VERTICAL REFERENCES

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INTRODUCTION

This report was prepared by several contributors to stimulate discussions on Topic 3 on Vertical References at the IERS Workshop, held in Paris on 14 to 18 October 1996. This topic is rather important to the extent that many issues can be included under such a title and that several opposite points of view have been expressed on what IERS should do or not do in this area.

Just to illustrate this statement, here are the items mentioned as possible subjects of discussion of Topic 3 in the Workshop announcement as written by the IERS Directing Board:

- should IERS make an effort to put tide gauges in the ITRS?
- does IERS want to maintain a geoid?
- issues related to the geopotential;
- tidal variations and surface loadings;
- should IERS monitor the motion of the geocenter?

CONCEPTS AND TERMINOLOGY

We mention here the various concepts which can be referred to in this broad and somewhat fuzzy concept of vertical references. They belong to several disciplines which obviously can be relevant to this subject: geodesy, but also solid earth geophysics, oceanography and atmospheric science.

We can then view that vertical references are all surfaces close to the Earth's boundary which have some geometric, physical or practical interest:

- ellipsoid (E) which is a geometrically defined surface in a specific terrestrial reference system;
- geoid (G) which is an equipotential surface of the Earth's geopotential;
- sea surface (S) which is the ocean-atmosphere boundary;
- land topographic surface (T).

We could have also considered sea floor as the solid earth-ocean boundary. As it is still a very specific domain of Marine Geodesy, we did not consider it in this report. This attitude may have to be revised in the future.

Several common characteristics can be considered for these surfaces:

- Time variations: all these surfaces except E have some time variations at various levels both in the spatial and time domain.

- Physical modeling: some surfaces can be expressed through a physical model: G as equipotential of the geopotential, S as boundary of hydrodynamical equations...

- Realizations: the concepts of ideal definition and realization already applied for celestial and terrestrial systems can be also efficiently applied to these surfaces. Without giving a thorough insight of this topic, we mention here some ideas:

  - these surfaces can have various mathematical expressions: grids, contour lines, spherical harmonic expansions or other types of numerical approximation;

  - the definition itself can be done in various ways, for instance G can be ideally defined either by giving a particular point which belongs to this equipotential or by giving the potential value W_o;

  - in the case of G, Physical Geodesy offers the choice of slightly different surfaces: quasi-geoid, co-geoid;

  - the actual complete model is currently mapped into a simpler regularized model by applying some corrections (relativity, tides...). This can be done in slightly different ways whence various ideal definitions (in particular for S and G).

- Use as reference surface for height: these surfaces can be used to define various height systems for both scientific and practical uses: surveying, hydrography, mapping, reduction of gravity data, DTM.

Besides a pure conceptual point of view, the joint study of these surfaces (vertical references) is justified by the two by two connections realized by various types of measurements or numerical determinations. Here is a list of such connections:

- global or regional geoid determination, whatever technique, provide an E-G link;
- positioning of a point located on land topography with a space technique in a well defined reference system provides an E-T connection;
- positioning of a floating buoy with a space technique in a well defined reference system provides an E-S connection;
- spirit leveling on land benchmarks provides a G-T connection;
- satellite radar altimetry with precise orbits in a terrestrial reference system provides an E-S connection;
- coastal tide gauge recording provides a T-S connection;
- hydrodynamical modeling provides a G-S connection.

This very partial and schematic review has hopefully shown the variety of the topic.

EXISTING ACTIVITIES IN THIS AREA

It is out of the scope of this report to establish an extensive inventory of the groups which are already working in parts of this area. We have nevertheless considered it useful for non specialists to list some significant works at international level:

International activities

- the UNESCO International Oceanographic Commission (IOC) which is driving the GLOSS program (a network of 200 tide gauges with high standards including geodetic monitoring);

- IAPSO with its Commission on sea level and tides, to which is linked an ad hoc group common with IAG on Geodetic fixing of tide gauges (W.E. Carter, chairman);
- ICL has a panel on sea level (S. Zerbini, chairman);
- Permanent Service on Mean Sea Level (PSMSL) involved in many activities (GLOSS...). It is a FAGS service like IERS and IGS. A joint project IGS/PSMSL on installing IGS stations at tide gauges has been initiated;
- International Hydrographic Organization (IHO) for vertical datums for hydrography;
- Global Change/IGBP related activities.

IAG activities

In addition to the IAG umbrella on IERS, IGS and PSMSL, we can quote:

- Commission X on Global and Regional Networks (C. Boucher) in charge of leveling networks, with in particular a WG on Unification of Vertical datums (W. Kearsley);
- SSG 1.153 Precise marine positioning, surface and seafloor (D. Egge);
- CSTG WG on Fundamental Reference and Calibration Network, FRCN (G. Beutler);
- Special Commission 6 WEGENER (S. Zerbini);
- Commission XII on Geoid (H. Sunkel) with its International Geoid Service, IGeS (F. Sanso);
- Commission V Earth tides (H.G. Wenzel);
- Special Commission 3 Fundamental Constants (E. Groten);
- Special Commission 8 Sea level and ice sheets (W. Carter).

Bilateral or regional (e. g. European) activities

- DMA/GSFC global earth model with IAG validation group (M. Sideris);
- Science groups of the US/French satellite radar altimetric mission; TOPEX/POSEIDON and of the ESA ERS missions, as well as future ones (JASON...);
- European projects including geodetic fixing of tide gauges: SELF I and II, EUROGAUGE, HIBISCUS, Baltic Sea Project, EPTN, EUVN, Euro-GLOSS, EOSS...

IERS and a Global Vertical Datum

A first possible contribution of IERS would be to provide a realization of a Global Vertical Datum (GVD) which would be to some extent a logical extension of ITRF. IERS would consequently determine and disseminate as a new product an estimate of the height in the GVD for each ITRF station.

This implies several actions:

1) to extend the IERS Conventions in order to include a definition of a GVD: choice of a geoid and of a related height system, consistency within all IERS conventions (for instance tides);

2) to develop methods of realization and the relevant organization within IERS, taking into account existing groups (in particular working on geoid models or in leveling networks). We simply quote some progressive methods:

a) use of a global geopotential model (DMA/GSFC approach) to which the ITFS section of the IERS/CB has already worked in the IAG validation group;

b) combined use of a with ITRF ellipsoidal heights, regional leveling data and gravity data. This requires an access to a reliable data base of levelling data at ITRF sites and of course suitable gravity data;

c) more general combination using regional geoid models, satellite altimetry and other relevant data.

Another important aspect to be considered is the potential contribution of fundamental atomic clocks to this topic. They are direct sensors of the absolute geopotential through the relativistic gravitational effect on frequency.

A real question asked by several people is: why IERS should go into this business? Many groups have spend many efforts on the various aspects, as shown above. They have produced significant results and they know well what are the critical problems to solve!

During the discussion, several possible contributions from IERS were mentionned:

- in the definition of consistent specifications (which do not exist presently);
- by publishing a global realization at ITRF sites (which goes in the direction of FCRN stations);
- in the preparation of the future contribution of new techniques such as atomic clocks.

Finally, it was recommended to establish within IAG a working group on this topic through a cooperation of Commissions X (networks) and XII (geoid), with IERS as well as IAPSO representatives.

ITRF and geodetic fixing of tide gauges

The need to have a high quality and well distributed network of mixed permanent GPS and tide gauge stations is now well established (see GLOSS and IAPSO/IAG ad hoc group). As already mentionned, IGS and PSMSL are actively preparing a workplan.

Consequently, and through IGS, this net will be naturally expanding the ITRF network. Furthermore, IERS should consider whether some ITRF stations without GPS system could also be considered for colocation with tide gauges (for instance DORIS for which this was investigated and even recommended in the frame of TOPEX/POSEIDON). Definitively there is a need for clear specifications on the relative contributions of each contributing technique to this task: VLBI, SLR, GPS and DORIS... They are NOT identical, both on global level (datum) and individual station height quality!

In order to reach these objectives, there is a definite need for up-to-date standards for tide gauge fixing. The existing IAPSO/IOC/PSMSL documents are good for tidal recording but need to be developped on the geodetic aspects. It was recommended that the IAPSO/IAG working group previously mentionned should prepare technical specifications more detailed and up to date on the geodetic aspects than the already published reports. This group should take benefit of experts in this field.

IERS should be closely associated to that in order to contribute with its own competences to the fulfilment of the scientific/technical objectives identified above.

Global geopotential models

Active groups are working in this subject. Presently, they have impact on IERS activities through the physical modeling adopted by analysis centers for dynamical techniques. IERS Conventions are already dealing with this point.

The establishment of an IERS realization of a Global Vertical Datum would clearly create a new link to the geopotential models.

Vertical motions of the Earth crust

The vertical component of the position of a point linked on the land topographic surface is affected by a variety of motions. Besides special motions (we mean some active zones, or motions

linked to seismicity or volcanism, or land subsidence), the main causes are tidal responses and various loadings (atmosphere, ice, groundwaters).

Here the present questions are:

a) improvement of the models and of their consistency in the IERS Conventions;
b) effective use by the groups participating to IERS;
c) how IERS results could improve these models?
d) need of available ancillary data for accurate corrections, in particular global surface atmospheric pressure;
e) better local monitoring of ITRF sites and intercomparison with other data such as gravimetry or clocks (a question for the FRCN group?)

It was therefore recommended that these points should be discussed by the CSTG group on Fundamental Reference and Calibration Network.

Motion of the Geocenter

ITRS is presently defined as geocentric (including oceans and atmosphere). It is recognized that a correction model is needed to remove from the instantaneous station position on the crust the motion effect coming from the motion of the geocenter, in particular seasonal effects produced by the mass redistribution of oceans and atmosphere. Such a model still needs to be adopted for IERS Conventions.

Furthermore, dynamical techniques are currently realizing the geocenter through the adoption of a rigorously geocentric geopotential. The quality obtained for short term series (e. g. monthly) for SLR and now GPS (and potentially DORIS) should make feasible the determination of the geocenter coordinates as a set of parameters, similarly to EOP series.

A related problem is also to realize ITRF through a time series with a purely kinematical equation for time evolution. One may also think of revising the geocentric definition of its origin. These questions are presently discussed by the IERS WG on ITRF datum (J. Ray).

It was recommended that this group should continue and furthermore establish a pilot experiment on the determination of the geocenter by combined use of several time series from several techniques.

In addition, it was required that some geophysical models or estimations should be collected (tidal part, atmospheric and oceanic circulations).

CONCLUSIONS

The general goal of this report was to investigate the topic of vertical references in order to show that it is altogether important, interdisciplinary and widely opened. As many groups are already working on some aspects, the aim was to identify which specific contributions IERS could make in the short term in order to improve the whole topic.

We do not expect to have reached a definitive review of the subject. We hope nevertheless that the statements of this report and its recommendations will help to undertake some fruitful activities for various users, according to the missions that a Service such as IERS has.