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Components of the lunar gravitational tide in the terrestrial atmosphere and geomagnetic field

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Lunar gravitational potential contains 4 main oscillation components (Laplace, 1799-1827) :

1) **Lunar anomalistic monthly tide, ~ 27.55 days**

2) **Lunar zonal tide, ~13.66 days;**

3) **Lunar diurnal tide, ~ 24 hours 51 min;**

4) **Lunar semidiurnal tide, ~12 hours 25 min;**

$$\Phi_L = \frac{const}{D^3}\left[(\sin^2\phi - 1/3)(3\sin^2\delta_L - 1) - \sin 2\phi \sin 2\delta_L \cos\tau_L + \cos^2\phi \cos^2\delta_L \cos 2\tau_L\right]$$

↑1 ↑2 ↑1 ↑3 ↑4

D – Earth-Moon distance, φ – geographic latitude, δ_L is the lunar declination to the equator, τ_L - mean lunar local time angle

The main part of published results on atmospheric lunar perturbations is on the lunar semidiurnal tide (LSDT)

J.Lefroy, 1842 – first reliable extraction of the LSDT from atmospheric data (pressure data in 2 hours * 17 months, ampl. 0.07 mbar i.e. 5 times less than predicted by Laplace)

K.Kreil, 1850 – first indication of the LSDT in the magnetic field of the Earth

J.Egedal, 1929 – first indication of the LSDT in the upper atmosphere (by meteor heights)

R.Sawada, 1954 – first LSDT theoretical model for wide range of altitudes (0 – 200 km)

Lunar diurnal tide (LDT)	**Lunar zonal tide (LZT)**	**Lunar monthly anomalistic tide (LMAT)**
The most of early LDT extractions were done **without** taking the **lunar declination** into account **sin $(2\delta_L)$***cos τ_L Correct and statistically significant LDT extraction was found **in neutral wind components and PMSE volume reflectivity (Dalin et al., 2017).**	Atmospheric LZT was firstly found in noctilucent clouds occurrence probability and in summer nighttime relative cloud (tropospheric) area (Pertsev et al., 2007; Pertsev and Dalin, 2010). Later- in some other atmospheric and geomagnetic data	Problem of separation of solar (27-28 days) and lunar (LMAT, 27.55 days) cycles. Successful separation of the both effects was performed in the zonal and meridional wind and PMSE volume reflectivity (Dalin et al., 2017).

The list of lunar- induced oscillations is not completed !

- Some other lunar-induced oscillations are surely present in atmospheric and geomagnetic data !

- First example is the synodical semimonthly tide connected with lunar phases

The traditional problem of the lunar synodical semimonthly tide:

$$\nu = LT*360°/24h - \tau_L$$

ν - Phase Angle of the Synodical Month

LT - Solar Local Time

τ_L - Phase Angle of the Lunar Diurnal Tide

Aliasing in the special case of 24 h data sampling interval– (typical situation for all sun-synchronous satellite measurements and daily averaged ground-based measurements) -

N^{th} harmonic of the Synodical Month is not distinguishable from N^{th} harmonic of the Lunar Diurnal Tide

One needs to use a fine data sampling interval (e.g. 1 hour) in order to separate the Lunar Semimonthly Synodical Oscillation (~14.77 days) from Lunar Semidiurnal Tide (~12 h 25 min).

The first separation of the two oscillations in the atmospheric data:
Semenov and Shefov (1996).

Semimonthly Synodic Amplitude in OH* temperature ~ 9 K
Lunar Semidiurnal Amplitude ~ 1.5 K

More statistically careful recent result for winter OH* temperature:
Pertsev N. et al., (2015).

Semimonthly Synodic Amplitude in OH* temperature = 2.5 ± 0.8 K

Lunar Semidiurnal Amplitude = 0.3 ± 0.6 K (non significant)

PMSE 24 h data with 1h sampling interval

- Amplitudes and phases of the two oscillations in PMSE volume reflectivity logarithm:

(0.039 ± 0.016)*cos(2ν - 140°) – semimonthly synodical lunar tide

(0.021 ± 0.016)*cos(2τ - 14°) – lunar semidiurnal tide

[Dalin et al., 2017]

A probable mechanism of the semimonthly synodical oscillation (14.77 days) is the quadratic demodulation of the superposition of the semidiurnal solar (12 h) and semidiurnal lunar (12 h 25 min) oscillation

(Pertsev et al., 2015)

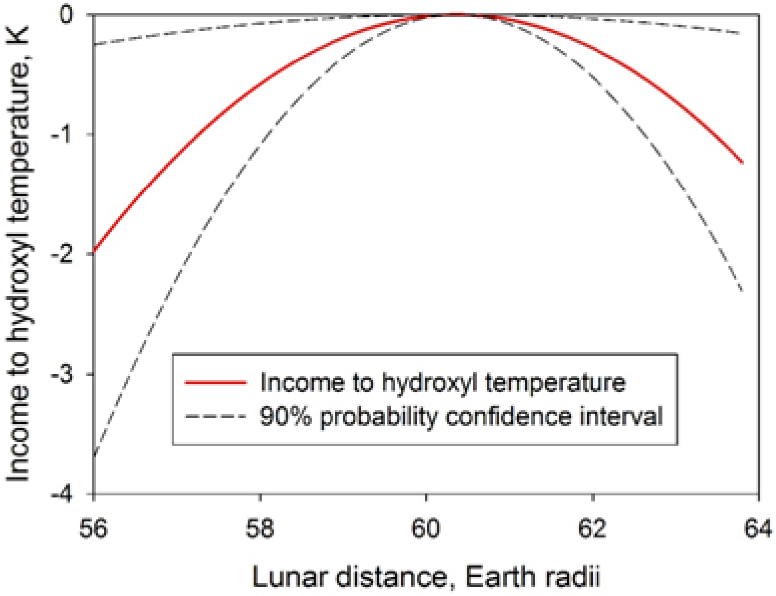
$$\left(A_S \cdot \cos\left(\frac{2\pi \cdot (t - t_S)}{12\ h}\right) + A_L \cdot \cos\left(\frac{2\pi \cdot (t - t_L)}{12\ h\, 25\, m}\right) \right)^2 = A_0 +$$

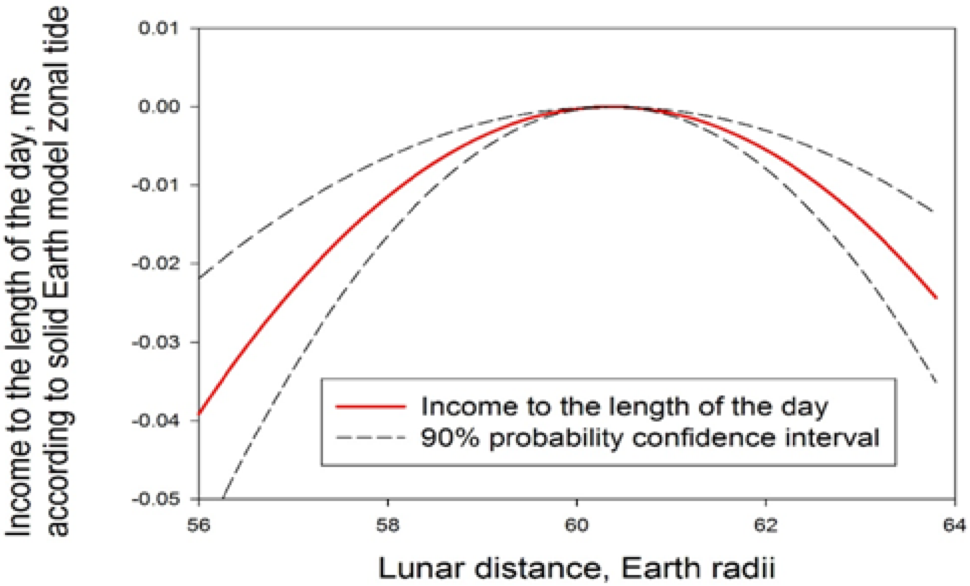
$$A_1 \cdot \cos\left(\frac{2\pi \cdot (t - t_1)}{6\ h}\right) + A_2 \cdot \cos\left(\frac{2\pi \cdot (t - t_2)}{6\ h\ 13 m}\right) +$$

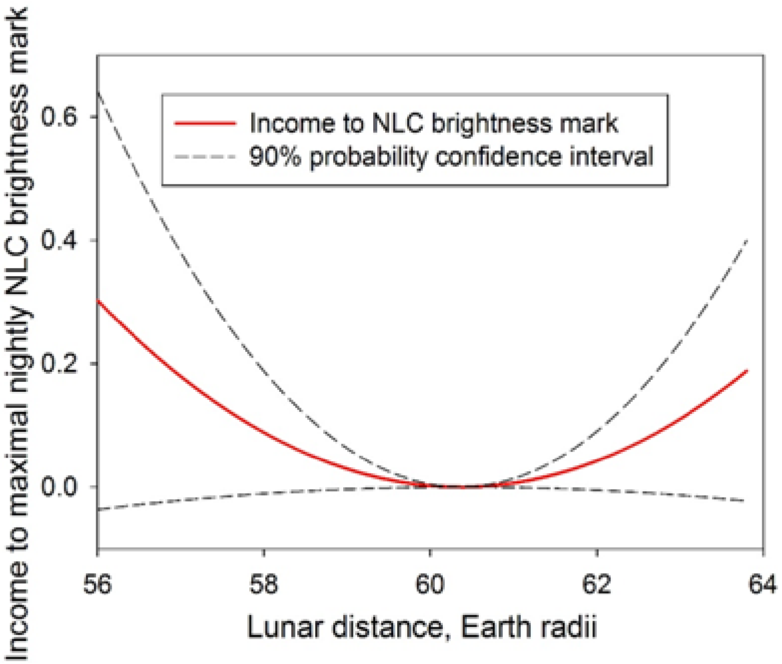
$$A_3 \cdot \cos\left(\frac{2\pi \cdot (t - t_3)}{6\ h\ 06 m}\right) + A_4 \cdot \cos\left(\frac{2\pi \cdot (t - t_4)}{14.77\ d}\right)$$

Some previous extractions of the **lunar semidiurnal tide (LSDT)** from atmospheric data (based on measurements with 24 h sampling) **must be revised**: the LSDT does express the **superposition** of the **lunar semidiurnal tide** and **lunar semimonthly synodic tide**, and the latter may have even larger amplitudes

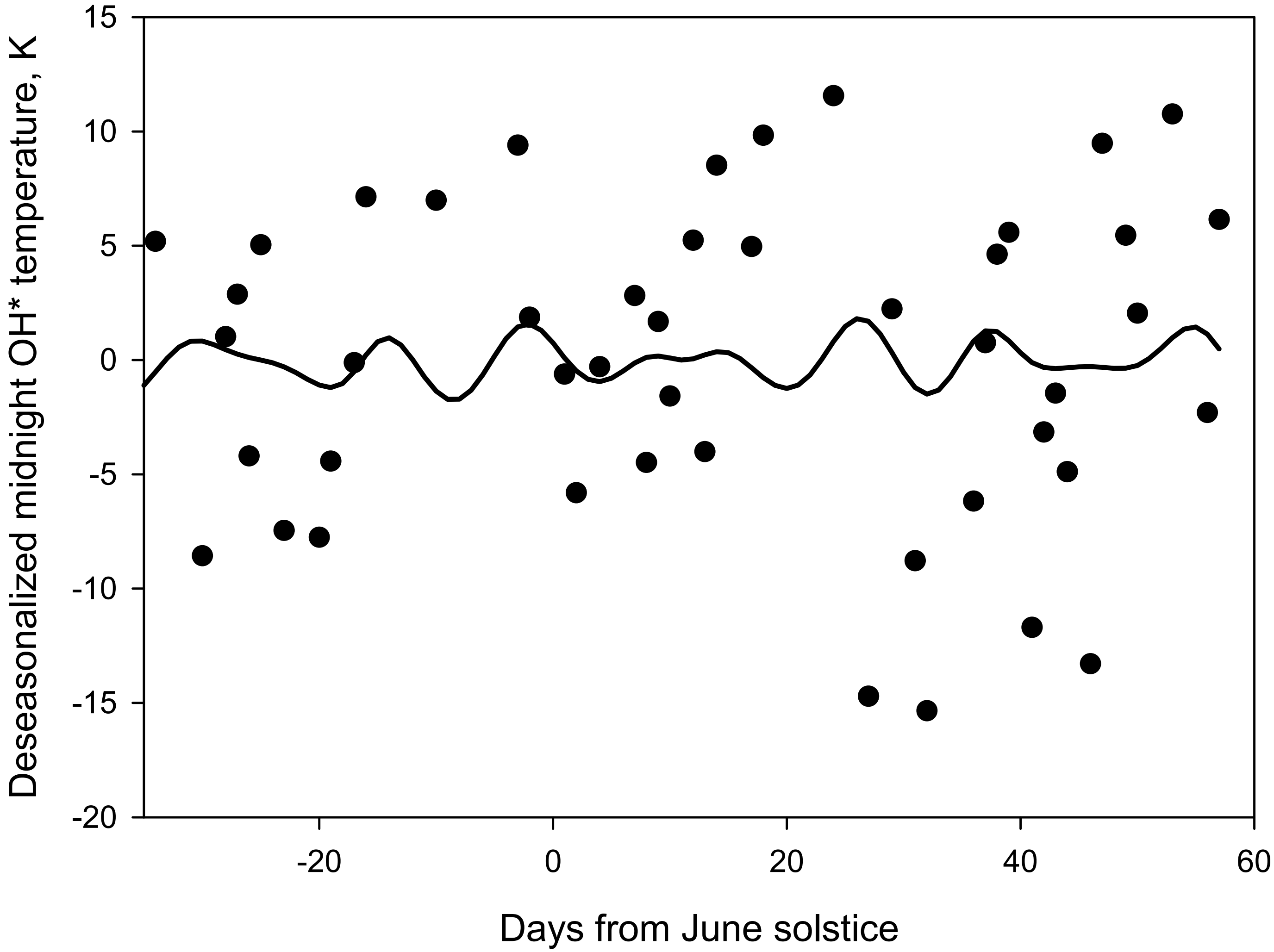
Non-monotonic dependence on the Earth – Moon distance D : generation of the second harmonic of the anomalistic month







- Dalin et al., JASTP, 2006
- Pertsev et al., JASTP, in preparation



Deseasonalized data for midnight Zvenigorod OH* temperature in 2012 (dots) and joint contribution of statistically significant lunar oscillations according to the multiple regression analysis results for 2000-2017.

Summary

- 1. The Moon is a powerful player in the space weather driving. Several oscillations of the lunar origin are surely present in various atmospheric variables and geomagnetic field, some of them provide an appreciable input to a variable variance.
- 2. The lunar semidiurnal tide is not the strongest component among atmospheric lunar oscillations in the range from several hours to several weeks.
- 3. Some statistically significant lunar oscillations have no a theoretical explanation in Laplace's classical tidal theory (e.g. strong semimonthly harmonic of the anomalistic tide) that is a challenge for theoretical studies of lunar oscillations in the atmosphere.
- 4. The lunar synodic semimonthly oscillation (~14.77 days) does exist and may be explained by the quadratic demodulation of the superposition between the solar semidiurnal tide (12 h) and lunar semidiurnal tide (12 h 25 min).

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Thanks !