Ionospheric Modelling in Indian Equatorial Region

SAG/SAC

ISRO

Contents

- Ionospheric Modelling: Need
- Equatorial Ionosphere:
    - Features
    - Problems
    - Related Issues for Low Latitude SBAS
- Modelling Activities:
    - Data Collection
    - Model Comparison and Validation
    - Testing New Algorithms
- Study of Scintillation and Bubbles

Ionospheric Modelling : Need

- **SBAS:** Iono-delay to be modelled in near real time and applied by user for correction
- Equatorial ionosphere is very dynamic

So, the challenge is to retain the standards, on one hand and to make the system useful for the very dynamic equatorial region, on the other.

Equatorial Ionosphere and Related Problems on SBAS

- **Large spatial and temporal gradients in the daytime**
  - **Induce large errors due to slant to vertical conversions at a fixed height (350 Km). Constant effective height may not be suitable**
  - **Adequacy of $5^o x 5^o$ grid**
- **Large spatial and temporal gradients and depletions in the post-sunset hours**
  - **Detection by reference stations**
- **Amplitude and phase scintillation and Bubbles**
  - **How will it affect continuity and availability?**

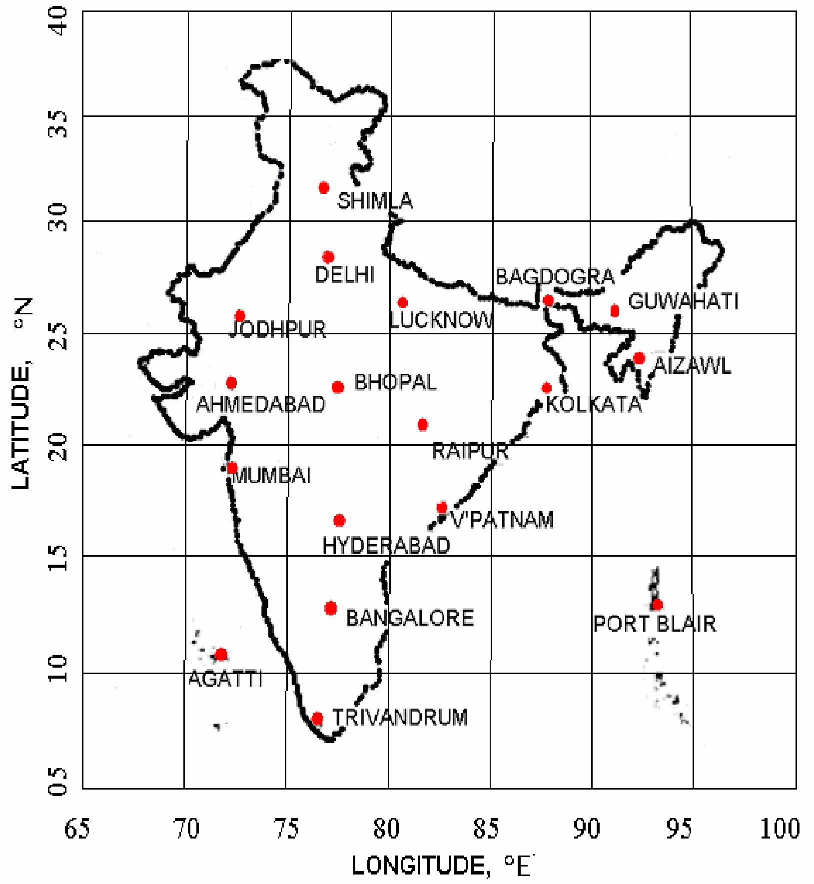
Ionospheric Modelling Activities

Activities taken up by ISRO to find the optimal solution in presence of these constraining impairments

Activities include:

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

Data Collection Stations



Grid Based Algorithms

Comparison and Validation of Models/Algorithms

- **Inverse Distance Weighted :**

  IPPs around an IGP contribute the iono-delay through weights proportional to the square of its inverse distance from the IGP

- **Planar Model :**

  IPP delays assumes a 1st order linear (planar) variation in the neighbourhood of an IGP from which delay at IGP is estimated

- **Kriging Technique :**

  IPPs around an IGP contribute the iono-delay through weights obtained from variation of correlations of detrended delay values with distance. It minimizes mean-square estimation error.

- **Statistical comparison and validation of all these models for both quiet days and disturbed days of year 2004-05**

- **Model giving minimum RMS error has been found to be Kriging**

Other Model Parameters

The most sensitive parameters that affect the modelling which need to be revisited considering the large gradients are:

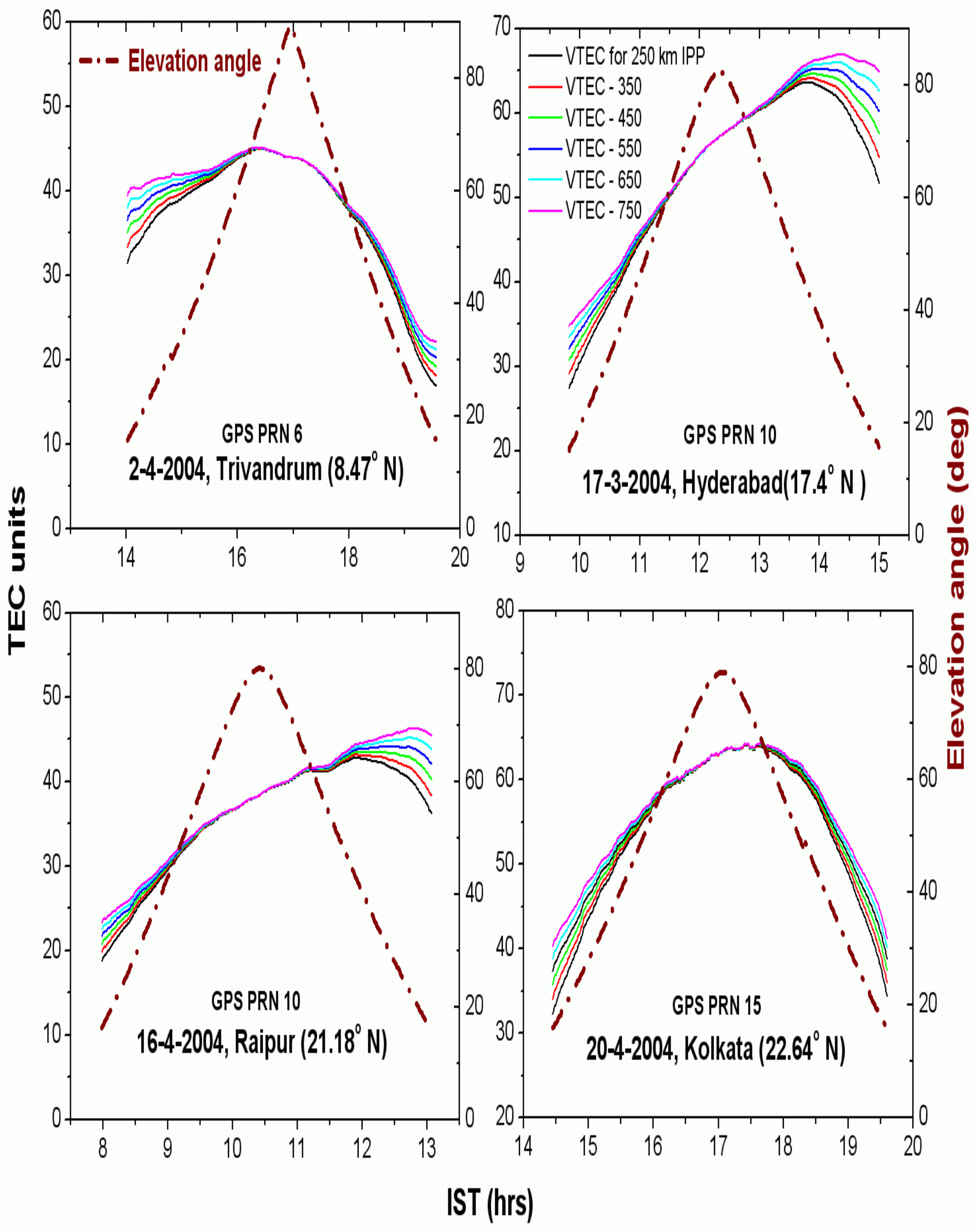
- Effective Height of TEC in single shell models

  - Presently used height is 350 Km
  - Conversion uses a secant function for mapping TEC from vertical to slant and vice-versa

- Grid size and Interpolation method from IGP to user IPP

  - Presently used grid size is 5° x 5°
  - Presently used technique is Bilinear interpolation

Slant to Vertical Conversion



- **Studies show that the variation in the effective altitude in the conversion of slant to vertical TEC did not show much variation, at least for elevation greater than 50º**

- **For low elevation angles and at local times of large TEC, the deviations appear to be significant.**

Study of Scintillation

•Scintillation causes GPS signal amplitude fading and phase fluctuations

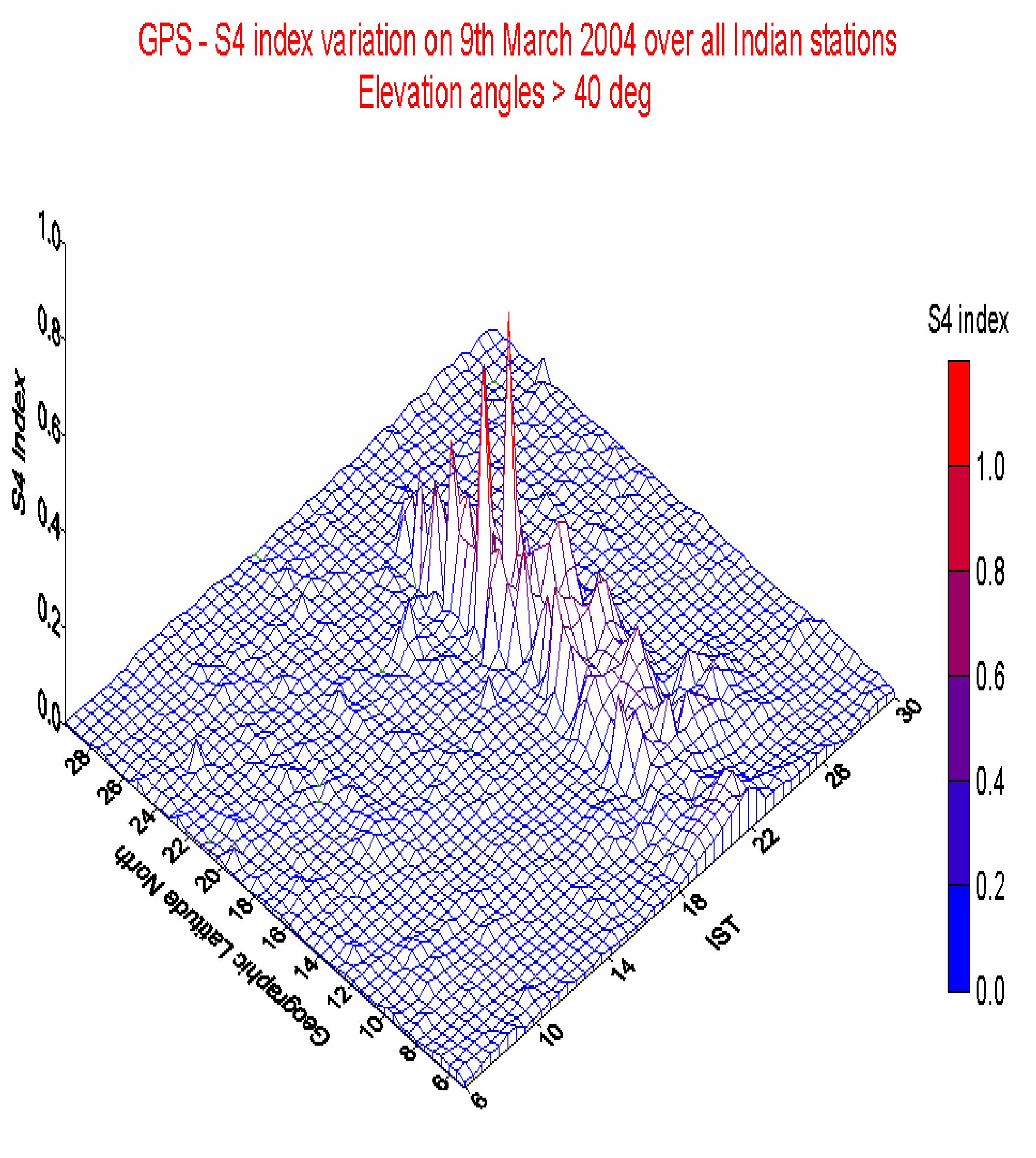
•May cause : loss of lock → service outage

•Studies done are:

- Morphological studies: Latitudinal & seasonal variation of S4 index during magnetically quiet and disturbed days.

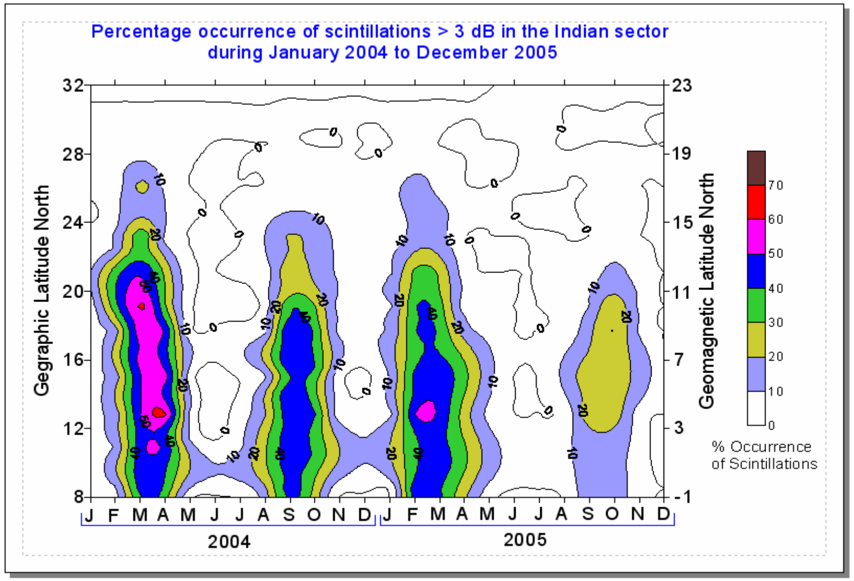
- Study percentage occurrence of S4 index exceeding 3, 6, 10 dBs to estimate possible GPS outages

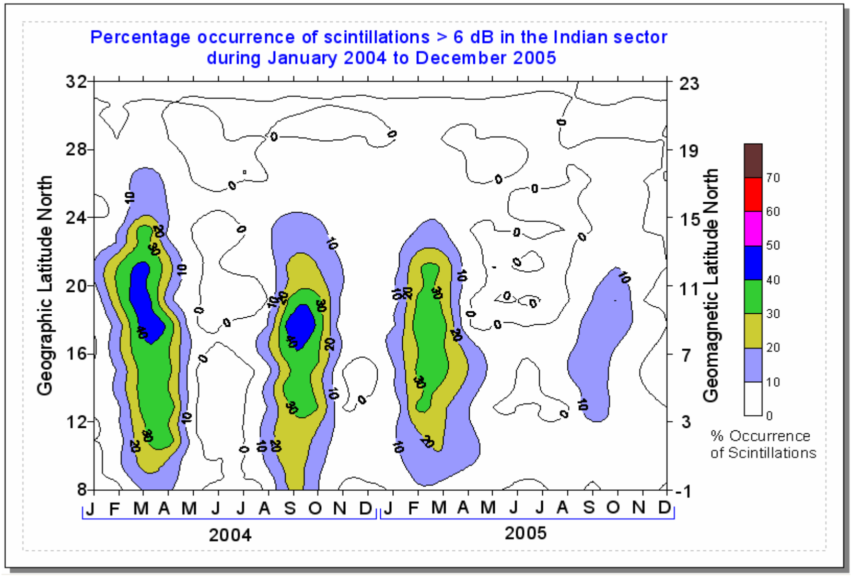
Variation of S4 index

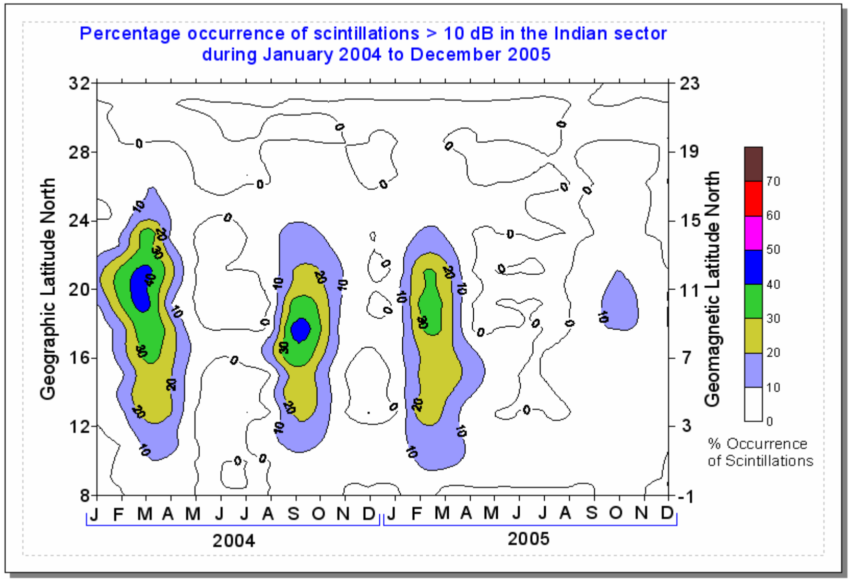


- **Scintillations are nighttime phenomena, normally occurring after sunset till post midnight.**
- **Highest levels of scintillations are observed between the Equatorial anomaly peak region.**
- **Minimum percentage of scintillation is observed over places which lie outside the**

Scintillation Statistics







Mainly occur in equinoctial months but do not occur every day even in those months

Study of Iono Bubbles

Ionospheric Bubbles:

- Small confined region, with depleted electron density
- Frequently form in equatorial regions just after sunset
- Rise into the F-region, where electron densities are otherwise high

Impact :

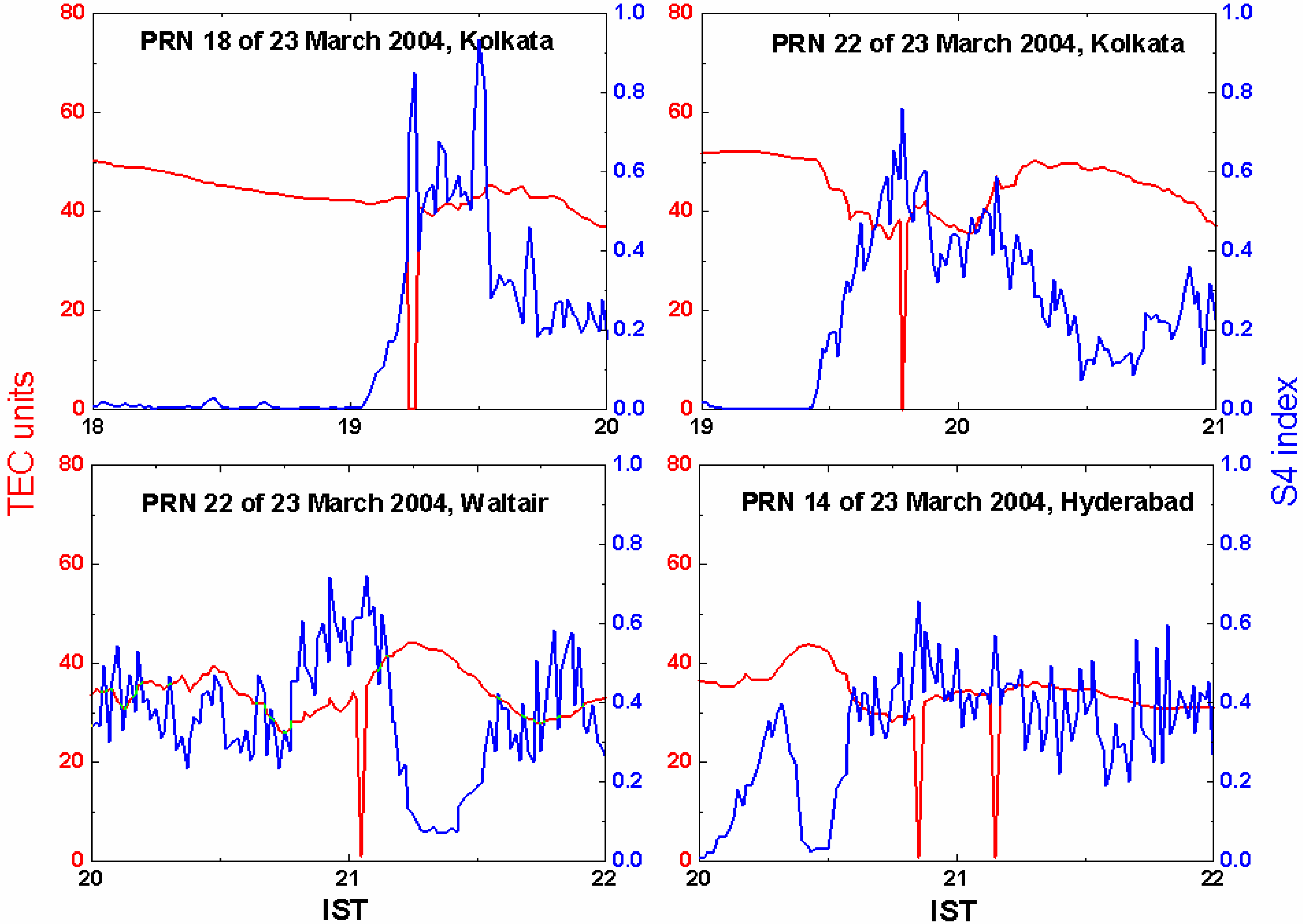
(i) Adequacy of conventional grid based model ?

(ii) Strong scintillations, causing loss of lock of GPS signals.

Statistical study of occurrence of bubbles in Indian region done to understand the extent of its effects on satellite navigation services.

Observation of Bubbles

Typical examples of Loss of lock of GPS receivers observed



Typical Examples of the loss of lock of the GPS receivers

Main features of Bubbles

The main observations of Bubbles over Indian region are:

(1) Ionospheric Bubbles are small, diversified and are not confined to Equatorial latitudes.

(2) Maximum number of bubbles are observed in the Equinoctial months of 2004 and 2005.

(3) The maximum number of L1 Loss of Lock also follows the same monthly pattern.

(4) The maximum number of bubbles and unlocks occur at stations, near the Equatorial Anomaly peak.

(5) They are observed only after sunset and up to midnight only.

Summary ...

1. **Grid Based Ionospheric Model :**

   Scopes of Better large scale model for equatorial region to be explored to deal with large gradients

   Develop and use Improved Mapping Function

   Grid size reduction may be tested for better performance

2. **L Band scintillation studies over Indian region** :

   Scintillation may degrade the service, mainly in equinoctial months and near anomaly peak region

   Develop L Band Scintillation Prediction Models

3. **Studies on Occurrence of Ionospheric Bubbles** :

   Undetected bubbles may cause large scale models to fail in a 5x5 grid based SBAS system

   Development of suitable user receiver based ionospheric depletion mitigation algorithm

Thank You

Models

2 Layer and Multi-Layer Ray Tomographic Model

Voxel-based 3-dimensional model

Vertical delay derived after obtaining density distribution using tomography

Modal Decomposition Tomographic Model

Electron Distribution assumed to be weighted sum of individual complete basis distributions

Vertical delay derived after obtaining density distribution using tomography

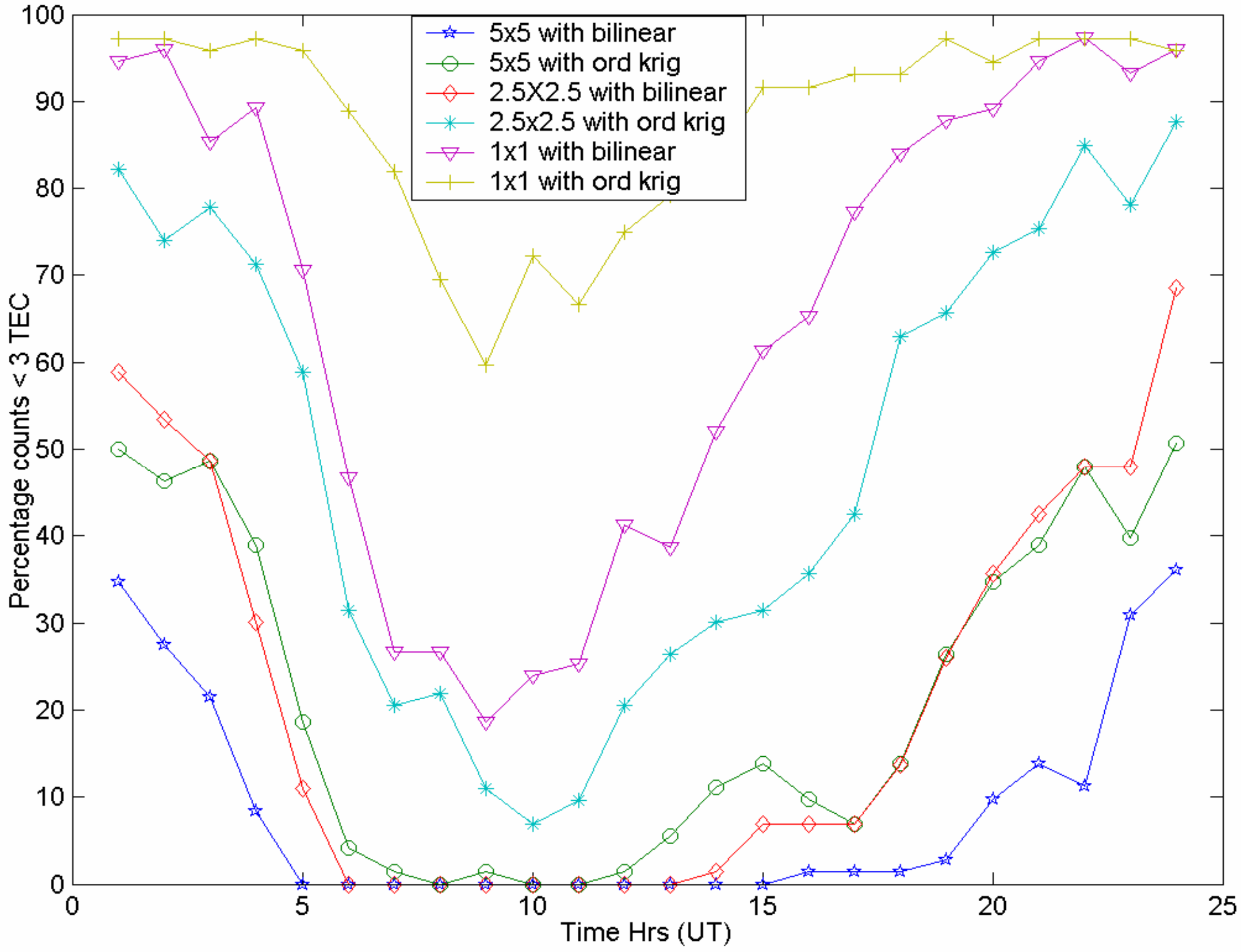
Two Shell Models

Vertical delay apportioned between IPPs at two different shell heights based on typical electron density distribution

For each layer IGP values obtained using one of the mentioned algorithms

Grid Size and User interpolation

Percentage of reconstruction accuracy< 3 TEC
Comparison for different Grid size and User Interpolation



Main features of Scintillations

The main observations of L Band Scintillation over Indian region are:

(a) Scintillations are generally nighttime phenomena, normally occurring after sunset till post midnight.

(b) Highest levels of scintillations are observed between around the Equatorial anomaly peak region.

(c) Minimum percentage of scintillation is observed over places which lie outside the equatorial anomaly.

(e) Daily variation of S4 index is large and is independent of magnetic index of the days.

Observation of Bubbles

Amplitude of TEC depletions from all the 18 Indian stations

Months	TEC depletion amplitudes in TEC units								*Total number of events*
	5-10	10-15	15-20	20-25	25-30	30-35	35-40	>40	
Jan 2004	2	0	0	0	0	0	0	0	2
Feb	7	1	1	0	0	0	0	0	9
Mar	184	67	34	10	2	0	0	0	297
Apr	75	12	2	0	0	0	0	0	89
May	0	0	0	0	0	0	0	0	0
Jun	0	0	0	0	0	0	0	0	0
Jul	2	6	0	0	0	0	0	0	8
Aug	5	1	0	0	0	0	0	0	6
Sep	121	35	12	7	1	1	0	0	177
Oct	77	33	12	4	2	1	0	0	129
Nov	1	0	0	0	0	0	0	0	1
Dec	2	1	0	0	0	0	0	0	3
Jan 2005	0	0	2	0	0	0	0	0	2
Feb	116	35	10	2	1	0	0	0	164
Mar	54	14	3	1	0	0	0	0	72
Apr	6	2	0	0	0	0	0	0	8
May	3	0	0	0	0	0	0	0	3
Jun	0	0	0	0	0	0	0	0	0
Jul	0	0	0	0	0	0	0	0	0