Geodesy on the move

Dealing with dynamic coordinate reference systems

Roger Lott

Chairman, IOGP Geodesy Subcommittee

IOGP Geomatics Industry Day

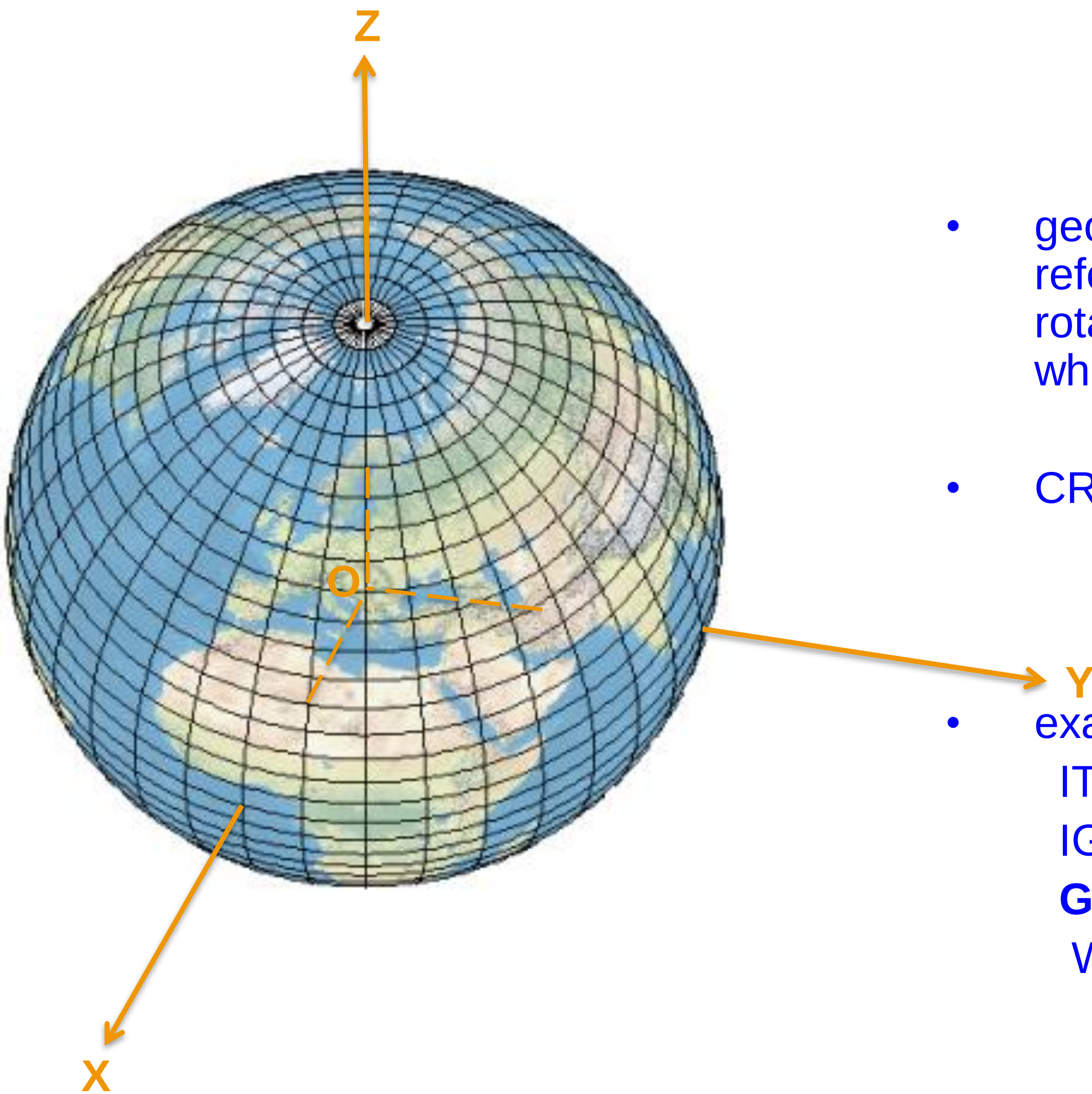
Stavanger, April 2017

Historic geodesy

- datum origin and geodetic network on the Earth's crust
- CRS is national or regional
- examples: ED50, NAD27, NAD83(86), AGD66, AGD84
- *coordinates do not change with time* = "static".
- mental image of a solid Earth: "Third Rock from the Sun"

International Association of Oil & Gas Producers

Earth-centred, earth-fixed frame



- geocentric Cartesian reference frame co-rotates with the Earth as a whole.
- CRS is global
- examples:

  ITRS ITRF88…ITRF2014

  IGSxx IGS00…IGb08

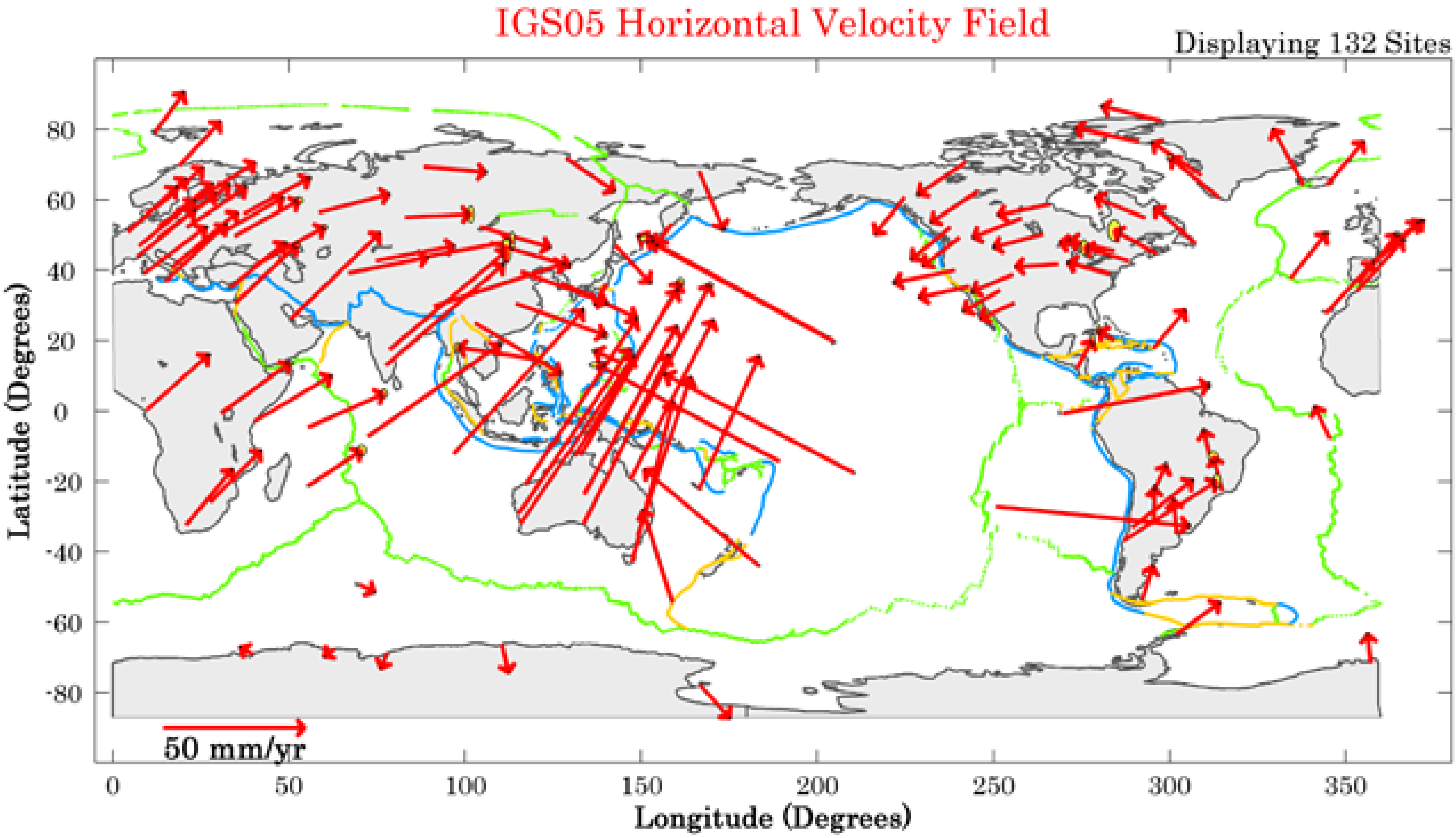
  GNSS CRSs:

  WGS 84 …WGS 84(G1762)

  PZ-90 …PZ-90.11

  etc.

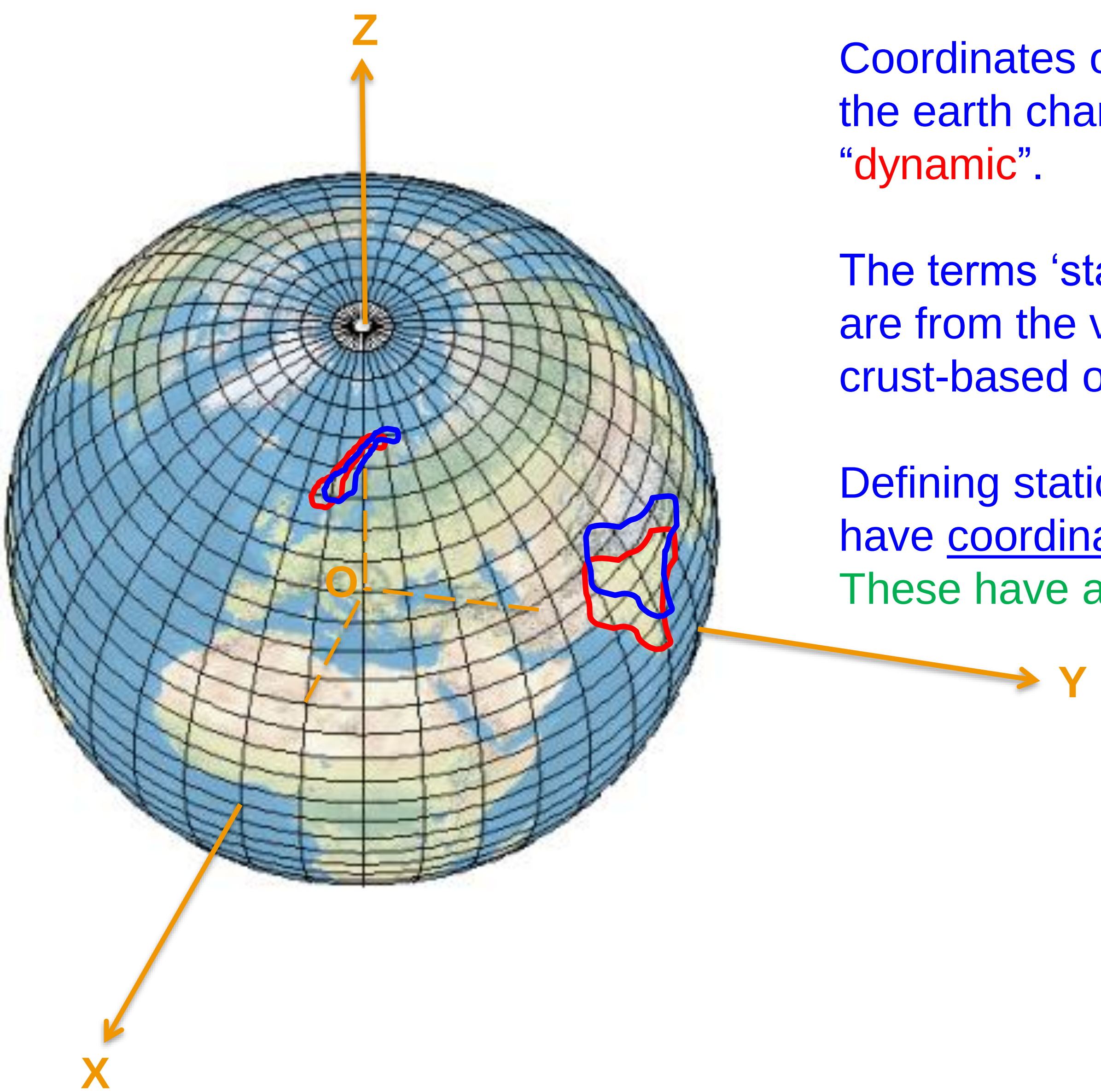
Tectonic plate velocities



EU ≈ 2.5 cm/yr Australia ≈ 7 cm/yr

International Association of Oil & Gas Producers

Plate motion in an ECEF frame



Coordinates on the surface of the earth change with time: "dynamic".

The terms 'static' and 'dynamic' are from the viewpoint of a crust-based observer.

Defining stations (on crust) have coordinates and rates.
These have a reference epoch.

ITRF-based static CRSs

- Snapshot of global dynamic system
  - defined to be same as ITRFxx at a specific reference epoch …
  - … but fixed to a plate – regional – static

  - examples:

    ETRF89, NAD83(2011), GDA94, GDA2020
    - modern national geodesy

  - reference from ITRF dealt with by time-dependent transformation
    - when ITRF updated, may be a new transformation and realization
      - ETRF89 … ETRF2000
      - NAD83(CSRS)v2 … NAD83(CSRS)v7

International Association of Oil & Gas Producers

Semi-dynamic reference frames

Hybrid, hoping to get best of all worlds

- static for applications that can ignore tectonic motion
- dynamic for those that require highest accuracy
- national or regional

Two approaches:

(1) True semi-dynamic

Two components

(i) static

(ii) time-dependent deformation model

- examples: New Zealand NZGD2000, Canada CGVD2013, NN2000

(2) Periodically-updated

- coordinates periodically updated
- example: Israel IG05, IG05/12

Trend is for future geodetic reference frames to be semi-dynamic

The issue

The apparent drift of dynamic CRSs has been ignored

- ETRF89 was defined to be ITRS at epoch 1989.0
- At 2.5cm per year, by 2017 ETRF89 differs from ITRF & ~~GNSS~~ WGS 84 by 75cm

- GDA94 was defined to be ITRF92 at epoch 1994.0
- At 7cm per year, by 2017 GDA differs from ITRF & ~~GNSS~~ WGS 84 by over 1.5m

With advances in real-time positioning technology the differences can be detected

- Australia traffic accident

Coordinate operation methods

Need to account for the temporal change of the dynamic CRS, as well as the movement of the traditional, plate-bound, CRS seen from the viewpoint of the dynamic CRS.

- **Time-dependent Helmert transformation**
  - 15 parameters
  - Two steps:
    1) 7 transformation parameter values for the desired epoch are computed from the rate parameters
    2) 7-parameter transformation applied
  - e.g. ITRFxx > ITRFyy, ITRF2008 > GDA94

- **Time-specific Helmert transformation**
  - 8 parameters
  - Two steps:
    a) coordinates to be converted within the dynamic CRS to this time
    b) 7-parameter transformation applied
  - e.g. PZ-90.11 to WGS 84 (G1150) [GLONASS to GPS]

- **Change of epoch** within a dynamic CRS (for time-specific step (a) above)
  - "coordinate propagation"
  - 5 parameters (3 geocentric or geographic coordinate velocities, start and finish times)
  - Velocities for station coordinates from:
    i. Station solution
    ii. Plate motion or deformation model

International Association of Oil & Gas Producers

Coordinate operations

Between CRSs both with static datum

- No time dependency

  e.g. ED50 > OSGB 1936, NGO 1948 > ED50

Between CRSs both with dynamic datum

- Time-dependent transformation

  e.g. ITRF2008 > ITRF2014

- Time-specific transformation

  e.g. PZ-90.02 > PZ-90.11

Between CRSs of different dynamism …

- dynamic, semi-dynamic, static

- … using different transformation methods

  time-dependent, time-specific

- with deformation or velocity grid

Time

Time referencing has three (four) contexts:

- Dynamic **CRS** reference epoch

  ITRF2008 reference epoch is 2005.0, ITRF2014 reference epoch is 2010.0
  - 2008 / 2014 just names
  - 2005.0 / 2010.0 = dates to which station coordinates & rates refer

- **Coordinate** data epoch
  - Attribute of data set, nothing to do with CRS definition
  - ITRF2008 @ 2014.65 ≠ ITRF2008 @ 2017.23 ≠ ITRF2008 [@2005.0]

- **Transformation** reference epoch, which in itself has two forms

  a. parameter reference epoch for time-dependent transformations

  b. transformation reference epoch for time-specific transformations

  - both of these are one of the transformation parameters

International Association of Oil & Gas Producers

The problems

1. **User confusion**

- complex
- all components of the problem vary over time.

2. **Inadequate metadata**: coordinate epoch not clear

3. **Indirect transformations**

- ETRF89 > ED50 versus ETRF89 > WGS 84 > ED50

4. Time-dependent **transformation methods only found in specialist software**

International Association of Oil & Gas Producers

Recommendations

1. **Users need to**
   - **be aware of whether the CRS is dynamic or static**
   - **in addition to the CRS being identified the time [epoch] of coordinates should be recorded when using a dynamic CRS**
     - **ITRF2014 @ 2017.23**
     - **WGS 84(G1762) @ 2017.23**
   - **convert data to common epoch before merging**
   - **be aware that WGS 84 ≈ ETRFxx (or any other ITRS-derived static CRS) is an increasingly unacceptable approximation – for sub-metre accuracies stop using it!**
2. **Software developers should**
   - **add time-dependent transformation methods**
   - **add velocity grids**
   - **allow for coordinate epoch as a dataset attribute**

International Association of Oil & Gas Producers

What is IOGP doing?

1. Guidance Note in preparation

2. Guidance note 373-17 revision (Gulf of Mexico)

3. Additions to EPSG Dataset
   - all realizations to be added
   - ensembles to be added
   - dynamic CRSs to be identified

International Association of Oil & Gas Producers