

# Map projections 1: principles

How can we 'project' a 3D globe onto a 2D display?

..only a globe maintains all spatial qualities without distortion



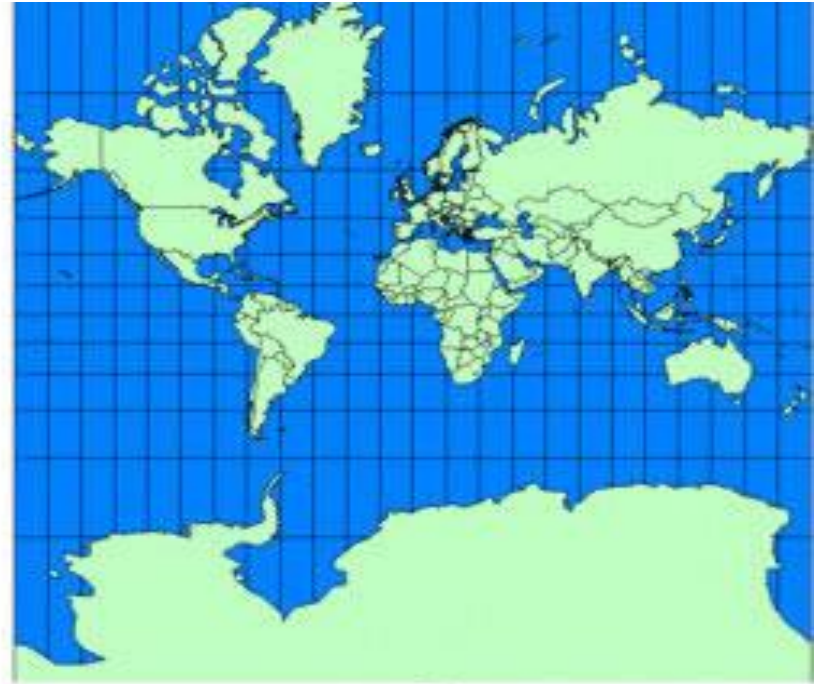
[https://imgur.com/t/science\\_and\\_tech/53iqEMC](https://imgur.com/t/science_and_tech/53iqEMC)

# What is a Map Projection?

a mathematical expression giving the 3D surface on a 2D map



1



2

This process always results in distortion

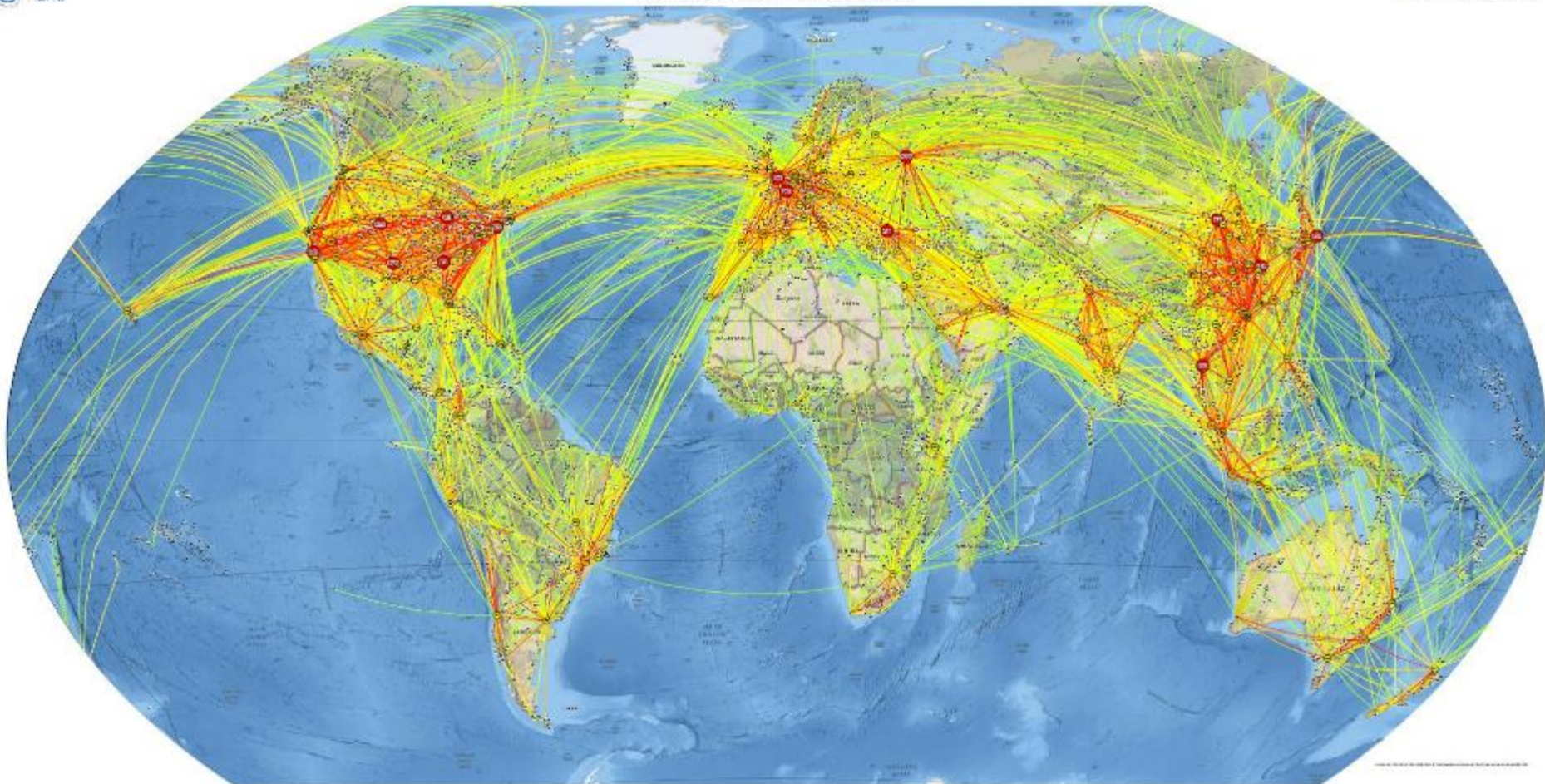


# Why don't planes fly on straight lines – well they do ...



ICAO TRAFFIC FLOW 2020 after the COVID-19

More info <https://gis.icao.int>



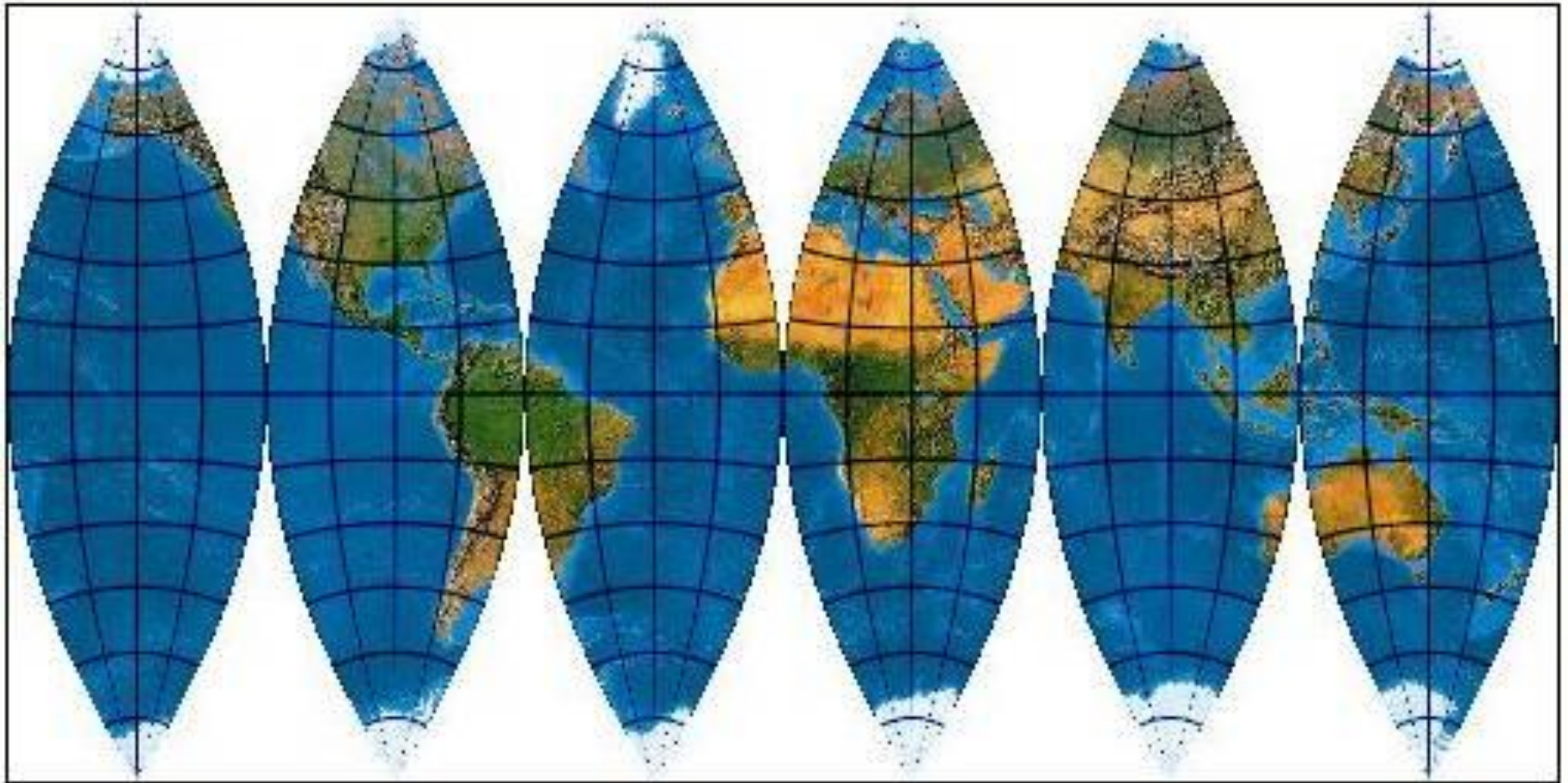
flight routes are 'great circles' ... straight line in 3D space – but curves here

The world could be mapped like orange peel ...  
- maybe not a problem locally, but it is for large areas



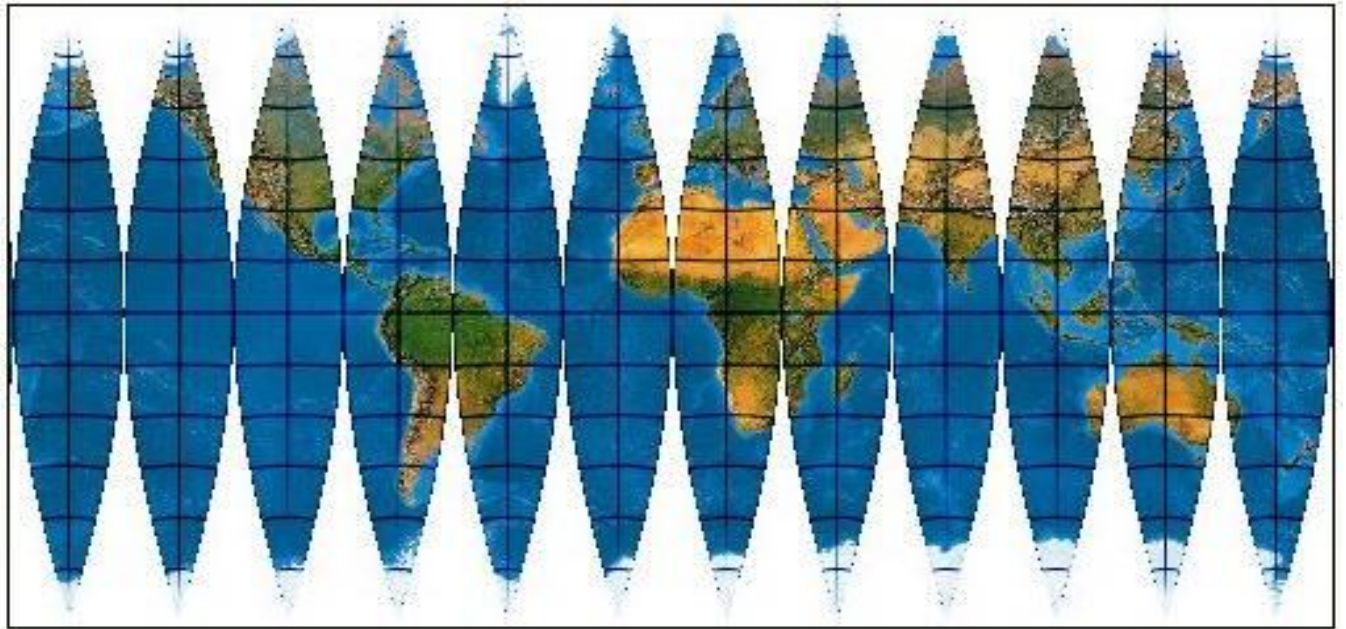


the strips would still have some curvature  
.. and gaps between the strips



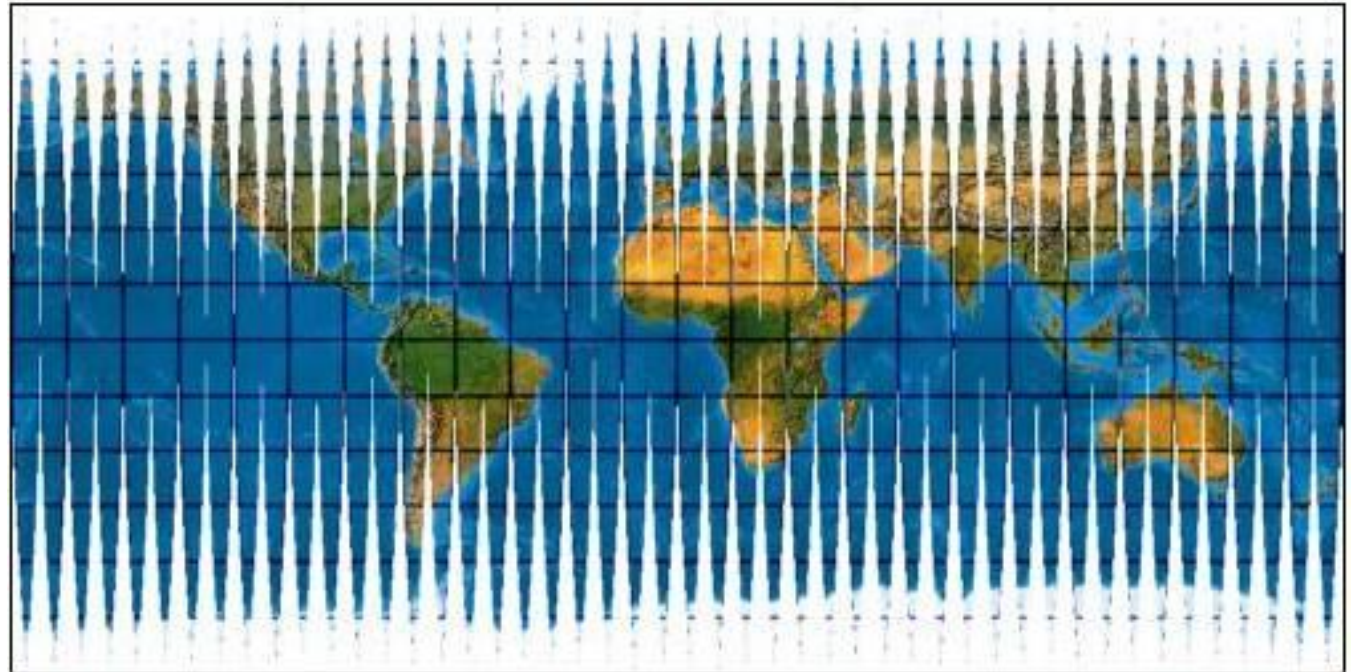
[http://boehmwanderkarten.de/kartographie/is\\_netze\\_globussegmente.html](http://boehmwanderkarten.de/kartographie/is_netze_globussegmente.html)

12 pieces



48 pieces

becoming like  
UTM zones..

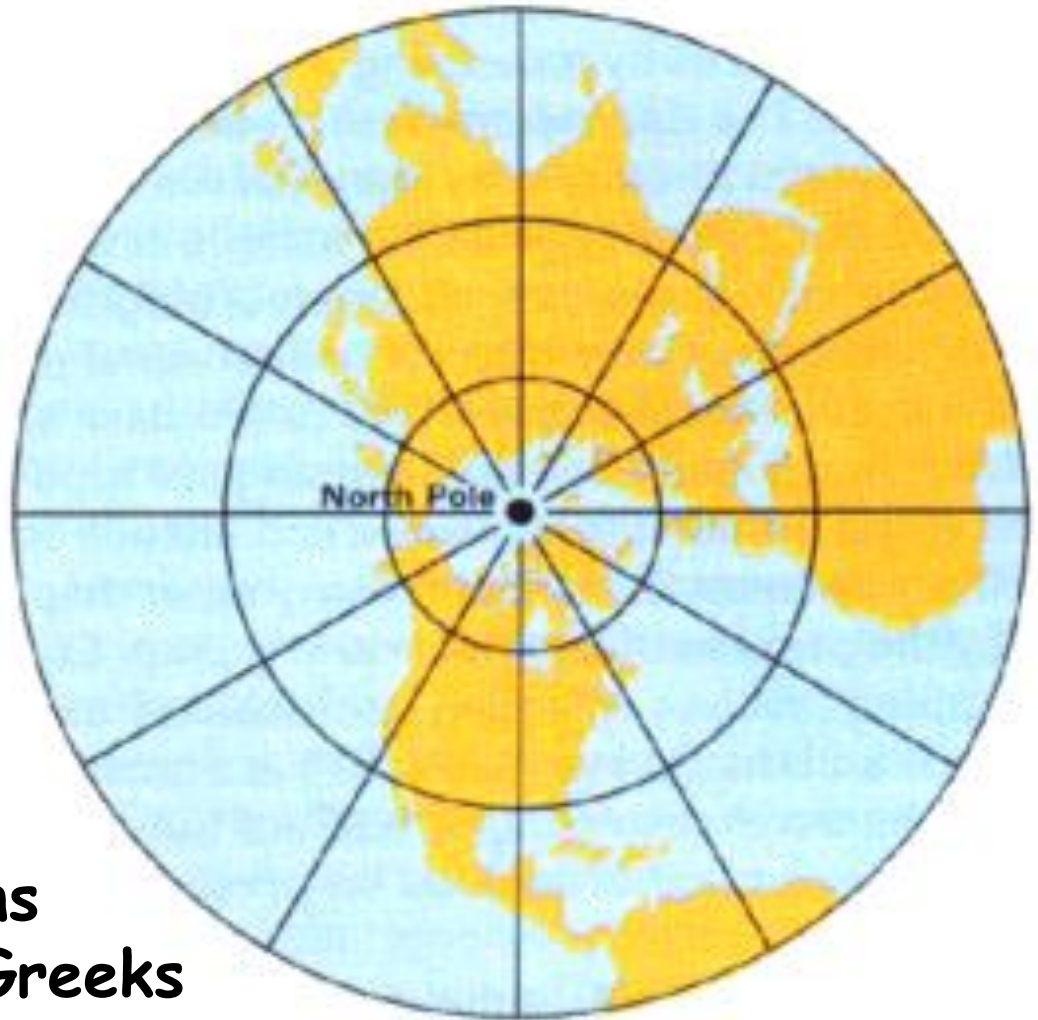
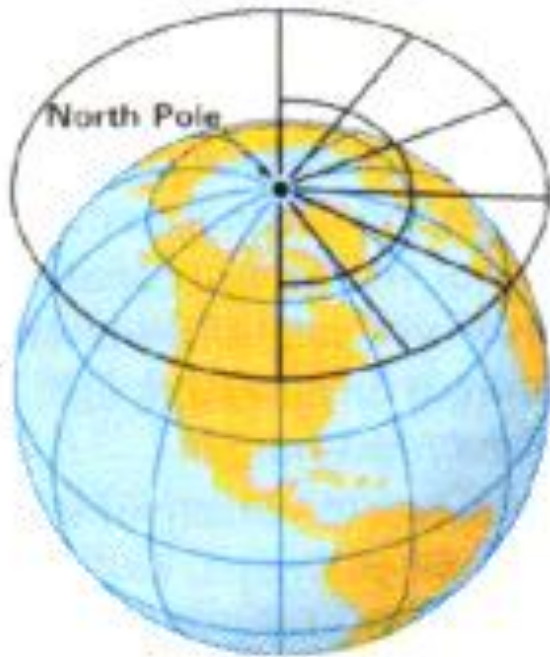




Or they can be made by literally 'projecting' the globe onto a map ...

## Azimuthal (planar) projections

Azimuthal projection



The earliest projections  
were by the 'ancient' Greeks

# Projection Terms

## 1. Scale Factor (SF)

$SF = \text{scale at any location} / \text{divided by the 'principal scale'}$

e.g. if scale = 1:2 million and principal scale = 1:1 million

then SF at that point = 1/2million divided by 1/1million  
= 1/2 (0.5)

e.g. Canadian NTS maps: 'scale factor 0.9996 at UTM zone edge'

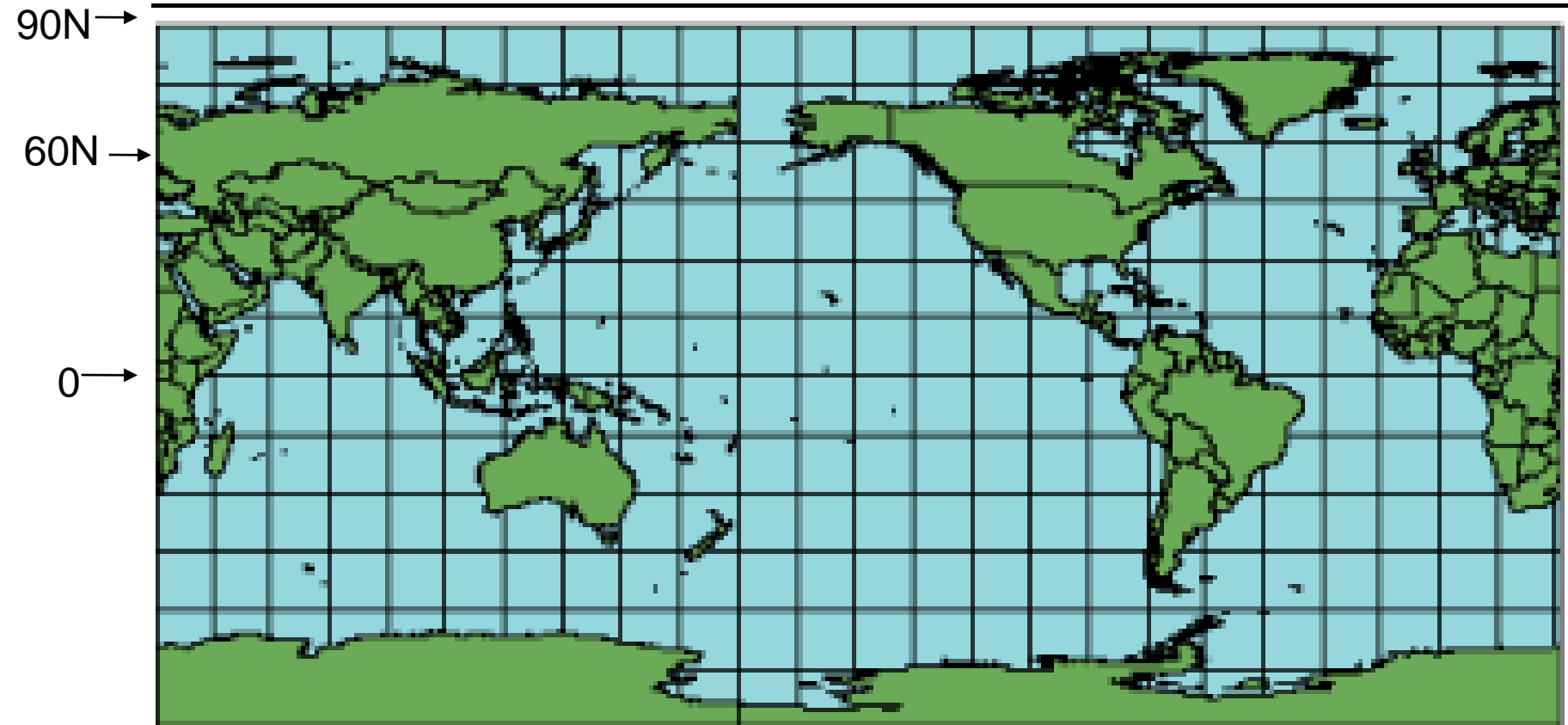
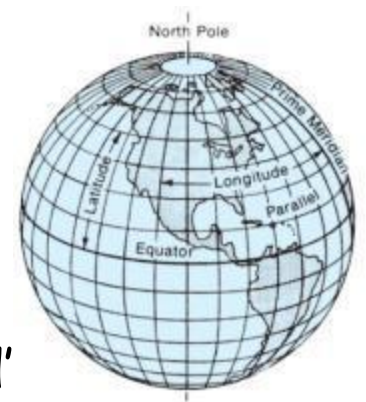


Then Plate Carree projection

e.g. where every line of latitude is equal in length

SF along lines of latitude are: equator  $SF = 1$ ;

at  $60^\circ\text{N/S}$ ,  $SF = 2$       at  $90^\circ$ ,  $SF = \infty$  'undefined'

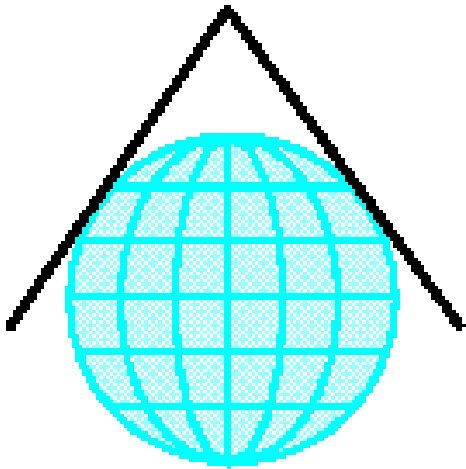


The SF in the other direction (along meridians) is 1

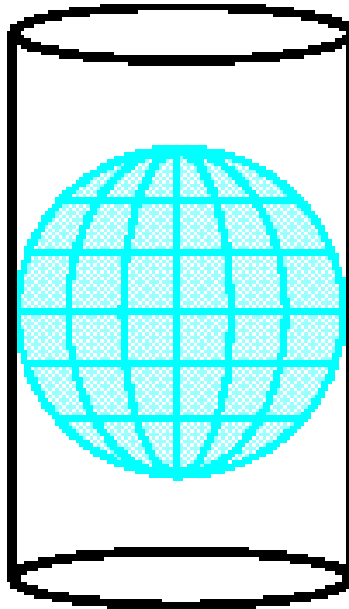
## 2. Developable surfaces:

A two dimensional surface onto which the globe is projected

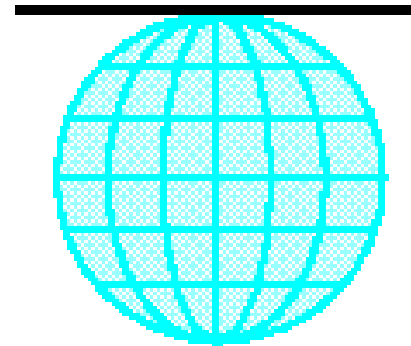
**Conic**



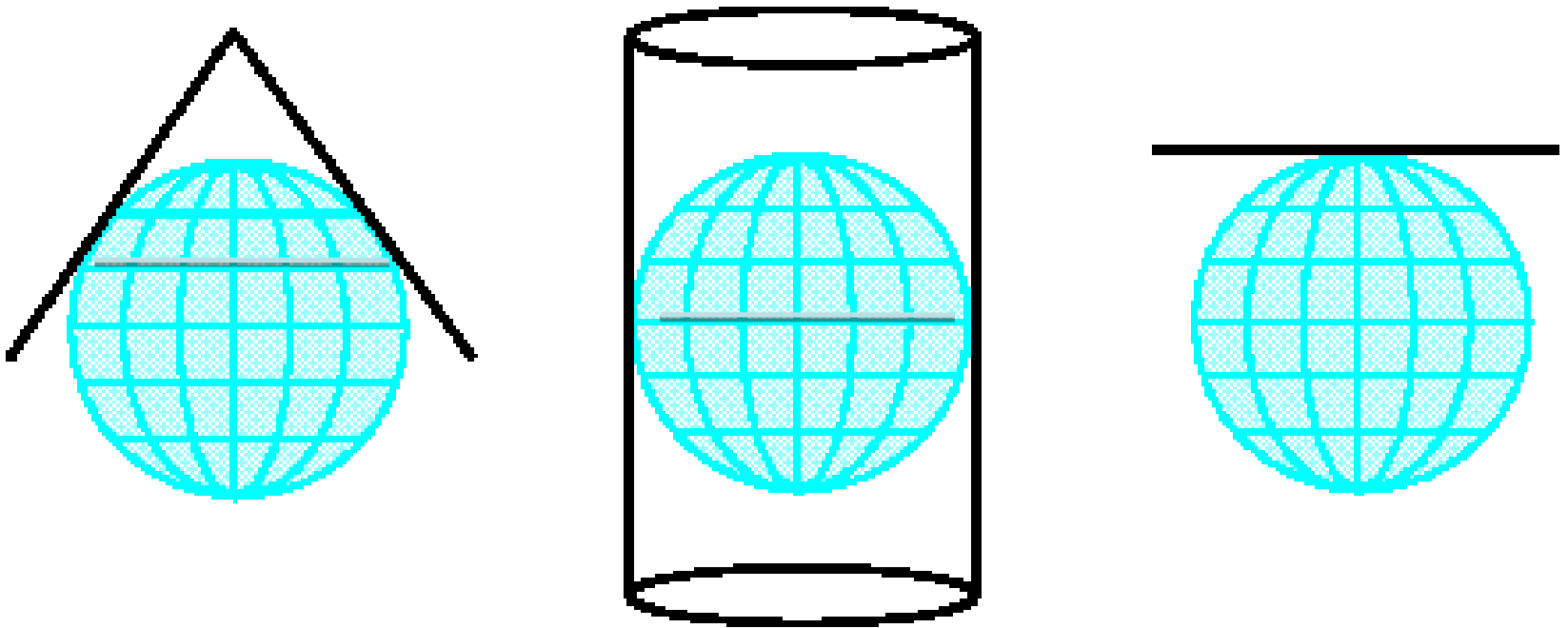
**Cylindrical**



**Azimuthal (planar)**



### 3. Standard Line



Distortion increases with distance between the 'globe' and the surface

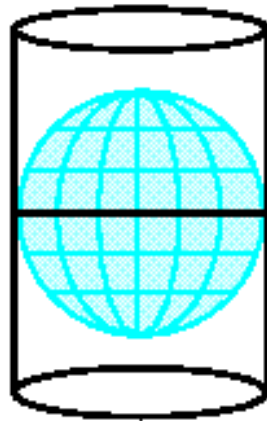
The standard line has a scale factor = 1  
(it is often the line of contact)



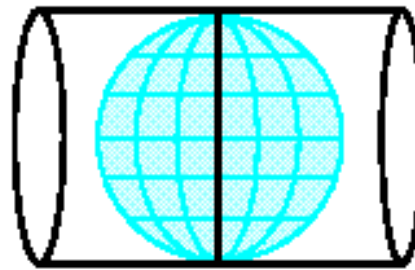
4.

## Drawing of Projection Orientation

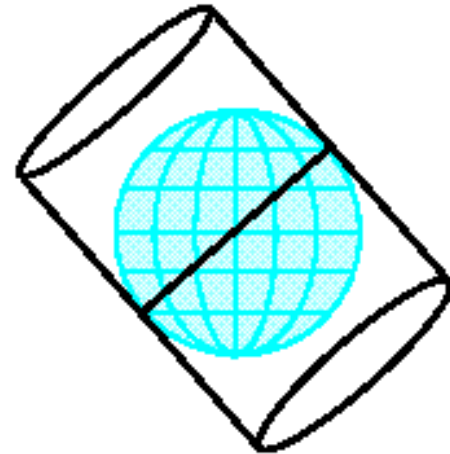
*Cylindrical projections:*



NORMAL



TRANSVERSE



OBLIQUE

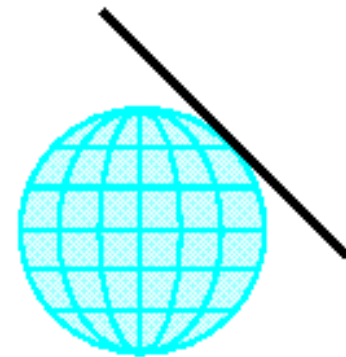
*Planar projections aspects:*



POLAR



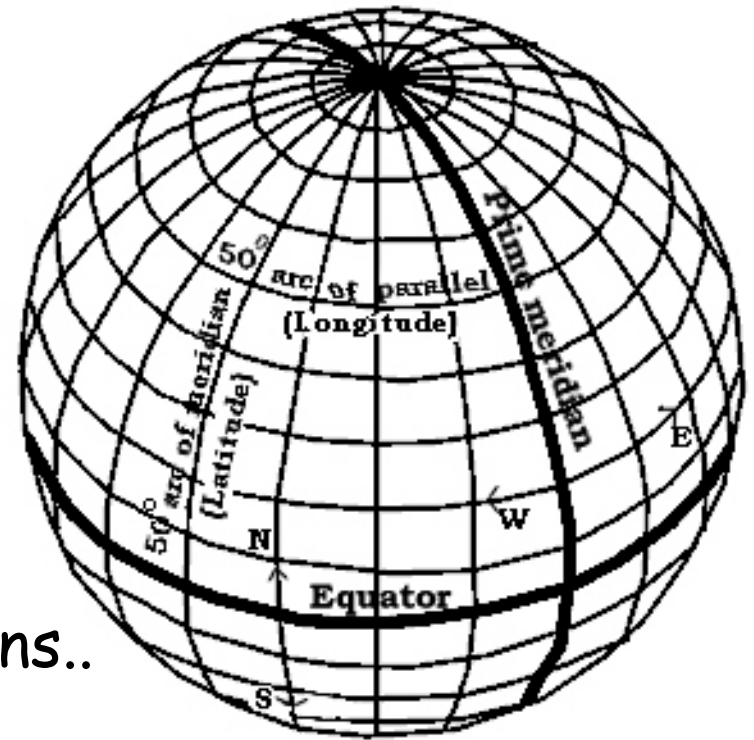
EQUATORIAL



OBLIQUE

## 5. Distortion: .... compare to the graticule:

- Lines of latitude are 'parallel' and evenly spaced.
- Meridians converge at the poles,  
(half the distance at  $60^\circ$  N/S).
- Scale factor is 1 in all directions.  
On the globe, but not any projections..



## **6. Projection properties**

**A projection can preserve**

**➤ Shapes or**

**➤ Areas or**

**➤ Distances or directions (but not all)**

**..... and never more than one of these**



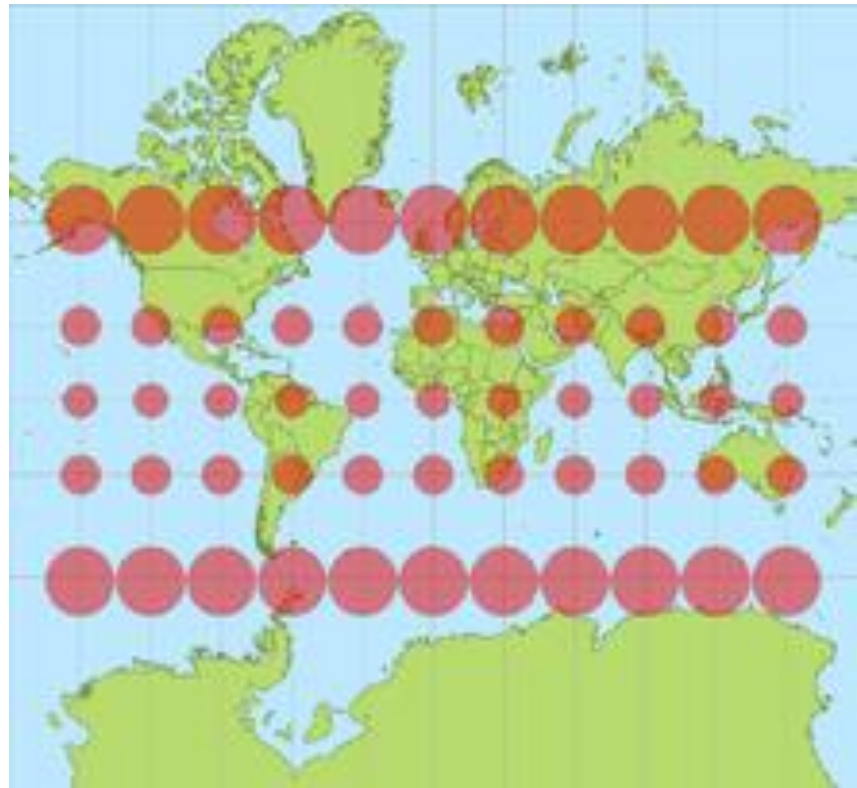
# a. Shape

A projection that maintains shape is '**conformal**'

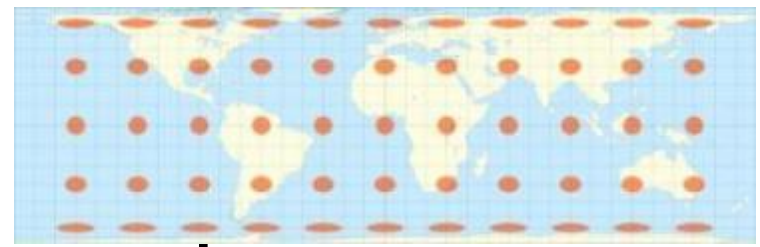
For example a 2x2 square becomes a 1x1 or 4x4 square. Stretching in one direction is **matched** by stretching in the other: that is, the scale factors are equal at a point in the two directions (i.e. there is 'equal-stretching').

**Circles (“Tissot’s Indicatrix”)** ->

These indicate the relative area compared to a standard area at the equator (the standard line)



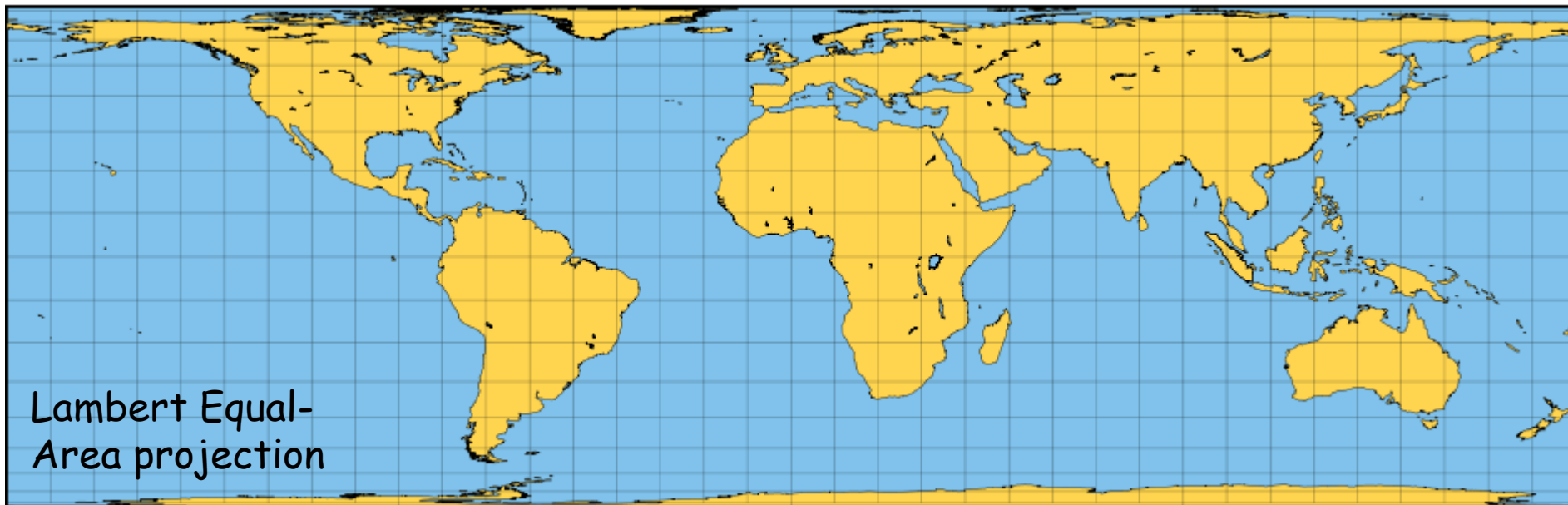
## b. Area



A projection that maintains area is **equal area**

This is achieved by sacrificing **shape**: stretching in one direction to counter for earth curvature must be **compensated** by compression in the other.

In other words, the product of the two Scale factors at any point in the two directions (N-S and E-W) = 1.0 (e.g.  $1 \times 1$ ,  $2 \times 0.5$  etc..)



Hence a projection CANNOT preserve both shape AND area

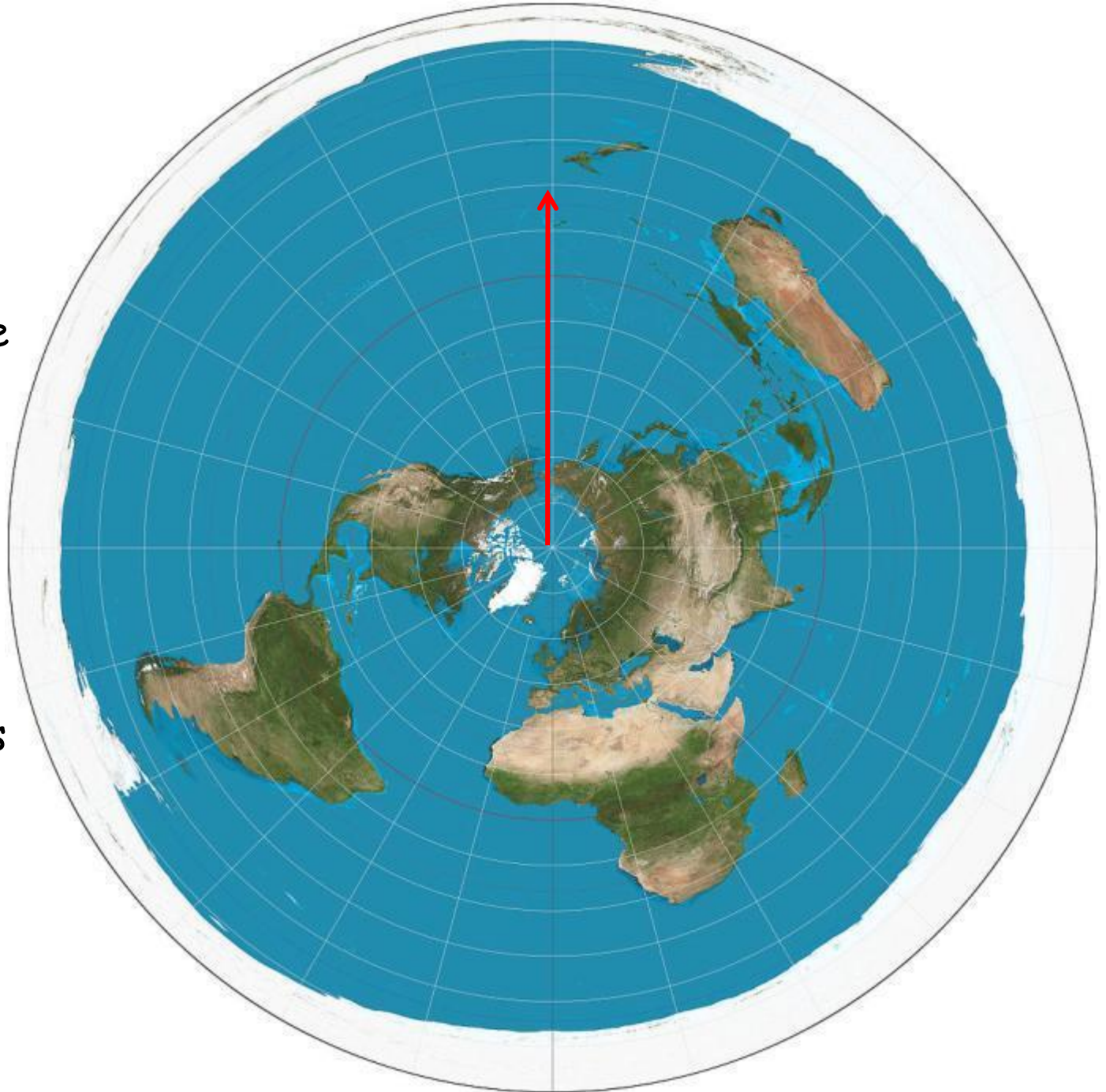
(equal versus compensating stretching)

# Projection properties: c. Distance

Distances can be correct in one direction from a line or in all directions from a point

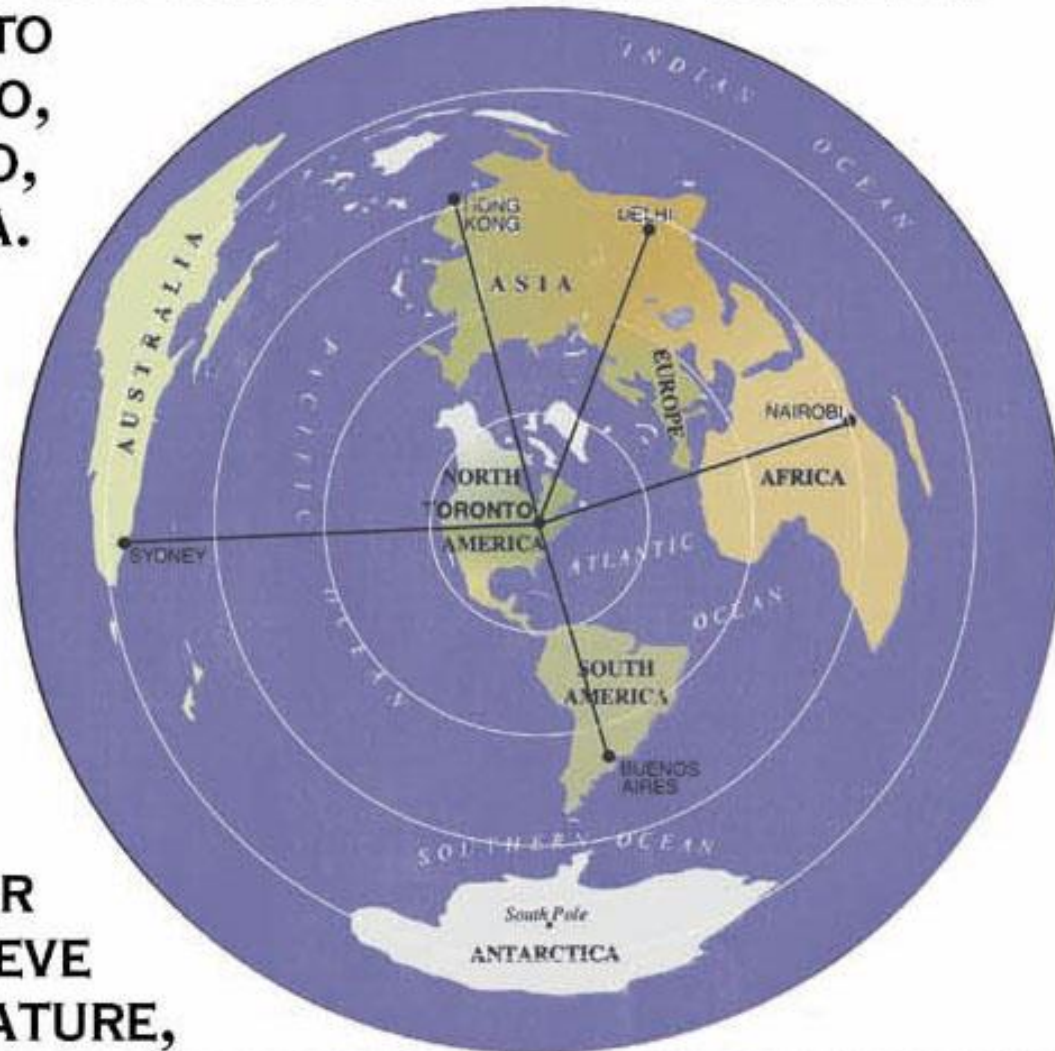
In these cases, the projection is 'equidistant'

## Azimuthal equidistant





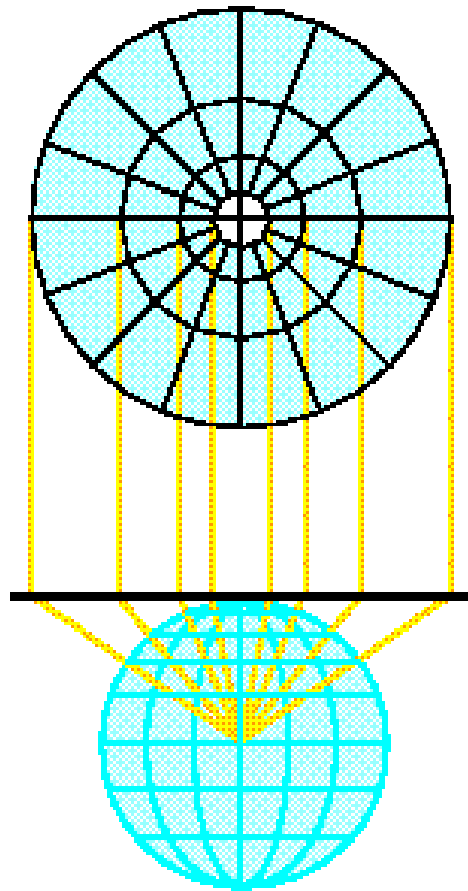
**GUELKE'S EQUIDISTANT PROJECTION TELLS YOU EXACTLY HOW FAR IT IS FROM ANYWHERE ON EARTH TO TORONTO, ONTARIO, CANADA.**



**IN ORDER TO ACHIEVE THIS FEATURE, YOU NEED TO SACRIFICE SOME SHAPES AND SIZES.**

# Projection types (based on the developable surface)

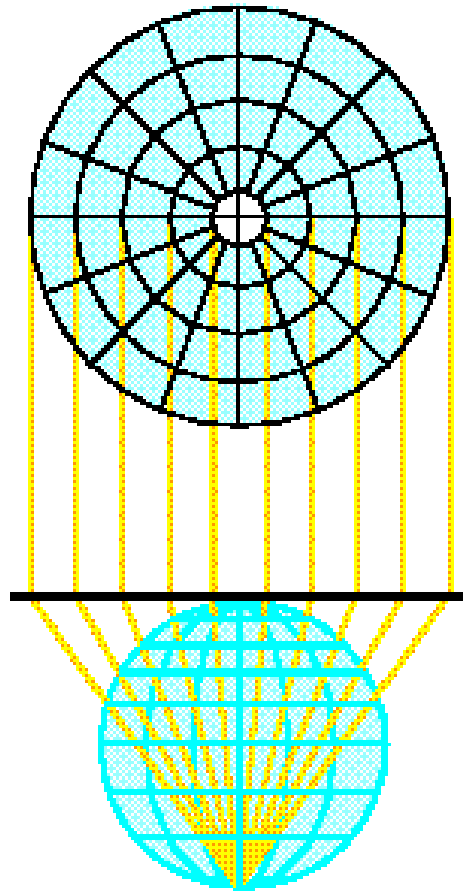
## I. Azimuthal projections



**GNOMONIC**

Great circles= straight lines

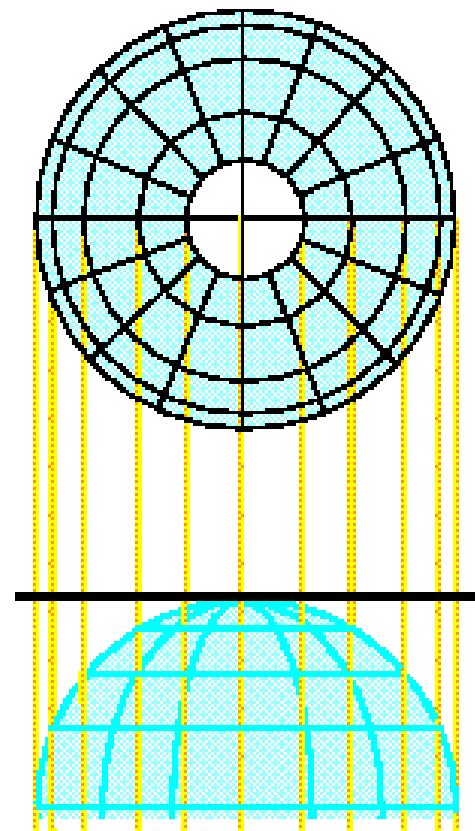
Thales 500BC



**STEREOGRAPHIC**

Conformal (shape)

Ptolemy 125BC



INFINITY

**ORTHOGRAPHIC**

'View from space'

Hipparchus 150BC

# Gnomonic projection

Probably the world's oldest map projection - 6<sup>th</sup> century BC

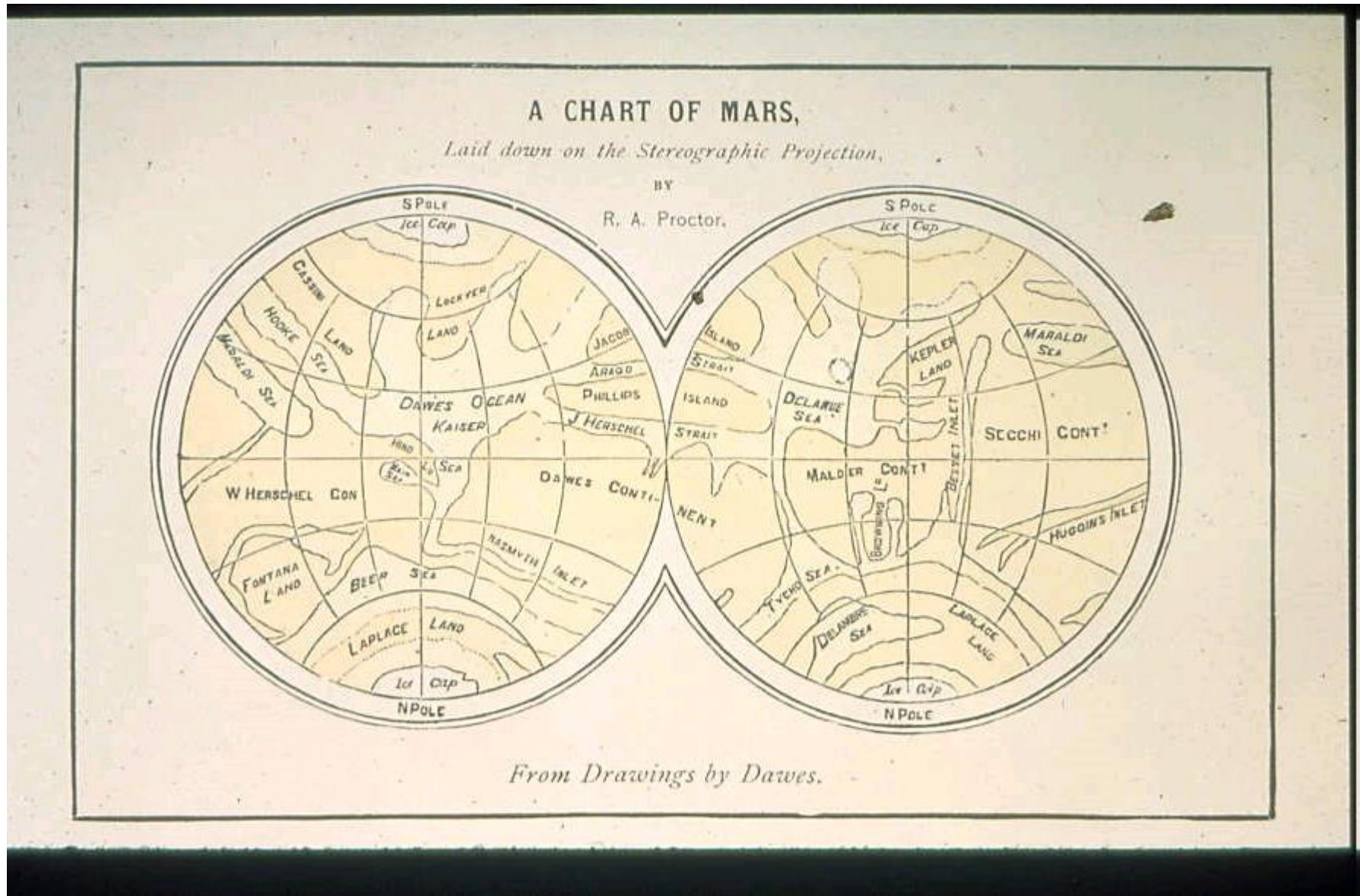
- the only one that shows all great circles as straight lines

(but cannot show one entire hemisphere)





# First map of Mars, 1867- equatorial stereographic



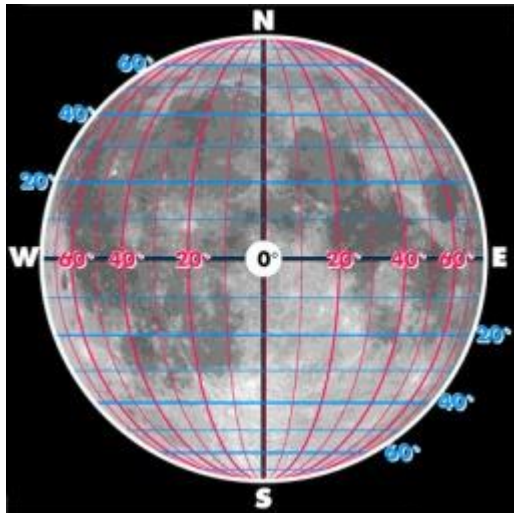
Dark / light = land / 'sea' .. Lines were called 'canals' ... names from geography



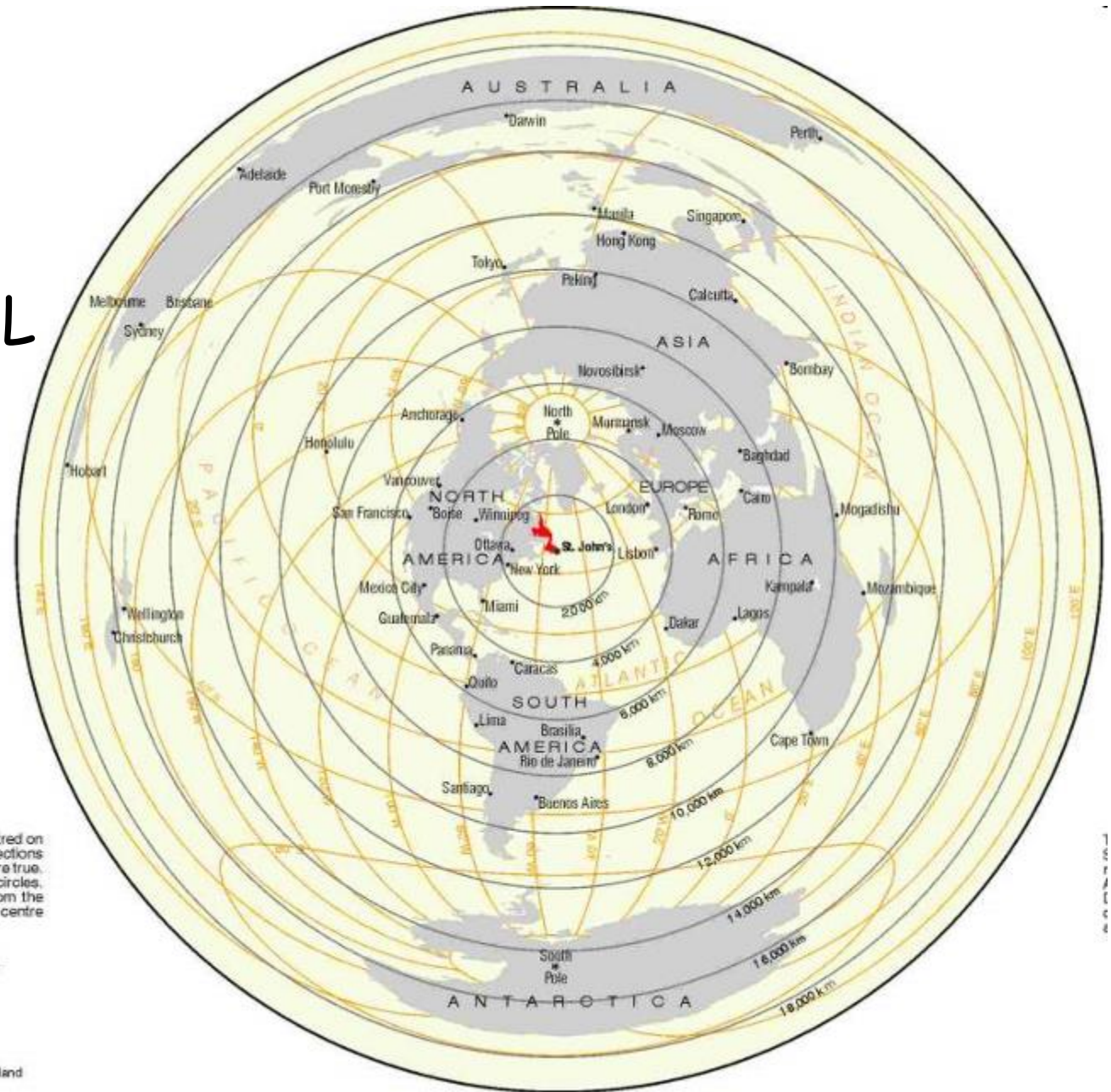
# Photomosaic 1960 (pre-NASA): Orthographic projection

Like Earth,  
longitude zero is  
arbitrary – a  
feature is chosen

The Prime  
Meridian of the  
Moon lies directly  
in the middle of the  
face of the moon  
visible from Earth.

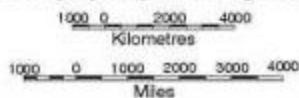


# Azimuthal equidistant centred on St. John's, NL



This is an AZIMUTHAL EQUIDISTANT PROJECTION centred on St. John's, Newfoundland. Only distances and directions measured along straight lines radiating from the centre are true. All straight lines passing through St. John's are great circles. Deformation of the earth surface increases outward from the centre and measurements taken other than through the centre are inaccurate.

SCALE along any straight line through the centre



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St. John's, Newfoundland, CANADA



## II. Cylindrical Projections 16<sup>th</sup> century

for early world maps

- They fill a rectangular shape

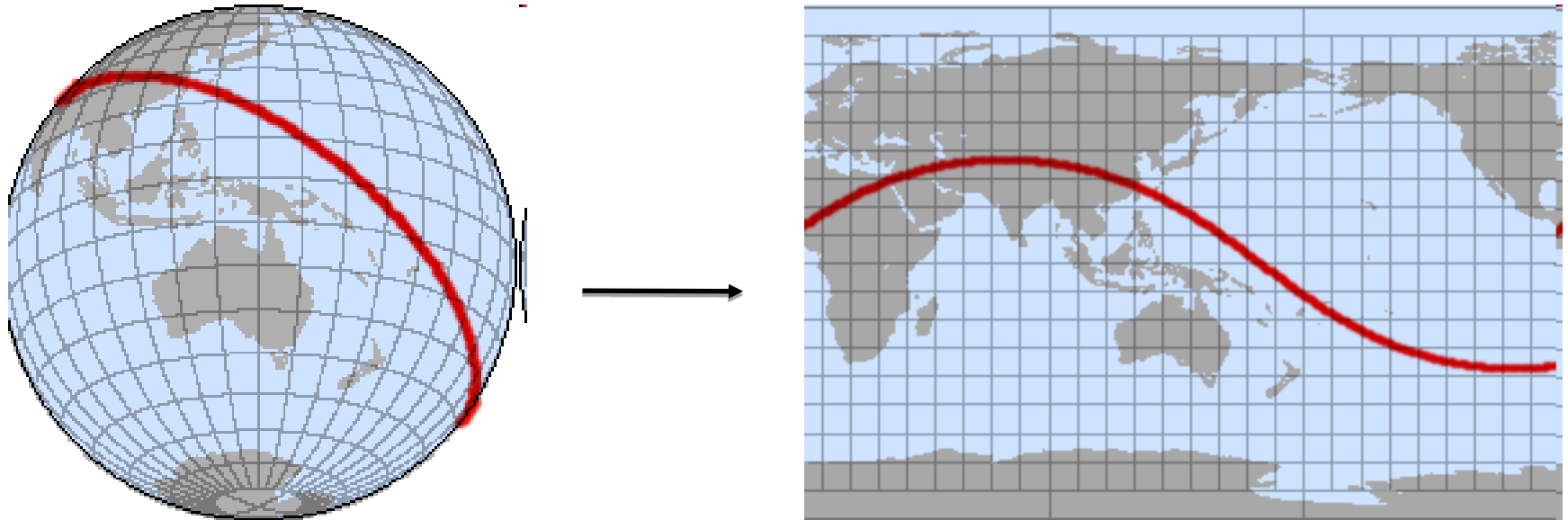


'Great circles' are straight lines in 3D space

e.g. meridians, equator, flight lines ... but not any other parallels

Of all projections, only the **gnomonic** retains all great circles as straight lines

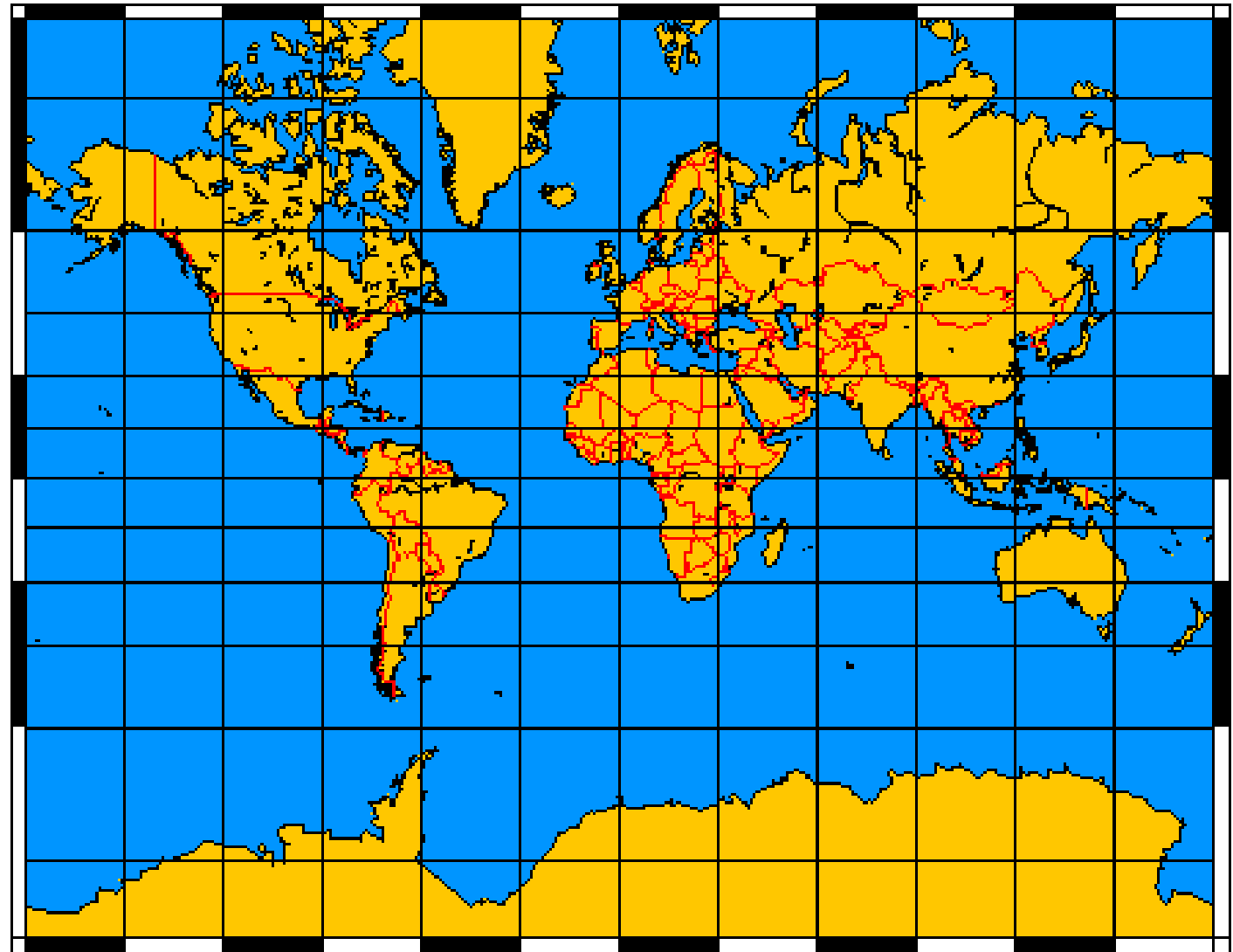
e.g. Equidistant rectangular projection





# Mercator's Projection 1569 - conformal = shape-preserving

180° -150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150° 180°



180° -150° -120° -90° -60° -30° 0° 30° 60° 90° 120° 150° 180°

km

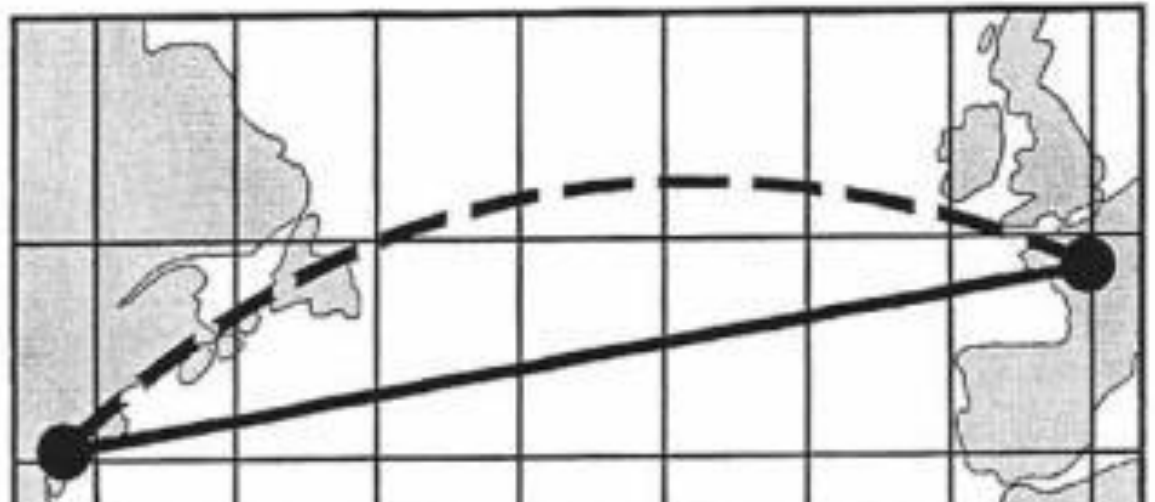
0 1000 2000

0 1000 2000

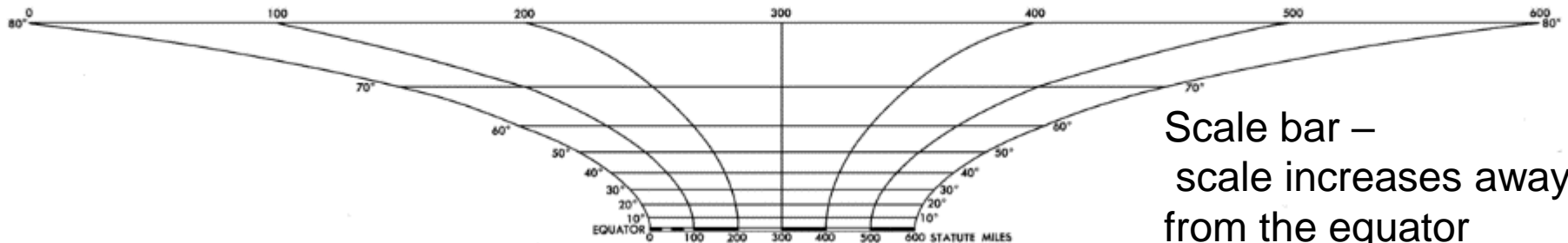
All 'straight lines' have constant compass bearings

= Rhumb lines (but the dashed line is the shortest route)

It became known as the "Navigator's friend"

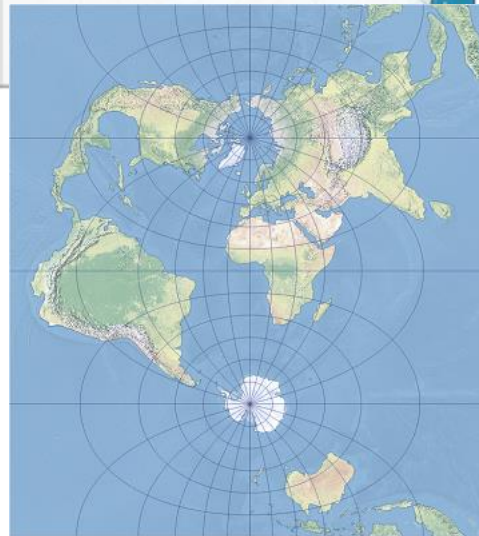
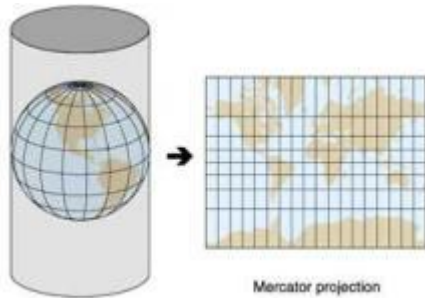
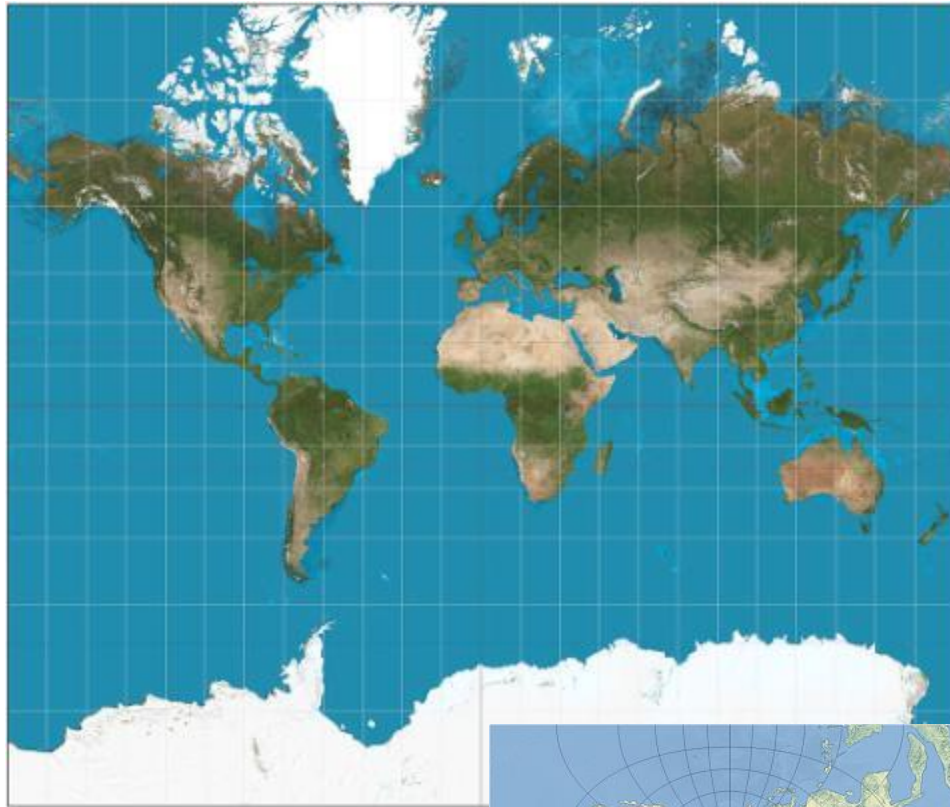


MERCATOR PROJECTION  
Scale 1:14,000,000  
One inch = 221 Statute Miles at the Equator



Scale bar –  
scale increases away  
from the equator

## Mercator (1569) 'normal'

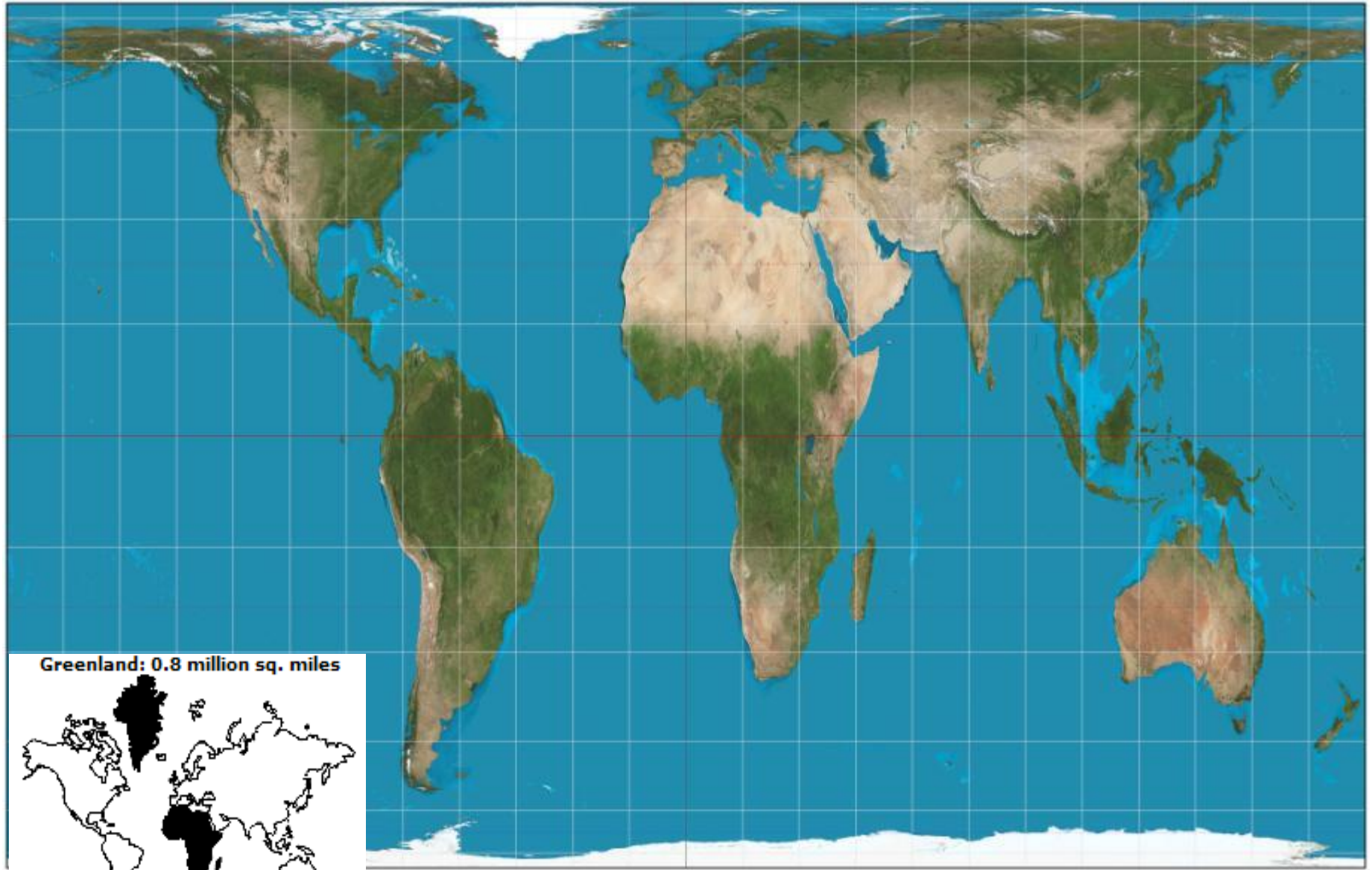


## Transverse Mercator (1772)



- The TM projection is the basis for the (Universal) UTM system
- Minimal distortion at a chosen longitude
- Adopted by Canada post WWII,
  - SYSTEM of 60 TM projections

# (1885) Gall-Peters projection (1972) – equal-area



Greenland: 0.8 million sq. miles



Africa: 11.6 million sq. miles

Corrects for area distortion, but note the impact on shape



### III. Conic projections - 18<sup>th</sup> century

The cone opens along a line of longitude

Latitude lines are curved sections of a circle

Longitude like 'spokes' of a wheel



# CONIC projections

(e.g. Albers)

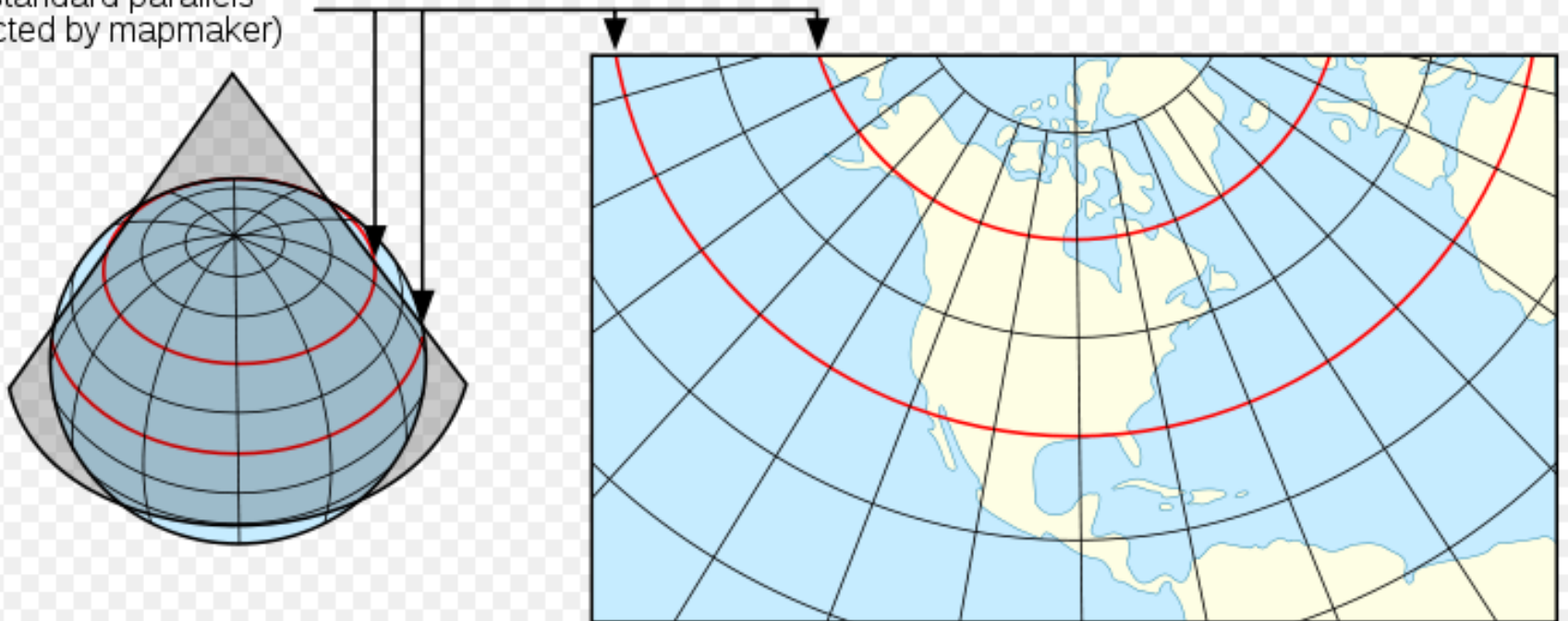
... are all 'normal orientation'

They can be varied by :

A: angle of the cone

B: 1 or 2 standard lines

Two standard parallels  
(selected by mapmaker)



# IV. Pseudo-cylindrical Projections

-19th century (and 20th) – mostly equal-area

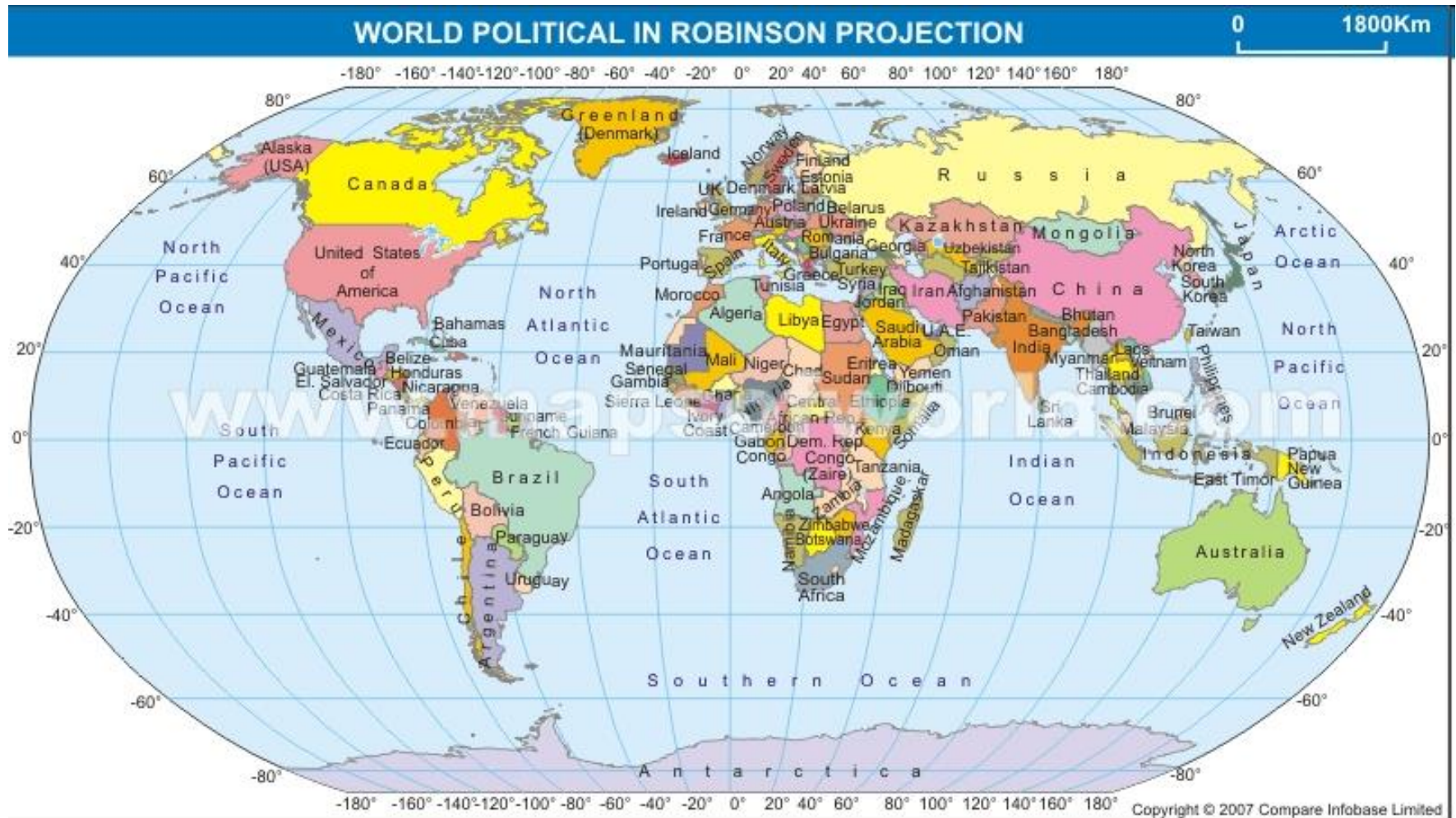
These are geometrically constructed. The parallels are generally equally spaced but are made more proportional to their real length to minimize distortion.



Mollweide, 1805

# Robinson projection (1963) adopted by National Geographic 1988

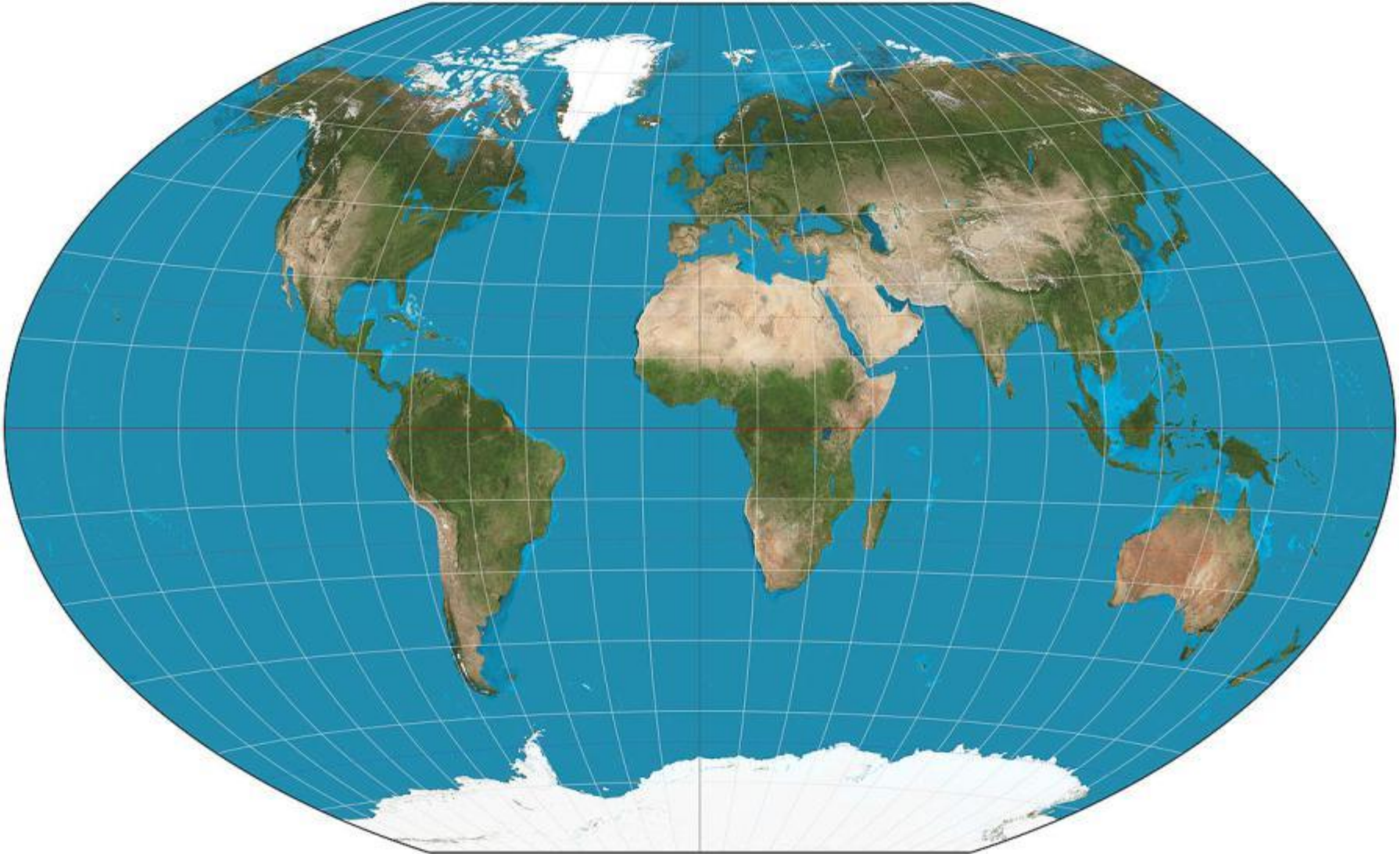
Poles drawn as lines to create better shapes



<http://www.mapsofworld.com/projection-maps/robinson/world-political-light.html>



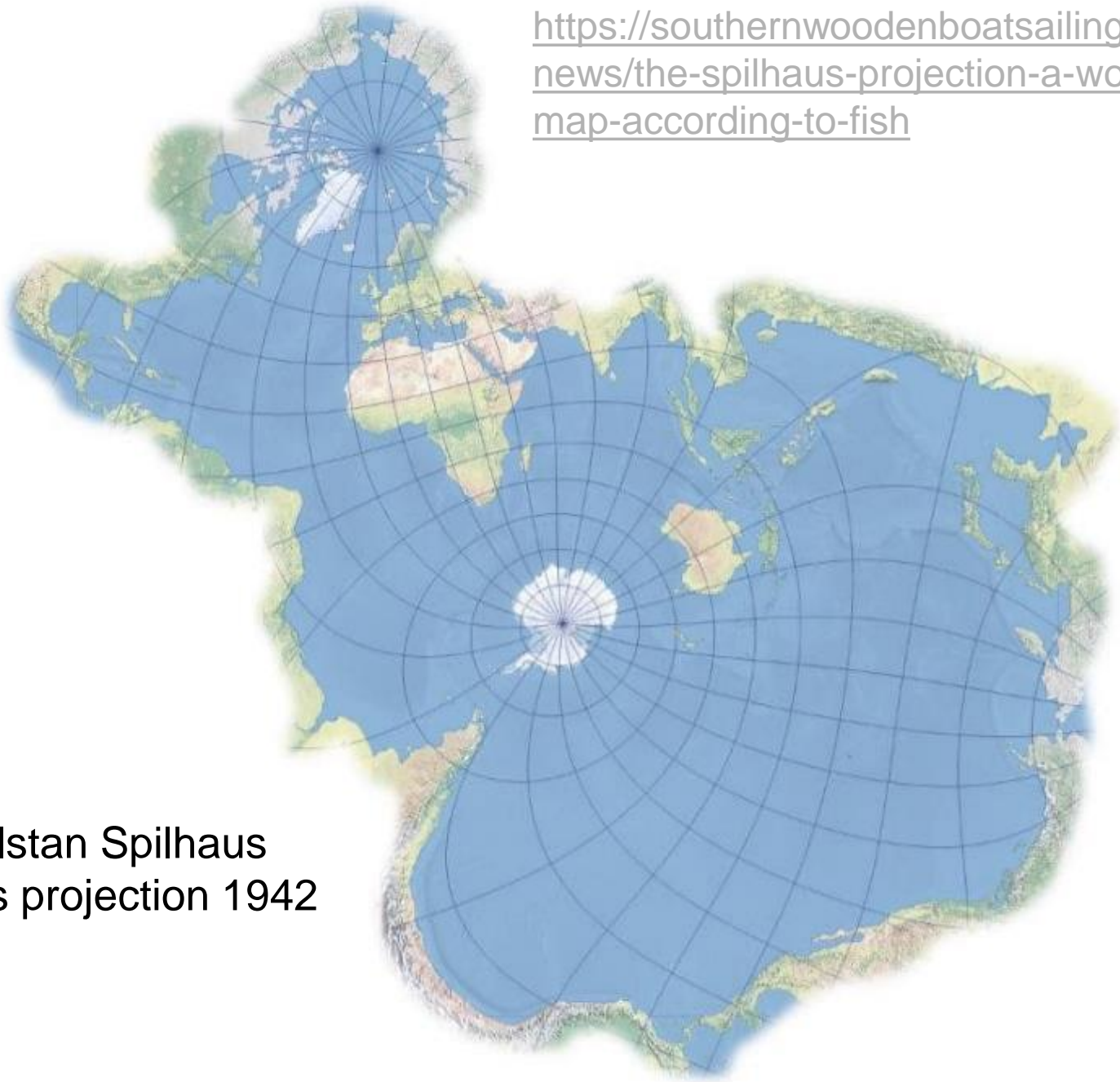
The **Winkel tripel (Winkel III)** by Oswald Winkel in 1921, adopted by National Geographic in 1998. The name *Tripel* refers to Winkel's goal of minimizing three kinds of distortion: area, direction (shape), and distance.



# IVa. Interrupted pseudo-cylindrical (e.g. Goode's, 1923)



<https://southernwoodenboatsailing.com/news/the-spilhaus-projection-a-world-map-according-to-fish>



Dr. Athelstan Spilhaus  
Spilhaus projection 1942



# Projections websites:

<https://gisgeography.com/map-projections/>

[https://en.wikipedia.org/wiki/List\\_of\\_map\\_projections](https://en.wikipedia.org/wiki/List_of_map_projections)



Map humour: The Moocator Projection



Cordiform projection

**Friday:  
projections  
in GIS / the  
digital world**

**Quiz3 to follow:**