Mission Operations Working Group
June 2-4, 2015

MLTAN: Theory & Practice

June 3, 2015

Mark A. Vincent

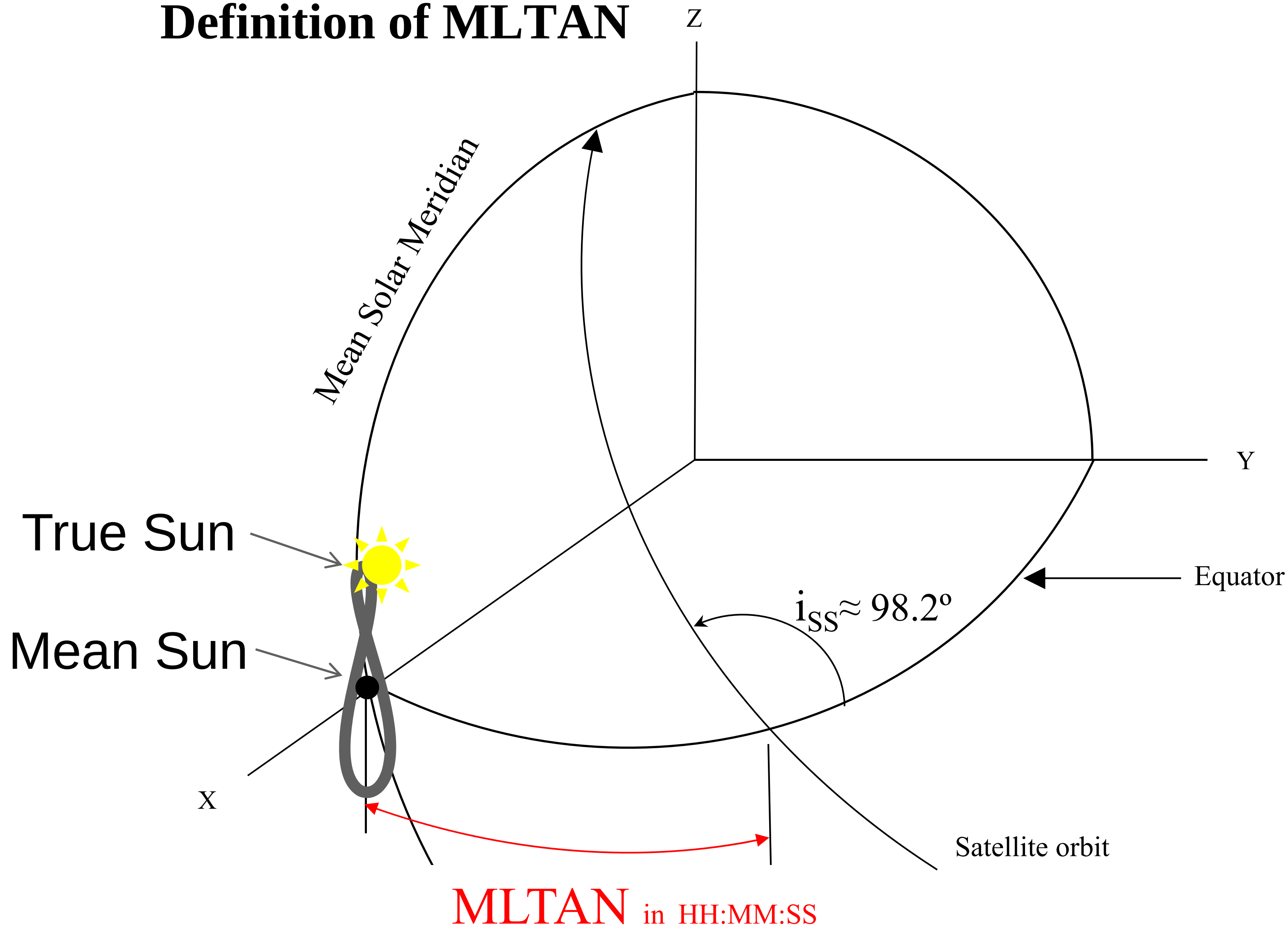
Raytheon

Customer Success Is Our Mission

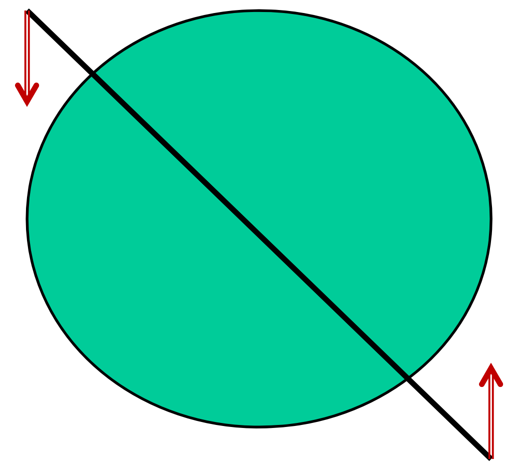
Outline

- 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



Sun-synchronicity



- Even zonals exert a torque on the orbit
- Dominant term is due to J_2 and with e small
- $d\Omega/dt = -3/2 * \mathrm{sqrt}(\mu)*R_e^2 * J_2*\cos(i)/a^{7/2}$
- Pick the correct i for a given a => Sun Synch

Luni-solar Perturbation

- Doubly-averaged Third-body Potential† has dominant term V α cos[2*($\Omega - \Omega'$)]
- Dominant term in Lagrange's Equations (with e small):

$$di/dt = - 1/(na^2 * \sin(i)) * dV/d\Omega$$

- Thus di/dt α sin[2*($\Omega - \Omega'$)]
- Maximum 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 di/dt > 0, morning orbits di/dt < 0

† W.M Kaula, "Development of the Lunar and Solar Disturbing Functions for a Close Satellite." Vol. 67, No. 5, 2005, pp. 300–303: Astronomical Journal, June, 1962.

Differential Effects

For satellites with different MLTAN's:

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

- Examples: for OCO-2 wrt Aqua $\Delta (\Omega-\Omega')$= "25 sec" †
  -> a 0.2% effect
- but CALIPSO/CloudSat wrt Aqua $\Delta (\Omega-\Omega')$ = "535 sec"
  -> a 4% effect
- Noting that for every $\Delta i = 0.0001$ deg there is about a Δ–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 Δ-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†)
- Again using the J_2 formula:

$$d\Omega/dt = d\Omega/dt_0\ (1 + \Delta a_0/a_0 - At/a_0)^{-7/2}$$

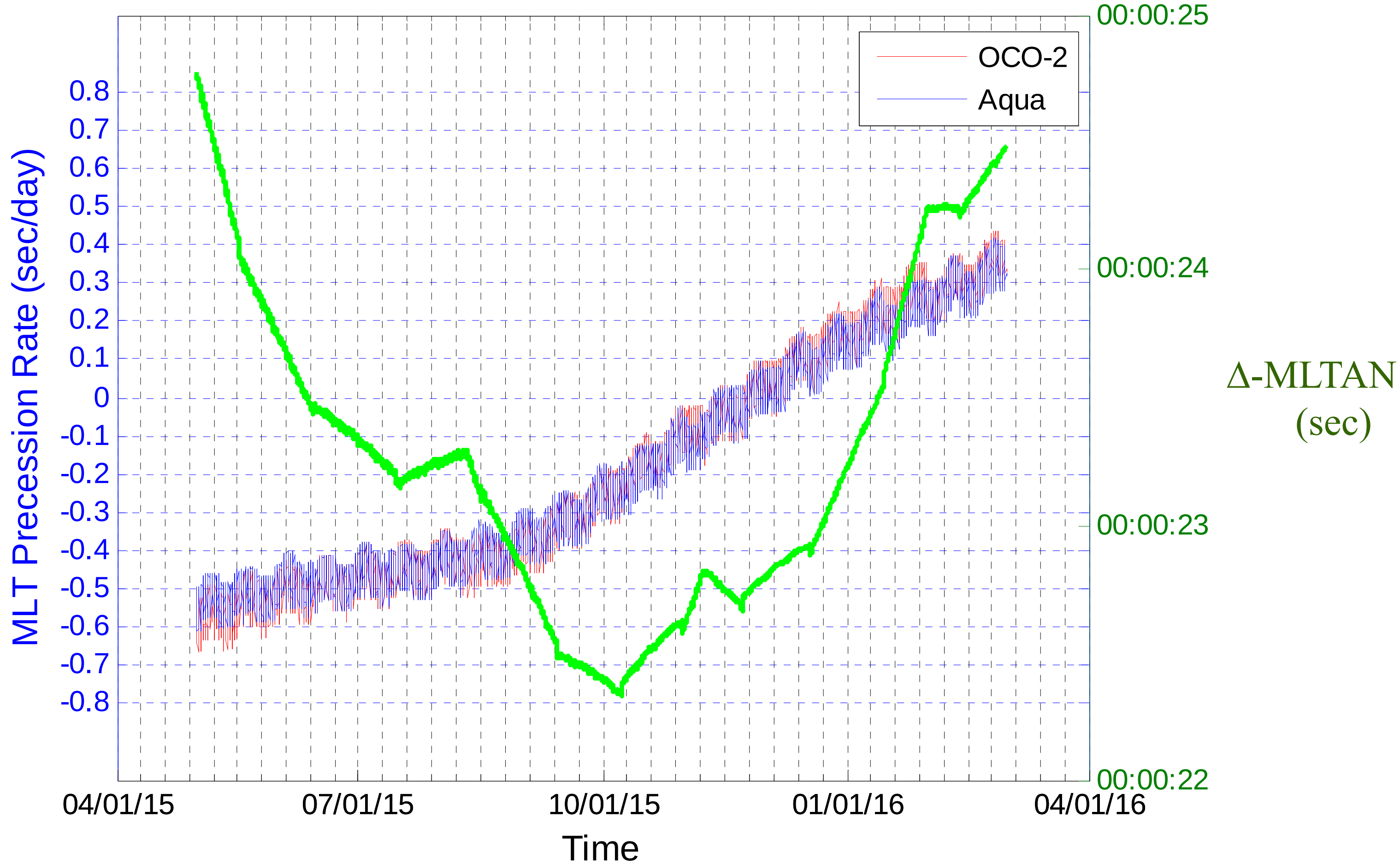
- Maximum $\Delta\Omega$ when $t = \Delta a_0/A$ and is equal to:

$$-7/4\ d\Omega/dt_0 * (\Delta a_0)^2 /(A*a_0)$$

- And $\Delta\Omega = 0$ at $t = 2*\Delta a_0/A$ (the end of circulation)
- Example: use A = 5m/day and $d\Omega/dt_0 = 0.9856$ deg/day (sun-synch) and $\Delta a_0 = 150$ m ->
- $\Delta\Omega_{MAX} = 0.0011$ deg -> 0.263 sec of Δ-MLTAN
- Thus somewhat negligible but interesting in the context of Aqua no-slew DMU

† Theoretical Evaluation of Atmospheric Drag Effects on the Motion of an Artificial Satellite, D. Brouwer and G. Hori, The Astronautical Journal, Vol 66, No. 5, June1961

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



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
- Ω: satellite Right Ascension of Ascending Node in True of Date Coordinates
- μ: Earth Gravitational constant*Mass
- R_E: Earth radius
- i: satellite inclination
- a: satellite semi-major axis
- Ω': 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)