IPCC AR4 2007

6.3.2 What Does the Record of the Mid-Pliocene Show?

The Mid-Pliocene (about 3.3 to 3.0 Ma) is the most recent time in Earth's history when mean global temperatures were substantially warmer for a sustained period (estimated by GCMs to be about 2°C to 3°C above pre-industrial temperatures; Chandler et al., 1994; Sloan et al., 1996; Haywood et al., 2000; Jiang et al., 2005), providing an accessible example of a world that is similar in many respects to what models estimate could be the Earth of the late 21st century. The Pliocene is also recent enough that the continents and ocean basins had nearly reached their present geographic configuration. Taken together, the average of the warmest times during the middle Pliocene presents a view of the equilibrium state of a globally warmer world, in which atmospheric CO_2concentrations (estimated to be between 360 to 400 ppm) were likely higher than pre-industrial values (Raymo and Rau, 1992; Raymo et al., 1996), and in which geologic evidence and isotopes agree that sea level was at least 15 to 25 m above modern levels (Dowsett and Cronin, 1990; Shackleton et al., 1995), with correspondingly reduced ice sheets and lower continental aridity (Guo et al., 2004).

Both terrestrial and marine palaeoclimate proxies (Thompson, 1991; Dowsett et al., 1996; Thompson and Fleming, 1996) show that high latitudes were significantly warmer, but that tropical SSTs and surface air temperatures were little different from the present. The result was a substantial decrease in the lower-tropospheric latitudinal temperature gradient. For example, atmospheric GCM simulations driven by reconstructed SSTs from the Pliocene Research Interpretations and Synoptic Mapping Group (Dowsett et al., 1996; Dowsett et al., 2005) produced winter surface air temperature warming of 10°C to 20°C at high northern latitudes with 5°C to 10°C increases over the northern North Atlantic (~60°N), whereas there was essentially no tropical surface air temperature change (or even slight cooling) (Chandler et al., 1994; Sloan et al., 1996; Haywood et al., 2000, Jiang et al., 2005). In contrast, a coupled atmosphere-ocean experiment with an atmospheric CO_2 concentration of 400 ppm produced warming relative to pre-industrial times of 3°C to 5°C in the northern North Atlantic, and 1°C to 3°C in the tropics (Haywood et al., 2005), generally similar to the response to higher CO_2 .

The estimated lack of tropical warming is a result of basing tropical SST reconstructions on marine microfaunal evidence. As in the case of the Last Glacial Maximum (see Section 6.4), it is uncertain whether tropical sensitivity is really as small as such reconstructions suggest. Haywood et al. (2005) found that alkenone estimates of tropical and subtropical temperatures do indicate warming in these regions, in better agreement with GCM simulations from increased CO_2 forcing (see Chapter 10). As in the study noted above, climate models cannot produce a response to increased CO_2 with large high-latitude warming, and yet minimal tropical temperature change, without strong increases in ocean heat transport (Rind and Chandler, 1991).

The substantial high-latitude response is shown by both marine and terrestrial palaeodata, and it may indicate that high latitudes are more sensitive to increased CO_2 than model simulations suggest for the 21st century

6.3.3 What Does the Record of the Palaeocene-Eocene Thermal Maximum Show?

Approximately 55 Ma, an abrupt warming (in this case of the order of 1 to 10 kyr) by several degrees celsius is indicated by changes in ^{18}O isotope and Mg/Ca records (Kennett and Stott, 1991; Zachos et al., 2003; Tripati and Elderfield, 2004). The warming and associated environmental impact was felt at all latitudes, and in both the surface and deep ocean. The warmth lasted approximately 100 kyr. Evidence for shifts in global precipitation patterns is present in a variety of fossil records including vegetation (Wing et al., 2005). The climate anomaly, along with an accompanying carbon isotope excursion, occurred at the boundary between the Palaeocene and Eocene epochs, and is therefore often referred to as the Palaeocene-Eocene Thermal Maximum (PETM). The thermal maximum clearly stands out in high-resolution records of that time (Figure 6.2). At the same time, ^{13}C isotopes in marine and continental records show that a large mass of carbon with low ^{13}C concentration must have been released into the atmosphere and ocean. The mass of carbon was sufficiently large to lower the pH of the ocean and drive widespread dissolution of seafloor carbonates (Zachos et al., 2005). Possible sources for this carbon could have been methane (CH_4) from decomposition of clathrates on the sea floor, CO_2 from volcanic activity, or oxidation of sediments rich in organic matter (Dickens et al., 1997; Kurtz et al., 2003; Svensen et al., 2004). The PETM, which altered ecosystems worldwide (Koch et al., 1992; Bowen et al., 2002; Bralower, 2002; Crouch et al., 2003; Thomas, 2003; Bowen et al., 2004; Harrington et al., 2004), is being intensively studied as it has some similarity with the ongoing rapid release of carbon into the atmosphere by humans. The estimated magnitude of carbon release for this time period is of the order of 1 to 2×10^{18} g of carbon (Dickens et al., 1997), a similar magnitude to that associated with greenhouse gas releases during the coming century. Moreover, the period of recovery through natural carbon sequestration processes, about 100 kyr, is similar to that forecast for the future. As in the case of the Pliocene, the high-latitude warming during this event was substantial (~20°C; Moran et al., 2006) and considerably higher than produced by GCM simulations for the event (Sluijs et al., 2006) or in general for increased greenhouse gas experiments (Chapter 10). Although there is still too much uncertainty in the data to derive a quantitative estimate of climate sensitivity from the PETM, the event is a striking example of massive carbon release and related extreme climatic warming.