Satellite observations of tropospheric NO₂ vertical column densities (VCDs) over Southeast Asia including China and Japan are analyzed based on measurements from four satellite sensors: GOME, SCIAMACHY, OMI, and GOME-2, during the time period from 1996 to 2011. The inter-annual variations and the consistency between the different satellite datasets are investigated and compared with several emission inventory for Asian region. The tropospheric NO₂ VCDs over the study area have been simulated with Community Multi-scale Air Quality (CMAQ) model and then comparedly analyzed with those retrieved from satellite observations in order to validate the accuracy of the emission inventories. The fifteen years tropospheric NO₂ VCDs data (1996-2011) from GOME, SCIAMACHY, OMI, and GOME-2 shows high increasing trends in China, especially in Beijing and Shanghai. Most of the results from the model simulations of horizontal tropospheric NO₂ VCDs distribution generally agree well with satellite measurements. Overall, the discrepancies among the CMAQ model and satellite retrievals are mainly due to inaccurate emission inventories fed into the model and the uncertainties in the satellite retrievals. However, as a result of the consistency between satellite-retrieved and model simulated tropospheric NO₂ VCDs, it suggests that integration of satellite data with air quality model can be used to evaluate and improve the accuracy of emission inventories.

### Methodology and Data

1. Satellite retrievals:
   - Satellite-based tropospheric NO₂ columns are retrieved from level-2 products of GOME, SCIAMACHY, OMI and GOME-2 published in the TEMIS website (http://www.temis.nl).

2. Emission inventory:
   - REAS emission: Regional Emission inventory in Asia.
   - MACCity emission: Global emission inventory.
   - Kyoto Univ. emission(AIM): Regional Emission in Asia.

3. Model description:
   - WRF 3.3: 6km mesh (Jan – Dec, 2005)
   - NCEP-CSFR: 5.6km grids)
   - Noah land-surface model
   - WSM 6-class grid-scheme
   - CMAQ 4.7
   - Chemistry: CB-05-AERO5
   - Boundary condition: MOZART4

### Seasonal Variability of NO₂

Time series of monthly tropospheric NO₂ columns from GOME, SCIAMACHY, OMI & GOME-2 satellites for the Megacities in SEA including China & Japan from 1996-2011 were compared.

- Shanghai has the highest increasing trend of 21.5% per year followed by Beijing with 14.1% per year (Hid, year 1996).
- Mult-Low-latitude zone: maximum of tropospheric NO₂ columns can be seen during winter (November-February) & minimum during summertime (June-August).
- Equator-latitude zone: maximum of tropospheric NO₂ columns can be seen during rainy season (June-August) & minimum during rainy season (December-February).

### Comparison between CMAQ output and Satellite NO₂ VCD

Comparison between CMAQ output and Satellite NO₂ VCD at Satellite over-pass time (10:30 LST): There are clear annual variation in northern part of China. It seems that there is no influence of a long-range transport.

### Summary

- Regarding the qualitative relationship between the satellite NO₂ VCDs data and emission inventory around the megacities, it became clear that it is well in agreement especially in Beijing and Shanghai.
- It was clearly shown that systematic errors exists in our original emission inventory used in the CMAQ simulation by the comparison between model simulation and satellite observation for Year 2005.
- In particular, the systematic underestimate exists in the area along the shore of China and the Indochnese Peninsula.
- On the other hand, overestimation was seen around several area and cities, such as northern India and Singapore.
- The tendency of an underestimate may be strong in the winter of the Northern Hemisphere.
- We need to identify the reason. (emission? or meteorology?)

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