1.2 Characterizing ITCZ dynamics and breakdown on synoptic timescales in observations

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1. Introduction

On seasonal timescales, the Intertropical Convergence Zone (ITCZ) has been assumed to be a feature nearly in steady state. Its latitudinal location migrates seasonally with the sun. The picture of the ITCZ is quite different on synoptic timescales (order of 10 days). From day to day, the ITCZ is highly dynamic and changeable as seen in visible and infrared geostationary satellite images (GOES). The ITCZ is observed to go through a lifecycle that ends when the zonally extended structure breaks down into individual disturbances.

Figures 1 and 2 show an example of an ITCZ breakdown event. Figure 1 contains infrared (IR, left panel) and visible (VS, right panel) GOES satellite images, one per day, respectively, shown on Sept. 19, 21, 23, 24 and 29, 2000, from top to bottom. The American continent and the islands of Hawaii are outlined in green. On 19 Sept. 2000, ITCZ convection was shallow in the vertical as evidenced by the weak signal in the IR image and strong signal in VS. An easterly wave can be seen entering the domain from the east. It did not disturb the ITCZ, but quickly moved toward the NNW along the coast. The ITCZ intensified into a deep ITCZ two days later (21 Sept.), and started undulating from its western end. The ITCZ broke into three pieces on 23 Sept. due to vortex roll-up, which will be described shortly. The produced disturbances were rather weak and not well organized. They moved toward higher latitudes (not shown) and dissipated. On 29 Sept. , a new ITCZ had re-formed in the same region as before around 10° N. This process, referred to as ITCZ breakdown by Nieto Ferreira and Schubert (1997, hereafter NFS), has been simulated in both a barotropic dynamical model (NFS) and in a fully 3-dimensional, primitive-equation model (Wang and Magnudottir 2005, hereafter WM05). WM05 also studied the effects of different background flows on this process and the effects of different vertical structure of the prescribed heating. They suggest that this is an efficient mechanism for pooling vorticity in the tropics, which represents the very earliest stage of cyclogensis.

Here we define ITCZ breakdown so that it includes all breakdown events, whether they are triggered by interactions with external disturbances or arising through dynamical instability within the ITCZ. The following two categories of ITCZ breakdown are identified:
(1) Breakdown due to interaction with westward propagating disturbances (WPDs), which include easterly waves possibly originating over Africa (e.g., Avila and Clark 1989) and tropical disturbances that were initiated in flow over the central American topography (e.g., Zehnder and Powell 1999).
(2) Breakdown due to dynamical instability of the ITCZ (e.g., NFS; WM05), named the vortex roll-up (VR) mechanism here.

ITCZ breakdown has been largely ignored due to difficulty in identifying the event in conventional meteorological dmeteorological data, especially in the tropical eastern to central Pacific where observations are sparse. The difficulty is mainly associated with horizontal resolution of observational products. The horizontal resolution of conventional reanalysis data ($2.5° \times 2.5°$) is not fine enough to depict ITCZ breakdown events. We have analyzed NCEP reanalysis data and did not identify any ITCZ breakdown events. Sobel and Bretherton (1999) reached similar conclusions. According to our modeling study (WM05), T106 resolution ($1.1° \times 1.1°$) is the minimum horizontal resolution in a dynamical model that will produce strong enough horizontal wind shear to allow the VR mechanism to be initiated. In addition, in data poor regions, such as the tropical central to eastern Pacific, reanalysis data is often heavily influenced by model assumptions.

ITCZ breakdown has been assumed to be most active during the summer and fall seasons, overlapping with the hurricane season. We examined our data through the entire year to confirm the extent of the active season, then focused on the active seasons of 1999–2003. The goals of this study are:
(1) to identify occurrences of ITCZ breakdown in the Northern Hemispheric tropical central to eastern Pacific and
(2) to determine the breakdown mechanism of each case, using satellite cloud images and other datasets (see next section).

2. Datasets

We use the following three independent datasets to identify ITCZ breakdown events.

(1) *GOES-west visible (VS) and infrared images (IR):* GOES VS and IR images are available from to 1980 to July 12, 2004 on NCDC Historical GOES Browse Server [1]. We use these data for the entire year from 1999 to 2003, inclusive. GOES-west is centered at 135° W on the equator and covers the central and eastern Pacific. The brightness of VS images indicates albedo, which can be used to infer cloud thickness. The thicker the cloud, the higher the albedo. For IR images, the brightness indicates the temperature at cloud top, which can be used to infer the height of the cloud top. Therefore, a deep convective system would be bright both on IR and VS images while a shallow convective system would be rather dark on an IR image and white on a VS image. By combining

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[1] http://cdo.ncdc.noaa.gov/GOESBrowser/goesbrowser

VS and IR images, one can deduce whether the ITCZ is shallow or deep. Usually, a cloud strip only visible on VS images has its cloud top not far from the top of the planetary boundary layer and can be identified as a shallow ITCZ.

(2) *NCEP Global Tropospheric Analyses:* This dataset is of 1° × 1° horizontal resolution, has 26 vertical levels, and is recorded four times per day. It is available for the time period from September 1999 to the present. We compute relative vorticity on pressure levels that we use to locate the disturbances produced from ITCZ breakdown and to verify that vorticity is increasing in time while vorticity is pooling within the ITCZ. We also verify that vorticity is increasing/decreasing in time while disturbances produced from ITCZ breakdown are deepening/dissipating. The disadvantage of this dataset is that it is an analysis product that has been processed by a model, which has little observational input in the area of interest. The underlying model assumptions appear to sometimes affect the accuracy of the dataset. For example, we find that on occasion the vorticity field appears more patchy in the dataset than in the same field calculated from QuikSCAT data and from the GOES cloud images at the same time. However, this dataset is the highest resolution gridded analysis product available.

(3) *QuikSCAT scatterometer wind:* This dataset is of 0.25°× 0.25° resolution with two scans (ascending and descending) per day, from September 1999 to the present. It covers nearly 93% ocean surface on the globe. The 10-meter wind is derived from surface roughness, approximately equivalent to an 8–10 minute mean surface wind with an accuracy of 2 m/s in wind speed, and an accuracy of 20° in wind direction. In-situ studies (e.g.,Bourassa et al. 2003) report that the scatterometer winds are more accurate than the mission stated objectives. Relative vorticity is calculated from the daily averaged zonal and meridional wind components. The daily average is taken when both ascending and descending scans are available at the grid point. When only one observation is available at a grid point, it is used without any averaging.

3. Methodology

We look through the three available datasets and visually detect ITCZ breakdown that occurred during 1999–2003. The criteria for ITCZ breakdown are as follows:

(1) On satellite images, before the ITCZ breaks, an elongated cloud band must be detected on VS images, and for a deep ITCZ, it has to be detected on IR images as well. The cloud band then undulates and pools in regions. Some of the cloud clusters may break off from the ITCZ as it evolves. For a breakdown of the entire ITCZ, only isolated disturbances are produced. The evolution of ITCZ breakdown is a continuous process and the produced disturbances can be traced back to the ITCZ. See Fig. 1 for an example.

(2) In NCEP and QuikSCAT wind-derived vorticity fields, elongated positive vorticity patches line up at a certain latitude (usually at 10° N). During breaking, vorticity is pooled in regions, and while pooling, the value of vorticity increases in time, and the roll-up should be detected in the field of low-level vorticity.

All ITCZ breakdown events are cataloged into three types according to the dynamical mechanism that triggered the event. The three types are: vortex roll-up (VR), westward propagating disturbances (WPDs), and a mix of the above two mechanisms (VR+WPDs). The mixed type is due to both of the two mechanisms taking place in two different regions. WPDs frequently induce breakdown in the eastern Pacific, and the VR mechanism generally leads to breakdown in the central Pacific. The two mechanisms may occur at the same time, or VR in the central Pacific may follow WPD induced breakdown in the east Pacific.

To further understand the convection type or depth of the ITCZ that is undergoing breakdown, three sub-types, “shallow”, “deep”, or “shallow+deep” were defined to indicate the depth of each event. “Shallow” means that the ITCZ has its cloud top close to the top of the boundary layer. This type of event is not seen on IR images. “Deep” means a deep ITCZ breakdown event. Cases that have shallow ITCZ with some elements of deep convection embedded within it are defined as “shallow+deep”.

4. Results

ITCZ breakdown has a strong annual cycle. After looking through the GOES-west images, we found that ITCZ breakdown events occurred mostly during May to October, which will be referred to as the active season. Only 4 events occurred outside that season for the five years studied. We have identified 65 cases of ITCZ breakdown during the 1999–2003 active seasons, summarized in Tables 1 and 2. The detailed list can be found at http://essgrad.ps.uci.edu/∼ccwang/ITCZ-list.pdf. Twenty-seven out of 65 events were due to the VR mechanism. Twenty-seven out of 65 events were due to WPDs, 10 events were due to the combined effects of both mechanisms, and 1 event could not be classified. If cataloged by the type and depth of convection (Table 2), there are 38 events of deep ITCZ breakdown, 12 events of shallow ITCZ breakdown, and 15 events of “shallow+deep” ITCZ breakdown. Elements of deep convection within a shallow ITCZ may accelerate the process of ITCZ breakdown since they produce an uneven vorticity distribution in the ITCZ. Local maxima within the ITCZ often become the regions of vorticity pooling and centers of individual vortices after ITCZ breakdown.

Table 1: Number of ITCZ breakdown events during the active season each year, classified by mode of breakdown.

	VR	WPDs	Both	not sure	total
1999	6	5	3	0	14
2000	6	7	1	1	15
2001	4	3	3	0	10
2002	4	5	2	0	11
2003	7	7	1	0	15
	27	27	10	1	65

Table 2: Number of different ITCZ types in each year.

	shallow	Deep	Both	total
1999	5	7	2	14
2000	3	7	5	15
2001	0	6	4	10
2002	0	11	0	11
2003	4	7	4	15
	12	38	15	65

5. Discussion

We found that although the number of ITCZ breakdown events induced by the VR mechanism is the same as that triggered by WPDs, most of the latter cases (WPDs triggered events) produced named tropical storms. More than two thirds of those events produced disturbances that reached hurricane level. By contrast, less than a quarter of the VR induced events produced named tropical storms. This discrepancy can be explained in part by two different characteristics:

(1) *The size:* When the WPDs move into the tropical eastern Pacific, they are well developed disturbances, compared to the local disturbances in that region. On the other hand, the disturbances produced by the VR mechanism are usually rather weak and are all about the same strength. The unequal size and intensity of the disturbances in the former case gives the larger ones a better chance of distorting and ”collecting” the smaller disturbances (e.g., Ritchie and Holland 1993) while intensifying as they propagate westward. Therefore, although these two mechanisms lead to about the same number of ITCZ breakdown events, there are more named tropical cyclones generated by the WPDs mechanism.

(2) *The location:* The eastern Pacific is a more favorable region for cyclogenesis than the central Pacific. The ITCZ is observed to reform in the eastern Pacific as quickly as in a day. The WPDs propagate into the tropical eastern Pacific in sequence. They disturb the ITCZ and may break off its easternmost end. These vortices tend to move NNW along the Mexican coast, and usually do not disturb the western part of the ITCZ.

The contribution of WPDs to tropical cyclone formation appears more important than that due to the VR mechanism because WPDs create more numerous “named” tropical cyclones. However, for moisture transport out of the tropics, both mechanisms are important. The VR mechanism creates numerous small disturbances. Even though only a few of these disturbances developed into named tropical cyclones, the small disturbances still play an important role in transporting moisture toward higher latitudes.

The timescale of ITCZ breakdown varies from 5 days to about 3 weeks. The tropical atmosphere always tends to generate an elongated ITCZ. We found that the ITCZ may re-form in a time interval as short as just one day. The VR and WPDs mechanisms disturb the ITCZ and lead to its breakdown. Cyclonic background flow and warmer sea surface temperature lead to enhanced convection. From our modeling study (WM05), we found cyclonic background flow will enhance the wind shear on both sides of the PV strip and accelerate the evolution of ITCZ breakdown. The lifecycle of the ITCZ is determined by a combination of all the above factors.

6. Future work

The conventional approach we presented here is constrained greatly by data quality. The problems with NCEP analysis data make it less reliable than the satellite data. GOES images only show the cloud fields which do not represent dynamical fields directly. A new approach using Gaussian mixture models combined with a Markovian state-space model, will be applied to identify the ITCZ and the following breakdown in satellite datasets only. The idea is that using a probabilistic model, we can integrate different measurements made at different times as well providing a well-founded framework for parameter learning and state sequence estimation over time. We will model and detect an ITCZ structure in a set of single “static” images at a particular time-point (e.g., on a particular day) and follow this by generalizing from single time-points to tracking the dynamic evolution of ITCZ structures through multiple time-points.

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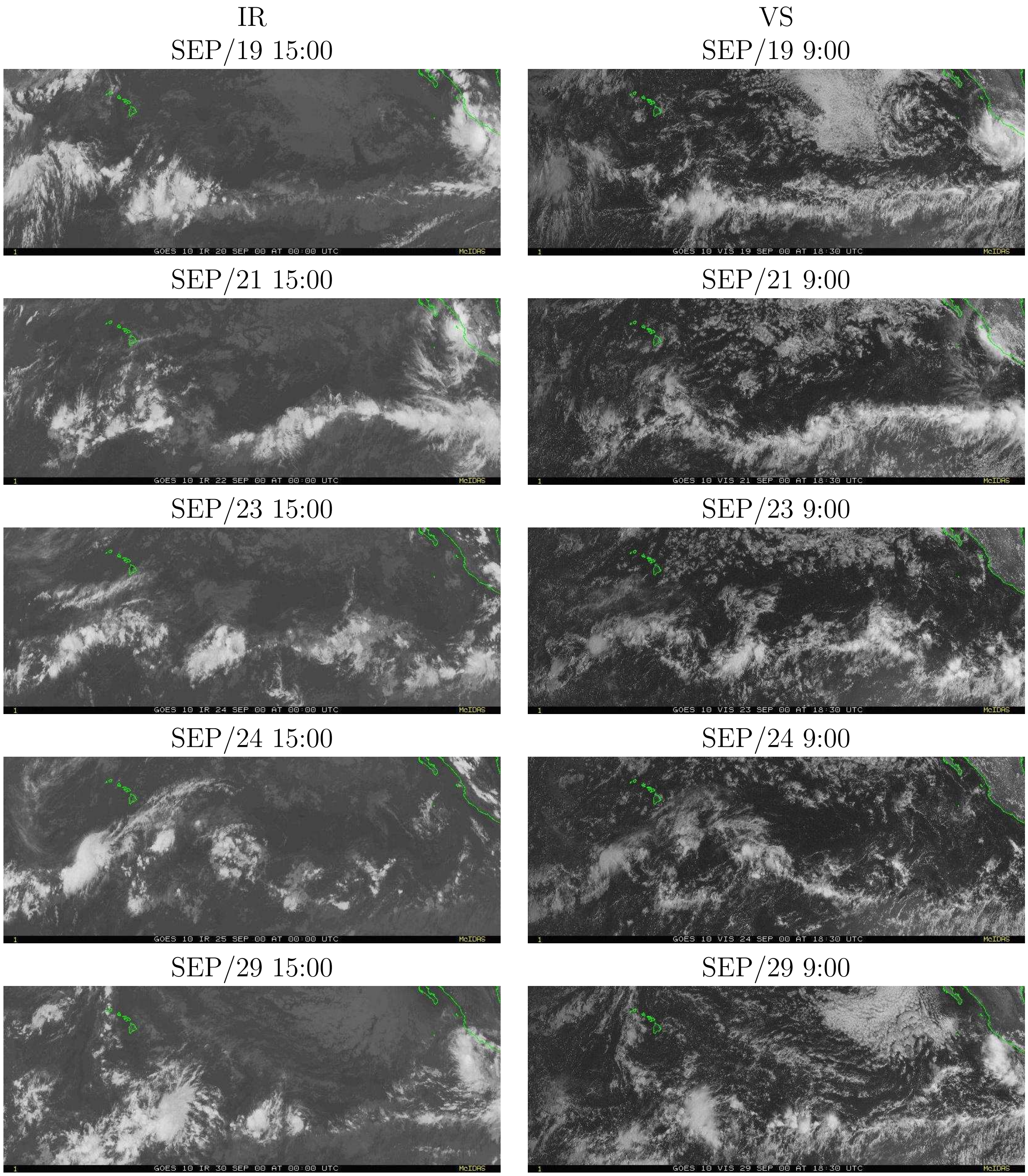

FIG. 1: ITCZ breakdown that occurred in September 2000. The American continent and the islands of Hawaii are outlined in green. Domain shown here is from equator to 30° N, 180 to 100° W The left column is for IR images and the right column is for VS images. Dates from top to bottom are September 19, 21, 23, 24, and 29. Time indicated is the local time at 135° W.

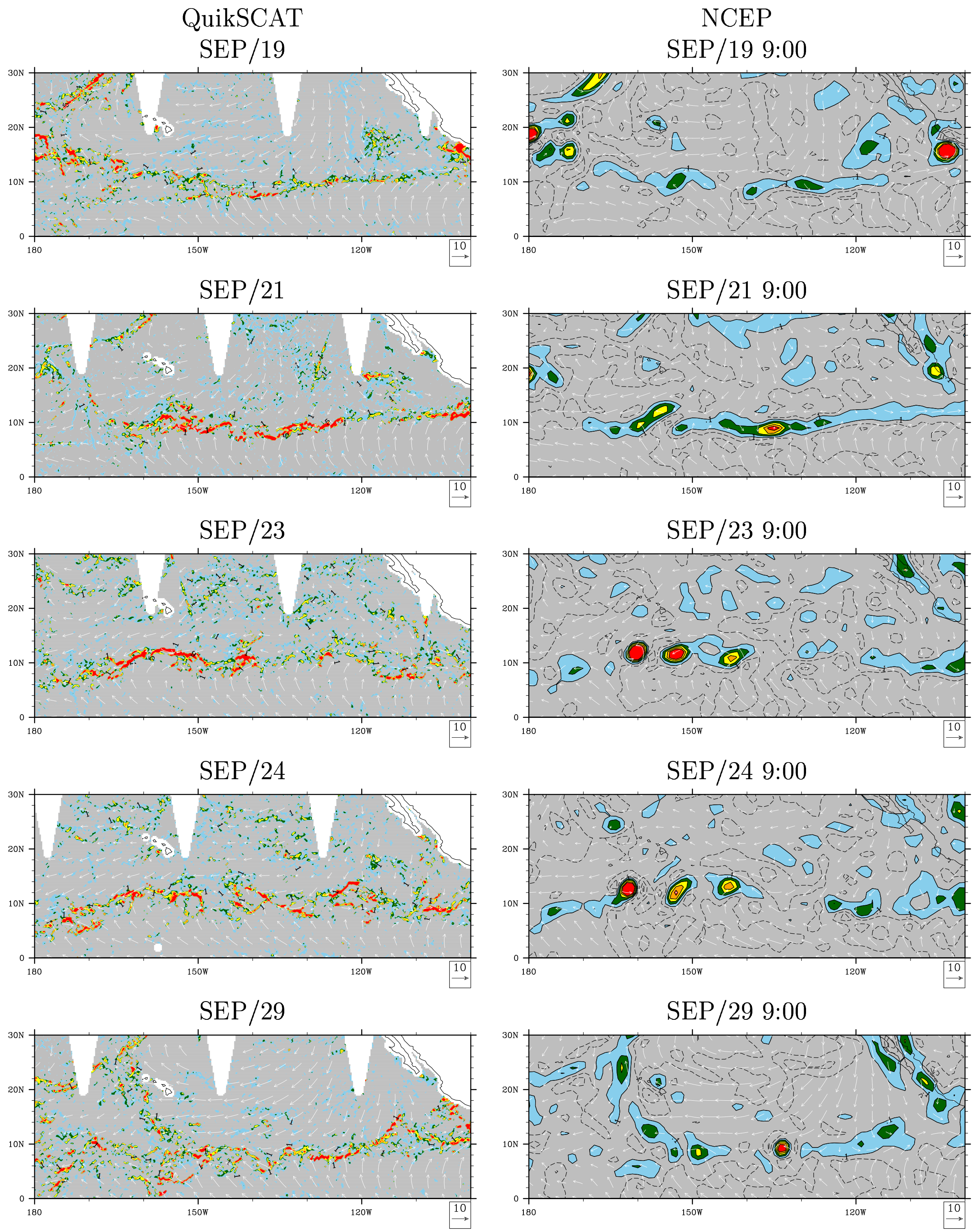

FIG. 2: The left column is for QuikSCAT daily vorticity and wind fields. The right column is for NCEP vorticity and wind at 975 hPa. Dates from top to bottom are September 19, 21, 23, 24, and 29, 2000. Time indicated is the local time at 135° W. Wind vector unit is m/s and vorticity unit is $10^{-5}s^{-1}$. Contour interval is $0.2 \times 10^{-5}s^{-1}$ with zero contour suppressed. White areas in QuikSCAT are missing values. Blue, green, and red indicate values of vorticity in excess of 0.1, 0.3, and 0.9 $\times 10^{-5}s^{-1}$, respectively.