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On the Variability of TEC in the Indian Low Latitude Sector

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On the Variabilities of TEC in the Indian Low Latitude Sector

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Contents:

- Basic concepts of Electrojet and Equatorial Ionization Anomaly (EIA)
- Morphological features of GPS -TEC measured at four different Indian Latitudes
  - *diurnal, day to day, seasonal and latitudinal variations*
- TEC and solar activity indices
  - *Sunspot Number, Solar Flux (F 10.7), EUV*
- EIA and its association with Equatorial Electrojet (EEJ) using GPS TEC from 9 different stations (8.47^0N to 31.09^0N) along the common meridian of 77^0E
- Variations in the grid (5^0 x 5^0) based measurements of GPS TEC in the Indian low latitude sector

EQUATORIAL ELECTROJET

Definition

- The **equatorial electrojet (EEJ)** is a narrow band of current at the E-region altitudes of the ionosphere flowing eastward along the dayside dip equator.

Generation Mechanism

- The worldwide solar-driven wind flowing across filed lines results in the E-region Sq-current system that produces an intensified eastward electric field at the equatorial day side of the ionosphere.

Measurement

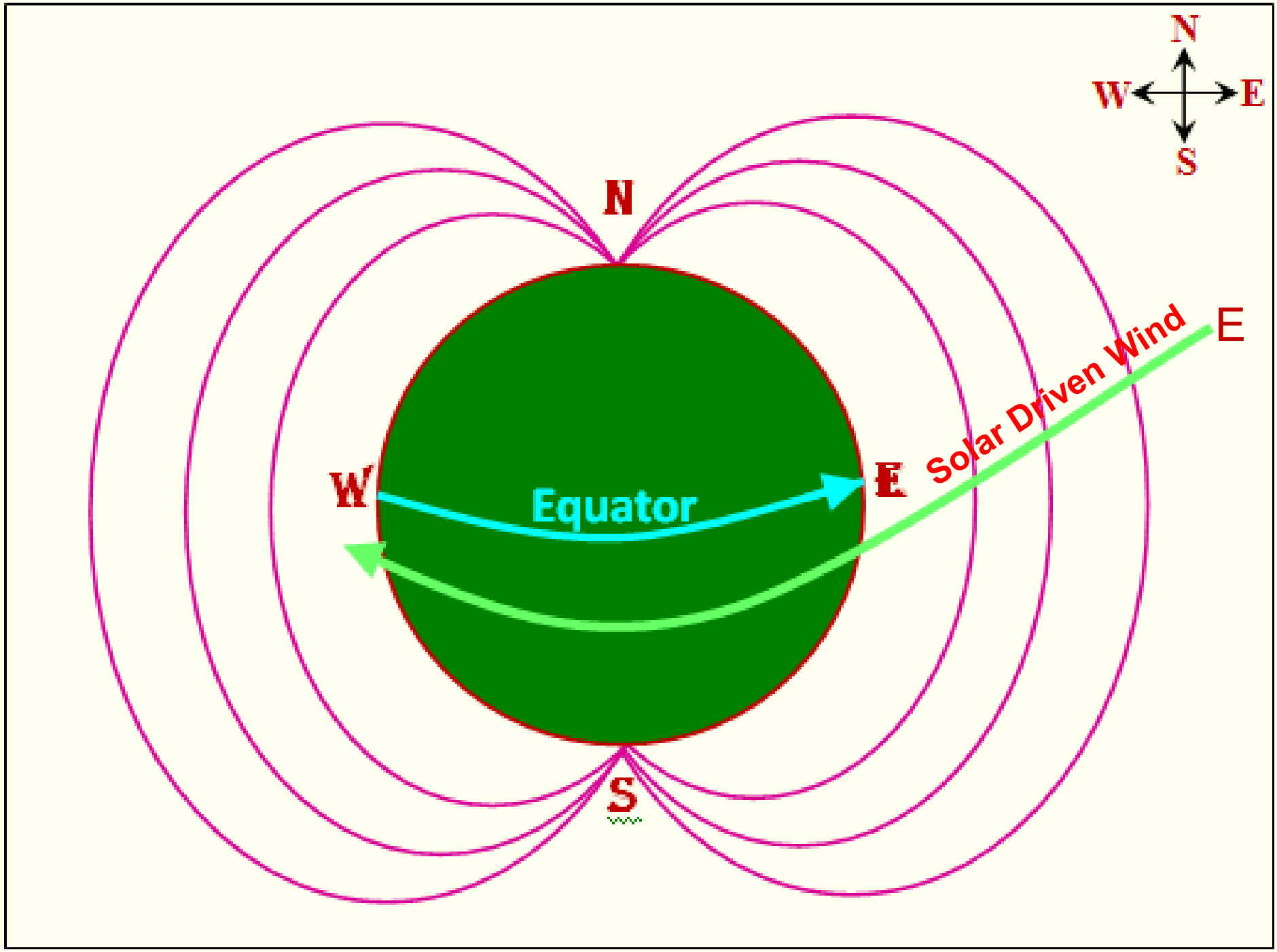
- This manifests itself in the enhancement of the horizontal component (H) of the earth's magnetic field at the magnetic equator with the maximum occurring at $\pm 3^0$ on either side of the equator.

- Why the EEJ is confined to ± 3^0 geomagnetic latitude

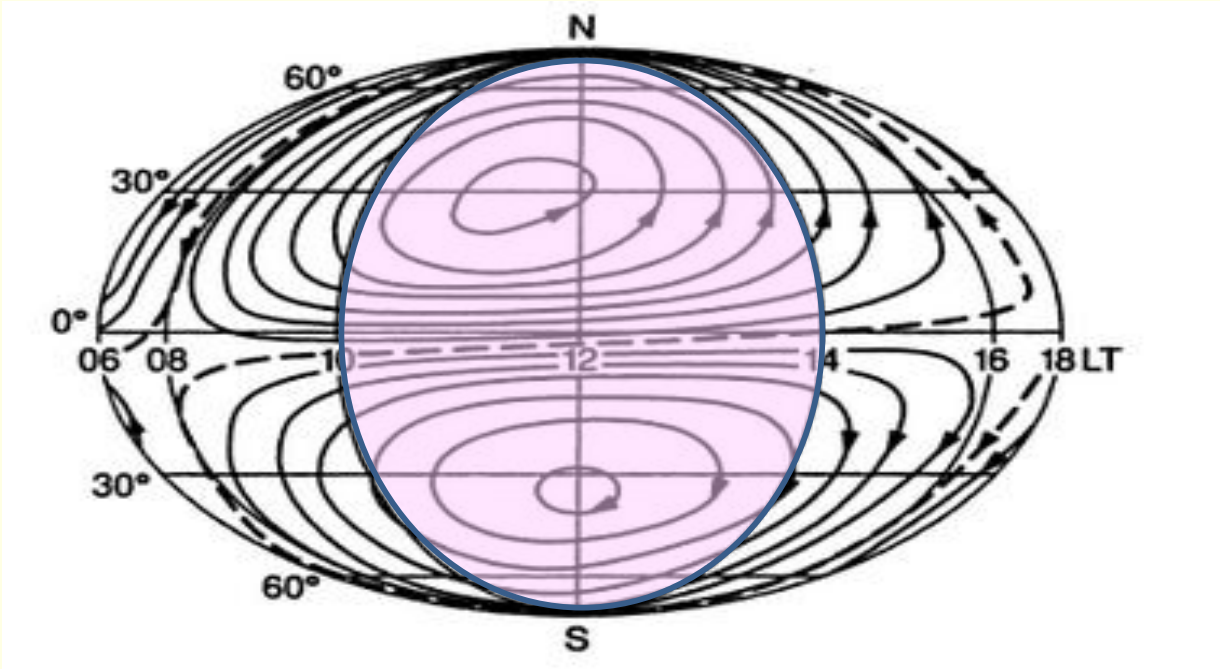
  It is dictated by the magnetic field line geometry which is horizontal and perpendicular to the magnetic equator.

- Why only at the E-region altitudes

  Because the conductivity is maximum at the E-region altitudes of 100 to 110 km where the gyro frequency (ω) and collision frequencies (υ) are nearly equal.


N
W
E
S
N
W
Equator
E
Solar Driven Wind
E
S

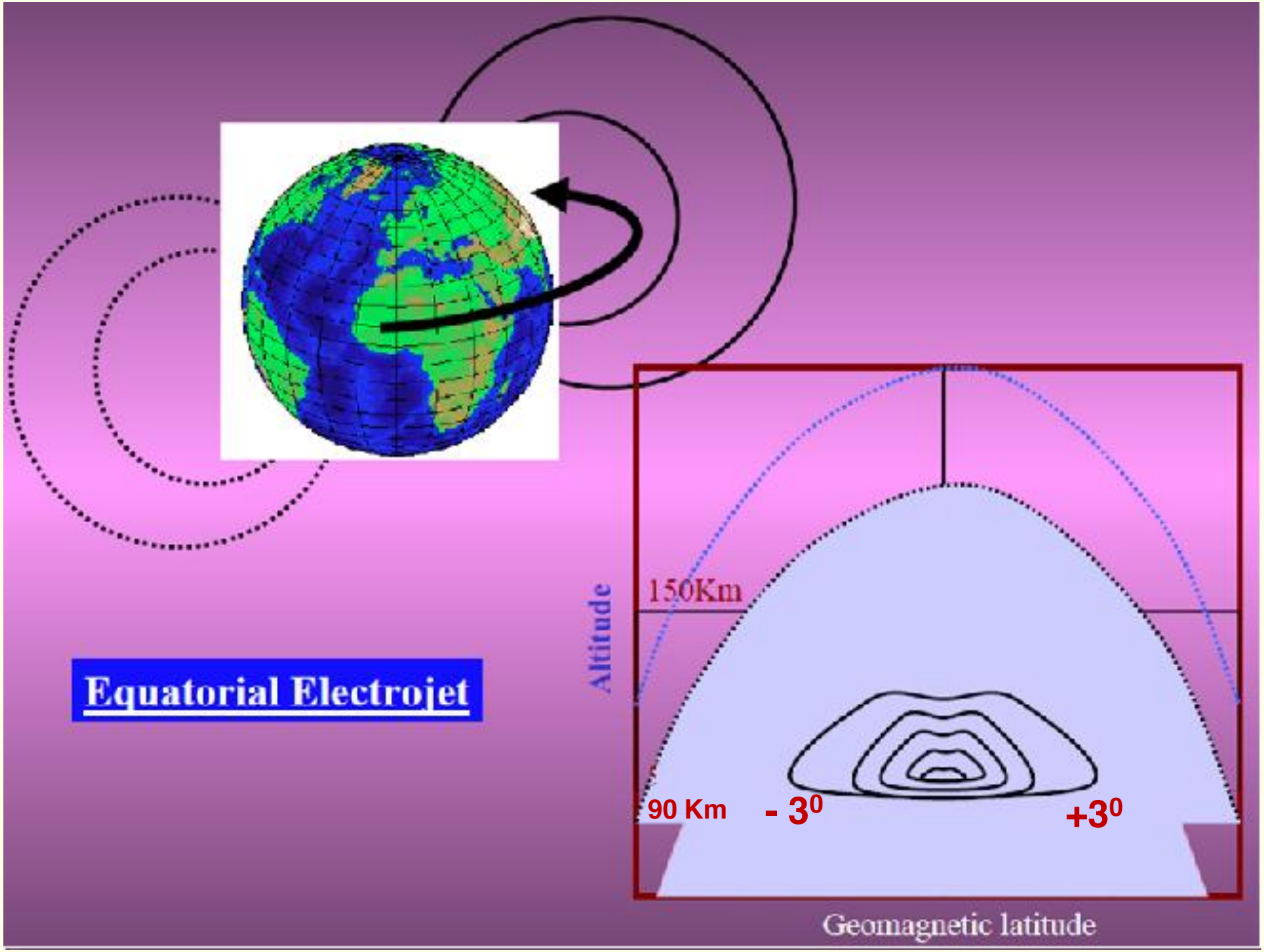
Sq Current System



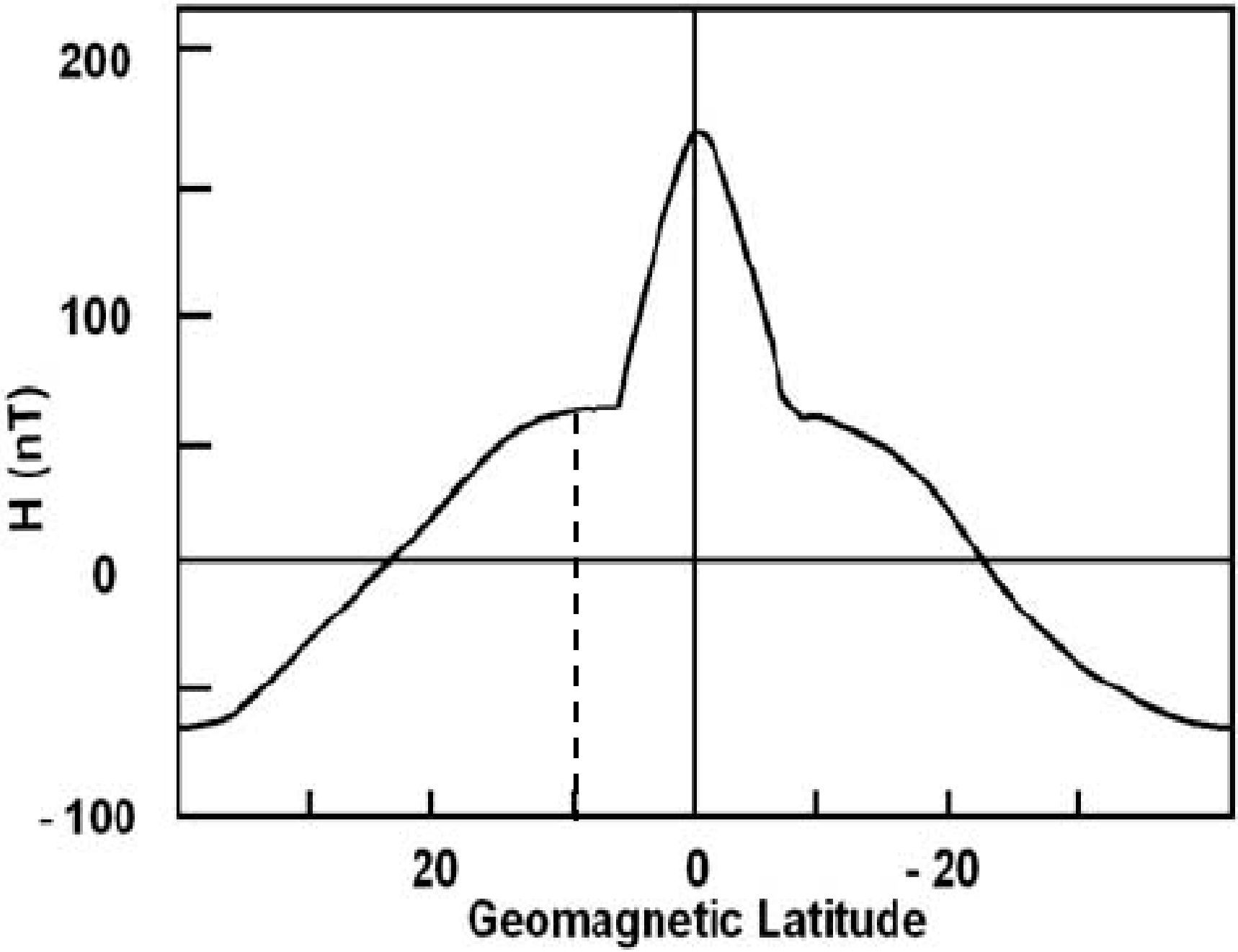
Global view of the average Sq current system

- At the geomagnetic equator, the Sq current systems of the southern and northern hemisphere merge with each other and intensify to form a ***jet-like current*** in the E-region of the ionosphere, which is called as ***Equatorial Electrojet.***

- The special geometry of the magnetic field over the equator (nearly ⊥ to the wind) together with the nearly perpendicular incidence of solar radiation causes an enhancement in the effective conductivity which leads to an amplification of the jet current over the equator.


Equatorial Electrojet
Altitude
150Km
90 Km
- 3⁰
+3⁰
Geomagnetic latitude

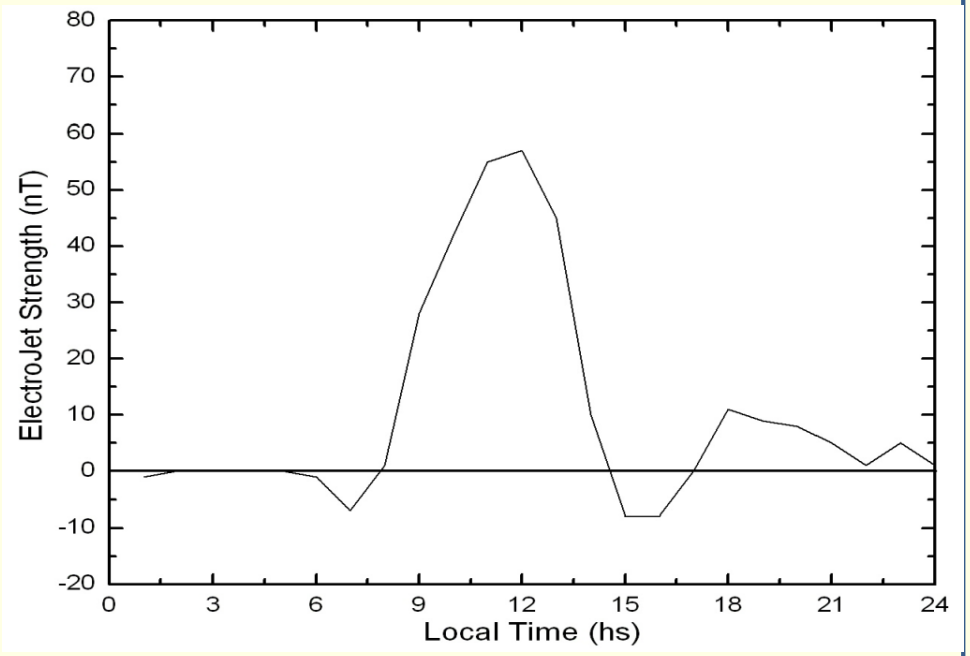
HORIZONTAL COMPONENT OF EARTH'S MAGNETIC FIELD (H)

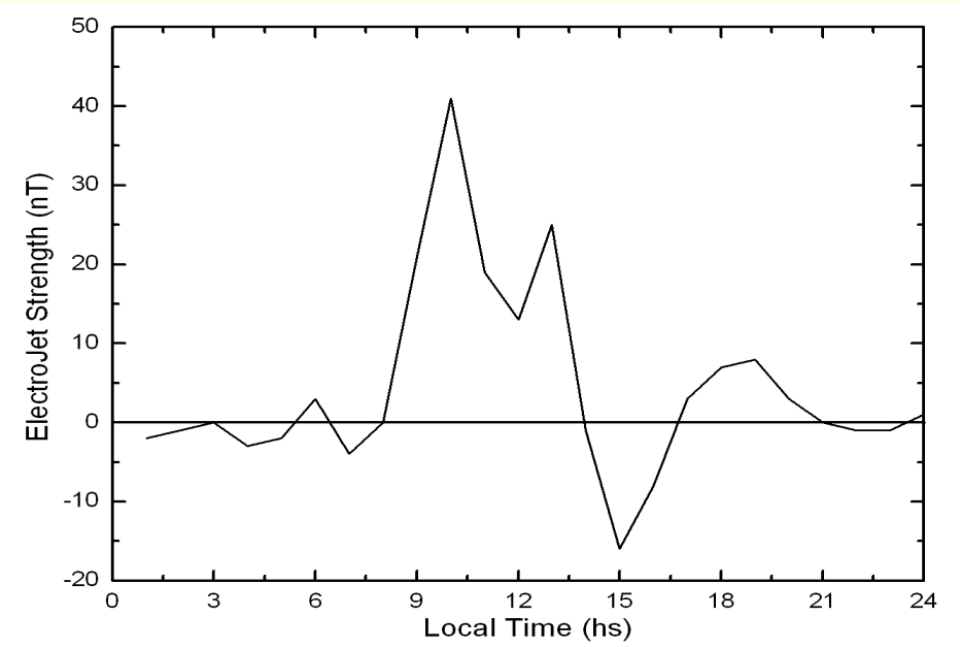


- The Electrojet is measured in nano Tesla (nT) by taking the difference in the horizontal components of the earth's magnetic filed at the magnetic equator and at a location about 10^0 away from the equator so as to subtract the components of the magnetic fields from the inter planetary magnetic field (IMF), etc.,

- In the case of Indian sub continent
  Trivndrum (0.7^0) – Alibag (10^0) are generally used to derive the electrojet strength

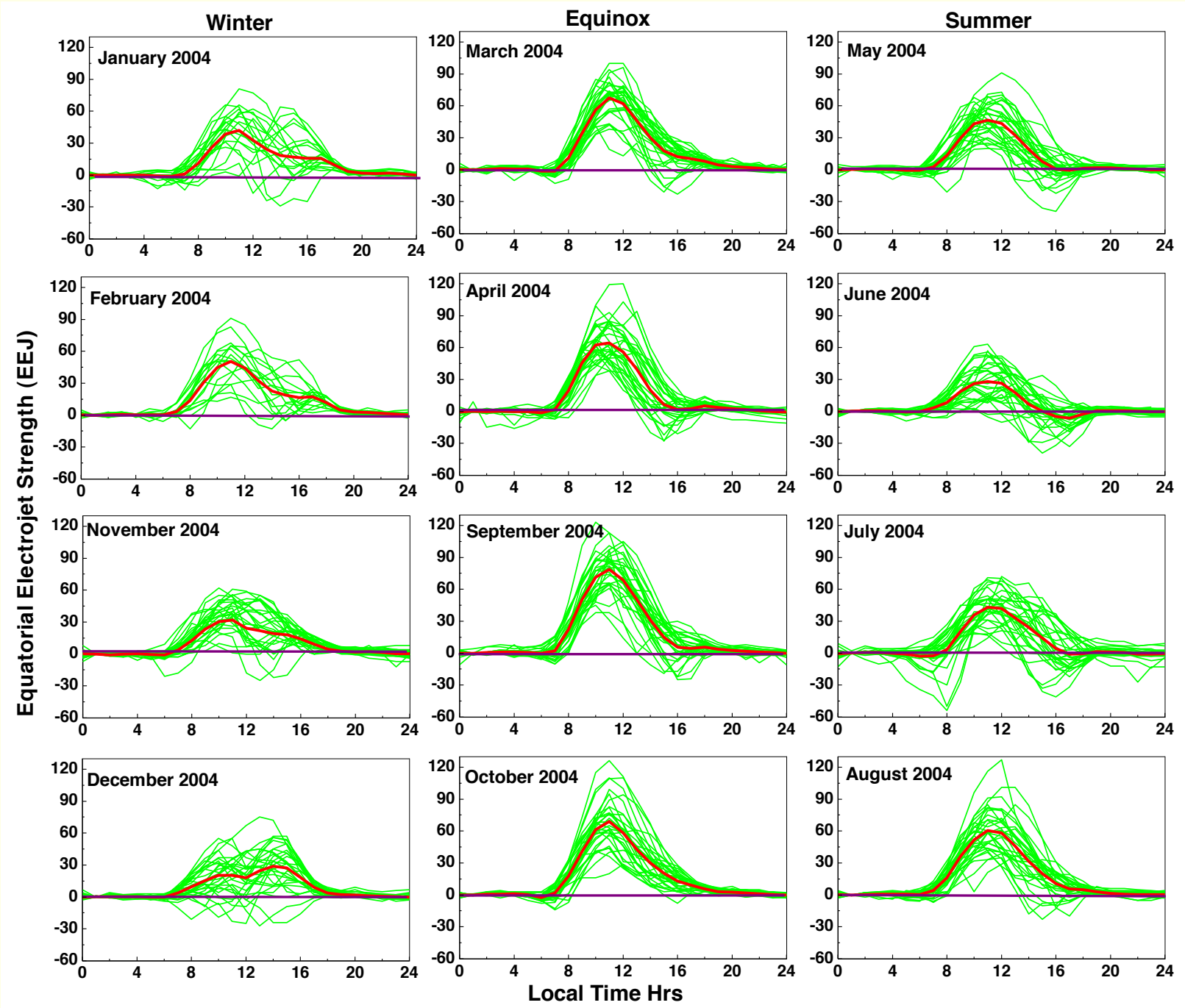
Equatorial ElectroJet (EEJ)



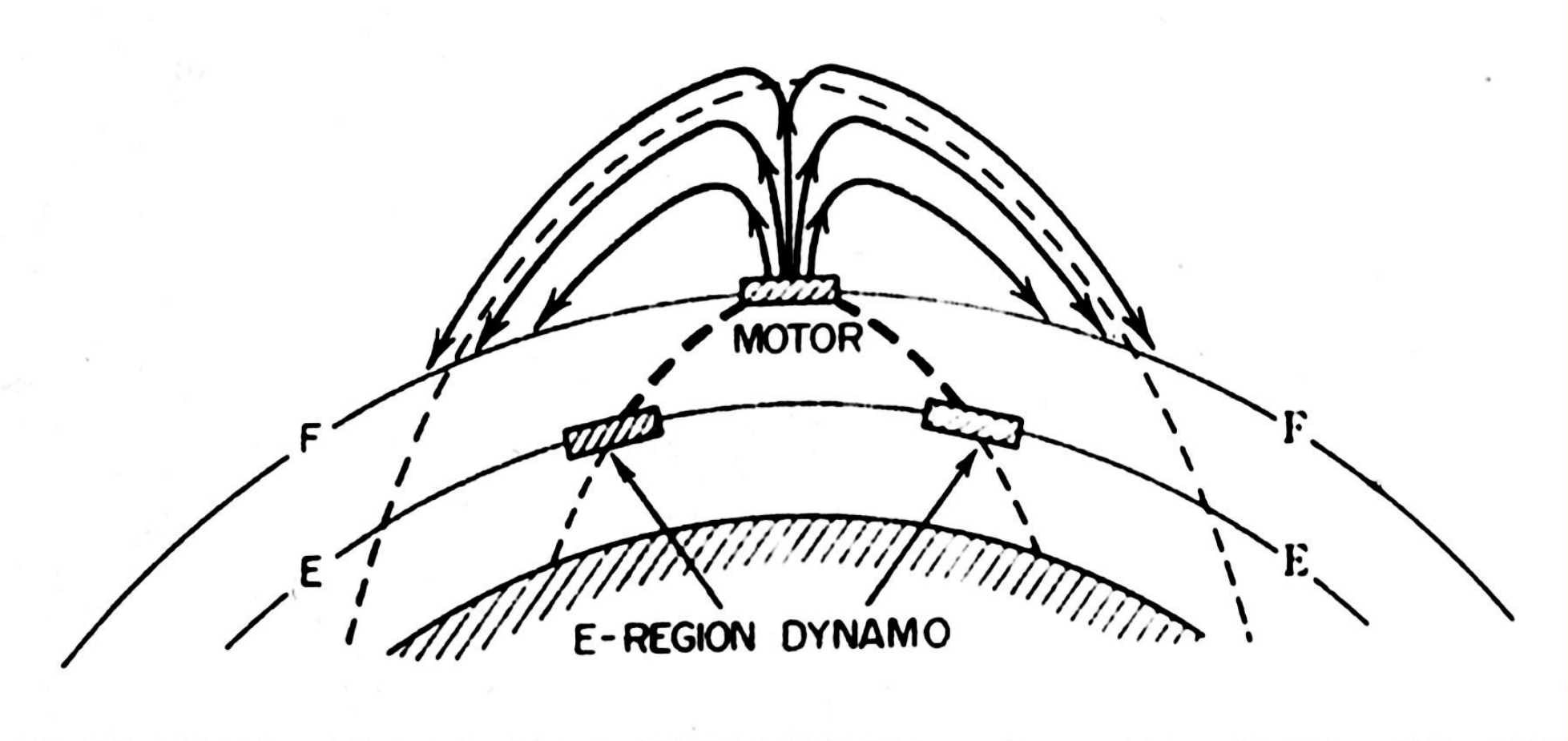


Counter ElectroJet (CEJ)

Electrojet Strength at an equatorial station, Trivandrum



Equatorial Ionization Anomaly



- The F-region geomagnetic anomaly. Near the equator the electric fields of the atmospheric dynamo in the E layer are conveyed upwards along geomagnetic lines of force to the motor in the F layer where they produce an upwards movement of the plasma during the day. The raised plasma then diffuses down lines of force to produce enhanced concentration at places on each side of the equator and decreased concentration at the equator itself. [Ratcliffe. 1972].

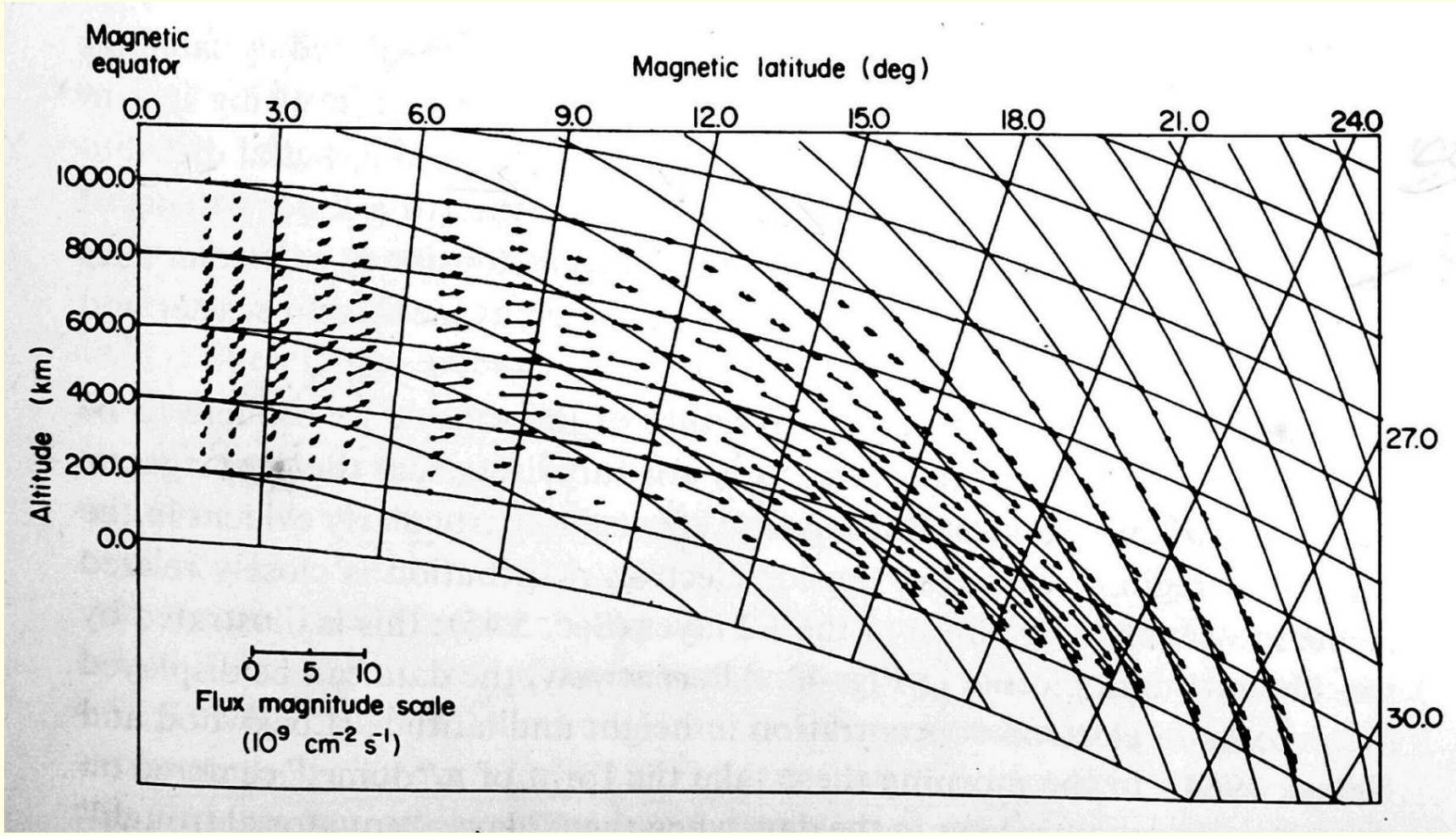
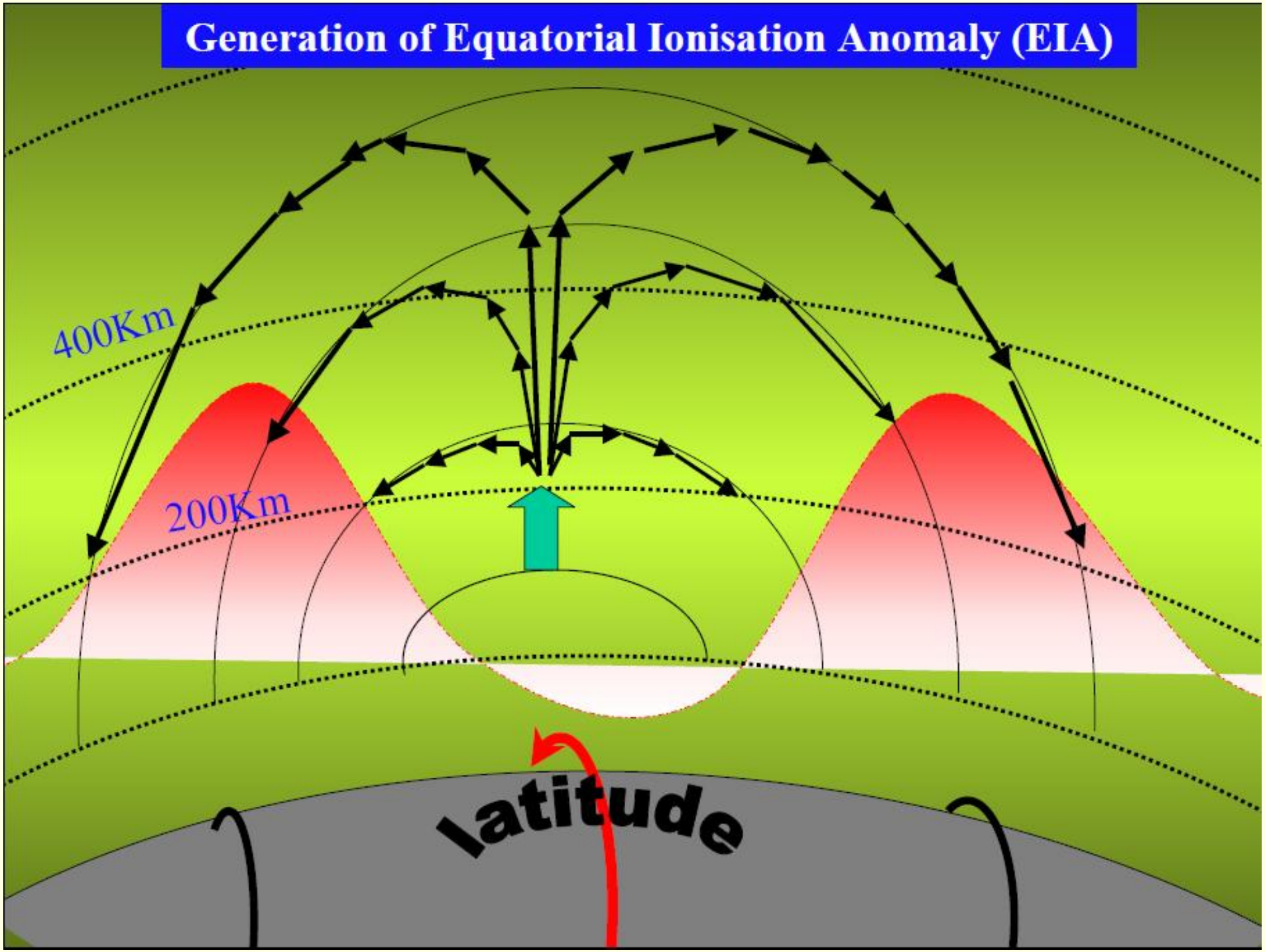
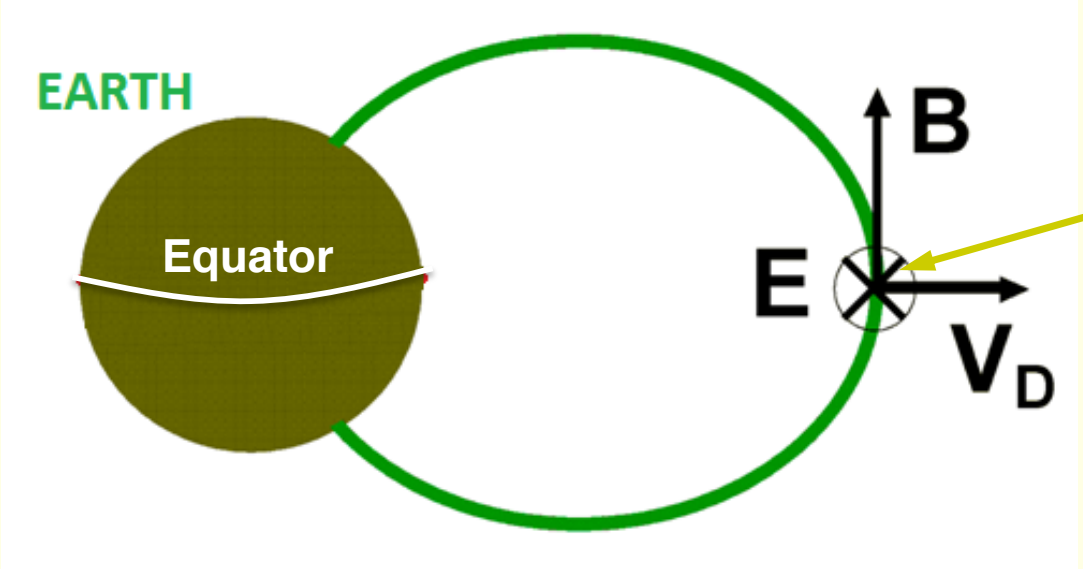


Fig. The "equatorial fountain." Vector plot of electron flux in the meridian plane, in a theoretical steady-state model of the equatorial F region. The motions are due to the combined action of plasma diffusion along magnetic field lines and electromagnetic drift across field lines, produced by an assumed distribution of eastward electric field. The magnetic field lines are shown every 200 km above the equator [Hanson and Moffett (1966)].

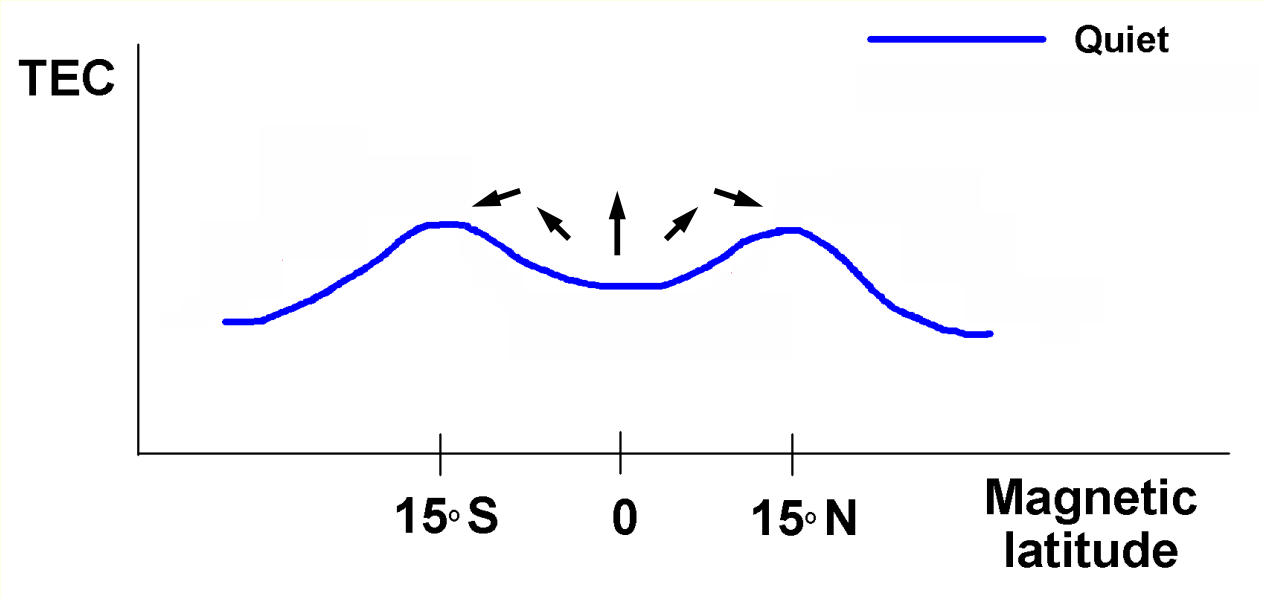
Generation of Equatorial Ionisation Anomaly (EIA)

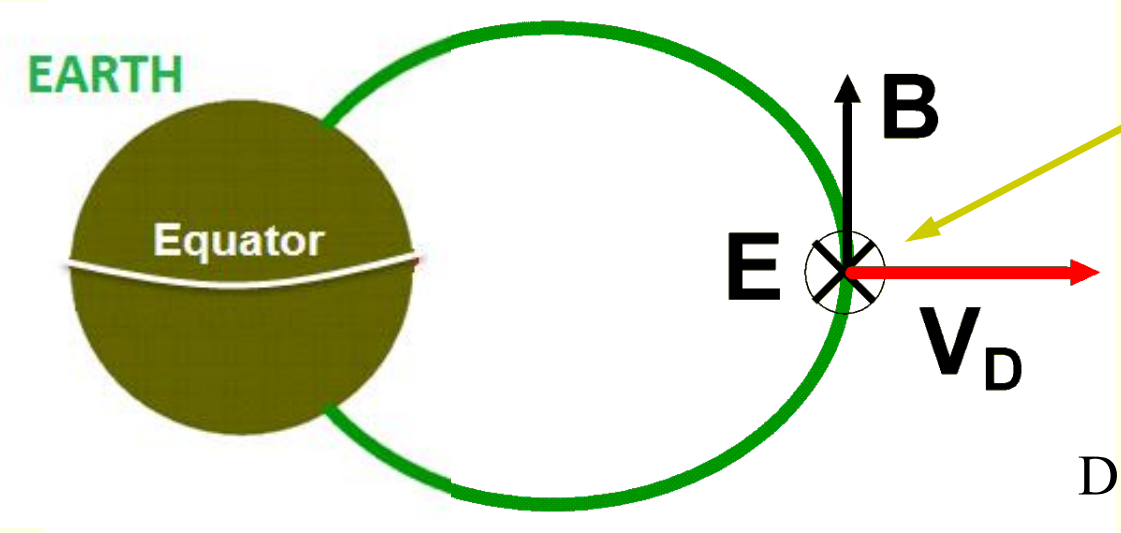




Eastward Electric Field

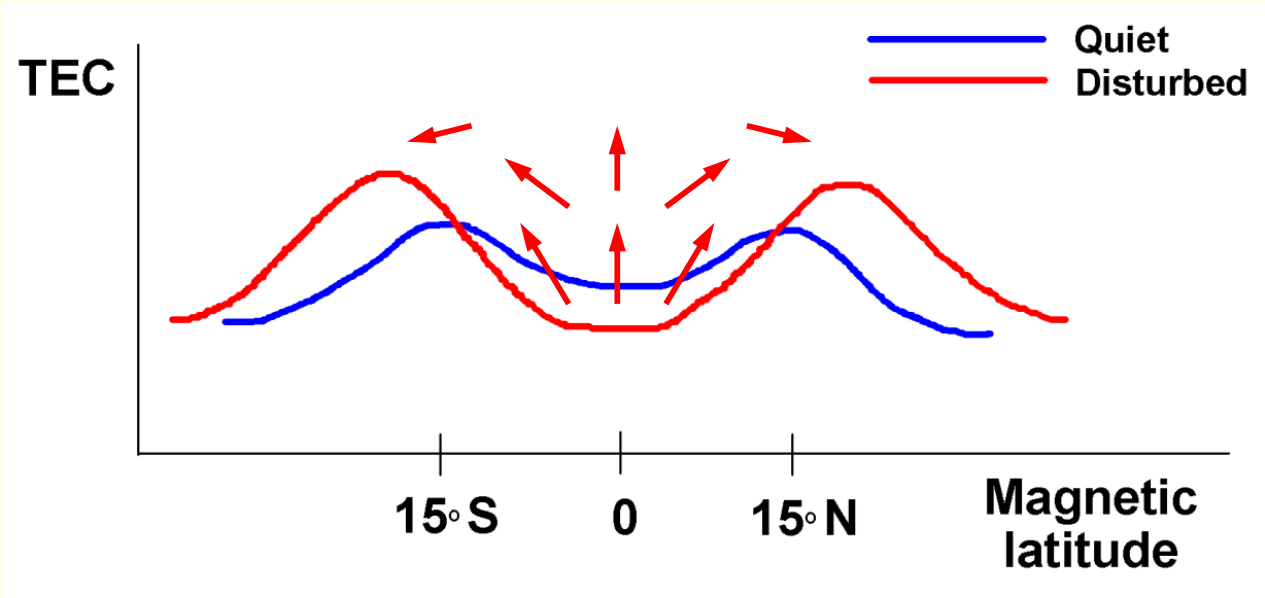
Daytime ~ 9 LT to 21 LT

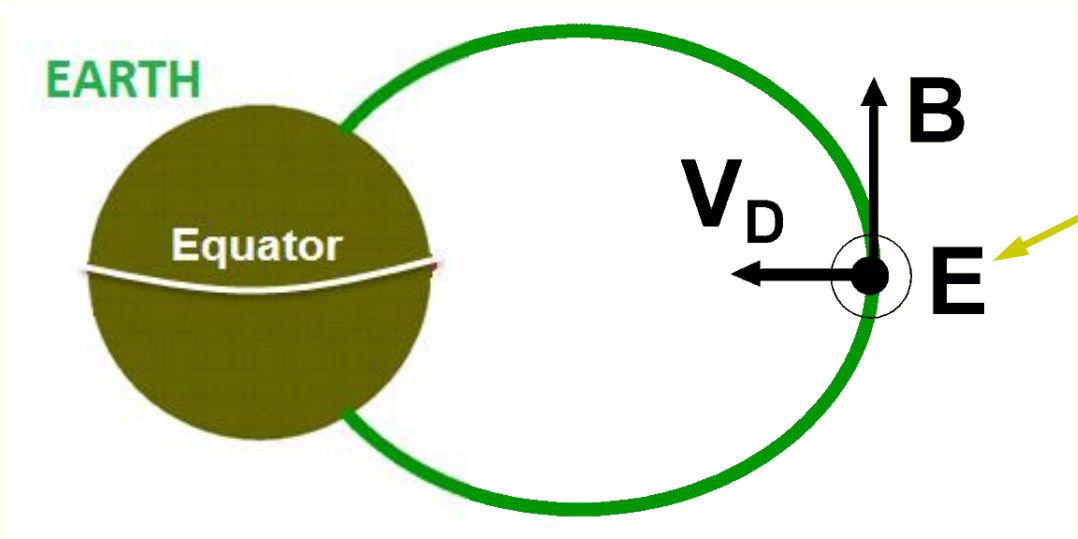




Intensified Eastward Electric Field

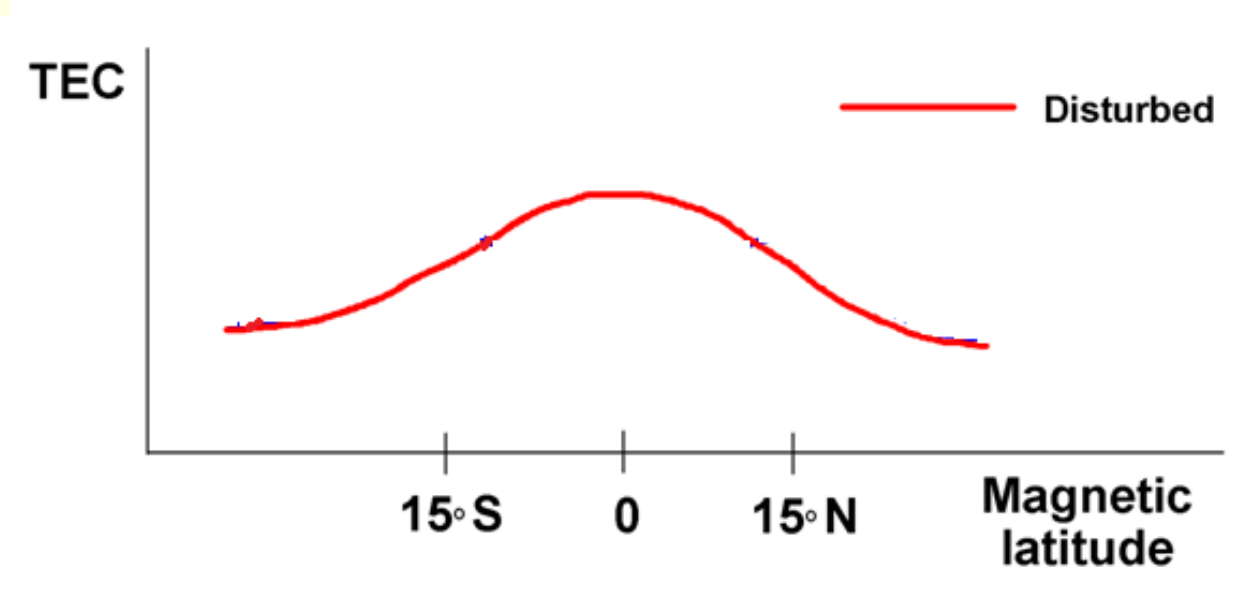
Daytime ~ 9 LT to 21 LT



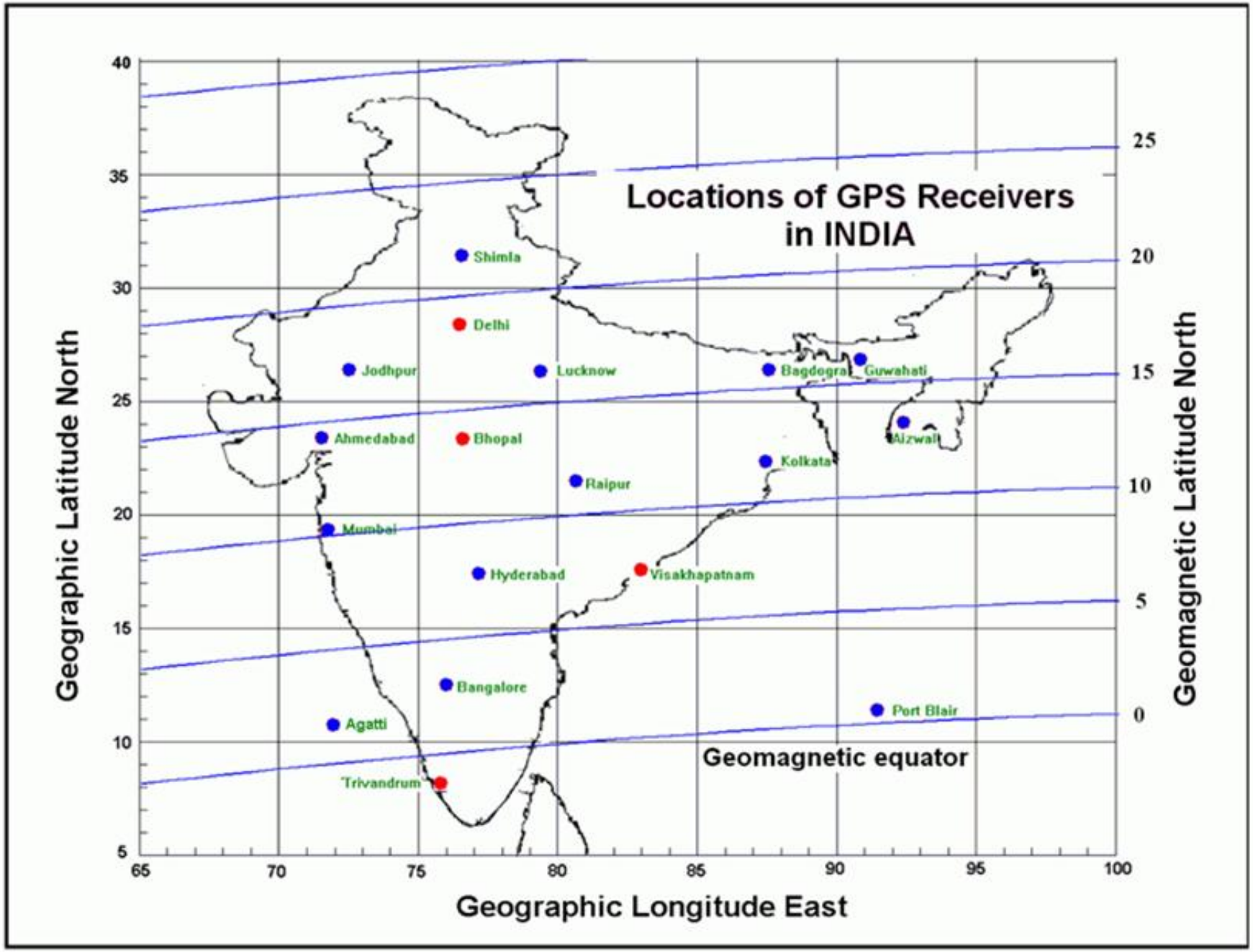


Westward Electric Field

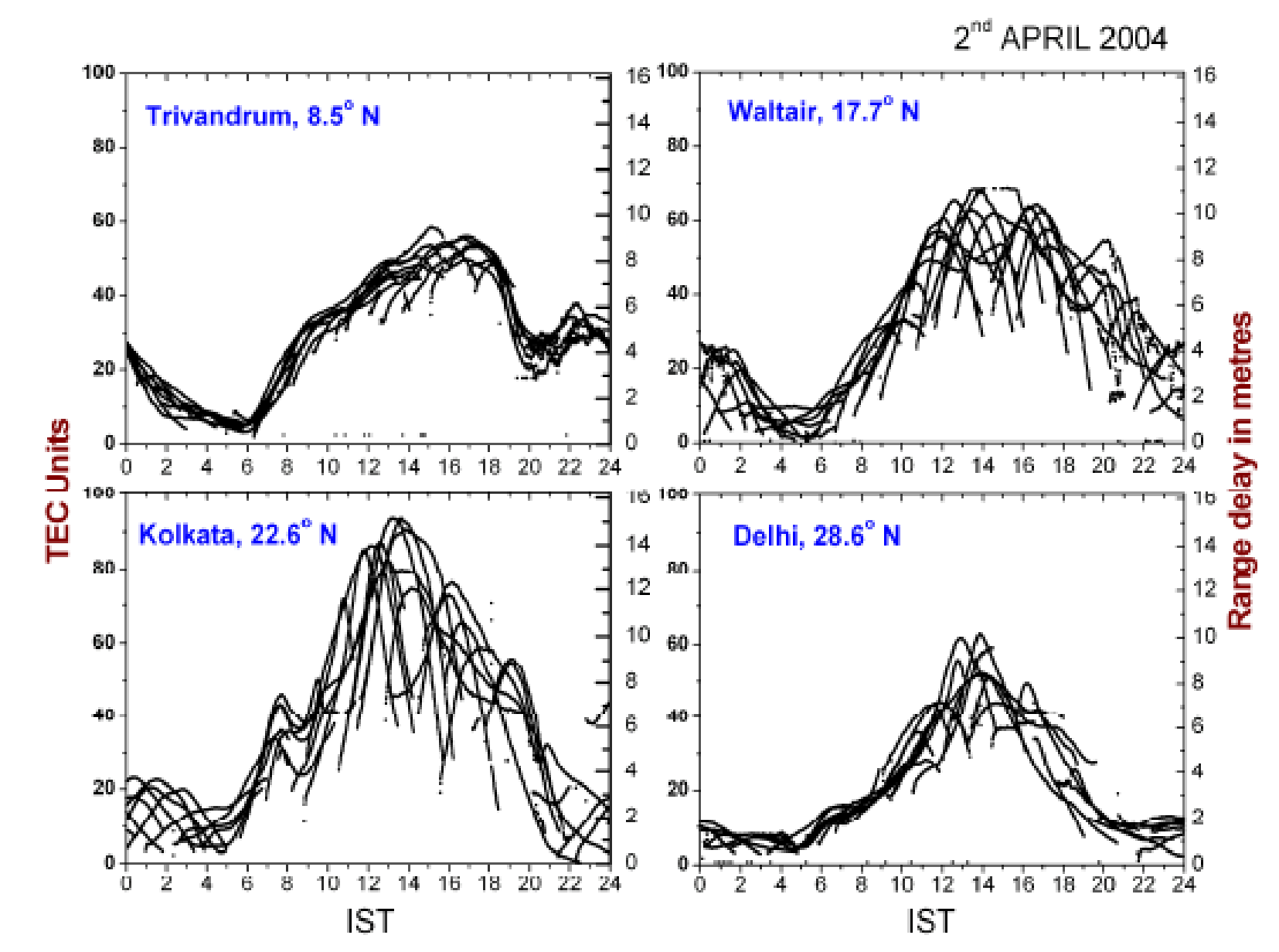
Daytime ~ 9 LT to 21 LT



Morphological features of GPS-TEC in the Indian equatorial and low latitudes

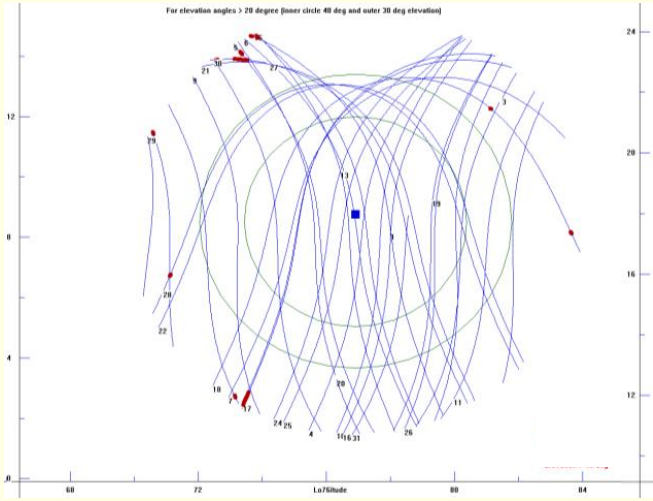


Locations of GPS Receivers in INDIA

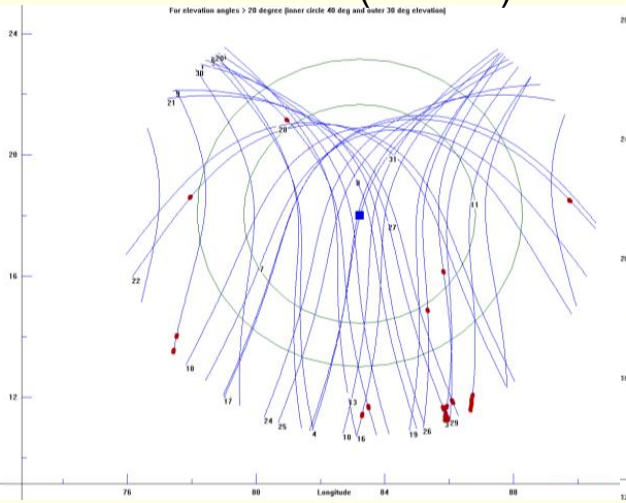


The diurnal variation of vertical TEC/range delays measured using GPS receivers from four different stations near the equator (Trivandrum), the low latitude (Waltair), the anomaly crest region (Kolkata) and beyond the crest region (Delhi)

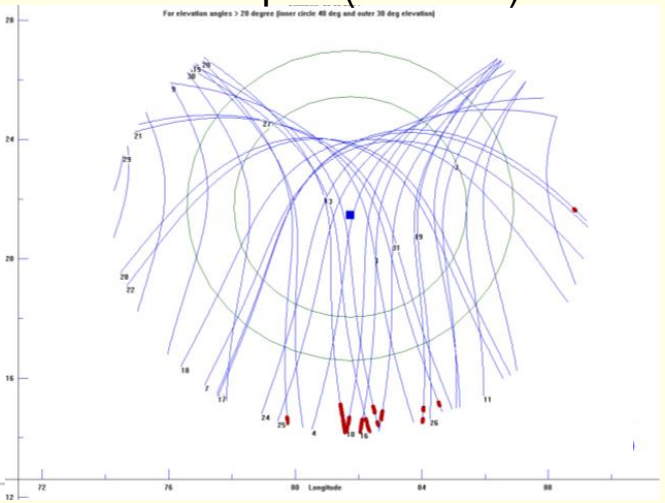
Trivandrum (8.47^{0}N)



Waltair (17.7^{0}N)

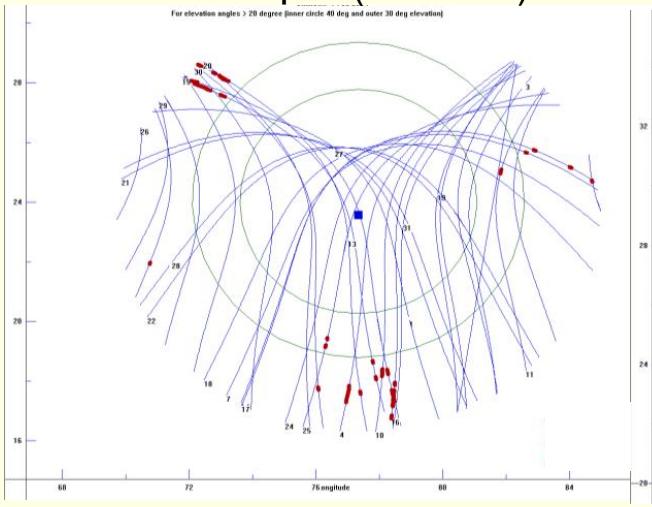


Raipur (21.18^{0}N)

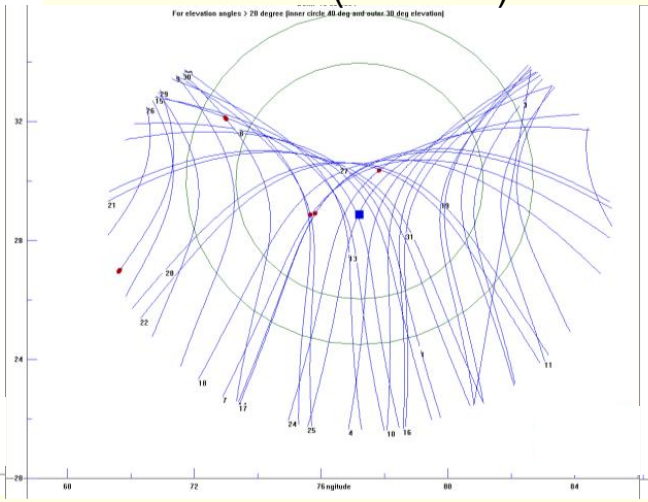


Latitude

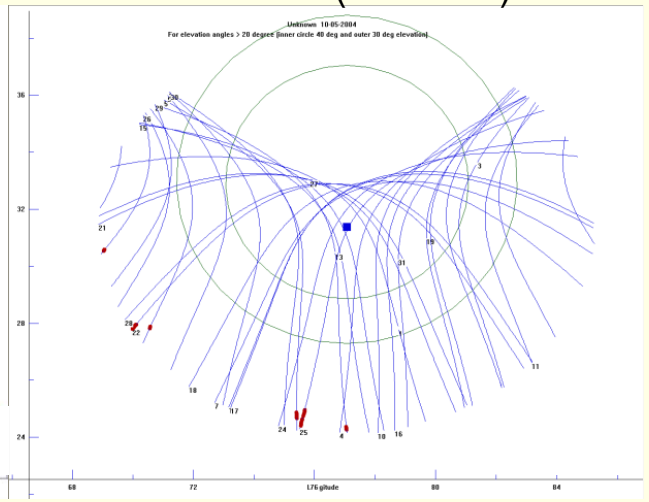
Bhopal (23.28^{0}N)



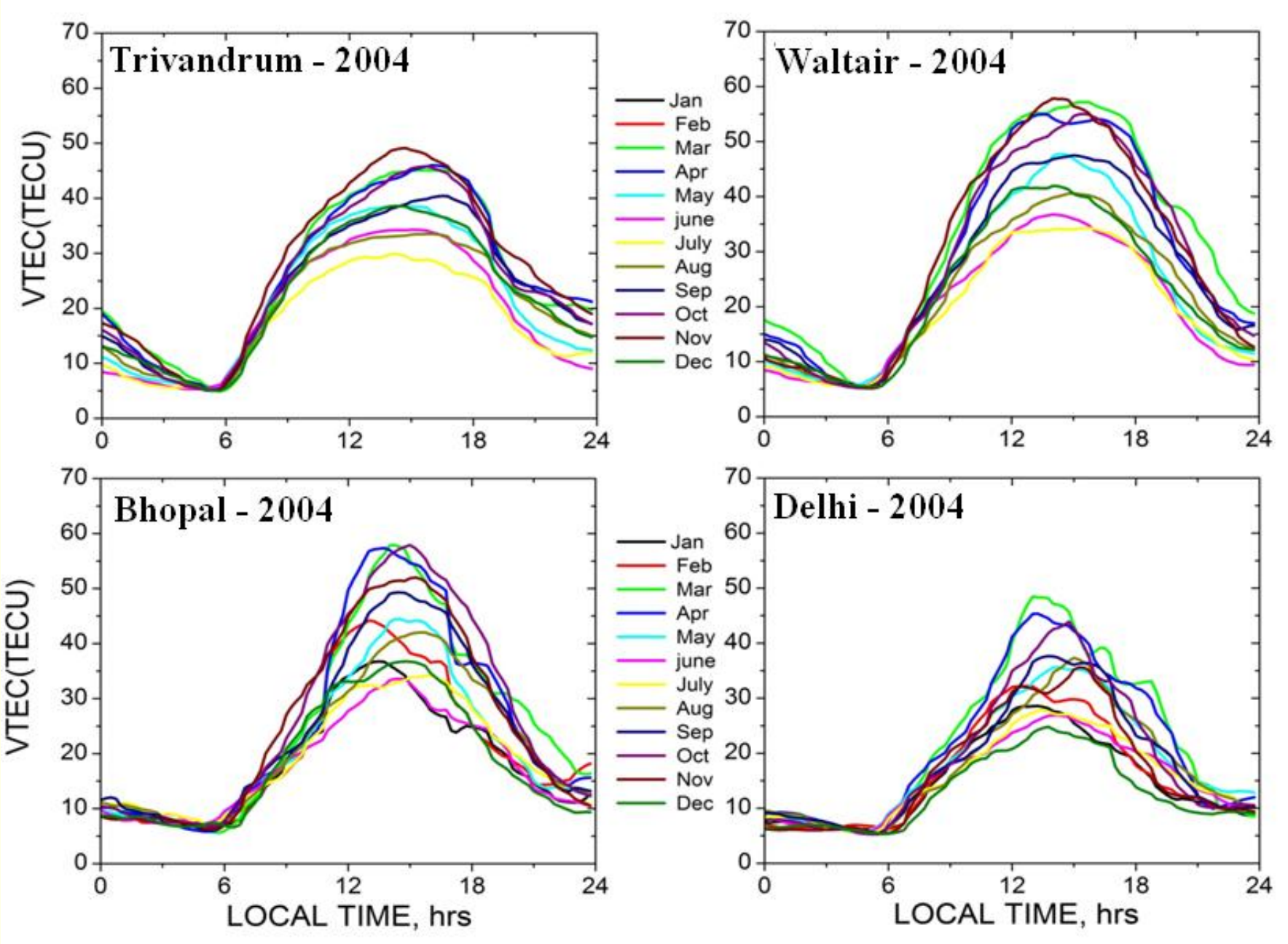
Delhi (28.58^{0}N)



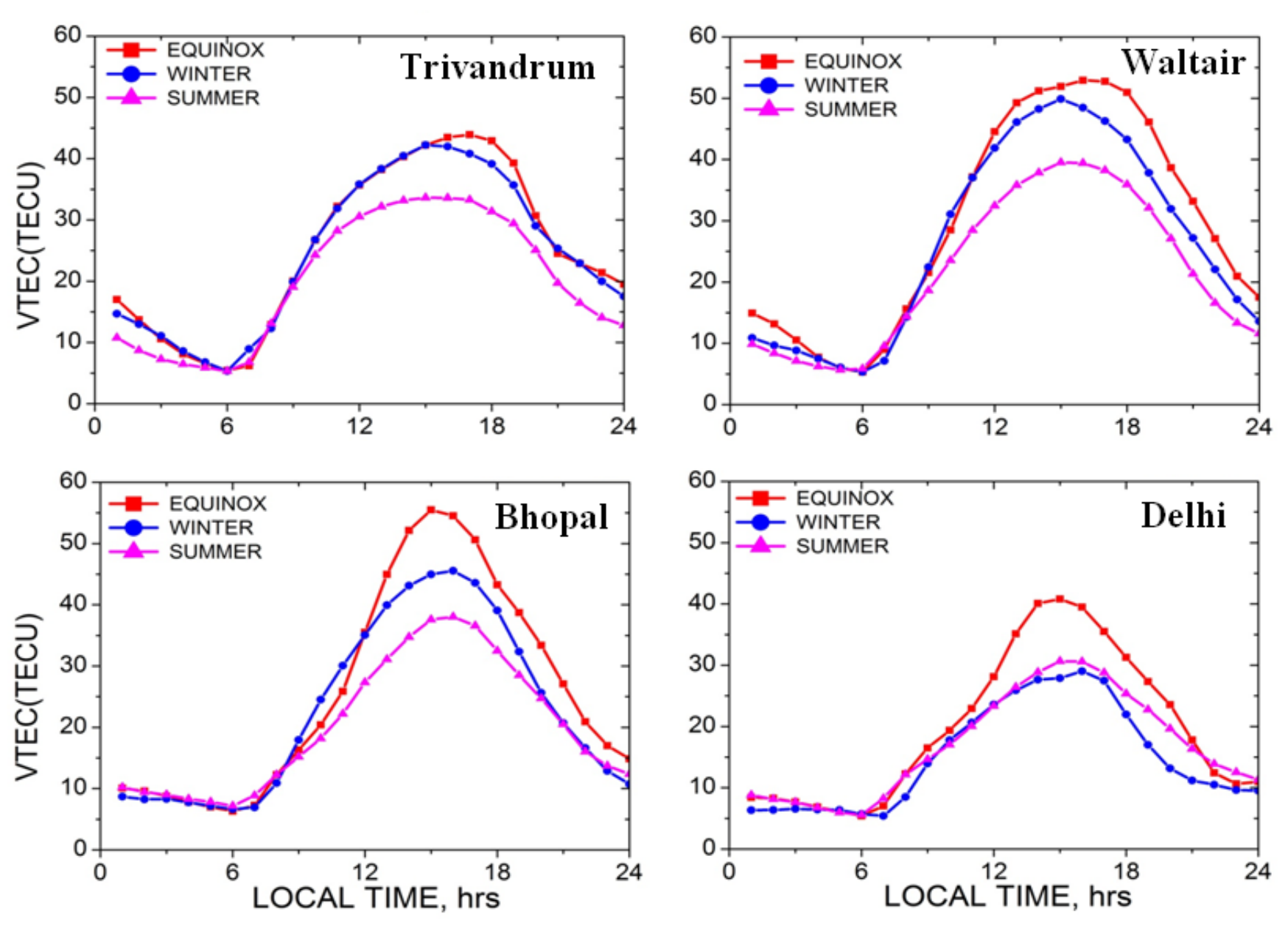
Shimla (31.09^{0}N)



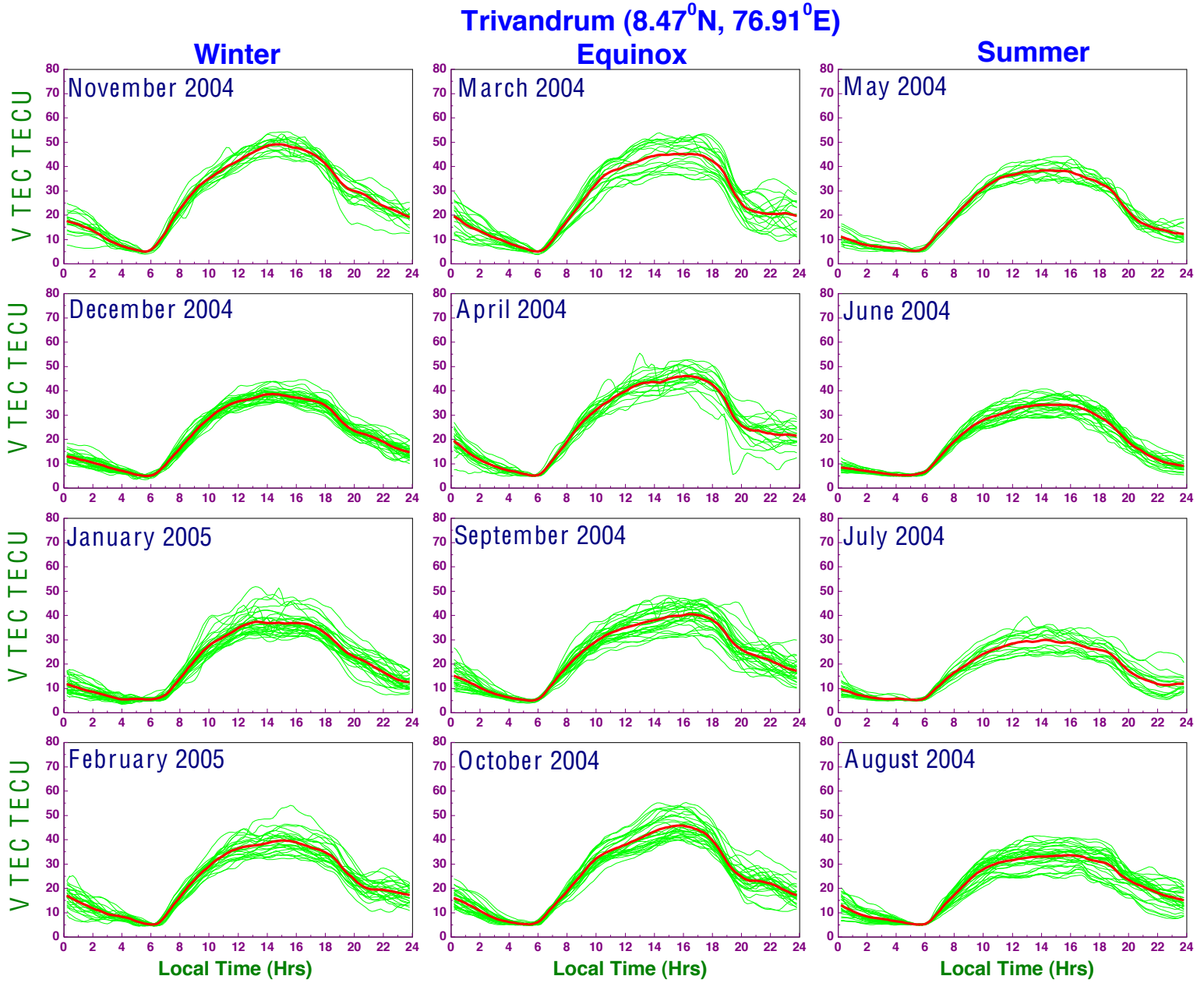
Longitude



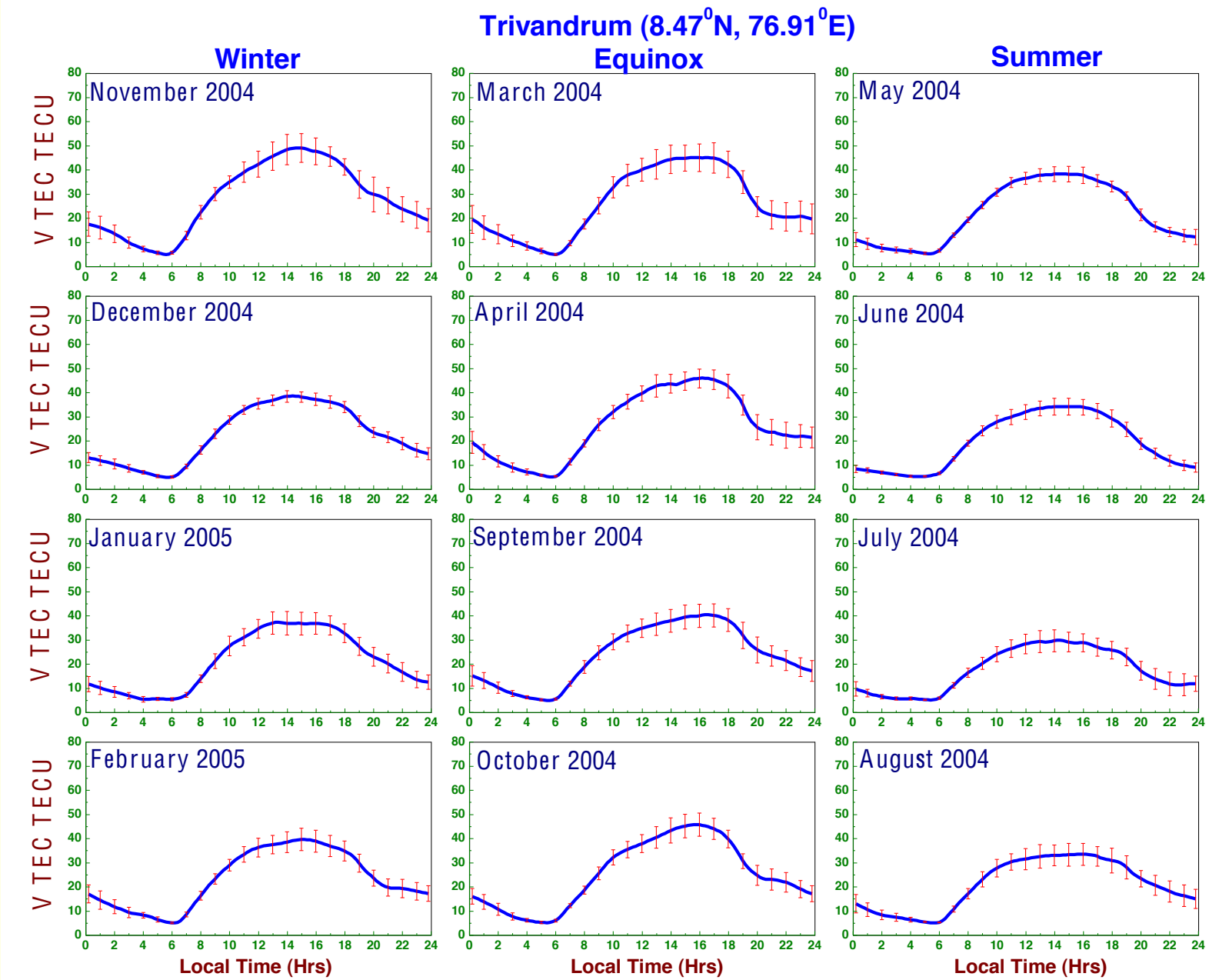
Monthly mean diurnal variation of the TEC over four different stations, Trivandrum, Waltair, Bhopal and Delhi during the period from January 2004 to December 2004



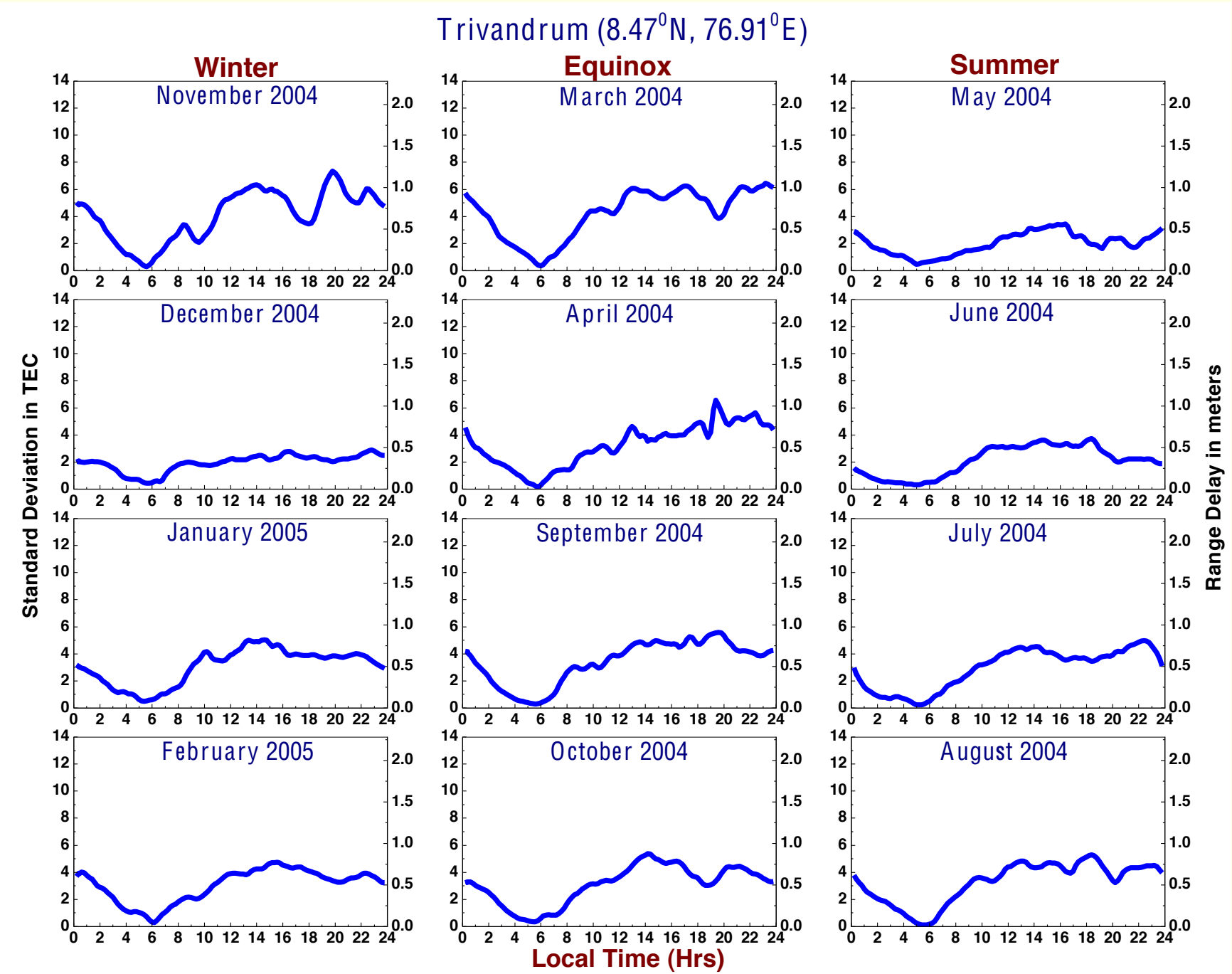
The mean diurnal variation of TEC over four different stations, Trivandrum, Waltair, Bhopal, Delhi for three different seasons equinox, winter and summer during the period from January 2004 to December 2004.



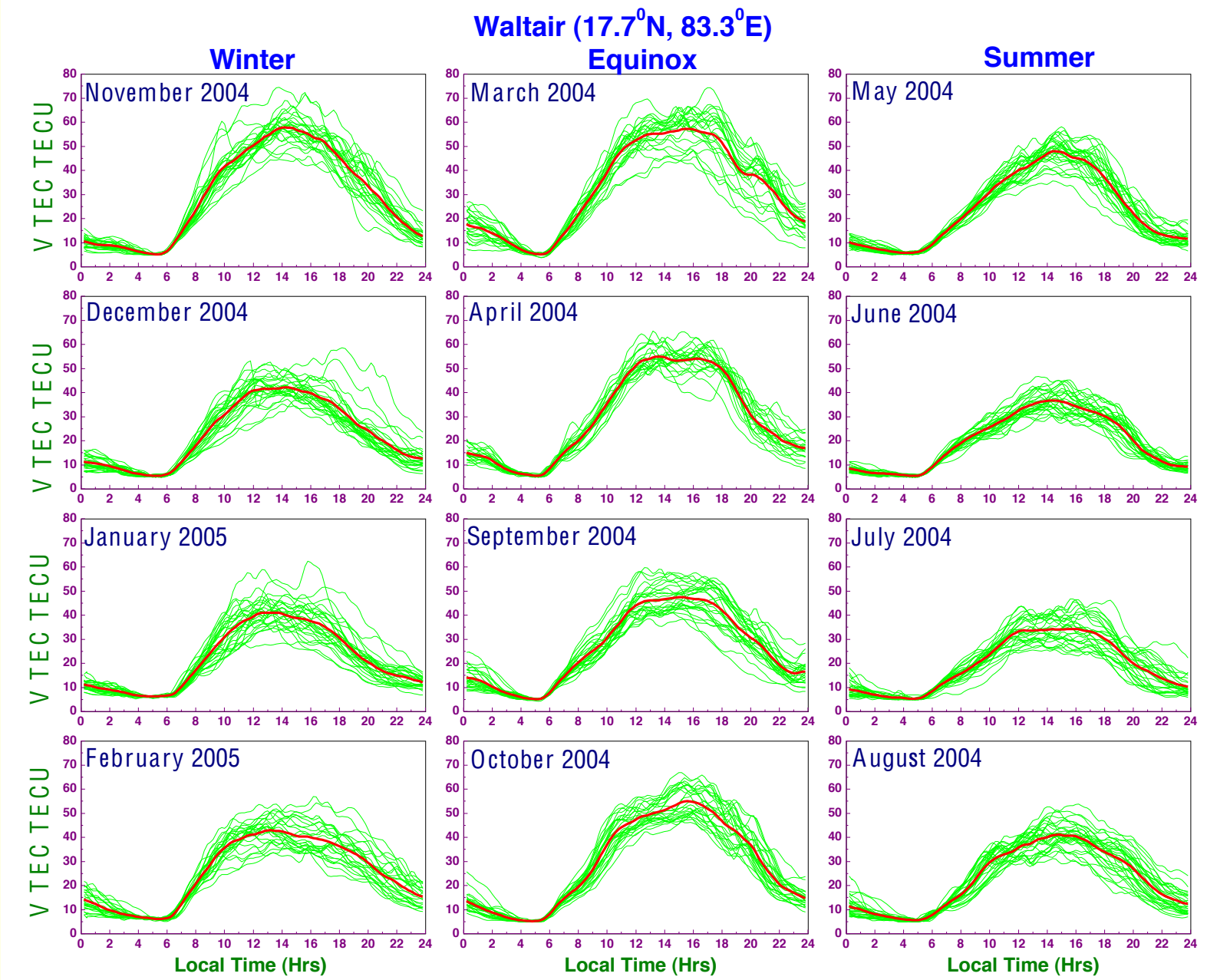
Mass plots of TEC for each month (showing the typical day to day variability) measured from the GPS signals at the equatorial station Trivandrum.



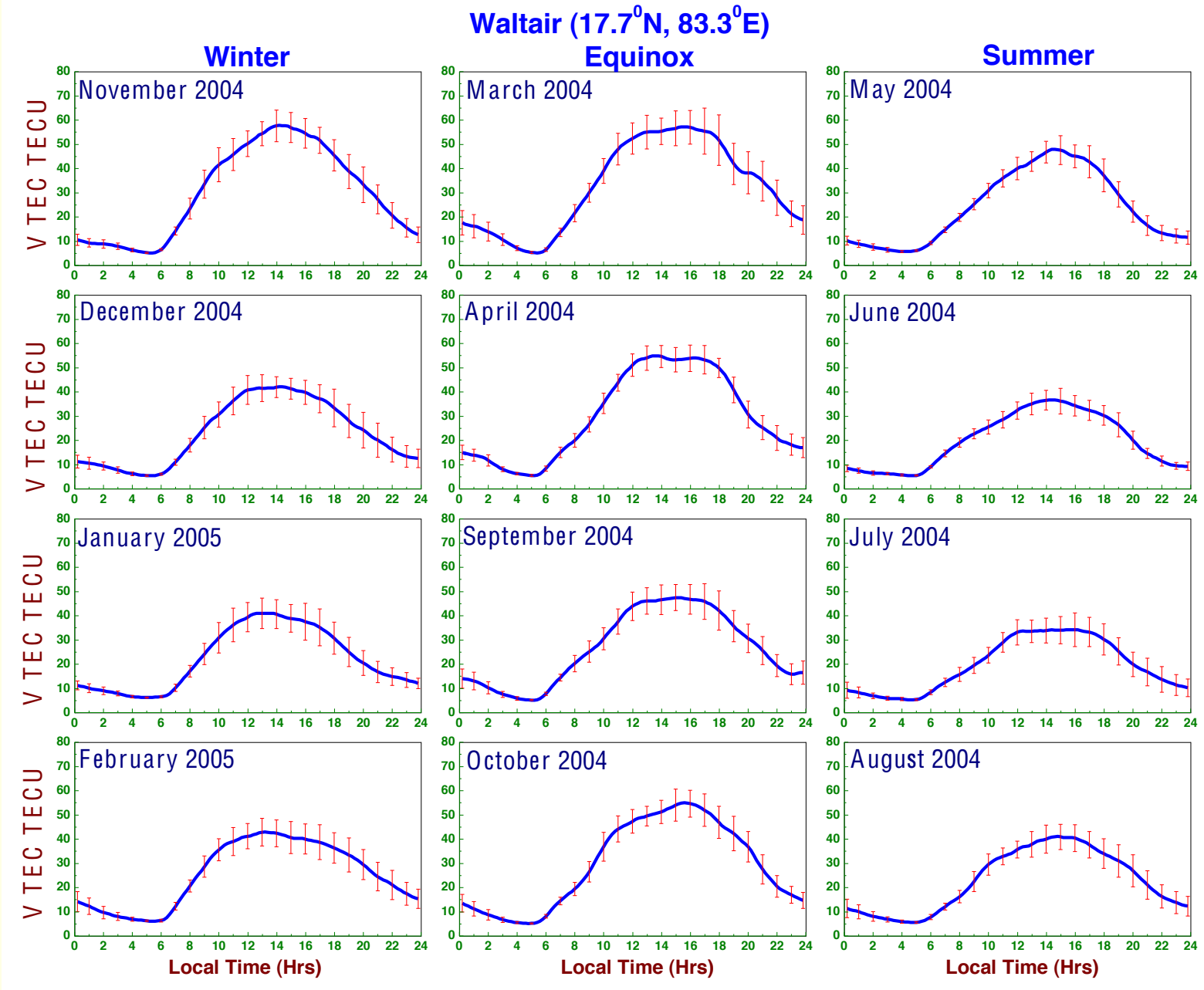
Average diurnal variation plots showing the standard deviations of the day-to-day variability in TEC over Trivandrum



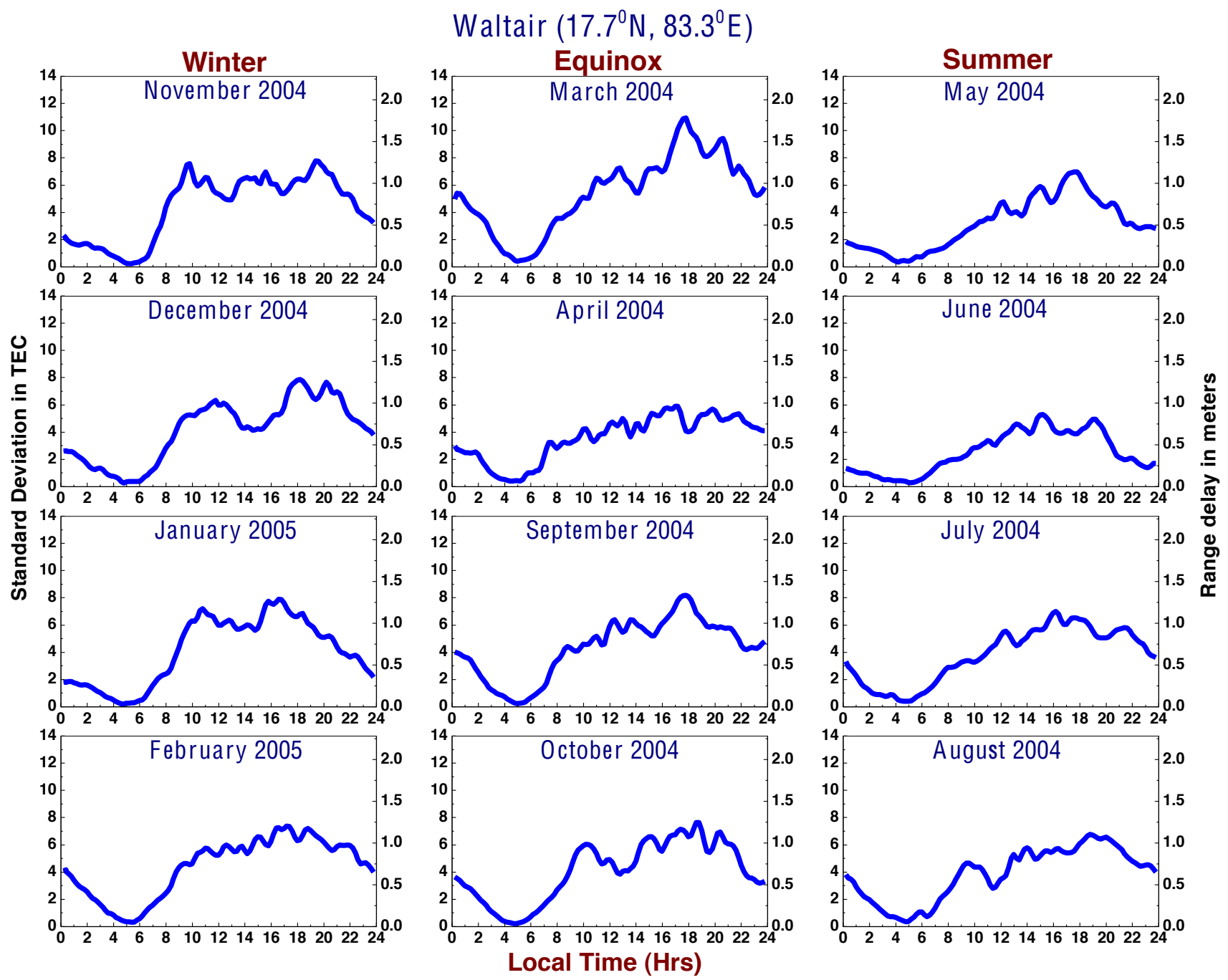
Monthly average diurnal variation of standard deviations in TEC over Trivandrum



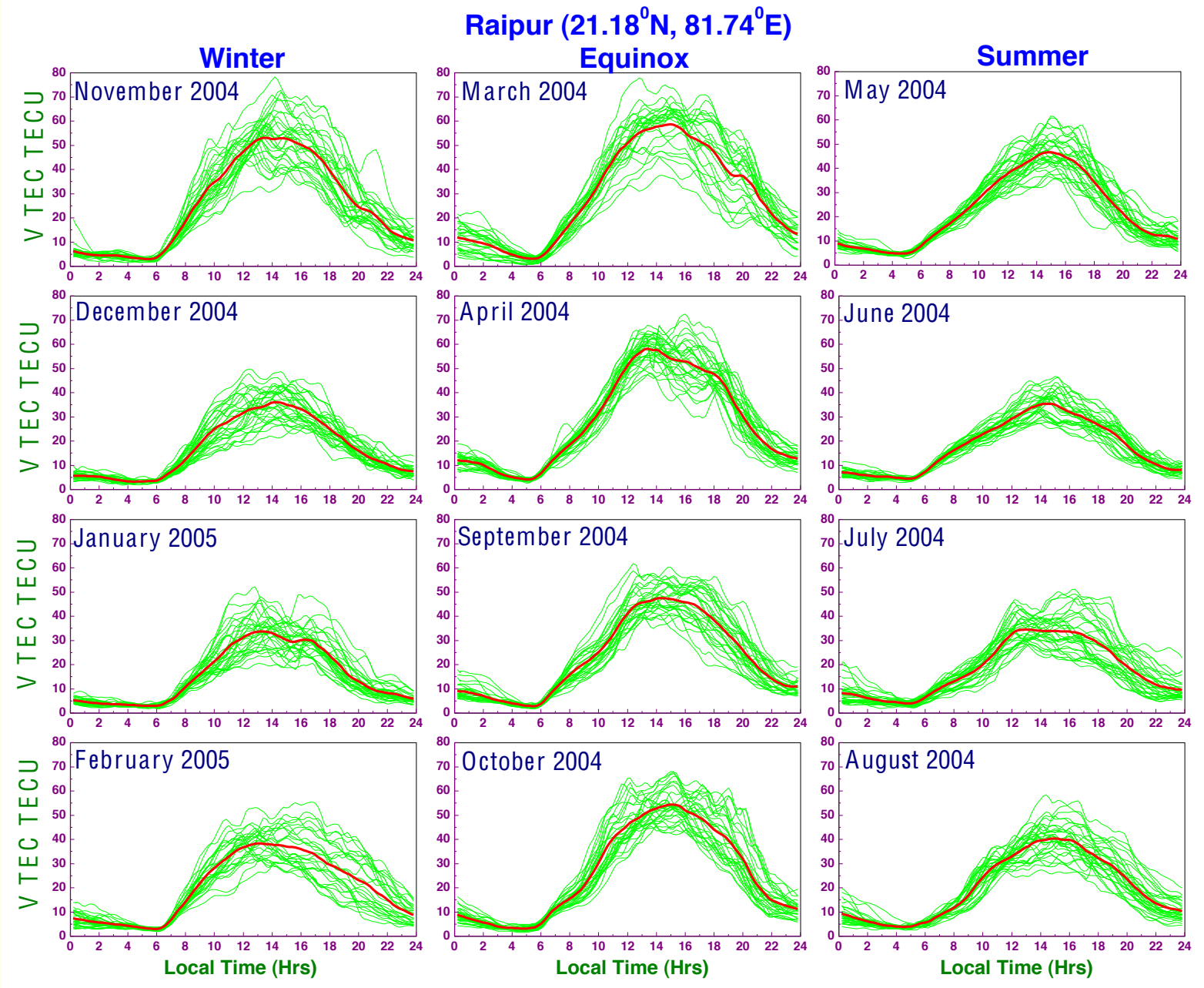
Mass plots of TEC for each month (showing the typical day to day variability) measured from the GPS signals at Waltair, located at the inner edge of the EIA



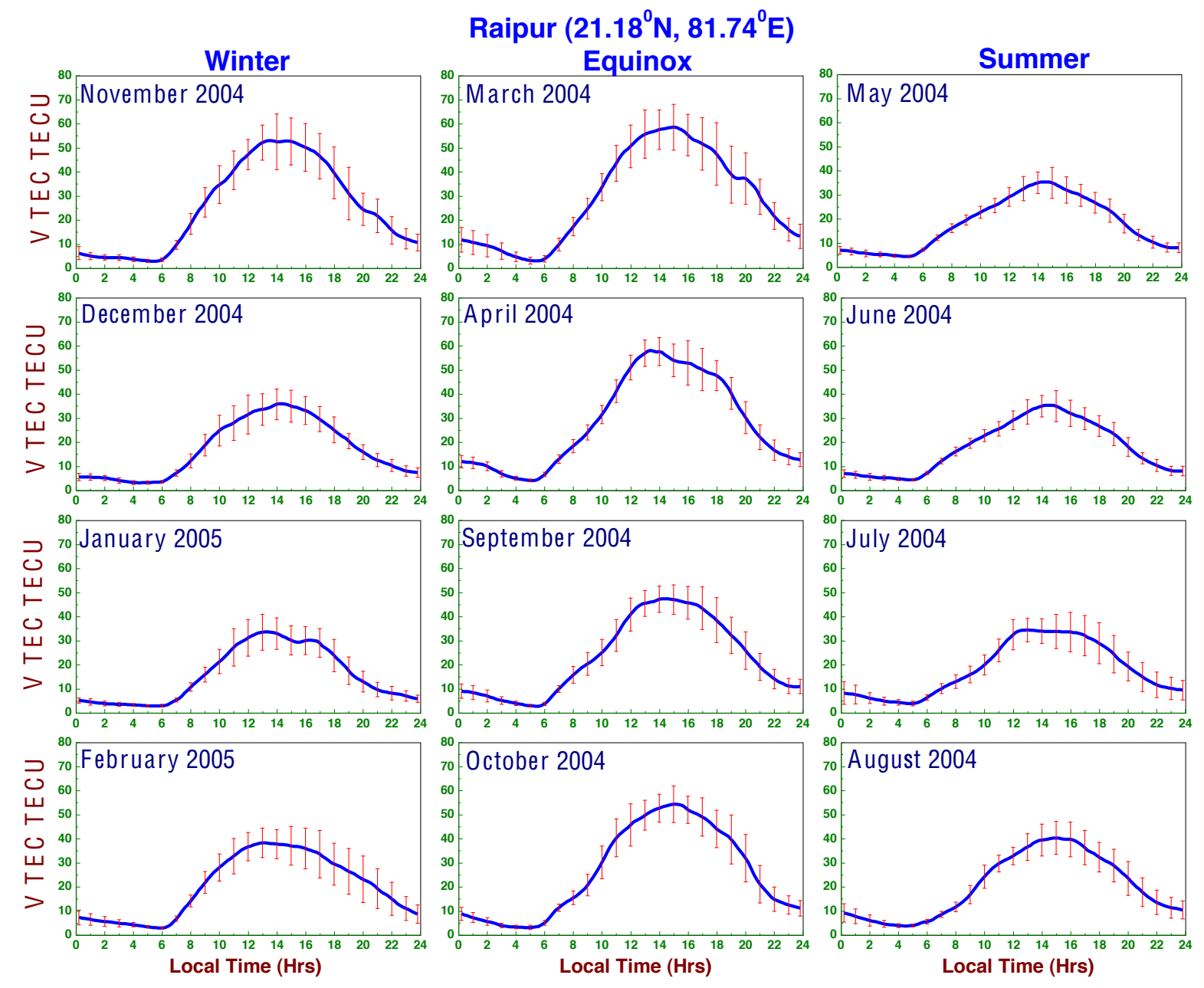
Average diurnal variation plots showing the standard deviations of the day-to-day variability in TEC over Waltair



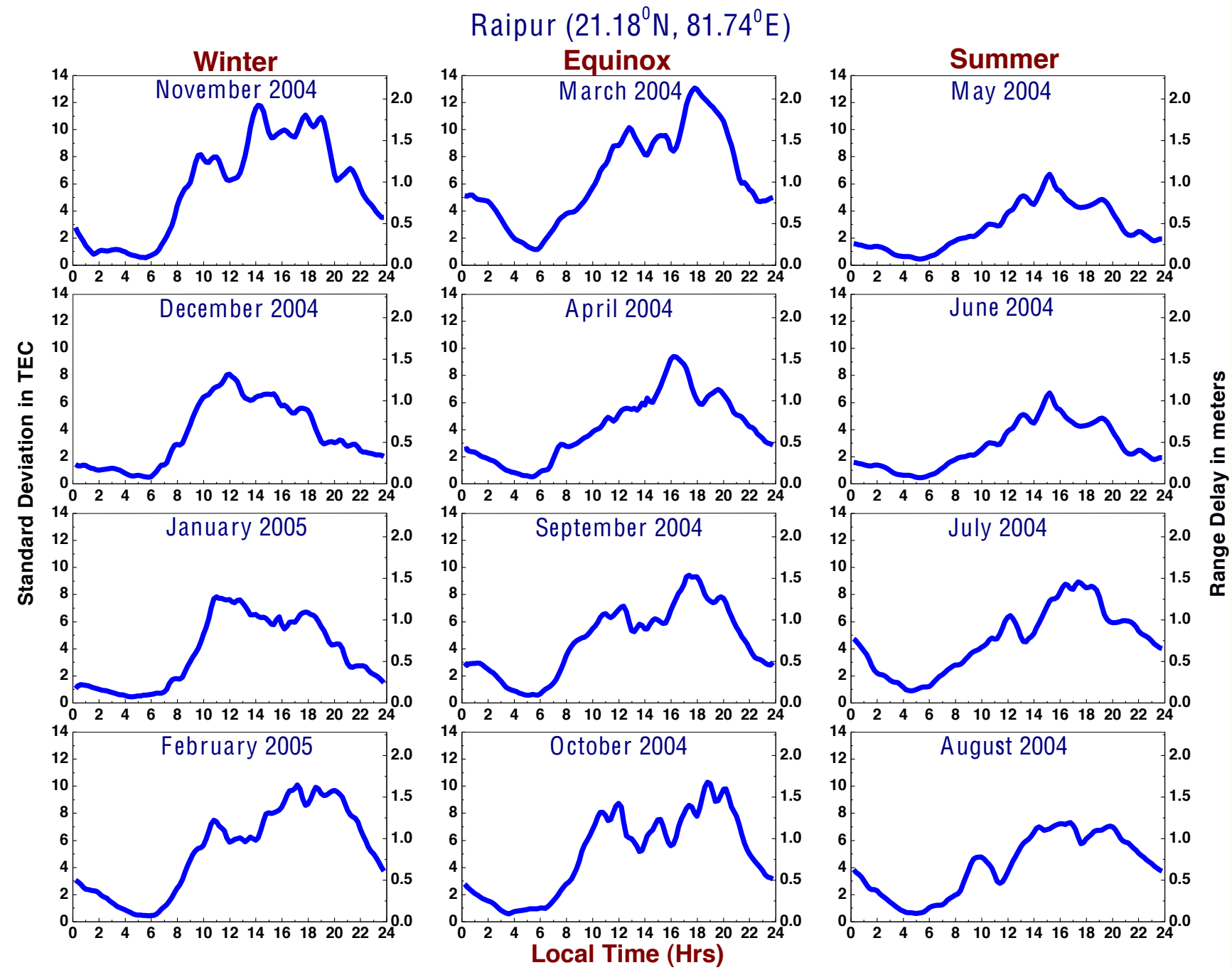
Monthly average diurnal variation of standard deviations in TEC over Waltair



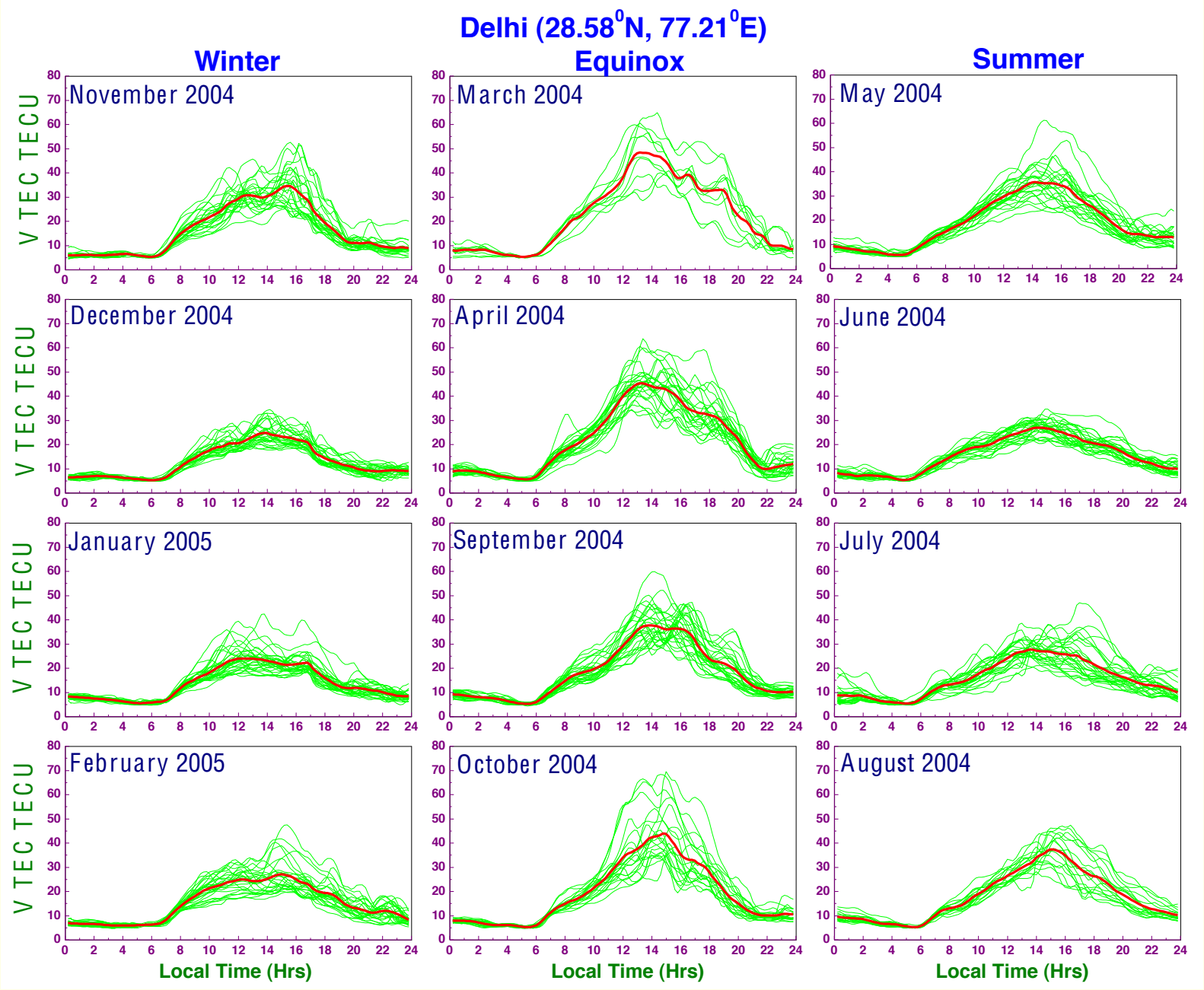
Mass plots of TEC for each month (showing the typical day to day variability) measured from the GPS signals at Raipur, located at the crest of the EIA



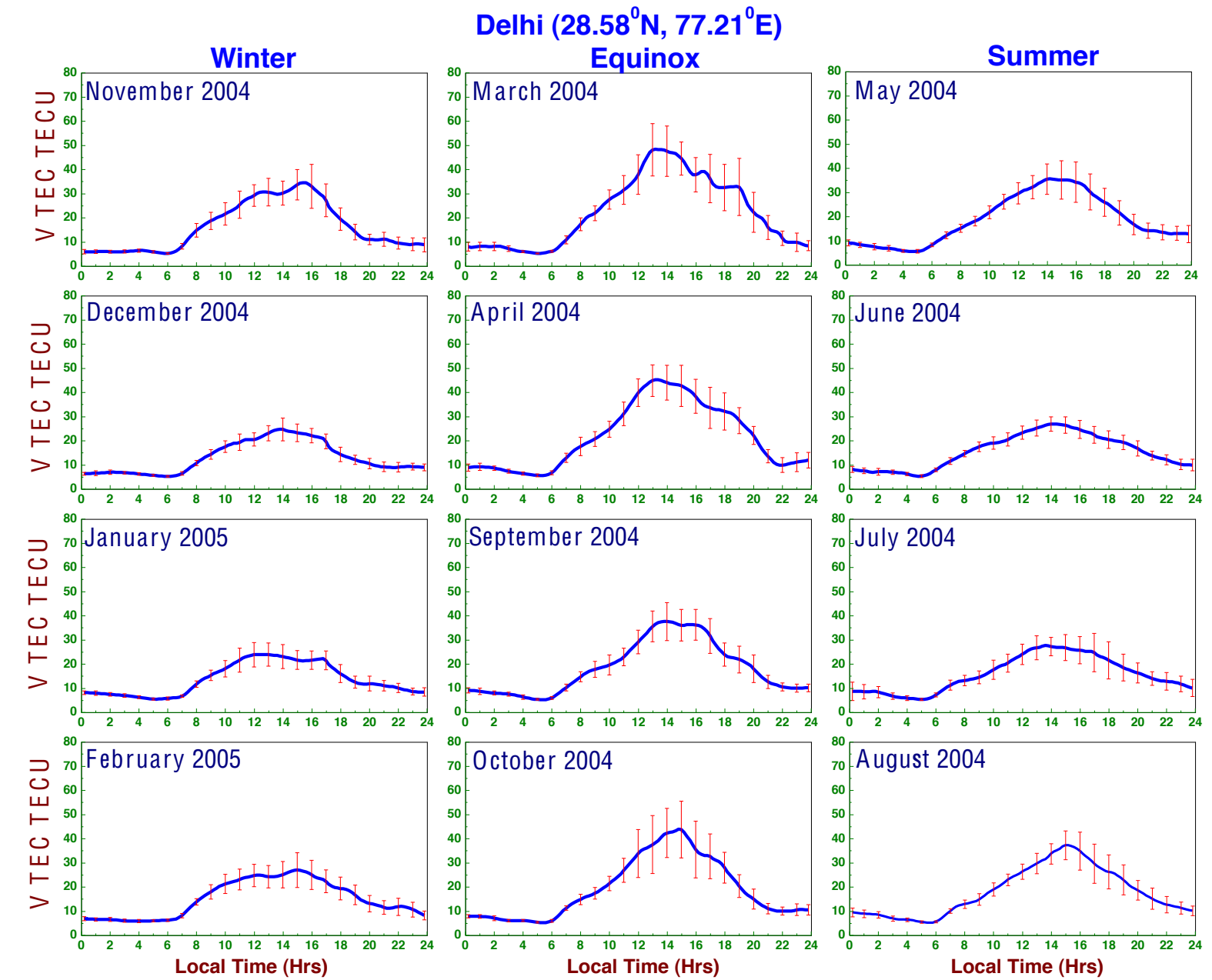
Average diurnal variation plots showing the standard deviations of the day-to-day variability in TEC over Raipur



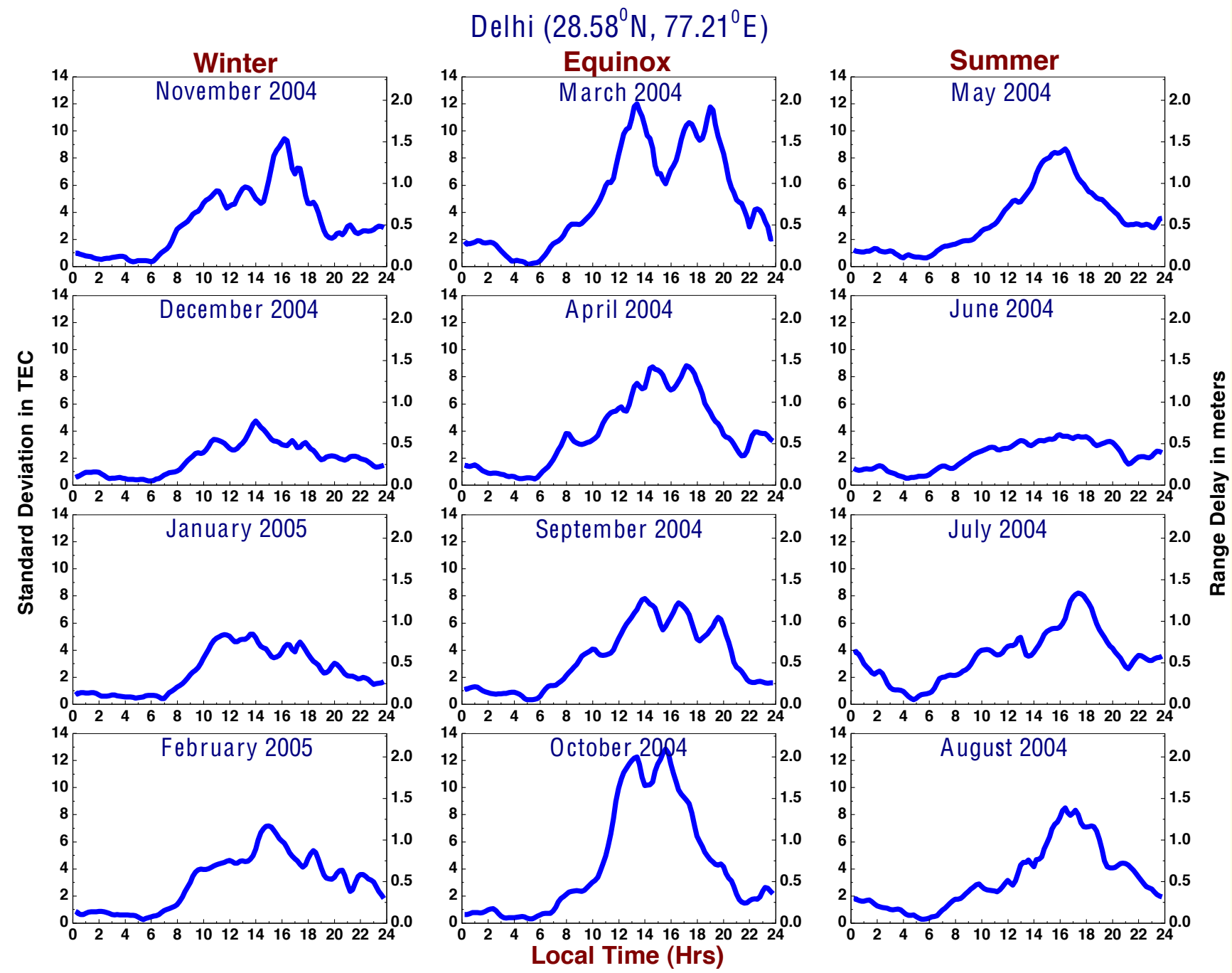
Monthly average diurnal variation of standard deviations in TEC over Raipur



Mass plots of TEC for each month(showing the typical day to day variability) measured from the GPS signals at Delhi, located at the outer edge of the EIA

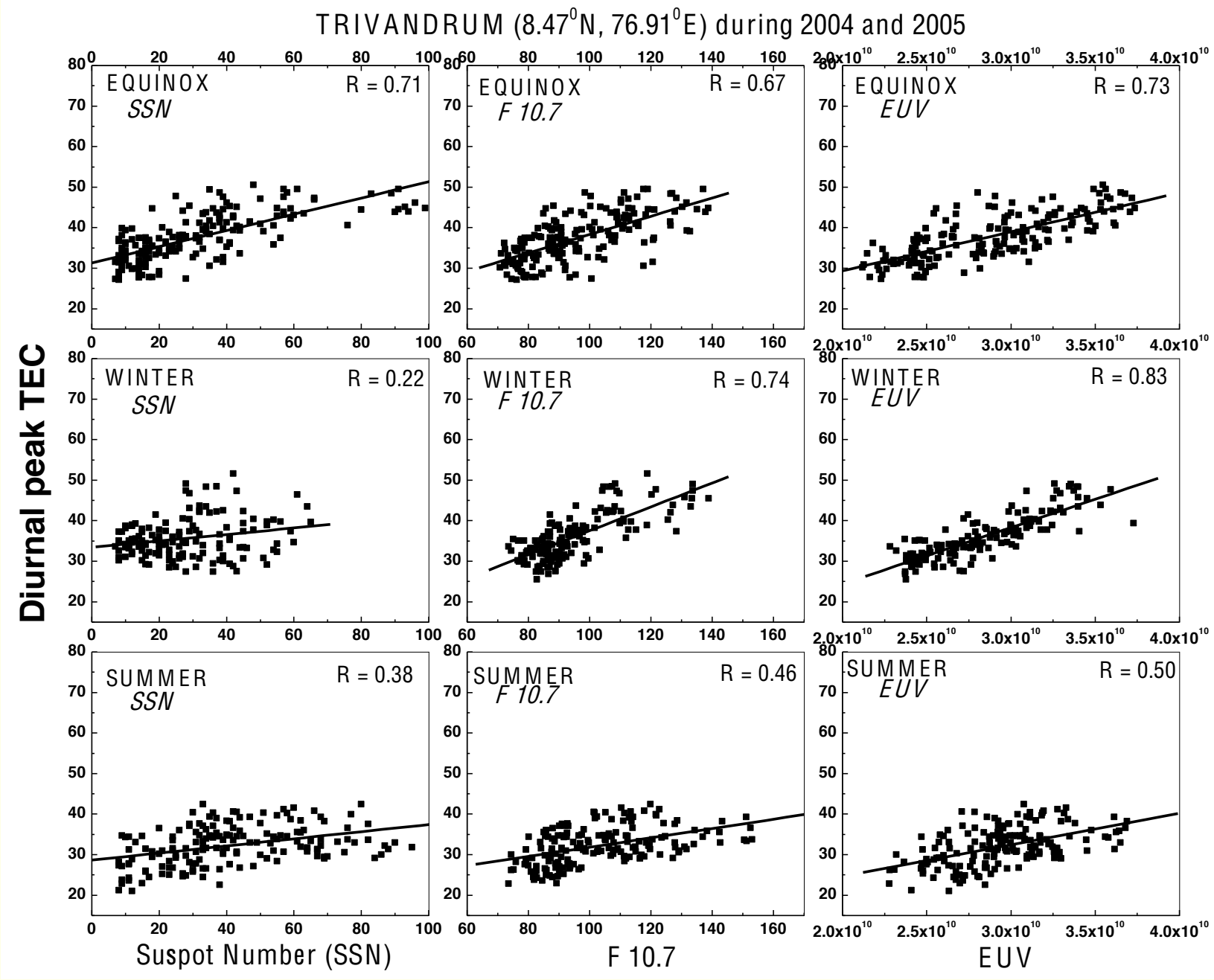


Average diurnal variation plots showing the standard deviations of the day-to-day variability in TEC over Delhi

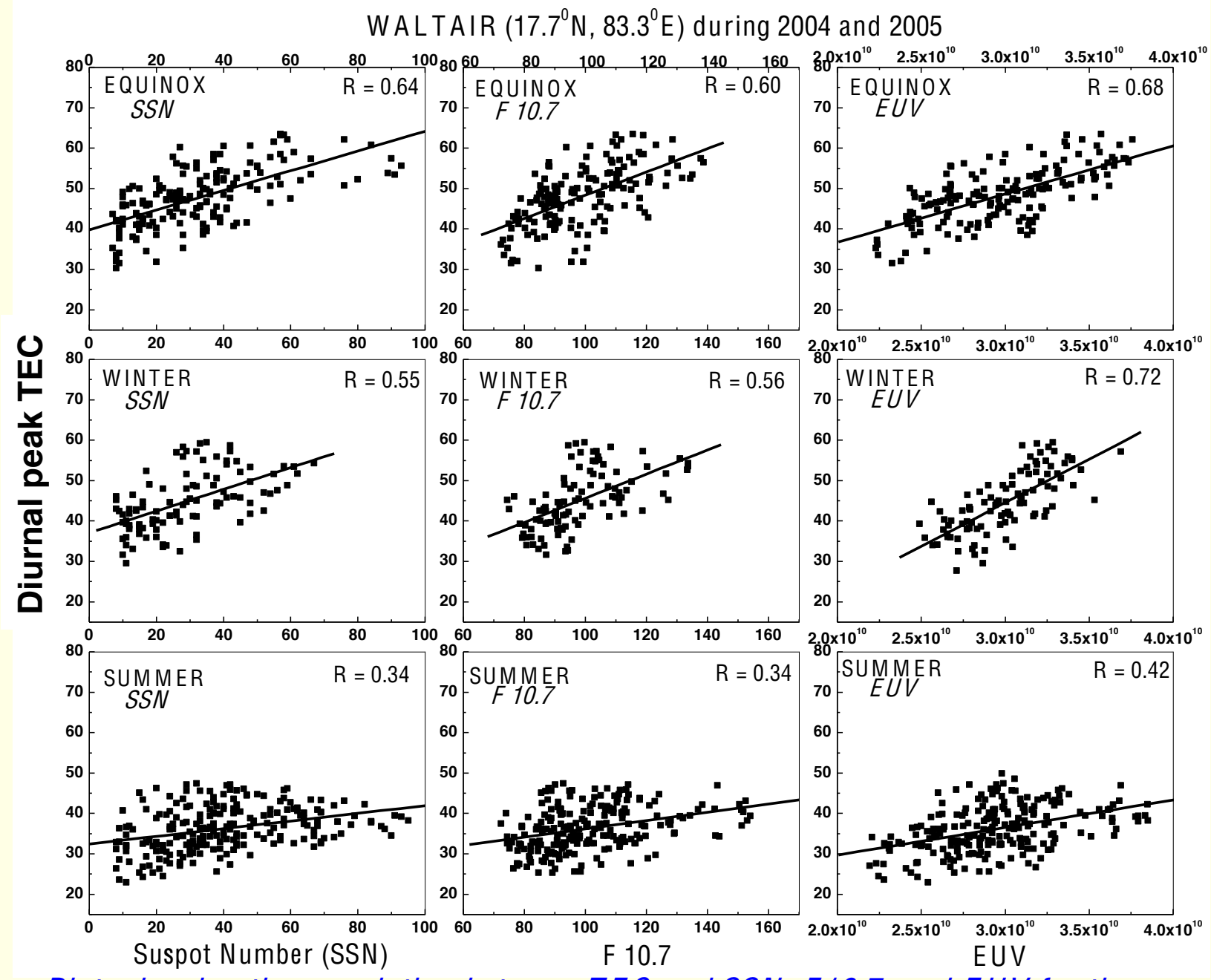


Monthly average diurnal variation of standard deviations in TEC over Delhi

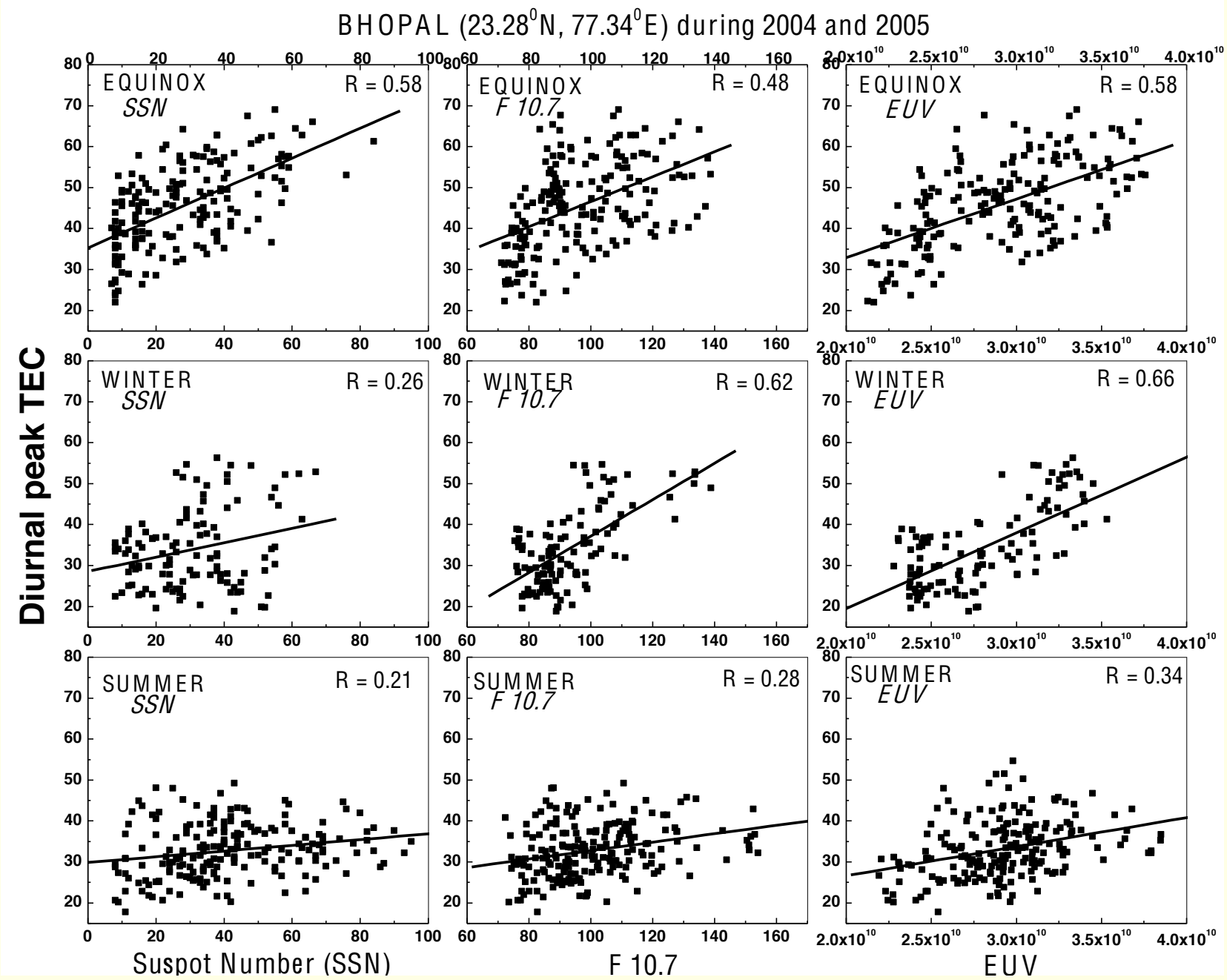
Variation of durnal peak Total Electron Content with solar activity indices



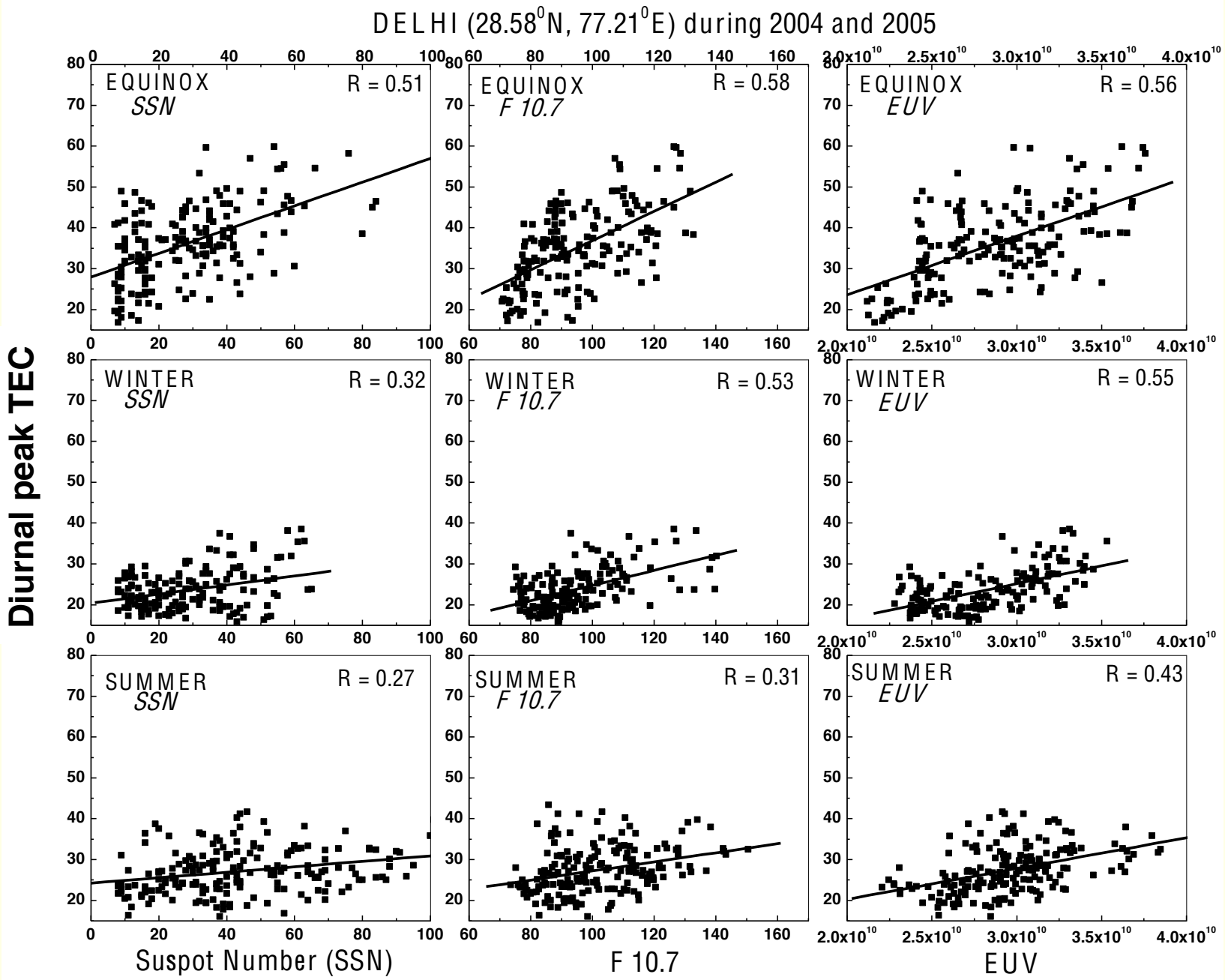
Plots showing the correlation between TEC and SSN, F10.7, and EUV for three different seasons over Trivandrum during the period from 2004 to 2005.



Plots showing the correlation between TEC and SSN, F10.7, and EUV for three different seasons over Waltair during the period from 2004 to 2005.

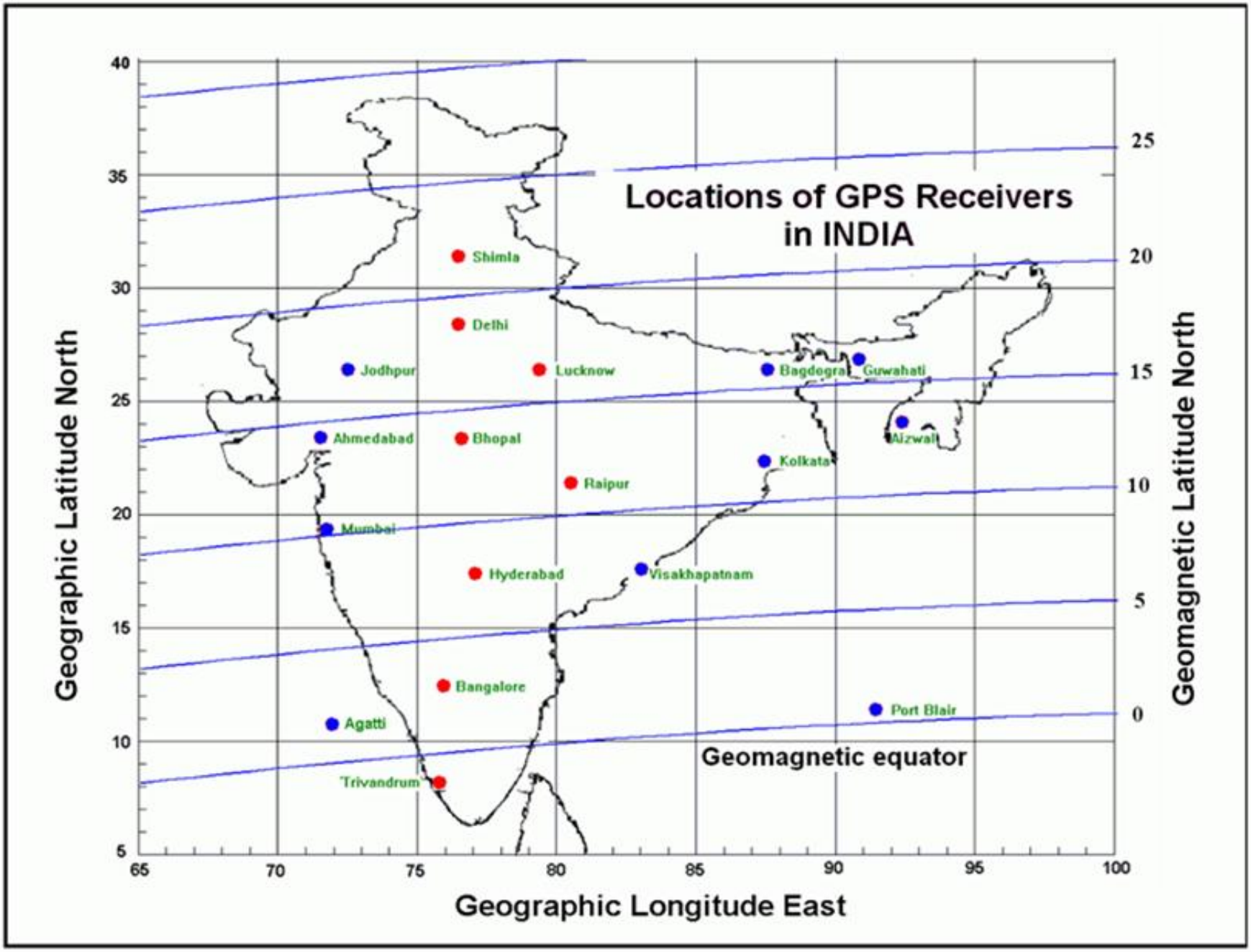


Plots showing the correlation between TEC and SSN, F10.7, and EUV for three different seasons over Bhopal during the period from 2004 to 2005.

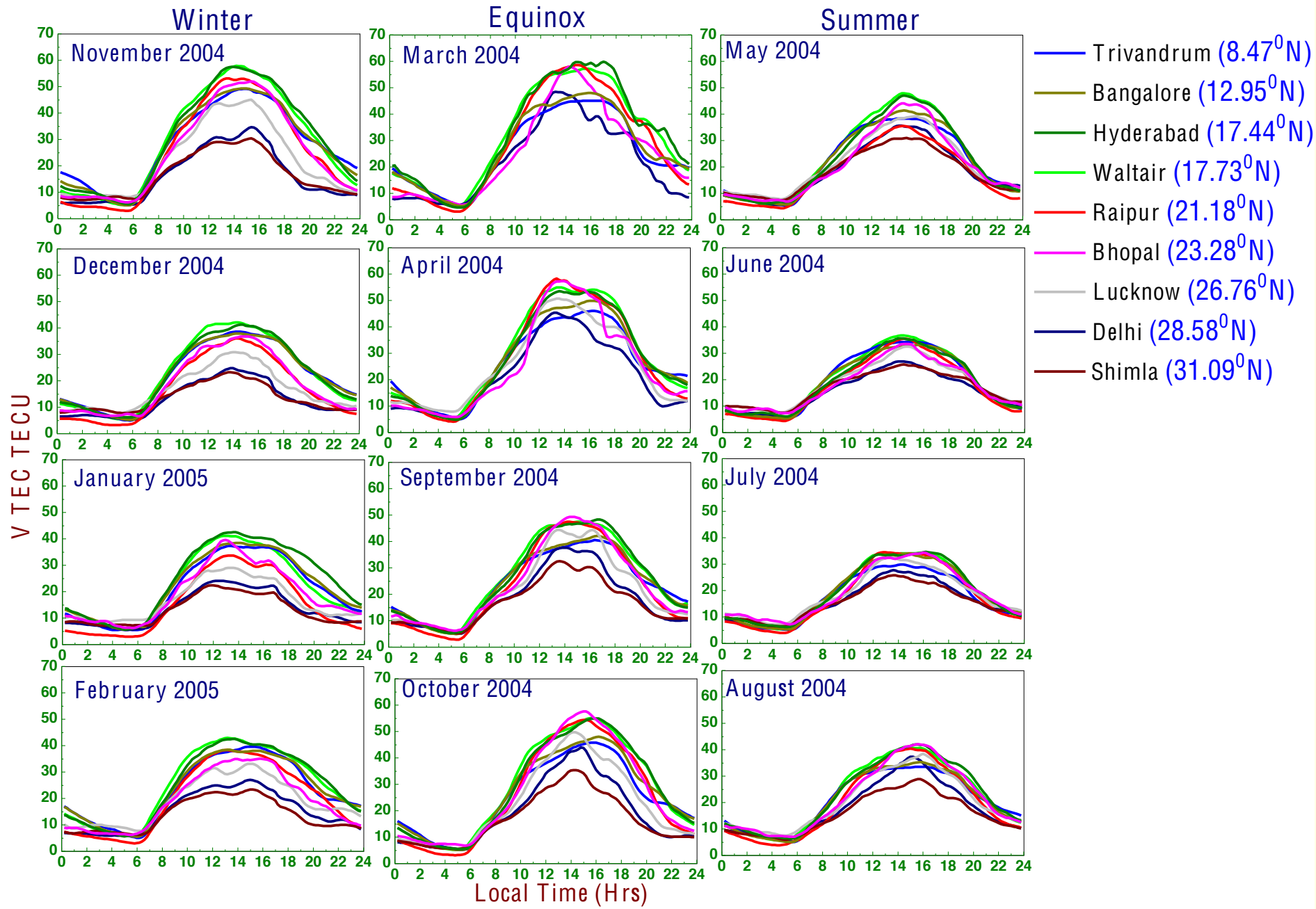


Plots showing the correlation between TEC and SSN, F10.7, and EUV for three different seasons over Delhi during the period from 2004 to 2005.

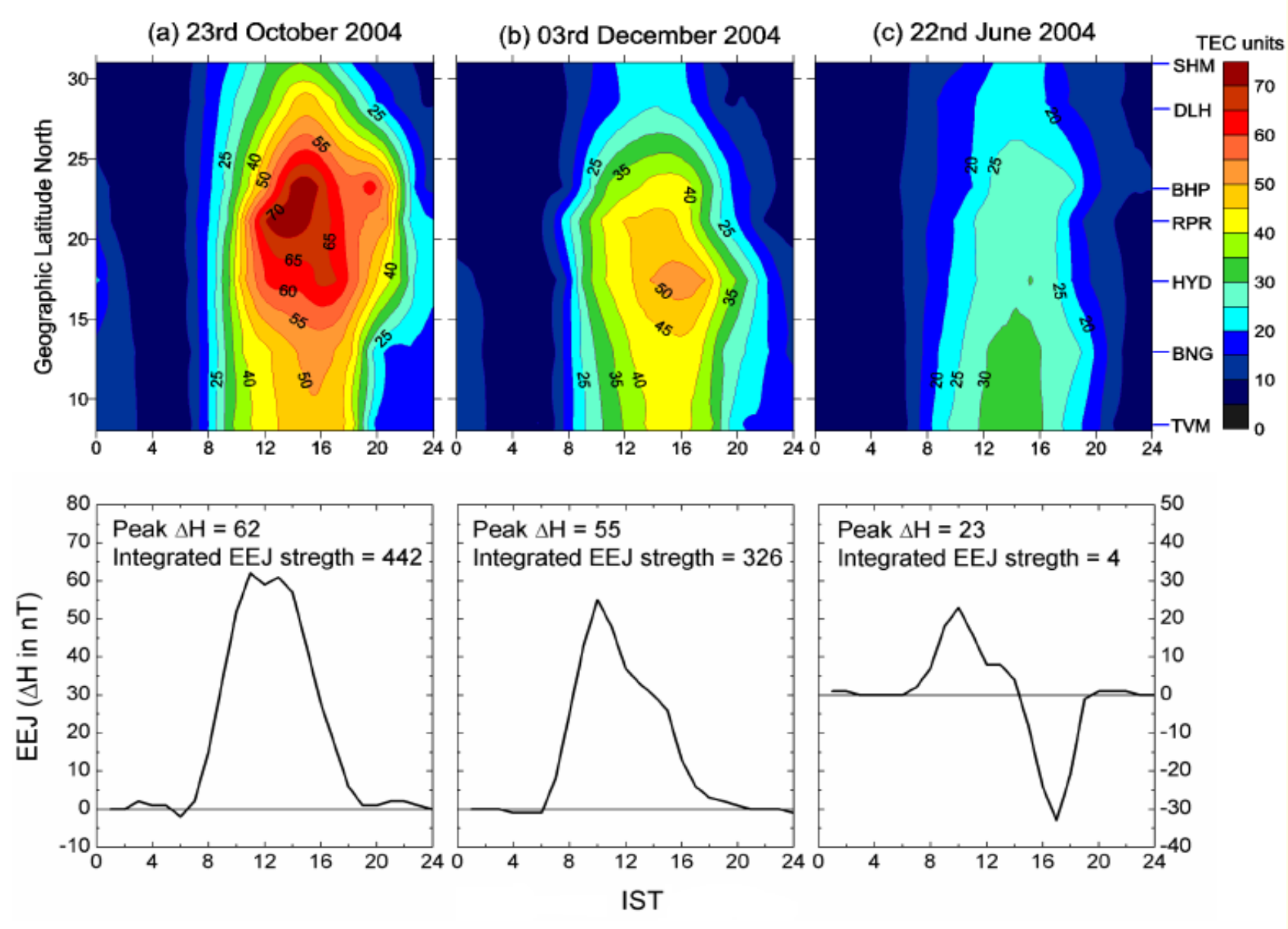
Equatorial Ionization Anomaly and its association with Integrated Equatorial Electrojet Strength



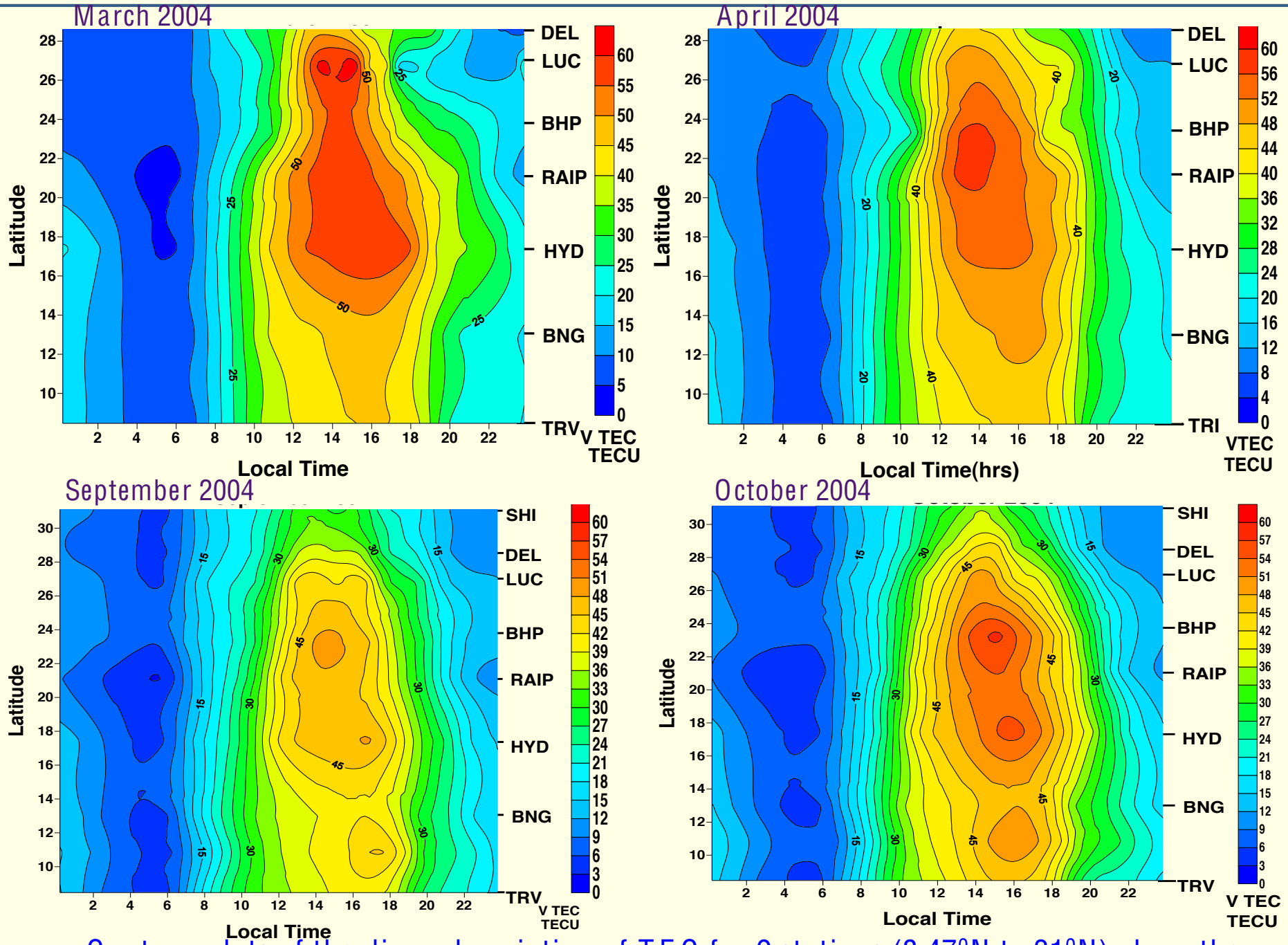
Locations of GPS Receivers in India



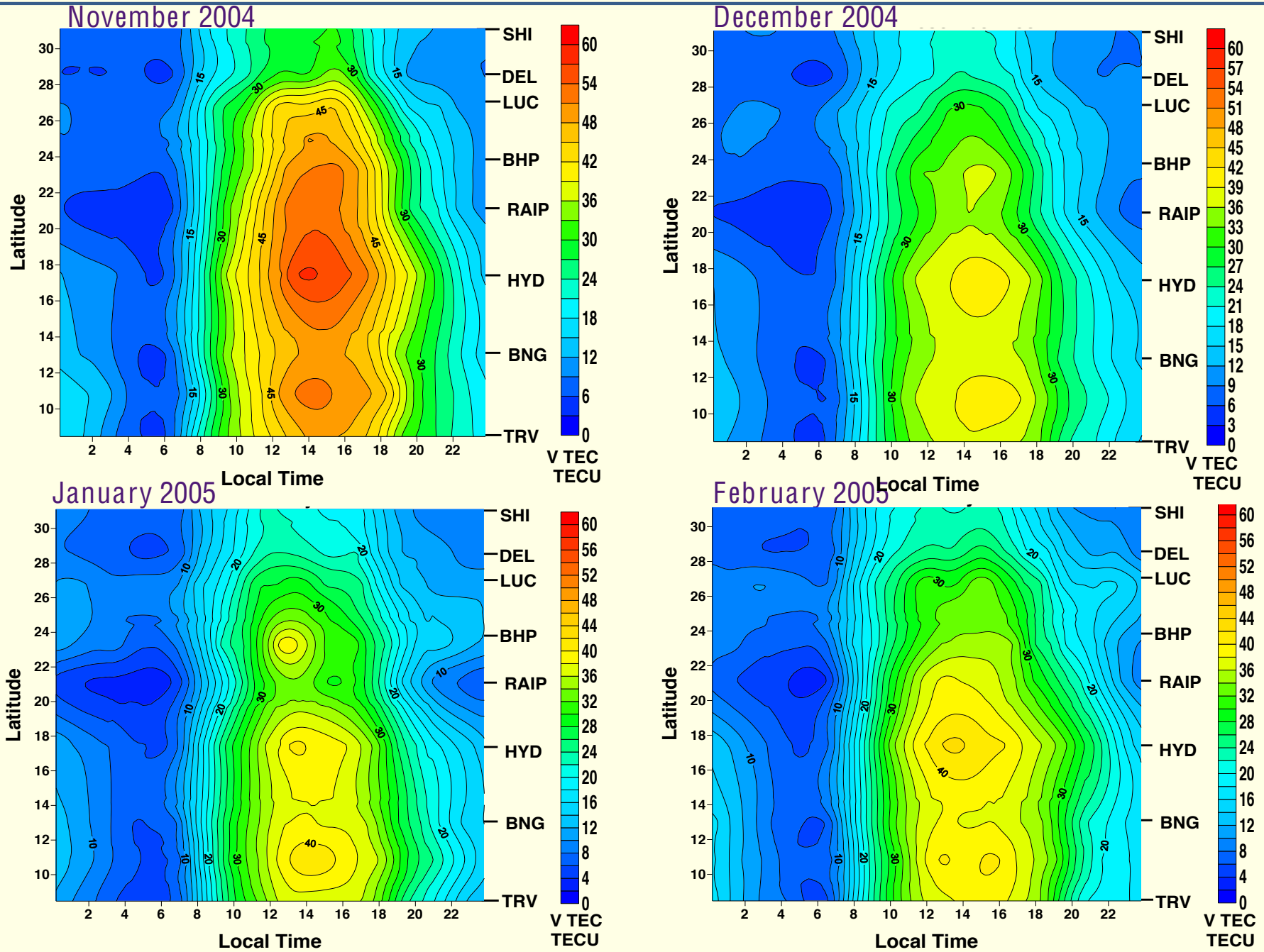
Monthly average diurnal variations at 9 different stations along a common longitude of 77⁰ E



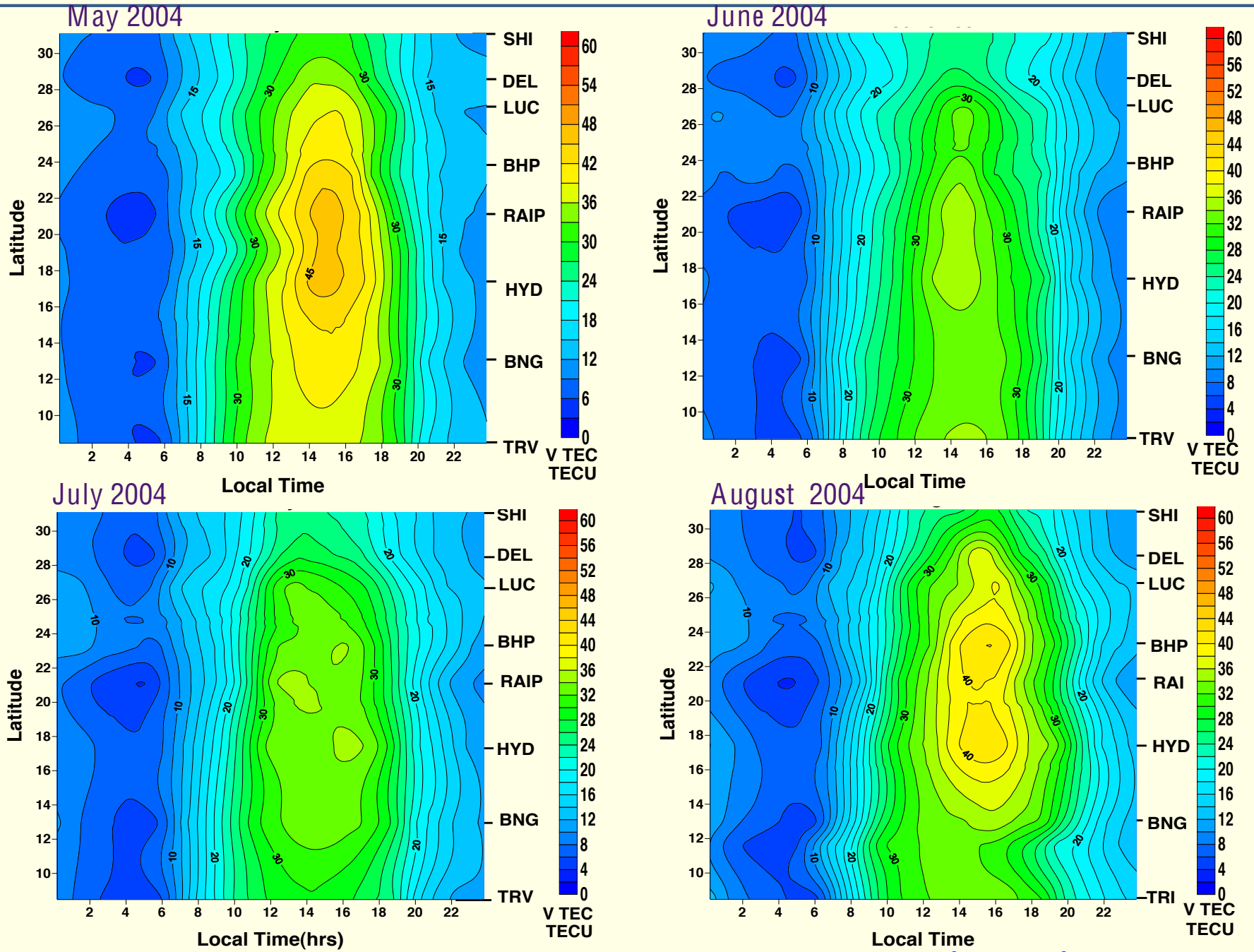
Typical contour plots of the diurnal variations of TEC, drawn as a function of latitude for (a) an equinoctial day, (b) a winter day and (c) a summer day along with the corresponding diurnal variations of the equatorial electrojet strengths.



Contour plots of the diurnal variation of TEC for 9 stations (8.47^{0}N to 31^{0}N) along the common longitude of 77 ^{0}E during Equinoctial months

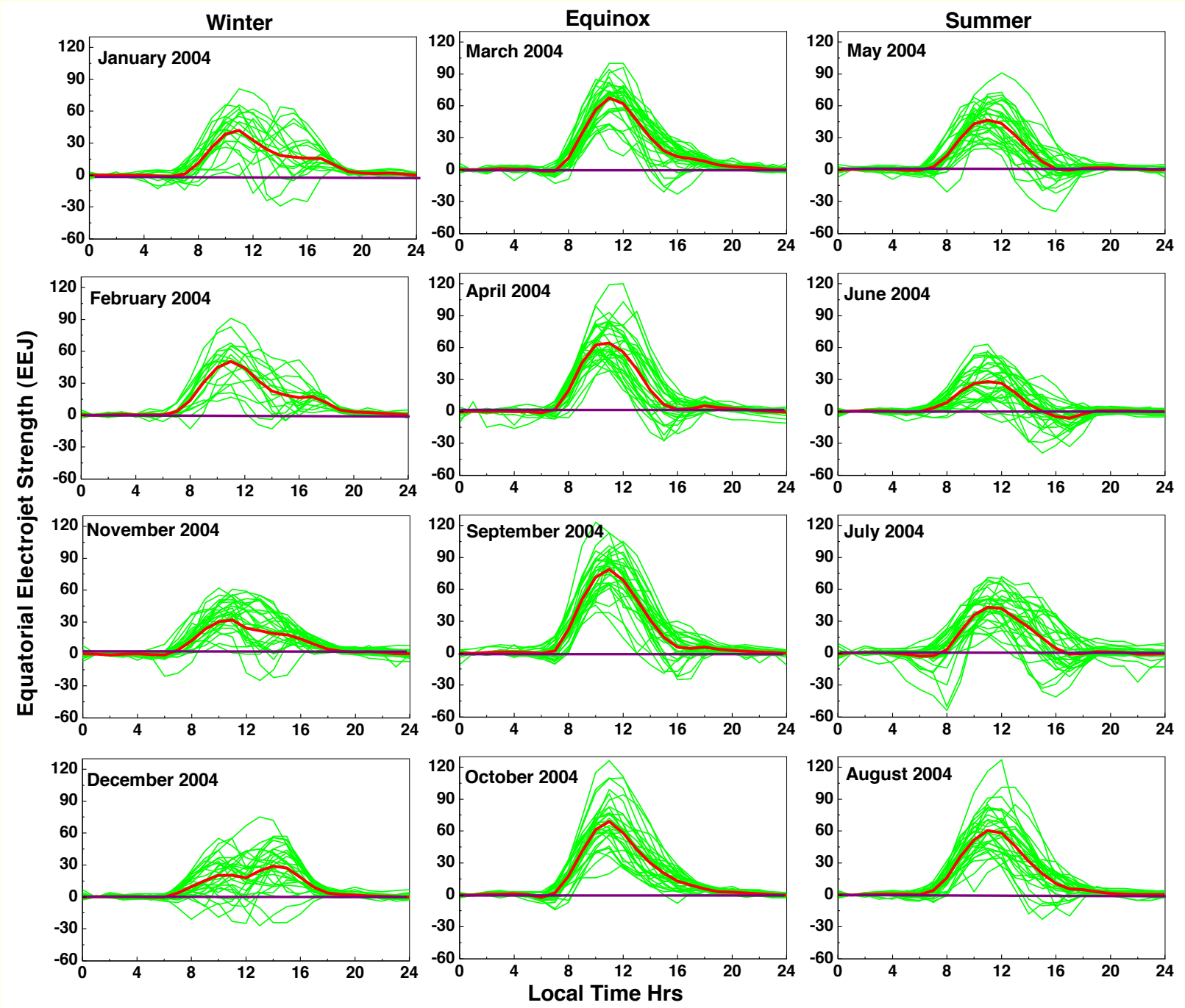


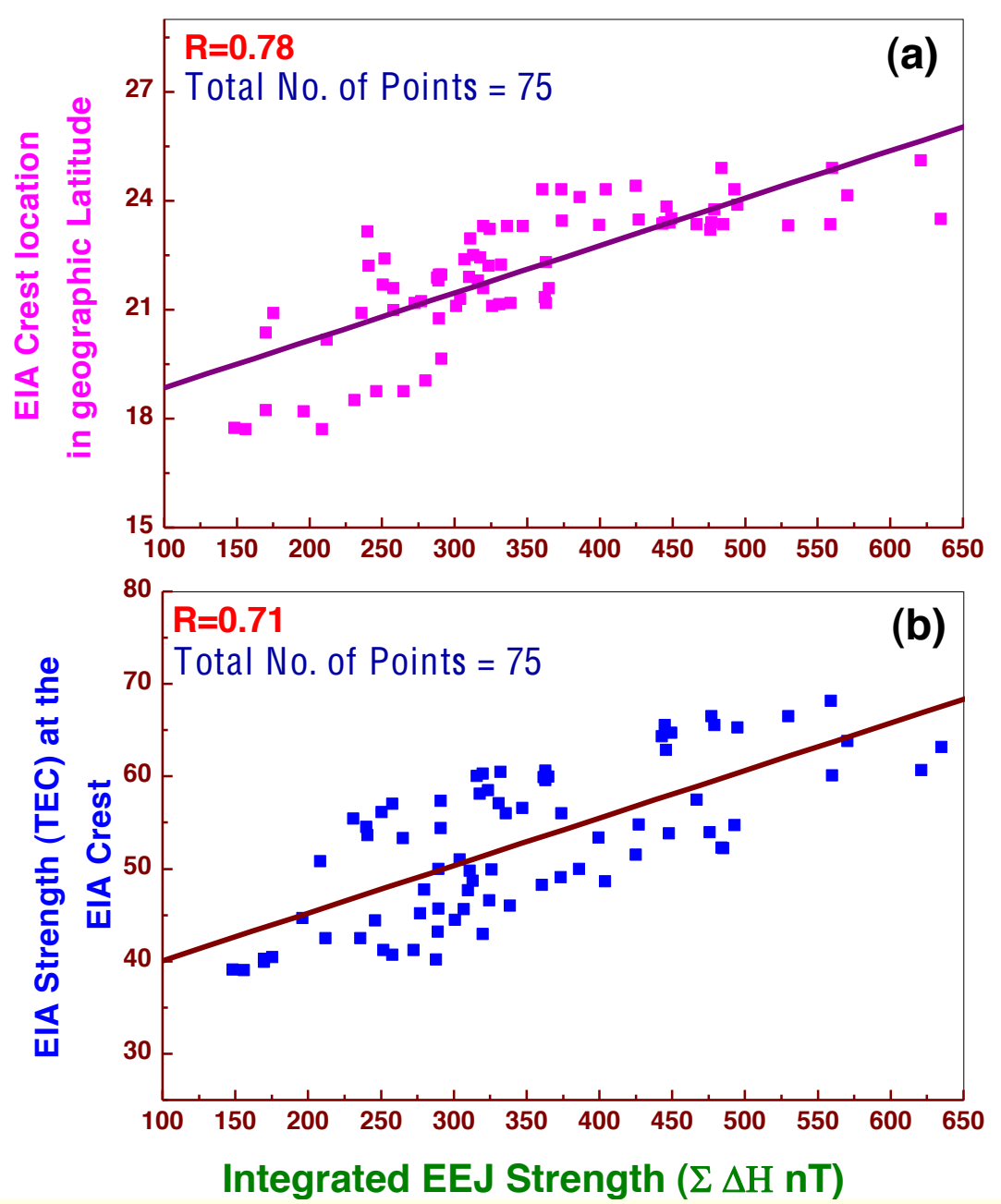
Contour plots of the diurnal variation of TEC for 9 stations **(8.47⁰N to 31⁰N)** along the common longitude of 77⁰E during Winter months



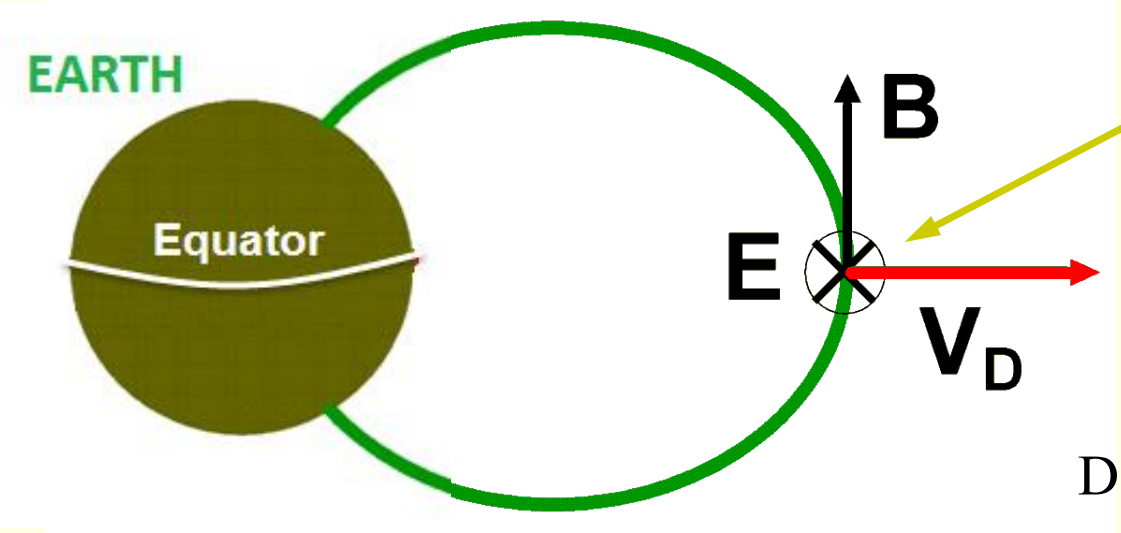
Contour plots of the diurnal variation of TEC for 9 stations (8.47^{0}N to 31^{0}N) along the common longitude of 77 ^{0}E during Summer months

Electrojet Strength at an equatorial station, Trivandrum



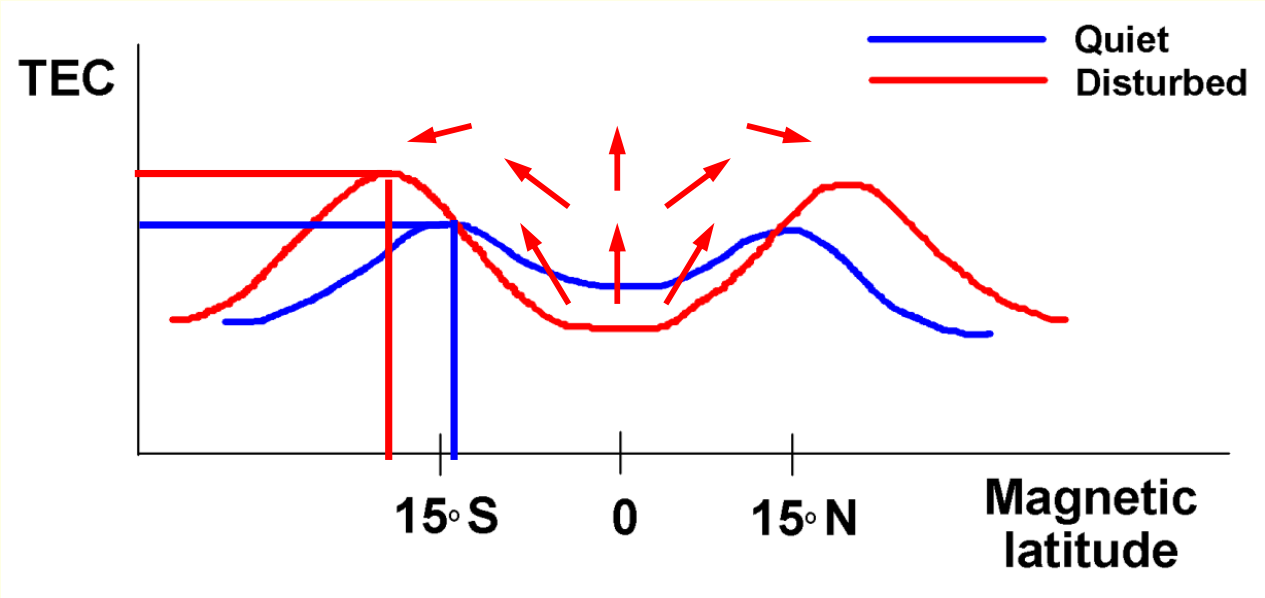


Variation of (a) Location and (b) peak electron density of the crest of EIA as a function of Integrated Equatorial Electrojet Strength during geomagnetically quiet days



Intensified Eastward Electric Field

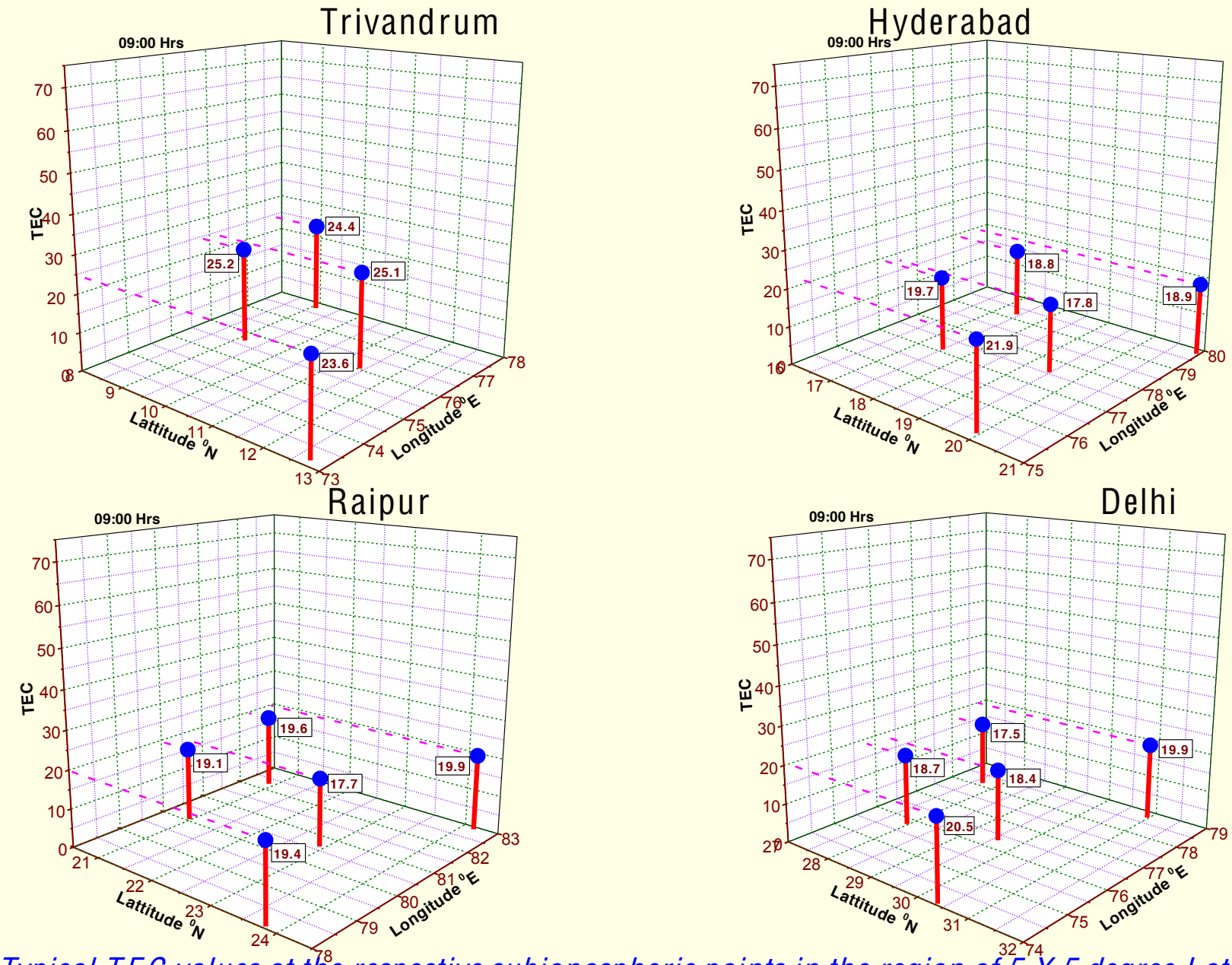
Daytime ~ 9 LT to 21 LT



Variations of the GPS measured

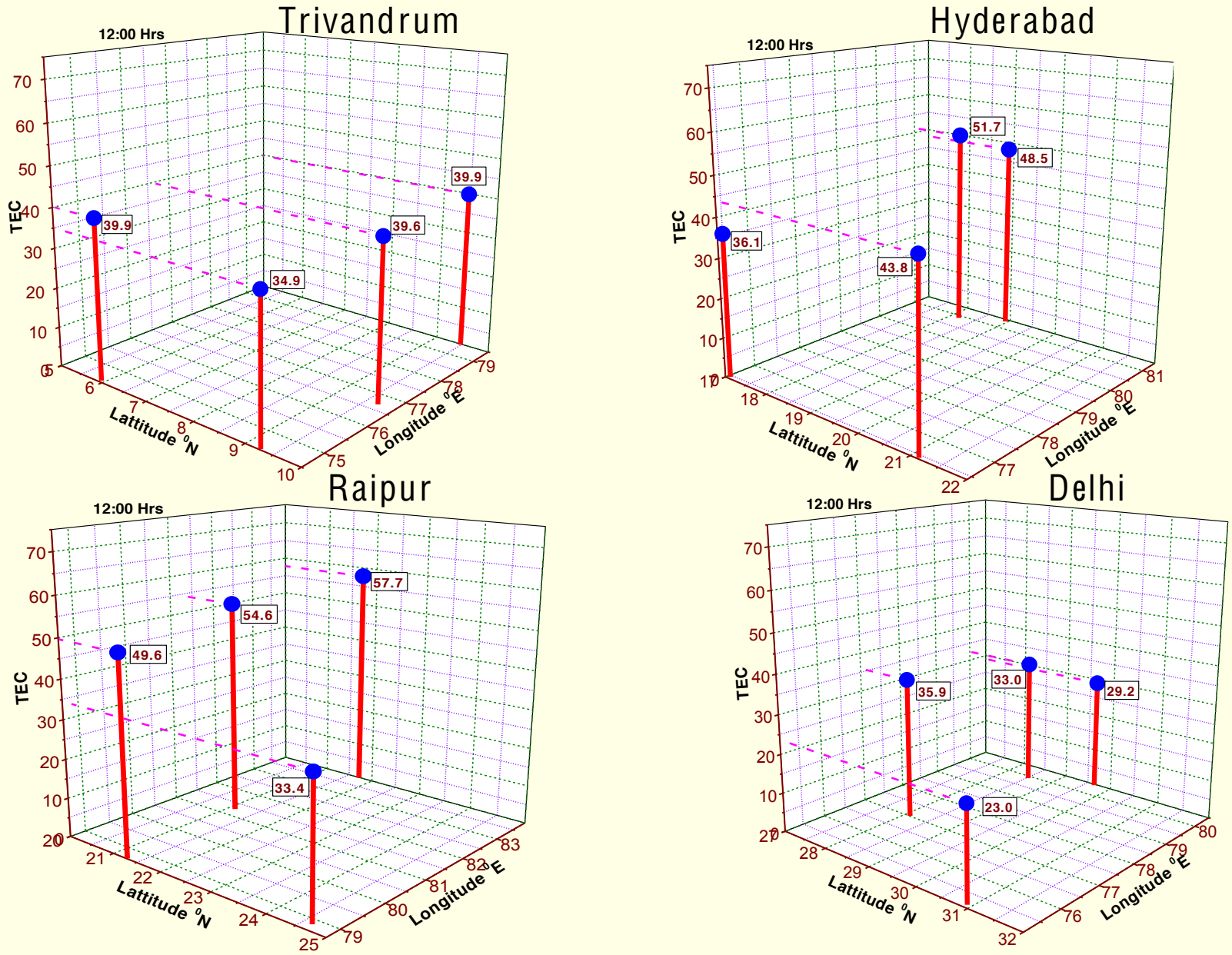
Total Electron Content in the 5^0 x 5^0 grid

5th May 2004 (09:00 Hrs LT)



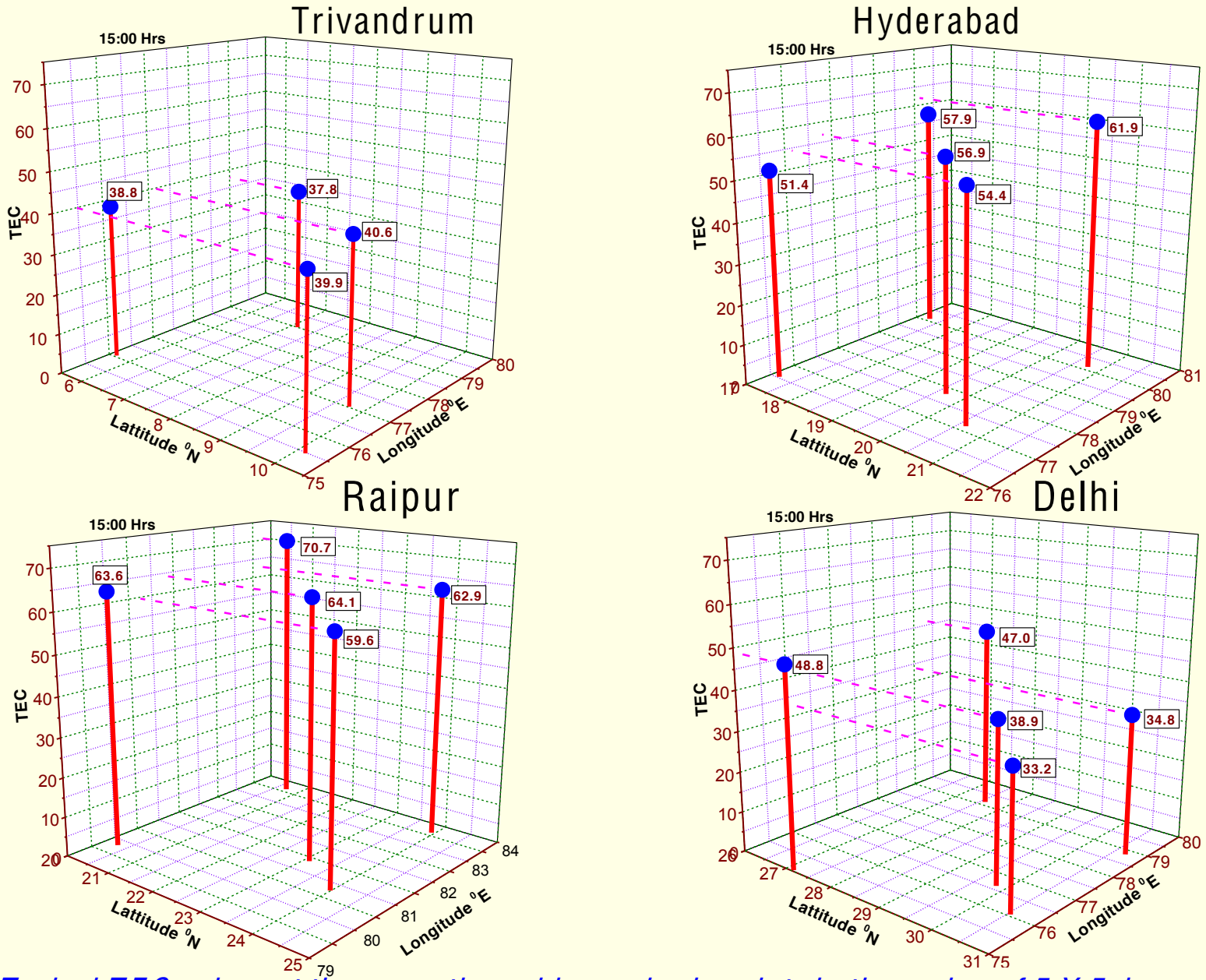
Typical TEC values at the respective subionospheric points in the region of 5 X 5 degree Latitude and Longitude at four Indian typical stations Trivandrum Hyderabad, Raipur and Delhi at a specific local time of 09:00 Hrs on 5th May 2004

5th May 2004 (12:00 Hrs LT)



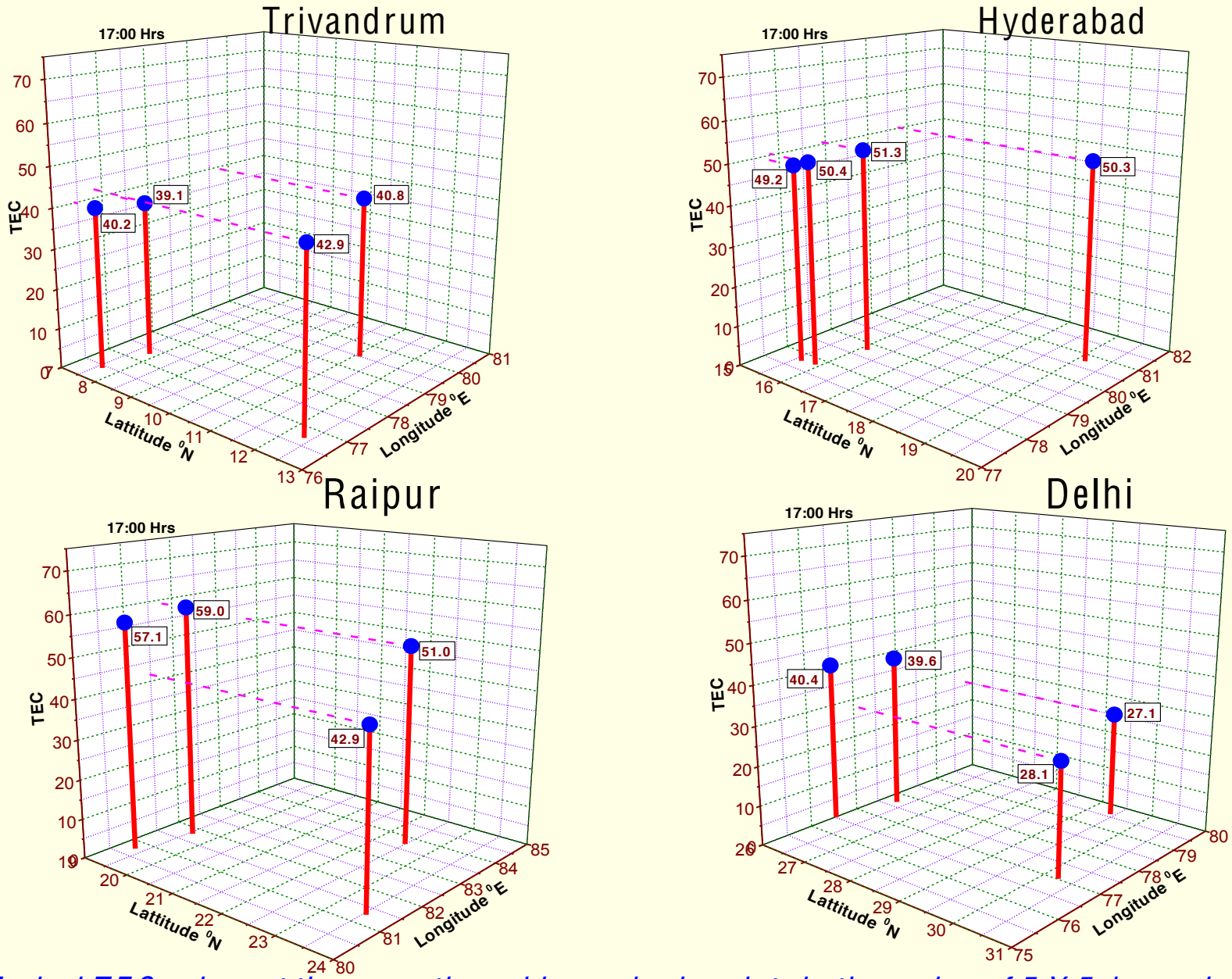
Typical TEC values at the respective subionospheric points in the region of 5 X 5 degree Latitude and Longitude at four Indian typical stations Trivandrum Hyderabad, Raipur and Delhi at a specific local time at 12:00 Hrs noon on 5th May 2004

5th May 2004 (15:00 Hrs LT)

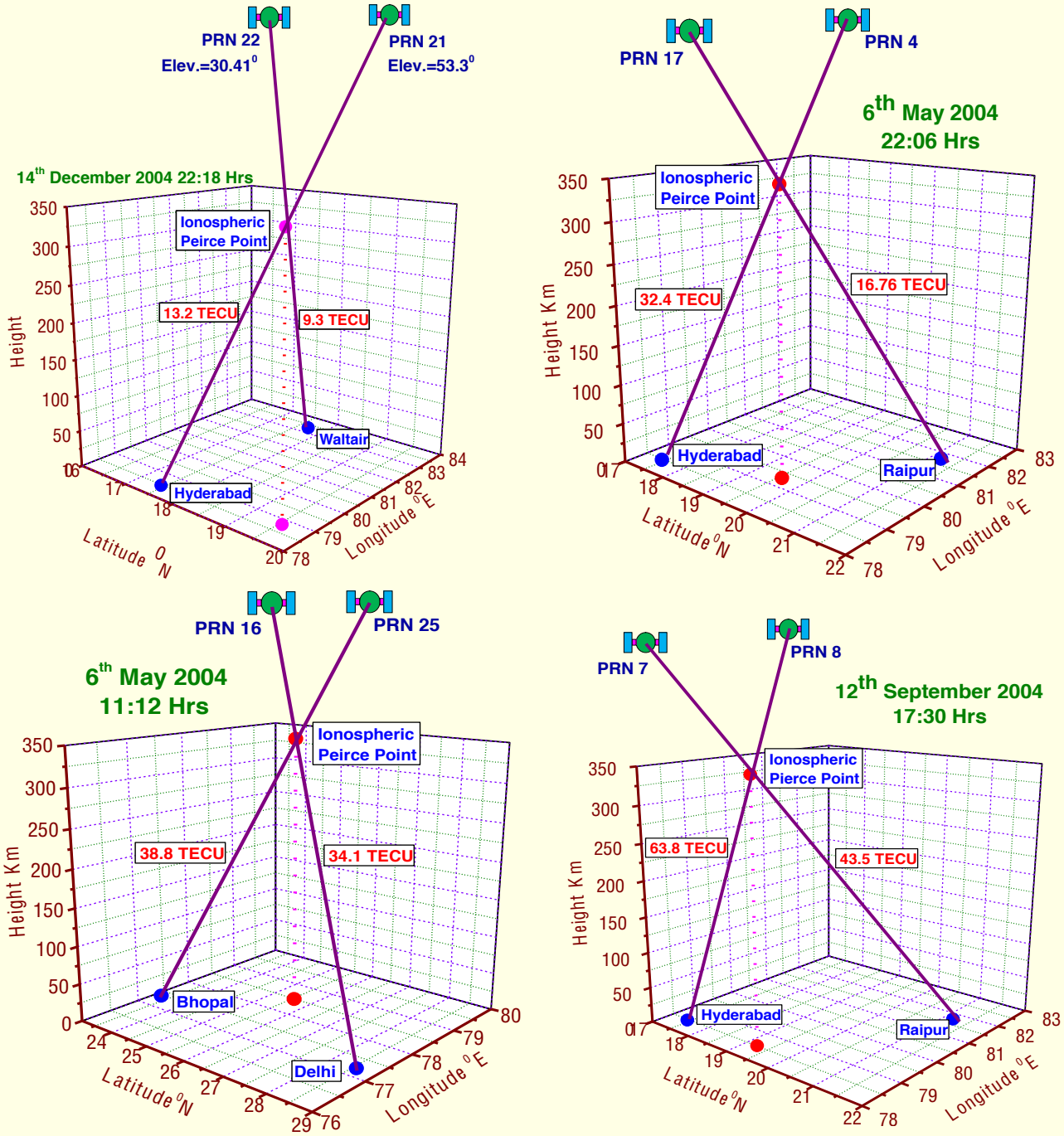


Typical TEC values at the respective subionospheric points in the region of 5 X 5 degree Latitude and Longitude at four Indian typical stations Trivandrum Hyderabad, Raipur and Delhi at a specific local time at 15:00 Hrs on 5th May 2004

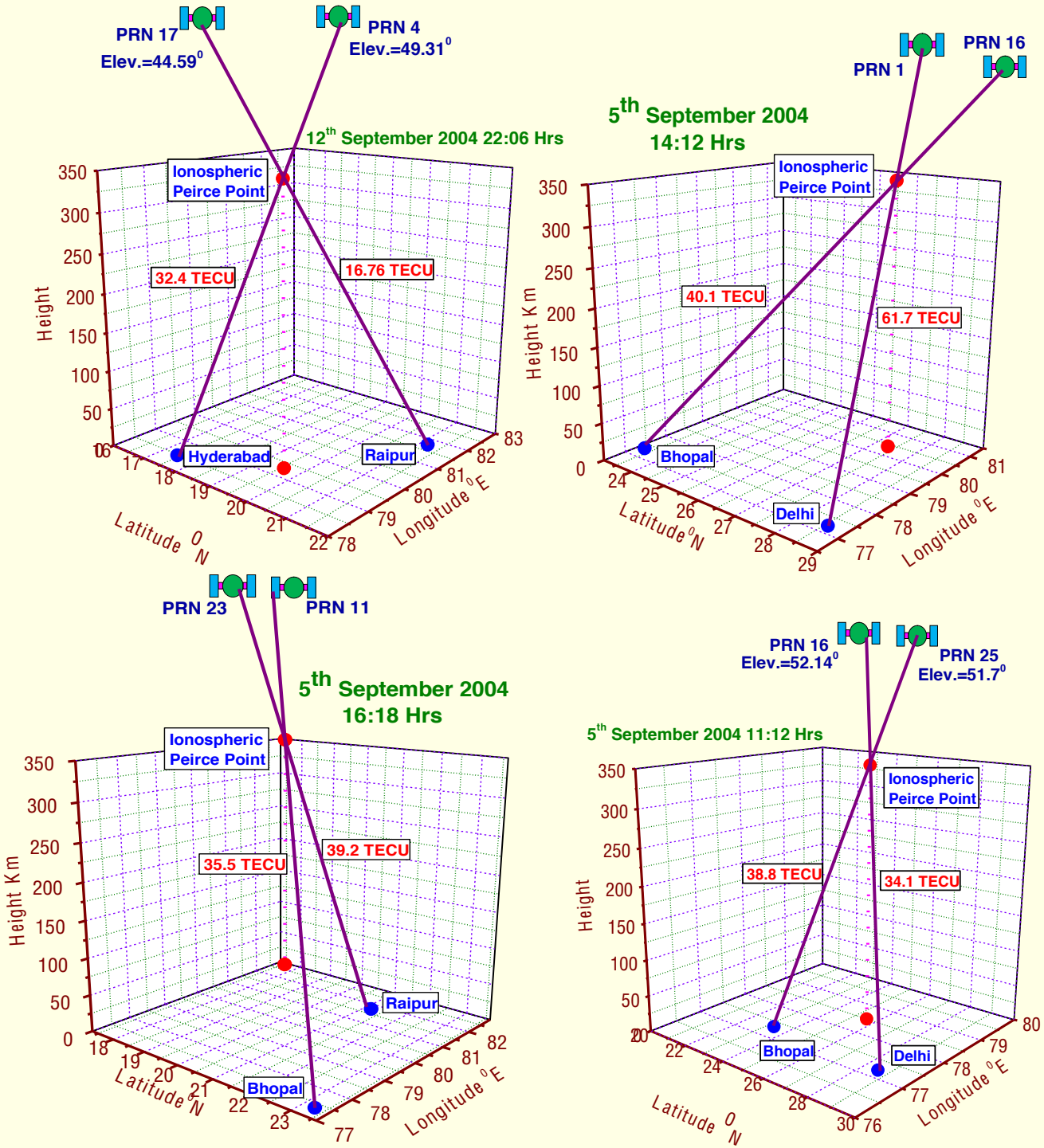
5th May 2004 (17:00 Hrs LT)



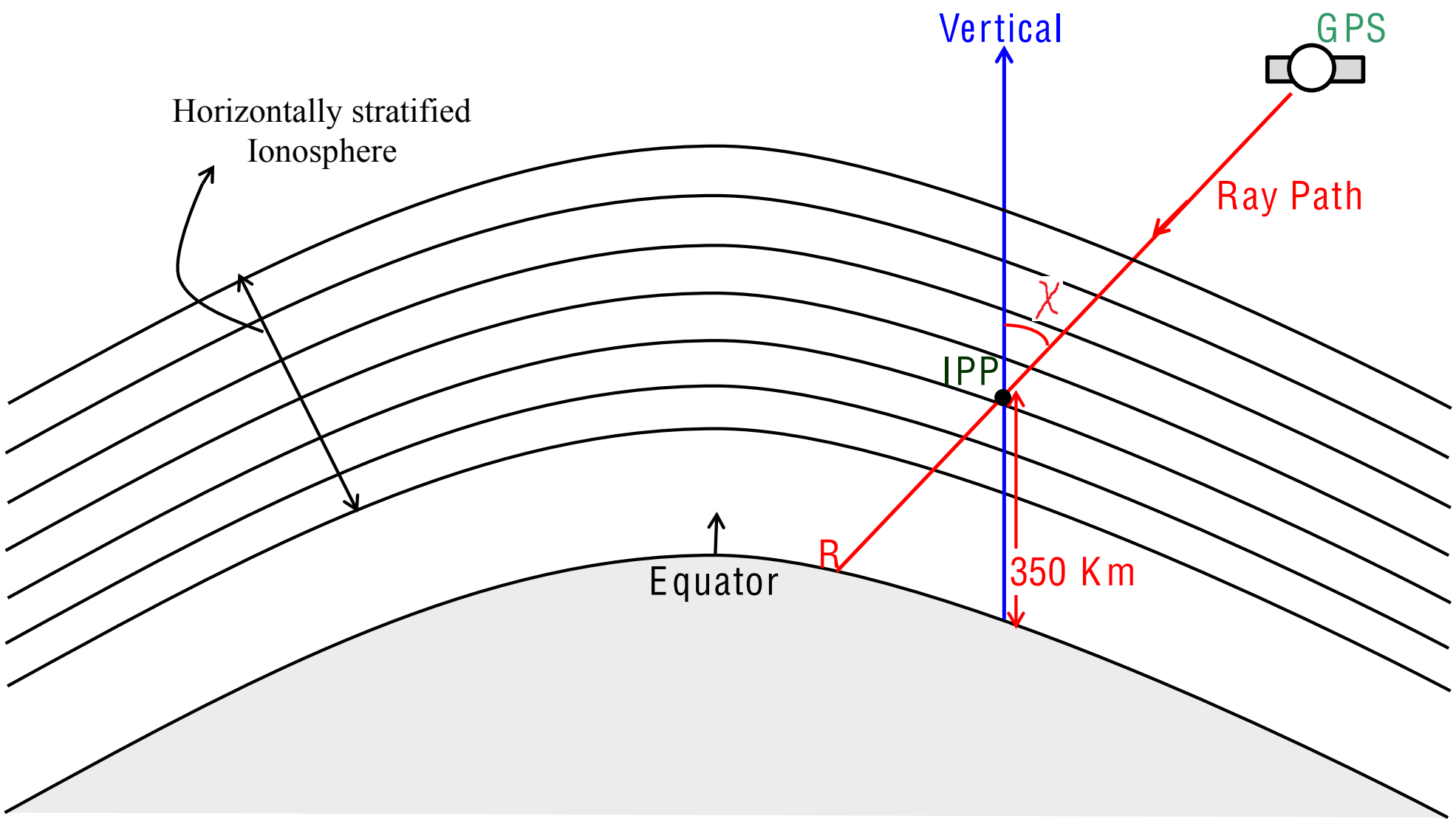
Typical TEC values at the respective subionospheric points in the region of 5 X 5 degree Latitude and Longitude at four Indian typical stations Trivandrum Hyderabad, Raipur and Delhi at a specific local time of 17:00 Hrs PM on 5th May 2004



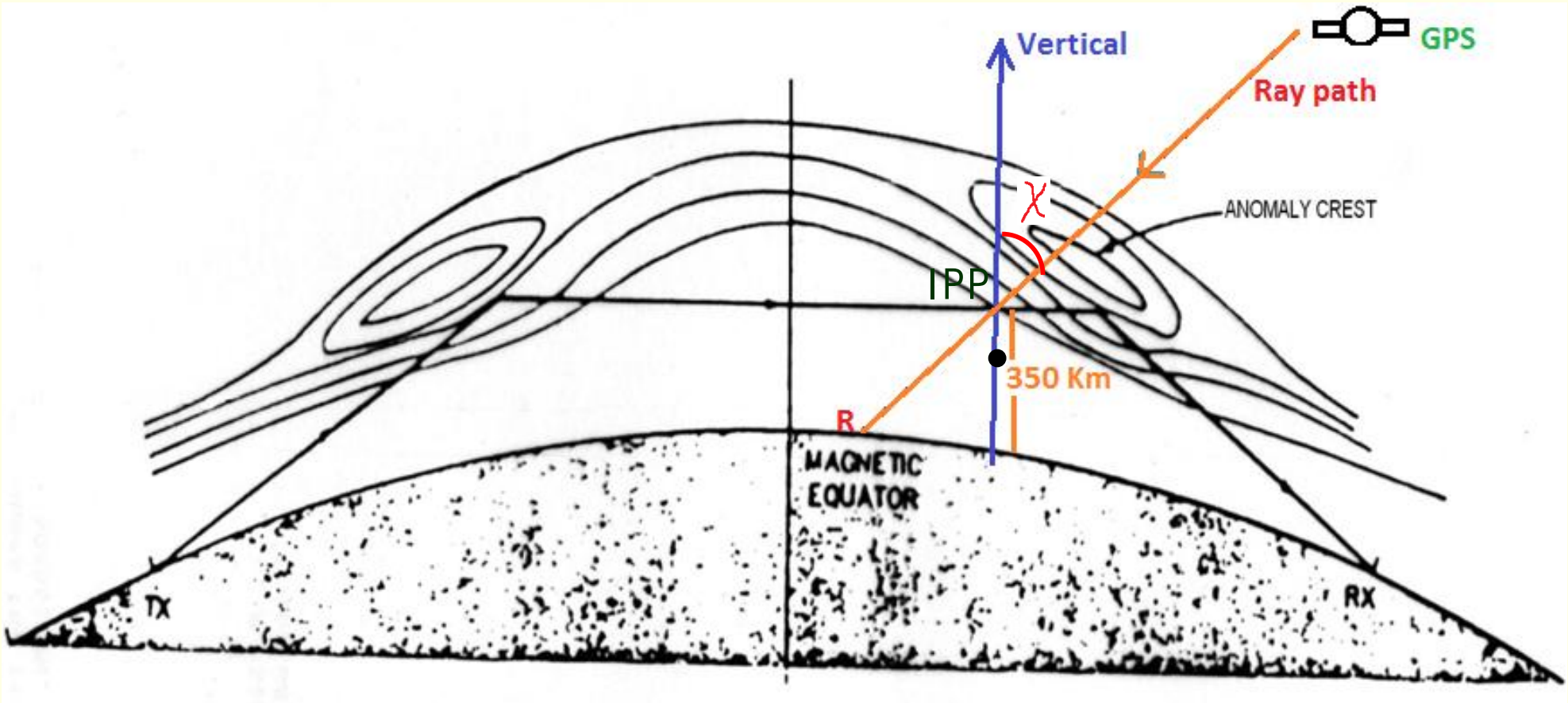
TEC derived from two different and simultaneous ray paths at the same location of the sub ionospheric point showing significant variability in their values



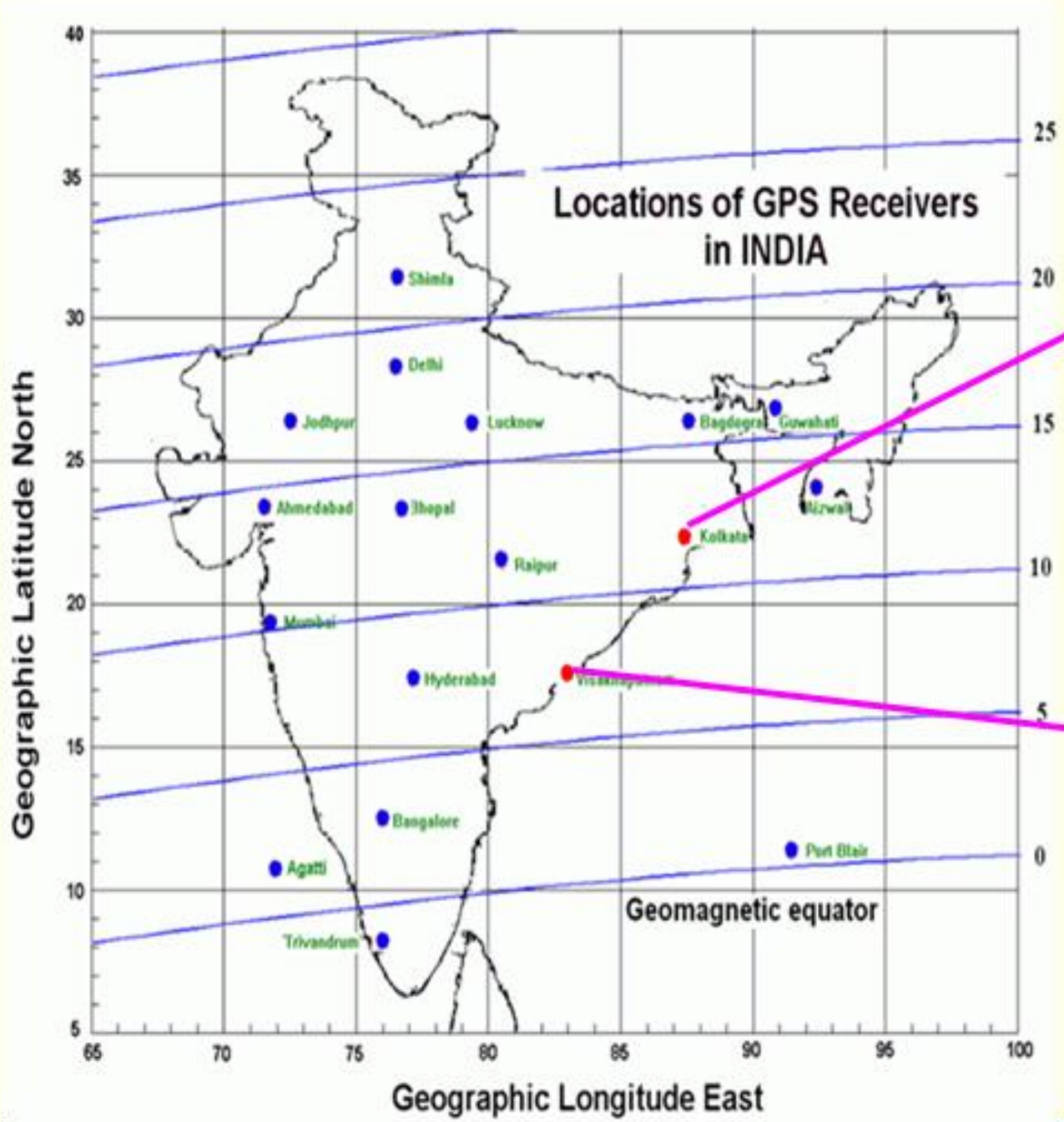
TEC derived from two different and simultaneous ray paths at the same location of the sub ionospheric point showing significant variability in their values

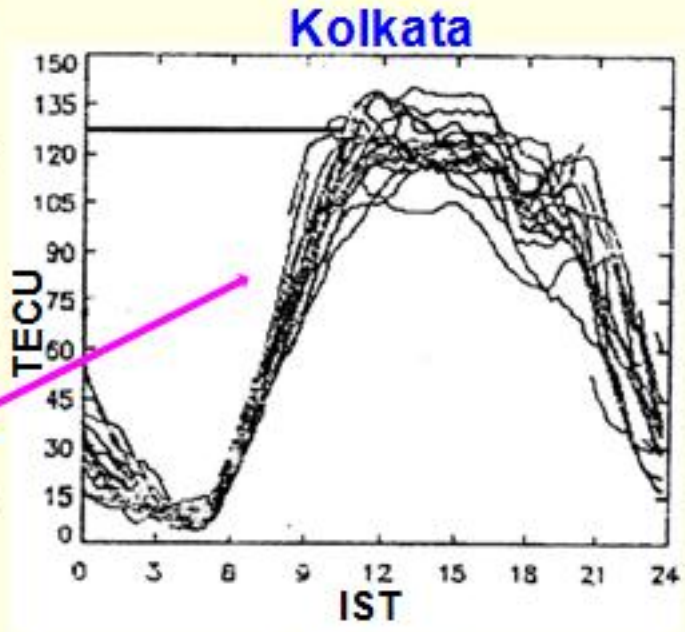


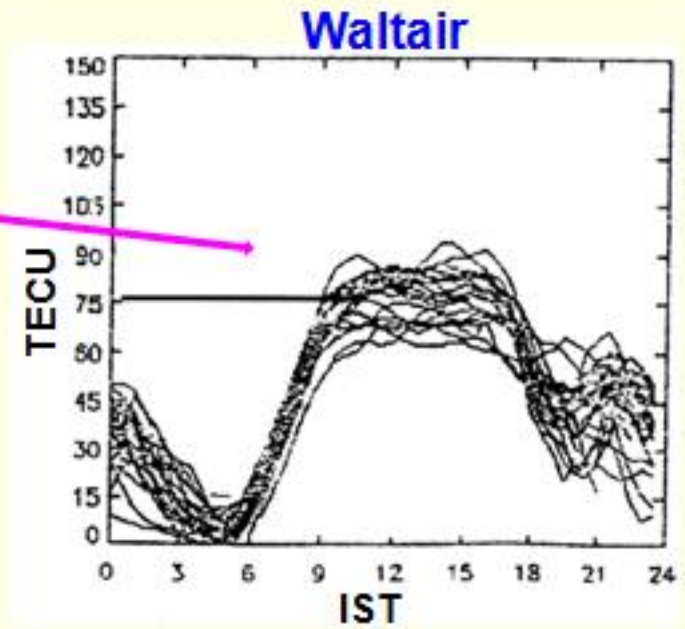
View Plot showing the conversion of STEC *to* VTEC
on a horizontally stratified ionosphere


Vertical
GPS
Ray path
ANOMALY CREST
χ
IPP
350 Km
R
MAGNETIC
EQUATOR
TX
RX

Diurnal variation of TEC over Kolkata and Waltair during high solar activity years







Current Challenges in Beacon Research with respect to Satellite Based Navigation systems in the low latitude sector

1) Measurement of absolute TEC for accurate evaluation of the range delays in the trans-ionospheric signals

2) Prediction of TEC ahead of time with reasonable accuracy demanded by satellite based navigation

3) SBAS applications – 5^0 x 5^0 grid based interpolation technique – inadequacy in the equatorial and low latitudes because of large spatial gradients due to EIA (8 to 10 TEC units per each degree latitude) during high solar activity period.

4) Mapping function errors in the conversion of Vertical TEC to Slant TEC and vice versa due to large gradients around the EIA region.

5) Day-to-day variability in TEC

6) Storm time variations in TEC

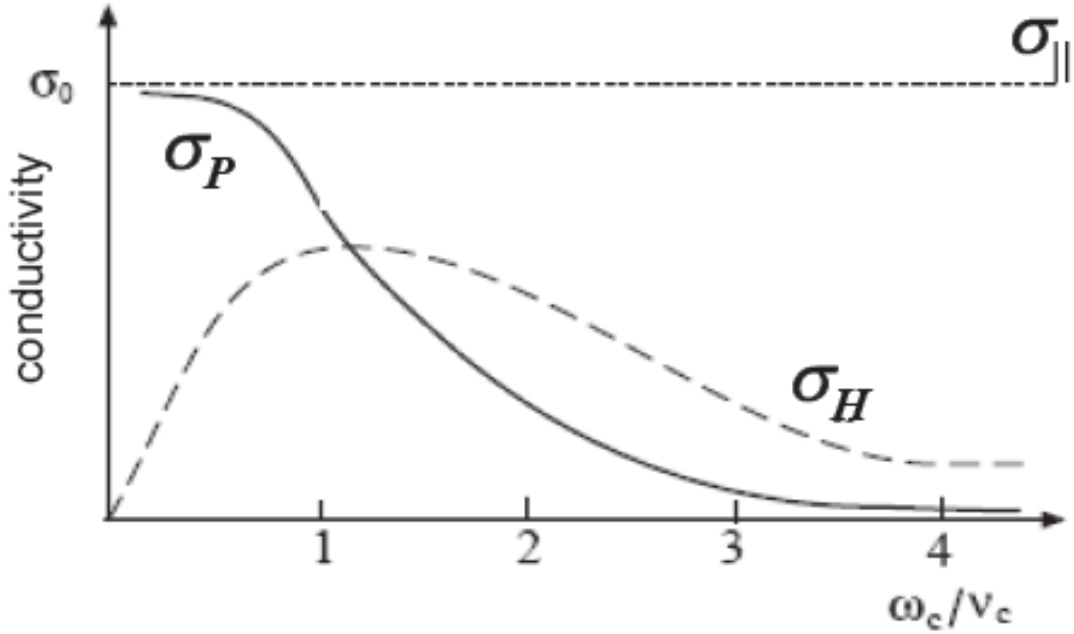
7) To the existing constellation of GPS, if GLONASS and GALELIO satellites also become operational, more vertical ray paths can be used with minimum mapping function errors for TEC measurements at any location

8) Increased L-band scintillation activity is expected at the EIA crest region with the increase in the solar activity

9) Loss of lock of receivers – To identify threshold amplitudes of scintillations

10) In the equatorial and low latitude sectors over different parts of the globe, measurements of TEC and scintillations to be intensified to buildup strong database that will help in modeling and in increasing the prediction capability of TEC and Scintillations.


THANK YOU



The significance of different elements of the conductivity tensor depends on the relation between the gyro frequency (ω) and collision frequency(υ).

$\omega << \upsilon_c$

Collisions prevent the gyro motion
→ particles move ∥ E
→ σ_p : **Pedersen** Current (⊥ **B** ∥**E**)

$\omega >> \upsilon_c$

Particles able to make many gyrations before scattering by a collision
→ $E \times B$ drift dominates
→ σ_H : **Hall** Current (⊥ **B** ⊥**E**)

IONO-SBAS MEETING: INDIAN GAGAN Programme

ICTP – TRIESTE, ITALY (20-21 April, 2012)

Prof. P.V.S. Rama Rao

Andhra University, INDIA

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AAI

OBJECTIVE

To provide Satellite-based Navigation services with accuracy and integrity required for civilian and aviation applications over Indian Air Space.

Better Air Traffic Management over Indian Airspace.

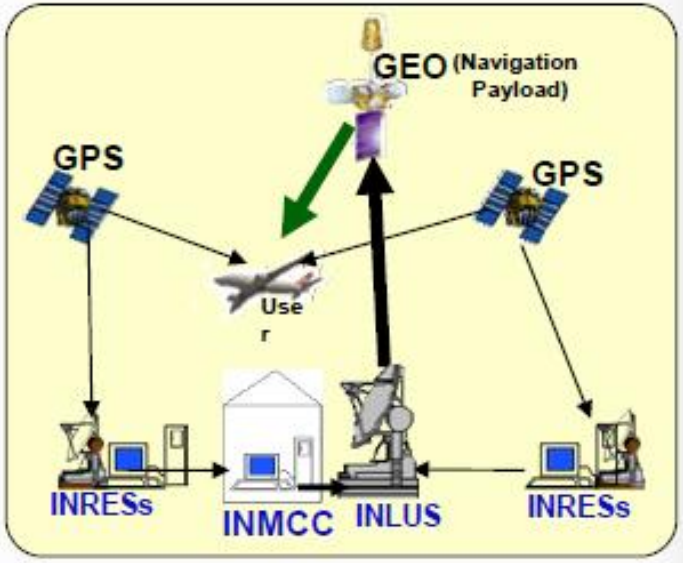
GAGAN CONFIGURATION

Indian Space Research Organisation

SPACE SEGMENT

Three GEO Satellites

- Two operational Navigation Payloads
- One in-orbit spare Navigation Payload



GROUND SEGMENT

- Indian Master Control Centre (INMCC)
- Indian Navigation Land Uplink Station (INLUS)
- Indian Reference Stations (INRES)
- Communication links

GAGAN – INMCC Facility Bangalore

Indian Master Control Centre

Source: ISRO and Airport Authorities of India

11 Meter Up-Link Antenna

Source: ISRO and Airport Authorities of India

Application of SBAS Receiver

Applications

- For Aviation
  - High Accuracy, Global Coverage, Direct En-route, Reduced and Simplified equipment on-board & ground
- Other Potential Users
  - Survey, Land Management Scientific Research, Business solutions, Geodynamics etc.,

Tasks Ahead

- Signal In Space tests including air-borne receivers
- Production of SBAS Receivers
- User Meet

The implementation of the GAGAN Programme is in two phases

- GAGAN-TDS (Technology Demonstration System)
- GAGAN – FOP (Full Operation Phase)

GAGAN-TDS –Performance

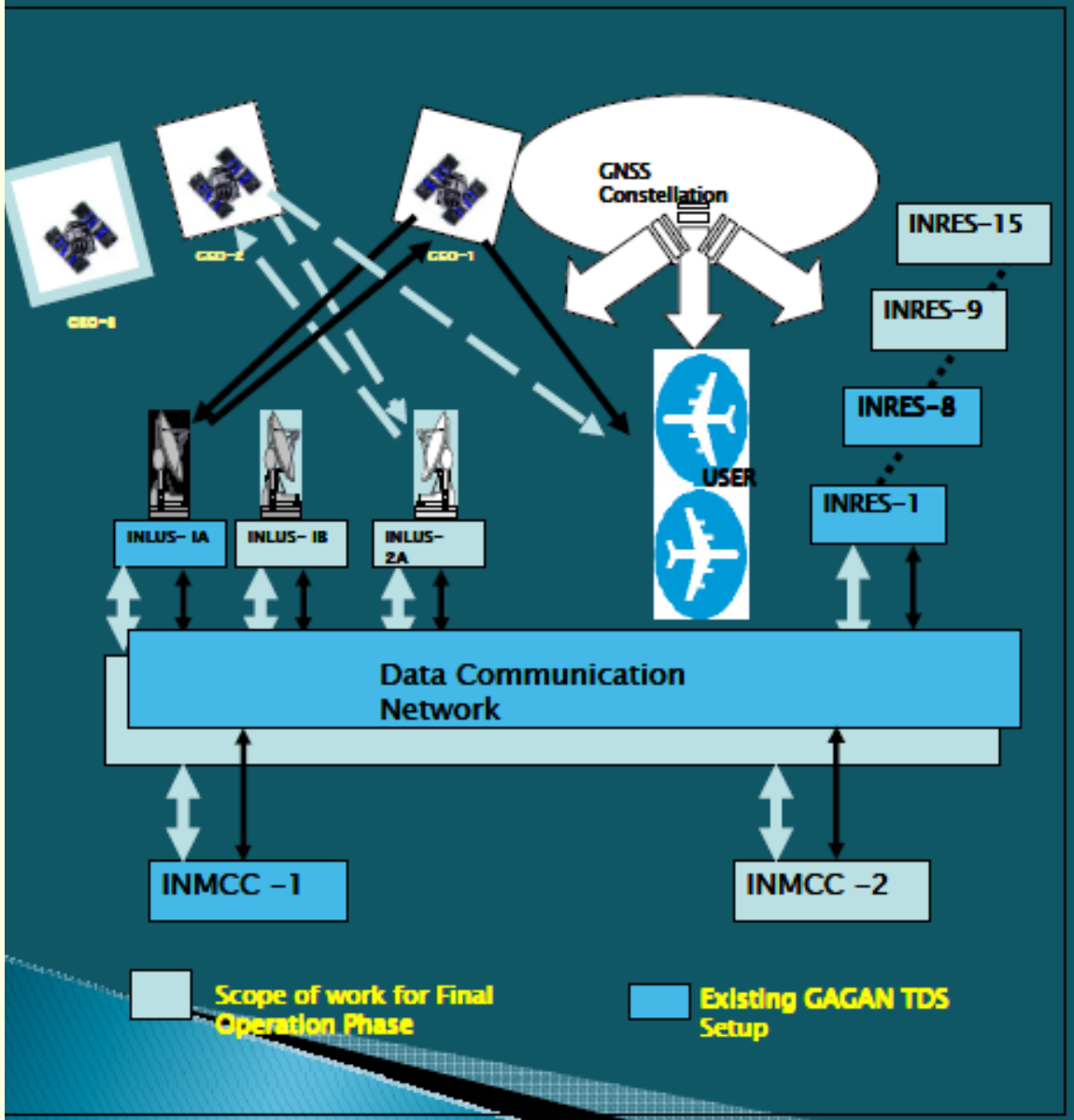
- Only accuracy has been verified (7.6m Vertical and Horizontal 95% of the time within the perimeter of INRESs). Verification results were well within the performance requirements
- SBAS Receiver is able to lock GAGAN PRN 127 (GSAT-8) and process the GAGAN messages for providing SBAS position. Results were satisfactory
- Ranging Capabilities were Demonstrated
- Perimeter sites exhibited good performance also
- In TDS phase there were no Integrity and Level of service requirements

GAGAN - FOP Objective

1) To establish a fully operational SBAS with redundancies and to
2) Establish suitable region specific IONO model and to get
3) safety Certification for the system for the Civil Aviation use.

- The GAGAN Full Operational Phase (FOP) objective is to provide a certified navigation system for all phases of flight by augmenting the TDS system suitably

GAGAN-FOP Configuration



System/Activities Completed

System	FOP
INRES	15 (3 chains)
INMCC	2
INLUS-SG	2
O&M	2
Iono Model (Equatorial)	IGM-MLDF
GEO	1 (GSAT-8)
INLUS-RF	1
COM Links	2

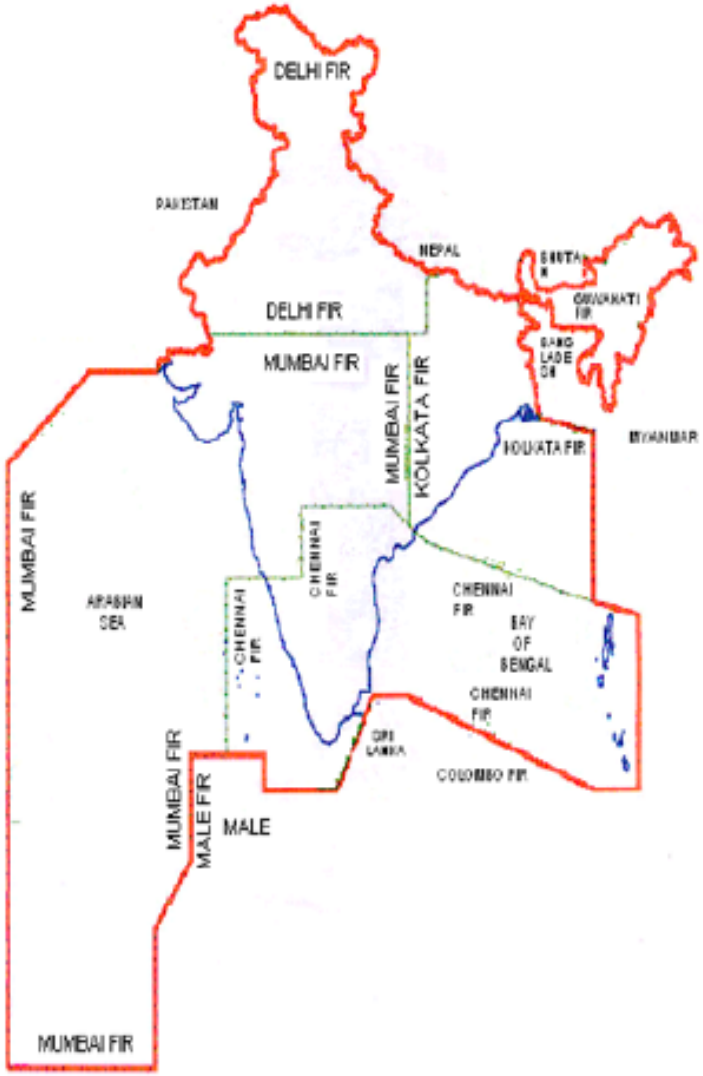
System/Activities Planned

System	FOP
INLUS-RF	2
GEO	GSAT-10, 15
Comm. Links	1

GAGAN: Performance Objective

The objective of GAGAN-FOP is to realize a certified and operational SBAS for all phases of flight path over the Indian FIR to provide the air navigation services of

- ❖RNP 0.1 en route navigation within Indian FIR
- ❖APV-1/1.5 precision approach over the landmass of Indian FIR



Performance Requirements

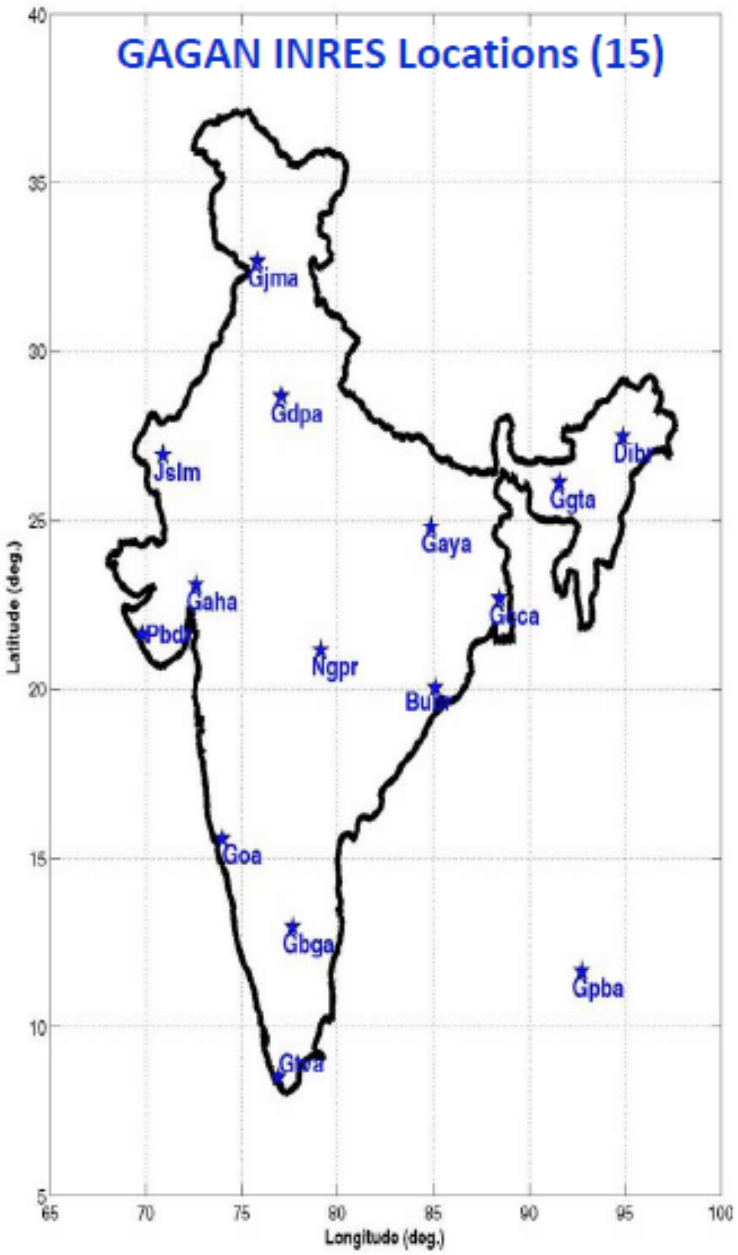
Flight Phase	Accuracy	HAL	VAL
RNP 0.1	72 m (H)	185 m	N/A
APV 1.5	33.5 m (H) 9.8 m (V)	40 m	50 m

Iono. model

Grid Based Ionosphere Model For GAGAN

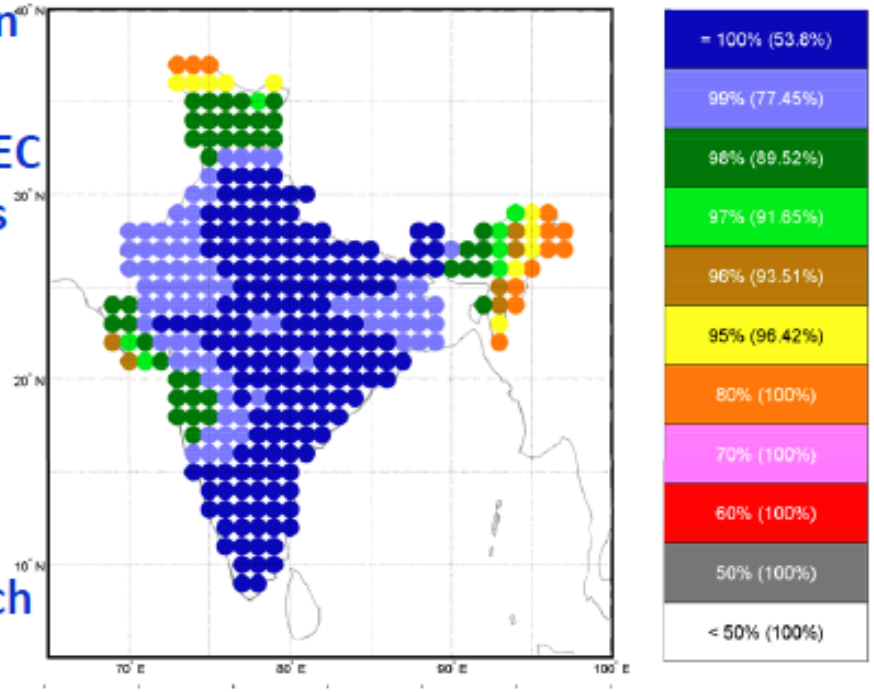
IGM-MLDF (ISRO GIVE Model-Multi Layer Data Fusion):

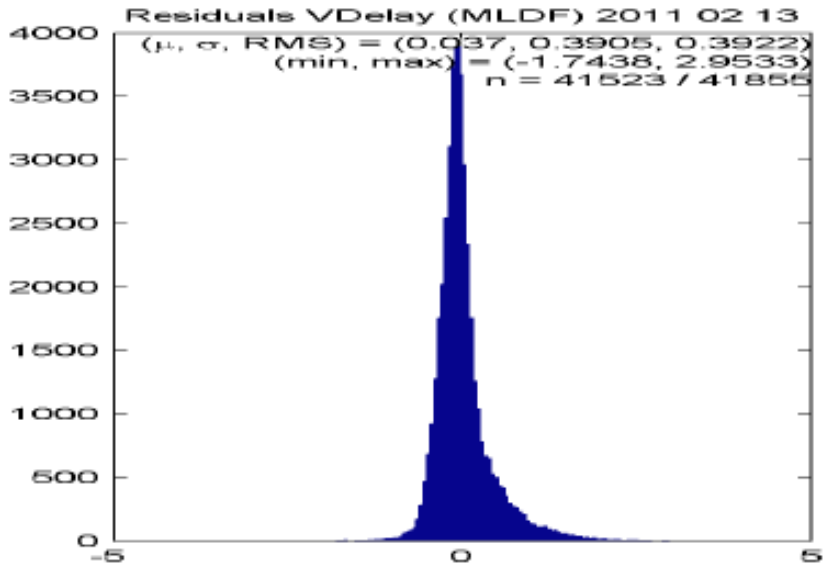
- New Multi layer Grid Based Model
- Uses Data Fusion Technique
- Provides GIVD, GIVE at 350 km (as per MOPS)
  - This model does not call for any change to the existing SBAS message structure
  - No change for the legacy users

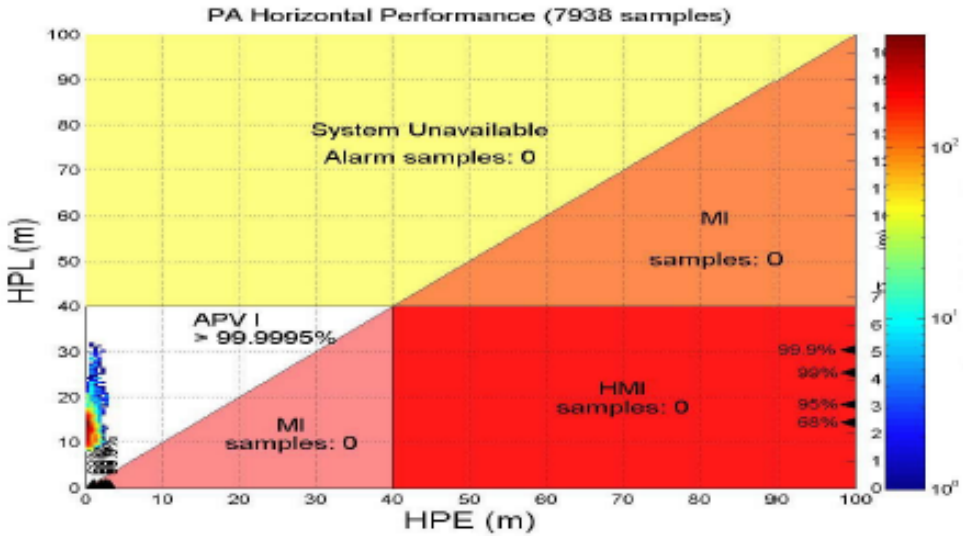


IGM-MLDF: Preliminary Results

- Joint activity between ISRO and Raytheon
- Algorithm evaluated using the measurement based model data (ISRO-TEC data) for selected nominal & stormy days over 2004-07
- Algorithm is under evaluation with high quality live data collected over 15 INRES locations
- The live data (supertruth) contains measurements from 2/3 INREEs from each of the INRES



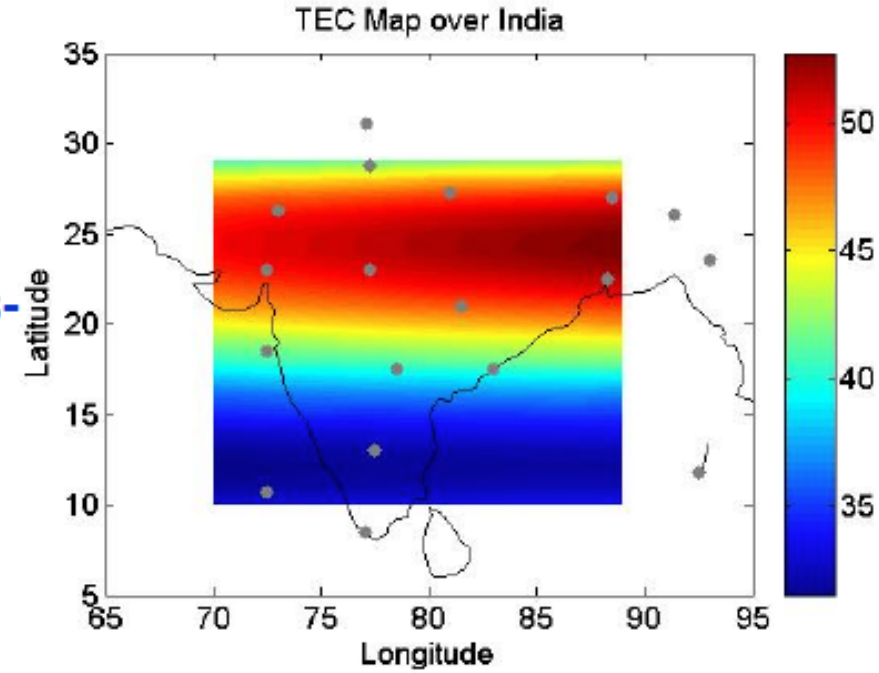




GAGAN TEC Data

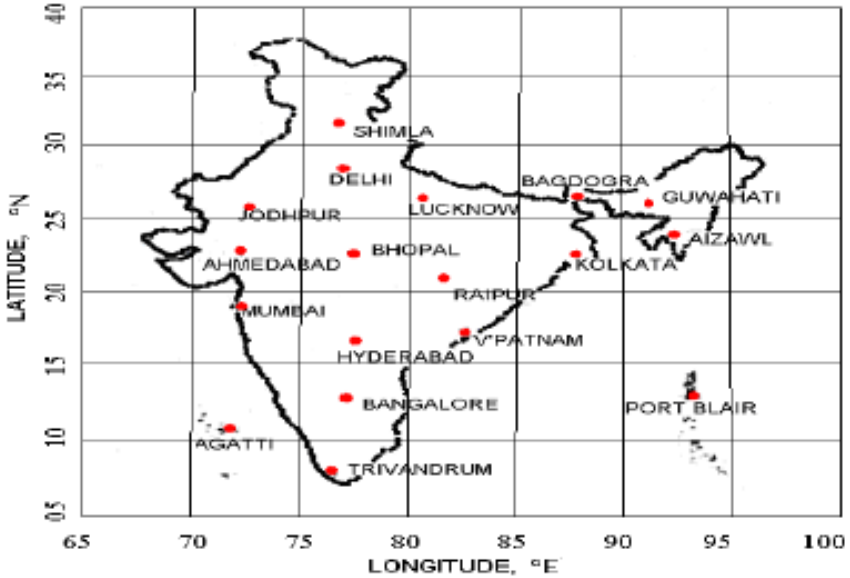
Measurement Based Ionosphere Model - ISRO TEC Model

- **Based on real data from GAGAN TEC stations combined with Physics-based Semi-empirical Model**
- **Provides TEC Map over Indian region**



Activities include:

- **Data Collection and Archival**
- **Model Comparison and Validation**
- **Testing New Algorithms**

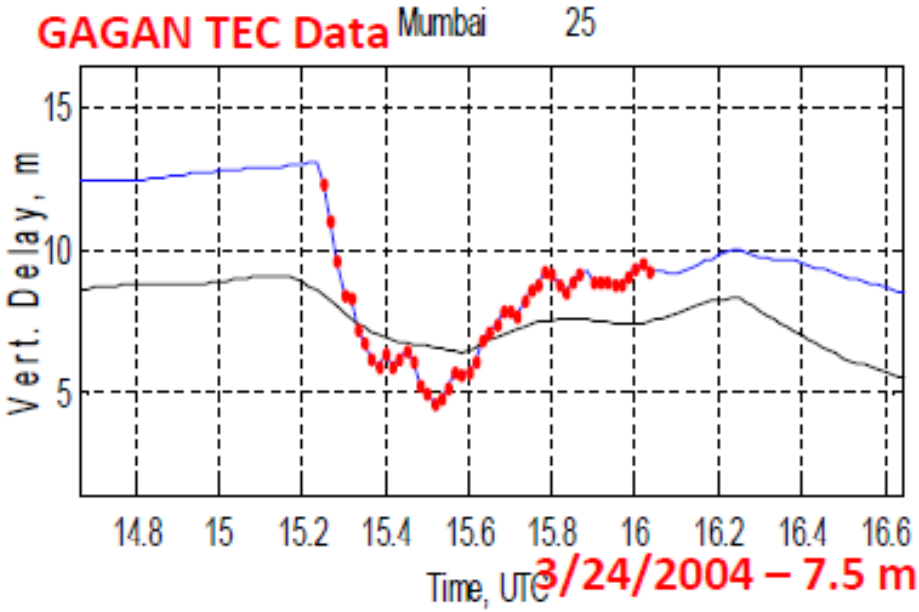


Depletion Studies

- **Depletion:**
  - Post sunset events
  - Local phenomena (i.e., Depletion observed by an user may/may not be observed by any of the INRES)
  - User protection against depletion: Mitigated through the ground model

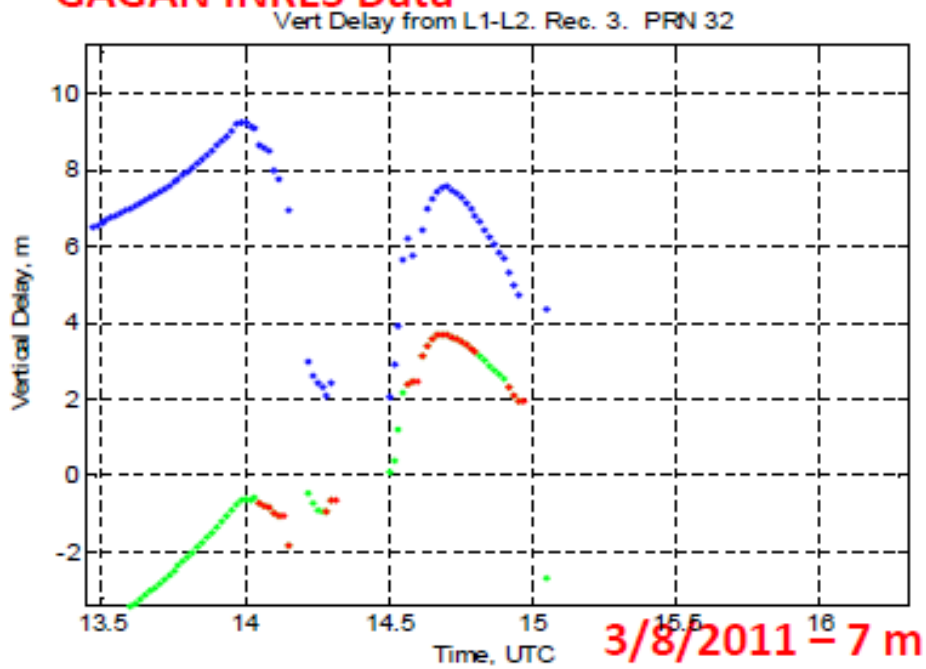
- **Observations:**
  - Indicates that the depletion with >0.5 m magnitude occur during 5:30 p.m. – 3:30 a.m. local time.
  - Maximum observed depth:7 - 7.5 m

GAGAN TEC Data



3/24/2004 – 7.5 m

GAGAN INRES Data



3/8/2011 – 7 m

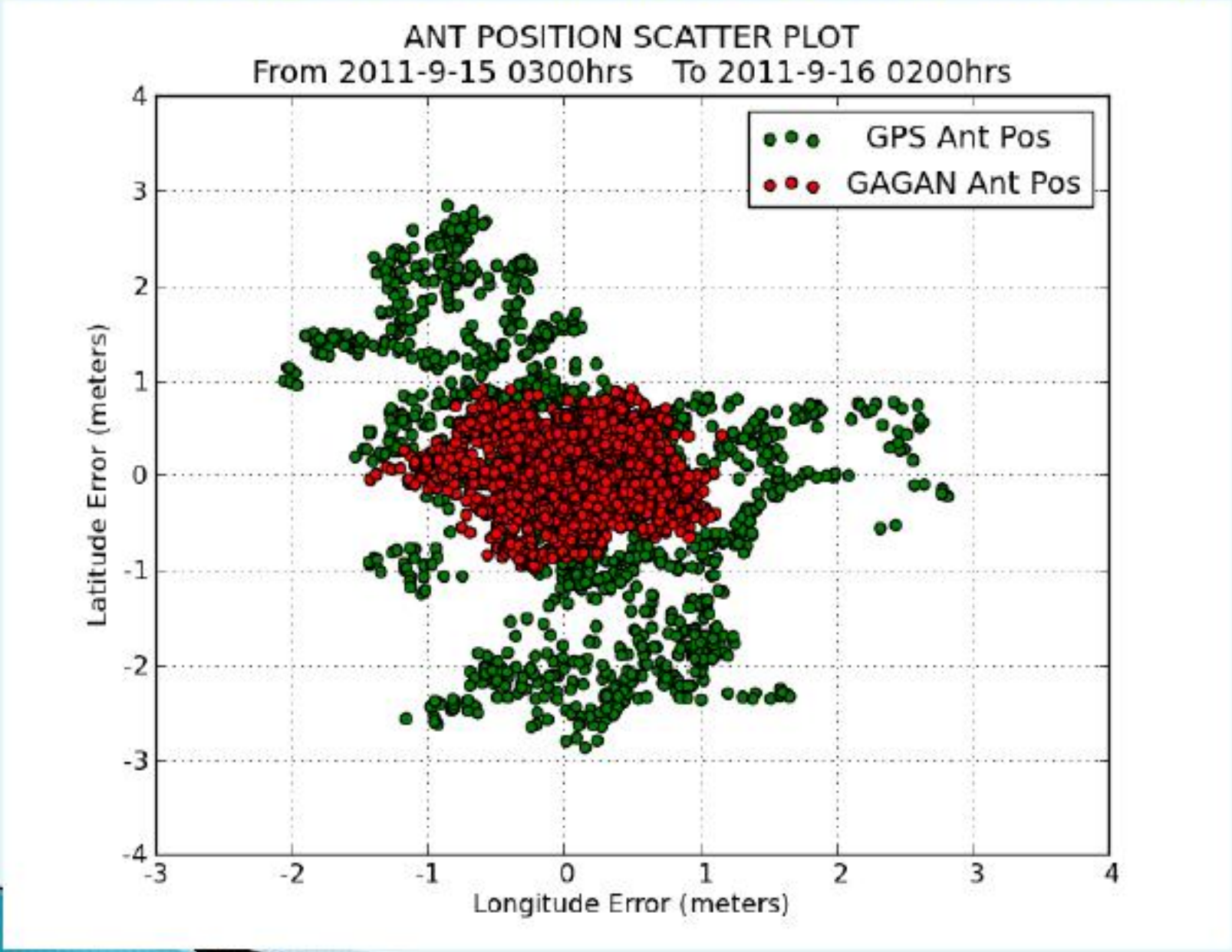
GAGAN payload on GSAT-8: Completion of ground and in orbit test

- GSAT-8 carrying GAGAN Payload launched on 21 May 2011
- INLUS RFU Subsystem Tested and Evaluated
- GSAT-8 GAGAN Payload IOT Completed

1st Signal In Space from GAGAN payload received on 13-Sep-2011

Preliminary Performance using SBAS Receiver

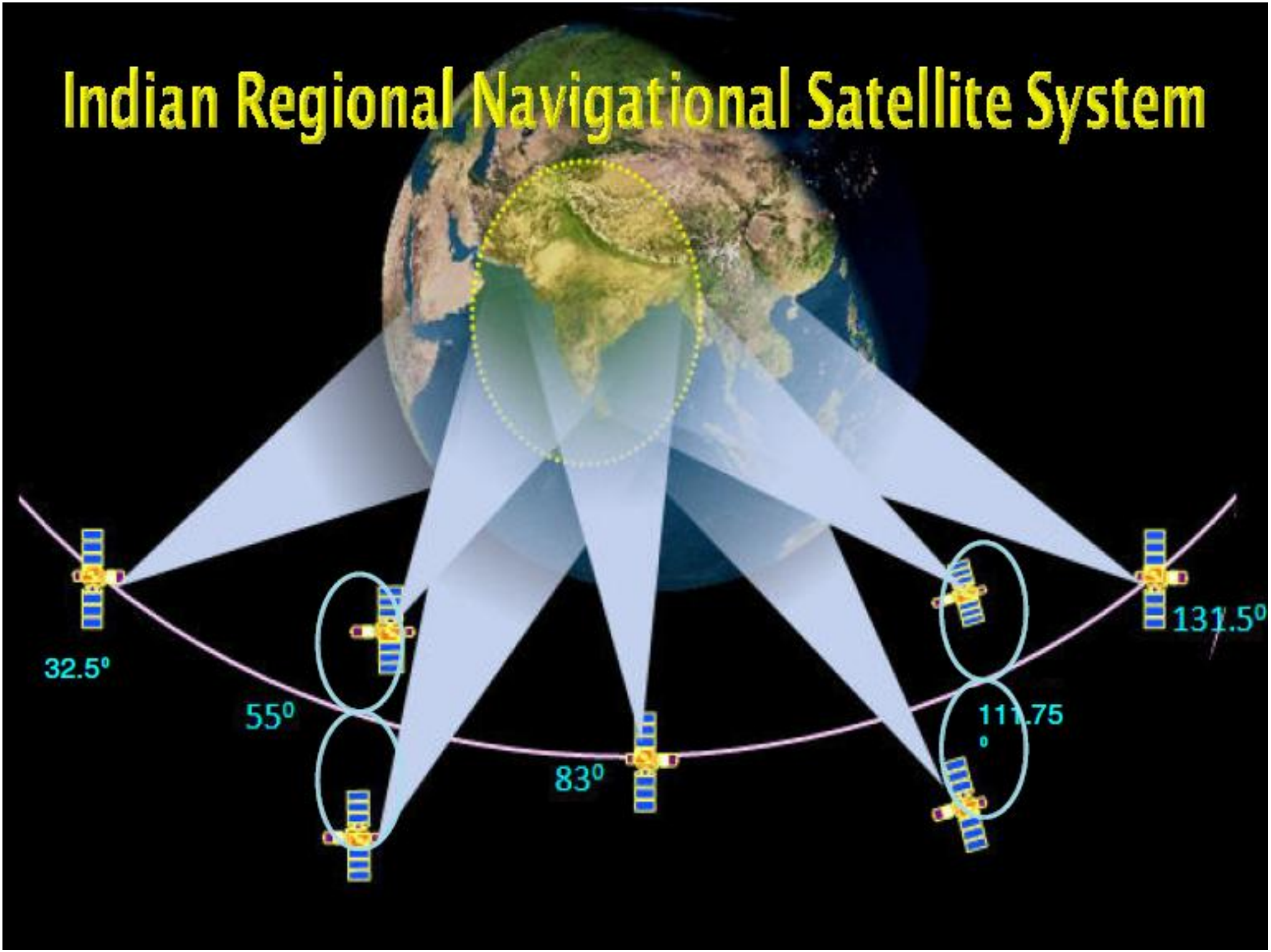
GAGAN versus GPS scatter plot and position uncertainties (15-Sep-2011)



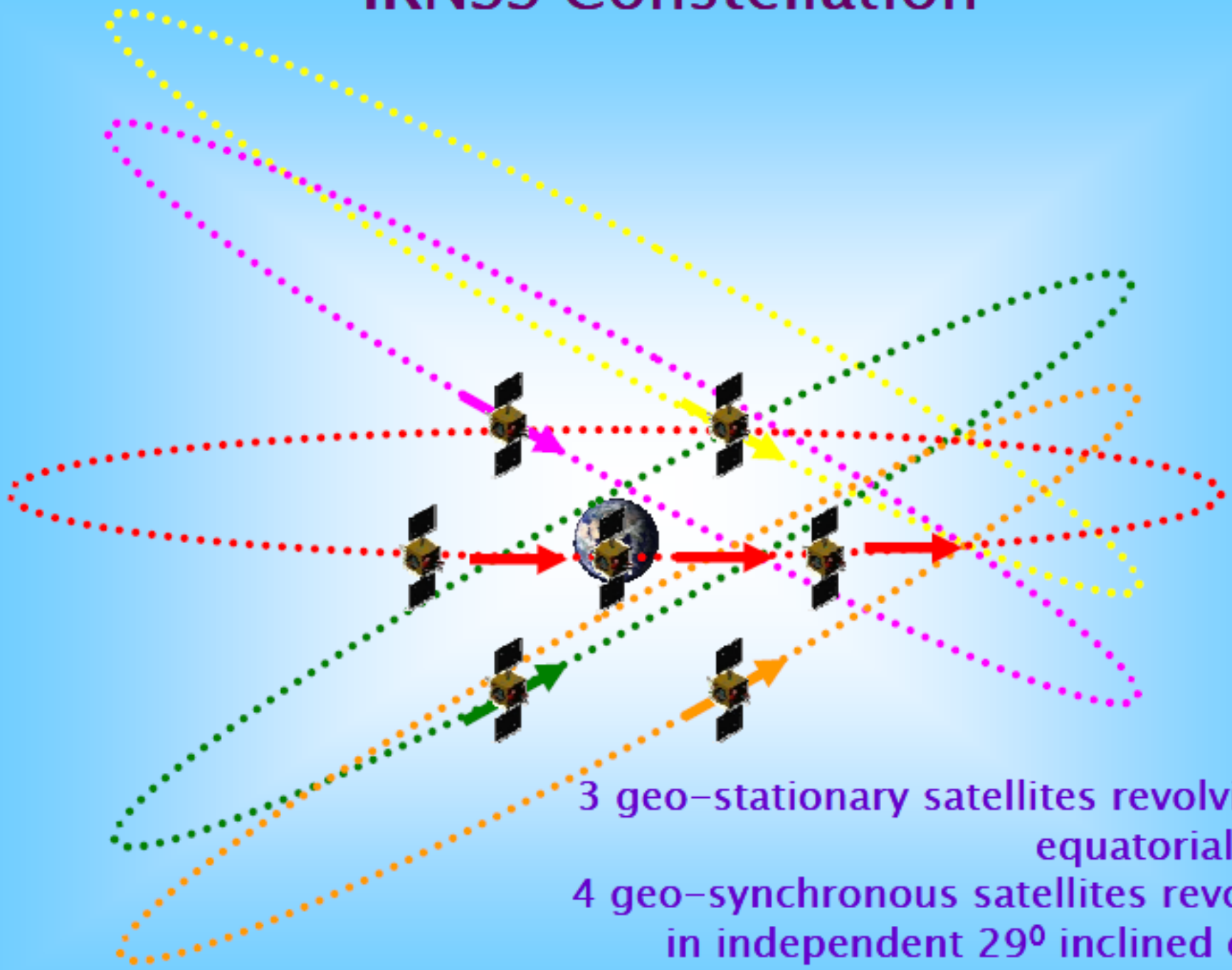
GAGAN - CURRENT STATUS

- After the GSAR-8 is launched, flight test with small aircraft has been carried out for all the four parameters Accuracy, availability, integrity and continuity.
- Satisfactory results are achieved for CAT- I & II approaches.
- Enroute – 250 m Decision Height
- Integrity (MCS – Satellite – User) – 6 Sec has been achieved.
- GSAT -10 (PRN 128) will be launched between July-December 2012.
- The three Ionospheric models developed by ISRO are successfully tested.
    1. MLDF (Multi Layer Data Fusion) Model
    2. TEC model
    3. Depletion model
- The installation of ground based equipment are in the final stage
- The system is expected to be certified and operational in the year 2013

Indian Regional Navigational Satellite System



IRNSS Constellation

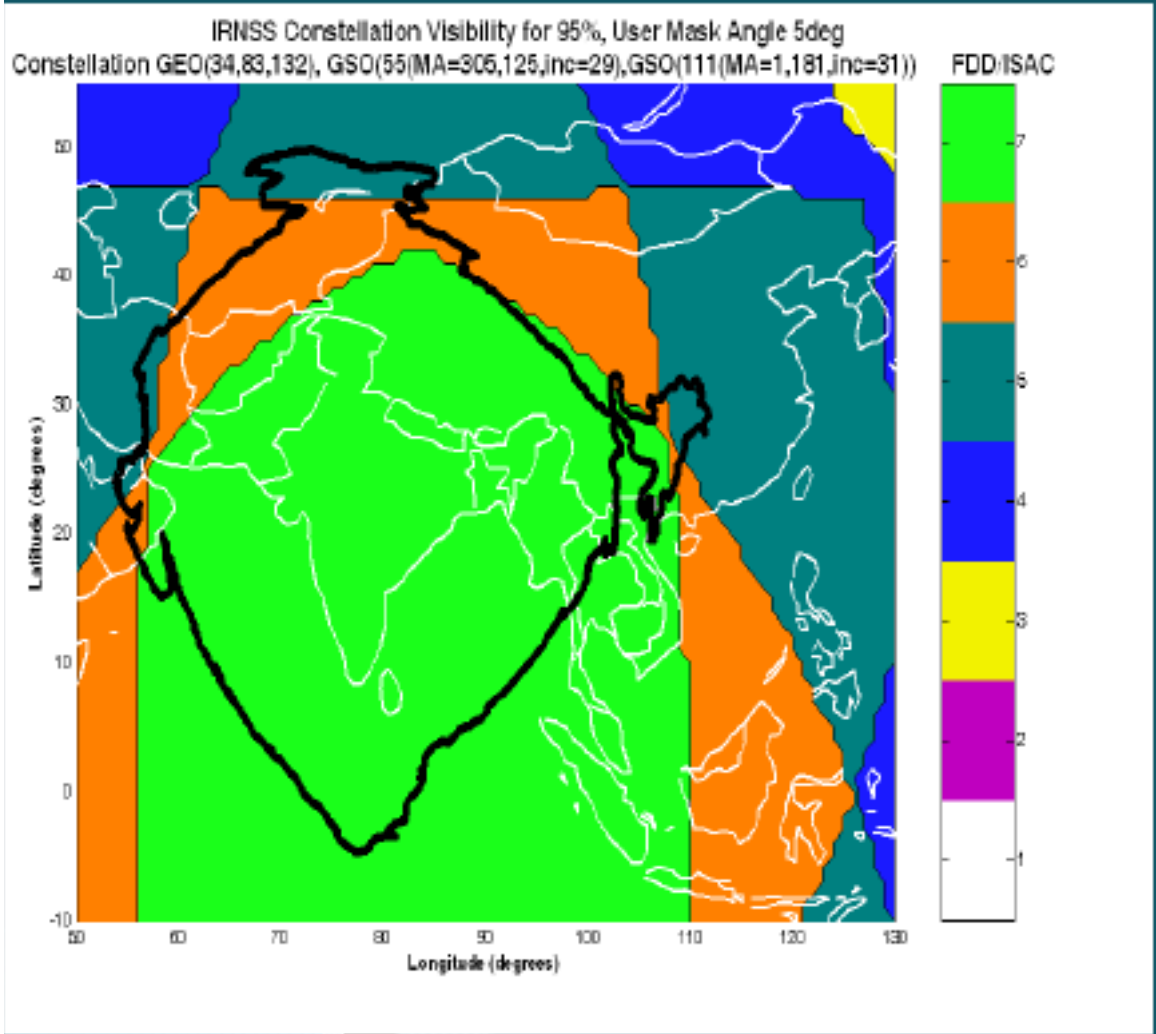


3 geo-stationary satellites revolving in equatorial orbit

4 geo-synchronous satellites revolving in independent 29⁰ inclined orbits

IRNSS SERVICE AREA DEFINITION

IRNSS Visibility



S. No	Service Area	Description of the service area
1	Primary Service Area	Indian land mass and 1500 km from Indian geopolitical boundry

- Targeted position accuracy better than 20 metres

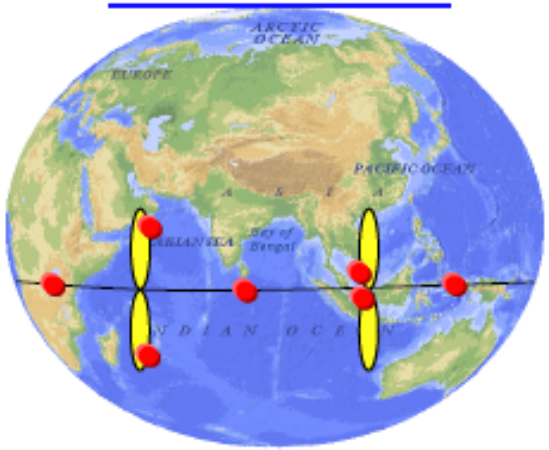
IRNSS: INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM

- Refers to an independent Indian Regional Navigation Satellite System providing navigation services over Indian Region.

IRNSS ELEMENTS

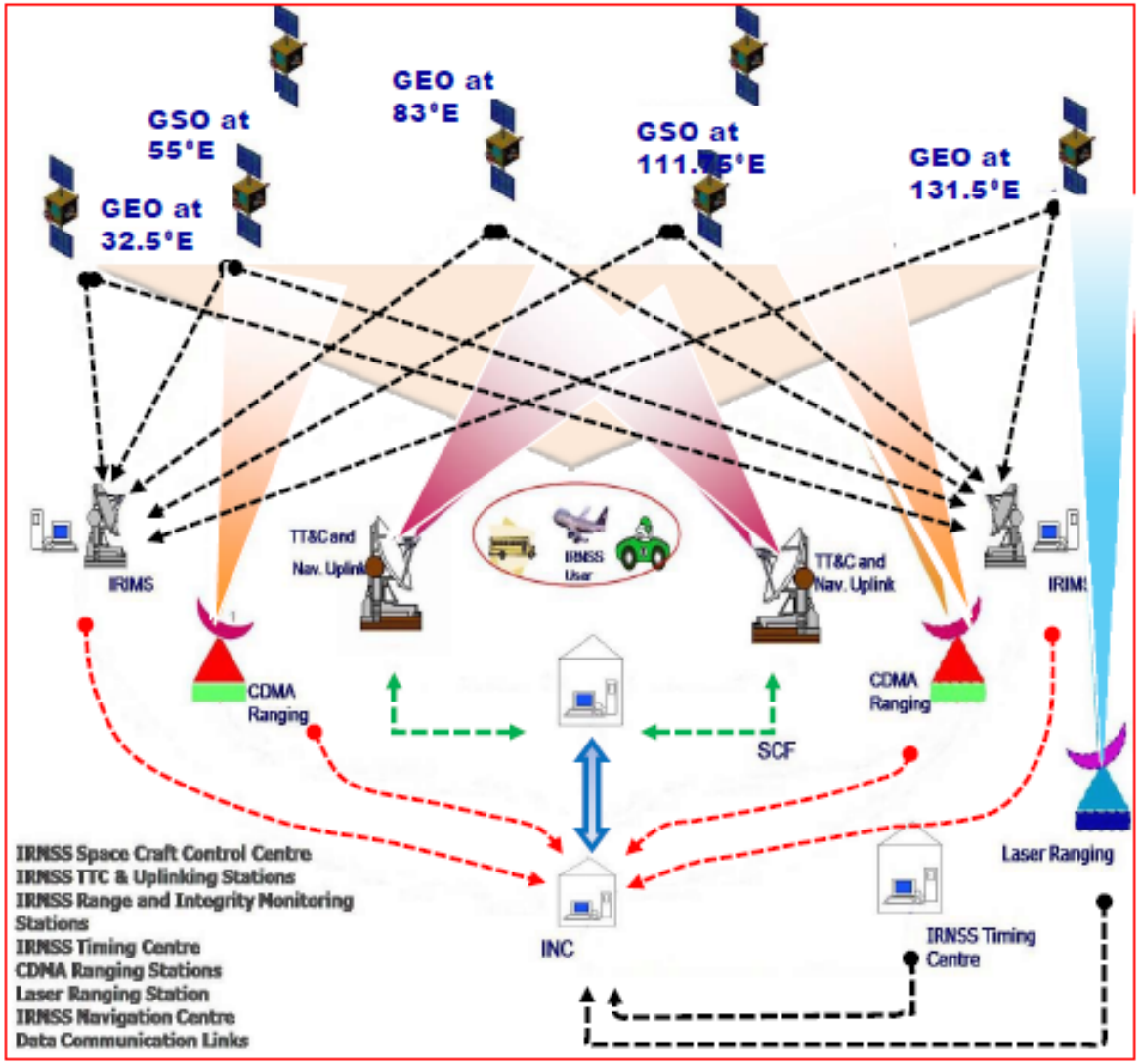
- Space Segment
- Ground Segment
- User Segment

SPACE SEGMENT



IRNSS SERVICES

Service Type	Freq. Band
Standard Positioning Service	L5(1176.45Mhz) S(2492.028hz)
Restricted Services for Special Users	L5 S



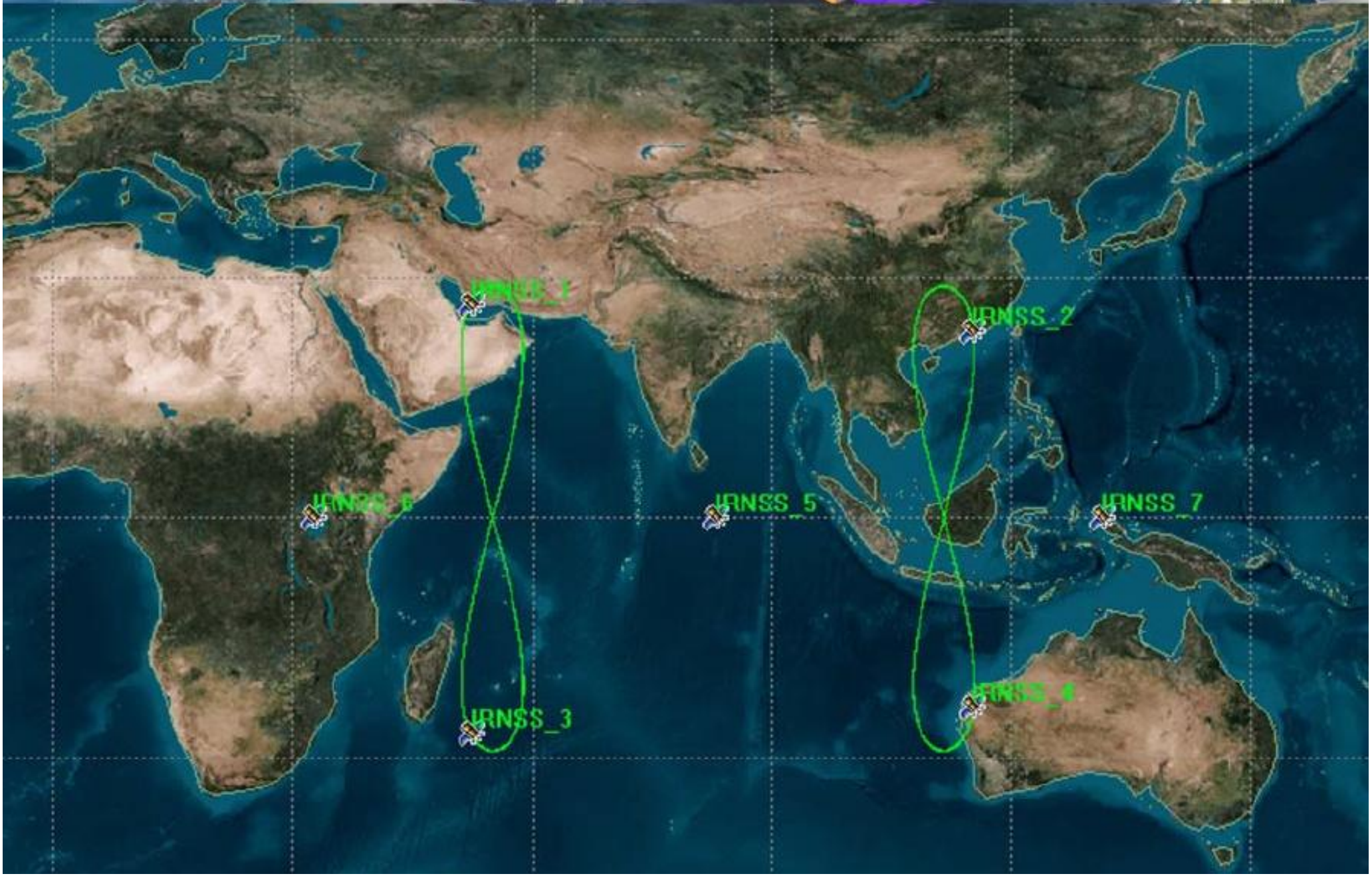
IRNSS Configuration

Space Segment

- Space Segment consists of Seven satellites
- 3 Satellites in Geo-Stationary orbit at 32.5°, 83° and 131.5° East.
- 4 Satellites in GEO Synchronous orbit placed at inclination of 29° with Longitude crossing at 55° and 111.75° East.
- Two spare satellite are also planned.
- The Satellites are specially configured for the Navigation. Same configuration for GEO and GSO which is desirable for the production of the satellites. Production plan & schedule are worked out.
- IRNSS Satellites are to be launched by the Indian launcher PSLV.
- The first Satellite will be launched in 2012.The subsequent launches are planned once in Six months. The full constellation will be operational by 2015.

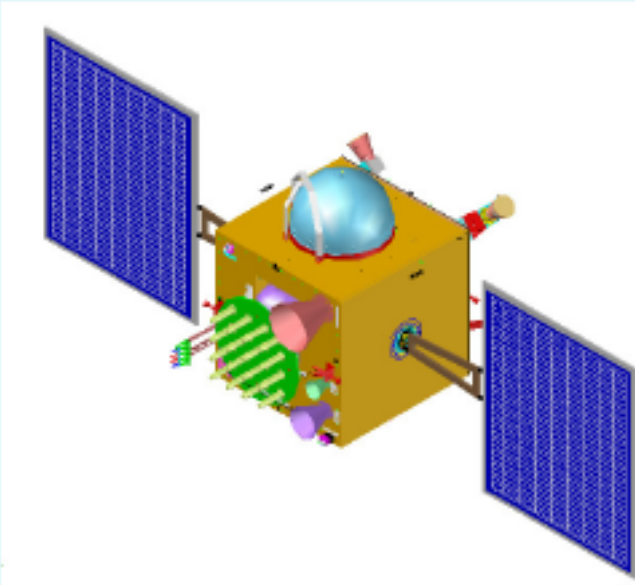
IRNSS SPACE SEGMENT

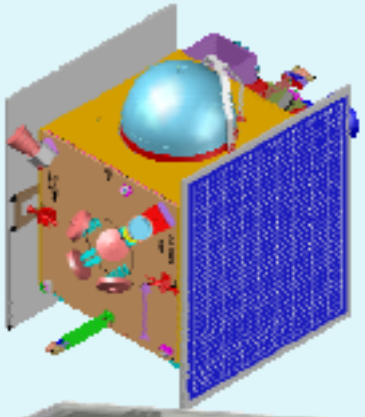
Indian Space Research Organisation



IRNSS Satellite

- IRNSS Satellites are designed around I-1K bus.
- Dry mass of around 600 kgs and lift off mass of 1425 kgs
- Power generation capability of 1600 W and payload power requirement of 901 W
- Navigation Payload Transmits SPS and RS signals in L5 and S Bands.





- Payload utilizes highly stable Atomic Frequency Standards for generation of Navigation Signals.

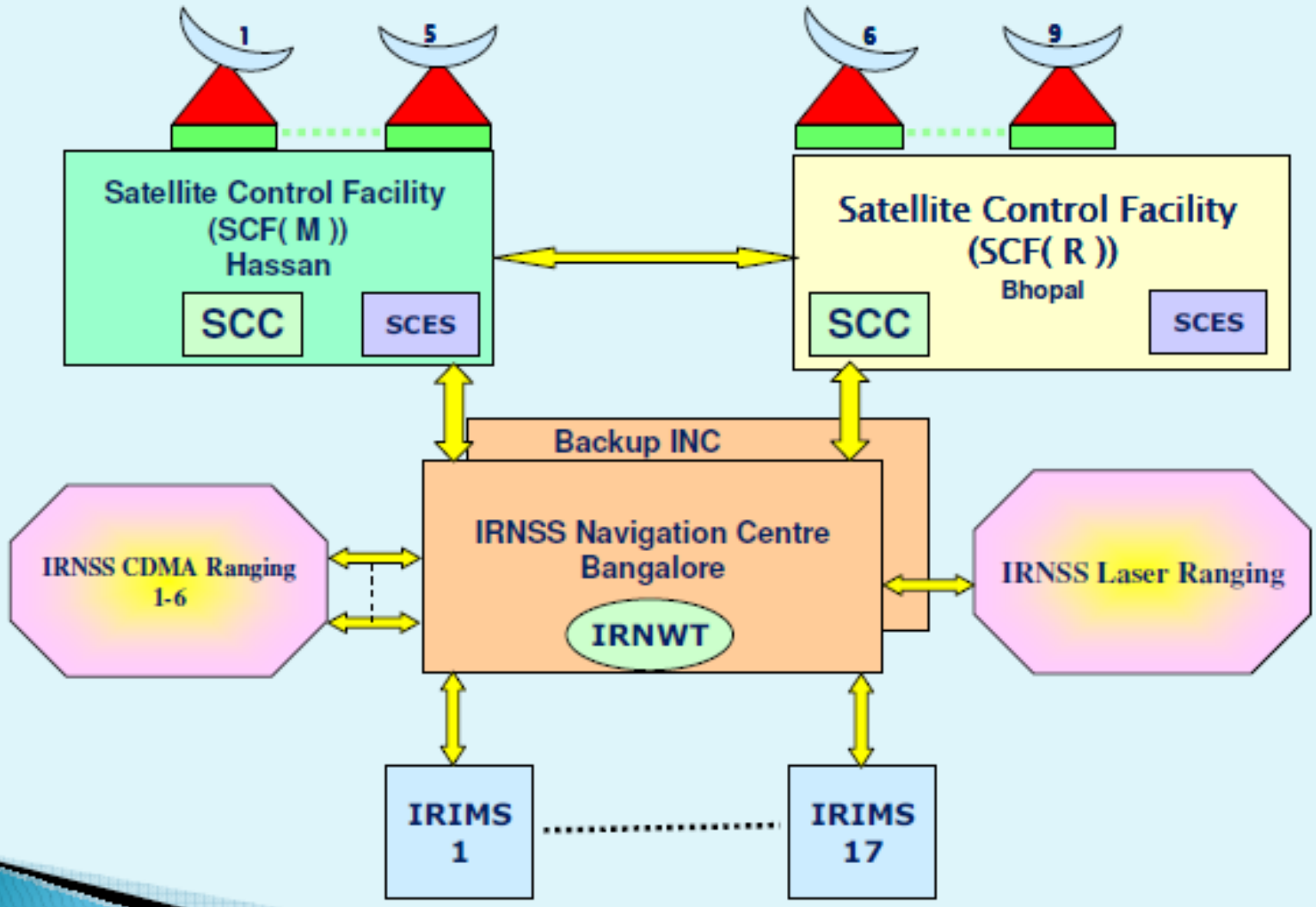
- 3 Axis control of the satellite with Yaw steering capability to optimize the use of Solar Panels and to support the thermal control of the satellite

Ground Segment Subsystems

- IRNSS Satellite Control Earth Stations – 9 Nos
- IRNSS Satellite Control Centre (IRSCC) – 2 Nos
- IRNSS Range and Integrity Monitoring Stations (IRIMS) – 17 Nos

- IRNSS Navigation Centre (INC) – 2 Nos
- IRNSS Network Time (IRNWT) – 2 Nos
- IRNSS CDMA Ranging Stations (IRCDR) – 4 Nos
- IRNSS Data Communication Network (IRDCN) – 2 Nos

Ground Segment Architecture

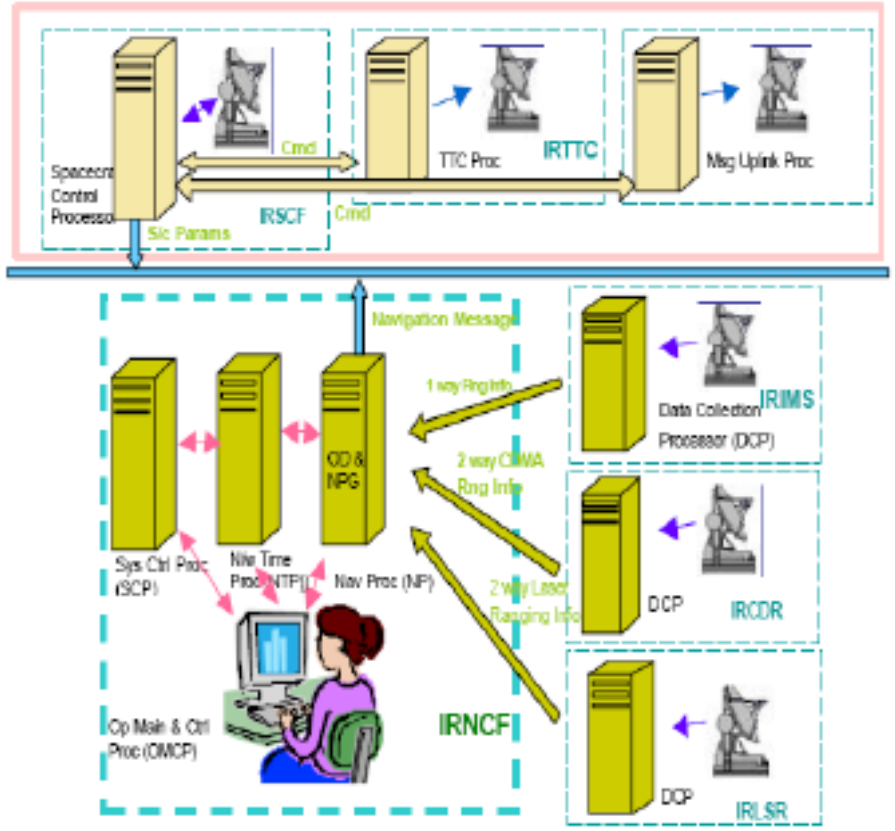


Major Elements Of Navigation Software

Navigation software will be deployed in the IRNSS Navigation Centre. The software modules interface with various subsystems of the ground segment and generate navigation parameters, required for broadcast from spacecraft.

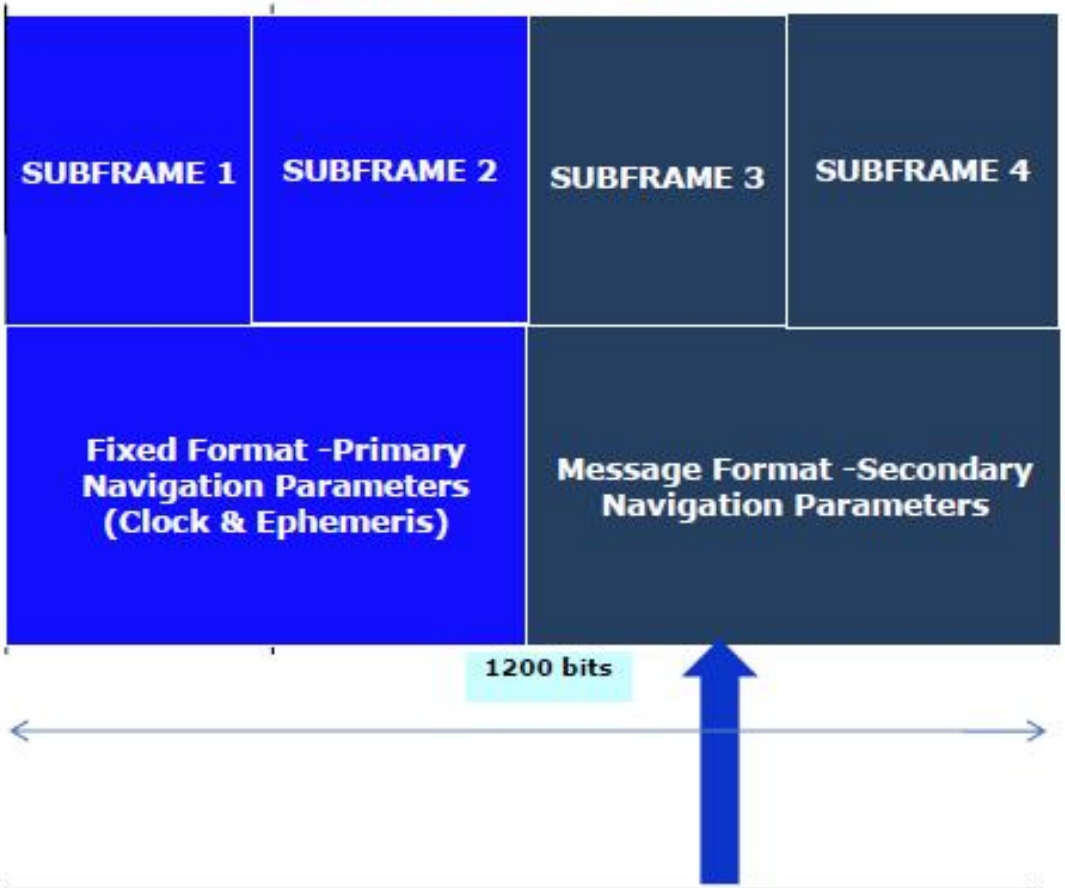
Navigation software generates the following in 4 sub-frames:

- Primary Parameters
  - Satellite ephemeris , clock
  - Satellite health status & accuracy
- Secondary Parameters
  - Satellite almanac
  - Ionospheric corrections-coefficients
  - IRNSS time difference w.r.t UTC /GNSS
  - Ionospheric gird delay parameters
  - Encryption keys
  - Text messages
  - Differential corrections
  - Earth orientation parameters
  - Auto Nav Parameters



Ionosphere Corrections In IRNSS

IRNSS Data Structure



1. Co-efficient based (4α & 4β) Iono. Corrections
2. Grid Based Iono. Corrections (on L5)

User Segment

- The user segment consists of IRNSS receivers operating in
  - Single Frequency (L5 or S band)
  - Dual Frequency (L5 and S band)

- Single frequency and dual frequency receivers shall receive both SPS and RS signals.

Indian Space Research Organisation

IRNSS SERVICES

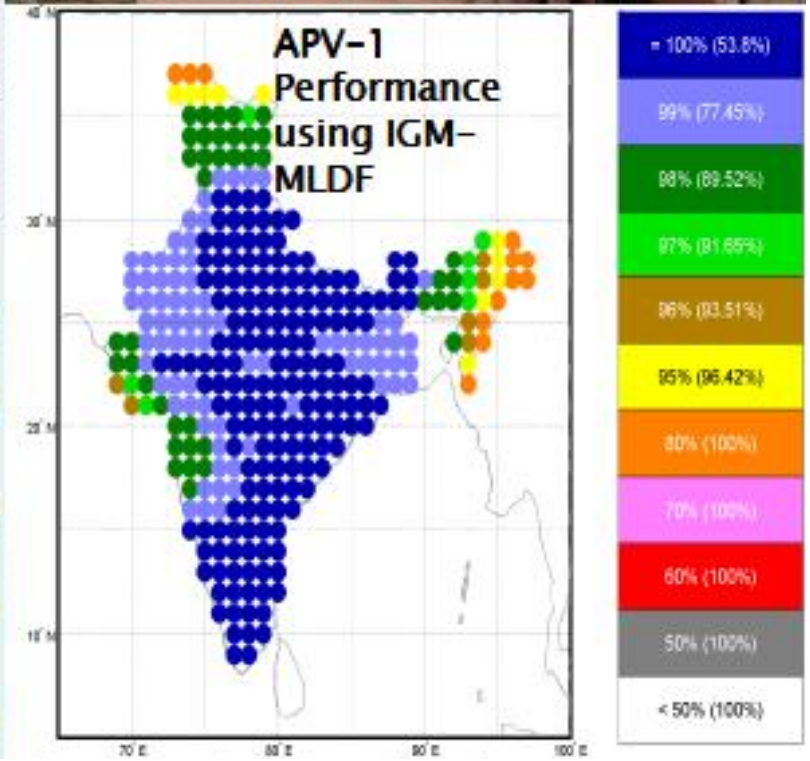
Service Type	Signals	Frequency Band
Standard Positioning Service	1 MHz BPSK	L5 (1176.45 MHz) S (2492.08 MHz)
Restricted Services for Special Users	BOC(5,2)	L5 (1176.45 MHz) S (2492.08 MHz)

ISRO Participation to International GNSS Forum

- ISRO is an active member of International Committee of GNSS (ICG).
- ISRO participated in many bilateral discussions with GPS, GALILEO etc. on Interoperable and compatible signal structure.
- ISRO is hosting a QZSS Monitoring Station site in ISTRAC.

Major Activities (GAGAN)

Completed	Planned Activities
Ground Elements	
INLUS-2 at Bangalore: Completed	Test & Evaluation
Proto M&C system for INLUS RFU	Development in DO-178B
DELHI (Nangloi) INLUS-3 FMA: Civil works initiated	Commissioning by Apr'12
Ionosphere Algorithm	
ISRO developed IGM-MLDF model	Incorporation into operational system
Agreed by AAI, DGCA, RTN	Review by TRT for Certification
Space Segment	
GSAT-8 launch, IOT & integration	GSAT -10,15 launch & integration
System Acceptance Test	
Preliminary Completed in Dec'10	Final during Jun'12
Certification by DGCA	
Work Initiated	Completion by Jun'13



GAGAN Task team with Raytheon team


GAGAN
GPS Aided Geo Augmented Navigation
Indian Satellite Based Augmentation System
Airports Authority of India
ARCHITECTURE
GAGAN Coverage 82°E
GEO (GSAT/INSAT)
(L1,L5)
GEO (GSAT/INSAT)
(L1,L5)
GPS
GPS
GPS
THANK YOU
INLUS
INRES
INMCC
FIBRE OPTIC
Navigation - Air, Sea And Land
Positioning Applications
Survey
Image Correction
GIS
Timing
Surveillance/fleet Monitoring