GPS and ITS APPLICATIONS IN EARTHQUAKE STUDIES

By

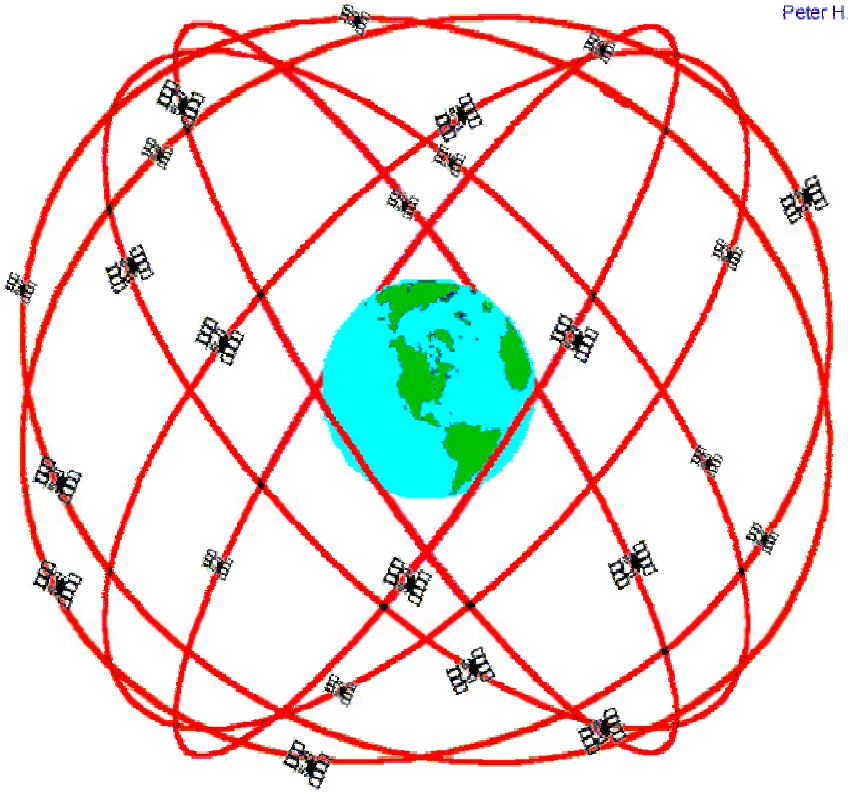
Dogan AKSARI

Global Positioning System

Introduction

GPS

ERROR SOURCES



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Presentation Title

Main Topic

First Subtopic

Second Subtopic

Body of Topic

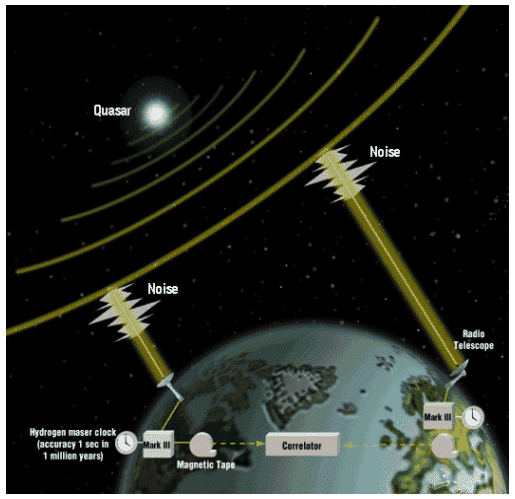
Number of Slide

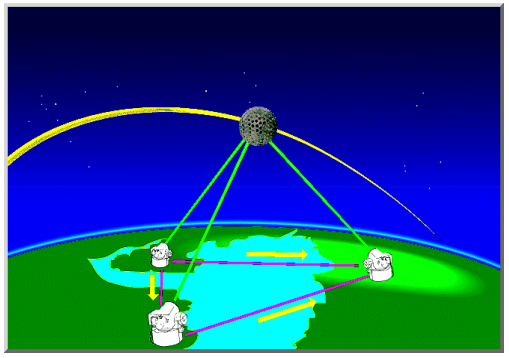
- GEODETIC METHOD = EDM, VLBI, SLR ..... GPS
- GPS=Economic and Precise
- GPS = HIGH PRECISION, ECONOMIC
- GEOPHYSICS USES GPS TO EXPLAIN
  - Plate Movement and Plate Boundary Deformations
  - Volcanic Deformation
  - Glacial Isostatic Adjustment and Sea Level Change
  - Landslide and Dam Deformations
  - **Earthquake Studies**
    - **Interseismic Deformation**
    - **Coseismic Deformation**
    - **Postseismic Deformation**

- GPS Overview
- **Earthquake Studies**
  - **Interseismic Deformation**
  - **Coseismic Deformation**
  - **Postseismic Deformation**
- Studying 17 Agustos 1999 Kocaeli Earthquake provided GPS Observations

Geodesy

Space Geodesy





Geodetic Methods

VLBI (Very Long Baseline Interferomerty)
SLR (Satellite Laser Ranging)
LLR (Lunar Laser Ranging)
GPS (Global Positioning System)

GPS

- 1957 Launch of first satellite, SPUTNIK by former Soviet Union
- 1957 TRANSIT system by USA

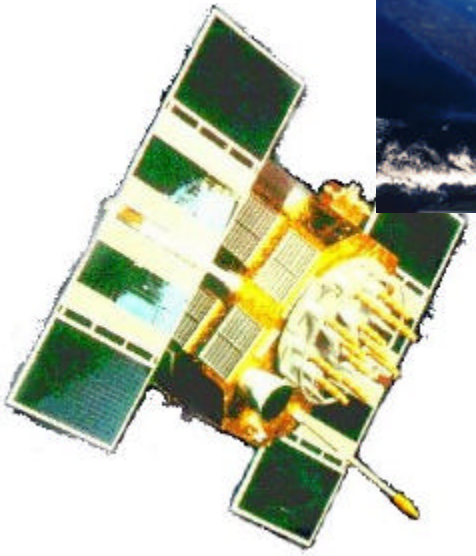
  6 orbit planes, 6 satellites, 1100 km above the earth
- 1967 ZIKADE system by former USSR

  6 orbit planes, 6 satellites, 1100 km above the earth
- 1974 GPS by USA
- The GPS became fully operational on December 8, 1993
  - 6 orbit planes, 24 satellites, 20200 km above the earth
- The Global Positioning System is based on the US Department of Defense's NAVSTAR Satellites.
- GPS costs $12 billion.
- Error add into satellite signals, called SA (Selective Availability)
- Military receivers have a description key to remove SA error.
- SA was totally removed at May 2, 2000.

- Space Segment
  - Satellites
- Control Segment
  - Control Stations
    - Master Control Station
    - Monitor Stations
    - Ground Control Stations
  - Antennas
- User Segment
  - People
  - GPS Receivers

Satellites

24 satellites
6 orbiting planes
55 degree inclination
20200 km above Earth
12 hours of orbit
5 hours view in horizon



Signals

L1 carrier (154*10.23 MHz)

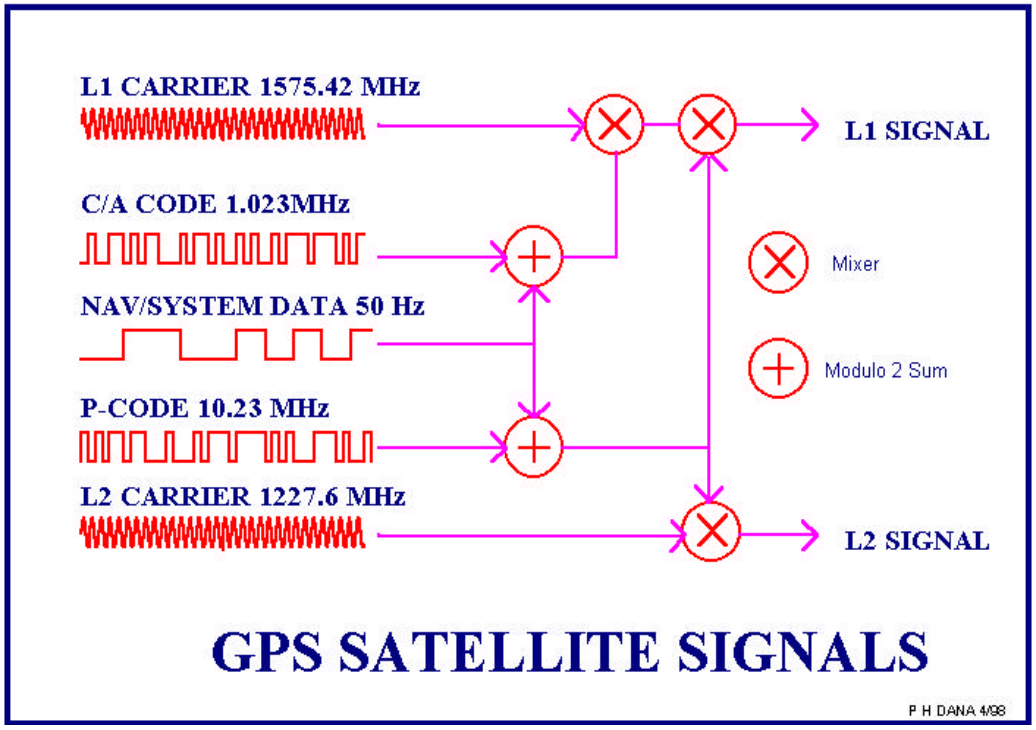
P code + C/A code + data message

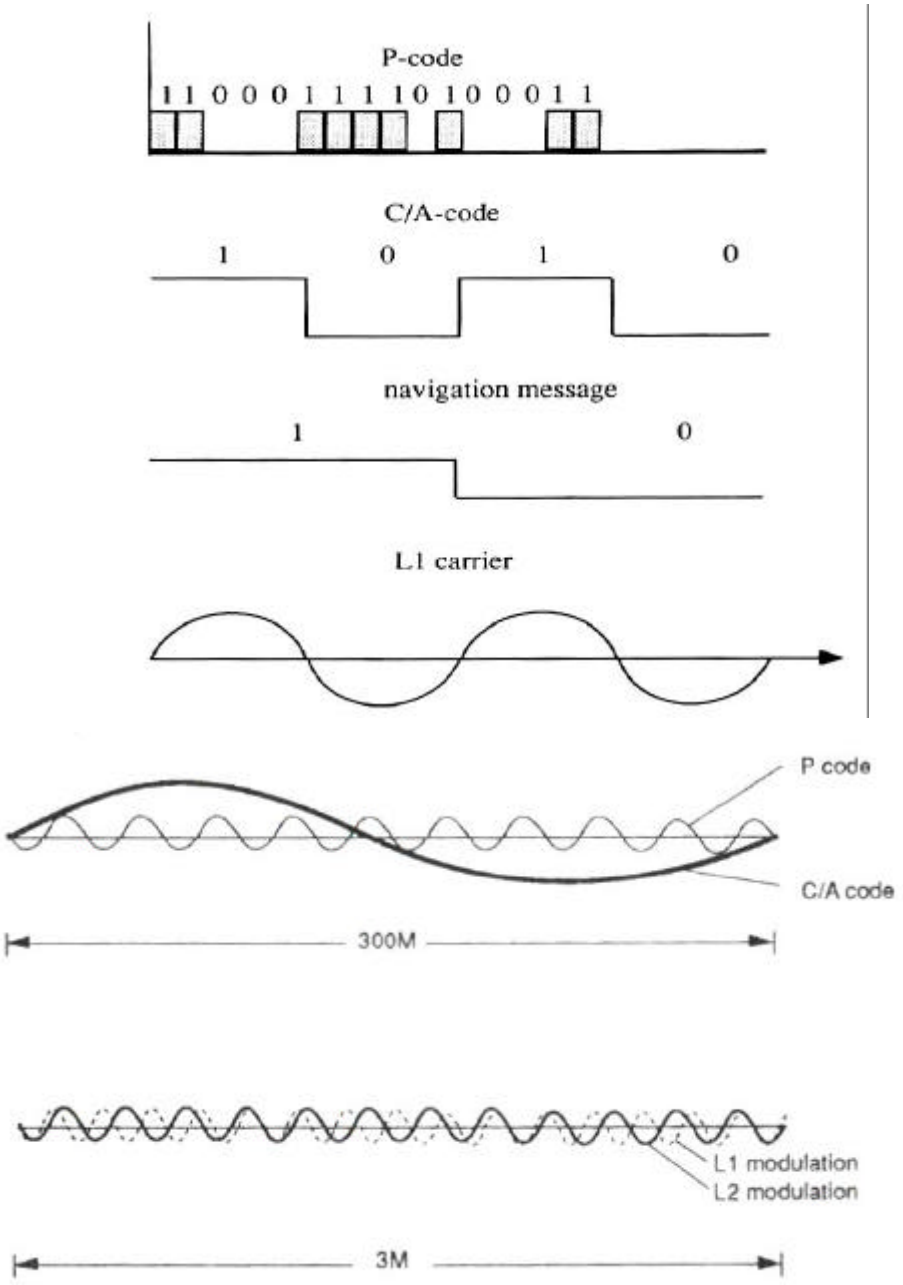
l_{L1}=19.05 cm

L2 carrier (120*10.23 MHz)

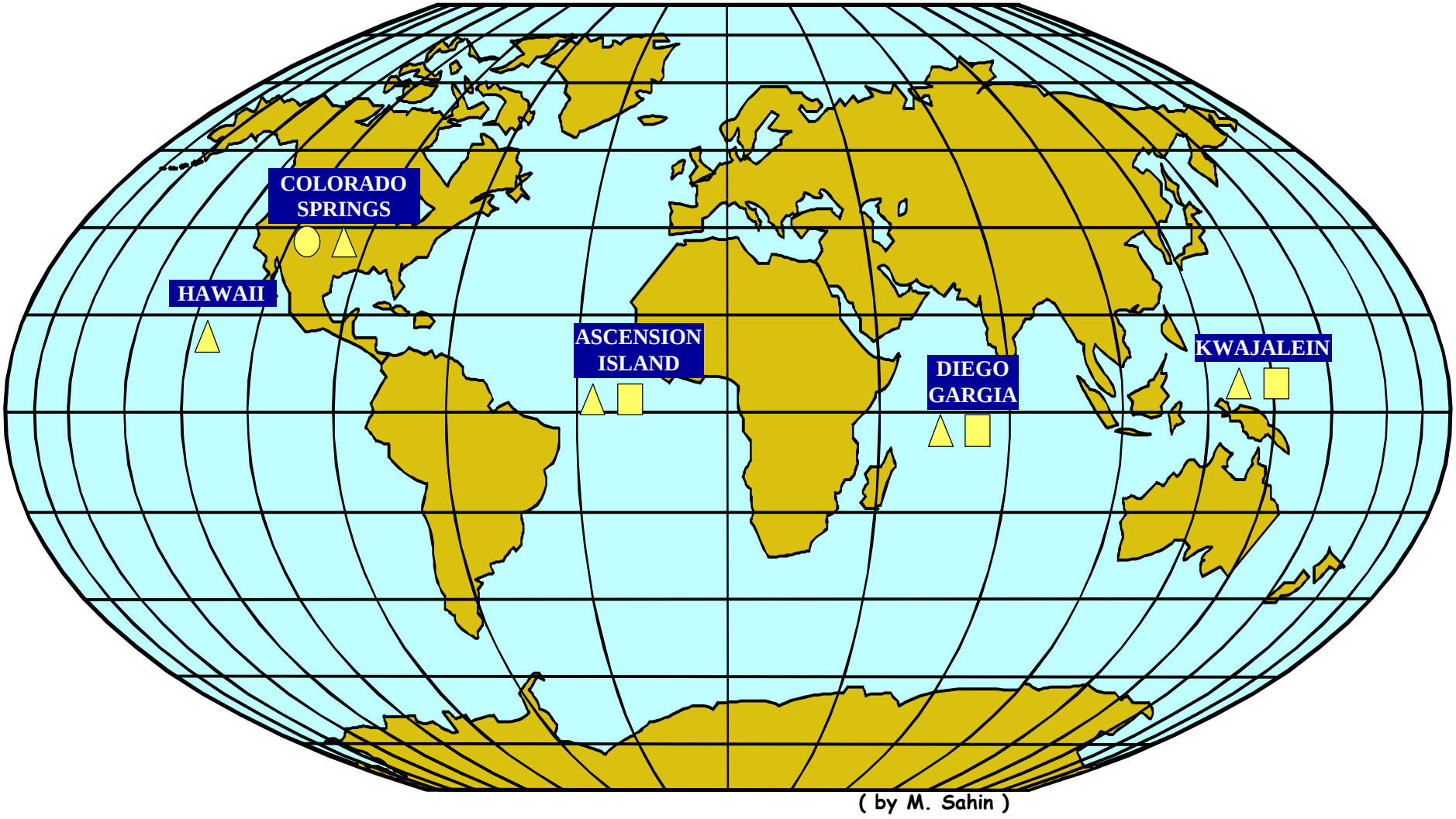
P code + data message

l_{L2}=24.45 cm





Distribution



User Segment

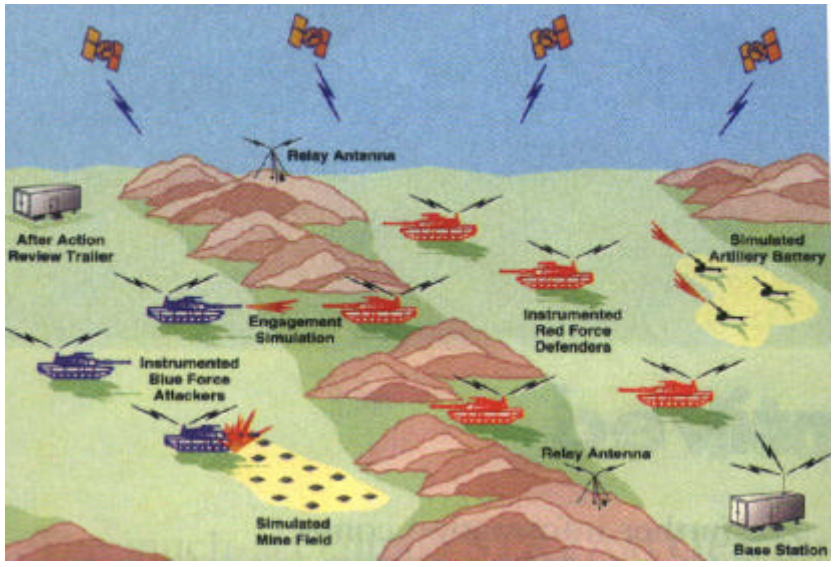
User Community

Civilian

Military

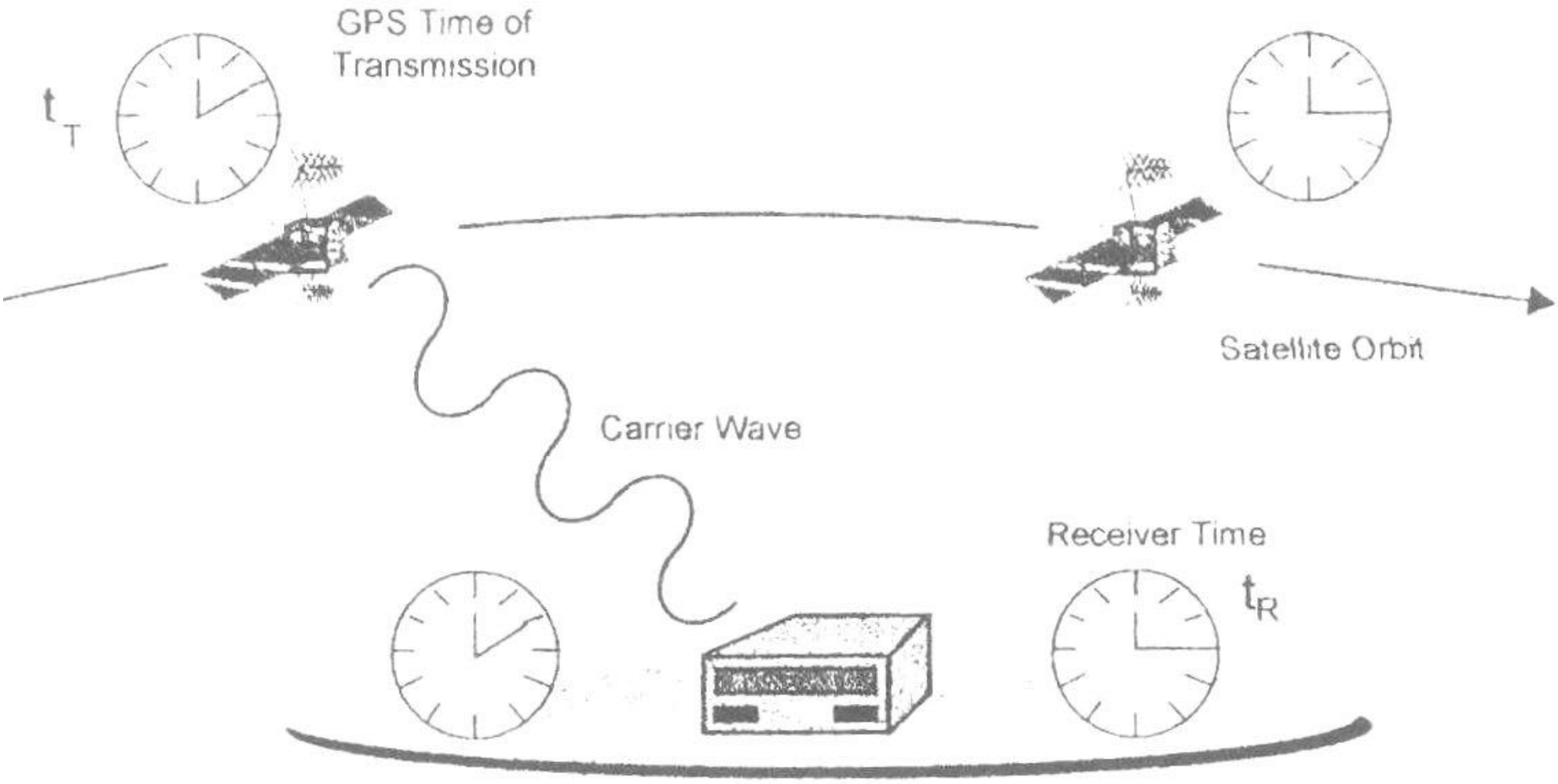
Receiver

Trimble
Ashtech
Rogue
Leica
Javad ...



- **Code PseudoRange**
  - P and C/A codes.
- **Carrier Phase PseudoRange**
  - Phases of L1 and L2 carrier signals
  - Single-Difference, Double-Difference ...

Codes PseudoRange

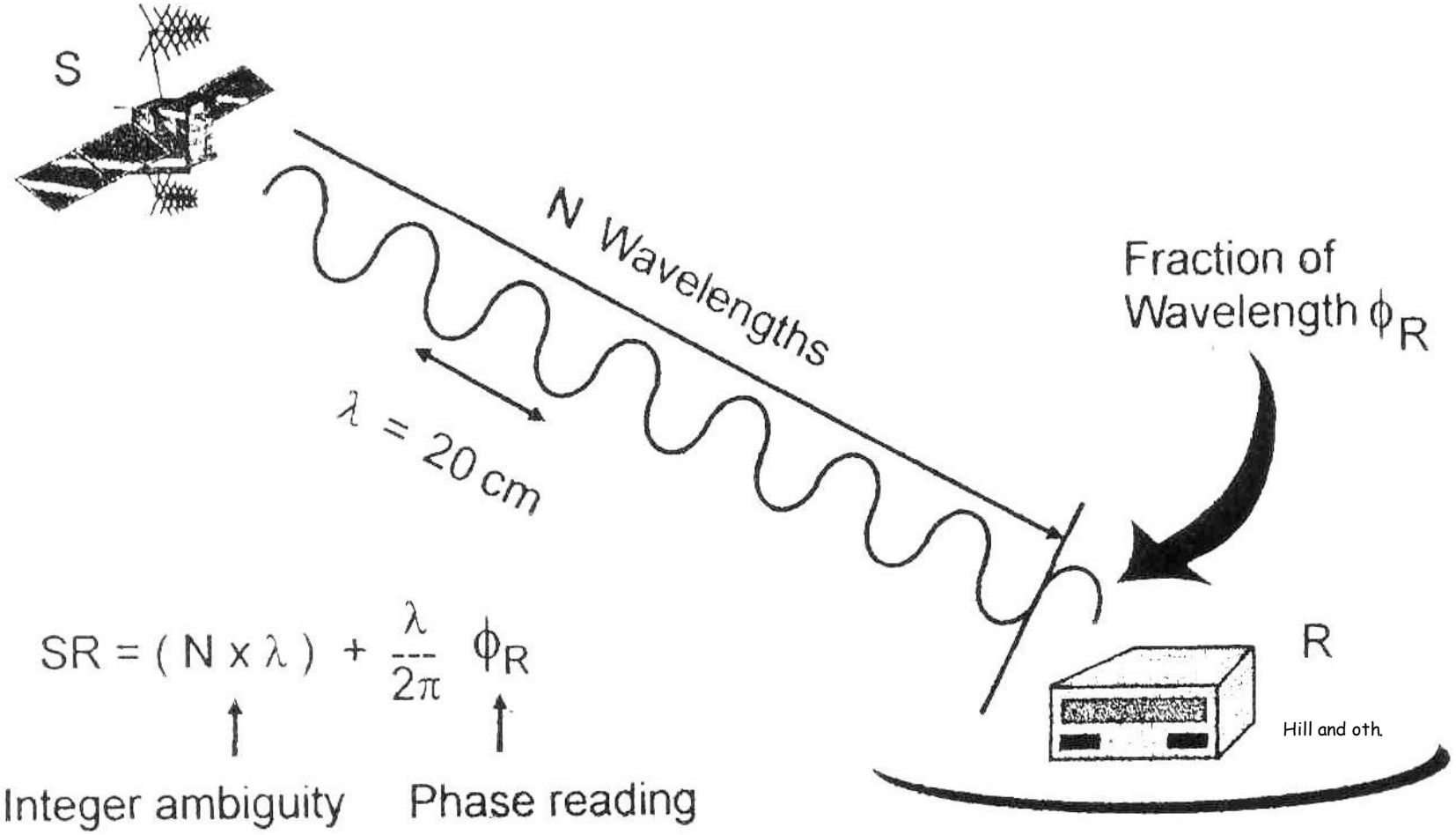


(Pseudo-) Range = $t_R - t_T$

Hill and oth.

Carrier Phases PseudoRange

- Phases of L1 and L2 carrier signals
  - L3, L4, L5



Carrier Phase Observations

$$f_A^k(t) = -\frac{f}{c} r_A^k(t) + N_A^k + f^k(t) - f_A(t) + other\ errors$$

Where, f_A^k : phase measured at A for k at time t

r_A^k : geometric range from A to k

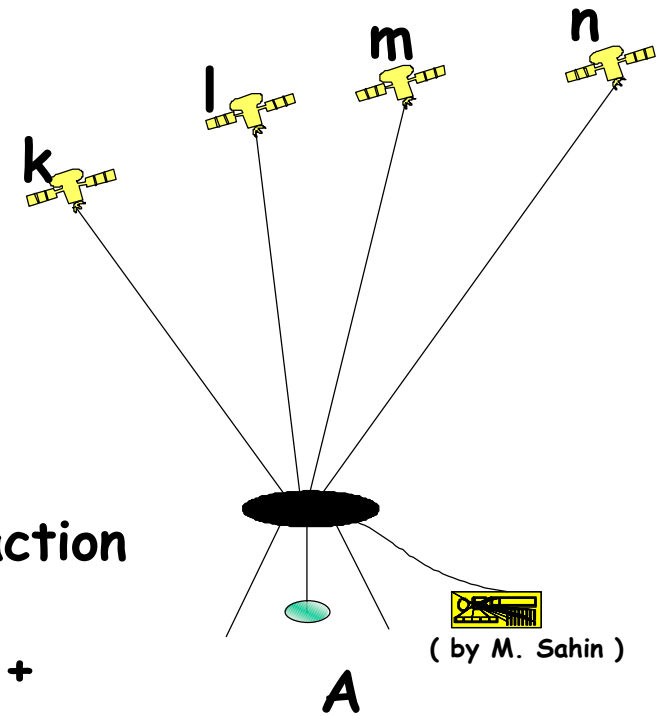
N_A^k : initial unknown integer number of cycles between k & A

f^k : Satellite clock error

f_A : Receiver clock error

f : frequency of signal

c : speed of light



Other errors

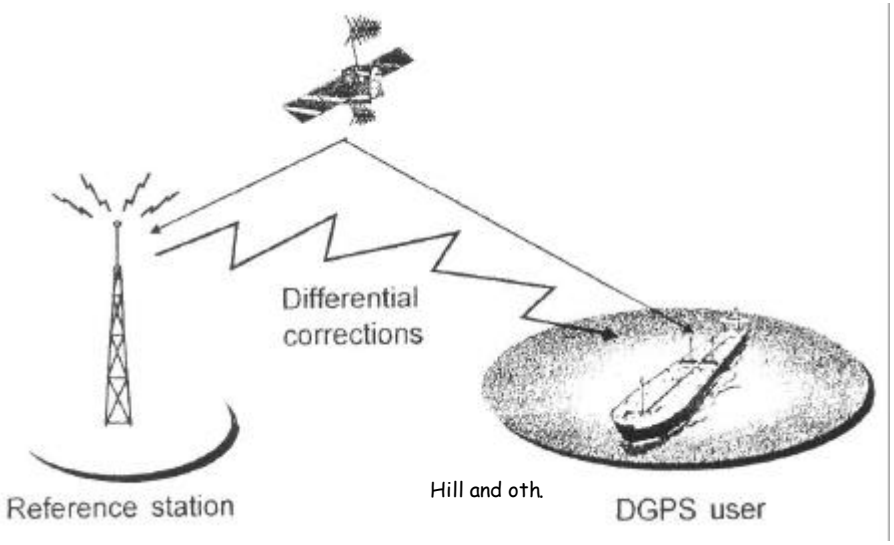
= Tropospheric refraction + ionospheric refraction
+ noise & biases + multipathing effects
+ antenna phase center offset & variation +
etc..

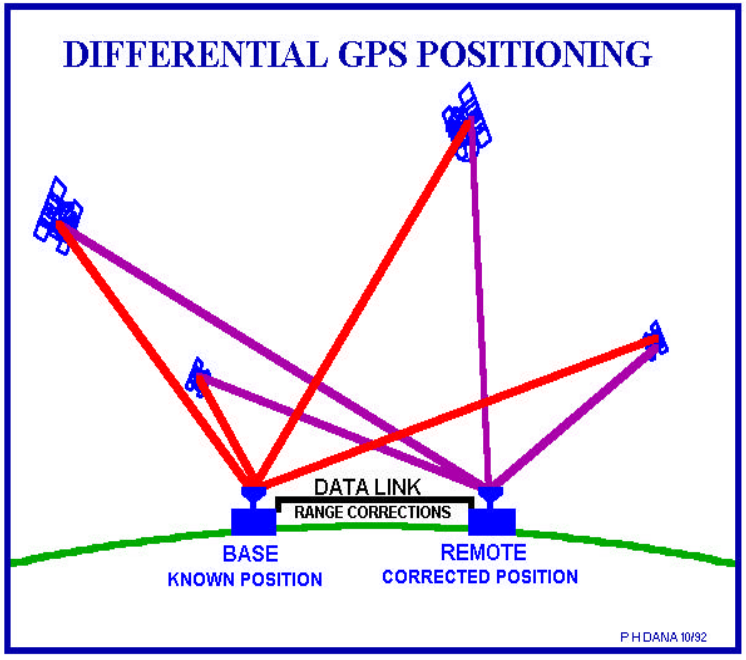
Codes PseudoRange

Differential GPS

Diferential Code

Diferential Carrier





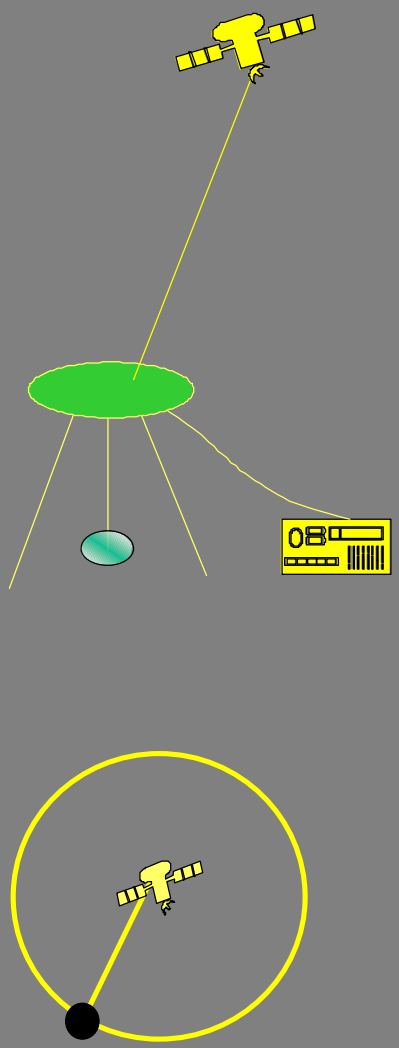
GPS ERROR SOURCES

ERROR SOURCE	TYPICAL RANGE ERROR	DGPS (CODE) RANGE ERROR <100 KM REF-REMOTE
SV CLOCK	1 M	
SV EPHEMERIS	1 M	
SELECTIVE AVAILABILITY	10 M	
TROPOSPHERE	1 M	
IONOSPHERE	10 M	
PSEUDO-RANGE NOISE	1 M	1 M
RECEIVER NOISE	1 M	1 M
MULTIPATH	0.5 M	0.5 M
RMS ERROR	15 M	1.6 M
ERROR * PDOP=4	60 M	6 M

PDOP=Position Dilution of Precision (3-D) 4.0 is typical

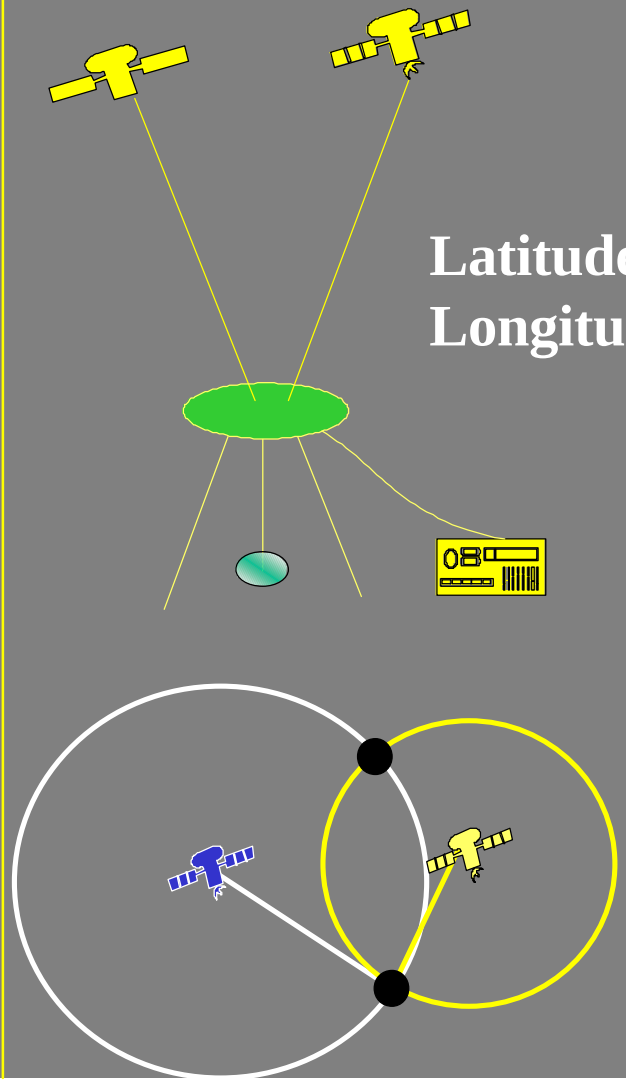
Satellite Positioning

1 satellite



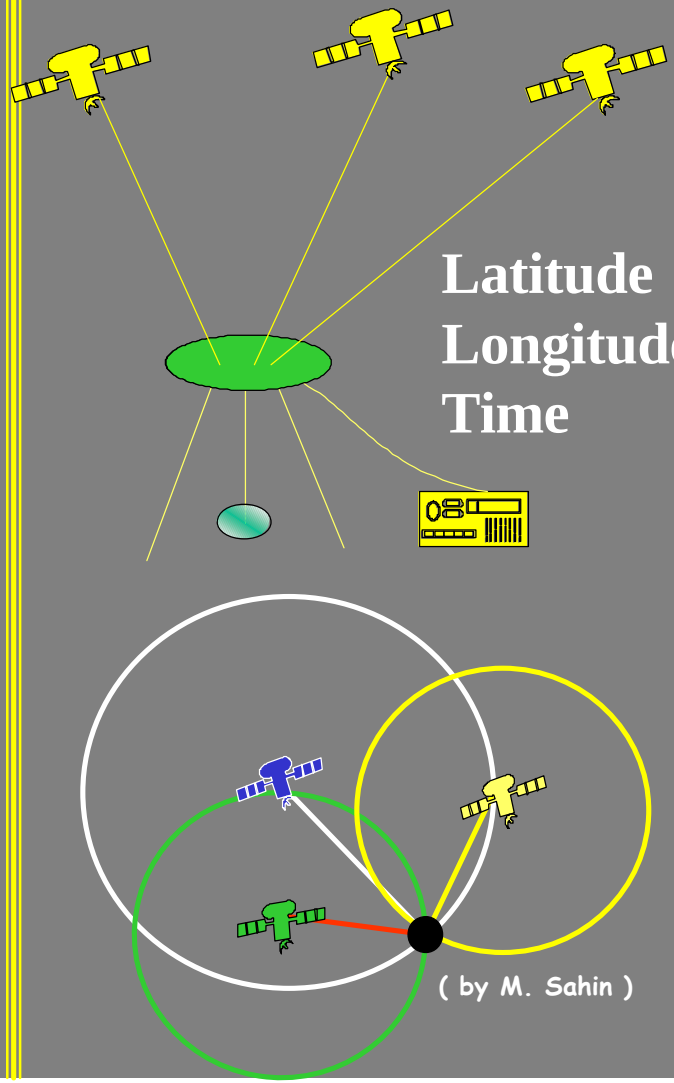
2 satellites

Latitude
Longitude



3 satellites

Latitude
Longitude
Time



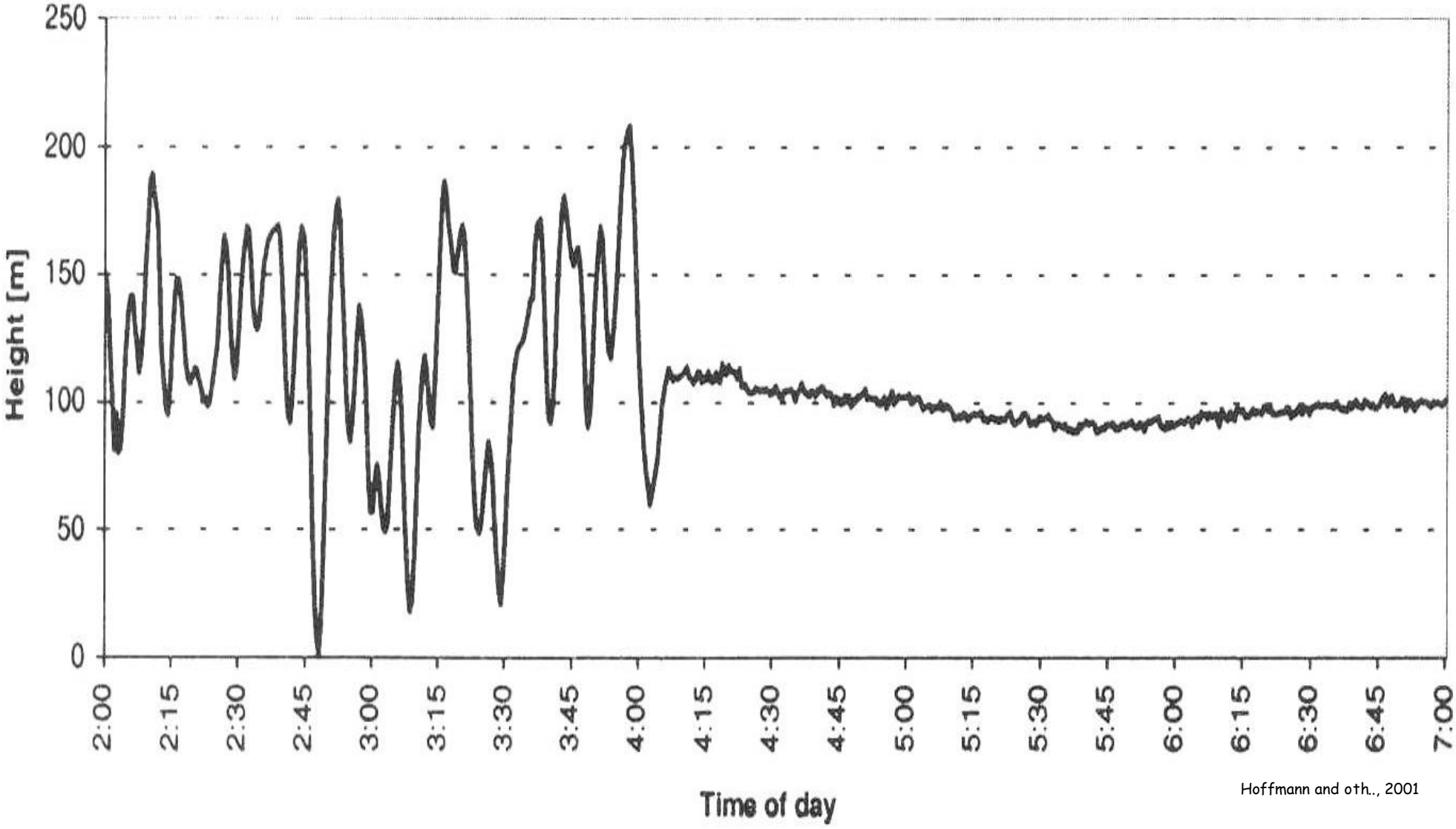
POSITIONING

- **Absolute Positioning**
  - Navigation, Code Observation
- **Diferential Positioning**
- **Relative Positioning**
  - Static Relative Positioning
  - Fast Static Relative Positioning
  - Kinematic Relative Positioning

Types

- SELECTIVE AVAILABILITY (SA)
- GEOMETRIC DILUTION OF PRECISION (GDOP)
- IONOSPHERIC EFFECT
- TROPOSPHERIC EFFECT
- OTHER EFFECTS

Selective Availability



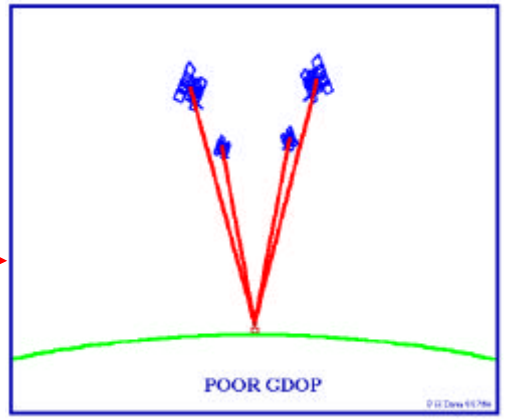
Hoffmann and oth.., 2001

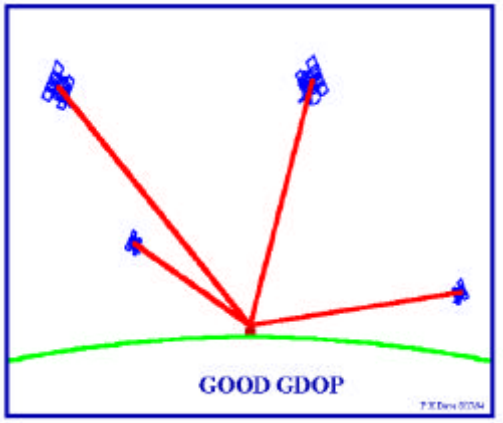
HEIGHT VARIATION IN THE STATION KOOTWIJK (NEDERLANDS)
DURING THE SA TRANSITION ON MAY 2, 2000

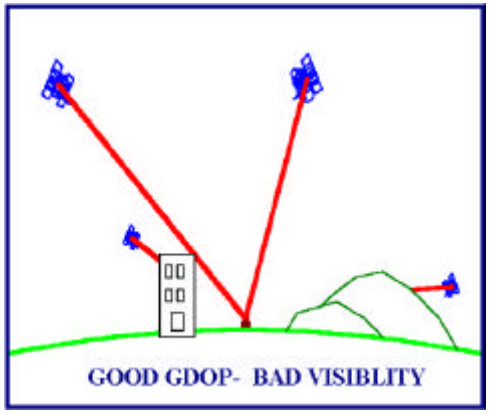
GDOP

GEOMETRIC DILUTION OF PRECISION (GDOP)

- Range vector differences between the receiver and the SVs
  - **Poor GDOP**
  - **Good GDOP**
  - **Good Computed GDOP and Bad Visibility**







- GDOP Components
  - **PDOP** : Position Dilution of Precision (3-D), sometimes the Spherical DOP.
  - **HDOP** : Horizontal Dilution of Precision (Latitude, Longitude).
  - **VDOP** : Vertical Dilution of Precision (Height).
  - **TDOP** : Time Dilution of Precision (Time).

Atmospheric Effects

⇒ IONOSPHERIC EFFECT

⇒ 50-500 Km.

⇒ Delay: 10 meters.

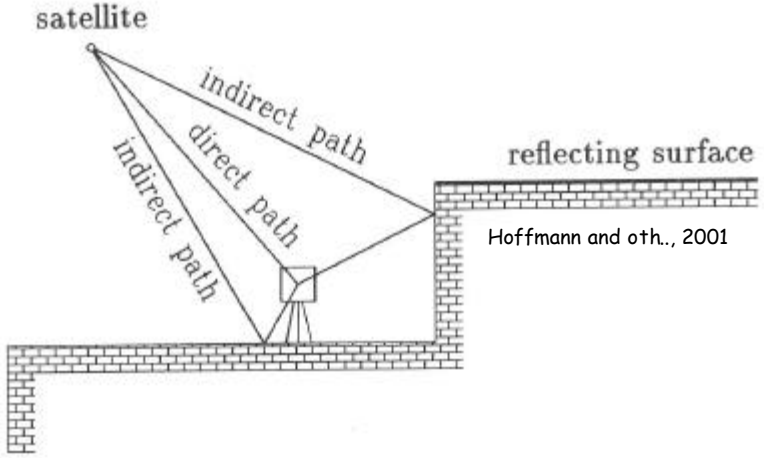
⇒ TROPOSPHERIC EFFECT

⇒ 8-13 Km.

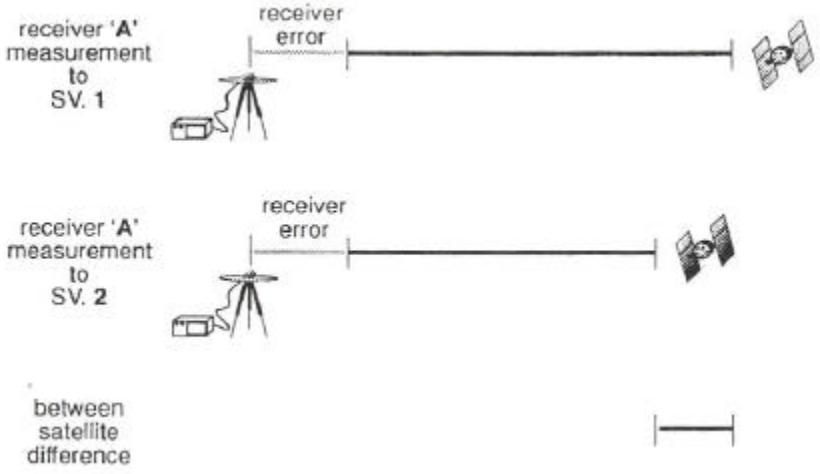
⇒ Delay: 1 meter.

Others

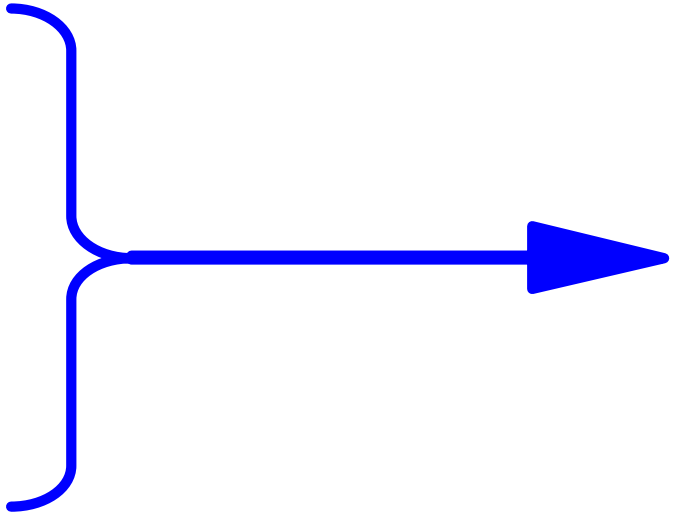
- SV clock errors
- Ephemeris data errors
- Multipath (Ghost)
- Control segment mistakes
- User mistakes
- Receiver errors
- Noise and bias errors



Hoffmann and oth., 2001

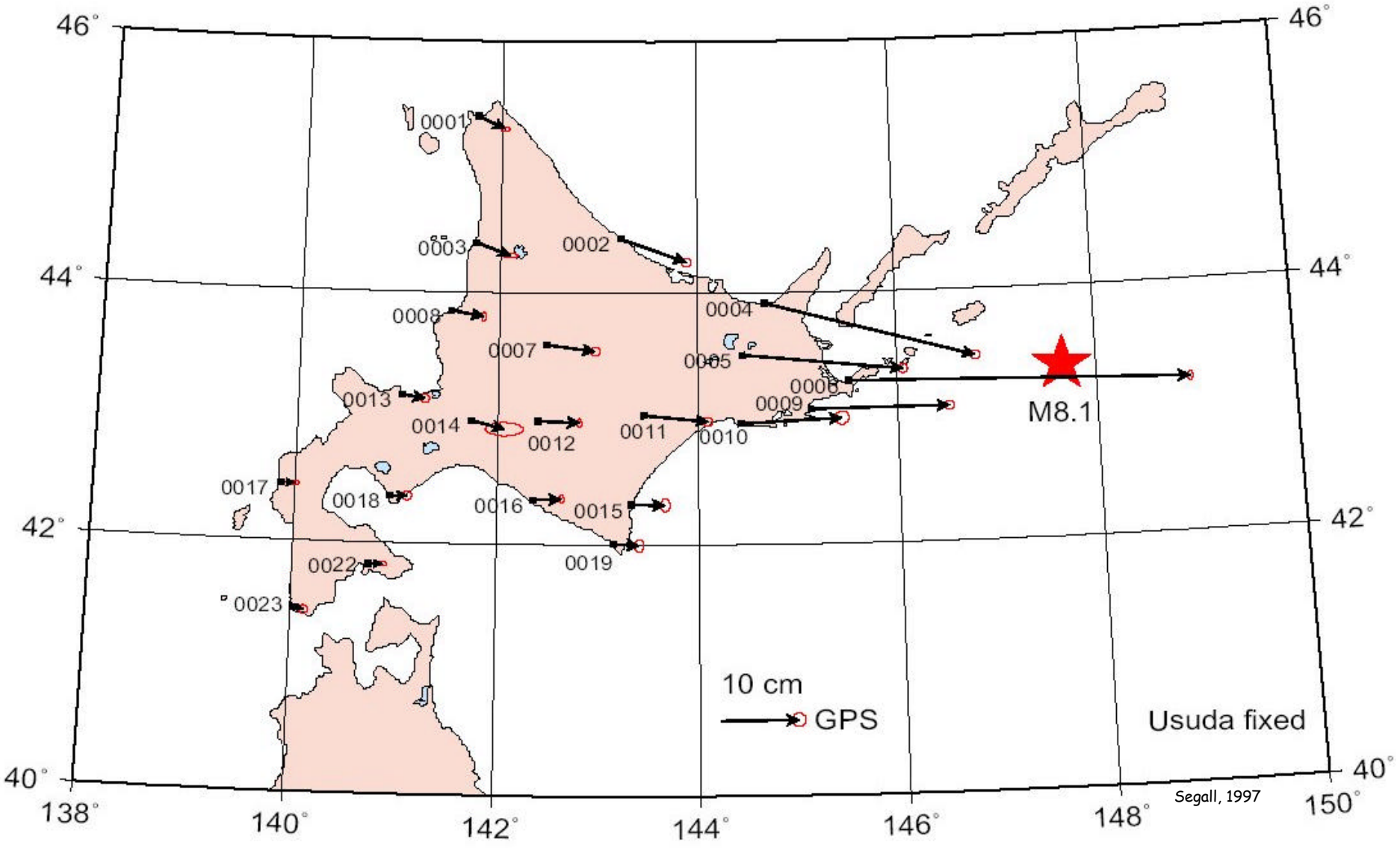


- **GEOPHYSICS USES GPS TO EXPLAIN**
  - Plate Movement and Plate Boundary Deformations
  - Volcanic Deformation
  - Glacial Isostatic Adjustment and Sea Level Change
  - Landslide and Dam Deformations
  - **Earthquake Studies**
    - **Interseismic Deformation**
    - **Coseismic Deformation**
    - **Postseismic Deformation**



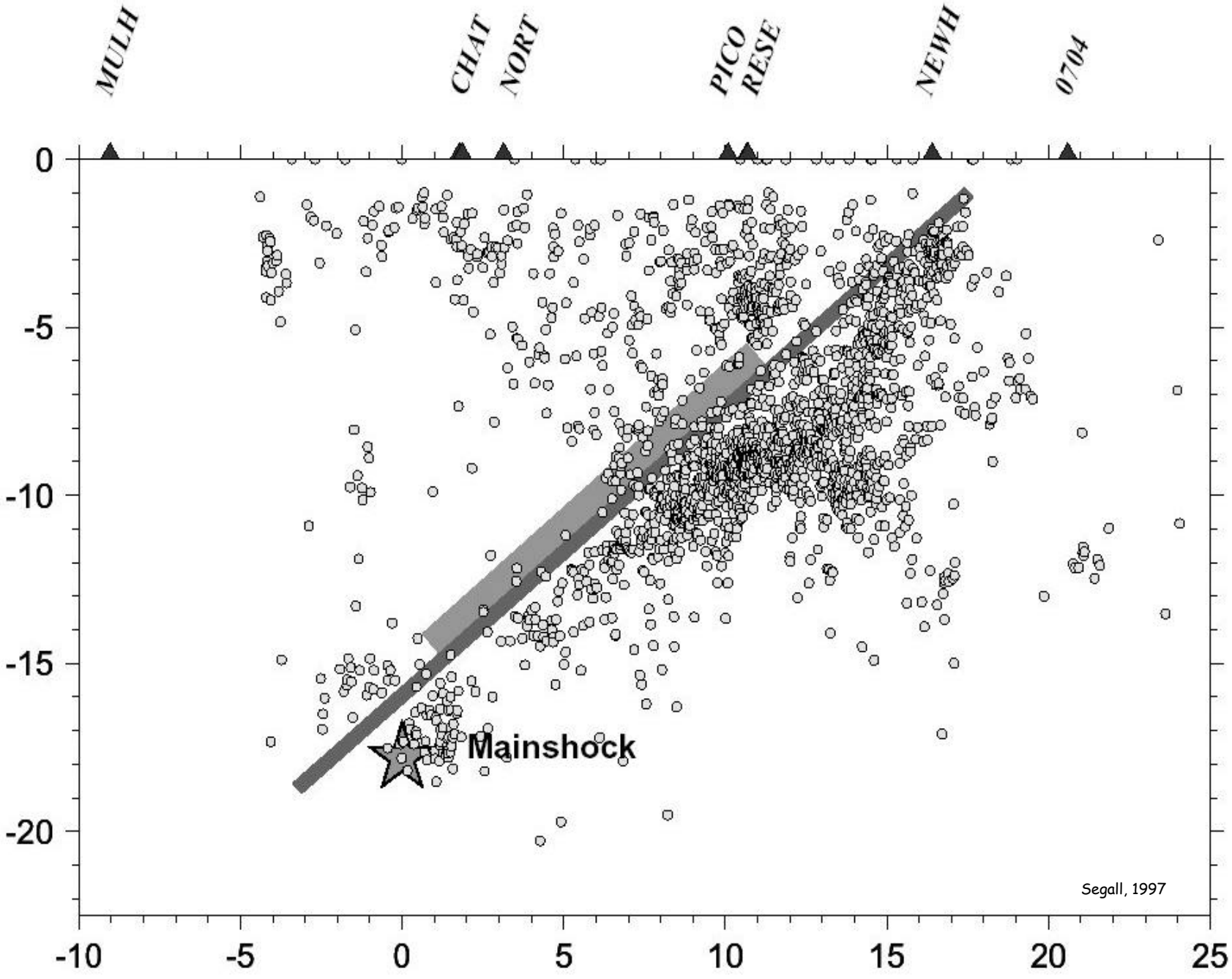
Earthquake Studies Coseismic Deformation

M8.1 Kurile Island, Hokkaido-Toho-Oki, Japan, Earthquake, 1994.



M6.7 Nothridge, 1994

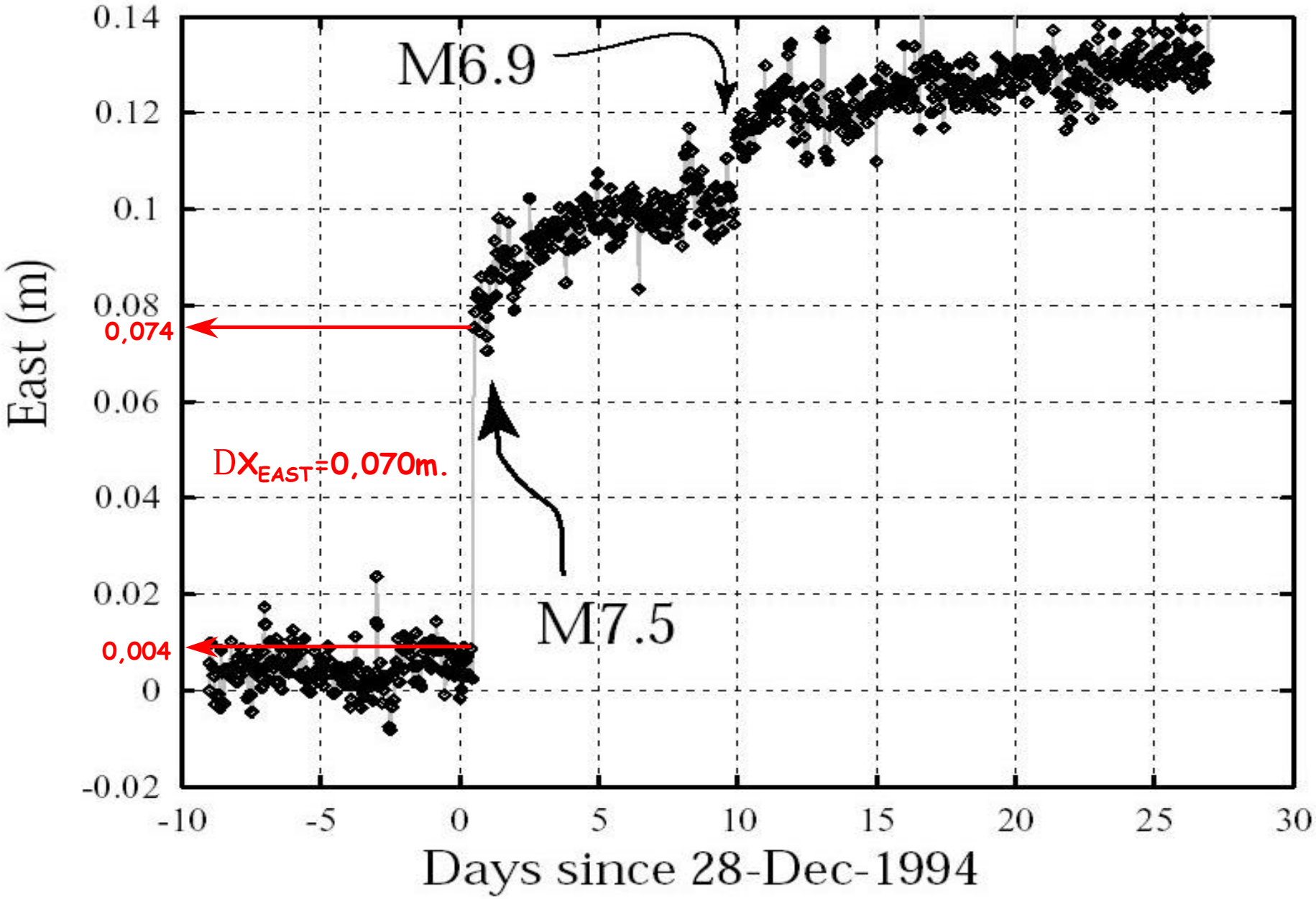
Earthquake Studies Coseismic Deformation



Aksari, D. 2002

Earthquake Studies Postseismic Deformation

M7.5 Sanriku Haruka Oki, Japan, Earthquake, 1994



Earthquake Studies
Interseismic Deformation

- Many of interseismic studies is in southern California
- Northridge Earthquake
  - Donnellan, 1993, M~6.4 ⟹ 1994, M6.7
- Benett ve oth. (1996), Donnellan and oth. (1993), Feigl and oth. (1993)

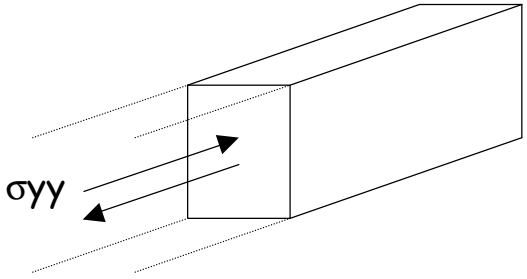
Earthquake Studies
Modeling of GPS Data for Geophysical Studies

Point Coordinate

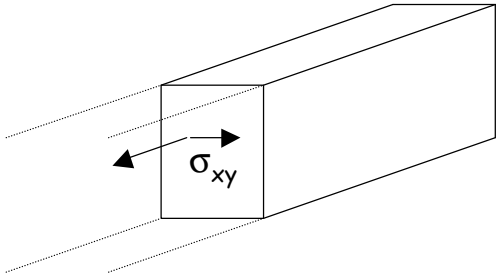
Measurement Style Duration

Vectorial Coordinate

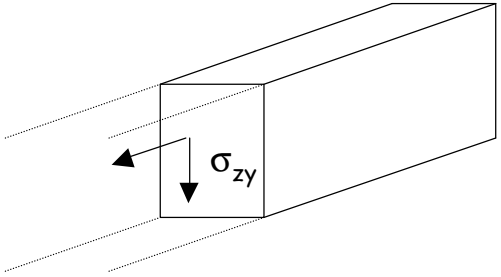
There are three mod of a substance are exposed to dislocation



1. mod deformation.



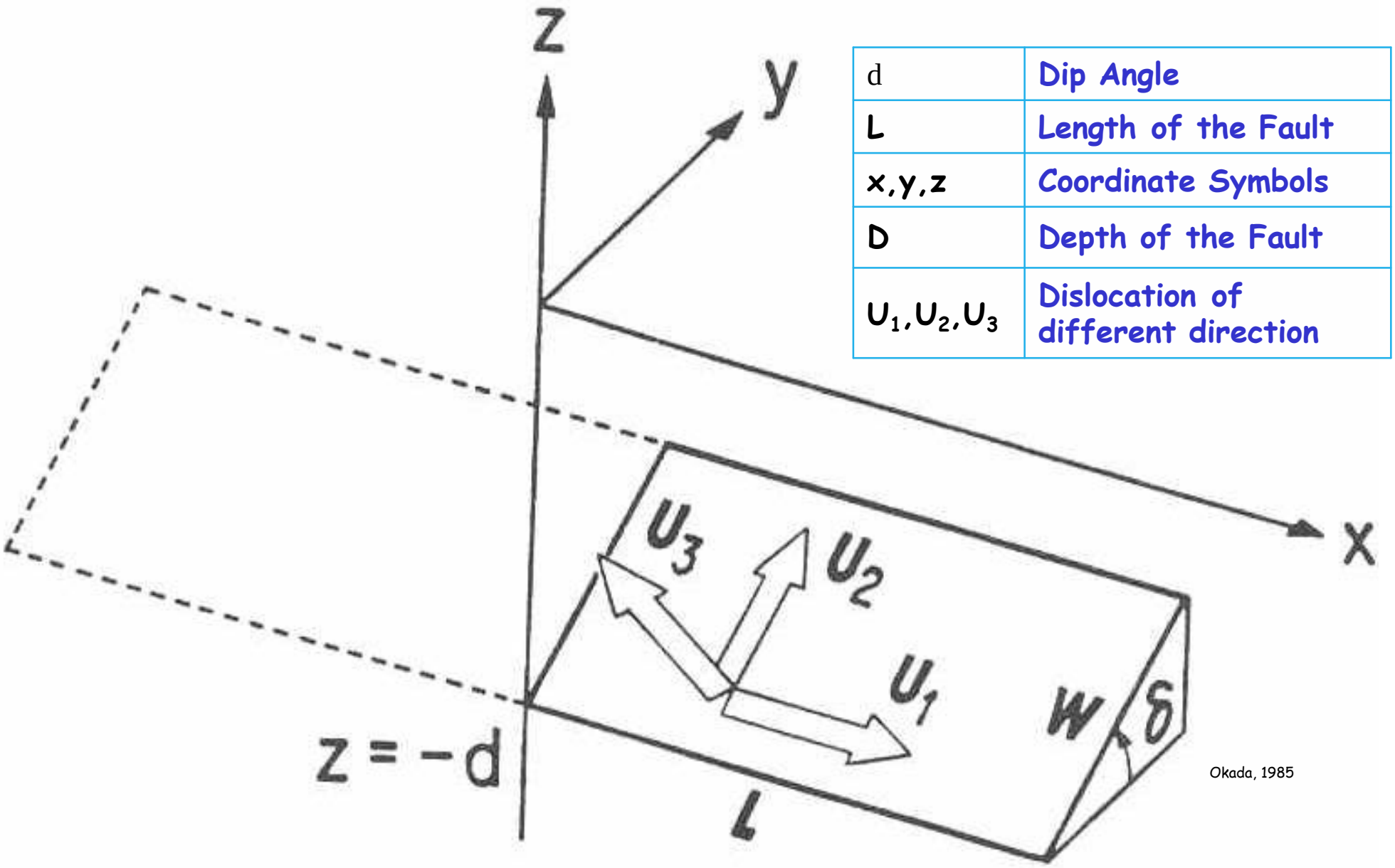
2. mod deformation.



3. mod deformation.

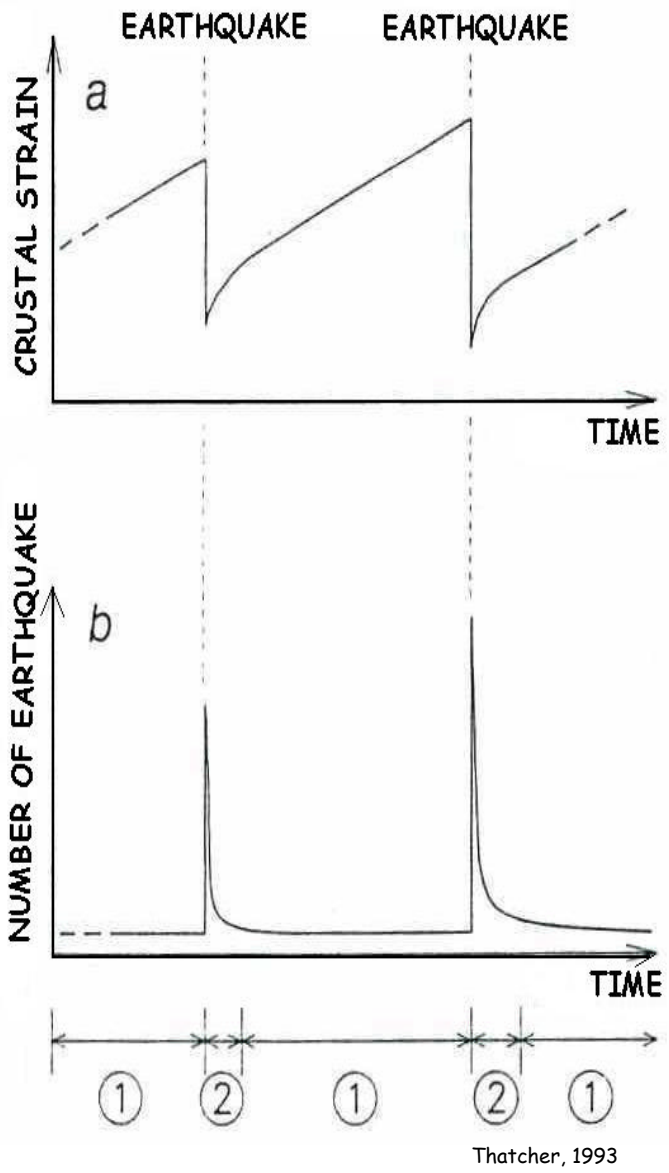
Earthquake Studies
Effects of the Source Geometry on Dislocation Area

d	Dip Angle
L	Length of the Fault
x,y,z	Coordinate Symbols
D	Depth of the Fault
U_1, U_2, U_3	Dislocation of different direction

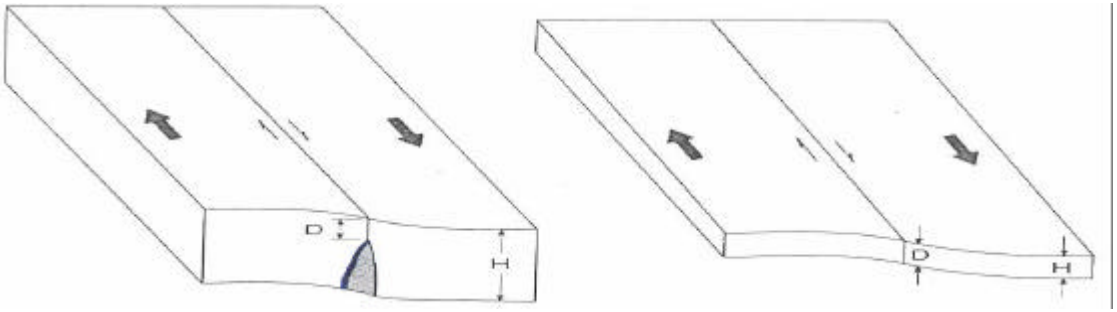


Okada, 1985

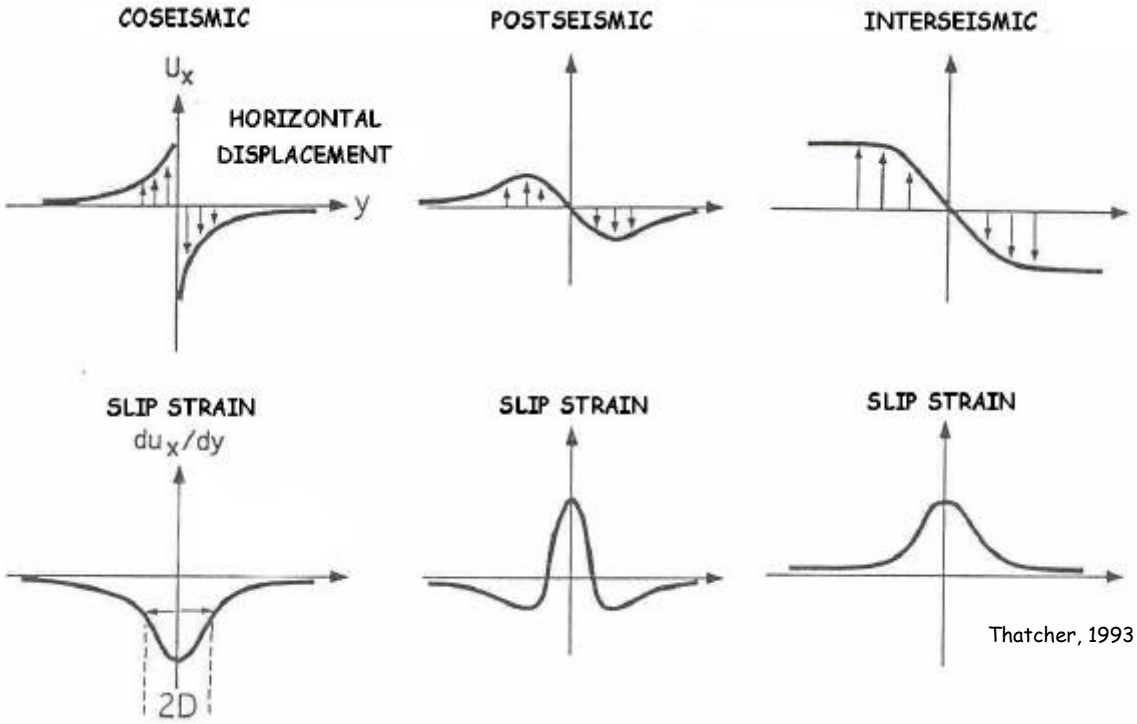
Deformation Cycle of Earthquake and Strain Relation



Thatcher, 1993

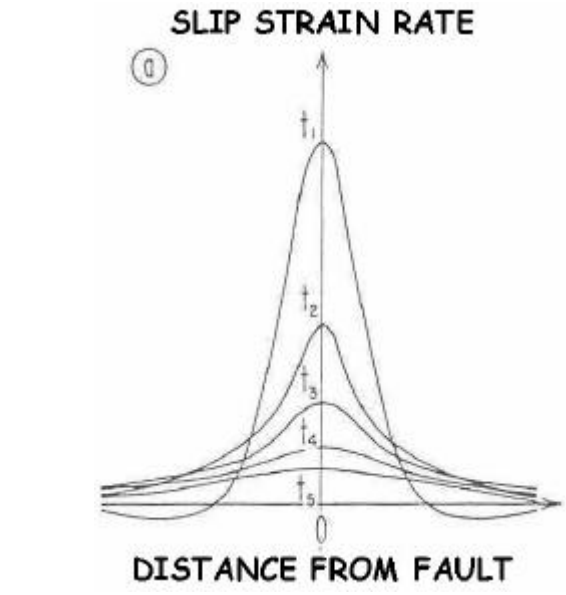


Thatcher, 1993

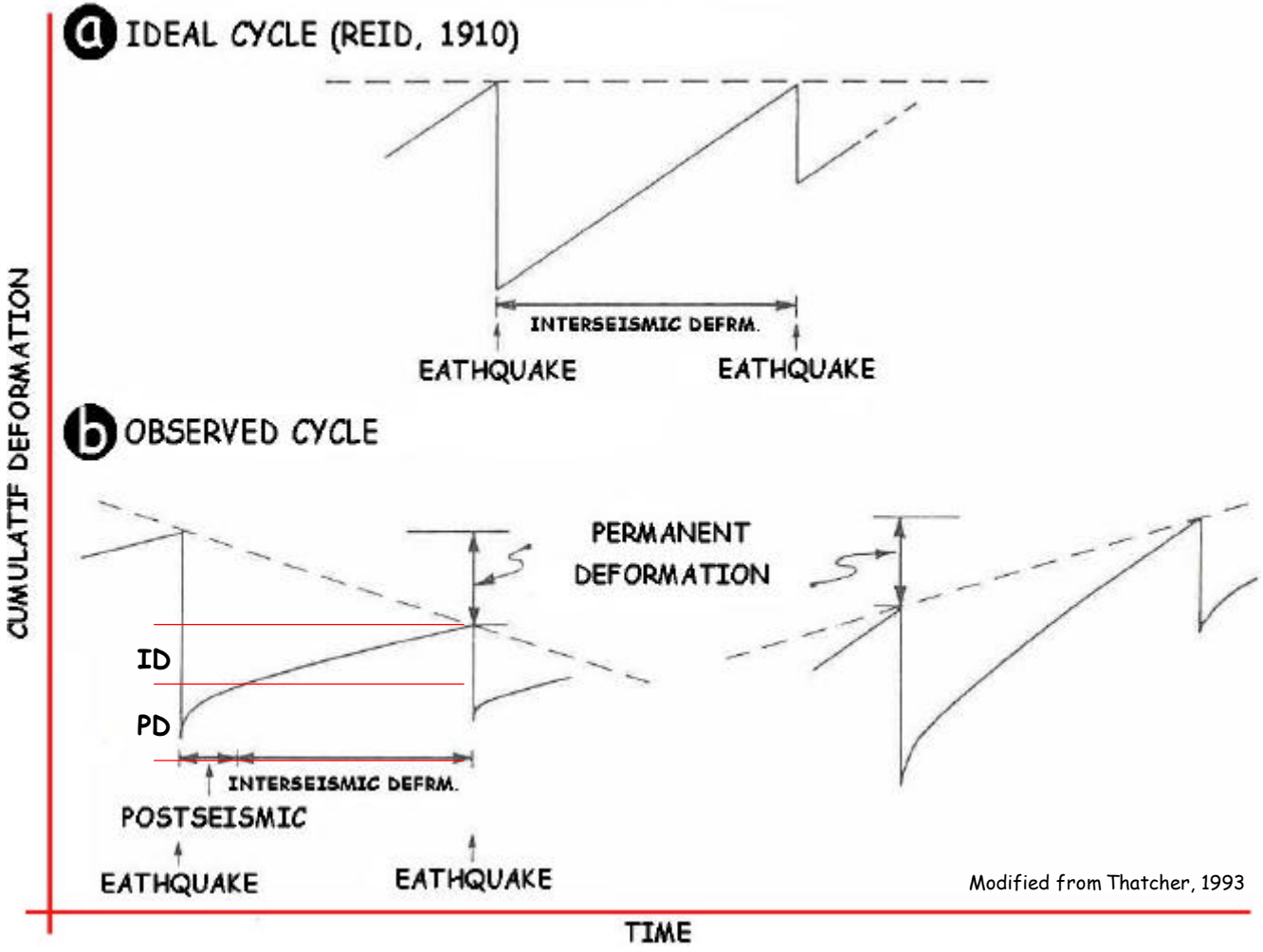


Thatcher, 1993

Deformation Cycle of Earthquake and Strain Relation

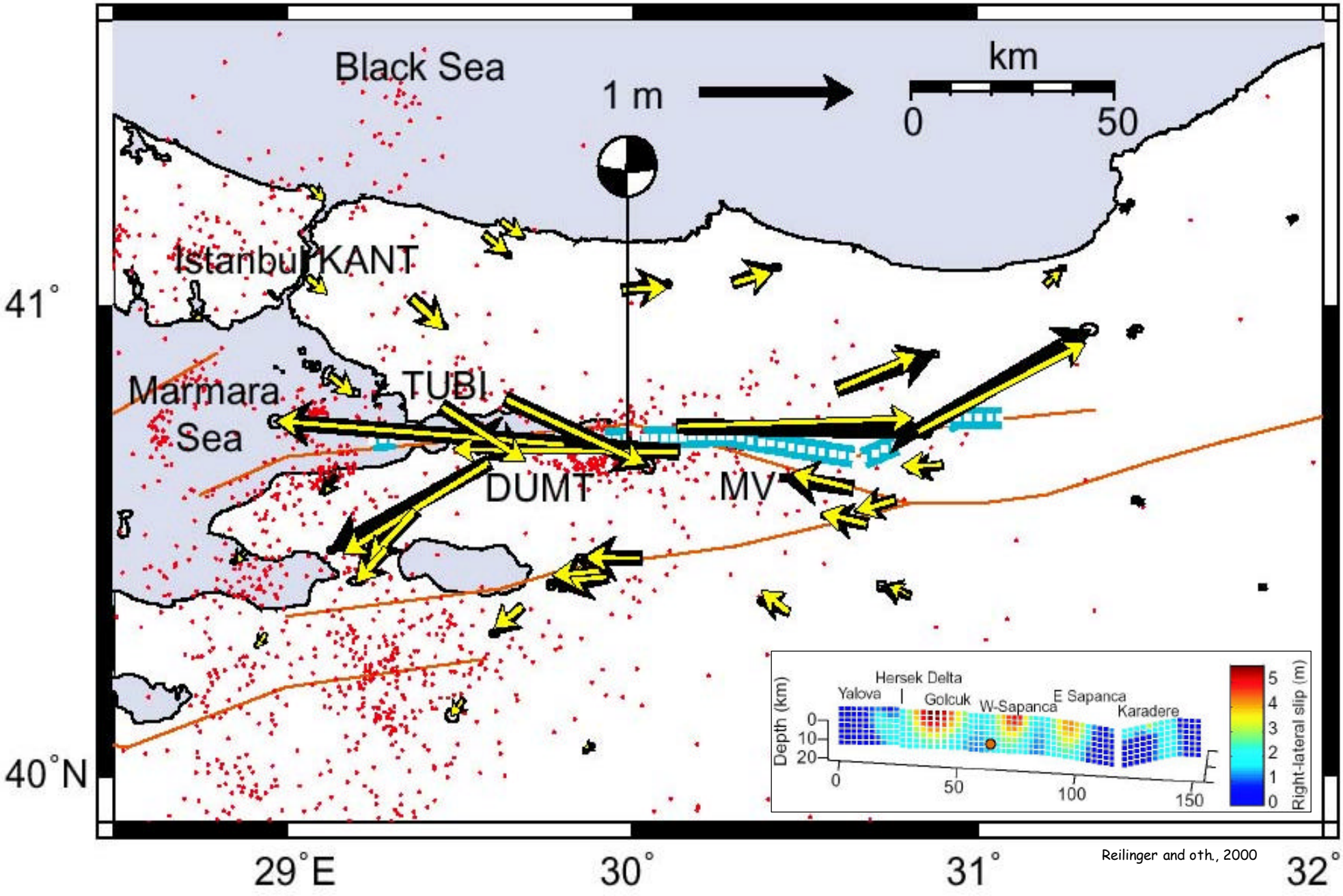


Thatcher, 1993



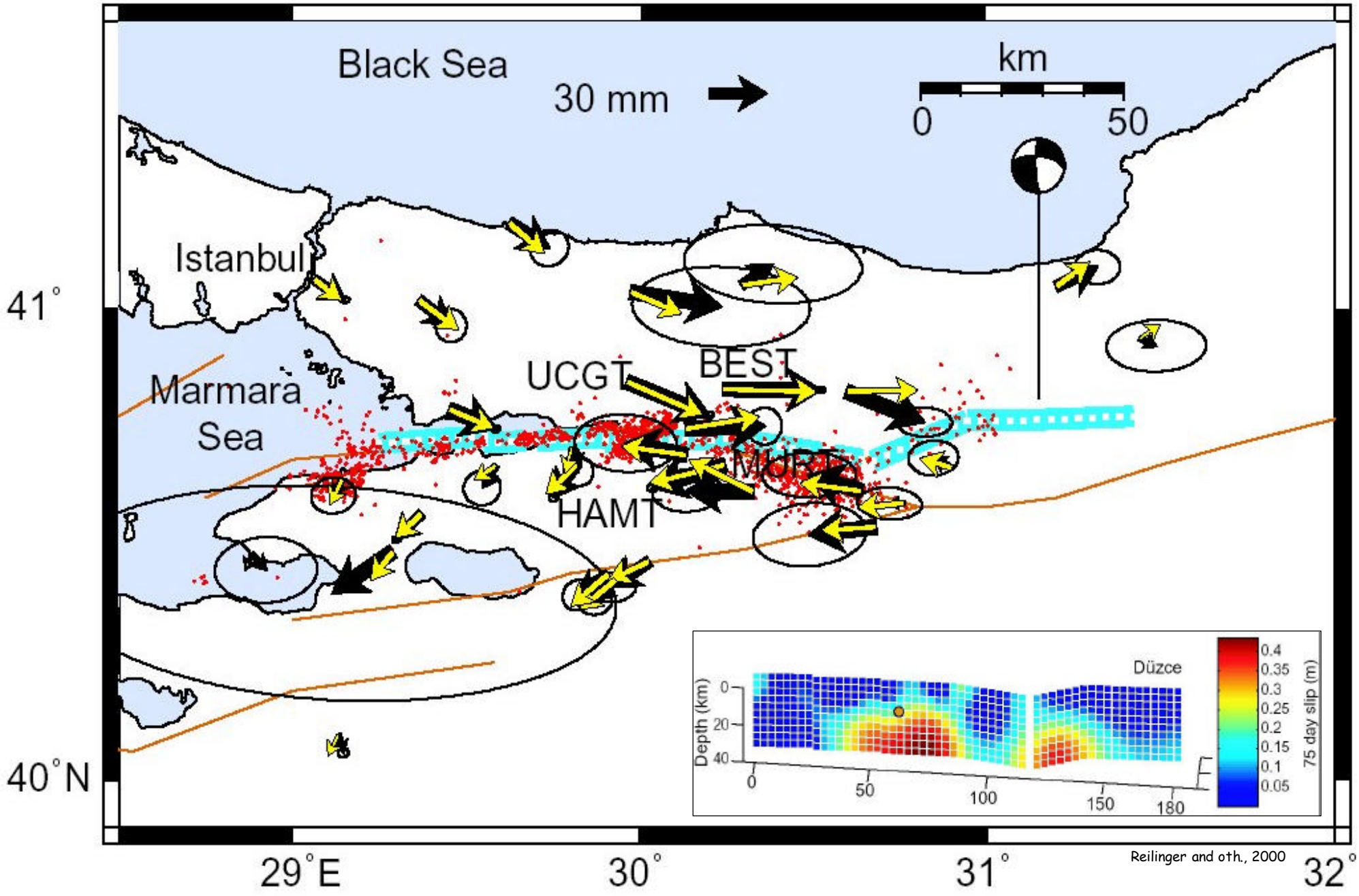
Modified from Thatcher, 1993

Examples of GPS Studies for 1999, Kocaeli Earthquake



Reilinger and oth., 2000

Examples of GPS Studies for Kocaeli Earthquake

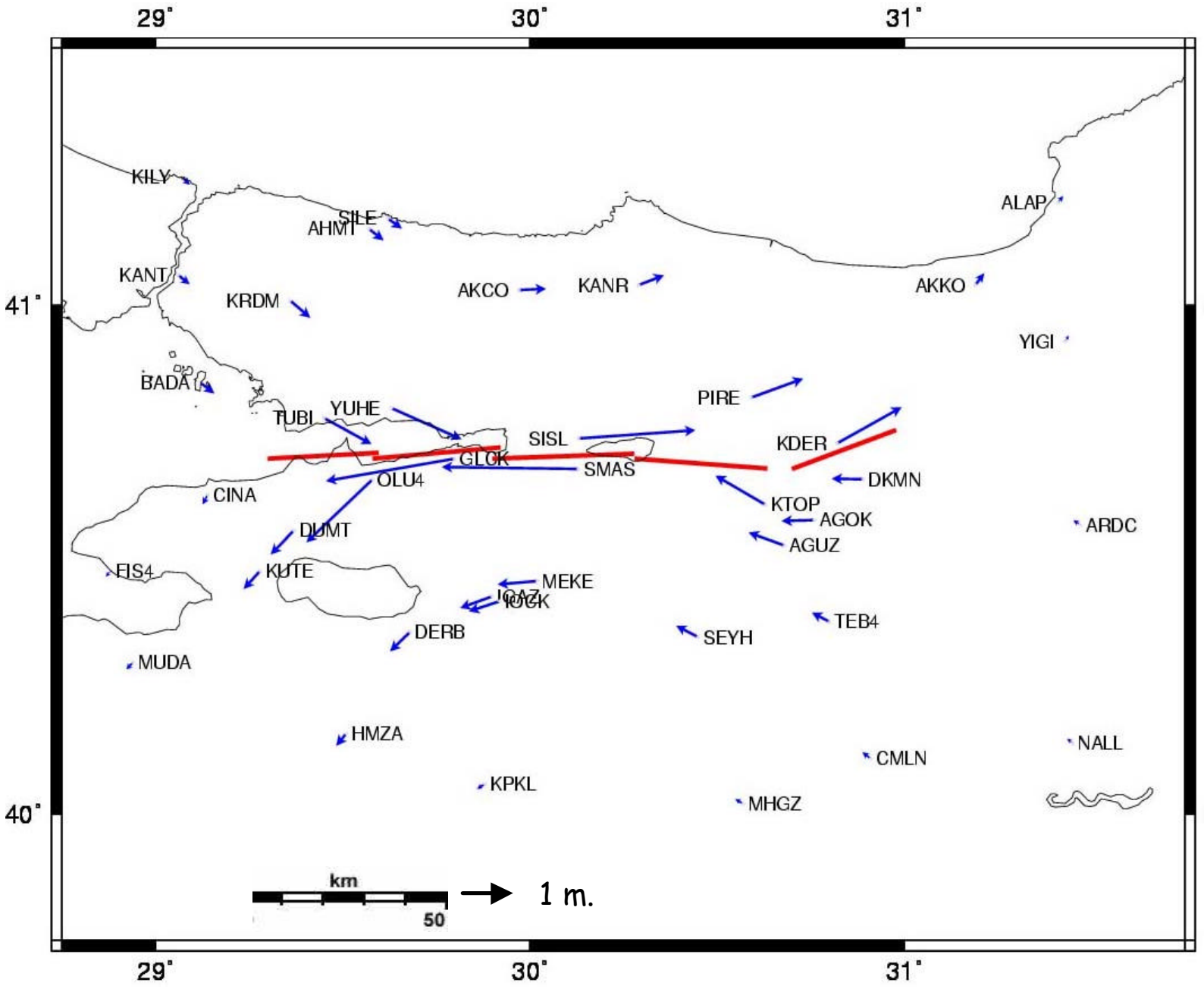


Modeling Program

- Modeling Program
  - uses Okada's definitions
  - was written by Semih Ergintav and oth.
    - (TUBITAK-MRC-EMSRI).
  - reads the data from a file
  - calculates displacements at two dimension for every defined point.

- Then, saved data is given to GMT as input file. GMT plot the data on a map.

Examples of Moddelling Program



Şekil No	1. Fay	2. Fay	3. Fay	4. Fay	5. Fay
Enlem (°)	40.7	40.7	40.7	40.7	40.68
Boylam (°)	29.3	29.58	29.9	30.28	30.7
Strike (°)	87	85	88	94	70
Derinlik (km)	20.0	20.0	20.0	20.0	20.0
Eğim Açısı (°)	90.0	90.0	90.0	90.0	90.0
Uzunluk (km)	25	29	32	30	25
Genişlik (km)	20.0	20.0	20.0	20.0	20.0
x Yönünde Atım (cm)	-100	-570	-550	-400	-300
y Yönünde Atım (cm)	0.0	0.0	0.0	0.0	0.0

RESULTS and SUGGESSIONS

- ✓Precise and economic method
- ✓Geophysics
  - ✓earthquake studies and deformation analysis
    - ✓Interseismic deformation
    - ✓Postseismic deformation
    - ✓coseismic deformation
- ✓Kocaeli Earthquake
- ✓a computer program
- ✓MAGNET

- **Aksari, D., 2001,** GPS Nedir? GPS Yardimiyla Jeofizik Problemlerine Nasil Çözüm Bulunur?, Bitirme Tezi, ITÜ Maden Fakültesi, Istanbul.
- **Argus, D.F., Heflin, M.B., 1995.** Plate Motion and Deformation Estimated with Geodetic Data From the Global Positioning System. Geophys. Res. Lett., 22: 1973-1976.
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December, 2002