

Joint interpolation of 3-component GPS velocities constrained by elasticity

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GPS Interpolation

Single component:

Multi-component:

Single component:

Splines (Sandwell, 1987, Wessel & Bercovici, 1998, etc)

GPS Imaging (Hammond et al, 2016)

and many others...

Multi-component:

Single component:

Splines (Sandwell, 1987, Wessel & Bercovici, 1998, etc)

GPS Imaging (Hammond et al, 2016)

and many others...

Multi-component:

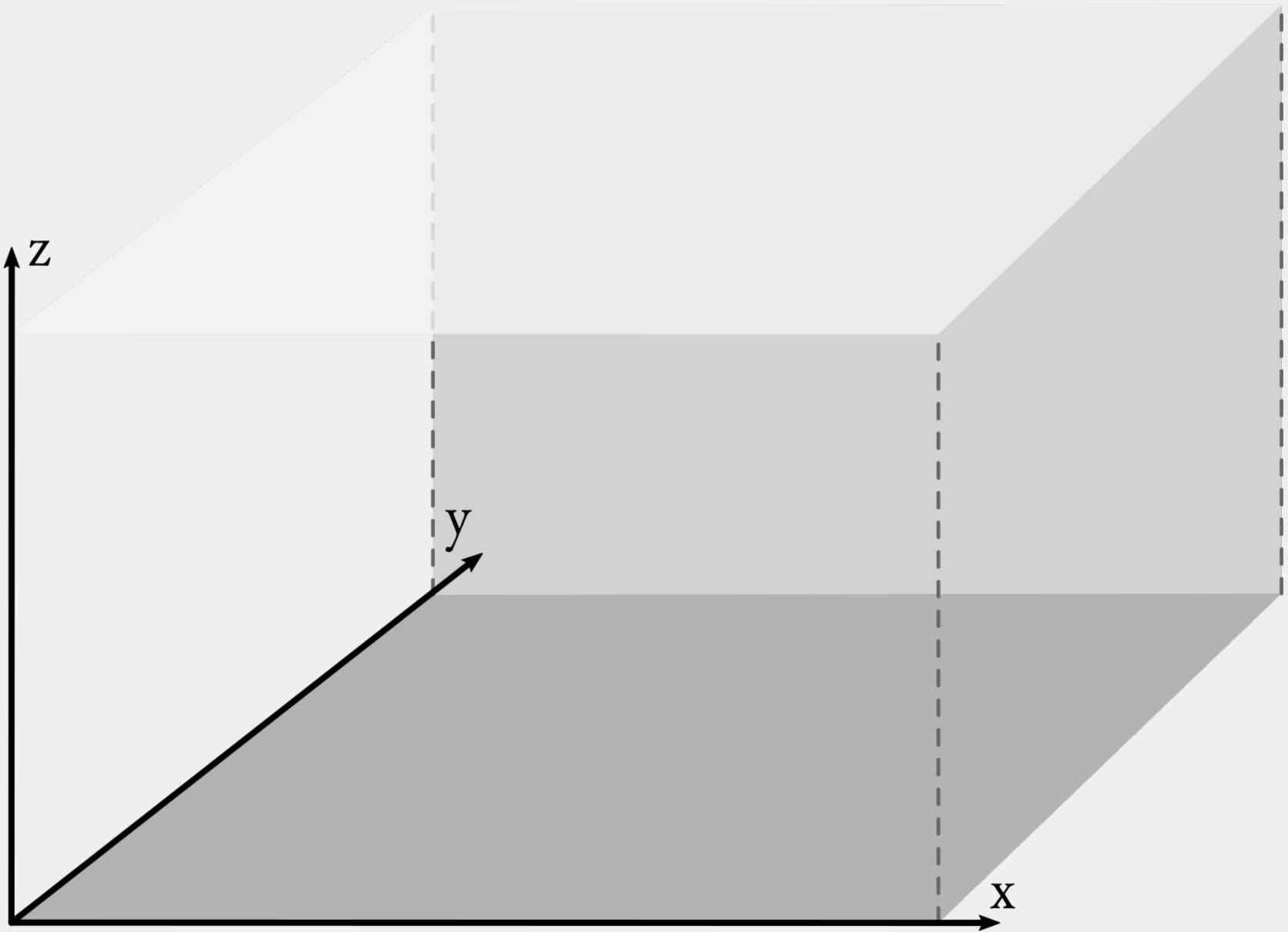
Finite-element elastic Green's functions

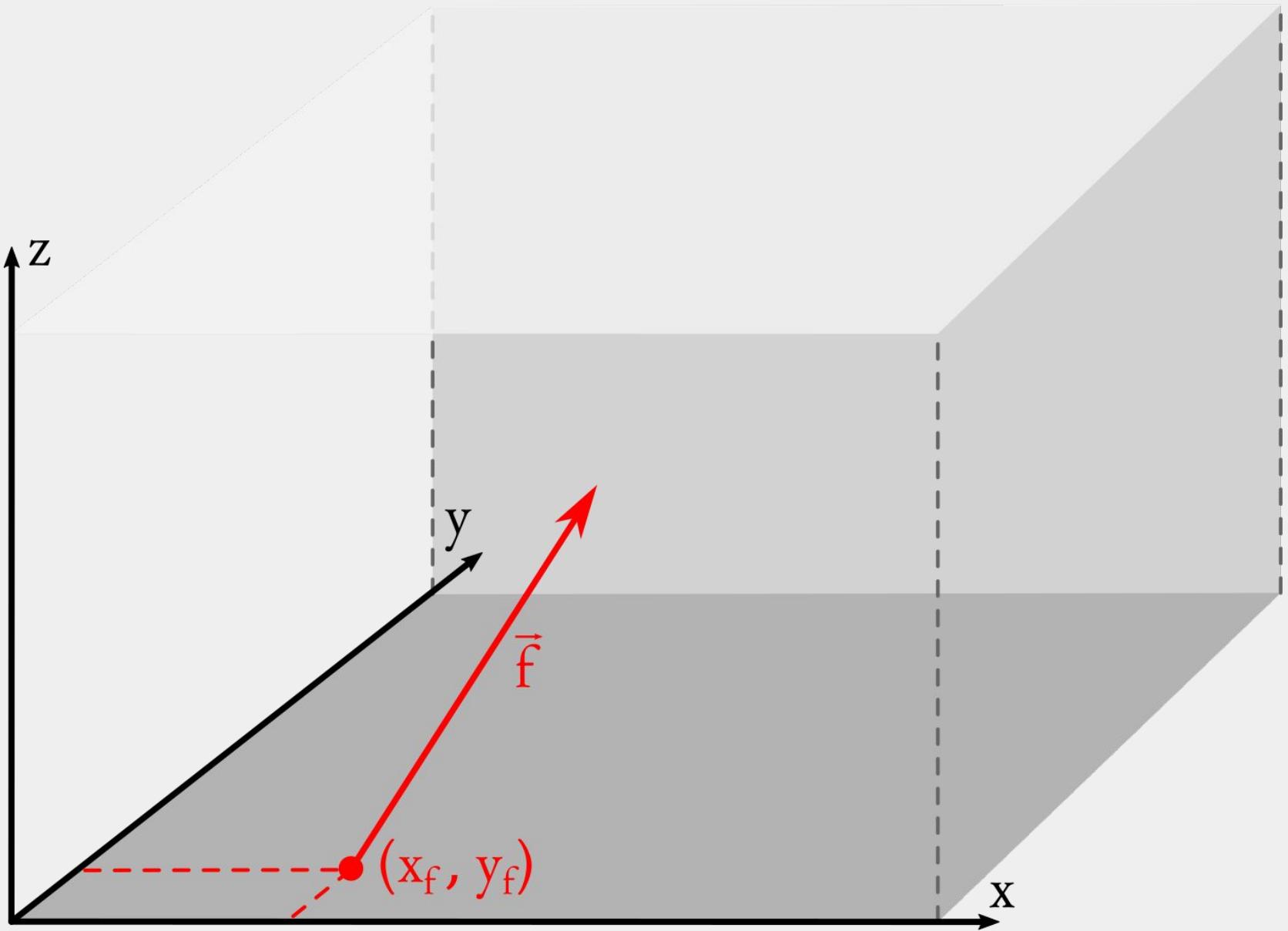
(Haines et al., 2015)

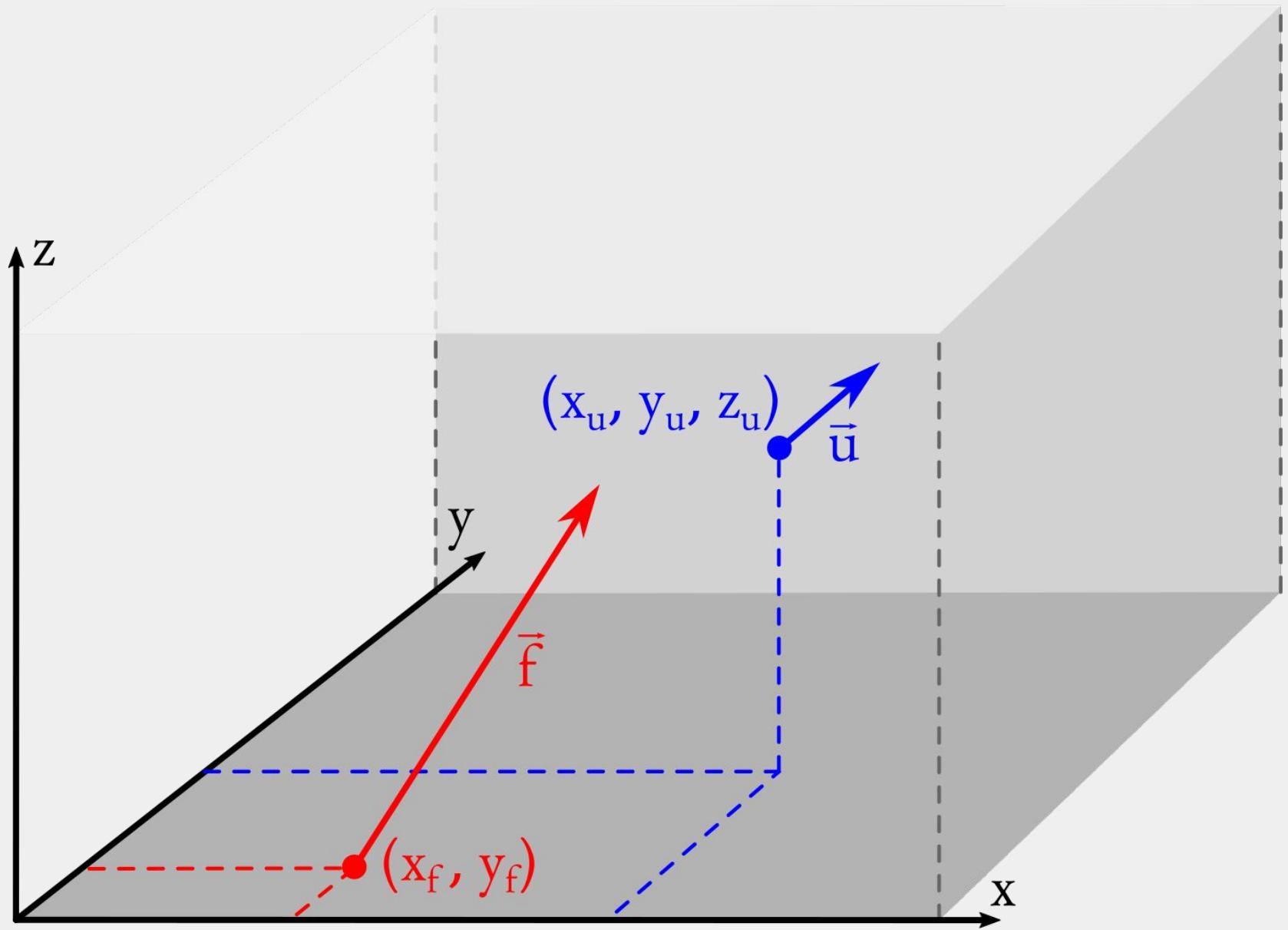
Analytical elastic Green's functions

(Sandwell & Wessel, 2016)

3D elastic
Green's
functions







$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}$$

Green's functions

$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}$$

(Okumura, 1995)

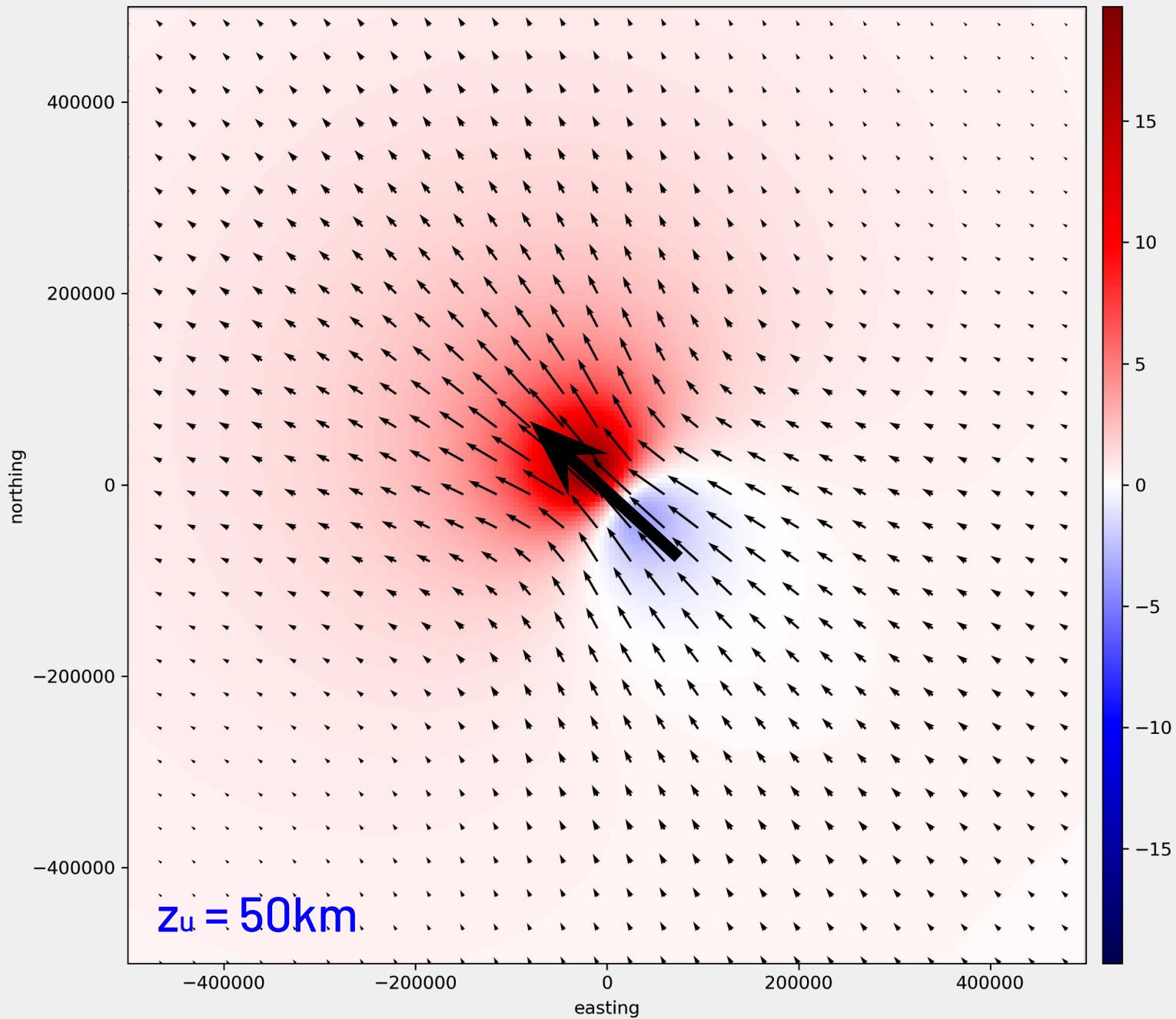
Green's functions

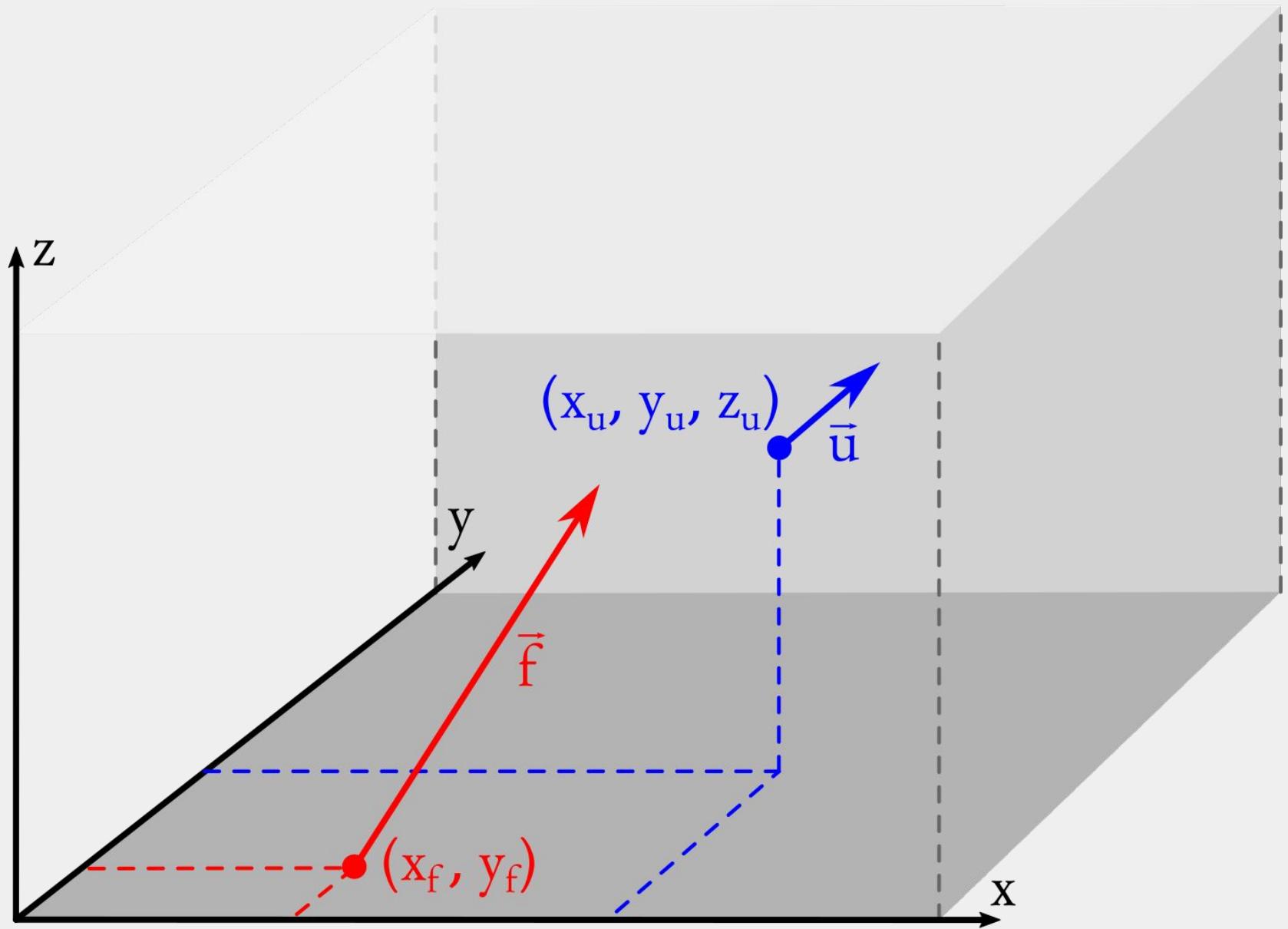
force

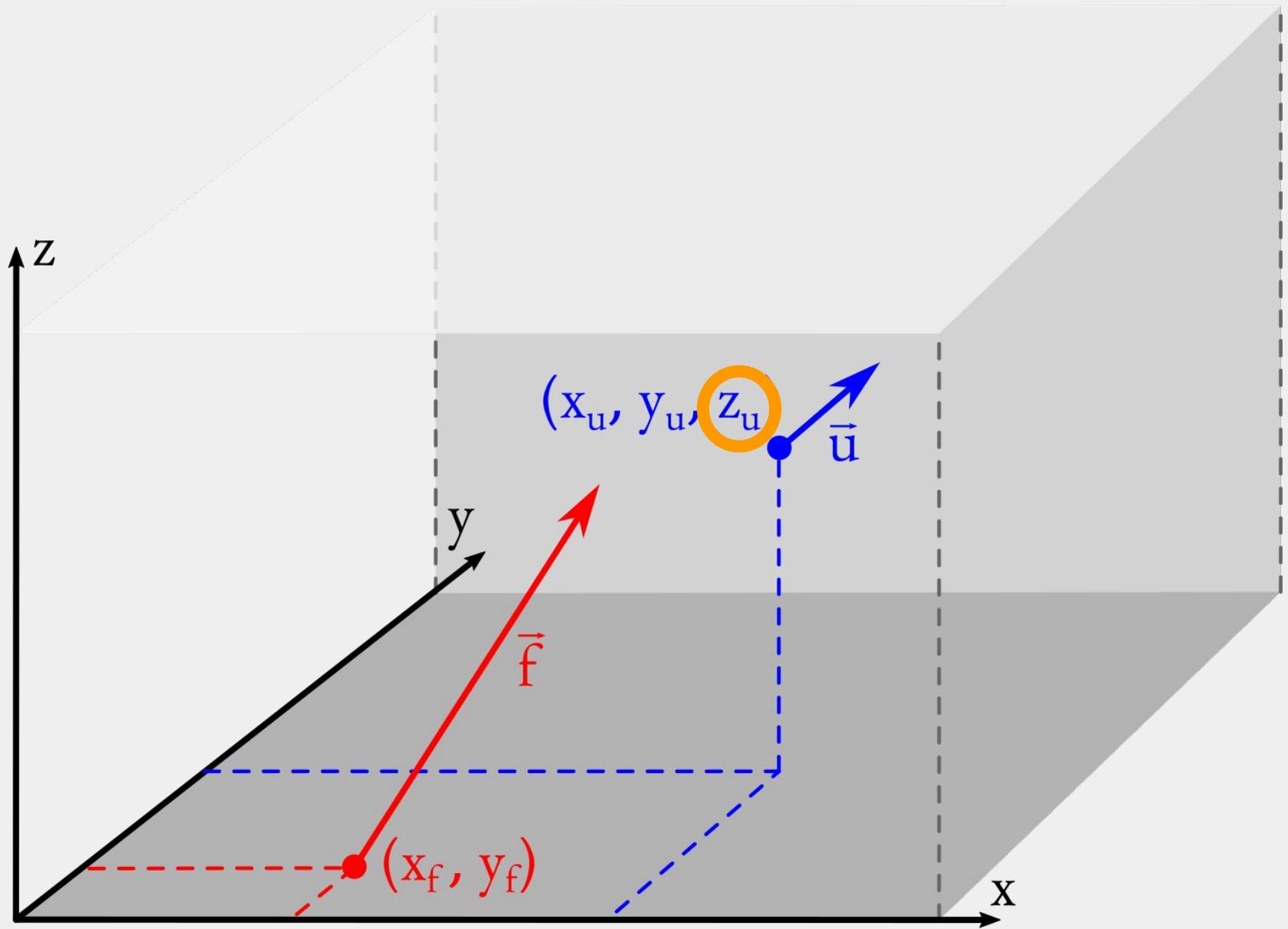
displacement

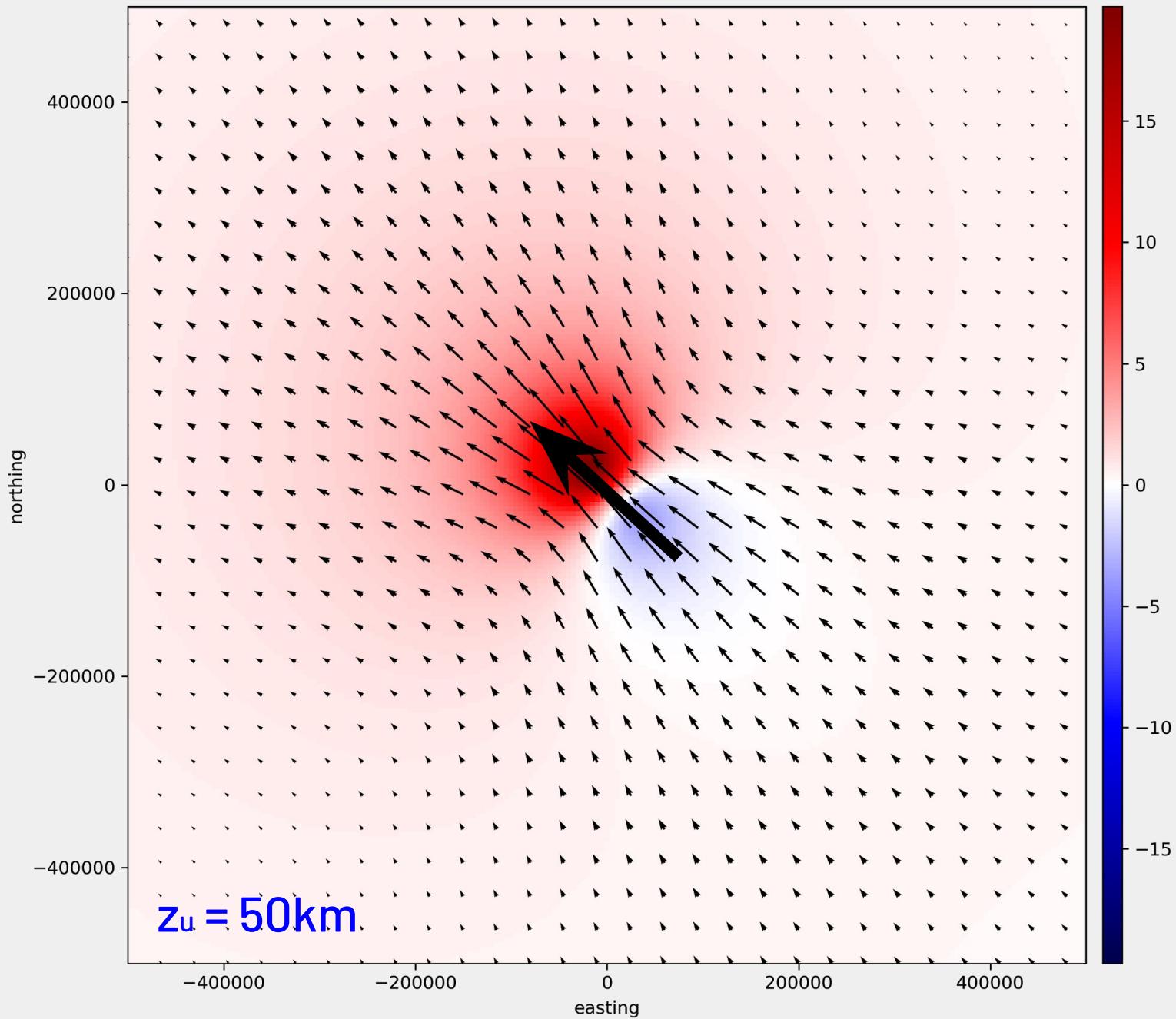
$$\begin{bmatrix} G_{xx} & G_{xy} & G_{xz} \\ G_{yx} & G_{yy} & G_{yz} \\ G_{zx} & G_{zy} & G_{zz} \end{bmatrix} \begin{bmatrix} f_x \\ f_y \\ f_z \end{bmatrix} = \begin{bmatrix} u_x \\ u_y \\ u_z \end{bmatrix}$$

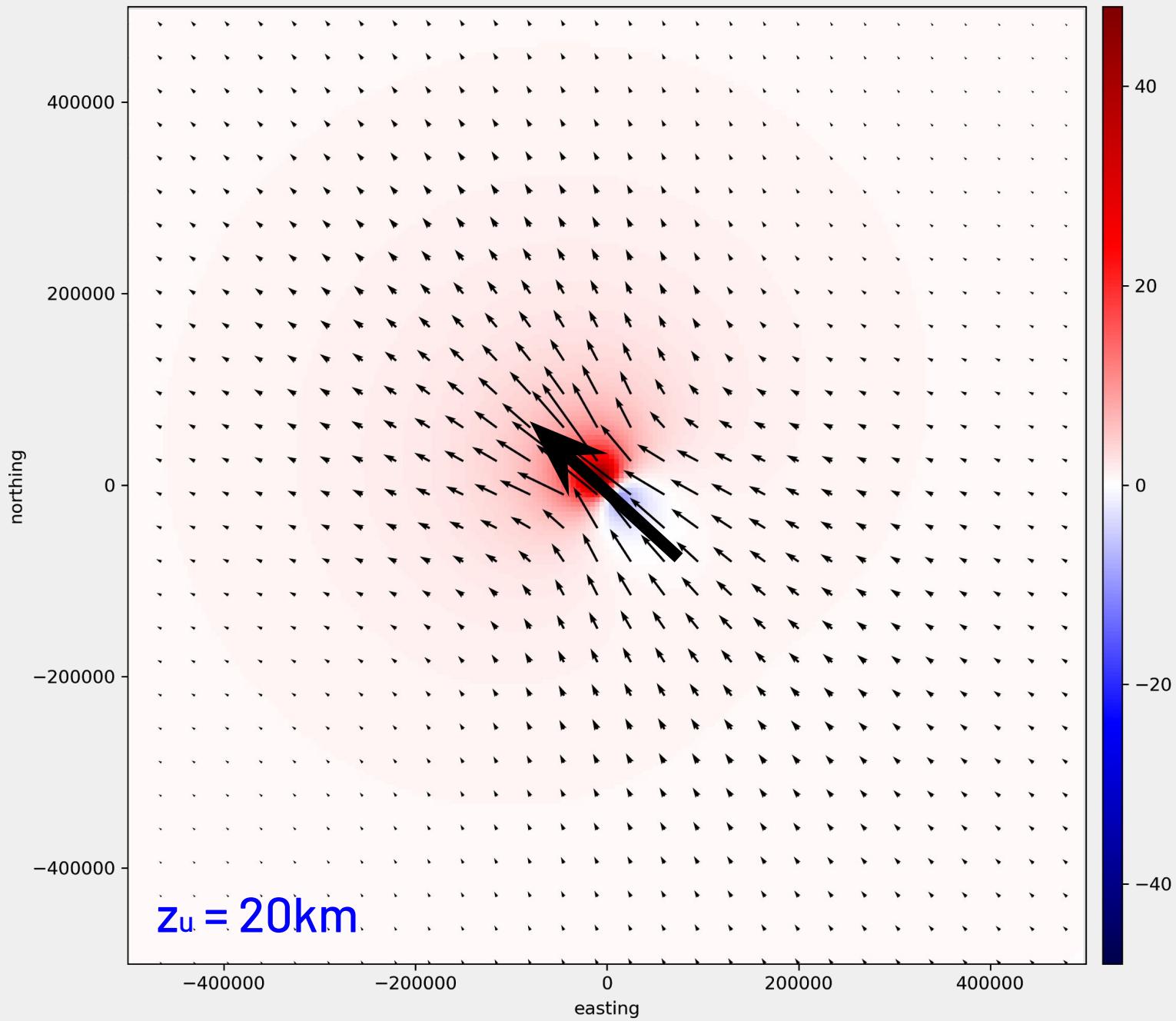
(Okumura, 1995)





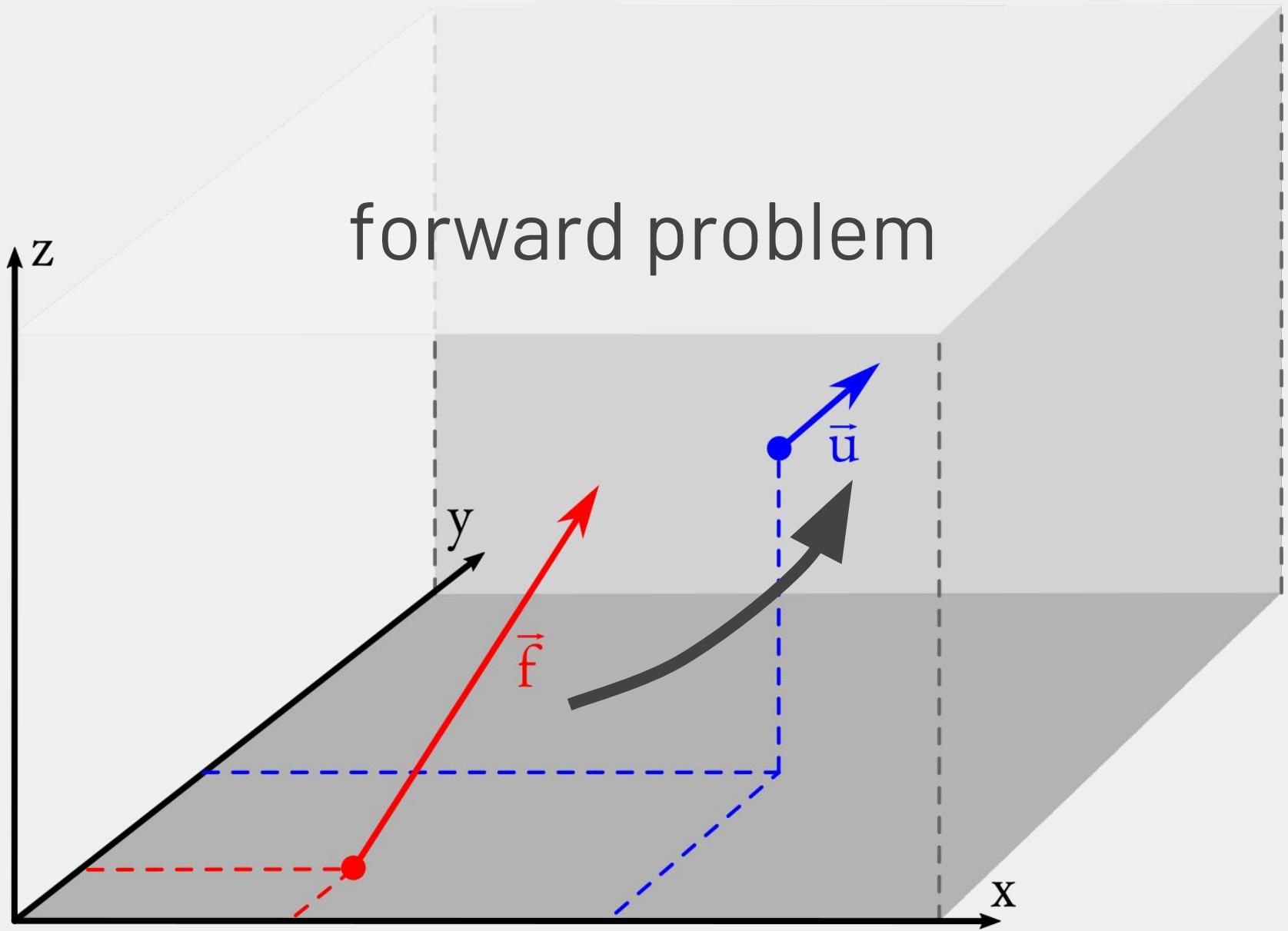




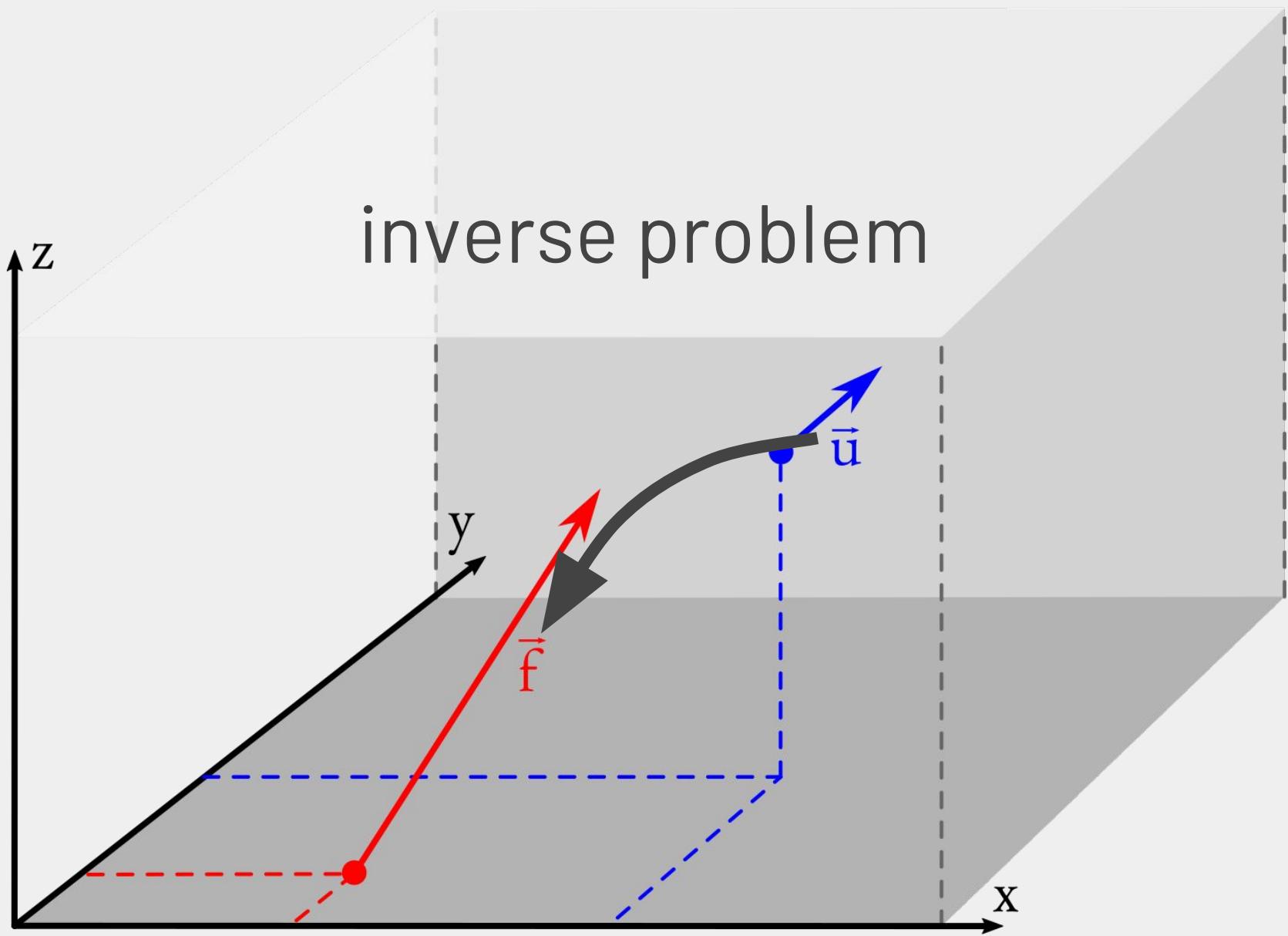


Inverse problem

forward problem



inverse problem



M forces

$\vec{f}_1, \vec{f}_2, \dots, \vec{f}_M$

N displacements

$\vec{u}_1, \vec{u}_2, \dots, \vec{u}_N$

forward problem

$$\begin{bmatrix} \bar{\bar{G}}_{xx} & \bar{\bar{G}}_{xy} & \bar{\bar{G}}_{xz} \\ \bar{\bar{G}}_{yx} & \bar{\bar{G}}_{yy} & \bar{\bar{G}}_{yz} \\ \bar{\bar{G}}_{zx} & \bar{\bar{G}}_{zy} & \bar{\bar{G}}_{zz} \end{bmatrix} \begin{bmatrix} \bar{f}_x \\ \bar{f}_y \\ \bar{f}_z \end{bmatrix} = \begin{bmatrix} \bar{u}_x \\ \bar{u}_y \\ \bar{u}_z \end{bmatrix}$$

forward problem

$$\begin{bmatrix} \bar{\bar{\bar{G}}}_{xx} & \bar{\bar{\bar{G}}}_{xy} & \bar{\bar{\bar{G}}}_{xz} \\ \bar{\bar{\bar{G}}}_{yx} & \bar{\bar{\bar{G}}}_{yy} & \bar{\bar{\bar{G}}}_{yz} \\ \bar{\bar{\bar{G}}}_{zx} & \bar{\bar{\bar{G}}}_{zy} & \bar{\bar{\bar{G}}}_{zz} \end{bmatrix} \begin{bmatrix} \bar{f}_x \\ \bar{f}_y \\ \bar{f}_z \end{bmatrix} = \begin{bmatrix} \bar{u}_x \\ \bar{u}_y \\ \bar{u}_z \end{bmatrix}$$
$$\bar{\bar{\bar{G}}} \quad \bar{f} \quad \bar{u}$$

weighted least-squares solution

$$\left(\bar{G}^T \bar{W} \bar{G} + \mu \bar{I} \right) \hat{\bar{f}} = \bar{G}^T \bar{W} \bar{u}$$

weighted least-squares solution

$$\left(\bar{G}^T \bar{W} \bar{G} + \mu \bar{I} \right) \hat{\bar{f}} = \bar{G}^T \bar{W} \bar{u}$$



regularization

interpolation = forward modeling

$$\bar{u} = \bar{\bar{G}} \hat{f}$$

Controlling parameters:

regularization parameter μ

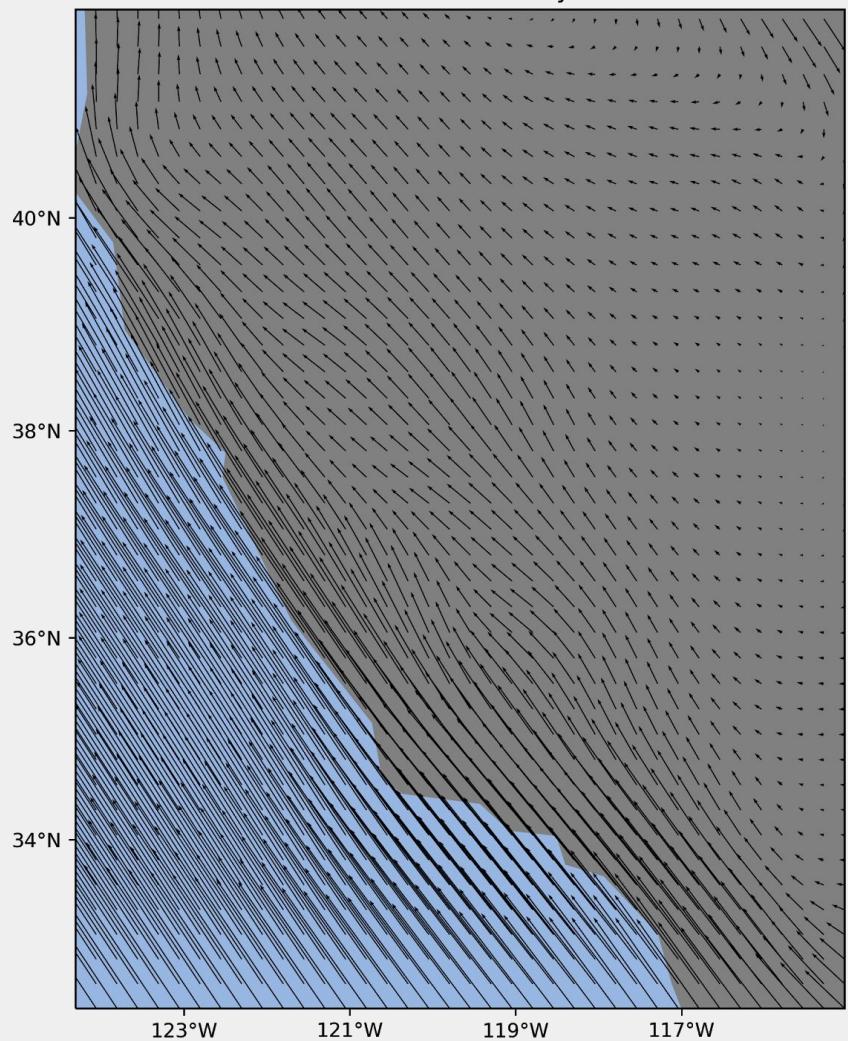
height of displacements z_u

Poisson's ratio ν

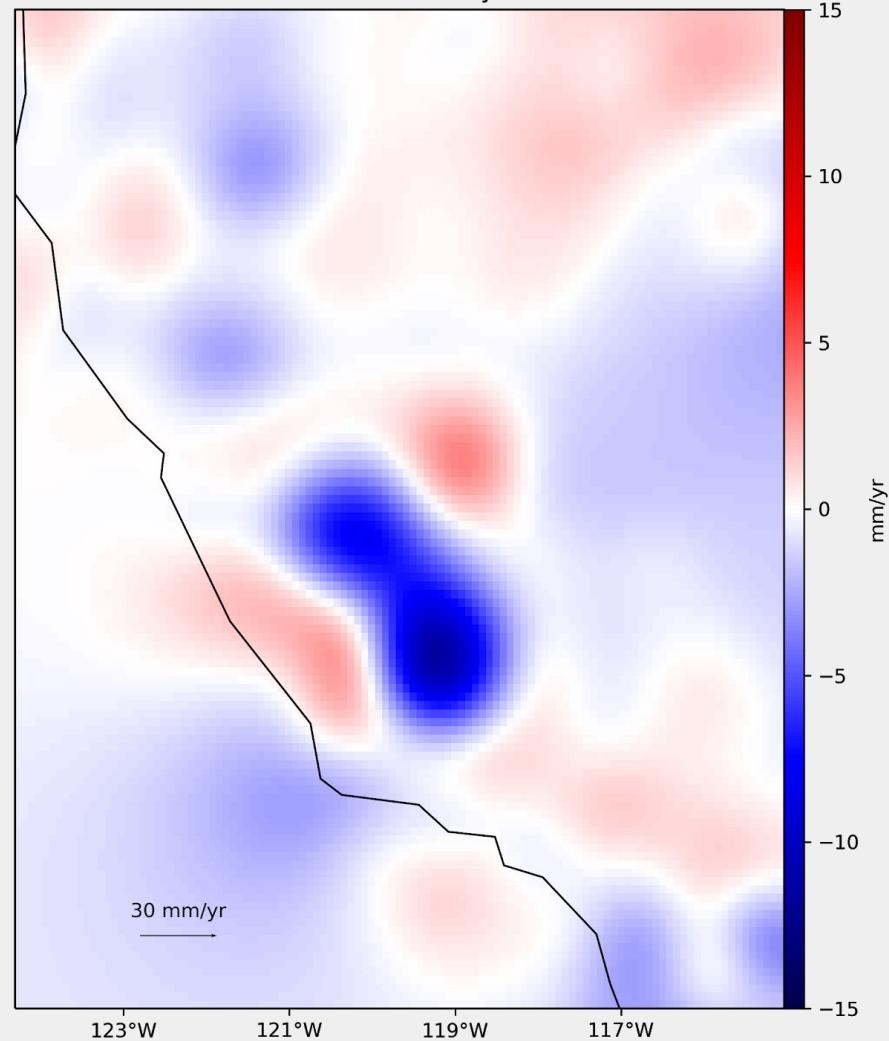
force locations (x_f, y_f)

Synthetic data

Horizontal velocity

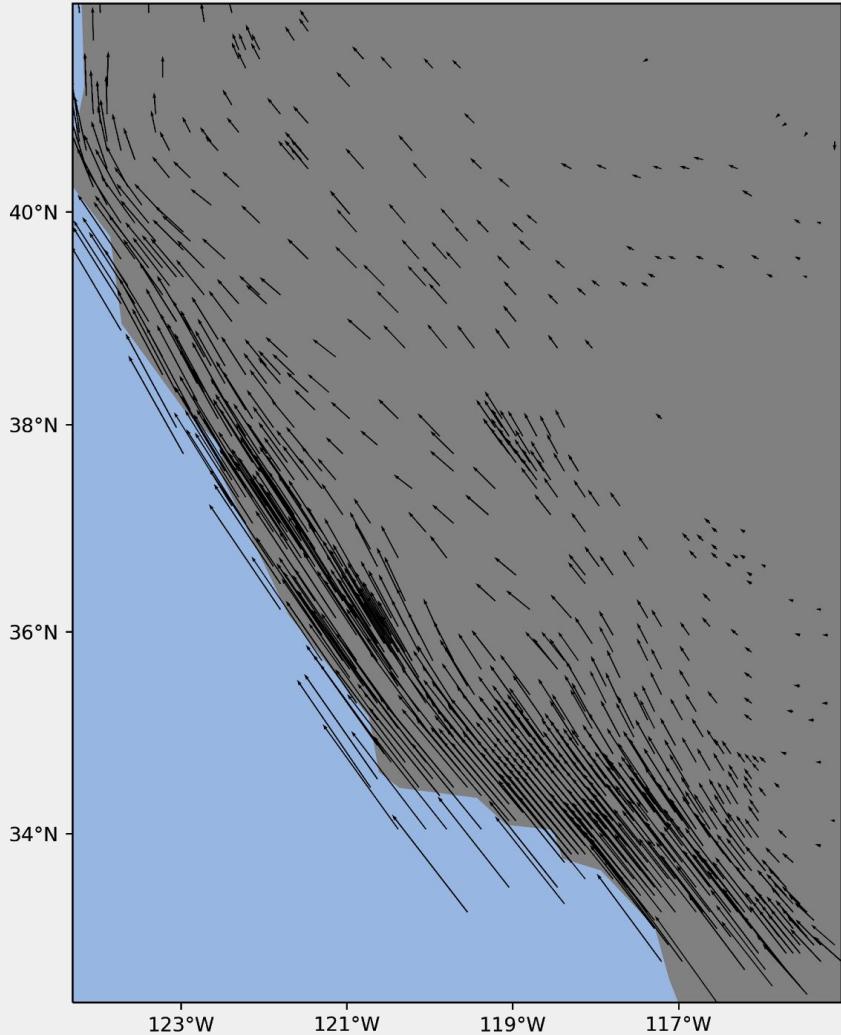


Vertical velocity

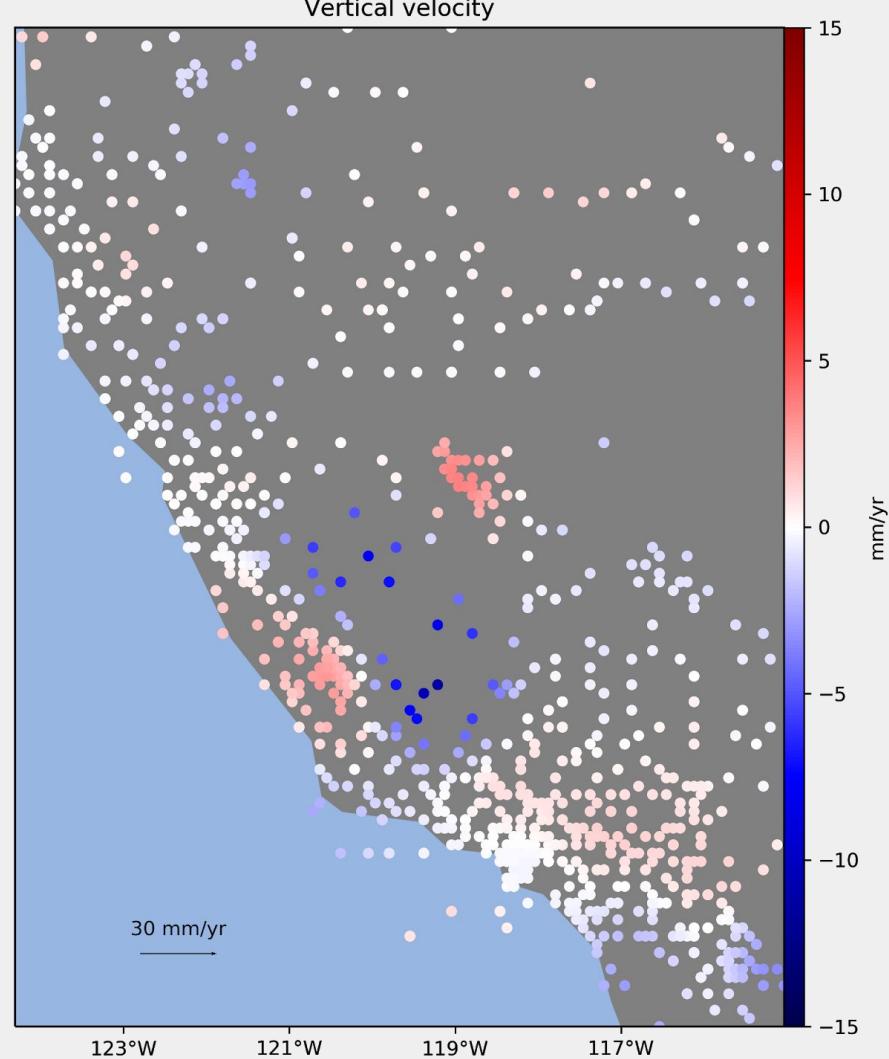


random sample

Horizontal velocity



Vertical velocity



Controlling parameters:

regularization parameter 10

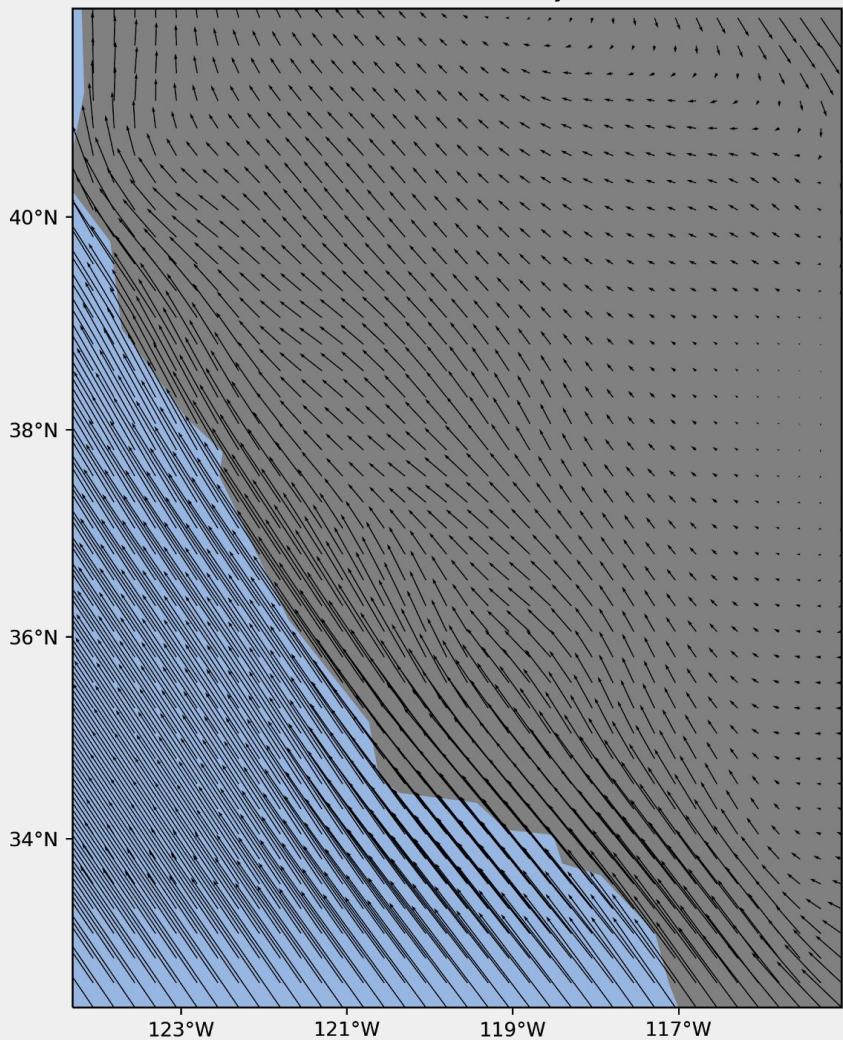
height of displacements 100 km

Poisson's ratio 0.5

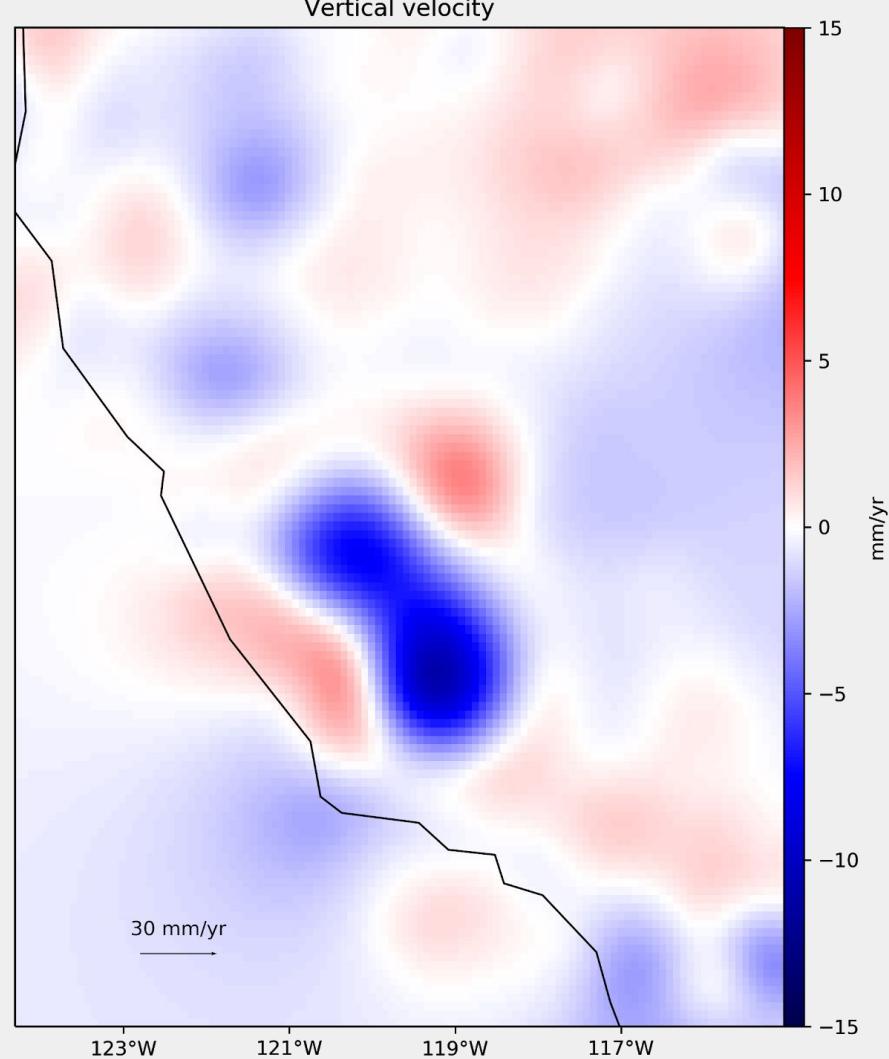
force locations same as data

gridded solution

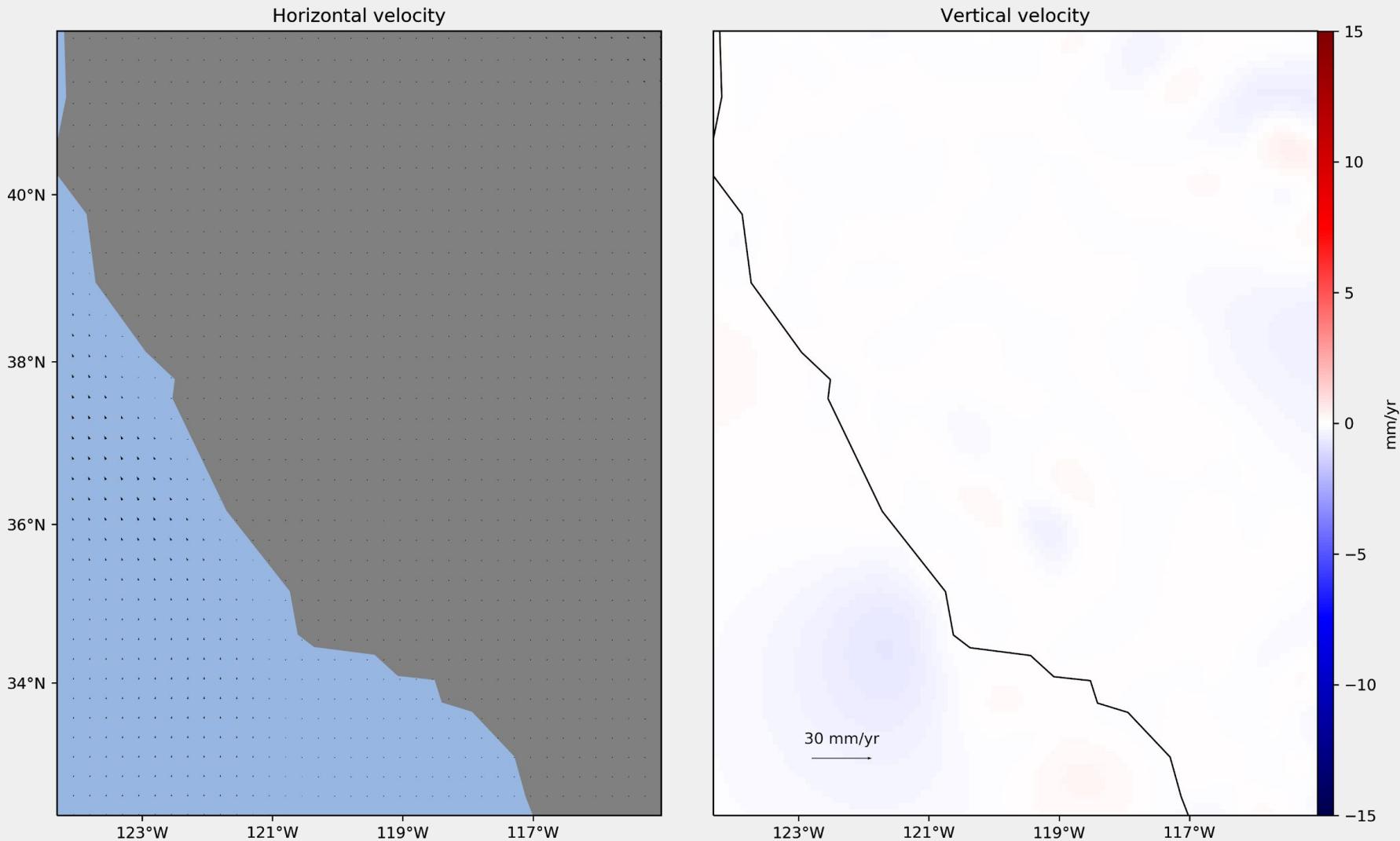
Horizontal velocity



Vertical velocity

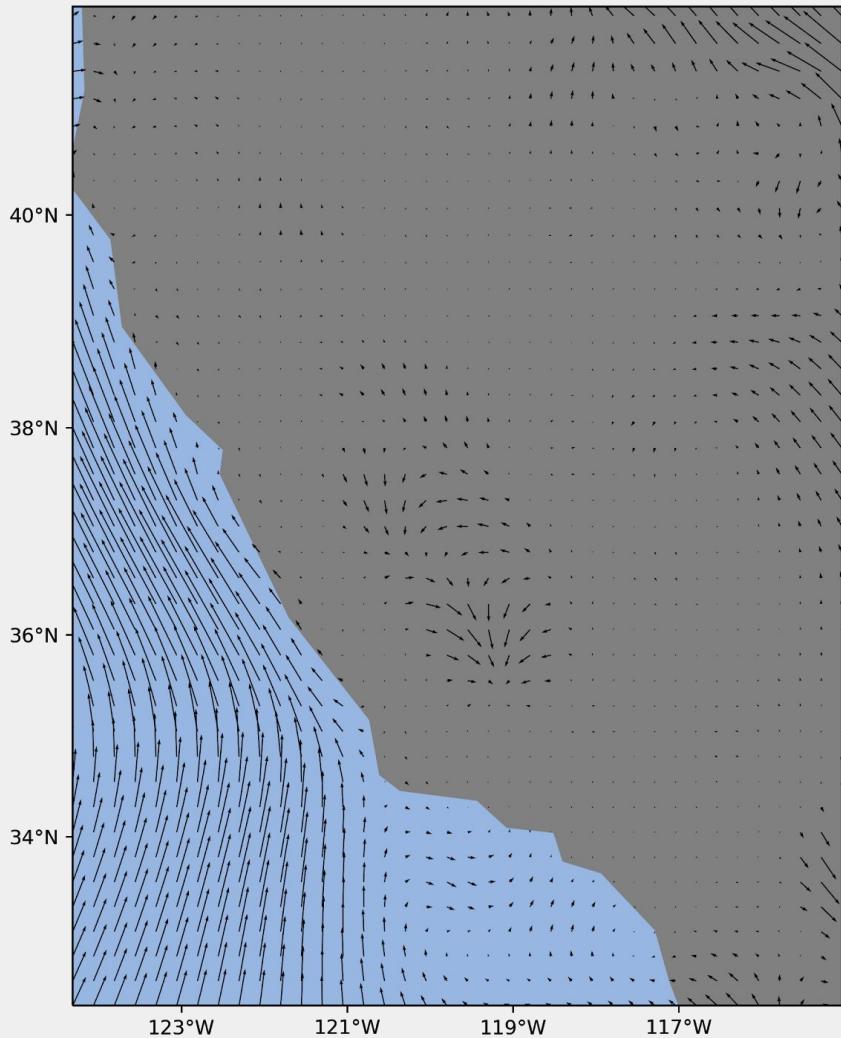


residuals

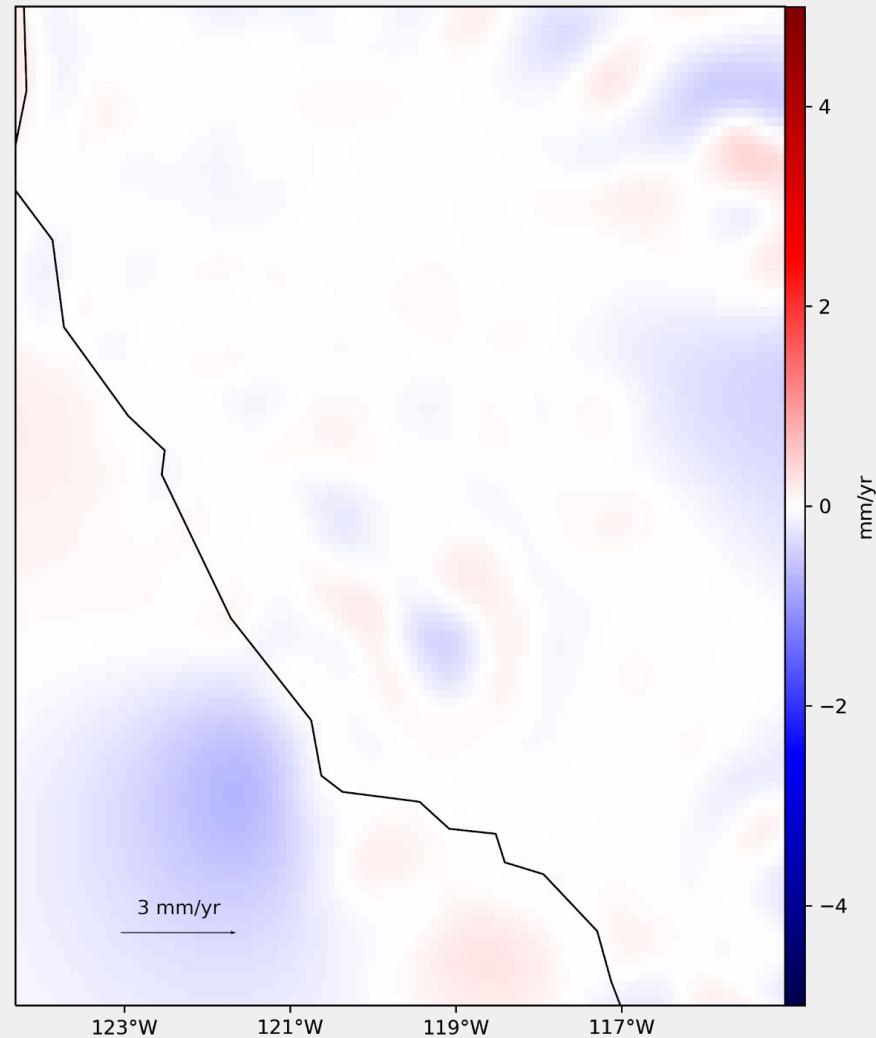


residuals (exaggerated)

Horizontal velocity



Vertical velocity



Automatic tuning

Controlling parameters:

regularization parameter μ

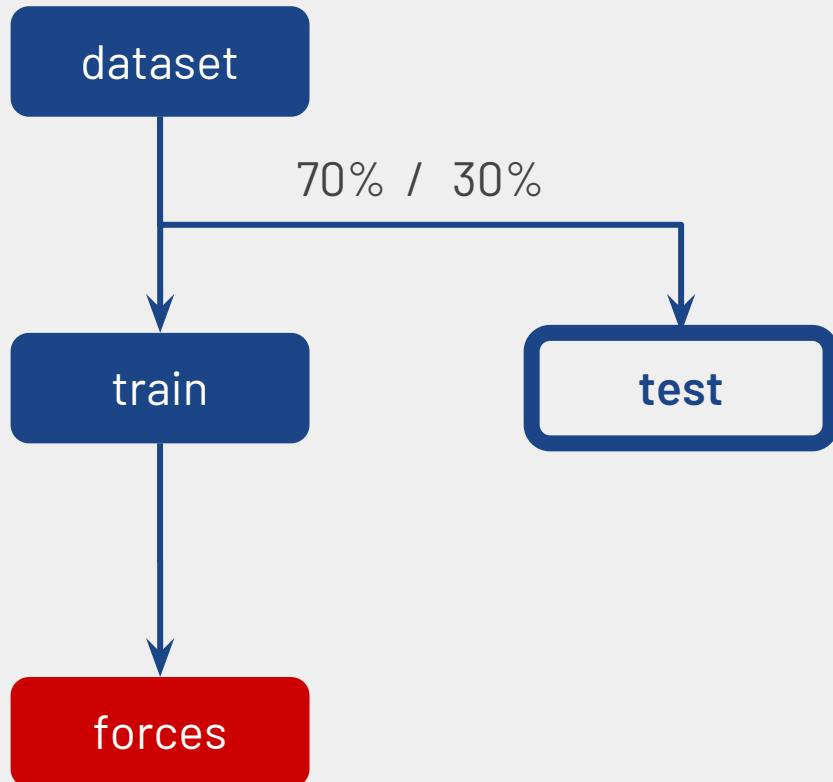
height of displacements z_u

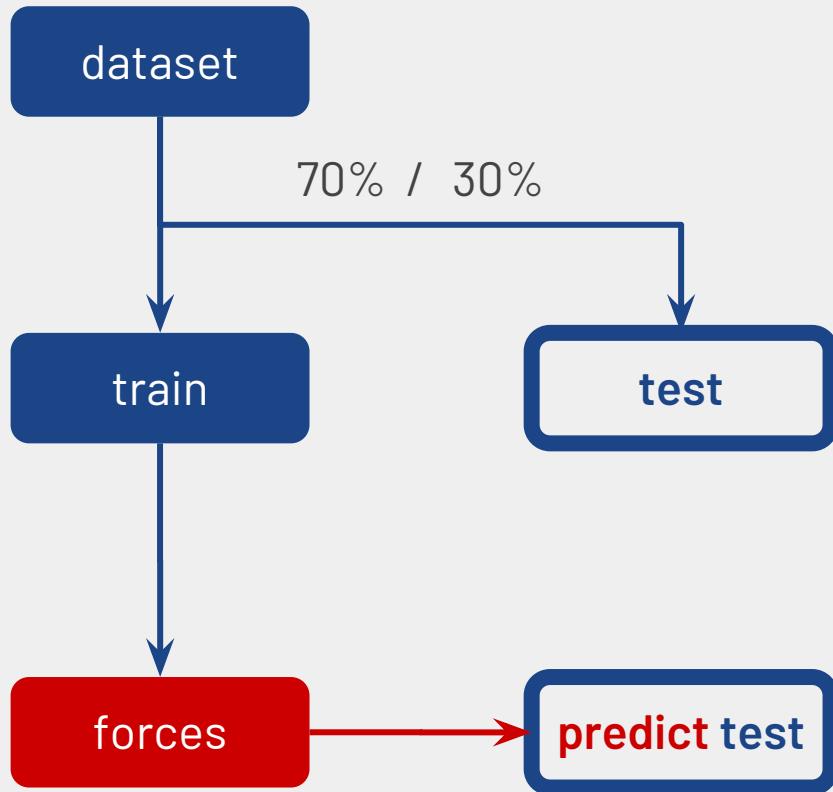
Poisson's ratio ν

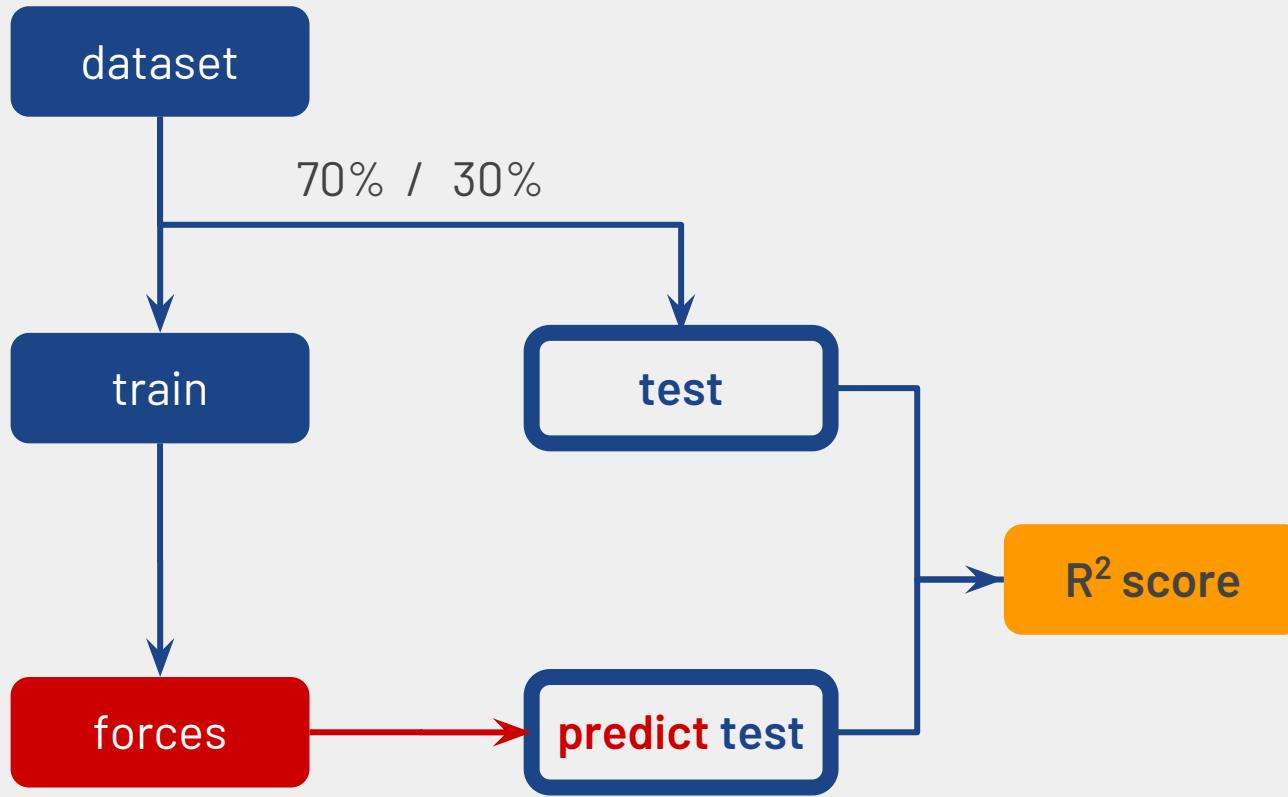
force locations (x_f, y_f)

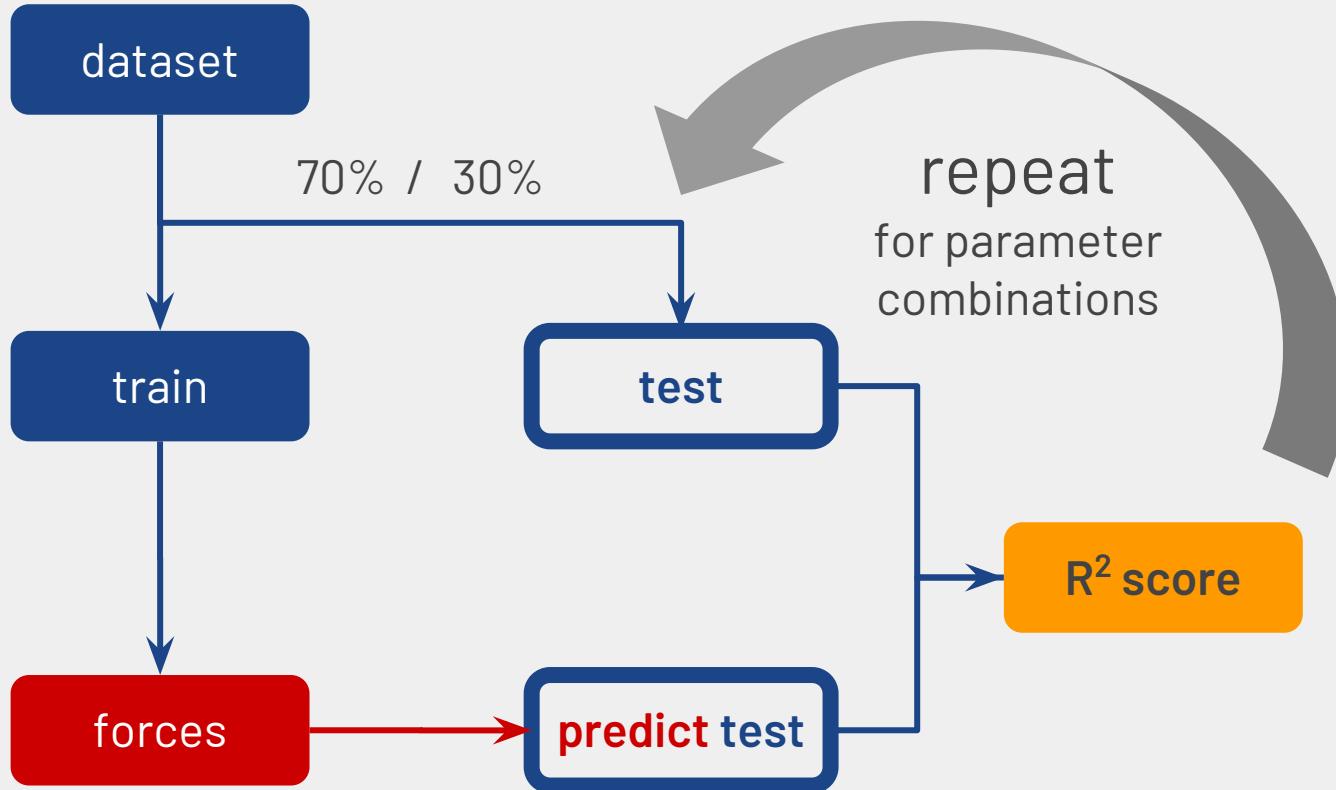
dataset

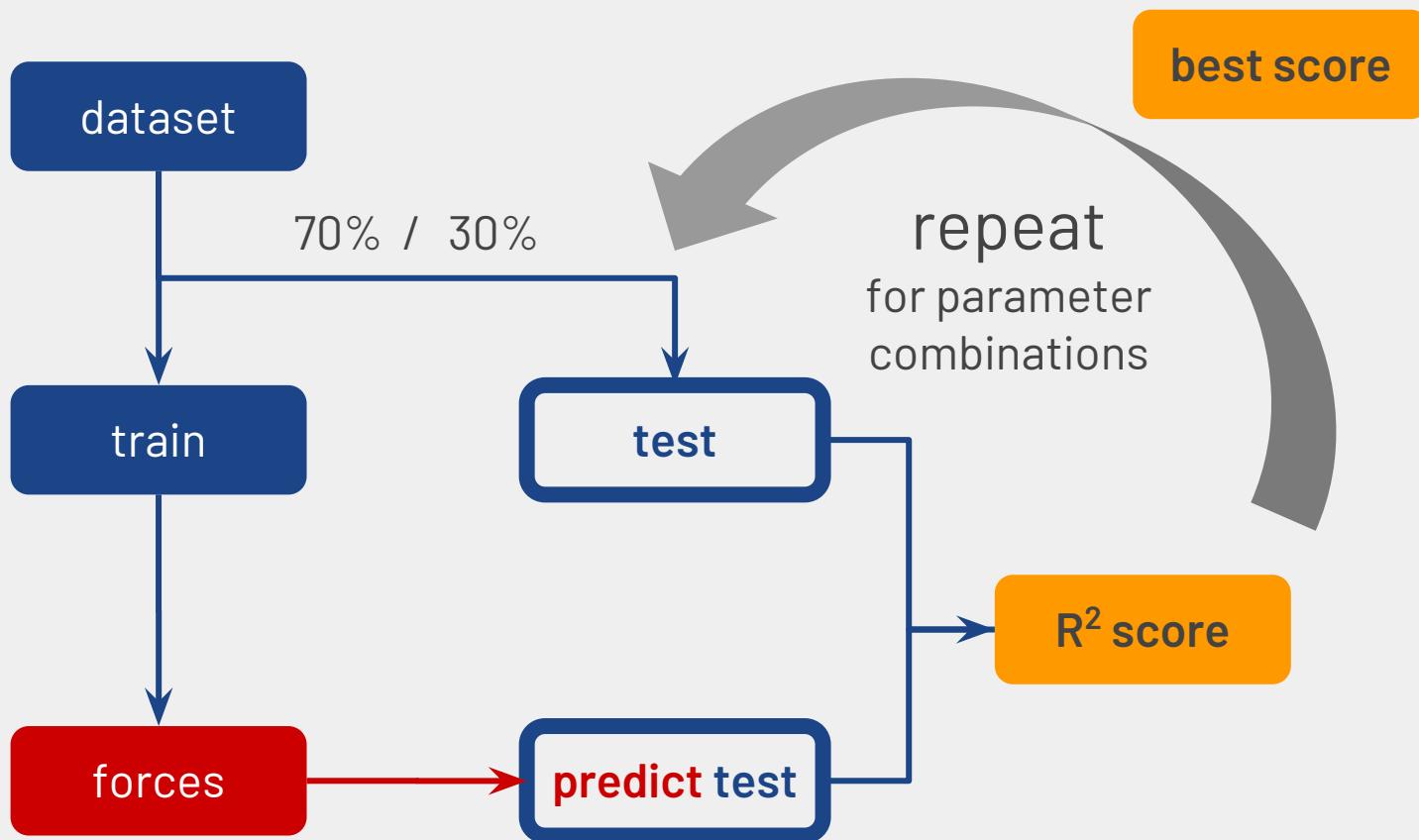


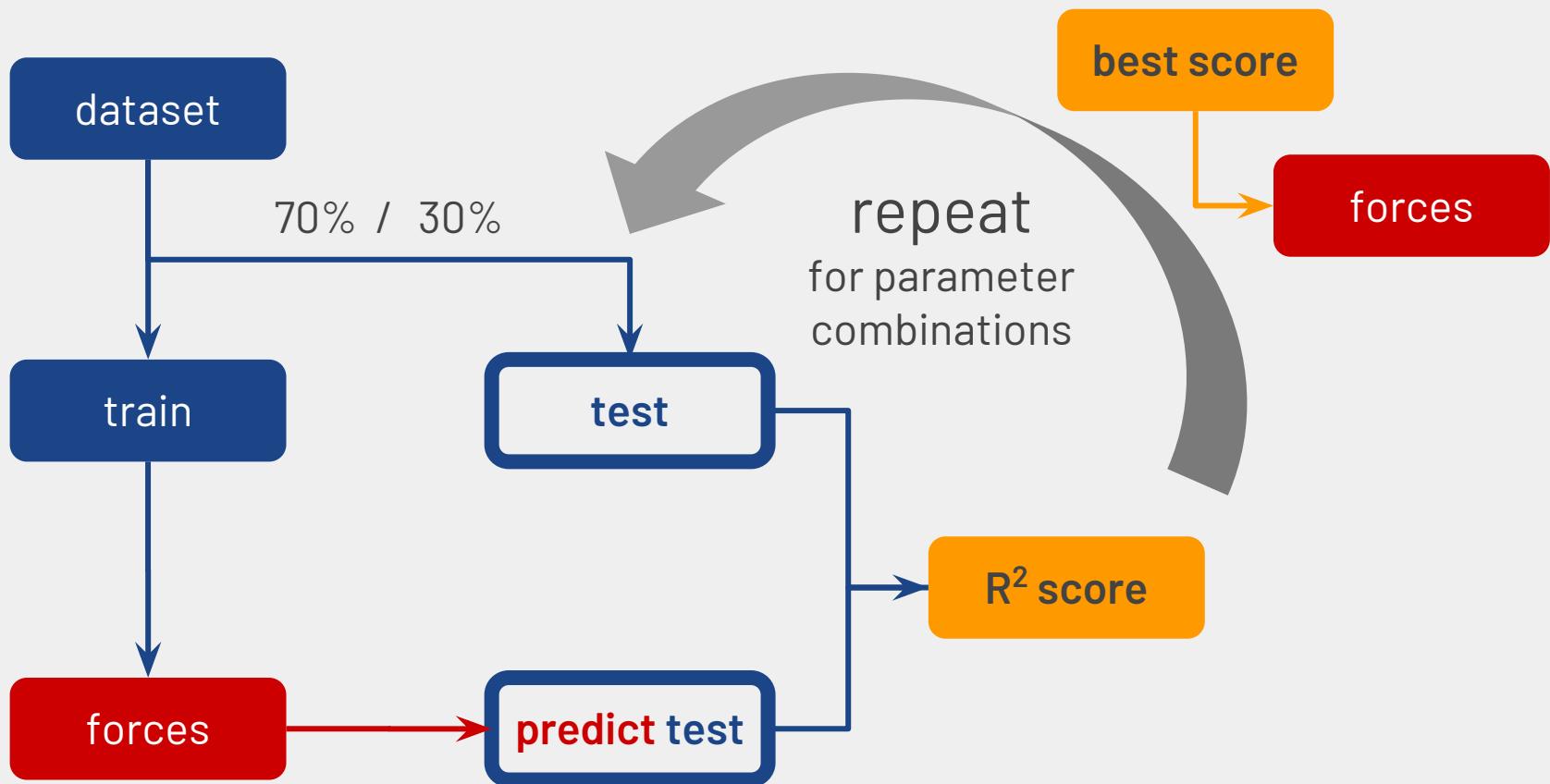












US West Coast

Plate Boundary Observatory 2017 data

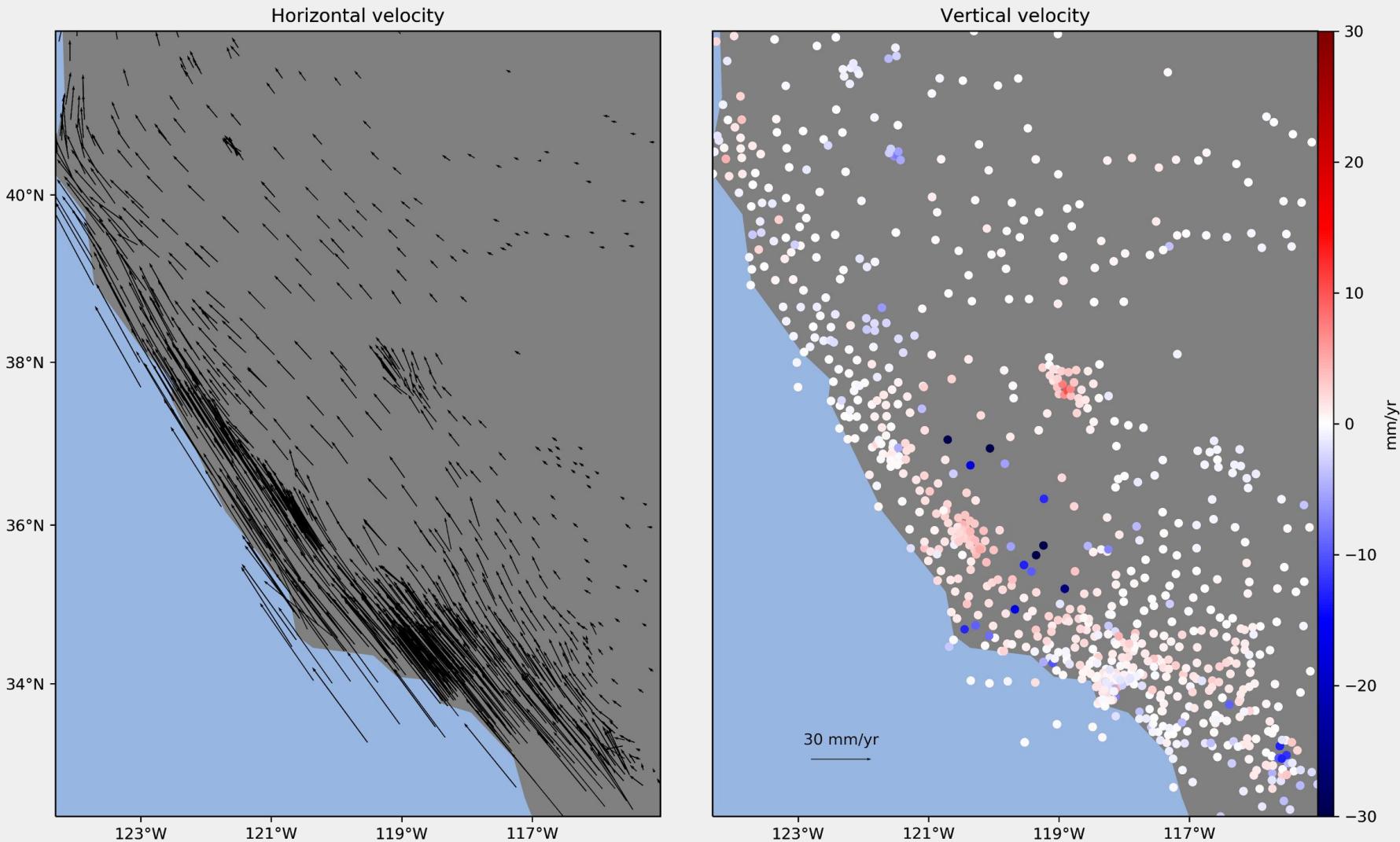


Plate Boundary Observatory 2017 data

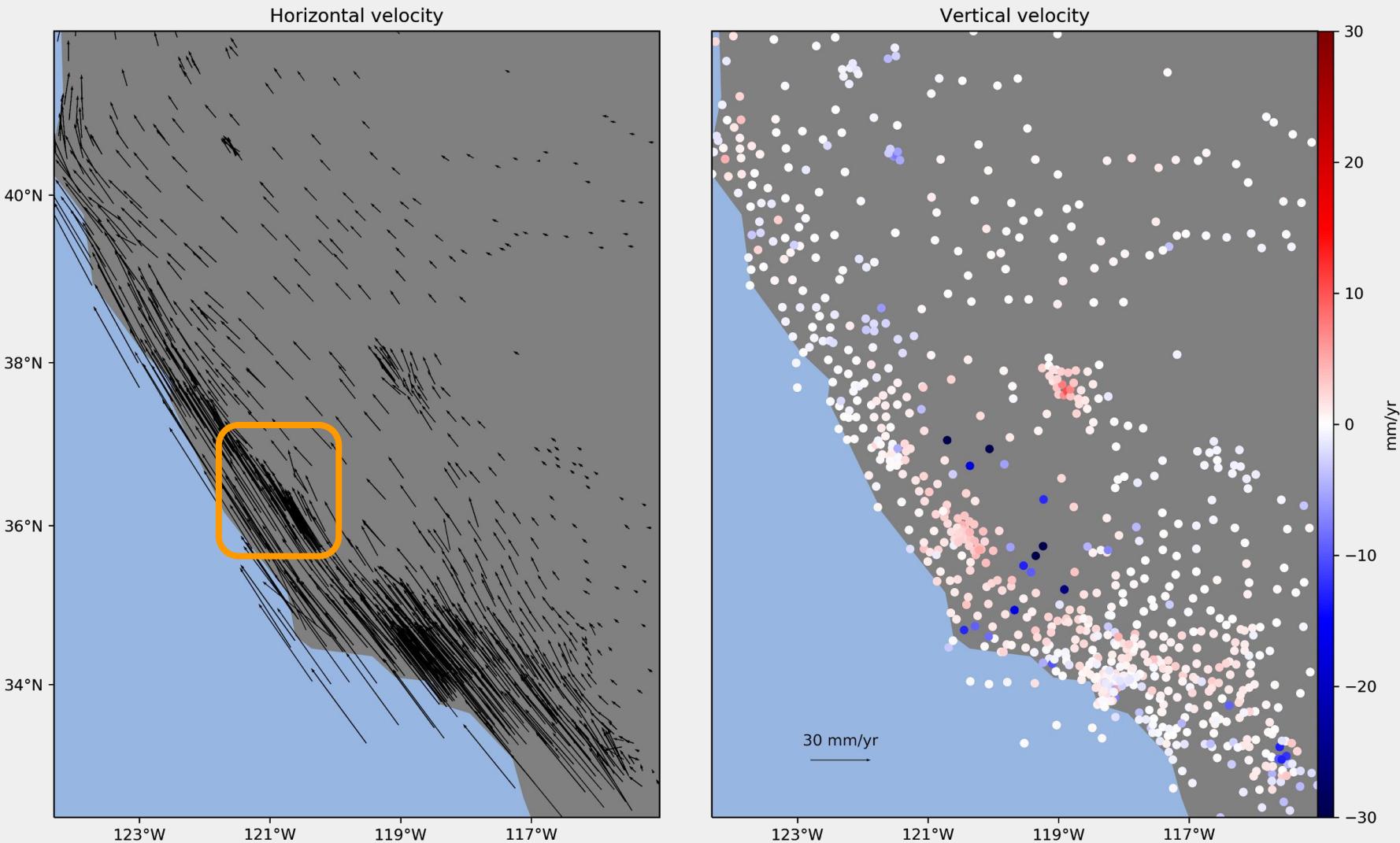


Plate Boundary Observatory 2017 data

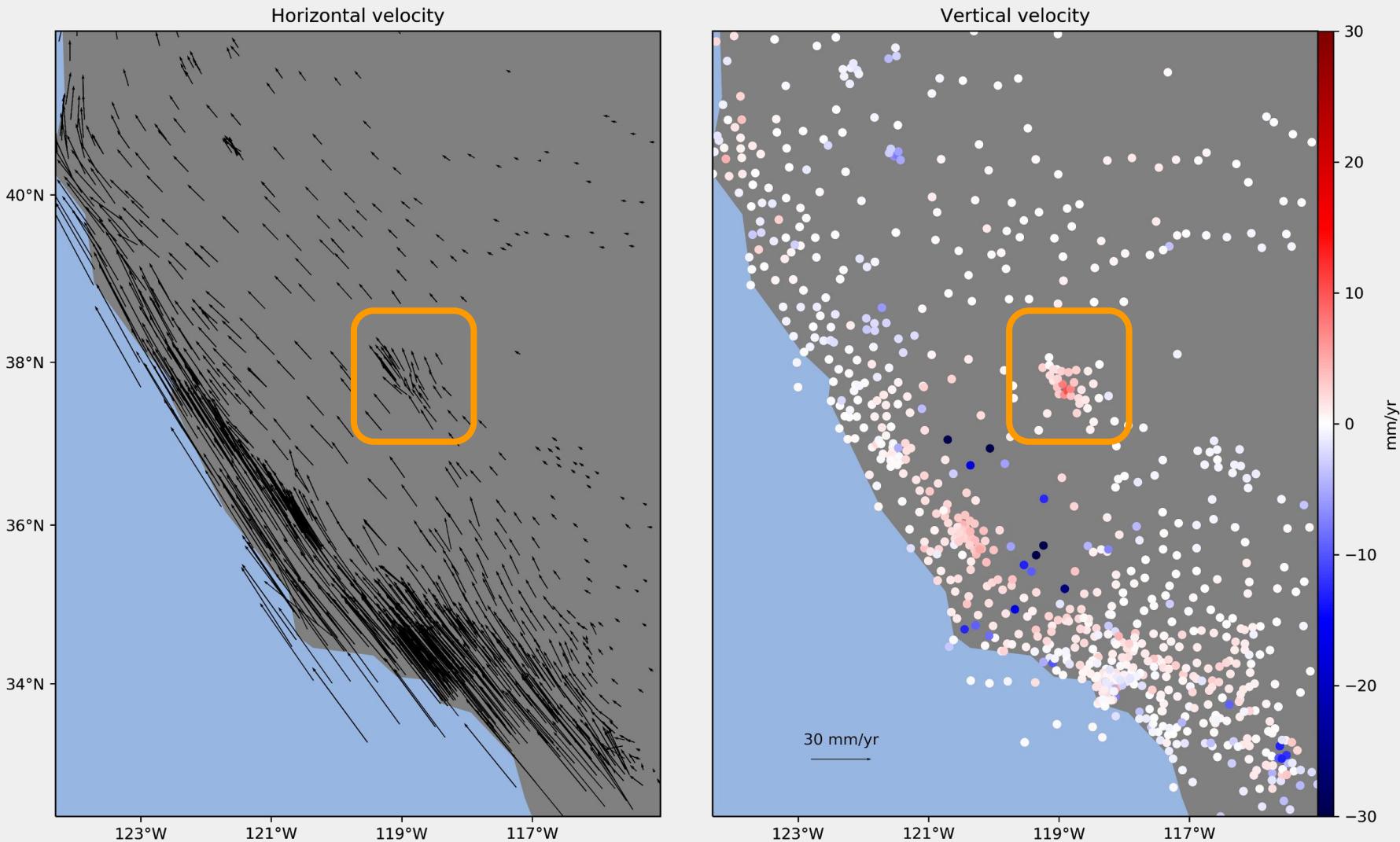
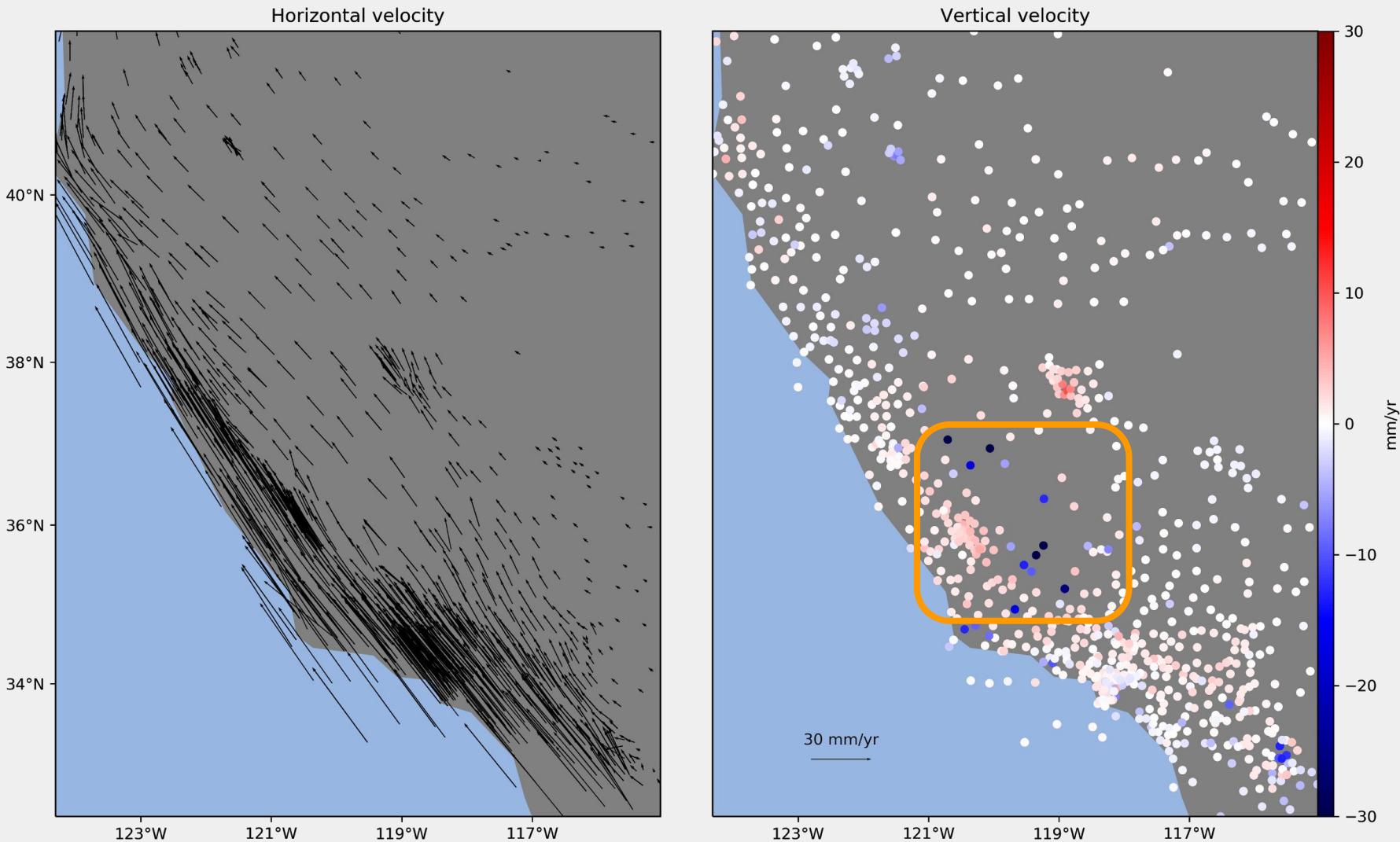


Plate Boundary Observatory 2017 data



Auto-tuned parameters:

configurations tested 120

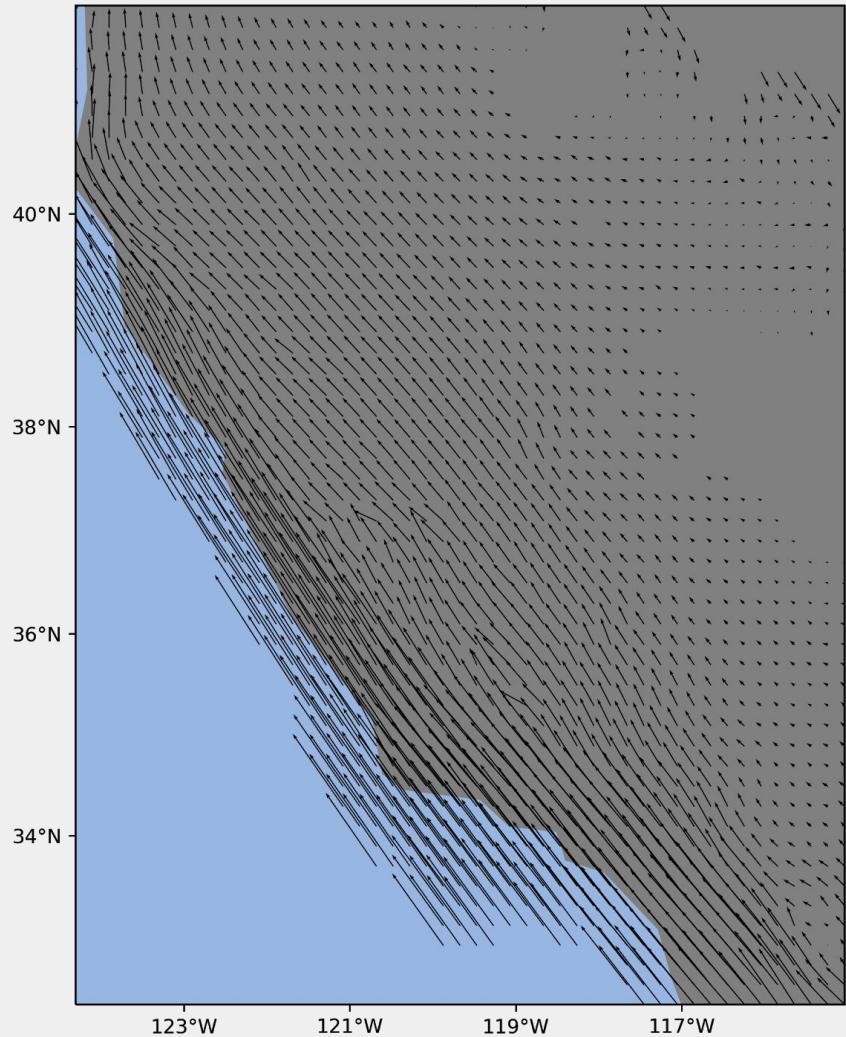
regularization parameter 50

height of displacements 10 km

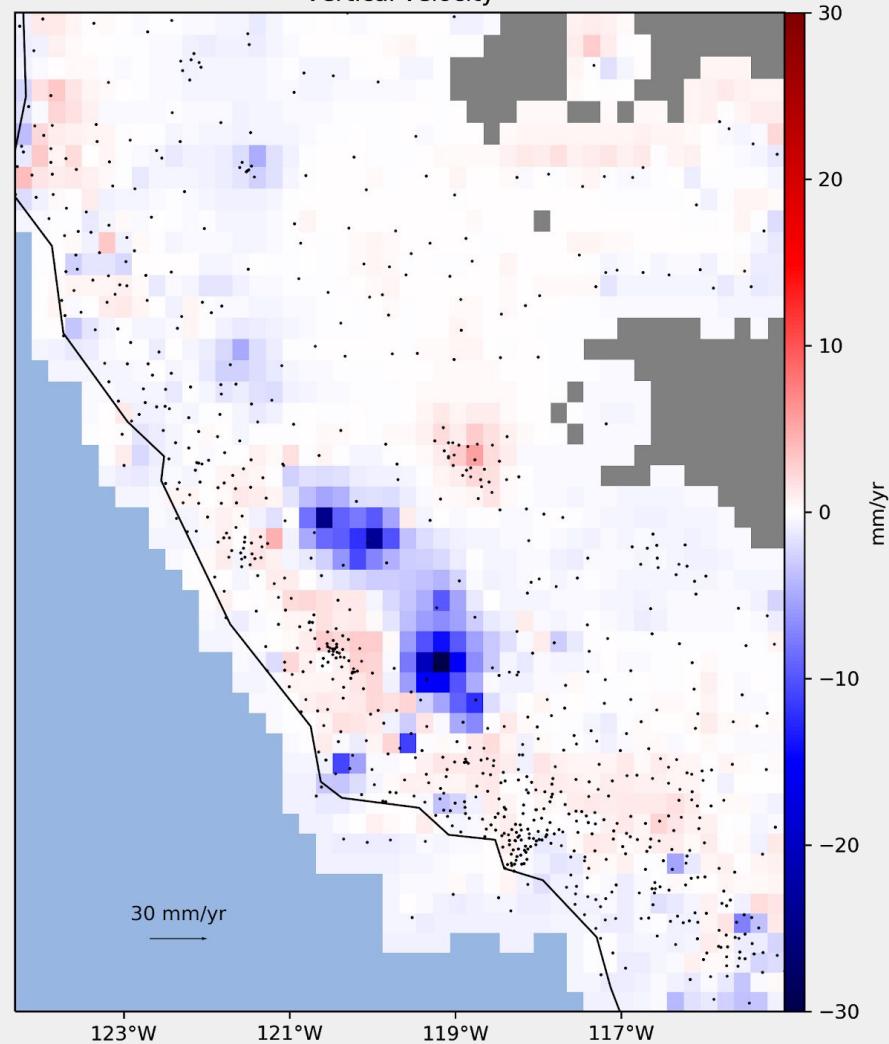
Poisson's ratio 0.5

force locations (fixed) same as data

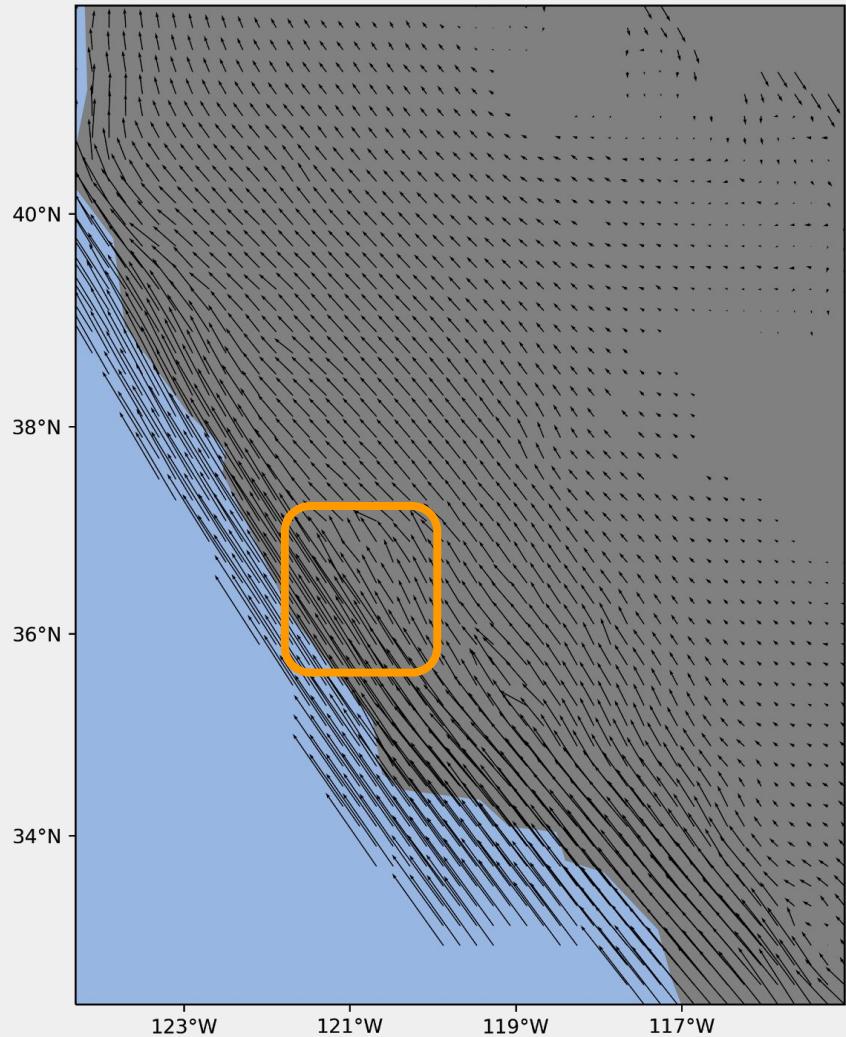
Horizontal velocity



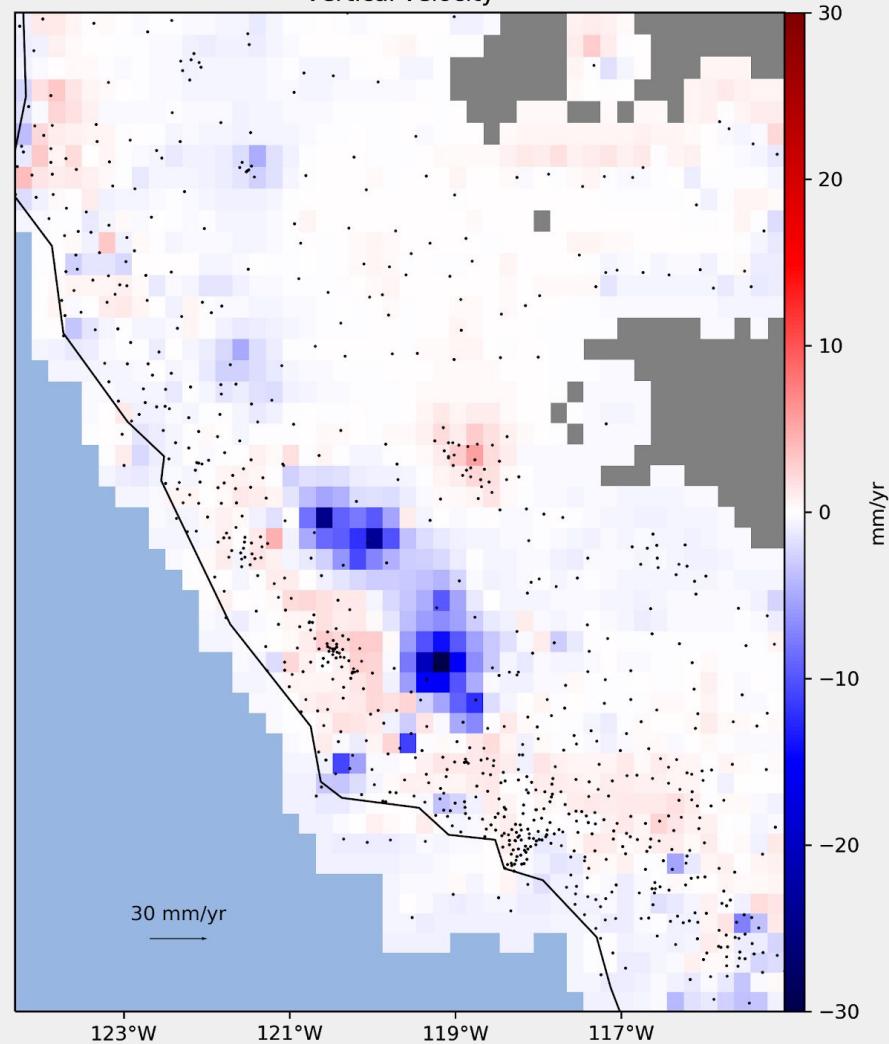
Vertical velocity



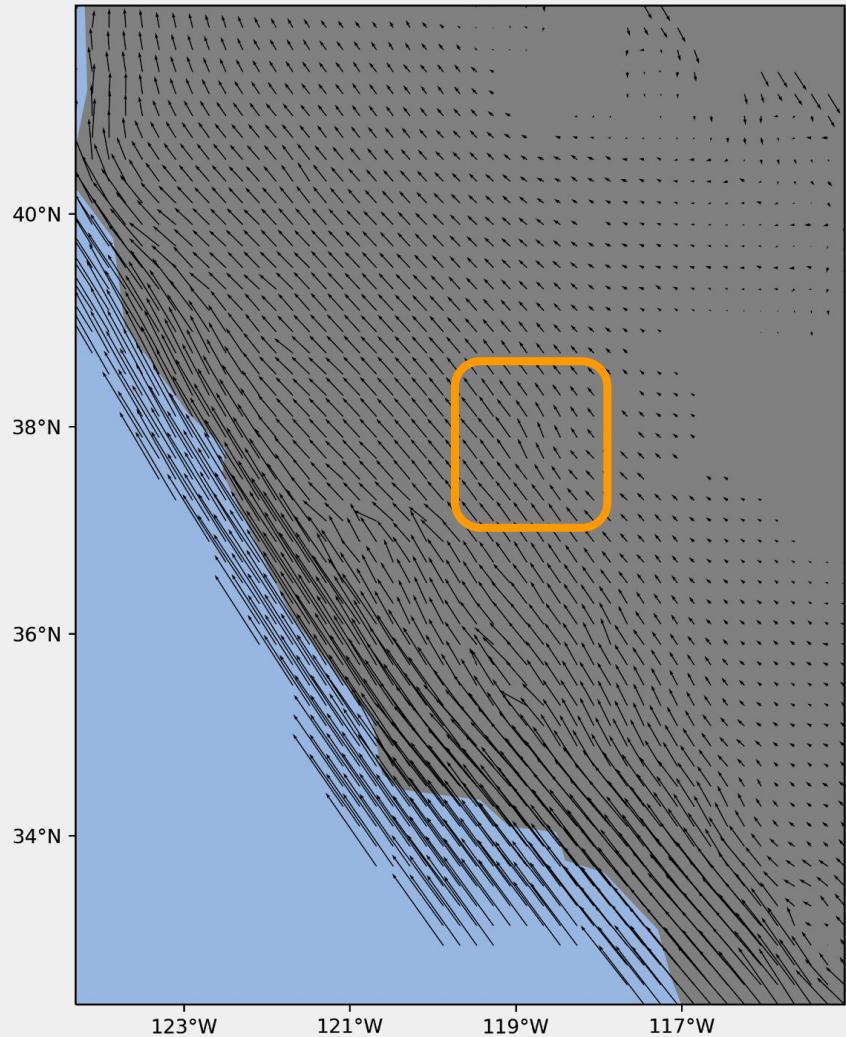
Horizontal velocity



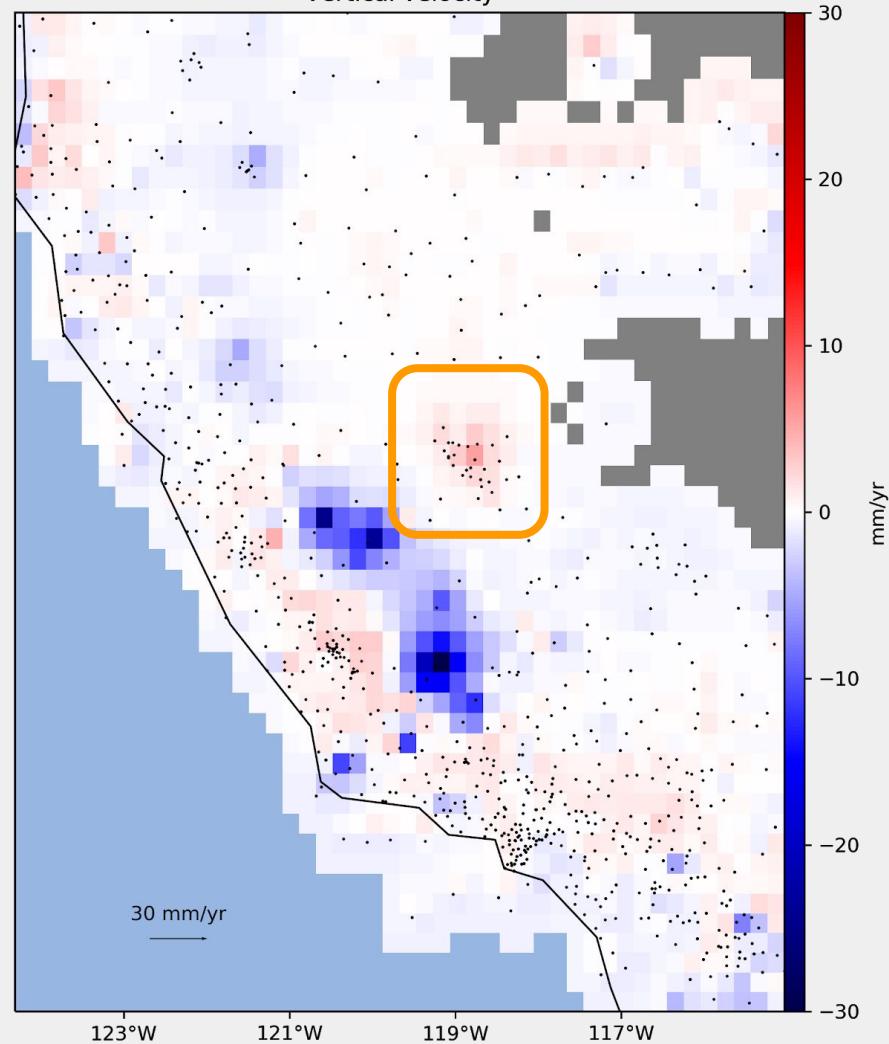
Vertical velocity



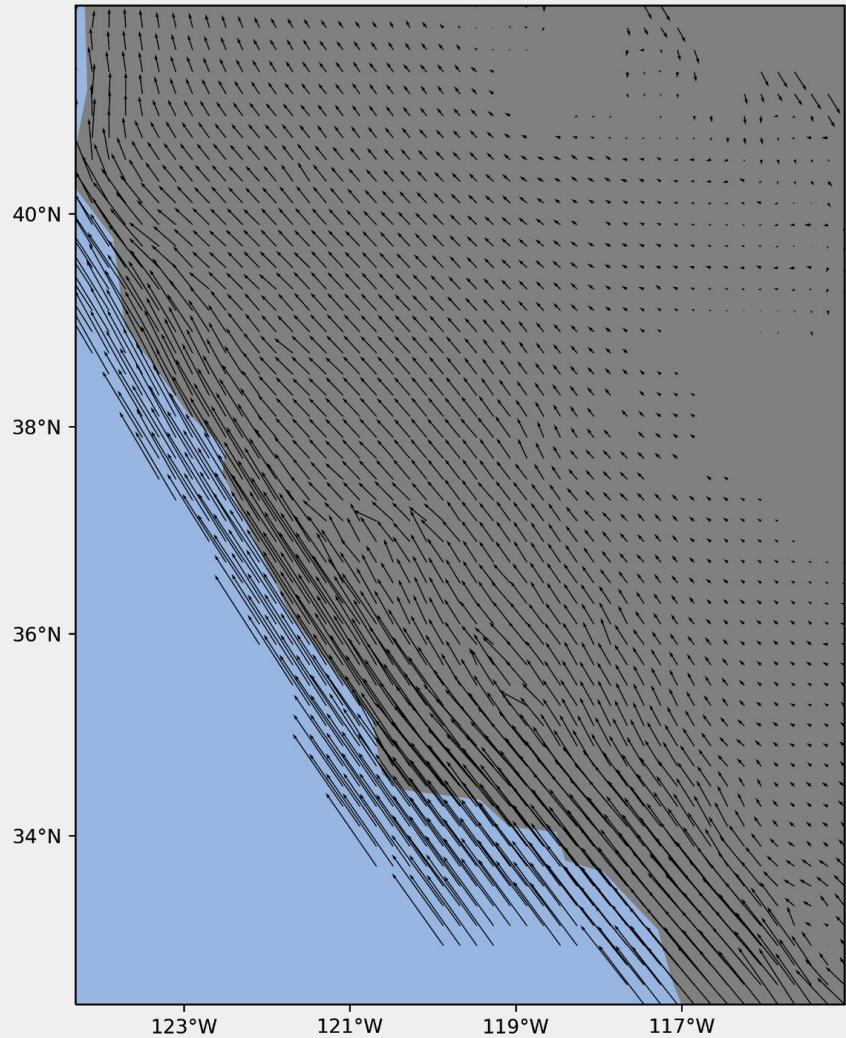
Horizontal velocity



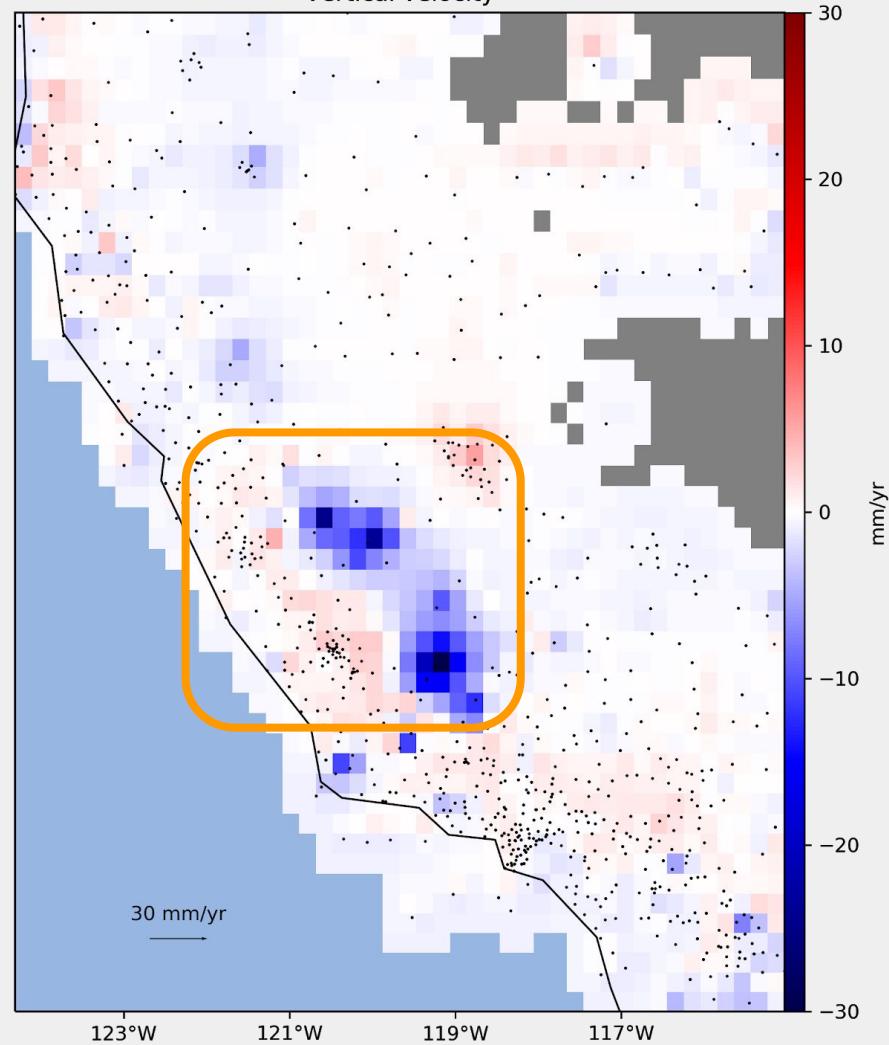
Vertical velocity



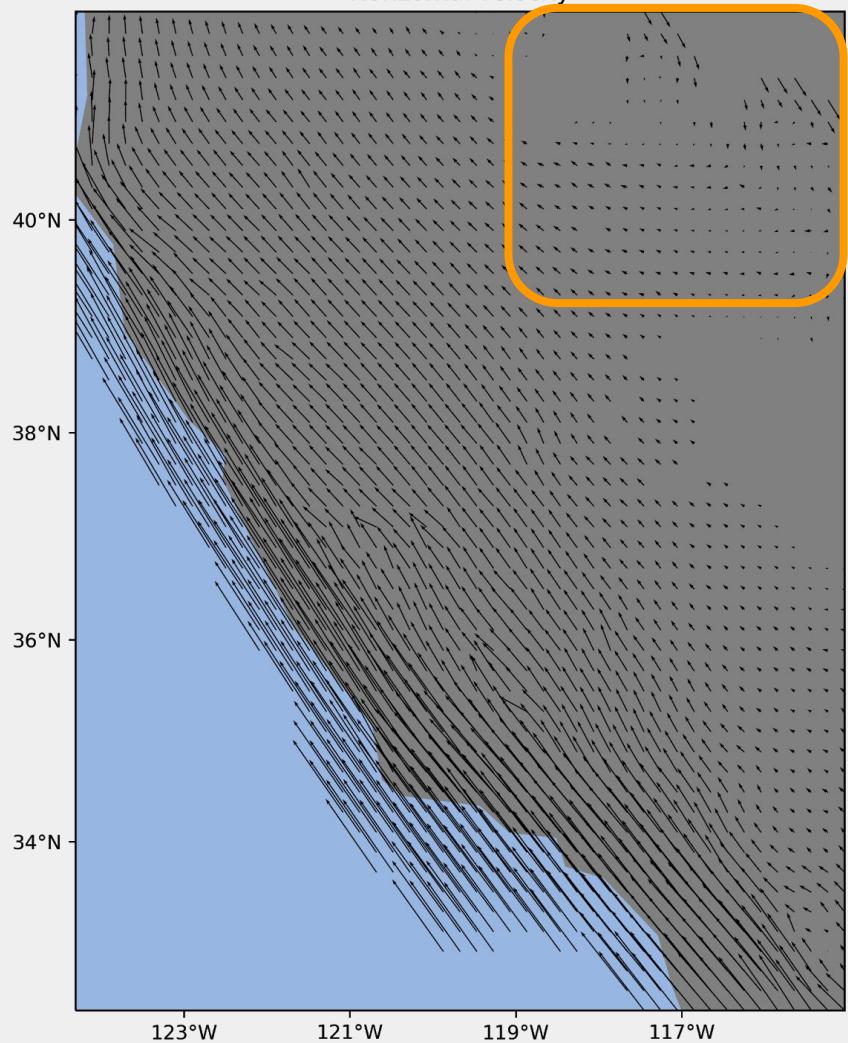
Horizontal velocity



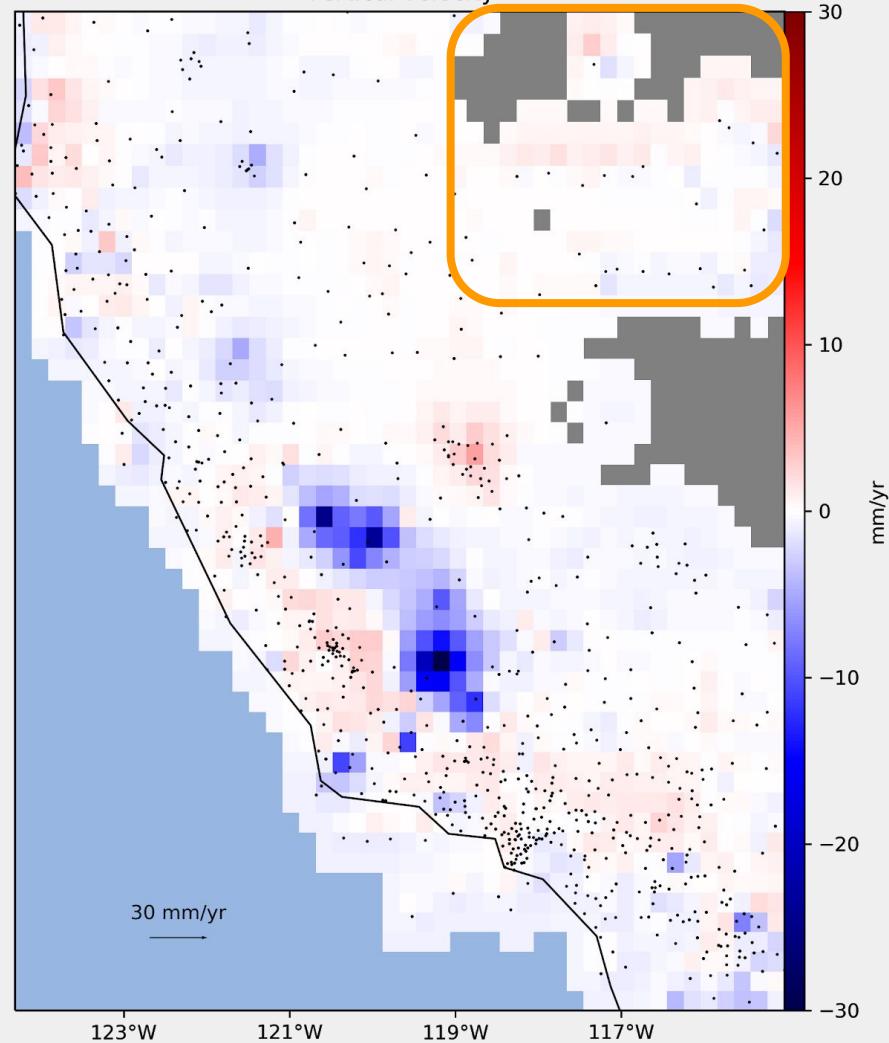
Vertical velocity



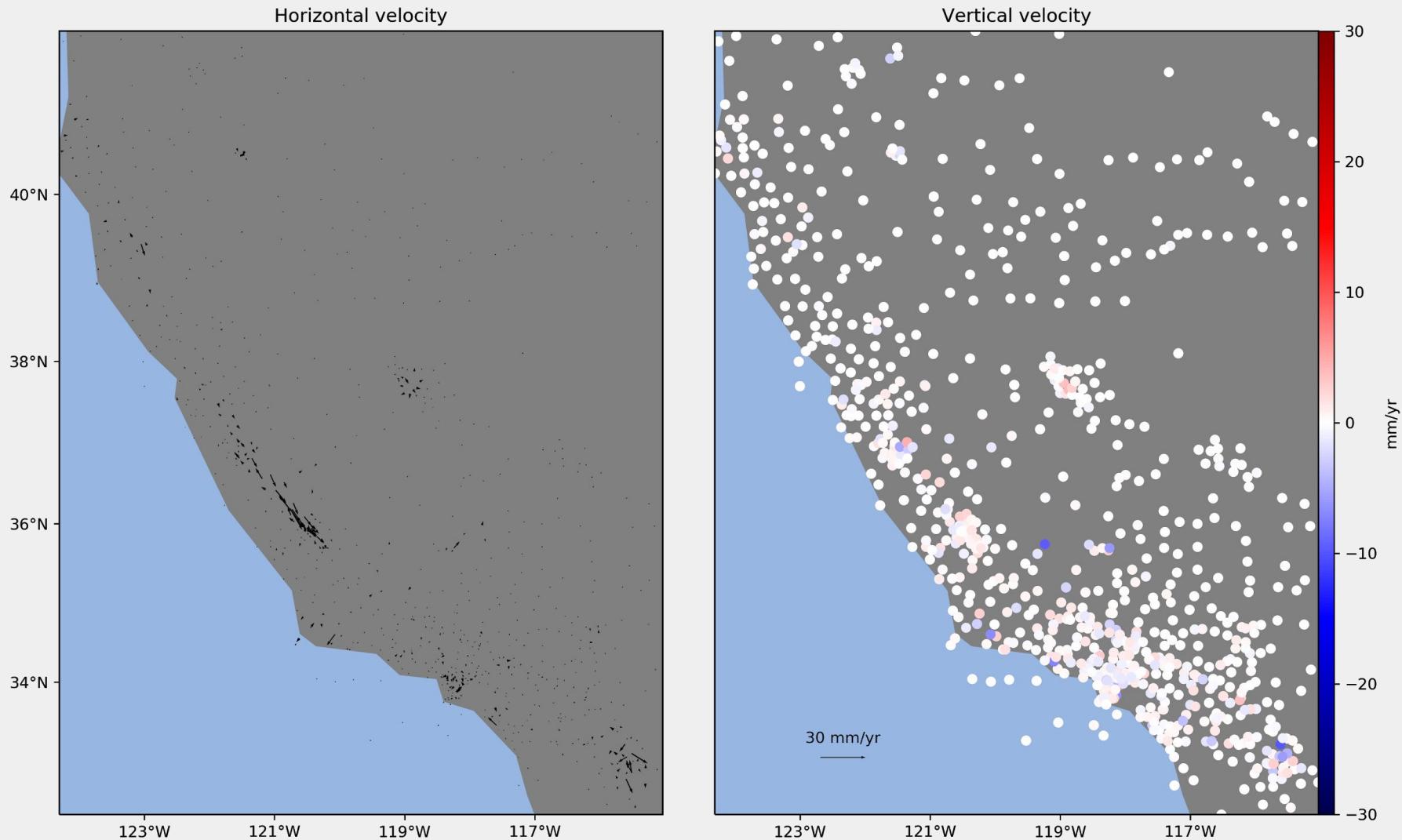
Horizontal velocity



Vertical velocity

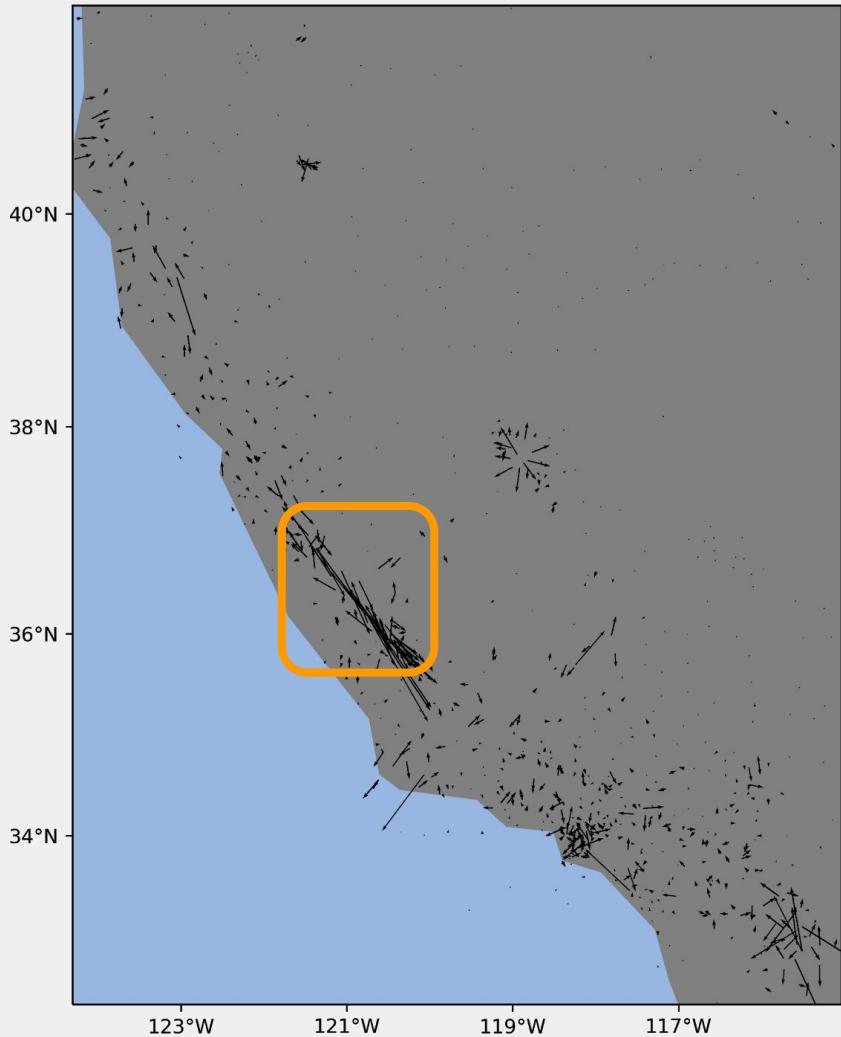


residuals

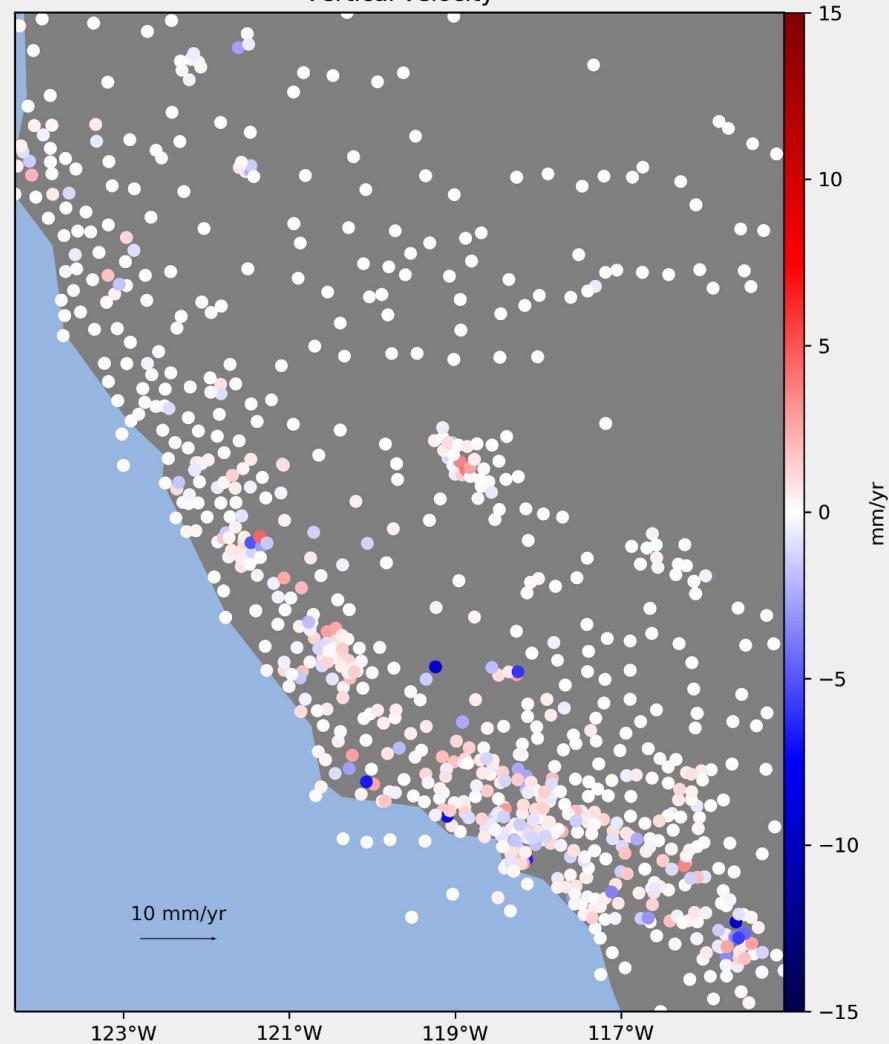


residuals (exaggerated)

Horizontal velocity

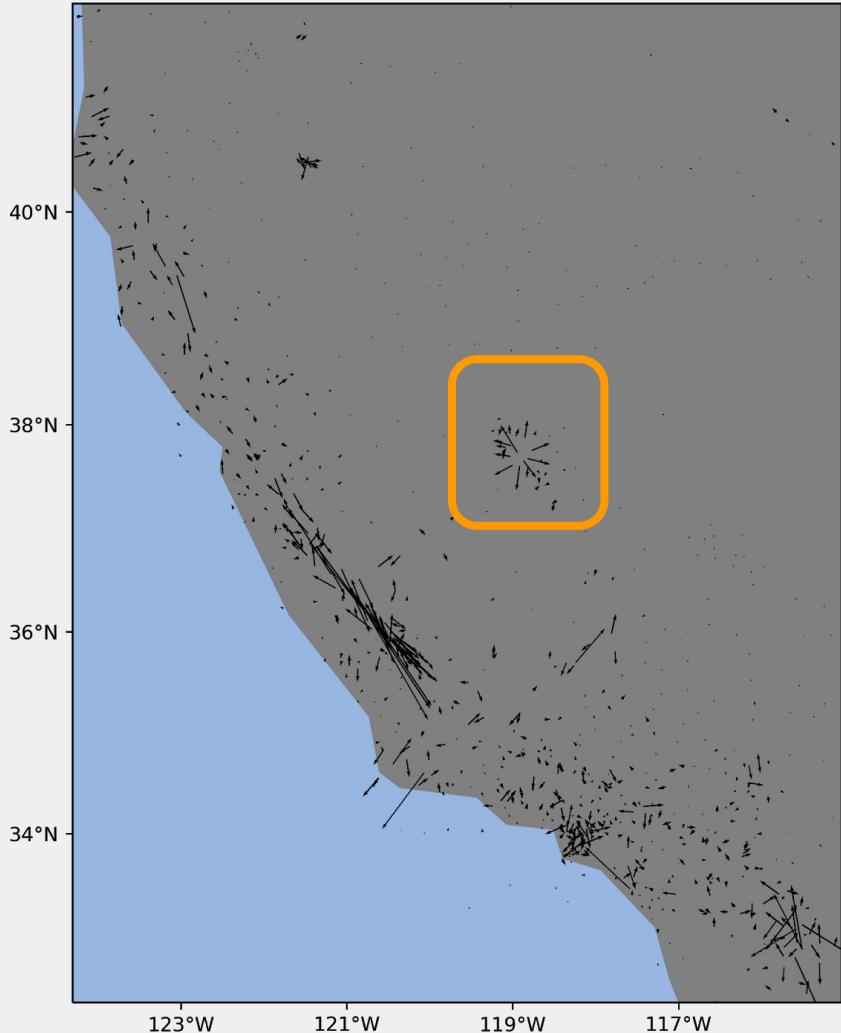


Vertical velocity

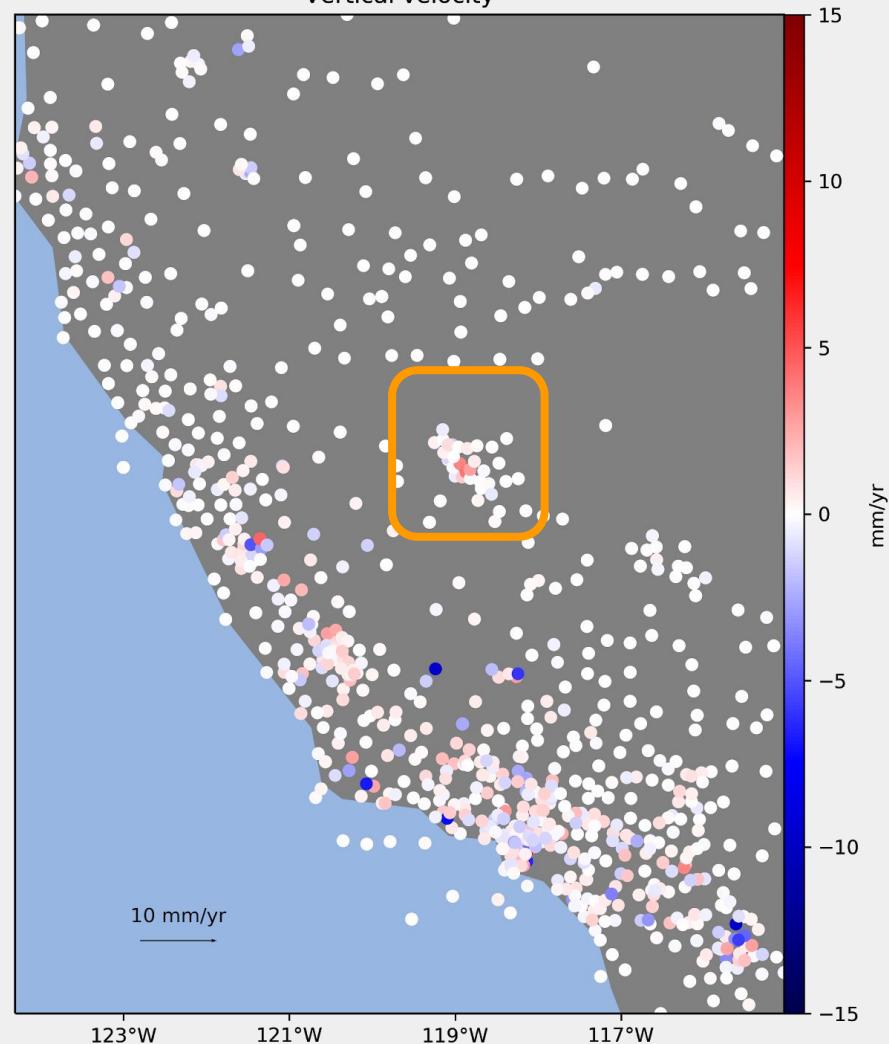


residuals (exaggerated)

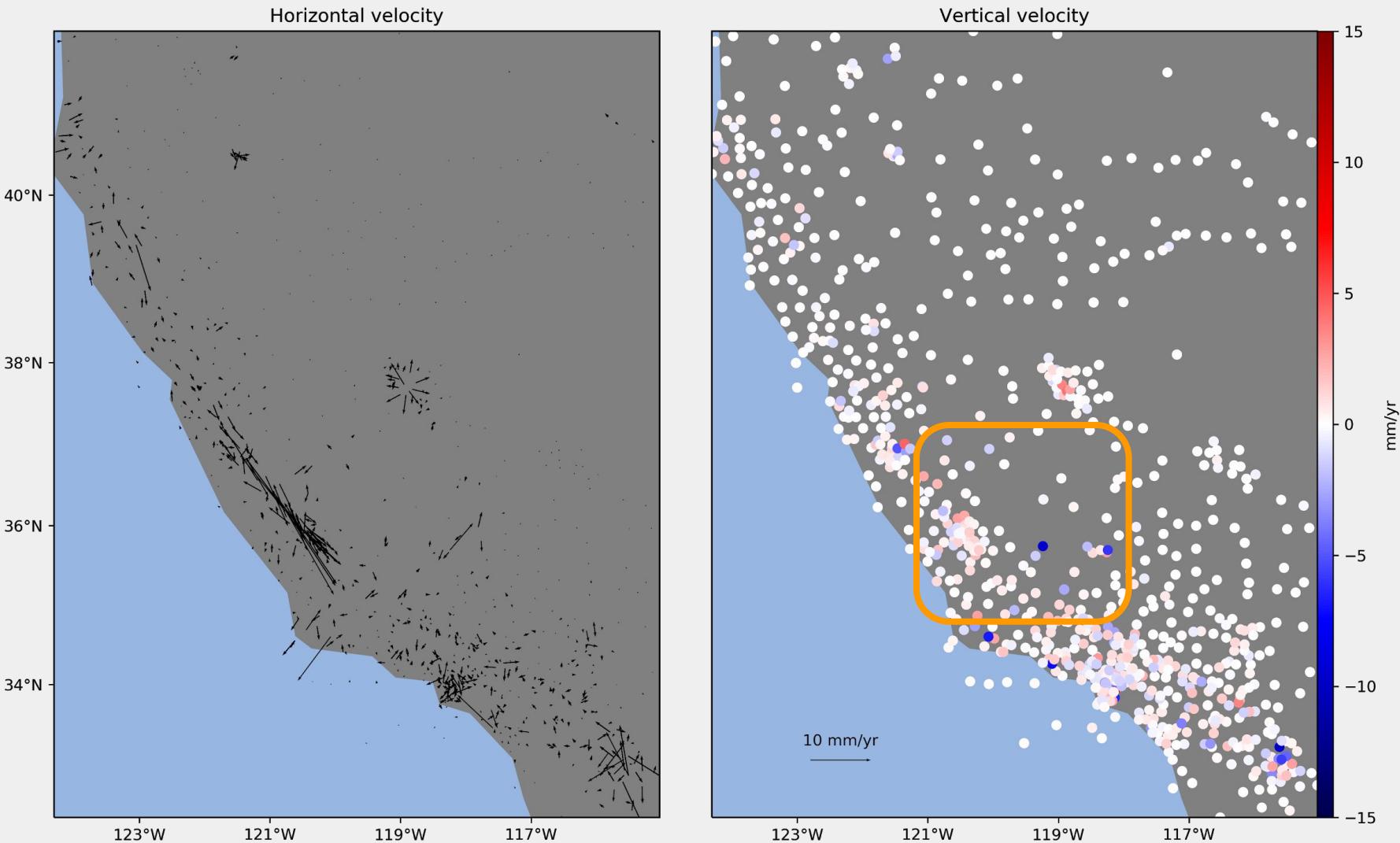
Horizontal velocity



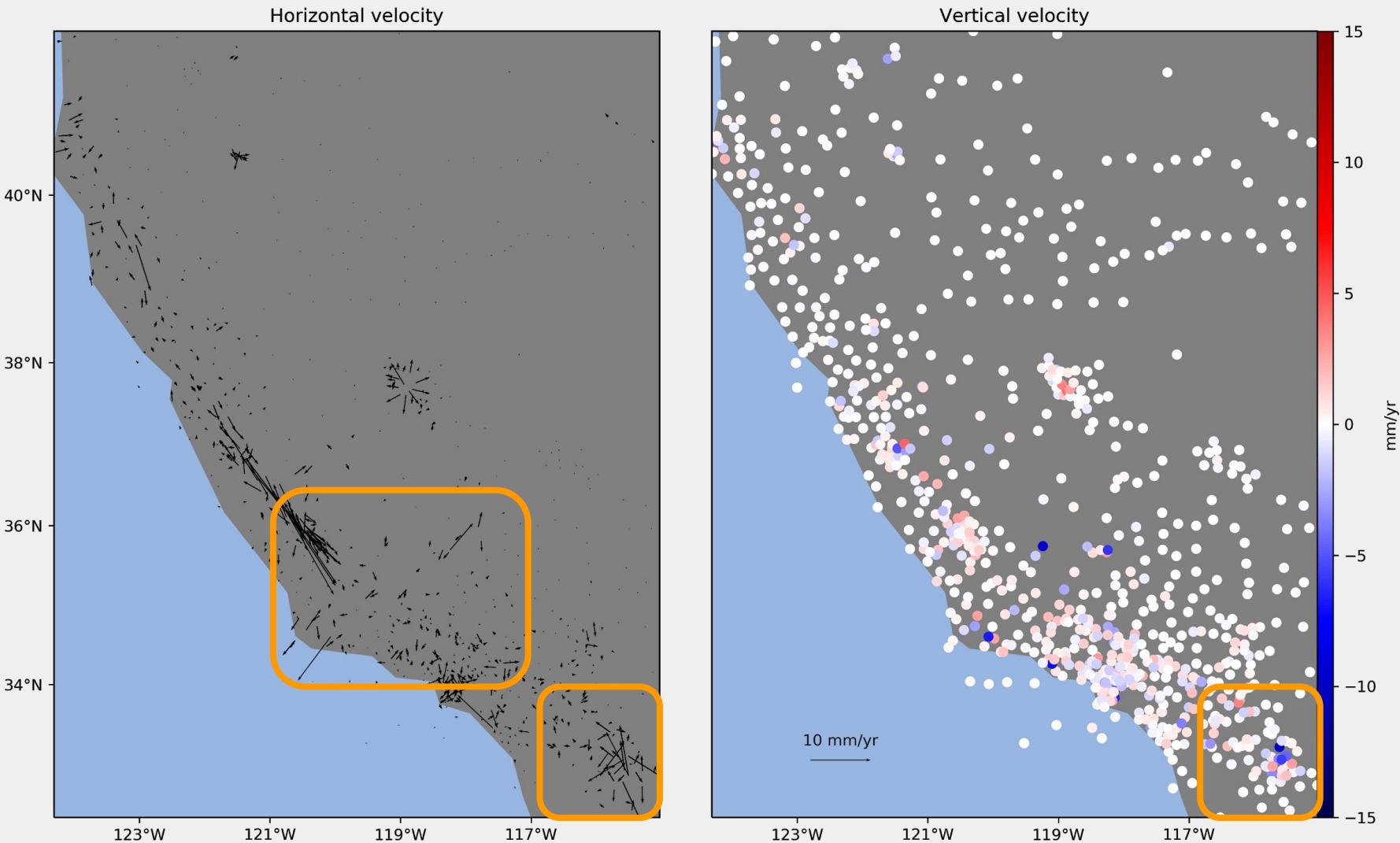
Vertical velocity



residuals (exaggerated)



residuals (exaggerated)



Conclusion

Main points:

Joint 3-component interpolation

Slower than other methods

Weighted solution + automatic tuning

Main points:

Joint 3-component interpolation

Slower than other methods

Weighted solution + automatic tuning

Future work:

Weights + location of forces

Comparison with other methods

Applications to other areas

Faster execution + larger datasets

Acknowledgements

EarthScope PBO data provided by UNAVCO through the GAGE Facility with support from the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA) under NSF Cooperative Agreement No. EAR-1261833.

Download slides + source code: www.leouieda.com

Built on the Verde **open-source** Python library: github.com/fatiando/verde



Feel free to photograph and share this presentation. doi:10.6084/m9.figshare.6387467

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