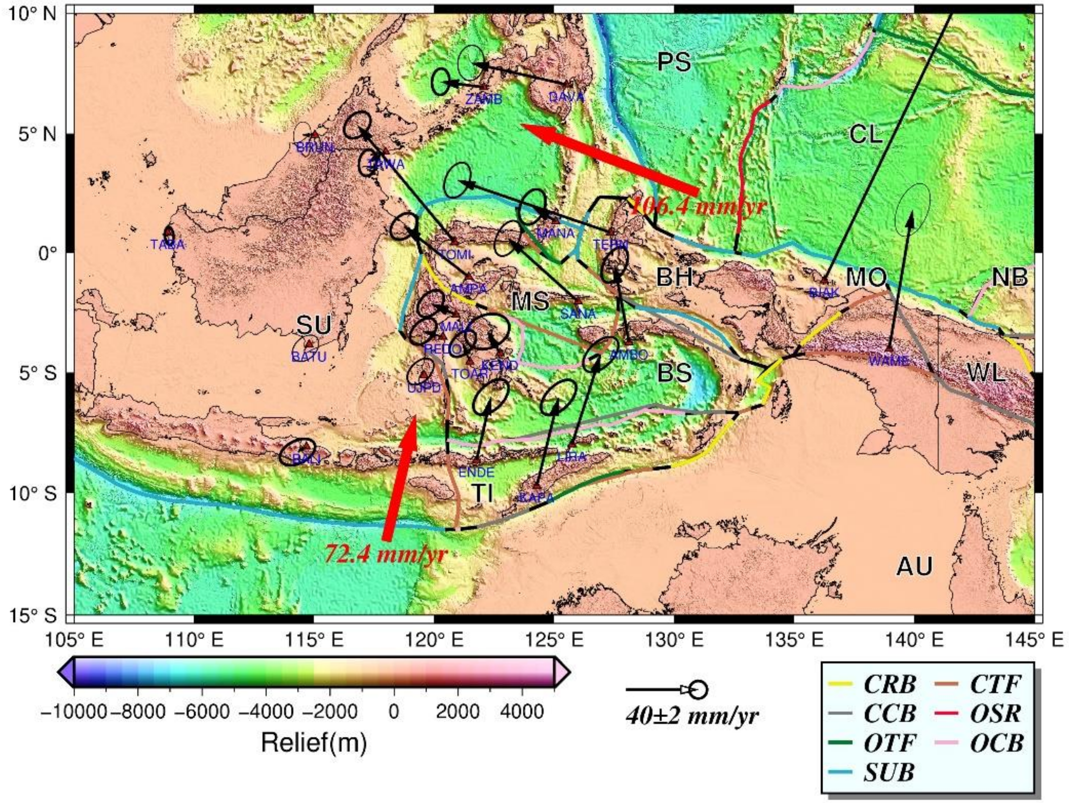
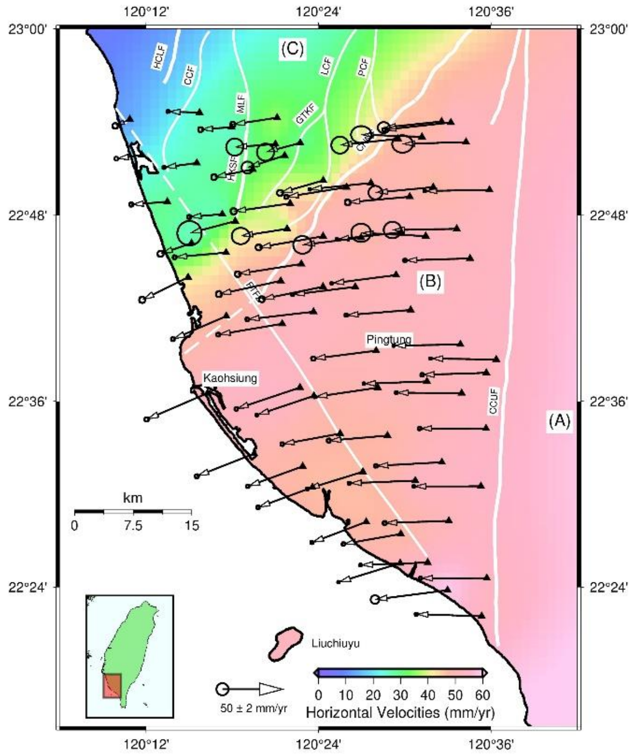
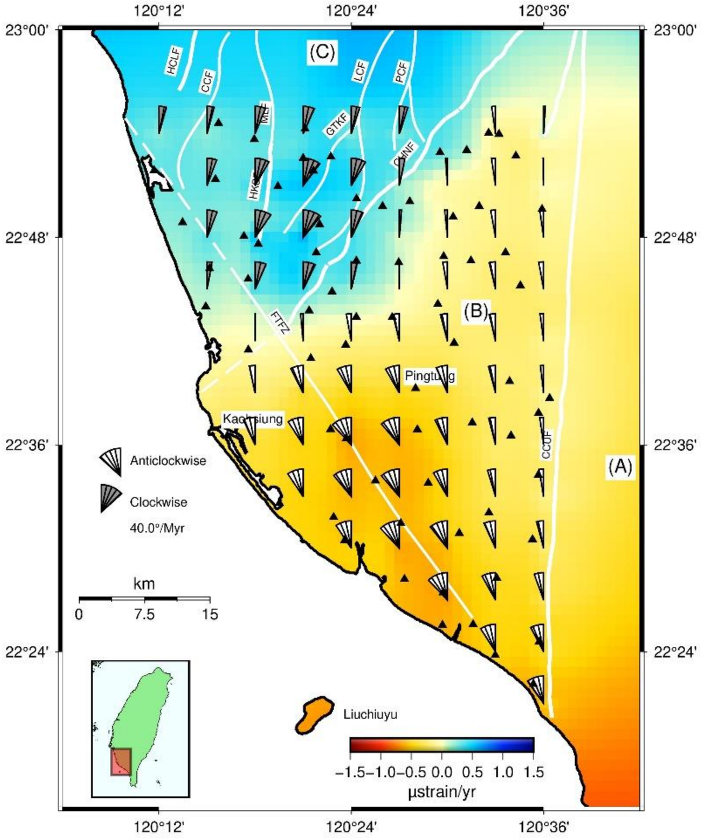
GMT Lect08 : Drawing GPS Data







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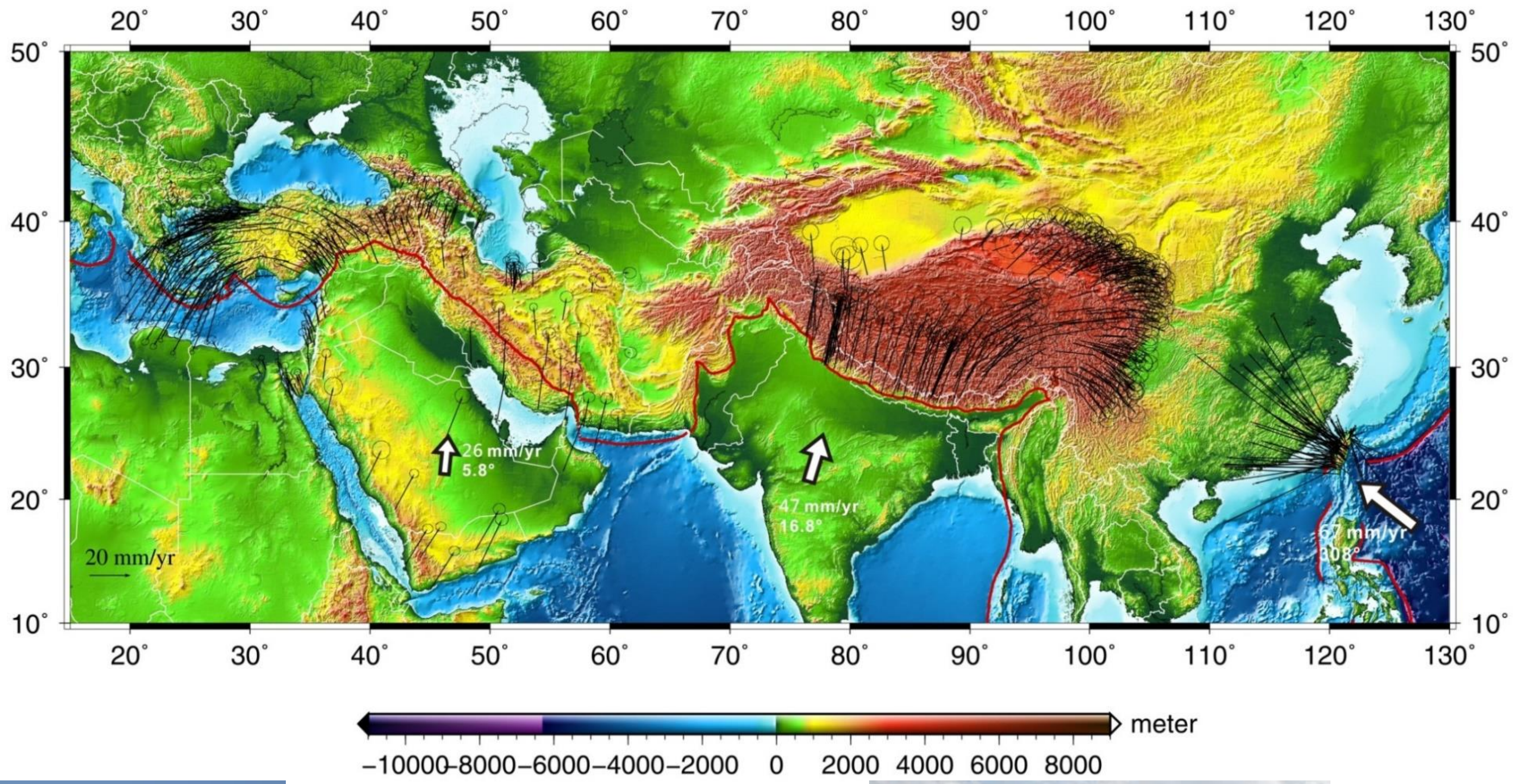
絲路計畫(II):對比研究地球的兩大碰撞造山帶



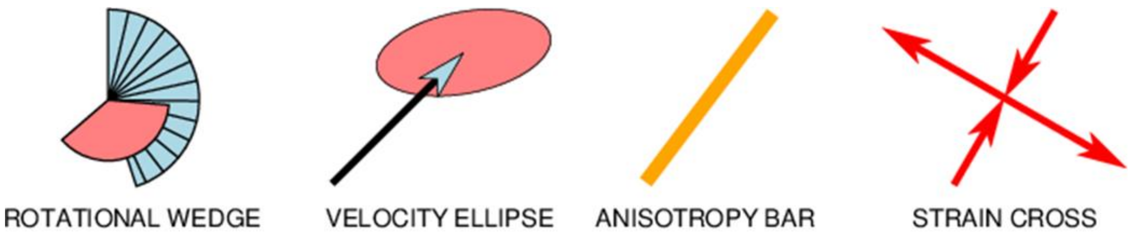
臺灣大學拔尖計畫:

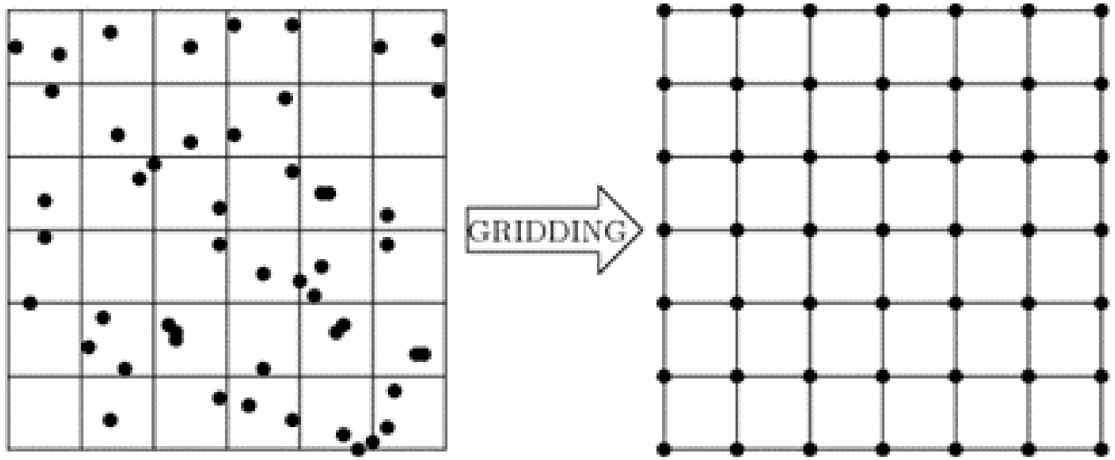
gmt commands

surface - Grid table data using adjustable tension continuous curvature splines (使用可調節張量連續不規則曲線的曲率對資料進行網格化)

velo - Plot velocity vectors, crosses, and wedges on maps (繪製GPS速度向量、主軸應變速率及旋轉率)

grdsample - Resample a grid onto a new lattice (對網格文件做重採樣)





- Reference for surface: Smith, W. H. F, and P. Wessel, 1990, Gridding with continuous curvature splines in tension, Geophysics, 55, 293-305.

gmt velo: -Se

Plot velocity vectors, crosses, and wedges on maps
C:/programs/gmt6/share/doc/html/supplements/geodesy/velo.html

*gmt velo [**table**] -Jparameters -Rregion **-S**format[scale][/args][+ffont] [**-A**parameters] [-B[p|s]parameters]*
[-Ccpt] [-Dscale] [-Efill] [-Gfill] [-H[scale]] [-I[intens] [-L[pen[+c[f|l]]]] [-N] [-U[stamp]] [-V[level]]]
[-W[pen][+c[f|l]]] [-Z[m|e|n|u][+e]] [-X[a|c|f|r][xshift]] [-Y[a|c|f|r][yshift]] [-di[+ccol]nodata] [-eregexp]
[-hheaders] [-iflags] [-pflags] [-qiflags] [-ttransp] [-:[i|o]] [--PAR=value]

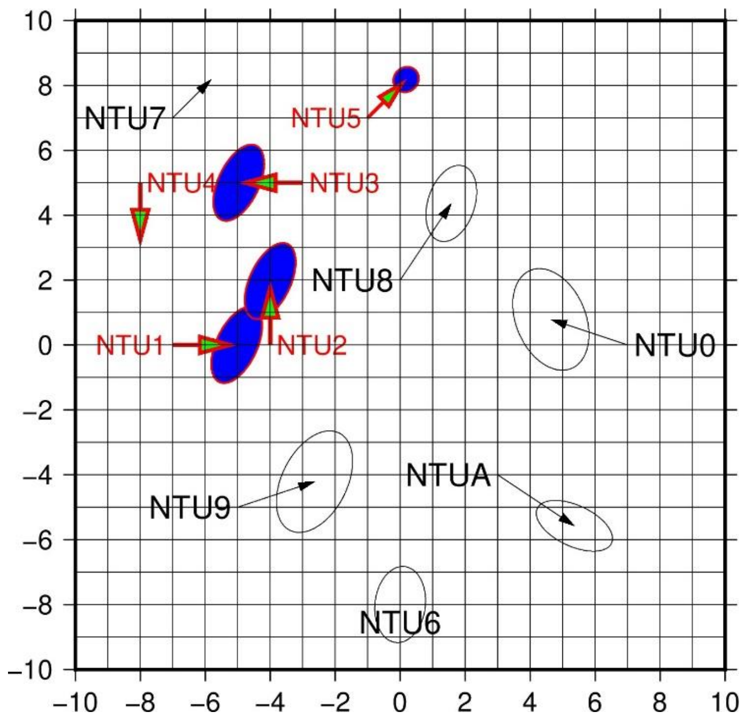
- Reads data values from files [or standard input] and will plot velocity arrows on a map. Most options are the same as for **plot**, except **–S**
- **-S:** Selects the meaning of the columns in the data file and the figure to be plotted (選項決定要繪製哪一種符號，及其輸入資料的格式)

-Se[*velscale*/]*confidence*[**+f***font*] : Velocity ellipses in (N,E) convention

velscale: sets the scaling of the velocity arrows. This scaling gives inches (unless c, i, or p is appended). (控制向量的縮放比例，預設單位由參數PROJ_LENGTH_UNIT 決定，也可以自己添加長度單位i、c、p)

confidence: sets the 2-dimensional confidence limit for the ellipse, e.g., 0.95 for 95% confidence ellipse (設置橢圓的2D信賴或置信區間的極限，比如0.95代表95%信賴區間)

fontsize: sets the size of the text in points



Open and run: Lect08A1.bat or Lect08A1.sh

```
REM Long. Lat. Evel Nvel Esig Nsig CorEN SITE
REM (deg) (deg) (mm/yr) (mm/yr)
echo -7. 0. 5.0 0.0 2.0 3.0 0.500 NTU1 > GPS1.gmt
echo -4. 0. 0.0 5.0 2.0 3.0 0.500 NTU2 >> GPS1.gmt
echo -3. 5. -5.0 0.0 2.0 3.0 0.500 NTU3 >> GPS1.gmt
echo -8. 5. 0.0 -5.0 0.0 0.0 0.500 NTU4 >> GPS1.gmt
echo -1. 7. 3.0 3.0 1.0 1.0 0.100 NTU5 >> GPS1.gmt
gmt velo GPS1.gmt -R-10/10/-10/10 -Wthin,red -Se0.2c/0.39+f12 -Ba2g1
-BWeSn -Jx0.2i -Ggreen -Eblue -L -N -A1c+p3p+e
```

Input file format:

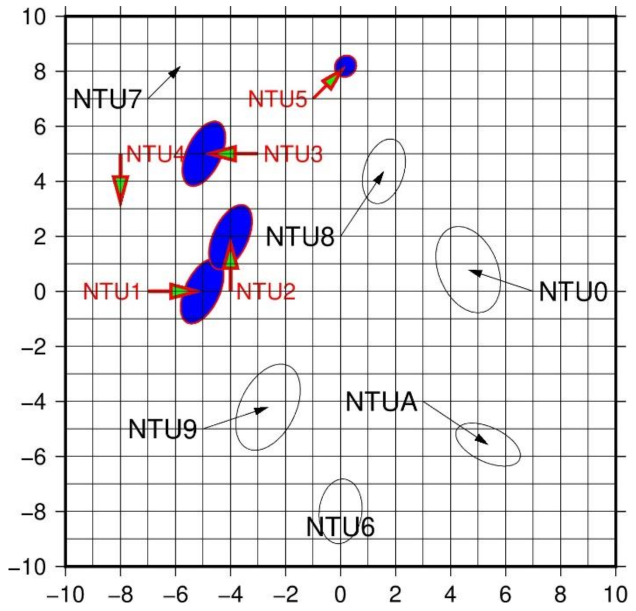
1, 2: longitude, latitude of station (測站經度及緯度)

3, 4 (Evel, Nvel): eastward, northward velocity (Nvel) (向量的東向分量及北向分量)

5, 6 (Esig, Nsig): uncertainty of eastward, northward velocities (1-sigma) (東向分量及北向分量的不確定度，一個標準差)

7 (corEN): correlation between eastward and northward components (東向分量和北向分量的相關性)

8 (site): name of station (optional)



gmt velo **GPS1.gmt** -R-10/10/-10/10 -Wthin,red **-S**e0.2c/0.39+f12 -Ba2g1 -BWeSn -Jx0.2i -Ggreen -Eblue -L -N **-A**1c+p3p+e

-W: Set pen attributes for velocity arrows, ellipse circumference and fault plane edges. [Defaults: width = default, color = black, style = solid] (設定速度向量箭頭、橢圓輪廓以及斷層面邊界的顏色)

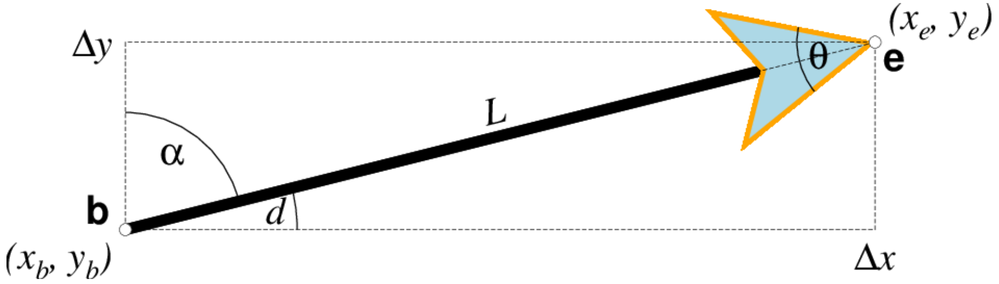
-G*fill*: Specify color (for symbols/polygons) or pattern (for polygons) [Default is black] (指定符號或多邊形的填色或填入樣式)

-E*fill*: Sets the color or shade used for filling uncertainty wedges (-Sw) or velocity error ellipses (-Se or -Sr). [If -E is not specified, the uncertainty regions will be transparent] (設定扇形不確定度[-Sw]或速度誤差橢圓[-Se, -Sr]的填色)

-L: Draw lines. Ellipses and fault planes will have their outlines drawn using current pen (see -W) (繪製線段。使用該選擇，則橢圓和斷層面會根據-W選項繪製輪廓)

-N: Do NOT skip symbols that fall outside the frame boundary specified by -R. [Default plots symbols inside frame only]

-A*parameters*: Modify vector parameters. For vector heads, append vector head size [Default is 9p]. See **Vector Attributes** for specifying additional attributes. [Defaults: width = default, color = black, style = solid] (修改向量的屬性，參考繪製向量屬性參數)



gmt velo **GPS2.gmt** **-S**e0.2c/0.39/14 **–A**0.25c+p0.25p+e

- All vectors require you to specify the begin point and the end point, or alternatively the direction d and length L, while for map projections we usually specify the azimuth instead.

- **Vector Attributes are controlled by options and modifiers**: Several ***modifiers*** may be appended to vector-producing options for specifying the placement of vector heads, their shapes, and the justification of the vector (向量用頭表示方向，一個向量由向量線和向量頭組成。向量線與一般的線沒有區別，由畫筆屬性控制)

+p[*pen*]: sets the vector pen attributes. If no pen is appended then the head outline is not drawn. [Default pen is half the width of stem pen, and head outline is drawn] (繪製向量頭的畫筆屬性，如果沒有附加筆，則不會繪製頭部輪廓，表示不繪製向量頭的輪廓)

+e: Places a vector head at the end of the vector path [none]. Optionally, append **t** for a terminal line, **c** for a circle, **a** for arrow [Default], **i** for tail, **A** for plain open arrow, and **I** for plain open tail. Further append l|r to only draw the left or right half-sides of this head [both sides] (在向量線的終點加上向量頭)

Please try:
(1) -**S**e0.4c/0.95/10, (2) **–A1**c+p1.5p+eA, (3) Combination of +e with t, c, a, i, I and r.

gmt velo: -Sr

*gmt velo [**table**] -Jparameters -Rregion **-S**format[scale][/args][+ffont] [**-A**parameters] [-B[p|s]parameters]
[-Ccpt] [-Dscale] [-Efill] [-Gfill] [-H[scale]] [-I[intens] [-L[pen[+c[f|l]]]] [-N] [-U[stamp]] [-V[level]]]
[-W[pen][+c[f|l]]] [-Z[m|e|n|u][+e]] [-X[a|c|f|r][xshift]] [-Y[a|c|f|r][yshift]] [-di[+ccol]nodata] [-eregexp]
[-hheaders] [-iflags] [-pflags] [-qiflags] [-ttransp] [-:[i|o]] [--PAR=value]*

-Sr[velscale/]confidence[+ffont]: Velocity ellipses in rotated convention

Parameters are expected to be in the following columns:

1,2 longitude, latitude, of station

3,4 eastward, northward velocity

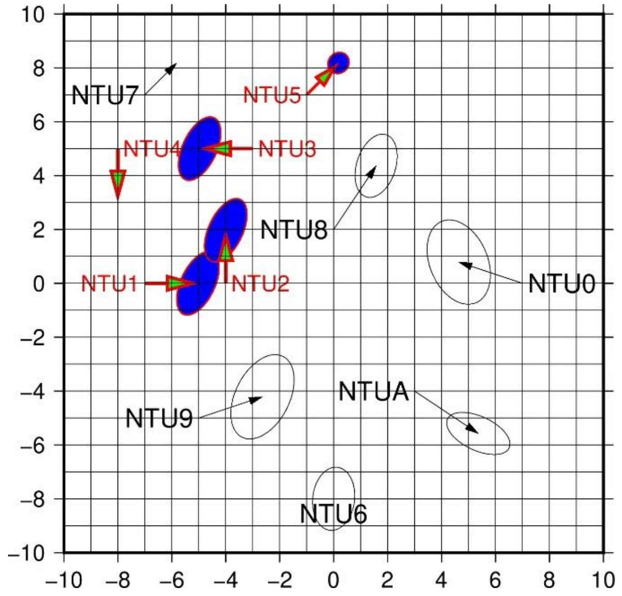
5,6 semi-major, semi-minor axes（橢圓的半長軸和橢圓的半短軸）

7 counter-clockwise angle, in degrees, from horizontal axis to major axis of ellipse（橢圓的長軸相對于水平方向逆時針旋轉的角度）

8 Trailing text: name of station (optional)

Standard Input file

127.366	36.374	19.8	-10.9	2.6	1.8	172.6	TAEJ
140.087	36.106	-41.5	8.6	2.6	1.6	175.1	TSKB
109.221	34.369	10.1	2.4	3.6	3.2	179.1	XIAN
121.200	31.100	20.7	-8.5	2.6	1.8	173.7	SHAO
114.357	30.532	26.7	-13.2	2.8	2.0	173.6	WUHN



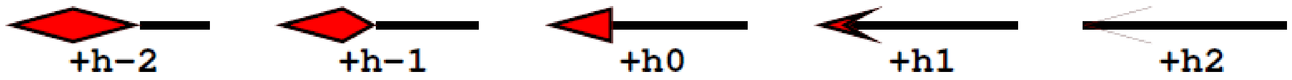
gmt velo GPS2.gmt -Se0.2c/0.39/14 –A0.25c+p0.25p+e

+a*angle*: Sets the angle of the vector head apex [30]. [(控制向量箭頭的頂端的夾角，預設值為30度。若向量頭形狀為t或c 則表示端點線或端點圓圈的大小)

+b[t|c|a|A|i|I][l|r]: Places a vector head at the beginning of the vector path [none]. Further append l|r to only draw the left or right half-sides of this head [both sides]. (在向量線的起點加上向量頭)

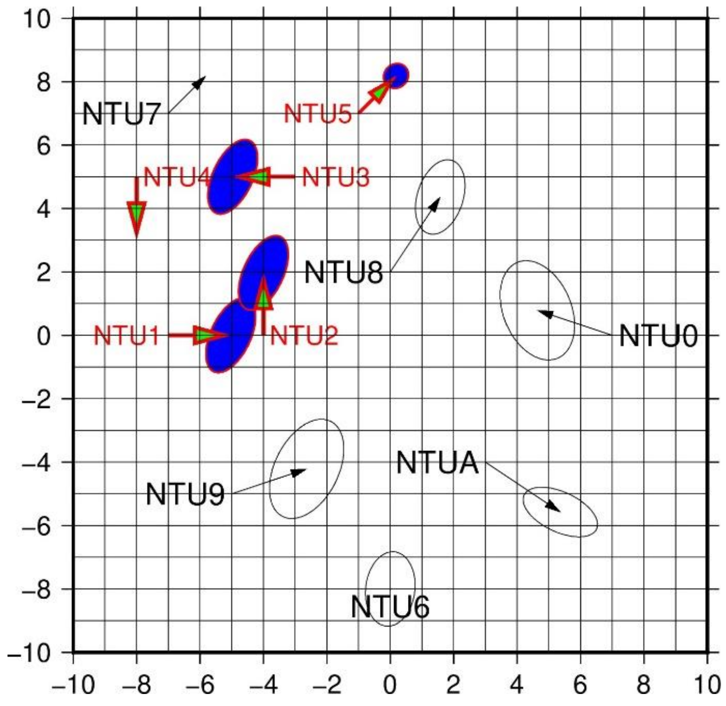
+g-|*fill*: turns off vector head fill (if -) or sets the vector head fill [Default fill is used, which may be no fill] (設置向量頭的填色，fill為-，表示不填色)

+h*shape*: Sets the shape of the vector head (range -2/2). Default is controlled by MAP_VECTOR_SHAPE [0] (控制向量頭的形狀，shape 可取-2 到2 之間的值。設置該子選項的值等效於修改參數MAP_VECTOR_SHAPE，預設值為0）



+l: Draws half-arrows, using only the left side of specified heads [both sides] (只控制繪製左半個向量頭）

+r: Draws half-arrows, using only the right side of specified heads [both sides] ((只控制繪製右半個向量頭）



gmt velo GPS2.gmt -Se0.2c/0.39/14 –A0.25c+p0.25p+e

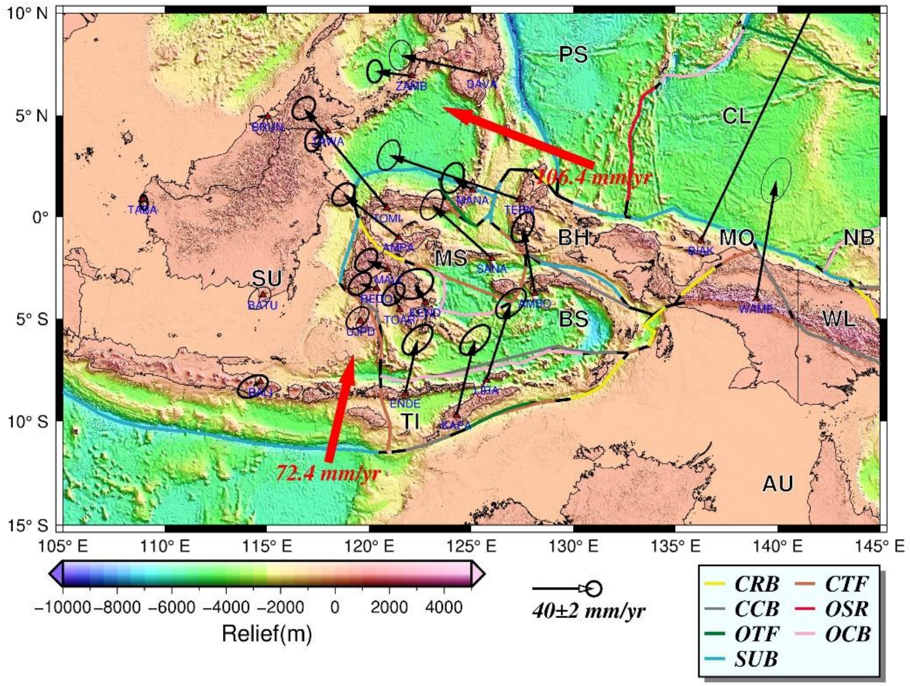
+m[f|r|t|c|a][l|r]: Places a vector head at the mid-point the vector path [none]. Append f or r for forward or reverse direction of the vector [forward] (在向量線的中間加上向量頭)

+j*just*: determines how the input x,y point relates to the vector. Choose from beginning [default], end, or center

+n*norm*: Scales down vector attributes (pen thickness, head size) with decreasing length, where vector plot lengths shorter than norm will have their attributes scaled by length/norm [arrow attributes remains invariant to length]. For Cartesian vectors specify a length in plot units, while for geovectors specify a length in km.該子選項使得向量長度小於norm 時，向量頭的屬性會根據向量長度按照length/norm 縮放。預設下向量頭的大小不隨向量線的長度變化而變化)

+t[b|e]*trim*[unit] : Shift the beginning or end point (or both) along the vector segment by the given trim. If the modifiers b|e are not used then trim may be two values separated by a slash, which is used to specify different trims for the beginning and end. Positive trims will shorted the vector while negative trims will lengthen it [no trim] (增長或縮短向量線首端或尾端的長度，*trim*為正值表示縮短向量線，為負值表示增長向量線)

Open and run: Lect08A2.bat or Lect08A2.sh



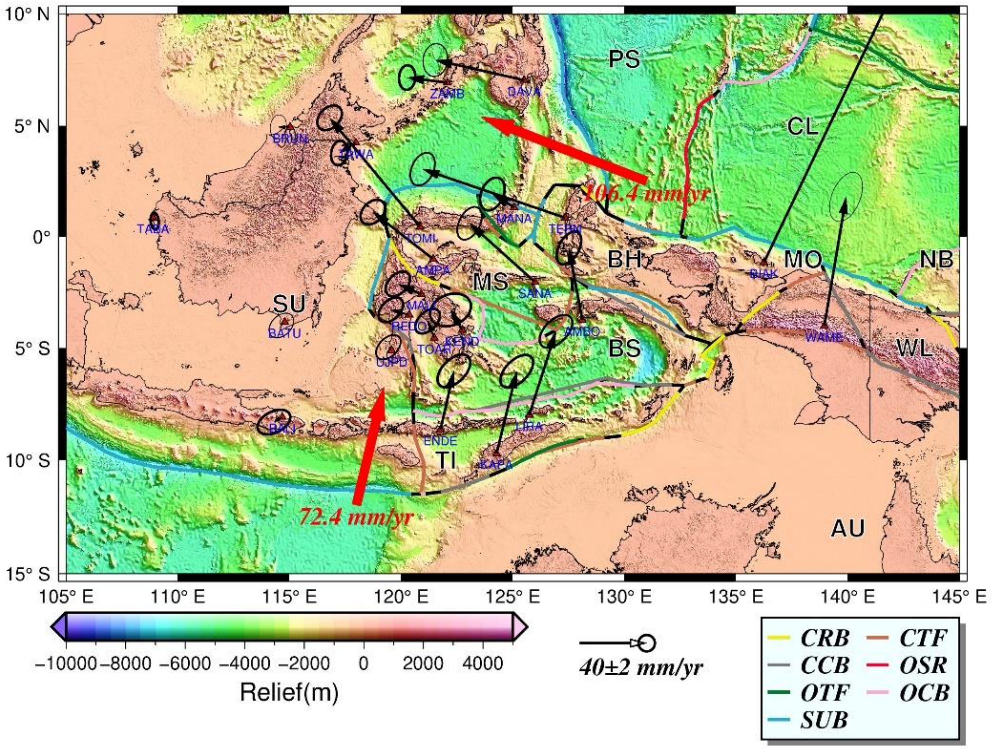

```
gmt plot PB2002_steps.dat_CRB.txt -W2p,239/239/8 -l"CRB"+N2
gmt plot PB2002_steps.dat_CTF.txt -W2p,206/107/74 -l"CTF"
gmt plot PB2002_steps.dat_CCB.txt -W2p,123/123/123  -l"CCB"
 gmt plot PB2002_steps.dat_OSR.txt -W2p,255/0/49 -l"OSR"
gmt plot PB2002_steps.dat_OTF.txt -W2p,0/123/49 -l"OTF"
gmt plot PB2002_steps.dat_OCB.txt -W2p,255/173/214  -l"OCB"
gmt plot PB2002_steps.dat_SUB.txt -W2p,41/173/206 -l"SUB"
```

```
gmt legend -Dg145.0/-15.0+w4.5c+o0.0c/1.0c+jTR -F+p1p+gazure+s --FONT_ANNOT_PRIMARY=16p,7
```

- **-l***[label][modifiers]*: Add a legend entry for the symbol or line being plotted.（繪製的符號或線條添加圖例記錄）

+Ncols(+n for GMT 6.0.0): Change the number of columns used to set the following legend items

- **-F**[+cclearanc (es][+gfill][+i[[gap/]pen]][+p[pen]][+r[radius]][+s[[dx/dy/][shade]]]: Without further options, draws a rectangular border around the legend (設定圖例框的背景屬性）



gmt plot GPS_AndreaWalpersdorf_Table1.txt -St0.2c -Gred -W0.5,0 -V

gmt velo GPS_AndreaWalpersdorf_Table1.txt -Se0.015/0.95+f0 -A0.15i+a30+e -W1.5,black -Gblack -V

gawk "{ print $1, $2, $8 }" GPS_AndreaWalpersdorf_Table1.txt | gmt text -F+f8p,0,blue -D0/-0.1 –V

echo 118.000 -12.000 16.5 70.5 0 0 0.7557 1 | gmt velo -Se0.015/0.95+f0 -A0.3i+a30+e -W6p,red -Gred -V

echo 118.000 -12.000 72.4 mm/yr | gmt text -F+f16p,7,red+jMC -D0.0/-0.1 -V

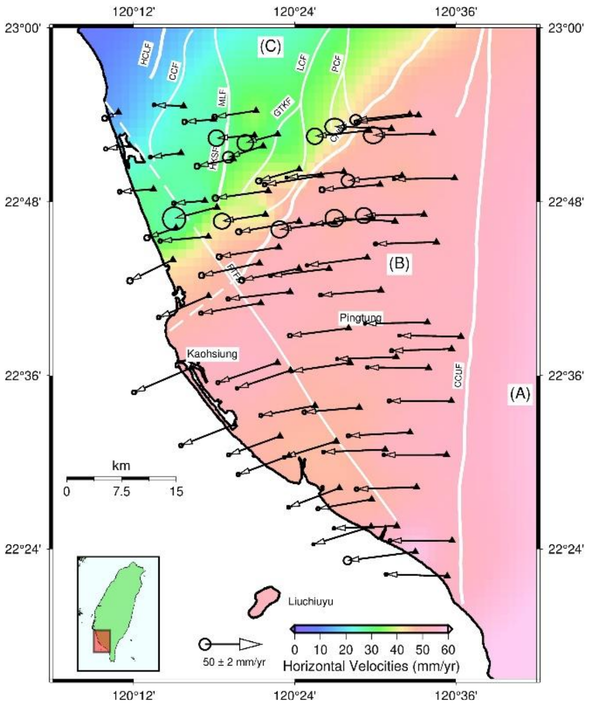
Input file format:

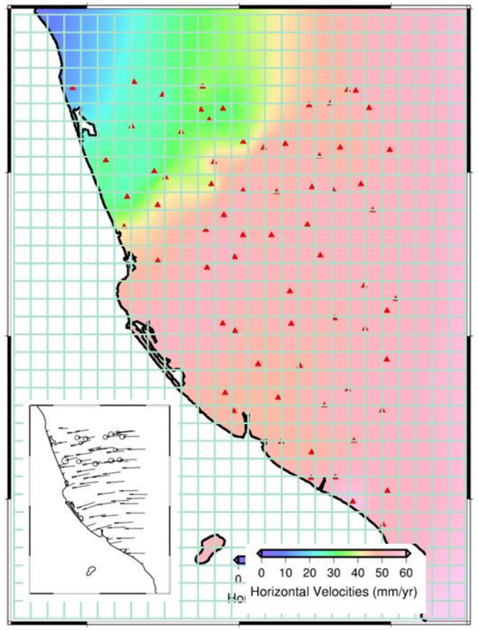
GPS_AndreaWalpersdorf_Table1.txt

```
128.1169 -3.7500  -8  43 3 4 0.46   AMBO
121.4362 -1.0032 -36  28 3 3 0.34   AMPA
114.6800 -8.0936  -5  -3 4 3 0.40   BALI
```

-F[+a[angle]][+c[justify]][+f[font]][+h][+j[justify]]+l|+r[first] |+ttext|+z[format]]

- Text is placed horizontally, using the primary annotation font attributes (FONT_ANNOT_PRIMARY), and centered on the data point.





Open and run: Lect08B1.bat or Lect08B1.sh

```
REM create gridfile of hori. velo.
gawk "{print $1,$2,sqrt($3*$3+$4*$4)}" velh.gmt | gmt surface -
R120.1/120.7/22.25/23.0 -Gvelh.grd -I0.01 -T0.25 -C0.1 -V
gmt grdinfo velh.grd > velh.info
```

Please open **velh.gmt**

Long.	Lat.	Ve(mm/yr)	Vn(mm/yr)	stdVe	stdVn	CorNE	Site
120.1811	22.9031	-11.85	-5.34	0.92	0.94	0	G149
120.1950	22.8647	-20.69	-2.95	0.65	0.65	0	G151
120.2246	22.8146	-29.23	-2.35	0.64	0.68	0	G153
120.2487	22.7334	-37.29	-18.33	1.02	1.02	0	G156
120.2527	22.7701	-25.19	-8.64	1.01	0.99	0	I042
120.2588	22.8562	-26.65	-3.65	0.51	0.51	0	G152

Please open velh.info and check dimensional size

```
velh.grd: x_min: 120.1 x_max: 120.7 x_inc: 0.00111111111111 name: x
n_columns: 541
velh.grd: y_min: 22.25 y_max: 23 y_inc: 0.00111111111111 name: y n_rows: 676
```

gmt surface

- **surface** reads randomly-spaced (*x, y, z*) triplets from standard input [or *table*] and produces a binary file of gridded values *z*(*x, y*) by solving the differential equation (away from data points)

$$(1-t)\nabla^2(z) + t\nabla(z) = 0,$$

- where ***t*** is a tension factor between 0 and 1, and ∇ indicates the 2-D Cartesian Laplacian operator. (從標準輸入或ASCII格式的檔 中讀取離散的數據點(x, y, z)，通過解微分方程，得到網格化的數據 z(x, y) 並生成網格檔。其中t 是0到1之間的張量因數，∇ 是拉普拉斯算子)

- Here, ***t* = 0** gives the "minimum curvature" solution. Minimum curvature can cause undesired oscillations and false local maxima or minima [See *Smith and Wessel*, 1990] (

- Nota bene: There must be at least 4 points in each dimension, otherwise **surface** cannot be used (在每個維度上至少必須有4個點，否則無法使用 **surface**)。
- If your data is equally spaced (x, y, z) data, please do not use **surface** to generate grid files. The correct approach is to use **xyz2grd** to generate the grid file (如果你的數據是等間隔的 (x, y, z) 數據，請不要使用 surface 生成網格檔。正確的做法是使用xyz2grd生成網格檔)

*gmt surface [**table**] **-G**outputfile.nc **-I**increment **-R**region [-Aaspect_ratio|m] [**-C**convergence_limit[%]] [-Jparameters] [-Dbreakline_file[+z[level]]] [-Lllower] [-Luupper] [-Mmax_radius] [-Nmax_iterations] [-Q[r]] [-Ssearch_radius[m|s]] [**-T**[i|b]tension_factor] [-V[level]] [-W[logfile]] [-Zover-relaxation_factor] [-aflags] [-bibinary] [-dinodata[+ccol]] [-eregexp] [-fflags] [-hheaders] [-iflags] [-qiflags] [-rreg] [-wflags] [-:[i|o]] [--PAR=value]*

```
gawk "{print $1,$2,sqrt($3*$3+$4*$4)}" velh.gmt | gmt surface -Rswshad.grd -Gvelh.grd  -T0.25 -C0.1
```

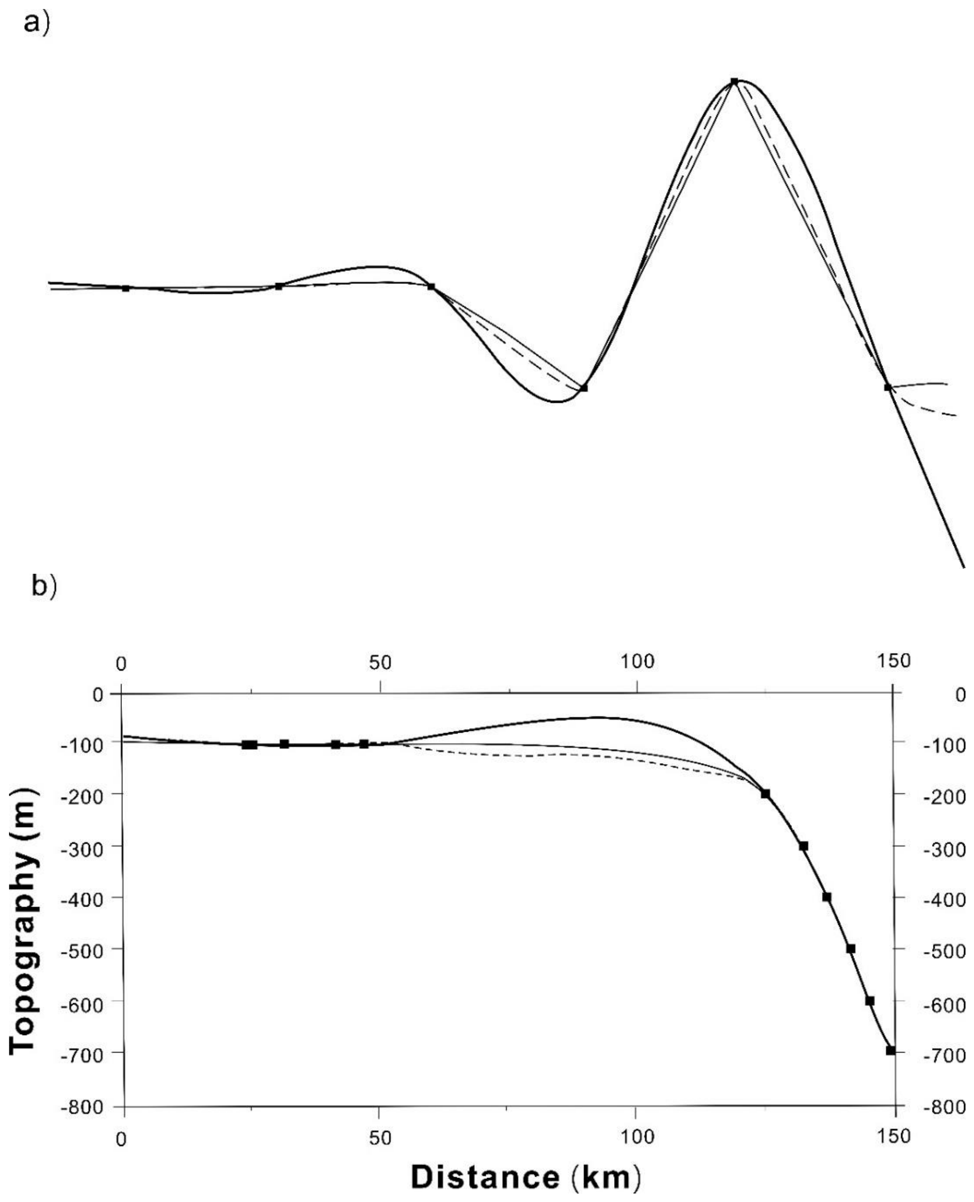
−C*convergence_limit[%]*: Iteration is assumed to have converged when the maximum absolute change in any grid value is less than *convergence_limit*. (Units same as data z units). Alternatively, give limit in percentage of rms deviation by appending %. Default is scaled to $1e^{-4}$ of the root-mean-square deviation of the data from a best-fit (least-squares) plane.

-T[i|b]*tension_factor*: These must be between 0 and 1. Default = 0 for both gives minimum curvature solution. Experience suggests:

1. T ~ 0.25 usually looks good for potential field data
2. T should be larger (T ~ 0.35) for steep topography data.
3. T = 1 gives a harmonic surface (no maxima or minima are possible except at control data points).

- It is recommended that the user pre-process the data with blockmean, blockmedian, or blockmode to avoid spatial aliasing (空間混疊) & eliminate redundant data. (See Lecture 09)

Gridding with continuous curvature splines in tension



(a) Cross-sections through surfaces produced with splines in tension.

Black squares: data constraints Heavy line: minimum-curvature end member

Thin line: harmonic end member

Dashed line: intermediate case using some tension.

(b) Cross-section through a continental shelf and slope.

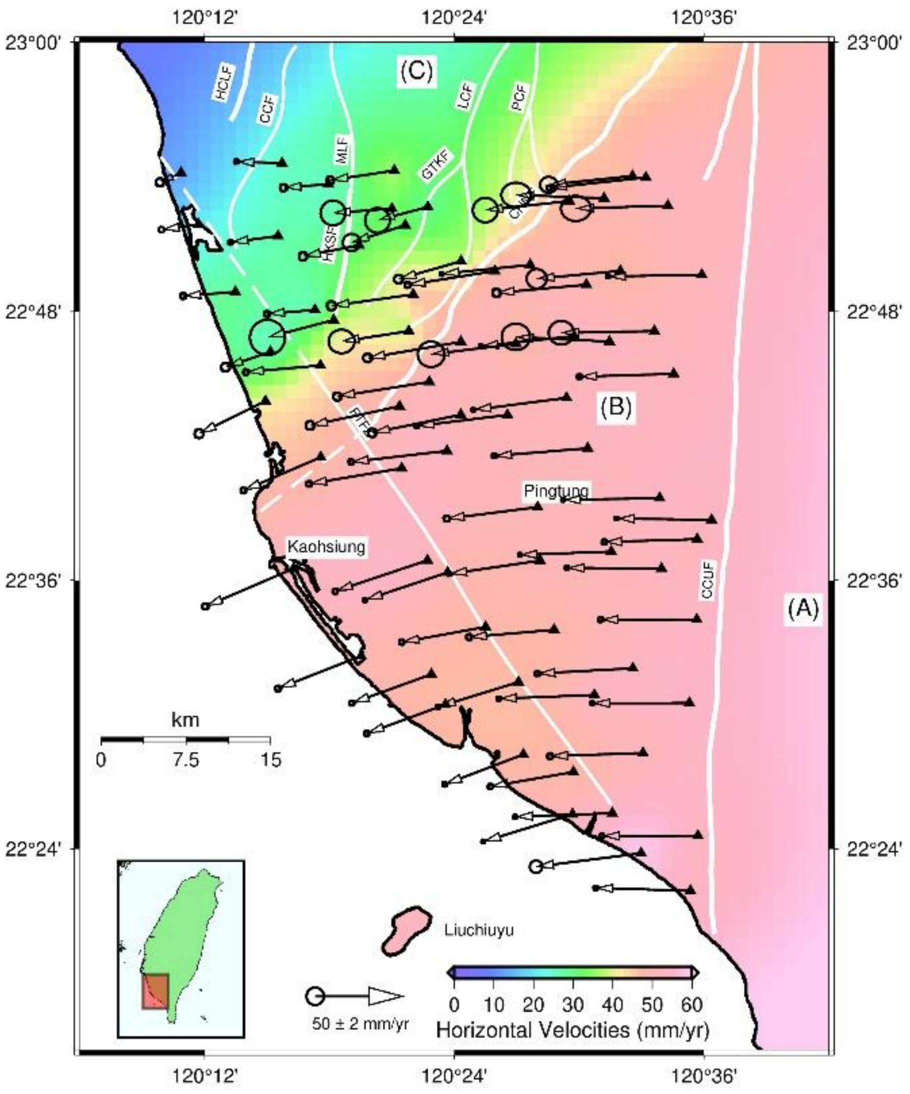
Black squares: intersection between the measured bathymetry (dashed line) and 100 m isobath contours.

Heavy line: intersections (contour coordinates) were gridded

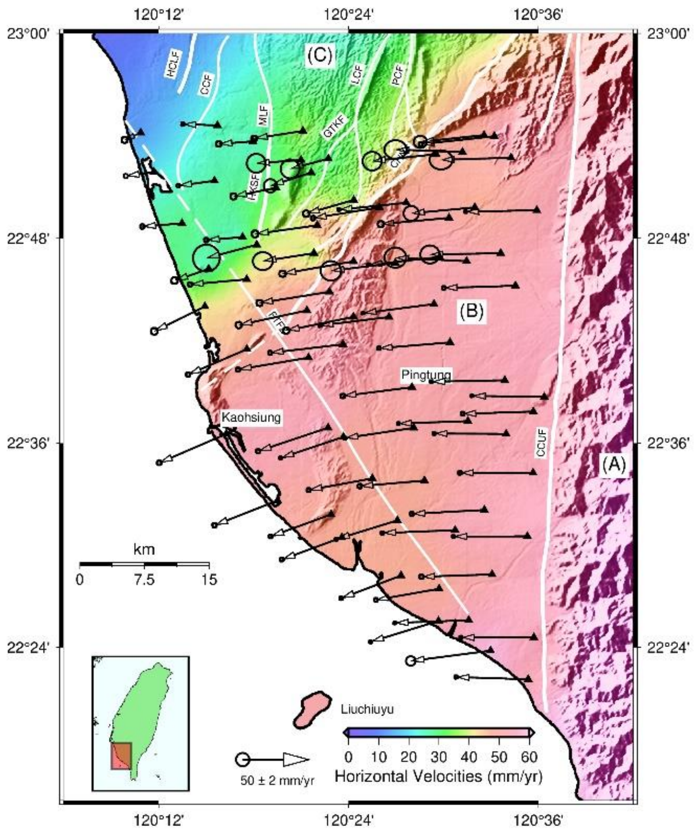
using minimum curvature

Thin line: intersections (contour coordinates) were gridded using some tension

Open and run: Lect08B1.bat or Lect08B1.sh




```
gmt velo velh.gmt -Se.015/0.95+f0 -A0.15i+a30+e -W1.5p,black -h1 -V
REM draw gps station
gmt plot velh.gmt -St.06 -W2p,0/0/0 -G255 -h1 –V
gmt inset begin -DjBL+w1.5i/1.5i+o0.1i/0.1i -M0.002i
gmt coast -W0.25p,0 -JM? -R119.5/122.5/21.6/25.5 -Glightgreen -Sazure -Btblr --MAP_FRAME_TYPE=plain -V
echo 120.10 23.00 > temp
echo 120.10 22.25 >> temp
echo 120.70 22.25 >> temp
echo 120.70 23.00 >> temp
gmt plot temp -W1.5p,0 -Gred -t50 -V
gmt inset end
```



REM create gridfile of hori. velo.
gawk "{print $1,$2,sqrt($3*$3+$4*$4)}" **velh.gmt** | gmt surface -R120.1/120.7/22.25/23.0 -Gvelh.grd -I0.001 -T0.25 -C0.1 –V
gmt grdsample **velh.grd** **-G**temp.nc **-R**swshad.grd -V
gmt grdinfo **temp.nc** > temp.nc.info
gmt grdinfo **swshad.grd** > swshad.grd.info
gmt begin %prefix% jpg A+m0.5c
REM create basemap
gmt grdimage **temp.nc** -Cvelh.cpt **-I**swshad.grd -Ba0.2f0.2 -BWESN -R120.1/120.7/22.25/23.0 -Jm121.0/10.5i -V

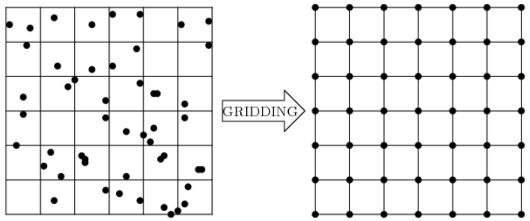
temp.nc: x_min: 120.1 x_max: 120.7 x_inc: 0.00111111111111 name: x n_columns: 541
temp.nc: y_min: 22.25 y_max: 23 y_inc: 0.00111111111111 name: y n_rows: 676

swshad.grd: x_min: 120.1 x_max: 120.7 x_inc: 0.00111111111111 name: x n_columns: 541
swshad.grd: y_min: 22.25 y_max: 23 y_inc: 0.00111111111111 name: y n_rows: 676

Q: Why –Iswshad.grd?

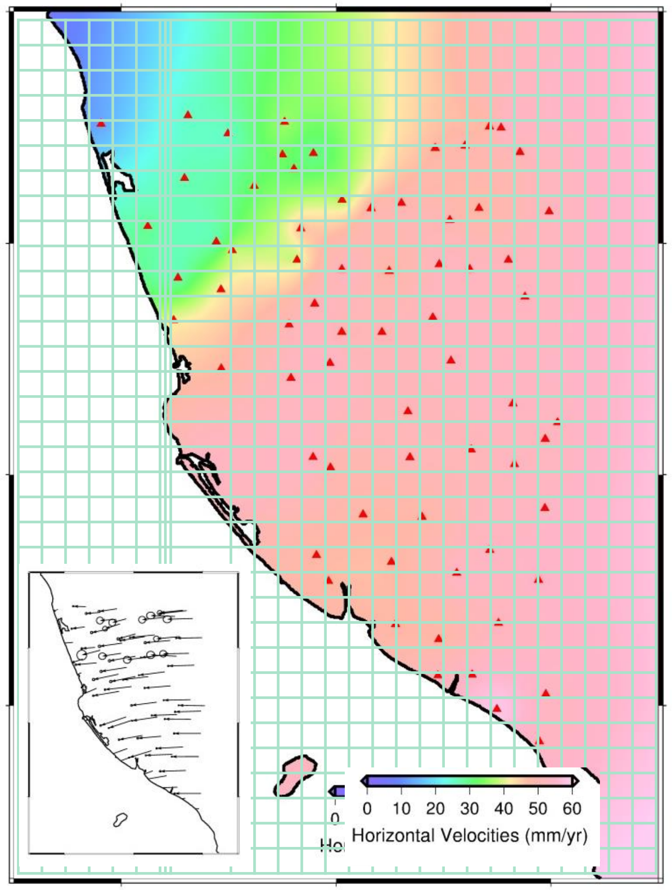
Please open temp.nc.info and swshad.grd.info: check dimensional size

Gridding data

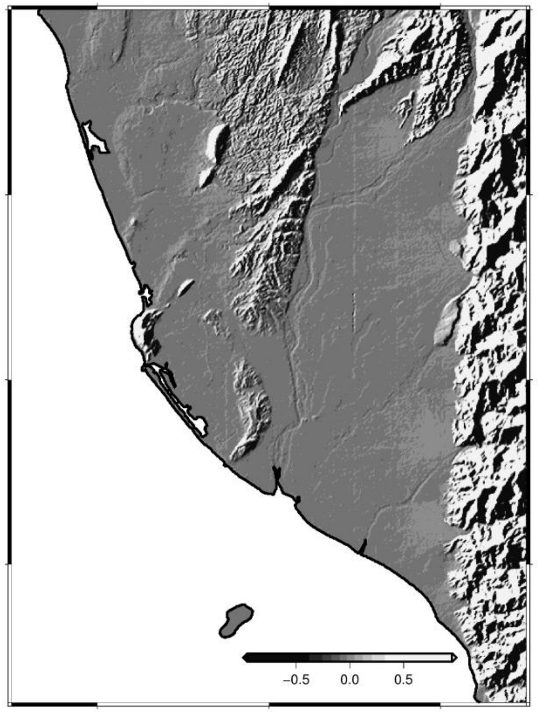


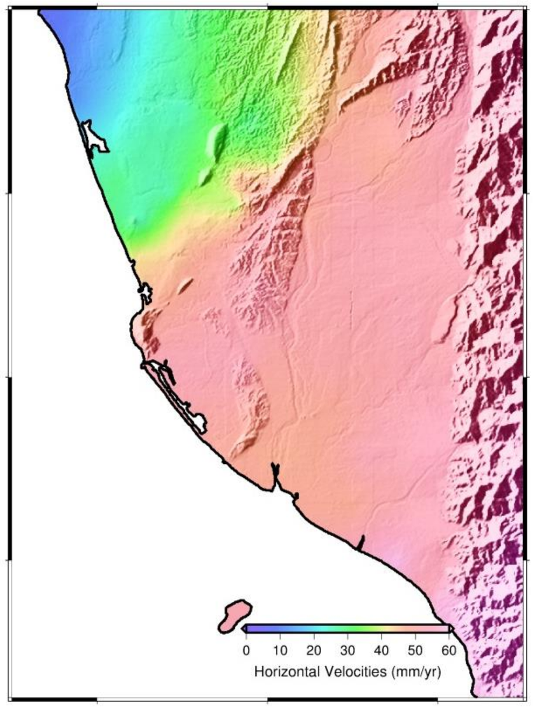

```
gmt grdgradient sw.grd -Nt1 -A300
  -Gswshad.grd
gawk "{print $1,$2,sqrt($3*$3+$4*$4)}" velh.gmt | gmt surface
-R120.1/120.7/22.25/23.0 -Gvelh.grd -I0.001 -T0.25 -C0.1 –V
gmt grdsample velh.grd -Gtemp.nc -Rswshad.grd -V
gmt grdimage temp.nc -Cvelh.cpt -Iswshad.grd -Ba0.2f0.2 -
BWESN -R120.1/120.7/22.25/23.0 -Jm121.0/10.5i -V
```

Velh.gmt →temp.nc (541 x 676)



swshad.grd(541 x 676)





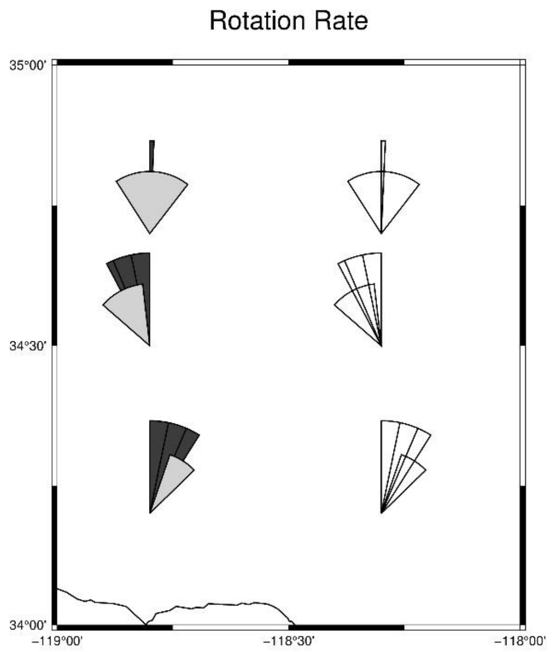
grdsample

Resample a grid onto a new lattice

*gmt grdsample **in_grdfile -G**out_grdfile [**-I**increment] [-Rregion] [-T] [-V[level]]*
[-fflags] [-nflags] [-rreg] [-x[[-]n]] [--PAR=value]

gmt grdsample **velh.grd -G**temp.nc **-R**swshad.grd -V

- Reads a grid file and interpolates it to create a new grid file with either: a different registration (-r or -T); or, a new grid-spacing or number of nodes (-I), and perhaps also a new sub-region (-R) (讀取一個網格檔，並對其做插值以生成一個新的網格檔。新舊網格檔可能的區別在於：不同的配準方式(-r或-T)；不同的網格間隔或網格節點數(-I)或不同的網格範圍(-R))
- A bicubic [Default], bilinear, B-spline or nearest-neighbor interpolation is used; see -n for settings (網格檔插值方式有多重，預設使用bicubic 插值，可以使用-n 選項設置其它插值方式)
- grdsample safely creates a fine mesh from a coarse one; the converse may suffer aliasing unless the data are filtered using grdfft or grdfilter（該模組可以安全地將粗網格插值為細網格；反之，將細網格插值為粗網格時，則可能存在混疊效應，因而需要在插值前使用grdfft 或grdfilter對網格檔做濾波）



Open and run: Lect08C1.bat or Lect08C1.sh

```
gmt begin rotationrate jpg A+m0.5c
REM lon lat rotation rate (rad/yr) rotationR_sigma (rad/yr)
echo 241.2 34.2 5.65E-08 1.17E-08 > rotationR1.gmt
echo 241.2 34.5 -4.85E-08 1.85E-08 >> rotationR1.gmt
echo 241.2 34.7 4.46E-09 3.07E-08 >> rotationR1.gmtt
gmt velo rotationR1.gmt -JM15c -R241/242/34/35 -Ba0.5f0.25 -
BWeSn+t"Rotation Rate" -Sw3c/1.e7 -W1p -G60 -E210 -D2
```

Input file format for rotation wedge: -Sw

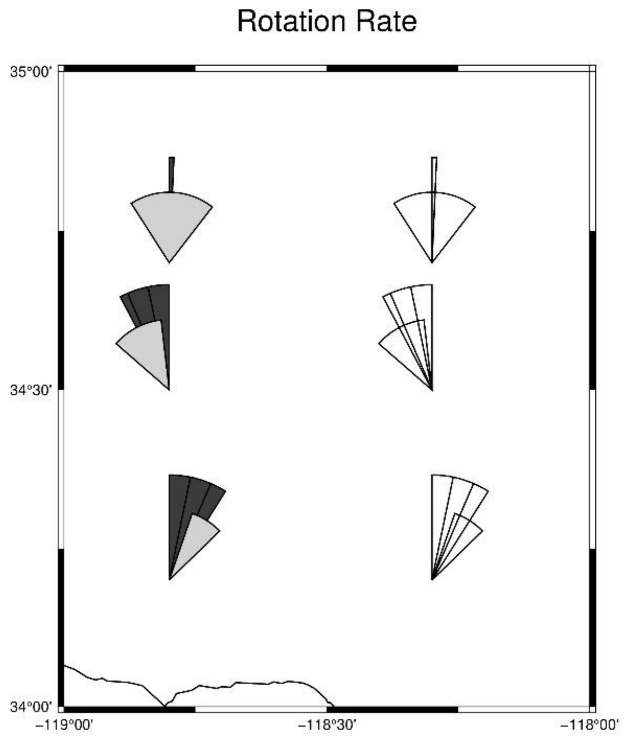
1, 2: longitude, latitude, of station (測站經度及緯度)

3: rotation in radians (旋轉扇形圖的旋轉角度，弧度為單位)

4: rotation uncertainty in radians (旋轉扇形圖的旋轉角度的不確定度，弧度為單位)

−Sw*wedgescale*/*wedgemag*: Rotational wedges. *wedgescale* sets the size of the wedges in inches (unless c, i, or p is appended). Values are multiplied by **wedgemag** before plotting (旋轉扇形，扇形大小由*wedgescale*單位決定，也可以自己添加長度單位i、c、p 。在繪圖之前，數值要先乘上*wedgemag*)

- For example, setting wedgemag to 1.e7 works well for rotations of the order of 100 nanoradians/yr (Q: How to set wedgemag? Why 1.e7?)




```
gmt velo rotationR1.gmt -JM15c -R241/242/34/35 -Ba0.5f0.25 -BWeSn+t"Rotation Rate" -Sw3c/1.e7 -W1p -G60 -E210 -D2
.....
gmt velo rotationR2.gmt -Sw3c/1.e7 -W1p -D2
```

-E*fill*: Sets the color or shade used for filling uncertainty wedges (-Sw) or velocity error ellipses (-Se or -Sr).

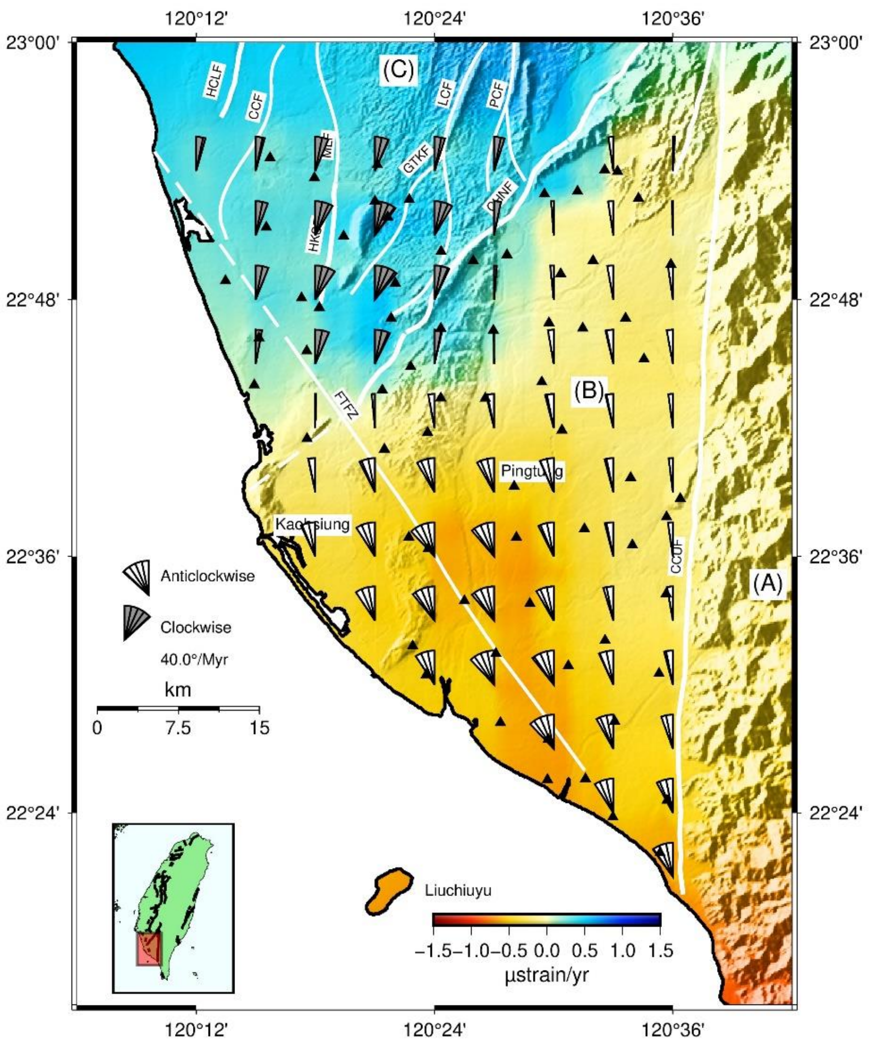
[If -E is not specified, the uncertainty regions will be transparent] (設定扇形不確定度[-Sw]或速度誤差橢圓[-Se, -Sr]的填色)

-G*fill*: Specify color (for symbols/polygons) or pattern (for polygons) [Default is black] (指定符號或多邊形的填色或填入樣式)

-D*Sigma_scale*: Used to **rescale** the uncertainties of velocities (-Se and -Sr) and rotations (-Sw). Can be combined with the confidence variable (調整-Se 和-Sr中速度不確定度以及-Sw中旋轉不確定度的縮放比例。此參數可與置信區間confidence一起控制不確定度的繪製)

Please try:
(1) **-S**w3c/1.e7 -W1p -G60 -E210 **-D1**
(2) **-S**w3c/1.e7 -W1p **-D0.5**

Open and run: Lect08C2.bat or Lect08C2.sh




```
gawk "{print $1,$2,$3}" rot.gmt | gmt surface -R%range%
-Grot.grd -I0.001 -T0.25 -C0.1

gmt grdsample rot.grd -Gtemp.nc -Rswshad.grd

gmt grdimage temp.nc -Crot.cpt –Iswshad.grd -
R%range% -Jm121.0/10.5i -Ba0.2f0.2 -BWESN

…..

velo rot_p.gmt   -Sw.3/1.2e6 -W1p,0/0/0 -G150
velo rot_n.gmt   -Sw.3/1.2e6 -W1p,0/0/0 -Gwhite
```

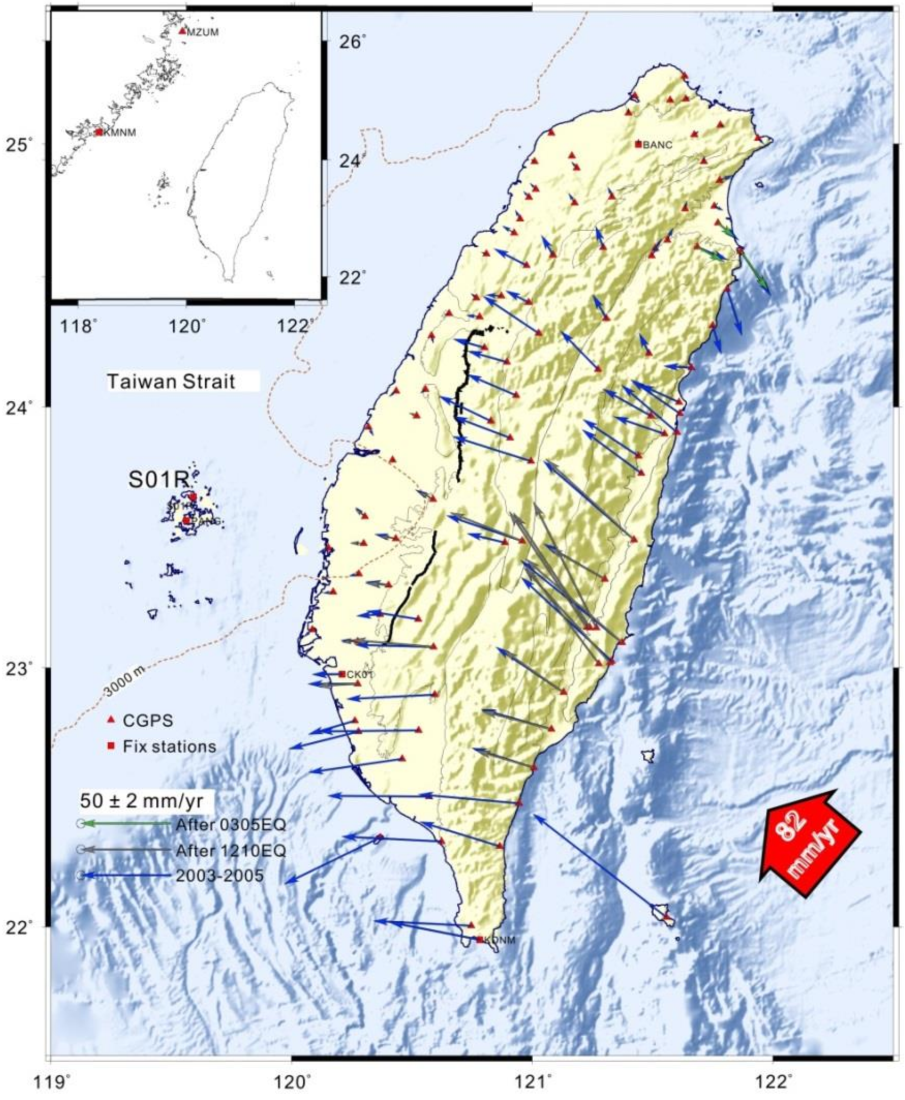
rot_p.gmt

120.2000	22.9000	0.233E-06
120.2500	22.7500	0.155E-06
120.2500	22.8500	0.300E-06

rot_n.gmt

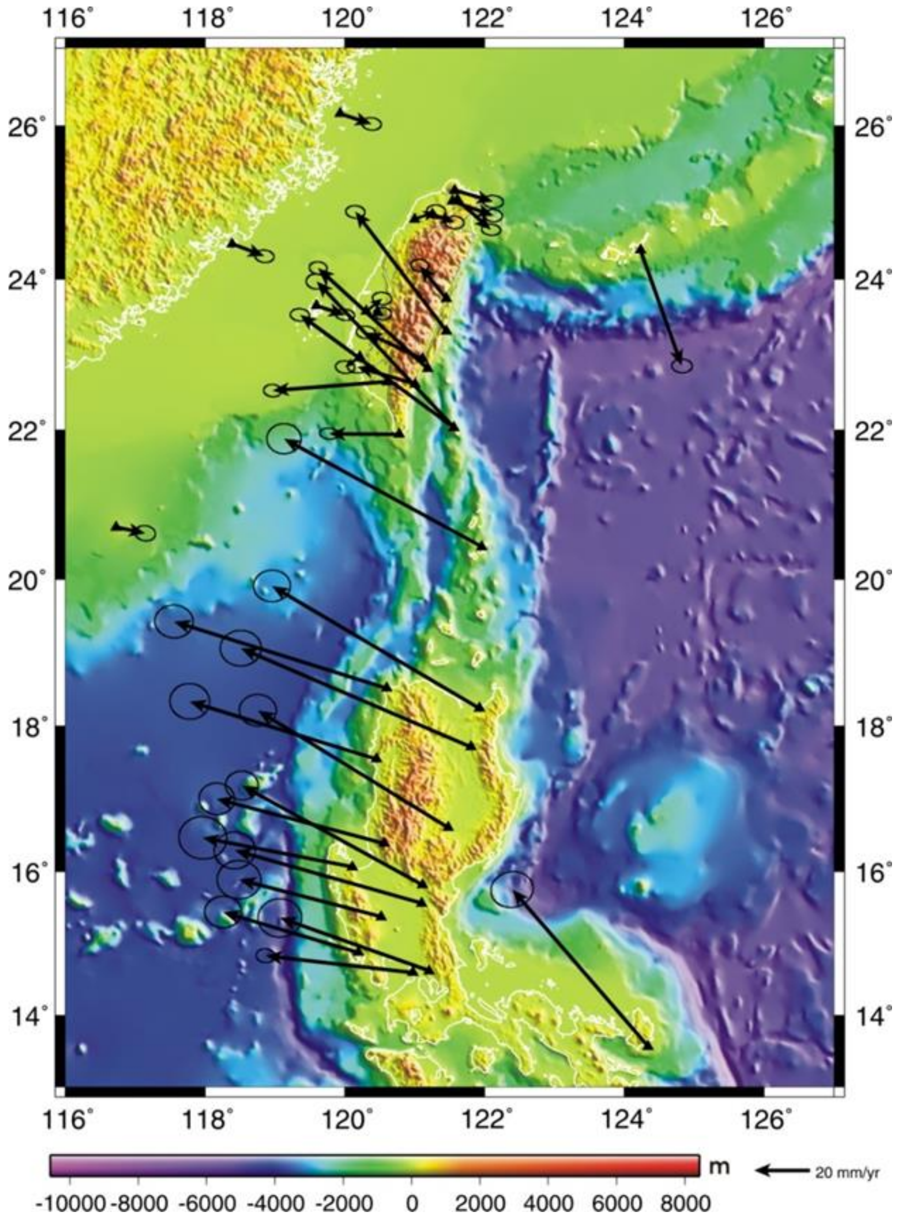
120.3000	22.6500	-0.177E-06
120.3000	22.6000	-0.367E-06
120.3500	22.7000	-0.779E-07

Exercise 08C



- Using velo (-Se or –Sr?) to draw GPS velocity field in Taiwan with continuous GPS data around Taiwan published by Lin et al., in JGR, 2010 (see PDF)
- Use ASTER GDEM as a basemap (lecture 05)
- With active faults of GSMMA (Geological Survey and Mining Management Agency) (version of 2010) in Lecture 05
- Suggestion: First draw velocity field without topography, if it's fully successful, then put it with relief and active faults

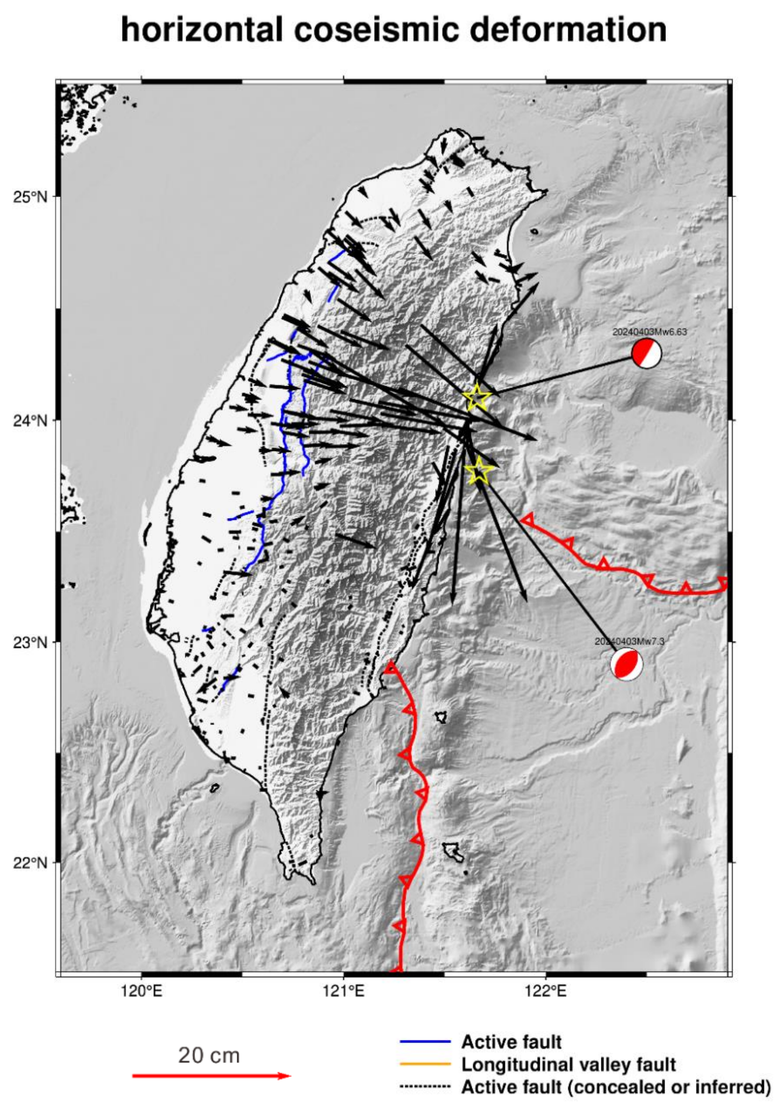
Exercise 08b

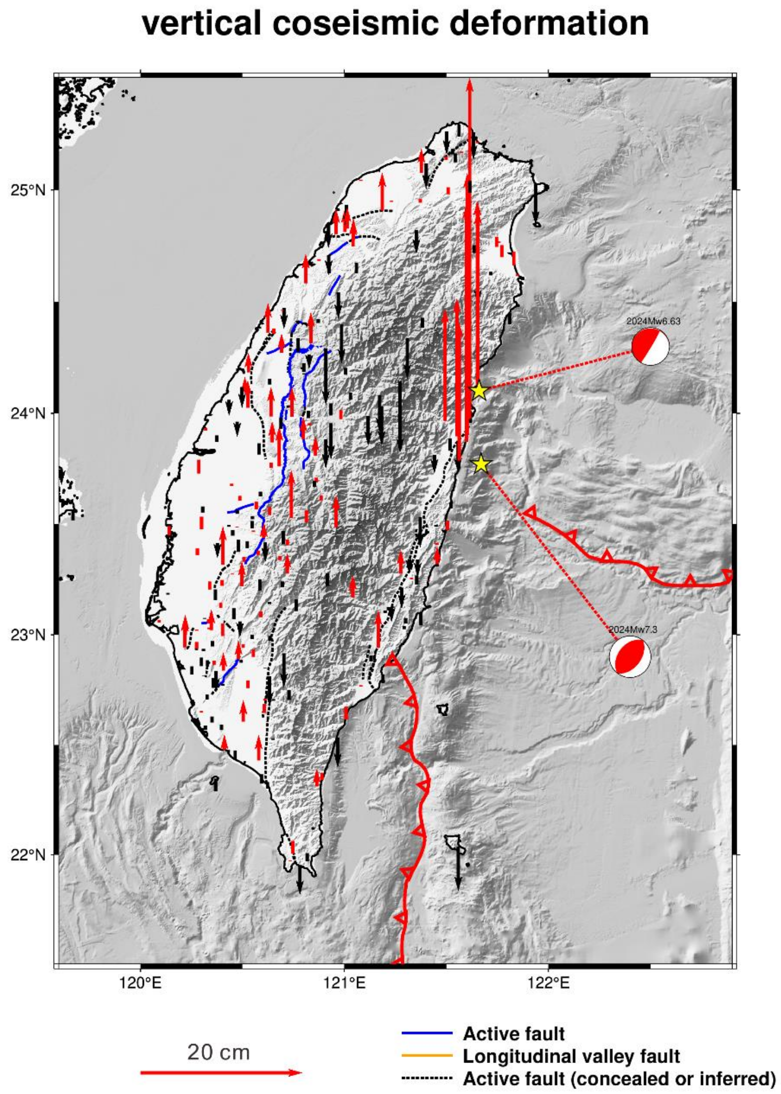


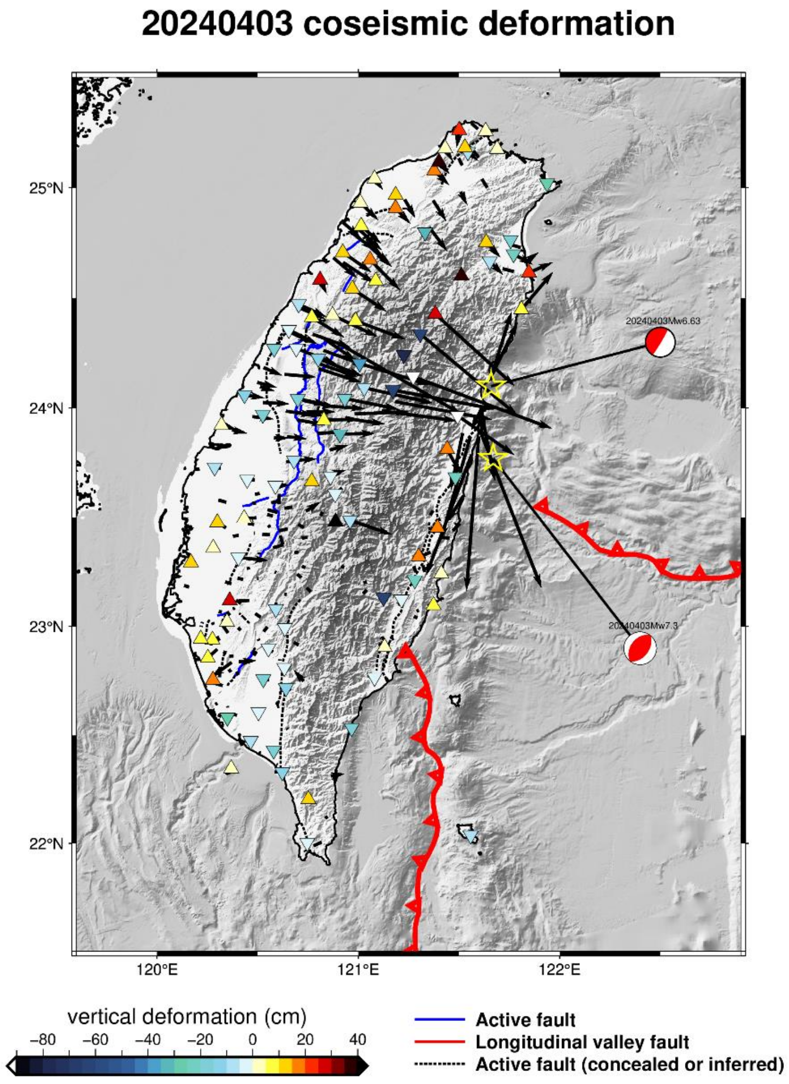
- Using velo (-Se or –Sr?) to draw GPS velocity field from Taiwan to Philippines with GPS data published by Yu et al., GRL, 1999 (see PDF)
- Use grdcut to cut the region from global 15 arc-second bathymetric grid as a basemap @earth_relief_15s.grd
- Suggestion: First draw velocity field without topography, if it's fully successful, then put it with relief.

Exercise 08c

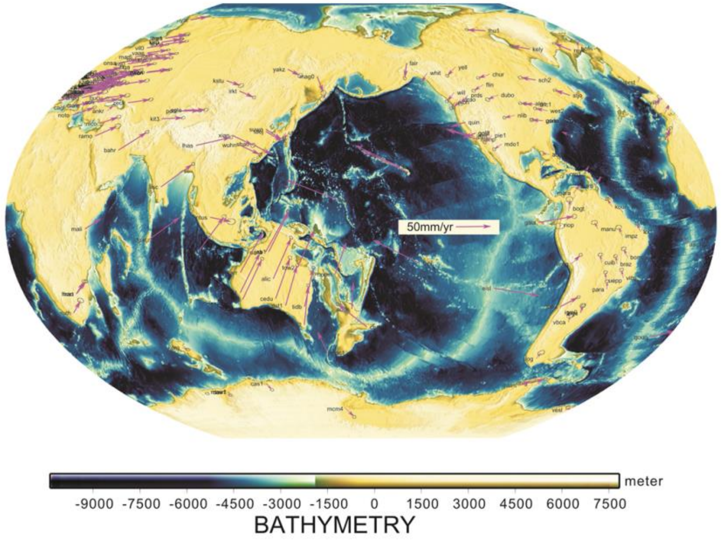
➢ Coseismic deformation of 0403 ML 7.3 Hualien earthquake from GNSS





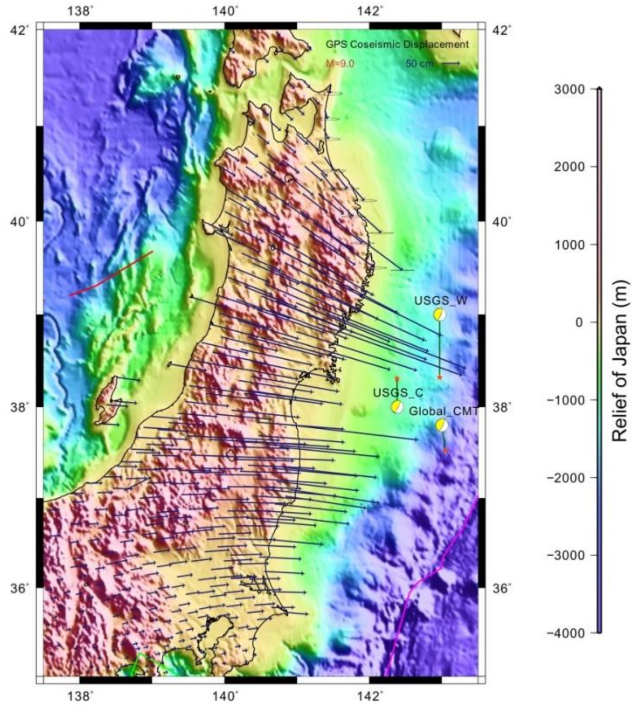


Homework 08



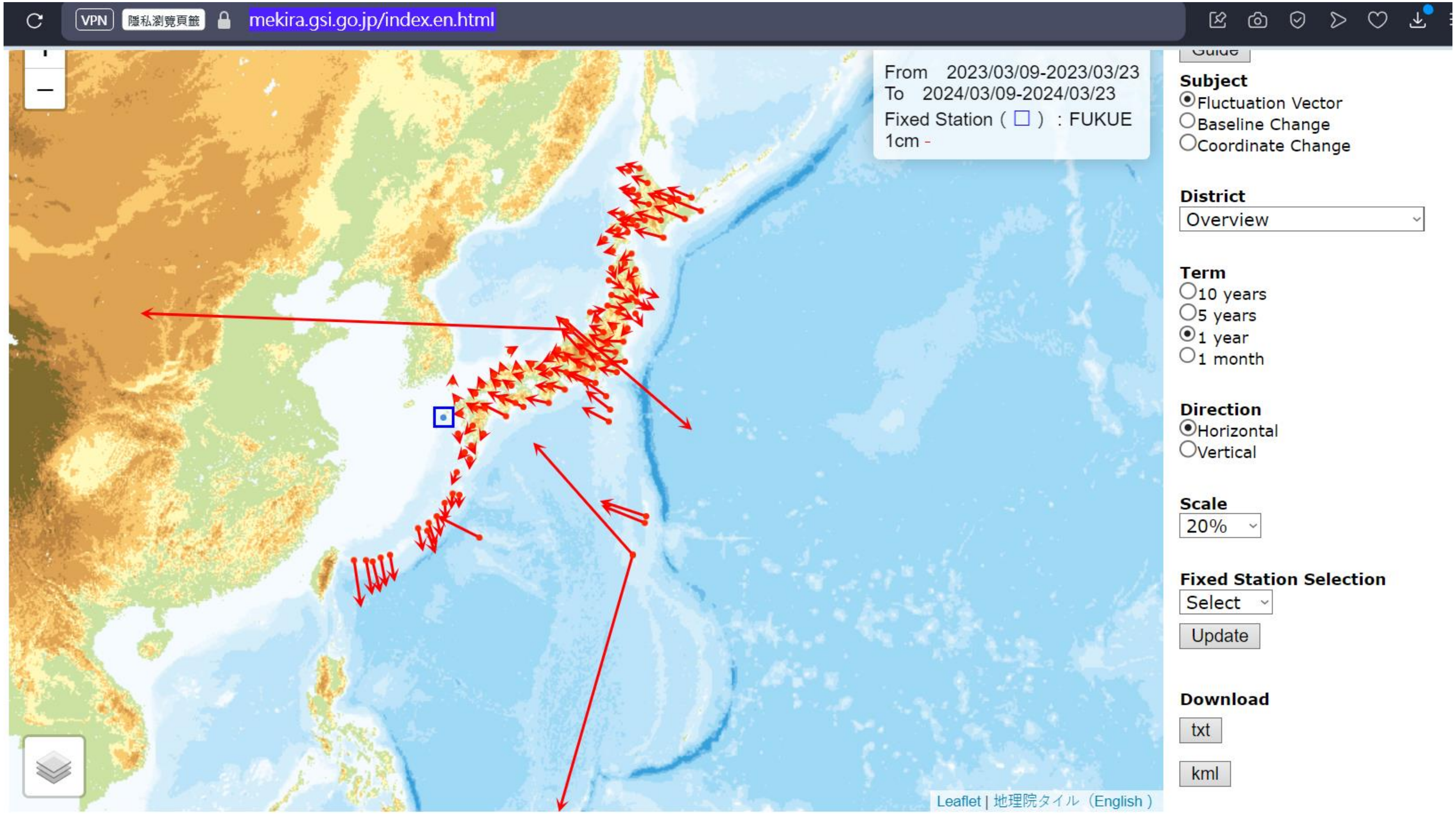
One of following subjects:

- Global GPS velocity data (gpsvel_1.0_cfa.gmt.txt) on global topographic data (@earth_relief_01m.grd)
  Data source: https://www.unavco.org/data/gps-gnss/gps-gnss.html
- The Geospatial Information Authority of Japan (GSI) with @earth_relief_15s.grd
  http://mekira.gsi.go.jp/project/f2/en/index.html
  - Data in homework directory: SCEC, GSI_Japan with @earth_relief_15s.grd
  - Coseismic and postseismic deformation from 2011 off the Pacific coast of Tohoku Earthquake (Mw 9.0) @earth_relief_15s.grd and focal mechanism of main shock

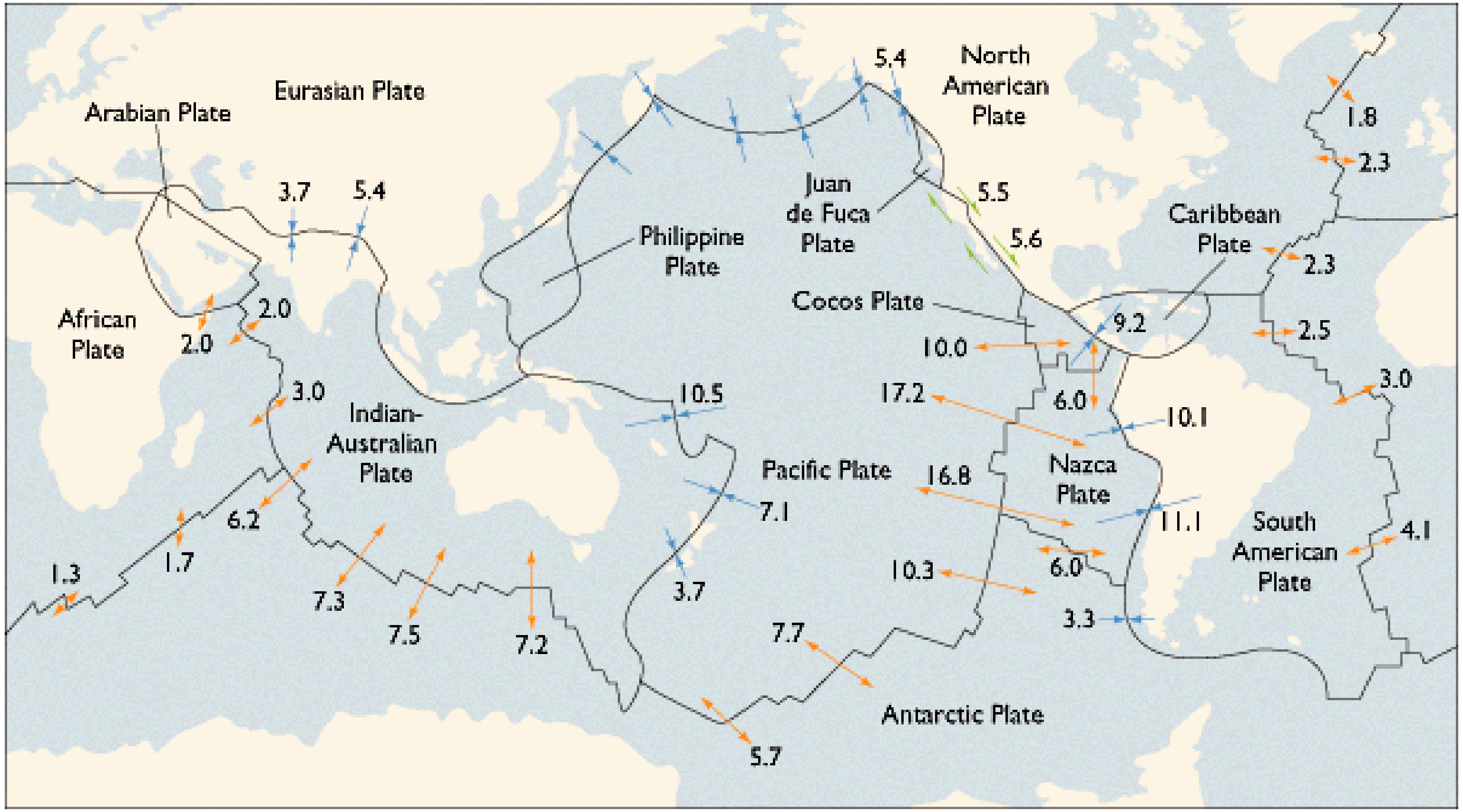


Crustal Movement in Japan

https://mekira.gsi.go.jp/index.en.html

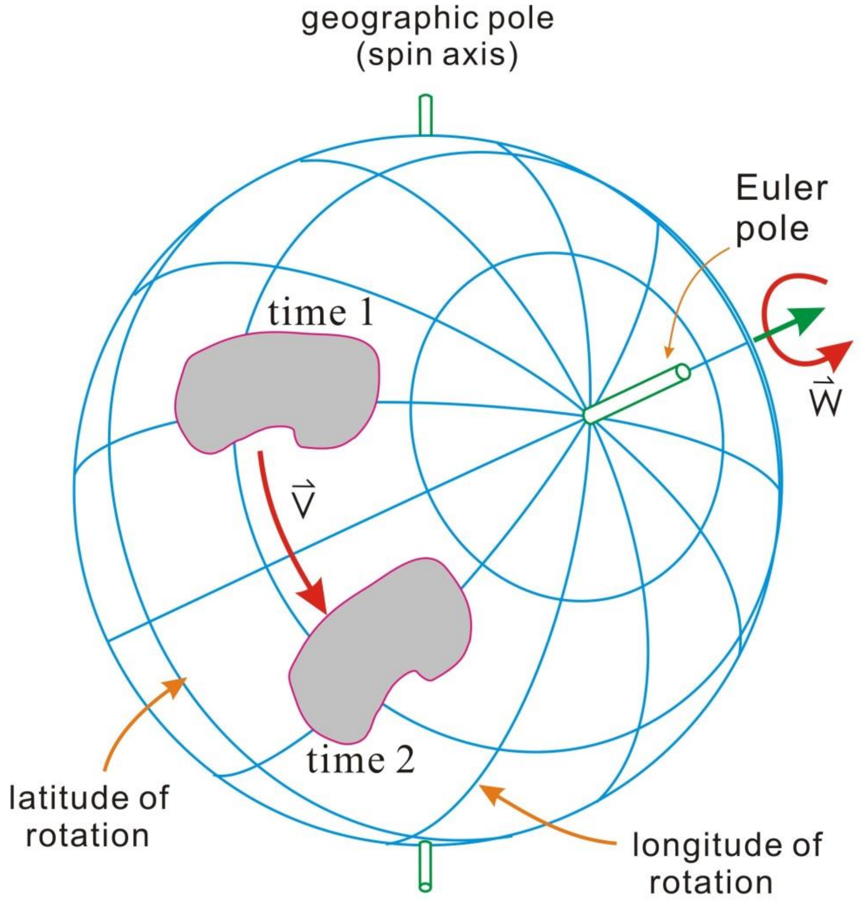


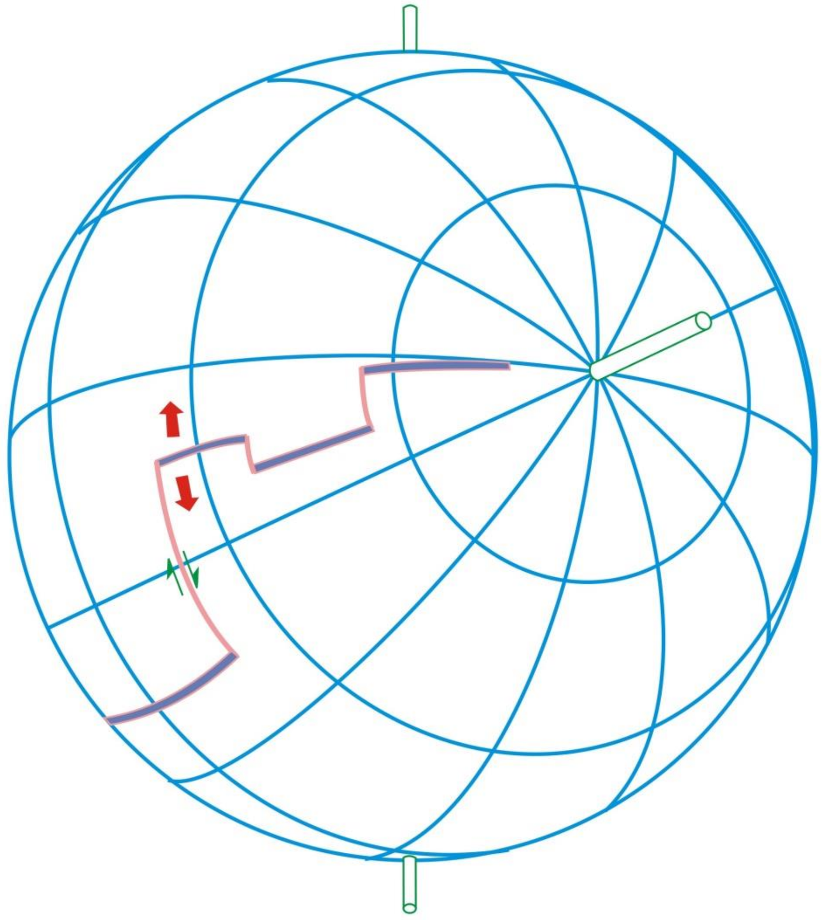
Relative Plate Motions



Jyr-Ching HU
Department of Geosciences, NTU

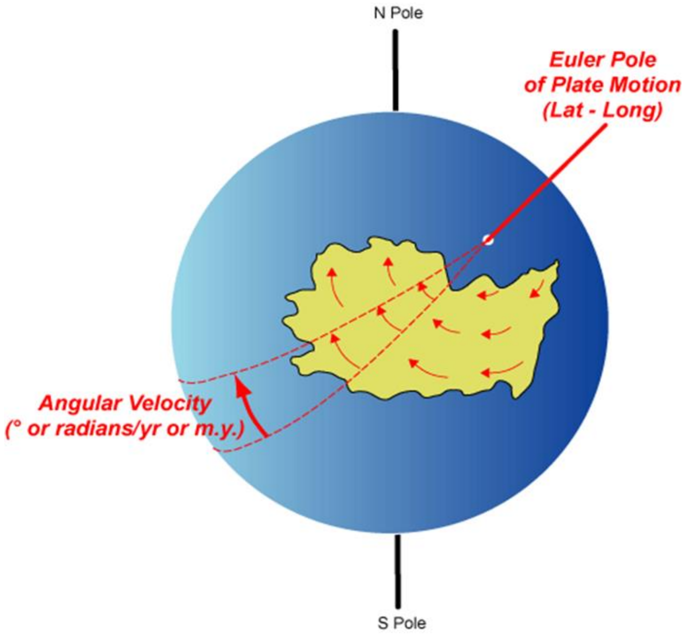
Describing the motion of plates on the Earth's surface

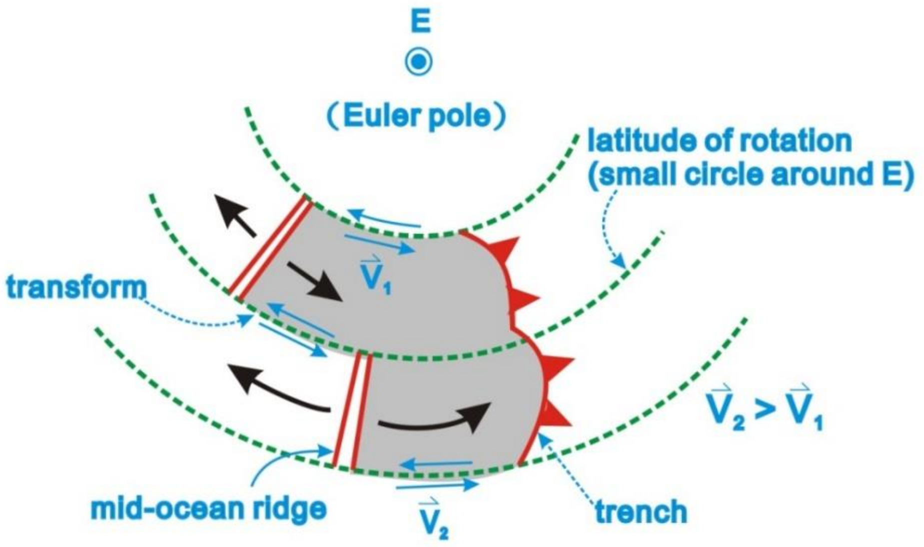




Relative Plate Motions

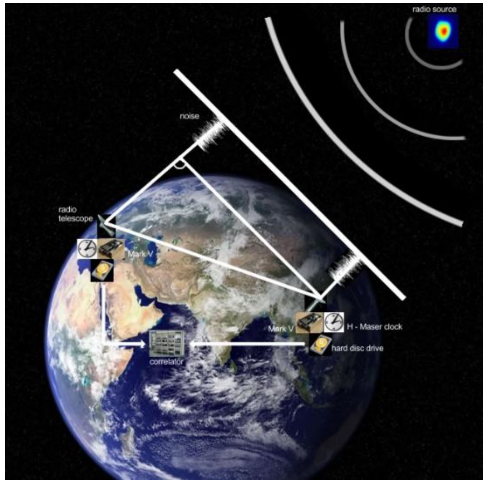
- All plates are moving about on a sphere
- ***Euler's theorem***: Relative motion between two plates across the surface of the sphere is uniquely defined by a singular angular rotation about a pole of rotation (**Euler Pole**)
- Euler pole tends to remain fixed for long periods of time
- Transform faults are geometrically linked to the Euler poles
- The transform fault to act with true tangential motion, it must lie on a small circle, the center of which is the Euler pole





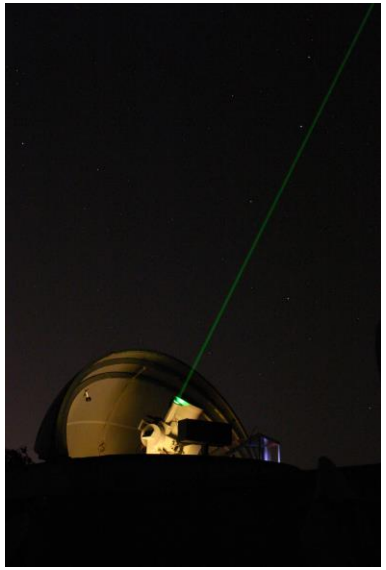
Relative Plate motions

1. Orientation of transform faults: Small circles centered on the pole of relative motion of the two plates. Pole of rotation is found by constructing great circles at right angles to the trends of the transform faults, and finding their intersection
2. Variation in spreading rate: Velocity of motion between two plates is maximum at 90° from the Euler Pole, and decreases to 0 at the Euler Pole by cos ϕ (latitude)
3. Magnetic stripes: Provide both rate and direction
4. Earthquake focal mechanism solutions: Give relative direction of movement (but not rate)
5. Actual direct measurements: Surveying, GPS surveying, VLBI (Very-long-baseline interferometry, 特長基線干涉測量法), SLR (Satellite laser ranging, 衛星雷射測距), ….



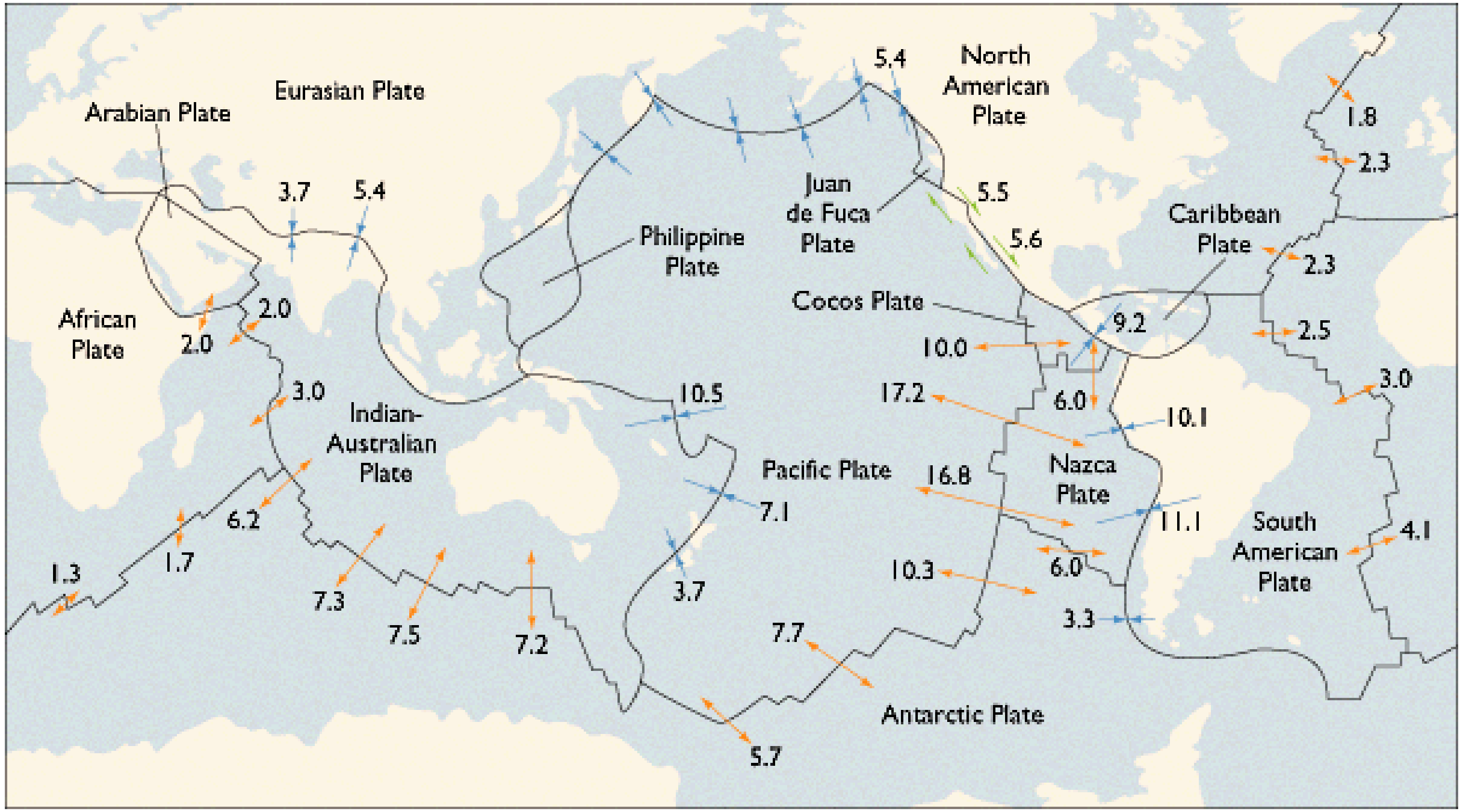
www.gfz-potsdam.de/en/section/space-geodetic-techniques/topics/geodetic-and-astrometric-vlbi/

阿塔卡瑪大型毫米波天線陣中的一些無線電望遠鏡



By Jörg Weingrill - www.flickr.com/photos/joerg73/7830472996/in/album-72157631174550554

NUVEL-1 (Northwesern University VELocity): Global Relative Plate Motion Model



- 277 spreading rates, 121 transform directions, 724 earthquake slip vectors from around the world
- To find motion of 12 Major plates:
- Some motions are derived using data from other plates by plate circuit closure.
- Used to describe average plate motions over the past 3 million years and compare them to shorter-term motions from earthquake and space geodesy.

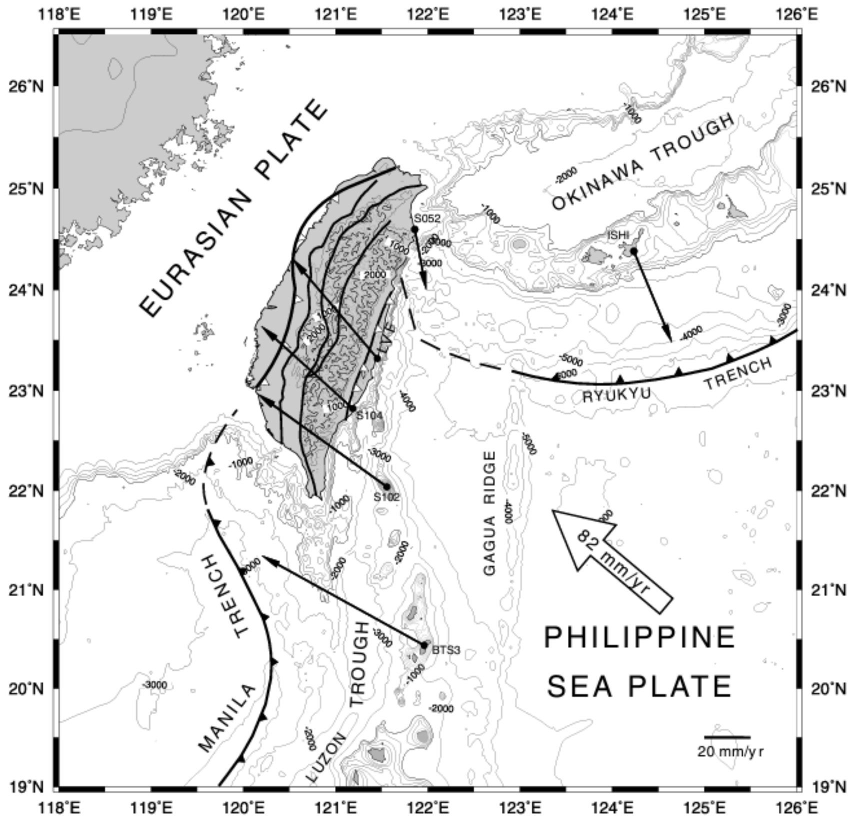
DeMets et al., 1990, GJI

PH-EU relative plate motion estimated at 23ºN 122ºE

Rotation pole			Linear velocity		Ref.
Lat.	Long.	ω(º/Ma)	V. (mm/yr)	Azi. (º)	
1. 44.50	150.62	1.200	70.7	309	Seno, 1977
2. 48.20	157.00	1.090	73.7	309	Seno et al., 1993
3. 47.30	154.40	1.060	68.2	310	Seno et al., 1987
4. 38.80	142.00	1.950	83.8	314	Huchon, 1986
5. 37.00	141.00	1.600	65.3	315	Ranken et al., 1984
6. 48.26	162.45	1.227	105.0	321	Minster & Jordan, 1979

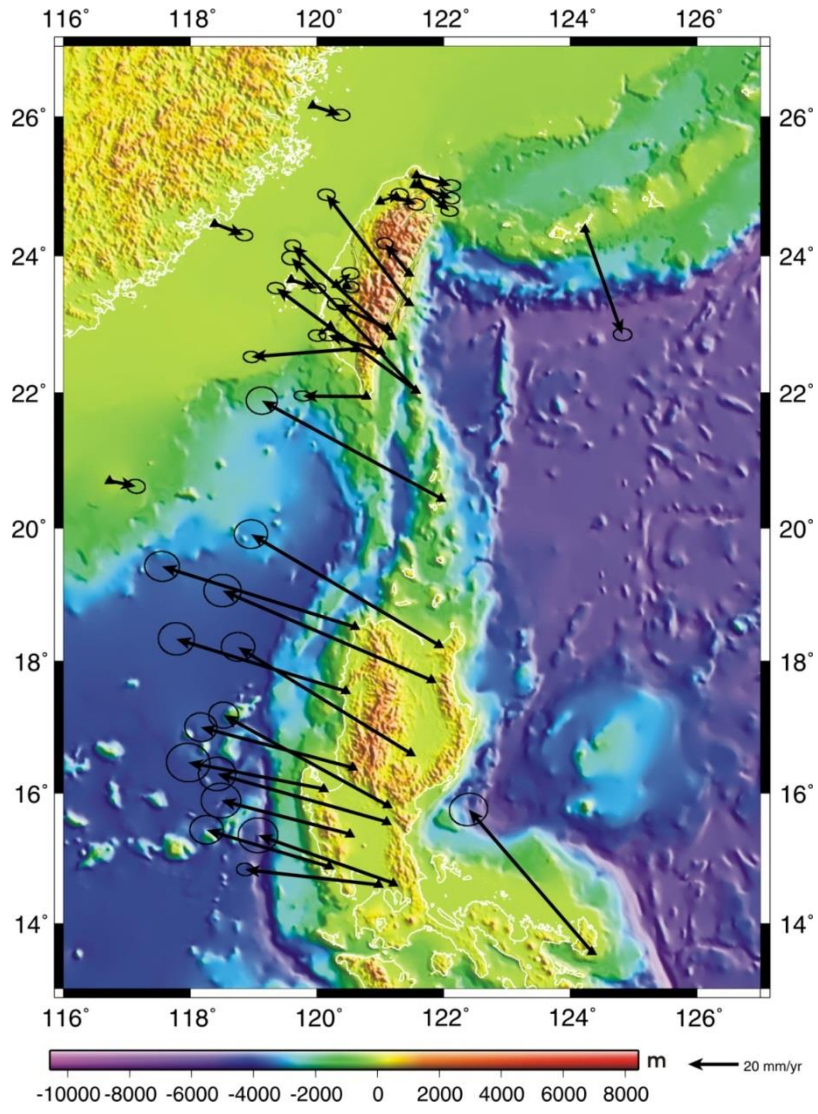
Hu et al., Tectonophysics, 1996

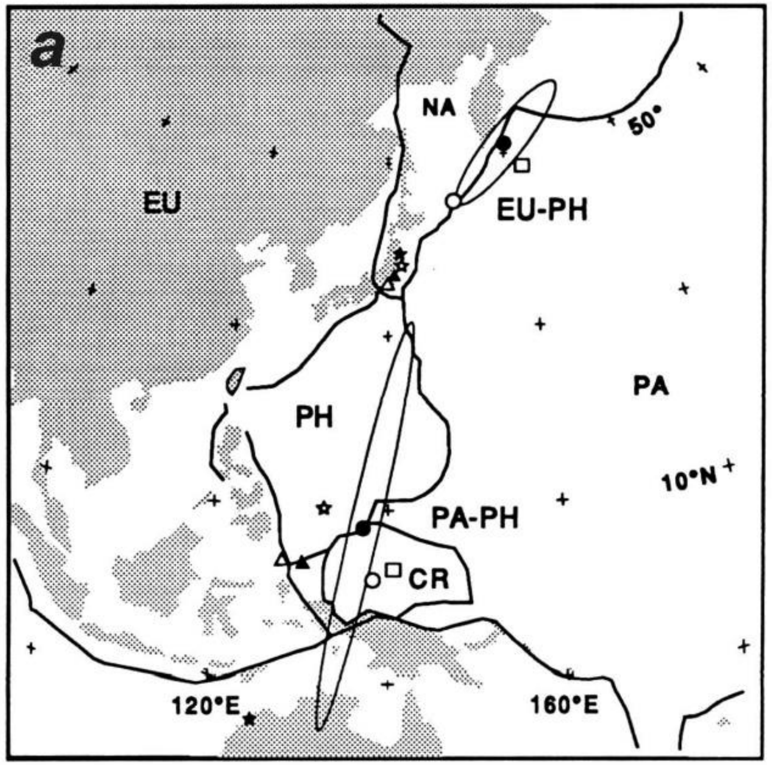
Collision and trench retreat model

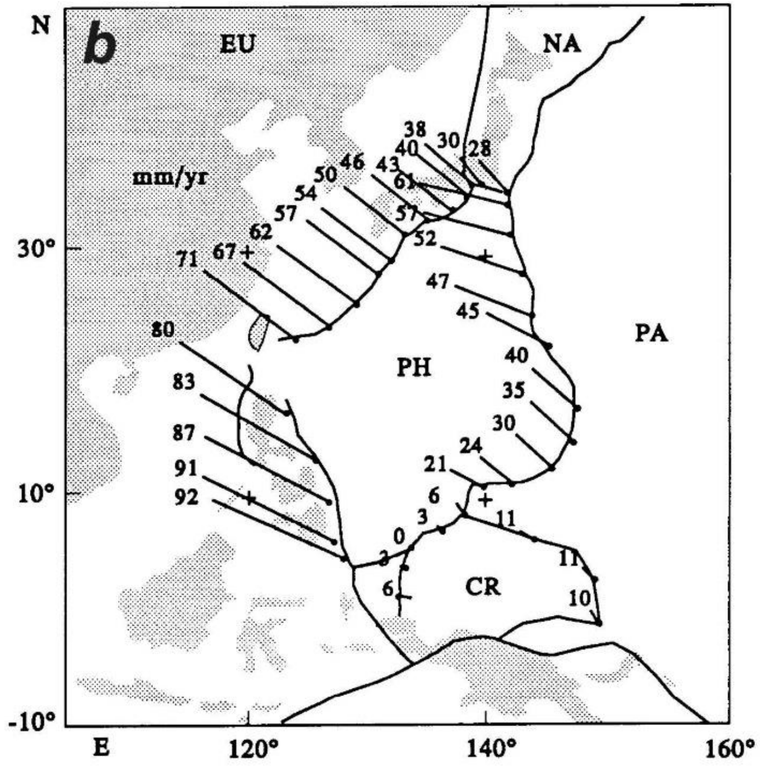


Hu et al., GSA, Spec. Paper, 2002

GPS Velocity Field of Taiwan-Luzon Area



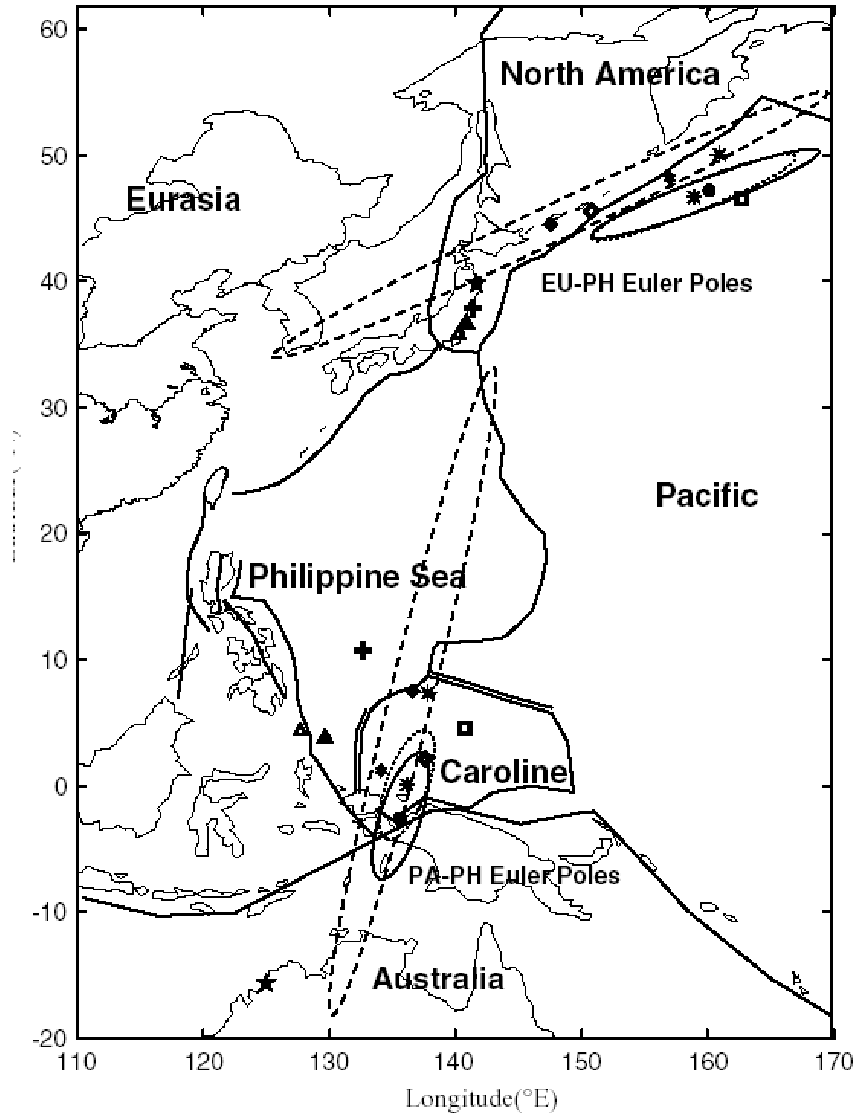




Seno et al., 1993

Data from Yu et al. GRL, 1999

Motion of the Philippine Sea plate consistent with the NUVEL-1A model



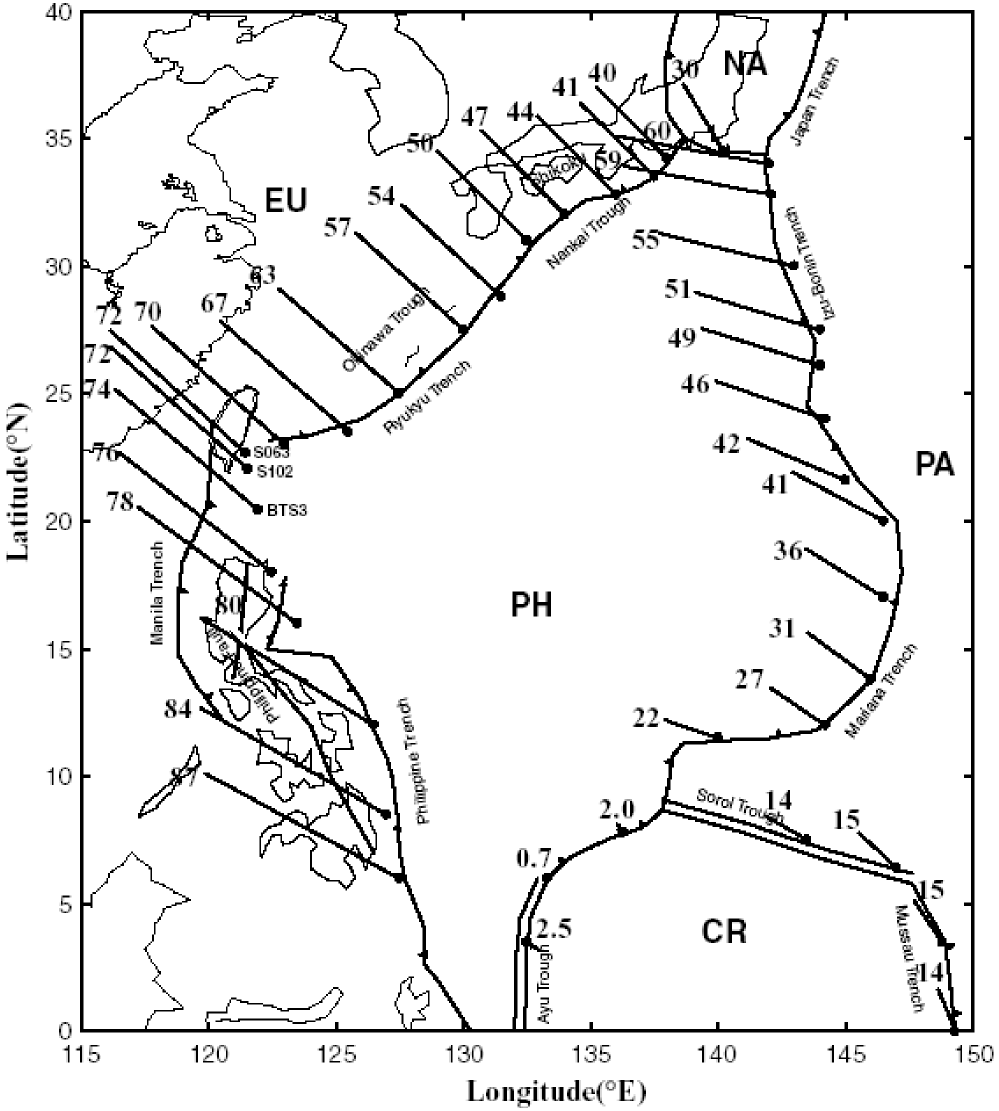
Solid star: Chase, 1978;
Open square: Minister & Jordan, 1978;
Open triangle: Karig, 1975;
Plus sign: Huchon, 1986;
Solid triangle: Ranke et al., 1984;
Open diamond: Seno et al., 1977;
Solid diamond: Seno et al., 1993;
Solid circle: Zang et al., 2002 (Nuvel-1)

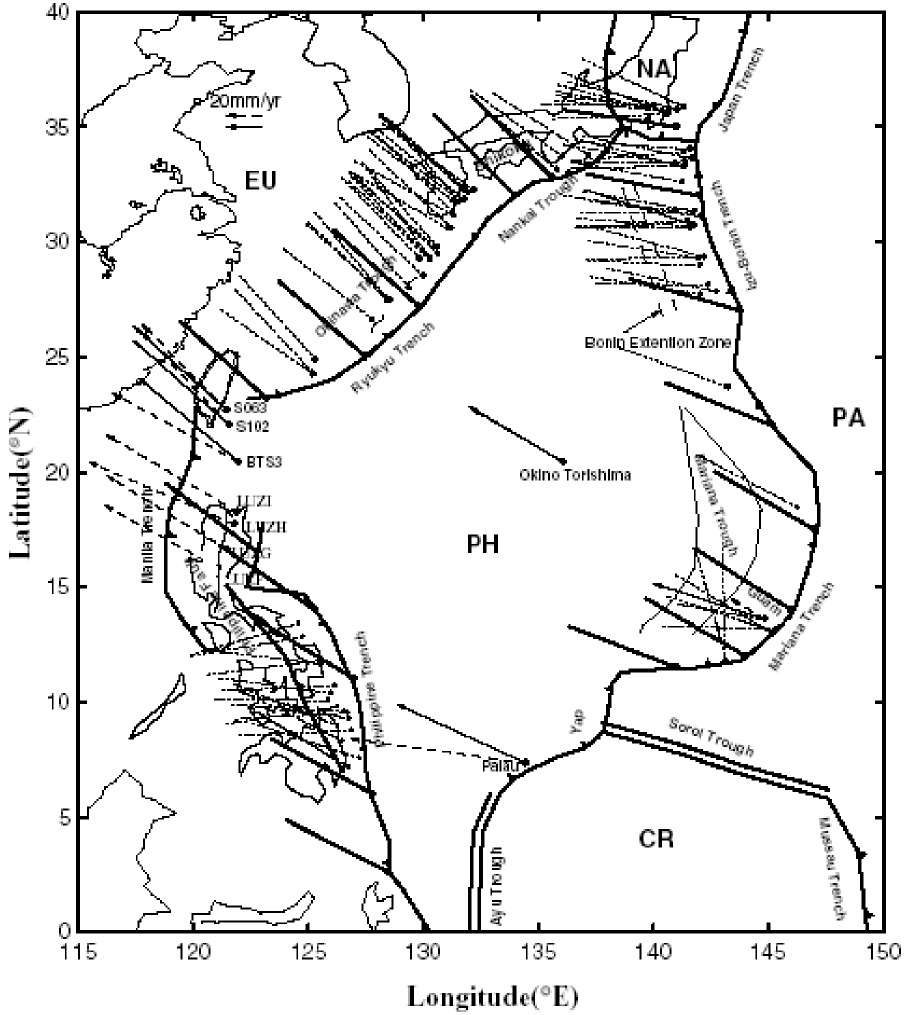
N-1: NUVEL-1
N-1A: NUVEL-1A
A: Zang et al., JGI, 2002
B: Seno et al., JGR,1993

Euler vectors of some plate pairs

Plate pair	Lat. of pole (°N)			Lon. of pole (°E)			Rotation rate (deg Myr^{-1})		
	A		B	A		B	A		B
	N-1	N-1A		N-1	N-1A		N-1	N-1A	
PH-PA	2.38	-0.11	-1.24	-44.34	-43.85	-45.81	0.961	0.964	1.000
EU-PH	46.99	46.67	48.23	159.83	158.90	156.97	1.020	1.035	1.085
CR-PH	5.00	6.20	6.24	135.10	134.20	134.09	0.300	0.400	0.700
PA-CR	-5.71	-4.18	-10.13	135.91	137.52	134.43	0.665	0.568	0.309

Motion of the Philippine Sea plate consistent with the NUVEL-1A model



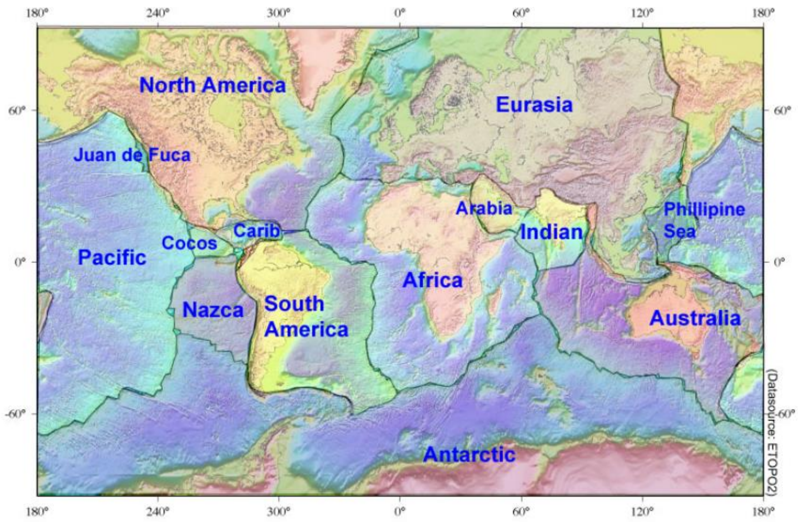


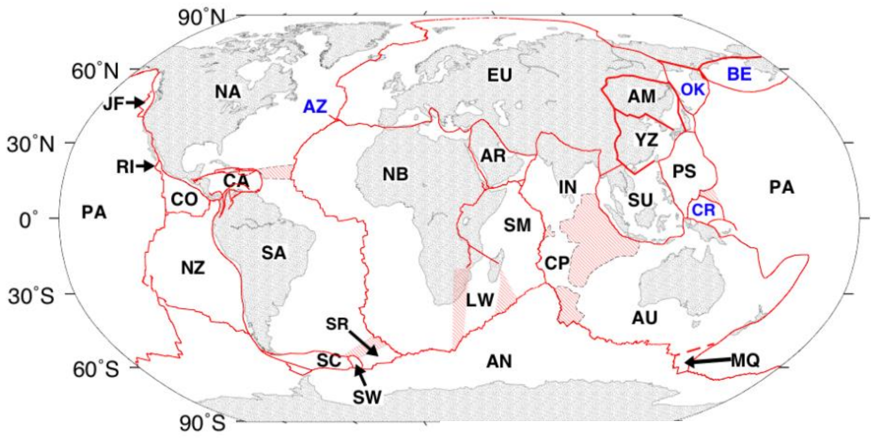
Zang et al., JGI, 2002

Plate motion calculator

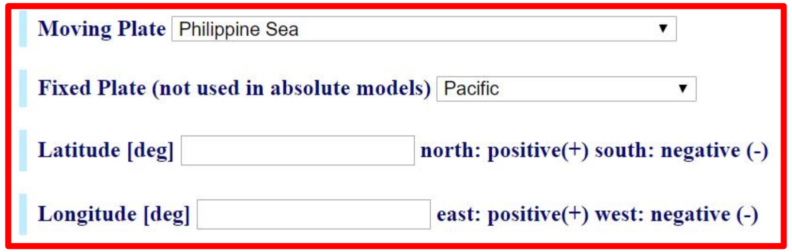
http://ofgs.aori.u-tokyo.ac.jp/~okino/platecalc_new.html

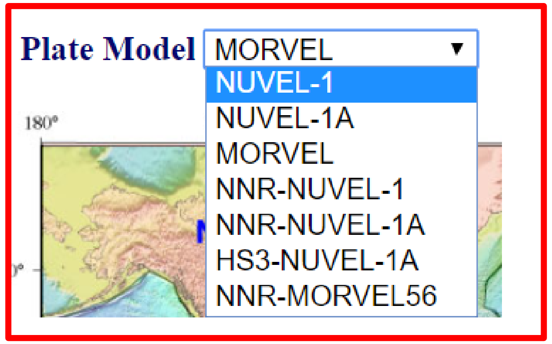
- Plate Motion Calculator calculates: relative and absolute plate motion direction and speed at any point on the earth.
- Original web-based calculator: developed by K. Tamaki in mid 90's and then has been revised/maintained by K. Okino.





Left: NUVEL-1(A)____________________ Right: MORVEL





References of Models

- **NUVEL-1**: Relative Motion Model, Pacific Plate fixed, 2 m.y. average velocity

DeMets, C., R. G. Gordon, D. F. Argus, and S. Stein, Current plate motions, Geophys. J. Int., 101, 425-478, 1990

- **NUVEL-1A**: Revised version of NUVEL-1, Euler poles are same

DeMets. C., R. G. Gordon, D. F. Argus, and S. Stein, Effect of recent revisions to the geomagnetic reversal time scale on estimate of current plate motions, Geophys. Res. Lett., 21(20), 2191-2194, 1994

[Note 1] Model parameters for Philippine Sea Plate are based on Seno et al. (JGR, 1993)

[Note 2] Velocities calculated based on NUVEL-1 and NUVEL-1A may be 4.5% and 2% faster than those measured by space geodetic methods by using VLBI/SLR (Gordon, Nature 1993) ()

- **MORVEL**: Relative Motion Model, Pacific Plate fixed. New model for 25 tectonic plates, mid-ocean ridge spreading rates and faults azimuths are used to determine the motions of 19 plates, and GPS station velocities and azimuthal data are used for 6 smaller plates with little or no connection to mid-ocean ridges

DeMets, C., R. G. Gordon, and D. F. Argus, Geologically current plate motions, Geophys. J. Int., 181, 1-80, 2010

- **NNR-NUVEL-1A**: Absolute Motion Model, No net rotation (無整體旋轉參考架)

DeMets. C., R. G. Gordon, D. F. Argus, and S. Stein, Effect of recent revisions to the geomagnetic reversal time scale on estimate of current plate motions, Geophys. Res. Lett., vol. 21, no. 20, 2191-2194, 1994

- **HS3-NUVEL-1A**: Absolute Motion Model, hotspot reference frame

Gripp, A.E., and Gordon, R.G., Young tracks of hotspots and current plate velocities, Geophys. J. Int., 150, 321-361, 2002.

- **NNR-MORVEL**: Absolute Motion Model, No net rotation, for MORVEL 25 plates and Bird (2003)'s 31 plates

Argus, D.F., Gordon, R.G and DeMets, C. Geologically current motion of 56 plates relative to the no-net rotation reference frame, Geochemistry, Geophysics, Geosystems , 12, doi:10.1029/2011GC00375., 2011.

Bird, P. An updated digital model of plate boundaries, Geochemisty, Geophysics, Geosystems, 4, 1027, doi:10.1029/2001GC000252, 2003.

MORVEL & NNR-MORVEL56 plate velocity estimates & information

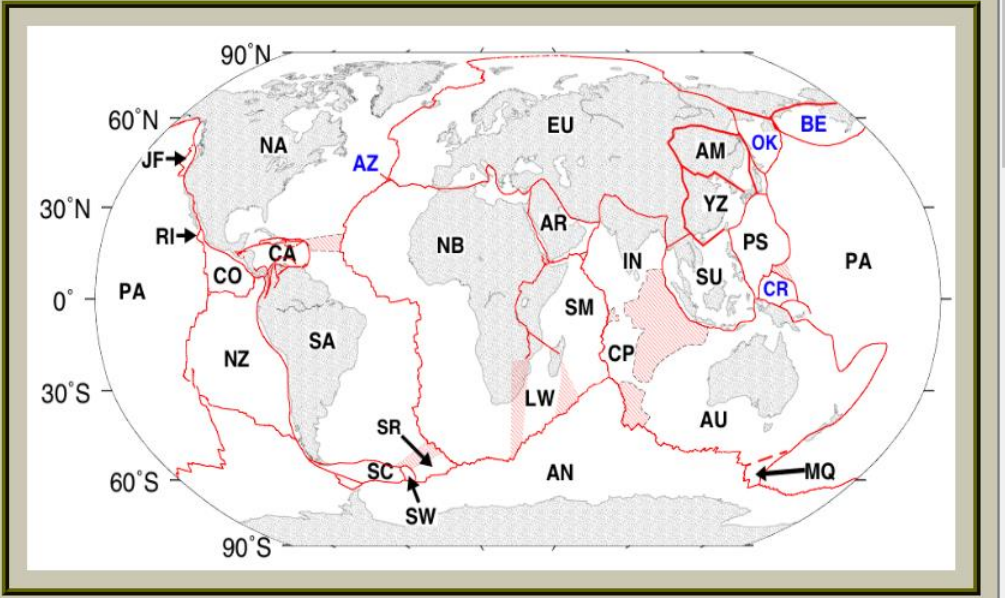
C. DeMets, D. Argus, & R. Gordon

http://www.geology.wisc.edu/~chuck/MORVEL/

Options:
1. Home page
2. Motion calculators
3. MORVEL information
4. Magnetic profiles
5. Transform faults
6. GPS velocities
7. MORVEL source data
8. Citation & acknowledgment
9. MORVEL angular velocities
10. NNR-MORVEL56 angular velocities
11. ERRATA (Table 4)
12. Plate boundaries

Purpose: This Web site helps users calculate the present relative or no-net-rotation velocities of selected tectonic plates with the MORVEL or NNR-MORVEL56 angular velocities. It also provides information and source data for MORVEL, NNR-MORVEL56, and their underlying data.

History: The MORVEL plate motion project began in the late 1990s via a National Science Foundation grant to professors Charles DeMets of the University of Wisconsin-Madison and Richard Gordon of Rice University. MORVEL is a set of angular velocities and uncertainties that describes the geologically recent motions of 25 tectonic plates that collectively cover 97.2% of Earth's surface. MORVEL is constructed from marine geophysical, seismologic, and geodetic data from archives and investigators in ten different countries and employs many more data than the NUVEL-1 and NUVEL-1A plate motion estimates, which were published in 1990 and 1994. Finished in 2008 after nearly a decade of intensive data analysis, MORVEL is the most complete, self-consistent estimate of geologic plate motions ever published.



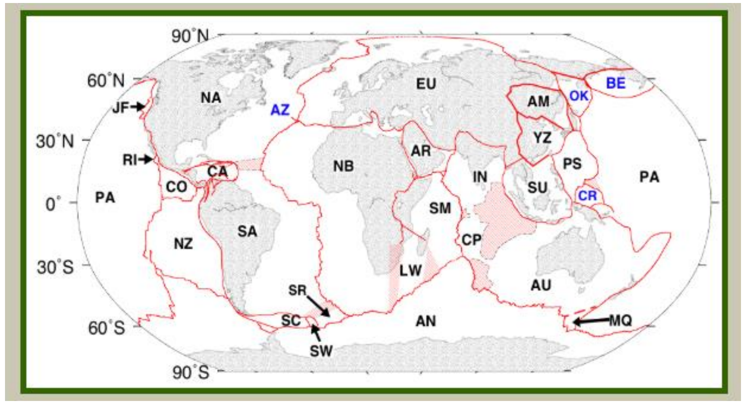
NNR-MORVEL56 is a set of angular velocities that describe the motions of 56 plates relative to a no-net-rotation reference frame. Spearheaded by Dr. Donald Argus of the NASA Jet Propulsion Laboratory, NNR-MORVEL56 extends the 25-plate MORVEL model, which covers 97.2% of Earth's

- Click the options: 2. Motion calculators; 9. MORVEL angular velocities; 10. NNR-MORVEL angular velocity; 12. Plate boundaries

MORVEL plate motion calculator (25 plates)

http://www.geology.wisc.edu/~chuck/MORVEL/motionframe_mrvl.html

Output formats are rate/azimuth and GMT psvelo (velo for GMT 6)



AM: Amur	**AN**: Antarctic	**AR**: Arabia	**AU**: Australia	**CA**: Caribbean
CO: Cocos	**CP**: Capricorn	**EU**: Eurasia	**IN**: India	**JF**: Juan de Fuca
LW: Lwandle	**MQ**: Macquarie	**NA**: N. America	**NB**: Nubia	**NZ**: Nazca
PA: Pacific	**PS**: Philippine Sea	**RI**: Rivera	**SA**: S. America	**SC**: Scotia
SM: Somalia	**SR**: Sur	**SU**: Sundaland	**SW**: Sandwich	**YZ**: Yangtze

Step 1: Select stationary and moving plates.

Fixed plate: Enter two-letter code from list above -

Moving plate: Enter two-letter code from list above -

Step 2: Input coordinates for velocity calculation.

Type or cut-and-paste latitude, longitude pairs in decimal or integer degrees, one pair per line.

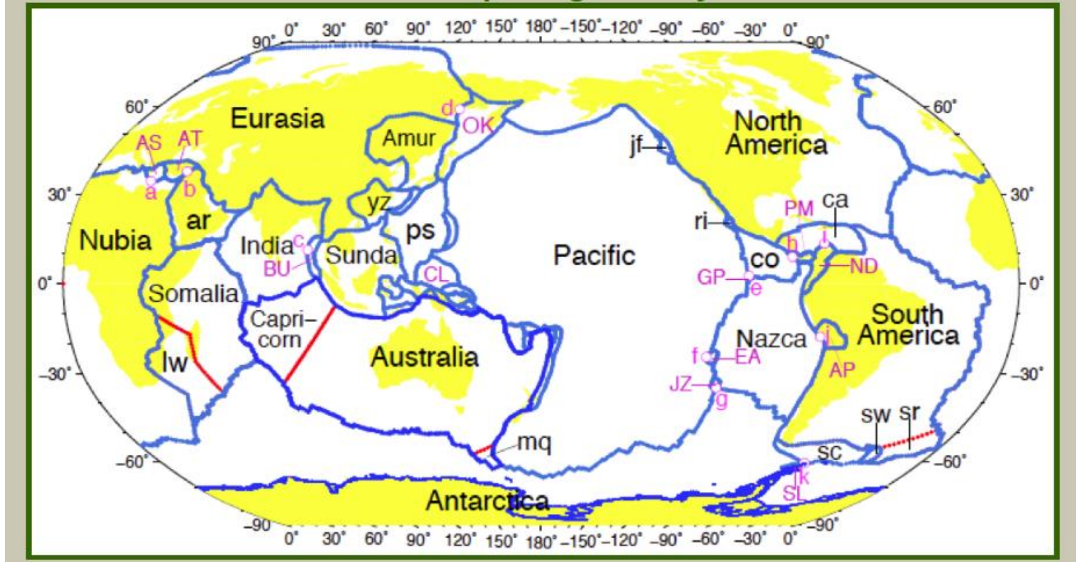
WARNING: Latitudes should be geocentric (spherical Earth) rather than geodetic.

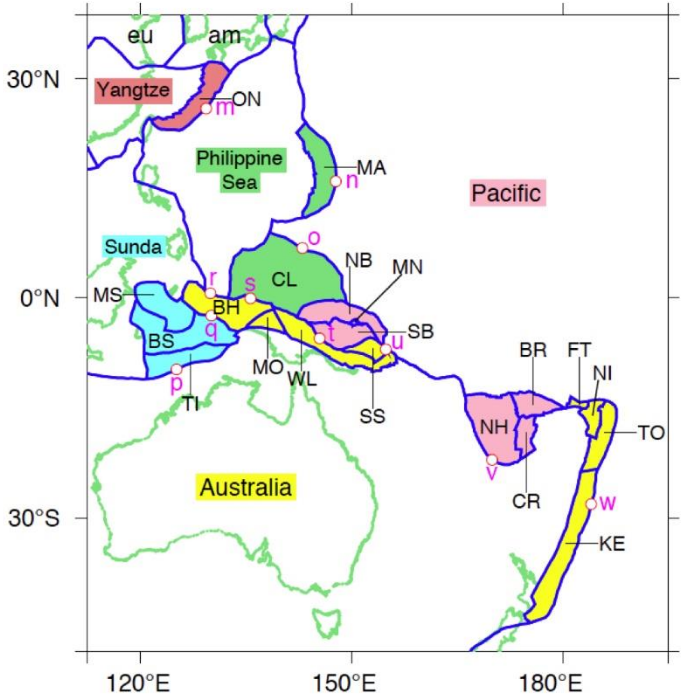
Example 1: **45°N, 50°E** should be entered **45, 50** or **45.0, 50.0**
Example 2: **30.4°S, 120.6°W** should be entered **-30.4, -120.6**

NNR-MORVEL56 plate motion calculator

http://www.geology.wisc.edu/~chuck/MORVEL/motionframe_nnrm56.html

Global plate geometry





Two-letter plate codes needed for calculator

XX: No-Net-Rotation frame

AS: Aegean Sea	AM: Amur	AP: Altiplano	AT: Anatolia	AN: Antarctic	AR: Arabia	AU: Australia
BR: Bahnoral Reef	BS: Banda Sea	BH: Birds Head	BU: Burma	CP: Capricorn	CA: Caribbean	CL: Caroline
CO: Cocos	CR: Conway Reef	EA: Easter	EU: Eurasia	FT: Futuna	GP: Galapagos	IN: India
JZ: Juan Fernandez	JF: Juan de Fuca	KE: Kermadec	LW: Lwandle	MQ: Macquarie	MN: Manus	MO: Maoke
MA: Mariana	MS: Molucca Sea	NZ: Nazca	NA: N. America	NH: New Hebrides	NI: Niuafo'ou	ND: North Andes
NB: North Bismarck	NU: Nubia	OK: Okhotsk	ON: Okinawa	PA: Pacific	PM: Panama	PS: Philippine Sea
RI: Rivera	SW: Sandwich	SC: Scotia	SL: Shetland	SS: Solomon Sea	SM: Somalia	SA: S. America
SB: S. Bismarck	SU: Sundaland	SR: Sur	TI: Timor	TO: Tonga	WL: Woodlark	YZ: Yangtze