
**1st Joint IAG Commission II and IGFS Meeting**

"*International Symposium on Gravity, Geoid and Height Systems*"

September 19-23, 2016, Thessaloniki, Greece

# Realization aspects of the International Height Reference System

## An exposure of some open problems

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# International Height Reference System (IHRS)

*Working definition:*
*(by Ad-hoc group on IHRS, Travaux de l' IAG, vol. 39)*

The IHRS is a geopotential reference system co-rotating with the Earth in its diurnal motion in space.

The associated coordinates in that system are:

geopotential values $W(\mathbf{X})$

geocentric Cartesian coordinates **X**

(and their changes in time)

# IHRS scientific objectives

- To merge Earth's geometrical and physical representations in a consistent and useful way.
- To provide an accurate (1 cm or better) and stable physical height frame that is accessible by space geodetic techniques.
- To facilitate the geophysical "predictability" and "interpretability" of:
  - vertical station motions
  - surface gravity variations
  - sea level rise

# Heighting in the IHRS context

- The **primary vertical coordinates** are scalar potential differences.

$$C(\mathbf{X}) = W_o - W(\mathbf{X})$$

- **Physical heights** are derived by suitable metrics.

$$H(\mathbf{X}) = \frac{W_o - W(\mathbf{X})}{\tilde{g}(\mathbf{X})}$$

The parameter "$W_o$" reflects the **vertical datum** of the IHRS and it needs to be clearly specified in its definition.

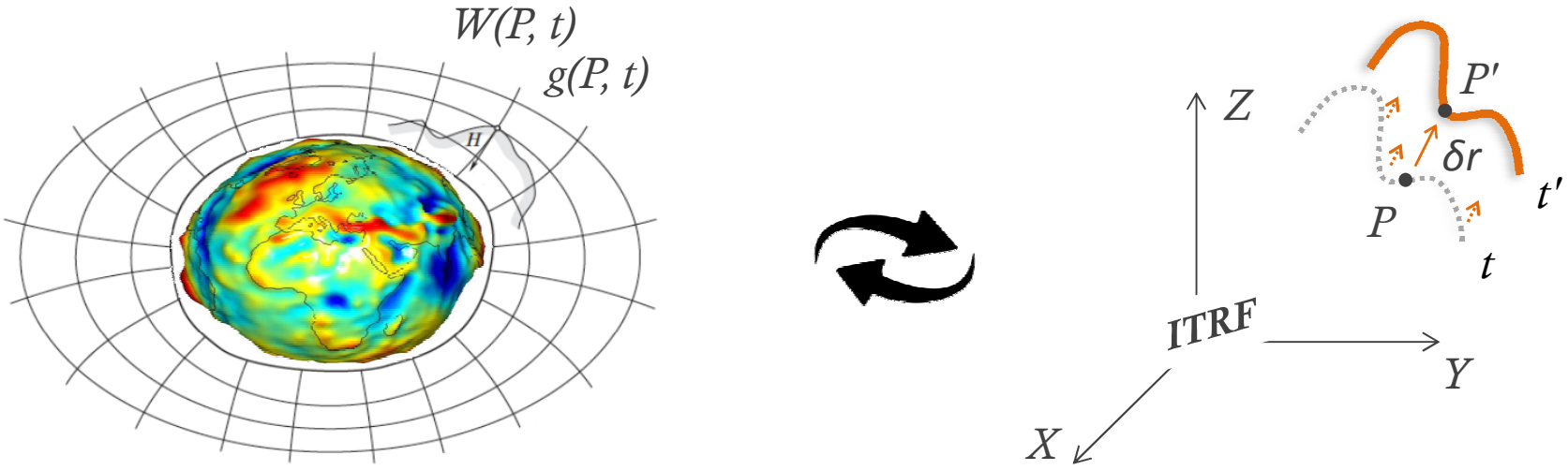
# Conventions for the definition and the realization of IHRS

*(IAG Resolution 1, Prague 2015)*

1. The **vertical reference level** is an equipotential surface of the Earth's gravity field with the geopotential value $W_o$.
2. Parameters, observations, and data shall be related to the **mean tidal system** and the **mean crust**.
3. Unit of length is the *m* and unit of time is the *sec* (SI).
4. The **vertical coordinates** are the geopotential numbers with respect to the reference level $W_o$.
5. The **spatial reference** of the position *P* for the geopotential determination $W_P = W(\mathbf{X})$ is related to the ITRS.

- $W_o = 62\,636\,853.4\ m^2\ s^{-2}$ (datum realization).

# Open problems …




**Correlating Earth's time-variable gravity field and its deforming geometry is a complicated task!**

# IHRS in the deforming Earth

| | Geopotential representation | Frame definition | Remarks |
|---|---|---|---|
| *"semi-dynamic" approach* | $W(\mathbf{X}(t))$ | GGM with **fixed** Stokes' coefs<br>Time-dependent 3D Cartesian positions | Physical heights (& their temporal changes) given wrt. a **mean gravity field** that is linked to ITRF |
| *"fully-dynamic" approach* | $W(\mathbf{X}(t),t)$ | GGM with **time-dependent** Stokes' coefs<br>Time-dependent 3D Cartesian positions | Physical heights (& their temporal changes) given wrt. the **actual gravity field** that is linked to ITRF |

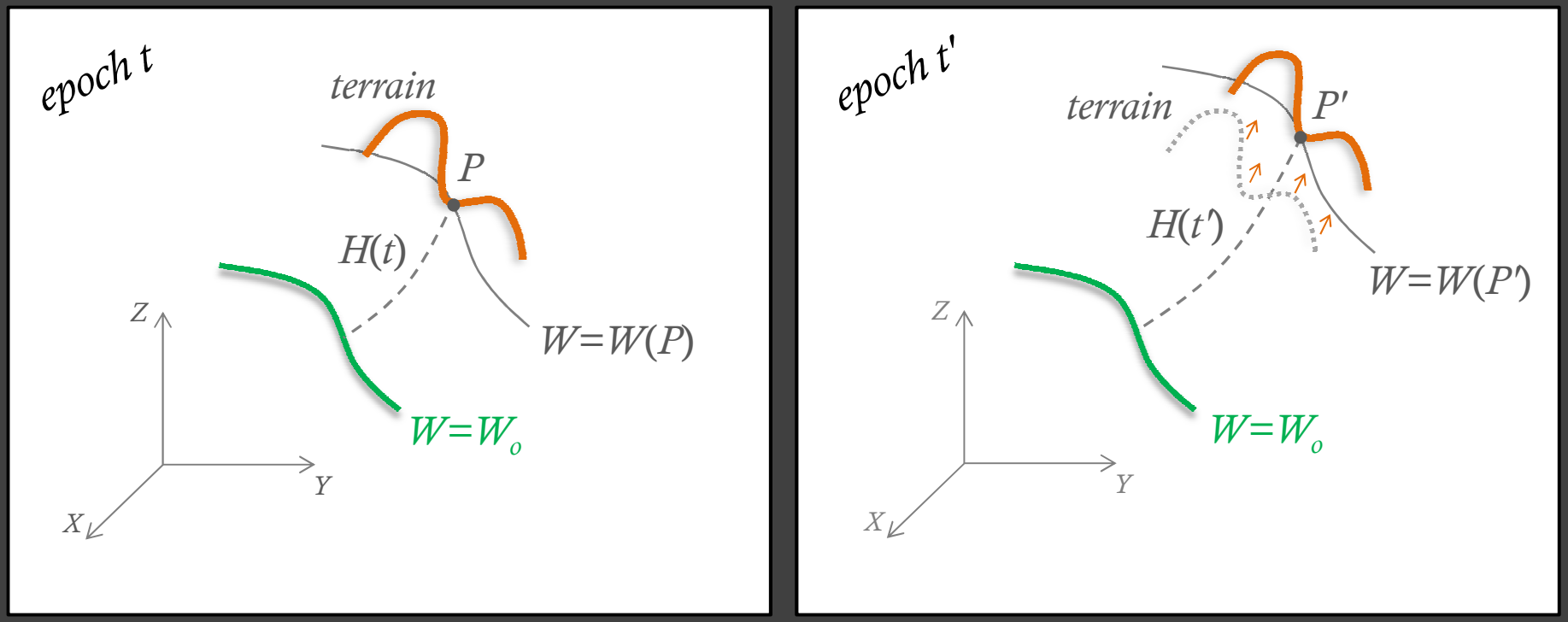
# IHRS in the deforming Earth

| | Geopotential representation | Frame definition | Remarks |
|---|---|---|---|
| *"semi-dynamic" approach* | $W(\mathbf{X}(t))$ | **Static** geoid model<br>---<br>Time-dependent 3D Cartesian positions | Physical heights (& their temporal changes) given wrt. a **mean gravity field** that is linked to ITRF |
| *"fully-dynamic" approach* | $W(\mathbf{X}(t),t)$ | **Time-dependent** geoid model<br>---<br>Time-dependent 3D Cartesian positions | Physical heights (& their temporal changes) given wrt. the **actual gravity field** that is linked to ITRF |

# IHRS in the deforming Earth

| | Geopotential representation | Realization tools | **Key issues to consider** |
|---|---|---|---|
| *"semi-dynamic" approach* | $W(\mathbf{X}(t))$ | $C_{n,m}, S_{n,m}, N$<br>$\mathbf{X}(t_o), \dot{\mathbf{X}}$<br>… | **Choice of geopotential representation**<br>**Temporal evolution & geoph "predictability"**<br>**Alignment to ITRS/ITRF**<br>**Frame densification** |
| *"fully-dynamic" approach* | $W(\mathbf{X}(t),t)$ | $C_{n,m}(t_o), \dot{C}_{n,m}$<br>$S_{n,m}(t_o), \dot{S}_{n,m}$<br>$N(t_o), \dot{N}$<br>$\mathbf{X}(t_o), \dot{\mathbf{X}}$<br>… | |

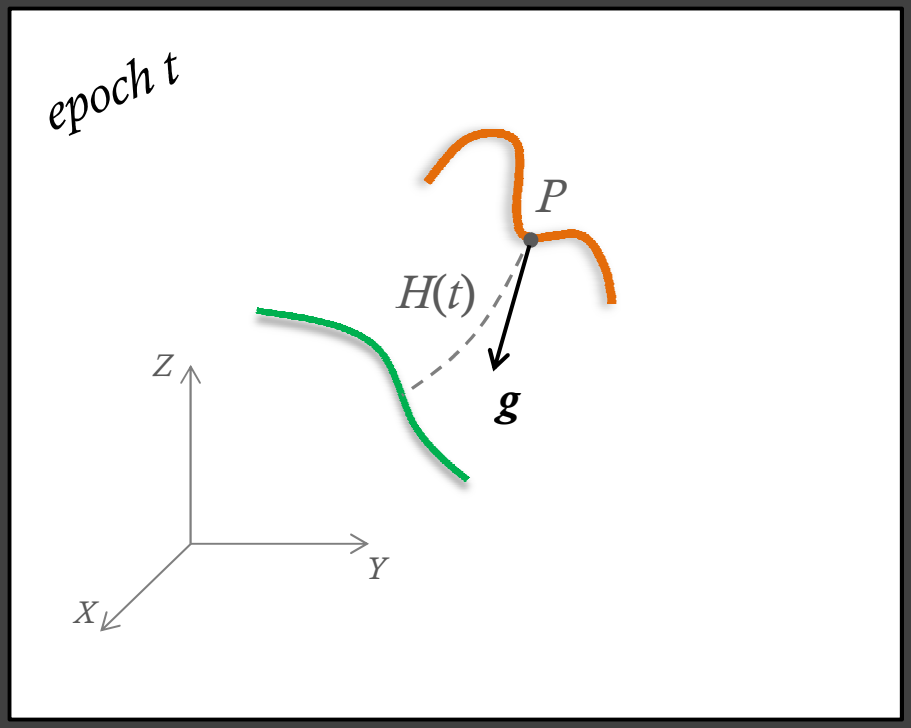
# IHRS realization
## (semi-dynamic approach)

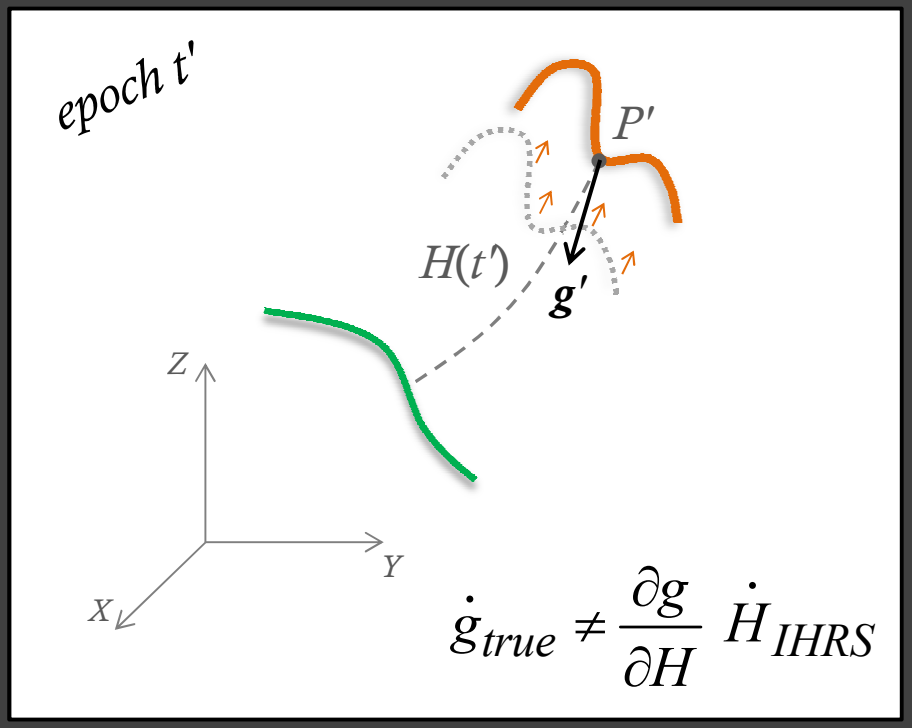



A mean (static) representation of the gravity field is used.

**Physical height changes in IHRS reflect true vertical displacements!**

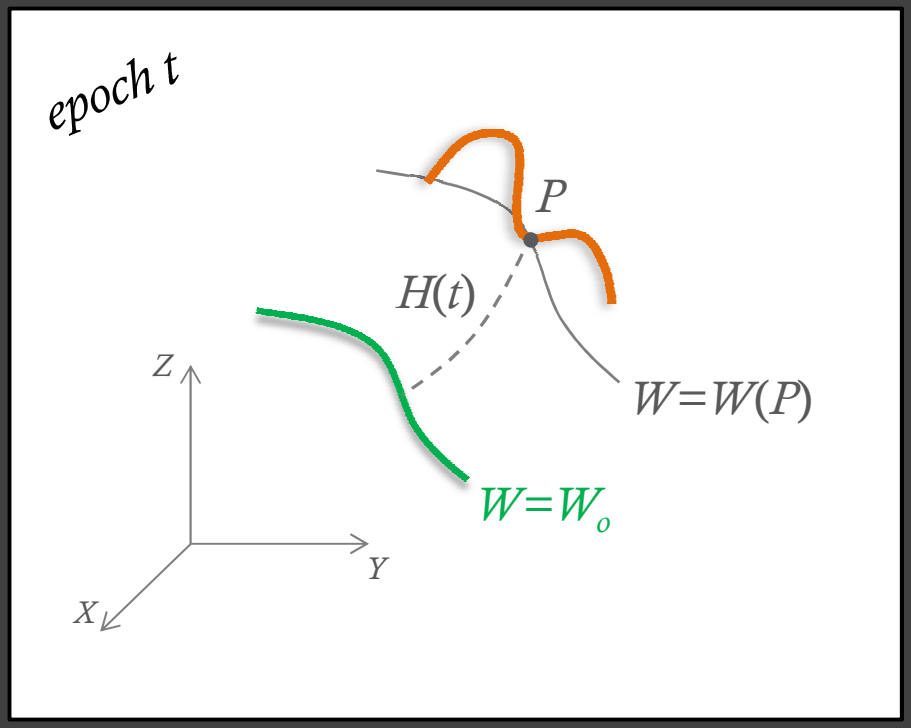
# IHRS realization
## (semi-dynamic approach)

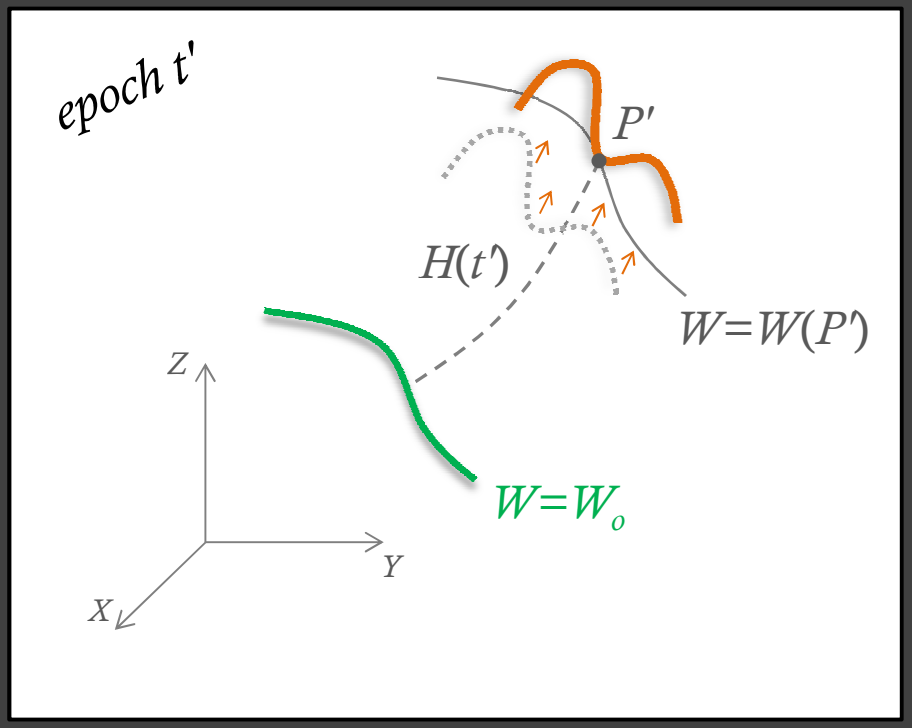



**but temporal variations of observed gravity cannot be fully attributed to the physical height changes in IHRS!**

# IHRS' temporal evolution
## (semi-dynamic approach)




$$\dot{H}_{IHRS} = \dot{h}_{IHRS} \quad (\dot{N} = 0)$$

$$\dot{W}_{IHRS} = \vec{\mathbf{g}}(P) \cdot \dot{\mathbf{X}}_{IHRS} \neq \dot{W}_{true}$$

$$\mathbf{X}(P') = \mathbf{X}(P) + \dot{\mathbf{X}}_{IHRS}(t' - t)$$

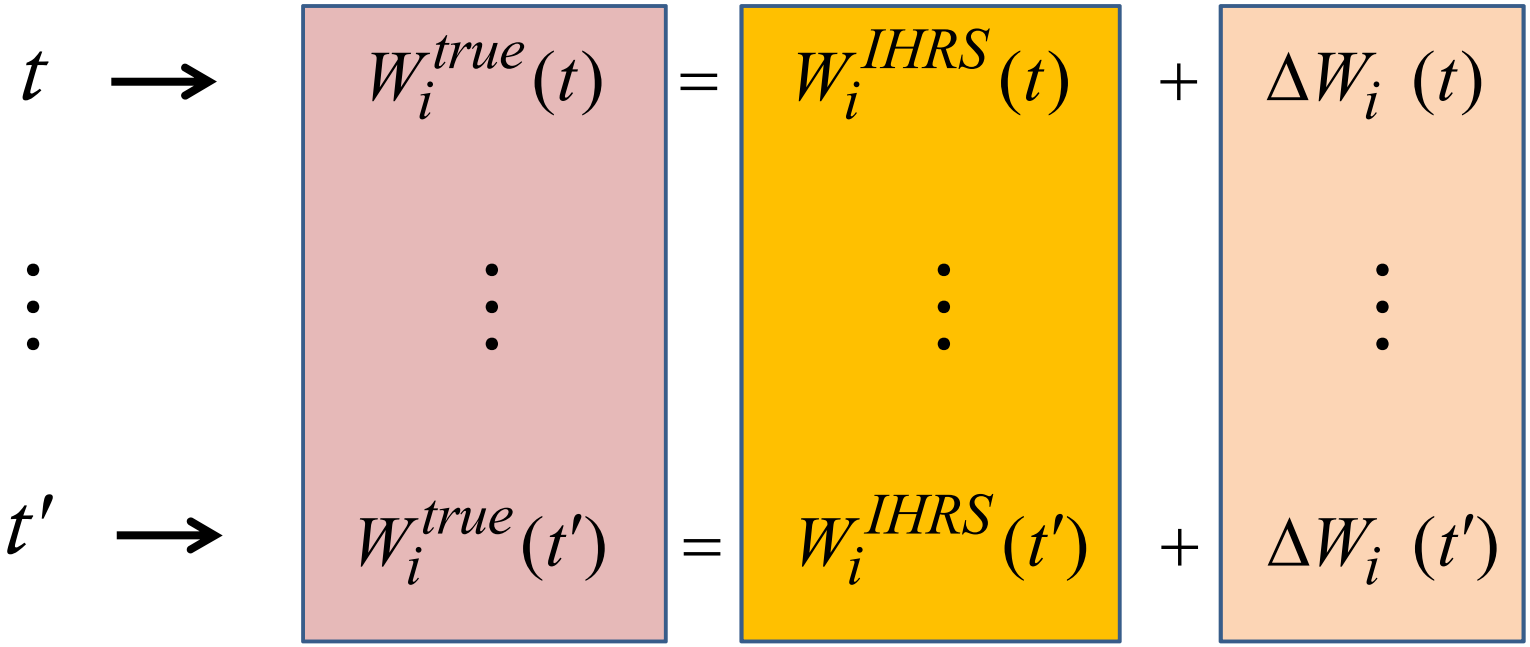
# Geophysical monitoring
## (linearized context)

$$\dot{g}_{true} \approx \underbrace{\frac{\partial g}{\partial H}\dot{H}_{IHRS}}_{\dot{g}_{IHRS}} + \left(\partial g/\partial t\right)$$

Inferred from models
Observed (GRACE)

$$\dot{W}_{true} \approx \underbrace{\vec{\mathbf{g}}\cdot\dot{\mathbf{X}}_{IHRS}}_{\dot{W}_{IHRS}} + \left(\partial W/\partial t\right)$$

# Geophysical monitoring
## (time series context)




e.g. evaluated by GRACE models at current point position

e.g. mass-transport & loading effects on the gravity potential

# Two (more practical) questions

1) If IHRS will support the **unification of existing local/regional VDs**, then how are we supposed to deal with the different "potential scales" ?

   e.g. are we allowed to simply merge a leveling-based height frame with IHRS?

2) What will be the value of spirit-leveled data in the realization and temporal evolution of IHRS?

# Some comments on $W_o$

- Same parameter – different roles/meanings
  - *conventional "zero" vertical level for IHRS*
  - *best estimate of global MSL from altimetry data*
  - *$L_G = W_o/c^2$ (IAU 2000 Resolution)*
  - *Earth reference model (i.e. $W_o \leftrightarrow U_o$)*
- Is there any profound reason to update $W_o$ in the context of (future) IHRS realizations?
- Should "$W_o$" be *tagged* in the IHRS conventions? ($t_o$, *GM*, $\omega$, other)

# Conclusions

- IHRS is a much-needed tool to unify the three pillars of geodesy!
- Three crucial items need to be elucidated:
  - choice of geopotential representation
  - its alignment procedure to ITRS/ITRF
  - the time-dependent character of IHRS and its geophysical “predictability”
- and …

# Conclusions

Is the **mean tidal system** the best choice for the definition of the IHRS ?