SLR School - Session 3: Corrections and Error Sources

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Session 3: Corrections and Error Sources

- What corrections do we add to our basic range data?
- Where do they come from?
- How do we calibrate and get the most accurate data products?
- What are the error sources to our ranging data?
- Accurate timing: how do we get it? How good is it? Improvements?
- The importance of ground surveys and how do we do them
- Spacecraft centre of mass: modelling considerations and operational issues

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Session 3: Corrections

What do I mean by “corrections” here?

correction (kəˈrɛkʃən)

n

1. the act or process of correcting
2. something offered or substituted for an error; an improvement
3. the act or process of punishing; reproof
4. (Mathematics) a number or quantity added to or subtracted from a scientific or mathematical calculation or observation to increase its accuracy

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The basic corrections we are going to discuss serve the purpose of achieving the required **accuracy** from the SLR **technique**…

They do **not** imply that the measurements themselves, at a technical level, are inaccurate

Session 3: Corrections

To recap:

- SLR observations (NPs) →
- Orbit propagation and parameter estimation

The SLR observable is TOF, **not** distance

Time-of-flight is not what we need in the analysis stage:

We need to convert TOF to ranges, multiplying by the speed of light + applying some corrections

Photo: M.Wilkinson

However accurate TOF measurements are, without corrections distances are off by metres

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Session 3: Corrections – tropospheric delay

Troposphere: lowest layer of Earth's atmosphere

Geometric path length != Optical path length

OPL = geometric length x refractive index

Depends on pressure, temperature and composition, which are heterogeneous and time variable

We compute appropriate corrections using models

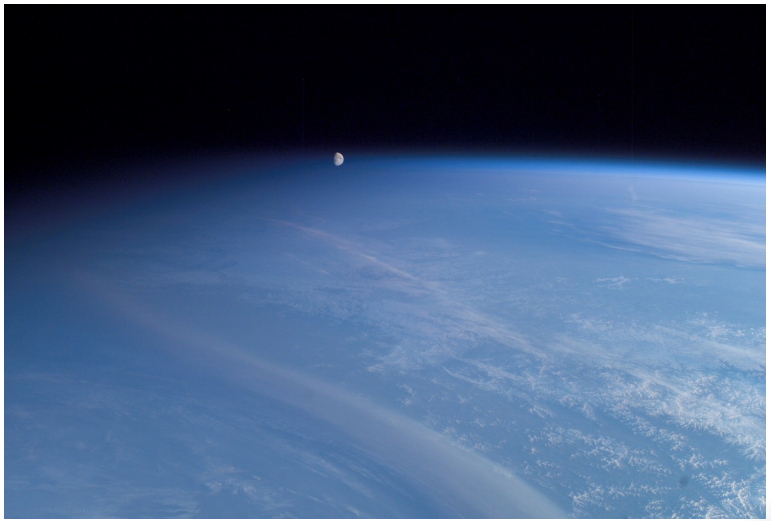


Photo: NASA

Session 3: Corrections – tropospheric delay

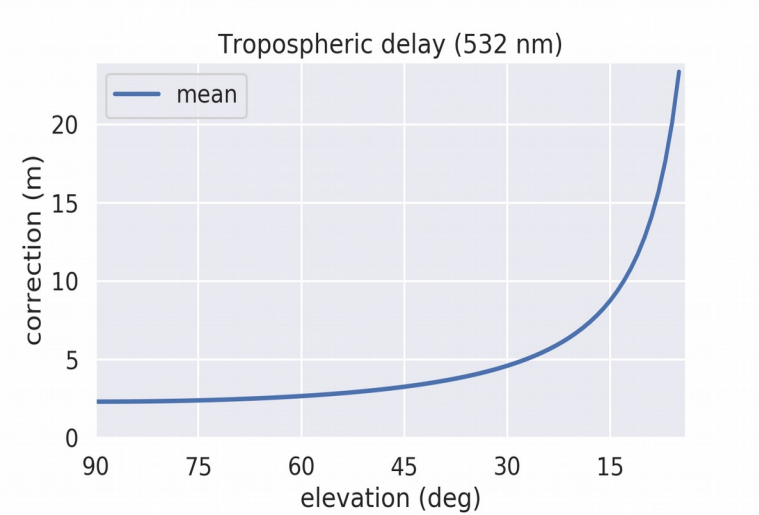
Normally the total delay at the zenith is computed, followed by a projection to the angle of interest

Currently we use the Mendes-Pavlis model (2004)

- Zenith delay accuracy: sub-mm
- Mapping function: sub-cm

Developed from ray-tracing computations, using satellite observations of the atmosphere

Assumption: spherically symmetric atmosphere



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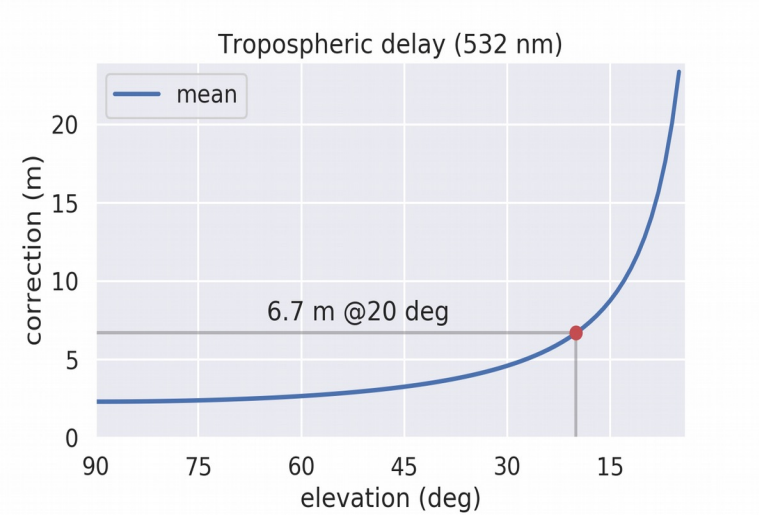

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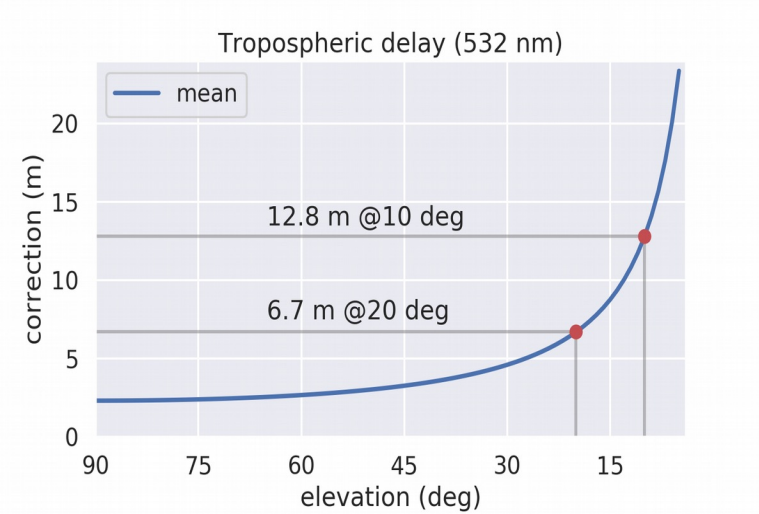

Session 3: Corrections – tropospheric delay

Test: orbit fit **without** applying any corrections

- Data: LAGEOS & LAGEOS-2 normal points from the global network (7 days)
- Only dynamic parameters estimated (satellite positions, force model)
- Quantity of interest: observed minus computed residuals

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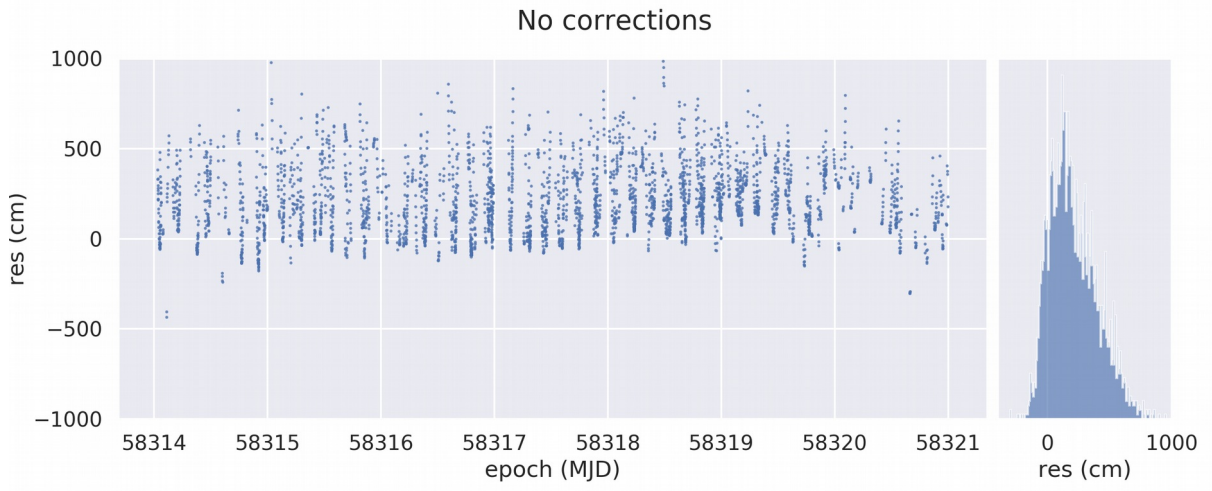
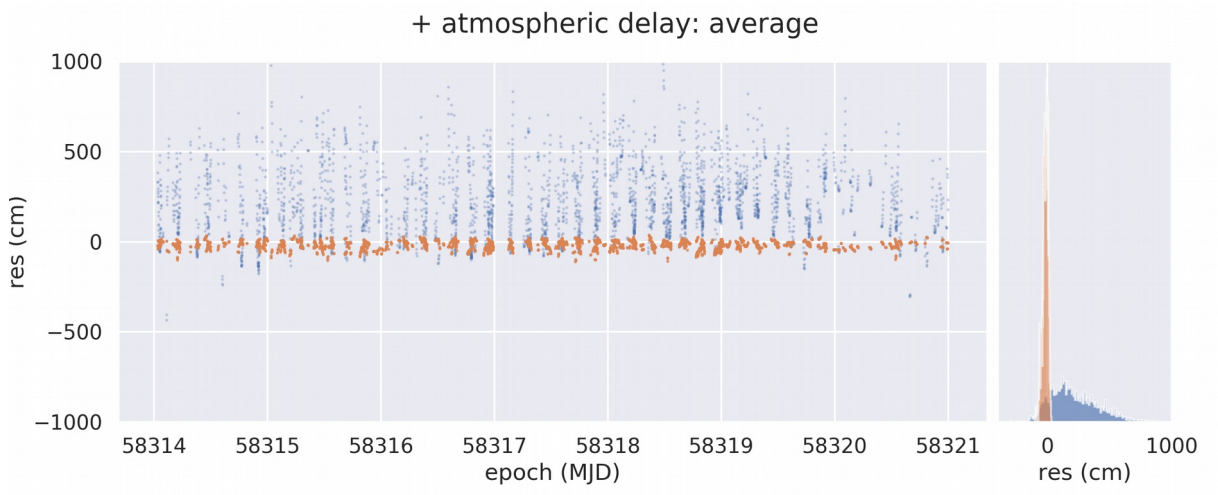


- Very poor orbital fit (no better than several metres)
- Evident systematic signatures in histogram of residuals
- Possibly only good for orbit predictions, if at all

Session 3: Corrections – tropospheric delay

Test: **mean** atmospheric delay



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- No meteorological data employed, simple average delay applied

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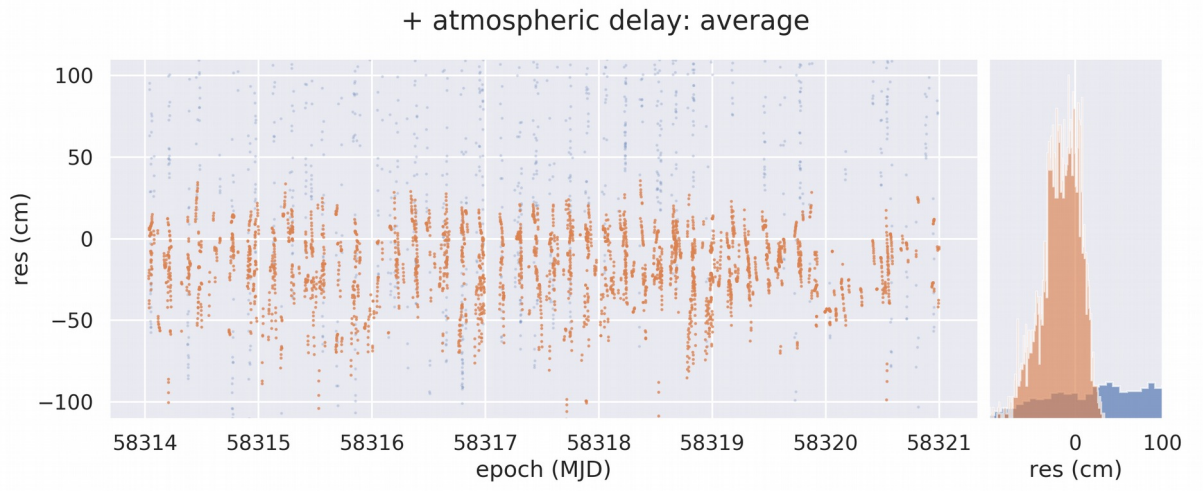
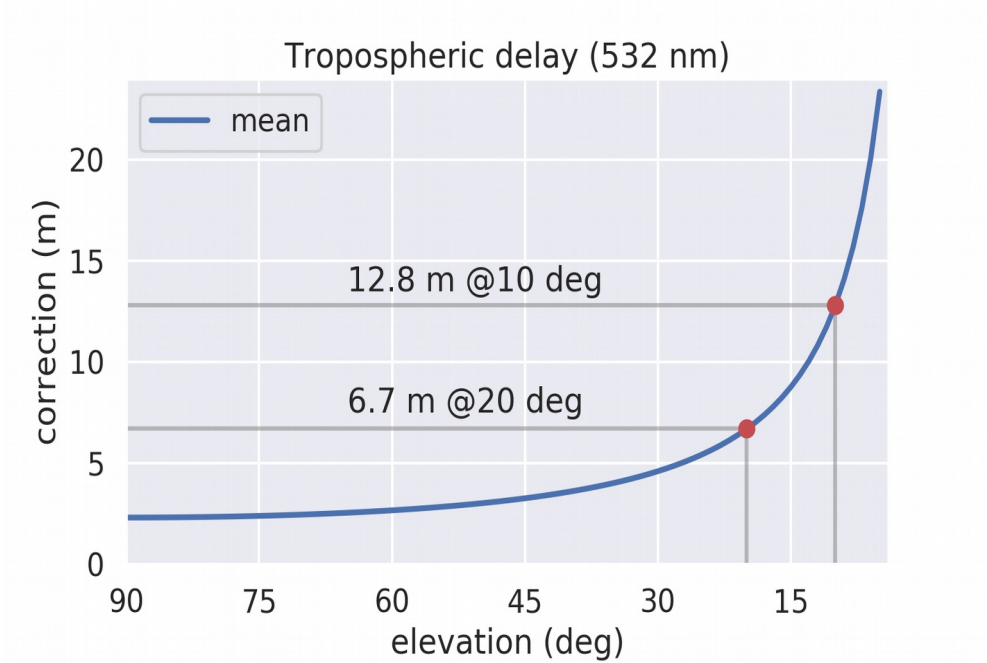


- Massive improvement in orbit fit (one order of magnitude)
- No meteorological data employed, simple average delay applied
- But clearly not good enough: RMS = 22.0 cm; mean residual offset = -16.5 cm
- Distribution of residuals evidently non-Gaussian

Session 3: Corrections – tropospheric delay



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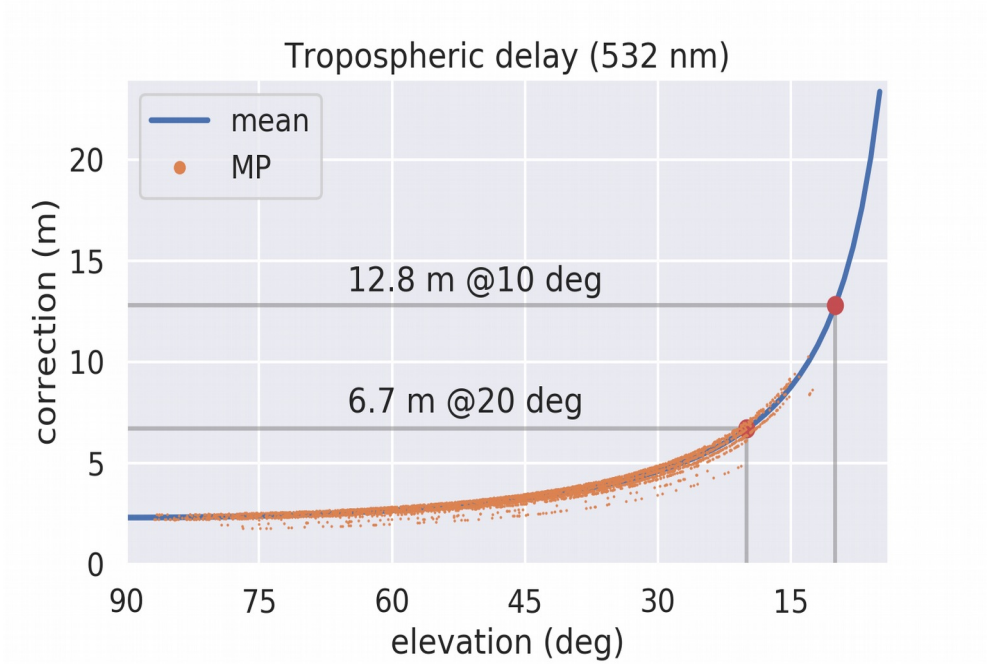

Model used to compute delay values

Variables: P, T, RH, elev., wavelength, latitude, height

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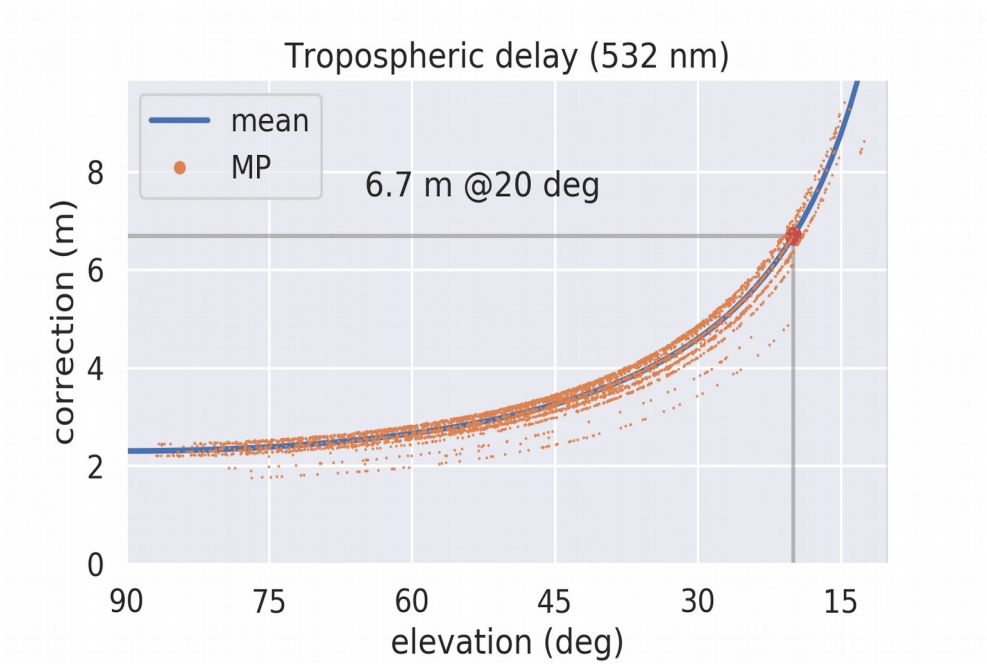

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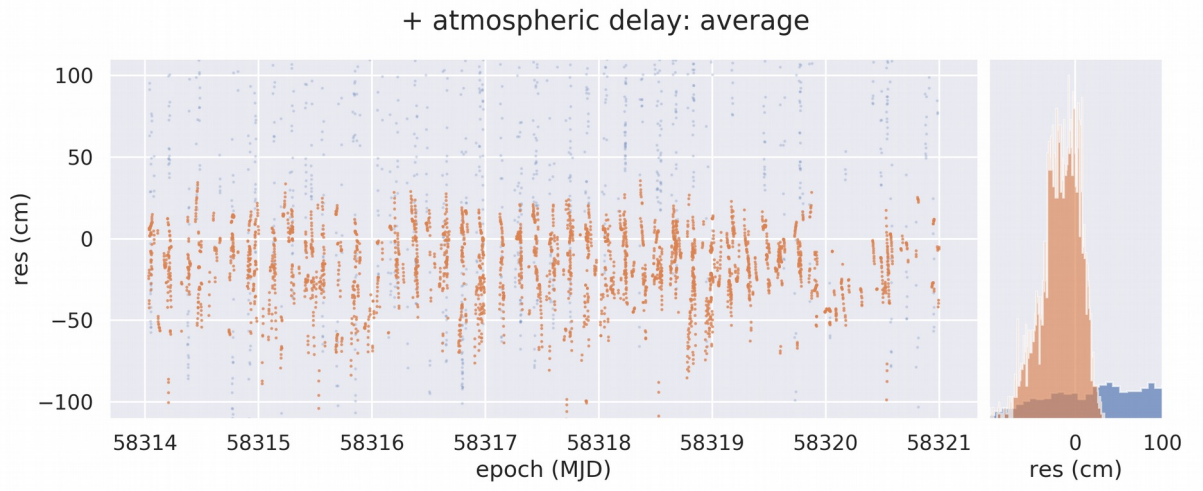
Test: full model atmospheric delay



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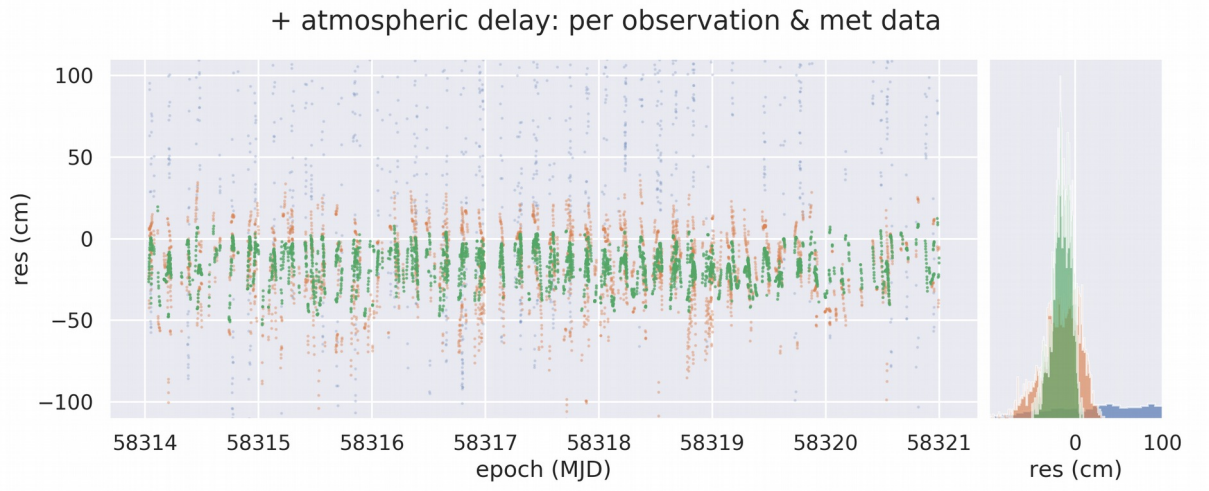

- Much better fit and distribution of residuals
- RMS = 11.0 cm; residuals mean offset = -15.7 cm

Session 3: Corrections – tropospheric delay

A curiosity?

- Tropospheric delay model contains a corrective factor dependent on the concentration of atmospheric CO_2
- Recommended value: 375 ppm

- Very small correction, will it ever matter?

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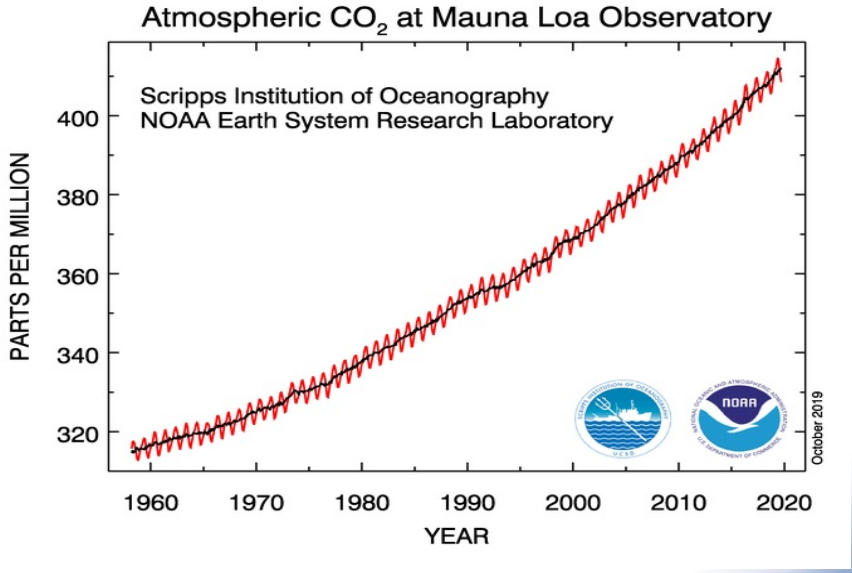
CO2 concentration in 1976 : 330 ppm
2019 : 410 ppm

Total zenith delay @330 ppm : 2.447487 m
Total zenith delay @410 ppm : 2.447592 m



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- Delay @330@10 deg : 13.5812 m
- Delay @410@10 deg : 13.5818 m (+ 0.6 mm)
- Delay @550@10 deg : 13.5828 m (+ 1.6 mm)

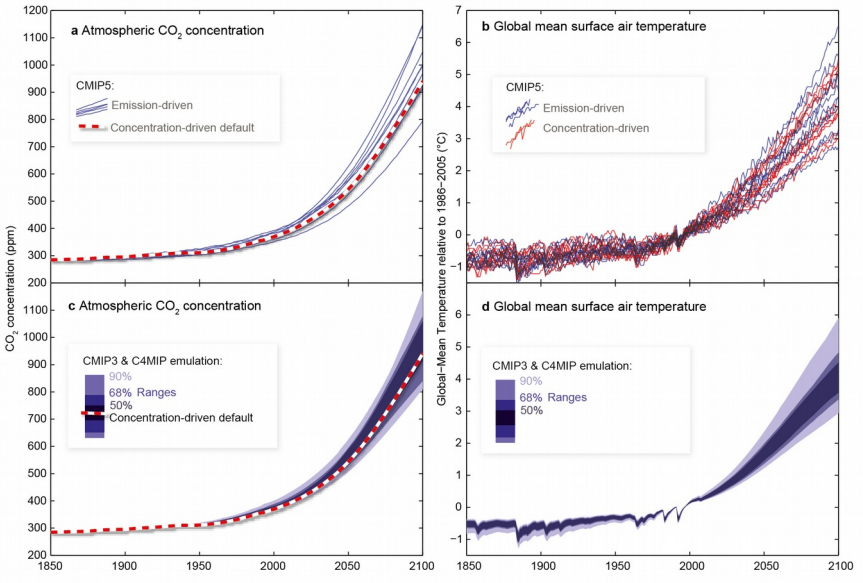
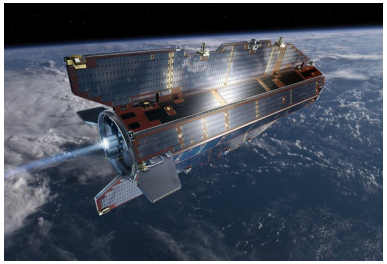


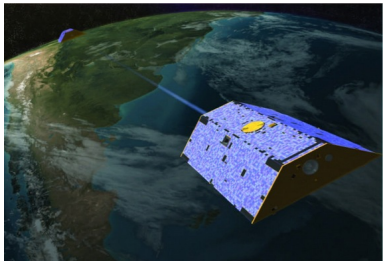
Figure 12.36 | Simulated changes in (a) atmospheric CO_2 concentration and (b) global averaged surface temperature (°C) as calculated by the CMIP5 Earth System Models (ESMs) for the RCP8.5 scenario when CO_2 emissions are prescribed to the ESMs as external forcing (blue). Also shown (b, in red) is the simulated warming from the same ESMs when directly forced by atmospheric CO_2 concentration (a, red white line). Panels (c) and (d) show the range of CO_2 concentrations and global average surface temperature change simulated by the Model for the Assessment of Greenhouse Gas-Induced Climate Change 6 (MAGICC6) simple climate model when emulating the CMIP3 models climate sensitivity range and the Coupled Climate Carbon Cycle Model Intercomparison Project (C⁴MIP) models carbon cycle feedbacks. The default line in (c) is identical to the one in (a).

IPCC, 2013: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

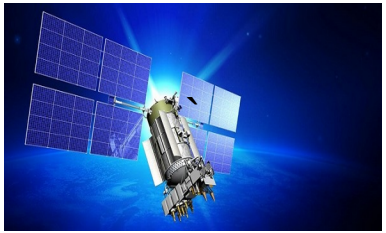
SLR space segment

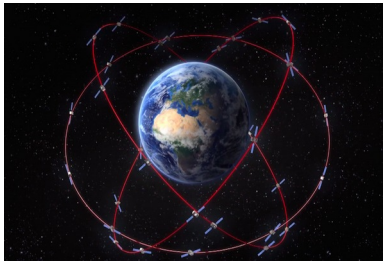
Earth observation

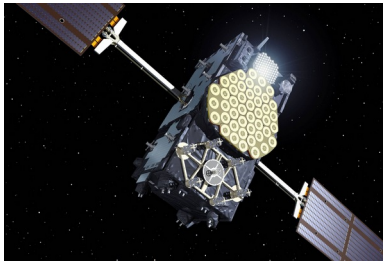




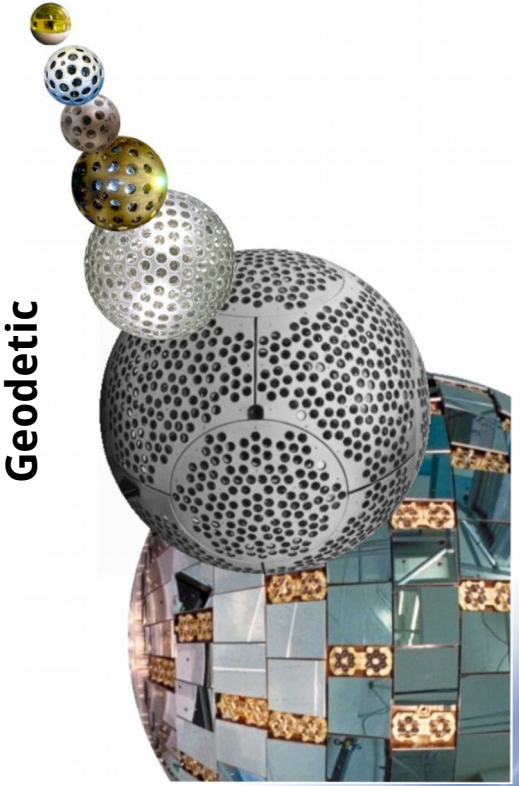
GNSS constellations







Geodetic



Session 3: Corrections and Error Sources

Summary

- SLR measures round trip time of flight between stations and optical reflection points of retroreflector arrays in orbit, using light pulses that propagate through the atmosphere in the near Earth environment
- Thus, we need to apply corrections to accurately derive distances from the measured TOF
- Tropospheric delays, centre of mass offsets, and relativistic delays are essential corrections applied to SLR data to achieve mm-level accuracies
- CoM offsets are system-specific, and dependent on how they operate → ideally stations should acquire data in a consistent way