Diagnosing the Horizontal Scales of Sea Surface & Marine Air Temperatures

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Motivation

Turbulent air-sea fluxes of momentum and heat are often calculated from gridded fields of the meteorological and oceanographic parameters that drive the surface exchange using parameterizations that depend on sea surface (SST) and marine air temperature (MAT), winds and humidity. It is important for air-sea interaction research to characterize the spatial and temporal scales of each of these variables, and in the resulting air-sea fluxes, to construct fields of the fluxes, and the variables on which they depend. This is particularly important for understanding large-scale long-term changes in air-sea forcing as observations are sparse in some regions and periods (*Freeman et al.*, 2017). Knowledge of the spatial scales will also help to quantify the uncertainty due to mismatches in satellite orbits and measurement footprints when measurements from different missions are combined to construct gridded air-sea flux produces from satellite data (*Cronin et al.*, 2019).

Differences in spatial scales also indicate how tightly the ocean and atmosphere are coupled. If their spatial scales are comparable, it can be interpreted as both being tightly coupled, large fluxes and high variability will occur when differences in scales are large.

Data

As an example we estimate the spatial scales of SST from the ESA CCI satellite dataset (*Merchant et al.*, 2019) and for MAT we use the ECMWF ERA5 reanalysis (*Hersbach et al.*, 2020). The analysis is based on anomalies of data aggregated to a 1°spatial grid and 5-day intervals (pentads). Anomalies are available directly for the ESA CCI SST, but for ERA5 MAT the annual cycle is estimated by fitting the first 4 annual harmonics to each grid point. The resulting Fourier series is removed from the data at native resolution prior to pentad aggregation.

Parameterizing the horizontal scales of the anomalies

The spatial scales are estimated by fitting ellipse-shaped (major and minor axes plus rotation angle) non-stationary anistropic covariance functions to the anomaly covariances (*Karspeck et al.*, 2012; *Paciorek and Schervish*, 2006). The chosen function is the Matérn covariance, which allows a flexible shape parameter (ν) which varies between the exponential ($\nu = 0.5$) and Gaussian ($\nu \to \infty$) limit. ν is fixed here at 0.5.

Figure 1 shows the axis-lengths for the fitted ellipses for January. It is possible to calculate from these ellipses a covariance matrix relating variability between every pair of points on the global map (*Karspeck et al.*, 2012; *Paciorek and Schervish*, 2006). Examples are shown in Figures 2 and 3, illustrating how the simple ellipses become more complex when the non-stationary information from all regions is combined. More technical details can be accessed via the link below.

This approach is a parameterised kriging that can be used to smooth data and generate spatially-complete fields. It is less prone to the overconfidence than a full covariance/principal component analysis; instead we only assume the spatial scales to be temporally stationary. For example, this approach does not assume the ENSO pattern to be stationary; even if length scales are large in the ENSO region, a much higher uncertainty will be assigned to unobserved parts of the Equatorial Pacific.

Please refer to the Links section for a more complete description.

Links

Project CLASS: This poster: Technical details:

Horizontal scales for MAT, Pacific vs Atlantic, January

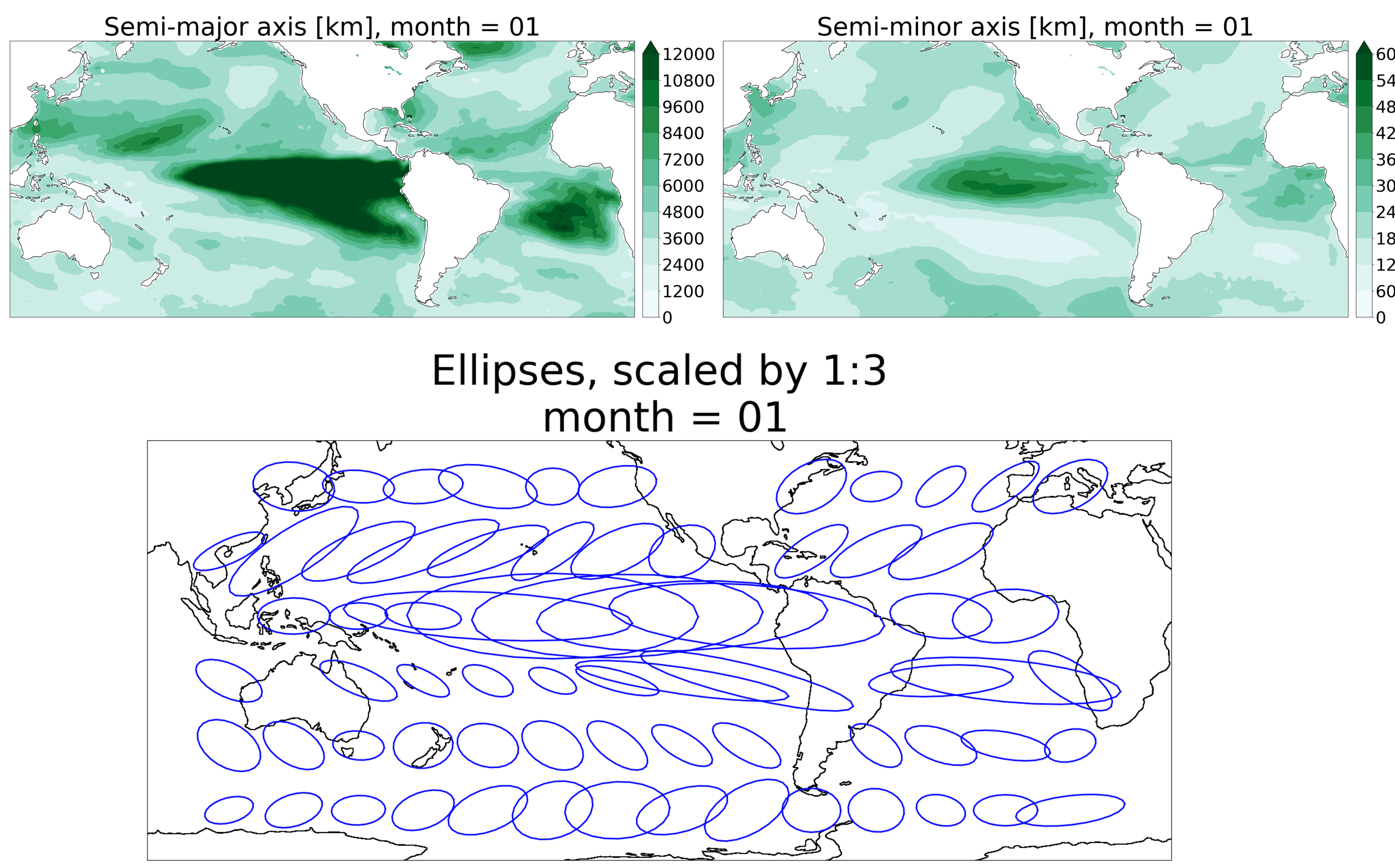

Figure 1. Jan (near ENSO phase peak) ellipse parameters for ERA5 marine air temperature

Shown above are the length scales (major/minor axes, scaled ellipses) estimated from ERA5 MAT (aka 2m T). One can see the largest scales are found in the equatorial Pacific. Secondary maximums are found in tropical Atlantic.

Scale comparisons

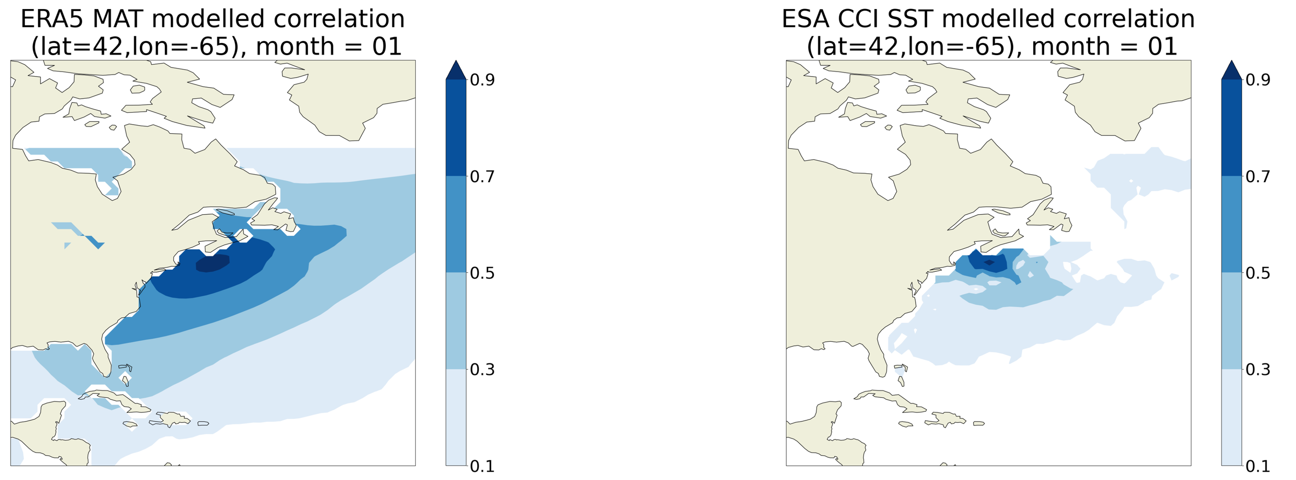

Figure 2. January MAT (left) and SST (right) modelled ellipse and correlation near Boston (42N 65W)

Spatial scales for SST are considerably shorter than MAT. In winter, much of coastal air temperature anomalies are often driven by continental Arctic air masses. The Gulf Stream retains its high-degree of spatial variability. This contrast is fundamental to air-sea energy exchange, and has important implications for extra-tropical cyclone genesis.

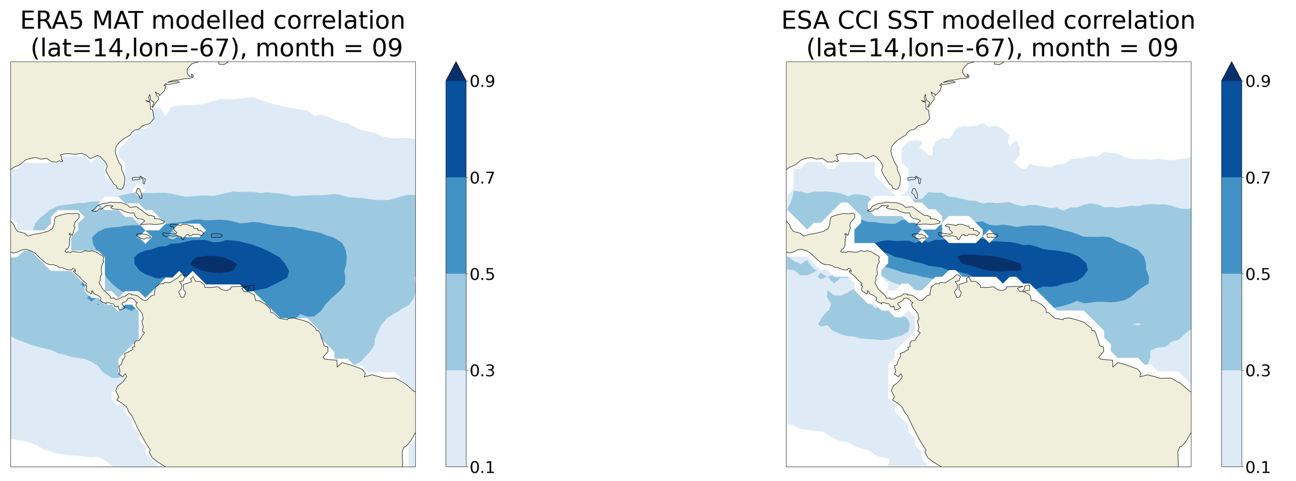

Figure 3. Same as Fig. 2 but for September Caribbean Sea (14N 67W)

In contrast with the West Boundary Current example above, this tropical case shows scales that are more comparable, suggesting tight coupling between the atmosphere and ocean.

Horizontal scales for SST, Pacific vs Atlantic, January

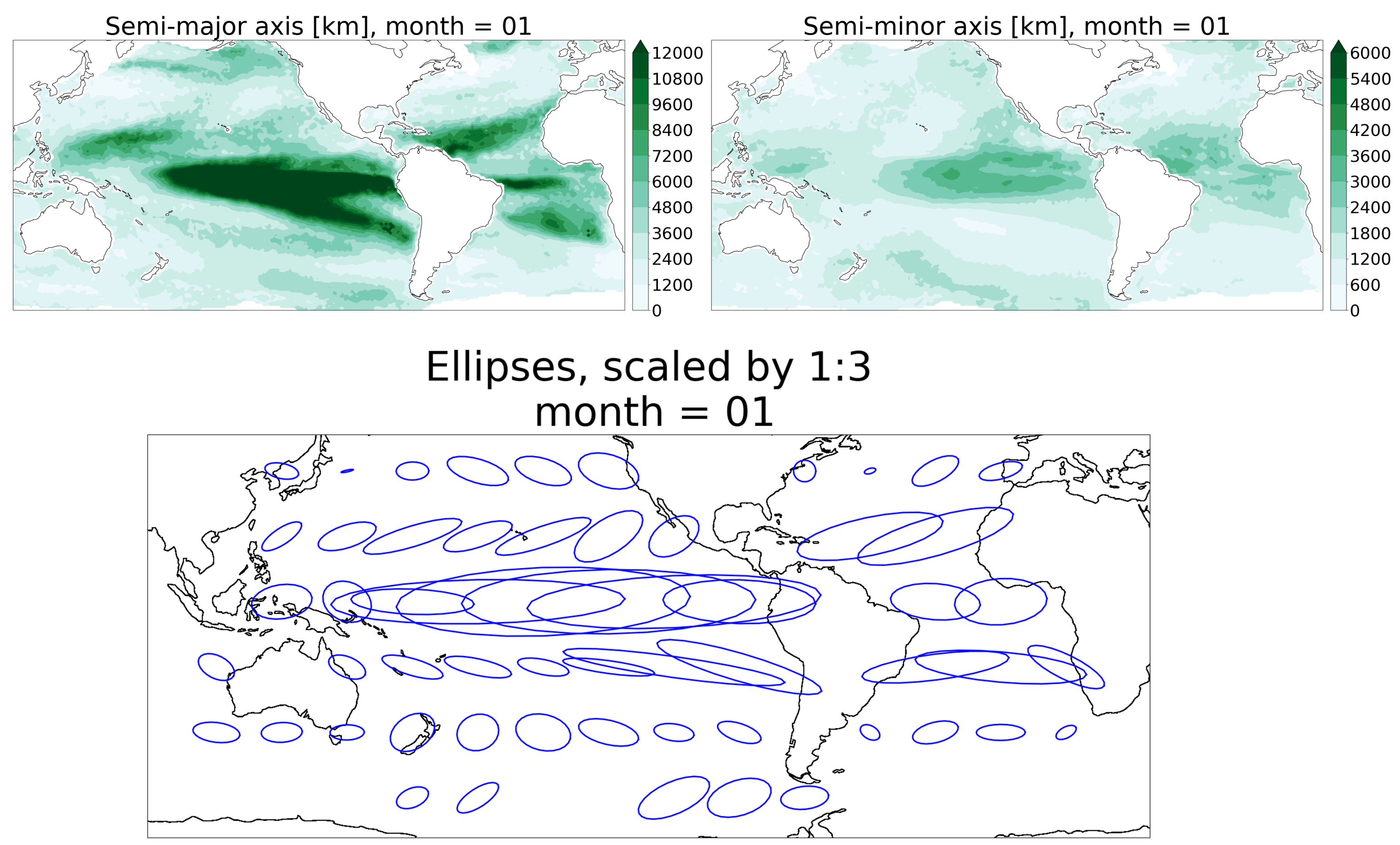

Figure 4. Jan (near ENSO phase peak) ellipse parameters for ESA CCI SST

Shown above are the length scales (major/minor axes, scaled ellipses) estimated from ESA CCI SSTs. Certain parts of the Western Boundary Current (i.e. Gulf Stream and Kuroshio) have much shorter scales than MAT.

Current progress and future plans

The computations use python-based modules which will be made publicly available once development is complete.

Future plans:

- Apply method to irregular instantaneous data like ICOADS (*Freeman et al.*, 2017).
- Apply method to other variables, including ones that are relevant to air-sea interaction and fluxes such as wind speed, humidity and and air-sea temperature difference.
- Explore use of the calculated scales for the quantification of sub-gridscale variability and observational uncertainty from observations in ICOADS.

References

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