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大氣科學

學門研究成果發表會

論文摘要集

- 氣候分析與模擬
- 綜觀至中小尺度天氣動力
- 高層大氣與太空
- 大氣物理化學

A 組(13:40~14:40)				
	分組	編號	姓名	身分別
1	A	C01	陳毅軒	PI
2	A	S01	賴淑華	PI
3	A	P02	劉千義	PI
4	A	M03	林書正	Postdoc
5	A	C04	黃婉如	PI
6	A	S04	汪愷悌	PI
7	A	P05	陳正平	PI
8	A	M06	遲正祥	Postdoc
9	A	C07	蘇世顥	PI
10	A	S07	施驊珊	Postdoc
11	A	P08	梁茂昌	PI
12	A	M09	陳維婷	PI
13	A	C10	蘇俊彥	PI
14	A	S10	蔡宗哲	PI
15	A	P11	張立德	PI
16	A	M12	劉清煌	PI
17	A	C13	曾莉珊	PI
18	A	S13	游振雄	PI
19	A	P14	歐陽長風	PI
20	A	M15	鄧旭峰	PI
21	A	C16	梁禹喬	PI
22	A	S16	林其彥	PI
23	A	P17	陳詠昌	Postdoc
24	A	M18	林博雄	PI
25	A	C19	Hien Bui	PI
26	A	M20	蔡世樵	PI
27	A	S20	陳世平	PI
28	A	C22	黃彥婷	PI
29	A	M23	游政谷	PI
30	A	C25	方思惟	PI
31	A	M26	鍾吉俊	Postdoc
32	A	C28	曾弘毅	Postdoc
33	A	M30	林沛練	PI
34	A	C32	卓盈旻	Postdoc
35	A	C35	李威良	PI
36	A	S23	張富淵	PI
37	A	C38	曾開治	PI

B 組(14:40~15:40)				
	分組	編號	姓名	身分別
1	B	M01	周昆炫	PI
2	B	C02	柯亘重	PI
3	B	S02	陳佳宏	PI
4	B	P03	洪惠敏	PI
5	B	M04	廖宇慶	PI
6	B	C05	徐辛	PI
7	B	S05	陳炳志	PI
8	B	P06	鄭芳怡	PI
9	B	M07	鍾高陞	PI
10	B	C08	張瓊尹	PI
11	B	S08	林映岑	PI
12	B	P09	陳韡鼐	PI
13	B	M10	陳如瑜	PI
14	B	C11	林永富	Postdoc
15	B	S11	蔡明信	Postdoc
16	B	P12	王聖翔	PI
17	B	M13	黃心怡	Postdoc
18	B	C14	洪志誠	PI
19	B	S14	張起維	PI
20	B	P15	李家偉	PI
21	B	M16	馮欽賜	PI
22	B	C17	張凱威	PI
23	B	S17	朱延祥	PI
24	B	M19	侯昭平	PI
25	B	S19	王寶貫	PI
26	B	C21	張譯心	Postdoc
27	B	M22	林哲佑	Postdoc
28	B	S22	查傑希	PI
29	B	C24	羅敏輝	PI
30	B	M25	陳舒雅	PI
31	B	C27	陳勇志	Postdoc
32	B	M28	陳鑫澔	Postdoc
33	B	C30	潘任飛	PI
34	B	M31	賴信志	PI
35	B	C33	謝旻耕	Postdoc
36	B	C36	林冠慧	PI

C 組(16:00~17:00)				
	分組	編號	姓名	身分別
1	C	P01	王祥恒	PI
2	C	M02	蔡嘉倫	PI
3	C	C03	王嘉琪	PI
4	C	S03	郭政靈	PI
5	C	P04	莊銘棟	PI
6	C	M05	林冠任	PI
7	C	C06	張瓊文	PI
8	C	S06	蔡龍治	PI
9	C	P07	吳鍾愷	Postdoc
10	C	M08	張偉裕	PI
11	C	C09	談珮華	PI
12	C	S09	楊雅惠	PI
13	C	P10	林傳堯	PI
14	C	M11	楊明仁	PI
15	C	C12	郭冠廷	Postdoc
16	C	S12	吳宗祐	Postdoc
17	C	P13	張頊瑞	PI
18	C	M14	宋偉國	PI
19	C	C15	王儷樵	PI
20	C	S15	邱奕中	Postdoc
21	C	P16	王悅晨	Postdoc
22	C	M17	楊舒芝	PI
23	C	C18	李庭慧	Postdoc
24	C	S18	蘇清論	PI
25	C	C20	Yulizar	Postdoc
26	C	M21	鄭凌文	Postdoc
27	C	C23	曾琬鈴	PI
28	C	M24	王重傑	PI
29	C	C26	涂建翊	PI
30	C	M27	邱彥超	Postdoc
31	C	C29	陳昭銘	PI
32	C	S21	劉正彥	PI
33	C	C31	許晃雄	PI
34	C	C34	陳冠杰	Postdoc
35	C	M29	陳柏孚	PI
36	C	C37	蕭立朋	Postdoc

Process-Level Diagnostics of Marine Stratocumulus in TaiESM1: Insights into Parameterization Successes and Deficiencies

TaiESM1 中海洋層積雲的過程層面診斷:洞察參數法的成功與不足之處

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Abstract

Marine stratocumulus clouds strongly influence Earth's radiation budget by reflecting incoming solar radiation, yet many general circulation models (GCMs) struggle to simulate them, primarily due to parameterization deficiencies. In contrast, the Taiwan Earth System Model version 1 (TaiESM1) can realistically simulate marine stratocumulus clouds and associated cloud radiative effects, although the reasons for this performance remain unclear. To investigate this, we conduct short-term hindcast simulations for July 2001, coinciding with the DYCOMS-II field campaign over the northeastern Pacific, together with complementary single-column model (SCM) simulations of its RF01 and RF02 flight observations. Detailed tendency analysis of cloud liquid water and related variables is used to quantify contributions from individual parameterizations and their interactions. Results show that stratocumulus maintenance depends on (1) sufficient moisture transport by the turbulence scheme; (2) conversion of moisture to cloud liquid by the cloud macrophysics scheme; and (3) cloud liquid diffusion by the turbulence scheme. In the cloud layer, the turbulence and macrophysics schemes exhibit a delicate balance, and their residual determines cloud evolution. In the subcloud layer, the turbulence scheme unrealistically diffuses cloud liquid to the surface layer, which is then removed by the macrophysics scheme, causing spurious cooling and moistening tendencies. This unrealistic behavior requires correction. This study demonstrates that combining field observations, short-term hindcast simulations, SCM experiments, and tendency analysis provides a powerful framework for diagnosing parameterization behaviors, successes, and deficiencies. This framework is broadly applicable to other cloud-related biases in GCMs.

Keywords: marine stratocumulus; TaiESM1; short-term hindcast; DYCOMS
關鍵字:海洋層積雲; TaiESM1; 短期後報模擬; DYCOMS

季內振盪的變化與颱風扮演的角色

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A TC-removed technique was applied to global analyses to study the impact of TCs on the summertime subtropical ISO propagating over the western North Pacific (WNP). The TC-removed ISO pattern showed a westward shift from the area between Taiwan and Japan to the northern South China Sea. The monsoon trough thus weakened after TCs were removed from the circulation fields. Furthermore, the interaction between the ISO and submonthly wave patterns also showed weaker signals after TC removal. However, the activity over the South China Sea remained considerable strong because fewer TCs passed through this area. Therefore, the ISO and submonthly wave patterns retained considerable intensity over the South China Sea. The higher frequency of TC occurrences in the westerly phase results in a more pronounced energy reduction following TC removal compared to the easterly phase. Moreover, synoptic-wave PKE exceeds its submonthly counterpart, and the baroclinic conversion exhibits a north-south orientation, both due to the upstream recurving TCs that redirect their paths toward Japan. These findings reinforce our knowledge of climate variability, thus advancing climate modeling accuracy. This research underscores TCs' substantial impact on atmospheric circulations, highlighting their role in coordinating the submonthly wave patterns, synoptic waves, and ISOs in the WNP. This enhanced knowledge facilitates a more accurate explanation of climate variability. Nevertheless, comprehensive analyses and assessments across the global domain are essential to fully include the broader implications and variability of TC interactions with atmospheric perturbations worldwide.

雲-輻射-SST 反饋機制對太平洋熱帶海表面溫度分布之影響

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摘　要

本研究著重在探討臺灣地球系統模式（Taiwan Earth System Model, TaiESM1）於熱帶太平洋地區降水與對流模擬之偏差，特別針對雲量與短波輻射之回饋機制進行分析。熱帶東太平洋的雙間熱帶輻合帶（double Inter-Tropical Convergence Zone, double ITCZ）為氣候模式中長期存在之模擬問題，可能與海表面溫度（Sea Surface Temperature, SST）梯度、熱通量收支、雲與對流之參數化設計有關。過去研究顯示，對流過強與雲層深度模擬偏差會導致風場與蒸發的增強，進而改變海洋環流與 SST，形成正回饋效應並加劇模擬誤差。

本研究使用 TaiESM1 之 AMIP 與 historical simulation，並以第五代歐洲中期天氣預報中心再分析資料（ERA5）與 CERES 衛星資料為比較基準，分析 1985–2014 年間熱帶太平洋（20°S–20°N, 120°E–80°W）地區之地表短波輻射（SW）、SST、對流強度與雲量模擬。結果顯示，TaiESM1 在副熱帶地區出現明顯 SW 正偏差，造成 SST 偏暖，耦合前後的 SW 模擬亦存在結構性差異，顯示海氣交互作用會影響對流與雲量分布進而改變輻射收支。

進一步的 SST–SW 線性回歸分析顯示，TaiESM1 模擬之 SST–SW 回饋強度普遍偏強，部分區域（如赤道中太平洋、西北太平洋）出現回饋符號錯誤。季節分析指出，北半球春季（MAM）為 double ITCZ 最明顯的季節，TaiESM1 在此季節中對回饋結構的模擬偏差最大，與對流深度與雲特性模擬不準有關。

本研究顯示，TaiESM1 雲–輻射回饋機制的模擬表現對降水與 SST 偏差有明顯影響，未來應進一步分析模式內部參數化方法，釐清回饋誤差的成因與成長機制，以提升模式整體模擬能力。

關鍵字：臺灣地球系統模式、海氣耦合模擬偏差

Seasonal Variation of Diurnal Rainfall Characteristics over Vietnam

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This study explores the characteristics and mechanisms of diurnal rainfall in Vietnam (VN), focusing on two key aspects: (1) the ability of Integrated Multi-satellite Retrievals for GPM (IMERG) to capture regional and seasonal sub-daily rainfall patterns; (2) the influence of multi-scale atmospheric processes in shaping these patterns. Data from 171 rain gauge stations served as a reference for the evaluation. Results indicate that while IMERG underestimates the magnitude of diurnal rainfall variation, it successfully identifies regional and seasonal differences in diurnal rainfall timing. Key findings include: (1) Southern VN predominantly experiences late-afternoon rainfall across all seasons; (2) Central VN shifts from late-afternoon rainfall dominated in spring-summer to nocturnal rainfall dominated in autumn-winter; (3) Northern VN displays mixed characteristics, with southern areas showing seasonal patterns like central VN, while northern areas are dominated by nocturnal rainfall year-round. Examining the maintenance mechanisms reveals that diurnal rainfall in southern VN is primarily influenced by local breezes (land-sea and mountain-valley breezes) interacting with topography, exhibiting minimal seasonal variation in timing. In central VN, significant seasonal changes in diurnal rainfall timing are driven by the seasonal shift in the location of moisture flux convergence, affected by specific humidity and low-level wind. In northern VN, the complex interplays between local breezes and the clockwise veering rotation of larger-scale diurnal wind circulation over the Gulf of Tonkin and the South China Sea, along with topographical influences, are crucial for diurnal rainfall formation. These findings highlight the importance of multi-scale atmospheric dynamics in modulating regional diurnal rainfall variations over East Asia.

Soil Moisture Regimes as a Framework to Understand Hydroclimate Change and Extremes

以土壤水分作用型態理解水文氣候變遷與極端事件

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Abstract

Recognizing soil moisture regimes provides a powerful framework for understanding hydroclimate dynamics. The soil moisture–evapotranspiration relationship is inherently nonlinear, with dry, transitional, and wet regimes defined by whether surface fluxes are limited by water or energy. These regimes fundamentally regulate how the land surface modulates climate variability and extremes.

The rapidly expanding availability of daily records of soil moisture, surface heat fluxes, and near-surface atmospheric states—from in situ observations, observation-constrained products, satellite retrievals, and Earth system model simulations—has enabled the development of data-driven approaches to track soil moisture regimes across historical periods and future projections. Using the proposed approaches, I have shown that: (1) multiple satellite- and observation-based datasets consistently identify similar global geographic patterns of soil moisture regimes; (2) Earth system models forced by idealized CO_2 increases robustly project expanding transitional regimes, during which land–atmosphere interactions are most active; (3) soil moisture regimes evolve not only through changes in soil moisture distributions but also through shifts in the threshold values that separate regimes; (4) nonlinear soil moisture–surface heat flux coupling in transitional regimes likely acts as a key feedback amplifying compound hot–dry extremes; and (5) the regime in which a compound hot–dry extreme emerges strongly shapes its development.

Together, identifying soil moisture regimes sharpens process-level interpretation of land–atmosphere coupling, strengthens climate-model evaluation, and provides mechanistic insight into hydroclimate change and extremes.

Keyword: Soil Moisture Regimes, Hydroclimate Change, Hydroclimate Extremes, Surface Heat Flux

關鍵字：土壤水分作用型態、水文氣候變遷、水文氣候極端事件、地表熱通量

印度半島人為氣膠對季風肇始的影響

Anthropogenic aerosol impacts on the Indian Summer Monsoon Onset

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[2]National Taiwan University

Abstract

This study aims to investigate how anthropogenic aerosol emissions over the Indian Peninsula modulate the onset of the Indian summer monsoon (ISM) through thermodynamic, dynamic, and aerosol–convection feedback processes. Motivated by emerging observational and modeling evidence, including changes in circulation and precipitation during the COVID-19 lockdown period, the research examines how aerosols alter diabatic heating over the Tibetan Plateau, influence the South Asian High, suppress pre-onset convection, and modify moisture transport from the Indian Ocean. Using CESM1 experiments, the first phase of this proposal analyzes anthropogenic aerosol impacts on monsoon onset timing and associated circulation changes. The second phase introduces two additional sensitivity experiments that disable convective wet scavenging, allowing quantification of aerosol removal effects and feedback on aerosol accumulation, atmospheric stability, and ISM onset variability. By integrating thermodynamic diagnostics, moisture budget analysis, and ensemble simulations, this study aims to construct a unified aerosol–convection–circulation interaction framework. Expected outcomes include improved mechanistic understanding of aerosol-driven monsoon modulation, enhanced attribution of aerosol effects on ISM onset timing, and new insight into the role of wet scavenging in shaping pre-monsoon conditions.

Keywords: Indian monsoon onset, anthropogenic aerosol emissions, CESM1, aerosol-convection-circulation interaction

A Physics-Guided Deep Learning and Statistical Hybrid Framework for Surface Observation Gridding and Downscaling in Taiwan's Complex Terrain

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This study investigates the high spatial variability and non-stationarity of surface meteorological fields resulting from Taiwan's complex terrain and dynamic weather systems. Long-term climate observational data in Taiwan face significant challenges regarding spatiotemporal heterogeneity. Surface stations before the 1980s were extremely sparse, and although the number of automated stations has increased since then, they remain disproportionately concentrated in plains and urban areas. Consequently, mountainous regions with rugged terrain have long remained observational blind spots. To address these limitations, traditional gridding methods (e.g., Inverse Distance Weighting, Kriging) are often constrained by assumptions of isotropic spatial correlation and by the absence of atmospheric physical constraints. These methods frequently fail to accurately capture temperature lapse rates or orographic precipitation characteristics in mountainous areas, leading to physically inconsistent estimation biases.

To overcome these challenges, this study proposes an innovative "Physics-Guided AI-Statistical Hybrid Framework" designed to reconstruct a continuous, high-quality gridded meteorological dataset for Taiwan spanning the past 30 years. The project execution is divided into three core phases. The first phase, "Feature Extraction," uses ERA5 reanalysis data and machine-learning clustering algorithms to precisely extract "weather regime" features, which are then integrated with topographic factors to construct environmental feature vectors. The second phase, "Hybrid Statistical Modeling," employs Deep Neural Networks to learn spatial covariance structures dynamically under varying atmospheric conditions. This process generates covariance matrices with "flow-dependent" characteristics, which are then integrated into a Best Linear Unbiased Estimator mathematical framework to produce physically consistent backbone grids at a 25-km resolution. The final phase, "High-Resolution Grid Generation via Downscaling," applies our self-developed Multi-Input Super-Resolution (MISR) model. By incorporating physical constraints into the data-processing workflow, the model refines the coarse-grid data, downscaling it to a horizontal resolution of 1 km.

This research is expected to successfully produce a high-quality gridded meteorological dataset covering the past 30 years, with spatial resolutions ranging from 25 km down to 1 km. The outcome aims to effectively correct estimation errors during early, data-sparse periods, providing a stable, continuous, and reliable foundation for meteorological information for long-term climate analysis and extreme weather event research in Taiwan.

Resolution Dependence of Tropical Poleward Energy Transport in Aquaplanet GCMs

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Abstract

The tropical atmosphere plays an important role in transporting energy poleward and driving the global circulation. However, understanding and simulating this fundamental aspect of our climate remains difficult due to its sensitivity to convective parameterizations and horizontal resolution. This study focuses on benchmarking the resolution dependence of tropical poleward energy transport in two aquaplanet atmospheric general circulation models with disabled convective parameterizations: a nonhydrostatic high-resolution (100–6 km) finite-volume cubed-sphere model with a full physics package and a lower-resolution (300–100 km) hydrostatic spectral model with idealized moist physics. Despite differences in their physics and numerics, both models demonstrate that column-integrated poleward moist static energy transport by the mean meridional circulation increases with resolution in the deep tropics, while transport by transient eddies decreases. These changes are associated with enhanced gross moist stability that switches from negative to positive due to an increasingly top-heavy mean circulation and reduced eddy activity diffusing water vapor along an unchanging mean moisture gradient. Further analysis rules out extratropical baroclinic eddies and radiation as the main drivers of these changes. Instead, the resolution dependence of both the mean meridional circulation and transient eddies appears to reflect the resolution dependence of tropical explicit (unparameterized) deep convection. We speculate the multiscale interactions of convection allow for a coupling between gross moist stability and eddy moisture flux, leading to their concurrent changes with resolution. We discuss the implications of this resolution dependence for developing theories and models of the tropical atmosphere.

Keyword: Resolution Dependence, Tropical Energy Transport, Hadley Cell, Transient Eddies, Aquaplanet GCMs

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ISO Modulations on Landfalling Tropical Cyclones in the Philippines

季內振盪對菲律賓登陸熱帶氣旋之影響

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ABSTRACT

Landfalling tropical cyclones in the Philippines (LTC_{PH}) occur most frequently in October–December (OND) than July–September (JAS). LTC_{PH} concentrate in the region north of 14° N during JAS, but increase evidently in the region south of 14°N during OND. This study examines modulations of the 30–60-day intraseasonal oscillation (ISO) on LTC_{PH} in JAS and OND during strong convective (CON) and non-convective (N-CON) ISO phases. In both JAS and OND, the major ISO anomaly during the CON phase is an elongated anomalous cyclone across the South China Sea (SCS) and tropical western North Pacific (WNP). The WNP tropical cyclones (TCs) were driven by anomalous southeasterly flows along the interior of this anomalous cyclone toward the Philippines. For the N-CON phase, the dominant ISO anomaly is an anomalous anticyclone extending southwestward from the oceans east of Taiwan toward the SCS. LTC_{PH} were steered by anomalous easterly or northeasterly flows in the southern part of this anomalous anticyclone. Both the anomalous cyclone and anticyclone and their steering flows expand more southward in OND than JAS. This assists more LTC_{PH} to move along a more southern track toward the region south of 14° N during OND. Numbers of LTC_{PH} in the CON phase are about 2.9 (3.4) times as many as those in the N-CON phase during JAS (OND) facilitated by ISO anomalies of increased moisture content and decreased vertical wind shear. During the CON phase, the dominating anomalous cyclone connects with a southeastward intensification of the monsoon trough during JAS and a northwestward intensification of the equatorial trough during OND. During the N-CON phase, the governing anomalous anticyclone associates with a southwestward amplification of the western Pacific subtropical high (WPSH) during JAS and zonal and meridional intensifications of the WPSH and Siberian high during OND.

Maritime Deep Tropical Convection in Convection-permitting Simulation: A Unified Representation

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Abstract

Convection-permitting models explicitly simulate convective coherent structures larger than the model's horizontal resolution while truncating smaller-scale counterparts. To investigate how unresolved convective structures associated with deep convective processes affect storm features in convection-permitting simulations, a deep convection scheme that enables a unified representation of deep moist convection is developed. The key variable in the scheme is fractional convective cloudiness (σ), which controls the vertical eddy transports and determines the partitioning of the water phase change processes between parameterization and explicit simulation. Together with a steady-state plume model with memory and stochasticity, the unified scheme parameterizes σ for each realization of grid-scale processes.

Using the Cloud Model 1 with the unified scheme, idealized convection-permitting simulations (dx 3 km) driven by mean conditions of the GATE Phase III field experiment are carried out. The results show that unresolved deep convection dominates the vertical energy transport in the early stages of simulated storms, and its dominance gradually weakens as the storms develop. The parameterized detrainment leads to the early occurrence of mid-to-high level clouds. In comparison with the ordinary convection-permitting simulation, the unified scheme contributes to a pronounced congestus mode in the vertical velocity profile of mature storms, as the vertical eddy transport enhances dry static stability. In addition to improving the representation of deep moist convection across scales, the development of the unified scheme suggests an alternative framework for investigating multiscale interactions associated with deep convective processes.

Keyword: Deep moist convection, unified representation, convective updraft cloudiness, convection-permitting model

A Changing El Niño–Typhoon Relationship Under a Warming Climate

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Abstract

The 2023 El Niño produced an unprecedented western North Pacific (WNP) configuration, with record-low typhoon frequency but an unusually high proportion of super typhoons (reaching 50%). Despite being a strong El Niño, the WNP displayed non–El Niño oceanic conditions, sustained by residual La Niña heat, Atlantic–Pacific teleconnections, and anthropogenic warming. Unfavorable atmospheric conditions suppressed genesis, yet elevated subsurface heat in the WNP fueled rapid intensification of storms that did form, revealing a growing decoupling between typhoon frequency and intensity. This event highlights a shift in typhoon drivers: from atmospheric dynamics toward oceanic thermal structure under climate change. As such non-canonical El Niño patterns become more frequent in a warming climate, predictive frameworks must move beyond ENSO-centric metrics to integrate cross-basin interactions, ocean memory, and long-term warming in order to improve forecasts and strengthen resilience in vulnerable coastal regions.

Deep convection despite strong surface inhibition—examples with cloud-resolving and anelastic convective entity models

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Abstract

Convection triggering under strong convective inhibition (CIN) is examined using three cloud-resolving models: the Vector Vorticity Model (VVM), the Anelastic Convective Entity (ACE) model, and the Superparameterized Community Atmosphere Model (SPCAM). Results here challenge the conventional wisdom inferred from parcel theory that CIN strictly controls convection initiation. All three models produce precipitation even with weak initial vertical velocity (w), highlighting effects of nonlocal perturbation pressure and dynamic entrainment. For a near-surface initial perturbation of kilometer-scale horizontal dimension, a comparable depth of vertical velocity develops almost instantly due to the nonlocal pressure effects. Convection consistently initiates near the top of the inversion layer, indicating that entrainment at these heights is more important than surface-based processes. Once w exceeds a certain threshold—substantially lower than anticipated by parcel theory—the timing and intensity of precipitation remain largely unchanged. This suggests that overcoming CIN is not the primary limiting factor for convection. Model differences reveal the impact of gravity waves, particularly in SPCAM, where wave interactions strongly influence convection. A reduced-humidity experiment with VVM further exhibits convection initiated by gravity waves interacting with dynamic entrainment, even for a near-surface initial perturbation, making the outcome highly sensitive to small variations in w. These findings make a strong case for replacing traditional CIN-based parcel models with advanced convection representations in global models to address persistent biases in the diurnal cycle of precipitation.

Keyword: Anelastic nonlocal dynamics, Convection initiation, Convective inhibition, Cloud-resolving models

季內震盪對梅雨及颱風之影響

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研究一選擇短週期季內振盪(10–30 天，ISO-S)顯著的 2017 年 6 月 2–4 日，以及長週期振盪(30–90 天，ISO-L)顯著的 2007 年 6 月 3–9 日梅雨極端降水個案進行觀測資料診斷分析與數值模式敏感度實驗模擬。結果顯示 ISO-S 於 2017 年個案具東移特性，透過調整中高層風場結構削弱垂直風切，使梅雨降水型態由集中劇烈轉為分散持續；中低層氣旋性擾動與強化之西南氣流促進了水氣輸送與輻合，有利深對流雲系發展而提升降水強度。ISO-L 於 2007 年個案中呈北移後西傳特性，個案前期透過低層負位勢高度擾動、中層槽線維持及上層輻散區域，促進鋒面提早南壓進入臺灣；後期則誘導上層輻散區域擴張，使垂直上升運動範圍擴大，降水影響區域由鋒面周遭擴展至廣泛區域。

研究二使用 K-means 分群法針對 1979–2022 年間 ERA5 再分析資料之 850 hPa 風場進行天氣型態(Weather Types, WT)分類，並引入 Classifiability Index(CI)作為評估分群穩定度之指標，作為後續建立季節曆之基礎。首先測試 9 種不同的分析範圍，找出其中最能穩定捕捉東亞次季節轉換者有二；此二範圍之分析皆得到 9 類天氣型態，其中除有 3 類以相當之頻率好發於冬季之外，其餘 6 類則分別主導春、台灣梅雨、長江梅雨、颱風、早秋、晚秋等次季節之天氣型態。 進一步利用 point-biserial correlation 探討個天氣型態與夏季季內震盪(BSISO)之間可能的關係，結果顯示長江梅雨天氣型態的出現與 BSISO 呈現正相關，尤其當長江梅雨天氣型態出現在颱風季時，與 BSISO 之正相關更高。颱風天氣型態的出現則與 BSISO 呈現負相關，當颱風天氣型態出現在長江梅雨季時亦然(雖為較低之負相關值)。

關鍵字：季內震盪、梅雨鋒面、颱風、極端降水、天氣型態、次季節

Seasonal cycle and ENSO on modulating the long-term variation and impact of Indo-Pacific Warm Pool

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Abstract

The observation yields the area of Indo-Pacific Warm Pool (SSTs exceeding 28°C, hereafter WPA) fluctuates with annual cycle and multiple timescales, which primarily determined by the annual cycle, ENSO (2-7 years) and long-term (period >20 years) time scales. How the annual cycle and ENSO on modulating the long-term variation and impacts of WPA were investigated. It revealed that the regression of SSTs and atmospheric circulations onto to interannual component of WPA yields an El Niño-like pattern, whereas exhibits a Mega La Niña like structure for that of the long-term component (i.e., WPA without ENSO). That is the regression onto long-term component of WPA was partially offset by ENSO. It became important to remove off the effect ENSO in investigating the long-term impact of WPA.

The regression onto the long-term component of WPA yields an enhanced Walker circulation, which was modulated by seasonal cycle in response to the south-north migration of ITCZ. The regression in MAM similar to SON yields an anomalous convection/descent in Maritime Continent/equatorial eastern Pacific. In JJA, the convection moves form Maritime continent to northern Indian Ocean, whereas it returned southward to SPCZ in DIF. The anomalous convection in JJA potentially enhanced the Indian summer monsoon and modified the Africa boreal monsoon rainfall to northward extending. Whereas the accompanied subsidence tend to suppress the convection over the western North Pacific. In DJF, the anomalous convection in SPCZ forced a large-scale subsidence in southern America. It created a dry conditions, which enhanced and modified Amazon drought southward extension recently.

Keywords: Indo-Pacific Warm Pool, SST, annual cycle, ENSO, long-term

Contrasting Yet Connected: Cold Tongue Variability in the Atlantic and Pacific

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The equatorial cold tongues in the Atlantic and Pacific Oceans are integral to tropical climate variability through strong ocean–atmosphere coupling. Despite their shared dynamical foundations, the two systems exhibit pronounced contrasts in mean state, dominant feedbacks, and variability characteristics. This study investigates cold tongue variability from the complementary perspectives of ocean dynamics, atmospheric processes, and air–sea coupling. Using reanalysis datasets and model outputs, we examine variability across seasonal, interannual, and decadal timescales, with particular emphasis on the role of mean-state differences and feedback mechanisms. We further explore Atlantic–Pacific linkages mediated by atmospheric teleconnections and large-scale circulation changes. By adopting a unified, multi-timescale framework, this work focuses on both the contrasts and connections between Atlantic and Pacific cold tongues and their implications for tropical climate variability and predictability.

Changes in Polar Atmosphere and Hydrology Under Global Warming: Mechanisms Revealed by Observations, High-Resolution Weather and Traditional Climate Model Simulations, and New AI Climate Emulations

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Abstract

Anthropogenic global warming has caused substantial climate change in Arctic regions. The Norwegian Svalbard region has experienced record-breaking changes in the surrounding environment, ecosystems, and regional climate regime. The present study integrated surface observations and reanalysis data sets with simulations from the Weather Research and Forecasting (WRF) regional model, which offers high-resolution spatiotemporal information, to investigate the mechanisms of atmospheric changes in the Svalbard region under global warming. A comparison of summer conditions in 2013 and 2023 revealed a substantial increase in the 500 hPa geopotential height field accompanied by a weakening of surrounding pressure gradient forces and wind speeds. These changes were dynamically linked to a reduction in vertical motion: Weakened upward motion hampered the efficiency of moisture transport from the lower to the upper atmosphere. The consequent atmospheric warming and reduction in lower-level moisture led to a marked reduction in the volume of upper-level cold clouds. This reduction in cold-cloud cover resulted in an increase in incoming shortwave radiation that heated the surface and intensified increases in surface temperatures. In addition, the large-scale 500 hPa geopotential height increase can be revealed by the Arctic warming associated with sea-ice loss, simulated by both traditional climate models and new AI climate emulator. Our findings highlight the changes in regional atmospheric and hydrological conditions in the Svalbard region in the first decades of 21st century and underscore the need for high-resolution regional models, together with traditional climate models and new AI approaches, to determine the mechanisms underlying these changes.

Keyword: amplified Arctic warming, hydrometeorological climate change, high-resolution regional model, TaiESM1, Google's NeuralGCM.

Stratospheric-tropospheric mass exchange associated with tropopause folds

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Abstract

Tropopause folds (TFs) are regarded as the main mechanism for stratosphere-troposphere exchange (STE) in the midlatitude region and play an important role in the redistribution of gases and aerosols between the troposphere and stratosphere. However, studies characterizing what fraction of STE is associated with tropopause folds are lacking. In this study, we use Lagrangian trajectories to estimate STE mass flux and the TF detection algorithm by Škerlak et al. (2015) to determine whether trajectories associated with STE are related to TFs. Trajectories and TF detection are performed on the ERA5 model-level data at 0.5° spatial and 3-hourly temporal resolution. By matching exchange events to TFs using a temporal and spatial separation threshold of 1 hr and 300 km (based on the method of Sprenger et al., 2003), we find that in the Northern Hemisphere during year 2022 the annual average stratosphere-to-troposphere (STT) mass transport of all transport events is ~1.14×10^{10} kg s^{-1}, while those associated with TFs account for roughly 34.8% of it. For troposphere-to-stratosphere (TST) transport, the average transport rate is ~5.91×10^{9} kg s^{-1}, with TFs accounting for 27.4%. We plan to perform this analysis for the period 1980–2023 and assess the presence of trends in transport and the role of TFs in both STT and TST.

Diagnosing ENSO Behavior Biases in TaiESM

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Abstract

ENSO event location and persistence have received increasing attention over the past two decades, with reports of more frequent Central Pacific (CP-type) events and multi-year episodes. Here, we systematically evaluate ENSO diversity in TaiESM, Taiwan's in-house Earth system model. We use the Oceanic Niño Index (ONI) to identify events and then classify them by spatial pattern (Eastern Pacific, EP-type; Central Pacific, CP-type) and persistence (single-year, SY; multi-year, MY). TaiESM overestimates the fraction of CP-type El Niño events, whereas La Niña occurrences are biased toward the EP type. Regarding persistence, TaiESM produces too many SY events in both phases. TaiESM captures the first-order contrast between EP-type and CP-type El Niño, but the SST anomalies are overly strong, particularly for EP-type El Niño and CP-type La Niña. The overly strong CP-type La Niña, potentially linked to an excessively strong preceding El Niño, leads to cold SST anomalies persisting into the second year. The evolution of CP-type El Niño is also biased, with an unrealistic phase transition toward the second year in TaiESM. These results highlight systematic biases in TaiESM ENSO location, persistence, and amplitude, motivating ongoing dynamical diagnostics.

Climate Change and Climate Interventions (C3I): Impacts and Physical Mechanisms

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Abstract

As many people around the world are experiencing an unprecedented increase in extreme events that greatly affect human life, the environment, and the economy, it is crucial to understand the underlying physical mechanisms of these events, how climate change influences them, and potential solutions. We proposed a project that has three main objectives: (i) to deepen understanding of the physical processes driving changes in extreme events caused by climate change, (ii) to investigate how these extreme events – such as heavy rainfall, heatwaves, floods, and droughts – impact the climate, and (iii) to explore strategies for combating climate change while promoting decarbonization.

We will adopt a collaborative and interdisciplinary approach, combining atmospheric physics, climate modeling, and artificial intelligence/machine learning to address these challenges. Our research will examine the atmospheric processes responsible for changes in extreme events within a context of a changing climate. This includes studying the timing of their emergence, the contributions of mean conditions and variability, and the effects of both internal and external forces on these extreme changes. Conversely, we will also investigate how these extreme events influence the climate itself, with a particular focus on the land-atmosphere-ocean interaction processes. Additionally, we will delve into research related to climate intervention, specifically solar radiation management, to gain further insights into the fight against climate change, its effectiveness, and its potential side effects.

Keyword: climate change, climate extreme, climate intervention, solar radiation management, climate modeling

Spatially divergent hydroclimatic responses to deforestation in the Maritime Continent

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Abstract

Tropical forests strongly regulate regional hydroclimates, yet the spatial structure of precipitation responses to deforestation remains poorly constrained in the convectively active Maritime Continent. Using 4-km, hourly convection-permitting WRF simulations, we examine how idealized land-cover changes from forest to grassland and barren land affect precipitation across spatial and intensity scales during four representative months in 2010. Deforestation amplifies rainfall heterogeneity, producing distinct moistening and drying regimes linked to altered land–sea thermal gradients and mesoscale circulation. Reduced-rainfall regions experience more dry hours and weakened convection, while moistening areas show intensified coastal convection, revealing an emergent "wet-get-drier, dry-get-wetter" response to forest loss.

Keywords: Deforestation, moistening, drying, WRF

Cloud-Fog-Induced Radiation Attenuation Weakens Land Control and Suppresses Microclimate Variability

雲霧造成之輻射衰減削弱陸地過程影響性並抑制微氣候變異度

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Abstract

Land type fundamentally shapes the distribution of surface heat fluxes, thereby defining the core characteristics of land-atmosphere interactions. Downward radiation serves as the primary energy input for these interactions, but its variability is strongly influenced by the dynamic variation of clouds and fog. These variations play a crucial role in shaping the spatial heterogeneity of hydro-climatological cycles. However, limitations in the temporal continuity and spatial resolution of satellite and radiosonde observations hinder our ability to capture the diurnal evolution of near-surface atmospheric vertical structures. To address this challenge, we investigate the influence of fog events on the spatiotemporal variation of microclimate across different land types using paired *in-situ* meteorological stations and near-surface vertical temperature profilers. During fog events that simultaneously affect both a forested site and an adjacent open field, the near-surface air temperature difference between two land types decreases significantly from 4.58±2.49°C to 1.51±1.09°C at noon, and from -3.57±2.03°C to -1.20±3.46°C at 7:00 AM, respectively. Vertical temperature profiles further reveal that fog stabilized the near-surface atmosphere, reducing the vertical temperature gradient at noon from -0.56±0.12°C/m under non-foggy conditions to -0.24±0.03°C/m under foggy events. Additionally, fog temporarily inhibits land-atmosphere interactions by diminishing incoming shortwave radiation. The consequent suppression of surface heat flux forms a stable and uniform vertical structure. These findings highlight the critical role of fog in modulating microclimatic spatiotemporal variation and underscore its broader implications for understanding land-atmosphere coupling under changing land use and climate.

Decoding Anthropogenic Influences on Tropical Pacific SST Patterns

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The observed lack of surface warming in the southeastern and central equatorial Pacific stands in sharp contrast to climate model projections, which consistently simulate an enhanced equatorial warming pattern. A recent assessment suggests that the zonal sea surface temperature (SST) gradient has historically been regulated by strengthening mechanisms but is projected to shift toward dominance by weakening mechanisms in the future (Watanabe et al., 2024). A pressing question therefore remains: *When will the weakening of the equatorial zonal SST gradient emerge?*

To address this question, I review recent work from my group and collaborators, focusing on the fast and slow components of tropical Pacific SST pattern responses to anthropogenic aerosols, stratospheric ozone, and greenhouse gases, diagnosed using idealized step-function experiments. Across all forcings, the evolution of tropical Pacific SST patterns can be interpreted through three distinct stages: (1) fast atmospheric circulation adjustments and their associated wind-driven ocean responses; (2) mixed-layer temperature changes governed by surface air–sea heat fluxes; and (3) gradual, density-driven ocean circulation adjustments.

Taken together, anthropogenically forced SST pattern responses exhibit distinct timescales and complex variability, reflecting the interplay between rapid atmospheric adjustments and slow oceanic reorganization. This framework highlights that the emergence of a weakened equatorial zonal SST gradient is not a monotonic response to external forcing, but instead depends on the relative timing and magnitude of competing fast and slow processes—an insight that has important implications for interpreting near-term tropical Pacific trends and improving confidence in future climate projections.

Key words: Walker Cell, SST patterns, anthropogenic climate change

Assessment of Decadal Variability in East Asia and Its Impact on the Predictability of Extreme Heatwaves and Cold Surges

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Abstract

Extreme temperature events, including summer heatwaves and winter cold surges, pose significant risks to public health, agriculture, and energy systems across East Asia. This study demonstrates that both types of extreme events exhibit decadal predictability through well-established teleconnection mechanisms originating from distinct climate modes.

For summer heatwaves, we identify the Pacific Meridional Mode (PMM) as a prime driver of decadal temperature variability over Taiwan and East Asia. Analysis of 59 years of observational data (1960–2018) reveals a significant correlation between PMM indices and summer temperatures. During positive PMM phases, warm SST anomalies in the eastern Pacific trigger cross-Pacific wave train propagation, inducing anticyclonic circulation and subsidence over East Asia. This atmospheric stabilization reduces monsoonal moisture transport while increasing surface shortwave radiation, resulting in elevated summer temperatures. Linear baroclinic model experiments and CMIP6 historical simulations confirm these physical mechanisms.

For winter cold surges, we establish the North Atlantic Oscillation (NAO) as a key predictor of cold surge frequency in East Asia, including Korea, Japan, and Taiwan. The dynamical mechanisms of wave propagation linking NAO to East Asian trough development create cold-surge-favorable environments during winter. Leveraging the skill of climate models in capturing NAO decadal variability, we develop a statistical-dynamical hybrid framework combining decadal prediction datasets with statistical regression models.

Our findings demonstrate that extreme temperature events in East Asia, both heatwaves and cold surges, can be predicted on multi-annual to decadal timescales when teleconnection mechanisms are properly characterized. This hybrid approach, integrating numerical climate predictions with statistical downscaling, offers a promising framework for regional extreme event prediction that overcomes climate model biases at local scales, providing valuable climate information for adaptation planning across East Asia.

Keywords: Decadal predictability; East Asia; Heatwaves; Cold surges; Pacific Meridional Mode; North Atlantic Oscillation; Teleconnections; Climate variability

Irreversibility of the Amazonian Hydrological Cycle under CO_2 Removal, Aerosol Forcing, and Land Use Change

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The Amazon Basin is a critical component of the Earth system, where strong land-atmosphere coupling makes regional hydroclimate highly sensitive to anthropogenic forcing. Here we assess the reversibility of Amazonian hydroclimatic responses by combining idealized CO_2 ramp-down experiments with historical analyses of aerosol and land use impacts.

We anlyze the Community Earth System Model (CESM) simulations with a scenario in which atmospheric CO_2 concentrations rise to 1,468 ppm and then decline along the same trajectory. Despite symmetric forcing, the Amazon exhibits strongly non-linear and asymmetric responses. During the late ramp-down phase, evapotranspiration increases sharply due to enhanced canopy transpiration under warmer temperatures and increased shortwave radiation, while precipitation continues to decline as circulation changes strengthen subsidence and elevated evaporative demand accelerates soil moisture loss. These processes reduce plant water-use efficiency, weaken ecosystem resilience, and promote persistent drying even as CO_2 concentrations return to baseline levels.

We further examine dry-season hydroclimatic trends from 1980 to 2014 using the CESM2 Large Ensemble. Declining anthropogenic aerosol loading over the northern Atlantic warms the Northern Hemisphere, establishes a meridional SST dipole, and shifts regional circulation northward, enhancing subsidence over the Amazon. Concurrently, land use change weakens evapotranspiration-driven moisture recycling, particularly in the southern Amazon, increasing water stress and suppressing net primary productivity.

Together, these results demonstrate that Amazonian hydroclimate and ecosystem functioning can exhibit lasting and potentially irreversible responses to both global and regional anthropogenic forcings, with persistent risks to forest carbon sinks and the basin’s climate-regulating role even under net-zero emissions pathways.

Seasonal ITCZ Control on ENSO Responses to Extratropical Volcanic Forcing

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Abstract

The response of El Nino Southern Oscillation (ENSO) to a strong volcanic eruption is determined by several controls, included the spatial structure of the volcanic forcing. In the case of extratropical eruptions, a mechanism contributing to post-eruption ENSO evolution involves the forced inter-hemispheric energy imbalance and the associated displacement of the Intertropical Convergence Zone (ITCZ). In this study, using 100 members of diverse (in locations and magnitude) idealized volcanic forcing ensembles from the Max Planck Institute Earth System Model (MPI-ESM1-2-LR), we find that the large (>= 10 Tg Sulfur) north and south extra-tropical eruptions lead to strong El Niño-like and weak La Niña-like responses in the winter next year, respectively, which can be attributed to the opposite displacement of summer ITCZ. Due to the seasonal migration of ITCZ, the southward displacement responses to large north extra-tropical eruptions facilitates an El Niño development in summer with westerly anomalies in the equatorial Pacific, while the northward displacement of south extra-tropical eruptions has a mixture of westerly and easterly anomalies, leading to a weak La Niña-like responses. Furthermore, when separating the 100 members based on initial ENSO states, distinct ENSO responses are found and significant differences in ENSO tendency can be found even 5 years after eruptions. This study stresses the importance of seasonal differences in ITCZ displacement when studying extratropical forcing and contributes to explains the inconsistency of ENSO responses to past volcanic events.

Keyword: volcano impact, energy transport, climate dynamics, extratropical eruptions, ENSO, El Niño

西北太平洋與南海海域颱風頻率年代際變化

Interdecadal variability of tropical cyclone activity over the western North Pacific and South China Sea

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西北太平洋秋季（九月至十月，SO），颱風生成位置有明顯的年代際變化。從第一時期 (1970 至 1996 年，IP1）到第二時期 (1998 至 2020 年，IP2），颱風於 20°N 以北地區發生機率提高，在 20°N 以南地區則被抑制。大尺度調節過程顯示，西北太平洋地區海表面溫度（SST）整體上升，伴隨大氣環流中心向北移動。太平洋副熱帶高壓和季風槽北移，導致副熱帶地區產生異常的反氣旋式環流距平，南海和台灣東側海域則產生異常的氣旋式環流距平，有利於颱風生成位置往北偏移。與此同時，向東南延伸的季風槽往西北方向撤退，導致西北太平洋東側區域出現異常的反氣旋式環流，減少南側颱風生成。

秋季影響南海的颱風個數於 2000 年前後有所轉變，除了由西北太平洋移入南海的「移入型」減少外，南海海域本地生成的「在地型」颱風數量也減少。比較 1979 – 1999 年與 2001 – 2023 年兩時期的環流場發現，受到自孟加拉灣經南海延伸至熱帶西北太平洋的低層反氣旋環流異常所影響，讓南海與西北太平洋颱風生成與移動路徑受到影響，同時讓南海受到颱風影響的頻率降低。

關鍵字 ： 颱風、秋季、西北太平洋、南海、大氣環流

Evolution of Atmospheric Energy Budget under Global Warming Linking to the Changes of Walker Circulation

Abstract

The energy transport of the atmosphere is tightly coupled to atmospheric circulation. As the CO2 concentration rises and global warming occurs, a variety of climate feedbacks as well as anomalous ocean heat uptake act to modulate the net energy input (NEI) of the atmosphere, perturbing the energy transport which demands changes in atmospheric circulations. In this study, by analyzing the abrupt-4xCO2 simulations of CMIP6, we investigate the evolution of the atmospheric energy budget, particularly its spatial distribution, and connect the anomalies to the responses of the Walker circulation. It is found that, in the first 2-3 decades after the quadrupling of CO2 concentration, the anomalous NEI features a land-sea contrasting pattern, with the dominating energy source of the atmosphere located over lands. In addition to negligible surface flux changes over land compared to the downward surface flux in oceanic regions, the more positive lapse rate and cloud feedback over land also contribute to the larger NEI over land. The pattern of NEI anomalies then evolves toward an ocean-dominating pattern, in which the NEI anomalies over lands vanish and a strong energy source over the tropical Pacific emerges, reflecting the El Nino-like warming pattern in the quasi-equilibrium stage.

The redistribution of energy source and sink of the atmosphere impacts the atmospheric energy transport and, in turn, atmospheric circulation in the tropics. Inspired by existing energetic theories that connect the anomalous atmospheric energy transport and adjustments of tropical circulations, we investigate the relationship between the redistribution of energy and the responses of Walker circulation. The changes of Walker circulation are highly correlated to the relative strength of the energy source in the Afro-Eurasia and equatorial Eastern Pacific. An energetic decomposition analysis suggests the model-mean Walker circulation strengthens due to the land-sea contrast of NEI in the initial warming stage; the uncertainty among climate models, on the other hand, is determined by the NEI anomalies in the Pacific, which may be associated with the strength of ocean dynamical thermostat as suggested by previous studies. As time evolves, the energy source in the equatorial Eastern Pacific becomes dominant and the Walker circulation weakens.

Tropical Cooling in Recent Decades: Contrasting Northern and Southern Extratropical Influence

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Growing evidence highlights the critical role of extratropical influences in shaping tropical sea surface temperature patterns. One proposed explanation for coupled climate models' failure to reproduce the observed cooling trends over the Southeast and equatorial Pacific is their underestimation of teleconnections from the Southern Ocean—a bias partly linked to persistent double-ITCZ and low-cloud errors.

Here, we use a set of idealized simulations to assess the relative importance of Northern versus Southern Hemisphere influences on the tropics, showing that this influence depends on timescale. Using the fully coupled climate model CESM1, we apply radiative forcings separately in the extratropics of each hemisphere. In the initial years, heating the northern extratropics cools the equatorial Pacific more effectively than equivalent southern cooling. This occurs because anomalous northern warming can reach the equator only from the west, due to the northward-displaced climatological tropical rainband, thereby triggering equatorial Bjerknes feedback more efficiently. On multi-decadal timescales, all experiments produce equatorial responses matching the sign of the imposed forcing. Notably, southern extratropical perturbations generate stronger subtropical cell and equatorial SST responses, indicating that the Southern Hemisphere exerts significant long-term control over the tropical Pacific.

Building on these mechanistic findings, we compare observational records with CMIP6 historical simulations over recent decades. The results highlight a timescale-dependent shift from Northern to Southern Hemisphere dominance in shaping tropical Pacific SST trends, helping to reconcile model–observation discrepancies and offering a pathway toward improved historical attribution and future projections.

Interdecadal Variation of Spring Rainfall in Taiwan and Modulations of Global Warming and Pacific Decadal Oscillation

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ABSTRACT

Spring rainfall in Taiwan during February–April (FMA) shows a profound decreasing trend in the period 1980–2022. This decreasing trend is found to be jointly modulated by the trend components of global warming and interdecadal evolutions of the Pacific Decadal Oscillation (PDO) from its positive to negative phase over the past four decades. In contrast, interdecadal oscillation components of the PDO weakly impact interdecadal decreases in Taiwan's spring rainfall. Both global warming and interdecadal PDO variability cause moderate warming in the tropical western North Pacific and strong warming over the northern North Pacific. The former causes height fields over the tropical western Pacific to shift northward to result in an anomalous cyclone in association with the weakening of the subtropical high to the south of Taiwan. This anomalous cyclone is also affected by a Matsuno-Gill-type response to sea surface temperature warming and an anomalous convergent centre over the tropical western Pacific around 150° E. In the northern North Pacific, strong SST warming displaces height fields northward to make an anomalous anticyclone via the weakening of the Aleutian Low. Taiwan is meridionally embedded by the above anomalous cyclone and anticyclone. This circulation pair induces anomalous easterly moisture flux to pass over Taiwan, which then turns southward into the South China Sea. Moisture transport from the tropical region toward Taiwan is suppressed, resulting in an evident decrease in spring rainfall.

Suppression of marine heatwave activity by tropical cyclone-induced upper ocean cooling

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Abstract

Marine heatwaves (MHWs) have drawn substantial scientific attention due to their profound biological and economic impacts, especially in the context of climate change. This study highlights the crucial role of tropical cyclones (TCs) in disrupting MHWs by altering ocean temperatures. As demonstrated by Tropical Cyclone Bavi, intense sea surface temperature (SST) cooling, reaching up to 7°C, immediately terminated a mature MHW and suppressed subsequent MHW development for up to eight months. More generally, based on post-TC MHW cases (reoccurring within one month) during 2014-2023, we discovered that MHW disruption duration is proportional to the magnitude of TC-induced SST cooling, approximately 5-7 days per degree of cooling. At a broader scale, a 20-year (2004-2023) analysis revealed 99% significant inverse relationships between seasonal MHW and TC activity. These findings suggest that TCs can act as natural regulators, effectively mitigating heat stress from MHWs and potentially serving as a lifeline for marine ecosystems.

台灣地球系統模式發展計畫-氣候科學與模擬能量之精進與國際參與

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摘要

本計畫旨在提升台灣於長期氣候變遷模擬與極端氣候監測剖析能力，同時增進我國在國際氣候變遷科學研究之參與。本計劃提出的研究方向皆是目前國內外氣候變遷科研的關鍵議題: 1. 開發第二代台灣地球系統模式，2. 以台灣名義參與國際氣候變遷模擬研究計畫 CMIP7，3. 提供具東亞及本地氣候特徵之全球氣候模擬結果，4.年代預報研究量能建構，5. 氣候變遷趨勢湧現與極端天氣/氣候事件之監測與歸因 。預期具體貢獻如下:在學術發展方面，將提升台灣學研界氣候模式發展以及對氣候變遷的理解與推估能力；在技術創新方面，將開發新的氣候參數化模組與模式架構，建置台灣自行設計的新世代地球系統模式；在應用方面將拓展台灣氣候變遷研究觸角，深化與廣化國內氣候衝擊研究社群對氣候變遷趨勢的詮釋能力；在國際能見度方面，將參與國際氣候模擬與推估研究活動，貢獻本土產製氣候變遷資料，作為編撰 IPCC-AR7 的科學基礎，嶄露台灣氣候科研實力，提升國際影響力；在經濟效益方，將提供全球與東亞推估氣候資訊以進行台灣氣候變遷推估，定量評估全球暖化對台灣風光電、企業、農林漁牧等的衝擊；在社會(政策)影響面的間接效益為提供全球與東亞推估氣候資訊以進行台灣氣候變遷推估，用於定量評估全球暖化對水資源、自然災害、生態、健康與人民福祉等的衝擊，做為規劃與落實合宜的氣候變遷調適作為的依據。

The Relationship Between ENSO and the Annual Cycle of the East Asian and Western Pacific Monsoon Revealed by a Low-Level Circulation Weather-Type Calendar

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The monsoon systems over the Asian–western North Pacific (AWP) region influence the livelihoods of more than one-third of the world's population. Using a K-means cluster analysis, daily 850-hPa wind data over the AWP monsoon region for a 46-year period (1979–2024) are classified into nine low-level circulation weather types (WTs). Based on the occurrence frequencies of these WTs, two distinct progression patterns from boreal summer to winter are identified.

A strong East Asian summer monsoon (EASM) corresponds to more frequent occurrences of WT featuring low-level anticyclonic circulation over the western North Pacific, while a strong East Asian winter monsoon (EAWM) corresponds to more frequent occurrences of WTs characterized by low-level northerly winds over the South China Sea and the Philippine Sea. The variability of EASM and EAWM is synchronized during the developing phase of ENSO events. The strong-to-strong pattern, characterized by a strong East Asian summer monsoon (EASM) followed by a strong East Asian winter monsoon (EAWM), is associated with developing La Niña events. In contrast, the weak-to-weak pattern, in which a weak EASM is followed by a weak EAWM, is linked to developing El Niño events. No clear relationship is found between anomalous EASM conditions and the preceding EAWM.

Observational evidence from this study suggests that low-level wind anomalies over the South China Sea and the Philippine Sea during the peak summer period from mid-July to August serve as a precursor, indicating favorable conditions for subsequent air–sea coupling processes over the AWP monsoon region that are crucial for ENSO development. These findings have important implications for the evaluation and improvement of subseasonal-to-seasonal forecast models.

Can a Single Sounding Predict the Weather? An AI Downscaling Framework for Local-Circulation-Dominated Flow over Taiwan's Complex Topography

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Abstract

Typical AI downscaling models ingest large datasets, obscuring physical insight and straining computational resources. A key innovation of this study is the use of compact, physically grounded inputs. Instead of relying on high-dimensional meteorological fields, the model is driven by a single upstream sounding—a 32-element vector representing the vertical wind profile from the surface to the mid-level troposphere—along with time-of-day information. This design choice is rooted in insights from kilometer-scale ensemble simulations using the TaiwanVVM cloud-resolving model, which demonstrate that synoptic wind structure at multiple heights contains sufficient information to drive the diversity of local circulation evolutions over complex terrain. We show that AI models can be trained to reconstruct 2 km-resolution near-surface winds of Taiwan from a single upstream sounding. Jacobian-based sensitivity analysis quantifies the influence of each sounding element, showing that the model primarily depends on wind speed near 560 m, lower-level wind direction, and time of day when estimating winds at 100 m, confirming physically consistent learning. The lean input also enables a transformer-based architecture, which further reduces MSE and improves generalization, especially in rugged mountain valleys. These results demonstrate that compact, physically grounded inputs yield interpretable AI downscaling.

Spatiotemporal Characteristics and Long-Term Changes of Extreme Rainfall Events in Taiwan

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Abstract

Extreme rainfall events (EREs, ≥ 80 mm day^{-1}) in Taiwan were examined for their spatiotemporal characteristics from 1960 to 2022 using an event-based tracking method. Climatologically, Taiwan experiences approximately 11 EREs annually, with the highest frequency and magnitude occurring during the tropical cyclone (TC) season (July–October, 56%), followed by the early summer season (May–June, 33%). Spatially, EREs exhibit a west-to-east migration from spring to winter, corresponding to the monsoonal transition, with higher-magnitude events predominantly concentrated in the central and southern mountainous regions.

EREs demonstrate significant variability on both interannual and secular timescales. Their interannual frequency is strongly modulated by ENSO-related sea surface temperature anomalies. During the summer of El Niño developing years, an anomalous cyclonic circulation triggered by El Niño in the western North Pacific intensifies the monsoon flow and increases the frequency of landfalling TCs, leading to more frequent EREs. In contrast, the subsequent anticyclonic circulation anomaly in autumn suppresses ERE occurrence, with this reduction persisting into the summer of the following decaying years. The long-term variation of EREs exhibits a significant upward trend in both frequency and intensity. This enhancement is largely attributed to a deceleration in TC translation speeds at landfall and a higher proportion of westward-tracking storms making landfall in central Taiwan. Additionally, intensified TC-related ascent has partially contributed to this trend.

Keywords: extreme rainfall event; interannual variation; long-term trend; ENSO; monsoon flow; tropical cyclone

台灣極端降雨事件之時空分布與長期變化研究

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關鍵字: 極端降雨事件、年際變化、長期趨勢、聖嬰南方震盪、季風環流、熱帶氣旋

第二代台灣地球系統模式發展

李威良、許晃雄、梁信謙、許乾忠、蔡宜君、杜佳穎、陳奕穎、陳毅軒
中央研究院環境變遷研究中心

我們以 CESM3 為基礎進一步發展第二代台灣地球系統模式 (TaiESM2)，除了保留並精進 TaiESM1 原有的特徵，包括深對流的觸發機制、雲的宏觀物理、氣膠模組、以及三維地形對地表太陽輻射之影響之外，且採用了新的大氣動力架構、海洋模式、與雲微物理模組，以改進模擬精確度與增進計算效率，進一步提升對東亞及台灣地區具關鍵影響性之關鍵氣候因子的模擬與剖析能力。並擴展其在極端事件氣候特徵、氣候變異機制及未來暖化風險評估等方面之應用潛力。最終將使 TaiESM2 成為適用於國內氣候研究社群之地球系統模式平台，並積極參與 CMIP7 及其他國際氣候變遷模擬與推估計畫。

關鍵字：地球系統模式，CMIP7

Variability of East Asian summer monsoon in the last five centuries: model-data comparison

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The East Asian summer monsoon (EASM) is a distinctive component of the Asian climate system due to orographic forcing. Unlike Indian summer monsoon which occurs within the South Asian monsoon trough and presents a uniformity of rainfall distribution allowing for an All Indian Rainfall index to measure its variability, the definition of the EASM intensity has been much more complicated. One of the main reasons is the extensive domain of the EASM encompassing tropics, subtropics and midlatitudes and thus the complex space and time structures making it difficult to quantify the EASM variability. Despite the challenges, studying the evolution of EASM over hundreds or thousands of years is essential to build a comprehensive understanding on the monsoon behaviors and their associations with the general circulations. Many previous studies used geochemical proxy records from oceanic sedimentary or continental archives to build paleo-EASM indices. And most of the reconstruction was made by rainfall information retrieved from the records at certain sites, owing limited spatial coverage and restricted explanatory power for the overall EASM.

In this study, we present a novel approach to reconstruct a paleo-EASM index. First, the present Western North Pacific monsoon index approach (Wang et al. 2008, in Journal of the Climate) was used to calculate the wind fields (zonal and meridional winds at 850hPA) from 1950 to 2020 using ERA5 data and rainfall data from NOAA Precipitation Reconstruction over Land to construct the modern EASM index and to investigate the relationships between rainfall and circulation anomalies. Then, the EASM rainfall pattern was projected to the gridded REACHES (Reconstructing East Asian Climate Historical Encoded Series) (Wang et al., 20018 in Scientific Data) historical climate index data so that a reconstructed REACHES EASM index can be derived considering both temporal and spatial variability. The index was then compared with other indices for justification. Importantly, the REACHES EASM index reveals multidecadal and centennial variabilities during Little Ice Age, and a significant turn of domination of Indian monsoon to East Asian monsoon into the 18th century, corresponding to previously well-documented decline of extreme events and warmer temperature in the century.

Evaluating the Impact of Global Warming on Tropical Cyclone Genesis in the Western North Pacific: A Comparative Study of Tropical Cyclone Genesis Indices Using CMIP6 Models

2026 年大氣科學學門研究成果發表會

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摘　要

熱帶氣旋是對沿海地區影響最嚴重的自然災害之一，在全球暖化情境下，其未來生成變化仍高度不確定。CMIP6 模式雖能合理模擬大尺度氣候變異，但受限於約 100 公里的粗解析度，難以直接解析熱帶氣旋生成過程。本研究利用兩種熱帶氣旋生成潛勢指數 χGPI 與 χMqGPI，評估 22 個 CMIP6 模式對西北太平洋熱帶氣旋生成變化的投影。其中 χMqGPI 為 χGPI 的改良版本，以總水氣凝結量取代原有潛勢指標。

結果顯示，兩項指數在模擬平均生成空間分布及年際變化上，皆與觀測具有良好一致性。然而，由於空間變異度偏低，χGPI 的技巧分數多低於 0.2；相較之下，χMqGPI 在所有模式中的技巧分數可達 0.4–0.8。在未來暖化情境下，兩指數呈現相反趨勢：χGPI 顯示生成增加，而 χMqGPI 則顯示生成減少，且後者與先前可解析熱帶氣旋模擬研究結果一致。進一步分析指出，中層對流層的濕熵不足與總水氣凝結量減少，是導致生成下降的主要原因。隨著暖化加劇，西北太平洋的大尺度熱力環境愈發不利於熱帶氣旋生成，使兩指數差異更加明顯。本研究顯示，即使使用粗解析度模式，仍可透過適當指數提升熱帶氣旋生成投影的可靠性。

關鍵字：熱帶氣旋生成指數、氣候變遷

Phenomena and Processes: A New MJO Diagnostic Framework using Moisture Mode Theory as the Testbed

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Abstract

A unified diagnostic framework is proposed to bridge theoretical, phenomenological, and process-oriented approaches for investigating the Madden-Julian Oscillation (MJO). Building upon a physical theory (moisture mode theory in this study) and linear inverse modeling, the framework links the statistical behavior of observable indices to the underlying physical processes governing column moisture evolution. Applied to the MJO in ERA5 reanalysis and 15 CMIP6 models, the framework reveals that most models simulate an MJO that propagates too slowly eastward across the basins, and decays too rapidly, especially over the Maritime Continent. By projecting model biases in column-integrated water vapor-based MJO indices onto individual terms of the moisture budget, we diagnose the physical origins of their errors. Systematic biases are primarily tied to misrepresented meridional moisture advection and compensating errors between vertical moisture transport and convective drying, while their relative importance varies across basins. This process-resolved perspective explains the inter-model diversity in MJO simulations and provides a physically interpretable bridge between dynamical theory, model evaluation, and observational constraints—offering a transferable framework for diagnosing variability in other climate phenomena.

Keywords: Madden-Julian Oscillation, Phenomenological Diagnostic, Process-oriented Diagnostic, Moisture Mode, Linear Inverse Modeling

閃電研究的發展、結構與趨勢：一項全面性的文獻計量分析

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摘　　要

閃電在大氣動力、氣候系統與公共安全中扮演關鍵角色。然而，其研究版圖，包括主題焦點、研究趨勢、研究社群與合作網絡等面向，仍相對缺乏全面性的探討。本研究透過對 4,419 篇關於閃電的期刊論文進行書目計量分析，以填補此研究缺口。結果顯示，近數十年來的研究產出大幅增加，主因來自技術進步，以及對閃電在環境與社會面向重要性的日益重視。本研究辨識出七個主題群，涵蓋從閃電物理過程之基礎研究到更廣泛的跨領域議題。不同的專門研究社群聚焦於各自的子領域，其成果主要發表於地球物理、氣象與跨學科期刊。全球合作則以美國、中國與歐洲為主要領導者，其他地區的研究貢獻亦逐漸提升。此一全面性的概述，可為希望掌握並投入快速發展之閃電研究領域的科學家與政策制定者提供重要洞見。

關鍵字：大氣、社會科學、閃電、雷暴、大氣電學

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嘉義晴空大氣邊界層觀測實驗計畫
--全大氣觀測與模擬實驗--

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摘　要

本研究團隊於112年夏季開始對劇烈天氣系統的生成、發展與維持機制規劃一系列的分析與研究，初期規劃以了解對流降水發生前的晴空環境條件為重點。因此，經過廖宇慶與林沛練教授、陳韡鼐研究技師與劉千義副研究員、蔡世樵副教授、黃柔嫚副教授的詳細討論後選定嘉義為主要分析觀測場域。以多部掃描式都卜勒光達為主，搭配各式可在晴空條件下蒐集大範圍、高時空解析度大氣觀測資料的儀器，並使用WISSDOM與TPTRS來建構三維的風場及熱力場。其結果除了可用來進行對流降水前兆的研究，也可應用在模式、衛星驗證甚至航空安全的各類相關分析。

本研究團隊規劃嘉義晴空大氣邊界層觀測實驗(Clear-air Atmospheric Boundary Layer Experiment at Chia-Yi, CABLE-2024)，實驗執行日期為113年8月11日至9月3日，共24天。本次實驗整合了台灣大氣科學主要的學術、研究及作業單位的儀器，研究團隊包含了文化大學、中央大學、國防大學、嘉義大學、臺灣大學、中央研究院、中央氣象署與空軍氣象聯隊。研究團隊成功的蒐集到在弱綜觀環境條件下9起對流降水事件，且完整紀錄對流降雨發生前晴空大氣邊界層的觀測資料。其中微型探空施放340次，都卜勒光達資料約2100筆，垂直指向光達約20000筆，雷達剖風儀約6500筆，多頻道微波輻射儀11000多筆。參與實驗學生與助理約30名，學門PI約10名。觀測資料經過初步品質管控處理，並進行初步分析。後續觀測資料已正在進行更完整的分析並將提供學門內相關研究人員使用，期以將觀測實驗效益最大化。

114年7月17日到8月14日於嘉義進行全大氣觀測與模擬實驗(Full Atmospheric Observations and Simulations Experiment, CABLE-FAOSE-2025)。本次實驗規劃透過一系列對全大氣(包含大氣邊界層與太空大氣)的觀測與模擬實驗，各類參與實驗的儀器從10部增加到23部。除此之外，於實驗計劃中進行模擬、衛星與資料反演研究工作的老師分別有成功陳佳宏老師(全大氣耦合模式)、中央院林傳堯老師(大氣模式)與劉千義老師(衛星、邊界層水氣與穩定度及其發展)、楊明仁老師(大氣模式)、張凱威老師(衛星)、葉大綱老師(水氣反演：GNSS)、廖宇慶老師(三維大氣動力與熱力場反演：WISSDOM與TPTRS)。此為學門內首次跨次領域的合作，結合大氣與太空的觀測與模擬預期將可對太陽活動、重力波、閃電與對流降水系統的生成、發展、增強之關聯與交互作用進行深入探討。

關鍵字：大氣邊界層、晴空、對流、全大氣

西北太平洋長時間滯留熱帶氣旋特性：年代際變化與威脅轉移

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摘　要

熱帶氣旋（TC）移動速度是衡量其威脅的關鍵因素，而長時間滯留的熱帶氣旋（LSTC，定義為移動速度最慢的 10%）往往會造成長時間強風暴雨並提高侵襲地區的致災風險。因此，本研究旨在填補 LSTC 歷史變化、地理分佈與時間特徵研究的空白，分析 1970 至 2023 年西北太平洋地區的 LSTC 數據，並採用 IBTrACS、EM-DAT 及 ERA5 等資料庫進行定性定量與氣候變遷相關分析，其中 LSTC 的定義標準為 48 小時平均速度低於 7.0 kph（V48H）或 72 小時平均速度低於 8.5 kph（V72H）。在探討影響慢速移動的因素時，本研究指出微弱導引氣流、阻塞高壓及全球暖化趨勢皆可能導致 TC 滯留；而根據過去 55 年的歷史案例與季節性分析，逾半數的 LSTC 發生於秋季。以 2024 年侵襲台灣的康森颱風為例，其滯留（排名第 32 位）便與鞍型場天氣系統造成的導引氣流不明確有關。此外，研究亦發現近期（2000–2023 年）LSTC 的總體發生頻率雖顯著下降，但滯留緯度呈現從早期的北緯 20 度以南移向北側的明顯轉變；季節上則表現為夏季頻率下降、秋季上升，而從氣候分佈來看，TC 慢速區主要位於台灣、菲律賓與華南地區，且台灣南部與東部海域的移速亦有減緩趨勢，顯示 LSTC 威脅可能增加。綜上所述，本研究全面概述西北太平洋 LSTC 的時空特徵與年代際變化，指出雖然近期 LSTC 事件總頻率下降，但其滯留區域正逐漸向台灣東部與南部海域集中；因此，未來工作將著重於環境系統診斷與數值模式預測，並拓展至全球 TC 特性的比較研究，以提供決策者更具前瞻性的洞見。

關鍵字：長時間滯留熱帶氣旋（LSTC）、年代際變化、氣候變遷、導引氣流與鞍型場

The application of observed and retrieved meteorological variables from radar/lidar data to improve short-term QPF on rainy days and to study PBL under clear-air conditions

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ABSTRACT

This presentation contains two parts. In the first part, by using Doppler weather radar observations, a multiple-Doppler radar wind synthesis technique (WISSDOM), and a thermodynamic retrieval method (TPTRS), one can retrieve the 3-D wind, pressure, temperature, rainwater mixing ratio, and moisture over complex terrain. The retrieved meteorological variables are utilized to re-initialize a high-resolution numerical model. It is found that through this procedure, the quantitative precipitation forecast (QPF) skill over mountainous areas can be significantly improved up to six hours. The moisture field plays a crucial role in producing the correct rainfall forecast. A combination of various rainfall scenarios forecasted by different microphysical schemes is suggested in order to provide a stable and reliable rainfall forecast. In the proposed approach, radar data from only two radar volume scans are sufficient to shorten the model spin-up time, and efficiently improve the rainfall forecasts.

In the second part of the presentation, by using scanning Doppler wind lidar observations, WISSDOM and TPTRS are applied to provide high-resolution 3-D wind and thermodynamic fields in a clear-air PBL. In one field experiment held in a rural area, the major features of a PBL, including land-sea breeze, nocturnal low-level jet, the diurnal cycle in the temperature field, and a semi-diurnal cycle in the pressure field, can be accurately captured. In the second field experiment held in an airport, the regions of low-level wind shear can be identified within a three-dimensional space. Such synthesis methods can be executed in a round-the-clock manner with minimal human effort. The high-quality data sets could be applied for various purposes, such as the study of boundary layer development, initiation of afternoon thunderstorms, air pollutant dispersion, numerical model verification, and real-time monitoring of aviation safety in airports.

Analysis and forecast of typhoon Chanthu (2021) using an ensemble radar data assimilation system: Investigation on Factors leading to Rapid Intensification

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Abstract

This study assimilates the ground-based radar observation for analysis and forecast of typhoon Chanthu (2021) using the WRF-local ensemble transform Kalman filter radar assimilation system (WLRAS). To explore the optimal configuration, the radar data assimilation (DA) experiments are conducted with various setups including different model horizontal resolutions and DA frequencies. The impact of these setups on the analysis and prediction of Chanthu is examined.

According to an observational study by Fang et al. (2024), Chanthu experienced rapid intensification (RI) during its northward movement off the east coast of Taiwan. They identified several factors influencing Chanthu's RI, including TC-terrain interaction and vertical wind shear. The RI feature of Chanthu is successfully captured by the forecast initialized from the WLRAS analysis, demonstrating the high capability of the RDA system. However, the RI behaviors vary with different experiment configurations. Therefore, these DA experiments are analyzed and compared with radar observations to jointly validate the factors contributing to Chanthu's RI.

Key words: radar data assimilation, tropical cyclone prediction, rapid-intensification

Characterizing Rapid Intensification in Tropical Cyclones: A Multi-method Approach

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Abstract

Rapid intensification (RI) of tropical cyclones (TCs) presents complex characteristics, posing significant challenges for accurate forecasting. The current RI definition is based on approximately the 95th percentile of overwater intensity changes in the National Hurricane Center (NHC) best-track database for the Atlantic and eastern North Pacific basins during 1995–2012, evaluated at 12-, 24-, 36-, and 48-hour lead times. This study investigates the deterministic differences in TC structure between RI and non-RI TCs, using varying RI definitions, with data from the International Best Track Archive for Climate Stewardship (IBTrACS) in the western North Pacific from 1959 to 2022. Composite analysis was conducted using azimuthal averages of equivalent potential temperature, potential vorticity, and vertical velocity from ECMWF Reanalysis v5 (ERA5) data to identify optimal RI thresholds, focusing on inner-core and upper-level structures that drive RI through mechanisms such as convective bursts, warm core formation, and outflow interactions.

Under the 95th percentile definition, the RI threshold has risen markedly in recent decades to 42.5 kt/24h, versus 35 kt/24h reported by Lee et al. (2016), signaling intensified TC strength during RI. To evaluate the RI index, three machine learning models, Random Forest (RF), Support Vector Regression (SVR), and Artificial Neural Networks (ANN), assessed the RI index on refined 2013–2022 data, based on a continuous intensification rate (IR) metric scaled to 0–10, where the RI index is computed as the mean accessed value from each model for combinations of wind speed thresholds and time intervals. These models yielded consistent heatmaps with peaks in mid-to-high thresholds (65–75 kt over 24–36 h), indicating robust performance and reduced algorithm-specific bias.

Extending to forecasting (1981–2022, RI onset focus), RF and SVR showed strong predictive skill linking higher indices to greater probabilities of subsequent TC intensity increases, though ANN exhibited biases, likely due to its greater sensitivity to reduced training data volume. These approaches offer a robust, continuous RI metric to advance forecasting by merging statistical and physical insights.

嘉南平原對流肇始熱動力實驗:利用氣象雷達反演近地表二維水氣場資訊

2026 年大氣科學學門研究成果發表會

鍾高陞[1]　廖宇慶[1]　林沛練[1]　張保亮[2]　楊舒芝[1]　張偉裕[1]　蔡嘉倫[3]
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摘　　要

本研究將首次以台南七股雷達、TEAMR移動式雷達觀測所觀測之折射指數，藉由反演技術獲得晴空與降雨期間近地表高時空解析度之二維水氣場；搭配數部多頻道微波輻射儀，並整合掃瞄式都卜勒雷達、光達，建構嘉南地區都市尺度(urban scale)之三維動力、熱力結構，其目的在了解與分析海陸風、冷池與地形效應之下沉風等對於對流肇始(convection initiation)進而產生劇烈降水之天氣系統做進一步研究；觀測時間預計3-5 周（115年6月下旬－7月下旬），除雷達、光達、微波輻射儀外，補充以剖風儀、微型探空、地面站與自行開發之閃電儀器、地基GNSS反演水氣、衛星資訊等多源觀測，進行資料分析、資料同化，並與國內外研究機構合作，以增進台灣地區都市尺度(urban scale)天氣預報之能力與飛行安全相關之應用。

關鍵字：雷達折射指數、二維水氣、掃描式光達、反演技術、對流肇始

Statistical Analysis of the Lagrangian Evolution of the Convective Precipitation Dual-Polarimetric Radar Variables over Northern Taiwan

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Abstract

Short-duration, intense precipitation from afternoon thunderstorms in summer often causes disasters. The early warning of these rapidly developing convective systems remains challenging. This study uses dual-polarimetric measurements (DPMs) to investigate the microphysical characteristics of convective cells at different stages of development (developing, maturing, and dissipating). The afternoon thunderstorm events from the Taiwan-Area Heavy Rain Observation and Prediction Experiment (TAHOPE) were employed and analyzed using the Storm Motion Analysis by Radar Tracking (SMART). Intensive convective systems were identified with a reflectivity threshold of 40 dBZ and a minimum area of 10 km^2. The temporal evolution of the convection was investigated their DPM fraction (Z_{DR} > 1.5 dB, K_{DP} > 0.5 $^0km^{-1}$). At the early developmental stage, the Z_{DR}-fraction exhibits high values at mid-levels, then gradually decreases as precipitation transitions to the mature stage and dissipates. The K_{DP}-fraction remains relatively low in the initial phase, and subsequently increases at mid-to-upper levels before the mature stage. During the mature stage, the K_{DP}-fraction exhibits high values at lower to mid-levels and then significantly weakens during dissipation. The evolution of Z_{DR}- and K_{DP}-fractions indicates the microphysical process of large raindrops being carried aloft by updrafts, with high liquid water content at mid-level; subsequently, the raindrops descend to the surface during the dissipating stage. The statistical analysis indicates that significant vertically Integrated liquid (VIL) maxima correspond to more pronounced changes in Z_{DR}- and K_{DP}-fractions. In particular, the Z_{DR}-fraction shows significantly higher values and fractions at the onset of the developing stage, suggesting that this feature may serve as an early warning indicator of intensive convection driven by thermal forcing.

有效整合大渦模擬與觀測以研究複雜島嶼地形之午後對流組織過程
Effective Integration of Large Eddy Simulations and Observations to Study the Organization of Afternoon Thunderstorms Over Complex Island Topography

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Abstract

This four-year project develops an integrated scientific strategy as a key pathway to advance the physical understanding of afternoon convection over complex island topography and, in turn, to improve its prediction and climate-change projections. Instead of treating observations, high-resolution modeling, and data-driven approaches as separate efforts, we combine large-eddy simulations (LES) with realistic and idealized terrain, multi-sensor observations and field campaigns, and physics-explanable machine-learning (ML) models into a single, synergistic framework. Most previous studies isolate either local circulations under weak synoptic forcing or strongly forced events, and there is a lack of unified quantitative framework linking boundary-layer energetics, low-level vorticity dynamics, background moisture–flow regimes, and anthropogenic forcing. Using the Chiayi–Tainan Plain to Alishan (CTPA) region as a natural laboratory, this project addresses these gaps under two working hypotheses: WH1 — Mountain convection is energetically controlled, with the first diurnal rainfall peak set by local morning CAPE and the second by upslope moist static energy (MSE) transport; and WH2 — Plain convection is governed by the low-level vorticity balance among sea-breeze vertical shear, cold pools, and terrain-modified flows. Methodologically, the project couples four main components: (1) Multi-year analyses of ERA5 reanalysis, soundings, surface rain gauges, and satellite data classify upstream integrated vapor transport regimes and relate them to the spatial and diurnal organization of rainfall over Taiwan. These statistics define an observationally constrained parameter space that guides LES experiment design. (2) TaiwanVVM LES with realistic Taiwan topography are performed for representative historical cases, sensitivity experiments, and anthropogenic scenarios (pseudo–global warming, aerosol reduction, and coastal land-use change). Dedicated diagnostic tools—a tracer-based MSE transport scheme (for WH1) and a cold-pool tracking and vorticity–circulation diagnostic (for WH2)—quantify how energy and momentum pathways respond to environmental and forcing changes. (3) Targeted field campaigns along the CTPA transect deploy dense surface WXT networks, UAV-borne and balloon-borne Storm Tracker sondes, and ground-based remote sensing to capture the evolution of boundary-layer energetics, sea-breeze penetration, and cold-pool propagation, after the establishment of standardized procedures for ground check and quality control among sensors across various platforms. Case selection, deployment strategy, and Intensive Observation Day decisions are iteratively guided by TaiwanVVM output and a two-stage ML model trained on the LES ensembles. (4) Idealized island LES systematically vary background winds, stability, moisture, and terrain geometry to derive scaling relationships between boundary-layer energetics, circulation scales, and convective organization, and to generalize Taiwan's results to other tropical and monsoon islands. Expected outcomes of this project include a process-level, transferable framework for organized afternoon convection over complex island topography, physically consistent diagnostics and ML-ready predicting tools, and improved scientific assessments for the impacts of anthropogenic activity on organized afternoon convection in future climates.

Keywords: Diurnal Convection, Field Observations, Large-Eddy Simulation, Boundary-Layer Energetics,

Complex Topography

Bright Band Statistics and Correction of Vertical Reflectivity Profiles Using Polarimetric Radar

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Abstract

In the context of monitoring the snow-to-rain transition within the melting layer (ML) of a typical stratiform cloud, the reflectivity field (Z) often exhibits artificial enhancements known as the bright-band (BB). Beyond the BB, Z often decreases rapidly with range due to beam-broadening effects and the weak backscattering from snowflakes and ice crystals. In contrast, the presence of mixed-phase hydrometeors within the ML leads to a marked reduction in the cross-correlation coefficient (ρ_{HV}). The radial profile of ρ_{HV} is found to correlate well with that of Z within the ML, and provides more reliable BB discrimination than Z alone. Consequently, a polarimetric vertical profile of reflectivity (PVPR) correction method is proposed to reconstruct intrinsic Z profiles from observed ρ_{HV} signatures, thereby mitigating biases and improving the accuracy of quantitative precipitation estimation (QPE). Initial applications of this approach to German C-band radar data have yielded encouraging results. However, further refinement is required to accommodate Taiwan's distinct climatological conditions, particularly during wintertime, when shallow convection is frequently embedded within stratiform precipitation and complicates BB detection and correction. To address these challenges, BB characteristics derived from the RCWF radar in northern Taiwan are statistically analyzed and parameterized. The resulting models are used to simulate observed Z profiles and to adapt the PVPR correction framework for regional application. These efforts aim to enhance BB correction performance and improve radar-based QPE in complex precipitation regimes.

Keyword: bright band, vertical profile of reflectivity, polarimetric radar, quantitative precipitation estimation (QPE)

The Role of Moist Absolutely Unstable Layer (MAUL) in Orographic Precipitation: Result from TAHOPE IOP 2

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Abstract

Terrain plays a significant role in modulating the diurnal cycle of moist convection and rainfall. During the warm season, mountainous regions exhibit pronounced day-night variations in convective activity and precipitation due to orographic lifting. Beyond the mechanical aspects of orographic lifting, these motions can destabilize the atmosphere by lifting moist and conditionally unstable air to saturation (Kirshbaum et al. 2018). This process can result in the formation of moist absolutely unstable layers (MAULs; Bryan & Fritsch 2000), where the lapse rate of a saturated layer exceeds the moist adiabatic lapse rate. Bryan and Fritsch (2000) and Mechem et al. (2002) first highlighted MAULs within MCSs over the midlatitude United States and the tropical western Pacific, respectively. In both studies, MAULs extended horizontally for hundreds of kilometers along the axis of MCSs and vertically up to ~100 mb, primarily formed by mesoscale lifting induced by cold pools. Although there is increasing recognition of MAUL as a critical factor in extreme precipitation, no prior studies have examined its occurrence in Taiwan's heavy rainfall events. This knowledge gap is particularly surprising given Taiwan's humid subtropical environment, which is often conducive to deep convection. This study seeks to address this gap by investigating whether complex terrain can induce MAUL formation and subsequently enhance extreme orographic rainfall during the TAHOPE/PRECIP IOP 2. The main objective is to identify the physical processes through which terrain contributes to MAUL development. In addition, the relationship between MAUL and heavy rainfall will be explored.

Using high-resolution WRF simulations with the control (CNTL) run with full terrain and the sensitivity tun without Taiwan terrain (NTER) in this study, we will show that Taiwan topography plays a critical role in enhancing moisture flux convergence

(MFC) and supporting the formation of deep in TAHOPE IOP 2, persistent MAULs that precede intense precipitation. The key physical processes are summarized in Figure 1 below.

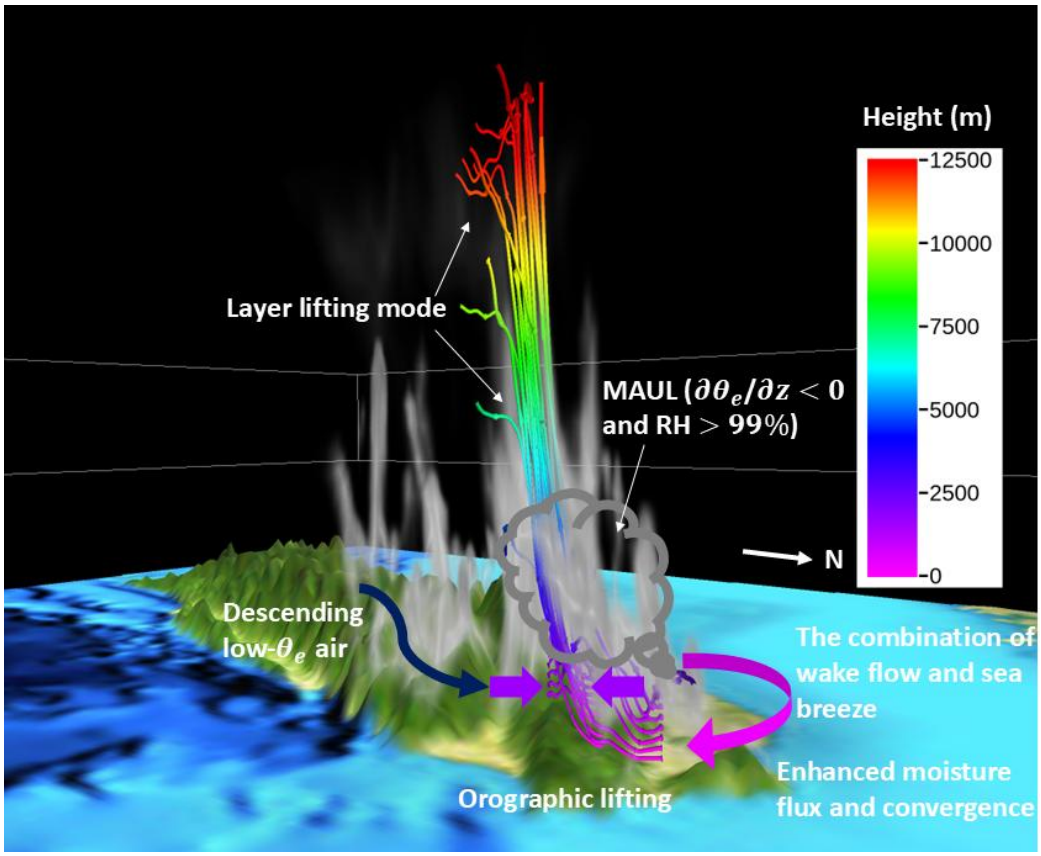

Figure 1. Conceptual 3D visualization of the physical processes leading to MAUL formation and extreme orographic rainfall in CNTL. Arrows illustrate the interaction of wake flow and sea breeze enhancing moisture flux convergence, with orographic lifting forcing layer lifting of inflow. The layer lifting mode supports the development of MAULs (defined by $d\theta_e/dz < 0$ and RH > 99%) and intense convection. Descending low-θ_e air intrudes from the southeast, possibly maintaining the low-level convergence. Trajectories are colored by altitude to illustrate the vertical extent of updrafts.

When the southwesterly monsoon is blocked by Taiwan's topography, enhanced MFC develops in the wake region. The interaction among wake flow, sea breeze, and upslope flow transports abundant moisture from the ocean toward the mountain slope, a process shown to be critical for mountain flooding. The sustained upslope lifting in CNTL leads to the development of deep MAULs extending from near the surface up to ~5 km altitude. Trajectory analysis reveals that these MAULs are associated with coherent layer lifting, in contrast to the shallower MAULs in NTER, where ascent is

parcel-based and limited. These terrain-induced MAULs create a favorable thermodynamic environment for convection development. Moreover, our results suggest a consistent relationship between MAUL volume and subsequent hourly rainfall. When MAUL volume exceeds 2000 km^3 (3000 km^3), the following hour's peak rainfall often surpasses 40 mm (80 mm). While the timing of MAUL and rainfall peaks may differ, this threshold-like relationship highlights the diagnostic potential of MAUL volume as a precursor to extreme precipitation events. Thus, this suggests that terrain-enhanced moistening plays a critical role in preconditioning the environment for MAUL development and subsequent extreme rainfall. More details will be given at the presentation of the conference.

大氣科學研究與應用資料庫

中文字體請採用新細明體
(若使用A4紙張左、右及上方需各空2.54公分)

用字大小以微軟中文視窗WORD為例

題目 : 16 點加粗
作者及單位 : 10 點加粗
段名 : 14 點加粗
內容 : 10 點

劉清煌[1]　　李奕德[2]
中國文化大大學[1]　國家太空中心[2]

摘　要

大氣科學研究與應用資料庫為國科會大氣學門核心設施之一，研討會時將說明大氣科學研究與應用資料庫之近況與未來之規劃，本資料庫於2026/1/16舉辦使用者線上說明會，近百人報名參加，將於研討會時分享說明會之成果。

關鍵字：大氣科學研究與應用資料庫、資料庫、核心設施

梅雨季豪雨個案之雲解析差時系集模擬與預報能力評估

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摘要

本研究採用 CReSS（Cloud-Resolving Storm Simulator）模式之差時系集模擬／預報系統進行實驗設計。模擬解析度分為 2 km 與 1 km，其中 2 km 解析度模擬除控制組外，另設計三組實驗組，分別於 t=12、t=14 與 t=16 小時更新模式邊界條件，以評估差時邊界更新對降雨預報之影響。1 km 解析度模擬則以 2 km 模擬結果作為初始與邊界條件，進一步進行高解析度動力降尺度模擬。研究個案為 2017 年 6 月 2 日臺灣北海岸地區受梅雨鋒面伴隨準滯留性雨帶影響所引發之致災型極端降雨事件。觀測資料顯示，該事件最大日累積雨量達 645 mm。6 月 2 日凌晨，梅雨鋒面逐漸接近臺灣北部外海，並於北部地區滯留約 10 小時，導致基隆及北海岸地區出現超大豪雨。

本研究透過上述預報實驗設計，期望能取得更多系集成員及更具多樣性的降雨情境模擬結果，以提升對極端降雨事件之提前預警能力，並作為防災決策之參考依據。結果顯示，2 km 解析度模擬可於事件發生前約 3–4 天成功再現全臺累積雨量之主要空間分布，雖整體雨量仍有低估現象，但在預報技術評估方面，其 TS 得分（Threat Score, TS）於中等門檻值（130 mm）可達約 0.4；相似性技術得分（Similarity Skill Score, SSS）則約為 0.7，其中北部地區之 SSS 更可達 0.8 左右。在 1 km 解析度模擬中，整體 SSS 表現約為 0.6，惟模擬結果顯示梅雨鋒面南移時間較實際觀測略早；若調整至與觀測降雨分布較為一致之情境下，SSS 可提升至約 0.7，顯示高解析度模擬在適當時序條件下，具備進一步提升降雨空間結構預報能力之潛力。

未來將選取其他極端降雨事件（包含颱風個案），以評估此差時系集預報實驗設計之適用性與穩定度，期能進一步貢獻於定量降水預報（QPF）能力之改進，並提升極端天氣防災預警之實務應用價值。

臺灣南部邊界層結構與午後對流系統演變之相關性研究

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摘要

台灣南部地區面海背山，邊界層內伴隨海陸風與山谷風等局部環流，邊界層結構相當複雜，對午後雷暴發展及降雨預報具有相當大挑戰。本研究團隊過去已發表數篇期刊探討台灣南部邊界層特性，結果顯示大尺度環流與中央山脈地形影響下，台灣南部地區海陸風、山谷風、背風渦旋與邊界層交互作用相當複雜，並且於冬季東北風時可產生密度流，快速傳送台灣中部汙染源到南部。然而對於夏季午後對流系統的移動與演變而言，對流系統產生的冷池效應伴隨之密度流對雷暴的移行須更深入研究。由於密度流屬於穩定大氣之波動現象，台灣冬季常伴隨近地層逆溫現象形成穩定大氣，配合地形局升氣流產生密度流現象，但夏季午後地面加熱顯著，並不易產生穩定大氣現象，當對流發展後，伴隨的冷池效應雖然有機會與上層空氣產生穩定大氣，但對流的移行與發展，與環境垂直風切、對流內部環流特徵以及邊界層均有密切關係，須運用高解析度資料進一步分析雷暴的內部結構。2022 Taiwan-Area Heavy rain Observation and Prediction Experiment (TAHOPE)與 2024 Kaohsiung-Pingtung Experiment (KPex)均收集高解析觀測資料，本研究透過 TAHOPE 等密集觀測資料，配合數值模式 Weather Research and Forecasting (WRF) 分析台灣南部邊界層局部環流特性以及午後雷暴內部結構，預期對流的移行與發展將有更深了解，並提升對雷暴伴隨的定量降水預報能力。

關鍵字：午後對流系統、邊界層、TAHOPE、WRF

掩星資料對東北與西北太平洋大氣長河預報的改進與挑戰

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摘　　要

本研究近三年透過數值實驗與統計分析，探討掩星資料對東北與西北太平洋大氣長河的預報改進與挑戰，分析他們的強度、登陸與降水特徵對掩星資料的敏感程度，並討論其中的物理機制與不敏感的可能原因。本研究先針對東北太平洋典型大氣長河進行實驗，此部分主要探討掩星資料對大氣長河結構強度與登陸過程的改進程度。結果顯示，掩星資料可顯著提升大氣長河發生率與強度的預報表現，但對於其移動與登陸預報的影響並不顯著。此特徵導致掩星資料對大氣長河的降水預報改進有限，僅在海面上有正面顯著的貢獻。由於東北太平洋大氣長河的降水量遠低於西北太平洋，此特徵可能減少降水預報對掩星資料的敏感性。為了進一步探討掩星資料對大氣長河致災性強降水預報的可能影響，本研究亦針對西北太平洋非典型大氣長河進行實驗。結果顯示，掩星資料對低壓中心的位置影響不大，但可大幅改進大尺度環境水氣與風場，提升大氣長河水氣通量的預報強度與位置，進而顯著改善致災性強降水低估的情形。此改進特徵在預報前期影響顯著，但在預報後期並無顯著貢獻。整體而言，掩星資料可顯著改進模式預報的低層風場與中層水氣特徵，進而提升兩海域大氣長河的預報表現，其中又以低層風場的改進較為重要。本研究未來將進一步探討大氣長河預報對掩星資料改進的敏感區域與高度，並分析其中的物理機制。

關鍵字：大氣長河、掩星資料、區域模式、水氣通量、降水預報

臺灣-菲律賓 VOTE-氣象合作成果說明

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摘要

「臺菲國合 VOTE 計畫：建立無隙縫颱風海洋氣象及短期氣候預報能力(2/3)」為期 3 年(2024-2026)，參與人員涵蓋臺灣及菲律賓兩國氣象單位及大學之大氣科學研究人員，延續前二期計畫成果，強化臺菲跨國之氣象合作。藉由加強大氣、氣候、海象、雷達資料分析及改進颱風、氣候、海浪數值預報等方式，提升兩國常遭遇之颱風、豪雨等劇烈天氣系統的路徑、降雨區域及降雨量之預報能力。今年進行與達成之項目包括完成 1.持續提供 PISTON、WAIP 預報技術資源及教育訓練，以深化菲方的颱風預報技術；2.完成在菲律賓海域選定一個假想航線進行藍色公路預報雛形的建置，向 PAGASA 人員展示預報圖繪製的流程和作法；3.完成進行在地化處理與優化雙偏極化雷達定量降雨估計(QPE)，採用複合式並經在地化調整的降雨估計方法，可反映臺灣特有雨滴粒徑特性並提升雷達 QPE 準確度；4.應用 Analysis Blending Scheme 與地基式 GNSS 系統資料同化之技術發展，將經驗分享並提供 PAGASA-WRF 相關教育訓練；5.結合 CWA 與 PAGASA 雷達資料在颱風早期監測預警的優勢，以及進一步了解在複雜地形影響下，颱風降雨結構及強度變化特徵的潛力；6.利用各國氣象預報作業中心短期氣候模式的事後預報資料，評估其在東亞不同季節與不同領先時間的預報表現。依據各模式對各類極端事件與季風指標的相對能力進行比較，篩選對臺灣與東亞表現較佳的模式，以提升區域短期氣候預報能力；7.分析菲律賓降雨雲微物理特性並建立土壤溼度再分析產品。本年度研究各項研究工作皆按計畫順利執行，詳細研究成果將於研討會中完整報告。

關鍵詞：臺菲國合計畫、颱風預報、波浪預報、雷達回波、氣候模式、雨滴譜儀資料

Improving the performance of the multiscale WRF-radar ensemble data assimilation system with the multiscale dependent inflation

Shu-Chih Yang, Jhing-Yueh Liu, Jhe-Hui Lin and Kuan-Jen Lin

A multiscale radar ensemble assimilation framework has been established by applying the successive covariance localization (SCL) to the WRF-radar LETKF assimilation system (WLRAS). WLRAS-SCL has proven beneficial in representing convection development associated with the meiyu fronts and improving short-term rainfall prediction involving multiscale interactions. However, the issue of under-dispersive small-scale spread can limit the effectiveness of SCL in assimilating dense observations when radar assimilation is conducted with a long cycling period. To overcome such a deficiency, we propose a scale-dependent inflation (SDI) to enlarge the ensemble spread at different scales. The SDI method is developed based on the discrete wavelet transform.
We conducted radar assimilation experiments for the heavy rainfall events on 19 August 2019 with active convection spanning several hours in northern Taiwan under the influence of a front north of Taiwan and a tropical depression southeast of Taiwan. The environmental flow and multiscale features affect the initialization and development of the convection in the Taipei Basin. While the WLRAS-SCL successfully improves the intensity of heavy rainfall, the use of SDI provides small-scale wind correction and thus further enhances the orientation and location of the heavy rain in the 3-hour forecast. The sensitivity experiments confirm that perturbing the small-scale dynamical variables improves the rainfall forecast skill more effectively than the small-scale thermodynamic variables. The SDI analysis will be used to construct the mechanisms for initializing and developing the long-hour convection development on 19 August 2019.

2022 年尼莎颱風外圍環流與東北季風共伴效應之數值模擬初步研究

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摘　要

2022年尼莎颱風暴風圈未直接影響臺灣，但卻衍生全國統計共268件災情及經濟損失，由於降雨集中在北北基宜，因此半數以上淹水發生在雙北地區，期間最大累積雨量在宜蘭縣，宜蘭縣內台7線及台7甲線省道受損嚴重。據國家災害防救科技中心全球災害事件簿統計，尼莎颱風造成全臺農業產物及民間設施損失約3,239萬元，造成7337戶停電。創下颱風未登陸，卻造成大量災損的驚人記錄。尼莎颱風於臺灣南部之巴士海峽通過時，其颱風中心遠離臺灣，但外圍環與東北季風產生共伴效應，造成明顯之線狀對流系統。這些線狀對流系統自海面生成後，不斷移入臺灣北部，受到北臺灣複雜地形影響後，產生局部強降水。透過海氣耦合模式WRF-ROMS (Weather Research and Forecasting Model-Regional Ocean Modeling System, WRF-ROMS)進行模擬後發現，尼莎颱風在通過巴士海峽附近，海洋暖水能量，導致其快速增強，而這也是海面上線狀對流系統持續增強的重要能量來源之一。模擬結果顯示，海水溫度由南向北遞減，但在颱風通過及線狀對流系統不斷生成後，海溫則是有降低的現象。臺灣海峽受到東北季風及兩岸地形效應影響，海溫下降最快。臺灣北部近海，在提供線狀對流回波發展後，海溫逐漸下降，臺灣東南部海面之海溫，因提供部分颱風外圍環流之對流系統發展，亦有海溫下降的情形，但海溫下降的速度較慢。由於海洋表面暖水層厚度，受太陽輻射影響，存在越北越薄、越南越厚的情形，因此本次尼莎颱風由巴士海峽通過時，才有機會透過海水大量且快速的補充能量，使其強度增強，並結合東北季風，間接強化了外圍環流之線狀對流系統的強度。

關鍵字：尼莎颱風、強降水、線狀對流系統、共伴效應、海溫變化

嘉義地區夏季午後對流前兆之聯合觀測研究

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摘　要

臺灣夏季午後常受熱對流影響，易產生短延時強降雨、雷暴與強陣風等劇烈天氣，對短時天氣預報與防災作業造成顯著挑戰。嘉義地區位於中南部平原與丘陵交界，午後對流活動頻繁且具高度局地性與突發性，其生成前之大氣邊界層結構與可量化前兆值得深入探討。本研究利用2024年8月11日至9月3日「嘉義晴空大氣邊界層觀測實驗（CABLE）」多源觀測資料，整合掃描式都卜勒光達、雷達剖風儀、微型探空、地面氣象站及ERA5再分析資料，分析嘉義地區夏季午後對流之前兆特徵。

研究聚焦於對流生成前1~3小時之大氣環境演變，初期以2024年8月13日與14日兩個具代表性的午後對流事件進行分析，建立相當位溫垂直梯度、低層垂直風切、低層輻合／散度場及水氣通量輻合等四項前兆指標。結果顯示，對流事件前常伴隨潛在不穩定層加深、低層風切與輻合增強，以及水氣持續匯聚，且各指標於時序上呈現一致性變化。

此外，本研究結合資料品質控管流程，針對光達信噪比設定門檻值，以確保風場反演與動力指標之可靠性，並逐步建立前兆指標之量化範圍。為提升研究結果之代表性與應用性，後續擴充分析樣本，納入未具午後對流發展之事件日進行對照驗證。結果顯示，非午後對流事件日中各前兆指標多未同時達到臨界強度，顯示本研究建立之指標具辨識對流潛勢之能力。綜合結果顯示，本研究所提出之前兆指標可於晴空條件下提前1~3小時提供午後對流潛勢訊號，具短時臨近監測與預警應用潛力。

關鍵字：午後對流前兆、CABLE、都卜勒光達、雷達剖風儀、微型探空、ERA5

颱風環境下之種雲播雲地形降水模式之發展：以蘇拉颱風(2012)為例

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摘要

本研究發展並評估一套專為颱風環境設計的種雲播雲地形降水模式，旨在釐清地形降水增強的主導機制及其對降水空間分佈的影響。研究將以 2012 年蘇拉颱風影響臺灣北部大屯山區期間為個案，進行深入分析。本研究整合多項觀測資料，包括五分山雷達(Wu-Fen-San, WFS)之雷達觀測、中央氣象署(CWA)雨量站資料，以及大屯山密集雨量觀測網(Da-Tun Rain Gauge Network, DTRGN)之高解析度雨量資料，用以分析降水之時空演變特徵與強度變化。此外，利用 ERA5 再分析資料於地形上游的資料點代表個案大氣環境條件，作為種雲播雲地形降水模式之輸入資料，以模擬地形降水分佈。

研究結果顯示，在 8 月 1 日 11:00 UTC 至 8 月 2 日 00:00 UTC 期間，大屯山區的降水可明確區分為兩個階段：層狀降水(stratiform precipitation, SP)階段與對流降水(convective precipitation, CP)階段。模式模擬結果與觀測資料之比對顯示，種雲播雲機制在 SP 階段中對地形降水加強具有關鍵影響，能有效再現迎風坡降水顯著增強的特徵。然而，在 CP 階段，模式明顯低估降水量，此一偏差可能源於模式在描述深對流降水過程上的侷限性，包括強對流上升氣流、冰相微物理過程，以及降水生成與演變的快速時間尺度變化。此外，對流系統在複雜地形上停留時間相對短暫，使得以種雲播雲機制為基礎的地形降水模式更難以準確捕捉颱風雨帶中降水的快速變化。整體而言，本研究進一步精緻化並驗證了種雲播雲地形降水模式於颱風環境下的適用性，並為未來在複雜地形區域進行熱帶氣旋降水模擬與預報提供重要參考與物理上的啟示。

關鍵字：地形降水、颱風、種雲播雲機制、地形降水模式、大屯山區

Formative Mechanisms of Offshore Convective Systems during an Aircraft Crash (伴隨飛機失事事件之離岸對流系統形成機制探討)

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Abstract

Under rapidly evolving synoptic flow, coastal precipitation systems influenced by complex terrain present significant forecasting challenges and operational hazards to aviation and military activities, and their formative mechanisms remain insufficiently understood. This study used Doppler radar data, surface observations, and reanalysis data to document the formation of two offshore convective lines (i.e., Taiwan rainbands; TRs) and to examine the connection between one of them and an aviation accident. The two TRs exhibited distinct formative mechanisms and occurred at different offshore distances owing to a transition of the large-scale prevailing winds from east-northeasterly to more easterly flow. Low-level convergence produced by orographic blocking alone, as well as by the combined effects of orographic blocking and thermally driven offshore flow, was responsible for the formation of the two TRs. Notably, one TR coincided temporally and spatially with an aircraft accident. These results reveal the complexity of offshore convection formation and suggest that heavy rainfall associated with TRs may result in hazardous weather conditions for aviation safety and military activities.

keywords：orographic precipitation (地形降水), Taiwan rainband (臺灣雨帶), aviation accident (飛機失事), Doppler radar (都卜勒雷達)

熱帶氣旋降水趨勢、機制及微物理過程之分析探討

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摘要

近期研究已顯示熱帶氣旋(tropical cyclones，TCs)降水強度在全球暖化的情境下發生顯著變化，而臺灣在颱風影響下亦有降水增加的趨勢，這些洋面與陸地 TC 降水演變趨勢及其背後可能的原因目前尚待釐清。對於多山的臺灣而言，TC 與地形交互作用引發的降水加強現象特別重要，這其中牽涉複雜的地形效應與微物理過程，至今我們的了解仍非常有限。本研究計畫將結合氣象衛星、雷達、地形降水模式及其它觀測數據，進行長期統計分析與個案研究，目標在於系統性探討西北太平洋與臺灣 TC 降水的長期變化趨勢、颱風降水強度與大氣環境條件的關聯性及其背後可能的物理與動力機制。此外，透過地形斜坡舉升與種雲播雲過程的理論基礎，計畫擬發展一套適用於臺灣山區的降水模式，作為解析颱風環境地形降水的重要診斷工具。同時，為拓展台灣複雜地形下 TC 降水過程的理解，將針對 TC 期間臺灣西南部河谷地區之降水加強現象，分析其發生頻率與潛在物理過程，並應用雙偏極化雷達觀測，探討 TC 環流中的中小尺度對流系統在受到地形影響前後的演變、降水粒子的水物變化與微物理過程，以期深化我們對於對流性背景降水與複雜地形交互作用的認識。

關鍵字：熱帶氣旋，氣象衛星，地形效應，地形降水，都卜勒氣象雷達，微物理過程

臺灣地區豪大雨預報實驗相關成果

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English Abstract

An extreme Mei-yu rainfall event occurred on 2 June 2017 along the northern coast of Taiwan, where a peak amount of 635 mm fell in about 10 hours from 0100-1100 LST. Using ensemble-based sensivity analysis, an earlier study (Wang et al., 2021) showed that the areal-averaged rainfall in the wider region surrounding northern Taiwan in this event was influenced by frontal moving speed, frontal intensity (contrast), and location and timing of frontal disturbance in experiments using grid sizes of 2.5-5 km, but peak amounts in such runs were no more than 360 mm, suggesting low predictivity for its occurrence. Using 1-km grid size, predictions in a later study (Wang et al., 2023), on the other hand, showed that a peak amount of up to 541 mm can be achieved with a finer grid, but the detailed rainfall pattern and maximum amount are strongly dictated by the presence of a frontal low-pressure disturbance that affected the location and persistence of the surface convergence zone, thus again suggesting high nonlinearity and low predictability. However, in some initial times about 2.5-3 days before the event, the evolutions were more favorable for larger and more concentrated rainfall.

In this study, the above extreme rainfall event is further examined, using ensemble forecasts both at 1 km and larger grid sizes, including the experiments carried out in the Taiwan Area Heavy-rainfall Prediction Experiment (TAHPEX). Special attention is given on the predictability of this extreme event and the strategy to produce useful results more effectively with longer lead times for early warning and preparation.

Keywords: Extreme rainfall; Mei-yu season; predictability; cloud-resolving model.

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GNSS 偏極化掩星資料與數值模擬之比較

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摘　要

偏極化無線電掩星（Polarimetric Radio Occultation，PRO）是一種新近提出的無線電掩星技術，除可反演傳統的掩星產品（如偏折角與折射率）外，亦能量測偏極化相位差移。先前研究已顯示，PRO 量測結果與雲中水象粒子的垂直分布密切相關。憑藉此一獨特的觀測能力，PRO 探空資料為評估數值天氣模式中的雲微物理參數化法提供了極具潛力的工具。

本研究比較了 PRO 觀測與 WRF 模式對 2019 與 2021 年三個颱風個案的模擬結果。模式分別以 ERA5 與 NCEP FNL 資料作為初始條件，並採用五種微物理參數化方法：Purdue Lin、WSM6、Goddard、Thompson 及 Morrison。模擬得到的水象粒子分布呈現顯著差異，可能受到初始條件、微物理參數化選擇、颱風位置、環流結構以及雨帶分布等因素的影響。

研究結果顯示，採用 Goddard、Thompson 與 Morrison 微物理方法的模擬，普遍能在高度上再現與 PAZ PRO 觀測相近的相位差移峰值。其中，Goddard 微物理參數化法在颱風路徑預報以及最大相位差移幅度的模擬表現上，與 PRO 觀測最為一致。此外，由 36 組集合預報所得到的集合平均結果，亦與決定性預報模擬結果相當一致。整體而言，本研究的比較分析顯示，PRO 觀測資料在評估與約束數值天氣預報模式中不同微物理參數化方法的表現方面，具有相當大的應用潛力。

關鍵字：偏極化掩星、相位差移、微物理參數化

Characteristics of Disaster-Causing Heavy Rainfall in Taipei City and Implications for Urban Disaster Response

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Abstract

Short-duration intense rainfall produced by severe convective storms is one of the most critical weather hazards in Taipei City, a densely populated metropolitan area surrounded by complex terrain. Under climate change, both historical observations and future high-emission scenarios indicate increasing rainfall intensity, leading to a growing risk of urban flooding and other weather-related disasters. Understanding the characteristics of disaster-causing heavy rainfall and its radar-observed features is therefore essential for improving early warning and emergency response.

This study investigates the temporal evolution, intensity thresholds, and radar signatures of heavy rainfall events associated with severe convection in Taipei City using long-term rain gauge observations, weather radar data, and disaster records. Event-based analyses show that rainfall intensification can occur rapidly through the merging of convective cells. A representative thunderstorm case in the Taipei Basin demonstrates that such cell mergers can generate extreme rain rates exceeding 60 mm within 20 minutes, closely corresponding to observed urban flash flooding. In addition to heavy rainfall, strong wind gusts frequently accompany these events. Microbursts, identified through radar features such as descending precipitation cores and pronounced near-surface divergent outflows, can produce wind gusts exceeding 10 m s^{-1}, further amplifying hazard impacts on the urban environment.

Short-duration rainfall accumulation is a key precursor to disaster occurrence: when 40 mm accumulates within 60 minutes, about 35% of events intensify to hourly rainfall exceeding 60 mm, increasing to 63% when the same amount occurs within 30 minutes and often followed by rapid intensification. As rainfall intensity increases, disaster-prone areas tend to shift from the southern part of the city toward the eastern and northern districts, influenced by prevailing southwesterly flow and terrain effects.

Overall, this study demonstrates how radar-based analysis combined with rainfall statistics can improve the identification of high-risk convective rainfall events and provide scientific support for refining warning indicators and enhancing urban disaster resilience under a changing climate.

Keywords: Climate Change, Heavy Rainfall, Disaster Response, Taipei City

臺北市致災性強降雨特性及其對都市防災應變之影響

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關鍵字：氣候變遷、強降雨、防災應變、臺北市

梅雨季台灣南側持續性西南氣流之降水特徵與形成機制

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摘　要

西南氣流（southwesterly flow; SW）為一綜觀尺度的強風系統，負責輸送暖濕空氣至台灣周遭，對梅雨季（5 月 15 日至 6 月 15 日）的降水具有關鍵影響。本研究採用歐洲中期天氣預報中心第五代再分析資料（fifth-generation reanalysis from the European Centre for Medium-Range Weather Forecasts; ERA5）與台灣地面氣象站觀測數據，檢視 1979 至 2022 年梅雨季期間持續性西南氣流（prolonged SW; PSW）的環流與降雨特徵，並探討其與南台灣周邊極端降水事件之關聯。統計結果顯示 PSW 與持續性強降雨（persistent heavy rainfall; PHR）具有高度的共現性。75%的 PHR 事件發生於 PSW 期間，且 60%的 PSW 個案伴隨有 PHR 發生。此外，高達 83%的 R99.9 極端降雨事件（第 99.9 百分位降雨強度）皆與 PSW 相關。合成分析指出，PSW 的建立與維持仰賴特定的綜觀尺度環流型態，包括西太平洋副熱帶高壓稍向東退、南亞高壓強度維持，以及東亞地區低壓系統的持續存在。上述氣壓配置共同建立了持久的西南風場，導致台灣周邊風速顯著增強，並造成長達 84 至 126 小時的水氣累積。本研究結果凸顯了綜觀氣壓場配置在維持 PSW 及激發 PHR 中的關鍵角色，並為梅雨季 PSW 的預報提供了量化的參考指標。

關鍵字：西南氣流、極端事件、持續性降水

Process-based Evaluation of a Data-Driven Tropical Cyclone Model Boosted by Lagrangian Limited-Area Transformers

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Abstract

Data-driven weather prediction models (DWPs) offer advantages in rapid forecasting and often demonstrate superior synoptic-scale predictive skills compared with traditional numerical weather prediction models. However, global DWP models typically operate at coarser temporal and spatial resolutions and remain limited in their ability to accurately predict tropical cyclone (TC) wind structure and rainfall. These limitations arise in part from the need to compromise between learning specific features of TCs and effectively representing diverse weather systems globally.

Here, we develop a Lagrangian limited-area transformer for typhoon-following DWP (LLAT.ty) with an increased temporal resolution of three hours. This transformer-based model is trained using TC-centered ERA5 reanalysis from 2007 to 2020. Notably, LLAT.ty explicitly predicts the TC center location, enabling the generation of three-dimensional TC structure forecasts at continuous time steps, provided that boundary conditions from global model forecasts through one-way or two-way boundary interactions. Reforecasts of all 2024 typhoons show that LLAT.ty improves TC track predictions relative to the baseline FourCastNETv2 global DWP. Furthermore, LLAT.ty provides additional predicted variables essential for TC forecasting, including rainfall and vertical motion.

Idealized simulations based on LLAT.ty are conducted to further assess whether the model effectively learns the underlying physical processes required to produce accurate TC position and structure forecasts. The results demonstrate that LLAT.ty produces realistic TC responses to variations in sea surface temperature, latitude-dependent Earth rotation, and vertical wind shear that governs convective asymmetry. The model also successfully simulates the formation and evolution of beta gyres, which exert a physically consistent influence on TC motion. Overall, LLAT.ty bridges the efficiency of global DWPs with TC-specific physical fidelity, offering a promising framework for data-driven TC forecasting.

Keywords: Tropical cyclone, Deep learning, Transformer, Process-based evaluation

臺灣邊界層水氣與熱動力特性及降雨微物理之研究

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摘要

本研究分析了 2018-2022 年六月（梅雨季後期）東沙島海洋邊界層噴流(MBLJ)與台灣劇烈降雨的關聯性。將天氣型態分為四類：MBLJ-HR（噴流伴隨劇烈降雨）、MBLJ-NoHR（噴流無劇烈降雨）、NoMBLJ-NoHR（無噴流無劇烈降雨）及氣候平均值(CLIM)。研究發現，MBLJ-HR 情境下西南風最強，強風軸從東沙島延伸至台灣，為濕 MBLJ（水平水氣通量>100 g kg^{-1} m s^{-1}）；MBLJ-NoHR 情境風速略弱，且風軸偏西北移動，為乾 MBLJ（水平水氣通量>60 g kg^{-1} m s^{-1}）。MBLJ-HR 的 700hPa 西南風 SLLJ 軸心通過整個台灣，水氣充足，降雨極值出現在中央山脈及雪山山脈的西南側迎風面與西南部沿岸區。MBLJ-NoHR 則因西太平洋高壓西北延伸籠罩台灣南部，使台灣西南部的地形阻滯效應增強，且 SLLJ 軸心位於台灣以北，降雨微弱。NoMBLJ-NoHR 情境下為弱西南季風，水氣不足，整個台灣區域降雨極少。研究證實濕 MBLJ 對台灣劇烈降雨具關鍵影響，主要透過暖濕西南氣流受地形舉升與阻滯效應產生降雨，而乾 MBLJ 或無 MBLJ 情境則因水氣通量不足或 SLLJ 位置不利，無法在台灣產生劇烈降雨。本研究進一步分析了 1999-2018 年六月，南海海洋邊界層噴流(MBLJ)與中國東南部、台灣降雨如何受準雙週震盪(QBWO)調節。研究發現，準雙週震盪對 MBLJs 有強烈調節作用：QBWO 抑制對流階段(P2)，南海北部 MBLJ 頻率增加，水氣輸送增強，中國東南部與台灣梅雨鋒面活動與降雨增強；QBWO 活躍對流階段(P4)，南海北部 MBLJ 頻率減少，南海北部降雨增強但中國東南部內陸降雨減弱。P2 階段，中國東南部 R1、R2 北部、R3 降雨峰值增強，主要歸因於加強的西南季風、頻繁的 MBLJs 增加水氣輸送，強化梅雨槽內的鋒生作用及水氣幅合。台灣地區強降雨源於顯著梅雨鋒面東南傳播及 MBLJ 水氣供應受地形抬升/阻擋。P4 階段，中國東南部內陸降雨被抑制，而南海北部沿海降雨增強，主要因南海北部 QBWO 對流增強，但西南季風減弱導致水氣輸送減少及鋒生作用減弱。

KPEx 觀測實驗期間背風渦流及邊界層演化與臺灣西南部空氣品質關聯性之探討

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摘要

複雜地形效應一直是空氣污染研究中的重要課題。臺灣位於歐亞大陸與太平洋交界，地形起伏劇烈且人為排放密集，使大氣環流與空氣品質之交互作用更加複雜。本研究結合 NASA ASIA-AQ 計畫，於 2024 及 2025 年冬春兩季在臺灣中南部進行多站點垂直大氣觀測實驗（高屏觀測實驗，KPEx），並結合 WRF 模式模擬，探討臺灣空氣品質較差區域之氣象與流場特徵。

觀測與模擬結果顯示，不同月份之天氣型態對流場結構與污染分布具有顯著影響。2024 年 2–3 月主要受高壓出海與高壓迴流影響，盛行偏東至東南風，臺灣西半部易出現高 $PM_{2.5}$ 濃度，並與弱風、夜間逆溫及混合層高度受抑制等不利擴散條件密切相關。KPEx 觀測顯示，大氣垂直結構具有明顯分層特性，可區分為邊界層、繞流層及西風層。觀測期間，日間邊界層高度約為 200–1000 公尺，夜間則降至約 100–500 公尺。此種分層結構明顯抑制污染物之垂直擴散，導致近地表 $PM_{2.5}$濃度升高。

風場分析顯示，近地面風向多為東北風至東南風，而在高空層則轉為西風或西南風。中尺度模式模擬結果進一步指出，氣流通過中央山脈後，臺灣西南部陸地與近海區域易形成背風渦流，並伴隨明顯的海陸風環流，使中高層下沉氣流抑制污染物向上擴散，進一步加劇地表污染。此外，探空觀測亦顯示高空層仍存在顯著 $PM_{2.5}$濃度，例如 2024 年污染峰值高度可達 1600–4500 公尺；2025 年於澎湖西嶼背景站之觀測結果亦顯示，境外污染可能透過高空傳輸影響臺灣。

整體而言，本研究指出臺灣空氣品質深受地形與氣象條件影響，其中背風渦流與海陸風環流為關鍵機制。研究成果有助於深化對臺灣區域性污染成因之理解，並可作為後續空氣品質分析與模式模擬之重要參考。

關鍵字：背風渦流、空氣污染、邊界層、KPEx

Construction of the Lunar Magnetic Field Integration Platform and Its Application: Simulation Study of Solar Wind-Lunar Mini-Magnetosphere Interaction

月球表面磁場整合平台及其應用之一: 太陽風與月球微型磁層交互作用之模擬研究

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Abstract

The Moon does not have a global magnetic field. Still, it does have local crustal fields, i.e., the so-called magnetic anomalies that typically have average intensities of ~10 nT, with some exceeding several hundred nT. These anomalies may perturb the solar wind, slowing it down and changing its direction. We conduct two-dimensional magnetohydrodynamic (MHD) simulations to examine the interaction between the solar wind and the lunar mini-magnetosphere. When the solar wind approaches the Moon at right angles, the Moon's magnetic field pushes toward the surface. However, if the wind is parallel, the magnetic field is dragged along, increasing magnetic strength and potentially causing localized reconnections that accelerate plasma. Since these anomalies function like mini-magnetospheres, the velocity shear at their boundaries can trigger the Kelvin-Helmholtz instability, leading to nonlinear waves that can extend hundreds of kilometers above the lunar surface. Our findings may help explain shock-like structures observed above the lunar surface at altitudes over 100 km since the Explorer 35 and Apollo missions, as confirmed by subsequent spacecraft such as Lunar Prospector, Kaguya, and ARTEMIS. Additionally, we propose developing a user-friendly lunar magnetic field platform that would enable researchers to simulate and analyze the distribution of the lunar surface magnetic field and correlate this data with satellite measurements. The purpose of this project is to integrate magnetometer data from across different countries to improve a global lunar magnetic field model and facilitate international research collaboration.

Key words: Moon, Lunar Magnetic Anomalies, MHD simulation, Solar-Wind Interactions, Platform

GNSS 三維電離層斷層掃描研究北美日全食電離層響應

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摘　　要

本研究旨在精進三維電離層斷層掃描技術，並探討全球導航衛星系統(GNSS)訊號在電離層中的傳播影響。研究採用無初始值搭配最小平方約制的方法，解決電漿濃度空間上的不連續與不適定性問題，並將程式碼優化至Python 3與Google Colab雲端運算環境，以提升分析效率。本研究利用此系統分析2024年4月8日北美日全食事件對電離層之影響。斷層掃描結果顯示，日食期間電漿濃度顯著減少，其減少區域主要集中在電離層F2層峰值附近(約300公里高度)，最大降幅約為22%。與2017年日食事件相比(最大降幅40%、高度260公里)，本次事件受太陽極大期與季節性背景電漿濃度較高之影響，呈現不同的響應特徵。研究證實本系統不需依賴經驗模式作為初始值，即可有效捕捉日食引發的三維電離層電漿空洞效應與垂直結構變化，有助於釐清不同地球物理條件下的電離層物理響應機制。

關鍵字：GNSS斷層掃描、三維電離層電漿結構、日全食、最小平方約制

Plasma chemical model for an enhanced green emission following a gigantic jet near Taiwan

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Abstract

The "Green Ghost" is a recently identified faint green emission at approximately 90 km altitude that follows a sprite (Lyons, 2022; Passas-Varo et al., 2023; Huang et al., 2024), a type of transient luminous event. It is believed that the top of a gigantic jet (GJ) is similar to a sprite, as the streamer corona region is initiated by an electrode-like leader from lower altitudes (De Silva and Pasko, 2013). We investigate the GJ events near Taiwan from 2022 to 2024. After checking the video, we found that one of these GJ events was followed by distinguished green emissions. On June 22, 2024, at 19:52:35 LT, a GJ was recorded simultaneously by two optical cameras at the Taitung Southern Cross-Island Yakou station and Lulin Observatory. Triangulation placed the event at 19.6°N, 121.0°E, approximately 400 km from the observers. The subsequent green emission, located at an altitude of 80-100 km, had an estimated average brightness of 198.8±2.7 Rayleighs, a value within the typical range for the background O(^{1}S) airglow (150-270 R). The emission's brightness decayed exponentially with a characteristic time of ~0.6 s, which is comparable to the 0.74 s radiative lifetime of the O(^{1}S) → O(^{1}D) transition. We propose that the generation of this green emission requires the GJ to penetrate altitudes above 90 km, where it can excite a sufficient population of ground-state oxygen atoms, potentially triggered by a diffusion region analogous to those observed at the top of red sprites.

Keyword: Gigantic jets, Green Ghost

哨聲波在月球電離層之功率傳輸分布模擬

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摘　要

本報告先簡述模擬地球電離層樹狀巨大噴流產生之哨聲波特徵之成果，接著再以月球電離層哨聲波之功率傳輸模擬成果為主。一般而言，因為月球電離層十分稀疏，是當成無碰撞效應的。本研究為首次由包含碰撞效應的全波方程式求解，計算低於 10 赫茲之月球哨聲波從月表向上傳播至一百公里高的功率傳輸比。這些波動在繞月之繞極軌道衛星 Kaguya 及 Lunar Prospector 衛星上都曾被觀測到，也被認為是從較低的高度產生再往上傳播至這些衛星的高度。我們參考前人由 Chandrayaan 一號衛星電離層資料所建立太陽風作用下的月球電離層模型，將電離層環境設定具有四種主要離子種類(CO_2^+,H_2O^+,OH^+,H_3O^+)且環境絕對溫度 150 度與 400 度兩種情況，而磁場環境則以月殼磁場來計算以探討經緯度分布情形。計算結果發現碰撞頻率可到幾赫茲左右，恰巧和波頻接近;計算結果也顯示波頻增加，功率傳輸比會降低;較強的磁場強度與較大的磁場向量及月表夾角的功率傳輸比較高;隨著溫度升高，功率傳輸比也隨之增加，這些結果皆與觀測哨聲波強度在頻率上的分布、發生率與月磁強度分布、以及與太陽天頂角關係等一致。若納入太陽風速度產生的都卜勒頻移時，在上述衛星儀器可觀測的頻率範圍內(16 赫茲以下)，功率傳輸比超過-3 分貝的月面分佈呈現出更明顯的南北不對稱性，與已知的波強度和發生率分布相符合。諧波型的哨聲波主要在較低的月表高度被衛星觀測到，這也可能是因為在高度較高處高頻部分會衰減較多。未來的研究方向將以模擬這些波動在不同的電漿環境下之群速分布為主。

關鍵字：哨聲波功率傳輸、全波方程式、碰撞效應、月球電離層、月殼磁場、都卜勒頻移

應用深度學習於福衛二號高空大氣閃電影像儀之高空短暫發光現象全球分布與季節性變化研究

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摘　要

搭載於福爾摩沙衛星二號(FORMOSAT-2）的高空閃電影像儀(Imager of Sprites and Upper Atmospheric Lightning, ISUAL），針對發生於對流層與電離層之間的高空短暫發光現象(Transient Luminous Events, TLEs）進行研究。使用深度學習技術，系統性地建構了 2004 年 7 月至 2016 年 6 月之 ISUAL TLE 事件清單，共包含 66,586 筆事件。ISUAL 為首個專門用於 TLE 觀測的衛星任務，成功描繪了 TLE 的全球分布，並揭示其顯著的空間型態差異。研究結果顯示，精靈(elves)最常出現在海洋上空，紅色精靈(sprites)主要分布於陸地，光暈(halos)多見於沿海地區，而藍色噴流(blue jets)與巨大噴流(gigantic jets)則主要集中於低緯度地區。本研究以創新方法融合 ISUAL 的 TLE 觀測資料與全球雷電定位網(World Wide Lightning Location Network, WWLLN)的強雷電分布，建立全球 TLE 發生密度圖，彌補了過往在中高緯度與軌道間隙無法觀測的缺憾。校正後的全球 TLE 發生率為每分鐘 47.08 事件，顯著高於先前研究結果，其中各類事件的發生率分別為：精靈 32.74、紅色精靈 5.94、光暈 2.98、藍色噴流 5.40，以及巨大噴流 0.02(事件/分鐘)。此外，依據柯本氣候分類法(Köppen climate classification)分析不同氣候帶中的 TLE 發生率，結果顯示熱帶與溫帶地區的發生率較高，其中紅色精靈在炎熱夏季氣候區尤為頻繁。為進一步探討潛在的外部驅動因子，我們也分析完整 11 年太陽活動週期與夜間 TLE 發生之關聯性，結果顯示兩者僅存在微弱相關($R \leq 0.3$)，並指出氣象因素相較於太陽活動，更可能是主導 TLE 變異的主要機制。

關鍵字：高空短暫發光現象、閃電、高空閃電影像儀

Evolution of post-sunset equatorial plasma bubbles: relationships to the equatorial ionospheric anomaly induced by pre-reversal enhancement electric fields

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摘要

This study presents GNSS radio occultation (RO) observational analyses on deducing the relationships and dependences between post-sunset EPB occurrences and EIA strength variability. The RO data were acquired from the FS7/COSMIC2 Program from 2020 to 2025. In this study, we incorporate both effects from crest peak electron density (N_{emax}) and crest-to-trough N_{emax} ratio and propose a new EIA strength parameter defined as the mean of northern and southern crest-to-trough N_{emax} differences to recognize and characterize the post-sunset EIA features. Both seasonal–longitudinal appearances of intense post-sunset EPB occurrences and strong EIA events occurred on more or less 30 days expanded from when and where magnetic flux tubes align with the sunset terminator at the magnetic equator but have more intense EPB and/or strong EIA days during southern (northern) hemispheric summers in the South American area (the Central Pacific area and the Africa area). It is well consistent with Tsunoda's hypothesis during the evening pre-reversal enhancement (PRE) and reveals more informationt on day-to-day variability, intensities and extents of post-sunset EPB occurrences and EIAs subject to seasonal, longitudinal, and solar cycle variability. Moreover, the local-time evolutions of peak post-sunset EIAs occurred during 19~20 LT which is earlier than that of the obtained experimental peak (i.e., 20:20 LT) of post-sunset EPB occurrences. We expect that the post-sunset EIA detection could be a potential precursor for post-sunset EPB occurrence.

Keywords: post-sunset equatorial plasma bubble (EPB); equatorial ionospheric anomaly (EIA); equatorial spread F (ESF); GNSS radio occultation (RO) observation; radio scintillation

火星地殼磁場
對熱氧與重離子非熱逃逸之數值模擬研究

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摘 要

火星的大氣逃逸過程是其長期氣候與大氣演化的重要控制機制之一。由於火星缺乏全球性偶極磁場，其上層大氣與電離層結構高度受到太陽風、行星際磁場以及行星局部地殼磁場的共同影響。其中，非熱逃逸過程在火星大氣流失中扮演關鍵角色，特別是熱氧（hot oxygen）與重離子逃逸，對上層大氣結構與動力學具有顯著影響。本研究結合三維測試粒子蒙地卡羅模擬與多流體磁流體力學模型，系統性分析火星地殼磁場與感應磁場結構對非熱大氣逃逸的影響。我們首先探討地殼磁場對熱氧動態與逃逸速率的調制效應，並進一步以感應磁場邊界（Induced Magnetosphere Boundary, IMB）高度變化作為火星受擾與壓縮事件的分類指標，分析不同磁場條件下離子逸散行為的差異。模擬結果顯示，當考慮地殼磁場效應時，整體熱氧逃逸速率相較於無磁場情境增加約 23%。在南半球地殼磁場分布較為集中的區域，局部熱氧逃逸速率甚至可提升至原本的兩倍。此顯著的南北半球不對稱性，主要源於受局部磁場拓撲與電磁力（特別是霍爾電場力）控制的電漿傳輸過程，造成離子與電子空間密度分布的重組，以及沿磁力線方向之離子加速與導引效應，進而提高強磁區域內熱氧的逃逸效率。此外，透過比較在不同 IMB 高度條件下之氧離子的逃逸通量與空間分布，本研究探討感應磁場結構對火星重離子逸散效率的影響。為更準確描述低高度區域的離子加速與逃逸通道，我們亦結合現有數值模擬結果反演離子軌跡，進一步釐清地殼磁場與感應磁場在重離子逸散過程中的角色。

關鍵字：火星大氣逃逸、火星地殼磁場

Applying Artificial Intelligence for Space Science and Technology

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The rapid evolution of orbital operations has introduced complex challenges that exceed the capabilities of traditional physics-based models and classical signal processing. This presentation explores the transformative role of artificial intelligence (AI) across three critical domains: environmental forecasting, on-orbit perception, and resilient communications. To address the volatility of the space environment, we first investigate Transformer architectures for sequence-to-sequence prediction of ionospheric Total Electron Content (TEC), capturing non-linear geophysical forcings that elude analytical models. Then, we present a lightweight Long Short-Term Memory (LSTM) network designed for real-time GPS orbit correction, demonstrating that compressed AI can operate within the stringent computational constraints of satellite hardware to enhance positioning accuracy. Furthermore, to improve Space Situational Awareness (SSA), we propose an optimized, lightweight neural network based on the YOLO baseline for on-orbit object detection. By implementing innovative modules such as the Lightweight Path Aggregation Network (LPAN) and the Adaptive Reception Field Module (ARFM), our method achieves high detection sensitivity for multi-scale objects while minimizing computational redundancy. Finally, we reimagine digital communication by replacing rigid receiver blocks with an end-to-end LSTM-based demodulator for QPSK signals. By processing raw passband waveforms directly and utilizing curriculum learning, the model effectively mitigates severe inter-symbol interference and noise. Collectively, these studies illustrate that specialized AI architectures are essential for the next generation of autonomous, resilient, and precise space systems.

Keywords: Deep Learning, Ionospheric Total Electron Content, GNSS Orbit Correction, Space Situational Awareness, Satellite Navigation, Communications

太陽閃焰之活躍區電漿特性與準週期脈動研究

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摘　要

太陽閃焰為發生於太陽活躍區的劇烈爆發現象，依其是否伴隨日冕物質拋射，通常可區分為噴發型或受限型事件。先前研究多著重於閃焰磁場結構的演化，甚少關注閃焰發生前活躍區的電漿物理特性。本研究利用高時間解析度之多譜線與多波段觀測資料，結合光譜分析與差分發射計量分析，探討噴發型及受限型閃焰於爆發前階段，日冕環足點區域之都卜勒速度、非熱速度、體發射計量以及電漿密度等參數的時變情形。我們發現兩類閃焰在爆發前呈現明顯不同的前兆特徵，噴發型閃焰於爆發前顯示上升流速隨時間增強、電漿密度下降的趨勢，而受限型閃焰的上升流速則逐漸降低，且電漿密度維持相對穩定的狀態，此差異推測與日冕環是否發生顯著擴張或抬升有關。本研究彌補了過去對於閃焰發生前一小時內電漿特性研究的不足，尤其是在電漿密度演化方面提供了關鍵證據。另一方面，於閃焰期間在多個波段的時變曲線中所觀測到之準週期脈動現象，已被認為是閃焰的重要本質特徵之一，但因準週期脈動在時間尺度及空間分布上展現高度多樣性與複雜性，其物理機制至今仍未有一致性的結論，可能來自於磁重聯過程中能量的間歇式釋放，或是閃焰日冕環內波模振盪所導致的電磁輻射調制效應。我們預計將結合多衛星的多儀器與多波段觀測資料，分析太陽高能輻射中準週期脈動的時間、空間與能譜特性，期望能為診斷閃焰能量釋放與非熱電子加速提供關鍵的觀測依據。

關鍵字：太陽閃焰、差分發射計量分析、準週期脈動

大氣科學學門共用計算服務平台

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摘要

隨著全球氣候變遷加劇極端天氣事件，如洪災與旱災，對氣象模擬的精確度和即時性提出了嚴峻的挑戰。為滿足高解析度氣象預報和全球氣候模擬的龐大運算需求，高效能運算 (HPC) 成為關鍵技術。國家高速網路計算中心 (NCHC) 利用本土的 「臺灣杉三號」超級電腦（結合多核心 CPU 和 GPU），為臺灣大氣學界提供安全且高效的 HPC 服務。在 2025 年一月至十一月，大氣領域的使用量已佔臺灣杉三號總用量的 25%，應用於空氣污染預報、全球氣象模式等重要研究。考量到一般排程等待時間過長，為確保颱風期間或每日所需的連續、不中斷模擬能即時進行，本計畫已專門在臺灣杉三號上建置一個專屬的計算服務平臺。此平臺執行至今邁入第五年，持續獲得學界的正面肯定，透過 NCHC 的技術支援與使用狀況分析，確保此重要科研基礎設施能夠永續且高效地運營，保障臺灣氣象學術研究在關鍵時間內產出重要成果。

關鍵字

大氣科學、高速計算、雲端服務

Surface Water Availability-Temperature Index (SWATI): A Satellite-Based Approach for Global Drought Monitoring

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Abstract

Drought monitoring is critical for sustainable irrigation management and agricultural resilience in the context of climate change. This study introduces the Surface Water Availability-Temperature Index (SWATI), a satellite-derived indicator developed to assess drought conditions. The SWATI is constructed using the Euclidean distance method, integrating three remote sensing variables: the Normalized Difference Latent Heat Index (NDLI), the Normalized Difference Vegetation Index (NDVI), and Land Surface Temperature (LST). Its performance was assessed against five datasets, such as Global Land Surface Satellite (GLASS) soil moisture (SM), Soil Moisture Active Passive (SMAP) SM, evapotranspiration (ET), Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) rainfall, and Temperature-Vegetation-Shortwave infrared reflectance Dryness Index (TVSDI). At the national scale, the SWATI showed high correlations with GLASS SM, while continental-scale analysis revealed higher correlations with SMAP SM ($-0.83 \leq r \leq -0.54$, $p < 0.01$) compared to TVSDI ($-0.80 \leq r \leq -0.47$, $p < 0.01$). Spatiotemporal analysis further demonstrated robust agreement between SWATI and four datasets, with more than 43% of the total area showing the high consistency. These results confirm that the SWATI effectively indicates SM and enables the production of high-resolution dryness maps at the global scale. In conclusion, the SWATI is an effective drought monitoring approach, and its further utilization will be essential for irrigation management in data-scarce regions.

Keywords: Drought monitoring; global scale; irrigation management, soil moisture (SM); Surface Water Availability-Temperature Index (SWATI).

2024 年母親節磁暴引發之電離層電漿洞

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本研究分析了福爾摩沙衛星五號(FORMOSAT-5, F5)先進電離層探測儀(Advanced Ionospheric Probe, AIP)與福爾摩沙衛星七號(FORMOSAT-7/COSMIC-2, F7C2)離子速度儀(Ion Velocity Meter, IVM)所量測的離子密度與速度，發現在 2024 年 5 月 10 日母親節磁暴期間，大西洋磁赤道區域形成了顯著的電離層電漿空洞。觀測顯示，F5/AIP 與 F7C2/IVM 在空洞內分別紀錄到 1.7×10^4 #/cm³與 1.6×10^3#/cm³的離子密度；同時，兩者分別於 720 km 與 550 km 高度測得了向上與向下的垂直離子運動。結合全球電離層規範(Global Ionospheric Specification, GIS)同化的電子密度廓線，進一步揭示了電子密度在 440 km 與 760 km 處呈現峰值，此結果顯示相對的垂直離子速度是形成該雙峰結構的關鍵因素。

流星雷達觀測流星和Es不規則體之技術與科學

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摘　要

本計畫規劃利用中壢特高頻雷達(52 MHz)和流星雷達(39.9 MHz)來研究中高層大氣和流星，測量中氣層和E層(MLT)的風場、大氣擴散係數與溫度，以及探討E層電漿不規則體(Es)和流星消融電漿的關係。目前執行第一年，著重於(1)理解流星雷達系統及其回波訊號特性、(2)開發多元的回波定位方法、(3)分析流星雷達觀測Es回波的特性等，分別簡述如下：

(1) 中壢流星雷達建立完成約3年，以五根天線排列成十字型接收流星軌跡的反射回波，同時也會收到來自電離層Es的回波訊號(Es回波)，因此要利用流星回波來推導當地中性風場，必須剔除Es回波。廠商提供的處理流程已進行剃除Es回波的工作，篩檢出每個流星回波並加以儲存，可提供線下的分析。其他產出有流星回波的來向角、發生高度、都卜勒速度等，並據以演算而提供80-130 km之間的中性大氣風場和擴散係數，擴散係數可進一步推導中性大氣溫度。

(2) 流星雷達系統利用J. Jones (1998)或D. Holdsworth(2004)的方法來計算流星軌跡反射回波的來向角和高度，本研究除了重製其演算過程之外，也開發MUSIC和NC-Capon演算法來定位。MUSIC和NC-Capon演算法是非線性的反演過程，較具抗雜訊能力，也有機會推導出雙重回波中心的情況，有利於更深入的研究。

(3) 流星雷達是24小時全天域的觀測，探討Es回波是流星雷達的資料加值應用。相較於窄波束的VHF雷達，流星雷達可觀測到更廣域的Es回波，提高更多機會來探討E層運動及物理特性。目前已分析許多Es的回波。

關鍵字：流星雷達、回波定位、Es電漿不規則體、MUSIC、NC-Capon

Measurements of deep space radiation aboard the ispace *Resilience* lunar lander

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Abstract

Regions outside of Low Earth Orbit (LEO, altitudes above approximately 1000 km) are classified as "deep space". The deep space environment poses many challenges for human and robotic exploration, including stronger ionizing radiation fluxes, more extreme temperature variations, as well as limited data downlink volume. With the growth of flight opportunities to deep space aboard government and commercial lunar missions, characterizing the radiation environment and its effects on electronics during these missions is of critical importance for both crewed and uncrewed missions. Utilizing one of the growing number of rideshare opportunities offered by commercial lunar mission providers, we have completed the rapid development and deployment of a Deep Space Radiation Probe (DSRP), which was launched aboard the HAKUTO-R Mission 2 (M2) *Resilience* lunar lander from Commercial Lunar Payload Services provider ispace, inc. on January 15, 2025, immediately commencing operations following launch. Mounted on the exterior of the lander with minimal shielding, DSRP measured the radiation dose, dose rate, and single event upset (SEU) rate throughout the five-month mission, including multiple passes through the radiation belts, at distances far beyond the Moon, as well as in lunar orbit, being active for over 97% of the five-month mission, which was considerably longer than most other recent commercial lunar lander missions.

The largest measured radiation dose rates are considerably larger than those aboard past lunar missions during lower solar activity levels, oftentimes inside shielded spacecraft. Passage through the radiation belts and solar radiation storms were correlated with increases in dose rate, while bit flips caused by single event upsets (SEUs) that can result in data corruption and flight software malfunction were detected throughout the course of mission, not solely during events where higher particle radiation fluxes are expected such as solar radiation storms. A steady background deep space dose rate was also observed during quiet times due to galactic cosmic rays. The radiation data provided by DSRP with its unusually long mission duration will be beneficial for the development of future spacecraft electronics and crewed missions to deep space and the Moon, especially considering the long duration habitation plans of lunar exploration programs such as Artemis.

Keyword: Space radiation, lunar exploration, single event effects

The Ionospheric Impact of Artificial Space Object Reentry

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Abstract

The Sporadic E layer (Es) is a type of ionospheric irregularity characterized by thin, highly ionized plasma clouds. Its formation is generally attributed to the combined effects of meteor ionization and the wind shear effect of the neutral atmosphere's background wind field. As radio waves penetrate the highly non-uniform plasma distribution within the Es layer, they undergo rapid fluctuations in signal strength, known as ionospheric scintillation. The S4 index is the standard parameter used to quantify this phenomenon.This study aims to conduct a long-term analysis of radio wave disturbances in the ionospheric E region using the Radio Occultation (RO) technique. We utilized S4 data spanning Solar Cycles 24 and 25 from the FORMOSAT-3 / COSMIC (F3/C) and the succeeding FORMOSAT-7 / COSMIC-2 (F7/C2) satellite constellations. These data were correlated with the Solar Activity Index (F10.7 Flux Index) and the statistical count of re-entering artificial space objects.

Previous research based on F3/C data consistently indicated a clear negative correlation between the low-latitude S4 intensity and solar activity. However, by integrating F7/C2 S4 data and extending the time series into the recent solar cycle ascending phase, the results showed a dramatic shift. The correlation between low-latitude S4 and solar activity has become highly positive, completely contrary to historical observations.To rigorously validate this contradiction, we compared the correlation analysis between low-latitude E layer S4 and the F10.7 flux across two distinct solar cycle ascending phases, confirming the total inversion of the relationship. Furthermore, an independent analysis revealed a striking high positive correlation between the low-latitude E layer S4 intensity and the number of re-entering artificial space objects. This robust statistical link strongly suggests that the anomalous S4 variability is tied to non-natural interference factors. Based on these correlation analyses, we hypothesize that the increasingly severe space debris problem in recent years has exerted a significant influence (or pollution) on the natural variability of the Earth's ionosphere and the global communication environment.

Space debris re-entry may alter the formation, structure, and dissipation rates of the Es layer by generating additional ionization sources. The results of this study not only demonstrate that the influence of human activities has extended into the upper

atmosphere but is also beginning to impact the space weather system. This discovery poses a substantial impact on critical applications such as global navigation accuracy and satellite communication stability, urgently necessitating a deeper geophysical assessment of the environmental consequences of space debris.

The Three-dimensional Electron Density Reconstruction by Using Global Ionospheric Specification Extended (GIS-Extended)

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Abstract

This study employs the global ionospheric specification (GIS) data assimilation model to reconstruct the three-dimensional electron density structure of the ionosphere and plasmasphere. It employs a Gaussian-Markov Kalman filter to assimilate ground-based GNSS and FORMOSAT-7/COSMIC-2 radio occultation slant total electron content (TEC) observations. The study extends the model's altitude boundary from the ionosphere to the lower plasmasphere, ranging from 1,000 to 21,000 km. An observing system simulation experiment (OSSE) is conducted to assess the accuracy of the reconstructed electron density, with results indicating that the model effectively reconstructs both the ionosphere and the plasmasphere. A significant geomagnetic storm occurred on Mother's Day of 2024 (May 10-12), with the Dst index dropping to -412 nT, the lowest value since November 2003. GIS electron density analysis indicates that this geomagnetic storm significantly affected the ionosphere for approximately two days, whereas the plasmasphere remained affected for more than two days. Furthermore, after the geomagnetic storm began to affect the plasmasphere, plasma density rose sharply for one day, then declined noticeably for more than a day.

Keywords: Data Assimilation, GNSS-RO, Ionosphere, Geomagnetic storm

Estimate of Drift Velocity of Ionospheric Sporadic E irregularities Made with High Frequency Surface Wave Radar

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Abstract

It has long been shown that the ionospheric clutters detected by HFSWR can be exploited to explore useful information on ionosphere. In this study, a diffuse type of ionospheric clutters observed by a high frequency surface wave radar (HFSWR), which are characterized by widely spread both in range and Doppler velocity with a distinct bottom boundary in a concave upward (or necklace-like) pattern, are employed to deduce horizontal U and vertical W drift velocities of the plasma irregularities associated with diffuse sporadic E (Es) layer. Under the assumptions of W<<U and straight line approximation to the Doppler velocity contour in radar illuminating area, a theoretical quadratic function that relates Doppler velocity Vr of ionospheric clutters to their ranges R is derived. A comparison shows that the theoretical R-Vr function can well describe the bottom boundary of the ionospheric clutters. After best fitting the theoretical quadratic function to HFSWR-observed ionospheric clutters, vertical and horizontal drift velocities together with height of the Es irregularities responsible for the necklace-like ionospheric clutters can be estimated. The result shows that the estimated heights of the Es irregularities are consistent with the virtual height of the diffuse Es layer observed by ionosonde. In addition, we find that the horizontal and vertical velocities are in ranges between 30 and 80m/s and -5 and 10 m/s, respectively, which are in general agreement with the predictions of horizontal wind model (HWM) in magnitude.

操作型中壢流星雷達系統校驗分析研究

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摘要

流星雷達具有對 70~140 公里之間中氣層、低熱氣層觀測能力，對於該範圍中性風場觀測結果已成熟並獲得認可。流星燃燒後，產生電漿粒子形成流星尾，流星尾電漿團將凍結在背景大氣中並隨著背景風場移動。流星雷達觀測流星尾的飄移速度，可獲得觀測範圍的背景水平中性風場，再利用中性風場進行電離層散塊 E 層、重力波、潮汐現象等相關研究，一直不斷被進行著。台灣地區，電離層散塊 E 層主要發生高度範圍在 80~120 公里之間，在中低緯度其發生機制有風切理論與電漿不穩定(Plasma Instability)理論。在流星雷達觀測範圍內，電離層電漿不規則體的閃爍現象，影響電波傳播在民生國防上的應用。新建置的中壢流星雷達系統軟硬體產出的低電離層環境參數，可應用於該高度範圍內的相關研究議題。因此流星雷達產出資料的品質可靠度，必須要經過審慎之驗證。本研究利用中壢特高頻雷達發展的流星雷達觀測技術，建立新中壢流星雷達的流星尾觀測技術及完整資料分析能力，能有效篩選出雷達回波中品質符合要求之的流星尾訊號，使用雷達原始資料進行流星尾的空間定位並建立信號分析流程相關技術。進而與原廠提供資料進行比對，驗證新中壢流星雷達系統分析軟體功能，初步確認產出的低電離層環境參數具有品質與可靠度。

Gravity Wave Breaking atop Storms Occurred along Coastal China on July 29, 2016: Observations, Modeling, and Impact

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Abstract

This is an eyewitness account of the internal gravity wave breaking atop storms occurred along coastal China on 7/29/2016 and model simulation of the event. A group of sea breeze thunderstorms occurred on July 29, 2016 in 1300-1700 LST along the coastal region south of Yangtze River in China. On that day, the senior author (PKW) took a commercial flight from Beijing to Taipei and eye-witnessed the development of this group of storms and made plenty photographic recordings of the storm top features as seen from the aircraft during the flight. The storm tops exhibit clear features of internal gravity wave breaking as manifested by the presence of jumping cirrus, turbulent anvil surface and above anvil cirrus plumes (AACP). In order to gain a wider perspective of the storm environment, we retrieved the Himawari-8 satellite visible images of these storms.

The simultaneous aircraft and satellite observations make it possible to identify individual storms in both sets of data. By carefully matching up the storms in aircraft photographs and satellite images, we can make very clear interpretation of features seen in satellite images from the respective aircraft photos of specific storms.

We performed both single cloud model simulations of a few selected storms to understand the dynamics and thermodynamics of the storms and WRF modeling of the complete storm group to understand the impact of the storm activities to the stratosphere. The single cloud model results demonstrate that the internal gravity wave breaking causes the water vapor to penetrate through the tropopause and enter the stratosphere. The WRF model results show that the storm activity produced extensive gravity waves that transported substantial energy and momentum from the troposphere to the upper atmosphere.

電漿泡光學偵測與掩星擾動分析

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本計畫結合衛星與地面觀測以及機器學習方法,發展一套可自動偵測與量化大氣暉光影像中低緯度電漿泡（Equatorial Plasma Bubble, EPB）結構的工具。我們以 NASA GOLD 任務之 135.6nm 大氣暉光影像作為訓練與測試目標,將該任務每 15 分鐘掃描大西洋區域經緯度影像轉換為 Apex height 座標，並經由標準化沿經度發光強度，辨識暉光暗帶所對應的電漿匱乏區域，進一步推估 EPB 的位置、寬度、形狀以及東西向漂移速度等資訊。本研究也以福衛七號（FORMOSAT-7/COSMIC-2, F7/C2)之 IVM 現地量測、掩星電子密度(Electron Density Profile, EDP)，以及地面 GNSS 觀測推得之總電子含量變化 ROTI，對本計畫所偵測的 EPB 資訊交叉驗證。作為本研究工具的延伸應用，我們藉由本工具協助標記 2020–2022 年 F7/C2 大量掩星 EDP 資料，建立以系集袋裝樹（Bagged Trees, BTs）為核心演算法的機器學習分類模型，利用時間、日期、經緯度位置、F10.7 太陽活動指數以及電子密度震盪強度等多項特徵，自動區分正常與不規則 EDP。結果顯示，以午夜時間區分的兩項模型皆可達到逾九成以上的 F1 分數與 Kappa 值，並在不規則 EDP 發生率統計中，與 F7/C2IVM 與 GNSS ROTI 偵測之 EPB 分布一致，證實 EPB 是造成大多數不規則 EDP 的主因。針對 2022 年 1 月 15 日 Hunga Tonga-Hunga Ha'apai 火山爆發事件，本研究 發現全球不規則 EDP 比例在短時間內大幅升高至逾八成，並經由 BTs 分類結果、RO 閃爍指數、ROTI 與 IVM 聯合分析，指出火山之 Lamb Waves 引發之超大尺度 EPB 為導致 RO 品質惡化的主因。本研究將 GOLD 長期暉光影像、利用掩星 EDP、IVM 以及地面 GNSS 觀測輔助，整合為一套標準化且可應用在暉光影像的 EPB 偵測工具。亦利用此工具建立受到 EPB 影響之低品質 RO 資料標記工具，不僅可用於提高資料同化與電離層模式的可靠度，也可直接延伸應用至福衛八號 DIAT 及臺灣地面大氣暉光觀測之多波段影像，為未來低緯度太空天氣監測與通訊風險評估提供重要的科學工具與作業基礎。

台灣地區颱風與地震引起之移行電離層擾亂

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摘　　要

台灣位處颱風盛行和地震頻繁地區。本研究擬利用高頻都卜勒探測系統紀錄之都卜勒頻移，觀察颱風和地震引起的移行電離層擾亂特性。經過35年之研發與改進，台灣高頻都卜勒探測系統已是為全球最先進且最精確的系統。1組發射機、10組接收機、5個探測頻率，使得都卜勒探測系統可以同時記錄50個電波反射點的都卜勒頻移變化。因此。此系統可以同步三維觀察台灣上空颱風和地震引起之移行電離層擾亂。本研究將分析不同強度海上和陸上颱風都卜勒頻移變化，尋找造成明顯移行電離層擾亂的颱風強度門檻值，並探討海上和陸上背風波或山岳波對颱風移行電離層擾亂之影響。此外，本研究亦將比對不同規模之台灣和遠地地震所引發的都卜勒頻移變化，找出引發明顯地震移行電離層擾亂的地震規模門檻值，並探討遠距場與近距場雷利波引發地震移行電離層擾亂傳播特徵和物理機制。

關鍵字：高頻都卜勒探測系統，都卜勒頻移，颱風，地震，移行電離層擾亂

Investigation of space weather impacts on global ionospheric electron density distribution by using FORMOSAT-7/COSCMIC-2 observations

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The objective of this study is to examine the ionospheric response to major and minor geomagnetic disturbances during 2019-2025, a six-year period involving deep solar minimum conditions and solar maximum days with intense geomagnetic activity. There were about 185 geomagnetic disturbances occurred during this period, with the disturbed conditions persisting for multiple days during most of the events. Out of these, 25 events were major geomagnetic disturbances, including two extreme events. These disturbances triggered intense positive variations in the low- and mid-latitude ionosphere on several occasions and long-lasting negative storm effects over a wide range of longitudes. Hourly, three-dimensional, Global Ionosphere Specification (GIS) electron density profiles constructed from the slant total electron content measurements by FORMOSAT-7/COSMIC-2 constellation and ground-based global navigation satellite system receiver network are used to estimate the impact of the minor and major geomagnetic storms. A superposed epoch analysis is carried out, with the time of maximum interplanetary electric field as the zero-epoch time, and the local-time and latitude variations of the GIS electron density are investigated by using previous 5-day average as the quiet-time reference. The results reveal ~200% enhancement in the average electron density over low latitudes over the longitude that falls at local-noon sector at the zero-epoch time. Maximum electron density response occurs within about 3.5-4 hours after the zero-epoch. In the night sector, the enhancement occurs after 5-12 hours of the zero-epoch. The latitude variation reveals classic storm-time behavior in solar maximum, with stronger response occurring earlier over mid- and low-latitudes and propagating to equatorial region. The storm effect lasts for about 3-days over the mid- and low-latitudes. The results are further compared with the corresponding variations of IMF parameters and O/N2 ratio, and the possible factors that contribute to the observed extreme positive response are examined.

Spatiotemporal analyses of pre-earthquake ionospheric anomalies associated with the M7.1 Indonesia earthquake observed by FORMOSAT-7/COSMIC-2

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Abstract

FORMOSAT-7/COSMIC-2 (F7/C2) was successfully launched on 25 June 2019 into a mission orbit at about 550 km altitude, with a 24° inclination and an orbital period of about 97 minutes. The mission consists of a constellation of six small satellites, providing observations with high temporal and spatial resolution. Each satellite is equipped with a Tri-GNSS Radio Occultation System (TGRS) and an Ion Velocity Meter (IVM), enabling simultaneous measurements of ionospheric electron density vertical profiles as well as in situ plasma parameters at satellite altitude, including ion density, ion temperature, and ion velocity. These instruments are well suited for investigating the structure and dynamical characteristics of the equatorial and low-latitude ionosphere. In this project, F7/C2 radio occultation and in-situ measurements, together with total electron content (TEC) data from the Global Ionosphere Map (GIM), are used to investigate ionospheric disturbances associated with the M7.1 earthquake that occurred on 14 November 2019 near Kota Ternate, Indonesia. Preliminary results indicate that the GIM TEC above the epicentral region exhibited a pronounced enhancement approximately 19–20 days prior to the earthquake. Further spatial and temporal analyses reveal that this anomaly shows clear regional localization and persistence, suggesting that it may be related to the earthquake preparation process. This project aims to fully exploit the advantages of the F7/C2 constellation in terms of high spatiotemporal resolution and multi-parameter observations. Through a detailed case study of the M7.1 Kota Ternate earthquake, the analysis seeks to achieve spatiotemporal anomaly detection capabilities comparable to those of global ionospheric maps, while further integrating in-situ plasma parameters, pre-earthquake electric fields inferred from ion velocity measurements, and vertical electron density structure derived from radio occultation profiles. This integrated approach is expected to provide a more comprehensive characterization of the spatiotemporal behavior and physical consistency of pre-earthquake ionospheric anomalies (PEIA), and to establish a concrete and reproducible research framework for PEIA studies.

Keyword: FORMOSAT-7/COSMIC-2, pre-earthquake ionospheric anomaly, pre-earthquake electric fields

The Spatial Distribution of Heat and $PM_{2.5}$ in the Urban Area With Green Spaces

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Abstract

Urban green space plays a critical role in buffering the air quality and extreme heat for the population living in the city area under increasingly serious climate challenges. Urbanization deteriorates air quality through traffic pollution and poor ventilation, and the heat island effect is enhanced through impermeable paving and waste heat. A balanced solution is needed to maintain commercial and living functions and benefit the population's physical and psychological health in the city area. However, the government's urban planning began many decades ago. How the evidence of urban green space shows beneficial function for the population is critical for designing a new urban layout for the next generation. This study used meteorological parameters and $PM_{2.5}$ data in Taipei and Taichung in Taiwan to analyze the relationship between urban green space and air quality, Urban Heat Island Index, and Physiological Equivalent Temperature. The results may be helpful for urban planning and informed consideration of ecosystem service values of urban green space.

Keyword: urban green space; air pollution; UHI; PET

Observational Characteristics of Raindrops, Cloud Properties, and Aerosol in Warm Cloud Precipitation

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Abstract

This study investigates high-temporal-resolution interactions between aerosols, cloud properties, and raindrop characteristics during two winter seasons in Northern Taiwan, thus addressing the limited temporal resolutions of previous studies. Observational data of rain characteristics from a Parsivel2 disdrometer, cloud data from the Himawari-8 satellite, and PM2.5 aerosol concentrations were used to estimate variations in the raindrop size distribution (RSD) for different cloud intensities, aerosol levels, and relative humidity (RH). The results showed that warm rain predominantly contributes to winter precipitation, exhibiting shallower cloud tops, warmer cloud temperatures, larger cloud optical thickness, and smaller cloud droplets compared to non-warm rain. Regarding rain types, drizzle characterized by uniform small raindrop size and light rain demonstrated a greater variability of raindrop size with a high concentration of large drops. During warm rain cases where intense cloud, elevated PM2.5 levels, and high RH co-occur, drizzle generated larger raindrops with a wider RSD compared to light rain. In contrast, under high PM2.5 levels, light rain experiences constrained raindrop growth due to the saturation effect and a lower RH. These findings reveal that variations in the RSD—particularly the mass-weighted mean diameter (Dm)—are driven by distinct cloud property responses under intense cloud conditions, high aerosol loadings, and varying RH, highlighting complex interactions among aerosols, cloud properties, and raindrops

Keyword: Aerosol–cloud–precipitation interactions, raindrop size distribution, cloud properties, aerosol loading, cloud intensity, winter precipitation

Interactions between Anthropogenic Pollution and Plant Emissions on Aerosol Formation Mechanisms and Properties: Experimental and Observational Studies

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Abstract

In this study, we investigate the impact of interactions between SO_2 (an anthropogenic pollutant) and plant-derived VOC emissions on aerosol formation and properties. Using chamber experiments, we quantify how the addition of SO_2 alters the oxidation pathways of biogenic/anthropogenic VOCs, and the resulting secondary organic aerosol (SOA), affecting composition, volatility, nucleation, and growth dynamics. Parallel field observations, made with our air-quality box (AQB) systems, monitor chemical composition (CO, NO, NO_2, O_3, and CO_2), ambient aerosol number/size distributions, and temporal variation under real atmospheric conditions. Together, these experimental and observational datasets allow us to assess how the combination of natural and anthropogenic emissions affects the physical and chemical properties of aerosols. The combined results enhance our understanding of aerosol generation mechanisms and variability in real-world environments, with implications for air quality, aerosol-cloud interactions, and regional climate effects.

Keywords: Aerosol, SO_2, VOC, SOA, Air quality box.

台灣地區 $PM_{2.5}/O_3$ 濃度、污染天氣類型及氣象因子之關聯

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摘　要

The concentrations of $PM_{2.5}$ and O_3 are strongly influenced by polluted weather patterns and meteorological conditions. This study first examined these three factors—namely, pollutant concentrations, polluted weather patterns, and meteorological conditions—individually, followed by an analysis of their pairwise interactions. $PM_{2.5}$ and O_3 episodes were each classified into 12 distinct categories. Based on observational data from 2006 to 2024, 37.2% of $PM_{2.5}$ episodes in Taiwan during the northeast monsoon season were attributable to a combination of long-range transport (LRT) from the Asian continent coupled with local pollution in northern, central, and southern Taiwan (PW1), as well as LRT alone (PW2). Similarly, 35.1% of O_3 episodes occurred under comparable conditions (OW1 and OW2). Nevertheless, stratospheric intrusion may constitute an additional source that requires further validation. Orographic blocking by the Central Mountain Range (CMR) induces the polluted weather patterns PS1, PS2, PW3, PW4, PTY, OS1, OS2, OW3, OW4, and OTY, which collectively account for 20.4% and 24.1% of all $PM_{2.5}$ and O_3 pollution episodes, respectively. Seasonal variations reveal that $PM_{2.5}$ concentrations peak in winter, followed by spring and autumn, with the lowest values observed in summer. In contrast, O_3 concentrations are highest in spring and autumn, moderate in winter, and lowest in summer. The ventilation index (VI) remains low across southern Taiwan, indicating poor dispersion. Only a minor fraction of easterly airflow crosses the Central Mountain Range (CMR) and subsides over northern, central, and southern Taiwan. Northerly and easterly flows are more turbulent than westerly and southerly flows. For PW1, PW2, and PTN polluted weather patterns, wind speed, temperature, and relative humidity (RH) are lower, while VI is higher, compared to "other" polluted weather patterns and $PM_{2.5}$-ordinary days. For OW1, OW2, and OTN patterns, O_3 concentrations are relatively high in the CM, CE, YCN, and KP air quality areas, with average sunshine duration (SS) of 6.4–7.1 hours and global radiation (GR) of 15.0–16.7 MJ m^{-2}. For "other" polluted weather patterns, average SS and GR across Taiwan range from 5.1–7.3 hours and 15.8–17.7 MJ m^{-2}, respectively.

關鍵字：$PM_{2.5}$, O_3, polluted weather patterns, meteorology

How the Recondensation-Induced Nucleation Shapes Urban Aerosol Number

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Abstract

Air-quality models frequently underestimate urban particle number concentrations (PNC), particularly in the nucleation and Aitken size ranges, while reproducing $PM_{2.5}$ mass more accurately. This persistent low-PNC/high-$PM_{2.5}$ bias suggests that key number-forming processes are missing from current modeling frameworks. Here we investigate Recondensation-Induced Nucleation (RIN), a physically motivated mechanism in which pre-existing ambient aerosols are vaporized during engine combustion and subsequently re-nucleate as exhaust gases cool, enhancing particle number with little net change in mass.

We present controlled four-stroke engine experiments conducted under three intake conditions: ambient air, particle-free purified air, and aerosol-laden air. A distinct nucleation mode below ~30 nm appears only when ambient or seeded aerosols are present in the intake air, providing direct laboratory evidence for RIN. Increasing intake aerosol loading enhances exhaust PNC, but with a strongly sub-linear response, indicating a self-limiting process. To interpret these findings, we employ idealized aerosol parcel-model simulations of the H_2SO_4–H_2O system that resolve heating-induced evaporation and cooling-induced nucleation. The simulations demonstrate rapid in-cylinder evaporation of pre-existing particles, followed by burst nucleation during cooling that is regulated by condensation and coagulation sinks, explaining the observed saturation behavior.

A parameterized RIN module is then implemented in the Community Multiscale Air Quality (CMAQ) model and applied to regional simulations over Taiwan for November 2020. Without RIN, CMAQ underestimates observed PNC at the urban Xitun site by ~75% while overestimating $PM_{2.5}$ by ~21%. Incorporating RIN substantially improves model performance: depending on assumed particle size distribution parameters, the PNC bias is reduced to as low as 14%, with negligible impact on $PM_{2.5}$. The RIN mechanism effectively transfers aerosol mass from the accumulation mode to Aitken-mode number, also correcting the long-standing underestimation of the Aitken-to-accumulation number ratio in urban environments.

Our results demonstrate that RIN provides a missing mechanistic link between combustion microphysics and ambient ultrafine particle abundance. Including this process in air-quality models significantly improves the simulation of health-relevant particle number concentrations and helps reconcile the divergent biases in aerosol mass and number commonly found in urban simulations.

Impact of PBL Processes and Urbanization on Fine-Scale Meteorological Simulation

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Abstract

The planetary boundary layer (PBL) plays a critical role in regulating meteorological variability and the transport and dispersion of air pollutants in metropolitan regions. In recent decades, rapid economic development and urban expansion in Taiwan have resulted in substantial land-use changes, intensifying the urban heat island effect and exacerbating air pollution. In this study, a high-resolution meteorological modeling system coupled with urban canopy parameterizations and multiple PBL schemes is employed to investigate PBL physical processes and to characterize the thermal and dynamic structures of the PBL over urban areas. The simulations further incorporate the Local Climate Zone (LCZ) classification framework, using ten LCZ urban types to improve the representation of urban land use and building morphology. To examine urban air pollution in greater detail, an air quality model is applied to explore the interactions among urbanization, PBL processes, and air quality. Preliminary results indicate that simulations using the ten LCZ urban types exhibit more pronounced spatial heterogeneity than those using a single urban category. In addition, the PBL schemes tend to overestimate daytime vertical mixing and underestimate nocturnal cooling, leading to an underestimation of pollutant concentrations. Details can be discussed during the conference.

冰核濃度對西北太平洋冬季海洋性邊界層雲的影響

Ice Nuclei Influence on Wintertime Marine Boundary-Layer-Topped Clouds over the Northwestern Pacific

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摘　要

東亞冬季的冷空氣潰流(Cold-Air Outbreak, CAO)常在海面上形成海洋性邊界層雲(Boundary-Layer-Topped Cloud, BLTC)。此區雲系受沿岸工業與海運排放影響，過往研究指出其對凝結核(Condensation Nuclei, CN)濃度變化相當敏感，且在暖雲與混合態雲中呈現不同反應。在冷空氣背景下，雲冰需依賴冰核(Ice nuclei, IN)啟動凝華或過冷水凍結等冰成過程，而東亞冬季沙塵事件頻繁，沙塵作為 IN，其濃度變化也將影響 BLTC 的雲結構、降水與輻射特性。

本研究使用 Weather Research and Forecasting (WRF)模式與本團隊開發的 NTU 雲微物理方案，選取個案嘗試討論混合態 BLTC 在不同 IN 數量濃度下的雲結構、降水行為與雲的氣膠易感度(Cloud Susceptibility to Aerosol, CSA)變化。結果顯示 BLTC 的冰化(Glaciation)程度會隨 IN 數量濃度上升而增加，雲頂逐漸接近完全冰化。降水量亦因 IN 數量濃度增加而提升，最高增幅超過一倍，並伴隨雲覆量降低約 10%、區域反照率下降超過 50%。降水類型從低 IN 濃度時的軟雹主導，轉變為軟雹和雪共同主導；然而在因海溫高於冰點的條件下，地面降水以液態為主。此外低 IN 濃度時，冰化程度與降水對 IN 不敏感，與衍生性冰晶(Secondary Ice)機制的作用有關。

在氣膠間接效應方面，IN 數量濃度增加會降低 BLTC 降水 CSA 的絕對值，使高 IN 濃度下降水對 CN 濃度漸趨不敏感。此外，IN 數量濃度的改變也會使降水 CSA 的符號發生轉換，使雲水含量、雲反照率、雲覆量與全區域反照率等 CSA 表現出顯著非線性（雙轉折）的特徵。

關鍵字：冰核、氣膠間接效應、海洋性邊界層雲、雲的氣膠易感度

Keyword: Ice Nuclei, Aerosol Indirect Effect, Marine Boundary-layer-topped Cloud, Cloud Susceptibility of Aerosol

Impact of climate extremes on local carbon and hydrological cycles

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Abstract

Global warming is often discussed in terms of rising average temperatures (+1.1 °C since pre-industrial times), but the most profound impacts on biogeochemical cycles arise from changes in climate variability rather than mean trends. A warmer atmosphere holds approximately 7% more water vapor per degree Celsius (Clausius-Clapeyron relation), energizing the hydrological cycle. This leads to an intensification of weather patterns where wet regions become wetter and dry regions drier, punctuated by increasingly frequent and severe extremes such as heatwaves, droughts, and heavy precipitation events. These extremes act as "shocks" to the global/regional/local carbon and hydrological cycles, often triggering non-linear responses that can override years of gradual carbon sequestration or stable water flow. As noted previously, extreme events can instantaneously reverse the carbon sink function of ecosystems, releasing vast amounts of CO_2 and creating positive feedback loops that further accelerate warming. This study is thus proposed to study the impact of climate extremes on local/regional carbon and hydrological cycles.

Keyword: Global warming, climate extremes, terrestrial carbon cycles, hydrological cycles

以車載移動風光達探討西部平原邊界層空間不均勻與背風渦旋下沉效應

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摘要

本研究以車載移動光達與固定式都卜勒風光達觀測，結合 ERA5 再分析渦度（ζ）與 Okubo–Weiss（OW）參數，釐清臺灣西南部邊界層高度的空間不均勻性及其與反氣旋型背風渦旋之動力關聯。車載剖面顯示西部平原混合層高度（MH）存在明顯「南北轉換」：北側（雲林–嘉義）MH 可達約 1.8–2.0 km 且氣膠垂直分布較均勻；但南側（臺南–高雄）MH 會突降至約 1.2–1.4 km，同時出現氣膠重新集中於低層的滯留特徵，呈現邊界層受壓縮的結構。

進一步統計固定站資料顯示，反氣旋渦度強度與對流邊界層高度（CBLH）、MH 及 760 m 附近垂直風速（Wz）具有高度一致的系統性變化：渦度愈強，CBLH/MH 愈低，且伴隨更強下沉（Wz 更為負值）；夜間在強渦度情境下，MH 可低至約 350 m，顯示渦旋下沉可顯著壓縮穩定邊界層。 同時，背風渦旋具有中尺度且持續性的特徵，平均尺度約 46 ± 18 km。

整體結果指出：反氣旋型背風渦旋並非靜態存在，而會隨日變風場與地形誘導環流調整，其下沉中心的位移可動態控制西南部沿海邊界層厚度與氣膠垂直分布，進而影響污染物稀釋與滯留的時空型態。

關鍵字：移動風光達、邊界層、背風渦旋

Exploration of complex physical and chemical processes of a severe haze episode over central Taiwan

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Abstract

Nitrate is one of the significant inorganic aerosols and is frequently experienced as the dominant component during air quality events in central Taiwan. This study examined a haze event with unprecedented PM2.5 levels and peaked at 110 μg/m³ in central Taiwan's urban areas (UAPRS station) during 04-05 November 2021. Data showed PM2.5 at UAPRS was 29.0 μg/m³ during the day and 89.7 μg/m³ at night. Notably, nitrate dramatically increased from 4.4 to 39.0 μg/m³, contributing 43.5% to the nighttime rise in PM2.5 in central Taiwan on the event day.

Simulation results indicated that the lee-side vortex, driven by the interaction between the ambient flow and the Central Mountain Range (CMR), facilitated the accumulation of pollutants, transporting them northward to the ocean and then returning as the ambient wind direction changed from easterly to southeasterly. Additionally, the swept-back plume in the afternoon, driven by the lee-side northwesterly flow and overlaid with urban pollution, was a key contributor to the first PM2.5 peak at 20:00-22:00 LST on November 4. The mechanisms study revealed that nitrate aerosol was dominant, with N_2O_5 hydrolysis playing a critical role in its formation in the nocturnal atmospheric chemistry. Furthermore, the convergence of the lee-side northwesterly flow with the mountain downslope wind at midnight, combined with the reduction in planetary boundary layer height, enhanced the second PM2.5 peak, which occurred between 02:00 and 03:00 LST on November 5. The findings of this study can be applied to other regions with similar complex topography, pollution environments, and comparable relief.

利用研究級簡易微型感測器探討易感受族群之微環境微粒暴露與熱暴露

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Abstract

Numerous studies have shown that exposure to excessively hot environments or poor air quality can cause cardiovascular and respiratory diseases. In Taiwan's Central Air Quality Control Region, Nantou County experiences relatively few days of good air quality, with Zhushan Township being the most affected. Accordingly, this study focuses on the Zhushan area to investigate particulate matter (PM) and heat exposure among elementary school children in their daily living environments. A total of 28 elementary school children were recruited for personal exposure monitoring. Among them, 7 participants in summer and 8 in winter were further selected for simultaneous indoor and outdoor household monitoring. Continuous 24-hr measurements were conducted over five consecutive days without disrupting daily routines. Each child carried three miniature monitoring devices: a portable all-in-one micro-sensor (AS-LUNG), a temperature and illuminance data logger (HOBO UA), and a temperature/humidity/illuminance/external-channel logger (HOBO U12). These instruments collected data on PM, carbon dioxide, temperature, relative humidity (RH), and illuminance. Temperature, RH, and illuminance data were converted into wet bulb globe temperature (WBGT), and multiple regression models were applied to assess the factors influencing personal PM exposure. Results showed that personal $PM_{2.5}$ and PM_{10} exposure in summer and winter complied with 24-hr air quality standards across all microenvironments. WBGT-based heat hazard levels consistently fell within the cautionary and alert ranges. In households, $PM_{2.5}$ and PM_{10} concentrations in both seasons remained below regulatory thresholds: outdoor levels complied with Taiwan's ambient air quality standards, while indoor levels met the requirements of the Indoor Air Quality Management Act. Correspondingly, WBGT heat hazard levels in household settings also remained within the cautionary and alert categories. When personal exposure was examined in relation to indoor and outdoor levels, the analysis showed that a 1 μg/m³ increase in indoor and outdoor particulate concentrations resulted in personal exposure increases of 0.0259–0.0377 μg/m³ and 0.0103–0.0275 μg/m³, respectively, with R^2 ranging from 59% to 67%. Using indoor measurements to predict personal exposure, increases in indoor PM, RH, and carbon dioxide levels, as well as decreases in temperature, were all positively associated with higher personal exposure (R^2 = 55–66%). When using outdoor measurements, increases in outdoor levels and decreases in temperature were significantly associated with higher personal exposure, though with slightly lower explanatory power (R^2 = 43–55%). Overall, this study demonstrates that summer and winter personal exposure and household indoor and outdoor PM measurements were well below regulatory limits, while heat stress remained within cautionary ranges. Predictive models based on indoor and outdoor measurements performed well, with the combined indoor–outdoor approach providing the strongest predictive capability for personal particulate exposure.

Keyword: elementary school children, particulate matter, heat stress, research-grade low-cost sensor

夜間輻射冷卻與逆溫垂直結構對於空氣污染之影響

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Abstract

Nighttime air pollution episodes frequently occur in central Taiwan during winter and early spring under stable atmospheric conditions. This study investigates the role of nighttime radiative cooling and the development of the nocturnal stable boundary layer (NSBL) in regulating $PM_{2.5}$ concentrations over Douliu, Taiwan, during 2020-2025. Unmanned aerial vehicle (UAV) vertical observations are used to characterize the nocturnal vertical structure of meteorological variables and $PM_{2.5}$, while ERA5 reanalysis radiation data are employed to quantify nighttime radiative cooling. A total of 351 nighttime UAV profiles were analyzed to examine the characteristics of nocturnal temperature inversions and stable boundary layer. The curvature of the potential temperature profile (γ) is applied as a diagnostic parameter to describe the evolution of the NSBL. The results show that nocturnal surface temperature inversions occur frequently, accounting for approximately 41% of nighttime flights, with the bottom of the inversion layer mainly forming at altitudes below 50 m and an intensity of 1-4°C per 100 meters. These inversion conditions are mainly associated with negative curvature ($\gamma < 0$), indicating strong surface radiative cooling and suppressed turbulent mixing. During inversion nights, surface $PM_{2.5}$ levels averaged 65 μg m^{-3}, representing a 15% increase compared to non-inversion nights (56.4 μg m^{-3}), demonstrating the critical influence of nocturnal stable boundary layer on pollutant accumulation.

A case study conducted during 1-2 December 2024 illustrates the coupled evolution of radiative cooling, NSBL structure, and $PM_{2.5}$ under clear-sky and weak wind conditions associated with a persistent high-pressure system. During this event, net longwave radiation remained below -60 W m^{-2} throughout the night, leading to progressively strengthened surface inversions, with the inversion height reaching up to 200 m and near-surface $PM_{2.5}$ concentrations exceeding 80 μg m^{-3}. After sunrise, surface heating broke down the stable layer, shifted γ toward positive values, and rapidly reduced $PM_{2.5}$ concentrations. The strong positive correlation ($r = 0.66$) between inversion intensity and $PM_{2.5}$ concentration confirms the dominant role of radiative cooling and induced boundary layer stability in controlling nighttime air quality over Douliu. These results highlight the importance of nocturnal stable boundary layer processes driven by radiative cooling in shaping wintertime air pollution over Douliu and underscore the need to explicitly consider nighttime boundary layer dynamics in air quality assessment and management.

Keyword: Radiative cooling, Nocturnal Stable Boundary layer (NSBL), Nocturnal surface temperature,

Air quality, UAV observations.

Field-based assessment of methane mitigation in rice paddies under contrasting irrigation regimes in a subtropical region using DNDC model

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Abstract

In response to growing concerns over greenhouse gas emissions from rice cultivation, water-saving irrigation practices have increasingly been recognized as potential mitigation strategies. This study presents a comparative evaluation of methane (CH_4) emissions under two contrasting irrigation regimes—continuous flooding (CF) and drip irrigation (DI)—based on a field experiment in a subtropical rice-growing region of Taiwan. By combining direct field-based CH_4 flux measurements with process-based simulations using the DeNitrification–DeComposition (DNDC), this work provides one of the first empirical assessments of DI-induced CH_4 responses under subtropical region of Taiwan, offering diagnostic insights into how irrigation management influences methane emission dynamics. Measured results showed that DI reduced mean CH_4 emissions by 85.1% compared with CF, while maintaining rice yield. Temporal variations in CH_4 fluxes were characterized by low and stable emissions during the fallow and maturity stages, whereas pronounced emission peaks occurred during the vegetative stage, particularly following irrigation, fertilization and rainfall events. DNDC simulations captured the general temporal patterns of CH_4 variability but showed notable discrepancies in soil moisture representation and cumulative emission magnitudes, particularly under CF conditions. Sensitivity analysis further indicated that simulated CH_4 emissions were most responsive to parameters related to soil water status and irrigation management. This study provides field-based evidence that drip irrigation can effectively mitigate CH_4 emissions from rice paddies in a subtropical region without yield penalties, and highlights the importance of hydrological variability and event-driven processes in shaping both observed and simulated CH_4 dynamics.

Keyword: Rice paddy field, CH_4, drip irrigation, continuous flooding, DNDC model

2024 ASIA-AQ/KPEx飛航量測VOC特性分析

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摘　要

為了解亞洲各大都會的空品狀態與空污成因，美國NASA與台灣多個官學研單位於2024年春季同步進行ASIA-AQ亞洲空品飛航觀測暨KPEx高屏實驗，NASA兩架科研飛機(G-III和DC-8)於此期間飛經台灣西南平原上空，一共完成四次密集觀測(IOP)，其中DC-8於2024年2/15 (IOP-1)、3/13 (IOP-3)、3/27 (IOP-4)出動觀測，搭載質譜儀(GC/MS)即時監測飛航路徑沿線之揮發性有機化合物(VOC)濃度變化，本研究即針對歷次IOP的觀測結果，分析台灣對流層不同高度的VOC分佈與特性。

結果指出，三次IOP因不同的氣象型態而呈現明顯不同的VOC垂直分佈特徵，並可能影響不同高度的臭氧生成貢獻。例如IOP-1時普遍污染物濃度較低，視為該季節無空污事件時的一般狀態；IOP-3時大氣垂直混合狀態較均勻，2500 m以下各高度呈現較為一致的VOC特徵分佈；IOP-4時遭遇高壓迴流之天氣型態，背風渦流與變界層抑制了垂直擴散，致使污染物含VOC集中於近地表，呈現高濃度狀態。

本研究並利用VOC間之比值關係，如苯(benzene)、甲苯(toluene)、乙苯(ethylbenzene)等BTE特性，並搭配特定交通源示蹤劑如甲基第三丁基醚(MTBE)等，解析不同高度的臭氧前驅物可能來源。結果顯示，所有IOP期間MTBE集中分佈於交通源相關之BTE特性區間；另利用Ox評估氣團光化特性，例如IOP-1和IOP-4時，較高的Ox與交通源明顯相關，對比之下IOP-3時Ox與BTE關聯性較弱，顯示當時空氣組成受區域性主導，而非為當地排放。以1000 m為分界，IOP-1和IOP-4時皆呈現高低空明顯不同的VOC特徵，而IOP-3時上下層空氣的VOC特性則十分相似，說明天氣型態對高屏地區空污的影響甚為深遠，在制定管制政策時必須納入考量。

關鍵字：亞洲空品飛航觀測(ASIA-AQ)、高屏實驗(KPEx)、揮發性有機化合物(VOC)、臭氧

(ozone)、甲基第三丁基醚(MTBE)

雲霧沉降及局地性環流與空氣污染交互作用之探討

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摘要

在總計畫「氣膠對雲霧微物理性質及降水時空分布之影響」本子計畫「雲霧沉降及局地性環流與空氣污染交互作用之探討」於人為源與生物源交會之雲嘉平原與山區，利用鄰近人為污染(中部與雲嘉南空品區)與陡峭山型及多雲霧特性，藉由不同海拔現地量測空氣中污染物組成之時空變化，探討雲霧沉降及局地性環流與空氣污染交互作用。結果顯示於山區採集 $PM_{2.5}$、PM_{10} 之顆粒濃度，證實 PM 顆粒濃度會受到山區採樣點之山谷風環流所影響並於白天逐漸累積。山區 Σ9PAEs、Non-PAEs、VOCs 白天濃度皆高於夜晚，受山谷風環流影響。本研究初步證實了 PBL 與污染物濃度蓄積有關。當 PBL 高度與山區採樣點海拔相近時，山區採樣點污染物濃度上升；當 PBL 高度於山區採樣點海拔之下，山區污染濃度下降。當 PBL 高度鄰近地表時(約 250~500 公尺)，平地污染物濃度明顯上升，於冬季時最為明顯。本研究結果發現污染物在垂直分布上，固相 Σ9PAEs、Non-PAEs 於山區及平地之間具有顯著差異($p<0.05$)，平地濃度皆大於山區。VOCs 於山區及平地之間統計具有顯著差異($p<0.05$)，平地濃度高於山區。雲嘉地區的雲霧水中主要 PAEs 為 DEHP(24.10±14.24 μg/L)，Non-PAEs 塑化劑濃度為 DEHT(7.55±0.52 μg/L)、DINCH(24.74±7.32 μg/L)；雨水中主要 PAEs 塑化劑為 DMP(13.66±0.49 μg/L)、DEHP(11.11±4.59 μg/L)、DNOP(11.42±0.14 μg/L)、DINP(12.44±2.54 μg/L)。山區雲霧水中 PAEs 濃度>雨水 PAEs 濃度。雲霧水的 PAEs 掃除係數較雨水的掃除係數高，分子量大小與蒸氣壓高低不但影響 PAEs 在大氣中的濃度，也影響了濕沉降時對於不同塑化劑的掃除係數。

關鍵字: 局地性環流、空氣污染、雲霧水、邊界層

Why Does $PM_{2.5}$ Accumulate Inland? Seasonally Distinct Roles of Autumn Sea–Land Breeze Circulation and Winter–Spring Easterly Leeside Flow

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Abstract

Air quality deterioration over the inland and leeside plains of west-central Taiwan occurs recurrently during different seasonal transition periods but is driven by distinct yet related meteorological mechanisms. This study integrates long-term surface observations, intensive field measurements, ground-based remote sensing, vertical profiles from unmanned aerial systems, and high-resolution numerical simulations to investigate multiscale controls on inland $PM_{2.5}$ accumulation under two representative regimes: autumn sea–land breeze circulation and late-winter to early-spring easterly flow associated with high-pressure peripheral circulation. During autumn, weak synoptic forcing allows thermally driven sea–land breezes to dominate pollutant transport, with daytime inland penetration of coastal air masses and nighttime boundary layer collapse promoting $PM_{2.5}$ accumulation over inland urban areas. In contrast, during the winter-to-spring transition, persistent easterly background flow interacting with the Central Mountain Range produces sheltered leeside environments characterized by reduced wind speeds, low-level convergence, and shallow, stable planetary boundary layers over the west-central plains. Under both regimes, vertical observations consistently show that elevated $PM_{2.5}$ concentrations coincide with boundary layer heights of only a few hundred meters and enhanced atmospheric stability, indicating strong vertical confinement of pollutants. Mesoscale thermal circulations further modulate the leeside background flow, enhancing inland convergence and nocturnal accumulation. Collectively, these results demonstrate that although the dominant circulation drivers differ between seasons, inland $PM_{2.5}$ deterioration in Taiwan is governed by a common multiscale coupling framework in which weak synoptic forcing, terrain-modulated mesoscale circulations, and diurnal boundary layer evolution jointly control horizontal transport and vertical dispersion. The findings show the importance of seasonally dependent mechanisms and vertical structure observations for understanding and forecasting air quality degradation in mountainous coastal regions.

Keyword: $PM_{2.5}$ accumulation, Sea–land breeze circulation, Easterly leeside flow, Boundary layer stability