Geodesy on the move
Dealing with dynamic coordinate reference systems

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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”
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
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
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
     1. **static**
     2. **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 by 75cm WGS 84

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

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
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 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
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**
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
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