8D.7 TROPICAL–EXTRATROPICAL INTERACTIONS CONDUCIVE TO INTRASEASONAL VARIABILITY IN THE NORTHERN HEMISPHERE AVAILABLE POTENTIAL ENERGY

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1. INTRODUCTION

The goal of this study is to investigate tropical–extratropical interactions (TEIs) that can significantly influence Northern Hemisphere (NH) zonal available potential energy (A_Z) on intraseasonal time scales (e.g., one-to-two weeks). This study is motivated by the substantial intraseasonal variability of the NH A_Z during late 2007. First, the NH A_Z increased by 29% relative to climatology between 27 October and 15 November (Fig. 1). This period of increasing NH A_Z coincided with the progression of anomalous tropical convection associated with the Madden–Julian Oscillation (MJO) from the Maritime Continent onto the western Pacific Ocean.

Second, the NH A_Z decreased by 32% between 15 November and 3 December (Fig. 1) in conjunction with the tropical and extratropical phases in the life cycles of western North Pacific (NP) tropical cyclones (TCs) Mitag, Hagibis, and 26W . This period of decreasing NH A_Z coincided with the warmest 850-hPa temperature observed in December at Barrow, AK, between 1948 and 2008. The evolution of the tropical and extratropical NP flow in late 2007 represents an extraordinary example of TEIs that were conducive to NH A_Z intraseasonal variability and to the occurrence of downstream high-impact weather events.

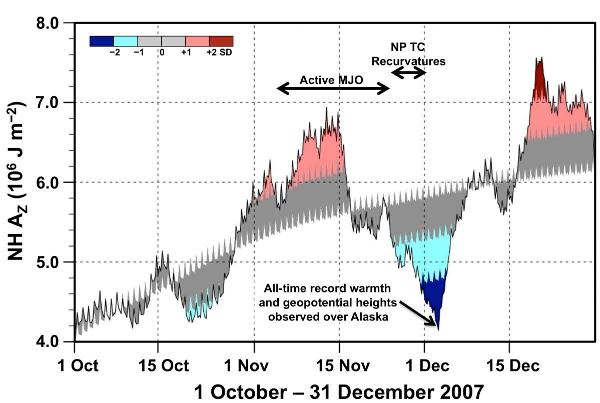

Figure 1. Four-times daily NH A_Z (10^6 J m^{-2}) and standardized departure from climatology (shaded according to scale) between 1 October and 31 December 2007.

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2. METHODOLOGY

A_Z is approximated by the variance of zonally averaged temperature on an isobaric surface (Lorenz 1955, p. 160) as given by Carlson (1998, p. 116):

$$A_Z = \frac{R_d}{g\sigma}\int_{100\,\mathrm{hPa}}^{1000\,\mathrm{hPa}}\int_{\sigma}\frac{1}{2}\left(\frac{\|T\|''}{s}\right)^2 \mathrm{d}\sigma\,\mathrm{d}\ln p. \qquad (1)$$

The terms in (1) have their usual meteorological meaning with s = map average static stability parameter, σ = surface area (chosen as 20–85°N over a full latitude circle), ( )" = deviation from area average, and ‖ ‖ = zonal average. A_Z is primarily generated by regional or large-scale diabatic processes that strengthen the zonally averaged meridional temperature gradient on an isobaric surface and is primarily depleted by the meridional transport of warm air poleward (or cold air equatorward) along an equatorward-directed temperature gradient (Lorenz 1955). A smaller contribution to A_Z depletion is accomplished in conjunction with warm air rising at low latitudes and sinking at higher latitudes. The equations for the time rate of change of A_Z can be found in Carlson (1998, p. 118).

A climatology of NH A_Z is derived four-times daily using the 2.5° × 2.5° NCEP–NCAR reanalysis for 1979–2008. The standardized departure (anomaly) relative to climatology is calculated using a 21-d running mean. The 30-yr standardized anomaly and standardized anomaly tendency are utilized to investigate (i) the characteristic NP flow patterns associated with NH A_Z intraseasonal variability and (ii) the influence of TEIs on NH A_Z intraseasonal variability.

3. CHARACTERISTIC NORTH PACIFIC FLOW PATTERNS

Characteristic NP flow patterns associated with NH A_Z intraseasonal variability are determined using the 30 largest standardized anomaly 5-d tendency maxima (generation) and minima (depletion) between September and December from 1979–2008. Composite analyses suggest that periods with NH A_Z generation are characterized by a poleward-shifted, zonally elongated NP jet stream (NPJ) and quasi-zonal flow over the NP, whereas periods with NH A_Z depletion are characterized by an anomalously strong and zonally retracted NPJ over the western NP (not shown). The latter composite additionally suggests the occurrence of highly amplified flow over the eastern NP in association with blocking and/or downstream baroclinic development. The composite NP flow patterns imply that periods of NH A_Z intraseasonal variability may be influenced by TEIs that modify the meridional temperature gradients over the NP, and via thermal wind balance, can modify the structure and evolution of the NPJ.

4. TROPICAL–EXTRATROPICAL INTERACTIONS

The influences of the El Niño Southern Oscillation (ENSO), the MJO, and western NP TC recurvature in TEIs over the western NP are considered in the study. The NH A_Z standardized anomaly (hereafter referred to as NH A_Z') is compared with (i) ENSO using values of the Niño 3.4 sea surface temperature (SST) anomaly for 1990–2008; (ii) the MJO using values of the Climate Prediction Center (CPC) MJO index for 1979–2008 and values of the Wheeler and Hendon (2004) MJO index for 1979–2008; and (iii) western NP TC recurvature day as defined by Archambault (1D.2) for September–December 1979–2008. The composite flow patterns over the NP in section 3 suggest that positive values of NH A_Z' will be manifested by a relatively stronger and zonally elongated NPJ, whereas negative values of NH AZ' will be manifested by a relatively weaker and zonally retracted NPJ with blocked flow or downstream baroclinic development over the eastern NP.

4.1 NH A_Z and ENSO

The NH A_Z' is compared to the positive phase of ENSO (El Niño) by determining all days with Niño 3.4 SST anomalies >1.5°C. A lag-day composite time series illustrates that the NH A_Z' increases nearly in phase with the Niño 3.4 SST anomaly with a time lag of ~100 d (Fig. 2). The relationship between NH A_Z' and Niño 3.4 SST anomalies suggests that El Niño modulates NH A_Z on seasonal-to-interannual time scales.

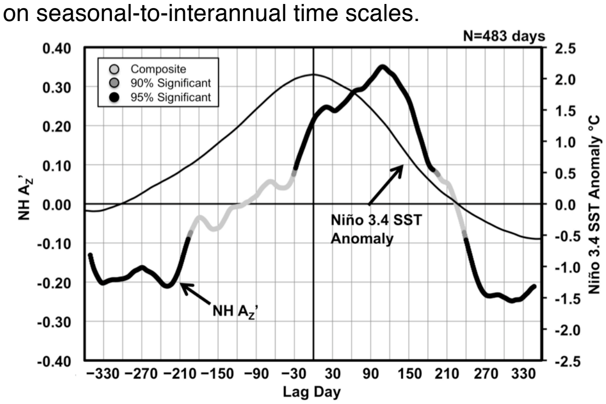

Figure 2. Lag-day composite of NH A_Z' and Nino 3.4 SST anomaly for days with Niño 3.4 SST anomalies >1.5°C between 1990 and 2008. Statistical significance given at 90% and 95% confidence levels as determined by a two-sided Student's *t* test.

4.2 NH A_Z and the MJO

The NH A_Z' is compared to the convectively active phase of the MJO by determining all days when the CPC MJO index at 100°E is less than −1. A lag-day composite time series illustrates that the NH A_Z' generally increases with convection associated with the MJO crossing from west to east over 100°E, and reaches a maximum ~6–12 days later (Fig. 3). Composite time series for longitudes 120°E, 140°E, and 160°E demonstrate a "right-to-left shift" in the maximum NH A_Z', consistent with the eastward progression of the MJO at ~6 m s^{-1} (not shown). The relationship between NH A_Z' and the CPC MJO index value at 100°E suggests that the MJO likely modulates NH A_Z variability on intraseasonal time scales.

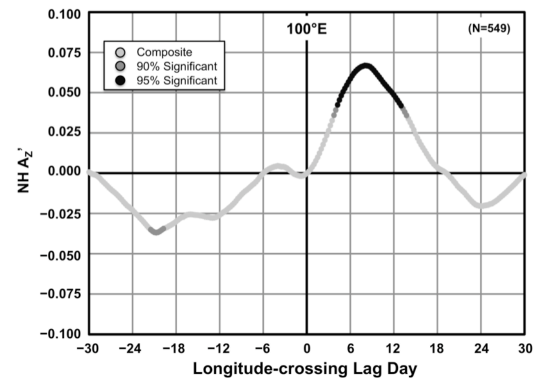

Figure 3. Lag-day composite of NH A_Z' for days with the CPC MJO index value at 100°E less than −1 between 1979 and 2008. Statistical significance as defined for Fig. 2.

The NH A_Z' is compared to the phases in the life cycle of the MJO by evaluating the Wheeler and Hendon (2004) MJO index (Fig. 4). The connection between NH A_Z' and the phases in the life cycle of the MJO illustrates a tendency for positive NH A_Z' during periods with MJO convection over the Maritime Continent, and negative NH A_Z' during periods with MJO convection over the Western Hemisphere and Africa. The evolution of NH A_Z' between phases 4 and 7 is consistent with results using the CPC MJO index.

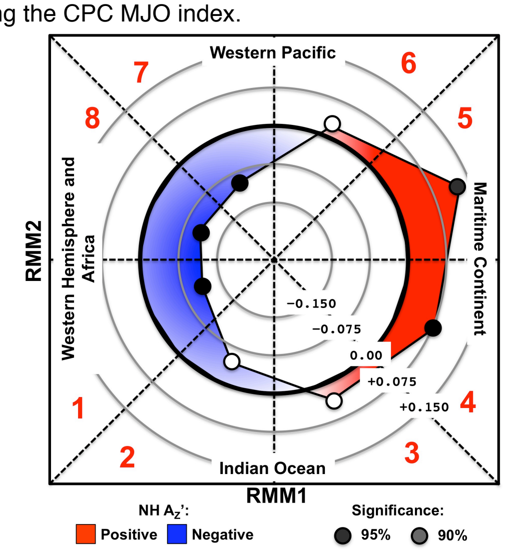

Figure 4. Composite NH A_Z' presented in MJO phase space defined by Wheeler and Hendon (2004). Values are averaged within each phase. Convectively active MJO periods are considered by investigating index values >1. Statistical significance as defined for Fig. 2.

4.3 NH A_Z and western NP TC recurvature

The NH A_Z' is also compared to western NP TC recurvature. TC recurvature is defined based on a transition in the zonal component of the TC motion from west to east (Archambault 1D.2). A lag-day composite time series illustrates that NH A_Z' generally increases and reaches a maximum ~2–3 d prior to TC recurvature (Fig. 5). An abrupt transition to negative NH A_Z' values occurs over the succeeding 7–10 d. Examinations of TC recurvature events in which TCs undergo extratropical transition (ET) and reintensify as an extratropical cyclone illustrate an ~40% larger decrease in NH A_Z' (not shown). The relationship between NH A_Z' and western NP TC recurvature suggests that TC recurvature (and ET) likely modulates NH A_Z variability on synoptic-to-intraseasonal time scales.

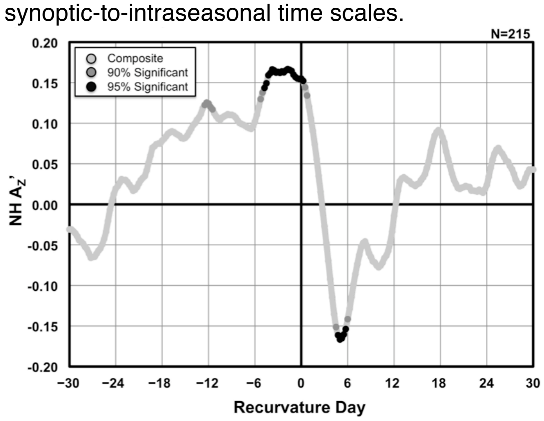

Figure 5. Lag-day composite of NH A_Z' for days with western NP TC recurvature between September and December 1979–2008. Statistical significance as defined for Fig. 2.

5. Synthesis

NH A_Z' variability in association with ENSO, the MJO, and western NP TC recurvature likely highlights the influence of tropical convection and poleward heat and moisture transport on the evolution of the variance of zonally averaged temperature on an isobaric surface, manifested as changes to the zonally averaged meridional temperature gradient over the NP.

For example, deep moist convection associated with the MJO or a TC likely influences A_Z generation and positive values of A_Z' by contributing to a maximum in latent heat release and diabatic heating. As a result, the zonally averaged meridional temperature gradient over the NP would increase and imply the presence of a zonally elongated NPJ. Oppositely, TC recurvature and/or ET likely influences A_Z depletion and negative values of NH A_Z' by contributing to a poleward transport of warm air along an equatorward-directed temperature gradient. As a result, the zonally averaged meridional temperature gradient over the NP would decrease and imply the presence of a zonally retracted NPJ, and possibly the occurrence of blocking and/or downstream baroclinic development over the eastern NP.

The foregoing results suggest that the MJO and western NP TC recurvature (El Niño) influence NH A_Z' variability on synoptic-to-intraseasonal (seasonal-to-interannual) time scales. In an idealized scenario, these oscillations/features could operate in concert to influence NH A_Z' variability and possible high-impact weather events downstream (Fig. 6):

1. Anomalously warm SSTs associated with an El Niño event enhances the zonally averaged meridional temperature gradient, resulting in positive values of NH A_Z'.
2. Convection associated with the MJO influences subtropical anticyclogenesis over the western Pacific and enhances the meridional temperature gradient, resulting in positive values of NH A_Z'.
3. Western NP TCs recurve around the subtropical anticyclone and are accompanied by convection that enhances the meridional temperature gradient, resulting in positive values of NH A_Z'.
4. TC recurvature and/or ET influences a poleward transport of warm air that weakens the meridional temperature gradient, resulting in negative values of NH A_Z'.
5. Downstream baroclinic development resulting from TC recurvature and/or ET promotes additional meridional displacements of warm and cold air over the Western Hemisphere, resulting in negative values of NH A_Z'.
6. The transition from positive to negative values of NH A_Z' may be associated with downstream high-impact weather events.

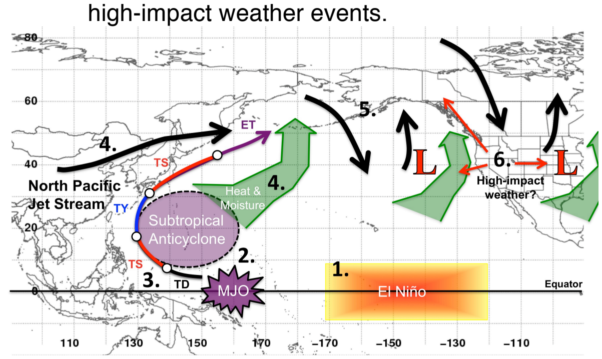

Figure 6. Schematic depiction of idealized interactions between El Niño, the MJO, western NP TC recurvature, with possible downstream high-impact weather events.

6. References

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