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Ionospheric Response to the Total Solar Eclipse of July 22, 2009 as Deduced from VLBI and GPS

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Outline

- Brief introduction of Total Solar Eclipse on July 22, 2009
- Observations
- Total Electron Content (TEC) Reduced by GPS
- TEC Reduced by VLBI
- Comparison of VLBI- & GPS-based TEC
- Summary and outlook

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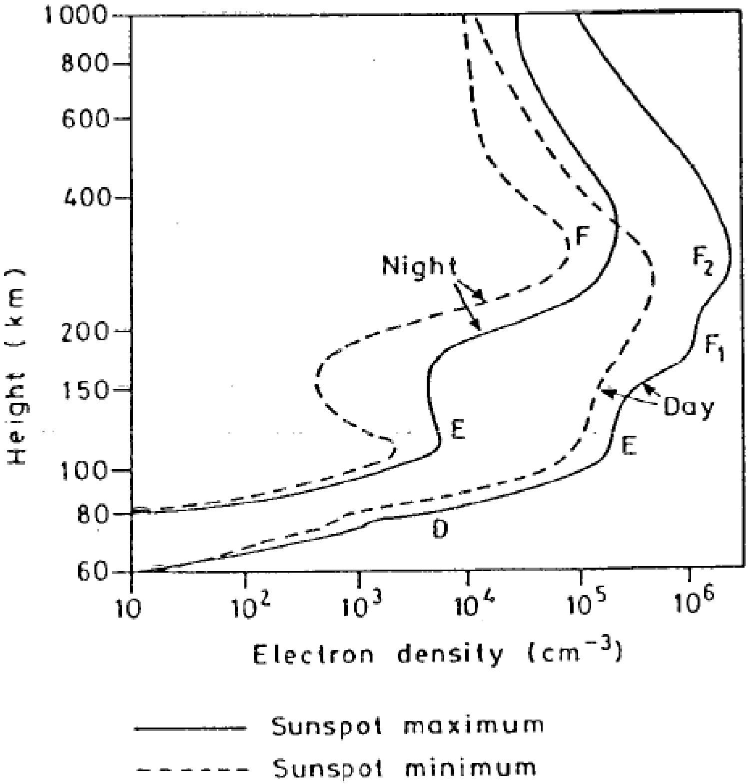
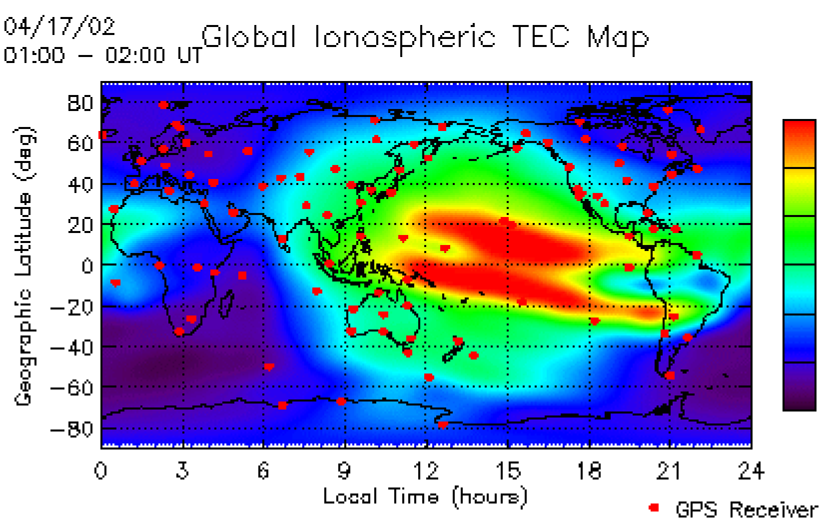
Ionospheric Distributions

Typical model of Electron Content



Typical distributions of Global Total electron density



Relation between TEC variations and Eclipse

- The eclipse causes the change of ionisation in the E- & F- region of the ionosphere;
- TEC is a good indicator of the state and dynamics of F-region of ionosphere;
- The electron density in E region will decrease greatly during the eclipse;
- GPS provides the high temporal & spatial resolution of TEC distribution;
- VLBI also determines TEC measurements by S/X dual-band observations.

Introduction of Total Solar Eclipse on July 22, 2009

- The longest total solar eclipse during the 21st century, occurred over China at latitudes of about 30^0N in the morning of July 22, 2009;
- Providing a unique opportunity to investigate the influence of the sun on the earth upper ionosphere. And Shanghai is located near the central line of the total eclipse belt.

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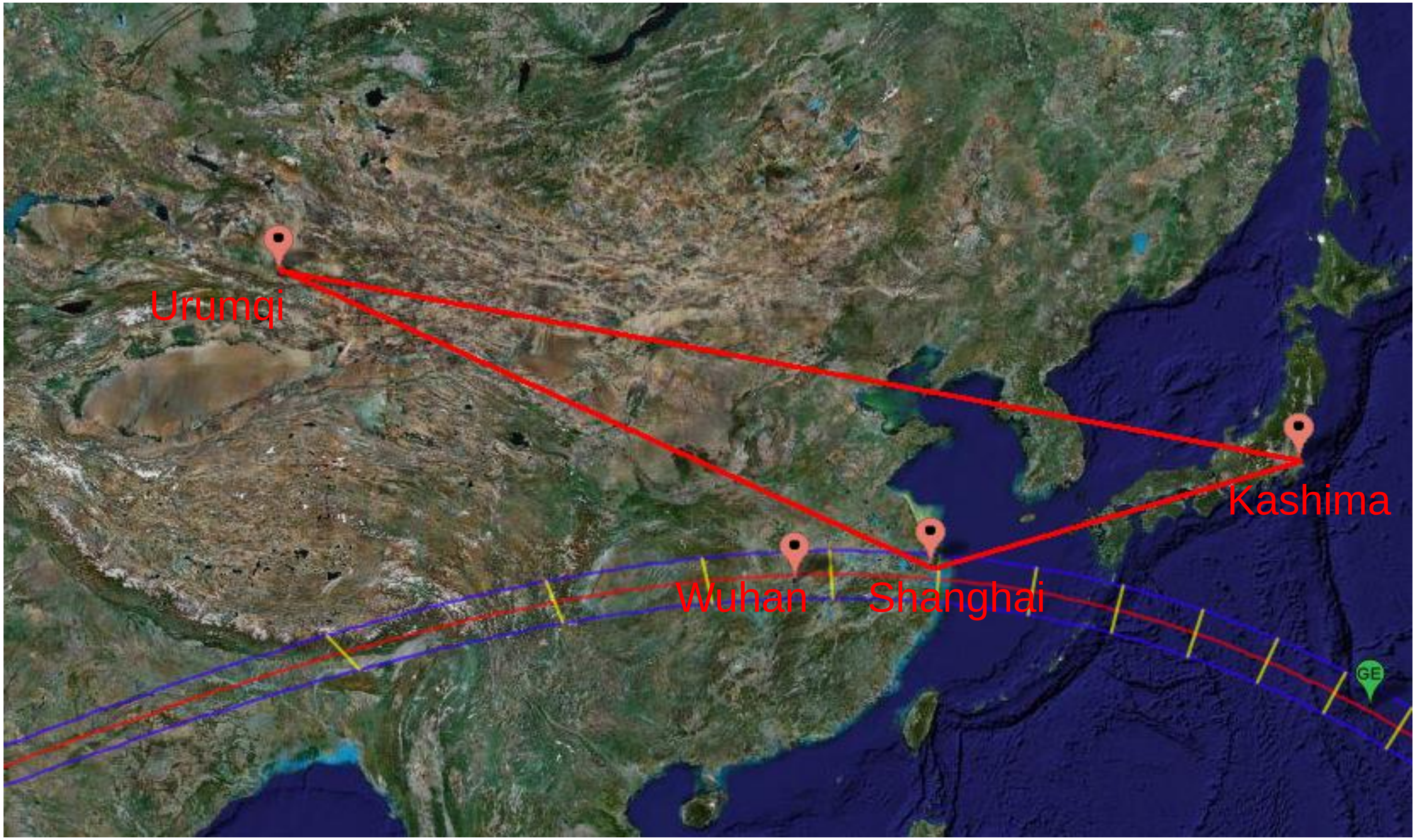
Map of the total solar eclipse path on July 22, 2009, and distribution of VLBI and GPS sites.



Introduction of Total Solar Eclipse 22 July, 2009

- Predicted solar eclipse time for Shanghai and Wuhan on July 22, 2009. (UT)

site	First contact	Second contact	Third contact	Fourth contact
SH	00:23	01:36	01:41	03:01
WH	00:14	01:24	01:29	02:46

TEC Reduced by GPS

- Downloading GPS data files (o & sp3)from IGS website;
- The single site technique is employed to obtain the diurnal TEC variations of GPS stations;
- GPS measurements for satellites of different directions are averaged;
- The multi-site technique is used to produce the TEC maps for Yangtze Delta Region (with 5 min interval).

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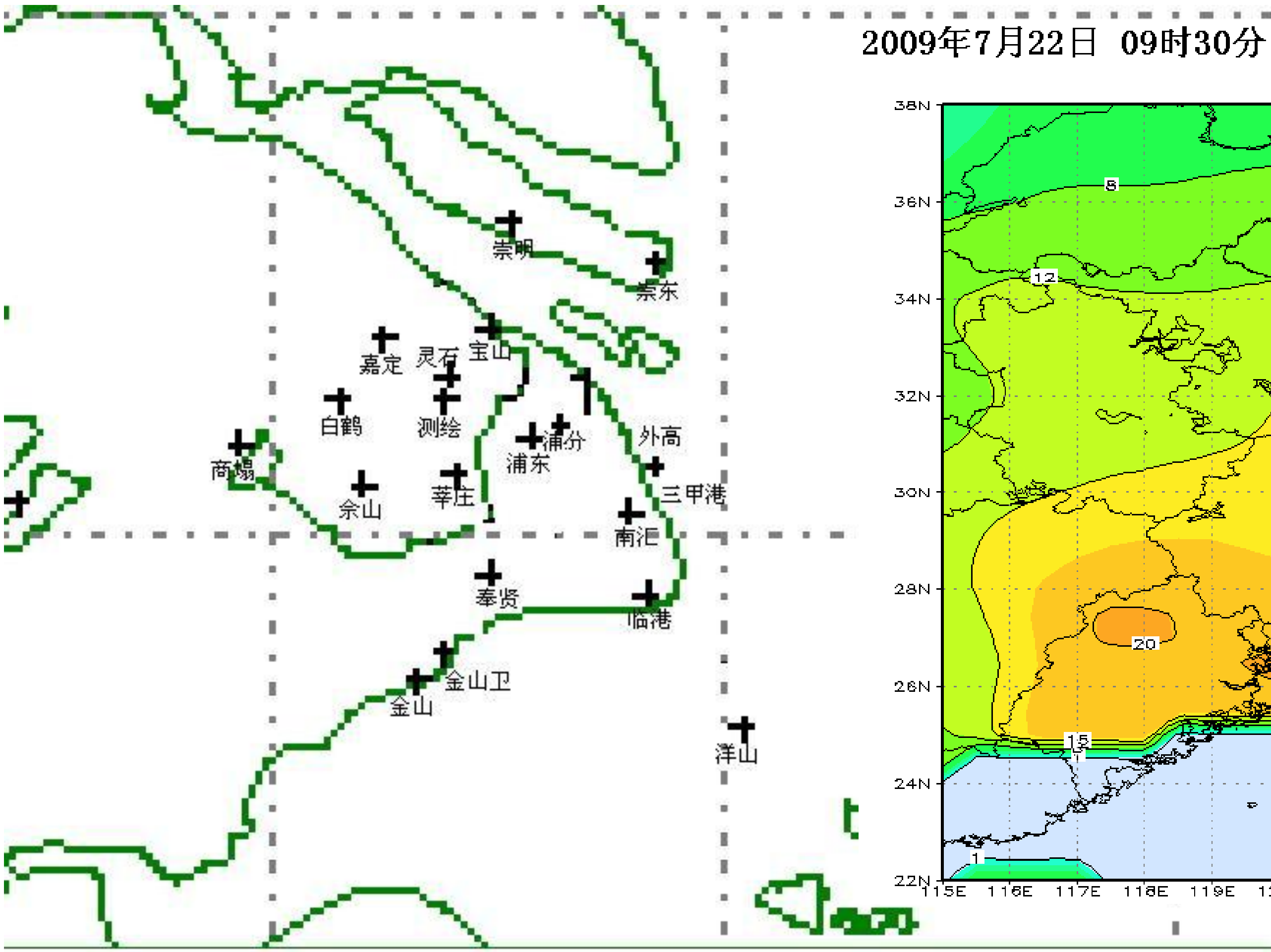
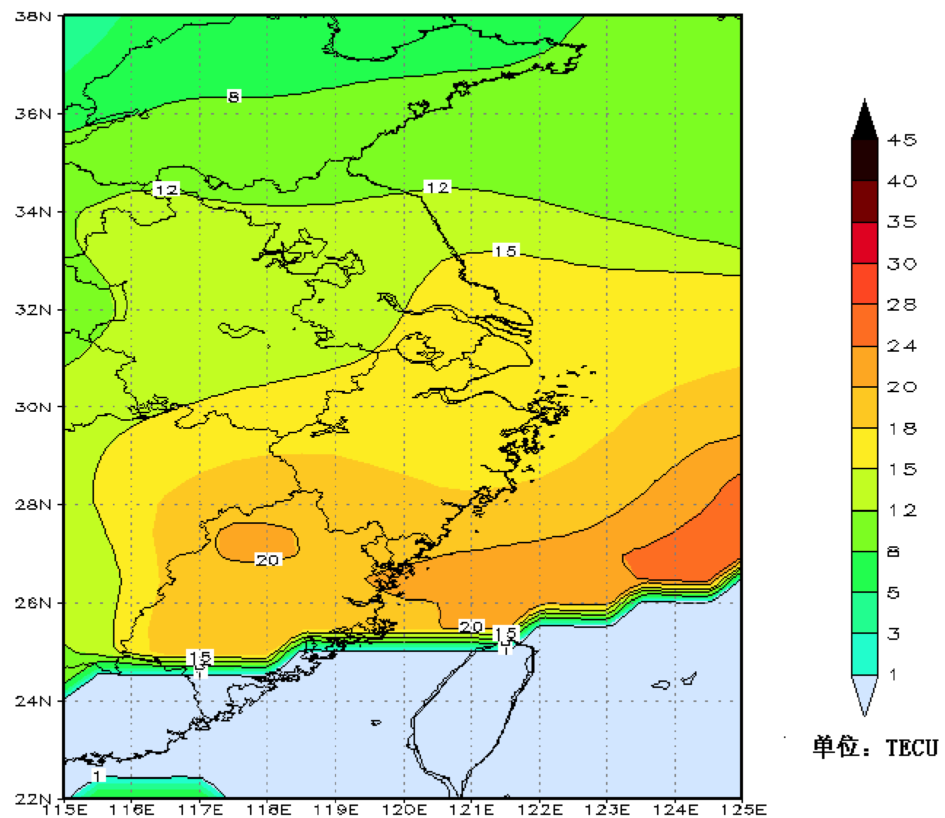
The GPS Network of Yangtze Delta Region



2009年7月22日 09时30分 华东地区电离层电子总密度分布图



The eclipse effect in diurnal variations of TEC by GPS

- Single-layer model at the height of 350km is used to estimate the TEC;
- The TEC is modeled as the functions of local time in subionospheric point (SP) and latitude difference between receivers and SP.
- Mapping function used to convert the slant TEC(STEC) to vertical TEC (VTEC).

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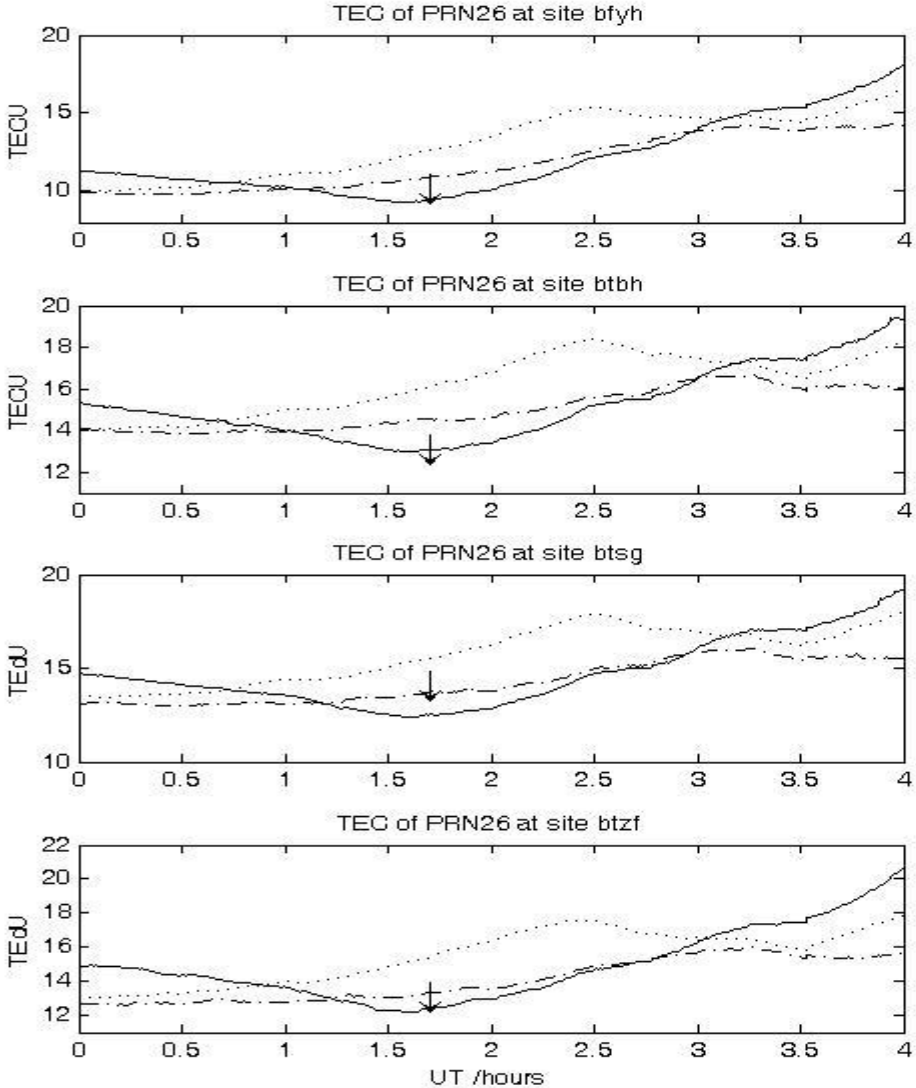
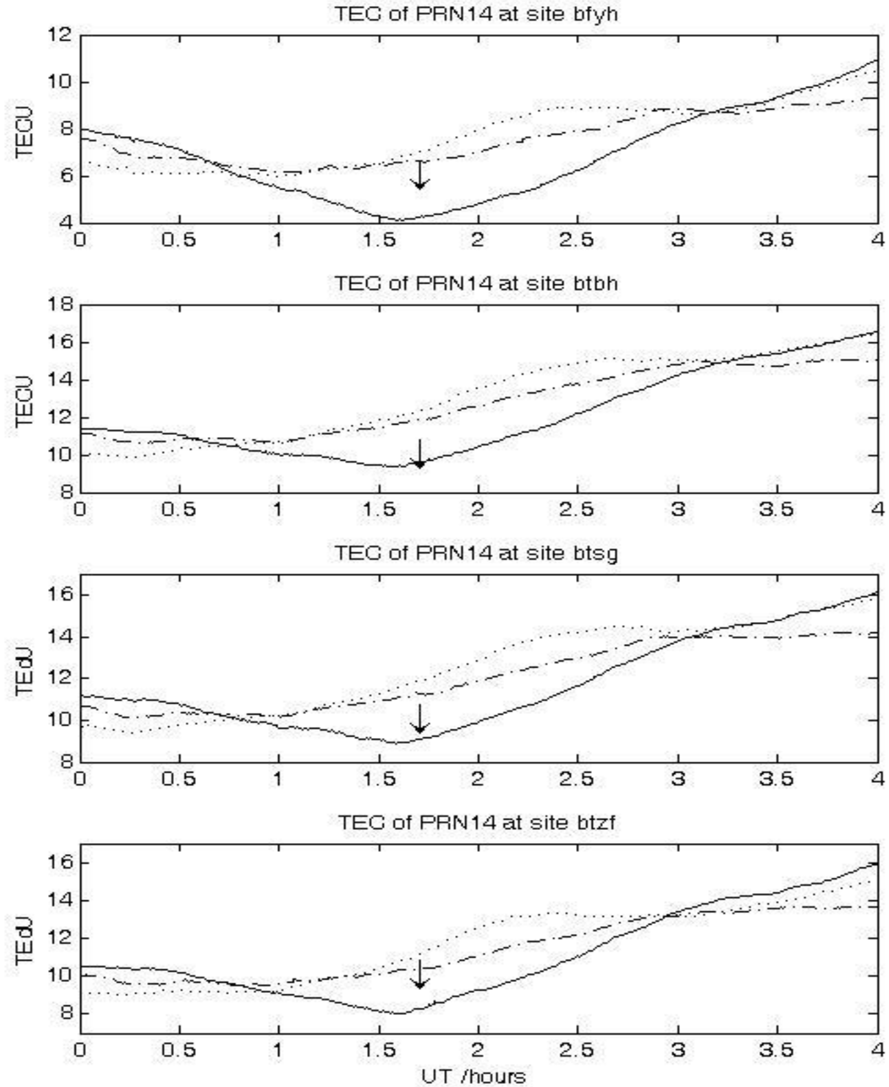


- The arrows show the time of TEC max phase of eclipse.
- Obvious TEC depression is shown here during the eclipse.
- The min of TEC value is near to the max phase of TEC for PRN 26 (< 5 min).

- Temporal TEC variations along satellite passes for PRN 26 at btyh, btbh, btsg & btzl on July 21(dashed line), 22(solid line) & 23(dotted line)



- The arrows show the time of TEC max phase of eclipse.
- Obvious TEC depression is shown here during the eclipse.
- The mim of TEC value is near to the max phase of TEC for PRN 14(< 5 min).

- Temporal TEC variations along satellite passes for PRN 14 at btyh, btbh, btsg & btzl on July 21(dashed line), 22(solid line) & 23(dotted line)

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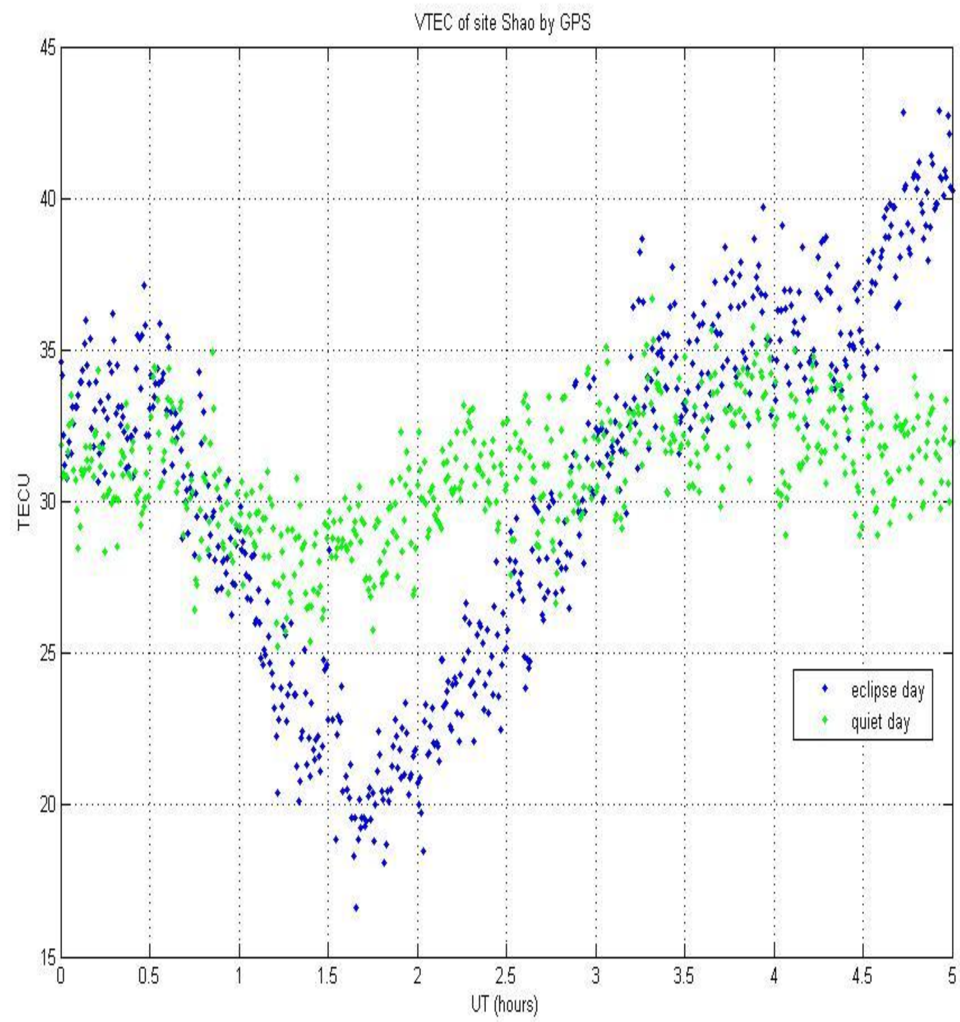

The absolute levels of TEC on eclipse day are lower relative to the quiet day;
The depression arrives at ~5TECU at the max eclipse time.

- VTEC variations observed over single site (SHAO) on July 21(green dot), 22(blue dot)。

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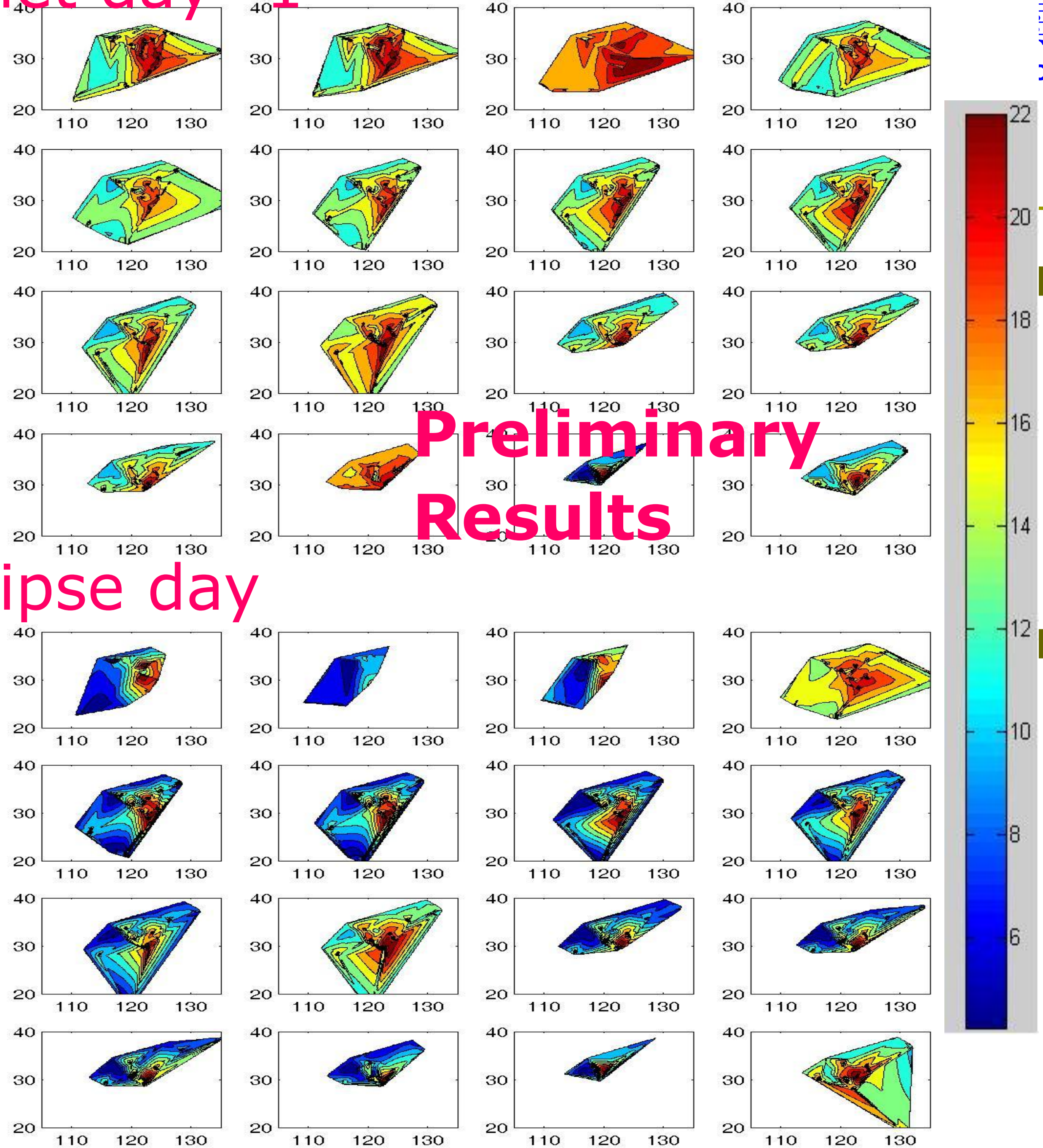
Quiet day -1

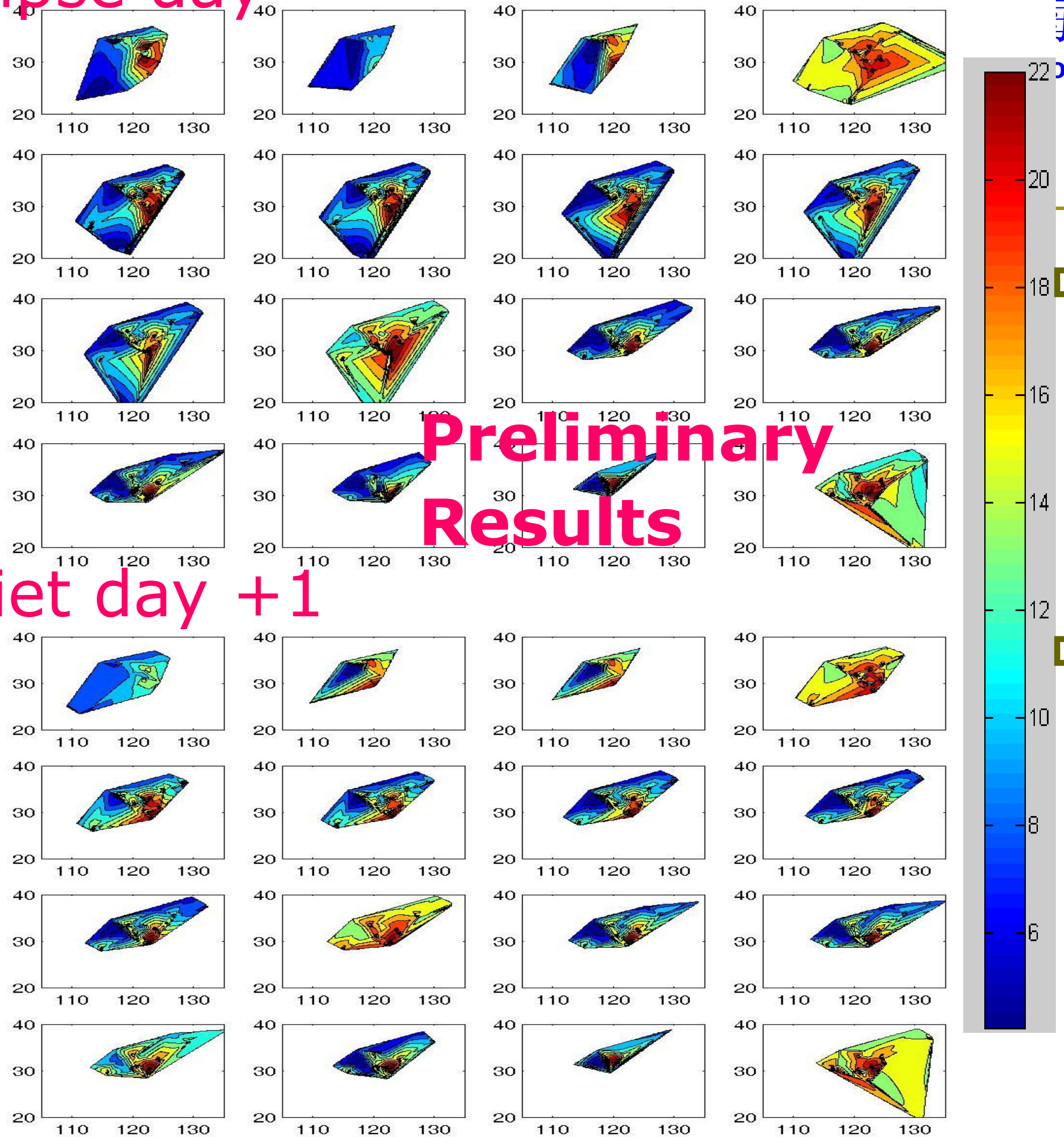
Eclipse day



Preliminary Results

- Map of TEC Network of Yangtze River Region every 5min (00:45-02:00)
- Obvious TEC decease on eclipse day than the former quiet day

Eclipse day



Preliminary Results

Quiet day +1

- Map of TEC Network of Yangtze River Region every 5min (00:45-02:00)
- Obvious TEC decease on eclipse day than the later quiet day

VLBI observations

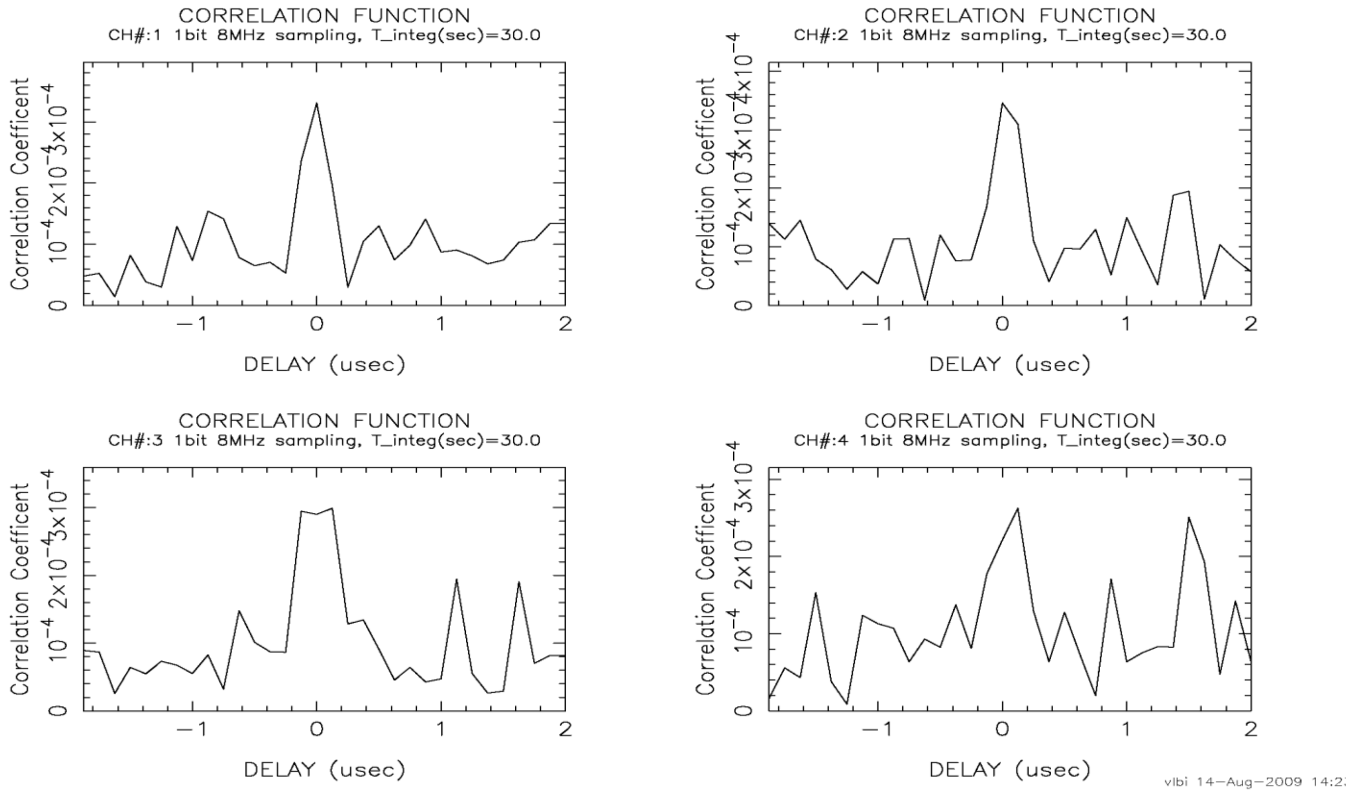
- Time: From UT22:00 21 July – UT 07:00 22 July
- Sites: Shanghai, Kashima & Urumqi
- Radio sources: continuous observation of 4C39.25 about 4 hours with 25 deg of solar angles;
- S/X dual-band observation mode;
- TEC values derived from S/X bandwidth synthesis delay after data correlation.

VLBI observation mode

- 16ch×8Mbps/ch, 10X+6S
- F CDP-SX SX KASHIM34 SESHAN25 URUMQI

```
C SX X  8210.99  10000.0   1 Mk341:2   4.00 1(-1,3)
C SX X  8220.99  10000.0   2 Mk341:2   4.00 1(7)
C SX X  8250.99  10000.0   3 Mk341:2   4.00 1(11)
C SX X  8310.99  10000.0   4 Mk341:2   4.00 1(15)
C SX X  8420.99  10000.0   5 Mk341:2   4.00 1(19)
C SX X  8500.99  10000.0   6 Mk341:2   4.00 1(23)
C SX X  8550.99  10000.0   7 Mk341:2   4.00 1(27)
C SX X  8570.99  10000.0   8 Mk341:2   4.00 1(0,4)
C SX S  2217.99  10000.0   9 Mk341:2   4.00 1(8)
C SX S  2222.99  10000.0  10 Mk341:2   4.00 1(12)
C SX S  2237.99  10000.0  11 Mk341:2   4.00 1(16)
C SX S  2267.99  10000.0  12 Mk341:2   4.00 1(20)
C SX S  2292.99  10000.0  13 Mk341:2   4.00 1(24)
C SX S  2302.99  10000.0  14 Mk341:2   4.00 1(28)
R SX   8.000
```

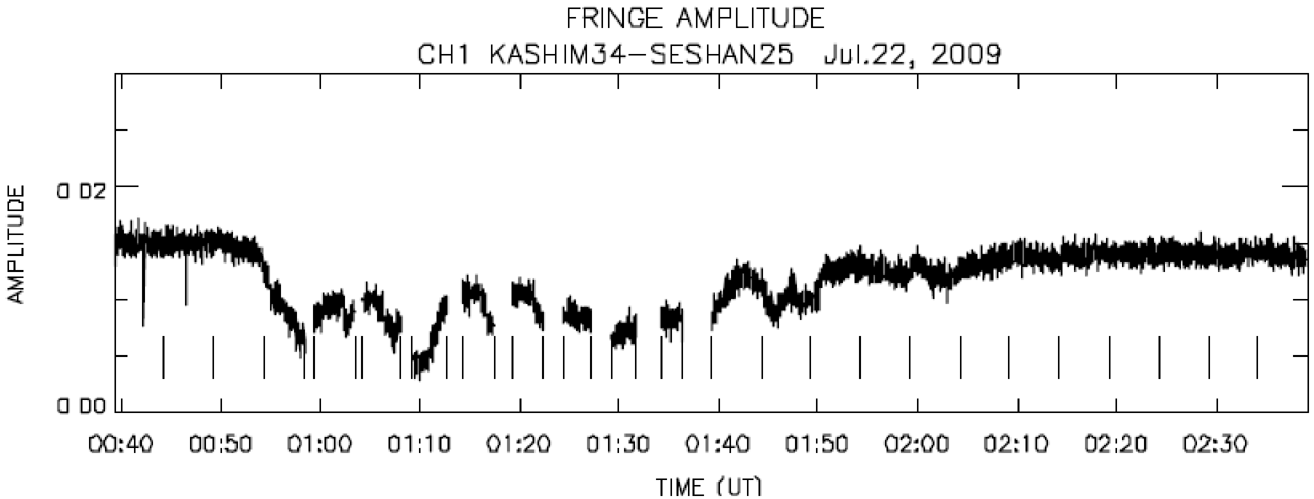
Fringe searching results @ Kashima



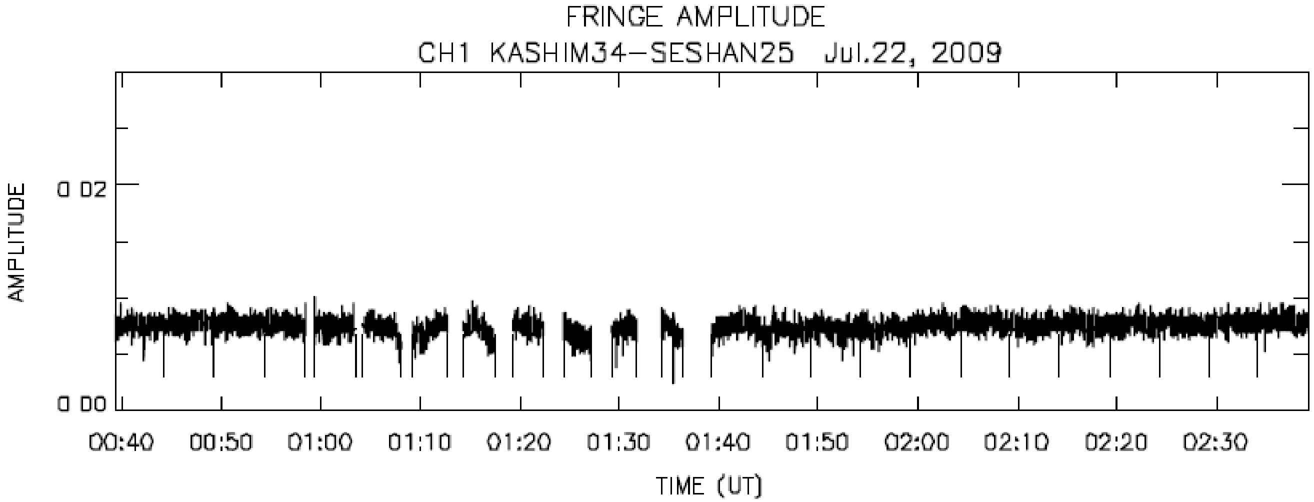
Correlation amplitude variation on the Kb-Sh baseline

- The fluctuations of amp is due to the heavy rain in Shanghai.

- X band

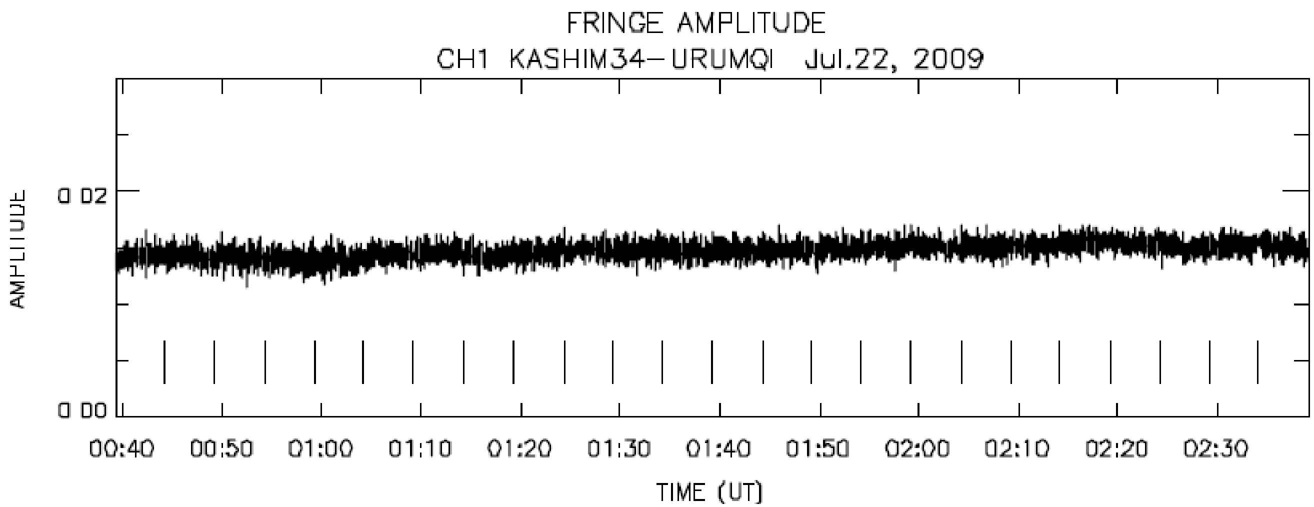


- S band

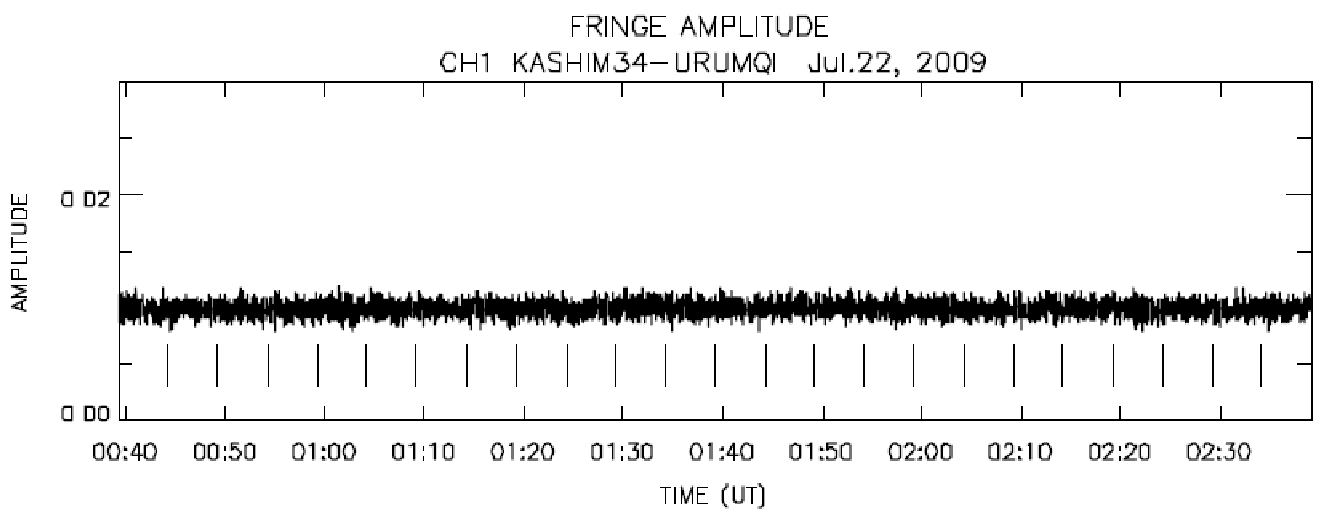


Correlation amplitude variation on the Kb-Ur baseline

- X band

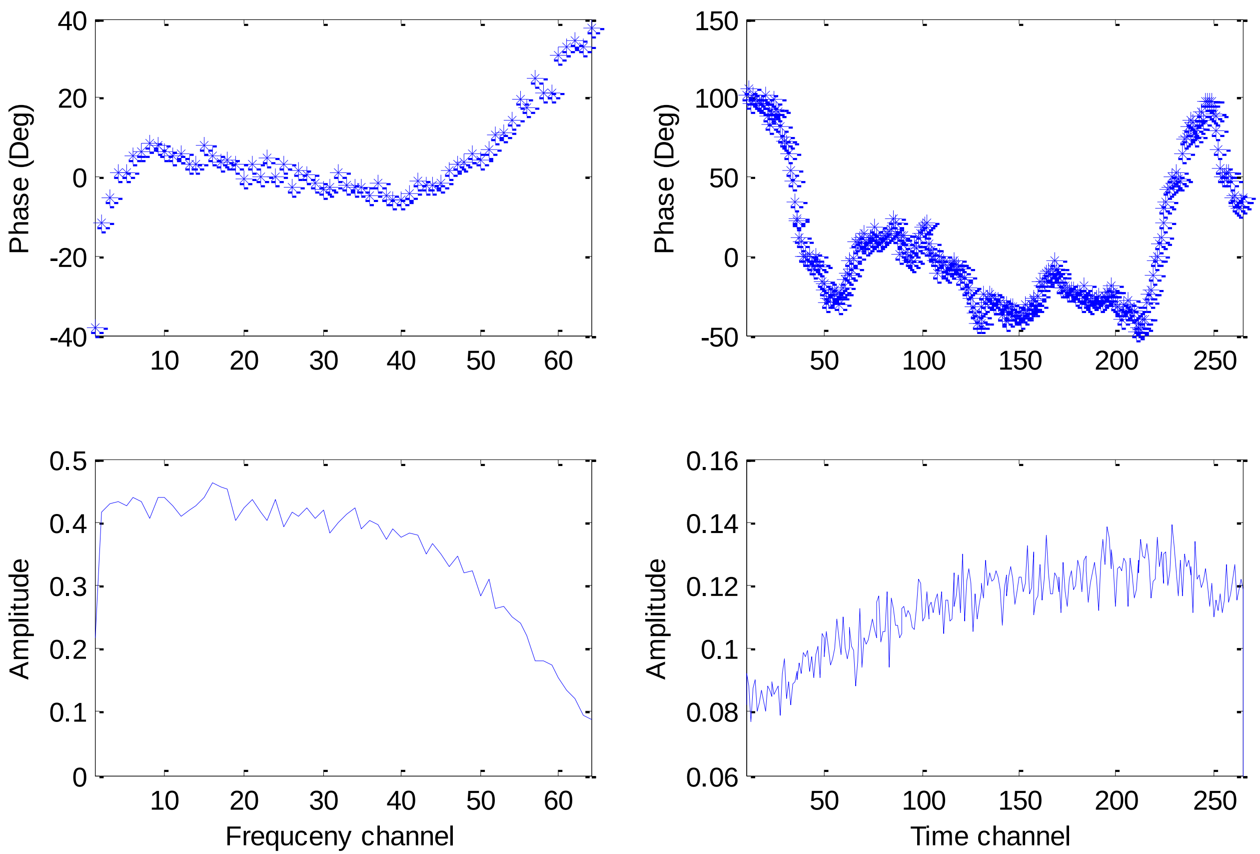


- S band



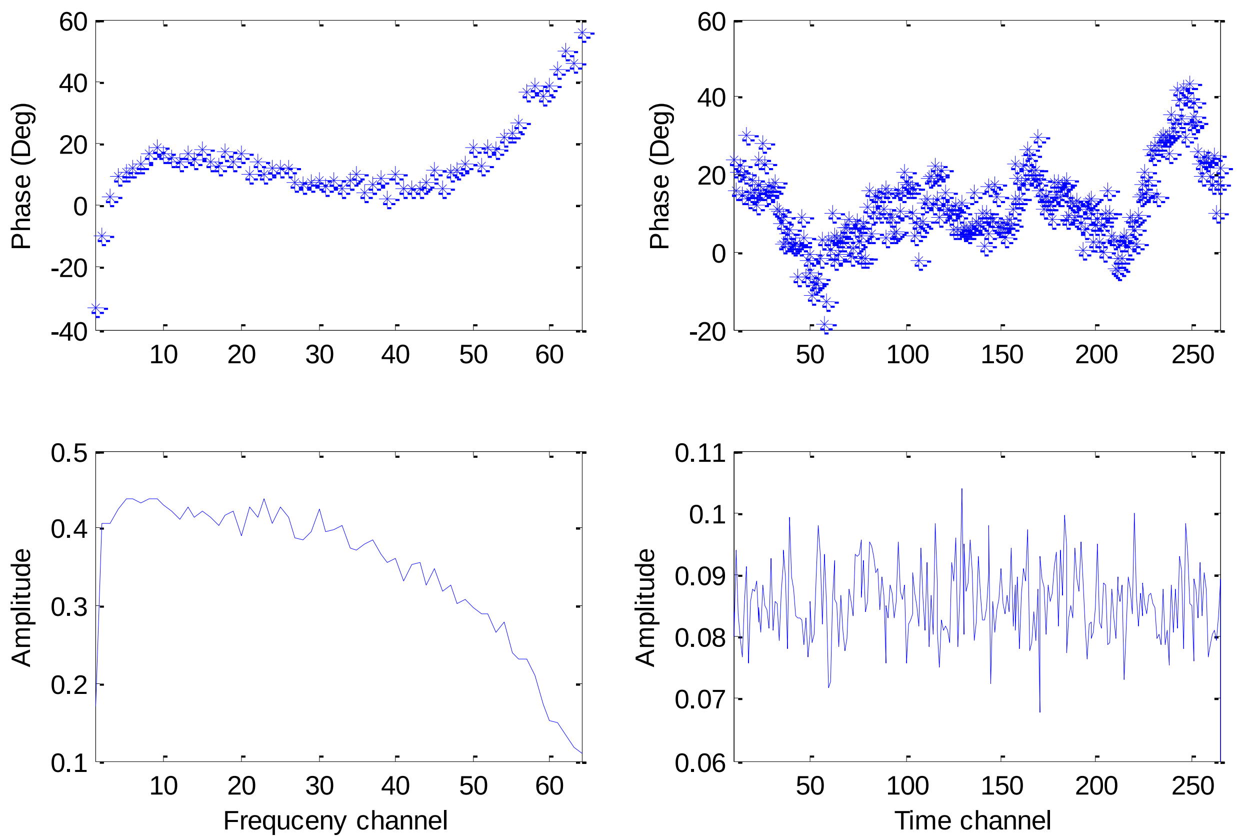
Correlation phase variation

- 2009203013910000_4C39.25_KS_X



Correlation phase variation

- 20092030139100000_4C39.25_KS_S



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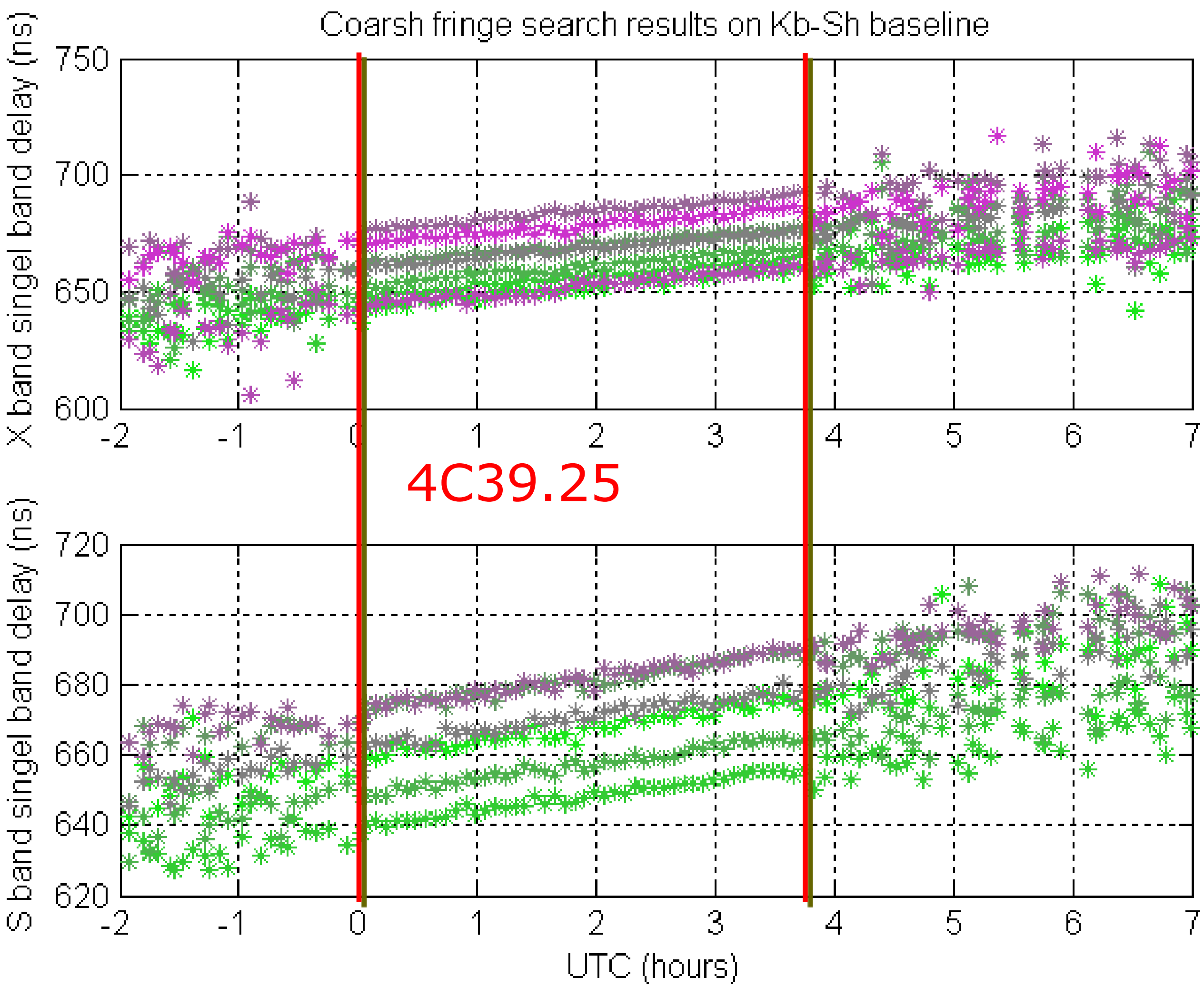
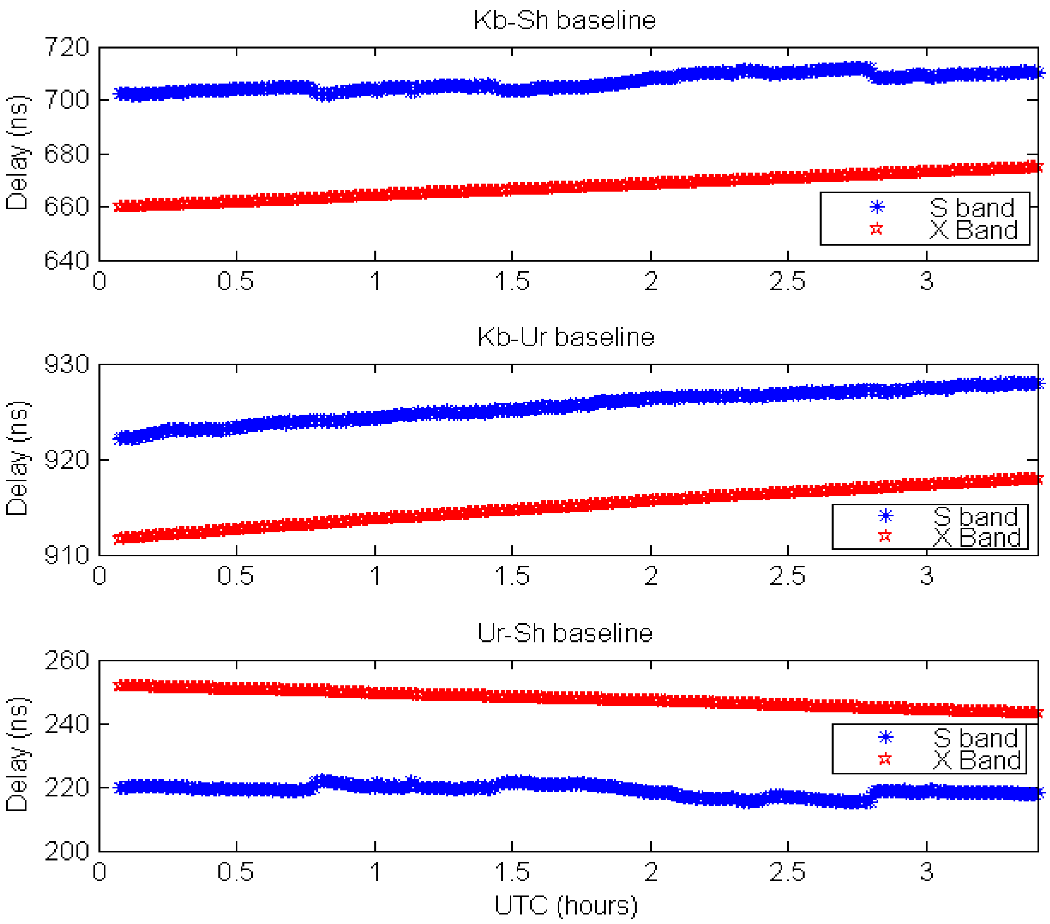
S/X single-band delay



Bandwidth synthesis delay for 3 baselines

- Integration time is 30s for the strong source 4C39.25



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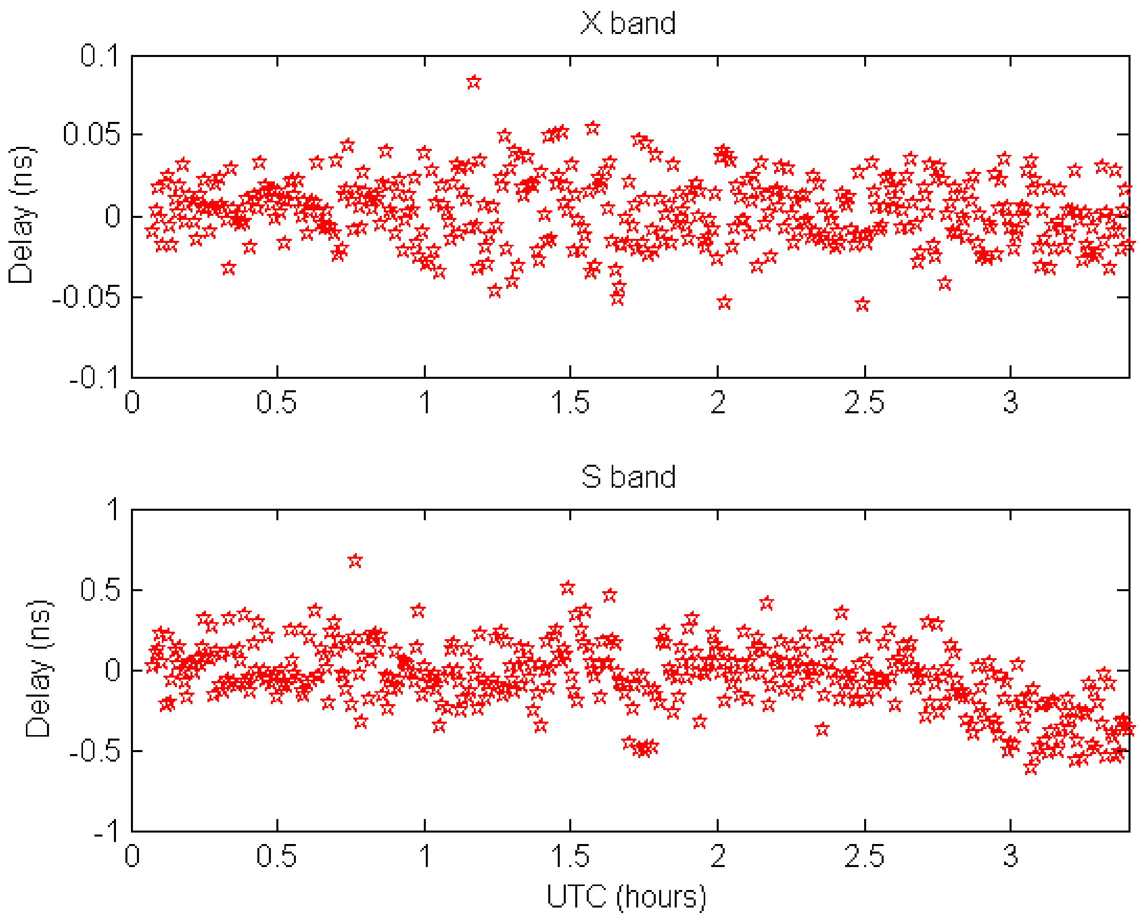
Kb-Sh-Ur closure delay



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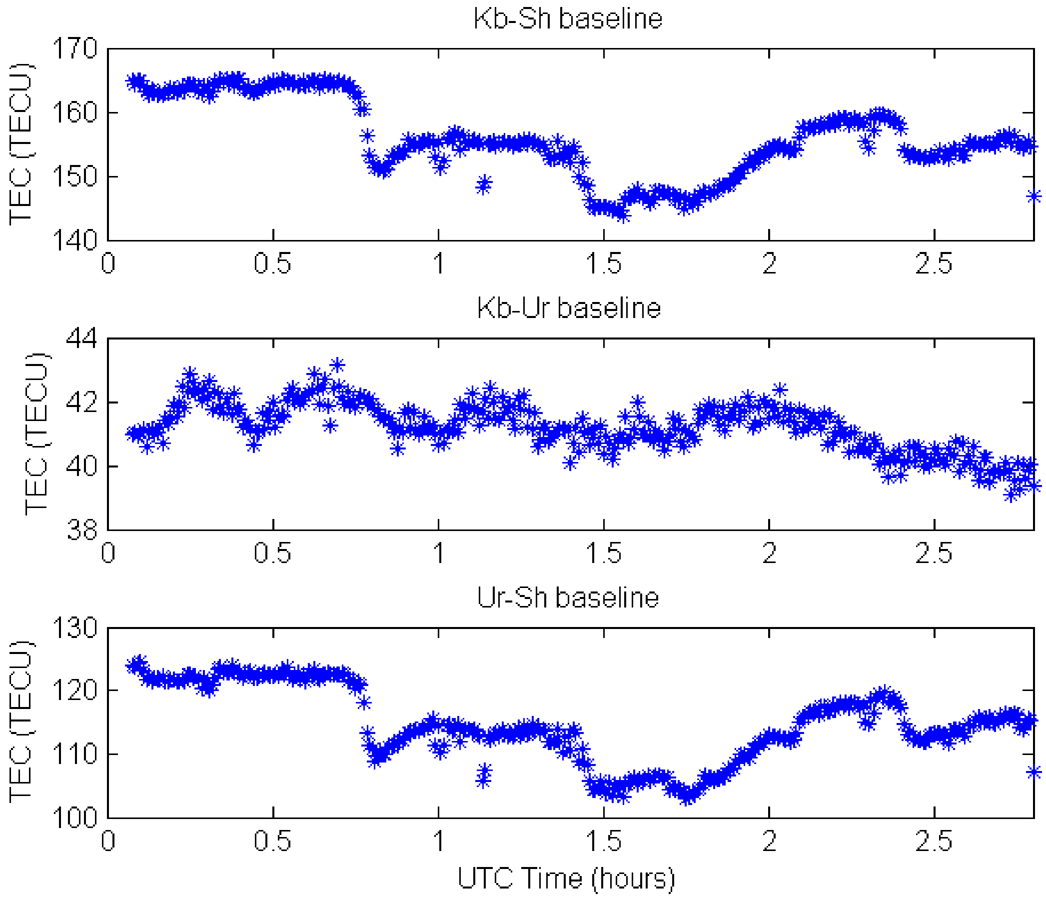
Preliminary TEC results

- TEC variation on 3 baselines



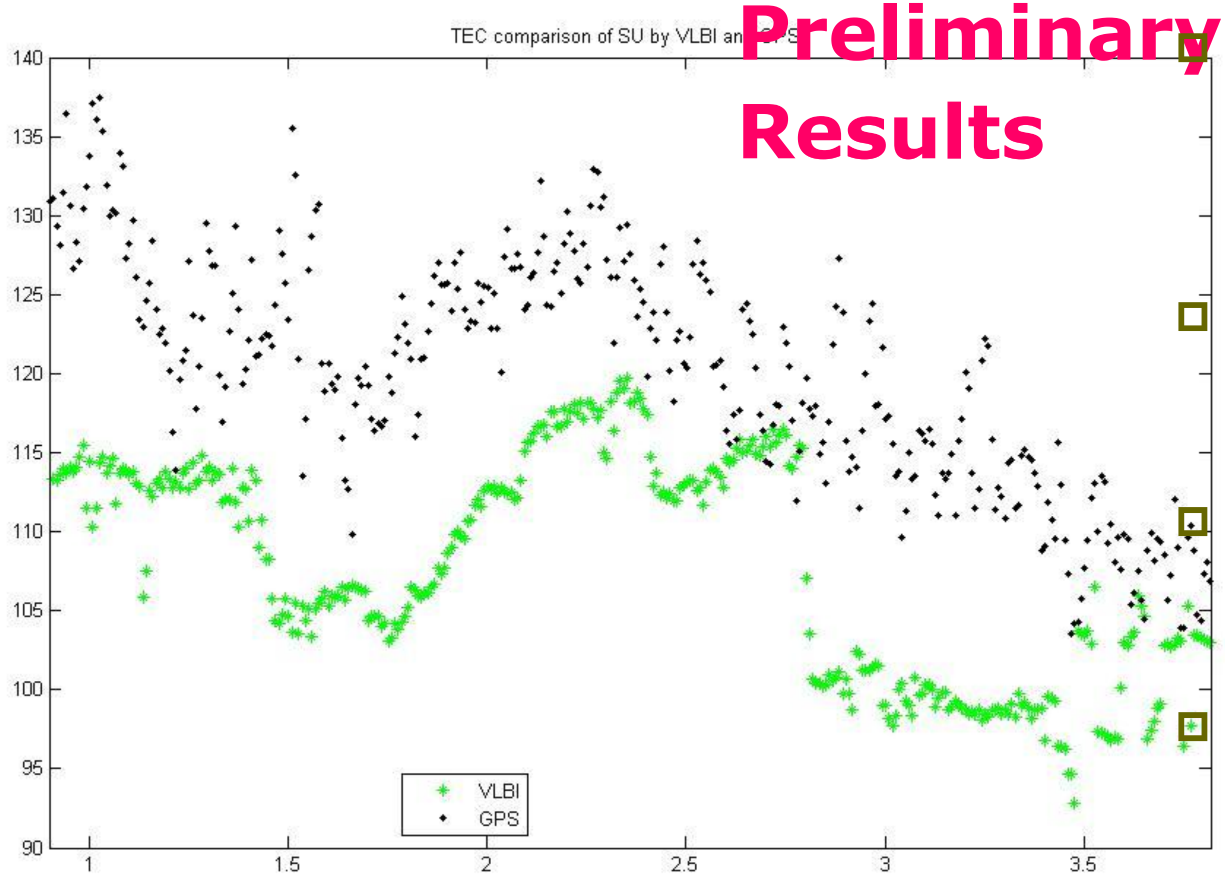
- Obvious decrease of TEC occur at the max eclipse time on Sh- related baselines.

Comparison of VLBI and GPS-based TEC

- Calculating the VTEC of 3 GPS co-located sites;
- Mapping to the VLBI observation directions by mapping function (Slant TEC);
- Obtaining the difference of STEC between two sites of the baselines;
- Analysis of the differences.

Comparison Results

Preliminary Results



- Both detected the Obvious decrease of TEC occur at the max eclipse time;
- High correlation of TEC reduced by the two methods;
- Further analysis for jump in VLBI results;
- Precision of GPS results needs to be improved.

- Comparison of VLBI (green) and GPS-based (black) TEC of baseline SH-UR on eclipse day 。

Summary

- Obvious TEC depression is detected in diurnal variations and more distinctly in TEC variations along individual satellite passes;
- The max depression was observed at the max phase of the solar eclipse.
- The 2D TEC maps show the eclipse introduced remarkable changes in the structure of the ionosphere. 20-40% TEC depression compared to quiet day.
- Comparison of VLBI and GPS-based TEC shows both of the two technology detected the obvious ionospheric variations during the eclipse.
- Correlation amplitude and phase shows large variations at X band on the baselines to Shanghai due to the heavy rain during the solar eclipse.

Outlook

- Applying better interpolation method in producing 2D map for better precision;
- Further analysis of the correlation of TEC reduced by VLBI and GPS;
- Further analysis for jump in VLBI results;
- Precision of GPS results needs to be improved.

Thanks for your attentions!