Atmospheric Chemistry

Prepared by Benjamin Cotts
Stanford University, Stanford, CA

IHY Workshop on
Advancing VLF through the Global AWESOME Network
Overview

- LEP Events
- Early/fast Events
- Gamma Ray Burst (GRB) Events
- Atmospheric Chemistry
LEP Event Properties

1. Onset delay ($\Delta t \sim 0.5\text{-}2\text{ s}$) between sferic and onset
2. Differential onset delay with respect to $L$-shell (~0.5s)
3. Onset duration ($t_d \sim 1\text{-}2\text{ s}$) of secondary ionization
4. Large ionospheric region of disturbance, ~ 2000 km
5. Occur very frequently
6. Recovery typically ~ 10-100 s
Recovery Signatures of LEP

Peter 2007

Pasko and Inan, 1994
Early VLF Event Properties

- Rapid onset delay ($\Delta t < 20$ ms)
- Rapid onset duration ($t_d < 20$ ms)
- Typically recover in $\sim 30$-200 s
- Event amplitudes $\sim 0.2$-0.8 dB, rarely $> 1$ dB
- Causative CGs $< 50$ km from perturbed path
  - Lateral extent of disturbances $\sim 100$ km

Source: [Johnson and Inan 1999]
Long Recovery Early/fast Events

23 February 2006

- NAU-Boston
- NAU-Taylor

NAU amplitude at Gander

~20 Minutes

~100 Sec

NAU phase at Gander

~14 Minutes

NAU amplitude at Boston

~15 Minutes

~200 sec

NAU phase at Boston
Gamma-Ray Bursts

- Associated with very energetic explosions
  - Collision of Neutron stars
  - Magnetar

- Typically lasts a few ms to several minutes

- Accidentally discovered by Vela-3 spacecraft in 1967
Massive Gamma-Ray Burst

Figure 1. The $\gamma$-ray flux versus time, showing the peak [Terasawa et al., 2005], oscillating tail [Hurley et al., 2005] and the afterglow ($\propto t^{-0.85}$ [Mereghetti et al., 2005]).

From Inan et al. 2007
Second Timescale Characteristics

From Inan et al. 2007
Hour Timescale Characteristic

*Recovery lasts for over 1 hour!*

*From Inan et al. 2007*
Overview

- Ionospheric chemistry
  - Model Framework
  - Constituents/Parameters
Chemistry Model: Species

Electrons:
- $N_e$ - Electrons
- $N^+$ - Light positive ions
- $N_x^+$ - Heavy positive ions (cluster)
- $N^-$ - Light negative ions
- $N_x^-$ - Heavy negative ions (cluster)

Light positive ions:
- $O_2^+$, $N_2^+$, $NO_2^+$

Light negative ions:
- $O^-$, $O_2^-$

Heavy positive ions:
- $H^+(H_2O)_n$

Heavy negative ions:
- $NO_3^-$, $NO_3^-(H_2O)_n$

Not part of the model, just illustrative:

Neutrals:

$H_2O$: 

\[ \text{Not part of the model, just illustrative:} \]
\( N_e \xrightarrow{\beta} N^- \)

\( N^- \xrightarrow{\gamma} N_e \)

\( N_x^- \xrightarrow{\gamma_x} N_e \)

\( N^+ + N_e \xrightarrow{\alpha_{d}} \text{Neutral} \)

\( N^+ + N_e \xrightarrow{\alpha_{d}^c} \text{Neutral} \)

\( *N^+ + N^- \xrightarrow{\alpha_i} \text{Neutral} \)

\( N_x^+ + N^- \xrightarrow{\alpha_i} \text{Neutral} \)

\( N^+ + N_x^- \xrightarrow{\alpha_i} \text{Neutral} \)

\( N_x^+ + N_x^- \xrightarrow{\alpha_i} \text{Neutral} \)

\( N^- + \text{nH}_2\text{O} \xrightarrow{A} N_x^- \)

\( N^+ + \text{nH}_2\text{O} \xrightarrow{B} N_x^+ \)

\( \beta \) - attachment:

\( \gamma \) - detachment from light negative ions

\( \gamma_x \) - detachment from heavy negative ions

\( \alpha_i \) - mutual neutralization

\( \alpha_{d}, \alpha_{d}^c \) - dissociative recombination

\( A \) - rate of conversion \( N^- \rightarrow N_x^- \)

\( B \) - rate of conversion \( N^+ \rightarrow N_x^+ \)
Model of Ionospheric Chemistry

- 5 constituents:
  - $N_e$ - electrons
  - $N^+$ - light positive ions $O_2^+$, $NO_2^+$, $N_2^+$, ...
  - $N_x^+$ - positive ion clusters $H^+(H_2O)_n$
  - $N^-$ - light negative ions $O^-$, $O_2^-$, ...
  - $N_x^-$ - heavy negative ions $NO_3^-$, $NO_3^-(H_2O)_n$

Coefficients:
- $\alpha_i$ - mutual neutralization
- $\alpha_d, \alpha_d^c$ - dissociative recombination
- $\beta$ - attachment:
  - 3-body and 2-body (in $E$)
- $\gamma$ - detachment from light negative ions (value uncertain):
  - Electron affinity=0.4 eV $\rightarrow$ highly dependent on $T$
  - During daytime: photodetachment=0.4 s$^{-1}$
  - Also due to active species, $N_{ac}$: O, N, $O_2(a^1\Delta_g)$
- $\gamma_x$ - detachment from heavy negative ions, approximately=0 (electron affinity = 3.91 eV), photodetachment = 0.002 s$^{-1}$ (during daytime)
- $B$ - rate of conversion $N^+ \rightarrow N_x^+$
- $A$ - rate of conversion $N^- \rightarrow N_x^-$
- $Q$ – Ionization source; Cosmic ray only source at low altitudes $Q_{cr}$ (peaks at $\sim$15 km)
- Recall Gamma-Ray Burst
- Relaxation matches model results, 2 stages:
  - Free electrons are quickly attached, $\tau_1 \sim (\gamma + \beta)^{-1}$
  - Positive and negative ions recombine, $\tau_2 \sim (\alpha_i N_i)^{-1} \sim 10^4$ s
Gamma-Ray Burst

- Ionization profile recovery
Bibliography

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- Ferguson, 1979
- Arijs, 1992
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- Pasko and Inan, 1994
- Rodger et al., 1998
- Inan et al., 2007
- Lehtinen and Inan, 2007