Modelling of greenhouse gases and related species in the Arctic environment

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Numerical modelling of greenhouse gases (GHGs) has become an integral part for understanding amplitude and variability in their concentrations and sources/sinks, atmospheric transport and climate implication. Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are the three major species studied in the Arctic Green Network of Excellence (GRENE), a programme funded by the Ministry of Education, Culture, Sports, Science and Technology-Japan (MEXT). In addition some of the ozone depleting substances, e.g., methyl chloroform (CH_3CCl_3), have provided strong constrain on the global mean abundance of hydroxyl (OH) radical and its relative abundance in the northern and southern hemispheres (NH/SH OH ratio; Patra et al., 2014). Being the main destroyer of many of the GHGs (e.g., CH_4, hydrofluorocarbons), accurate quantification of OH was needed for estimation of CH_4 sink in the troposphere, and thus the sources on the Earth's surface by inverse modelling (Patra et al., 2016). OH is also contributes to chemical production of CO_2, up to ~50% of land/ocean sink. The modellers are also required to verify the accuracy of model transport using tracers of short (e.g., ^{222}Rn with 3.8 days) and long (SF_6 with 3200 yrs) lifetimes. For understanding of the carbon cycle science, analyses of oxygen (O_2/N_2) variability are also conducted. List of chemistry-transport models (CTMs) participating in the Arctic GRENE programme are given Table 1.

Table 1. Summary of atmospheric models participated in the Arctic-GRENE project (✓denotes forward simulation of concentrations, and ☑ denotes both forward simulations and regional sources/sinks inverse modeling using the model).

Model Name*	Institution	Chemical species simulated for carbon, nitrogen cycle studies and atmospheric transport						
		CO_2	O_2/N_2	CH_4	N_2O	SF_6	CH_3CCl_3	^{222}Rn
ACTM	JAMSTEC	☑	✓	☑	☑	✓	✓	✓
JMA-CDTM	MRI/JMA	☑				✓		✓
NICAM-TM	MRI	☑		✓		✓		✓
NIES-TMi8	NIES	☑	✓	☑		✓		✓
STAG	AIST	☑	✓			✓		✓
MJ98-CDTM	MRI/JMA	☑				✓		✓

*Detailed description of models can be found in Patra et al. (2014) for ACTM, Maki et al. (2013) for JMA-CDTM, Niwa et al. (2012) for NICAM-TM, Belikov et al. (2013) for NIES-TMi8, Taguchi et al. (2013) for STAG, Deushi and Shibata for MJ98-CDTM.

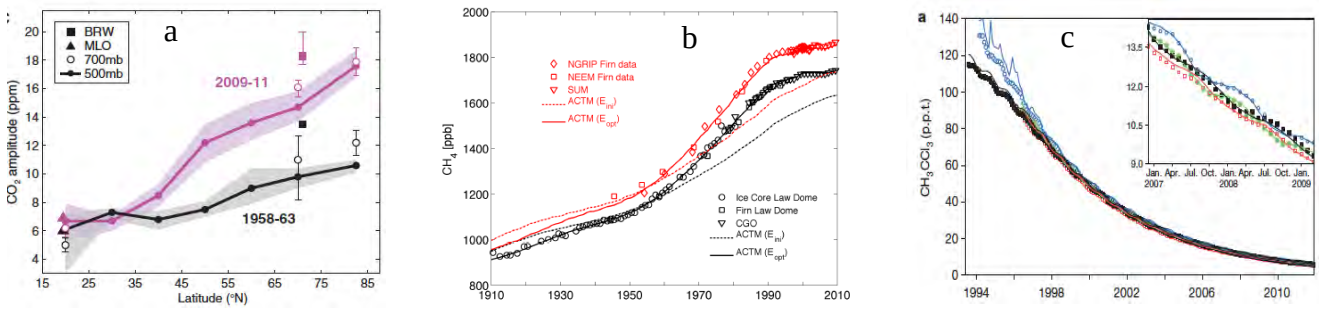

Figure 1. Examples of recent changes in GHGs and related species concentrations; left (a): observed CO_2 seasonal cycle amplitude change since the International Geophysical Year (from Graven et al., 2013; copyright Science), center (b): model - observation comparison of CH_4 over the past 100 years (Ghosh et al., 2015), right (c): simulation of observed CH_3CCl_3 decay for estimation OH in troposphere (Patra et al., 2014; copyright Nature). The detailed modelling capabilities of different participating groups are listed in Table 1.

Figure 1 shows examples of observed and model simulated concentrations of CO_2, CH_4 and CH_3CCl_3. Using the direct CO_2 measurements at the surface sites and aircrafts in the lower-middle troposphere during 1958 and 2011, an increase in seasonal amplitude of CO_2 throughout the troposphere is detected (Graven et al., 2013). The detection of longterm trends in GHGs is key to track the changes in

biospheric and anthropogenic activities on the Earth's surface, and it is suggested that the CO_2 seasonal amplitude increase with time is mainly caused by greater carbon assimilation in the summer months over the boreal latitudes. Using model simulations and analysis of ^{13}C isotopic fractionation in atmospheric CH_4 over the past 100 years (Fig. 1b), the fastest increase rate during 1955-1990 is attributed to enhanced biomass burning (Ghosh et al., 2015). For modelling of atmospheric CH_4, the transport and chemistry in ACTM have been evaluated using SF_6 and CH_3CCl_3 (Patra et al., 2014). We are continuing to collaborate with various observational groups in Japan for further elucidating the variations in GHGs in the Arctic region, e.g., model results are being used for analysis of the observational data collected as a part of the Arctic GRENE project; e.g., O_2/N_2 (Goto et al.; Ishidoya et al., in prep.), CH_4 on the ship cruises (Tohjima et al., 2016).

Several inverse modeling schemes are also being developed using forward transport models developed in AIST, JAMSTEC, JMA, MRI and NIES. Figure 2b shows examples of CO_2 fluxes estimated for the arctic region in comparison with the global total fluxes for the land and ocean regions as estimated by ACTM in JAMSTEC. Analyses of CO_2 fluxes for different parts of the globe suggest that the difference between winter release and summer uptake is increasing in the boreal regions (Fig. 2c using NICAM-TM at MRI; Niwa et al., 2012, updated) and that the flux amplitude change is mainly governed by the summer uptake increase (Welp et al., 2016). A multi-model analysis of CO_2 inversion fluxes using the flux tower measurements at Yakutsuk, in Siberia and biogeochemical cycle models is being conducted for understanding the trends in CO_2 fluxes due to climate variations (Takata et al., 2015, also in prep.).

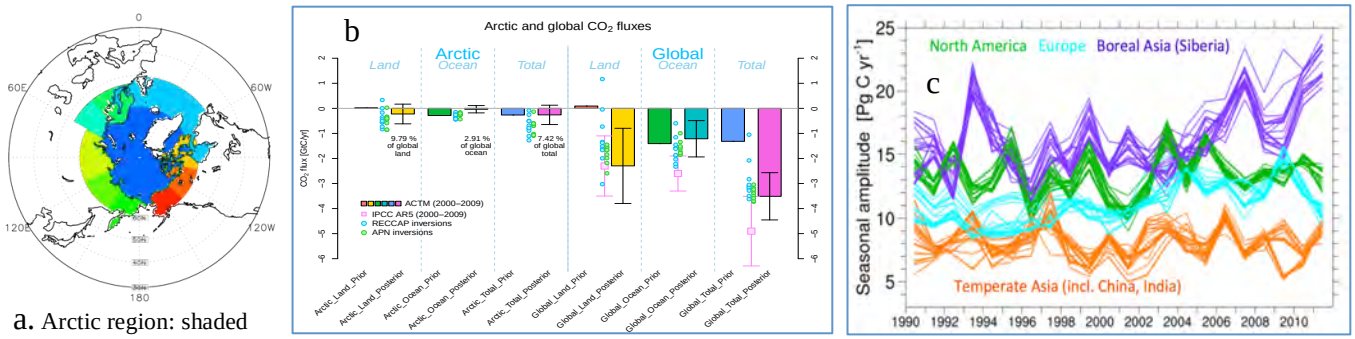

Figure 2. Distribution of CO_2 sources and sinks around the Arctic region (a) compared to the global totals as simulated by ACTM (b; middle panel), and CO_2 flux amplitude change for 4 major regions in the Northern Hemisphere by NICAM-TM (c: right panel).

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