

The logo for MAAGM, where the letters "M", "A", "G", and "M" are in a dark brown, bold, sans-serif font. The central letter "A" is replaced by a stylized human figure in a light blue color, with a circular head and two legs extending downwards.

Orientation to True North for Seismic Stations:
Review of Field Practices and
New Instruments to Improve Accuracy and Operational Efficiency

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EGU26-22593



LOKI

High-grade remote optical sensors

Omni-tilt seismometer
Long-base strainmeter
10ppm pressiometer
...

NJORD

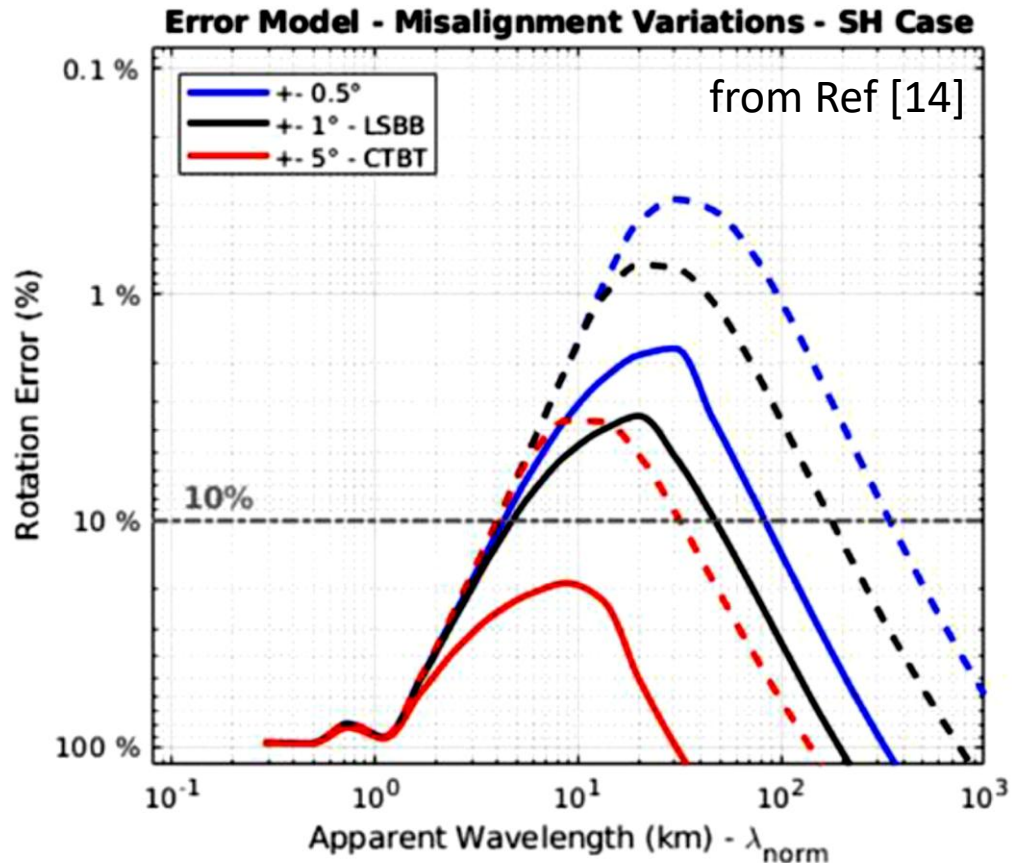
True North station orientation

Årian gyrocompass
exail optical gyrocompass
Laser alignment kit
...

Station Orientation need

Modern seismic data analysis needs good orientation

Array-derived rotation uncertainty as a function of varying sensors' misalignment



RUSCH et al. (2020)

“Array-derived rotations ...”

*“The amount of uncertainty associated to **array-derived rotation** decrease by one order of magnitude if the gyrocompass is used instead of the compass [...].*

Furthermore, for a chosen amount of uncertainty, the normalized wavelength band is increased and encompasses to a greater extent the long-period normalized wavelengths”

(From ref [14])



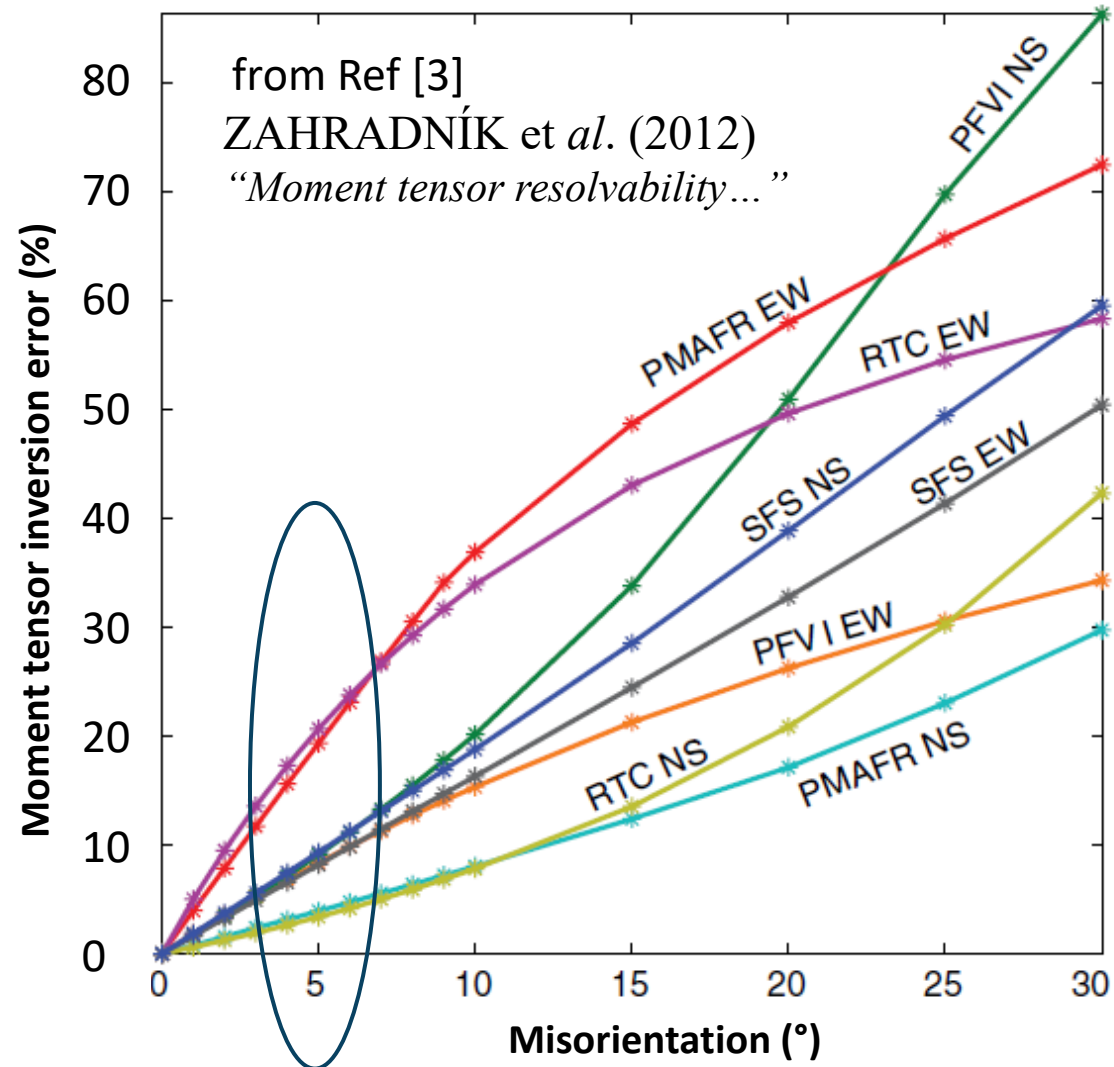
“ The two most influential sources of uncertainty are the instrumental phase response and the stations' misalignment.

For those two sources of uncertainty, the standard guidelines are insufficient when applied to array-derived rotation.”

(From ref [14])

Modern seismic data analysis needs good orientation

Moment tensor inversion error versus the misorientation of 1 over 11 stations



Modern seismic data analysis needs good orientation

- Receiver functions, amplitudes analysis, direction of propagations [1]
- Moment tensor inversion: 10° leading to up to 40% error [3]
- Modern 3-Component observations [4]
- Seismic wave separation [12]
- Array Derivative Rotation [14]
- Seismic wave polarization [ongoing work from CEA]
- Back Azimuth estimation [ongoing work from CEA]

“The accuracy of many seismic measurements, such as receiver functions, amplitudes, and propagation directions, highly depends on the accuracy of a sensor’s orientation (Laske, 1995; Ekström et al., 1997; Baker and Stevens, 2004; Niu and Li, 2011; Shen and Ritzwoller, 2016).” (from Ref [1])

Station
orientation
quality

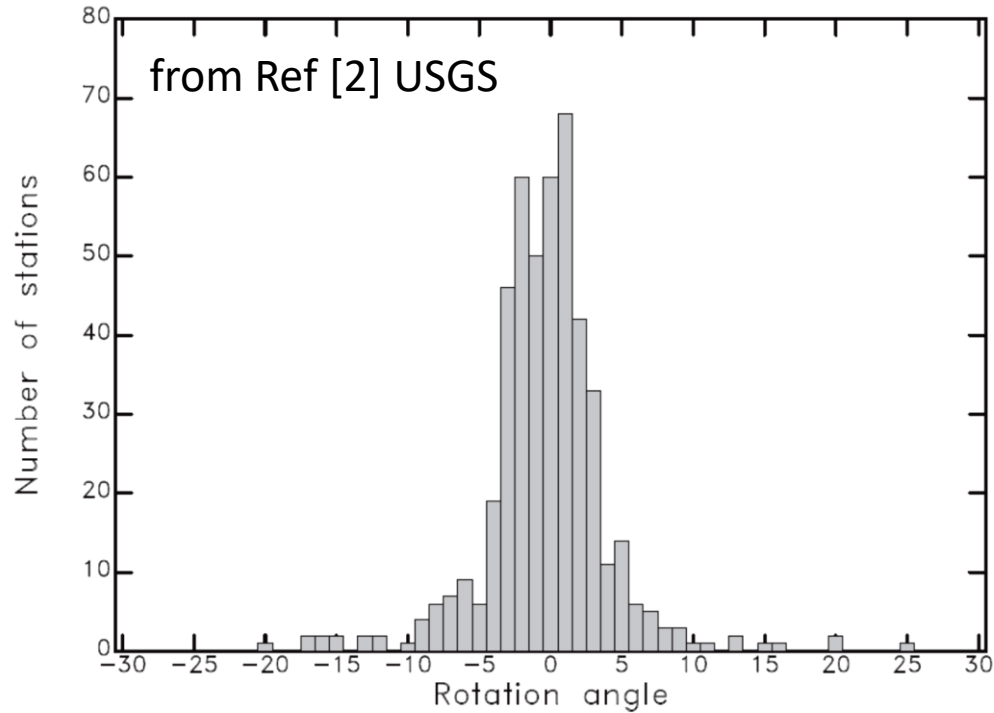
Stations misorientations using a magnetic compass

Worldwide average station misorientation : $\sigma \approx 6^\circ$

- 32% of Spanish Broadband National Network $> 15^\circ$ misorientation (Rueda and Mezcuca (2015))
- Misorientation of more than 100 stations of EOBSarray has $\sigma = 11,6^\circ$ (cf ref [1])
- 41.3% of ANSS stations have misorientations $> 4^\circ$ (cf ref [2])
- 11/30 stations of AlpArray in Austria have misorientations $> 7^\circ$ (cf ref [5]), and 12/26 stations of AlpArray in Hungary have misorientations $> 6^\circ$ (cf ref [6])
- 24% of 473 stations of USArray have misorientations $> 4^\circ$, and 10% $> 7^\circ$ (cf ref [10])
- 270/800 = 34% of CNDSN have misorientations $> 8^\circ$ (cf ref [12])

“There is no universally recognized body in the world of seismology that has the authority to establish standards related to seismometer instrumentation. Instead, each organization issues its own specification.” (from ref [13])

Stations misorientations using a magnetic compass



▲ **Figure 3.** Histogram showing the distribution of rotation angles for 473 USArray stations.

Ringler et al. (2013)

“Seismic station installation orientation errors ...”

“The determination of the northward direction has been routinely performed for years with the use of standard compass, with the best accuracy being 5° in the case of no magnetic disturbances in the nearby surroundings. However, such accuracy is no longer sufficient.” (from Ref [4])



“This strongly suggests magnetic compasses should not be used for finding true north.” (from Ref [2])

Stations misorientations using a magnetic compass

Niu et al. (2013)
“Component azimuths of the
CEArray ...”

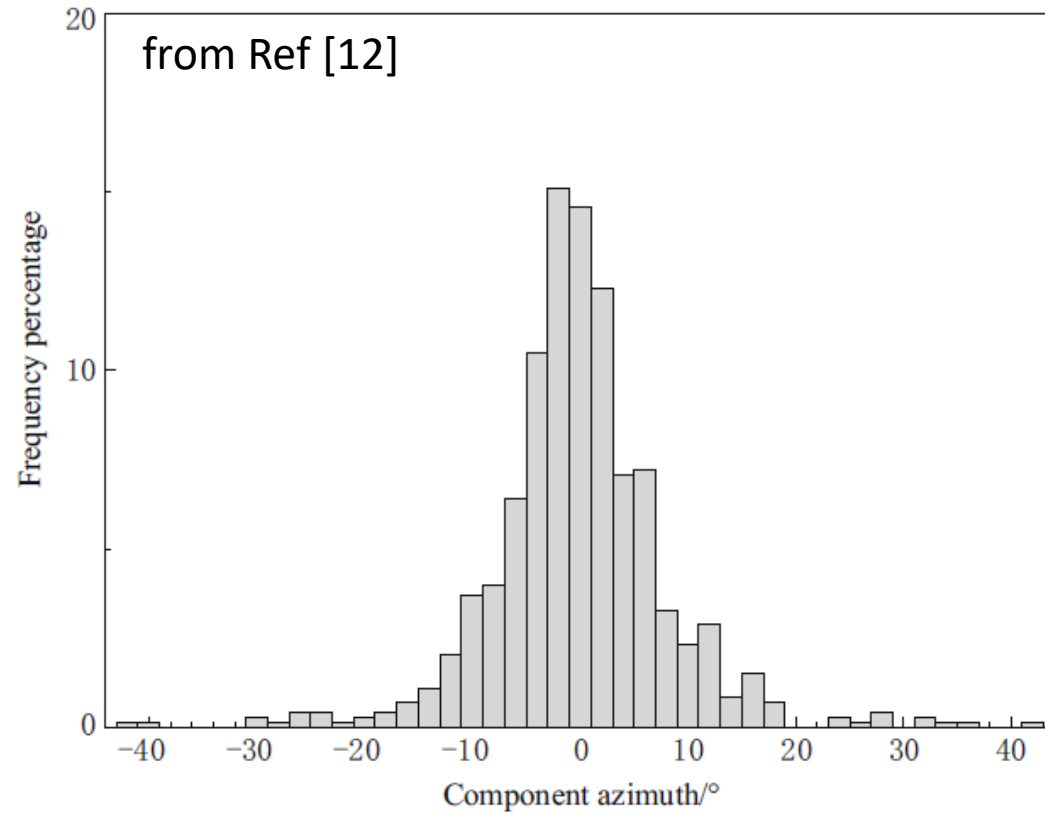
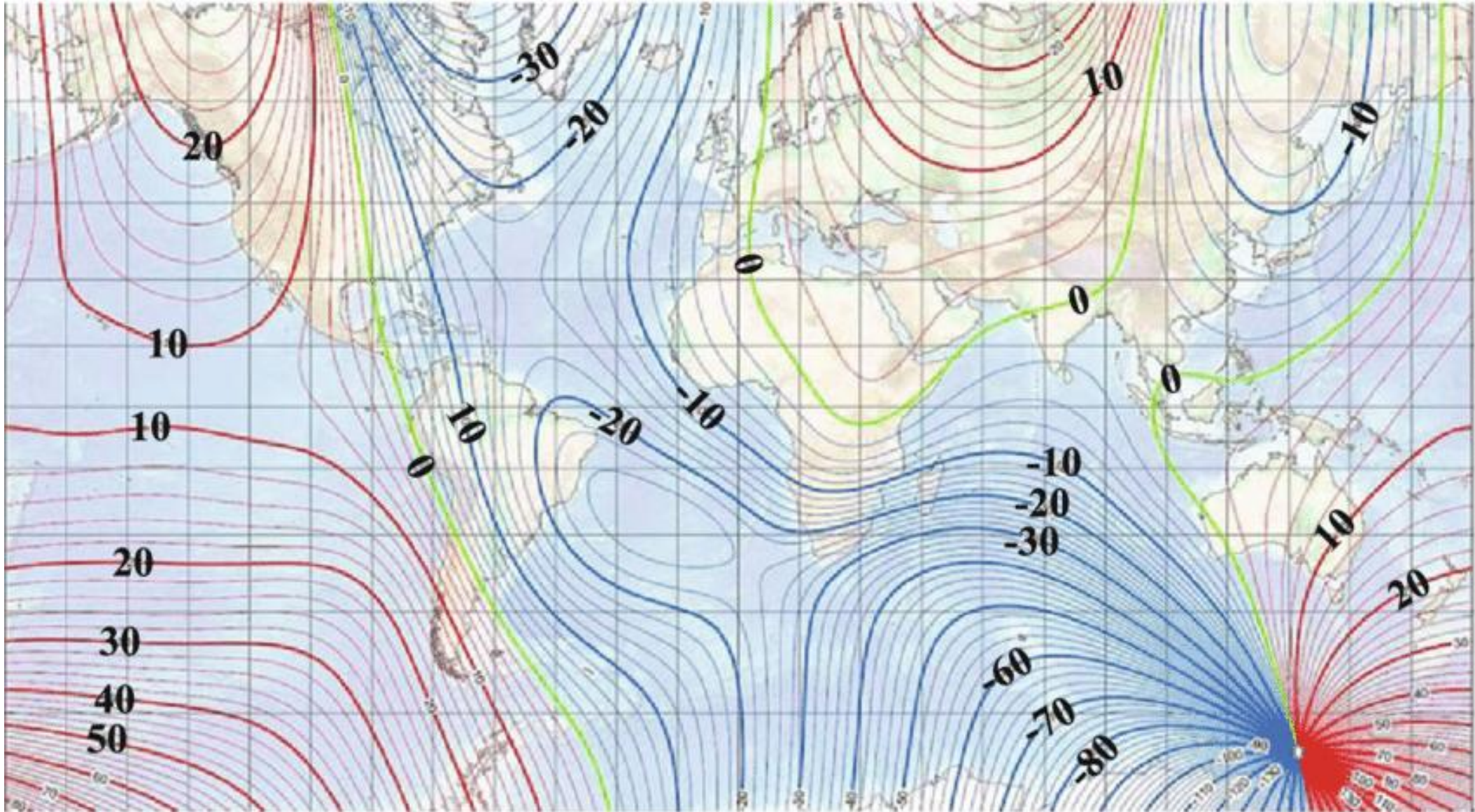


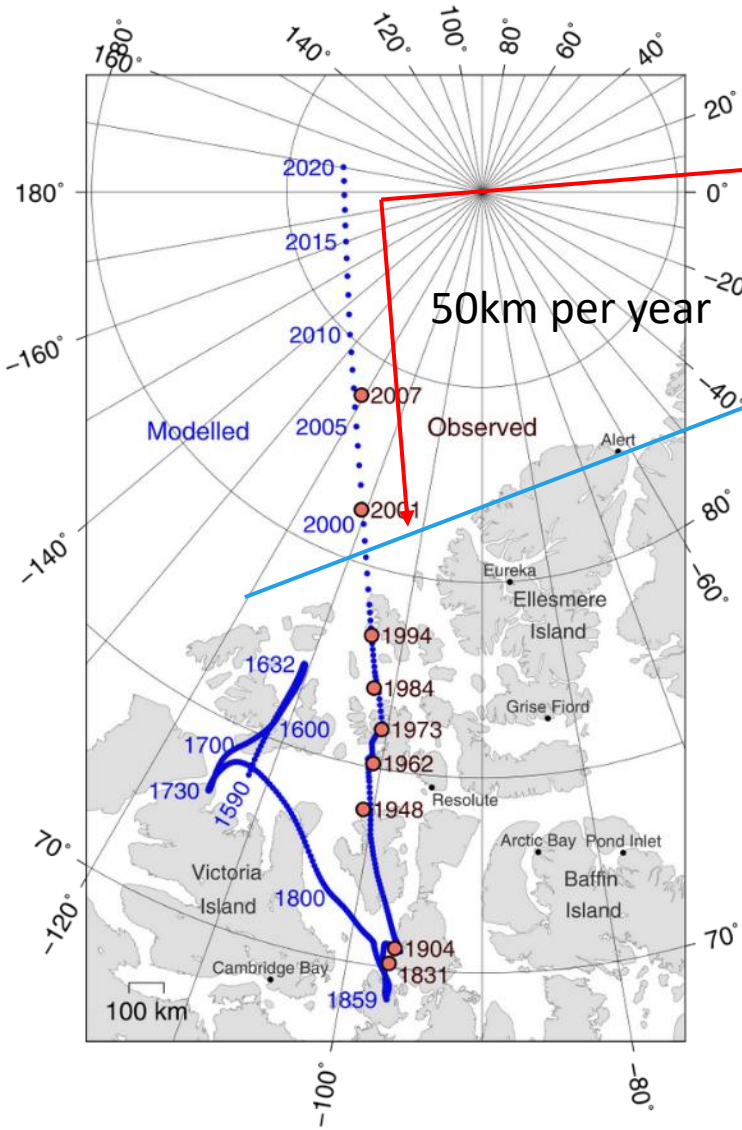
Figure 5 Histogram showing the distribution of the BHN component azimuths measured at the 803 CEArray stations.

Reasons for poor magnetic orientation

Magnetic North is not the same everywhere



Magnetic North is moving



5000km @ 45° latitude

50km per year

Using 1 year old declination table :

$$\begin{aligned} \text{Angular error @45}^\circ &= \\ &= 50/5000 \text{ rad} = \\ &= \mathbf{0,6^\circ} = \\ &= \mathbf{0,42^\circ \text{ seclat}} \end{aligned}$$

Local heterogenities

- Ferromagnetic minerals
- Volcanic rocks
- Metal structure (reinforced concrete)
- Electrical infrastructure
- Buried metallinc object nearby
- ...the station itself !

Post processing ?

Post installation station orientation

Various methods documented

depending of sensors kind and available well localized seismic source

- Teleseismic
 - Pwave Particle motion
 - Polarization of intermediate period surface waves
 - ...
- Tidal model
- For OBS, boat with GNSS passing by

But with limited impact on data sensor use

- Additional delicate work
- Corresponding misorientation often single use
(not attached to metadata of the sensors)
- Even when attached, not always taken into account by data-users properly

Orientation error estimation

Total orientation budget error

> Compass accuracy

Datasheet

Operation

Seclat

Sigma OR Max ?

+

> Transfer error

Mechanical

Optical

Resolution

Focus

*“Using a **gyrocompass** to find true north and a sunshot (such as **theodolite**) to transfer the reference line is one of the most accurate methods to assess the sensor orientation. Unfortunately, the **cost and weight** of such equipment restricts their availability for many temporary seismic experiments.” (from ref [12])*

Seclat unit

Latitude (°)		Heading accuracy (°) for 0.23° seclat
North Pole	90	360,0
Spitzbergen	80	1,32
Igloolik	70	0,67
Alaska	60	0,46
Canada	50	0,36
New-York	40	0,30
Texas	30	0,27
Hawaiï	20	0,24
Costa-Rica	10	0,23
Equator	0	0,23

Gyrocompass accuracy is given in **degree seclat** rather than plain degrees because the **heading error depends on latitude**.

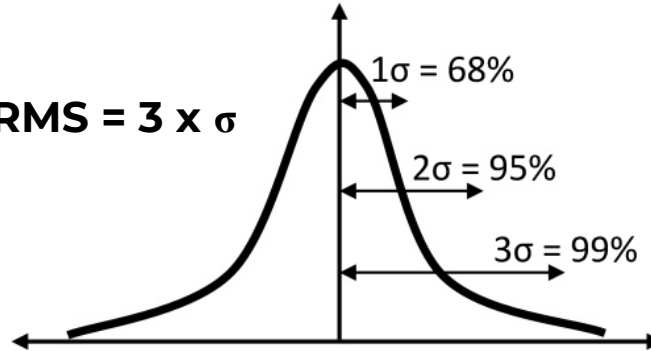
The compass senses the horizontal component of Earth's rotation, which scales with $\cos(\text{latitude})$. As you move away from the equator, the same gyro bias produces a larger heading error, proportional to $1/\cos(\text{latitude})$.

$$\text{Spec [}^\circ\text{]} = \text{Spec[seclat]} / \text{cos_lat}$$

RMS value

Without extra indication, gyrocompass specifications are always expressed in $\text{RMS} = 1.\sigma$

MAX error = 3 x RMS = 3 x σ



RMS definition is valid for error estimation of a time series

Operation is crucial: latitude needed

3

Case Number or
Seistans Serial Number

Optical
gyrocompass
case



CONTROL | INSTALLATION | **SETUP**

CONTROL | INSTALLATION | **SETUP**
POSITION FIX

CONTROL | INSTALLATION | SETUP

Heading 301.063°

Roll 0.133°
Pitch 0.257°



Latitude 48°0.000041' N
Longitude 008° W

Fine Alignment 

SEISTANS

POSITION FIX

▼ Manual Position



Latitude 0° 0' N
Longitude 0° E

Label

Shortcuts

Delete

Manual position forced

Operation is crucial: error subtraction

Optical gyrocompass case

Alignment phase

4

CONTROL | INSTALLATION | SETUP

Heading 321.801°
Roll 0.034°
Pitch 0.269°

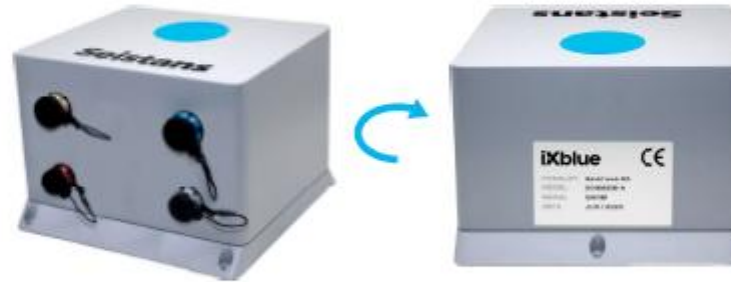
Latitude 59°39.000000' N
Longitude 28°31.000019' E

STATUS
Alignment
Remaining Alignment Time: - 00:04:40s

SEISTANS


Wait 5'

5




Turn 180°

6

CONTROL | INSTALLATION | SETUP

Heading 326.674°
Roll 0.045°
Pitch 0.260°

Latitude 59°38.999999' N
Longitude 28°31.000079' E

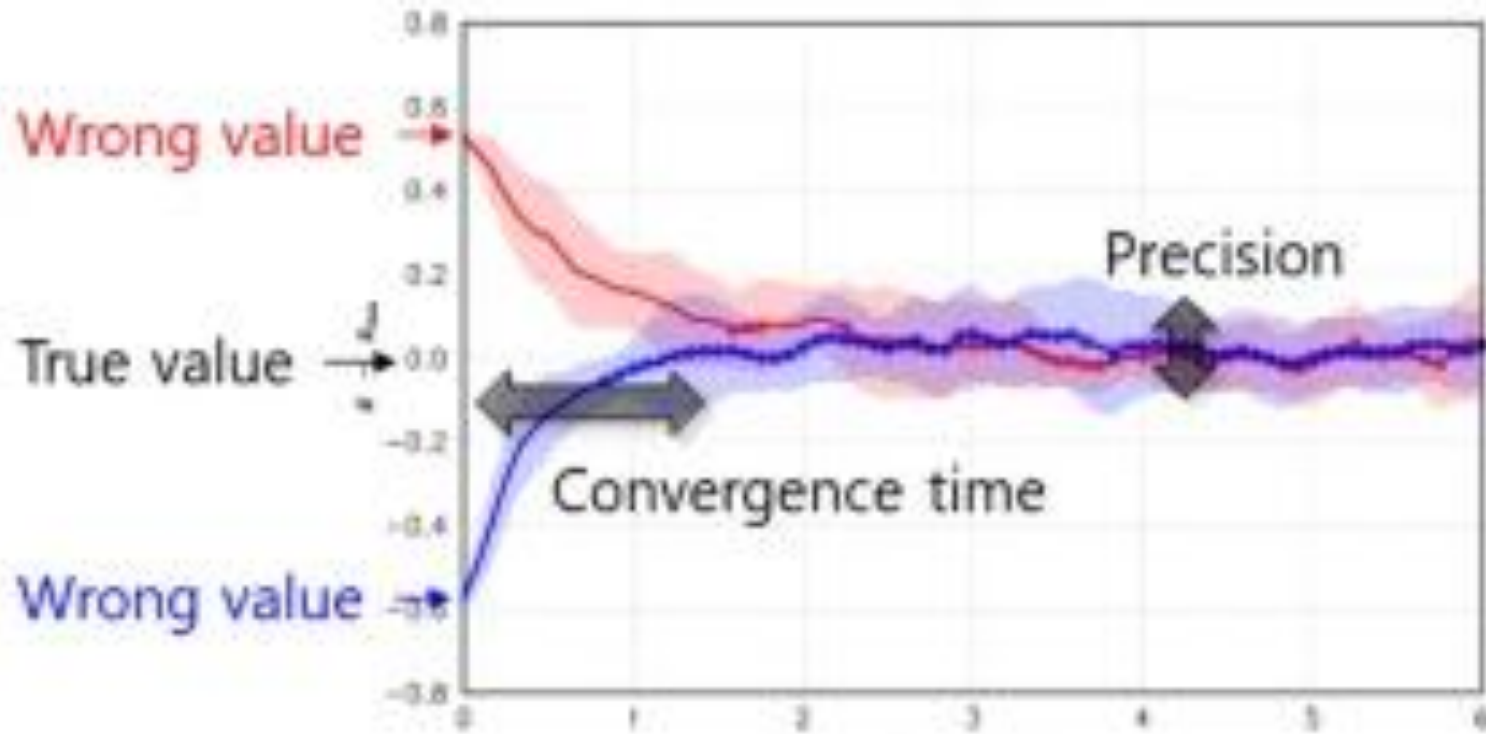
STATUS
Fine Alignment
Remaining Fine Alignment Time: - 00:10:00s

SEISTANS


Wait 10'

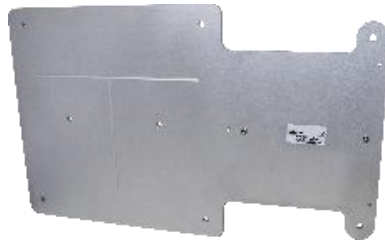
Operation is crucial: optimal duration

Optical
gyrocompass
case



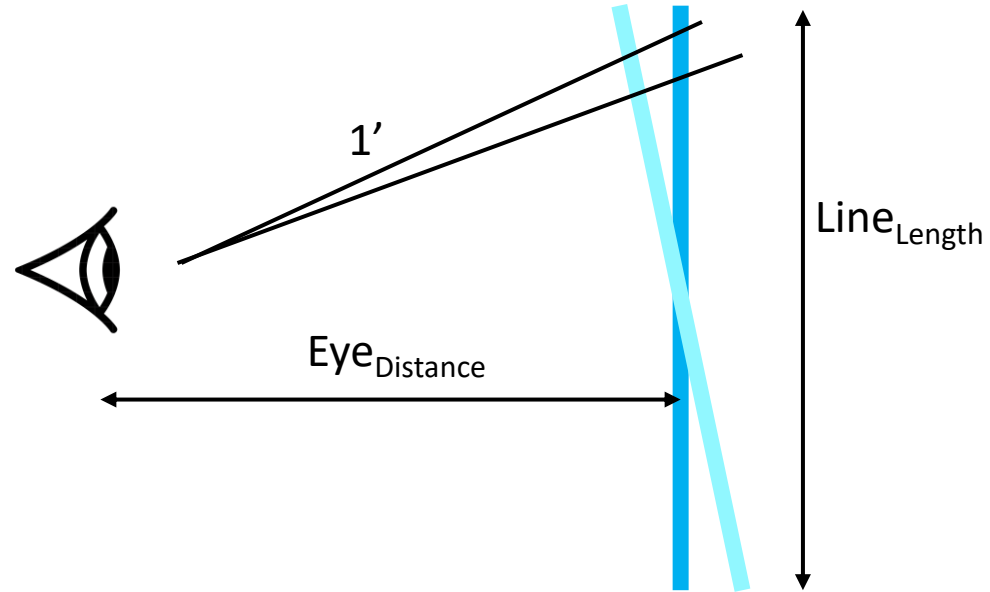
Then transferring the True North

Precisions pins contact	Grooves	Precisions pins contact	Laserline
+/-0.10°	+/-0.10°	+/-0.10°	+/-0.25°
Dedicated interface needed + contact needed	Prior to installation	Dedicated interface needed + contact needed	Contactless



Optical error : distance error

1' eye angular resolution →



Laserline

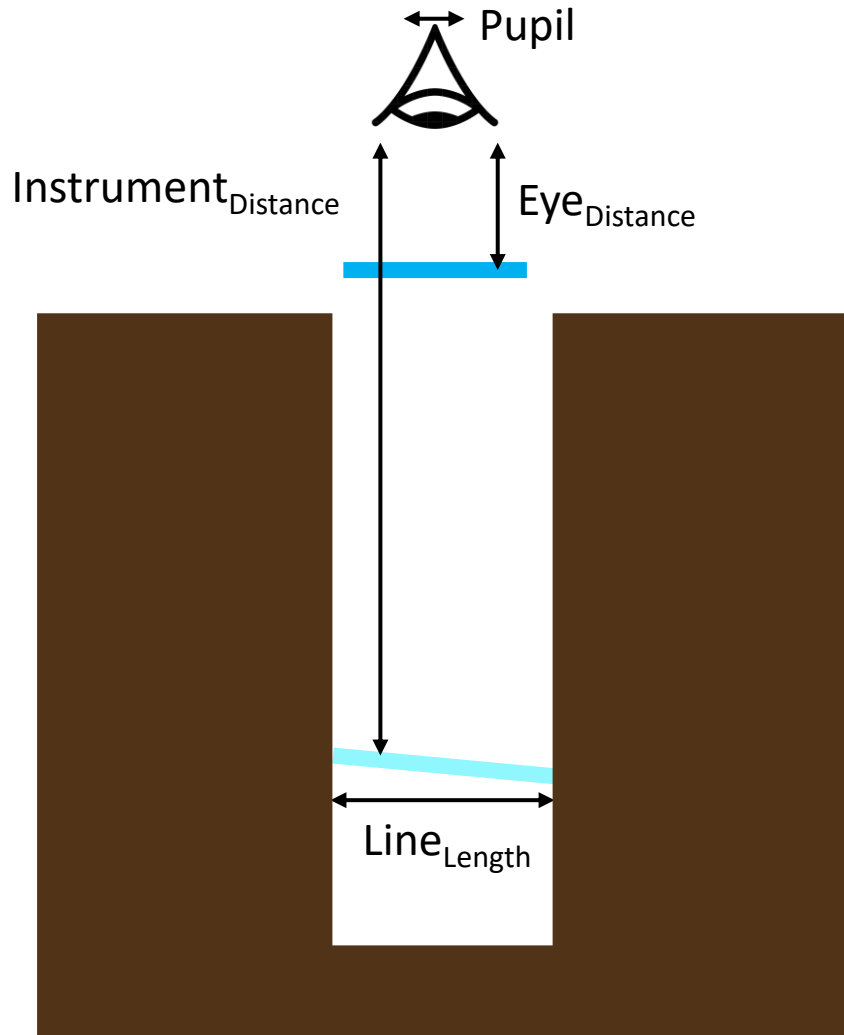
+/-0.25°

Contactless

$$Angular_{error} = \text{atan} \left(\frac{2 * \text{atan}(1') * Eye_{distance}}{Line_{length}} \right)$$

45cm Eye_{Distance} and 6cm Line_{Length} = 0,25°

Optical error : focus error



Laserline

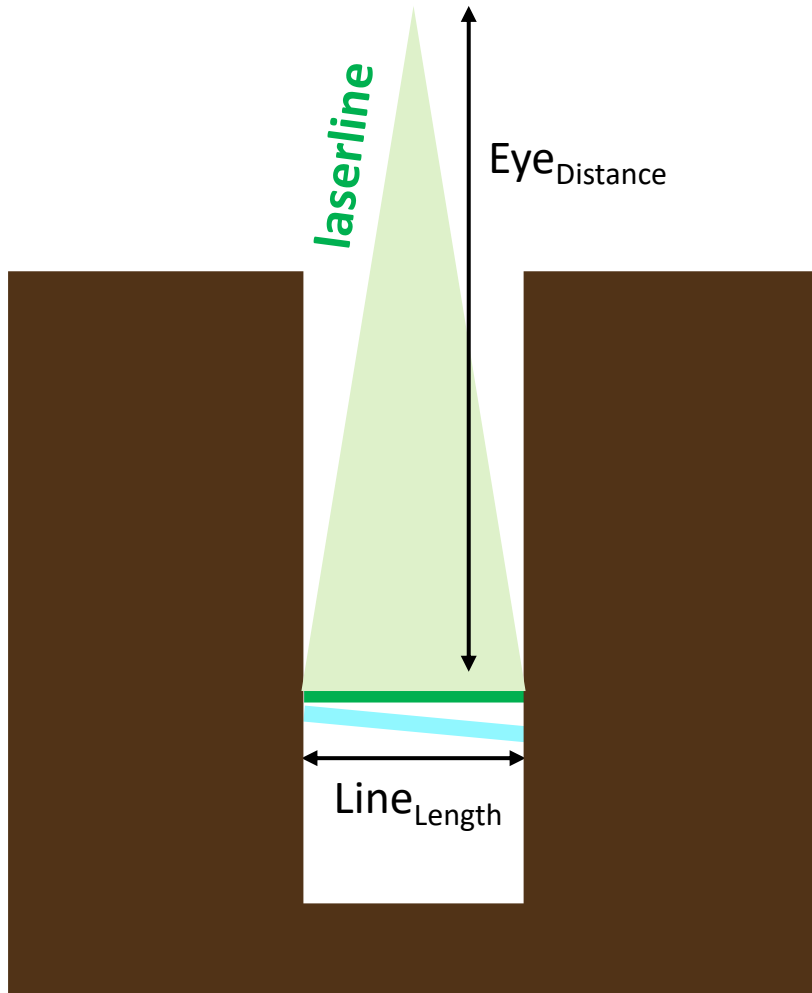
+/-0.25°

Contactless

$$FocusAngular_{error} = \text{atan} \left(\frac{DefocusBlur}{Line_{length}} \right) = \text{atan} \left(\frac{Pupil \cdot \left(1 - \frac{Eye_{distance}}{Instru_{Distance}}\right)}{Line_{length}} \right)$$

45cm $Eye_{Distance}$ and 2m $Instru_{Distance}$ = 3° (!)

Reducing focus and distance errors



To avoid Focus error → laserline

But distance error remains :

$$200\text{cm Eye}_{\text{Distance}} \text{ and } 6\text{cm Line}_{\text{Length}} = 1,1^\circ$$

Photography can significantly reduce this $< 0,2^\circ$

Provided the camera is integrated so as not to occlude the laser line

Gyrocompass solutions

Requirements

- **Gyrocompass the most reliable and efficient tool to orientate a station, but it has drawbacks limiting its use as a standard tool for all the station**
 - Expensive [1][2][4][9][11]
 - Heavy [1][11] (mechanical)
 - Export restriction [2][9] (main optical ones)
 - + Transfer the North to the instrument is an additional challenge

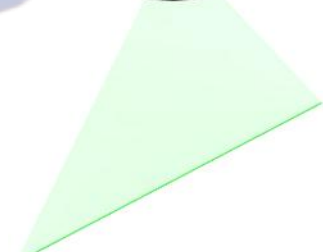


MAAGM propose a dedicated product line for station orientation

- Field compatible (low weight, size and Power)
- 'Free of Export'
- GNSS denied compatible (but Åstrakal)
- Optimized for static use
- Addressing North transfer challenge

NJORD product lines

Product	Atlans 5	Octans 9	Åstrakal	Årian
Manufacturer	exail	exail	MAAGM	MAAGM
Export Restrictions	Export-free	Export-free	Export-free	Export-free
North Finding	AHRS Optical ✓ True North	AHRS Optical ✓ True North	Dual GNSS ✓ True North	Single Gyro ✓ True North
Cost	X k€	1,5 * X k€	0,1 * X k€	0,4 * X k€
Power Consumption	6W	6W	2W	4W
Heading Accuracy (without GNSS)	0.23° seclat RMS	0.1° seclat RMS	N/A	0.9° seclat (1sigma)
Heading Accuracy (with GNSS)	0.15° seclat RMS	0.05° seclat RMS	0.2° seclat RMS	N/A
Roll & Pitch Accuracy (with GNSS)	0.02° RMS	0.006° RMS	0.4° RMS	N/A
Interfaces	Ethernet, RS232, RS422	Ethernet, RS232, RS422	Ethernet, RS232	Bluetooth, USB-C
With Åligner	wifi	wifi	wifi	Bluetooth
Availability	now	now	now	June 2026



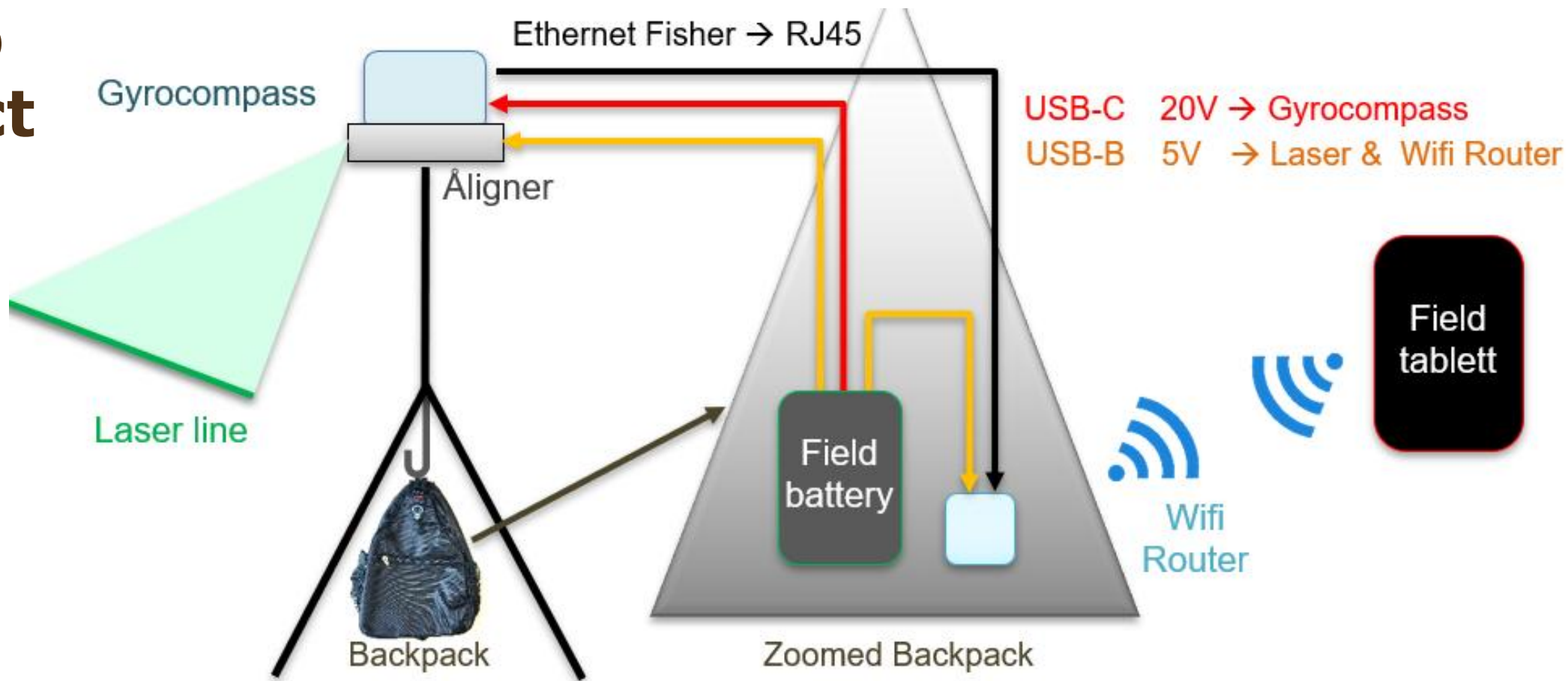
Optical gyrocompass + Åligner laser toolkit

**NJORD
product
lines**



Åligner laser toolkit

**NJORD
product
lines**



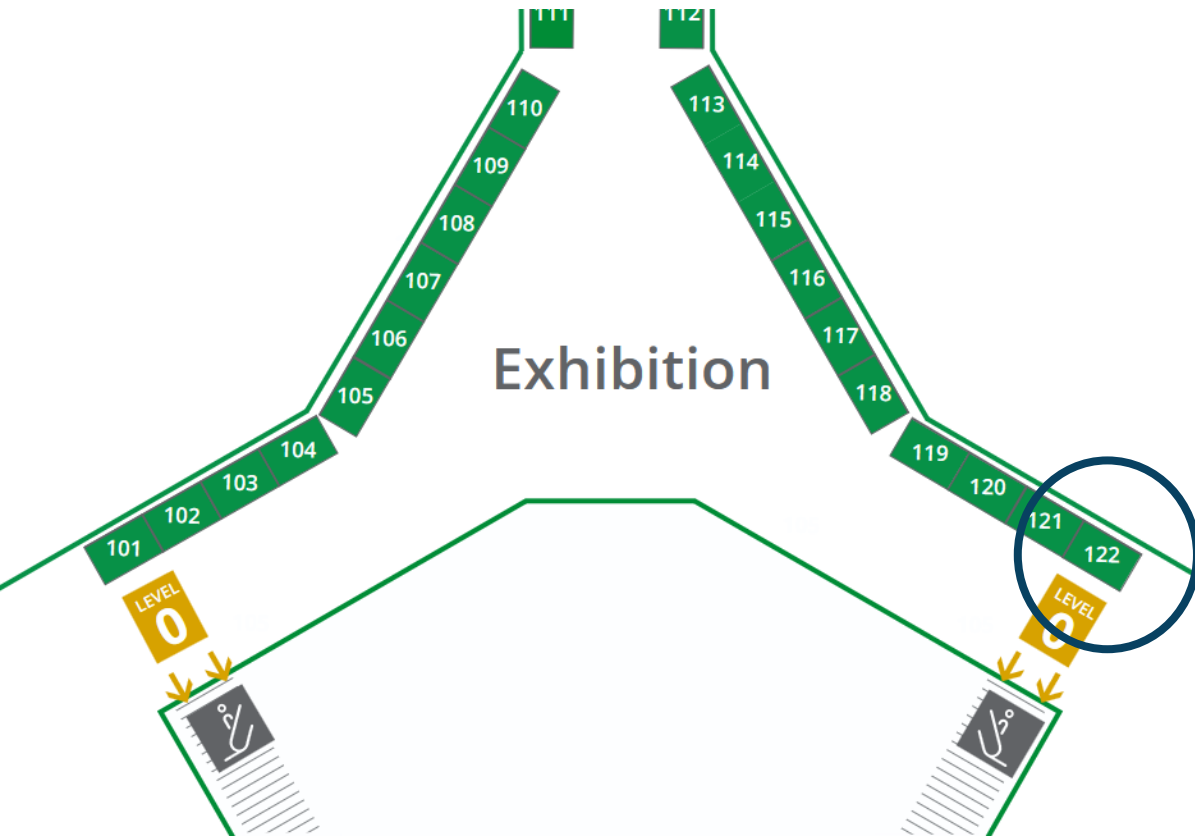
True North Finder With integrated motorized laser and camera

- No aiding sensors required (no GNSS, no magnetics)
- 0.9° seclat accuracy
- Export-free
- Affordable
- Two optical modes: provides or measures azimuth
- Two alignment references available: mechanical & optical
- < 4 min alignment time
- One-day field autonomy
- Compact, lightweight and robust
- Handheld, field-ready device
- Android interface
- Integrated camera
- Wireless communication
- Compatible with the Åligner kit
- 4kg -- 120 Ø x 230 h – USB-C – IP66



More information at our booth

#122, floor 1, in front of right escalator



**White paper about station orientation
to be released soon.
Let us know at our booth
if you are interested**

References

- [1] XU, Hongrui, LUO, Yinhe, TANG, Chi-Chia, et al. Systemic Comparison of Seismometer Horizontal Orientations Based on Teleseismic Earthquakes and Ambient-Noise Data. Systemic Comparison of Seismometer Horizontal Orientations. *Bulletin of the Seismological Society of America*, 2018, vol. 108, no 6, p. 3576-3589.
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- [13] <http://nnsn.geo.uib.no/eworkshop/index.php?n=Main.Orientation>
- [14] Roxanne RUSCH. Array-derived rotations carried out using the LSBB seismic array: quantification and graphical representation of the uncertainty. *Sciences de la Terre*. Université Côte d'Azur, 2020. Français. NNT:2020COAZ4054 <https://tel.archives-ouvertes.fr/tel-03177660>