Element transport to riverine systems from forest-peatland complexes: ZOTTO footprint area

Prokushin A.S.1,3, Pokrovsky O.S.1, Korets M.A.1, Karpenko L.V.1, Titov S.V.1, Schulze E-D.3
1V.N. Sukachev Institute of Forest SB RAS, Akademgorodok 50/38, Krasnoyarsk, Russia
2LMTGOMP, Université Paul Sabatier-CNRS-IRD, 14 avenue Edouard Belin, 31400 Toulouse, France
3Siberian Federal University, Sovetsky 79, 660041 Krasnoyarsk, Russia
prokushin@ksc.kras.ru

Introduction

West Siberia peatlands store at least 70.2 Pg C and cover ca. 600,000 km². These peatlands receive large attention in last decades primarily because of their great potential for carbon release to the atmosphere through enhanced CO₂ and CH₄ gas emissions (Peregon et al., 2009). On another hand, the release of dissolved organic carbon to streams and rivers has emerged as an additional and crucial negative term in the carbon balance of peatlands (Frey and Smith, 2003). The Ob’ and Yenisey Rivers, draining Western Siberia Lowland en route to the Kara Sea, transport more dissolved organic carbon (DOC) than any other river of the Arctic Ocean basin (Holmer et al., 2011). Thus, to predict the response of West Siberia peatlands to climate warming requires also exploring riverine element fluxes in the sense of (i) terrestrial sources and (ii) controlling mechanisms.

Rationale

Since 2006, the scientific and infrastructural platform of Zotto Tall Tower Observatory (ZOTTO, http://www.zottoproject.org) provides the unique opportunity to monitor and quantify the anticipated changes in biogeochemical cycles in this important region of the globe. Although the major efforts of ZOTTO are devoted to the atmospheric processes, the aim of this synergetic study was to link terrestrial ecosystems to aquatic chemistry with emphasis on carbon species.

Study site, material and methods

Remote sensing technique and field campaigns in footprint zone of ZOTTO Tall Tower Observatory (60°N, 90°E) have been performed to analyze and link properties of landscape (Fig. 1) to biogeochemistry of rivers draining the area (Fig. 2). Within ZOTTO footprint area 12 bogs of different genesis (ombrotrophic and minerotrophic) have been selected and comprehensively investigated for peat depths, peat layer age (radiocarbon), element content, biochemical (lignin CuO oxidation), and stable isotope (δ13C) of δ13C and δ18O in peat samples (Fig. 3) composition and carbon accumulation rates. Peat samples were also identified for analysis of peat-forming plant species and study of microbial composition and activity. In parallel, regular water sampling has been arranged on several rivers draining research area: with biweekly interval for Bolsheaja Khobja and Razviliki rivers (Table 1), and occasionally for Khobja, Tugino and Semyannik rivers (watershed area 1.3–554 km²) to obtain spatio-temporal variation of chemical composition and element export. Comparative analysis of C species (TC Analyzer), anions (IC), cations (ICP-MS) and dissolved inorganic matter in different seasons and peat waters up to 200 cm depth (50, 50–100 and 200 cm) sampled in bogs of different genesis has been conducted to trace likely terrestrial sources of matter in surface waters and its seasonality.

Finally, GIS-based analysis of 12 selected watersheds (Fig. 2) has been applied to evaluate key watershed parameters (total area, land cover classes, Table 1) influencing chemical composition of river waters (e.g. DOC, DIC, C, SO4, Ca, Mg, K, Na, Fe, Al, REE etc.).

Results and discussion

The entire territory between Sym and Tiches Rivers (left tributaries of Yenisey River) located within the ZOTTO footprint area are covered by pine forests (52%), peatbogs of different genesis (37%), dark conifer taiga (9%), broad-leaved forests (2%) and burned areas (2%). Twelve analyzed watersheds have diverse diversity in proportion of these classes providing an excellent opportunity to trace the key vegetation types driving the biogeochemistry of surface waters in the area (Table 1).

Hydrological regime of ZOTTO streams is typical for boreal regions with summer season dominance in annual runoff (Fig. 4a). Summer-fall high flow events occur when precipitation exceeds ca. 5 mm a day (Fig. 4b). Chemical composition of river waters follow changes of discharges with the increase of DOC (Fig. 5) and elements correlated with organic colloids (e.g. Fe, Al, Zn, REE, Ti, Cr, Mn) under similar conditions. In opposite, the low flow periods are characterized by elevated concentrations of inorganic load (e.g. DOC, Ca etc.). Specifically, (Table 1), was found to indicate local groundwater input. High concentrations of this element have been traced in the solutes of deep minerotrophic peat horizons (sedge peat).

Dissolved "true" lignin (VSC) and its constituents in rivers demonstrate significant seasonal fluctuations in both studied rivers (Fig. 6a). In general, vascular lignin content in DOC decreases following decrease of discharges. On the other hand, "false" lignin (Razviliki) showed steady increase of mass signal (p-phenols) during frost-free season (Fig. 6b), and Khojba River has negligible seasonal changes with overall dominance of p-phenols (ca. 45% of total).

In terms of DOC basin sources, these two rivers in their links to vegetation types (i.e. peatland vs. forests). Area of lignin composition analysis (Fig. 7a) revealed that B. Khojba DOM evidently linked to peatlands (e.g. upper Sphagnum sp. peat DOM), and B. Khojba DOM linked to mosses (as shown for deep (200 cm) sedge peat). Latter case is indicative for an input of DOC from forests.

Riverine DOC concentrations in footprint area rivers demonstrated the strong relationships with basin peatland area at all seasons (Fig. 7b). Forested terrains played a role only at spring (r=0.61, p<0.05). The total river basin area correlated negatively with DOC concentrations, but determined an increase of inorganic loads.

C export from watersheds (3.6±0.2 gC/m²a) is dominated by OC-57% of total dissolved C) and POC (with an increase of larger basins (Table 2). Particulate OC may contribute as much as 20% of total C export from watersheds annually.

Conclusions

Vegetation type and disturbances significantly affects chemical composition of river waters. Peatbogs and forests are the dominant of the ZOTTO footprint area driving the riverine biogeochemistry. Particularly, the export of C from basins is increasing with the extent of peatland coverage. Disturbances like logging and/or fires have an opposite effect. Total riverine export of C from watersheds (Rch) in the order of 0.2–1.2 gC/m²a is roughly 10% of peat bog NEE or 2% of pine forest NES (Schulze et al., 2002). However, significant portion of organic C might be mineralized in rivers, leading to lower DOC concentrations in rivers of large-size watersheds. However, taking into consideration dissolved inorganic carbon (45% and 46% in rivers, such hydrological path way is the crucial route of terrestrial C losses.

Acknowledgements

This work has been supported by joint Russian-French grant RFBR-CNRS # 08-05-95205 (GDRI CAR-WET-SB) and Ministry of Education and Science of the RF # 11.G34.31.0014 "megaramag" for leading scientists (Prof. E-D. Schulze).

Table 1. Land cover classes within the research area and 12 basins of selected streams and rivers.

<table>
<thead>
<tr>
<th>Land cover classes</th>
<th>Area, km²</th>
<th>Land cover classes</th>
<th>Area, km²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood plains</td>
<td>11.4</td>
<td>Spruce forest</td>
<td>8.9</td>
</tr>
<tr>
<td>Grasses</td>
<td>11.4</td>
<td>Birch forest</td>
<td>5.5</td>
</tr>
<tr>
<td>Forest</td>
<td>11.4</td>
<td>Picea forest</td>
<td>3.2</td>
</tr>
<tr>
<td>Water bodies</td>
<td>11.4</td>
<td>Open water bodies</td>
<td>2.0</td>
</tr>
<tr>
<td>Total area, km²</td>
<td>11.4</td>
<td></td>
<td>30.3</td>
</tr>
</tbody>
</table>

Table 2. Seasonal and annual rivers C export estimates.

<table>
<thead>
<tr>
<th>River</th>
<th>Basin area, km²</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer-fall</th>
<th>Annual</th>
<th>Winter</th>
<th>Spring</th>
<th>Summer-fall</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverine</td>
<td></td>
<td>DOC</td>
<td>DIC</td>
<td>POC</td>
<td>Total</td>
<td>DOC</td>
<td>DIC</td>
<td>POC</td>
<td>Total</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>3.25</td>
<td>0.30</td>
<td>3.55</td>
<td>4.55</td>
<td>1.54</td>
<td>1.07</td>
<td>2.81</td>
<td>3.55</td>
</tr>
<tr>
<td>SD</td>
<td></td>
<td>1.36</td>
<td>0.30</td>
<td>1.22</td>
<td>1.47</td>
<td>0.11</td>
<td>0.11</td>
<td>0.11</td>
<td>0.45</td>
</tr>
<tr>
<td>Std. deviation</td>
<td></td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Fig. 1. Land cover classes and location of analyzed peatland and river sampling areas.

Fig. 2. Dynamics of dissolved organic carbon (a) and changes in element composition in river flow (b).

Fig. 3. Structure of (1) the major organic oxide products, (2) phenol aromatic and (3) hydroxylic (polyoxyethylene monosulfate and saccharides) characteristics of dissolved peat groups and plant. Adapted from Headges and Erf 1990 and Amor et al. 2012.

Fig. 4. Long-term monthly runoff (a) and changes in river water level (b) in relation to precipitation (c).

Fig. 5. Concentrations of dissolved organic carbon (a) and changes in element composition in river flow (b).

Fig. 6. Concentrations of dissolved organic carbon (sum of vandil C, syringaldehyde (S) and coumaric acid (C) (sterotipon) (a) and p-phenols (b) in river flow.