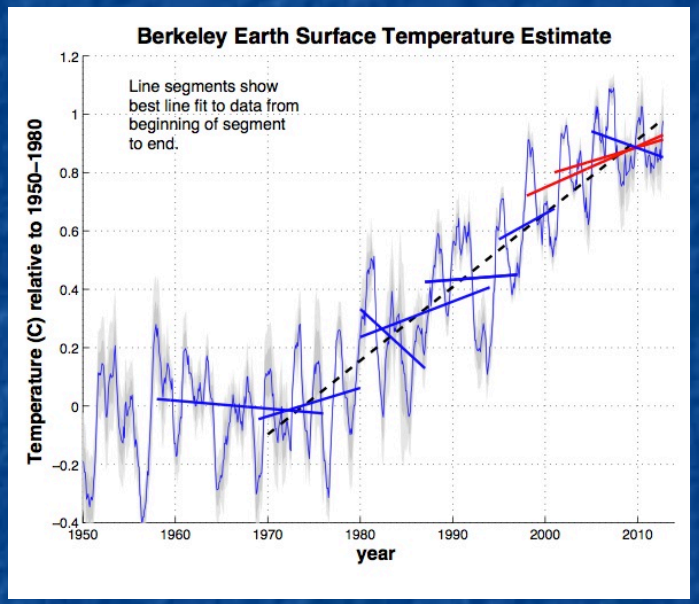
Much touted "Pause" refers to final short segment

Is this significant? No, at least not yet

Not given the large overall variations

Not unless pause continues a lot longer

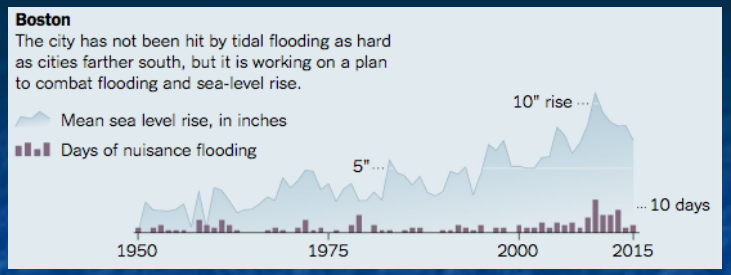
At this point "pause" = statistical variation

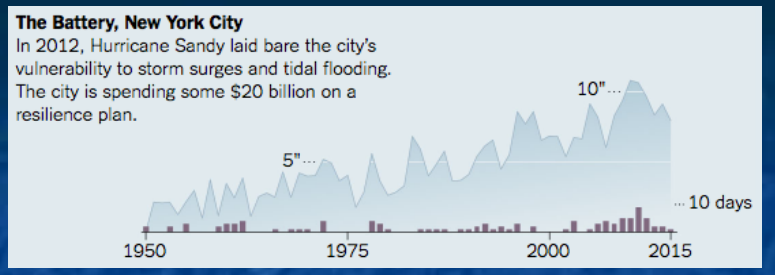


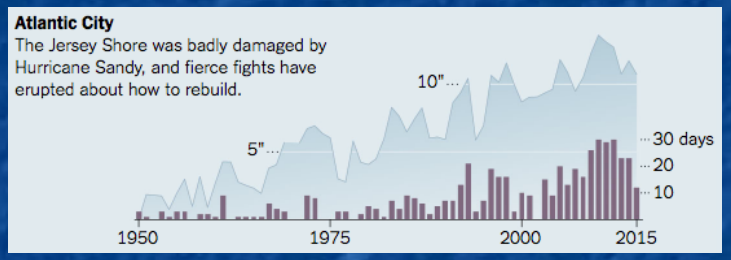
Source: BerkeleyEarth.org

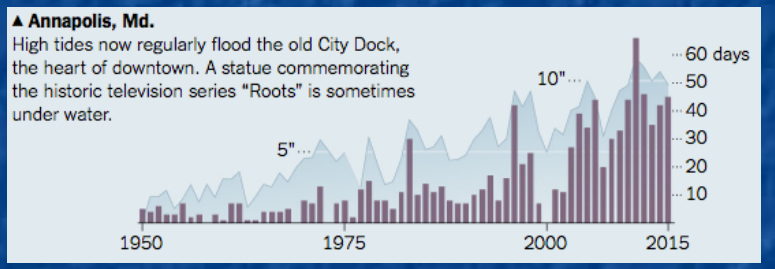
And when data are averaged enough to quiet variation, trend is clearly upward

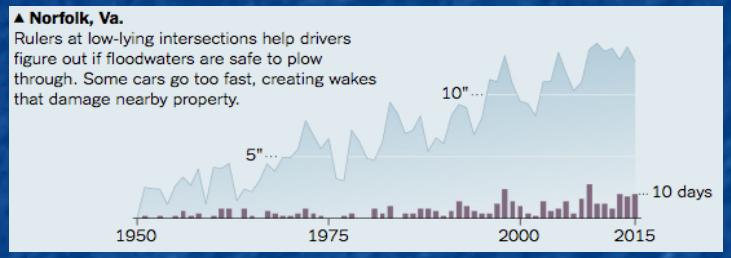
NEW Correlations: NYT (9/2016) - "Sharp Increase in 'Sunny Day' Flooding:"

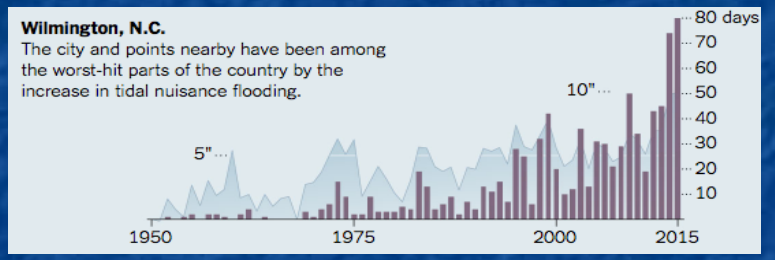


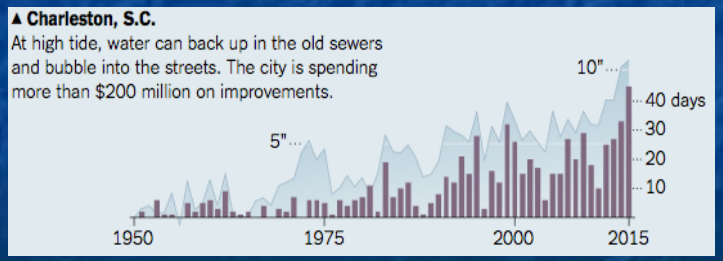


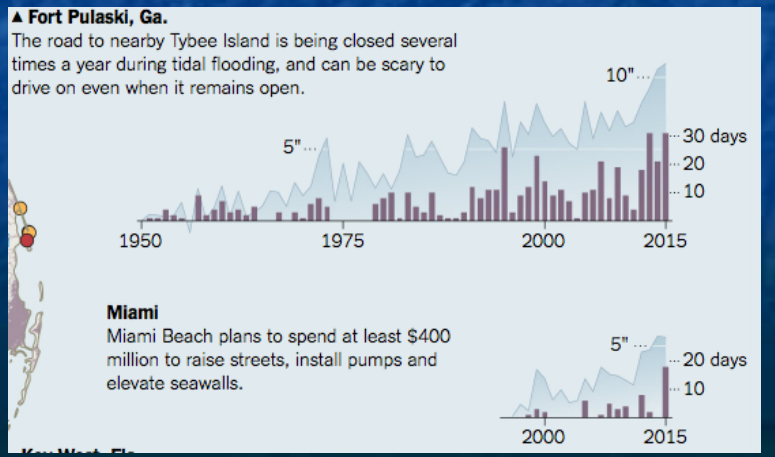












"Mean sea level rise is relative to 1950, or 1996 for Virginia Key, Miami.

Sources: National Oceanic and Atmospheric Administration; National Ocean Service; William Sweet et al., "Sea Level Rise and Nuisance Flood Frequency Changes Around the United States"

FIGURE: http://www.nytimes.com/interactive/2016/09/04/science/global-warming-increases-nuisance-flooding.html

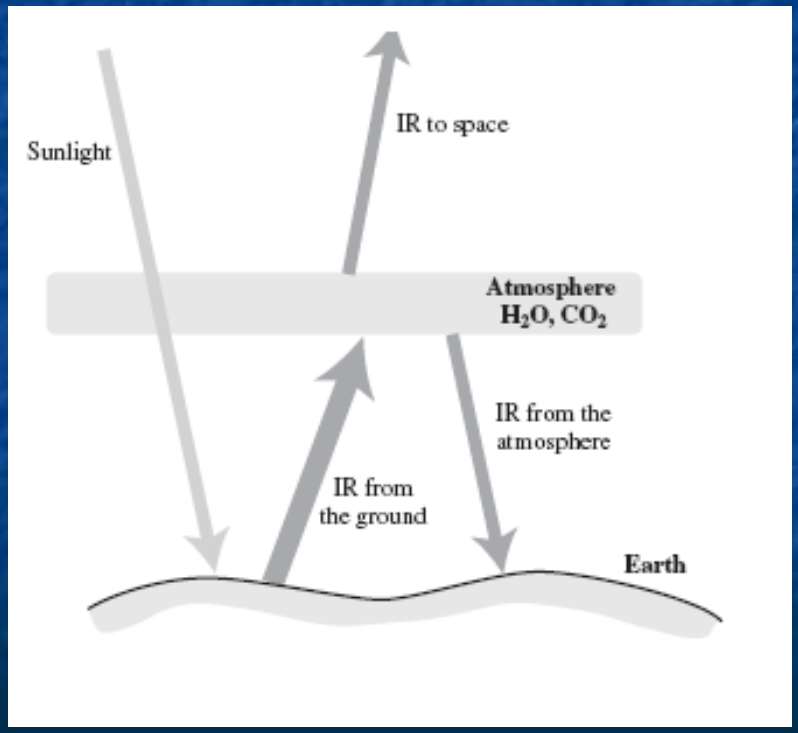
ARTICLE: http://www.nytimes.com/2016/09/04/science/flooding-of-coast-caused-by-global-warming-has-already-begun.html?_r=0

But ***predicting*** *climate changes would be a lot more convincing!*

And so on to the topic of: **Building Climatological Models**

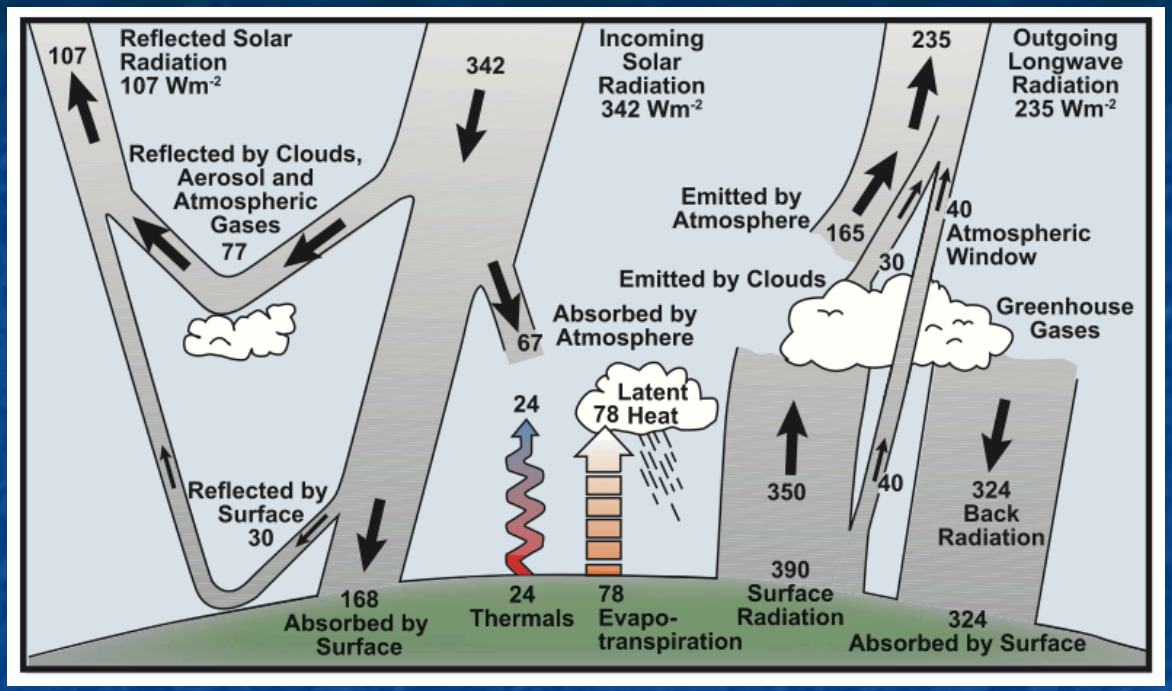
A very basic representation of the effect of greenhouse gases:

Sunlight in => Heats Ground => IR radiation upward => Some bounced back



From Richard Muller's "Physics for Future Presidents"

But there is a whole lot more going on in the atmosphere:



And one of the hardest things to model is the effect of water vapor

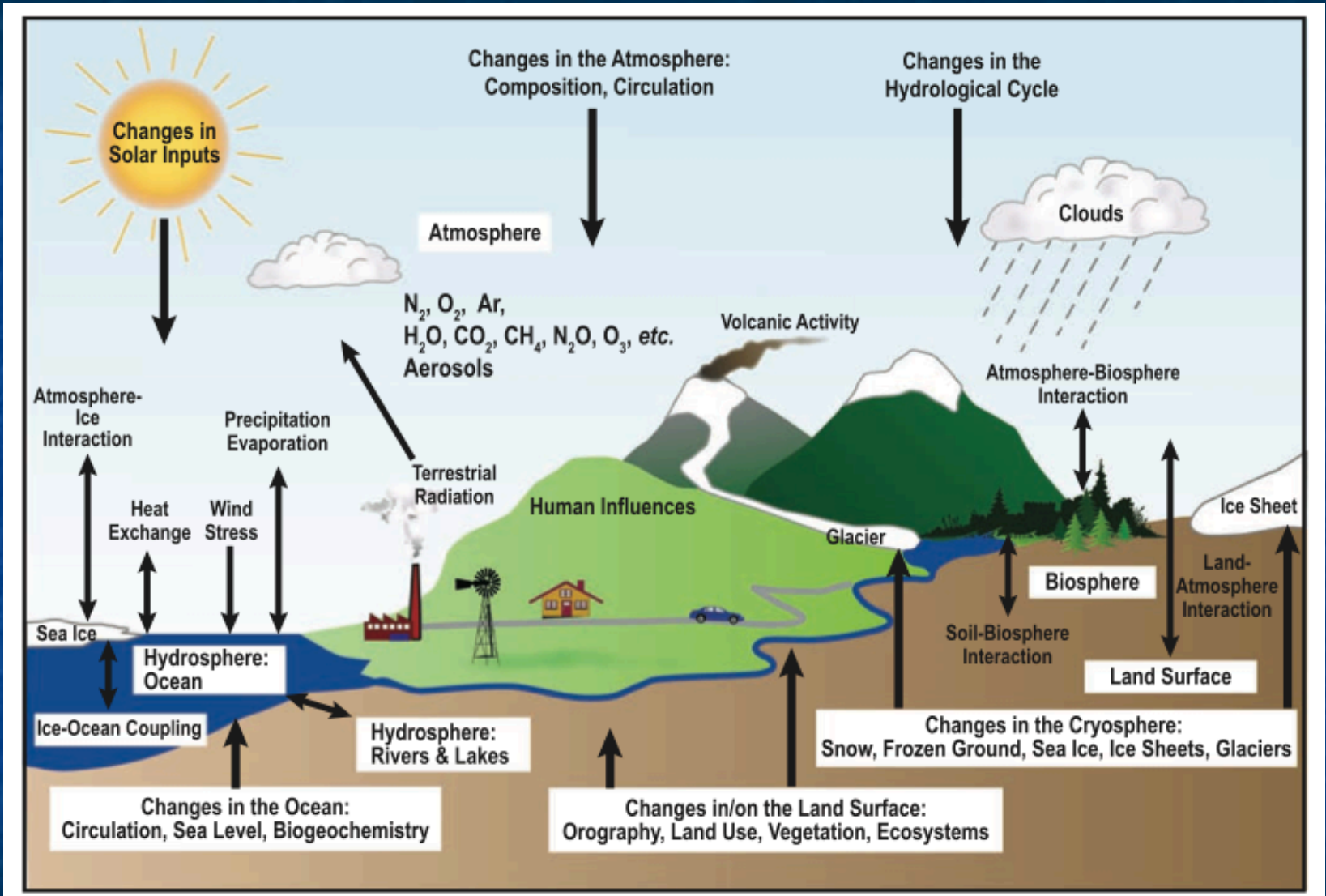
As a **vapor** it is the **strongest** greenhouse gas => heat trapping => **Warming**

But as **clouds** it reflects back incoming sunlight => **Cooling**

AND <u>all sorts of things</u> influence its conversion vapor ⇔ clouds

IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 96)

Here are some of those other "things" that must be taken into account:



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 104)

Taking climate model development in smaller steps:

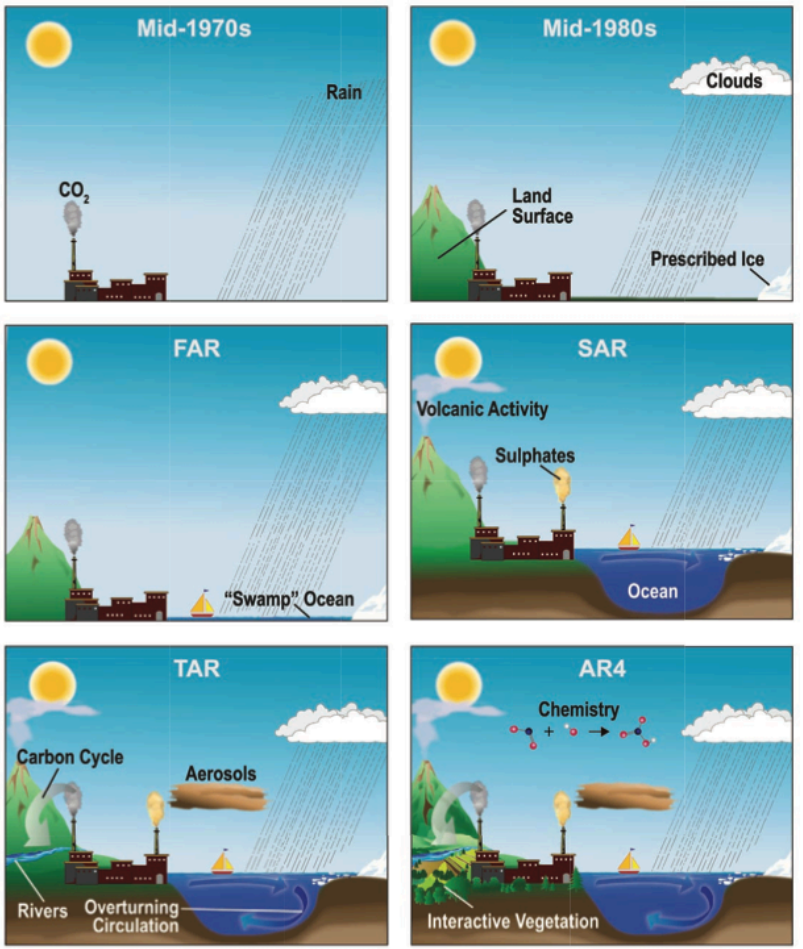


Figure 1.2. *The complexity of climate models has increased over the last few decades. The additional physics incorporated in the models are shown pictorially by the different features of the modelled world.*

Acronyms do **not** refer to science involved:

FAR: First Assessment Report (1990)

SAR: Second Assessment Report (1996)

TAR: Third Assessment Report (2001)

AR4: Fourth Assessment Report (2007)

For a Nobel Prize winning UN chartered body, IPCC could sure TRY a lot harder to be understood!

Confirmed: Nature Climate Change, March 2016 [1]

Linguistic Analysis of IPCC Summaries for Policymakers and Associated Coverage

"IPCC (reports) clearly stand out in terms of low readability, which has remained relatively constant despite the IPCC's efforts to consolidate and readjust its communications policy. In contrast, scientific and quality newspaper coverage has become increasingly readable and emotive."

Figure: IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 99)

1) http://www.nature.com/nclimate/journal/v6/n3/full/nclimate2824.html

BREAKING NEWS:

(Relevant news articles I've not yet fully researched and/or verified)

The Real Reason Scientists Downplay the Risks of Climate Change

Author's preview of their new book:

"Discerning Experts: The Practices of Scientific Assessment"

(as published in The Guardian, October 2019) [1]

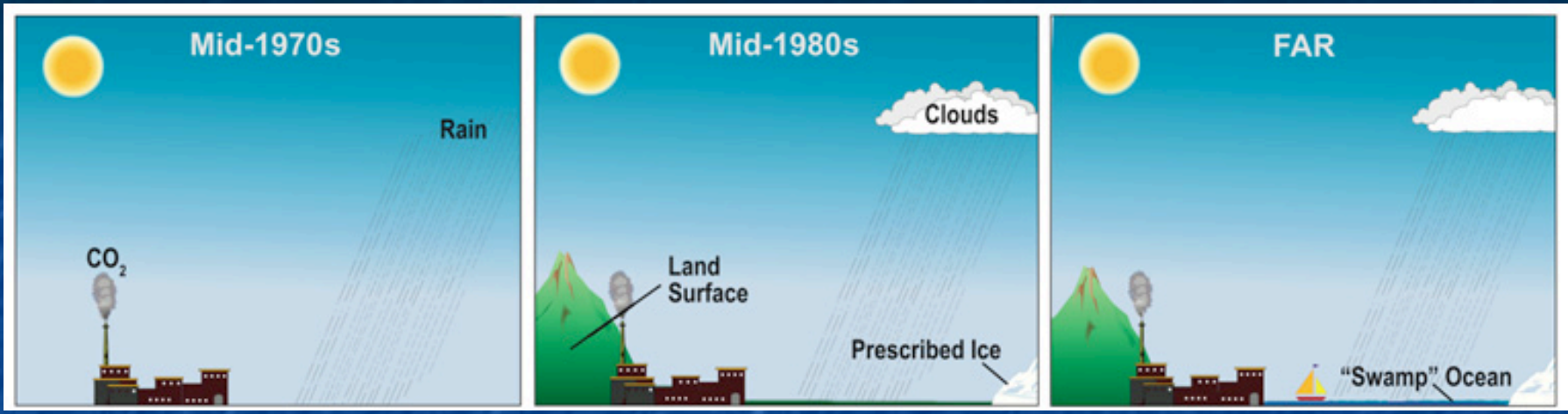
"While climate skeptics and deniers often accuse scientists of exaggerating the threats associated with the climate crisis, the available evidence suggests the opposite."

"Consider a case in which most scientists think that the correct answer to a question is in the range one to 10, but some believe that it could be as high as 100. In this case, everyone will agree that it is at least one to 10, but not everyone will agree that it could be as high as 100. Therefore, the area of agreement is one to 10, and this will be reported as the consensus view."

"To scientists, we suggest that you should not view consensus as a goal. Consensus is an emergent property, something that may come forth as the result of scientific work, discussion and debate. When that occurs, it is important to articulate the consensus as clearly and specifically as possible. But where there are substantive differences of opinion, they should be acknowledged and the reasons for them explained."

1) https://www.theguardian.com/commentisfree/2019/oct/25/the-real-reason-some-scientists-downplay-the-risks-of-climate-change?CMP=Share_iOSApp_Other

Ignoring acronyms and instead focusing on dates:



Models of 1970's and 1980's were REALLY crude!

Initial focus was almost entirely on the atmosphere

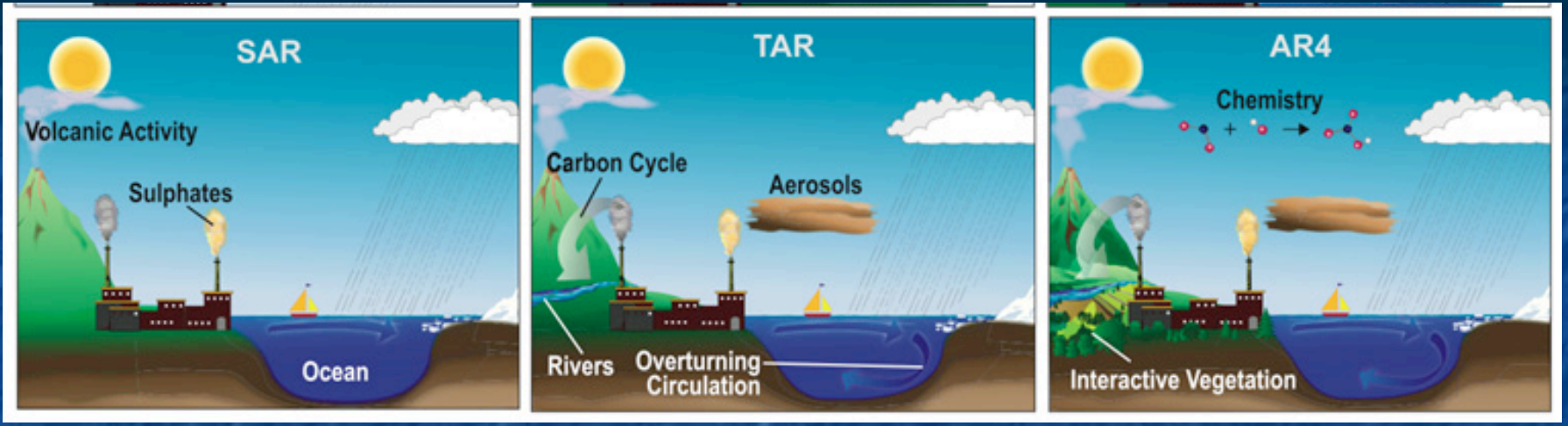
Starting with ONLY the effect of CO_2 (and not even clouds!)

Which WAS sort of natural given question of greenhouse effects

1980's: Atmosphere + clouds + simple land topography and ice masses

~1990: Oceans finally introduced but as shallow uniform "swamp" seas

Moving to developments 1990 to 2007:



1996 (SAR): Addition of volcanoes, other gases, and deep oceans!

2001 (TAR): More gases, deep ocean currents and flows

2007 (AR4): Vegetation as something more than green ground

That is, as something that actually absorbed CO_2 and emitted O_2

Plus atmospheric photochemical reactions / conversions (e.g., "smog")

I.E., **finally** accounting for most things we **knew** would be important!

In same period there was HUGE improvement in spatial resolution

Early spatial resolution was **awful**!

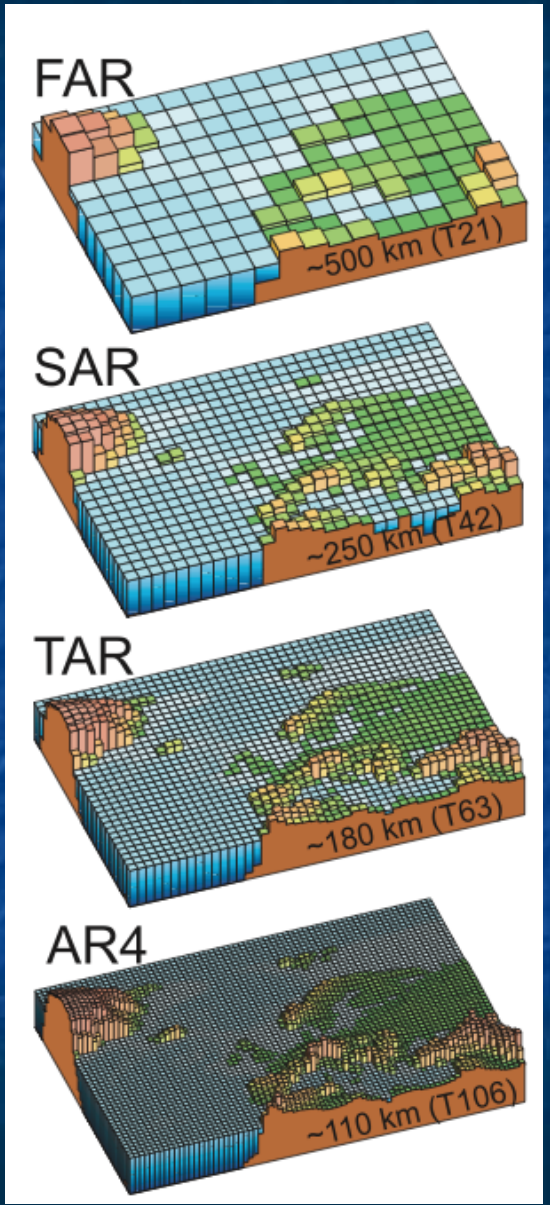
Can you even recognize 1st model's location?

Averaging can obliterate localized effects

Averaged Mtn. + plain ≠ net effect of each!

Only in TAR (2001) is Europe easily recognized!

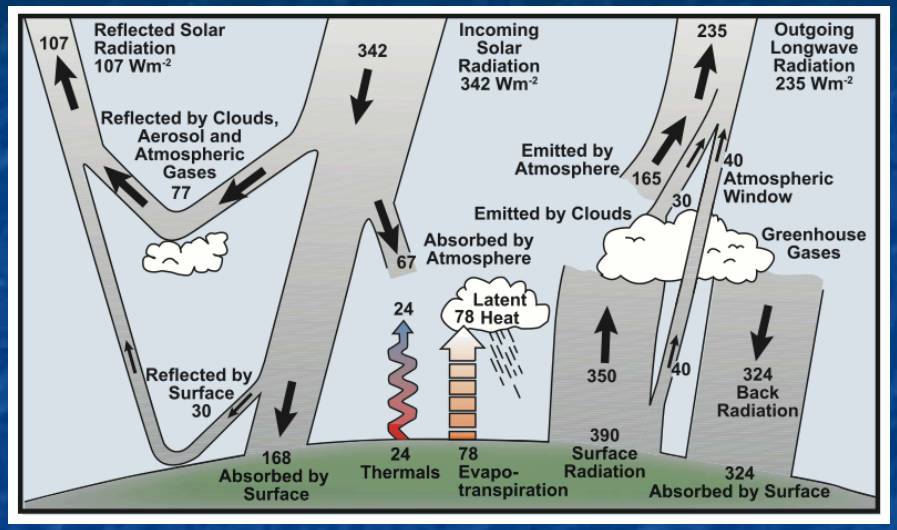
Only in AR4 (2007) is its diversity well represented!



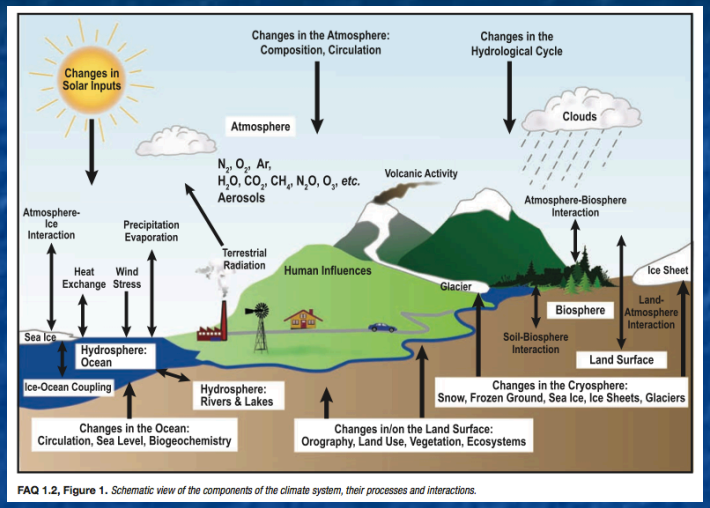
IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 113)

Why was development so slow? It's a huge problem!

Accounting for all these atmospheric effects:

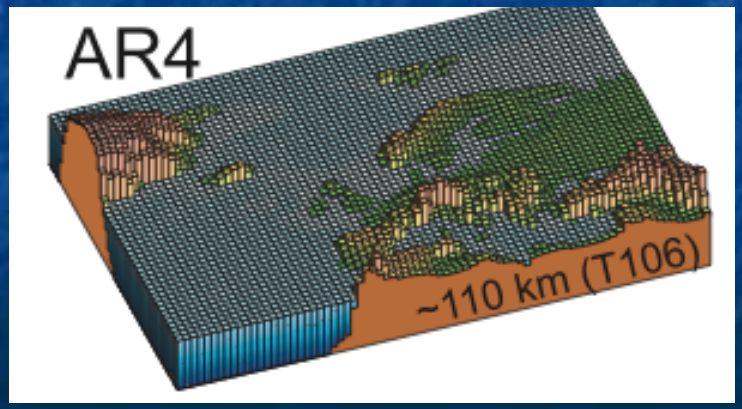


And all these ground effects:



FAQ 1.2, Figure 1. *Schematic view of the components of the climate system, their processes and interactions.*

And doing so, with at least this resolution, over the **entire** world



Scientific challenges were HUGE!

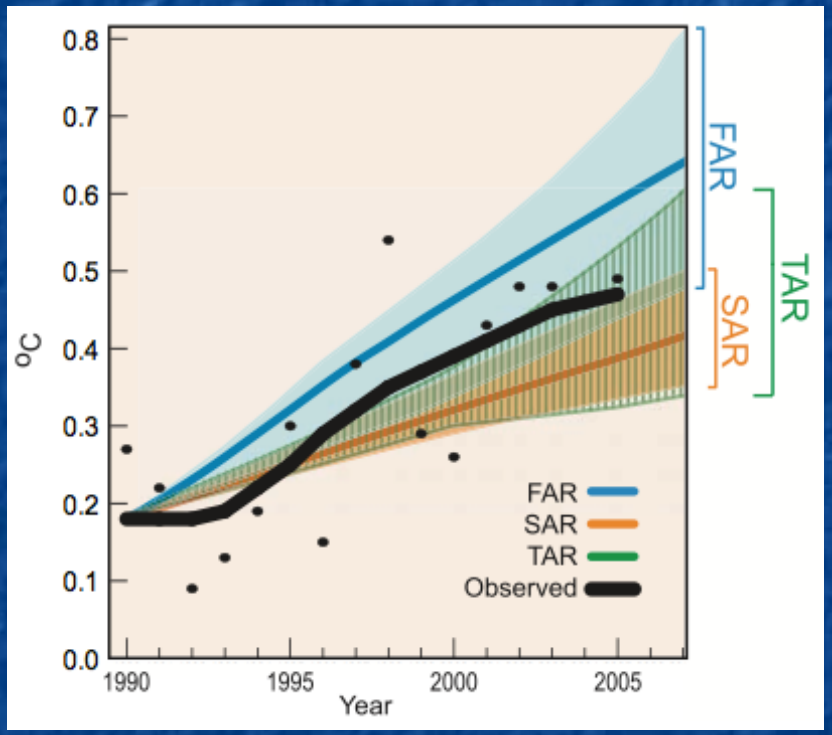
Computational challenges were huge!

OK, so the models now seem ~ complete, what do they say?

Looking **backwards,** modeling temperature evolution 1990 to present**:**

Models track observed temperature trend

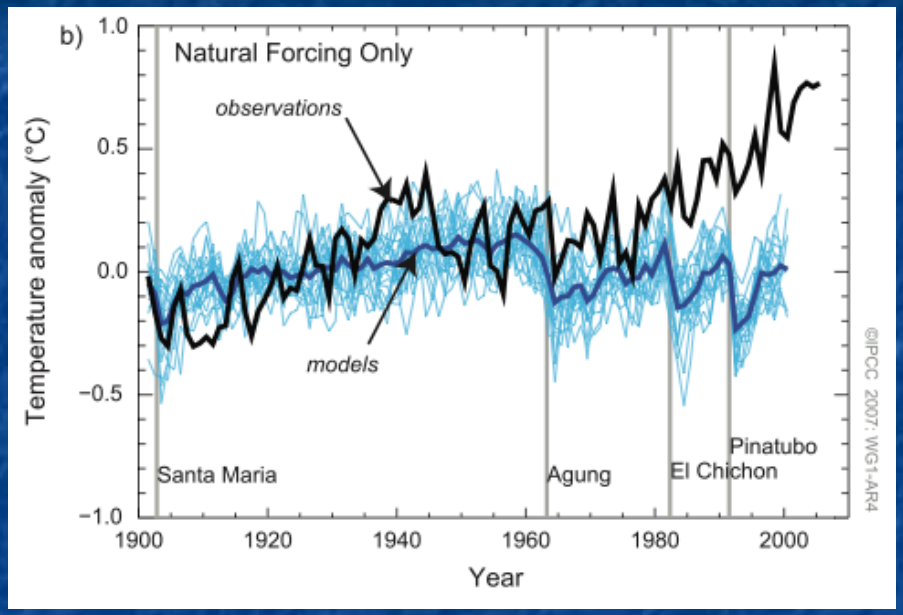
With later TAR perhaps most accurate



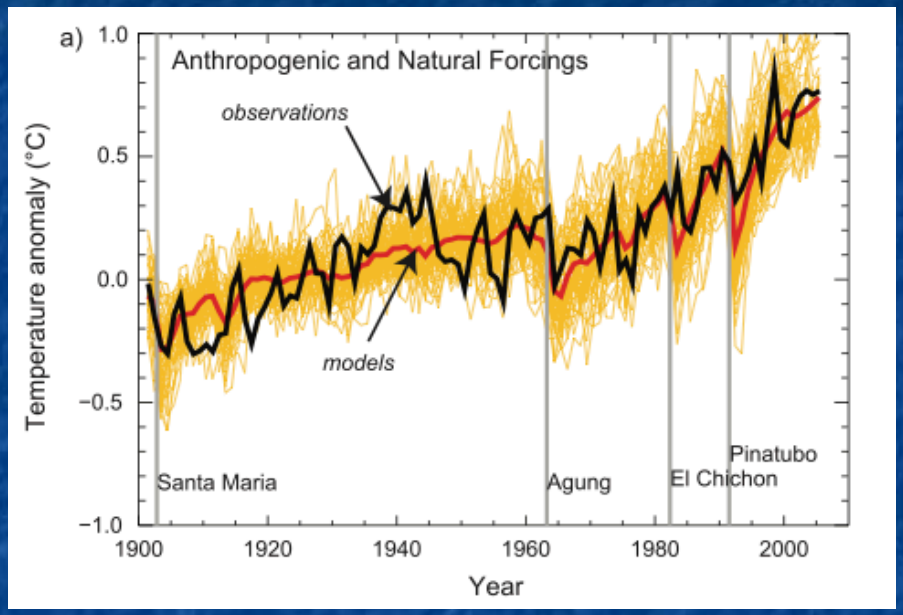
IPCC Fourth Assessment Report – Working Group 1 – 2007 (p .98):

OR modeling recent temperature with or without manmade effects

Natural effects only:



Adding in manmade effects:



Above modeling seems to substantiate man's role

But all such models contain a HUGE number of "adjustable parameters"

And **any scientist** knows that fitting data to an adjustable model is easy

Even if you do your damndest to **avoid** tweaking results into agreement

IPCC Fourth Assessment Report – Working Group 1 – 2007 (p .62)

The true scientific test is PREDICTION!

Further, in this case, we very much want to predict effects of OUR actions

In this field those are called "**forcings**"

As in "driven by man-made forces"

vs. "driven by natural forces"

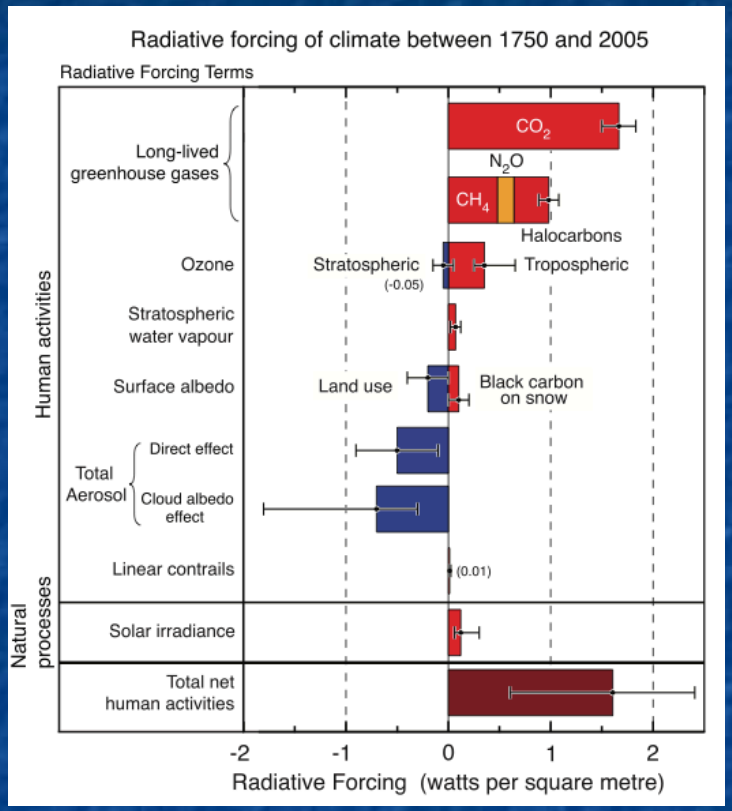
Here is a chart of possible "forcings"

Divided into manmade (top)

And "natural" (low-middle band)

Some of which drive warming (red)

Some of which drive cooling (blue)



IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 136)

Bars = **PREDICTIONS** of the magnitudes of each forcing

Which are given in units of Δ Heat absorbed by earth / meter^2 / time

Here are time-integrated forcings (with sub-divisions):

Biggest "warmers" are:

- LONG LIVED greenhouse gases

  i.e., CO_2, N_2O, CH_4

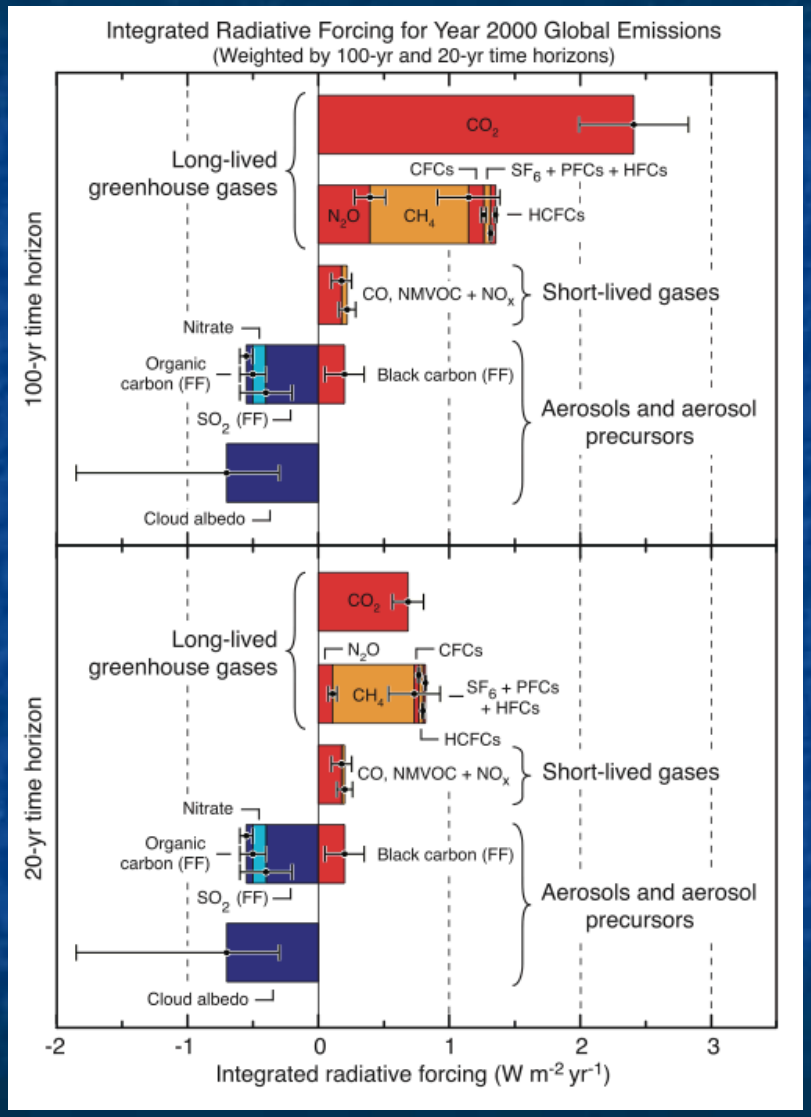
Biggest "coolers" are:

- Cloud cover

  Why modeling H_2O vapor ⇔ Clouds

  is so CRITICAL for correct results!

- SO_2, nitrates . . .



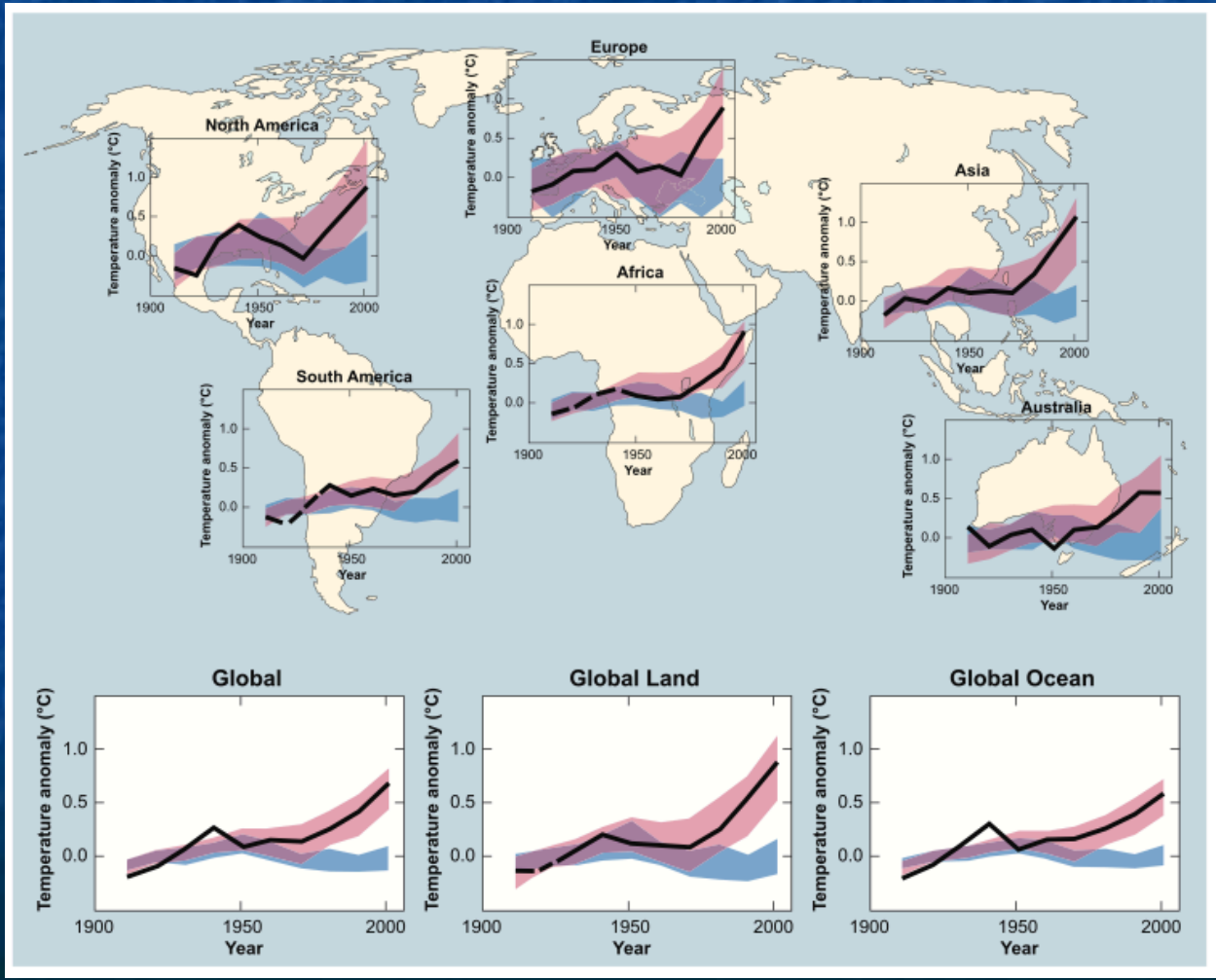
IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 206):

Putting this all together – NOW look at the colored bands!

Black lines = Measured temperatures

Blue bands = Models incorporating only natural forcings

Pink bands = Models adding in man-made forcings

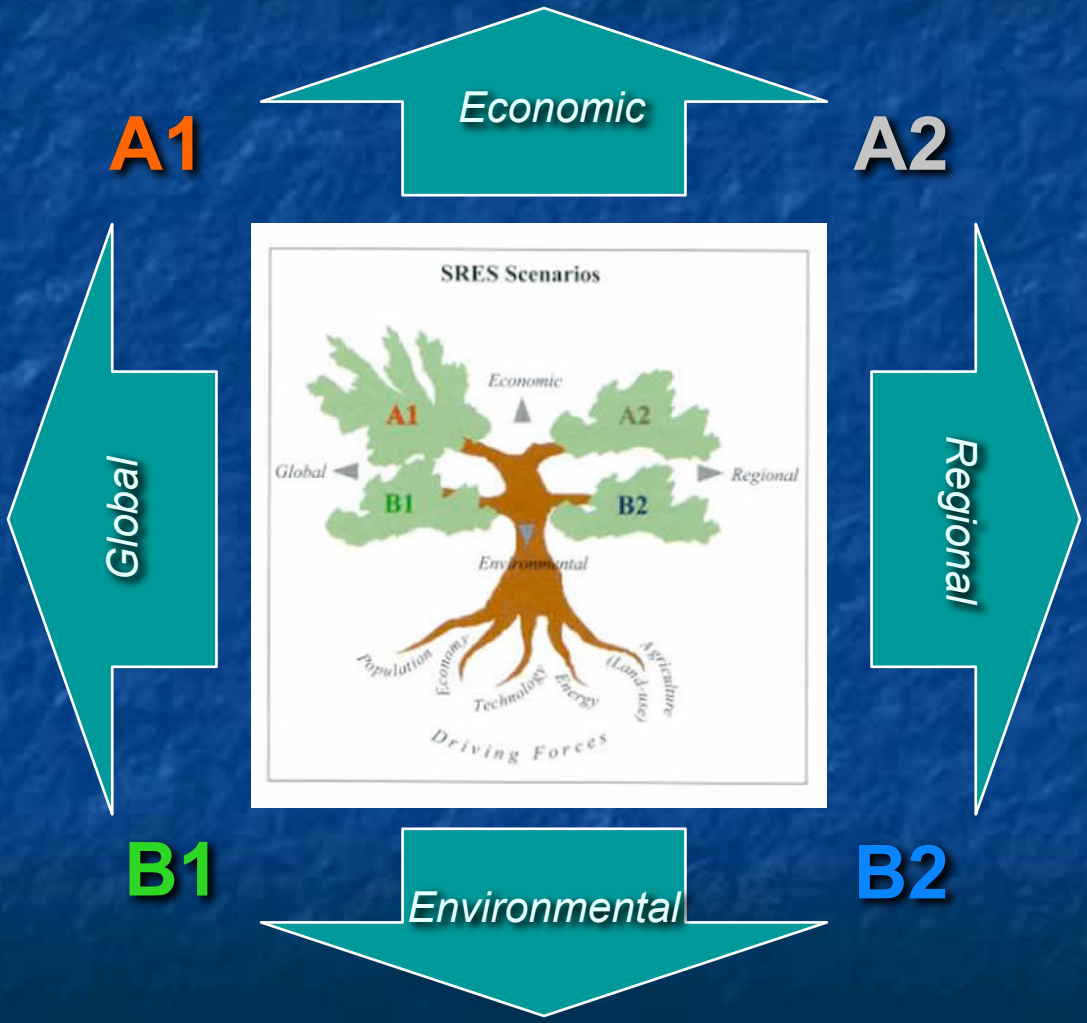


According to these models, man's actions make the critical difference!

IPCC Fourth Assessment Report - WG1 – 2007 (p. 11)

Or looking forward but with different things driving human actions

What IPCC labels "SRES scenarios" (special report on emissions scenarios)



Center: IPCC's http://sedac.ipcc-data.org/ddc/sres/

Surrounding: My attempt at clarification

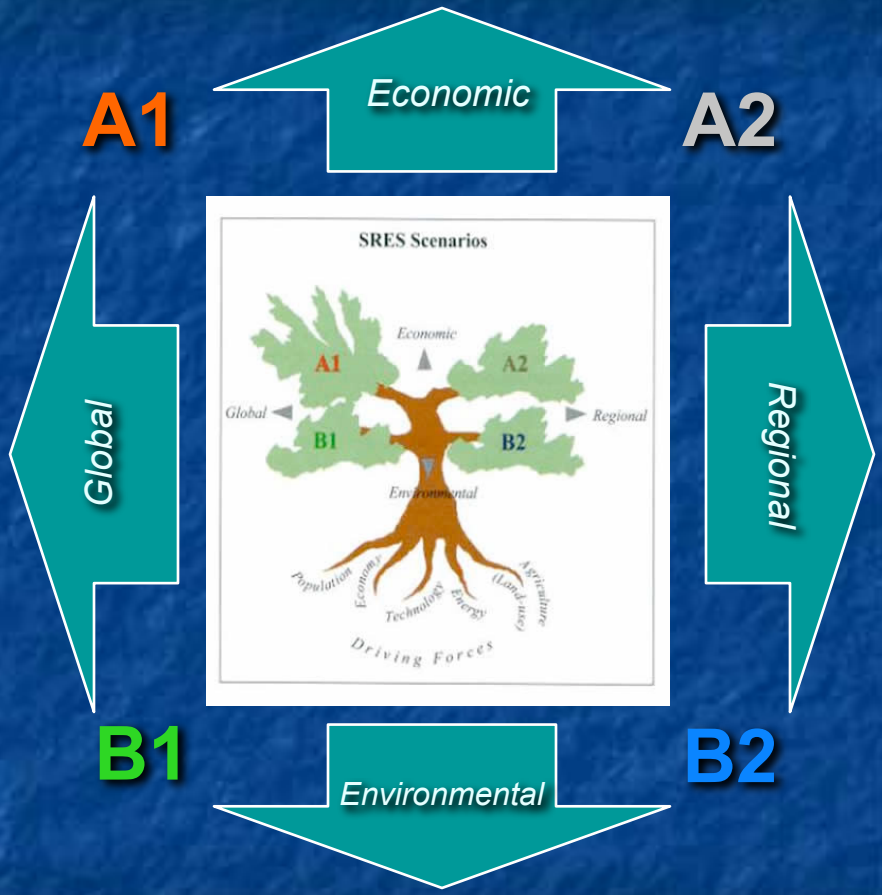
Further translating out of IPCC Speak:

A1 = Coordinated **global** actions driven by **economic** development

A2 = Uncoordinated **regional** actions driven by **economic** development

B1 = Coordinated **global** actions driven by **environmental** concerns

B2 = Uncoordinated **regional** actions driven by **environmental** concerns



http://sedac.ipcc-data.org/ddc/sres/

Or if you want the details:

A1: The A1 scenarios are of a more integrated world. The A1 family of scenarios is characterized by:
Rapid economic growth.
A global population that reaches 9 billion in 2050 and then gradually declines.
The quick spread of new and efficient technologies.
A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide.
There are subsets to the A1 family based on their technological emphasis:
A1FI - An emphasis on fossil-fuels (Fossil Intensive).
A1B - A balanced emphasis on all energy sources.
A1T - Emphasis on non-fossil energy sources.

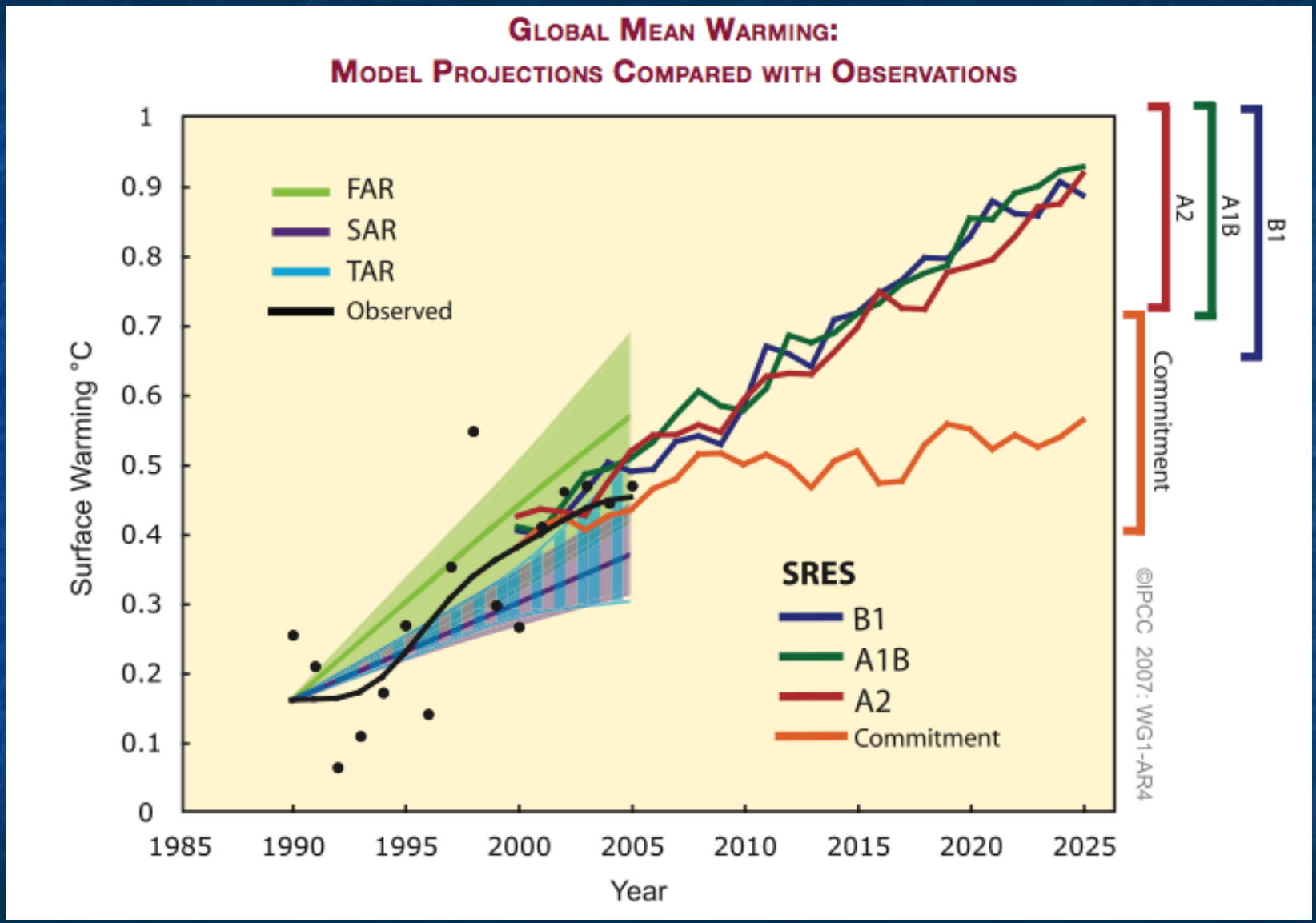
A2: The A2 scenarios are of a more divided world. The A2 family of scenarios is characterized by:
A world of independently operating, self-reliant nations.
Continuously increasing population.
Regionally oriented economic development.

B1: The B1 scenarios are of a world more integrated, and more ecologically friendly. The B1 scenarios are characterized by:
Rapid economic growth as in A1, but with rapid changes towards a service and information economy.
Population rising to 9 billion in 2050 and then declining as in A1.
Reductions in material intensity and the introduction of clean and resource efficient technologies.
An emphasis on global solutions to economic, social and environmental stability.

B2: The B2 scenarios are of a world more divided, but more ecologically friendly. The B2 scenarios are characterized by:
Continuously increasing population, but at a slower rate than in A2.
Emphasis on local rather than global solutions to economic, social and environmental stability.
Intermediate levels of economic development.
Less rapid and more fragmented technological change than in A1 and B1.

http://en.wikipedia.org/wiki/Special_Report_on_Emissions_Scenarios

Which then yield these alternate predicted trends



IPCC Fourth Assessment Report – Working Group 1 – 2007 (p .69):

Some explanations and observations:

"Commitment" = If we **now** halt any **further** change in atmosphere

That is, we have already **committed** (made) atmospheric changes

What will those alone (via a sort of momentum) now inevitably produce?

Apparent answer: Stabilization of temperature

Different economic/globalization scenarios?

- Worst case extremes are very similar

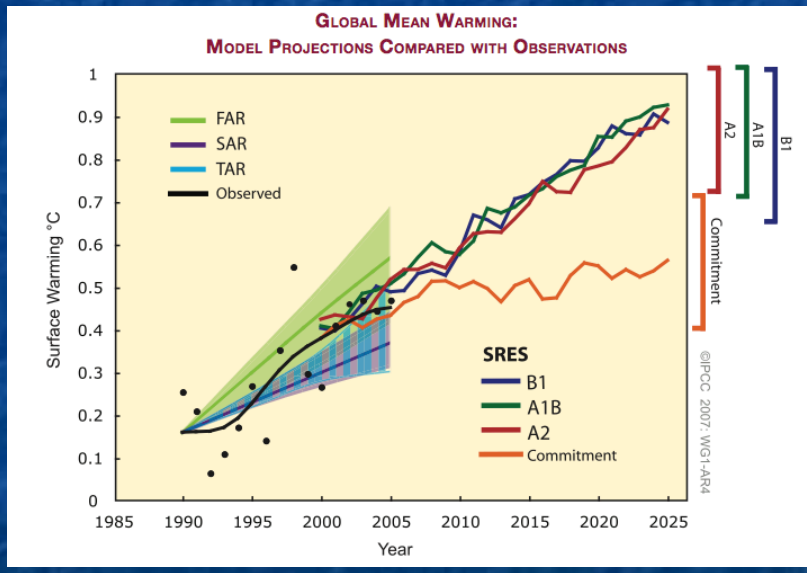
- Best cases diverge

Best results are (naturally) for B and A/B drivers

(Environment or Environment & Economics)

ONLY BEST B1 case => ~ Stabilization

(i.e. STRONG coordinated global action focusing on environment impact)



IPCC Fourth Assessment Report – Working Group 1 – 2007 (p. 69):

Bottom lines?

True, classic, scientific test of a theory is its ability to predict the unknown

In this context, that means the future

So wearing **only** the scientist's hat, we'd just wait to see what happens

But we are also guinea pigs IN this experiment

With our survival (or at least our civilization's survival) at stake

So how might we come to a quicker judgment?

As a scientist I'd ask:

1) Are the models now realistic and complete?

Answer (finally) seems to be yes

2) Are the various models converging?

Which I ask because (contrary to conspiracy theorists):

I know that we scientists are intensely competitive

And that we can fight like cats and dogs

ESPECIALLY ABOUT NEW THEORIES!

Indeed, the **best** way to build a worldwide scientific reputation

is to **not** follow the crowd, but to **stand out** from it!

Thus:

Given scientist's drive to stand out, if the model results are CONVERGING,

it would suggest to me that model details HAVE been worked out

That is, increased accuracy of models should drive a **convergence**

that would counter scientists' natural tendency to disagree

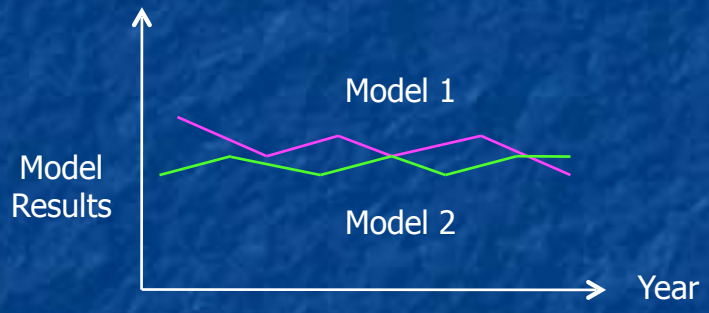
Young field:

Preliminary models =>

Moderate/poor agreement =>

Low confidence level

Mature field:



Refined models =>

Good agreement =>

High confidence level

My personal response?

Rather than focusing on only **averaged model results**

As distilled into the reports of organizations such at the IPCC

I pay particular attention to **how model results now DIFFER**

That comparison allowing me to better judge the maturity of the field

Where do I now identify issues / inadequate understanding?

1) Water in the atmosphere: Dispersed IR transparent vapor vs. Clouds

2) Incomplete data on deep ocean temperatures

3) Incomplete understanding of ocean currents

Why are these important?

Why is our understanding of them still inadequate?

1) Water's conversion from vapor to clouds:

Water vapor is our atmosphere's most concentrated heat-absorbing gas

But condensed into clouds, it scatters solar energy back out into space

But how important is vapor <=> cloud conversion in climate modeling?

Climate models often calculate the "equilibrium climate sensitivity" (ECS)

= The predicted ΔTemperature if CO_2 rose to twice pre-industrial levels

Embarrassingly, with the same input parameters, different models yield

a ~ 2:1 range of temperature change predictions. Further:

scatter has **"changed little over the past several decades"** [1]

Recent studies have tried to pin down the source of this persistent scatter

1) http://science.sciencemag.org/content/338/6108/792

These studies build upon the fact that:

Satellites have already accumulated substantial data on world cloud cover

So the authors tested models' "predictions" of past (known) cloud cover

Some models did much better. For example, models putting more effort into calculating humidity transfer between locations and altitudes

The authors then compared the same models' predictions of future ECS ΔT

They found that models that better accounted for **past** cloud cover also produced strongly reduced scatter in ECS **predictions**

They also noted that those better models predicted significantly larger temperature changes then found in the IPCC averaging of **all** models [1, 2]

1) http://science.sciencemag.org/content/338/6108/792
2) https://www.nature.com/articles/nature24672

2) Deep ocean water temperature

Why is **DEEP** ocean temperature so important?

First, while it takes little energy to change the temperature of a gas

it takes immensely more energy to change the temperature of a liquid

Thus, as one NASA article put it, the deep ocean is

"Earth's Big Heat Bucket . . . Where Greenhouse Heat Hides" [1, 2]

Second, liquids absorb gases, particularly cold liquids [3]

The ocean depths thus store huge amounts of dissolved CO_2

Third, in cold deep water, dissolved methane converts to a solid "clathrate" [4]

This solid sequesters vast amounts of super greenhouse gas methane,

which could be liberated if the surrounding water warmed enough

1) https://earthobservatory.nasa.gov/Features/HeatBucket/
2) https://www.ncei.noaa.gov/news/ocean-heat-reveals-more-about-climate
3) https://www.usgs.gov/news/ocean-absorption-carbon-dioxide-more-makes-methane-emissions-seafloor-methane-seeps
4) https://en.wikipedia.org/wiki/Methane_clathrate

But we know surprisingly little about ocean temperatures:

North Atlantic shipping has collected centuries of surface temperature data

But we have much poorer data on the much larger South Pacific [1,2]

Further, via buoys, we've only recently begun to acquire deepwater data

Some climate models do not account for this shift in measurement technique,

to the point of even lumping together shallow and deepwater data

This has contributed major discrepancies [3, 4] to the point of even producing

now discredited reports of an hiatus in ocean warming [5, 6]

Given the oceans' huge role in both heat and gas storage

how can we accept this absence of data (=> absence of understanding)?

1) https://oceanbites.org/is-the-deep-ocean-warming-too/
2) https://earthobservatory.nasa.gov/Features/HeatBucket/
3) http://advances.sciencemag.org/content/3/3/e1601545
4) http://advances.sciencemag.org/content/3/1/e1601207
5) https://phys.org/news/2017-01-steady-oceans-years.html
6) https://science.nasa.gov/science-news/science-at-nasa/2014/06oct_abyss

3) Ocean Currents

Our understanding of ocean **CURRENTS** is similarly limited

These ocean-circling "thermohaline" currents (such as the Gulf Stream)

transfer huge amounts of heat between equatorial and polar seas

This affects ocean and air temperatures as well as

major global weather patterns (e.g., hurricanes, typhoons, El Nino . . .)

These currents are now largely driven by the convection occurring as

colder (denser) polar water slips beneath warmer equatorial water

Climate change will alter these pole to equator temperature gradients

Finally, fresh water from melting polar glaciers will lighten polar seawater,

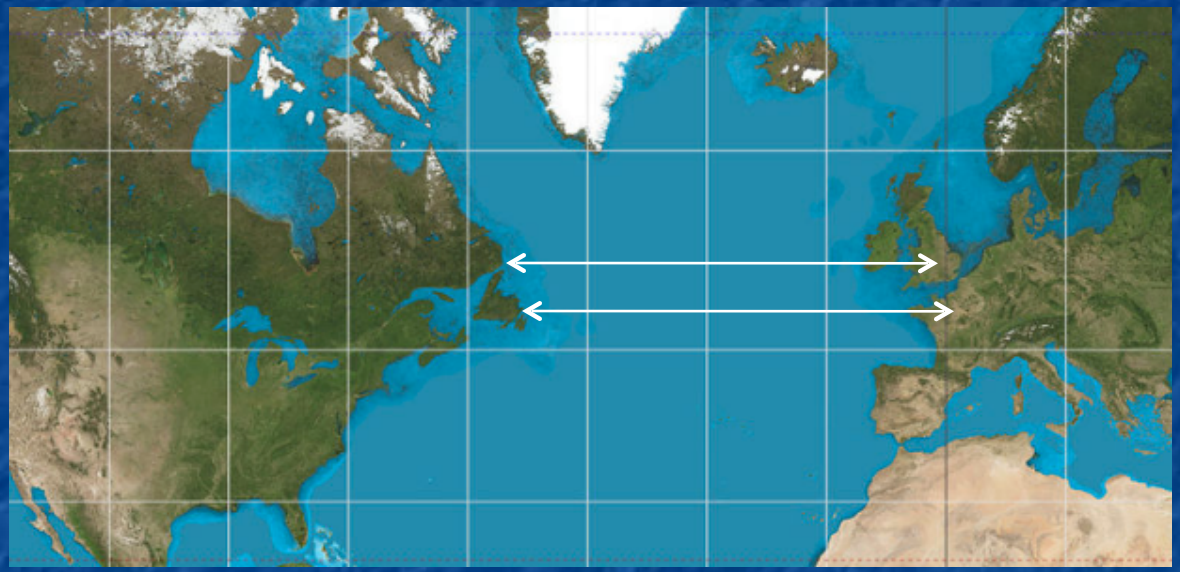
diminishing the density-driven convection that produces these currents

Which could alter or even shut down some of these currents

Reducing North-South heat transfer, hugely compounding climate change

For instance, if the Gulf Stream ceased driving warm waters toward Europe,

temperatures near the Atlantic would tend to equalize by latitude



Driving the temperatures of London toward those of Labrador

and the temperatures of Paris toward those of Newfoundland

(burrr!)

As with deep ocean temperature, the challenge is again to:

Gather much better/complete data on our less well known oceans

And use those data to refine our ocean temperature and flow models

To learn more about the importance of ocean currents see:

Yale's excellent tutorial on worldwide ocean currents:

"How Climate Change Could Jam the World's Ocean Circulation" [1]

Physics Today's discussion of a particular southern hemisphere current:

"Ocean Currents Respond to Climate Change in Unexpected Ways" [2]

MIT's technical (but somewhat cryptic) explanation of ocean behavior:

"The Role of Oceans in Climate Change" [3]

1) https://e360.yale.edu/features/will_climate_change_jam_the_global_ocean_conveyor_belt
2) http://physicstoday.scitation.org/doi/pdf/10.1063/PT.3.3415
3) http://web.mit.edu/fnl/volume/215/rizzoli_stone.html

BREAKING NEWS:

(Relevant news articles I've not yet fully researched and/or verified)

The oceans' circulation hasn't been this sluggish in 1,000 years. That's bad News
Washington Post - April 2018 [1]

Reporting on:

Observed Fingerprint of a Weakening Atlantic Ocean Overturning Circulation
Nature Magazine - April 2018 [2]

"Our findings show that in recent years the AMOC (Atlantic meridional overturning circulation) appears to have reached a new record low . . . an unprecedented event in the past millennium . . . decline since the 1950s is very likely to be largely anthropogenic" [2]

"Weakening may already have an impact on weather in Europe. Cold weather in the subpolar Atlantic correlates with high summer temperatures over Europe, and the 2015 European heat wave" [2]

"Continued global warming is likely to further weaken the AMOC in the long term, via changes to the hydrological cycle, sea-ice loss and accelerated melting of the Greenland Ice Sheet, causing further freshening of the northern Atlantic . . . AMOC is one of the well documented 'tipping elements' of the climate system" [2]

1) https://www.washingtonpost.com/news/energy-environment/wp/2018/04/11/the-oceans-circulation-hasnt-been-this-sluggish-in-1000-years-thats-bad-news/

2) https://www.nature.com/articles/s41586-018-0006-5

So I will be keeping a close watch on the three topics above

As I try to expand my knowledge about climate change modeling

and evaluate the maturity (and thus likely accuracy) of such modeling

But as a citizen, a father, and a grandfather

While I'll continue to try and sort such details out

I'm acting on evidence that models are already accurate enough!

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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.