Spatial filtering for high-resolution modelling

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ECMWF

EERIE
European Eddy-Rich ESMs

Filtering on non-global fields requires going beyond spectral methods

- Filtering
  - … localized in geographical space
  - … on non-global domains
  - … inherently non-global fields (ocean)

- fast & efficient
- easy to use
- conserving filtered quantity
- good treatment of coastlines / missing values
- works on a variety of grids (lat-lon, reduced Gaussian, tripolar, unstructured ocean grids)
- flexibility for setting filter lengthscale

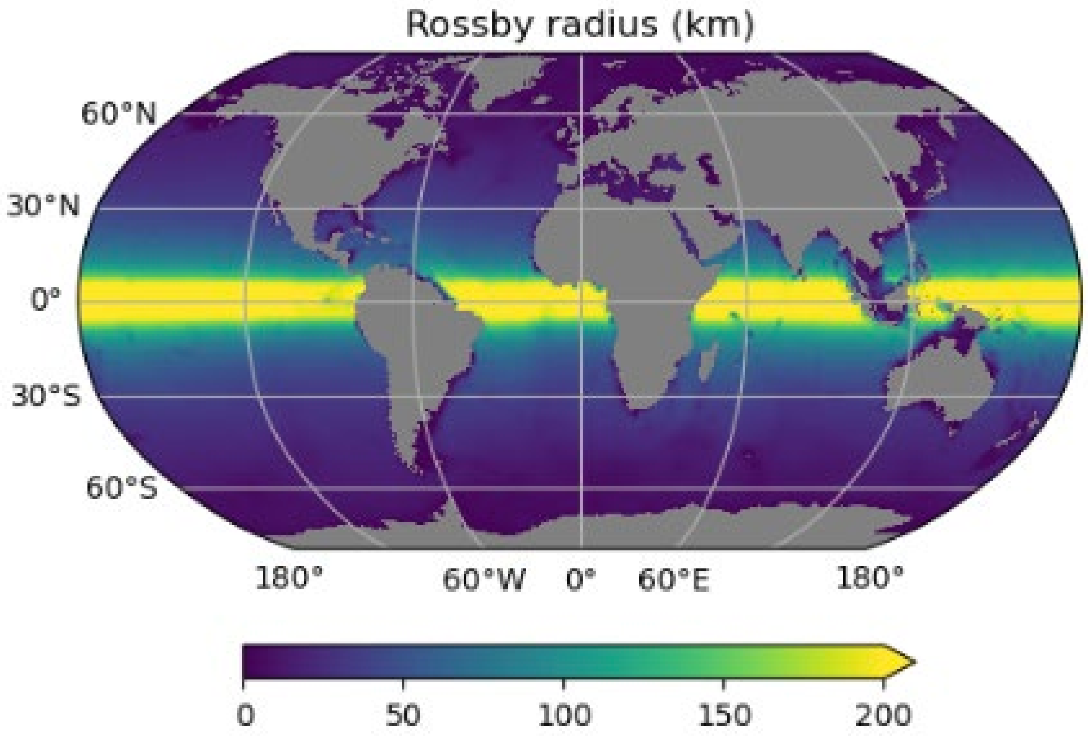
- Here: Focus on filtering in gridpoint space, particularly to include ocean variables

Tools

- gcm-filters
  - Diffusion-based
  - Great flexibility in filtering lengthscale
  - Supports only regular grids
  - Fast on GPUs
- FlowSieve
  - Based on convolution of a Helmholtz decomposition
  - Preserves well physical properties
- MIR
  - Works on reduced Gaussian grids
  - Well integrated into the ECMWF toolchain
  - Difficult to work on custom data
- implicit_filter
  - Very fast
  - Only fixed lengthscale
  - Only specific grids
- … many others!

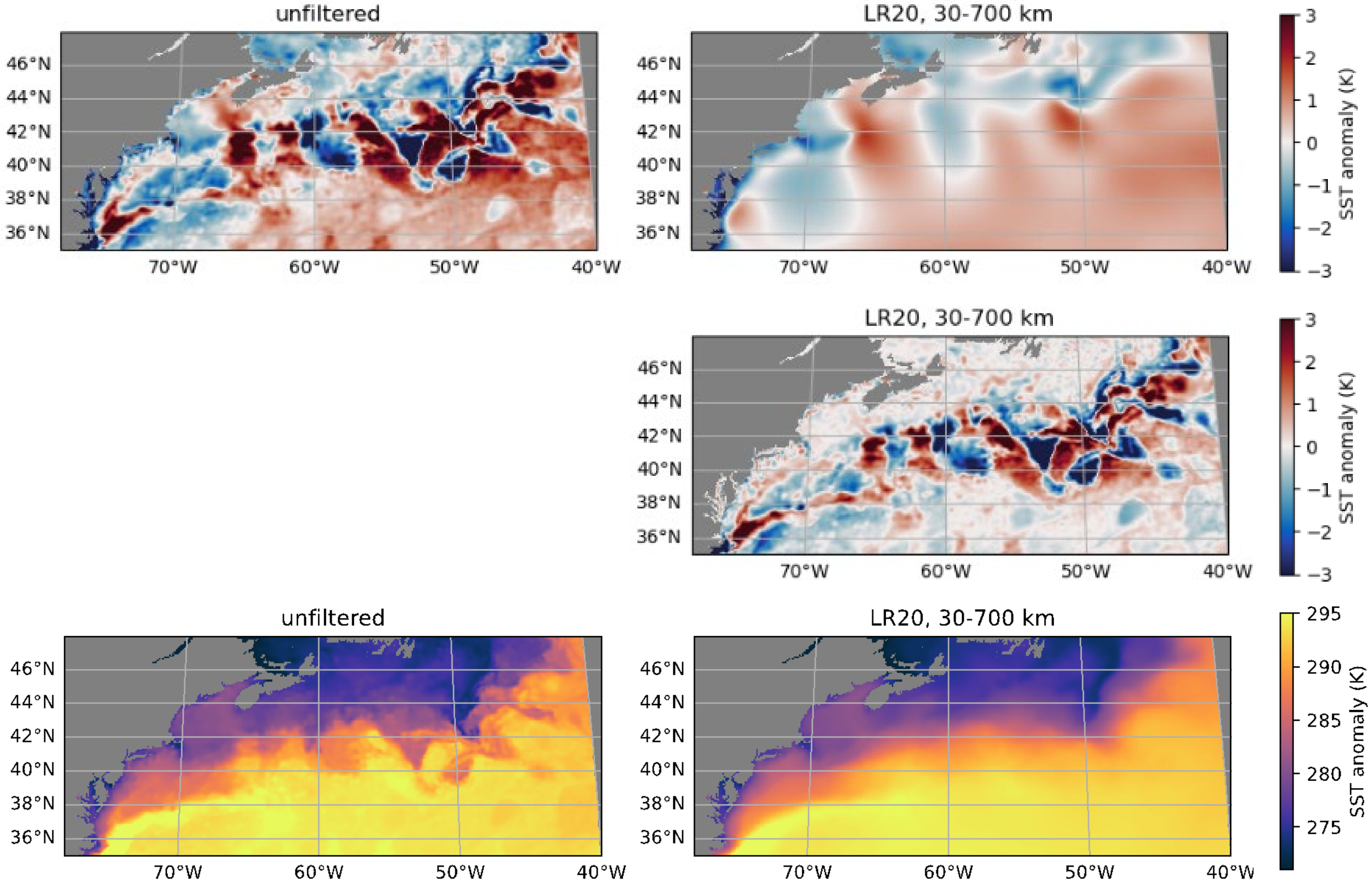
SST boundary conditions for IFS-AMIP simulations for EERIE

- Investigating the impact of ocean mesoscale features for weather and climate
- Multidecadal IFS AMIP runs with and without ocean mesoscale
- Remove time-varying ocean mesoscale using a diffusion-based filter as a multiple of the local Rossby radius
- ➔ gcm-filters



Grooms et al. (2021), Loose et al. (2022)

Filter SST anomalies with 20 x the local Rossby radius



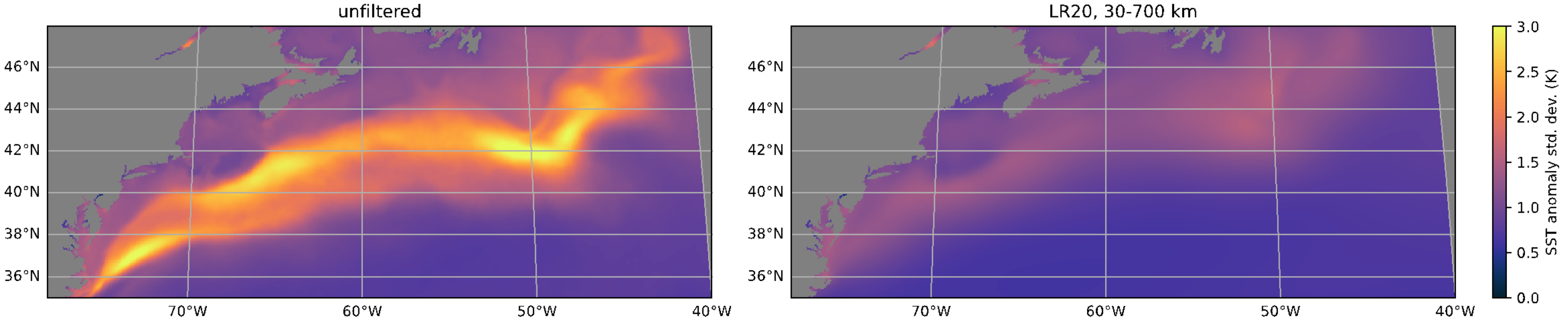
low-pass filtered

high-pass filtered

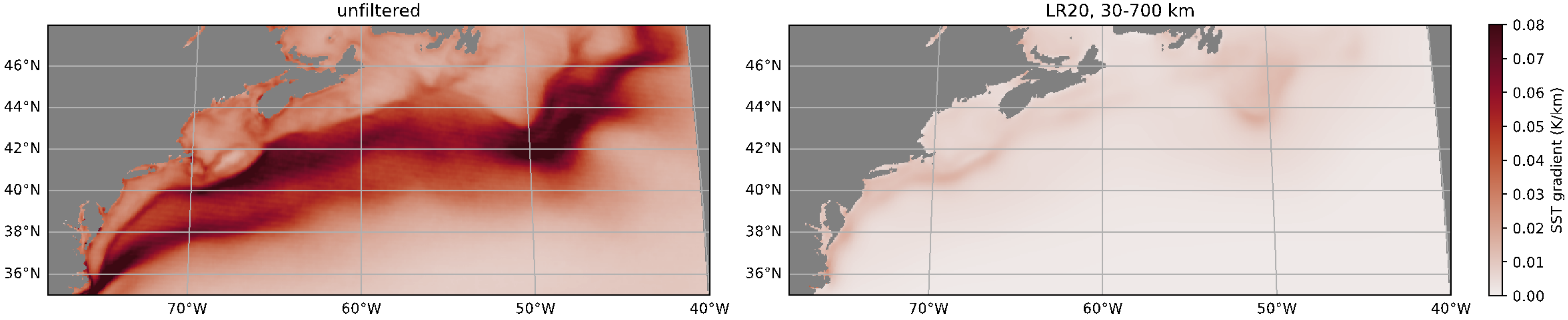
reconstructed

Filtering strongly reduces spatio-temporal variability and SST gradients

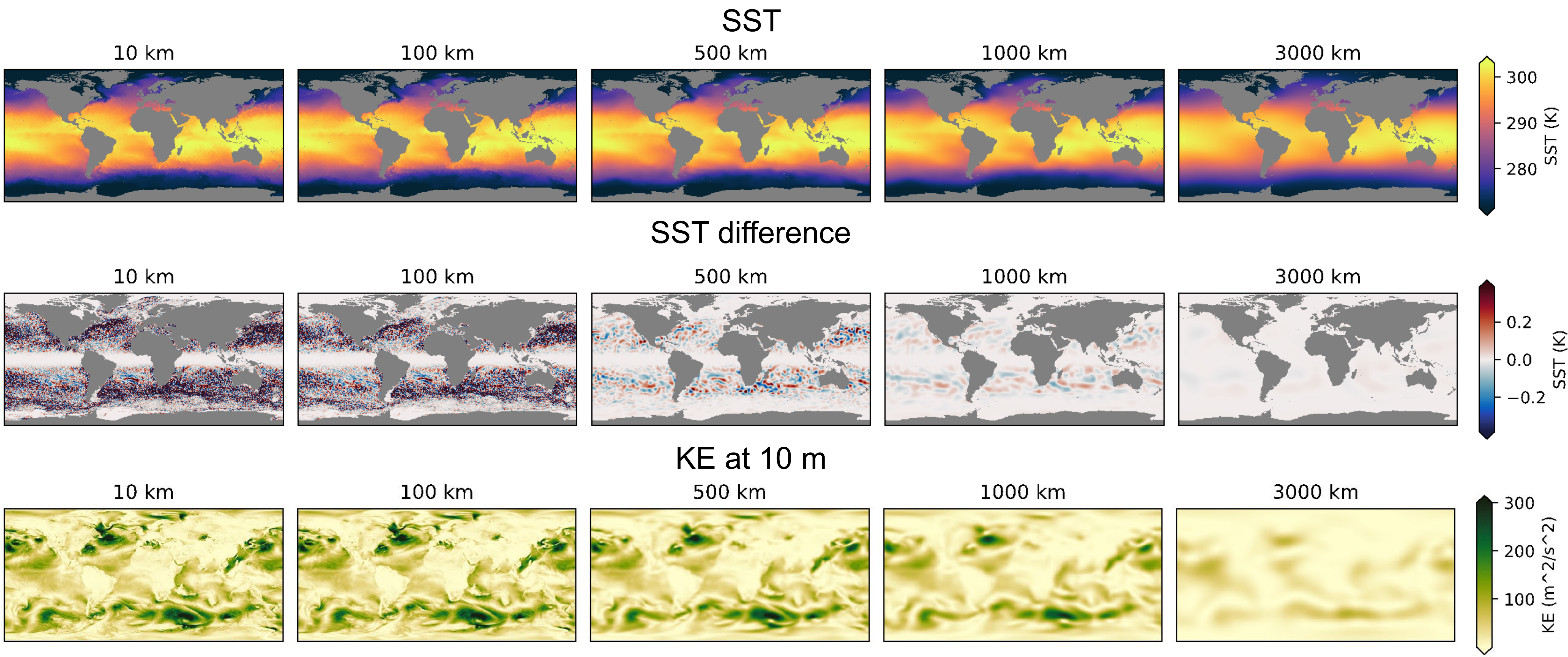
SST anomaly standard deviation



Mean SST anomaly gradient

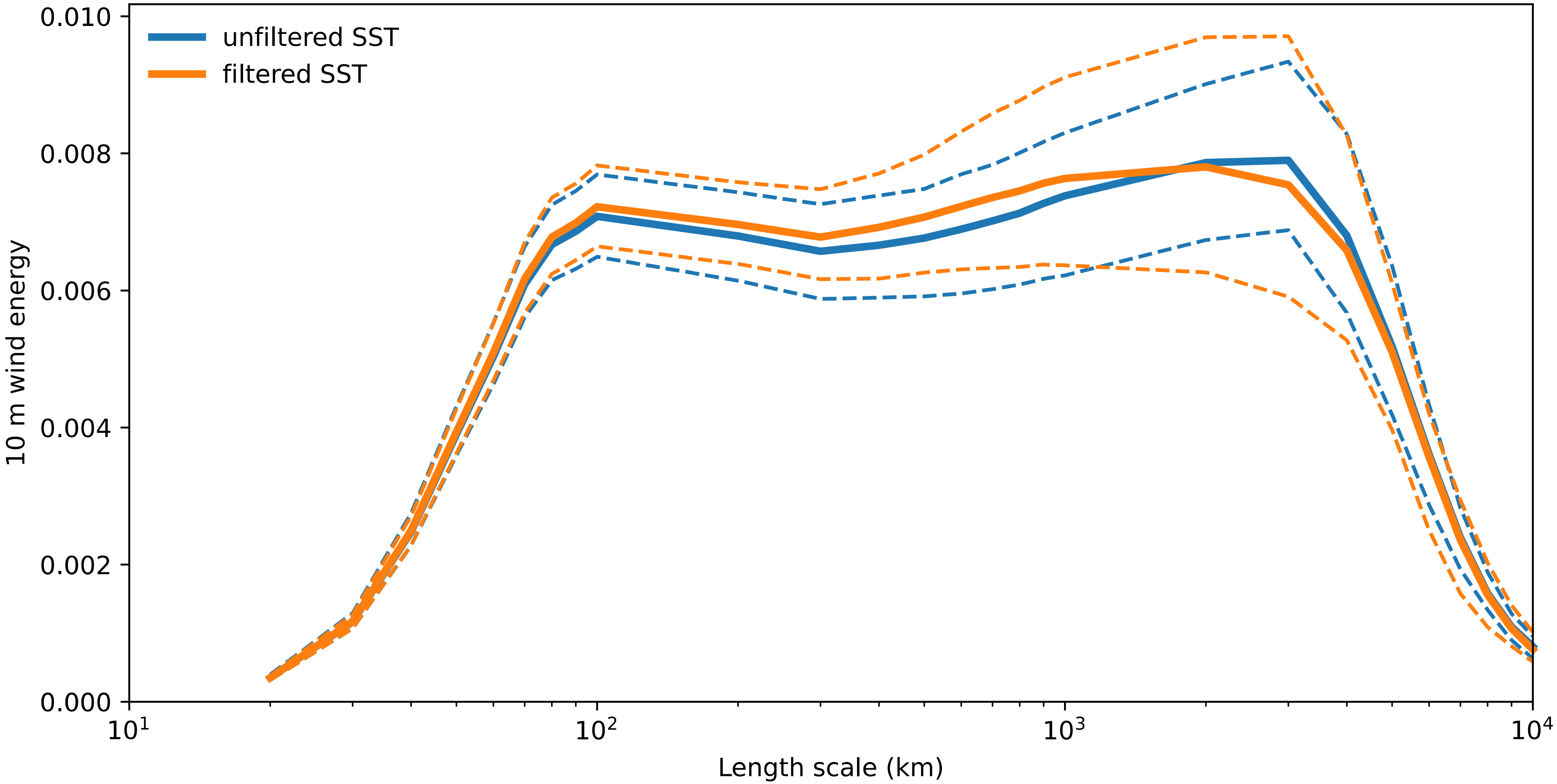


Model fields as function of scale



Runs are just completing – stay tuned!

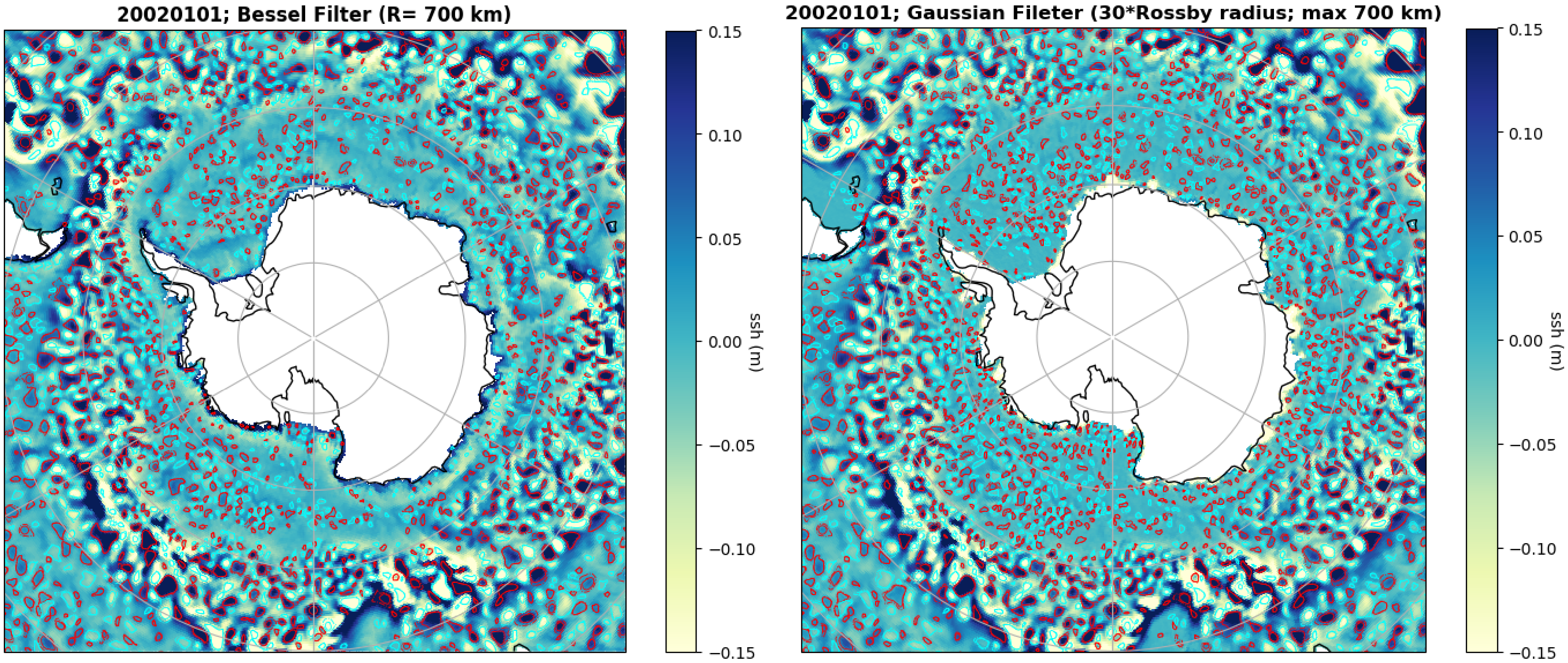
Energy of surface winds as function of scale



Ting-Chen Chen

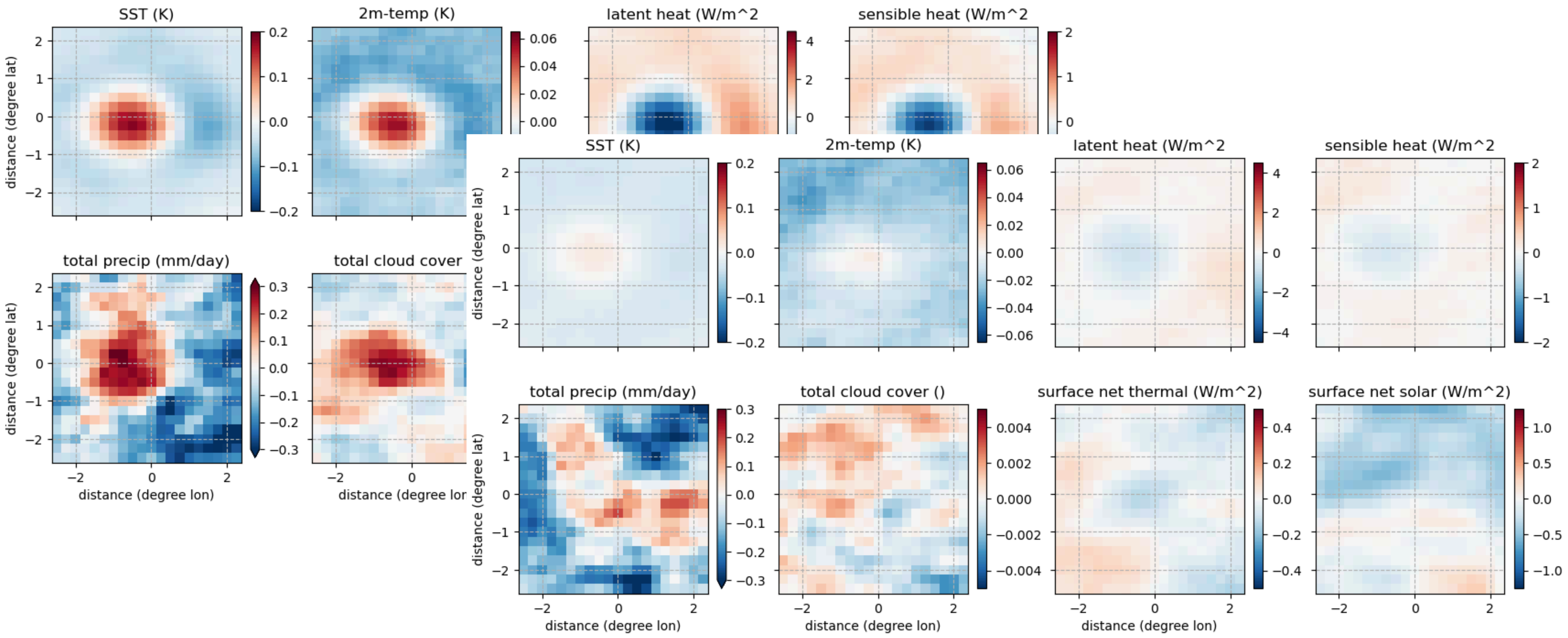
Eddy tracking

- Using scale-aware gcm-filters py-eddy-tracker identifies more and smaller eddies in the high latitudes



Eddy-composites

- Eddies identified by eddy-tracking can be composited for the mean response to eddies



Filtering ocean surface velocity fields via coarse-graining

Assets:

- Designed for **non-Euclidian spherical geometry**, compatible with filtering domain of arbitrary size (instead of, e.g., classical Fourier over "small enough" domains), up to global Earth.
- Convolution operator has nice **commutation properties** (Aluie et al., 2019), e.g. filtered non-divergent input velocity fields will remain non-divergent through filtering.
- Access the fluid energy spectrum **localised in geographical space** (unlike spherical harmonics, which are inherently global).
- **Masked fields** (such as ocean ones) can be "inoffensively" dealt with filling (with zero's).
- Existing **open-source library FlowSieve** (Storer et al., 2022).

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Global energy spectrum of the general oceanic circulation

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Check for updates

Benjamin A. Storer[1], Michele Buzzicotti[2], Hemant Khatri[3], Stephen M. Griffies[4] & Hussein Aluie[1]

Advent of satellite altimetry brought into focus the pervasiveness of mesoscale eddies $\mathcal{O}(100)$ km in size, which are the ocean's analogue of weather systems and are often regarded as the spectral peak of kinetic energy (KE). Yet, understanding of the ocean's spatial scales has been derived mostly from Fourier analysis in small "representative" regions that cannot capture the vast dynamic range at planetary scales. Here, we use a coarse-graining method to analyze scales much larger than what had been possible before. Spectra

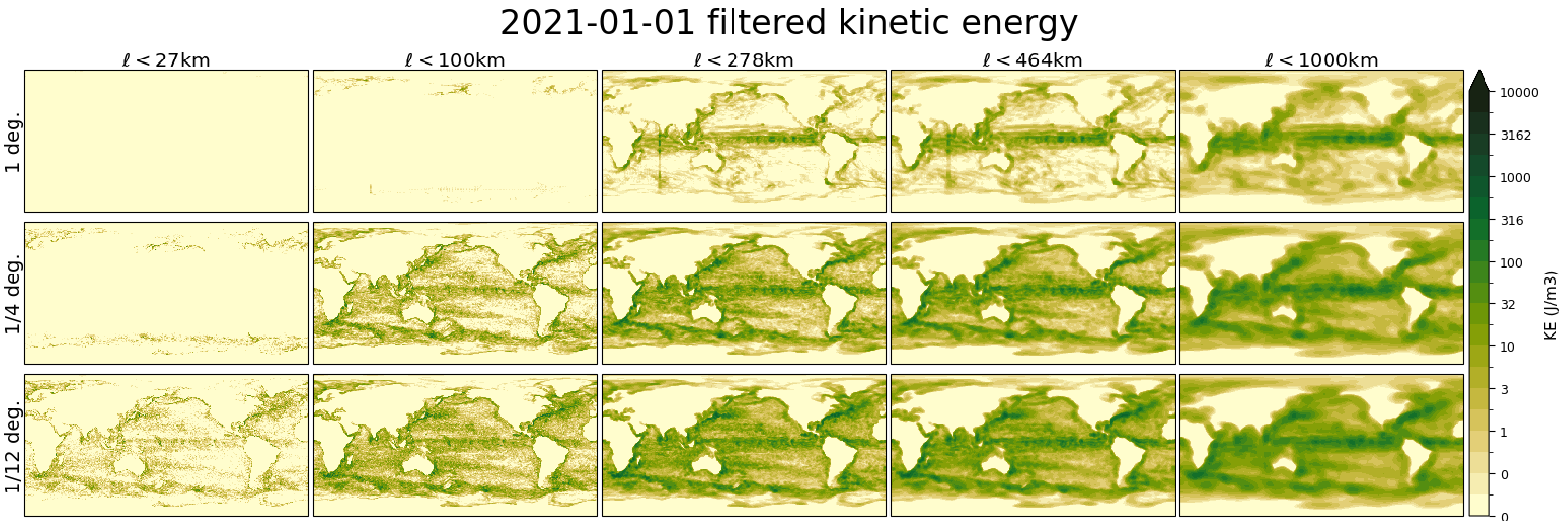
Drawback: Computationally expensive, especially for fine grids with large length scales (code is not GPU ready yet).

Aluie, H. Convolutions on the sphere: commutation with differential operators. *Int J Geomath* **10**, 9 (2019). https://doi.org/10.1007/s13137-019-0123-9

Storer, B.A., Buzzicotti, M., Khatri, H. *et al.* Global energy spectrum of the general oceanic circulation. *Nat Commun* **13**, 5314 (2022). https://doi.org/10.1038/s41467-022-33031-3

Filtering ocean surface velocity fields via coarse-graining

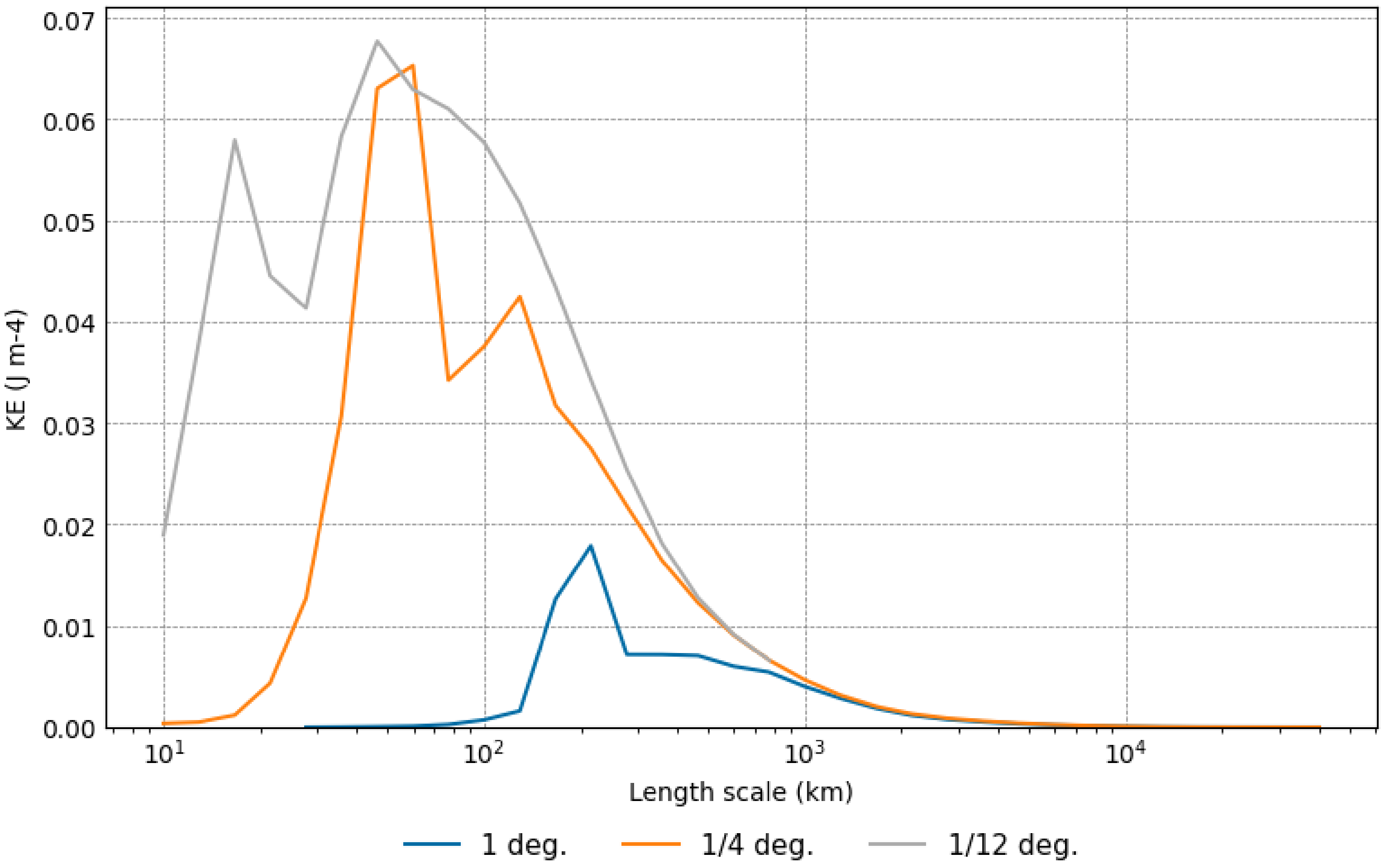
Charles Pelletier



- Results obtained from one single daily mean (for each configuration).
- Low-pass filtered ocean surface kinetic energy for various length scales (columns) from three NEMO ocean model experiments of varying resolution (rows).
- Smallest representable energy corresponds to the model grid spacing.
- 1/12 is expectedly more eddying; eddy-permitting (1/4 deg) and eddy-resolving (1/12 deg) are vastly more similar than quasi-laminar (1 deg), which is also expected.
- Larger-scale structure (western boundary currents) represented fairly well even with coarse resolution model.

Charles Pelletier

Filtering ocean surface velocity fields via coarse-graining



- Energy spectrum can be assessed by integrating global-scale the filtered energy spectrum and differentiating with respect to grid-scale.
- 1/4º and 1/12º have roughly comparable energy distribution across larger scales.
- Mesoscale eddies O(10-100km) withhold most of the kinetic energy.
- 1º significantly much less energetic, even up to ~1000km (10 grid cells).

Still work in progress! The larger scales from the plot above are under-sampled (due to computational limitations). We hope that further investigations can reveal energy bumps related to larger-scale structures (e.g., Antarctic Circumpolar Current around 10^4km), which Storer et al. (2022) report on.

Summary

- A variety of tools exist for spatial filtering in gridpoint space
- No one fit for all applications, with ongoing developments
- Useful for pre-processing, post-processing and analysing model output
- Ongoing work!