Solar record based on cosmogenic isotopes (^{10}Be & ^{14}C)

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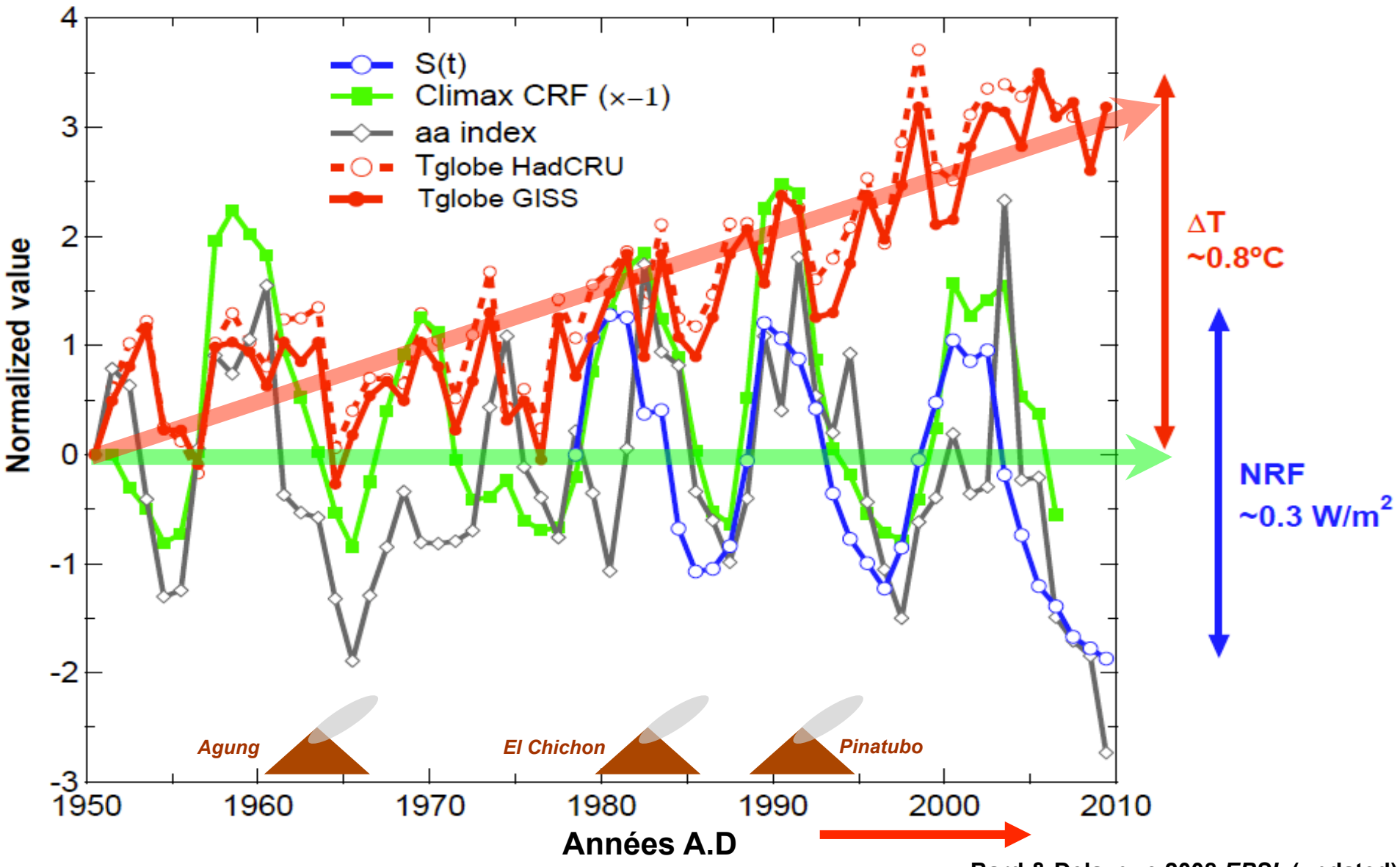
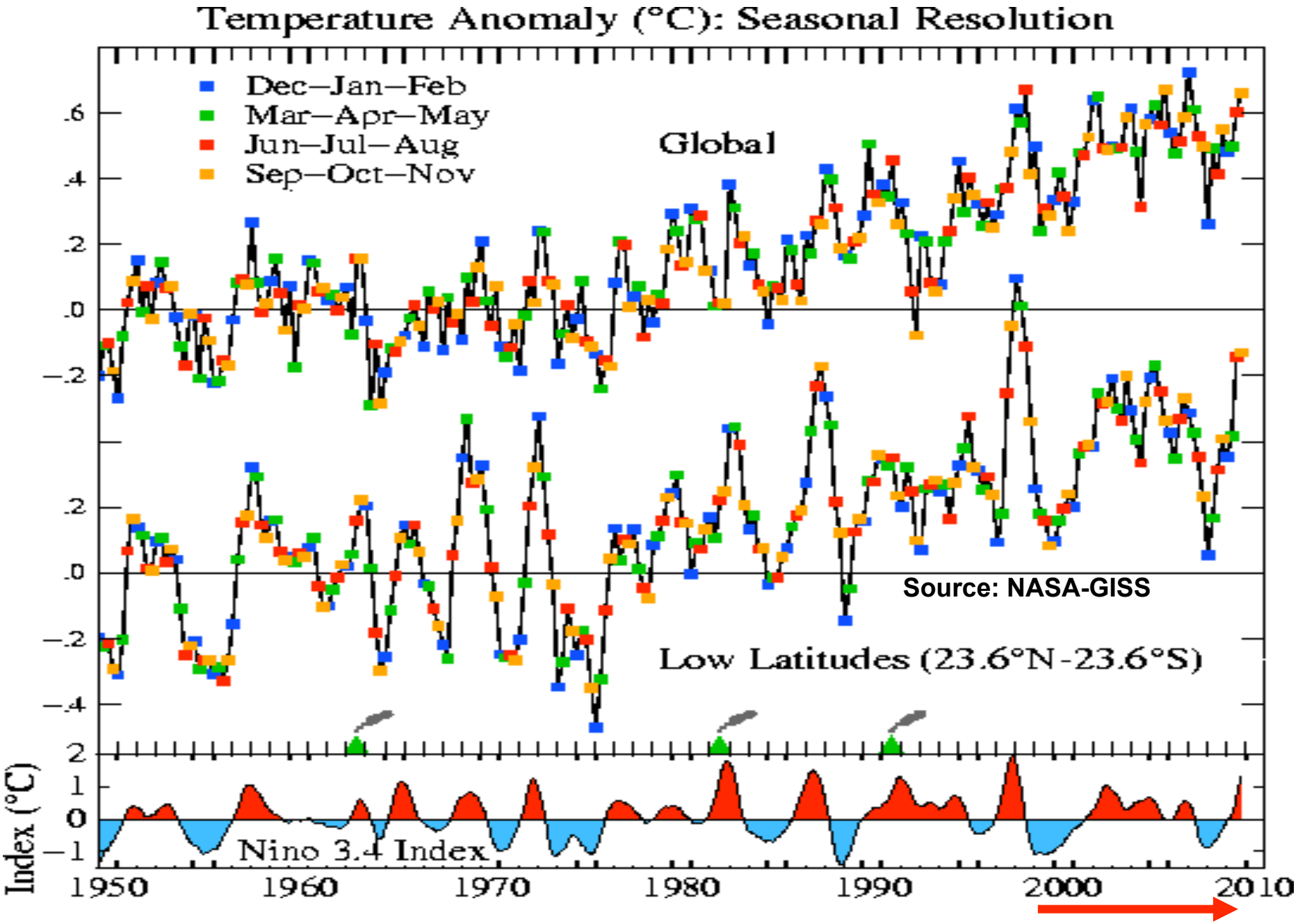
Over the past 60 years, the total irradiance and heliomagnetic modulation of cosmic rays doesn't seem to show a long-term trend that could have contributed to global warming



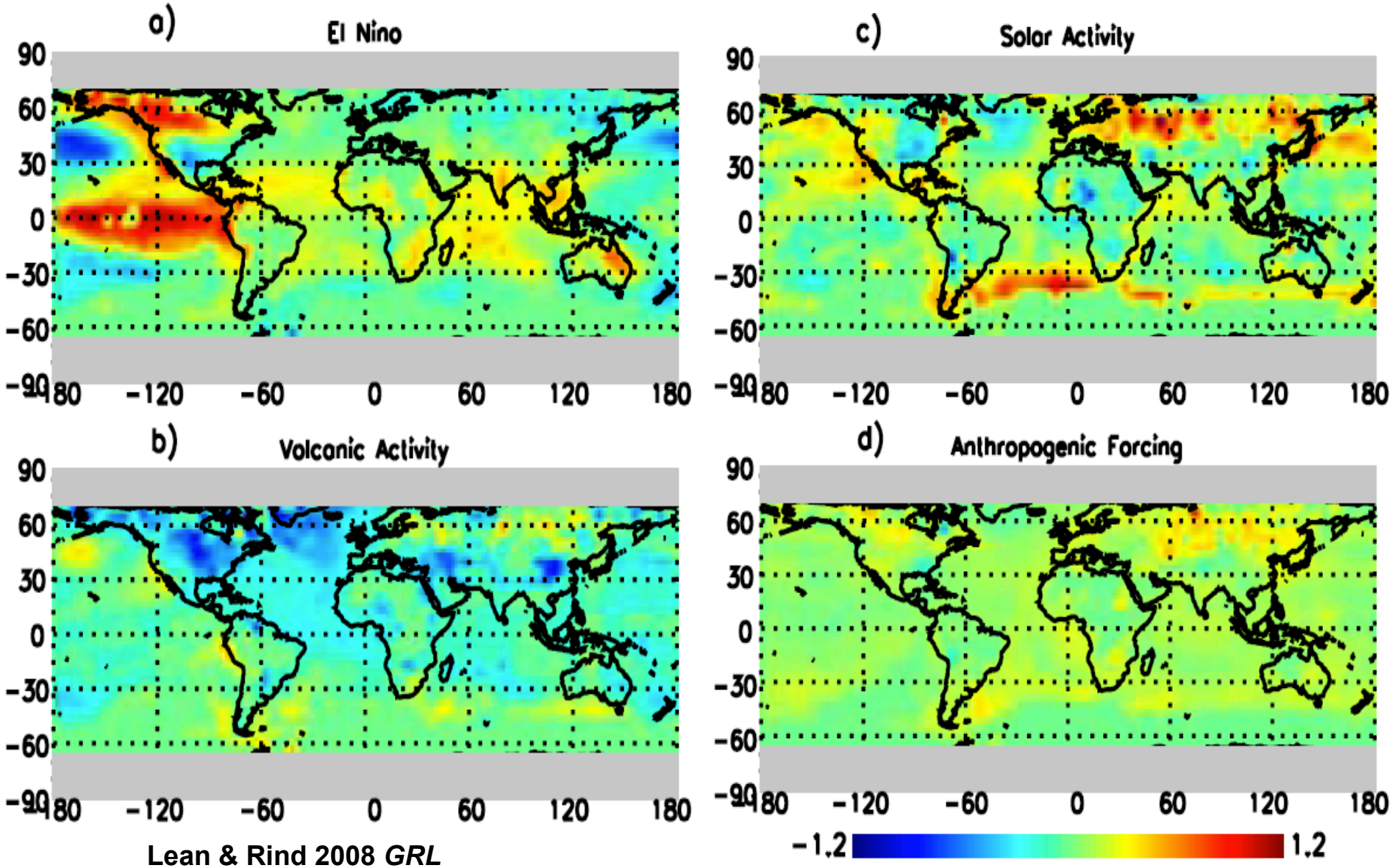
Bard & Delaygue 2008 *EPSL* (updated)

Beyond the annual mean T: seasonal and zonal variations



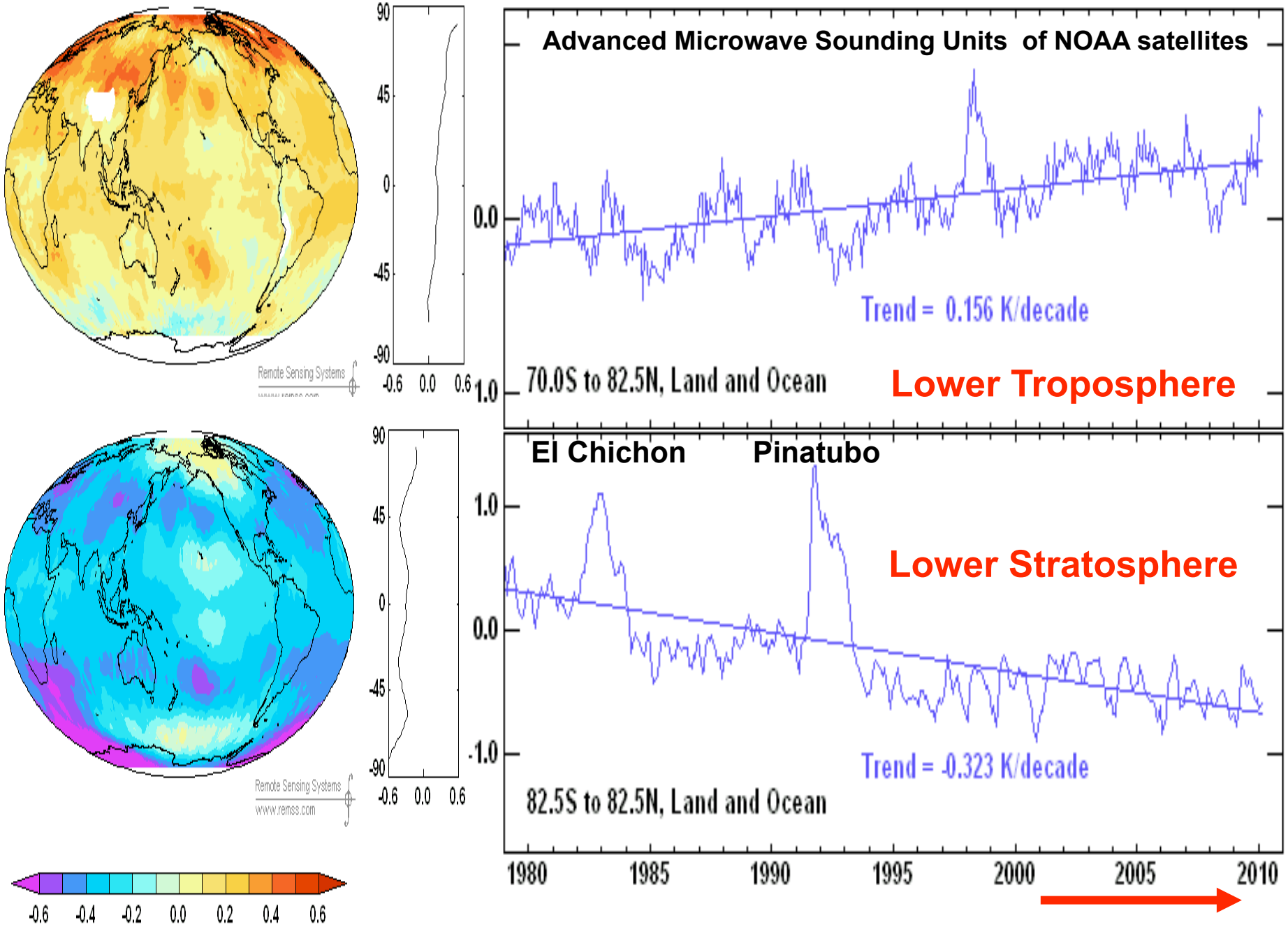
Beyond the annual mean temperature:

multivariate spatial correlation analysis (1889-2006)

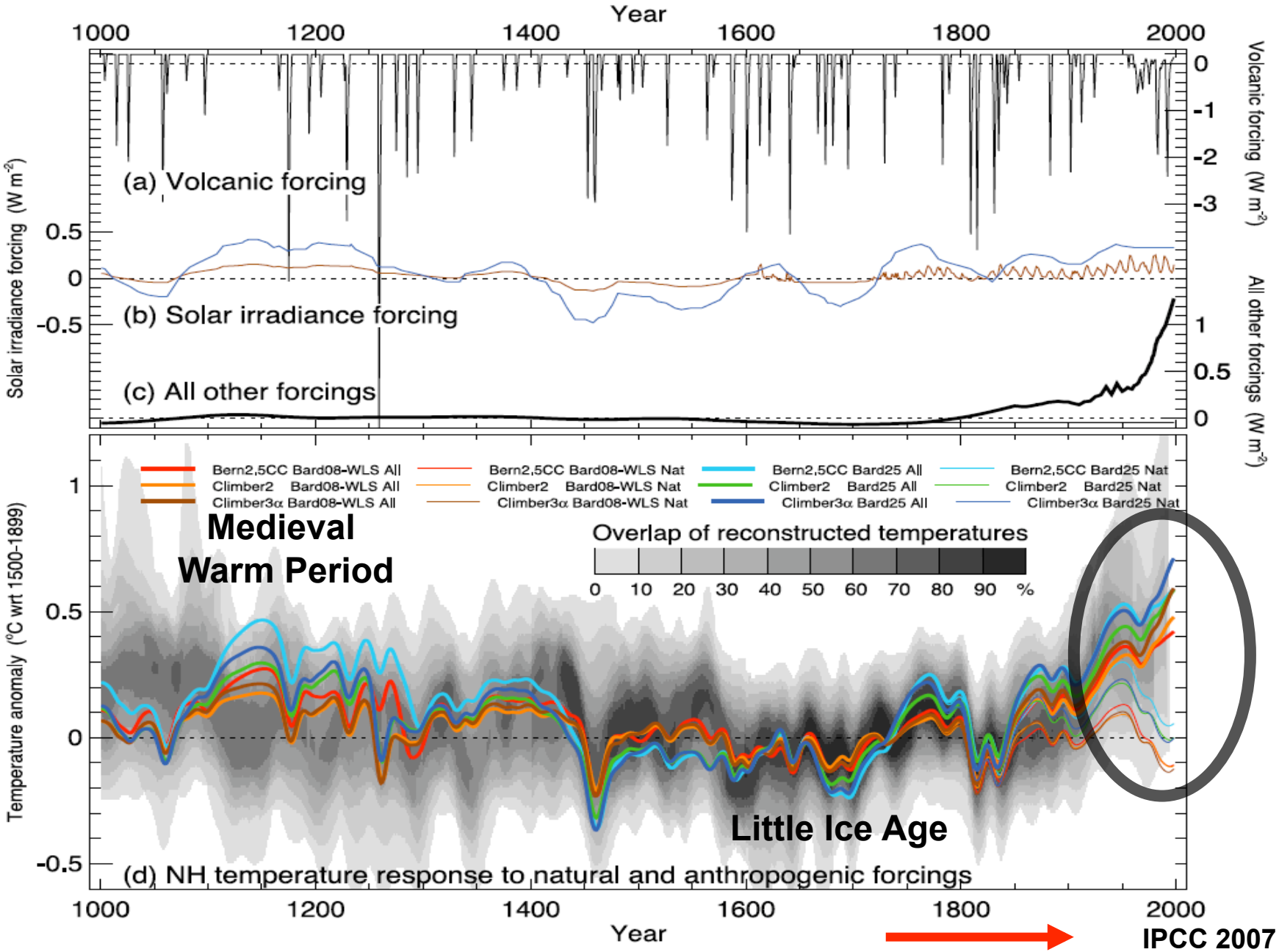


Lean & Rind 2008 *GRL*

Beyond the annual mean temp : altitudinal variations

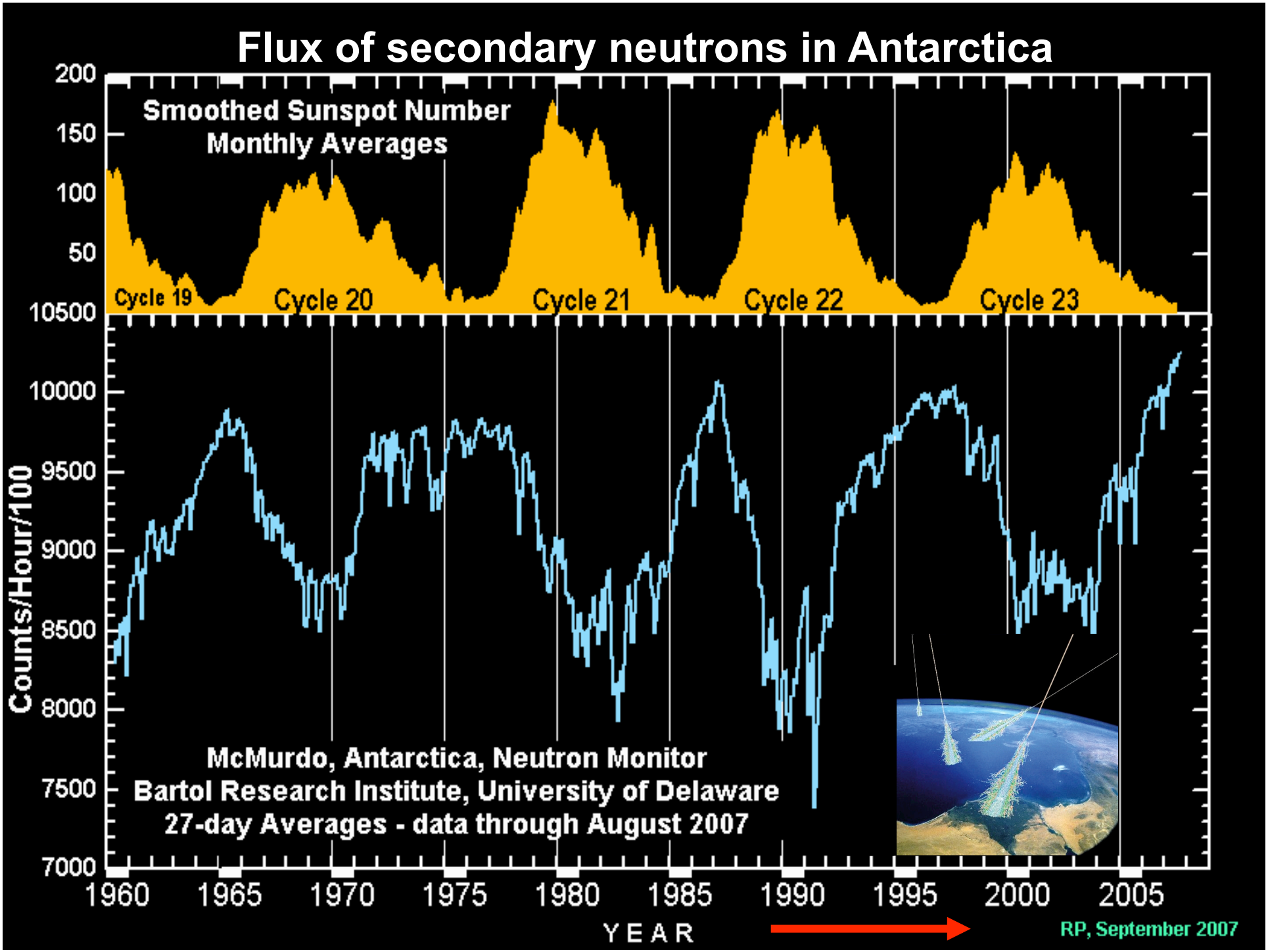


Model data comparison for the last millennium

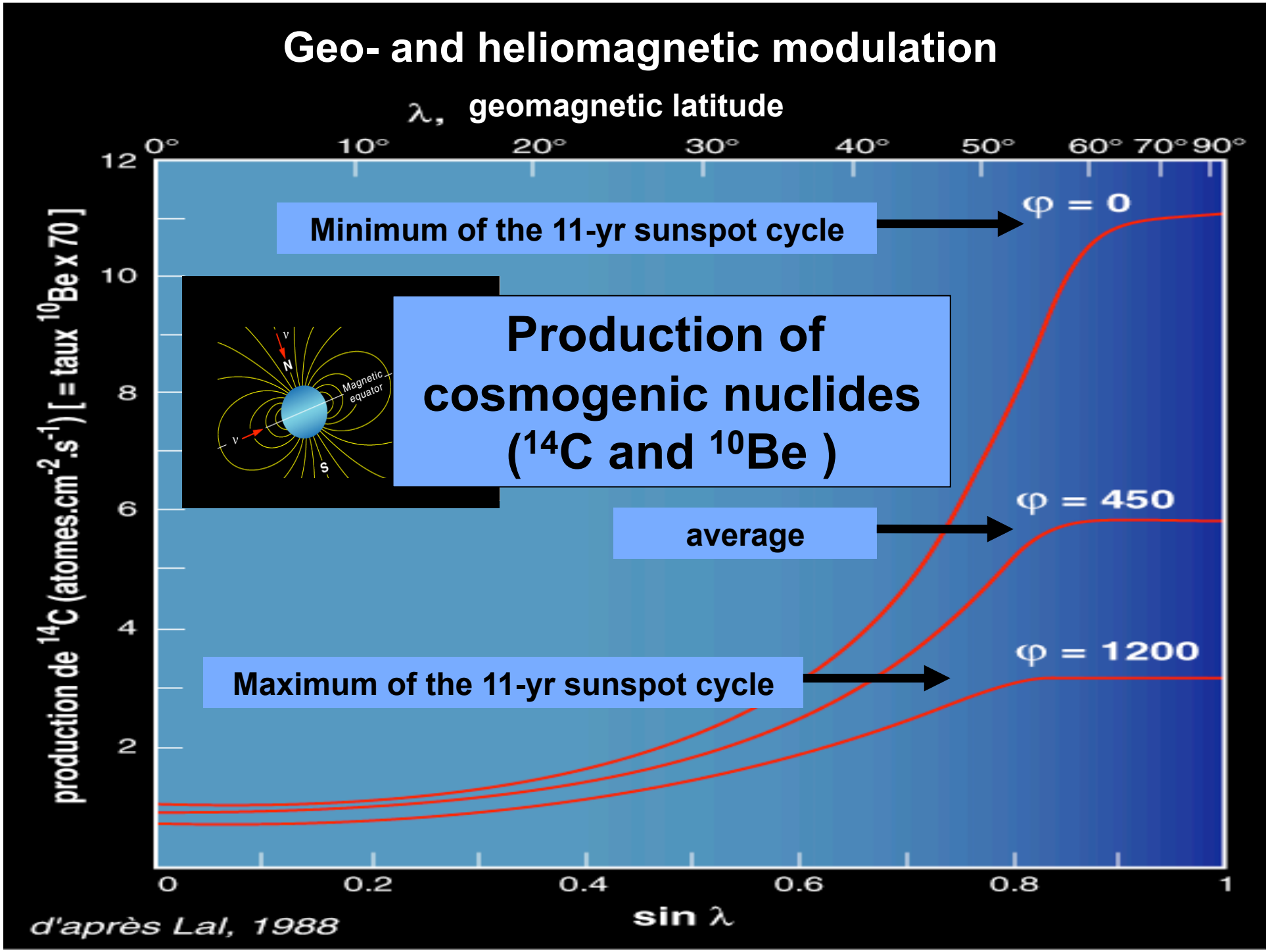


IPCC 2007

Flux of secondary neutrons in Antarctica



Geo- and heliomagnetic modulation



^{10}Be production as a function of altitude, the solar modulation parameter Φ and the intensity of the geomagnetic dipole M/M_o

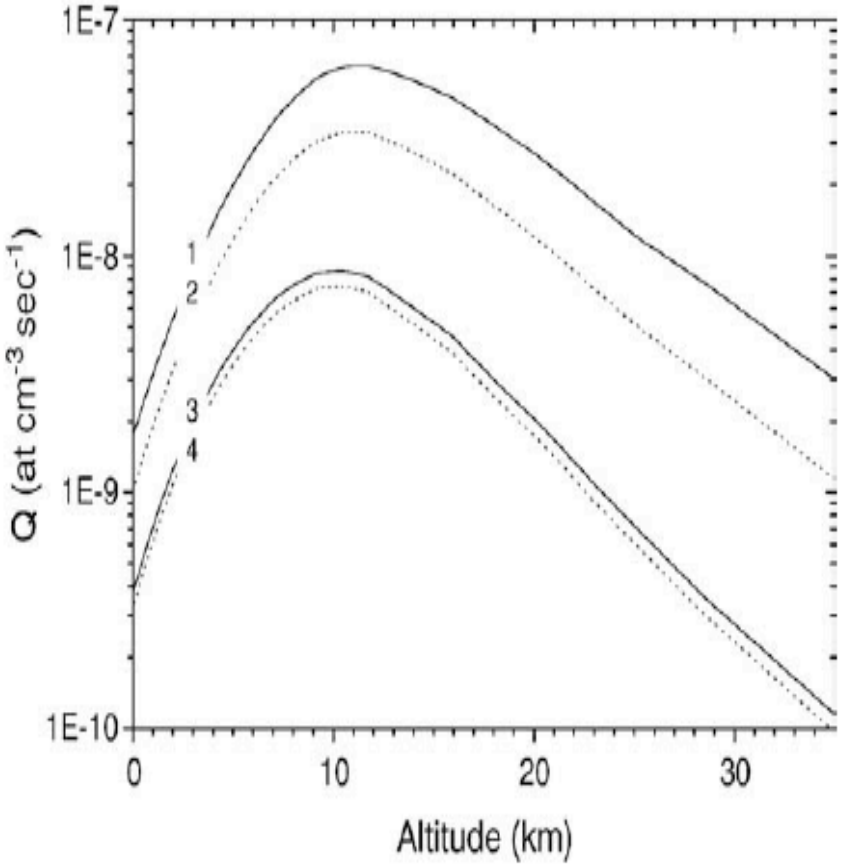


Fig. 2. Local production Q (atoms cm^{-3} s^{-1}) of ^{10}Be in the atmosphere as function of altitude. Different curves correspond to: 1 – solar minimum ($\phi = 300$ MV), polar region; 2 – solar maximum (ϕ=1000 MV), polar region; 3 – solar maximum, equator; and 4 – solar maximum, equator.

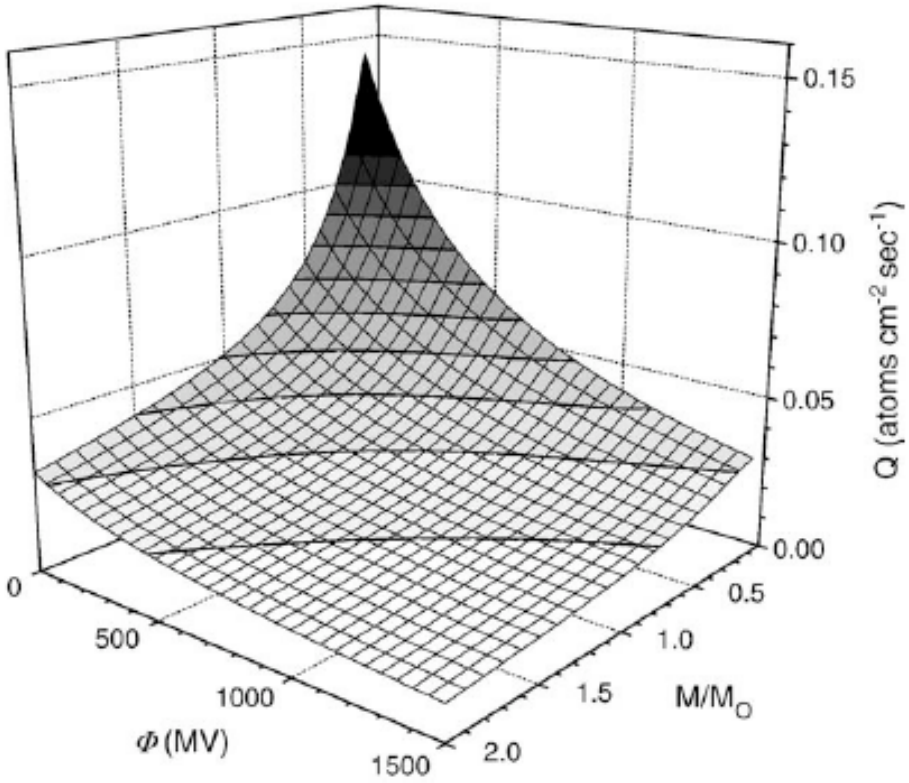
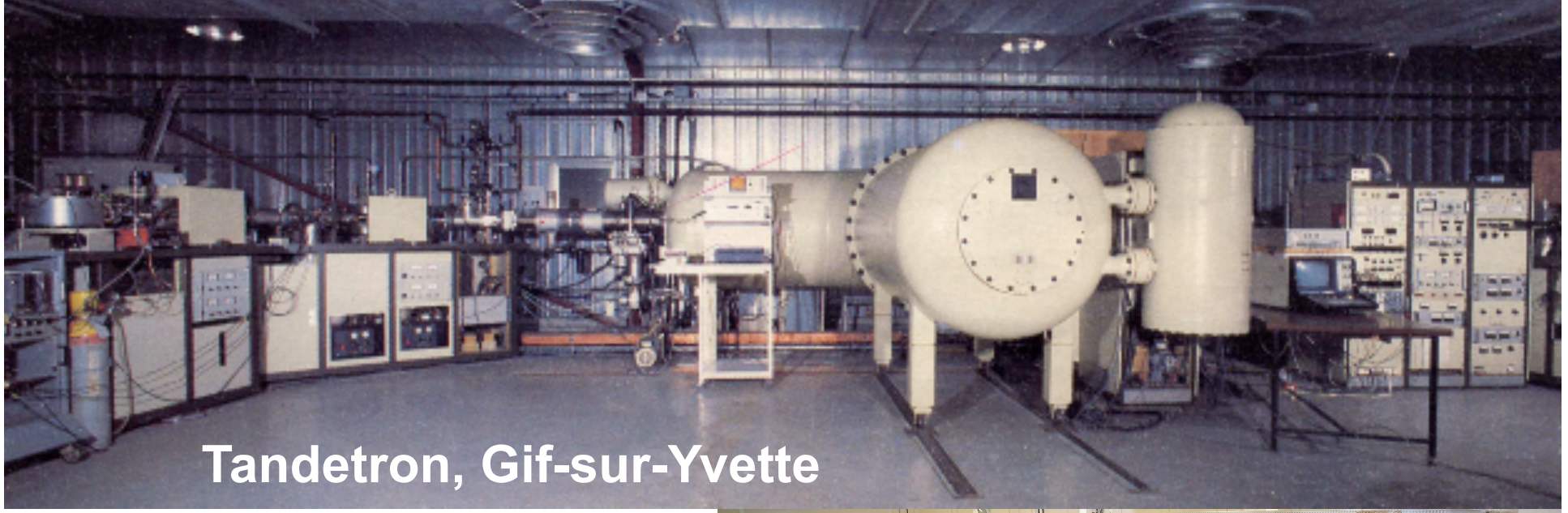
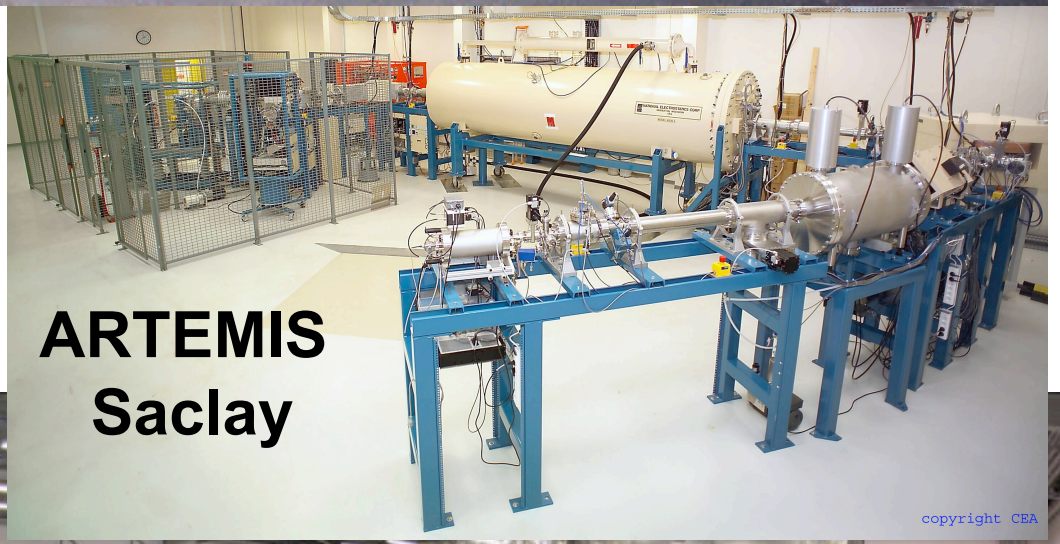


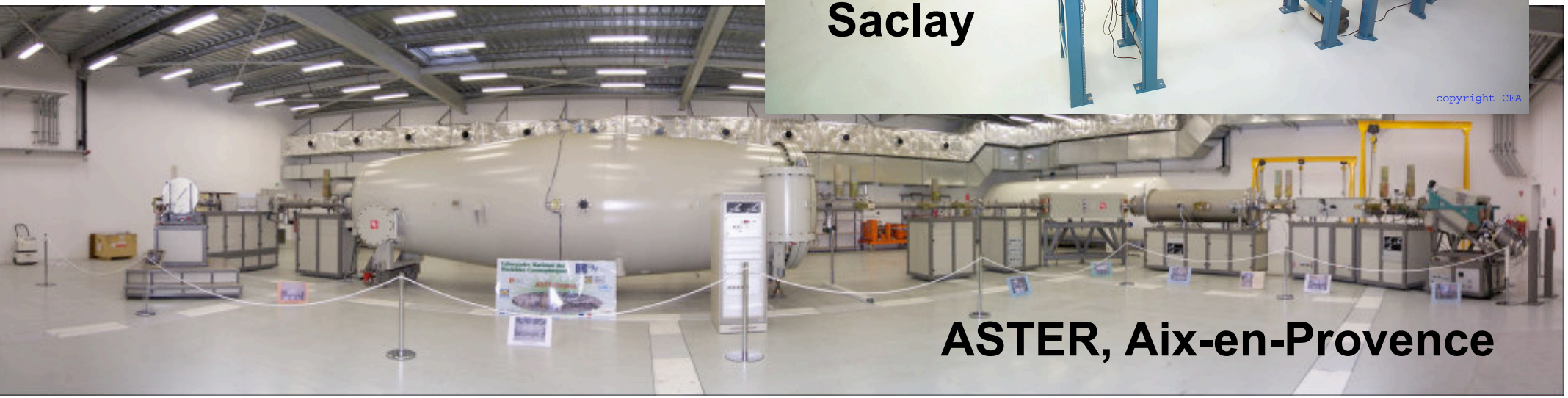
Fig. 1. Global production rate (atoms cm^{-2} s^{-1}) of ^{10}Be as function of the modulation potential ϕ and the magnetic dipole strength relative to the present one, M/M_o.

Kovaltsov & Usoskin 2010 *EPSL*

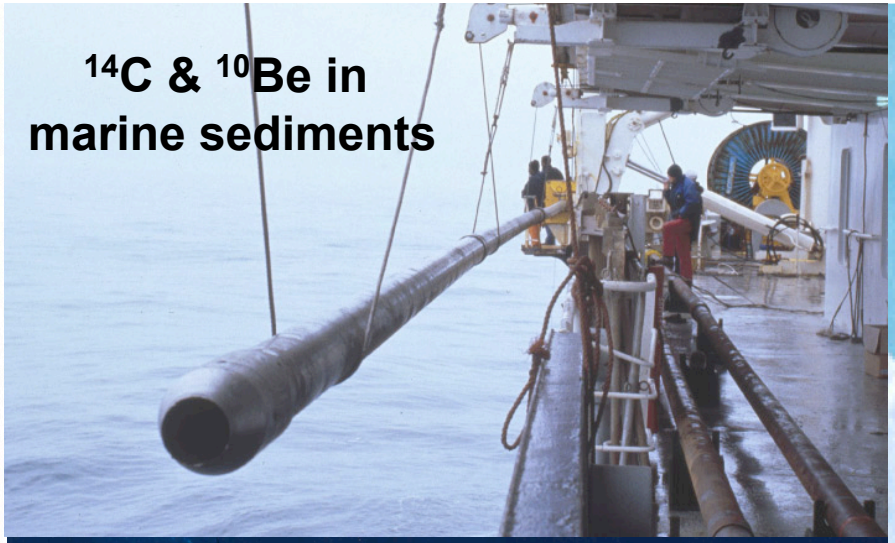


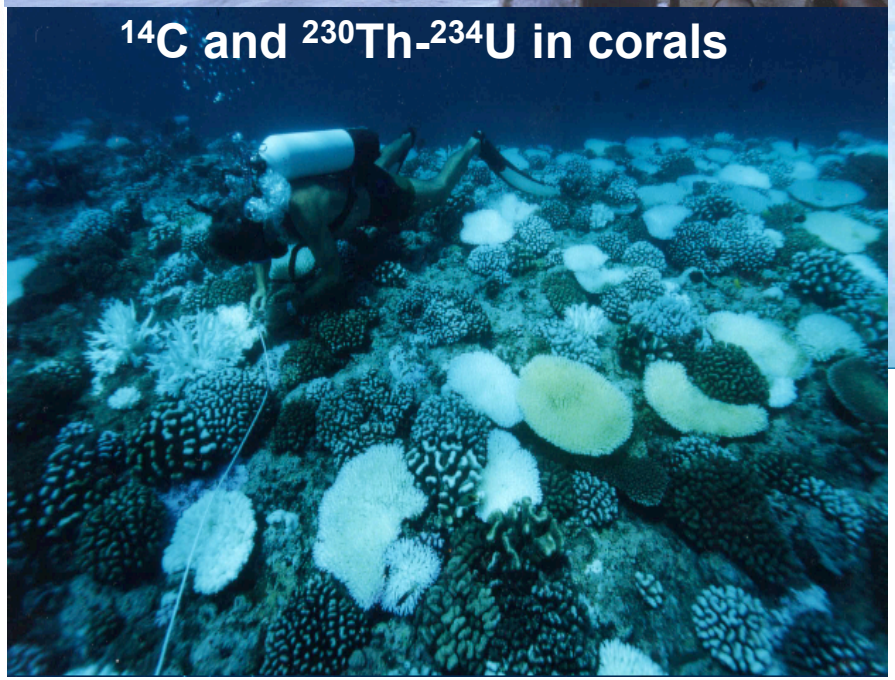
^{14}C, ^{10}Be and ^{36}Cl by Accelerator Mass Spectrometry



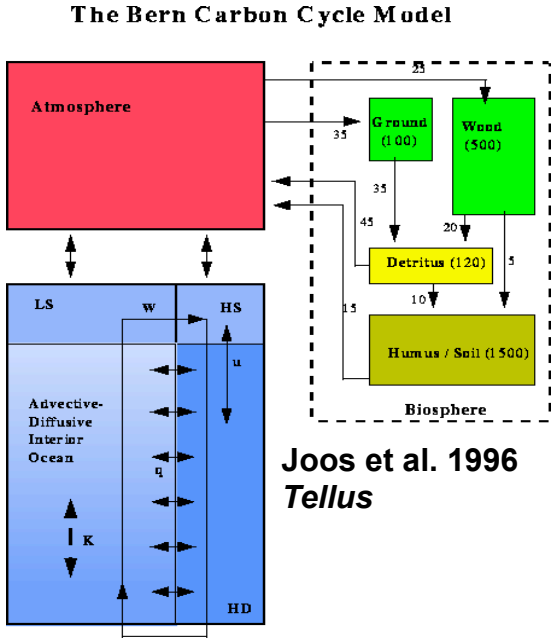


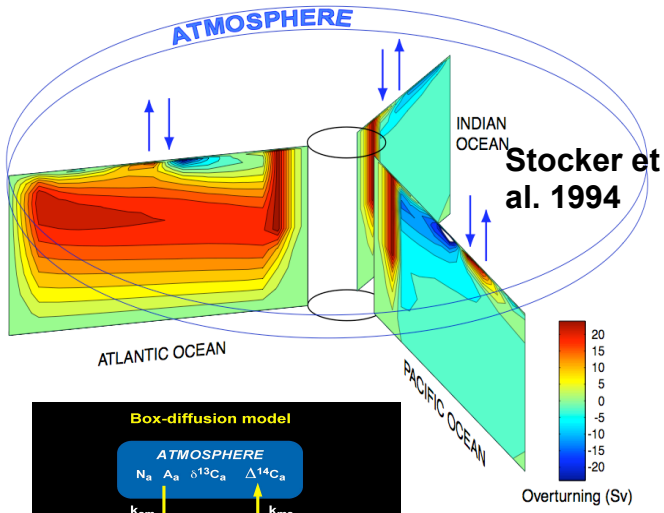
Beyond the 17th century, the only way to study the solar activity is to measure cosmogenic nuclides in various "geological" archives

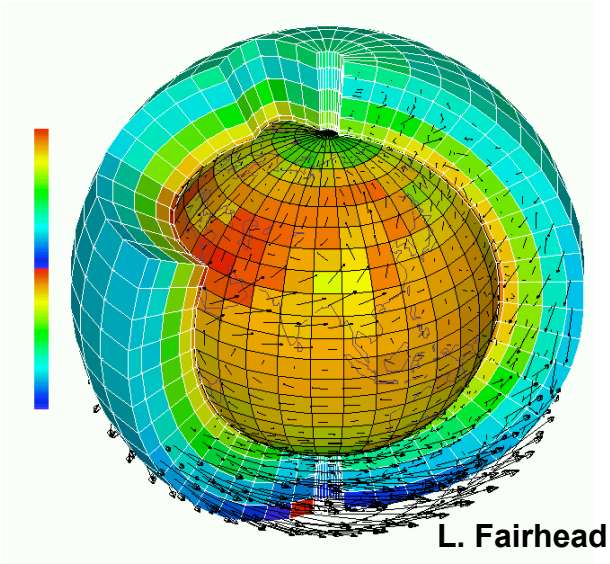


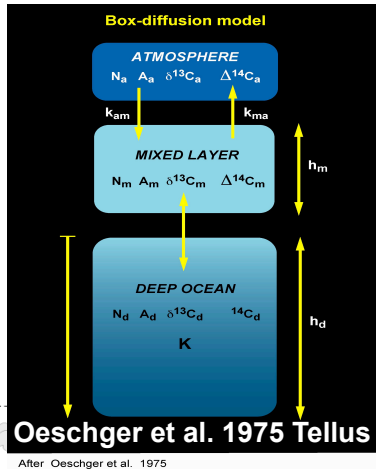


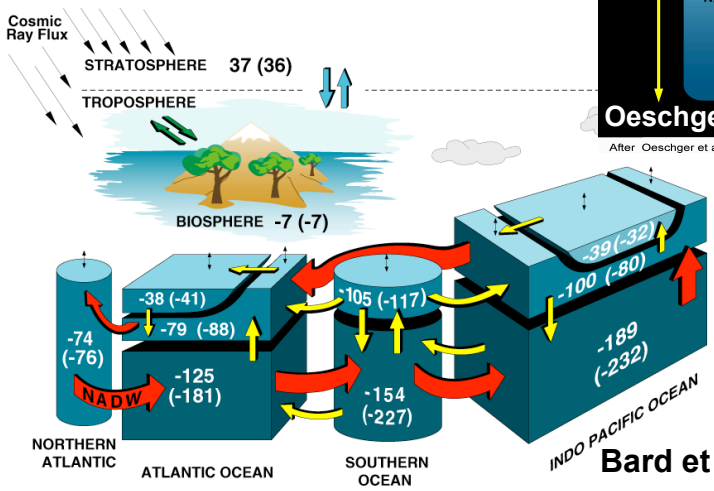
Comparing ^{14}C and ^{10}Be records requires the use of numerical models of various complexity

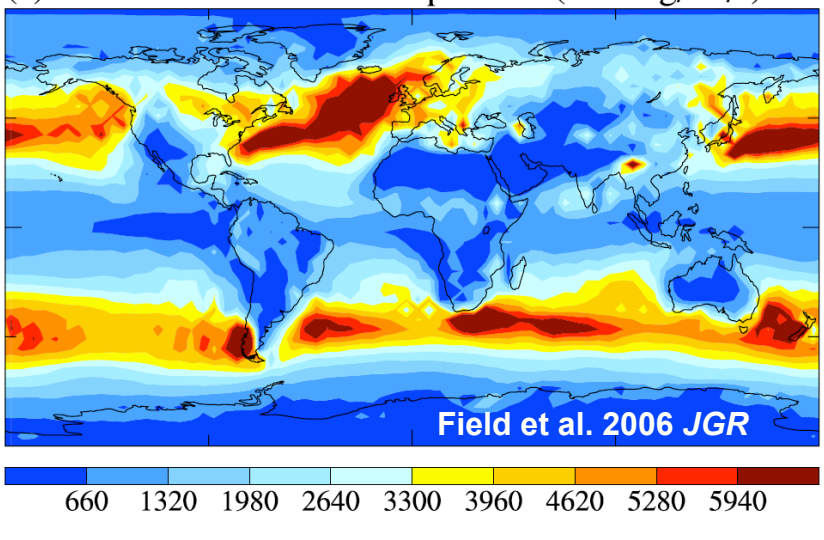




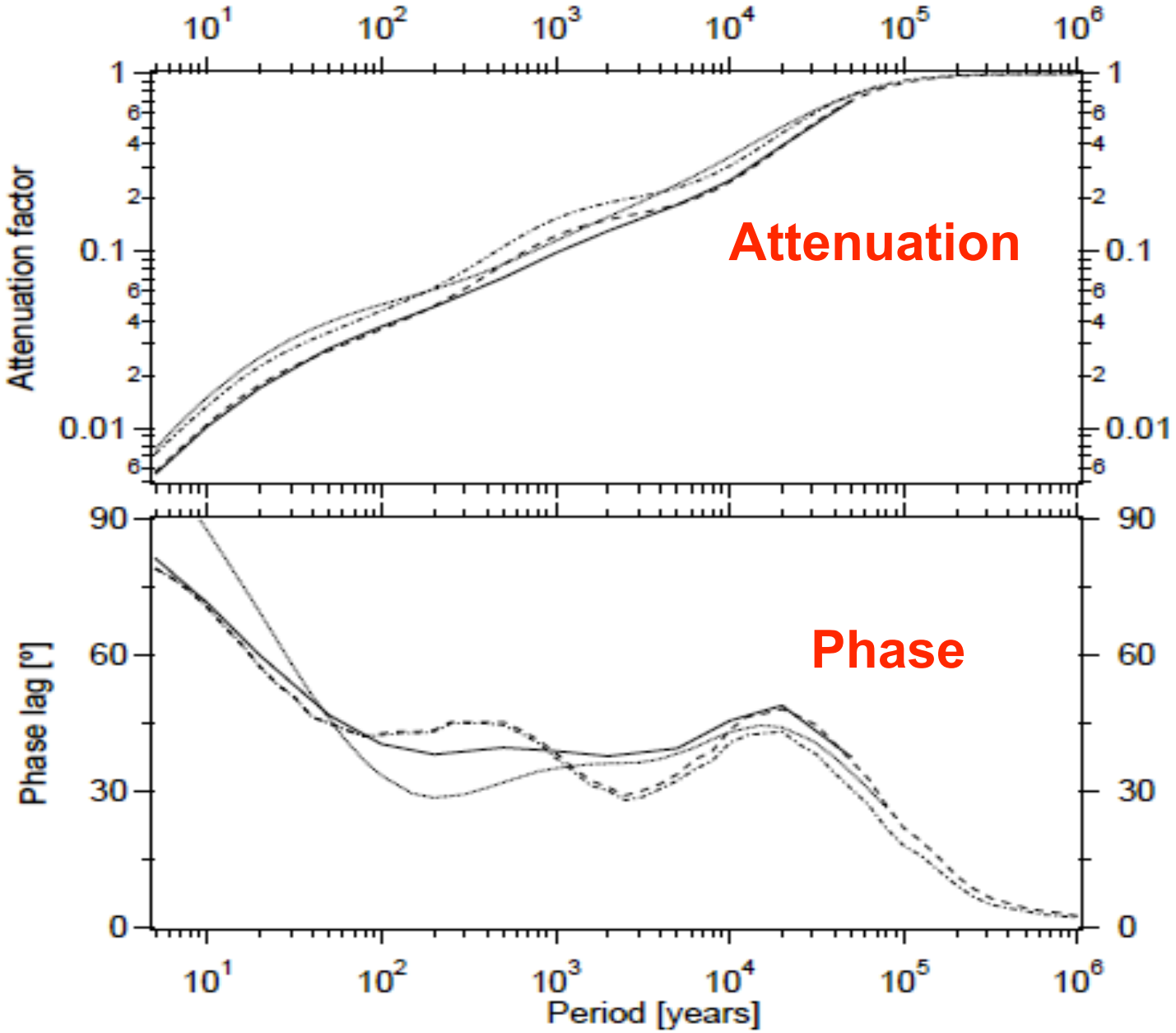






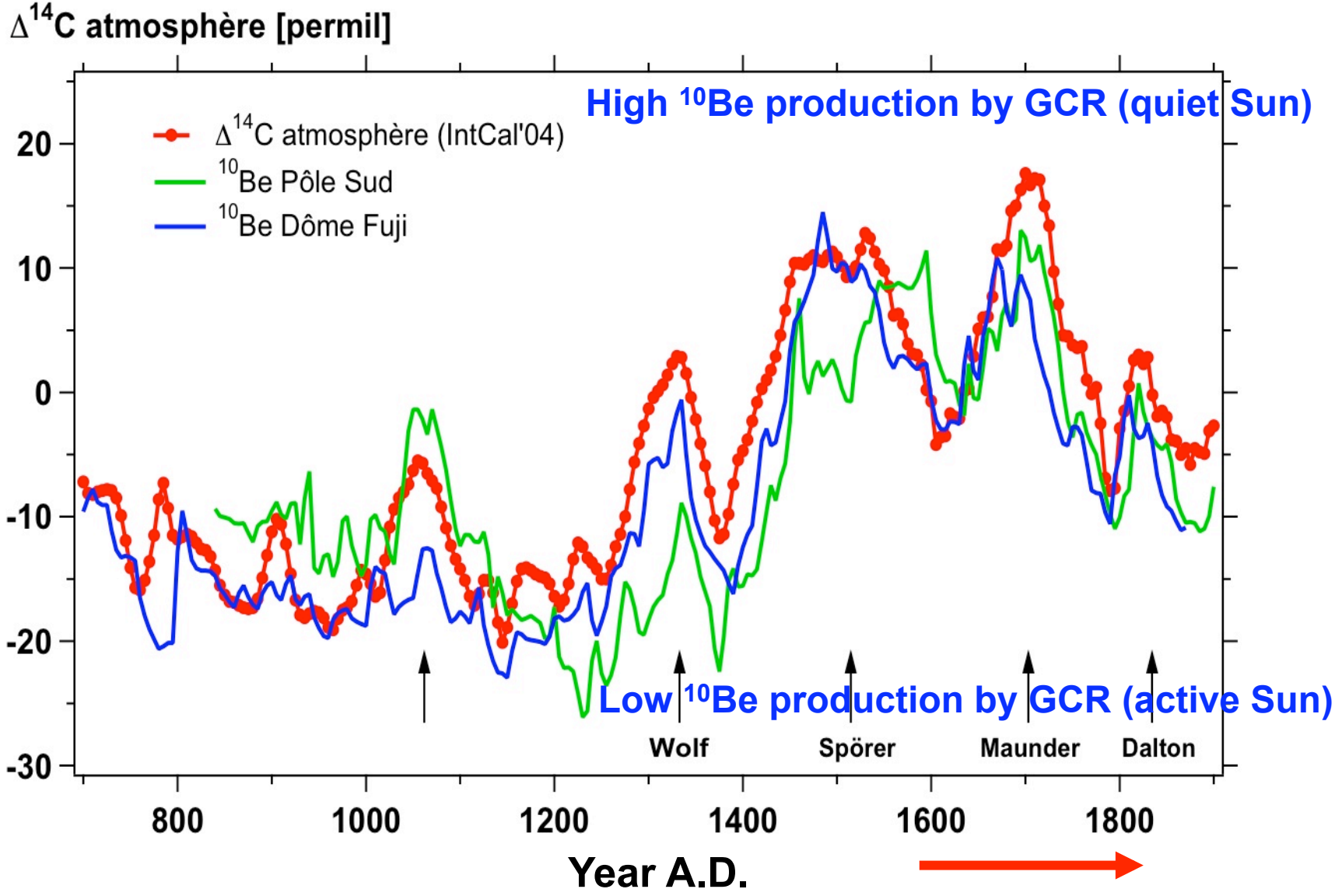


Geochemical cycles are low-pass filters for ^{14}C & ^{10}Be



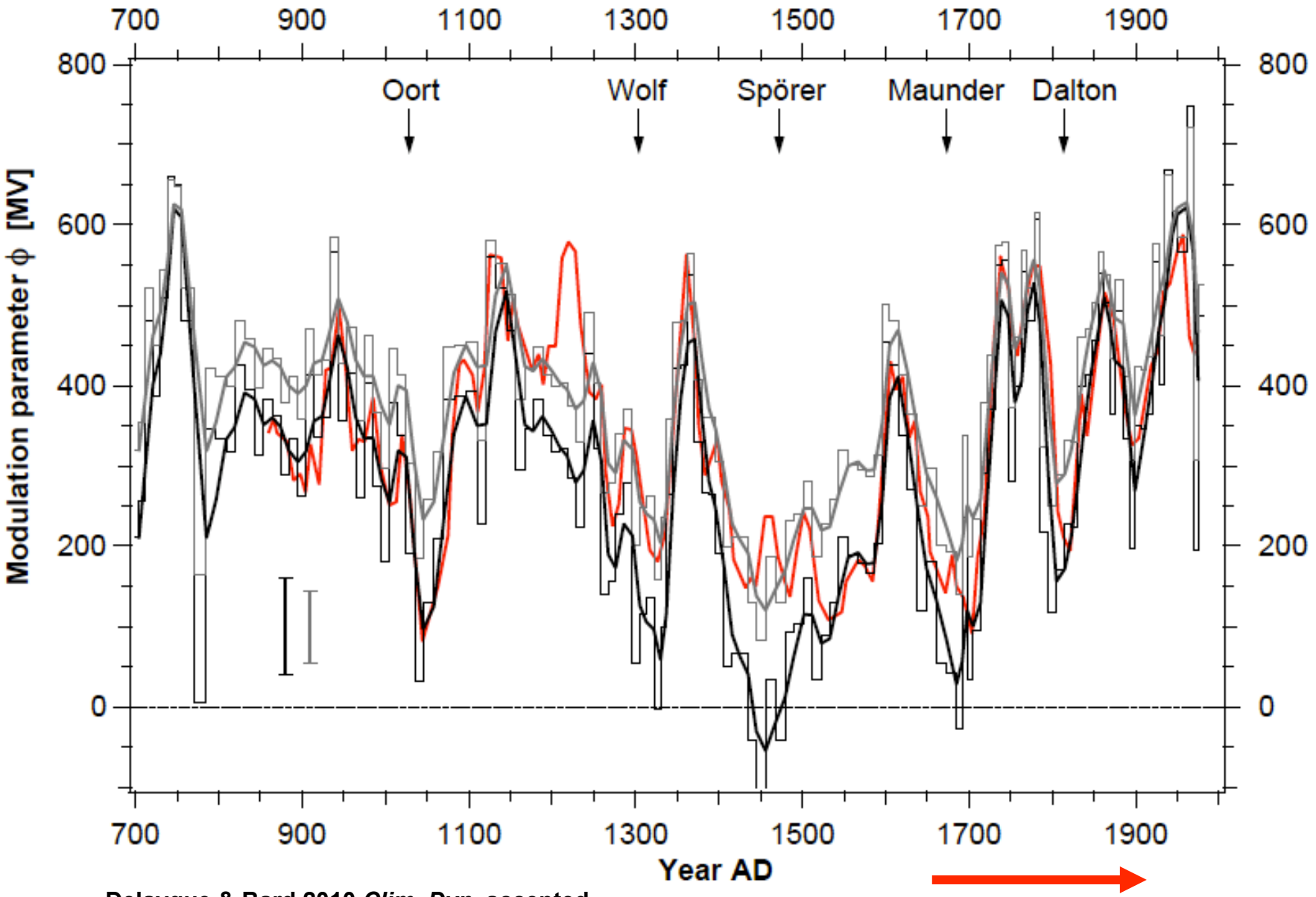
Delaygue & Bard 2010 *Clim. Dyn.* accepted

^{10}Be in ice cores from Antarctica and ^{14}C in tree-rings (all converted in ^{14}C units)

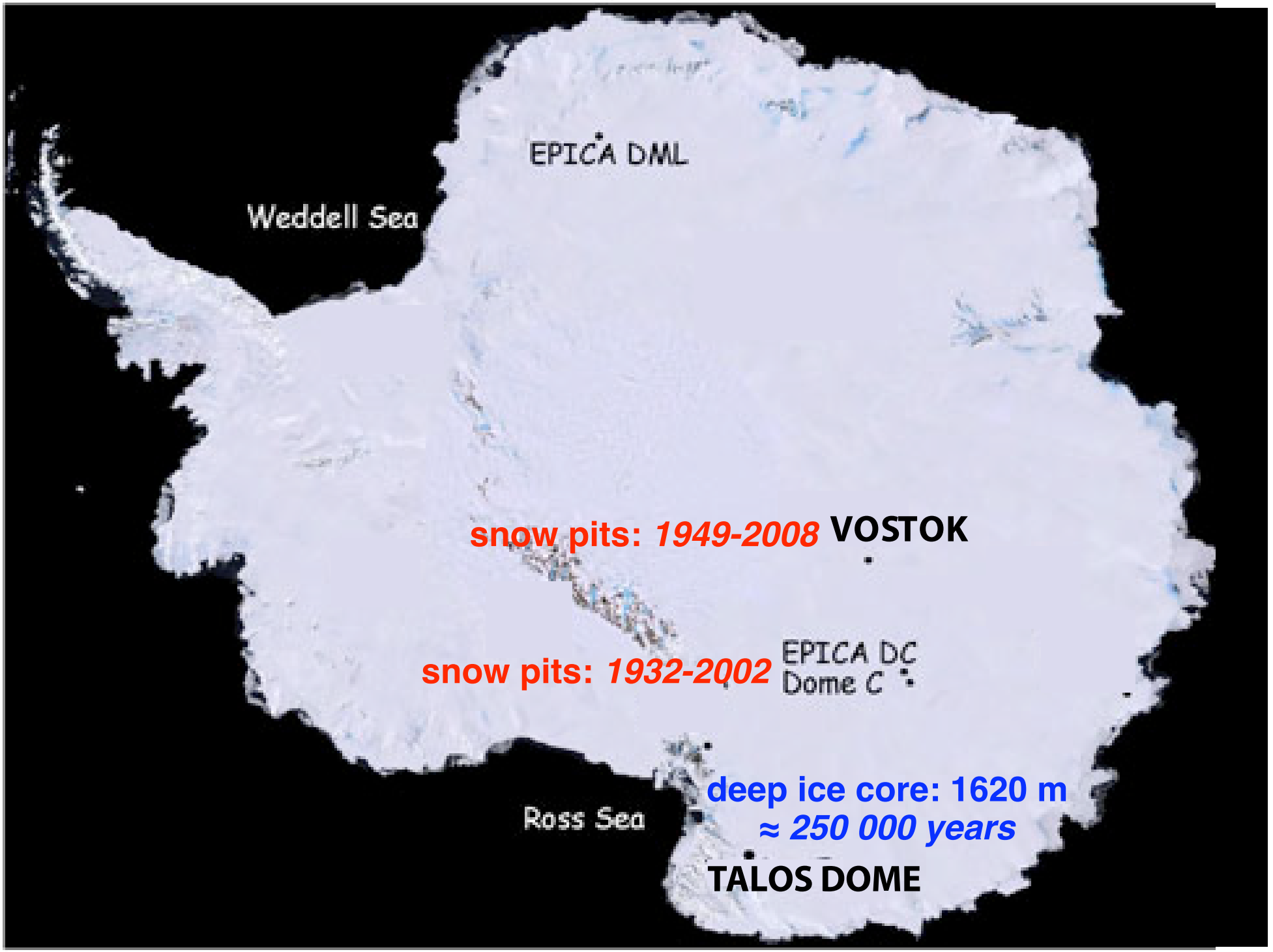


Bard et al. 1997 *EPSL*, 2000 *Tellus*, Horiuchi et al. 2008 *QG*, Delaygue & Bard 2010 *Clim. Dyn.*

An Antarctic stack of ^{10}Be-based solar activity for the past millennium



Delaygue & Bard 2010 *Clim. Dyn.* accepted


EPICA DML
Weddell Sea
snow pits: 1949-2008
VOSTOK
snow pits: 1932-2002
EPICA DC
Dome C
deep ice core: 1620 m
≈ 250 000 years
Ross Sea
TALOS DOME

A new high-resolution ice-core allowing to scale the variability during the glacial period with that of the recent past (11-yr cycle, Maunder-type events …)

French-Italian base of Talos Dome Ross Sea area (drilling in 2005-06)

Some conclusions about cosmogenic isotopes

- Time-series of the solar activity can be obtained with cosmogenic nuclides overlapping with other data over recent periods: TSI since 1978, geomagnetic index since 1868, sunspots since 1610, aurorae borealis since ca. 1500…
- The Sun varies over decades to millennia between active phases and solar minima (cycles of ca. 11, 90, 150 & 200 years, Maunder type minima),
- Overall, the Sun spent about a quarter of the last 7000 years in solar minima, often "deeper" that the Maunder Minimum.

Some remaining questions

- How was the Sun behaving during the (a) Maunder Minimum?
  Was the 11-yr cycle still present (some hint but still inconclusive) ?
  How rapid are the transitions in and out the (a) Maunder Minimum ?
- What is the best way to convert solar "proxy" data (^{10}Be, ^{14}C) in terms of irradiance and other effects relevant to Earth climate ?