

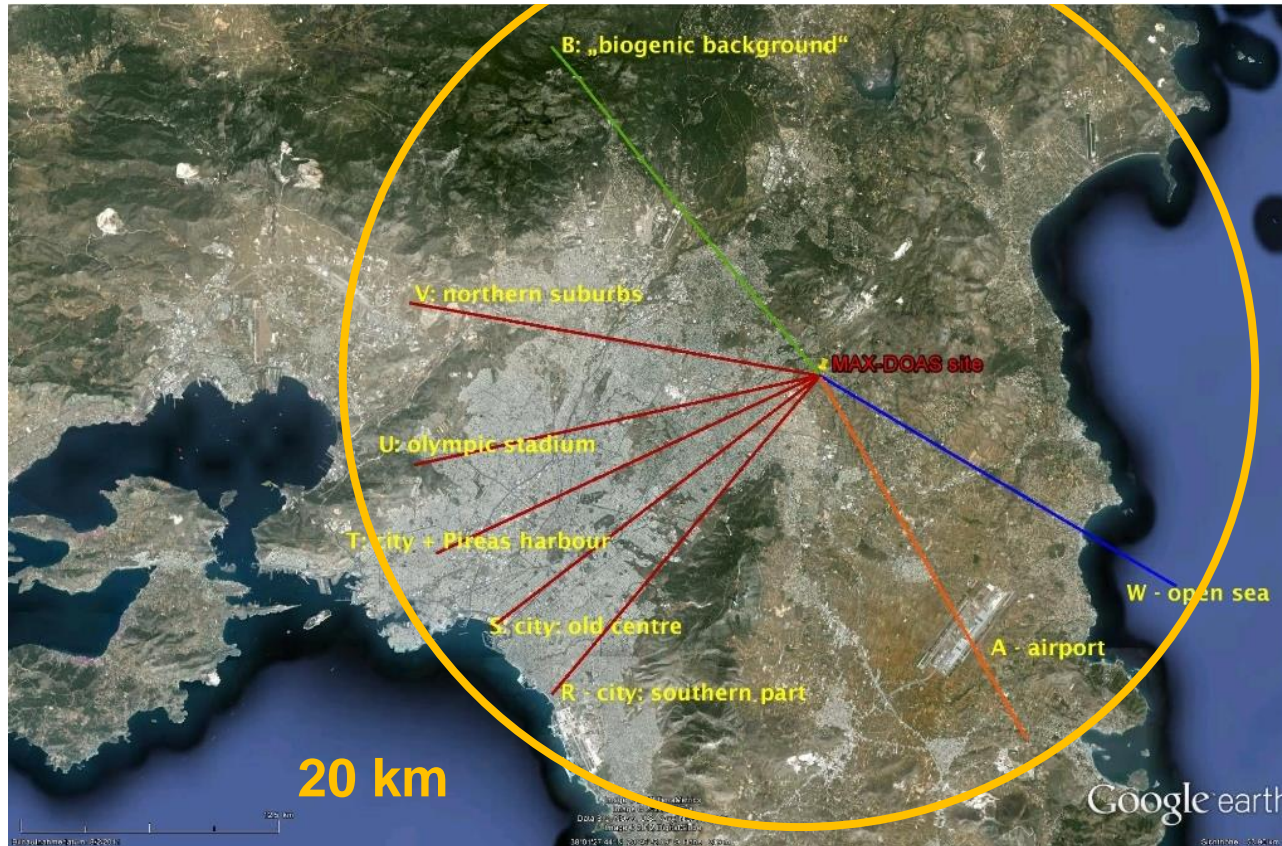
Spatial and temporal variability of NO₂ in Athens observed by MAX-DOAS

NORS / NDACC / GAW workshop
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MAX-DOAS Measurements in Athens

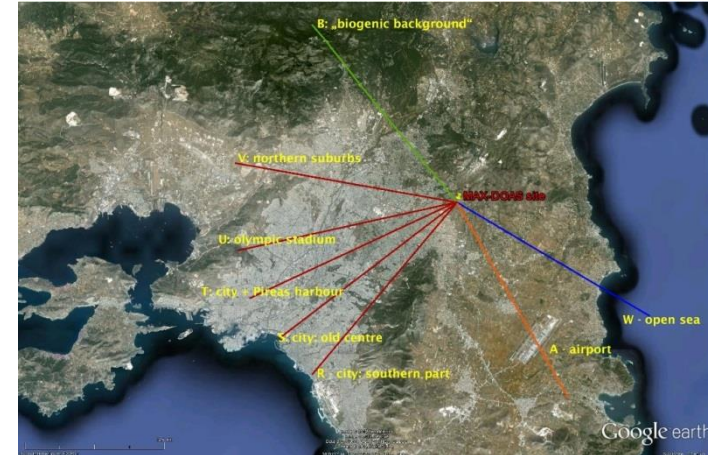
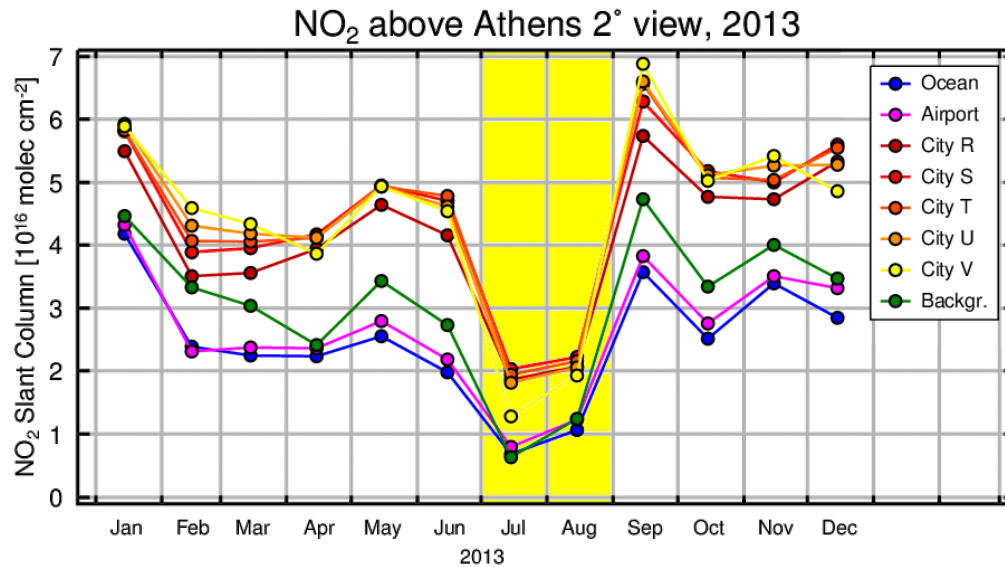


- Oct 2012 – now
- 330 – 500 nm
- 8 viewing azimuths
 - Ocean
 - Airport
 - City x 5
 - Background
- $-1^\circ \dots 30^\circ$ elevation + zenith
- 15 minutes cycle
- Closest zenith reference

- 3.2 million inhabitants
- Emissions from industry and transportation
- Intense photochemistry
- Affected by fires and Sahara dust events

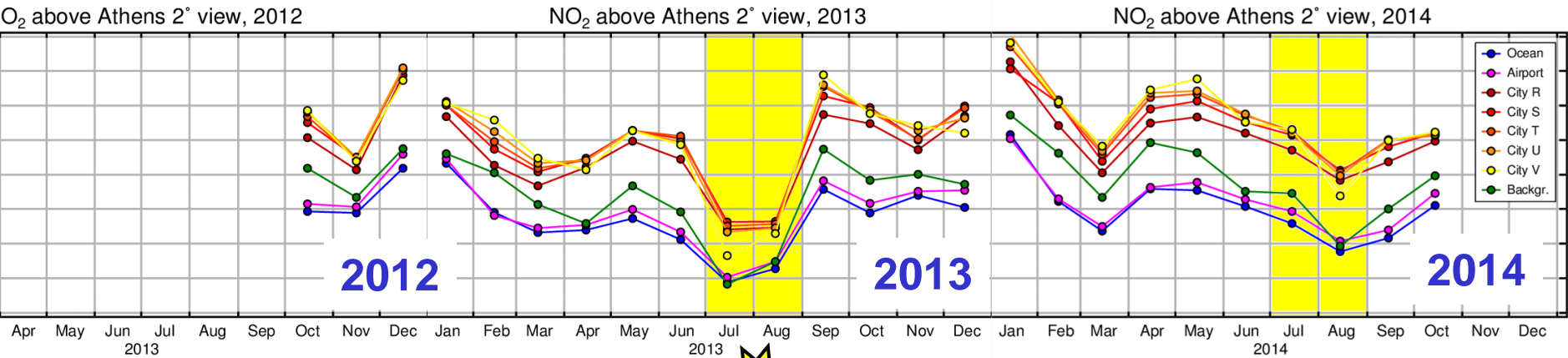


Annual variation

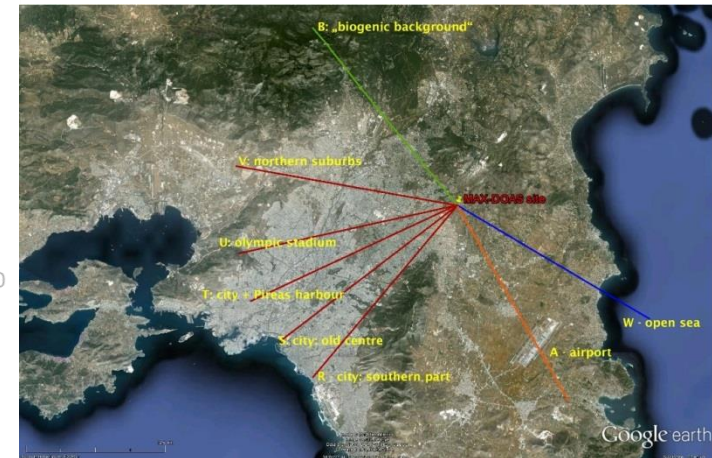
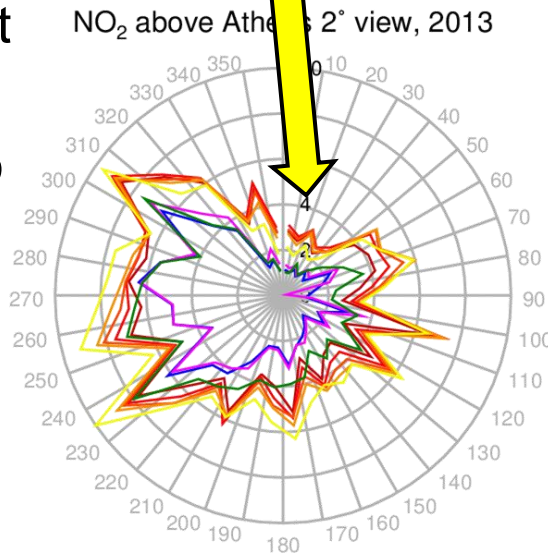


- Very pronounced summer minimum (more than factor of 2) during 2013
- Slightly lower values in Feb – June, slightly larger in Sep – Jan
- All viewing directions have similar seasonality
- Large gradient over observational area (factor of 2)

Annual variation

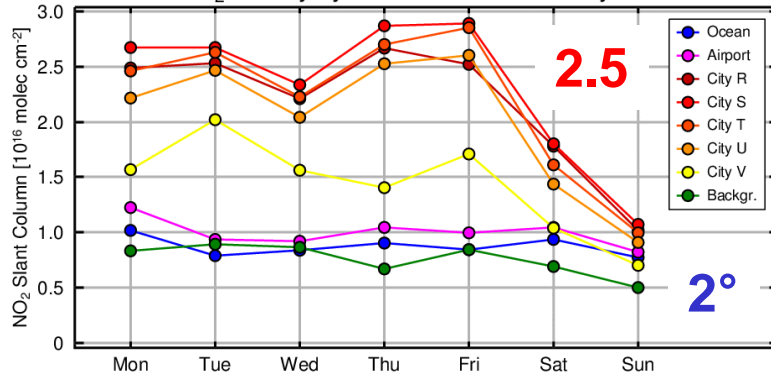


- Summer minimum not repeated each year
 - Probably not linked to emissions
- => meteorology?

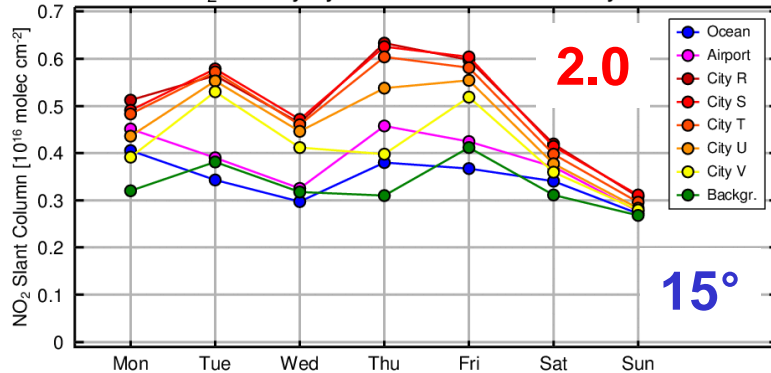


Weekly Cycle

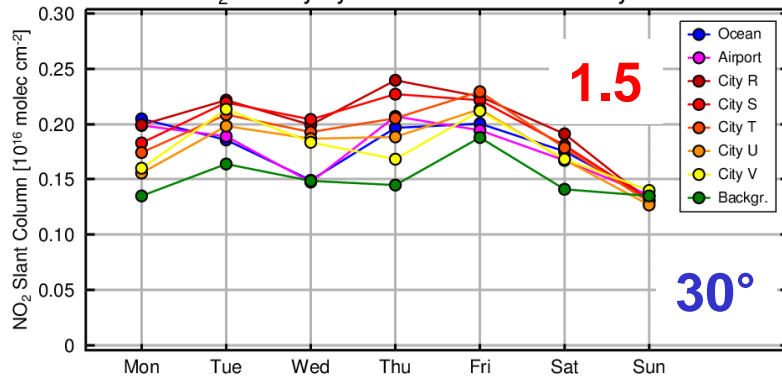
NO₂ weekly cycle Athens 2° view July 2013



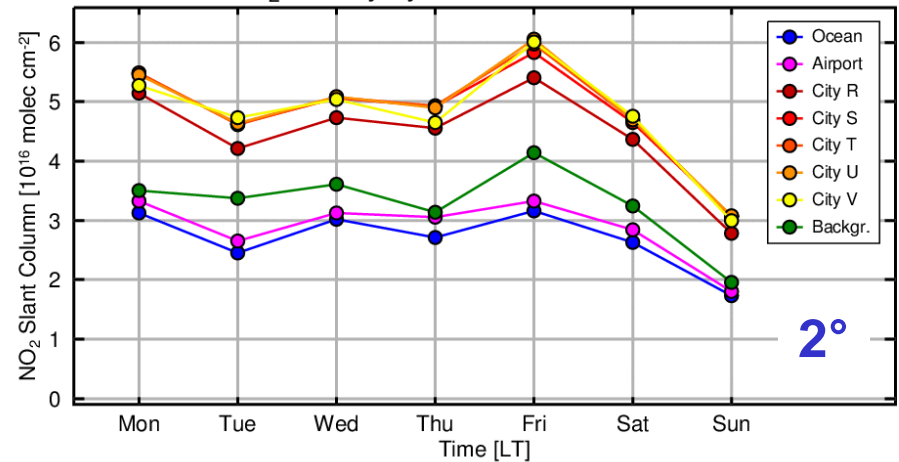
NO₂ weekly cycle Athens 15° view July 2013



NO₂ weekly cycle Athens 30° view July 2013



NO₂ weekly cycle Athens 2° view 2013

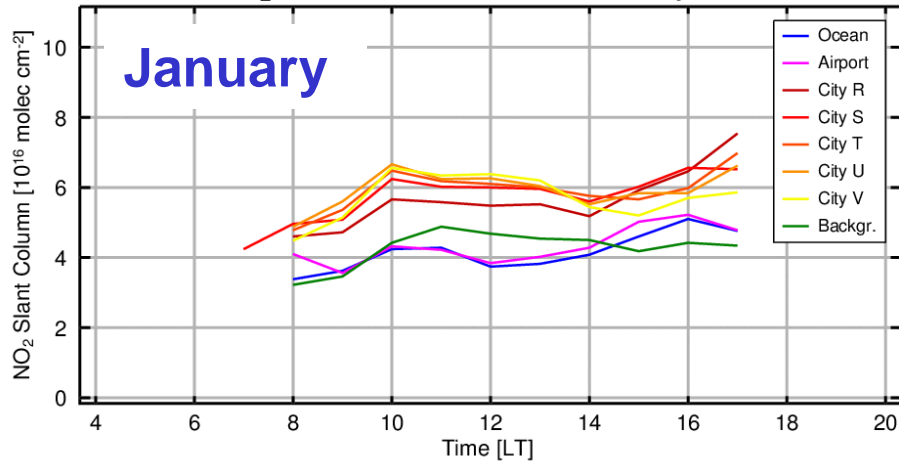


- Very clear weekly cycle
- Most pronounced over city directions
- Best seen during summer
- Most pronounced in lowest elevation angles
=> background NO₂?

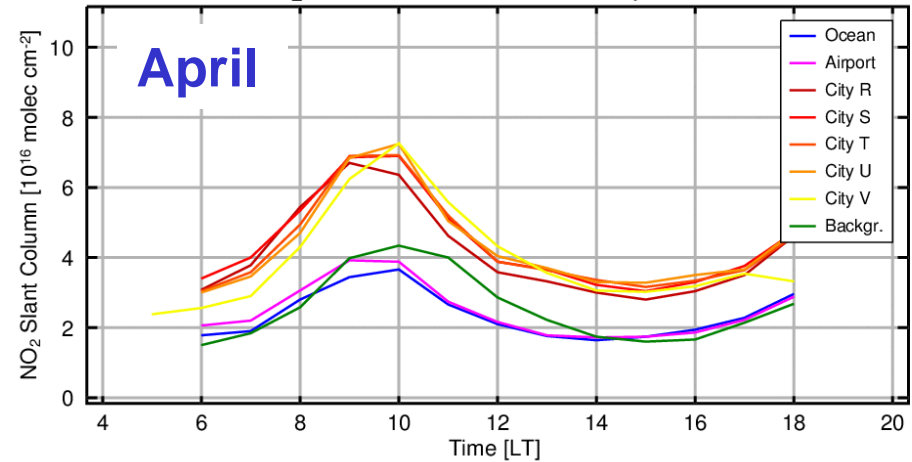


Diurnal Variation

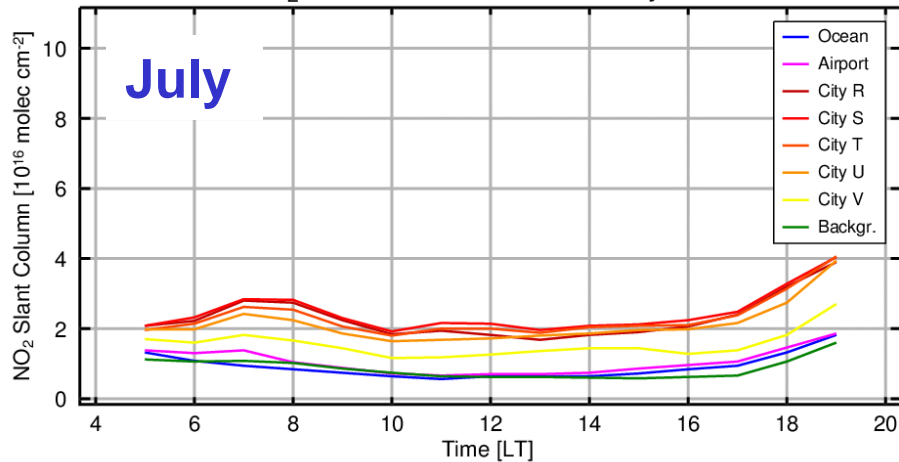
NO₂ above Athens 2° view January 2013



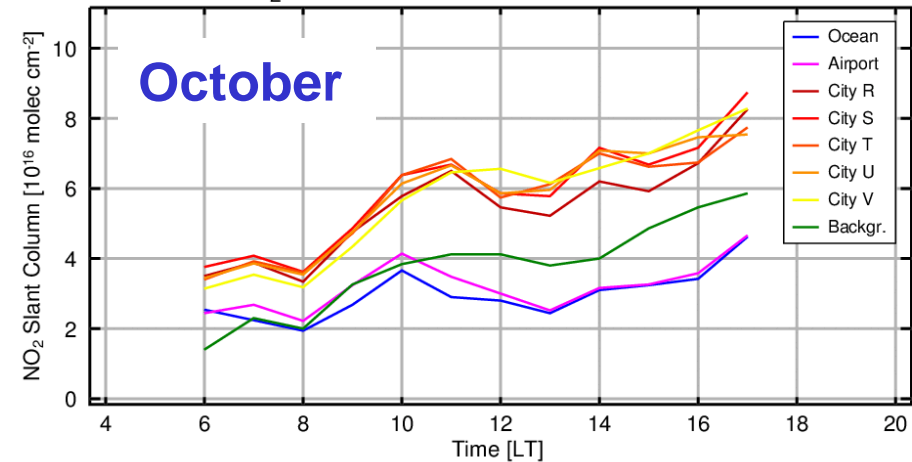
NO₂ above Athens 2° view April 2013



NO₂ above Athens 2° view July 2013

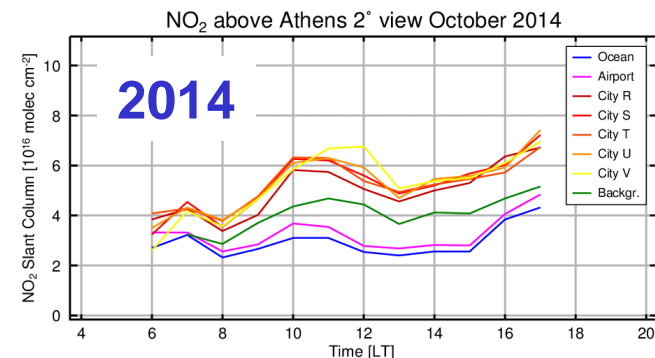
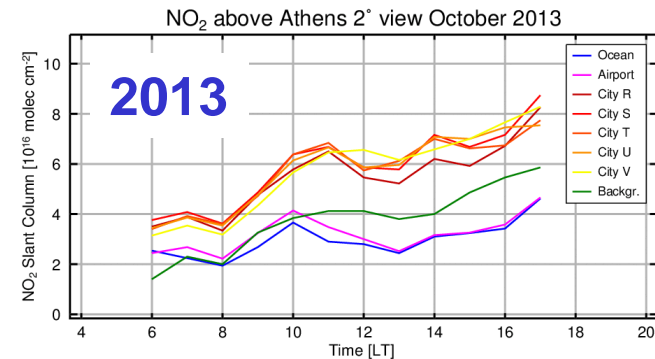
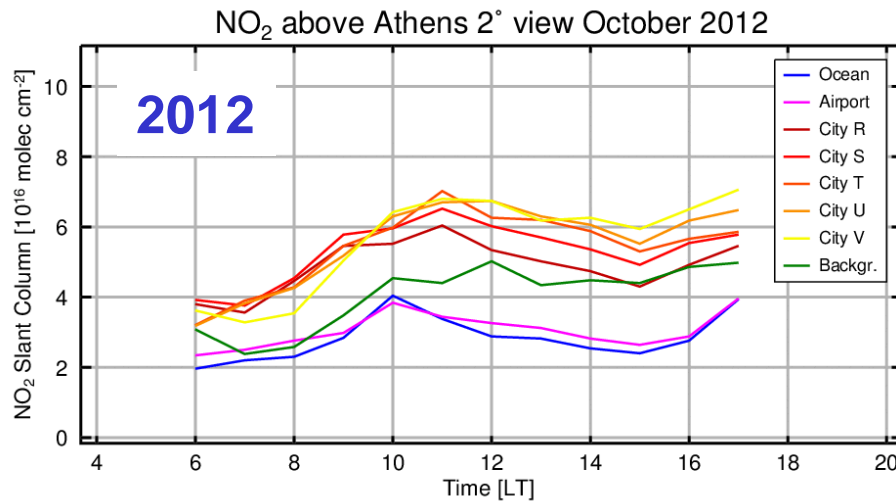


NO₂ above Athens 2° view October 2013

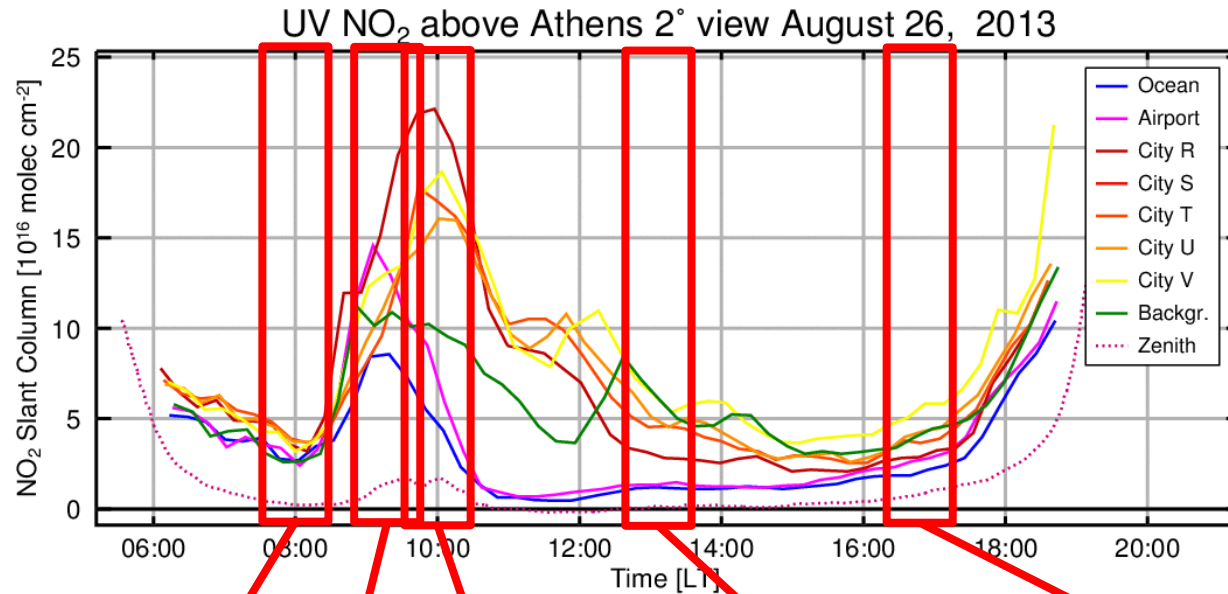


Diurnal Variation

- Large variability in daily profile
- Clear separation between viewing directions
- Background direction starts with low values in the morning but often approaches city directions over the day
- Tendency of morning peak
- Monthly averages dominated by individual days



Spatial Gradients



All directions low
values

Maximum
clean regions

Maximum
city

Background
direction
largest

residential
direction
largest



Challenges

The results look good, but so far are only slant columns. Why?

Because there are some complications:

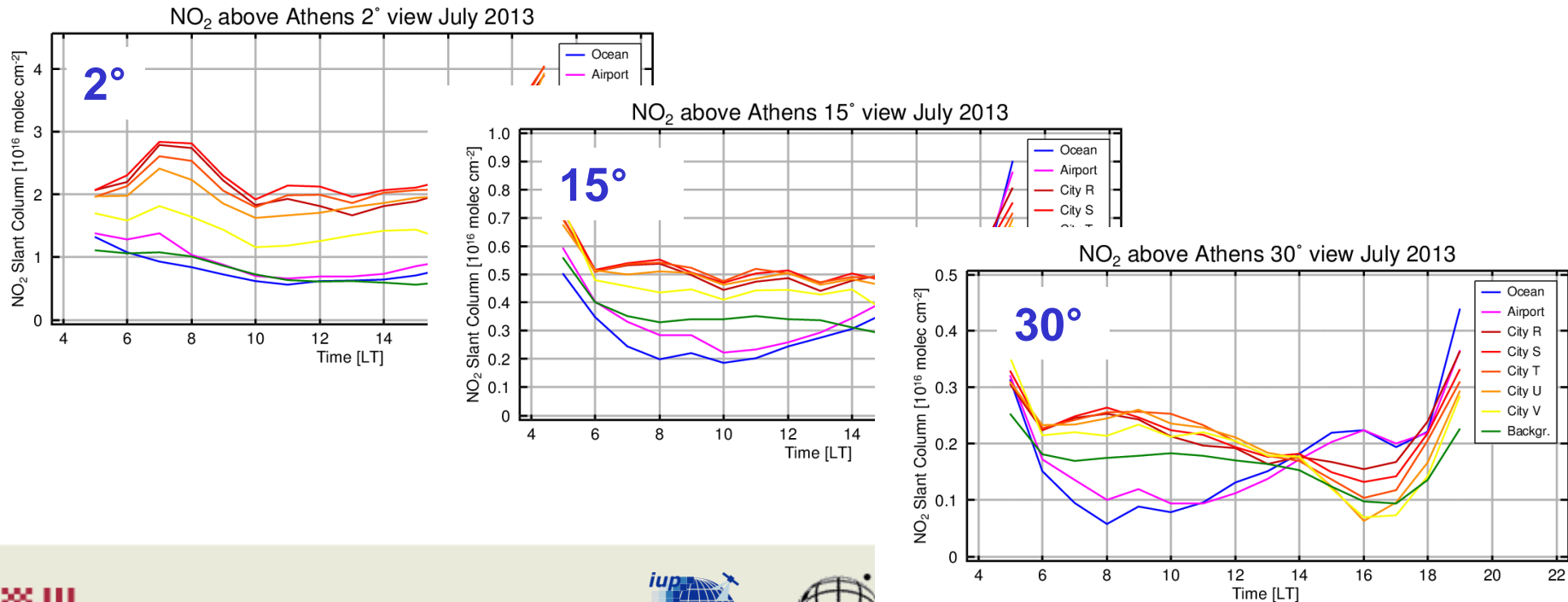
- 1) the sun is not in the zenith
- 2) NO_2 is not homogeneous
- 3) Athens is not flat



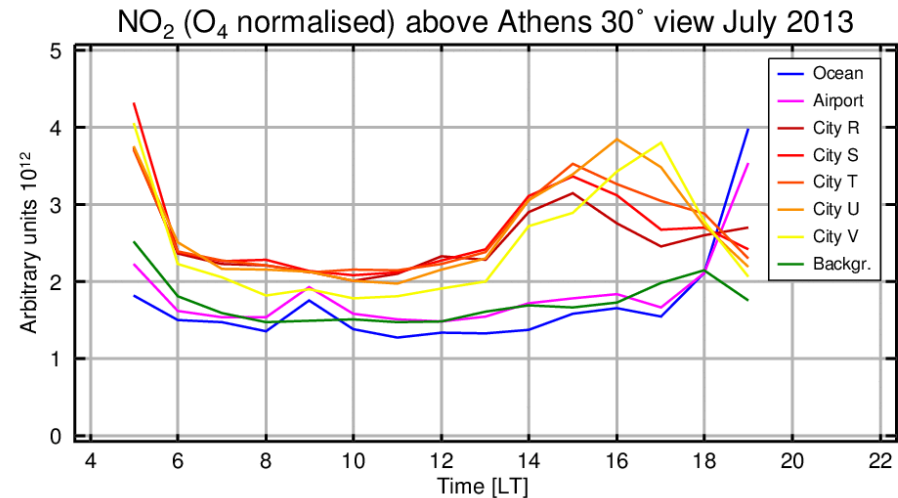
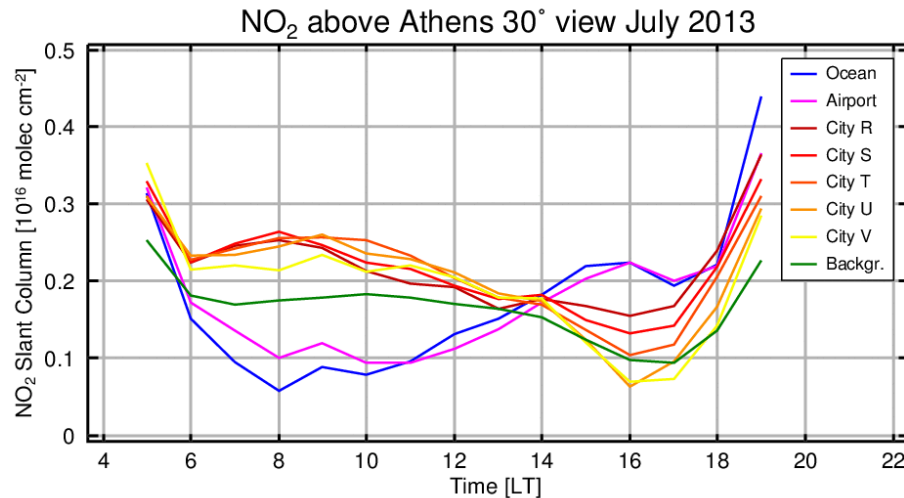
The Sun is not in the Zenith

In the past, often the columns from the 30° direction were used to compute tropospheric vertical columns

- Simple AMF (1)
- Scattering point above boundary layer results in similar AMF for largest part of tropospheric column
- Reduced problems from clouds, aerosols and pointing accuracy



The Sun is not in the Zenith



- Clear solar azimuth dependence of 30° viewing direction
- Can be corrected to first order by dividing through O₄ column but result is not consistent with 2° measurements
- Radiative transfer calculations and a priori NO₂ profile needed for accurate results

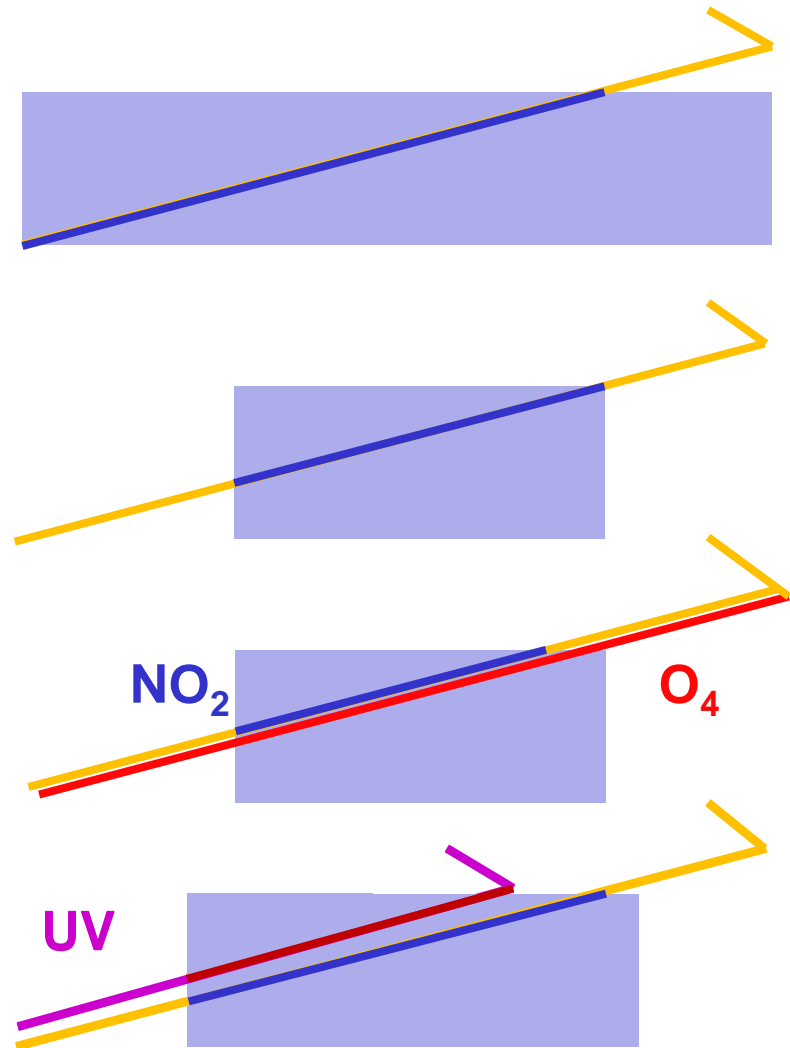
NO₂ is not homogeneous

- Ideal MAX-DOAS situation: NO₂ is horizontally homogeneous
- Real situation in Athens is clearly different

⇒ NO₂ slant column does not only depend on NO₂ concentration, and light path, but also on plume extent

⇒ Normalisation with O₄ does not work as O₄ gives light path, not light path through plume

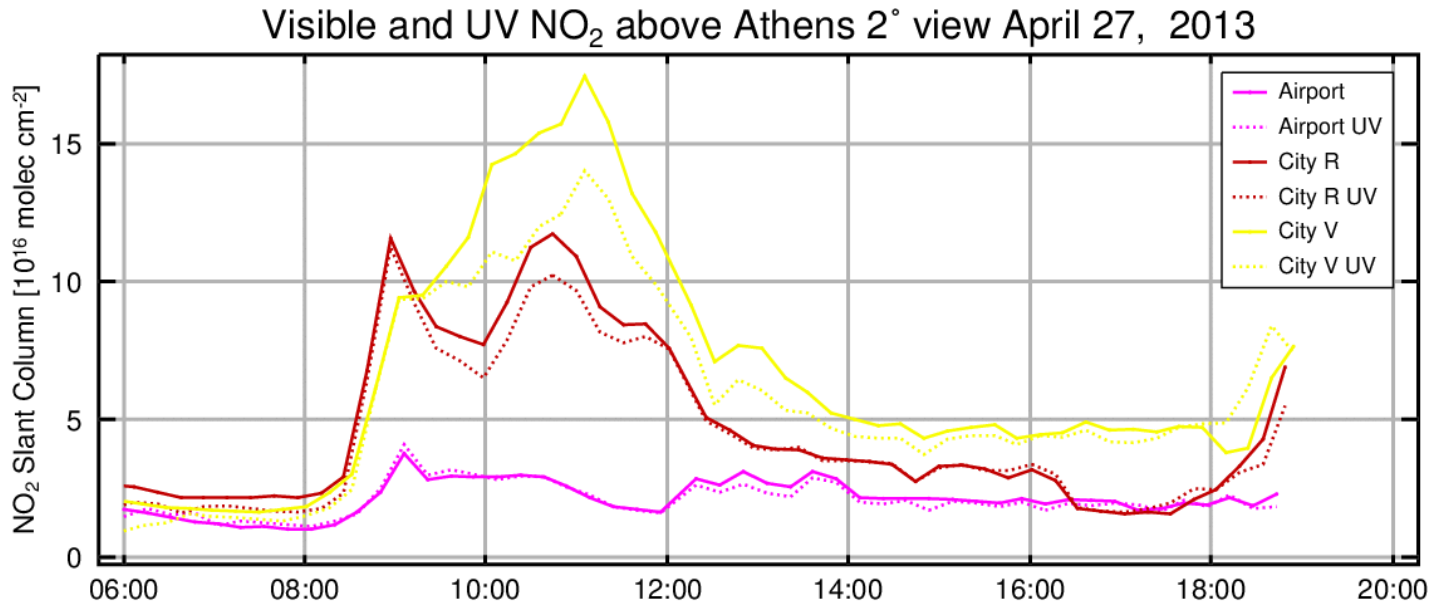
⇒ **Maybe use fits in different wavelength ranges?**



NO₂ is not homogeneous

Vis:
425 – 497 nm

UV:
338 – 380 nm



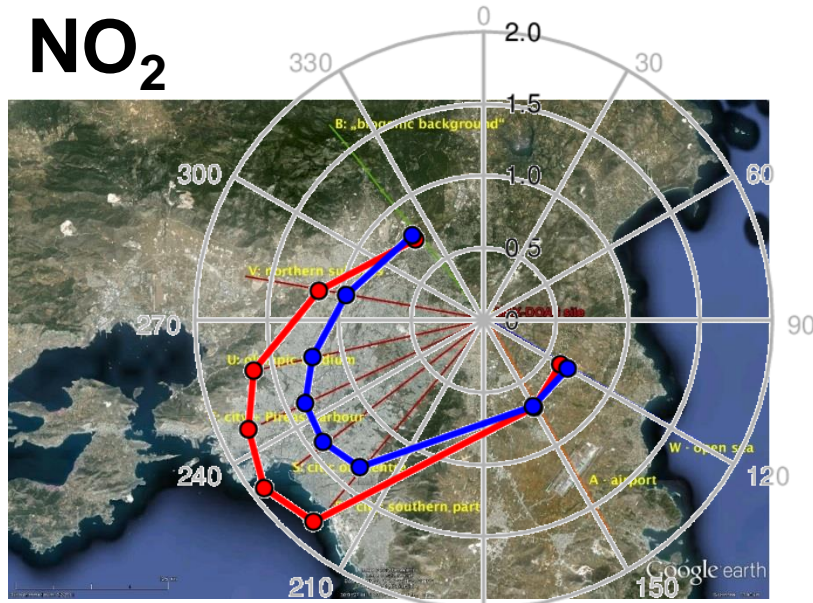
- Airport direction no differences => very close
- City direction small differences => close
- Residential direction large difference => farther away



NO₂ Difference with Wavelength

NO₂ above Athens 2° view, July 2013, 10:00 LT

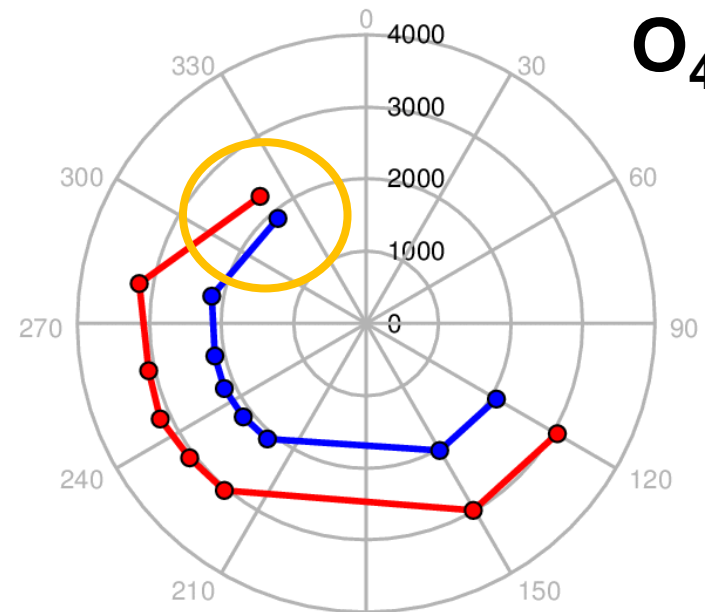
NO₂



UV
visible

O₄ above Athens 2° view, July 2013, 10:00 LT

O₄



- In monthly averages, there is a clear pattern of lower UV retrieved NO₂ columns over the city
- O₄ columns are very similar in all directions => not a solar azimuth effect
- Implies that NO₂ over the city is farther away than in A, W, and B directions

Summary and Conclusions

- Two years of MAX-DOAS measurements of NO₂ in Athens have been analysed
- There is a clear minimum in summer 2013 (northerly wind directions), and only small annual variation elsewhere
- The weekly cycle is very pronounced, in particular for lower viewing elevations and in summer
- The diurnal pattern varies strongly between months and from day to day
- Large spatial gradients are observed, mainly between city and background but also varying during the day
- Solar azimuth dependence of geometric VC is obvious
- Plume extent has large impact on results and can be estimated using visible + UV measurements
- Boundary layer evolution is important factor for hill top observations



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