기후 분과 / 기후 2-1

An idealized model for the spatial structure of the eddy-driven Ferrel cell in mid-latitudes

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Conceptual models of the midlatitude atmospheric circulation have added greatly to understand its behavior. Here, we present a new conceptual model for the spatial structure of the Ferrel cell. The poleward heat flux resulting from the baroclinic growth of eddies leads to a decrease in the meridional temperature gradient, which is parameterized through a down-gradient eddy diffusion coefficient D. Similarly, the eddy momentum flux, influenced by barotropic wave breaking, is assumed to be proportional to a factor M>0 to the horizontal shear of the zonal mean zonal wind, thereby enhancing the intensity of the zonal mean zonal wind at upper levels. By incorporating the parameterization of turbulent eddies into the zonal-mean quasi-geostrophic potential vorticity equation, a balance is achieved, resulting in eddy-driven circulations in mid-latitudes akin to the Ferrel cell. The meridional structure of the temperature exhibits two primary features. The first feature is a linear decline in anomalous potential temperature, inducing westerly winds in mid-latitudes. The second feature corresponds to jet streams generated by eddy momentum fluxes. Along with the jet streams, the eddy driven circulations exhibit the downward (upward) motion at the southern (northern) flank of the jets. The meridional structure of the circulation is influenced by three key factors. The first factor is a structural number denoted as D/SM, where S is the dry static stability affecting the life cycle of synoptic eddies in mid-latitudes. The second factor relates to the planetary size and the third factor is the vertical structure of the atmosphere, associated with eigenvalues of the vertical mode in the heat equation. The combination of these three factors within the characteristic equation also determines the location and number of eddy-driven jets in mid-latitudes.

기후 분과 / 기후 2-2

온실 온난화 하에서 북대서양 SST가 ENSO에 미치는 영향의 변화 : CMIP5와 CMIP6의 비교

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열대 북대서양 해수면 온도 변동성이라 불리는 NTA (North Tropical Atlantic)는 열대 및 아열대를 통해 겨울철 엘니뇨-남방진동 (El Niño – Southern Oscillation)을 유발할 수 있습니다. 그러나 북대서양 해수면 온도 아노말리가 ENSO 에 미치는 영향에 대한 향후 변화는 여전히 논란의 여지가 있습니다. CMIP5를 활용한 연구에서는 온실가스 증가에 따른 미래 기후에서 NTA-ENSO의 관련성이 약화될 것으로 보고된 반면, Jo & Ham (2023)은 CMIP6 모델에서 북대서양 해수면 온도가 ENSO 에 미치는 영향이 증가한다고 제안하였습니다.

본 연구에서는 Coupled Model Intercomparison Project (CMIP) 5와 CMIP6 모델을 서로 비교하여 온실 온난화로 인한 NTA-ENSO 관계의 강도에 뚜렷한 변화가 있음을 보여줍니다. 온실 온난화에 따른 NTA가 ENSO에 미치는 영향은 CMIP5에 비해 CMIP6에서 강화되었습니다. 아열대 북동 태평양의 더 습윤한 평균 상태와 적도 중앙 태평양에서 나타나는 ENSO 성장에 영향을 미치는 피드백 프로세스 즉, 표층 바람 응력에 따른 해양의 민감도 변화는 열대 북대서양 해수면 온도가 ENSO에 미치는 영향을 강화하는 주요 요인입니다. 따라서 CMIP5와 CMIP6 모델 간의 온실 온난화에 따른 평균 상태(배경장)의 차이는 NTA-ENSO 관계의 강도를 조절할 수 있습니다.

Key words: 지구시스템 모델, 열대 대양 간 상호작용, 온실 온난화, 해양 민감도 변화

Expanding but weaker western North Pacific High in a Warmer La Niña Environment

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Subtropical high (SH) offers valuable insights into extreme weather associated with tropical convection in the western North Pacific (WNP). These semi-permanent atmospheric patterns significantly influence the prevailing weather patterns over the ocean basin during the boreal summer. Key climatological attributes of SH include its spatial expansion and regional variability, both responsive to environmental changes.

The westward expansion of the western North Pacific subtropical high (WNPSH) indicates a constricted area for tropical convection (Yun et al., 2023), thereby assessing the large-scale inhibition of tropical cyclone (TC) activity. Notably, the SH extends furthest westward during La Niña events in conjunction with a warmer environmental context, which is believed to be reflected in the vorticities associated with TC activities, as evidenced by the frequency, intensity, and duration of local convection events. Conversely, during the maximum westward extension of SH, localized positive vorticities emerge within the subtropical high, suggesting that such expansion may not necessarily enhance high anomalies across the region. The regional variability of SH can be assessed through its strength, which is defined as the inhibition of regional convection. A greater strength indicates the presence of divergent, drier air masses and a reduction in tropical convection in specific areas. The climatological distribution of geopotential height and convective precipitation amounts serves as an indicator of regional SH strength. To analyze climatic characteristics during the summer, the regional SH strength is quantified using outgoing longwave radiation (OLR), which is regarded as both a fingerprint of the environmental background and a resultof tropical convection. Resultsshow that a La Niña environment, characterized by diminished convection at lower latitudes, is associated with a more extensive westward expansion of the WNPSH, albeit with reduced strength in the central region. Furthermore, global warming appears to inhibit tropical convection at lower latitudes while enhancing SH strength at higher latitudes. However, the increase in OLR at higher latitudes is less pronounced than that at lower latitudes, implying that the convective inhibition experienced in a warmer environment at lower latitudes results in a weaker WNPSH strength than anticipated, without a corresponding meridional compensation of OLR through the seesaw mechanism. This seesaw pattern illustrates a correlation between the large-scale expansion of the SH and the small-scale fluctuations in SH strength.

Key words: Subtropical high, Tropical convections, OLR

기후 분과 / 기후 2-4

Tropical Cyclone Risks under warmer environment in Western North Pacific

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It is important to monitor tropical cyclones (TCs) in relation to their surrounding environment, as TCs are the significant natural disasters in the western North Pacific. Gil and Kang (2024) proposed Localized ACE (LACE), which is a geographical smoothing technique using accumulated cyclone energy. They assess TC risks using LACEP (LACE partial contribution) based on climatological LACE. This study investigates the pattern of TC risks for warmer environments based on LACE and LACEP Model. The result shows that TC activity shrinks in a warmer environment compared to the climatological period (1991–2020). According to LACEP, more frequent TCs pose risks in warmer East Asian regions. The coastal regions of the Philippines are particularly affected by the intensity among various risk factors. Additionally, it has been confirmed that the Ryukyu Islands experience a higher TC risk of slow movement, resulting in variations in TC movement. Furthermore, the increase in frequency and duration of TCs near the East Asian regions exposes residents to greater risks. These results quantify localized TC risks at Eulerian perspective. However, there is still a need to enhance TC information for the periphery of active TC regions.

Key words: Risk map, Tropical cyclone, LACE, LACEP, Global warming

기후 분과 / 기후 2-5

Dynamics of extreme surface winds inside North Atlantic storms

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North Atlantic storms are among the most severe weather systems, causing enormous economic damages and threatening human lives. These storms are typically characterized by cyclonic convergent surface winds, strong updrafts, and precipitation. However, extreme surface winds are often observed within the storm where downdrafts develop. The present study investigates the dynamical and thermodynamical characteristics of the horizontal winds impinging on the cold frontal surface and the associated downdrafts. It is shown that the cyclonic winds into the cold frontal surface are mainly responsible for the downdrafts that transport the high-altitude horizontal momentum to the surface and cause intense surface winds. About half of the North Atlantic storms are accompanied by the downdrafts especially in the southern and western parts of the storm center. The results presented in this study have far-reaching implications for improving the prediction of devastating surface winds of frontal systems.

Keywords: Atlantic storm, extreme wind, downdraft, cold front

기후 분과 / 기후 2-6

과대확장된 남반구 해들리 순환에 대한 CMIP6 모델 간 모의 차이 과정

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해들리 순환은 지구 온난화에 따라 최근 수십 년 동안 극 방향으로 확장되는 추세이다. CMIP6 (Coupled Model Intercomparison Project Phase 6) 모델들은 확장이 미래 기후에 더욱 가속화될 것으로 예측하고 있으며, 모델 간 확장 정도의 예측 범위 차이 또한 크게 나타난다. 이러한 모델 간 차이는 특히 남반구에서 두드러지는데 크게는 약 2° 까지 나타나는 것으로 밝혀졌다. 본 연구해서는 남반구 해들리 순환 확장 예측에서 모델 간 차이를 유도하는 메커니즘을 살펴보고자 한다. 16개의 CMIP6 모델을 사용하였으며, 모델 간 차이는 과거 기후재현(historical) 실험과 미래 기후 SSP (Shared Socio-economic Pathway) 5-8.5 시나리오 실험에 모의된 동서평균 유선함수 추세의 모델 간 EOF (Empirical Orthogonal Function)를 통해 확인하였다. 해들리 순환 추세의 모델 간 차이를 나타내는 첫 번째 모드는 약 49.7 %의 변동성을 설명하며, 남반구 해들리 순환 확장 정도와 약 0.94의 높은 상관계수를 보이며 유의한 상관관계를 나타냈다. Kuo-Eliassen 방정식을 이용하여 분석한 결과, 비단열 가열, 경도방향 에디 운동량 및 경도방향 에디 열속은 각각 14, 21, 18 %의 기여도를 보였다. 배경장의 경우, 상대적으로 과대확장 모의를 보이는 모델은 남태평양 수렴대에서의 강수 증가, 아열대 지역의 경압불안정 감소 그리고 중위도 제트의 극 방향 이동 증가를 보이는 경향을 나타냈다. 이는 배경장 추세의 경향에 대한 편향을 줄임으로써 해들리 순환 예측의 불확실성을 줄일 수 있음을 시사한다.

Key words : 해들리 순환, CMIP6, Inter-model spread, 미래기후 시나리오

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