

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 products 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 anisotropic covariance function to the anomaly covariances (Karspeck *et al.*, 2012; Paciorek and Schervish, 2006). The chosen function is the Matérn covariance, which allows a flexible shape (ν) between the exponential ($\nu = 0.5$) and Gaussian ($\nu \rightarrow \infty$) limit. ν is usually fixed and is set to the 0.5 exponential limit.

Covariance between two points (x and x'):

$$c(x, x') = \frac{\sigma\sigma'}{\Gamma(\nu)2^{\nu-1}} \frac{|\Sigma|^{1/4} |\Sigma'|^{1/4}}{|\Sigma|^{1/2}} (2\sqrt{\nu})^\nu K_\nu(2\sqrt{\nu}) \quad (1)$$

This ellipse-based non-stationary anisotropic approach is essentially a parameterised kriging. It is less prone to the overconfidence to the temporal stationarity of teleconnection patterns, which a full covariance/principal component analysis would do; instead we 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 Links section for a more complete description.

Links



Horizontal scales for MAT, Pacific vs Atlantic, January

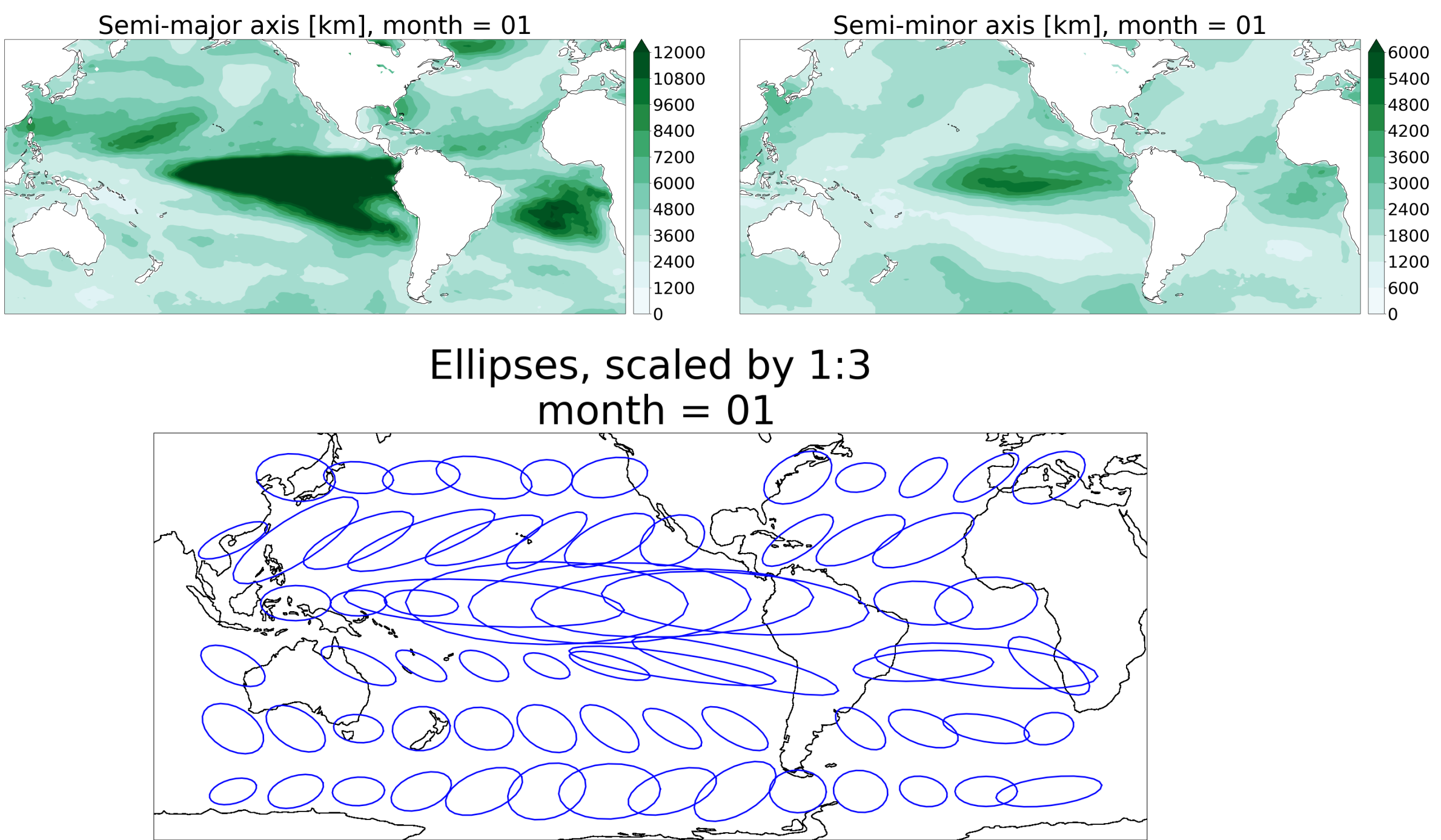


Figure 1. Jan (near ENSO phase peak) ellipse parameters for ERA5 marine air temperature

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

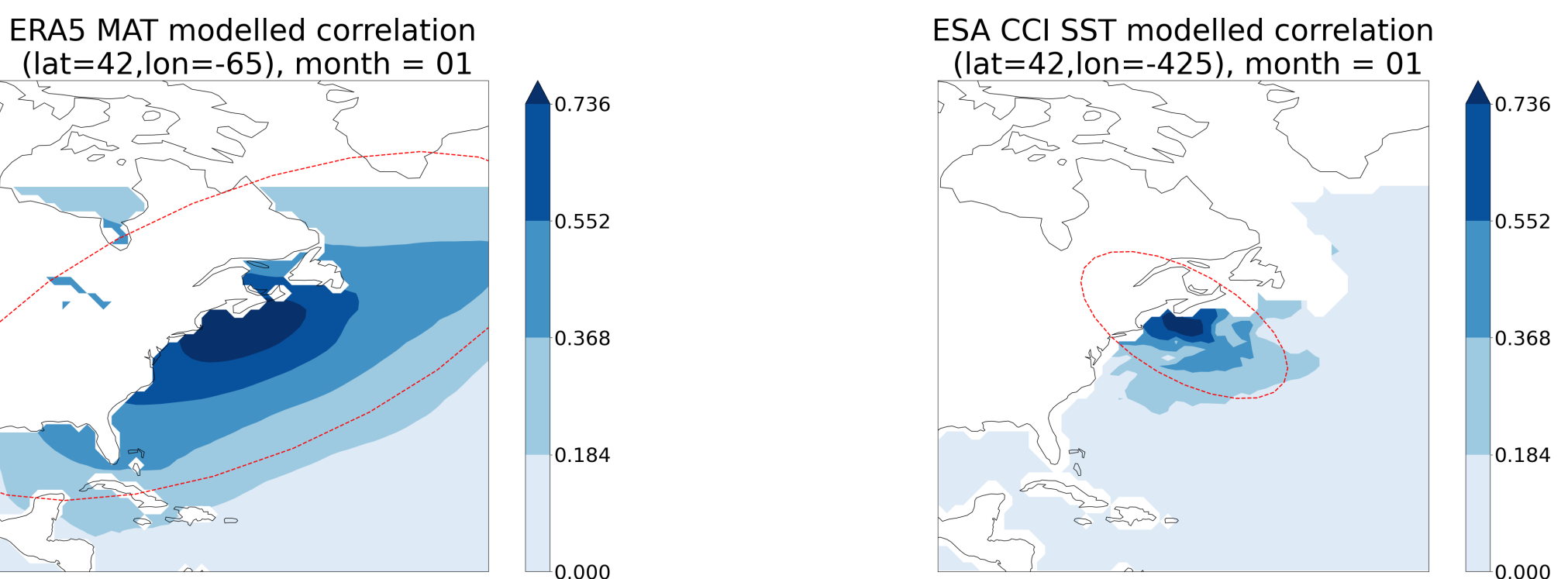


Figure 2. January MAT (left) and SST (right) modelled ellipse and correlation near Boston (42N 65W)

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 highly spatial variable nature. This contrast is important to air-sea energy exchange, and have important implications to extra-tropical cyclone genesis.

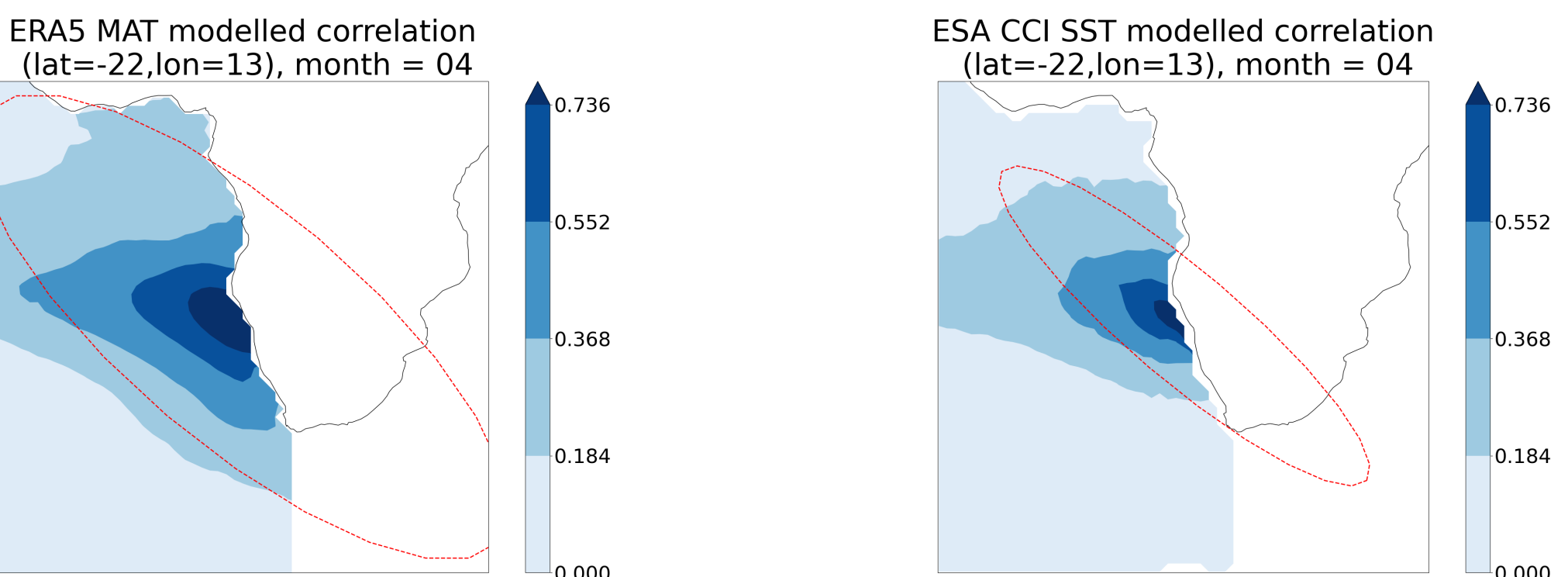


Figure 3. Same as Fig. 2 but for April near Walvis Bay (22S 13E)

While SST horizontal scales remains less than the MAT scales, but the difference is clearly less than the Gulf Stream case. Orientations are also essentially the same. This suggest a tighter coupling of both as one expect for Eastern Boundary Currents, observable from stratocumulus decks formed by the coupling.

Horizontal scales for SST, Pacific vs Atlantic, January

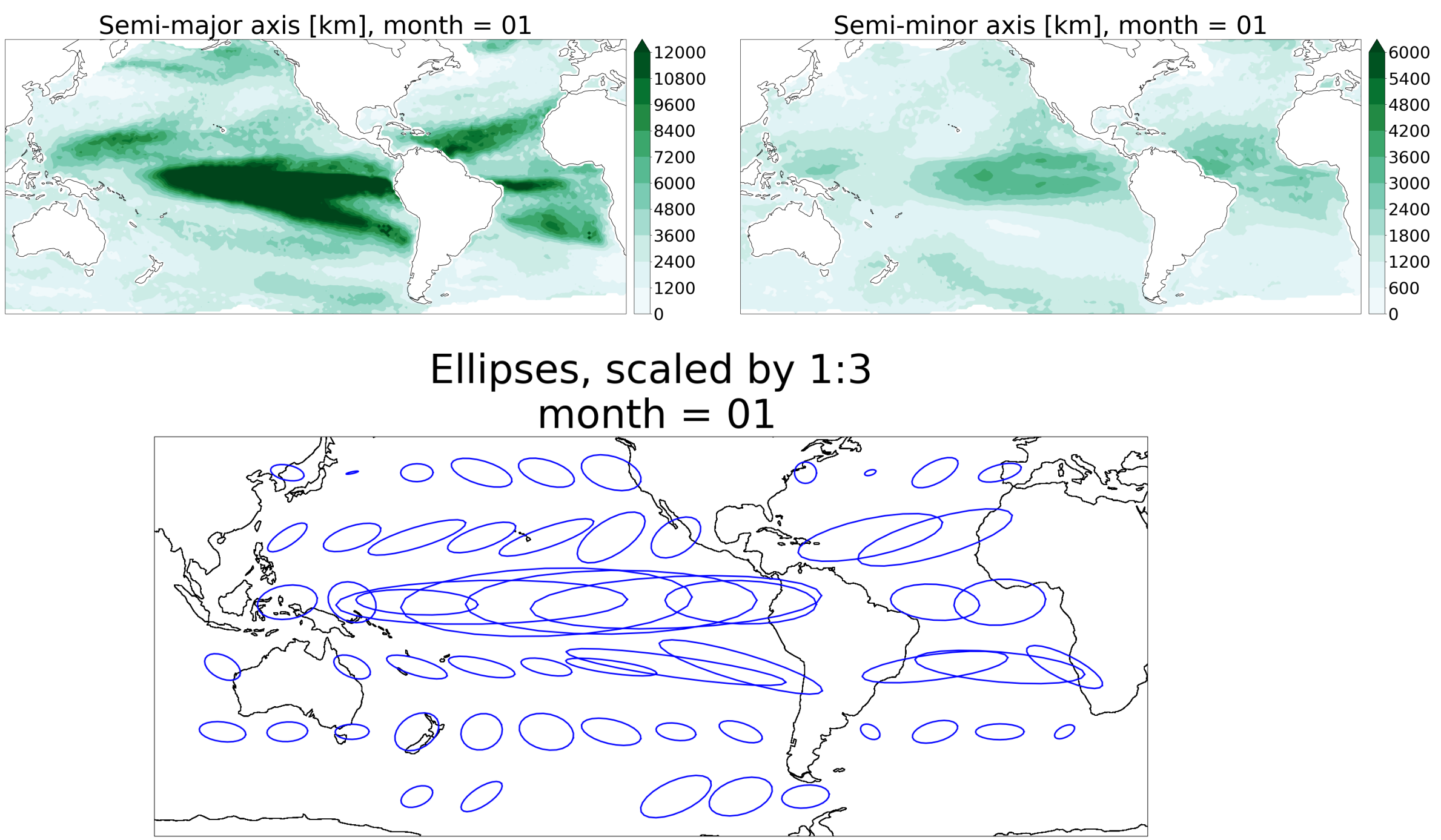


Figure 4. Jan (near ENSO phase peak) ellipse parameters for ESA CCI SST

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

Python-based modules are developed to carry out these computation, and would be released on GitHub when ready.

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 like wind speed and MAT minus SST.
- Diagnose variability and uncertainty to point instantaneous observations (like ships) and processed gridded data (like NWP reanalysis and satellite analyses).

References

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Acknowledgements

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