Comparison of black carbon and ozone variability at the Kathmandu "hot spot" and at the southern Himalayas

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Background and purpose of the study

- **Black carbon** (**BC**) and **tropospheric ozone** (**O_3**) are two key short-lived climate forcers/pollutants (**SLCF/P**), with harmful implications for climate, human health and ecosystems

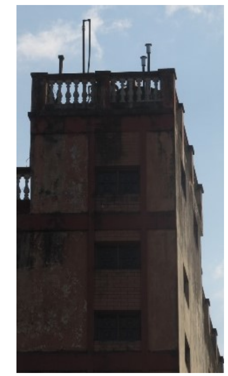
- South Asia is one of the "hot spots" for air pollution and climate; air masses from the highly polluted areas (e.g., **Indo-Gangetic Plain** and the **Himalayan foothills**) can move to the high Himalayas

↓

- **Multi-year comparison** of BC and O_3 variability, for investigating the role played by emissions in the PBL of the Kathmandu megacity **in influencing the variability of the SLCF/P in the southern Himalayas**

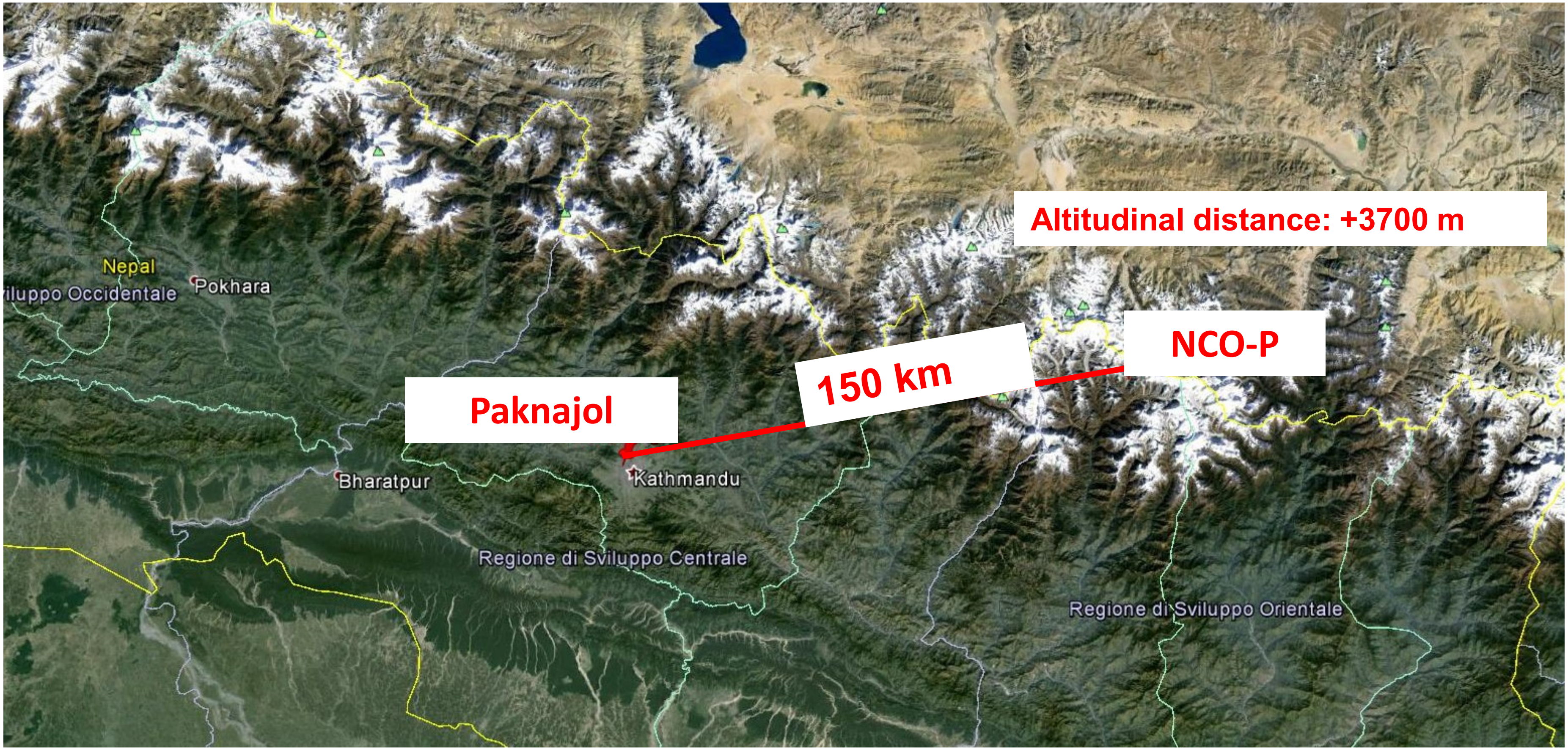
Measurement sites

- **Paknajol – Kathmandu**:
  - Urban site in the Kathmandu Valley (1380 m a.s.l.)
  - Part of the 2013 SusKat campaign, measurement extended to Oct. 2015
  - Influence of near pollution sources, mainly anthropogenic
  - Representative of the ABC “hot spot”



- **Nepal Climate Observatory-Pyramid (NCO-P)**:
  - Remote high-altitude site (5079 m a.s.l.)
  - Representative of the background conditions of the free troposphere
  - No direct sources of pollution
  - Measurements covered the period 2006 – 2015

Measurement sites



SLCF/P variations at both stations

Period of study: **February 2013 – October 2015**

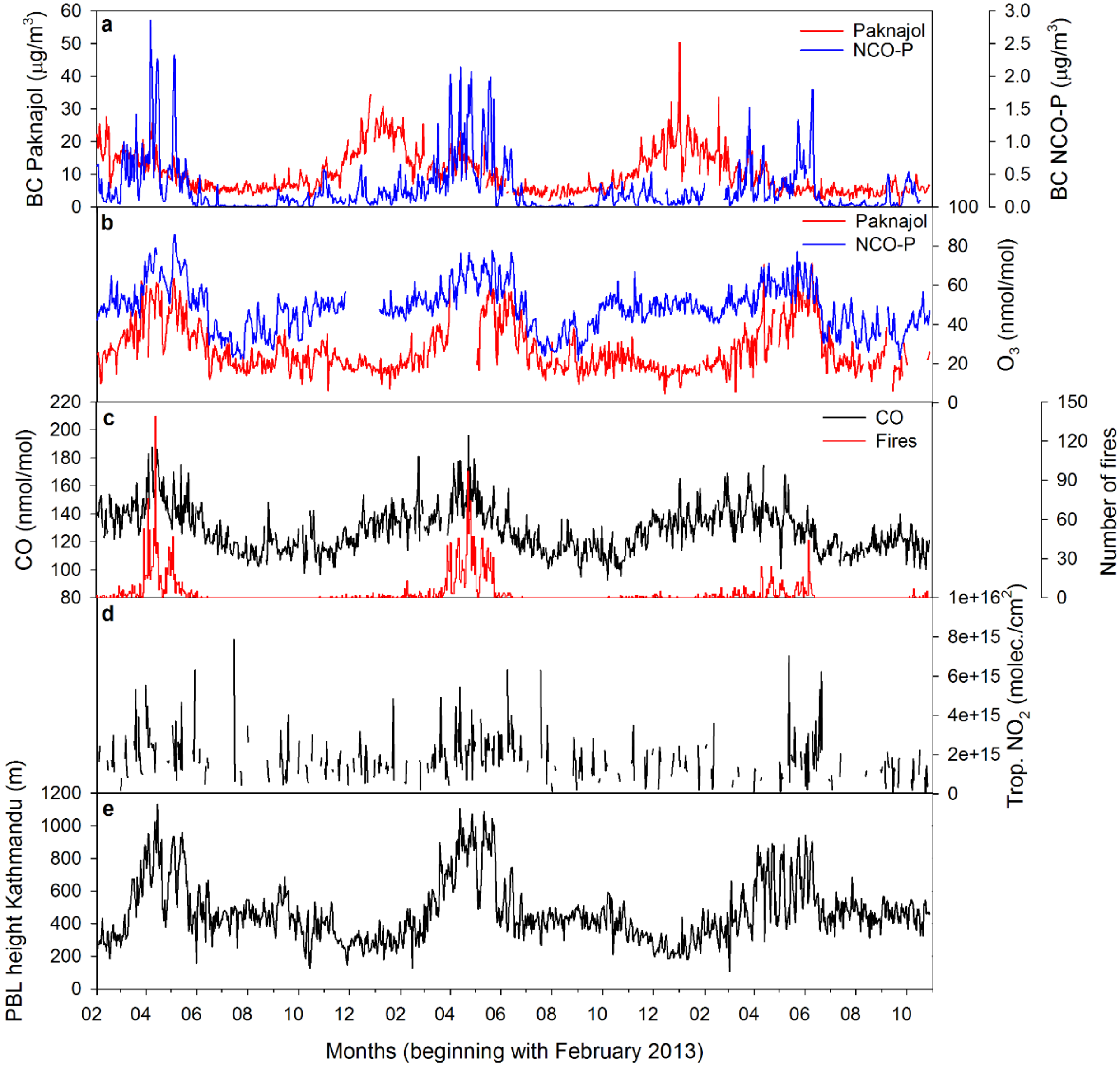
BC

O_3

CO at Kathmandu and Fires

NO_2 at Kathmandu

PBL height Kathmandu



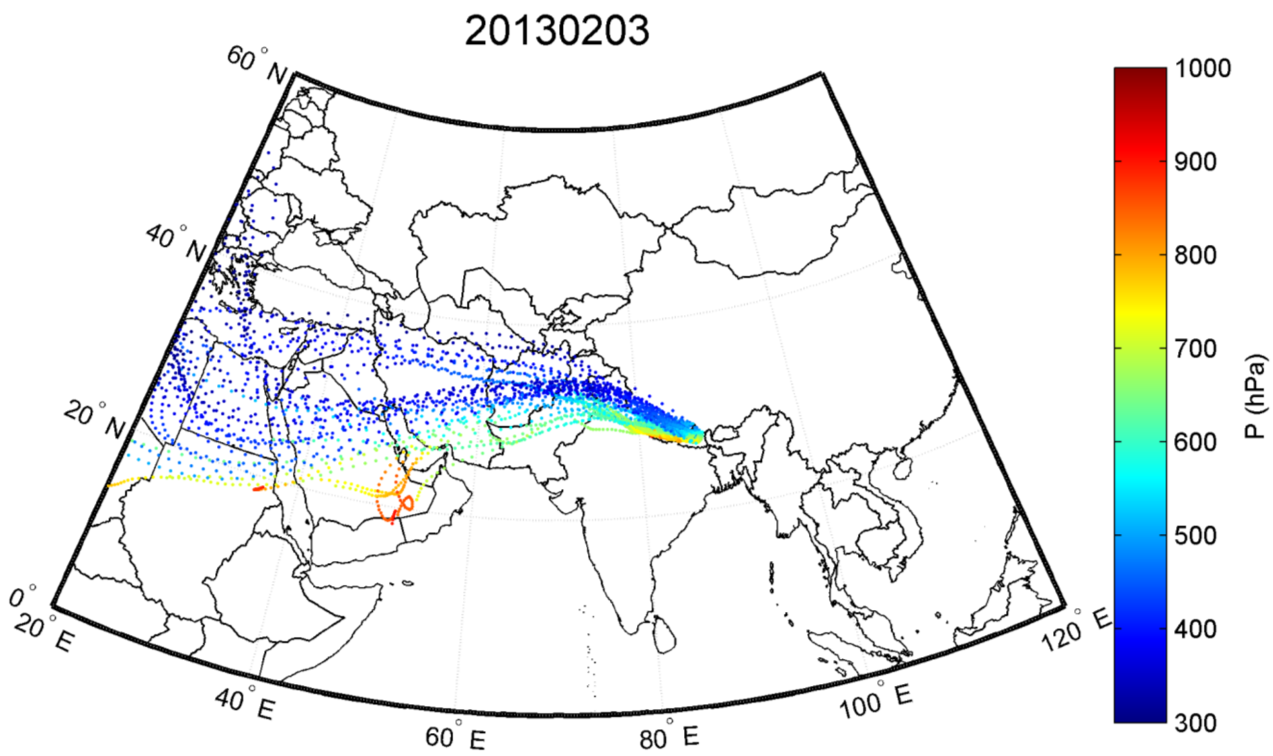
AIRS/Aqua
MODIS

OMI/Aura

ERA-Interim

Back-trajectories at NCO-P

- 5-d back-trajectories starting at NCO-P
- Computed with **LAGRANTO**, based on the ERA-Interim reanalysis of the ECMWF
- A set every 6 hours (0, 6, 12, 18 UTC)
- Temporal resolution: one point every 2 h



Approach motivation

Atmos. Chem. Phys., 15, 6007–6021, 2015
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Atmospheric Chemistry and Physics
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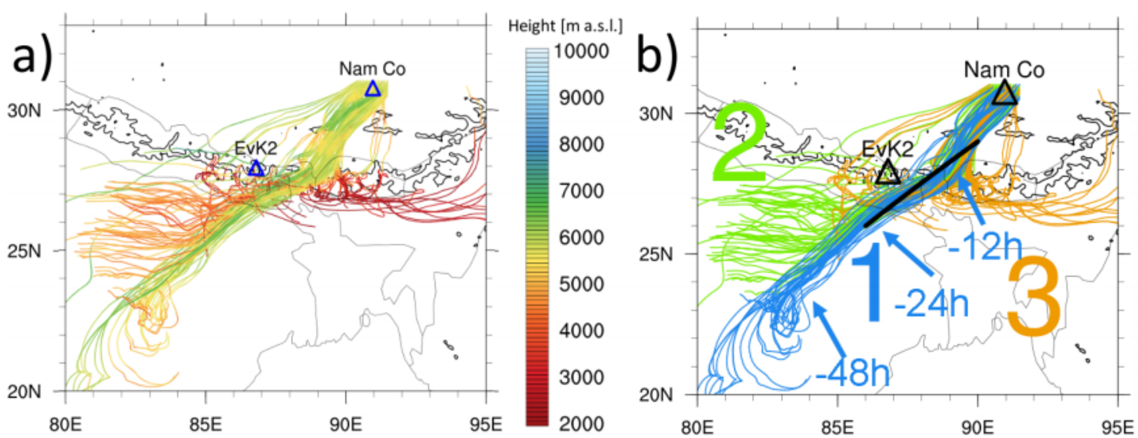
Atmospheric brown clouds reach the Tibetan Plateau by crossing the Himalayas

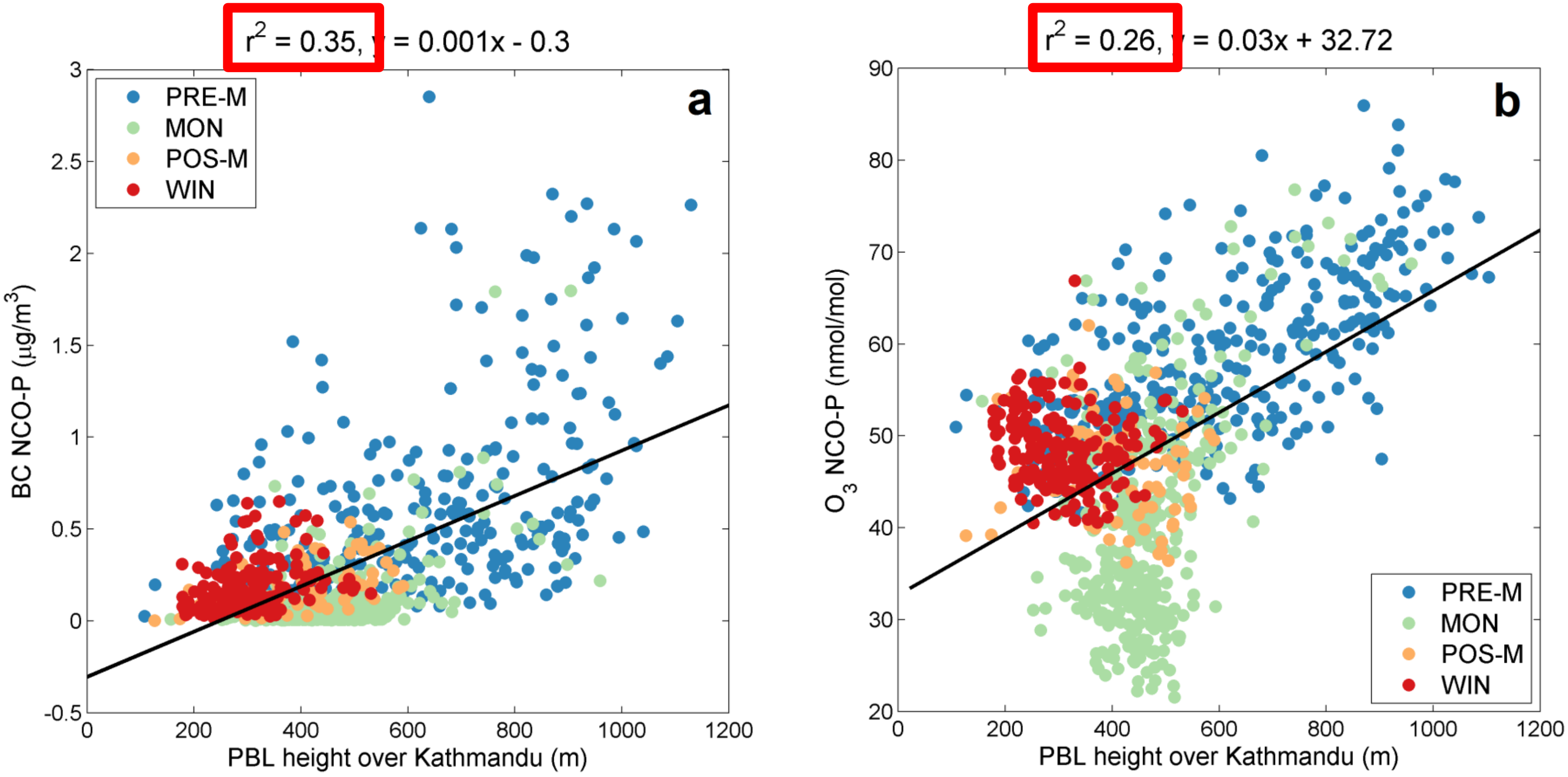
ONLY CASE STUDY, NO SYSTEMATIC ASSESSMENT

Lüthi et al. (ACP, 2015), used trajectory calculations based on the high-resolution numerical weather prediction model COSMO to locate the source regions and study the mechanisms of pollution transport in the complex topography of the Himalayas.

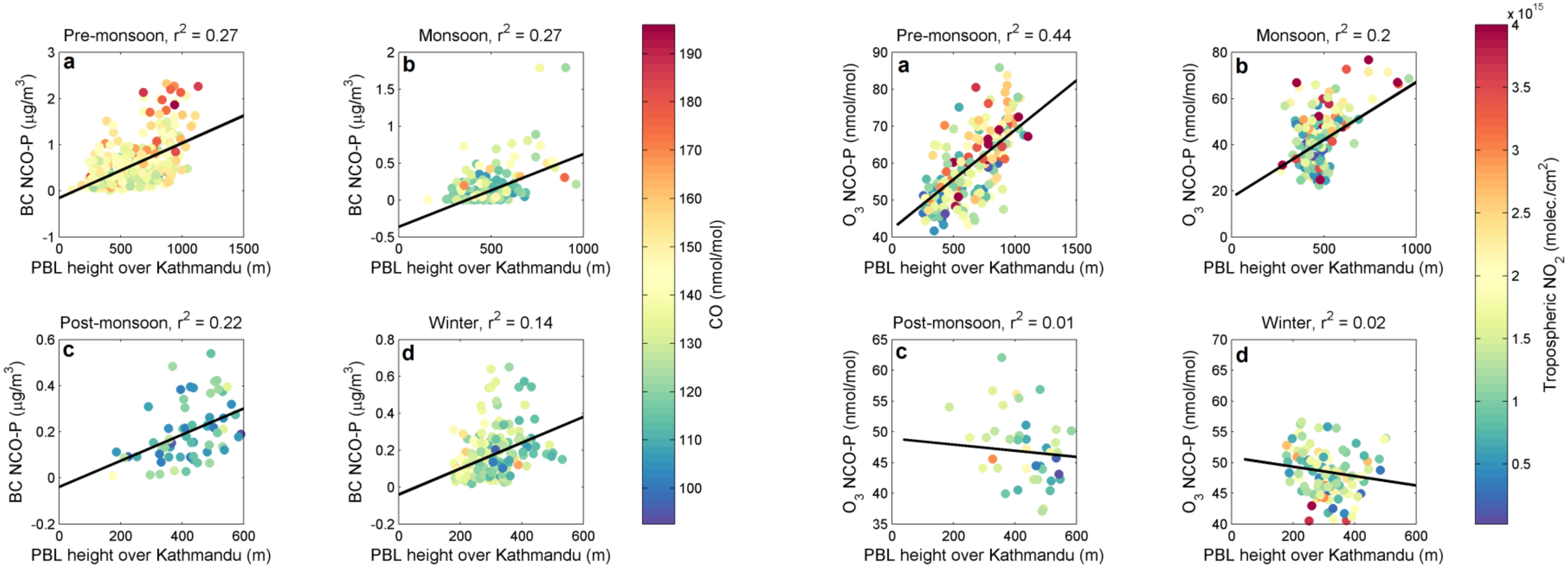
“Lifting and advection of polluted air masses over the great mountain range is enabled by a combination of synoptic-scale and local meteorological processes. After accumulation of pollutants over the plains and vertical convection, synoptic-scale transport along isoentropes carries the polluted air masses across the Himalayas”.



BC and O_3 at NCO-P as a function of PBL height



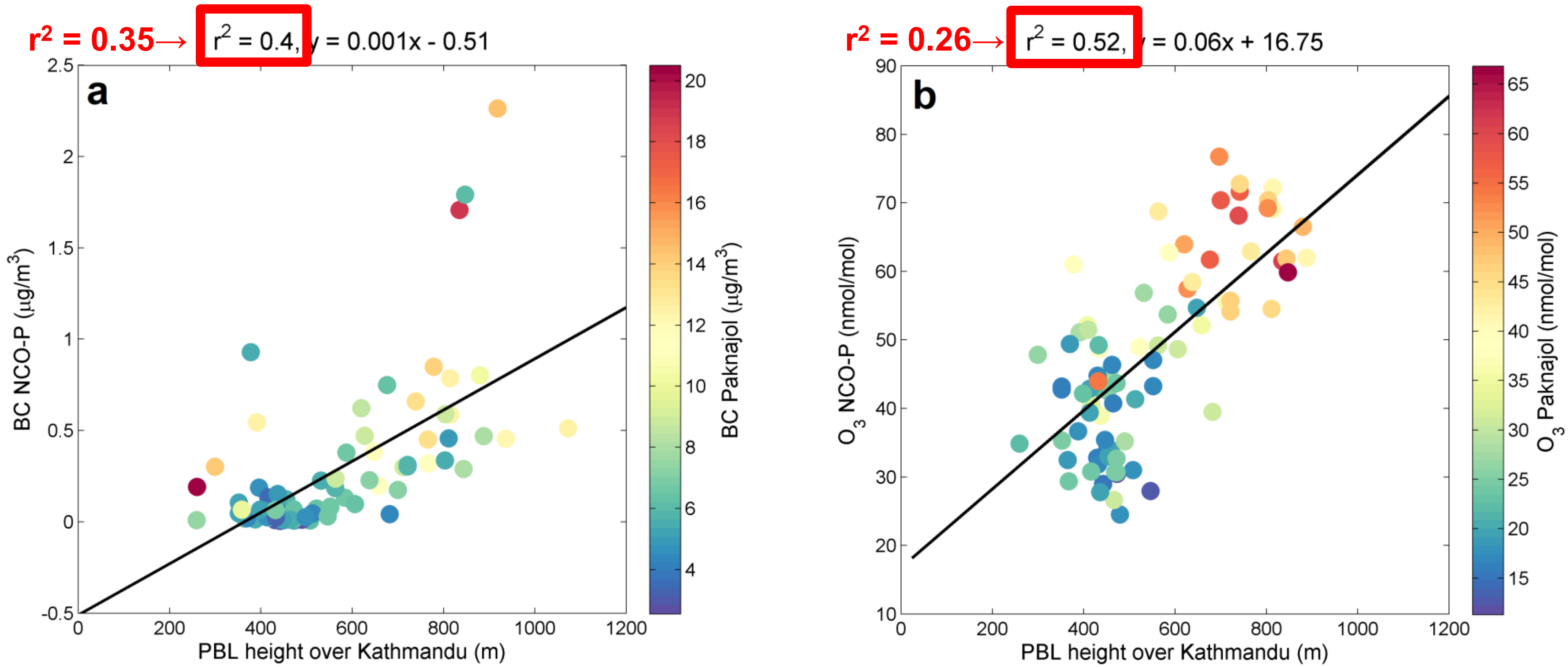
BC and O_3 vs PBL, as a function of CO and NO_2



- CO is a **tracer for combustion** processes, NO_2 is a **precursor** for O_3
- Correlations maintained when applied to each season separately
- Combustion processes in Kathmandu can represent a **source** of BC for NCO-P
- Anthropogenic emissions in Kathmandu could affect, after **photochemical production**, O_3 variability at NCO-P

Correlations including also back-trajectories

- Selection of at least **3% of daily trajectories** arriving at NCO-P that have passed over Kathmandu PBL in the past 5 days



- **40%** and **52%** of the **BC** and **O_3 variability** at NCO-P is explained by the **PBL variations** over Kathmandu, on days in which air masses crossed the PBL over Kathmandu and then arrived at NCO-P

Conclusions

- We investigated the **role of PBL and air mass transport** in affecting the BC and O_3 variability in the southern Himalayas, **over 2013 – 2015**

- **BC and O_3** concentrations **at NCO-P** are **linearly correlated** (r^2=0.27 and r^2=0.25) **with PBL** height over Kathmandu

- **The effects of PBL** variations over Kathmandu megacity **explain 40% and 52% of the BC and O_3 variability at NCO-P**, on days in which air masses arriving at NCO-P have likely crossed PBL over Kathmandu

Aerosol and Air Quality Research

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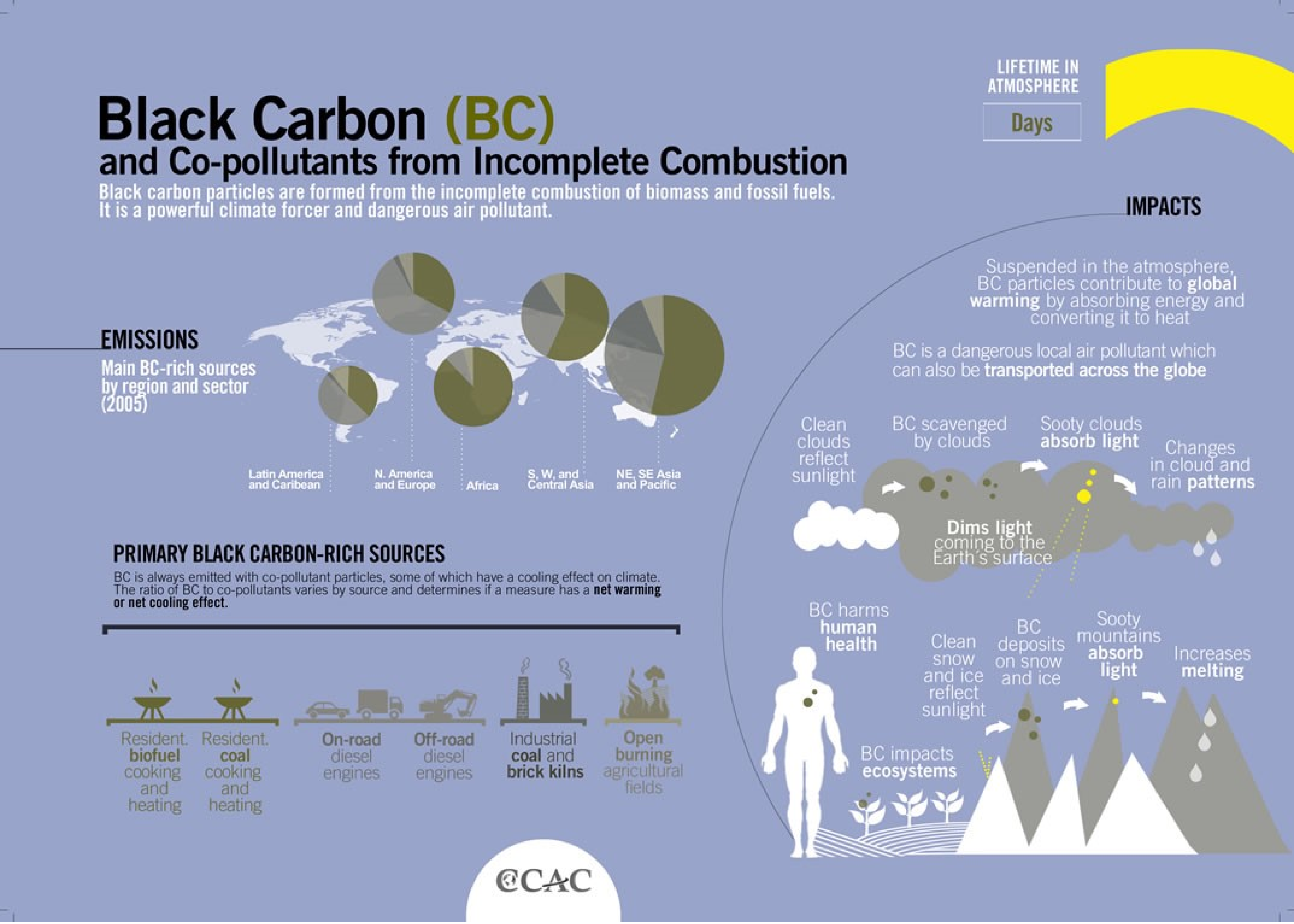
Thank you!


Black Carbon (BC)
and Co-pollutants from Incomplete Combustion
Black carbon particles are formed from the incomplete combustion of biomass and fossil fuels.
It is a powerful climate forcer and dangerous air pollutant.
LIFETIME IN ATMOSPHERE
Days
EMISSIONS
Main BC-rich sources by region and sector (2005)
Latin America and Caribean
N. America and Europe
Africa
S, W, and Central Asia
NE, SE Asia and Pacific
PRIMARY BLACK CARBON-RICH SOURCES
BC is always emitted with co-pollutant particles, some of which have a cooling effect on climate.
The ratio of BC to co-pollutants varies by source and determines if a measure has a net warming or net cooling effect.
Resident. biofuel cooking and heating
Resident. coal cooking and heating
On-road diesel engines
Off-road diesel engines
Industrial coal and brick kilns
Open burning agricultural fields
IMPACTS
Suspended in the atmosphere, BC particles contribute to global warming by absorbing energy and converting it to heat
BC is a dangerous local air pollutant which can also be transported across the globe
Clean clouds reflect sunlight
BC scavenged by clouds
Sooty clouds absorb light
Changes in cloud and rain patterns
Dims light coming to the Earth's surface
BC harms human health
Clean snow and ice reflect sunlight
BC deposits on snow and ice
Sooty mountains absorb light
Increases melting
BC impacts ecosystems
CCAC

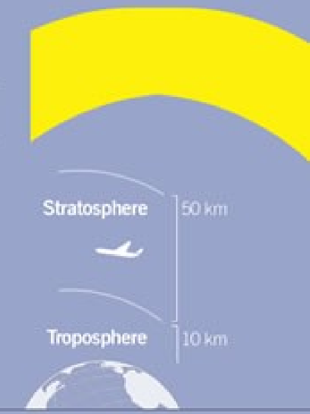
UNEP, 2014

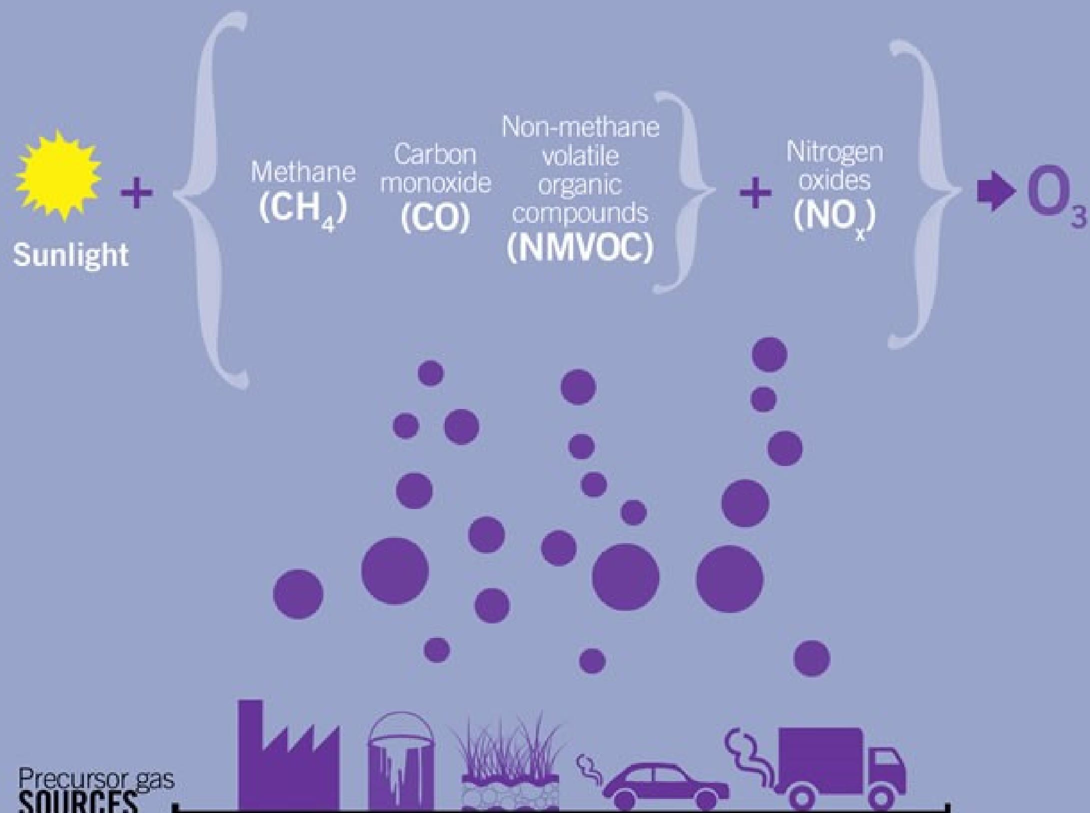
Tropospheric Ozone (O_3)

Tropospheric Ozone (O_3) is a major air and climate pollutant. It causes warming and is a highly reactive oxidant, harmful to crop production and human health. O_3 is known as a 'secondary' pollutant because it is not emitted **directly**, but instead forms when precursor gases react in the presence of sunlight.

LIFETIME IN ATMOSPHERE

Weeks





IMPACTS

O_3 precursors can be carried round the globe, making it a **transboundary pollution problem**

Tropospheric O_3 **warms the atmosphere**

O_3 damages plants and affects **agricultural production**:

- Reducing photosynthesis
- Reducing the plants ability to sequester carbon
- Reducing health and productivity of crops

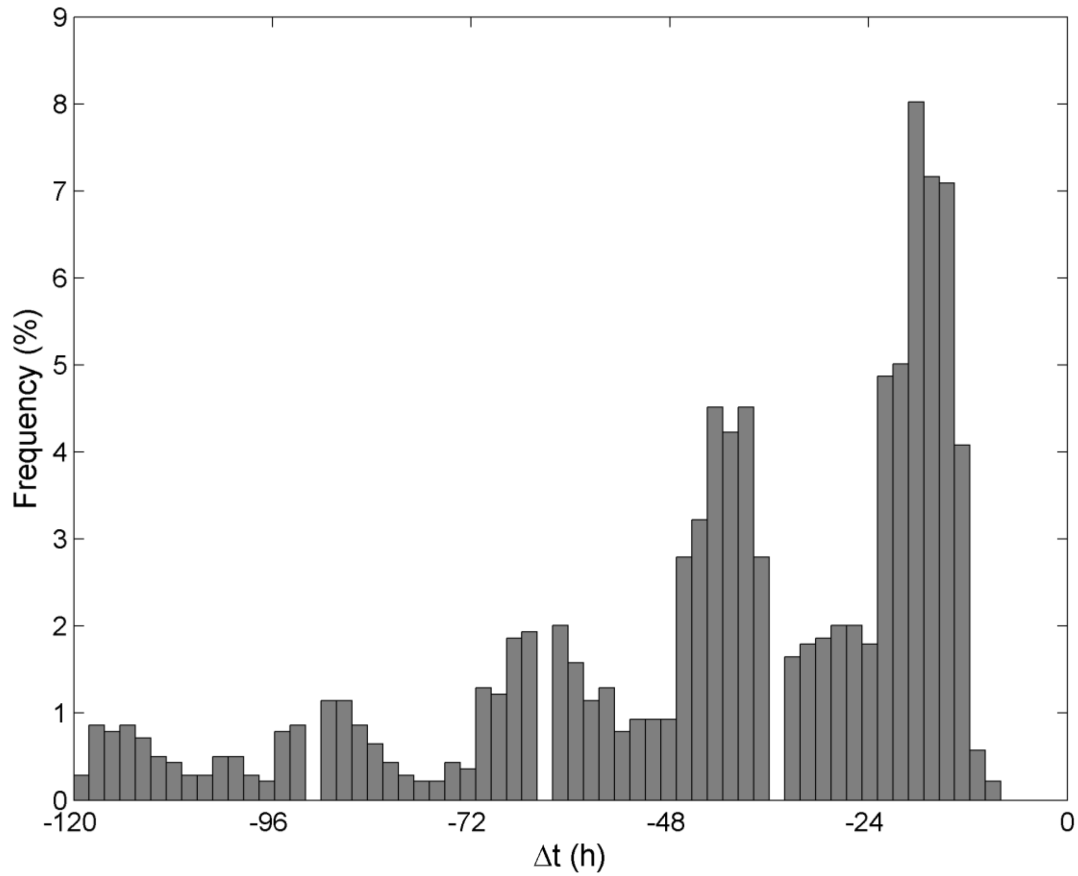
O_3 air pollution causes over **150 thousand premature deaths** every year, and **millions more chronic diseases**, particularly in children and the elderly

CCAC

UNEP, 2014

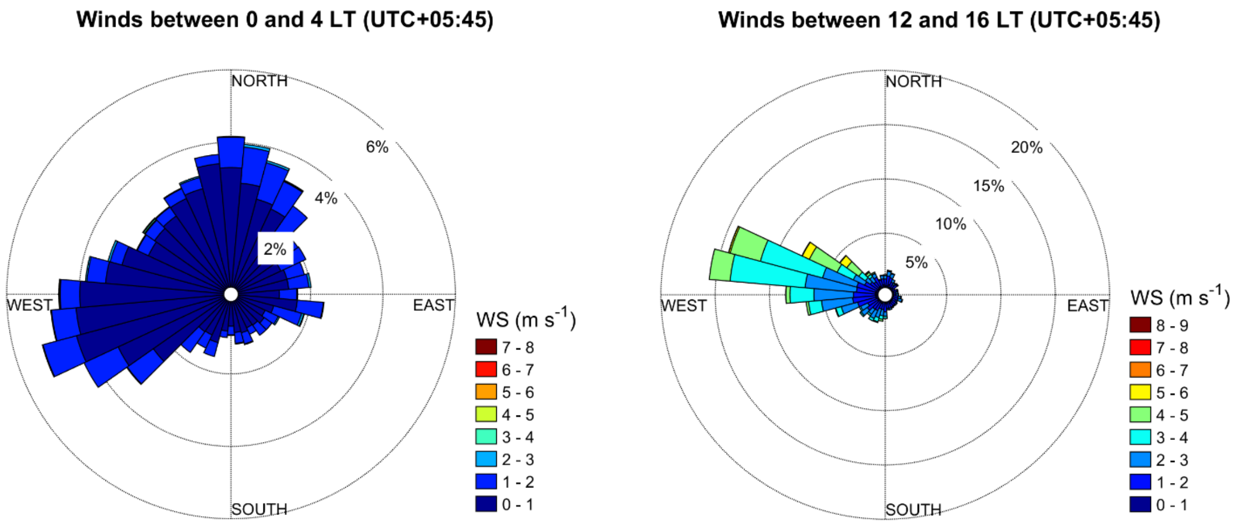
Travel times between Kathmandu and NCO-P

Histogram of Δt, i.e.: the time difference between the crossing of the Kathmandu PBL and the arrival of the same air-mass at NCO-P

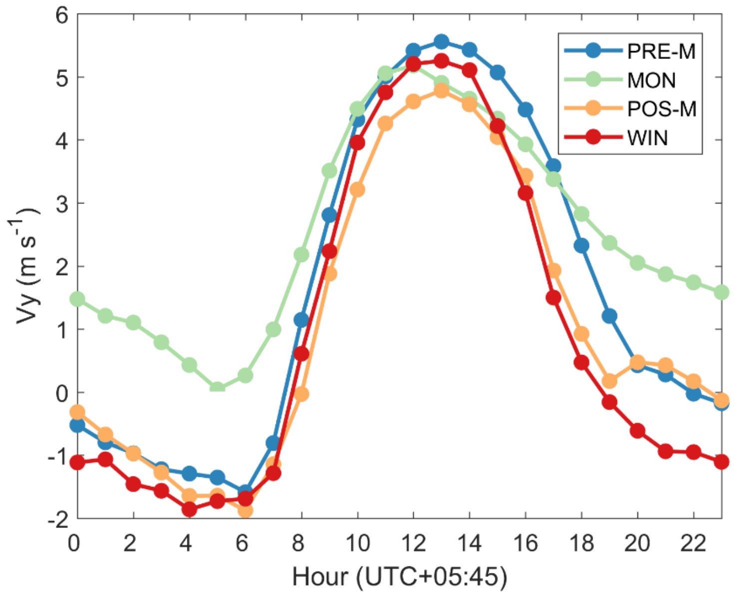


Typical local circulation systems at both sites

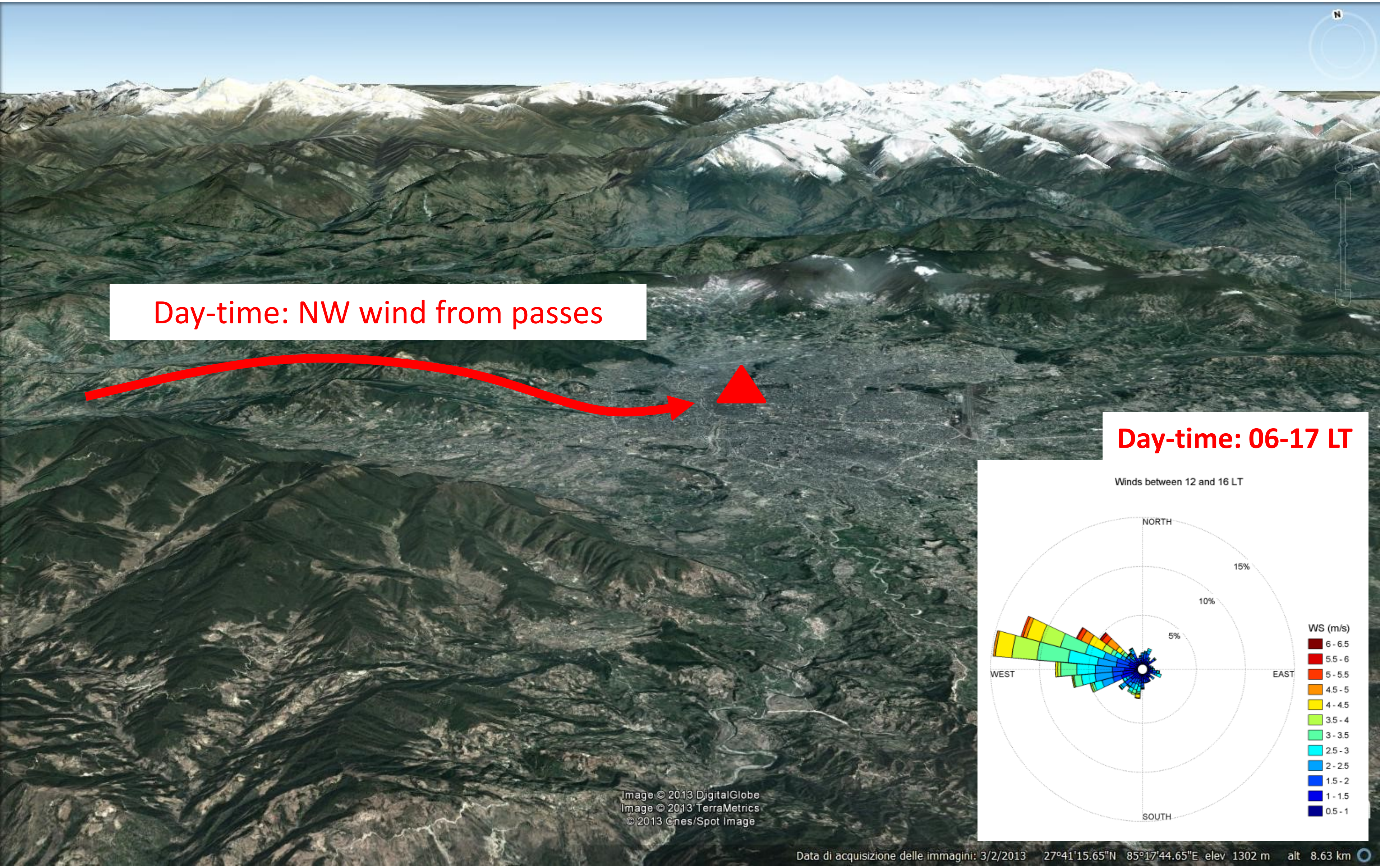
PAKNAJOL



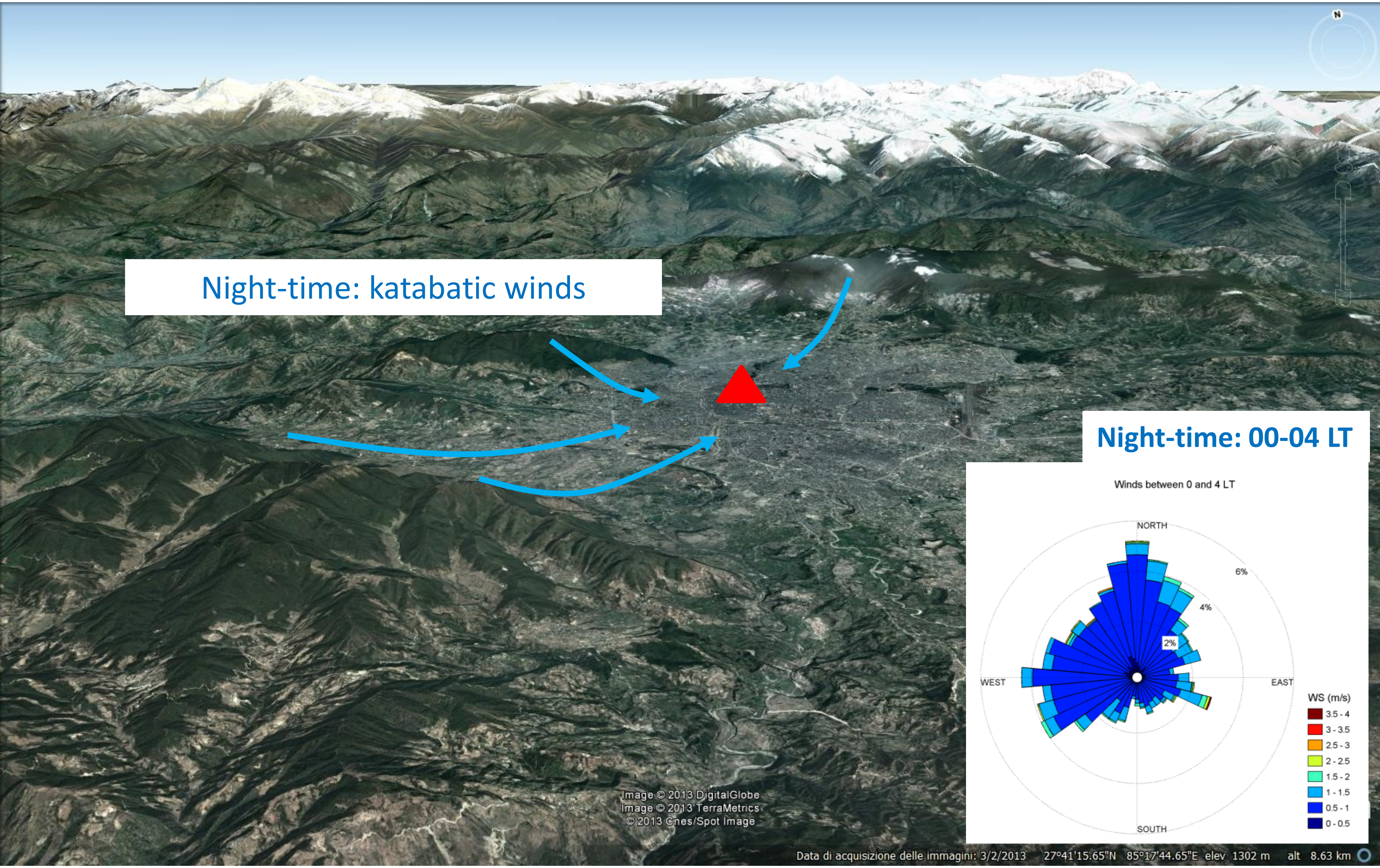
NCO-P



Paknajol meteorological overview



Paknajol meteorological overview



CO and NO_2 values over Kathmandu

- CO is derived from AIRS/Aqua L3 daily retrievals (AIRX3STD), with a spatial resolution of 1°x1° and temporal resolution of twice per day (day and night), at the vertical slice of 850 hPa. Units are nmol/mol, i.e., CO mixing ratio. Here we averaged both daytime and nightime values, to have better coverage and to minimize day/night difference.

- NO_2 is given as the number of molecules in an atmospheric column from surface to TOA. Only data for which cloud radiance fraction is less than 30% are used. Data are derived from OMI/Aura NO_2 retrievals (OMNO2d), with a spatial resolution of 0.25° x 0.25°, and temporal resolution of daily values. Units are molec./cm^2.

LAGRANTO back-trajectories and PBL height

- Set of 5-d back-trajectories starting at NCO-P every 6 hours (0, 6, 12, 18 UTC) calculated with Lagrangian analysis tool LAGRANTO. Model calculations are based on 6-h ERA-Interim reanalysis of the ECMWF. Each set has 12 back-trajectories, with endpoints shifted by ±1° in lat/lon and ±50 hPa with respect to NCO-P. The temporal resolution is a point every 2 h.

- PBL height over Kathmandu is retrieved from the ERA-Interim reanalysis dataset. The spatial resolution is approx. 80 km (T255 spectral). The Kathmandu value was obtained by linear interpolation with the two closest grid points. The temporal resolution is a value every 3 h, averaged to obtain daily values

Approach motivation

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“Lifting and advection of polluted air masses over the great mountain range is enabled by a combination of synoptic-scale and local meteorological processes. During the days prior to the event, winds over the Indo-Gangetic Plain (IGP) are generally weak at lower levels, allowing for accumulation of pollutants and thus the formation of ABCs. The subsequent passing of synopticscale troughs leads to southwesterly flow in the middle troposphere over northern and central India, carrying the polluted air masses across the Himalayas.”