Covariance of Meiyu Front and Tropospheric Jet Variability on Daily and Interannual time scales

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This abstract must be 150 words or less.

1. Introduction

China receives about 60% of its rainfall from May to August, a phenomenon referred to as the East Asian Summer Monsoon. Regional peak rates occur from the end of May to the middle of July, when precipitation occurs in continuous frontal bands induced by the Tibetan Plateau upstream. This feature is known as the Meiyu Front, and the duration of its appearance as Meiyu Season. In the annual mean, the Meiyu Front has been claimed to show northward progression and abrupt transitions between preferred latitudes[*Ding and Chan*, 2005]. Anecdotal evidence suggests an abrupt shift in rainfall patterns beginning in the 1970s, with Northern China experiencing severe droughts and Southern China flooding ("North Dry South Wet"), leading the Chinese government to embark on one of the most expensive engineering products in the history of mankind, the South-North Water Transfer Project. In spite of attempts to attribute observed change to global warming, no mechanism has been agreed on.

Regional prediction of climate change under global warming presents greater difficulty than global projection. In the 5th edition of the IPCC report, the CMIP 5 model suite does not come to a consensus on the sign of future summer rainfall changes in East Asia (ADD CITATION). Several authors have proposed templates for regional mechanisms resulting from CO2 forcing. Radiative constraints on precipitation allow the separation of two terms, global mean response and local circulation effects[**?**]. The"rich get richer" mechanism anticipates increased rainfall in regions of net precipitation and decreases in regions of net evaporation due to amplified moisture transport[*Held and Soden*, 2006]. *Lintner and Neelin* [2007] and *Chou et al.* [2009] proposed a more comprehensive set of phenomena based on model projection of changes in convective regions. These include not only the"rich get richer" but also the "upped ante" mechanism, wherein convective margins see droughts because increased humidity in convective regions raises the threshold for convection and moisture gradients are stronger. This framework has been used to understand ENSO-related rainfall variability in South America. However, it is difficult to apply these existing theories to a region with high spatial and temporal heterogeneity such as East Asia.

A new paleoclimate study proposes the tropospheric jet as an indicator of past rainfall patterns in China [*Nagashima et al.*, 2011][*Nagashima et al.*, 2013]. The authors study a marine sediment core in the Sea of Japan, downstream from both the Taklamakan Desert and Gobi Desert, and are able to differentiate between dust from each of these sources using electron spin resonance (ESR) and grain size. In the present day, Gobi Desert dust is only advected during spring before the tropospheric jet passes north of the Tibetan Plateau and [*Roe*, 2009], whereas the mechanism of transport of Taklamakan Desert dust remains active in summer when the jet occupies a low variability position on the northern flank of the Tibetan Plateau. Therefore, they attribute increases in Gobi Desert dust to longer springs and shorter summers. Since Holocene changes in precipitation match the timing of abrupt changes in their record, they therefore conclude that the tropospheric jet controls precipitation variability over millennial time scales.

The present work aims to test this apparent coupling of the jet and Meiyu Front in the present-day. Current theory suggests that the tropospheric jet plays a major role in Meiyu formation, either by zonal advection of sensible heat from the Tibetan Plateau upwind

[*Sampe and Xie*, 2010], or as part of the orographically forced circulation that produces meridional wind convergence over China[*Chen and Bordoni*, 2014]. Past work has compared jet and Meiyu variability over shorter time periods or with coarse resolution*Liang and Wang* [1998], but none has systematically performed a comparison with daily data. Since the behavior of the tropospheric jet is coupled to global climate variability, our work holds the promise of attributing rainfall trends in China to global change via the jet.

The climatology of the Meiyu Front has been studied[*Ding and Chan*, 2005] but no full catalog of interannual and daily variability has previously existed. We use 57 years of rain gauge data over China at .25 by .25 degree resolution[*Yatagai et al.*, 2012]. These data were processed with a Meiyu detection algorithm. Our algorithm uses a convergent algorithm to detect continuous zonal precipitation structure and returns information about whether a Meiyu Front is visible on each day, as well as the position, meridional tilt and intensity if a front exists. Poor fits are isolated by using a quality score Q which measures the percentage of rainfall occurring within 300 km of our attempted fit. Our method shows good preliminary ability to reproduce known properties of the jet and northward progression during Meiyu Season.

We first attempt to define a transition date from spring to summer behavior in the jet database, and equivalently from Meiyu Season to post-Meiyu in our new catalog. Preliminary evidence suggests a long-term perturbation in mean jet path in East Asia from the 1960s to present with later onset of summer jet and shorter total duration of summer jet. In our Meiyu database it is more difficult to extract an exact transition date due to high-frequency variability in space and time. However, we observe an apparent shift in the timing of northward progression of the Meiyu Front between 1951-1970 and 1988-2007. If both databases demonstrate a robust decadal shift, they may provide an explanation for the anecdotal South Wet-North Dry pattern of rainfall change.

Finally, we use our knowledge of daily Meiyu positions to isolate preferred configurations for different dates, as well as probability distributions of the tropospheric jet associated with each configuration. If a robust change in mean jet progression is detected, we may be able to isolate a corresponding shift in Meiyu distribution that may have previously gone unnoticed due to extreme temporal variability in the data.

In the following text we seek to achieve the following objectives: 1) Define an objective climatology of the Meiyu front; 2) Show the positions of the tropospheric jet associated with different configurations of the tropospheric jet; 3) Show that the Meiyu front and tropospheric jet covary on a daily scale; and 4) Suggest a dynamic lens to understand the observed climatology of Meiyu front and jet.

2. Data sets

The analysis contained in this paper relies on two data sets, APHRODITE and Schiemann et al's database of jet counts. APHRODITE (Asian Precipitation - Highly-Resolved Observational Data Integration Towards Evaluation of the Water Resources) [*Yatagai et al.*, 2012]. The APHRO_MA_V1101 product includes 57 years (1951-2007) of daily precipitation (PRECIP product, units mm day^{-1}) and station coverage (RSTN product) on a .25° × .25° grid (roughly 25 km spacing) between 60°E-150°E and 15°S-55°N.

For tropospheric jet variability, we employ a database based on ERA-40 reanalysis data developed by *Schiemann et al.* [2009]. Their database includes every appearance of a tropospheric jet in East Asia for 1958-2001 at 6-hourly intervals using simple criteria: Positive zonal wind and local maximum in excess of 30 m/s.

3. An "objective" Meiyu climatology

3.1. Algorithm

We develop an adaptive algorithm to detect the position of the Meiyu front on a given day. For each day from 1951 to 2007 (20819 days total), we first find the quantity and latitude of maximum rainfall for each longitude point. Then, we use the simple criterion of there being a 5 degree continuous chain of maxima over 10 mm/day (20 consecutive cells). If such a band exists the "ismeiyu" switch is flipped to 1. We then try to linearly fit these maxima, excluding any maximum that is more than 5 degrees of latitude away from the precipitation centroid given by $< L >= \frac{\sum P_i y_i}{\sum P}$. Next using, this first fit as starting point, we now find the maxima within a n-degree latitude window of the best fit line, where we progressively shrink n with each iteration. The choice of n does not greatly impact fit quality. In our experiment, we repeated the fit for $n=$ ... . Given a final fit, we report the latitude of the front at 105°E, the mean intensity of rainfall along the center of its axis and the tilt (in degrees). We also report a quality score Q which indicates the percentage of rainfall that falls within 3 degrees of our best fit line, such that statistical calculations can be repeated only days with a clear front for the purpose of confirmation.

3.2. Defining Meiyu season

Figure 1 shows a Hövmoller diagram of latitudes occupied by the Meiyu Front in the 57-year mean. Four local maxima of Meiyu events can be observed: 1) A "pre-Meiyu" from May 1-31 over southern China (Ding and Chan's first position); 2) Meiyu Season, in which the preferred latitude of the front shifts by almost ten degrees from June 1-July 15 (Ding and Chan stage 2); 3) A "post-Meiyu" of persistent 4) Cyclone season over Southern China. The storms during season 4 can be distinguished from earlier Meiyu events in southern China because their propagation direction is westward, opposite to eastward Meiyu storms. The combination of stages 3 and 4 corresponds to the third stage of the Meiyu in Ding and Chan, but only the core of Meiyu season (their stage 2) features significant front migration. Figure 2 shows that even in winter, rainfall events in China tend to be frontal, but their frequency increases up to almost 100% during Meiyu Season, and a surge in intensity can be seen around June 1 where mean rainfall along the front exceeds 25 mm/day. The mean tilt of the front is approximately 8 degrees.

4. Preferred jet positions

Monthly changes in the position of the jet have previously been reported in]

5. Covariance of jet and Meiyu anomalies

6. Dynamics

The covariance of Meiyu front positions and tropospheric jet latitudes previously demonstrated also clarifies a dynamical reason for their seasonality. As shown, Meiyu season consists of intense rainfall from June 1st to July 1st with a shift in latitude of almost 10 degrees over the course of that month. After . The lens of forced convergence by the Tibetan Plateau. In the climatological mean, *Chen and Bordoni* [2014] demonstrated that the Meiyu front exists primarily due to forced mechanical convergence by the Tibetan Plateau upstream. They showed this by using experiments in which the Tibetan Plateau's height was reduced by 95%. We argue that our results similarly show the role of the Tibetan Plateau in generating a strong Meiyu front. When the jet impinges on the Tibetan Plateau from late May to early July, the high topography induces meanders that force standing waves in jet configuration, pushing it further north from 80E to 100E and then further south into China. This in turn anchors strong rainfall along the Meiyu front in China. When the jet moves further north to its preferred summer position, which occurs just north of the Tibetan Plateau, it is no longer deflected and the front is significantly weaker, though events do still occur as seen in Figure 1. We confirm this hypothesis by showing the climatology of precipitable water vapor from SSRI from time A, time B, time C and time D (last figure). During the early and late stages of Meiyu season precipitable water content is concentrated along bands that intersect central China. However, in July and August, the latitude of the moisture vapor front has shifted much further north, over northern China, and both the Bay of Bohai and the Korean Peninsula and Japan all have much greater precipitable water. However, the lack of mechanical forcing is shown by the weakness of rainfall in those events (<20 mm/day versus 25-30 mm/day over southern and central China during Meiyu season.

Acknowledgments. APHRODITE is...

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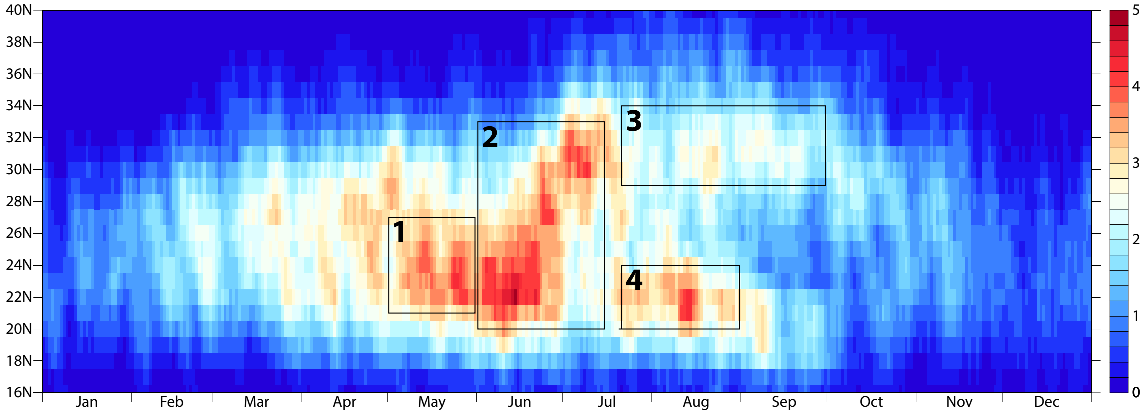

Figure 1. Climatology of the Meiyu Front, 1951-2007. 1) Pre-Meiyu 2) Meiyu 3) Cyclone season in Southern China 4) Storms advected by summer jet

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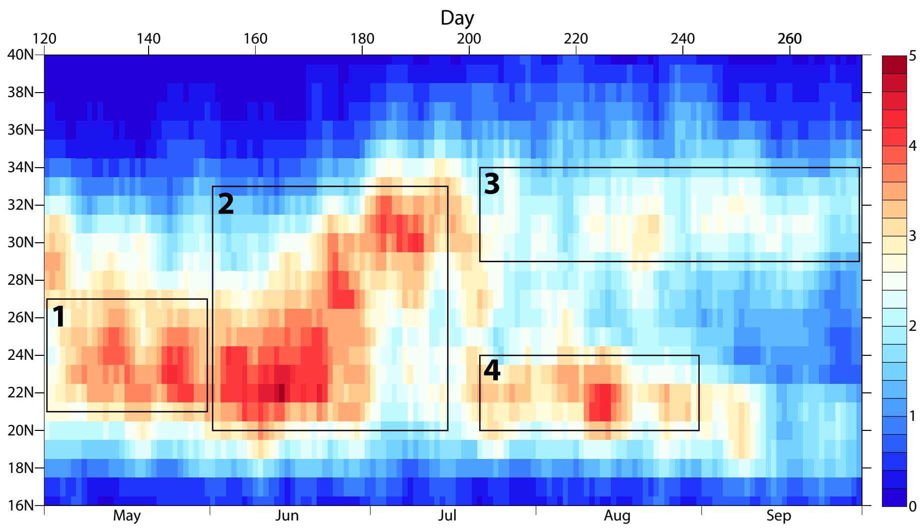

Figure 2. Climatology of the Meiyu Front, 1951-2007. 1) Pre-Meiyu 2) Meiyu 3) Cyclone season in Southern China 4) Storms advected by summer jet. MJJAS only.