National Aeronautics and Space Administration

The Heliophysics Big Year

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NASA Heliophysics Education Activation Team

NASA's Big Questions

1. **What causes the Sun to vary?**
2. **How do the Earth and the heliosphere respond?**
3. **What are the impacts on humanity?**

These Big Questions form the basis for the

Framework for Heliophysics Education

https://science.nasa.gov/learn/heat/big-ideas/

The Framework for Heliophysics Education

What are the impacts of the Sun on humanity?

1.1 The Sun is really big and its gravity influences all objects in the solar system. (PS2, ESS1)

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

1.3 The Sun's energy drives Earth's climate, but the climate is in a delicate balance and is changing due to human activity. (PS1, PS2, PS3, LS4, ESS2, ESS3)

How do the Earth, the solar system, and heliosphere respond to changes on the Sun?

2.1 Life on Earth has evolved with complex diversity because of our location near the Sun. It is just right! (PS3, PS4, LS1, LS2, ESS2)

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

2.3 The Sun is the primary source of light in our solar system.(PS1, PS2, PS3,PS4, ESS1)

What Causes the Sun to Vary?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

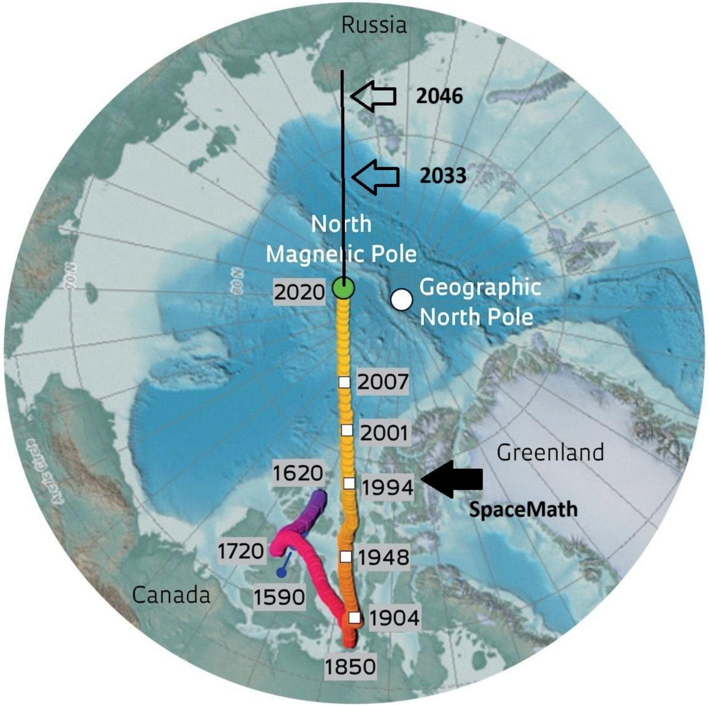
3.2 Energy from the Sun is created in the core and travels outward through the Sun and into the heliosphere. (PS1, PS3, PS4, ESS1, ESS2, ESS3)

3.3 Our Sun, like all stars, has a life cycle. (PS1, LS1, ESS1)

Earth's Magnetic Pole Wander

The magnetic poles of Earth do not stay fixed, but wander geographically.

Why does this happen?



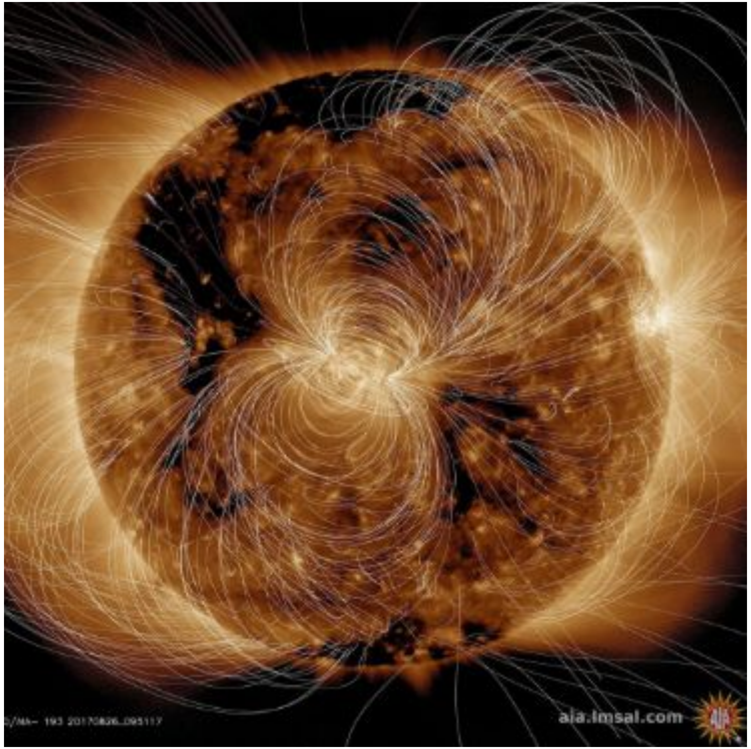
https://revistapesquisa.fapesp.br/en/the-wandering-north-pole/

Our magnetic sun – The magnetic dynamo

Our sun generates a powerful magnetic field through the motion of plasma below its surface.

A combination of rotation and convection creates currents in the solar plasma that periodically grow and weaken, and shift position.

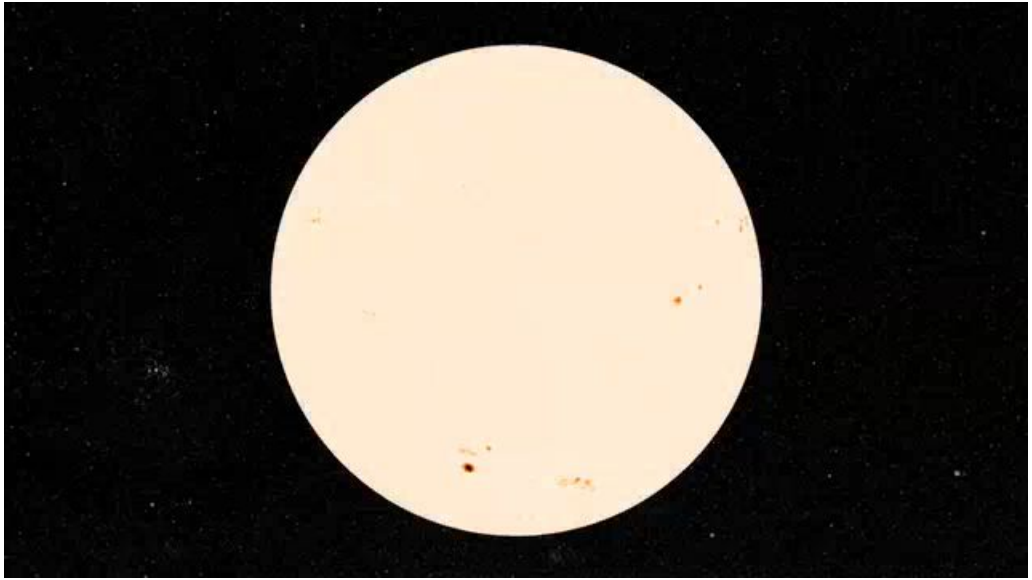
This creates the 11-year sunspot cycle.



NASA/ SDO

Our magnetic sun

Thanks to satellites such as SOHO and the GONG program, we can look below the solar surface, and with powerful mathematical models, and see how the magnetic field is created.

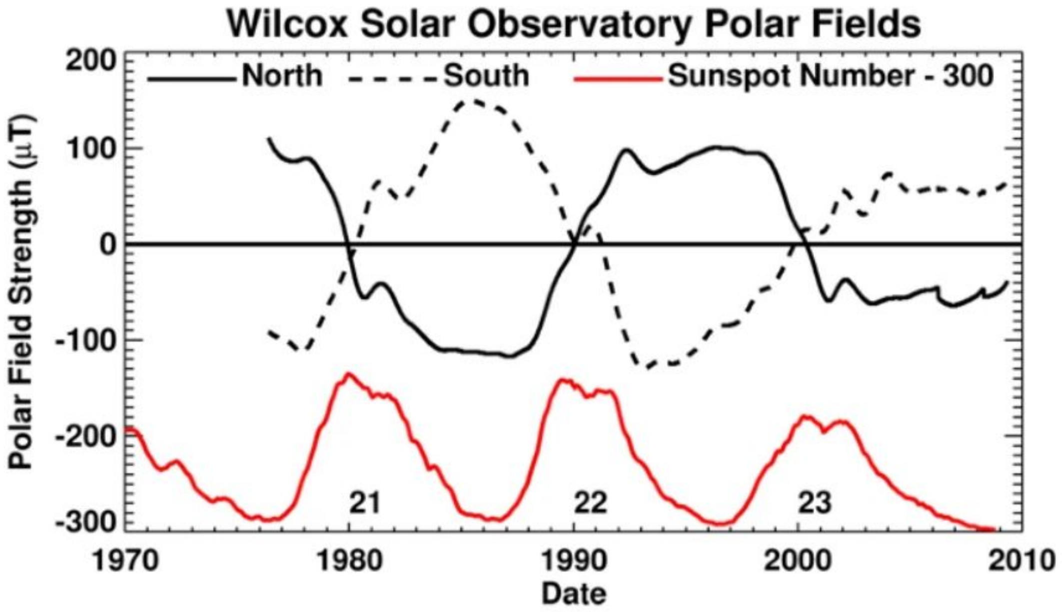


NASA/ SDO / SVS

Our magnetic sun

Here is a plot of the sun's polar field strength and how its strength and polarity change with each sunspot cycle.

It takes a full 22-years for the sun to complete one full magnetic cycle. This is called the Hale Cycle.

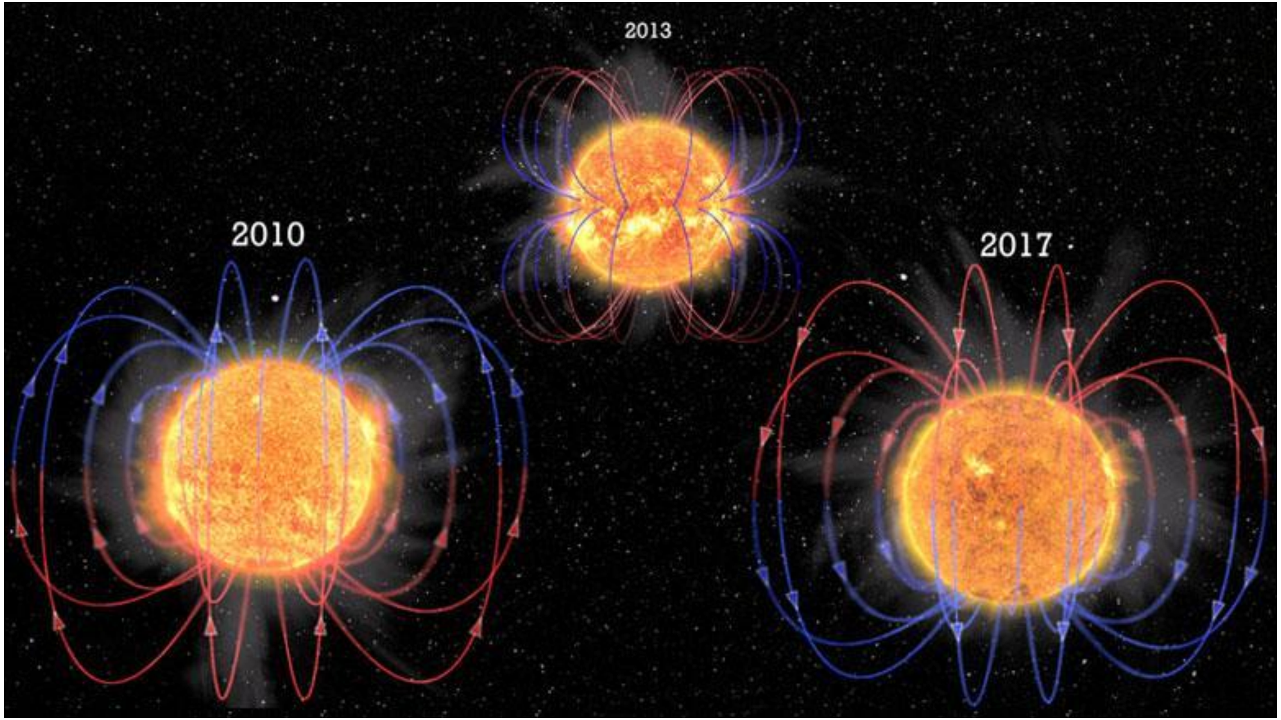


https://link.springer.com/article/10.12942/lrsp-2010-1

Our magnetic sun

Each sunspot cycle, the sun's magnetic poles flip polarity.

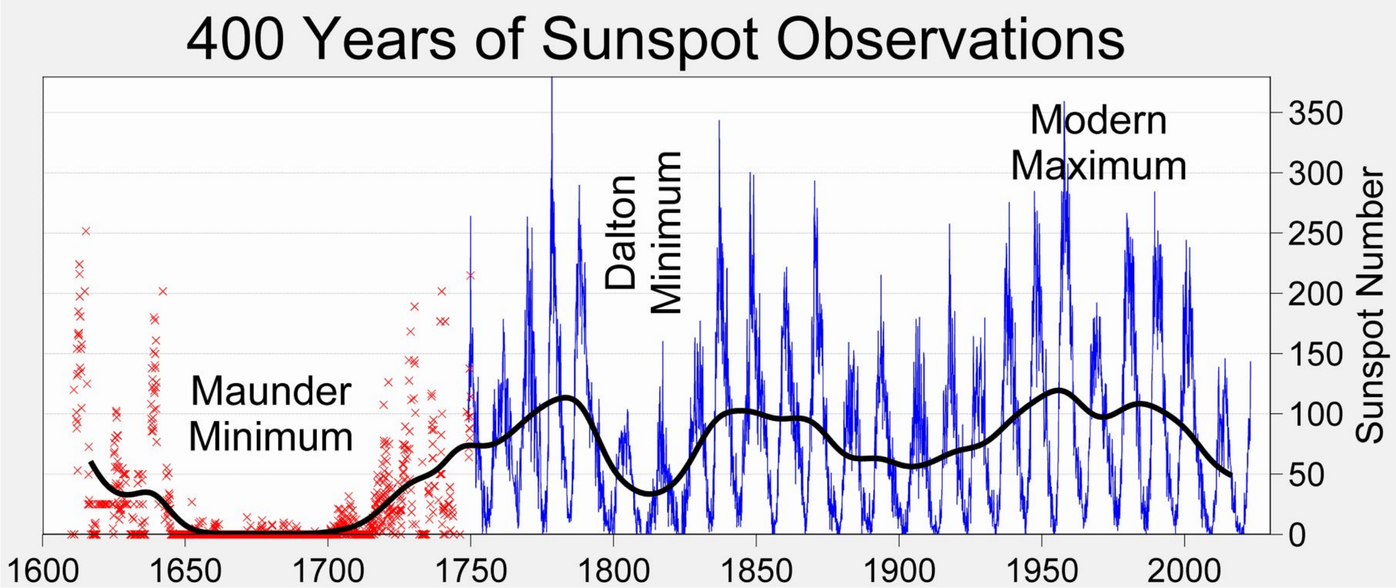
With Magnetic Dynamo Theory and supercomputers, we can watch how this process happens.



NASA/SDO/A. Strugarek et al; Illustrations: L. Almeida, Federal University of Rio Grande do Norte (UFRN), Brazil

Our magnetic sun

On the sun, we have only tracked magnetic polarity reversals since 1600.



https://en.wikipedia.org/wiki/Solar_cycle

Our magnetic sun

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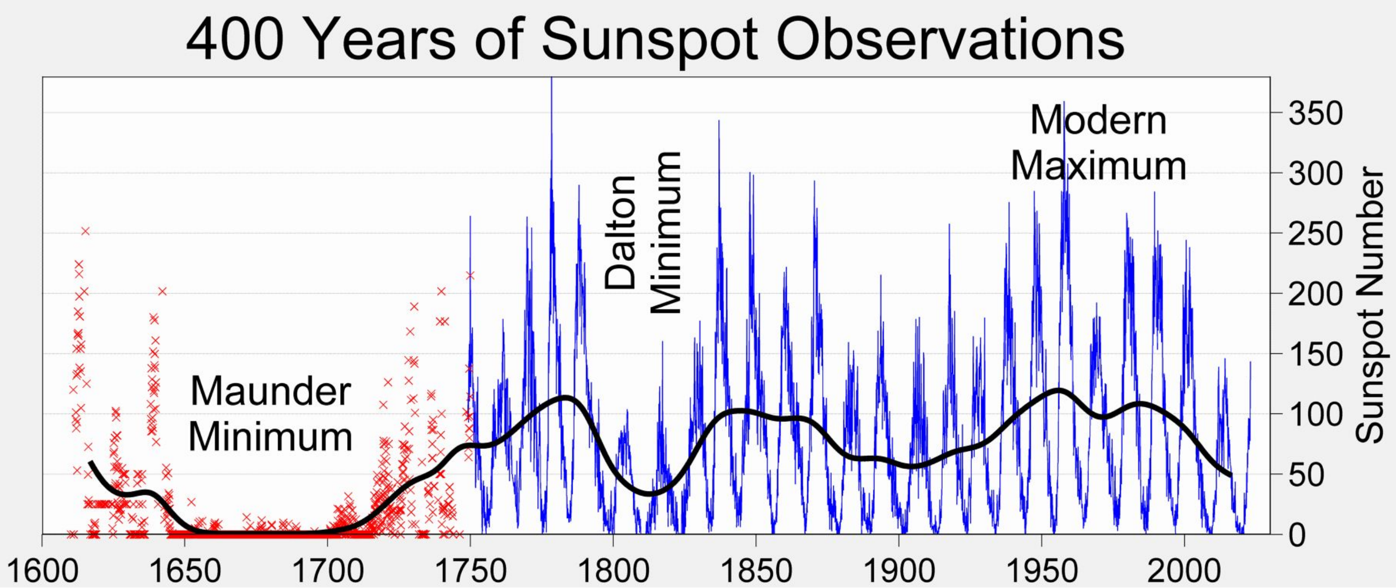


https://en.wikipedia.org/wiki/Solar_cycle

Math Alert!

(2025-1750)/25

11 years/cycle

Our magnetic Earth

Our Earth also generates a magnetic field.

Instead of currents in a plasma
It has a liquid iron-nickel outer core that circulates and undergoes convection just like the sun.

Because of the faster rotation and higher density, Dynamo Theory predicts a much longer 'sunspot cycle' for Earth lasting over 250,000 years.

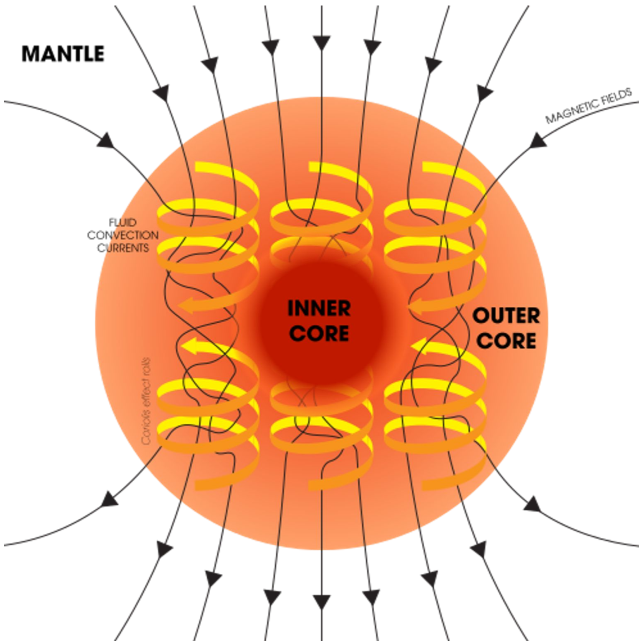
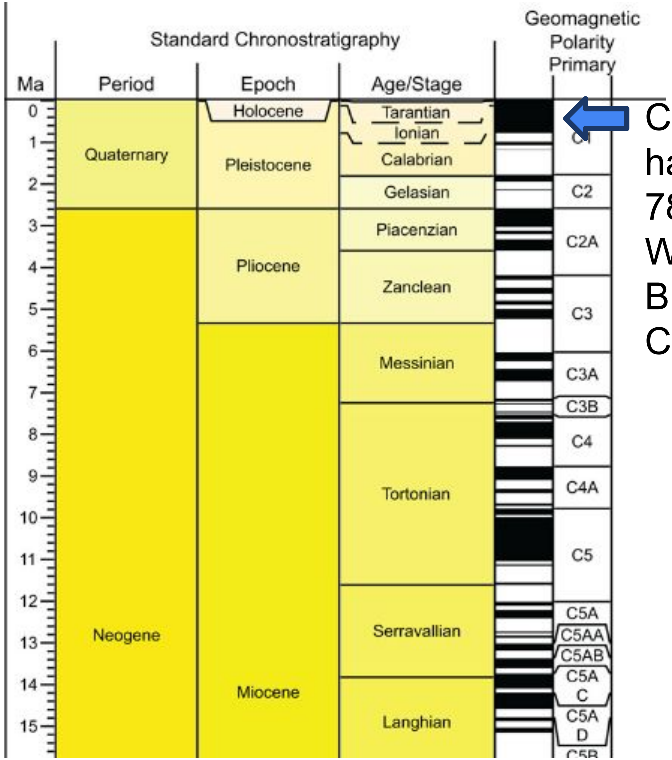


Image by Wikipedia: Dynamo Theory; USGS

Our magnetic Earth

For Earth, magnetic polarity information is captured in cooling magma, and so we can trace magnetic reversals back for 100s of millions of years.

Over a period of 83 million years,183 reversals have been detected.



Current reversal happened 781,000 years ago. We are now in the Brunhes-Matuyama Chron

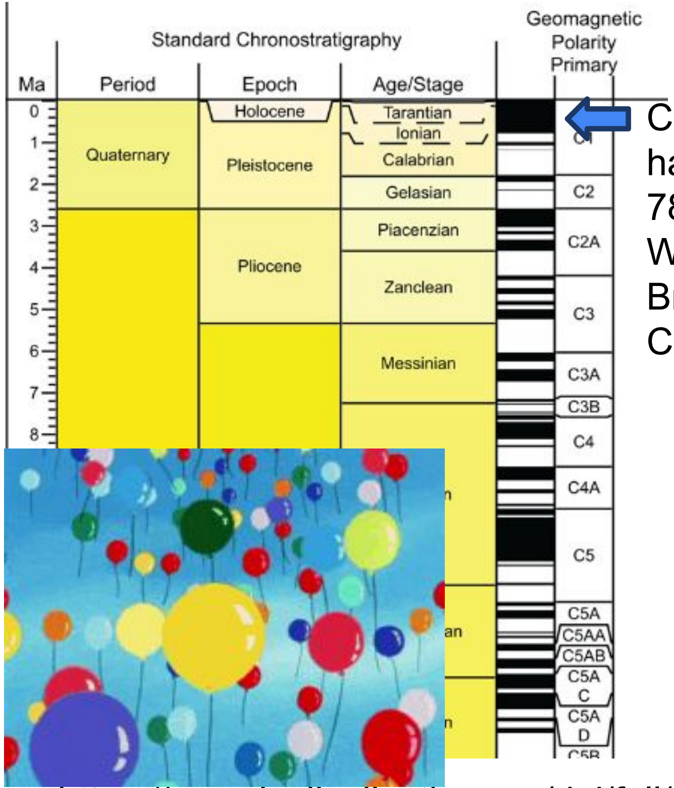
https://www.lyellcollection.org/doi/full/10.1144/sp373.17

Our magnetic Earth; Introductory math

For Earth, magnetic polarity information is captured in cooling magma, and so we can trace magnetic reversals back for 100s of millions of years.

Over a period of 83 million years,183 reversals have been detected.

Math Alert!
83,000,000 / 183 = 450,000 years



Current reversal happened 781,000 years ago. We are now in the Brunhes-Matuyama Chron

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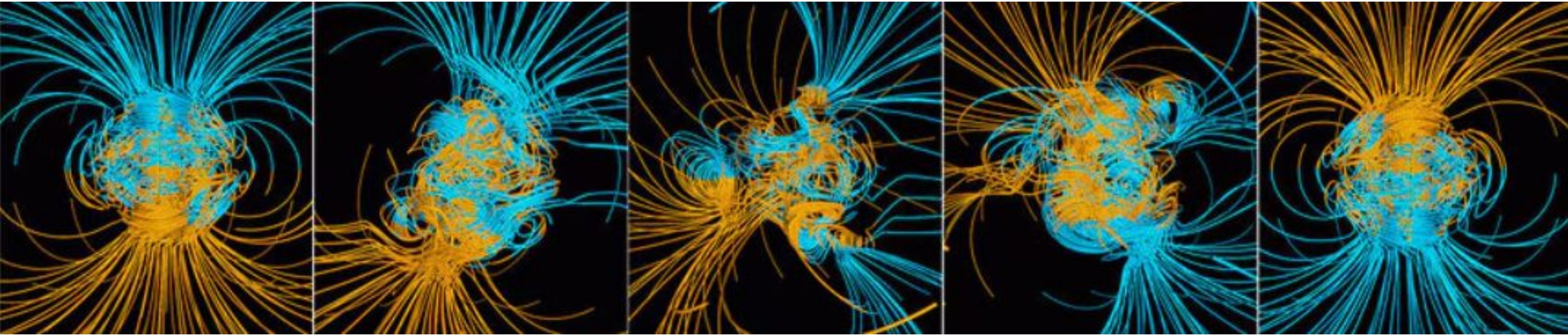
Our magnetic Earth

With supercomputers we can actually start to model what such reversals look like on Earth using Magnetic Dynamo Theory.

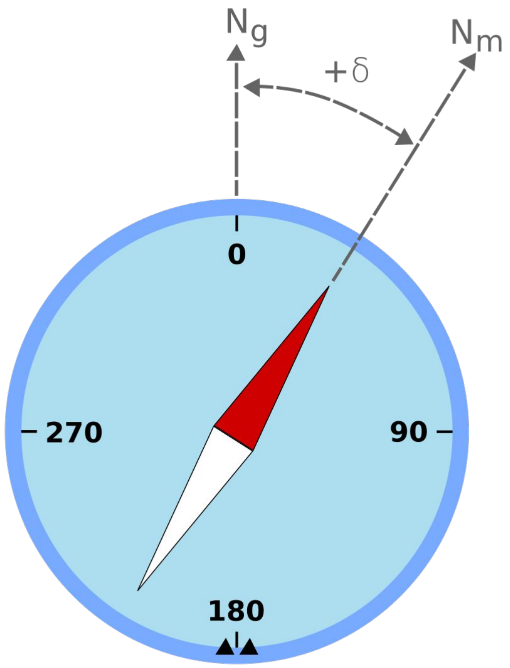


Credit: Gary Glatzmaier

https://www.semanticscholar.org/paper/Magnetic-Polarity-Reversals-in-the-Core-Glatzmaier-Coe/92a04227faf71a4498c9d1e7446f9b13b67d129d

Our magnetic Earth

At each point on Earth, the angle between the compass needle pointing to Magnetic North and the actual geographic North Pole is called the magnetic Declination.

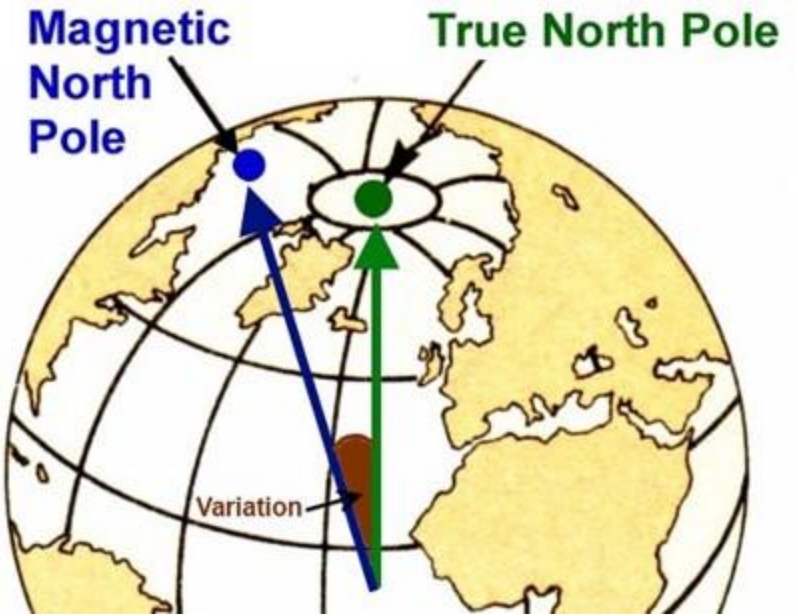


https://en.wikipedia.org/wiki/Magnetic_declination#/media/File:Magnetic_declination.svg

Our magnetic Earth

On Earth's surface these changes cause the surface field to vary over time.

Mariners knew about this in the 1700s because they relied on magnetic compasses to give them accurate bearings for navigation.

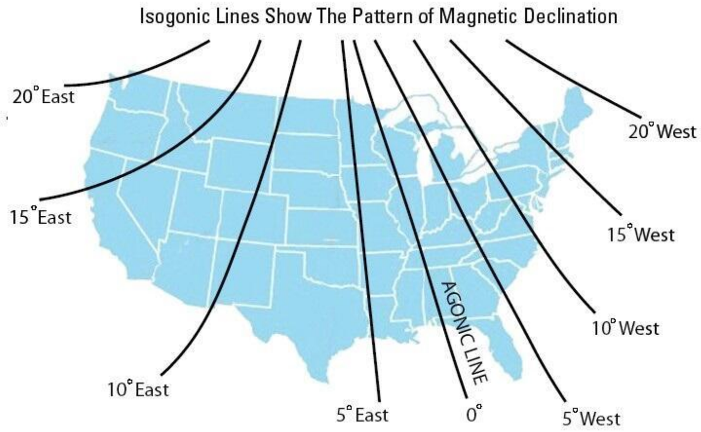


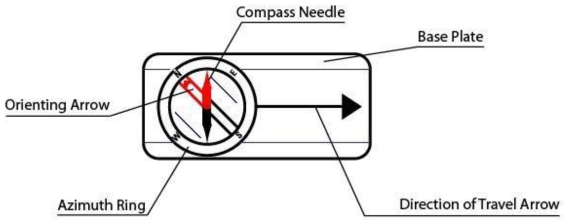
https://www.marine-education.co.uk/2019/08/31/taking-bearings-on-a-nautical-chart/

Our magnetic Earth

Compasses west of the Mississippi River the angle between geographic North and magnetic North will be an angle towards the east.

Example, in Northern California, Magnetic North is 15-degrees to the east of Geographic North.





https://www.usgs.gov/educational-resources/magnetic-declination-varies-considerably-across-united-states

NASA HEAT

Our magnetic Earth: Intermediate math

In the High Sierras, the declination is 12 degrees East.

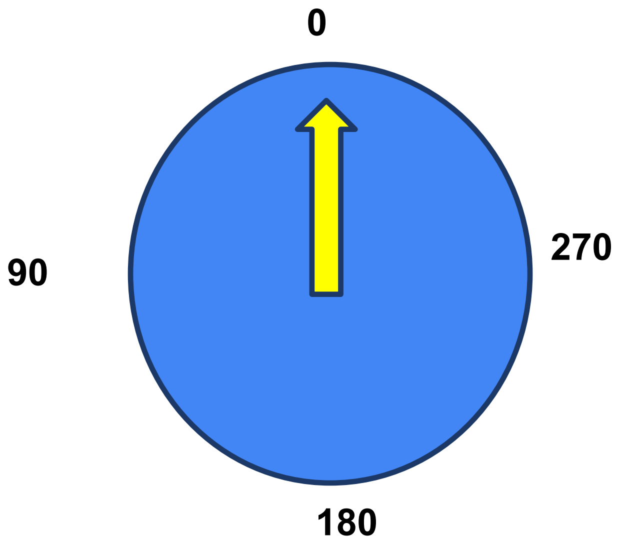
The map says that from where I am standing my destination is one kilometer due North.

What will my compass bearing have to be so that I am walking in the right direction?

Our magnetic Earth: Intermediate math

In the High Sierras, the declination is 12 degrees East.

This means that True Geographic North is 12-degrees to the East of Magnetic North.

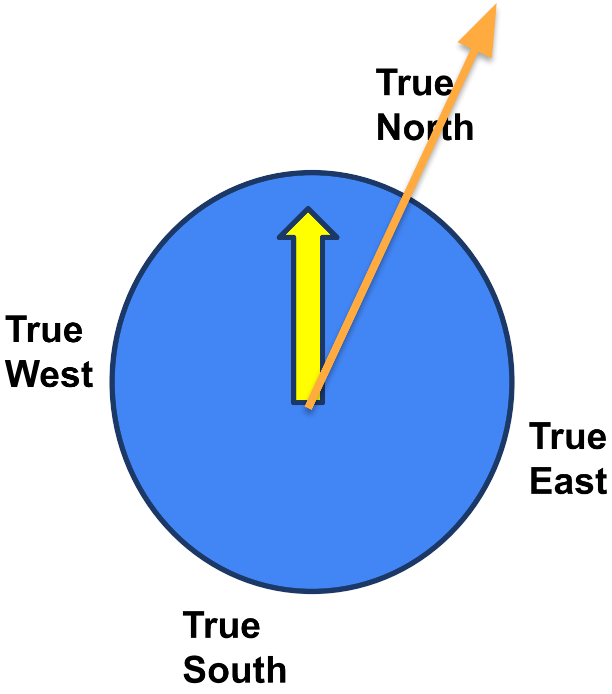


Our magnetic Earth: Intermediate math

In the High Sierras, the declination is 12º East.

This means that True Geographic North is 12º to the East of Magnetic North.

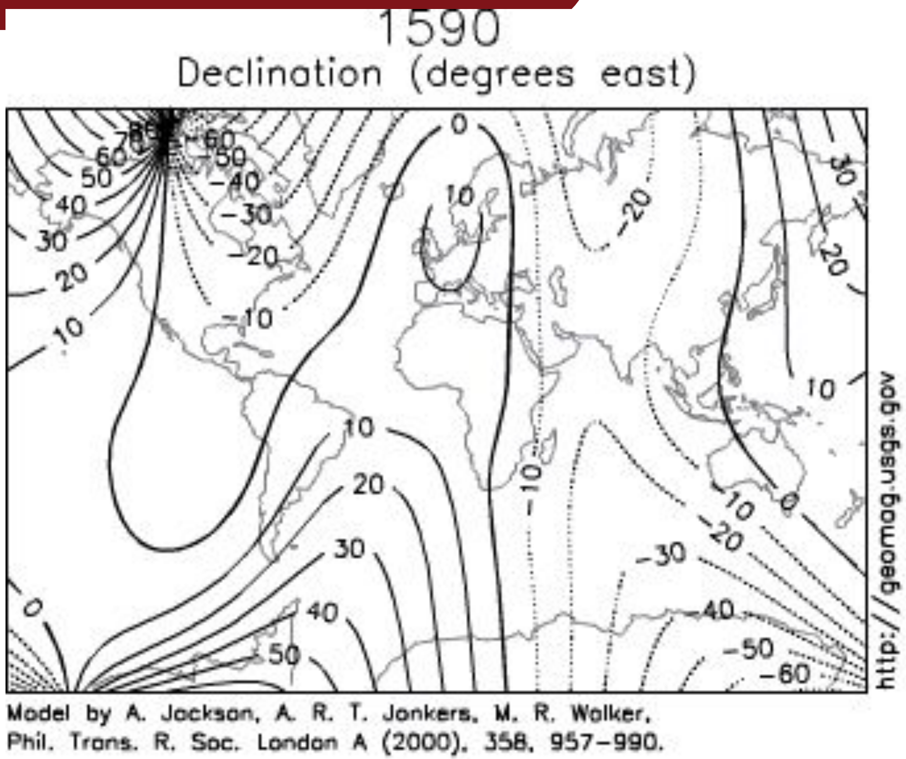
So, the compass bearing is 12º East
Walk in that direction.



NASA HEAT

Our magnetic Earth

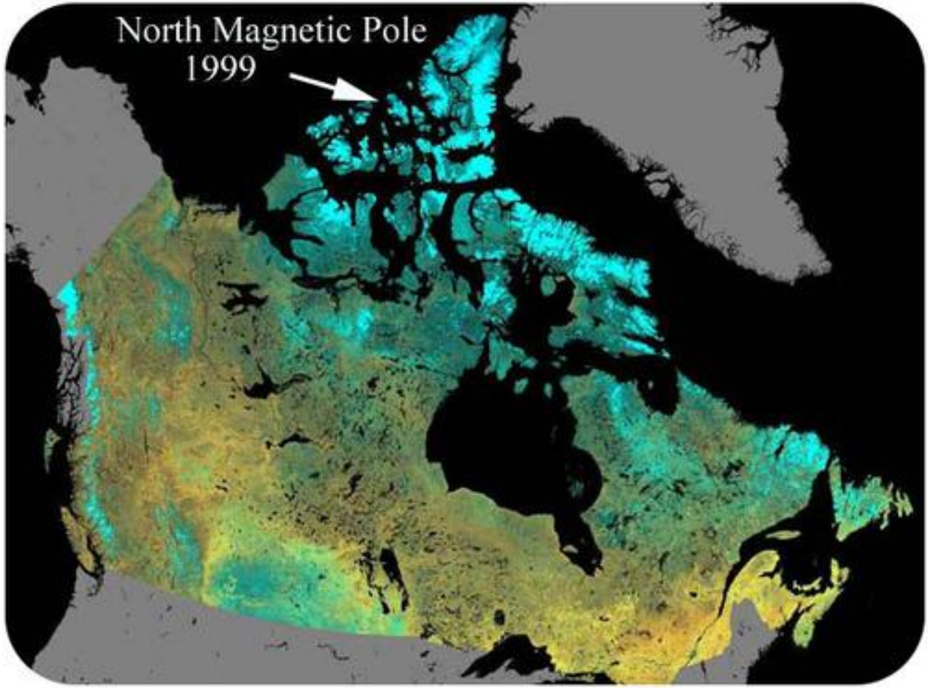
The magnetic declination changes from year to year, so older navigation maps had to be re-drawn every few years at great expense.



https://en.wikipedia.org/wiki/Magnetic_declination#/media/File:Earth_Magnetic_Field_Declination_from_1590_to_1990.gif

Our magnetic Earth

Magnetic declination changes because the North Magnetic Pole is not located in a fixed place on Earth's surface.



https://courses.lumenlearning.com/geo/chapter/reading-continental-drift-2/

Our magnetic Earth

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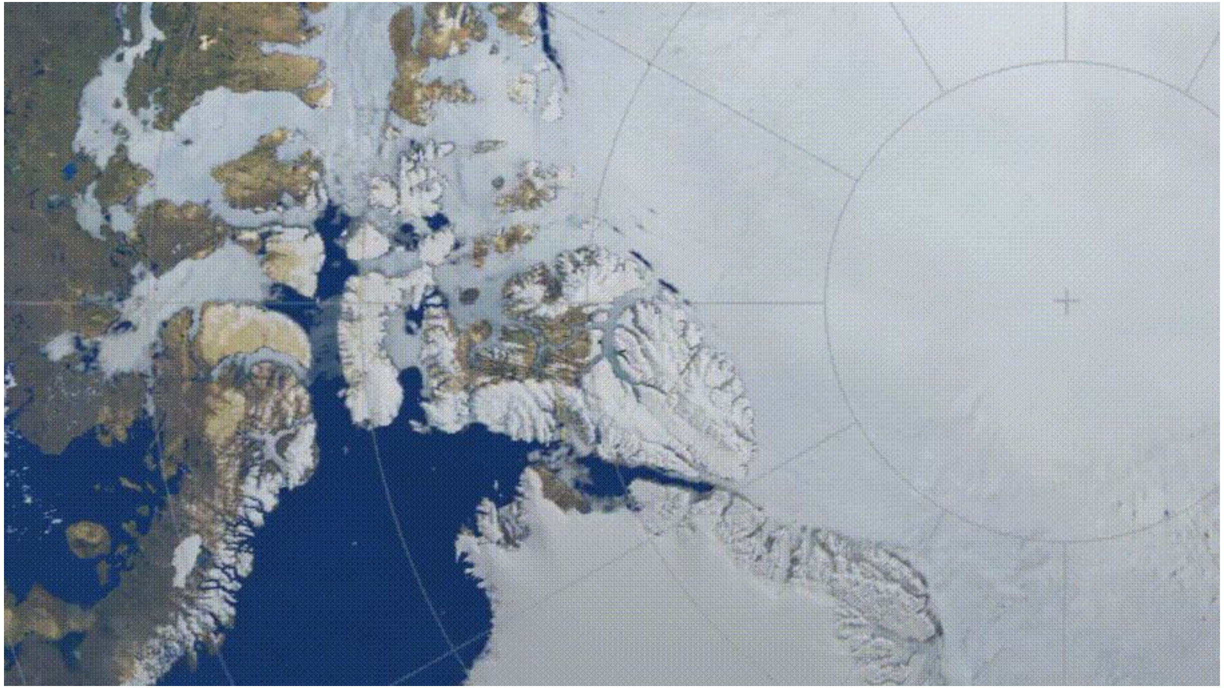
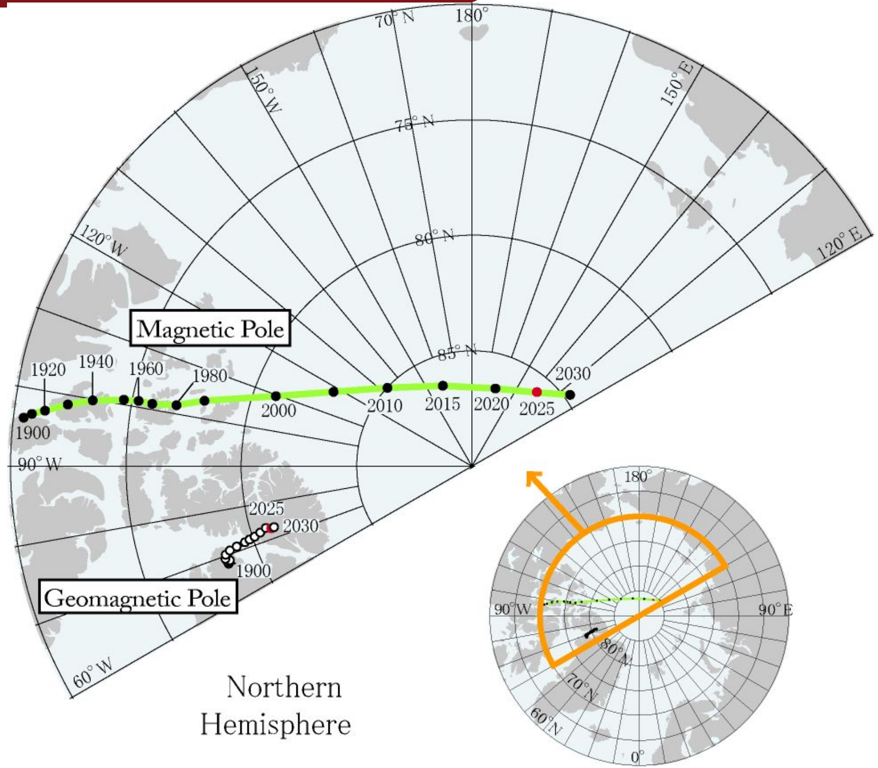


https://allthatsinteresting.com/magnetic-north-pole-moving

Our magnetic Earth; Advanced Math

The motion is not uniform in speed. The dots are spaced every 10 years before 2000 and every five years since 2000.

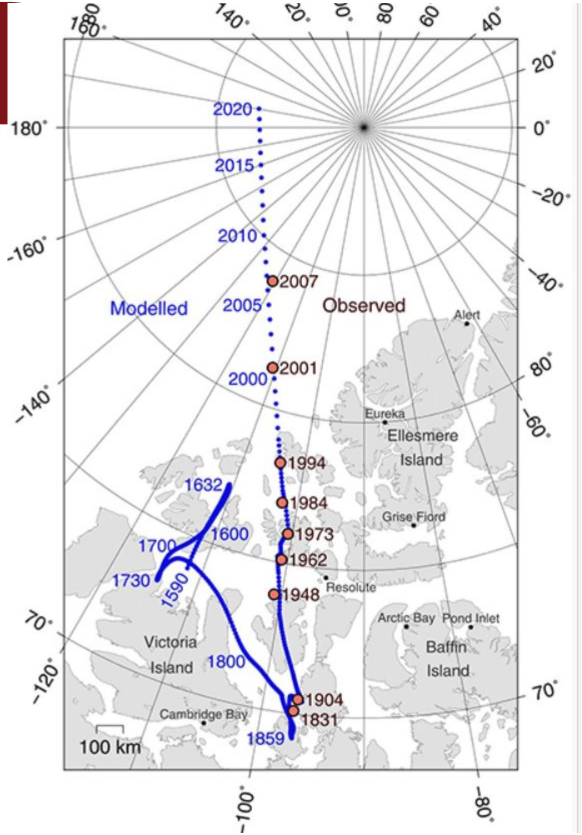


https://wdc.kugi.kyoto-u.ac.jp/poles/polesexp.html

Our magnetic Earth: Advanced Math

Modeling the speed of the change

Year		Distance
1962		0 km
1984		160 km
2007		0 km
2020		600 km



https://www.earthdate.org/episodes/the-wandering-pole

Our magnetic Earth: Advanced Math

Estimating the speed of the change

Year		Distance
1962		0 km
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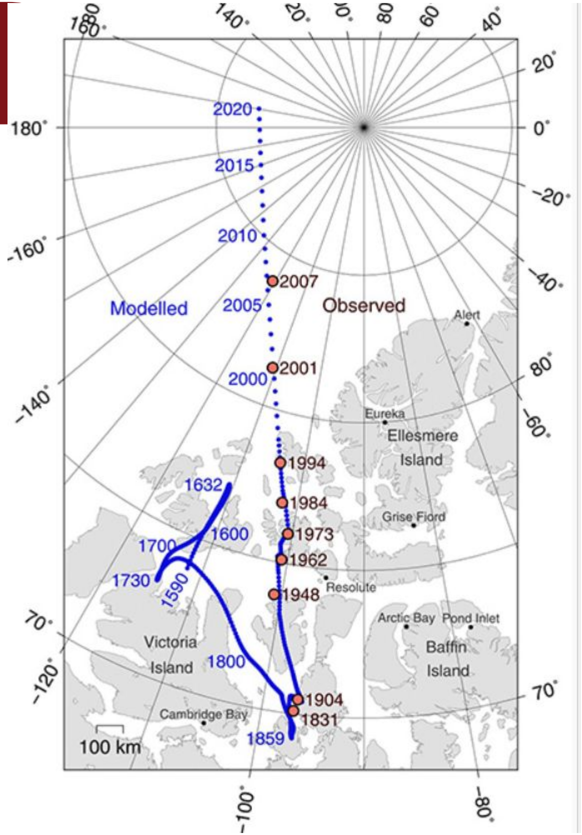

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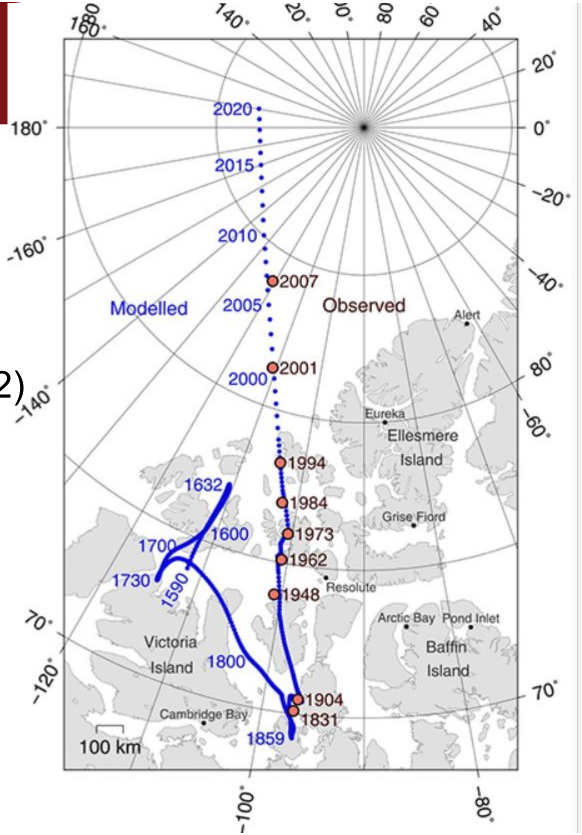
Our magnetic Earth: Advanced Math

Estimating the speed of the change

Year		Distance
1962		0 km
1984		160 km
2007		0 km
2020		600 km

Speed = 160 km/(1984-1962)
= 160 km/22 yrs
= **7 km/yr**



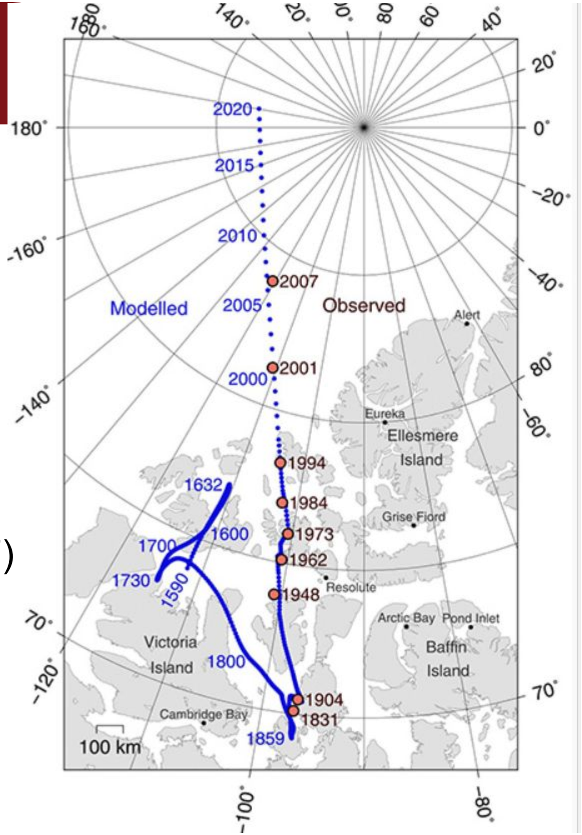
https://www.earthdate.org/episodes/the-wandering-pole

Our magnetic Earth: Advanced Math

Estimating the speed of the change

Year		Distance
1962		0 km
1984		160 km
2007		0 km
2020		600 km

Speed = 600 km/(2020-2007)
= 600 km/13 yrs
= 46 km/yr



https://www.earthdate.org/episodes/the-wandering-pole

Our magnetic Earth: Advanced Math

Estimating the speed of the change

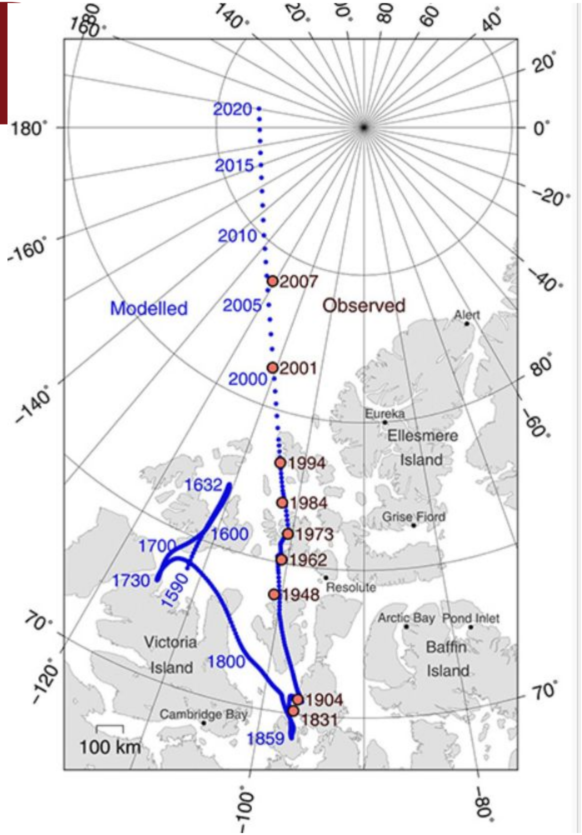
Year		Distance
1962		0 km
1984		160 km
2007		0 km
2020		600 km

Speed = 7 km/yr

Speed = 46 km/yr

Polar wander is speeding up!

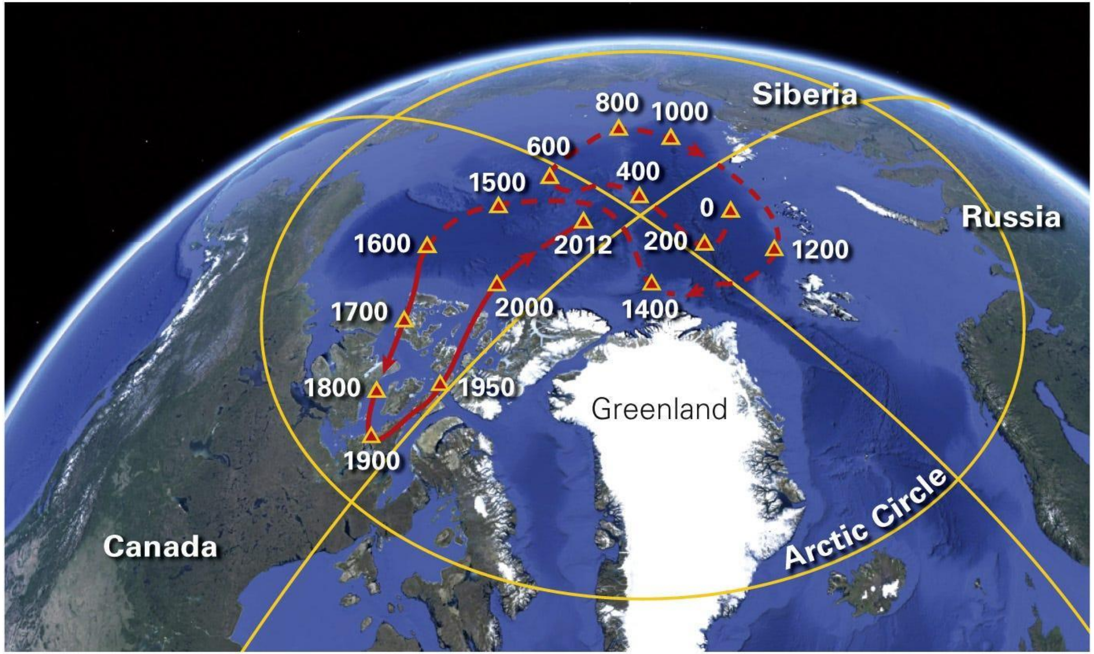
46 km/yr = **126 meters/day**.



https://www.earthdate.org/episodes/the-wandering-pole

Our magnetic Earth

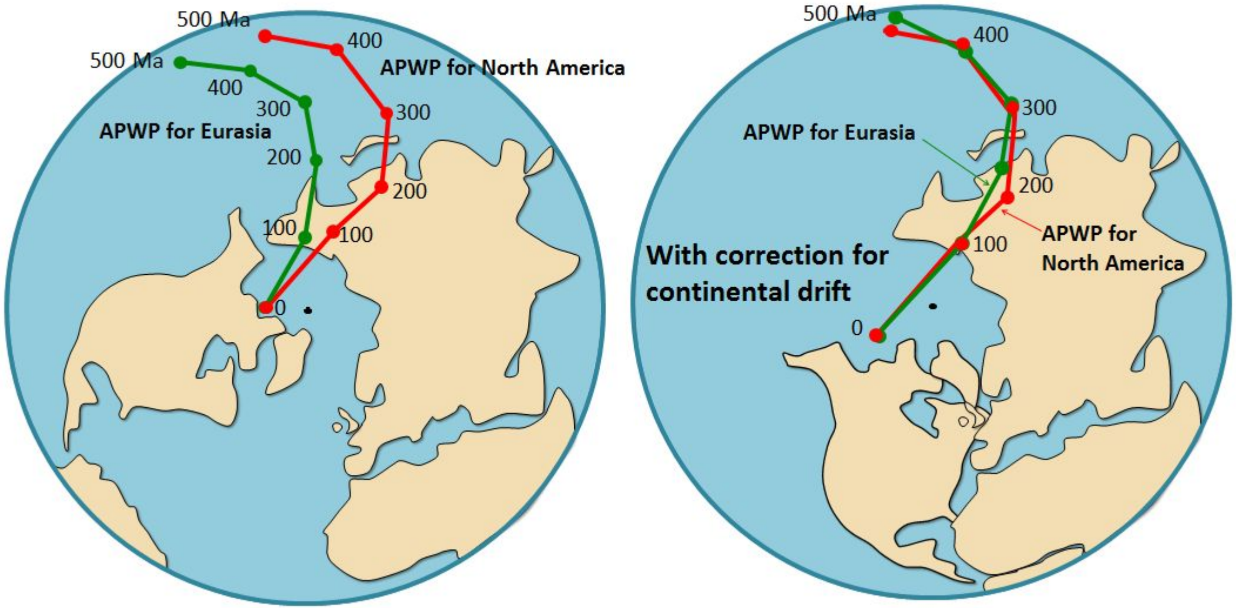
This Polar Wander has been going on for centuries.



https://utahgeology.com/were-the-ice-ages-really-just-true-polar-wandering-events/

Our magnetic Earth

Hard to map over millions of years because of continental drift.



https://openoregon.pressbooks.pub/earthscience/chapter/7-3-geological-renaissance-of-the-mid-20th-century-2/

Next Time – Extreme Space Weather and Habitable Worlds