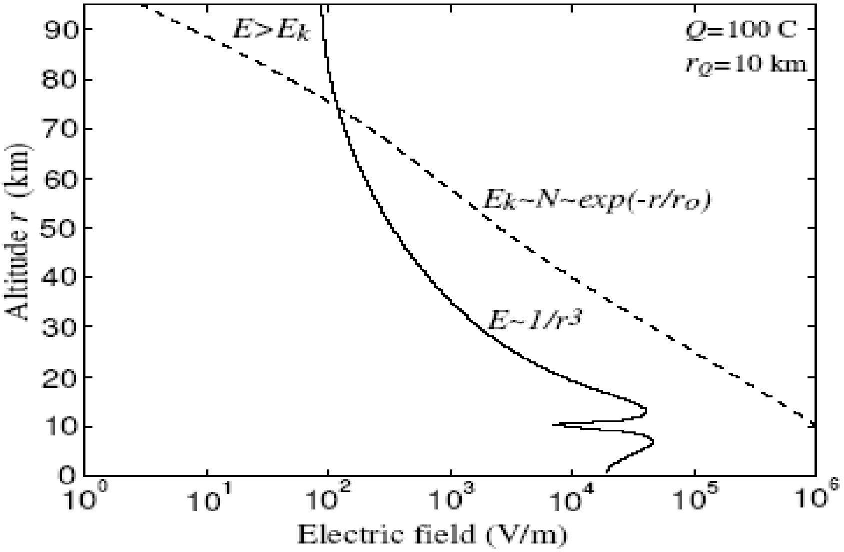
Observation of transient luminous events and their impact on the chemistry of the atmosphere

E. Arnone - arnone at fci.unibo.it

Dipartimento di Chimica Fisica e Inorganica, University of Bologna, Italy

OUTLINE:

introduction to TLEs
TLE observation
TLE chemistry observation
summary



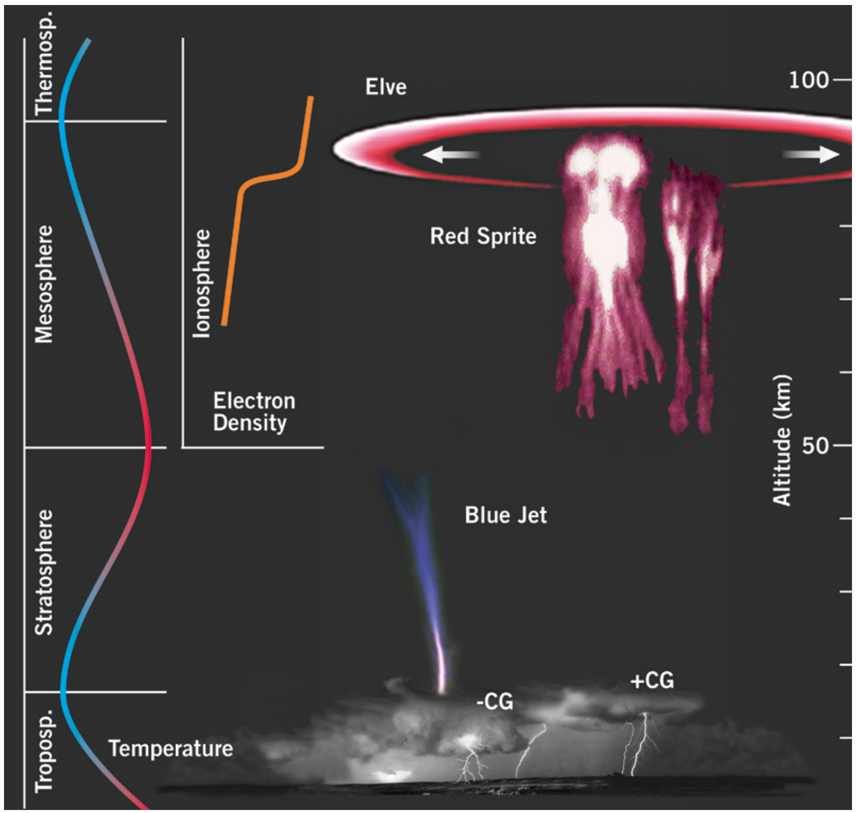
OUTLINE:

introduction to TLEs
TLE observation
TLE chemistry observation
summary

"If the electric moment of a cloud is not too small, there will be a height above which the electric force due to the cloud exceeds the sparking limit."

C.T.R. Wilson, Proc. Phys. Soc. Lond., Vol. 37, P. 32D,1925

The family of transient luminous events (TLEs)

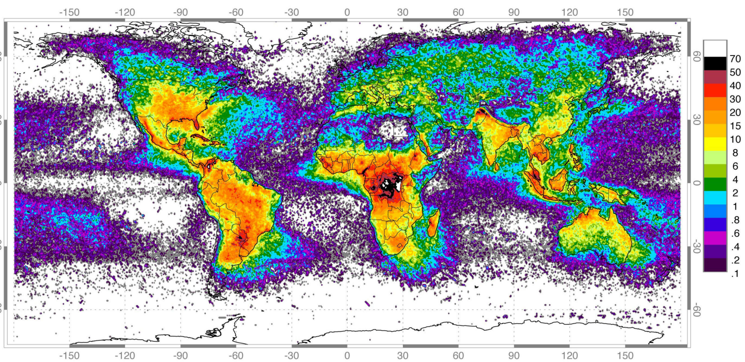


[Neurbert 2003]

- **Elves:**
  - Rings of emissions at lower edge of the ionosphere
  - 1-10 ms duration
  - Stimulated by electromagnetic pulse from lightning
  - Primarily red
- **Sprites**:
  - Luminous emissions in the mesosphere
  - 10-100 ms duration
  - Generated from positive cloud to ground (+CG) lightning
  - Primarily red
- **Blue jets**:
  - Injected from cloud tops
  - 100-1000 ms duration
  - Generated with or without CG activity
  - Primarily blue

TLE global occurrence distribution

ISUAL observations (Chen et al. 2008)



High Resolution Full Climatology Annual Flash Rate

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

Lightning activity (Christian 2003)
global rate 40/second

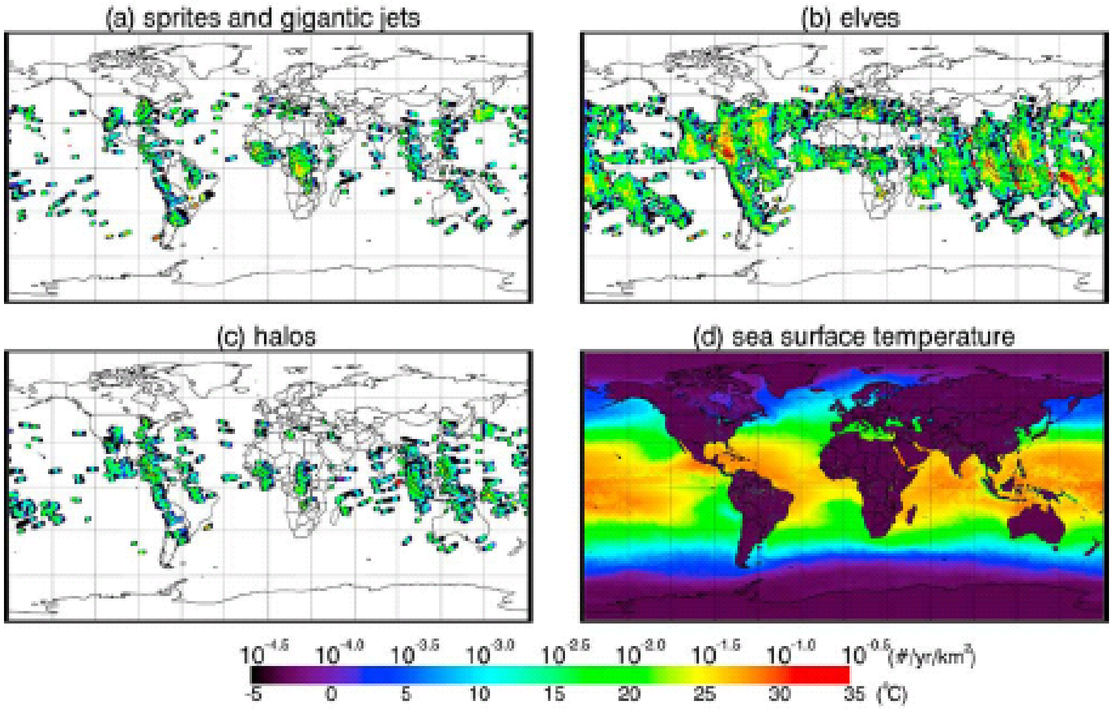
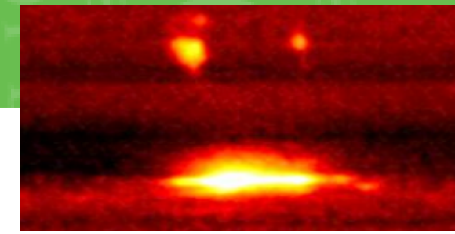


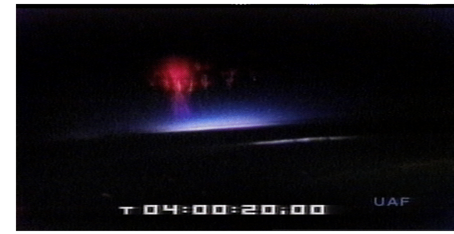
Figure 3. The global occurrence density of major TLEs: (a) sprites and gigantic jets (gigantic jets are marked by red filled circle), (b) elves, and (c) halos. The mean sea surface temperature between July 2004 and December 2005 is displayed in Figure 3d for comparison. (Data Source: PO.DAAC, JPL.)

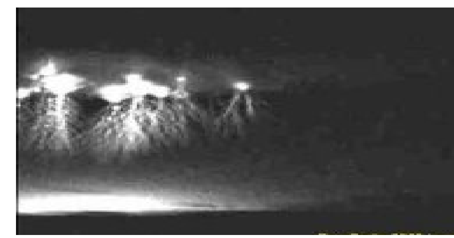
Sprite global rate: 3/minute (Ignaccolo et al. 2006)

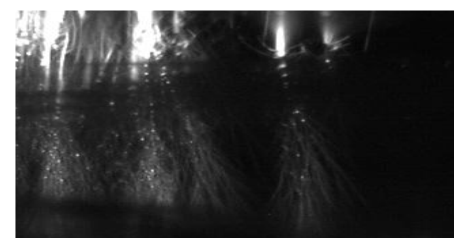
TLE optical observations

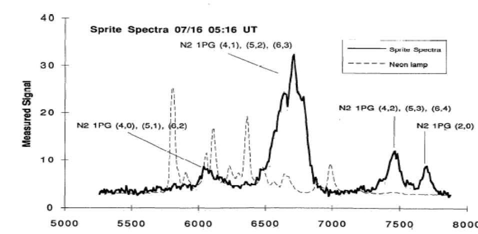
Eurosprite low light camera system installed at Pic du Midi (Pyrenees)



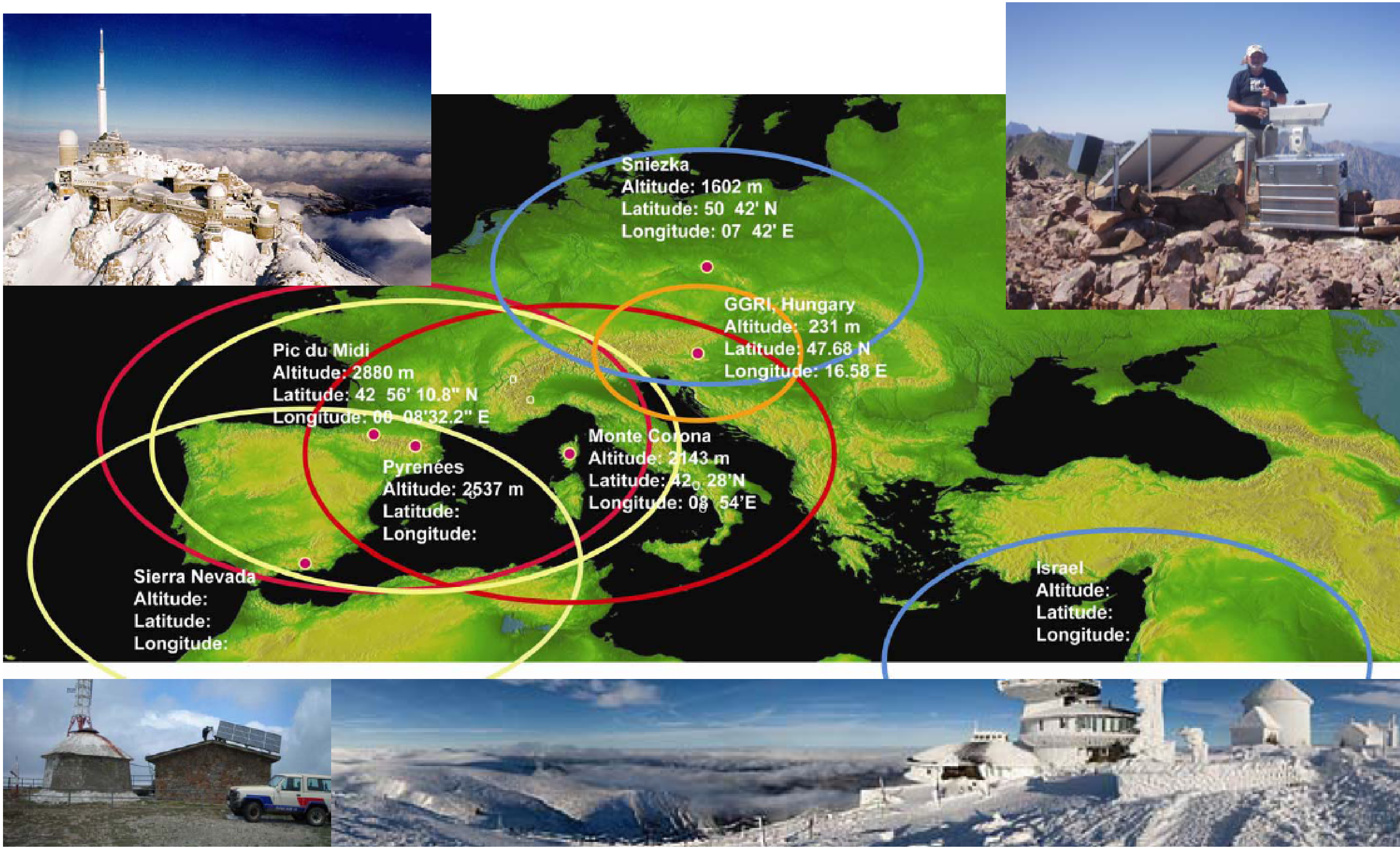




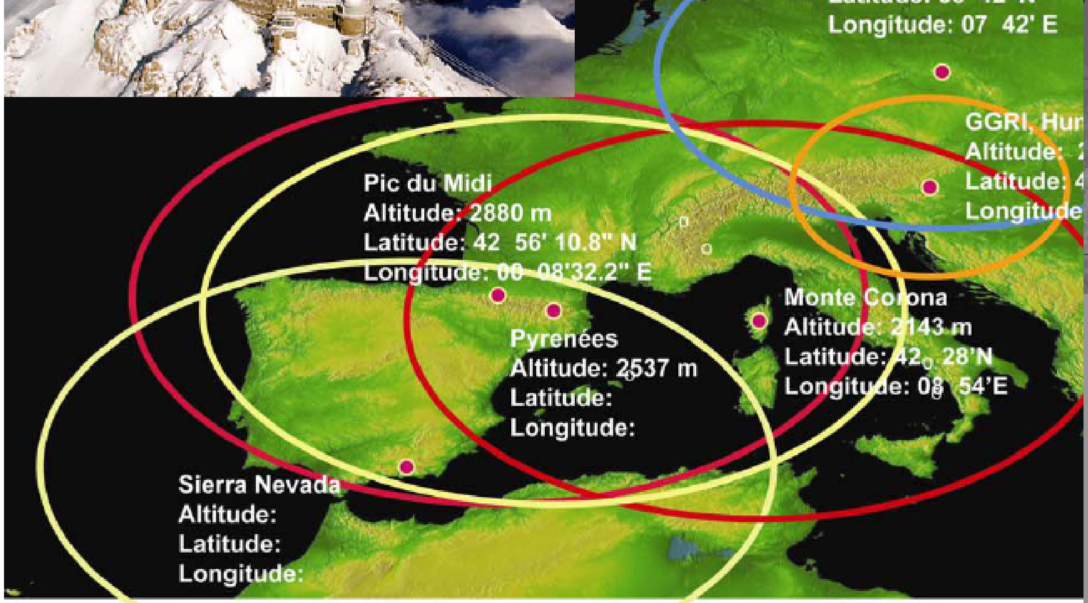


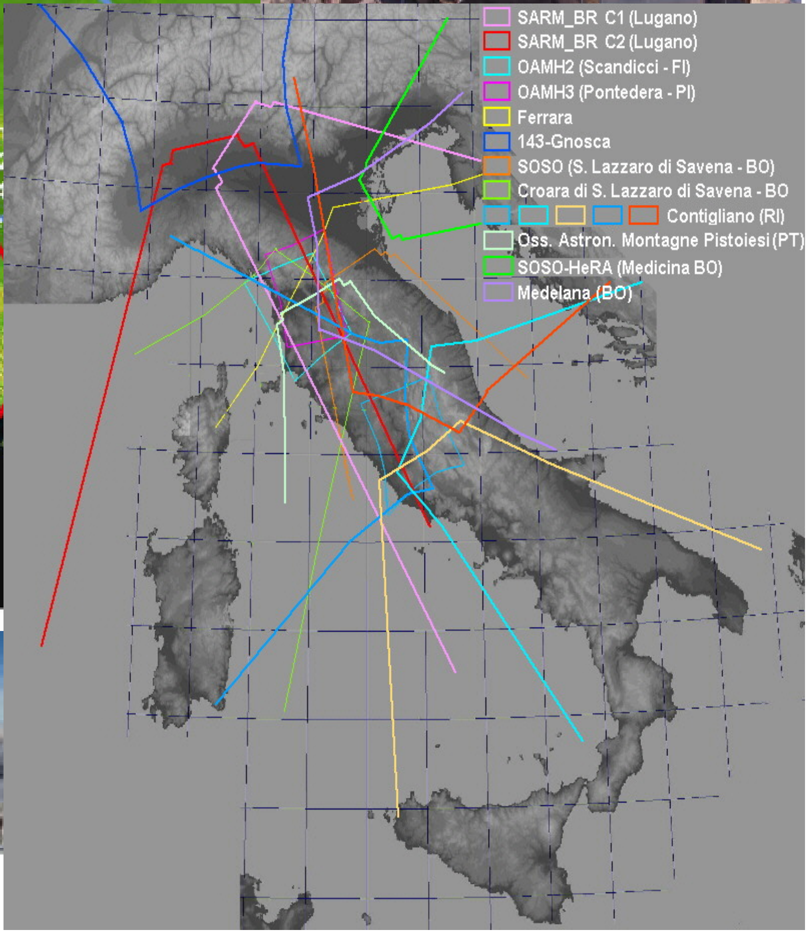


EuroSprite network

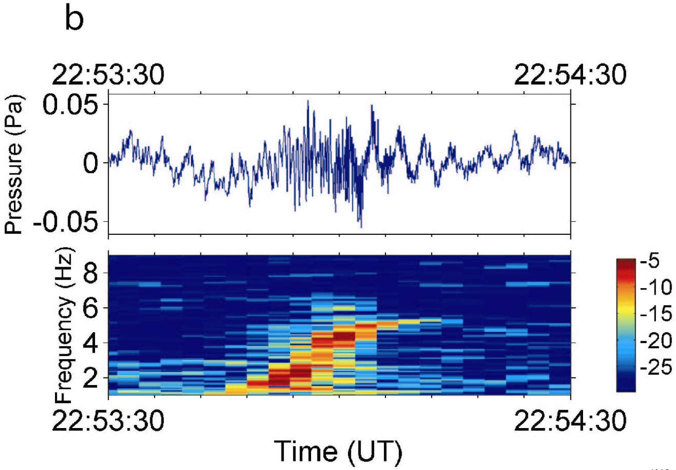


EuroSprite network

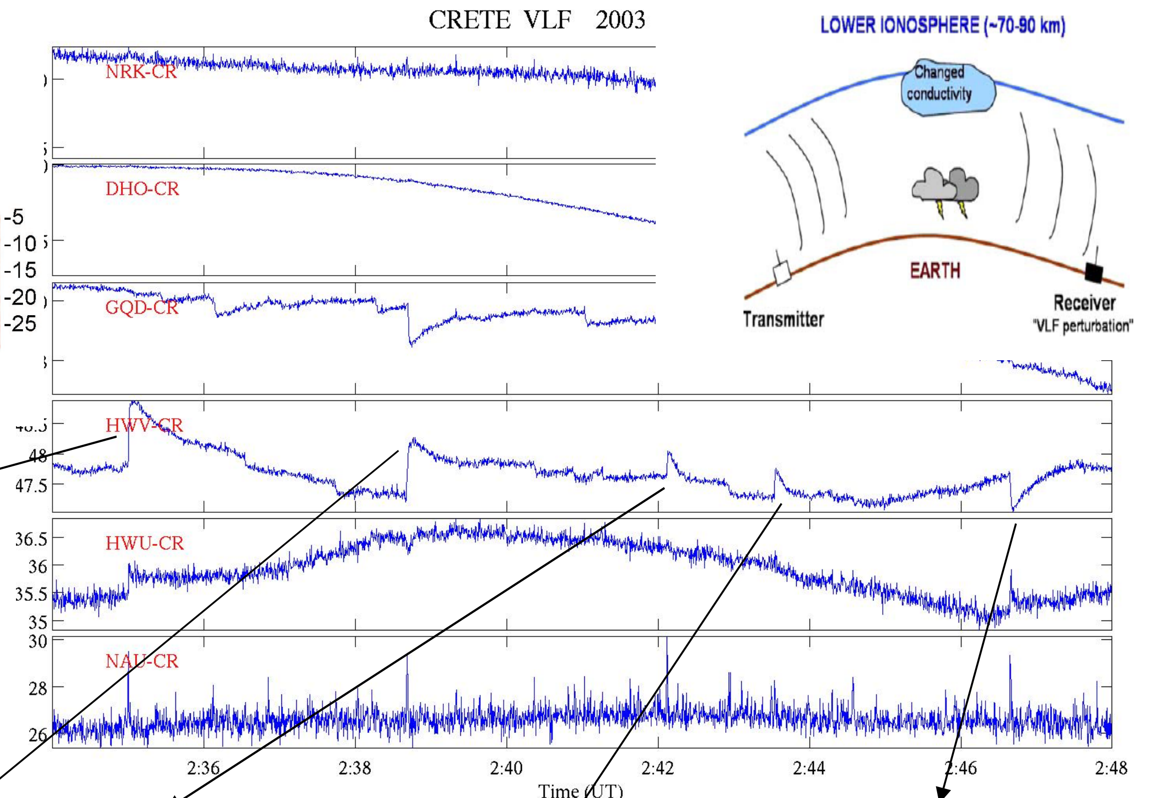


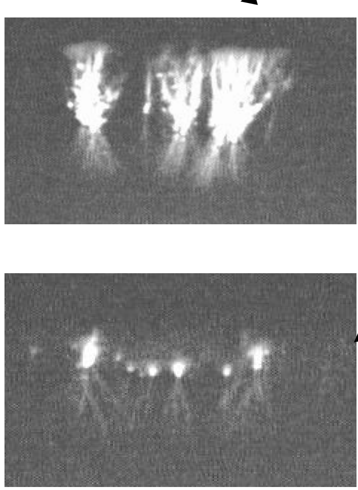


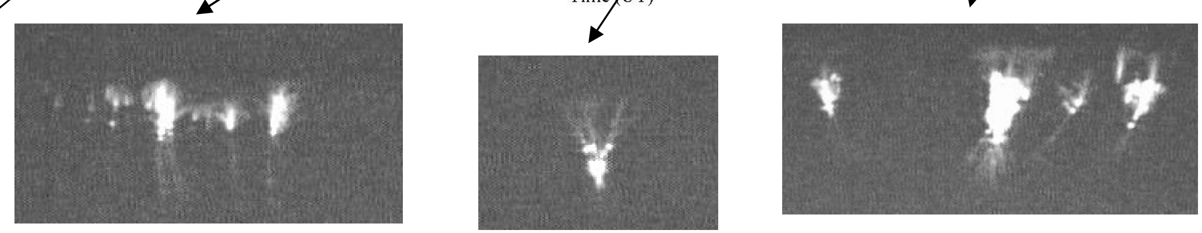
Sprite radio and infrasound signals



Farges *et al*. GRL, 2005.

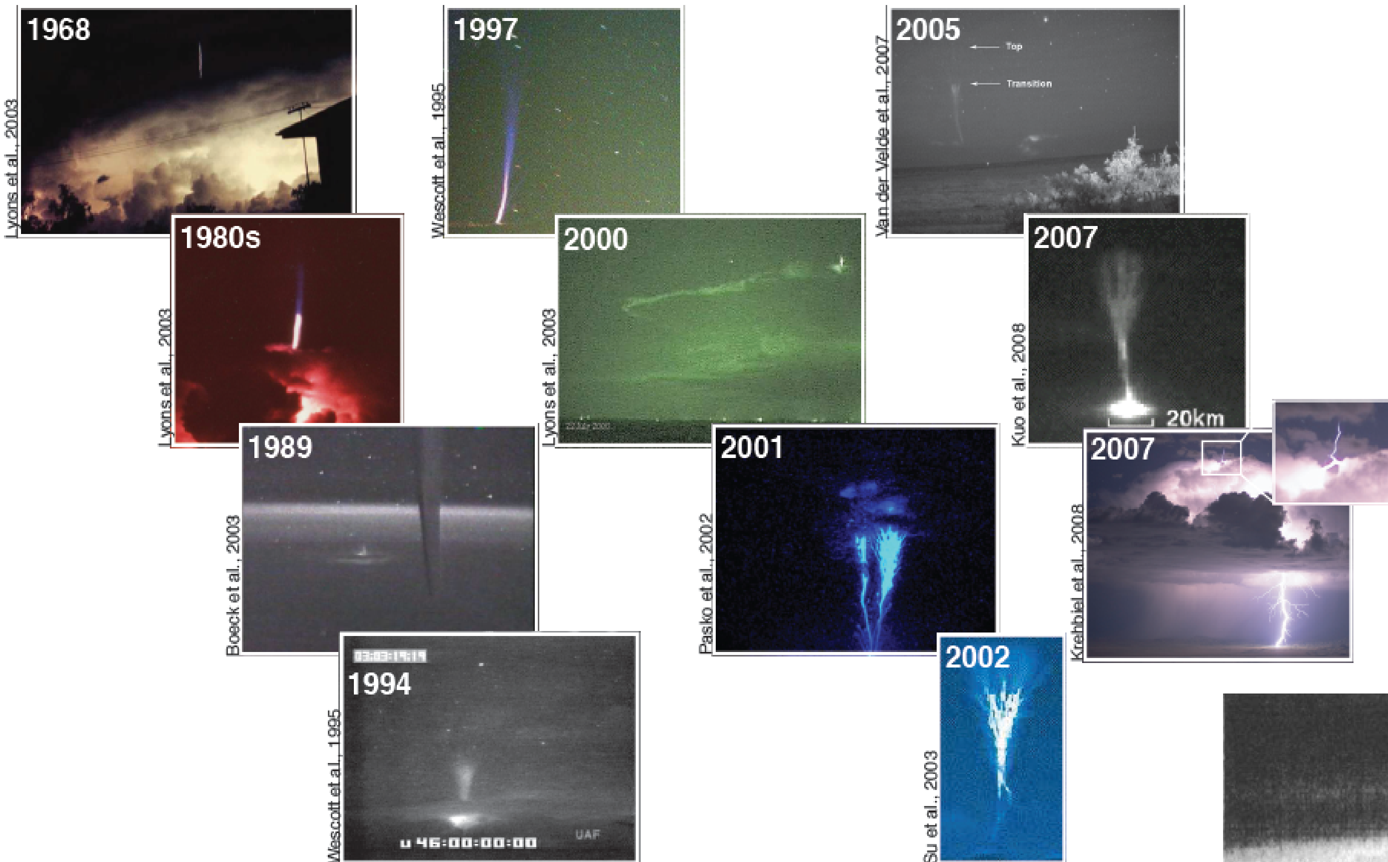


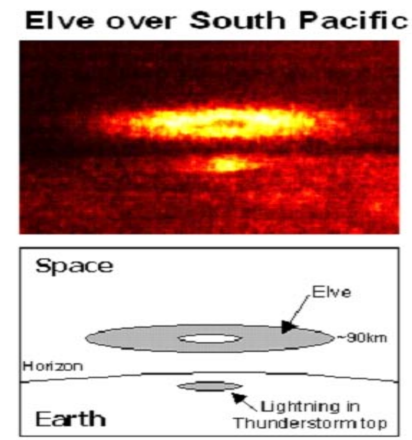


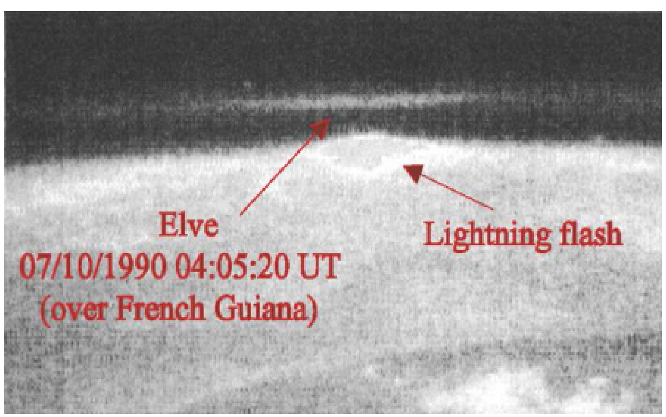


Haldoupis et al., JGR, 2004; *Mika et al*., JGR, 2004

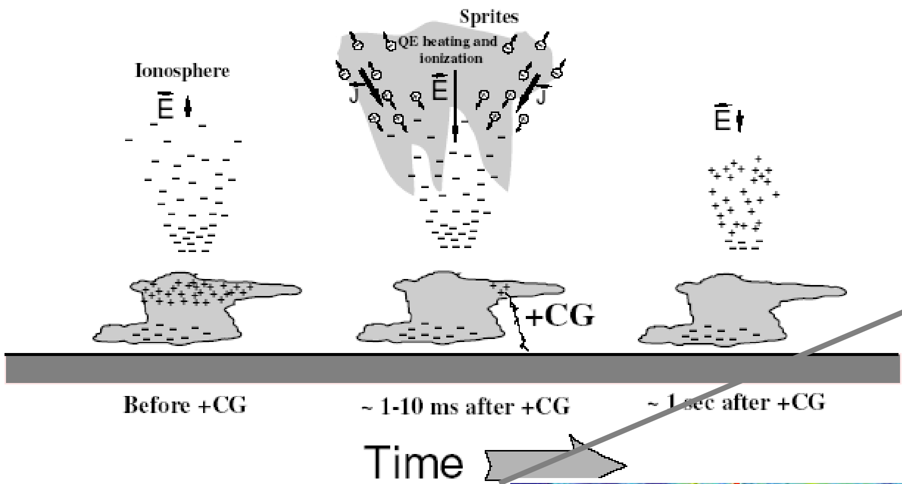
Blue Jets, Gigantic Jets and Elves

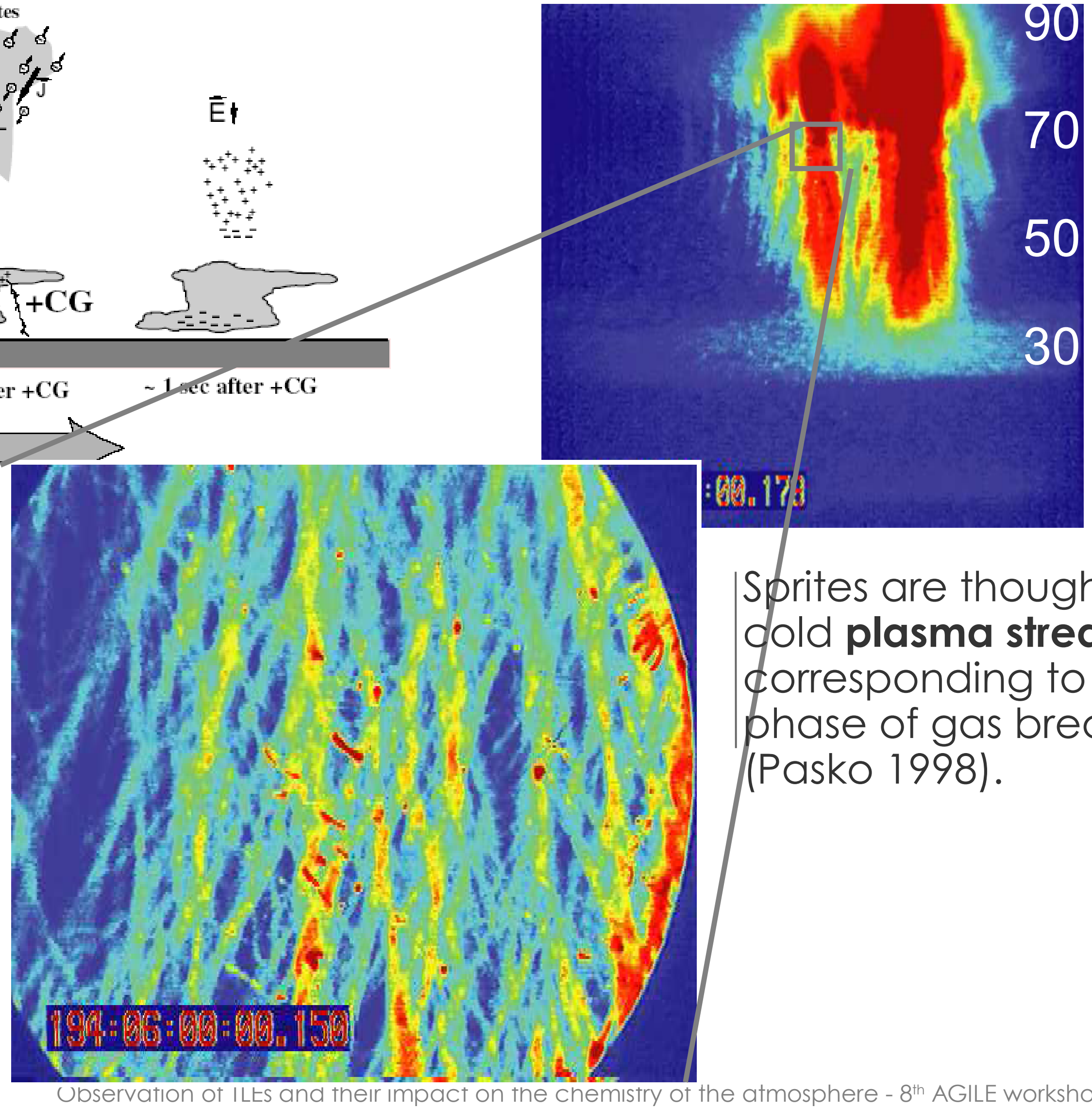






Sprites



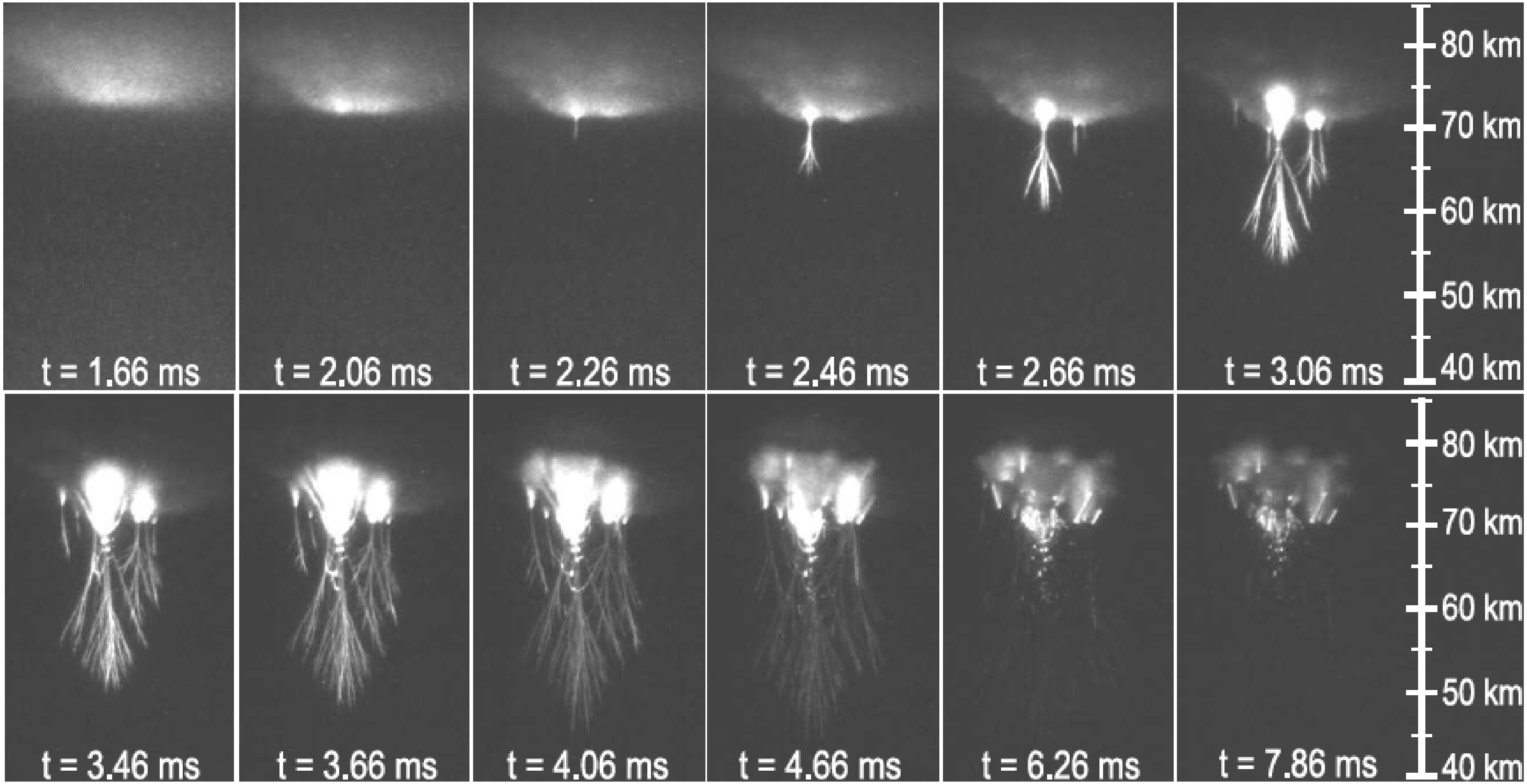


Telescoping images of a bright sprite event [Gerken et al. 2000]

The measured streamer diameters are ~100 to 200 m, at altitudes 60 - 85 km.

Sprites are thought to be cold **plasma streamers** corresponding to the first phase of gas breakdown (Pasko 1998).

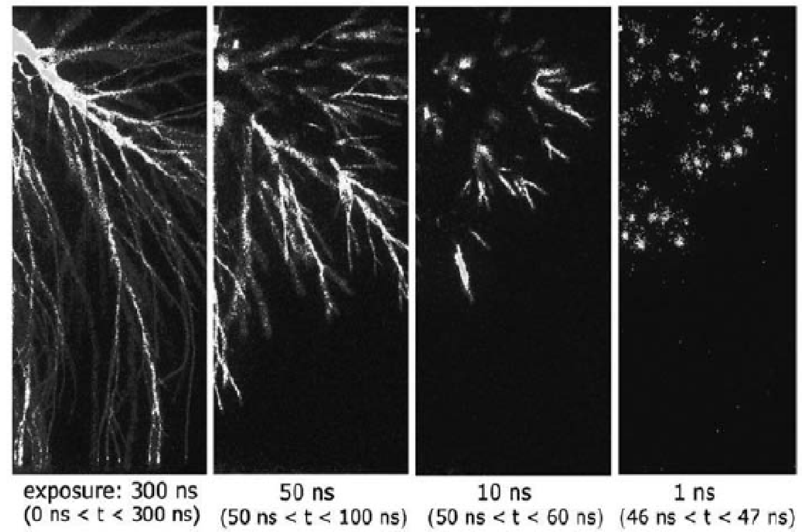
Sprite high speed video recording

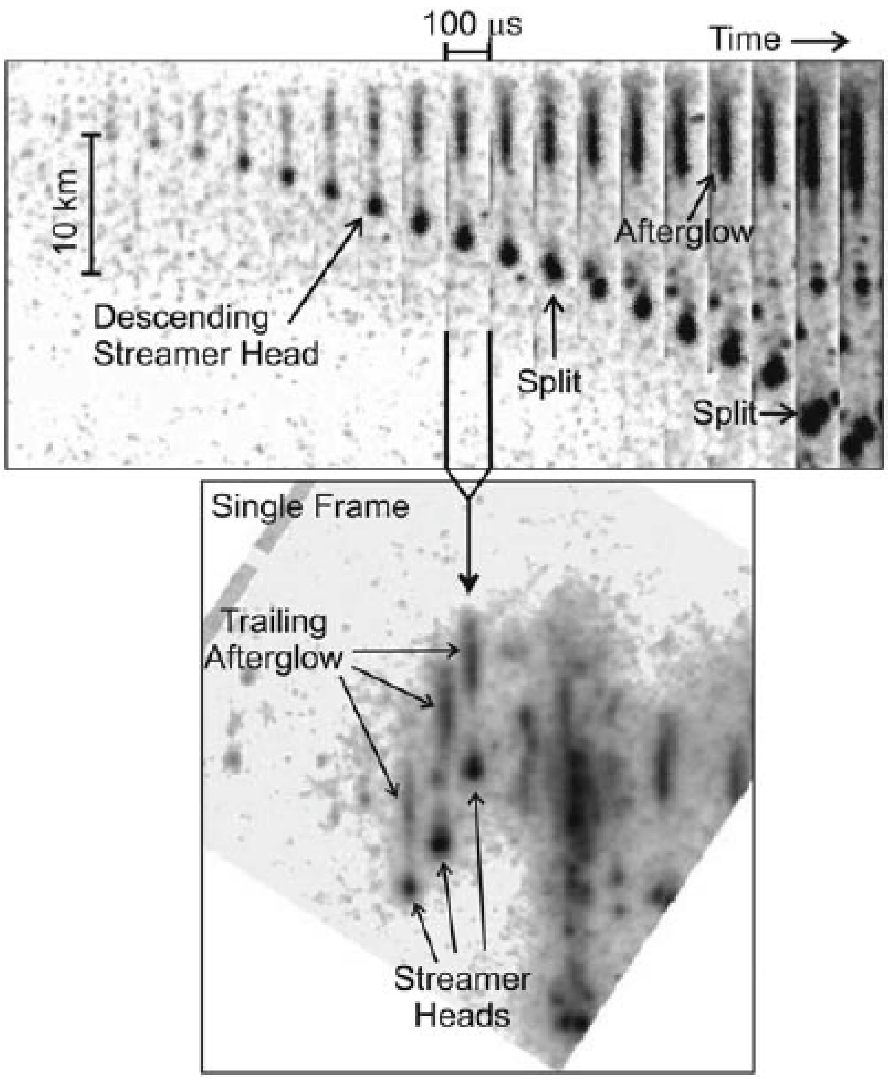


[Cummer et al., Geophys. Res. Lett., 33, L04104, 2006]

Sprite streamer development

Ebert et al. 2008





Mc Harg et al. 2009

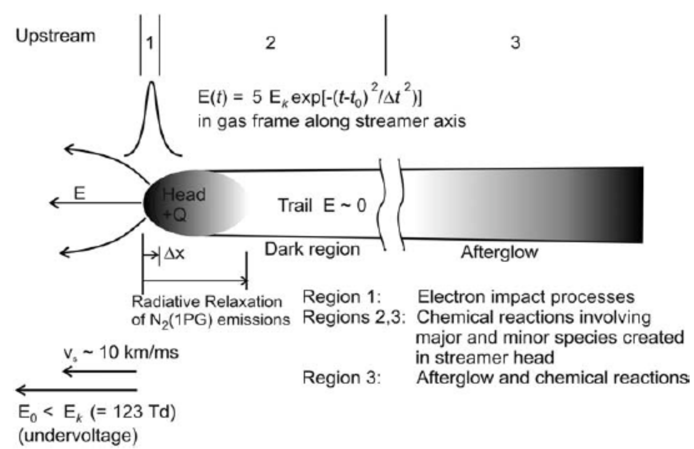


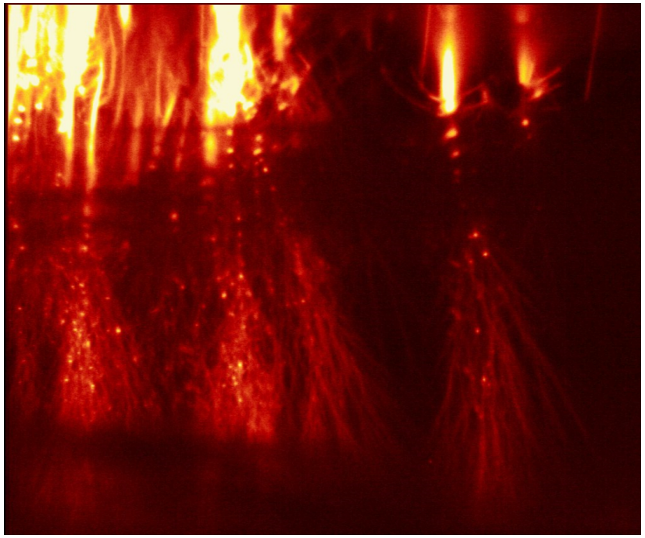
Figure 5. Simplified positive sprite streamer based on kinetic considerations and the observations

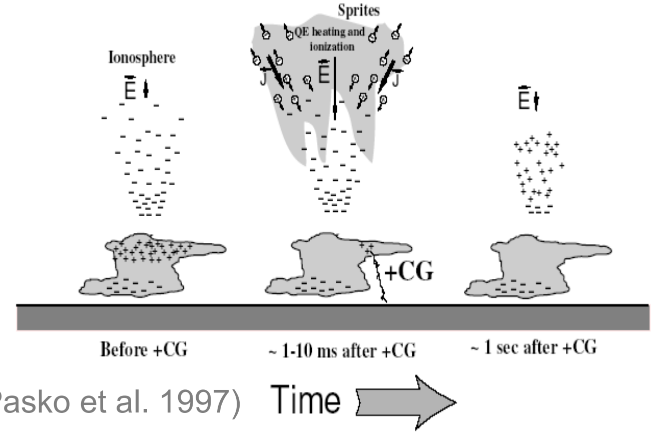
Sentman et al. 2008

Sprites and NO_x

NO_x increase induced by TLEs:

- NO_x increase expected because of air plasma processes
- 2 orders of magnitude due to sprites, Lyons and Armstrong 1997
- 10% local increase by 1 blue jet, Mishin 1997
- suggestion of chemical impact, Stenbaek-Nielsen et al. 2000
- Local changes, e.g. Armstrong 2000, Sentman et al. 2000, Hiraki et al. 2004, Enell et al. 2005
- No global signature, Arnone et al. 2005



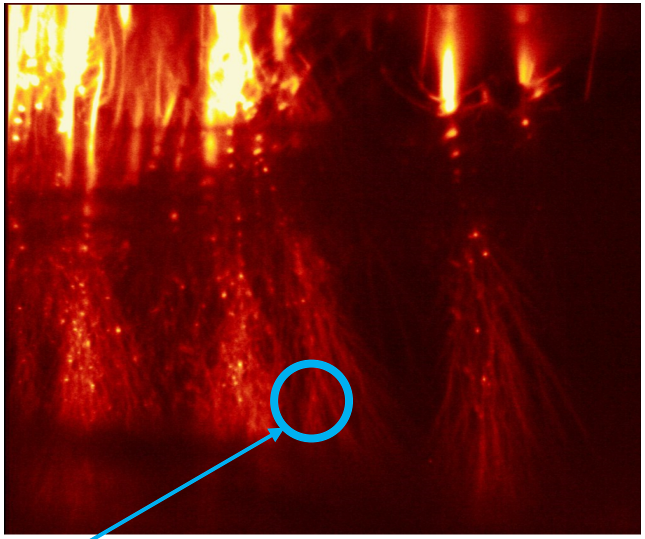


(Pasko et al. 1997)

Sprites and NO_x

NO_x increase induced by TLEs:

• NO_x increase expected because of air plasma processes
• 2 orders of magnitude due to sprites, Lyons and Armstrong 1997
• 10% local increase by 1 blue jet, Mishin 1997
• suggestion of chemical impact, Stenbaek-Nielsen et al. 2000
• Local changes, e.g. Armstrong 2000, Sentman et al. 2000, Hiraki et al. 2004, Enell et al. 2005
• No global signature, Arnone et al. 2005

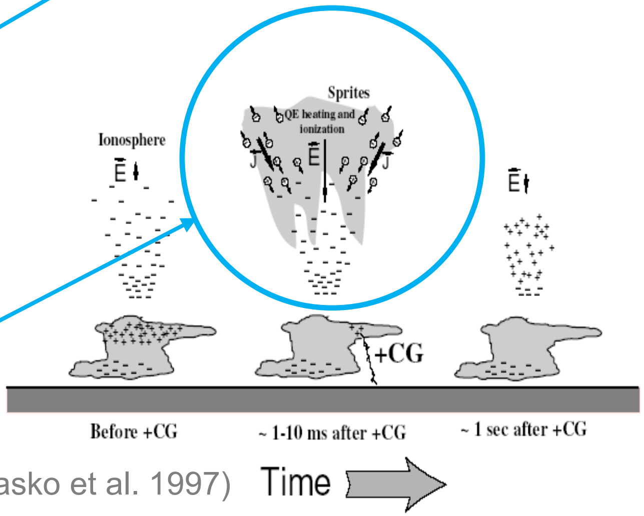


2008/2009

Models: tens to hundreds of % within streamer at 70 km height - modelling by Enell et al., Sentman et al., Hiraki et al., Gordillo-Vázquez

Observations:

• tens of percent at 50-60 km height above thunderstorms – satellite local correlation by Arnone et al.
• no global signature – satellite climatological work by Rodger et al.



(Pasko et al. 1997)

Model sprite-NOx

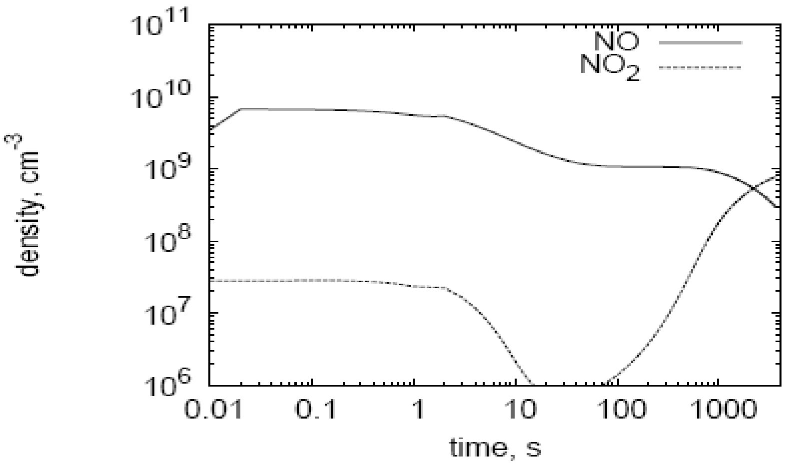
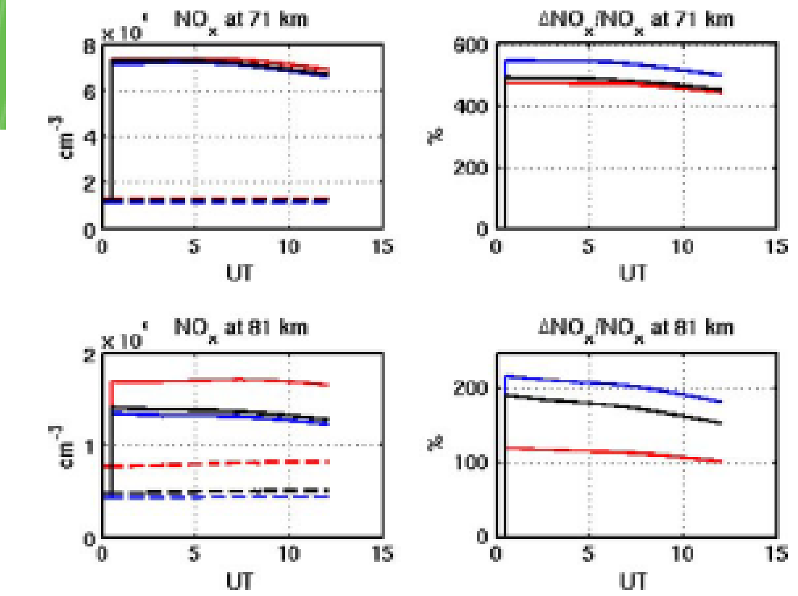
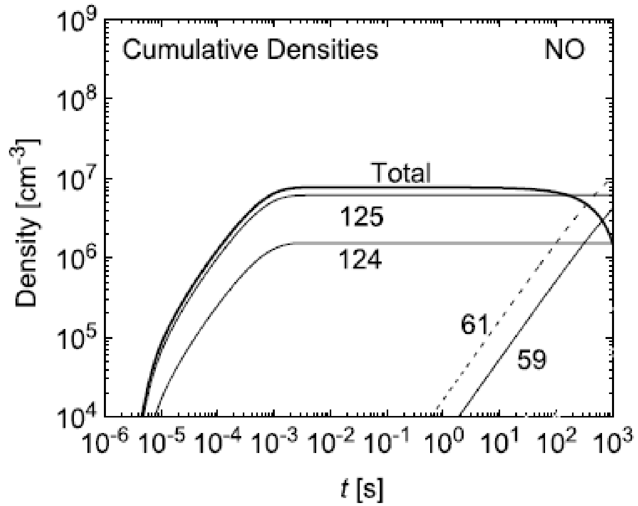


Fig. 3. Temporal density variations for NO_x species at 60 km altitude in the same condition as Fig. 2; solid and dashed lines show those of NO and NO_2, respectively, after initiation of streamer at $t=0$.

Hiraki et al. 2008



Enell et al. 2008



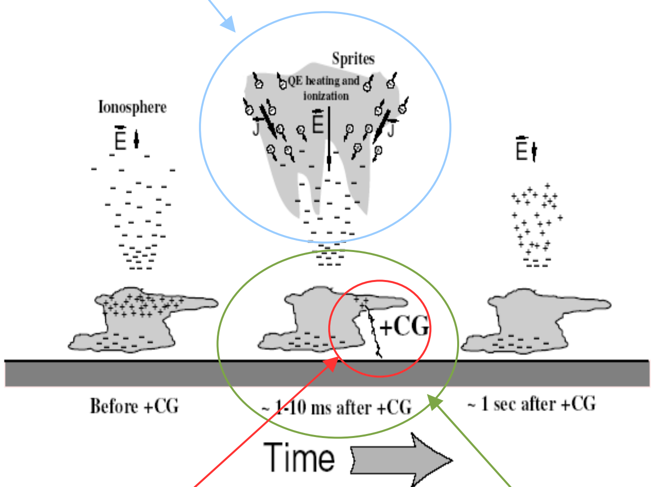
Sentman et al. 2008

Sprite chemistry models predict hundreds of % enhancement of NOx

Observing TLE chemistry:

Sprites:

- Direct sprite observations: EuroSprite campaigns 2003-2009



MIPAS and GOMOS onboard ENVISAT

+CGs:

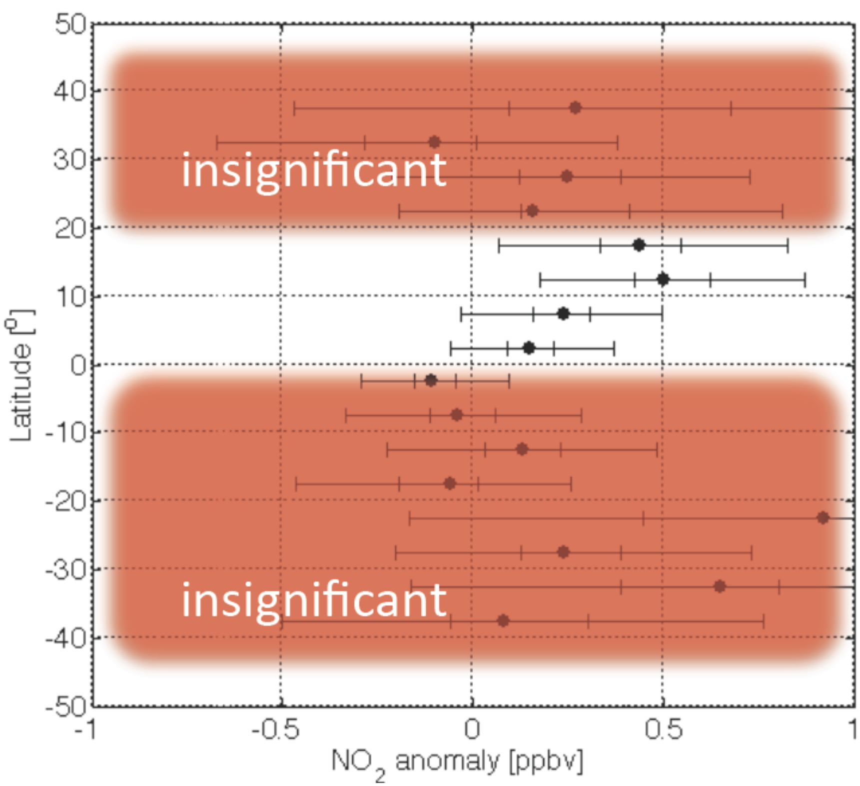
- Local (Italian) lightning detection network, LINET - CESI

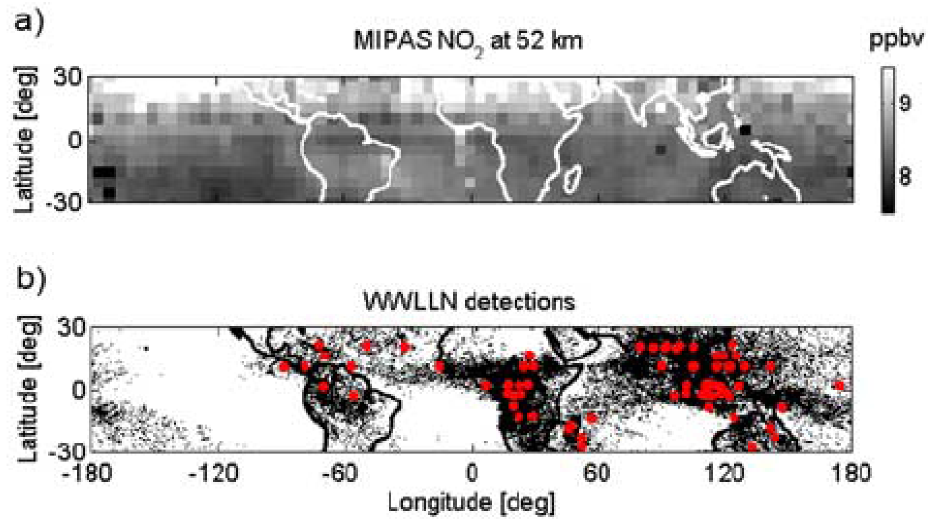
Lightning: Global lightning detection networks (WWLLN)

- A global network of lightning location VLF sensors
- ~ 1% efficiency on lightning stroke detection (strongest strokes) but detection of most thunderstorms (Jacobson et al. 2006)

Using lightning as a thunderstorm/sprite proxy

Observations of sprite chemistry (Arnone et al 2008, 2009):
5-10% increase of NO_2 at 50 km altitude above thunderstorms

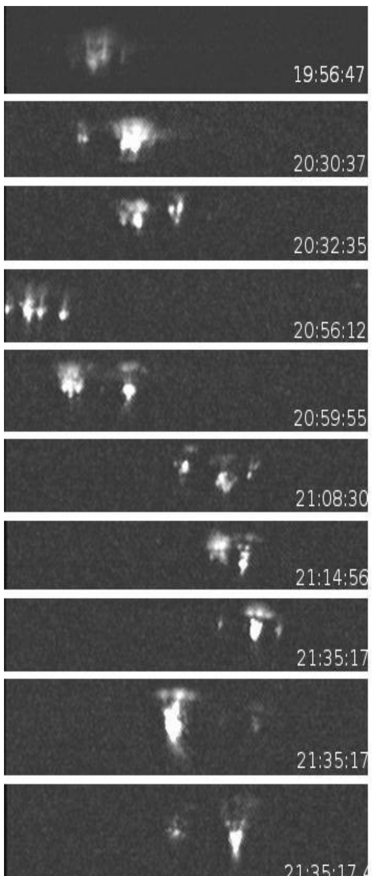


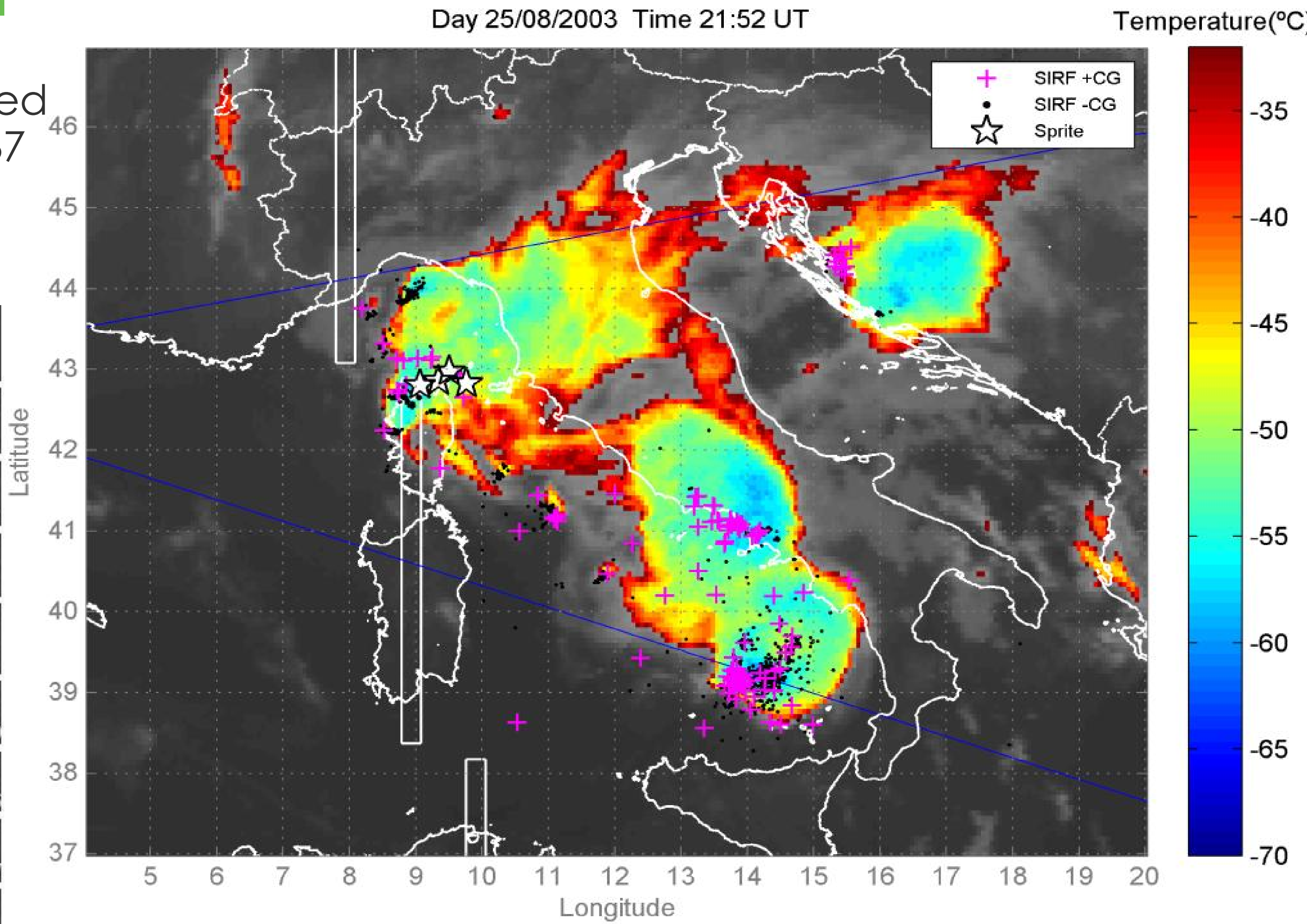


Rodger et al 2008 with GOMOS: no sprite-NO_2 signature at global scale.

Case study from Eurosprite 25 August 2003

25 Aug 2003
11 TLEs observed
19:56 and 21:37





Conclusions

- **Thunderstorm** activity in the troposphere can initiate TLEs and TGFs.
- TLEs: **Blue jets** (15-40 km, 100-1000 ms) are the upward analogous of lightning, **sprites** (40-90 km, 10-100 ms) are produced by electric field changes above the thundercloud, while **elves** (90 km, 1-10ms) are caused by the EM pulse propagating from a lightning stroke.
- Recent research shows sprites and other **TLEs can exert a local impact on the atmospheric chemistry**, especially through production of NOx.
- **Models** predict tens to hundreds of percent change within sprite streamers.
- Use of **satellite** measurements to study TLE-induced chemical perturbations:

    Feasible for persistent changes (e.g. in NO_2) but transport issue

    Difficult for direct emissions because of short coincidence window: need coupled observations (ASIM)

- Use of **MIPAS2D** showed anomalous local enhancements of NOx in regions of sprite activity. Seeking more coincidences. MIPAS2D data available to end users.

Acknowledgement to:
A. Kero, F. São Sabbas, S. Soula, M. Carlotti, E. Papandrea, B.M. Dinelli, P. Bonasoni et al., EuroSprite team
Marie Curie MERG-CT-2007-209157