Business Topics

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Agenda

- Indicators and forecasts
- Housing
- Testing the climate change model

Polynomial Cointegration Tests of the Anthropogenic Theory of Global Warming

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Introduction

- IPCC: Carbon emissions induce global warming
- Anthropogenic theory “tested” by calibration
- Since 1997 climatologists use cointegration
- Greenhouse gases are I(2)
- Polynomial cointegration tests reject anthropogenic theory

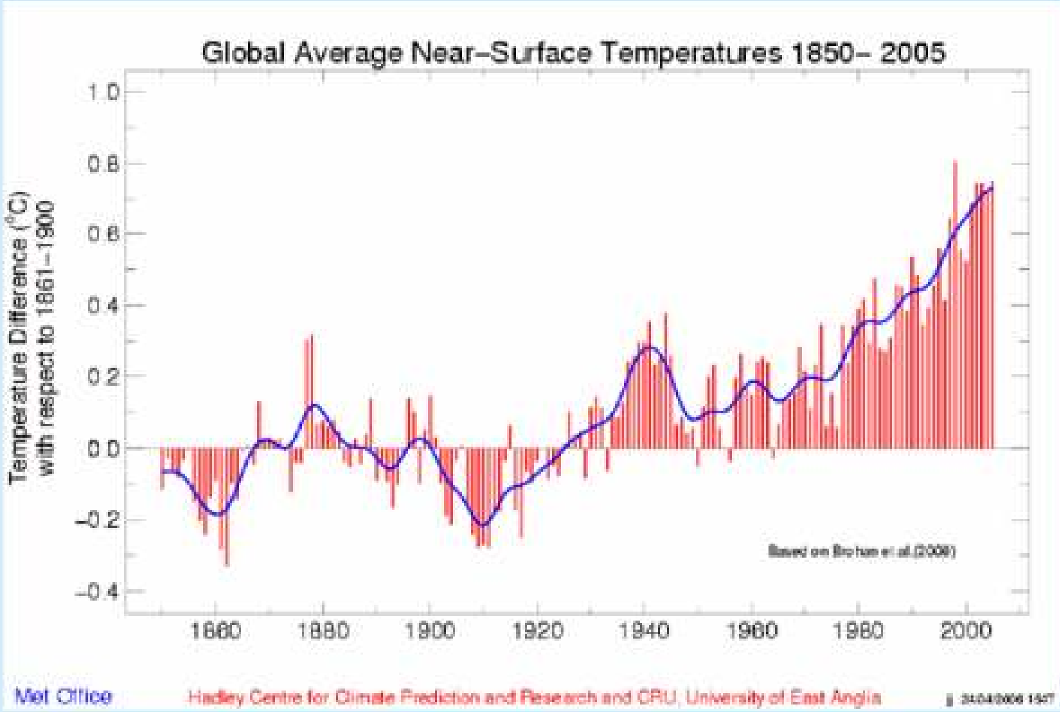
Road Map

- Climate Data: 1850 – 2007
- Palaeoclimatics
- IPCC and politics of global warming
- Circular Flow Models
- Greenhouse gas theory
- Polynomial cointegration
- Results

Global Temperature since 1850

Figure 1.3 The Earth has warmed 0.7°C since around 1900.

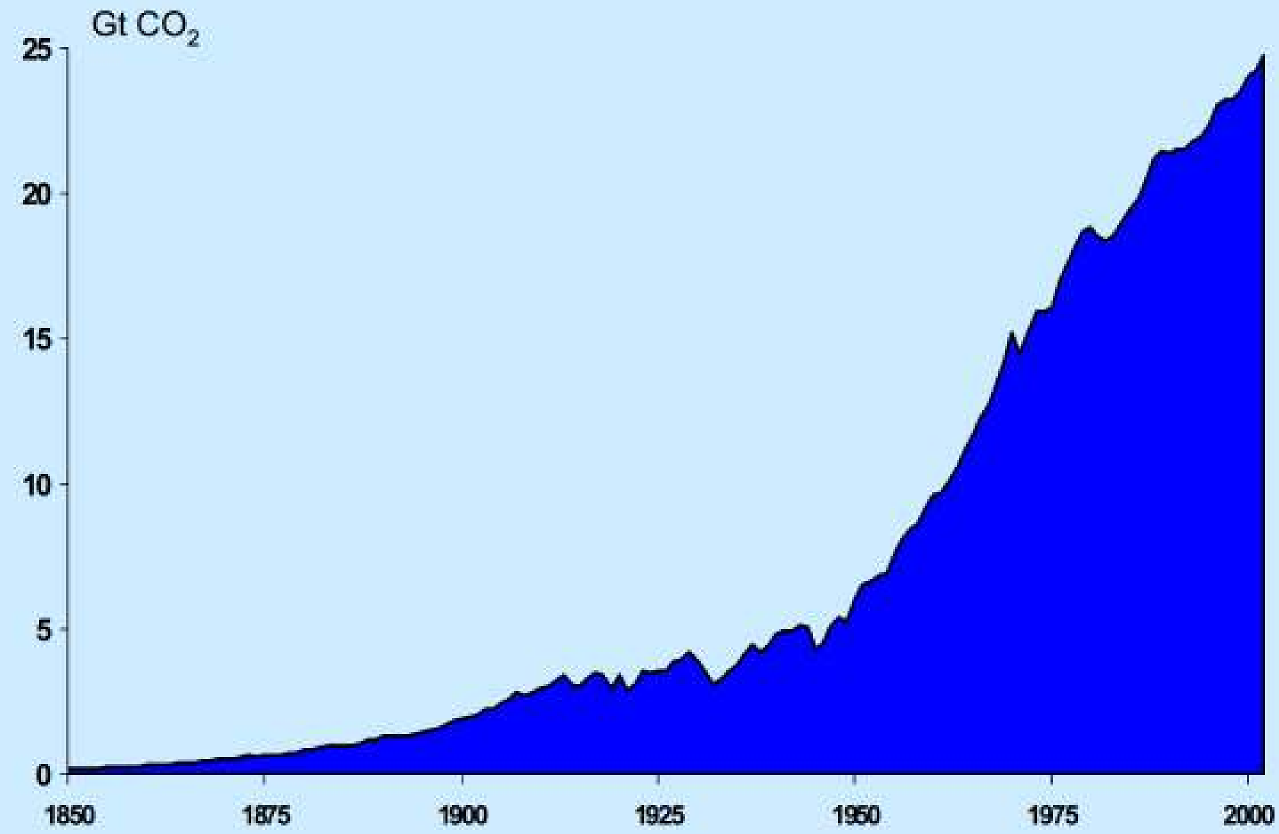
The figure below shows the change in global average near-surface temperature from 1850 to 2005. The individual annual averages are shown as red bars and the blue line is the smoothed trend. The temperatures are shown relative to the average over 1861 – 1900.



Source: Brohan et al. (2006)

CO2 Emissions since 1850

Figure 7.2 Global CO_2 emissions from fossil-fuel burning and cement over the long term



Source: Climate Analysis Indicators Tool (CAIT) Version 3.0. (Washington, DC: World Resources Institute, 2006)

IPCC

Intergovernmental Panel on Climate Change

- Established in 1988 by UNEP & WMO.
- 1995 Report: “The balance of evidence suggests a discernable human influence on global climate.”
- Doubling of atmospheric CO_2 will raise global temperature by 1-3.5ºC.
- Kyoto Protocol 1997.
- 2001 Report: Greenhouse effect “very likely to exist.” Doubling of CO_2 concentrations raises temperature by 1.5-4.5ºC.
- 2007 Report: “Most of the observed increase in global average temperature since the mid 20th century is *very likely..”* Doubling raises temperature by 2-4.5 ºC.
- Stern Review 2007
- Obama 2009

Main Conclusions

- No long run relationship between global temperature and the level of atmospheric CO2 concentration.
- Temperature and solar irradiance are stationary in 1st differences.
- Greenhouse gases are stationary in 2nd differences since 1850.
- Greenhouse theory confirmed in **changes** in atmospheric CO2 .
- Blame the sun: solar irradiance at 10,000 year high.
- Economic growth not to blame for global warming.
- Reverse causality is likely from temperature to atmospheric CO2 .
- Greenhouse theory “corroborated” by calibration in IPCC.

Newsweek

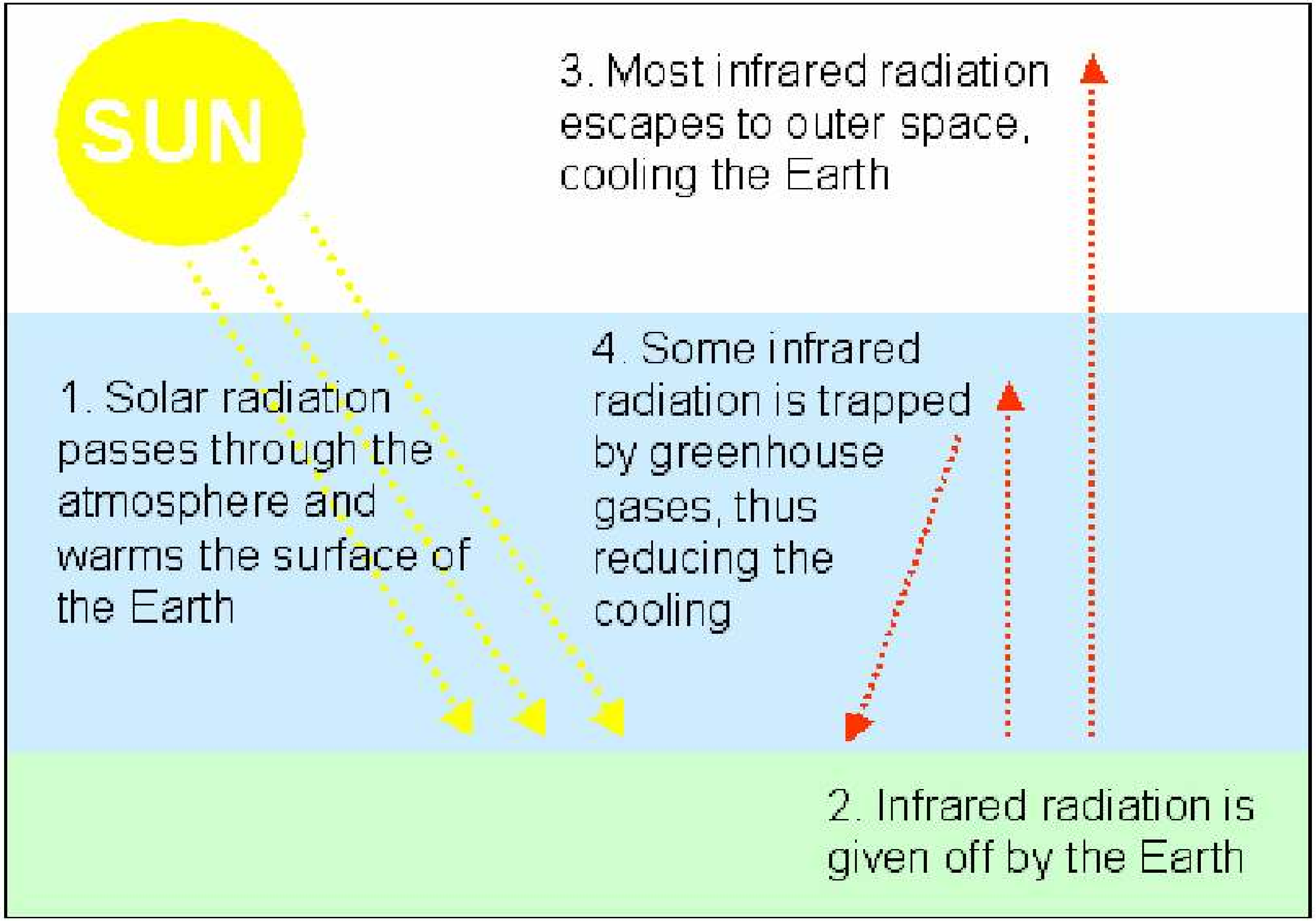
April 18, 1975

“The central fact is that after three quarters of a century of extraordinarily mild conditions, the earth’s climate seems to be cooling down… Climatologists are pessimistic that political leaders will take any action to compensate for climatic change, or even to allay its effects. They concede that some of the more spectacular solutions proposed such as melting the arctic ice cap by covering it with black soot…might create problems far greater than they solve.”

Greenhouse Gases

- Atmospheric concentrations (particles per mil): Oxygen (~20%), Nitrogen (~80%), Greenhouse gas (~0.04%), Water (~1%)
- CO2 0.0384%, methane (CH_4) 0.000176%, nitrous oxide (N_2O) 0.0000321%
- Residence times (approx): CH_4 10 years, N_2O 100 years, CO2 absorbed by oceans & biosphere
- Radiative forcing (watts per m^2): $rfCO_2 = \alpha \ln CO_2$
- α varies inversely with CO_2
- $\alpha_{N2O} = 10\alpha_{CH4} \quad \alpha_{CH4} = 20\alpha_{CO2}$

The Greenhouse Effect



Source: DEFRA (2005)

Palaeoclimatics

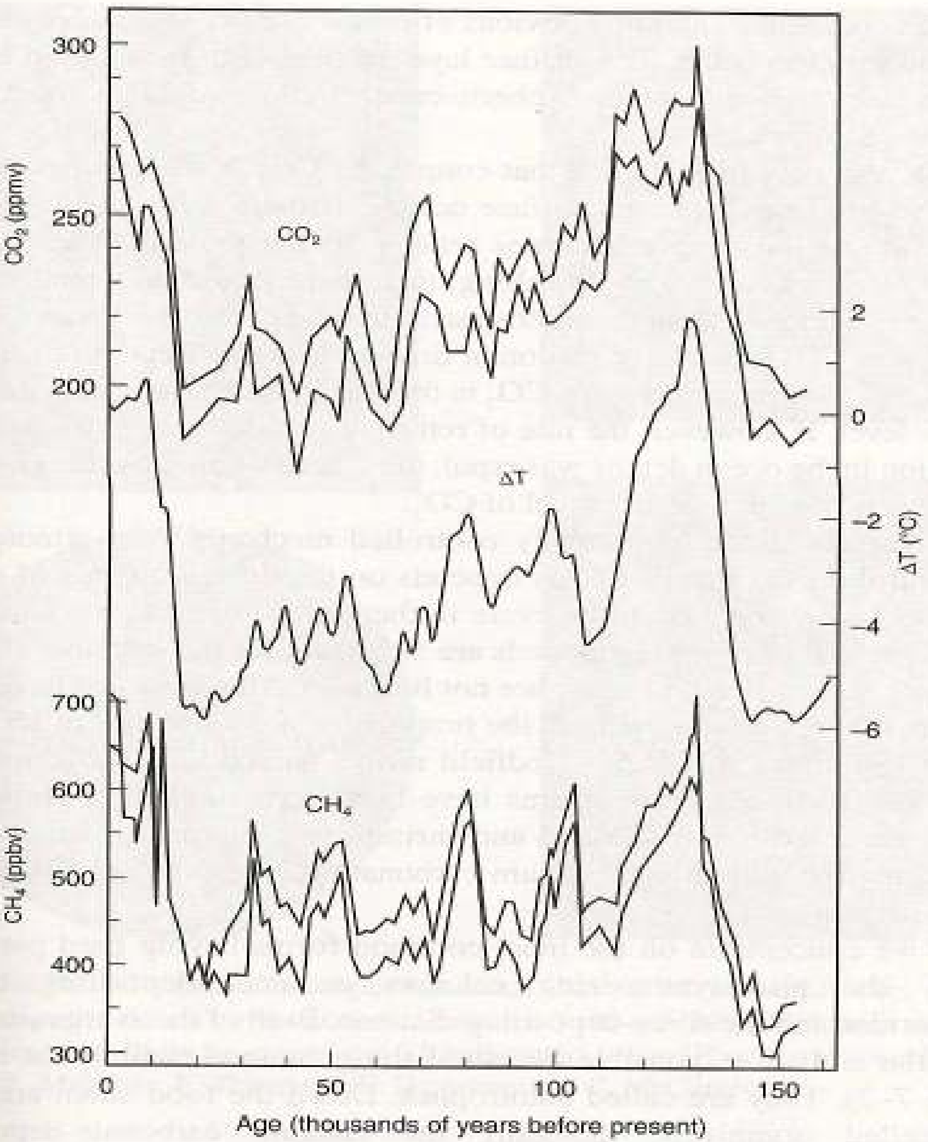


FIGURE 7–1 The variation of CO_2 and methane over time as inferred from an ice core (Vostok) from Antarctica (from J. M. Barnola, D. Raynaud, Y. S. Korotkevich, and C. Lorius, 1987, *Nature,* v. 329, p. 408, and

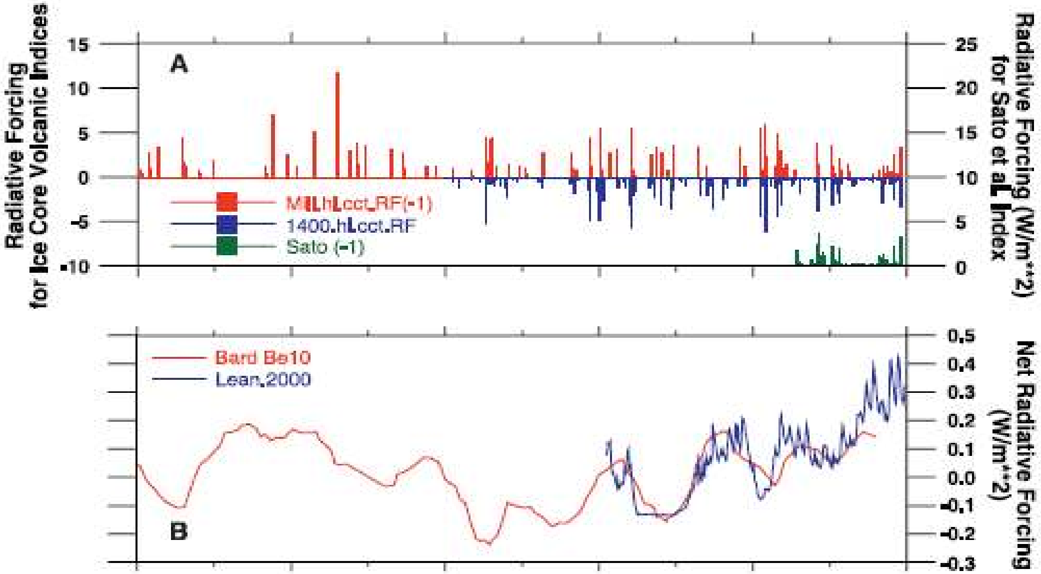
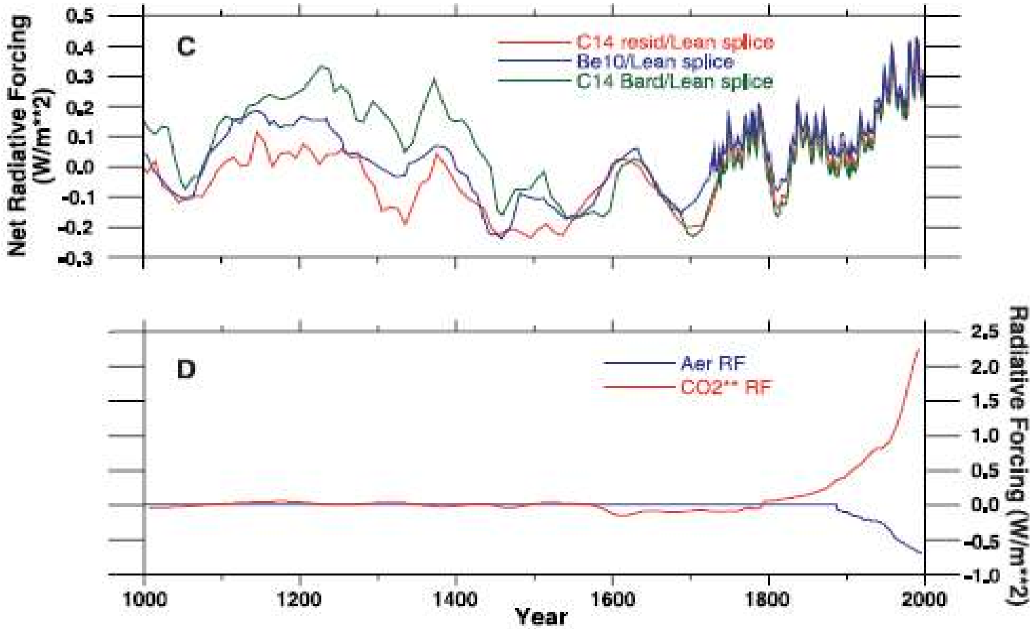
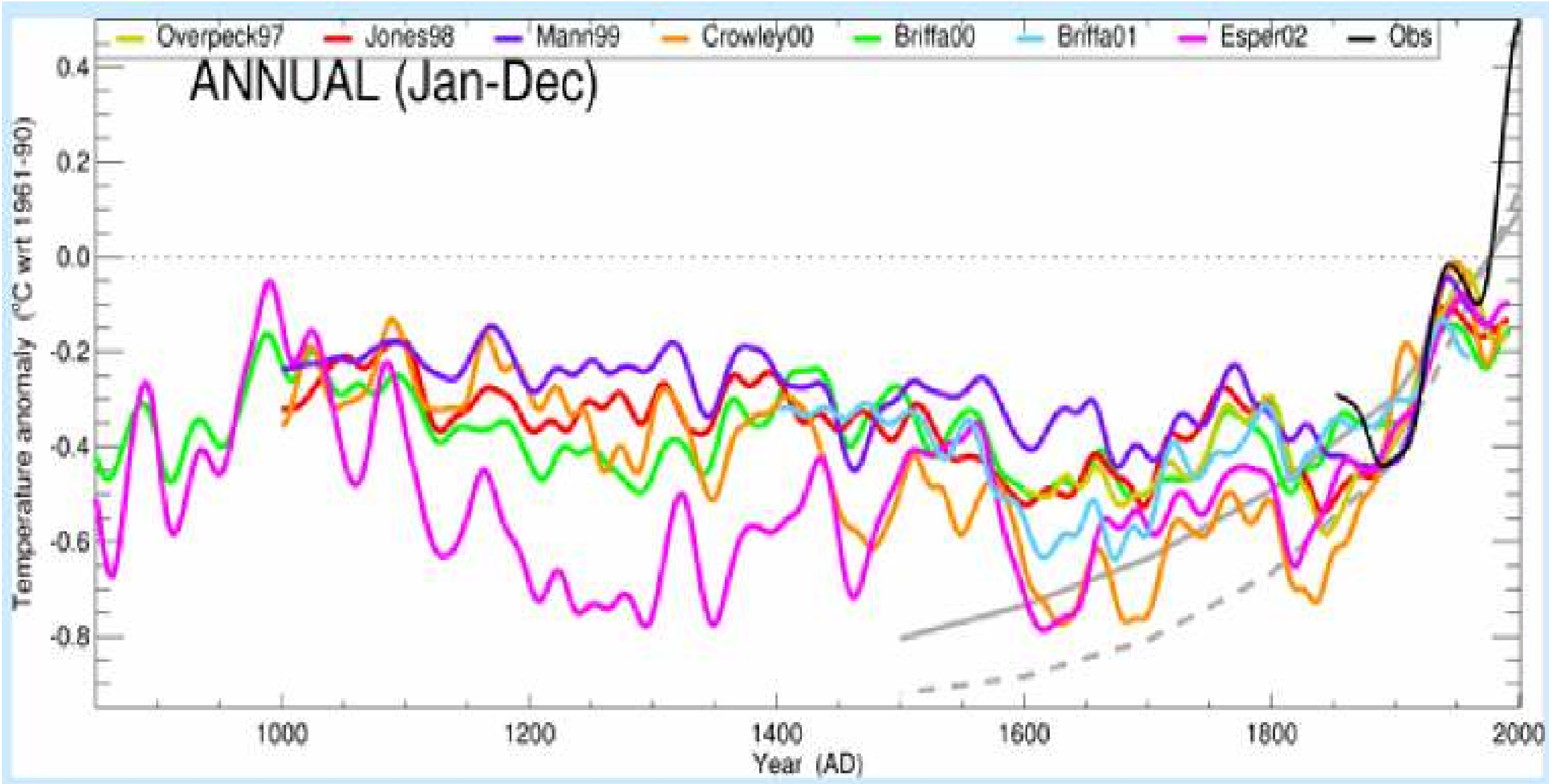


Fig. 2. Forcing time series used in the model runs (note scale changes for different panels). (A) (Red) Ice core millennial volcanism time series from this study (multiplied by −1 for display purposes); (blue) ice-core Robock and Free (*19*) reconstruction from 1400 to the present after adjustments discussed in (*9*) and (*25*); and (green) Sato *et al.* (*28*) Northern Hemisphere radiative forcing, updated to 1998 and multiplied by −1 for display purposes. (B) Example of splice for solar variability reconstructions, using the ^{10}Be-based irradiance reconstruction of (*30*) (red) and the reconstruction of solar variability from Lean *et al.* (*5*) (blue). (C) Comparison of three different reconstructions of solar variability based on ^{10}Be measurements (*30*) (blue), ^{14}C residuals (*31*) (red), and calculated ^{14}C changes based on ^{10}Be variations (*30*) (green). (D) Splice of CO_2 radiative forcing changes 1000–1850 (*35*) (red) and post-1850 anthropogenic changes in equivalent GHG forcing and tropospheric aerosols (blue).



Temperature since 800



Theory

A Simple GCM

T = temperature
S = solar irradiance
C = atmospheric CO_2 concentration
E = anthropogenic emissions of CO_2
A Uptake of atmospheric CO_2
GWP = gross world product

$$T_t = \alpha_0 + \alpha_1 S_t + \alpha_2 C_t + u_t$$

$$\Delta C_t = E_t - A_t$$

$$A_t = \beta_0 - \beta_1 T_t + \beta_2 C_t + \beta_3 E_t + v_t \ (Henry's\ Law)$$

$$\ln E_t = \phi + \pi \ln GWP_t + e_t$$

General Solution of GCM

E(u) = E(v) = 0

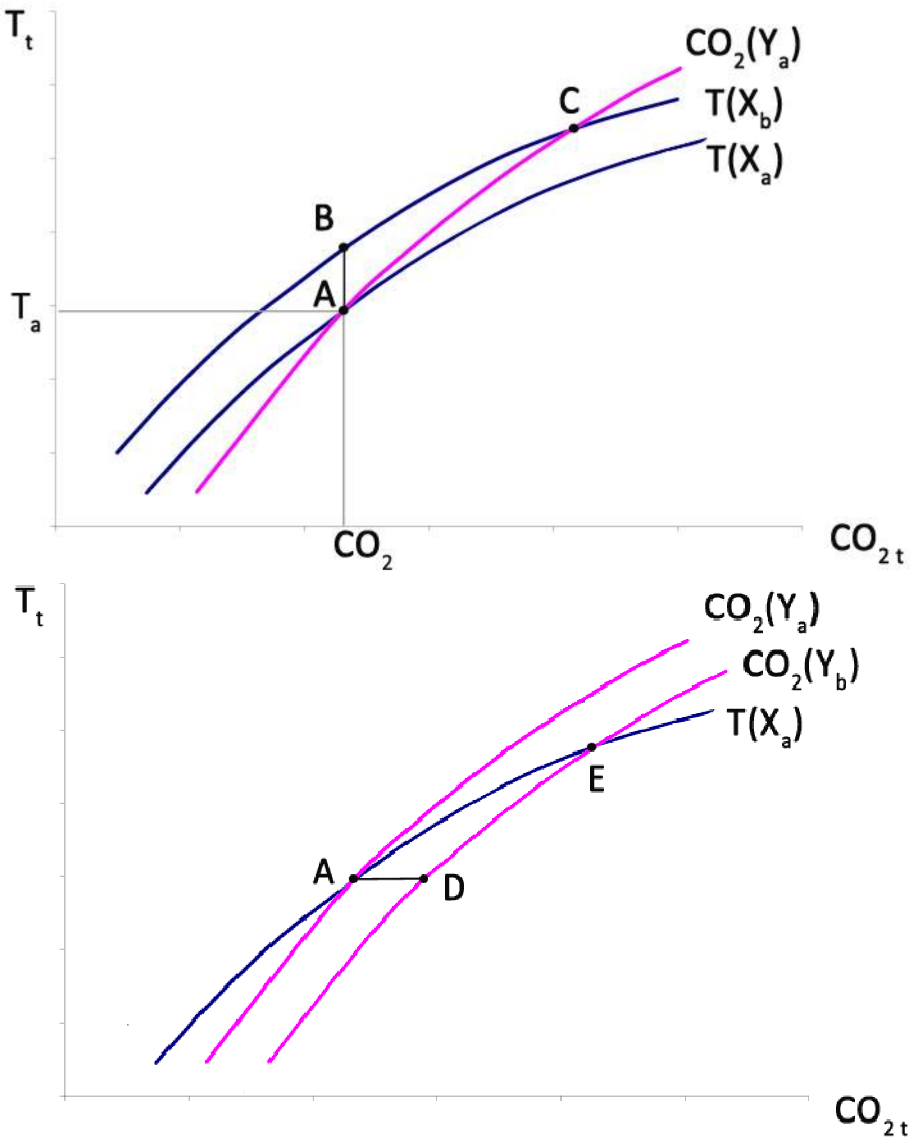
$$T_t = \frac{\lambda(\beta_2\alpha_0 - \alpha_2\beta_0)}{1-\lambda} + \alpha_1(1+\beta_2)\sum_{i=0}^{\infty}\lambda^{i+1}S_{t-i} - \alpha_1\sum_{i=0}^{\infty}\lambda^{i+1}S_{t-i-1} + \alpha_2(1-\beta_3)\sum_{i=0}^{\infty}\lambda^{i+1}E_{t-i} \quad (9)$$

$$C_t = \frac{\lambda(\beta_1\alpha_o - \beta_0)}{1-\lambda} + \alpha_1\beta_1\sum_{i=1}^{\infty}\lambda^{i+1}S_{t-i} + (1-\beta_3)\sum_{i=1}^{\infty}\lambda^{i+1}E_{t-i} \quad (10)$$

$$\lambda = \frac{1}{1+\beta_2 - \beta_1\alpha_2} < 1 \ \ (\beta_2 > \beta_1\alpha_2)$$

$$\frac{dT}{dE} = \frac{\alpha_2(1-\beta_3)}{\beta_2 - \beta_1\alpha_2}$$

Climatic Equilibrium



Empirical Methodology

Calibration v Estimation

- Meteorologists & climatologists calibrate.
- Economists borrowed calibration in 1980s.
- DSGE models = GCM models.
- Calibration “mimics empirical moments”.
- Critique: Pagan (1994), Hansen & Heckman (1996), Sims (1996).
- IPCC informed by calibration.
- Observational equivalence.
- Policy implications not robust.

Estimation

- Spurious regression in nonstationary data.
- Cointegration tests:
  - Stern & Kaufmann (1997), Kaufmann & Stern (2002)
  - Kaufmann, Kauppi & Stock (2006) Mills (2009)
  - Liu & Rodriguez (2005)
- Results “confirm” IPCC.

Order of Integration

- Covariance stationarity: mean, variance, covariance independent of time.
- $\Delta^d Y_t = e_t \sim I(0)$
- $Y \sim I(d)$
- Dickey-Fuller (1976) test: H_0: d = 1
- Phillips-Perron (1988) test: H_0: d =1
- Kwiatkowsky, Phillips, Schmidt & Shin (1992): H_0: d = 0

Principles of Cointegration

- $Y = \alpha + \beta X + u$
- $Y \sim I(1)$
- $X \sim I(0)$ or $I(2)$ plim$\beta = 0$
- $X \sim I(1)$ $u \sim I(1)$ spurious regression
- $u \sim I(0)$ cointegrated (not spurious)
- Superconsistency ($T^{1½}$): plim$\beta = \beta$ despite dependence between X and u
- t – statistics invalid

Polynomial Cointegration Engle-Granger

- $T = \alpha_0 + \alpha_1 S + \alpha_2 C + \alpha_3 M + u$
- $T \sim I(1)$, $S \sim I(1)$, $C \sim I(2)$, $M \sim I(2)$
- $u \sim I(0)$?
- $C = \gamma_0 + \gamma_1 M + g$
- $g \sim I(1)$?
- $T = \alpha_0 + \alpha_1 S + \alpha_4 g + u$
- Haldrup (1994): $C = \beta_0 + \beta_1 S + \beta_2 T + \beta_3 M + v$
- Kaufmann et al (2006), Mills (2009) use T as regressor!

Polynomial Cointegration Johansen Method

- Johansen (1995) Juselius (2007)
- $\Delta C_t = \omega_0 + \omega_1 \Delta M_t + \Delta z_t$ $z \sim I(1)$
- $C_t = \omega_0 t + \omega_1 M_t + z_t$
- $T_t = \pi_0 + \pi_1 S_t + \pi_2 z_t + p_t$ $p \sim I(0)$
- Liu and Rodriguez (2005)
- S strongly exogenous!

Data

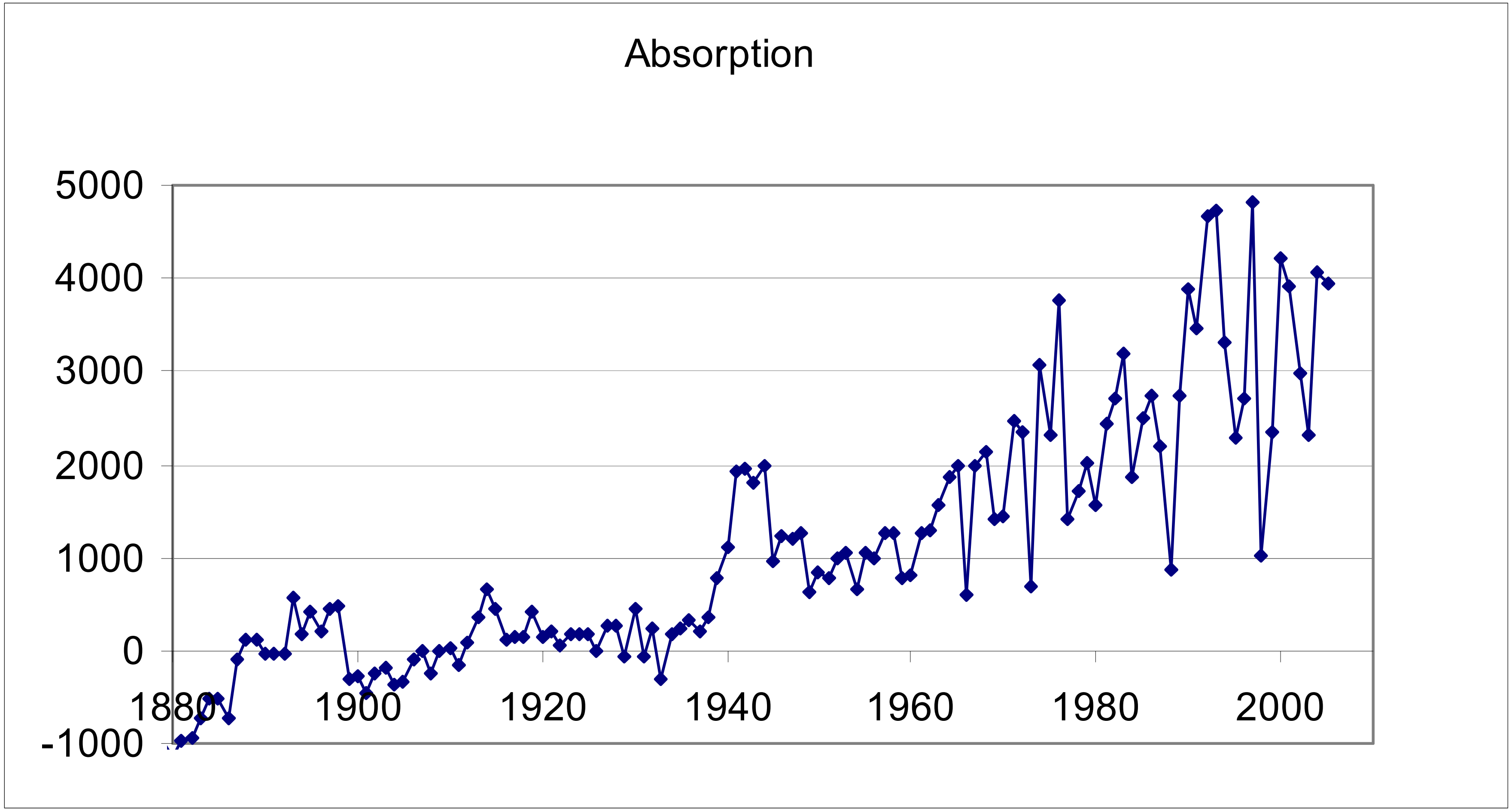
Data Sources

- Annual 1850 - 2006.
- Most data from NASA.
- Emissions: Boden, Marland & Andres (2009).
- Temperature data from 1880.
- Uptake of CO_2.
- Data problems

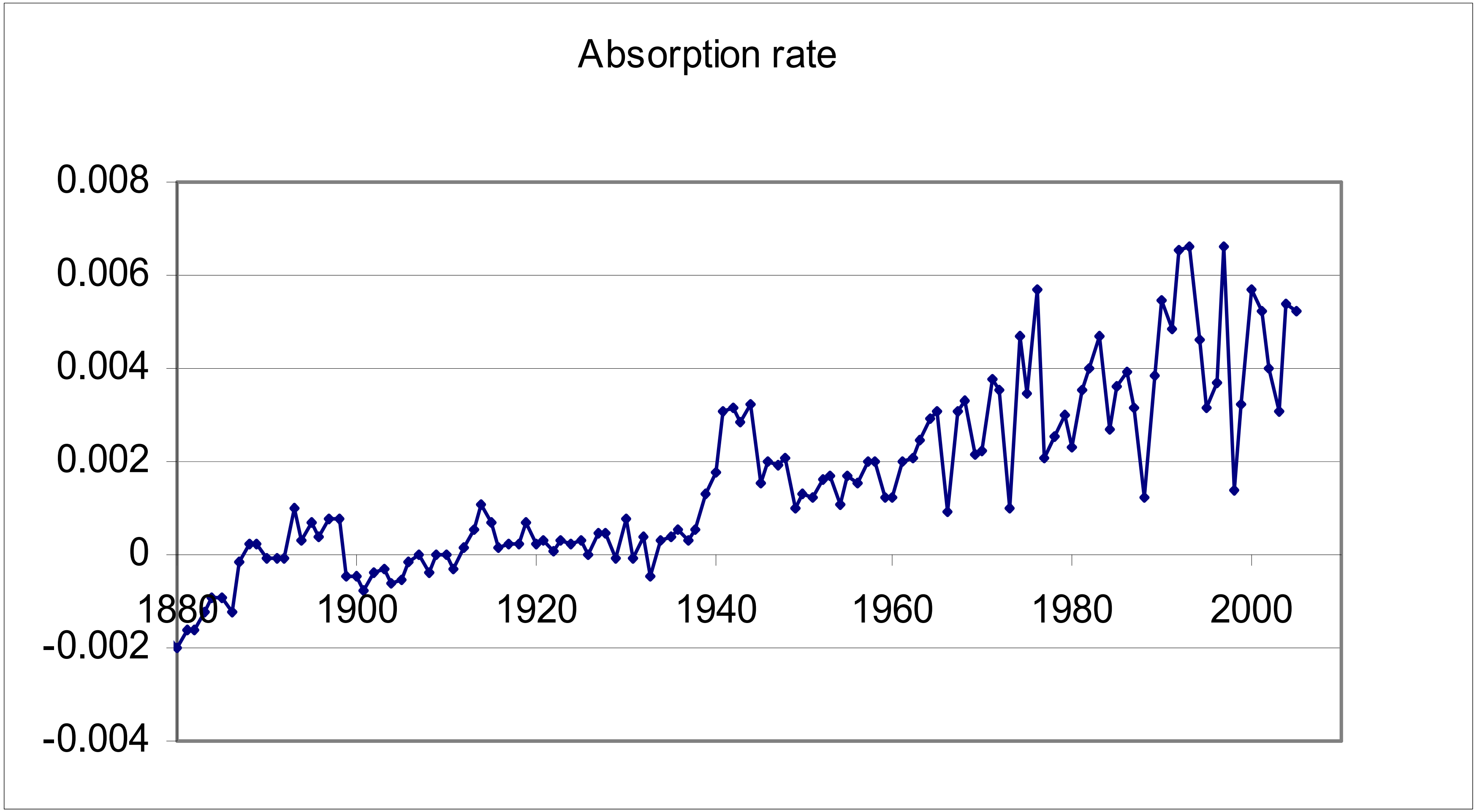
Uptake of CO_2

- Biosphere
- Ocean
- Invisible Sink
- $\Delta CO2 = E - A$
- E   anthropogenic emissions
- V   volcanic emissions
- $A = B + O + IS - V$ (net uptake)
- Deforestation decreases B

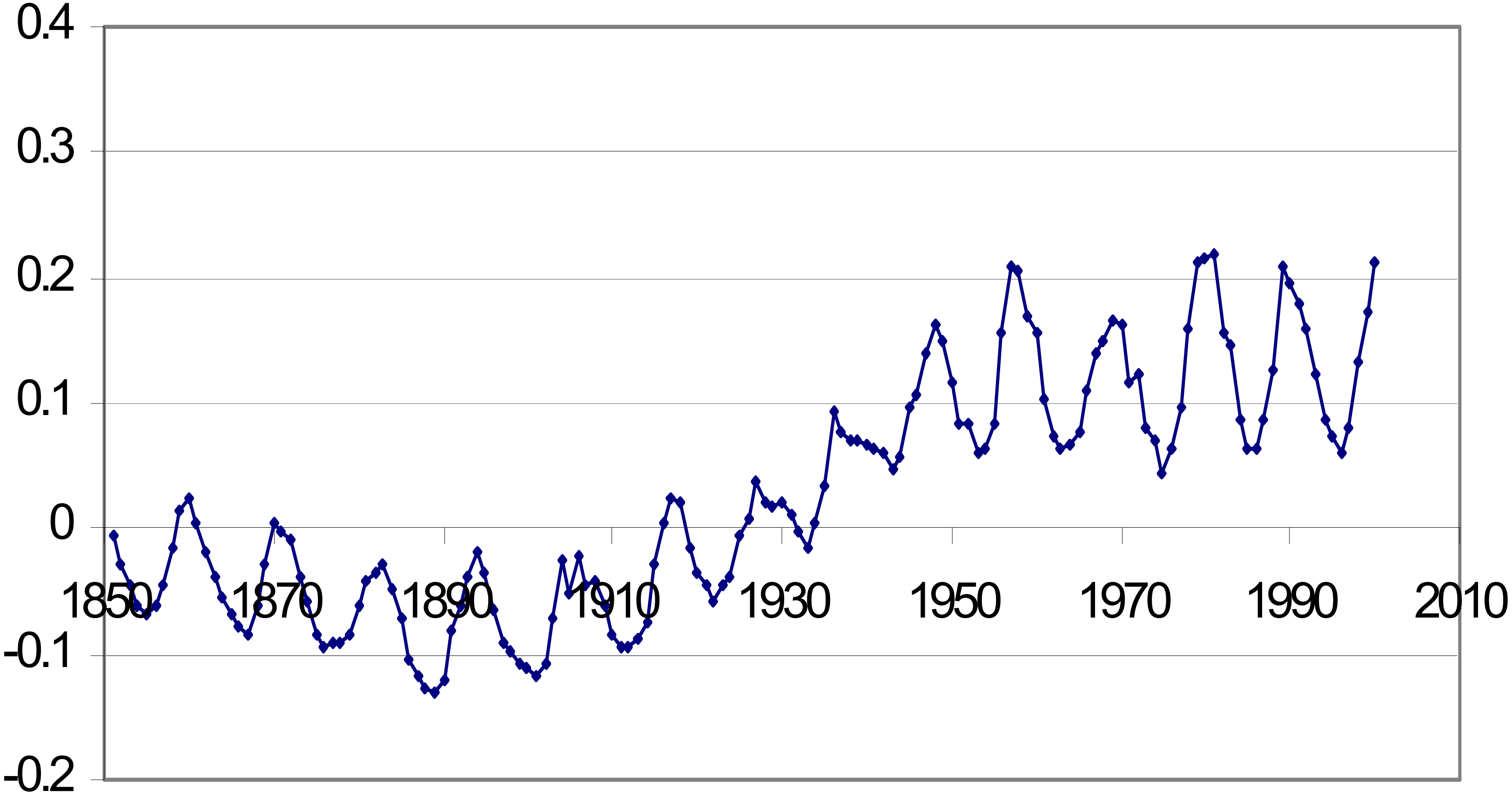
Residual Net Uptake of CO_2



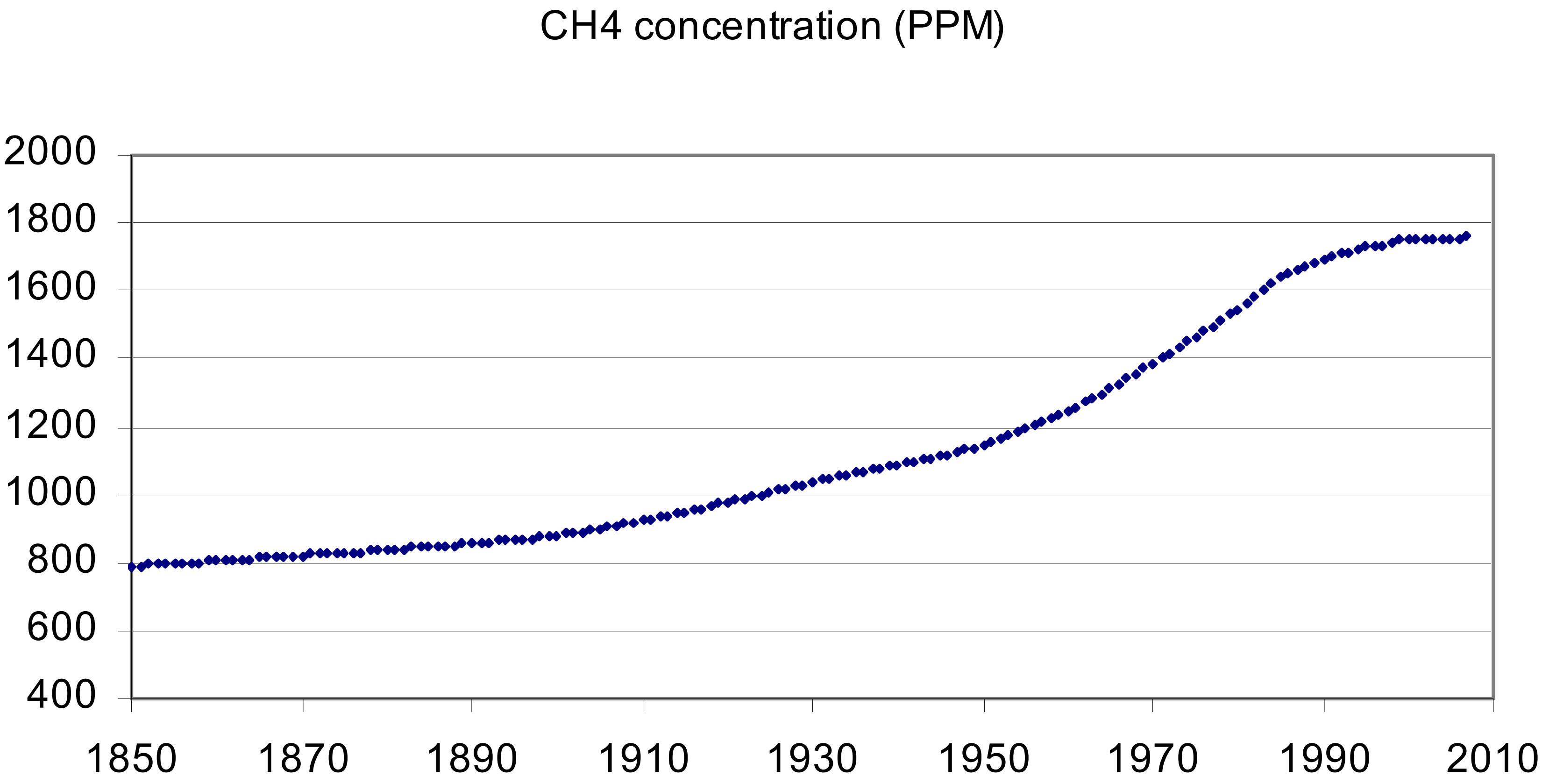
Rate of Uptake of CO2



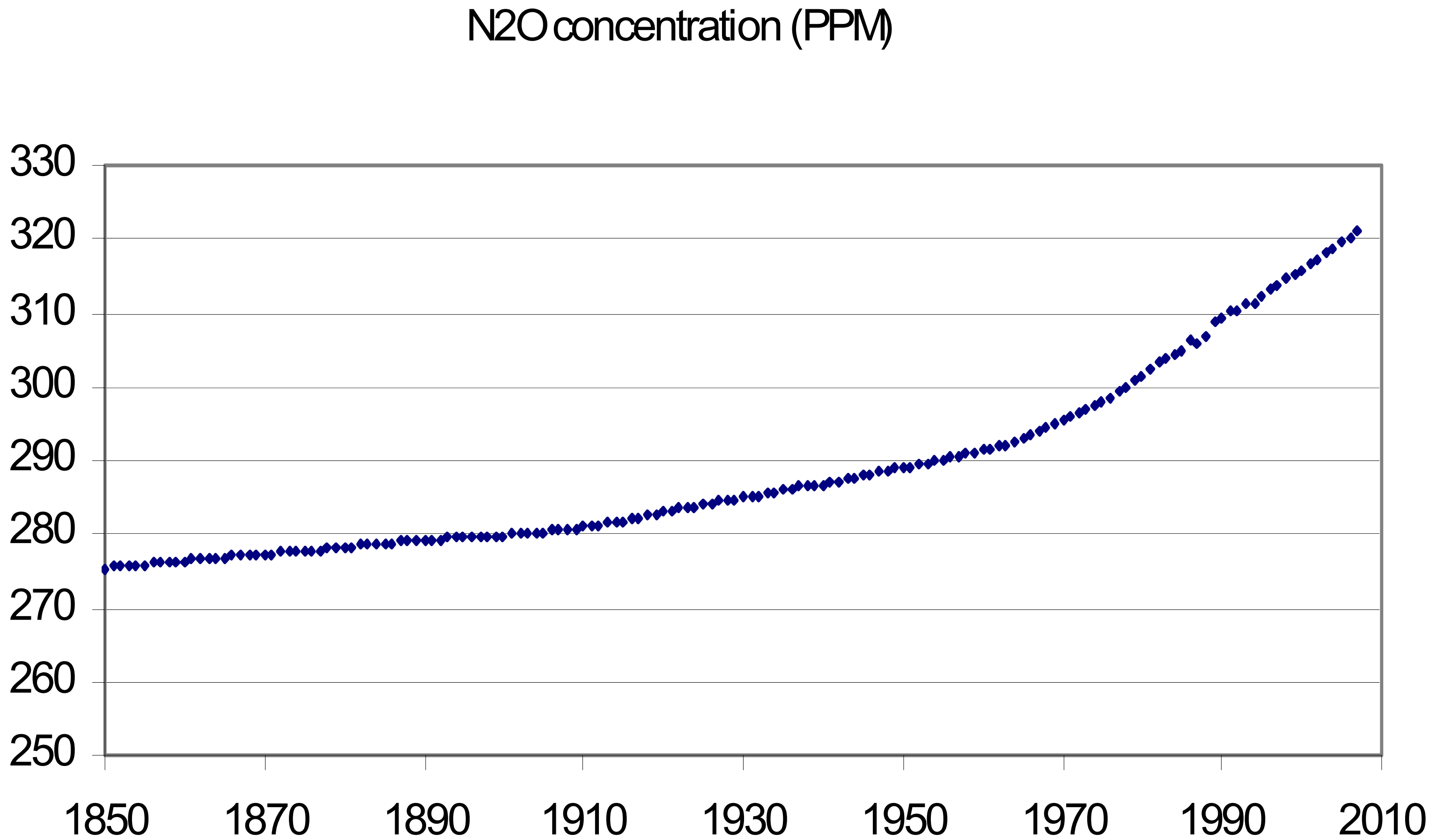
Solar Irradiance



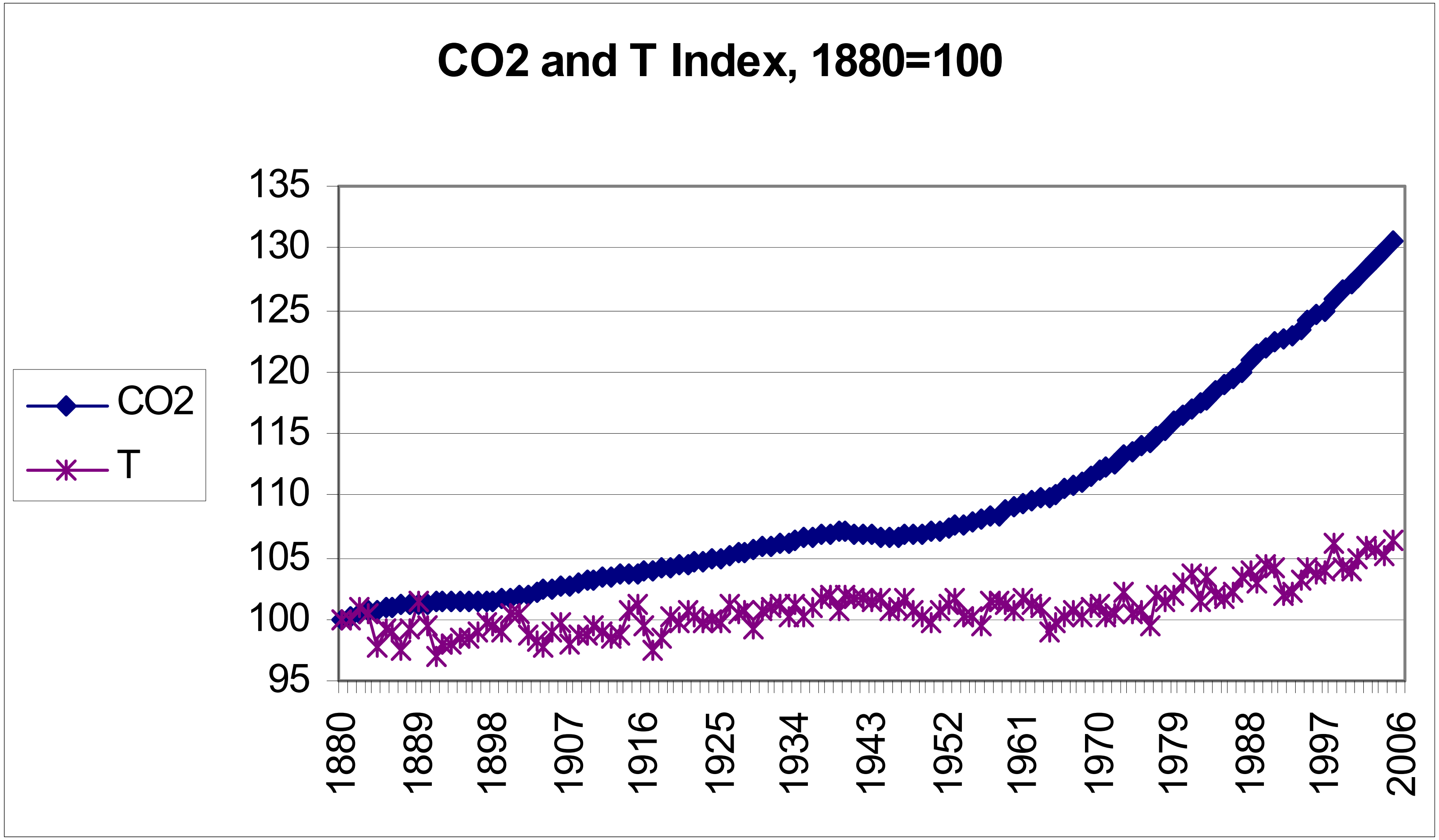
Methane


CH4 concentration (PPM)
2000
1800
1600
1400
1200
1000
800
600
400
1850
1870
1890
1910
1930
1950
1970
1990
2010

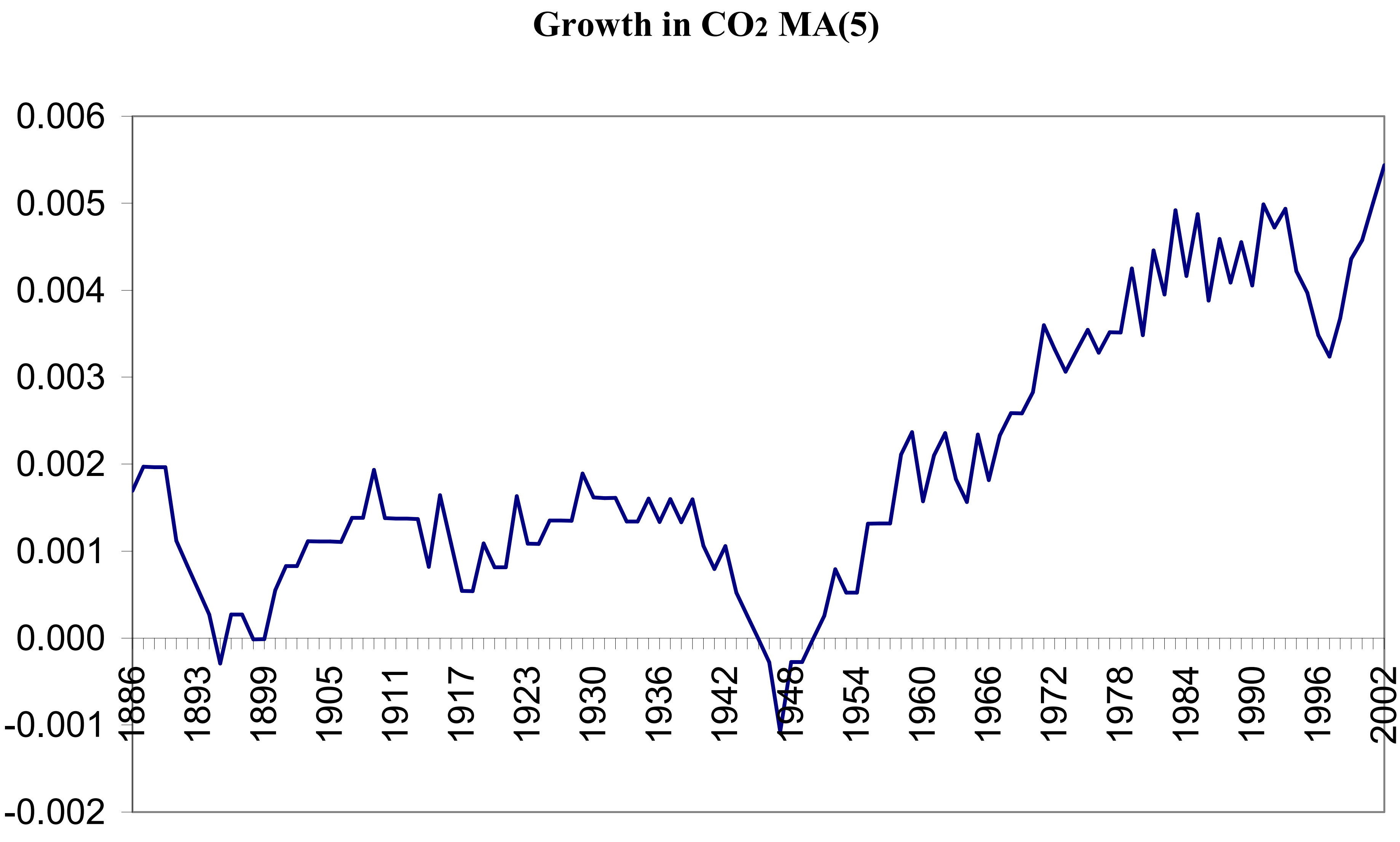
Nitrous Oxide



Temperature v C02



DlnCO2- 5 year av.



Results

The Order of Integration of Atmospheric CO_2

Test	d	Root	Trend	log	lags	ADF	DW	PP	KPSS
1	0	1.02	yes	no	0	9.22	1.13	5.83	0.81
2	1	0.85	no	no	0	-3.47	2.49	-2.88	2.72
3	1	0.96	no	no	4	-0.98	1.99		
4	1	0.96	no	yes	4	-1.38	1.99	-3.25	2.66
5	2	-0.35	no	no	0	-17.77	2.22	-21.04	0.05
6	2	-1.18	no	no	4	-6.88	2.02		
7	1	0.94	no	no	2	-1.38	2.12	-2.77	2.72
8	2	-0.35	no	no	0	-17.77	2.22	-21.04	0.05

The PP test used the Newey-West bandwidth default of 4 lags and the KPSS test uses a bandwidth of 3 lags. The number of lags in the table refers to the number of augmentations in the ADF test statistic. In tests 2 -8 the critical values for ADF and PP at $p = 0.463$ are -2.886 and for KPSS 0.05. In test 1 these critical values are -3.442 and 0.146 respectively.

Orders of Integration

Series	d
CO2	2
Temperature	1
CO2 Emissions	1
Solar irradiation	1
Methane	2
N2O	2
CO2 absorption	1
Rate of absorption	1

Greenhouse Gases

$rfCO_2 = 0.391 + 0.000034 rfCH_4 + 0.0046 N_2O + g$

Sample: 1850 – 2008 $s = 1.635$ $R^2 = 0.9959$

$d_g = 0$: ADF4 = -2.411 PP = -1.846

KPSS = 0.579

- $d_g = 1$: ADF4 = -4.43   PP = -14.04

  KPSS = 0.085

Temperature Model

Engle - Granger

- Modified greenhouse model: 1st differences
- $T = 13.90 + 1.5S + 10.06\Delta rfCO_2 + 36.88\Delta rfN_2O$
  $- 41.5\Delta rfCH_4 + 0.268g$
- Sample: 1885 – 2006   se = 0.1487 $R^2 = 0.5991$
- ADF4 = -5.315***   PP = -7.062***   KPSS = 0.311***
- Haldrup critical value = -5.2
- Dropping g makes no difference
- Dropping S does! ADF = -2.1 KPSS = 1.1
- Dropping ΔGHG: ADF = -3.04 KPSS = 0.5

A COMMON MISTAKE

- Haldrup (1994): LHS should be I(2)
- Kaufmann & Stern (2002), Kaufmann, Kauppi and Stock (2006), Mills (2009): LHS = T ~ I(1)
- Incorrect ADF ≈ -7
- Correct ADF ≈ - 2.5!
- Critical value ≈ -5.2

Uptake of C02

Engle - Granger

- $A_t = 4604.18 + 0.562E_t – 349.32T_t$
  Sample 1880 – 2008   s = 657.6 R^2 = 0.7625

ADF4 = -4.174   PP = -8.182   KPSS = 0.277

Drop T: ADF = -4.56 PP = -9 KPSS = 0.228

Drop E: ADF = -3.58 PP = -7.33 KPSS = 1.34

- $A/CO2 = U_t = 17.437 + 0.0016E_t – 1.298T_t$
  Sample 1880 – 2006   s = 2.02 R^2 adj = 0.7266

ADF4 = -3.885   PP = -7.627   KPSS = 0.393

Drop T : ADF = -4.11 PP = -8.31 KPSS = 0.362

Drop E: ADF = -3.52 PP -7.06 KPSS = 1.36

Error Correction Model

Temperature

$$\Delta T_t = 0.0056 - 0.134\Delta T_{t-2} - 0.196\Delta T_{t-3} + 0.72(\Delta S_t - \Delta S_{t-2}) + 4.83\Delta^3 rfC_t$$

(0.5) (1.71) (2.51) (2.09) (4.08)

$$+254.8\Delta rfN_2O_{t-2} - 0.52u_{t-1}$$

(2.41) (6.38)

Adj R squared = 0.384 DW = 1.97 LM = 2.24 se = 0.12

Error Correction Model

Uptake Rate CO_2

$\Delta U_t = -0.00006 – 0.5\ EC_{t-1} – 0.2\Delta U_{t-1}$

(-0.06) (-4.85) (-2.15)

$-0.16(\Delta U_{t-1} - \Delta U_{t-4}) + 0.0000015\Delta E_{t-5}$

(-3.02) (1.65)

$+ 0.00067\Delta T_{t-2}$

(1.23)

R^2 adj = 0.383 se = 0.00089 DW = 2.114

LM = 0.909

Impulse Responses for Temperature

Year	Solar Irradiance 1 watt/m^2	$rfCO_2$ 1 watt/m^2	$\Delta rfCO_2$ 1 watt/m^2
1	0	0.253	0.253
2	1.444	-0.110	0.143
3	0.750	0.163	0.305
4	0.910	0.082	0.387
5	1.000	0.074	0.461
6	1.350	-0.051	0.456
7	1.370	0.014	0.471
?	1.470	0	0.539

$rfCO_2 = 0.1867 \ln CO_2$

$$e = \frac{\partial T}{\partial CO_2}\frac{CO_2}{T} = m\frac{dCO_2}{drfCO_2}\frac{CO_2}{T} = m\frac{(e^{0.1867} + CO_2)CO_2}{T}$$

Conclusions

- Greenhouse gases are I(2) since 1850
- Temperature and solar irradiance are I(1)
- Global temperature does not polycointegrate with greenhouse gases
- Sun is main driver of global warming
- Misuse of cointegration
- Anthropogenic evidence is spurious
- Johansen polycointegration: methodological lacuna

The Bottom Line

- Rise in global temperature in 20th century 0.7 degrees C.
- Solar irradiance rose by about 0.3 watts (per sq.m.), contributing 0.44 degrees.
- Atmospheric CO_2 rose 35% in the century; delta($rfCO_2$) also rose, contributing 0.15 degrees- is now stable.
- On latest data T has stabilized since 1990; so has solar irradiance.
- If the sun continues to be stable, T will also stabilize.

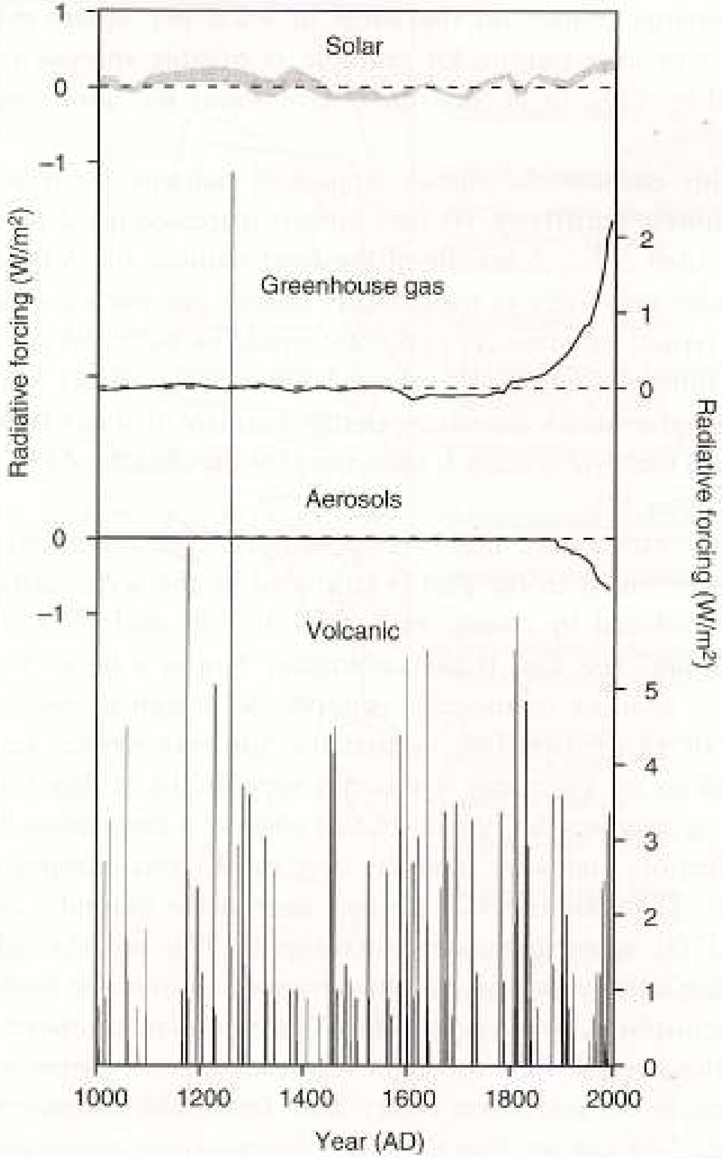


Fig. 11.6 Reconstructed history of radiative climate forcings from solar variability, greenhouse gases, anthropogenic aerosols, and volcanic particle emission to the stratosphere. Replotted from Crowley (2000).

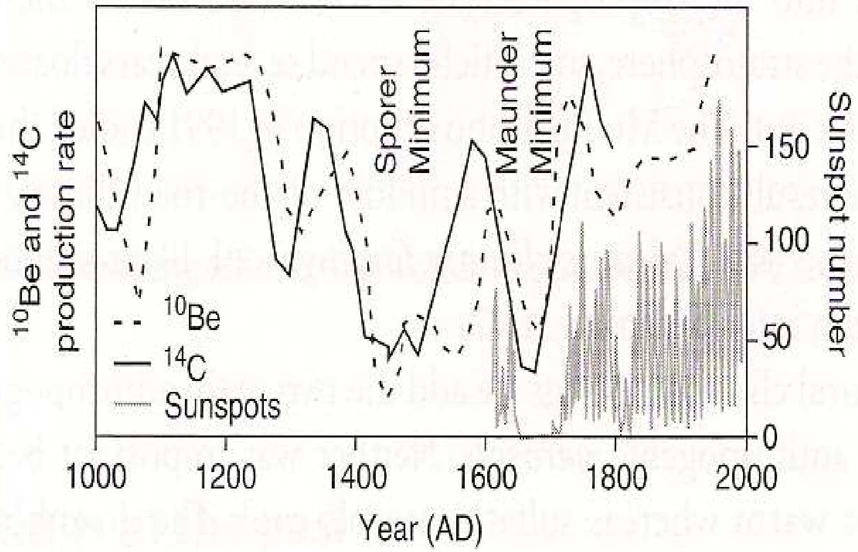


Fig. 11.7 History of sunspot number and cosmogenic isotope production over the past 1000 years. Data from Beer (2000) and Lean (2000).