P1.36

RE-EXAMINING TROPICAL PLUMES AND SUBTROPICAL JET STREAKS

Peter Knippertz*, and John R. Mecikalski
University of Wisconsin, Madison, Wisconsin

1. INTRODUCTION

Tropical plumes (TPs) are elongated bands of mainly upper- and mid-level clouds stretching for several thousand kilometers from the Tropics poleward and eastward into the subtropics, typically accompanied by a subtropical trough to the west penetrating into the Tropics and a subtropical jet (STJ) streak along the plume. Several conceptual models have been developed for the dynamics of TP generation. Early papers (e.g., McGuirk et al. 1988) postulated that quasi-geostrophic forcing associated with large-scale Rossby waves triggers the eruption of the cloud plumes. More recently, Blackwell (2000) used a barotropic shallow-water model of the upper-troposphere to demonstrate that TPs can be initiated by convergent forcing of a basic mean state. He suggests that the convergence is caused by large-scale cold advection and subsidence, which may be associated with extratropical wave train activity. In contrast, Mecikalski and Tripoli (1998) view TPs as the upper branch of an enhanced thermally direct circulation driven by latent heat released along the ITCZ, as convection responds to the changes in inertial stability caused by southwesterly advection of low potential vorticity (PV) air through a large-scale wave. All studies regard the clouds of TPs as outflow from tropical convection.

This paper uses ECMWF analyses and data from a case study with the UW-NMS model of a TP over the Atlantic Ocean in March 2002 to test the different observational and model derived hypotheses for TP genesis. The high spatial (75 km) and temporal (1 h) resolution of the available data allows for the calculation of very accurate trajectories to trace back the origin and characteristics of 'plume parcels'. The model's water condensate density is used as a proxy for clouds. An updated dynamic model of TPs and the accompanying STJ streaks will be presented. This new view of TPs draws together the views of two main ideas into one complete mechanistic view of the TP genesis process.

2. RESULTS

Inspection of PV maps for the 340–350K layer and infrared satellite images reveal the following important steps toward plume genesis over the Atlantic Ocean:

* *Corresponding author address*: Peter Knippertz, Dept. of Atmospheric and Oceanic Sciences, University of Wisconsin, 1225 W. Dayton St., Madison, WI 53706; e-mail: pknipp@aos.wisc.edu

- Tropical outflow over the East Pacific encroaches into the western portion of the large-scale ridge over Central America (see schematic in Fig. 1). The kinetic energy gained from the latent heat release within the convective updraft and the low horizontal restoring forces due to the advection of low PV air from the equatorial East Pacific allow the outflow to spread northwards (c.f. Mecikalski and Tripoli 1998) and eventually to penetrate into the subtropical stratosphere.
- The ensuing dramatic change in environmental vertical stability this air mass experiences leads to a strong compression of the atmospheric column (along the converging isentropic levels), production of anticyclonic relative vorticity as PV is conserved in this air mass and a consequent sharp turning back into the tropical troposphere (southern trajectory in Fig. 1). This process leads to a deepening and zonal contraction of the ridge.
- The associated negative PV anomaly affects nearby stratospheric air to the east and 'drags' it into the Tropics. This air mass is then in turn subject to opposite changes: lower environmental vertical stability, column stretching, strong localized convergence in the eastern portion of the ridge and sharp cyclonic turning in an equatorward amplified and zonally contracted trough (northern trajectory in Fig.1). Previously near gradient wind balance, this flow becomes highly ageostrophic when forced to enter the deep Tropics. 'Going up' the gradient of Montgomery potential, the flow decelerates, turns sharply and then accelerates again away from the Tropics forming a STJ streak.
- The equatorward amplification of the trough initiates a southwesterly advection of low PV air on its eastern side, allowing convection over South America to spread its outflow away from the equator, similarly to the development over the East Pacific during the first step (see above). This outflow forms the southern portion of the emerging TP and further adds kinetic energy to the system. This is clearly revealed by the high-resolution trajectories (not shown).
- In contrast, trajectories within the originally subtropical stratospheric air subside on isentropic surfaces and warm adiabatically when entering the tropical troposphere, eventually taking up moisture through mixing with tropical air masses. Being accelerated back into the subtropics these parcels rise, cool, and form the northern portion of the cloud band (northern trajectory in Fig. 1). Since absolute moisture contents are small at upper-tropospheric levels, the associated latent heat release changes the parcels' potential temperature very little. It can be shown that a large portion of the cloud plume is actually formed

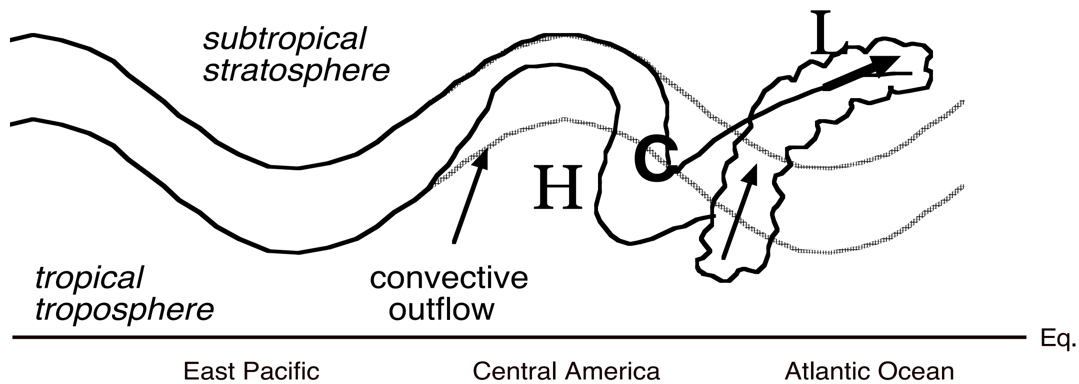

FIG. 1. Schematic of TP genesis. Thick black lines are trajectories at 345K; stippled lines show the original large-scale wave undisturbed by convective outflow (thin arrows). H and L indicate high and low Montgomery potential, C convergence. The STJ streak accompanying the TP is depicted by a thick black arrow. For further explanation, see text.

dynamically rather than by advection of convective outflow.

This explains the puzzling fact that plumes tend to spread faster than the wind at outflow levels. The importance of the dynamics is further confirmed by kinetic energy considerations, revealing that the acceleration of the STJ streak is mainly due to the rotational component of the wind flowing down the geopotential (Montgomery potential) gradient and to a lesser degree by divergent convective outflow.

3. CONCLUSIONS

The PV and trajectory analysis of a TP case over the Atlantic Ocean in March 2002 reveals that a complicated interaction between tropical convection and the extratropical circulation rather than simple quasigeostrophic forcing by large-scale waves as postulated by McGuirk et al. (1988) is responsible for plume genesis. Presented results show some agreement with the model derived ideas of Blackwell (2000), such as the existence of strong subsidence and convergence in the eastern portion of the ridge upstream of the TP, the loss of rotational balance of subtropical flow entering the Tropics and the ensuing deceleration, turning and formation of a STJ streak and a TP in association with an equatorward amplification and zonal contraction of the trough. The important advance made by the present study is that it demonstrates the convergence to result from a prior disturbance of the STJ in the region of the upstream ridge forcing stratospheric air to enter the tropical troposphere. This approach explains the observed localized nature of the convergence better than extratropical large-scale cold advection as assumed by Blackwell (2000). The importance of changes in the inertial stability field through large-scale advection of low PV air for tropical convective outflow postulated by Mecikalski and Tripoli (1998) is confirmed both for the actual plume genesis and the initiating disturbance upstream of the ridge. This way the present study integrates the at first hand contrary views of Blackwell (2000), and Mecikalski and Tripoli (1998) into one more elaborated concept of TP genesis.

4. REFERENCES

Blackwell, K. G., 2000: Tropical plumes in a barotropic model: A product of Rossby wave generation in the tropical upper troposphere. *Mon. Wea. Rev.,* **128,** 2288–2302.

McGuirk, J. P, A. H. Thompson, and J. R. Schaefer, 1988: An eastern Pacific tropical plume. *Mon. Wea. Rev.,* **116,** 2505–2521.

Mecikalski, J. R., and G. J. Tripoli, 1998: Inertial available kinetic energy and the dynamics of tropical plume formation. *Mon. Wea. Rev.,* **126,** 2200–2216