GEODESY FOR A RESILIENT AFRICA

2. Scientific Applications in geodesy, geophysics and Earth system monitoring

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DORIS special session

AIMS African Institute for Mathematical Sciences CAMEROON · COSPAR COMMITTEE ON SPACE RESEARCH · WEST AFRICAN MARGIN · Nansen Scientific Society · University of Manitoba Centre for Earth Observation Science · University of Cape Town · NANSEN-TUTU CENTRE MARINE ENVIRONMENTAL RESEARCH · IUGG UGGI · OceanDataLab

Who am I?— Scientific background

Samuel Nahmani – IGN – IPGP / Géodata Paris, France

2006 — Engineering degree in geodetic and geographic sciences
ENSG-Géomatique (now Géodata Paris)/ IGN
→ reference systems, observing networks, geodetic infrastructure

2012 — PhD in environmental sciences
UPMC, now Sorbonne University
GPS/GNSS and the water cycle in West Africa
→ water vapor, monsoon, climate applications

2012 — present — Researcher in space geodesy
GNSS, DORIS, tropospheric products, reference frames, precise orbits and EOP
→ connecting geodetic measurements to geophysical signals

Selected references: Bock et al., 2008 ; Hinderer et al., 2011 ; Nahmani 2012 ; Nahmani et al., 2012 ; Nahmani et al., 2019 ; Sakic et al., 2026a

Capacity building : Sakic et al., 2026b

Who am I?— Community and infrastructure roles

Samuel Nahmani – IGN – IPGP / Géodata Paris, France

2020 — present — Co-head of the IGN-IPGP/JPL IDS Analysis Center
DORIS processing and contribution to IDS / ITRF products
→ precise orbits, reference frames, long-term geodetic consistency

2023 — present — Secretary General of the French National Committee for Geodesy and Geophysics — CNFGG
French participation in IUGG activities
→ national communities matter for global geodesy

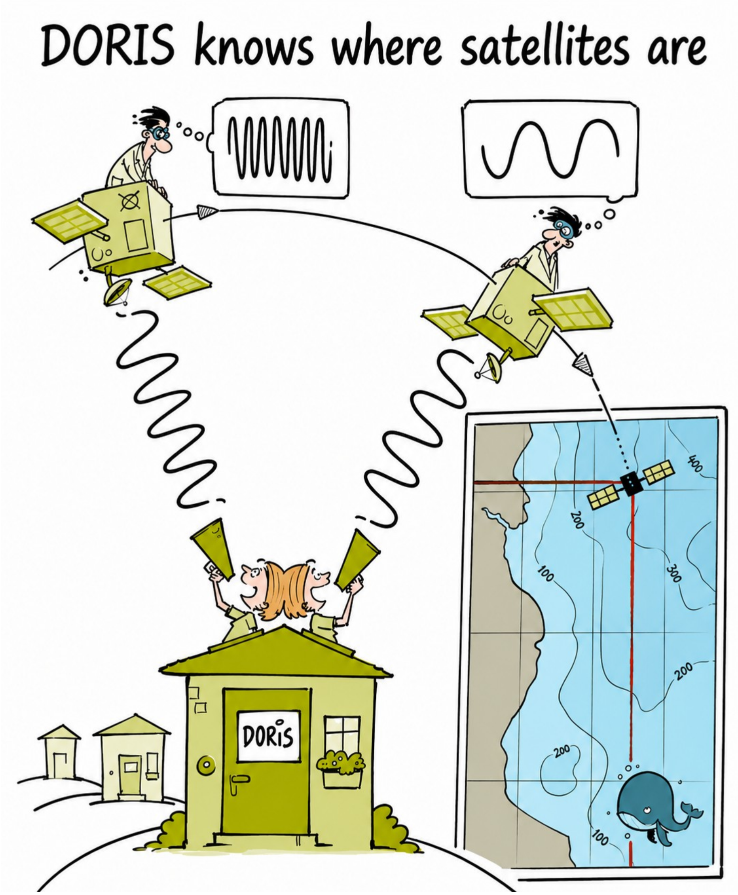
2024 — present — Technical Adviser to the United Nations Global Geodetic Centre of Excellence
Global geodesy supply chain: stations, data, analysis, standards, capacity and governance
→ resilient Earth observation needs resilient geodetic infrastructure

Today I will connect Africa, water, DORIS and the global geodesy supply chain.

From signal to meaning to access

Where this talk fits in the DORIS special session

Maria – How DORIS works



Cartoon: Tom Fiedler / IAG–GGOS Geodesy Cartoon, CC BY 4.0

From signal to meaning to access

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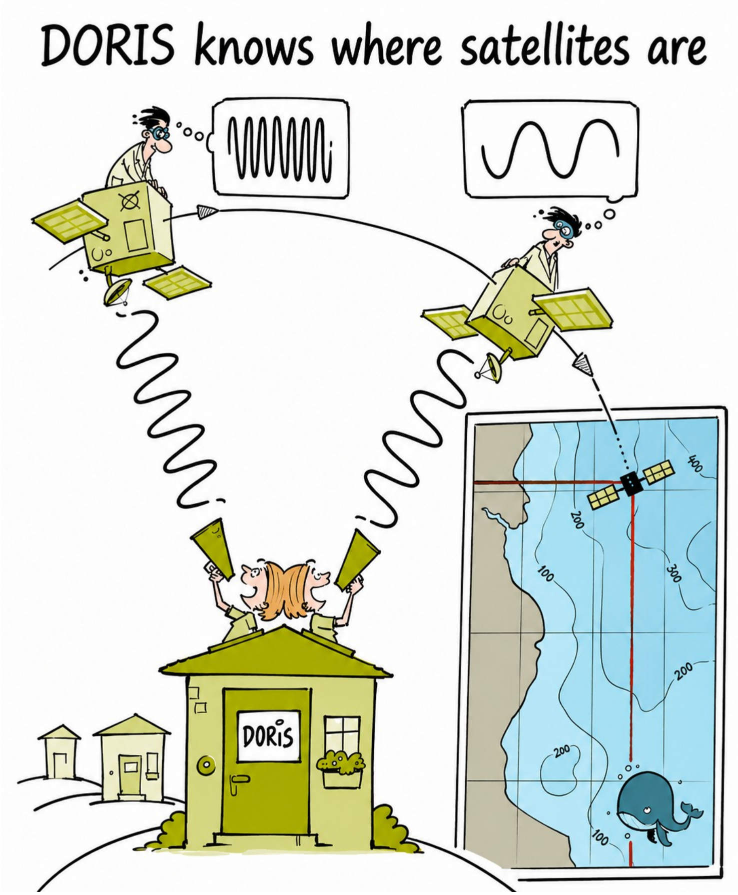
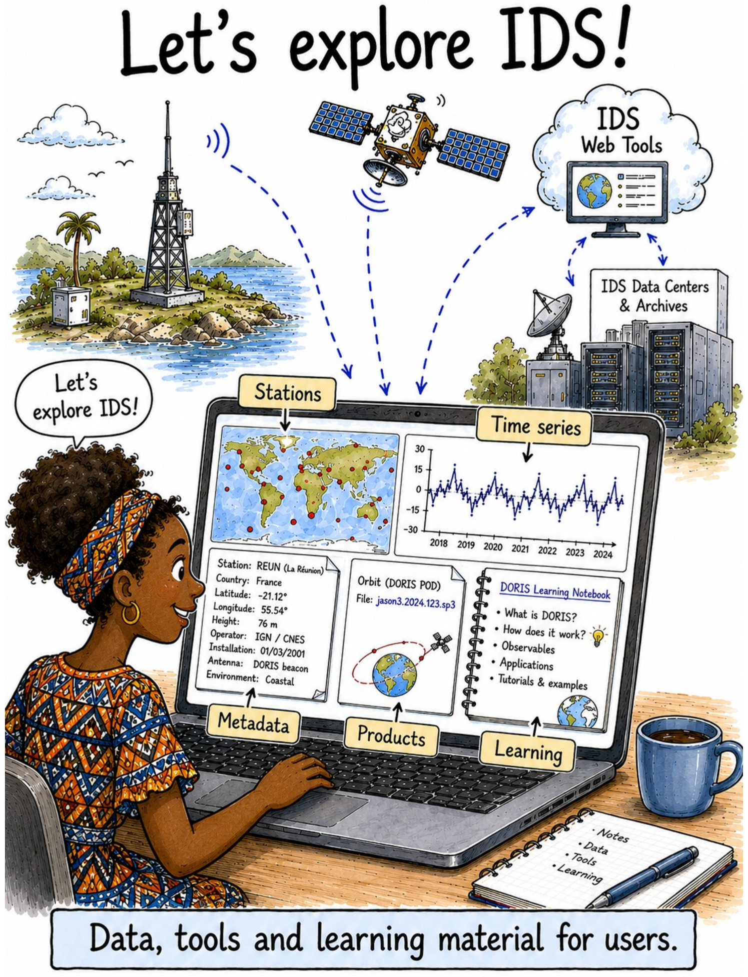


Cartoon: Tom Fiedler / [IAG–GGOS Geodesy Cartoon, CC BY](#) 4.0

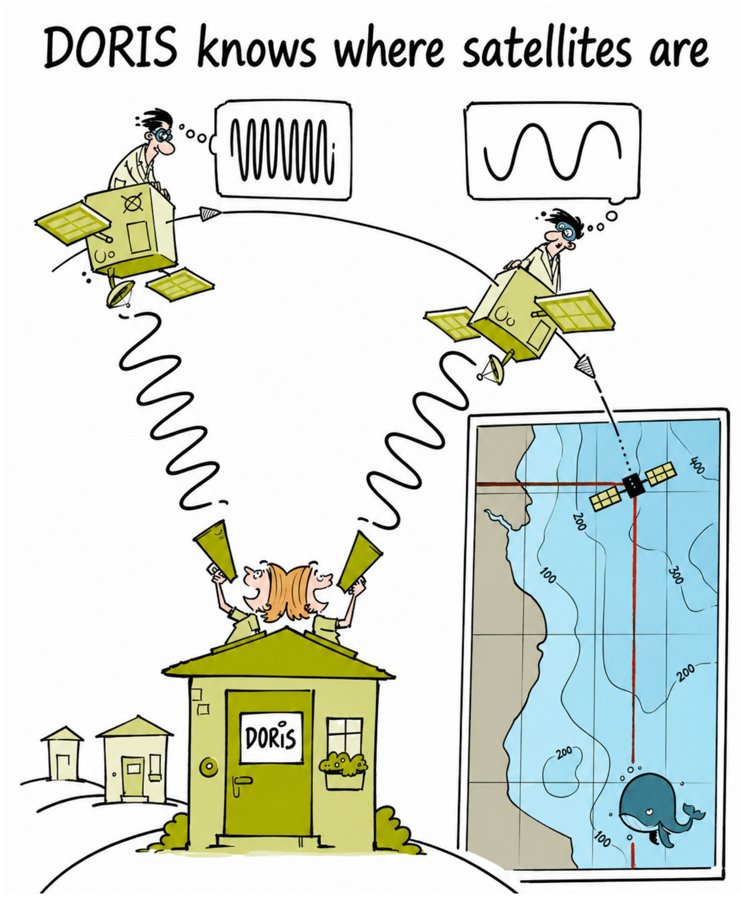
Laurent – How to use IDS



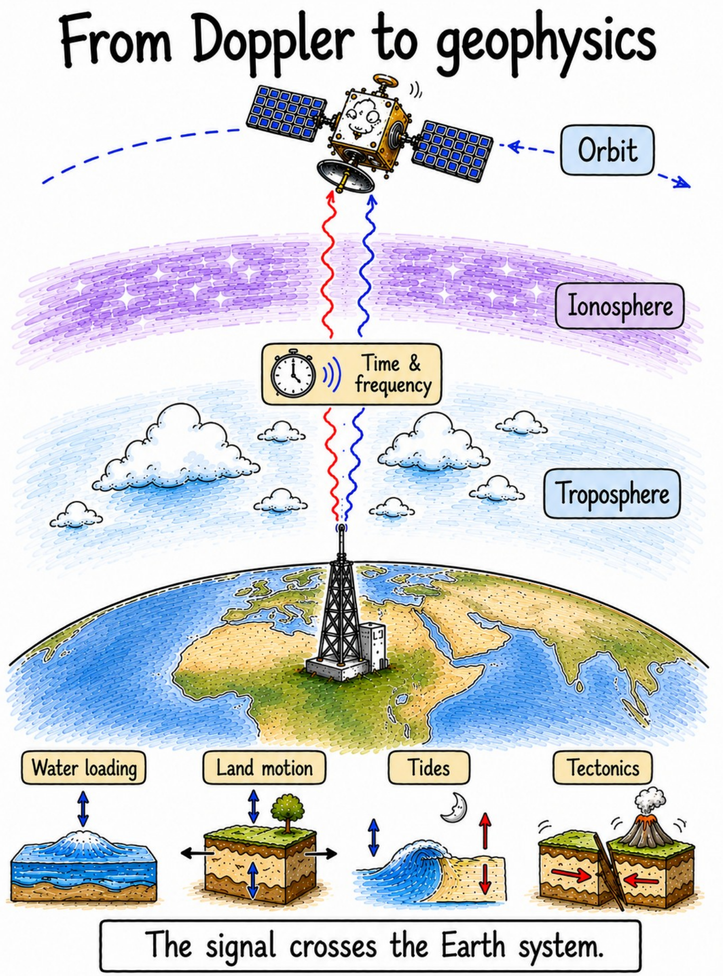
From signal to meaning to access

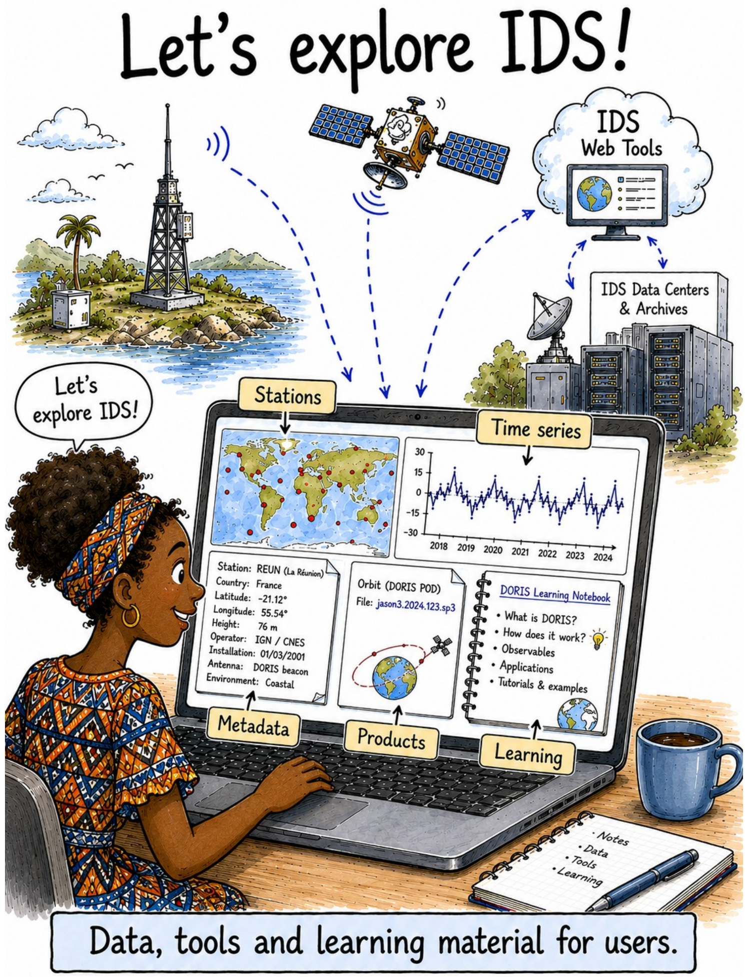
Where this talk fits in the DORIS special session

Maria – How DORIS works	Samuel – Why DORIS matters	Laurent – How to use IDS



Cartoon: Tom Fiedler / IAG–GGOS Geodesy Cartoon, CC BY 4.0





DORIS is upstream infrastructure that helps make climate-relevant observations reliable.

ids.central.bureau@ids-doris.org

Reactivating the foundations

Before applications: what space geodesy provides

1

Space-geodetic systems

Observing geometry from ground and space

GNSS · DORIS
SLR · VLBI

Four complementary techniques provide the raw geometry of the Earth system.

2

Precise geometry

Turning measurements into a stable frame

Precise orbits
Reference frames
ITRF · EOP

Where is the satellite? What is our global ruler? How does Earth rotate?

3

Earth-system observations

Measuring a changing planet

Sea level · land motion
Water · atmosphere
Ionosphere

Geodetic products become inputs for Earth-system monitoring.

4

Climate-resilience questions

From measurements to interpretation

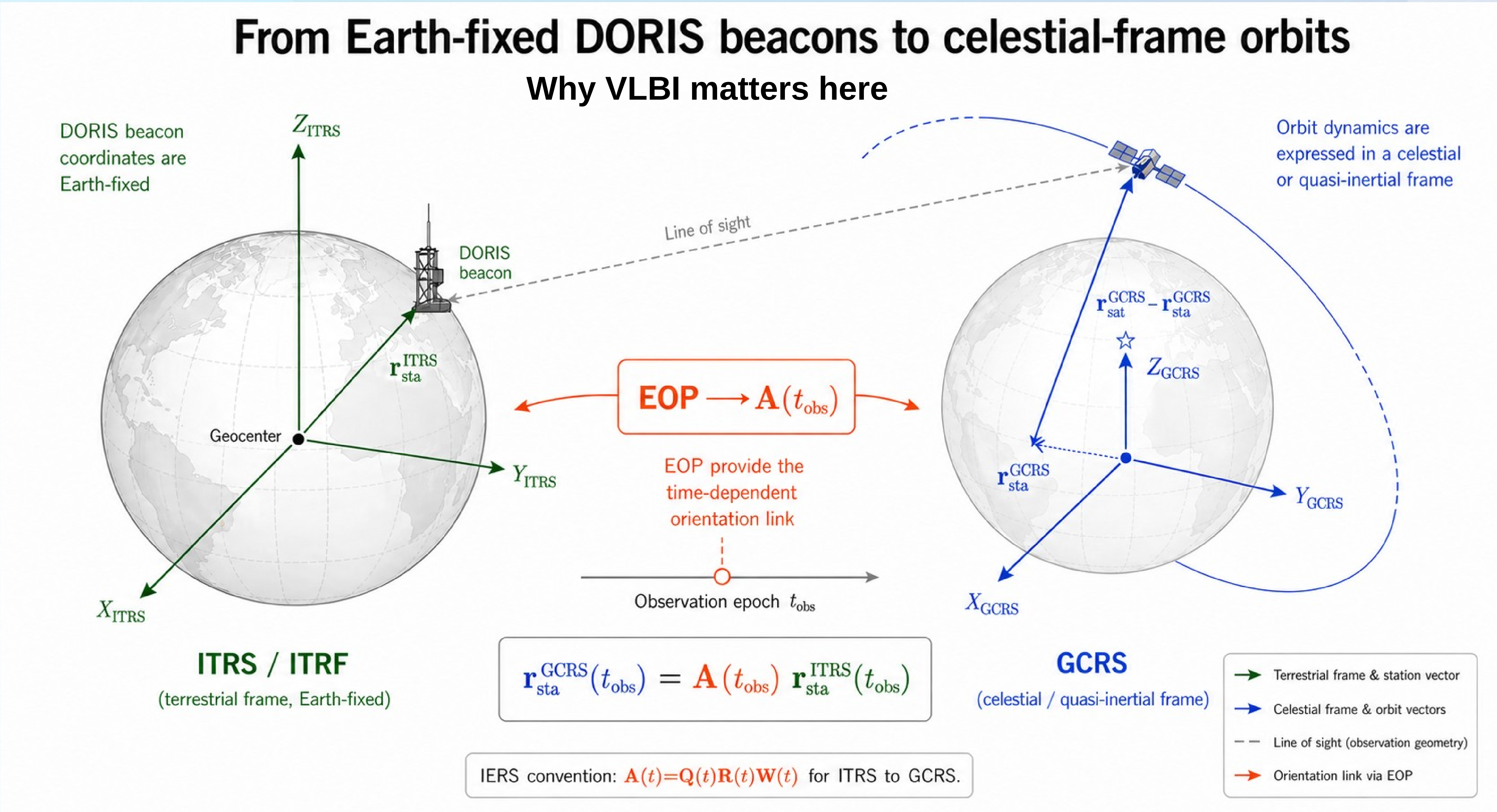
Coasts · droughts
Floods · water resources

Reliable decisions depend on reliable long-term observations.

Climate signals need stable geometry.

Space geodesy provides the stable geometry behind long-term Earth observation.

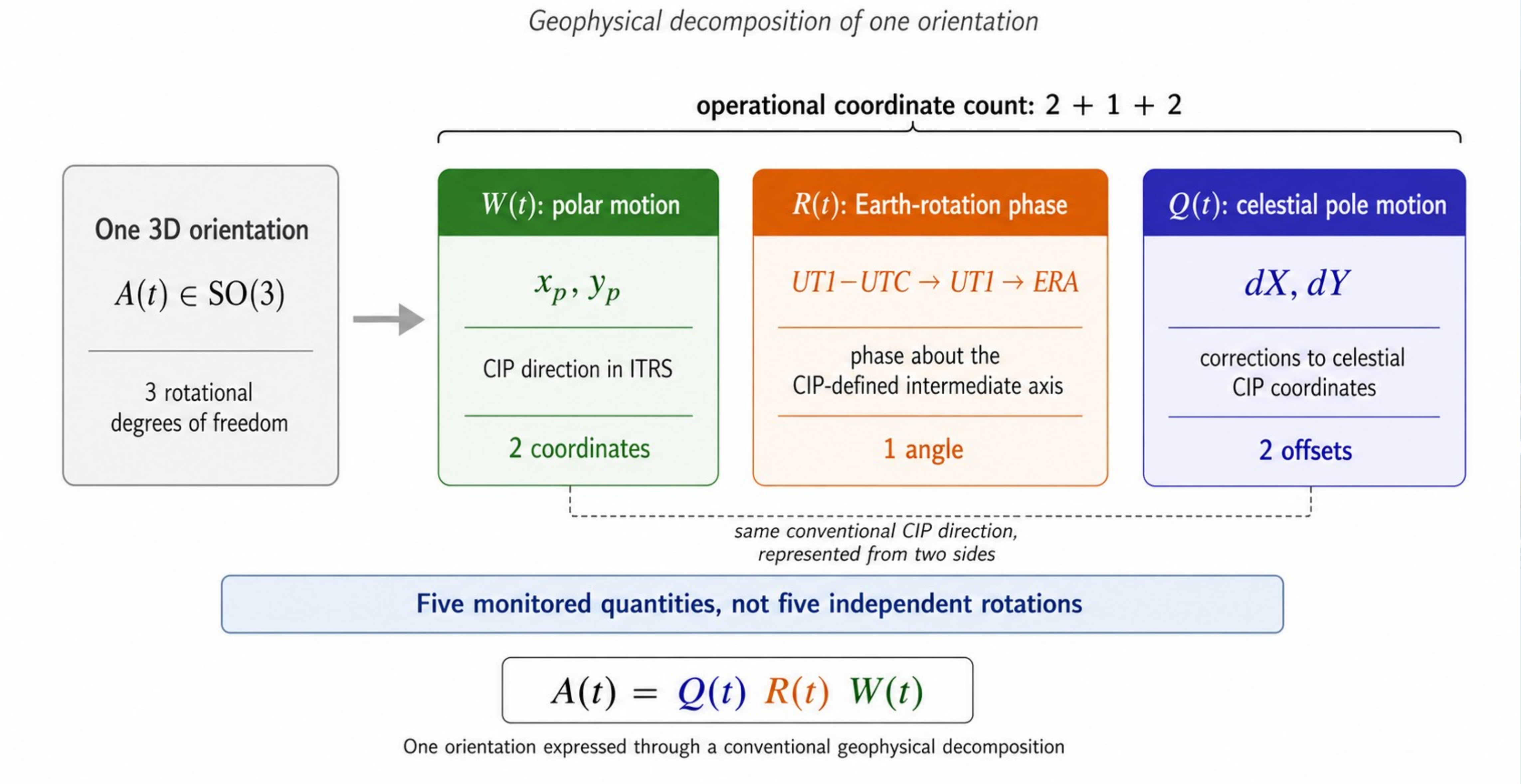
Why VLBI matters here



Satellite techniques can contribute to polar motion and LOD-related information, but VLBI is essential for UT1–UTC and celestial pole offsets.

From [Nahmani S. and A. Pollet, 2026]

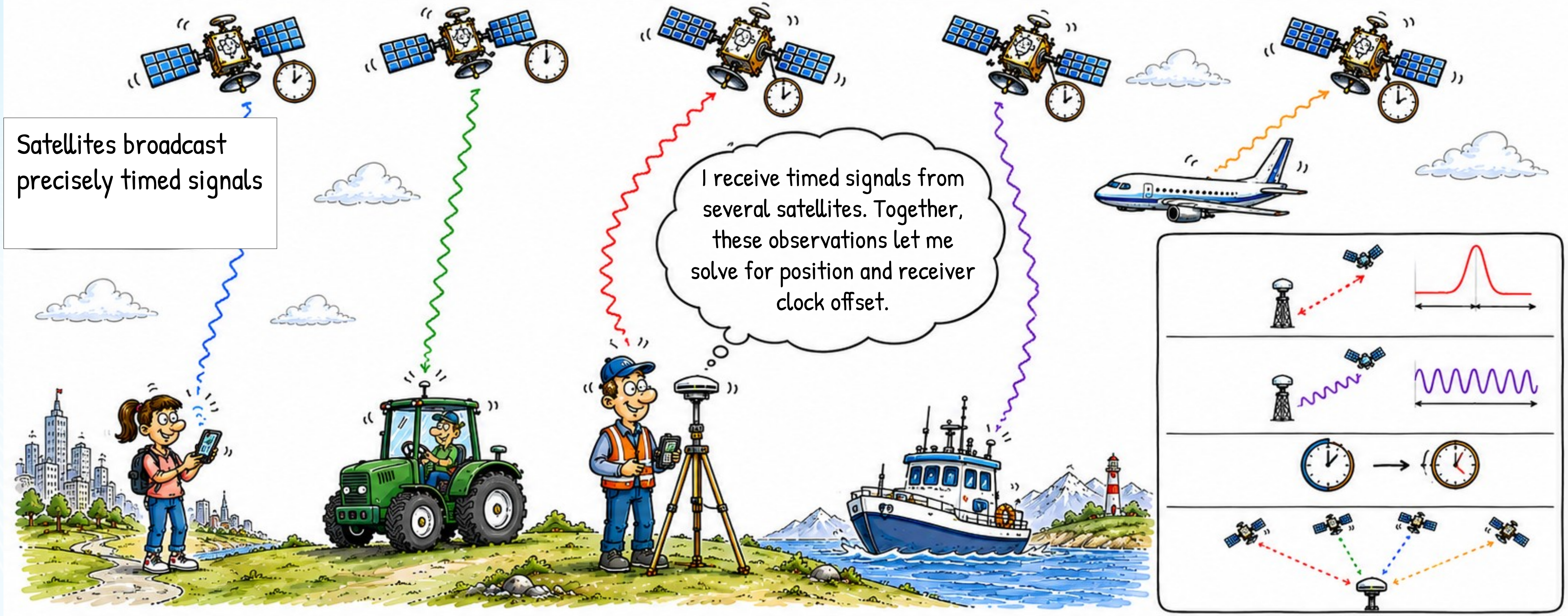
Operational EOP monitoring: geophysical decomposition



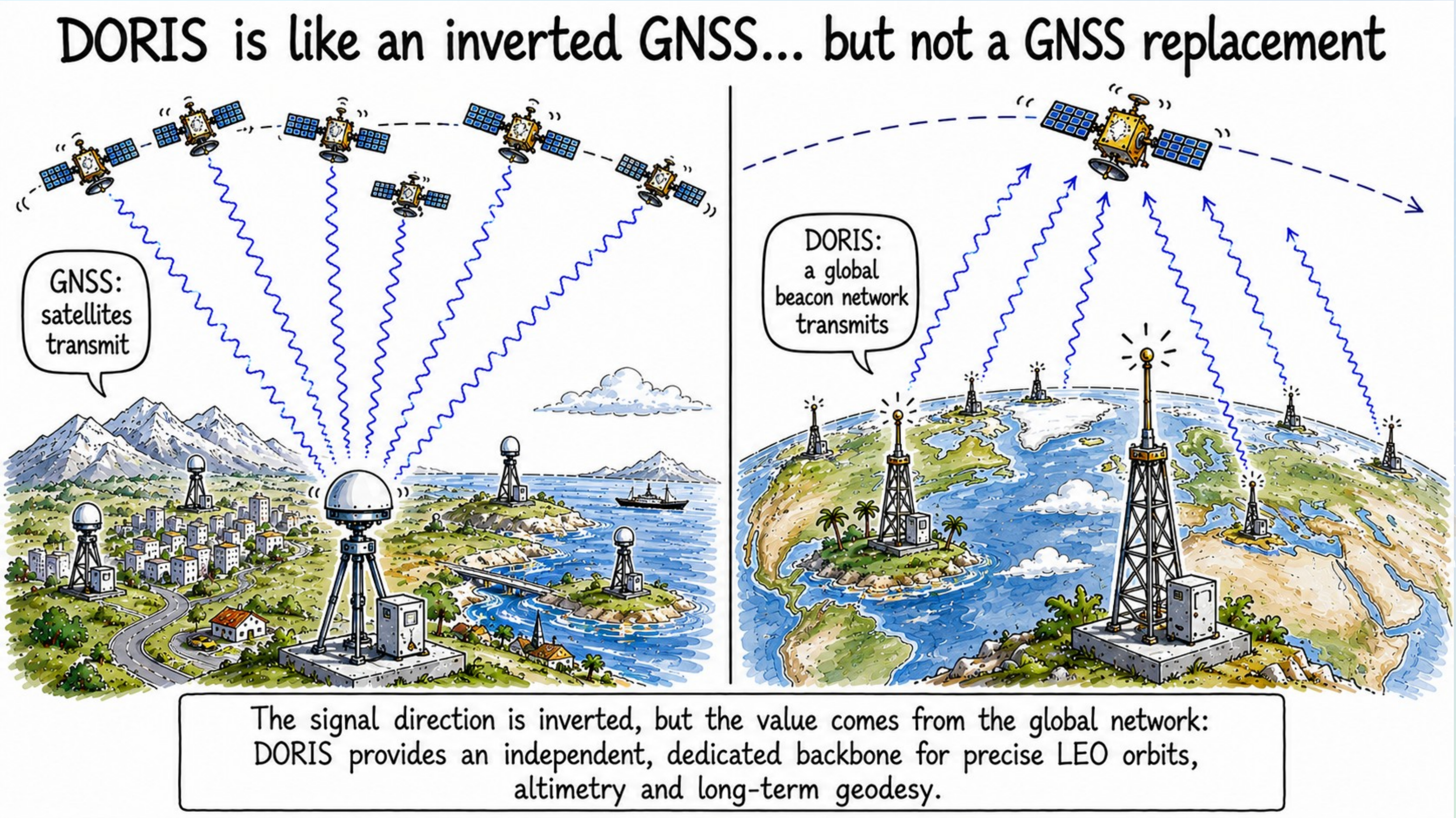
From Nahmani S. and A. Pollet, 2026

GNSS helps receivers know where they are

Satellites broadcast precisely timed signals



GNSS satellites broadcast precisely timed radio signals. Code measurements provide pseudo-ranges; carrier phase provides much higher precision, but with integer ambiguities. With at least four satellites, the receiver estimates position and receiver clock offset. GNSS also supports navigation, surveying, reference frames, Earth observation and many geodetic applications.


DORIS is like an inverted GNSS... but not a GNSS replacement
GNSS: satellites transmit
DORIS: a global beacon network transmits
The signal direction is inverted, but the value comes from the global network: DORIS provides an independent, dedicated backbone for precise LEO orbits, altimetry and long-term geodesy.

Same physics, different observation geometry

Why the GNSS analogy helps — and where it stops

	GNSS	DORIS
Signal direction	Satellites → ground	Beacons → satellite
Receiver location	Mostly on Earth	Onboard the satellite
Network logic	Many receivers observe GNSS satellites	A global beacon network tracks LEO satellites
Shared physical ingredients	Time · frequency · propagation · frames · orbits	Time · frequency · propagation · frames · orbits
Main message	Familiar entry point	Independent tracking geometry

The analogy is useful for intuition, but DORIS has its own measurement geometry and network logic.

Today we invert the GPS story

Same signal-path physics — opposite observation geometry

GNSS course	DORIS story
Satellite → Signal path → Ground receiver	Ground beacon → Signal path → Satellite receiver

Shared physical ingredients

H_2O	Troposphere	ZTD = ZHD + ZWD ZWD ↔ atmospheric water vapor	GNSS	DORIS
f	Ionosphere	frequency-dependent delay dual-frequency combinations	GNSS	DORIS
t	Time & frequency	clocks · oscillators · time tagging Doppler counts need frequency stability	GNSS	DORIS
↯	Local environment	multipath / reflections for GNSS local reflections & site effects for DORIS	GNSS	DORIS
v	Antenna & motion	phase-center effects · station motion plus orbit dynamics for satellite tracking	GNSS	DORIS

Water is already in the measurement chain:
- **gas phase → ZWD / water vapor**
- **liquid surfaces → reflections, multipath or local site effects**

Invert the geometry, keep the physics — and keep the geophysics in the model.

What makes a DORIS measurement scientifically rich?

A compact observable — an Earth-system model

1 The beacon is on a moving Earth

Tectonics · vertical land motion · post-seismic · volcanic deformation

Solid-Earth tides · ocean / atmosphere / hydrology loading · monument stability

The station is attached to a living Earth, not to an abstract fixed point.

2 The signal path is physical

Troposphere · ZWD · ionosphere · light-time

Clocks · phase wind-up · propagation effects

What is first corrected for orbit determination can become geophysical information.

3 The satellite orbit is Earth-system modeling

Gravity field · time-variable gravity · atmospheric drag · solar radiation pressure

Attitude · antenna phase center · force modeling

A precise orbit is a dynamic model of the satellite interacting with the Earth system.

4 DORIS has specific sensitivities

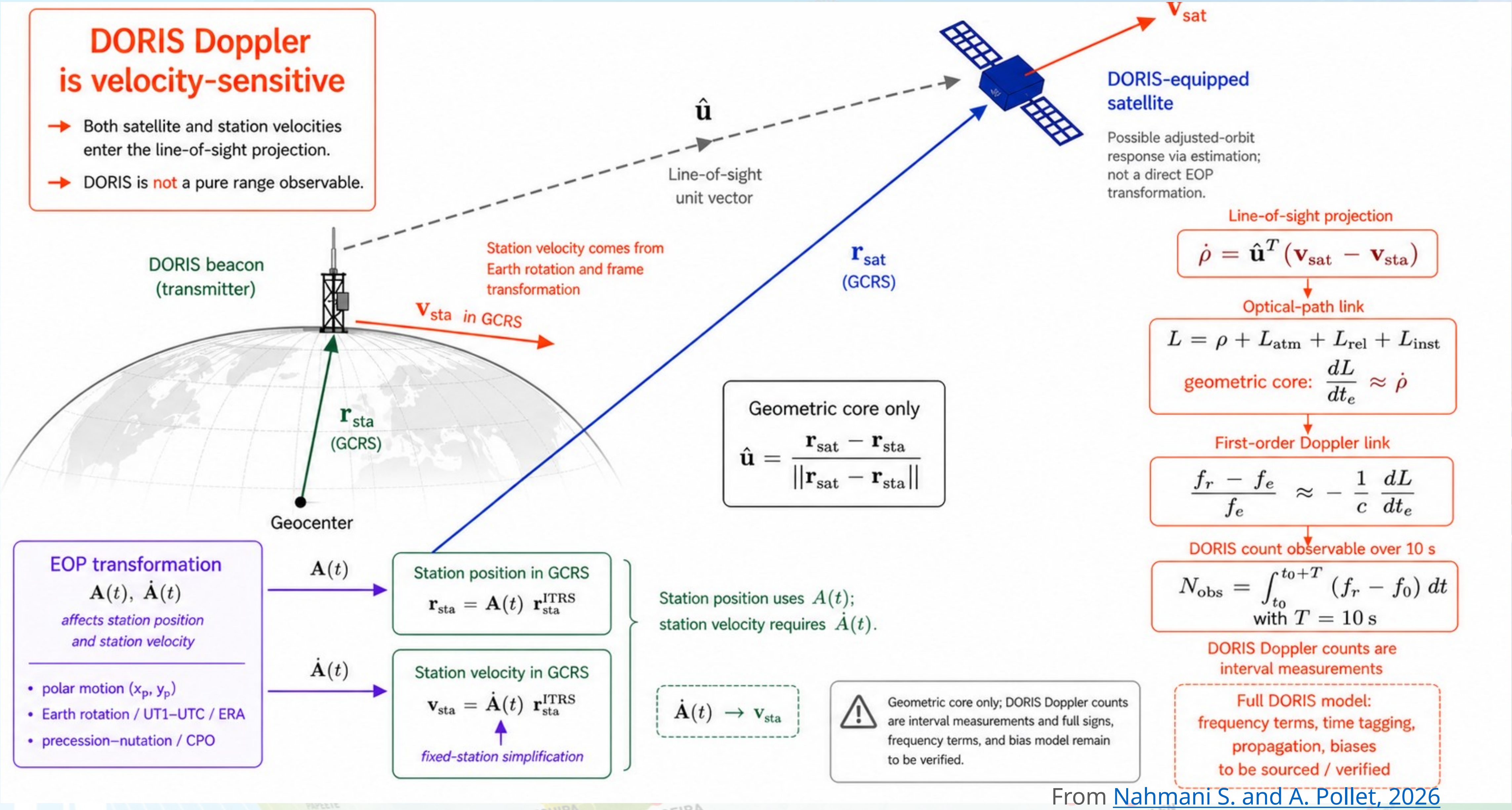
On-board clock / USO · frequency stability · South Atlantic Anomaly

Station environment · instrumental biases · site quality

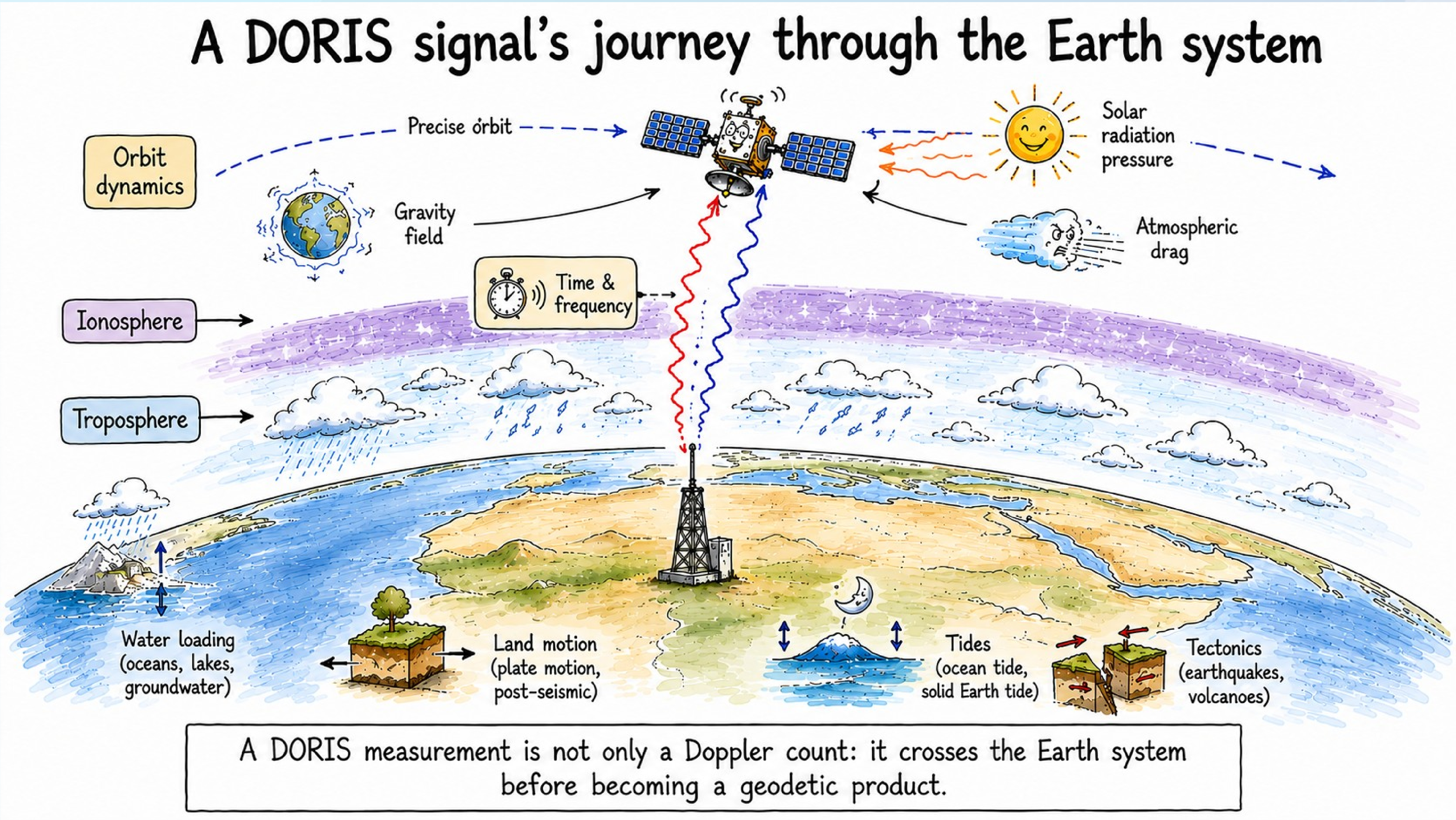
The system has its own strengths and vulnerabilities to understand and monitor.

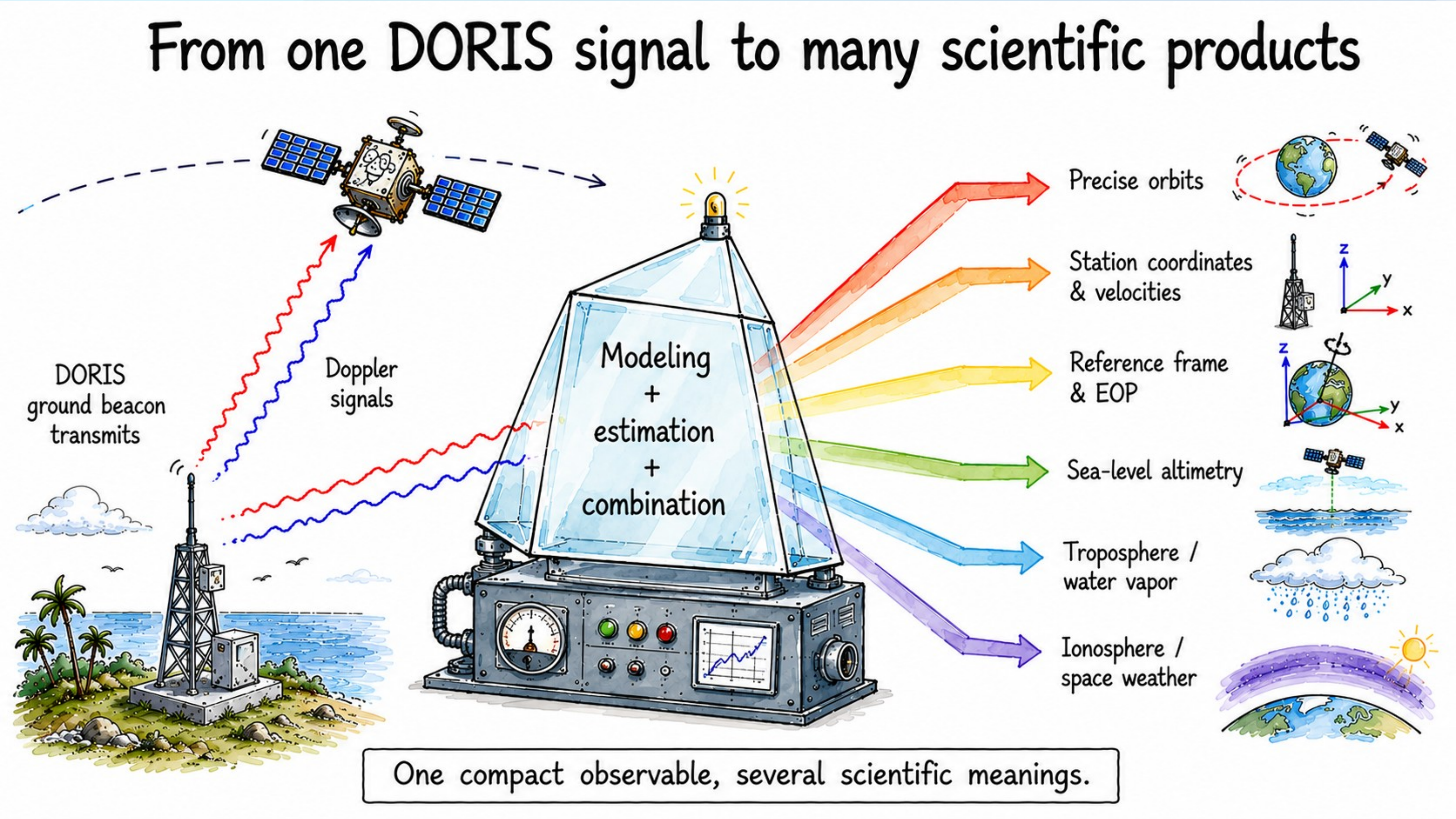
These are not only nuisances: they are also the doors through which DORIS connects to geophysics.

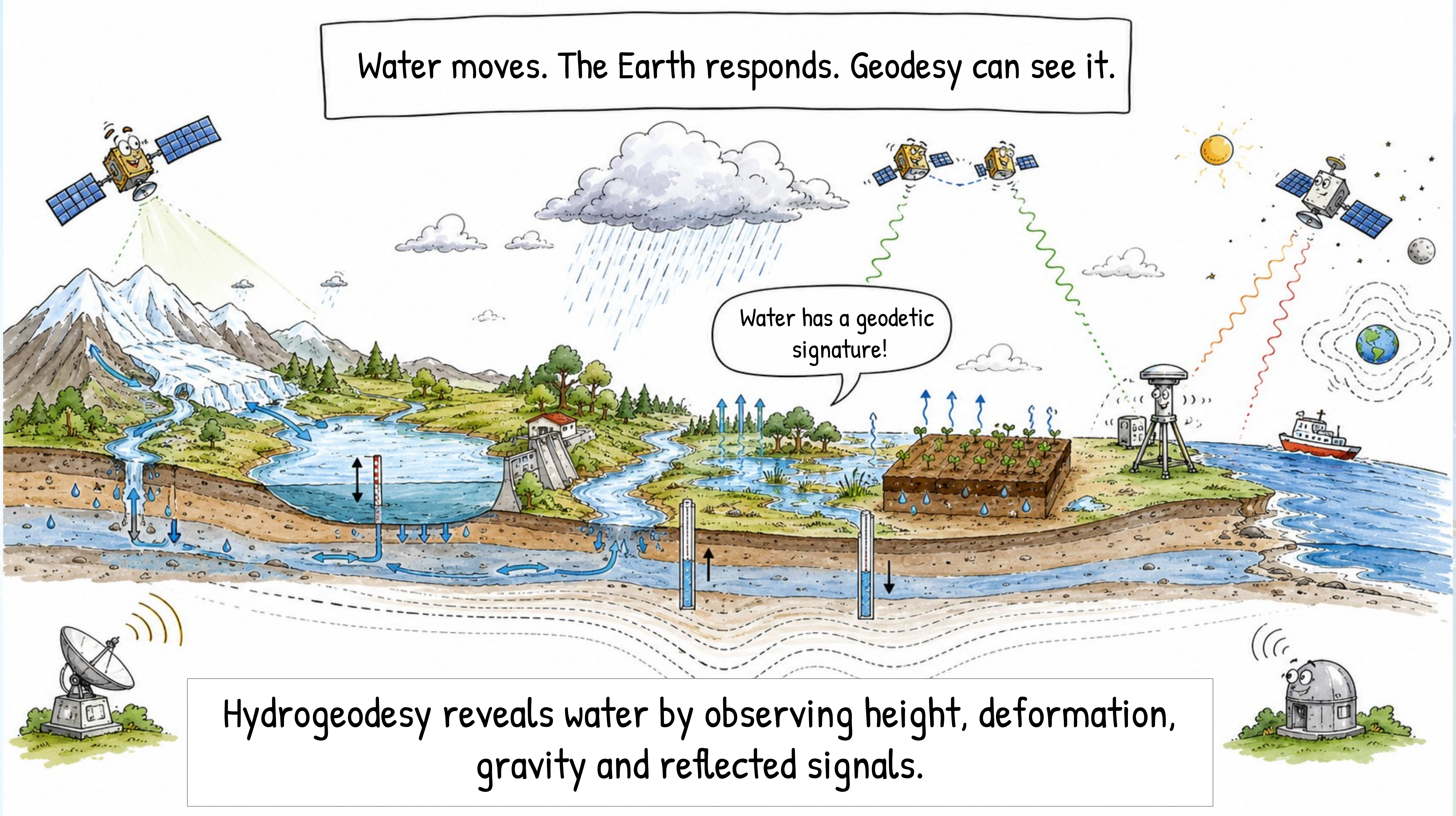
Opening the DORIS Doppler observation equation



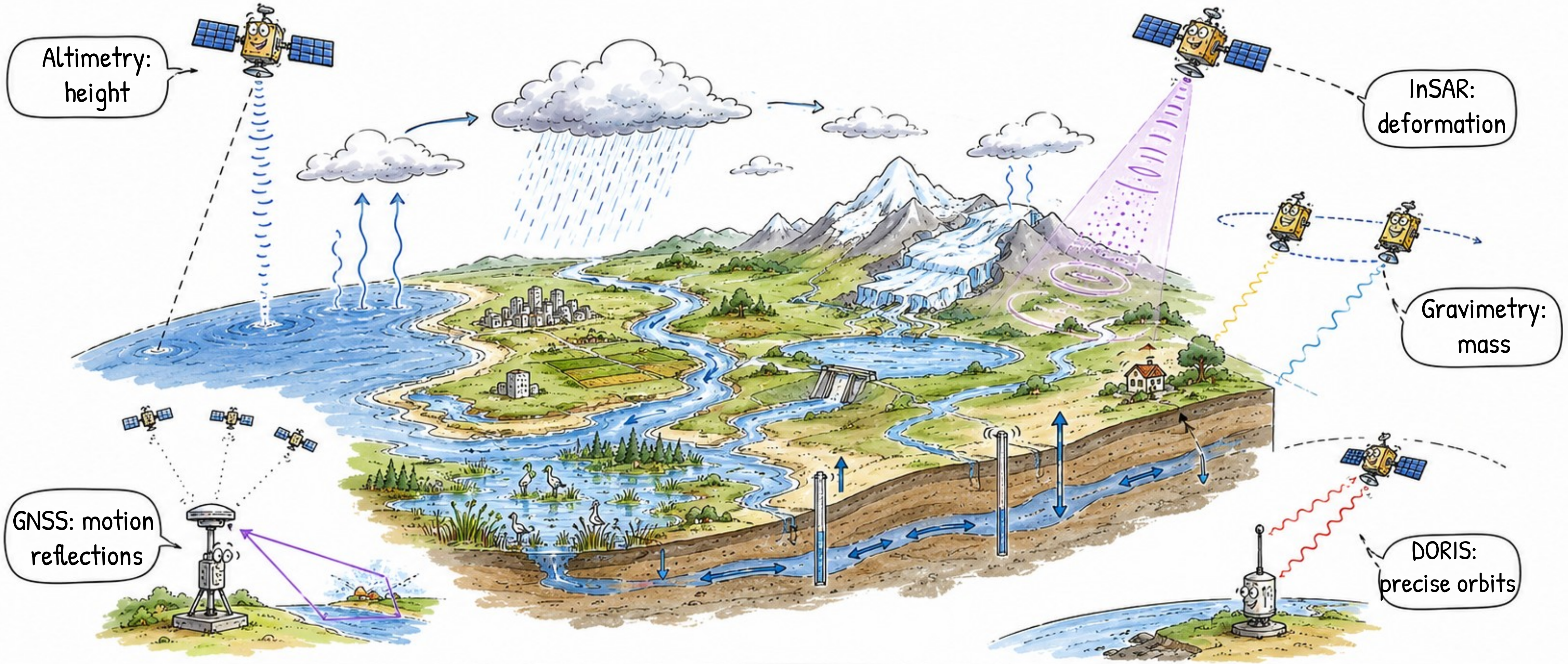
From Nahmani S. and A. Pollet, 2026


A DORIS signal's journey through the Earth system
Precise orbit
Orbit dynamics
Gravity field
Solar radiation pressure
Atmospheric drag
Time & frequency
Ionosphere
Troposphere
Water loading (oceans, lakes, groundwater)
Land motion (plate motion, post-seismic)
Tides (ocean tide, solid Earth tide)
Tectonics (earthquakes, volcanoes)
A DORIS measurement is not only a Doppler count: it crosses the Earth system before becoming a geodetic product.


From one DORIS signal to many scientific products
DORIS
ground beacon
transmits
Doppler
signals
Modeling
+
estimation
+
combination
Precise orbits
Station coordinates
& velocities
Reference frame
& EOP
Sea-level altimetry
Troposphere /
water vapor
Ionosphere /
space weather
One compact observable, several scientific meanings.


Water moves. The Earth responds. Geodesy can see it.
Water has a geodetic signature!
Hydrogeodesy reveals water by observing height, deformation, gravity and reflected signals.

No single technique sees the whole water cycle



Hydrogeodesy works because techniques are complementary.

Hydrogeodesy is powerful — but not simple

Integrated, scale-dependent and model-dependent measurements

1 Different observables

G **Gravity:** mass / water storage
GRACE-like view

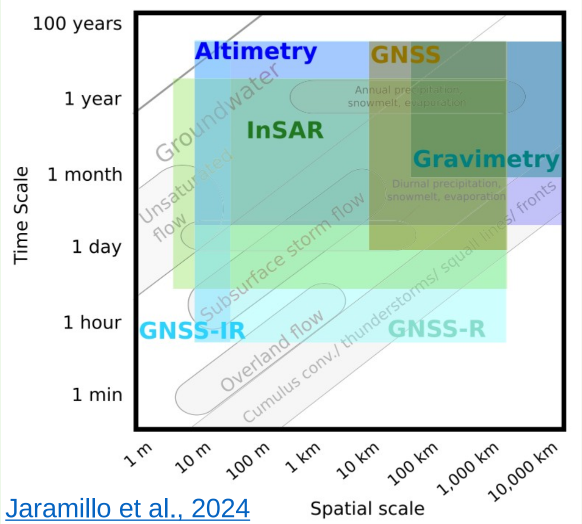
A **Altimetry:** height
oceans · lakes · rivers

I **InSAR:** deformation
local to regional motion

G **GNSS:** motion · atmosphere · reflections
ZWD · loading · GNSS-IR

D **DORIS:** supports altimetry · frame consistency · station-motion diagnostics · atmosphere
upstream backbone ZWD · loading

2 Different scales



Jaramillo et al., 2024

No single sensor covers all relevant **space–time scales** of the water cycle.
The same process may appear as mass, height, deformation or delay.

3 Interpretation limits

Integrated signals
one measurement mixes several processes

Processing & model errors
orbits · clocks · atmosphere · ionosphere

Solid-Earth response
rheology · loading · GIA · post-seismic

Reference-frame consistency
long-term signals need stable geometry

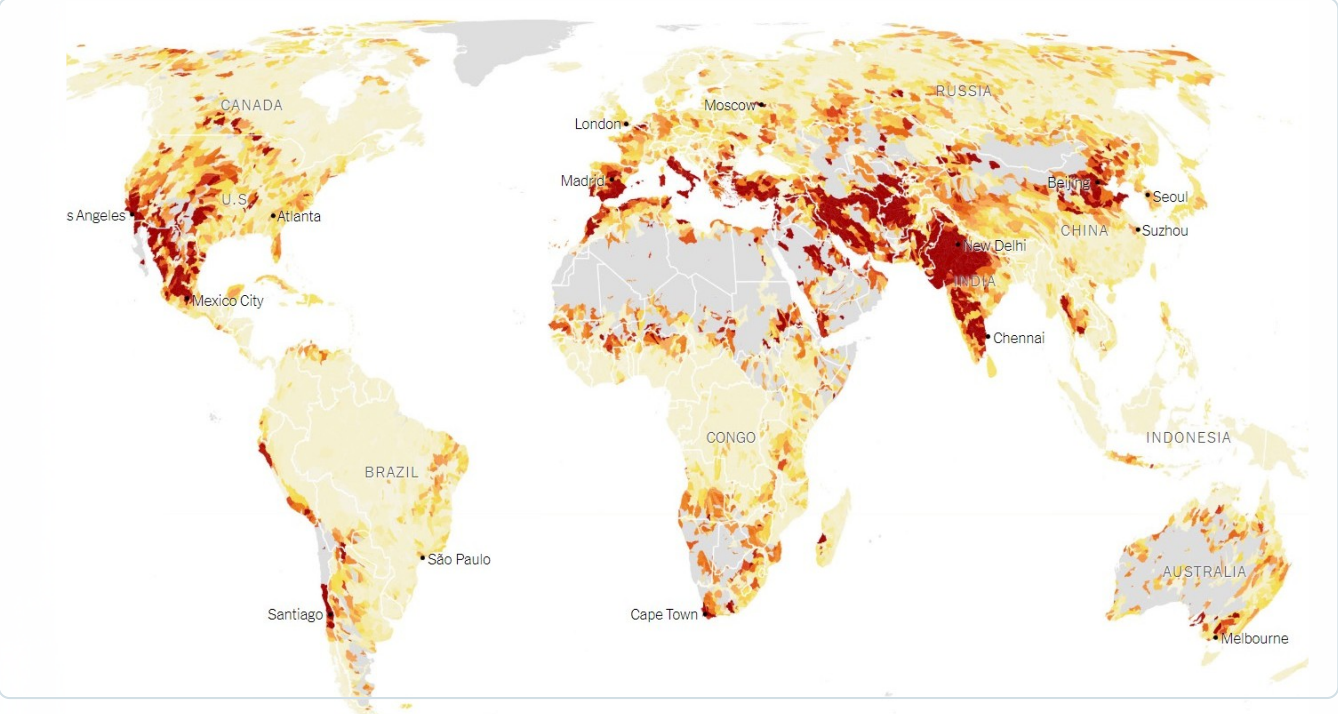
Validation
field data and hydrological models remain essential

Hydrogeodesy extends hydrology — but interpretation requires geodesy, Earth modeling and validation.

Why hydrogeodesy matters

Water pressure, climate variability and sparse in situ observations

Water pressure is spatially uneven — and locally severe



Water-stress level

Low — High — Extremely high

Source: water-stress map / WRI Aqueduct; adapted from K. Chanard course material - @New York times (data: World Resources Institute, Aqueduct water risk atlas)

Why geodesy helps

1 Water is a resilience issue

Droughts, floods, reservoirs, groundwater and river basins need spatially consistent monitoring.

2 Direct observations remain incomplete

Field hydrology is essential, but gauges, wells and metadata may be sparse or fragmented.

3 Hydrogeodesy extends hydrology

Geodetic techniques add height, deformation, gravity, water vapor and reflected-signal information.

Goal: turn scattered observations into comparable long-term signals.

Hydrogeodesy helps make water visible where direct observations are sparse or fragmented.

The African geodetic data paradox

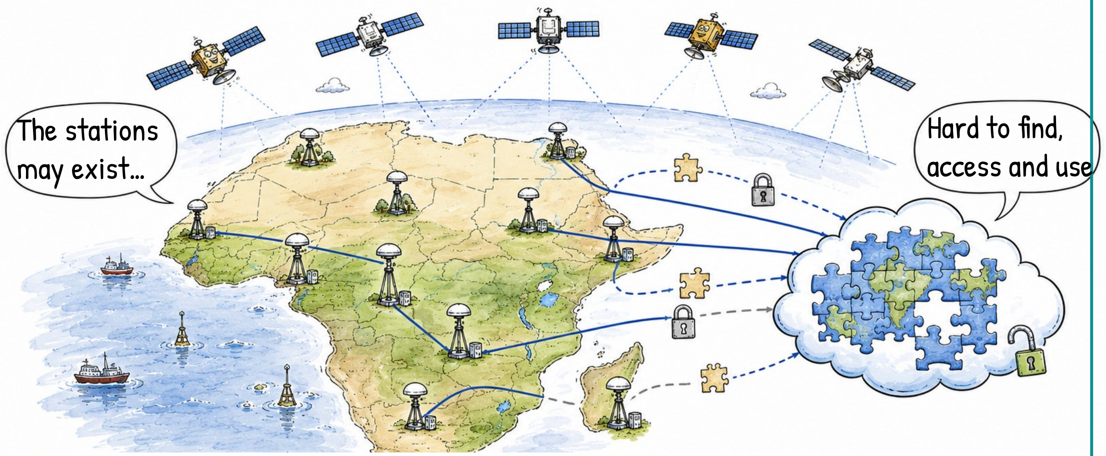
Stations exist — but science-ready open data chains remain fragile

1 · Geodetic infrastructure exists

AFREF / CORS initiatives: stations and reference-frame infrastructure are present.

Source: AFREF/AODC material

2 · The bottleneck is the data chain



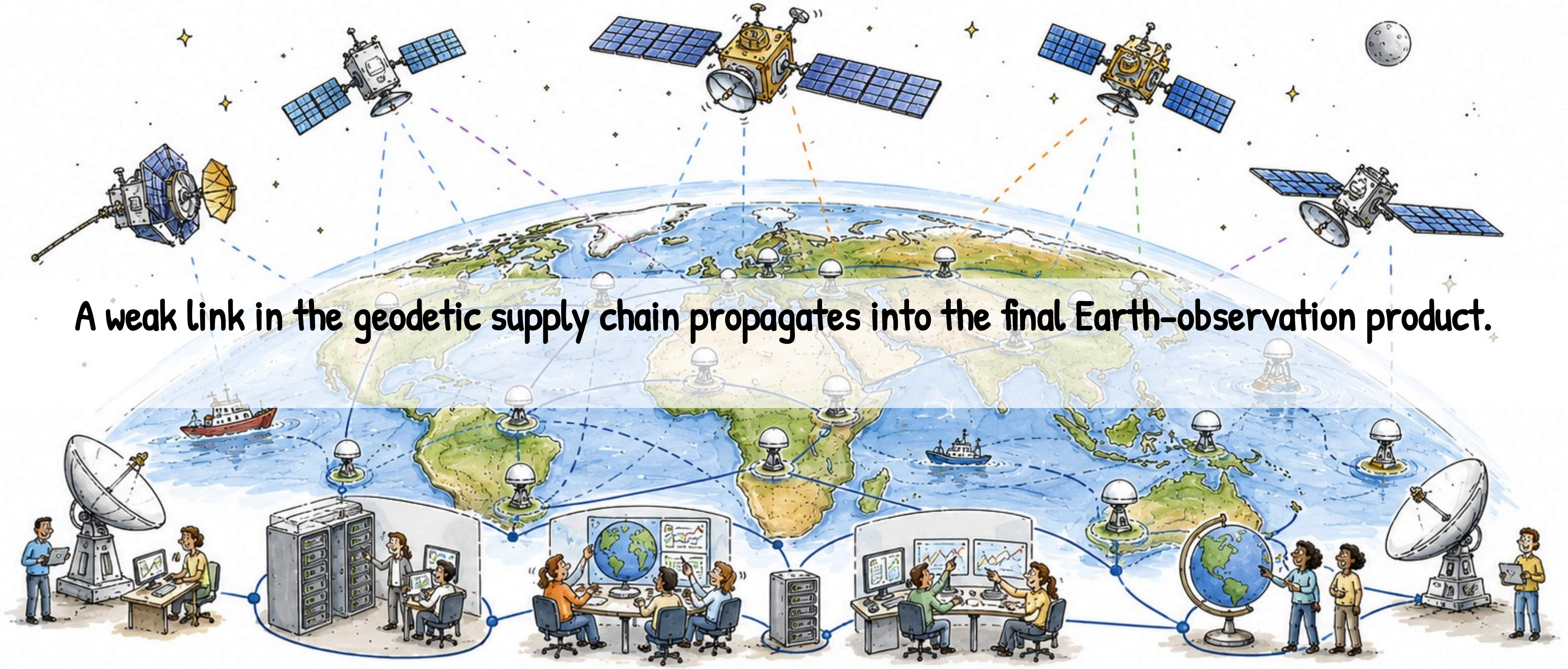
For climate and water applications, a station is useful only if its data can be found, understood, processed and trusted.

open access | continuity | metadata | processing | governance

The issue is not only stations; it is the full observation and data-access chain.

The paradox: Africa needs geodesy for water and climate resilience, but usable open data chains remain harder to build than stations alone.

Geodesy is a supply chain

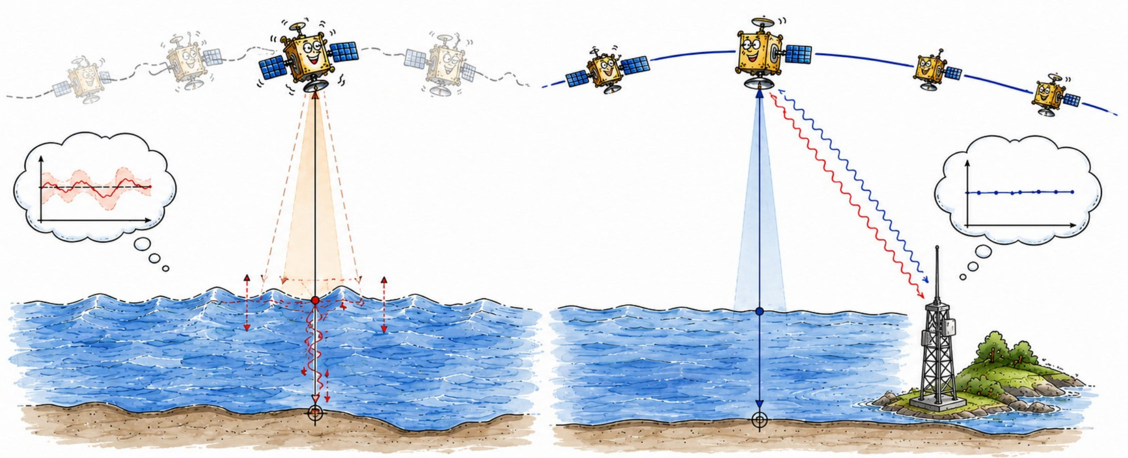


A weak link in the geodetic supply chain propagates into the final Earth-observation product.

Stations & satellites → Data & metadata → Data centers → Analysis centers →
Reference frames, orbits & EOP → Earth-observation products → Decisions

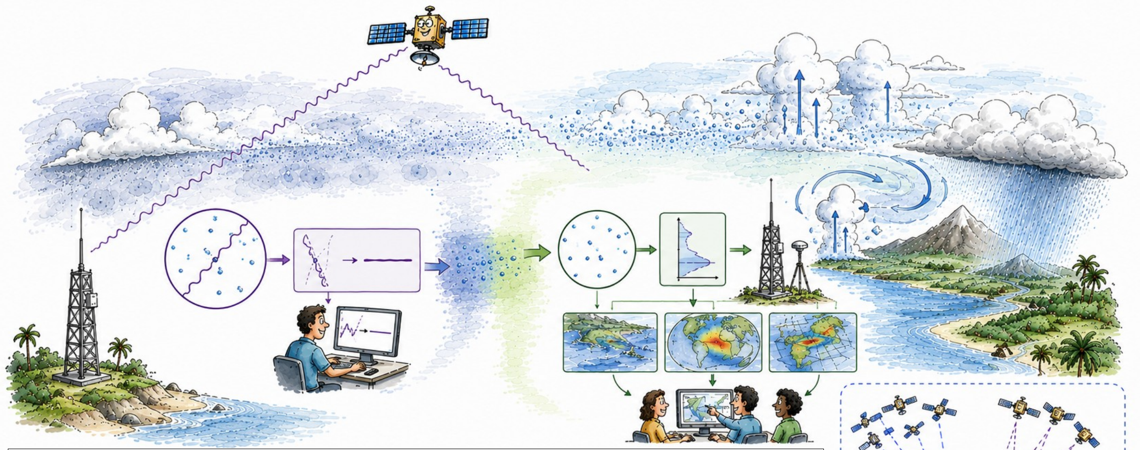
Where DORIS fits in Earth-system monitoring

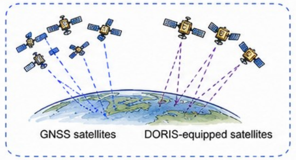
Altimetry and precise orbit



Precise orbit first, sea level after.

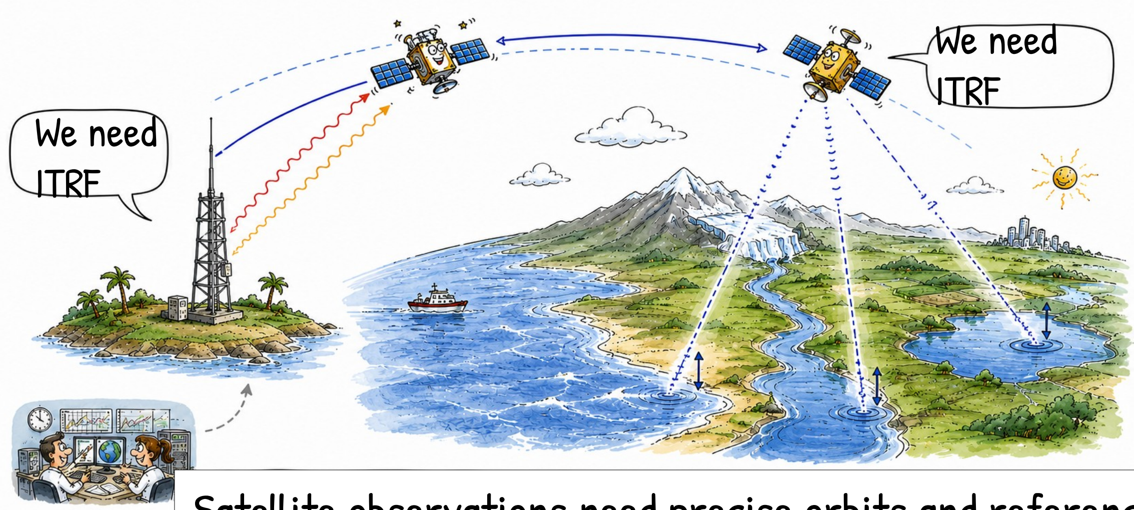
Signals through the troposphere





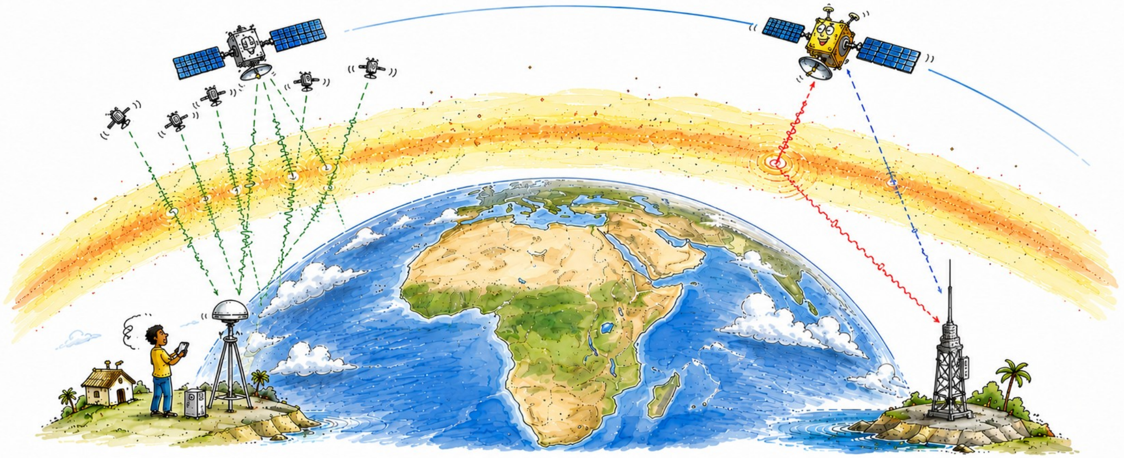
A correction can become a climate signal.

Precise orbits + TRF



Satellite observations need precise orbits and reference frames

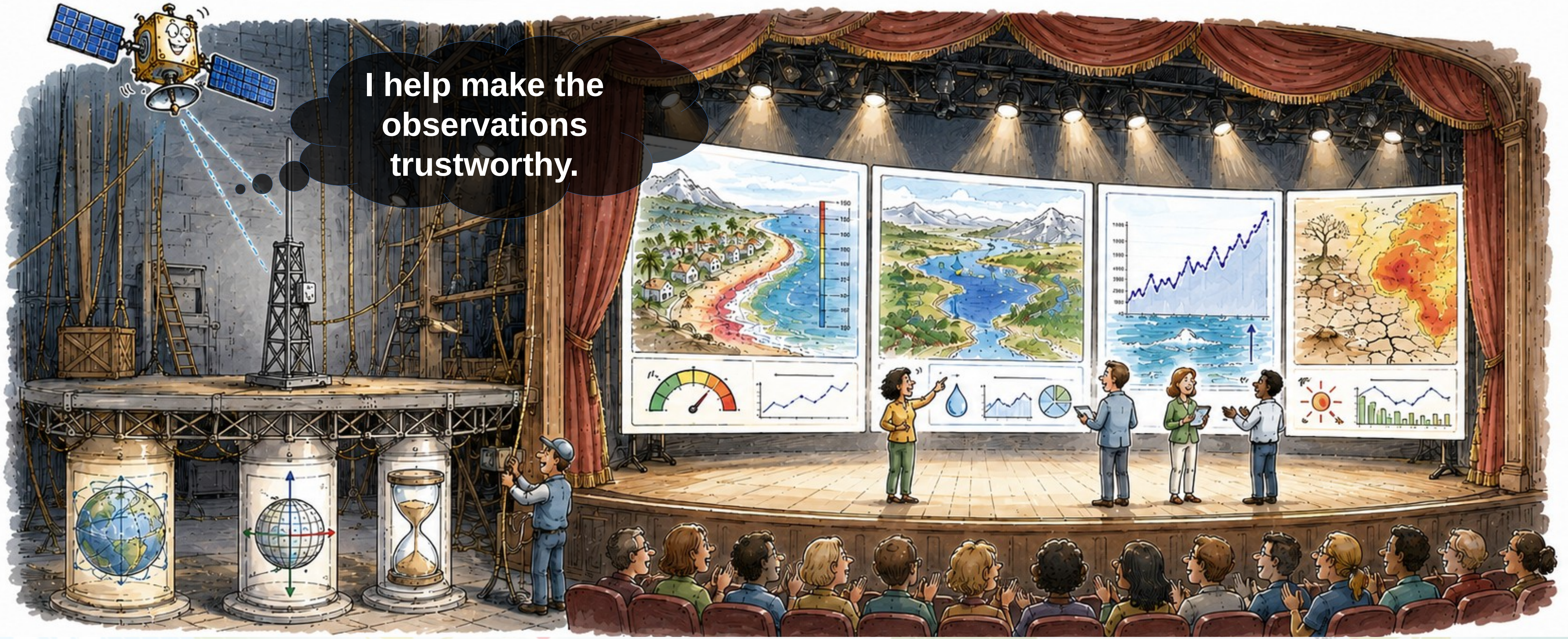
Signals through the ionosphere



Comparison GNSS/DORIS

doris.org

DORIS works backstage, but it makes the show reliable



DORIS is a backbone contributor: it supports precise orbits, reference frames and long-term consistency.

Key points to take home

- DORIS is not a GNSS replacement; it is complementary.
- A DORIS measurement crosses the Earth system before becoming a product.
- Hydrogeodesy makes water visible through height, deformation, gravity and signals.
- Africa needs not only stations, but open, continuous and documented geodetic data chains.
- DORIS helps make altimetry, reference frames and long-term Earth observation reliable.

I focused on why DORIS matters. Laurent will now show how IDS gives access to data, products, metadata, tools and learning material.

Material for the presentations:

PDF presentations on the IDS website

DORIS days: https://ids-doris.org/resources/capacity-building/doris-days.html

Summer schools : https://ids-doris.org/resources/capacity-building/summer-schools.html

YouTube

DORIS overview (2025) (presentation in English)