PRODUCTION OF NEW CLEMENTINE UVVIS MAP PRODUCTS TIED TO THE LRO REFERENCE FRAME.

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Introduction: The Clementine mission provided an opportunity to collect a global dataset of the Moon over a broad set of wavelengths. The Ultraviolet/Visible (UVVIS) camera acquired nearly 600,000 observations in five narrow bandpasses (415, 750, 900, 950, and 1000 nm). These digital images were later reduced into a global multispectral mosaic and a series of mineralogy and maturity maps [1-5], which have been used in numerous studies to advance our knowledge of the Moon and are frequently used today by the lunar science community. After the mission ended, several image-based control networks were constructed to improve the geodetic accuracy of the map projected UVVIS images.

In the late 1990s, the United States Geologic Survey (USGS) and the RAND Corporation used over 500,000 match points to systematically control 43,871 images in the 750 nm global basemap [3,4,9] to create the Clementine Lunar Control Network (CLCN). However, this analysis ignored topographic effects during the triangulation (i.e. assumed a spherical Moon with a radius of 1737.4 km) and later investigations showed the existence of large horizontal offsets (8-10 km) in the resulting maps due to extreme changes in the camera orientation parameters [8].

Later work improved upon this initial control network, with the creation of the Unified Lunar Control Network (ULCN) 2005 produced by the USGS [9]. While the ULCN 2005 included the local radius of the Moon during image triangulation, significant offsets (mean = 1.09 km; median = 1.59 km; Figure 1) still exist when compared to the current lunar reference frame defined by the Lunar Reconnaissance Orbiter mission. For this study, we use images acquired by the Lunar Reconnaissance Orbiter Camera (LROC) [10] to update the Clementine UVVIS internal and external orientation parameters in order to create precise and accurate map products that are registered to the LRO reference frame.

Controlling UVVIS images to the LRO Reference Frame: To improve the observational geometry of each Clementine UVVIS image, we first identified LROC Wide Angle Camera (WAC) images acquired under similar lighting conditions (i.e. difference in subsolar point between observations < 5°) that cover the UVVIS field of view. In many cases, a single Clementine image may match multiple WAC observations due to significant spatial overlap at higher latitudes and the extensive WAC temporal coverage (>7 years).

After calibrating and applying a photometric correction to the image pair, each WAC image with nearly identical lighting is map projected to the surface using a precise global DTM (GLD100) [11] and the latest LRO ephemeris provided by the Lunar Orbiter Laser Altimeter (LOLA) and Gravity Recovery and Interior Laboratory (GRAIL) teams [12]. Using the DTM, updated ephemeris, and refined LROC camera model parameters, WAC images have a geodetic accuracy of better than 45 m [13], which is much better than the UVVIS spatial resolution (~250 m). These calibration and mapping procedures are carried out using Integrated Software for Imagers and Spectrometers (ISIS) [14], which is developed and maintained by the USGS. The mapped WAC images are then transformed back into the UVVIS camera space using an ISIS utility called *map2cam*.

The UVVIS/WAC image pairs that are then in a common geometry are subsequently registered using a series of control points. These control points are automatically derived using an ISIS utility called *findfeatures* that applies feature-based matching algorithms to detect similar features in each image. The software takes advantage of the OpenCV framework, which allows the user to select from a broad range of feature detectors, extractors, and matchers [15]. These control points are then used to define the intrinsic camera properties (focal length and lens distortion) and refine the camera orientation.

Deriving the Intrinsic Properties of the UVVIS Camera: Before this project, the focal length and optical distortion of each UVVIS band were known only imprecisely. From the output of *findfeatures*, we collected hundreds of thousands of UVVIS line and sample coordinates tied to points on the lunar surface (latitude, longitude, and radius) using coordinates of the corresponding feature identified in the WAC image(s). Using procedures developed for in-flight calibration of the LROC WAC [13], we derived a precise focal length and optical distortion function for each band (Figure 2). We found that the focal length varied as a function of wavelength with the 415 nm band having a focal length of 89.858 mm and the 1000 nm band having a focal length of 89.985 mm. This difference in the focal length (0.15%) is likely due to lateral chromatic aberration in the optics and introduces a ~0.7 pixel error corner-to-corner when comparing images of same area with the 415 and 1000 nm bands. By updating the interior orientation parameters and camera model defined in the UVVIS Instrument Kernel (IK), these distortions and offsets can be accounted for and removed during map projection.

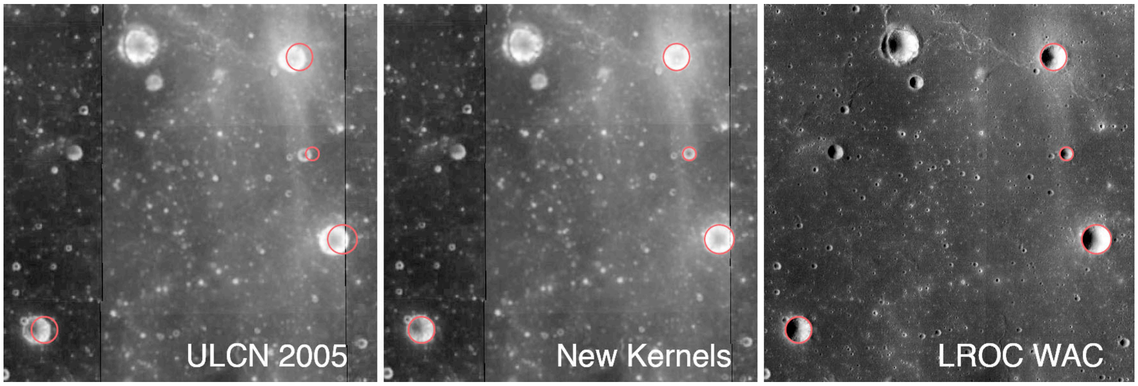

Figure 1- (Left) Example Clementine UVVIS mosaic created using ephemeris derived from the ULCN 2005. (Middle) Same UVVIS image set map projected using the newly derived camera model, ephemeris, and camera pointing. (Right) LROC WAC mosaic of the same region map projected in the LRO reference frame. The red circles around several of the large craters highlight the spatial offset observed in previous control networks.

Deriving Precise Camera Orientation. Using the same control points identified with *findfeatures* and our new Clementine UVVIS camera model, we can solve for the exterior orientation parameters for *each* unsaturated UVVIS image that contains illuminated terrain (note: The CLCN and ULCN 2005 focused on a small subset of images and warped the remaining image mosaics to the controlled 750 nm mosaic). To adjust for offsets in the placement of UVVIS images on the lunar surface, the orientation (stored in the NAIF Camera Kernel (CK) and Frames Kernel (FK)) and/or spacecraft location (stored in NAIF Spacecraft Position Kernel (SPK)) can be refined.

Using the GRAIL gravity model [12] and tracking data collected during the Clementine mission, we recalculated the ephemeris (SPK) for the spacecraft. In addition, from the control points identified with *findfeatures*, we removed the remaining residual offsets between the UVVIS images and the LRO reference frame by updating the camera pointing (archived in the CK and FK).

SPICE Updates: To enable access to the updated geometry, we are currently constructing and testing a new SPK, IK, FK, and CK. These updated kernels will be archived in the Planetary Data System (PDS) and will be accessible in an upcoming ISIS distribution as well as other utilities that use the common SPICE routines developed by NASA's Navigation and Ancillary Information Facility (NAIF). With these new kernels, images can be map-projected with sub-pixel accuracy to the geodetic grid defined by the LRO mission, thus enabling quick future cross-mission analysis without the need to manually align the datasets.

Updated UVVIS Map Products: The updated geometry will also be used to create a series of global UVVIS map products in the LRO reference frame. We are mosaicking a new Clementine global basemap from the 750 nm images as well as building a multispectral mosaic using each of the five UVVIS band. These new maps will also be used to calculate a new set of mineralogy (TiO_2, FeO) and the optical maturity maps [4,5] that are registered (not warped) to the LRO reference frame. These new map products will be archived later this year in the PDS.

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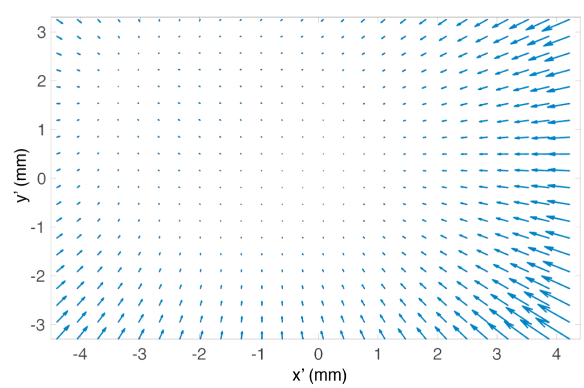

Figure 2 – Example optical distortion map of the 750 nm band. (note: the size of the arrows are not to scale)