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Title: Ionospheric ~~Total Electron Content (~~TEC~~)~~ Mapping from ~~Global Positioning System (~~GPS~~)~~ Orbit Using ~~Very High Frequency (~~VHF~~)~~ Radio Receivers

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Ionospheric TEC Mapping from GPS Orbit Using VHF Radio Receivers

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This paper presents an overview of an opportunity to produce 24/7 global total electron content (TEC) maps using very high frequency (VHF) radio receivers aboard the Global Positioning System (GPS) satellite constellation. Eleven such receivers are currently being used aboard the GPS constellation to detect and locate VHF lightning events across the globe. As a VHF lightning signal propagates from the ground to the satellites, the dispersive effects of the ionosphere and plasmasphere cause the higher frequency components of the signal to arrive at the satellites before the lower frequency components. By measuring the signal time-of-arrival at several frequencies we can derive the TEC between the lightning event and each satellite sensor that detects the event. Using multi-satellite time-difference-of-arrival techniques we can geolocate the lightning and the ionospheric penetration point of the lightning-satellite line-of-sight quite accurately. A single ground station currently provides regional TEC coverage over the western hemisphere. Four well-placed ground stations could eventually provide global, near-real-time TEC measurements to supplement existing systems, especially over broad ocean areas where current ground-based techniques have limited coverage. The paper will describe the measurement technique, discuss some preliminary mapping results and propose a path forward for possible implementation.

Ionospheric TEC mapping from GPS orbit using VHF radio receivers

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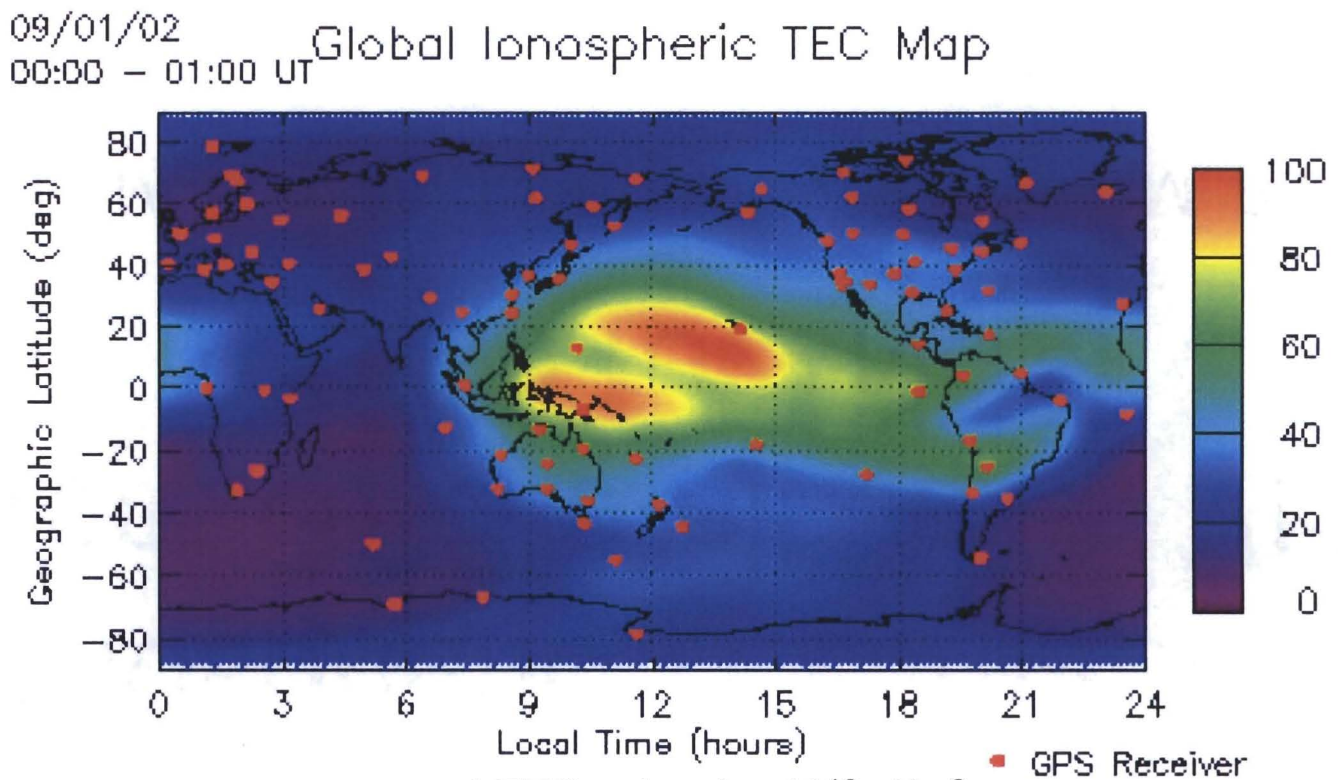
Motivation

Utilize dispersed lightning events detected by satellite-based VHF sensors to enhance global ionospheric total electron content (TEC) monitoring

JPL

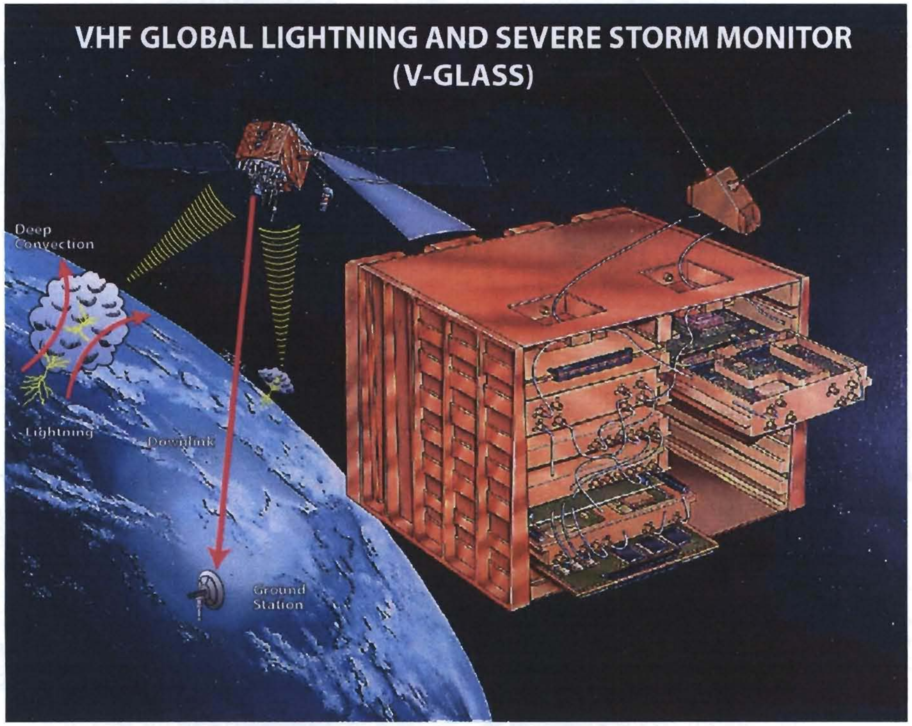


1 TEC unit = 1 x 10^{16} el/m^2

Outline

- Hardware platforms
  - V-GLASS
  - FORTE
- VHF TEC Monitoring Capabilities
  - $1/f^2$ traditional vs. Appleton-Hartree fitting method
  - Non-linear Ionospheric Removal Algorithm (NIRA)
- Summary

GPS: V-GLASS:
(VHF Global Lightning And Severe Storm Monitor)



MISSION

Global VHF Lightning and Total Electron Content (TEC) Monitoring

Lightning detection as proxy for monitoring deep convection

An extension of an already-scheduled DoD mission using existing h/w and s/w

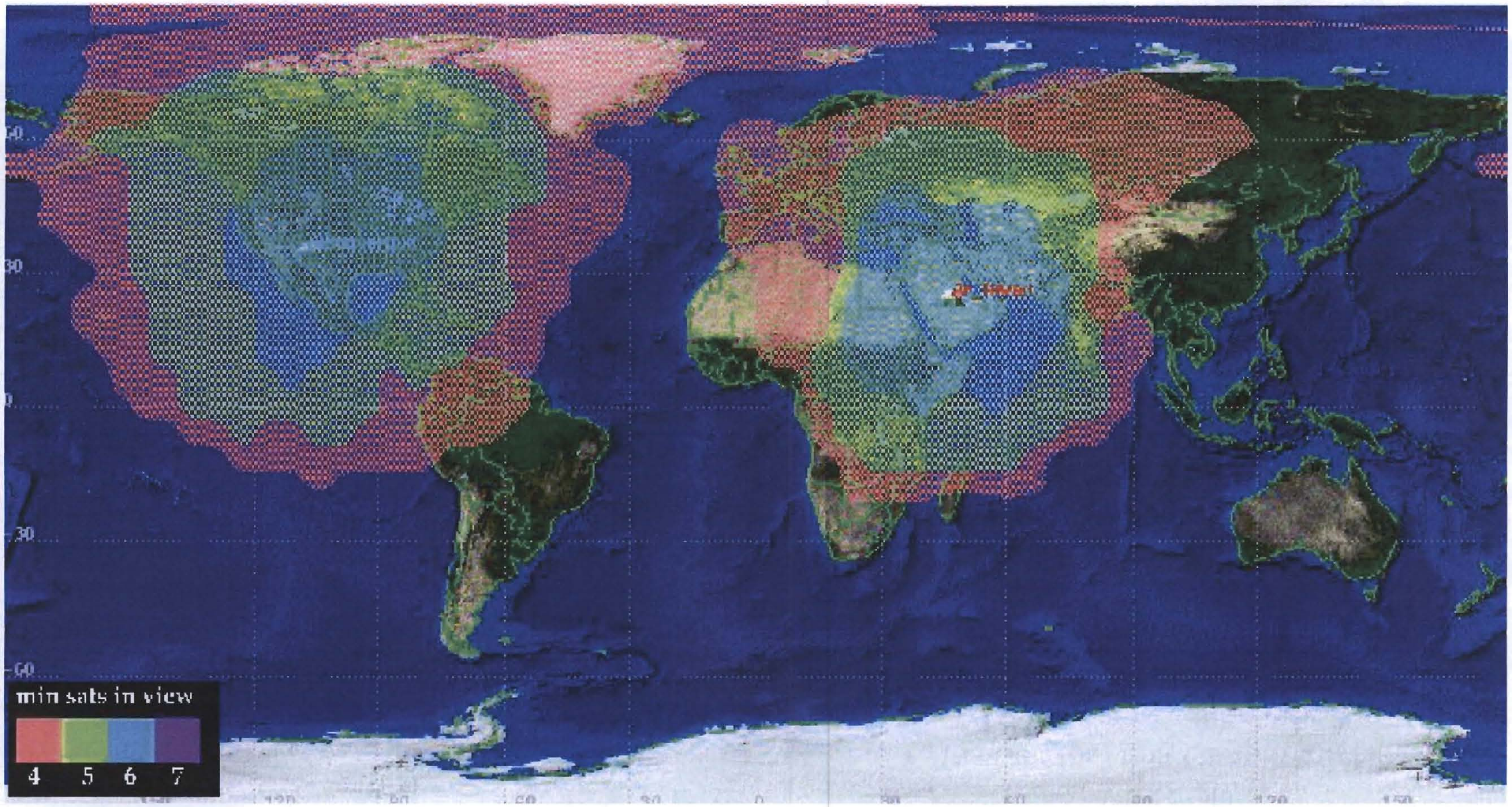
SENSORS

Type: Broadband VHF receivers
Capability: Event time, 3D location, TEC
Lightning/sec/sat: ~ 1
Coverage: 1 gnd stat. (regional, near real-time)
~4 gnd stats. (global, near rea-time)

PLATFORM

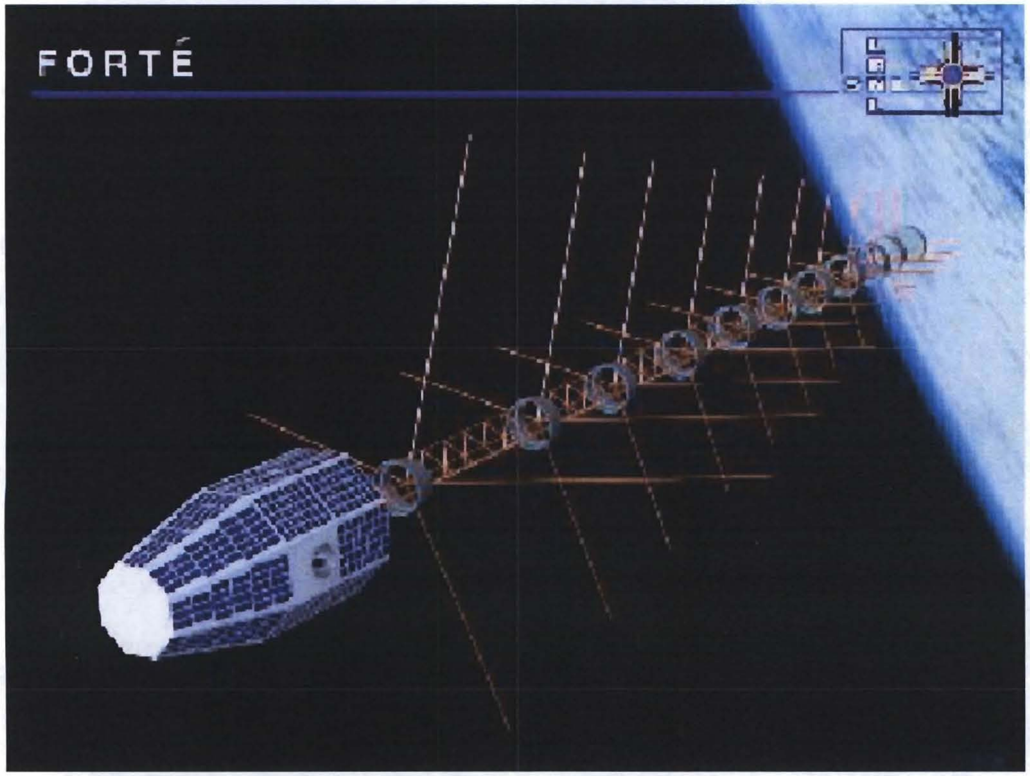
Platform: GPS Constellation (24 Block IIF/III satellites)
Altitude: 20,000 km
Launches: 2009-2016

V-GLASS Coverage (Lightning/TEC)



Typical continental coverage for ground stations in Albuquerque, NM (current) and the Eastern Hemisphere (e.g.).

FORTE: Fast On-Orbit Recording of Transient Events



MISSION

- Testbed for Next Generation Nuclear EMP Sensor Technology.
- Space-based Lightning Detection.

PLATFORM

Altitude: ~ 825 km
Inclination: 70 degrees
Launched: August 29, 1997

SENSORS

Type: Broadband VHF receivers
- (26 – 300 MHz)
- 1 ms or better resolution

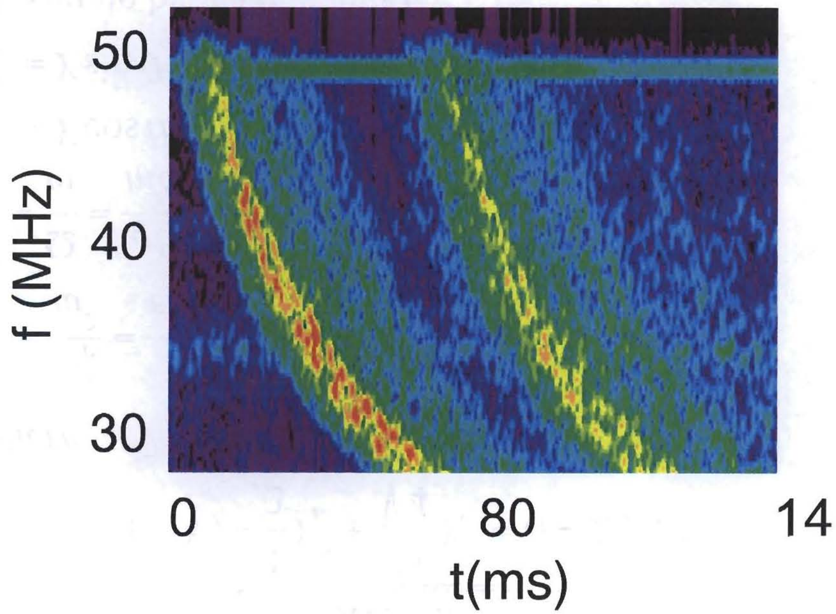
Photodiode (PDD)
-15 mS resolution

CCD Imager (LLS)
-10 km location accuracy

Data: Optical/VHF Waveforms
Event times
Event location

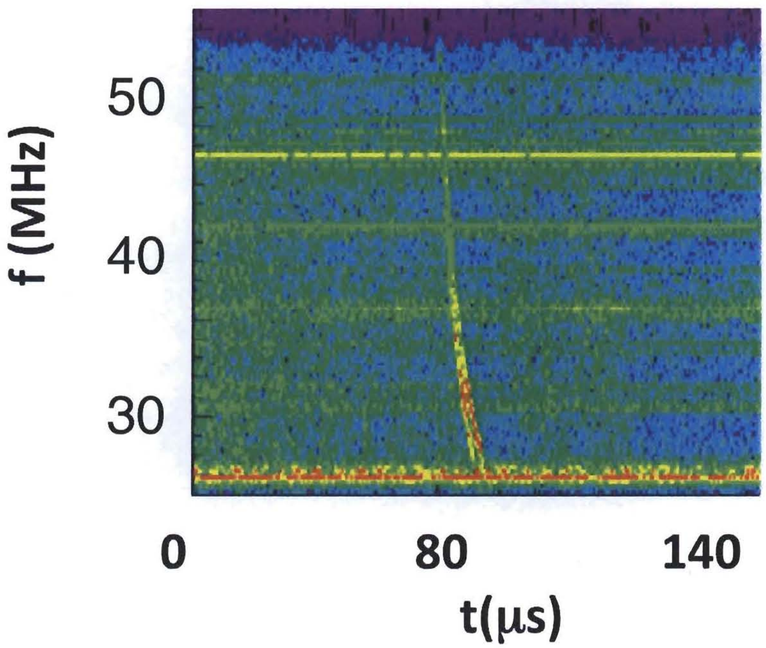
GPS-Satellite-observed VHF Lightning Types

FORTE Strong VHF Pulse



- In-cloud discharge, generation mechanism unknown
- Impulsive (~ 10 ms); compact (100's meters)
- Weak/no optical emission (Light, '02)
- Fundamentally linked to convection (Suszcynsky, '03)
- Indicator of severe weather ? (Wiens, '05)

FORTE Cloud-Ground (-CG)



- Cloud-to-ground discharge (attachment) (Jacobson, '02)
- Intense, impulsive (~ 100 ns), common
- Fundamentally linked to convection
- Vertically oriented dipole emission (Shao, '01, '04)

TEC Determination from Dispersed RF Pulse:

$1/f^2$ vs. Appleton-Hartree

Appleton-Hartree Dispersion Equation

$$n^2 = 1 - \frac{X(1-X)}{(1-X) - \frac{1}{2}Y_t^2 \pm \sqrt{\frac{1}{4}Y_t^4 + (1-X)^2 Y_L^2}};$$

where

$$X = \frac{\omega_p^2}{\omega^2} = \frac{ne^2}{\varepsilon_o m \omega^2};$$

$$Y = \frac{\Omega}{\omega} = \frac{qB}{m\omega};$$

$$Y_L = Y\cos\vartheta;$$

$$Y_T = Y\sin\vartheta;$$

ϑ = angle between k and B

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Taylor-expanded form of Appleton-Hartree Dispersion Equation ("quasi-longitudinal approximation")

$$n \approx 1 - \frac{1}{2}\left(\frac{f_p}{f}\right)^2 + \frac{s}{2}\frac{f_p^{\,2}\Omega}{f^3}\cos\vartheta - \frac{1}{4}\frac{f_p^{\,2}}{f^4}\left[\frac{f_p^{\,2}}{2} + \Omega^2(2-\sin^2\vartheta)\right] + \ldots$$

Only if

$$\frac{1}{4}\frac{Y_t^4}{Y_L^2} << (1-X)^2$$

Wave freq. >> Plasma freq.
and
Propagation not perpendicular (within 0.5°) to B-field

TEC Determination from Dispersed RF Pulse:

$1/f^2$ vs. Appleton-Hartree

Appleton-Hartree Dispersion Equation

$$n^2 = 1 - \frac{X(1-X)}{(1-X) - \frac{1}{2}Y_t^2 \pm \sqrt{\frac{1}{4}Y_t^4 + (1-X)^2 Y_L^2}};$$

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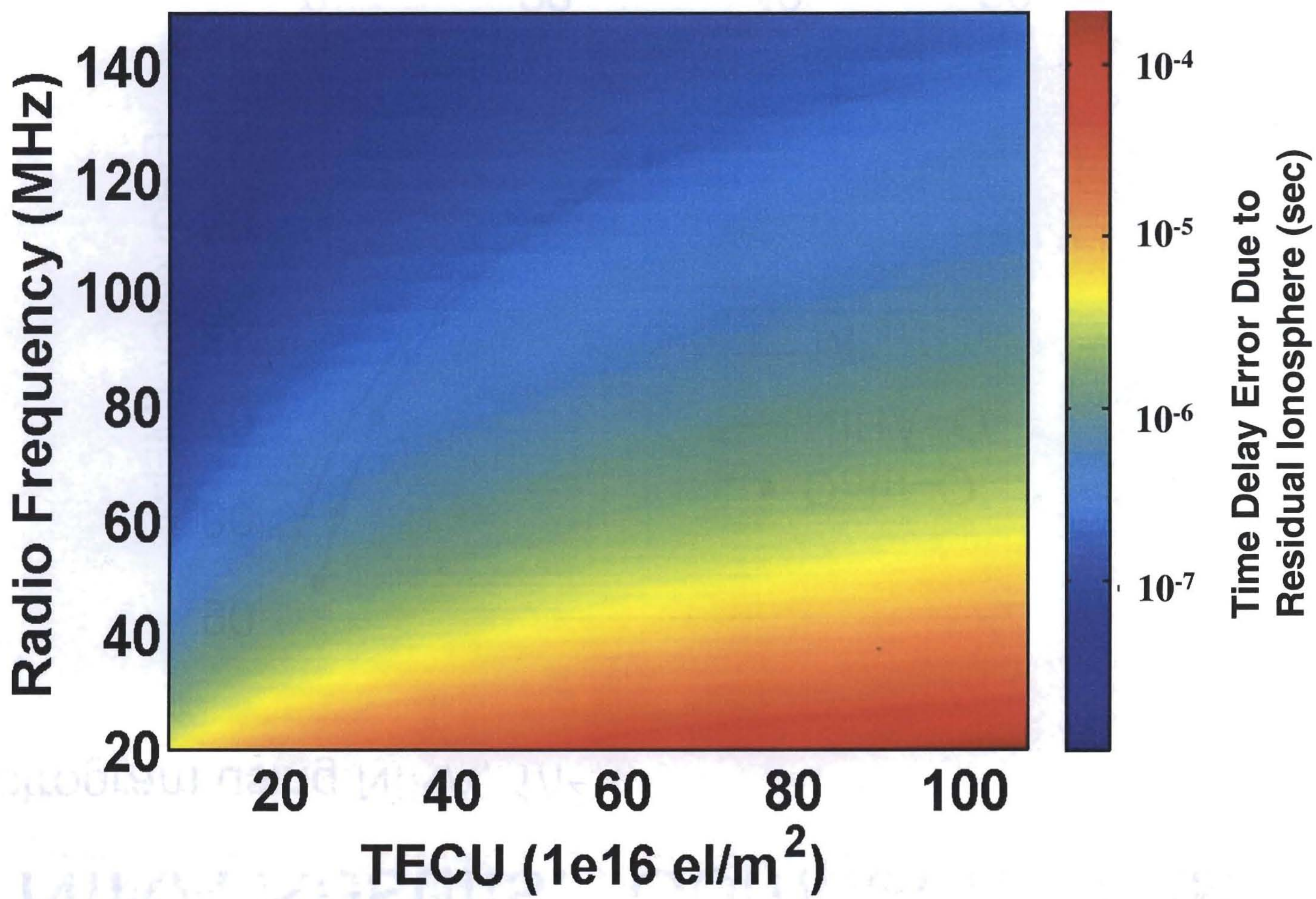
$1/f^2$ approximation

Only if

$$\frac{1}{4}\frac{Y_t^4}{Y_L^2} << (1-X)^2$$

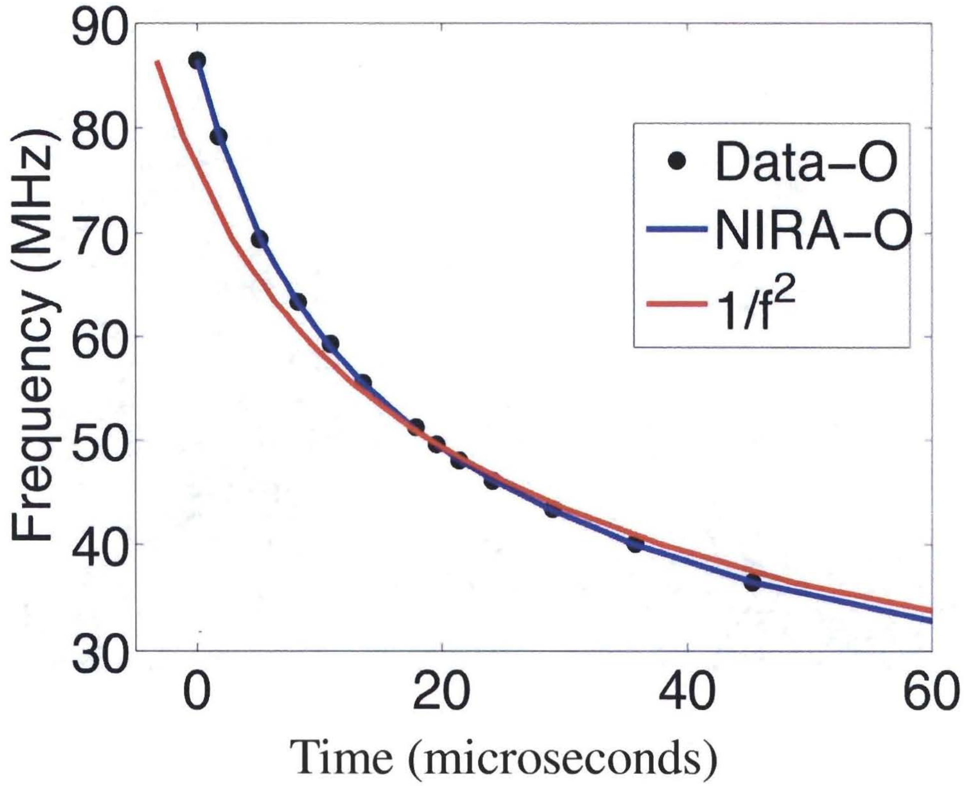
Wave freq. >> Plasma freq.
and
Propagation not perpendicular (within 0.5°) to B-field

Cost of Using Quasi-Longitudinal Approximation

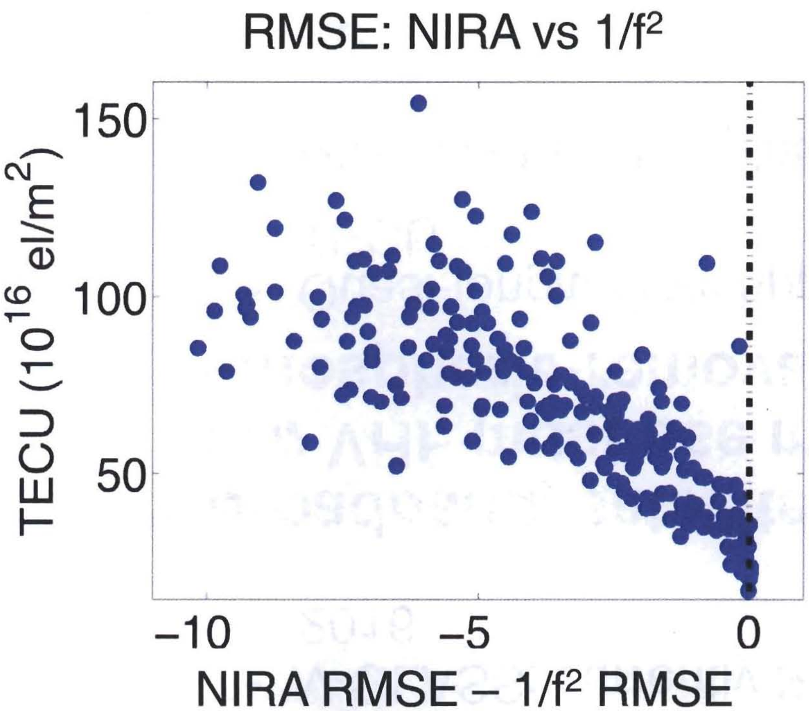


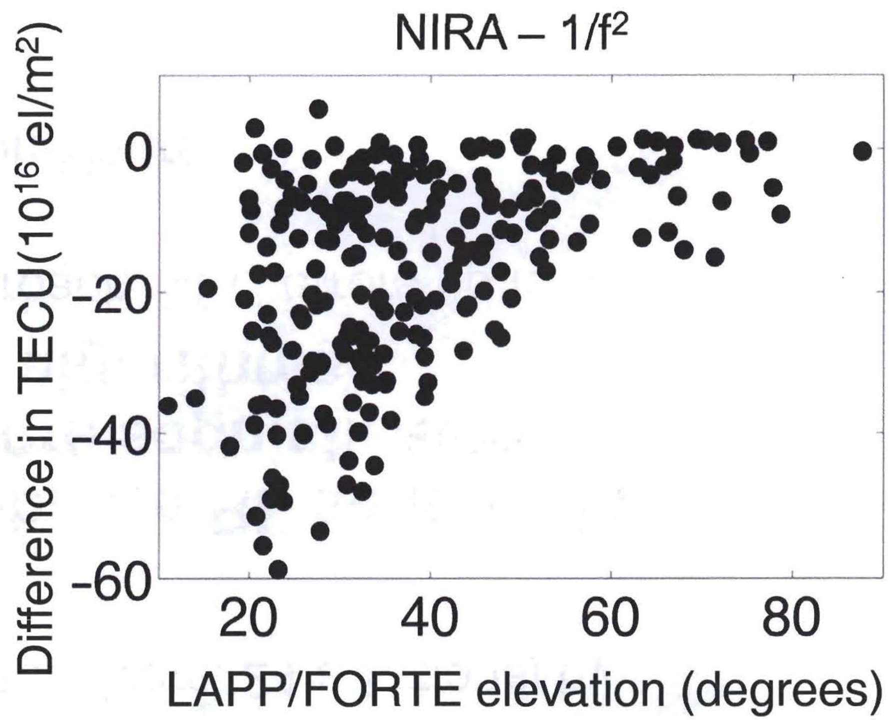
NIRA Results: Comparing Fits

- Fit spectrogram using NIRA, $1/f^2$



NIRA Results: NIRA versus $1/f^2$





- NIRA consistently has lower RMSE than $1/f^2$ across wide range of TEC conditions

- $1/f^2$ consistently overestimates TEC compared to NIRA
- TEC difference between NIRA and $1/f^2$ can be as much as 60 TECU

Summary

- **Lower VHF satellites to be used to enhance global TEC monitoring capabilities**
  - FORTE (testbed)
  - V-GLASS: currently 9 receivers, 24 additional by 2016
- **Broadband, satellite-based RF sensors in low VHF must use more sophisticated ionospheric-removal algorithms**
  - Quasi-longitudinal approach: TEC errors up to 60 TECU
  - NIRA fits to full Appleton-Hartree