Effects of the 2011 Tohoku Earthquake on VLBI Geodetic Measurements

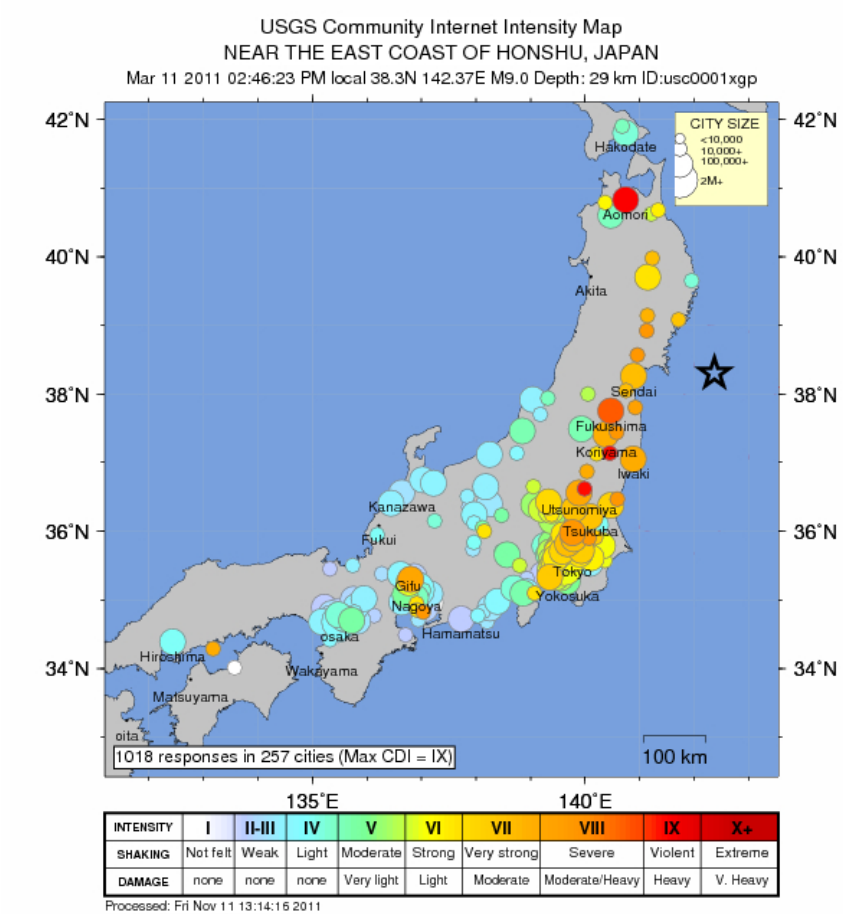
Dan MacMillan, Dirk Behrend
NVI, Inc./NASA/GSFC

Shinobu Kurihara
Geospatial Information Authority of Japan

Overview

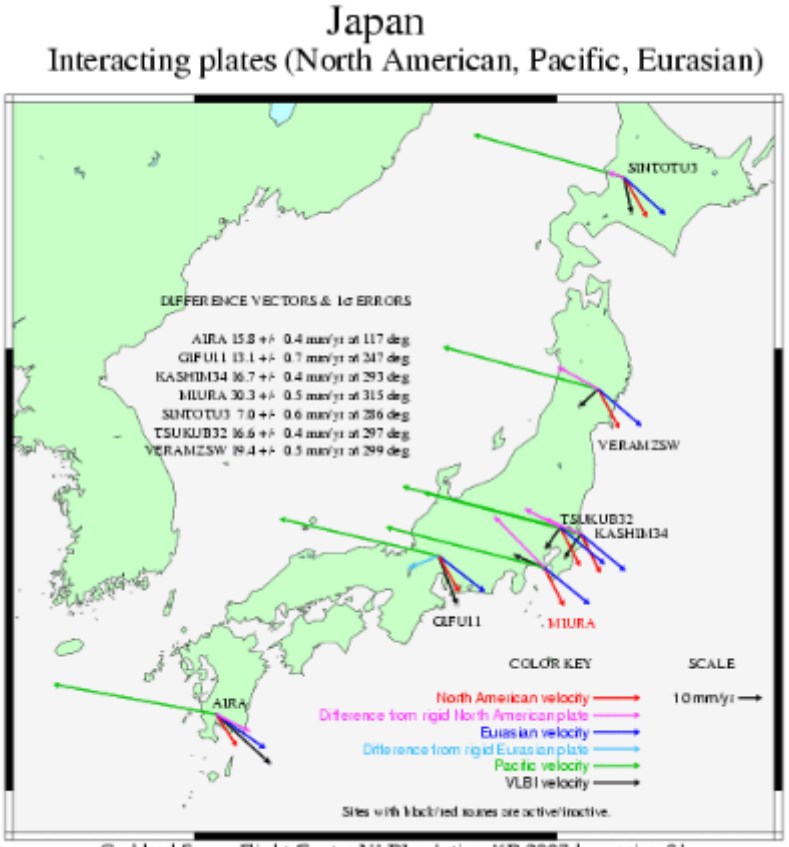
- Earthquake background
- Measured Tsukuba site position change
- Intensive VLBI sessions using TSUKUB32
- 24-hour R1 VLBI sessions with TSUKUB32
- Tsukuba position series update service

Earthquake Background



The epicenter of the magnitude 9.0 earthquake on March 11, 2011 at 05:48:24 GMT was located at a depth of about 29 km at 38.30°N and 142.37°E. This location is about 340 km NNE of the city of Tsukuba, the location of the VLBI telescope TSUKUB32.

Earthquake Background



Goddard Space Flight Center VLBI solution KB 2007dn version 01
NUVEL1A-NNR reference frame. 1σ (realistic) error ellipses.

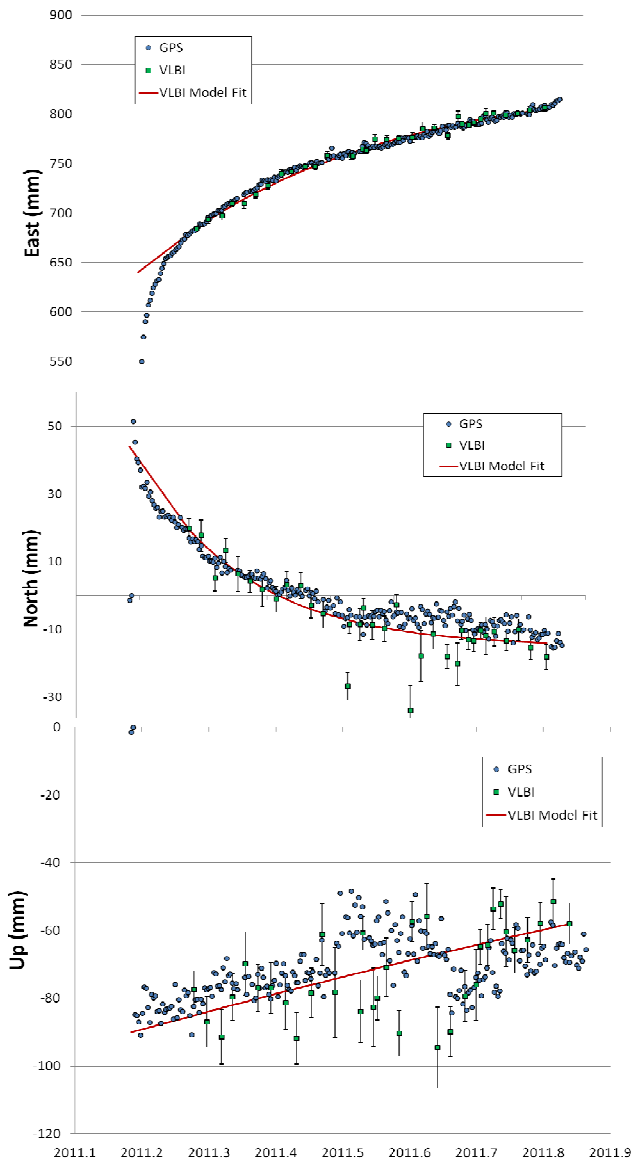
The co-seismic displacement is primarily in the east-west direction which is consistent with the direction of the Pacific plate velocity at Tsukuba.

Post-Earthquake Station Position

Compare the GPS and VLBI post-earthquake behavior

- GPS TSKB daily UEN series from JPL
  - Produced by Mike Heflin
  - latency 8-15 days
  - produced after each week of final orbits are computed
- Estimate the long-term GPS UEN rates and annual amplitudes prior to the earthquake and remove from the full series
- Estimate the VLBI R1 UEN offsets from TRF pre-earthquake position/velocity
  - currently how we handle TSUKUB32 operationally

Post-Earthquake Station Position



Transient decay model

$X(t) = X_0 + X_1 [1 - \exp((t-t_0)/\tau_c)]$

	X_0	X_1	τ_c
East	640 mm	196 mm	131 days
North	44 mm	-59 mm	62 days

- Fit through VLBI data, earliest R1 session was April 11, 2011
- Model can't fit GPS data back to earliest data after earthquake.

- Large scatter June-Aug - possible difference in motion of VLBI and GPS receivers (other seismic activity??)
- GPS/VLBI separation ~ 300 m

Intensive Experiment Sessions

- The IVS carries out operational one-hour Intensive sessions every day of the week to determine rapid UT1-UTC.
- The Kokee-Wettzell baseline is observed from Monday through Friday in Int1 sessions.
- On the weekend, the Int2 Intensives observe on the Tsukuba-Wettzell baseline.
- After earthquake, observed Kokee-Wettzell baseline in sessions right before Int2 sessions

TSUKUB32-WETTZELL Intensives

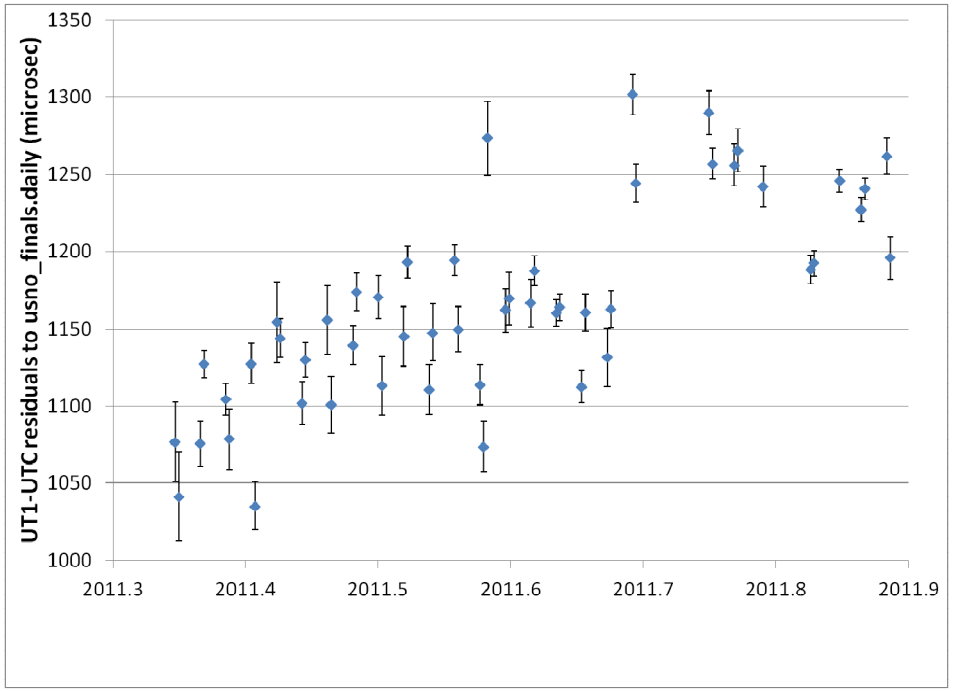
- In analysis of one-baseline intensives, the positions of the 2 baseline sites are fixed to a priori positions.

- Any error in the a priori positions will propagate to UT1 error

- UT1 sensitivity is largest for East errors, which also is the direction of maximum change after the Earthquake

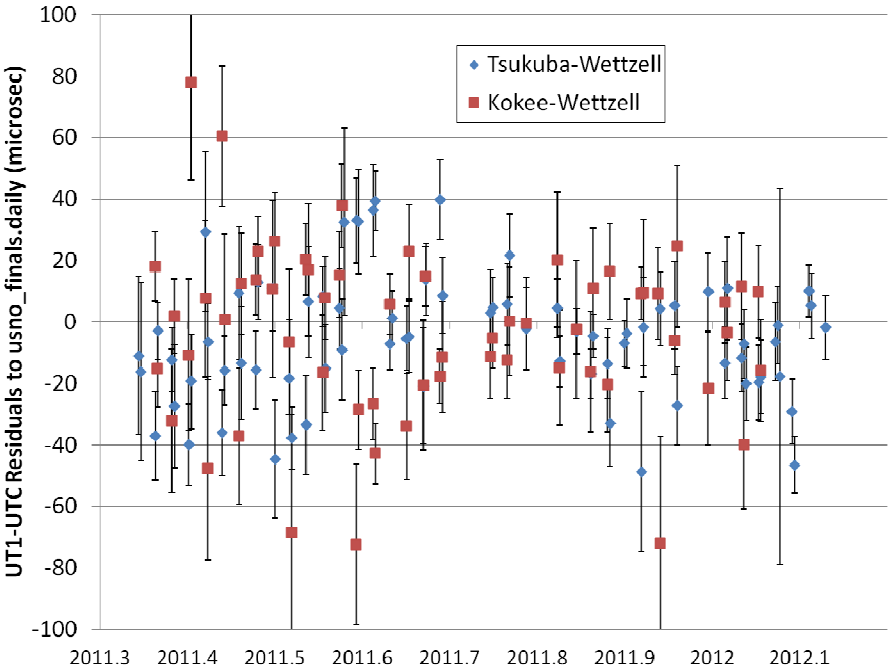
Tsukuba UEN Component	UT1-UTC Sensitivity to UEN change
Up	+0.25 µsec/mm
East	-1.50 µsec/mm
North	-0.85 µsec/mm

TSUKUB32-WETTZELL Intensives



- If no correction is applied for Tsukuba, UT1 diverges from the usno_finals combination solution
- We have investigated procedures for determining a good a priori position for TSUKUB32 suitable for Intensive analysis.
  - use the non-linear post-earthquake GPS position change to correct the VLBI position

TSUKUB32-WETTZELL Intensives



- Compare our series with the usno_finals combination solution

- With the GPS correction, UT1 from the TS-WZ and KK-WZ baselines agree at the same level with usno_finals

Baseline	Period	Bias (μsec)	WRMS (μsec)
KK-WZ	Weekend since EQ	-2.8	14.4
TS-WZ	INT2 since EQ	-5.9	15.4
KK-WZ	2009-2011	-3.7	15.1
TS-WZ	2010 INT2	-10.1	15.7

TSUKUB32 Position Operational Service

- We are currently providing a postseismic correction for the position of TSUKUB32

- Based on GPS series generated by JPL

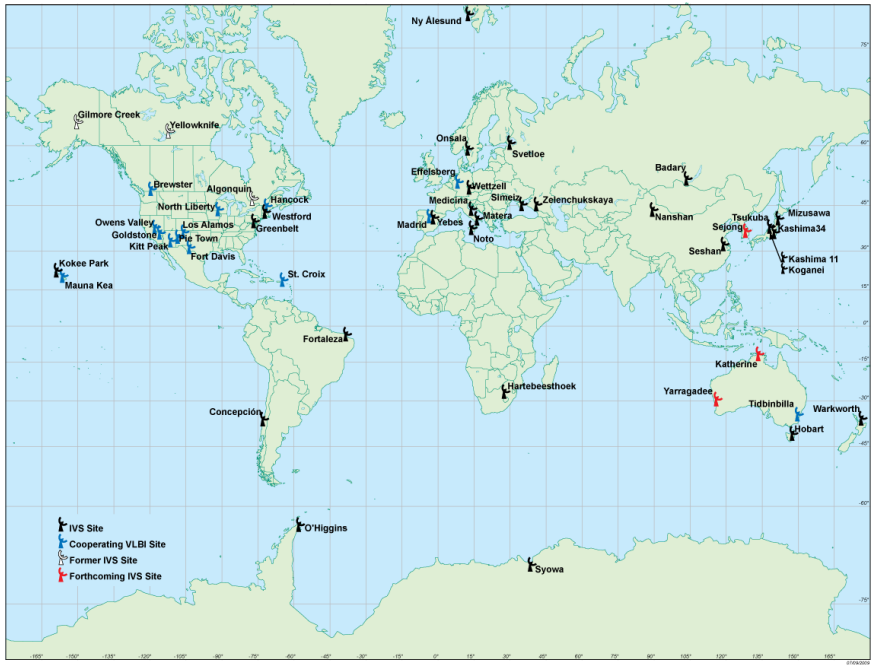
- For each point in the post-earthquake non-linear series, make a linear fit over the last 30 days to smooth the series and provide a prediction forward (for operational use)

- Files are updated every day with the latest GPS data

- Latency is 8-14 days

- Files are provided by ftp:
  ftp://gemini.gsfc.nasa.gov/pub/misc/dsm/tsukuba

24-Hour TSUKUB32 R1 Sessions



- IVS observes 24-hour sessions on a regular basis typically using a network of 7-10 stations.
- TSUKUB32 observes primarily in the operational weekly R1 network
- Observed until 7 March 2011 (four days before the earthquake)
- Resumed observing on 11 April 2011.

24-hour TSUKUB32 R1 Sessions

Possible Analysis Options

1. Estimate Tsukuba position for each session (current GSFC procedure)

2. Delete Tsukuba data

3. Apply post-earthquake GPS correction to a priori Tsukuba position
   Don’t estimate Tsukuba position each session

24-hour TSUKUB32 R1 Sessions

EOP Formal Uncertainties

Analysis Option	Xp µas	Yp µas	UT1 µs	ψ µas	ε µas
Estim TS	68	67	3.2	111	45
No TS	91	82	4.1	163	69
GPS corr	54	60	2.5	110	45

- TSUKUB32 is very important for the network geometry
- Estimating TSUKUB32 position each session weakens the data from TSUKUB32
- Applying GPS correction for post-Earthquake change strengthens contribution from TSUKUB32 data

24-hour TSUKUB32 R1 Sessions

EOP Comparisons with GPS

		Offset	Rate	WRMS
X-pole (µas)	1	-108 ± 30	-18 ± 44	112
	2	-73 ± 40	-78 ± 57	111
	3	-70 ± 29	-23 ± 42	90
Y-Pole (µas)	1	149 ± 31	74 ± 46	112
	2	110 ± 38	169 ± 55	120
	3	137 ± 30	94 ± 44	90
LOD (µs/d)	1	0.1 ± 3.4	1.2 ± 4.9	16.0
	2	-9.3 ± 5.6	12.4 ± 7.9	19.5
	3	-0.4 ± 3.6	1.9 ± 5.1	16.3

1. Estimate TSUKUB32 position each session (current practice)
2. Remove TSUKUB32 data
3. Apply GPS correction instead of estimating the position

Conclusions

- Post-seismic relaxation is ongoing and the position of Tsukuba is continuing to change nonlinearly relative to the pre-earthquake long-term rate.

- VLBI UT1-UTC estimates from the Tsukuba-Wettzell baseline Intensives are clearly better after correcting the VLBI a priori position of Tsukuba using GPS data.

- VLBI polar motion agrees better with IGS EOP when the post-earthquake GPS correction is applied in 24-hour R1 session analysis.

- We have developed a procedure to compute the latest post-earthquake GPS correction operationally for use in rapid service analysis of Intensive sessions involving TSUKUB32.