The Extratropical Transition of Tropical Cyclone Hary (2002)

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ABSTRACT

The processes behind extratropical transition (ET) are not particularly well understood, despite numerous studies into this complex stage in the life of a tropical cyclone (TC). Furthermore, virtually no studies of ET have been performed in the Southwest Indian Ocean. While a likely cause of the relative lack of studies stems from the region's remoteness from dense surface-based observational networks, this same remoteness also makes the region a prime area to observe processes from the idealized perspective of computerized analyses. As such, a subjective analysis of the ET of TC Hary (2002) is described, followed by a first attempt at a single-variable objective determination of the ET timing within Hary's life cycle.

1. Introduction

Tropical cyclone (TC) activity spans the majority of the ocean basins around the world, each with its own unique set of local effects that play a role in the life cycle of storms in that basin. Virtually all of these basins have been researched to some extent, with much of the focus falling onto extratropical transition (ET) events in the northwest Pacific and Atlantic basins. However, due to large landmasses and other basin-specific features, data from these basins are not necessarily applicable to all basins around the world. Examining these ET events in the Southwest Indian basin presents several benefits when compared to similar research in other basins.

One of the unique aspects of observing meteorological events over the Southwest Indian Ocean is its apparent independence from the observational networks that are dense throughout the northern hemisphere. There are few surface observations taken within the basin, due to the relative remoteness of the basin’s waters. Similary, the upper air observations taken upstream of the region include only two sites taking twice-daily soundings (in northern Madagascar), and six additional locations taking once-daily soundings throughout South Africa. As such, it appears that modeling of this region is not greatly affected by ground-truth observational data, hence leaving the processes associated with events such as ET to be presented in the near-idealized manner of a numerical model.

2. Data and methodology

An examination of best track data from the Regional Specialized Meteorological Center (RSMC) La Reunion and via Joint Typhoon Warning Center (JTWC) data aided in the initial examination of Hary as an interesting ET event to study. As a tropical cyclone, Hary was analyzed by the JTWC with max winds of 140kts and a central pressure of 898hPa during the early morning hours of March 10, 2002, just off the northeast coast of Madagascar. The storm did not make landfall, but instead turned south and eventually southeastward as it began ET. It is this time frame, beginning on 11/00z and continuing through the maturing of the extratropical cyclone approximately 10 days later, that was initially examined for this paper. Gridded data from the European Centre for Medium-Range Weather Forecasts (ECMWF) Interim reanalysis (of 1.5° square resolution) was utilized in the analysis of Hary. GEMPAK plots of this data were analyzed to provide a subjective analysis of the timing of Hary’s ET as well as create possible objective tools for determining the timing of the ET period.

In order to test objective tools, a solid subjective analysis must first be performed (as in section 3). Seeing as data scarcity in this region is an admitted deficiency, analyses were only performed at 12-hourly intervals. This time sampling method also allows for a slight overestimation of the true time period of ET, which ensures as many of the related processes are captured regardless of their portrayal in the computerized analyses. It is with these conservative methods that the all date determinations will be made throughout this paper, both in the subjective analysis and the attempts at an objective approach to the subject.

3. Subjective analysis of ET timing

In order to perform a succinct yet accurate subjective analysis of Hary's ET, maps of the entire basin were created for 250hPa, 850hPa, and the surface. Satellite images, available from the Naval Research Laboratory's tropical cyclone page, also aided in the analysis process. Of initial note, during the day on March 11th, two features were apparent in the vicinity of Madagascar. In the lower levels, TC Hary is positioned off the eastern coast of central Madagascar, and is represented by an expectedly weak pressure minimum, most likely due to the nature of the gridded data. On the western side of the island, a weak surface trough presents itself, well-aligned with the coast. Aloft, the anticyclone associated with Hary is located just over 10° east of the cyclone's surface position, while the surface trough on the western coast of the island has an even more impressive signature at 250hPa. By 12/12z, the upper level trough has progressed eastward and is beginning to interact with the weak upper-level representation of Hary, noted by a small area of weaker wind barbs in Fig. 1a. This figure also shows that Hary is now represented at 250hPa by a weak trough that appears poised to merge with the approaching shortwave trough just to its west. An examination of the 850hPa temps to the west of the cyclone (as shown in Fig. 1b) shows little in the way of cold air advection, with the apparent "surge" of colder (15-18°C) air attributed to the motion of the TC's warm core making the cooler air appear cyclonically shaped. Furthermore, temperatures in the area 12 hours prior were actually cooler still, though this may be in part due to a weak diurnal signal evident in the maps equatorward of about 30°S.

Twelve hours later (by 13/00z), maps shows the apparent beginnings of an ET. Fig. 2a. shows the beginnings of cold air advection on the western side of the storm. On the eastern side of the storm, advection is not quite as strong, but a low level jet is taking shape north of a region of convergence (especially at the surface, Fig. 2b) and slightly tighter temperature gradient. Both sides of the storm are showing increasing signs of frontogentical processes, and it seems safe to assume that ET is underway at this point. In order to maintain our conservative methodology, the time for the beginning of ET can be determined to be 12/12z, as the processes described at 13/00z have likely been occurring for several hours before that time. A further confirmation of this determination is apparent when observing infrared imagery over the time period in question. Figure 3 contains six-hourly satellite images from 12/12z to 13/00z in which the system still has a mostly tropical appearance at 12z, but central convection is slowly lost by 18z and is virtually gone by 13/00z. Also of note is the persistent banding feature extending south and east from the system's center, likely indicative of the aforementioned region of warm frontogenesis. This series of satellite images support the assumption that ET processes began between 12/12z and 13/00z, further confirming the declaration that the ET of Hary began shortly after 12/12z.

Determining of the ending of ET is not quite as clear cut as determining its beginning. The latter requires simply looking for any sign of extratropical processes starting to occur within the envelope of the tropical cyclone, while the former entails looking for a sign that the cyclone has lost all of its tropical features. As many of these tropical features are not well represented in the larger scale datasets produced by global analyses, a broader approach must be taken in these analyses. In Evans and Hart (2003), they establish the need to declare the end of an ET event when the system resembles a mid-latitude system through the entire vertical structure of the system. In addition, thermal wind balance requires the development of an upper level trough above the cyclone to complete its transition into a mid-latitude cyclone. This cold upper trough began developing early in the ET process, but does not fully align with the lower-level cyclone until approximately 14/12z (shown in Fig. 4a). At the same point, the cyclone finally loses its warm low-level center (Fig 4b). With frontal zones well defined and extending both north and east from the cyclone, it seems the loss of the warm core is a final indicator of the completion of the ET process. Visible satellite imagery (not shown) from 14/06z support the declaration of Hary as an extratropical cyclone sometime between the 14/00z and 14/12z time frames, though this determination could not be made from satellite alone due to the weak presentation of frontal zones over the relatively homogenous and stable ocean waters present in the mid-latitudes of a large ocean basin. Having examined these points and invoking the conservative methodology for declaring beginning/end dates, the best determination of a time for the end of ET falls on 14/12z, but is likely not long after 14/00z. Examination of data into the 15th shows the system beginning to briefly fill and seemingly reach a point of warm seclusion, a sign of a fully matured mid-latitude cyclone, indicating that the process was most certainly complete by the chosen time. For comparison purposes, JTWC data declared Hary to be extratropical at 14/00z, while best track data from RSMC La Reunion labels the system extratropical at 13/12z. Both times agree reasonably well with the dates determined in this study and go to show the potential spread of such determinations. It is also logical that both times are sooner in the cyclone's life as the methodology used here was intended to give a longer ET period than operational centers are likely to use.

4. Objective analysis of ET timing

No widely accepted definition of ET exists within the meteorological community today, although the cyclone phase-space diagrams developed by Evans and Hart (2003) provides a three-variable approach to the methodology, resulting in a pair of phase-space diagrams which each contain a plot of the cyclone's evolution through time. Between the two, it is fairly simple to determine where a cyclone is in its life cycle – be it fully tropical, undergoing ET, or a fully cold-core mid-latitude system. In an attempt to make determining such information even simpler for operational forecasters, it seems plausible that a single-variable approach would make operational activities simpler. While a detailed investigation of possible variables is beyond the scope of this paper, a few were examined. Two of the variables that showed promising results involved Q-vectors, as described in Martin (2006). First, plots of Q-vector convergence were constructed in order to investigate the strength of low-level frontogenesis. These plots (not shown) conveyed a clear portrayal of frontogenetical regions, but presented much the same signals as apparent in maps of the Q_n magnitude. For this study, Martin's definition was also used, describing Q_n as the cross-isentropic component of the Q-vector. This field was chosen under the principle that cross-isentropic Q-vectors in an idealized barotropic cyclone should be virtually nonexistent, and would grow as baroclinic processes began to occur, with a large jump in the magnitude of these values signaling the beginning of the ET process. A time series of these plots is provided in Fig. 5, where it can be observed that the evolution of the Q_n values are not as clear-cut as expected. While Hary is still classifiable as a TC, the distribution of Q_n contains magnitudes of no more than about 80 x 10^{-11} K m^{-1} s^{-1} and is a symmetric dipole in the eastern and western semicircles of the storm (Fig. 5a). As the previously determined ET period begins, the distribution first loses the symmetry displayed during its tropical phase (Fig. 5b) and begins to increase in magnitude as it morphs into a shape more representative of the forming frontal zones around the cyclone (Fig. 5c). Similarly, at the end of ET (14/12z), the cyclone is beginning to temporarily level out as a mid-latitude cyclone, leading to a decrease in the strength of its frontogenesis, which is well reflected in the Q_n magnitude fields (Fig. 6). Of note, the presentation of Q_n in Fig. 6b shows the magnitude almost falling under the 80 [UNITS] threshold, with the analyzed maximum value well beneath this threshold by 14/12z. This corresponds well with the statement made in section 3, which stated that the ET of Hary likely concluded shortly after 14/00z. Based on the analyses of TC Hary, a threshold of 80 x 10^{-11} K m^{-1} s^{-1} for the magnitude of the Q_n vector appears to correspond well to the endpoints of Hary's ET. However, further analysis with a significantly larger data set would need to be pursued before being able to declare any variable useful in single-handedly determining ET boundaries.

5. Summary

The extratropical transition of Tropical Cyclone Hary was a fairly routine event for the Southwest Indian Ocean basin, where an average of just under 4 ET events are observed annually (Griffin, submitted to ATM305). A small shortwave trough embedded in the subtropical jetstream initiated the recurvature and transition process late on the 12^{th}, which quickly progressed into a case of strong frontogenesis in both the warm and cold frontal zones. With the development of frontal regions and a cold core at upper levels, the final step in completing the transition was the loss of the system's low-level warm core, a process which was completed early on the 14^{th}. A similar time frame was suggested by the objective analysis based on the magnitude of the cross-isentropic component of the Q-vector. One case study by itself does not provide a reliable basis on which to use such objective methods, though it does show promise that one-variable approaches could be possible in the future.

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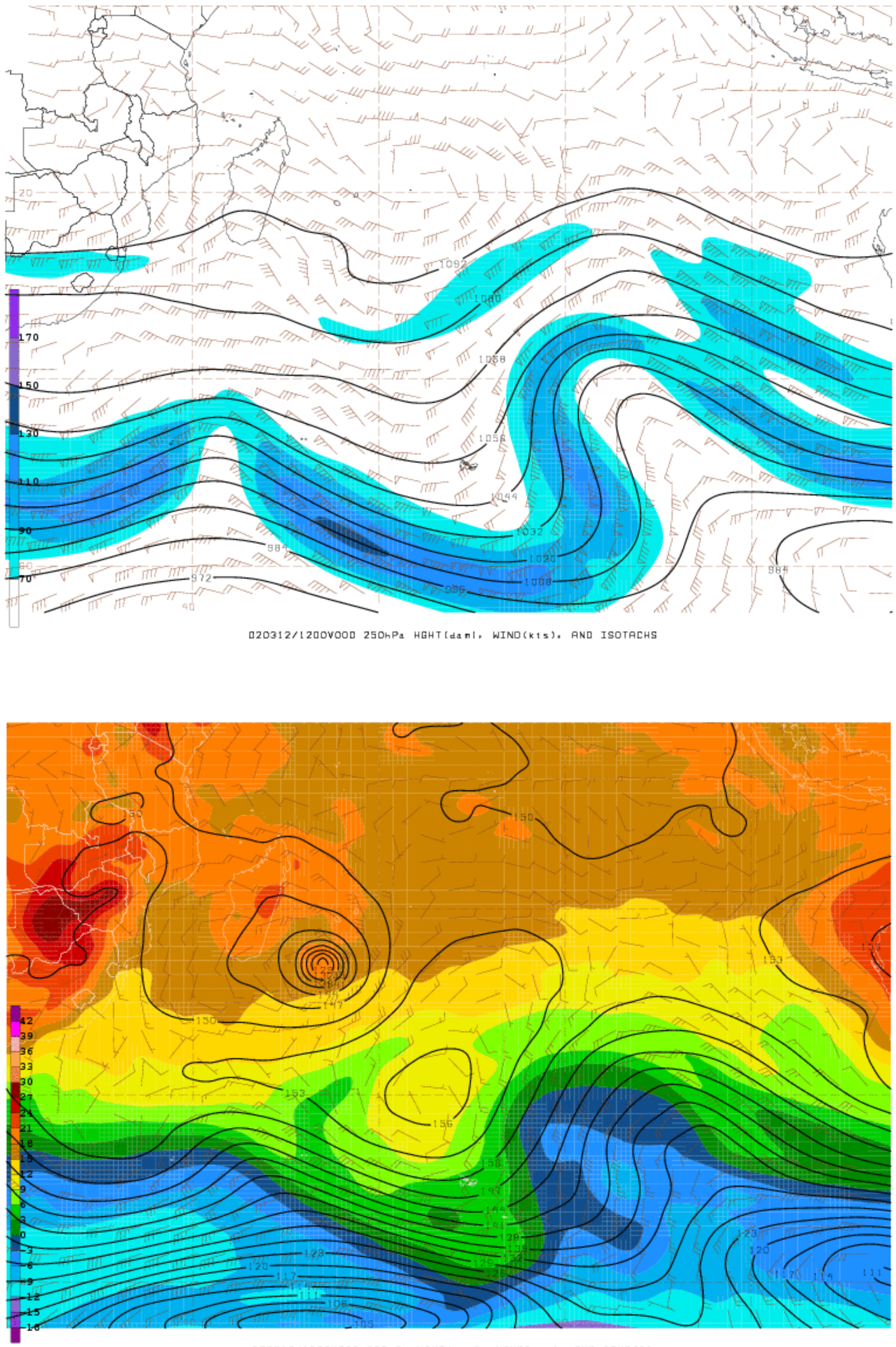


Fig. 1. (top) 250hPa heights (dam), winds (kts), and isotachs for March 10, 2002, at 1200 UTC. (bottom) 850hPa heights (dam), winds (kts), and temperatures (°C) for the same time as top.

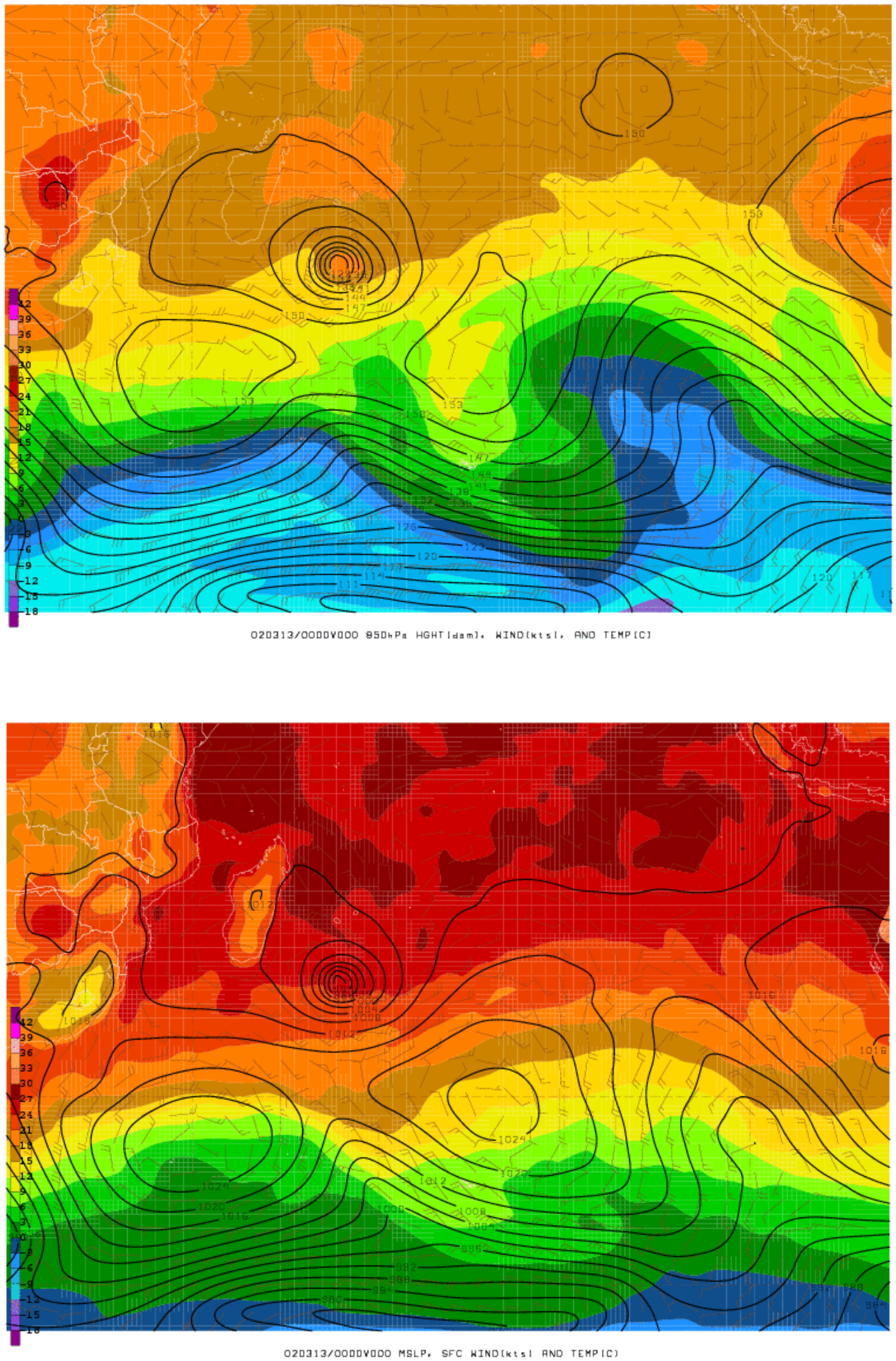
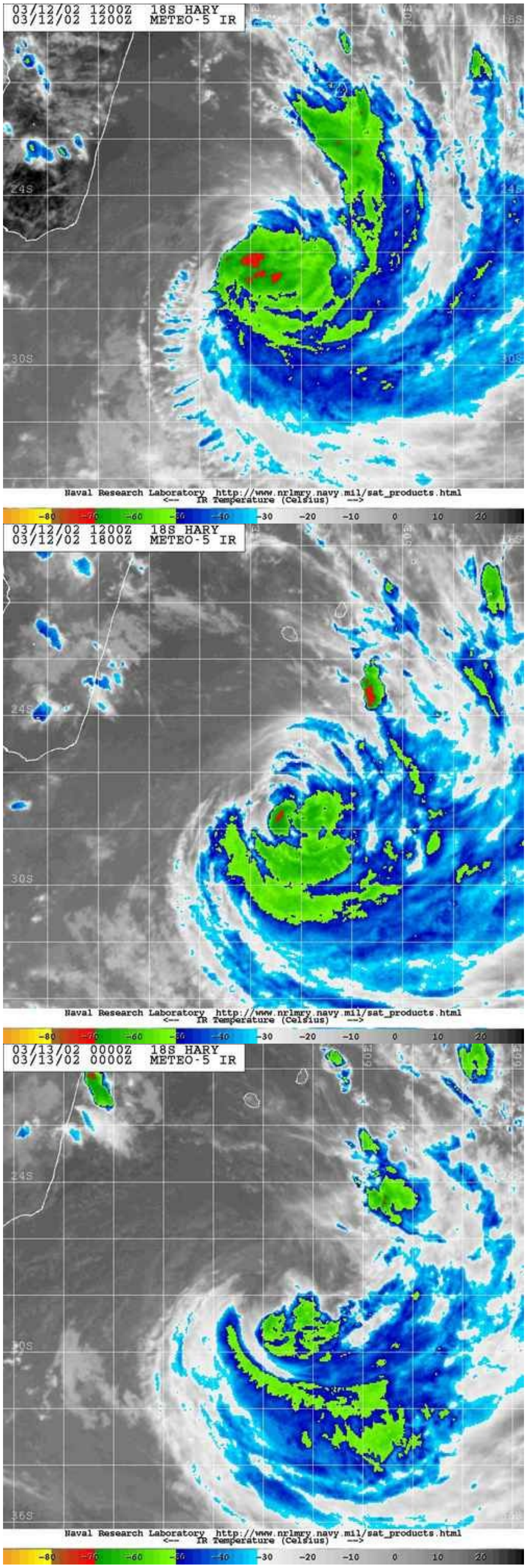


Fig. 2. (top) As in Figure 1(b), but for March 13 at 0000 UTC. (bottom) Mean sea level pressure (hPa), surface winds (kts), and temperatures (°C), for the same time as top.



(a)

(b)

(c)

Fig. 3. METEO-5 Infrared images of TC Hary at (a) March 12, 2002, 1200 UTC (b)1800 UTC and (c) the 13th at 0000 UTC. Images obtained from the Naval Research Laboratory in Monterey's tropical cyclone webpage.

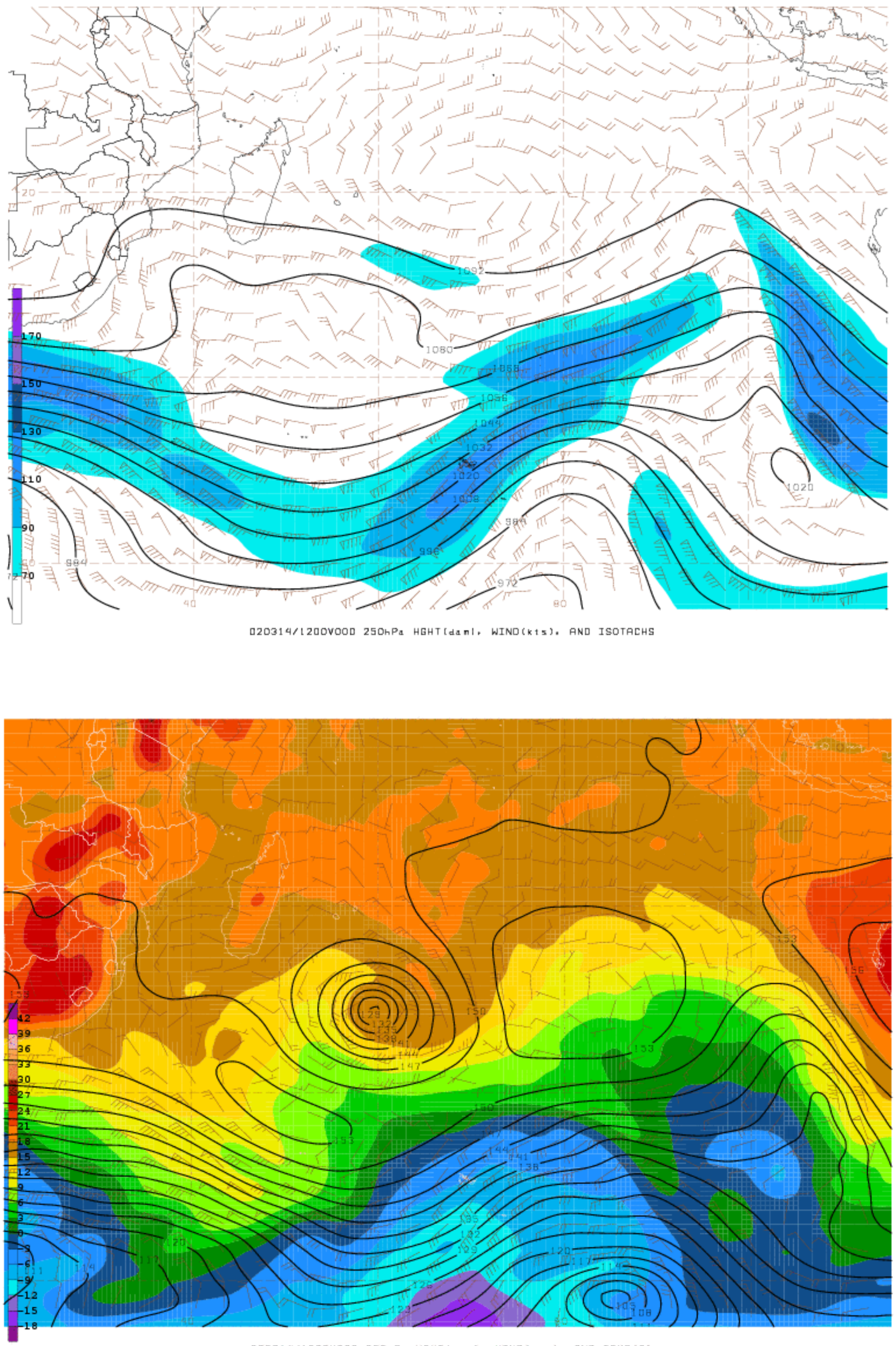
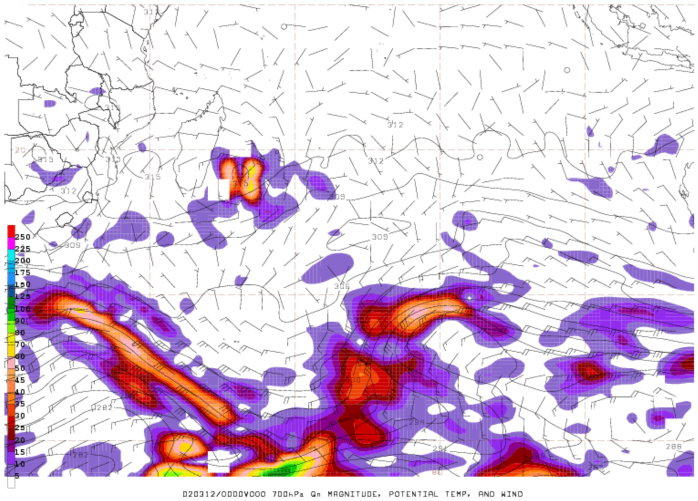
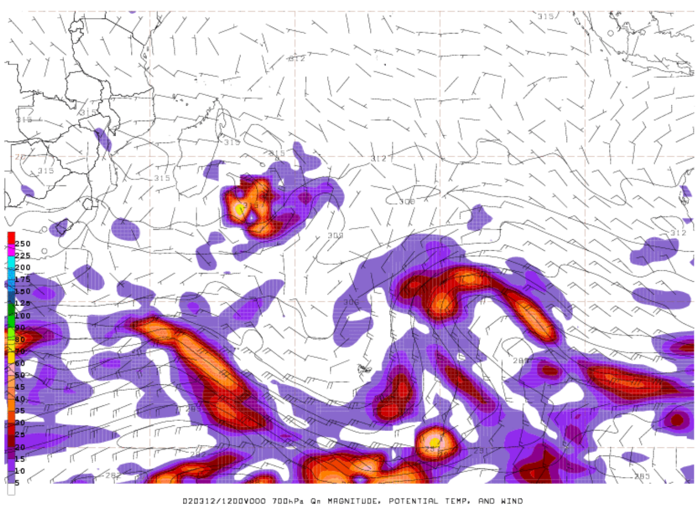


Fig. 4. As in Fig. 1, but for March 14, 2002, at 1200 UTC.

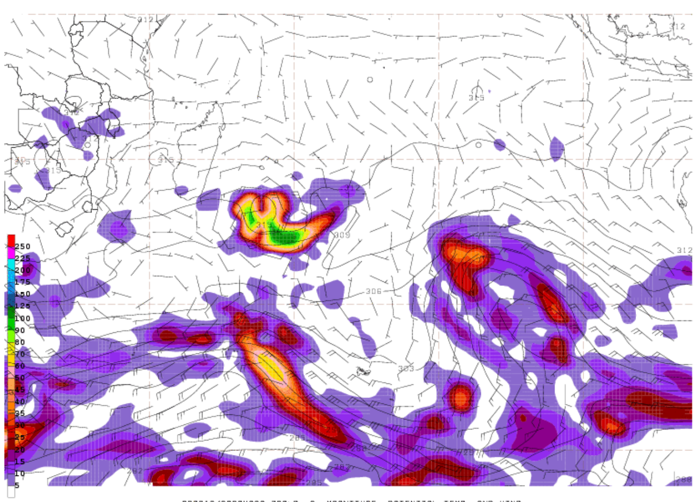


(a)

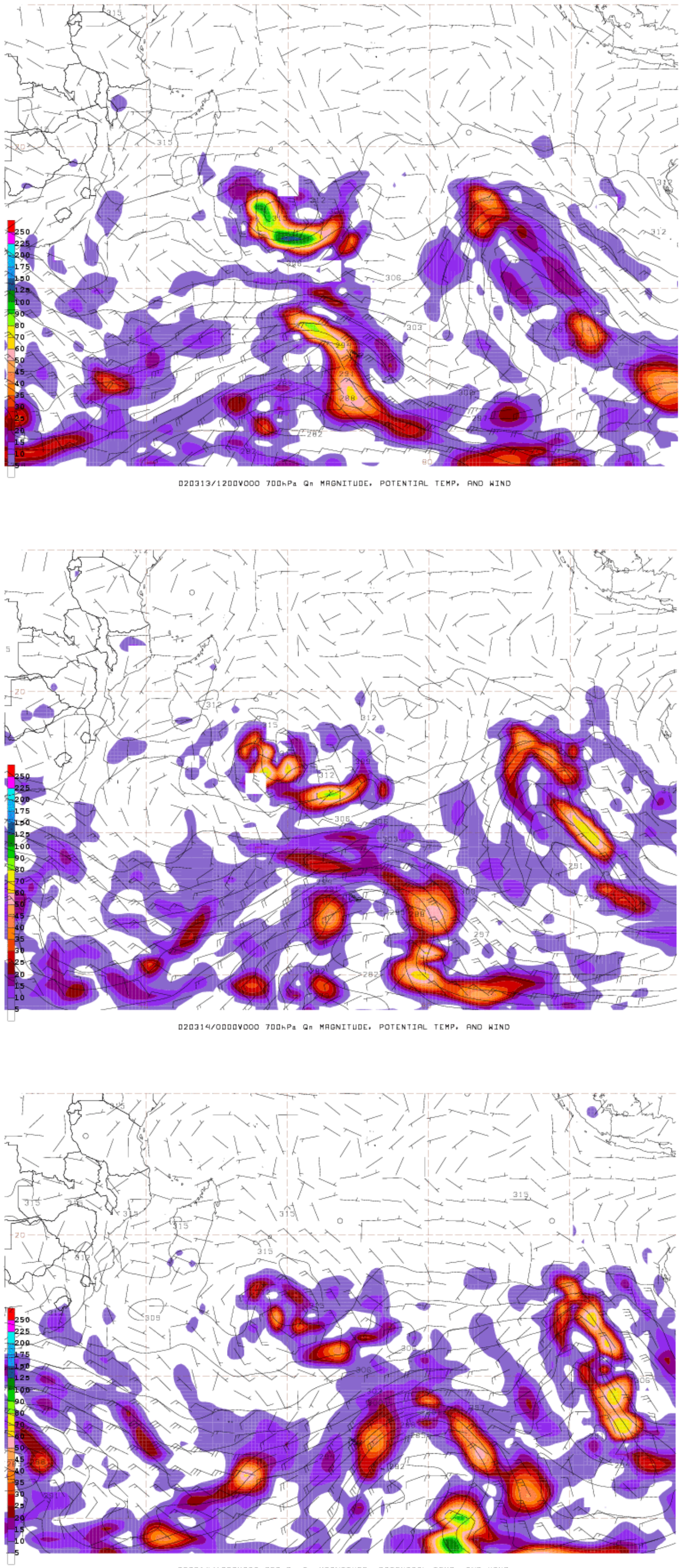


(b)

Fig. 5. Plots of the cross-isentropic component of the Q-vector, potential temperature (K), and wind (kts), all at the 700hPa level. (a) is for March 12 at 0000 UTC, (b) is for March 12 at 1200 UTC, and (c) is for March 13 at 0000 UTC.



(c)



(a)

(b)

(c)

Fig. 6. As in Fig. 5, but for (a) March 13 at 1200 UTC, (b) March 14 at 0000 UTC, and (c) March 14 at 1200 UTC.