adjTomo — Automated, Open-Source Workflow Tools for Adjoint Tomography and FWI

PYATOA SeisFlows
github.com/adjtomo

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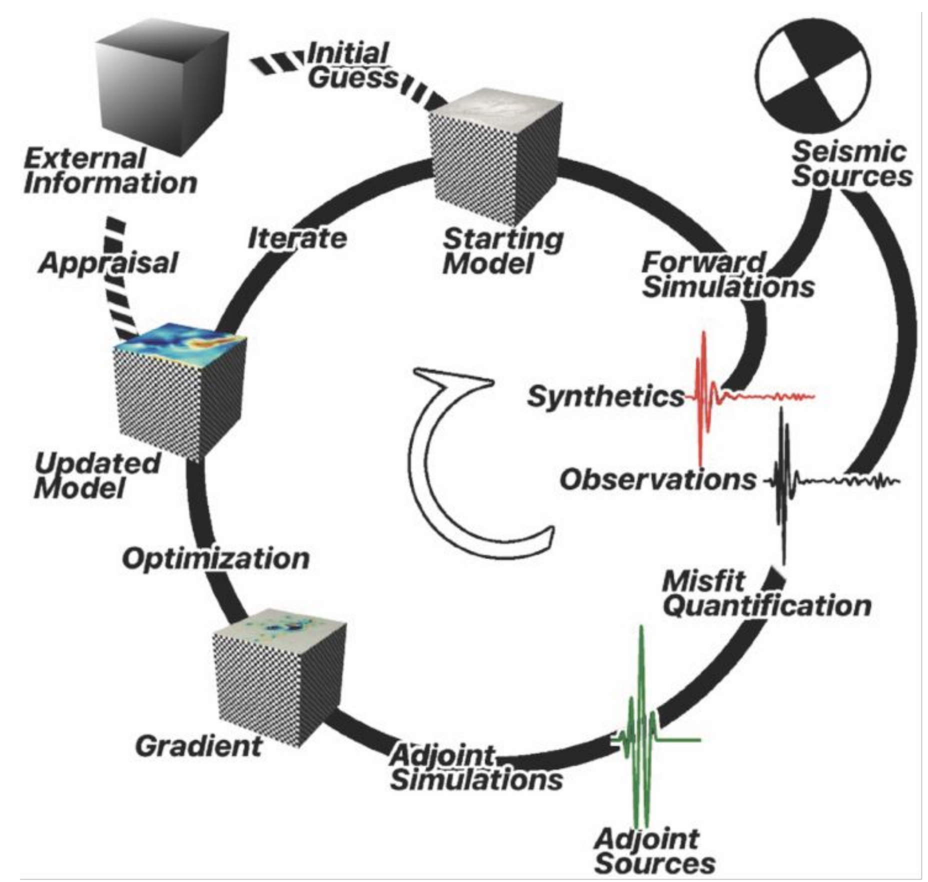
BACKGROUND

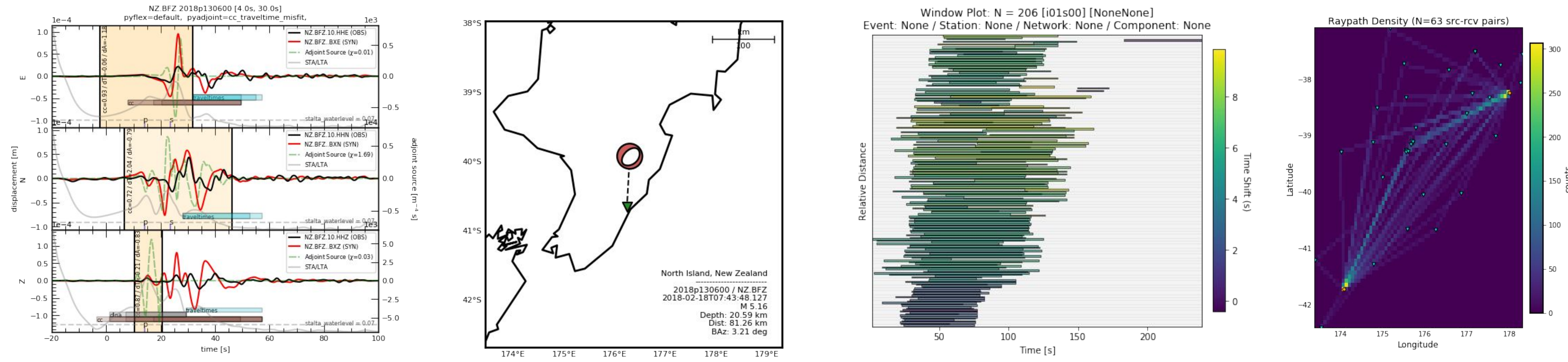
- Adjoint tomography (full waveform inversion) performs **iterative model updates** to minimize data-synthetic misfit.[1]
- Full-scale inversions are **computationally and algorithmically complex**, involving >hundreds of numerical simulations.
- **adjTomo** is a toolkit of open-source Python packages that automate and facilitate the adjoint tomography workflow.
- These tools have been used to run seismic inversions in 2D and 3D **using laptops, workstations and high performance computers**.



The adjoint tomography workflow.[2] Starting at top middle, an initial model is guessed using a-priori information (geologic maps, tomographic models). Forward simulations are run to generate synthetic waveforms which are compared against data. Data–synthetic misfit is backprojected as an adjoint source to quantify the gradient of an objective function. The starting model is updated to minimize the misfit function. The inversion is performed iteratively until convergence.

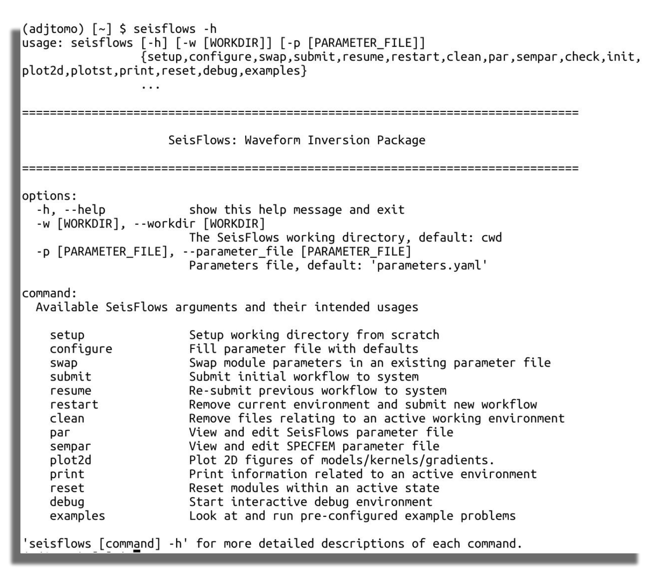
MAIN PACKAGES

- **Pyatoa**[2] is a **misfit quantification** and **inversion assessment** package for seismic imaging.
- Pyatoa is a high-level Python package for waveform manipulation (*ObsPy*), window selection (*Pyflex**), adjoint source creation (*Pyadjoint**), data storage (*PyASDF*) and inversion assessment (*Pandas*). [* also part of *adjTomo*]



A gallery of Pyatoa visualizations: (left) Misfit quantification figure with windows generated by Pyflex and adjoint sources created using Pyadjoint; (2nd from left) Source-receiver map; Pyatoa is built around ObsPy objects, which are used for metadata access, waveform processing and plotting; (2nd from right) Visualization of misfit windows against source–receiver distance; (right) simple raypath density figure to show source–receiver connections via available data.

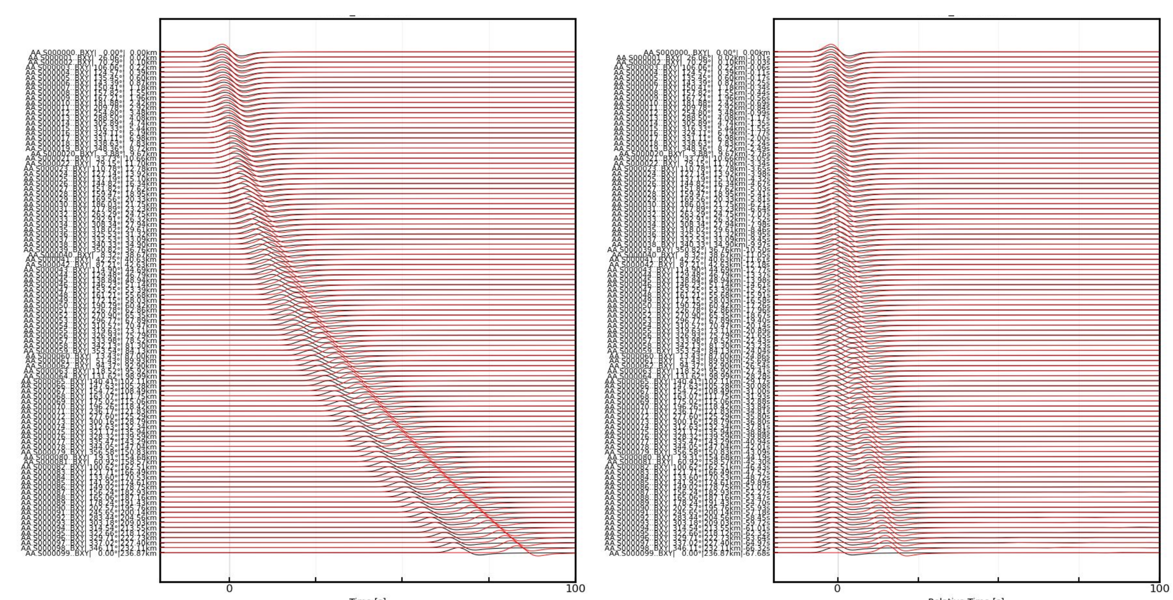
- **SeisFlows**[3] is an automated workflow tool for seismic imaging.
- Key features include:
  - Wrapper for numerical solvers: SPECFEM2D/3D/3D_GLOBE
  - Single system interface from laptop toy problems to HPC jobs
  - Built-in nonlinear optimization library for model updates
  - Command line tool, debug mode and checkpointing



(Left) SeisFlows operates with a command line tool and a parameter file. Its modular design allows Users to test their workflows on small problems (using SPECFEM2D and a local machine) and then quickly transition to larger scales (3D on HPCs).

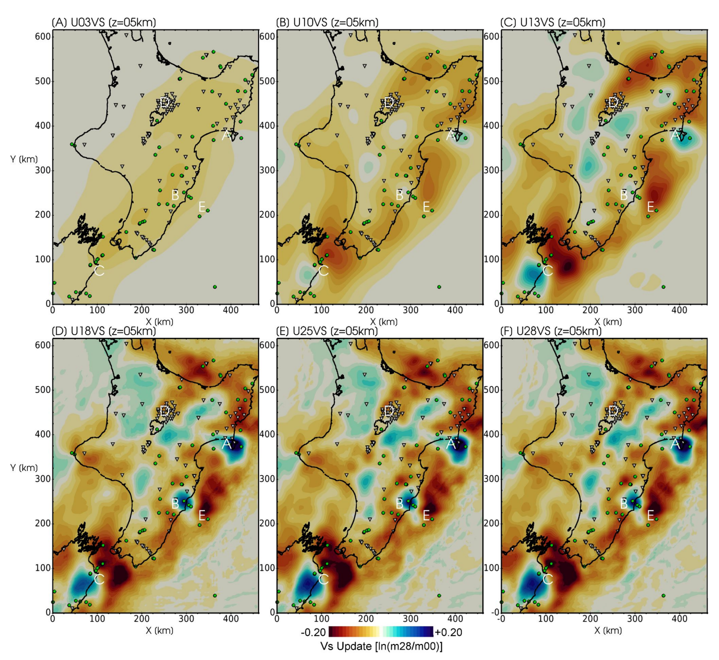
(Right) Two record sections from PySEP's RecSec tool, showing two sets of synthetics (red and black) generated using SPECFEM2D. Far right, RecSec has applied a move out of 3.5km/s (the S-wave velocity of the initial model used to generate the black synthetics).

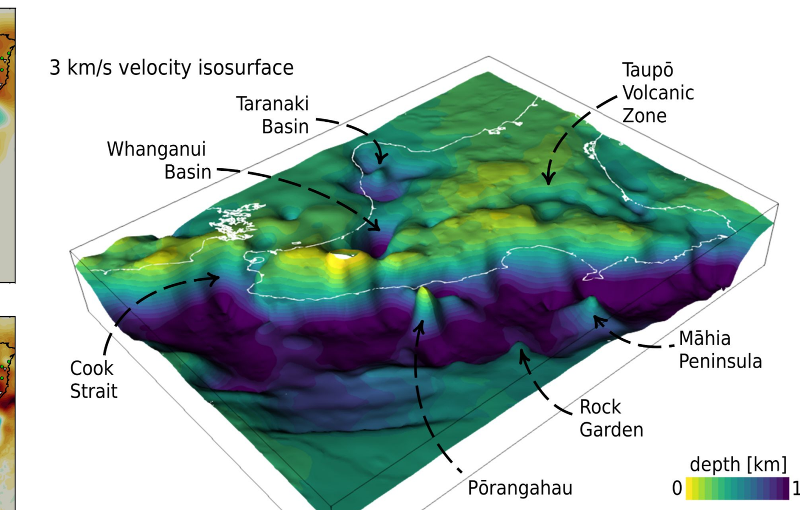
- **PySEP** is a seismic data retrieval tool used to gather waveforms and metadata.
- PySEP contains **RecSec**, a *rec*ord *sec*tion plotter which can be used to rapidly visualize data (and synthetics), with various processing options (e.g., move out, below).



APPLICATIONS

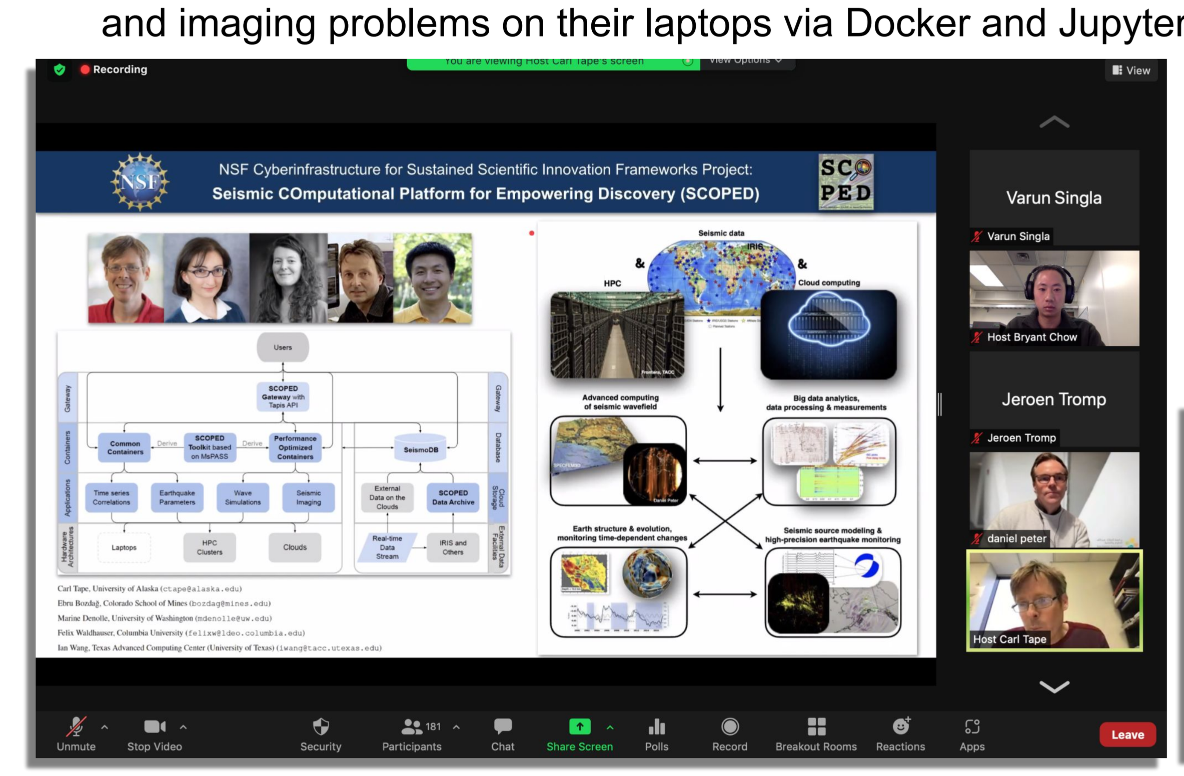
- **SeisFlows** + **Pyatoa** have been applied to scientific problems ranging from synthetic 2D inversions to a high-resolution 3D study of the Hikurangi subduction zone and the North Island of New Zealand.[4,5]





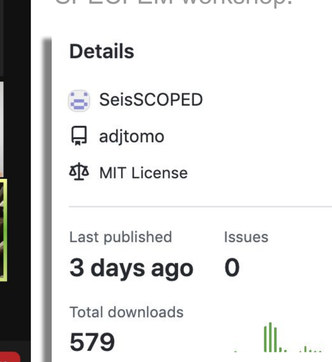
(Left) Model updates with respect to a starting 3D velocity model of the north Island of New Zealand over the course of 28 L-BFGS iterations run on a New Zealand HPC. Velocity changes of over ±30% seen in the final model (warm colors = initial model too fast). (Right) 3 km/s velocity isosurface through the final velocity model (M28), colored by depth. We interpret two positive velocity perturbations at depth as previously-unrecognized, deeply-subducted seamounts within the Hikurangi subduction zone.

- **adjTomo** was used to run a virtual SPECFEM Users Workshop (*October 15–17, 2022*) with >180 participants running 2D forward simulations and imaging problems on their laptops via Docker and Jupyter.



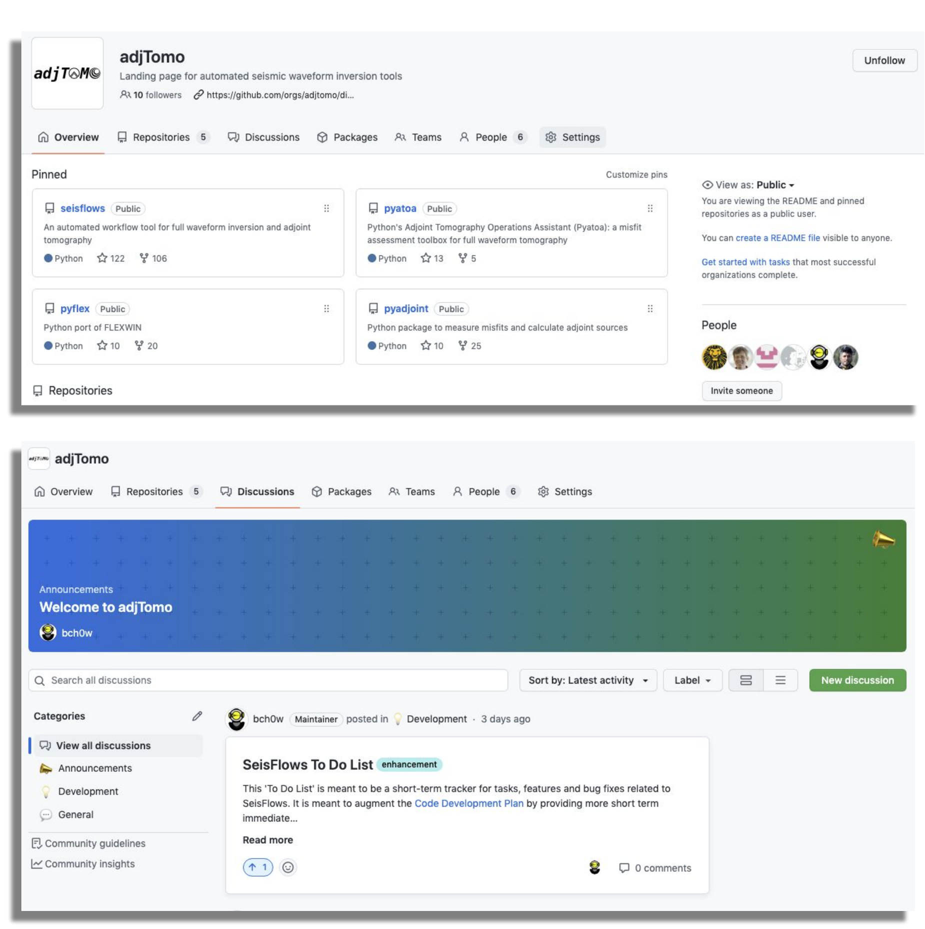
(Left) Zoom screenshot from the opening day of the SPECFEM Users workshop. Note the 181 virtual participants.

(Below) Stats for container downloads of the adjTomo Docker container, which was used to run the SPECFEM workshop.



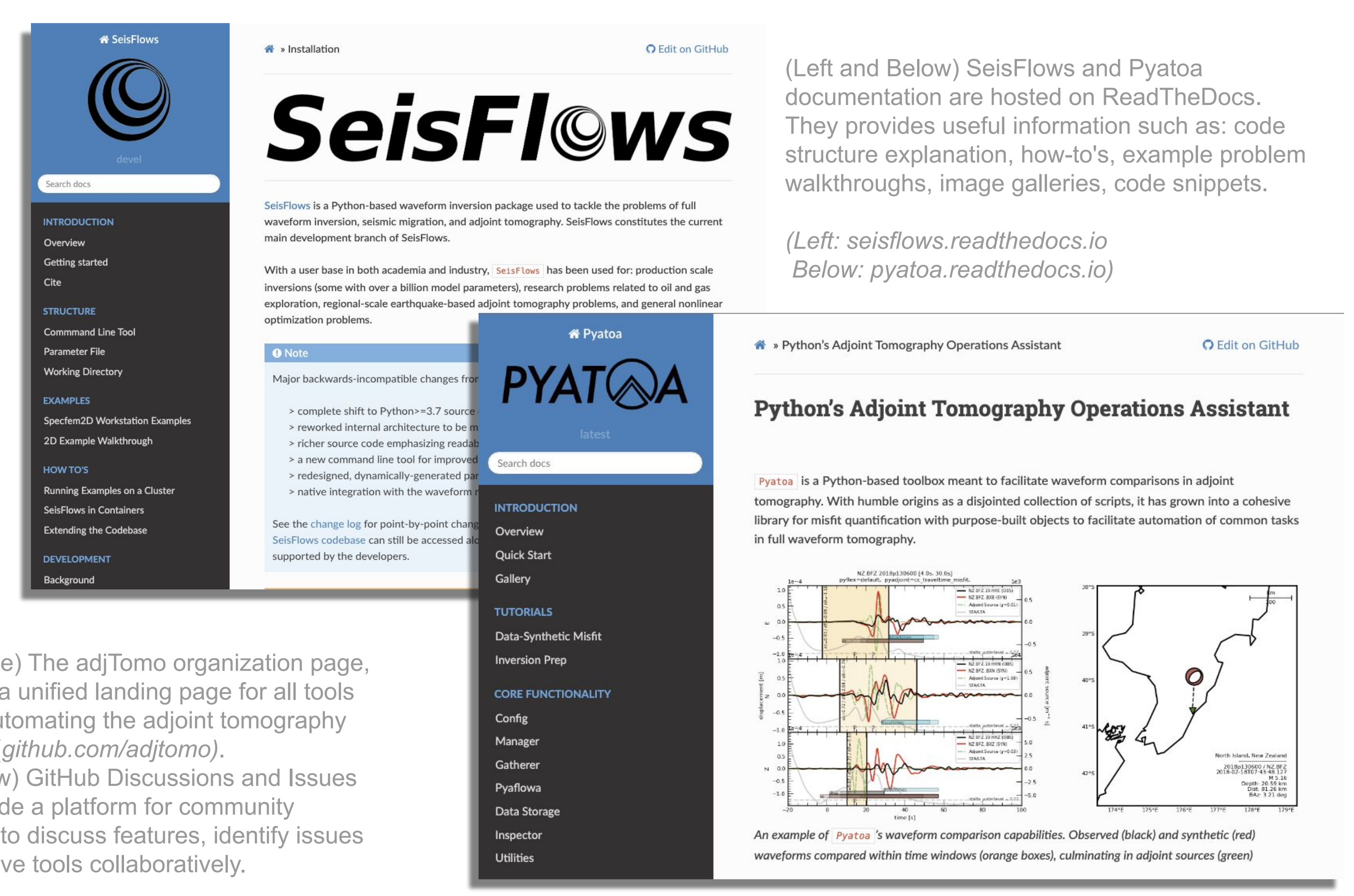
SUPPORTING MATERIAL

- The **adjTomo GitHub organization** provides a single landing page for packages, documentation and community discussion.



(Left above) The adjTomo organization page, providing a unified landing page for all tools used in automating the adjoint tomography workflow (*github.com/adjtomo*).
(Left below) GitHub Discussions and Issues tabs provide a platform for community members to discuss features, identify issues and improve tools collaboratively.

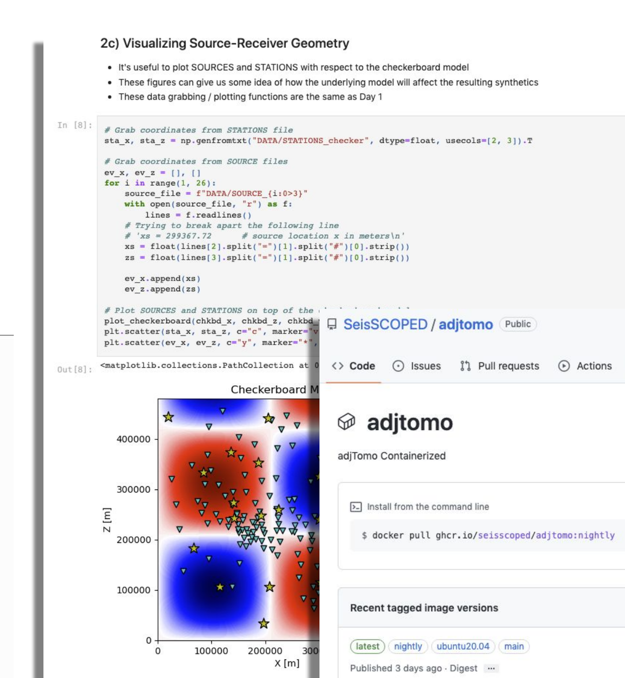
- **Documentation** covers public API, examples and walkthroughs to help new Users. **Test suites** (using *pytest*) ensure code stability during development.



(Left and Below) SeisFlows and Pyatoa documentation are hosted on ReadTheDocs. They provide useful information such as: code structure explanation, how-to's, example problem walkthroughs, image galleries, code snippets.

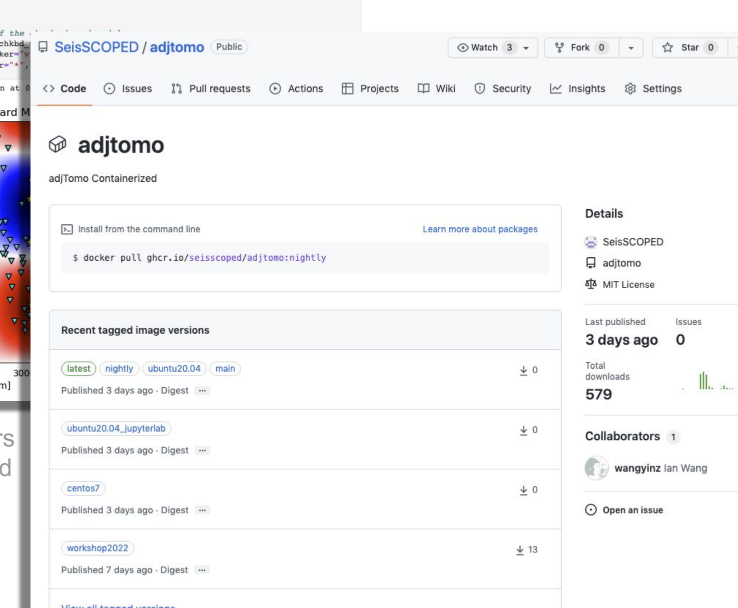
*(Left: seisflows.readthedocs.io
Below: pyatoa.readthedocs.io)*

- **adjDocs** hosts Jupyter-based teaching material based on **Docker** containers that conveniently package software.



(Left) Teaching material crafted in Jupyter Notebooks allow new users to run code and learn material from a single file.

(github.com/adjtomo/adjdocs)



(Right) Docker containers host adjTomo and related software for ease of access/use in teaching and research.

(github.com/seisscoped)

FUTURE WORK

- **adjTomo** is in a current state of development. We aim to expand the toolkit to a variety of workflows, methodological approaches and HPC systems.
- **Imaging study** regions using adjTomo that are ongoing or planned include:
  - Alaska statewide (*Amanda McPherson; UAF*)
  - Anisotropy in the Alaska subduction zone (*Aakash Gupta; UAF*)
  - Nenana basin, interior Alaska (*Yuan Tian; UAF*)
  - Northern Alaska (*Bryant Chow; UAF*)
  - Northern offshore Hikurangi subduction zone (*Shun Adachi; Kyoto University*)
  - Nankai + Kyushu subduction zones (*Samriddhi Mishra; Kyoto University*)

REFERENCES

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Find me on GitHub!
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