Methane emissions from the East Siberian Arctic Shelf

Friedemann Reum,
Mathias Goeckede, Scot Miller, Anna Michalak, John Henderson, Charles E. Miller,
Martin Heimann

With contributions from
Ute Karstens, Wenxin Zhang, Tuomas Laurila, Ed Dlugokencky

AGU Fall Meeting, 2016-12-16, San Francisco
The East Siberian Arctic Shelf

- Large carbon deposits in seafloor
- Reservoir size may exceed amount of $\text{CH}_4$ in atmosphere (see IPCC, 2013)
## The East Siberian Arctic Shelf

### Annual CH$_4$ emissions from the shelf:

<table>
<thead>
<tr>
<th>Reference</th>
<th>1yr budget [Tg CH$_4$/yr] (global: 550-850)</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shakhova et al. 2014</td>
<td>17</td>
<td>bottom-up</td>
</tr>
<tr>
<td>Berchet et al. 2016</td>
<td>0 - 4.5</td>
<td>top-down</td>
</tr>
<tr>
<td>Thornton et al. 2016</td>
<td>2.9</td>
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</table>

No agreement on CH$_4$ budget. One reason: limited data coverage
Objective

• Goal:
  - Estimate the annual CH$_4$ budget of the East Siberian Arctic Shelf

• Method:
  - Inverse model of atmospheric CH$_4$ transport
  - Existing monitoring network + new station Ambarchik (Reum et al., in prep.)
Data coverage

- Improved coverage of the shelf with our station Ambarchik:
Data coverage

- Improved coverage of the shelf with our station Ambarchik:
Data coverage

- Quality-controlled Ambarchik CH$_4$ record
Geostatistical inverse modeling

- Bayesian inverse model, but:
- Prior flux and covariance parameters estimated based on atmospheric data

→ an objective method to infer covariances
→ overcomes lack of prior knowledge of fluxes

- Also in this study: enforce non-negative fluxes

References: Miller et al. 2014, Michalak et al. 2004
Prior flux: “auxiliary variables”

- Variables that correlate with CH$_4$ fluxes → represent flux patterns
- Example:

$$\text{prior} = \beta_1 \ast \text{Siberia Shelf} + \beta_2 \ast \ldots$$

Ice-free ocean
ASI-SSMI, Kaleschke et al.
Prior flux: “auxiliary variables”

- Considered for prior ocean CH$_4$ flux:

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<td>Sea ice</td>
<td>ice-free ocean fraction, sea ice growth, sea ice melt</td>
<td>Ice barrier, Brine rejection, Accumulation below ice</td>
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## Results: auxiliary variables

Considered for prior ocean CH$_4$ flux / selected by model:

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Results: auxiliary variables

- For land fluxes, considered/selected variables describe:
  - wetland emissions (LPJ-GUESS, Zhang et al. 2013)
  - lake emissions
  - fire
  - anthropogenic emissions
  - a constant
Results: posterior CH$_4$ flux

Annual mean CH$_4$ flux 10/2014 - 09/2015

- little structure in shelf flux (see outlook)
Results: posterior CH$_4$ flux timeseries

Annual mean CH$_4$ flux 10/2014 - 09/2015
Results: posterior $\text{CH}_4$ flux timeseries

- Central shelf north of Ambarchik:
  - time series follows auxiliary variable (ice-free ocean)
  - no spring flux
  - strong autumn flux
Outlook: 1yr CH$_4$ budget of the shelf

- Auxiliary variables have to represent flux patterns accurately!

  → need to represent e.g. Hot Spots:

Summertime CH$_4$ flux pattern of the East Siberian Arctic Shelf derived from local measurements. Shakhova et al. 2010, Fig. 1D
Conclusions

- New station Ambarchik provides valuable data about East Siberian Arctic Shelf
- A simple model of sea ice cover explains patterns in ocean CH$_4$ fluxes
- For annual CH$_4$ budget of shelf, proper representation of flux patterns by auxiliary variables is crucial
References

- IPCC 5th assessment report, 2013
- Berchet et al. 2016, ACP, doi:10.5194/acp-16-4147-2016
- Kaleschke et al., ASI Algorithm SSMI-SSMIS sea ice concentration data
Appendix
The East Siberian Arctic Shelf II

- Permafrost degradation $\rightarrow$ methane flux to water column $\rightarrow$ emission to atmosphere

[Adapted from Jansen 2014]
Inferring fluxes from atmospheric data

- Path and CH$_4$ mixing ratio of an air parcel:

Known initial mixing ratio 1900 ppb CH$_4$

Boundary layer height

Measurement 2000 ppb CH$_4$

+40 ppb

+60 ppb
Geostatistical inverse modeling II

- Perfect world: minimize model - data mismatch:
  \[ L_s = \frac{1}{2}(z - Hs)^T R^{-1} (z - Hs) \]

- Reality: underconstrained problem \( \rightarrow \) also minimize mismatch to prior flux:
  \[ L_s = \frac{1}{2}(z - Hs)^T R^{-1} (z - Hs) + \frac{1}{2} (s - s_p)^T Q^{-1} (s - s_p) \]

- GIM: also optimize the prior flux and covariance parameters:
  \[ L_{s, \beta} = \frac{1}{2}(z - Hs)^T R^{-1} (z - Hs) + \frac{1}{2} (s - X \beta)^T Q^{-1} (s - X \beta) \]

Equations from Michalak et al. 2004
GIM III: Covariance parameter estimation

- Restricted maximum likelihood
- find the values of the covariance parameters that maximize the probability of the measurements

\[ p(z|\theta, r) = \int_{S} p(z|\beta, \theta, r) \, d\beta \]

Kitanidis 1995 Eq. 9
GIM IV: Model selection

- qualitative explanation: BIC = fit to data + model complexity

\[ BIC_j = -2 \ln(\hat{L}_j) + k \ln(n) \]

Mueller et al. 2010 Eq. 4
Results: fit of atmospheric data

- modeled CH4 mixing ratios (plausibility check)
Discussion of Uncertainties

- What can happen in areas my station network does not see?

  → Fitting 7x the current total ESAS budget estimate into the area that contributes only 20% to the total influence on the atmospheric data → still plausible mixing ratios