

PropCode2 Notes

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1 Introduction

PropCode2 is a MATLAB implementation of the algorithm described in Chapter 3 of *The Theory of Scintillation with Applications in Remote Sensing* by Charles L. Rino, John Wiley & Sons IEEE Press, 2010. The algorithm simulates electromagnetic (EM) wave propagation in a fully three-dimensional medium. Although **PropCode2** is a direct extension of **PropCode1**, it is configured to explore the statistical theory of scintillation. The statistical theory confines the structure configurations to realizations of statistically homogeneous processes, as described in book Chapter 3. Homogeneous processes admit position invariant moments and a spectral density function (SDF). Turbulence is characterized by a power-law SDF. The directory

`\AtmosphereScintillation`

contains MATLAB utilities to support the turbulence model and the mean reference atmospheric refractive index profile. The directory

`\IonosphereScintillation`

contains MATLAB utilities to support analytic scintillation results such as weak- and strong-scatter limits. It also contains the geometric translations for oblique propagation and anisotropic structure that support **PropCode3**. The Chapter 3 results use only isotropic structure with atmospheric turbulence as a model.

The directory

`\PdComputation`

contains MATLAB utilities to compute various probability density functions (pdfs) and probability of detection (Pd) utilities. All these utility directories support examples from book Chapters 2, 3, 4, and 5.

Execution of the **PropCode2** examples follows the **PropCode1** execution sequence:

1. Run `SetPath4PropCode2` to put main code and support directories on the MATLAB path.

2. In the selected or copied example folder, run the `SetupPropCode2*` script to generate `*.mat` files containing the variables required by the main program code (now on the MATLAB path). The names of the `*.mat` files generated by the `Setup*` scripts contain the name `Setup` and a date-time stamp that uniquely identifies the setup `*.mat` file.
3. In the selected or copied example folder, run `PropCode2`, which will initiate a GUI-driven file selection utility.¹ Selection of the appropriate `Setup*.mat` file will initiate execution of `PropCode2` using inputs from the selected `Setup*.mat` file. Screen output will indicate the code progress. The main code outputs include a `*.mat` file and binary data files. Each output file contains the setup time stamp, which facilitates management of the input and output associated with multiple runs in the same directory folder.
4. Run the display codes initiated in scripts with book Figure numbers to generate the book figures.

As with `PropCode1`, the codes have been written for exploration not as general purpose utilities. The user is also forewarned that the examples are dimensioned to run on a 64 bit computer with at least 6 GBytes of memory. To run the examples with less memory the 4096-by-4096 output array can be reduced. Typical execution times are given in the specific `PropCode2` examples.

2 Example Descriptions

The folder

```
... \PropagationCode2
```

contains the `PropCode2` source code, subroutines, analysis codes, and display utilities. The subdirectory

```
... \PropCode2_Examples
```

contains the script `SetPath4PropCode2`, which must be run first to place the appropriate directories on the propagation path. No auxiliary directories are needed for these examples.

The folder `\MakeChapter3Figures` contains scripts that will generate the book Chapter 3 figures that supplement the forward propagation simulations.

2.1 PropCode2 Examples

The `PropCode2` examples are intended to demonstrate scintillation phenomena in highly turbulent propagation environments. Power-law parameters have

¹The GUI lists all the `*.mat` files **in its current directory**, which may not be the desired example directory. It is up to the user to select the appropriate `Setup*.mat` file generated in step 1.

been varied to cover the range of phenomena for which at least limiting-form theoretical results are available. This is discussed in detail in book Chapter 3. Of particular interest is strong focusing, which has been simulated with very fine detail ad over a large dynamic range. The beautiful intensity structure patterns associated with strong focusing have been known for some time. To explore them further a movie example is included. To maintain the full resolution in three-dimensions the movie file is 30 Gbytes, but once the file is in memory the movie will play using Quicktime.

Descriptions of the specific examples follow. All the examples, including movie generation, will run in less than 1 hour on a high-end PC. The MATLAB functions that perform the various supporting operations such as generating realizations of turbulent structure are structure to make their structure transparent. Details can be found in book Chapter 3.

2.1.1 Shallow Slope

To generate the shallow-slope example, transfer the MATLAB active directory to

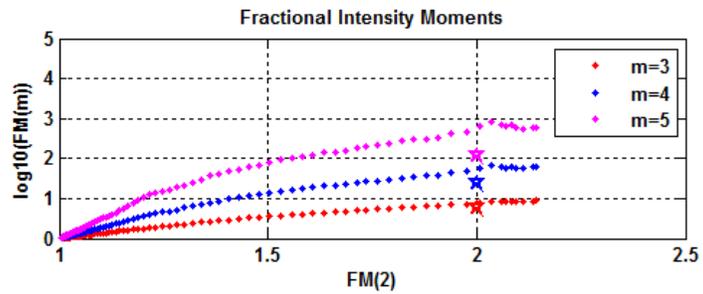
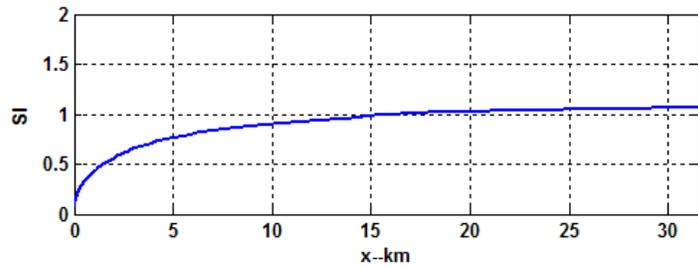
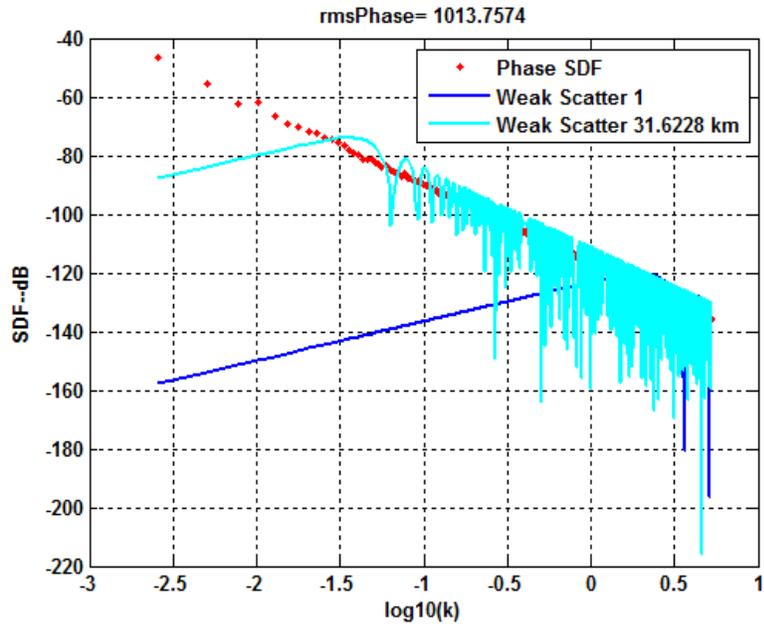
```
... \PropCode2.Examples\SmallSlope
```

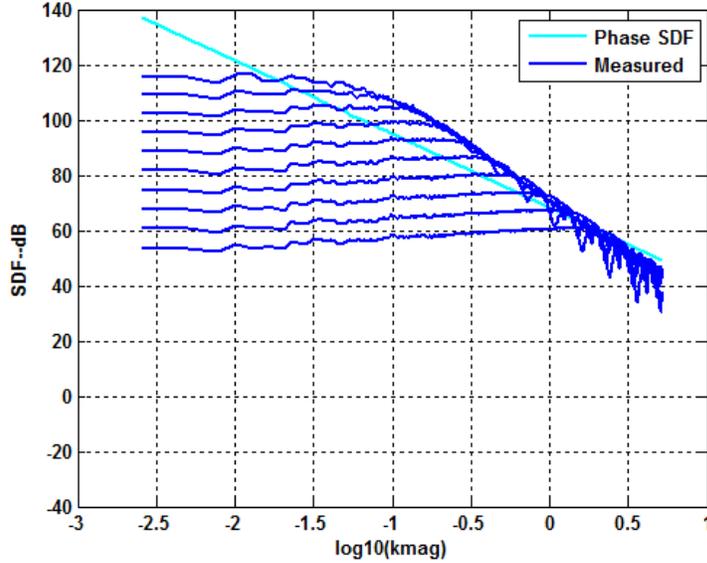
and run the script `SetupPropCode2`. As a test of the setup structure, run `MakeFig311`, to generate Figure 2.1.1 (book Figure 3.11), which shows the radial wavenumber spectrum constructed from a realization of the turbulent structure (red). The spectrum is uniform over the sampled range of frequencies. The overlays show the weak-scatter form of the intensity spectrum at exit plane of the first slab (blue) and at the largest propagation distance (cyan). Running `PropCode2` will generate the complex field execution.

To display the results run the script `DisplayPropCode2Out`. Upon GUI selection of the output file, the following three figures are generated. The upper frame of Figure 2.1.1 (book Figure 3.12) shows the scintillation index as a function of distance. The theory predicts a monotonic increase to saturation ($SI = 1$). The fact that the measured index exceeds unity by a small amount is a statistical fluctuation. The lower frame shows intensity moments 3, 4 and 5, normalized to the second intensity moment. Thus, $FM(2) = SI^2 + 1$. The pentagrams indicate the fractional moment for exponentially distributed (Rayleigh) intensity fluctuations $FM(m) = m!$. Although the SI index is close to unity, the higher order fractional moments indicate a departure from Rayleigh statistics.

Figure 2.1.1 (book Figure 3.1.3) shows the evolution of the intensity radial wavenumber spectrum with an overlay of the theoretical phase radial wavenumber SDF for reference. The power-law tail portion of the intensity spectrum has the same slope and in this case coincides with the phase SDF.

Figures 2.1.1 and 2.1.1 (book Figures 3.21 and 3.22) show, respectively, the intensity field and power spectrum of the complex field. One can see filaments in the intensity structure that suggest significant departure from speckle (Rayleigh distributed fluctuations). The SDF of the complex field shows a bright central





(low spatial frequency) region sitting on a plateau. Recovering the underlying phase spectrum from the output would be very difficult, as discussed in Chapter 3.

2.1.2 Large Slope

To run the large-slope example transfer the active MATLAB directory to

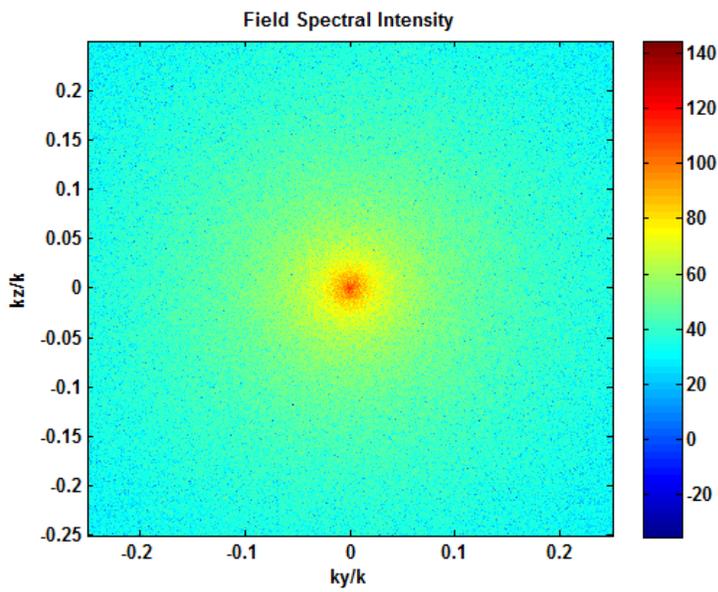
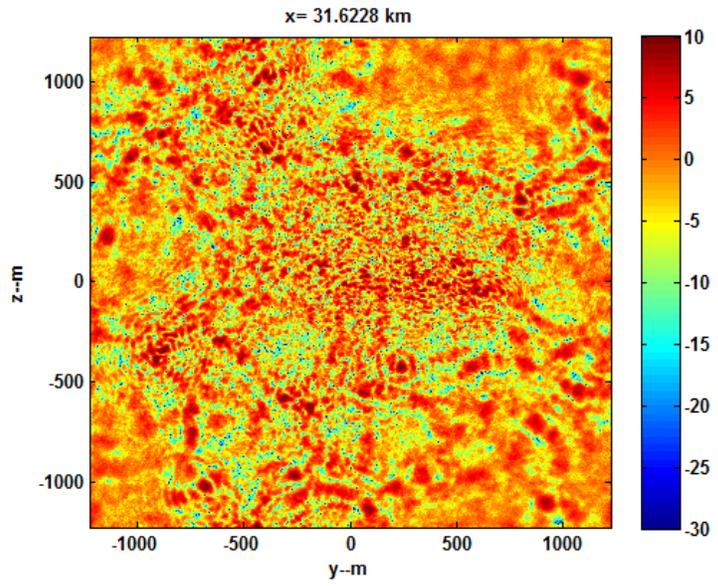
```
... \PropCode2.Examples \LargeSlope
```

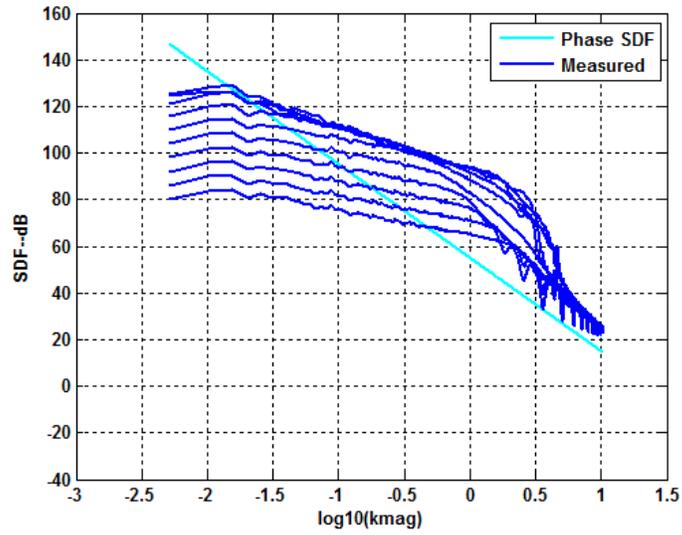
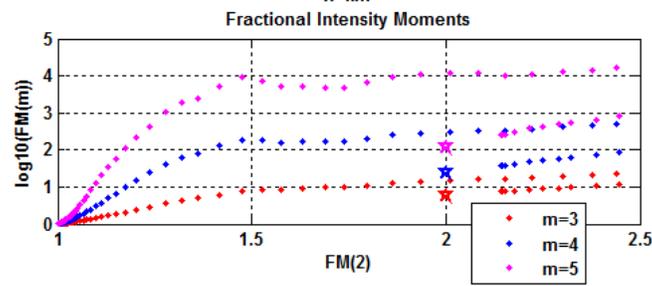
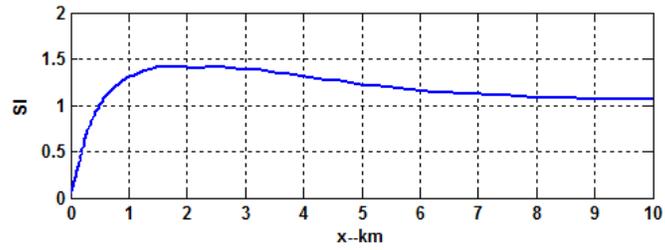
and run `SetupPropCode2`. Next run `PropCode2` to generate the output complex field as before. The following 3 figures can be generated by executing the script `RunDisplayPropCode2Out` as before. Figure 2.1.2 (book Figure 3.14) shows the evolution of the scintillation index (upper frame) and the fractional moments (lower frame). The tendency of the intensity statistics to converge to Rayleigh is a predicted result described in Chapter 3 of the book. Figures 2.1.2 and 2.1.2 (book Figures 3.23 and 3.24) show, respectively, the intensity field and power spectrum of the complex field at the maximum distance.

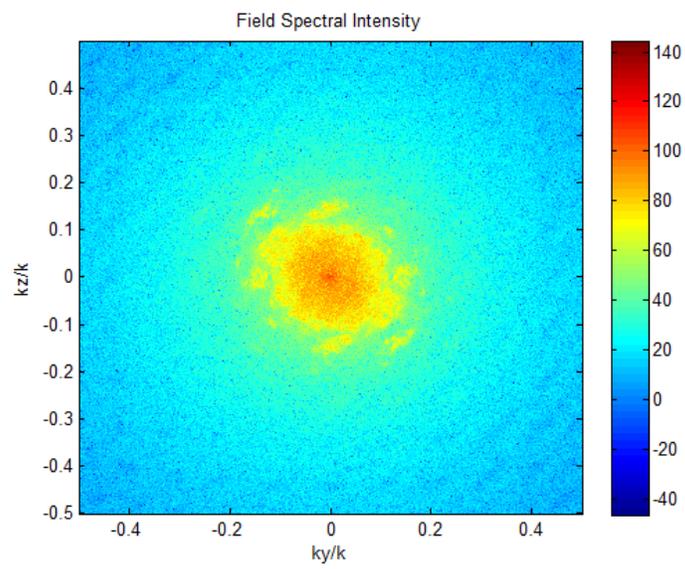
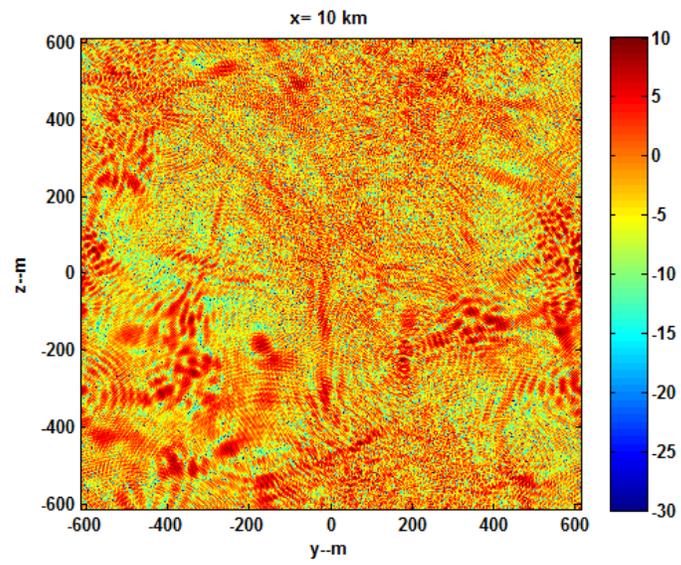
2.1.3 Strong Focusing

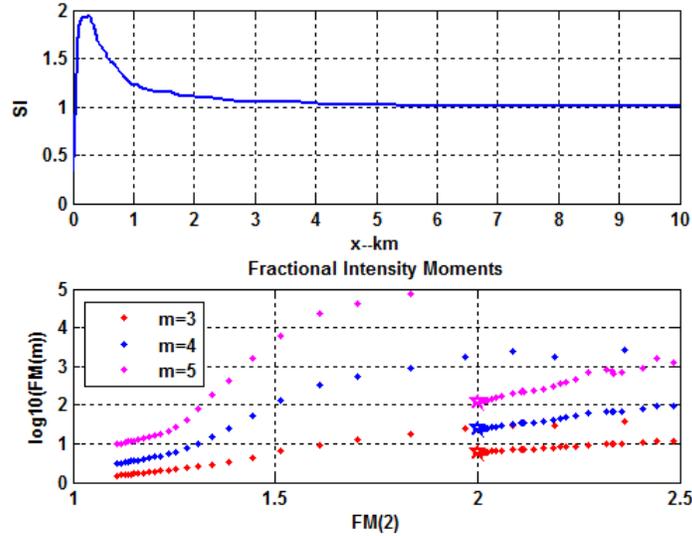
To run the strong-focusing example transfer the active MATLAB directory to

```
... \PropCode2.Examples \StrongFocusing
```









and run `SetupPropCode2`. Running `PropCode2` followed by `DisplayPropCode2Out` will reproduce Figures 2.1.3 (book Figure 3.16) and 2.1.3. Figure 2.1.3 shows the evolution of the SI index, which achieves its maximum value at 265 m from the phase screen. Subsequent propagation to 10 km shows that the statistics have converged to Rayleigh as predicted by theory. Figure 2.1.3 shows the very homogenous distribution of the intensity distribution. As theory predicts, there is an initial pronounced departure from Rayleigh statistics, but if the propagation distance is increased significantly enough, the intensity statistics become speckle like.

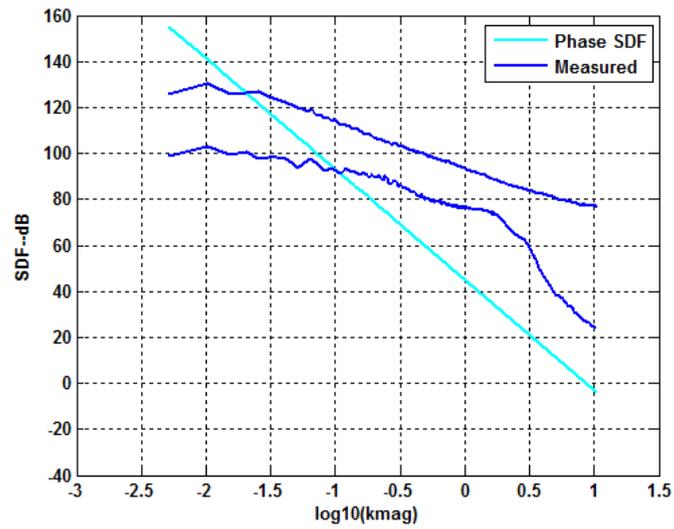
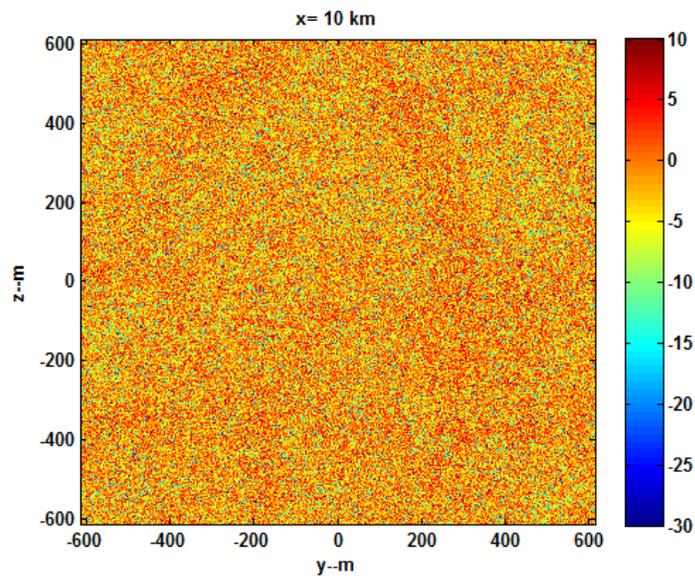
A second simulation initiated with `SetupPropCode2a` followed by `PropCode2` will terminate the computation at the distance where SI achieves its maximum value. Executing `DisplayPropCode2Out` with GUI selection of the second run will generate the following figures (book Figures 3.25 and 3.26), the latter of which is a dramatic example of strong focusing.

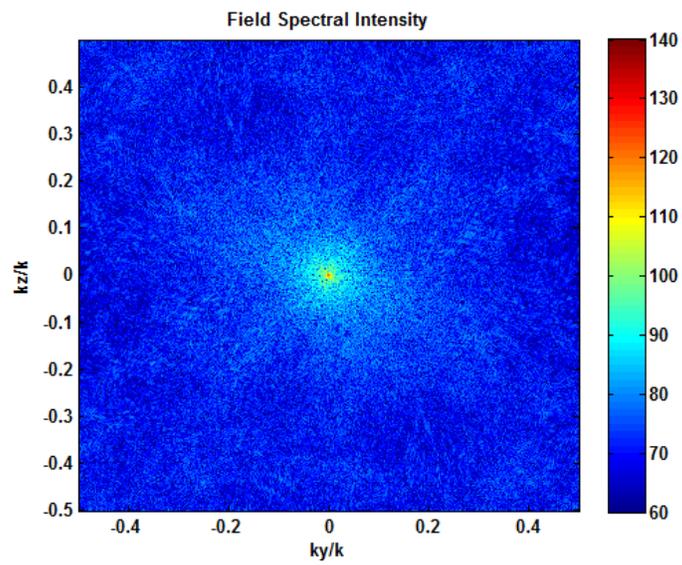
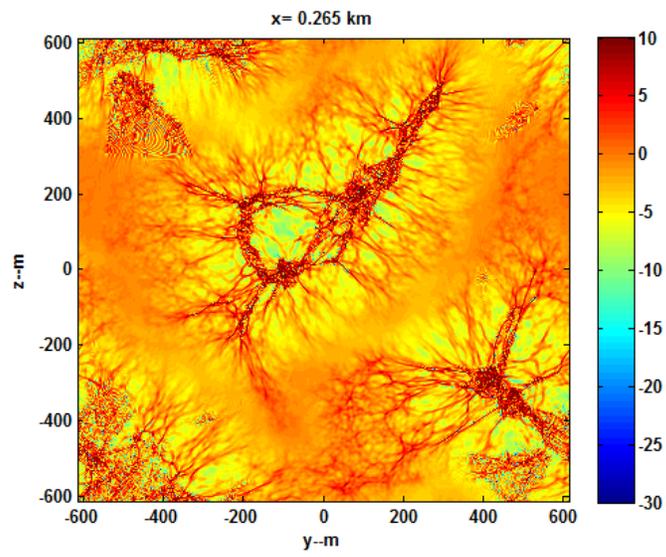
2.1.4 Strong Focusing Movie

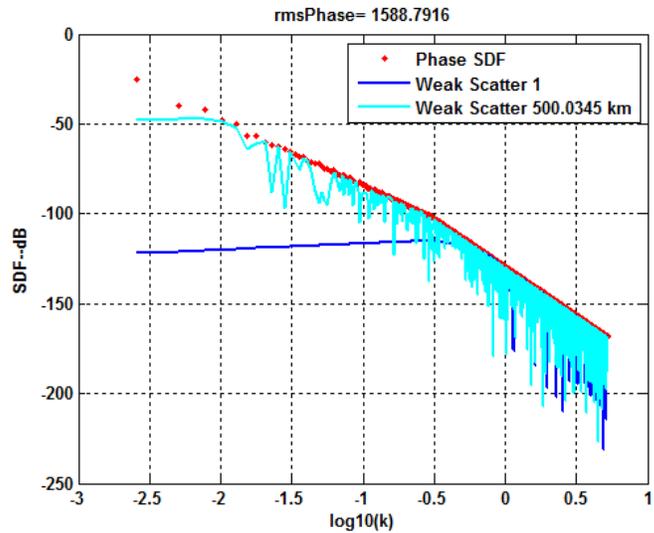
The movie example can be found in the folder

```
... \PropCode2_Examples \StrongFocusingMOV
```

Executing the setup utility followed by an execution of `PropCode2` will generate the output. The display utility is configured to generate an `.avi` movie file.







2.1.5 Two-Slope

An SDF with two power-law segments is a more flexible model. Running the script `SetupPropCode2` in the directory

```
... \PropCode2.Examples\TwoSlope
```

will generate the a `*.mat` file for the two component power law shown in Fig 2.1.5, which can be reproduced by executing `ReadSetupFile2`. Running `PropCode2` followed by `DisplayPropCode2out` will reproduce Figures 2.1.5 and 2.1.5.

