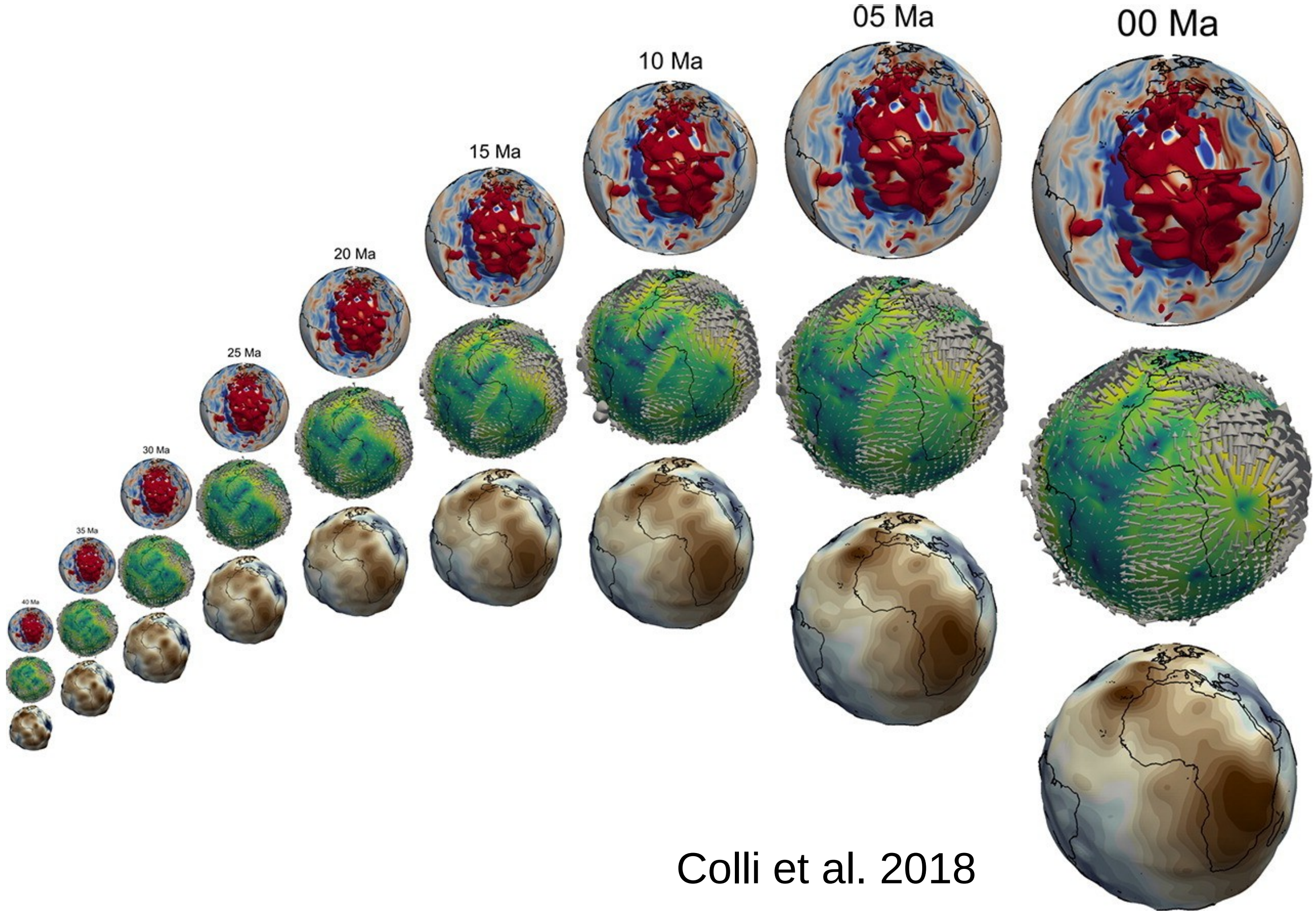
LUDWIG-
MAXIMILIANS-
UNIVERSITÄT
MÜNCHEN

Mantle Flow Trajectories in the Presence of Poorly Constrained Initial Conditions: Analysis of an Ensemble of Models

A. Taiwo[1], H.-P. Bunge[1], B.S.A. Schuberth[1], and G. Craig[2]

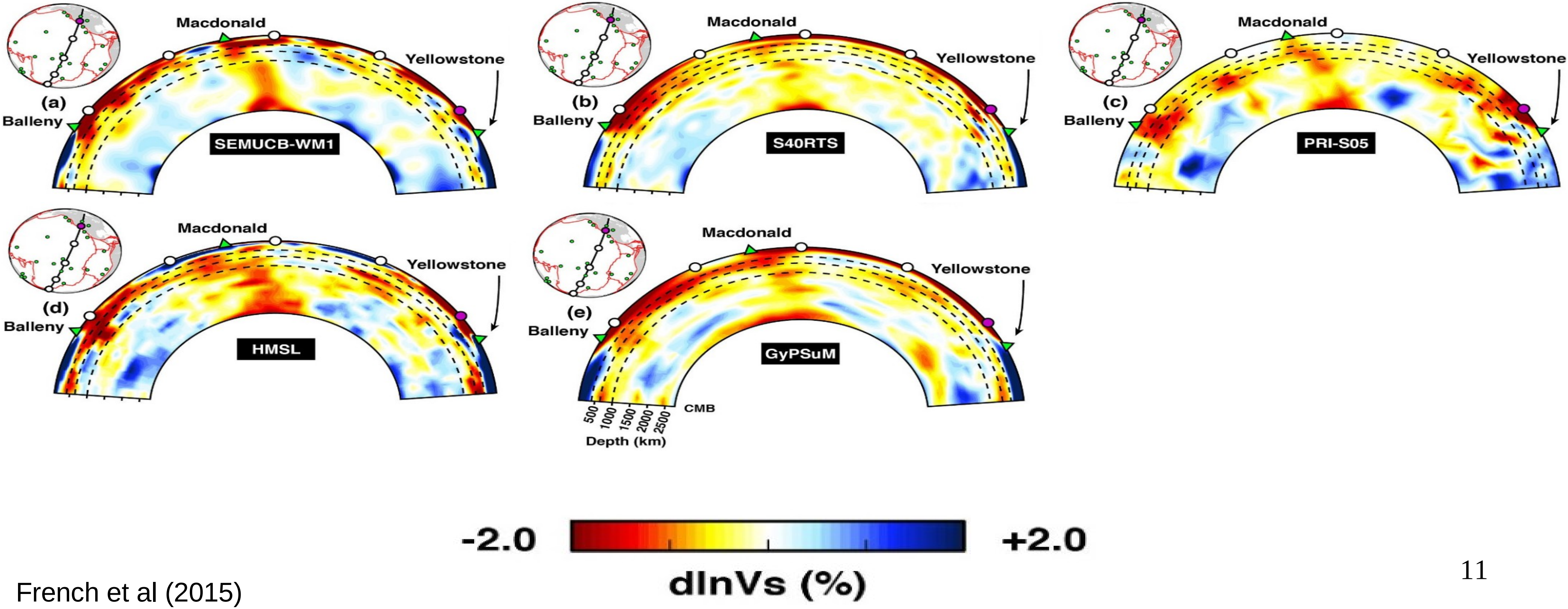
[1]LMU Geophysics
[2]LMU Meteorology

We seek to link the present-day state of the Earth's mantle with its past states



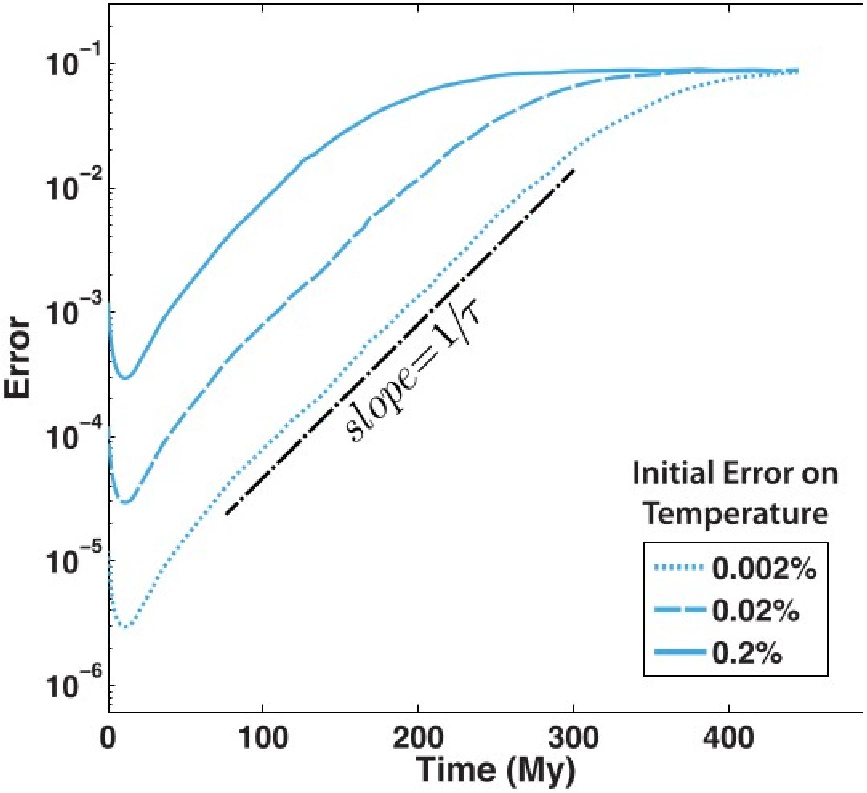
Colli et al. 2018

This retrodiction problem is hindered by uncertainties in the mantle's present day state



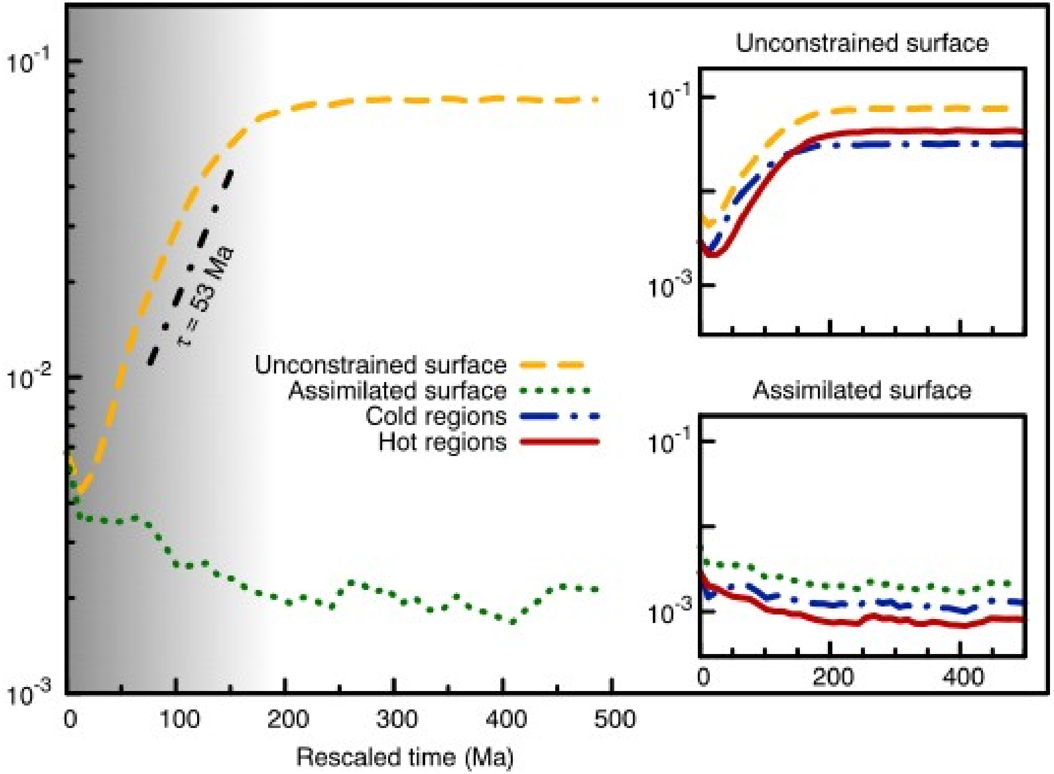
French et al (2015)

Exponential errow growth



Bello et al, 2014

Trajectories converge via assimilation of the surface velocity field

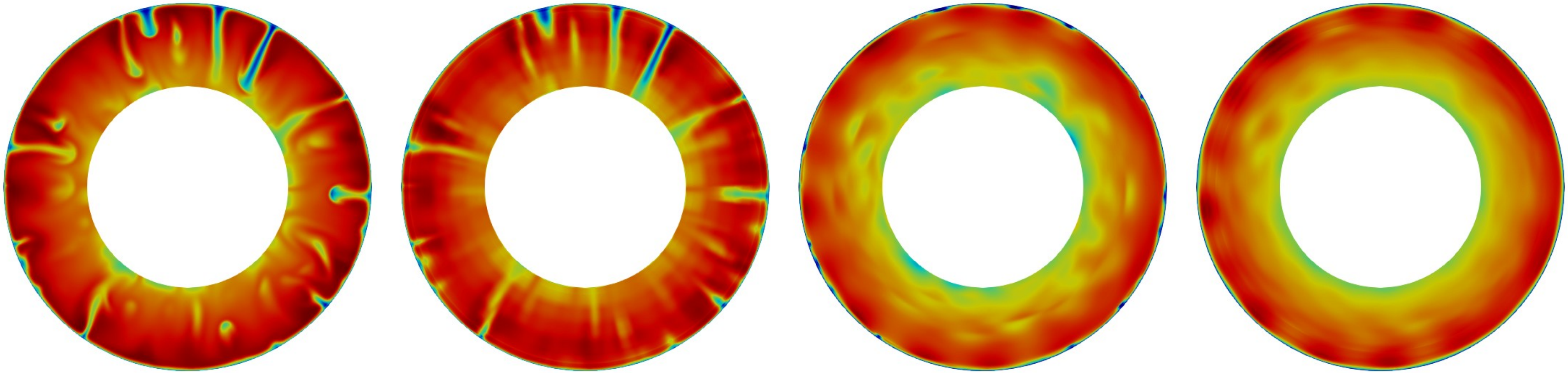


Colli et al, 2015

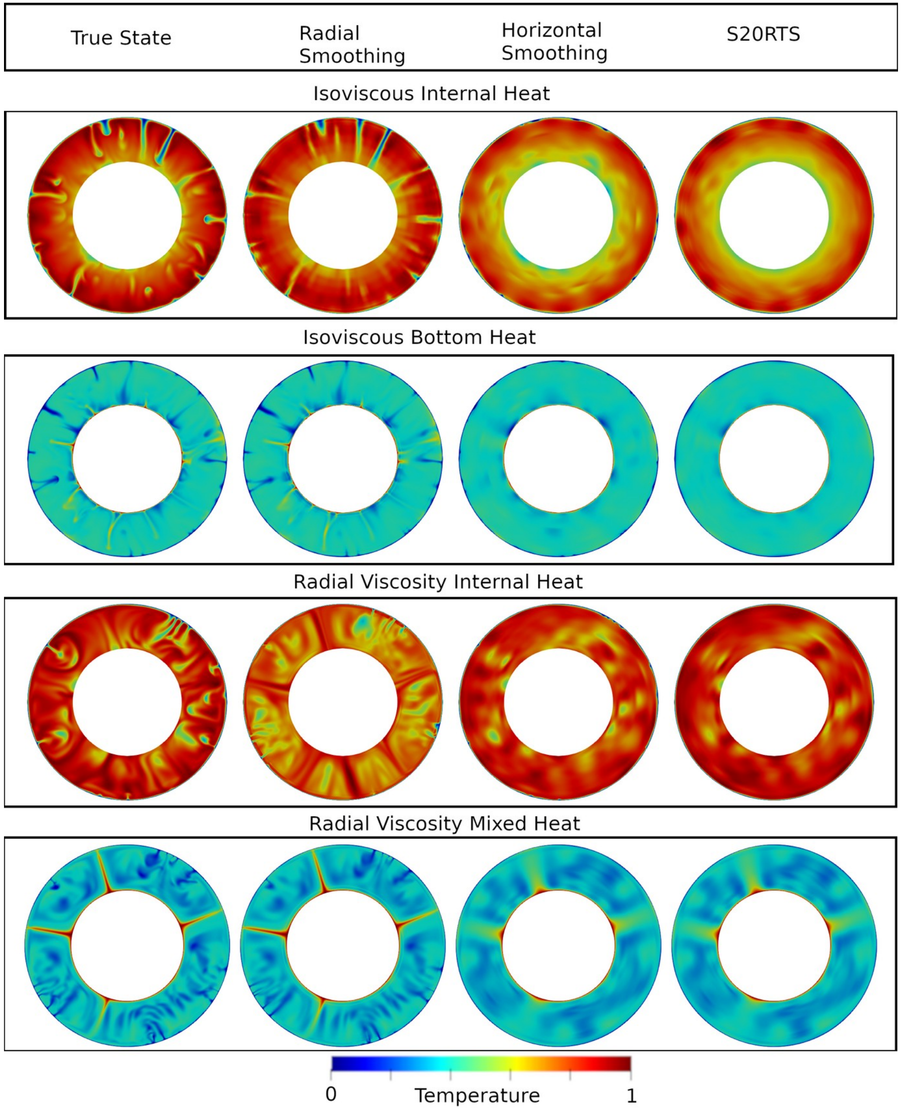
Initial States (Analogues to Seismic Filtering)

True State	Radial Smoothing	Horizontal Smoothing	S20RTS

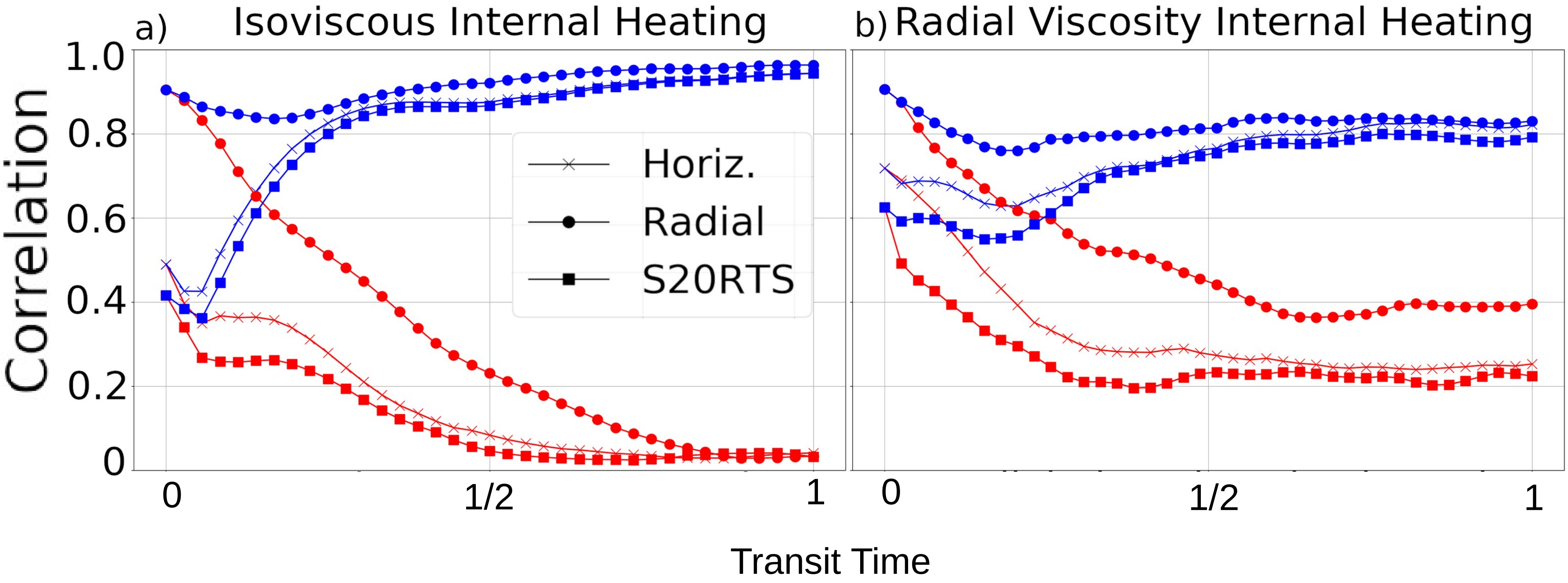
Isoviscous Internal Heat



Initial States

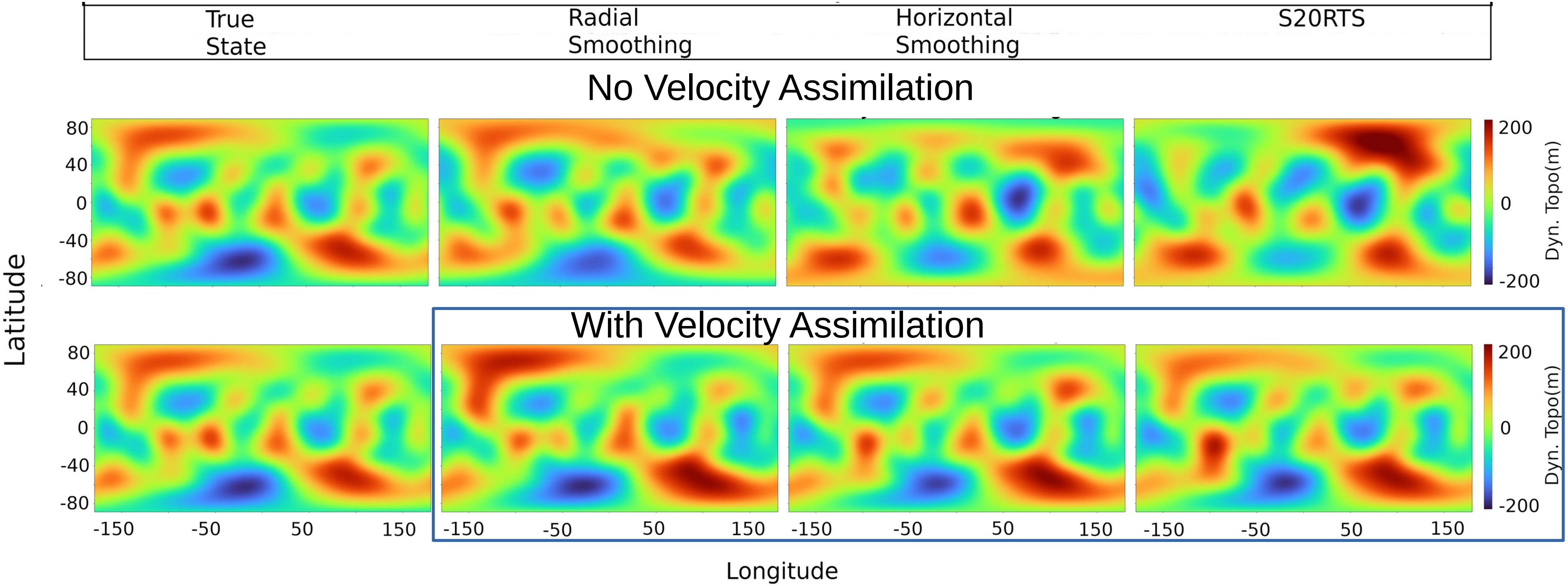


Correlation Curves (after a transit time)

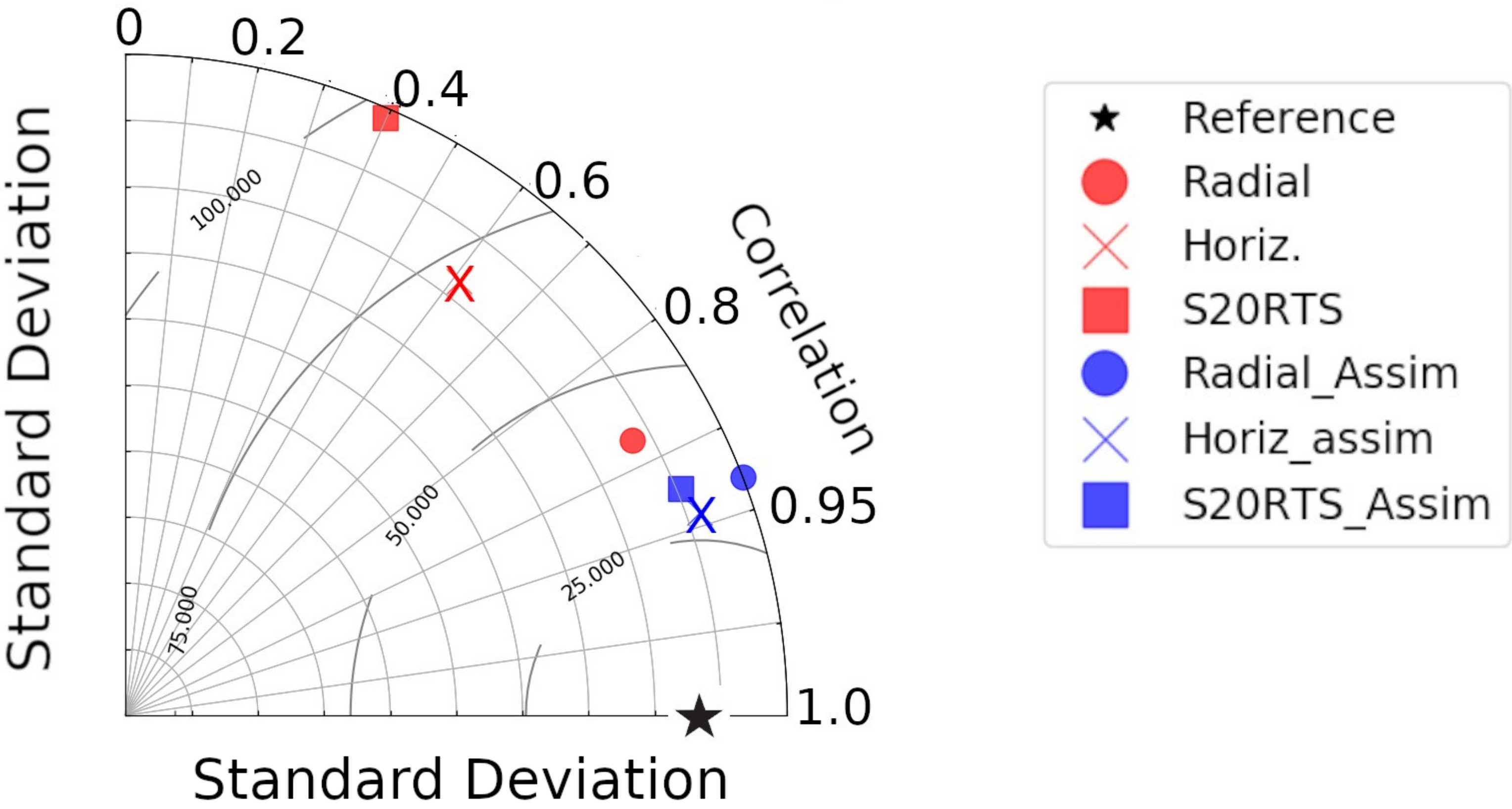


Blue = with assimilation; red = without assimilation

Dynamic Topography - Radial Viscosity Internal Heating

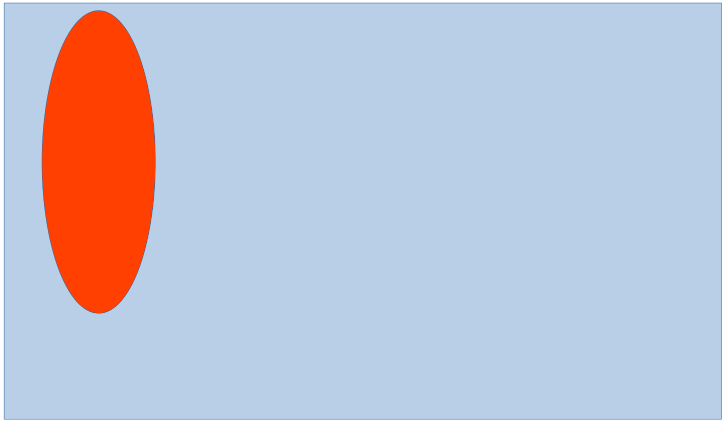


Taylor Diagram – Radial Viscosity Internal Heating

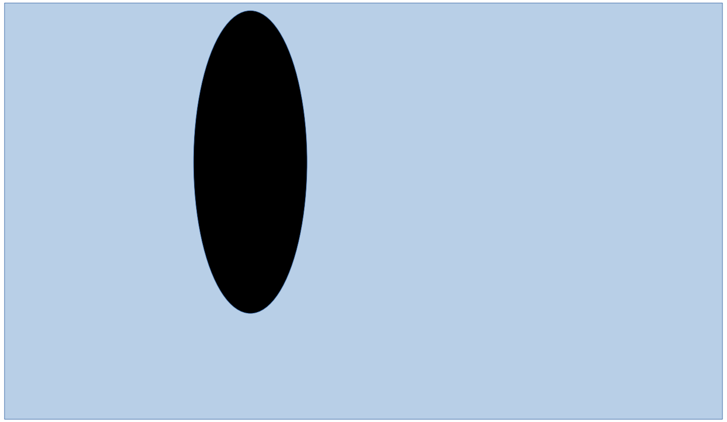


Traditional grid point metrics: Double Penalty Problem

True/Reference



Perturbed



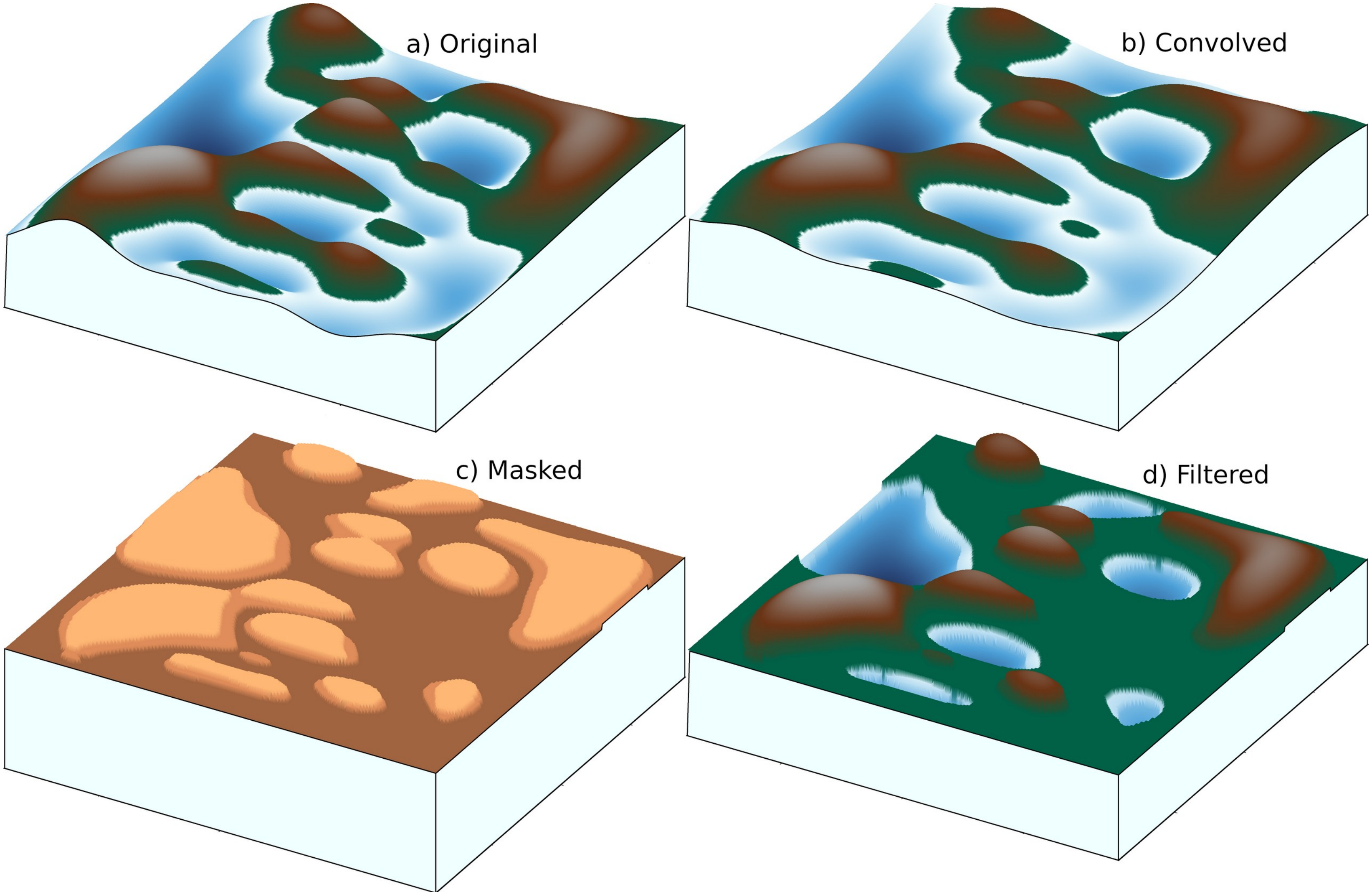
Same prediction, different locations

Observed topography = 200m
Forecast topography = 200m

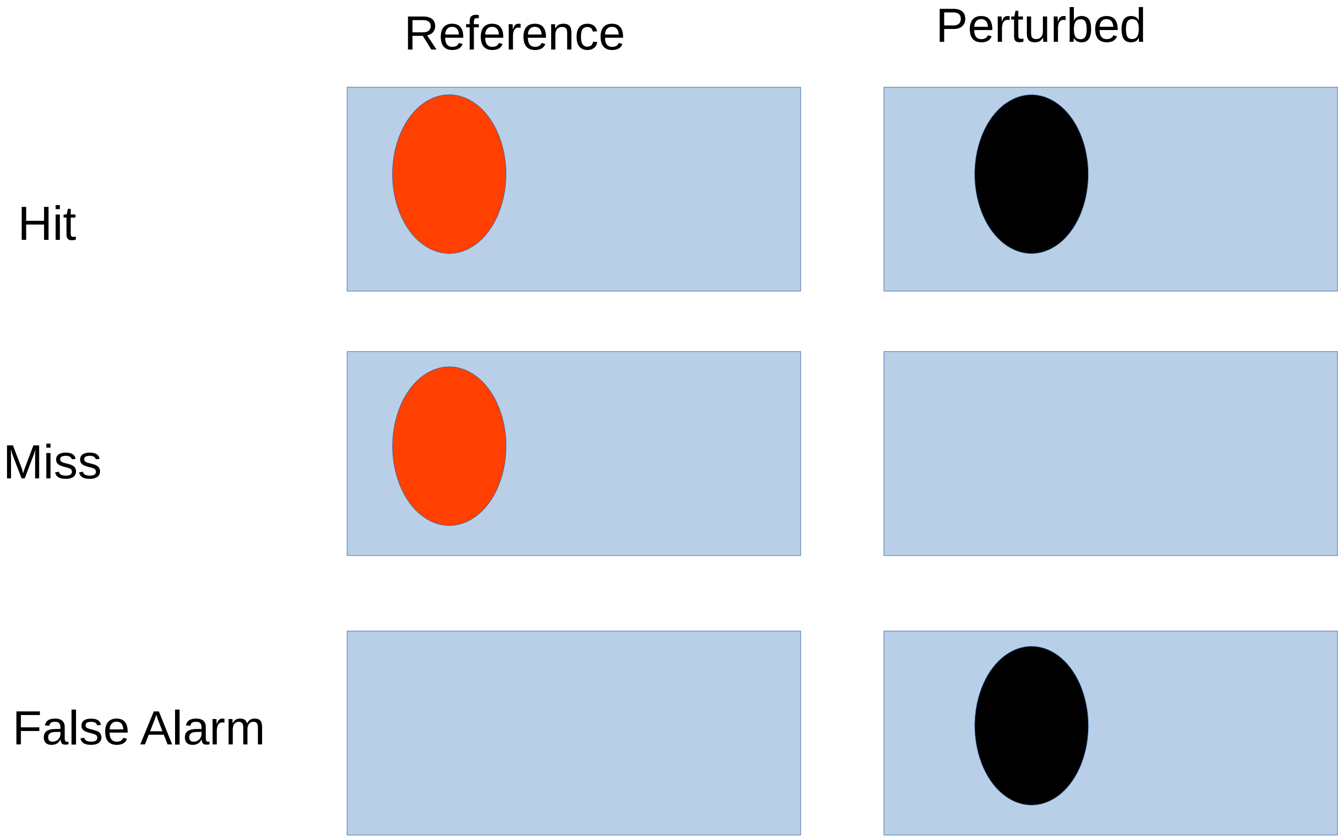
RMS error = $\sqrt{\frac{(200-0)^2+(0-200)^2}{2}} = 200\,m$

There is a need for metrics that reward correct model predictions even if location is slightly offset

Object Identification



Object Matching



Object Matching

Critical Success Index (CSI) = hits / (hits + misses + false alarms)

Probability of Detection (POD) = hits / (hits + misses)

False Alarm Ratio (FAR) = false alarms / (hits + false alarms)

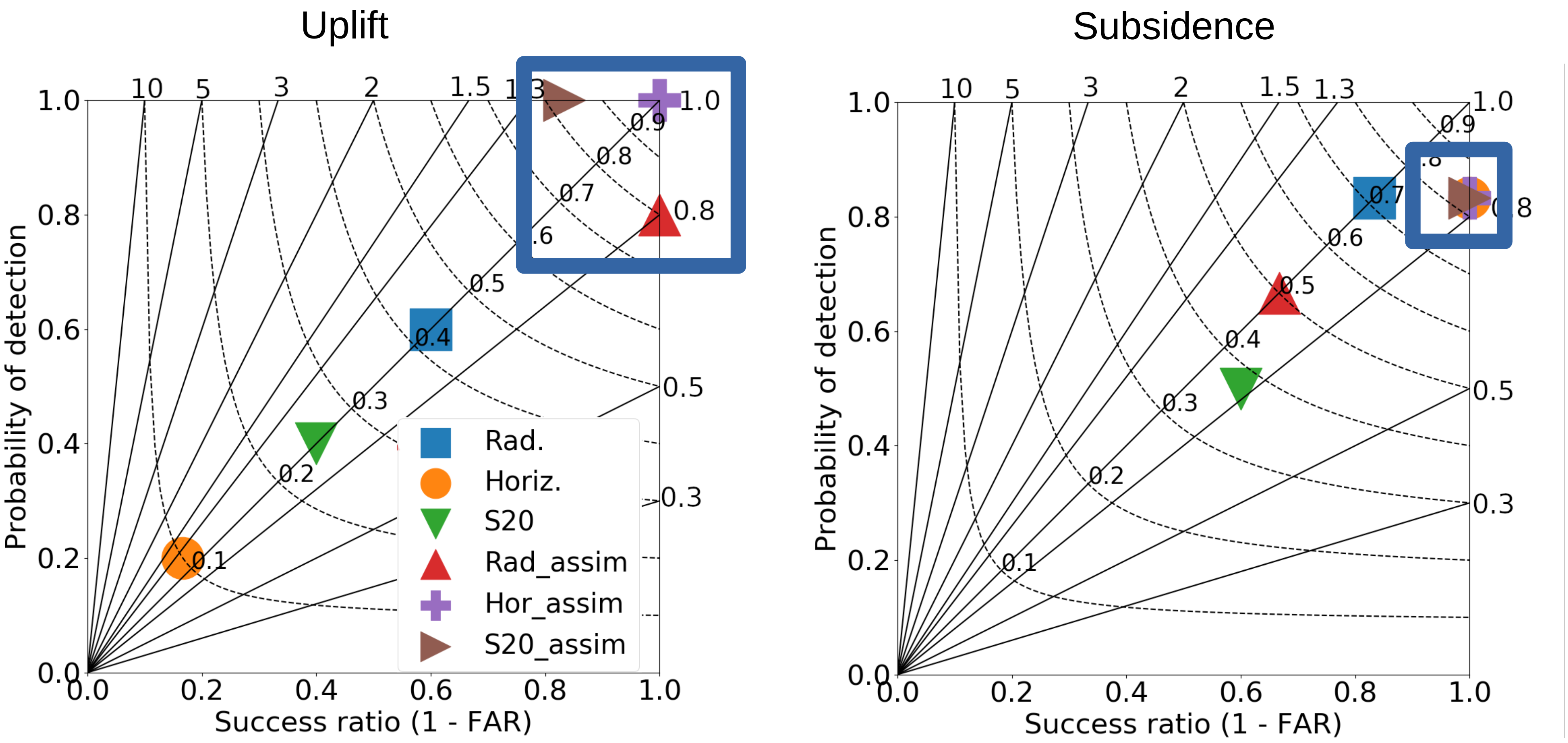
Success Ratio (SR) = 1 - FAR

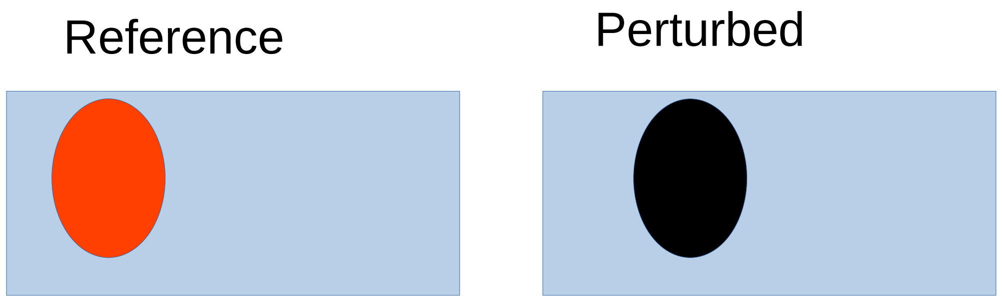
Bias = (hits + false alarms) / (hits + misses)

For all models, we summarise these scores on a Performance Diagram

Radial Viscosity Internal Heating

Upper right corner = better models





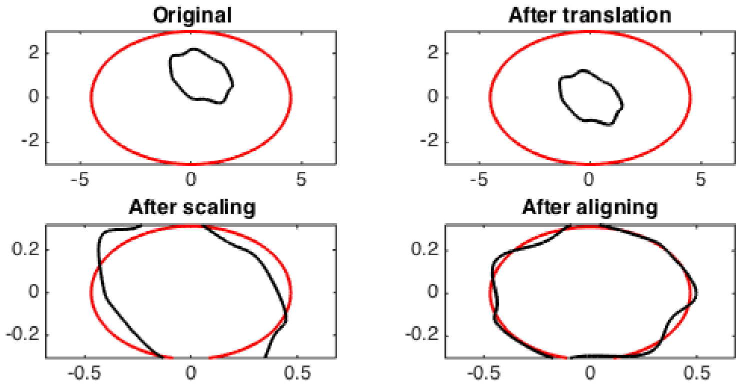
The performance diagram only measures the presence (absence) of objects

How well do matched reference and perturbed objects compare in terms of average topography, shape and locations

Procrustes Shape Analysis

Given two matrices A and B with same dimensions, we seek a (orthogonal) transformation matrix T that minimises the Frobenius norm of A – TB

In our case, A and B represent latitude and longitude coordinates for the boundaries of identified objects in the reference and perturbed fields

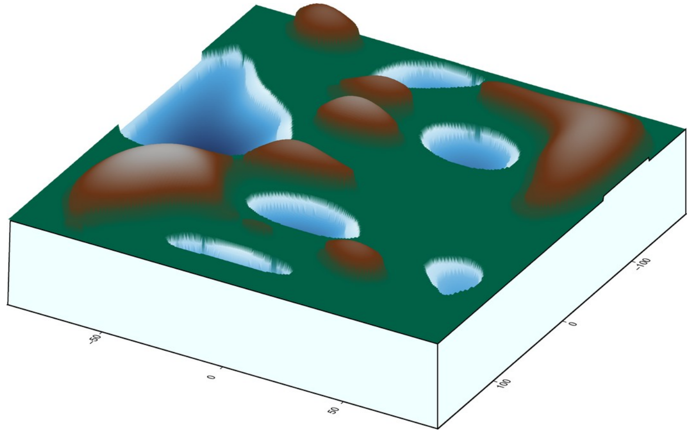


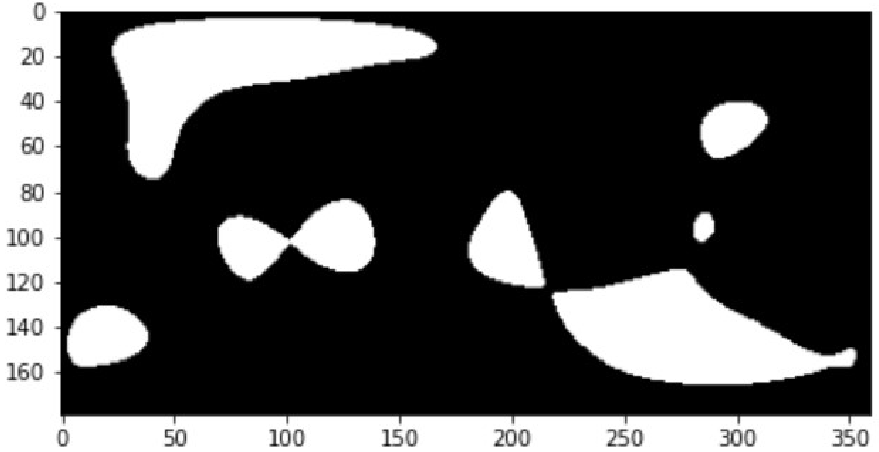
Source: https://www.chebfun.org/examples/geom/Procrustes.html

Boundary Extraction

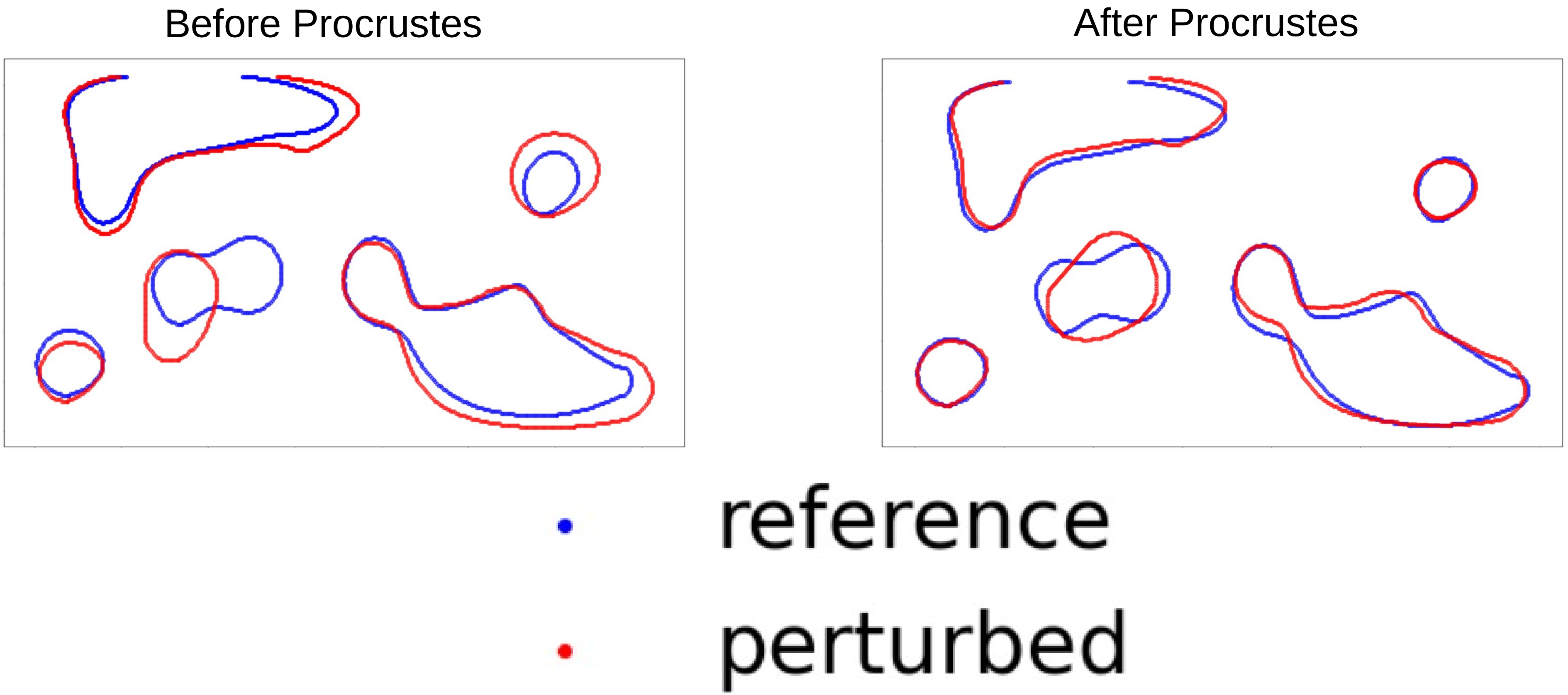
We extract the boundaries of each object using a marching squares algorithm

The algorithm extracts iso-valued contours from a binary image via a linear interpolation





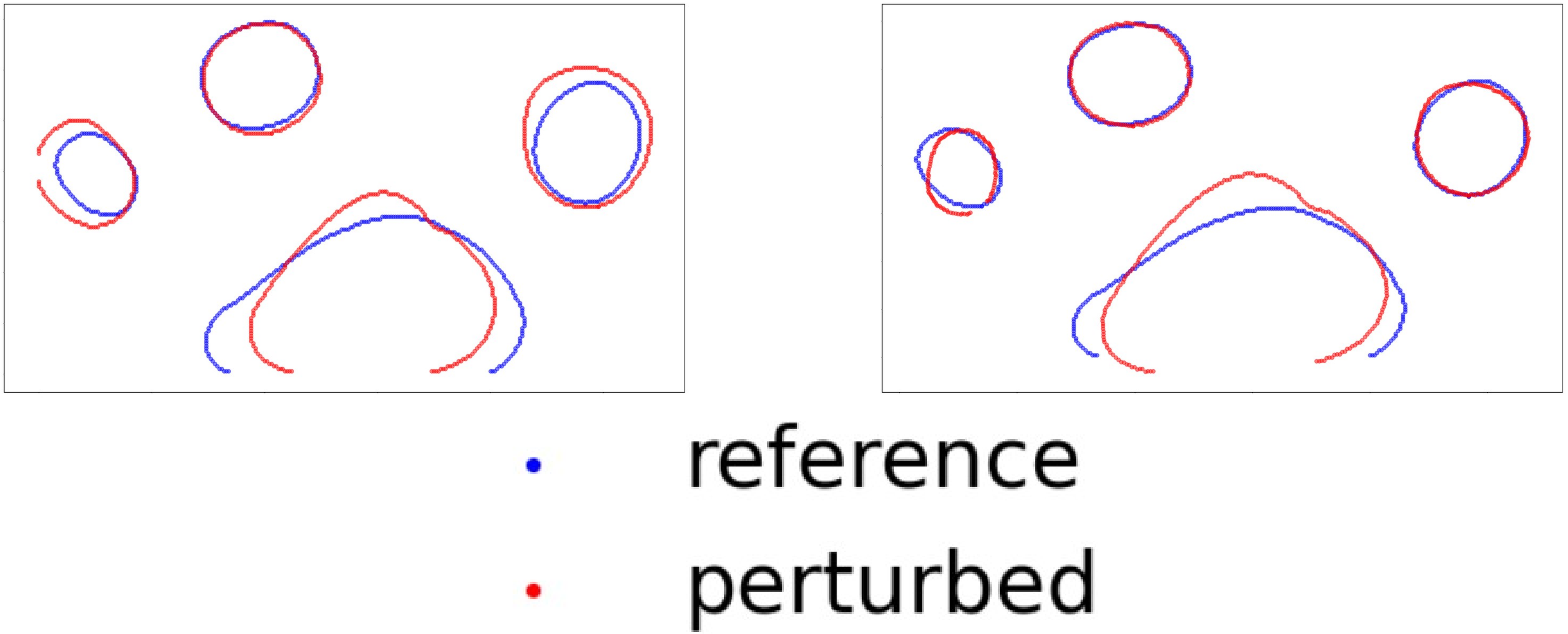
Uplift



Subsidence

Before Procrustes

After Procrustes



Procrustes algorithm produces the following:

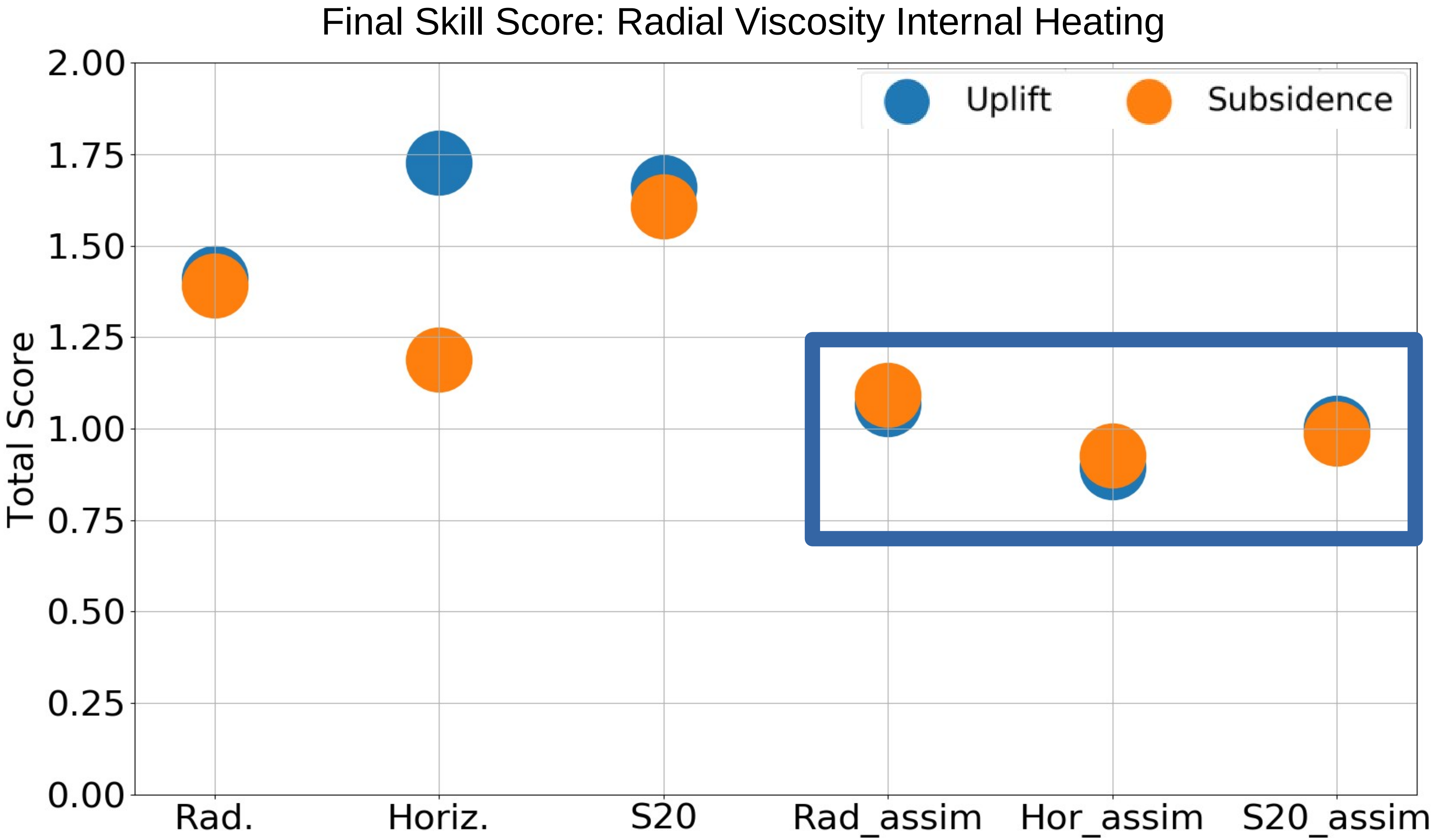
1) The sum of squared errors between boundaries of matched objects, normalized between 0 and 1

2) The difference in average topography between the matched objects also normalized between 0 and 1

Minimum (best) skill score (SS) = 0
Maximum (worst) skill score (SS) = 1 + 1 = 2

For N matched objects, we average the scores:

Final skill score = (SS_1 + …. + SS_N) / N



Final Skill Score: Radial Viscosity Internal Heating
Total Score
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Uplift
Subsidence
Rad.
Horiz.
S20
Rad_assim
Hor_assim
S20_assim

Discussion

- Assimilation of the surface velocity field can help correct the trajectories of mantle cicrulation models (MCMs)
- Since mantle temperature field cannot be directly observed, it is important to test MCMs against the geological record
- Traditional grid-point metrics suffer from the double penalty problem
- Object identification methods represent a more viable method for comparing geological observations
- Skill scores, which take all object properties into account provide a highly accurate metric for ranking models, in a way similar to what a human observer would do