# Data Assimilation for the time-dependent reconstruction of continents.

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## Aim

**Assimilate Paleomagnetic data** to reconstruct the motion of continents over the last **hundreds of Myr**, while preserving basic **geodynamical principles**.

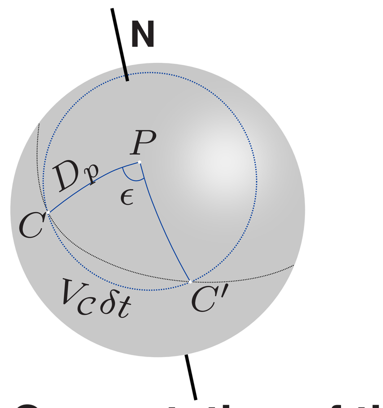
## Motivation

- Using **plate tectonic theory**, we can integrate a wide range of geological and geophysical observations to produce **kinematic plate tectonic reconstructions**. These reconstructions are built via a **largely manual process** of integrating many individual time-dependent regional tectonic histories into a **geometrically self-consistent global model**, making the **quantitative estimation of uncertainties** very complex.
- The **particle filter** provides a statistically consistent framework within which one can assimilate **data of variable nature and source** within a **dynamical model**, providing quantitative uncertainties on the estimated trajectory of the system.

**Here, we demonstrate a first step to building a data assimilation framework for plate tectonics reconstructions: we apply a particle filter to reconstruct time-dependent continental configurations and motions.**

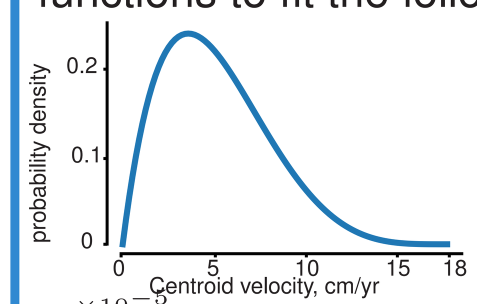
## The Forward Model

**Continents motions are solid body rotations:**
At Each timestep, we compute the rotation of each continent during the time $\delta t$ (here $1$ Myrs). This rotation is determined by 3 parameters:

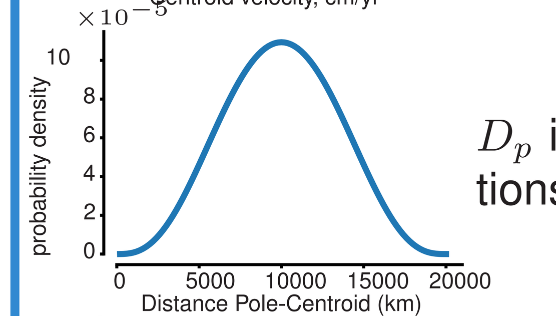



- $D_p$, the distance from continent centroid to the Euler pole (pole of rotation)
- $V_C$, the velocity of the continent's centroid
- $T_s$, the fraction of the current rotation to be kept for the next rotation

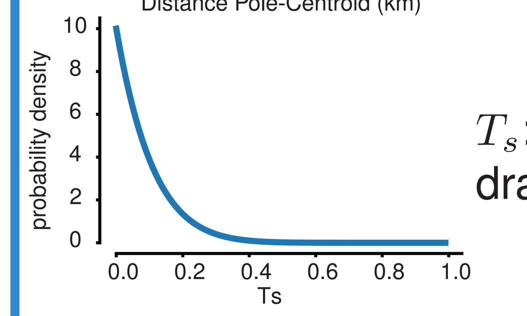
**Computation of the Random drift for each continent:**
$D_P$, $V_C$ and $T_s$ are **random variables**. Each of them follows a beta function. We choose the parameters (a, b) of those beta functions to fit the following geodynamical constraints:




$\max(V_C) = 18$ cm/yr maximum, mode $\in [2, 3]$ cm/yr



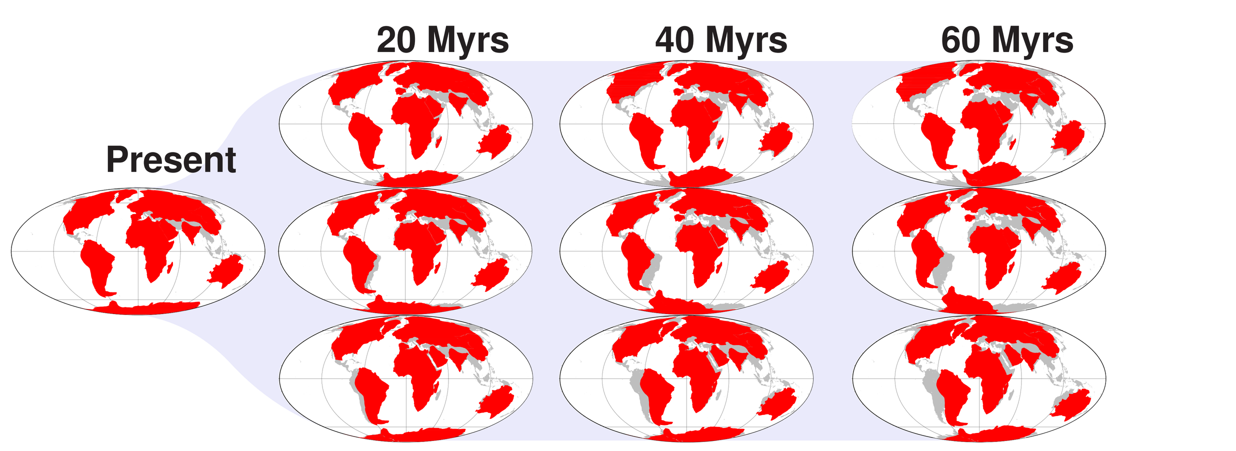

$D_p$ is related to spin vs translation motions for continents: mode at $10000$ km.



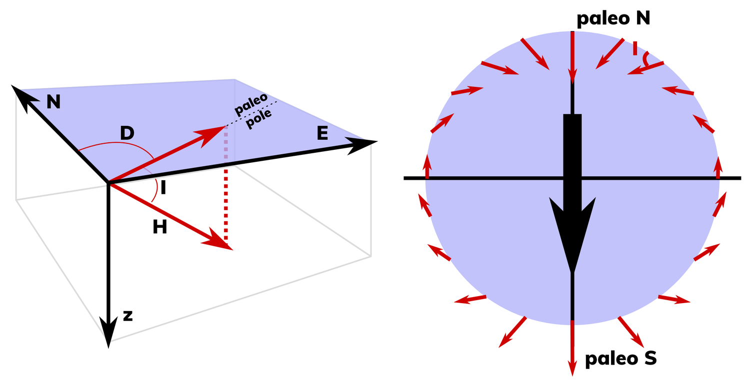

$T_s$: how often the continents change drastically their trajectory.

**Collision rules:**
If during a timestep, two continents overlap each other, then they form a cohesive block and are rotated together.

## Example Random Drift scenario




## Observations

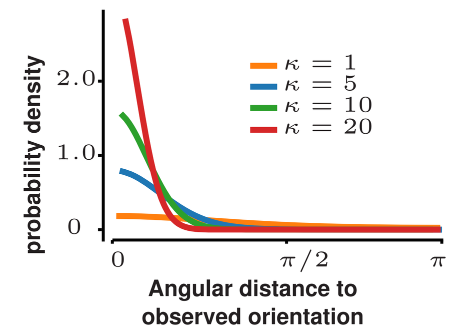



Database of inclination and declination of the magnetic field fossilized in rocks

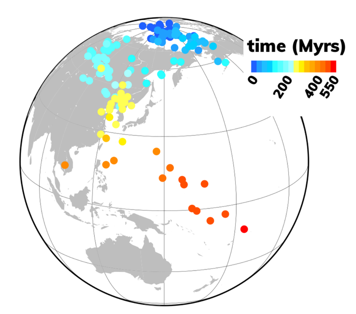
Uncertainties modelled with Fisher statistics:

$$p(\mathbf{h}^p)_{(\mathbf{h}^o,\kappa)} = C(\kappa)\exp(\kappa[\mathbf{h}^o]^T\mathbf{h}^p)$$

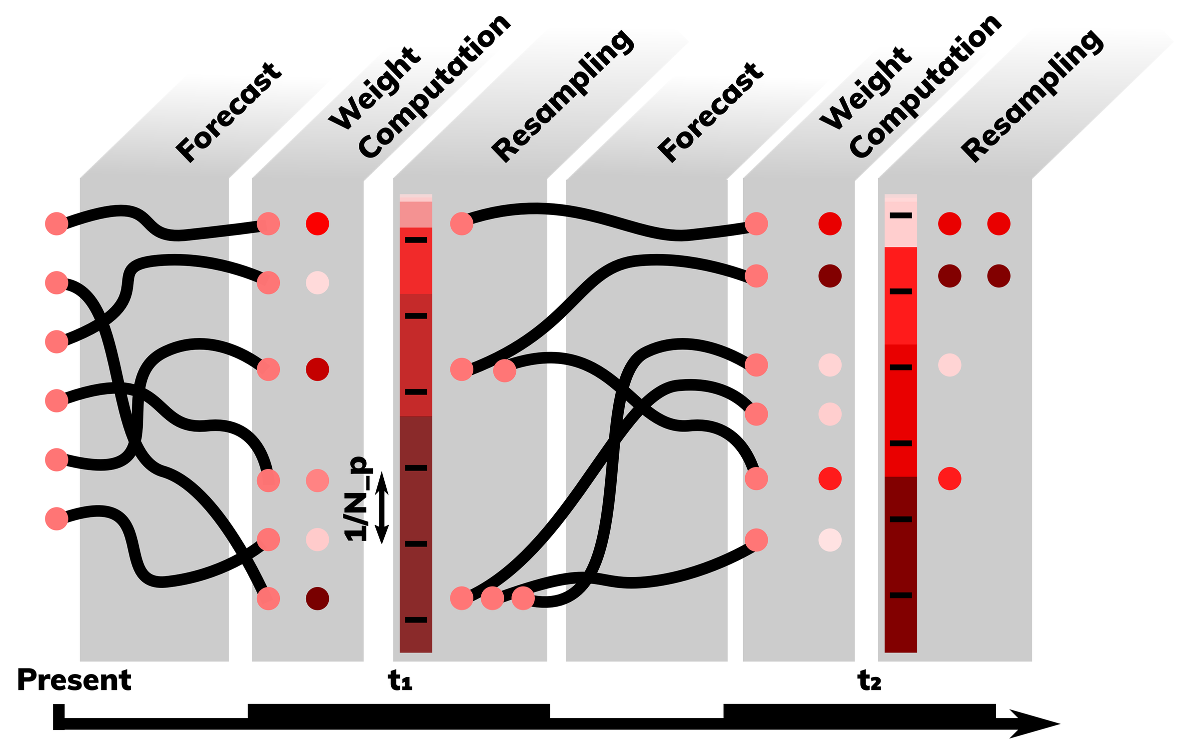
with $C(\kappa) = \dfrac{\kappa}{2\pi(e^{\kappa} - e^{-\kappa})}$




North America paleopoles computed from the inclination declination database used in Tetley [2018], dated from 0.5 to 550 Ma




## Data Assimilation Method




**We use a particle filter [van Leeuwen et al., 2018]:**

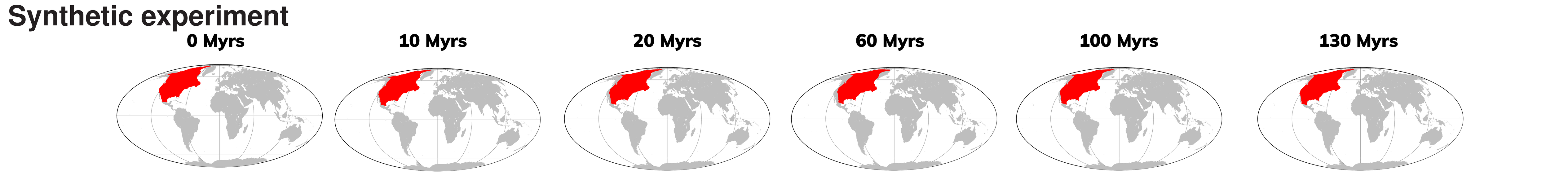
**Initial setup**
$N_p$ particles $\{\mathbf{x}_0^{n_p}\}_{n_p\in[1,N_p]}$ with identical continental blocks, but different random rotations.
weight: $\{\omega_0^{n_p} = 1/N_p\}_{n_p\in[1,N_p]}$
pdf: $p(\mathbf{x}_0) = \sum_{n_p=1}^{N_p} \omega_0^{n_p}\,\delta(\mathbf{x}_0 - \mathbf{x}_0^{n_p})$,
with $\delta$ the dirac function.

**loop over observations:**

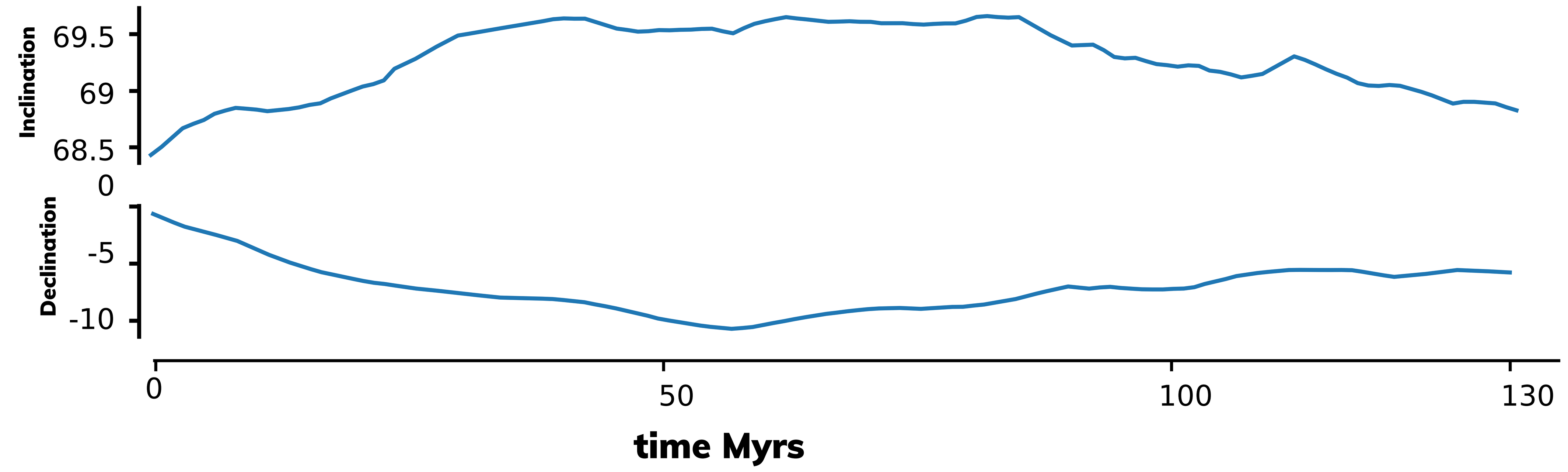
- **Forecast**: see forward model.
- **weight computing**: $\forall n_p \in [1, N_p]$,
  $\omega_k^{n_p} = \dfrac{p(\mathbf{y}|\mathbf{x}_k^{n_p})}{\sum_{j=1}^{N_p} p(\mathbf{y}|\mathbf{x}_k^{j})}$ with $p(\mathbf{y}|\mathbf{x}_k)$ a multivariate Fischer distribution with each component independant of the other.
- **Stochastic universal resampling.**

## Preliminary Tests

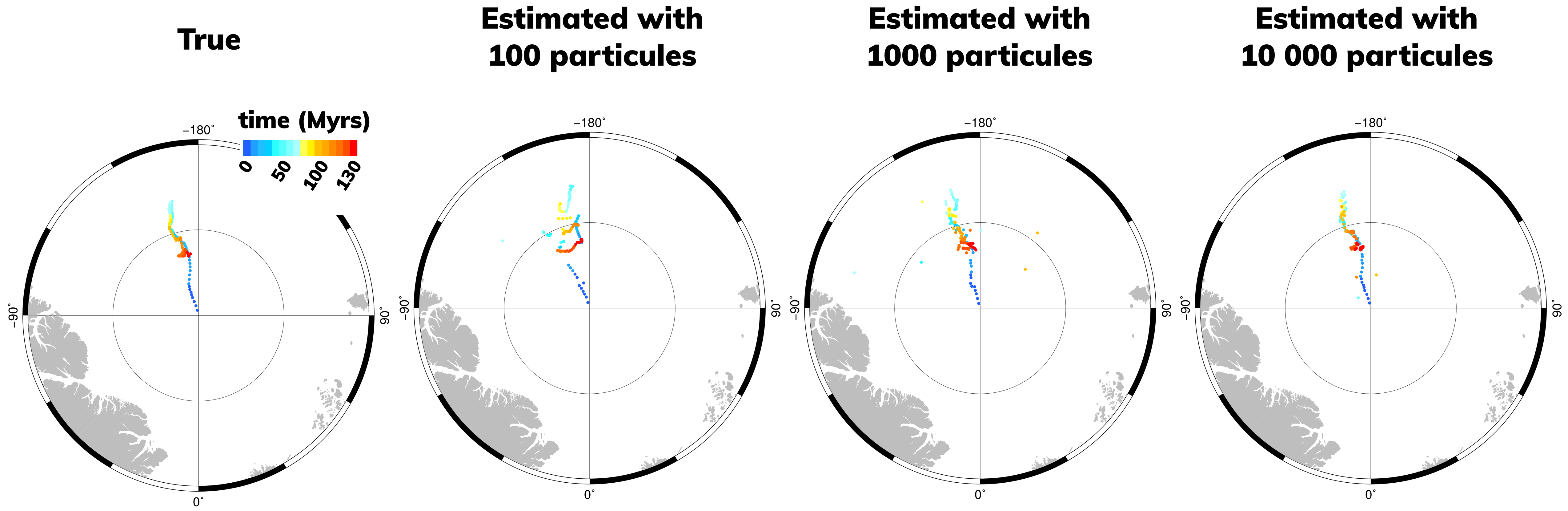
**Synthetic experiment**




**Observations**




**Apparent polar Wander**




## Conclusions

- We have developed a data assimilation framework for paleomagnetic data:
  - based on the **Particle Filter**,
  - with a continental drift model **consistent with basic geodynamics rules**,
  - where the uncertainties on observations are taken into account.
- For single continents synthetic experiments, a number of particles of ca. $10000$ allows us to estimate the trajectory of continents for at least $130$ Myrs.

## The way forward

- Perform synthetic tests with data at multiple sites and on different continents
- Optimize forward code to allow for more particles
- test different resampling techniques, while conserving geodynamical constraints.

## References

Michael G. Tetley. *Constraining Earth's plate tectonic evolution through data mining and knowledge discovery*. University of Sydney, 2018.

Peter Jan van Leeuwen, Hans R Künsch, Lars Nerger, Roland Potthast, and Sebastian Reich. Particle filters for applications in geosciences. *arXiv preprint arXiv:1807.10434*, 2018.