Evaluation of nitrous oxide (N_2O) retrievals from IASI/Metop A

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Nitrous oxide (N_2O), with a lifetime of approximately 120 years, is the third most significant greenhouse gas after carbon dioxide (CO_2) and methane (CH_4), contributing to global warming. It has a global warming potential 300 times greater than CO_2 over a 100-year horizon. N_2O emissions are not regulated by the Montreal Protocol and, although they are subject to the Kyoto Protocol, the observed annual increase of ~0.25% in N_2O over the past decade is expected to continue until 2100. N_2O emissions arise from both biotic (living organisms) and abiotic (environmental factors such as water, soil, and air) processes, with sources being 1) 60% natural and 2) 40% anthropogenic. In 2019, the annual average concentration of N_2O in the atmosphere was approximately 332 parts per billion per volume (ppbv).

Despite its importance, tropospheric N_2O measurements and surface emission sources remain globally understudied, with limited surface observations. However, sparse FTIR/NDACC instruments monitor N_2O profiles, and satellite observations in the thermal infrared (TIR) from IASI (Ricaud et al., 2009), AIRS, and GOSAT (Kangah et al., 2017) provide valuable global data. GOSAT-2/TANSO-FTS-2, which, theoretically, has some sensitivity to lower tropospheric N_2O, offers potential for studying surface emissions using inversion methods.

This poster presents a summary of the validation work carried out on the IASI N_2O retrieved using an optimal estimation method TN_2OR (Toulouse N_2O Retrieval) , as well as a preliminary comparison with GOSAT-2 N_2O products for 2019. IASI N_2O have been validated with HIPPO aircaft campaign and NDACC N_2O profiles at 300 hPa for 2011 (Chalinel et al., 2022), and compared with GOSAT-2 N_2O products for 2019.

TN_2OR characteristics

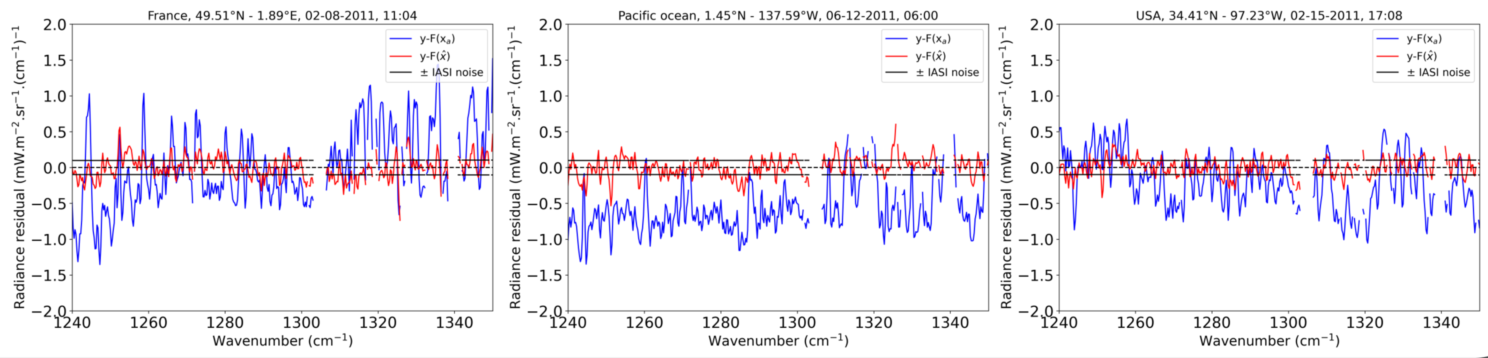
TN_2OR is an inversion tool that combines the RTTOV v12.3 radiative transfer model with the Levenberg-Marquardt optimal estimation method. Input data includes the Level 1C observations from the IASI-MetopA instrument. The algorithm enables the simultaneous retrieval of several parameters: N_2O, H_2O, CH_4, atmospheric temperature (T), surface temperature (T_{surf}), and surface emissivity (ϵ). The table below presents the uncertainties and apriori informations used in TN_2OR.

The a priori profile of N_2O used in the inversion process is based on averages derived from the HIPPO 1-5 aircraft measurement campaigns (2009–2011) combined with simulations from the LMDz-INCA v6 model.

Parameter	Uncertainty	A priori
N_2O	0.8 %	HIPPO/LMDz-INCA
CH_4	1 %	MACC/CAMS
H_2O	10 %	IASI L2
T	0.5 K	IASI L2
T_{surf}	1.5	IASI L2
Emissivity	0.15	0.984 (Konda et al., 1994)

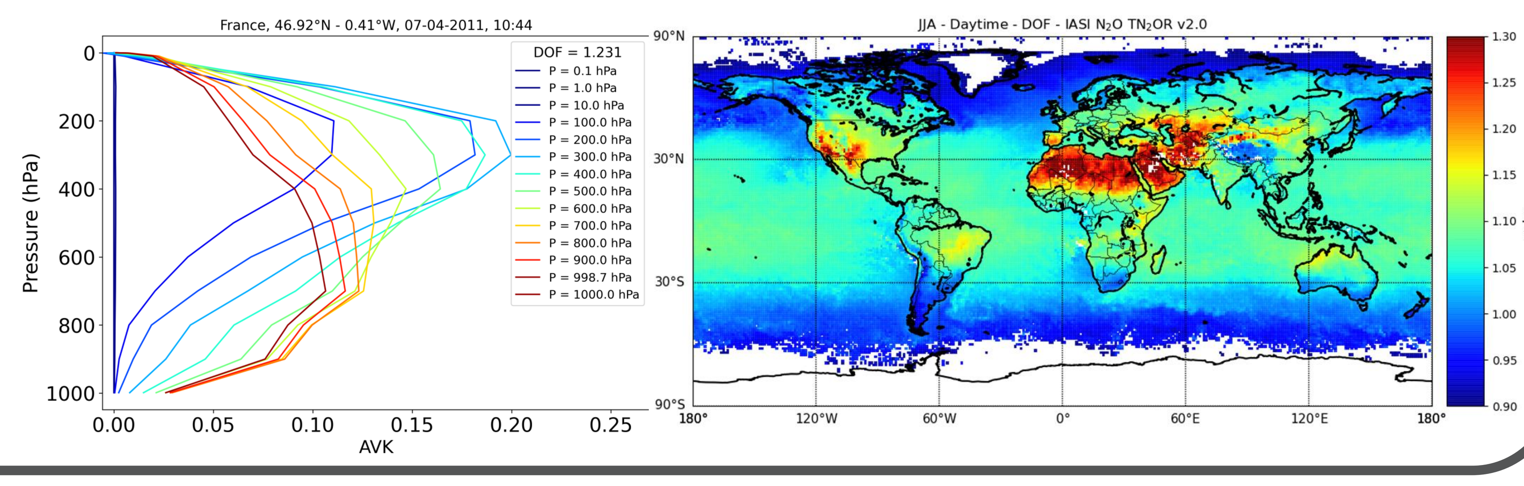
Radiance Residuals

The IASI channels selected for radiance calculations fall within the 1240–1350 cm⁻¹ window. A meticulous selection of relevant channels is done within this range. After the inversion, the radiance residuals are significantly reduced and tend to be consistent with the instrumental noise level of IASI demonstrating that TN_2OR, combined with RTTOV v12.3, effectively reproduces the observed radiances.

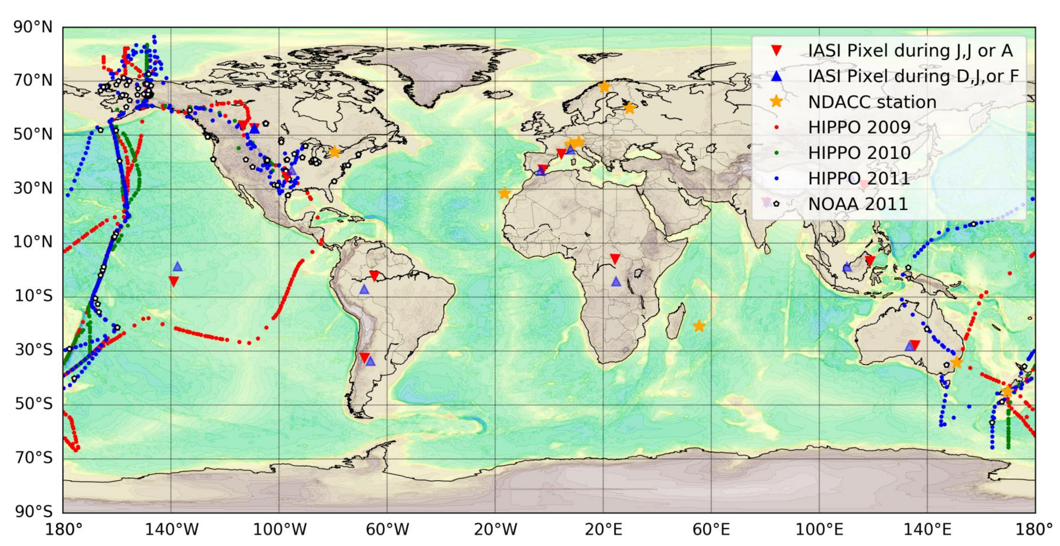


Vertical Sensitivity

The averaging kernels of the retrieved N_2O show a maximum sensitivity in the mid-to-upper troposphere (≈ 300–400 hPa). Furthermore, for all retrieved pixels (whether observed under favorable or unfavorable conditions, but exclusively in clear-sky scenarios), the degrees of freedom for the signal (DOF) are estimated to be around 1. This suggests that distinguishing vertical levels is generally challenging which implies analyzing the averaged columns instead. However, by focusing on the best sensitivity level, specifically at 300 hPa, it is possible to have a better understanding of the mid-to-upper tropospheric N_2O spatiotemporal variability because of the minimal impact of the a priori.

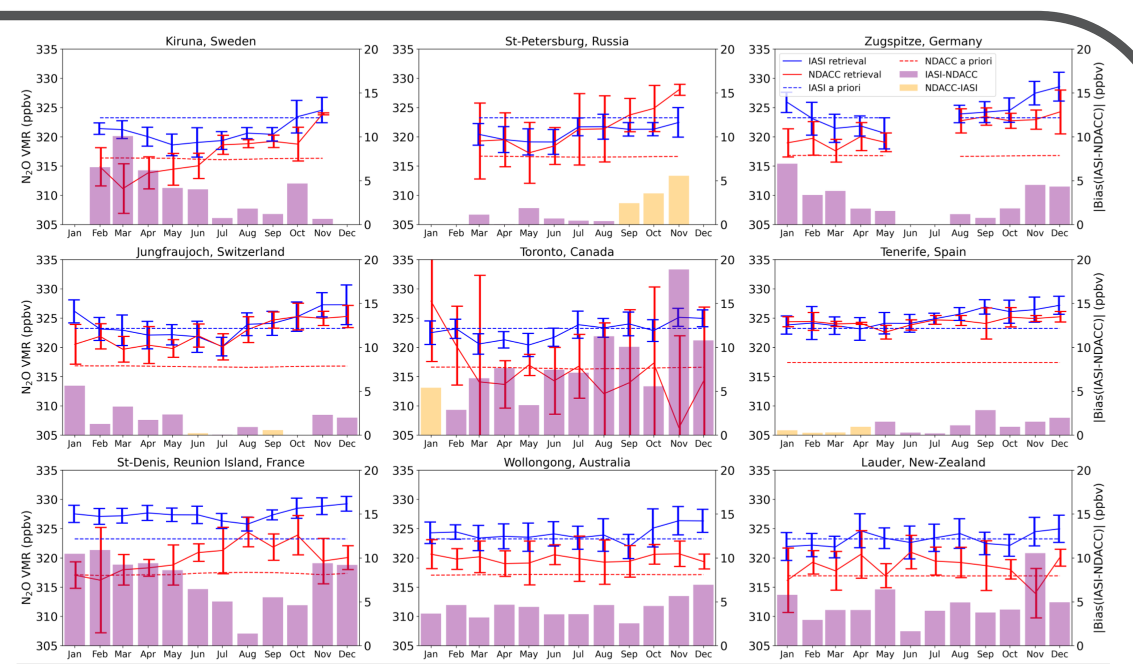


IASI validation



IASI vs NDACC

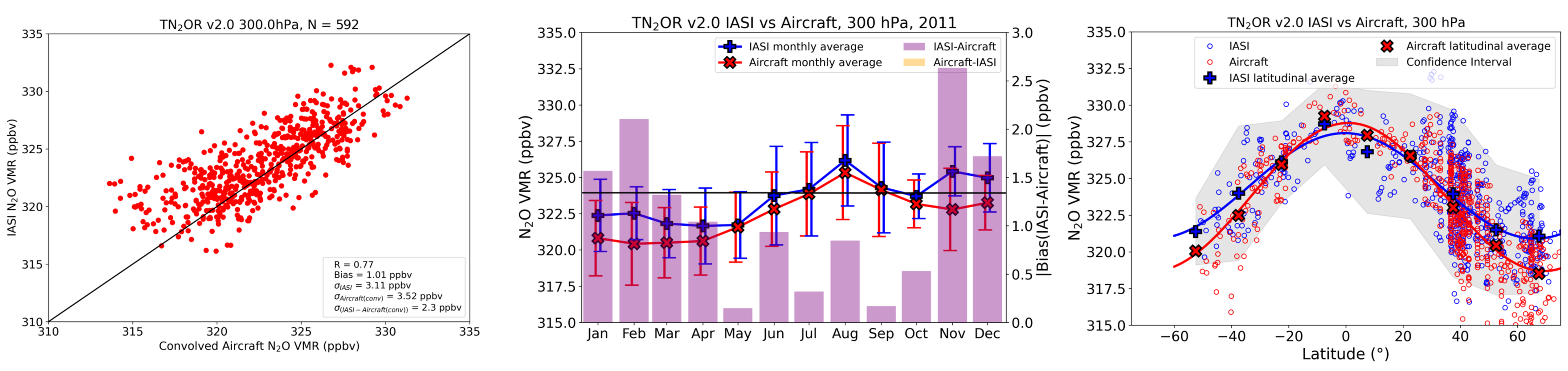
Station	Lat	Lon	H0 (m amsl)	R	Bias (ppbv)	σ(IASI) (ppbv)	σ(NDACC) (ppbv)
Kiruna	67.84°N	20.41°E	419	0.56	4.0	1.8	3.48
St Petersburg	59.9°N	29.8°E	20	0.85	−0.78	1.17	3.25
Zugspitze	47.42°N	10.98°E	2964	0.69	3.01	2.45	2.19
Jungfraujoch	46.55°N	7.98°E	3580	0.7	1.56	2.16	2.16
Toronto	43.66°N	79.40°W	174	−0.28	7.18	1.51	4.93
Tenerife	28.30°N	16.48°W	2367	0.56	0.7	1.32	0.68
St-Denis	20.9°S	55.5°E	85	−0.16	7.51	0.94	2.45
Wollongong	34.41°S	150.88°E	30	0.38	4.33	1.2	0.61
Lauder	45.04°S	169.68°E	370	0.1	4.76	1.09	1.92



The NDACC stations have the advantage to provide the profiles of N_2O that could be compared to collocated IASI profiles. For the Northern hemisphere stations, the behavior of the monthly evolution is quite similar for the different stations with a small positive slope well seen by IASI and NDACC. We can see an amplitude of 5–8 ppbv above Jungfraujoch and Zugspitze, and a much smaller one over Tenerife with an amplitude of 1–2 ppbv. Conversely, over Kiruna and St Petersburg, the NDACC N_2O amplitude is twice the one of IASI, likely because of the cold surface during the winter months inducing a weaker sensitivity of IASI. In general, IASI N_2O mixing ratios are higher than NDACC N_2O except over St Petersburg where the bias is negative but relatively weak (−0.78 ppbv). Over the Kiruna station, the bias is higher (≈4 ppbv) still likely due to the cold surface during the winter-spring period. The NDACC observations for Toronto can be considered as outliers with a negative slope and an unrealistic maximum-minimum amplitude of ≈18 ppbv.

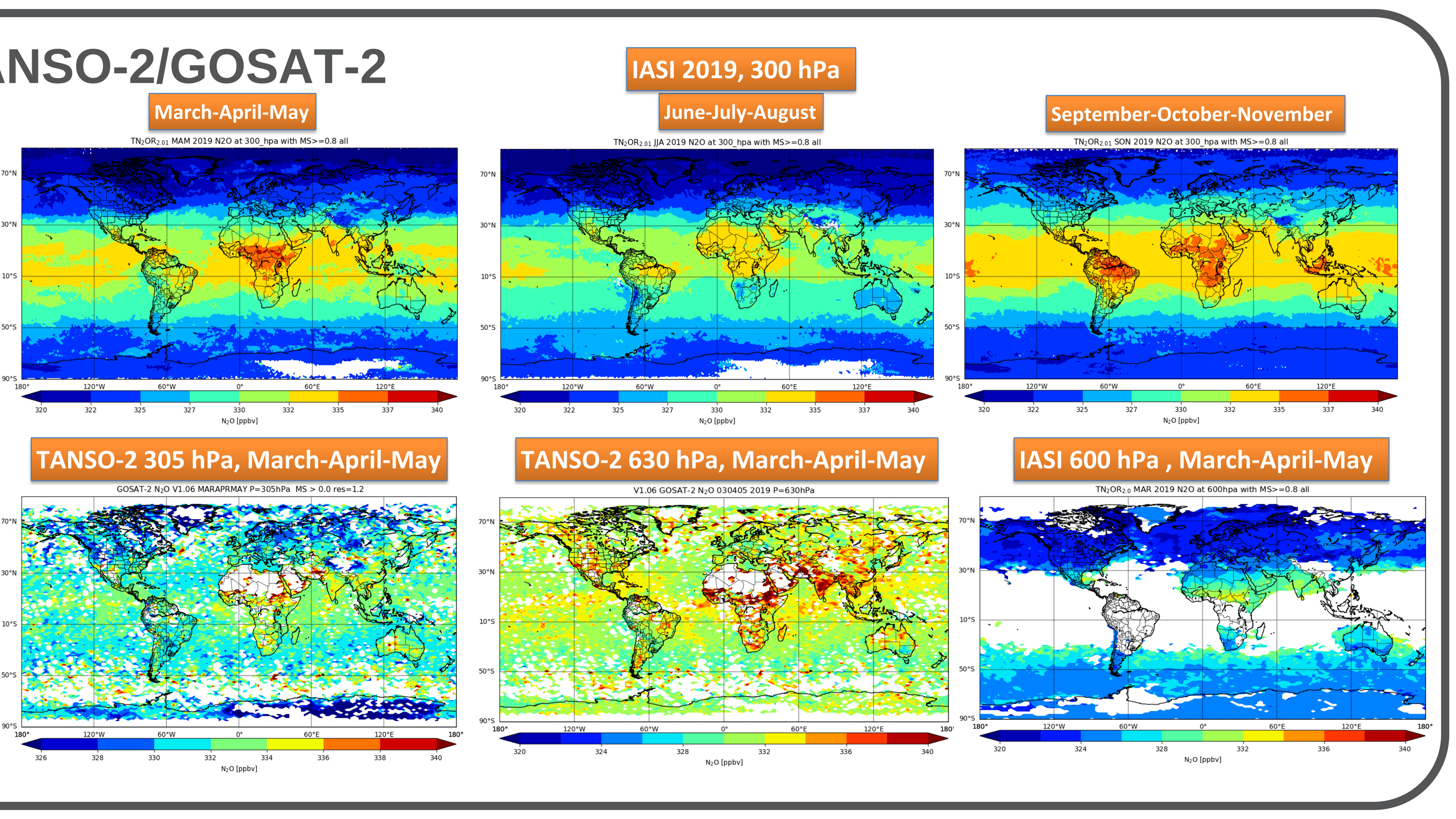
IASI vs HIPPO/NOAA

TN_2OR products from IASI at 300 hPa were validated using the HIPPO 1-5 airborne measurements, which were not used for the calculation of the a priori, as well as NOAA in-situ airborne measurements performed in 2011. The comparison between the collocated airborne measurements and IASI N_2O results in a correlation coefficient of R=0.77, a bias of 1.01 ppbv and a random noise of 2.3 ppbv. The seasonal variations for the year 2011 are globally consistent with a significant discrepancy observed in November 2011. Except for November, the difference remains below 2 ppbv. Additionally, the latitudinal variations are consistent with maxima in the equatorial regions and minima over high latitude regions.



Preliminary comparisons with TANSO-2/GOSAT-2

Preliminary comparisons have been performed between IASI and TANSO-2 mid-to-upper tropospheric N_2O retrievals seasonally averaged for the year 2019. We average the data into 1.2° x 2.4° boxes for TANSO-2 and 1° x 1° for IASI.
For the March-April-May (MAM) period, some consistent features are observed over Asia, Northern America and over Africa. The two datasets also exhibit the expected south-north latitudinal gradient.
The latitudinal variation, consistent with Chalinel et al., 2022, is systematically observed on the IASI TN_2OR product. It is important to note that the seasonal N_2O maps from TANSO-2 show less data compared to IASI, resulting in apparent noisy TANSO-2 N_2O fields.
We also observe, in the mid-lower troposphere (≈600 hPa) for MAM, high N_2O mixing ratios over southern Asia and equatorial Africa for TANSO-2, not present for IASI. This can be explained by the high sensitivity of TANSO-2 compared to IASI at this level. The white areas in the IASI N_2O fields correspond to missing data with a measurement sensitivity less than 0.8. A large part of sub-tropical data have been then removed, showing the lack of vertical sensitivity of IASI compared to TANSO-2.



Conclusions

TN_2OR was designed to retrieve global N_2O mixing ratios from IASI radiances. These retrievals were performed for the entire years 2011 (Chalinel et al., 2022) and 2019, as well as for specific dates and regions collocated with airborne HIPPO 1-5 campaigns. The algorithm was validated by comparing IASI-derived products with data from HIPPO and NOAA airborne campaigns as well as NDACC stations. The results have shown a correlation of 0.77 between IASI and HIPPO/NOAA data and a bias of 1.01 ppbv.

On the global scale and for 2019, mid to upper tropospheric N_2O mixing ratios derived from IASI and TANSO-2 displayed consistent features in Asia, North America and over Africa in MAM.

Future work could use a more extensive dataset from IASI and TANSO-2 to study the annual variability of both datasets. It would also be interesting to use TN_2OR to retrieve N_2O from future observations with better instrumental performances, such as IASI-NG. IASI-NG will have a better vertical sensitivity similar to TANSO-2 to improve the accuracy of N_2O emission sources.

References:

Chalinel, R., et al., Global-scale observation and evaluation of nitrous oxide from IASI on MetOp-A, Remote Sens., 2022.
Kangah, Y., et al., Summertime upper tropospheric nitrous oxide over the Mediterranean as a footprint of Asian emissions, J. Geophys. Res. Atmos., 122, doi:10.1002/2016JD026119, 2017.
Konda, M.; Imasato, N.; Nishi, K.; Toda, T. Measurement of the sea surface emissivity. J. Oceanogr. 1994, 50, 17–30.
Ricaud, P., et al., Equatorial total column of nitrous oxide as measured by IASI on MetOp-A: Implications for transport processes, Atmos. Chem. Phys., 9, 3947-3956, 2009.

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