Holomorphic Functions to Characterize Human Retinotopic Mapping

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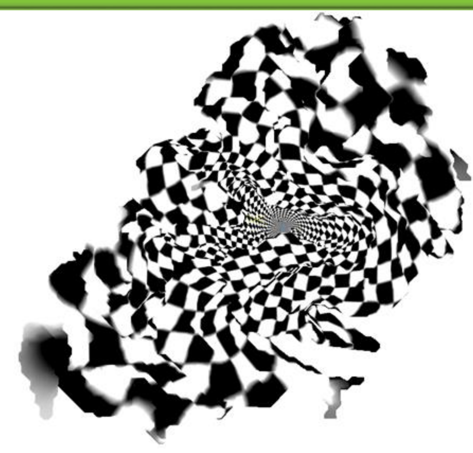

Introduction

Retinotopic data of the early visual areas have been well studied and several mathematical models [1,2,5,6] have been proposed to describe its properties like cortical magnification, foveal confluence, and anisotropicness. The complex-log transform model [8] and subsequent variants [1,2,6,7,9] are the standard for current retinotopy research. The predictions of these models have been experimentally verified in both humans and primates. The mapping is based on a conformal model with azimuthal shearing. To characterize the mapping, the model is fitted to the data using labeled point correspondences and optimized by minimizing an error measure [5]. In this work, instead of starting with a model and fitting the data to it, we attempt to directly measure the distortion in the mapping using the Beltrami coefficient. This direct approach requires a smooth mapping dataset which is never possible with retinotopy experiments using fMRI. Therefore we attempt preprocessing of the data using regression fitting of the retinotopy data. It is important to note that we are not assuming a conformal model with shear here then fitting the dataset to it. We simply treat the dataset a set of points that we can apply regression analysis to estimate the relationships among the variables. The dataset that we obtain after regression is a smooth mapping with no inconsistencies in the fMRI data. We can directly measure the Beltrami coefficient from this dataset and use it to drive the model parameter choices.

Method

I Retinotopic maps are constructed using fMRI data collected using the standard travelling wave experiment [3, 10].

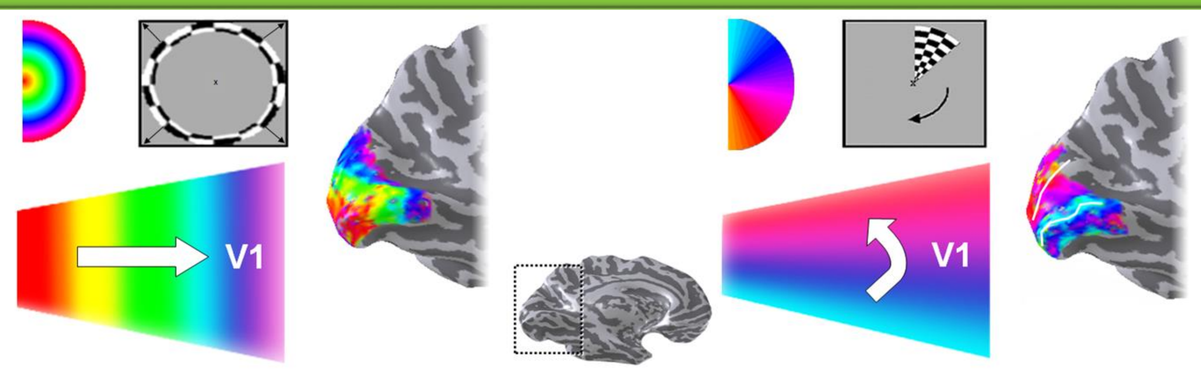

Figure 1. Data collection using standard traveling-wave fMRI method.

II We use spherical conformal mapping to map the primary visual cortex, which is a topological disk, to a planar disk.

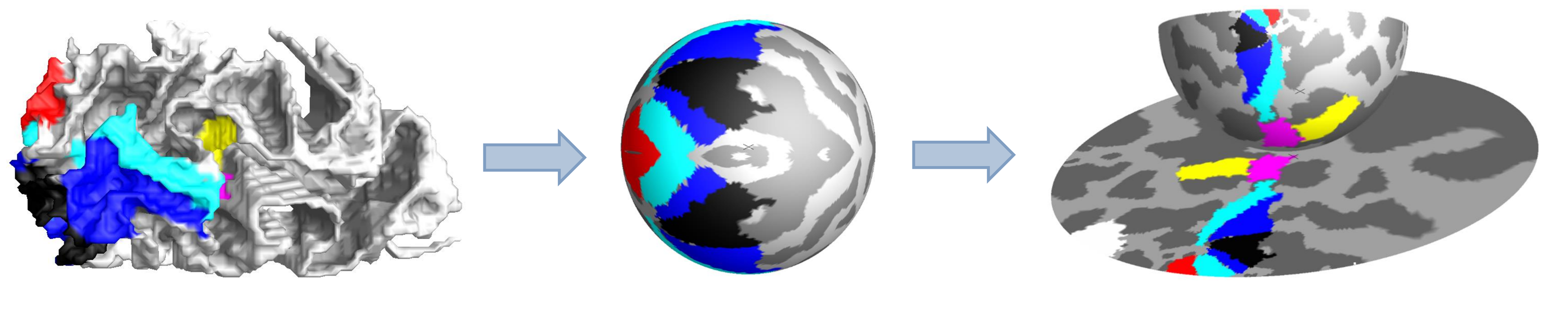

Figure 2. Spherical Conformal flattening

III After the mapping, we select a vertex point where the functional data corresponds to the center of the retinal visual field (foveal center) and transform it to center of the disk using a Möbius transformation. Then we extract eccentricity (Fig. 3A) and polar angle (Fig. 3C) data from the labeled region of interest (Fig. 3B) that was done on the original cortical surface.

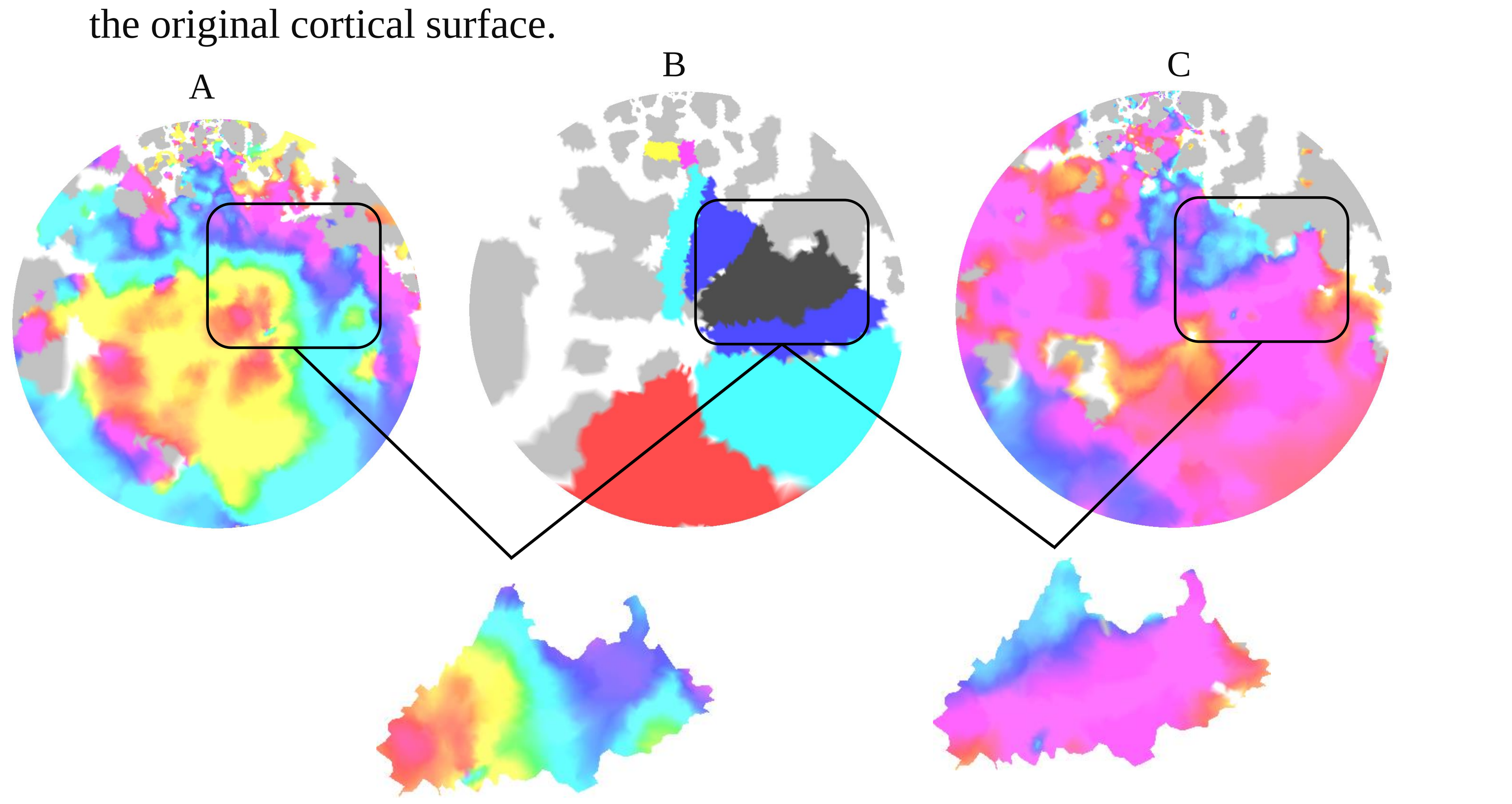

Figure 3. Extracting functional data from primary visual area (V1).

IV We cut a wedge containing V1 from the disk. The wedge is made by intersecting two lines that encloses V1 at the vertex point chosen above. We rotate the wedge so that it lies at the center of the visual hemifield it represents.

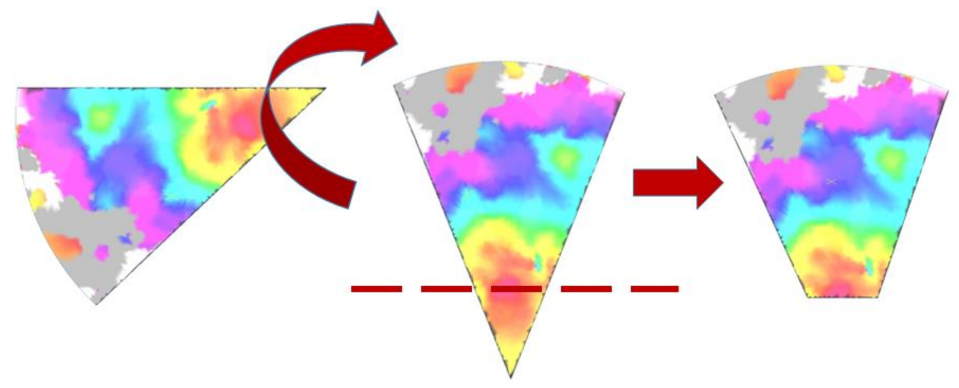

Figure 4. Orienting the visual region for plotting

V We sort the vertices according to their radial and angular distance in the visual field which are obtained simply by decoding the functional color data. Then we plot the data with the independent variable as radial or angular distance in the visual field and the dependent variable as the location of the functional data on the cortical surface.

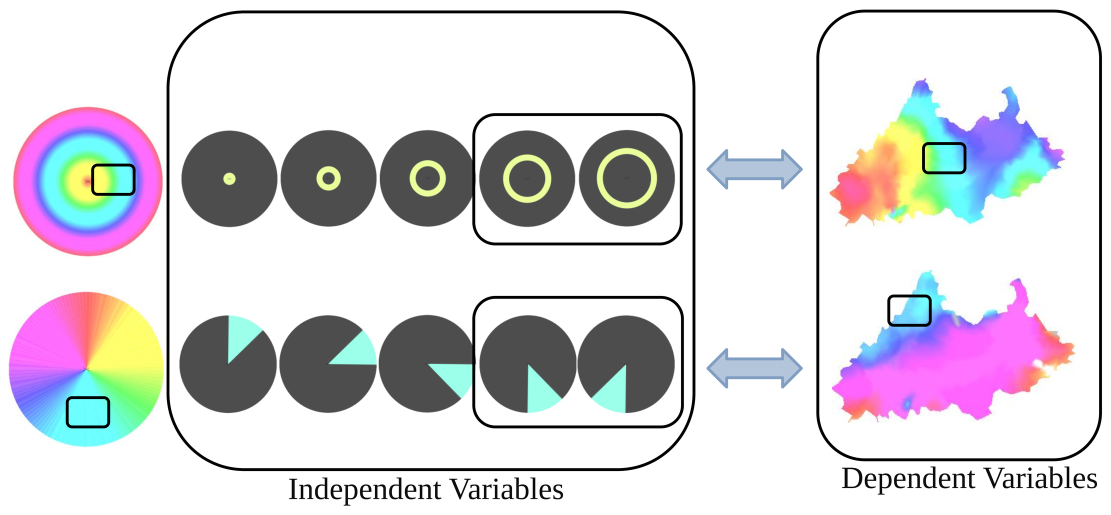

Figure 5. Plotting the data

Results

We show the linear least squares fitting as well as the smooth fMRI data projected back onto the mesh in Fig. 6 for one subject. The first row compares the smooth fMRI data (left) versus the original fMRI data (right) for eccentricity while the second row compares the polar angle data. We have not eliminated outliers in these preliminary results. The data can also be fitted using other convex functions. However, using higher order functions may overfit the data. Our preliminary fitting results show that the dataset set has a particular trend. We look to further explore the data preprocessing step and the regression step to eliminate outliers and better fit the resulting dataset. Beltrami coefficient measurements of the data using linear curve fitting shows that a conformal model approximates the data quite well as expected since the flattened surfaces was flattened using a conformal algorithm. Using other functions to better fit the data trend will result in deviation from conformality which the Beltrami coefficient also shows. Our results can independently verify if the dataset is conformal first before attempting to fit the data to the model. Unlike the Wedge-Dipole model [5], our goal here is not to construct a single mapping of visual areas V1, V2, and V3 but rather we want to understand what the mappings are when mapping from one area to another.

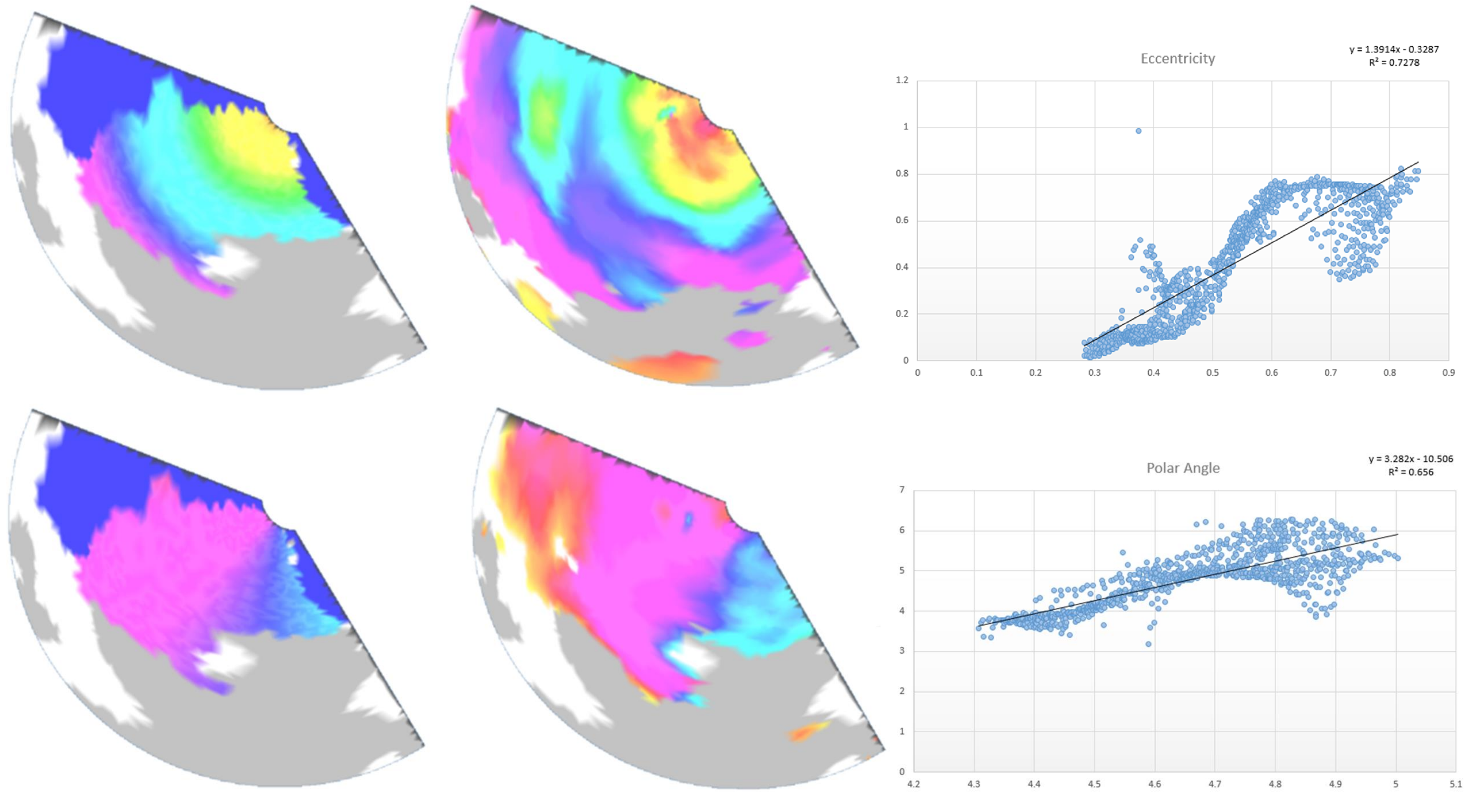

Figure 6. Data Fitting Results

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