Analysis of variability in atmospheric methane in the Arctic

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1. Motivation

Methane (CH_4) is an important greenhouse gas contributing 0.5 Wm^{-2} to radiative forcing. Since 2006, the atmospheric CH_4 growth rate has increased again after being quasi-stable for circa 1 decade. This change has caused concerns that it may be the response to climate feedbacks in the Arctic, where there is a potential for a large release of CH_4 under warmer conditions via wetlands and methane hydrate destabilisation.

2. Observation sites

In-situ atmospheric measurements from:
- Zeppelin (ZEP) (79.0°N, 11.9°E)
- Pallas (PAL) (68.0°N, 24.1°E)
- Barrow (BRW) (71.3°N, 156.6°W)

These sites were chosen as they have records from at least the early 2000s. Fig. 1 shows mean footprints, calculated with the Lagrangian Particle Dispersion model FLEXPART, associated with the highest and lowest 10-percentile CH_4 concentrations at each site over the whole record. At ZEP and PAL, high concentrations are associated with transport from western Siberia and Europe, low with the North Atlantic. At BRW, high concentrations associated with eastern Siberia and Alaska, low with the Arctic.

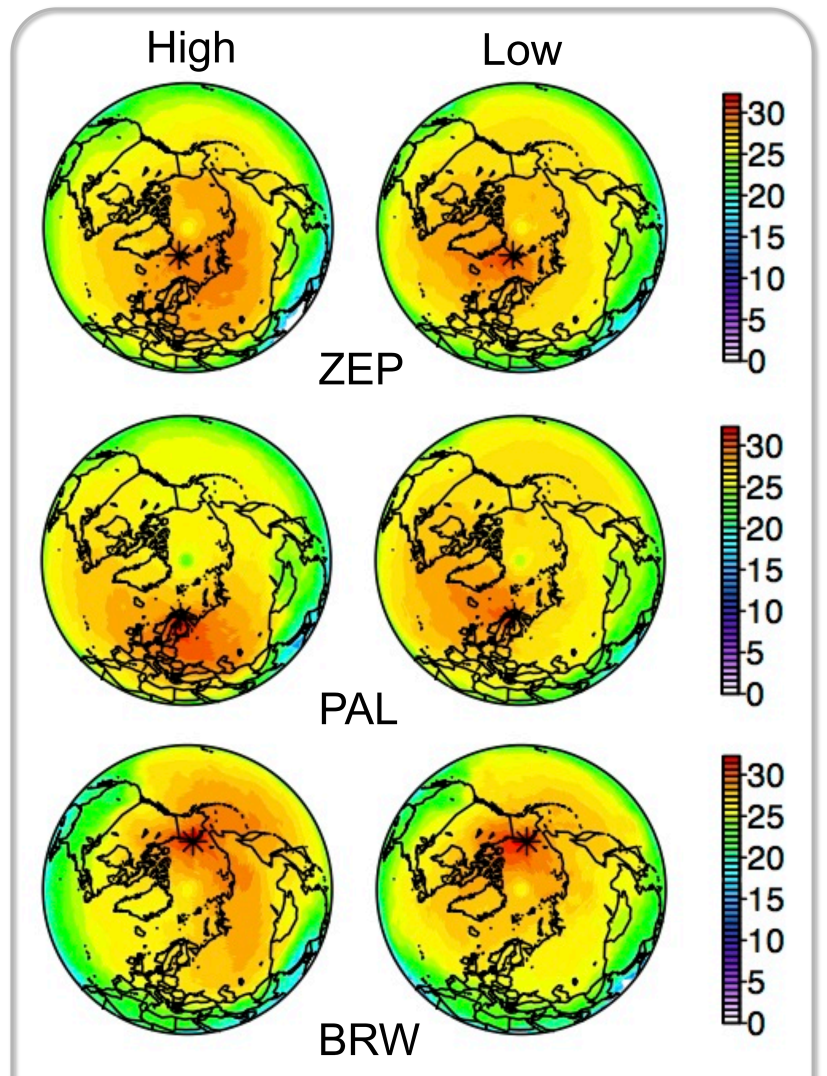


Figure 1. mean footprints for upper/lower 10 percentile data

3. Variability in atmospheric transport

Cluster analysis was used on all FLEXPART footprints (2001-2012) for each site to group the footprints into typical transport "patterns". Fig. 2 shows the normalized annual occurrence frequency of each cluster. Inter-annual variability is seen in the frequency of some clusters (shown in the legend). In 2007, there was an increase in occurrence of transport from within the Arctic region. This can be understood in that 2007 was a very warm year in the Arctic (2007 was also the year with the lowest summer sea-ice extent). Overall, we do not find any trends in the occurrence frequency of any of the clusters.

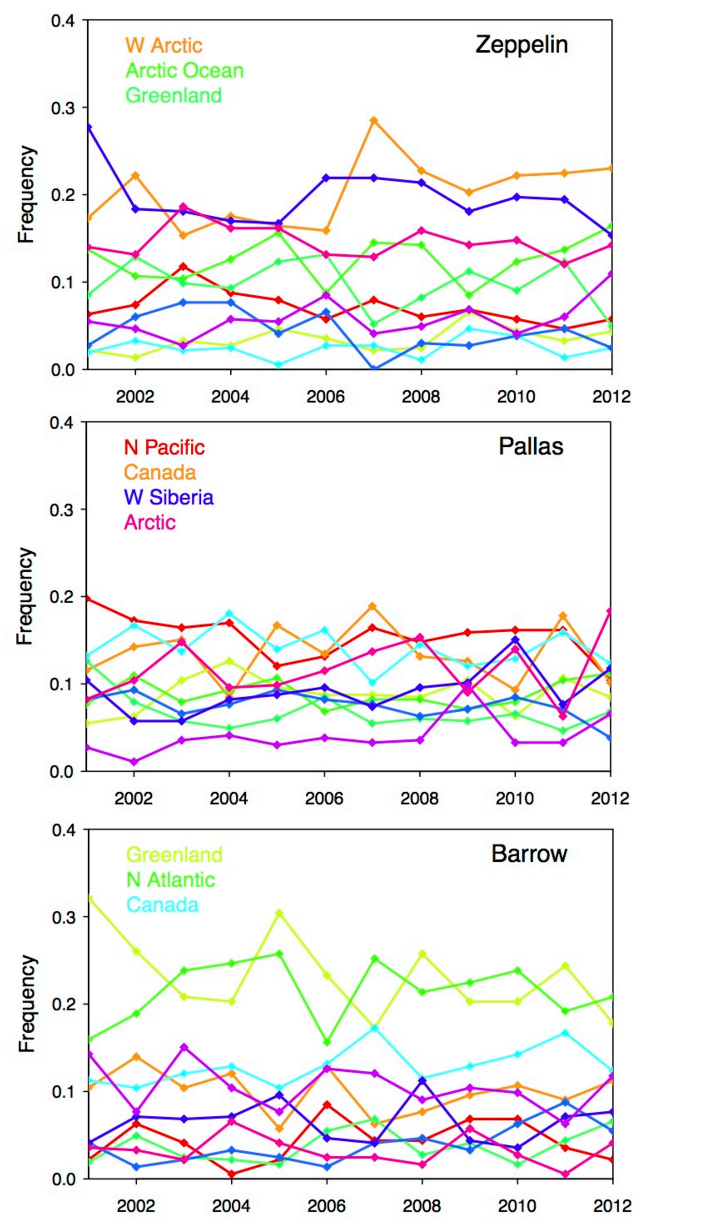


Figure 2. transport cluster occurrence frequency

4. Atmospheric growth rate of CH_4

The annual atmospheric growth rate of CH_4 in the Arctic (Fig. 3, red line) deviates somewhat from the global mean (blue line). Positive anomalies are seen at ZEP and PAL in 2003, 2007, 2009, 2012, and negative anomalies in 2004, 2006, 2010, 2011. Positive anomalies are also seen in 2007 at BRW, SUM and ALT. The 2003 anomaly may be related to high CH_4 emissions from Siberian wildfires (Shvidenko et al. 2011).

The modelled growth rate at ZEP (Fig. 4, grey line), using climatological fluxes and FLEXPART coupled to TM5, reproduces the 2007 anomaly but not those in 2008-2009 and 2010-2011.

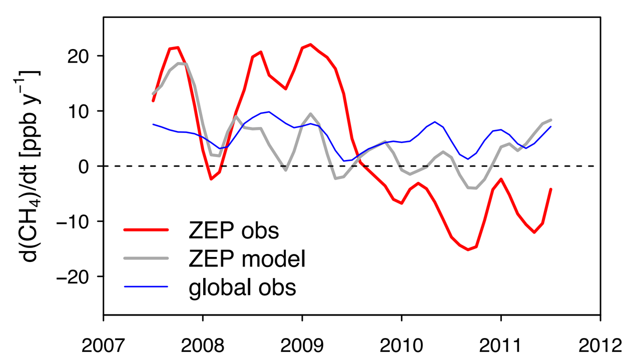


Figure 4. growth rates at Zeppelin

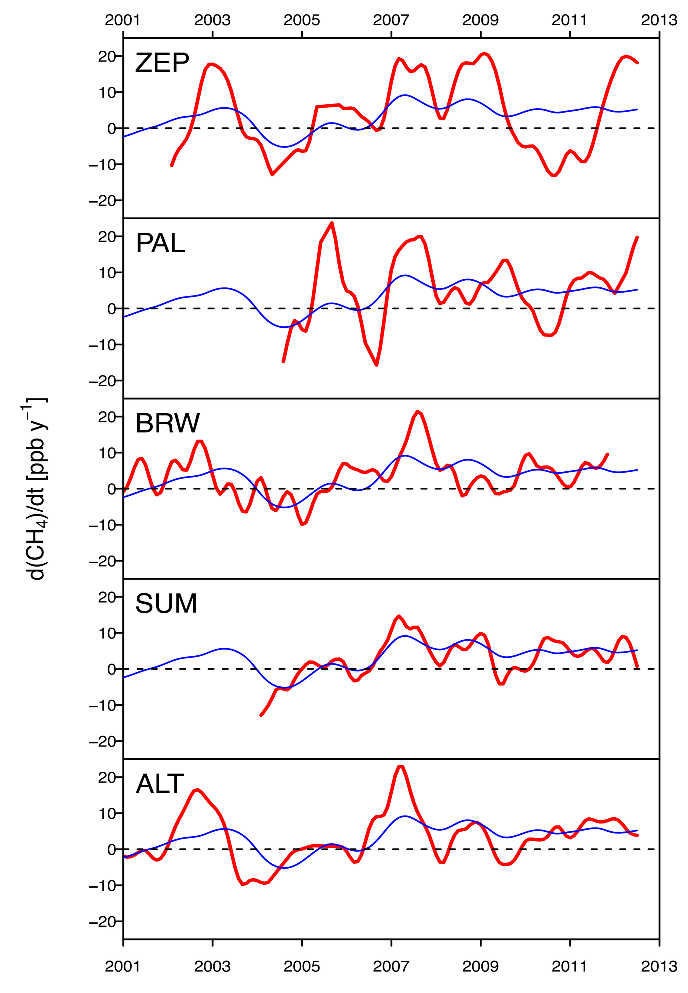
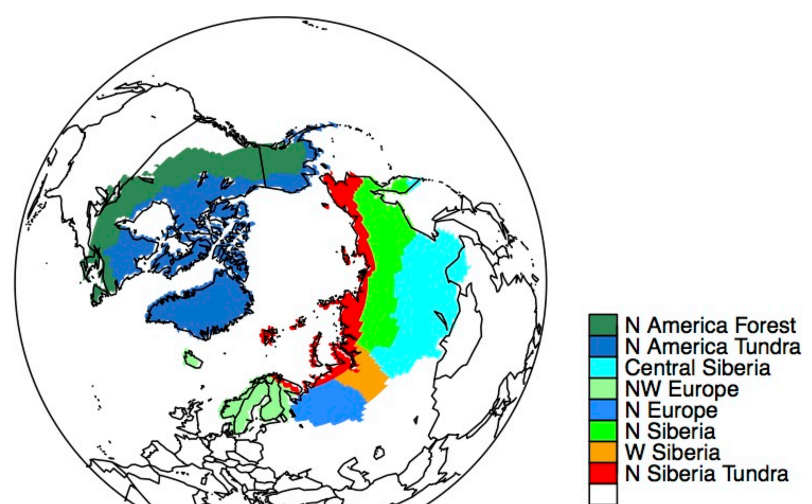


Figure 3. atmospheric growth rates

5. Correlation with soil temperature

Annual anomalies in CH_4 growth rate at ZEP, PAL and BRW are correlated with the seasonal maximum in the area-weighted mean soil temperature (from ECMWF ERA-interim data). For ZEP and PAL, the correlation was strongest with soil temperature in western Siberia (see Fig. 5) and for BRW with soil temperature in northern Canada and Alaska.
- ZEP: $R^2 = 0.51$ (p-value = 0.013)
- BRW: $R^2 = 0.51$ (p-value = 0.013)
- PAL: $R^2 = 0.27$ (p-value = 0.15)

At PAL, it was also correlated with the length of growing season in northern Siberia ($R^2 = 0.48$, p-value = 0.04)



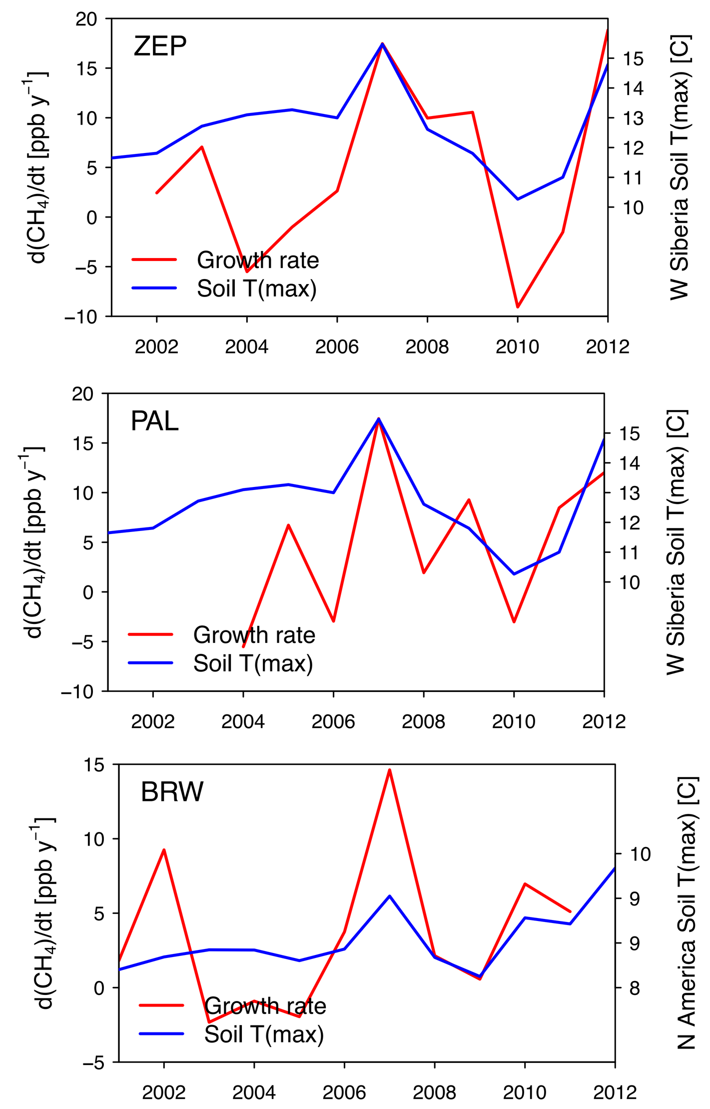


Figure 5. annual anomalies in CH_4 growth rate and seasonal maximum soil temperature

6. Wetlands as drivers of Arctic CH_4 variability

Measurements of $\delta^{13}C$ in CH_4 have been made at ZEP since 2008 and indicate that wetland emissions influence CH_4 concentrations measured at ZEP in summer (Fisher et al., 2011). Retro-plume analyses show that these are associated with transport from western Siberia, where there are wetlands. Figure 6 shows Keeling plots for observations at ZEP during the growing season. The intercept indicates predominantly wetlands sources with values between -66 and -59‰.

Wetland emissions of CH_4 are sensitive to temperature with a Q_{10} estimated at approximately 4.0 (Blodau, 2002).

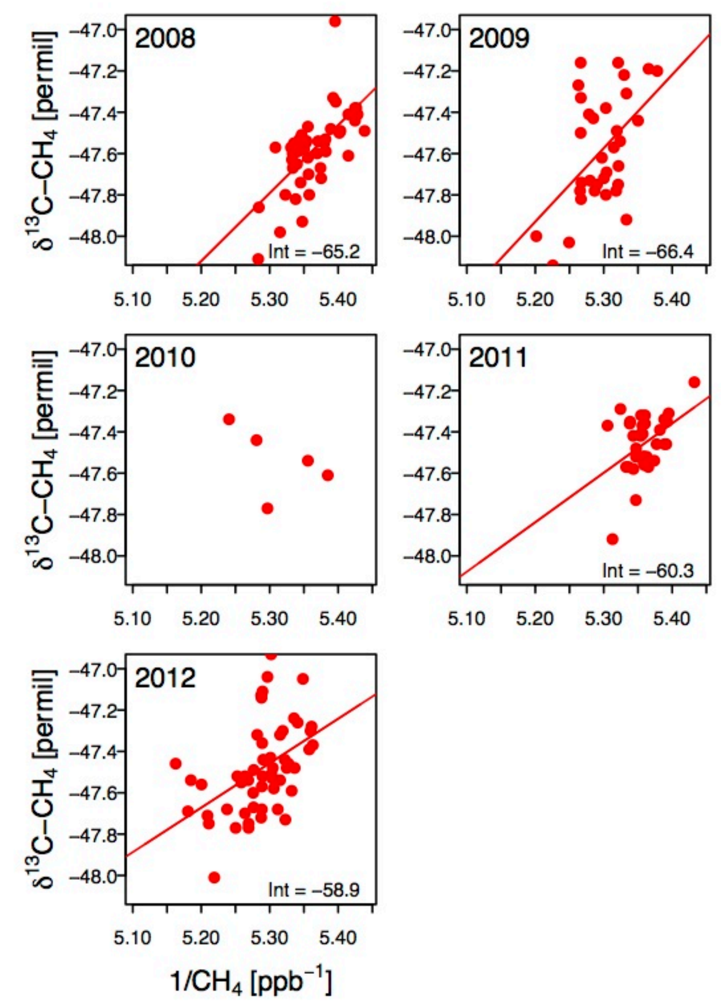


Figure 6. Keeling plots for observations at Zeppelin during the growing season (May to October) for each year. The intercept ('Int') is shown for each year when the p-value ≤ 0.1)

7. Conclusions

Inter-annual variability in the growth rate of atmospheric CH_4 in the Arctic deviates notably from the global mean. The variability is correlated with maximum seasonal soil temperature in western Siberia (at ZEP and PAL) and northern Canada and Alaska (at BRW). Wetland emissions are sensitive to soil temperature and are the likely mechanism behind the observed correlation. Atmospheric transport also contributes to the observed variability, e.g. in 2007, but cannot alone explain all the variability. Furthermore, we do not find any evidence for trends or sustained changes in atmospheric transport to the Arctic observation sites between 2001 and 2012.

Acknowledgements

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References

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