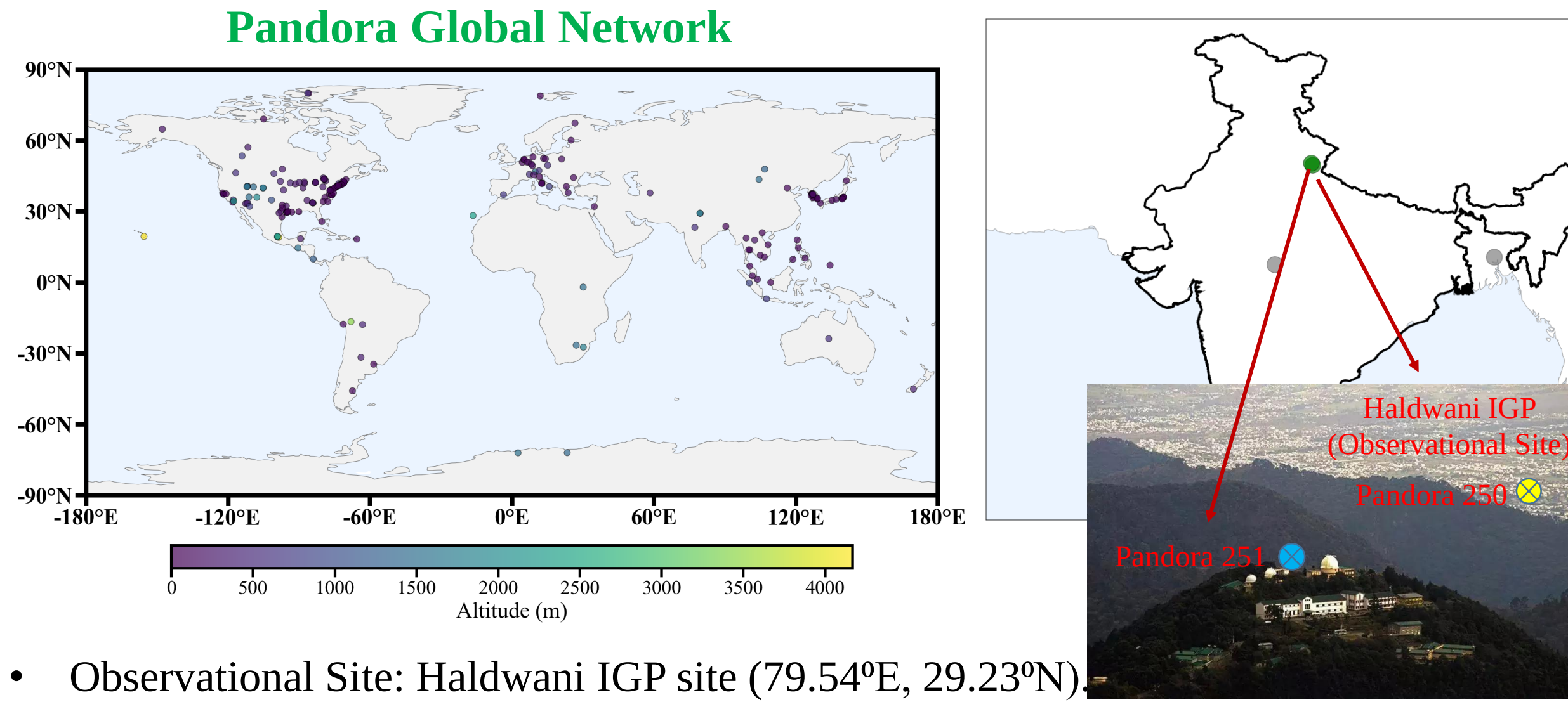


## Introduction

- Trace gases are vital to atmospheric processes, but even small increases in their concentrations can have significant impacts.
- Regular and continuous monitoring of trace gases is therefore essential.
- Simultaneous monitoring of ozone and its precursors is crucial for understanding tropospheric chemistry.

## Motivation, PGN and Observational Sites

- Limited columnar observations over South-East Asia.



## Observational Techniques and Data

### Pandora Spectrometer

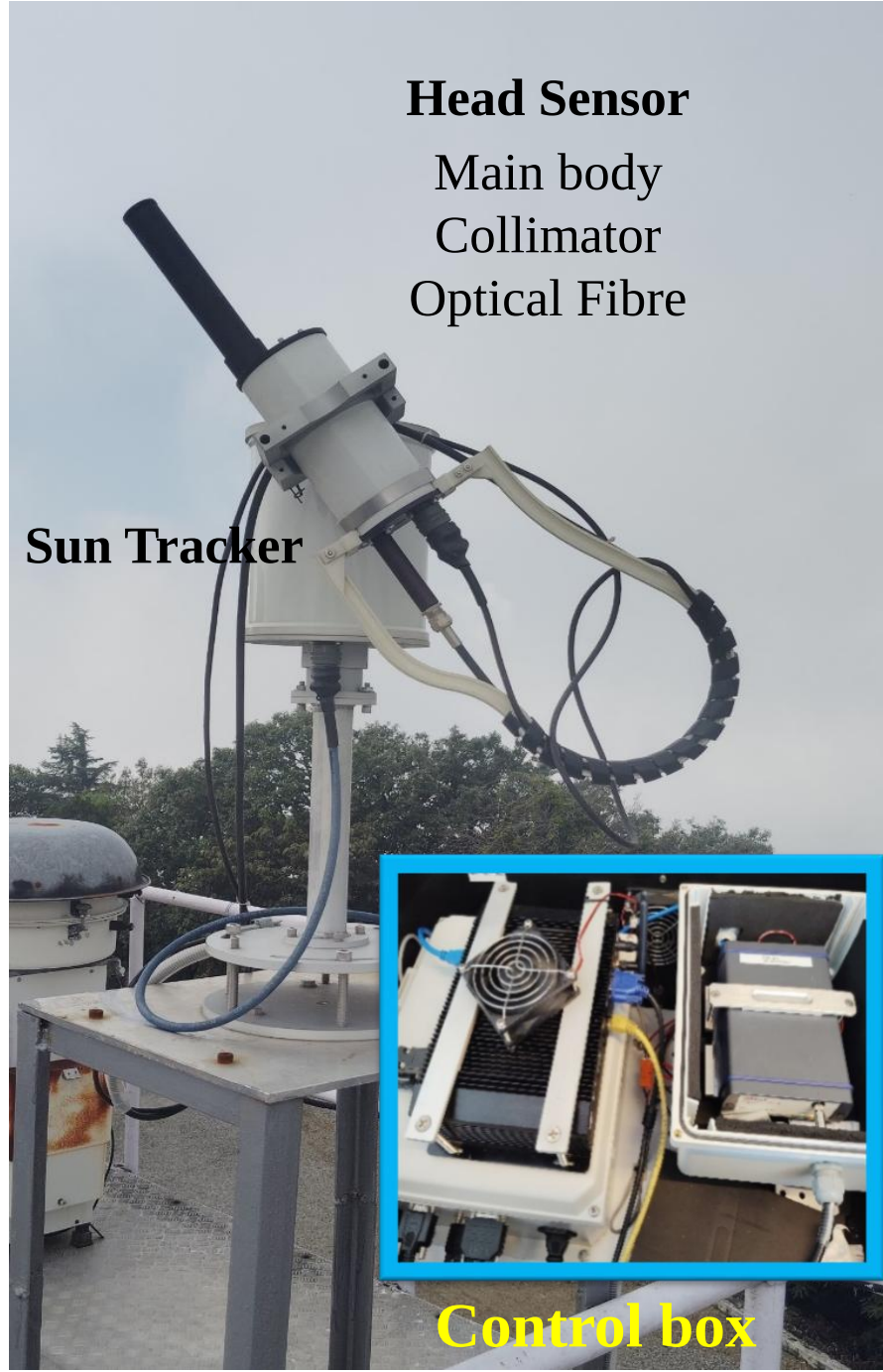
- Pandora spectrometer is for ground-based remote sensing of different trace gases using UV-Visible light (280- 530 nm).

#### ❖ Observation Modes:

- Direct sun:** Total column
- Sky-Scan mode:** Lower tropospheric (LT) column (0-4 km AGL) and surface concentration

#### ❖ Output products:

**Total column** (NO<sub>2</sub>, O<sub>3</sub>, HCHO, SO<sub>2</sub>, Water Vapour), **Tropospheric column** (NO<sub>2</sub>, HCHO) and **Surface Concentration** (NO<sub>2</sub>, HCHO).



## Satellite Data

#### ❖ Sentinel-5P TROPOMI

- Measures: SO<sub>2</sub> Total Vertical Column
- Spatial Resolution:  $\sim 5.5 \times 3.5 \text{ km}^2$
- L2 data of total column SO<sub>2</sub>.
- Quality flag (qa >0.6)



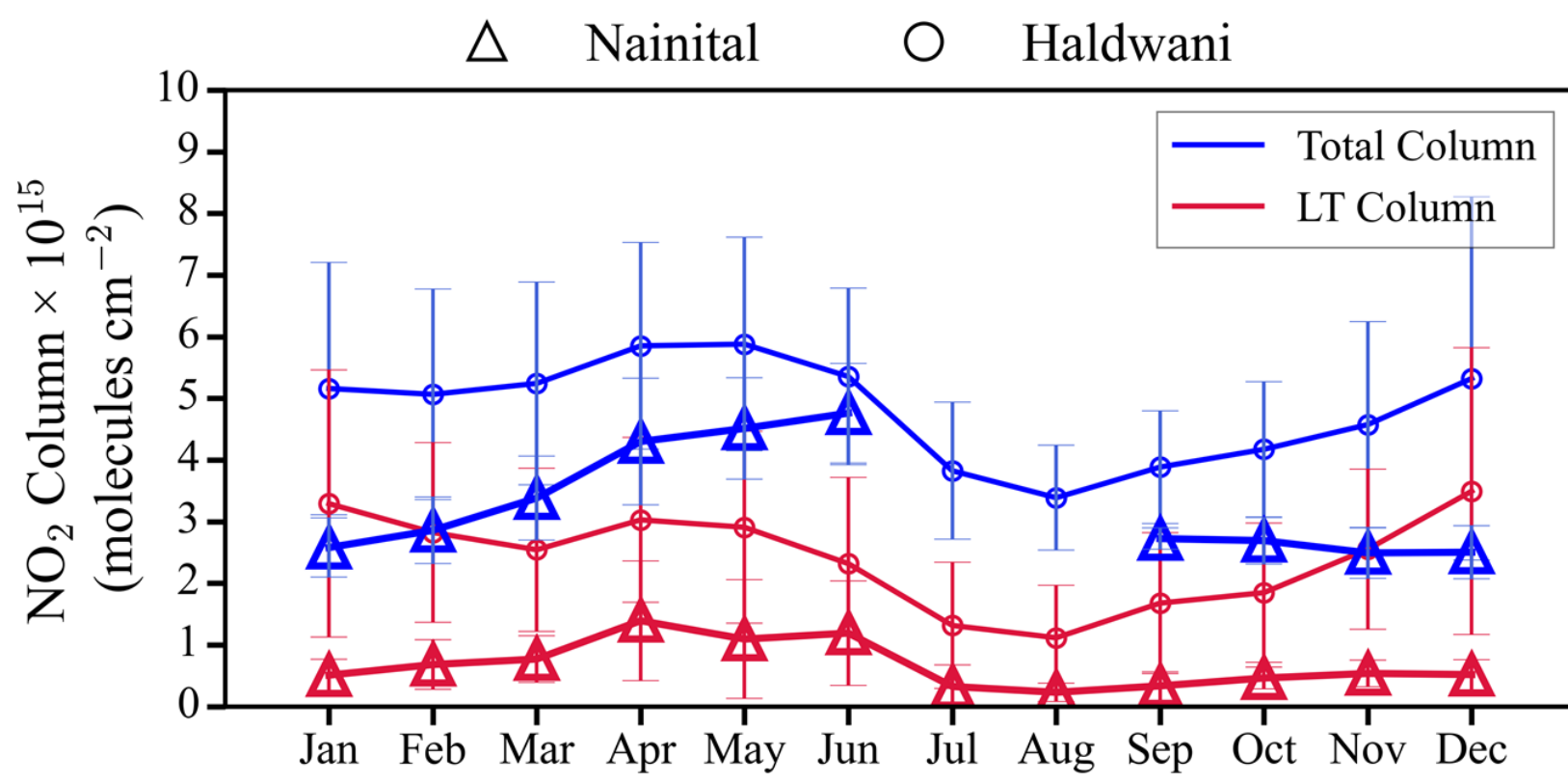
#### ❖ Infrared Atmospheric Sounding Interferometer (IASI)

- Measures: SO<sub>2</sub> Total Vertical Column and SO<sub>2</sub> altitude.
- Spatial Resolution:  $\sim 50 \times 50 \text{ km}^2$

## Results and Discussion

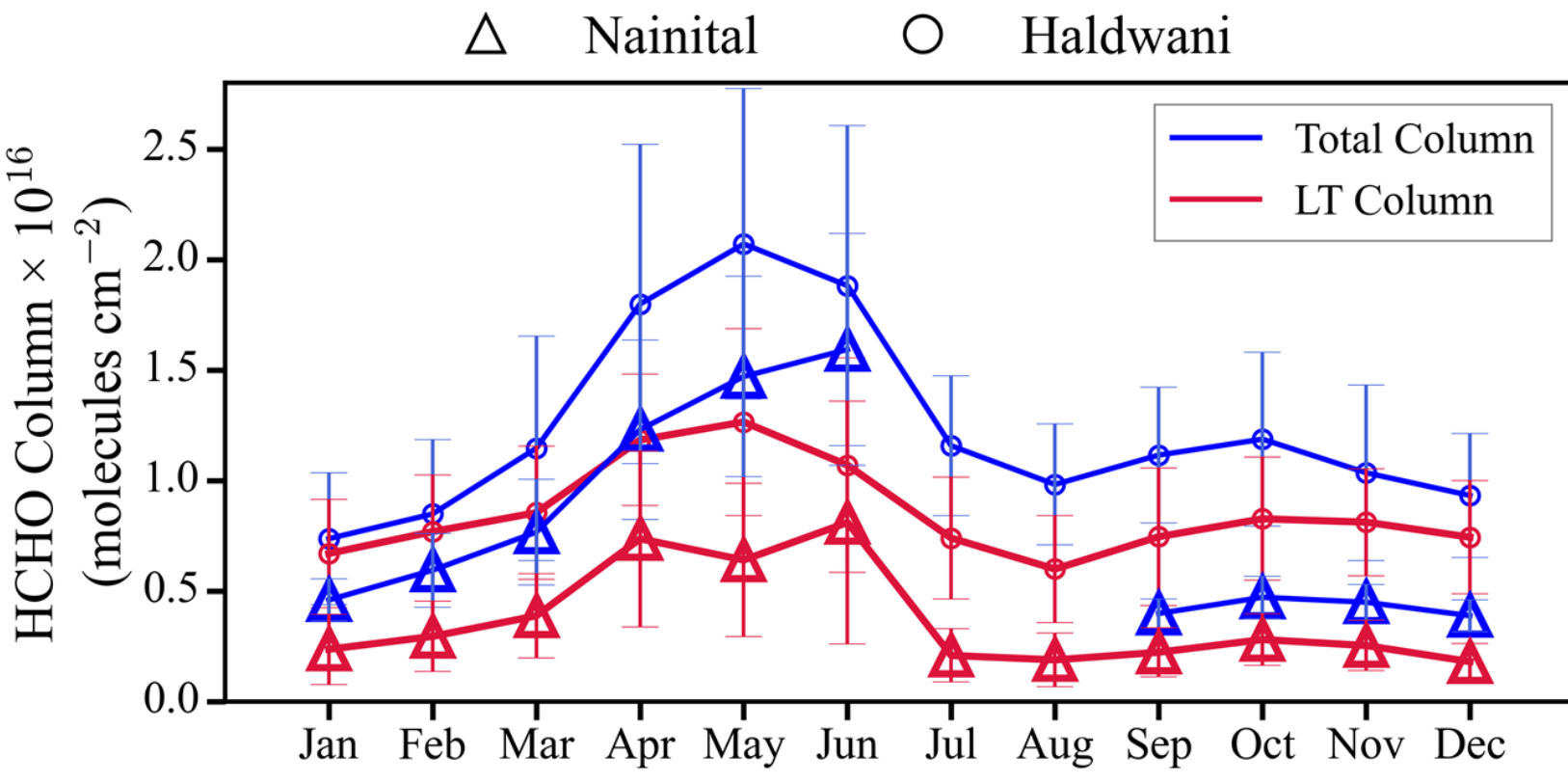
### 1. Monthly Variations

#### Column Nitrogen dioxide (NO<sub>2</sub>)



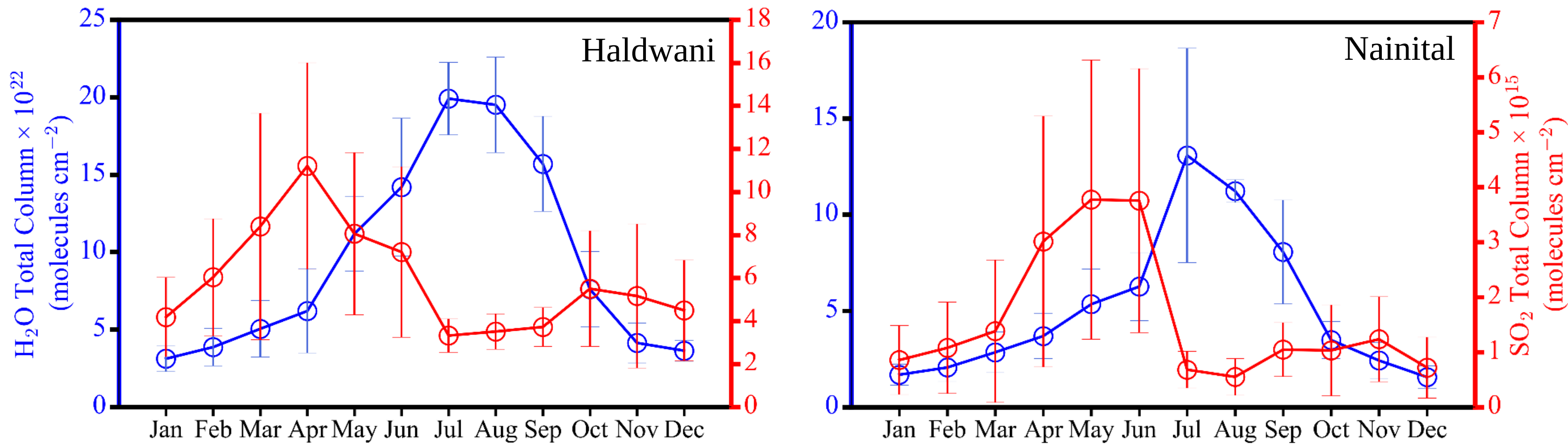
- Weaker solar radiations and lower boundary layer height leads to higher value of NO<sub>2</sub> over Haldwani has during the winter season.

#### Column Formaldehyde (HCHO)



- Main peak during spring and slightly higher value during autumn season.
- Combined effect of solar radiations and emissions.

#### Column Water Vapour (H<sub>2</sub>O) and Sulphur dioxide (SO<sub>2</sub>)

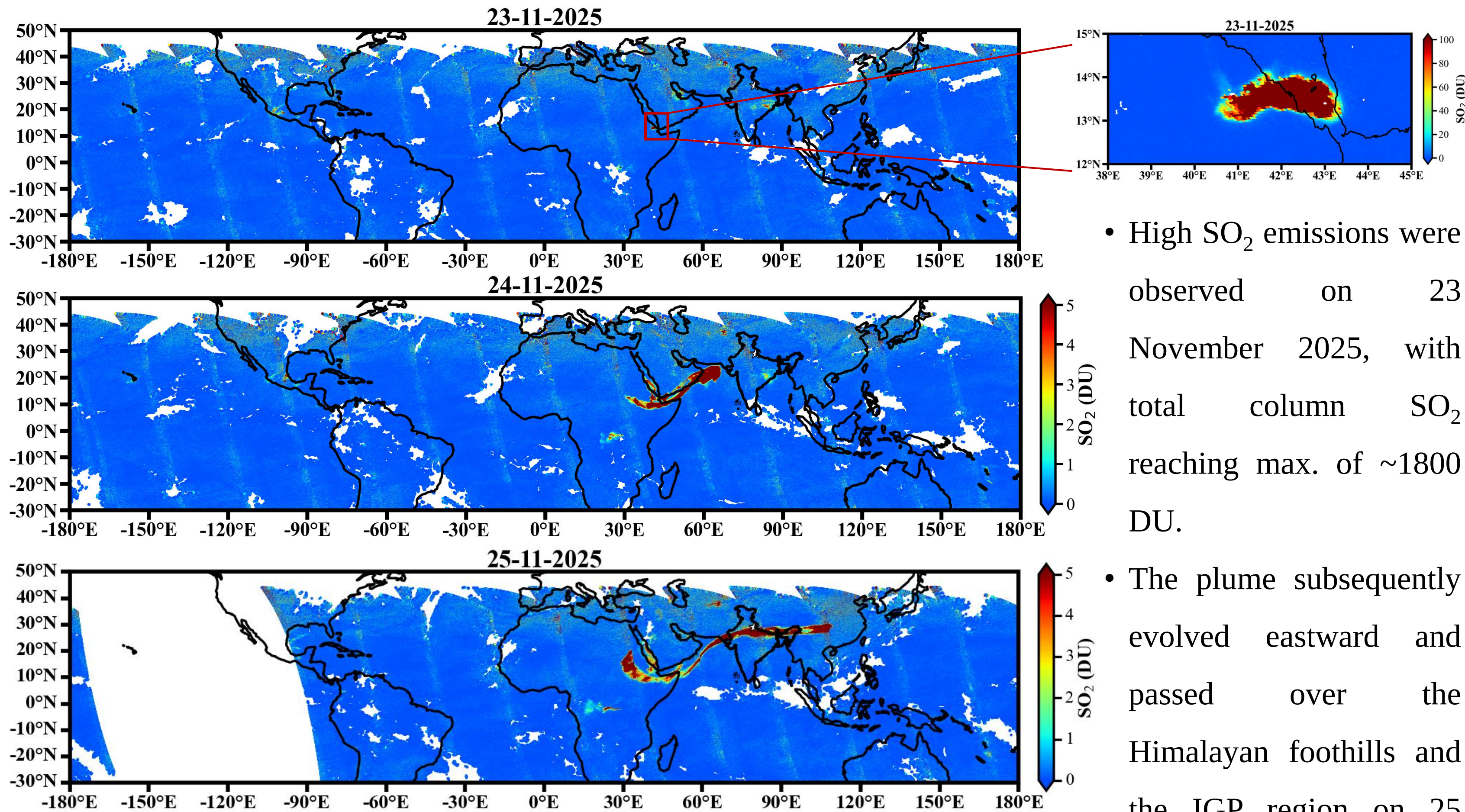


- Total-column SO<sub>2</sub> peaks in spring, contrasting with the typical winter maximum over the IGP.
- No major power plants near the observation site as potential SO<sub>2</sub> sources.
- Higher wind speeds and a well-mixed boundary layer during spring may enhance regional transport to the site.

## 2. Ethiopia's Hayli Gubbi Volcanic Eruption

- Eruption occurred on 23<sup>rd</sup> November, 2025 at around 8:30 UTC.
- Location: Latitude 14.06-15.88 °N and Longitude 41.48-42.92 °E.

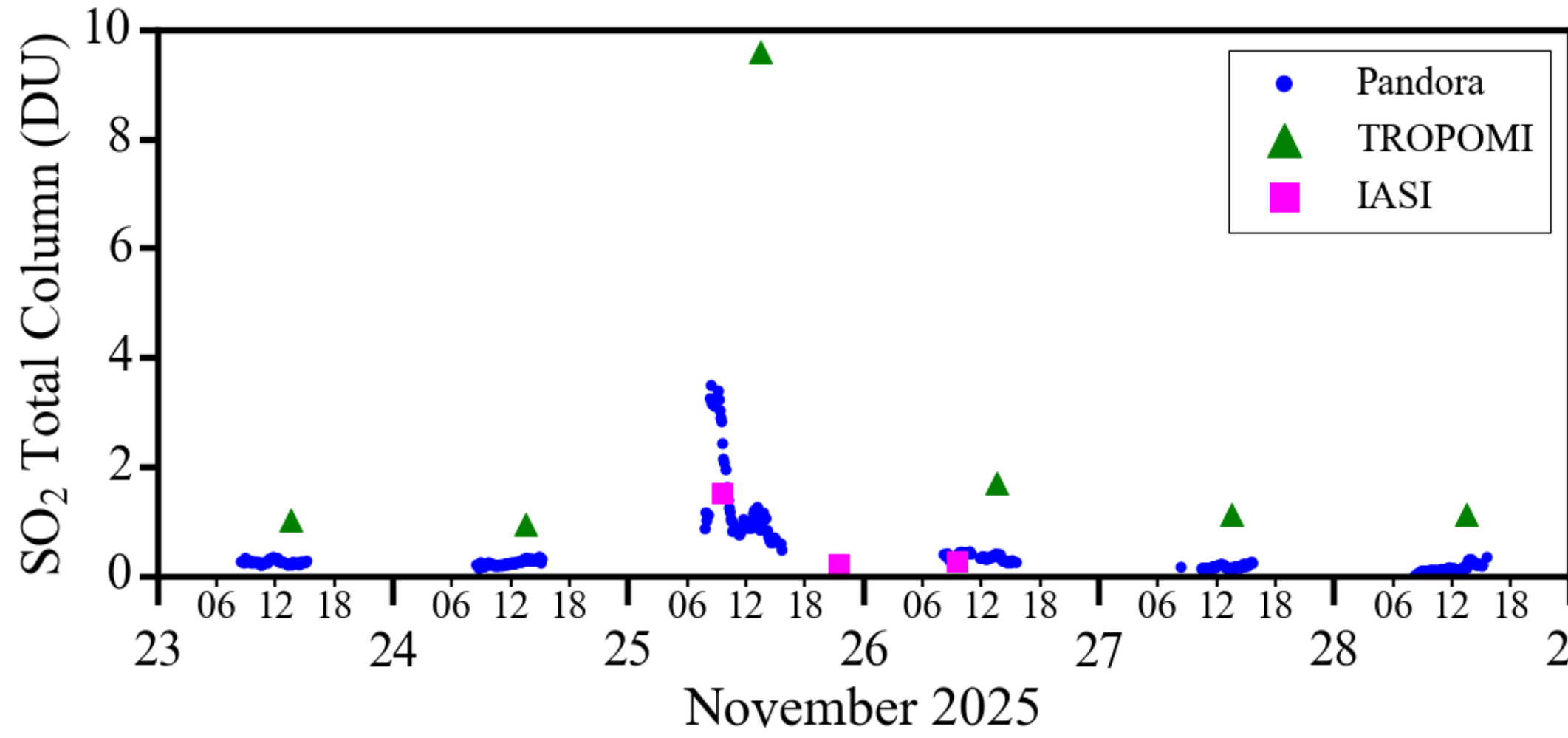
#### Plume Evolution Imagery



- High SO<sub>2</sub> emissions were observed on 23 November 2025, with total column SO<sub>2</sub> reaching max. of  $\sim 1800$  DU.
- The plume subsequently evolved eastward and passed over the Himalayan foothills and the IGP region on 25 November 2025.

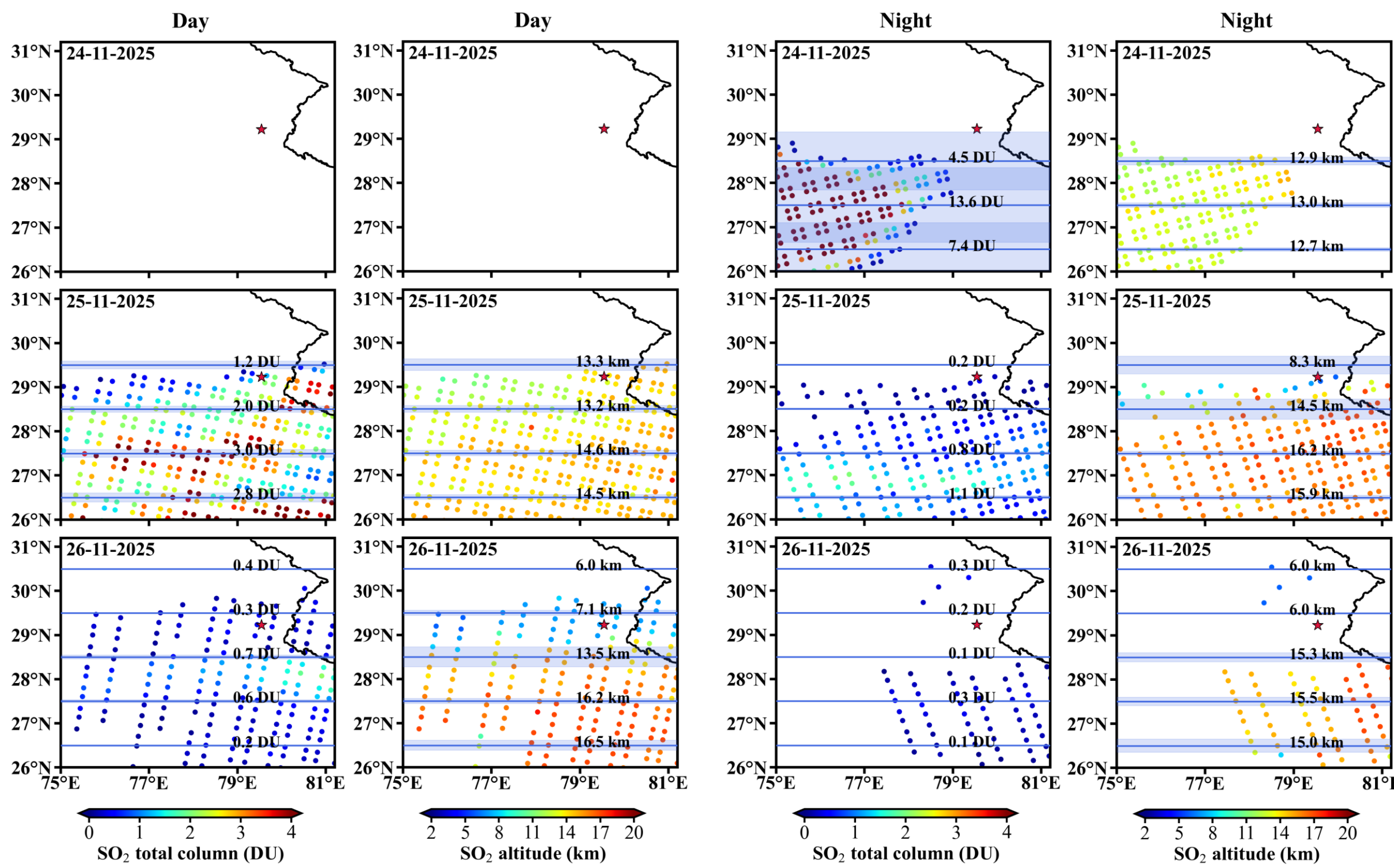
TROPOMI total column SO<sub>2</sub> plume evolution from 23<sup>rd</sup> to 25<sup>th</sup> November, 2025.

#### Temporal Evolution of Total Column SO<sub>2</sub>



- Satellite data were analyzed within a  $1^\circ \times 1^\circ$  region centered on the Pandora location.
- Pandora total-column SO<sub>2</sub> reached a maximum of  $\sim 3.5$  DU on 25 November, approximately 9 times higher than on the surrounding days.

#### IASI-Based SO<sub>2</sub> Plume Evolution Over the Observational Site



- 24 November: SO<sub>2</sub> plume reached the vicinity of the observational site, with SO<sub>2</sub> total-column values of 13 DU at center of plume during the IASI evening overpass.
- 25 November: Plume passed over the Pandora location, with SO<sub>2</sub> total-column values of  $\sim 1.2$ –2 DU and a plume height of  $\sim 13$  km.

## Conclusion

- The volcanic SO<sub>2</sub> plume reached the Himalayan foothills and IGP region on 24 November (evening).
- On 25 November, the plume crossed the Pandora location, with SO<sub>2</sub> total-column values of  $\sim 1.2$ –2 DU and a plume height of  $\sim 13$  km.
- High-altitude and rapid eastward transport suggests association with the subtropical jet, limiting the plume's long-term influence on near-surface air quality over India.