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Machine learning operations (MLOps) for weather applications

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EMS 2022, OSA1.9 Machine Learning and Computer Vision in Weather and Climate

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Why MLOps is needed

90 percent of all ML models never make it into production.

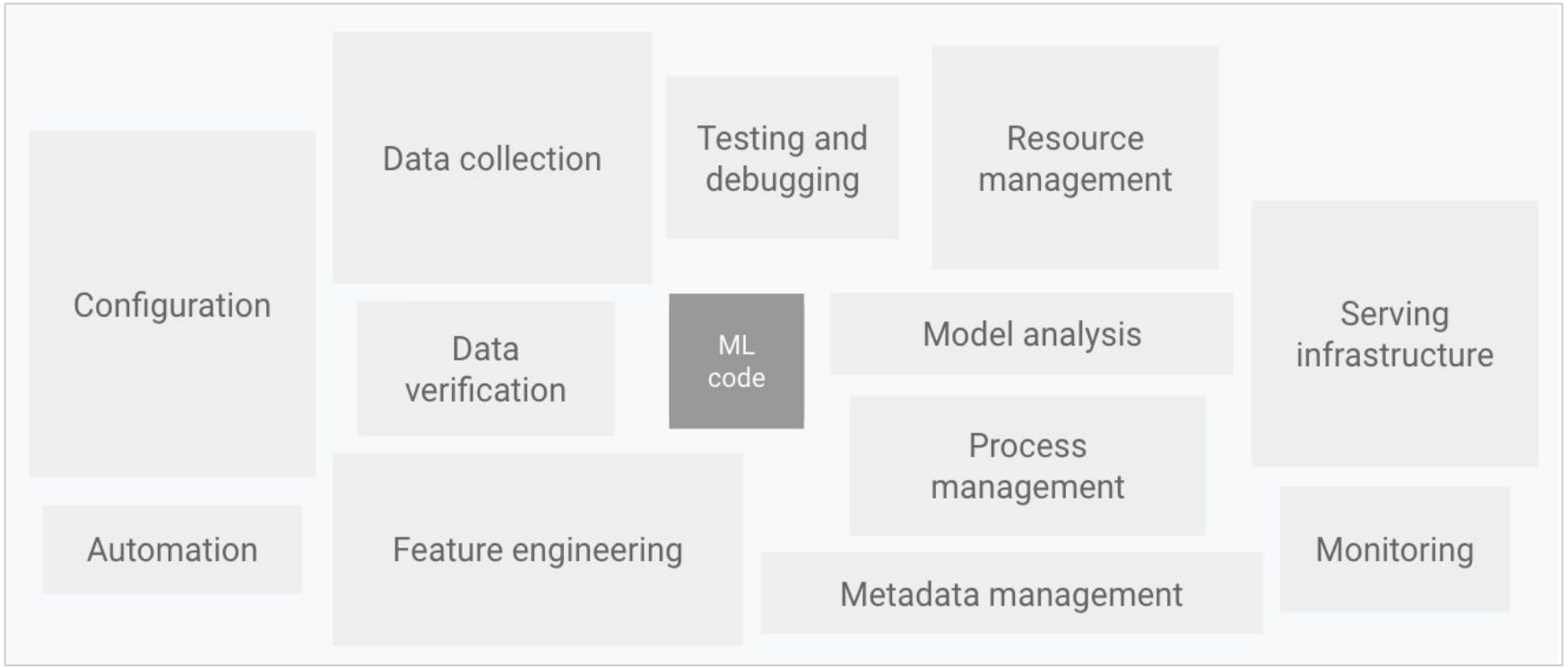
When it happens, typically …

- Long and slow process, with many manual steps.
- Difficult to maintain *(technical debt*).
- Project-specific solutions *(low code reusability).*
- Performance below expectation (*train-serving skew*).



ML system in production

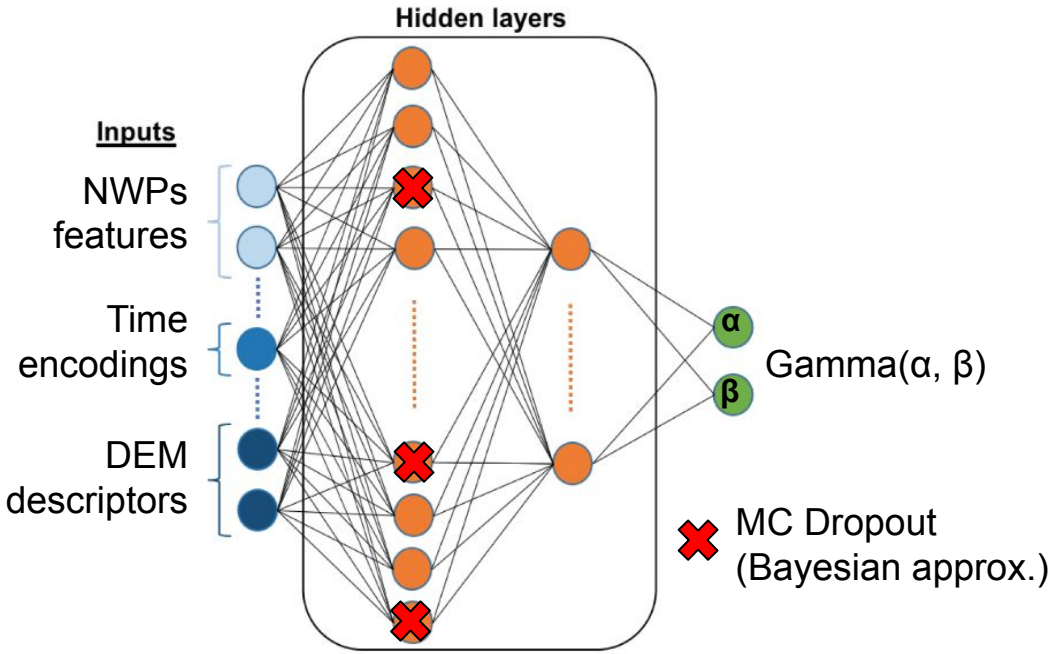
Sculley et al 2015, NIPS



Models change, pipelines remain: the real challenge isn't building a particular ML model, the challenge is building an integrated ML system and to *continuously* operate it in production.

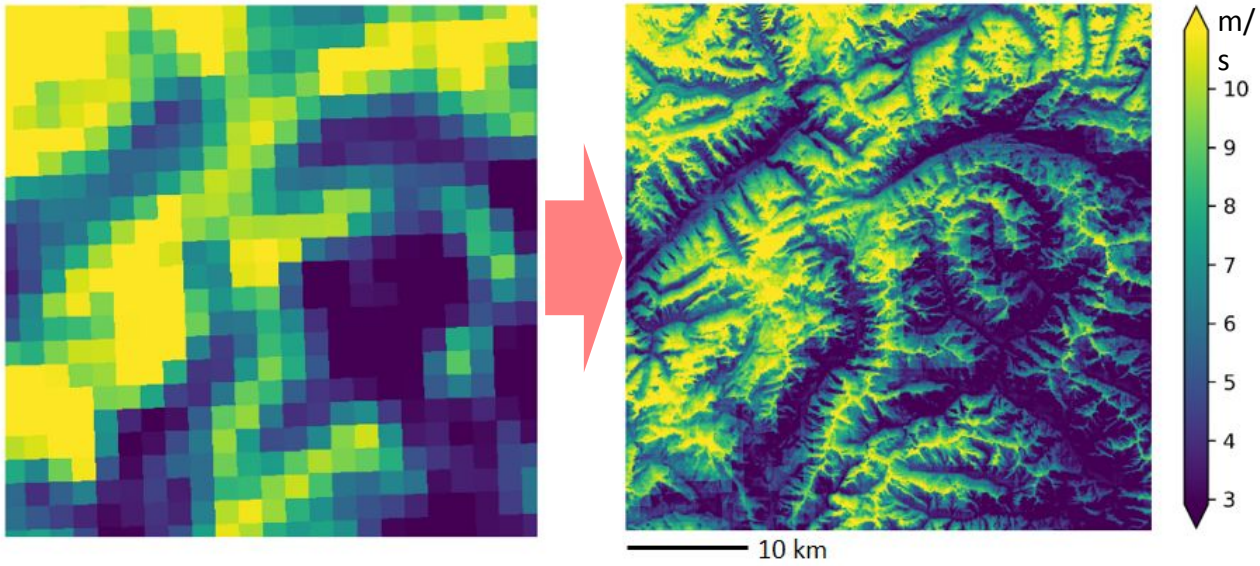
Case study: Postprocessing of surface winds

Talk on Tue, OSA1.1:
C. Spirig, **Lessons learnt from implementing a postprocessing suite for probabilistic seamless weather forecasts**



COSMO-E
2 km resolution

MLPP model
100 m resolution



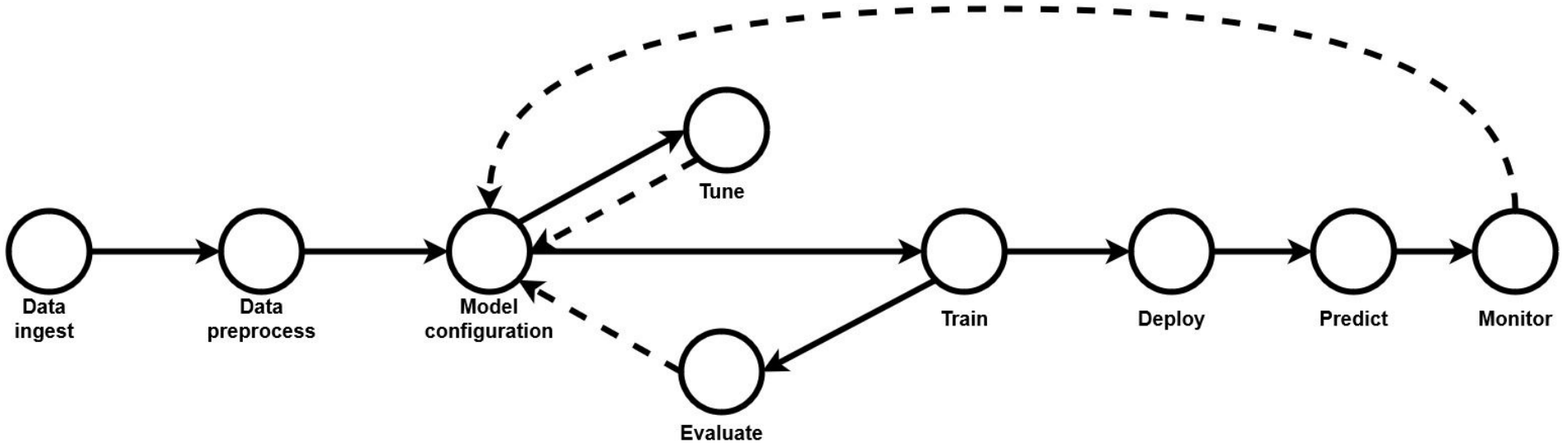
Large volumes of data from various sources in different formats.

Complex and expensive preprocessing of inputs.

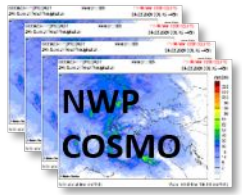
Large set of hyperparameters to be tuned.

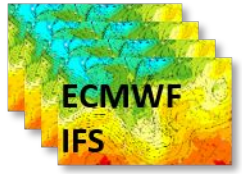
Probabilistic and multivariate evaluation of prediction skill.

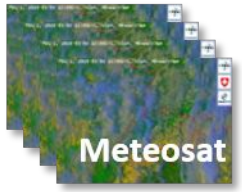
Machine learning pipeline

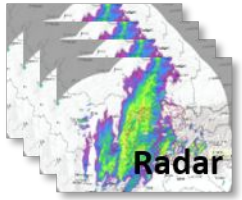


A unified and semantic access to gridded data to feed ML pipelines.





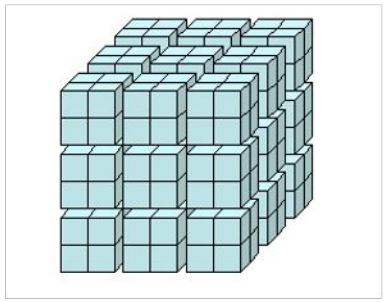




subset / preprocessed multi-dimensional data

real-time ingestion

GrideFix



compressed chunked arrays to efficiently manipulate large data



rapid access through metadata handling



cloud native

Zarr

Open Geospatial Consortium

CF MetaData

GrideFix demo

Discover

Example: Availability of several variables

If more than one variable is queried, all the timestamps obtained contain all of the variables.

In [7]:
```
source = 'COSMO-2E'
tags = 'operational,numerical weather prediction,ensemble,surface,forecast'
variable_list = 'air_temperature,eastward_wind,northward_wind,wind_speed_of_gust'
timestamps = requests.get(f'{DISCOVER_URL}/sources/{source}/timestamps?variable={variable_list}&t
timestamps = timestamps.json()
print(f'\n Timestamps available for variables {variable_list} in dataset ({source},{tags}):')
print(f'{timestamps[0]}, {timestamps[1]}, {timestamps[2]} ... {timestamps[-1]}')
```

```
 Timestamps available for variables air_temperature,eastward_wind,northward_wind,wind_speed_of_g
ust in dataset (COSMO-2E,operational,numerical weather prediction,ensemble,surface,forecast):
2022-01-23T12:00:00, 2022-01-23T18:00:00, 2022-01-24T00:00:00 ... 2022-02-17T18:00:00
```

Retrieve

Example: Download several variables for one dataset and specific timestamp

Provide the set of variables for the desired timestamp.

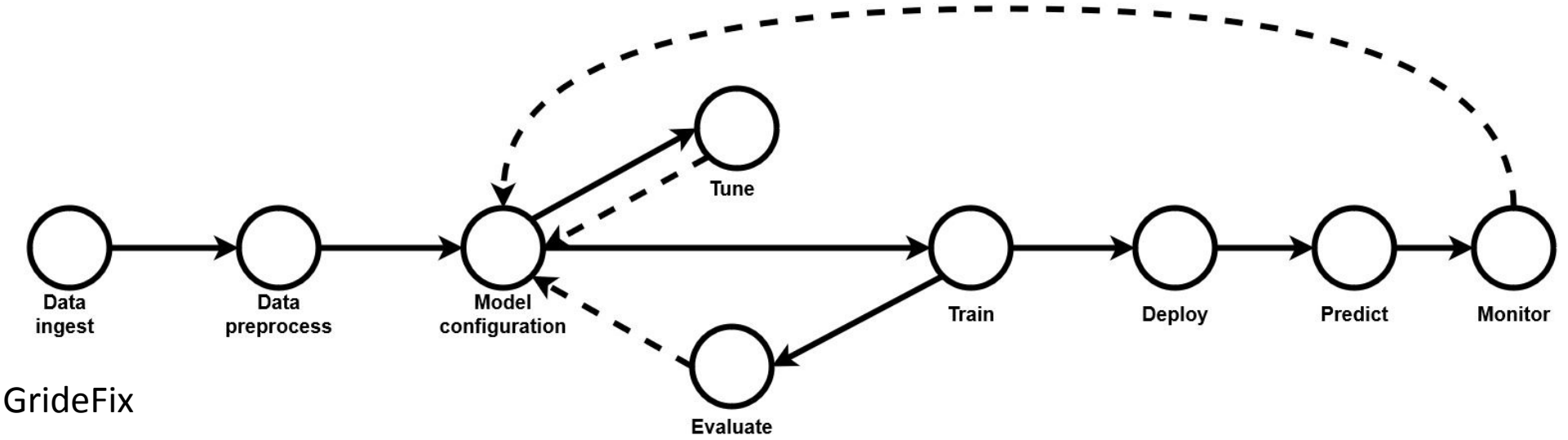
In [9]:
```
import xarray as xr
```

In [10]:
```
# Get dataset and inspect
source = 'COSMO-2E'
tags = 'operational,numerical weather prediction,ensemble,surface,forecast'
variable_list = 'air_temperature,eastward_wind,northward_wind,wind_speed_of_gust'
%time dataset = xr.open_dataset(f'{RETRIEVE_URL}/sources/{source}/tags/{tags}/timestamps/{timesta
dataset
```

```
CPU times: user 126 ms, sys: 63.1 ms, total: 189 ms
Wall time: 19 s
```

Out[10]:
```
<xarray.Dataset>
Dimensions:                  (forecast_reference_time: 1, realization: 21, t: 121, y: 127, x: 18
8)
Coordinates:
  * forecast_reference_time  (forecast_reference_time) datetime64[ns] 2022-02...
  * realization              (realization) float64 0.0 1.0 2.0 ... 19.0 20.0
    time                     (forecast_reference_time, t) datetime64[ns] 2022...
    longitude                (y, x) float64 5.52 5.548 5.577 ... 10.87 10.9
    latitude                 (y, x) float64 45.49 45.49 45.49 ... 48.1 48.1 48.1
Dimensions without coordinates: t, y, x
Data variables:
    air_temperature          (forecast_reference_time, t, realization, y, x) float32 ...
    eastward_wind            (forecast_reference_time, t, realization, y, x) float32 ...
    northward_wind           (forecast_reference_time, t, realization, y, x) float32 ...
    wind_speed_of_gust       (forecast_reference_time, t, realization, y, x) float32 ...
Attributes:
    crs:           EPSG:4326
    tags:          ["ensemble", "surface", "operational", "forecast", "numeri...
    source:        COSMO-2E
    source_crs:    EPSG:4326
    description:   MeteoSwiss ensemble forecasting system
    bounding_box:  [5.304744720458984, 45.49021530151367, 10.898223876953125,...
```

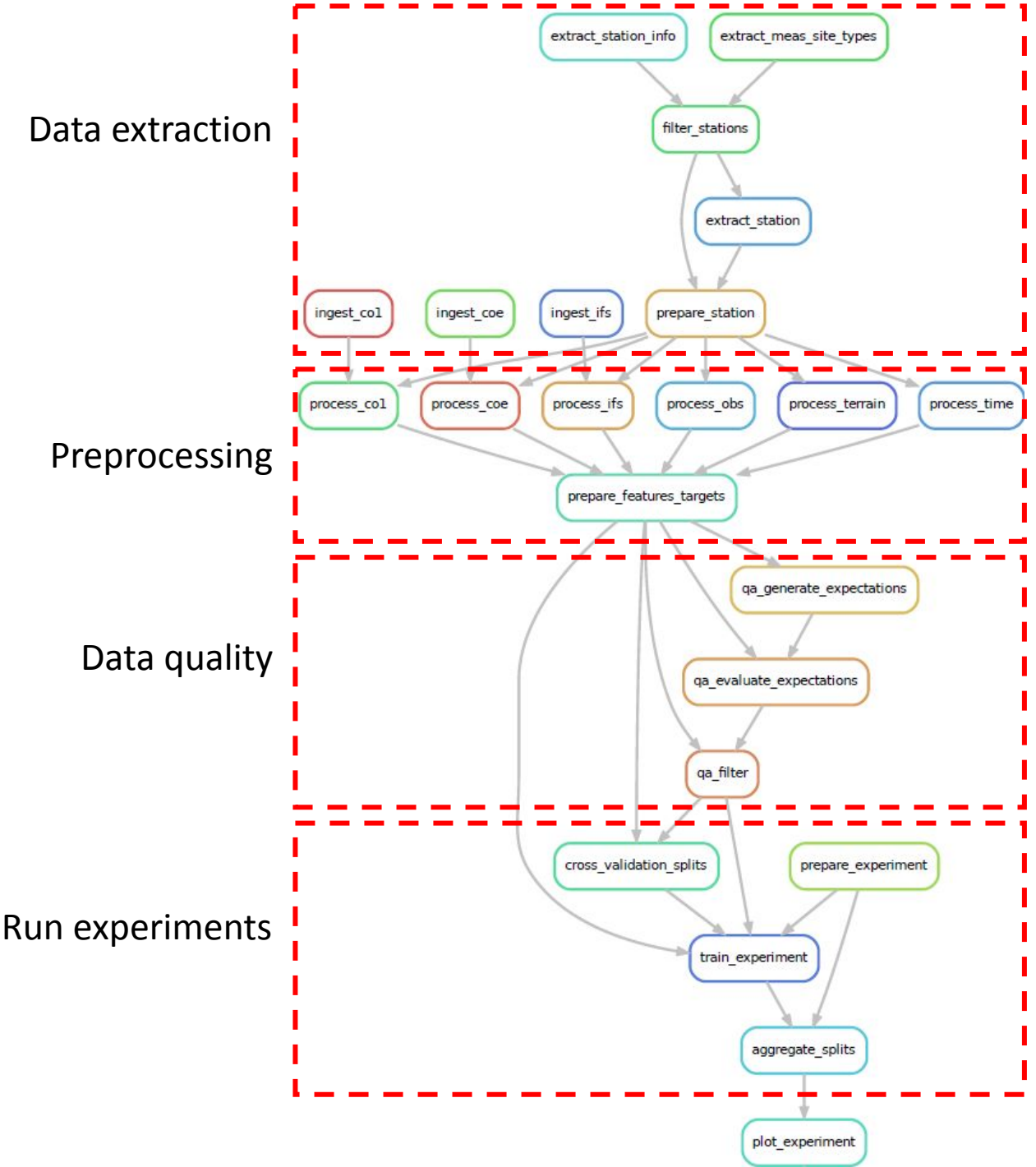
Machine learning pipeline



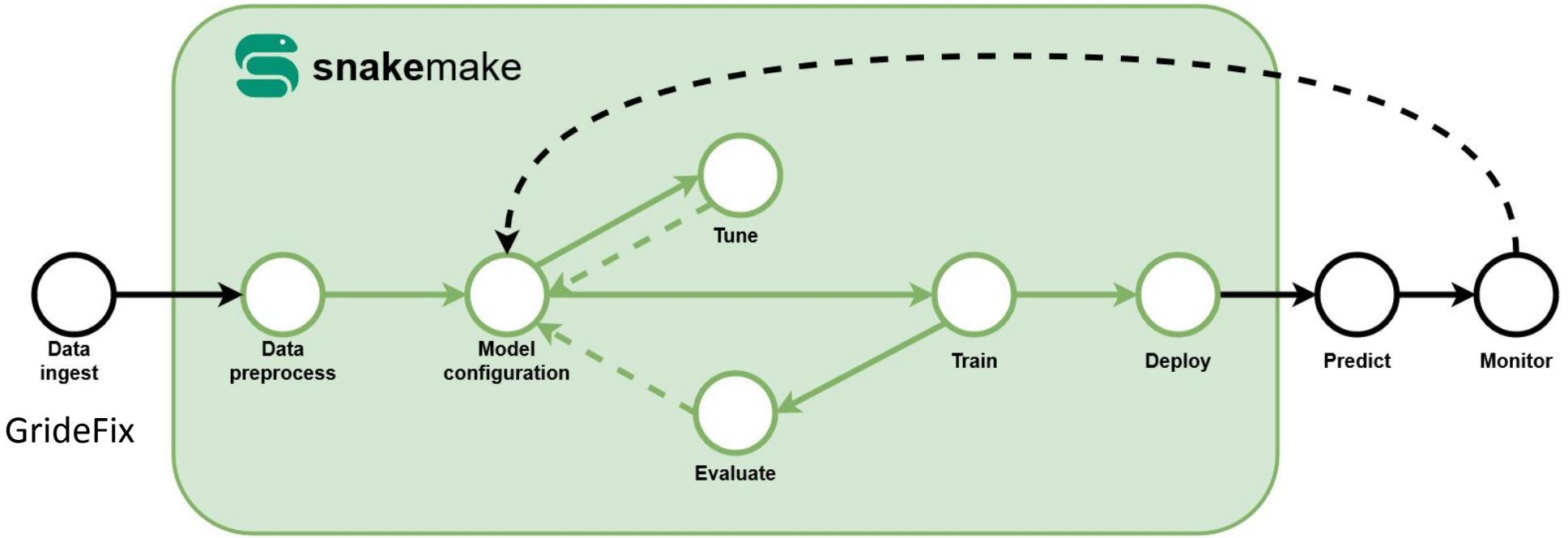
GrideFix

Workflow management with Snakemake

- Not a mainstream tool, but a **good fit** for us. (ask me why!)
- Provide **reproducible and scalable** ML pipelines.
- Organize work in separate tasks and connect them creating a graph (“**DAG**”).
- Orchestrate jobs and **allocate resources** on HPC/cloud.



Machine learning pipeline

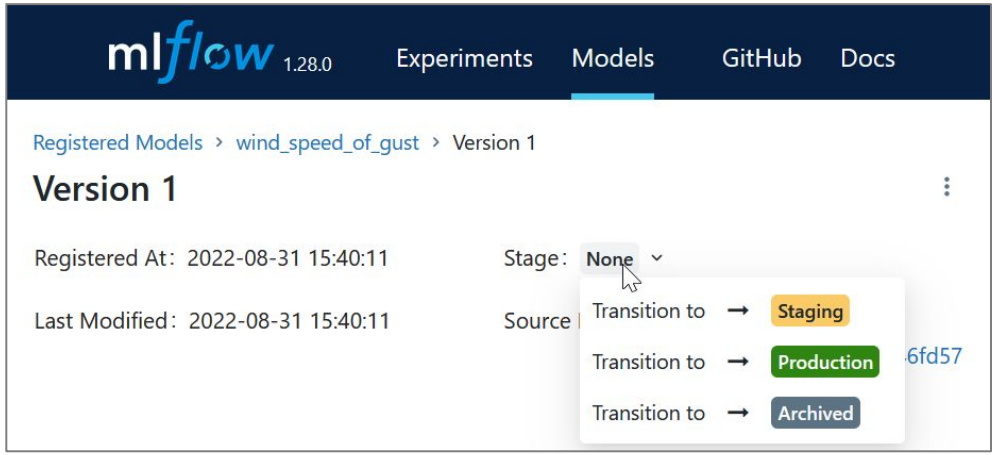


GrideFix

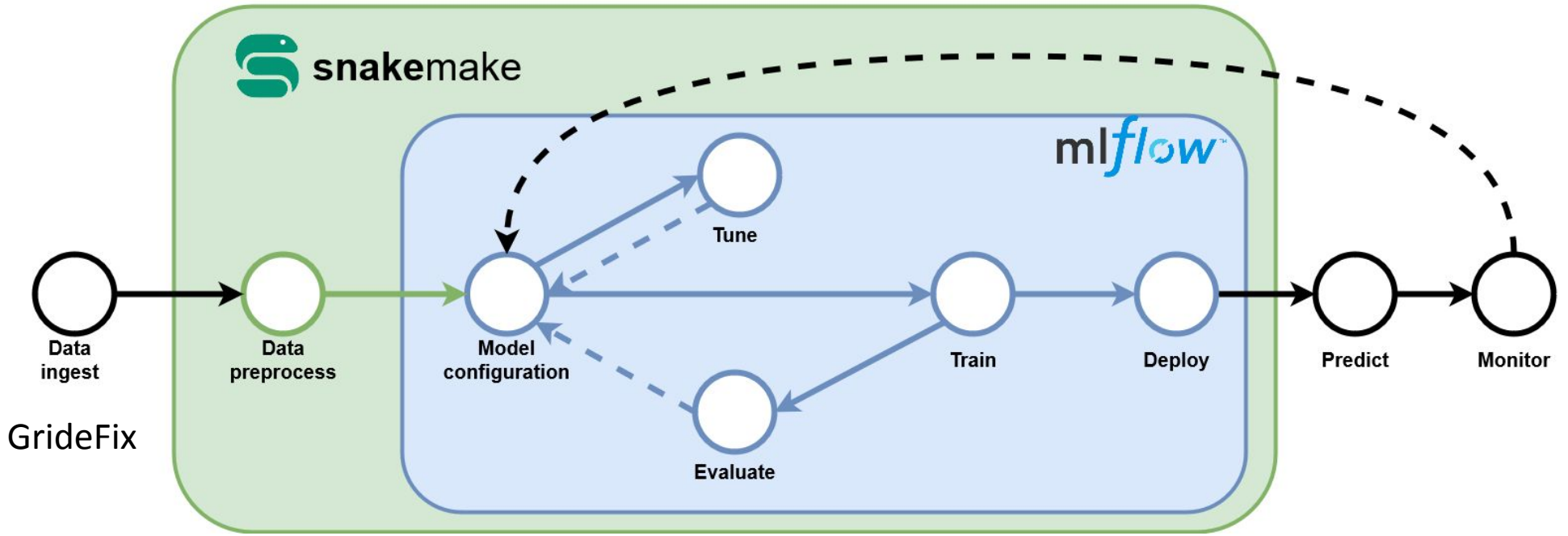
Tracking experiments with MLflow

- Wildly **popular** ML tracking tool.
- **Log experiments** in a SQL database.
- Explore results and **compare runs**.
- Store and **manage models** in a central repository.
- It can be **easily integrated** into an existing training pipeline.





Machine learning pipeline



GrideFix

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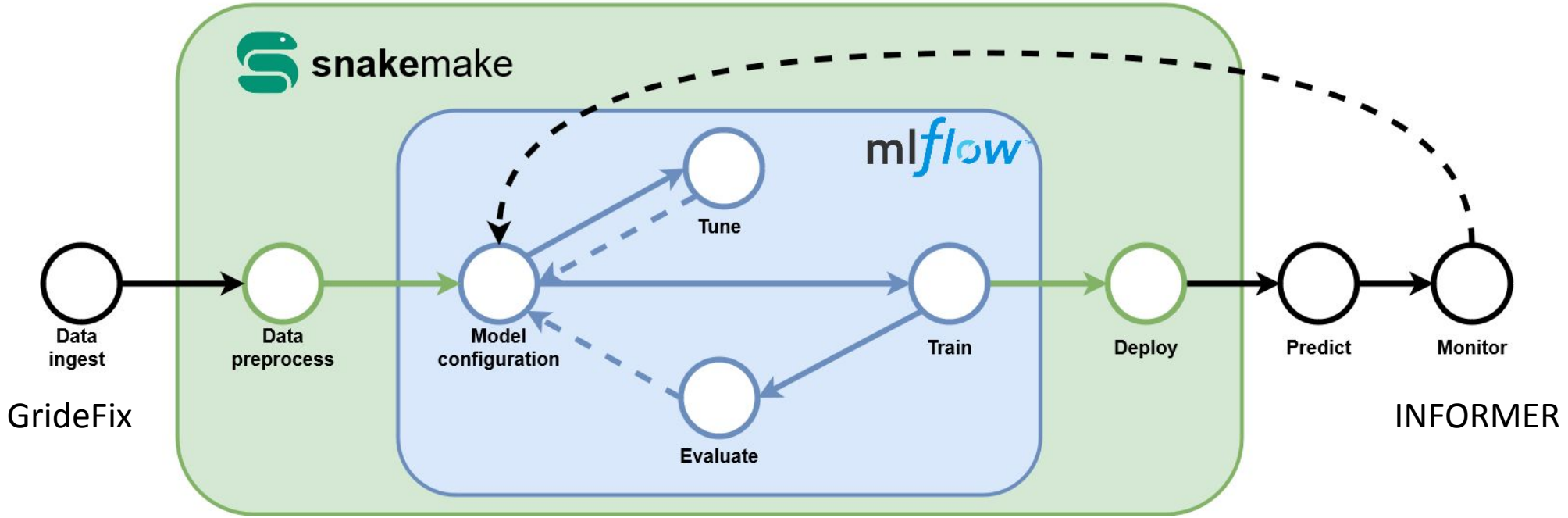
Poster on Wed, OSA1.5:
J. Bhend, **Objective verification for development and monitoring of automated weather forecasts**



Machine learning pipeline

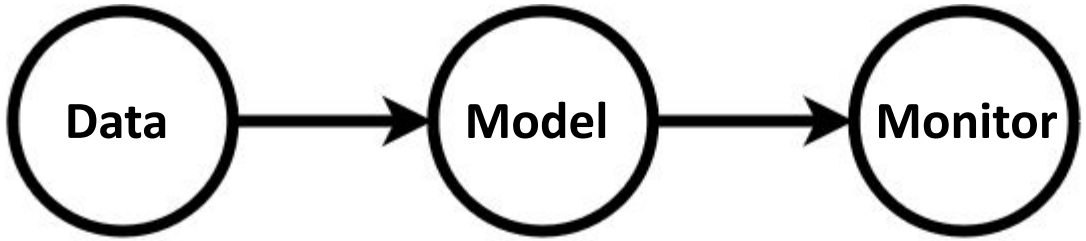


Conclusions

- MLOps is the set of practices that aims to deploy and maintain machine learning models in production **reliably and efficiently**.
- It is NOT only about deploying an offline-trained model as a prediction service, but also includes **automating** (some of) the steps done by scientists (data collection, preprocessing, …).
- Vast ML tooling ecosystem, difficult to navigate. Hence, important to **share experiences** within our community.

What MLOps practices/tools are being used in the weather and climate community? Let's talk!

Thank you! Questions?



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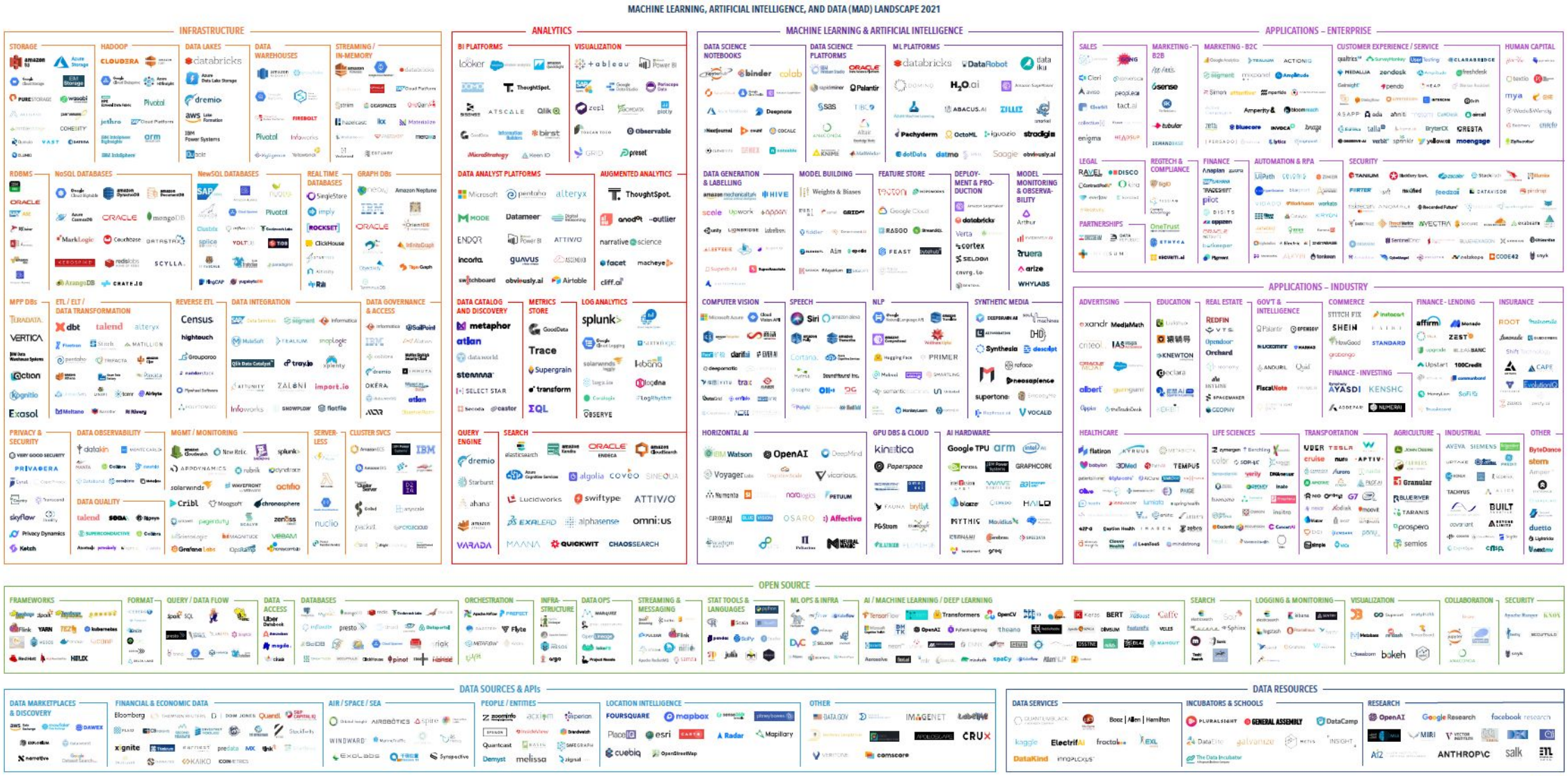
MeteoSwiss

A vast ML tooling landscape …



Challenges

- **Team skill**: ML scientists focus on data analysis and experimentation, not software engineering, and will lack some more technical skills.
- **Development**: ML is experimental in nature and a fast evolving discipline. Strong need to allow quick exploratory work while maintaining reproducibility and code reusability.
- **Testing**: more involved than traditional software QA, as it requires data and model validation, too.
- **Deployment**: it is NOT only about deploying an offline-trained model as a prediction service, but also includes automating all the steps done by scientists (data prep, training, validation).
- **Production**: Skill will decay in time. Need to track quality and be able to easily take action.

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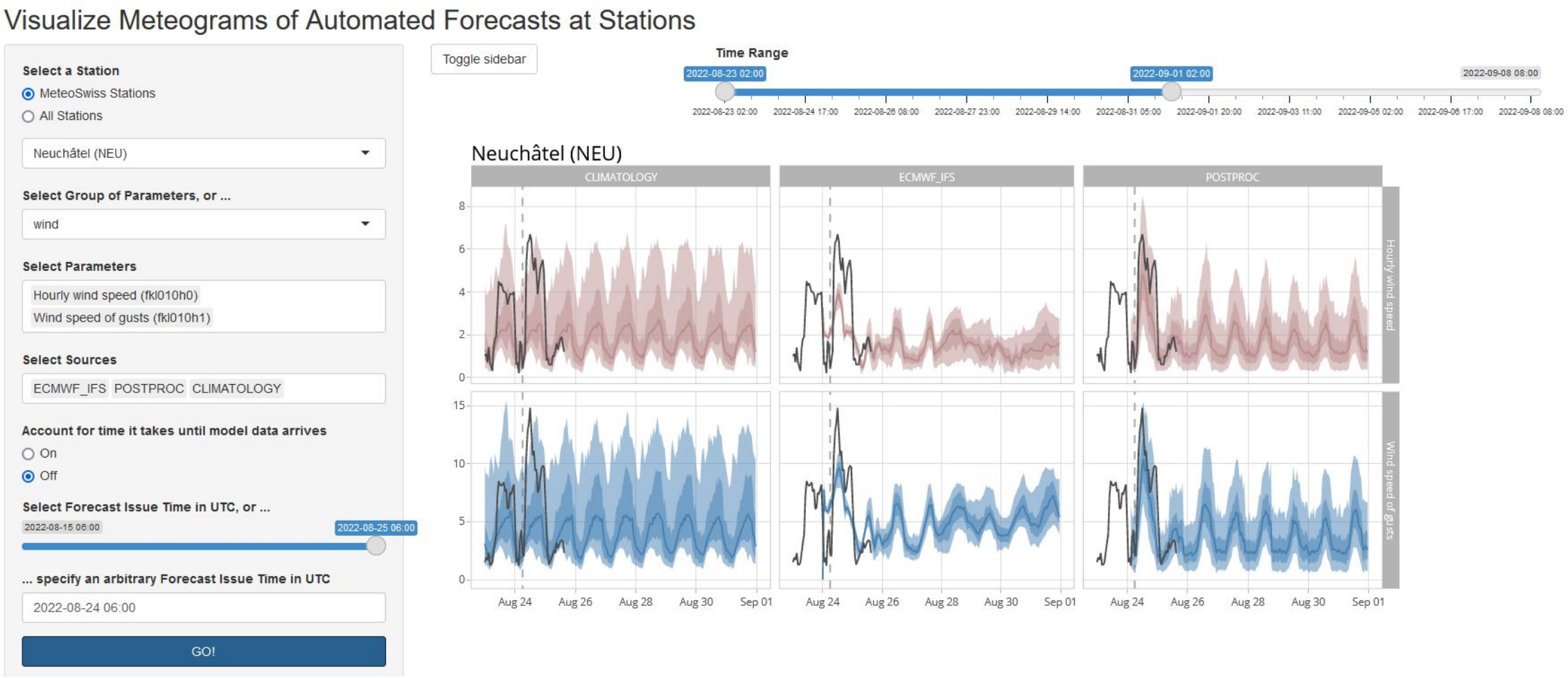

INFORMER Diagnostics

