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Variability of methane fluxes over high latitude permafrost wetlands

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Motivations

Atmospheric methane plays an important role in the global climate system. Due to significant amounts of organic material stored in the upper layers of high latitude permafrost wetlands and a strong Arctic warming trend, there is concern about potentially large methane emissions from Arctic and sub-Arctic areas. The quantification of CH_4 fluxes and their variability from these regions therefore plays an important role in understanding the Arctic carbon cycle and changes in atmospheric methane concentrations.

Experiment setup

Direct measurements of CH_4 fluxes in permafrost regions are sparse, very localized, inhomogeneously distributed in space, and thus difficult to use for accurate model representation of regional to global CH_4 contributions from the Arctic. We aim to improve spatial coverage and spatial representativeness of fluxes by using airborne eddy covariance measurements across large areas. The research aircraft POLAR 5 was equipped with a turbulence nose boom and a fast response CH_4 analyzer.

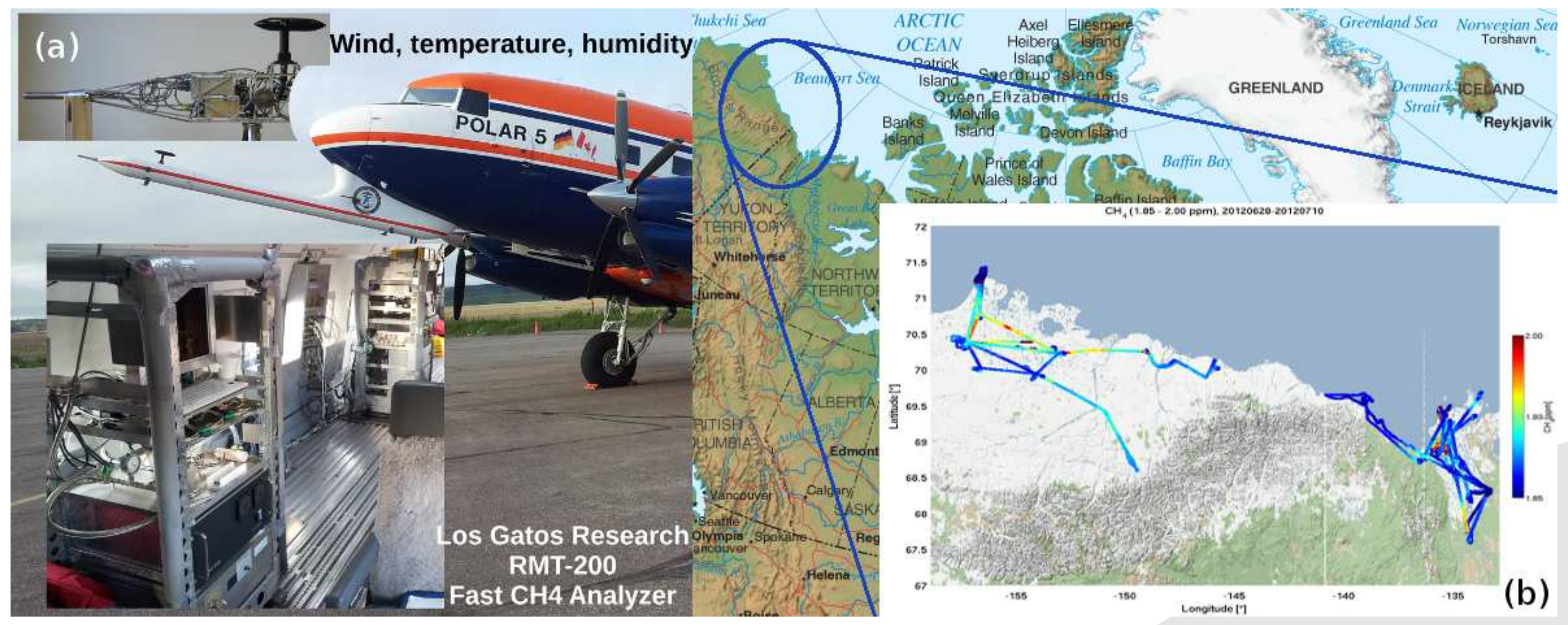

Figure 1: Aircraft instrumentation for CH_4 flux measurements (a). Flight paths and CH_4 concentration measurements from the AIRMETH-2012 campaign (b).

The AIRMETH 2012 (Airborne measurements of methane) campaign was carried out from 28 June to 10 July 2012 across the entire North Slope of Alaska and the Mackenzie Delta in Canada.

Data analysis

For effective data analysis outliers in high-frequency time series were removed using a despiking test. The spatial separation of the gas analyzer from the turbulence nose boom leads to time lags between wind and concentration measurements according to the wind speed and direction. In addition, each instrument has a response time. Therefore, using the cross-correlation analysis, the scalar time series were corrected for time lags compared to the vertical wind component. The dataset derived after this step was used to estimate the Reynolds-averaged fluxes.

Co-spectra and orgive analysis

In order to cover the whole turbulent spectrum and at the same time to resolve methane fluxes on a regional scale, different integration paths were analyzed and validated through analysis of co-spectra and convergence of ogives.

Flux corrections

The frequency response corrections including time response, sensor separation, scalar/vector path averaging, high pass filtering, and digital sampling were performed. The Webb-Pearman-Leuning (WPL) term was used to compensate for the fluctuations of temperature and water vapor that affect the measured methane and water vapor fluctuations.

Acknowledgments

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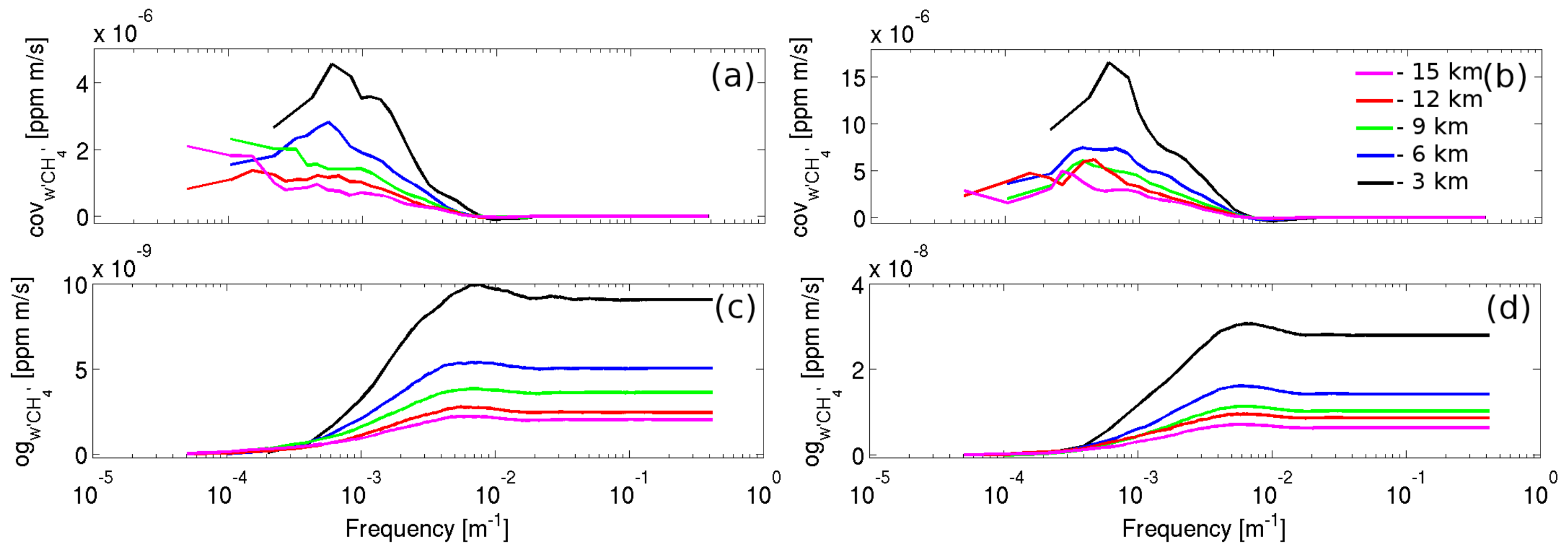

Figure 2: Averaged co-spectra (a,c) and ogives (b,d), CH_4 flux measured across the North Slope of Alaska (a,b) and the Mackenzie Delta in Canada (c,d). The color corresponds to different leg length (magenta - 3 km, red - 6 km, green - 9 km, blue - 12 km, black - 15 km).

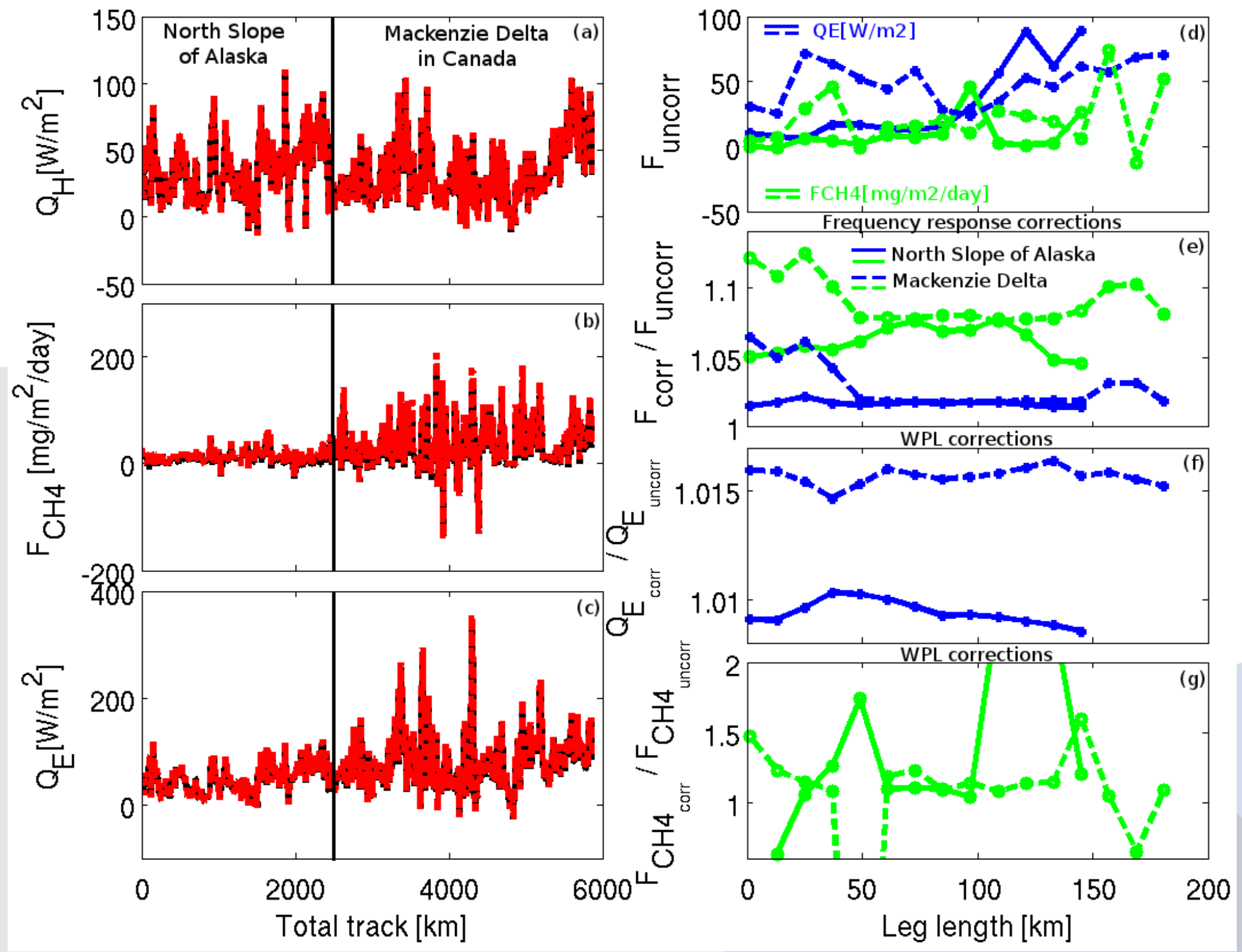

Figure 3: Corrected (red) and uncorrected (black) sensible heat Q_H (a), methane F_{CH_4} (b) and latent heat Q_E (c) fluxes. Ratio of co-spectrally (e) and WPL (f,g) corrected and uncorrected Q_E (blue) and F_{CH_4} (green) fluxes.

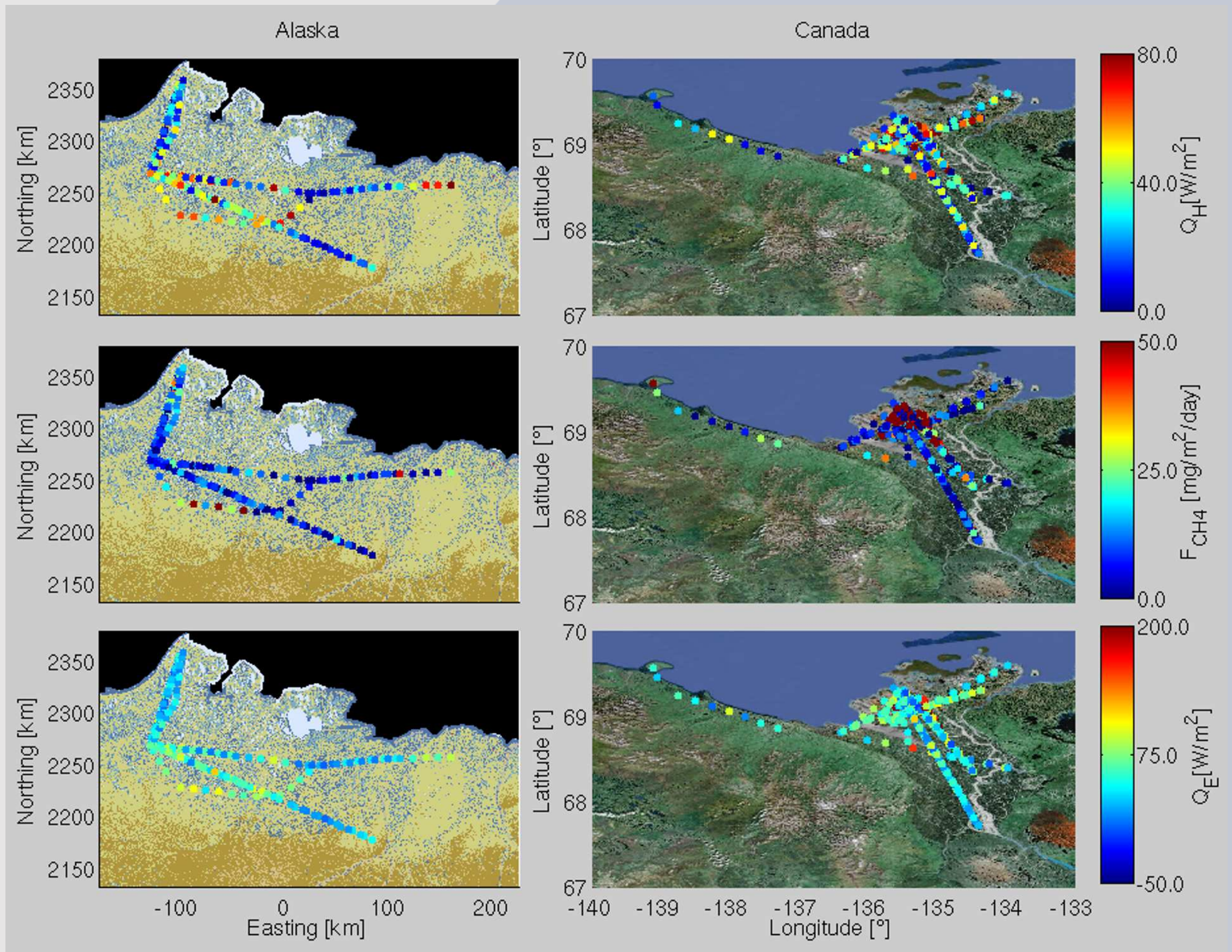

Figure 4: Sensible heat Q_H (a,b), methane F_{CH_4} (c,d) and latent heat Q_E (e,f) fluxes measured across the North Slope of Alaska (a,c,e) and the Mackenzie Delta in Canada (b,d,f).

Fluxes over permafrost wetlands

Methane emissions measured over the Mackenzie Delta were higher and generally more variable in space, especially in the outer Delta with known geogenic methane seepage. On the North Slope, methane fluxes were larger in the western part than in the central and eastern parts.

WRF model simulations

The supplemented high resolution (1 km, 30 min) simulations from the Weather Research and Forecasting (WRF v3.2.1) model exploring the dynamics of the atmospheric planetary boundary layer (PBL) were used to analyze high methane concentrations occasionally observed within the boundary layer with a distinct drop to background level above.

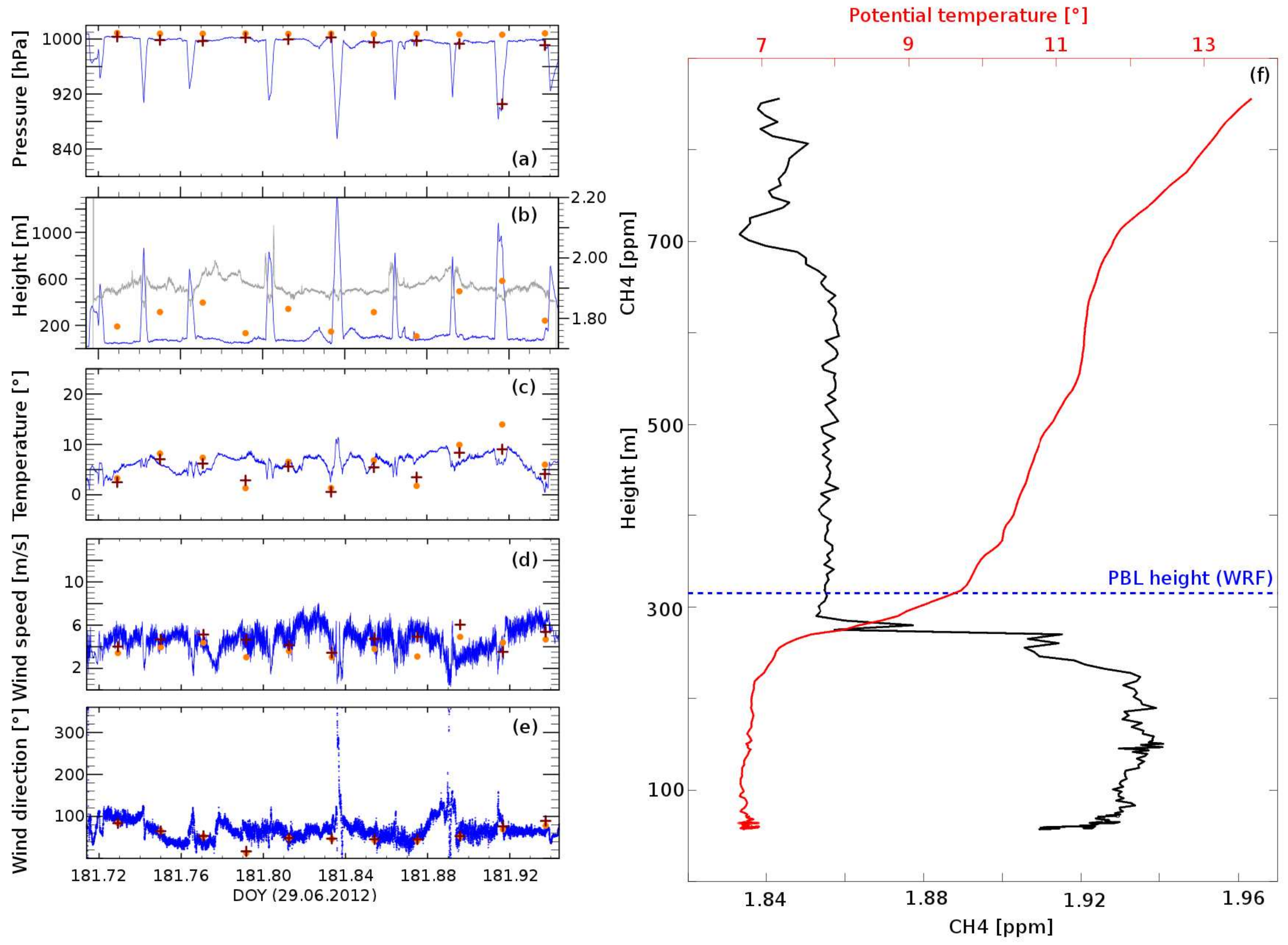

Figure 5: Left: pressure (a), flight altitude (b), planetary boundary layer height (b), CH_4 concentration (b), temperature (c), wind speed (d) and wind direction (e) on 29.06.12 obtained with airborne measurements (blue) and simulated with WRF model on the surface level (circle) and flight altitude (cross). Right: potential temperature (red) and CH_4 (black) profiles measured on 29.06.2012 17:45 and modeled PBL height on 29.06.2012 18:00.

Conclusions

- According to the convergence of ogive functions the minimum path length has to be more than 10 km to cover the whole turbulent spectrum
- Frequency response corrections are usually in range between 2 - 20% except some values for CH_4 flux
- The WPL term to compensate sensible heat fluxes across the Mackenzie Delta is twice the WPL term across the North Slope of Alaska due to higher temperature and water vapor fluctuations
- Strong regional differences were detected over both investigated areas showing the non-uniform distribution of methane sources
- The WRF model with the YSU PBL scheme predicts in a case study PBL height accurate enough to explain drops of CH_4 concentration to background level

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