Kinematic and Diabatic Profiles from AMMA Sounding Data

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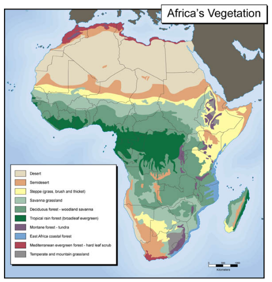
Introduction and Data Description



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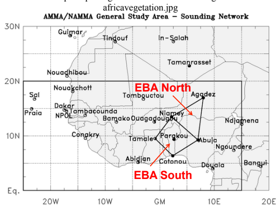


Introduction

- West Africa is a region with strong north-south climatic variations in atmospheric temperature and moisture, as demonstrated by the zonally banded structure of vegetation types shown in the map at left
- These meridional gradients in temperature and moisture are associated with a variety of interesting but incompletely understood weather phenomena, such as monsoon flows, African easterly waves, and convection organized on the mesoscale
- In the summer of 2006, the AMMA/NAMMA (African Monsoon Multidisciplinary Analyses / NASA AMMA) field campaign took place to collect weather observations in this historically data-sparse region to help improve our knowledge of such phenomena
- This work focuses on the use of radiosonde sounding data from the AMMA project to examine the vertical profiles of kinematic and diabatic variables

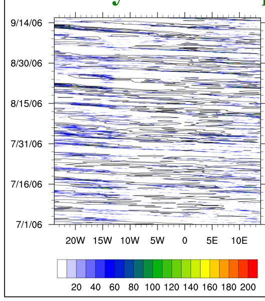
Datasets

- The primary dataset used in this work is a 1° resolution analysis of wind, temperature, moisture, and geopotential height prepared by Paul Ciesielski
  - The analysis was derived from the radiosonde data from AMMA, supplemented by the ECMWF special AMMA reanalysis in regions with sparse coverage
    - Sounding stations are shown in map at left, with the degree of fill of the circle indicating the completeness of that station's record
  - The dataset covers a domain from 0° to 20° N and 25° W to 15° E, indicated by the box in the map
  - Time resolution is every 6 hours, from June 1 to September 30, 2006
  - Analysis was performed on pressure levels, from 1000 to 50 hPa, at 25 hPa spacing
- Special focus in this work is placed on the two "enhanced budget arrays" (EBAs), the areas with the best sounding coverage, as labeled on the map
- Rainfall data used is TRMM 3b42 (multi-satellite analysis) precipitation rate data from NASA Goddard
  - 3-hour time resolution, 0.25° spatial resolution, over the same domain as the AMMA analysis

AMMA Analysis Known Issues

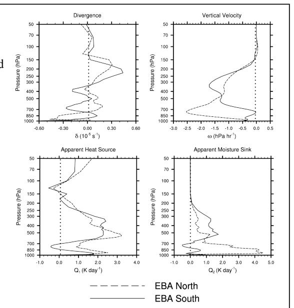
- The sounding humidity measurements are known to have a daytime dry bias
  - Work is ongoing to correct the moisture errors
- AMMA/NAMMA sounding data from ships, islands, dropsondes, and driftsondes were not used in creating the analysis
  - The exclusion of these sources should be of little impact in the data-rich EBA regions

Vorticity and Precipitation Hovmöller Plot



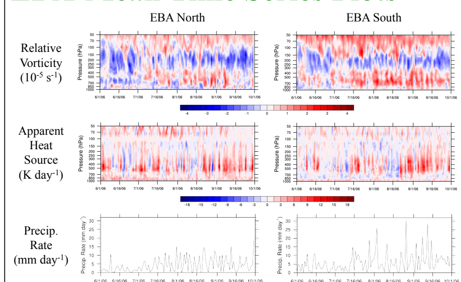
- Time vs. longitude plot of 6° to 14° N averaged:
  - 600 hPa relative vorticity, units: 10^{-5} s^{-1}
    - Contour lines from $1 \cdot 10^{-5}$ to $5 \cdot 10^{-5}$ s^{-1} in increments of $1 \cdot 10^{-5}$ s^{-1}
  - TRMM 3B42 precipitation rate, units: mm day^{-1}
    - Color fill from 10 to 200 mm day^{-1} in increments of 10 mm day^{-1}
- Many precipitation features slightly lead the vorticity features as both move westward, though vorticity and precipitation maxima are coincident at some times and locations
- Rainfall is a minimum in the 0° to 10° W band, with precipitation and vorticity more strongly correlated west of 10° W than east of 0°
- Relationship of convection to waves is subject of further study

EBA-Mean Vertical Profiles



- Vertical profiles were computed from the AMMA analysis, spatially averaged over the EBA North and South regions, and temporally averaged over the period July 1 – September 15, a more convectively active subset of the AMMA period in the EBA regions, for:
  - Divergence, units: 10^{-5} s^{-1}; Vertical velocity, units hPa hr^{-1}; Apparent heat source Q_1, units K day^{-1}; and Apparent moisture sink Q_2, units K day^{-1}
- Complex, multi-layered structures are apparent in these variables
  - Convergence generally present at low levels with divergence aloft, but more low-level convergence in north, mid-level convergence in south
  - Upward motion peaks at low levels in north, mid to upper levels in south
  - Q_1 peaks at 300-500 hPa, minima near 700-800 hPa, implying active downdrafts; peak near surface reflects boundary layer heating
  - Strongly positive Q_2 at low levels in the north, possibly associated with drying from boundary layer mixing, with Q_2 peaking more aloft over the south region

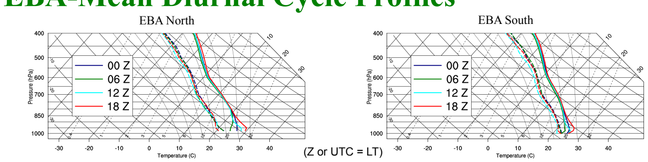
EBA-Mean Time Series Plots



- Precipitation rate also appears to vary on a general 3 to 4 day time scale, again consistent with African easterly wave influence
  - South region tends to have greater maxima in precipitation rate than north region
  - Both regions seem to be more active in terms of rainfall starting in early July and extending through the middle of September

- Data from the AMMA analysis and TRMM were spatially averaged over the EBA North and South regions, and daily means were computed to remove the diurnal cycle, for:
  - Relative vorticity, units: 10^{-5} s^{-1}; Apparent heat source Q_1, units K day^{-1}; and Precipitation rate, units mm day^{-1}
- Relative vorticity tends to be positive at low and mid levels and negative aloft
  - Earlier in the season, more negative vorticity at low and mid levels
  - Stronger positive vorticity values in the south region than the north
  - Variations in vorticity appear to have a general 3 to 4 day time scale, consistent with passage of African easterly waves
- Q_1 also varies with the passage of easterly waves
  - Minima near 750 hPa due to evaporative cooling
  - Boundary layer processes may dominate low-level variations

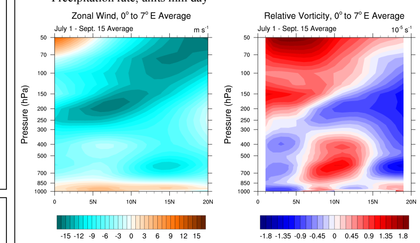
EBA-Mean Diurnal Cycle Profiles



- Temperature (solid curves) and dewpoint (dashed curves) from the AMMA analysis for July 1 through September 15 were spatially averaged over the EBA regions, then the data for each time of day were averaged to form mean profiles through the diurnal cycle
- Changes between times of day are most apparent below about 800 hPa, with a deep mixed layer building through the daytime and an inversion developing at night; the near-surface inversion in late afternoon may be a reflection of convective downdrafts
- More pronounced low-level changes in the drier north region compared to the south region
- Distinct change in stability in both regions near 0° C level, likely an indication of extensive stratiform precipitation systems

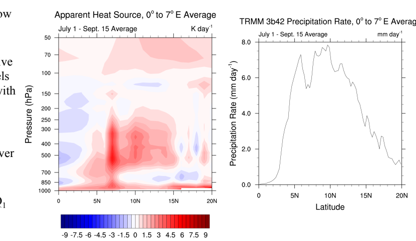
Vertical-Meridional Mean Profiles

- Data from the AMMA analysis and TRMM were zonally averaged over the longitude band from 0° to 7° E, corresponding to the longitudes of the EBA regions, and temporally averaged over the time period from July 1 to September 15, for:
  - Zonal wind, units: m s^{-1}; Relative vorticity, units 10^{-5} s^{-1}; Apparent heat source Q_1, units K day^{-1}; and Precipitation rate, units mm day^{-1}



- Westerlies predominate at low levels in this region
- Aloft, the core of the African easterly jet is evident near 600 hPa and latitudes 13° N to 16° N
- A strong easterly jet is apparent in the upper troposphere around 5° N to 10° N, extending northward and upward into the lower stratosphere
- Vorticity maximum-minimum pairs straddle the easterly jets – around 600 hPa and 14° N, and extending upward from near 5° N, 250 hPa to near 20° N, 60 hPa
- Vorticity also changes sign across a minimum in the easterlies located near 5-6° N at mid levels

- The wind patterns yield a maximum in relative vorticity at mid levels from 6° N to 14° N, but changes in the magnitude of the low-level westerlies also create a vorticity maximum in the lowest 150 hPa poleward of 15° N
  - This particular pattern of two vorticity maxima has been described in association with African easterly waves by many previous studies, such as Pytharoulis and Thorncroft (1999)



- Q_1 is generally positive at low levels, likely associated with boundary layer mixing
- Aloft, a broad zone of positive Q_1 exists at mid to upper levels from around 4° N to 15° N, with maxima near 7° N and 10° N
- A corresponding broad maximum in average precipitation rate is present over this same region
- Correspondence between north-south distributions of Q_1 and precipitation is generally good

Future Work

- Identify and track mesoscale convective systems (MCSs) using satellite data (TRMM, IR images, etc.) to explore their time- and location-varying influences on the vertical structures of diabatic heating in the AMMA analysis fields
- Generate composite vertical profiles of heating rates and other variables ahead of, within, and behind MCSs, as they cross the EBA regions and other areas to the east and west
- Investigate whether the heating profiles relative to MCSs vary based on the presence/absence of African easterly waves, the phase of the wave where the MCS is located, or the time of day

References and Acknowledgments

- Pytharoulis, I. and C. D. Thorncroft, 1999: The low-level structure of African easterly waves in 1995, *Mon. Wea. Rev.*, **127**, 2266-2280.

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