桃園岸基海流觀測網：雙基站高頻雷達之建置與驗證

Taoyuan Shore-Based Surface Current Observation Network: Implementation and Validation of a Bistatic HF Radar System

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摘　　要

高頻雷達可提供大範圍且連續的沿岸表層海流觀測，然而傳統單基站系統之觀測範圍容易受到海岸線配置、測站位置與雷達觀測幾何限制，可能產生空間覆蓋不足與觀測盲區。為提升桃園沿岸海流監測能力，本研究於中央氣象署桃園岸基海流觀測網之永安高頻雷達測站建置雙基站測試系統，並由國立中央大學與中央氣象署共同進行系統整合、觀測及資料比較驗證。

永安站之特色，在於單基站與雙基站系統共用相同的接收天線陣列，並可於相同時間觀測相同海域，但分別具有不同的發射與接收幾何架構。單基站系統之發射端與接收端位於同一測站，雙基站系統則由不同位置之發射端與永安接收端共同形成觀測幾何。此一配置可降低接收天線特性、觀測時間及環境條件差異所造成的影響，使單基站與雙基站資料得以在相對一致的條件下進行直接比較。

在系統建置方面，本研究完成雙基站相關硬體整合，並導入以全球導航衛星系統校準之每秒脈衝訊號及直接數位合成器相位控制為基礎的時間與頻率同步機制，以維持雙基站雷達運作所需之訊號同調性。資料處理流程包括雙基站橢圓幾何之散射點定位、雙基站布拉格頻率計算、都卜勒頻譜處理、接收通道相位與增益校正，以及雙基站徑向流速反演。

為驗證雙基站資料處理與海流反演流程，本研究將雙基站徑向流速與共用接收天線所得之單基站結果進行時間與空間配對，藉以比較不同觀測幾何下之流速變化、一致性、系統性差異及空間覆蓋特性。此種同時、同地且共用接收系統的比較方式，可減少不同儀器與不同觀測時段所造成的不確定性，並提供雙基站高頻雷達初步驗證之基礎。後續亦將導入浮標或其他現地海流觀測資料，進一步進行獨立驗證與誤差量化。

本研究建立桃園永安單基站與雙基站高頻雷達之整合測試環境，以及一套涵蓋硬體同步、幾何轉換、訊號校正、海流反演與比較驗證的處理架構，可作為未來擴充桃園岸基海流觀測網、改善近岸觀測盲區及提升沿岸海流監測韌性之基礎。

關鍵字：雙基站高頻雷達、岸基海流觀測網、表層海流、雷達觀測幾何、交叉驗證

Abstract

High-frequency radar provides wide-area and continuous observations of coastal surface currents. However, the spatial coverage of conventional monostatic systems is often constrained by coastline configuration, site location, and radar viewing geometry, potentially resulting in incomplete coverage and observational blind zones. To enhance coastal current monitoring along the Taoyuan coast, a bistatic HF radar test system was implemented at the Yongan HF radar site operated by the Central Weather Administration. System integration, observations, and data comparison were jointly conducted by National Central University and the Central Weather Administration.

A key feature of the Yongan site is that the monostatic and bistatic systems share the same receiving antenna array and simultaneously observe the same coastal waters, while operating with different transmitter–receiver geometries. In the monostatic configuration, the transmitter and receiver are located at the same radar site, whereas the bistatic configuration combines a spatially separated transmitter with the receiver at Yongan. This arrangement reduces the effects of differences in receiving antenna characteristics, observation time, and environmental conditions, thereby enabling direct comparison between monostatic and bistatic measurements under relatively consistent observational conditions.

For system implementation, the bistatic hardware components were integrated with a timing and frequency synchronization scheme based on Global Navigation Satellite System-disciplined pulse-per-second signals and direct digital synthesis phase control. This design maintains the signal coherence required for bistatic radar operation. The data-processing workflow includes scattering-point localization based on bistatic elliptical geometry, calculation of bistatic Bragg frequencies, Doppler spectral processing, phase and gain calibration of the receiving channels, and retrieval of bistatic radial current velocities.

To evaluate the bistatic processing and current-retrieval procedures, the retrieved bistatic radial velocities were matched in space and time with monostatic results obtained using the shared receiving antenna array. The comparison was used to examine current variability, consistency, systematic differences, and spatial coverage characteristics under the two radar geometries. This simultaneous and co-located comparison using a common receiving system reduces uncertainties caused by different instruments and observation periods and provides a basis for the preliminary validation of bistatic HF radar measurements. Buoy measurements or other in-situ current observations will subsequently be incorporated for independent validation and quantitative error assessment.

This study establishes an integrated monostatic–bistatic HF radar test environment at Yongan, together with a processing framework covering hardware synchronization, geometric transformation, signal calibration, current retrieval, and comparative validation. The framework provides a foundation for expanding the Taoyuan shore-based surface current observation network, reducing nearshore observational gaps, and improving the resilience of coastal current monitoring.

Key words : bistatic HF radar, shore-based current observation network, surface currents, radar geometry, cross-validation