# A ROCKET EXHAUST DEPLETION (RED) OF IONOSPHERIC TOTAL ELECTRON CONTENT DETECTED BY GPS

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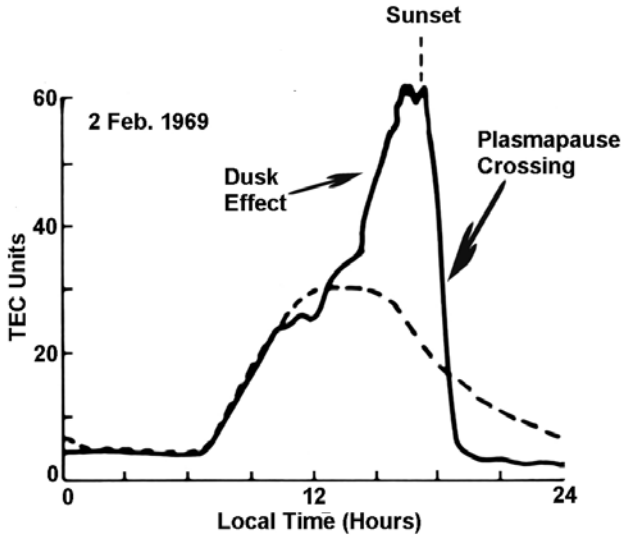
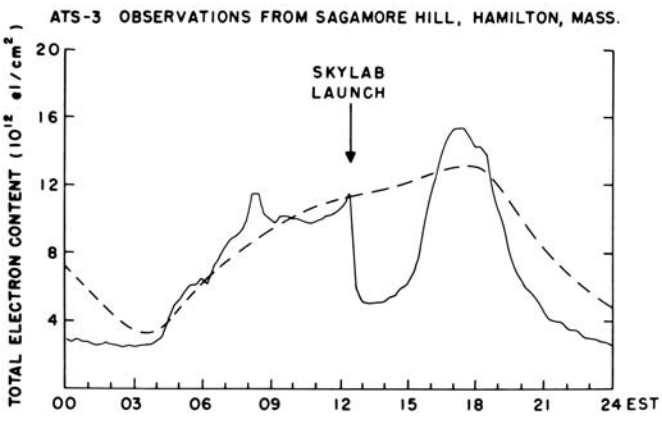
## MAJOR MODIFICATIONS OF THE IONOSPHERE

- Naturally-Occurring Ionospheric Storms
- Artificially-Induced Ionospheric Holes




"Storm-Enhanced Densities" SED's (& SAP's/SAID's)




"Rocket-Exhaust Depletions" RED's (& man-made Space Weather)

# IONOSPHERIC HOLE MAKING CHEMISTRY IN F-LAYER

- $O^+ + \begin{pmatrix} H_2O \\ H_2 \\ CO_2 \end{pmatrix} \rightarrow \begin{pmatrix} H_2O^+ \\ H_2^+, OH^+ \\ CO_2^+, O_2^+ \end{pmatrix}$ + Neutrals (incl. $O(^1D) \sim\sim\sim\rightarrow$ 6300Å photon)

Atomic Ions $\xrightarrow{fast}$ Molecular Ions

- Dissociative Recombinations

$XY^+ + e^- \xrightarrow{fast}$ Neutrals & Airglow

[Normal Aeronomy: $O^+ + \begin{pmatrix} N_2 \\ O_2 \end{pmatrix} \xrightarrow{slow} \begin{pmatrix} NO^+ \\ O_2^+ \end{pmatrix} + \begin{pmatrix} N \\ O \end{pmatrix}$

followed by $\begin{pmatrix} NO^+ \\ O_2^+ \end{pmatrix} + e^- \xrightarrow{fast}$ Neutrals & Airglow]



# Titan IV B-30 Launch on 30 April 2005

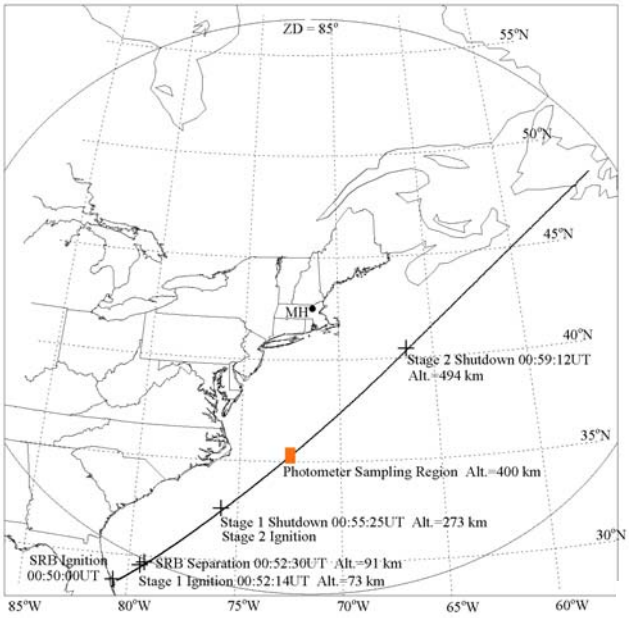
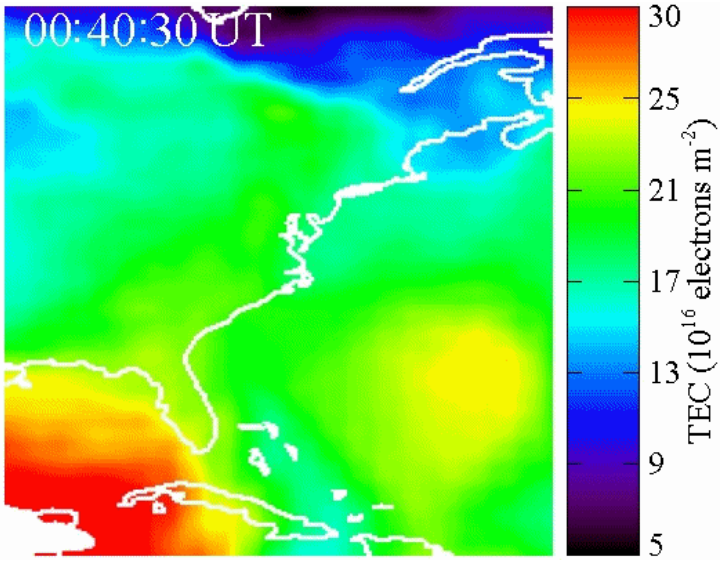



Table 1. Rocket engine and exhaust injection parameters for the Titan IV B-30 rocket launch on 30 April 2005.

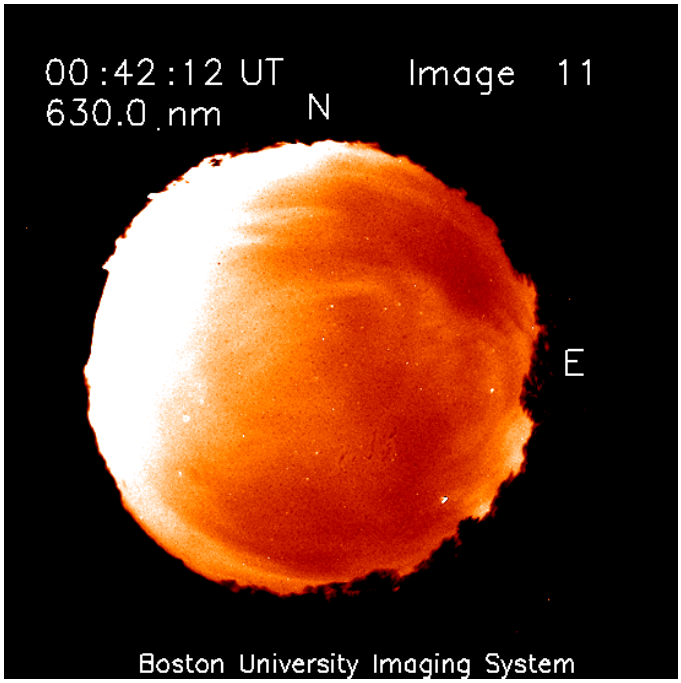
| Engine | Fuel & Oxidizer | Fuel Weight | Burn Period UT | Total Burn time | Exhaust Deposition Rate | Burn Altitude Region | Total Burn Region |
|---|---|---|---|---|---|---|---|
| Stage 0 (SRB's) | HTPB | 283,460 kg | 00:50:00 – 00:52:30 | 150 s | 1890 kg s$^{-1}$ | 0-91 km | 91 km |
| Stage 1 | $N_2H_4/N_2H_2(CH_3)_2$ & $N_2O_4$ | 140,600 kg | 00:52:14 – 00:55:25 | 191 s | 736 kg s$^{-1}$ | 73-273 km | 200 km |
| Stage 2 | $N_2H_4/N_2H_2(CH_3)_2$ & $N_2O_4$ | 31,750 kg | 00:55:25 – 00:58:47 | 227 s | 140 kg s$^{-1}$ | 273 - 494 km | 221 km |

# GPS Observations on 30 April 2005



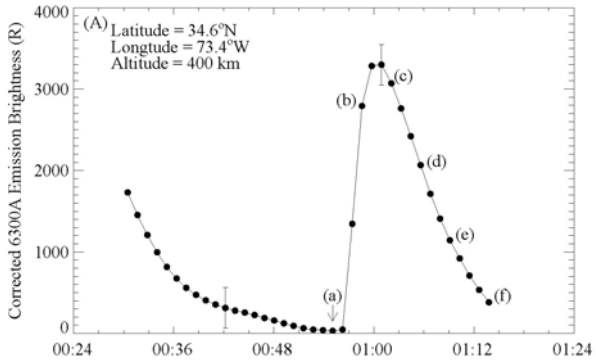


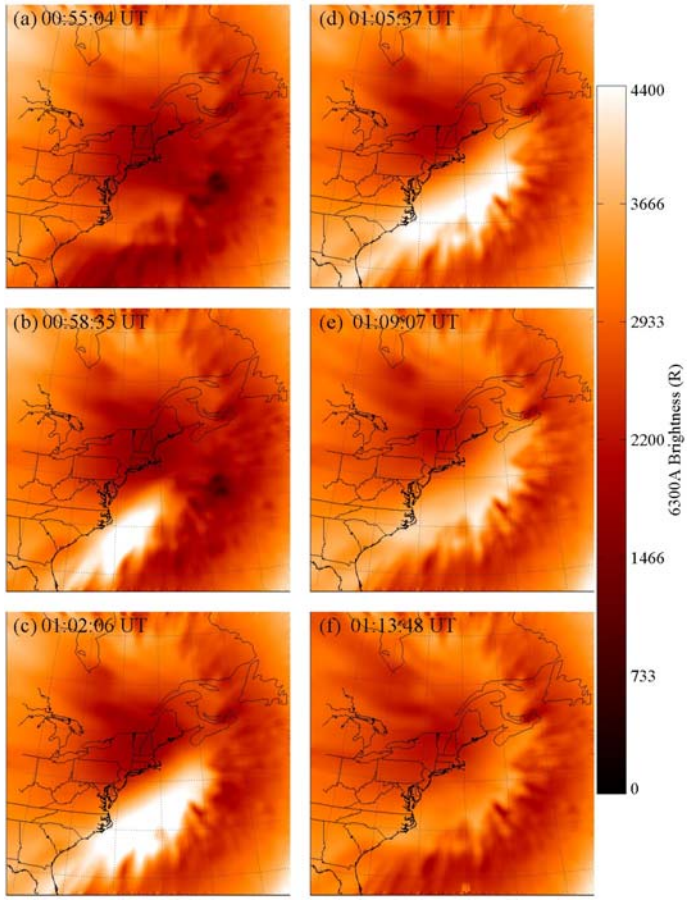

# All-Sky Airglow (6300A) Imaging at Millstone Hill on 30 April 2005



# RED Formation Sequence from Optics

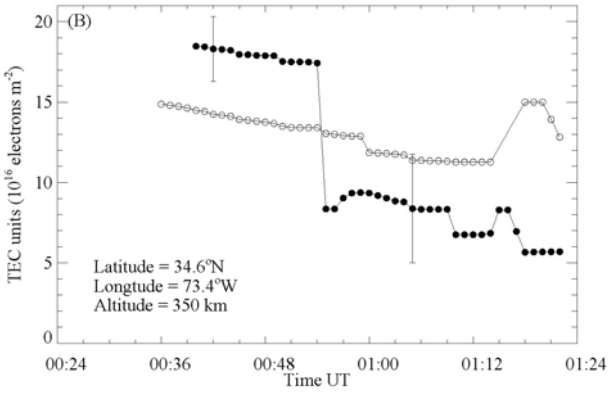
(Note: ~15$^{min}$ duration).

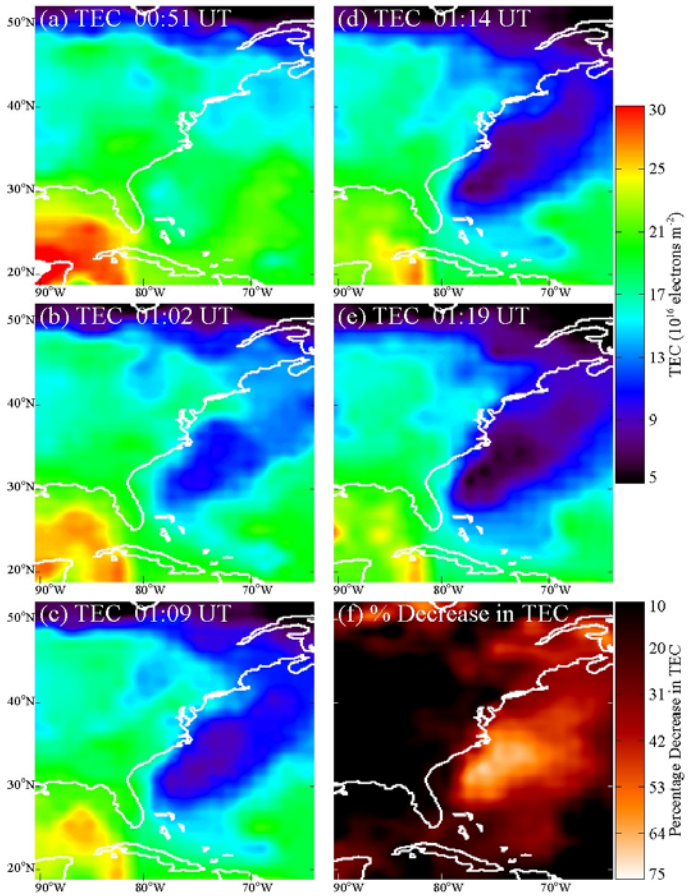



# RED Formation & Longevity from GPS

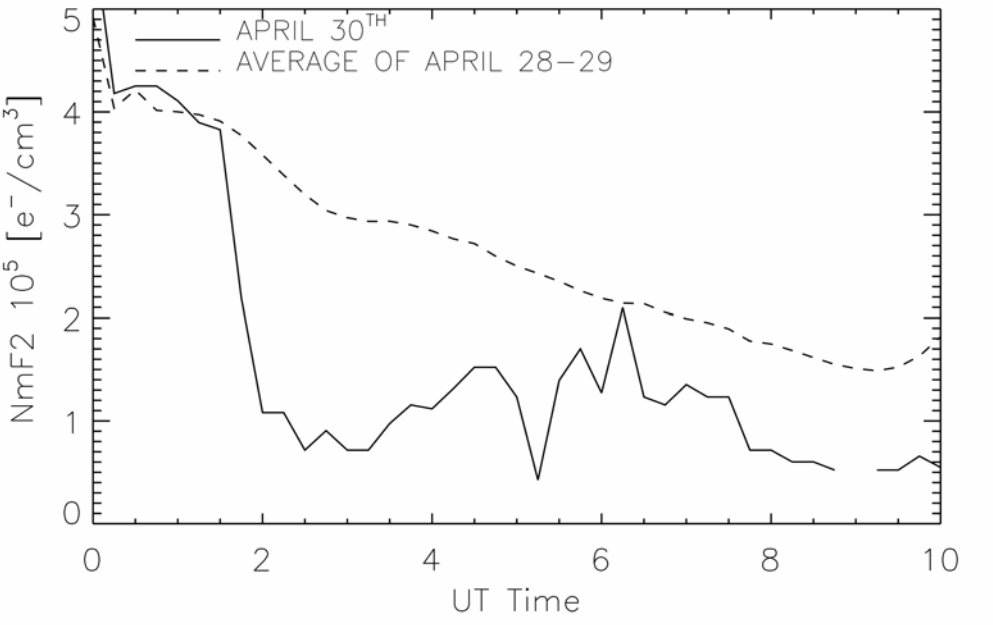
Note: No recovery to pre-event conditions.



# Other Diagnostic Systems on 30 April 2005

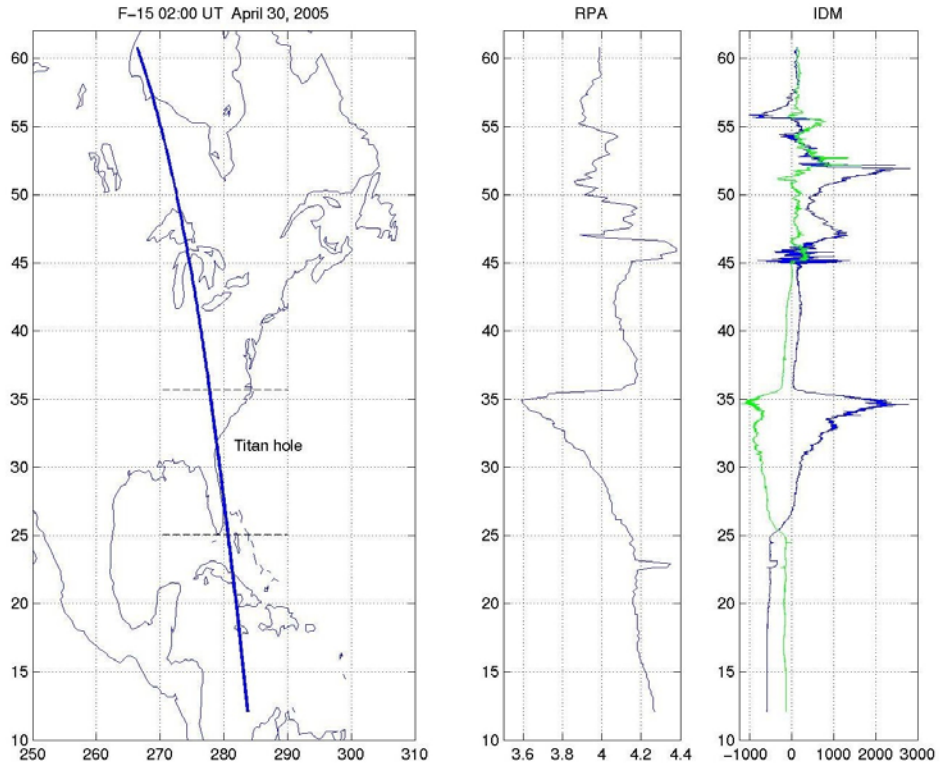
(a) RED in Wallops Island Ionosonde: $\Delta N_m F2$ ~-70%
(onset ~40$^{min}$ after Launch).






# Other Diagnostic Systems on 30 April 2005

(b) DMSP Pass at 02:00UT: $\Delta N_e$(~840 km) ~-20% (1$^{hr}$ 10$^{min}$ after Launch).



# SUMMARY

- TEC gradients have impact upon GPS navigation.
- TEC gradients can be caused by

SED onsets/terminations RED onsets

- Monitoring with routine radio/optical systems.
- Mechanisms fully understood.