

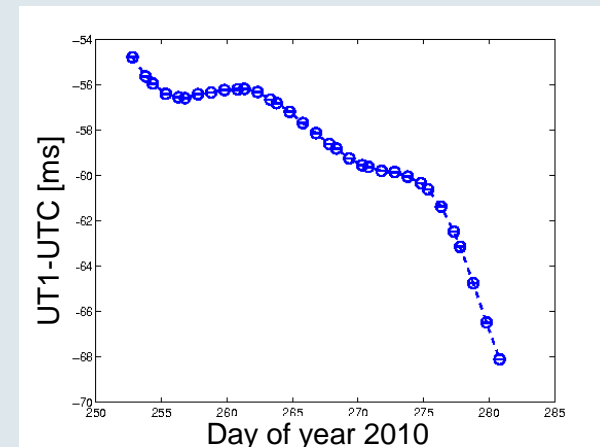
Session 3

Universal Time from VLBI Intensives with ray-traced delays

Matthias Madzak

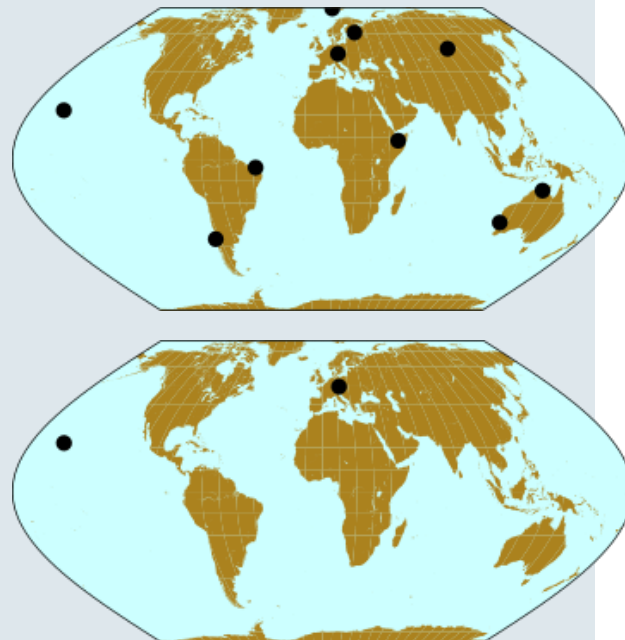
V. Nafisi, J. Böhm, H. Schuh

- VLBI is primary space geodetic technique for Universal Time (mid- and long term)
- EOP are important for positioning and navigation on Earth and in space
- Predictions require accurate EOP in near real-time

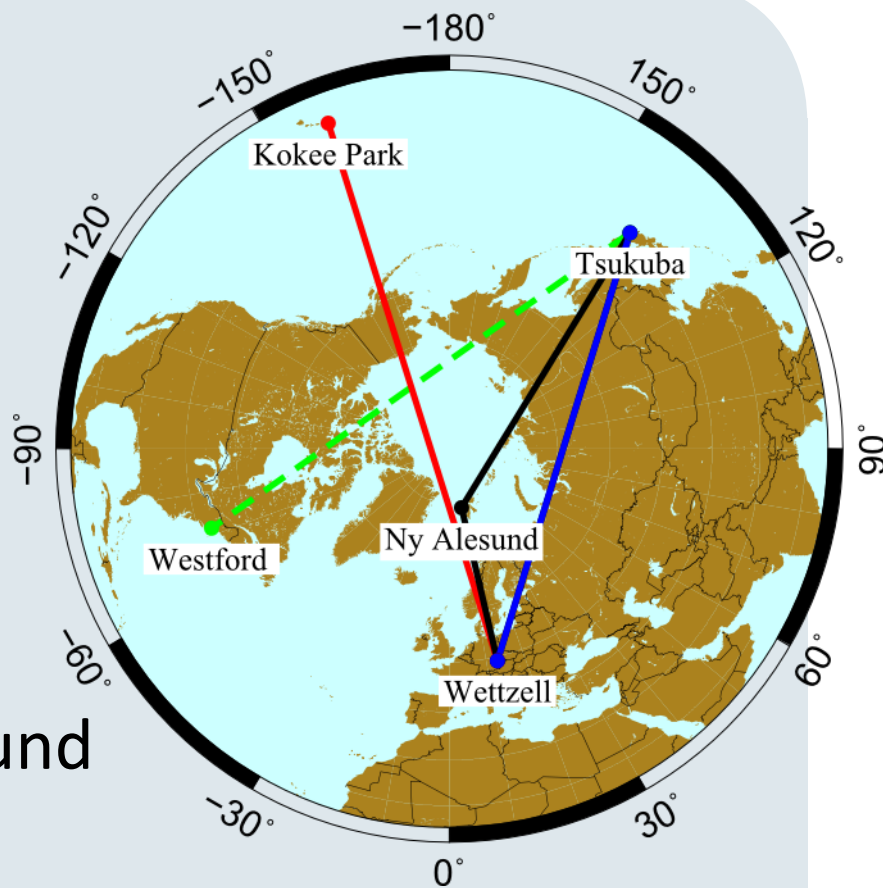


- 24h sessions (2-3 times per week): EOP estimation
 - Latency: 2 weeks
- 1h Intensive sessions: Single baseline, UT1 estimation
 - Latency: 3 minutes to 2 days

→ Less accurate but shorter delay



- **INT1**
 - **Kokee-Wettzell**
- **INT2 (e-transfer)**
 - **Tsukuba-Wettzell**
- **INT3 (e-transfer)**
 - **Tsukuba-Wettzell-NyAlesund**
- **Temporary**
 - **Tsukuba-Westford**

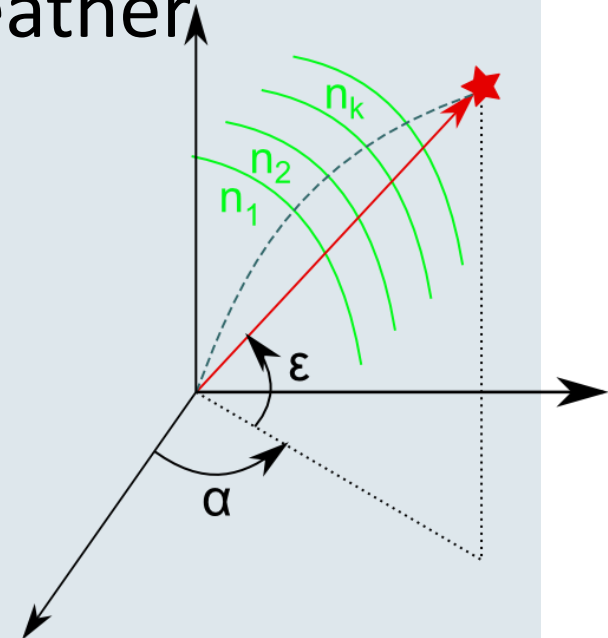


- Ray direction from numerical weather models (NWM)
- Eikonal equation

$$|\nabla L|^2 = n^2(\vec{r})$$

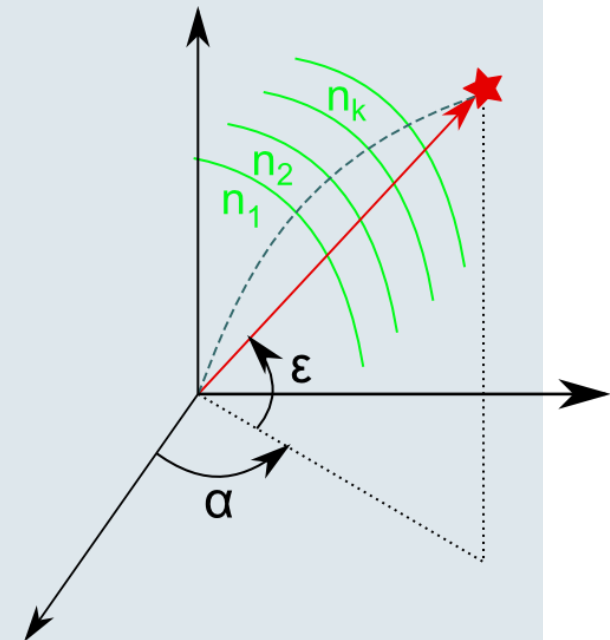
$\nabla L = \text{ray direction}$

$n = \text{refractive index}$



- 3D trajectory of ray \rightarrow path delay and bending effect

- 7 differential equations
- 6 solved simultaneously (Runge Kutta)
- Matlab (slow)
 - 2D
- ECMWF operational data
- 0.5° spatial resolution



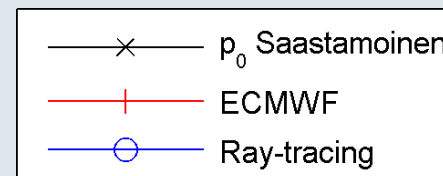
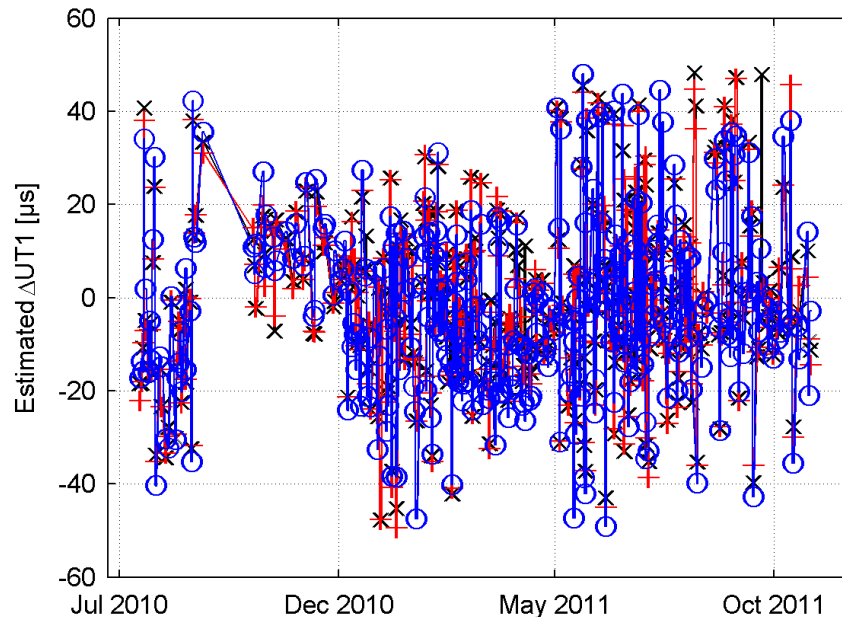
Nafisi et al., 2011

- 355 sessions from 15.07.2010 – 26.10.2011
- Vienna VLBI Software VieVS
- VTRF2008, modified due to Tsukuba Earthquake
- ICRF2
- High Frequency EOP (IERS Conventions 2010)
- IERS EOP daily rapid data (“finals”) nutation offsets and polar motion



- Estimated:
 - Linear clock and 1 ZWD per station (partial derivative: wet mapping function)
 - One UT1 value per session
- A priori tropospheric delays
 - Pressure at station, Saastamoinen, VMF1 (hydrostatic only)
 - ECMWF, VMF1 (hydrostatic and wet)
 - Ray-tracing (hydrostatic and wet)





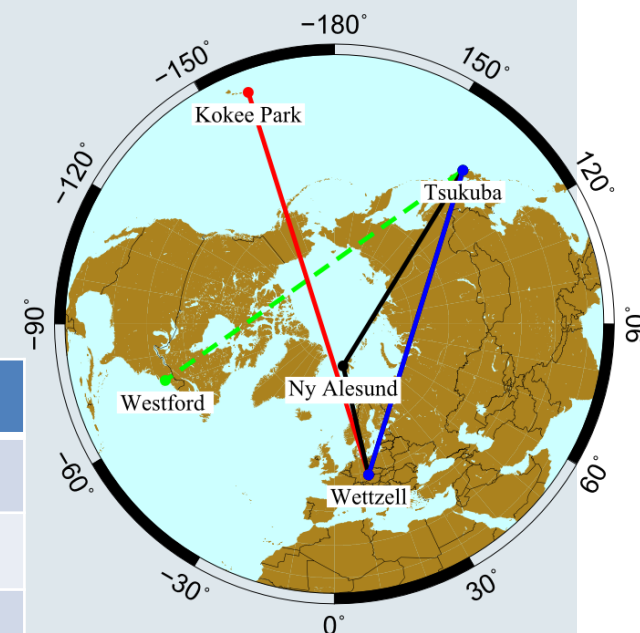
Tropospheric model	RMS w.r.t. IERS finals	Mean error
po Saastamoinen	17.8 μs	13.1 μs
ECMWF (hw)	17.8 μs	13.0 μs
Ray-tracing	18.3 μs	13.0 μs

- 335 Sessions
- 35 Outliers:
 $\pm 50\mu\text{s}$
 $< 100\mu\text{s}$ error

error = formal uncertainty

- Session separation
- RMS w.r.t. IERS finals (mean error)

	INT1	INT2/3	Ts-Wf
Ray-traced delays	only Wz	Ts and Wz	only Ts
Sessions	251	81	23
Scans (mean)	7-30 (16.7)	13-45 (39.7)	18-39 (30.6)
P ₀ Saastamoinen	17.6 (14.6)	18.6 (9.3)	9.5 (8.2)
ECMWF	17.7 (14.5)	18.4 (9.1)	9.2 (7.6)
Ray-tracing	18.3 (14.5)	17.8 (9.0)	8.1 (7.5)



Mean error = mean formal uncertainty

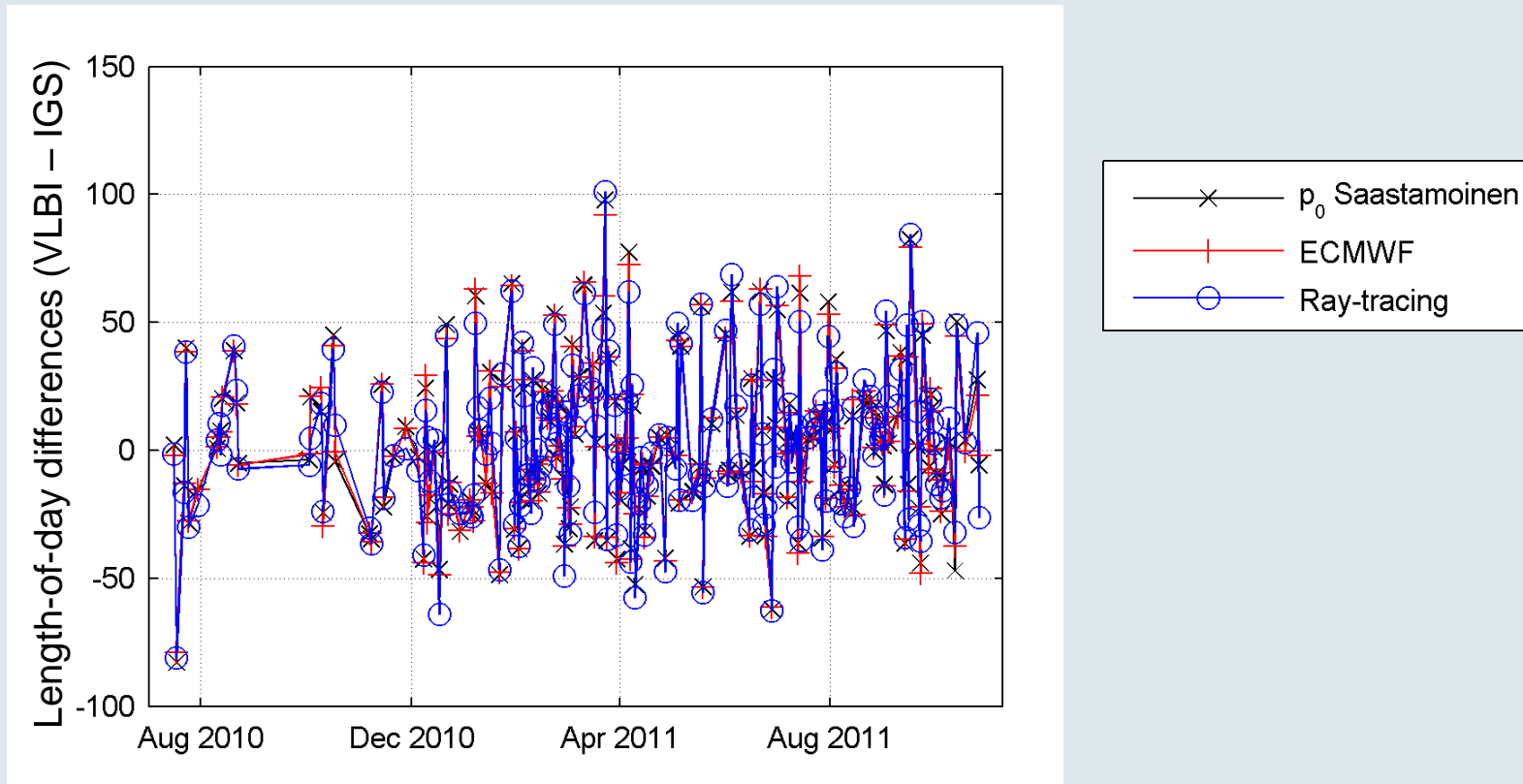
- External validation desirable
- Convert to length-of-day (lod)

$$lod = - \frac{\delta \Delta UT1}{\delta t}$$

- Compare to IGS lod
 - IGS final Earth rotation parameters

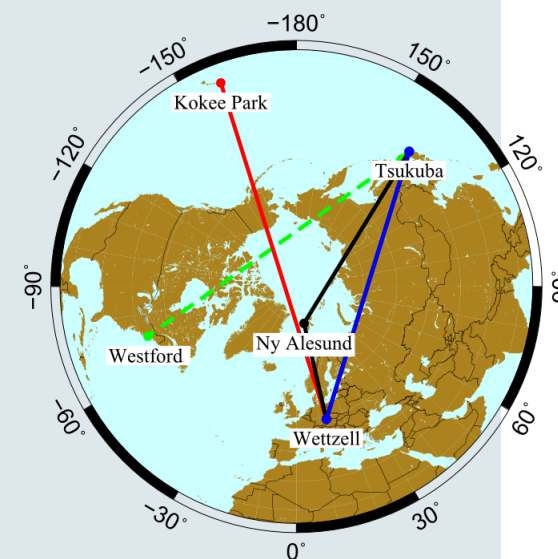


- Comparison to length-of day from IGS
(VLBI – IGS) [μs]

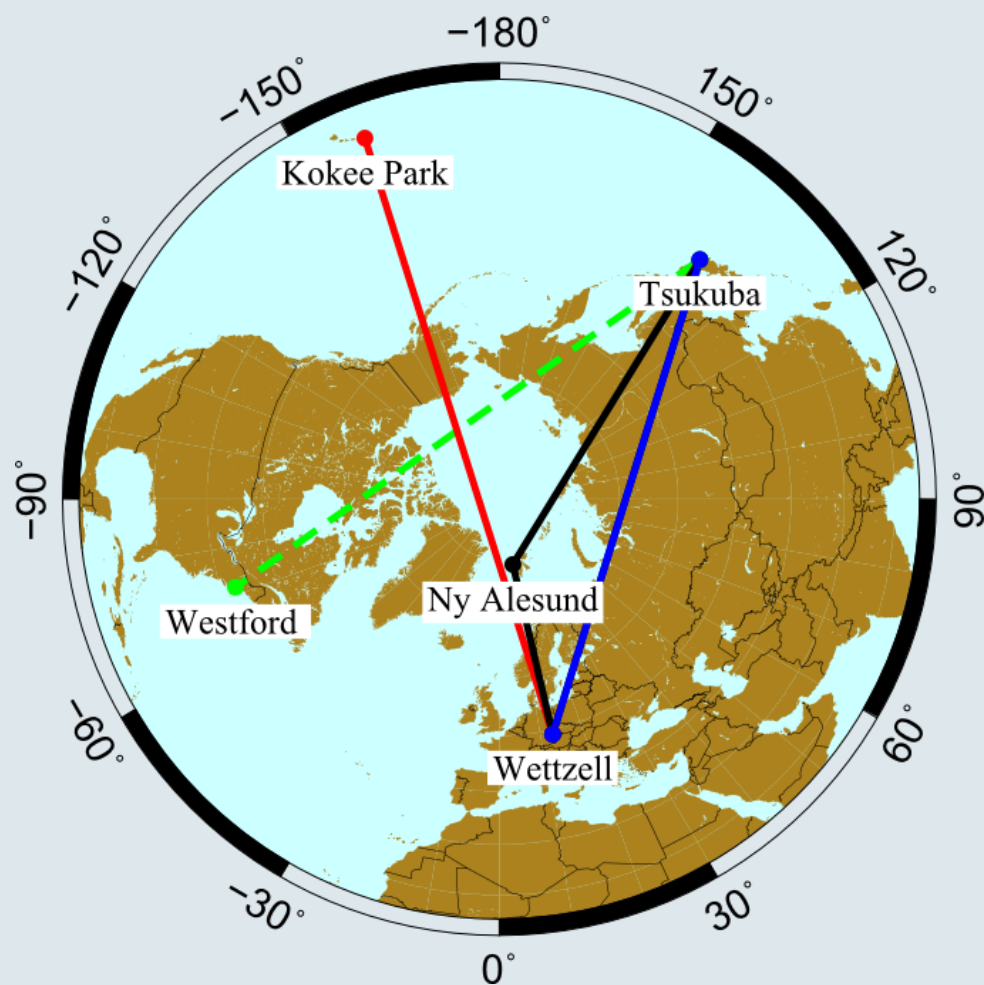


- Comparison to length-of day from IGS

Model	RMS lod w.r.t. IGS-lod [μs]			
	INT1	INT2/3	Ts-Wf	all
po Saastamoinen	30.8	27.1	24.6	29.8
ECMWF	30.4	26.1	25.1	29.3
Ray-tracing	30.8	25.3	23.5	29.5



- Intensives are important for UT1 estimation and prediction
- Ray-tracing slightly improves accuracy of some Δ UT1 estimates (e.g. those including Tsukuba)
- Delays are calculated routinely for Intensives
- Improve Analysis / Ray-tracing
 - 3D Ray-tracing
 - Gradients estimation



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