Ionospheric Tomography From The Owen's Valley LWA

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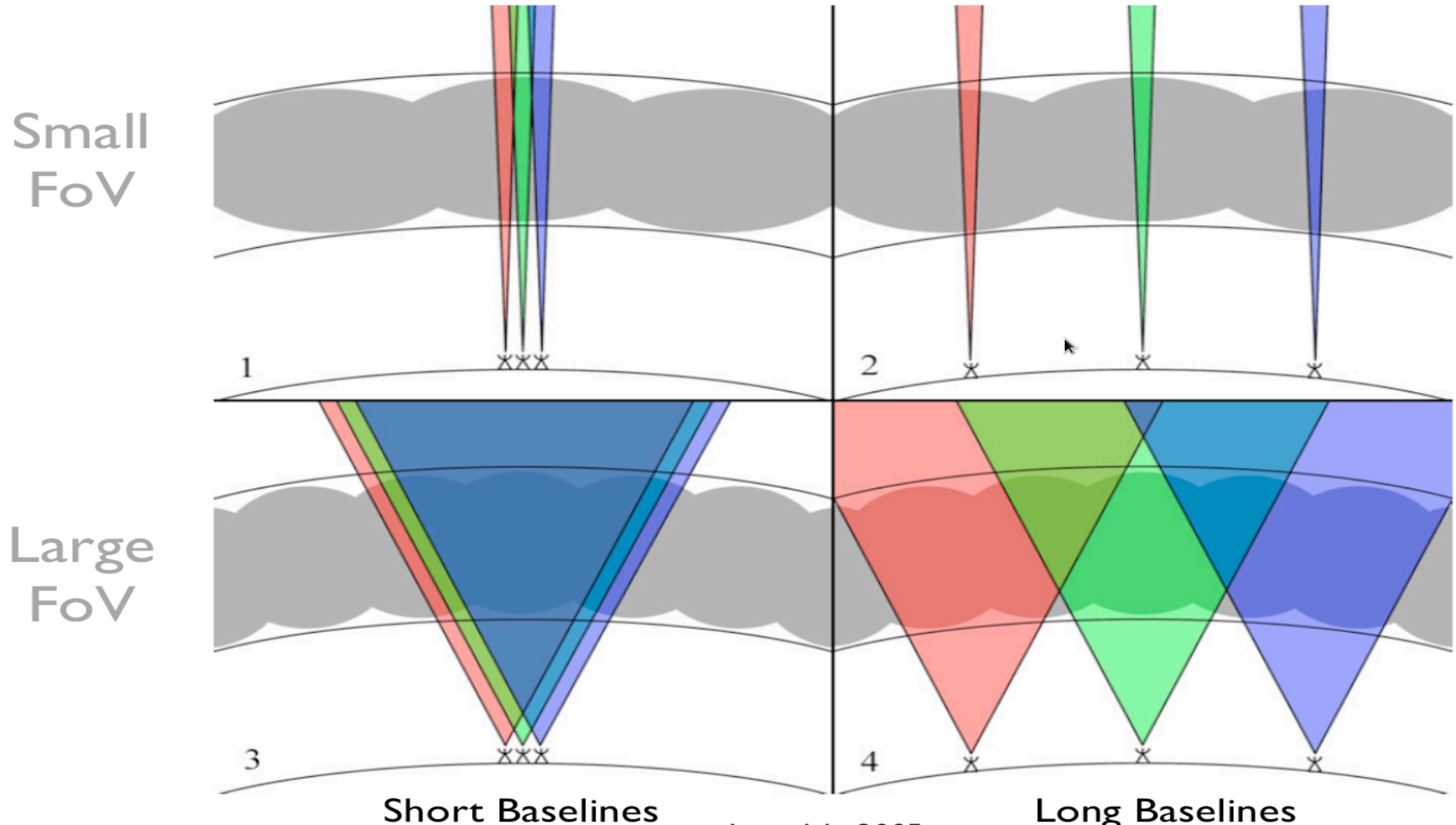
The big picture

- Ionosphere: a layer of earth's atmosphere
- ~200-1500 km altitude
- Corrupts LWA images
  - Reflection
  - Refraction
  - Absorption
  - Scintillation
- Need some way to calibrate past

LWA-OVRO: Compact; large FOV



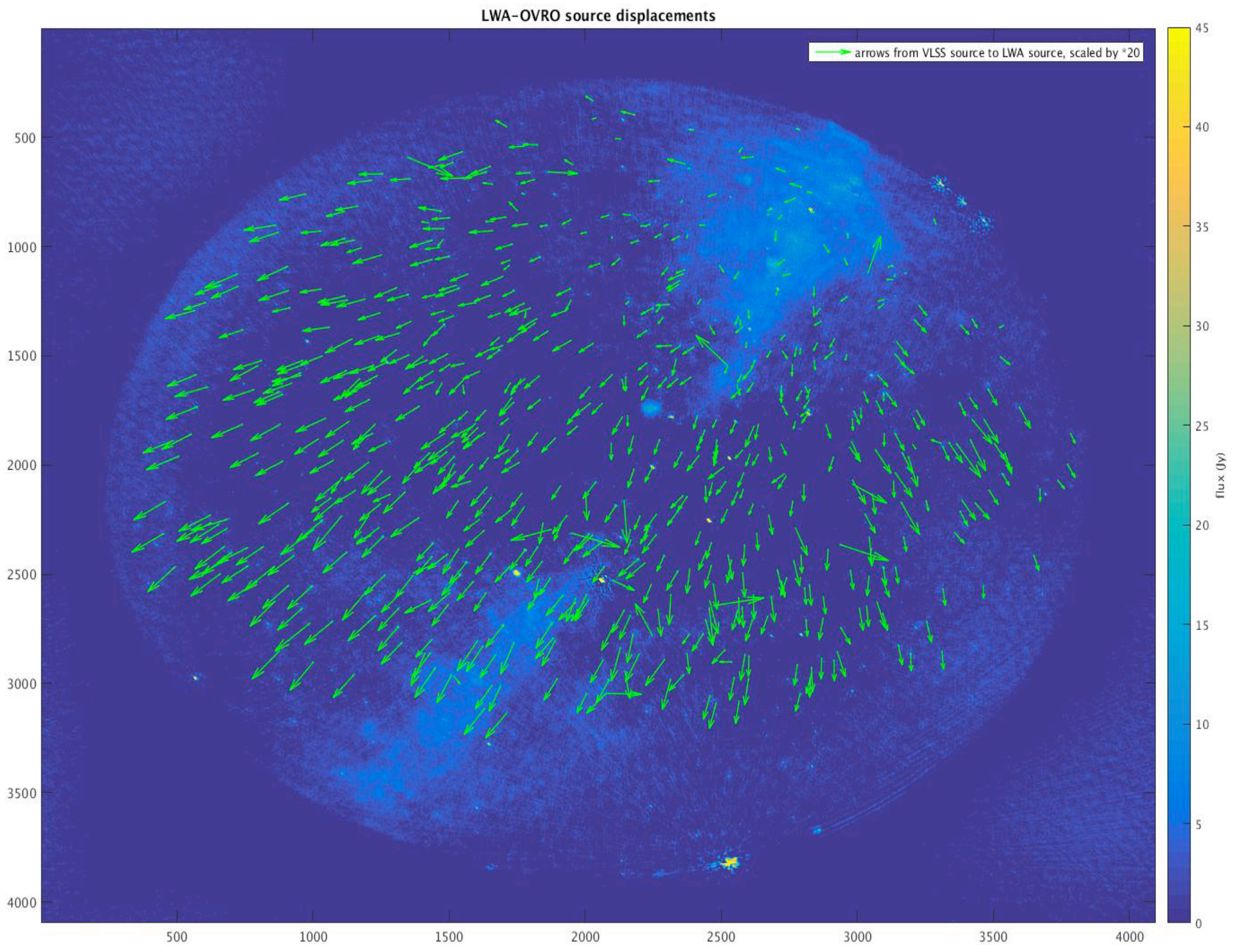
Lonsdale 2005
Intema et al. 2009

LWA-OVRO's Ionosphere Goals

- Ionospheric Science
  - Natural Hazard Detection
    - Strong focus of IARS group
    - Earthquakes; Tsunamis move ionosphere
    - Ionospheric waves can be detected before conventional methods
  - Serendipitous (eg. Plasma tubes)
- Radio-astronomical calibration

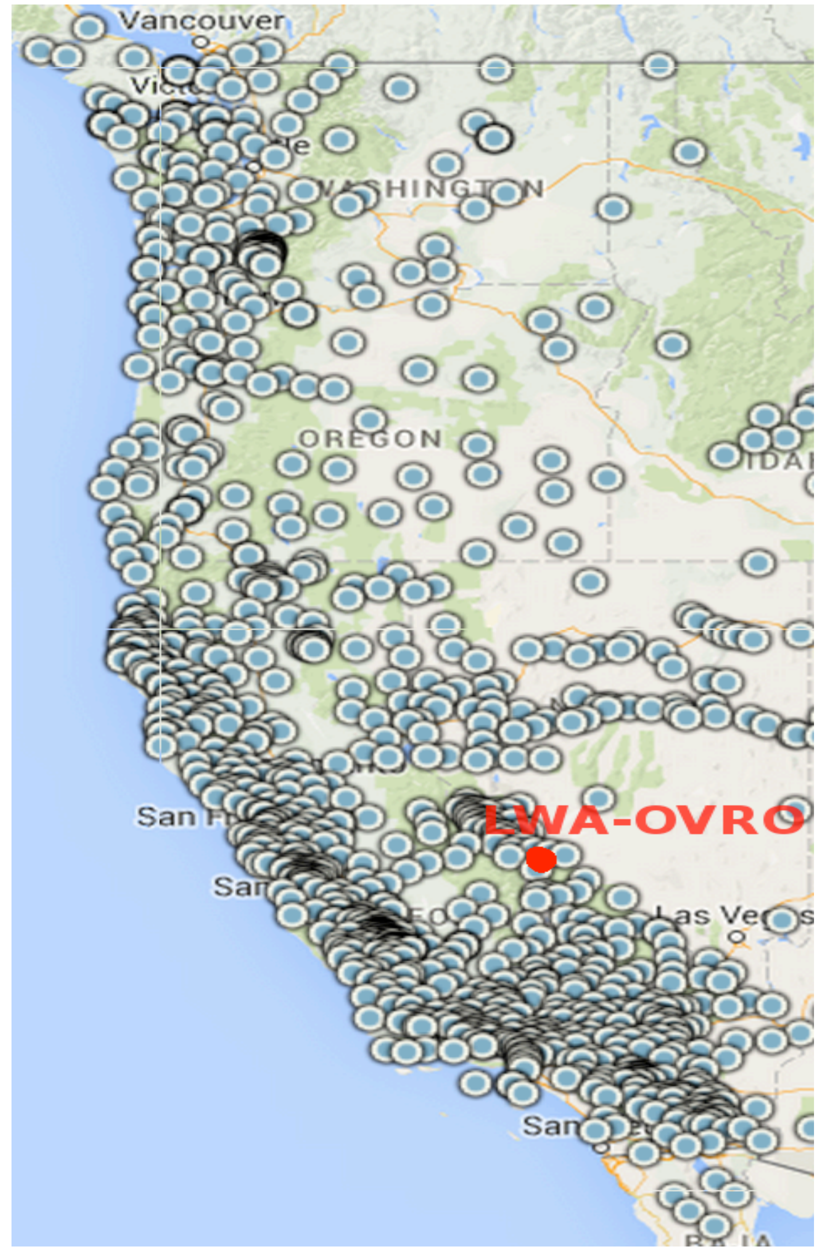
Point-source refraction map

- Long-baseline LWA can see many point sources
- Identify and compare positions to VLA sky survey (VLSS)
  - Image correction
  - All-sky ionosphere measurement
- Detection algorithm related to Lang et al. 2009


LWA-OVRO source displacements
arrows from VLSS source to LWA source, scaled by *20
flux (Jy)
500
1000
1500
2000
2500
3000
3500
4000
0
5
10
15
20
25
30
35
40
45

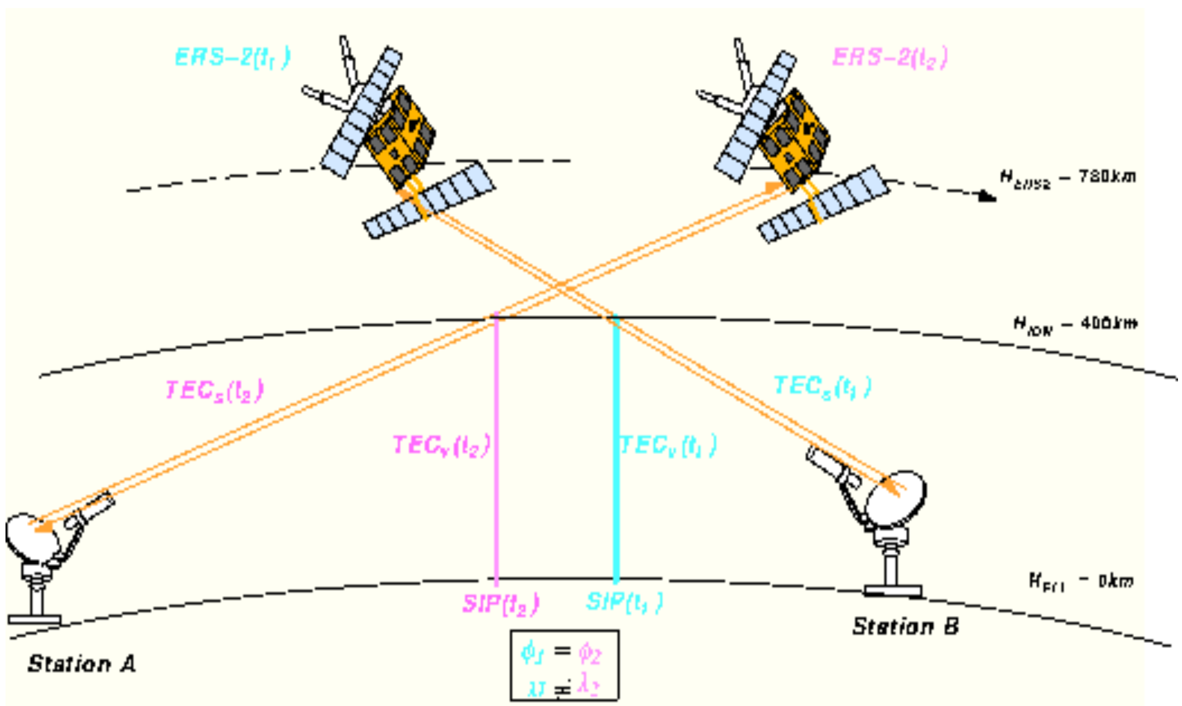
GPS Tomography (1)

- ~1400 GPS stations around California (for seismology)
- LWA-OVRO uniquely positioned for this (lucky!)
  - As long as you enjoy earthquakes....



GPS Tomography (2)

- Global Ionospheric Model (GIM) provided by JPL IARS group
- Reconstruct 3d map of ionosphere density
- Ray-trace through map to estimate distortion



GPS Tomography Pipeline

- Raw data freely available
- Parsed by JPL packages (GIPSY, GIM)
  - Cycle-slip detection
  - Carrier phase->coarse leveling
  - Global satellite & receiver bias estimation
    - (one bias per receiver, satellite: ~1400 biases total)
- Product: (SOBS, VOBS, IPP location, Sat#, Receiver#, etc)

GPS Problems (1)

- Appears to be further systematic
  - Instead of satellite, receiver biases, appears to be pass-by-pass bias
- My answer: fit a new SOBS bias on a pass-by-pass basis
  - 70,000 variables -> 50,000,000 data-points

Conclusions

- Very early work!
- Great potential for all-sky ionosphere measurement / calibration

Thanks!

Questions?

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Backup slides/old plots

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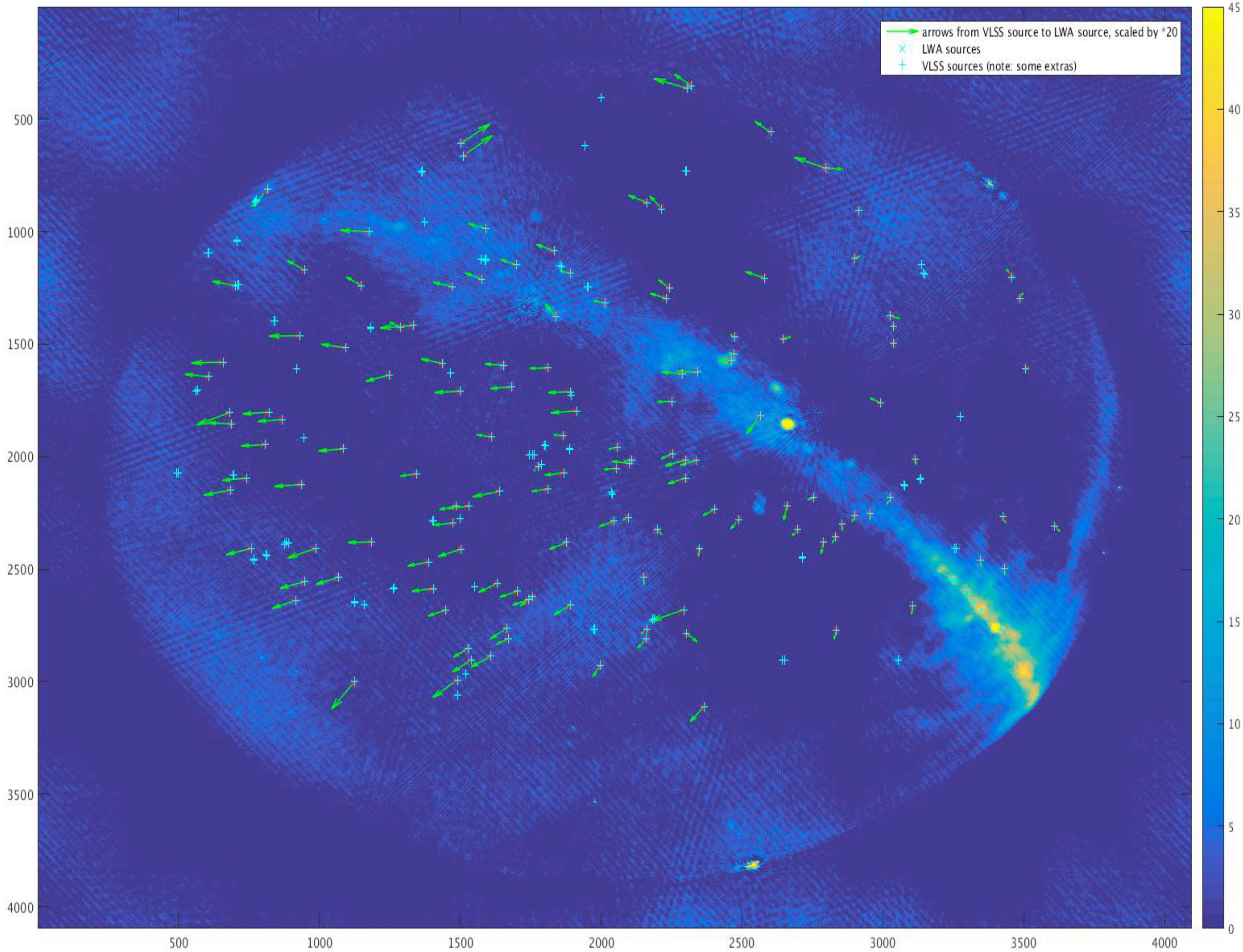
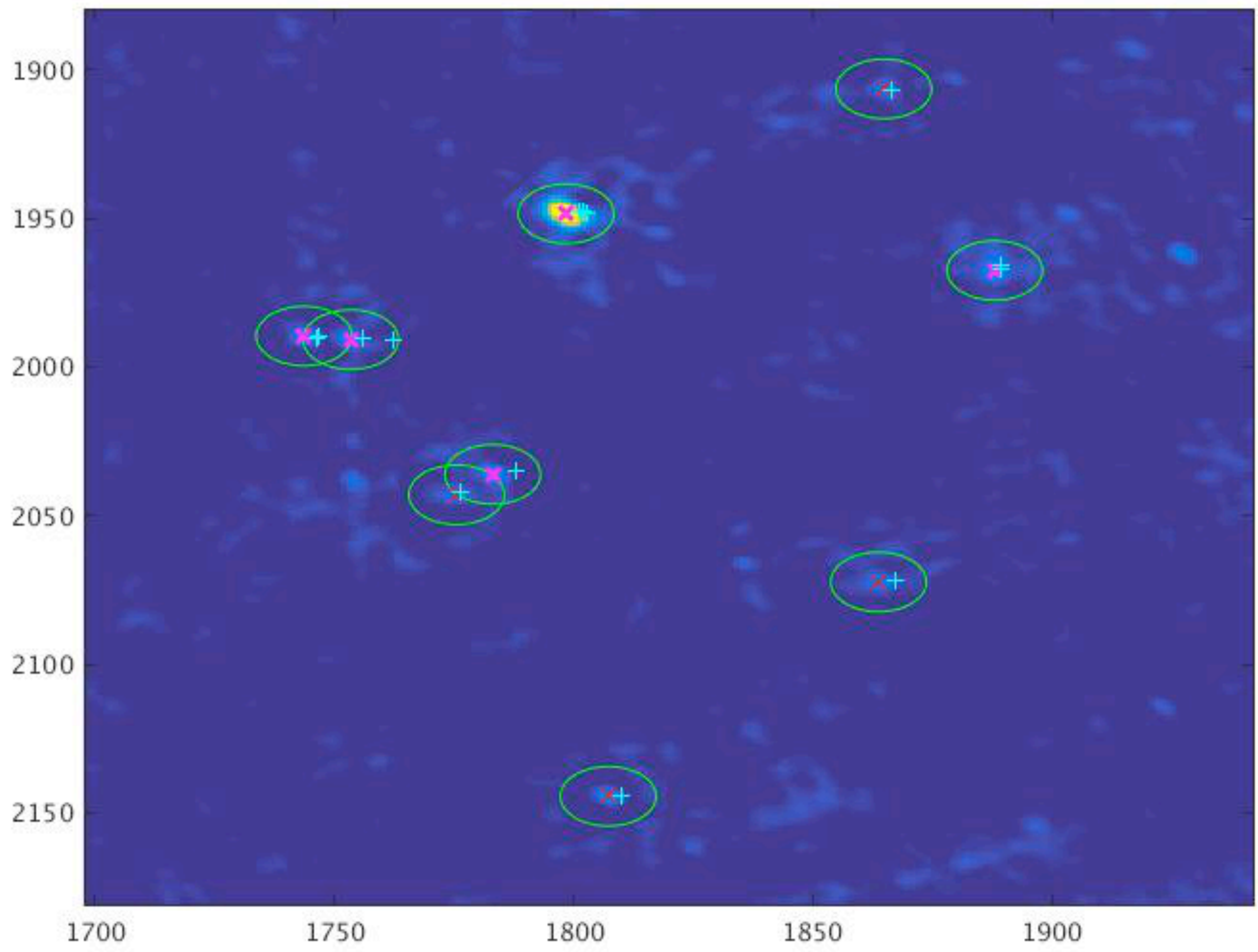
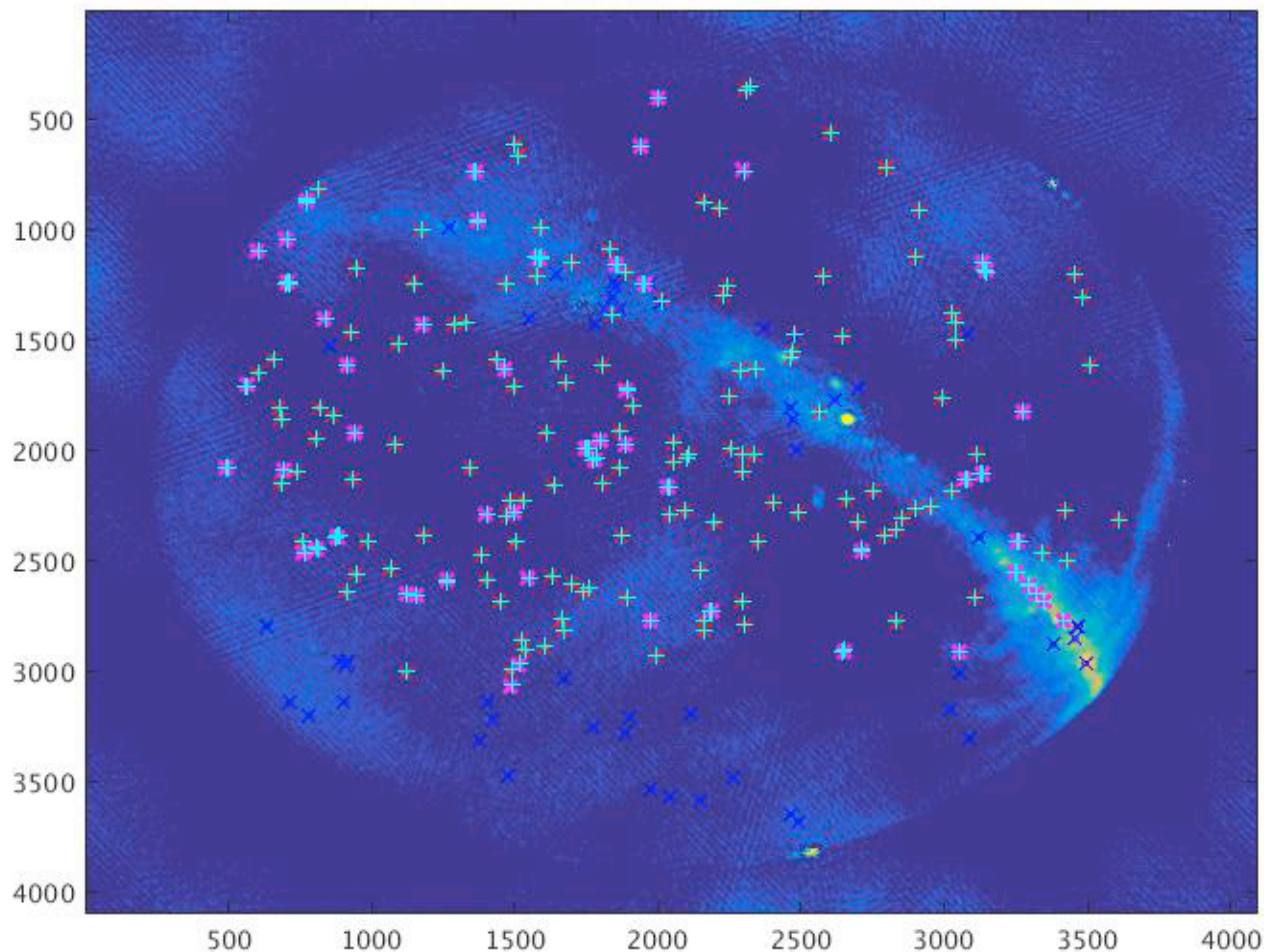
GPS Tomography (1)

- Direct measurements of Line-of-sight TECs using GPS
- Ideal Outcome:
  - 3d map of ionosphere
  - 20km resolution
  - ~3 vertical bases
  - <0.1 TECU accuracy



arrows from VLSS source to LWA source, scaled by *20
LWA sources
VLSS sources (note: some extras)


1900
1950
2000
2050
2100
2150
1700
1750
1800
1850
1900


500
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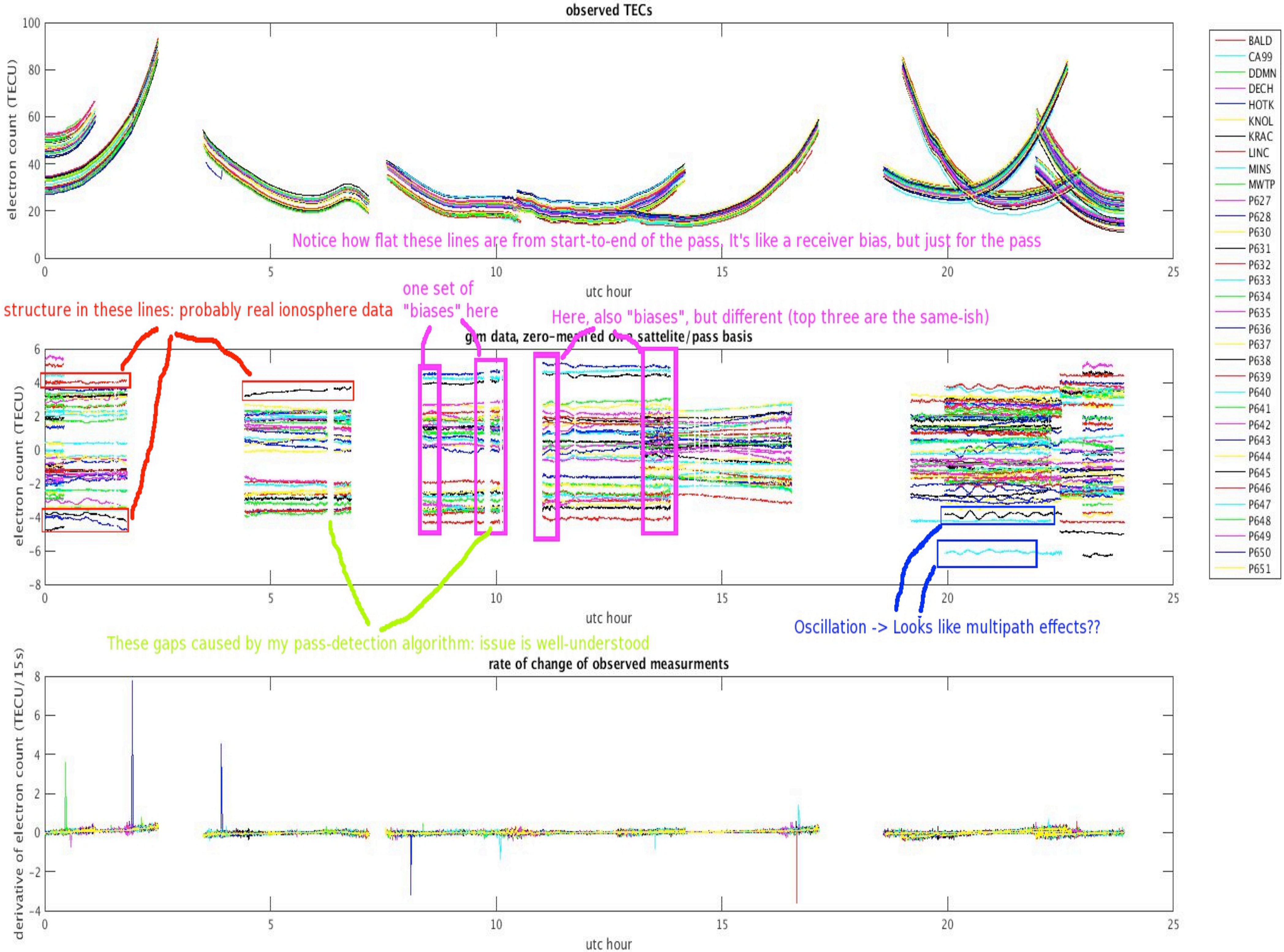
observed TECs
electron count (TECU)
utc hour
Notice how flat these lines are from start-to-end of the pass, It's like a receiver bias, but just for the pass
structure in these lines: probably real ionosphere data
one set of "biases" here
Here, also "biases", but different (top three are the same-ish)
electron count (TECU)
utc hour
These gaps caused by my pass-detection algorithm: issue is well-understood
Oscillation -> Looks like multipath effects??
rate of change of observed measurments
derivative of electron count (TECU/15s)
utc hour
BALD
CA99
DDMN
DECH
HOTK
KNOL
KRAC
LINC
MINS
MWTP
P627
P628
P630
P631
P632
P633
P634
P635
P636
P637
P638
P639
P640
P641
P642
P643
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P648
P649
P650
P651

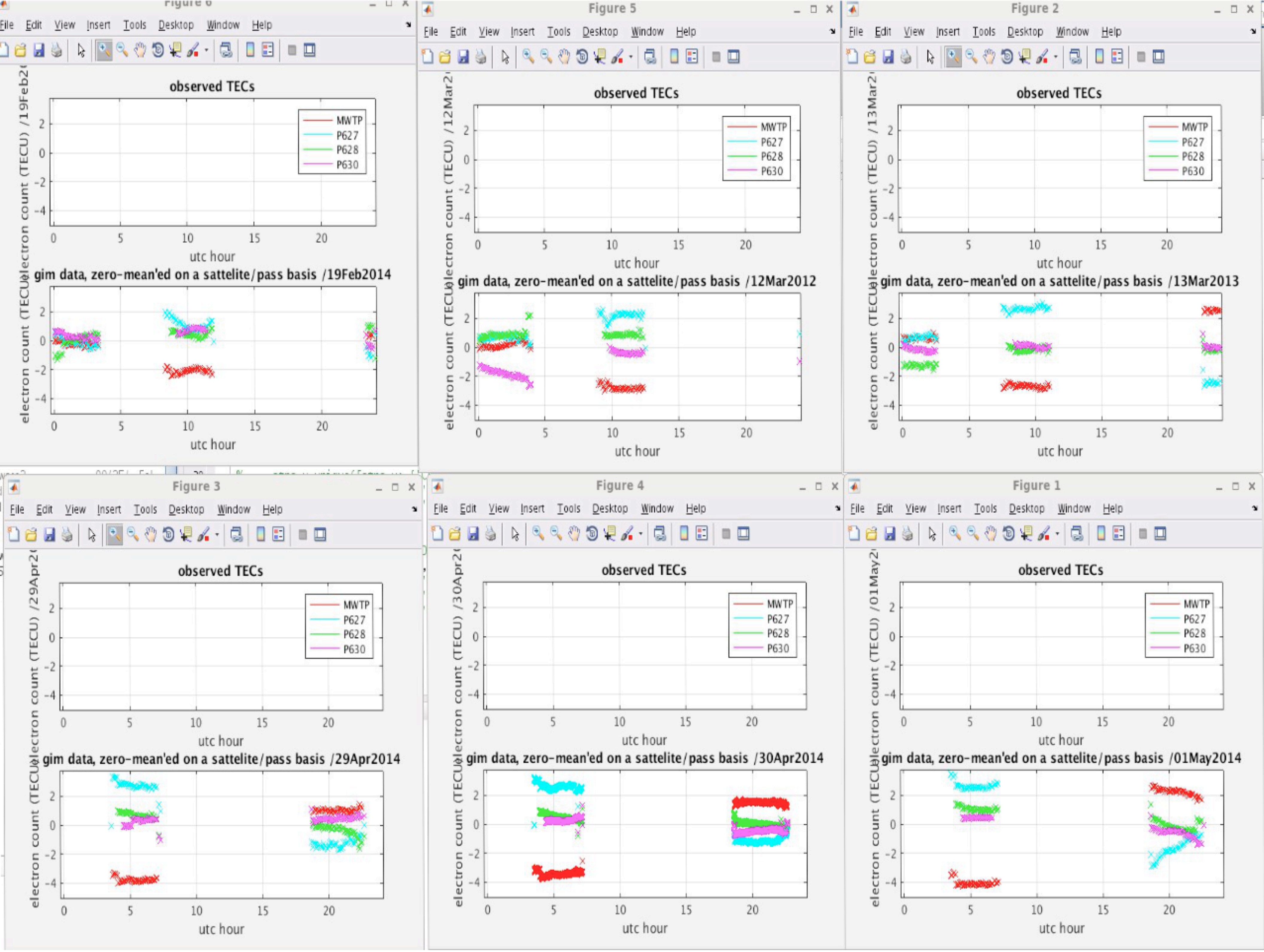
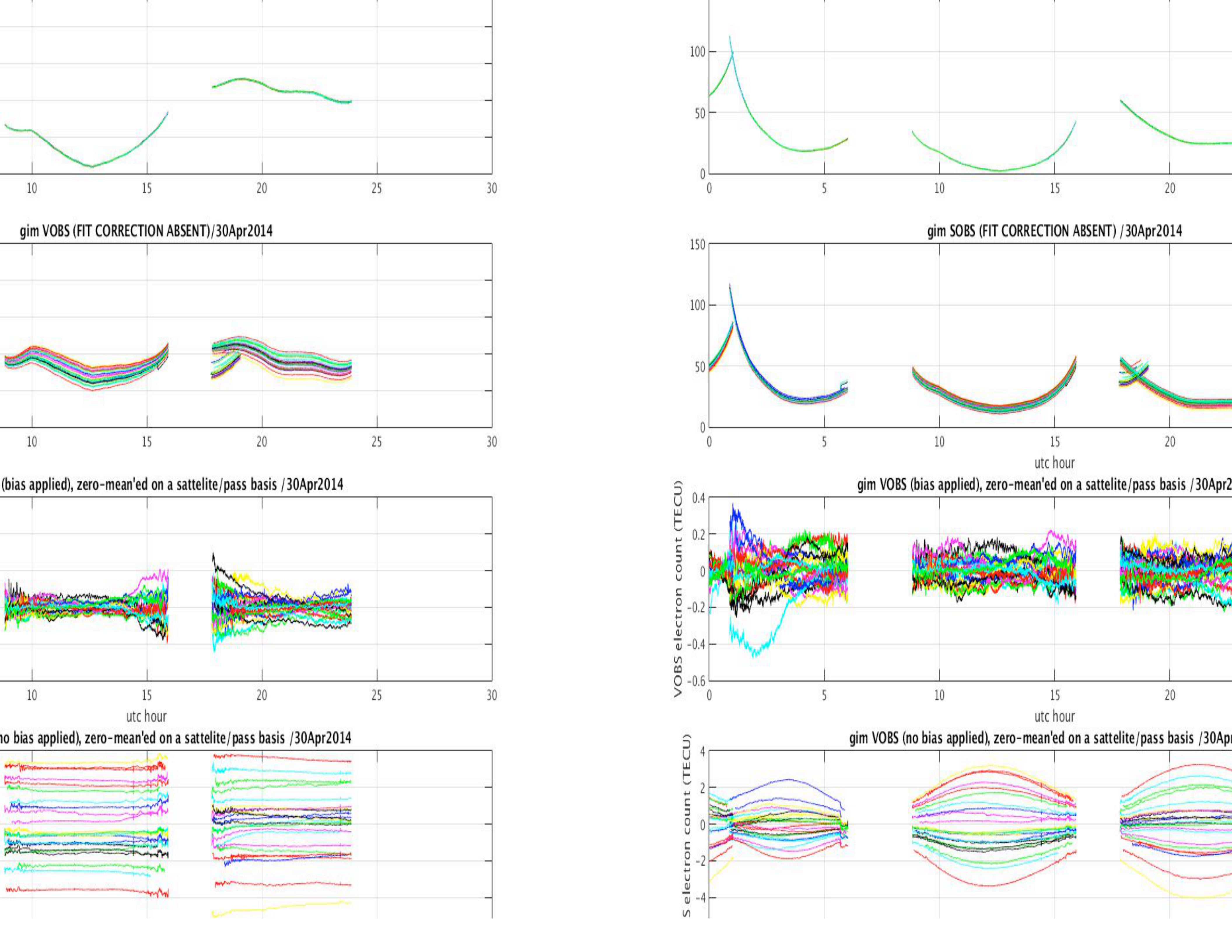
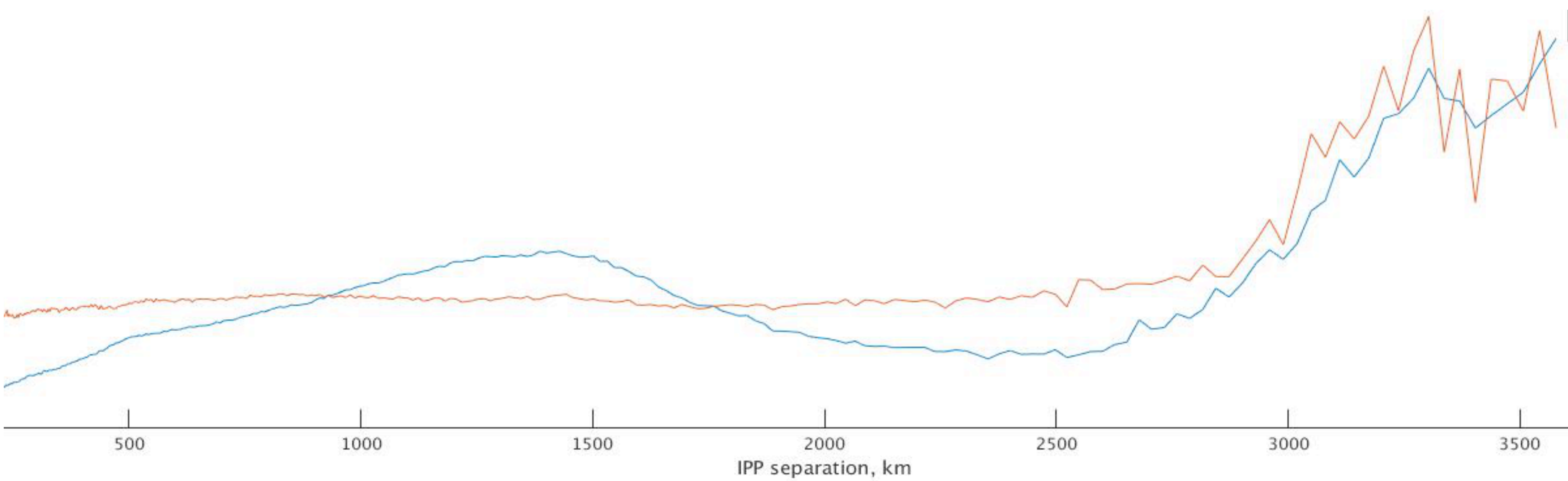


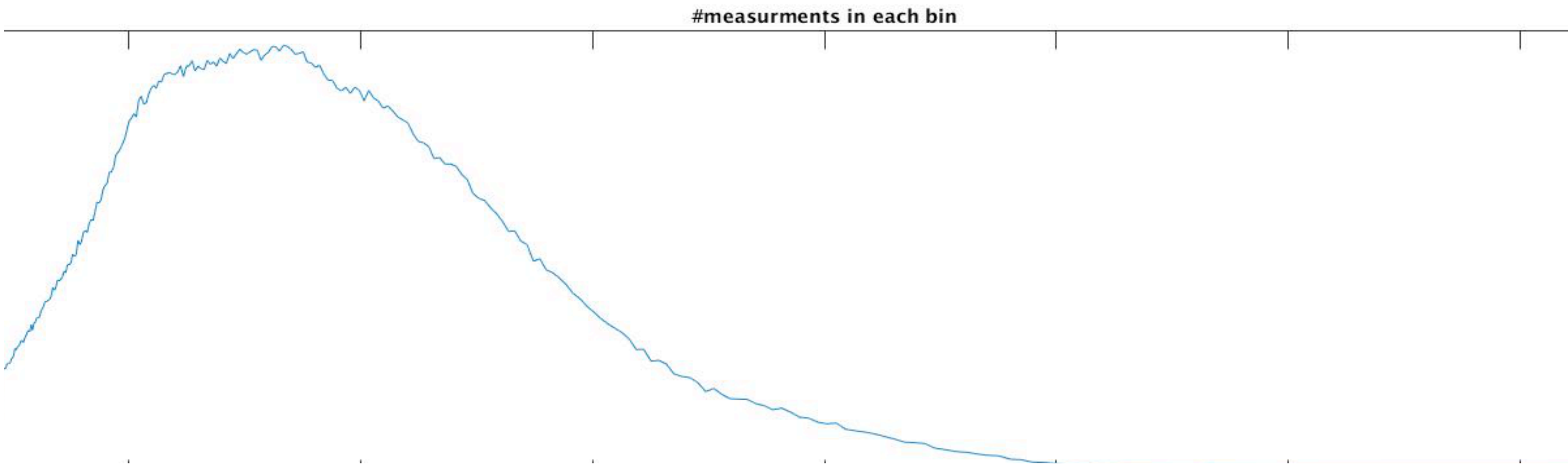
Figure 6
observed TECs
MWTP
P627
P628
P630
electron count (TECU) /19Feb2(
utc hour
gim data, zero-mean'ed on a sattelite/pass basis /19Feb2014
electron count (TECU)
utc hour
Figure 5
observed TECs
electron count (TECU) /12Mar2(
gim data, zero-mean'ed on a sattelite/pass basis /12Mar2012
Figure 2
observed TECs
electron count (TECU) /13Mar2(
gim data, zero-mean'ed on a sattelite/pass basis /13Mar2013
Figure 3
observed TECs
electron count (TECU) /29Apr2(
gim data, zero-mean'ed on a sattelite/pass basis /29Apr2014
Figure 4
observed TECs
electron count (TECU) /30Apr2(
gim data, zero-mean'ed on a sattelite/pass basis /30Apr2014
Figure 1
observed TECs
electron count (TECU) /01May2(
gim data, zero-mean'ed on a sattelite/pass basis /01May2014



gim VOBS (FIT CORRECTION ABSENT)/30Apr2014
(bias applied), zero-mean'ed on a sattelite/pass basis /30Apr2014
utc hour
no bias applied), zero-mean'ed on a sattelite/pass basis /30Apr2014
gim SOBS (FIT CORRECTION ABSENT) /30Apr2014
utc hour
gim VOBS (bias applied), zero-mean'ed on a sattelite/pass basis /30Apr2
VOBS electron count (TECU)
utc hour
gim VOBS (no bias applied), zero-mean'ed on a sattelite/pass basis /30Apr
S electron count (TECU)

Structure functions





What is this fitting madness

- Observed bias clearly in SOBS measurements
- Since target measurement is VOBS, should be able to fit bias without totally ruining desired measurement
- Fit is very hard!
  - 70e3 variables on 50e6 data-points

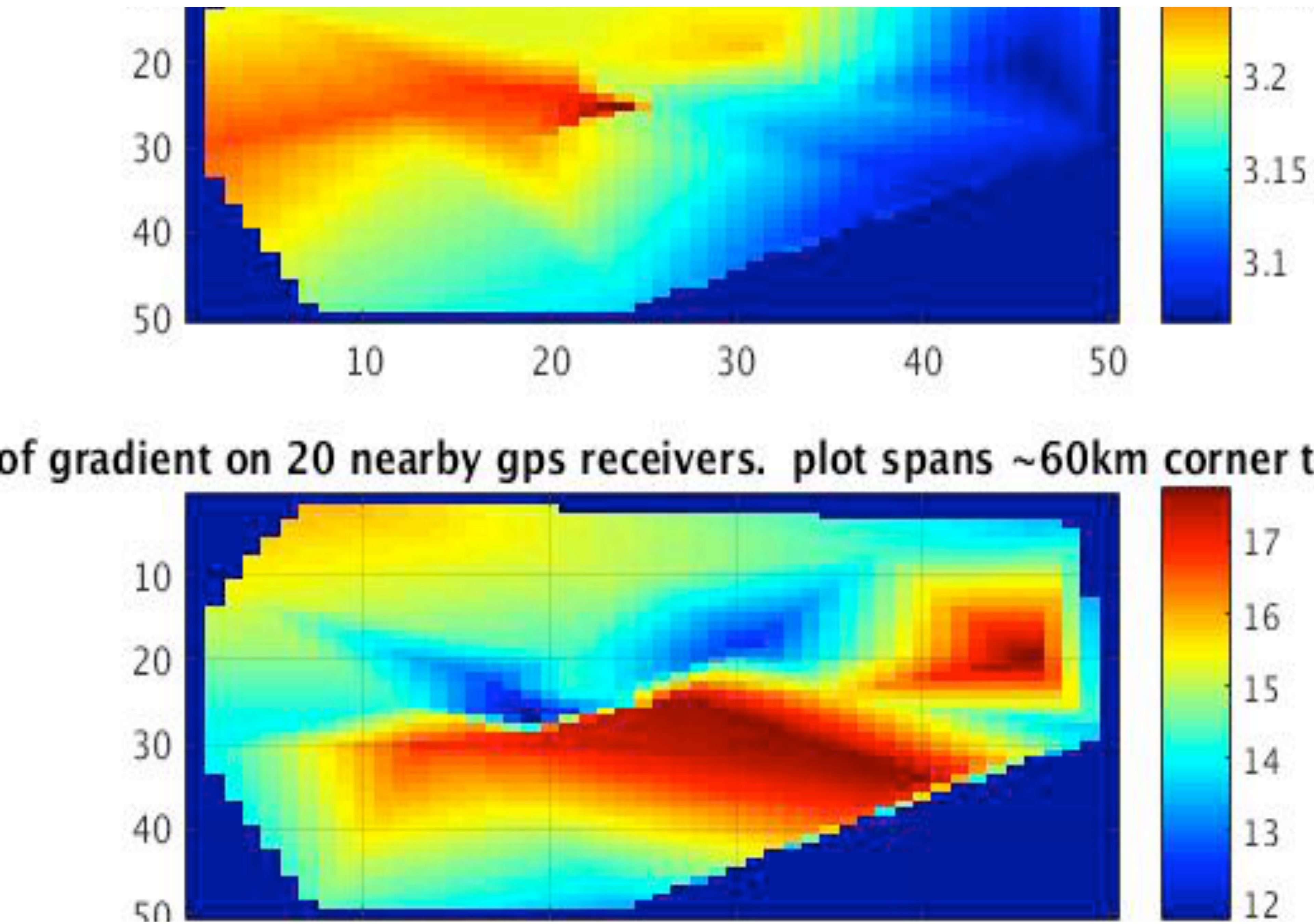
Definition of fit

- "IPPs which are nearby should have similar VOBS values"
- Minimize variance in (space, time) gridded VOBS by adjusting SOBS
- (put math here if I have time)

Fitting Challenges

- 50,000,000 measurements → 70,000 bias terms
- Extensive computational optimization necessary
- Massive cycle slips (bad GIPSY code?)
- VOBS estimate is only first order
  - Must filter error equations to include only measurements from nearby GPS receivers
- Need passes to have sufficient unique IPP gridding bins; need IPP gridding bins to have sufficient unique passes
  - Iterate filtering until convergence
- Need passes to all be coupled to each other

Gradient map (fitted on top)

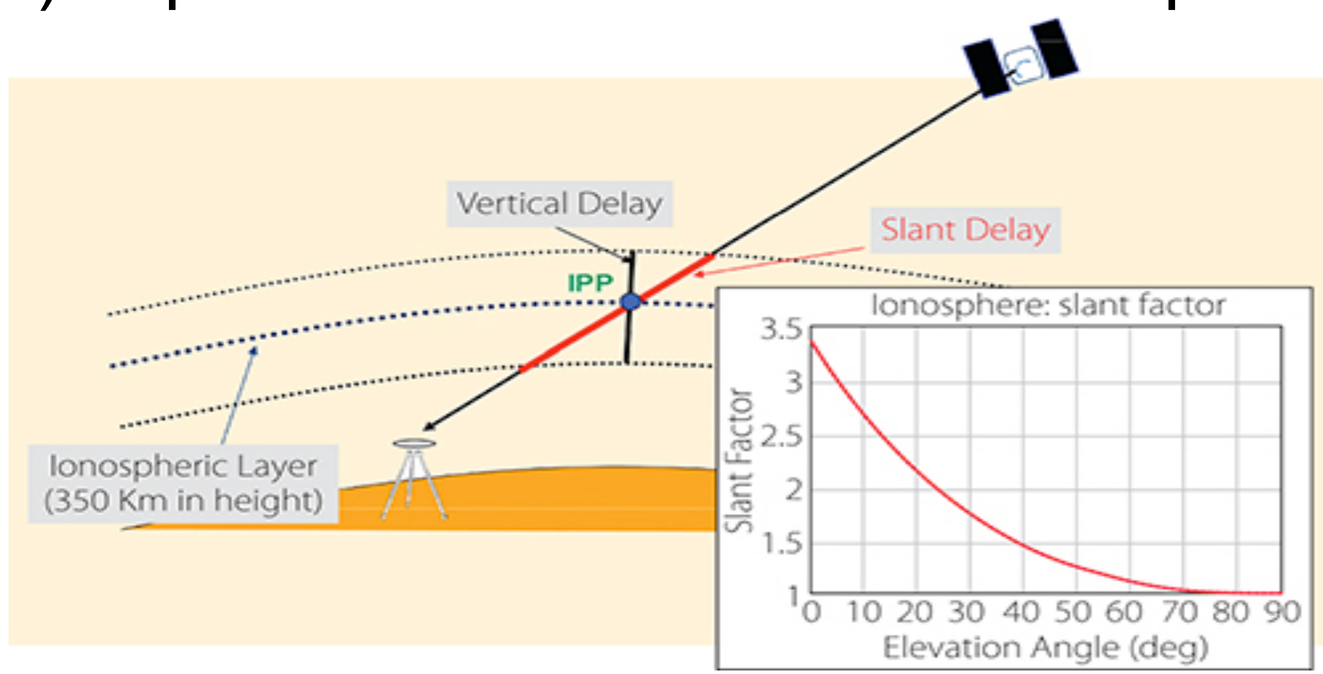


Structure functions

- Original GIM structure function is terrible! Does not decrease with decreasing distance
- Mine probably also bad: my structure function should be lower than original GIM at all distance scales
- Idea: poor coupling between IPPs of different satellites
  - Allows for bias drift in distant points' IPPs

GPS Tomography (2)

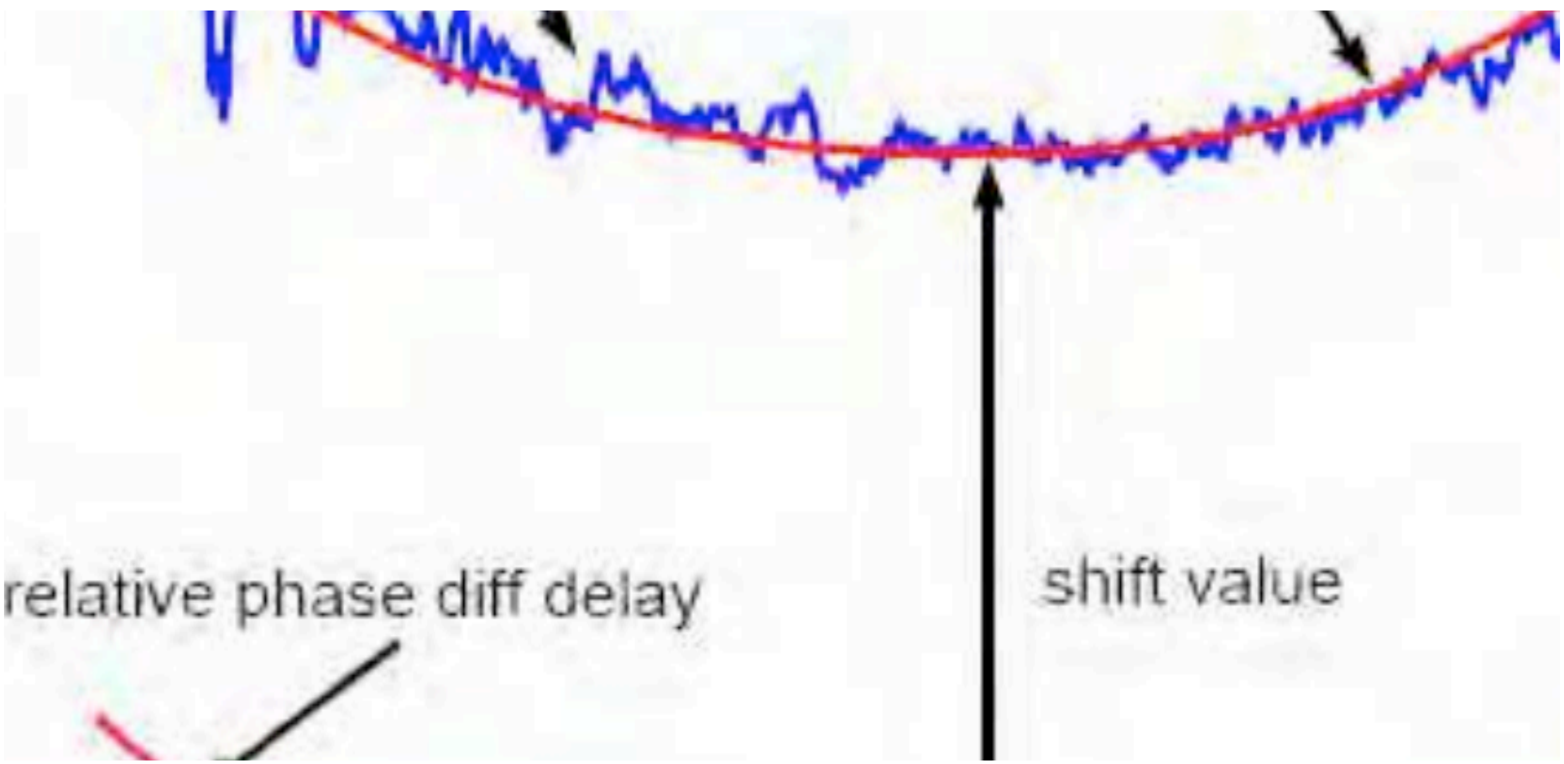
- GPS Measurable: “Slant TEC” (SOBS / STEC)
  - Line-of-sight measurement from receiver to satellite
- Common approach: assume ionosphere is thin
  - Implies linear conversion to Vertical TEC (VOBS / VTEC) at point of intersection with ionosphere



GPS Tomography: sources of error

- Clock drift
- Inter-frequency bias
  - One per receiver and satellite

- Phase leveling
  - Delay measurement noisy but absolute
  - Phase measurement clean but relative



GPS Problems (2)

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- Non-physical! But the data doesn't lie
  - Previously undiscovered source of GPS ionosphere bias?
  - Receiver multipath?