Title of the article

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Abstract.

The abstract goes here.

1. Introduction

Probably need a better introductory sentence or two. The use of general circulation models (GCMs) to evaluate global tropical cyclone (TC) characteristics in current and future climate has grown considerably over the last decade. It has been shown that GCMs can model TCs at horizontal resolutions upwards of 100 km with limitations [e.g., *Bengtsson et al.*, 2007; *Knutson et al.*, 2010; *Strachan et al.*, 2013]. As GCMs have advanced to even higher horizontal resolutions ($\leq$ 50 km) the simulated climatology of tropical cyclones has improved greatly [e.g., *Oouchi et al.*, 2006; *Zhao et al.*, 2009; *Murakami et al.*, 2012; *Manganello et al.*, 2012; *Satoh et al.*, 2012; *Bacmeister et al.*, 2014; *Wehner et al.*, 2014; *Reed et al.*, 2015]. Furthermore, the use of variable-resolution GCMs have shown to be useful for the study of regional TC climatologies at reduced computational cost compared to global high-resolution simulations [*Zarzycki and Jablonowski*, 2014].

Recently, intercomparisons have shown that the range of simulated TC climatology across different climate models can be large [*Camargo*, 2013; *Walsh et al.*, 2015]. It has also been shown that within individual GCMs TC characteristics can vary greatly depending on model design choices. Numerous studies have documented the large uncertainty in TC simulations due to the choice of individual subgrid parameterizations, mainly cumulus parameterizations [e.g., *Kim et al.*, 2012; *Reed and Jablonowski*, 2011; *Lim et al.*, 2014]), while others have focused on differences due to changes in whole parameterization suites [*Reed and Jablonowski*, 2011; *Bacmeister et al.*, 2014]. The dynamical core, the main fluid flow component of a GCM, has also been shown to be an important source of uncertainty for TC simulations, though less widely documented [*Reed and Jablonowski*, 2012; *Zhao et al.*, 2012; *Reed et al.*, 2015].

In this manuscript we describe another mechanism through which simulated TC properties are influenced by model design choices, in particular, the manner in which the ocean and atmosphere are coupled within the climate system. Section 2 provides an introduction to the modeling system used in this study and how coupling between the atmosphere and ocean is treated. Section 3 details the sensitivity of TCs to the ocean grid using a deterministic forecast framework while Section 3.1 investigates the impact on multi-year climate simulations. Section 4 assesses the results and offers further insight into their implications.

2. Model description

2.1. Community Atmosphere Model

In this paper, we utilize the Community Atmosphere Model (CAM), version 5 [*Neale et al.*, 2010]. The Spectral Element (SE) dynamical core option in CAM is used for all simulations. SE is the newest dynamical core available in CAM and is based upon continuous Galerkin spectral finite elements which are applied on a cubed-sphere grid [*Taylor et al.*, 1997; *Thomas and Loft*, 2005; *Taylor and Fournier*, 2010; *Dennis et al.*, 2012].

CAM-SE is coupled to land, ocean, and ice model components within the Community Earth System Modelling (CESM) framework. The land model is the Community Land Model (CLM) version 4.0 run in satellite phenology (SP) mode on a 0.23 by 0.31° latitude-longitude grid [*Oleson et al.*, 2010]. While CESM also allows for coupling to dynamic ocean and ice models, all of the simulations in this project utilize prescribed SSTs and ice cover concentrations.

2.2. Coupling within CESM

Because earth system model components generally are not integrated on the same spatial grid, CPL7 is used to couple various systems within the CESM framework [*Craig et al.*, 2012]. The coupler utilizes conservative remapping weights to regrid quantities between model components.

(Describe coupling procedure in CESM; draw schematic; confirm with T. Craig or Mariana).

During coupling between the atmosphere and ocean, state variables from the atmospheric grid are conservatively remapped to the ocean grid. Surface momentum stress (τ) and sensible and latent heat fluxes are calculated on the ocean grid. The quantities are then passed back to the atmospheric grid, allowing these quantities to be available to both the atmospheric dynamical core and subgrid physical parameterizations.

Generally, if the atmosphere and ocean are not on the same grid, the atmospheric grid consists of finer grid spacing.

Prescribed SSTs and ice are passed to the model on a 1°x1° grid and internally interpolated to the ocean and ice grids.

3. Deterministic simulations

To assess the differences in simulated TCs in a controlled, deterministic manner, we utilize two nearly identical CAM setups to complete short-term forecast simulations of observed storms. These simulations utilize the new, variable-resolution capability of CAM-SE [*Zarzycki et al.*, 2014].

The model is configured with an atmospheric grid with 1/8° (∼14km) resolution over the Atlantic Ocean and are initialized with a digitally-filtered atmospheric analysis from the National Center for Atmospheric Predictions's Global Data Assimilation System (GDAS). Observed SSTs are taken from NOAAOI and provided as input to the model on a 1°x1° grid. The land surface is modeled by the Community Land Model (CLM) version 4.0 and is initialized with a state nudged to be in balance with the atmospheric initial conditions. The model setup and initialization are further detailed in *Zarzycki and Jablonowski* [2015].

The only difference between the two setups is the grid used by the data ocean and ice models. The first set of simulations uses a displaced tripole grid with an equivalent resolution of 1° (gx1v6) while the second uses an ocean grid identical to the atmospheric grid with an equivalent resolution of 1/8°. Since the SST and ice cover data are provided at coarser scales than the model interpolates to, any differences in the results arise due to the differences in calculating of surface fluxes and momentum drag on the corresponding ocean grids.

Figure 1 shows the 120-hour forecast for Hurricane Leslie in the North Atlantic Ocean from the 2012 hurricane season. The simulation was initialized at 00Z on August 31st, 2012 and is valid at 00Z on September 5th, 2012. The forecast using the 1° ocean grid is on the left (Fig. 1a,c), with the 1/8° ocean grid on the right (Fig. 1b,d). All fields are extracted from the atmospheric model component. The top panels depict instantaneous lowest model level wind (black vectors) as well as the surface frictional stress vector (red). In the Fig. 1a, we note many instances where the vectors are not aligned. This results from the surface stress being calculated on the coarser grid. The atmospheric dynamical core then subsamples this coarser information to provide stress information at the same resolution used by the numerics. In Fig. 1b, the wind and stress vectors are essentially parallel (180° difference), indicating that the frictional drag is acting in parallel opposition to the wind. The higher resolution ocean grid preserves the resolution of the surface wind field during stress calculations. Additionally, the maximum magnitudes of the stress vectors are larger at the storm's radius of maximum wind in Fig. 1b. Since stress is directly correlated with the surface wind speed, this highlights that maxima in the wind field at the atmospheric grid cell scale are preserved with the higher resolution ocean grid, whereas these maxima are "smoothed" in the calculation where wind is first averaged to the coarser ocean grid (Fig. 1a). This is further evidenced by the fact that the integrated dot product (over a 5°x5° domain centered over the TC minimum surface pressure) of the two fields is approximately 10% smaller in the simulations using the 1° ocean grid. Therefore, the use of the coarser ocean grid results in a weaker frictional force used by the atmospheric dynamics.

The cumulative surface heat flux is shown on the bottom (sensible plus latent) for the two storms at the same forecast time. It is readily apparent that the coarser ocean grid (Fig. 1c) provides information back to the atmosphere with significantly less spatial structure than the 1/8° ocean grid (Fig. 1d). While the difference in 5°x5° integrated heat flux is relatively small (approximately 1%), it is clear that the spatial structure of the heat flux field is very different between the two model configurations. This may also play a role in storm dynamics with the 1° ocean grid providing a larger, more diffuse source of surface heating to the TC core than the high-resolution grid.

3.1. Climate simulations

JULIO/KEVIN CLIMATE SIMS

4. Discussion

Discussion goes here.

The issues outlined in the manuscript are rather trivial to correct for data ocean models, where specifying SSTs and applying coupled atmosphere-ocean calculations on the same grid is straightforward. More problematic adjustments arise when coupling to a dynamical ocean model. The vast majority of coupled simulations not only utilize differing resolutions between different model components, but also different numerical techniques and grids. Therefore, remapping between components is an absolute necessity.

The obvious recommendation to alleviate coupling inconsistencies when it is not feasible to use identical grids is to calculate these quantities on the finest resolution grid of the coupled system. In the vast majority of earth system models, this is typically the atmosphere. Performing coupling in this manner ensures that information passed back to a model component has not be interpolated to a resolution coarser than the compnent's native resolution during the coupling process.

However, it is not clear that technique is fully appropriate for dynamical ocean models, where aspects such as turbulent mixing may be sufficiently non-linear that merely averaging from a higher resolution grid may not be the most appropriate mechanism.

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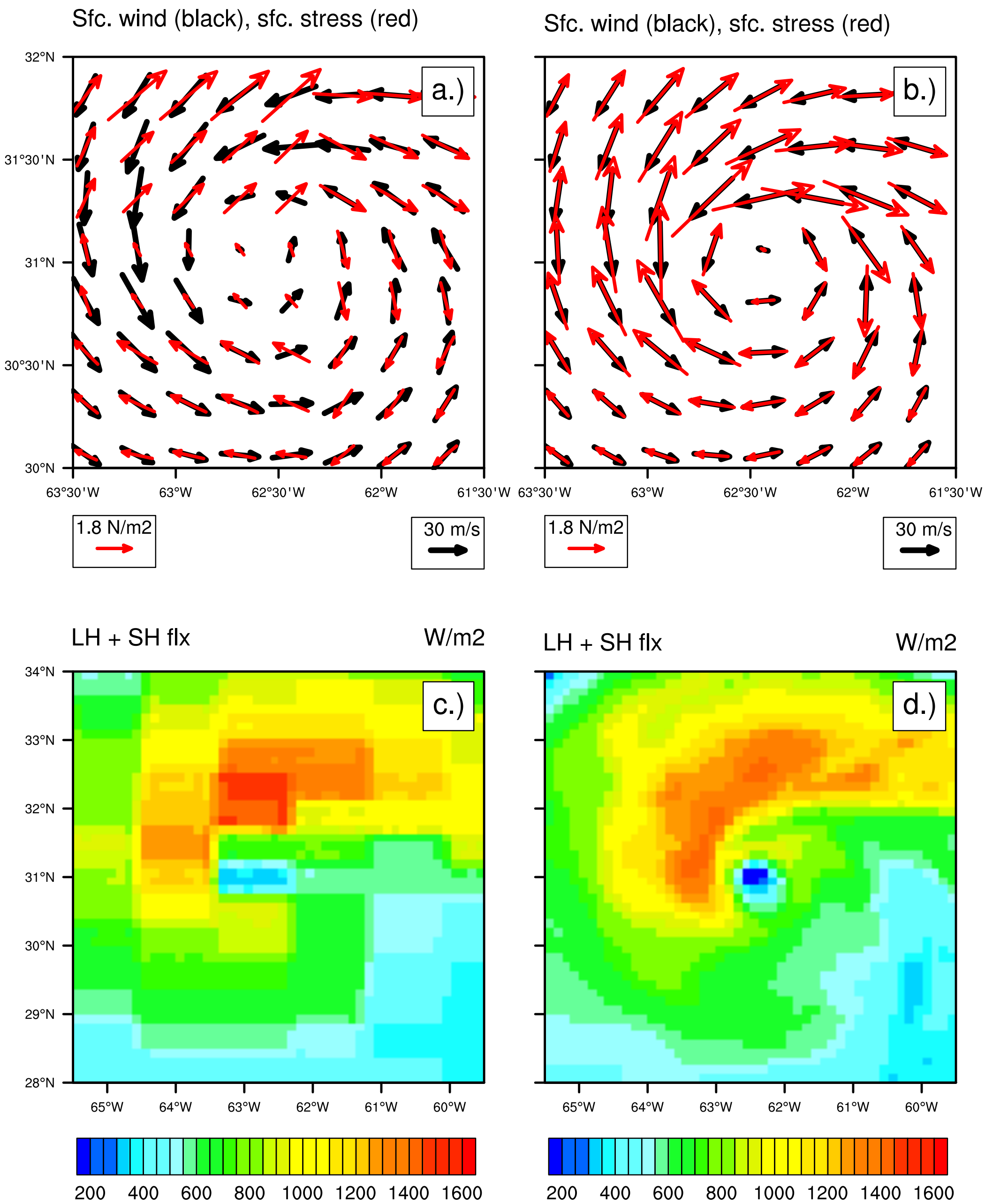

Figure 1. Figure caption