Interpreting GEMS geostationary satellite observations of the diurnal variation of nitrogen dioxide (NO_2) over East Asia

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IGC11

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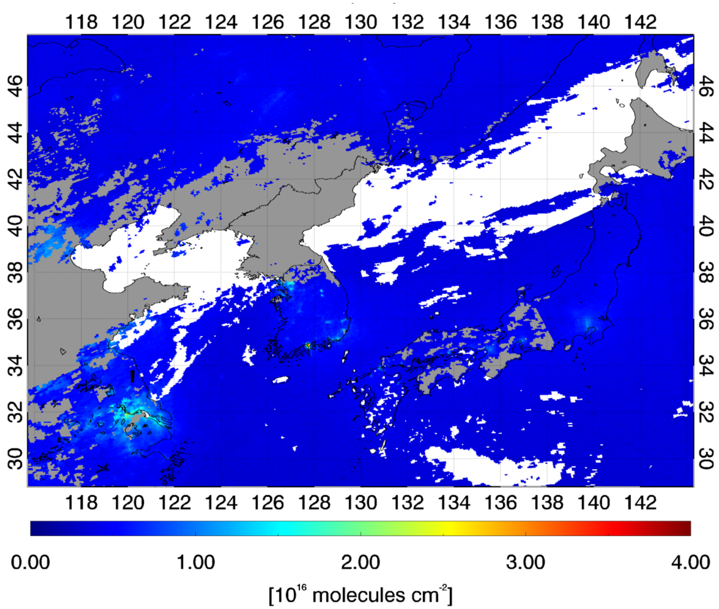
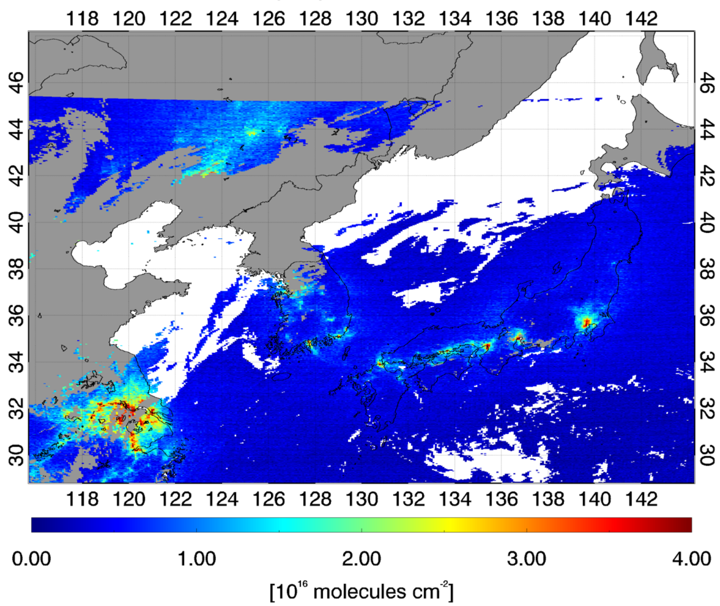
GEMS geostationary satellite instrument provides first hourly data of air pollutants over East Asia

Low-earth orbit (LEO)



Geostationary orbit



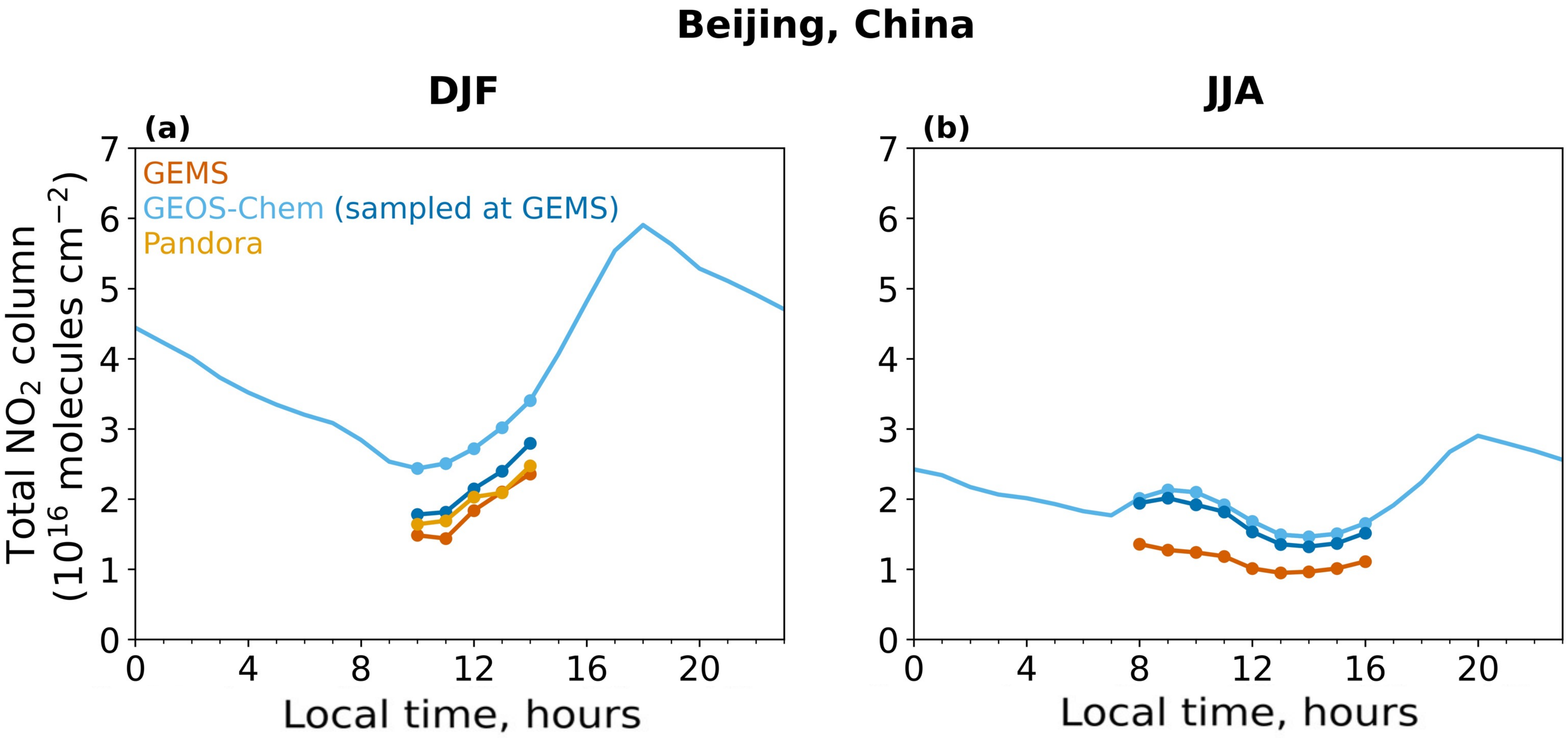
Advantages of geostationary satellite's hourly observations:

- Dense observations
- Better cloud clearing
- Continuous monitoring of pollution transport
- **Characterization of diurnal variation of emissions and chemistry**

[Figure from Hanlim Lee (PKNU)]

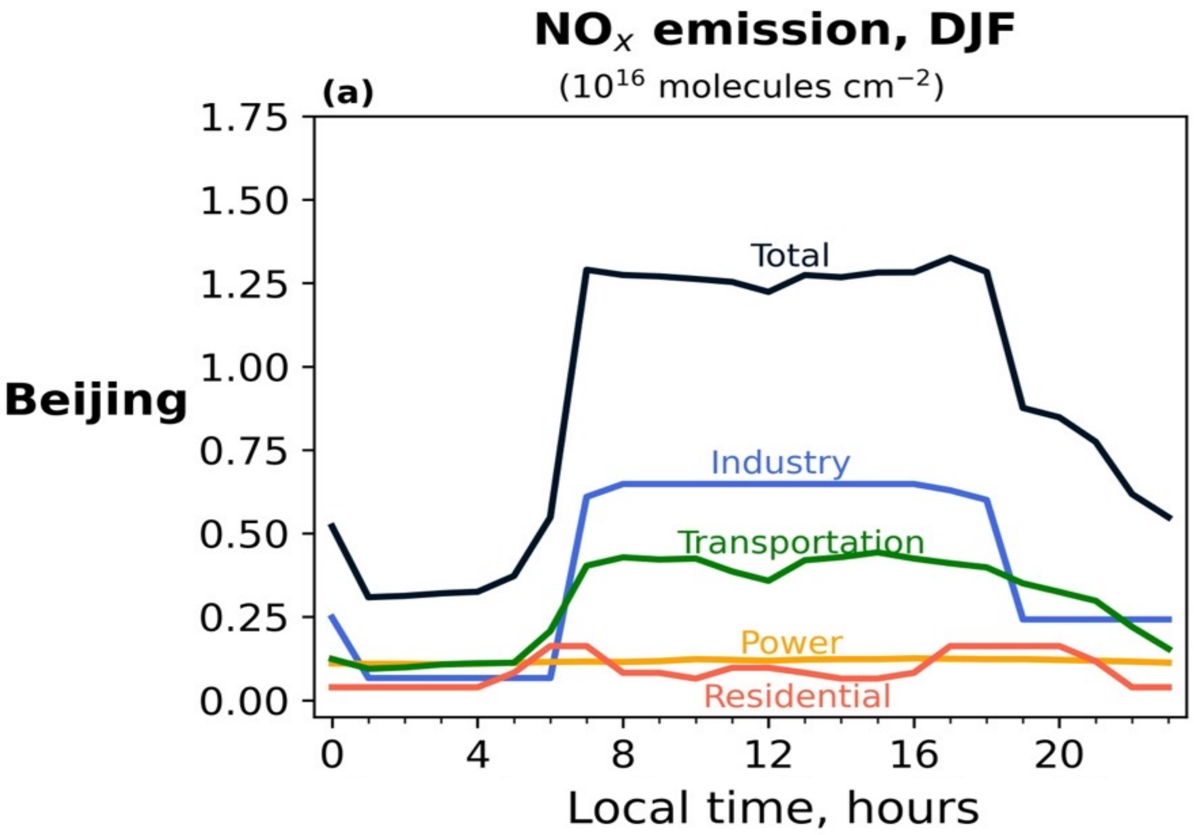
What drives the diurnal variation of the NO_2 column?

$$\left[\frac{\partial \Omega_{NO_2}}{\partial t}\right]_{net}$$



What drives the diurnal variation of the NO_2 column?

$$\left[\frac{\partial\Omega_{NO_2}}{\partial t}\right]_{net} = \frac{\Omega_{NO_2}}{\Omega_{NO_x}}\left(\boxed{\left[\frac{\partial\Omega_{NO_x}}{\partial t}\right]_{emission}} + \boxed{\left[\frac{\partial\Omega_{NO_x}}{\partial t}\right]_{chemistry}} + \left[\frac{\partial\Omega_{NO_x}}{\partial t}\right]_{transport}\right)$$



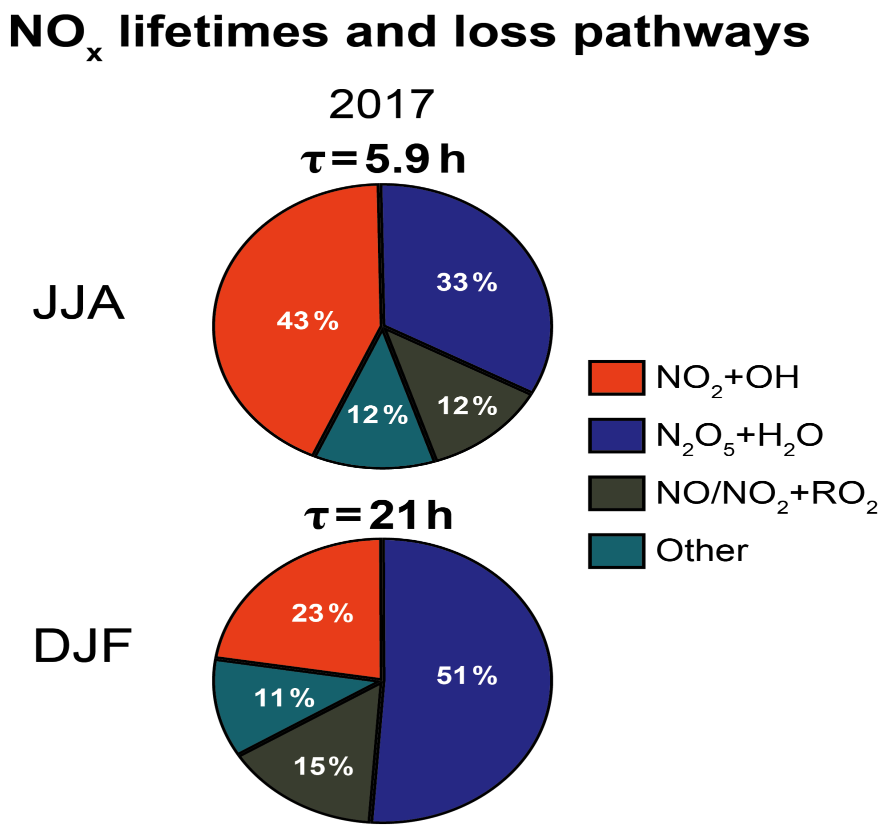
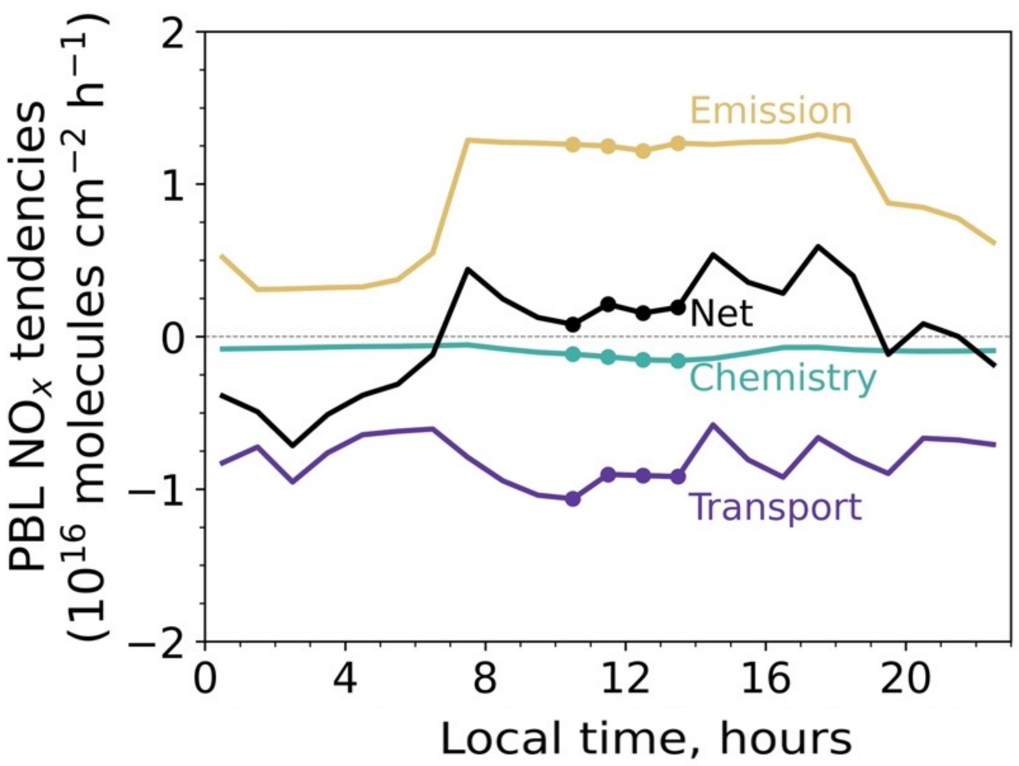
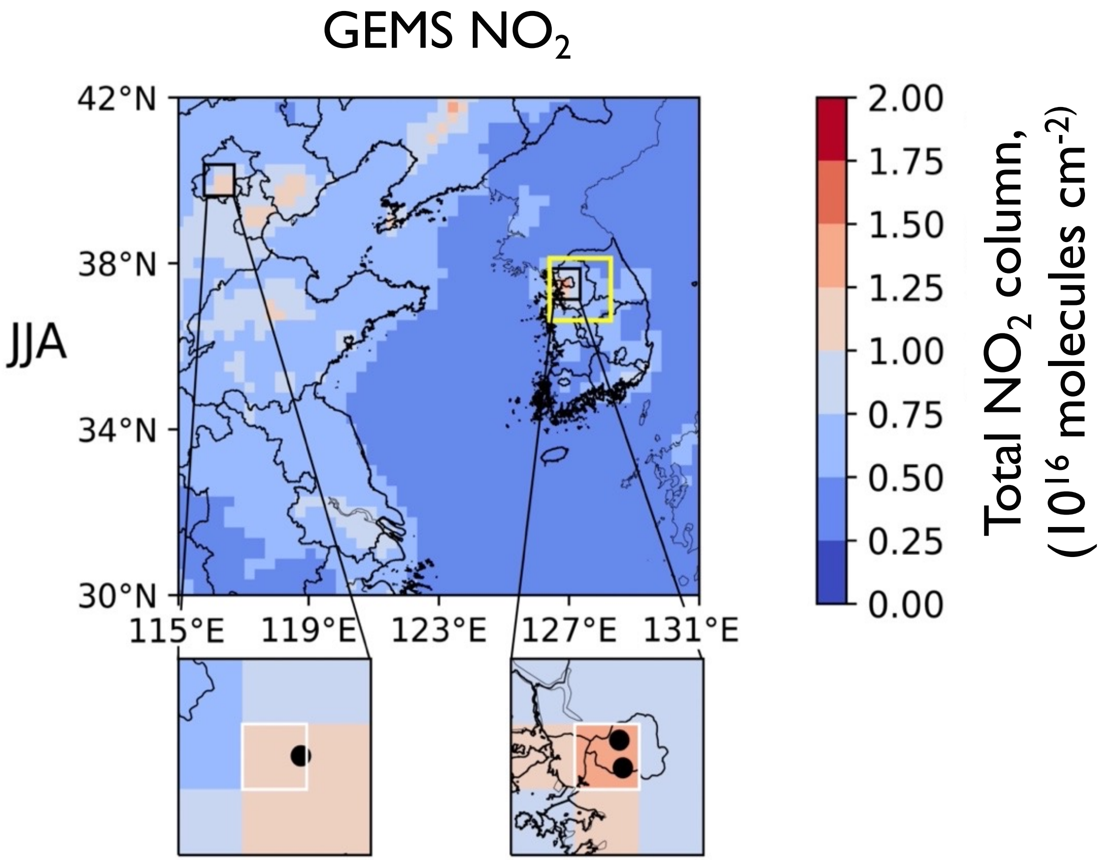


Figure of NOx lifetime and loss pathways from Shah et al. (2020)

The GEOS-Chem budget diagnostic helps to interpret the diurnal variation of the observed NO_2 column

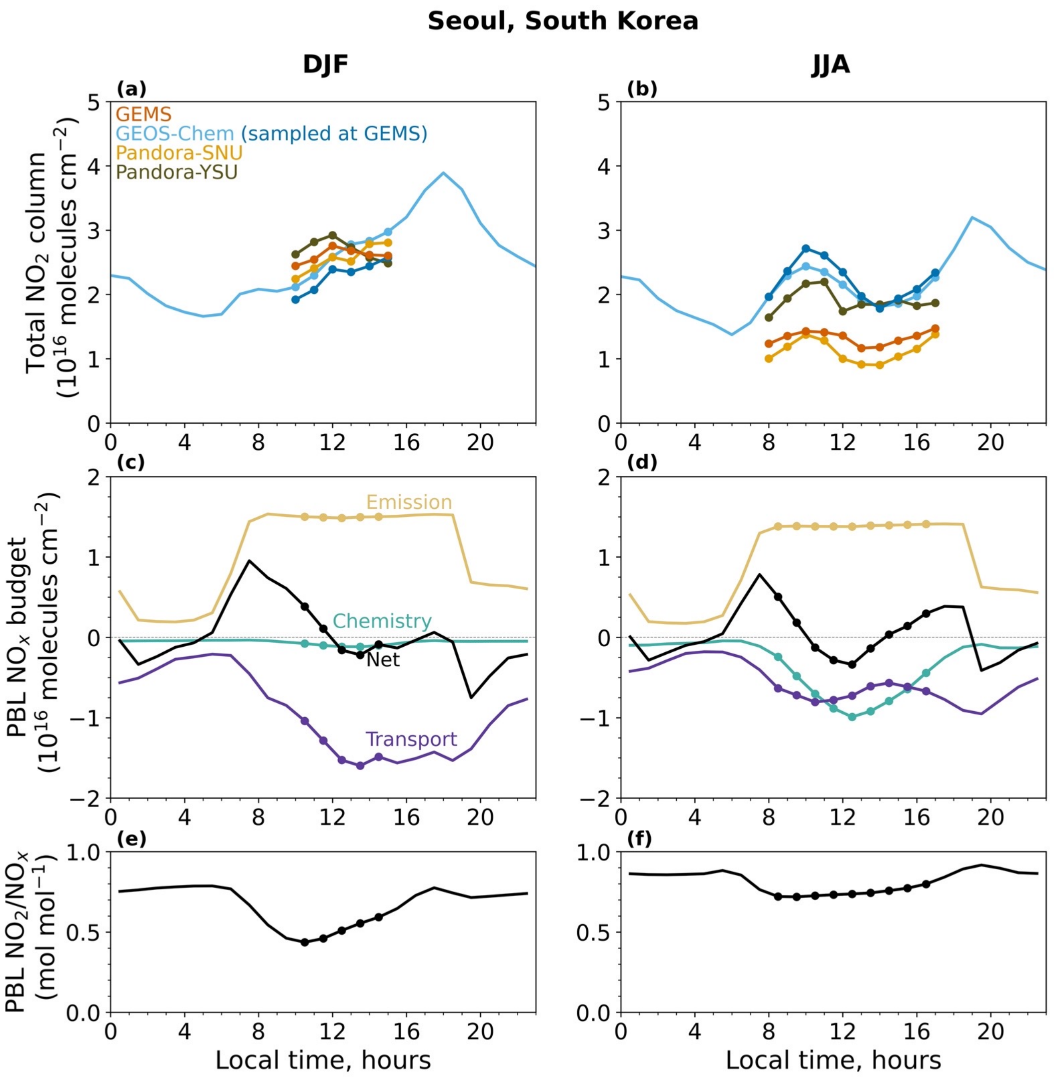




The budget diagnostic breaks down the different mass tendencies for any user-selected regional domain for selected species in the column, across each GEOS-Chem component (i.e., emission, transport, and chemistry).

Our analysis focuses on the 25km urban cores (white boxes) over Beijing and Seoul, and the 150km regional scale (yellow box) over the Seoul Metropolitan Area.

In winter, NO_2 increases during the day, while in summer, it reaches a minimum at 13-14 local time in the urban cores of Seoul and Beijing



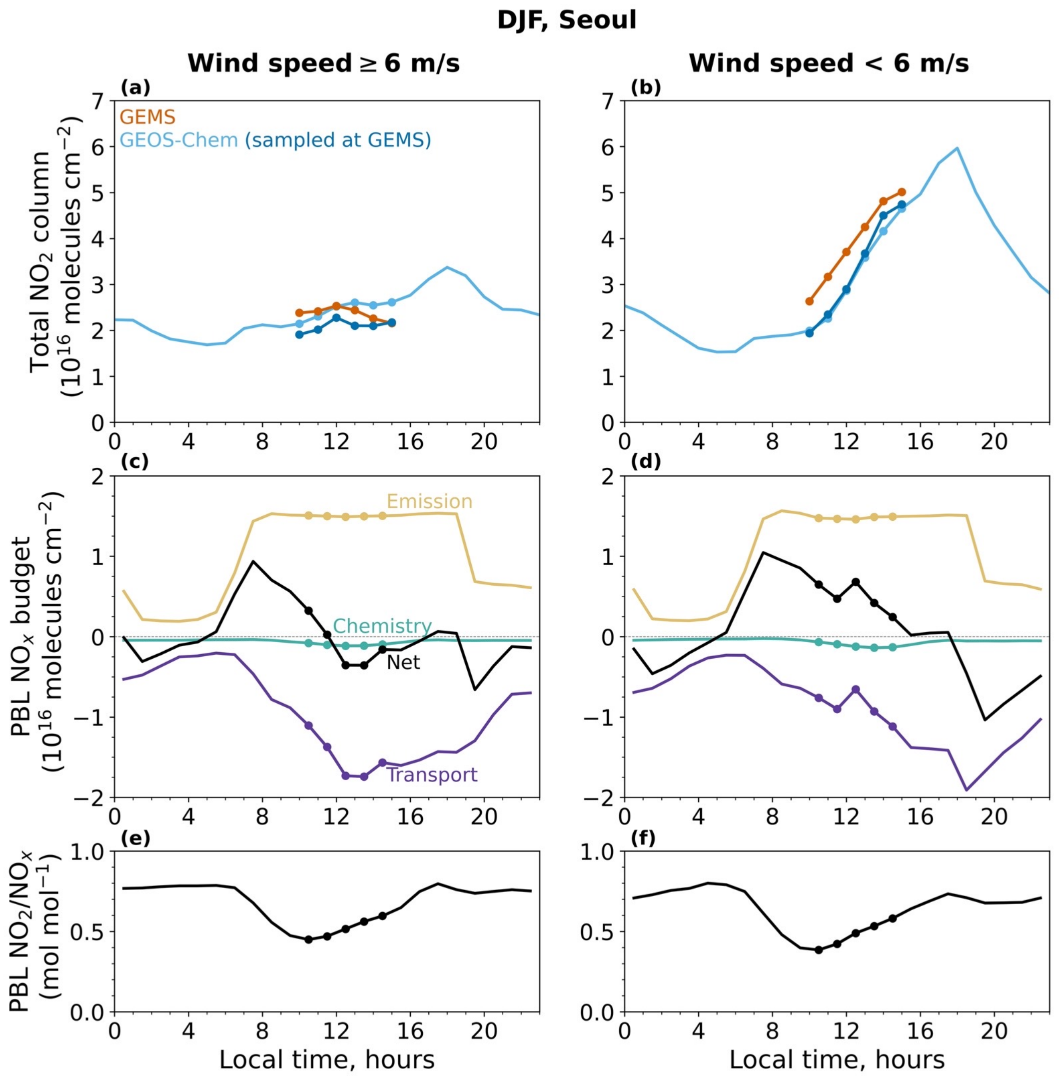
$$\frac{\partial \Omega_{NO_2}}{\partial t} = \left[\frac{\partial \Omega_{NO_x}}{\partial t}\right]_{net} \times \frac{NO_2}{NO_x}$$

- NO_2 levels in winter increase throughout the day due to high daytime emissions and an increasing NO_2/NO_x ratio caused by the entrainment of ozone

$$O_3 + NO \rightarrow NO_2 + O_2$$

- The chemical loss combined with transport drives a minimum in the NO_2 column around 13-14 local time

Segregating Seoul's winter data by hourly wind speed further demonstrates the effect of transport

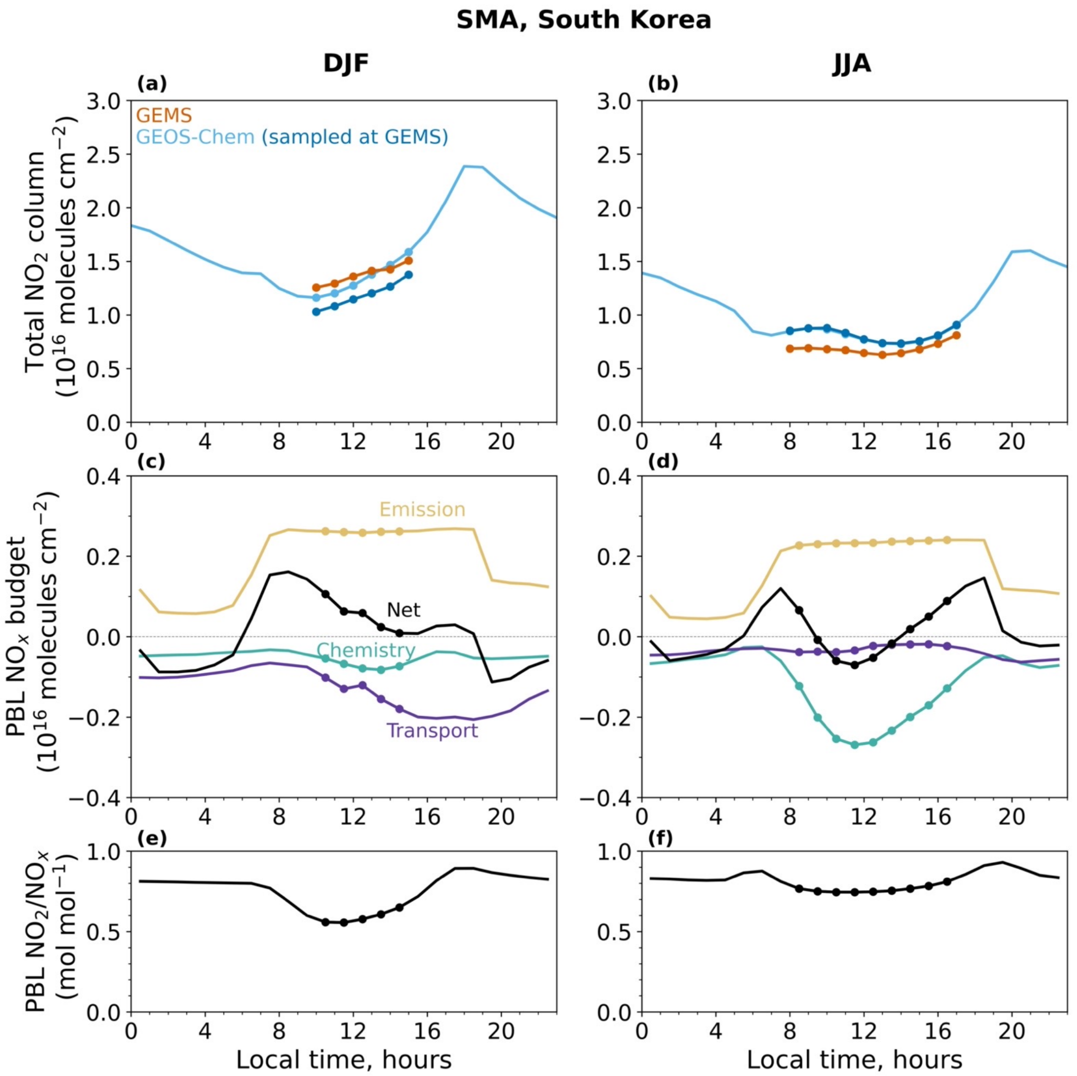


$$\frac{\partial \Omega_{\mathrm{NO_2}}}{\partial t} = \left[\frac{\partial \Omega_{\mathrm{NO_x}}}{\partial t}\right]_{\mathrm{net}} \times \frac{\mathrm{NO_2}}{\mathrm{NO_x}}$$

- **At high wind speed**:
  - Emission is balanced by transport, leading to weak diurnal variation
- **At low wind speed:**
  - NO_2 accumulates as transport cannot keep up with emissions

Transport is not negligible even at low wind speed (3 m/s) since the ventilation timescale for the 25km domain is only 2 hours

Broadening to a regional scale (150km) reduces the effect of transport in summer but not in winter



$$\frac{\partial \Omega_{NO_2}}{\partial t} = \left[\frac{\partial \Omega_{NO_x}}{\partial t}\right]_{net} \times \frac{NO_2}{NO_x}$$

- The diurnal variation observed by GEMS is consistent with the diurnal variation of emissions and chemistry in GEOS-Chem during the summer
- However, the signal is spatially diluted at a 150-km scale, affecting the interpretation
- A quantitative evaluation of emissions and chemistry will require an inverse analysis accounting for the effect of transport (e.g., CHEEREIO)

Takeaways

NO_x emissions are four times higher in the daytime than at night, driving an accumulation of NO_2 throughout the day offset by losses.

NO_2 in winter increases throughout the day due to high daytime emissions and increasing NO_2/NO_x ratio balanced by loss from transport.

In summer, chemical loss combined with transport drives a minimum in the NO_2 column at 13-14 local time. Spatial averaging can reduce the effect of transport, but quantitative analysis requires an inverse model.

Diurnal variation in air mass factor (AMF)

This work