Climatic and atmospheric histories over the past 700,000 years from the Dome Fuji deep ice core, Antarctica

Kenji Kawamura[1], Shuji Aoki[2], Takakiyo Nakazawa[2], Frédéric Parrenin[3], Kazue Suzuki[4], Ryu Uemura[5], Ayako Abe-Ouchi[6], Hideaki Motoyama[1]
[1]*National Institute of Polar Research*
[2]*Center for Atmospheric and Oceanic Studies, Tohoku University*
[3]*Laboratoire de Glaciologie et de Geophysique de l'Environnement, France*
[4]*The Institute of Statistical Mathematics*
[5]*University of the Ryukyus*
[6]*The University of Tokyo, Tokyo, Japan*

Polar ice cores record past climatic and atmospheric variations on various time scales from 1 to 100,000 years. Since 1995, the Japanese Antarctic Research Expeditions have drilled two deep ice cores at the Dome Fuji station in inland of East Antarctica. The first ice core reached 2503 m from the ice sheet surface, and it has provided environmental records for the past 340,000 years. The second ice core was recently drilled from the surface to 3035 m, very close to the bedrock. The ice near the bedrock is expected to be about 700,000 years old.

The analyses of the first Dome Fuji ice core have produced the histories of climate and atmospheric greenhouse gases, as well as accurate timescales for the ice core (Watanabe et al., 2003; Kawamura et al., 2003; 2007). Since then, we have improved and expanded our capacity for analyzing ice cores for gas concentrations and isotopic ratios, and applied them to the second Dome Fuji ice core. In particular, we generated a series of gas records for the deep part (340,000 – 700,000 years in age) of the second Dome Fuji ice core using a wet extraction method.

Timescale of the first Dome Fuji deep ice core for the past 340,000 years was established by tuning of measured O_2/N_2 ratios in trapped air to local summer insolation, with accuracy better than about 2000 years (Kawamura *et al*., 2007). We generated O_2/N_2 data of the second Dome Fuji ice core from 2400 m to 3028 m (340,000 – 700,000 years ago) at a 2000-year time resolution, with significant improvements in ice core storage temperature and mass spectrometry. In particular, the ice core had been stored at about -50 ˚C until the air extraction except during transportations, in order to prevent fractionation due to gas loss during storage. The precision of the new O_2/N_2 data set is improved by a factor of 3 over the best part in the previous data. Clear imprint of local insolation is recognizable in the O_2/N_2 data towards the deepest depths, enabling us to construct an accurate chronology for the past 700,000 years.

In order to reconstruct variations of atmospheric constituents, the Dome Fuji ice core was analyzed for concentrations of CH_4, N_2O and CO_2, $\delta^{15}N$ of N_2 and $\delta^{18}O$ of O_2 of the extracted air, as well as air content of the ice core. Most prominent feature in majority of the ice core data is roughly 100,000-year periodicity, as also seen in global ice volume and other climatic variables. On the accurate timescale described above, the increase of $\delta^{18}O$ of ice (a temperature proxy) for each glacial termination occurs in the rising phase of summer insolation at Northern high latitudes, consistent with the Milankovitch theory of glacial cycles that implies a role of boreal summer insolation and associated ice sheet response in controlling the global climatic variations. Atmospheric CO_2 concentrations co-vary with the Antarctic temperature especially for the deglacial warmings, suggesting an important role of Southern Ocean in amplifying and regulating the global climatic changes through controlling CO_2 levels. CH_4 concentrations show rapid increases during glacial periods coinciding with rapid warmings in Greenland and peaks of slow Antarctic temperature variations, consistent with so-called bipolar seesaw concept, coupling of Northern and Southern Hemispheres through changes in Atlantic meridional overturning circulation (AMOC). Sharp and large CH_4 increases are also seen at the end of all Antarctic warmings towards interglacial periods. Our data collectively suggest that weakening of AMOC and associated inter-hemispheric seesaw, perhaps caused by rising boreal summer insolation that melts continental ice sheets and reduce salinity of northern North Atlantic surface waters, are important as mechanisms for connecting changes in Northern Hemisphere ice sheets, Southern Ocean, atmospheric CO_2 and global climate.

References

Watanabe et al. (2003), Homogeneous climate variability across East Antarctica over the past three glacial cycles. Nature, 422, 509-512.

Kawamura et al. (2003), Atmospheric CO2 variations over the last three glacial–interglacial climatic cycles deduced from the Dome Fuji deep ice core, Antarctica using a wet extraction technique. Tellus, 55B, 126-137.

Kawamura et al. (2007), Northern Hemisphere forcing of climatic cycles in Antarctica over the past 360,000 years, Nature, 448, 912-916.