Inclination in oriented dust logger data in SPICE

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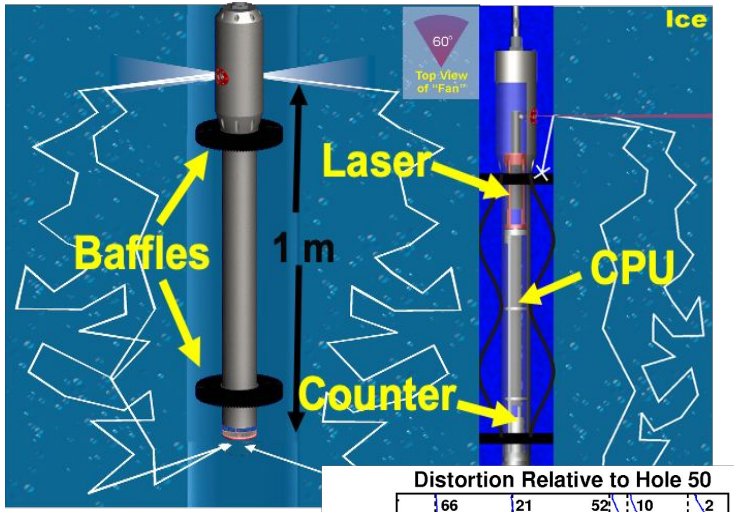
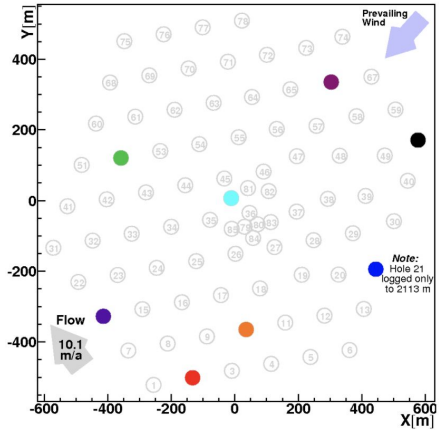
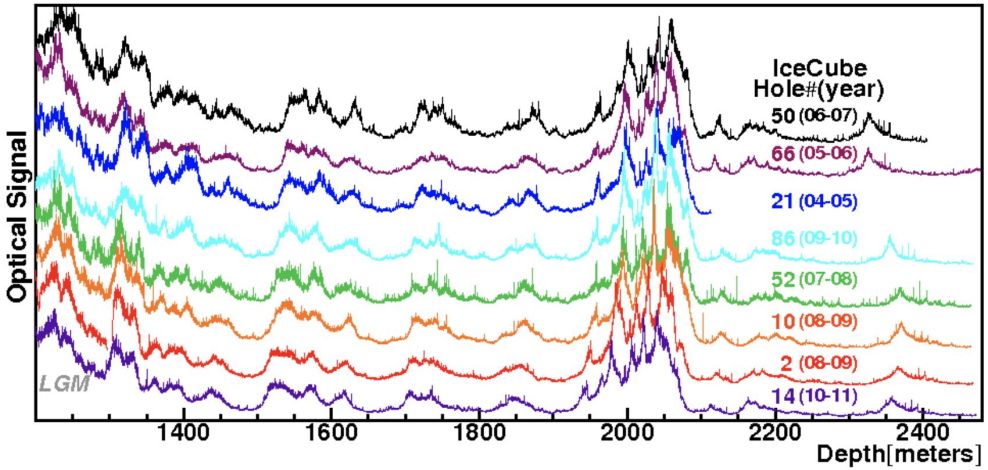
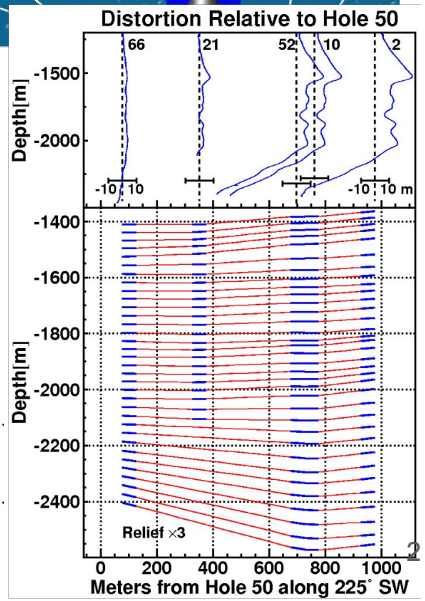
The dust logger

Emits light in the ice and detects backscatter.
In clear ice backscatter is caused by dust/particulate → detects dust vs depth
Instrument deployed in many locations and in several IceCube holes









Orientation sensor

APS Model 544 added to the dust logger in 2013 in order to determine laser orientation [Model 544 | Miniature Orientation Sensor]

3-axis fluxgate magnetometer and a 3-axis accelerometer

Used also in other instruments

In our case the output is raw data (3 + 3 values)

Deployed WAIS, Siple Dome, Minna Bluff, South Pole

Azimuth Accuracy	±1.2°
Toolface (Roll) Accuracy	±0.4°
Inclination Accuracy	±0.4°

Oriented dust logger at SPICE core

The oriented dust logger was deployed at SPICE in Dec 2016, Dec 2018 and Dec 2019

In each case two deployments (down and up)

Data from the “up” section is generally much cleaner

The rotation of the device is not controllable

Multiple runs are combined to get more azimuthal coverage vs depth (for anisotropy measurement)

Tool and data acquisition were **not** optimized for inclination

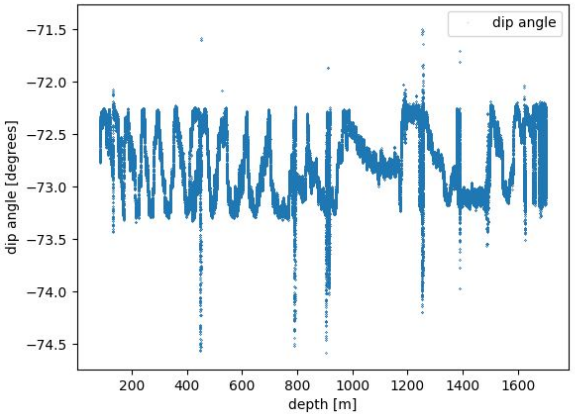
Magnetometer data

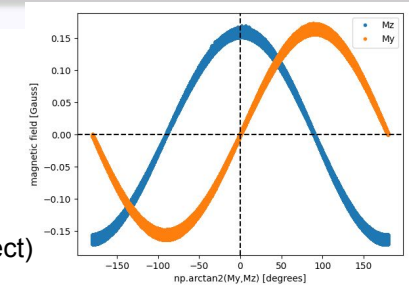
Model Used:	WMM-2020
Latitude:	90° S
Longitude:	0° W
Elevation:	2800.0 m Mean Sea Level

Notice this location is not the SPICE borehole location but magnetic field does not change too much

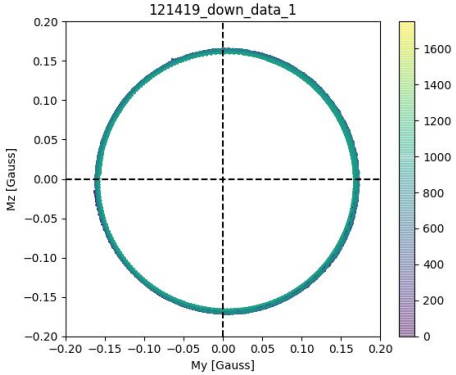
https://www.ngdc.noaa.gov/geomag/calculators

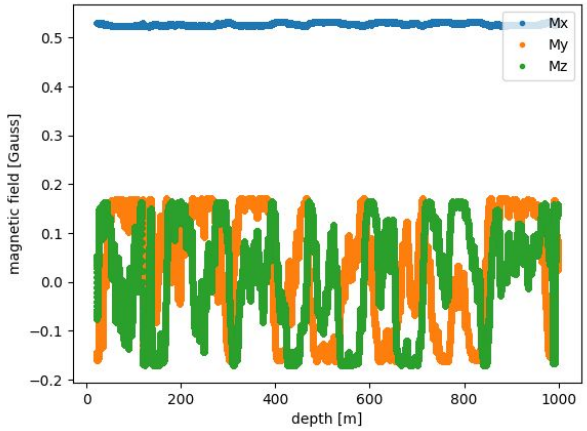
Date	Declination (+ E | - W)	Inclination (+ D | - U)	Horizontal Intensity	North Comp (+ N | - S)	East Comp (+ E | - W)	Vertical Comp (+ D | - U)	Total Field
2019-12-20	-30.7500°	-72.1285°	16,753.0 nT	14,397.7 nT	-8,565.7 nT	-51,956.8 nT	54,590.9 nT
Change/year	-0.1443°/yr	0.0352°/yr	13.8 nT/yr	-9.7 nT/yr	-43.3 nT/yr	66.6 nT/yr	-59.2 nT/yr
Uncertainty	0.42°	0.21°	128 nT	131 nT	94 nT	157 nT	145 nT



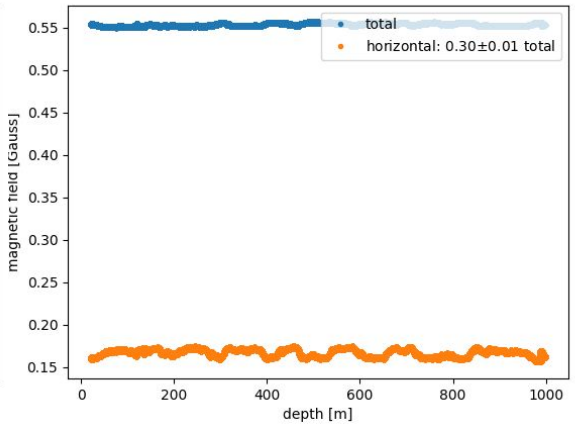


Calibration ok (not perfect)



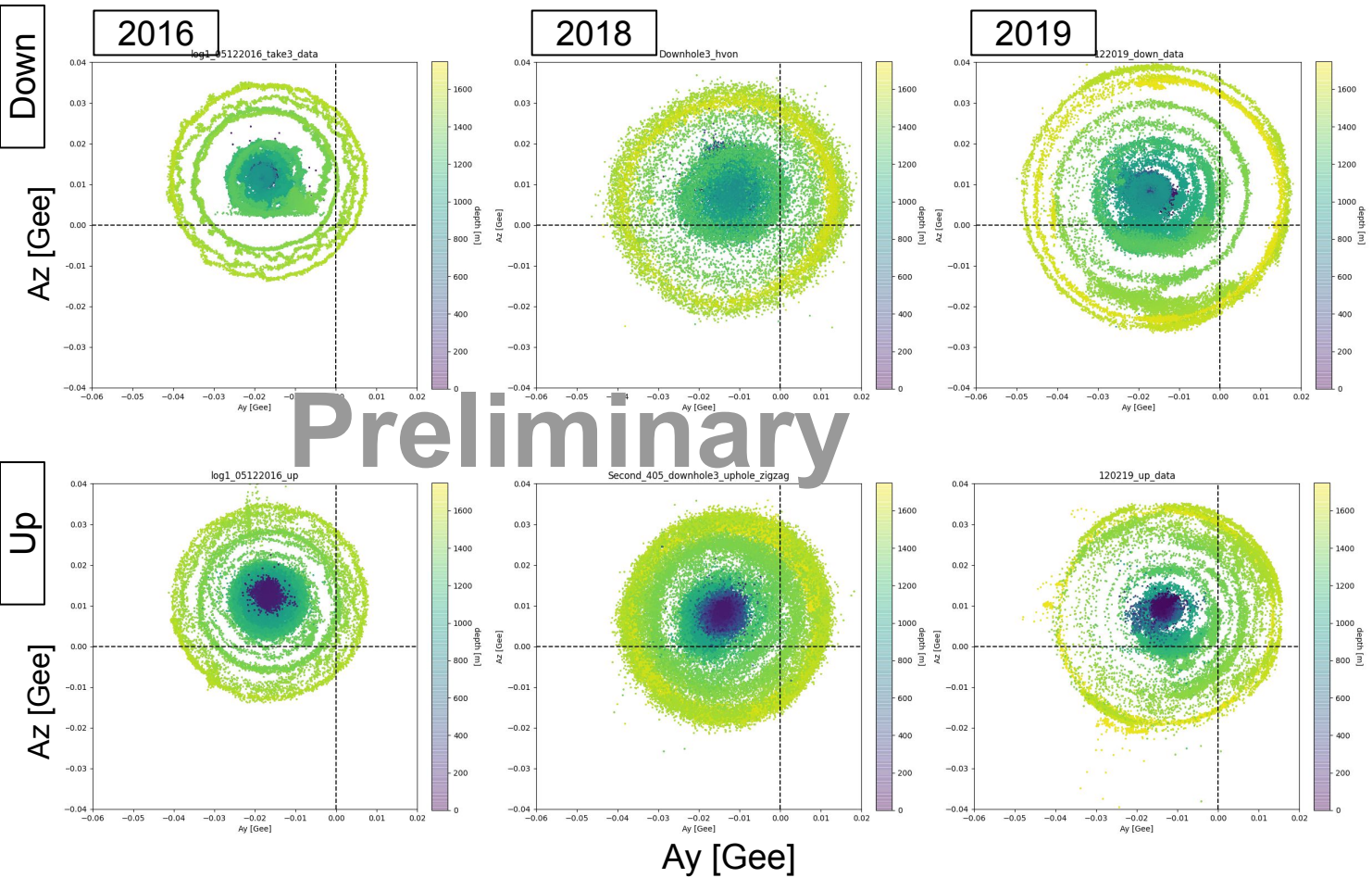


Mx positive as expected given that in our system x is parallel to the upgoing field



30% of the magnetic field is horizontal

Accelerometer data



Accelerometer data is noisy probably due to tool rattling around the hole

Effect especially large below 1000-1200m depth

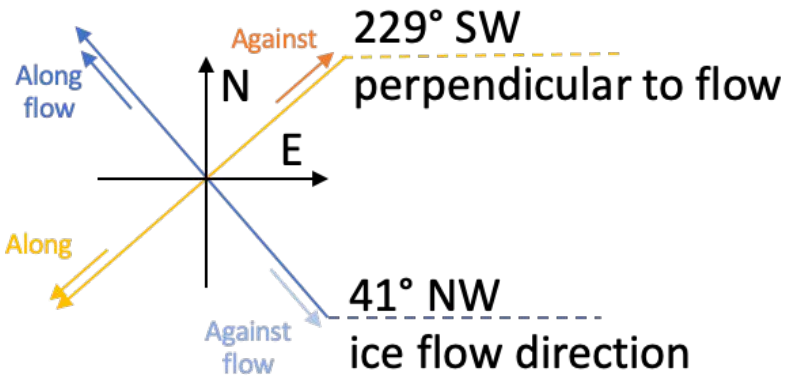
Inclination ideally is measured with tool at rest

Inclination vs depth vs azimuth and vs time

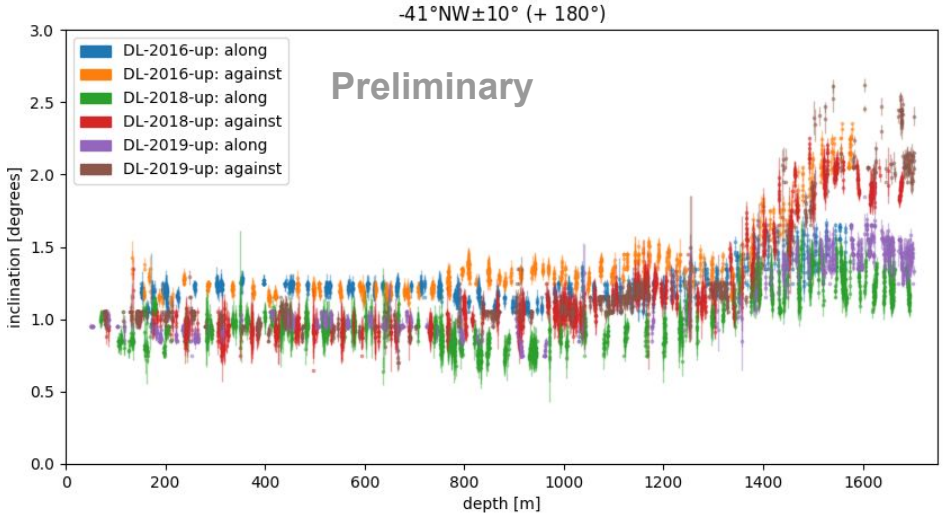
“Azimuth”: Since the instrument is vertical, I use the magnetic roll as indicator for the azimuth from the magnetic north and I compensate for the magnetic north direction to obtain the azimuth from the grid North direction.
No compensation for pitch, roll or dip angle (may be a large effect)

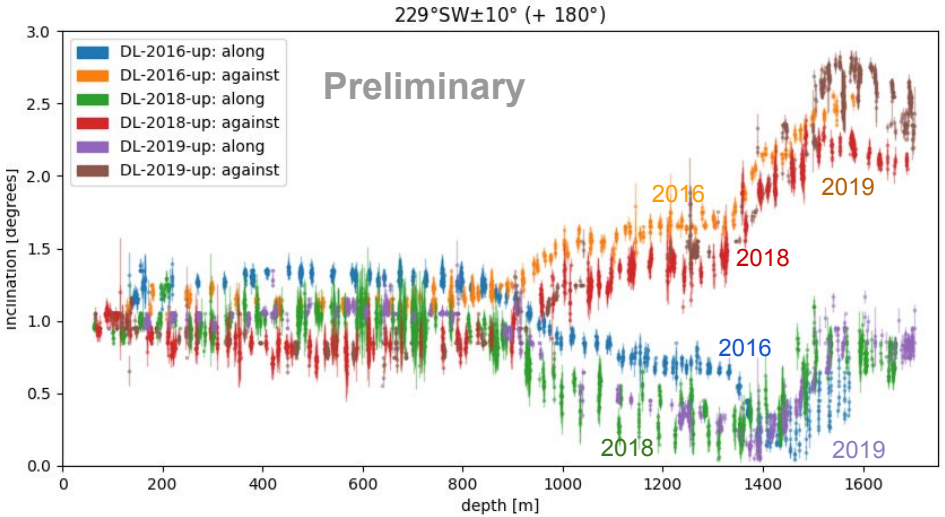
Compare inclination data “along” and “against” a certain angle (180 degrees offset)

Angles of interest:



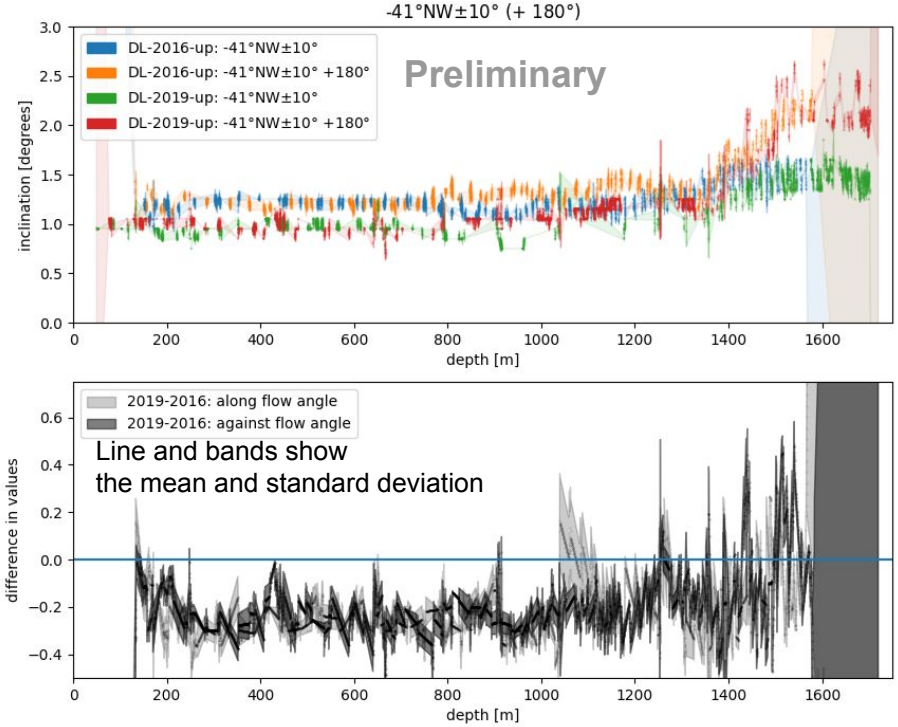
Comparison between 3 years

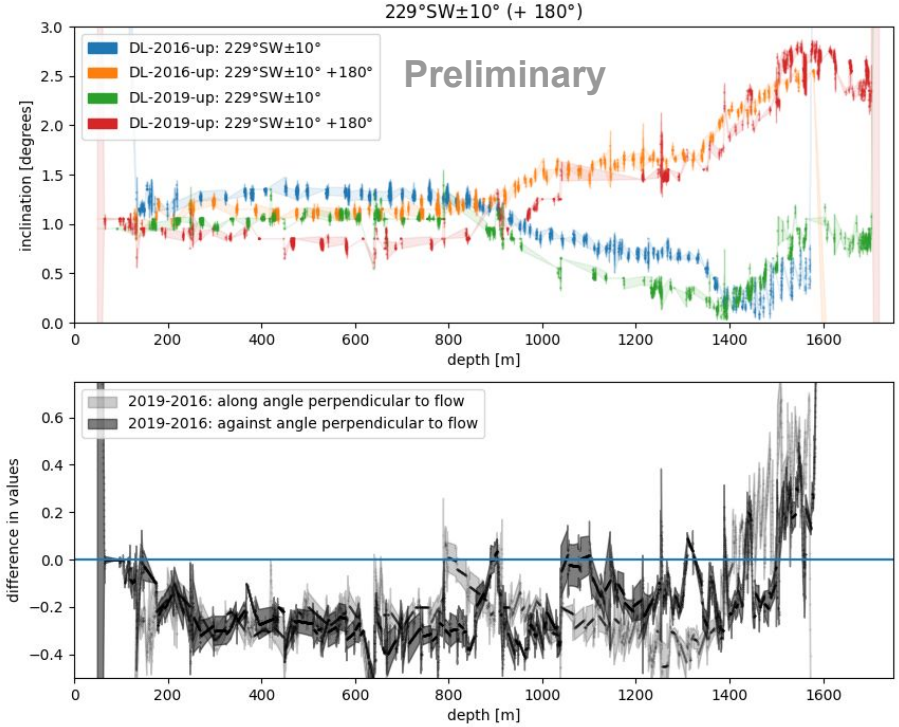




- Inclination shown in sensor's reference frame
- Bottom of the hole has a larger inclination
- Most of the change in time happened between 2016 and 2018
- Accuracy in azimuth and inclination to be further studied, especially offsets due to mounting of the instrument

2019 vs 2016



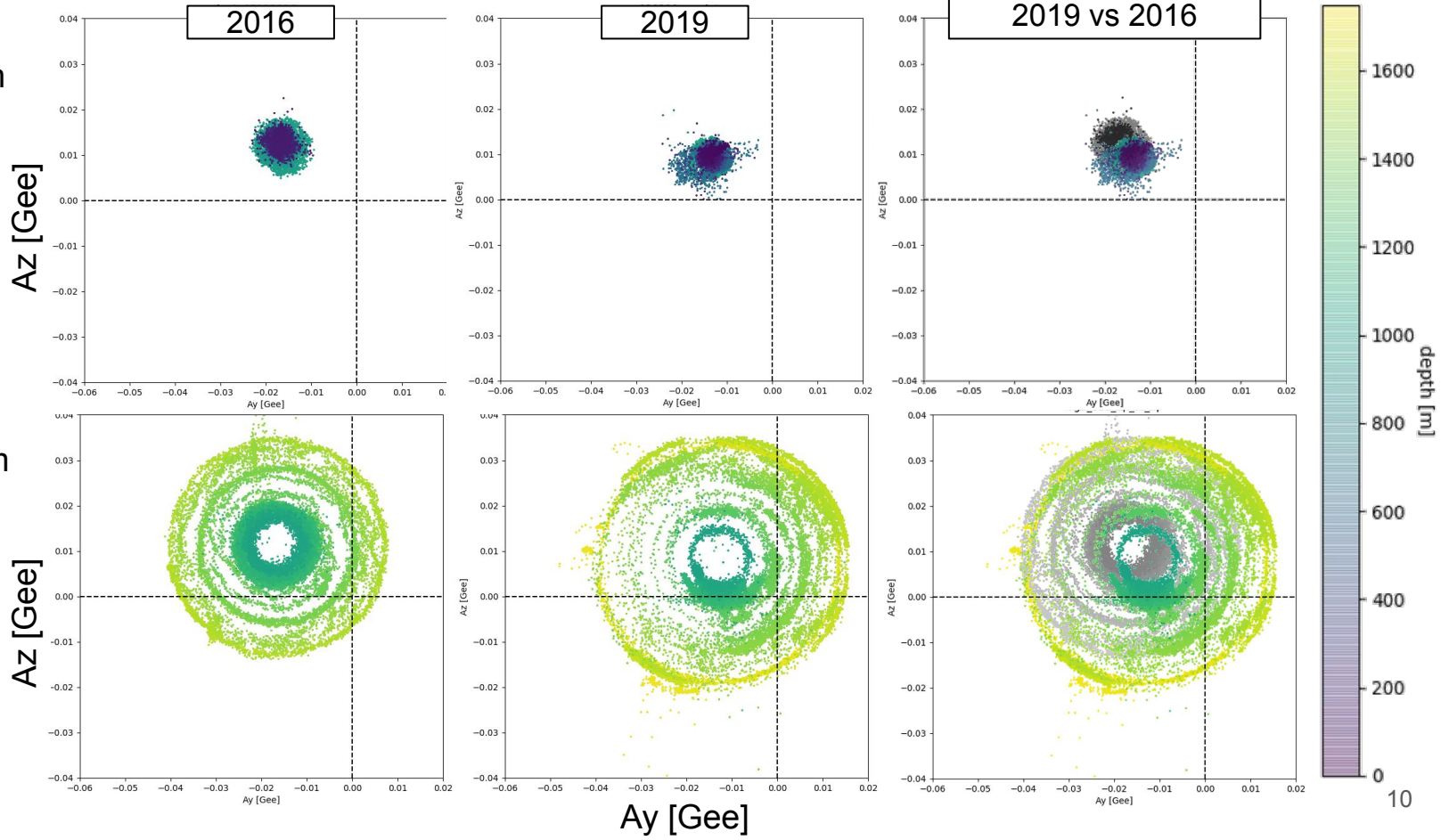


Measured inclination pattern is consistent throughout multiple runs and years
Hole seems to be “straightening up”, mostly at the top (?)

Accelerometer center vs time

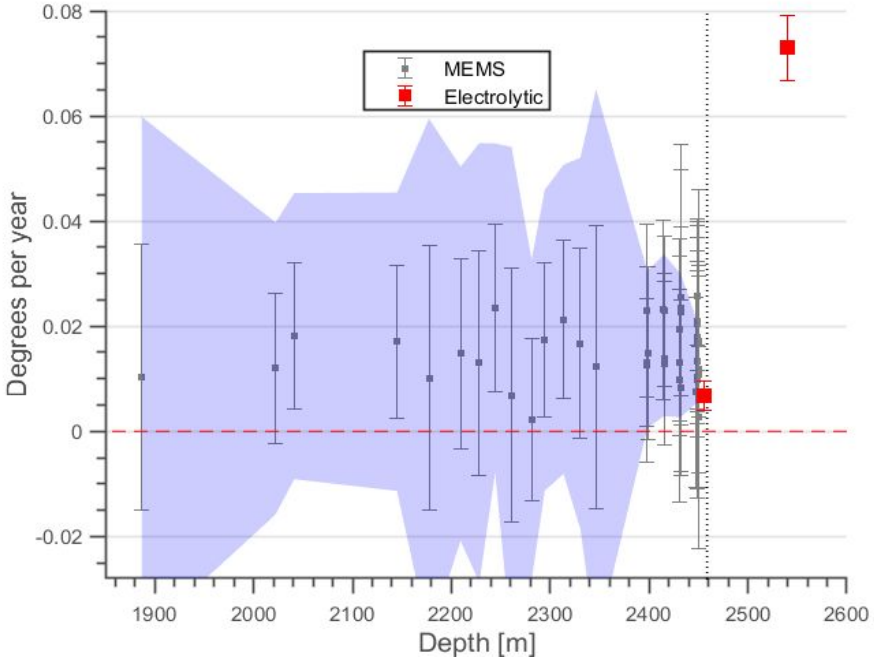
Above 1000m

Below 1000m

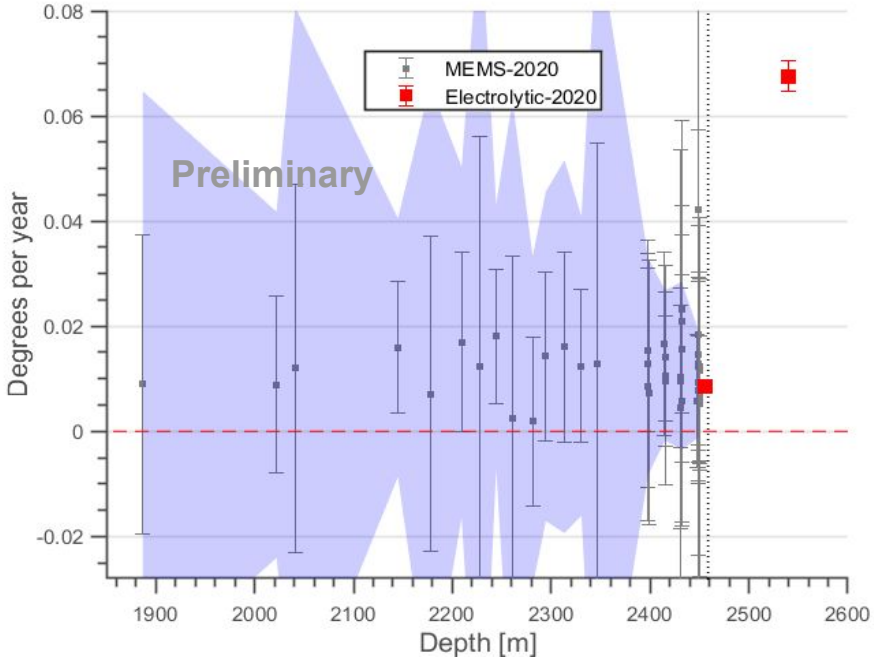


Inclinometer data from IceCube

Data published in 2015 paper



Updated plot (to December 2020)



Long-term average inclination from two electrolytic (red) and 42 MEMS (gray) tilt sensors. The electrolytics are at 2455 m (86% ice sheet depth) and 2540 m (90%). Error bars show standard deviation from trend and the shaded area is the MEMS 95% confidence.
(Right) Newer data over a longer baseline; note that new MEMS data are unprocessed.

Summary

Oriented dust logger data can be used in principle to monitor hole movement, although so far data taking has been optimized not for inclination measurement

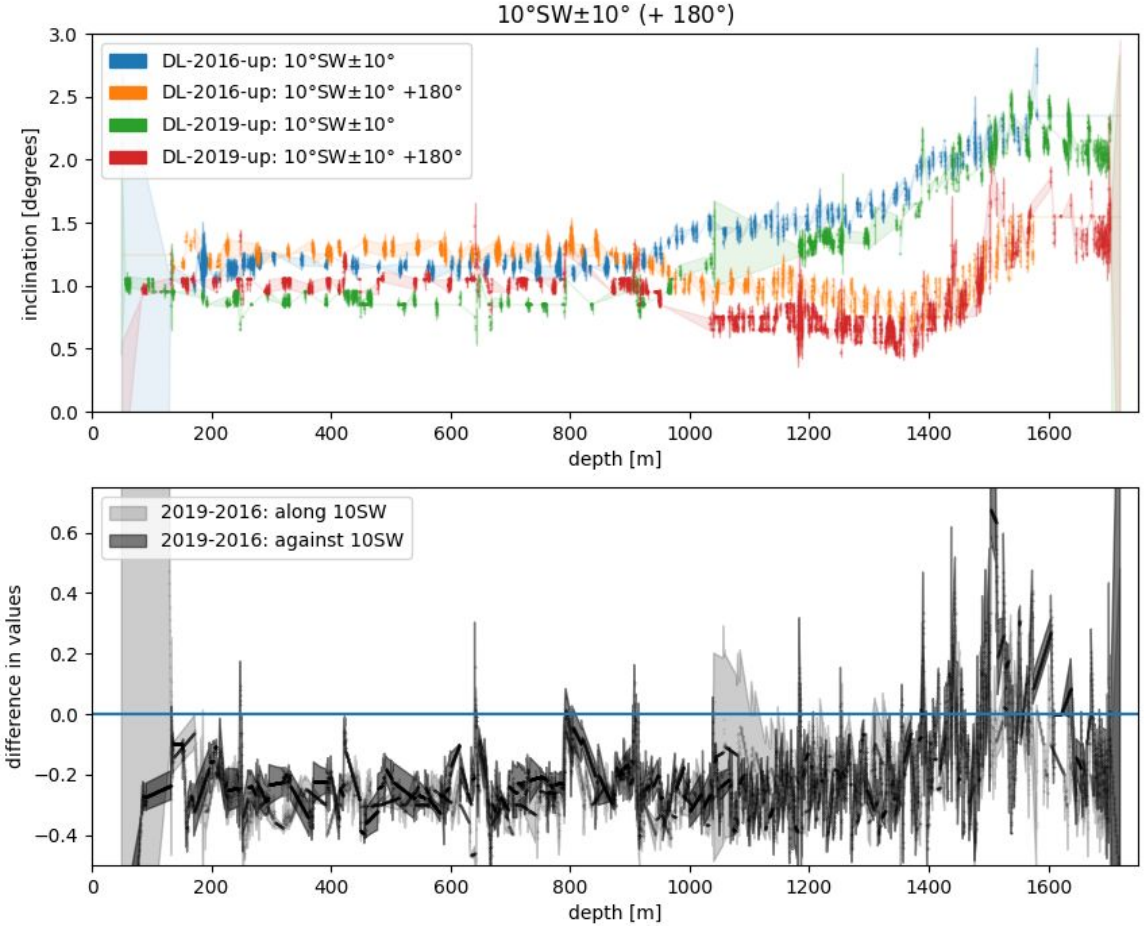
Data from orientation sensor is quite noisy due most likely to the tool moving and rattling in the hole

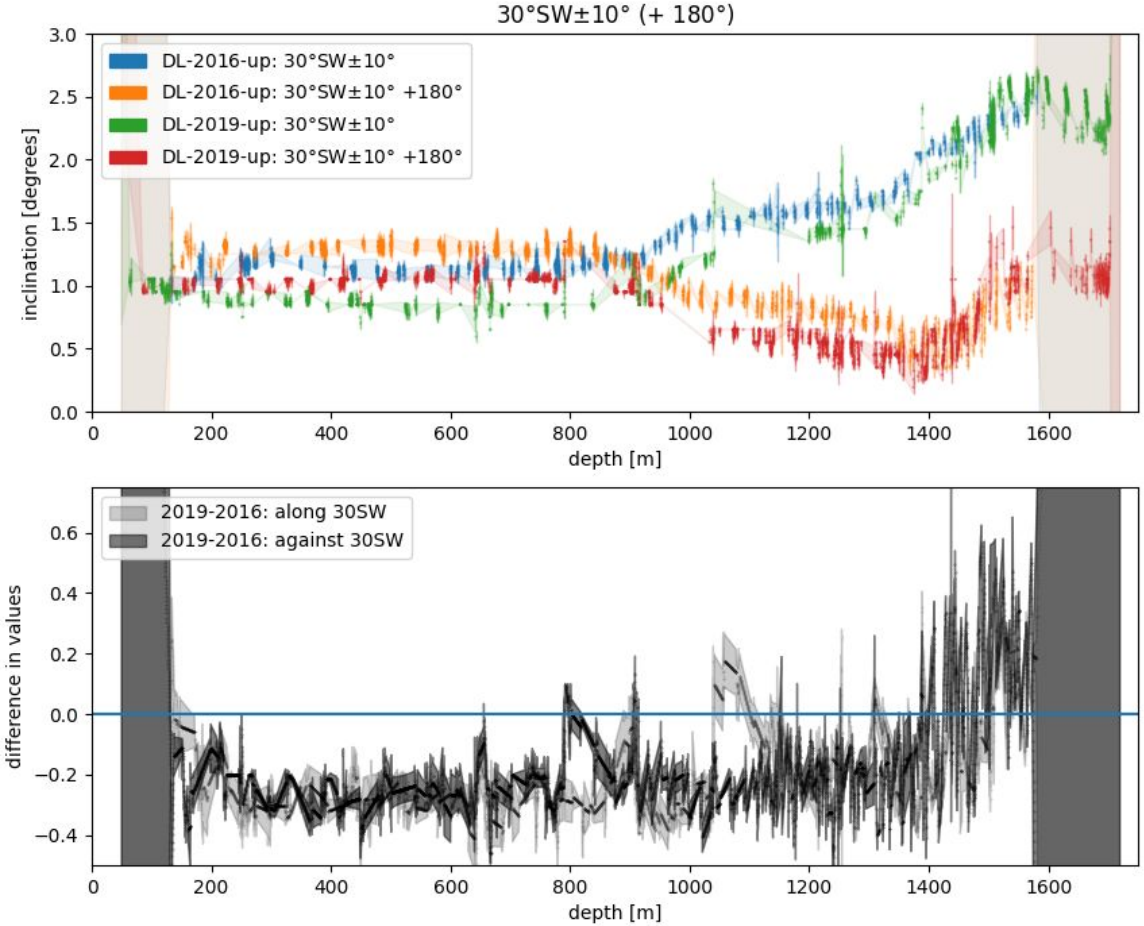
Data trends are consistent throughout the years

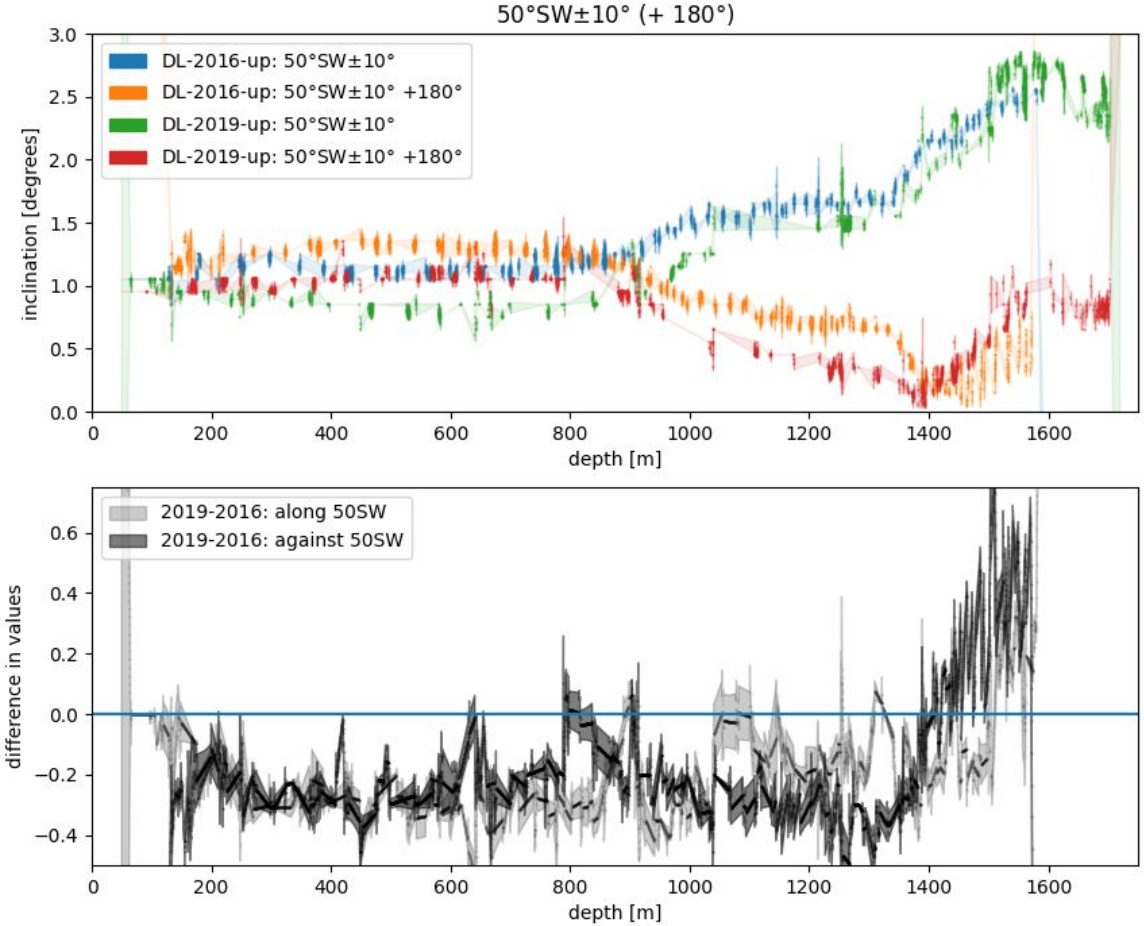
SPICE borehole seems to be straightening itself at the top: is this indication of a nonhomogeneous glacial flow vs depth?

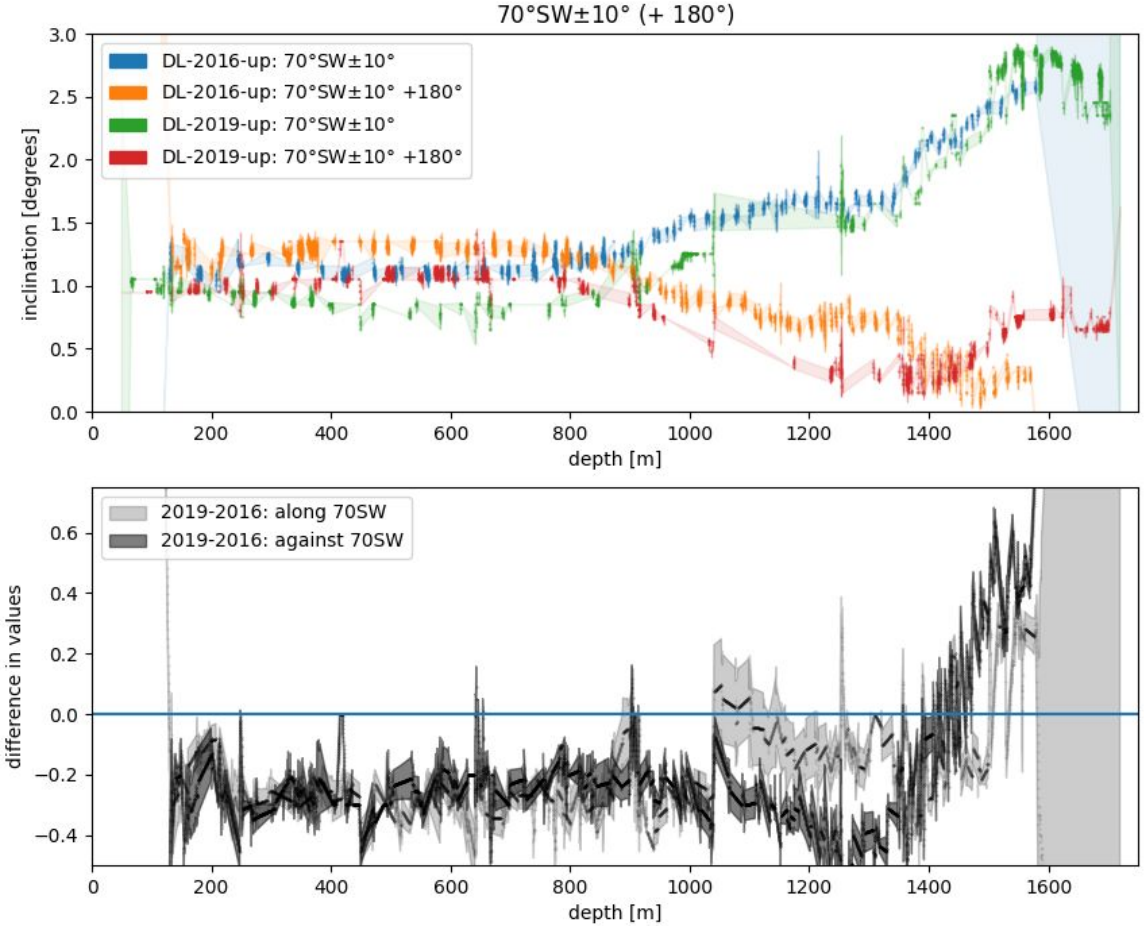
Definitely it is necessary to understand better the orientation sensor especially at locations with a large vertical magnetic field

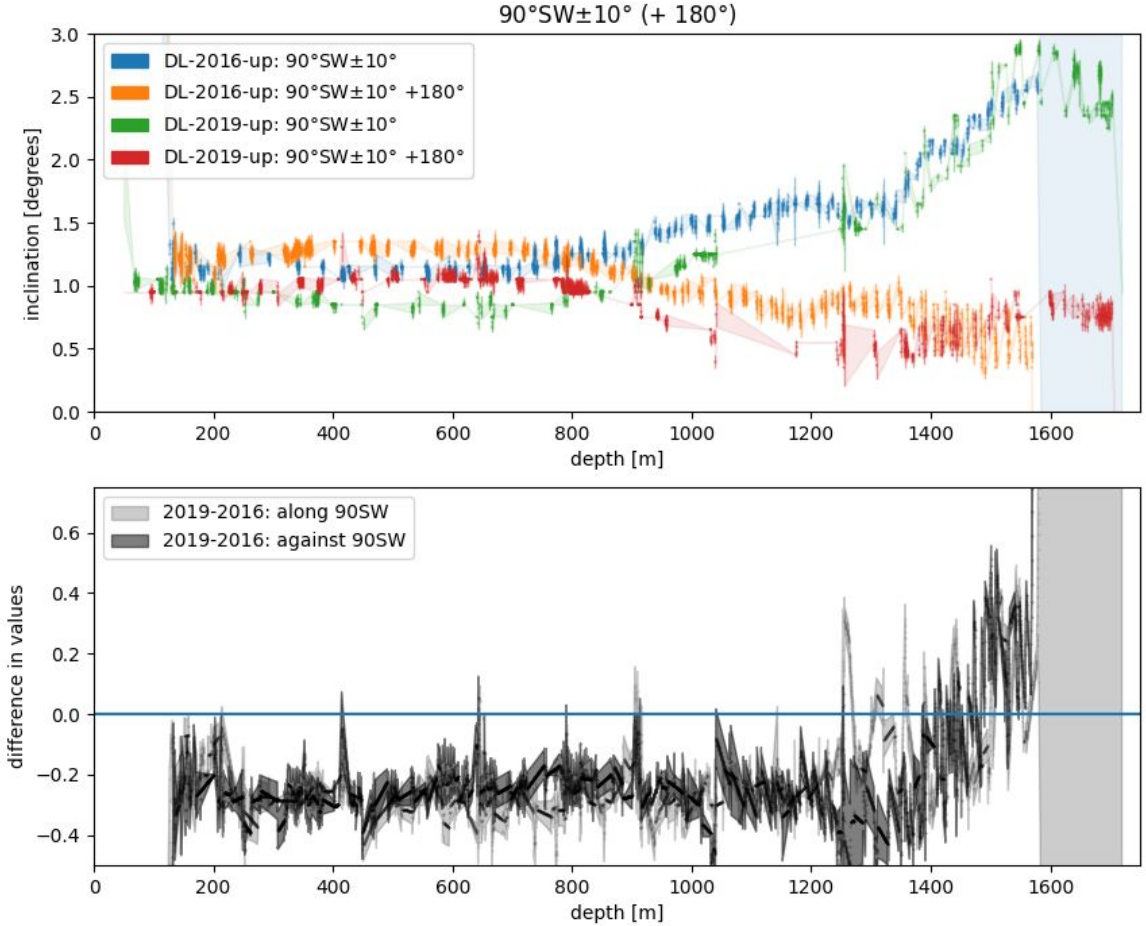
Updated inclinometer data consistent with published values

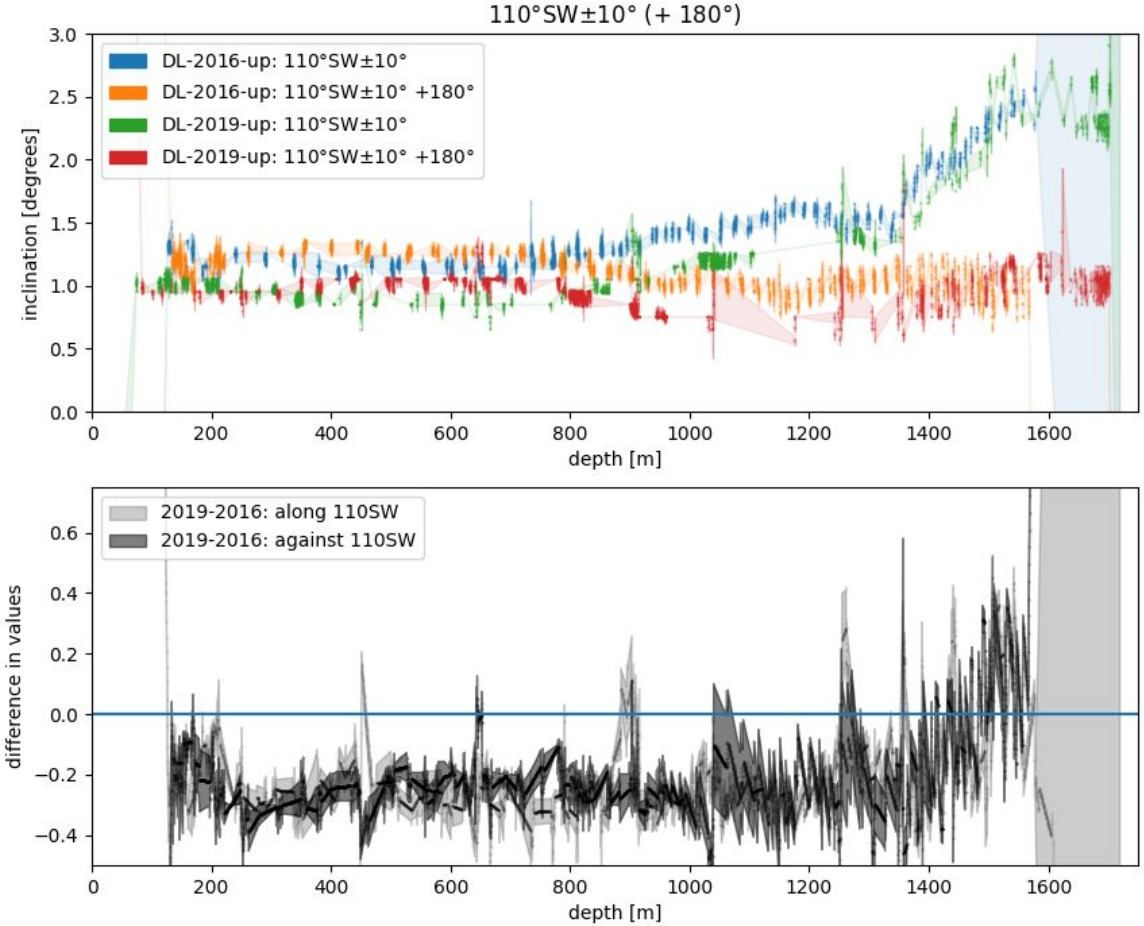

10°SW±10° (+ 180°)
DL-2016-up: 10°SW±10°
DL-2016-up: 10°SW±10° +180°
DL-2019-up: 10°SW±10°
DL-2019-up: 10°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 10SW
2019-2016: against 10SW
difference in values
depth [m]

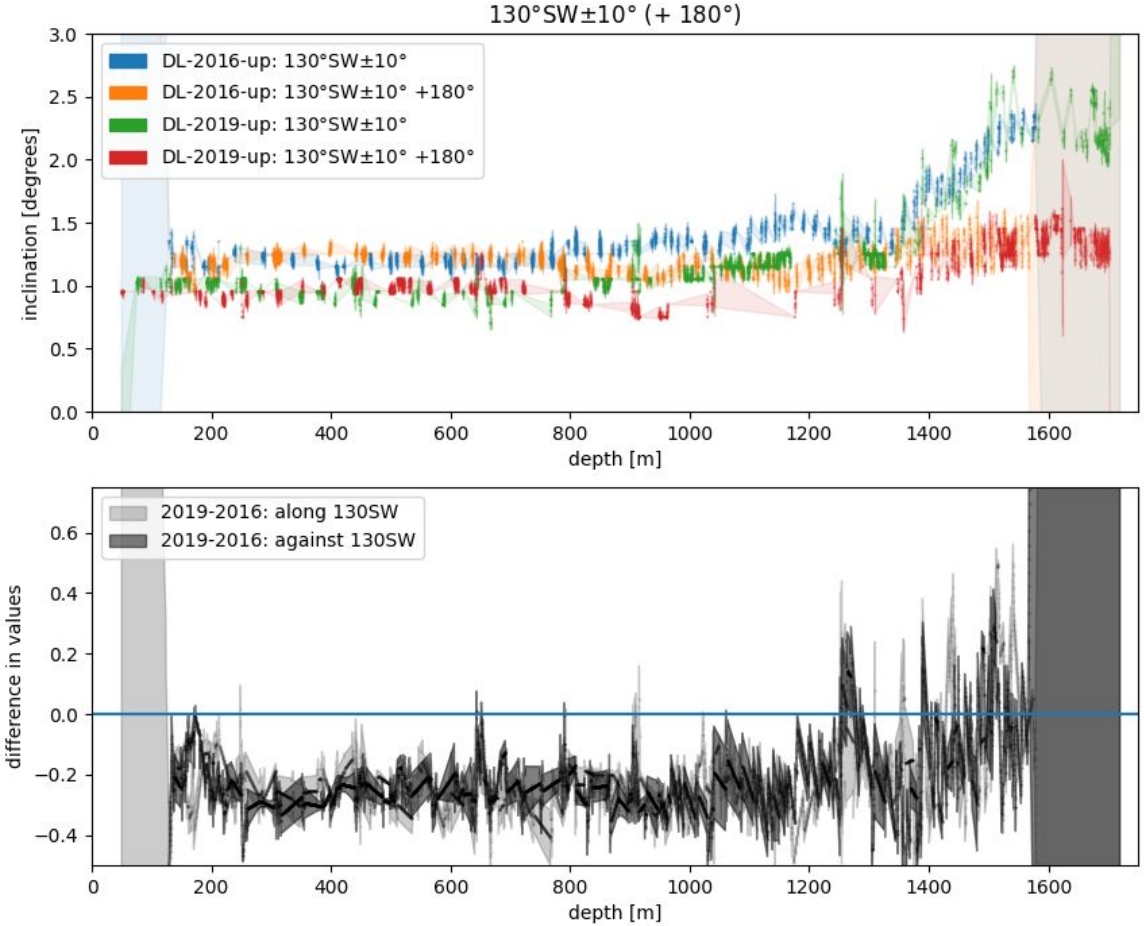

30°SW±10° (+ 180°)
DL-2016-up: 30°SW±10°
DL-2016-up: 30°SW±10° +180°
DL-2019-up: 30°SW±10°
DL-2019-up: 30°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 30SW
2019-2016: against 30SW
difference in values
depth [m]

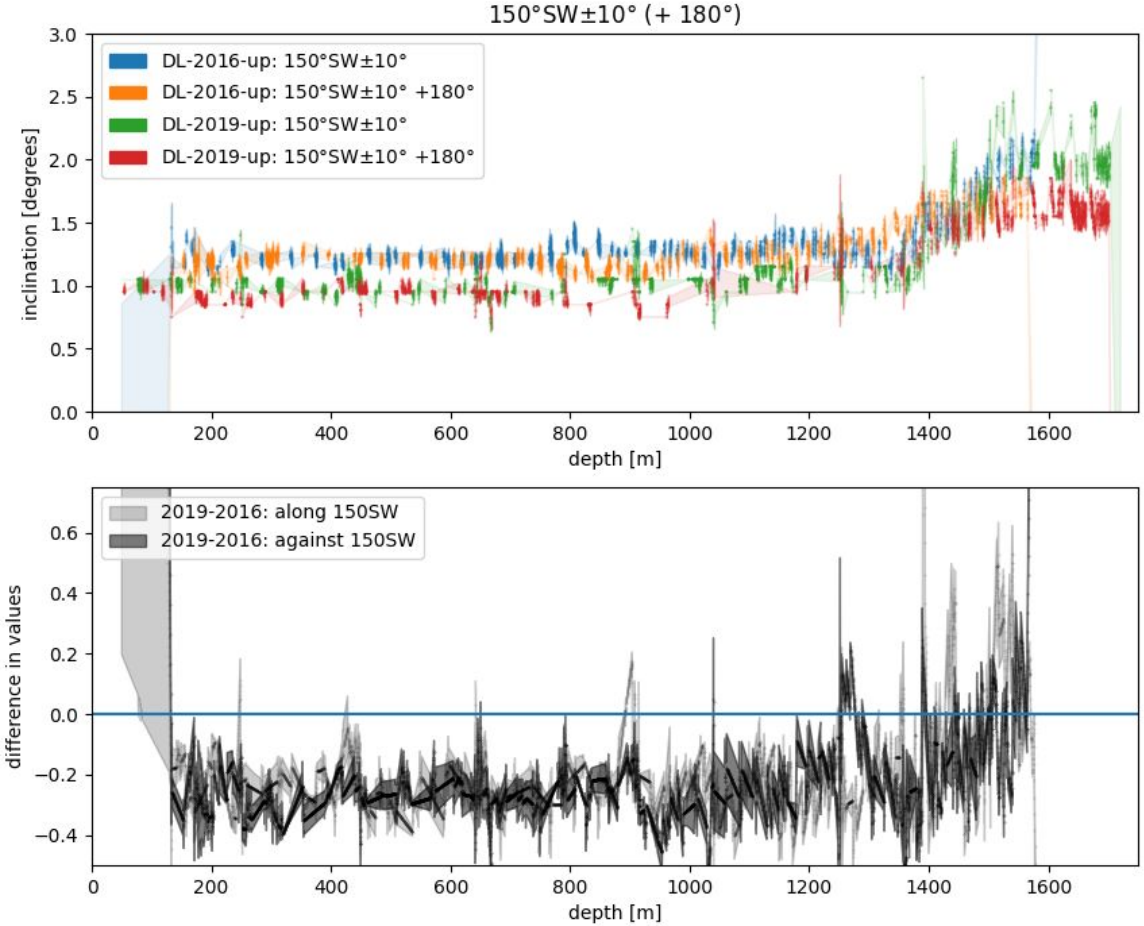

50°SW±10° (+ 180°)
DL-2016-up: 50°SW±10°
DL-2016-up: 50°SW±10° +180°
DL-2019-up: 50°SW±10°
DL-2019-up: 50°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 50SW
2019-2016: against 50SW
difference in values
depth [m]

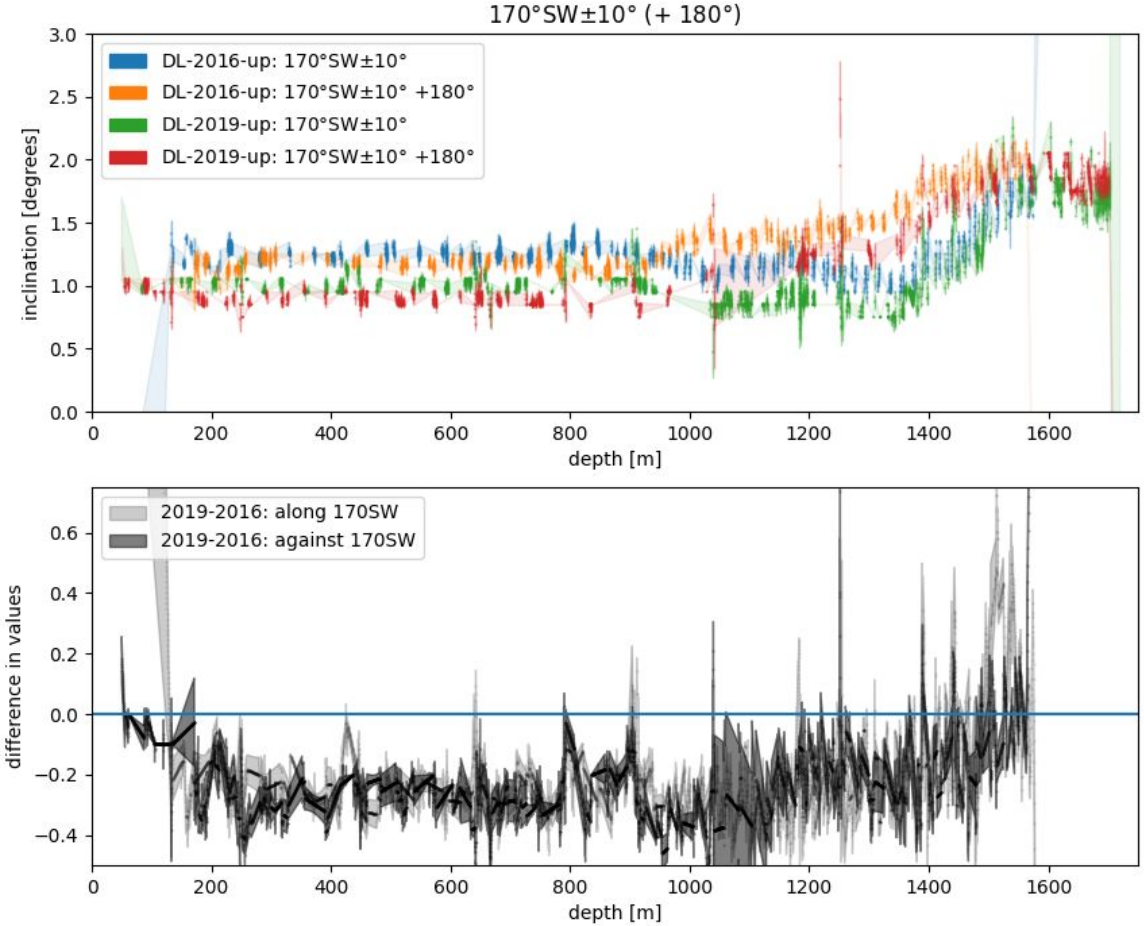

70°SW±10° (+ 180°)
DL-2016-up: 70°SW±10°
DL-2016-up: 70°SW±10° +180°
DL-2019-up: 70°SW±10°
DL-2019-up: 70°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 70SW
2019-2016: against 70SW
difference in values
depth [m]


90°SW±10° (+ 180°)
DL-2016-up: 90°SW±10°
DL-2016-up: 90°SW±10° +180°
DL-2019-up: 90°SW±10°
DL-2019-up: 90°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 90SW
2019-2016: against 90SW
difference in values
depth [m]


110°SW±10° (+ 180°)
DL-2016-up: 110°SW±10°
DL-2016-up: 110°SW±10° +180°
DL-2019-up: 110°SW±10°
DL-2019-up: 110°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 110SW
2019-2016: against 110SW
difference in values
depth [m]


130°SW±10° (+ 180°)
DL-2016-up: 130°SW±10°
DL-2016-up: 130°SW±10° +180°
DL-2019-up: 130°SW±10°
DL-2019-up: 130°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 130SW
2019-2016: against 130SW
difference in values
depth [m]


150°SW±10° (+ 180°)
DL-2016-up: 150°SW±10°
DL-2016-up: 150°SW±10° +180°
DL-2019-up: 150°SW±10°
DL-2019-up: 150°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 150SW
2019-2016: against 150SW
difference in values
depth [m]


170°SW±10° (+ 180°)
DL-2016-up: 170°SW±10°
DL-2016-up: 170°SW±10° +180°
DL-2019-up: 170°SW±10°
DL-2019-up: 170°SW±10° +180°
inclination [degrees]
depth [m]
2019-2016: along 170SW
2019-2016: against 170SW
difference in values
depth [m]

Accelerometer data (bonus)

Acceleration increases vs depth