regions, the expectations were that the response to filtering would vary with these flow characteristics. All filtering here is performed in the dissipation range of the Kolmogorov spectrum, at filter sizes from 4 to 16 times the DNS grid spacing. The small-scale (subgrid scale, SGS) dissipation was found by subtracting the filtered-field dissipation from the DNS-field dissipation.

In contrast to the DNS dissipation, the SGS dissipation is not necessarily positive; negative values indicate backscatter. Backscatter was shown to be spatially widespread in all modes of dissipation and in the total dissipation (25 to 60 percent of the domain). The maximum magnitude of the negative subgrid-scale dissipation was as much as 17 percent of the maximum positive subgrid-scale dissipation, indicating that, not only is backscatter spatially widespread in these flows, but it is considerable in magnitude and cannot be ignored for the purposes of LES modeling. The Smagorinsky model, for example, is unsuited for modeling SGS fluxes in the LES because it cannot render backscatter. With increased filter size, there is only a modest decrease in the spatial extent of backscatter. The implication is that even at large LES grid spacing, the issue of backscatter and related SGS-flux modeling decisions are unavoidable.

As a fraction of the total dissipation, the small-scale dissipation is between 10 and 30 percent of the total dissipation for a filter size that is four times the DNS grid spacing, with all OH cases bunched at 10 percent, and the HN cases spanning 24–30 percent. A scale similarity was found in that the domain-average proportion of each small-scale dissipation mode, with respect to the total small-scale dissipation, is very similar to equivalent results at the DNS scale. With increasing filter size, the proportion of the small-scale dissipation in the dissipation increases substantially, although not quite proportionally. When the filter size increases by four-fold, 52 percent for all OH runs, and 70 percent for HN runs, of the dissipation is contained in the subgrid-scale portion with virtually no dependence on the initial conditions of the DNS.

The indications from the dissipation analysis are that modeling efforts in LES of thermodynamically supercritical flows should be focused primarily on mass-flux effects, with temperature and viscous effects being secondary. The analysis also reveals a physical justification for scale-similarity type models, although the suitability of these will need to be confirmed in *a posteriori* studies.

This work was done by Josette Bellan and Nora Okong'o of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-46389

Superpixel-Augmented Endmember Detection for Hyperspectral Images

Hyperspectral image analysis can be used in remote sensing or industrial applications such as automated detection of manufacturing defects.

NASA's Jet Propulsion Laboratory, Pasadena, California

Superpixels are homogeneous image regions comprised of several contiguous pixels. They are produced by shattering the image into contiguous, homogeneous regions that each cover between 20 and 100 image pixels. The segmentation aims for a many-to-one mapping from superpixels to image features; each image feature could contain several superpixels, but each superpixel occupies no more than one image feature. This conservative segmentation is relatively easy to automate in a robust fashion.

Superpixel processing is related to the more general idea of improving hyperspectral analysis through spatial constraints, which can recognize subtle features at or below the level of noise by exploiting the fact that their spectral signatures are found in neighboring pixels. Recent work has explored spatial constraints for endmember extraction, showing significant advantages over techniques that ignore pixels' relative positions. Methods such as AMEE (automated morphological endmember extraction) express spatial influence using fixed isometric relationships — a local square window or Euclidean distance in pixel coordinates. In other words, two pixels' covariances are based on their spatial proximity, but are independent of their absolute location in the scene. These isometric spatial constraints are most appropriate when spectral variation is smooth and constant over the image.

Superpixels are simple to implement, efficient to compute, and are empirically effective. They can be used as a preprocessing step with any desired endmember extraction technique. Superpixels also have a solid theoretical basis in the hyperspectral linear mixing model, making them a principled approach for improving endmember extraction. Unlike existing approaches, superpixels can accommodate non-isometric covariance between image pixels (characteristic of discrete image features separated by step discontinuities). These kinds of image features are common in natural scenes.

Analysts can substitute superpixels for image pixels during endmember analysis that leverages the spatial contiguity of scene features to enhance subtle spectral features. Superpixels define populations of image pixels that are independent samples from each image feature, permitting robust estimation of spectral properties, and reducing measurement noise in proportion to the area of the superpixel. This permits improved endmember extraction, and enables automated search for novel and constituent minerals in very noisy, hyperspatial images.

This innovation begins with a graph-based segmentation based on the work of Felzenszwalb et al., but then expands their approach to the hyperspectral image domain with a Euclidean distance metric. Then, the mean spectrum of each segment is computed, and the resulting data cloud is used as input into sequential maximum angle convex cone (SMACC) endmember extraction.

This work was done by David R. Thompson and Rebecca Castaño of Caltech, and Martha S. Gilmore of Wesleyan University for NASA's Jet Propulsion Laboratory. For more information, contact iaoffice@jpl.nasa.gov. NPO-47358