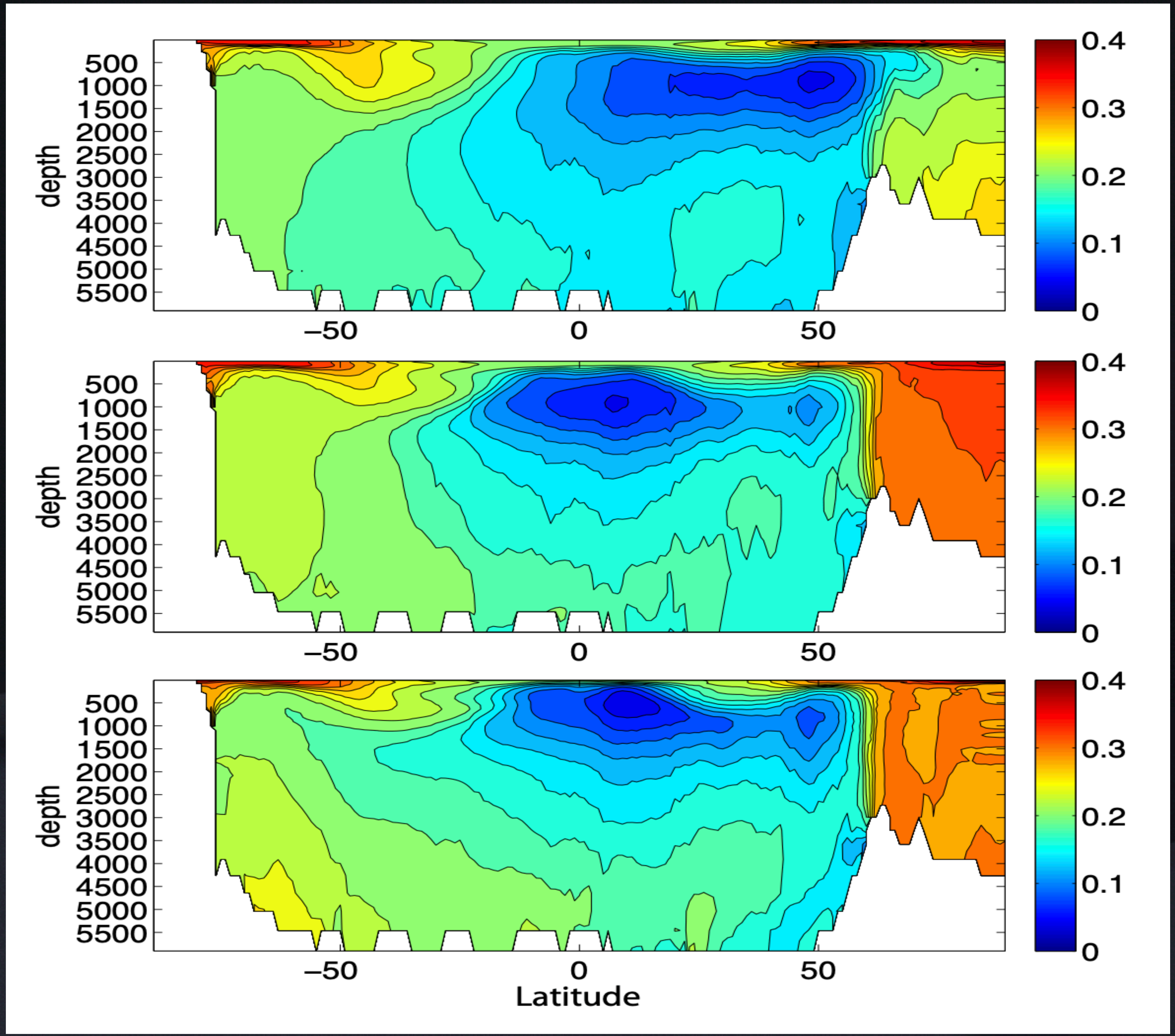
Hands-on Session : Digital Twins for Ocean Robots

JuliaEO26, Terceira, Azores

Gaël FORGET, 2026/01/08

Example : the ECCO4 ocean reanalysis

Learning Ocean Mixing Parameters from Argo (T/S profiles)



Forget, Ferreira, and Liang,, Ocean Sci., 11, 839–853, https://doi.org/10.5194/os-11-839-2015, 2015

Example : Forecasting Climate Tipping Points

What Observations Do We Need to Constrain Models?

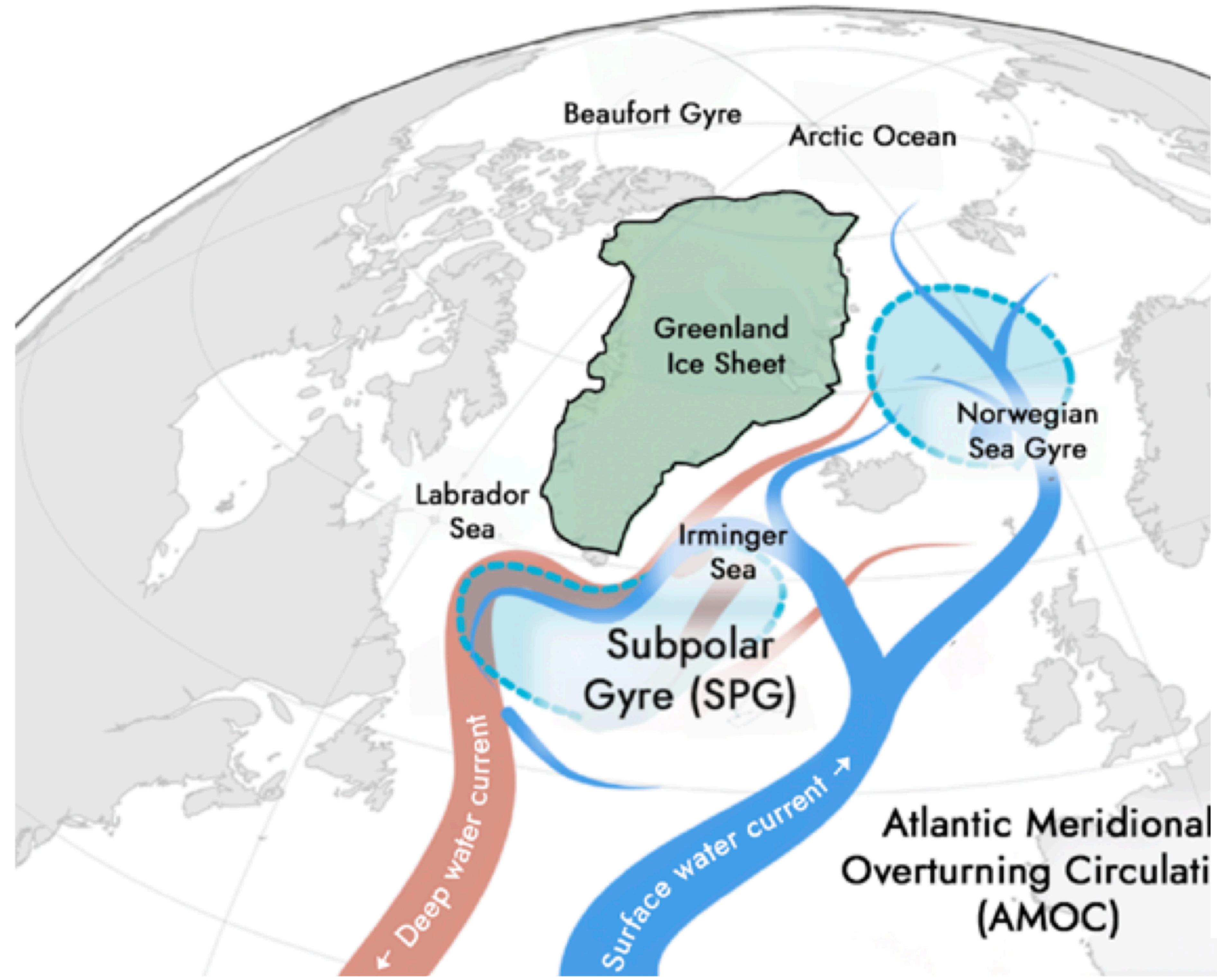


Figure 1: Tipping points targeted for demonstration of an early warning system: Greenland Ice Sheet (GrIS) and the North Atlantic Subpolar Gyre (SPG) Circulation. *The SPG links into the Atlantic Meridional Overturning Circulation (AMOC), also shown, but the latter will not be an immediate target of this programme. Adapted from Global Tipping Points report p.128.*

POLEMIX: Autonomous profiling observations to unravel the role of mixing in North Atlantic climate tipping points

Bieito Fernández Castro, University of Southampton

Team: Alice Marzocchi, Dirk Koopmans, Tillys Petit + Louis Clément, National Oceanography Centre; Gael Forget, Massachusetts Institute of Technology; Léo Lacour + Edouard Leymarie, Laboratoire d'Océanographie de Villefranche-sûr-Mer; Anneke Doeschate, Rockland Scientific Close

This team will develop and deploy a proof-of-concept observing system using autonomous profiling floats to continuously monitor turbulence and mixing across the North Atlantic Subpolar Gyre. By integrating these novel mixing data into ocean and climate models through advanced state estimation and digital twin frameworks, this team will enhance our mechanistic understanding of freshwater mixing, deep convection, and allow for more accurate predictions of the Gyre's tipping point.

Advanced Research + Invention Agency ARIA

https://www.aria.org.uk/opportunity-spaces/scoping-our-planet/forecasting-tipping-points

DTOR framework

Quick Recap

- Proc. JuliaCon Conf. : Forget, G., 2024: Digital twins for ocean robots., **6**, 164, https://doi.org/10.21105/jcon.00164
- GitHub : JuliaClimate and JuliaOcean organizations
- JOSS : MeshArrays.jl , OceanRobots.jl , and MITgcm.jl
- Package docs : all of the above, along with ClimateModels.jl and Climatology.jl

DTOR framework

Updates from 2025 (observations)

- OceanRobots.jl , ArgoData.jl , Climatology.jl
  - Geospatial mapping of sparse data
  - New Supported Datasets (XBT, CPR)
  - Parquet Format for Argo Data
  - Integration with Polygons packages

DTOR framework

Updates from 2025 (models)

- ClimateModels.jl , MITgcm.jl , Drifters.jl, MeshArrays.jl
  - Oceananigans.jl extension in ClimateModels.jl
  - Polygon array struct in MeshArrays.jl
  - Makie recipes for MeshArray and Polyarray
  - Support for NEMO model grid (MeshArrays.jl ...)
  - OSCAR surface current reanalysis (... Drifters.jl)

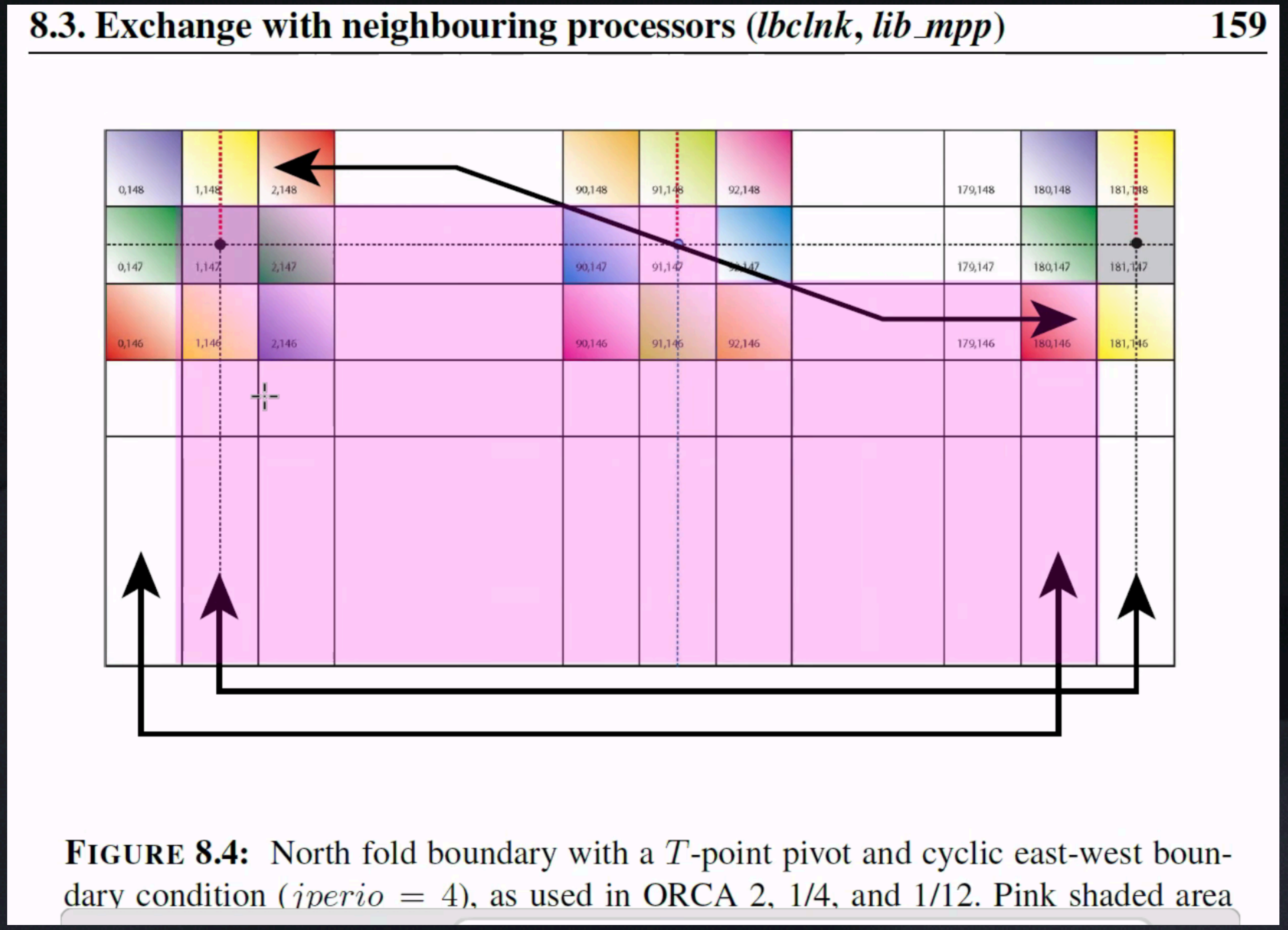

8.3. Exchange with neighbouring processors (*lbclnk*, *lib_mpp*) 159

FIGURE 8.4: North fold boundary with a T-point pivot and cyclic east-west boundary condition ($jperio = 4$), as used in ORCA 2, 1/4, and 1/12. Pink shaded area

Dataset Notebooks

Ship-based Observatories :

- ShipCruise_CCHDO.html (➪ code link) : CTD rosette and related data
- XBT_transect.html (➪ code link) : expendable Bathythermograph (XBT) data
- CPR_notebook.html (➪ code link : Continuous Plankton Recorder (CPR) data

Drifting Observatories :

- Float_Argo.html (➪ code link) : Argo profiling float data
- Drifter_GDP.html (➪ code link) : near-surface drifter time series
- Drifter_CloudDrift.html (➪ code link) : near-surface drifter statistics
- Glider_Spray.html (➪ code link) : underwater glider data

Moored Observatories :

- Buoy_NWP_NOAA.html (➪ code link) : NOAA station data (a few days)
- Buoy_NWP_NOAA_monthly.html (➪ code link) : NOAA station data (monthly means)
- Mooring_WHOTS.html (➪ code link) : WHOTS mooring data

External APIs

- OceanOPS.html (➪ code link) : global fleet of ocean observing systems
- Roce_interop.jl (➪ code link) : R-oce toolbox.
- Argo_argopy.html (➪ code link) : argopy python toolbox.

OceanRobots.jl

Search docs (Ctrl + /)

Home

User Interface

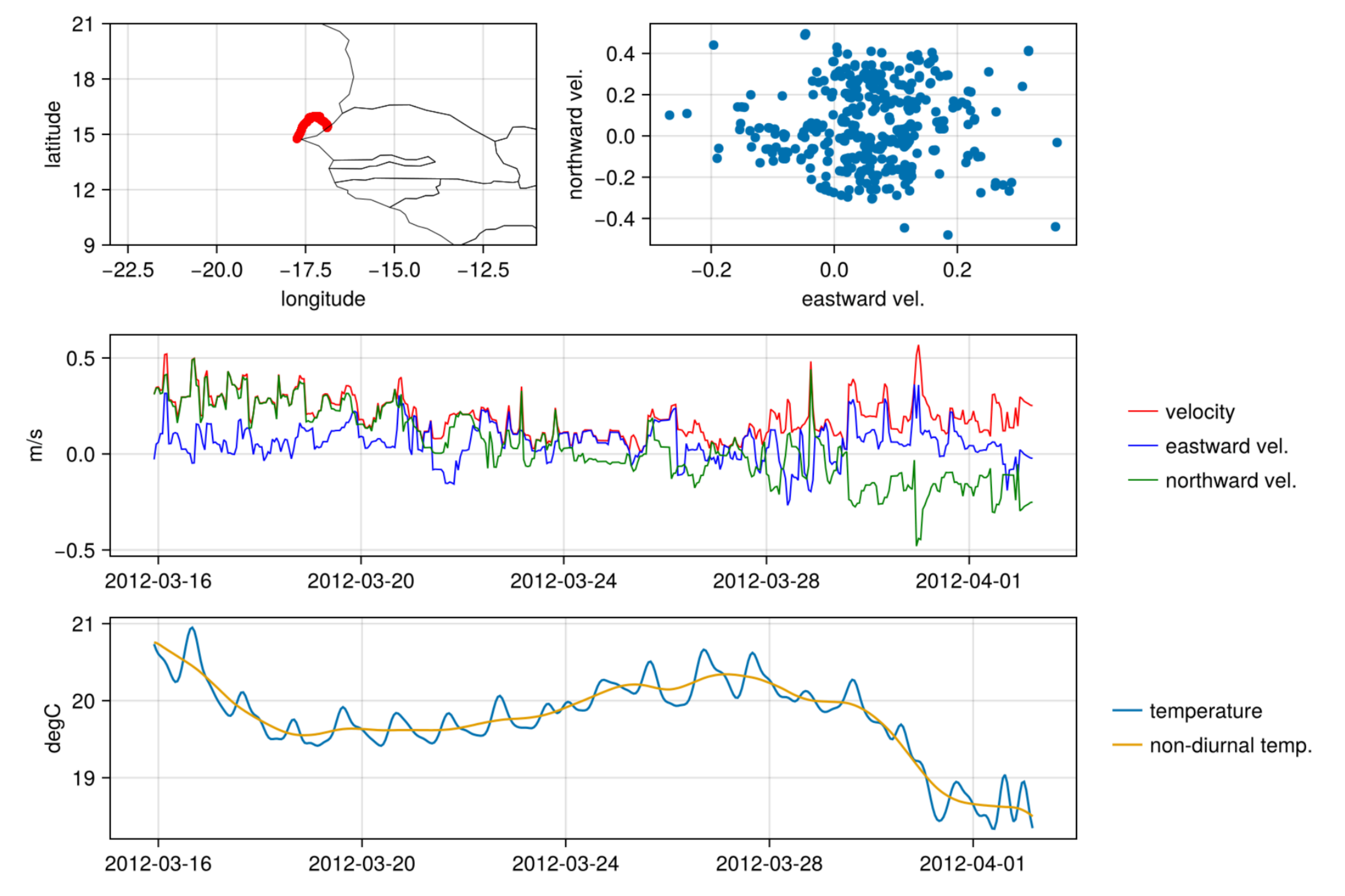
- Supported Datasets
- `read` methods
- `plot` methods
- `query` method
- Add-Ons

Notebooks

User Directions

Surface Drifters

```
using OceanRobots, CairoMakie
drifter=read(SurfaceDrifter(),1)
plot(drifter,pol=pol)
```



User Guide

As shown in the Examples section, the typical worflow is:

1. set up a `FlowFields` data structure (`F`)
2. set up `Individuals` (`I`) with initial position 📌 and `F`
3. displace `I` by `solve!(I,T)` following `I.F` over `T`
4. post-process by `I.🔧` and record information in `I.🔴`
5. go back to `step 2` and continue if needed

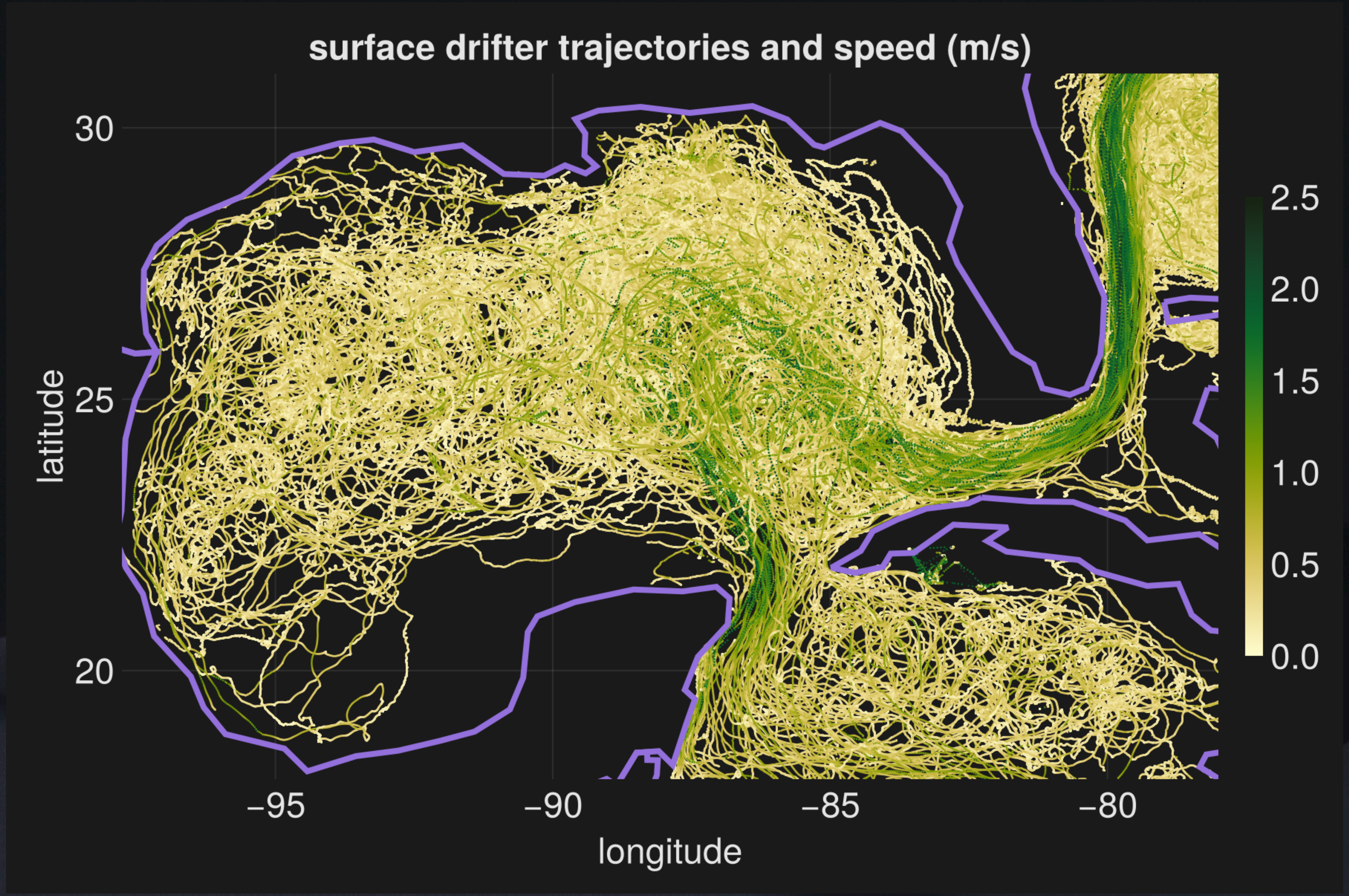
The data structures for steps `1` and `2` are documented below. Steps `3` and `4` normally take place as part of `solve!` (i.e. `∫!`) which post-processes results, using 🔧, records them in 🔴, and finally updates the positions of individuals in 📌. Since 🔴 is a DataFrame, it is easily manipulated, plotted, or saved in step `4` or after the fact.

```
using Drifters, CairoMakie
P=Drifters.Gulf_of_Mexico_setup()
F=FlowFields(u=P.u,v=P.v,period=P.T)
I=Individuals(F,P.x0,P.y0);
[solve!(I,P.T .+P.dT*(n-1)) for n in 1:P.nt]
summary(I.🔴)
```

```
"481000×4 DataFrame"
```

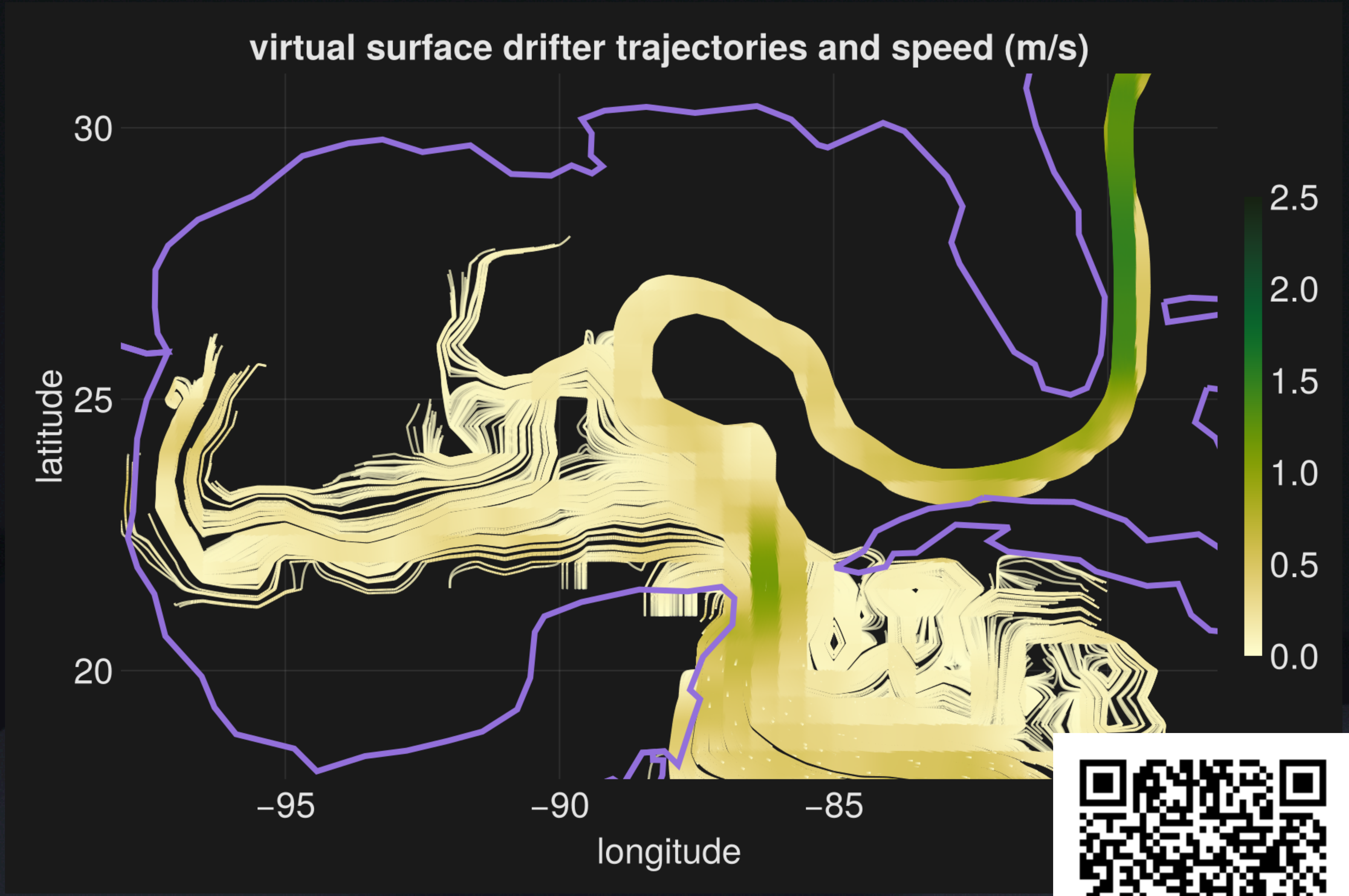
Ready for Learning!

Physical Twin



OceanRobots.jl (Observations)

Virtual Twin



Drifters.jl (basic emulator)

OceanRobots.jl

Search docs (Ctrl + /)

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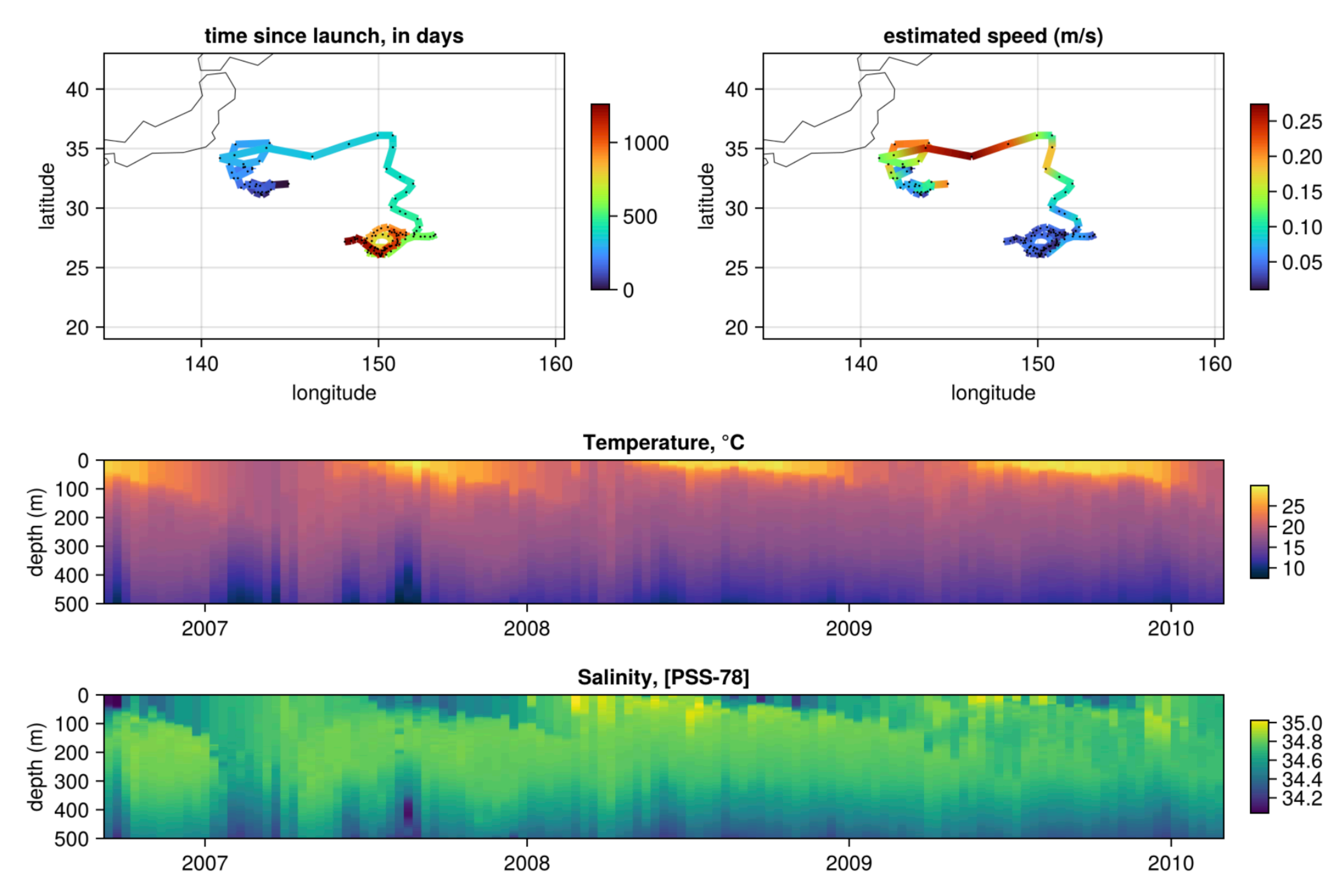
Notebooks

User Directions

Argo Profilers

```
using OceanRobots, CairoMakie
argo=read(ArgoFloat(),wmo=2900668)
plot(argo,pol=pol)
```



ClimateModels.jl

`ClimateModels.jl` provides a uniform interface to climate models of varying complexity and completeness. It is aimed at any model from highly simplified to whole Earth System models.

`ClimateModels.jl` also supports workflows that leverage model output available online. Version control, using *git*, allows for easy workflow documentation and reproducibility.

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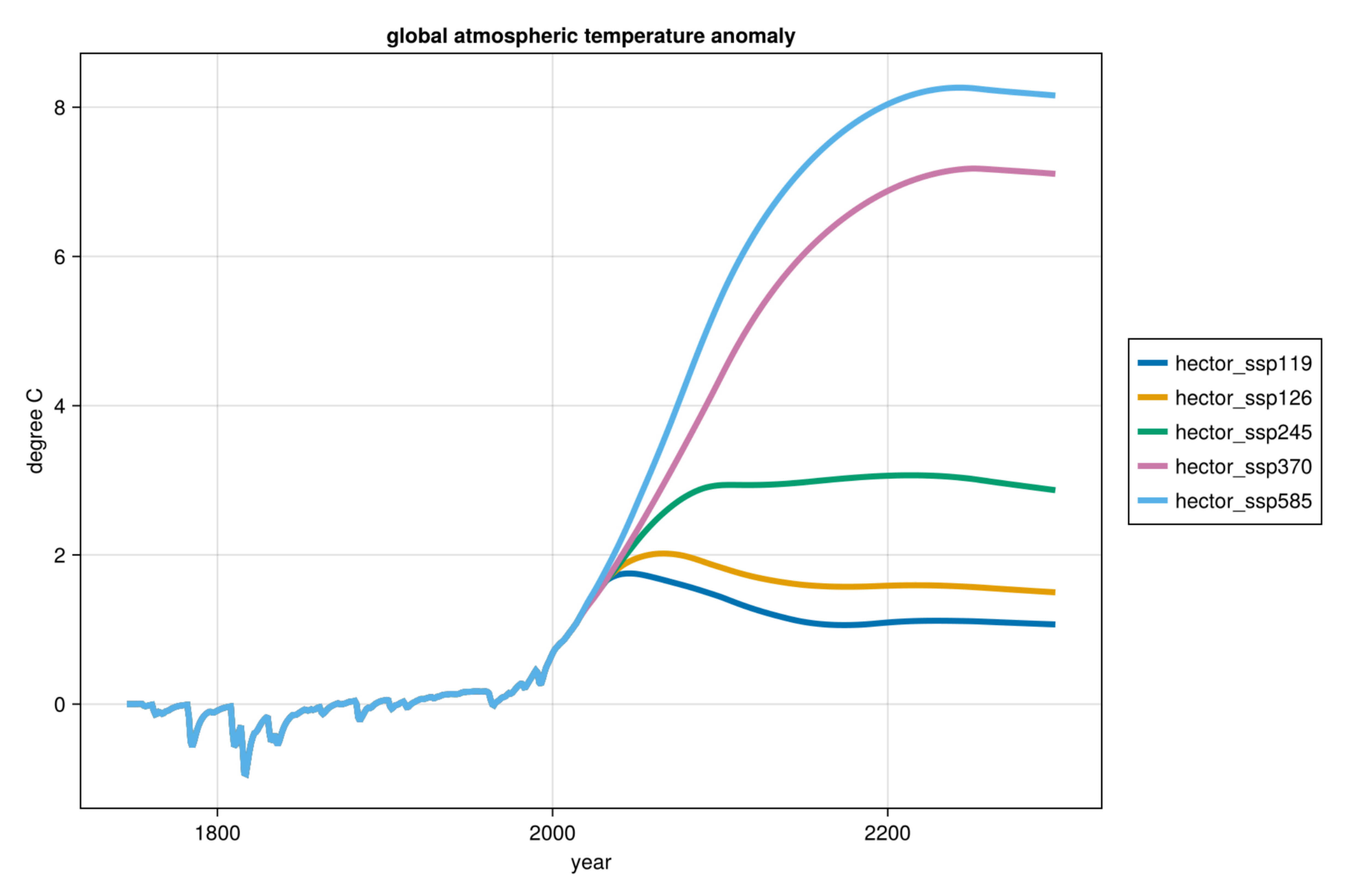

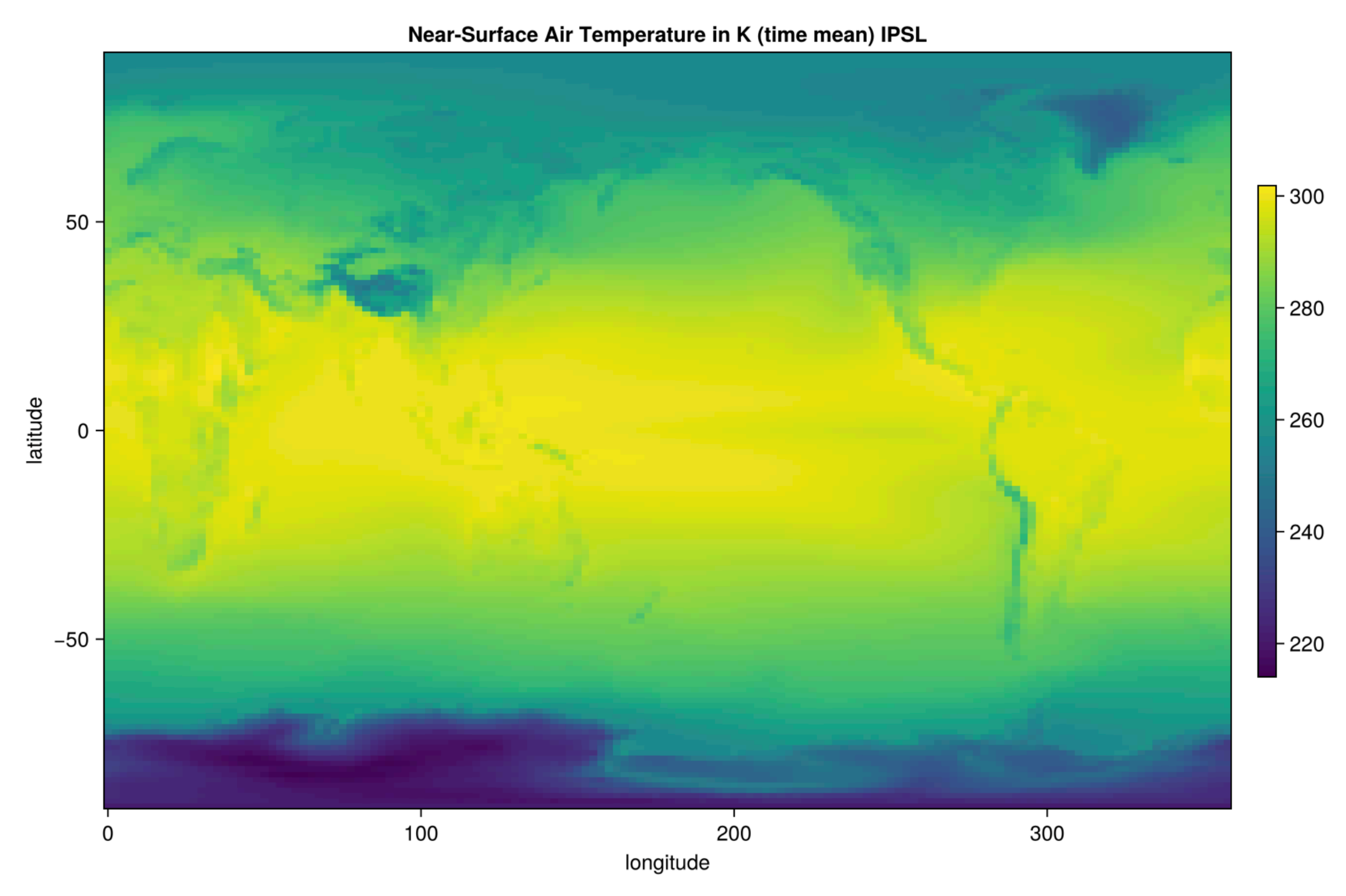

Interactive Emulator Simulations

(Using Hector in this example)

Replay Model Output from CMIP6

(IPSL climate model in this example)

Hands-On Activity

- Add climate scenario to Argo (using emulator from ClimateModels.jl)
- Estimate Global Mean from sparse data (e.g. using sample mean)
- How Many Floats do we need?

Near-Term Goals

- Support for new model grids in MeshArrays.jl (incl. MOM6 and Oceananigans.jl)
- More extensions in ClimateModels.jl (incl. ClimaOcean.jl & SpeedyWeather.jl)
- ...