APPLICATION OF IMAGE RESTORATION (JANSSON VAN-CITTERT) TO PLANETARY REMOTE SENSING NEUTRON COUNT RATE MAPS.

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Introduction: Maps of the lunar neutron albedo will be determined from the orbiting Lunar Exploration Neutron Detector (LEND) onboard the Lunar Reconnaissance Orbiter (LRO) spacecraft. Slated for an October 2008 launch, on a nominal yearlong mission, LEND will characterize the surface distributions of hydrogen and other cold trapped volatiles relevant to future exploration missions [1]. As part of the LEND mission planning activities the instrument team is investigating methods for enhancing the accuracy and quality of maps. Jansson Van-Cittert's (JVC) image restoration transform is cited in the literature in applications relevant to planetary remote sensing deconvolution applications [3-5]. Evaluation of the JVC transform is performed using neutron albedo maps derived from the orbiting Mars Odyssey (MO), High Energy Neutron Detector (HEND) mission which is similar in operational requirements and detector configuration to LEND. Results of this study indicated significant joint dependencies on the degrees of prior map smoothing required to mitigate noise, and choice of point spread function. Ramifications include higher fractional errors at local minima (important for local hydrogen evaluation), decorrelation of pixel intensities as a function of local image gradients and the introduction of spurious textural details.

LEND-HEND Measurements: Prior orbital measurements of lunar poles indicate the presence of hydrogen near the permanently shadowed, cold regions of craters [6,7]. As a resource for *in-situ* exploration, these regions are of critical interest for planning activities. The LEND instrument will take orbital measurements to determine hydrogen distributions of the lunar surface from 1-2 meters depth. Hydrogen, a moderator of neutrons, is elevated in polar regions yielding a commensurate decrease in the neutron flux. With the LRO altitude between 100km and 50km, LEND's efficient collimation will attain optimal spatial resolution of 5km and detection limits =100ppm in polar regions. Spatial resolution is enhanced by short integration times to offset the blurring effects of spacecraft trajectory and planetary motion [1]. The MO-HEND instrument is similar in operational requirements with a significant database of Martian surface distributions of neutrons. This dataset was selected as appropriately analogous to the projected LEND mapping datasets for evaluating the JVC transform [8].

Jansson Van-Cittert Transform: Jansson Van-Cittert deconvolution method is an iterative time-domain transform that generates successive approximations of an unknown impulse response. The method is used widely in image reconstruction applications in which a consistent blurring function has degraded an image *I*. Effects of the blurring is attenuated using the following iterative process: $I_{k+1} = I_k + r(O - p\otimes I_k)$, where O is a smoothed version of the raw image [2,3,5]. I_k is the k^{th} iteration image estimate, r is a relaxation function(s) that controls, pending implementation: pixel specific and/or image convergence controls. p is an estimate of the blurring / instrument point spread function, *psf*. The method proceeds by repeatedly adding a scaled r, high-pass filtered version, $(O - p\otimes I_k)$, of the present image iteration k to itself. Convergence is achieved as the difference between the original image estimate O, and the smoothed image at iteration I_k, approaches ~0. A critical factor in the quality of the reconstruction is the prior mitigation of map noise through Gaussian smoothing, which simultaneously attenuates both noise and signals. Residual map spatial structures are then amplified by the high-pass filter portion of the function.

Modeling and Image Deconvolution: For neutron detectors without imaging capabilities, numerical simulation is required to derive neutron albedo maps of a surface. This involves the modeling of spacecraft and instrument collimation factors with orbital ephemeredes to determine a surface region in which detected neutrons are attributed [1]. Through successive flyovers and sample time over each region a map of the neutron albedo is produced. For this study, a raw HEND neutron map of the Martian surface was produced at 1° resolution, *Figure 1* (*top*). Four configurations of the JVC transformation were implemented to study the effects of variable degrees of Gaussian smoothing and selection of *psf*. Two noise levels are studied by performing 1 or 2 initial low pass smoothings of the raw image. The smoothing kernel is defined as Gaussian [13°x13°,N(6,2), fwhm=4.7°]. Nomenclature for the one pass smoothing map is designated O_A, two pass O_B. Two, 2-dimensional Gaussian *psf*'s $[p_{17}, p_{31}]$, of differing spatial scale illustrate the dependencies of *psf* scale on inducing map texture and local spatial gradients. p_{17}=[17°x17°,N(8,2.8), fwhm=6.6°], p_{31}= [31°x31° ,N(15,4), fwhm=9.4°]. The total blurring *psf* was varied to reflect the further blurring of the instrument *psf* by the prior smoothing processes that determine $O_{A,B}$. Each image was transformed for 30 iterations yielding 4 result maps [A1, A2, B1, B2], *Figure 1*. *r* =1.0 for all iterations, no pixels entered negative domain during the process.

Discussion: Critical dependencies of the four JVC transform configurations are illustrated in the four maps. Numerical analysis of the 4 maps indicate the following concerns: Pixels are variably enhanced as a function of local spatial gradient causing pixels of initially equal value to become decorrelated; Global minima exhibited the largest fractional deviation from the map set μ=0.05cps, where the largest deviations from the mean are in A2 (low degree of smoothing, large *psf*). Induction of map textural details was investigated using Fourier analysis. Each maps average power spectrum was determined yielding 4 distinctly different spectra. Degree of prior smoothing is a critical factor in power induced to the image. As a result, variations in the degree of smoothing generate different maps for fixed *psf*. Granularity of the resulting image is due to joint dependencies *psf* spatial scale and degree of smoothing. Magnitude of power induced to the image is largest for [A2, B2], e.g., low smoothing and large kernel induce greatest degree of spatial detail. Further, induction of texture suggests spatial sensitivity, but in less smoothed, larger *psf* conditions, spatial details are due to textural amplification of residual noise in starting images $O_{A,B}$, rather than real detail.

References: [1] Mitrofanov I.G., LEAG-2005, #1690, [2] Jansson P.A., (1970), *J. Opt. Soc. Am.*, 60, 184-191, [3] Elphic et al., LPS-XXXVI #2297, [4] Prettyman T.H., LPS-XXXVI #1384, [5] Lawrence D.J., LPS-XXXVII #1893, [6] Feldman W.C., et al., Science (*1998*), [7] Feldman W.C. et al., *JGR-Planets*, 105, 4175-4195, [8] Mitrofanov I.G., *Science*, 297, (2002)

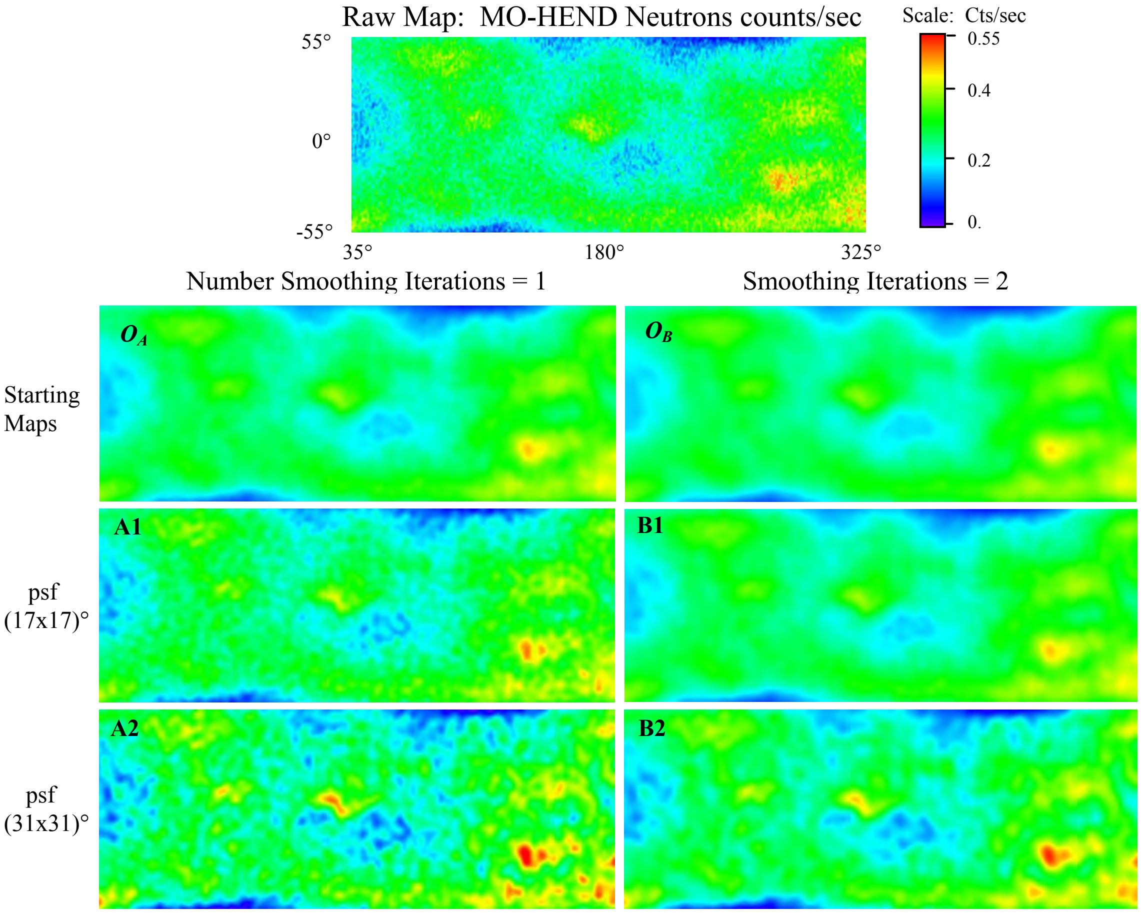

Figure 1: *Top row*: Raw MO-HEND neutron count rates [+-55, lat 35-325° lon]; *Middle 1*: Starting maps, [1, 2] Gaussian smoothing passes on raw map O_A ,O_B; *Middle 2*: JVC transform using small p_{17} *psf* on O_A,O_B. *Bottom*: JVC using a large p_{31} *psf*. Identical color scale for all maps (*top right*)