24th Meeting of the EVGA, Gran Canaria, Spain – March 19, 2019

Ionospheric calibration for K-band celestial reference frames

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Introduction

- CRF based on K-band (24 GHz) part of ICRF3
  - Very Long Baseline Array (VLBA) + Hobart-HartRAO
  - Mostly 2 Gbps data rate, testing 4 Gbps
  - Posters by De Witt et al, Krasna et al, and talk by Le Bail et al

\+ Advantage: less source structure compared to S/X

- S/X CRFs limited by a 20-30 µas source structure noise floor [Le Bail et al]

– Disadvantage: single-frequency observations

- About 95% of the K-band ionospheric effect needs to be corrected to get below S/X noise level

Accuracy depends on external ionospheric calibration

How to improve the ionospheric calibration?

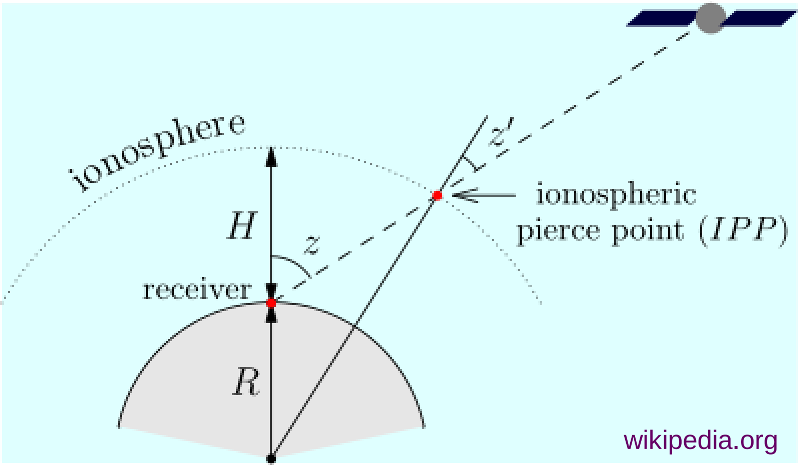
1. Improvements in ionosphere models

Ongoing investigation

2. Improvements from better model coverage of VLBI stations

Background – ionospheric corrections

- Dual-frequency observations: ionosphere-free linear combination
- Single-frequency observations: ionospheric delay determined from ionosphere models
- Simplest models: two-dimensional, single thin-layer approximation



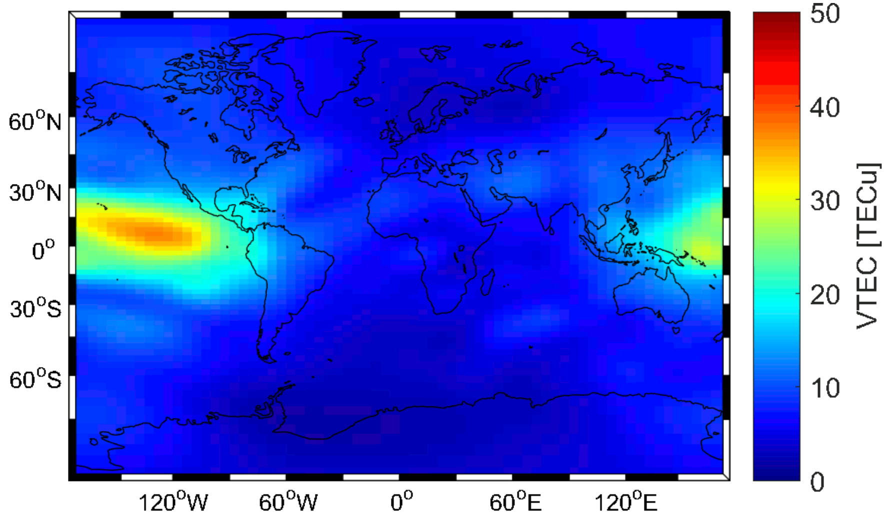
Ionospheric delay:

$$\tau_{\text{iono}} = \frac{40.3}{cf^2}\,\text{STEC}$$

STEC … slant total electron content

Global Ionospheric Maps (GIMs)

- International GNSS Service (IGS) operationally provides 2-dimensional maps of vertical total electron content (VTEC)
  - Based on a combination of GIMs from individual analysis centers
  - Temporal resolution: 2 hours
  - Spatial resolution: 5 deg (lon) x 2.5 deg (lat)
  - Stated uncertainty 2-8 TEC units (TECu)

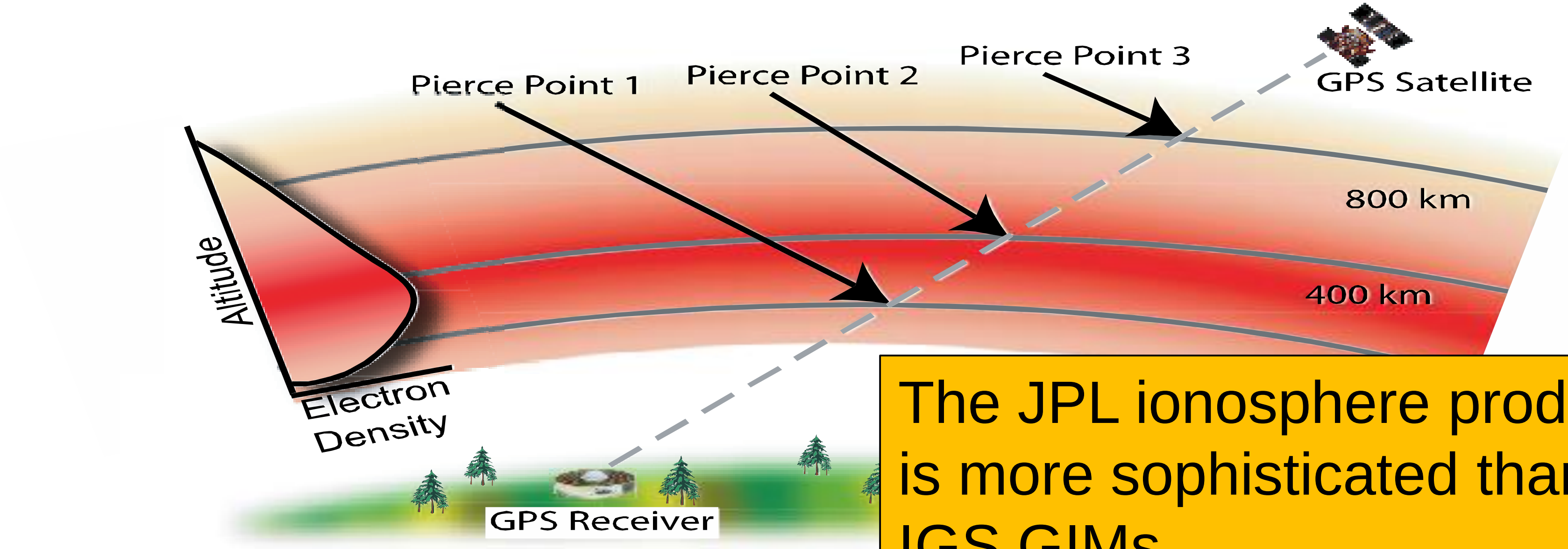


1 TECu ≈ 0.7 mm delay in K-band

2-h GIMs by JPL were used for the K-band ICRF3

JPL ionosphere product

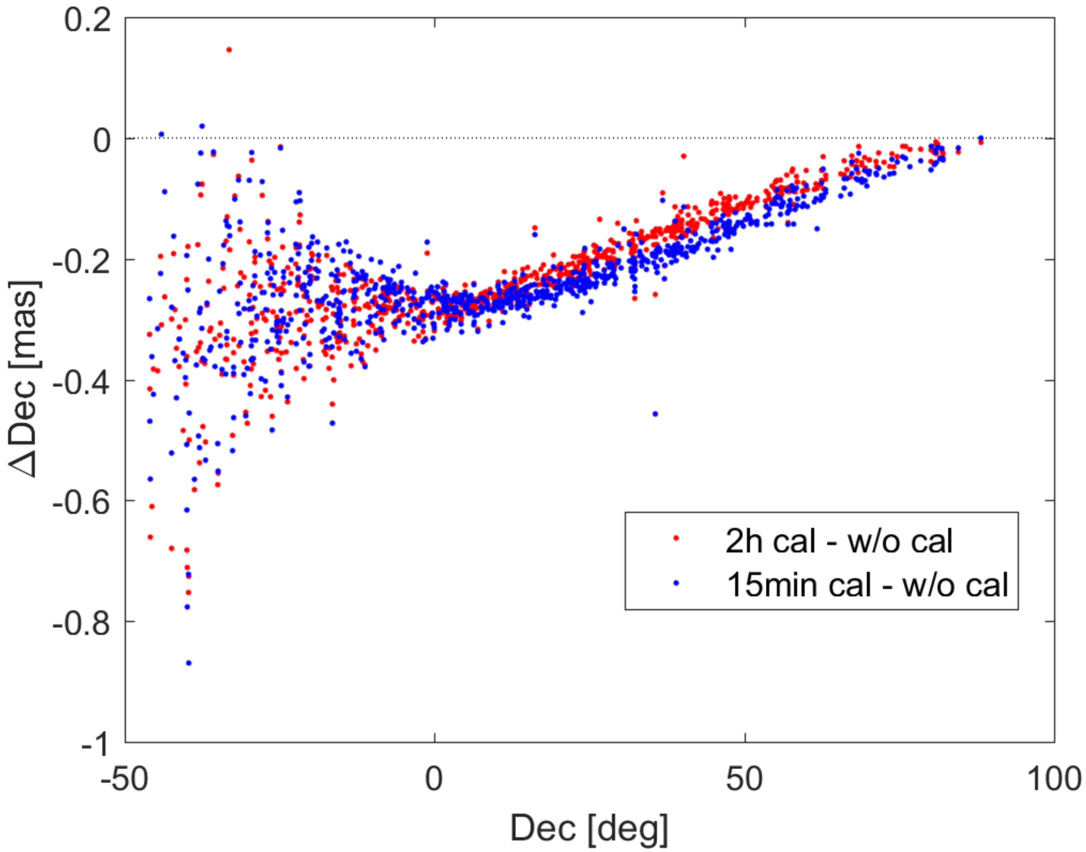
- JPL computes ionosphere models from GNSS data assuming 3 horizontal layers instead of a single one
  - Temporal resolution: 15 minutes
  - Spatial resolution: 330 base functions per layer instead of grid



The JPL ionosphere product is more sophisticated than IGS GIMs

K-CRF comparisons

- Preliminary results: VLBA sessions only (no HartRAO/Hobart)
- Comparison of K-CRF solutions
  1. without calibration
  2. 2h calibration
  3. 15min calibration



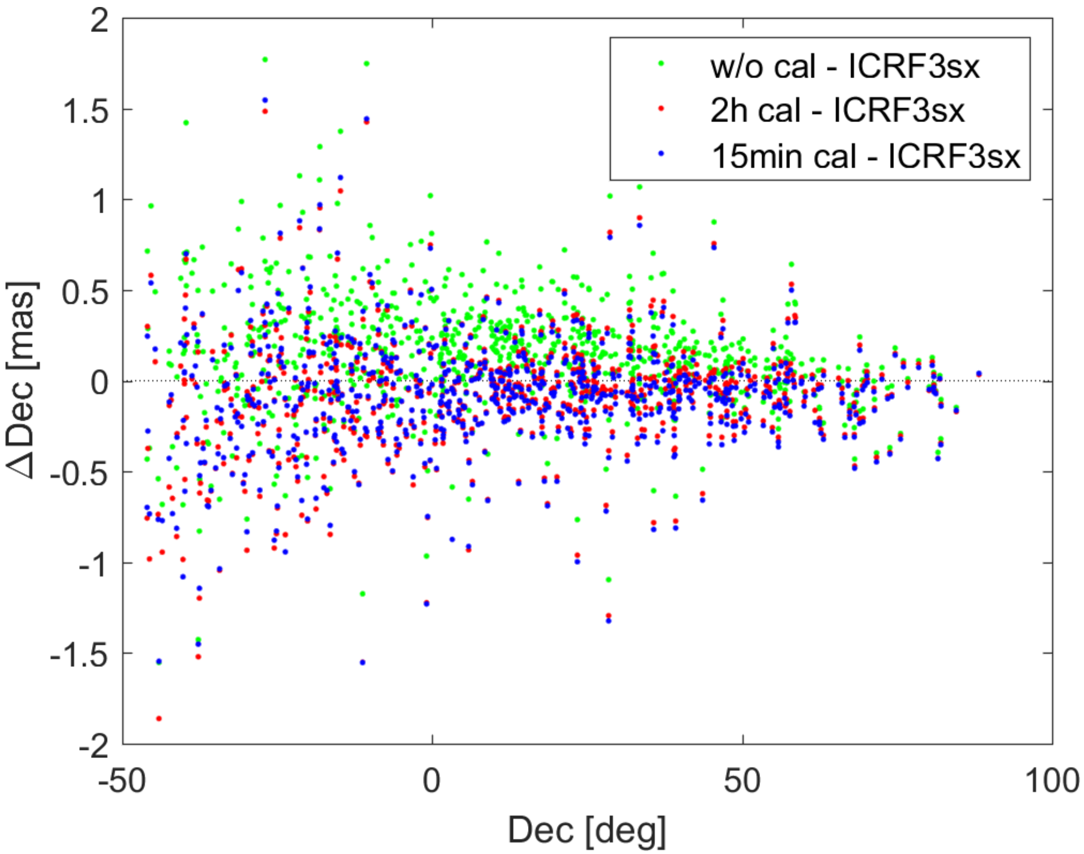
Difference w.r.t. w/o cal:

RMS [μas]	RA*cos Dec	Dec
2h cal	20	248
15min cal	24	252

K-CRF comparisons vs. ICRF3 S/X

Difference w.r.t. ICRF3:

RMS [µas]	RA*cos Dec	Dec
w/o cal	220	360
2h cal	220	320
15min cal	218	316



How to improve the ionospheric calibration?

1. Improvements in ionosphere models

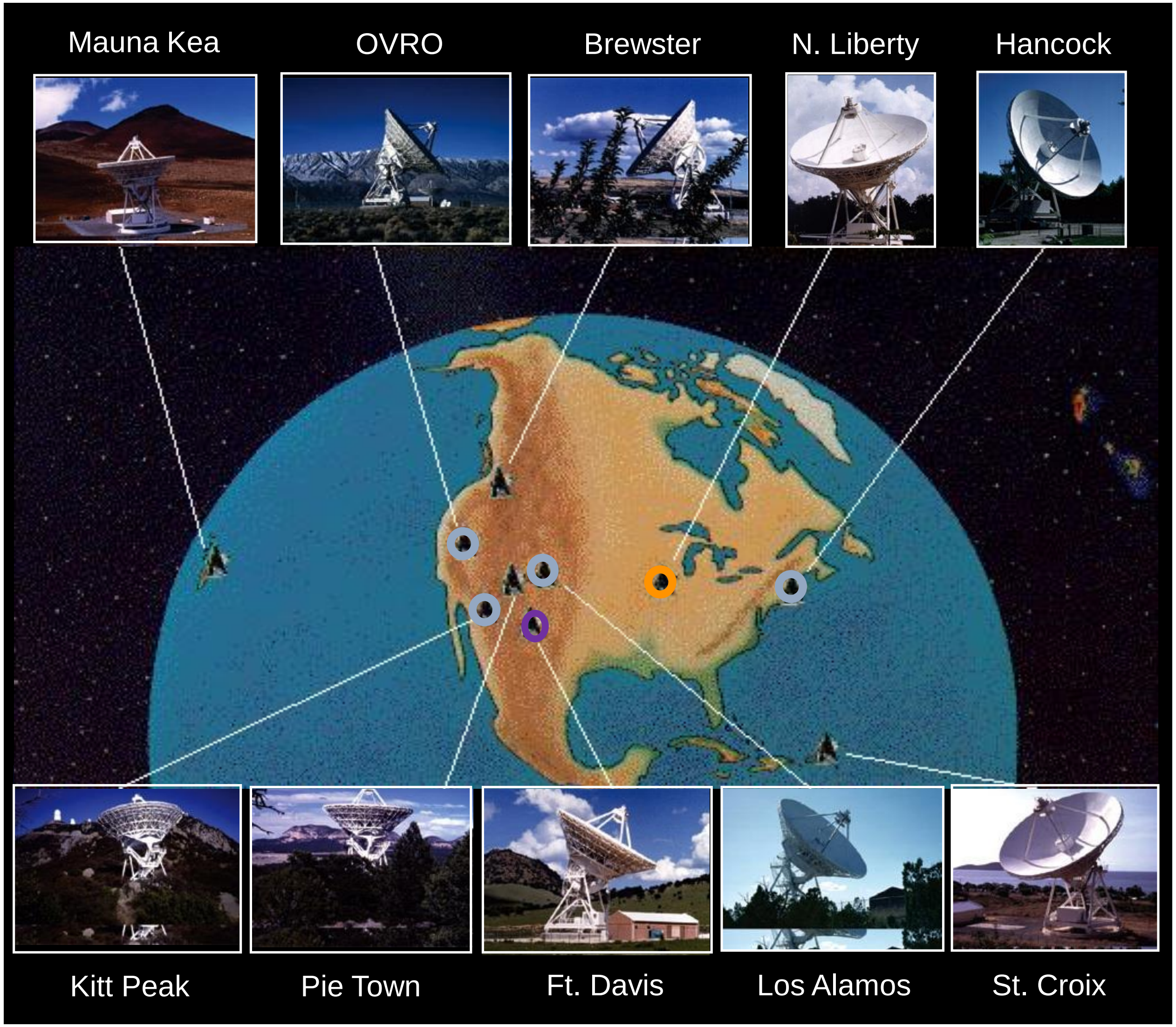
2. Improvements from better model coverage of VLBI stations

GNSS antennas at VLBA sites

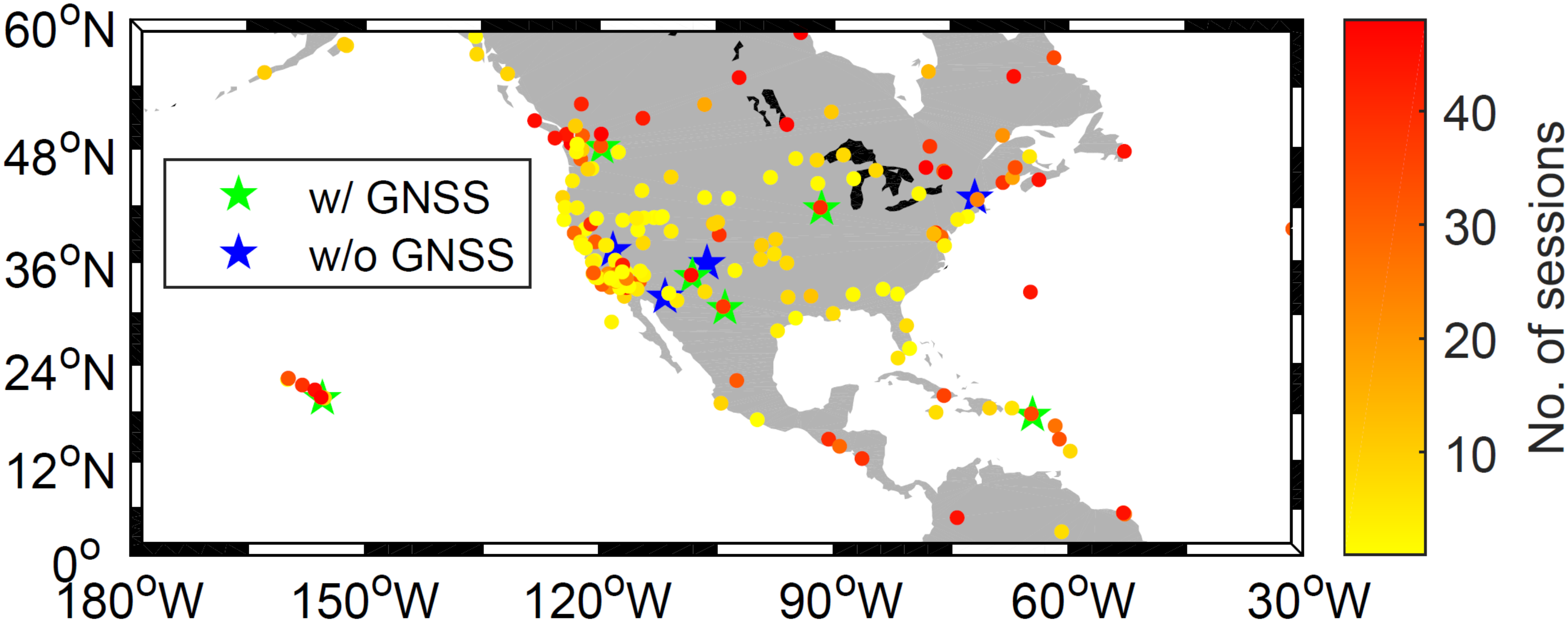
Very Large Baseline Array http://www.vlba.nrao.edu/

- Coverage gaps:
  - HN missing
  - OV missing
  - KP missing
  - LA missing

  - NL broken since Nov 2018
  - FD offset 8 km



GNSS station contributions to IGS GIM



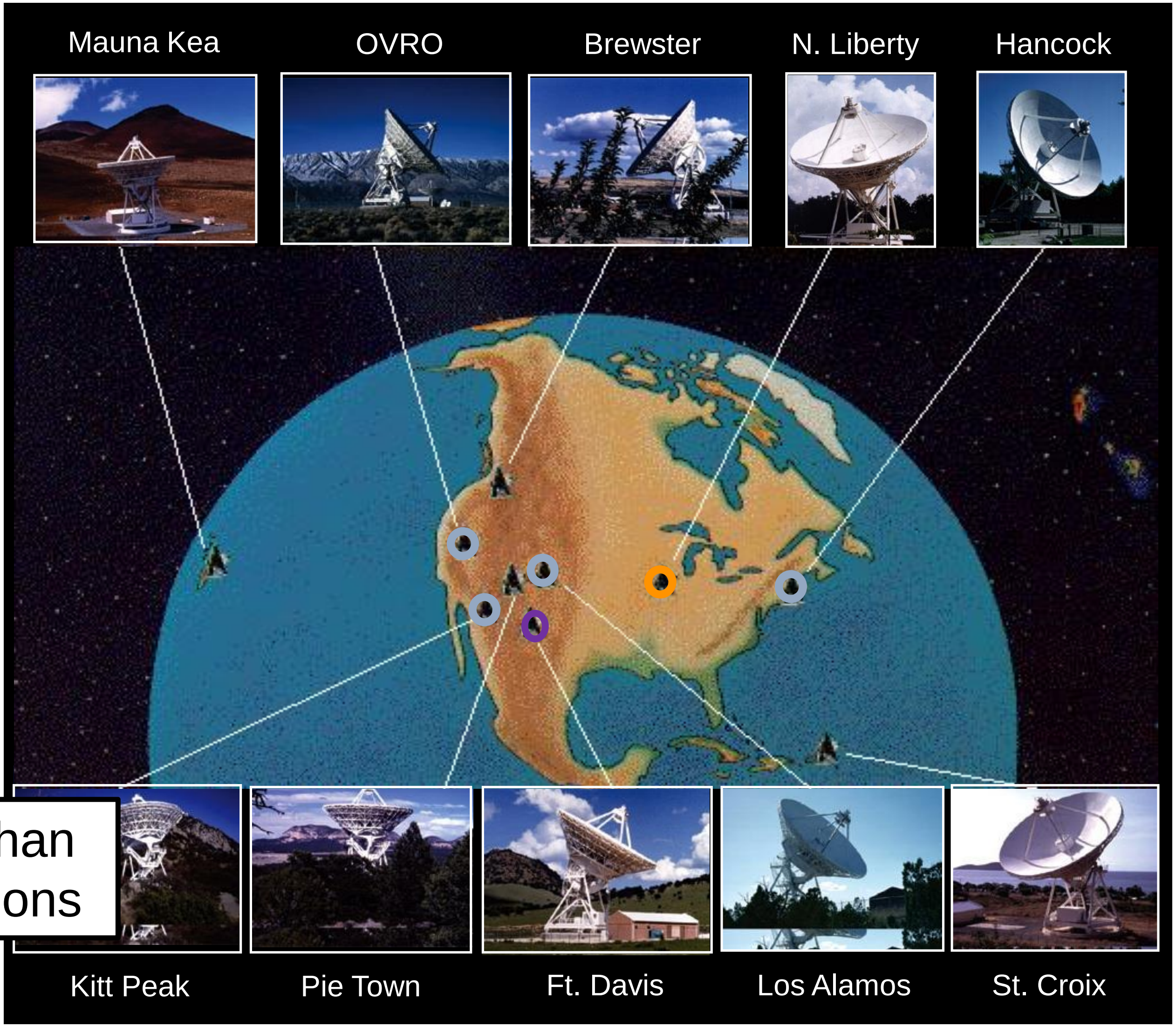
Colors indicate how often GNSS stations contributed to the IGS GIMs during VLBA sessions

Distances to active* IGS GIM stations

- HN 344 km
- OV 206 km
- KP 343 km
- LA 236 km

- NL 999 km
since Nov 2018
- FD 8 km

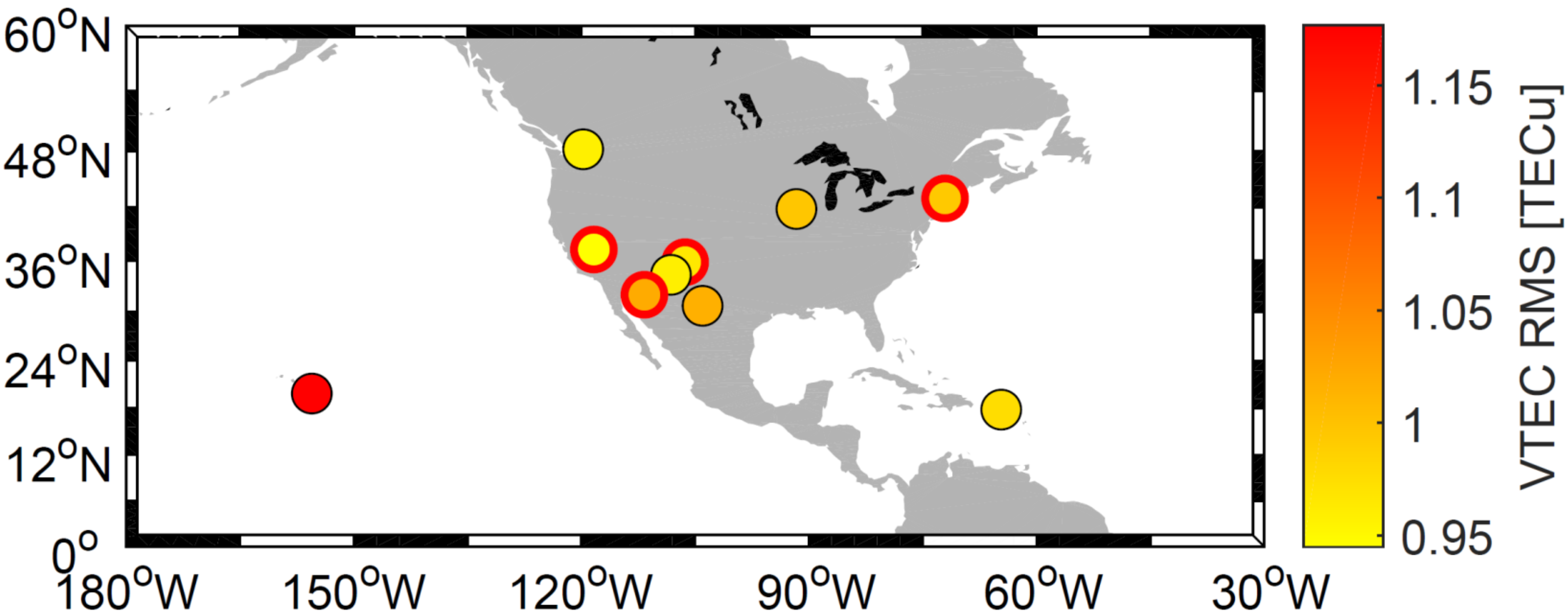
Very Large Baseline Array http://www.vlba.nrao.edu/



*contributed to more than half of the VLBA sessions

Precision of ionospheric model for VLBA sites

- IGS GIMs contain VTEC RMS as a measure of precision
- VTEC RMS averaged over K-band VLBA sessions

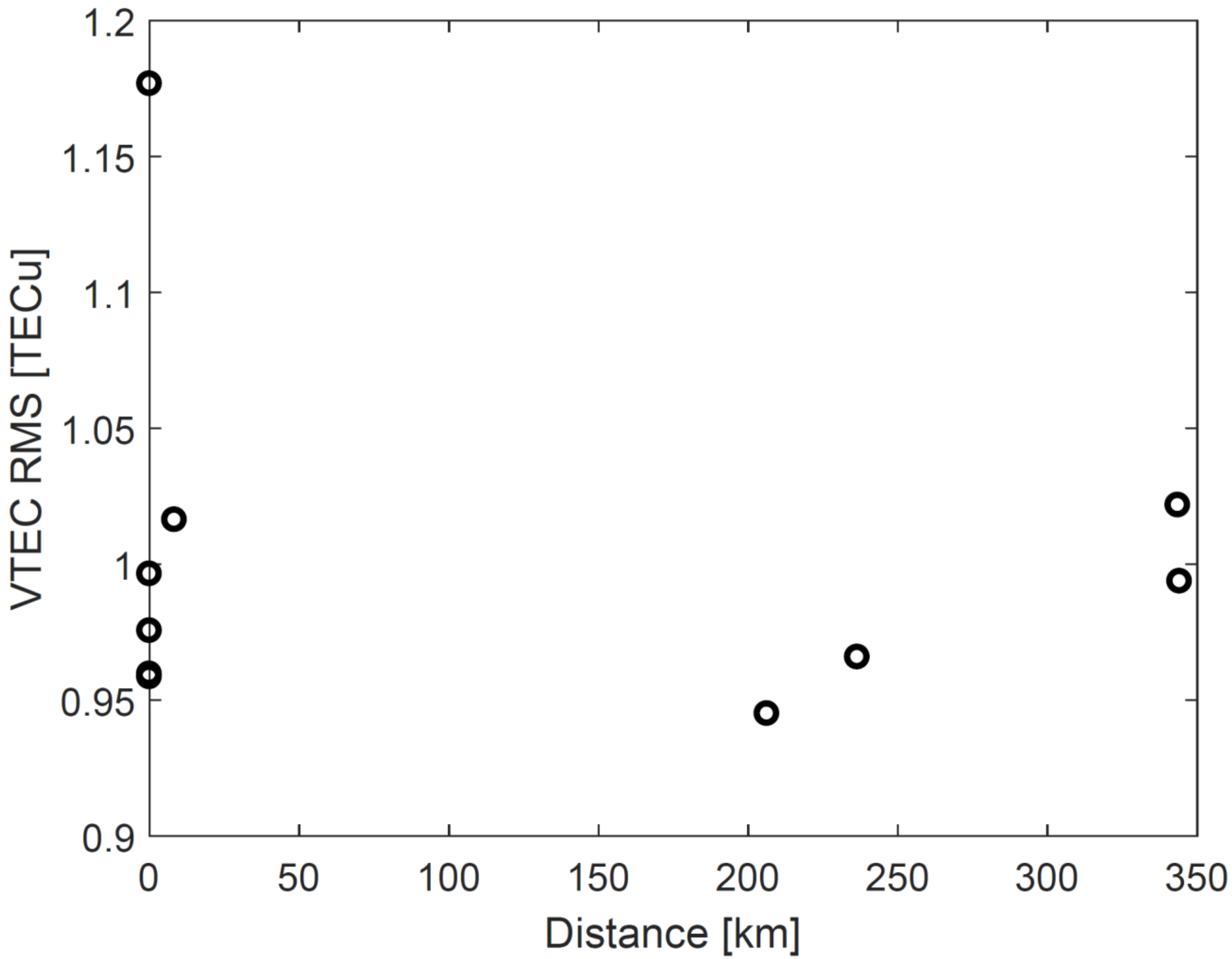


Red circles: missing GNSS station

Precision of ionospheric model for VLBA sites

Station name	GNSS on site	GNSS distance	VTEC RMS [TECu]	K-band delay RMS [mm]
HN-VLBA	0	344	0.99	0.72
LA-VLBA	0	237	0.97	0.70
NL-VLBA	0 / 1	0.068 / 999	1.00	0.73
OV-VLBA	0	206	0.94	0.69
PIETOWN	1	0.062	0.96	0.70
MK-VLBA	1	0.089	1.18	0.86
SC-VLBA	1	0.083	0.98	0.71
BR-VLBA	1	0.059	0.96	0.70
KP-VLBA	0	343	1.02	0.74
FD-VLBA	1	8.4	1.02	0.74

VTEC RMS vs. GNSS station distance



Conclusions

- **K-band** VLBI data has the potential to improve the CRF due to less source structure than S/X
- K-CRF accuracy depends on **ionospheric calibration**
- Implementation of ionospheric calibrations with **15 min** temporal resolution (vs. 2h previously – factor 8!)
  - Preliminary results: slightly better agreement with ICRF3 S/X
- Four VLBA sites **without GNSS stations** actively contributing to IGS GIMs
  - No significant degradation detected in the VTEC precision for these sites
  - Could be worse for N. Liberty (1000 km from active GNSS station)

Thanks for your attention!

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Acknowledgements

B. Soja's research was supported by an appointment to the NASA Postdoctoral Program at the NASA Jet Propulsion Laboratory, administered by Universities Space Research Association under contract with NASA. U.S Government sponsorship acknowledged. The VLBA is managed by NRAO, funded by the National Science Foundation, and operated under cooperative agreement by Associated Universities. The authors gratefully acknowledge use of the VLBA under the USNO's time allocation. This work supports USNO's ongoing research into the celestial reference frame and geodesy. HartRAO is a facility of the National Research Foundation (NRF) of South Africa. The Hobart telescope is operated by the University of Tasmania and this research has been supported by AuScope Ltd., funded under the National Collaborative Research Infrastructure Strategy (NCRIS). HK works within the project T 697-N29 funded by the Austrian Science Fund (FWF).