THE SCIENCE OF CLIMATE CHANGE

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Presented at:
‘Workshop on Climate Change and Water Utilities’
National Center for Atmospheric Research,
Boulder, CO.

March 15, 2004
SUMMARY

• Past temperature and CO$_2$ changes
• Causes of climate change
• Future global-mean temperature changes
• Future regional climate changes
• Policy responses – mitigation
• Conclusions
THE PAST RECORD

Observed changes in global-mean temperature, atmospheric composition, and emissions of greenhouse gases.
TEMPERATURE CHANGES: GLOBE vs USA

YEAR

USA (incl ALASKA)

GLOBE

TEMPERATURE RELATIVE TO 1961-1990 MEAN (degC)
KEY POINTS

(1) Strong overall warming trend in both records, due primarily to anthropogenic factors

(2) Considerable inter-annual and inter-decadal variability, due primarily to natural factors (e.g., ENSO, volcanic eruptions, changes in solar output, etc.)

(3) Regional variability much greater than global-mean variability
CAUSES OF CLIMATE CHANGE

HUMAN (‘ANTHROPOGENIC’) FACTORS
- Greenhouse gases (CO₂, CH₄, etc.)
- Sulfur dioxide and other aerosol precursors

NATURAL FACTORS
- External forcing (solar, volcanoes, etc.)
- Internally-generated variability
RELATIVE IMPORTANCE OF DIFFERENT SPECIES TO RADIATIVE FORCING
CONTRIBUTIONS TO GHG FORCING (YEAR 2000)

- CO2
- CH4
- N2O
- Trop O3
- Halos
EXPLAINING PAST CHANGES

(1) Climate change involves many different variables – surface temperature, tropospheric temperature, stratospheric temperature, precipitation, etc.

(2) The best variables to use to identify and distinguish human and natural influences on the climate system are those where the signal-to-noise ratio (SNR) is highest.

(3) Temperature generally has the highest SNR.

(4) The standard method is to compare a model-derived signal with observed changes.

(5) As an example I will consider tropopause height, which integrates the effects of tropospheric and stratospheric temperature changes.
TROPOPAUSE HEIGHT CHANGES: Model (PCM) versus observed
IDENTIFYING SPECIFIC CAUSES

The relative importance of different causal factors depends on the variable considered.
CONTRIBUTIONS OF DIFFERENT CAUSAL FACTORS

Contributions over 1900-1999

A Tropopause height

B Stratospheric temperature (T4)

C Tropospheric temperature (T2)

Legend:
- G (well-mixed GHGs)
- A (sulfate aerosols)
- O (ozone)
- S (solar)
- V (volcanoes)
- SUM (G+A+O+S+V)
PREDICTING FUTURE CLIMATE CHANGE

- Predict future socioeconomic changes
- Use these to predict future emissions
- From these predict changes in atmospheric composition
- Use these results to drive a climate model
NO-CLIMATE-POLICY CASES
(“Business As Usual”).
THE SRES EMISSIONS SCENARIOS
(The basic drivers for future climate change)

• The Intergovernmental Panel on Climate Change (IPCC) has sponsored production of a new set of ‘no-climate-policy’ emissions scenarios for GHGs, sulfur dioxide, and other gases

• These scenarios are based on a range of assumptions regarding future population, economic growth, energy technology growth, etc.

• The scenarios are published in a Special Report on Emissions Scenarios – hence the acronym SRES

GASES CONSIDERED BY SRES:

- CO₂
- CH₄
- N₂O
- SO₂
- Reactive gases (CO, NOₓ, VOCs)
- Halocarbons (CFCs, HCFCs, HFCs, PFCs, SF₆)
PREDICTING FUTURE GLOBAL-MEAN TEMPERATURE CHANGE
CARBON DIOXIDE (CO$_2$) PROJECTIONS
(emissions and concentrations)
FOSSIL CO2 EMISSIONS: SRES MEAN AND RANGE

MEAN

MAXIMUM

MINIMUM

FOSSIL CO2 EMISSIONS (GtC/yr)

YEAR

1990 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
SRES RANGE OF CO2 PROJECTIONS

CO2 CONCENTRATION (ppm)

YEAR

1990 2000 2010 2020 2030 2040 2050 2060 2070 2080 2090 2100
GLOBAL-MEAN TEMPERATURE PROJECTIONS
(accounting for all major sources of uncertainty)
PROBABILISTIC PROJECTIONS OF GLOBAL WARMING

GLOBAL-MEAN TEMPERATURE CHANGE FROM 1990 (°C)

1990-2030
1990-2070
1990-2100

TAR RANGE
RESULTS FOR PATTERNS OF CLIMATE CHANGE
(per 1°C global-mean warming)
Normalized annual-mean temperature and precipitation changes in CMIP2 1%/year CO₂ increase experiments

Normalized temperature change

Normalized precipitation change
MODELS GIVE A WIDE RANGE OF RESULTS FOR PROJECTED PRECIPITATION CHANGES
SPANNING THE RANGE OF POSSIBLE FUTURES
(blue = better models)

DJF PRECIP CHANGES vs DJF TEMP CHANGES (Control drift removed)

NORMALIZED PRECIPITATION CHANGE (%/deg C)

NORMALIZED TEMPERATURE CHANGE (degC/degC)

Sth. CA: 30 to 35N, 115 to 120W
WHAT CAN WE DO TO REDUCE THE MAGNITUDE OF FUTURE CLIMATE CHANGE?
ARTICLE 2 OF THE U.N. FRAMEWORK CONVENTION ON CLIMATE CHANGE

“The ultimate objective … is … stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous interference with the climate system … achieved within a time frame … to enable economic development to proceed in a sustainable manner”
THE KYOTO PROTOCOL
(Article 3, para. 1)

(For Annex B countries): “aggregate anthropogenic carbon dioxide equivalent emissions of (a range of) greenhouse gases (should) not exceed … assigned amounts … with a view to reducing … overall emissions of such gases by at least 5% below 1990 levels in the commitment period 2008-2012”
WHAT EXACTLY DOES THE KYOTO PROTOCOL MEAN?

- The stated target is for Annex B country emissions to be, on average, 5% below their 1990 emissions level by around 2010.
- In the absence of policies (i.e., under ‘Business As Usual’), Annex B emissions would increase substantially by 2010.
- A 5% reduction relative to 1990 represents, on average, a 16% reduction below BAU.
- For the U.S.A., given projected economic growth, the 5% target represents an even larger reduction relative to BAU – around 30%.
- This is part of the reason for the U.S.A.’s intransigence. It may also indicate that the Kyoto target is too much, too soon – and that the whole ‘targets and timetables’ concept is economically flawed.
EMISSIONS REQUIREMENTS FOR CO2 CONCENTRATION STABILIZATION

(Note: stabilization of emissions does not stabilize concentrations, but leads to steadily increasing concentrations – at around 100 ppm/century.)
CO2 CONCENTRATION STABILIZATION PATHWAYS

YEAR
1990 2010 2030 2050 2070 2090 2110 2130 2150 2170 2190 2210 2230 2250
CO2 CONCENTRATION (ppm)
350 400 450 500 550 600 650 700 750 800
P50 BASELINE
WRE450
WRE550
WRE650
WRE750
CONST EFOSS(2000)
KEY POINTS

(1) Stabilizing emissions does not stabilize concentrations (magenta line in plot)

(2) These concentration stabilization pathways depart from the ‘no-policy’ baseline (black P50 line in plot) in 2005 (450ppm stabilization), 2010 (550ppm), 2015 (650ppm) and 2020 (750ppm)

(3) A future departure date does not mean ‘do nothing’ until then – it means setting in place now the mechanisms for future (substantial) emissions reductions below the no-policy case
KEY POINTS

• Except for the 450ppm case, emissions can rise substantially above present levels and still allow concentration stabilization to be achieved

• After peak emissions, rapid reductions in emissions are required to achieve stabilization, implying a rapid transition to non-fossil energy sources and/or a rapid reduction in carbon ‘intensity’ (CO₂ emissions per unit of energy)

• Eventually, emissions must fall substantially below current levels

• Note that these results are for CO₂ alone – in practice the effects of other greenhouse gases must also be accounted for
WHAT SHOULD THE STABILIZATION TARGET BE?

(What does ‘dangerous interference’ mean?)
INPUT PDFs: CO2 stabilization concentration is controlled by warming limit, climate sensitivity and non-CO2 forcing.
CO2 CONCENTRATION STABILIZATION TARGET

CO2 CONCENTRATION (ppm)

PROBABILITY DENSITY (ppm^{-1})

- Median (615ppm)
- 10%
- 10% WARMING LIMIT
- LOW SENSITIVITY
- LOW NON-CO2 FORCING
- HIGH SENSITIVITY
- HIGH NON-CO2 FORCING
- LOW WARMING LIMIT
- HIGH WARMING LIMIT
CONCLUSIONS -- CLIMATE

- Humans have had a significant effect on climate, especially over the past 50 years
- CO₂ will be the dominant cause of future radiative forcing and climate change
- Future climate changes will be much larger and more rapid than in the past: 2 to 8 times
CONCLUSIONS -- POLICY

• Even with strong policies, substantial future climate changes are inevitable

• Stabilization of CO₂ concentration requires, eventually, very large reductions in emissions

• The stabilization target for CO₂ depends on what is judged to be ‘dangerous interference’, the climate sensitivity, and forcing from non-CO₂ sources. There is a probability of around 10% that the target should be below the current level.

• CO₂ concentration stabilization represents an enormous technological challenge for mankind
FURTHER INFORMATION


These reports are quite technical. Summaries are downloadable from the web site.

Pew Center on Global Climate Change (www.pewclimate.org).

The Pew Center has published many plain language reports on various facets of the global warming issue; downloadable.