대기역학 및 수치모델링 분과 / 대기역학 6-1

Urban impacts on a cold-frontal precipitation system passing over the Seoul metropolitan area: an ensemble simulation study

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Precipitation systems passing over cities can be modified by urban impacts. Compared with urban impacts on less-organized convective precipitation systems, urban modification of highly-organized or strongly-forced precipitation systems remains less understood. In this study, we examine urban impacts on a cold-frontal precipitation system passing over the Seoul metropolitan area, South Korea. For this, three sets of urban ensemble simulations with diurnal-mean anthropogenic heat intensities and urban momentum roughness lengths of (0 W m^{-2}, 1 m), (45 W m^{-2}, 2 m), and (90 W m^{-2}, 3 m) and a set of nonurban ensemble simulations are performed. Comparisons with observations show that the characteristics and passage of the cold front are acceptably reproduced in all sets of the ensemble simulations. Precipitation is enhanced by about 20–40% downstorm of Seoul in the urban ensemble simulations, with marginal delays in the movement of the precipitation system. The precipitation enhancement is hard to be discerned by a comparison between a single pair of urban and nonurban simulations, since the urban-induced precipitation enhancement is obscured by strong precipitation anomalies arising from different locations of precipitation cores in individual simulations. The downstorm precipitation enhancement is attributed to precipitation intensity increases in narrow cold-frontal rainband, which results from intensified frontal updrafts due to the increases in cross-frontal vorticity. The warm urban-heated air trailing the cold front after the frontal passage results in the increases in cross-frontal vorticity by decreasing temperature gradient at the frontal zone.

Keywords: Urban impacts, cold-frontal precipitation, cross-frontal vorticity, frontal updraft, urban heat island, ensemble simulations

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서울 주야간 복합 폭염 변화 대한 도시 열섬 효과의 영향

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복합 야간 폭염(CNHW; Compound Nighttime Heatwave)은 주간 폭염(TMAX ≥ 33 °C)이 야간 폭염(TMIN ≥ 25 °C)으로 이어지는 극한 고온 현상으로, 단일 폭염보다 더 큰 사회·경제적 피해를 유발한다. 본 연구에서는 최근 25년(2000-2024)간 서울의 도시화가 CNHW 변화에 미치는 영향을 분석하였다. 우선, ASOS (Automated Synoptic Observing System)와 AWS (Automatic Weather System) 지상 관측 자료를 기반으로 CNHW 발생일 평균 도시 열섬 효과(UHI; Urban Heat Island)의 강도를 분석한 결과, 야간(1.47 °C)이 주간(0.27 °C)보다 더 강하게 나타났다. 이는 UHI가 CNHW의 야간 온난화와 밀접한 연관이 있음을 시사한다.

서울은 지리적 특성상 해륙풍과 산곡풍이 복합적으로 작용한다. 주간에는 해륙 간 온도차(LSC; Land Sea Contrast)가 산곡 간 온도차(MVC; Mountain Valley Constrast)보다 커 서해로부터 저온 습윤한 해풍이 유입되는 반면, 야간에는 MVC가 우세하여 푄 현상으로 인한 고온 건조한 동풍이 서울로 유입되는 특징을 보여, 도시화와 결합될 경우 국지 순환 강화에 의한 야간 온난화가 극대화될 위험이 있다.

CNHW 발생에 대한 UHI의 영향과 기작을 규명하기 위해, 2018년 CNHW 사례(7/28-8/12)에 대한 WRF(Weather Research and Forecasting) SLUCM(Single-Layer Urban Canopy Model) 수치 실험을 수행하였다. 실험은 인공열(AH; Anthropogenic Heat)의 일 최대값을 각각 0과 140 W/m²로 설정한 두 실험(SL0, SL140;CTL)으로 구성된다. AH가 높게 적용된 실험에서는 서울 주야간 기온이 높게 모의 되었으며, 이 차이는 특히 야간에 두드러졌다. 이는 AH에 의해 강화된 서울의 주야간 국지 순환에 기인한 것으로, 2018년과 같은 안정한 대기 조건에서 인공열의 증가는 주간에는 해풍 유입을 강화시켜 상대적으로 온난화가 완화되는 반면, 야간에는 고온 건조한 동풍의 유입을 촉진시켜 온난화를 더욱 가중시키는 역할을 했음을 시사한다.

Keywords: 야간 폭염, 폭염, 도시 열섬 효과, 인공열, 해륙풍, 푄

대기역학 및 수치모델링 분과 / 대기역학 6-3

Role of surface drag on surface amplification of stratospheric sudden warming

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Stratospheric Sudden Warming (SSW) is often accompanied by tropospheric anomaly with a larger magnitude at the Arctic surface than in the upper troposphere. This downward influence of SSW, termed as a surface amplification, is modulated not only by the poleward mass flux near the tropopause but also the equatorward mass flux near the surface. In this study, we investigate the role of surface drag in the equatorward mass transport following SSW by conducting a series of idealized model experiments using dry dynamic-core general circulation model. By perturbing the surface friction coefficient after SSW onset, a nonlinear relationship between the Arctic surface pressure and the surface drag is revealed. This relationship, which is consistent with quasi-geostrophic zonal-mean dynamics, indicates that the relative magnitude of surface drag, compared to Earth's rotation, determines whether surface impacts of SSW are strengthened or suppressed. It is further shown that the surface drag in the current climate may belong to the former, enhancing the surface amplification. These results suggest that inter-model differences in surface impacts of SSW may partly arise from variations in surface drag parameterization, underscoring the importance of reducing its uncertainties.

Keywords: Stratospheric Sudden Warming, Surface amplification, Surface drag, Idealized model experiments

대기역학 및 수치모델링 분과 / 대기역학 6-4

Characterizing Blocking Mobility and Its Role in Northern Hemisphere Cold Extremes

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Atmospheric blocking, conventionally studied as a quasi-stationary phenomenon, often exhibits zonal movement under the influence of factors like the background flow and retrograding Rossby waves. However, the impact of this mobility on cold extremes remains under-investigated. This study classifies atmospheric blocking events during the winters of 1979/80–2020/21 into westward-moving, eastward-moving, and quasi-stationary types to analyze their distinct impacts on surface air temperature by region.

Our results show that westward-moving blocks occurred most frequently over the western North Pacific, whereas quasi-stationary blocks were dominant in most other regions. In terms of duration, westward-moving blocks consistently persisted longer than the other types across all regions. Notably, these long-lasting, westward-moving events were closely associated with inducing strong cold waves in downstream areas during their dissipation phase. This is attributed to the enhanced advection of cold Arctic air by blocking-induced low-level wind anomalies. These characteristics were successfully reproduced in CESM1-LENS simulations, suggesting that a better understanding of blocking mobility can contribute to improving extreme cold wave prediction.

Keywords: Blocking, movement direction, westward-moving blocking, surface impact, temperature advection

대기역학 및 수치모델링 분과 / 대기역학 6-5

Two different approaches to urban surface energy balance in examining surface urban heat islands with urban canopy models: Bulk and facet approaches

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Urban canopy models (UCMs) are useful tools for improving the simulation and understanding of urban impacts on weather and climate. UCMs simulate urban surface energy balance (SEB) at two levels: SEB for individual urban facets (roofs, roads, and walls) and SEB for an urban conceptual volume which extends from a below-ground depth to a level above the roof-top level. Previous studies employing UCMs analyzed the SEB for the urban conceptual volume and compared it with rural SEB to elucidate the causes of surface urban heat islands (SUHIs) (bulk approach). In this bulk approach, since the urban surface energy fluxes are represented at the top surface of the conceptual volume, the representative urban surface temperature satisfying the SEB is the radiative surface temperature inverted from the emitted longwave radiation there. Meanwhile, the thermodynamic urban surface temperature is represented by the surface temperatures of urban facets that satisfy the SEB for each facet, the causes of SUHIs based on them being yet to be thoroughly examined. This study examines the causes of SUHIs using facet surface temperatures simulated by a UCM. For this, the simulated SEB at individual facets is compared with rural SEB (facet approach). Two-dimensional idealized simulations are conducted using the Weather Research and Forecasting (WRF) model coupled with a UCM. The bulk and facet approaches yield different interpretations for factors affecting the daytime and nighttime SUHIs. For example, the mean net shortwave radiation over urban facets (net shortwave radiation inside the urban conceptual volume) is smaller (larger) than rural net shortwave radiation, being interpreted to weaken (intensify) the daytime SUHI in the facet (bulk) approach. The nighttime SUHI is primarily attributed to the trapping of longwave radiation (larger urban heat storage) in the facet (bulk) approach. This study reveals that the causes of SUHIs can be interpreted differently depending on the representation of urban SEB with the surface energy fluxes simulated by a UCM, suggesting that the facet approach is physically more consistent than the bulk approach for examining the causes of SUHIs.

Keywords: Urban surface energy balance, Urban canopy model, Surface urban heat island, Urban surface temperature

대기역학 및 수치모델링 분과 / 대기역학 6-6

Generation Mechanisms of Aviation Turbulence Events Leading to Aircraft Accidents in Korea Using High–Resolution Numerical Simulations

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The generation mechanisms of two turbulence events that occurred near the Korean Peninsula and led to aircraft accidents were investigated using high-resolution numerical simulations with the Weather Research and Forecasting (WRF) model. The first case occurred on 12 January 2020 at 0417 UTC: an aircraft that departed from Kitakyushu Airport, Japan, en-route to Incheon Airport, encountered moderate intensity turbulence in clear sky at an altitude of 25,000 ft (approximately 375 hPa) over Fukuoka. Turbulence was observed beneath the core of a jet stream, where wind speeds exceeded 90 m s^{-1} over South Korea and strong horizontal wind shear and deformation appeared at the location of turbulence encounter. A developed upper-level frontal system induced strong vertical wind shear and tropopause folding down to approximately 480 hPa. Despite the relatively stable stratification, the strong vertical wind shear caused the Richardson number to decrease, leading to the generation of turbulence through the Kelvin-Helmholtz instability. The second case was 27 May 2021 at 2253 UTC: an aircraft that departed from Gimpo Airport en-route to Jeju Airport encountered severe intensity turbulence at an altitude of 17,000 ft (approximately 515 hPa) over Yesan, South Korea. A localized front developed north of the turbulence encountered location and propagated southeastward, during which it generated gravity waves with a horizontal wavelength of about 10 km. The localized front induced strong vertical wind shear by the thermal wind relationship, and the propagation of the gravity waves enhanced the Kelvin-Helmholtz instability, resulting in turbulence. Additionally, the predictions of the Korean aviation Turbulence Guidance (KTG) system, which is the operational aviation turbulence forecasting system in Korea, were examined for the two turbulence cases. The KTG system appropriately predicted the first case in terms of intensity at the location of turbulence encounter, but it predicted null intensity for the second case. Comparison between the WRF simulation and the KTG system for the second case indicated the importance of model resolution in predicting turbulence.

Keywords: Aviation turbulence, Numerical simulation, Upper-level frontal system, Frontogenesis, Kelvin-Helmholtz instability

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