# 結合雙段式參數化風場與沿海淺水區海面阻力係數校正之暴潮模擬：2025 年丹娜絲颱風案例研究

# Storm Surge Simulation Combining a Two-Segment Parametric Wind Field with Sea Surface Drag Coefficient Calibration for Shallow Coastal Waters: A Case Study of Typhoon Danas (2025)

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## 摘　要

2025 年 7 月，中度颱風丹娜絲以較少見的移動路徑侵襲臺灣西南部，造成臺南七股等沿海低窪地區發生海水倒灌。潮位資料顯示，此次事件的暴潮反應具有顯著的局部差異及短延時特性。其中，東石潮位站呈現暴潮偏差由負值迅速轉為正值的水位變化，將軍潮位站則觀測到歷時短、振幅大的正暴潮尖峰。然而，氣象署現行作業化 COMCOT-SS 暴潮預報設定雖能掌握主要潮汐變化，對上述局部暴潮訊號的發生時間與振幅仍有明顯低估或偏移，顯示現行預報系統在沿海地形解析、颱風風場描述及海氣動量交換參數化方面仍有改善空間。

本研究採用 COMCOT-SS 暴潮模式，求解納入氣壓梯度力與海表面風剪應力的非線性淺水波方程式，並以控制變因方式逐步檢視影響丹娜絲颱風暴潮模擬的關鍵因素。首先，將臺灣西南沿海巢狀網格解析度由公里尺度提高至 200 m，以強化模式對潮間帶、沿海淺灘、港灣及複雜岸線的描述能力。其次，建立雙段式參數化風場，分別刻畫最大風速半徑內側的核心風速增長，以及外側環流的風速衰減，以呈現丹娜絲颱風風眼尺度較小且強風集中的風場特徵。此外，透過最大風速敏感度試驗，分析颱風強度變化對暴潮水位的影響。針對傳統深水或開闊海域阻力係數公式未必適用於臺灣西南沿海淺水環境的問題，本研究進一步結合 Charnock 關係、動態 Charnock 參數、粗糙長度上限及雙曲正切平滑函數，建構沿海淺水海面阻力係數 CD 的敏感度分析與校正方法。

研究結果顯示，提高地形解析度有助於改善局部水深及岸線的呈現，亦可降低測站所在格點選取所造成的不確定性，但僅調整地形解析度仍無法充分再現東石站的負暴潮偏差與將軍站的正暴潮尖峰。採用雙段式參數化風場後，模擬暴潮訊號在時間與空間上的分布更為集中，並改善東石站由負轉正的相位變化及將軍站的整體模擬誤差。增加最大風速可增強暴潮振幅，但仍不足以單獨重現兩測站的極端訊號。當雙段式風場與沿海淺水 CD 校正共同應用時，東石與將軍站的水位歷線及暴潮偏差模擬皆呈現較一致的改善。

綜合而言，丹娜絲颱風期間的暴潮預報誤差是沿海地形解析度、颱風風場結構、最大風速及海氣動量交換參數共同影響的結果。本研究建立的控制變因分析流程及淺水海面阻力係數校正方法，可提供臺灣西南沿岸暴潮預報系統進行事件型在地化調整的科學依據。未來仍須利用更多不同強度與路徑的颱風案例，以及獨立觀測資料，進一步檢驗相關參數的適用性與可移植性。

關鍵字：丹娜絲颱風、暴潮、COMCOT-SS、雙段式參數化風場、海面阻力係數、沿海淺水區

## Abstract

In July 2025, Typhoon Danas, classified as a moderate typhoon in Taiwan, followed an unusual track across southwestern Taiwan and caused seawater intrusion in low-lying coastal areas, including Qigu District in Tainan. Tide-gauge observations revealed highly localized and short-duration storm surge responses. At Dongshi, the surge residual rapidly transitioned from a negative to a positive value, producing a distinct fall–rise pattern. At Jiangjun, a short-lived positive surge peak with a large amplitude was recorded. Although the operational COMCOT-SS configuration used by the Central Weather Administration reproduced the principal tidal variations, it did not adequately capture the timing and magnitude of these localized surge signals. This discrepancy indicates potential limitations in coastal topographic representation, typhoon wind-field reconstruction, and air–sea momentum-transfer parameterization.

This study employed the COMCOT-SS model, which solves the nonlinear shallow-water equations with atmospheric pressure-gradient forcing and sea-surface wind stress. A sequence of controlled numerical experiments was conducted to identify the principal factors governing the storm surge response during Typhoon Danas. First, the nested-grid resolution along the southwestern coast of Taiwan was refined from the kilometer scale to 200 m to improve the representation of intertidal zones, shallow banks, harbors, and complex shorelines. Second, a two-segment parametric wind-field model was developed to separately describe the increase in wind speed within the radius of maximum wind and its decay in the outer circulation. This formulation was designed to represent the compact wind structure and concentrated strong winds of Typhoon Danas. Maximum-wind-speed sensitivity experiments were also performed to evaluate the influence of typhoon intensity uncertainty on surge amplitude. Because drag-coefficient formulations derived primarily for deep or open-ocean conditions may not be directly applicable to the shallow coastal waters of southwestern Taiwan, a sensitivity-analysis and calibration framework for the sea-surface drag coefficient CD was constructed using the Charnock relation, a dynamic Charnock parameter, an upper limit for aerodynamic roughness length, and a hyperbolic-tangent smoothing function.

The results indicate that increasing the topographic resolution improved the representation of local bathymetry and shorelines and reduced uncertainties associated with the selection of tide-gauge grid cells. However, topographic refinement alone was insufficient to reproduce the pronounced negative surge residual at Dongshi and the positive surge peak at Jiangjun. The two-segment wind field produced a more concentrated storm surge response and improved both the negative-to-positive phase transition at Dongshi and the overall simulation error at Jiangjun. Increasing the maximum wind speed amplified the simulated surge but could not independently reproduce the extreme signals observed at both stations. When the two-segment wind field was combined with the calibrated shallow-water CD, more consistent improvements were obtained in the simulated water-level time series and surge residuals at Dongshi and Jiangjun.

Overall, the storm surge forecast errors during Typhoon Danas resulted from the combined effects of coastal topographic resolution, typhoon wind-field structure, maximum wind speed, and air–sea momentum-transfer parameterization, rather than from any single factor. The controlled-experiment procedure and shallow-water drag-coefficient calibration framework developed in this study provide an event-based scientific basis for the local calibration of storm surge forecasting systems along the southwestern coast of Taiwan. Nevertheless, the applicability and transferability of the calibrated parameters should be further evaluated using additional typhoon events with different intensities and tracks, together with independent observational datasets.

Key words: Typhoon Danas, storm surge, COMCOT-SS, two-segment parametric wind field, sea-surface drag coefficient, shallow coastal waters