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Increased multi-year ENSO predictability under greenhouse gas warming accounted by large ensemble simulations and deep learning

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The El Niño/Southern Oscillation (ENSO) is the primary internal climatic driver shaping extreme events worldwide[1,2,3]. Its intensity and frequency in response to greenhouse gas (GHG) warming has puzzled scientists for years, despite consensus among models about changes in average conditions[4-16]. Recent research has shed light on changes not only in ENSO variability[5,7,8,10,13], but also in the occurrence of extreme[5,6,11,12,13,14] and multi-year El Niño[4,15], and La Niña[9,11,16] events under GHG warming. Here, we investigate potential changes in ENSO predictability associated with changes in ENSO dynamics in the future by using long-range deep-learning forecasts trained on extensive large ensemble simulations of Earth System Models under historical forcings and the future high GHG emissions scenario. Our results show a remarkable increase in the predictability of ENSO events, ranging from 35% to 65% under the high GHG emissions scenario due to reduced ENSO irregularity, supported by a broad consensus among multi-models. Under GHG warming, an El Nino-like warming flattens the thermocline depth with upper ocean stratification. This flattening of the thermocline depth leads to an increased transition frequency between El Niño and La Niña events, driven by strengthened recharge-discharge oscillation with enhanced thermocline feedback and SST responses to zonal wind stress. As a result, ENSO complexity would reduce with increased regularity and reduced skewness, increasing ENSO predictability. These results imply that the future social and economic impacts of ENSO events may be more manageable, despite an expected increase in the frequency of extreme ENSO events.

Key words: ENSO, deep learning, predictability, greenhouse warming

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Regionally asymmetric response of western North Pacific tropical cyclone activity to a CO_2 removal experiment

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Tropical cyclones (TCs) are inevitable natural phenomena with considerable socio-economic impacts on world's coastral regions, influencing climate mitigation and adaption policies. Despite their importance, research on how TC activity responds to CO_2 reduction has been relatively limited. Here, to explore the potential impact of carbon dioxide removal (CDR) on large-scale environmental conditions for TC genesis over the western North Pacific (WNP), we use an Earth system model with an idealized CDR scenario. Our findings reveal that the genesis potential index (GPI), averaged over the WNP TC development region (110° E – 180°, 5° – 35° N), does not exhibit hysteresis between the ramp-down and ramp-up periods. This absence of hysteresis is due to regionally asymmetric GPI hysteresis, characterized by west-east dipolar pattern. This dipolar GPI pattern is primarily driven by changes in vertical wind shear (VWS) associated with the weakening of the Walker circulation, which is influenced by El Nino-like sea surface temperature hysteresis.

Further simulations with a higher-resolution atmospheric model support these GPI results, showing no significant difference in the number of TCs over the WNP between the ramp-up and ramp-down periods. However, there is a notable 20.11% decrease in TC landfall frequency in East Asia, attributed to reduced TC genesis over the western part of the WNP between the two periods.

Key words: Tropical cyclone, carbon dioxide removal, genesis potential index, ENSO

Impact of climate engineering on subseasonal-to-seasonal (S2S) variability

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The influence of climate engineering on the dominant mode of subseasonal-to-seasonal (S2S) climate variability will be discussed. Among many climate engineering techniques, the most efficient method is known as the stratophseric aerosol injection (SAI) method. Using CESM2 WACCM SAI experiments, the change of the characterisitcs of the El Nino Southern Oscillation (ENSO) and Madden-Julian Oscillation (MJO) are analyzed. ENSO variability enhances when aerosol is injected at Southern Hemisphere (SH) latitdues. SH gets colder than the global warming scenario thus inducing the shift of the ITCZ and related circulation fields. The MJO variability reduces overall when climate engineering is deployed, while its eastward propagation strength differs in different injection latitude scenarios.

Keywords : Climate Engineering, MJO, ENSO

Interdecadal Changes and the Role of Philippine Sea Convection in the Intensification of Indian Spring Heatwaves

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Severe heatwaves have become increasingly frequent over the Indian subcontinent in recent decades. This study found that the increase in extreme heatwaves is related to a significant decadal change in surface temperatures over the Indian subcontinent, and revealed that the increase in convective activity in the Philippine Sea plays a crucial role in this decadal change in surface temperature. Specifically, the surface temperature over the Indian subcontinent in spring has increased significantly by approximately 0.64℃ in recent years (1998–2022: post-1998) compared to the past (1959–1997: pre-1998), leading to more intense and frequent heatwaves, particularly in March and April. The difference in atmospheric changes between these two periods shows that the enhancement of convective activity over the Philippine Sea drives an anomalous elongated anticyclonic circulation over the Indian subcontinent. This circulation pattern, marked by clearer skies and increased incident solar radiation, significantly contributes to the heat extremes in the Indian subcontinent. Additionally, stationary wave model experiments demonstrate that local diabatic heating over the Philippine Sea is significantly linked to robust spring Indian heatwaves through the Matsuno-Gill response.

Key words: Convective activity in the Philippine Sea, Indian Heatwaves

Influence of the Southern Annular Mode on Fast Ice Dynamics in Antarctica

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Antarctic fast ice is known to significantly influence the stability of ice shelves and the formation of Antarctic Bottom Water. Therefore, it is crucial to understand its variability, which has not been extensively explored. In this study, we analyzed the influence of the Southern Annular Mode (SAM) on fast ice variability during March. We found that the variability of circum-Antarctic fast ice in March correlates with the intensity of the Southern Annular Mode (SAM) from the preceding September, especially in the regions of Dronning Maud Land (DML) and the Amundsen Sea (AS). These connections are associated with the spring wind patterns driven by the September SAM and the subsequent loss of sea ice. In the DML and AS areas, a positive SAM led to a northward drift of sea ice near the coast, resulting in decreased sea ice during spring. This loss of sea ice was further amplified by an increase in net solar radiation due to lower albedo. As a result, coastal ocean swell increased during the summer, contributing to a reduction in fast ice by March. The strength of this relationship between SAM and fast ice variability may be influenced by the zonal asymmetry of SAM, which appears to be intensifying due to global warming.

Key words: Southern Annular Mode (SAM), Fast Ice, Sea Ice Loss, Zonal Asymmetry, Global Warming

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ERA5 재분석 자료를 이용한 우리나라 하층제트의 기후학적 특성 분석

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LLJ는 전세계 어디에나 존재하는 중요한 대기하층 현상이다. LLJ의 글로벌 “핫 스팟”으로 관심이 집중된 지역을 중심으로 LLJ의 기후 특성 및 형성 메카니즘에 관한 연구가 활발히 이루어졌다. 우리나라에서 LLJ 연구는 주로 남풍 또는 남서풍 LLJ와 호우와의 관련성을 중심으로 이루어져 왔으며, 국지적으로 중요한 LLJ의 특성을 다양한 시각에서 더 깊이 이해하고자 하는 연구는 거의 이루어지지 않았다. 본 연구에서는 ERA5 재분석 자료(1994~2023년)를 이용하여, 우리나라에서 나타나는 하층제트(Low level jet: LLJ)의 발생 빈도, 고도, 풍향·풍속에 대한 시공간적 변화 특성을 분석하였다. 장기간의 레윈존데 관측 데이터를 이용한 우리나라 LLJ의 기후 특성과 비교하여, ERA5 자료의 LLJ 표현은 다음과 같은 특징을 보인다. (1) 레윈존데 관측자료 보다 발생 빈도를 과소평가하는 경향이 있지만 레윈존데에서 나타난 LLJ 특성의 공간적 및 계절적 변화를 잘 표현한다. (2) 레인존데 관측자료에서 식별하기 어려운 LLJ 일변화 특성을 명확하게 보여준다. LLJ 빈도의 일변화는 야간에 싸인파 형태로 빈도가 증가하는 경향을 보이는데, 이는 특정 풍향의 LLJ에서 더 명확하다. 동해안의 서풍 LLJ는 야간에 빈도를 보이며. 동풍 LLJ는 일변화를 나타내지 않는다. (3) LLJ 빈도의 계절적 변화 동인을 설명한다. LLJ 발생 빈도는 6월에 거의 전 지역에서 낮아진다. 이는 봄철 대륙 동안에서 경압성에 의한 LLJ 발생 동인이 약화되고, 여름철 남서 계절풍의 영향이 나타나기 전 전환기 현상이다. LLJ는 다중 규모의 복잡한 현상이다. 호우에서 LLJ의 영향에 관련해서도 호우 시스템 외부에서 작용하는 큰 규모의 영향과 시스템 내부 구조와 결합한 더 작은 규모의 영향이 복합적으로 나타날 수 있다는 점을 고려할 때 LLJ의 입체적인 구조와 변화에 대해 더 상세히 분석할 필요가 있다.

Key words: 하층제트, ERA5 재분석, 레윈존데, 계절변동, 일변동, 기후 특성

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