A Simple VLBI Analysis

Geir Arne Hjelle

July 12, 2016

Part I

Background

Who am I?

- Geir Arne Hjelle
- Ph.D. in Complex Analysis from Norwegian University of Science and Technology (NTNU) in Trondheim, Norway
- Post.doc at Washington University in St. Louis
- Currently working as a space geodesy researcher at the Norwegian Mapping Authority (Kartverket)

Who am I?

- Geir Arne Hjelle
- Ph.D. in Complex Analysis from Norwegian University of Science and Technology (NTNU) in Trondheim, Norway
- Post.doc at Washington University in St. Louis
- Currently working as a space geodesy researcher at the Norwegian Mapping Authority (Kartverket)

At Kartverket I work in a small team where we are developing both mathematical and physical models for better positioning, as well as developing software to carry out the analysis.

What are we doing?

We seek to contribute to *better global reference frames*.

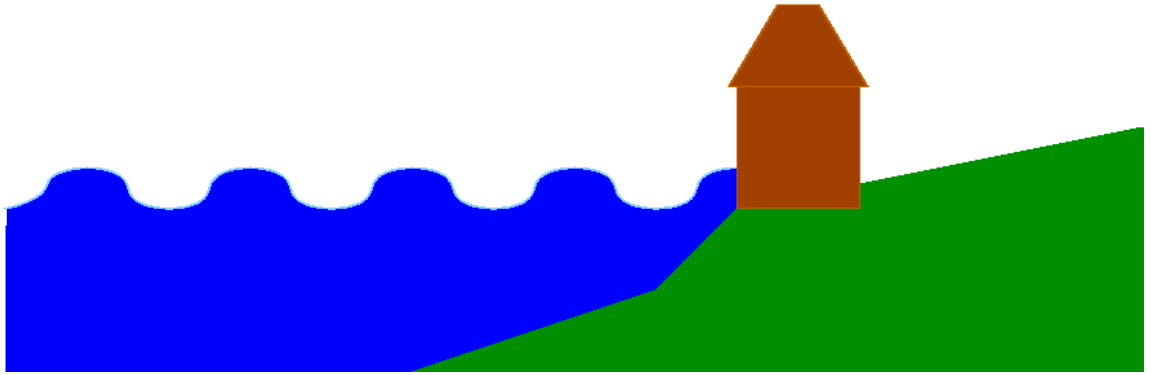
What are we doing?

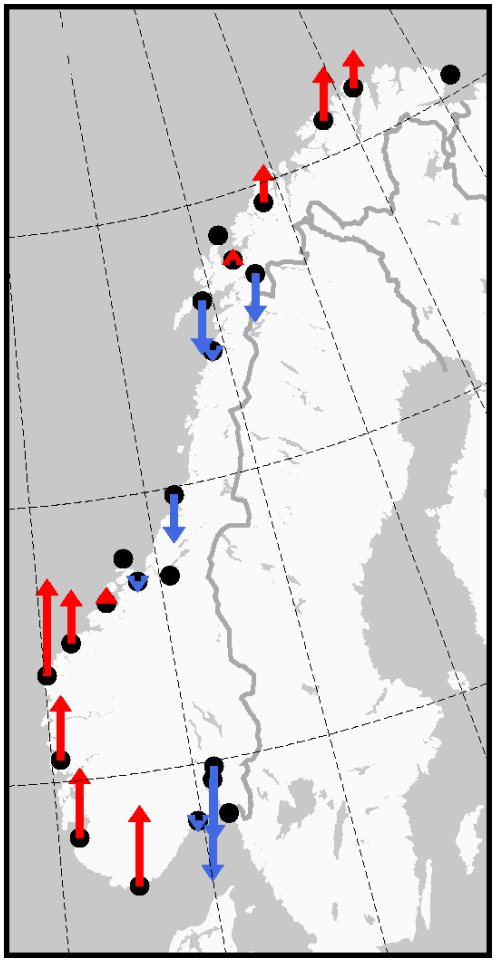
We seek to contribute to *better global reference frames*.

A reference frame is simply put a coordinate system. A global reference frame is necessary in order to compare positions at different places and at different times.

Example – Measuring sea level

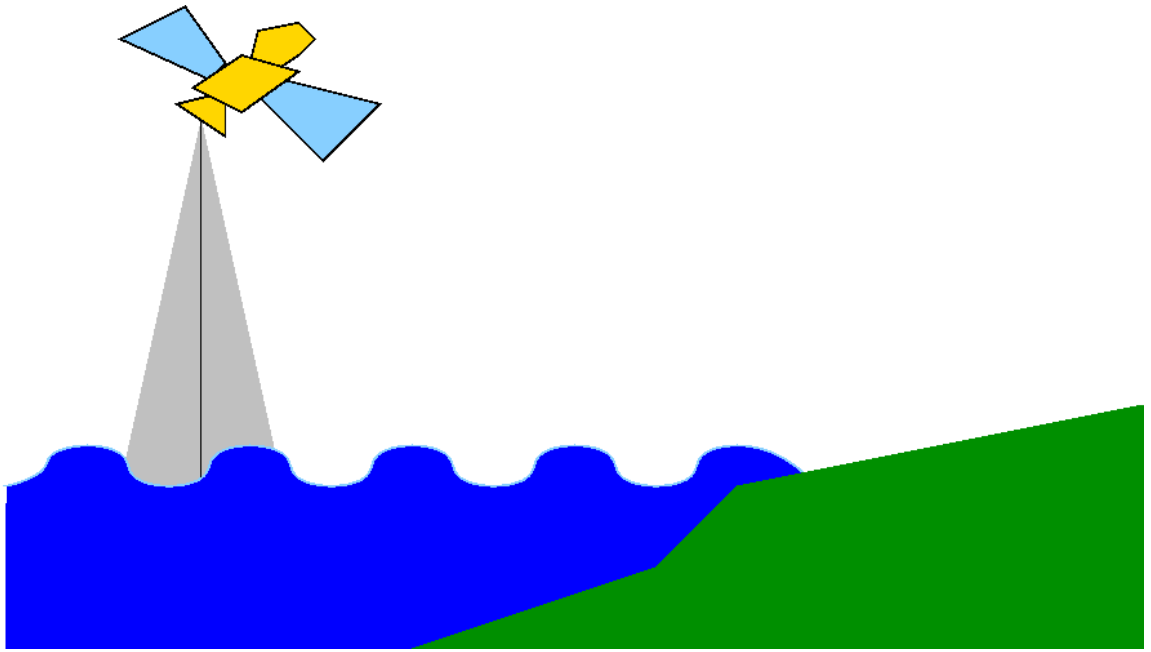
Traditionally sea level has been measured at fixed tide gauges.

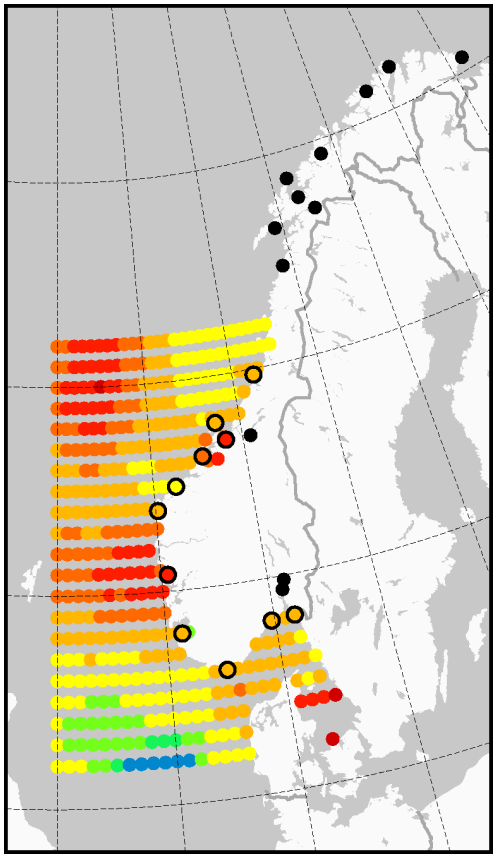




Example – Measuring sea level

Traditionally sea level has been measured at fixed tide gauges. Recently we can also measure sea level using altimery satellites.





Reference frames

Global reference frames are used to compare positions at different places and at different times.

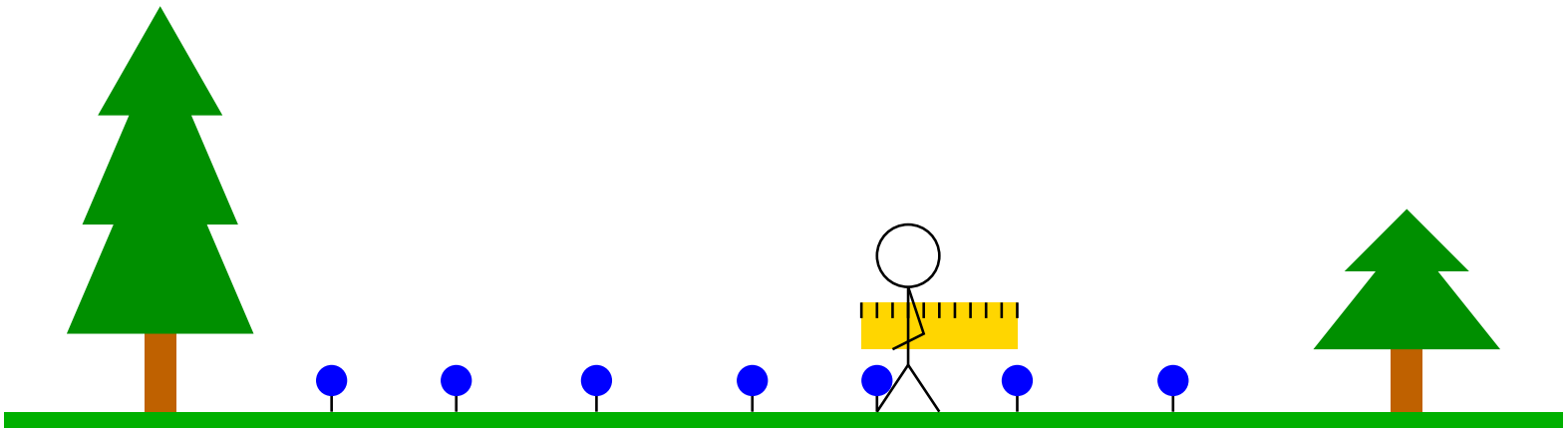
Reference frames

Global reference frames are used to compare positions at different places and at different times.

Reference frames

Global reference frames are used to compare positions at different places and at different times.

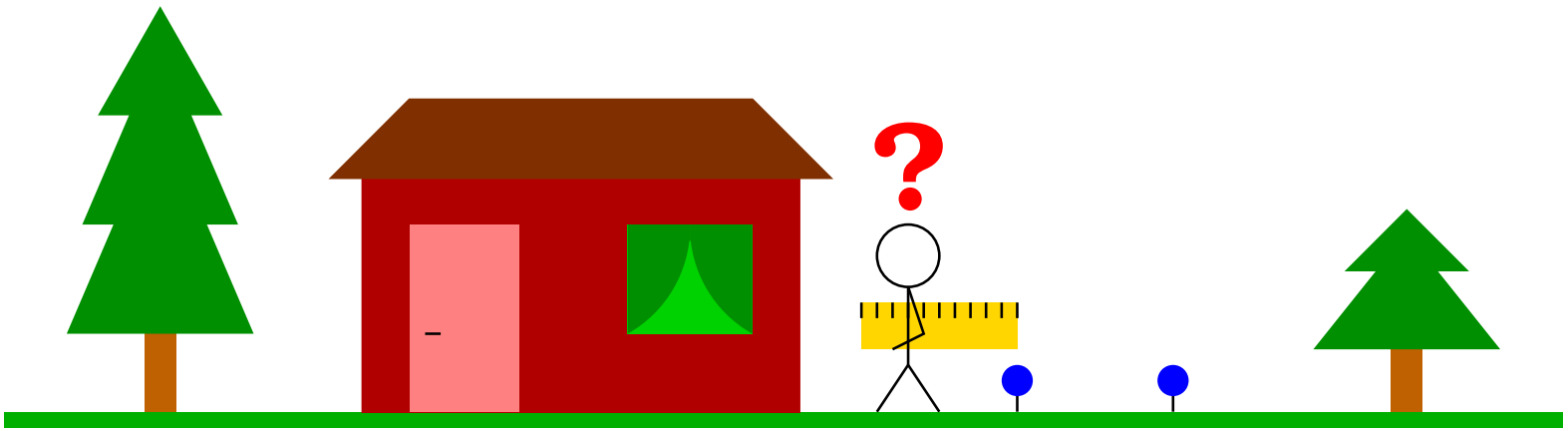
- The reference frames consists of *reference points* other points can be measured against.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

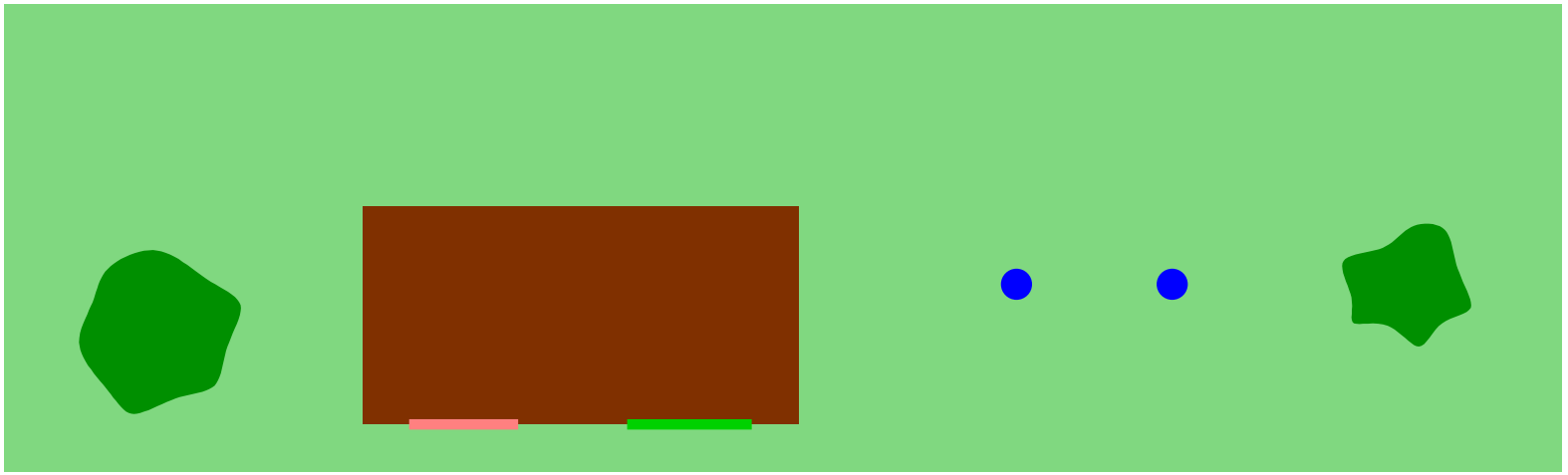
- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

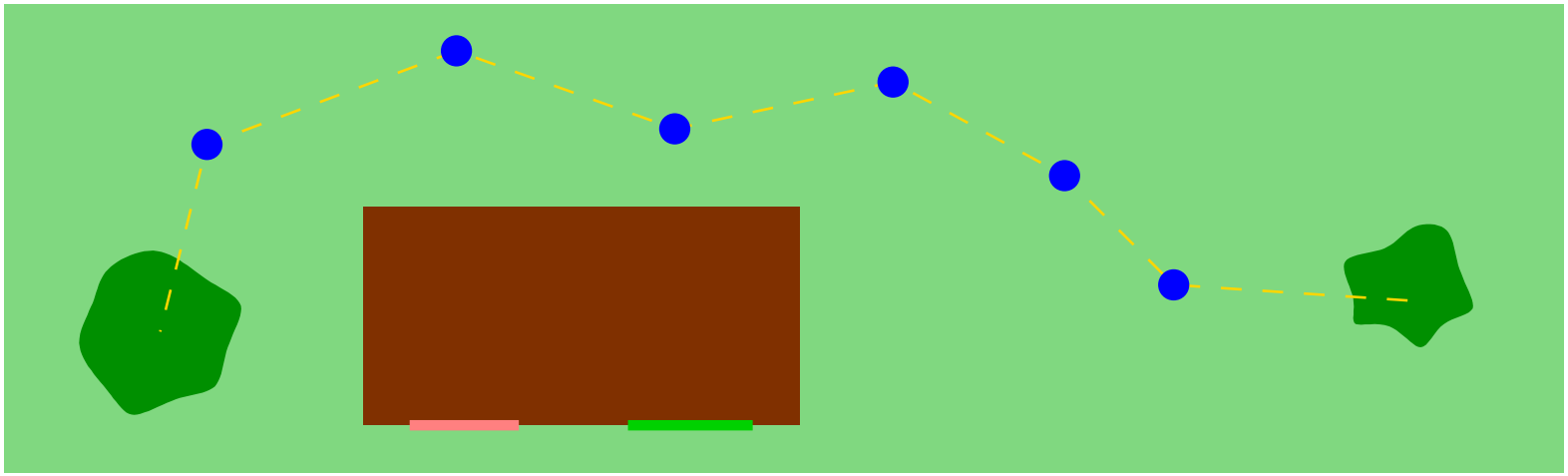
- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

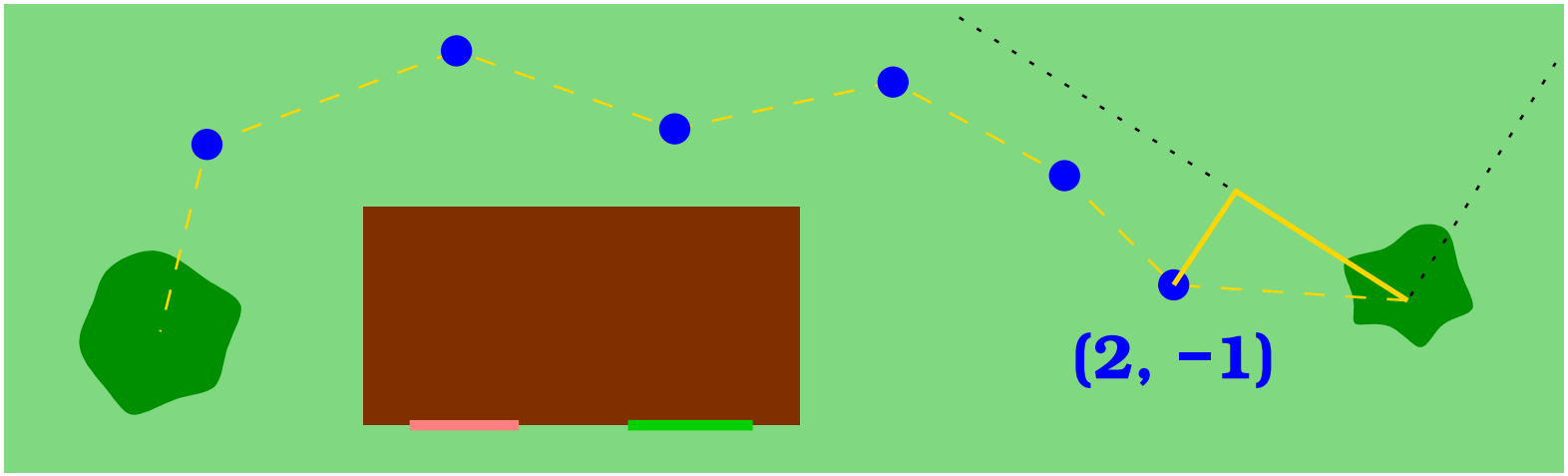
- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

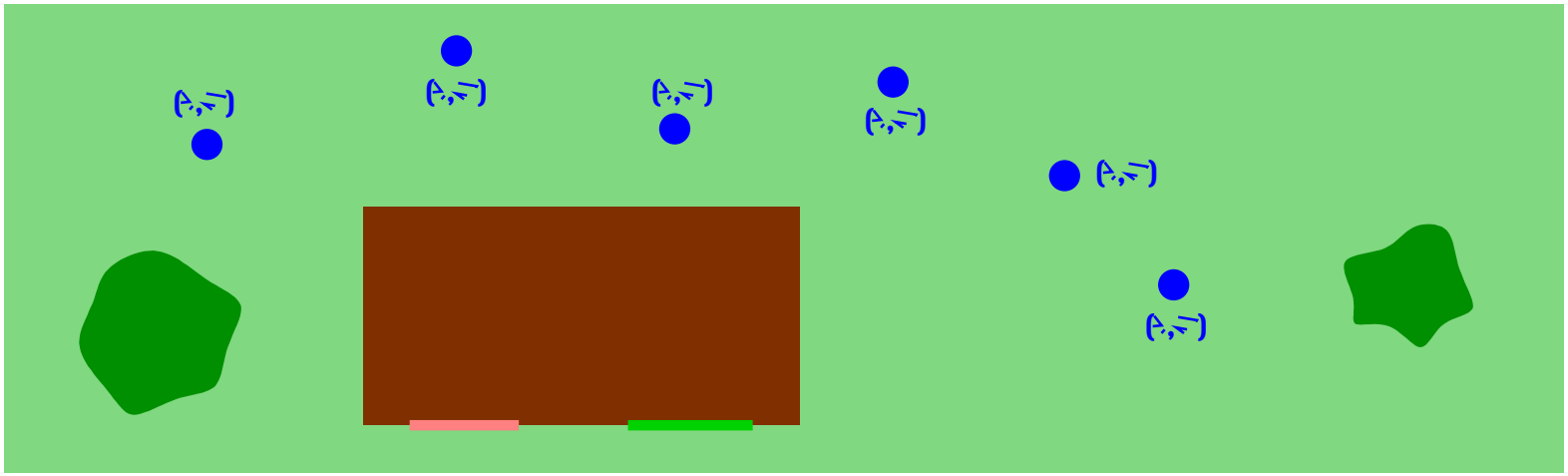
- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.
- Using calculations we can give each point a coordinate.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.
- Using calculations we can give each point a coordinate.

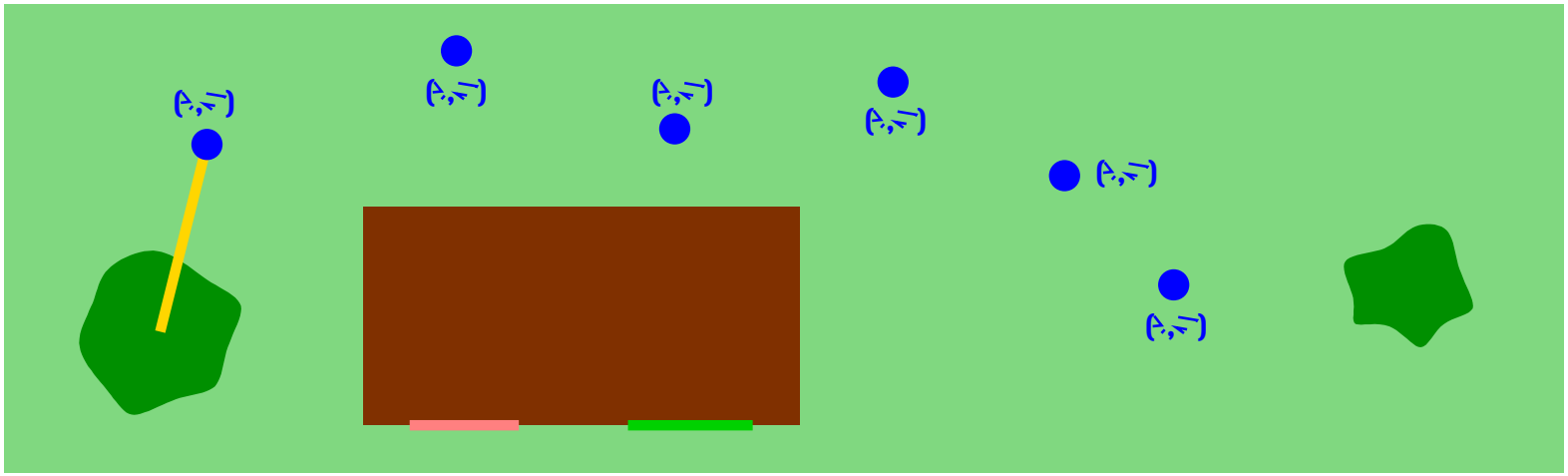


Kartverket

Reference frames

Global reference frames are used to compare positions at different places and at different times.

- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.
- Using calculations we can give each point a coordinate.
- The coordinates can be used to find the total distance.

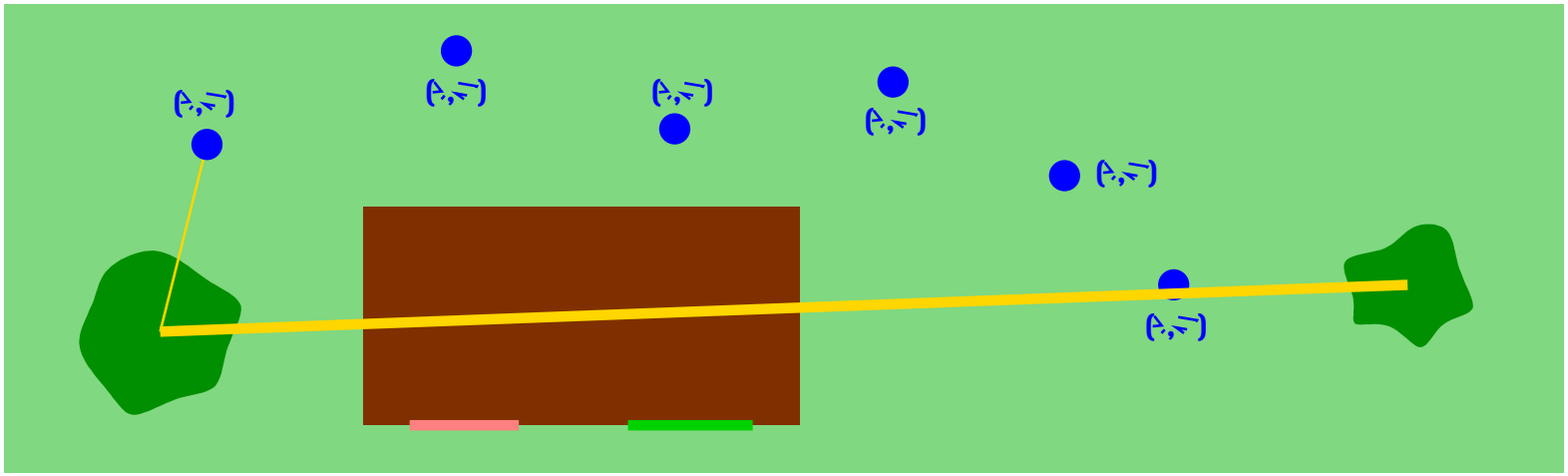


Kartverket

Reference frames

Global reference frames are used to compare positions at different places and at different times.

- The reference frames consists of *reference points* other points can be measured against.
- One challenge is that we can not always simply measure in a straight line.
- Using calculations we can give each point a coordinate.
- The coordinates can be used to find the total distance.



Kartverket

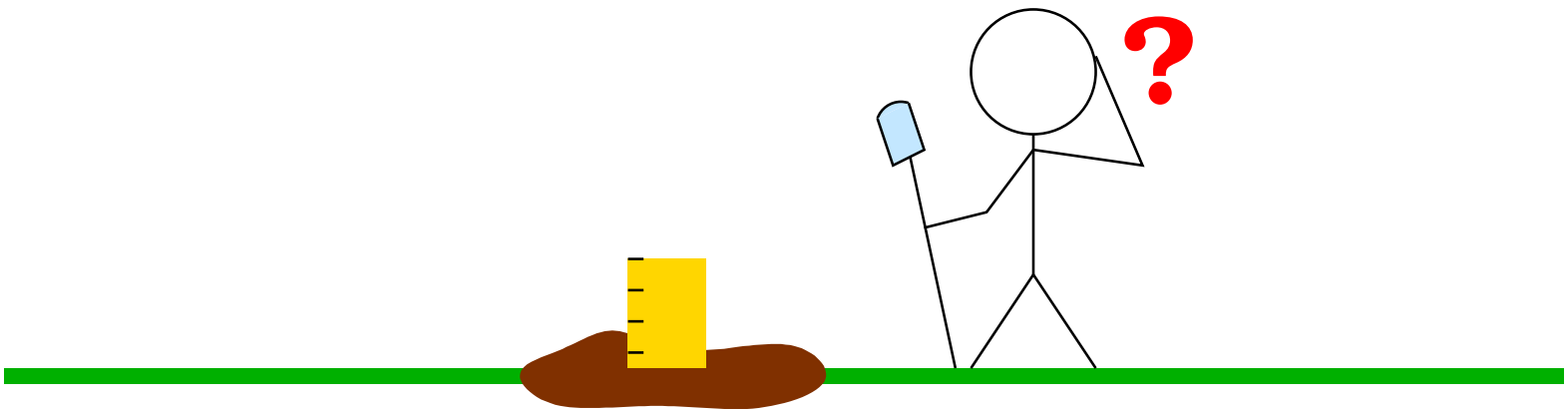
Reference frames

One challenge with global reference frames is that we choose the origin as the center of the earth.

Reference frames

One challenge with global reference frames is that we choose the origin as the center of the earth.

- We can not measure the reference points directly.



Reference frames

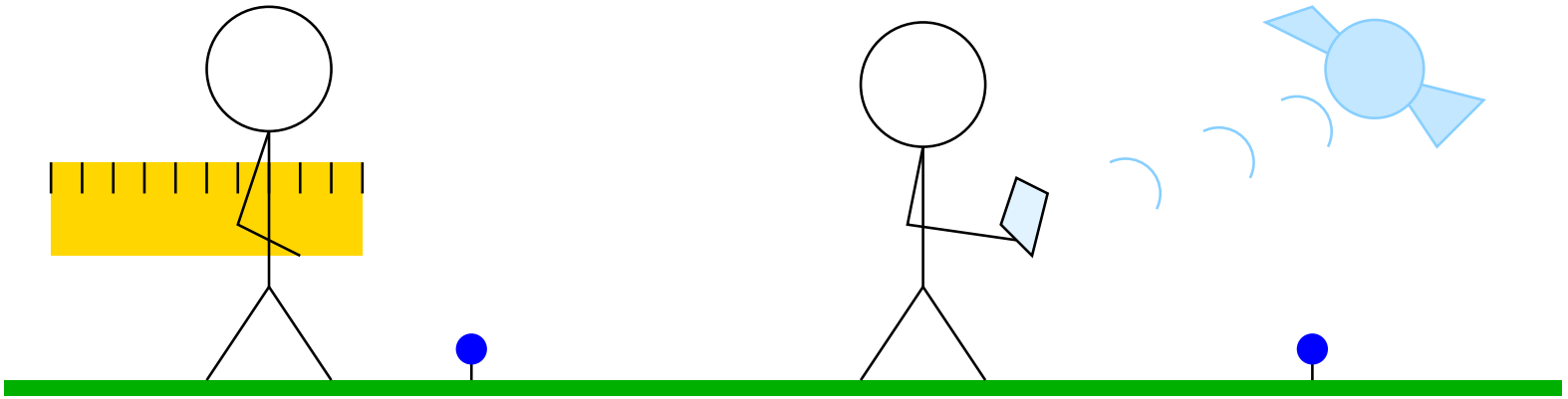
One challenge with global reference frames is that we choose the origin as the center of the earth.

- We can not measure the reference points directly.
- Instead we *guess* at the coordinates of the reference points, and correct them later through indirect measures.
  - That is, we *estimate* the position.

Reference frames

One challenge with global reference frames is that we choose the origin as the center of the earth.

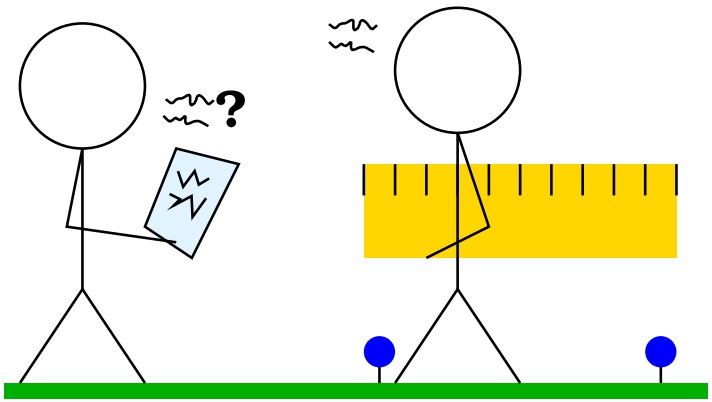
- We can not measure the reference points directly.
- Instead we *guess* at the coordinates of the reference points, and correct them later through indirect measures.
  - That is, we *estimate* the position.
- For the best possible corrections we *combine* different measuring techniques.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

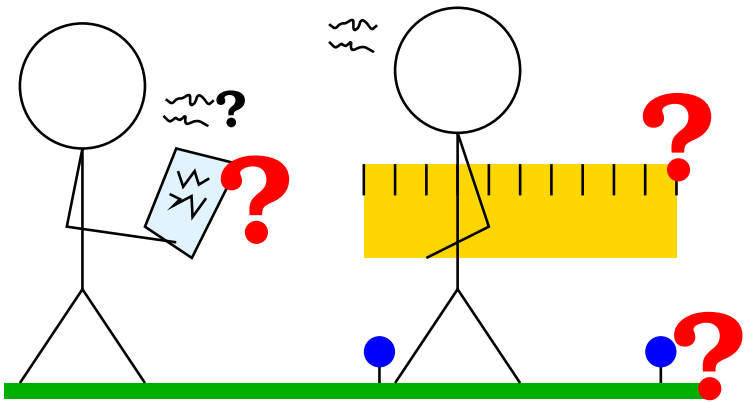
- Repeated measurements can give different results.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

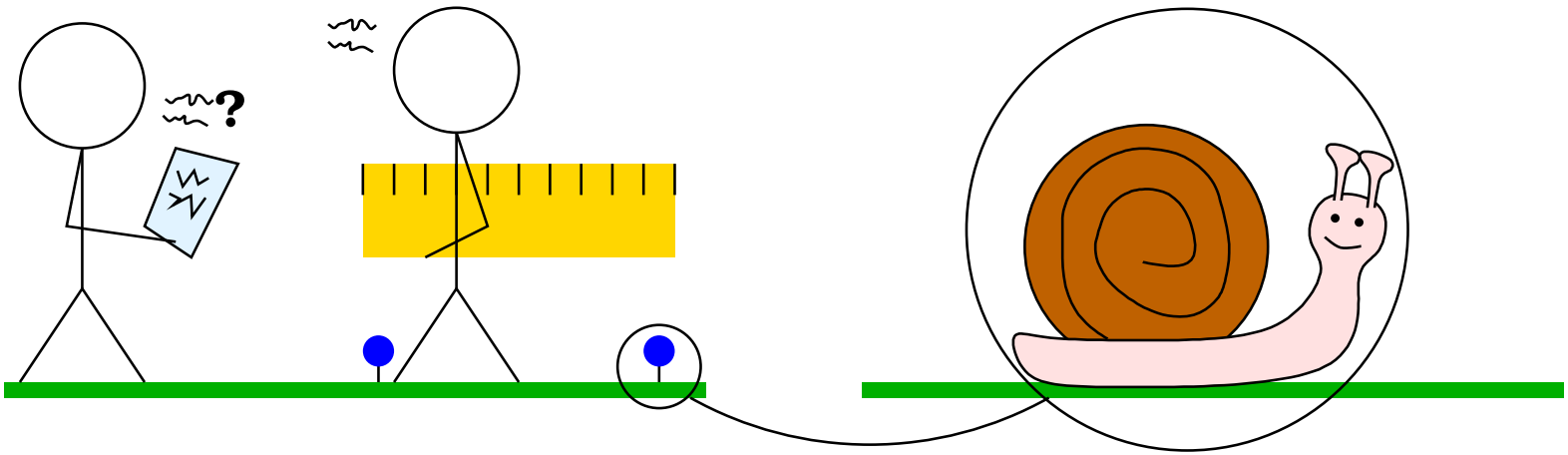
- Repeated measurements can give different results.
- There are many sources for uncertainties.



Reference frames

Global reference frames are used to compare positions at different places and at different times.

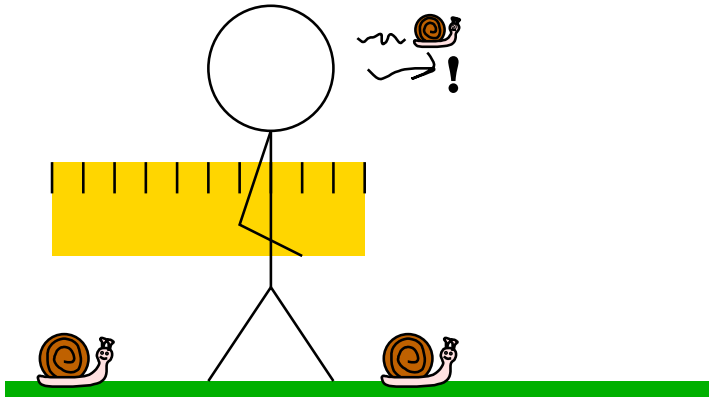
- Repeated measurements can give different results.
- There are many sources for uncertainties.
- If we assume that the reference points are moving



Reference frames

Global reference frames are used to compare positions at different places and at different times.

- Repeated measurements can give different results.
- There are many sources for uncertainties.
- If we assume that the reference points are moving we can estimate velocities.



Why are we doing this?

Global reference frames are necessary to

- monitor the climate over time,
- calculate precise satellite orbits, and
- take advantage of new technology within positioning.

Why are we doing this?

Global reference frames are necessary to

- monitor the climate over time,
- calculate precise satellite orbits, and
- take advantage of new technology within positioning.

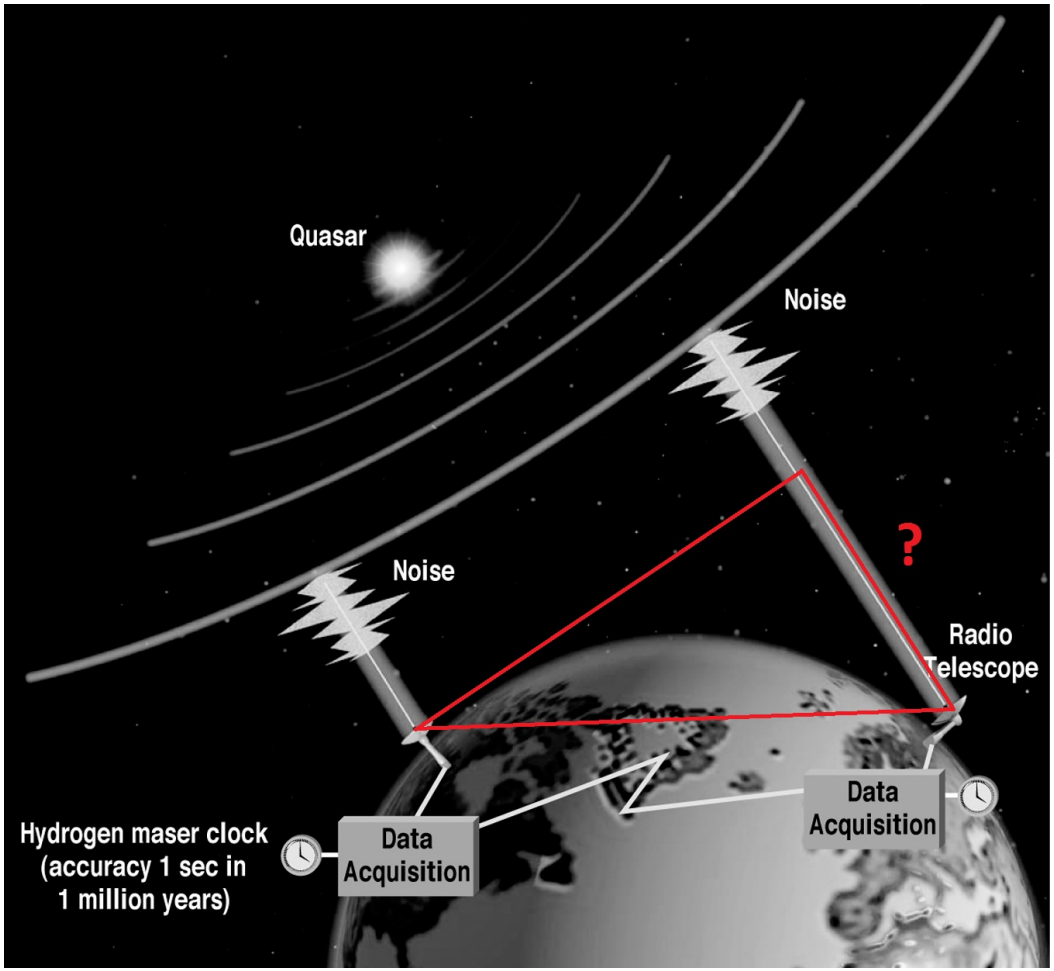
The four techniques mainly used in establising a global reference frame are

SLR	Satelitte Laser Ranging
GNSS	Global Navigation Satellite Systems (e.g. GPS)
VLBI	Very Long baseline Interferometry
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite

Part II

VLBI - Very Long Baseline Interferometry

VLBI – Observation



VLBI – Model and residual

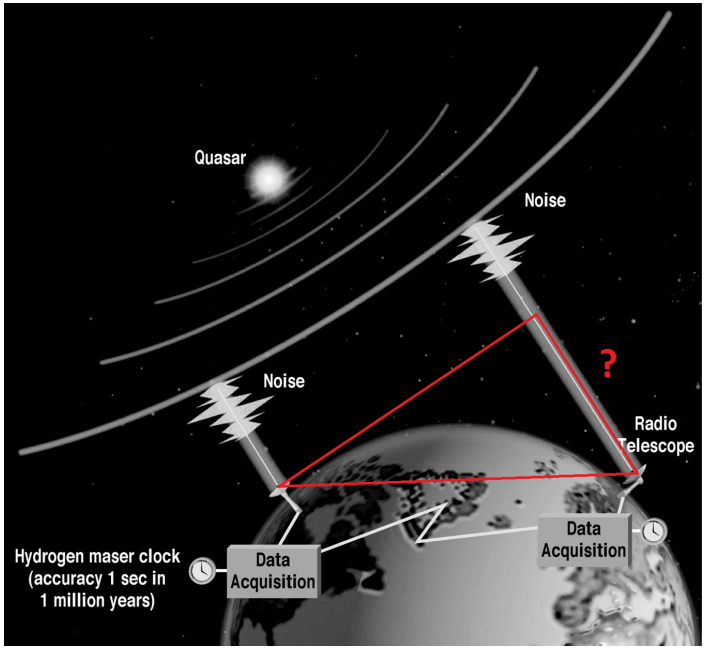
Theoretical delay

$$\tau = \tau_{geometric} + \tau_{grav} + \tau_{tropo} + \tau_{axisoffset} + \tau_{thermdef} + \tau_{clock} + \tau_{cable} + \tau_{iono}$$

Residual

$$residual = observation - model$$

The geometric delay



The geometric delay $\tau_{geometric}$ can be calculated based on station positions and radio source coordinates,

$$\tau_{geometric} = \frac{K \cdot b}{c}.$$

Here K is the unit vector in the direction of the radio source, and b is the baseline vector, that is $b = p_2 - p_1$, the vector from station 1 to station 2.

Part III

Creating a simple analysis

Software demo

Download the demo at

`https://github.com/gahjelle/vlbi_demo`

Hit *Clone or Download* and choose *Download ZIP*.