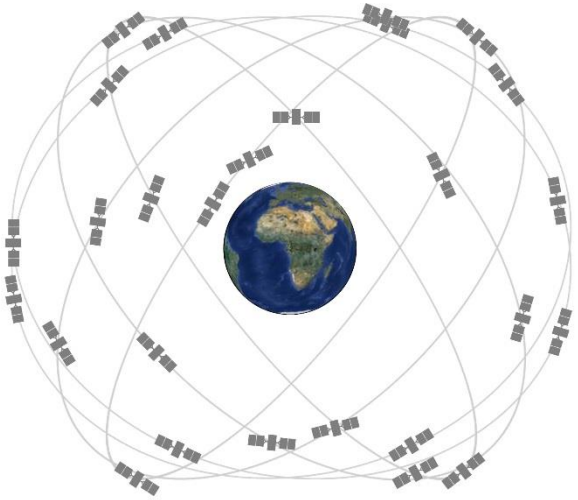
Investigations on precise orbit modeling of GPS satellites



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Geodetic Week 2015, Stuttgart, Germany

Introduction

Bachelor thesis on the effects of solar radiation pressure on GPS orbits

Student Project Assistant

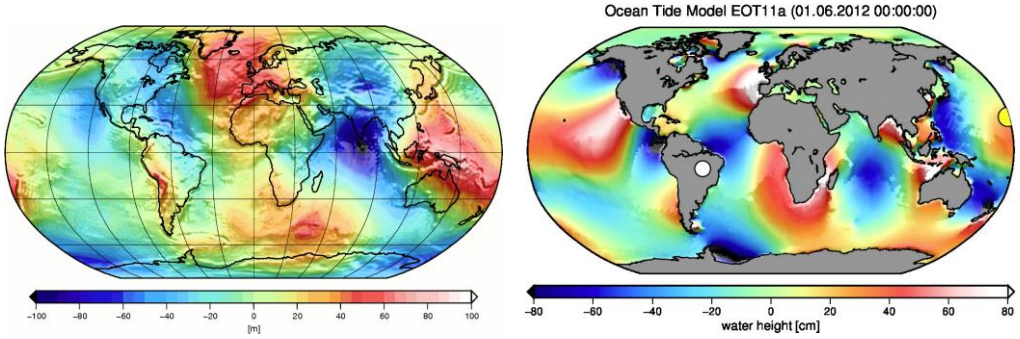
- Funded by the Austrian Research Promotion Agency (FFG)
- Main focus: GPS orbit modeling and orbit determination

Planned: Master thesis on precise orbit determination of GPS satellites

Investigated effects and models

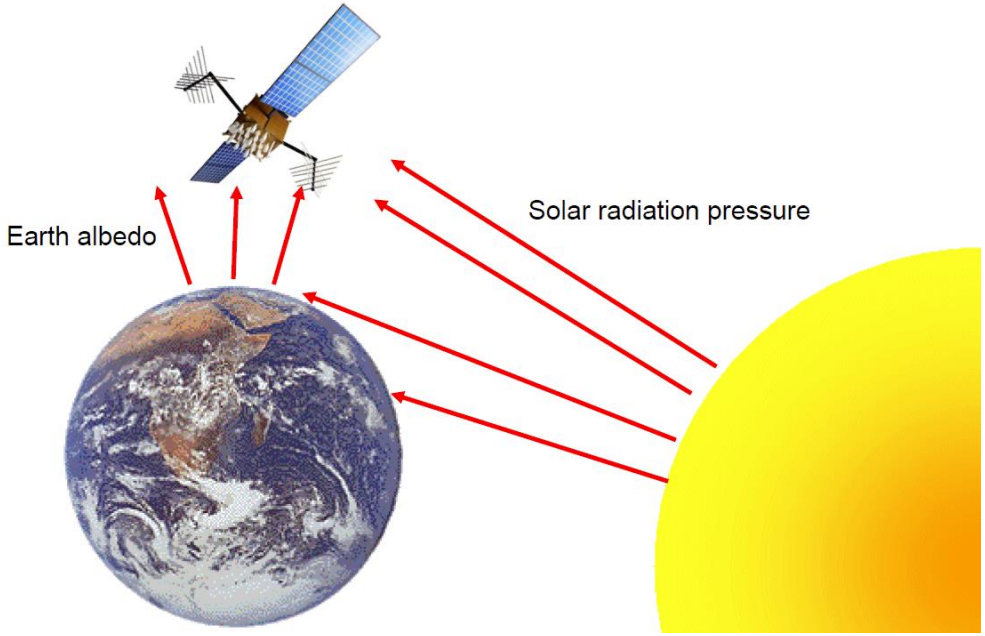
Conservative forces

- Gravity field model
- Ocean tides
- Global mass variations
- Pole tides and ocean pole tides



Non-conservative forces

- Solar radiation pressure
- Earth albedo
- Antenna thrust



Investigation approach

Numerical orbit integration using variational equations

- Orbit modeling only, no GPS observations involved

Estimation of parameters required for best fit to daily IGS final orbits

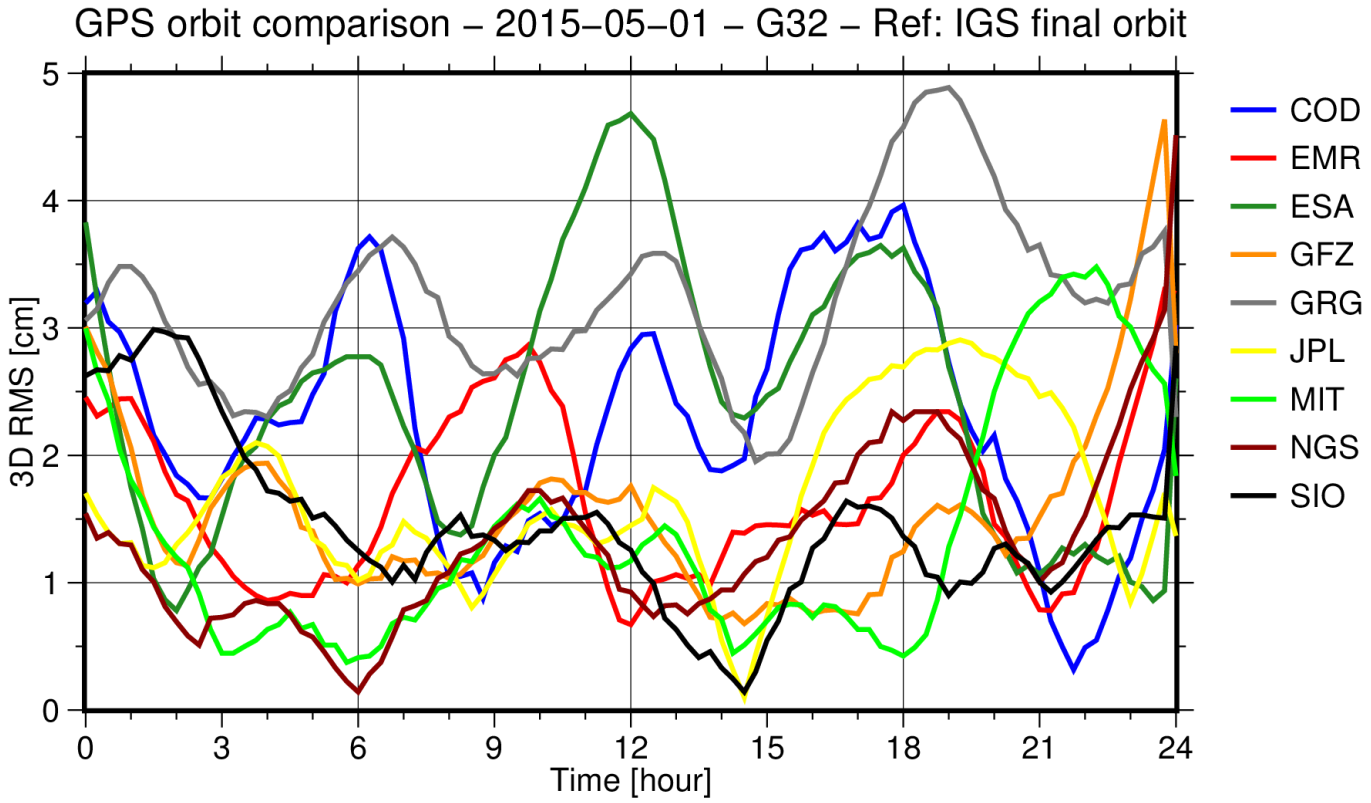
- Initial state vector (position, velocity)
- Solar radiation pressure parameters

Comparison approach

- Multiple solutions with investigated model enabled vs. disabled
- Multiple solutions with different models for investigated effect, if applicable
- Difference of the solutions as 3D RMS per epoch (60 sec. sampling)

IGS final orbits

Combination of orbits from 9 IGS analysis centers



Stated accuracy: 1D mean RMS: ~2.5 cm

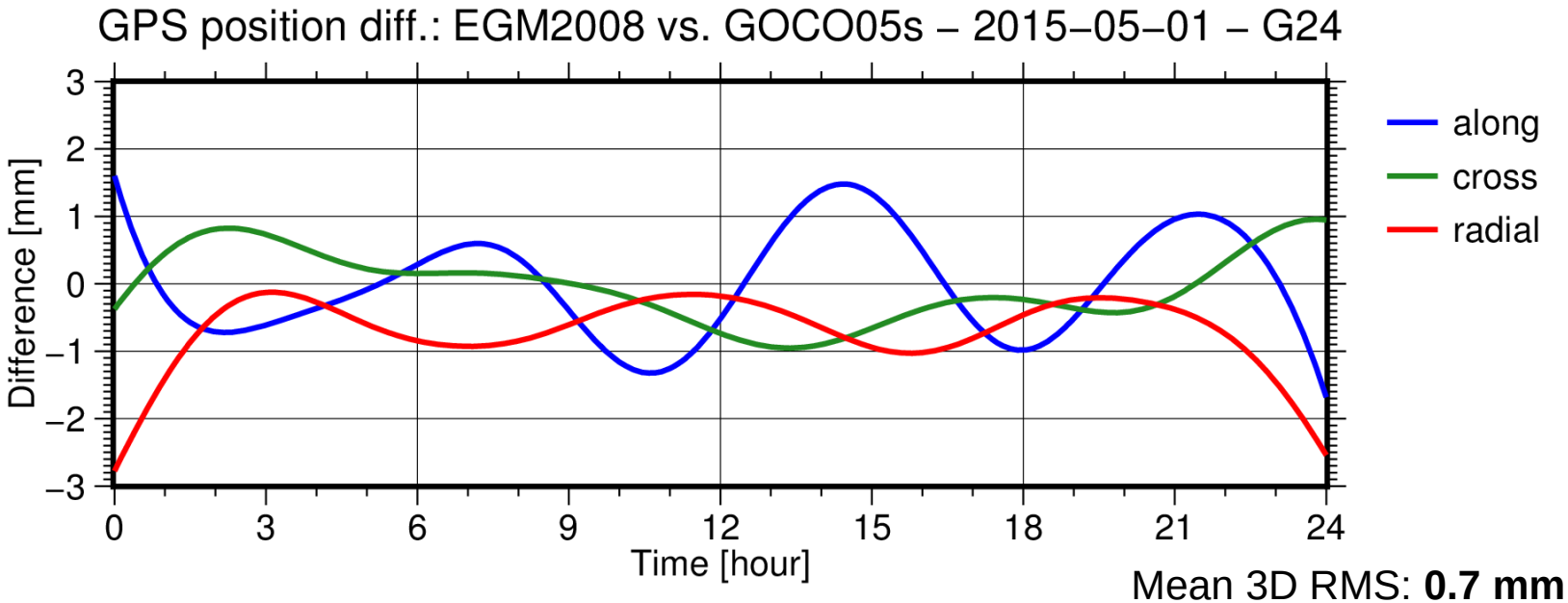
Conservative forces

Gravity field model selection

Current IGS recommendation: EGM2008

Most recent model: GOCO05s

- Published in April 2015
- Contains data from GOCE, GRACE, kinematic orbits, SLR



Mean 3D RMS: **0.7 mm**

Gravity field model selection

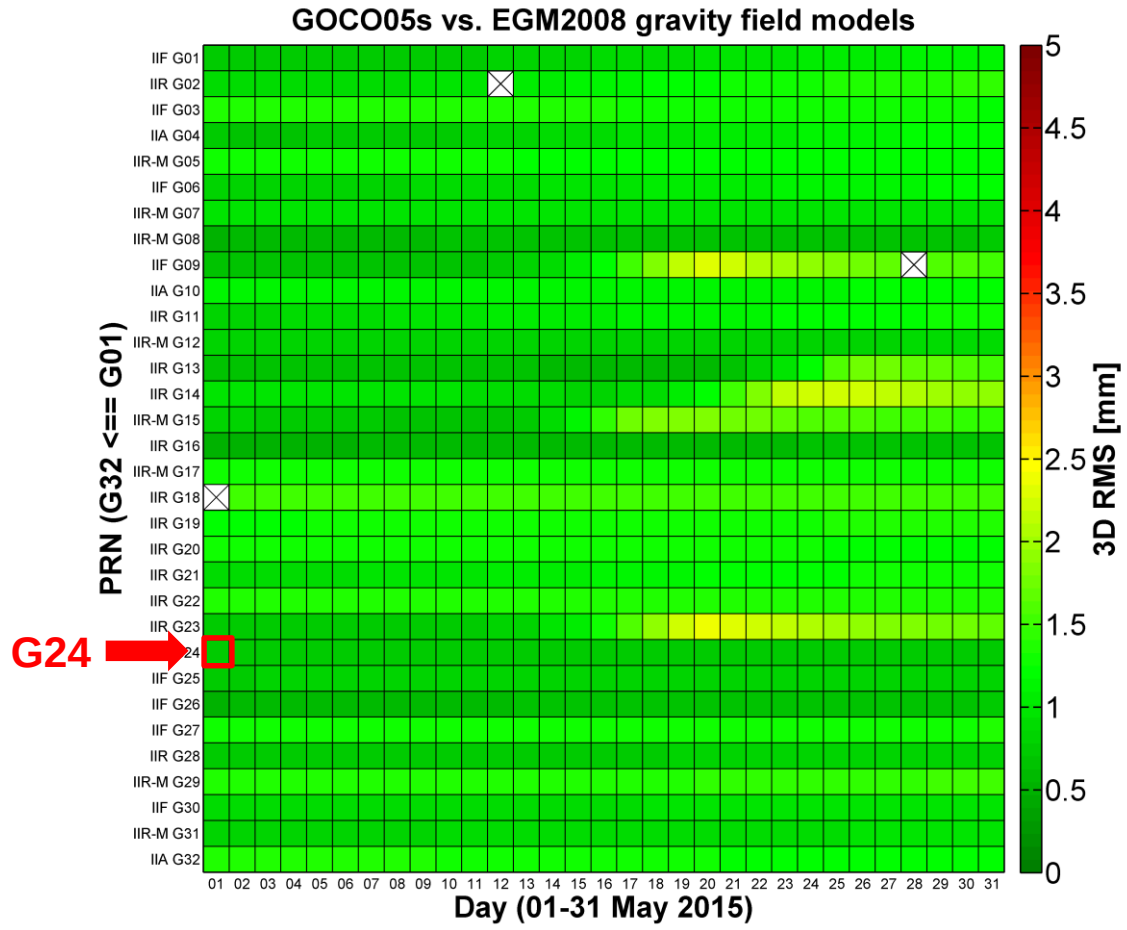
EGM2008

- Max. degree 2190
- Satellite and terrestrial data

GOCO05s

- Max. degree 280
- Satellite data only
- Higher accuracy at low degrees

Max. degree 10 sufficient
for GPS due to high altitude



EGM2008 vs. GOCO05s

- May 2015 mean 3D RMS: **1.0 mm** ➔ EGM2008 sufficient, GOCO05s recommended

Ocean tide models

EOT11a

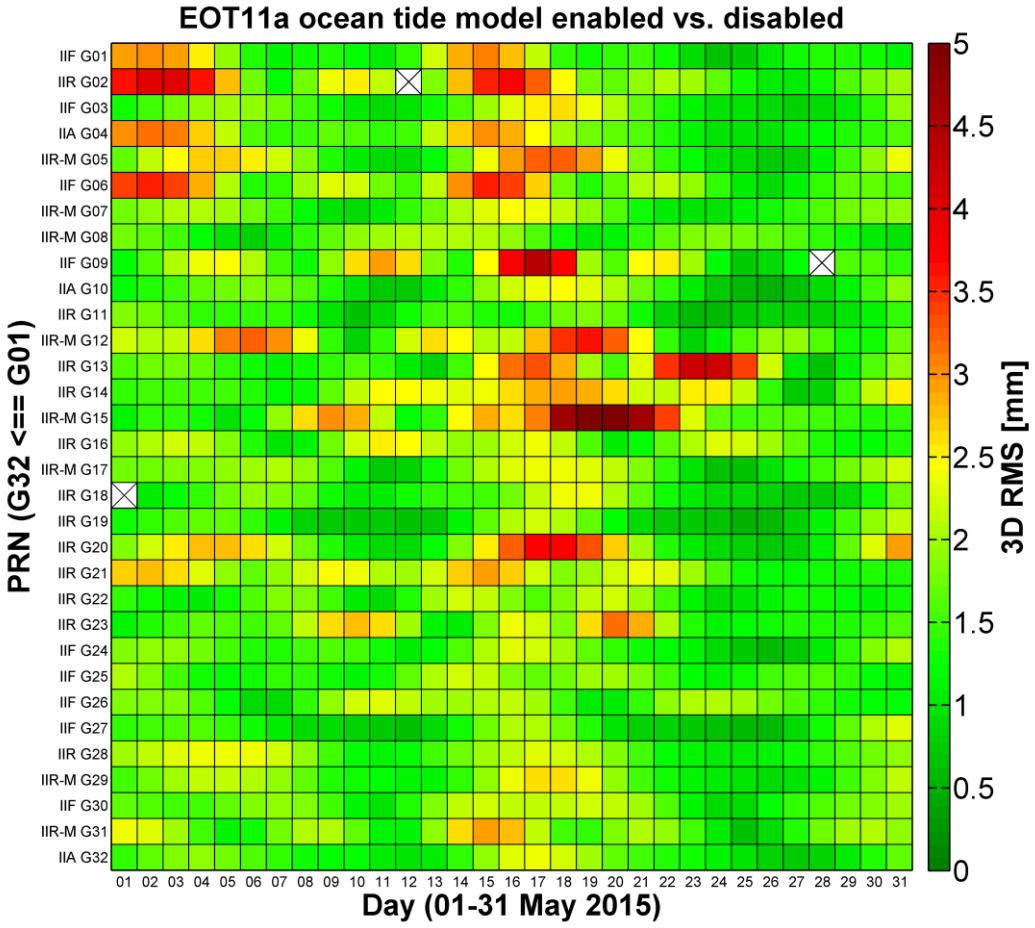
- Empirical Ocean Tide model
- DGFI, Germany

FES2004

- Finite Element Solutions
- CLS/CNES/LEGOS, France

EOT11a enabled vs. disabled

- May 2015 mean 3D RMS: **1.7 mm**



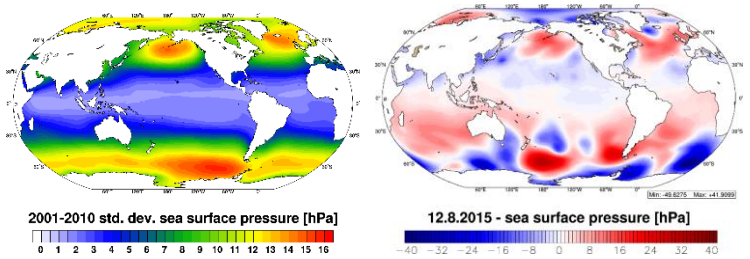
EOT11a vs. FES2004

- May 2015 mean 3D RMS: **0.0 mm** ➔ Use of an ocean tide model recommended
  No difference between models

Mass variations, pole tides and ocean pole tides

AOD1B mass variation model

- Atmosphere and Ocean De-aliasing Level-1B
- GFZ, Germany

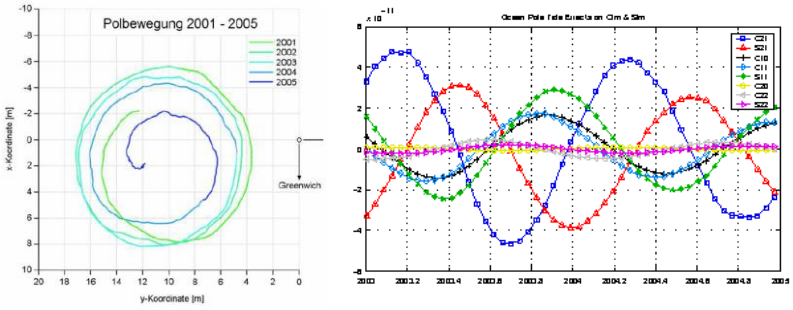


AOD1B enabled vs. disabled

- May 2015 mean 3D RMS: **0.3 mm** ➔ Consideration of mass variations not required

Pole tides and ocean pole tides

- Pole tide model: IERS 2010
- Ocean pole tide model: Desai (2004)



Pole tides and ocean pole tides enabled vs. disabled

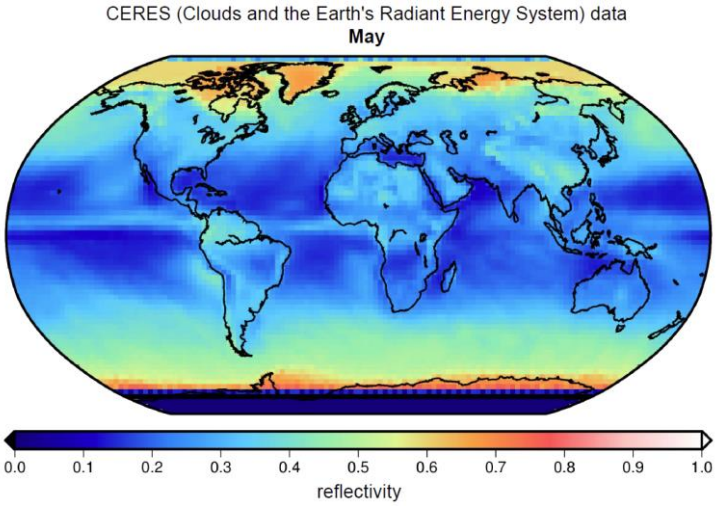
- May 2015 mean 3D RMS: **0.3 mm** ➔ Pole tides and ocean pole tides can be neglected

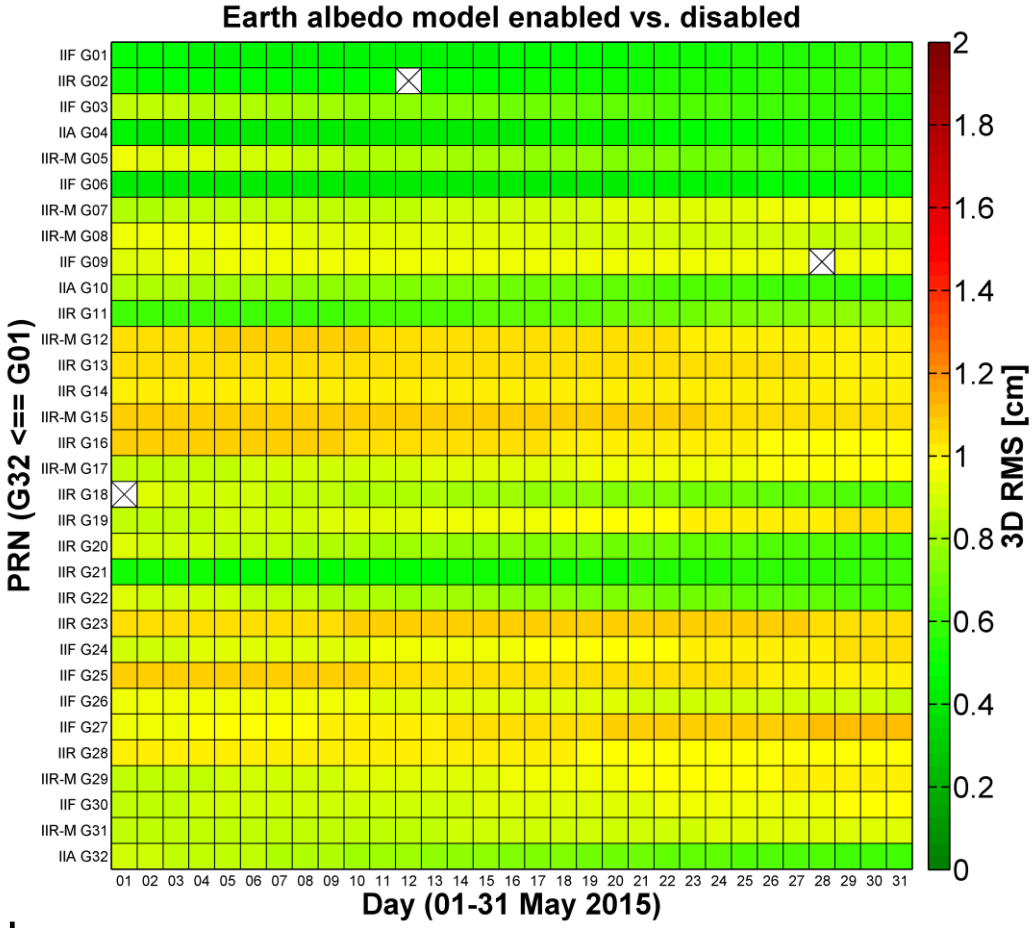
Non-conservative forces

Earth albedo

Box-wing model by
Rodriguez-Solano et al. (2011)

Based on CERES data





Earth albedo enabled vs. disabled

- May 2015 mean 3D RMS: **0.8 cm** ➔ Use of box-wing albedo model recommended

Solar radiation pressure

A priori box-wing model based on Rodriguez-Solano et al. (2011)

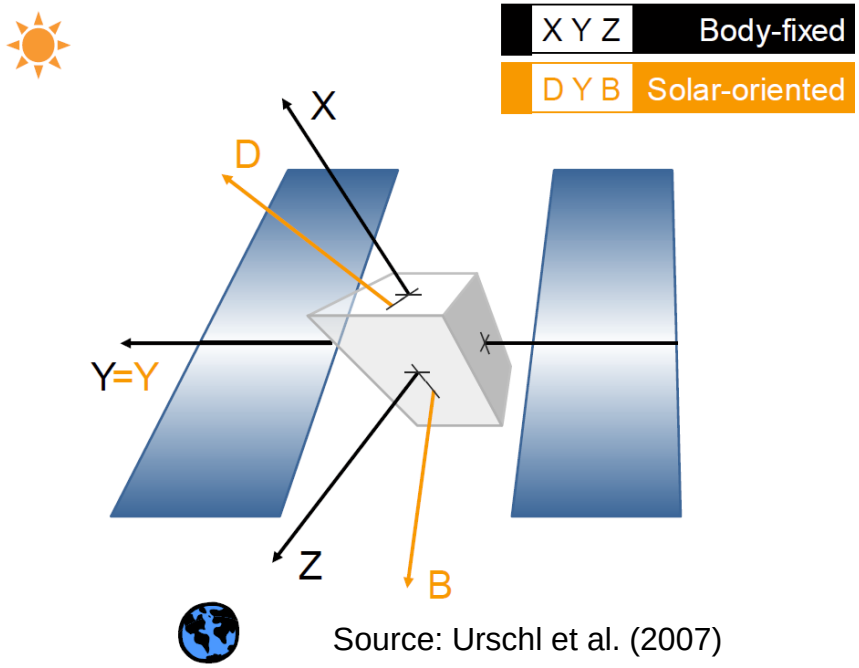
- A priori model only currently not sufficient

Extended CODE Orbit Model

- Constant terms: D_0, Y_0, B_0
- 1 per revolution terms: D_c, D_s, Y_c, Y_s, B_c, B_s

Update from CODE in January 2015

- 2 per revolution terms: D_{c2}, D_{s2}
- 4 per revolution terms: D_{c4}, D_{s4}



Source: Urschl et al. (2007)

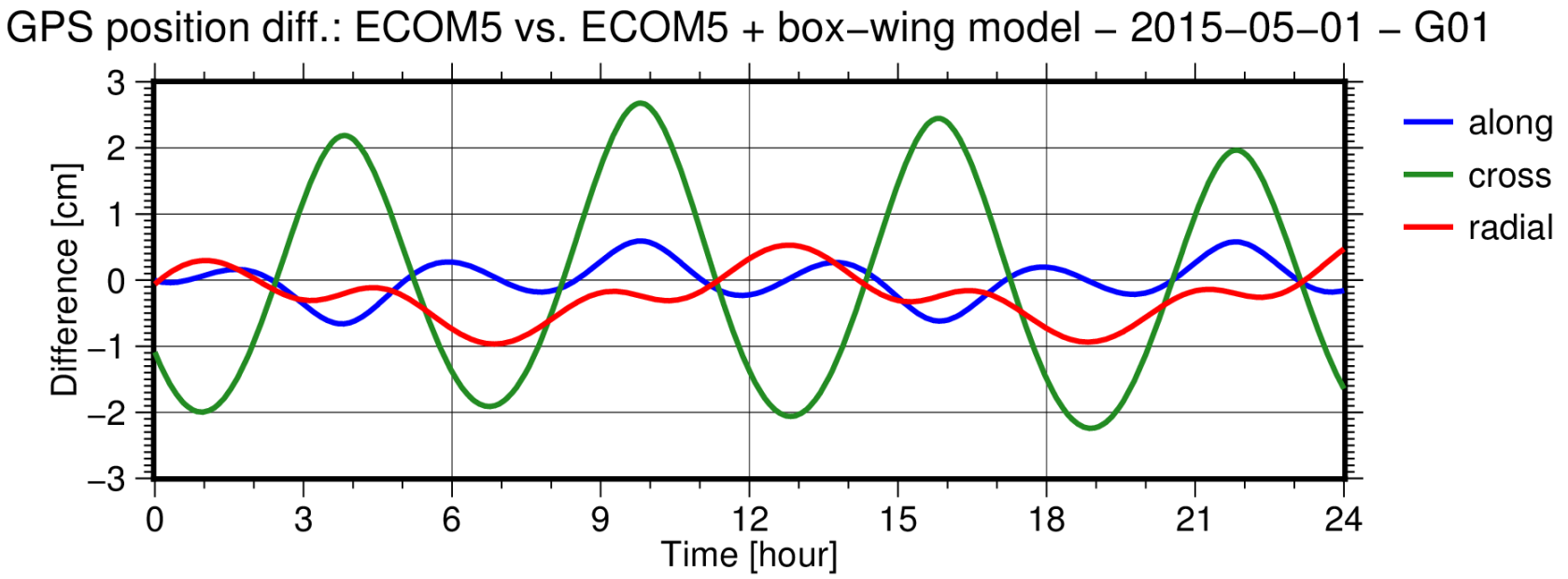
$$\boldsymbol{a_{SRP}} = D(\Delta u)\,\boldsymbol{e_D} + Y(\Delta u)\,\boldsymbol{e_Y} + B(\Delta u)\,\boldsymbol{e_B}$$

$$D(\Delta u) = D_0 + D_c\,cos(\Delta u) + D_s\,sin(\Delta u) + D_{c2}\,cos(2\,\Delta u) + D_{s2}\,sin(2\,\Delta u) + \ \ldots$$

Solar radiation pressure

ECOM 5 parameters

- Constant terms: D_0, Y_0, B_0
- 1 per revolution terms: B_c, B_s

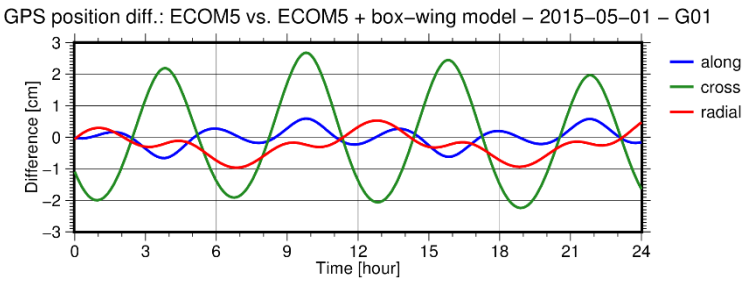


Significant 2 per revolution effects modeled by a priori box-wing model

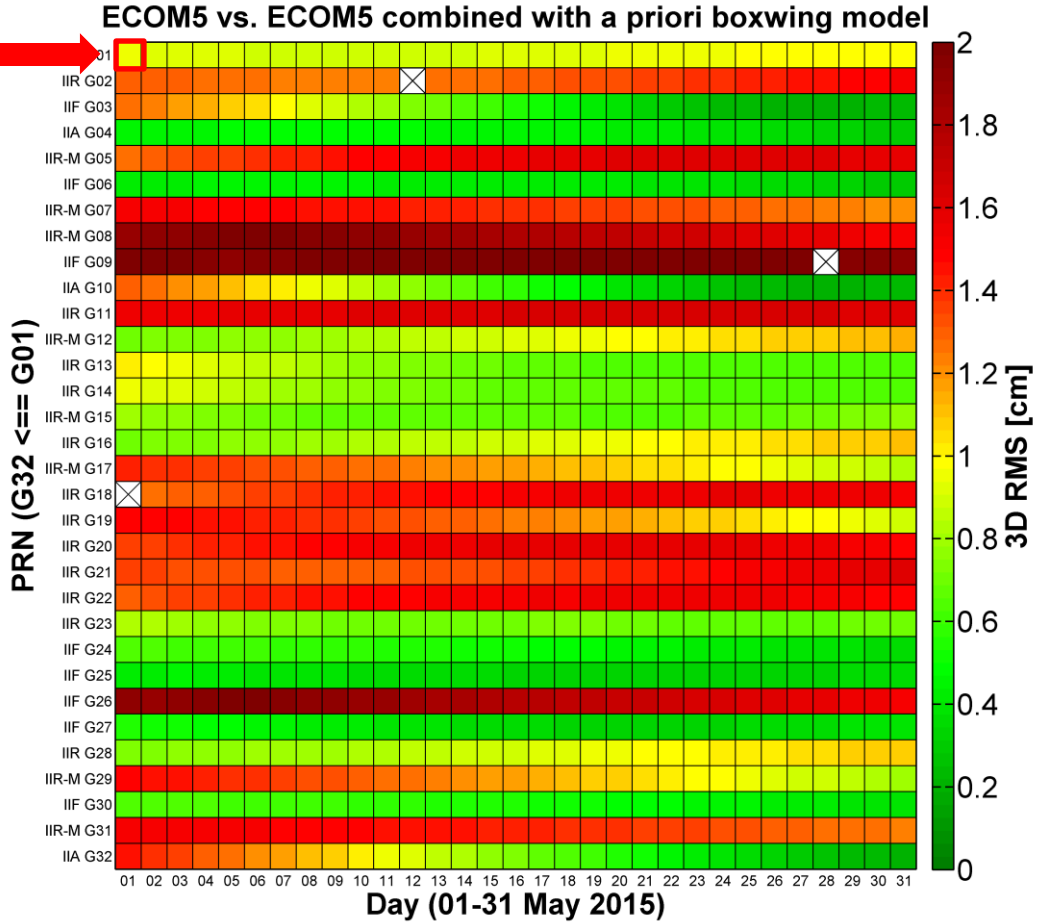
Solar radiation pressure

ECOM 5 parameters

- Constant terms: D_0, Y_0, B_0
- 1 per revolution terms: B_c, B_s



G01



ECOM5 vs. ECOM5 + box-wing

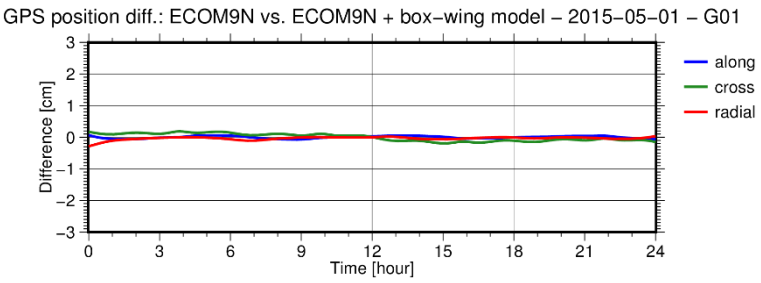
- May 2015 mean 3D RMS: **1.0 cm** ➔ Significant effects not caught by ECOM5 only

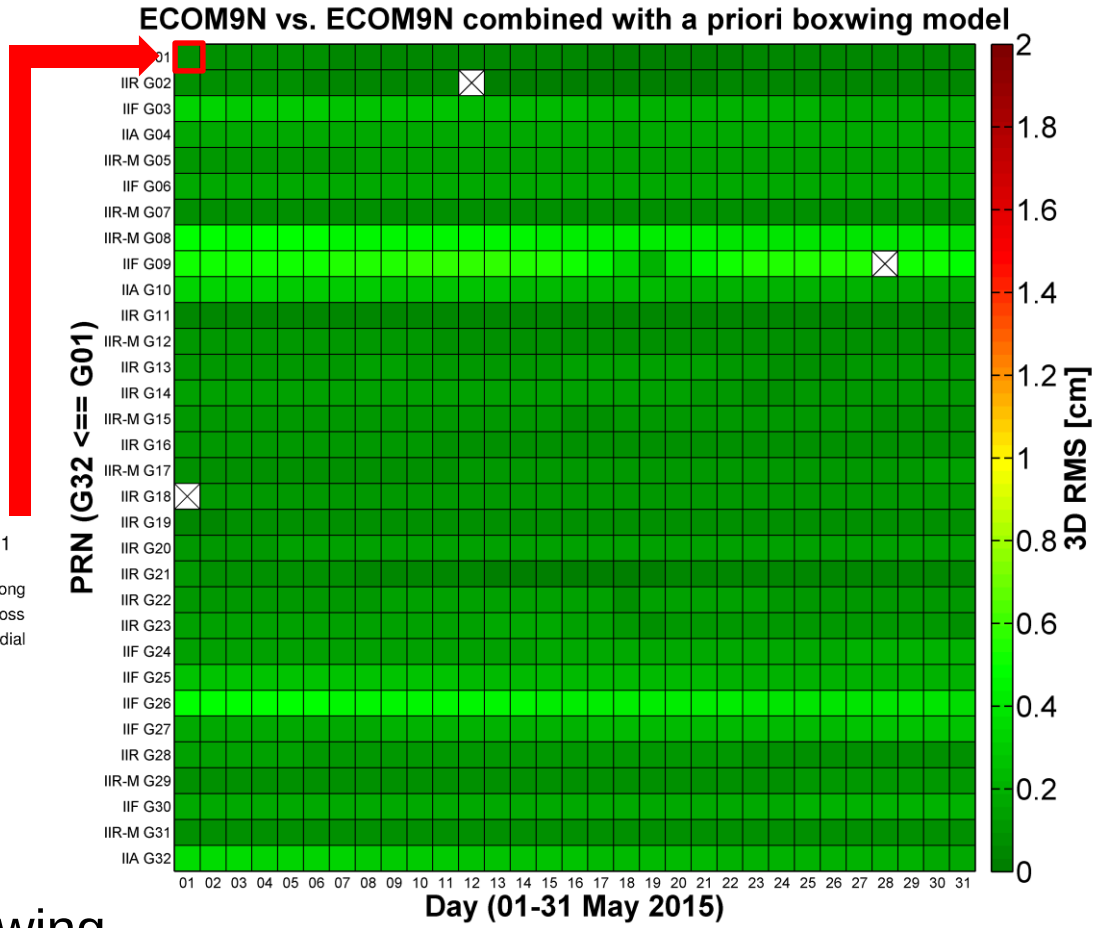
Solar radiation pressure

ECOM 9 parameters (new)

- Constant terms: D_0, Y_0, B_0
- 1 per revolution terms: B_c, B_s
- 2 per revolution terms: D_{c2}, D_{s2}
- 4 per revolution terms: D_{c4}, D_{s4}

G01





ECOM9N vs. ECOM9N + box-wing

- May 2015 mean 3D RMS: **0.2 cm** ➔ Most effects caught by ECOM9N only

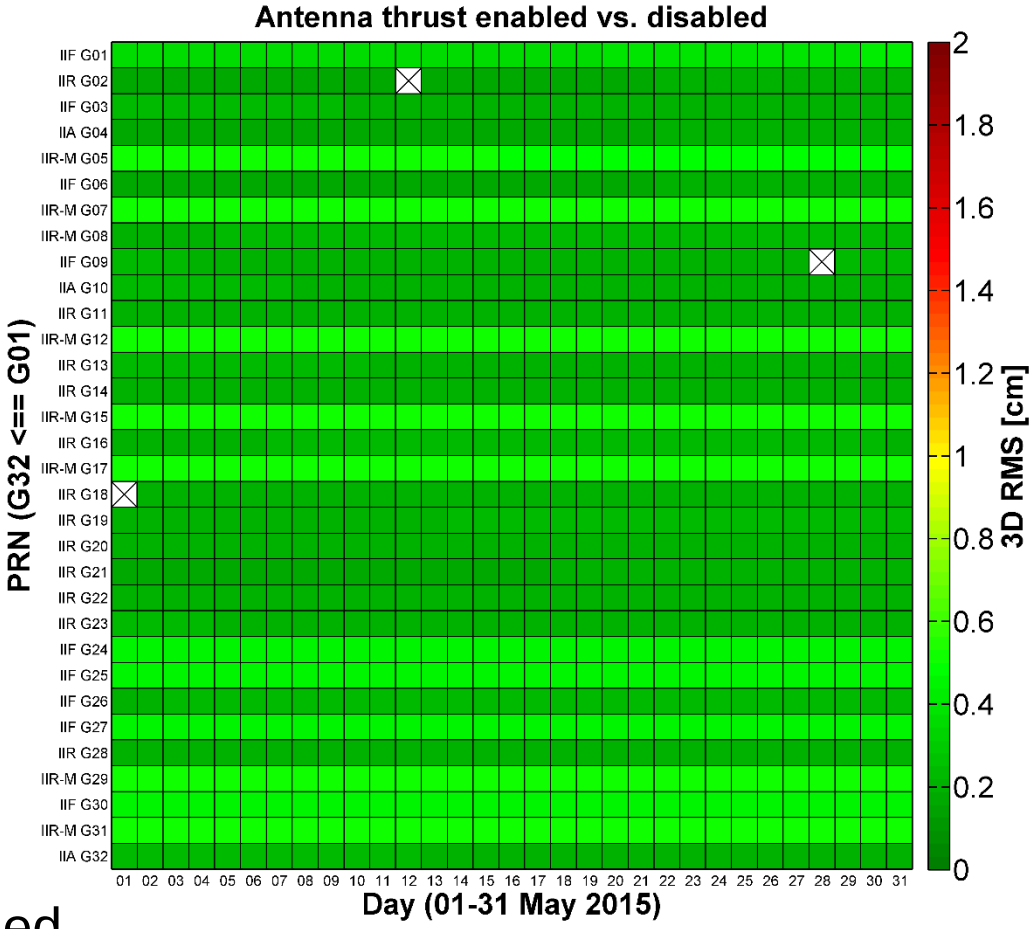
Antenna thrust

Transmission of GPS signals towards +Z axis (Earth)

Block-dependent trans. power (new signals with IIR-M, IIF)

IGS model values

- IIA: 76 W
- IIR: 85 W
- IIR-M: 108 W (no M) / 198 W
- IIF: 154 W (no M) / 249 W



Antenna thrust enabled vs. disabled

- May 2015 mean 3D RMS: **0.3 cm** ➔ Use of antenna thrust model recommended

Conclusion

Conservative forces

Gravity field model	EGM2008 sufficient, GOCO05s recommended
Ocean tides	Any current model recommended
Global mass variations	Neglectable
Pole tides and ocean pole tides	Neglectable

Non-conservative forces

Solar radiation pressure	Currently not modeled sufficiently by a priori box-wing model Estimation of 2 per revolution terms recommended (ECOM9N)
Earth albedo	Box-wing model recommended
Antenna thrust	Modeling recommended

Thank you for your attention!