On the ITRS Datum Specifications

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Introduction

Reference Systems are the *definition* of constants, conventions, models, and parameters, which serve as the necessary basis for mathematical descriptions of geometric and/or physical quantities and/or processes;

e.g.: metric, 3-dimensional, Cartesian, geocentric coordinate system with equatorial orientation and rotating with the Earth crust.

Reference Frames *realize* reference systems physically (materialization) and mathematically (parameter estimation);

e.g.: a number of physical points with coordinates computed from measurements according to the definition of the reference system.

Geodetic Datum is the unequivocal relation between reference frame and reference system *given* by a set of datum parameters;

e.g.: coordinates of the origin (X_0, Y_0, Z_0), directions of coordinate axes, scale as a unit of lengths (e.g., metre).

Fundamentals to be followed

Reference systems, the geodetic datum, and reference frames form an order of hierarchy:

Reference **systems** must be completely unaffected by the realization of reference frames and the geodetic datum, i.e., the realization of the system by the frame and the datum **must not** change the definition!

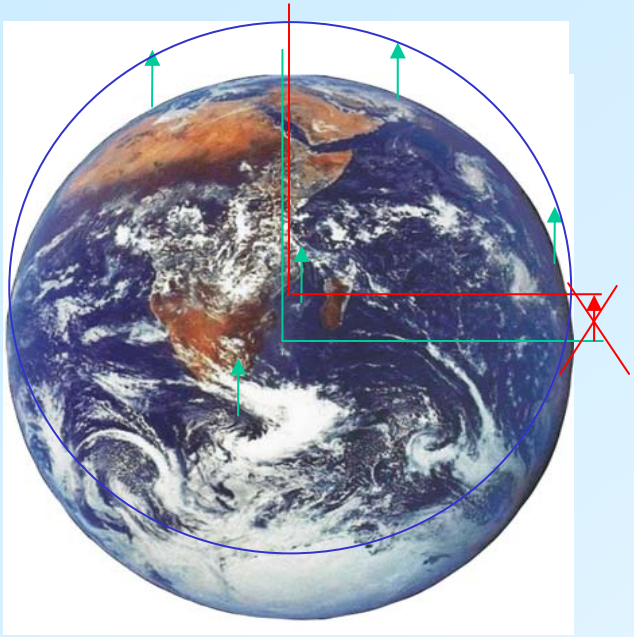
The realization of the **datum** has to be done by methods independent of the measurements of the reference frame, i.e., measurement errors or physical changes of the frame **must not** affect the datum!

The mathematical realization of the reference **frame** has to be done by algorithms that **fix** the datum parameters and follow strictly the rules defined by the reference system!

In a three-dimensional system we have to fix 7, and only 7, datum parameters.

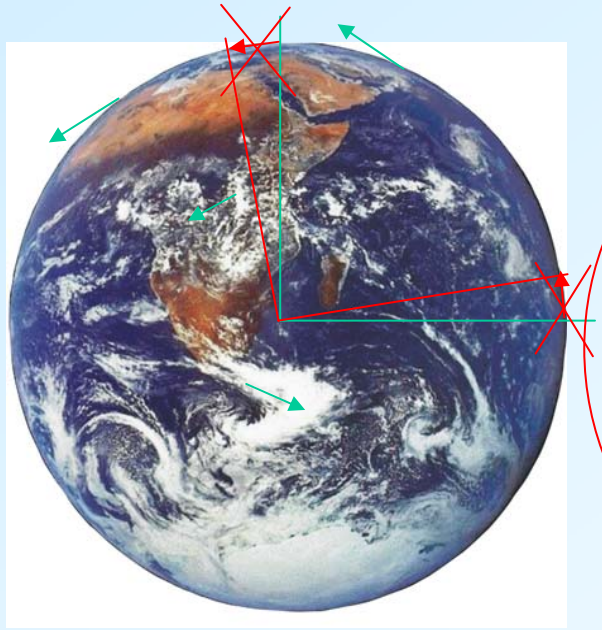
Fixing the origin, orientation and scale

Fix coordinates of the geo-centre to $X_0 = Y_0 = Z_0 = 0$



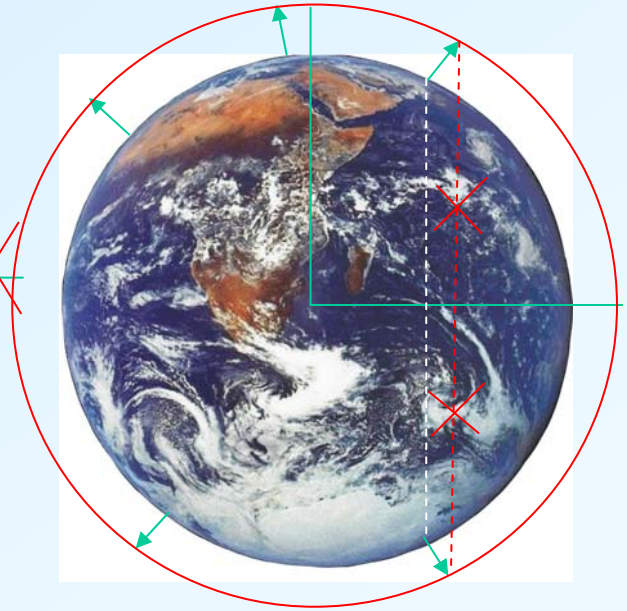
Coordinate changes do not change the origin. Variation of the geo-centre vs. origin is impossible by definition!

Fix direction of coordinate axes at a defined epoch.



Coordinate changes do not change orientation of axes of the reference coordinate system.

Fix the scale to metre by speed of light.



Baseline changes do not change scale. Ref. system scale changes are not possible.

How to fix the origin in the geo-centre?

Geo-centre = Earth centre of mass

$$X_0 = \iiint X \, dm / M$$
$$Y_0 = \iiint Y \, dm / M$$
$$Z_0 = \iiint Z \, dm / M$$

Spherical harmonics of the Earth gravity field:

$$C_{11} = \iiint X \, dm / a\,M$$
$$S_{11} = \iiint Y \, dm / a\,M$$
$$C_{10} = \iiint Z \, dm / a\,M$$

Using a gravity field model with $C_{11} = S_{11} = C_{10} = 0$ in satellite orbit determination fixes the origin always and unequivocally in the geo-centre, there is no degree of freedom for the position of the origin.

The geocentric ephemeris are transferred to the terrestrial coordinates by distance measurements (e.g., SLR). Range differences (GPS, DORIS) eliminate the relation to the geo-centre to a great extend.

Performing a coordinate transformation between the (moving) reference stations superposes a constraint, i.e., the origin of the reference system is re-defined from the centre of mass to the (centre of) the reference frame.

How to fix the orientation?

- The orientation is fixed conventionally at a certain epoch (BIH 1984), **not** by the 2nd degree and order spherical harmonics, which would be a better definition (consistent with origin), but is too weak in realization.
- Orientation changes are derived from observations at reference stations, i.e., we do not determine Earth orientation but the orientation of the reference frame.

  $\rightarrow$ Orientation changes are affected by (horizontal) station motions.
- Physical models of angular momentum changes (AAM, OAM, ...) have to be improved in order to separate EOP/ERP changes from reference frame motions.
- Physical models of crustal deformation (plate kinematics and plate boundary deformations) have to be improved (present-day geodetic models instead of geological models: APKIM vs. NUVEL).
- EOPs and (horizontal) station velocities are highly correlated. The condition of no-net-rotation (NNR) has to be introduced in a rigorous way and consistently with geodetic observations and models.

How to fix the scale?

- The scale is defined by the unit „metre“. The realization is a problem, because speed of light (c) is defined in vacuum, which does not exist.
- Each of the techniques has a problem in transferring the scale to the measurements because of

  - imperfect reduction from c in vacuum into c in atmosphere (refraction)

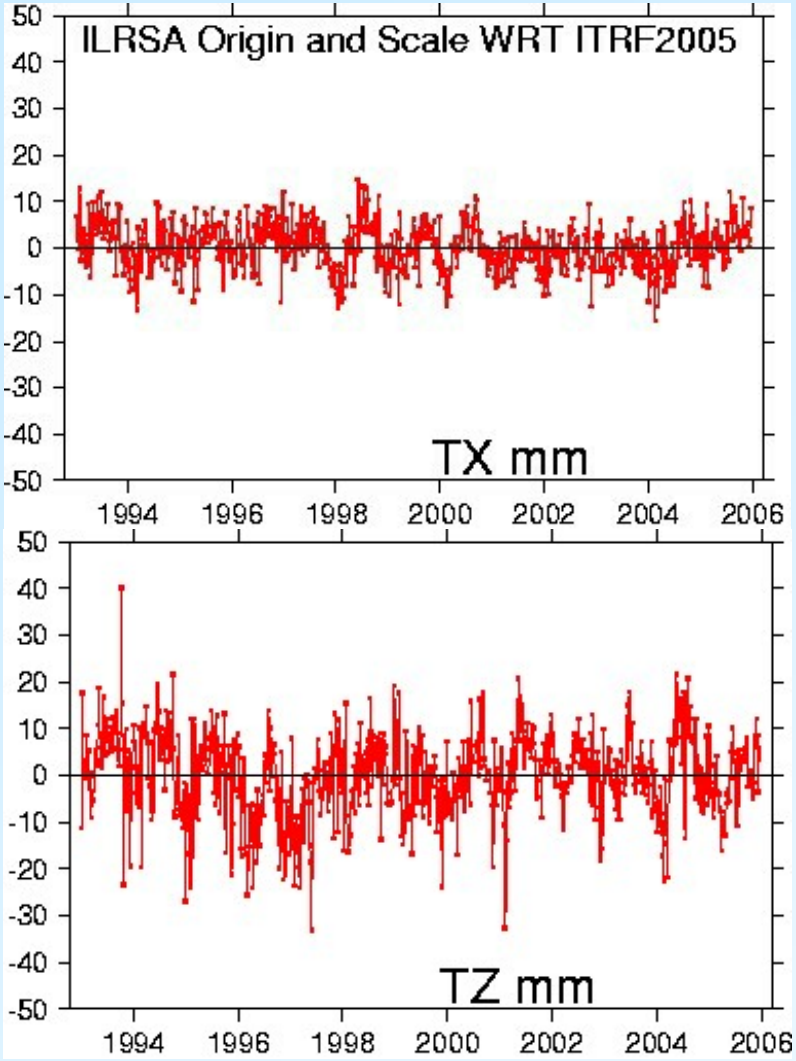
  - imperfect knowledge of the electronic centre w.r.t. instrument (biases)
- Improved calibration methods of distance determination from time measurements into the metric unit are required.
- Intensive investigations in the individual space techniques are under way (VLBI, SLR, GPS, DORIS).
- When deriving scale parameters from the reference frame, expansion of the frame (or the Earth, respectively) is transferred to the datum parameter of the reference system. This affects many global change studies (e.g. Earth expansion, polar uplift, geometric flattening).

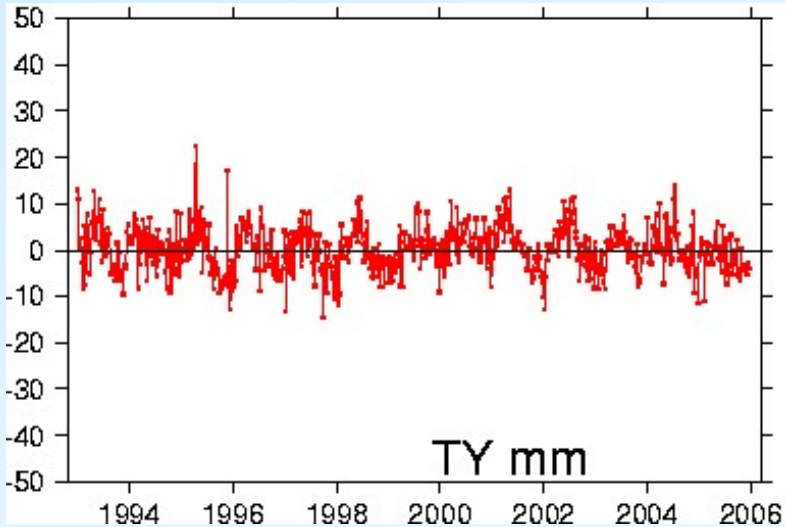
Problems for the Terrestrial Reference Frame

- Past ITRF solutions are **not** strictly geocentric, because there appear „geo-centre variations“ (origin w.r.t. geo-centre or vice versa).
- ITRF is **not** rotating with the present-day physical Earth crust, because a geological model is used averaging over millions of years.
- ITRF is **not** strictly metric, because metre is defined by speed of light c in vacuum and transformation to c in atmosphere is not unequivocal (SLR $\leftrightarrow$ VLBI).
- ITRF is **not** referring to the true Earth, because permanent deformation caused by external bodies is not included (tide-free system).
- There is **no** long-term stability of the reference system, because there are drifts of the origin, the orientation and the scale.
- The **datum** parameters defined for the ITRS are to a great extend replaced by transformation parameters between networks.

$\Rightarrow$ The deformations of the reference frame should not go into the datum parameters, but into the station coordinates (positions and velocities).

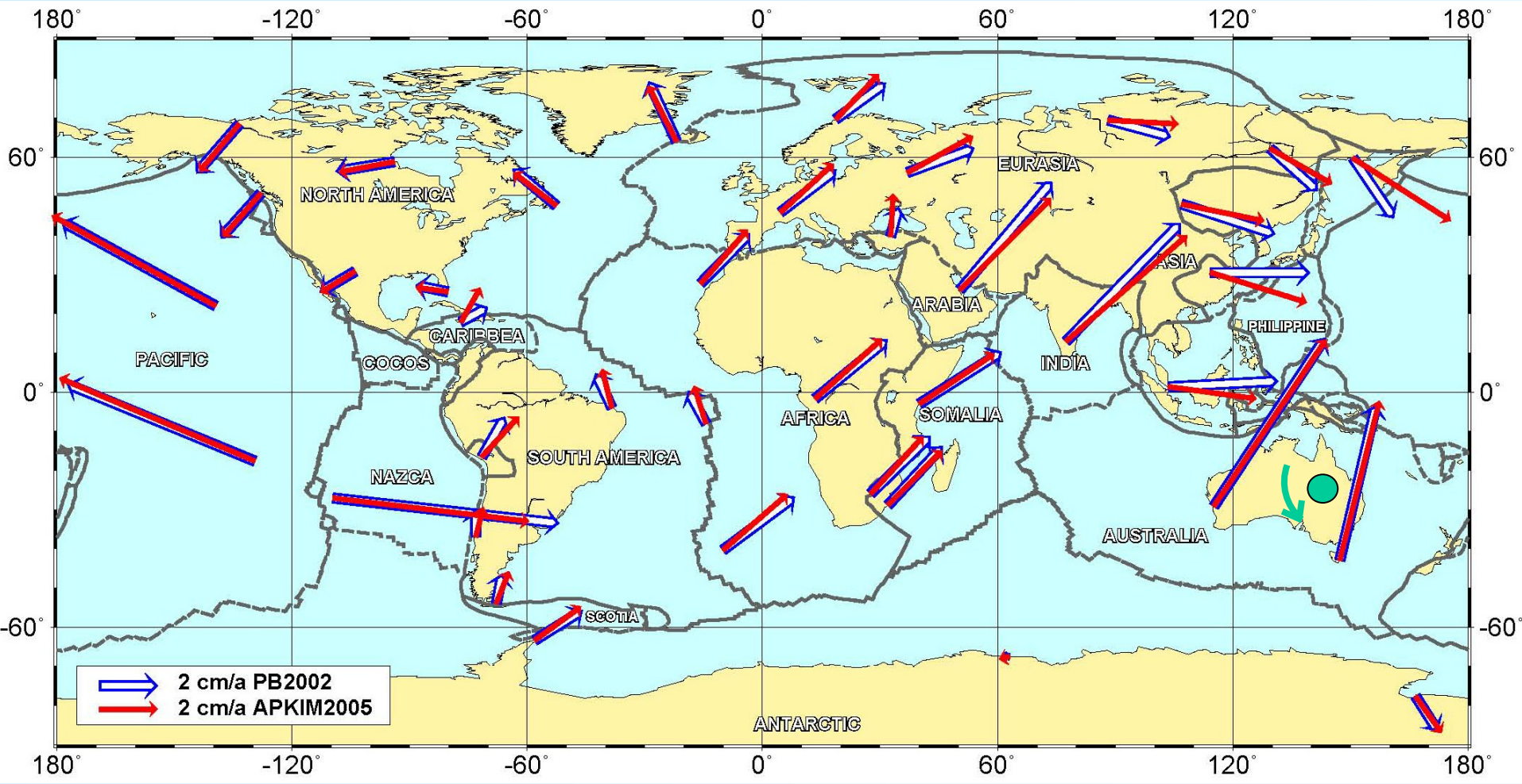
Parameters concerning the geo-centre (SLR)





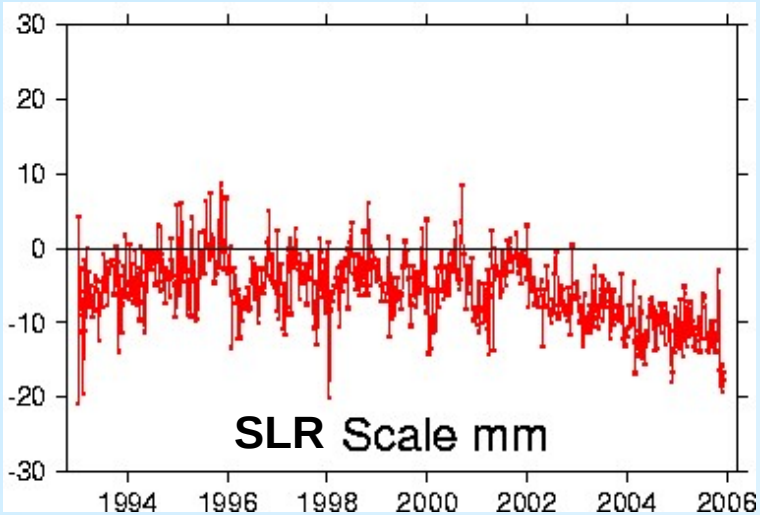
These parameters are not datum parameters (origin) of the ITRS, but transformation parameters (shifts) of the ILRS reference frame.
Changes in the selected frame stations may change the shifts.

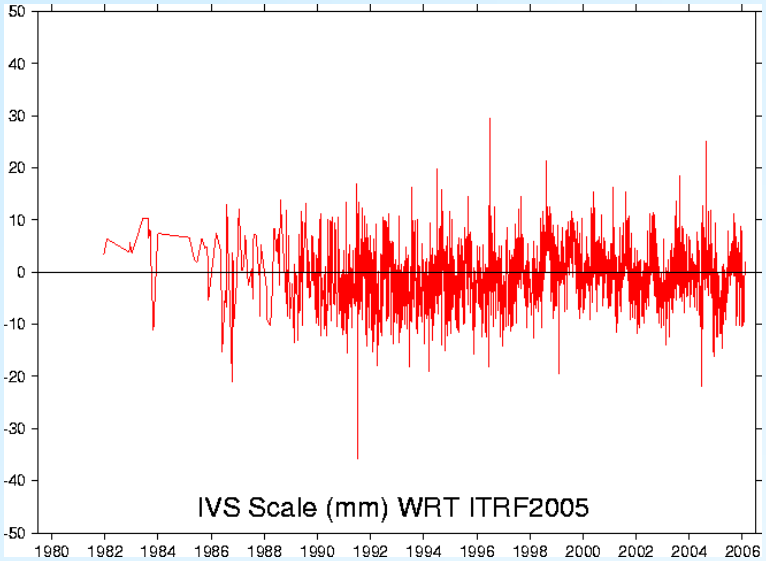
Rotation: ITRF2005 NNR vs. NNR NUVEL-1A



Rotation around Φ = -23.40, Λ = 143.47 with ω = 0.0569 mas/a (< 1,7 mm/a)

Parameters concerning the scale (SLR and VLBI)





These parameters are not datum parameters of the ITRS (unit of length), but the transformation parameters of the IVS and ILRS reference frames, respectively (e.g., expansions).

Changes in the selected frame stations may change the expansion.

An effect on the scale may appear, if varying transformation parameters are used for converting travel time measurements into distances (time dependent biases, reductions, ...)

Long-term stability of the Reference Frame

Transformation parameters of the series of ITRFs w.r.t. ITRF2000

	T1[m]	T2[m]	T3[m]	D[ppb]
ITRF05	-.0001	.0008	.0058	-0.40
ITRF00	.0000	.0000	.0000	0.00
ITRF97	.0067	.0061	-.0185	1.55
ITRF96	.0067	.0061	-.0185	1.55
ITRF94	.0067	.0061	-.0185	1.55
ITRF93	.0127	.0065	-.0209	1.95
ITRF92	.0147	.0135	-.0139	0.75
ITRF91	.0267	.0275	-.0199	2.15
ITRF90	.0247	.0235	-.0359	2.45
ITRF89	.0297	.0475	-.0739	5.85
ITRF88	.0247	.0115	-.0979	8.95

There is a trend in the translation and scale parameters due to the global translation of tectonic plates (ΔX = -11, ΔY = 13, ΔZ = 15 mm/a) and imperfect NNR condition of reference model NUVEL-1A.

There are also „rates“ of the transformation parameters, which transfer systematic parts in station velocities to the „datum parameters“.

ITRF realization by space techniques

- Modelling of space techniques has to be improved in order to reduce systematic effects (e.g., reduction to metre units).

  Studies have been made (IAG Commissions 1 & 4, and Services) focussing on the atmosphere (troposphere and ionosphere).

  → The goal must be to improve the parameters of physical models by geodetic observations.

- Modern space missions on mass displacements (gravity, altimetry, atmosphere sounding) have to be used for the realization of datum parameters (e.g., geo-centre, principal axes of inertia).

  Studies are under way (IAG Commissions 2 & 3, and Services) focussing on the mass transports in atmosphere and hydrosphere).

  → The goal must be to improve the realization of ITRF datum parameters by physical models derived from geodetic observations.

Missing components in reference frames

- The ITRF represents only the continental part of the Earth (plus some islands), two third of the Earth‘s surface, the oceans, are excluded.

  → Satellite altimetry covers the oceans.

- The ITRF provides 3-dimensional *geometric* coordinates (horizontal and vertical) and their time derivatives (velocities).

  For many applications *physical* coordinates, in particular physical heights (dynamic, normal, or orthometric), are required.

  → The requirements for a global Vertical Reference System (VRS) or World Height System (WHS) have been studied in a project of IAG.

  VRS / WHS need the same structure of „system – datum – frame“ as the ITRS / ITRF and equivalent consistent conventions
  (see presentation of J. Ihde).

Conclusions

- A thorough revision of the definition and conventions for the geodetic reference frames is required.
- The realization of the reference systems by reference frames has to follow exactly the definitions and conventions.
- All datum and frame issues for reference systems have to include the ocean and ice covered areas of the Earth, too.
- Physical height systems are important for many applications. They have to be considered in the same way as 3-D reference systems.
- The physical modelling of geodetic observations for reference frame purposes (atmosphere, new systems) has to be improved in future.

Thank you!