17A.1 SUBTROPICAL CYCLONES: OPERATIONAL PRACTICES AND ANALYSIS METHODS APPLIED AT THE JOINT TYPHOON WARNING CENTER

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1. INTRODUCTION

Subtropical cyclones develop about ten times per calendar year within the Joint Typhoon Warning Center (JTWC) area of forecast responsibility, most frequently in the western North Pacific, South Pacific, and South Indian Oceans. Although the mechanisms for subtropical cyclone formation vary, they tend to develop in areas of weak to moderate baroclinicity over sea surface temperatures ranging from 24 to 26ºC. Unlike their tropical counterparts, subtropical cyclones are characterized by a broad swath of maximum surface winds far removed from the circulation center. These wind and associated convective fields are often observed as asymmetric (OFCM 2013; Gyakum et al 2010).

Subtropical cyclones present unique challenges to JTWC (Barlow and Payne 2012; Kucas 2010). Analysis and forecasting procedures for subtropical and tropical cyclones differ significantly. Although the Center, in most cases, does not issue detailed forecasts for subtropical cyclones, JTWC forecasters are required to monitor these systems for potential transition into tropical cyclones, promulgate detailed subtropical cyclone analysis data in significant tropical weather advisories, and ensure that collaborating forecast agencies have the requisite information to effectively account for localized impacts. Because US Government partners rely upon JTWC analyses and forecasts to tailor meteorological products for impacted customers, accurately distinguishing subtropical cyclones from tropical and extratropical cyclones is essential. Of course, cyclones located in the subtropics often exhibit well-documented physical characteristics common to both extratropical and tropical cyclones (OFCM 2013). A universal, subjective analysis method to differentiate these cyclones in ambiguous, real-world situations has not been established by the research community. To address this shortcoming, JTWC has developed a cyclone phase classification method that synthesizes available remote sensing datasets and numerical model analysis fields to systematically guide the classification process. This adaptable method reduces the uncertainty and inconsistency that result from an unguided subjective approach and provides customers a clear representation of how these classifications are determined.

2. OPERATIONAL PRACTICES

Because JTWC does not routinely forecast the track, intensity, and wind radii for subtropical cyclones, careful analysis of these systems is required in order to formulate accurate winds and seas forecasts and to diagnose potential transition to a tropical cyclone (Davis and Bosart 2003; Davis and Bosart 2004). When the forecaster identifies a disturbance that appears subtropical in nature, he or she is required to designate and track the disturbance as an "invest." The forecaster subsequently determines the cyclone phase – extra-tropical, subtropical, or tropical – following a systematic process. Guided by a Cyclone Phase Classification Worksheet, this process enables the forecaster to formulate a sound cyclone phase assessment based on analysis data available in near real-time.

The structure and environmental conditions associated with subtropical cyclone invests are described in significant tropical weather advisories if either transition to a tropical cyclone is anticipated or if the central wind speeds associated with the subtropical cyclone invest meet or exceed JTWC tropical cyclone warning thresholds: 25 knots in the western North Pacific basin and 35 knots in the Indian Ocean and western South Pacific. If a subtropical cyclone invest is expected to transition into a tropical cyclone that will meet warning criteria within 24 hours, the forecaster is required to generate a Tropical Cyclone Formation Alert. A Tropical Cyclone Warning may be issued for a subtropical cyclone if US Government assets will be impacted and the current central wind speed meets or exceeds tropical cyclone warning thresholds.

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3. PHASE CLASSIFICATION WORKSHEET

The authors have developed a repeatable, guided process to classify cyclone phase, aided by the aforementioned Cyclone Phase Classification Worksheet. Based on a thorough review of the literature and forecaster experience, the authors generated a list of 13 observable criteria related to cyclone phase for which associated, near real-time data are routinely available:

- Moisture signature (total precipitable water)
- Symmetry of the low level circulation center (LLCC)
- Radius of maximum winds
- Symmetry of the 850 mb vorticity signature
- 850 mb maximum vorticity
- Deep convection structure
- Size of convective envelope
- Vertical wind shear
- Sea surface temperature
- Baroclinicity
- Core temperature anomaly
- LLCC position relative to the 500 mb subtropical ridge axis
- LLCC position relative to upper low

These criteria are included in an initial version of the cyclone phase classification worksheet. Similar to JTWC's Low/Medium/High (LMH) worksheet (Kucas and Darlow 2012), the phase classification worksheet includes multiple "value bins" corresponding to typical data ranges for each of the observable criteria (see Table 1). Numerical values are assigned to each value bin - negative values to typical characteristics of extratropical cyclones, null values to typical characteristics of subtropical cyclones, and positive values to typical characteristics of tropical cyclones.

To develop the worksheet's phase classification formulas, binned values for each of the 13 observable criteria were recorded for 41 total cyclone/synoptic time cases, including the subtropical transition of tropical cyclone 03W (2013). Because cyclone phase – tropical to subtropical to extratropical – can be characterized as a spectrum, the worksheet derives phase assessments from a mathematical calculation rather than a logical combination of environmental and storm-related features as applied in LMH worksheet. Thus, the designated "value bin scores" for each of the 13 observable criteria were summed to determine a final classification score for each of the 41 cases. Purely subjective phase assessments were simultaneously formulated and recorded for each case. The final classification scores from the worksheet were then compared to the subjective phase assessments. Total score ranges were then developed to provide a "best fit" to the subjective assessments. These total score ranges correspond to five cyclone phase categories: extratropical, borderline extratropical/subtropical, subtropical, borderline subtropical/tropical, or tropical.

Observable criteria	Dataset referenced	Value bins
Moisture signature	CIMSS MIMIC total precipitable water	-3: Frontal -2: Asymmetric dry -1: Symmetric dry 0: Asymmetric moist +1: Near-symmetric moist +2: Symmetric moist (55-60 mm) +3: Symmetric moist (>60 mm)
Symmetry of the LLCC	Scatterometer data, visible and microwave satellite imagery, radar imagery	*Long axis diameter divided by short axis diameter:* -1: Frontal 0: Greater than 2 +1: Between 1.5 and 2 +2: Nearly symmetric
Radius of maximum winds	Scatterometer data and microwave satellite imagery	-1: Frontal 0: Greater than 100 nm +1: 50 to 100 nm +2: Less than 50 nm
Symmetry of the 850 mb vorticity signature	CIMSS 850 mb vorticity product	*Long axis diameter divided by short axis diameter:* -1: Frontal

		0: Greater than 2 +1: Between 1.5 and 2 +2: Nearly symmetric
850 mb maximum vorticity	CIMSS 850 mb vorticity product	-1: Frontal 0: 25-50 /s x 10^-6, +1: 50-75 x 10^-6 /s x 10^-6 +2: >75 /s x 10^-6
Deep convection structure	Microwave satellite imagery	-2: Frontal -1: Asymmetric 0: Greater than 80% located poleward and east of center +1: 50 to 80% located poleward and east of center +2: Evenly distributed around LLCC
Size of convective envelope	Microwave satellite imagery	-1: Cloud system width > 900nm (front signature) 0 Cloud system width > 900nm +1: Cloud system width 600-900nm +2: Cloud system width < 600nm
Vertical wind shear (850-200mb)	CIMSS vertical wind shear product	-2: 40+ kts -1: 30-40 kts 0: 20-30 kts +1: 15-20 kts +2: < 15 kts
Sea surface temperature	STIPS email, SST charts	-1: < 24º C 0: 24-26º C +1: 26-28º C +2: > 28º C
Baroclinicity	Model analysis fields (1000-500 mb thickness, 850 mb temperature)	-2: Strong temperature gradient -1: Moderate temperature gradient 0: Weak temperature gradient +1: No temperature gradient
Core temperature anomaly	AMSU radial/height cross sections (CIRA and CIMSS)	-1: Cold anomaly in troposphere w/possible warm core near sfc 0: Warm anomaly at tropopause w/cold core in lower trop. +1: Warm anomaly peak at 300-250 mb (0.5-1C) +2: Warm anomaly peak at 300-250 mb (>1C)
LLCC position relative to the 500 mb subtropical ridge axis	Model analysis fields (500 mb streamlines)	-1: Poleward of STR 0: Near axis of STR +1: Equatorward of STR +2: At least 5 degrees latitude equatorward of STR
LLCC position relative to upper low	CIMSS upper-level feature track winds	-1: Associated with midlatitude low or shortwave trough 0: Low directly over LLCC +1: Low offset from LLCC +2: No upper low over LLCC

Table 1: Classification factors, evaluation datasets, and associated value bins included in the Cyclone Phase Classification Worksheet.

The lowest possible unadjusted final score on the phase classification worksheet, including all criteria (extratropical cyclone), is -18. The highest possible unadjusted final score (tropical cyclone) is 26. The unadjusted total score ranges for each classification category are:

Extratropical:	-18 to -8
Borderline extratropical/subtropical:	-7 to -5
Subtropical:	-4 to 4
Borderline subtropical/tropical:	5 to 7
Tropical:	8 to 26

These scores are derived from potential value bin scores from all 13 worksheet criteria. However, a few of these criteria may not be observable at worksheet analysis time due to scarcity of data or delays in data transmission. In order to provide consistent classification recommendations despite such data disruptions, the worksheet calculates a weighted ratio based on potential subsets of *available* data.

This weighted ratio is formulated in three steps. First, a total raw score is calculated by adding the value bin scores of only those criteria designated by the user (see Table 1). Next, total potential minimum and maximum scores are separately determined by adding the potential minimum and maximum value bin scores for each of the same user-designated criteria. Finally, the total raw score is divided by the absolute value of either the total potential minimum (if the raw score is negative) or maximum (if the raw score positive) value bin score. Because the ratio is thus weighted by potential maximum and minimum values, selecting criteria with a higher proportion of positive or negative value bin scores relative to the full (13 criteria) dataset should not significantly bias the final ratio, and associated assessment, toward either the extratropical or tropical end of the "phase spectrum."

The weighted ratio, ranging from -1 (extratropical) to 1 (tropical), is compared to the following values to determine the worksheet's final classification assessment:

Extratropical:
-1 to -.389 (-18/18 to -7/18)

Borderline extratropical/subtropical:
-.389 to -.278 (-7/18 to -5/18)

Subtropical:
-.278 to .192 (-5/18 to 5/26)

Borderline subtropical/tropical:
.192 to .269 (5/26 to 7/26)

Tropical:
.269 to 1 (7/26 to 26/26)

4. WORKSHEET APPLICATION

Forecasters access the cyclone phase classification worksheet through a PHP-based web-interface hosted on a JTWC computer server. To complete the worksheet, the forecaster enters data into a series of input boxes and drop down menus, as depicted in Figure 1.

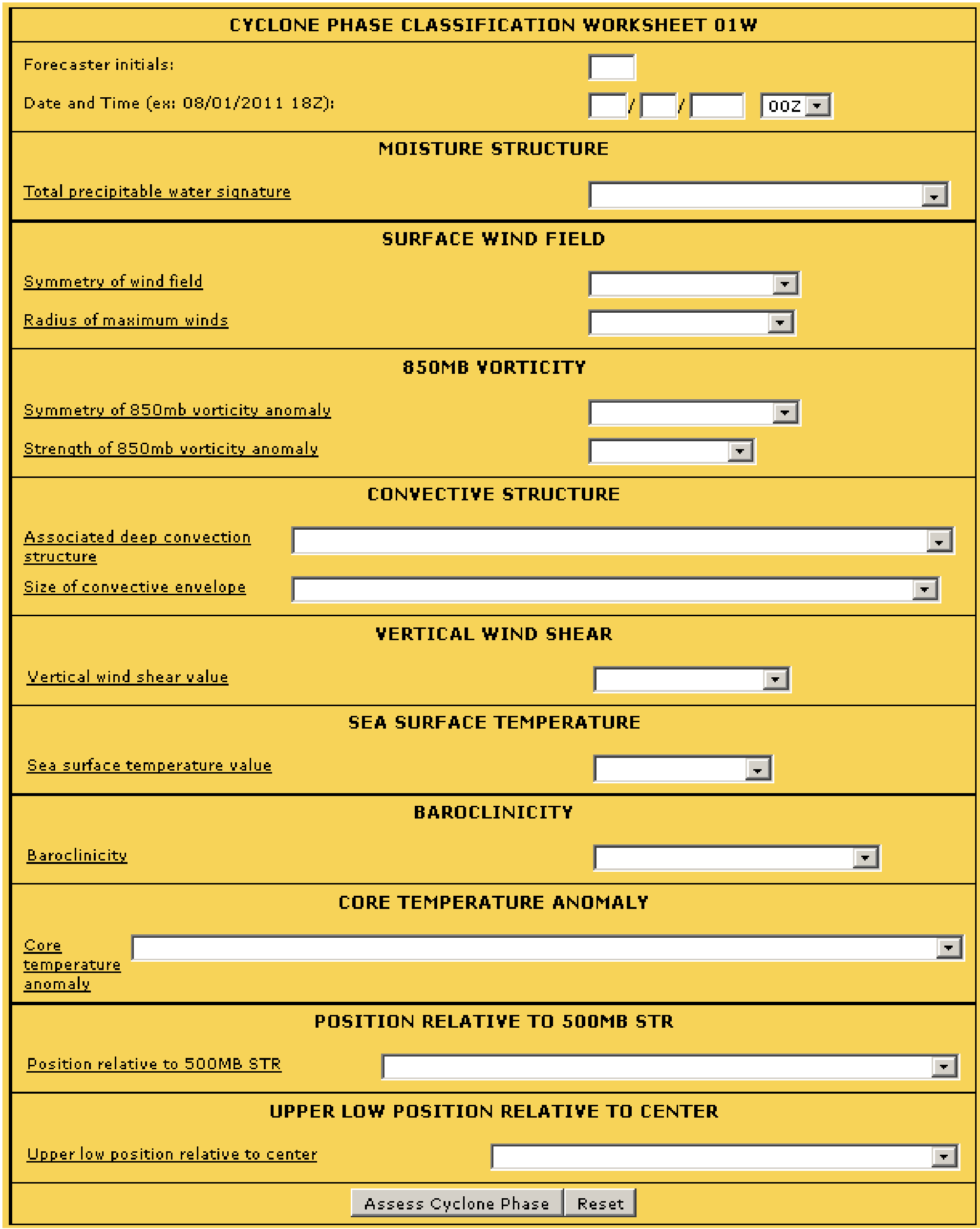


Figure 1: Cyclone Phase Classification Worksheet graphical user interface.

Hyperlinks to primary data sources for evaluating each of the observable criteria are included in the worksheet. Detailed guidance for interpreting these datasets and assigning appropriate value bins for each of the observable criteria, including sample imagery for visual comparison, is also provided to the forecaster (Figure 2).

After completing the worksheet, the forecaster receives a summary of data entered and is prompted for his or her subjective assessment of the cyclone's phase (tropical, subtropical, or extratropical) along with any relevant notes or comments before he/she clicks the "Assess Cyclone Phase" command button. The calculated assessment is withheld at this point to facilitate the collection of unbiased subjective assessments. These assessments will be considered when determining future adjustments to the worksheet criteria, value bins, and formulas (Figure 3).

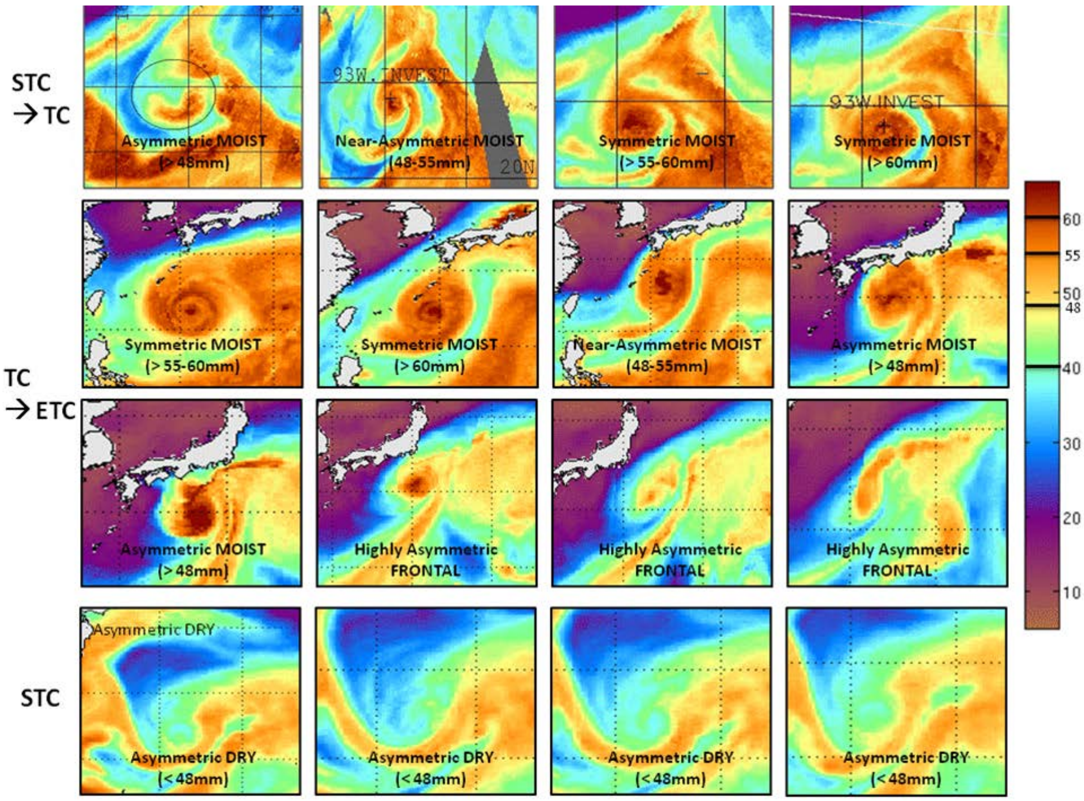
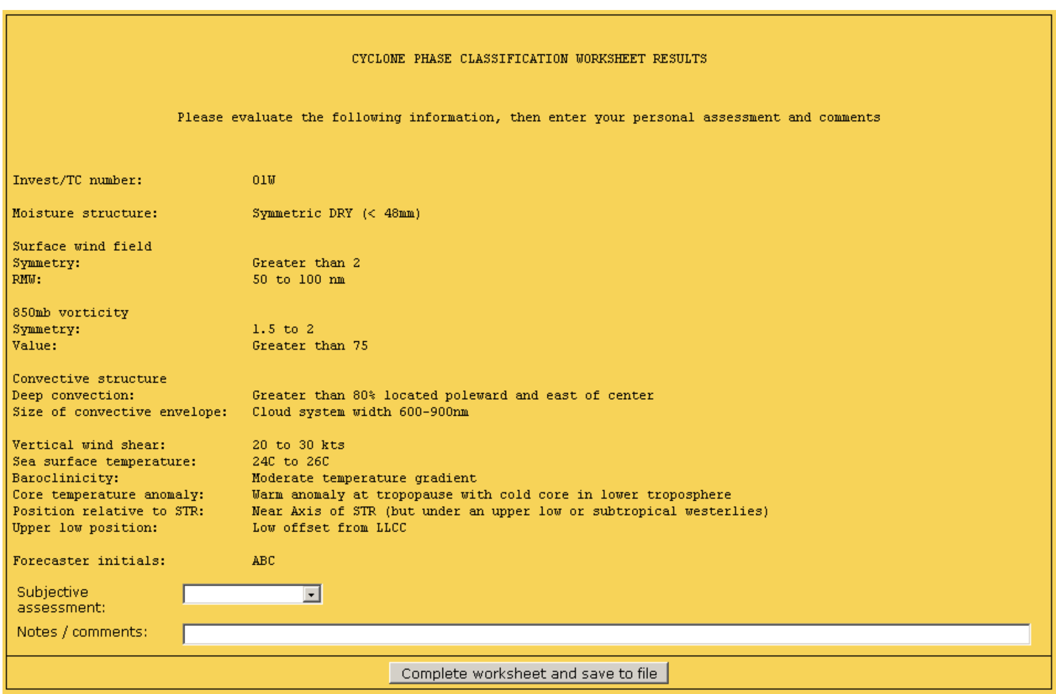


Figure 2: Example guidance for evaluating total precipitable water on the phase classification worksheet (Image source: UW-CIMSS).



CYCLONE PHASE CLASSIFICATION WORKSHEET RESULTS

Please evaluate the following information, then enter your personal assessment and comments

Invest/TC number:	01W
Moisture structure:	Symmetric DRY (< 48mm)
Surface wind field	
Symmetry:	Greater than 2
RMW:	50 to 100 nm
850mb vorticity	
Symmetry:	1.5 to 2
Value:	Greater than 75
Convective structure	
Deep convection:	Greater than 80% located poleward and east of center
Size of convective envelope:	Cloud system width 600-900nm
Vertical wind shear:	20 to 30 kts
Sea surface temperature:	24C to 26C
Baroclinicity:	Moderate temperature gradient
Core temperature anomaly:	Warm anomaly at tropopause with cold core in lower troposphere
Position relative to STR:	Near Axis of STR (but under an upper low or subtropical westerlies)
Upper low position:	Low offset from LLCC
Forecaster initials:	ABC
Subjective assessment:	
Notes / comments:	

Complete worksheet and save to file

Figure 3: Sample summary of data entered into the phase classification worksheet by the evaluating forecaster. The forecaster reviews these data, enters his or her subjective assessment, and provides written justification for the assessment.

The final screen provides a summary of the assessment and notes entered by the forecaster along with the final score and assessment according to the worksheet parameters and formulas (Figure 4).

CYCLONE PHASE CLASSIFICATION WORKSHEET RESULTS

Invest/TC number:	01W
Moisture structure:	Symmetric DRY (< 48mm)
Surface wind field	
Symmetry:	Greater than 2
RMW:	50 to 100 nm
850mb vorticity	
Symmetry:	1.5 to 2
Value:	Greater than 75
Convective structure	
Deep convection:	Greater than 80% located poleward and east of center
Size of convective envelope:	Cloud system width 600-900nm
Vertical wind shear:	20 to 30 kts
Sea surface temperature:	24C to 26C
Baroclinicity:	Moderate temperature gradient
Core temperature anomaly:	Warm anomaly at tropopause with cold core in lower troposphere
Position relative to STR:	Near Axis of STR (but under an upper low or subtropical westerlies)
Upper low position:	Low offset from LLCC
Classification score:	0.15384615384615
Classification assessment:	SUBTROPICAL
Forecaster initials:	ABC
Subjective assessment:	SUBTROPICAL
Notes / comments:	System displays subtropical characteristics.

Click here to run another cyclone phase classification worksheet

Figure 4: Example final assessment and summary of data provided by the phase classification worksheet.

5. DISCUSSION

Accurately analyzing cyclone phase is an important task in JTWC's forecasting mission. The cyclone phase classification worksheet is a key component of a guided, repeatable process designed to reduce ambiguity and increase consistency. Data collected during operational implementation of the worksheet, including binned observable criteria values and subjective phase assessments, will be evaluated *post-facto* to improve worksheet phase assessments through targeted adjustments to the criteria, value bins, and formulas. Future versions may also incorporate additional datasets, such as cyclone phase assessments from Florida State University's numerical model-based cyclone phase evolution products (Hart 2003) and SHIPS phase classification guidance (De Maria et al. 2005; CIRA-RAMMB 2014b). The worksheet may also be applied operationally to diagnose extratropical transition.

The phase classification worksheet is designed to provide reliable guidance derived through a systematic process. However, the forecaster makes the final assessment, which need not match the worksheet result. Ultimately, the forecaster will choose a course of action that is both meteorologically sound and provides actionable forecast guidance to customers consistent with JTWC's operational requirements.

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