The GFDL SEA Longwave Radiation Code

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Outline of the Talk

- The GFDL longwave radiation code
- Advantages
- Comparison with LBL results and satellite measurements
- CM3 results using the radiation code
- Disadvantages

The GFDL Longwave Code

- Basic reference : Schwarzkopf and Ramaswamy, 1999 : Radiative Effects of CH_4, N_2O, halocarbons and the foreign-broadened H_2O continuum, JGR 104(D8),9467-9488.
- Reference for aerosols and clouds: Donner et al, 2011 : J. Clim. 24 DOI 10:1175/2011JCLI3955.1

SEA Concept

- Radiative transfer equation (used for line-by-line (LBL) calculations) (Schwarzkopf and Fels, 1991)

  $Q(p) = c_p^{-1} g \frac{d}{dp} d/dp \int_0^\infty F_v(p) dv$

  $F(p) = B_v [T(0)] \tau_v(0,p) + \int_0^{p^s} dBv/dp' \, \tau_v(p,p') \, dp'$

  where $\tau_v(p,p')$ is a transmission function for the absorbing species at wavelength v and B the Planck function discussed previously
- A time-consuming calculation, impractical for models (may need 10^6 frequency intervals)

- The SEA concept uses the fact that the heating rate can be divided into a cool-to space (CTS) part (photon loss from an atmospheric level to space) and an exchange term (photon exchange between atmospheric levels)
- the SEA approximation assumes that the exchange term may be computed with little loss of accuracy on broad frequency bands. The CTS part is computationally efficient. This leads to the basic SEA equation:

- Heating rate calculation:
  $Q_{LW} = Q(exch) + (Q_{CTS}(exact) - Q_{CTS}(approx))$
- Exchange and approx CTS are computed on broad bands; exchange term for H_2O uses the emissivity approximation; CO_2, CH_4, N_2O transmissivities interpolated to profile (T,p,rgas) from LBL results
- H_2O Continuum is CKD2.1 or CKD2.4

SEA Frequency Ranges and Absorbers

Frequency Range cm-1	APPROX	CTS
0–160	1 band used for 0–560, 1400–2200 cm^{-1} range; H_2O lines using emissivity calculation	none
160–560	as in 0–160 cm^{-1} range	40 bands: H_2O lines, CKD continuum
560–800	1 band; H_2O lines, CKD continuum, LBL-derived CO2, 14 um N_2O, 4 halocarbons	3 bands: 14 um N_2O in 560–630 cm^{-1} band, H_2O lines, CKD continuum, CO_2, 4 halocarbons
800–990	1 band for 800–990, 1070–1200 cm^{-1} range; CKD H_2O continuum, 4 halocarbons	2 bands: H_2O lines, CKD continuum, 4 halocarbons
990–1070	1 band; O_3, CKD continuum, 4 halocarbons	1 band; O_3, H_2O lines, CKD continuum, 4 halocarbons
1070–1200	as in 800–990 cm^{-1} range	1 band; H2O lines, CKD continuum, N_2O, 4 halocarbons
1200–1400	1 band; H_2O lines using emissivity calculation, LBL-derived CH_4, N_2O	none
1400–2200	as in 0–160 cm-1 range	none

Summary of features of the SEA formulation. Column 1 gives the main frequency ranges employed. Column 2 gives the primary absorbers and algorithms used for broadband calculations (such as QAPPROX) in each main frequency range.

Column 3 gives the primary absorbers and algorithms used for narrowband cooling to space (QCTS) calculations in each main frequency range.

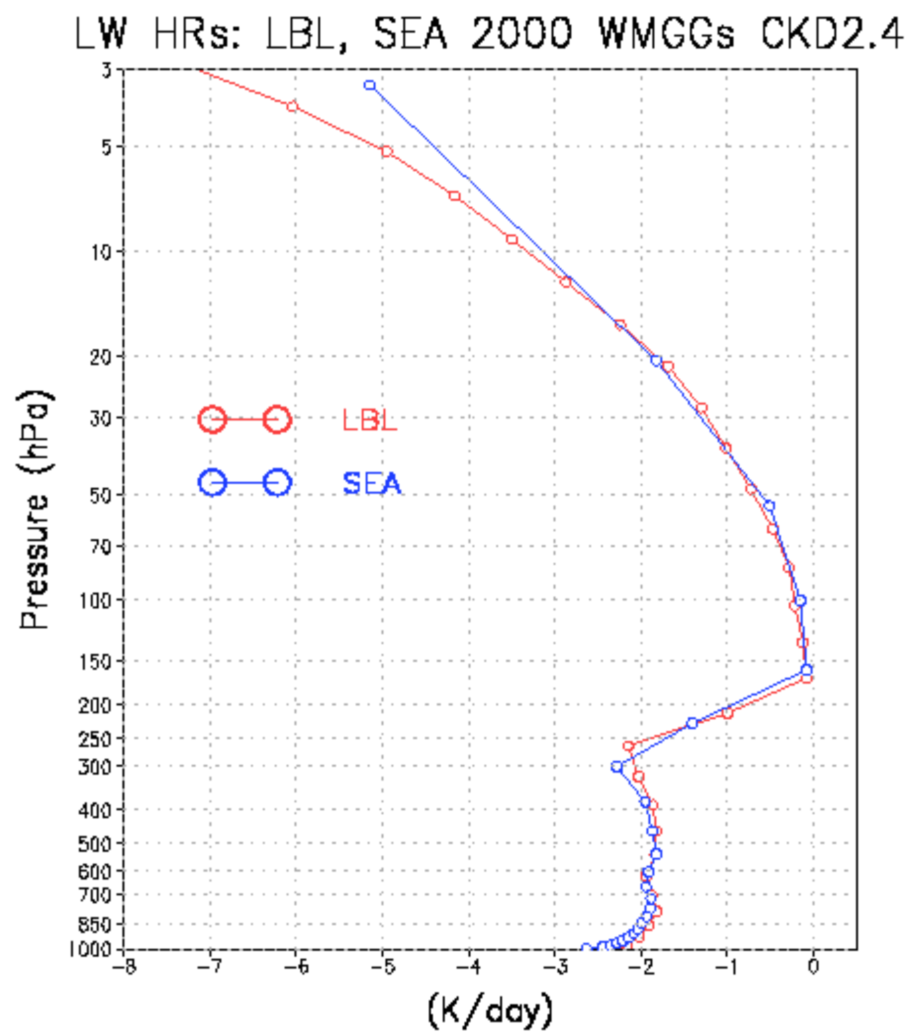
- Absorption (not scattering) of LW aerosols included; spectral optical properties inputted from external aerosol module. In 560-1400 cm^{-1} region.
- Cloud extinction coefficients parameterized from inputted drop concentrations/sizes. Spectrally varying emissivity in 560-1400 cm^{-1} region.

Advantages

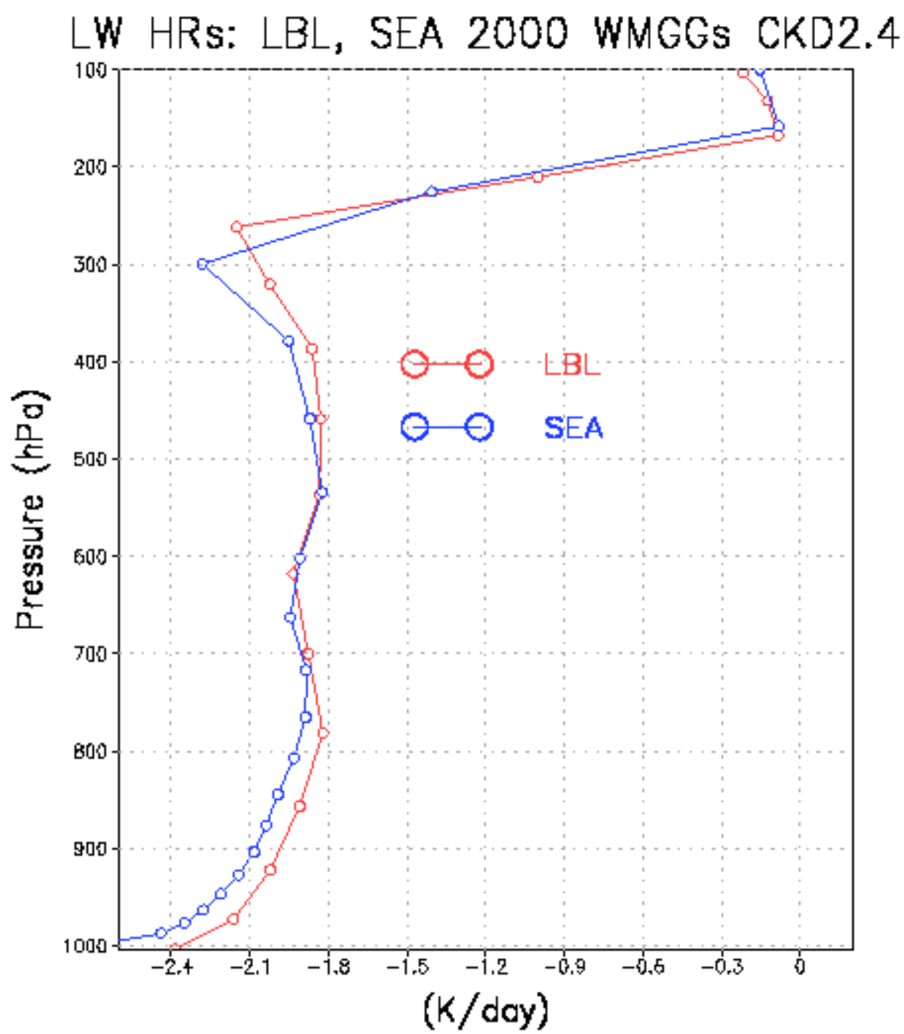
- Speed : on GAEA C2, radiation(LW+SW) for AM3 with 24 vertical levels, 144x72 horizontal grid takes ~ 1.2×10^{-5} sec/gridpoint
- Can include multiple minor species in exact CTS term, wide range of WMGG values. (presently 0-10000 ppmv CO_2, for example)
- Compatible with all “domain decompositions”
- High accuracy . TOA fluxes have been compared with satellite observations (Huang, 2007) and with LBL calculations (see above)

- The SEA algorithm is used in GFDL IPCC AR4 and AR5 simulations and compared with LBL and with other parameterizations as part of the IPCC process.

Comparison with LBL results and satellite measurements



LW HRs: LBL, SEA 2000 WMGGs CKD2.4
Pressure (hPa)
(K/day)
LBL
SEA
3
5
10
20
30
50
70
100
150
200
250
300
400
500
600
700
850
1000
-8
-7
-6
-5
-4
-3
-2
-1
0



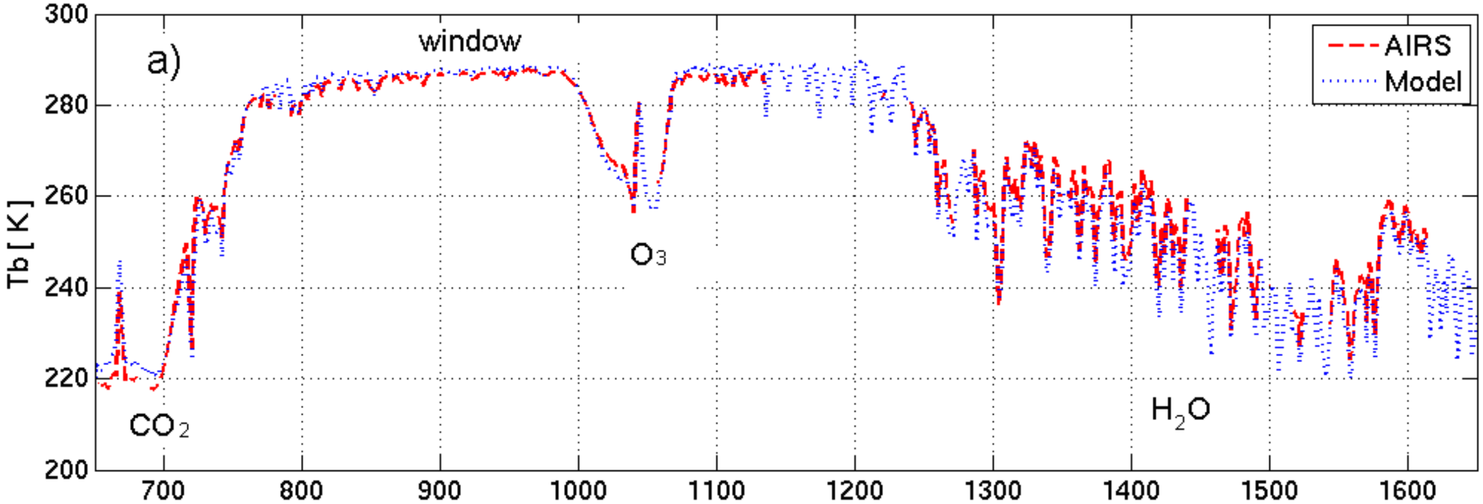
LW HRs: LBL, SEA 2000 WMGGs CKD2.4
Pressure (hPa)
100
200
300
400
500
600
700
800
900
1000
-2.4
-2.1
-1.8
-1.5
-1.2
-0.9
-0.6
-0.3
0
(K/day)
LBL
SEA

GCM vs. AIRS –

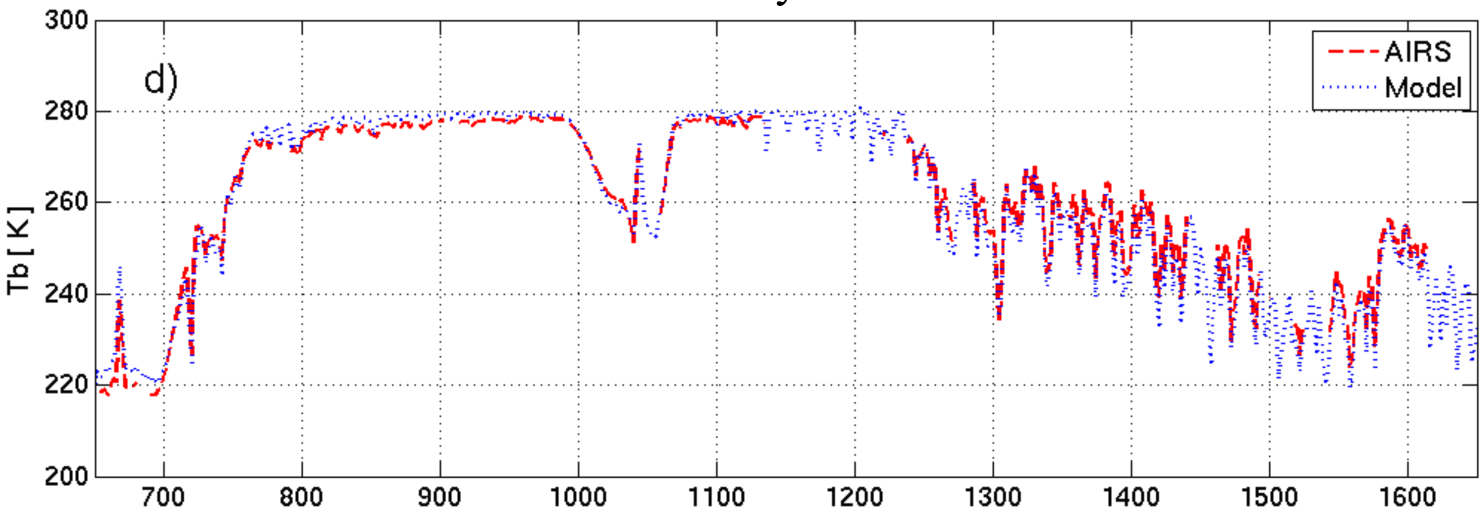
Global annual mean spectra

Note: Radiances (represented through brightness temperatures) are in the unit of Kelvin.

Clear-sky



Total-sky



[Huang et al. 2007 GRL]

Running and changing the radiation code

standalone model

- The standalone model is a subset of the model including those modules needed to obtain radiative fluxes and heating rates for different forcing agents
- This model can be used to test different parameter settings for:
  1) the radiative algorithm

2) Effects of changes in forcing agents
3) Effects of changes in parameters for aerosols, clouds, convection
and chemistry (to be discussed later)
4) effect of replacement of this SEA code with other algorithms (such as RRTMG)

- Model code and standalone code agree – except for the driver program
- Namelists and data files (pertaining to radiation) are the same and are described in following slides

Namelists

Most significant namelists affecting the radiative transfer code:

1) sealw99 – controls continuum, HITRAN catalog
2) radiative gases – controls amounts of well-mixed gases used in the AM3/standalone model, including time variation
3) radiation driver – controls which radiation algorithm to use, solar input and zenith angle specifications
4) aerosol – controls which aerosol species (sulfate,black and organic carbon, dust, sea-salt) are included
5) dust – controls dust amount
   ssalt – controls sea salt
6) aerosolrad_package – controls inclusion of eruptive volcanos (eg, Pinatubo, Krakatoa, etc) and humidifation factors for aerosols (which will be discussed in future classes)
7) ozone – controls ozone variation

many other namelist parameter changes will affect the results

datafiles

- The main datafiles needed to run the AM3/ standalone code are:
- 1) precalculated CO_2, CH_4 and N_2O transmission functions for
  14 CO_2 concentrations
  (165-10000 ppmv), 5 frequency ranges
  9 CH_4 concentrations (300-6000 ppbv, 1 frequency range

9 N_2O concentrations (180-800 ppbv), 3 frequency ranges

- spectral coefficients (narrow-band, wide-band) for H_2O lines and continuum coefficients (in the longwave spectrum)
- The coefficients and transmission functions are obtained using an offline LBL calculation;

the HITRAN 2000 line catalog has been used to obtain line strengths and line widths for CO_2,CH_4,N_2O and H_2O lines; can use HITRAN 2008

- Spectral coefficients for the shortwave code (ESF)
- Aerosol and volcanic optical properties (ext coefficients, asymmetry parameter, single-scattering albedo)
- Solar spectral data
- For applications where ozone and aerosol are not computed, files exist for aerosol and ozone climatology

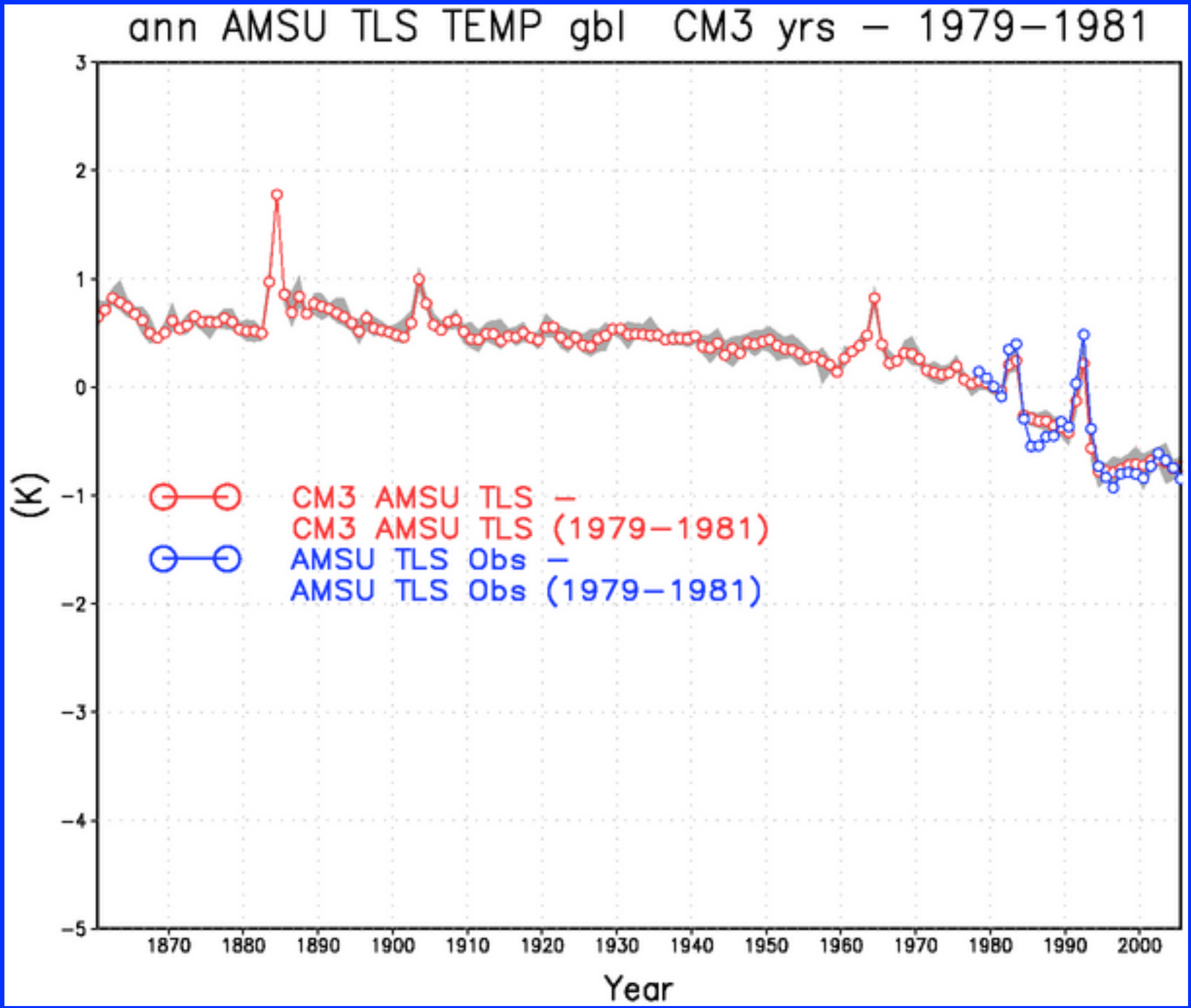
- All these data are in cpio files given in the xml files used to set up and run the model (discussed later), in particular sea_esf_dec_2009.cpio

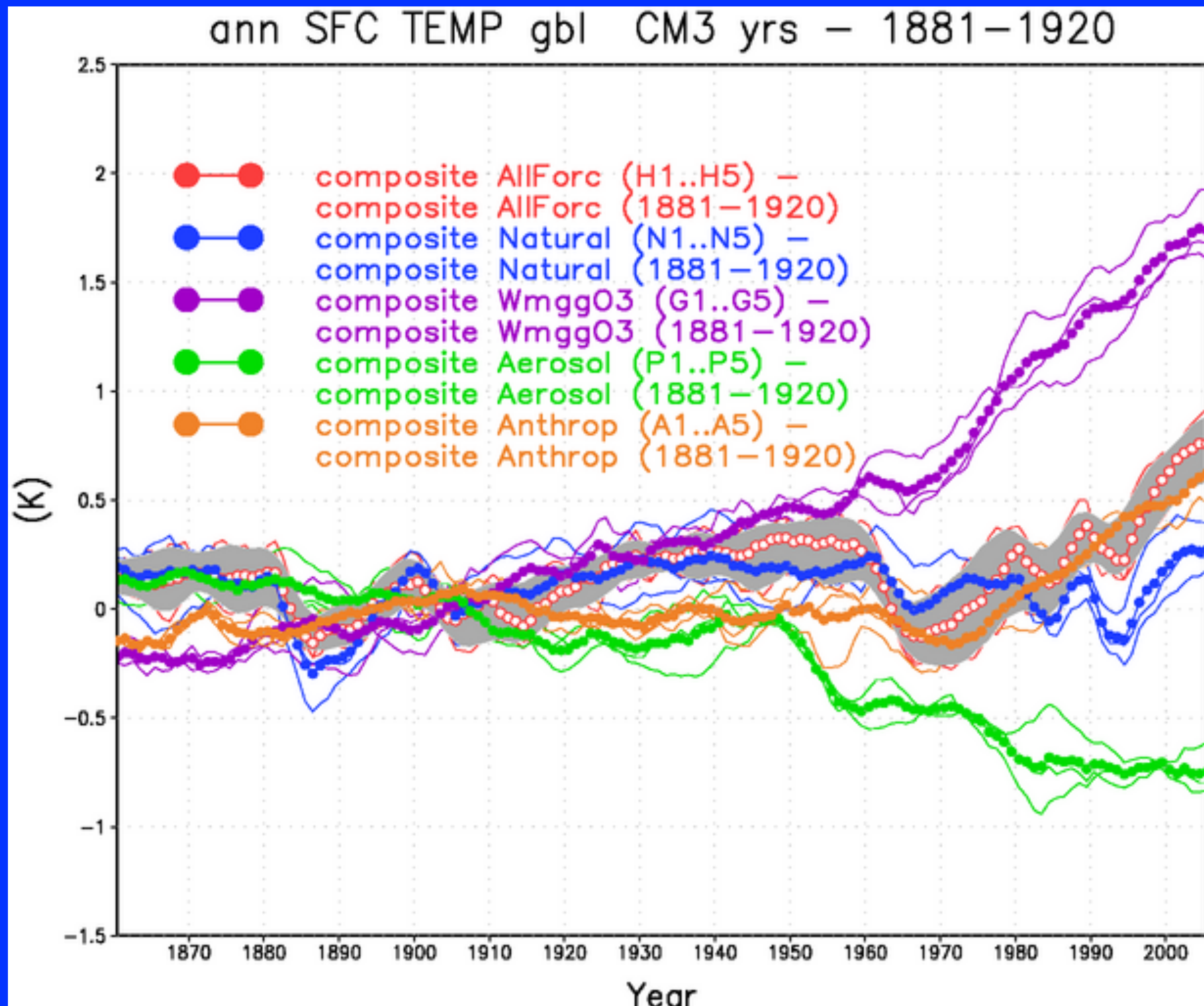
Radiation modules

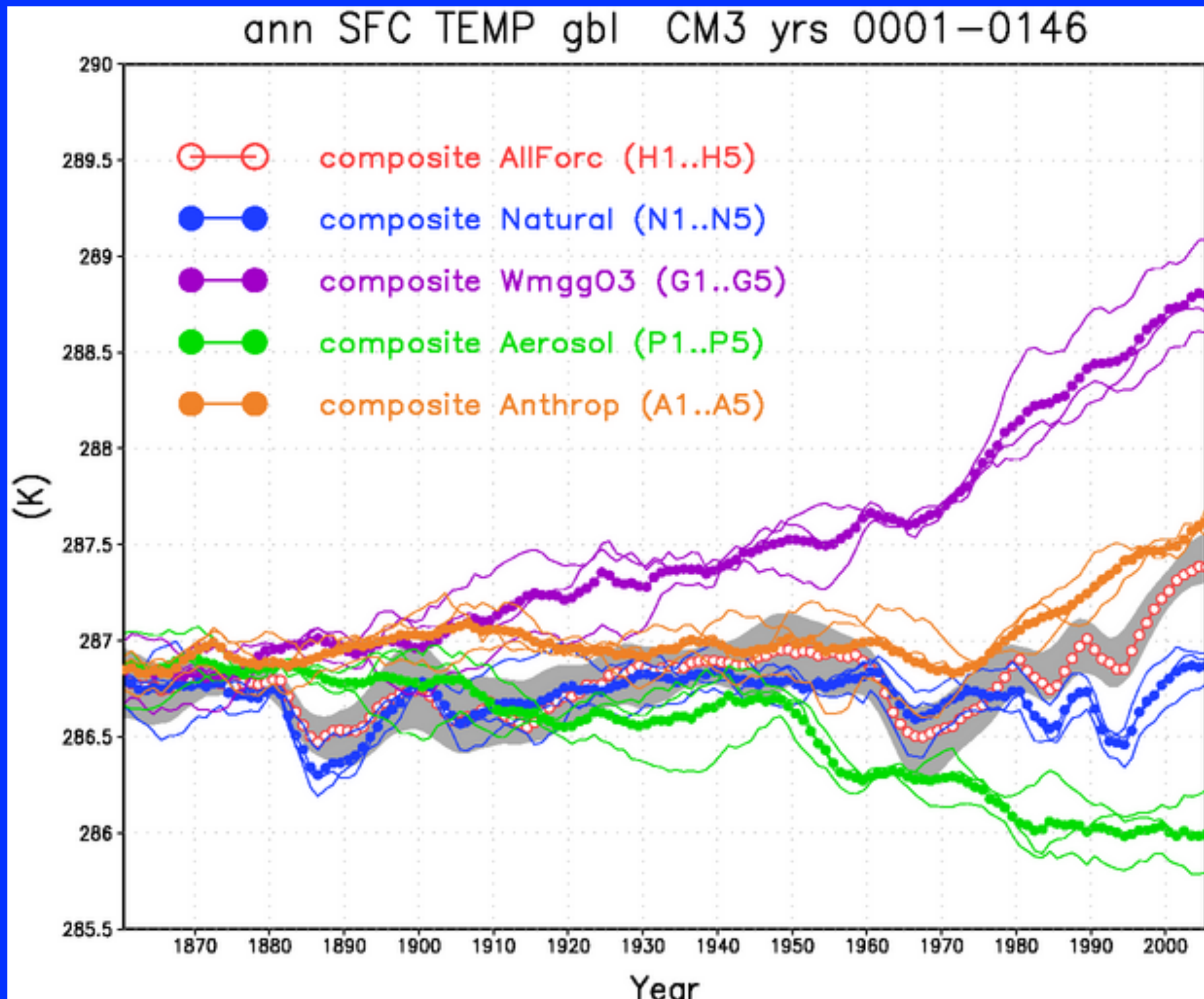
- Most of the (many) modules in computation of SW and LW radiative transfer are in /atmos_param/sea_esf_rad/
- /atmos_param/radiation_driver/radiation_driver.F90 calls the radiation code and fetches required (astronomy, diagnostic, etc) quantities

CM3 results

CM3 strat temp evolution vs satellite obs




ann SFC TEMP gbl CM3 yrs - 1881-1920
composite AllForc (H1..H5) -
composite AllForc (1881-1920)
composite Natural (N1..N5) -
composite Natural (1881-1920)
composite WmggO3 (G1..G5) -
composite WmggO3 (1881-1920)
composite Aerosol (P1..P5) -
composite Aerosol (1881-1920)
composite Anthrop (A1..A5) -
composite Anthrop (1881-1920)
(K)
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Year



ann SFC TEMP gbl CM3 yrs 0001-0146
composite AllForc (H1..H5)
composite Natural (N1..N5)
composite WmggO3 (G1..G5)
composite Aerosol (P1..P5)
composite Anthrop (A1..A5)
(K)
290
289.5
289
288.5
288
287.5
287
286.5
286
285.5
1870
1880
1890
1900
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1980
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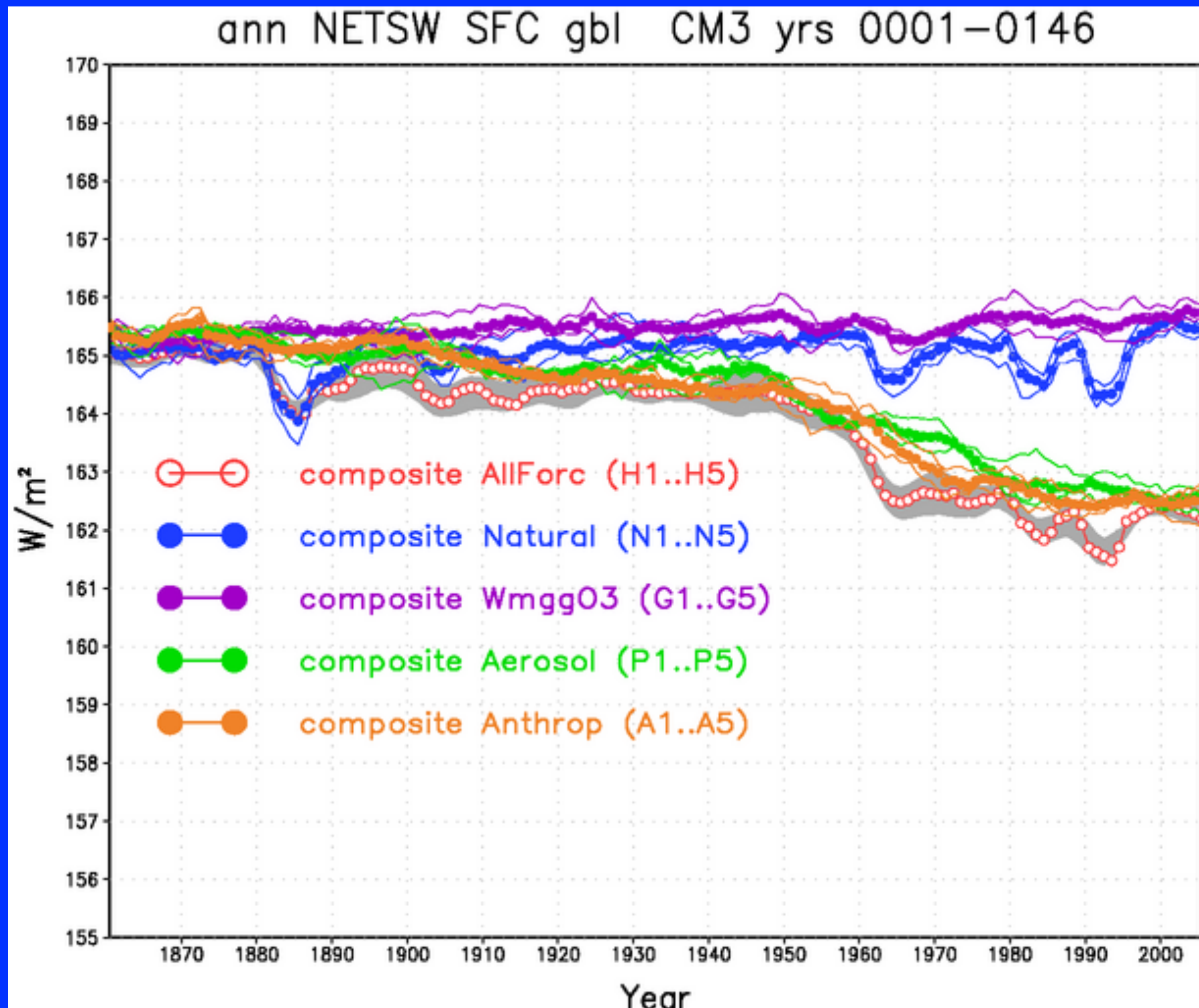
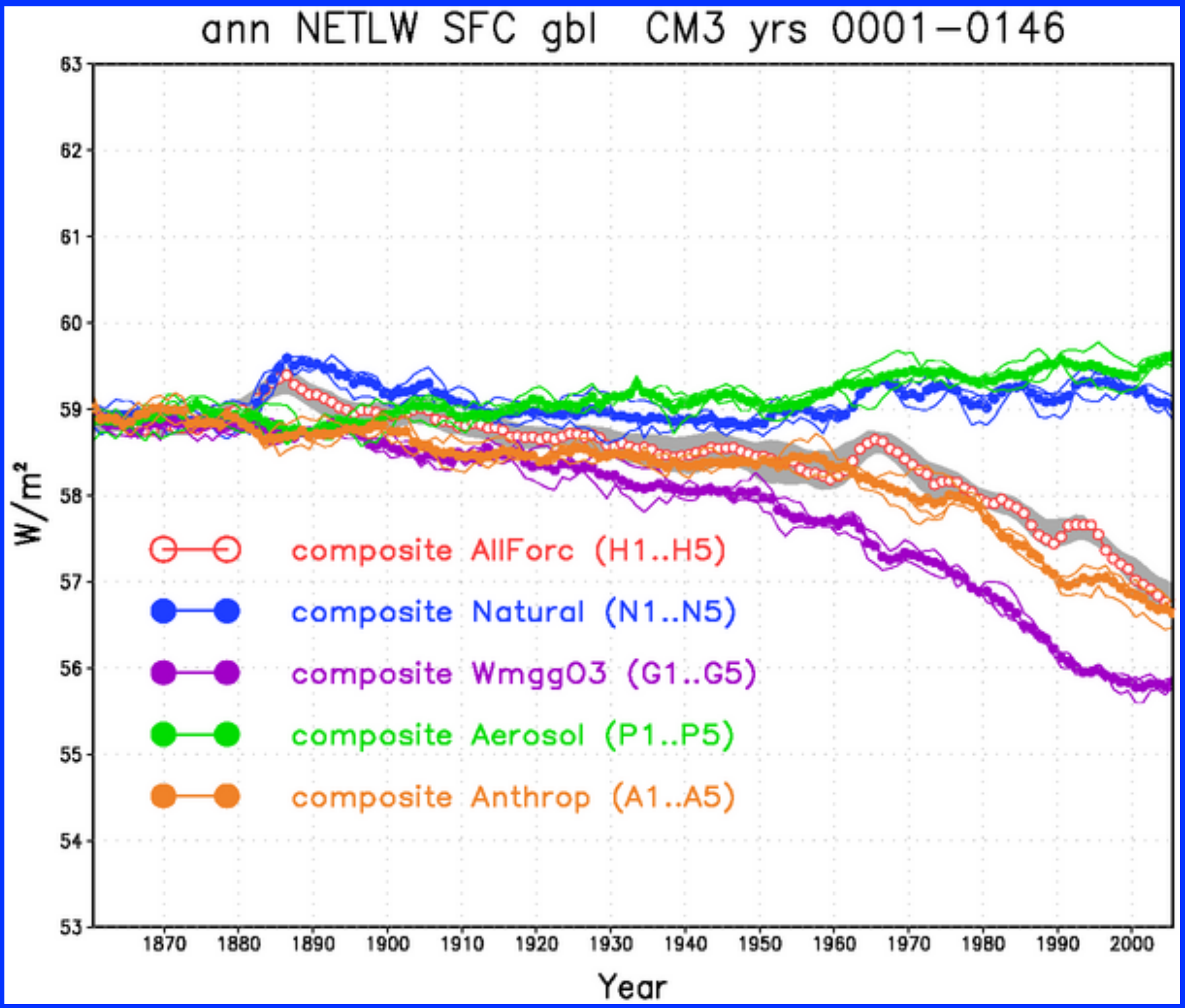
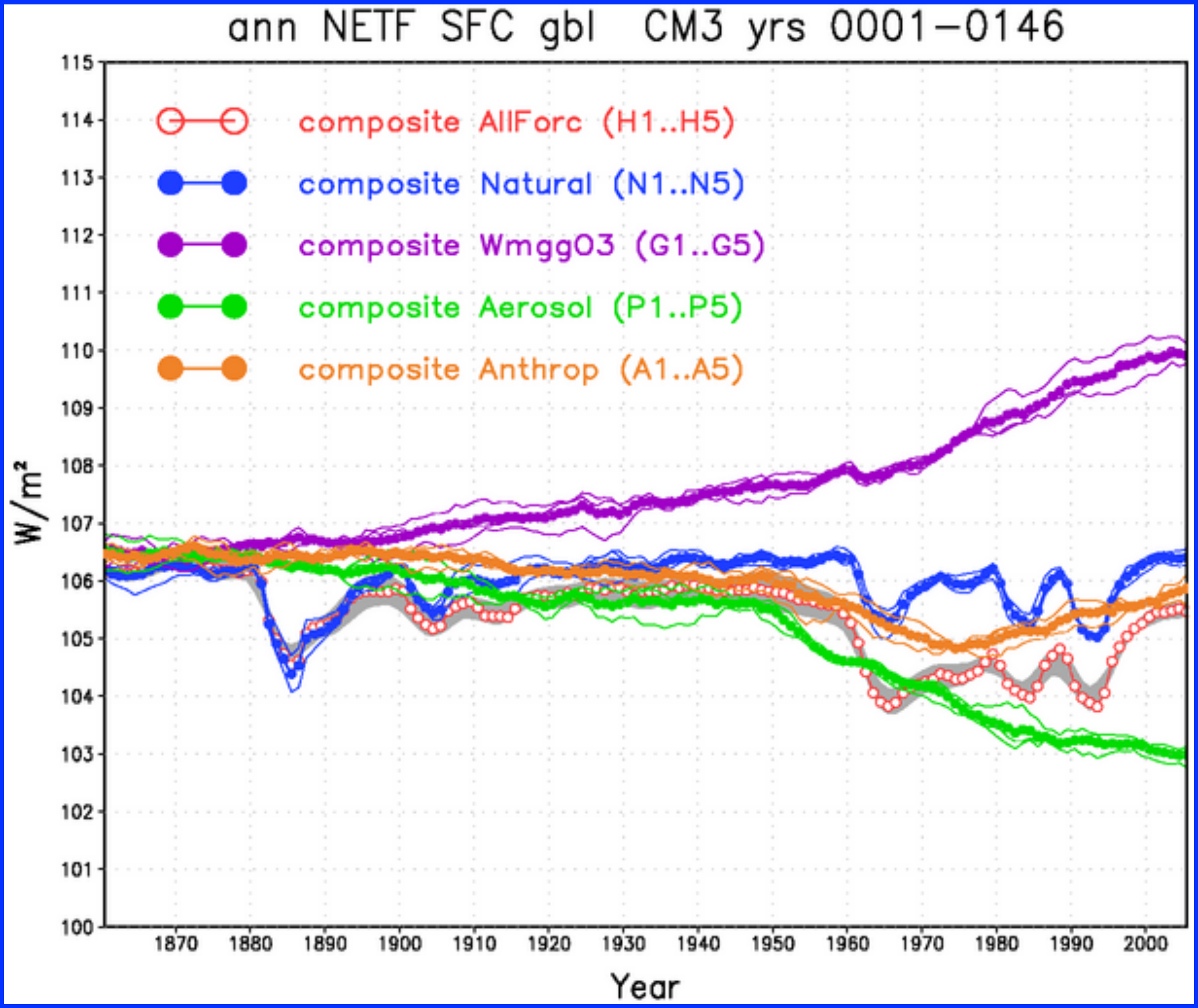
2000
Year



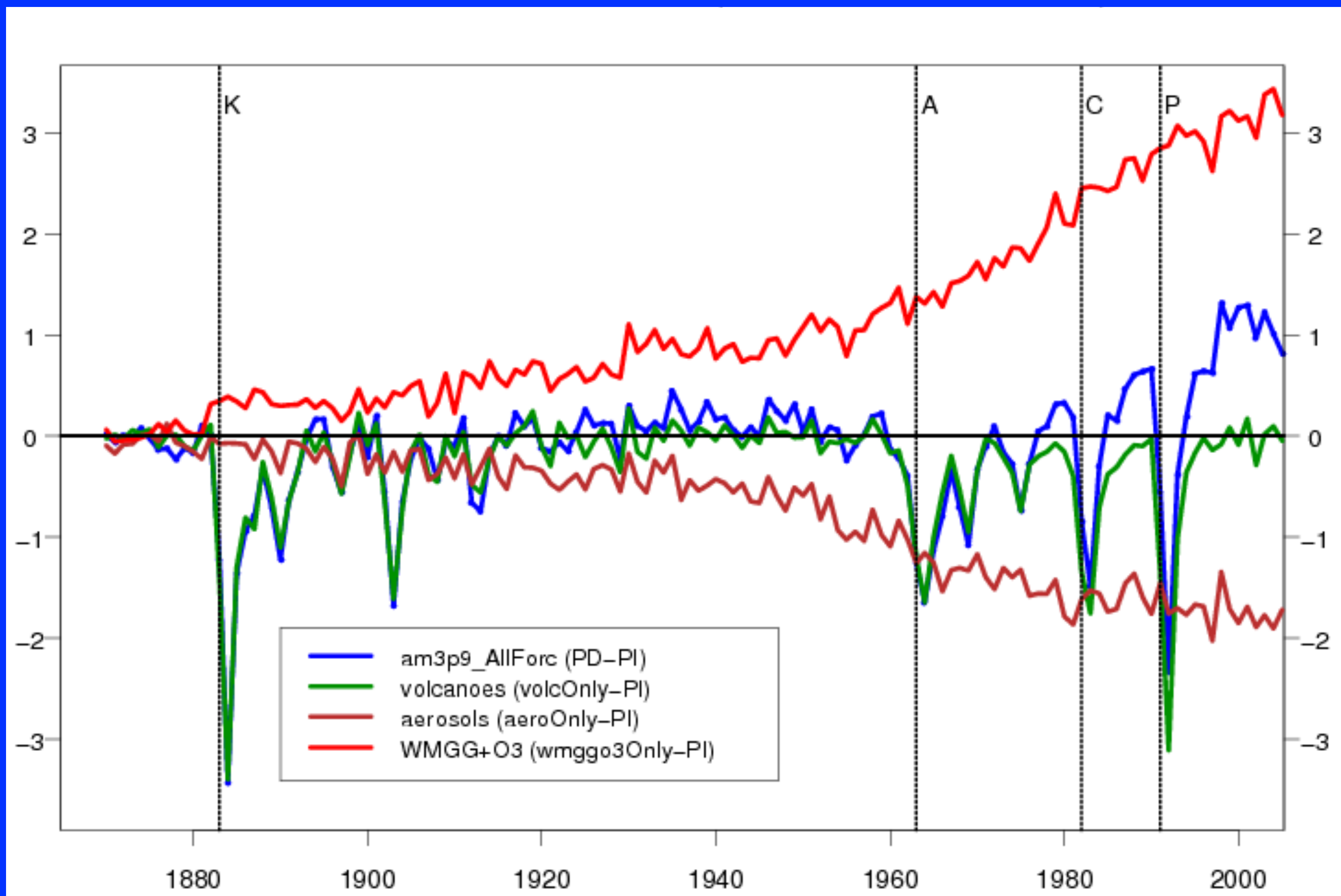
ann NETSW SFC gbl CM3 yrs 0001-0146
W/m²
Year
170
169
168
167
166
165
164
163
162
161
160
159
158
157
156
155
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
composite AllForc (H1..H5)
composite Natural (N1..N5)
composite WmggO3 (G1..G5)
composite Aerosol (P1..P5)
composite Anthrop (A1..A5)


ann NETLW SFC gbl CM3 yrs 0001-0146
W/m²
Year
composite AllForc (H1..H5)
composite Natural (N1..N5)
composite Wmgg03 (G1..G5)
composite Aerosol (P1..P5)
composite Anthrop (A1..A5)


ann NETF SFC gbl CM3 yrs 0001-0146
composite AllForc (H1..H5)
composite Natural (N1..N5)
composite WmggO3 (G1..G5)
composite Aerosol (P1..P5)
composite Anthrop (A1..A5)
W/m²
Year
115
114
113
112
111
110
109
108
107
106
105
104
103
102
101
100
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

Radiative Flux Perturbation (RFP)

W/m2



year

Disadvantages

- No capability for up, down LW fluxes except at TOA, SFC
- LW scattering not included
- Cloud heights are different in LW and SW
- Code can incorporate stochastic cloud treatment (Pinkus et al, 2006) but in a complicated way
- Code is more "complicated" due to CTS calculations, accounting for "nearby layers"