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Seasonal to inter-annual climate variability as simulated by the Variable-Resolution Earth System Model

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The dynamical behavior and time evolution vacillation of SH eddy-driven jet stream are analyzed within the numerical experimentation framework that uses an ESM on season to interannual climate timescales. The model simulation shows a great deal of improvement from the previous attempts that use coupled ocean-atmosphere climate models that compromise a number of climate forcings such as anthropogenic influence. The analysis presents an important insight into the ESM's systematic error notably on the daily climatological jet strength, meridional and vertical position of the get stream that happened much later of the year comparing to the reanalysis. The cause of the displacement is not clear.

Keywords: ERMs, Eddy-driven Jet stream, Systematic errors, Jet position and strength

INTRODUCTION

The need to understand the contribution of various climate forcings and their intricate interactions is of key importance in climate predictability studies. This objective may better be accomplished with the use of Earth System Models (ESMs) that interactively couple the ocean-atmosphere-land-cryosphere despite the use of ESMs though they are not widely practiced at seasonal to inter-annual climate timescales due mainly to computational consideration. The concept of complete climate system deployment is expedited through the Climate-system Historical Forecast Project (CHFP5) coordinated by the CLIVAR (Climate Variability and Productivity) Working Group on Seasonal to Interannual Prediction (WGSIP; Kirtman and Anna Pirani, 2009; Butler et al., 2016). The current work is, therefore, a mere attempt of presenting an early developmental phase of a Variable-resolution Earth System Model (VRESM) as sub-seasonal to inter-annual climate variability and predictability studies currently underway. The VRESM development is a joint effort of the Council for Scientific and Industrial Research (CSIR) in South Africa and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia.

We embark on the 3D structure of the eddy-driven (polar) jet stream to elucidate its dynamical and time evolution behaviour both in the NCEP (National Centers for Environmental Prediction) Reanalysis (R2; Kanamitsu et al., 2002; used as proxy for observation) and VRESM spaces over the southern hemisphere (SH). The jet stream (notably its meridional) positon has significant effect on extratropics weather and storm track variability on both hemispheres, and has become a centre of attraction over recent years. From the paleoclimate perspective, for instance, the wettest episode of the Holocene in the winter rainfall zone (WRZ) of South Africa occurred during the "Little Ice Age" (700–100 cal years BP) most likely in response to a northward shift of the jet stream (westerlies; e.g. Weldeab et al. 2013). Many studies also noted that the mean latitude of extratropical cyclones migrated poleward and cyclones have become fewer and more intense, over the last half of the 20th century (e.g., McCabe et al., 2001).

EXPERIMENTAL DESIGNS

The ESM applied here is a computational prototype of the VRESM and uses the conformal-cubic atmospheric model (CCAM) of CSIRO which is a σ-coordinate model with a semi-implicit semi-Lagrangian dynamics (McGregor, 2005). The CCAM includes a prognostic aerosol scheme, and can be applied consistently with the emission inventories and radiative forcing specifications of the Coupled Model Intercompariosn Project Phase Five (CMIP5). The dynamic land-surface model used is the CSIRO Atmosphere Biosphere Land Exchange model (CABLE) which includes a dynamic river routing scheme adapted from the CSIRO Mk3.5 CGCM and dynamic ocean. The Variable-resolution Ocean Model (VCOM) that coupled PISCES ocean biochemistry model and dynamic sea-sea is under development at the CSIR. Coupling of the ocean, atmospheric and land-surface components takes place every time-step. It is envisaged that VRESM will be applied on a 100 km horizontal resolution grid within the Coupled Model Intercomparison Project Phase Six (CMIP6), with a longer-term plan of performing global eddy-resolving (10 km resolution) simulations depending on the availability of supercomputing resources at the CSIR.

The experiment consists of two set of model integrations. The first simulation is an AMIP type experiment, performed for the period 1870-2015, using the AMIP sea-surface temperatures (SSTs) and sea-ice concentrations (SICs) provided through CMIP6 as lower boundary forcing. That is, the first simulation performed is an atmosphere only simulation, with the CCAM-CABLE system being forced at its lower boundary by the AMIP SSTs and SICs. In the second simulation performed, the atmosphere is coupled to the CSIRO ocean. The latter is nudged at its surface to the AMIP SSTs, using the spectral nudging method of Thatcher and McGregor (2010). That is, the second simulation is also forced to resemble the AMIP SSTs at the large scale, although regional ocean currents and related atmosphere-ocean fluxes are capable to develop freely. Both experiments are additionally forced by the time-varying CO2 and ozone fields provided through the CMIP5 archive for the period 1870-2100.

The eddy-driven polar jet stream position is detected using a cubic spline interpolant as in Gallego et al. (2005) except that our algorithm also considers the vertical movement the jet stream. The strength of the Jet is therefore assumedly associated with the value of the 3D position of the jet stream.

RESULTS

The daily climatology SH zonal average of the three jet attributes (strength, meridional and vertical positions) of the ESM (red)/ AMIP (black) simulations and NCEP reanalysis (blue) is shown in Fig. 1 (see caption for details). The amplitude of the jet attributes simulated by the model (light-red) is relatively wider than the NCEP (light-blue). Despite the model and NCEP general agreement in the seasonality of the jet variation, the result finds a noticeable systematic error in the model. Relative to the reanalysis, the time when the jet stream moves upward/poleward and intensify in its strength displaced toward the austral summer in the model. The consistency in the time evolution vacillation and trend of the jet stream, however, is encouraging particularly in its meridional and vertical movement (Fig. 2). This dynamical behavior is consistent with the finds of Yin (2005) for the 21st century SH midlatitude storm tracks using 15 coupled climate models. Furthermore, the similarity of the AMIP and ESM representation is presumable attributed to the spectral nudging method applied and is worth investigating under different strength of relaxation.

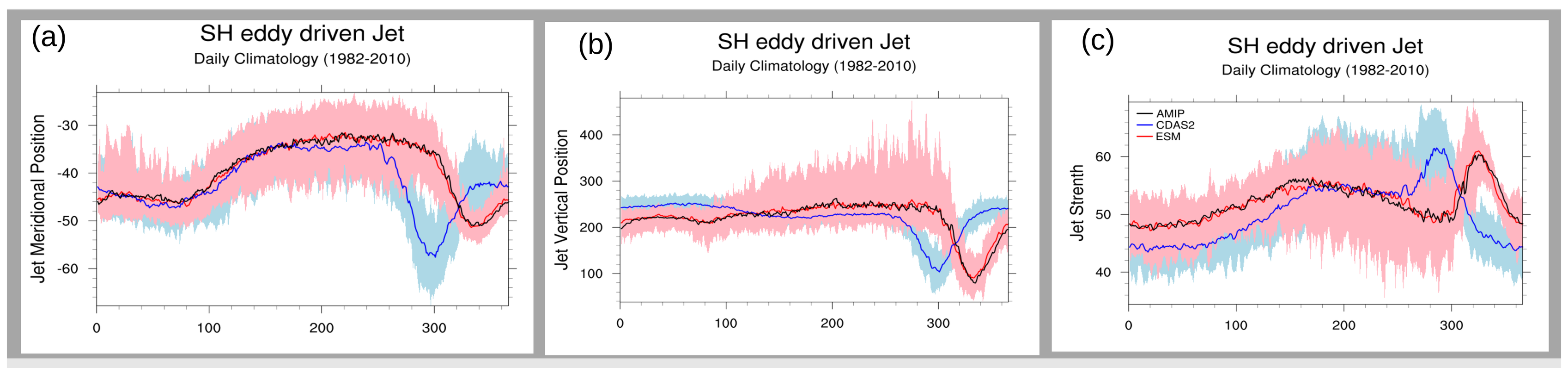

Figure 1:The daily climatology SH zonal average eddy-driven jet attributes (meridional position (a), vertical position (b) and strength (c) of the ESM (red)/ AMIP (black) simulations and NCEP reanalysis (blue). The amplitude represents the jet stream attributes in each longitude grid point of NCEP (light-blue) and ESM (light-red).

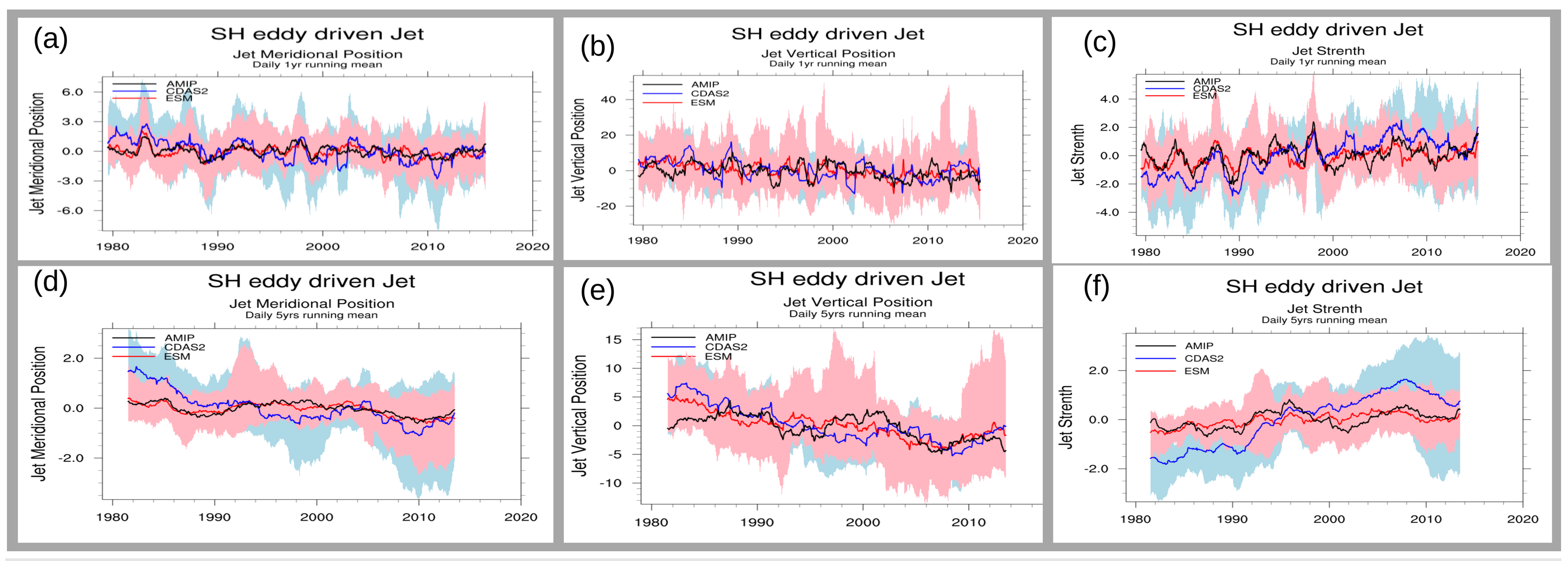

Figure 2: As in Fig 1 but for 1yr (a-c) and 5yrs (d-f) running mean daily anomalies for the period of 1979-2015.

DISCUSSION AND CONCLUSIONS

The dynamical behavior and time evolution vacillation of the eddy-driven jet stream are analyzed within the numerical experimentation framework that uses an ESM on season to interannual climate timescales. The ESM simulation demonstrates a great deal of improvements from the previous attempts that use coupled ocean-atmosphere climate models (CGCMs) that compromise a number of climate forcings such as anthropogenic influence (e.g. Mathoe et al 2015). The finding supports the notion that using complete climate systems may be a game changer approach in overcoming the models' weaknesses in simulating midlatitude climate variability on the seasonal to interannual timescales. The analysis provides an important insight into the modes' systematic error notably on the daily climatological jet strength, meridional and vertical position of the eddy-driven jet stream that happened much later of the year comparing to the reanalysis. The cause of the displacement is not clear and is deferred for future work.

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