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Seasonal Variation of the Direction of the Tropical Western Pacific Circulation and Its Climate Effects

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Abstract. Few places in the global ocean trade heat with the atmosphere as actively as the Tropical Western Pacific (TWP). When its currents shift with the seasons, the consequences travel. This paper pulls observational and modelling work from the literature into one synthesis on the directional and intensity changes of TWP circulation — and what they imply for climate variability. A few things come through. The monsoon's wind-stress curl decides where the North Equatorial Current (NEC) splits, and the splitting latitude — which moves through the year — controls how much water heads on into the Kuroshio versus the Mindanao Current. That same partition shapes the heat content and footprint of the Western Pacific Warm Pool, which feeds forward into ENSO onset and into how the cycle switches between phases. The atmosphere then responds in turn. Moisture transport adjusts, and observed precipitation anomalies across the Indo-Pacific line up with what the ocean is doing. No new model runs are reported here. The point made is simpler: seasonal TWP circulation is not background to climate prediction. It is one of the bridges linking western boundary variability to the climate response.

Keywords: Tropical Western Pacific, North Equatorial Current, ENSO, Western Pacific Warm Pool

1. Introduction

Few parts of the world ocean are tied as tightly to climate as the Tropical Western Pacific (TWP). The region is, in effect, a working laboratory for ocean–climate coupling. Hu et al. [1] gathered the larger picture in a wide-ranging assessment of Pacific western boundary currents — currents they linked to ENSO, to the Pacific Decadal Oscillation, and to inter-basin heat redistribution running through the Indonesian Throughflow. Qiu and Lukas [2] came at the problem from a more theoretical angle. They paired linear Sverdrup theory with a nonlinear reduced-gravity model, and used the combination to follow the NEC, the Mindanao Current, and the Kuroshio at the western boundary on both seasonal and interannual scales. The timing they pulled out is worth noting: October is when the NEC bifurcation reaches furthest north, with February pulling it back to its southernmost. Later, work tied to the OKMC programme [3] reinforced the picture — bifurcation latitude and the way transport is split turn out to shape the warm pool by lateral advection. Then, with 17 years of satellite altimetry on hand, Qiu and Chen [4] resolved further interannual-to-decadal shifts in the bifurcation east of the Philippines.

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On that backdrop, the present paper turns to the seasonal direction and intensity changes of TWP circulation — and the climate footprint they leave. Particular attention goes to the Warm Pool heat budget and to regional rainfall anomalies. The treatment is synthetic. It draws on multi-decadal observational evidence and on recent modelling, with representative case studies as anchors. No independent numerical experiment is attempted.

2. Seasonal variation characteristics of Tropical Western Pacific circulation

2.1. Wind-driven forcing and the Sverdrup balance

TWP circulation, at basin scale, answers to two forcings working together: the East Asian monsoon and the broader trade-wind system. The mechanism is Sverdrup. Curl of the surface wind stress sets meridional mass transport (V), and as the wind field migrates through the season the underlying transport pattern follows it. Boreal winter brings stronger northeasterly trades and a more vigorous NEC. In boreal summer it is the monsoonal regime that takes over, reworking the curl field and reshuffling the relative strength of the basin's major currents. Hu et al. [1] make the broader case here. Even with quantitative gaps still open, wind-driven western boundary currents carry real climatic weight — particularly where ENSO is concerned.

2.2. Latitudinal shifts of the North Equatorial Current (NEC) bifurcation

Of all the diagnostic features of TWP circulation, the most useful is probably the latitude at which the NEC splits as it nears the Philippine coast. Water hitting the coast above that latitude joins the Kuroshio Current (KC); water arriving below it heads south, into the Mindanao Current (MC). The dividing line is anything but fixed. It moves through the year, tracking shifts in the large-scale wind-stress field.

Some of this displacement is delivered by westward-propagating baroclinic Rossby waves. They carry wind-stress anomalies from the central and eastern Pacific back across the basin to the western boundary. On interannual-to-decadal timescales, Qiu and Chen [4] pin the bifurcation between roughly 10°N and 15°N — and toward the upper end of that range under El Niño. The OKMC programme [3] adds a complementary point. Position of the bifurcation, and how transport is split between the two outflow branches, both shape how the warm pool evolves in time.

2.3. Seasonal reciprocity of the Mindanao Current and the Kuroshio

Since the Kuroshio and Mindanao Currents are both supplied by the NEC, any movement of the bifurcation shifts the balance between the two outflow branches. On seasonal timescales, total NEC transport changes more slowly than the latitude at which the current splits; a northward or southward step in that latitude therefore reallocates the water budget between the two routes. According to Hu et al. [1], El Niño phases typically coincide with a northward bifurcation, alongside stronger NEC and Mindanao Current flow but a weakened Kuroshio and Indonesian Throughflow. La Niña phases generally swing toward the mirror image.

Qiu and Lukas [2] give the quantitative picture. The Kuroshio is at its seasonal transport minimum in boreal autumn — and that is exactly when the bifurcation lies furthest north and Mindanao flow is strongest. The resulting anti-phase pattern matters for the regional heat budget. It decides whether tropical water is exported poleward by the Kuroshio, or instead kept circulating around the equator via the Mindanao Current.

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2.4. The North Equatorial Countercurrent (NECC) and the ITCZ migration

The North Equatorial Countercurrent (NECC) flows the other way — east, against the prevailing trades. That makes it one of the most seasonally variable parts of the TWP circulation. Its annual evolution stays close to the meridional migration of the Intertropical Convergence Zone (ITCZ). East of the dateline, the NECC axis drifts north through the second half of each year [5]. The current reaches its peak speed and easternmost reach in the late-boreal-summer to autumn window, the same period in which the ITCZ sits at its northern seasonal limit. Across that stretch of months, the NECC works as a return path. Warm water from the western boundary is routed eastward, back into the central Pacific.

3. Climate effects of seasonal circulation variations

3.1. Thermal regulation of the Western Pacific Warm Pool (WPWP)

The size and heat content of the Western Pacific Warm Pool (WPWP) carry a clear seasonal imprint of TWP current reorganisation. The WPWP holds more warm surface water than anywhere else on the planet. That heat — and the moisture that travels with it — drives deep convection and feeds the large-scale atmospheric circulation. Qiu et al. [3] report that surface waters above 28°C can extend north of 17°N, with the warm pool's geography set by NEC bifurcation and by how transport is divided along lateral advective pathways. When the NECC strengthens seasonally, it pulls warm water east — in line with the direction Hsin and Qiu [5] document. Such horizontal rearrangements shift the air–sea temperature contrast near the surface. Convective intensity follows, and so does the upward latent heat flux into the troposphere.

3.2. Modulation of ENSO initiation and evolution

Seasonal circulation does not run in isolation. It is the oceanic backdrop on which interannual anomalies build. Hu et al. [1] traced the El Niño case: the western boundary currents send more water equatorward, and the cooler water they carry partially makes up for the warm-water discharge out of the equatorial belt. Qiu and Chen [4] worked the link from another angle. Using the Niño-3.4 index, they found that positive values went with a northerly NEC bifurcation, and negative values with a southerly one. ENSO phase and the TWP circulation state, in short, move together.

El Niño onset can also coincide with the seasonal NECC cycle going off-script. If eastward NECC transport stays vigorous while the trade winds ease, downwelling Kelvin waves become a possibility. They cross the basin, run for the South American coast, push the thermocline down, and warm the eastern Pacific surface. The result is enough of a nudge to tip the system into an ENSO transition. Hsin and Qiu [6] add a useful EP/CP distinction. Eastern-Pacific El Niños strengthen the NECC and displace it southward, and that displacement persists from the early development phase right through to maturity. Central-Pacific events leave a much fainter mark — position and intensity stay comparatively undisturbed.

3.3. Feedback on the Asian-Australian monsoon system

The coupling runs both ways. While the monsoon drives TWP circulation, the ocean returns the favour: shifting where surface heat is released, it works back on monsoon behaviour. In seasons with relatively strong Kuroshio transport, the resulting ocean-to-atmosphere heat flux is high enough to

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intensify the Western Pacific Subtropical High (WPSH) and push its western ridge further inland toward the East Asian coast.

The rainfall consequences are real. Hu et al. [1] note that in boreal winter the Kuroshio is an efficient route for warm-water transport, and that heat-content anomalies in the North Pacific western boundary currents show up later in the Asian Monsoon. The ocean–atmosphere coupling that follows is the thread linking TWP variability to regional precipitation and mid-latitude weather.

3.4. Regional sea level and coastal ecosystem impacts

Seasonal reshuffling of current pathways also leaves its mark on regional sea level, on coastal exposure, and on the conditions that set the stage for extreme weather. Sprintall and Révelard [7] tracked how Indonesian Throughflow (ITF) transport responds to ENSO and to the Indian Ocean Dipole. Pacific ENSO signals reach the Timor Passage by way of planetary waves originating in the Pacific. Sprintall et al. [8] take the analysis further: the water, thermal, and salinity transports the ITF carries feed back onto the coupled Pacific–Indian Ocean state, and local air–sea exchange and rainfall are reshaped along the way. And where these seasonal adjustments lift the sea surface or warm the upper ocean, they build a kind of background that tropical cyclones can grow into. That is more than an academic question. Mapping these transitions out has practical weight for disaster-risk reduction and for longer-term climate adaptation across Southeast and East Asia.

4. Conclusion

Reading the literature together, the seasonal circulation of the Tropical Western Pacific (TWP) is a current system whose state is locked to the East Asian monsoon and to seasonal change in wind-stress curl. The NEC bifurcation marches with the year — north in late summer, south in winter — and that march sets how mass and heat are split between the Kuroshio and the Mindanao Current. In parallel, the seasonal strengthening of the North Equatorial Countercurrent (NECC) redistributes heat inside the Western Pacific Warm Pool. Taken as a package, these adjustments help shape ENSO development, modulate the Western Pacific Subtropical High, and propagate into anomalous rainfall — from the Asian–Australian monsoon belt out across the islands of the Maritime Continent.

The analysis carries its caveats. Resting on synthesis of published studies and coarse-scale case evidence, it cannot reach the processes that demand dedicated high-resolution treatment — sub-mesoscale eddies, say, or deep baroclinic controls on surface variability. The geographic frame is narrow too. Links with neighbouring basins are touched on, not developed. A natural next step is to push further into inter-basin exchange, with the Indonesian Throughflow as the obvious bridge between the Pacific and Indian Oceans. A fuller treatment of those pathways would sharpen integrated climate interpretation. It also stands to improve the long-term predictive skill of climate models.

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