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# **Equatorial Atmospheric & Ionospheric Modeling for Space Surveillance**

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# Outline



## → Introduction

- Kwajalein Missile Range (KMR) long range tracking radars
- Ionospheric correction methods
- KMR ionospheric conditions
- KMR model overview
- Real-time GPS TEC determination
- Accuracy evaluation
- Summary



# ALTAIR/TRADEX Characteristics



**ALTAIR**  
VHF, 158 MHz  
UHF, 422 MHz



- US Army space surveillance and missile reentry vehicle tracking radars
- Equatorial location
- Two frequency tracking
  - ALTAIR: UHF/VHF
  - TRADEX: L-band/S-band

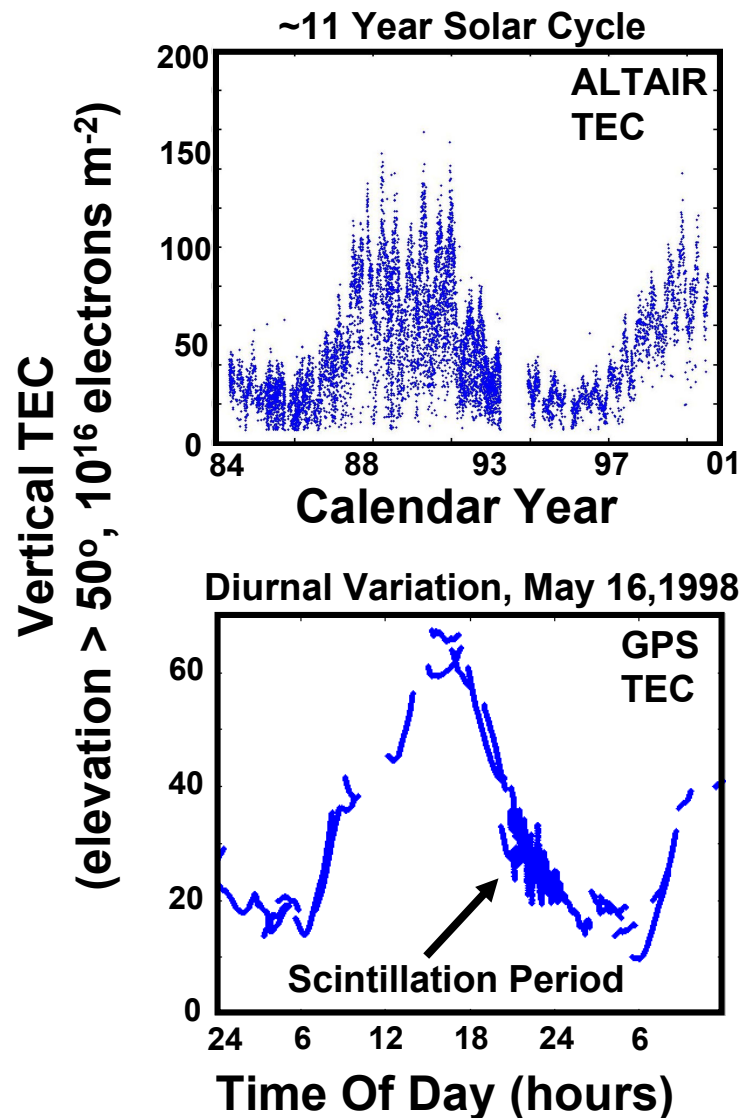


**TRADEX**  
L-band, 1320 MHz  
S-band, 2950 MHz

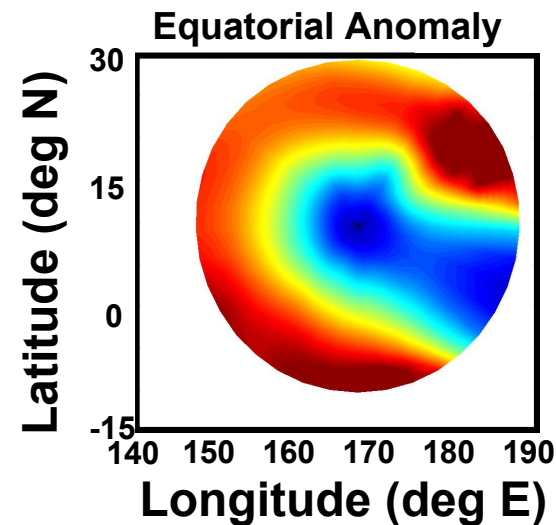
- Accuracy goal for ionospheric correction:
  - Within 6.5 TEC units; 100 m range at VHF or 14 m at UHF



# Impact of Ionosphere at KMR

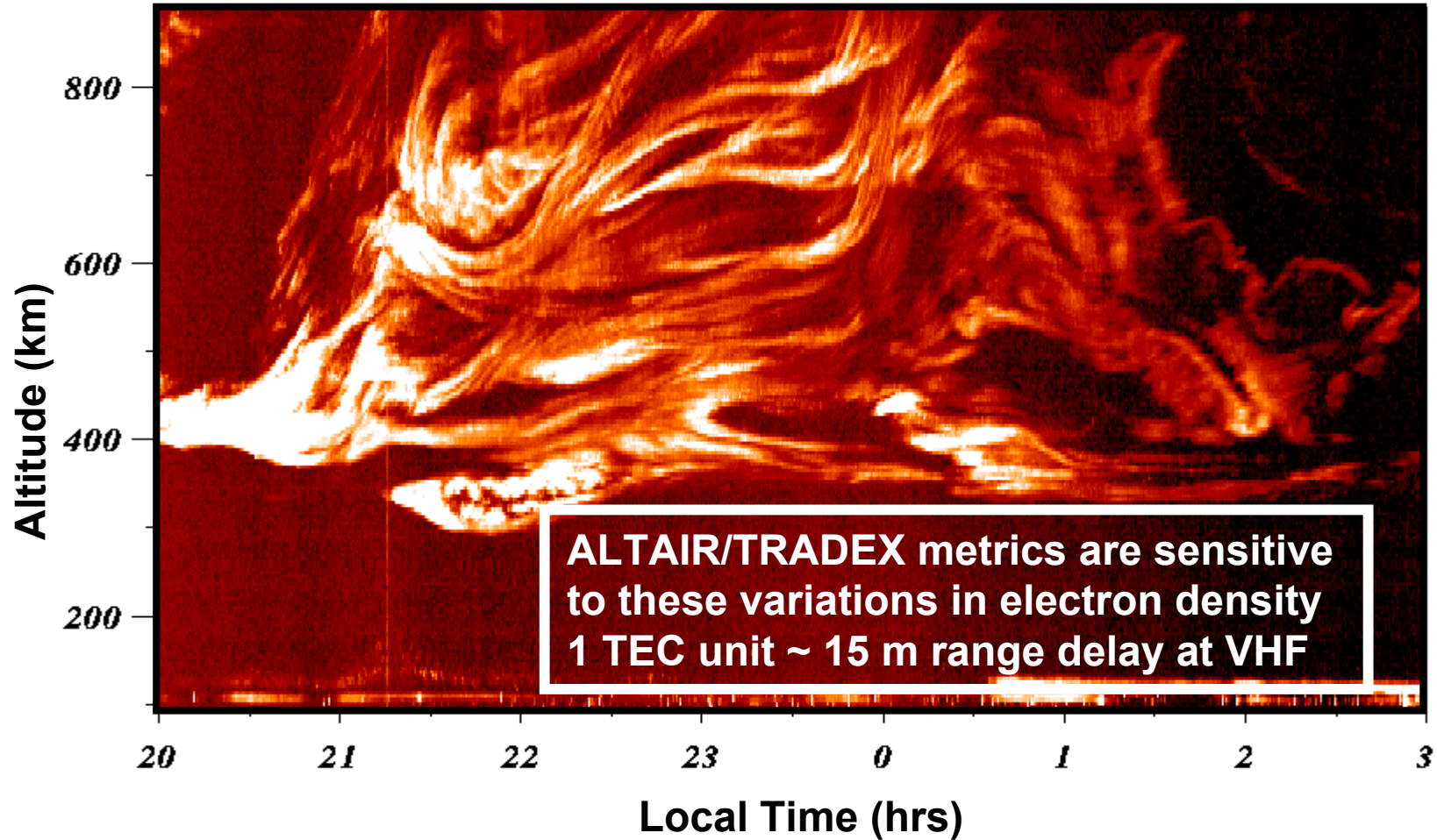


- Sophisticated modeling technique needed to meet space surveillance accuracy requirements
- Solar cycle, seasonal and diurnal enhancements, equatorial anomaly, TIDS, Plumes, E and F-region irregularities and enhanced plasmasphere





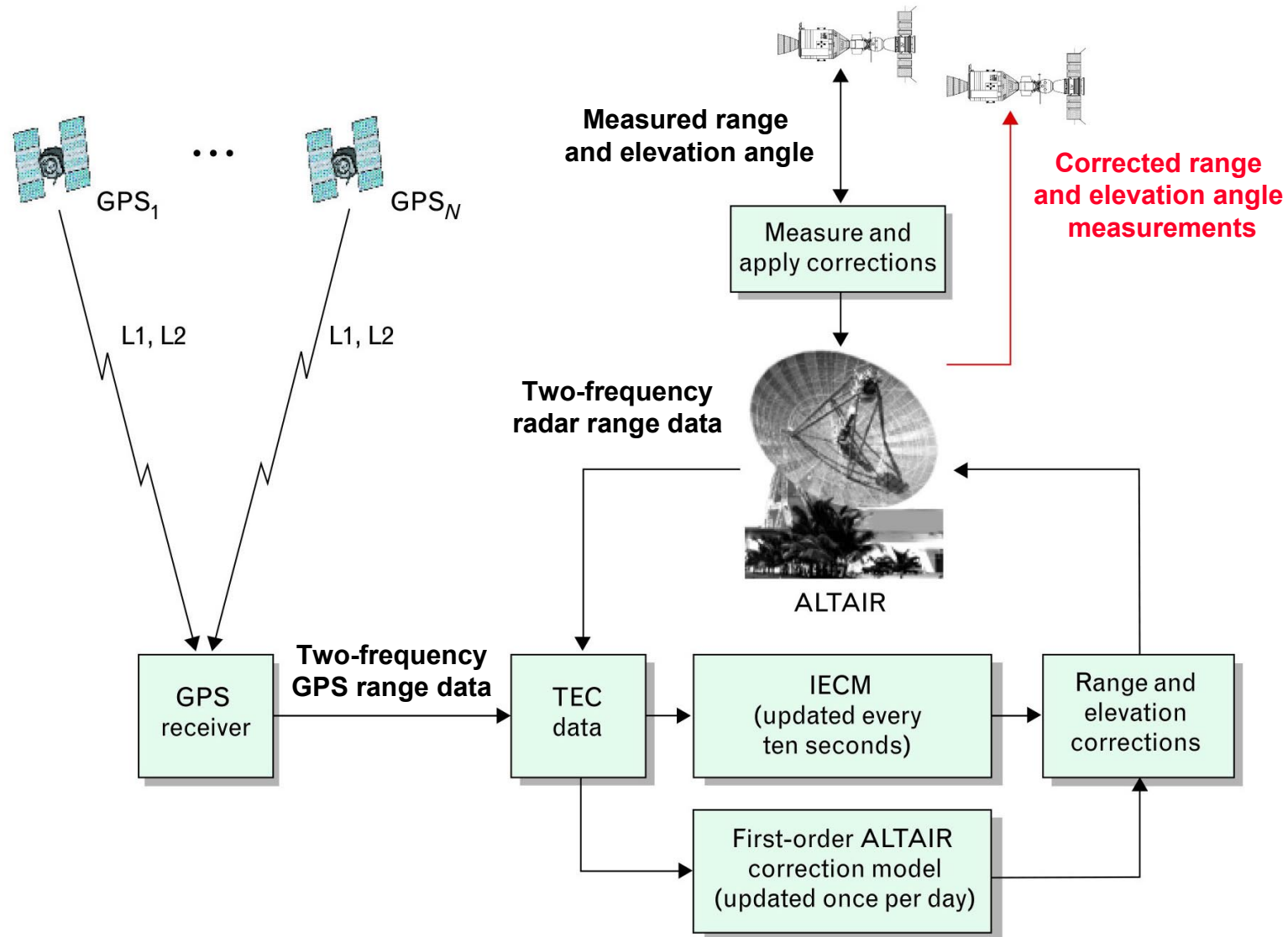
# Equatorial Spread-F



*Data obtained at Jicamarca Oct 22, 1996 (50 MHz)*

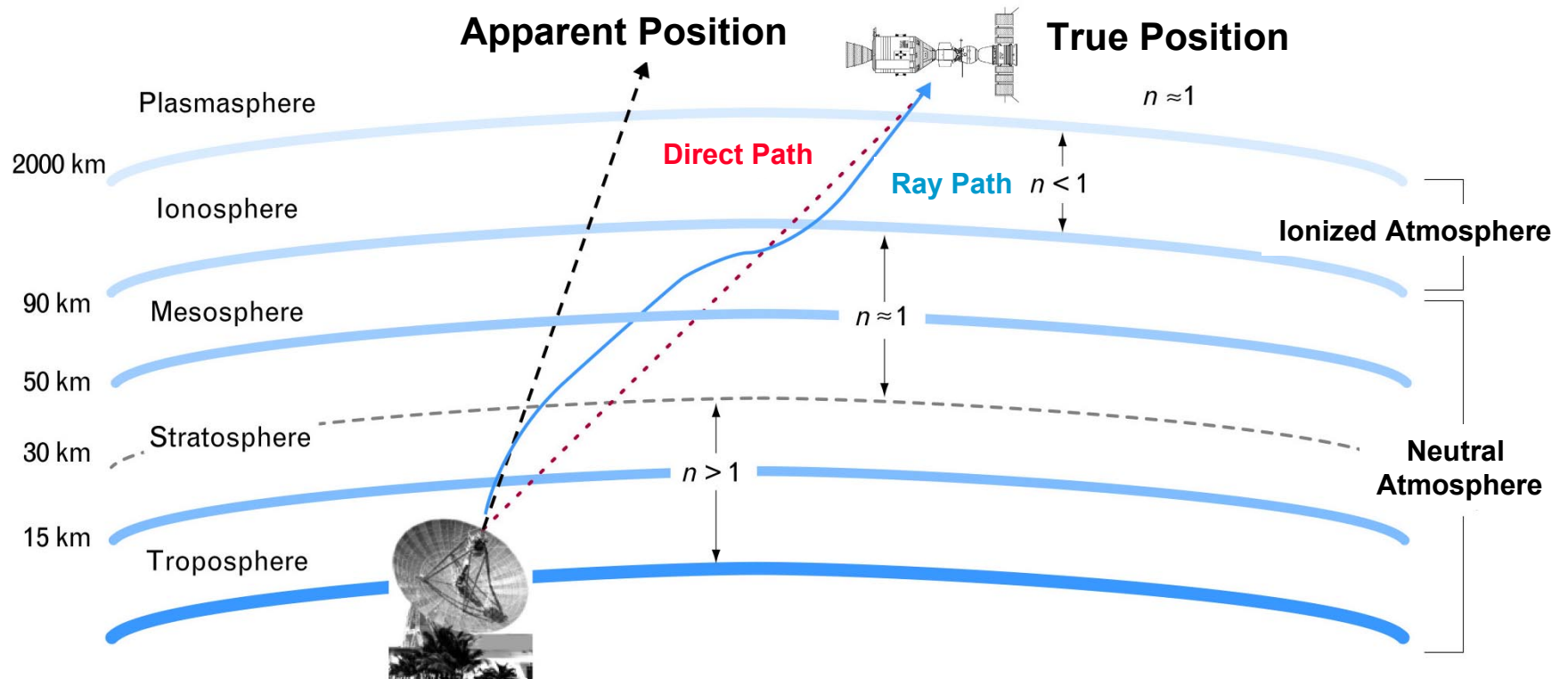


# Ionospheric Correction Methods





# Model Ray Path Geometry





# Outline



- **Introduction**
- ➔ **KMR model overview**
  - **Mean Tropospheric model**
  - **First-Order ALTAIR Ionospheric model**
  - **New Ionospheric Error Correction Model**
- **Real-time GPS TEC determination**
- **Accuracy Evaluation**
- **Status and summary**



# Tropospheric Model

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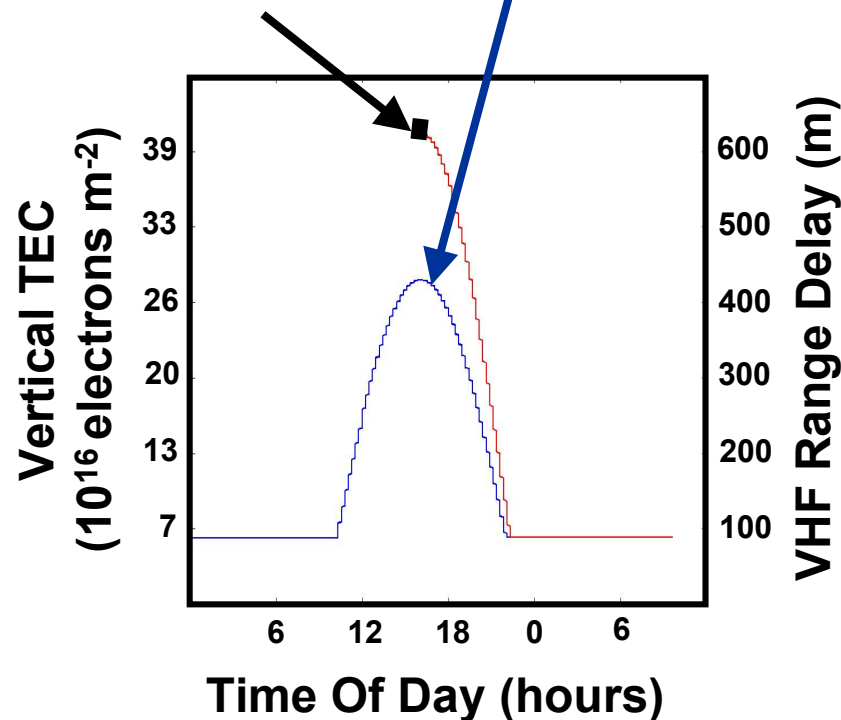
- **Mean tables are used for all real-time correction**
  - Covers 0-90 km altitude, (inert portion)
  - Troposphere, Stratosphere, Mesosphere
- **Range and elevation corrections as a function of range and elevation**
- **Derived from KMR radiosonde data spanning 1967-1976**
  - Function of temperature, pressure and relative humidity
- **Radiosonde data are collected prior to each reentry mission**
  - Post processed to obtain maximum accuracy for reentry data reduction



# First Order Vertical TEC Model

$$\text{Vertical TEC} = \phi_D + \phi_Y (660. + 740. (\cos(lt + ha + \phi_S)))$$

ALTAIR Vertical  
TEC Measurement

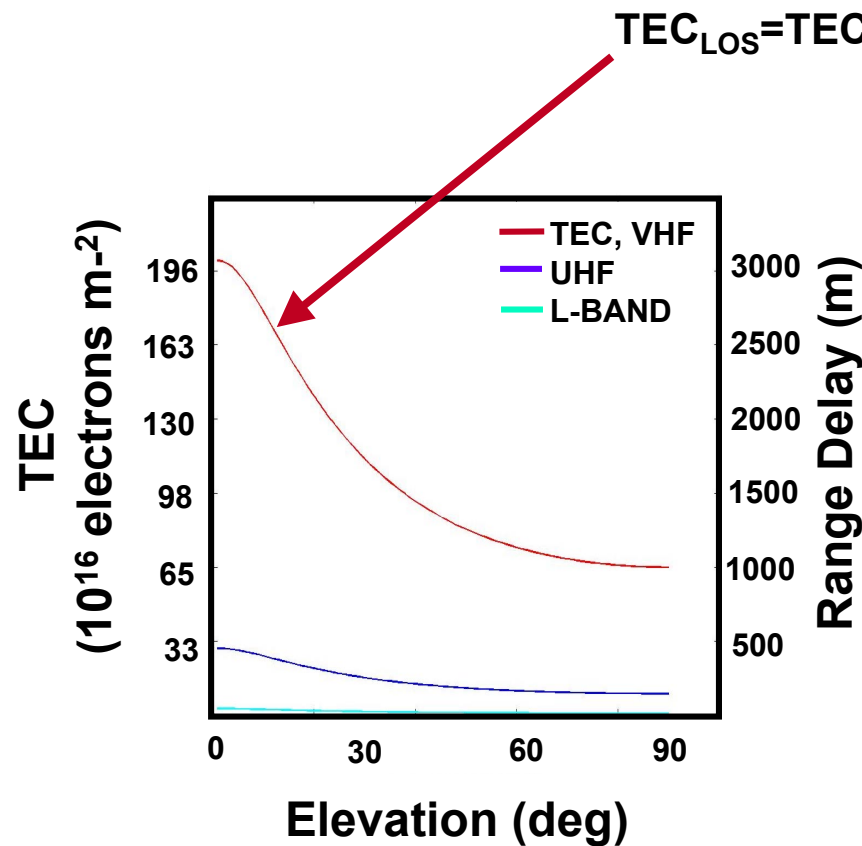


- Maintains knowledge of TEC at ALTAIR's vertical
- Derived from ALTAIR backscatter data
- In use from 1983 to 1998

$\phi_D$  = function of day of year  
 $\phi_Y$  = solar cycle amplitude factor  
 $\phi_S$  = seasonal phase term  
 $ha$  = hour angle of radar pointing  
 $lt$  = local time



# First Order Elevation Mapping Function

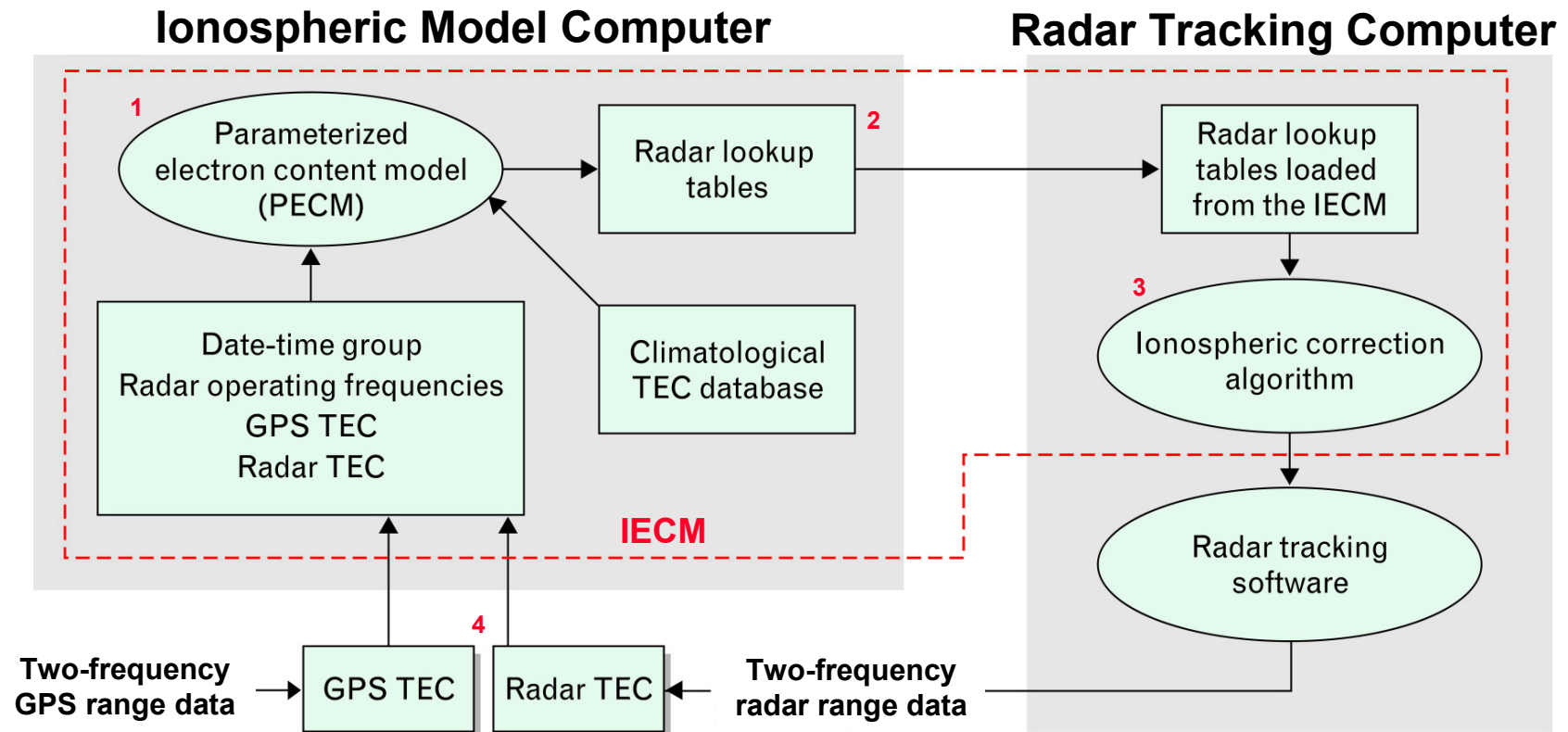


- “Maps” vertical TEC to arbitrary elevation and height
- Derived from multi-frequency reentry mission radar data
- Peak density height fixed at 400 km
- In use since ~1978

$TEC_{LOS}$  = line of sight TEC  
 $TEC_{VERT}$  = vertical TEC  
 $f(e)$  = elevation factor  
 $f_x h$  = height scale factor



# IECM and Radar Architecture





# PECM Features

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- **540 Base electron content models (ECM)**
- **ECMs are indexed by solar activity and seasons**
- **60 ECMs per day: 30 and 15 minute time separation**
- **Mean F10.7 value and time used to select specific ECM**
- **Real-time TEC data are used to adjust the ECMs**
- **Two dimensional ray trace is performed to produce IS file**
  - **Troposphere and ionosphere**
  - **True range and elevation as a function of apparent azimuth, elevation and range**



# Outline



- Introduction
- KMR model overview
- ➔ Real-time GPS TEC determination
  - Receiver installation
  - GPS TEC determination and calibration
- Accuracy evaluation
- Status and summary



# GPS Receiver Installation



- Site survey was executed to determine best receiver location
- Installation chosen to reduce multipath effects
- Temperature controlled
- Installation has proven to be trouble free



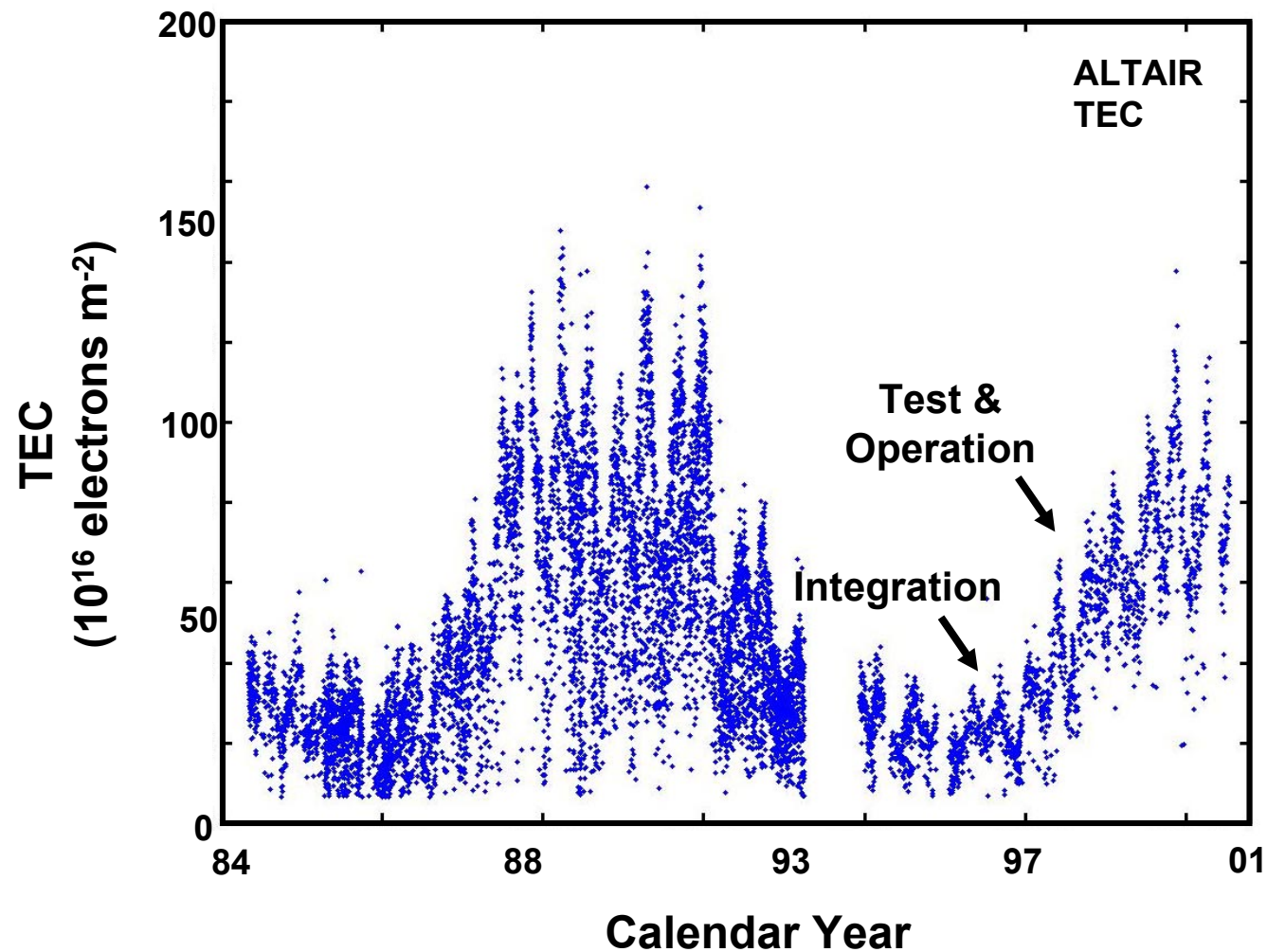
# Outline



- Introduction
- KMR model overview
- Real-time GPS TEC determination
- ➔ Accuracy evaluation
  - Radar versus IECM TEC
  - Calibration orbit residual error
- Status and summary

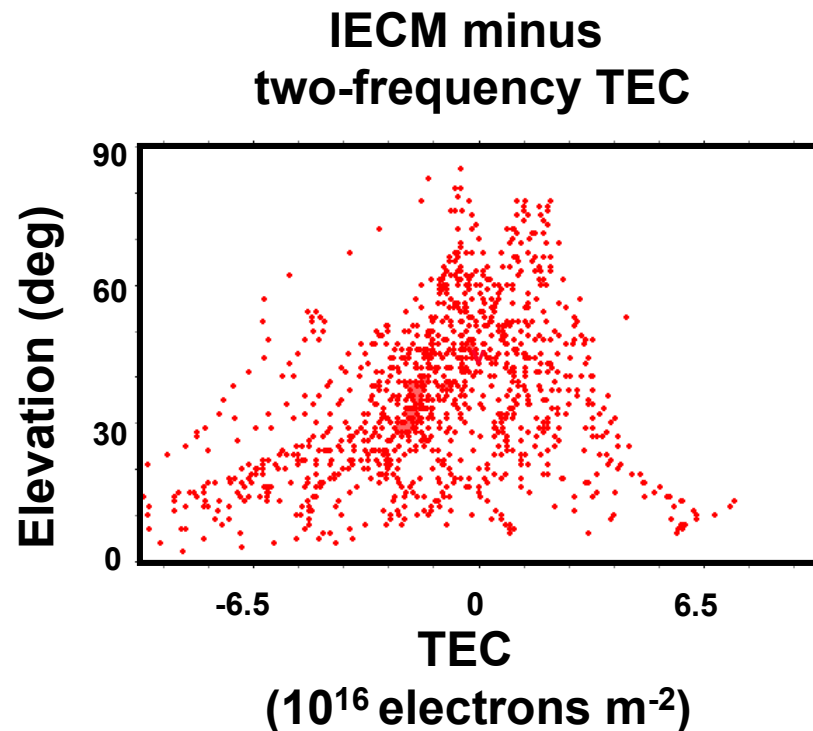


# Model Integration and Test





# Two Frequency Radar vs IECM TEC



- IECM/GPS versus radar line of sight TEC difference computed
- Data collected during **low solar activity** at altitudes between 700 km and 1500 km

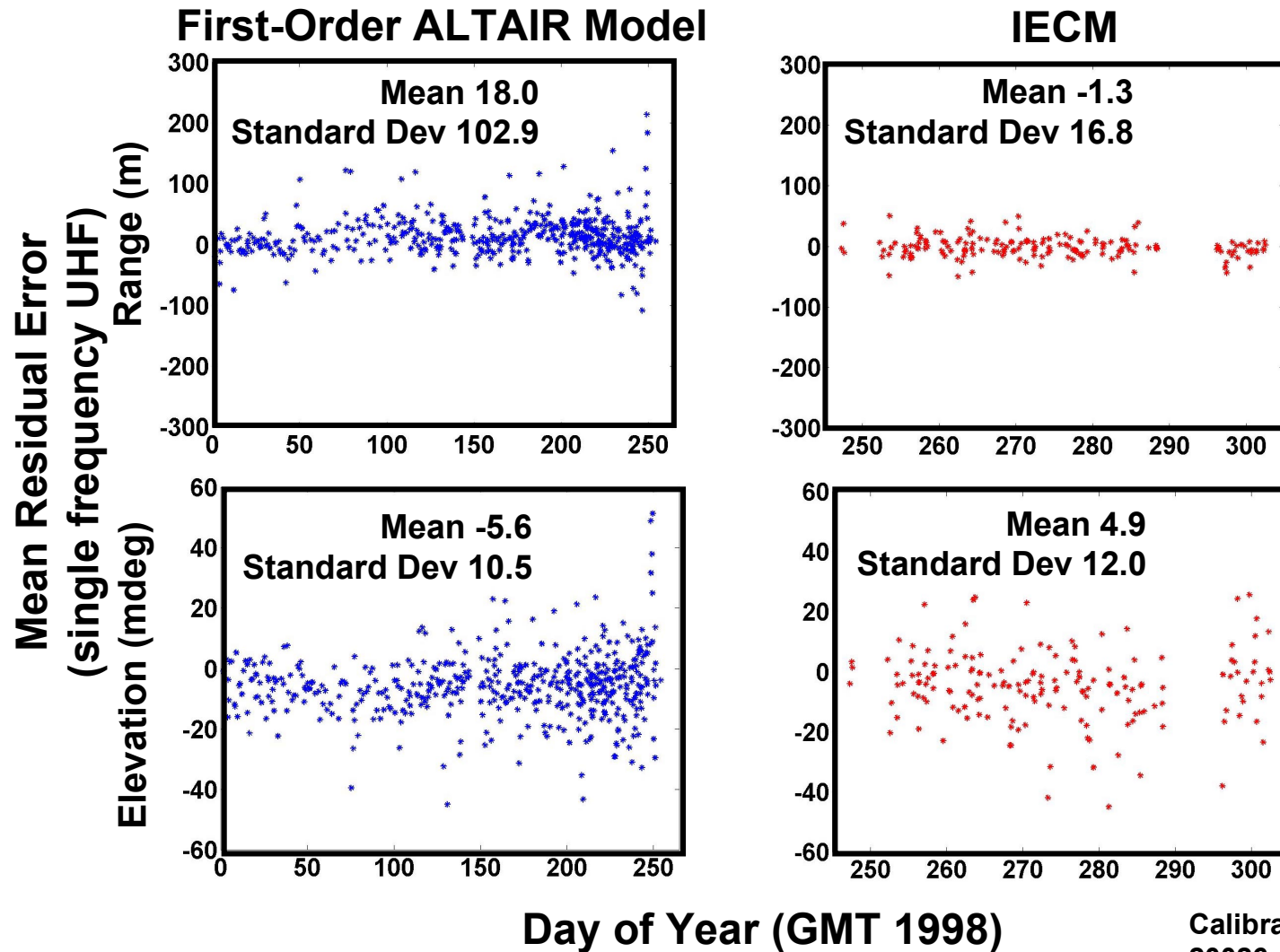
## Results:

- Within 6.5 TEC or 100 m VHF range above 20 degrees elevation



# Range and Elevation Measurement Error

*Altitude > 5000 km*





# Summary



- **The KMR atmospheric environment is challenging to model**
- **The first order ALTAIR model is inadequate**
  - **Effective only during periods of low solar activity**
- **The IECM combined with GPS TEC has proven effective**
  - **IECM is fully integrated and operational**
  - **Slated for use for the KMR radar modernization effort**
- **IECM accuracy results**
  - **Accurate during low and moderate solar activity**
  - **Significant improvement in single frequency UHF range accuracy at ALTAIR**
  - **Room for improvement during high solar activity**



# Metric Calibration Satellites



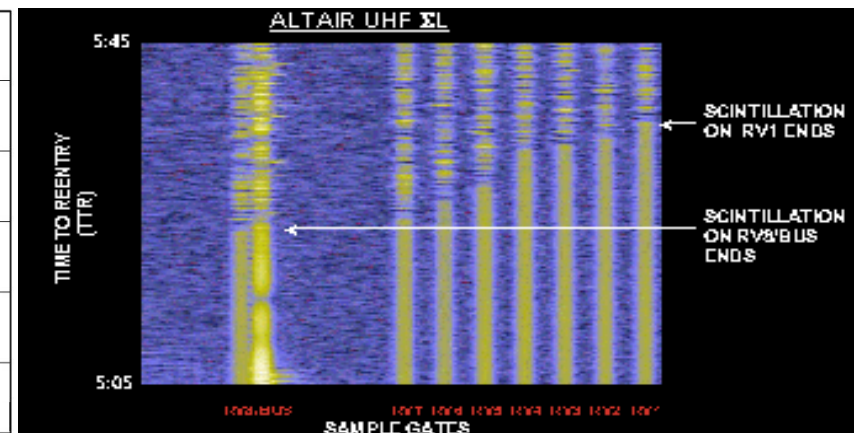
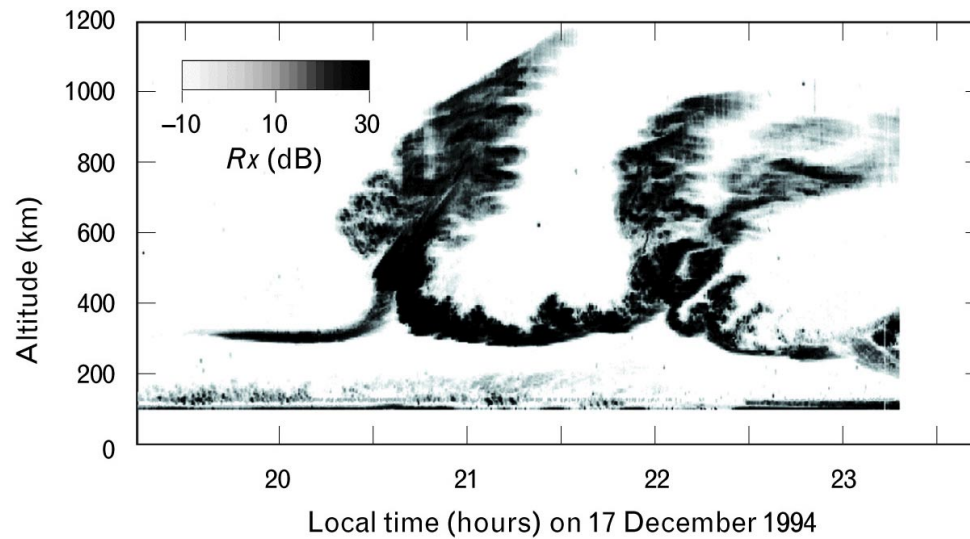
| <b>Name<br/>SCC #</b>     | <b>Semi-major<br/>axis (km)</b> | <b>Position<br/>Accuracy*</b> |
|---------------------------|---------------------------------|-------------------------------|
| <b>Lageos1<br/>8820</b>   | <b>12270.01</b>                 | <b>~1m</b>                    |
| <b>Lageos 2<br/>22195</b> | <b>12162.06</b>                 | <b>~1m</b>                    |
| <b>Cosmos<br/>19751</b>   | <b>25503.06</b>                 | <b>~25m</b>                   |
| <b>Cosmos<br/>20026</b>   | <b>25499.44</b>                 | <b>~25m</b>                   |

**\*Estimate of upper bound**

- **Precision orbits determined using NASA laser ranging and US Space Command Space Surveillance Network sensors**
- **Position accuracy smaller than radar measurement error for Lageos 1 and Lageos 2**



# Radio Frequency Scintillation

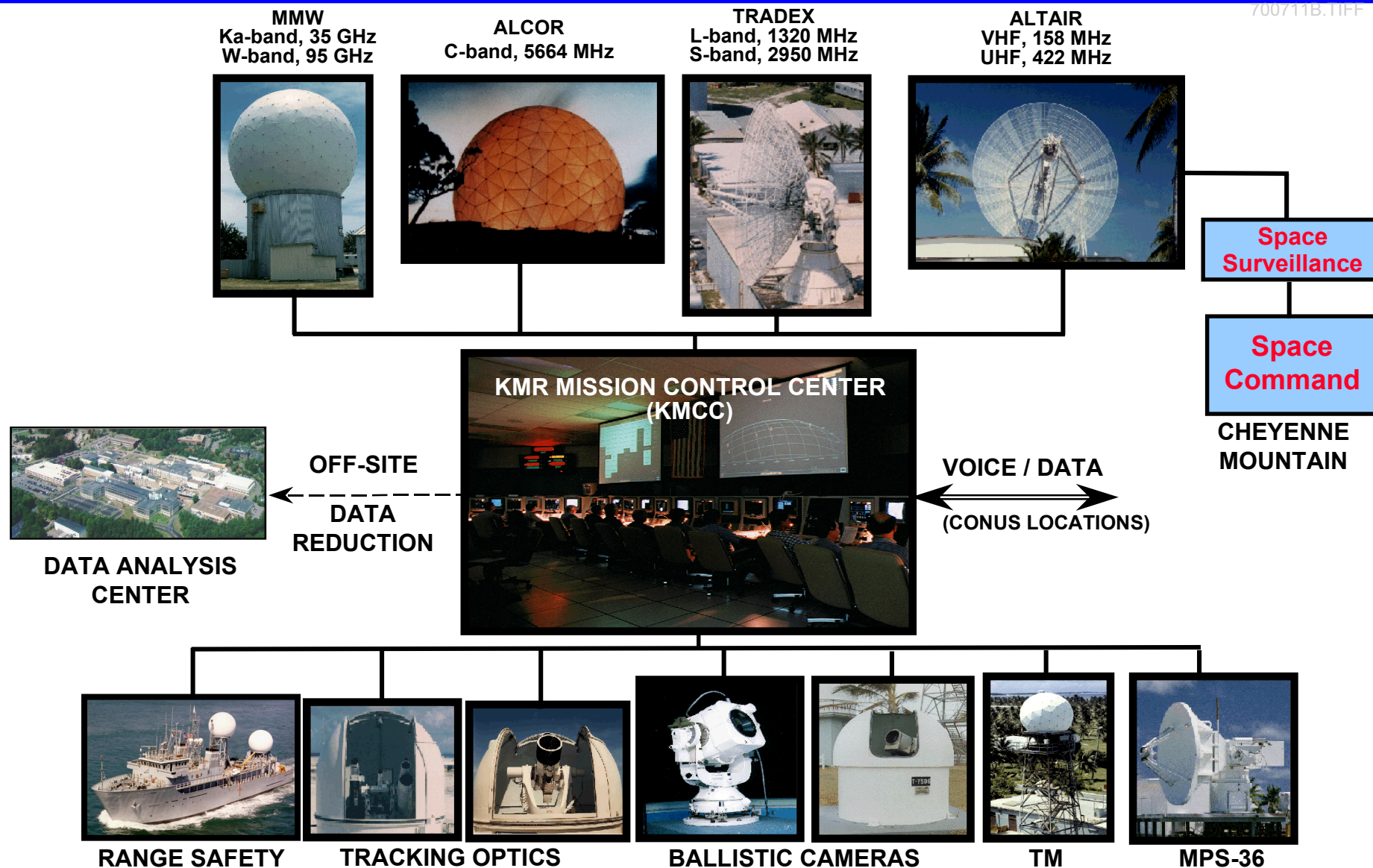




# KMR Sensor Network

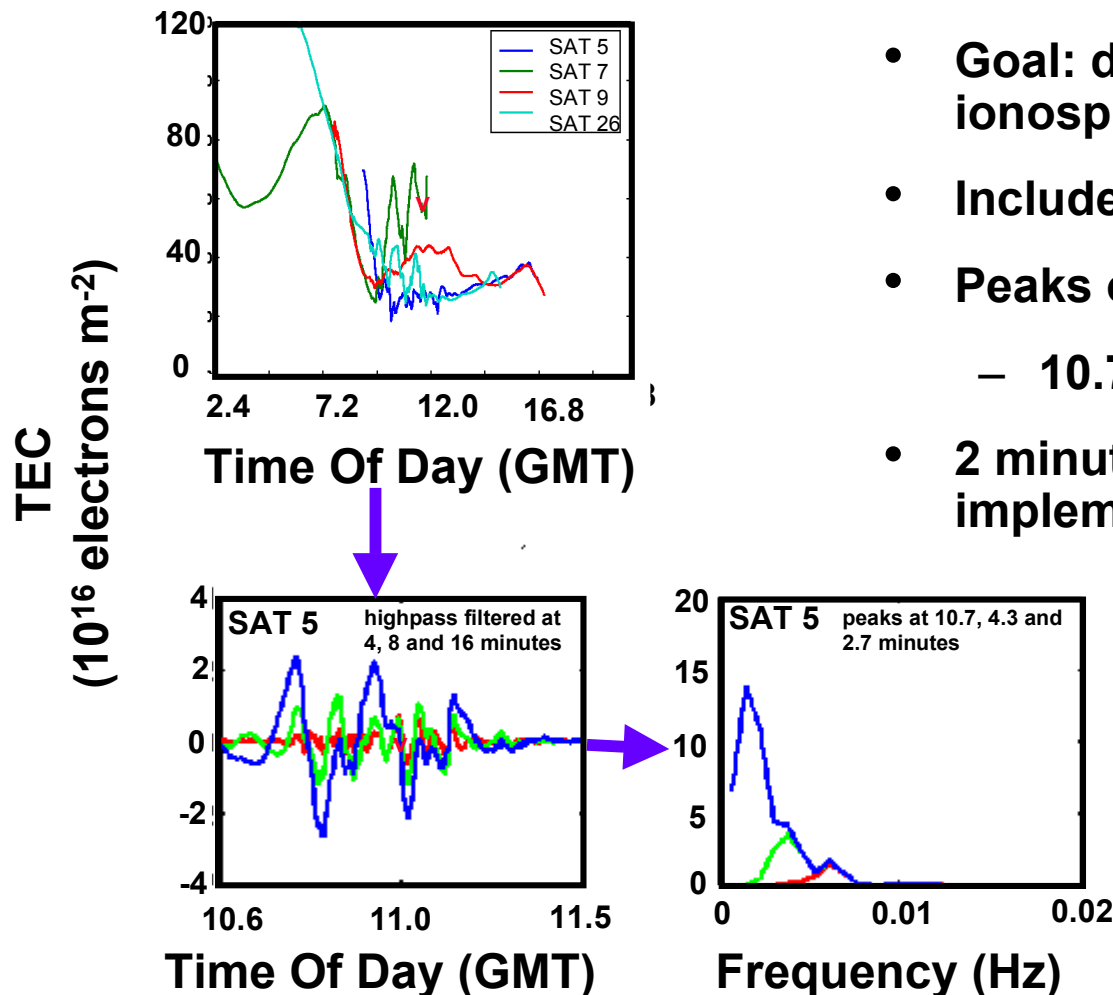


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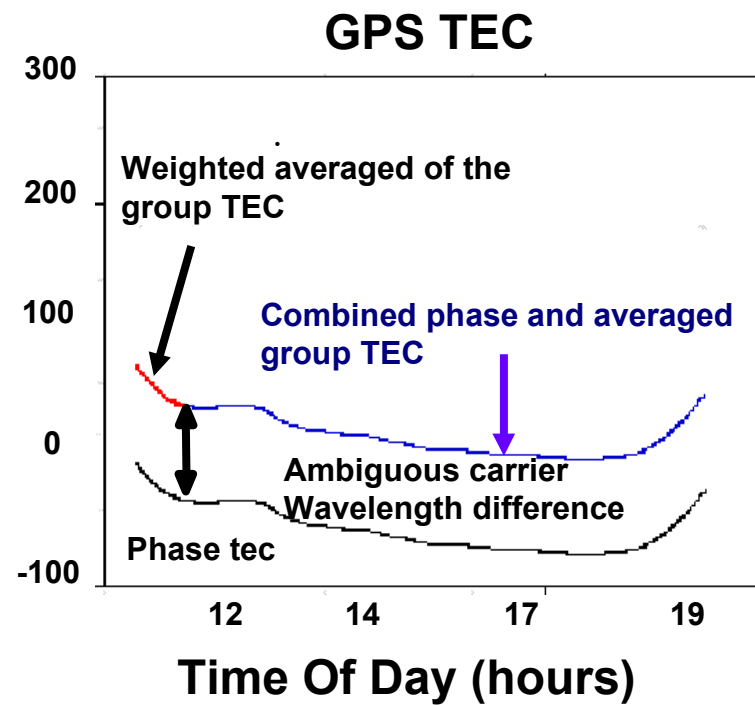
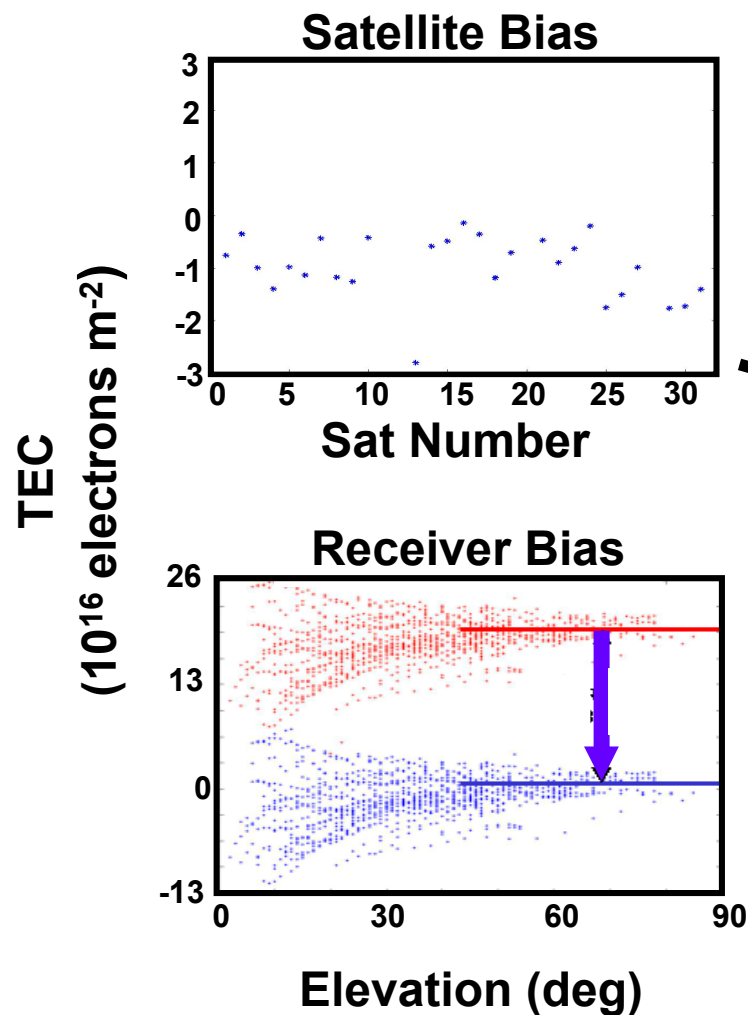
# Effect of Ionospheric Instabilities on TEC



- Goal: determine frequency of ionospheric fluctuations
- Included scintillation period
- Peaks occurred at:
  - 10.7, 4.3 and 2.7 minutes
- 2 minute update rate implemented for IECM



# GPS TEC Determination and Calibration





# Ionospheric Error Correction Model



- **Parameterized Electron Content Model (PECM)**
  - Base theoretical climatology model
  - Derived from global model PRISM
  - Real time data update algorithm
- **Ionospheric Specification Manager**
  - Manages radar correction table message traffic
- **Ionospheric Correction Algorithm**
  - Used to compute true to apparent and apparent to true range and elevation corrections from correction tables
- **TEC data reduction software**
  - Used to compute *real time* GPS and radar TEC