REDUCTION OF INSTRUMENT-DEPENDENT NOISE IN GALILEO NIMS DATA OF THE JOVIAN SATELLITE GANYMEDE USING THE PRINCIPLE COMPONENT ANALYSIS. K. Stephan[1], C. A. Hibbitts[2] and R. Jaumann[1], [1]Institute of Planetary Research, German Aerospace Center, [2]Applied Physics Lab. (Rutherfordstrasse 2, 14489 Berlin, Germany, Katrin.Stephan@dlr.de).

Introduction: The Near Infrared Mapping Spectrometer onboard the Galileo spacecraft acquired NIR reflectance spectra on the icy satellite Ganymede during its journey through the Jovian system [1]. The precision of related spectral analyses depends largely on the signal-to-noise ratio. Noise in the NIMS data was induced by radiation from the Jovian magnetosphere and patterns in images were caused by the motion of the scanning mirror. Usually, averaging several spectra increases the signal to noise ratio. However, this also causes the loss of spatial information that is essential for mapping the spectral variations.

To facilitate the analysis of NIMS spectra on a pixel-by-pixel base we used the Principle Component Analysis (PCA) to improve the signal-to-noise ratio of the NIMS data using their covariance matrices [2]. The PCA is often successfully used for qualitative data reduction in a way that the relevant image information is extracted and combined into fewer spectral channels. However, the resulting PC images are often difficult to relate to physical or chemical properties of the surface material. But, in our study the PCA is found useful to improve the quality of the NIMS data not only spatially but also spectrally by removing the noise component from each single NIMS pixel.

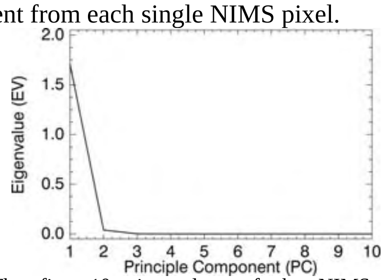

Fig. 1: The first 10 eigenvalues of the NIMS observation G1GNMEMPHIS characterizing the variance of the corresponding PC's.

Eigenvalues: Figure 1 shows the resulting eigenvalues of the NIMS observation G1GNMEMPHIS. As expected eigenvalues decrease with increasing PC (Fig. 1) indicating a lessening variance of the progressing principle components (PC's). Additionally, except for the first PC with an eigenvalue that represents about 95 % of the total variance the portion of the eigenvalues of the higher PC's regarding the total variance (< 1%) is far below the accuracy of the radiometric calibration of the NIMS instrument (10%, [3]). So, the corresponding PC's are expected to be dominated by noise. However, the eigenvalues of PC 2 through 4 vary distinctly from each other and possibly contain still unique relevant information.

PC images and eigenvectors: Figure 2 shows examples of PC images of the NIMS observation G1GNMEMPHIS and their corresponding eigenvectors. As expected the PC 1 contains the total albedo. The corresponding eigenvector shows the spectral characteristics of the main surface component, e.g water ice, and also the characteristics of the non-ice material [4] including an absorption at 4.25 µm caused by CO_2 trapped in the surface material [4,5]. Although the eigenvalues of the second PC's are already below the accuracy of the radiometric calibration (< 3%) they still contain some useful spectral information. The eigenvector seems to show a mixture of very large-grained ice at short waves and spectral charcteristics of the non-ice material at longer wavelength whereas the signal of the latter appears reverse in this eigenvector. In contrast, the PC 3 already shows the influence of noise although it still contains some relevant information as seen in the corresponding eigenvector (Fig. 2). Especially the Fresnel reflection peak of water ice at 3.1 µm indicative for amorphous or crystalline water ice [6,7] and the absorption of CO_2 at 4.25 µm seem to be enhanced in this eigenvector. Higher PC images and eigenvectors often show no relevant spectral information at all. However, some of these PC images are dominated by distinct striping like the PC 6 (Fig. 2). The stripes run more or less parallel to the movement of the scanning mirror. This striping effect can also be seen very well in the corresponding eigenvector and is supposed to represent the residual error of the dark signal substraction [3]. The two sets of resulting PC images were then seperately re-transformed into the original coordinate system. So, for each NIMS cube two resulting cubes were derived. One cube represents the improved spectra based on the PC's that include relevant information. This includes also PC images which are already influenced by noise but show still some relevant spatial variations. The other contains the PC's that found to be completely influenced by noise or striping. The number of PC images involved in the re-transformation depend on the individual NIMS observation. In case of the G1GNMEMPHIS observation 6 PC's were found that contain more or less relevant spectral information. Using less PC images would probably result in a change of the spectral information in the individual spectra.

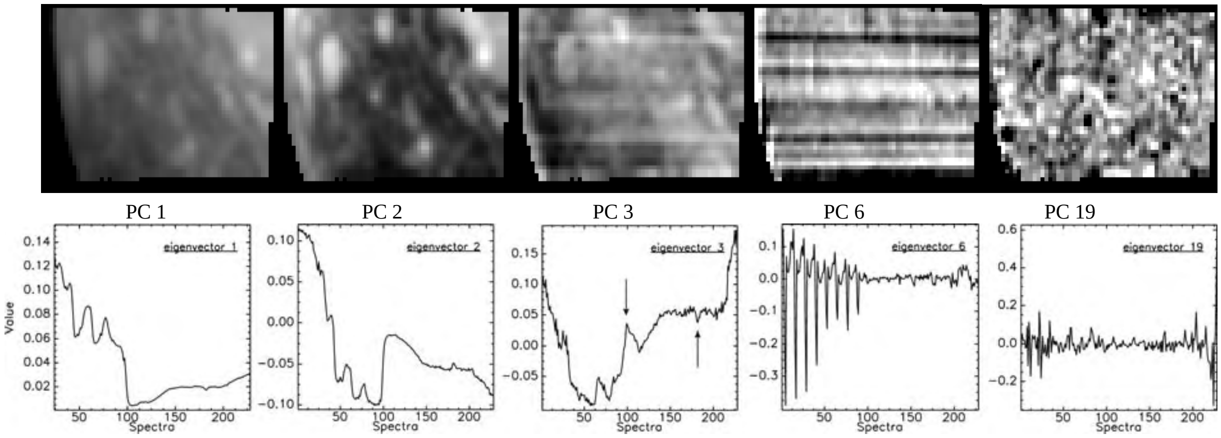

Fig. 2: Examples of PC images and the corresponding eigenvectors of the NIMS observation G1GNMEMPIS.

Resulting Ganymede spectra: Figure 3 shows an original single NIMS spectrum compared to the resulting spectra. In the wavelength region from 1 to 2.7 µm where the overall reflectance is high and significant water ice absorptions occur the signal to noise ratio also is commonly high. No distinct spectral changes between the original and the improved spectrum were observed and the noise spectrum is relatively smooth. This supports the assumption that the PCA does not change the spectral information in a way that can not be controlled. Usually the signal to noise ratio is distinctly lower longward 3 µm especially where the Fresnel reflection peak occurs. Whereas in the original spectrum this peak is sparely to be seen, the three peak feature characteristic for crystalline water ice is well recognizable in the improved spectrum. Further, the absorption of CO_2 at 4.25 µm is highly influenced by noise in the original spectrum. In the resulting spectrum the shape, wavelength position and depth is well defined.

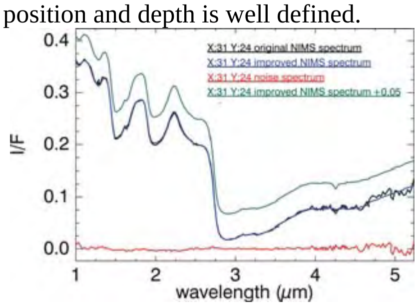

Fig. 3: NIMS spectrum of G1GNMEMPHIS compared to the corresponding improved and extracted noise spectrum after applying the PCA.

Figure 4 shows how band depth maps of this absorption vary depending on the different number of re-tranformed PC's. Relationships of the distribution of CO_2 to surface features are more or less masked by noise when using a high number of PC's. In contrast, the amount of noise is distinctly reduced if less PC's are involved and relationships to surface features can be analyzed. This is essential for the understanding of the source of the CO_2 in the surface material of Ganymede.

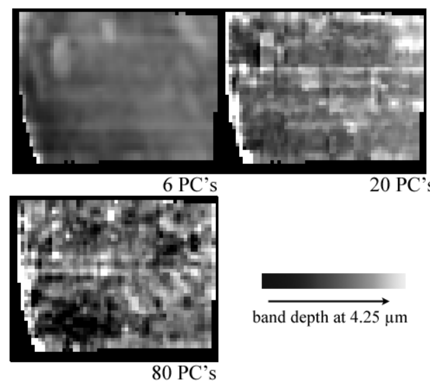

Fig. 4: Band depth map of CO_2 using varying number of PC'$_S$ for the inverse transformation (all images are shown with the same scale).

Conclusions : Applying the principle component analysis to NIMS data was found to be effective to reduce noise from NIMS spectra in such a way that each single spectrum is still quantitatively analyzable. This method was found to be especially effective for detecting instrument-dependent noise (such as patterning) that was not eliminated during the calibration process. This offers significant higher quality maps of measured spectral characteristics like band depth maps of specific absorptions that are essentiall for interpreting their distribution across Ganymede's surface.

References: [1] Carlson R. W. et al. (1996) *Science, 274,* 385–388. [2] Richards J. A. (1994) *Rem. Sens. Dig. Im. Anal,* 340. [3] Carlson, R. W. (1994). [4] McCord T. B. et al. (1998) *JGR, 103,* 8603-8626. [5] Hibbitts C. A. et al. (2003) *JGR,* 2-1 [6] Schmitt B. et al. In : *Solar System Ices* [7] Hansen & McCord (2004) *JGR, 109.*