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Interpolating Sparse Scattered Oceanographic Data Using Flow Information

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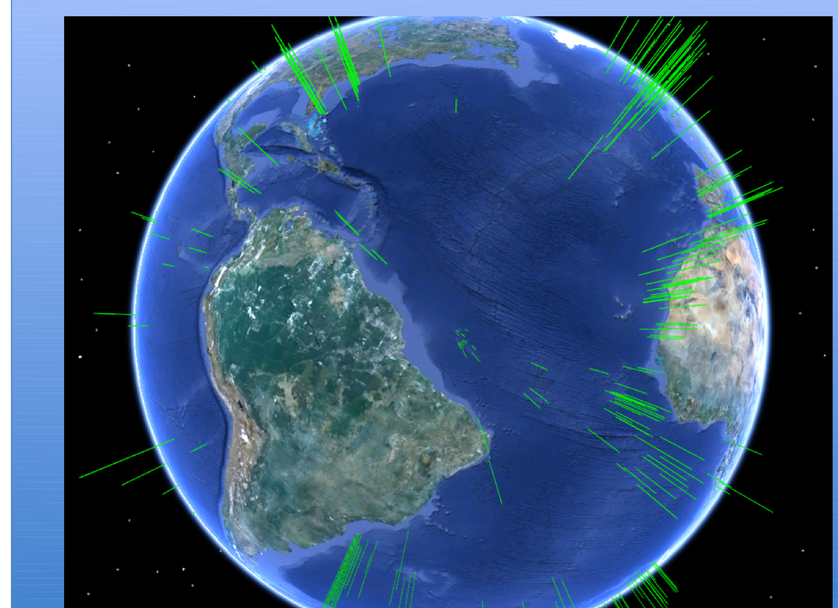
Introduction

We have developed a novel approach for interpolating sparse scattered data in the presence of a flow field. Typically, in order to visualize a scalar field representing a physical quantity such as salinity, temperature, or nutrient concentration in the ocean, scattered data interpolation is used to reconstruct the field of interest on a regular grid. For cases involving scattered samples that are quite sparse - such as is the case when using measurements from benthic foraminifera in deep sea sedimentary cores as a proxy for the physical properties of the past ocean – the standard methods of interpolation may not produce acceptable results. By exploiting known flow information, our method can improve the quality of such a reconstruction.



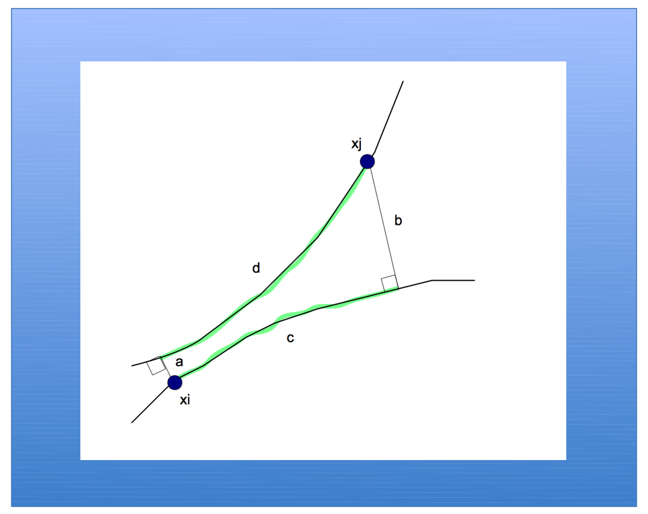
The green markers signify the locations of available d13C data from the Holocene, obtained via core samples drilled from the ocean floor. The extreme sparsity of these scattered data points makes it difficult to create a global reconstruction of the d13C scalar field using standard scattered data interpolation techniques, especially for regions such as the Atlantic, where very few data points exist.

Methods

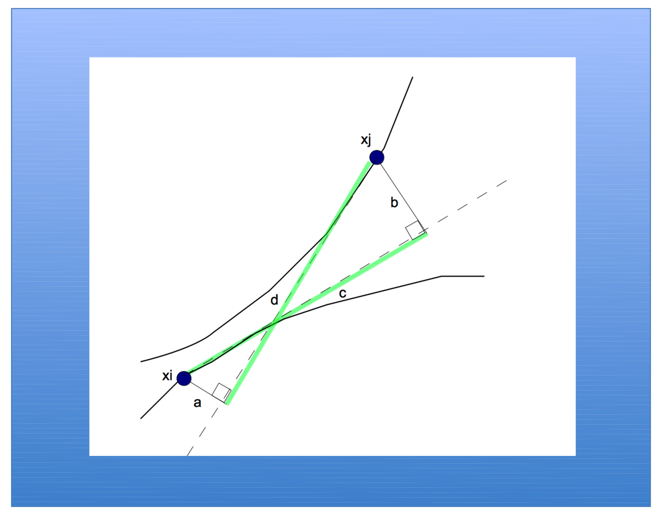
• Intuition: the values of a scalar field representing a given tracer quantity in the ocean should be more highly correlated along directions of flow than across them.

• Utilize the distinction between "distance along streamlines" and "distance across streamlines" in order to define alternative measures of distance which can be used with standard scattered data interpolation methods in order to transform these methods into flow-field-aware techniques.

• Such non-Euclidean, anisotropic measures of distance may or may not be proper distance metrics in the strict mathematical sense, although they should at least be symmetric in order for the resulting interpolators to be well-behaved.



The "exact" method for calculating distances from streamlines and distances across streamlines

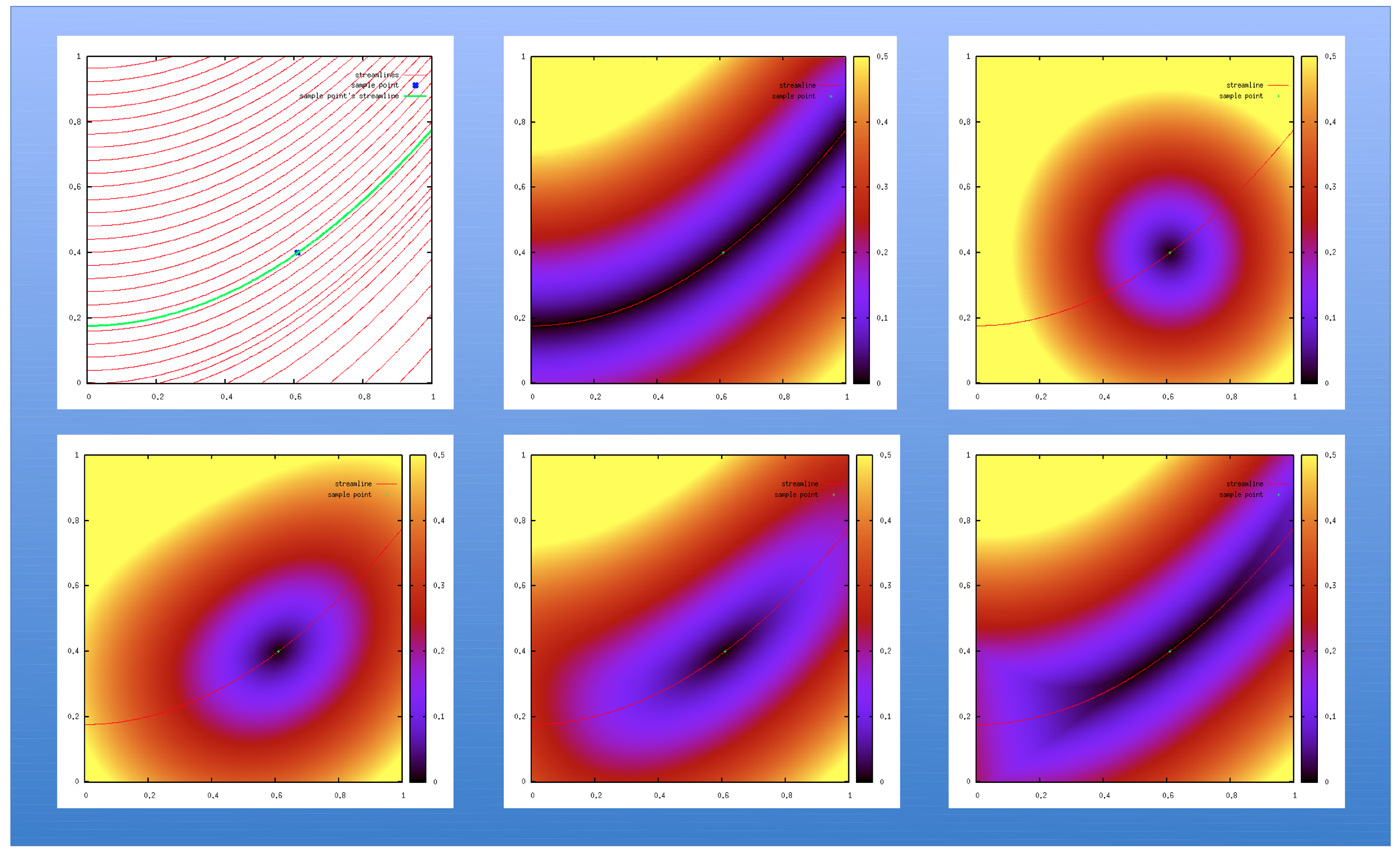


An approximate method for calculating the distance from and across streamlines; here, linearizations of the streamlines through the sample points are used

• Using non-Euclidean distance measures derived from exact distances measured along and between the streamlines of the flow field yields more accurate results, but the computation of a large number of streamlines is computationally expensive.

• As an alternative, approximations of the along-streamline and across-streamline components of the distance measure can be constructed by linearizing the streamlines about the points of interest (in other words, by considering flow directions only at these points); this is more efficient, but can create undesired artifacts.

• The factor that determines the relative influence of the along-streamline component of distance versus the across-streamline component of distance is an adjustable parameter of the method.

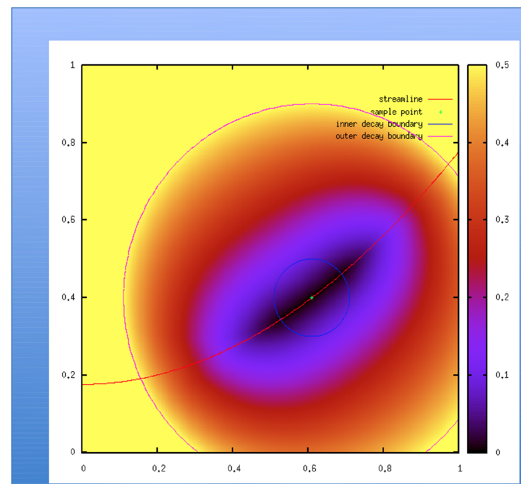


The figures above illustrate the construction of anisotropic distance measures using the concept of along-streamline and across-streamline distances, using the streamlines shown in the first plot. The upper middle plot is the distance plot under a distance measure computed using complete streamline information and with very little weight given to along-streamline distances, showing the distance of each point in the domain from the single point specified by the green marker. The next plot illustrates the situation for the standard Euclidean distance metric, which is isotropic. The three plots in the bottom row show the distance functions for anisotropic distance measures constructed using only localized approximations to streamlines. From left to right, these plots illustrate the effect of decreasing the value of the relative weight of along-streamline versus across-streamline distances. The last plot shows that undesirable artifacts can result when a strongly anisotropic distance measure is defined using locally approximated streamlines.

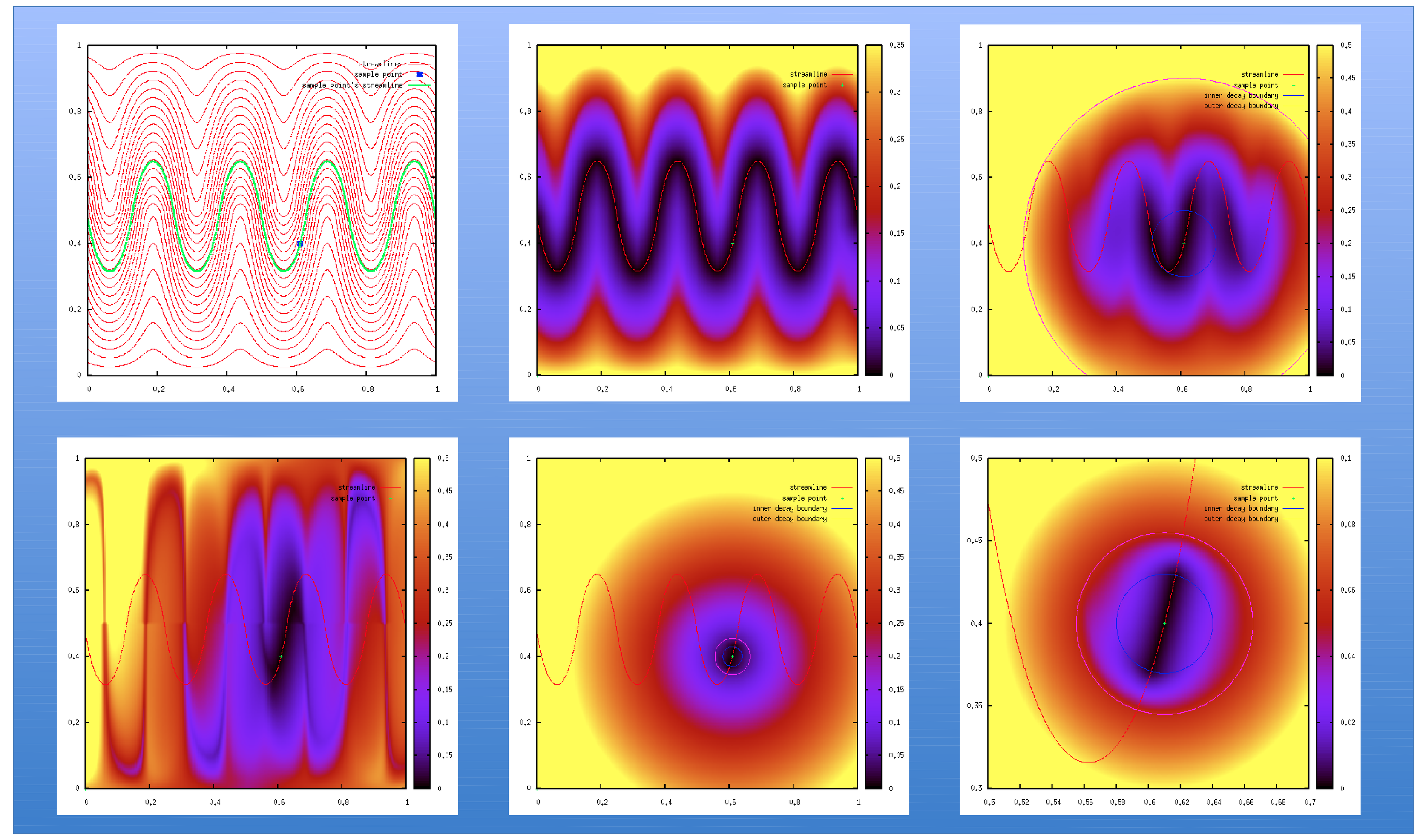
• As a further extension, anisotropies can be allowed to decay as the (Euclidean) distance between points becomes large.

• This introduces two more adjustable parameters: the inner and outer decay region radii.

• Any adjustable parameters (such as the factors and radii) can be set manually, or optimized dynamically using subsampling of the given data.



In this case, the streamline linearization artifacts in the previous case (above) have been eliminated by allowing the anisotropy to decay in the region between the two circles shown on the plot.

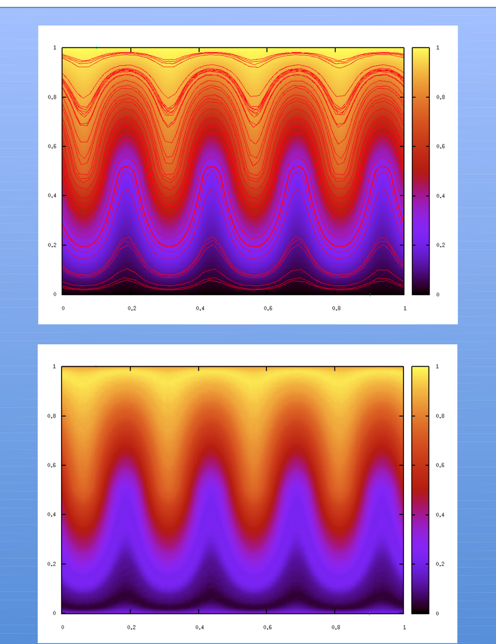


The plots above further illustrate the utility of distance measures with decaying anisotropy, using the streamlines in the plot at the upper left. The remaining two plots on the top row show distance measures constructed using full streamline information. The first utilizes a very small weighting of along-streamline distance. The other shows a similar distance measure, but with a decaying anisotropy. This is perhaps a more realistic representation of the correlations a scalar field might exhibit along such a streamline. The plots in the bottom row illustrate that using locally linearized streamline approximations with highly nonlinear streamlines can result in severe artifacts, but that by decaying the distance measure's anisotropic characteristics at an appropriate rate, such artifacts can be avoided.

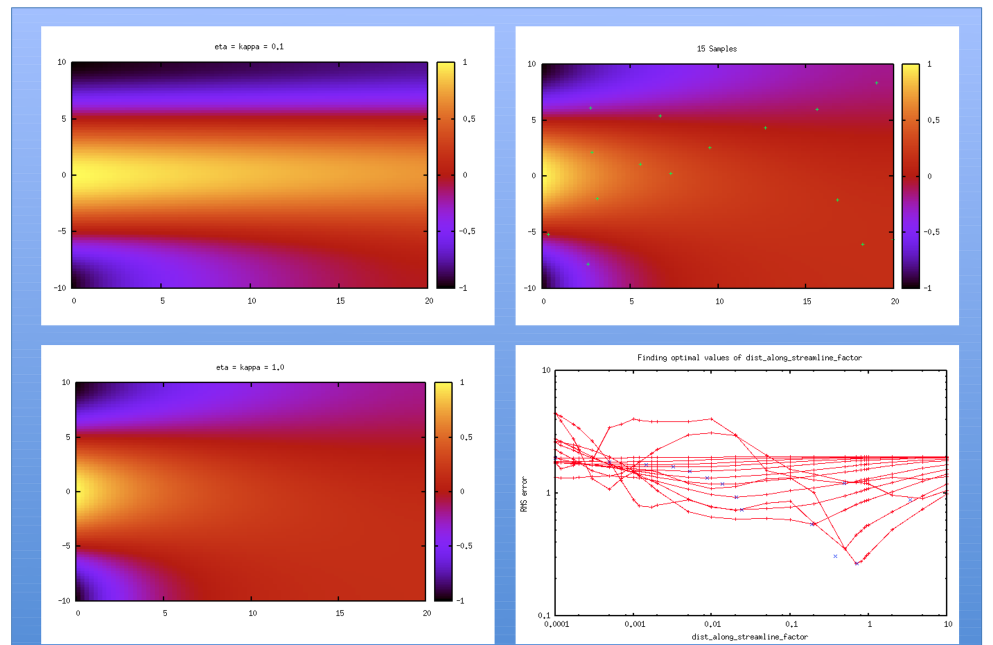
Preliminary Results and Future Work

• We have tested our flow-based interpolators using both simple analytic test cases and simulated 2D flow data. We have found that using flow information for interpolation can lead to more faithful reconstruction of a sparsely sampled scalar field.

• Future work: higher-order expansions for streamline approximation, spatially localized parameter optimization, extension to 3D and application to real oceanographic scattered data.



For a synthetic test case involving an oscillating function whose isocontours are exactly along the streamlines of the associated flow field, the scalar field can be reconstructed relatively well using only the flow field and two sample points.



The plots on the left show 2-dimensional flow fields (for two different diffusivities) created using a finite-difference discretization of an advection-diffusion model solved by computer simulation. Such examples have been used as test cases for our flow-based scattered data interpolation method (top right) and for testing the dynamic optimization of interpolator parameters (bottom right).