APPROACHES TO PRODUCTION OF INTERMEDIATE DATA PRODUCTS FOR CHARACTERIZING SYSTEMIC ANOMALIES IN THE CHANG'E-2 MICROWAVE RADIOMETER DATA.

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Introduction: In 2010-2011, China's Lunar Exploration Program (CLEP)'s Chang'e-2 orbiter's Microwave Radiometer (CE-2 MRM) obtained ~8.7 million passive microwave measurements of the lunar surface at 3, 7.8, 19.35, and 37 GHz with a nominal spatial resolution of 25 km (at 3 GHz) and 17.5 km (at other channels). [1] Comparisons between data from the CE-2 MRM's higher-frequency channels, modeled lunar albedo and brightness temperatures, and data from the Lunar Reconnaissance Orbiter (LRO) Diviner radiometer have previously been used to develop models of the radiative transfer and dielectric properties of the Moon. [2] We are currently pursuing an effort [3] to produce a quantitative model of CE-2 MRM data that will allow us to place better constraints on mineral variation, small rock abundance, and geothermal heat flux across the global Moon.

The CE-2 MRM dataset exhibits a number of unexpected characteristics that appear to render its absolute and in some cases relative calibration untrustworthy (see "Calibration Problems" below). Broadly speaking, the measurements from the longer-wavelength channels seem "worse," in the sense that they are more inconsistent with both brightness temperature models and colocated data from other instruments. This restricts our ability to fully characterize the thermal gradient and dielectric loss tangent at depths > 100 cm.

Calibration Problems: The data exhibit a number of illumination geometry, frequency, and/or diurnal-cycle-dependent offsets. The 3 and 7.8 GHz channels exhibit large (relative to the higher-frequency channels) offsets from modeled and coregistered thermal brightness temperatures. [6] Coregistration of high-resolution map-projected CE-2 MRM data with Diviner data on clear thermal features (e.g., crater rims) also appears in some cases to reveal frequency-dependent spatial offsets. There are some clear discrepancies between Chang'e-1 (CE-1) and CE-2 MRM measurements. Although CE-1's MRM was extremely similar, colocated measurements exhibit antenna temperature differences up to 10K.

Possible Contributors to these Problems: *Thermal contamination of cold sky horn antenna.* The CE-2 (and CE-1) MRM package included a "cold" horn antenna intended to receive only cosmic microwave background radiation. A number of researchers ([2], [4]) have suggested that the cold horn antenna's pickup pattern may have been considerably broader than assumed, causing it to receive significant contributions from the lunar surface, and that this thermal contamination effect may be responsible for some or all of the observed channel-dependent offsets. The sunlight leaking into the cold horn contributes to the local time-dependent offsets. This theory is supported by the fact that these offsets appeared to change in magnitude when CE-2 changed orbit patterns from noon-midnight to terminator and the cold horn was reoriented to face the sun(see fig. 1).

Faulty ground calibration. [5] suggests that thermal contributions from the lunar surface are inadequate to explain offsets observed in the data, and presents a model for correcting presumed errors in ground calibration that might have produced them. [6] presents a model for correcting the data using related brightness temperature constant offsets combined with contributions from the cold horn.

Channel-dependent variations in antenna pickup pattern. Most literature on the MRM data uses simple symmetric Gaussian models of antenna beam patterns for deriving brightness temperature. [7] characterizes the beam pattern in greater detail and presents a method for deconvolving the beam across the global Moon. Extending this analysis and examining it in conjunction with models such as [6] will constrain the contribution of ground or sky calibration errors to anomalies in the data. Coregistration with other high-resolution data sets such as Diviner around sharply-defined terrain features may also permit us to better-characterize model-derived portions of antenna sidelobes. Some offsets in T_B could also be explained by complex, broad sidelobe patterns.

Creating Data Products to Analyze these Problems: We have concluded that efficiently synthesizing these approaches requires the use of secondary data products that are easily digestible by high-level frameworks, permitting efficient coregistration of the data with related datasets and statistical-spatial data mining and comparison to iterative forward models. Planned products include:

Navigational materials. Fully characterizing these potential sources of error requires reconstruction of spacecraft navigational telemetry and other metadata useful for characterizing antenna attitudes, beam orientations, etc. CLEP's Planetary Data Archiving and Service System (PDASS) has released only a highly-reduced version of the MRM dataset that does not include navigational metadata other than time, CE-2's orbital height, and projected antenna boresight on the lunar surface. Utilizing *lhorizon* [8], a thick

wrapper to the JPL Horizons service, we acquired ephemeris data for CE-2's position across the duration of the CE-2 MRM dataset. We are currently validating these data and using them to construct SPICE kernels and related products. Preliminary versions of these are proving useful for modeling spatial dependencies in data anomalies (see Fig. 2). We believe they will also be useful to the community at large.

Map-projected products. We are producing a set of map-projected products at multiple scales optimized for coregistration with Diviner and ground-based radio observations. These will also form a basis for global maps of ilmenite composition and rock distribution.

Software. We are developing a statistical analysis and plotting package in Python, tentatively named *moonbow*, optimized for fusing radio-frequency photogrammetry with planetary ephemerides. This software is intended primarily for our internal use, but we believe it will have outside utility and plan to release it under a permissive open-source license.
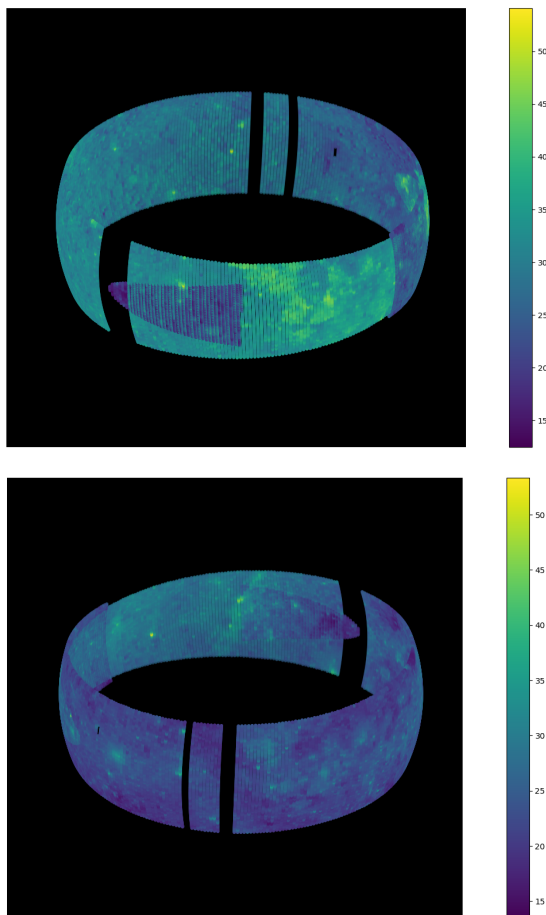

Fig. 1: Differences between latitudinally-modeled T_A residuals for 3 and 37 GHz channels near solar zenith (top) and nadir (bottom) in equatorial regions. 3D plots in rectangular selenocentric coordinates.

Roughly-symmetrical pattern of gaps in data at these illumination angles is due to CE-2's orbit pattern. Qualitatively inverted character is due principally to increased diurnal variation in T_B at higher frequencies. Other features may indicate variations in geophysical properties or offsets due to calibration.
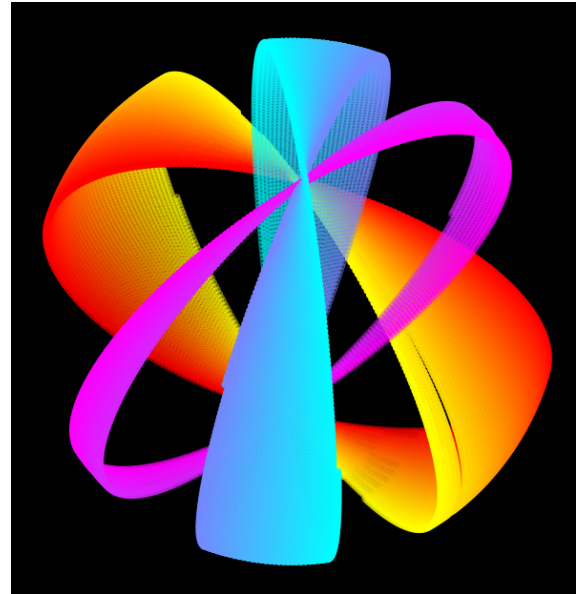

Fig. 2: Changes in CE-2 orbital pattern over the mission. 3D plot in rectangular selenocentric coordinates, colored by orbit number. Aqua and teal tones are from ~50 noon-midnight orbits; red and orange tones are from ~50 terminator orbits.

References:
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