Understanding Southern Ocean Cloud Controlling Factors on Daily Timescales in the Context of Extratropical Cyclones

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Abstract

Clouds and their associated radiative effects are a large source of uncertainty in global climate models. One region with particularly large model biases in cloud radiative effects (CRE) is the Southern Ocean. Previous research has shown that there are many dynamic "cloud controlling factors" that influence shortwave CRE, and that three important cloud controlling factors over the Southern Ocean are mid-tropospheric vertical velocity, surface thermal advection, and Estimated Inversion Strength (EIS), which have been shown to influence shortwave CRE on monthly timescales. Model errors may thus arise from biases in representing cloud controlling factors (atmospheric dynamics), in representing how clouds respond to those cloud controlling factors (cloud parameterizations), or some combination thereof. This study extends previous work by examining cloud controlling factors over the Southern Ocean on daily timescales in both observations and global climate models. This allows the cloud controlling factors to be examined in the context of transient weather systems, such as extratropical cyclones, and in the context of high pressure quiescent scenes. Composites of EIS and mid-tropospheric vertical velocity are constructed around extratropical cyclones to examine how the different dynamic cloud controlling factors influence shortwave CRE around the cyclone and how similar the model cyclones are to observations. On average, models tend to produce a realistic cyclone, when compared to observations, in terms of the dynamic cloud controlling factors. The difference between observations and models instead lies in how the models' shortwave CRE responds to the cyclone dynamics. In particular, the models' cloud radiative effects are too sensitive to perturbations in mid-tropospheric vertical velocity and, as a result, they tend to produce clouds that are too bright in the cold frontal region of the cyclone and too dim in the center of high pressure systems.

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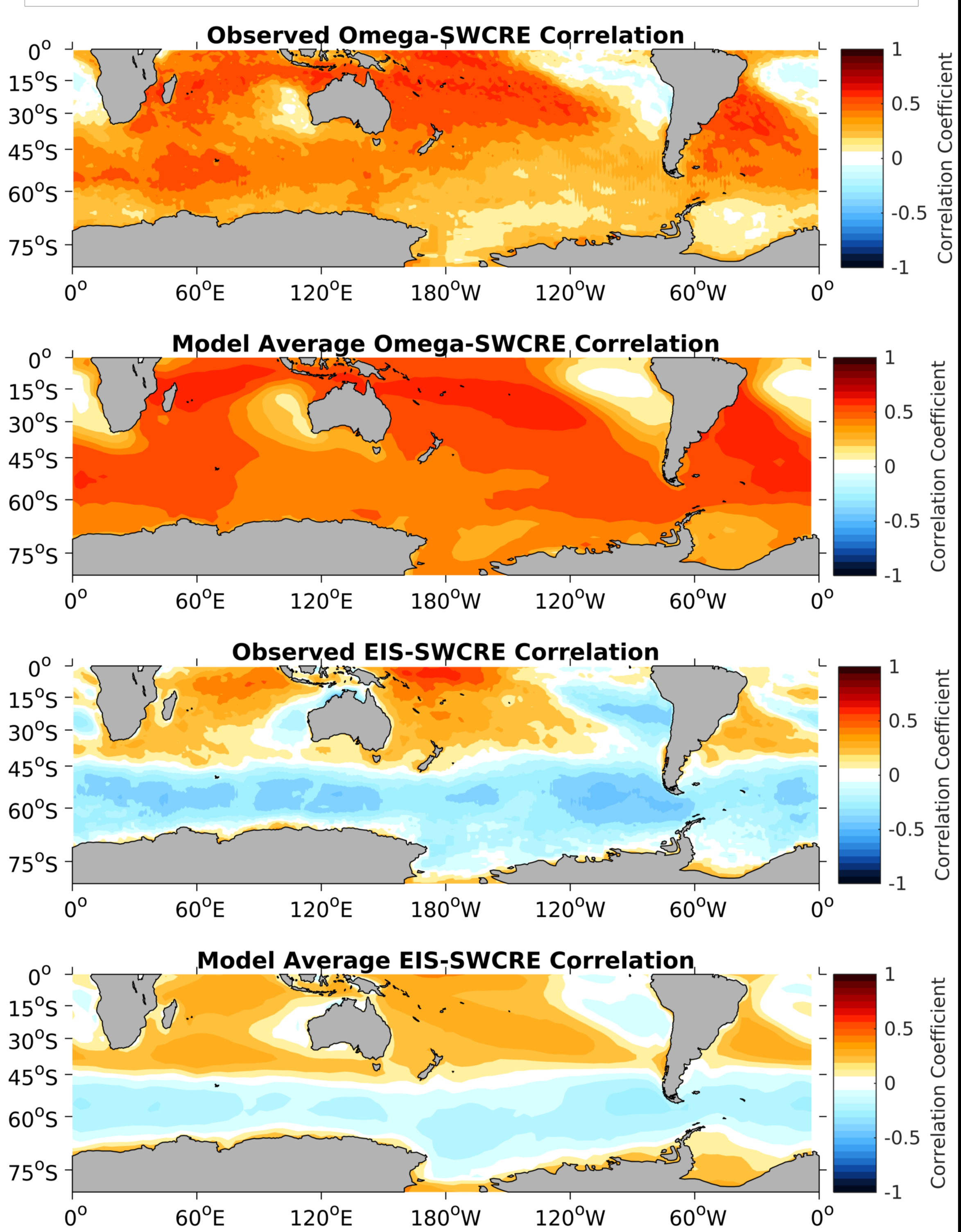
Background

Dynamic 'cloud controlling' factors are an effective means of understanding cloud fraction in the atmosphere (e.g., Qu et al. 2015). Two such parameters, estimated inversion strength (EIS) and 500hPa vertical velocity (ω), are considered here as they are both relevant to mid-latitude clouds and vary across extratropical cyclones (Naud et al. 2016).

Previously considered on monthly time-scales (e.g., Grise & Medeiros 2016), this work seeks to extend analysis to daily time scales where transient weather systems are of importance. Additionally, as is it thought that certain regions of cyclones influence the overall shortwave cloud radiative effect (SWCRE) bias in GCMs, (e.g., Bodas-Salcedo et al. 2014) this work seeks to understand the cloud controlling dynamics that define regions within cyclones.

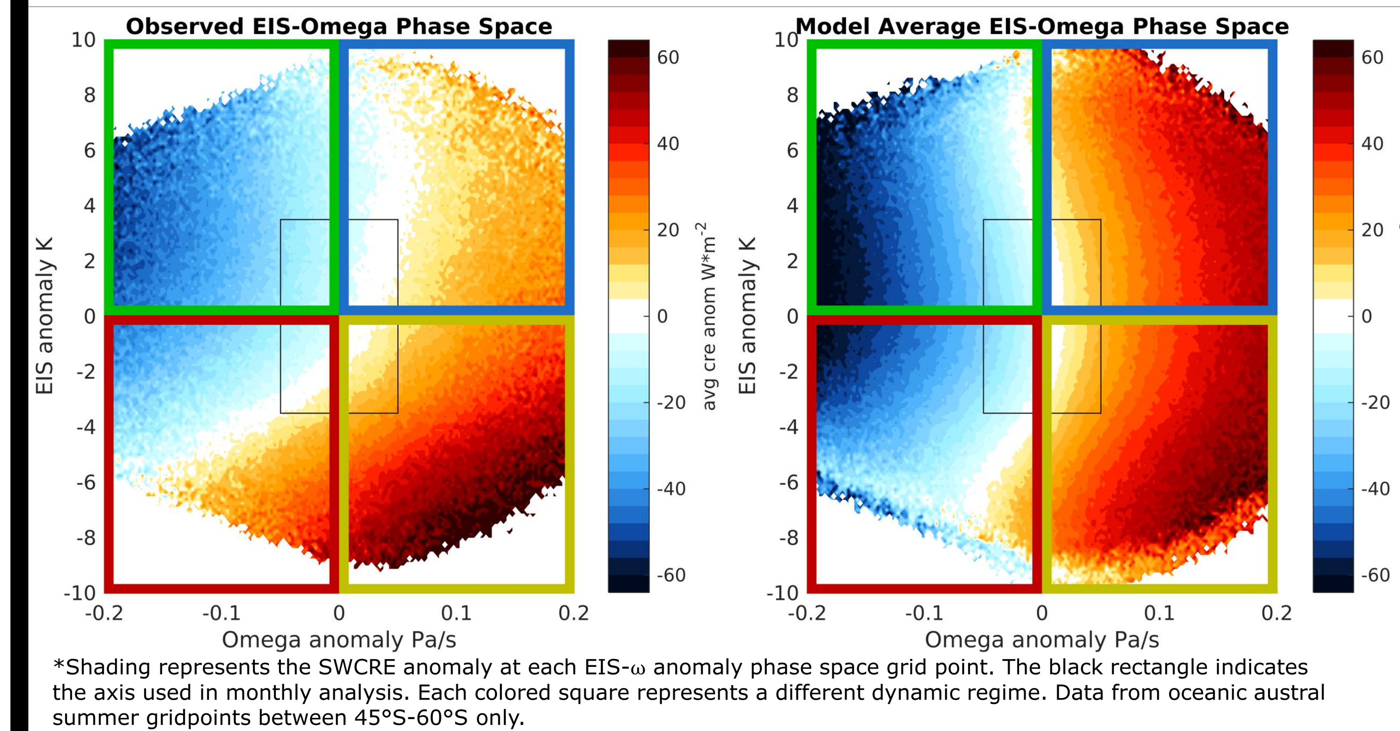


In the mid-latitudes, anomalies of EIS and SWCRE are inversely correlated, suggesting that stronger boundary layer temperature inversions lead to generally cloudier conditions.

Anomalies of vertical velocity (ω) and SWCRE are directly related, suggesting that rising motion leads to cloudier conditions.

In the midlatitudes, CMIP5 models tend to over-estimate the relationship between ω and SWCRE and under-estimate the relationship between EIS and SWCRE.

Daily EIS′-ω′ Phase Space

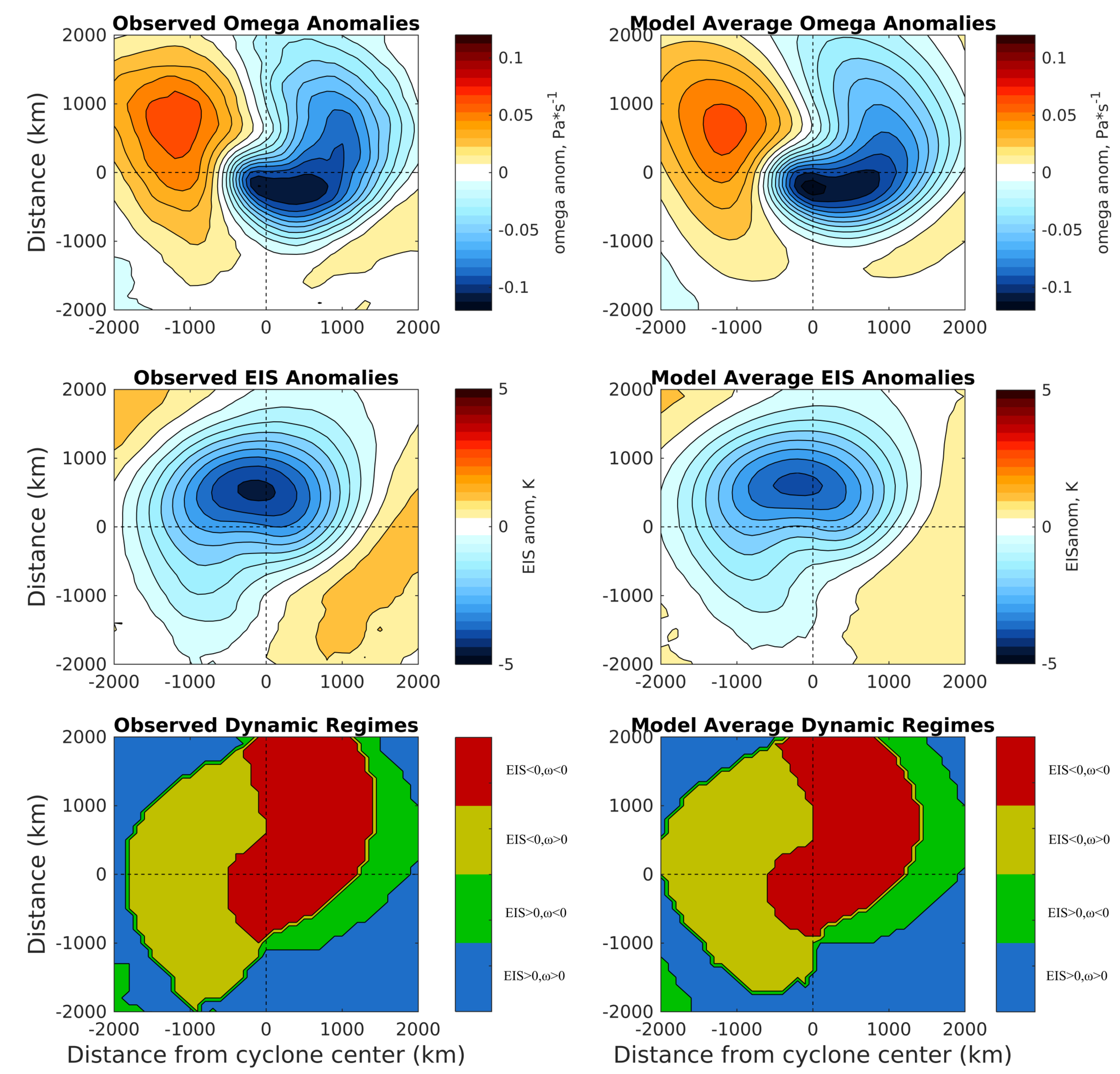


*Shading represents the SWCRE anomaly at each EIS-ω anomaly phase space grid point. The black rectangle indicates the axis used in monthly analysis. Each colored square represents a different dynamic regime. Data from oceanic austral summer gridpoints between 45°S-60°S only.

Results

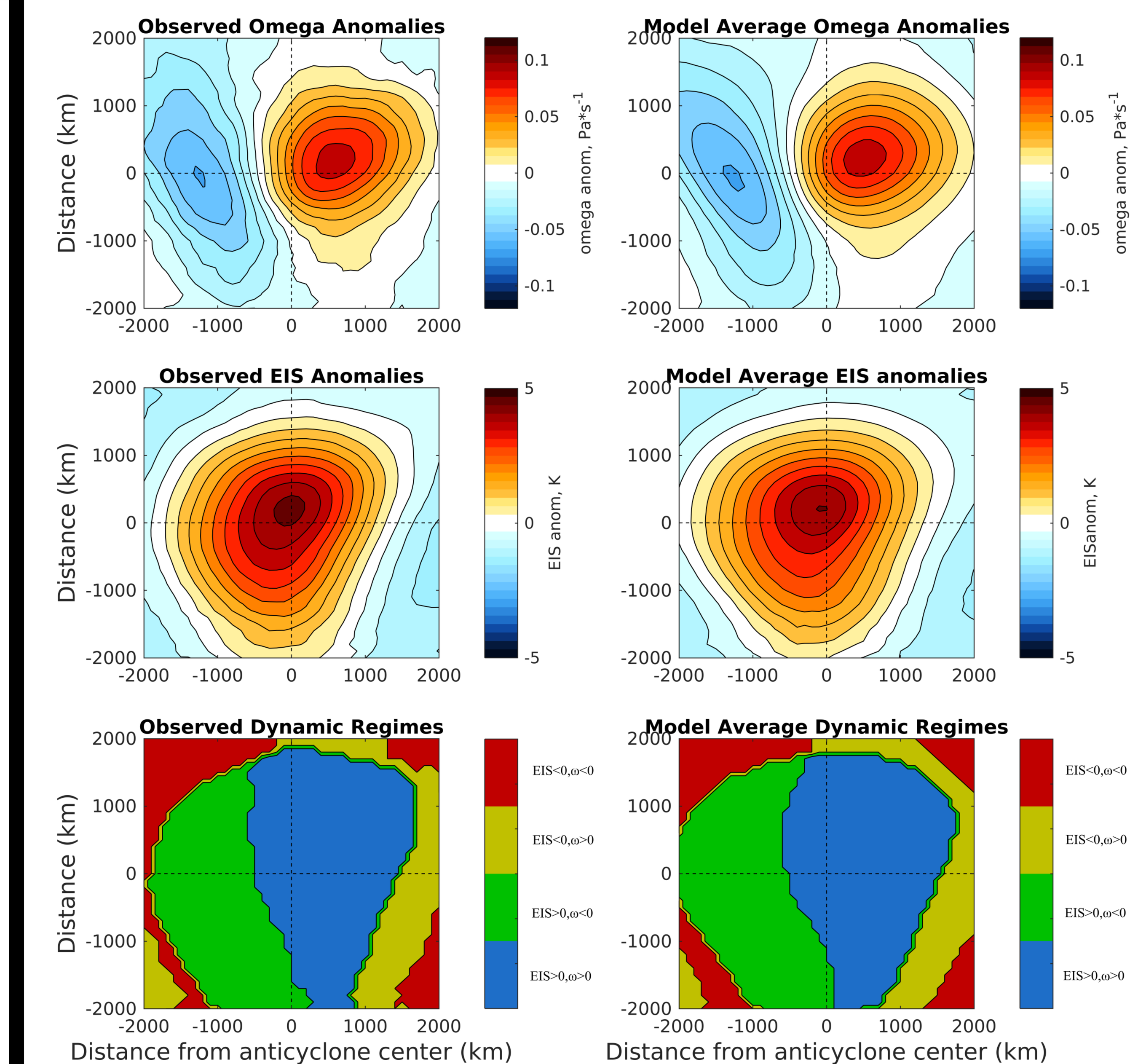
- **In observations, SWCRE is a function of both EIS and ω anomalies:**
  - Increases in EIS' lead to decreases in SWCRE
  - Increases in ω' lead to increases in SWCRE
- **On average, the models' SWCRE is solely a function of ω':**
  - Comparable to a Type I model from Grise & Medeiros (2016)
- **Two dynamic regimes are qualitatively similar:**
  - EIS'>0, ω'<0 (green) and EIS'<0, ω'>0 (yellow)
- **Two dynamic regimes are qualitatively dissimilar:**
  - EIS'<0, ω'<0 (red) and EIS'>0, ω>'0 (blue)

Cyclone Dynamics



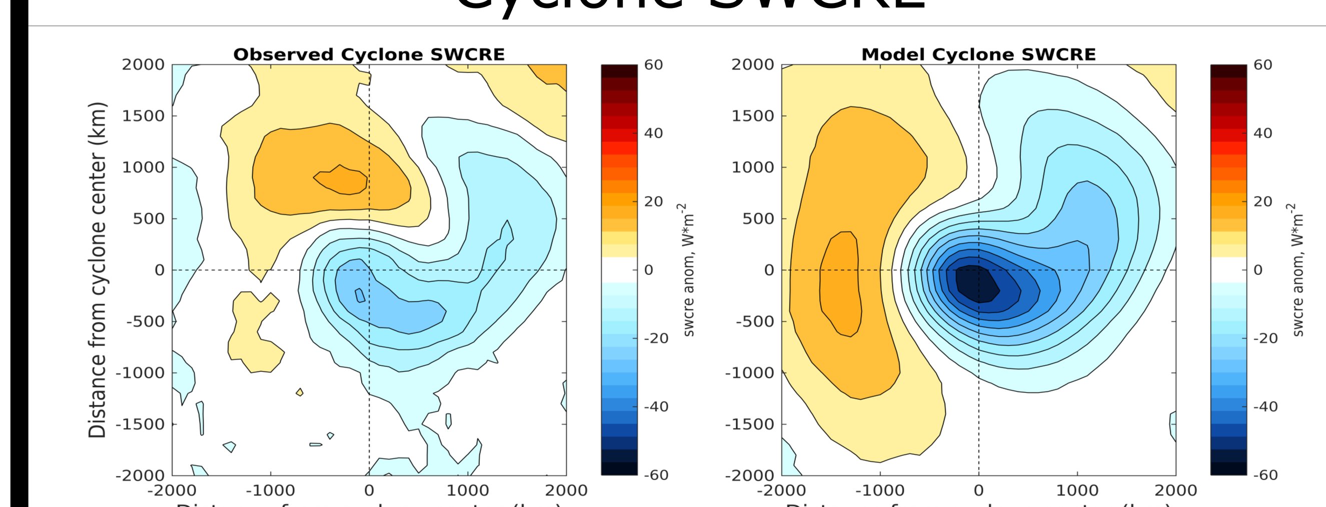
*Composites of EIS' (top), ω' (middle) and dynamic regimes (bottom) for observations (left) and models (right) average around locations of daily (DJF) minimum surface pressure anomalies (cyclones) for 45°S-60°S. Only Oceanic gridpoints are considered in constructing the composites.

Anticyclone Dynamics



*Composites of EIS' (top), ω' (middle) and dynamic regimes (bottom) for observations (left) and models (right) average around locations of daily (DJF) maximum surface pressure anomalies (anticyclones) for 45°S-60°S. Only oceanic gridpoints are considered in constructing the composites.

Cyclone SWCRE

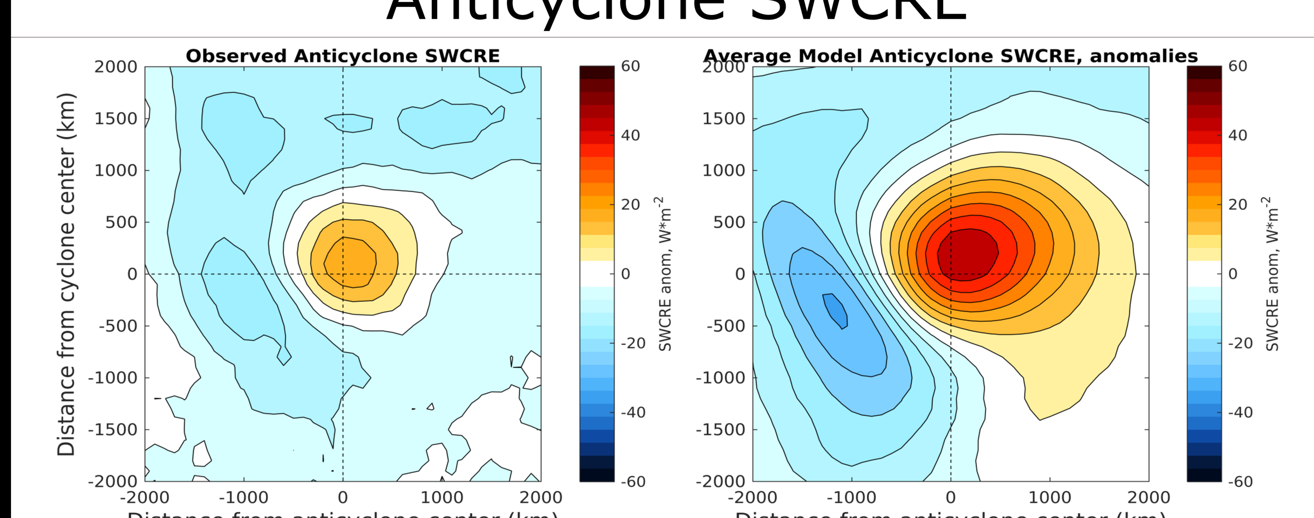


*Composites of SWCRE around daily (DJF) minimum surface pressure anomalies from 45°S-60°S. Oceanic gridpoints only.

While the models recreate the shape of the cyclone's SWCRE field well, there is a large bias in the frontal region of the cyclone where the models are too bright.

This region corresponds to the red dynamic regime (EIS'<0, ω'<0).

Anticyclone SWCRE



*Composites of SWCRE around daily (DJF) maximum surface pressure anomalies from 45°S-60°S. Oceanic gridpoints only.

In the case of anticyclones, the models contain a region of large positive SWCRE anomalies that does not exist to the same extent in the observations.

This region corresponds to the blue dynamic regime (EIS'>0, ω'>0).

Data & Methods

- EIS and 500 hPa ω calculated from ERA-Interim reanalysis (Dee et al., 2011; 2001-2016)
- CERES top of atmosphere cloud radiative effects, Ed4a (Loeb et al., 2012; 2001-2016)
- 10 CMIP5 AMIP (Taylor et al., 2012) runs, daily time-scale
- EIS calculated as in Wood & Bretherton (2006)
- Cyclone and anticyclone composites constructed from min/max daily surface pressure anomalies within the midlatitudes

Conclusions & Future Work

- **Daily model SWCRE responds differently to certain cloud controlling factors compared to observations:**
  - Not sensitive enough to changes in EIS' anomalies in the midlatitudes
  - Over sensitive to changes in mid-tropospheric ω'
- **There are two qualitatively dissimilar dynamic regimes within the EIS'-ω' phase space**
- **Model dynamics are comparable to observed dynamics**
  - Composites of EIS' and ω' in observed and modeled cyclones and anticyclones are similar in structure
  - The observed and modeled dynamic regimes within the context of weather systems are nearly identical
  - The dissimilar dynamic regimes exist in the context of midlatitude cyclones and anticyclones
  - The differing dynamic regimes occur in the frontal region of the cyclone and just downstream of the anticyclone center
  - These locations are co-located with large biases in the SWCRE' composites
- **Further research to consider more cloud controlling factors**
  - Other factors, such as surface sensible heat flux and temperature advection will be considered in future work

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