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Flow-Based Ocean Reconstructions from Sparse Observations

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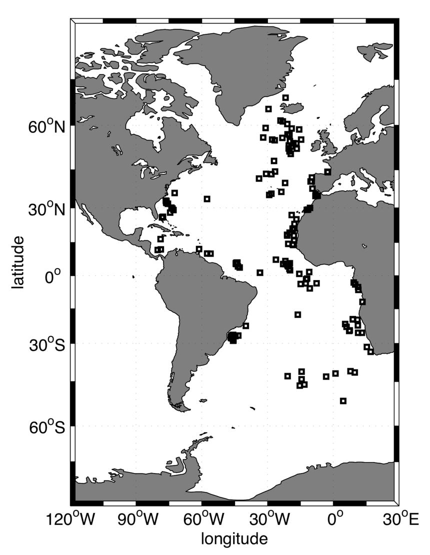
Introduction

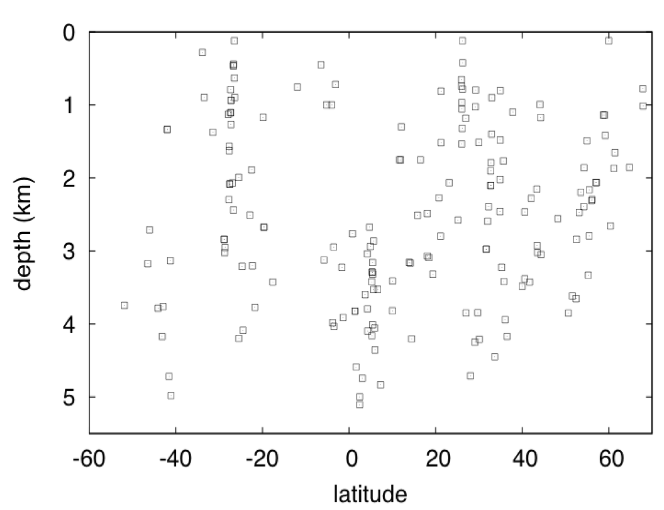
• Problem: high-quality, physically more accurate reconstructions from sparse data

• Data: measurements from benthic foraminifera in deep sea sedimentary cores (e.g., the data compiled by Marchal & Curry [1], shown below, or by Peterson, Lisiecki, & Stern [2])

• Solution: a flow-based reconstruction method useful for interpolating or approximating sparse scattered data in the presence of a flow field

• Insight: exploit correlations between ocean flow and quantities such as $\delta^{13}C$ in order to enhance reconstruction quality



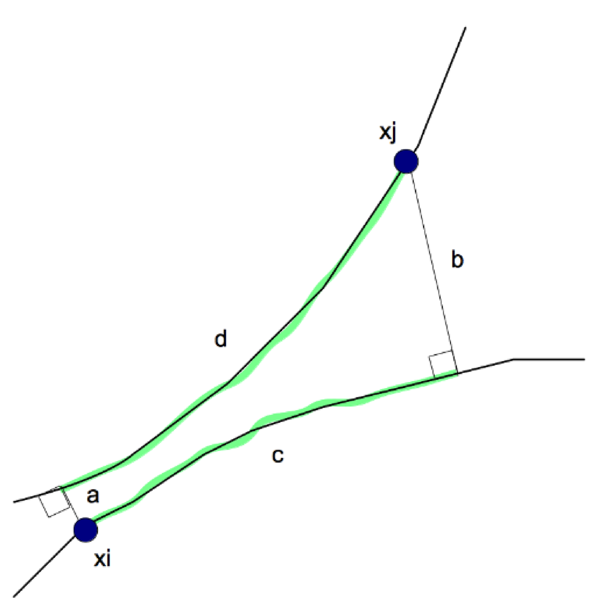


Methods

Non-Euclidean Distance Measures

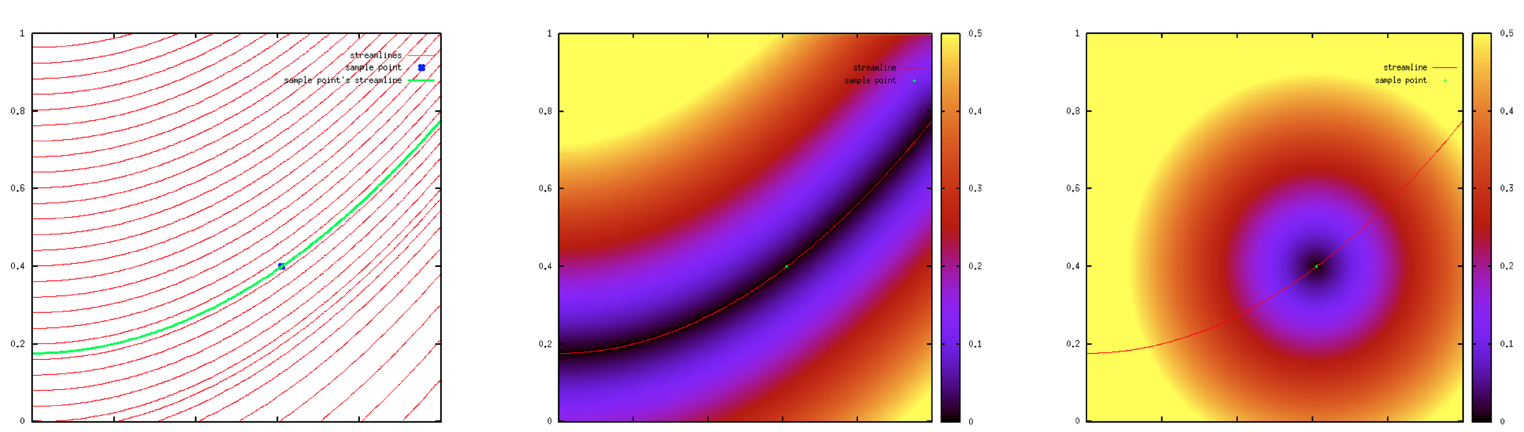
• Use non-Euclidean distance measures to exploit knowledge of flow

• Use a parameter α to assign a relative weight to distances along streamlines (the green distances in the figure to the right) versus distances across streamlines



• Distance functions are used in conjunction with optimal interpolation (OI)

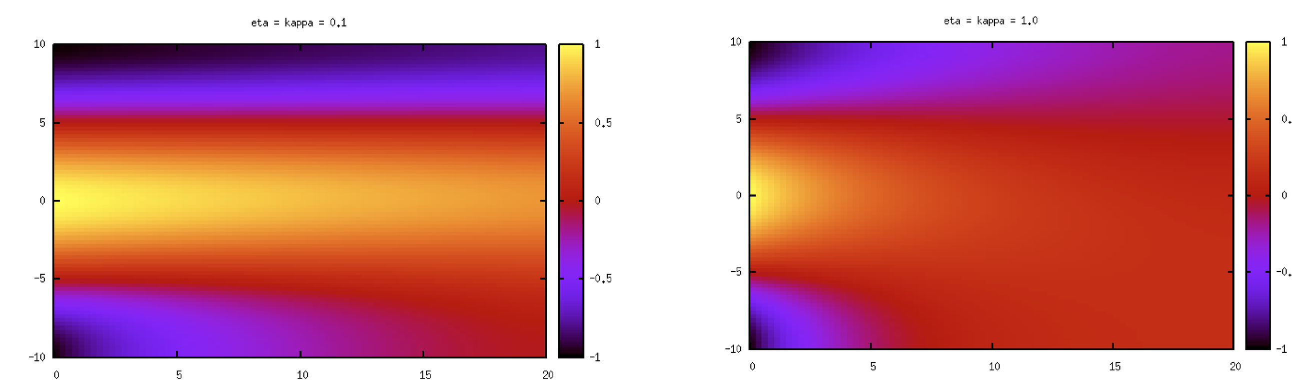
• The distance function illustrated in the middle plot below weights distances across streamlines highly in comparison to distances along streamlines; the distance function on the right is the standard Euclidean distance



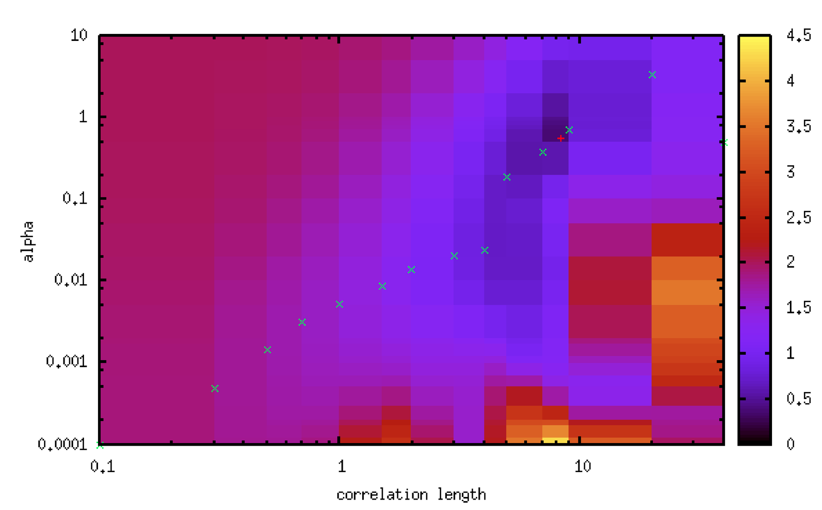
Advection-Diffusion Model Test Cases

•Simulated 2D flow data created through use of a discretized advection-diffusion model

•The plots below illustrate two such test cases, for two different values of diffusivity



Parameter Optimization



• Cross validation between the various samples used to define an objective function to be optimized

• Can then automatically find near-optimal values of parameters such as α

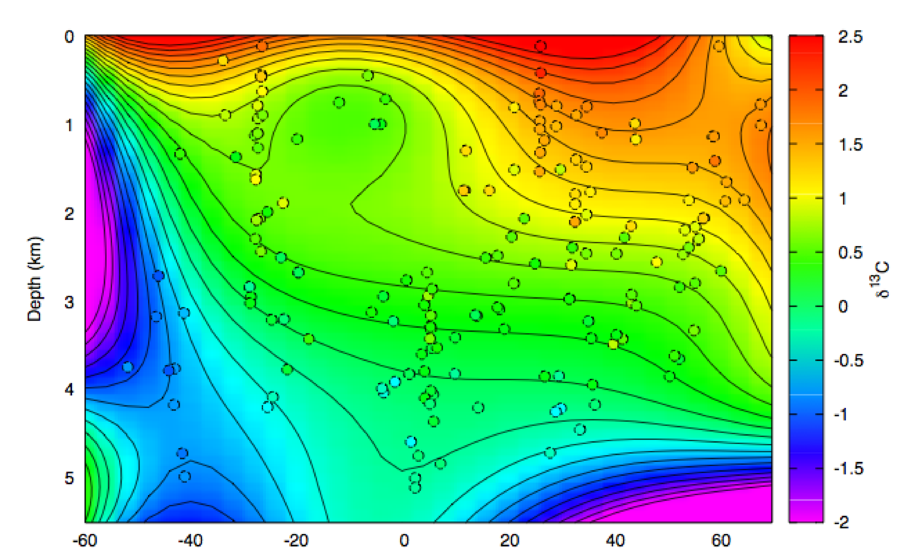
• Plot shows RMS error surface and the corresponding optimizations of α for given correlation lengths (green markers) and simultaneous optimization of correlation length and α (red marker)

Results

• 2D implementation of our flow-based reconstruction method tested using:
  • simple analytic test cases
  • simulated 2D flow data

• 2D version applied to observed ocean data mapped to longitudinal planes

• 3D version of the method also has been implemented and used to create 3D reconstructions of sparse ocean observations such as those in [1] and [2]



• The plot to the left is a reconstruction created using our method applied to the LGM $\delta^{13}C$ data of Marchal & Curry [1]

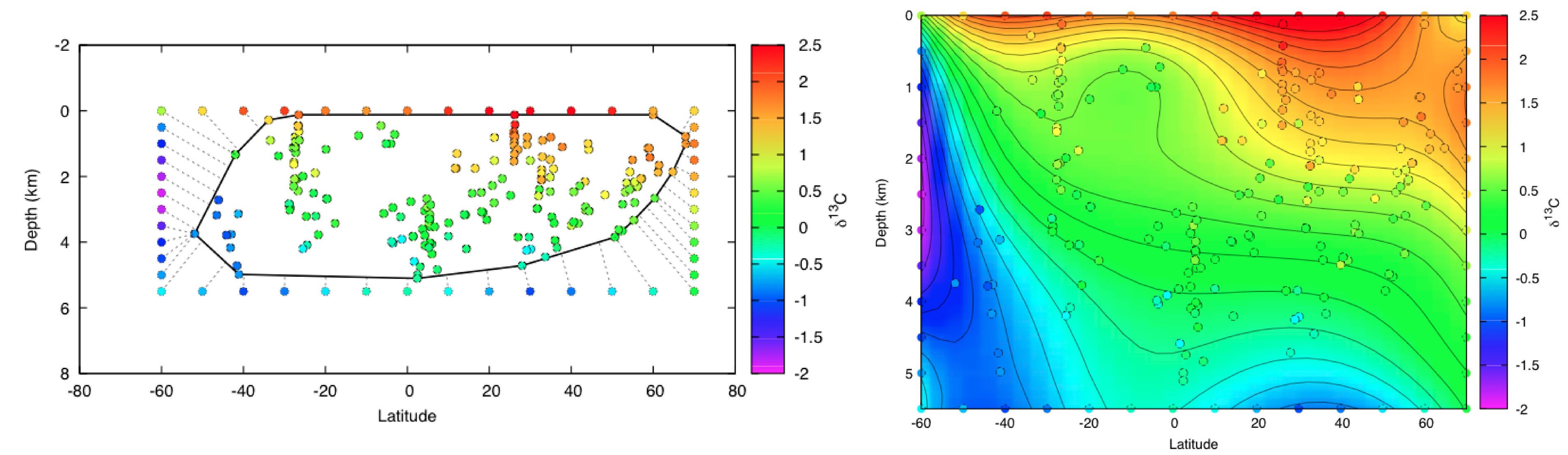
• The reconstruction is reasonable except for the extrapolation artifacts visible near domain boundaries

Extrapolation

• Implemented an extrapolation procedure to mitigate the effect of extrapolation near domain boundaries seen in the previous reconstruction

• Procedure:
  • compute convex hull around the samples (plot on left below)
  • linearly extrapolate data to the domain boundaries
  • re-run flow based reconstruction method with a collection of boundary points added to the original set of sample points

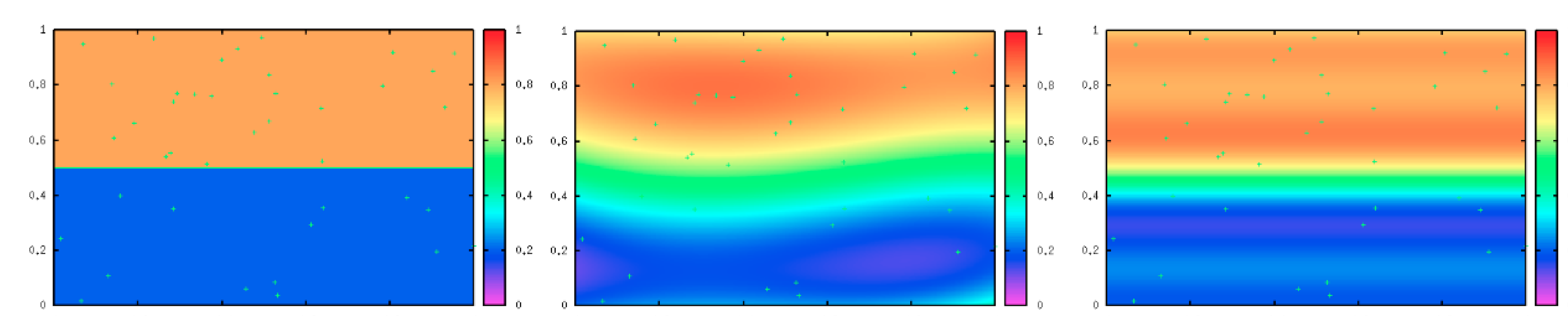
• Note the reduction in extrapolation artifacts in the reconstruction below (right) as compared to the original reconstruction



Water Mass Boundaries

• Our flow-based reconstruction method has desirable properties regarding reconstructions at water mass boundaries

• Shape of boundary of test case (left) is represented more accurately using our method (right) than by using OI only (middle)



Future Work

• Currently testing the 3D implementation of the flow-based reconstruction method

• Plan to use it to perform studies in which dense ocean data (observations of the modern ocean, computational simulations of past oceans) are sampled at various levels of sparseness and then reconstructed using our method, enabling assessment of performance of our method via a direct comparison with data

References

[1] Marchal, O. and Curry, W.B., (2008). On the abyssal circulation in the glacial Atlantic. *Journal of Physical Oceanography,* doi:10.1175/2008JPO3895.1

[2] Peterson, C., Lisiecki, L., and Stern, J. Deglacial whole-ocean $\delta^{13}C$ change estimated from 493 benthic foraminiferal records. Submitted to *Paleoceanography*.