National Land Surveying and Mapping Center, Ministry of the Interior

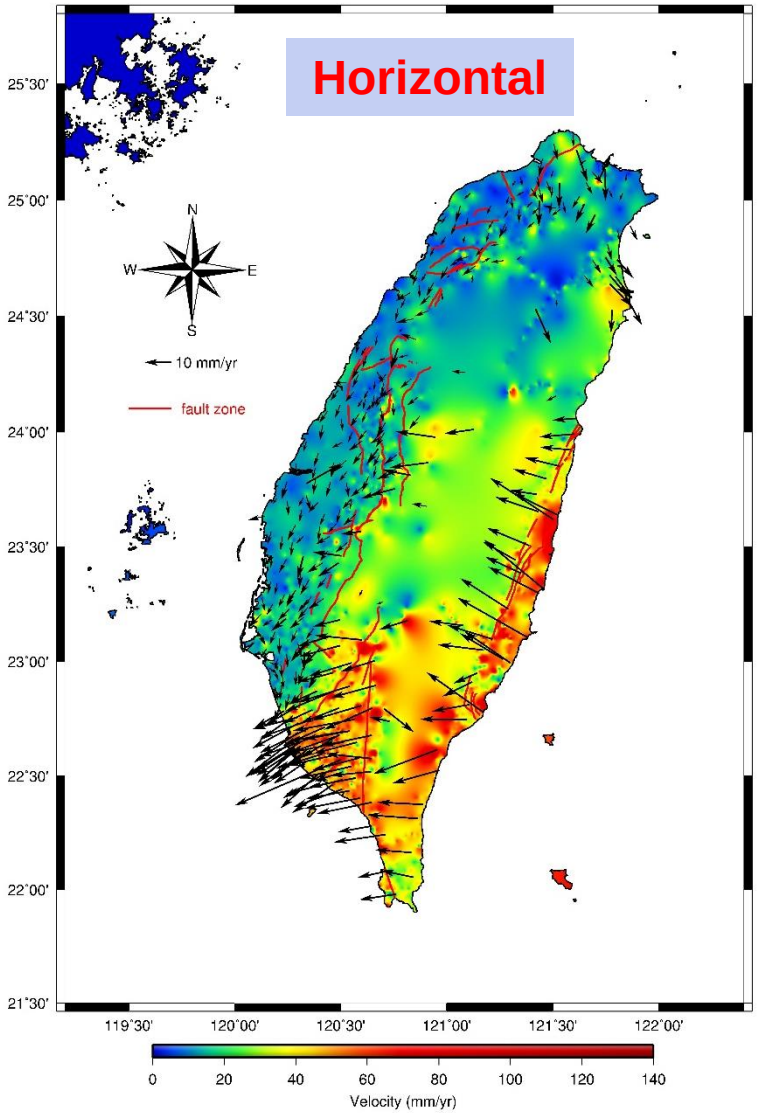
A Study on VBS-RTK Determining Legal Coordinates by 3D Real-time Coordinate Transformation

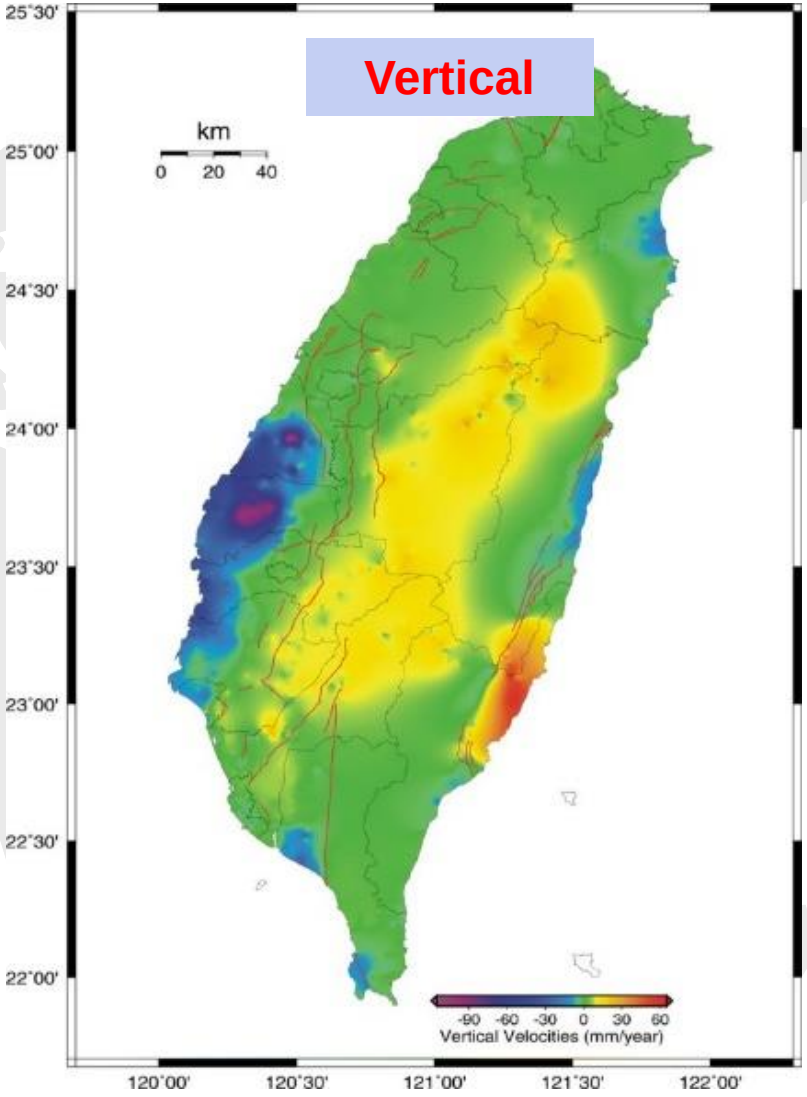
- National Land Surveying and Mapping Center, Ministry of the Interior

Feng-Fu Chuang

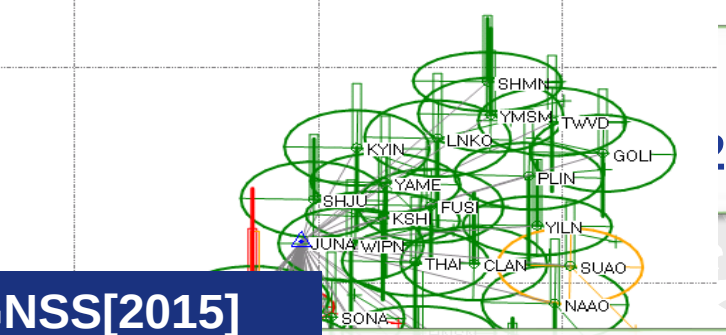
Velocity field of Taiwan

Background | Purpose | Method | Result | Conclusion



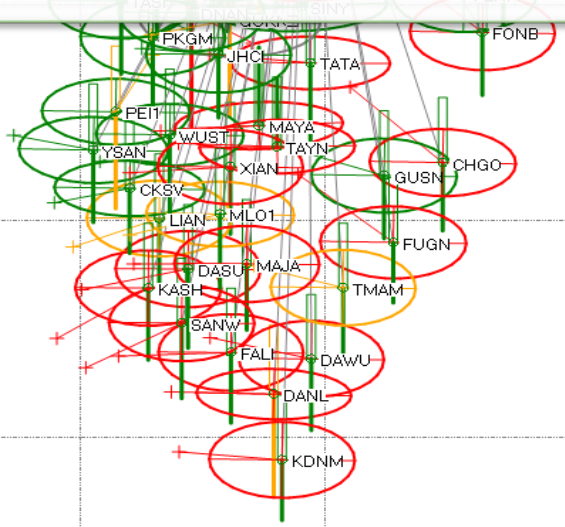


e-GNSS coordinate system



e-GNSS[2015]

- **Duration：2015.05.01～now**
- **Data：2014.12.01～2015.01.31，62days。**



Statu	Station Name	Station ID	Δ Northing [m]	Δ Easting [m]	Δ Height [m]	Δ 2D [m]	Δ 3D [m]
	TASO	76	-0.036	0.204	0.150	0.207	0.256
	FONB	14	0.110	-0.127	-0.007	0.168	0.168
	MAJA	23	-0.001	-0.116	-0.017	0.116	0.118
	FALI	25	-0.004	-0.114	-0.029	0.114	0.118
	DAWU	27	0.021	-0.090	-0.032	0.093	0.098
	KASH	28	-0.054	-0.086	-0.034	0.102	0.107
	TAYN	30	0.003	-0.079	0.022	0.079	0.082
	KDNM	34	0.008	-0.090	-0.002	0.091	0.091
	CHGO	40	0.101	-0.110	-0.023	0.149	0.151
	FUGN	73	0.088	-0.109	-0.002	0.140	0.140
	DASU	81	-0.023	-0.103	-0.054	0.105	0.119
	MAYA	86	-0.005	-0.078	0.052	0.078	0.094
	SANW	87	0.049	0.093	0.044	0.104	0.113
	XIAN	94	-0.005	-0.084	-0.020	0.084	0.087
	TATA	122	0.008	-0.086	-0.051	0.087	0.101
	DNAN	159	0.003	0.005	-0.156	0.006	0.156
	DANL	165	0.002	-0.089	-0.129	0.089	0.149
	SHJU	1	0.003	0.009	0.002	0.009	0.009
	TACH	2	0.002	0.009	-0.023	0.009	0.025
	FUSI	5	0.002	0.008	0.000	0.008	0.008
	DOSH	8	0.006	-0.008	-0.003	0.010	0.011
	SINY	11	0.000	-0.049	0.009	0.049	0.050
	VR03	17	-0.010	0.011	-0.024	0.015	0.028
	SHMN	4	-0.001	0.008	0.008	0.008	0.011
	KYIN	20	-0.003	0.008	-0.065	0.009	0.065
	FLNM	21	0.031	-0.045	0.040	0.055	0.067
	JHCI	26	0.002	-0.022	-0.008	0.022	0.024
	WUST	29	-0.008	-0.019	-0.077	0.020	0.080
	PKGM	33	0.002	0.003	-0.052	0.004	0.052
	SICH	36	-0.002	-0.026	0.028	0.026	0.038
	YILN	37	-0.007	0.031	0.010	0.032	0.033
	CLAN	49	0.002	0.020	0.029	0.020	0.035
	CKSV	70	-0.005	-0.022	-0.013	0.023	0.026
	TASI	75	-0.006	0.013	-0.038	0.014	0.041
	YMSM	77	0.004	0.017	0.076	0.017	0.078
	GUSN	94	0.015	-0.047	-0.007	0.049	0.050
	KFN2	3	0.011	-0.038	-0.021	0.039	0.044
	GOLI	5	0.002	-0.008	-0.007	0.008	0.011
	PLIN	104	0.002	0.021	-0.082	0.021	0.085
	DPIN	115	0.044	-0.046	-0.025	0.064	0.068

Legal geodetic and vertical datum of Taiwan

TWD97

- 1998.03.17 announced
- ITRF1984.0
- GRS80
- 2°TM
  - Central meridian:119,121
  - scale factor:0.9999
  - false easting:250km

TWD97[2010]

- 2012.03.30 announced

TWVD2001

- 2001 announced
- Keelung tide gauge data from 1957 to 1991
- Standard atmosphere environment on January 1, 1990

Purpose of this study

- **Users could obtain the legal coordinates in the field by e-GNSS.**
- **Accomplish Height Modernization(obtain orthometric height using GNSS) by e-GNSS.**
- **Connect the surveying results when updating the coordinates of e-GNSS**

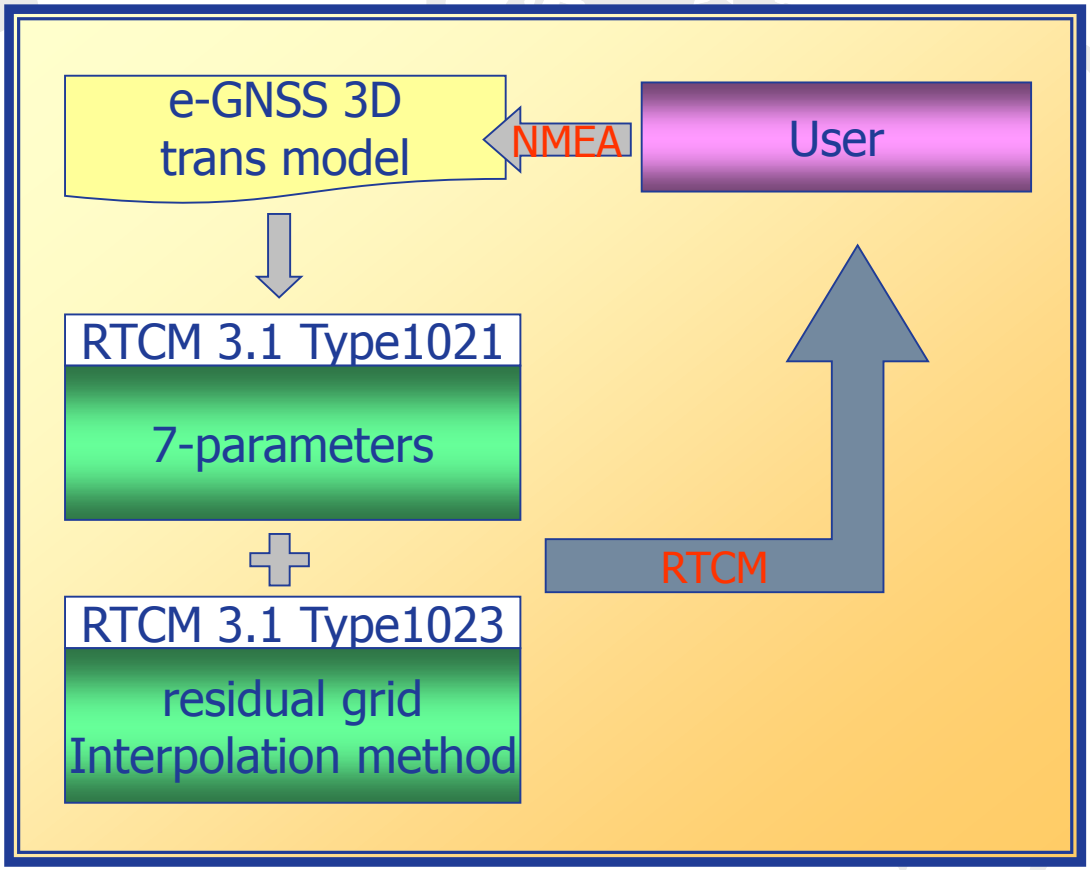
3D real-time coordinate transformation

❖ Type1021

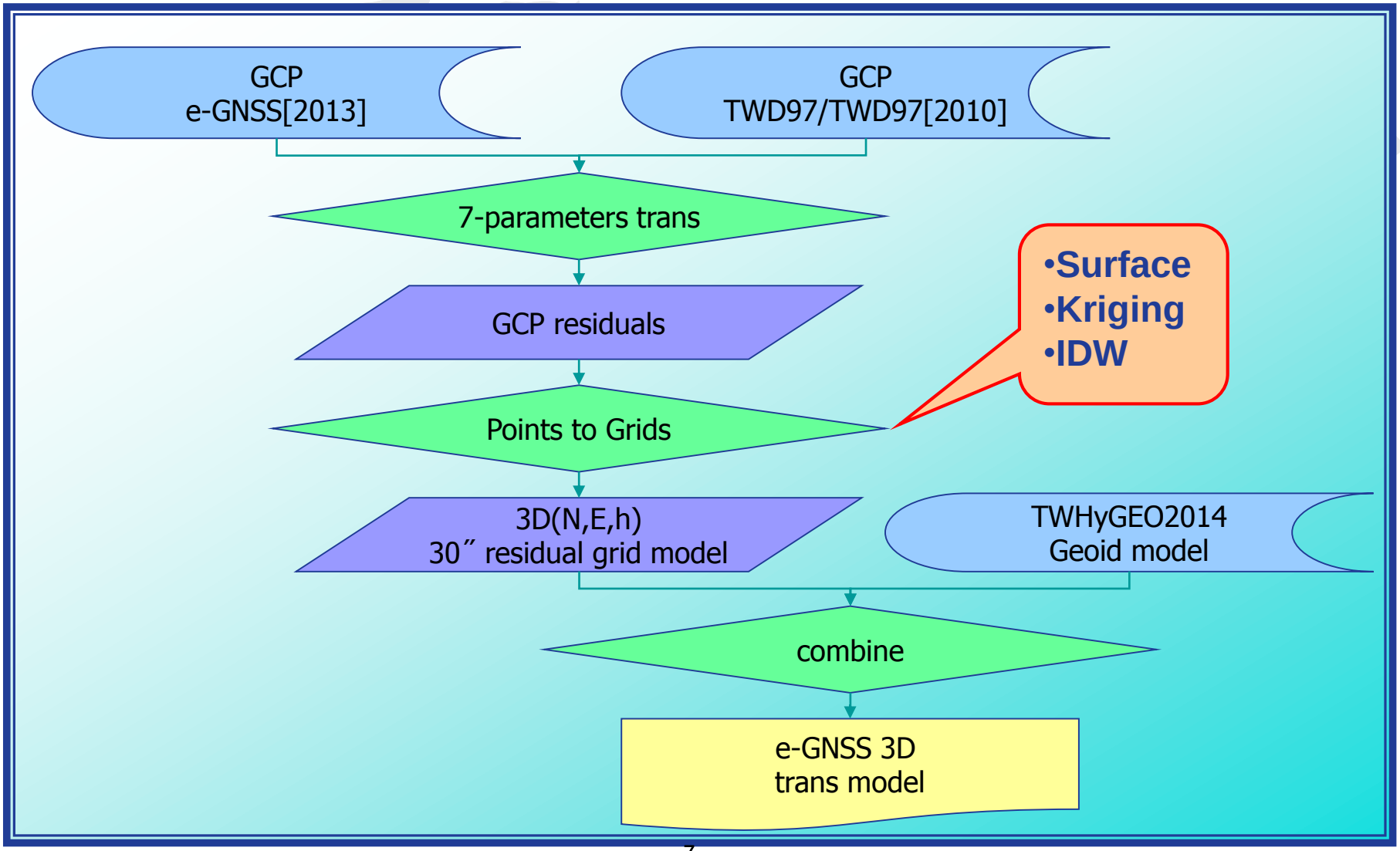
- Helmert Transformation, Strict formula
- Helmert Transformation, Linear Expression
- Abridged Molodenski Transformation
- Molodenski-Badekas (10-parameters) Transformation

❖ Type1023

- bi-linear
- bi-quadratic
- bi-spline

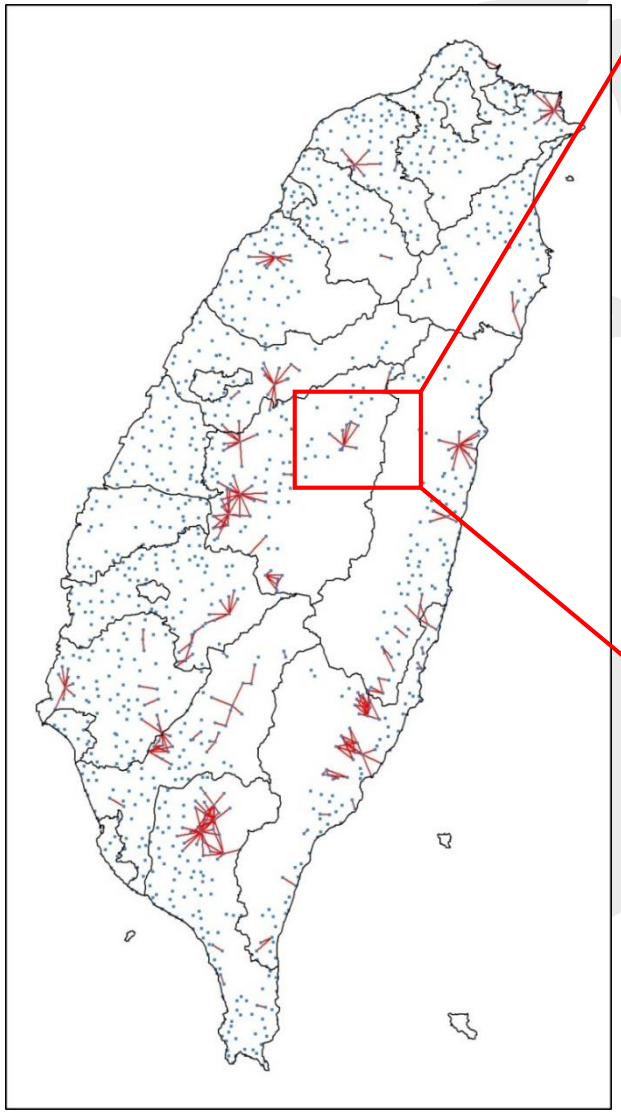


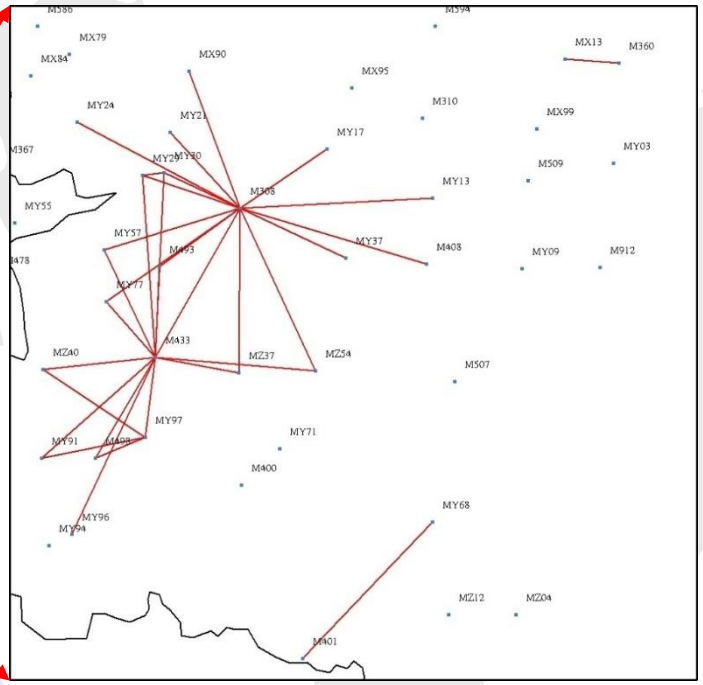
Establish residual grid method



e-GNSS[2013]→TWD97 common points

Background | Purpose | Method | Result | Conclusion



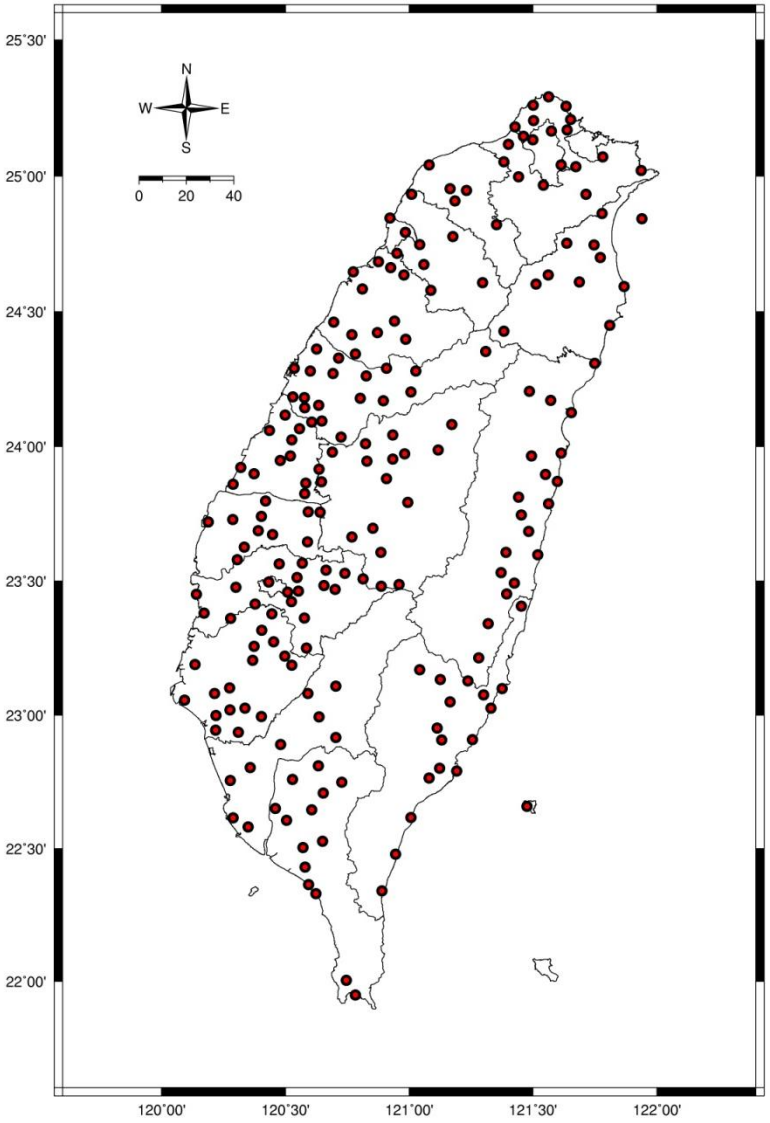


- each baseline under 20km
- relative accuracy better than 1/20,000

- 1,060 common points left

e-GNSS[2013]→TWD97[2010] common points

Background | Purpose | Method | Result | Conclusion



- **210 common CORS(Continuously Operating Reference Stations)**

Description of test data

- e-GNSS[2013]→TWD97

established data	1,060 common points
internal accuracy(N,E,h)	1,060 common points
external accuracy(N,E,h)	345 benchmarks
external accuracy(H)	408 benchmarks

- e-GNSS[2013]→TWD97[2010]

established data	210 CORS
internal accuracy(N,E,h)	210 CORS
external accuracy(N,E,h)	424 benchmarks
external accuracy(H)	408 benchmarks

e-GNSS[2013]→TWD97－internal accuracy-1/2

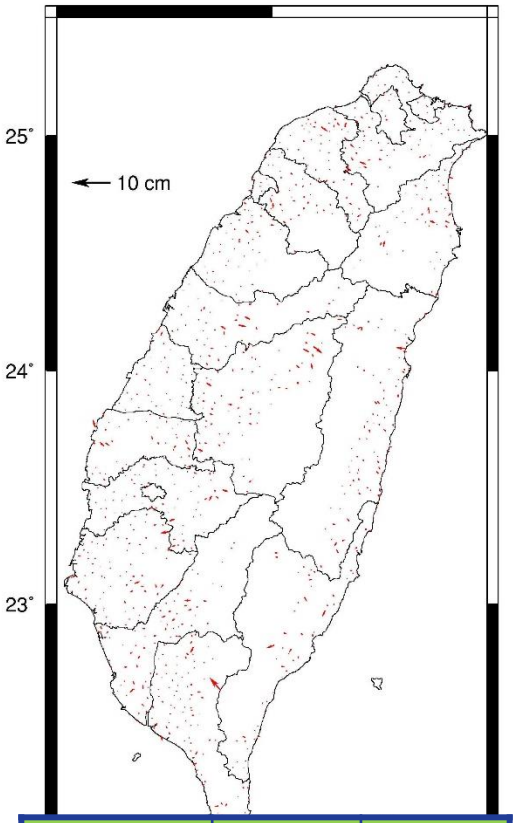
Background | Purpose | Method | **Result** | Conclusion

interpolation		bi-linear			bi-quadratic			bi-spline		
component		N	E	h	N	E	h	N	E	h
Surface	MAX	0.100	0.070	0.158	0.158	0.090	0.188	0.240	0.222	0.156
	MIN	-0.076	-0.090	-0.185	-0.094	-0.115	-0.220	-0.077	-0.159	-0.476
	STD	0.013	0.015	0.027	0.019	0.021	0.040	0.015	0.018	0.032
	MEAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	RMS	0.013	0.015	0.027	0.019	0.021	0.040	0.015	0.018	0.032
Kriging	MAX	0.044	0.029	0.160	0.046	0.050	0.160	0.048	0.537	0.160
	MIN	-0.023	-0.038	-0.050	-0.034	-0.059	-0.116	-0.030	-0.038	-1.350
	STD	0.005	0.005	0.011	0.009	0.010	0.021	0.005	0.017	0.043
	MEAN	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.000	-0.001
	RMS	0.005	0.005	0.011	0.009	0.010	0.021	0.005	0.017	0.043
IDW	MAX	0.061	0.025	0.214	0.063	0.051	0.214	0.248	0.660	0.216
	MIN	-0.022	-0.042	-0.088	-0.043	-0.058	-0.146	-0.049	-0.122	-1.291
	STD	0.005	0.005	0.012	0.011	0.012	0.025	0.011	0.022	0.042
	MEAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	-0.001
	RMS	0.005	0.005	0.012	0.011	0.012	0.025	0.011	0.022	0.042

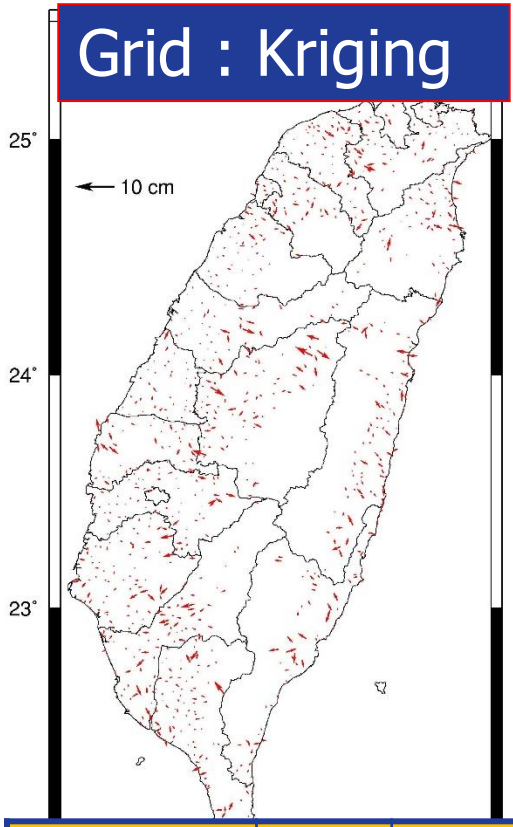
e-GNSS[2013]→TWD97－internal accuracy-2/2

Background | Purpose | Method | Result | Conclusion

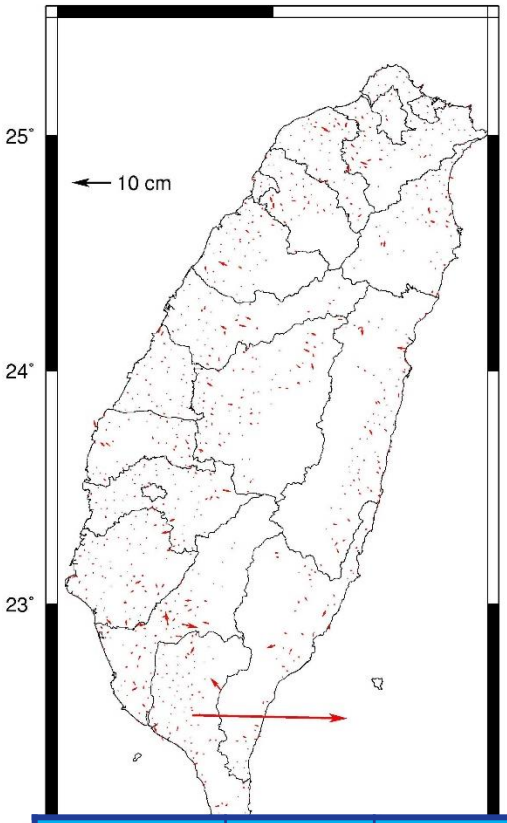
Grid : Kriging



bi-linear	N(m)	E(m)
Max	0.044	0.029
Min	-0.023	-0.038
STD	0.005	0.005
Mean	0.000	0.000



bi-quadratic	N(m)	E(m)
Max	0.046	0.050
Min	-0.034	-0.059
STD	0.009	0.010
Mean	0.001	0.000



bi-spline	N(m)	E(m)
Max	0.048	0.537
Min	-0.030	-0.038
STD	0.005	0.017
Mean	0.000	0.000

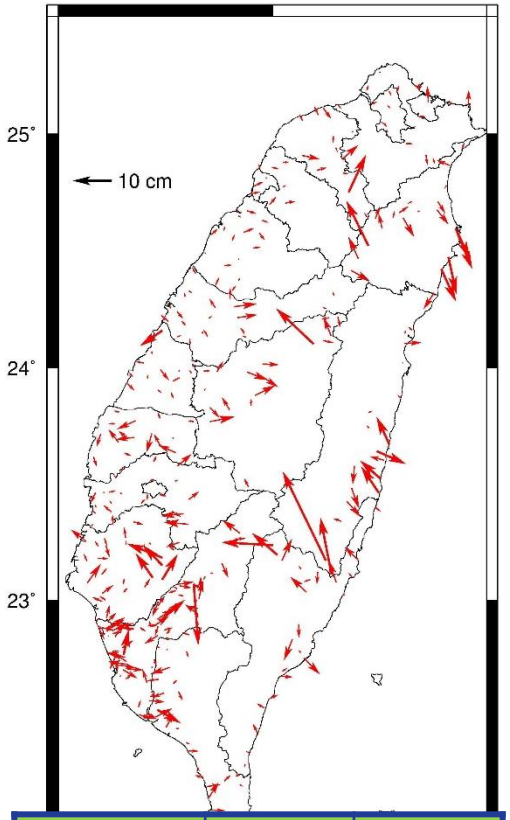
e-GNSS[2013]→TWD97－external accuracy-1/2

interpolation		bi-linear				bi-quadratic				bi-spline			
component		N	E	h	H	N	E	h	H	N	E	h	H
Surface	MAX	0.301	0.109	0.318	0.565	0.300	0.108	0.331	0.575	0.301	0.109	0.318	0.564
	MIN	-0.217	-0.135	-0.579	-0.340	-0.217	-0.133	-0.581	-0.342	-0.217	-0.135	-0.579	-0.340
	STD	0.046	0.036	0.101	0.119	0.046	0.037	0.100	0.122	0.046	0.036	0.100	0.120
	MEAN	0.005	0.005	-0.024	0.044	0.005	0.004	-0.025	0.050	0.005	0.005	-0.024	0.044
	RMS	0.046	0.036	0.103	0.127	0.046	0.037	0.103	0.132	0.046	0.037	0.103	0.128
Kriging	MAX	0.309	0.101	0.318	0.589	0.305	0.093	0.319	0.607	0.309	0.133	0.318	0.588
	MIN	-0.213	-0.179	-0.589	-0.365	-0.214	-0.177	-0.573	-0.375	-0.213	-0.179	-0.589	-0.365
	STD	0.040	0.035	0.094	0.130	0.040	0.036	0.094	0.133	0.041	0.036	0.094	0.130
	MEAN	0.007	0.004	-0.021	0.046	0.007	0.003	-0.022	0.053	0.007	0.004	-0.021	0.046
	RMS	0.041	0.036	0.097	0.138	0.041	0.036	0.096	0.143	0.041	0.036	0.097	0.138
IDW	MAX	0.343	0.107	0.318	0.550	0.329	0.103	0.318	0.563	0.343	0.130	0.318	0.549
	MIN	-0.205	-0.158	-0.639	-0.352	-0.205	-0.150	-0.640	-0.352	-0.205	-0.171	-0.638	-0.352
	STD	0.047	0.037	0.105	0.119	0.047	0.037	0.104	0.121	0.048	0.037	0.105	0.119
	MEAN	0.005	0.005	-0.025	0.043	0.005	0.004	-0.026	0.050	0.005	0.005	-0.025	0.043
	RMS	0.048	0.037	0.108	0.126	0.047	0.037	0.107	0.131	0.048	0.038	0.108	0.127

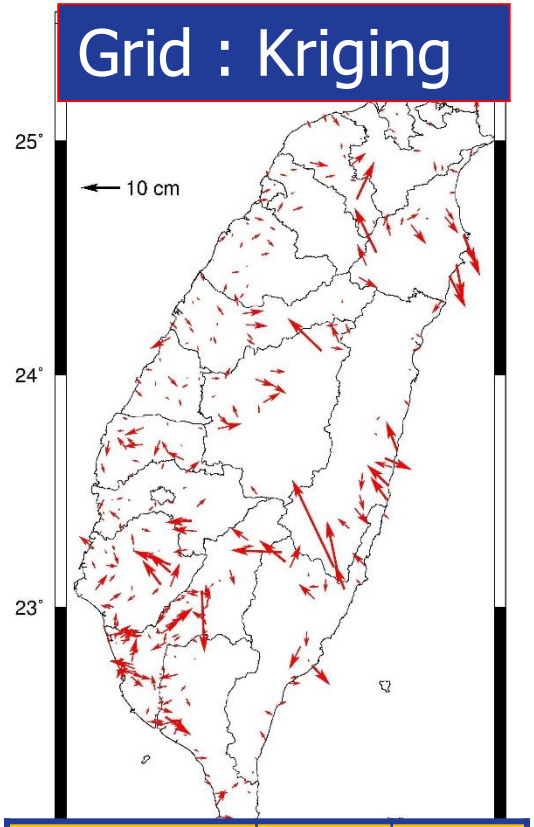
e-GNSS[2013]→TWD97－external accuracy-2/2

Background | Purpose | Method | Result | Conclusion

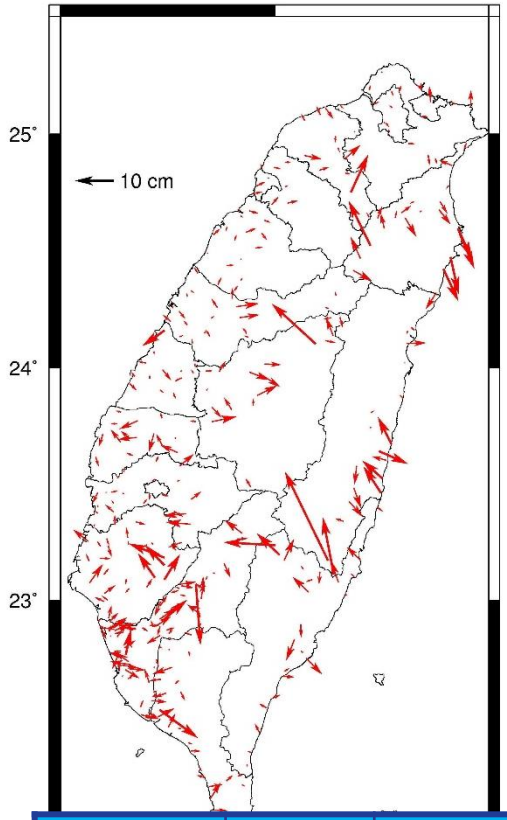
Grid : Kriging



bi-linear	N(m)	E(m)
Max	0.309	0.101
Min	-0.213	-0.179
STD	0.040	0.035
Mean	0.007	0.004



bi-quadratic	N(m)	E(m)
Max	0.305	0.093
Min	-0.214	-0.177
STD	0.040	0.036
Mean	0.007	0.003



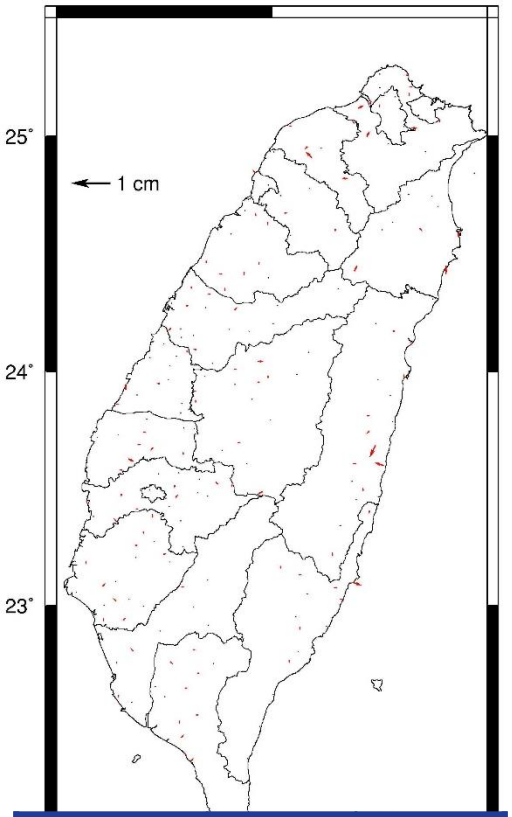
bi-spline	N(m)	E(m)
Max	0.309	0.133
Min	-0.213	-0.179
STD	0.041	0.036
Mean	0.007	0.004

GNSS[2013]→TWD97[2010]－internal accuracy-1/2

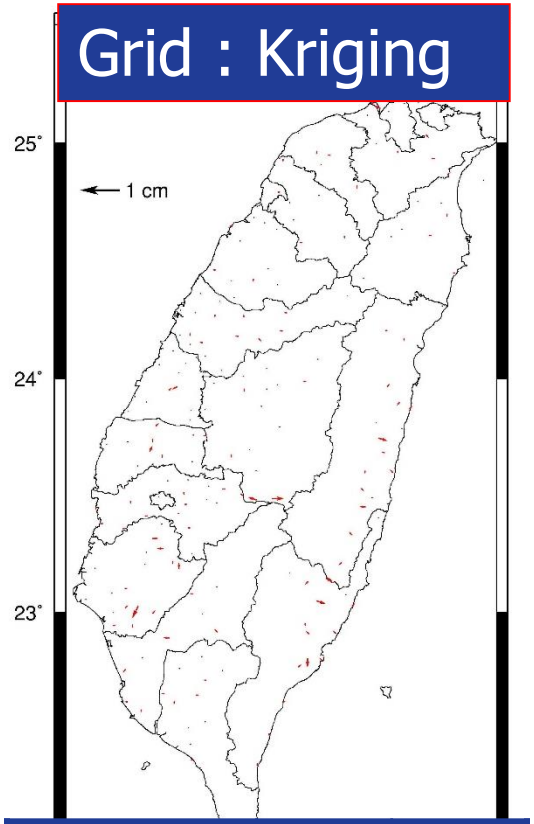
interpolation		bi-linear			bi-quadratic			bi-spline		
component		N	E	h	N	E	h	N	E	h
Surface	MAX	0.015	0.015	0.081	0.020	0.028	0.105	0.015	0.014	0.083
	MIN	-0.018	-0.015	-0.081	-0.025	-0.021	-0.097	-0.018	-0.015	-0.082
	STD	0.004	0.004	0.012	0.006	0.006	0.017	0.004	0.004	0.013
	MEAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	RMS	0.004	0.004	0.012	0.006	0.006	0.017	0.004	0.004	0.013
Kriging	MAX	0.002	0.003	0.014	0.002	0.004	0.015	0.002	0.004	0.015
	MIN	-0.004	-0.003	-0.016	-0.004	-0.003	-0.017	-0.004	-0.003	-0.017
	STD	0.001	0.001	0.003	0.001	0.001	0.003	0.001	0.001	0.003
	MEAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	RMS	0.001	0.001	0.003	0.001	0.001	0.003	0.001	0.001	0.003
IDW	MAX	0.001	0.001	0.005	0.005	0.005	0.023	0.001	0.002	0.020
	MIN	-0.002	-0.002	-0.010	-0.006	-0.005	-0.031	-0.003	-0.011	-0.011
	STD	0.001	0.001	0.001	0.001	0.002	0.004	0.001	0.001	0.002
	MEAN	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	RMS	0.001	0.001	0.001	0.001	0.002	0.004	0.001	0.001	0.002

GNSS[2013]→TWD97[2010]－internal accuracy-2/2

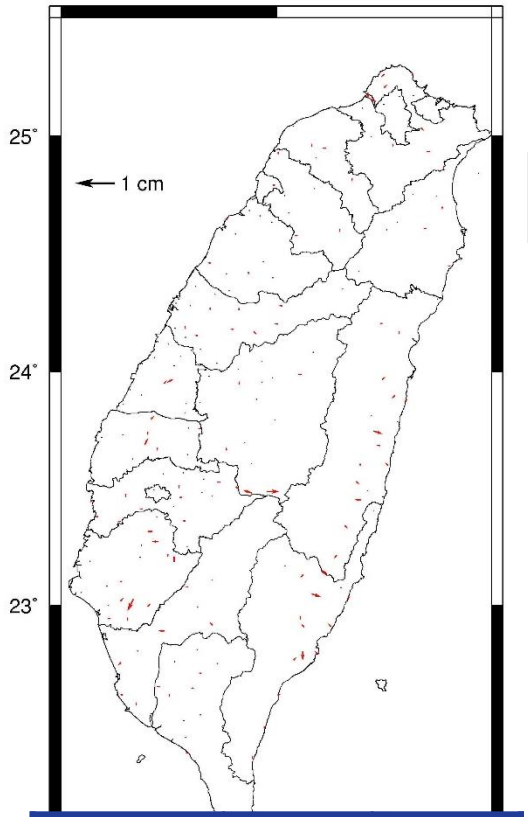
Grid : Kriging



bi-linear	N(m)	E(m)
Max	0.002	0.003
Min	-0.004	-0.003
STD	0.001	0.001
Mean	0.000	0.000



bi-quadratic	N(m)	E(m)
Max	0.002	0.004
Min	-0.004	-0.003
STD	0.001	0.001
Mean	0.000	0.000



bi-spline	N(m)	E(m)
Max	0.002	0.004
Min	-0.004	-0.003
STD	0.001	0.001
Mean	0.000	0.000

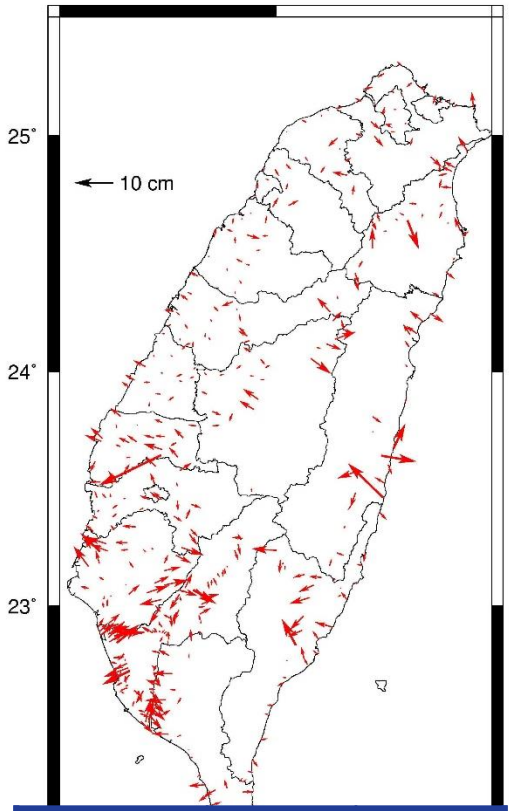
GNSS[2013]→TWD97[2010]－external accuracy-1/2

Background | Purpose | Method | **Result** | Conclusion

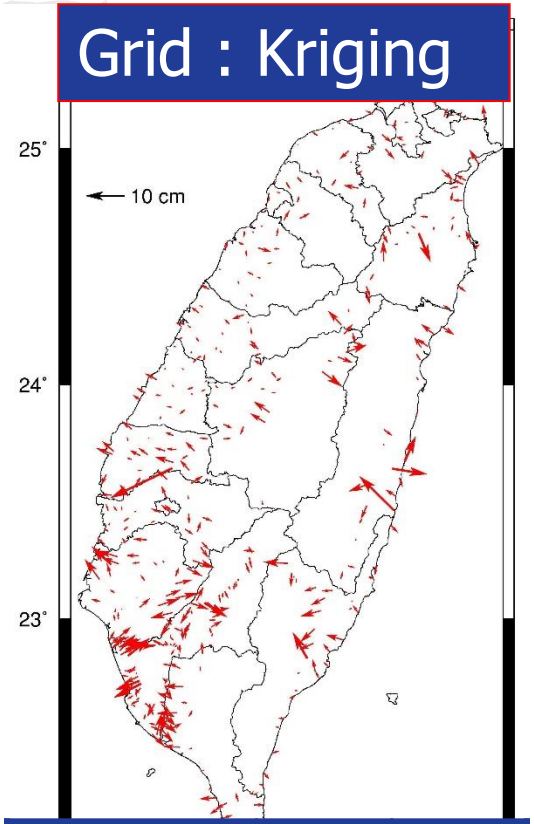
interpolation		bi-linear				bi-quadratic				bi-spline			
component		N	E	h	H	N	E	h	H	N	E	h	H
Surface	MAX	0.147	0.109	0.316	0.349	0.147	0.109	0.316	0.403	0.147	0.109	0.316	0.349
	MIN	-0.102	-0.210	-0.275	-0.304	-0.102	-0.210	-0.272	-0.277	-0.102	-0.210	-0.275	-0.301
	STD	0.027	0.034	0.068	0.075	0.027	0.034	0.068	0.079	0.027	0.034	0.068	0.075
	MEAN	0.002	-0.003	-0.028	-0.005	0.002	-0.003	-0.028	0.002	0.002	-0.003	-0.028	-0.005
	RMS	0.027	0.034	0.073	0.075	0.027	0.034	0.073	0.079	0.027	0.034	0.073	0.075
Kriging	MAX	0.118	0.121	0.311	0.344	0.118	0.120	0.311	0.397	0.118	0.121	0.311	0.343
	MIN	-0.104	-0.214	-0.307	-0.336	-0.103	-0.214	-0.301	-0.306	-0.104	-0.214	-0.307	-0.333
	STD	0.025	0.033	0.072	0.076	0.025	0.033	0.071	0.079	0.025	0.033	0.072	0.076
	MEAN	0.003	-0.002	-0.027	-0.005	0.003	-0.002	-0.027	0.002	0.003	-0.002	-0.027	-0.004
	RMS	0.025	0.033	0.077	0.076	0.025	0.033	0.076	0.079	0.025	0.033	0.077	0.076
IDW	MAX	0.170	0.104	0.312	0.345	0.173	0.104	0.312	0.345	0.170	0.104	0.312	0.344
	MIN	-0.104	-0.205	-0.269	-0.298	-0.104	-0.206	-0.266	-0.298	-0.104	-0.205	-0.269	-0.295
	STD	0.027	0.034	0.069	0.076	0.027	0.034	0.069	0.076	0.027	0.034	0.069	0.076
	MEAN	0.001	-0.004	-0.028	-0.006	0.001	-0.004	-0.028	-0.006	0.001	-0.004	-0.028	-0.005
	RMS	0.027	0.034	0.074	0.076	0.027	0.034	0.074	0.076	0.027	0.034	0.074	0.076

GNSS[2013]→TWD97[2010]－external accuracy-2/2

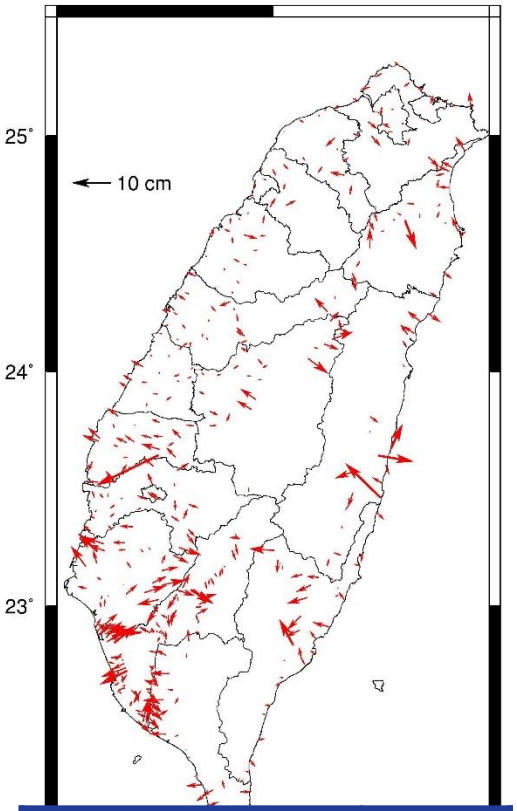
Grid : Kriging



bi-linear	N(m)	E(m)
Max	0.118	0.121
Min	-0.104	-0.214
STD	0.025	0.033
Mean	0.003	-0.002



bi-quadratic	N(m)	E(m)
Max	0.118	0.120
Min	-0.103	-0.214
STD	0.025	0.033
Mean	0.003	-0.002



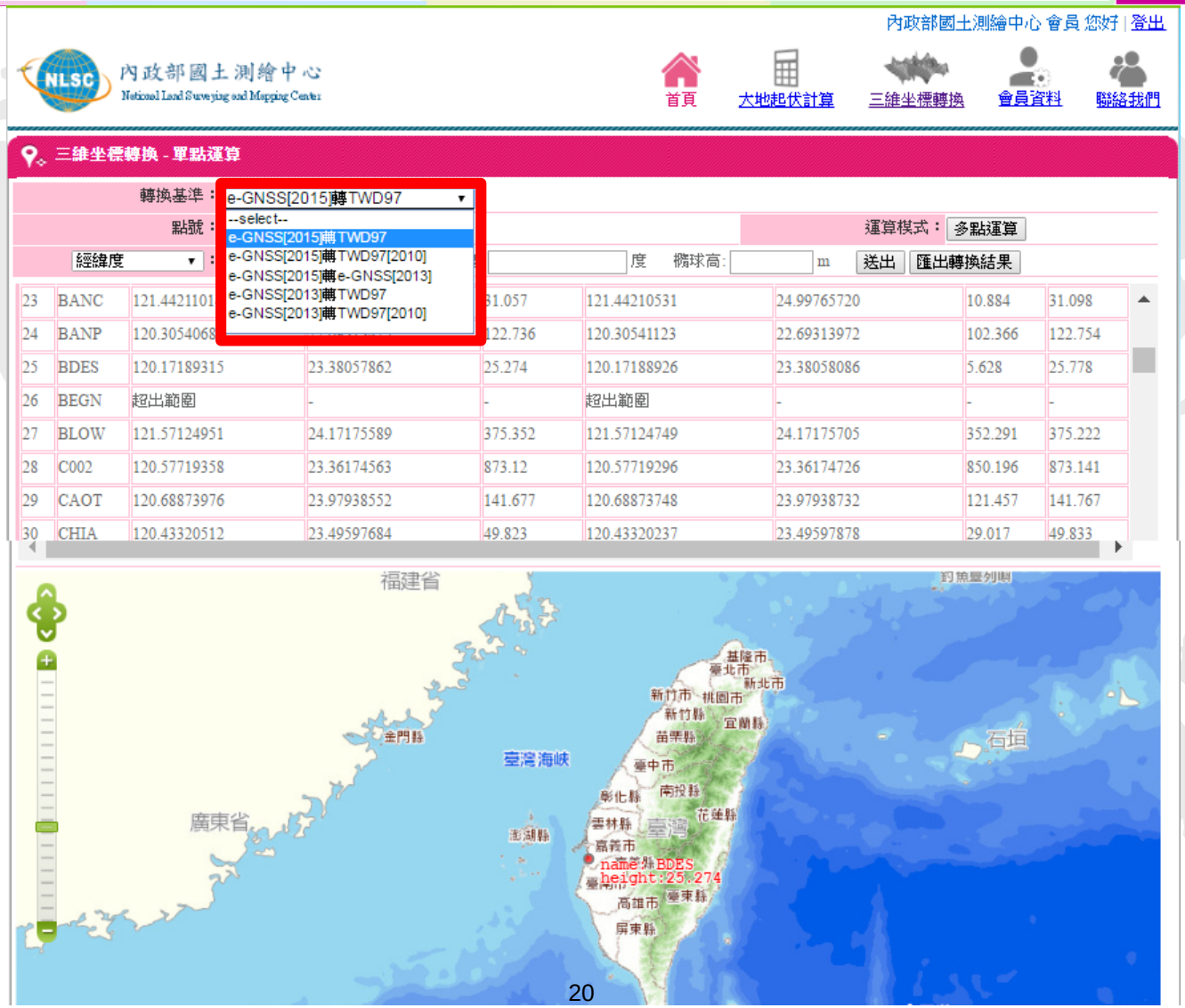
bi-linear	N(m)	E(m)
Max	0.118	0.121
Min	-0.104	-0.214
STD	0.025	0.033
Mean	0.003	-0.002

Conclusion

- **The transformed accuracy from e-GNSS[2013] to TWD97/TWD97[2010]/TWVD2001 was better than 5 cm for horizontal coordinates, and better than 10 cm for ellipsoid and orthometric height individually.**

- **The study shows that the best gridding algorithm was Kriging, the best interpolation algorithm was bi-linear.**

Practical application



Thank you for being here