# Software and troposphere delay model development for Satellite Laser Ranging

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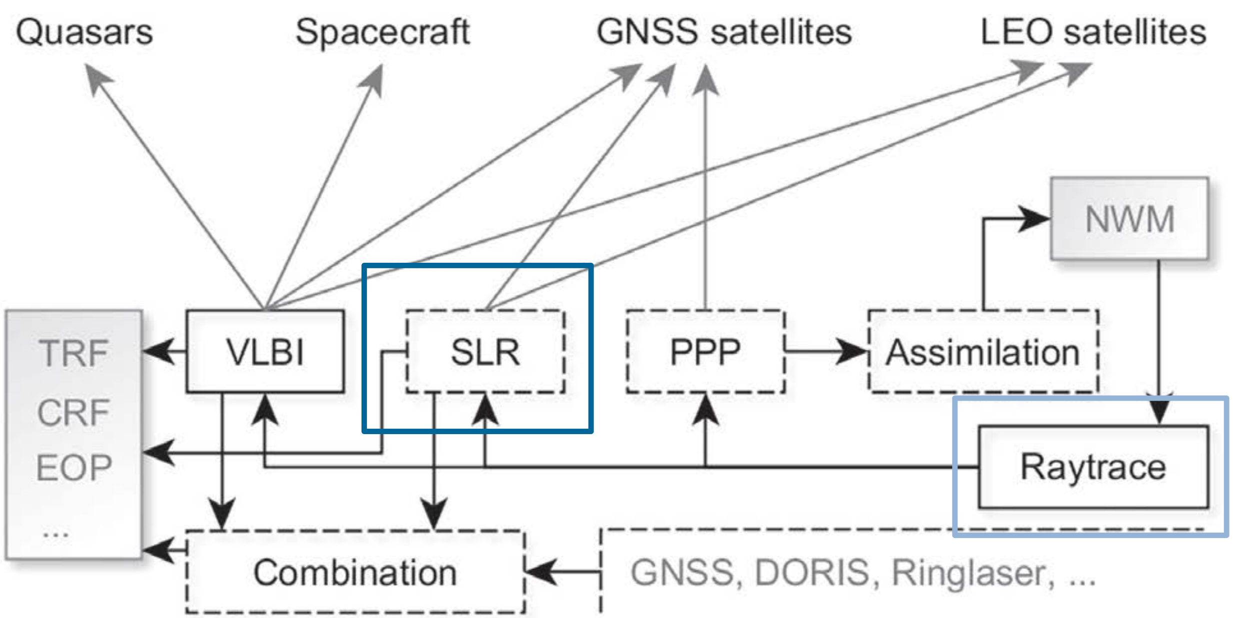
# SLR software development

- Vienna VLBI and Satellite Software **VieVS**




Böhm et al. (2018)

# VieVS – SLR module: design

- Software design similar to VLBI module

  → Benefits and synergies

### SLR_init

- Station coordinates
- Observation data
- Orbit data
- External corrections
- Datahandling file
- …

→

### SLR_mod

- Station biases
- Eccentricities
- CoM correction
- Troposphere delay model
- Solid Earth tides
- Atmospheric loading effects
- …

→

### SLR_lsm

- Station coordinates
- Orbits
- ERP
- …

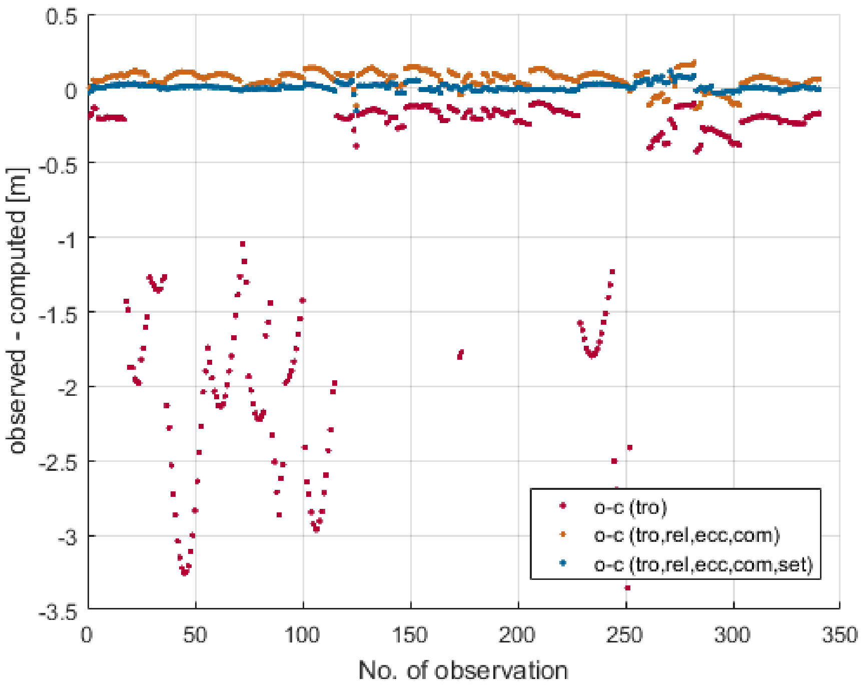
# VieVS – SLR module: improvements

- November 2017: two-week stay in Wroclaw

  → Improvements in SLR_mod

- Later: solid Earth tides added

| Residual statistics | | |
|---|---|---|
| o – c | Bias [m] | Std [m] |
| (tro) | -0.958 | 1.027 |
| (tro, rel, ecc, com) | 0.063 | 0.057 |
| (tro, rel, ecc, com, set) | 0.010 | 0.025 |



# ViеVS – SLR module: status and upcoming tasks

- **Status:** most correction models applied

  → accuracy 2-3cm

- **Next steps:**

  – Atmospheric pressure loading

    → http://vmf.geo.tuwien.ac.at/

  – Orbit integration

    (current solution: interpolated precise orbits)

# Tropospheric products for SLR

- Vienna Mapping Functions **VMF**

  → Well established MF for microwave techniques

  → Current version: **VMF3**

- Adaptation for optical frequencies: **VMF3o**

- Coefficients $a_h$, $b_h$, $c_h$, and $a_w$, $b_w$, $c_w$ estimated from **ray-tracing**

$$MF_h(\varepsilon) = \frac{1 + \frac{a_h}{1 + \frac{b_h}{1 + c_h}}}{\sin\varepsilon + \frac{a_h}{\sin\varepsilon + \frac{b_h}{\sin\varepsilon + c_h}}}$$

$$MF_w(\varepsilon) = \frac{1 + \frac{a_w}{1 + \frac{b_w}{1 + c_w}}}{\sin\varepsilon + \frac{a_w}{\sin\varepsilon + \frac{b_w}{\sin\varepsilon + c_w}}}$$

# RADIATE: optical ray-tracing

- **RADIATE**: VieVS ray-tracing software
- Refined piecewise-linear ray-tracing approach
- Wavelength-dependency for optical frequencies

  → fixed to 532nm

$$N_h = N_{gaxs} \frac{T_d}{P_d} Z_d R_d \rho$$

$$N_w = N_{gws} \frac{\rho_w}{\rho_{ws}} - N_{gaxs} \frac{T_d}{P_d} \frac{Z_d}{Z} \frac{e}{T} \varepsilon$$

Mendes & Pavlis (2004)

| Vertical interpolation levels | | |
|---|---|---|
| **Interval [km]** | **Increment** | **Data source** |
| 0 – 2 | 10 m | ECMWF |
| 2 – 6 | 20 m | ECMWF |
| 6 – 16 | 50 m | ECMWF |
| 16 – 36 | 100 m | ECMWF |
| 36 – 84 | 500 m | ECMWF / U.S. SA, 1976 |

# VMF3o: parameters

- $b_h, b_w, c_h, c_w$ estimated **once**

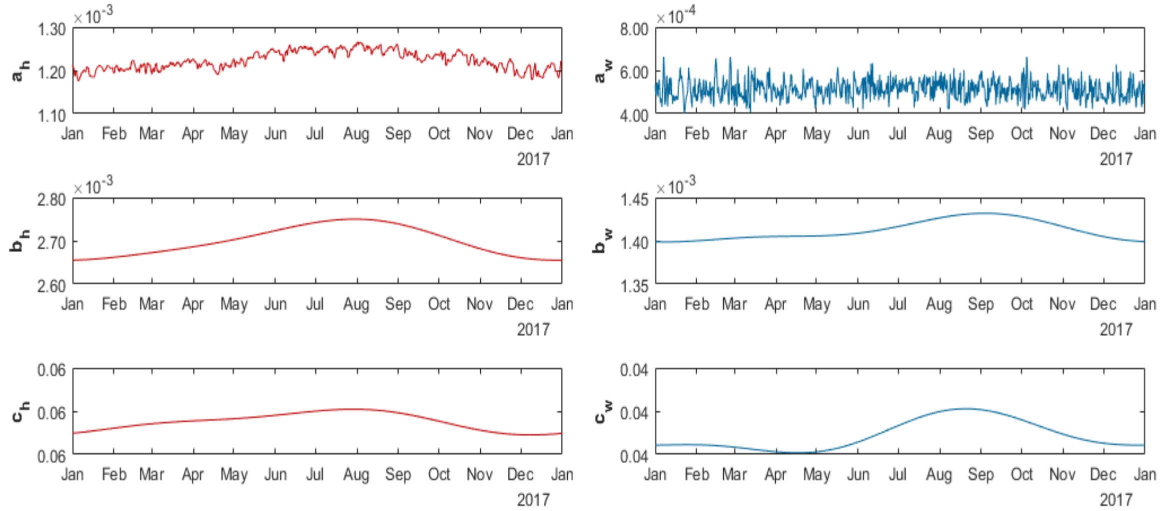
  → Spherical harmonics: degree/order 12, annual and semi-annual signals

- $a_h, a_w$ estimated **per epoch**

  → 6h resolution in discrete spatial resolution

- **ZHD** and **ZWD**

  → Ray-traced




Time series of hydrostatic (**red**) and non-hydrostatic (**blue**) coefficients of VMF3o for the year 2017 at **49.50° lat., 12.50° long.**

# VMF3o: first version

- $a_h$, $a_w$ estimated on 1°x1° grid
- Horizontal symmetry assumed
- Test period: 2005
- Reference solution: MP

| Difference of mean absolute observation residuals | | | | | |
|---|---|---|---|---|---|
| | **MP – VMF3o** | **MP – VMF3o(+ZWD)** | | **MP – VMF3o** | **MP – VMF3o(+ZWD)** |
| **1864** | -0.009 | -0.001 | **7810** | -0.049 | -0.105 |
| **1873** | 0.005 | 0.011 | **7811** | 0.002 | 0.007 |
| **1884** | 0.005 | 0.048 | **7824** | 0.011 | -0.123 |
| **7080** | -0.037 | -0.006 | **7825** | -0.046 | -0.074 |
| **7090** | -0.028 | -0.065 | **7832** | -0.044 | 0.021 |
| **7105** | -0.013 | 0.001 | **7838** | 0.020 | 0.075 |
| **7110** | 0.012 | 0.005 | **7839** | -0.005 | 0.007 |
| **7237** | 0.003 | 0.013 | **7840** | -0.007 | 0.015 |
| **7249** | 0.006 | 0.071 | **7841** | 0.007 | 0.000 |
| **7405** | -0.003 | -0.012 | **7941** | 0.008 | 0.051 |
| **7501** | -0.051 | -0.015 | **8834** | 0.014 | 0.022 |

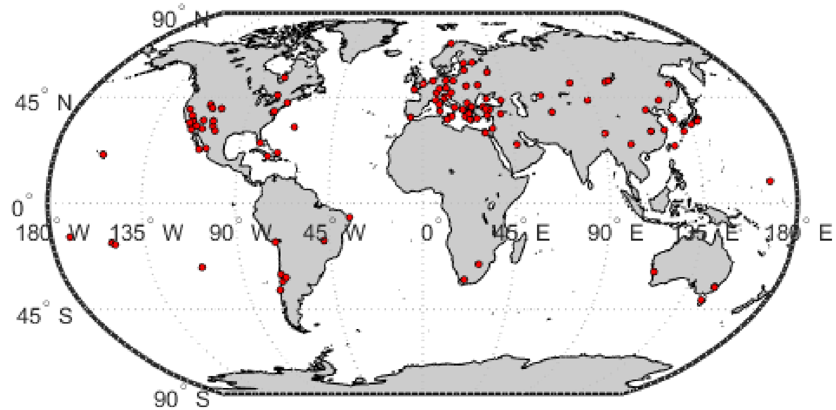
# VMF3o: current version

- **Station-wise** ray-tracing instead of 1°x1° grid
- Parameters:

  → $a_h, a_w$

  → **ZHD**, **ZWD**

  → $Gn_h, Ge_h, Gn_w, Ge_w$




Stations included for station-wise ray-tracing
→ VMF3o parameters available at these sites

- Wavelength-dependency!
- Availability:

  → 2001 – 2017 on VMF server

  http://vmf.geo.tuwien.ac.at/trop_products/SLR_prelim/

  → Future: ERA-interim, operational, forecast

# Summary

- **VieVS – SLR module** in progress
- Next steps:

  → Atmospheric pressure loading

  → Orbit integration

- **VMF3o** in validation phase
- Next steps:

  → Integration to fully automated processing on VMF server

# References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- **D. Landskron & J. Böhm (2018).** VMF3/GPT3: refined discrete and empirical troposphere mapping functions. *J Geod (2018) 92: 349.* https://doi.org/10.1007/s00190-017-1066-2
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