MLTAN: Theory & Practice

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Mark A. Vincent

Raytheon

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Outline

• Theory
  ➢ Basic sun-synchronous motion
  ➢ Luni-Solar Effect
  ➢ Differential Effects
  ➢ Effect of Circulation Orbit

• Practice
  ➢ OCO-2 IAM Strategy
  ➢ Solicit input from other missions
  ➢ Discussion
Definition of MLTAN

MLTAN in HH:MM:SS

True Sun
Mean Sun

Mean Solar Meridian

Equator

Satellite orbit

i_{SS} \approx 98.2^\circ
Even zonals exert a torque on the orbit

- Dominant term is due to $J_2$ and with $e$ small

\[
\frac{d\Omega}{dt} = -\frac{3}{2} \sqrt{\mu} R_e^2 J_2 \cos(i) / a^{7/2}
\]

- Pick the correct $i$ for a given $a$ => Sun Synch
Luni-solar Perturbation

• Doubly-averaged Third-body Potential† has dominant term $V \propto \cos[2*(\Omega - \Omega')]$
• Dominant term in Lagrange’s Equations (with $e$ small):
  \[
  \frac{di}{dt} = -\frac{1}{(na^2\sin(i))} \cdot \frac{dV}{d\Omega}
  \]
• Thus $\frac{di}{dt} \propto \sin[2*(\Omega - \Omega')]$
• Maximum $\frac{di}{dt}$ at MLTAN 9 AM and 3 PM
• Stable null at MLTAN 6 AM or 6 PM, unstable null at Noon or Midnight
• For afternoon orbits $\frac{di}{dt} > 0$, morning orbits $\frac{di}{dt} < 0$

Differential Effects

For satellites with different MLTAN’s:

\[ \Delta \ (\text{di/dt)/di/dt} = \cot[2*(\Omega-\Omega')] * \Delta (\Omega-\Omega') \]

• Examples: for OCO-2 wrt Aqua \( \Delta (\Omega-\Omega')= \text{“25 sec”} \) †
  -> a 0.2% effect
• but CALIPSO/CloudSat wrt Aqua \( \Delta (\Omega-\Omega') = \text{“535 sec”} \)
  -> a 4% effect
• Noting that for every \( \Delta i = 0.0001 \text{ deg} \) there is about a \( \Delta-\text{MLTAN} \) of 1 sec after a year (using the \( J_2 \) formula)

† Note quotations are used above since the difference in RAAN is usually assumed in degrees which must be converted to radians for the preceding formula, while a \( \Delta-\text{MLTAN} \) is usually assumed in seconds
Effect of the Circulation Orbit

- Consider a satellite dropping at a linear rate of \( A \) m/day, that is \( a = a_0 + \Delta a_0 - At \) after a DMU, \( a_0 \) being the A-Train reference semi-major axis (i.e. constant density assumed\(^\dagger\))
- Again using the \( J_2 \) formula:
  \[
  \frac{d\Omega}{dt} = \frac{d\Omega}{dt_0} \left(1 + \frac{\Delta a_0}{a_0} - \frac{At}{a_0}\right)^{-7/2}
  \]
- Maximum \( \Delta \Omega \) when \( t = \Delta a_0/A \) and is equal to:
  \[-\frac{7}{4} \frac{d\Omega}{dt_0} \ast \left(\frac{\Delta a_0}{a_0}\right)^2 / (A * a_0)\]
- And \( \Delta \Omega = 0 \) at \( t = 2 \ast \Delta a_0/A \) (the end of circulation)
- Example: use \( A = 5 \) m/day and \( \frac{d\Omega}{dt_0} = 0.9856 \) deg/day (sun-synch) and \( \Delta a_0 = 150 \) m ->
- \( \Delta \Omega_{\text{MAX}} = 0.0011 \) deg -> 0.263 sec of \( \Delta\text{-MLTAN} \)
- Thus somewhat negligible but interesting in the context of Aqua no-slew DMU

Example of a OCO-2 IAM#5 Bias of a 0.0002° Lower Inclination wrt Aqua

![Graph showing MLT precession rate over time with data points for OCO-2 and Aqua.](image-url)
Other Missions

• From B. Braun (thanks Barbara): CloudSat targets wrt CALIPSO rather than Aqua, however they also bias a little bit wrt to CALIPSO and may or may not follow CALIPSO if they do a mid-year inclination tweak
• From W. Zaidi (thanks Waqar):
  • Aqua prediction and its uncertainty is a separate subject
  • Aura targeting: same final IAM inclination as Aqua thus accepts delta-MLTAN change and modifies Phasing Control Box and/or RGT
• CALIPSO: To be discussed
• GCOM-W1: To be discussed
Back-up
Glossary

In order of appearance:

• IAM; Inclination Adjustment Maneuver
• $i_{SS}$: sun-synchronous inclination
• MLTAN: Mean Local Time of Ascending Node
• $J_2$: second-order zonal Earth gravity term
• $e$: satellite eccentricity
• $\Omega$: satellite Right Ascension of Ascending Node in True of Date Coordinates
• $\mu$: Earth Gravitational constant*Mass
• $R_E$: Earth radius
• $i$: satellite inclination
• $a$: satellite semi-major axis
• $\Omega'$: Sun Right Ascension of Ascending Node in True of Date Coordinates
• $n$: satellite mean motion
• $V$: Third-body potential (specifically the Sun in this case)