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Force models for GPS Orbit modeling

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Outline

- Radiation Pressure
  - Solar radiation pressure
  - Earth Radiation
  - Attitude modeling
  - Thermal forces
- Antenna Thrust
- Gravity

Based on:

ftp://ftp.igs.org/pub/center/analysis/

Solar Radiation pressure models

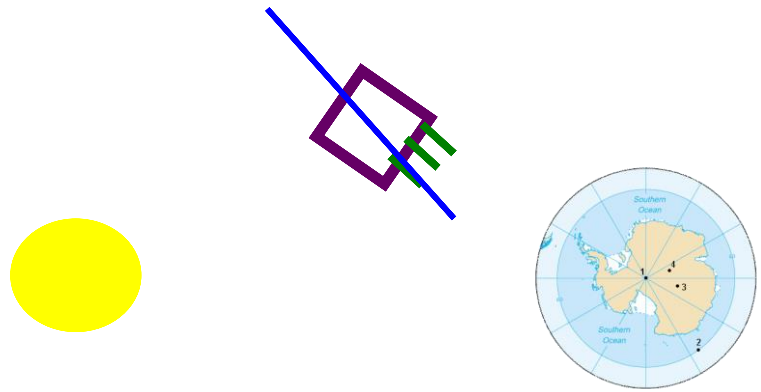
- Solar radiation pressure results from reflection of sunlight
- Difference between JPL style model and DYB style model at cm level (Sibthorpe et al 2011)

Solar radiation pressure models

- CODE DYB-style Model
  - CODE, GFZ, NOAA, USNO
- Empirical model
  - NRCAN+JPL , MIT+SIO
- Box-wing model
  - ESA, GRG

Attitude models

- Nominal: keeps solar panels pointed towards the sun and antenna pointed towards earth



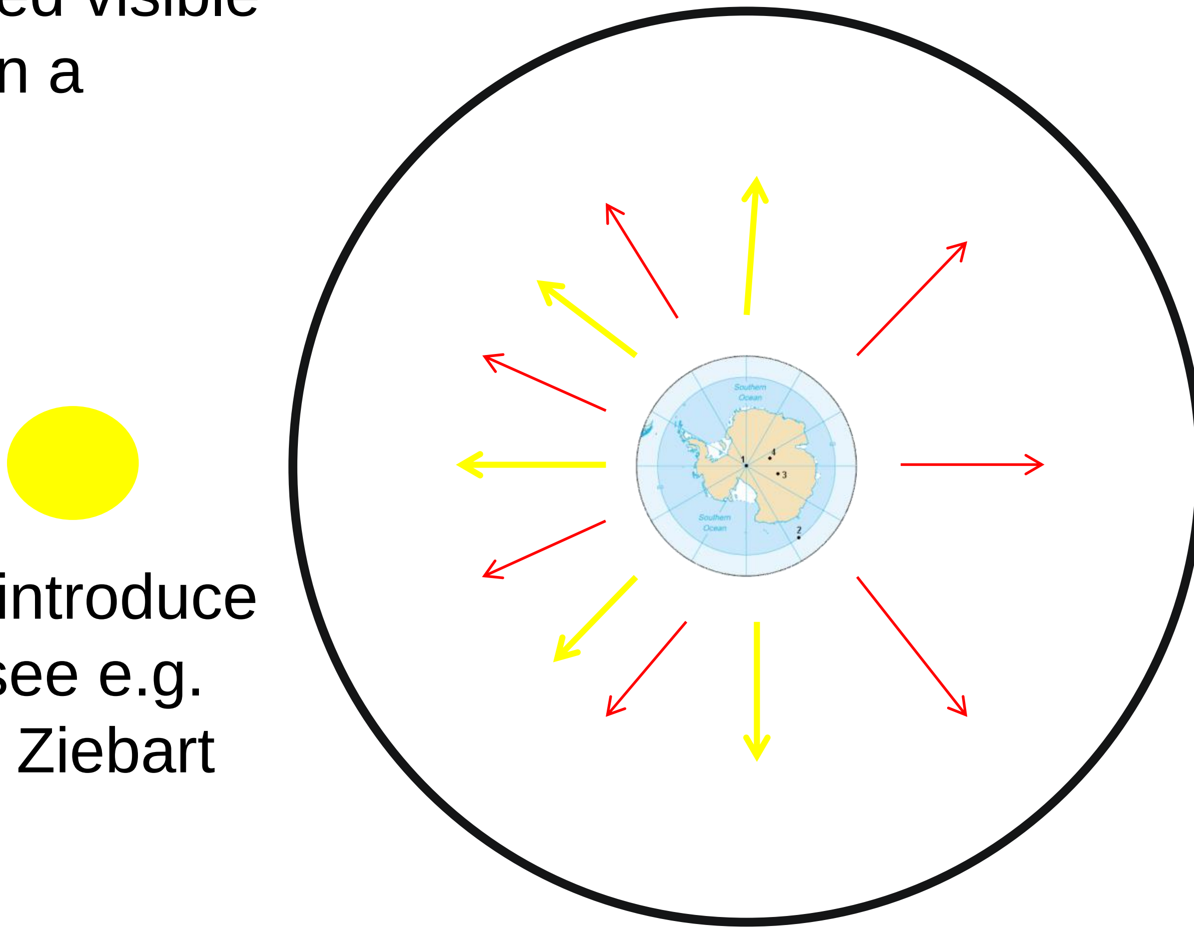
- Eclipse modeling causes substantial differences (2-3 cm RMS) between solutions

Attitude models

- None
  - NOAA, USNO
- Nominal
  - CODE, NRCan, ESA, GFZ, MIT, SIO, WHU
- Nominal + eclipse solution
  - GRG, JPL

Earth Radiation Pressure

The force of of reflected visible and emitted IR light on a GNSS satellite



Model variations can introduce bias at the cm level (see e.g. Rodriguez et al 2012, Ziebart 2009)

Earth Radiation Pressure

- Rodriguez-Solano et al 2012
  – GFZ, NOAA, CODE
- Knocke-Ries Model
  – JPL, NRCan
- Other similar model
  – GRG (incorporates ECMWF), ESA
- No model
  – WUH, USNO, SIO, MIT

Thermal models for the future?

- Direct thermal effect
  - non-uniform temperature and/or non-spherical shape
  - few meter level, but often absorbed by model parameters (Adhya et al 2005)
- Yarkovsky effect
  - tentatively detected at 10 cm level for Galileo (Svehla et al 2016 IGS Workshop)
  - force created by asymmetric thermal emission on rotating body

Antenna Thrust

- Thrust from transmitting navigation message
- typically in radial direction
- magnitude of 10s of cm

Antenna Thrust

- No information
  - MIT, GRG, USNO, WHU
- None
  - ESA (as of 2015), SIO
- http://acc.igs.org/orbits/thrust-power.txt
  - CODE, NRCan, JPL
- Rodriguez-Solano 2012 (constant 80W)
  - GFZ, NOAA

Gravity field

- EGM2008, 12x12
  - CODE, NRCan, GFZ, JPL, NOAA
- EIGEN-GLO5C 12x12
  - ESA
- EIGEN_6S (TVG)
  - GRG
- EGM 96 9x9
  - MIT, SIO
- JGM3 12x12
  - USNO
- EIGEN-GLO4S1 12x12
  - WHU

Gravity – 3rd body perturbers

- Can analytically compute max acceleration at conjunction/opposition and integrate for one MEO orbit
- Effects of bodies through Saturn are significant
- Differences beyond Saturn make little difference

Body	One orbit effect
Moon	3.8 km
Sun	1.4 km
Venus	5.7 cm
Jupiter	1.1 cm
Mars	7.6 mm
Mercury	7.1 mm
Saturn	0.6 mm
Uranus	12 μm
Ceres	0.1 μm
Pluto	0.4 nm

Gravity – 3rd body perturbers

- Sun and Moon
  - USNO, GOP, MIT, SIO
- Sun, Moon, Jupiter, Venus, Mars
  - CODE, NOAA
- All Planets + Sun and Moon
  - JPL, NRCAN, GRG
- All Planets + Sun, Moon, and Pluto
  - WHU, ESA, GFZ

Questions to ponder

- For most force models, each AC has slightly different and valid approach
- However, *significant* biases
- Areas of possible agreement:
  - Antenna Thrust, gravity field, 3^{rd} body perturbations
- Areas where we are probably stuck
  - Earth radiation pressure, solar radiation pressure, attitude modeling, thermal modeling

Further Consideration

- for LEOs:
  - Time-varying gravity, gravity field agreement
  - drag
- for future GNSS:
  - orbit normal attitudes