

Rapid economic growth leads to boost in NO₂ pollution over India, as seen from space



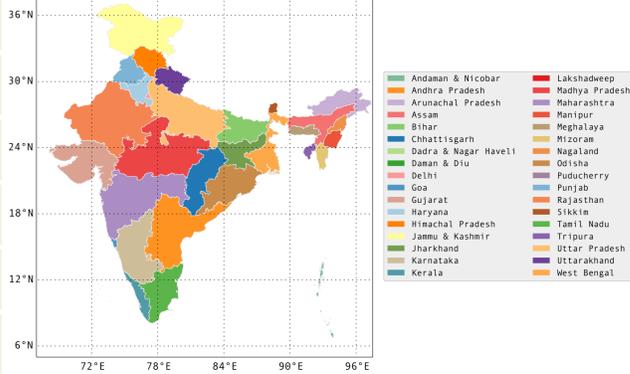
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India

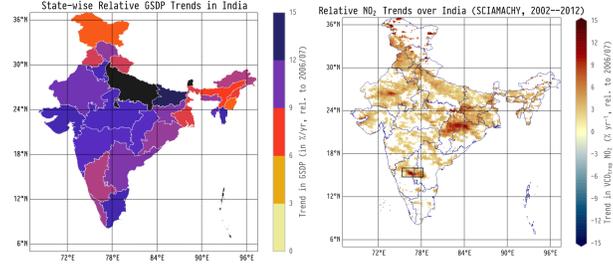
- Area 3.29 mn km²; 7th largest country in the world
- Population 1.25 bn people; 2nd largest population in the world; 18% increase 2001–2011
- GDP 2.3 tn USD (2015 est.); 7th largest economy in the world; 109% increase 2001/01–2010/11
- Federal country, consisting of 29 states and 7 union territories

Indian States and Union Territories



Motivation

- Economic growth unevenly distributed among Indian states (see left)
- NO₂ is a key atmospheric pollutant, with mainly anthropogenic sources
- NO₂ directly and indirectly (via tropospheric ozone production) affects human health
- NO₂ trends over India spatially inhomogeneous; strong trends in highly populated Indo-Gangetic Plain (in the North) and over the industrial regions in the East (Hilboll et al., 2013; see right)



20 years of NO₂ measurements from space

- Hyper-spectral measurements of a. direct sunlight (without atmospheric influence) and b. solar radiation scattered in the Earth's atmosphere.
- Data analysis with *differential optical absorption spectroscopy* (DOAS): calculation of the number of absorbing molecules along the light path.
- Estimation of the stratospheric NO₂ amount using chemistry-transport models.
- Calculation of the average lightpath through the atmosphere using *SCIATRAN* radiative transfer model (Rozanov et al., 2014).
- Target quantity: *Vertical Tropospheric Column* (VCD_{trop}), in molec cm⁻²

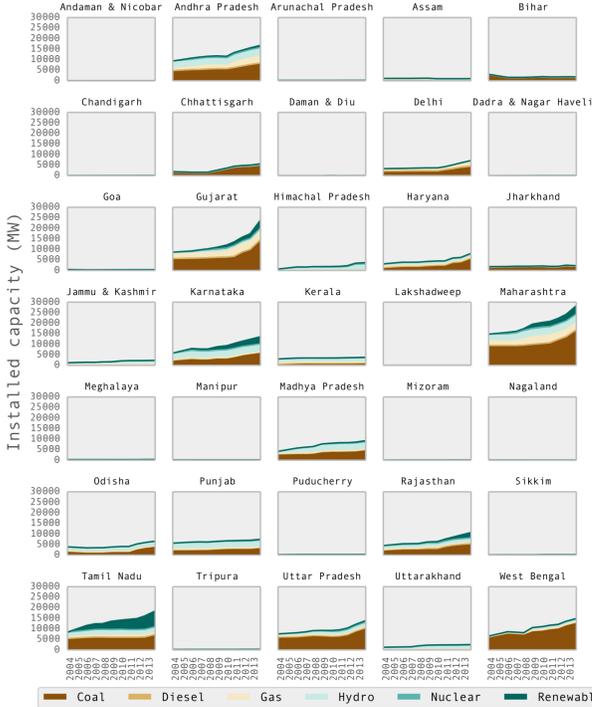
- Measurements from five spectrometers available, for different time spans, and with different equator crossing times:

GOME:	1995/10–2003/06	10:30LT
SCIAMACHY:	2002/08–2012/04	10:00LT
OMI:	2004/10–...	13:45LT
GOME-2(A):	2007/01–...	09:30LT
GOME-2(B):	2012/12–...	09:30LT

- Spatial resolution between 40×320km² (GOME) and 13×24km² (OMI)
- Global coverage within 6 days (SCIAMACHY) to 1 day (OMI)

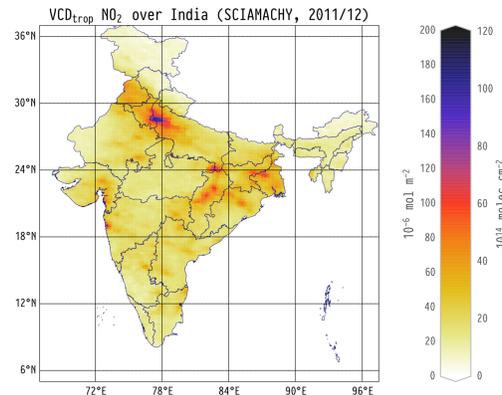
Electricity Generation

- Strong increase of power generation capacity in the major industrial states (Andhra Pradesh, Chhattisgarh, Delhi, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Odisha, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal)
- Most of the newly installed capacity is in the form of thermal (i.e., coal) power plants
- Only exemption is Tamil Nadu, where the newly installed capacity is almost entirely renewable



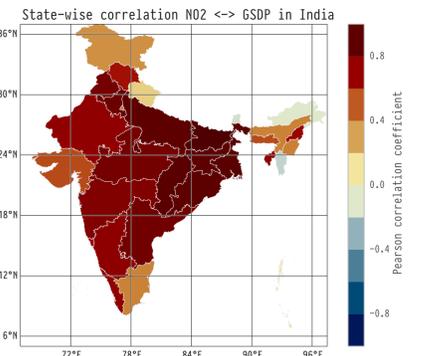
NO₂ over India

- Highest NO₂ load in the capital region (Delhi; in the North)
- Elevated NO₂ load in other major urban centers (Mumbai, Kolkata, Chennai, ...) and over industrial regions (Chhattisgarh, Odisha, Jharkhand, West Bengal)
- Some individual industrial hot-spots visible (cement production in Rajasthan, steel production in Karnataka)
- Low NO₂ load in large parts of the country



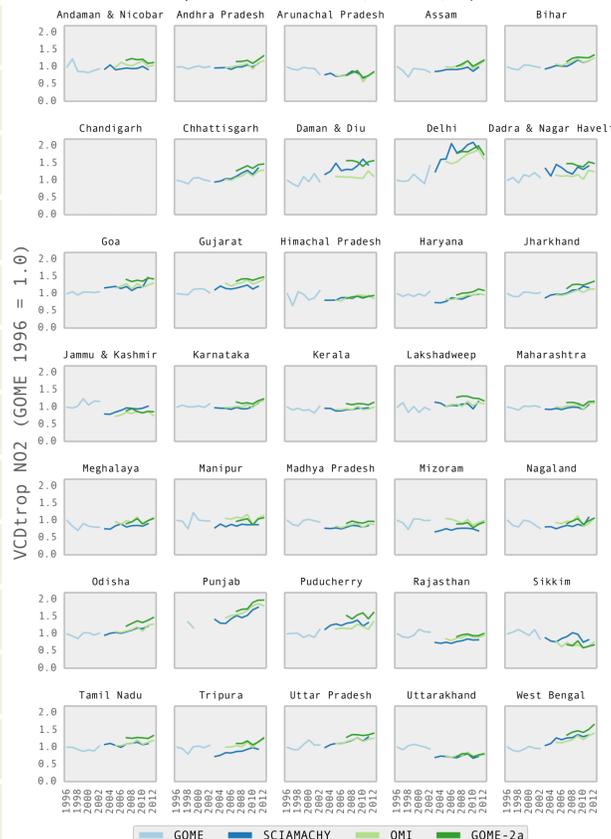
Correlation between NO₂ and GSDP

- Very strong correlation between gross state domestic product (GSDP) and NO₂ in the major industrial states (Chhattisgarh, Haryana, Odisha, Jharkhand, Uttar Pradesh, West Bengal)
- Considerably lower correlation in Tamil Nadu
- Still strong correlation in all other populated states
- Very low correlation in undeveloped, rural states



State-wise NO₂ trends

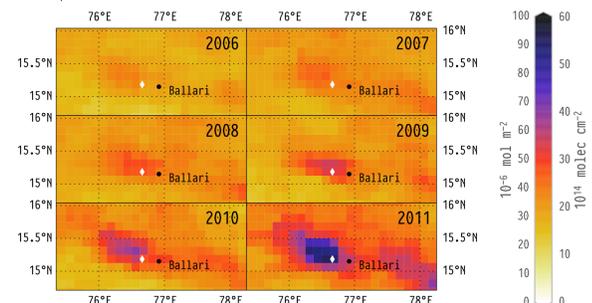
- Good consistency between sensors in virtually all cases (GOME values not reliable for all states due to low coverage and coarse resolution)
- NO₂ pollution more than doubled in Delhi 1996–2012, with a flattening during the last years
- All developed states show strong NO₂ increases >30% in 1996–2012
- Country-wide, the NO₂ increase is lower than economic growth (ca. 40% in 1996–2012 compared to 109% in 2001/01–2010/11)



Development of a new steel plant

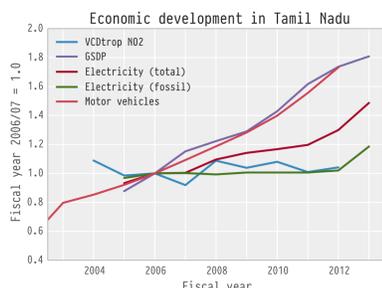
- In 2009, the Karnataka state government decided that the state wanted to move from just exporting ore to value-added production of steel, and India's largest blast furnace was installed at the Vijayanagar steel plant west of Ballari (total capacity 10 Mt yr⁻¹)
- Consequently, NO₂ pollution at the Vijayanagar site has more than doubled between 2006–2011
- The whole area downwind of the site since suffers from industrial air pollution levels

VCD_{trop} NO₂ over Ballari region (SCIAMACHY, 2006–2012)



Economic Development in Tamil Nadu

- Tamil Nadu has the 2nd largest economy of Indian states, and is its most urbanized and 3rd most developed state.
- Contrary to other populous Indian states, NO₂ pollution did not strongly increase in 2004–2012.
- Total installed power generation capacity increased comparably to other large states, but Tamil Nadu is the only state where this newly installed capacity is almost entirely renewable.
- Consequently, GSDP correlates very well with total power generation capacity and with the no. of motor vehicles, while the NO₂ pollution level did not significantly increase 2004–2014



Summary / Outlook

- Strong regional differences both in the absolute level of NO₂ pollution and in its increase over the past 20 years exist.
- Over the developed states, NO₂ pollution increased proportionally to the economic development over the past 15–20 years.
- The strong NO₂ growth rates of >10% yr⁻¹ in Chhattisgarh and Karnataka can clearly be attributed to soaring thermal power generation and steel production, respectively.
- The state Tamil Nadu has been able to limit its NO₂ pollution increase by heavily expanding electricity generation from renewable sources.

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