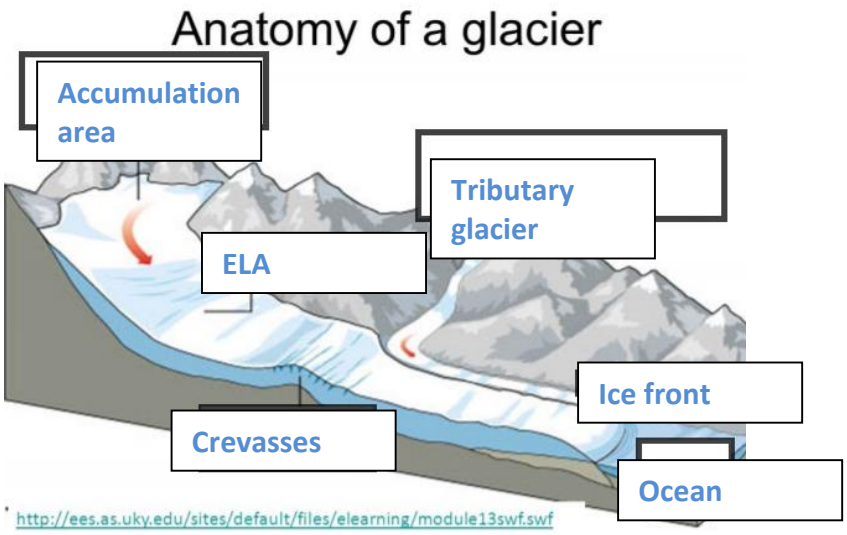
# WORKSHEET – ANSWERS
# TEACHERS' VERSION

# ARCTIC ISSUES: GLACIERS

**TASK 1. Put correct names on the alpine glacier scheme**




| | | |
|---|---|---|
| Accumulation area | Firn line (ELA) | Ice front |
| Tributary glacier | Ocean | Crevasses |

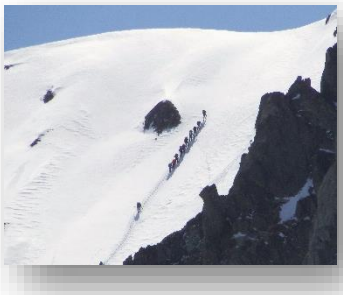
**TASK 2 Glacial landforms**

Combine the word with the corresponding definition and image. Be careful, 2 definitions and 2 images do not match to any of indicated terms

| | |
|---|---|
| Glacial moulin | Narrow, tubular nearly cylindrical, vertical shaft, hole or crevasse carved in the ice by surface meltwater. IMAGE: B |

| | |
|---|---|
| Nunatak | **An island of bedrock or mountain projecting above the surface of an ice sheet, highland icefield, or mountain glacier. IMAGE: A** |
| Moraines | **Effect of glacial deposition; fragments of rock transported by the glacier and deposited when it melts.IMAGE: D** |
| Hanging valleys | **They end with a waterfall at the cliff-face.IMAGE: E** |

1) A rock hill shaped by the passage of ice to give a smooth up-ice side and a rough, plucked and cliff-girt surface on the down-ice side
2) They end with a waterfall at the cliff-face.
3) Effect of glacial deposition; fragments of rock transported by the glacier and deposited when it melts.
4) An island of bedrock or mountain projecting above the surface of an ice sheet, highland icefield, or mountain glacier.
5) Circular basins carved by the base of a glacier as it erodes the landscape.
6) Narrow, tubular nearly cylindrical, vertical shaft, hole or crevasse carved in the ice by surface meltwater.

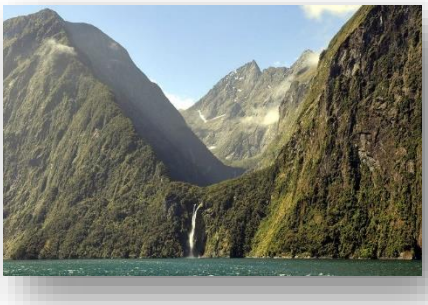
| | |
|---|---|
| A  | B  |

INTER ⇄ ACT

C

D

E



F

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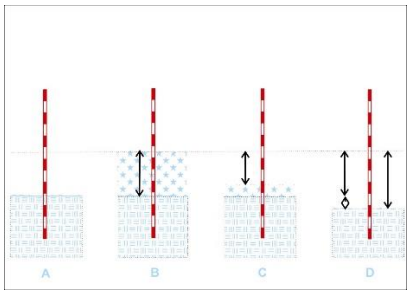
**TASK 3** Explain what's in the photo – what is the tool that this person is using what kind of glacier studying technique it is and how it works.
CLUE: check out scheme of use of this method




**This is an ABLATION STAKE, used in GLACIOLOGICAL METHOD -in situ (field) measurements. At a number of individual points the change in surface level is measured between two dates. Scientist use a rotary hammer drill to drill holes of known depth into the ice; into these holes they insert o poles(e.g. two meters long)called ablation stakes, which help record changes in glacier mass. They record exactly how deep each stake was implanted, so they can, on return visits, assess exactly how much ice has melted away (or accumulated) at each location simply by remeasuring the level of the ice surface against the stake.**

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**TASK 4 Match the beginning of the sentence on the left with a proper end on the right:**

| | |
|---|---|
| A temperate glacier (as opposed to a polar glacier), is a glacier that's essentially at the melting point… | … the time delay and amplitude of the radar waves scattered back towards the transmitter off any reflecting surface.. |
| Radar (radio detection and ranging) technology consists of a radio transmitter capable of sending out electromagnetic pulses and a receiver able to detect and record | … later falling as snow and becoming compacted in ice. |
| The water-ice in glaciers originally came from the oceans as vapor … | …so liquid water coexists with glacier ice. |
| According to the National Snow and Ice Data Center (NSIDC) if all glaciers melted today, | …the seas would rise about 70 meters. |

| | |
|---|---|
| When ablation is bigger than accumulation, it means that glaciers is retreating and … | … is the Equilibrium line altitude. |
| Tidewater glaciers undergo… | … there is negative mass balance |
| Paleoclimatology is based on | … studying isotopes in ice cores. |
| Where ablation is equal to accumulation … | …a process called calving |

**A temperate glacier (as opposed to a polar glacier)is a glacier that's essentially at the melting point, so liquid water coexists with glacier ice.**

**Radar (radio detection and ranging) technology consists of a radio transmitter capable of sending out electromagnetic pulses, and a receiver able to detect and record the time delay and amplitude of the radar waves scattered back towards the transmitter off any reflecting surface.**

**According to the National Snow and Ice Data Center (NSIDC), if all glaciers melted today the seas would rise about 70 meters.**

**The water-ice in glaciers originally came from the oceans as vapor later falling as snow and becoming compacted in ice.**

**When ablation is bigger than accumulation, it means that glaciers is retreating and there is negative mass balance.**

**Tidewater glaciers undergo a process called calving.**

**Paleoclimatology is based on studying isotopes in ice cores.**

**Where ablation is equal to accumulation is the Equilibrium line altitude.**

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**TASK 5 Are these sentences TRUE or FALSE? (underline the correct answer)**

During the last ice age (when glaciers covered more land area than today) the sea level was about 122 meters higher than it is today.

TRUE/FALSE

**FALSE (the sea level was about 122 meters LOWER than it is today, as more water was accumulated in solid form)**

The equilibrium-line altitude (ELA) marks the area on the glacier where accumulation is balanced by ablation

TRUE/FALSE

**TRUE**

Surge-type glaciers are very rare and were observed only in some parts of Antarctica

TRUE/FALSE

**FALSE In general, surge-typeglaciers have not been recognized in Antarctica.**

Titanic sank because of glacier's calving

TRUE/FALSE

**TRUE, In 1912, an iceberg broke off Jakobshavn. Titanic smashed into it and sank.**

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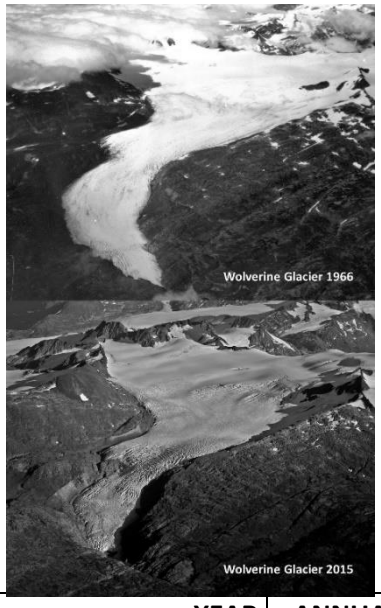
**TASK 6**

**Draw a figure based on given data (source: https://www2.usgs.gov/climate_landuse/clu_rd/glacierstudies/wolverine.asp**

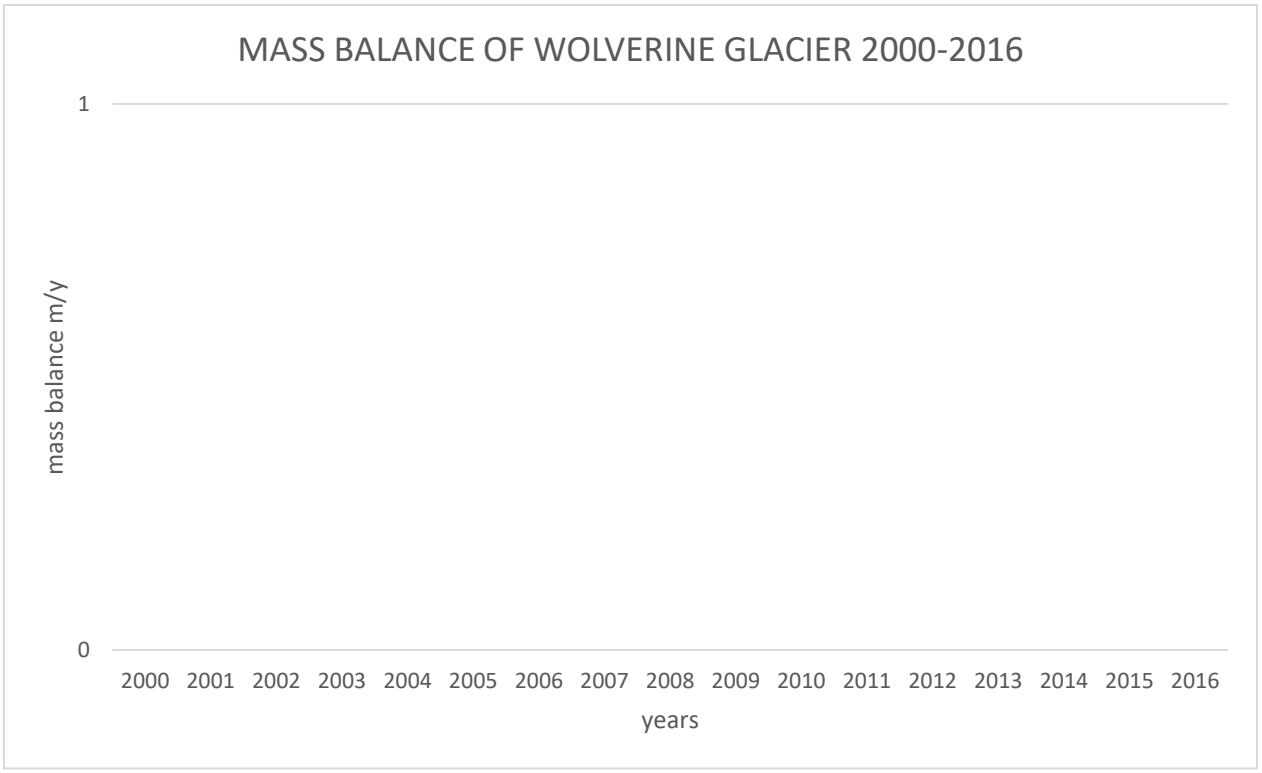
**Overview on mass balance data 2000-2016 – Wolverine glacier, south – east Alaska**


In 1966 scientists with the USGS began making direct measurements of surface mass balance at Wolverine Glacier, one of two "benchmark glaciers" in Alaska. Repeated measurements at three long-term "index" sites, in conjunction with local meteorology and runoff data, are used to estimate glacier-wide mass balances. These data constitute the longest continuous set of mass-balance data in North America (Josberger and others, 2007) which are used to understand glacier dynamics and hydrology, and to understand the glacier's response to climate change.

| YEAR | ANNUAL MASS BALANCE [m/year] |
|---|---|
| 2000 | -3.5 |
| 2001 | -3.09 |
| 2002 | -4.92 |
| 2003 | -5.81 |

| | |
|---|---|
| 2004 | -7.12 |
| 2005 | -7.27 |
| 2006 | -4.69 |
| 2007 | -5.86 |
| 2008 | -2.81 |
| 2009 | -6.11 |
| 2010 | -4.47 |
| 2011 | -6.62 |
| 2012 | -4.12 |
| 2013 | -5.91 |
| 2014 | -7.52 |
| 2015 | -7.69 |
| 2016 | -7.14 |



**TASK 7 Explore findings of an article - *Glacier Mass Balance and Regime: Data of Measurements and Analysis, Mark Dyurgerov, Occasional Paper No. 55, 2002, Institute of Arctic and Alpine Research, University of Colorado.***

Observe figures below (red lines only, for simplification).
Figure one: Mass balance of glaciers 1940 – 1998 (mm/year)

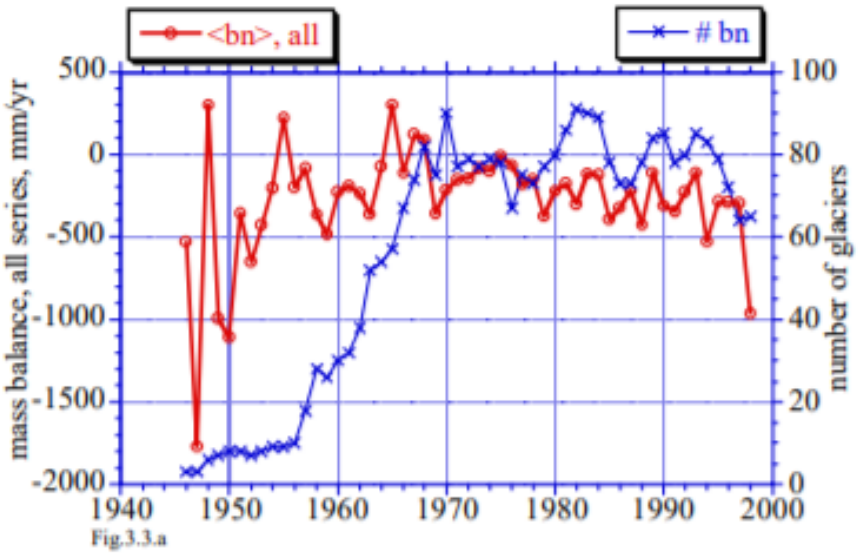


Fig.3.3.a

According to this data:

Are the glaciers growing or retreating, in general?

What's the tendency?

When does the tendency begin?

Figure 2: Mass balance extremes

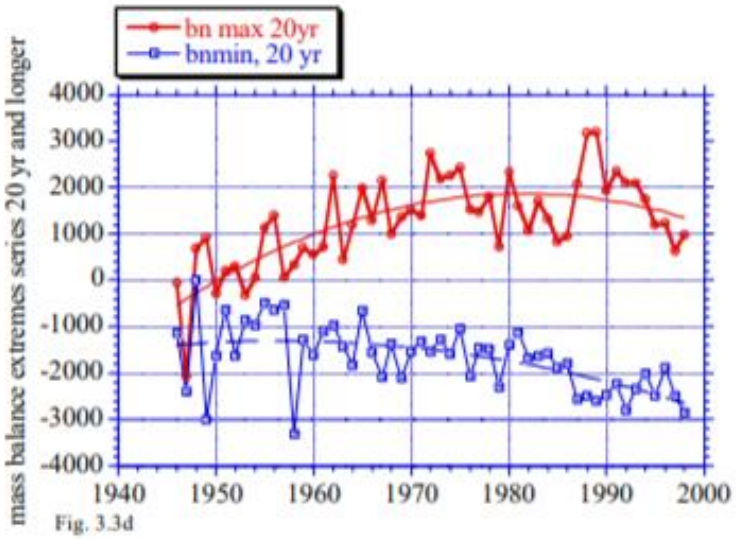


Fig. 3.3d

What about extreme values-maxima and minima? What can be observed?

**Annual mass balances calculated for all glaciers show tendencies to increased negative valuesstarting in the middle of 1970' s, with an accelerating annual rate of retreating at the end of 1980' s. The glaciers are therefore retreating. Extreme values calculated for relatively long time series (20 years and longer) show increases of maximums and minimums, this means they become more EXTREME.**

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**TASK 8 What if all the ice melts? Mathematical simulation.**

Use the data below to calculate-theoretically-how much would sea level rise **if all the ice melted?**
NOTE that these calculations are more demonstrative than accurate!
ALSO please note that we're not taking icebergs or sea ice into consideration – they're already floating in the sea, so if they melt it doesn't affect (hat much) the ocean level.

| | |
|---|---|
| **Earth's surface area** | *510 000 000 km²* |
| **Land covered area** | *150 000 000 km²* |
| **Ocean covered area** | *360 000 000 km²* |
| **Antarctica Area** | *14 000 000 km²* |
| **Average thickness of ice cap** | *2.1 km* |
| **Greenland Area** | *2 000 000 km²* |

| | |
|---|---|
| **Average thickness of ice cap** | *1.3 km* |
| **Other ice sheets Area** | *5 000 000 km$^2$* |
| **Average thickness of ice cap** | *0.1 km* |

REMEMBER: volume = area x height, so height=volume/area

UNITS:
Area – km$^2$
Height – km; in this case height=thickness of ice layer
Volume – km$^3$
TIPS: First, calculate how much water would be added to oceans.
Then, how thick would this new layer of water be.

| | |
|---|---|
| VOLUME OF WATER | 14x10 $^6$ x 2.1 + 2x10 $^6$ x 1.3 + 5x10 6 x 0.1 = (29.4+2.6+0.5) x10 $^6$ = 32.5 x10 $^6$ km $^3$ |
| THICKNESS OF NEW LAYER OF WATER | 32.5 x106km$^3$/ 360 x106km$^2$= 0.090 km = 90 m |

**This calculation is not 100% correct, can you tell why?** Taking this into consideration, will the actual sea level will be higher or lower than you calculated?

**A more realistic calculation should take into account that some lands will also be covered by ocean. So the water is not just growing "higher"it "spills"over the lands, as well. The actual sea level will be lower than we calculated.The same volume of melted ice should be divided by a larger area, so volume/area=height, and the height is LOWER.**

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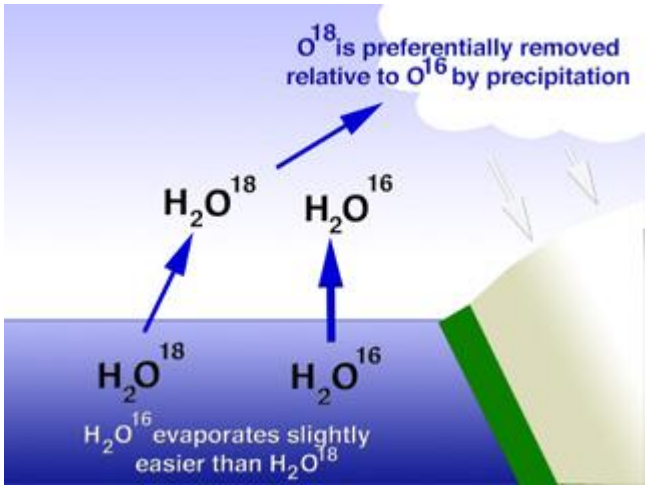
**TASK 8 * - for advanced**
**Paleoclimatology: key to our past and future**

Analyse figure below, showing results of ice core studies, identify glaciations and warm periods, when did they occur?

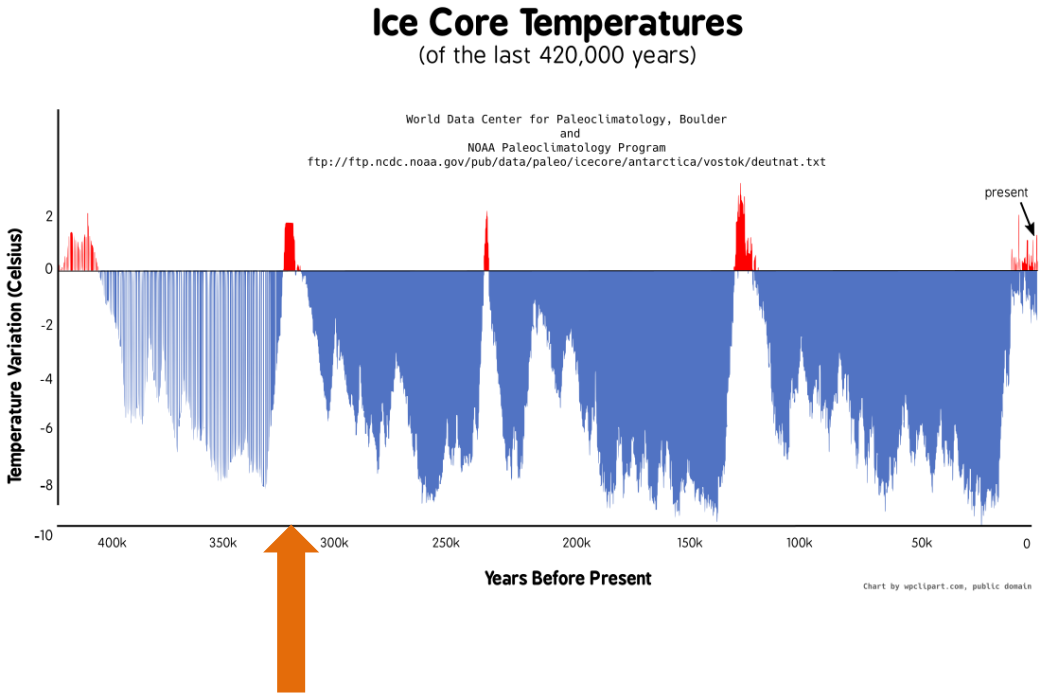
Oxygen is one of the most significant keys to past climates. Oxygen comes in heavy and light isotopes, which are useful for paleoclimate research. The ratio (meaning: relative amount) of these two types of oxygen in water changes with the climate.
The water-meaning ice in glaciers originally came from the oceans as vapor, later falling as snow and becoming compacted in ice.

Use information and image to determine **$^{18}O$ / $^{16}O$** ratio in air trapped in ice core layers from period indicated with a red arrow on TIME axis.
DECIDE: Is it higher than „normal" or lower than „normal"?

| |
|---|
| ***$^{16}O$ isotope is lighter so evaporates easily; $^{18}O$ isotope is heavier so condenses easily*** |




Source:
*http://www.globalchange.umich.edu/globalchange1/current/lectures/kling/paleoclimate/index.html*



**The rarer and heavier $^{18}O$ isotope in water generally evaporates after and condenses (and precipitates) out earlier than the lighter and more common $^{16}O$ isotope.**
**When water evaporates, the heavy water ($H_2{}^{18}O$) is left behind and the water vapor is enriched in light water ($H_2{}^{16}O$). This is simply because it is harder for the heavier molecules to overcome the barriers to evaporation. In other words: it has to be really warm to make heavy oxygen to go to the atmosphere in water vapor.**
**Because condensation is the result of cooling, the greater the fall in temperature, the lower the heavy isotope concentration will be.**
**The colder the environment, thequicker the atmospheric water vapor condenses, hence the quicker the18Oisotope is "removed", giving a lower ratio of $^{18}O$ to $^{16}O$.**
**Simpler explanation –it had to be really very warm so that this heavy water with 18O could evaporate from the ocean; later it came down as snow that turned into glaciers.Still it is heavier, so it falls down as snow more easily.**

**WARM CLIMATE –higher ratio $^{18}O$ /$^{16}O$in air trapped in ice core.**
**COLD CLIMATE –lowerratio $^{18}O$ /$^{16}O$in air trapped in ice core.**

**CONCLUSION: Warmer climate-as 325000 years ago(marked on axiswith an arrow –we observe higher temperatures) –higher 18O/16O ratio.**

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