Simulating the Colocation of High-Precision Microwave and Optical Techniques for Tropospheric Parameter Determination in Context of the ACES Mission

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A) Overview

Atomic Clock Ensemble in Space (ACES)

- **future** ESA mission (**2025** mount at **ISS**)
- **time transfer** concepts for tomorrow's technologies
- new generation of **high-precision space atomic clocks**
- **microwave link** terminal on ground and satellite
- **optical detector and reflector** on satellite.

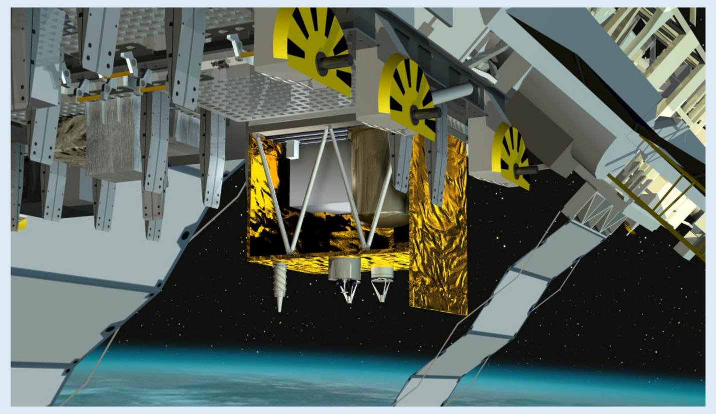


Fig. 1 ACES hardware at columbus module [1]

Problem formulation

- Wet part of troposphere underlies **high variations**
- Tropospheric **turbulences**
- Influences time synchronization
- **Microwave** system **biases**

Improved troposphere parameter improves **time transfer**

Full Scale Simulator

- **Pseudo two-way** microwave code and phase observations
- **one-** and **two-way multicolor** laser observations

Find simulator description in this paper, by scanning the QR code!
[2] Vollmair et al., 2023

Focus of this work

- **troposphere** parameter determination
- **colocation** of **optical** and **microwave** observations
- effects of different **weighting** methods
- extension of concept from **single-** to **multi-color**
- extension of concept from **one** to **net** of ground stations
- **synchronizing** multiple ground clocks

B) Troposphere Estimation Methods

Estimated parameters in **all** methods for **ku-band microwave** and **532 nm optical** observations:

- **Microwave** dependent **wet tropospheric horizontal gradient**
- Short-arc **orbit** parameter
- **Clock** offset and microwave dependent **system bias**

M1

„Classic" approach – **troposphere** parameter **estimated separately** for both techniques
- Microwave: **zenith wet delay**
- Optical: **no** troposphere parameter

M2

„Classic" approach – **troposphere** parameter **estimated separately** for both techniques
- Microwave: **zenith wet delay**
- Optical: **zenith dry delay**

M3

„Classic" approach – **troposphere** parameter **estimated separately** for both techniques
- Microwave: **zenith wet delay**
- Optical: **zenith wet delay**

M4

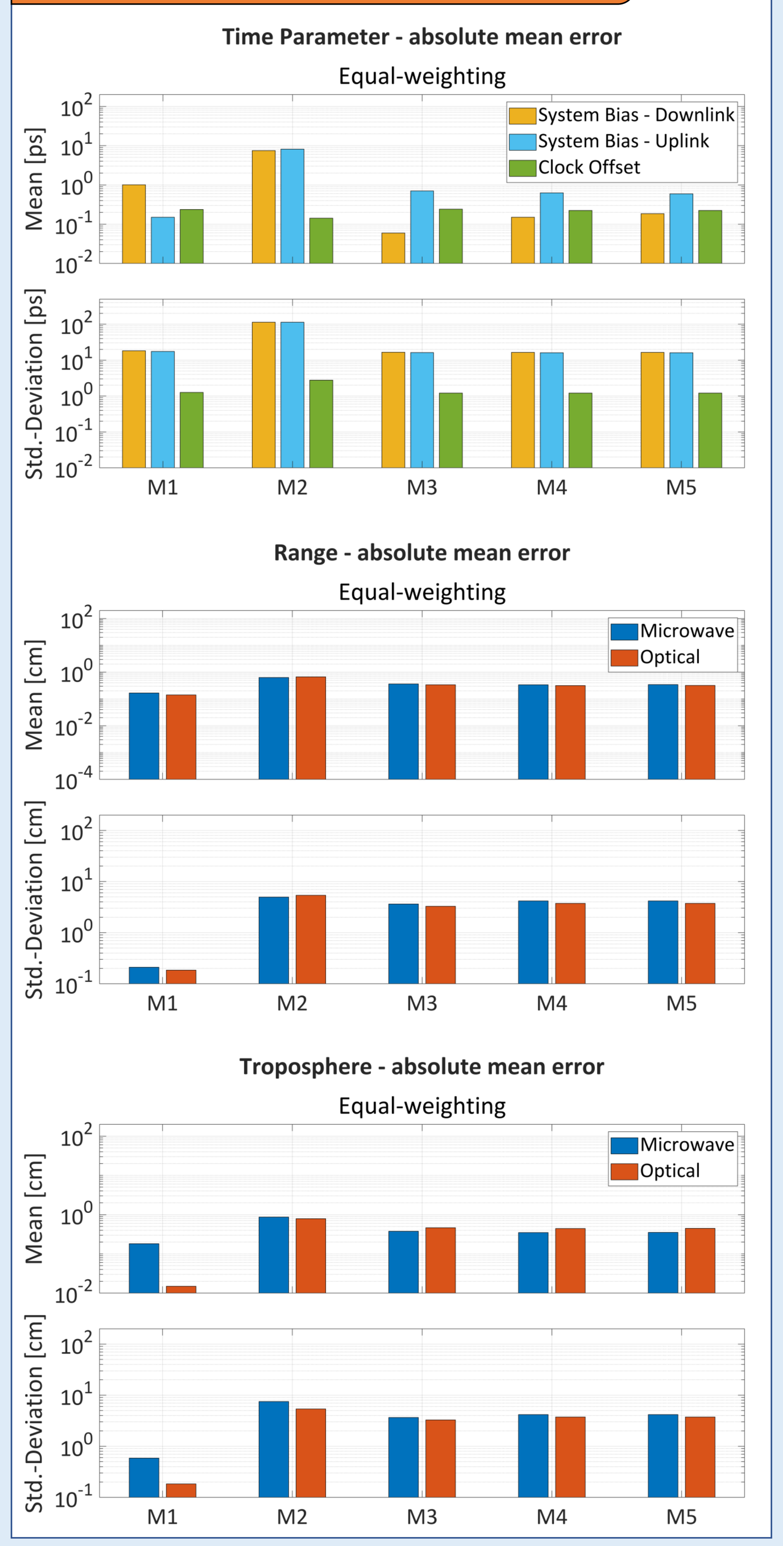
„**Common**" approach – **troposphere** parameter **estimated jointly**
- Microwave: **water vapour pressure** and **pressure** at ground station height
- Optical: **water vapour pressure** and **pressure** at ground station height

M5

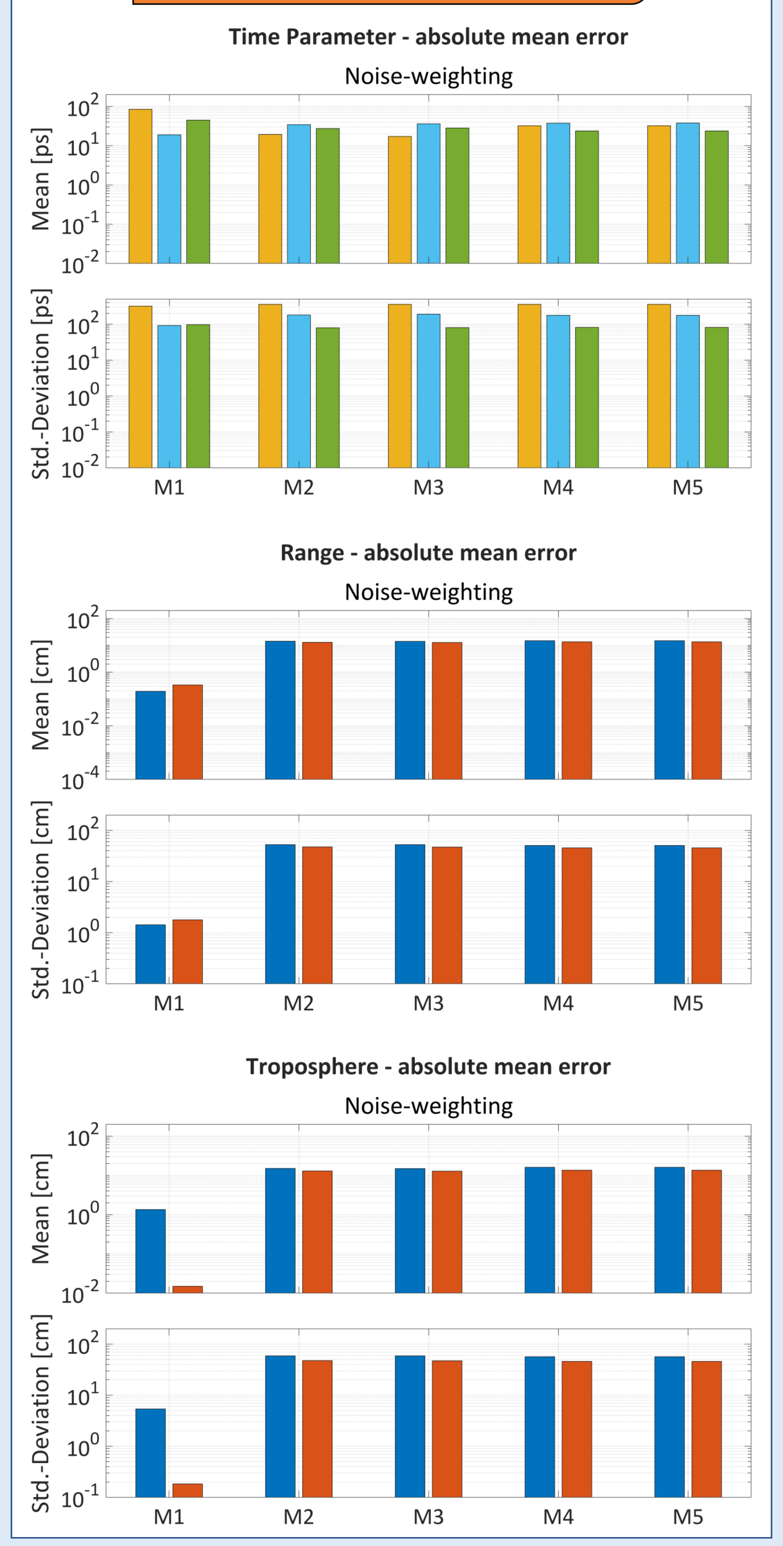
„**Common**" approach – **troposphere** parameter **estimated jointly**
- Microwave: zenith wet delay and **zenith dry delay scale factor**
- Optical: **zenith dry delay scale factor**

D) Impact on different Troposphere Estimation Methods

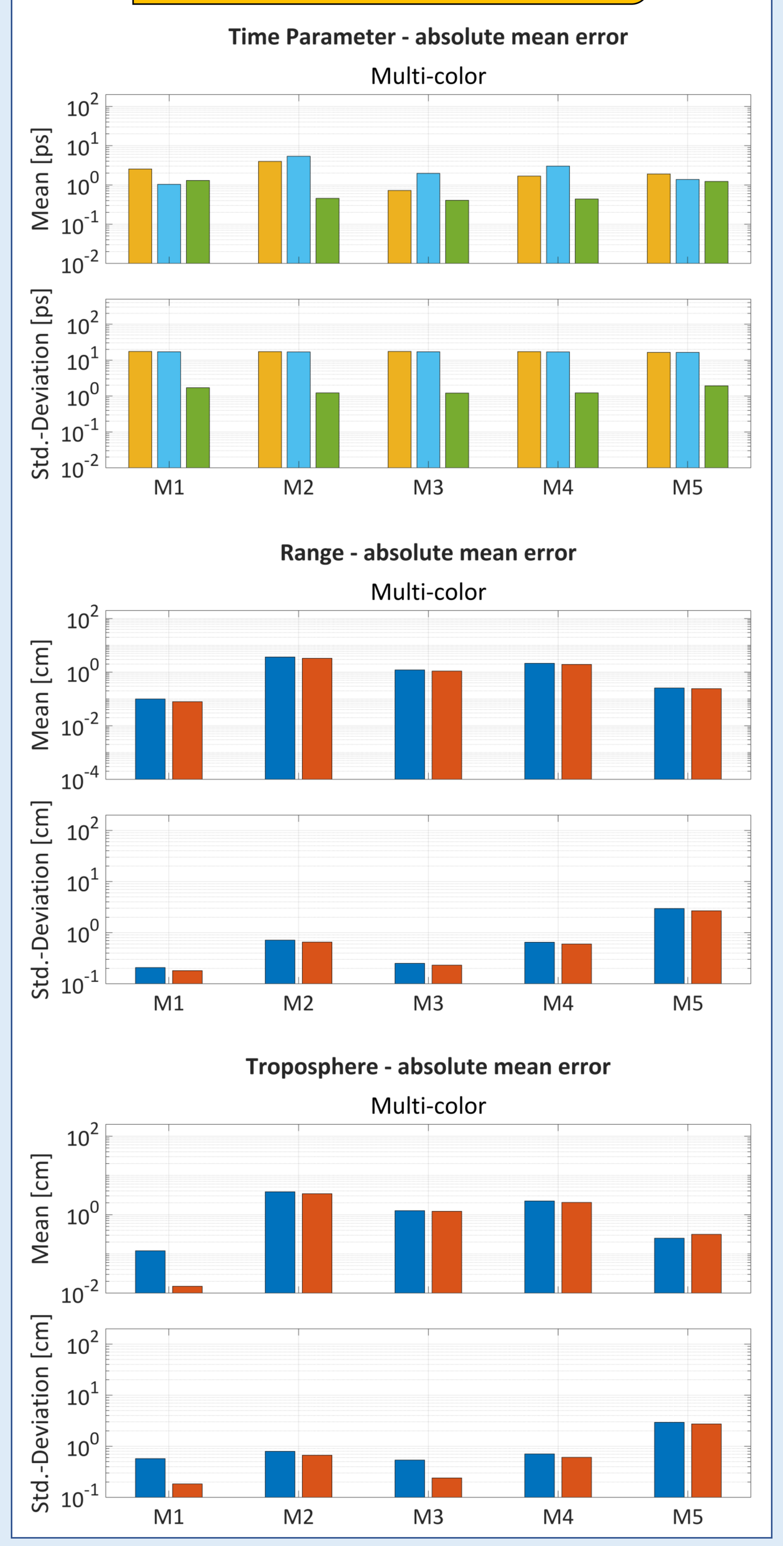
Equal Weighting - Reference



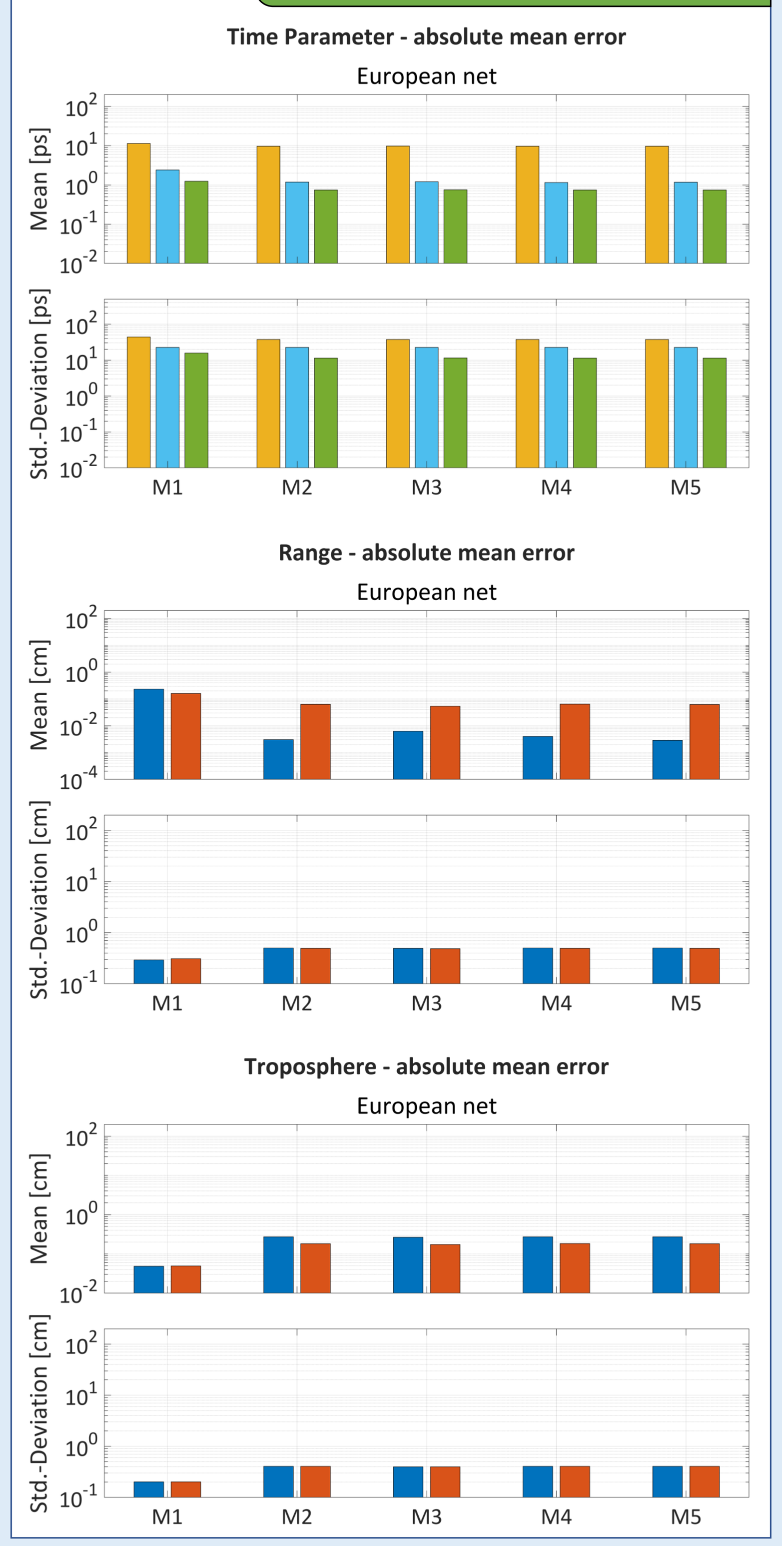
Noise Weighting



Multi-Color w. EW



European Network



C) Experiments

Weighting

To **combine optical** and **microwave** observation, **two stochastic models** are tested:
- **Weighting** by observation technique specific measurement **noise** – **1 : 187**
- **Equal weighting** of each technique – **1 : 1** (**EW**) → **Reference**

Multi-Color

Combination of **microwave** and **optical** observations on **532 nm** additionally
- with **optical** observations on **1064 nm** wavelength
- and **equal weighting** is tested

European Network

M1 – **M5** are applied to:
- One station (**WTZR**)
- Multi station (**European Network**)
- **At maximum 8 stations**
- **Only combination with optical 532 nm**
- **Equal weighting** is used

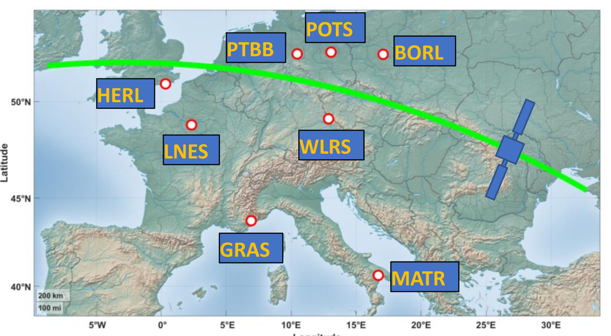


Fig. 2: Ground Station Network

E) Summary

Equal Weighting

- Equal weighting **improves** parameter **estimation** significantly
- **Time parameters** can be estimated with **picosecond precision** and **accuracy**
- **Stronger weight** on optical **„true" range** observations brings **benefit**

Multi-Color

- **Time parameter** are **affected** by systematic **errors** of **optical** system
- More **„true"** range observations **improve** short-arc **orbit** determination
- **Decrease** of **correlation** between **troposphere** and **orbit** parameters

European Network

- **Improves precision** and **accuracy** of all **troposphere** and **orbit** parameters
- **Degrades precision** and **accuracy** of **time** parameters
- This **needs** to be **investigated** in more detail in a separate study

M1 – M5

- Overall **M1** approach with **no optical troposphere** estimation performs **best**
- **High-precise troposphere** correction models for **optical** system are **needed**
- Otherwise, **common approaches** could be of **interest**

References:
[1] : CC BY-SA 3.0 IGO, ESA - D. Ducros, 2009, „ACES", https://www.esa.int/ESA_Multimedia/Images/2009/12/ACES
[2] : Vollmair, P.; Schlicht, A.; Hugentobler, U. Colocation in Time and Space of High-Precision Two-Way Optical and Microwave Observations for Calibration of a Microwave Ranging Link—The ACES Mission Case. Remote Sens. 2023, 15, 4897. https://doi.org/10.3390/rs15204897