Comparing TID Simulations Using 3D Raytracing and Mirror Reflection

Xueqin Huang[1], Bodo Reinisch[1], Gary Sales[1], Vadym Paznukhov[2], and Ivan Galkin[3]

[1] Lowell Digisonde International

[2] Boston College, Institute for Scientific Research

[3]University of Massachusetts Lowell, Space Science Laboratory

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TID Signature Observed by Vertical Digisonde Sounding

- Real height isodensity contours derived from 5-min sequence of vertical electron density profiles measured by the Millstone Hill Digisonde

Daytime Mid-Latitude TIDs

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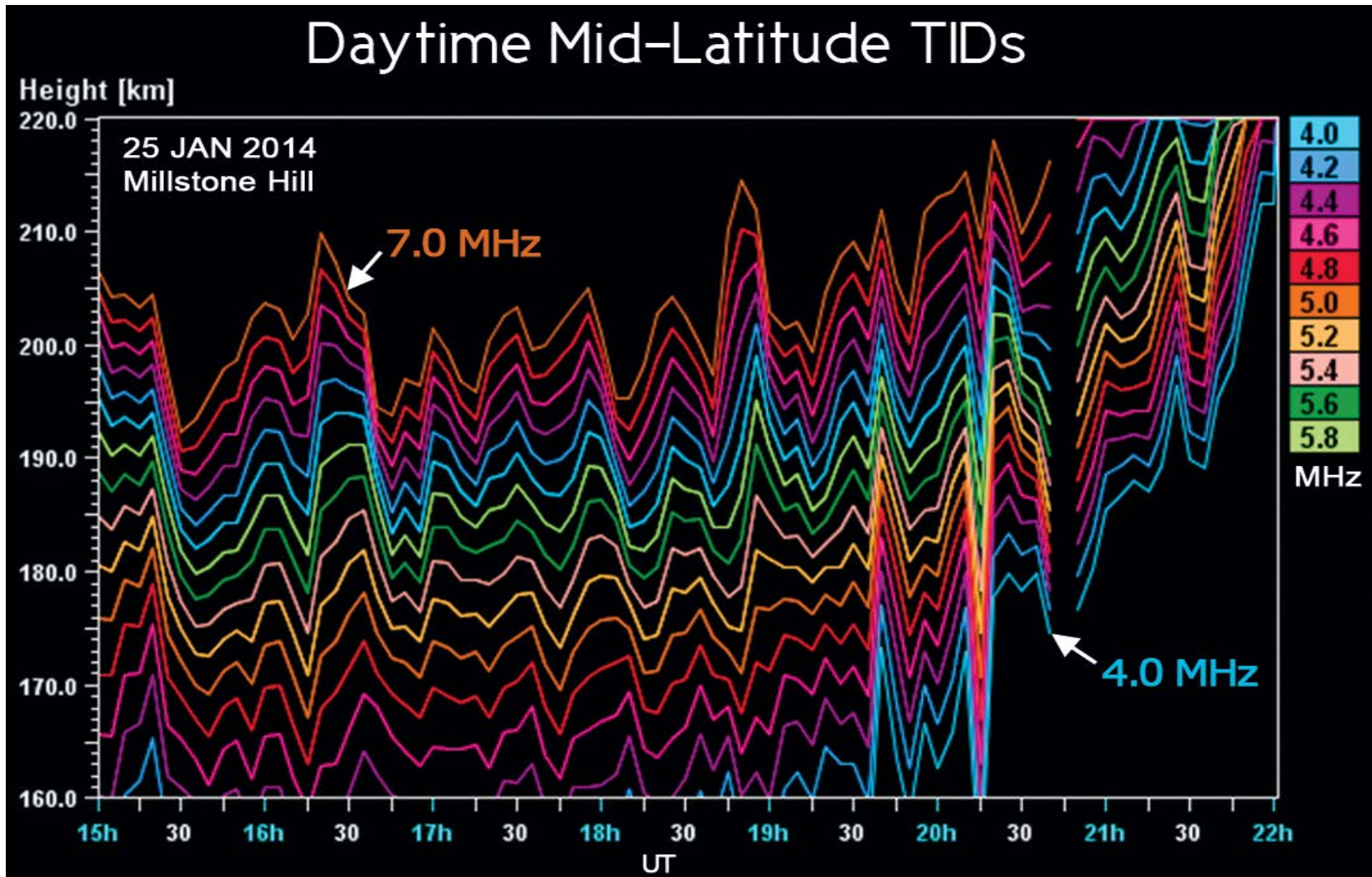
TID "FAS" Measurements

- The 7.85 MHz HF waves from the CHU transmitter at Ottawa (45.30N,284.39E) are received by the Millsone Hill Digisonde (42.60N, 288.50E), and the Doppler frequencies and the angles-of-arrival are measured.

Day number 60,2015 Millstone Hill

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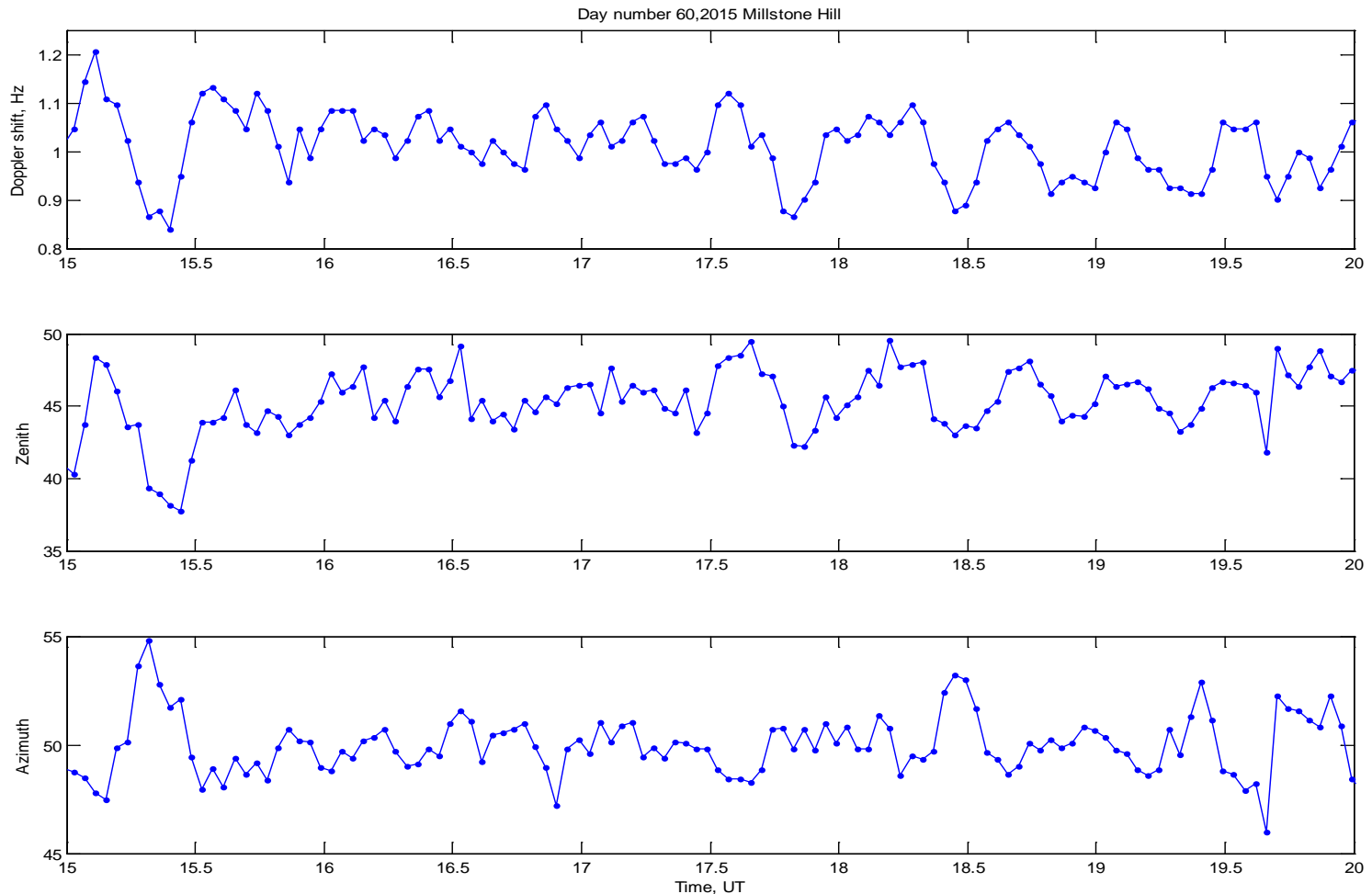
TID Simulations

- Questions:
  - How to describe the effect of TIDs on the ionosphere?
  - How to derive the TID parameters from the measured data?
- Simulations with raytracing:
  - Using a raytracing tool [Huang and Reinisch, 2006].
  - The 3D electron density structure of the ionosphere is assumed as

$$N(\lambda, \varphi, h, t) = N_{IRTAM}(\lambda, \varphi, h, t)\left[1 + A\cos(\Omega t - KD + \psi_0)\right]$$

$$\Omega = 2\pi/T, \quad K = 2\pi/\Lambda,$$

$N_{IRTAM}(\lambda, \varphi, h, t) = $ Real time IRI model: the IRI model parameters are updated with GIRO ionogram data every 15 minutes.

  - It is not feasible to use the raytracing tool to derive the TID parameters.
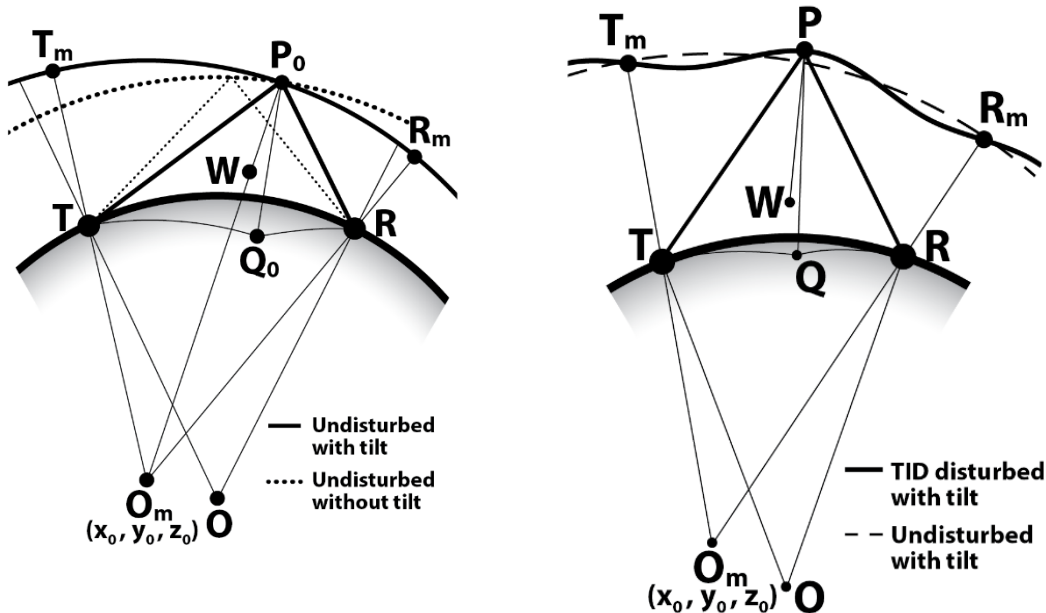
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TID Simulations

- Simulations with mirror model:

  - "FAS" technique: The ionosphere is replaced by a mirror [Paznukhov et al, 2012].

  - The TID effect is represented by a moving corrugated mirror:

$$r(\lambda, \varphi, h, t) = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} = r_{m0}\left[1 + A_m \cos(\Omega_m t - K_m D + \psi_{0m})\right]$$

  - Construction of the mirror:

 $r_{m0} \equiv P_0 O_m$ and (x_0, y_0, z_0) are determined by the measured data.

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- Nominal TID parameters:

Model Parameter	IRTAM Raytracing	Mirror Model
TID Amplitude	$A = 0.05$	$A_m = 0.00015$
TID Period	$T = 30$ min	$T_m = 30$ min
TID Wavelength	$L = 250$ km	$L_m = 250$ km
Initial Phase	$Y_0 = 0$	$Y_{0m} = 0$
Direction of TID Wave	170° from north	170° from north

- The amplitude A_m of the corrugation in the mirror model was judiciously selected so that the results from the IRTAM raytracing and the mirror simulations are close..

- The selected TID arameters are representative for small to medium scale TIDs.

- To investigate the effect of each individual parameter the simulations are repeated by changing one of the 5 parameters at a time.

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• Comparing the Simulation Results

1. Testing the effect of the TID amplitude.
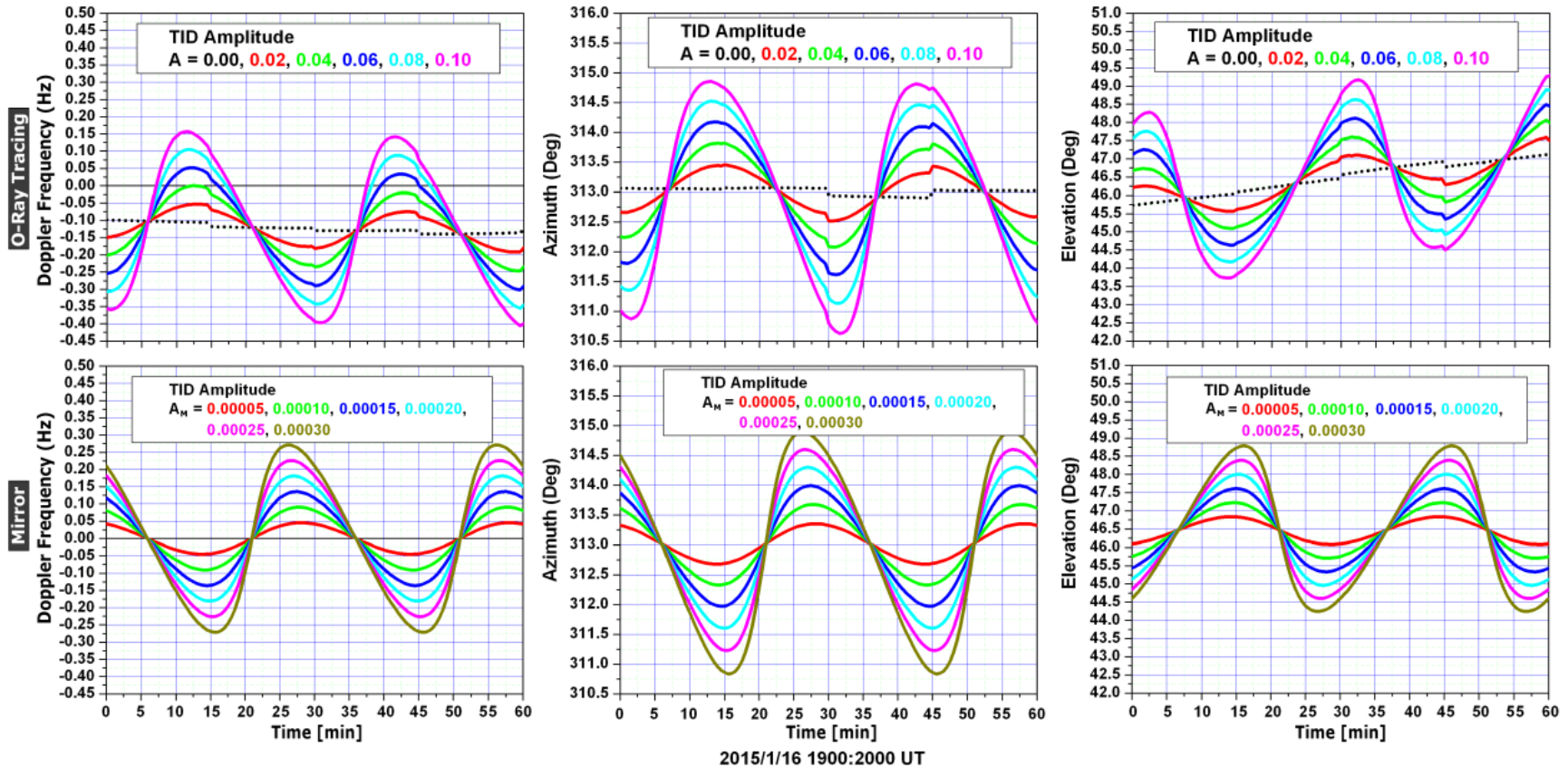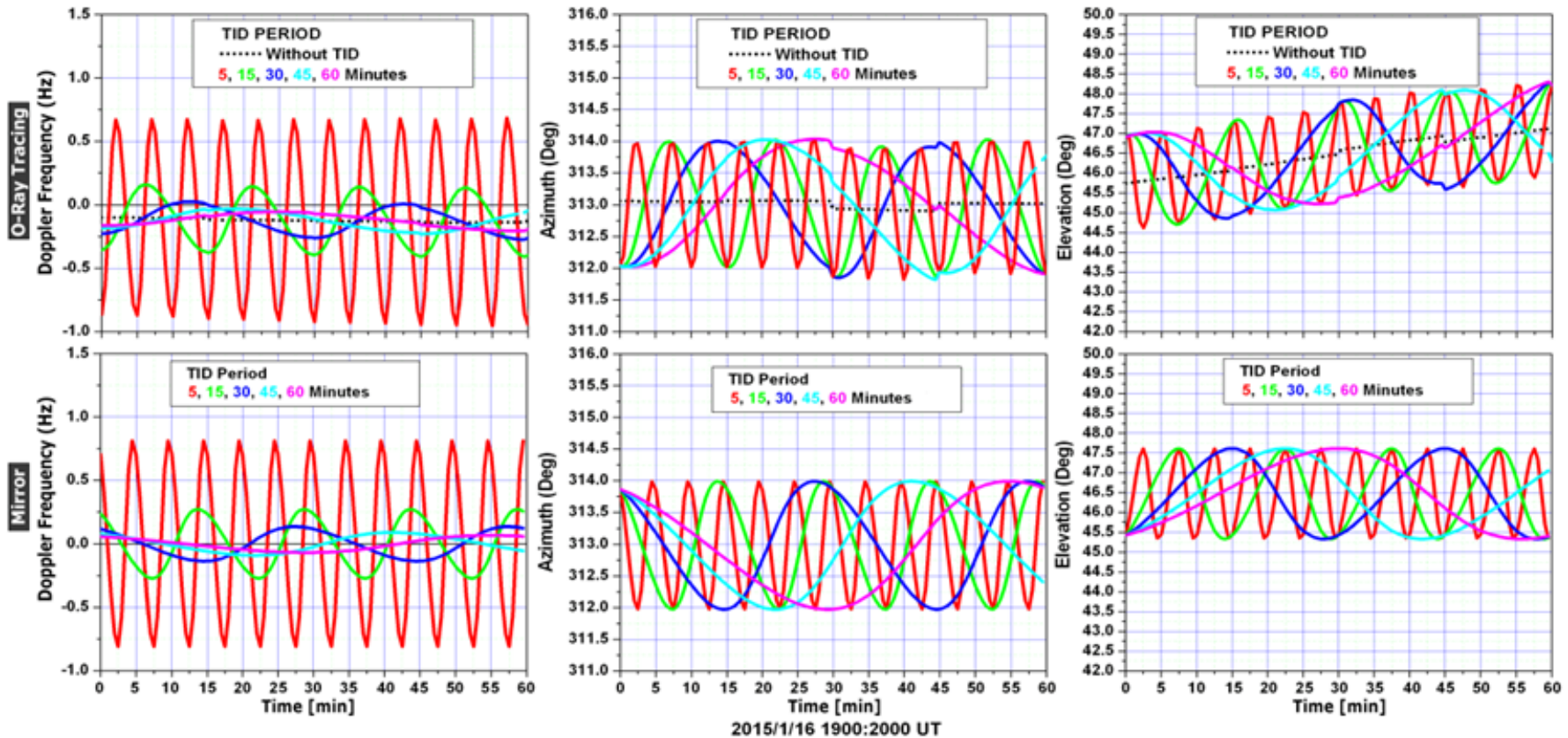

2015/1/16 1900:2000 UT

- • Results:
  - • For all curves, the variations with time are 180° out of phase.
  - • The curves either from raytracing or mirror simulation reach the average positions (zero-crossing) at the same time, but the peaks do not occur at the same time.
  - • Both simulations show that Doppler frequency, Azimuth, and Elevation are proportional to the amplitude.
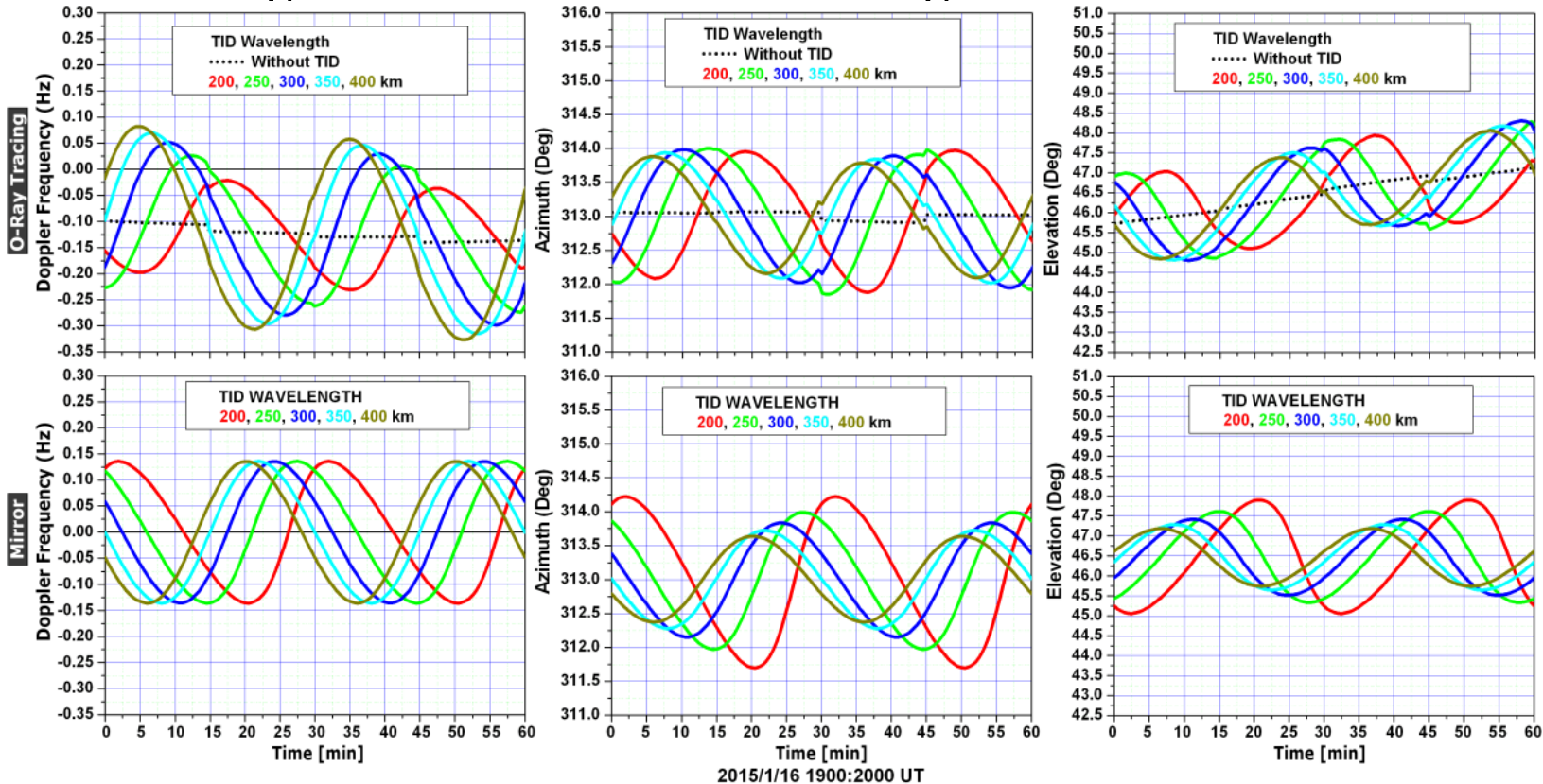
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Comparing the Simulation Results

2.   Testing the effect of the TID period.

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- Results:
    - For all curves, the variations with time are 180° out of phase.
    - The curves either from raytracing or mirror simulation reach the average positions at the same time, but the peaks do not occur at the same time.
    - Both simulations show that Azimuth and Elevation do not depend on the TID period. But the Doppler frequency exhibits a nonlinear relation to the TID wave period.
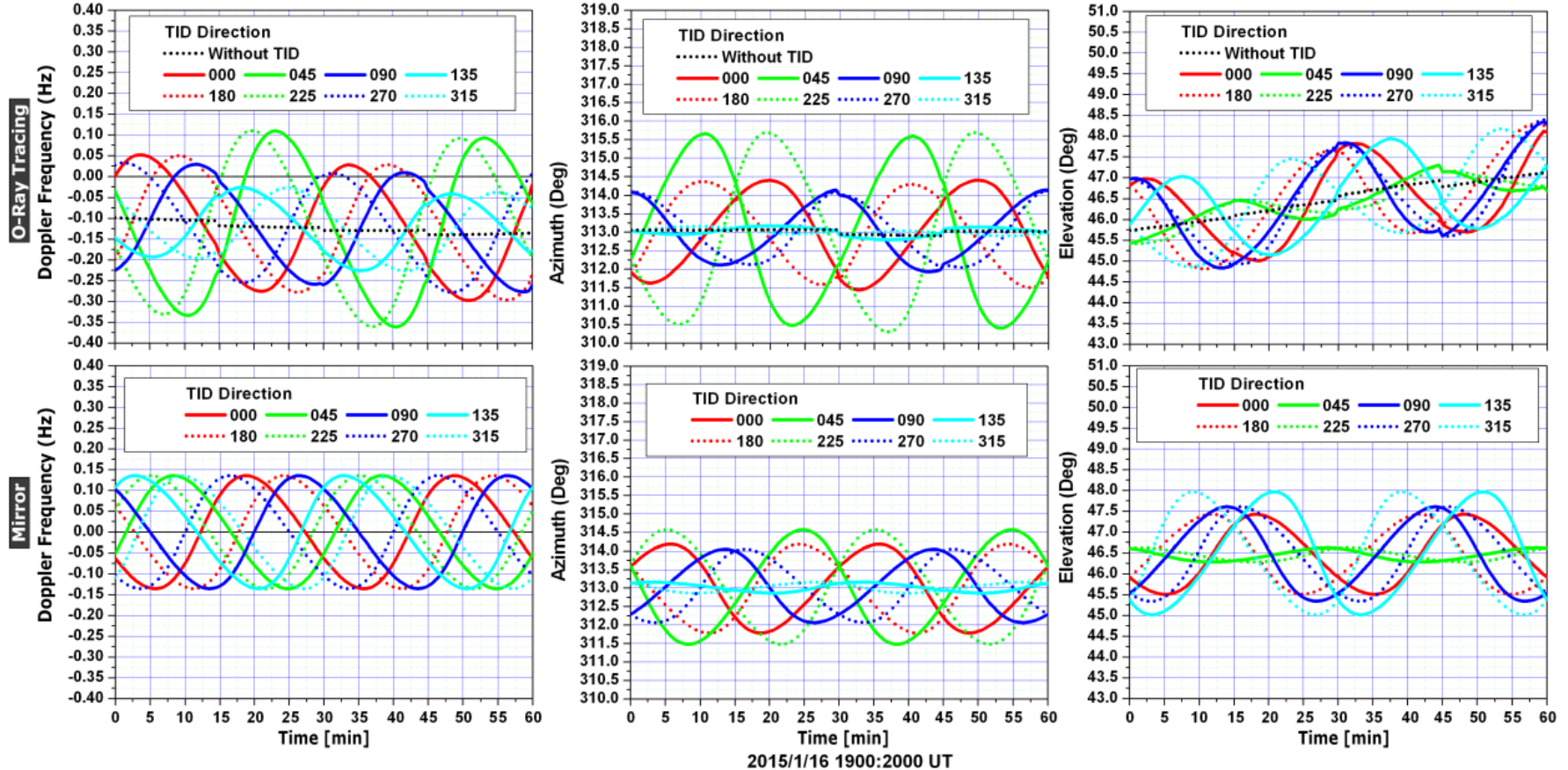
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Comparing the Simulation Results

3. **Testing the effect of the TID wavelength.**

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- Results:
  - For all curves, the variations with time are 180° out of phase.
  - The mirror Doppler frequency is independent of the wavelength while that from raytracing varies with wavelength.
  - Mirror Azimuth and Elevation are wavelength dependent while raytracing results are not.

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4.   Testing the effect of the direction of the TID wave.
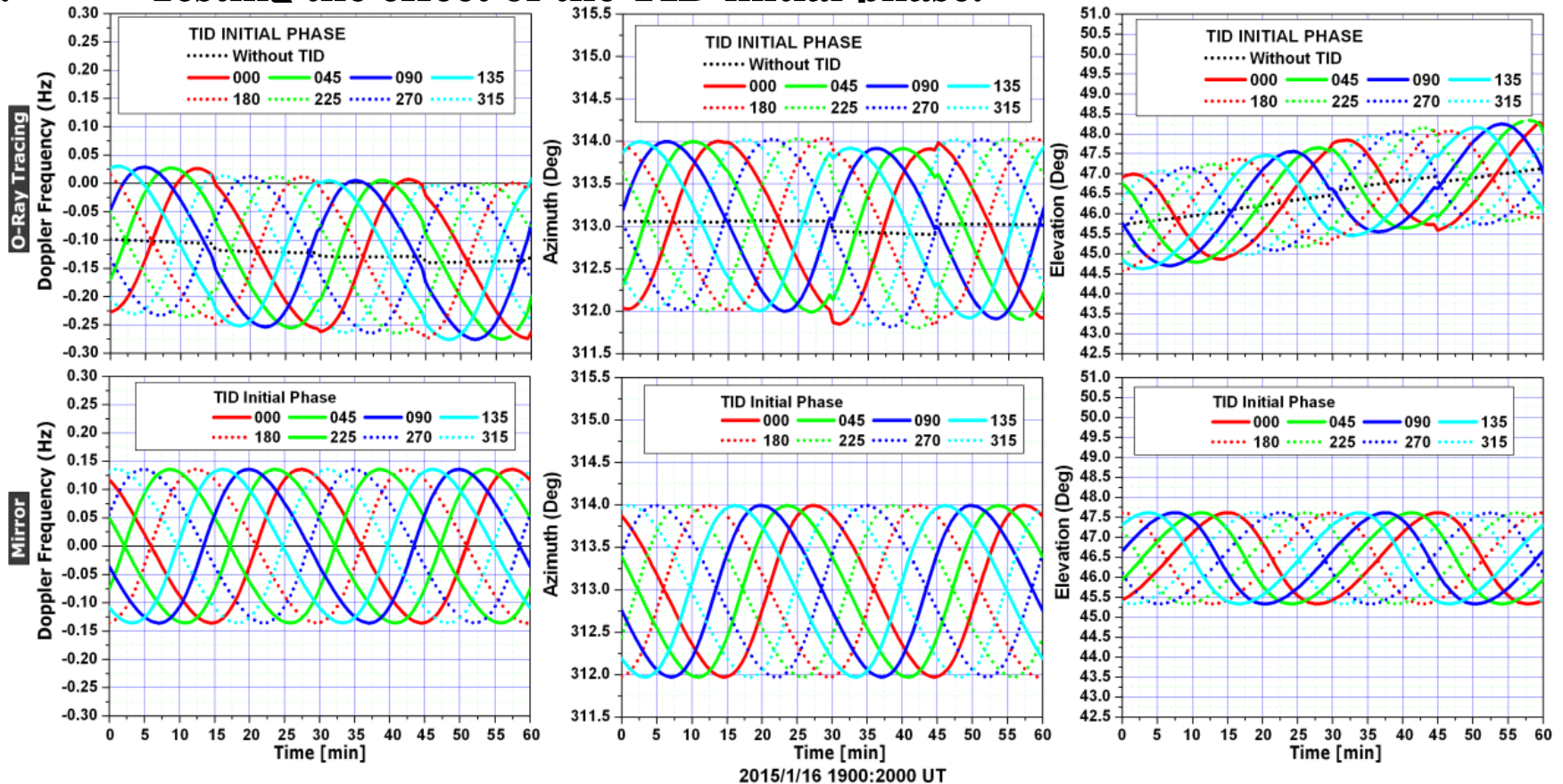

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- Results:
  - For all curves, the variations with time are 180° out of phase.
  - Mirror Doppler frequency is independent of the TID direction while raytracing Doppler frequency varies with the TID direction of propagation.

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Comparing the Simulation Results

5.   Testing the effect of the TID initial phase.

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- Results:
  - For all curves, the variations with time are 180° out of phase.
  - Doppler frequency, Azimuth and Elevation from raytracing and mirror simulation show phase shifts corresponding to the TID initial phase.

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Explaning the Comparison Results

- 180° out of phase.
  - Different definitions of TID in raytracing and mirror simulations:

    Raytracing: $N(\lambda,\varphi,h,t) = N_{IRTAM}(\lambda,\varphi,h,t)\left[1 + A\cos(\Omega t - KD + \psi_0)\right]$

    Mirror: $\quad r(\lambda,\varphi,h,t) = r_{m0}\left[1 + A_m\cos(\Omega_m t - K_m D + \psi_{0m})\right]$

  - Raytracing is controlled by the refractive index, n, which varies, to the first order of approximation, as

    $$n^2 = 1 - \frac{k}{f^2}N, \qquad dn = -\frac{k}{2nf^2}dN$$

    The minus sign indicates a180^o phase shift for all curves from the two simulations.

- Because of the limitation of the mirror model, one can not expect that the mirror simulation will exactly reproduce the IRTAM raytrcing results.

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Summary

- Using a simple but reasonable TID model, simulations were performed with IRTAM raytracing and mirror reflection. It is found that the mirror model can produce comparable results with the raytracing.

- The disagreements of the simulation results from the two approaches are expected and understandable.

- It is clear that any mirrors can not be served as a replacement of raytracing to describe the wave propagation in the ionosphere. However, because of its simplicity, it is feasible to use it to derive the TID parameters from the measured data with reasonable accuracy., but the mirror simulations is a valid approximation.

- Positioning the mirror at the "right height with the right tilt" requires assistance form the IRTAM model.

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