PropCode3 Notes

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1 Background

`PropCode3` is a MATLAB implementation of the algorithm described in Chapter 4 of the author's book *The Theory of Scintillation with Applications in Remote Sensing*

`http://www.wiley.com/WileyCDA/WileyTitle/productCd-047064477X.html.`

PropCode3 is an enhancement of PropCode2 as described in Chapter 2 of the book. The enhancements are best described with the help of Figure 1, which is book Figure 4.1. The figure shows the coordinate system used for the propagation calculation along the ray $\mathbf{R}$. The $x_P y_P z_P$ reference system is centered in the disturbed region between the source and the receiver. The application of primary interest is the measurement of satellite beacon transmissions that traverse the Earth's ionosphere. The ray path shown in Figure 1 is defined by the instantaneous position of the phase centers of the satellite antenna and the receiving antenna. The origin of the coordinate system is placed at the intercept point of a layer at a fixed height above the earth.

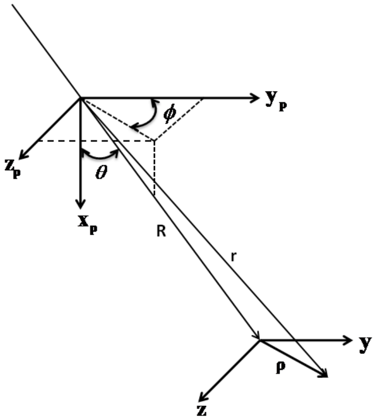
Execution of `PropCode3` requires inputs that define the geometry and the magnetic-field-aligned anisotropy in addition to the sampling and layer boundary definitions required for executing `PropCode2`. The `Setup*` script for `PropCode3` has been configured to accept a sequence of precomputed reference paths derived from the SGP4 satellite orbit code and the IGRF11 magnetic field model. With $\phi = 0$, $\theta = 0$, isotropic irregularities, and a common sampling structure, `PropCode2` results can be reproduced by `PropCode3`. The execution time is comparable to that of `PropCode2`, but the parameter space to be explored is substantially larger.

2 PropCode3 Examples

The folder

`...\PropagationCode3`

contains `PropCode3` and the utilities that support its execution. As noted above, however, the `PropCode3` incorporates anisotropic irregularity structure



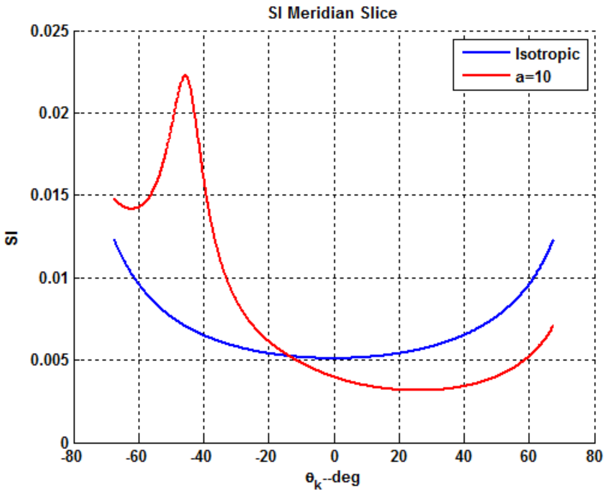
and oblique propagation as well a multiple paths with precomputed geometric and translational structures. Because the propagation code assumes frozen structure, the translational velocity has no impact on the static `PropCode3` outputs. However, an analysis code that processes the measurement-plane structure performs a one-dimensional scan along the translational velocity direction of the propagation path to simulate dynamic satellite receiver measurements.

Utilities that support `PropCode3` include a satellite orbit code, an Earth magnetic field code, and mapping path-integrated anisotropic structure. To execute the example, first transfer the MATLAB active directory to

`···\PropCode3_Examples`

and run the script `SetPath4PropCode3`. This will place the appropriate directories on the MATLAB path. The `SetPath4PropCode3` script will also prompt the user to locate the `\GPS_CoordinateXforms`, `\SGP4`, and `\IGRF` directories to place them on the MATLAB path. The `SetPath4PropCode3` can be edited to place the auxiliary directories on the MATLAB path without the prompt.

The book Chapter 4 has a number of Figures that illustrate the interplay between changing geometry in an anisotropic propagation medium. Scripts in the directories that are automatically placed on the MATLAB path starting with `Display*` will reproduce the book figures that are associated with `PropCode3`. For example typing `DisplaySI` will generate the book Figure 4.2 Figure 2, which compares the propagation angle dependence of the predicted scinillation. index for isotropic (blue) and anisotropic (red) structure. The propagation path is aligned with the elongated structure at 45°, which accounts for the enhancement. The remaining summary plots are reproduced by the orbit code



example from

`http://www.mathworks.com/matlabcentral/fileexchange/28888-satellite-orbit-computation.`

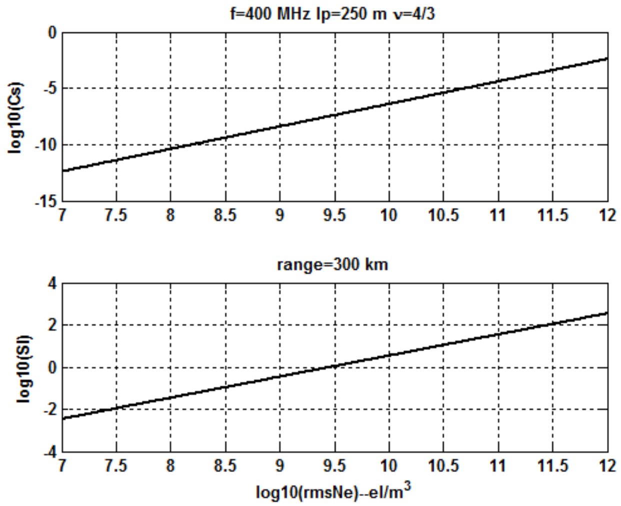
Executing script `ShowParameters` will present a menu of parameter selections. Defaulting (blank entry) each parameter input will reproduce Figure 2 (book Figure 4.7). The plot shows how the rms electron density drives the turbulent strength parameter C_s and the weak scatter SI index for a given frequency, slab thickness, and spectral index parameter. To the extent that the weak-scatter SI index is approaching unity, the simulation will produce strong scatter. This code is useful for exploring parameter ranges to increase or decrease the perturbation levels prior to committing to `PropCode3` execution. Running the script `EquatorialSI` will reproduce Figure 2 (book Figure 4.9), which shows the sensitivity to change in anisotropy. The informational examples up to this point are not required for `PropCode3` execution.

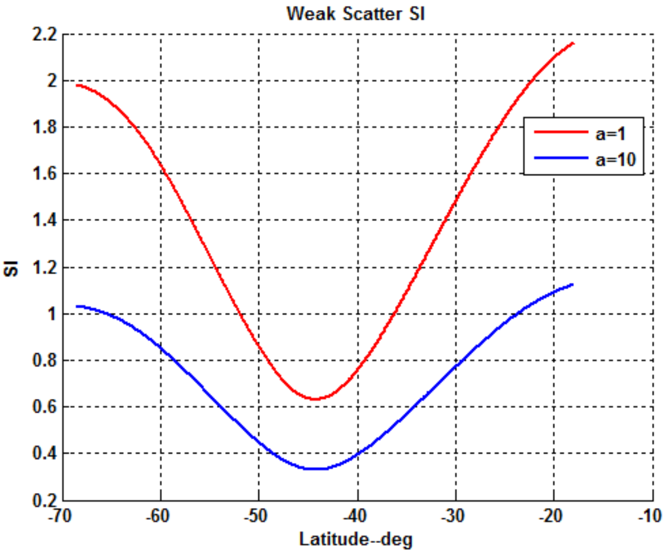
2.1 `PropCode3` Precomputation

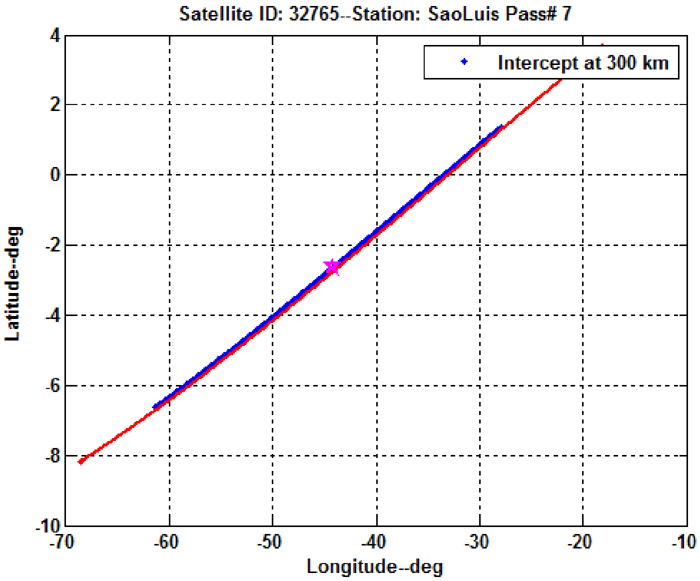
Transferring the active MATLAB directory to

`···\PropCode3_Examples\PropCode3Geom`

and running the script `GenerateSatelliteGeometry` will initiate a prompt to locate the SGP4 directory, which contains the TLE and station location inputs. At this point skip the prompts and run `GenerateGeometryInput`, which uses the intermediate file, but generated an additional `*GEOM` file with the model-dependent inputs needed for the simulation. The script has an optional set of displays to summarize the geometry file that will be used for the `PropCode3`


f=400 MHz lp=250 m ν=4/3
log10(Cs)
0
-5
-10
-15
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
range=300 km
log10(SI)
4
2
0
-2
-4
log10(rmsNe)--el/m3


Weak Scatter SI
SI
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
-70
-60
-50
-40
-30
-20
-10
Latitude--deg
a=1
a=10



run. For example, Figure 2.1 shows the longitude and latitude of the 300 km (default) ionospheric intercept point (book Figure 4.4). The magenta pentagram marks the station location. The fact that the station location is nearly on the trajectory shows that the pass is nearly overhead, which is desirable for scientific analysis.

Figure 2.1 (book Figure 4.5) shows the trajectory (magenta) superimposed on a map of the magnetic declination angle. To execute this code the file `Bz300` generated by the IGRF11 Demo code must be located at the prompt. The pass crosses the geomagnetic equator, but because of the changing magnetic field geometry a range of angles with respect to the magnetic field are encountered. This can be seen more directly in Figure 2.1 (book Figure 4.6), which shows the cosine of the angle between the propagation direction and the magnetic field direction (the Briggs-Parkin angle).

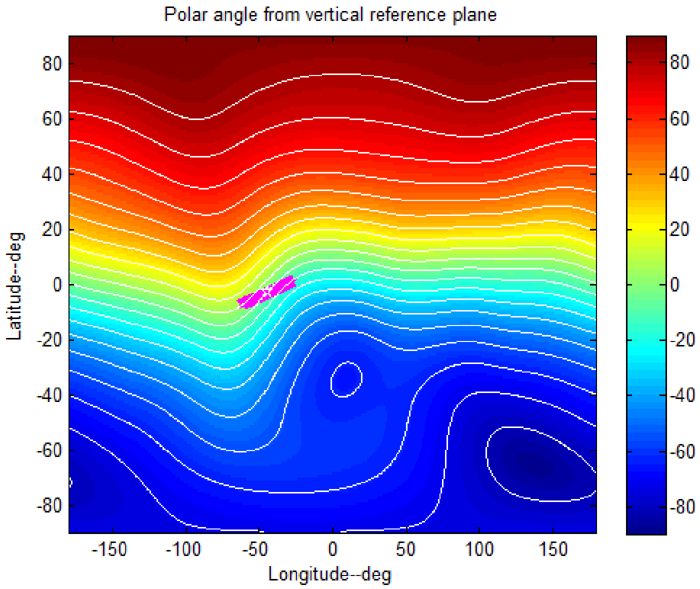
2.2 `PropCode3` Execution

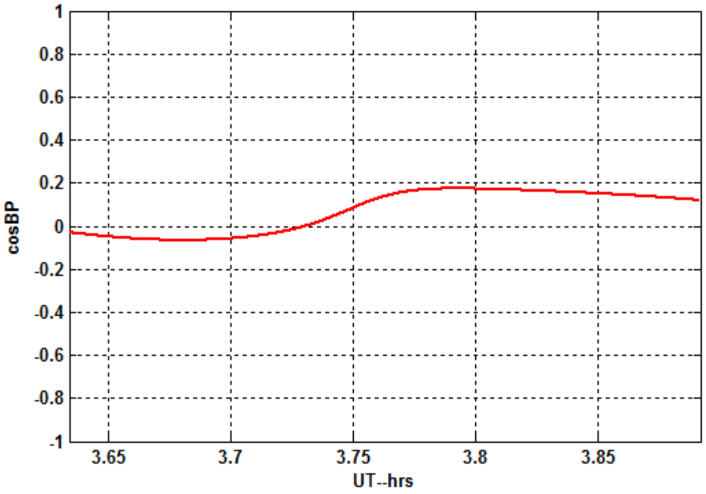
Once the `*GEOM.mat` has been generated in the

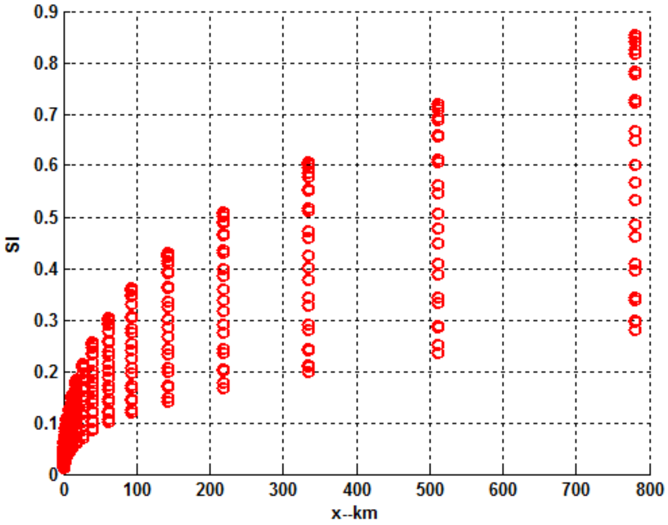
`···\PropCode3_Examples\PropCode3Geom`

directory, `PropCode3` execution follows the same steps as `PropCode3` execution. Transfer the MATLAB active directory to

`\PropCode3_Examples\BeaconSimulation`


Polar angle from vertical reference plane
Latitude--deg
Longitude--deg
80
60
40
20
0
-20
-40
-60
-80
-150
-100
-50
0
50
100
150
80
60
40
20
0
-20
-40
-60
-80


cosBP
UT--hrs
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
3.65
3.7
3.75
3.8
3.85



Running `SetupBeaconSim` executes `SetupPropCode3GEOM` to use 24 of the 47 geometric paths generated by the preprocessing operations just described. GUI input prompts the user to select the `*GEOM.mat` in the folder

···\\`PropCode3_Examples`\\`PropCode3GEOM`.

Figure**??** is generated to show the SI progression predicted from the weak-scatter formula for each of the 24 paths. At the maximum projected propagation distance, the SI index varies from moderate to near saturation.

Executing `PropCode3` will initiate the 24 consecutive run sequence. Each run generates 20 logarithmically spaced propagation steps from the initial layer; however, only the final field and the SI index at each step is retained to conserve storage. Typical execution times are ˜90 sec. per path. Once `PropCode3` has been executed, the program `AnalyzeCode3GEOMOut`, which is on the MATLAB path, can be executed to generate various displays for exploration. Following the `PropCode1 and PropCode2` structures, a single `*.mat` file summarized the multiple run outputs. Upon GUI selection of the input file, `AnalyzeCode3GEOMOut` requires the user input `[start, step, end]`. Entering `[1,1,1]` will reproduce book Figures 4.10, 4.11, and 4.14 and 4.15.[1] Figure 2.2 shows the receiver plane intensity for the first path. As discussed in book Chapter 4, the striated appearance of the intensity structure is a consequence of the field anisotropy. Note that the orientation follows the path 1 ellipse in Figure **??**. The white line is the projected trajectory of the apparent drift due to source motion.[2] The black

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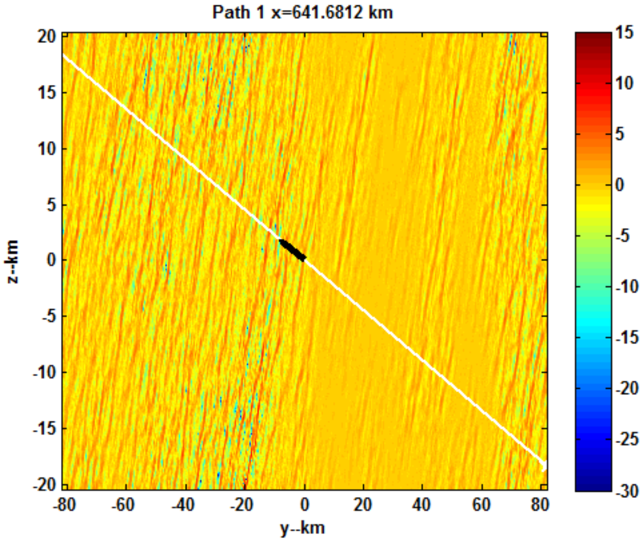
[1] The figures are not identical because the random number generator starts with a random seed selection.

[2] In the simulation the structure is stationary.

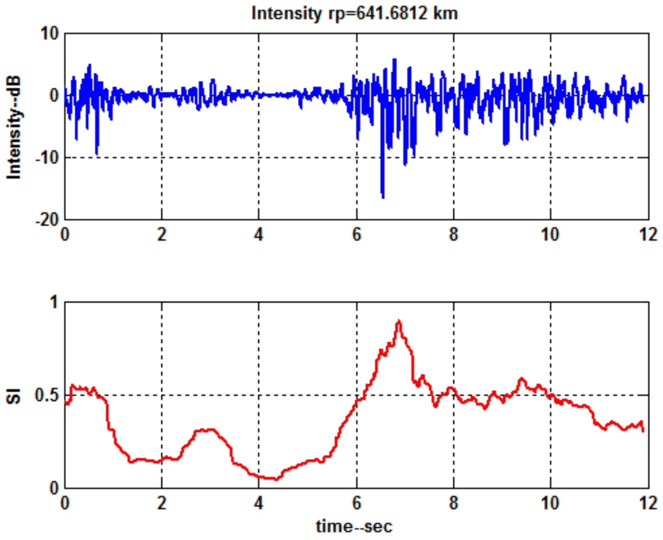


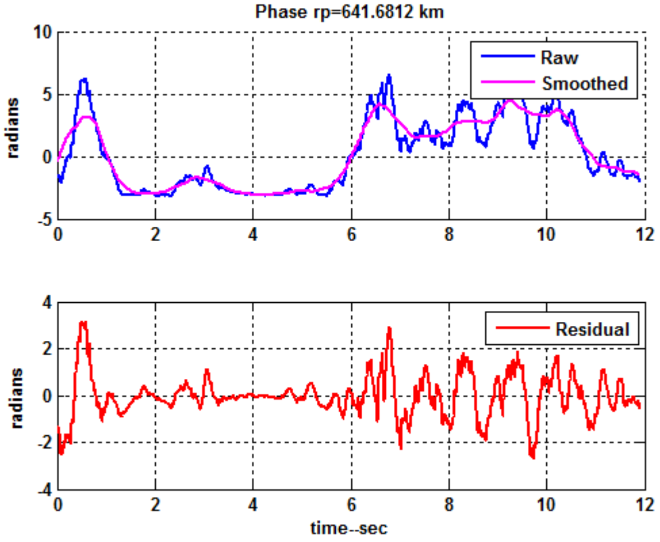
vector is a scaled projection of the apparent velocity. Under the assumption that the orbit change is invariant over the transit, that spatial structure can be converted to the time series that would be measured by a receiving antenna at the reference grid.

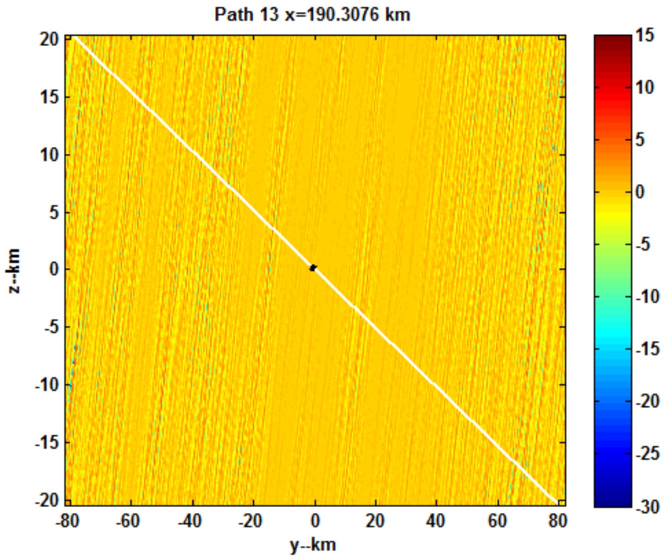
The upper frames of Figures 2.2 and 2.2 show, respectively, the measured intensity and phase reconstructed to remove 2π ambiguities. The lower frame of Figure 2.2 shows the the SI index measured over a sliding 0.75 sec. interval. The fact that the local scintillation structure varies even though the driving irregularity structure is nominally homogeneous is a consequence of the large-scale structure as discussed in book Section 4.5.3. In Figure 2.2 the magenta overlay in the upper frame is a 512 point centered boxcar average used to capture the large scale structure. One can see clearly that the large-scale phase structure coincides with the intensity variation. The residual phase variation would be identified with scintillation, although the partitioning is not rigorous.

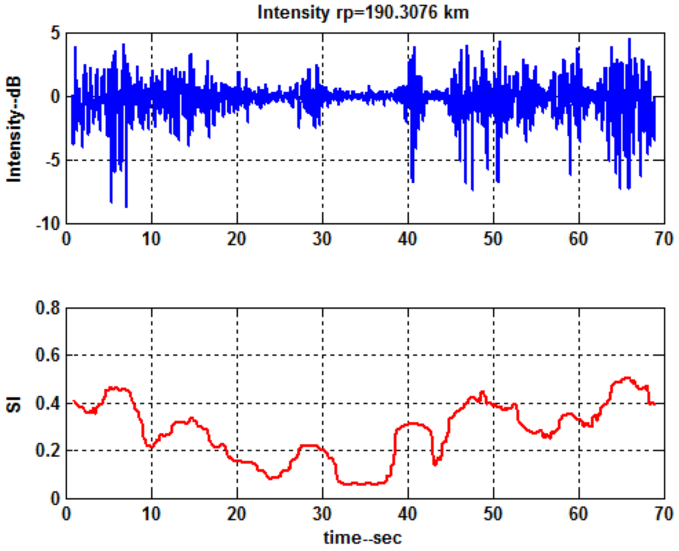
Rerunning `AnalyzeCode3GEOMOut` with input `[13,13,13]` will reproduce book Figures 4.12, 4.13, and 4.16, shown below, which summarizes the near overhead pass. As discussed in book Section 4.5.3.2, the near overhead path has a very small projected drift velocity, which complicates the interpretation in terms of in situ structure. For example, the finer detail in Figure 2.2 is a purely geometrical effect. The structure that produced it is invariant over the pass.

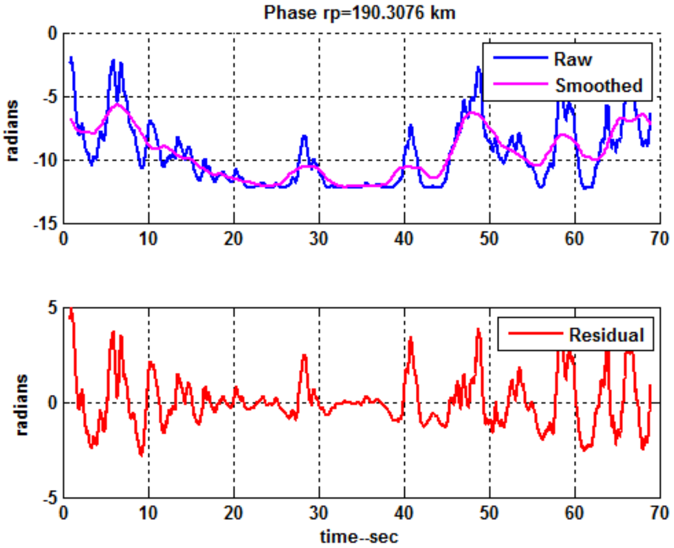
The final topic in book Chapter 4 is spectral analysis. Figure 2.2 (book Figure 4.16) shows the measured intensity (red) and phase (blue) spectra over the entire scan shown in Figure 2.2. The reason for using the entire scan rather


Intensity rp=641.6812 km
Intensity--dB
10
0
-10
-20
0
2
4
6
8
10
12
SI
1
0.5
0
time--sec

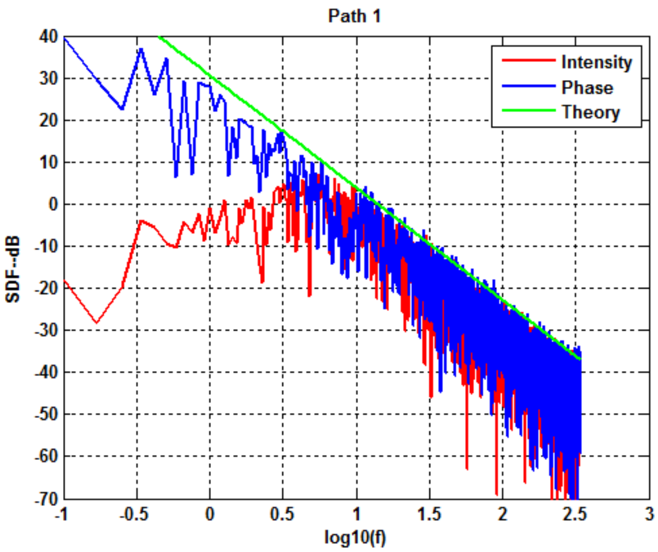

Phase rp=641.6812 km
radians
10
5
0
-5
Raw
Smoothed
0
2
4
6
8
10
12
Residual
radians
4
2
0
-2
-4
time--sec


Path 13 x=190.3076 km
z--km
y--km
20
15
10
5
0
-5
-10
-15
-20
-80
-60
-40
-20
0
20
40
60
80
15
10
5
0
-5
-10
-15
-20
-25
-30


Intensity rp=190.3076 km
Intensity--dB
5
0
-5
-10
0
10
20
30
40
50
60
70
SI
0.8
0.6
0.4
0.2
0
time--sec



than averaging shorter segments is to resolve the largest scale structure possible. As discussed in book Section 4.5.3.3, this seems to do the best job of recovering the theoretically predicted one-dimensional phase envelope plotted as the green overlay.


Path 1
Intensity
Phase
Theory
SDF--dB
log10(f)
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
-1
-0.5
0
0.5
1
1.5
2
2.5
3