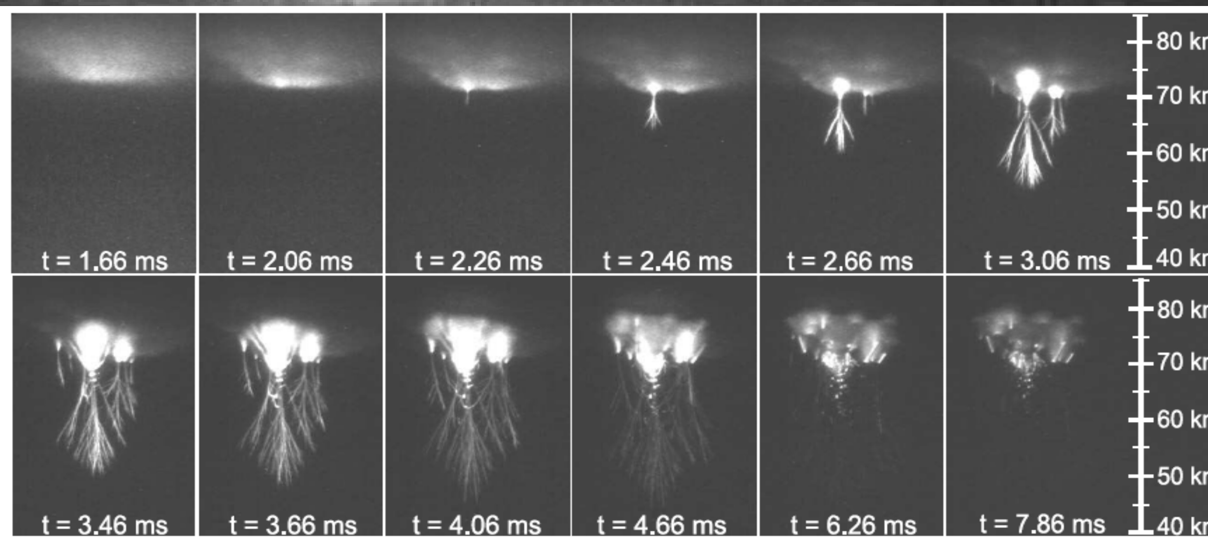
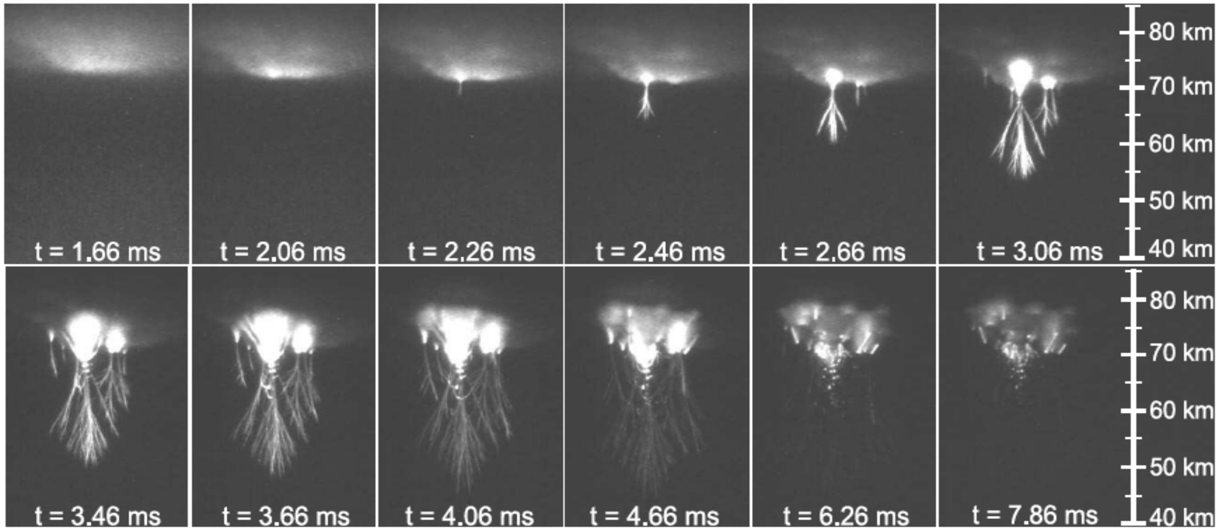
Sprite-induced chemistry

E. Arnone

ISAC-CNR, Bologna, Italy



(Cummer et al. 2006)

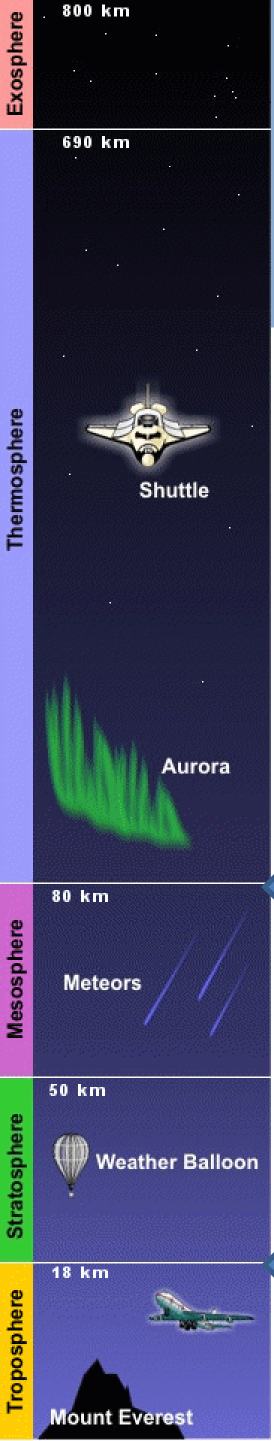


(Cummer et al. 2006)

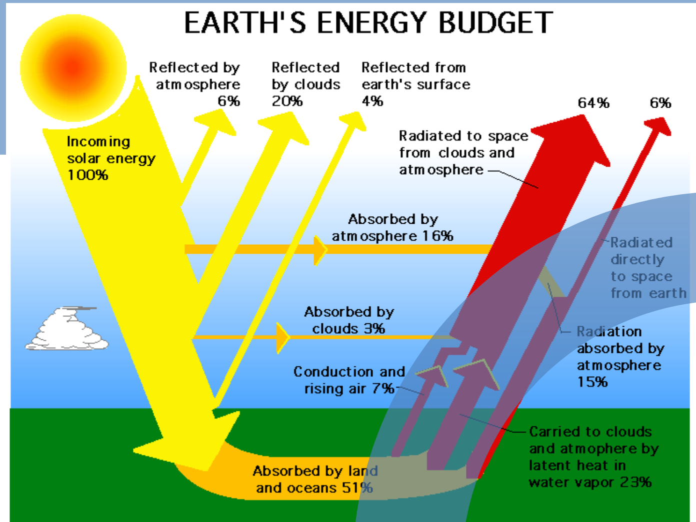
OUTLINE:

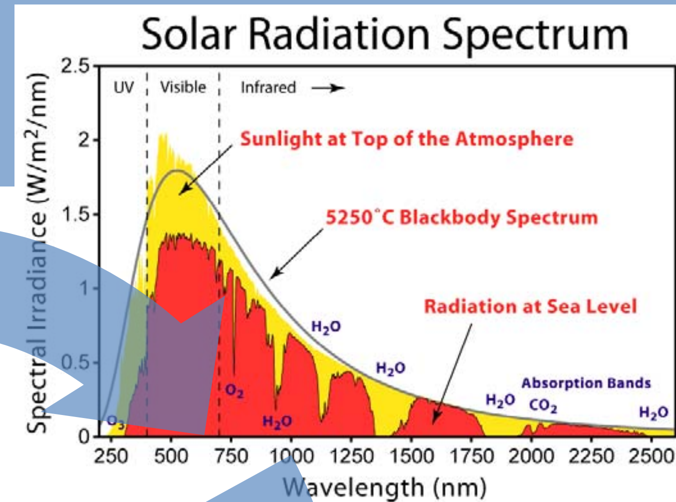
introduction
sprites and NOx
global impact
regional impact
conclusions

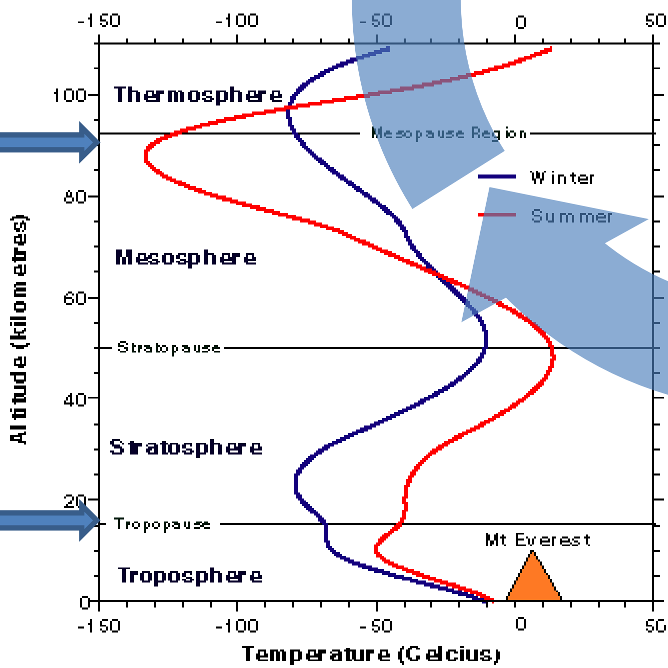
The atmosphere

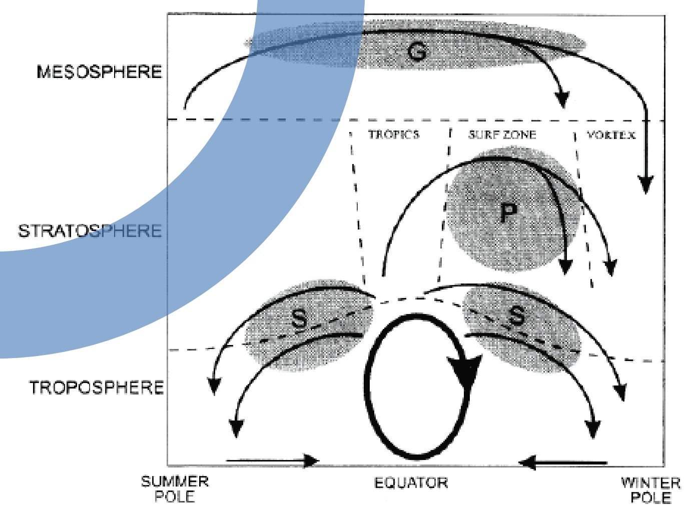


Radiation and chemistry



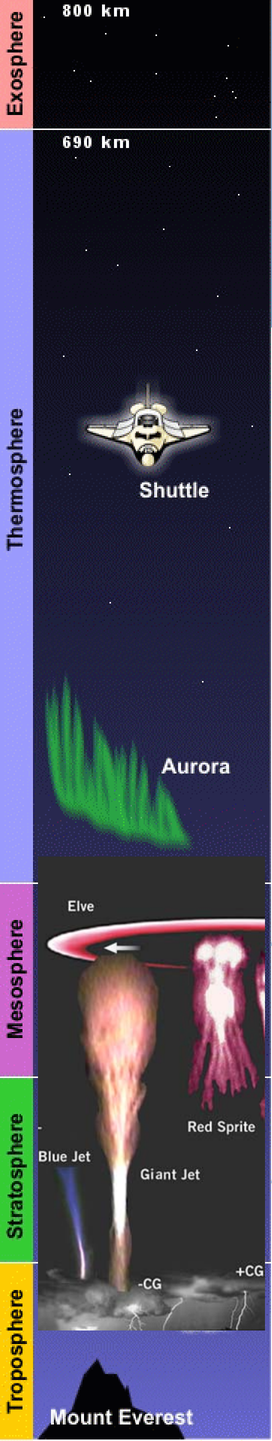


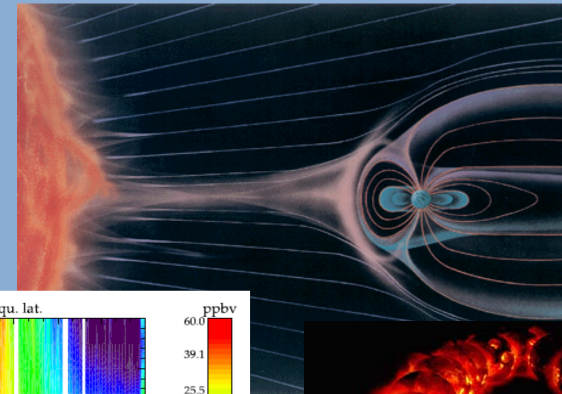


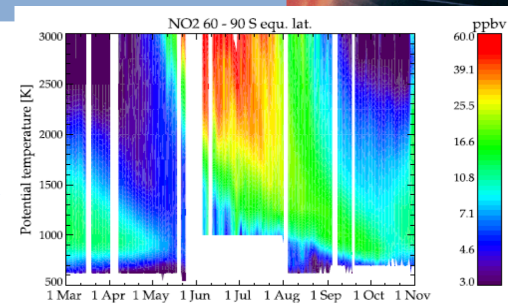


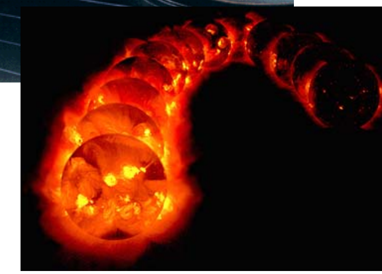
Dynamics: mean flow and waves

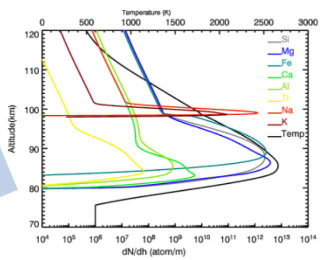
The middle atmosphere

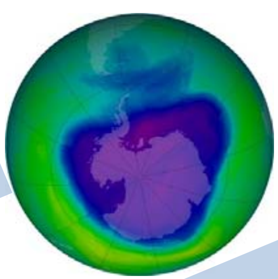


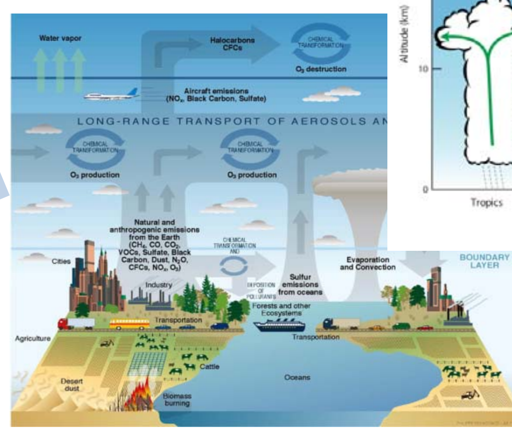


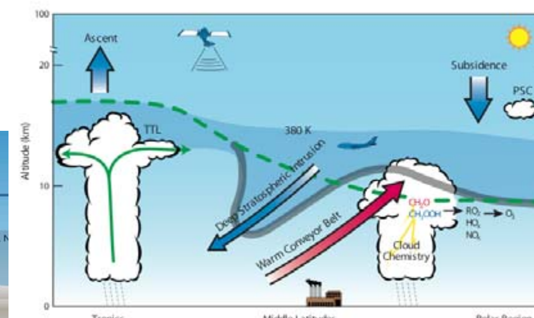






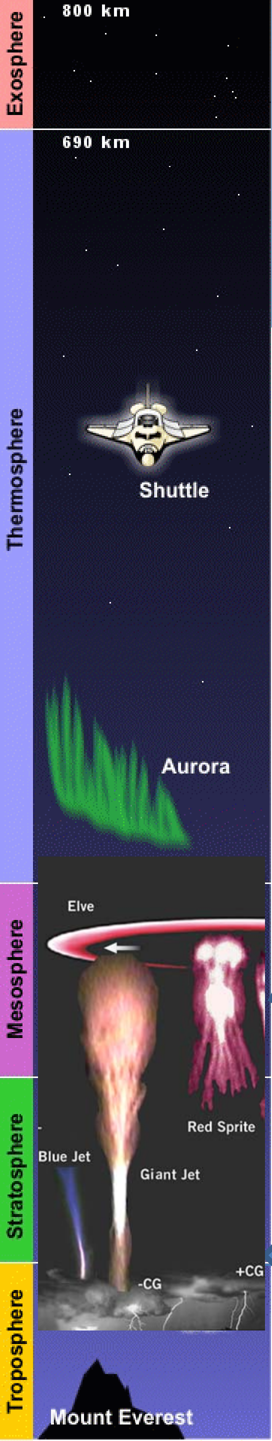


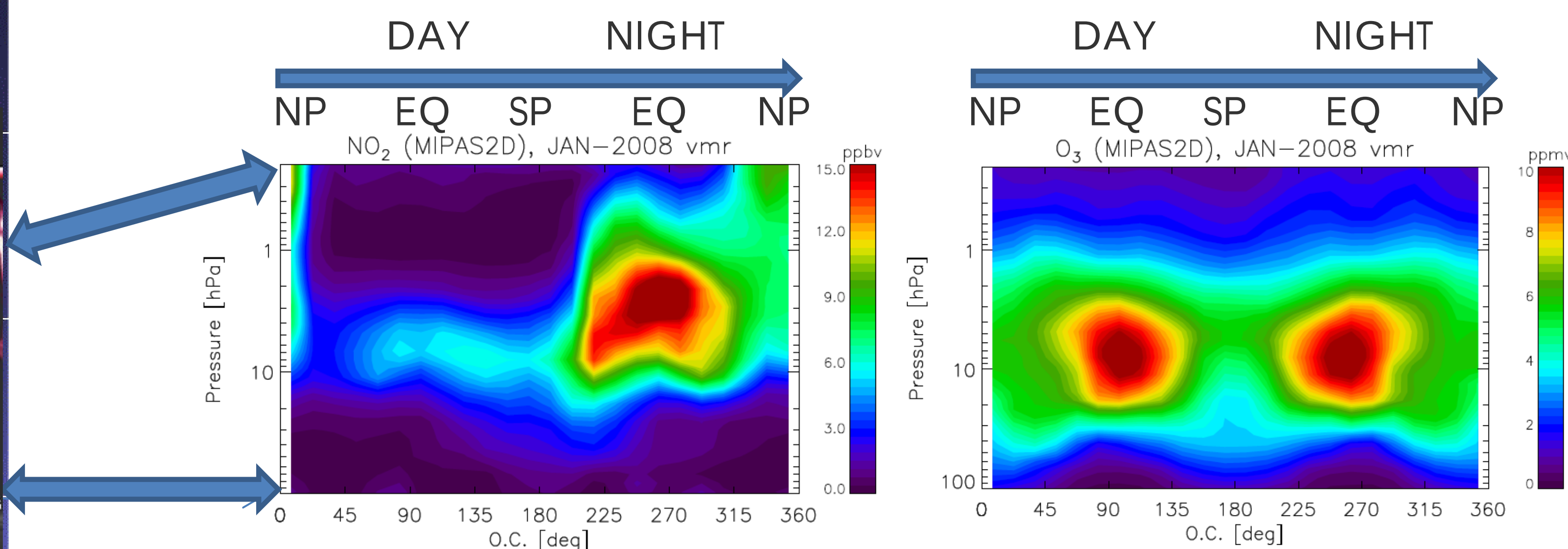




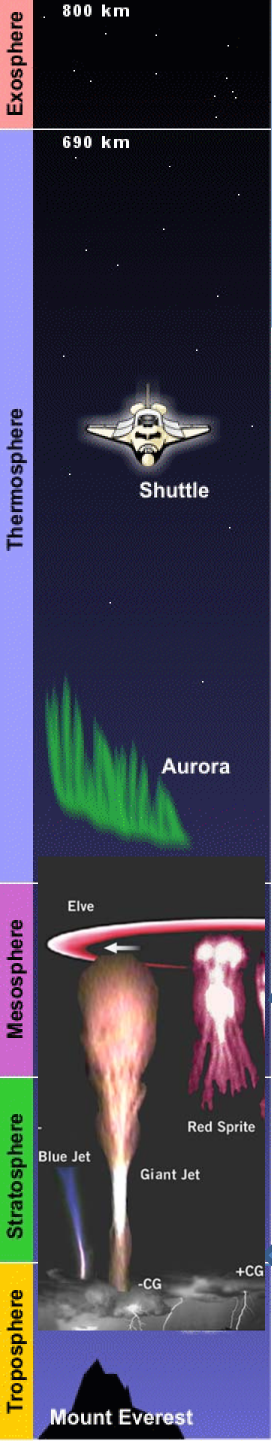
The middle atmosphere: NOx and ozone

(Arnone and Hauchecorne 2012)





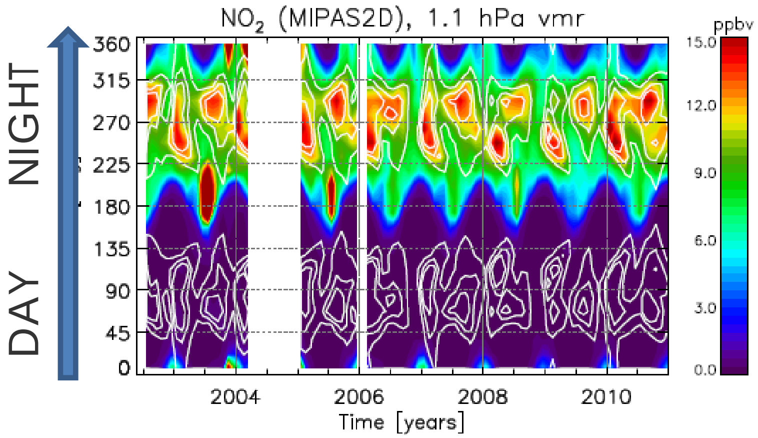
MIPAS NO2 (left) and O3 (right) along orbit January 2008

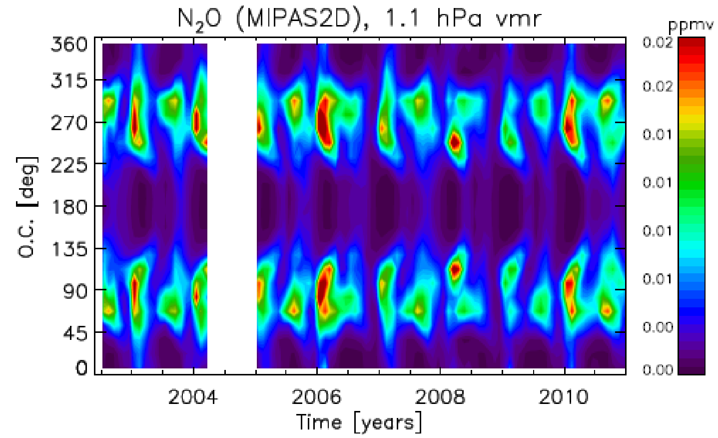


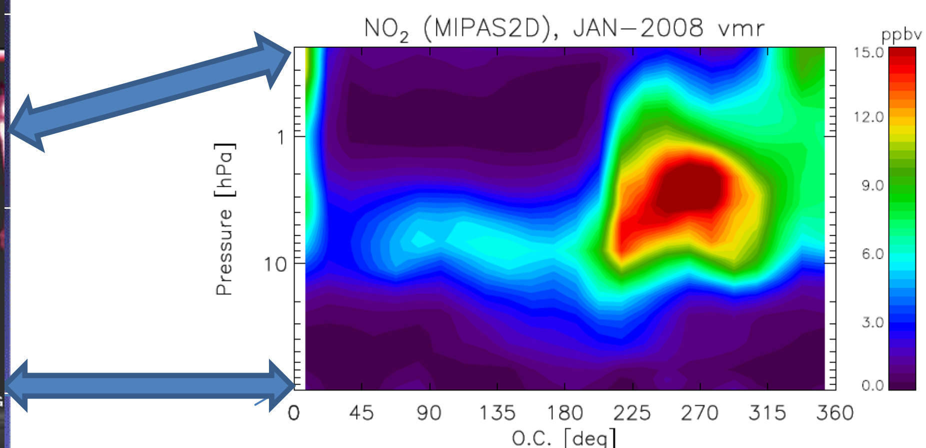
The middle atmosphere: NOx and ozone

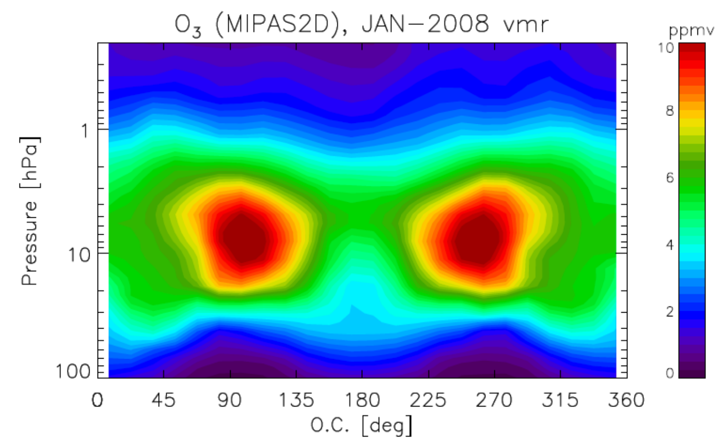
(Arnone and Hauchecorne 2012)

Timeseries of MIPAS NO2 (left) and N2O (right) along orbit at the stratopause



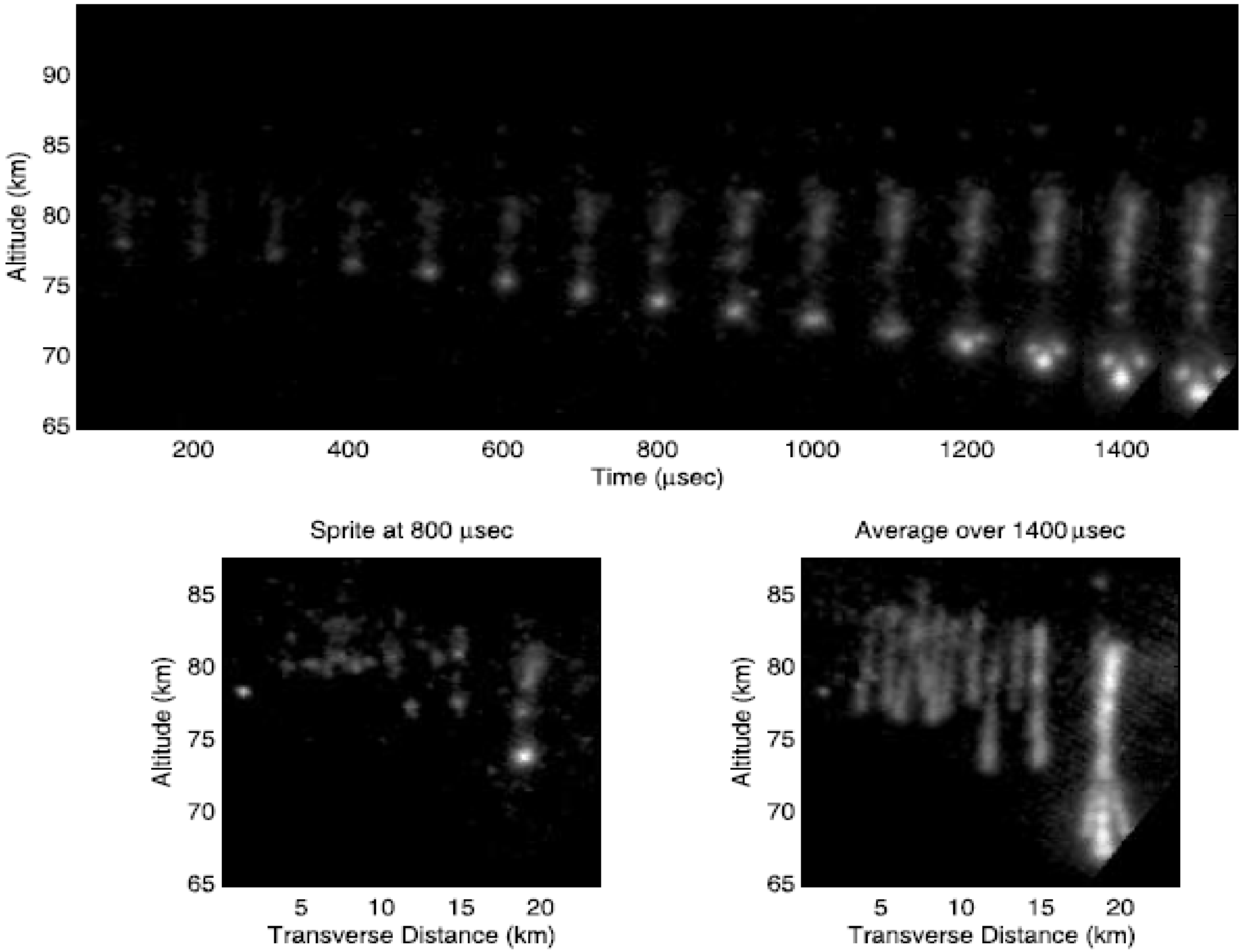






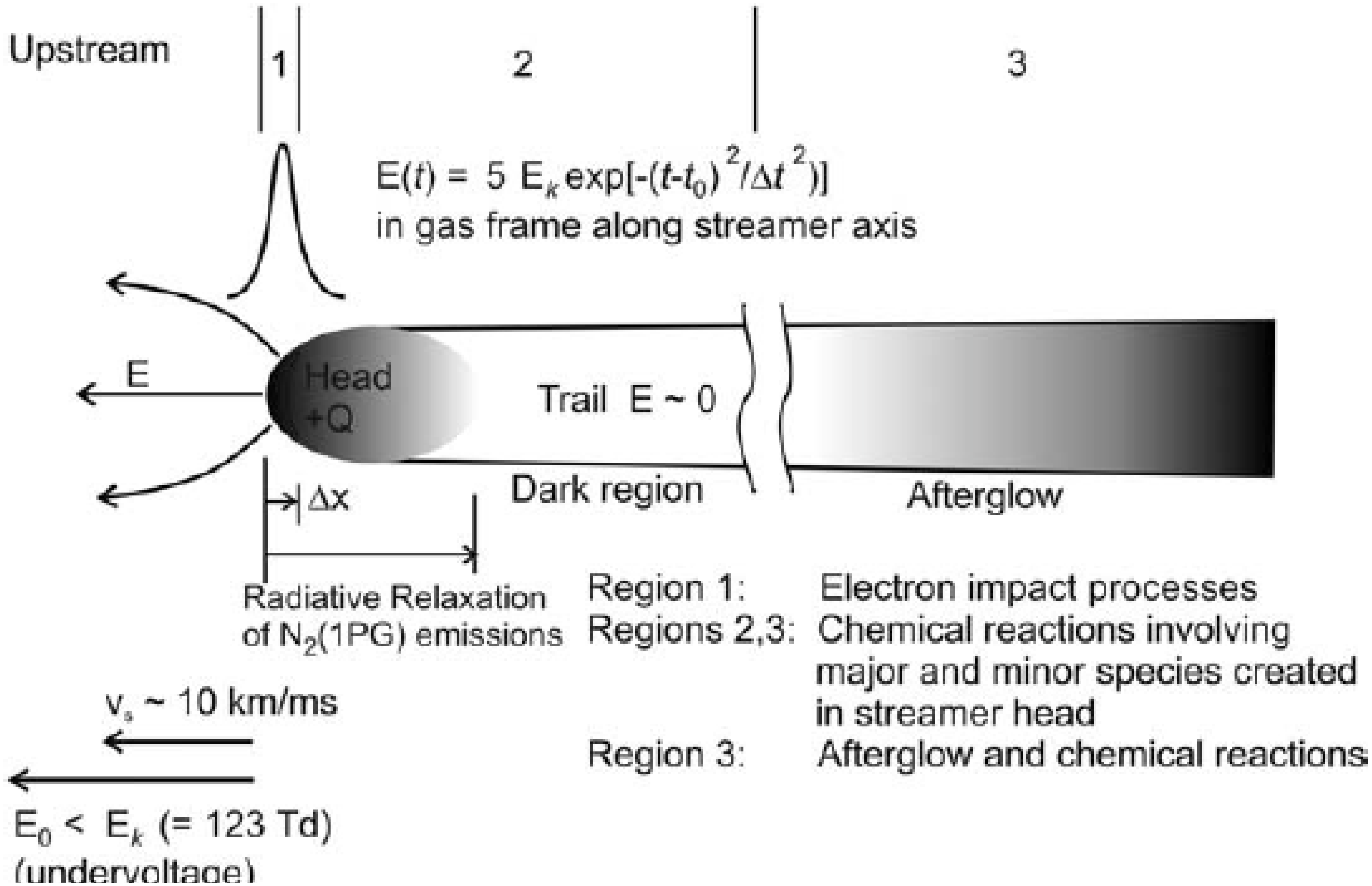
MIPAS NO2 (left) and O3 (right) along orbit January 2008

Sprite high speed video recording



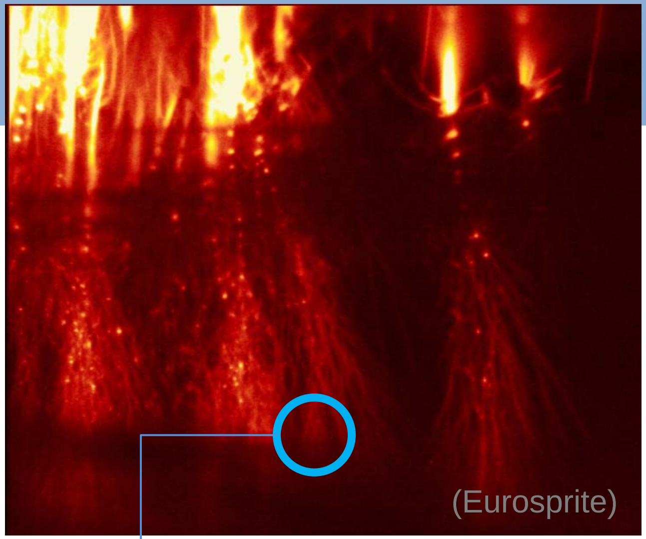
(McHarg et al. 2007)

Sprite streamer model



Simplified sprite streamer model (Sentman et al. 2008, 2009)

TLEs and NO_x



NO_x increase induced by TLEs:

- 2 orders of magnitude due to sprites, Lyons and Armstrong 1997
- 10% local increase by 1 blue jet, Mishin 1997
- Local changes, e.g. Armstrong 2000, Sentman et al. 2000
- Hiraki et al. 2004, O(1D) production by halos
- Lethinen and Inan 2007 persistent ionization in gigantic jet

Since 2008:

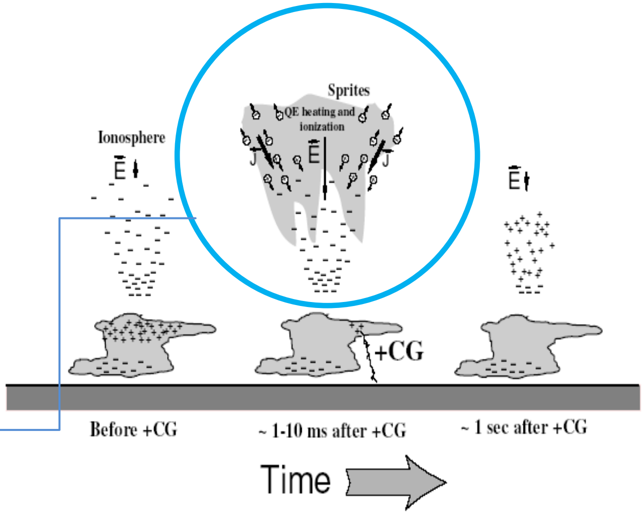
Models: up to orders of mangnitude NOx increase within streamer at 70 km altitude - modelling by Enell et al., Sentman et al., Hiraki et al., Gordillo-Vázquez

Laboratory:

Preliminary experiments predict large changes in NOx (Peterson et al. 2010) but questioned.

Observations

Possible local 10% NO_2 perturbation at 52 km above thunderstorms (Arnone et al. 2008, 2009), no global signature (Rodger et al. 2008).



(Pasko et al. 1997)

Model sprite-streamer NO_x

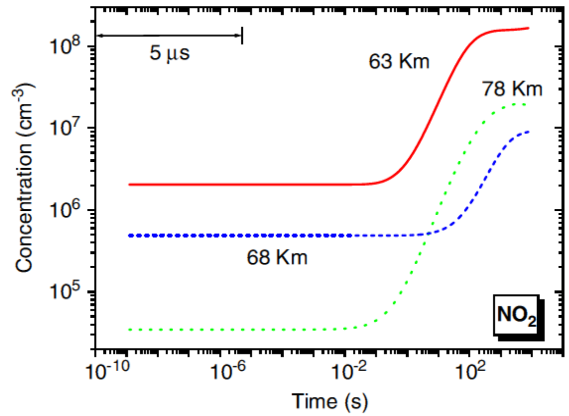
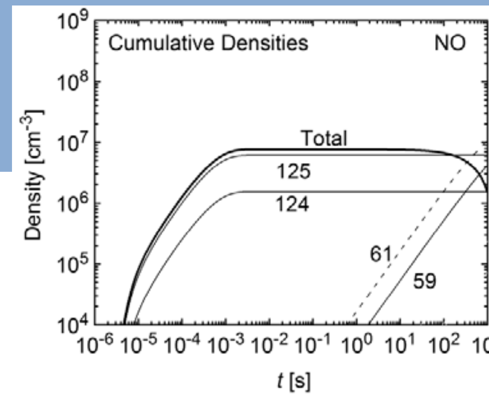


Figure 15. Time-dependent behaviour of the concentration of NO_2 under the conditions of a single sprite event for three different altitudes.

(Gordillo-Vazquez 2008)



(Sentman et al. 2008)

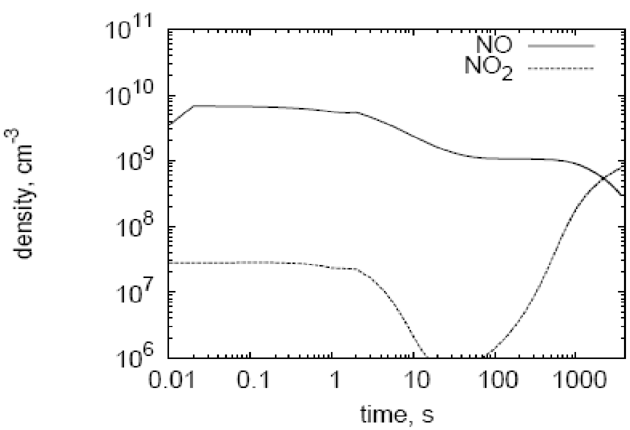
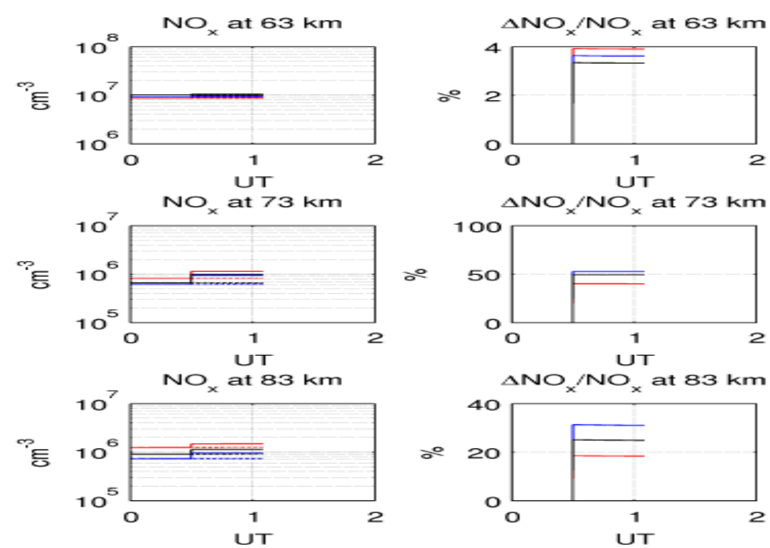


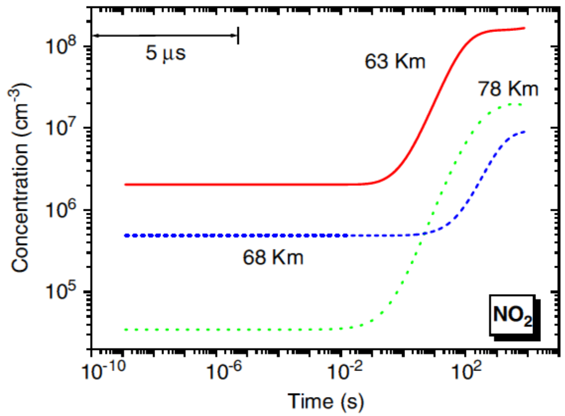
Fig. 3. Temporal density variations for NO_x species at 60 km altitude in the same condition as Fig. 2; solid and dashed lines show those of NO and NO_2, respectively, after initiation of streamer at t=0.

(Hiraki et al. 2008)



(Enell et al. 2008)

Model sprite-streamer NO_x



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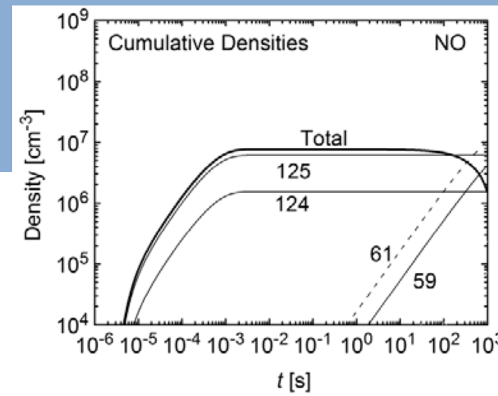

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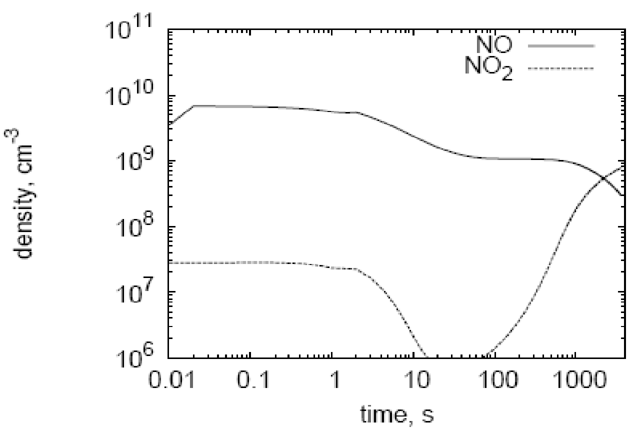

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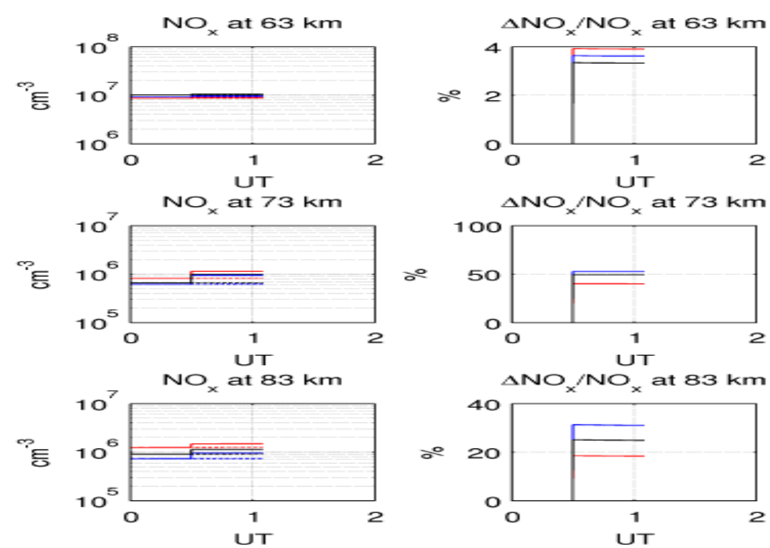
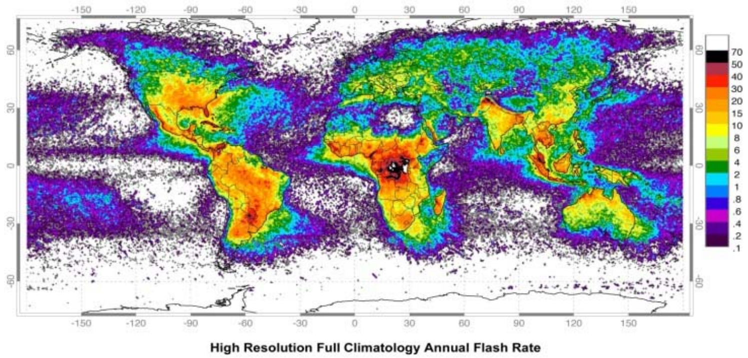


(Enell et al. 2008: use their sprite-NOx maximum case scenario and complete filling of sprite volume by streamers)

TLE global occurrence distribution



Global distribution of lightning April 1995-February 2003 from the combined observations of the NASA OTD (4/95-3/00) and LIS (1/98-2/03) instruments

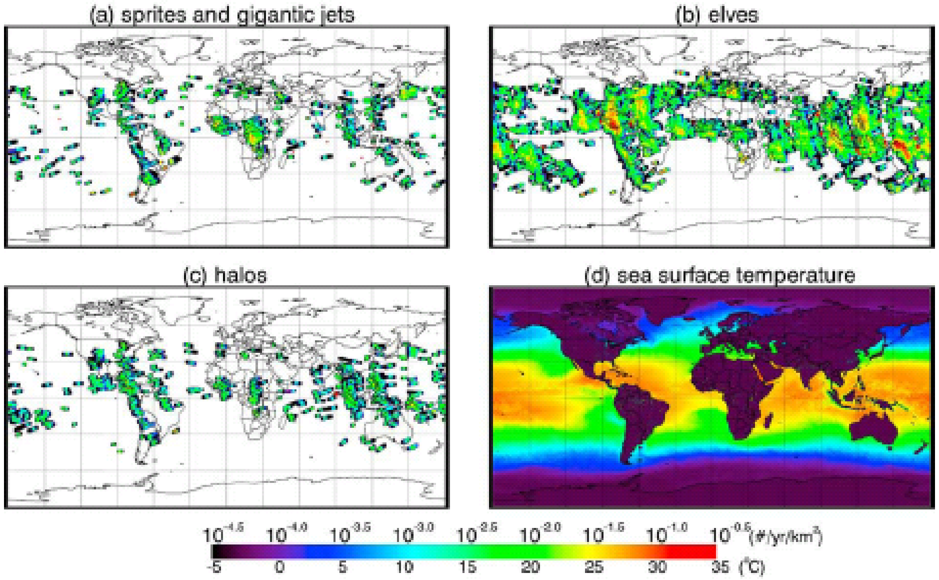


Figure 3. The global occurrence density of major TLEs: (a) sprites and gigantic jets (gigantic jets are marked by red filled circle), (b) elves, and (c) halos. The mean sea surface temperature between July 2004 and December 2005 is displayed in Figure 3d for comparison. (Data Source: PO.DAAC, JPL.)

ISUAL observations (Chen et al. 2008)

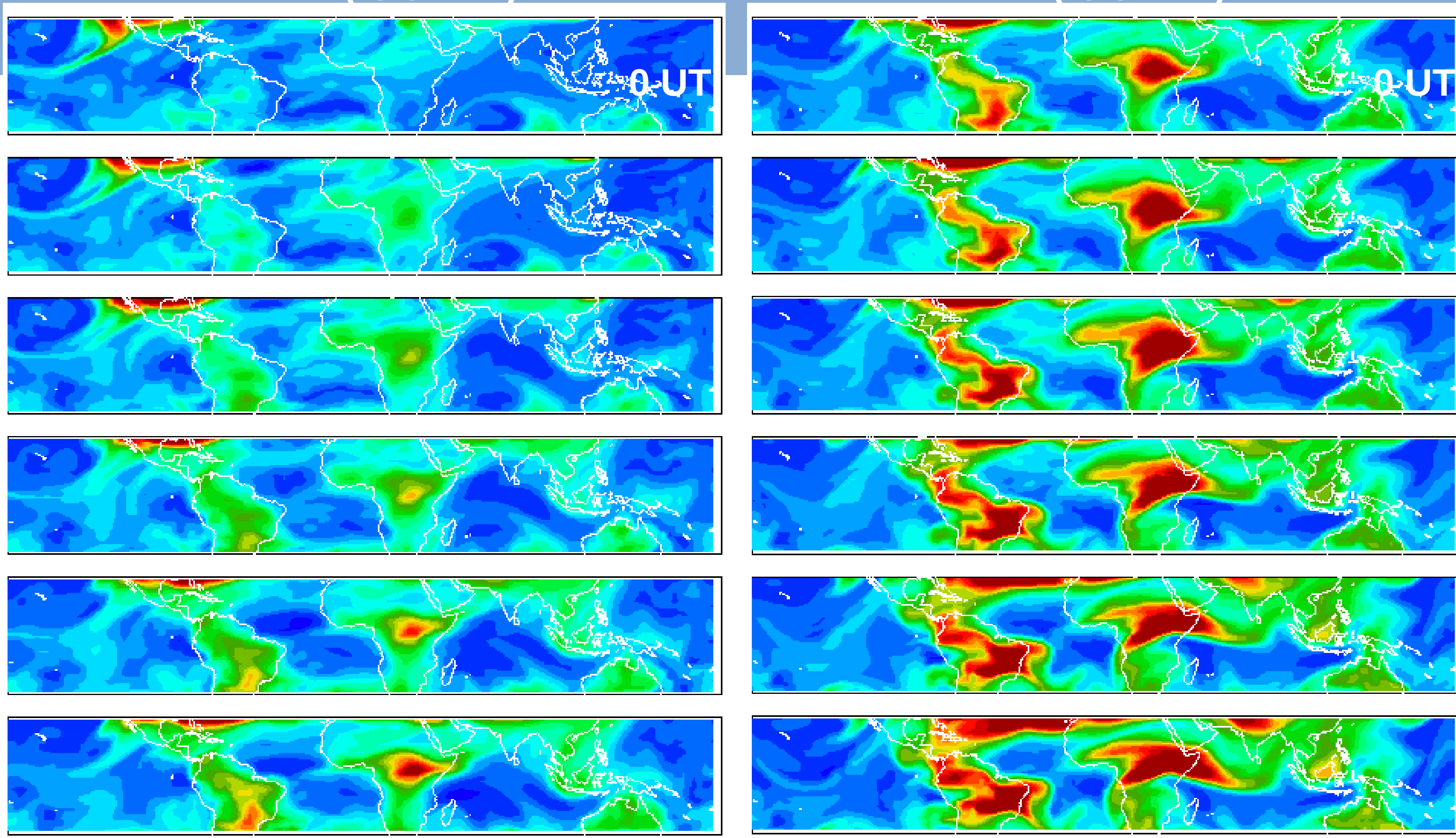
Use average global lightning activity (Christian 2003) with no day/season cycle

+

Global rate: 3/minute (Ignaccolo et al. 2006)

RESULTS: WACCM NO_x response at 70 km

DAY 1 (1/3/2011) **DAY 2 (2/3/2011)**



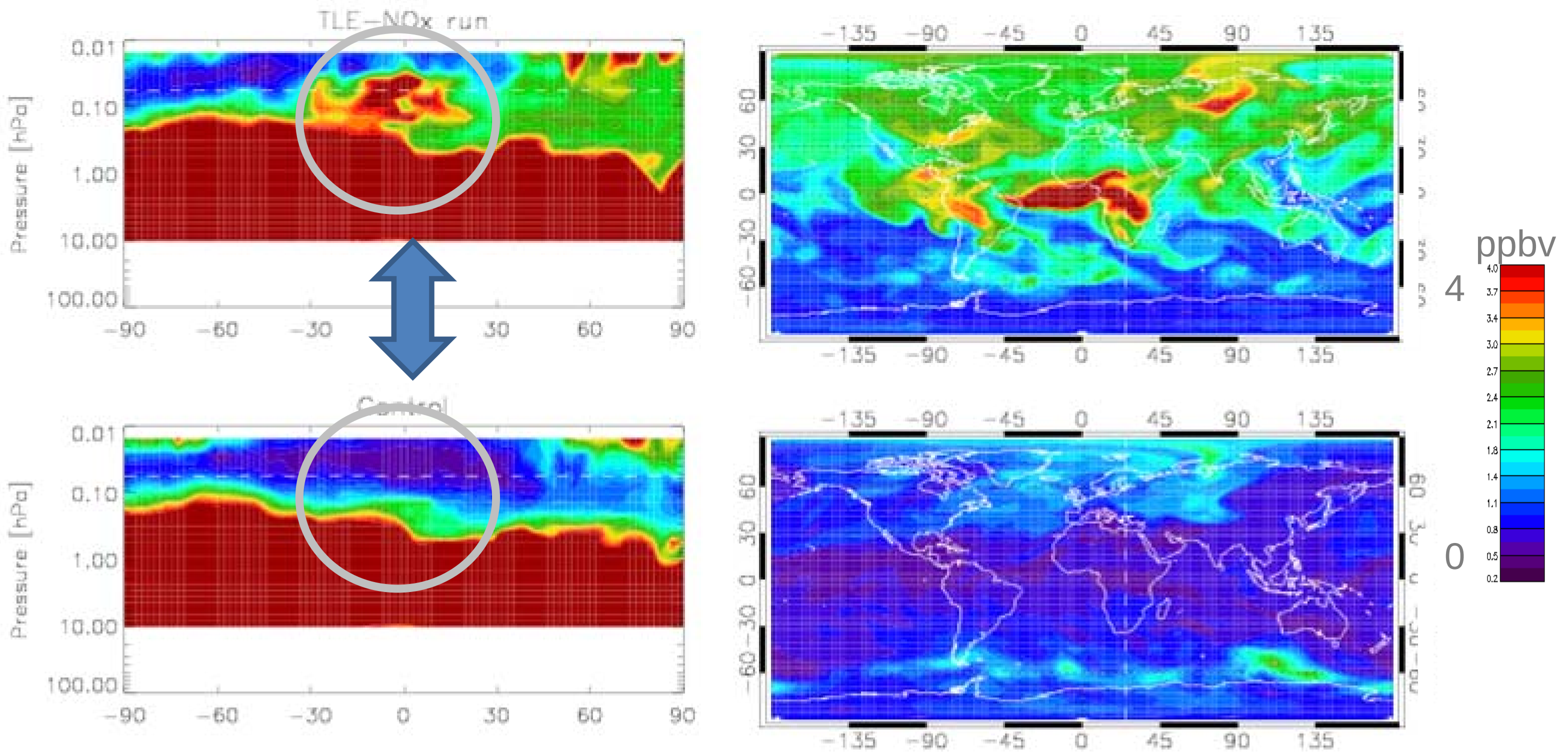
First build up above main lightning chimneys.
Spread due to transport (depends on season).

(Arnone et al. 2013 JGR submitted)

RESULTS: WACCM NO_x response day 24 (24/3/11)

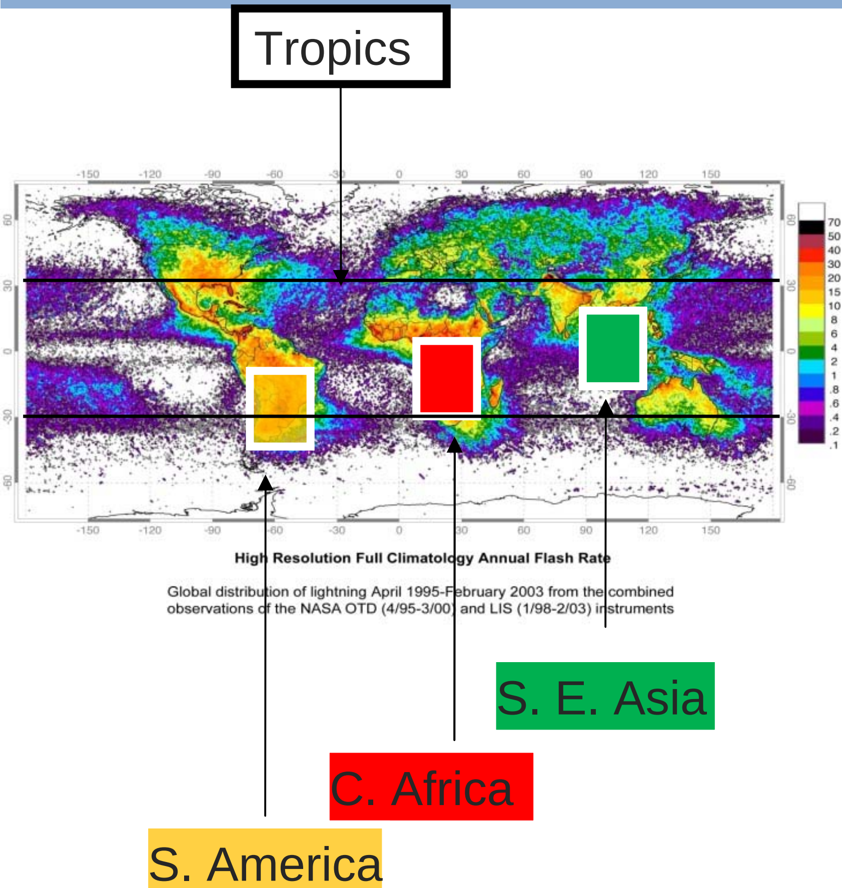
Perturbed simulation: 10x sprite-NOx

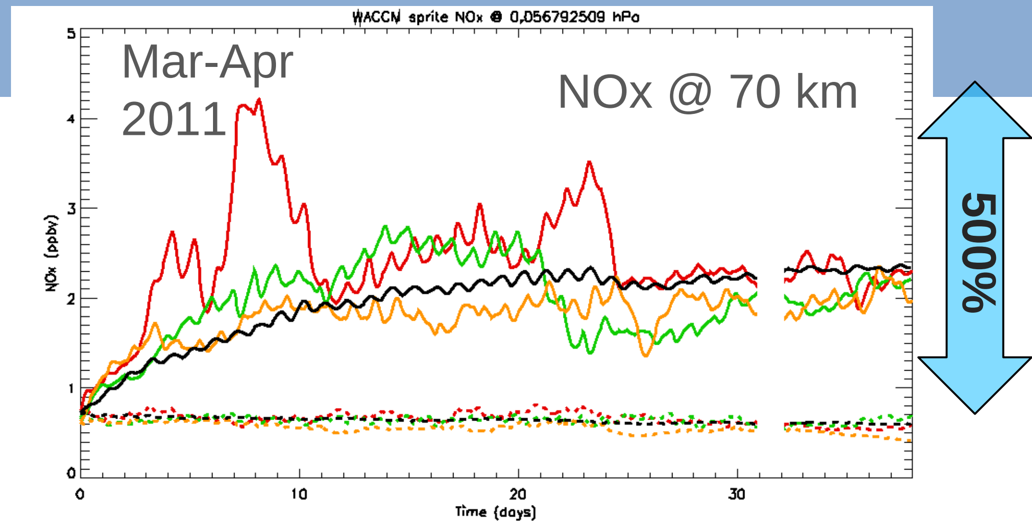
Control

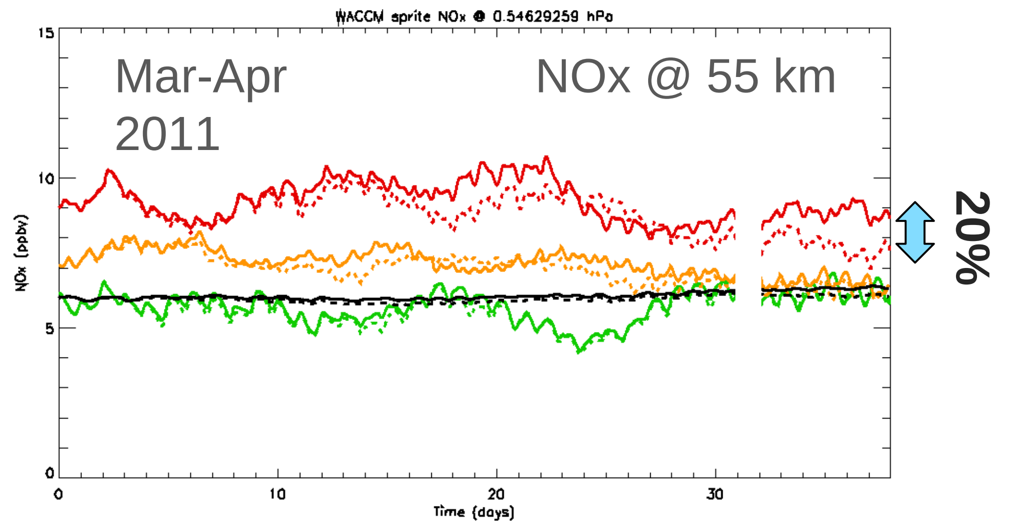


At perturbed altitude sprite-NOx becomes dominant source (up to > 500% increase).
Larger build up in Norther Hemisphere because of season (March).

Sprite-NOx in WACCM model







- Applied 10x NOx constant perturbation.

Sprite-NOx in WACCM model

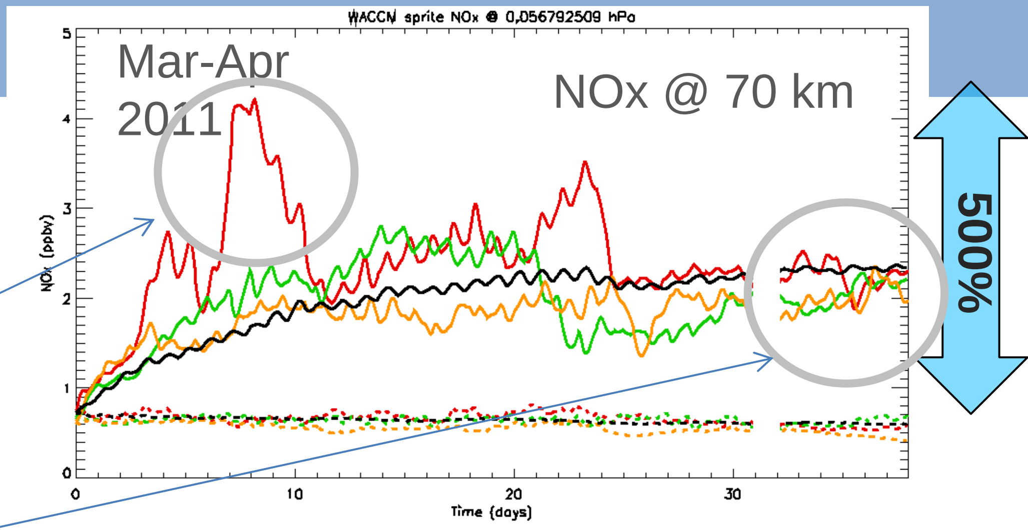
Applied 10x NOx perturbation constant in time:

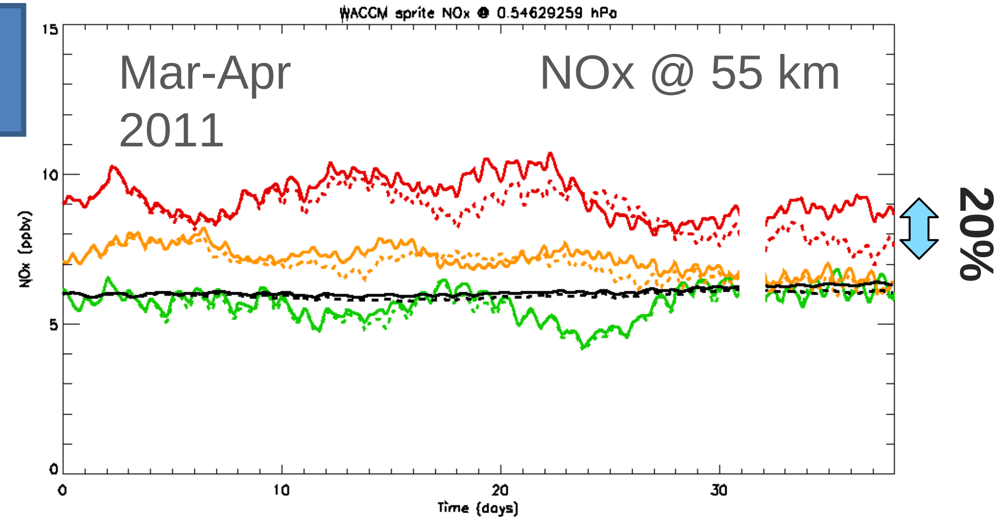
1. **Impulsive** response due to transport. At times build up at **70 km** can reach 500%.

2. Tendency to **homogenize** at 70 km: all regions reach a common average value.

3. **Saturation** due to photolysis: 100x perturbation lead to only 6x larger response compared to 10x perturbation.

4. At **55 km** response does not saturate or homogenize on the 40 day timescale.



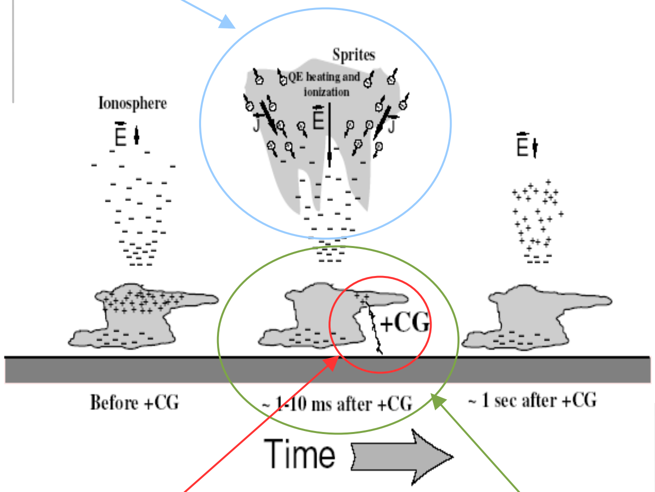


S. America C. Africa S. E. Asia

How to observe sprite-NOx

Sprites:

• EuroSprite campaigns 2003-2012



MIPAS/ENVISAT

+CGs:

• Italian/European lightning detection networks

(large +CGs needed for sprite production)

Lightning: WWLLN – The World Wide Lightning Location Network

• A global network of lightning location VLF sensors

• ~ 2-10% efficiency on lightning stroke detection (strongest strokes) but detection of most thunderstorms

GOMOS 50-70 km NO_2 and thunderstorms

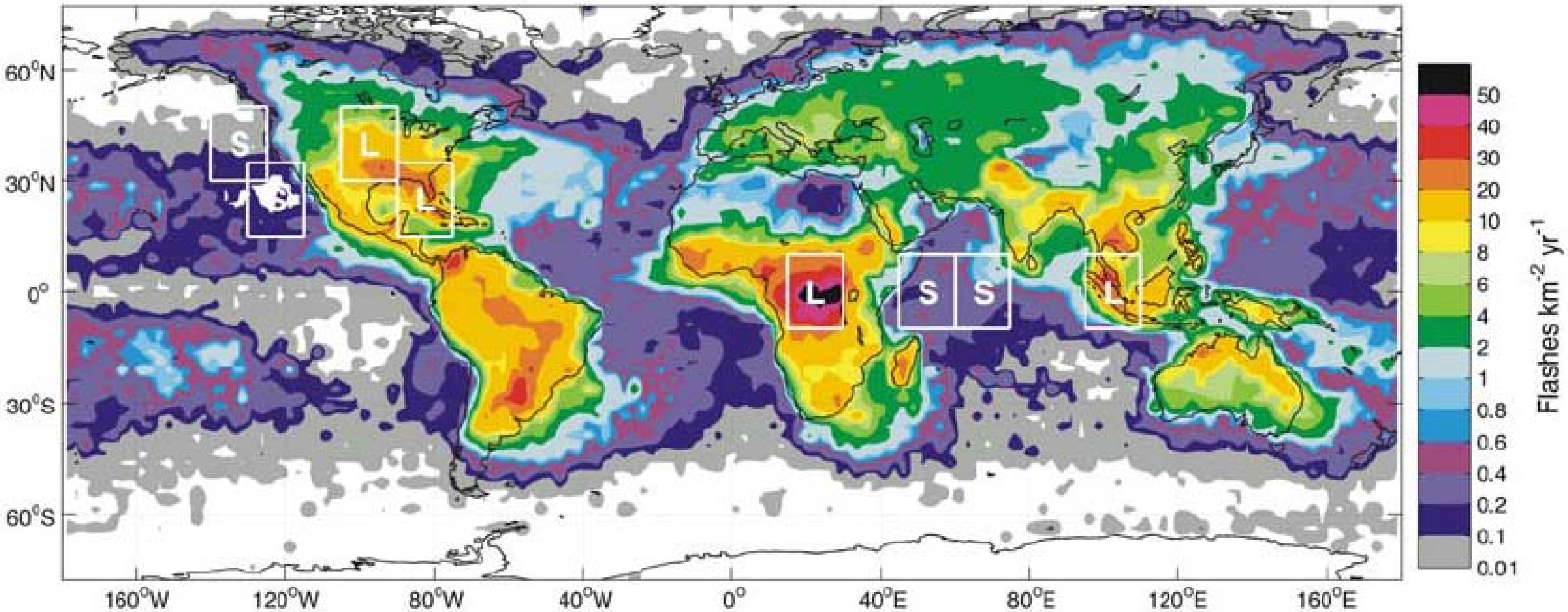


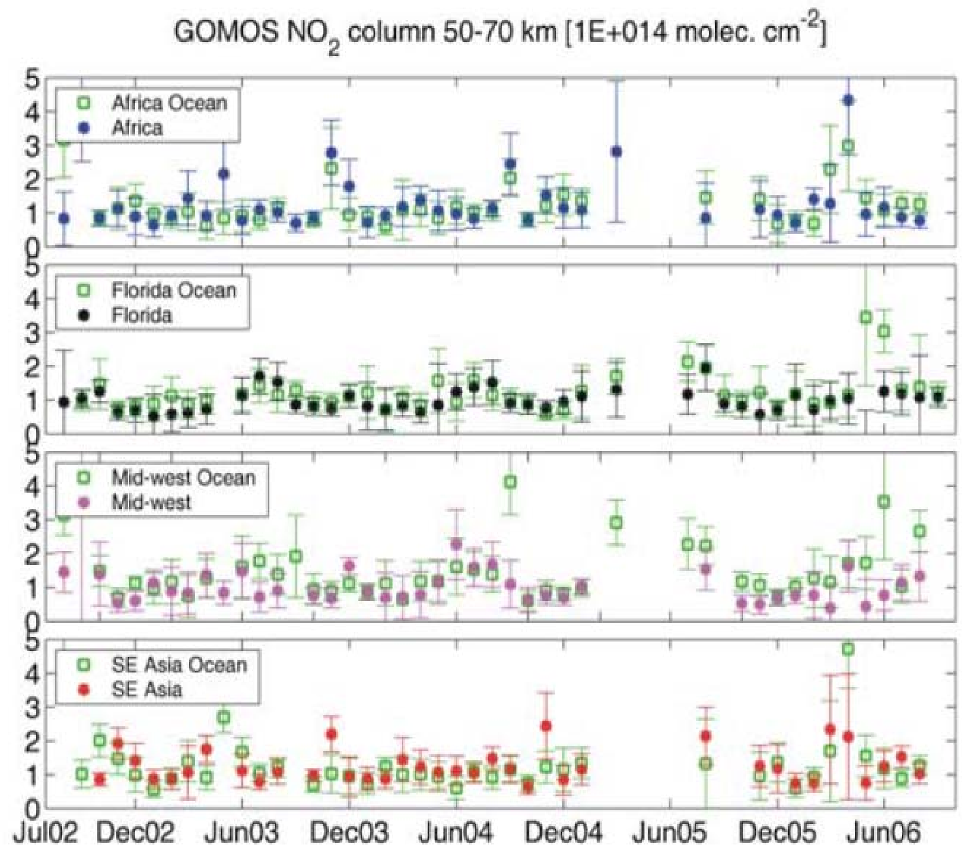
Figure 1. The annualized geographical distribution of total lightning activity determined from 5 years of OTD data in units of flashes km^{-2} yr^{-1}, after *Christian et al.* [2003]. Superimposed are white boxes indicating the land and oceanic regions, marked with a white "L" or "S", respectively, selected for examination in this study.

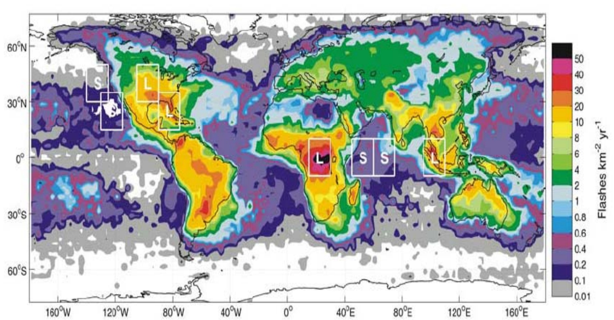
(Rodger et al. 2008)

GOMOS 50-70 km NO_2 and thunderstorms

(Rodger et al. 2008)

Time series of NO_2 partial columns above selected regions with high (land) and low (ocean) thunderstorm activity





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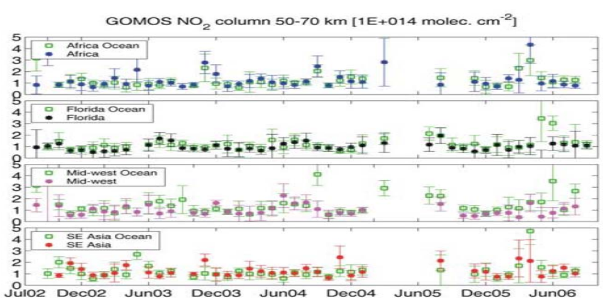
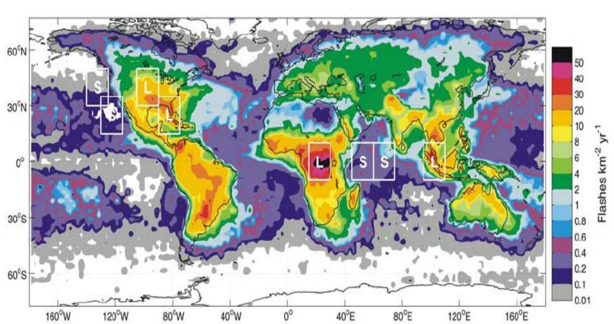
GOMOS 50-70 km NO_2 and thunderstorms: model interpretation

Rodger et al. 2008: OBSERVATIONS

Time series of NO_2 partial columns above selected regions with high (land) and low (ocean) thunderstorm activity





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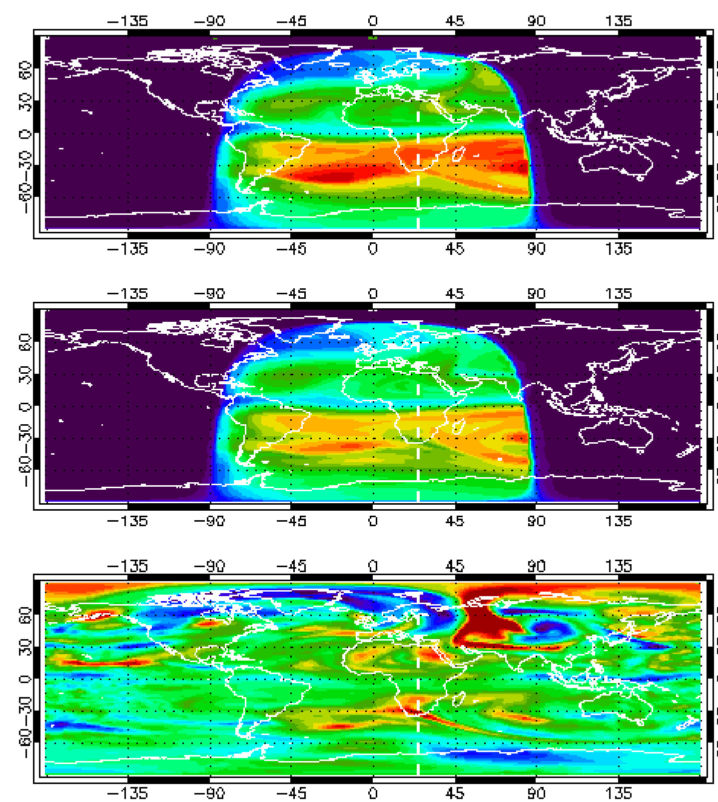
Even 100x sprite-NOx undetectable

Rodger et al. 2008 as seen by MODEL

WACCM model with sprite NO2 (top) and no perturbation (centre). Difference in % (bottom).

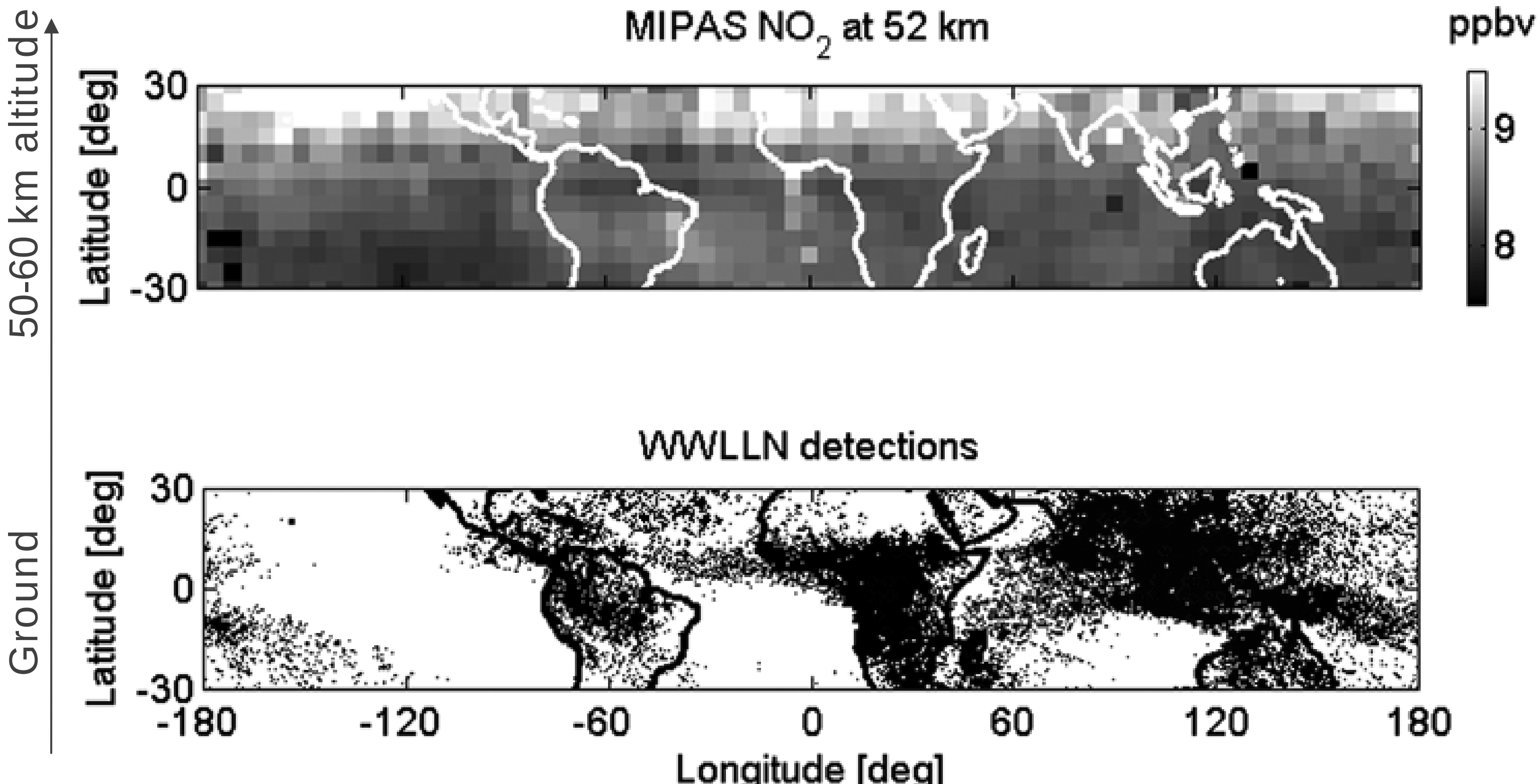


Sprite-NOx

standard

difference

MIPAS and WWLLN detection of thunderstorms

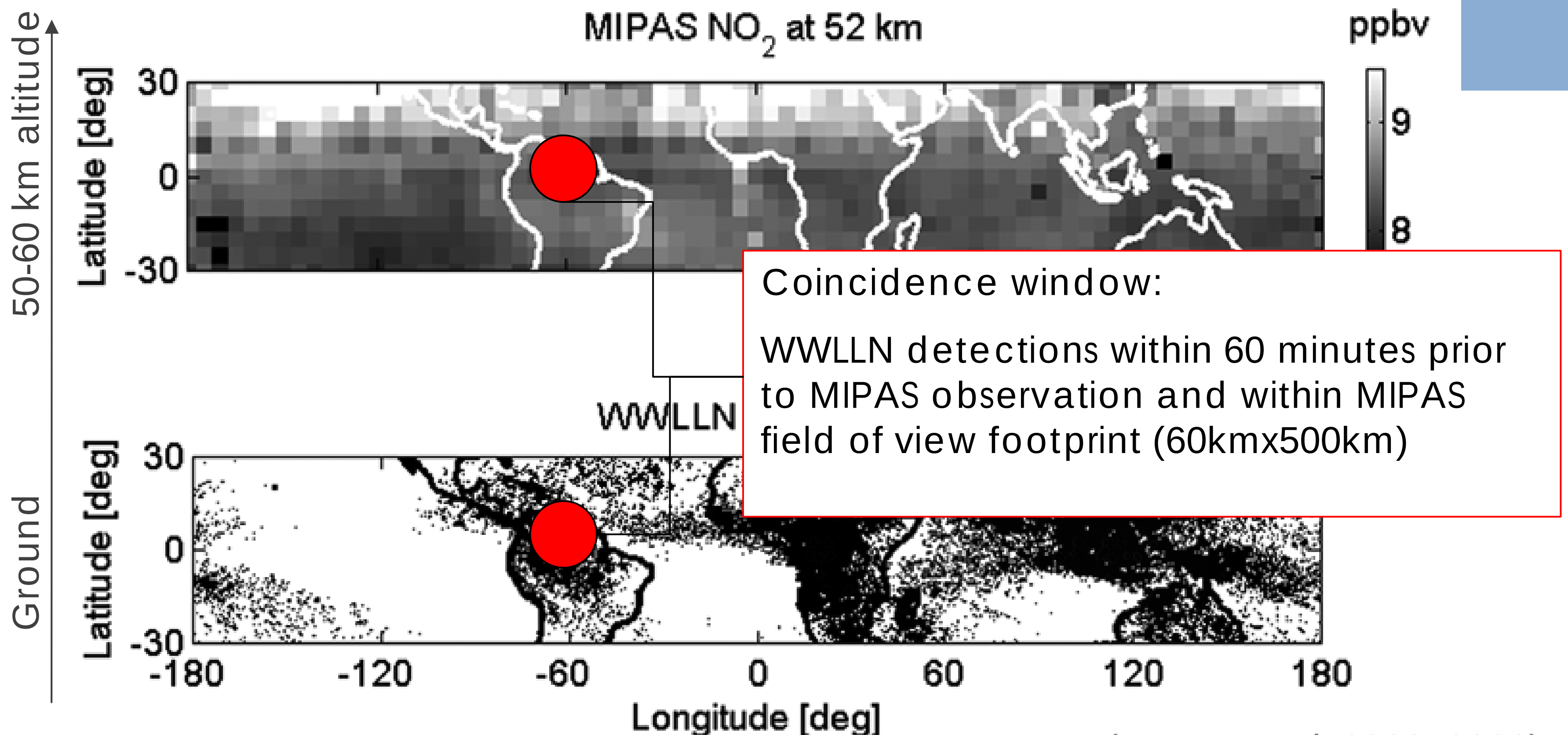


(Arnone et al. 2008, 2009)

Top: MIPAS2D mean nighttime NO_2 at 52 km height, Aug-Dec 2003

Bottom: WWLLN lightning detections Aug-Dec 2003

MIPAS and WWLLN detection of thunderstorms



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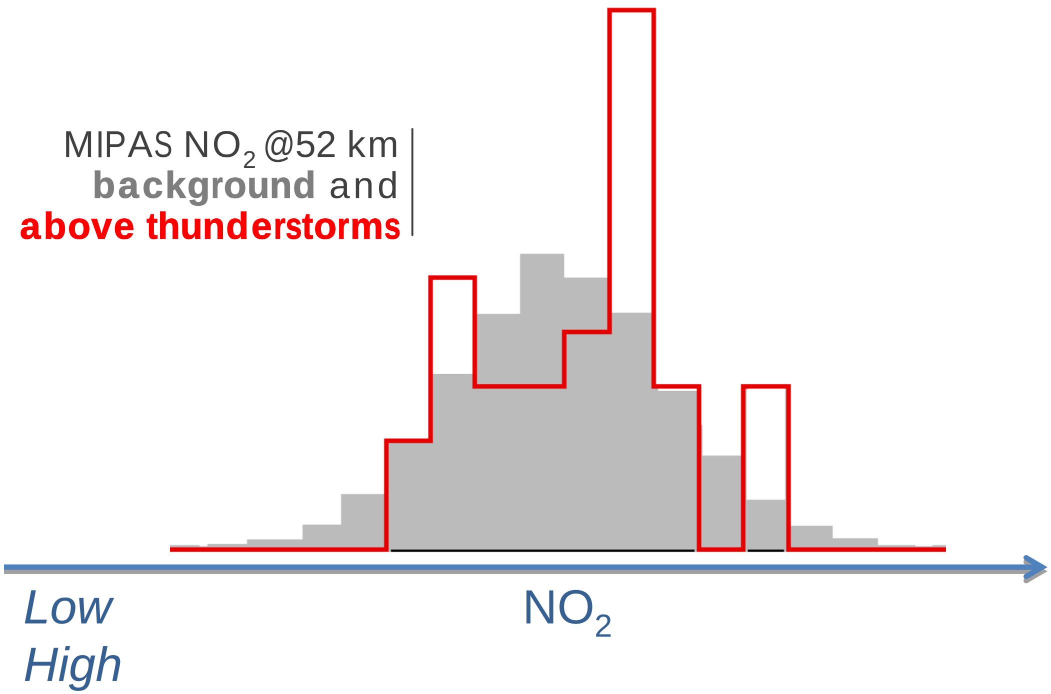
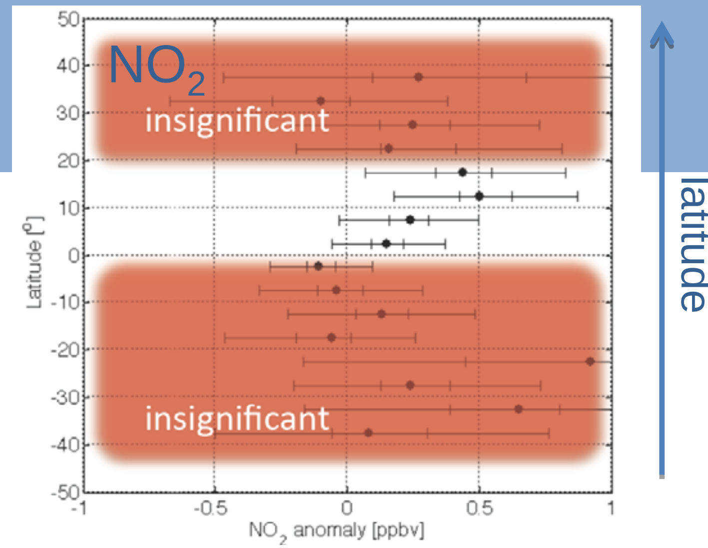
Top: MIPAS2D mean nighttime NO_2 at 52 km height, Aug-Dec 2003

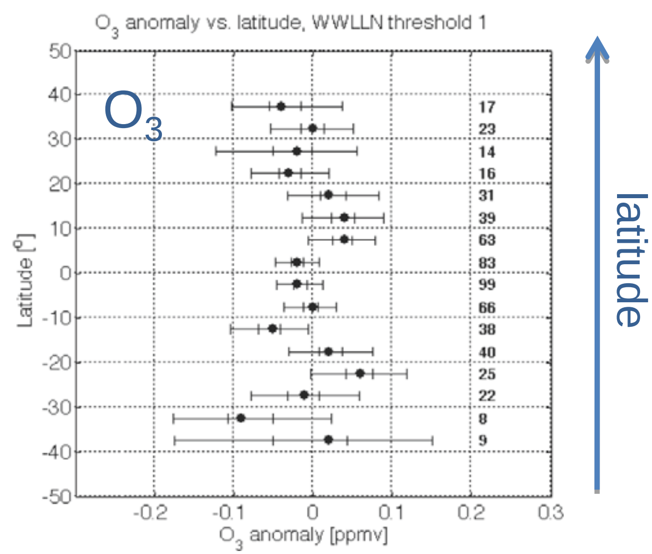
Bottom: WWLLN lightning detections Aug-Dec 2003

MIPAS and WWLLN detection of thunderstorms



(Arnone et al. 2008, 2009)



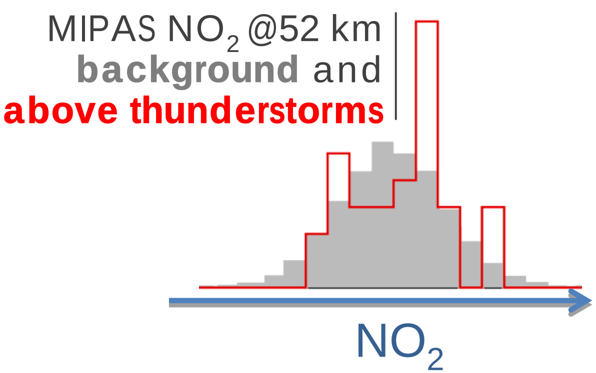


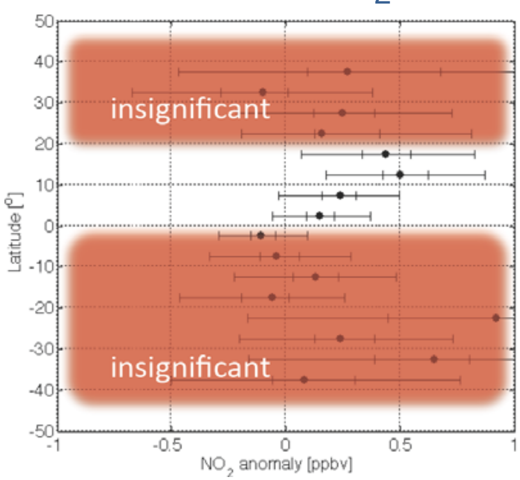
Top: MIPAS2D NO_2 anomalies at 52 km depending on latitude

Bottom: MIPAS2D ozone anomalies

MIPAS and WWLLN detection of thunderstorms: MODEL

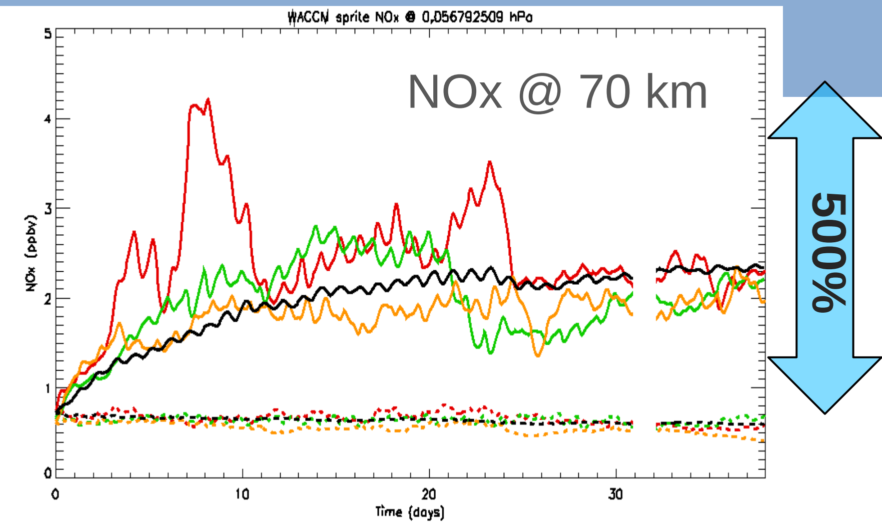
Arnone et al. 2008,2009: OBSERVATIONS

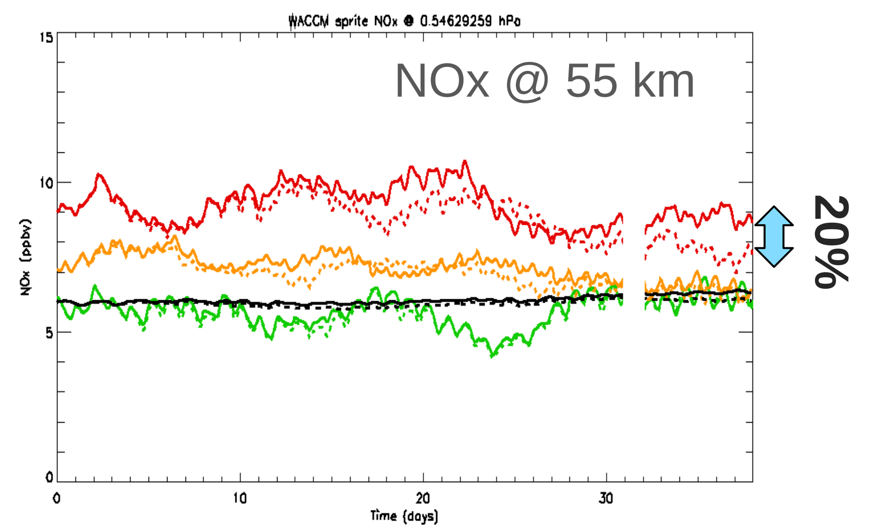




Possible build up of a few % at 55 km above active regions

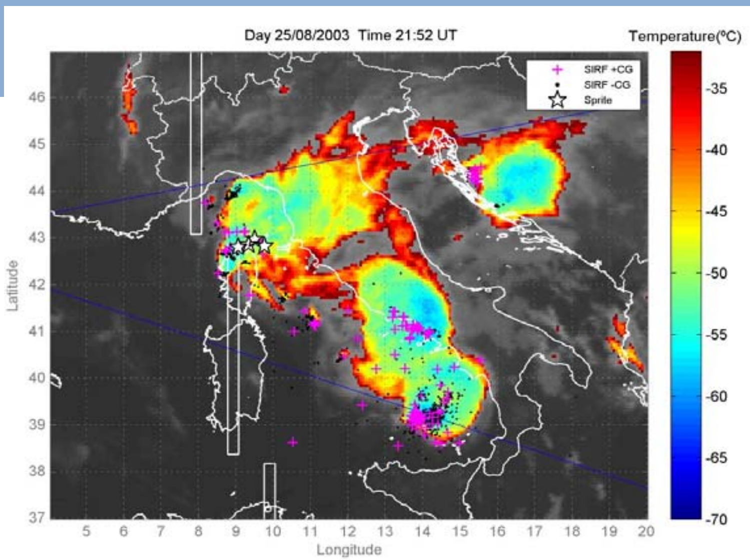
Arnone et al. 2008,2009: MODEL VIEW



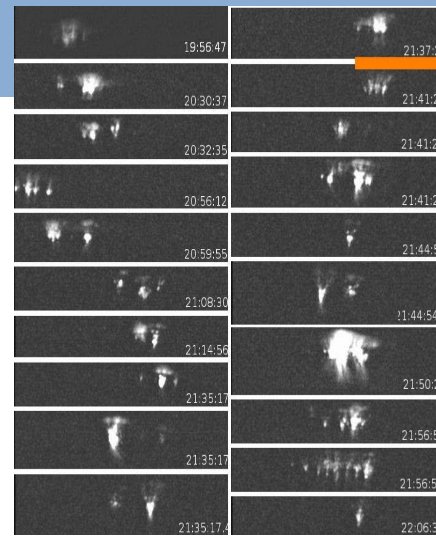


Model response builds above active regions change randomly (transport)

Case study with Eurosprite and MIPAS2D NO_2: 25 August 2003

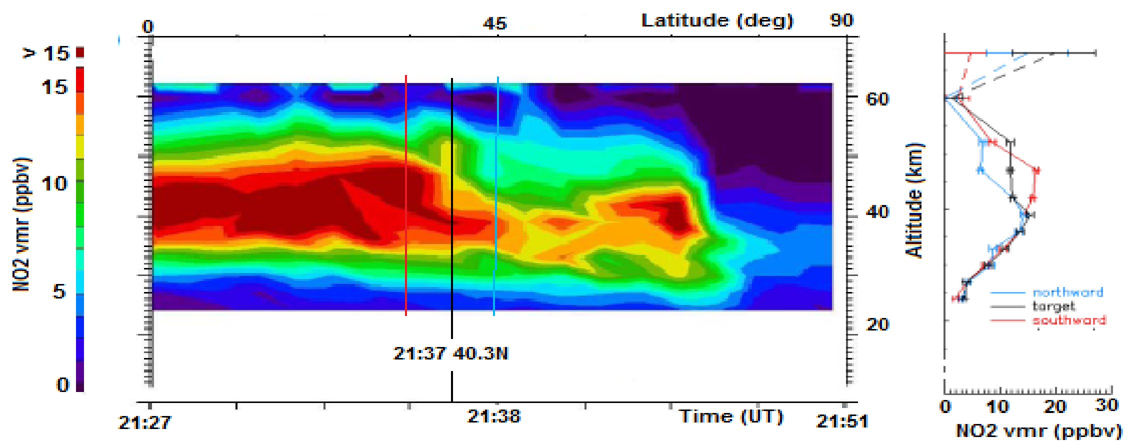


Thunderstorm with lightning (+), sprites (*), MIPAS footprint (boxes) and camera field of view (blue lines).

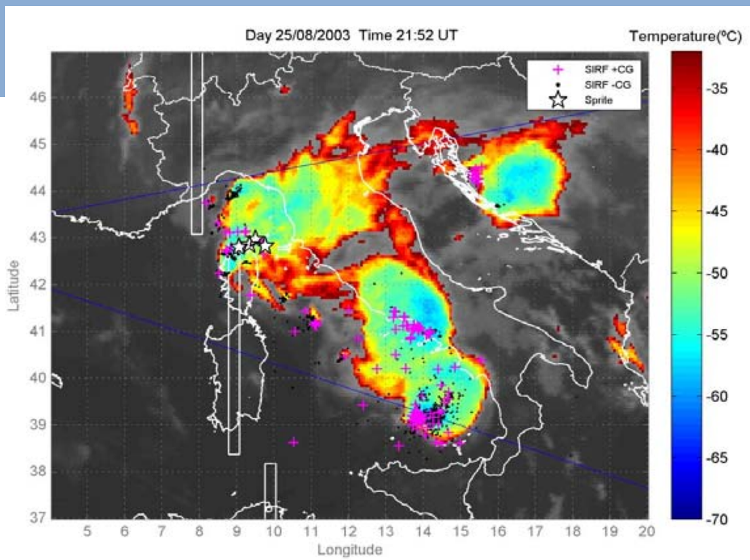


Sprites observed between 19:56 and 22:06.

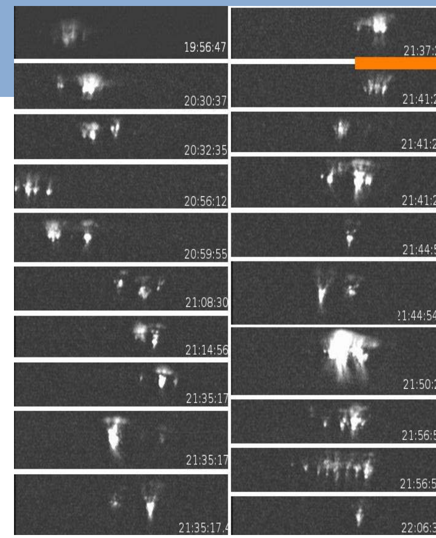
MIPAS NO_2 from orbit coincident with observed sprites



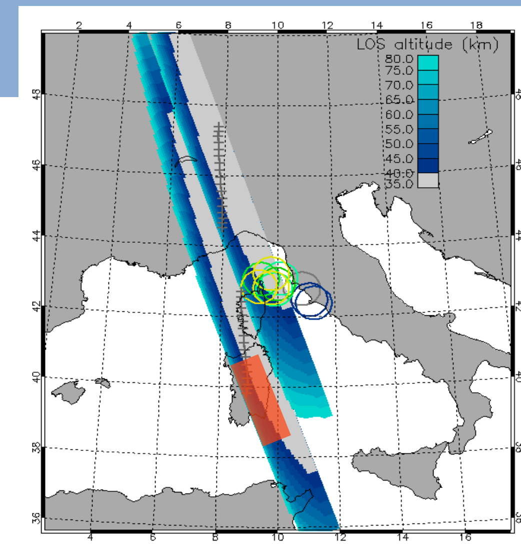
Case study with Eurosprite and MIPAS2D NO_2: 25 August 2003



Thunderstorm with lightning (+), sprites (*), MIPAS footprint (boxes) and camera field of view (blue lines).

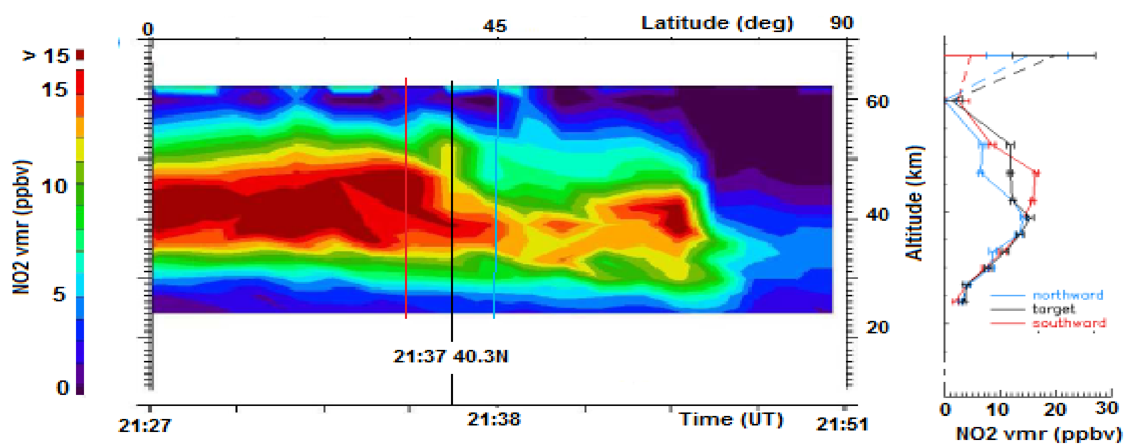


Sprites observed between 19:56 and 22:06.



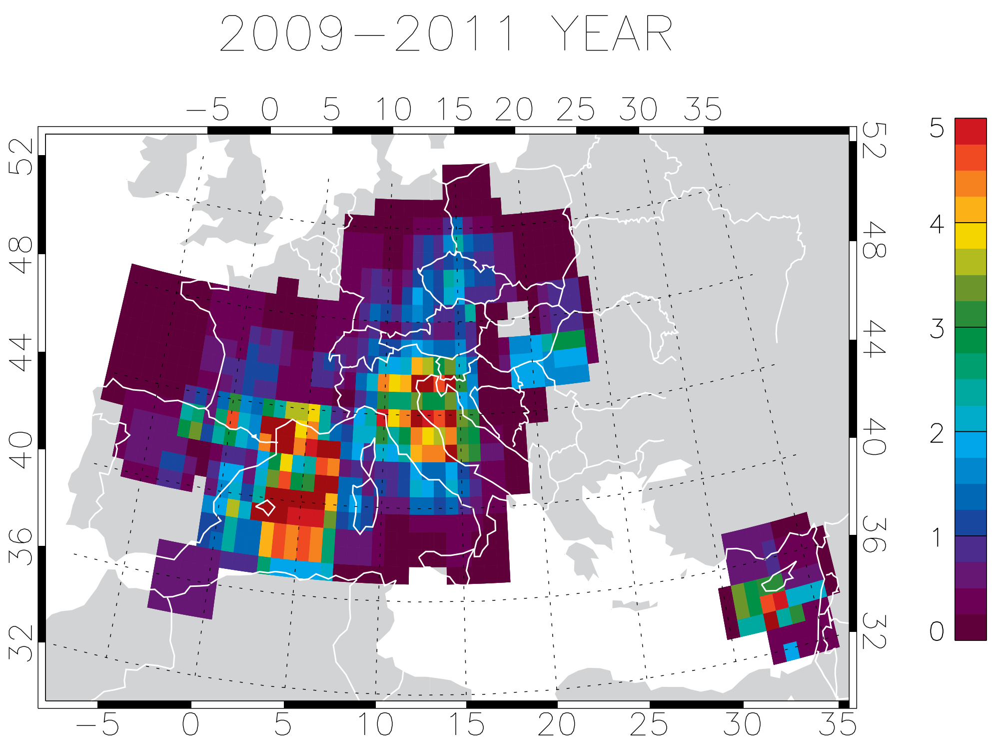
Sprite areas (circles) and MIPAS lines of sight (blue/gray shade).

MIPAS NO_2 from orbit coincident with observed sprites

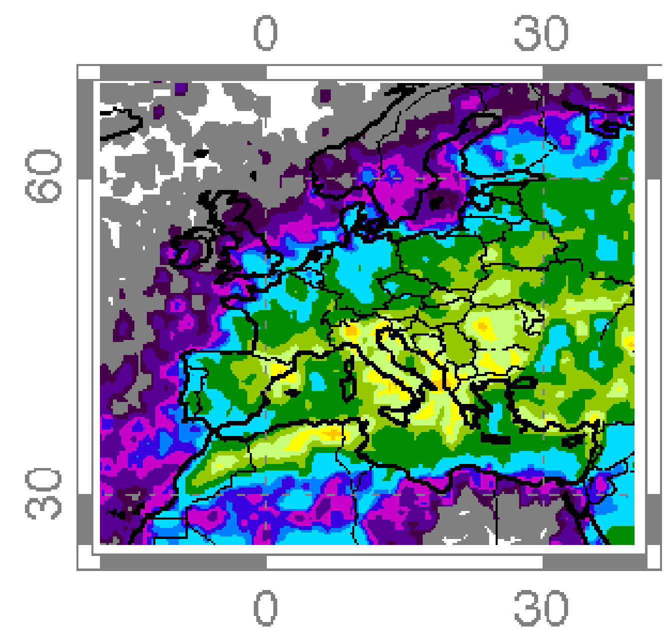


EUROSPRITE 2009-2011 observations

The first climatology of 3931 TLEs observed above 500 thunderstorms across Europe



Climatology of observed TLEs (TLEs lat-lon deg^{-2} yr^{-1}) 2009-2011

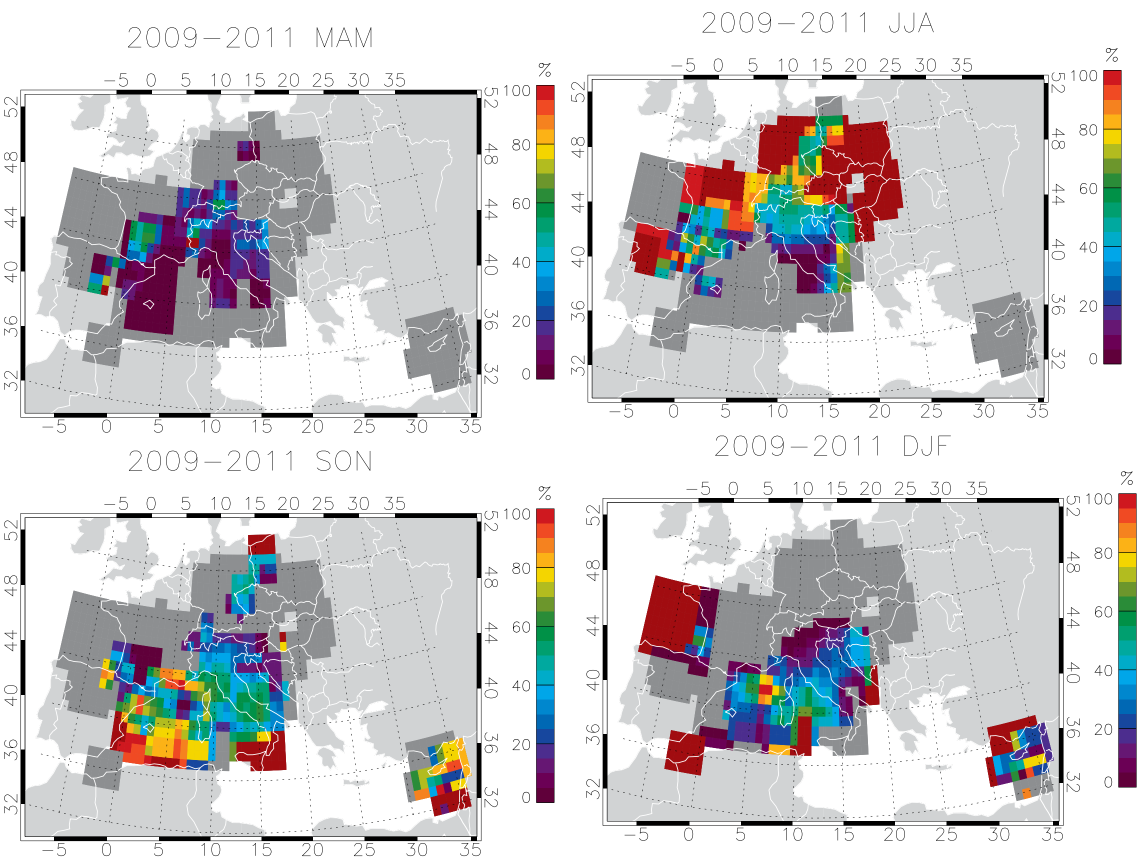


Lightning climatology (flashes km^{-2} yr^{-1})

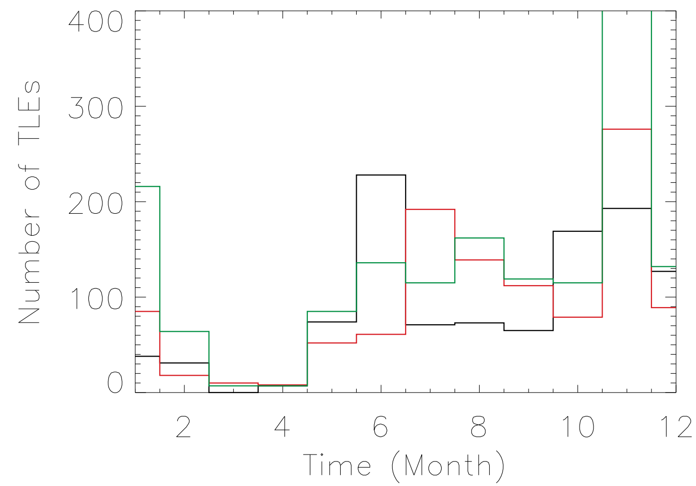
(Arnone et al. 2013 ACP to be submitted)

EUROSPRITE 2009-2011 observations

The first climatology of 3931 TLEs observed above 500 thunderstorms across Europe



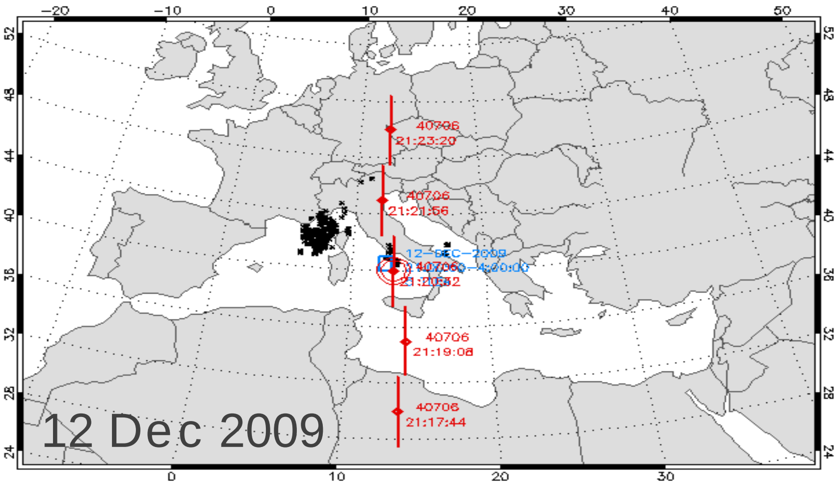
Seasonal distribution of TLEs in spring and summer (top) and autumn and winter (bottom) normalized by the 2009-2011 yearly average. Data are reported in percent.

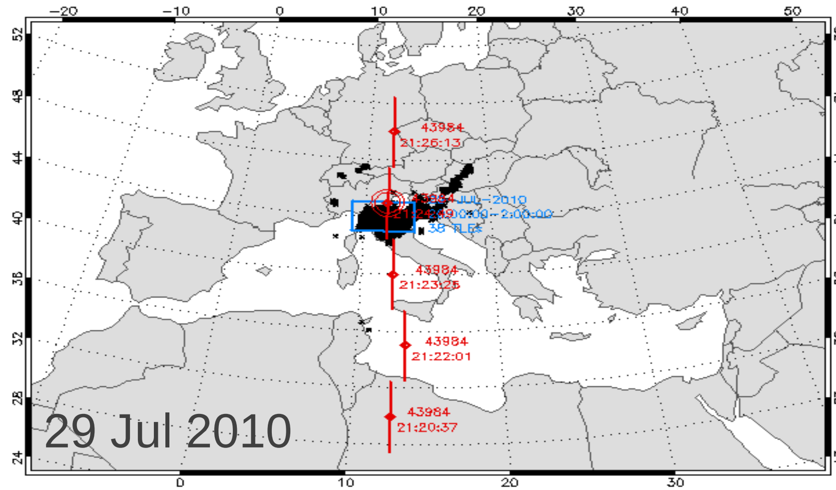


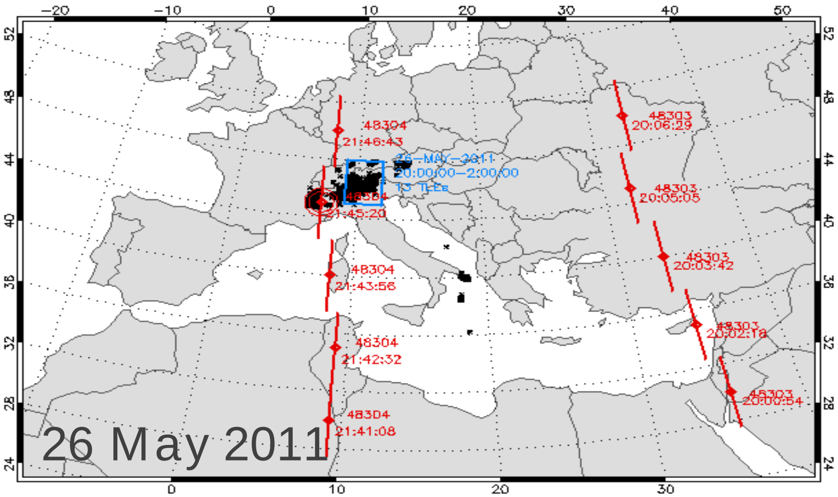
Average seasonal TLE cycle above Europe in **2009**, **2010**, **2011**.

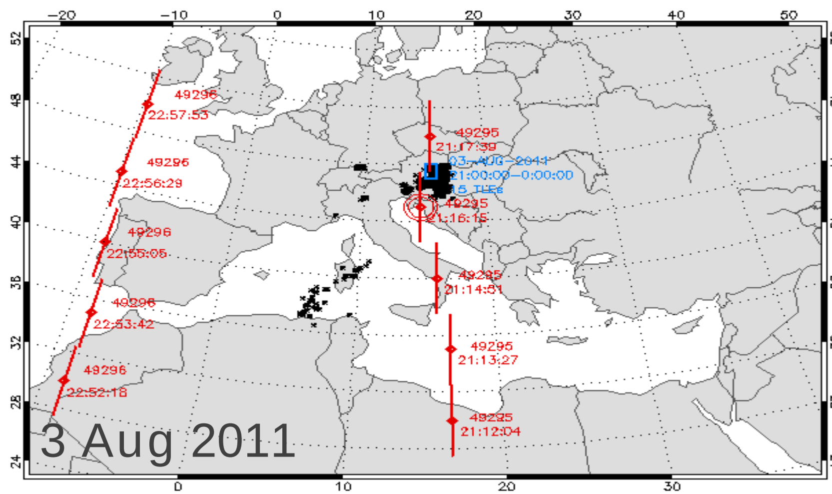
EUROSPRITE 2009-2011 observations and MIPAS2D NO_2

Case studies with thunderstorms+sprites and MIPAS coincidence



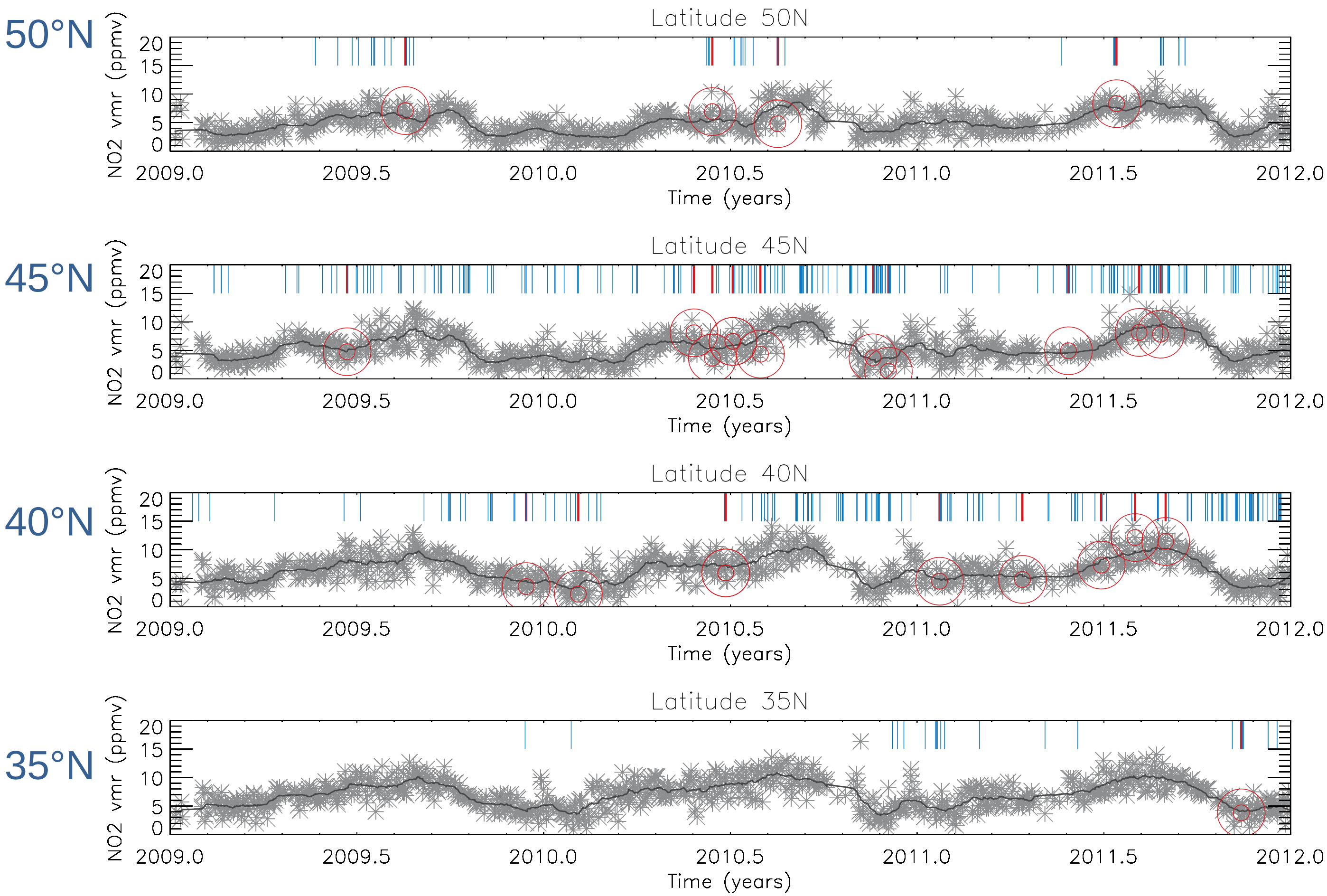






EUROSPRITE 2009-2011 observations and MIPAS2D NO_2

Case studies with thunderstorms+sprites and MIPAS coincidence



No consistent change in NO_2 coincident with sprite activity over Europe.

BUT

No perfect coincidence found.

MIPAS2D NO2 @ 52 km (*), **sprites (I)**, **sprites+MIPAS2D (O)** at latitude 35 ° to 50° N.

Conclusions

e.arnone@isac.cnr.it

- Use of satellite measurements and models to study sprite-induced chemical perturbations:
  - *Persistent changes in NO_2 are expected but are quickly diluted and transported throughout the Tropics.*
  - *Need to look at perturbation above individual thunderstorms. Difficulties in detection because of short coincidence window and low spatial resolution of measurements.*
- MIPAS2D look at sprite-NOx:
  - *Using **MIPAS/lightning**: **+5/10% in NO_2** at 52 km in coincidence with thunderstorm activity north of the equator. Confirm hint to sprite perturbation.*
  - *Using **MIPAS/sprites**: **a few cases with anomalously high** (tens %) **NO_2 but no conclusive** evidence. Need more sprites/chemistry observations over Tropics where activity is stronger.*
- Simulations ongoing to study sensitivity of satellite NO_2 to sprite- and lightning-NOx changes.

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