Assessment of the uncertainties in air mass and pollutants transboundary exchange over the continental part of the EANET region

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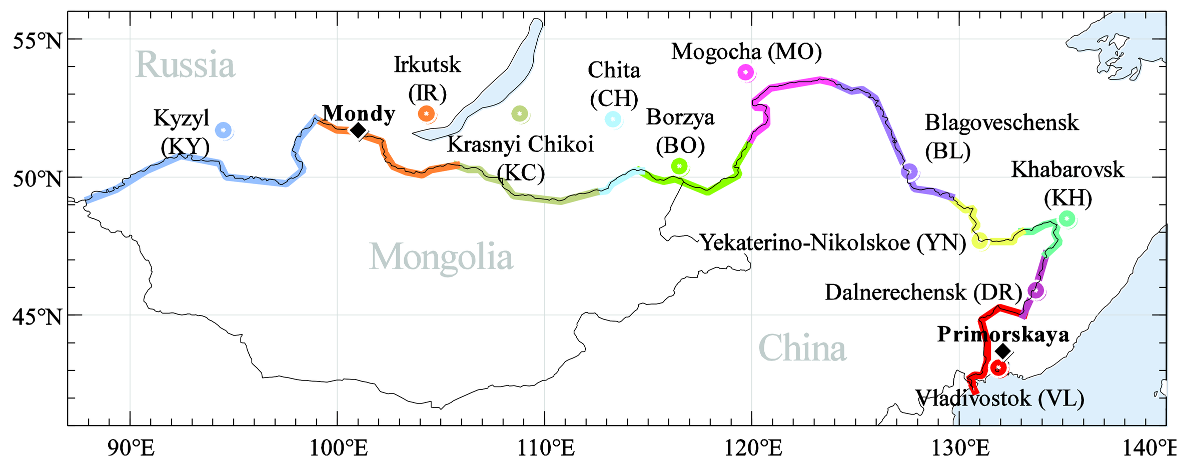
Abstract / Motivation

Airborne compounds containing sulphur and nitrogen play an important role in atmospheric chemistry. Being capable of absorbing solar radiation at different wavelengths, they are recognized to have a potential to influence the climate evolution on Earth. Current interest in studying these compounds arises due to their increased global input into the atmosphere in course of rapid economic development. Further important aspect, viz. the negative effect of these substances on human health, biota and human infrastructure, motivate a more practical investigation of their spatial and temporal distributions.

In this study, we attempt to quantify the uncertainties in air mass exchange in the lower troposphere across two regions of the Russian border in Eastern Siberia and the Russian Far East in 2000−2015. Subsequently, we estimate uncertainties in the transboundary transport of S- and N-bearing compounds, using the observations provided by EANET [3]. We find reckoned airmass and pollutant transport is a non-linear problem, which perceptibly depends on the assumptions used.

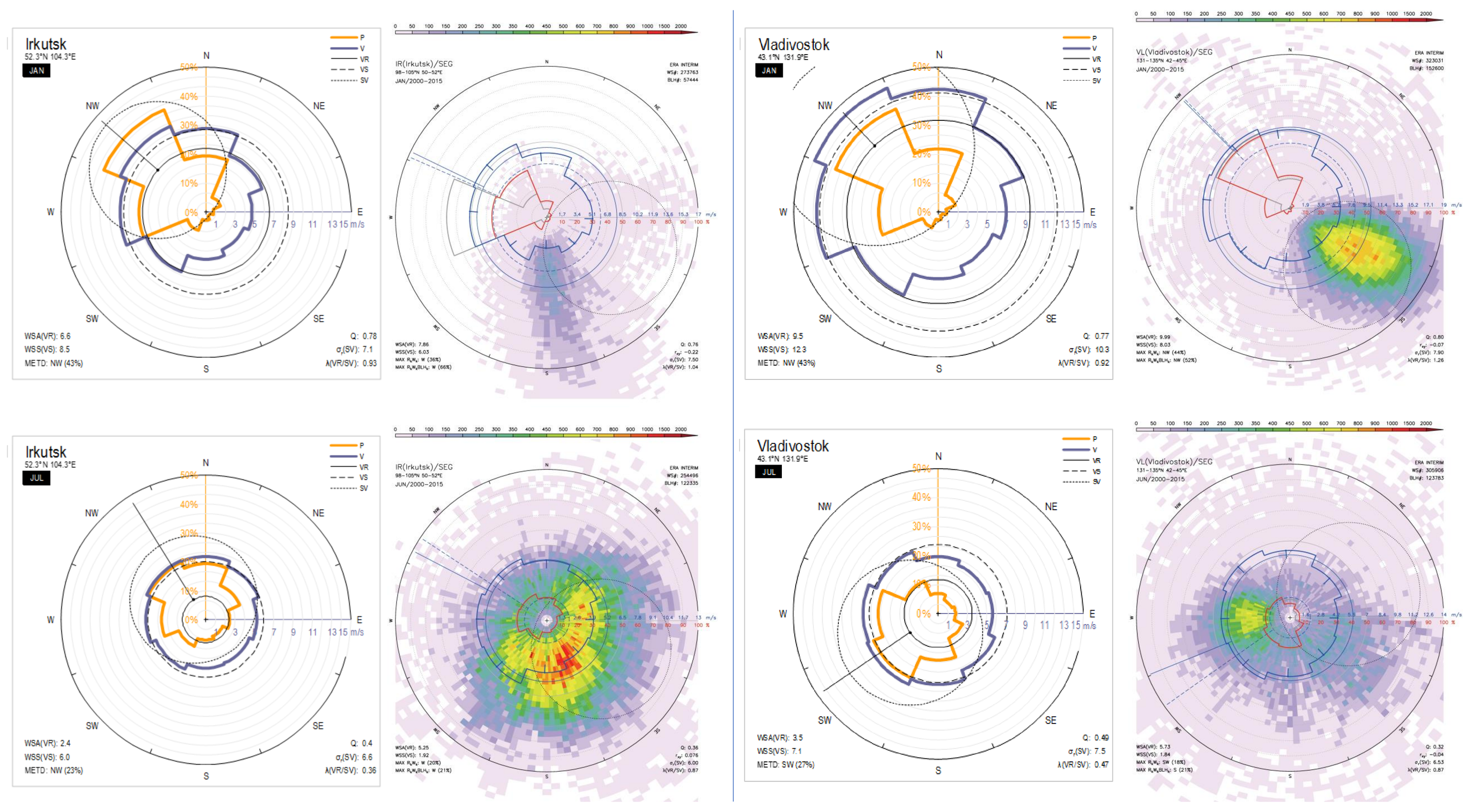
Data / Methods

We use meteorological data from long-term air sound data (ASD) on mean layer winds [1] and from the ERA INTERIM re-analysis (EIR) project [2]. Using a transboundary exchange model, we estimate the total and net amounts of air crossing the boundary segments around Irkutsk (IR) and Vladivostok (VL) aerological stations.



Locations of the selected aerological (air sounding balloon) stations (ASD) and EANET monitoring stations (diamonds) along the Asian border of Russia. Colors distinguish the border segments chosen as pertaining to particular stations.

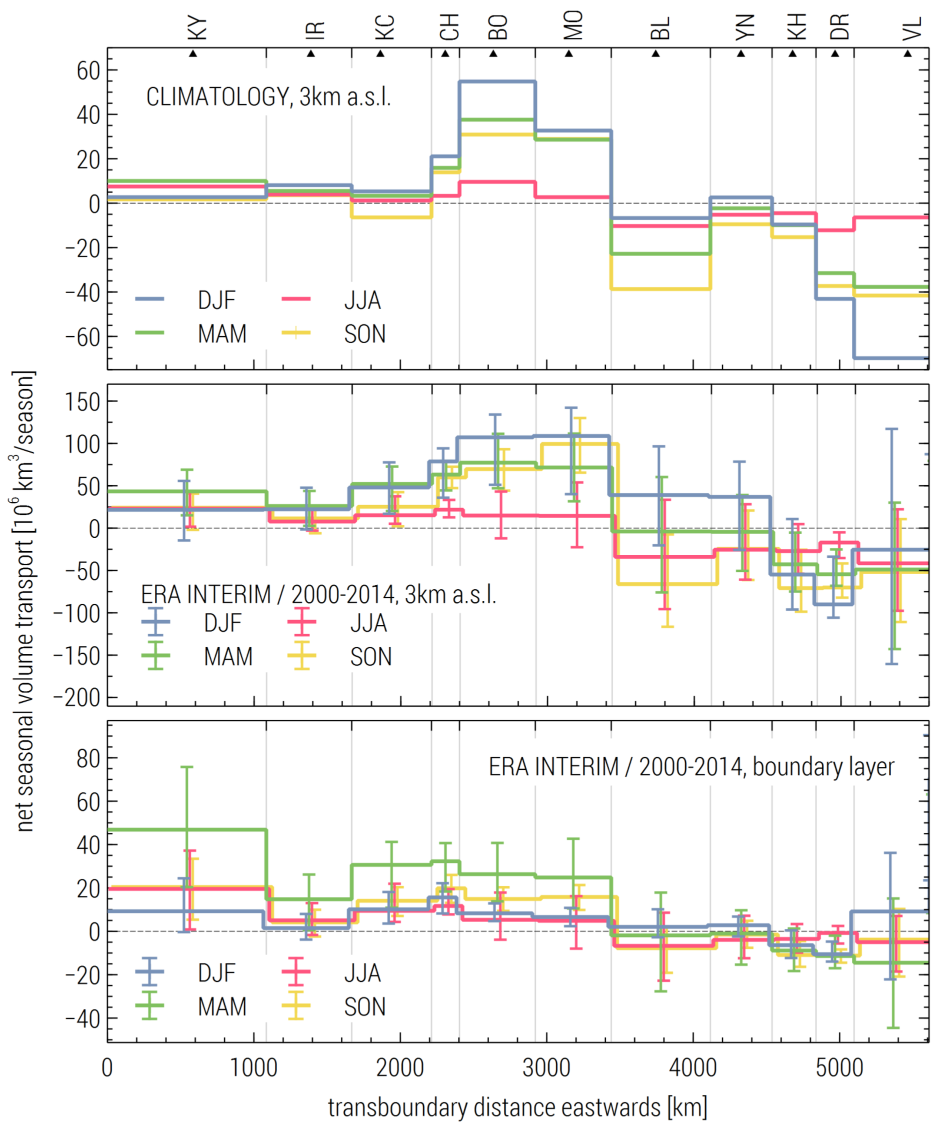
We compare transport terms derived (i) from the long-term wind statistics based on both ASD and EIR data, and (ii) from integrating 6h meteorological winds from EIR directly over the border segments cells. We find similar wind direction statistics in both meteorological datasets, however EIR favours stronger westerly winds at VL in summer, which results in more often air export from China to Russia in the Far East. There is less agreement on the wind strengths than wind directions between the datasets, with EIR often providing slower wind speeds. However, as the EIR data shows, wind patterns within 3km a.s.l. layer and boundary layer differ in direction and occurrence, hence favouring different net transport. This is an important assumption when species transport is calculated subsequently.



Eight-rhumb climatic wind statistics derived from the within a 3 km layer from ASD and EIR data (left and right panels of the pair), respectively. Thick contours represent the average wind speed (blue) and recurrence (orange) in respective rhumbs. The solid black circles refer to the average wind magnitude (radial lines indicate wind direction); the remaining circles denote the average wind standard vector deviation (dotted) and scalar wind magnitude (dashed). Note that the rhumb data are the result of numerical processing, as opposed to the input actual statistical data. Shaded areas present wind magnitude and occurrence within the BL.

Results / Net air trasnport

The resulting climatic (ASD) and directly (from EIR 6h terms) calculated non-equilibrium (net) transport terms are comparable in orders (tens of million km^3/month), however may differ substantially in temporal evolution or/and magnitude (see Figure on the right). Thus, EIR net transport over the IR segment has similar annual dynamics but is higher by a factor of ~4. An opposite ratio is derived for the VL segment (average ~6 vs. 13 of 10^6 km^3/month), with a distinct seasonality in the ASD but not in the EIR data. We attribute this discrepancy to the variations in wind direction with altitude, which cannot be resolved in the model fed with the ASD data. Calculated transport in the boundary layer (BL, provided by the EIR) supports this inference. Thus, the BL net transport temporal dynamics differ substantially from that within the 3 km layer, owing to the BL diurnal dynamics that favour non-equilibrium air transport mostly at daytime. The BL transport reaches at most $2{\cdot}10^6$ km^3/month in April-May during air export from Russia at the IR segment and re-import from China at the VL, respectively. A non-negligible BL air import from China into Russia occurs also over the IR segment throughout winter (at a 0.7−1.5 of 10^6 km^3/month rate).



Calculated net seasonal air transport by station using ASD (upper) and EIR (lower panels), respectively. Error bars denote the 2000−2014 inter-annual variation in seasonal averages.

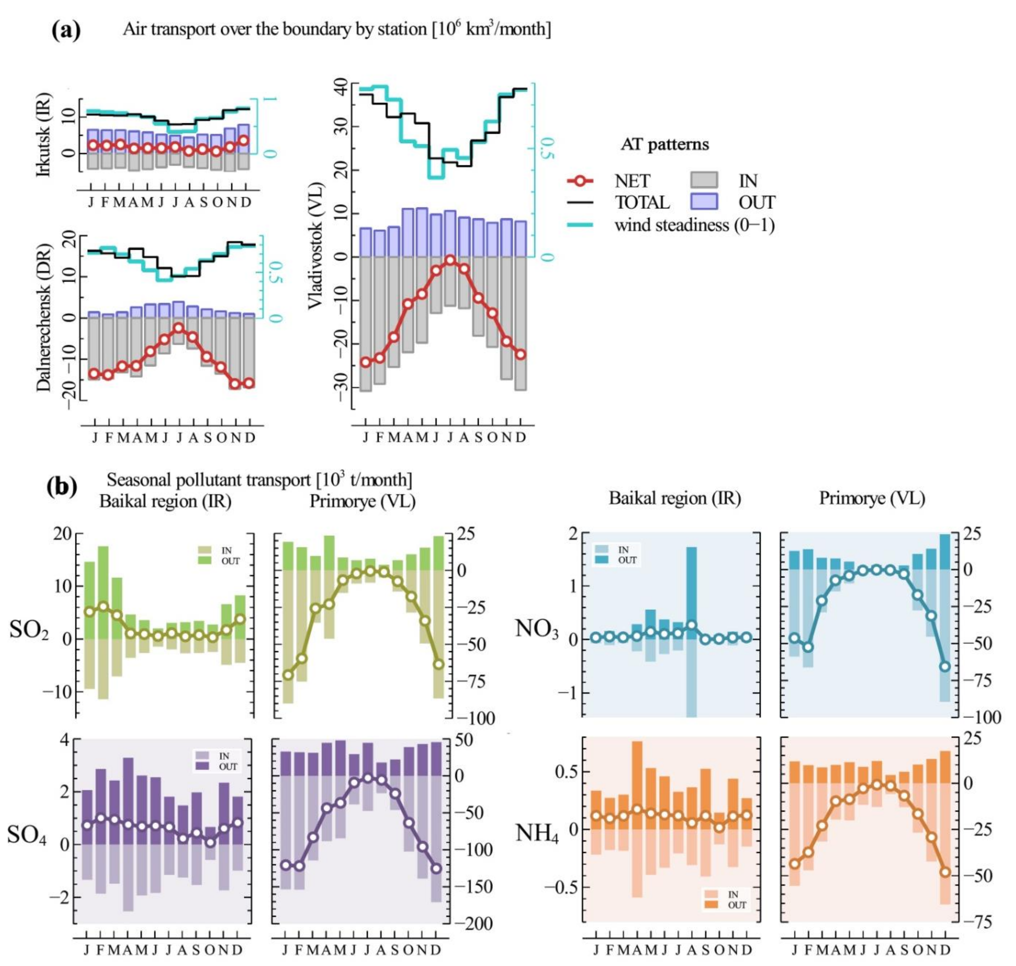
Results / Species transport / ASD

The resulting climatic (ASD) intra-annual dynamics of transport VL scales with net airmass transport, so pollutant transfer rates reach tens of thousand tons per month across about 540 km of this border segment. Whilst winter season provides 50−66% of the annual pollutant transferred mass, diminished net airmass transport and declining concentrations furnish its summer share at negligible 1−2%. Unlike that case the variations in net PT at IR region are much less in range being mainly propelled by the changes in pollutant abundances. Overall at IR segment the net pollutant transfer is positive (i.e., outward Russia) but comprises extremely lower total values for the comparable segment length of ~580 km (cf. Table).

Estimated seasonal and annual net pollutant transboundary transport across western (Baikal area) and eastern (Primorye) segments (IR/VL) for 2006−2008 (10^3 tons)†

Species	DJF	MAM	JJA	SON	Annual
SO_2	15.1 / −193.8	6.5 / −55.1	2.2 / −3.7	2.8 / −59.2	26.6 / −311.8
SO_4	2.6 / −367.8	2.4 / −163.2	1.6 / −17.3	1.1 / −183.2	7.7 / −731.5
NO_3	0.1 / −164.3	0.3 / −32.4	0.5 / −1.3	0.1 / −51.4	0.9 / −249.4
NH_4	0.3 / −129.0	0.4 / −41.2	0.3 / −4.8	0.3 / −52.5	1.3 / −227.5

† Positive and negative values denote fluxes outward and inward Russia, respectively.

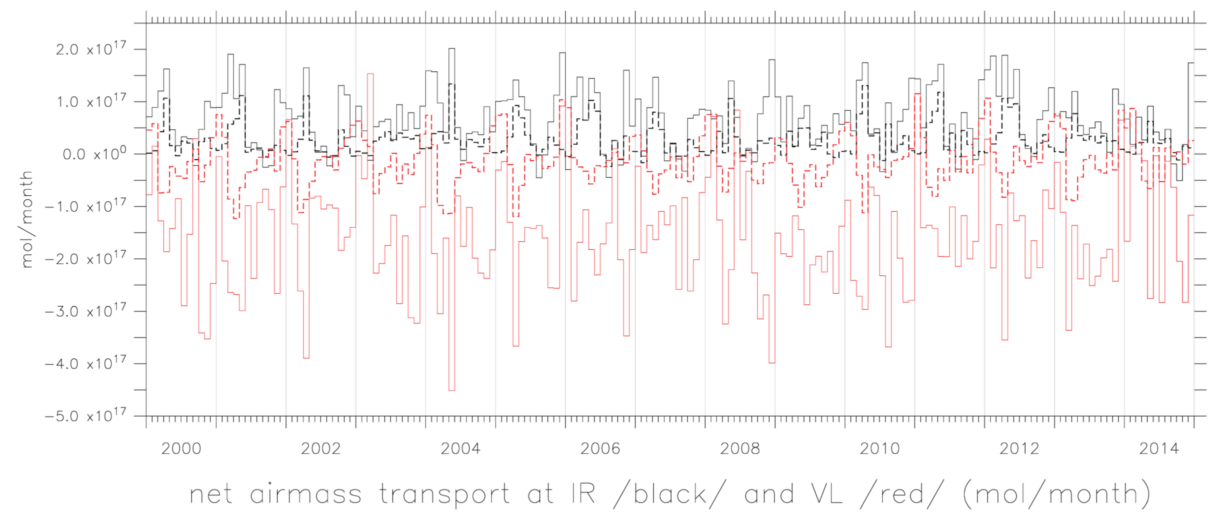


ASD-based calculation results of air mass (a) and pollution (b) transport across the border of Asian Russia at IR and VL segments. Note the varying axis scales in panel (b).

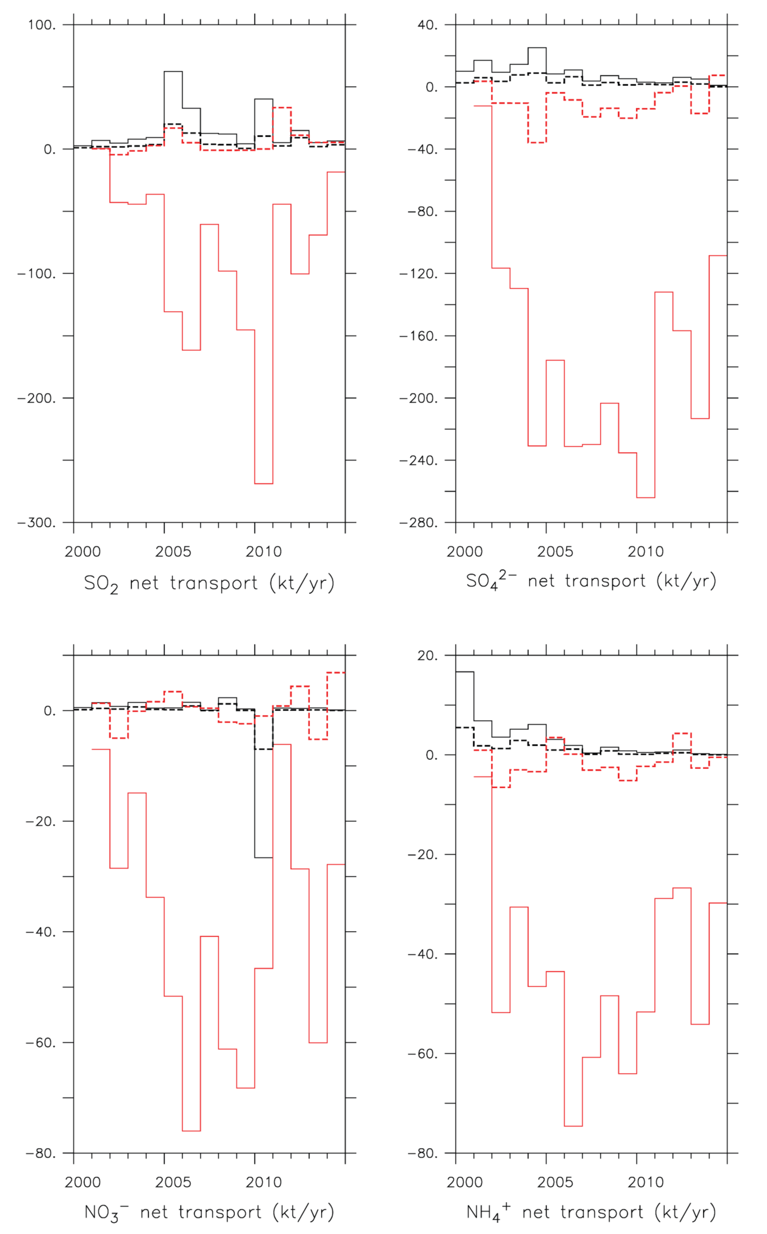
Results / Species transport / EIR

The resulting climatic (ASD) and directly (from EIR 6h terms) calculated non-equilibrium (net) transport terms are comparable in orders (tens of million km^3/month), however may differ substantially in temporal evolution or/and magnitude (cf. figures for ASD). The starkest difference is seen at VL between steadily negative (i.e. outwards Russia) transport within 3km a.s.l. and almost no transport within the BL.

Similar pattern is seen for species transport (cf. Figure on the right). Overall, figures for 3km a.s.l. are comparable between the ASD and EIR. Exceptionally large transboundary exchange occurs in 2005−2006 and 2010 at IR and in 2006, 2008−2009, 2014 at VL. In the BL, similar dynamic is seen for SO_4 and NO2 at Vl, however with no significant transport at IR.



Calculated EIR net airmass transport at the IR and VL segments of the transboundary. Solid and dashed lines refer to tre transport terms reckoned within 3km a.s.l. and BL, respectively.



Calculated net pollutants transport at the IR and VL segments of the transboundary using EIR and EANET data. Solid and dashed lines refer to the transport terms reckoned within 3km a.s.l. and BL, respectively.

References

1. Brukhan, F.F.: Aeroclimatic Characteristics of the Mean Winds over USSR (ed. Ignatjushina E.N.). Gidrometeoizdat, Moscow, 54 p., 1984 (in Russian).Izrael, Yu.A., *et al.*: Monitoring of the Transboundary Air Pollution Transport. Gidrometeoizdat, Leningrad, 303 p., ***187*** (in Russian).
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