Working with $M^3$ Data

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$M^3$ Data Tutorial at AGU

December 13, 2010
For Reference

- Slides and example data from today’s workshop available at http://m3dataquest.jpl.nasa.gov
- See Green et al. (2010) and Boardman et al. (2010) for complete descriptions of topics discussed here
Topics to be discussed

• M3 observation history
• Instrument design
• Data set description
• Calibration pipeline
• Walkthrough of calculating I/F with M3 L1B data in ENVI

slides online at http://m3dataquest.jpl.nasa.gov
M3 Mission History
Planned vs. Actual Flight

- Planned observation time was 4 two-month optical periods defined by equatorial solar zenith of 0-30°

- One month was to be contiguous low-resolution (Global Mode) overview; the remainder was to be used for the optimal high-resolution resolution data (Target Mode).
Planned vs. Actual Flight

- Thermal issues plagued the spacecraft as soon as it arrived at the Moon on November 8, 2008
- Lost the 1st of 2 star trackers before a single image was taken
- Extended commissioning phase was required, lasting into Jan 2009
Planned Vs. Actual Flight

- The ISRO Chandrayaan-1 Mission Operations team did a fantastic job redesigning the mission in real time throughout the mission lifetime.
- Despite all the challenges, M3 was able to meet minimum mission requirements thanks to heroic efforts on the part of Ch-1 and M3 team members.
- LOLA topography data was essential for orthorectification.
Planned vs. Actual Flight

• Impact on data:
  – Instrument was operated at less favorable viewing conditions, resulting in lower reflected surface signal, increased effects of shadows and highly variable thermal environment
  – The spacecraft acquired data intermittently during two optical periods
    • Almost all M3 data were acquired in reduced resolution (Global) mode; very few optimal resolution (Target) mode data acquired
    • Most of 2\textsuperscript{nd} optical period taken at higher orbit (200km vs 100km) and with no star tracker
M3 Optical Periods

- M3 observed data during two optical periods
- The team subdivided the optical periods based on data characteristics:

<table>
<thead>
<tr>
<th>Period</th>
<th>Dates</th>
<th>Image Strips</th>
<th>Orbit</th>
<th>Star Sensors</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP1A</td>
<td>Nov 18 - Jan 24</td>
<td>119</td>
<td>100 km</td>
<td>1 of 2</td>
<td>extended commissioning</td>
</tr>
<tr>
<td>OP1B</td>
<td>Jan 25 - Feb 14</td>
<td>247</td>
<td>100 km</td>
<td>1 of 2</td>
<td>operational, high solar zenith angles</td>
</tr>
<tr>
<td>OP2A</td>
<td>Apr 15 - Apr 27</td>
<td>197</td>
<td>100 km</td>
<td>1 of 2</td>
<td>operational, high solar zenith angles</td>
</tr>
<tr>
<td>OP2B</td>
<td>May 13 - May 16</td>
<td>20</td>
<td>200 km</td>
<td>0 of 2</td>
<td>S/C emergency, orbit raised</td>
</tr>
<tr>
<td>OP2C</td>
<td>May 20 - Aug 16</td>
<td>375</td>
<td>200 km</td>
<td>0 of 2</td>
<td>operational, variable conditions</td>
</tr>
</tbody>
</table>
M3 Environment During Data Acquisition

- Optimal low detector temperature acquisitions occurred during highest beta angles (angle between orbit plane and sun direction) and lowest signal.
M3 Coverage per OP + Targets
PDS Delivery Schedule

- Level 0 and Level 1B:
  - OP1: June 2010
  - OP2: December 31, 2010

- Level 2:
  - OP1 and OP2: June 2011
    still in progress

L0 = raw spacecraft data, L1B=radiance + backplanes, L2 = reflectance
M3 Instrument
Operational Modes

• **Target (Optimal Resolution)**
  – High spatial/spectral resolution mode
  – Only a few target observations were actually acquired

• **Global**
  – M3 Instrument acquires full resolution data then onboard software averages data to produce reduced resolution data
  – Lower resolution mode for mapping the entire Moon
  – Almost all M3 data were acquired in Global mode
**Spatial and Spectral Resolution**

- **Spectral Coverage:**
  - Target: 446-3000 nm
- **Spectral Resolution:**
  - Target: 10 nm
  - Global: 20 or 40 nm
- **Spatial Resolution:**
  - Target: 70 m/pixel
  - Global: 140 m/pixel
  - from 200 km orbit spatial sampling remains 140 m/pixel, but cross-track is ~280 m/pixel
• Pushbroom spectrometer
  – Each detector readout is 1 line of an image cube. The entire image is built as M3 moves along the ground track.

• High Spectral/Spatial Uniformity
  – Greater than 90% spectral crosstrack and spectral IFOV uniformity
M3 File Formats/PDS Structure
PDS Directory Structure

- Standard PDS structure

- Name ▲
  - CALIB
  - CATALOG
  - DATA
  - DOCUMENT
  - EXTRAS
  - GEOMETRY
  - INDEX
  - LABEL
  - README.TXT
  - ERRATA.TXT
  - VOLDESC.CAT

- Name ▲
  - 200811
  - 200812
  - 200901
  - 200902

- Name ▲
  - L0
  - L1B

- Name ▲
  - M3G20081201T064047_V01_L1B.LEL
  - M3G20081201T064047_V01_LOC_HDR
  - M3G20081201T064047_V01_LOC_IMG
  - M3G20081201T064047_V01_OBS_HDR
  - M3G20081201T064047_V01_OBS_IMG
  - M3G20081201T064047_V01_RDN_HDR
  - M3G20081201T064047_V01_RDN_IMG
  - M3G20081201T064047_V01_TIM_TAB
M3 File Naming Convention

M3G20090204T113444_V01_RDN.IMG

- Basename
- Version
- Data Type
- File Type

- Basename – covered next slide
- Version – always “V01” in June 2010 L1B PDS delivery
- Data type – tells you the type of information stored in the file
  - Possible values in L1B delivery:
    - L0 – raw spacecraft data
    - RDN – radiance
    - OBS – observational data (incidence, emission, phase angles, etc.)
    - LOC – location data (latitude, longitude, radius)
    - TIM – time of observation
- File Type – tells you the file format
  - Possible Values in L1B delivery:
    - IMG – raw binary image data
    - HDR – ENVI header
- L0, L1B – PDS label type
  - LBL – PDS label
  - TAB – tabular data stored in ASCII format
Example Basename: M3G20090204T113444

Always “M3”

Year 2009

Month 02

Day 04

Hour T 11

Minutes 34

Seconds 44

Observation mode: G=Global, T=Target

Note: Sorting by filename is only equivalent to sorting by observation time if you do not have global and target data mixed together. If you do have a mix of the two, remove the first three characters then sort by filename to also sort by observation time.
The following applies to all M3 image data:

- Files are raw binary data (no offset)
- Interleave is BIL (line-interleaved)
- Global data have 304 samples (columns) for all image types (except L0, which has 320)
- Target data have 608 samples (L0 has 640)
- Number of lines (rows) is variable (determined by length of observation)
- Data type is 32-bit floating point (LOC files are 64-bit double precision floating point)
- “Backplanes” = OBS, LOC, and TIM files
M3 Data types: L0

- L0 is raw spacecraft data, units are DN
- 320 samples which are reduced to 304 when converted to radiance (in Global mode, Target mode is 640/608)
  - The 16 columns that are removed are for monitoring dark signal level and scattered light
- Each frame has a 1280-byte header
- To directly compare L0 to radiance:
  - No sample or line flip starting Nov 16, 2008
  - Sample only flip starting Dec 18, 2008
  - Line only flip starting Mar 14, 2009
  - Sample and line flip starting Jun 18, 2009
**M3 Data Types: L1B RDN**

- Radiance data, units $W/(m^2 \text{ Sr } \mu \text{m})$
- Steps used to create radiance described in calibration slides
- PDS label or ENVI header can be used to open
- ENVI header contains:
  - Calibration steps
  - Target wavelengths
  - Target FWHM
  - Dark Signal Image
  - Anomalous Detector Map
  - Flat Field Image
  - Detector Temperature
  - Beta Angle
  - Sample/Line flip code
M3 Data Types: OBS

• List of bands in OBS file:
  – To-Sun Azimuth (deg)
  – To-Sun Zenith (deg)
  – To-M3 Azimuth (deg)
  – To-M3 Zenith (deg)
  – Phase (deg)
  – To-Sun Path Length (au-0.981919816030)
  – To-M3 Path Length (m)
  – Facet Slope (deg)
  – Facet Aspect (deg)
  – Facet Cos(i) (unitless)

• Values in the To-Sun Path Length band are the difference from the scene mean path length.
M3 Data Types: OBS

Phase band

Facet cos(i) band
M3 Data Types: LOC

- List of channels in LOC file:
  - Longitude (Degrees East 0-360)
  - Latitude
  - Radius
- Subtract lunar radius of 1737.4 km to get difference in elevation from reference sphere
- Based on LOLA topography (Boardman, 2010)
- Reference frame is Moon Mean Earth Polar Axes (MOON_ME) frame
M3 Data Types: LOC

Band 3 “Radius”

750nm albedo draped over Radius band
M3 Data Types: TIM

One ASCII text record per frame:

<table>
<thead>
<tr>
<th>Column 1: Frame Number</th>
<th>Column 2: UTC Time</th>
<th>Column 3: Year</th>
<th>Column 4: Decimal Day of Year</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>2008-11-18T22:26:03</td>
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<tr>
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<td>2008-11-18T22:26:03</td>
<td>2008</td>
<td>322.9347720008058</td>
</tr>
</tbody>
</table>

In OP2 the S/C is ascending and the time listing is reversed
Good Stuff in the PDS Directories

- **CALIB**
  - Record of detector temperatures, band pass functions, spectral calib. file (wavelength center positions), radiometric calibration coefficients

- **DOCUMENT**
  - [Data Product SIS](#) document that describes all files released to PDS down to the byte level, [Archive Volume SIS](#) describes PDS directory structure

- **EXTRAS**
  - Flat fields, anomalous detector element maps, quicklooks
Calibration
Current steps in radiance calibration (Version R)

- Raw image;
- Dark signal subtraction;
- Anomalous detector element interpolation;
- Interpolate filter edges c13, c50;
- Interpolate detector panel edges s81, s161, s241;
- Electronic panel ghost correction;
- Dark pedestal shift correction;
- Scattered light correction;
- Laboratory flat field;
- Image based flat field w/ photometry preserved;
- Apply radiometric calibration coefficients;
- Units (W/m^2/um/sr)

See Green et al (2010) for detailed description
Basic calibration equation

\[ L_{l,s,\lambda} = RCC_{\lambda}(C_{s,\lambda}(DN_{l,s,\lambda} - DS_{s,\lambda})) \]

- L = calibrated radiance
- RCC = Radiometric calibration coefficients
- C = term encompassing all correction factors (flat fields, etc.)
- DN = raw digital number
- DS = dark signal
Initial Steps of (ongoing) Level 2 Preparation
Converting Radiance to Reflectance

• Official M3 L2 Product is still under development
• Until that is available, team use an intermediate product called $I/F$

\[
\frac{I}{F} = \frac{L \pi d^2}{F}
\]

• Where:
  – $L$ = measured radiance in $\text{W/m}^2/\text{Sr}/\mu\text{m}$
  – $F$ = solar flux (solar spectrum) in $\text{W/m}^2/\mu\text{m}$
  – $d$ = Moon-Sun distance in AU
Download M3 Solar Spectrum

http://m3.jpl.nasa.gov/docs/solar_spec_global85.txt

- MODTRAN-based (See Green et al, 2010)
- Global resolution version can be downloaded in ASCII format from the above link
Download M3 Solar Spectrum

**File is tab-delimited ASCII text**

- 3 lines of header information to be skipped when importing

```plaintext
ENVI ASCII Plot File [Mon Nov 22 17:44:36 2010]
Column 1: Wavelength (nm)
Column 2: M3 SSG V3 (W/m^2/um)~~1

<table>
<thead>
<tr>
<th>Wavelength(nm)</th>
<th>M3 SSG V3 (W/m^2/um)</th>
</tr>
</thead>
<tbody>
<tr>
<td>460.989999</td>
<td>2022.662109</td>
</tr>
<tr>
<td>500.920013</td>
<td>1934.504639</td>
</tr>
<tr>
<td>540.840027</td>
<td>1875.621826</td>
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<tr>
<td>580.765015</td>
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<tr>
<td>620.689941</td>
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<td>660.609985</td>
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<td>700.537537</td>
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<td>730.479980</td>
<td>1324.721680</td>
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<tr>
<td>750.440002</td>
<td>1271.074707</td>
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<td>770.400024</td>
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<td>810.330017</td>
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<td>910.140015</td>
<td>879.042053</td>
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<tr>
<td>930.099076</td>
<td>838.584151</td>
</tr>
</tbody>
</table>
```
Example conversion of radiance to I/F in ENVI
Step 1: Import M3 Spectral Library

- Step 1:

- Step 2:

(Can also choose “ASCII File….” here but that has more steps)
Step 1: Import M3 Spectral Library

Step 3:

Step 4:
Step 1: Import M3 Spectral Library

Step 3: [Image of Spectral Library Builder with options to select, plot, and delete spectra.]

Click Plot

(Can save file as spectral library from File menu)

Done!
Step 2: Open Files

• Open radiance (RDN) file in ENVI:
  – File > Open Image File

• Open observations (OBS) file also
  – This step can be skipped if you want to use 1.0 AU for the Moon-Sun distance (~2% error)

• Open and plot the M3 solar spectrum if you have not already
Step 3: Get the Moon-Sun Distance

- Get mean distance from list of band names of the OBS file
- Could use per-pixel values in the To-Sun Path Length Band (band math)
Step 4: Call Spectral Math

- Select Spectral Math under Basic Tools menu (also under Spectral menu)
Step 5: Enter the expression

- Expression is:
  \[
  \frac{(s1 \cdot \text{dpi} \cdot 0.9866678^2)}{s2}
  \]

- Radiance
- Double precision \( \pi \)
- Moon-Sun distance squared
- Solar Spectrum

\[
\frac{I}{F} = \frac{L \pi d^2}{F}
\]
Step 6: Define s1

Click “Map Variable to Input File” and select your radiance (RDN) file.

Should end up with this:
Step 7: Define $s_2$

First Click: Select the expression $s1^1$ in the list.

Second Click: Click on the variable $s_2$ to map it to the selected expression.
Step 8: Choose Output File

- Then click "OK" and ENVI goes to work…
Last Step: Enjoy!
Check your work!

- Example radiance, observations, and I/F file posted to M3 website so that you can make sure you get the same answer we do:
- http://m3dataquest.jpl.nasa.gov

Presentation slides available there also