

3D KUWAHARA FILTERING IN SEISMIC FACIES ANALYSIS – PROGRAM **kuwahara3d**

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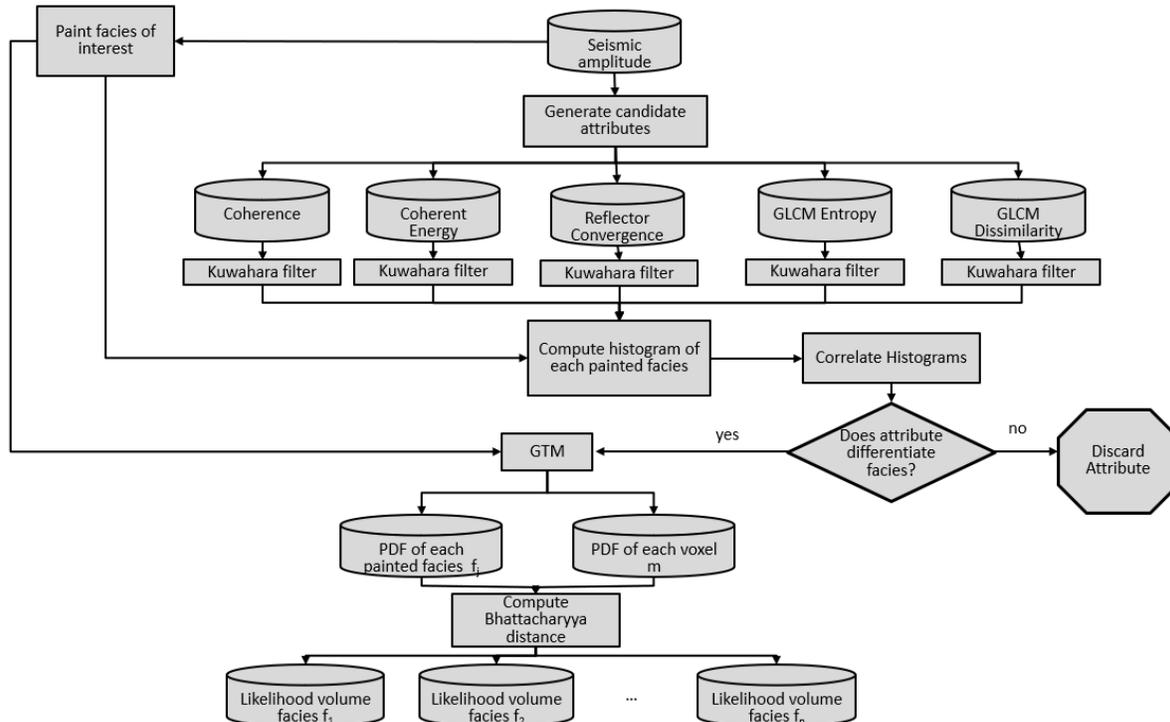
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Overview

The objective of seismic clustering algorithms is to generate a suite of seismic facies for large 3D volumes that exhibit similar attribute expressions. Determining which attributes best quantify a specific amplitude or morphology component seen by the human interpreter, is critical to successful clustering. Unfortunately, many patterns, such as coherence images of salt domes, result in “salt and pepper” classification. Application of 3D Kuwahara median filters smooths the interior attribute response and sharpens the boundary between adjacent facies, thereby preconditioning the attribute volumes for subsequent clustering. Although the figure below shows a GTM classification workflow, other classification workflows that use k-means, SOM, PNN, or RFDT are similar in that we need to do first choose candidate attributes and then filter the chosen attributes using a Kuwahara filter. The flow chart below shows the attribute analysis workflow developed by Qi et al. (2016) to differentiate salt from mass transport complexes from conformal sediments using a GTM algorithm:

Image Processing: Program **kuwahara3d**



In supervised or semisupervised classification, candidate attributes are evaluated by cross-correlating their histograms for each facies, with low correlation implying good facies discrimination and high correlation implying poor facies discrimination. Qi et al. (2016) and Lubo et al. (2021) show that 3D Kuwahara filtering significantly increases such facies discrimination.

Kuwahara filtering

The Kuwahara (1976) filter is an edge-preserving filter that was first developed for medical imaging applications and now is widely used in image processing. Luo et al. (2002) applied the Kuwahara filter to suppress random noise. A variation of this algorithm is implemented in the AASPI structure-oriented filtering program **sof3d** and in the volumetric dip computation program **dip3d**. Applied to photographs, Kuwahara filters result in piecewise monochromatic features separated by sharp boundaries. By localizing the smoothing, the Kuwahara filter properly removes detail, even additive “salt and pepper” noise in high-contrast regions while preserving the shape of the boundaries in low-contrast regions. Kyprianidis et al. (2009) found that the Kuwahara filter “maintains a roughly uniform level of abstraction across the image while providing an overall painting-style look”. Equally important, the Kuwahara filter will smooth rapidly varying attribute anomalies within salt and mass transport complexes to facilitate subsequent clustering.

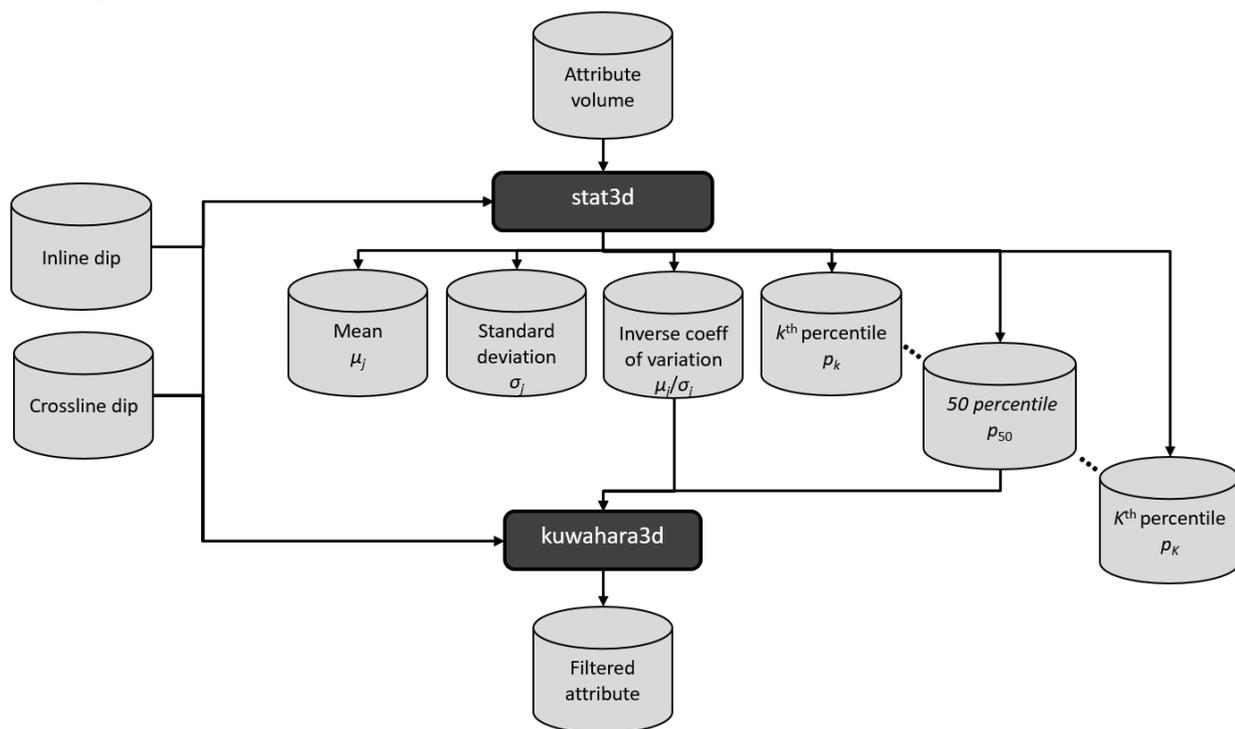
The Kuwahara filter searches all J -voxel windows containing a target output voxel. In our workflow, the analysis windows are oblique cylinders or rectangular prisms aligned whose tops and bottoms are aligned with structural dip. There are J overlapping windows containing the target voxel. For a given attribute, we use program **stat3d** to precompute the mean, μ , the median (p_{50} percentile), m , and the inverse coefficient of variation, $V^{-1} = \mu/\sigma$ for every voxel in the

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attribute volume. The filtered attribute will then be the value of the median (or optionally, the mean) associated with the window having the maximum value of inverse of the coefficient of variation. The smoothness and noise suppression of an image is controlled by the size of the analysis window. If the analysis window length is large, the image will be smoother, but somewhat blocky. If the analysis window is small, the image will be smoothed less, and the blocky pattern will be reduced. Numerical experiments show that cascading two or three small-window filters provided superior results to a single large-window filter at reduced computation cost.

The **kuwahara3d** computation flow chart

Program **kuwahara3d** requires first running program **stat3d**. Only two of the outputs of **stat3d** are used. You always need to input the inverse of the coefficient of variation. The maximum value of the inverse of the coefficient of variation determines the winning analysis window. In terms of smoothing, if you input the p_{50} percentile volume you will apply a median filter in the winning analysis window. Alternatively, if you input the mean volume you will apply a mean filter in the winning analysis window:



Output file naming convention

Program **kuwahara3d** will generate the following output files:

Output file description	File name syntax
Filtered attribute volume	kuwahara_filtered_ <i>unique_project_name_attribute_name_suffix</i> .H
Program log information	kuwahara3d_ <i>unique_project_name_suffix</i> .log

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Program error/completion information	kuwahara3d_
--	-------------

kuwahara3d_	<i>unique_project_name_suffix</i> .err
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where the values in red are defined by the program GUI. The output filtered data volume is written to the *kuwahara_filtered_.H* file. The errors we anticipated will be written to the **.err* file and be displayed in a pop-up window upon program termination. These errors, much of the input information, a description of intermediate variables, and any software trace-back errors will be contained in the **.log* file.

The inverse of the coefficient of variation

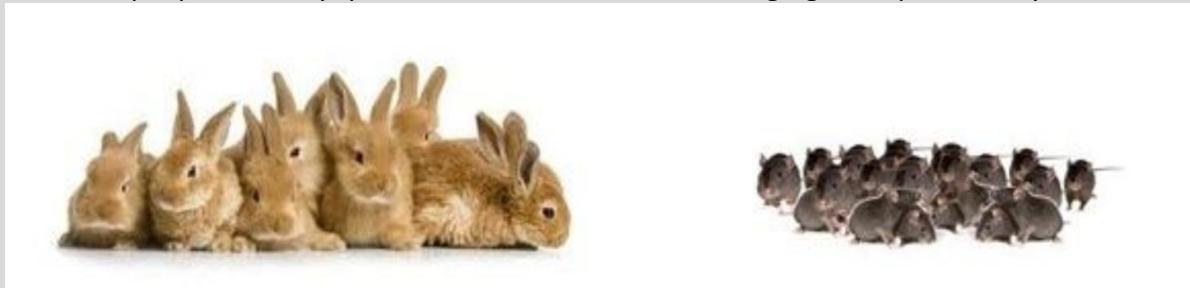
While the variance, standard deviation (Luo et al., 2002), and coherence (Marfurt, 2006) are good ways to choose the best analysis window for seismic amplitude data that exhibit a mean value of zero, seismic attributes have different statistics where the mean value can change significantly across different geologic features. For this reason, we find that the best choice of an overlapping window is the window with highest coefficient of variation, V , which is given by

$$V \equiv \frac{\sigma}{\mu}$$

where σ is the standard deviation, and μ is the mean value of the attribute values that fall within a given analysis window. In some cases, and for some attributes, the mean may be zero, so a more stable parameter to use is the inverse of the coefficient of variation.

$$V^{-1} \equiv \frac{\mu}{\sigma}$$

The example provided by quora.com shown in the following figure is particularly instructive.



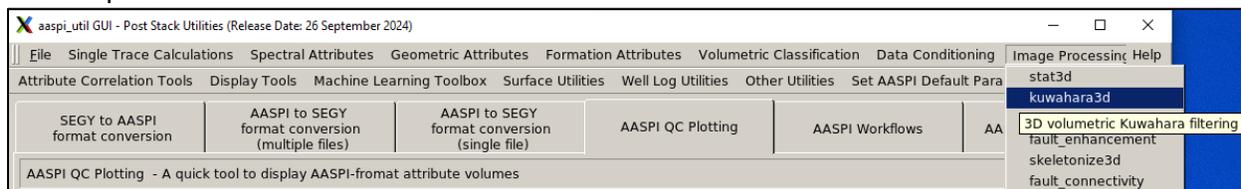
Here the question is “which sample exhibits greater variability—that of the rabbits or of the mice?” They go on to say:

The standard deviation of the weights of rabbits of 0.4 ounces is five times greater than that of the mice of 0.08 ounces. However, the mean weight of the rabbits is 16 ounces whereas the mean weight of the mice is once. Using equation 10, the coefficient of variability of the rabbits is only 2.5% whereas the coefficient of the mice is 8%. With this metric, the mice exhibit more variability.

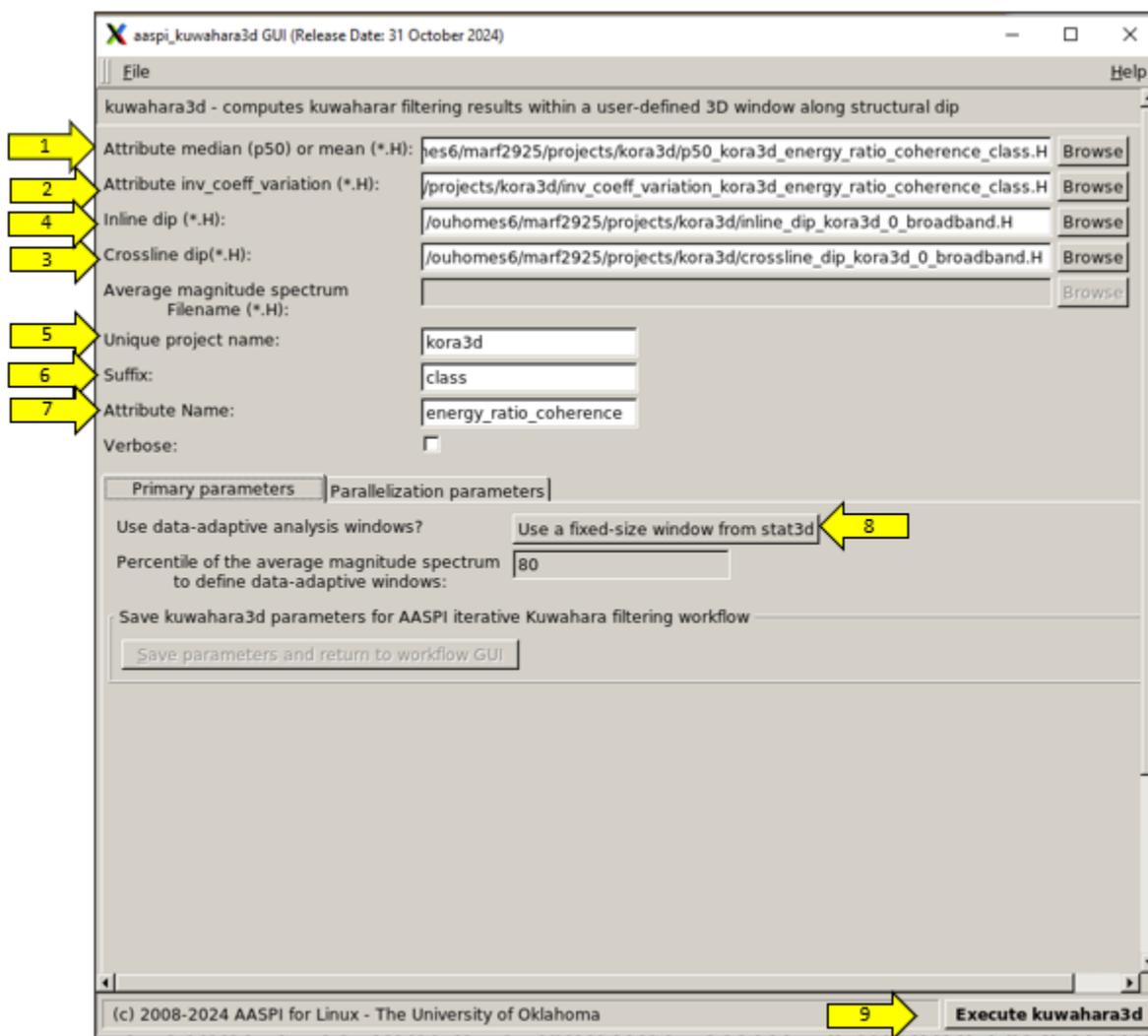
Image Processing: Program **kuwahara3d**

Invoking the **kuwahara3d** GUI

To begin, at the top far right of the **aaspi_util** or **aaspi_main** GUI, click the *Image Processing* tab, and drop down to find **kuwahara3d**:



The following GUI appears:



Begin by (1) selecting the attribute median (p_{50} percentile) or mean volume previously computed in program **stat3d**. The choice of the median will result in the median value of the winning analysis window whereas the mean will result in a mean value of the winning analysis window applied to the output. Next, select the (2) attribute inverse of the coefficient of variation also previously computed in program **stat3d**. In this example I have chosen an energy ratio similarity volume for the Kora3d survey previously processed using program **stat3d**. The analysis windows

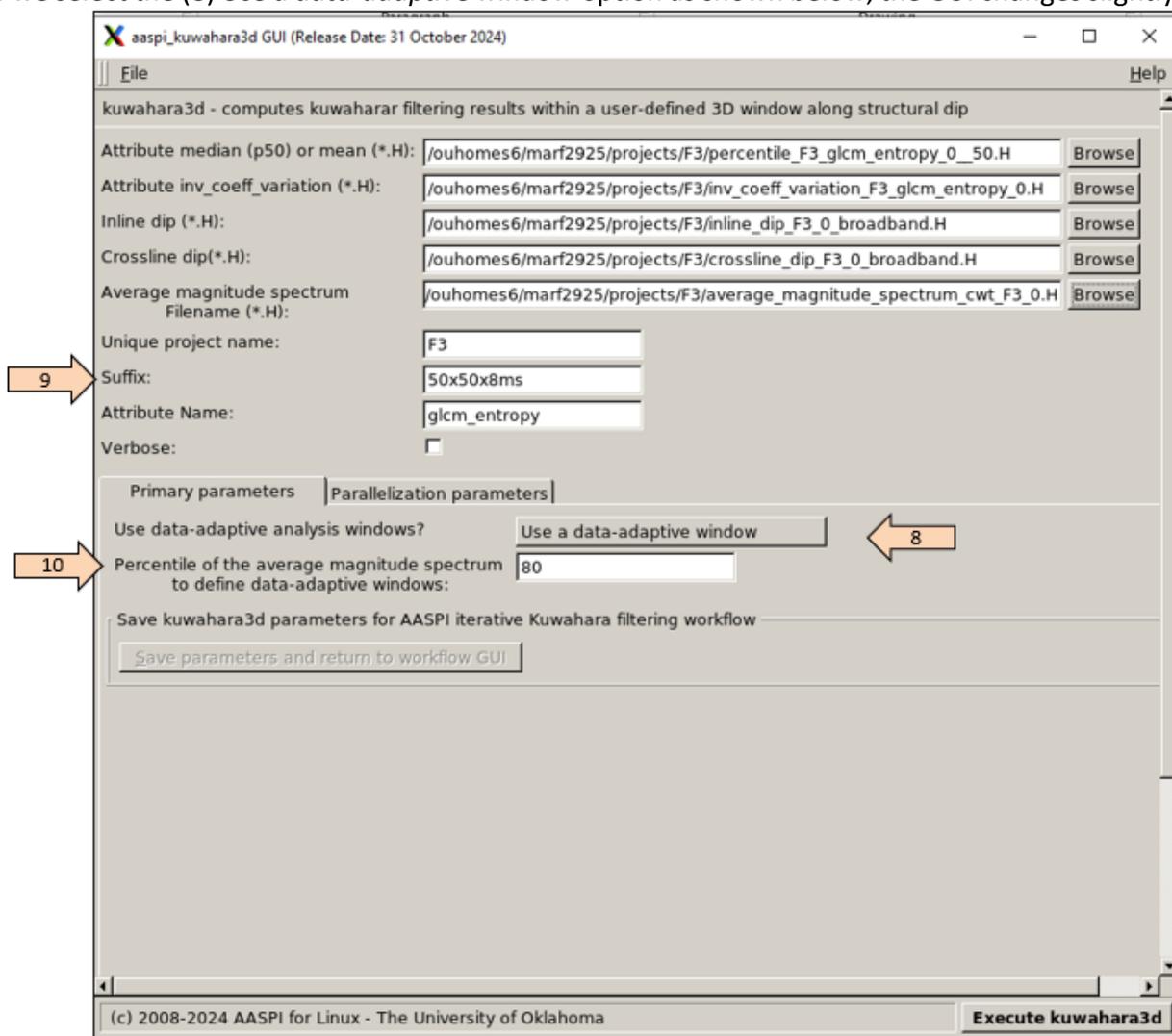
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are oriented along structural dip, so enter the (3) inline and (4) crossline components of volumetric dip as well. As with all AASPI programs we will want to add a (5) *Unique project name*, and a (6) *Suffix*. These two values as well as the (7) *Attribute name* are read from the input median or mean data volume and will be used in constructing the name of the output files.

The Primary parameters tab

For most data, and for target-oriented machine learning applications, you can (8) *Use a fixed-size windows from stat3d*. In this option, the range of the overlapping Kuwahara search windows will be defined to be the same as the analysis window used in program **stat3d**. After modifying the number of processors used, if necessary, simply (9) *Execute kuwahara3d*.

If we select the (8) *Use a data-adaptive window* option as shown below, the GUI changes slightly:



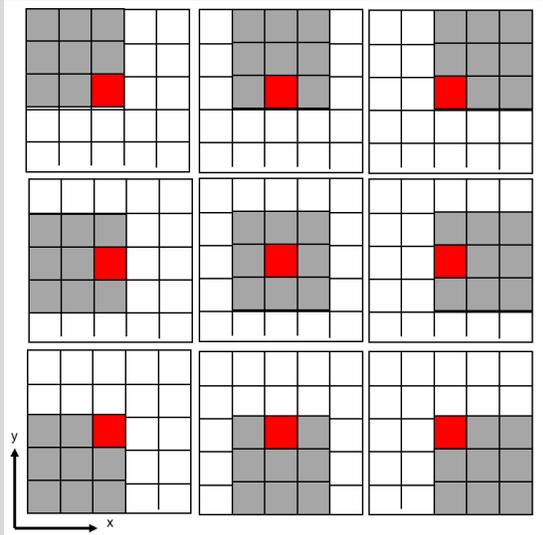
In this option, the window size will be determined by the three parameters: (9) the *Average magnitude spectrum* previously computed using program **spec_cwt** or **spec_cmp**, (10) the *Percentile of average magnitude spectrum* which gives a value f_{ref} . The adaptive window size is then defined by the period defined by $1/f_{ref}$ at each time or depth. Using the value of the velocity

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used in computing the structural dip volumes provides an adaptive analysis window length and height. In this case, the window size will typically become larger as we lose higher frequencies and vertical resolution with increasing time.

Overlapping windows

The following cartoon from Qi et al. (2016) shows the mechanics of Kuwahara filter analysis for a 2D example.



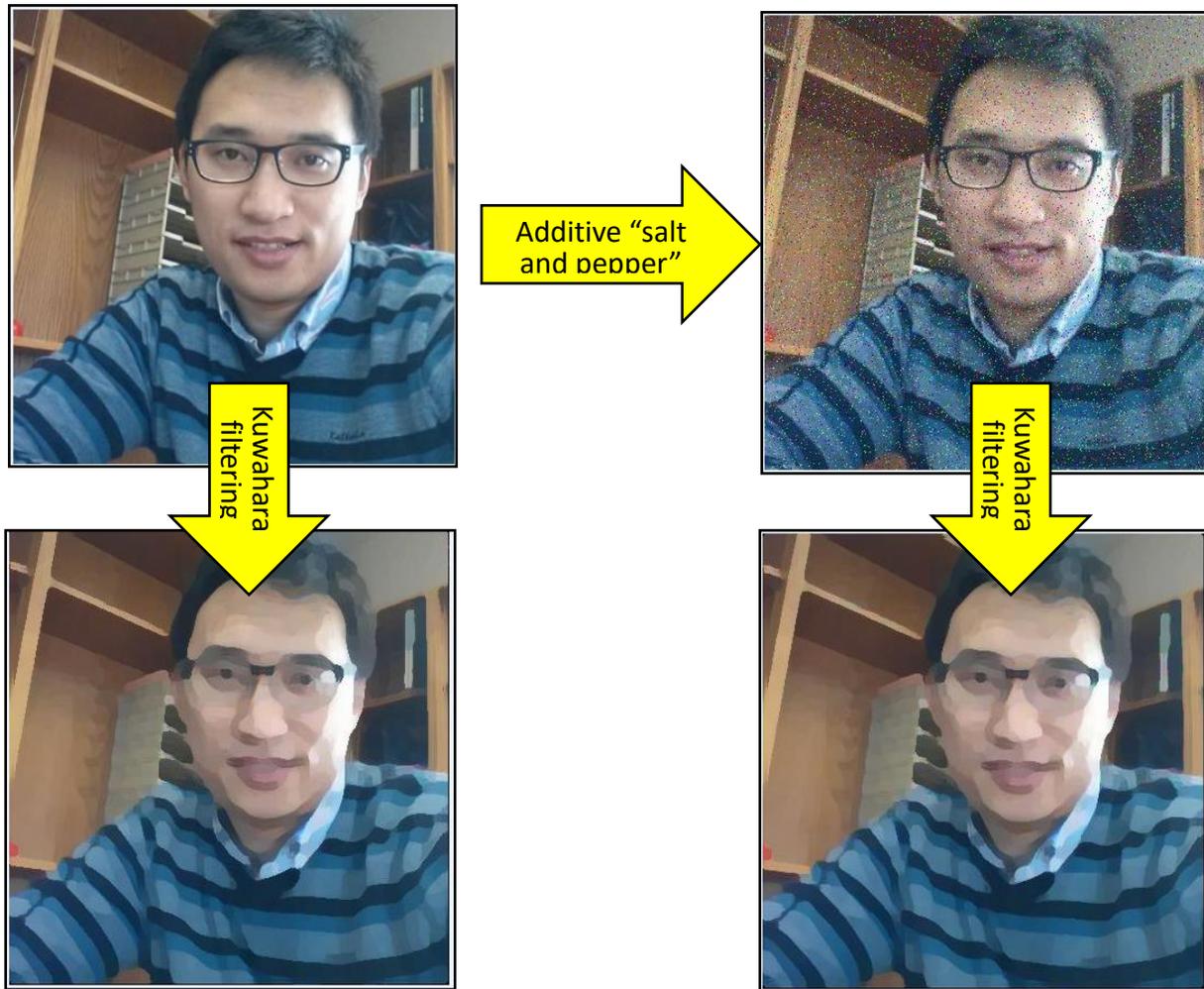
The input data include 25 samples centered about the red square. Gray squares indicate voxels used in the nine laterally shifted nine-sample analysis windows, each of which contains the output location indicated by the red square. The output is the mean or the median of that gray window that has the largest inverse of coefficient of variation. In 3D, we evaluate 125 neighboring voxels and compute the mean, the median, and standard deviation in 27 overlapping 3×3×3 analysis windows.

Examples

The documentation for AASPI program **dip3d** showed how we used a 3D Kuwahara filter to choose the best of multiple 3D overlapping windows to improve the lateral and vertical resolution of volumetric dip. The documentation for AASPI program **sof3d** showed how we used a 2D Kuwahara filter to choose the best of multiple 3D overlapping windows to apply structure-oriented filtering. In both of these examples we used the value of coherence in each window to choose the winning window.

Example 1: A 2D Kuwahara filter applied to a digital photograph

The figure below shows the application of a 2D Kuwahara filter to a photograph of Jie Qi. On the top left is the original photograph. On the top right is the same photograph with additive noise:

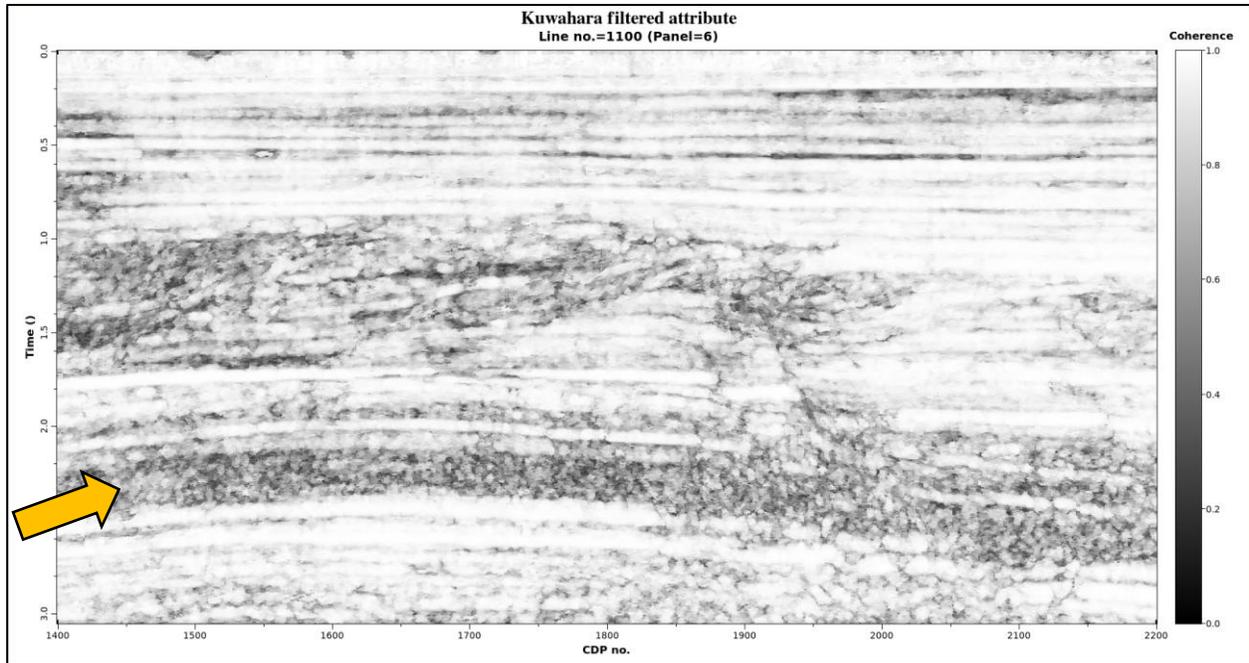


Qi et al. (2016) applied a 2D Kuwahara filter to both images to each of R, G, and B components of the photos. The Kuwahara filter smooths the noise and signal when they are smaller than the window size (such as the wood grain on the bookshelves) but preserves the major edges. Some of the edges, such as those on his cheeks and forehead, capture changes in lighting, but otherwise are not real, giving rise to a “paint-by-numbers” appearance.

Example 2: Application to the Kora3d survey

The results of executing the `kuwahara3d` GUI above gives a file named `kuwahara_filtered_kora3d_energy_ration_similarity_class.H` and looks like this:

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which we compare to the median (p50) and mean filtered attribute previously computed using program **stat3d**:

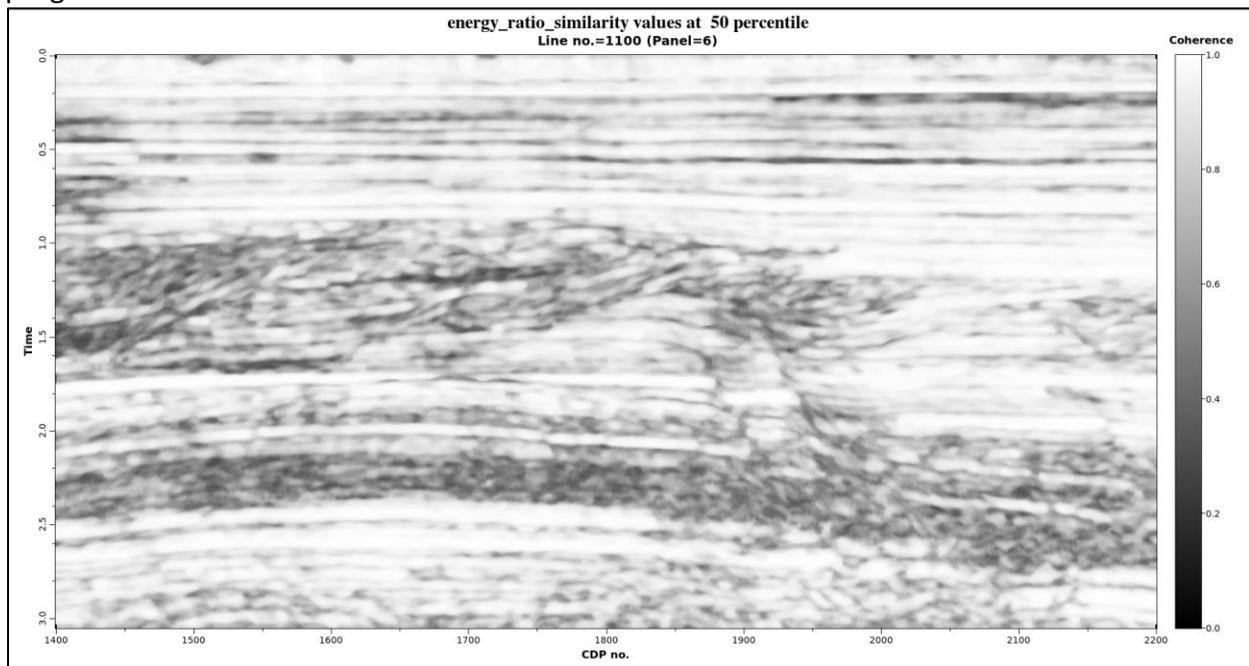
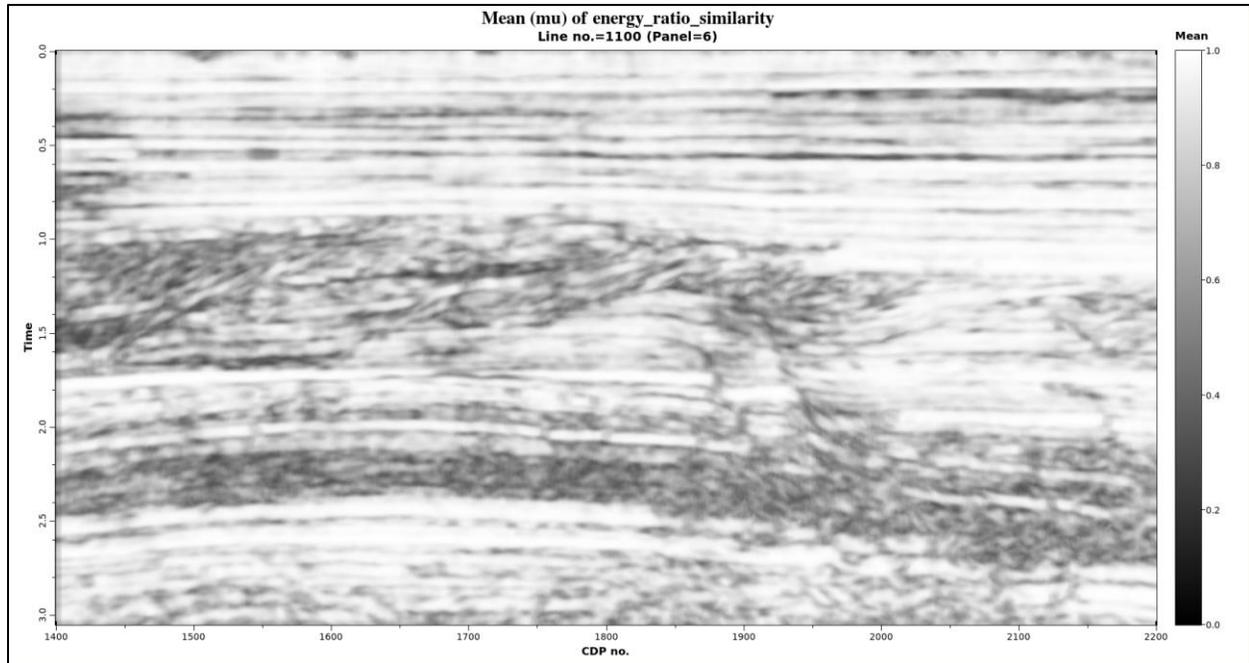


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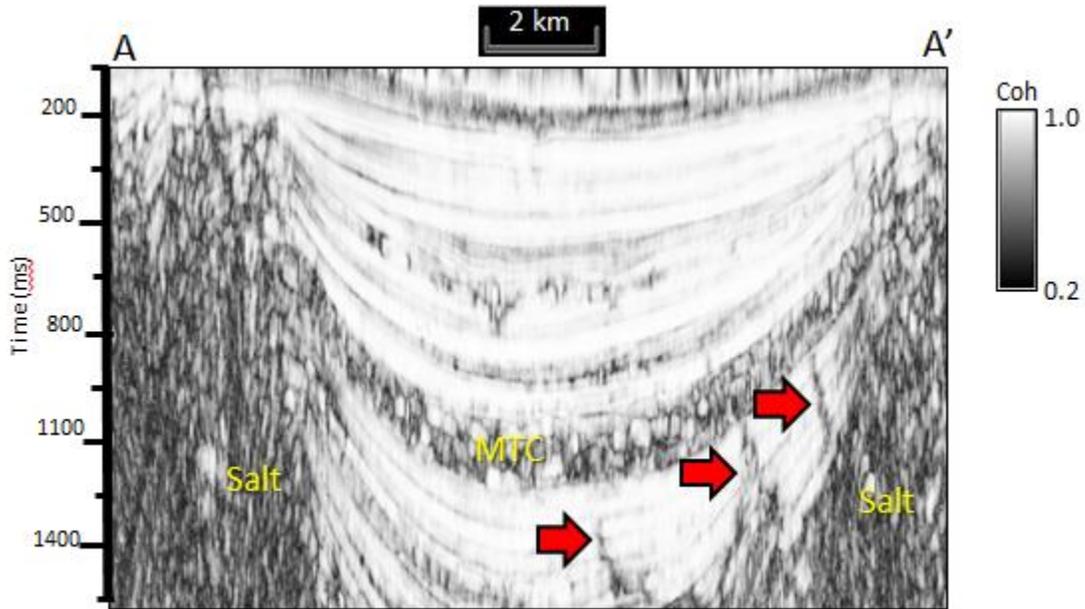


All three filters “smear” the salt-and-pepper discontinuity pattern seen in the original attribute volume of chaotic facies indicated by the orange arrow. Note also how the boundaries of the chaotic facies are sharper after Kuwahara filtering than when using the simpler median and mean filters of the same size.

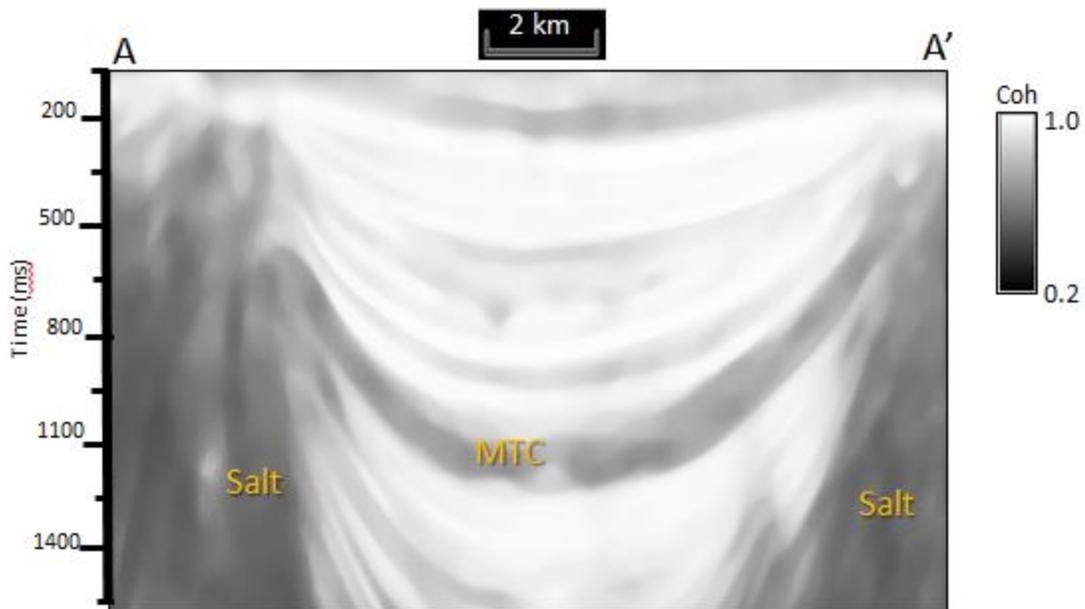
Example 3: Application to a Gulf of Mexico survey

The following example comes from Qi et al. (2016) who cascaded three iterations of Kuwahara filtering using a small $3 \times 3 \times 3$ analysis window in both programs **stat3d** and **kuwahara3d** for a Gulf of Mexico survey exhibiting conformal sediments, mass transport complexes and salt diapirs among other features. He found such cascading was not only more effective, but also computational more efficient than using a single $7 \times 7 \times 7$ analysis window. The first image shows a vertical slice through the original coherence volume:

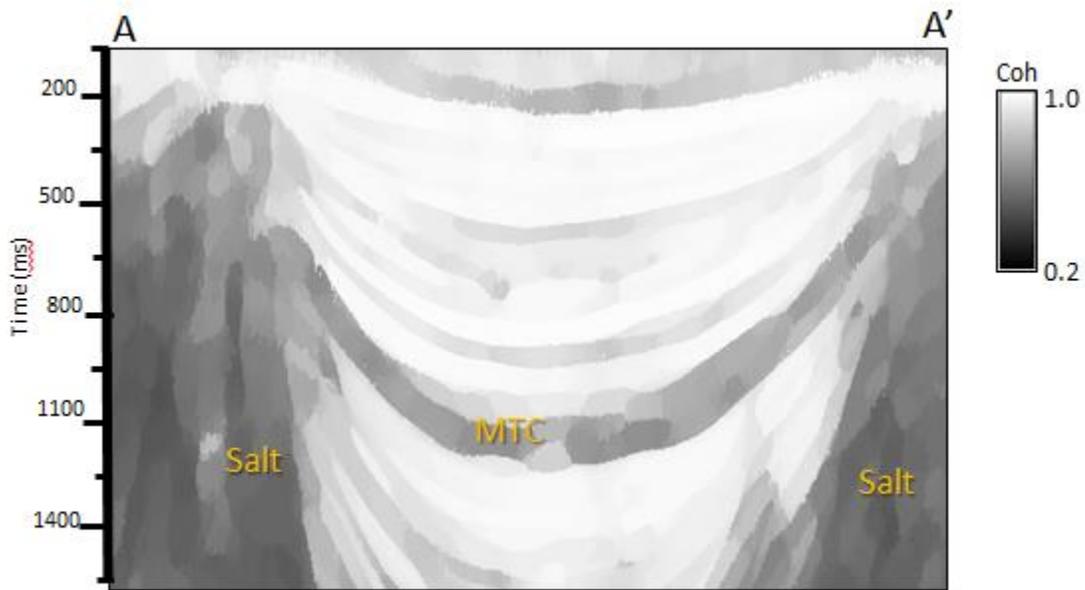
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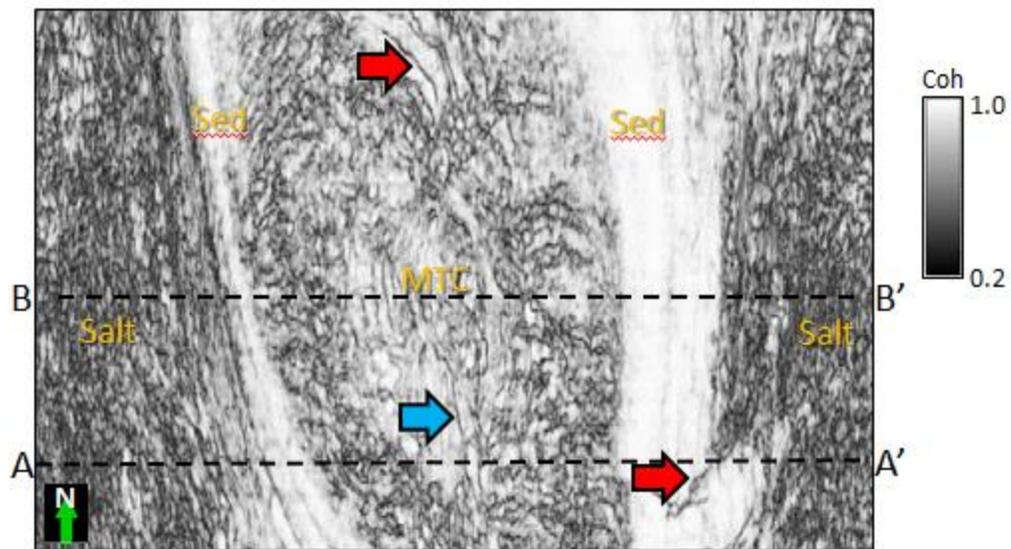
The next image shows the results of cascading three iterations of a 3×3×3 median filter using program **stat3d**, where you will note the salt-and-pepper pattern has been smoothed, but also the facies edges:



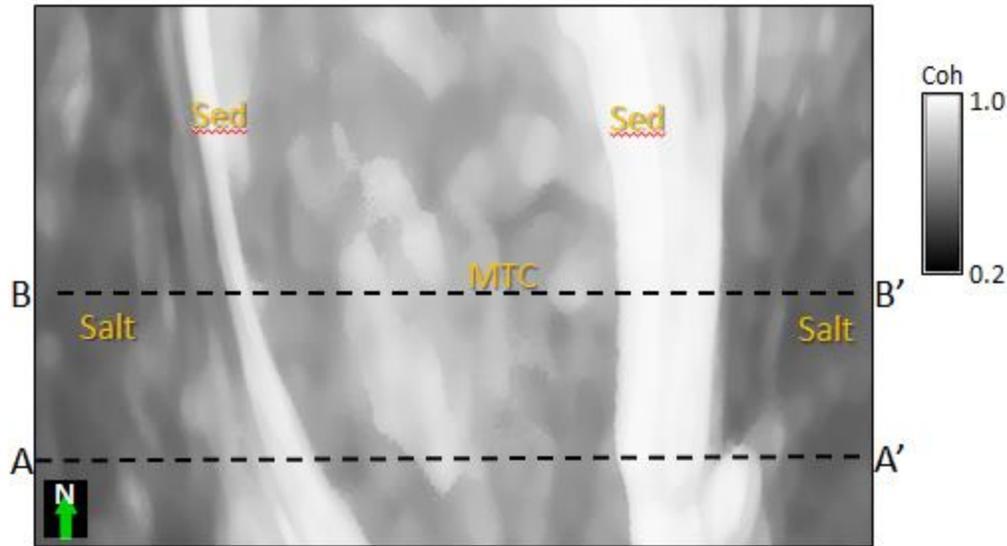
The final image shows the results of cascading three iterations of a 3×3×3 Kuwahara filter using programs **stat3d** and **kuwahara3d** together. Note that the smoothing is similar internal to the different facies, but the facies edges are sharper, facilitating subsequent machine learning seismic facies classification:



Qi et al. (2016) also examine time slices. The first time slice is through the original coherence volume:

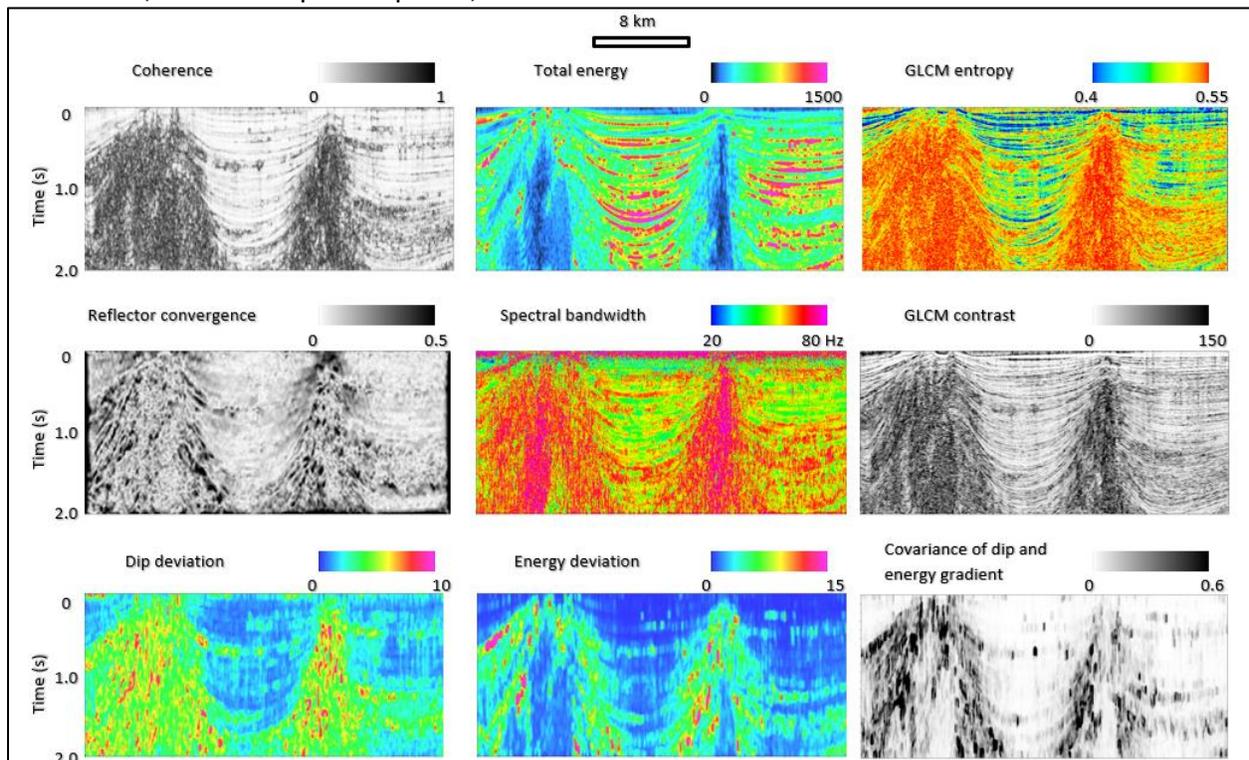


The next image shows the same time slice after cascading three iterations of a 3×3×3 Kuwahara filter using programs **stat3d** and **kuwahara3d** together where we see the boundaries between the salt, mass transport complexes, and conformal sediments are preconditioned for facies classification using machine learning.

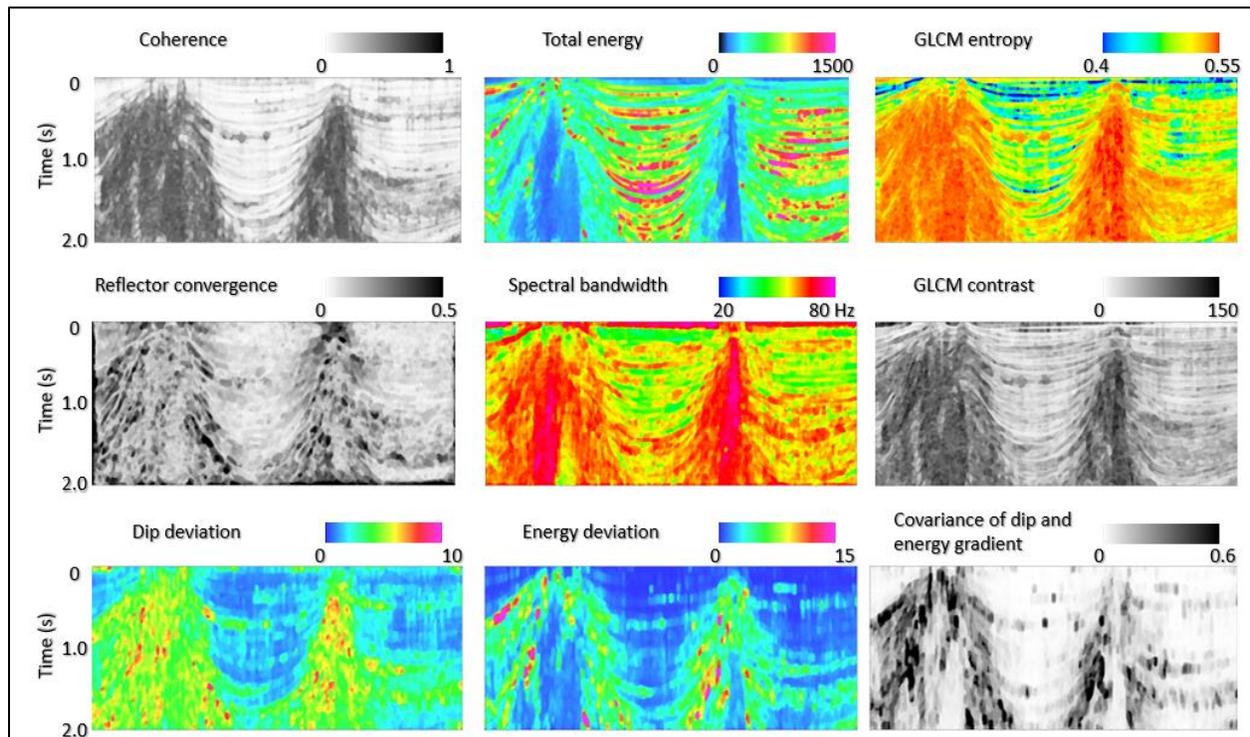


Example 4: Filtering of Gulf of Mexico attribute volumes for subsequent PNN analysis

The next sample shows Kuwahara filtering applied to eight different data volumes from Lubo-Robles et al. (2021) or a survey acquired offshore Louisiana, Gulf of Mexico, U.S.A. where we see salt domes, mass transport deposits, and conformal sediments.



In this work, the Kuwahara filter was performed as a single pass using a larger 5x5x5 voxel filter. The resulting attribute volumes shown below are piecewise smoother, preconditioning then for subsequent machine learning driven seismic facies classification. Note the reduction in “speckles” particularly within the salt and the preservation of sharp edges between different facies.



References

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- Qi, J., T. Lin, T. Zhao, F. Li, and K. J. Marfurt, 2016, Semisupervised multiattribute seismic facies analysis: *Interpretation*, 4, no. 1, SB91–SB106, doi: [10.1190/INT-2015-0098.1](https://doi.org/10.1190/INT-2015-0098.1).
- Qi, J., B. Zhang, B. Lyu, and K. Marfurt, 2020, Seismic attribute selection for machine-learning-based facies analysis: *Geophysics*, 85, O17–O35.