Regularization in Maximum Log-likelihood Method for CRISM Hyperspectral Image Cube

L. He[1], R. E. Arvidson[2], J. A. O'Sullivan[1], and D. V. Pollite[1],
[1]Department of Electrical and Systems Engineering, Washington University in St. Louis,
[2]Department of Earth and Planetary Sciences, Washington University in St. Louis

Methodology

❑Background

The Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on the Mars Reconnaissance Orbiter (MRO) began operating in 2006. CRISM is a push-broom hyperspectral imaging spectrometer from 362 to 3920 nm with 6.5 nm spectral band spacing and a smallest ground pixel size of 18 m. Since 2010 images have also been acquired using a gimbaled, along track oversampled (ATO) model, with significant pixel overlapping in the along-track direction. The oversampling allows reconstruction of projected image cubes at 9 to 12 m/pixel. CRISM operates as S (362 to 1030 nm) and L (1036 to 2650 nm) imaging spectrometers.

❑Pre-processing

1. Retrieval of surface Single Scattering Albedos (SSAs) via radiative modeling
2. Extrema removal by median filter in the spectral domain

❑Optimization

Measurements: $\mathbf{d} = [d_1, d_2, \ldots, d_N]^T$. Estimates: $\boldsymbol{\lambda} = [\lambda_1, \lambda_2, \ldots, \lambda_N]^T$. Image: $\mathbf{c} = [c_1, c_2, \ldots, c_M]^T$.
Linear System Model: $H \in \mathbb{R}^{N\times M}$, $\boldsymbol{\lambda} = H\mathbf{c}$.
Regularization: $\Phi_1(\mathbf{c}) = \sum_j w_j \sum_{c_k \in NA(c_j)} \beta\delta^2 \ln\cosh\frac{c_k - c_j}{\delta}$,
$\Phi_2(\mathbf{c}) = \sum_j w_j \sum_{c_k \in NE(c_j)} \eta(-\ln\frac{c_j}{c_k} - 1 + \frac{c_j}{c_k})$

$$\min_{\mathbf{c}} \sum_{i=1}^{N}\left[d_i \ln\frac{d_i}{\lambda_i} - d_i + \lambda_i\right] + \Phi_1(\mathbf{c}) + \Phi_2(\mathbf{c})$$
$$s.t.\ \boldsymbol{\lambda} = H\mathbf{c}$$

❑Algorithm

Algorithm Maximum Log-likelihood Method with Regularization

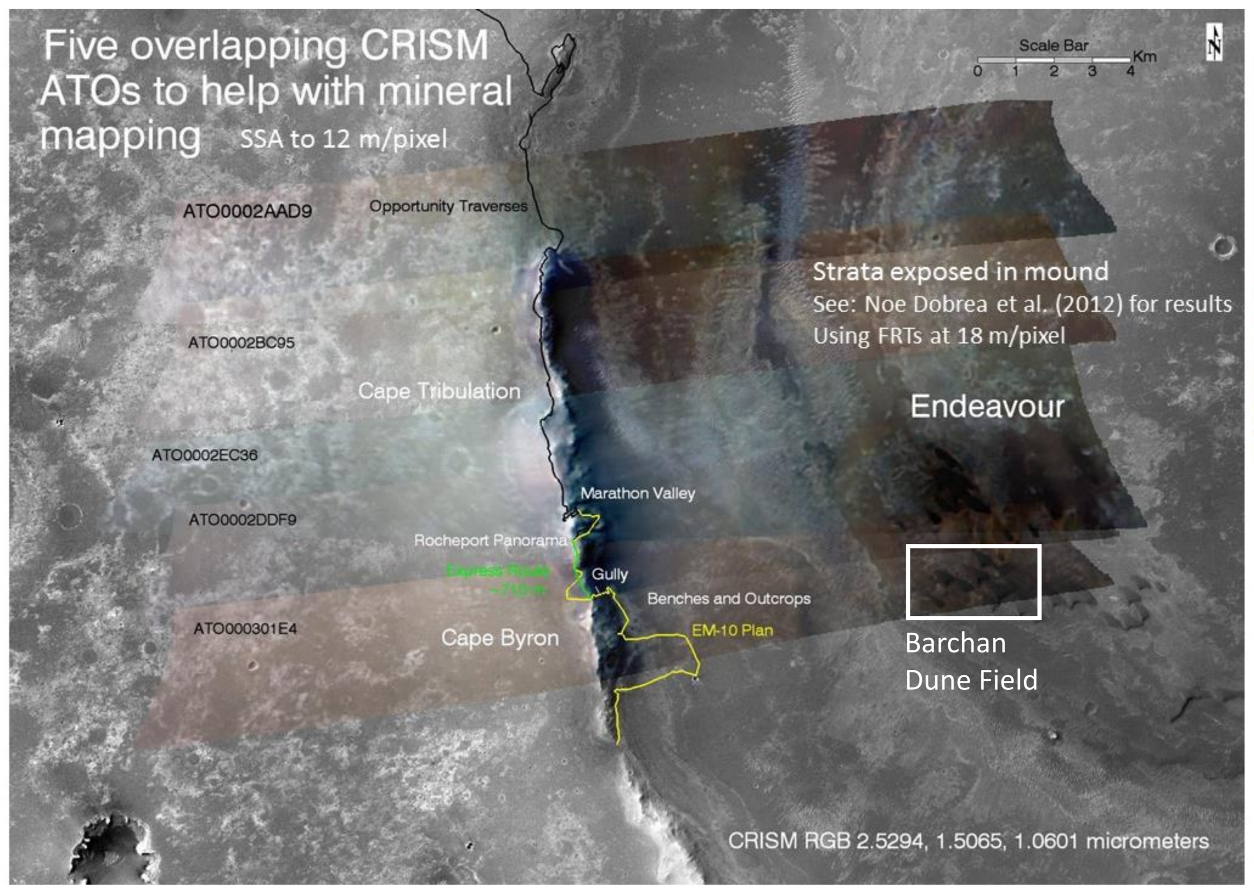
Input: measure data $\mathbf{d} = [d_1, \cdots, d_N]^T \in \mathbb{R}_+^N$, transfer function $H \in \mathbb{R}^{N\times M}$, maximum iterations $maxiter$, penalty parameter β, δ, η
Output: reconstructed image $\mathbf{c} = [c_1, \cdots, c_M]^T \in \mathbb{R}_+^M$, estimate data $\boldsymbol{\lambda} = [\lambda_1, \cdots, \lambda_N]^T \in \mathbb{R}_+^N$
Start:
Initialize $c^{(1)}$, compute sensitivity $\mathbf{h} = H^T ones \in \mathbb{R}^N$ where $ones = [1, \cdots, 1]^T \in \mathbb{R}^M$ and determine w_j
for $t = 1 \to maxiter$
Forward Projection: $\boldsymbol{\lambda}^{(t)} = H\mathbf{c}^{(t)}$
Data Modification: $b_i^{(t)} = d_i/\lambda_i^{(t)}$
Backward Projection: $\mathbf{f}^{(t)} = H^T\mathbf{b}^{(t)}$
Update: $\mathbf{c}^{(t+1)} =$
$\arg\min_{\mathbf{c}=[c_1,\cdots,c_M]^T} \sum_i -c_i^{(t)} f_i^{(t)} \ln c_i + h_i c_i + \Phi_1(\mathbf{c}) + \Phi_2(\mathbf{c})$
end

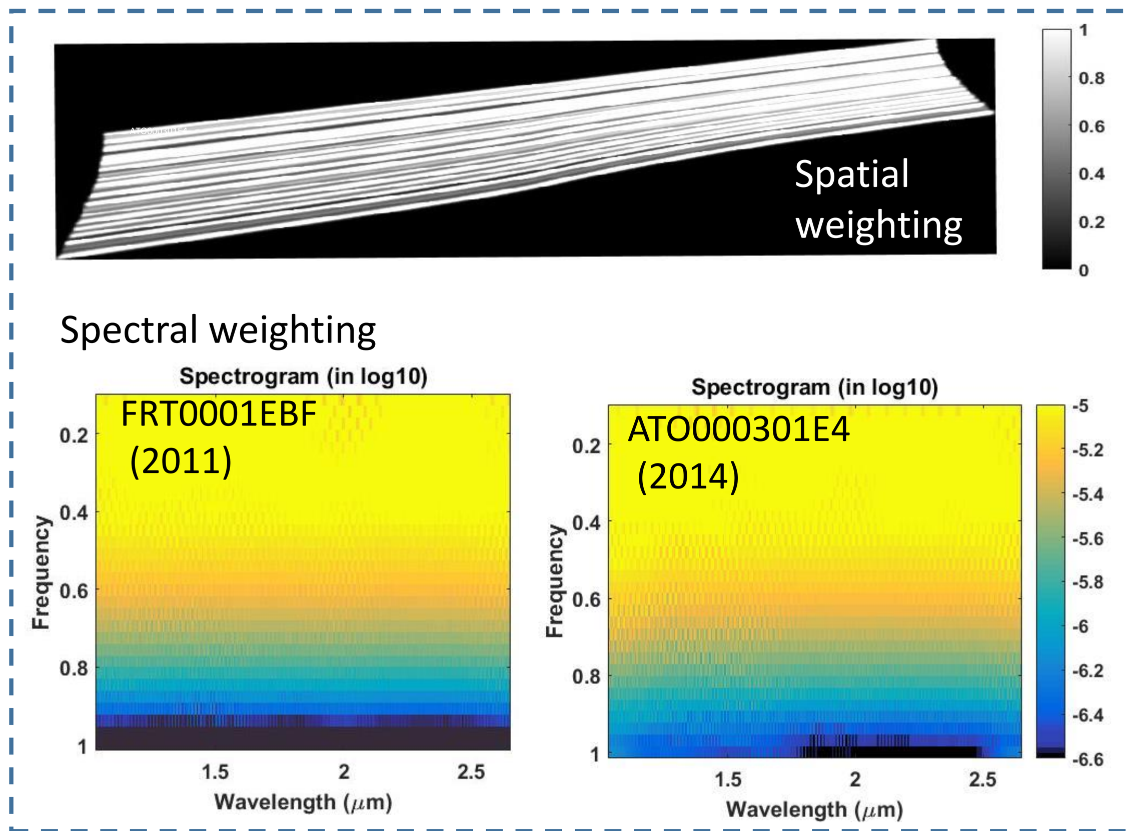
Note: 1. H^T is the transpose of H; 2. N is the number of measure data and M is the number of image pixels; 3.Update step is solved by our fast algorithm.

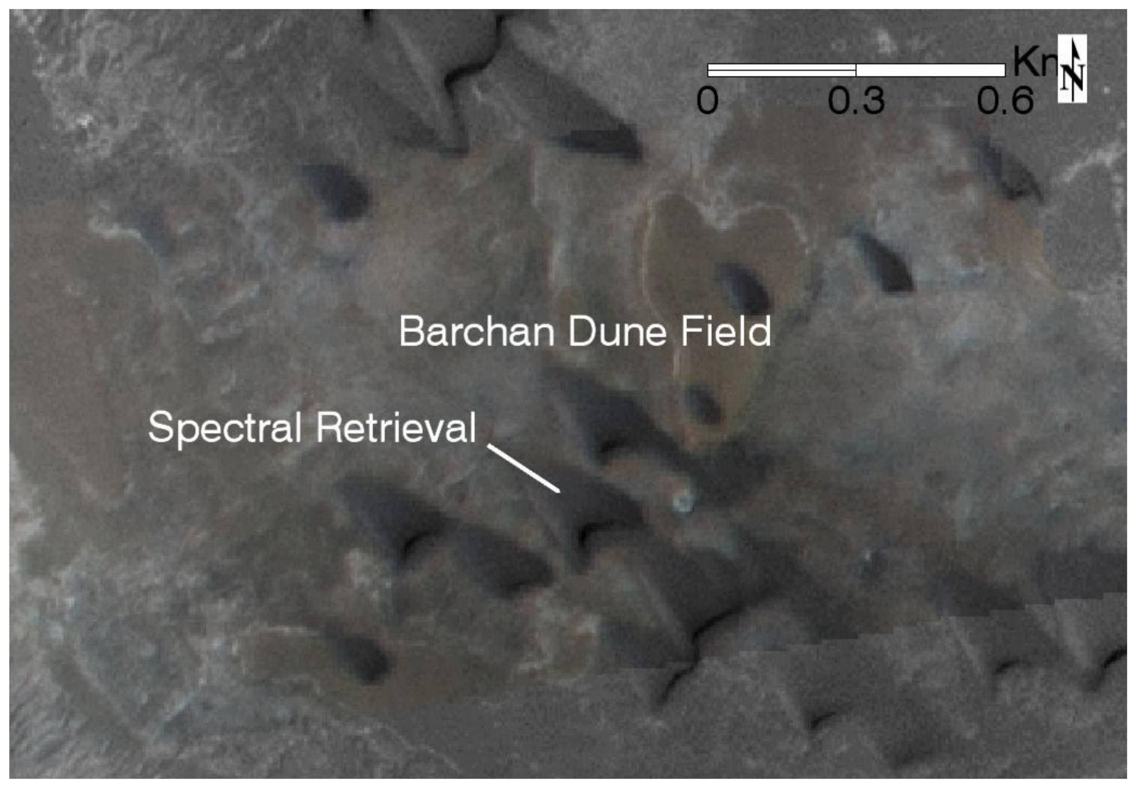
❑Conclusion

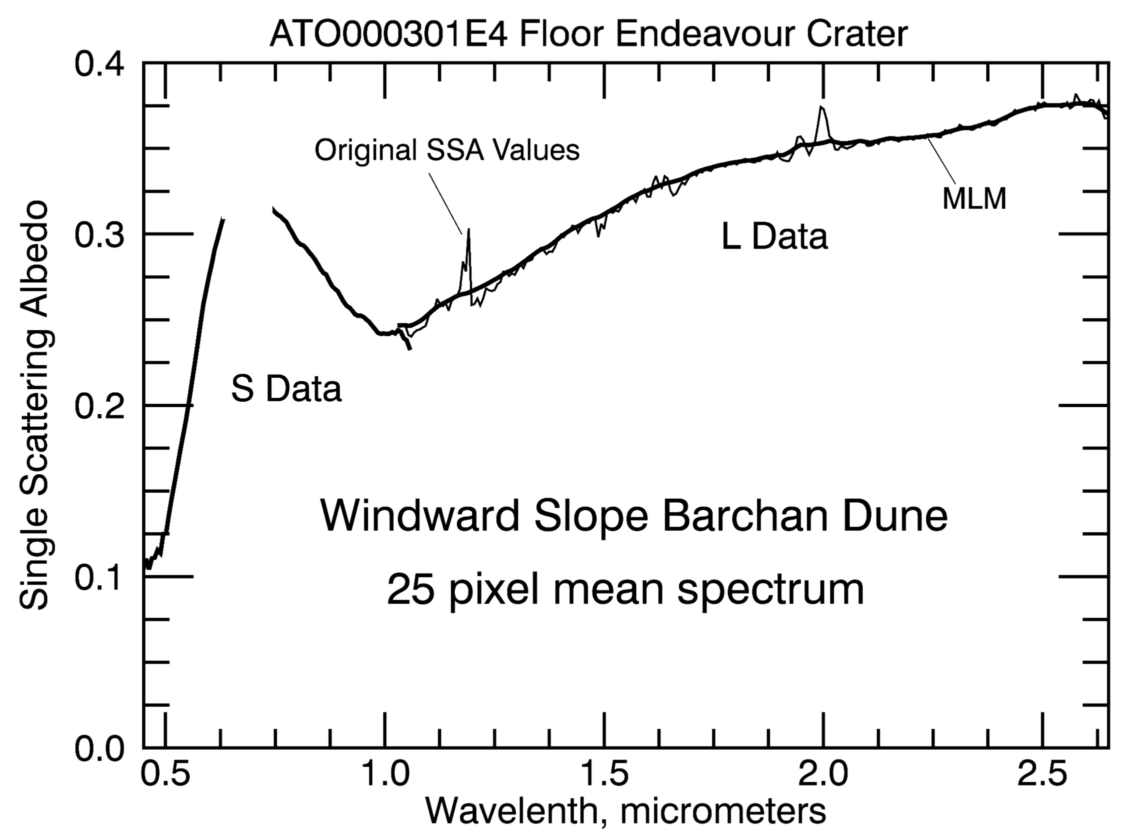
A new weighting penalty that depends on spatial sampling intervals and the spectral noise level as a function of wavelength is applied in the reconstructed image procedure. Using the penalized MLM procedure provides sharpened images and spectra in which noise is suppressed whereas fine-scale mineral absorption are preserved where noise levels allow such details to be preserved.

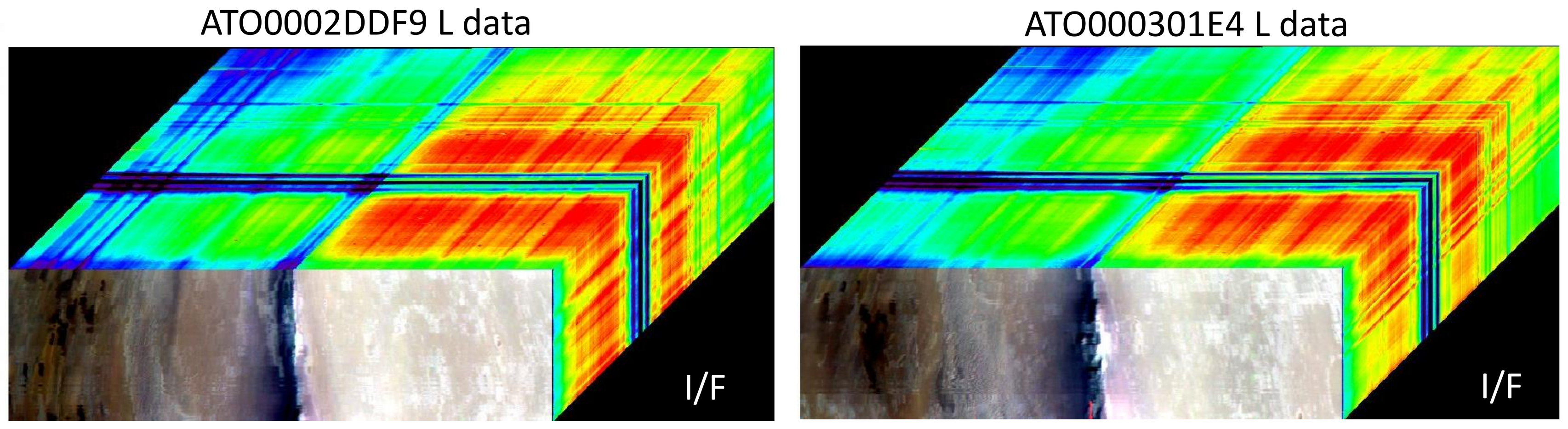
Example: Endeavour Crater



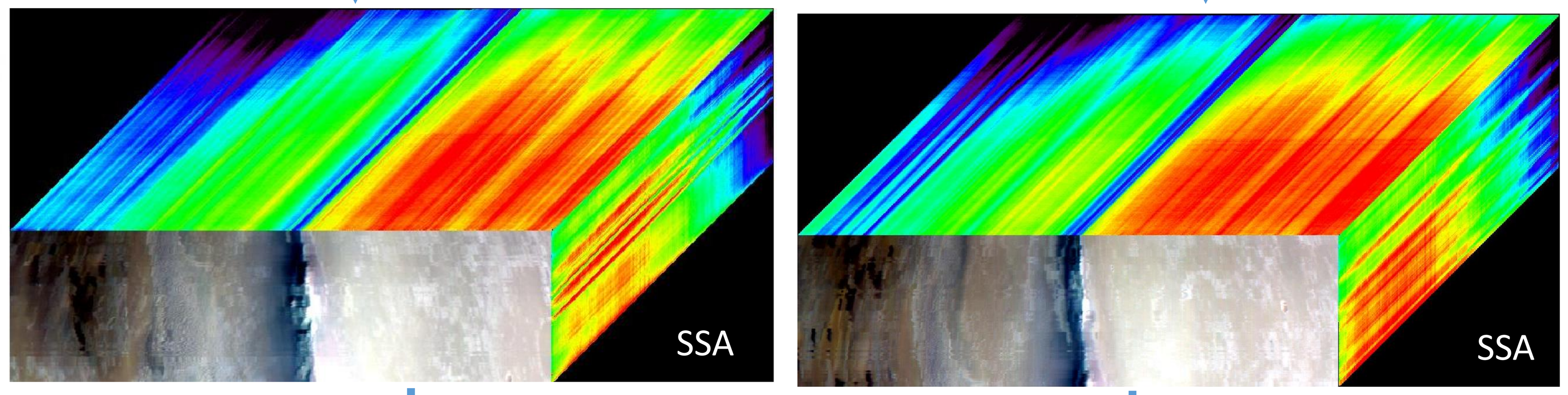




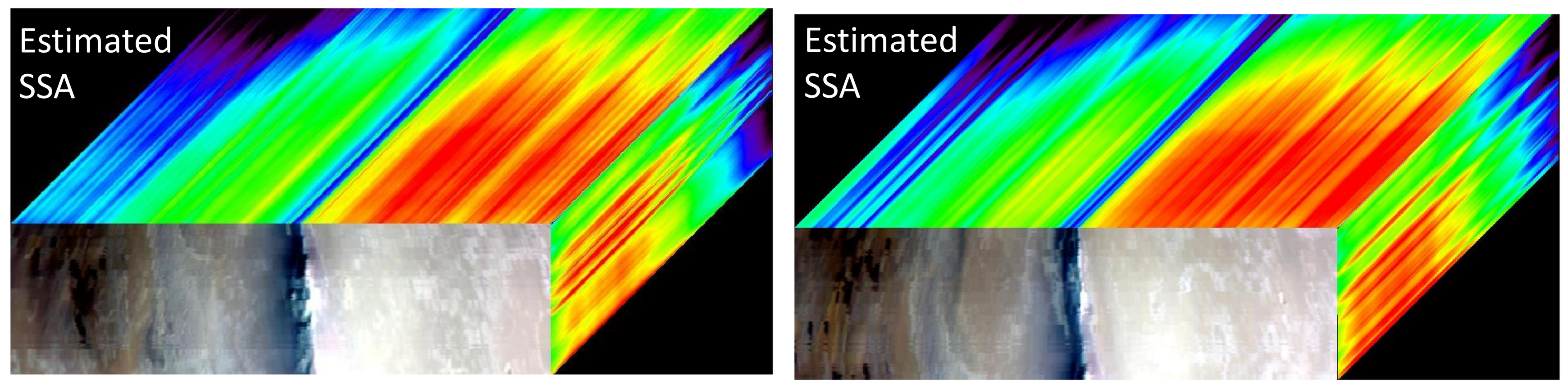


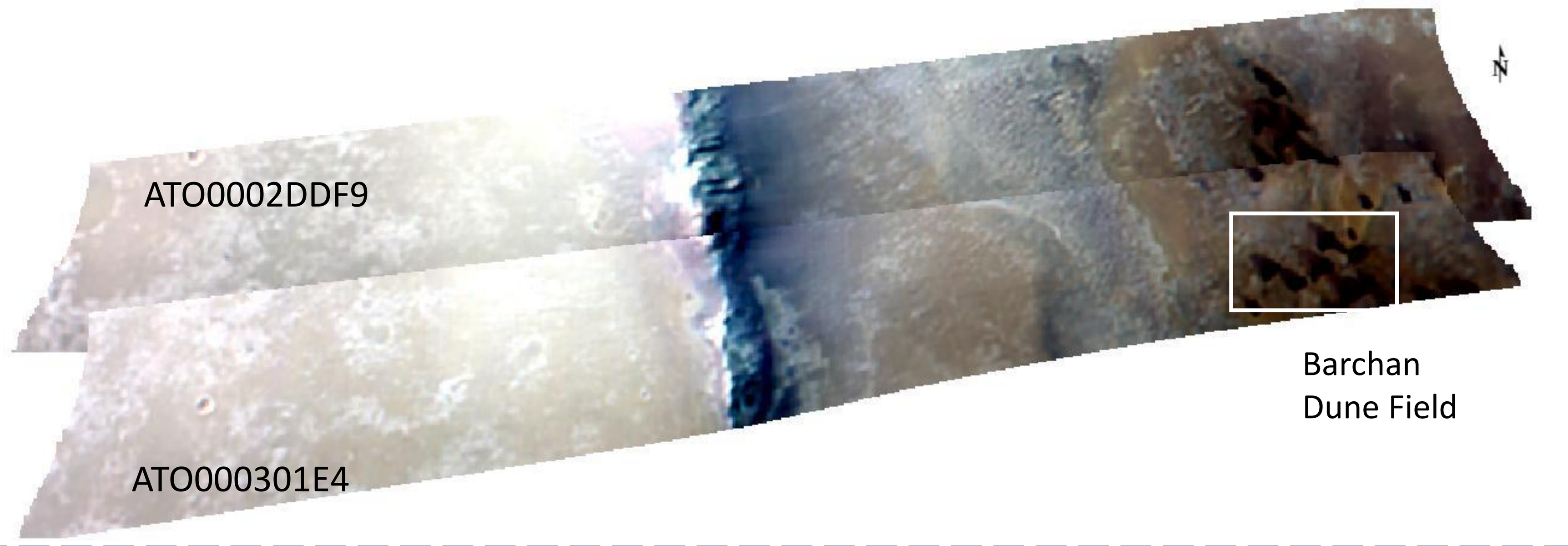


Lighting and viewing correction
Atmosphere correction, Median filter

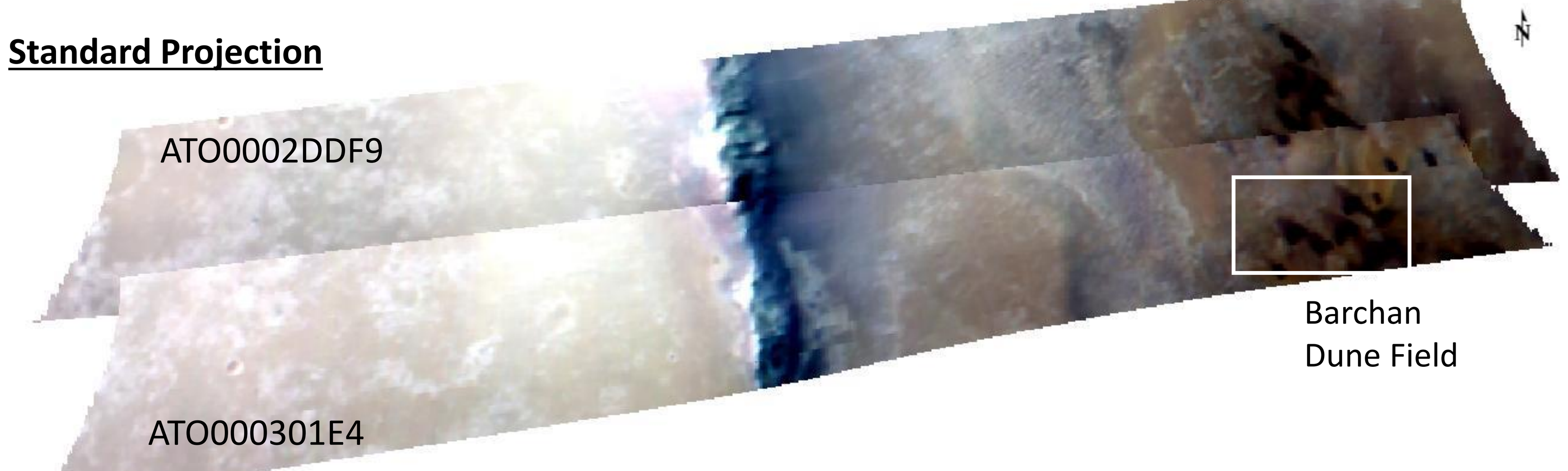


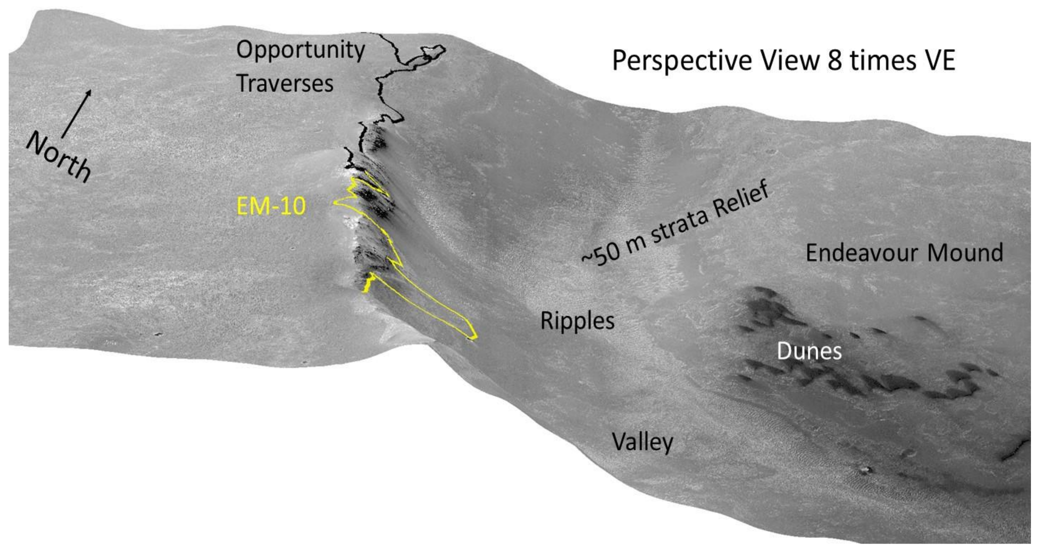
Weighting Penalty → **Regularized MLM**

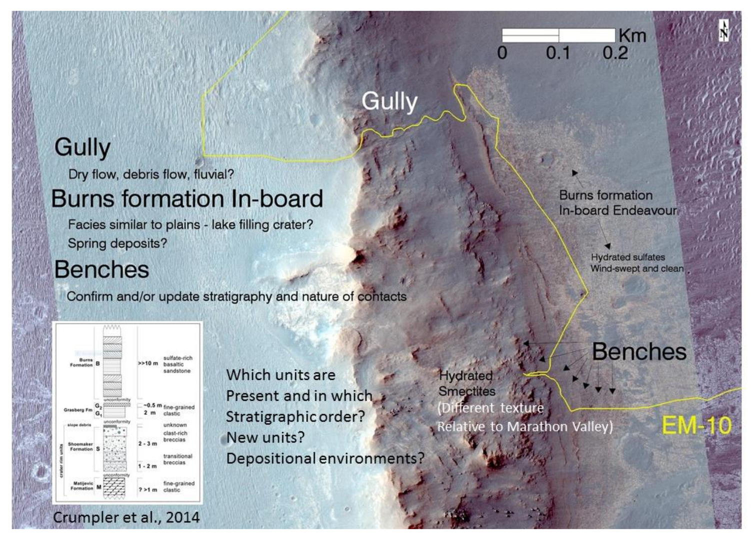




Standard Projection







Contact: linyunhe@wustl.edu