# Distinguishing tropical and extratropical dynamical regimes based on Rossby number statistics

[1]Steven Brey, [2]Nick Davis, [2]and Thomas Birner
[1]University of Washington, Seattle, Washington
[2]Colorado State University, Fort Collins, Colorado

## 1. Introduction

- Mid-latitudes are usually characterized by Rossby numbers ~.1 (consistent with geostrophic balance) where as the tropics are characterized by Rossby numbers ~1.
- Gaining an understanding of the structure of the Rossby number could be useful in determining the meridional extent of the tropical belt, which determines the locations of subtropical dry zones and their changing positions with climate change.
- This study shows how distinguishing tropical and extratropical dynamical regimes can be done based on Rossby number statistics. In this study we analyze scale dependencies of the Rossby number as a function of latitude using global coverage reanalysis data.

## 2. Guiding questions

This study uses reanalysis data from 1979 to 2009 (provided by ECMWF and NCEP/NCAR).

1) Can the breakdown of the precision of the geostrophic wind approximation tell us when we have entered the tropical regime?
2) Are there changes in the Rossby Number structure that are associated with the breakdown of the geostrophic approximation?
3) How does the Rossby number depend on the horizontal distance and time scales used to calculate it? Can these dependencies tell us something about large scale dynamics in the tropics?

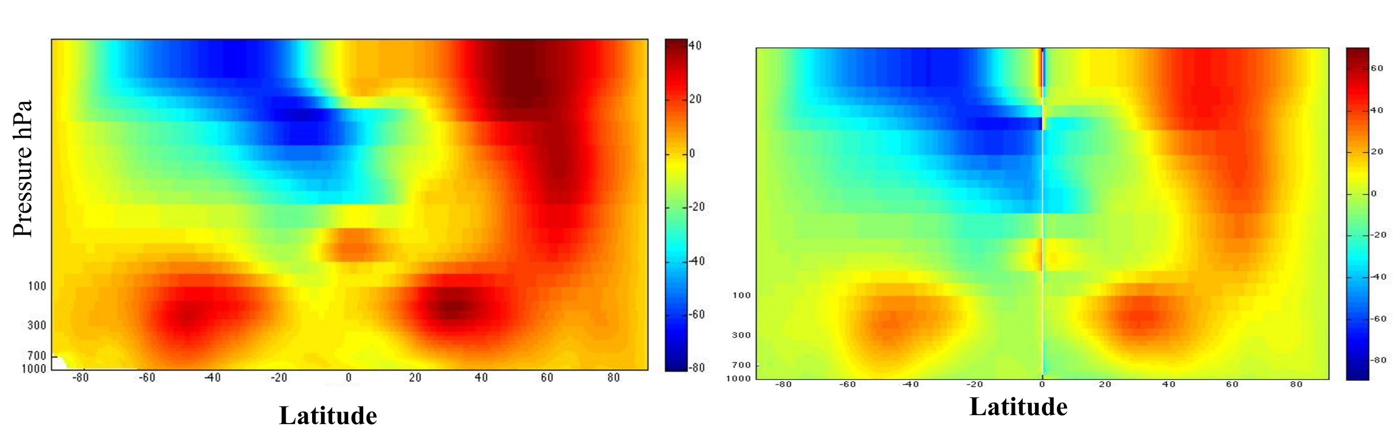
## 3. Breakdown of geostrophic wind approximation

(1) $$u_g = \frac{-g}{f}\frac{\partial Z}{\partial y}$$

**Method 1:** Geostrophically balanced wind in Cartesian coordinates

(2) $$fu + u^2\frac{\tan\phi}{a} = \frac{-g}{a}\frac{\partial Z}{\partial \phi}$$

**Method 2:** Geostrophically balanced wind in spherical coordinates



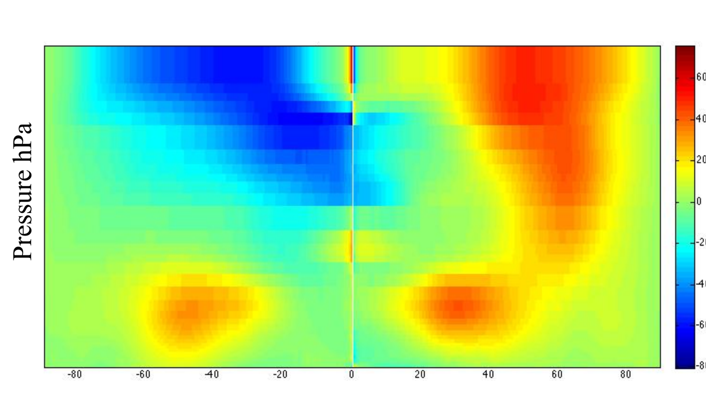




**Figure 1**: Zonal mean wind (m/s) in July, averaged from 1979 to 2009. Positive values are Westerly winds. Figure 1a is observed, figure 1b is geostrophic approximation (1), figure 1c is created using (2). Agreement between both geostrophic methods and observed wind indicates acceleration term in spherical coordinates can be neglected on large time scales. Geostrophic approximation is effective down to ~3 degrees on large timescales.

- Figure 1 shows that the error in the geostrophic approximation is greatest in the jet cores around the 250 hPa level.

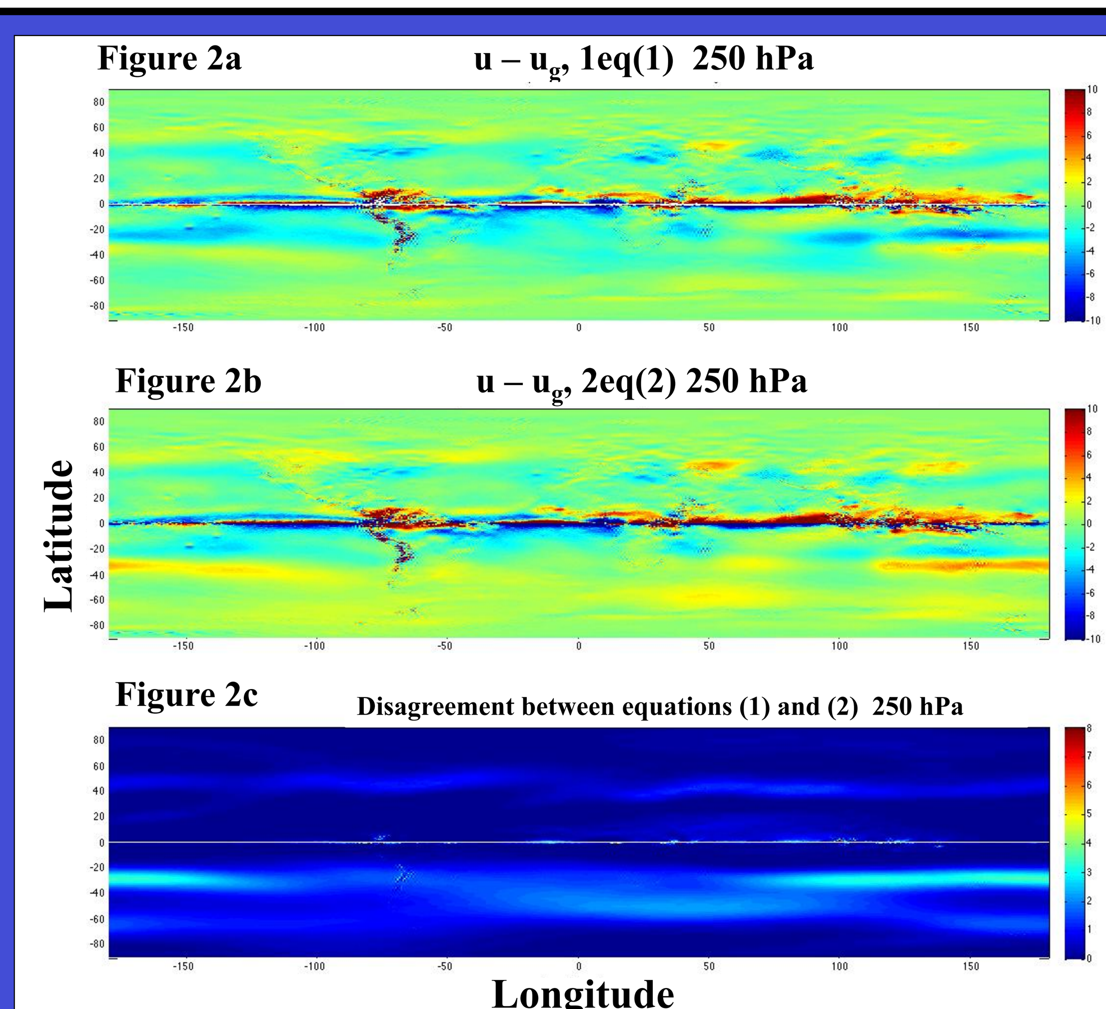



Figure 2 shows that the error has a longitudinal and latitudinal dependence, suggesting that the largest errors are within ~10 degrees of the equator.

- Neither view of the geostrophic wind indicates a latitudinal dependence farther than ~10 degrees away from the equator.
- Defining the tropics by this method would give a width of roughly 20 degrees latitude.

**Figure 2:** 2a shows Ageostrophic wind of method (1), 2b shows Ageostrophic wind of method (2), 2c shows disagreement between methods (1) and (2) at the 250 hPa level. U and calculations for Julys 1979-2009.

## 4. The Structure of the Rossby number

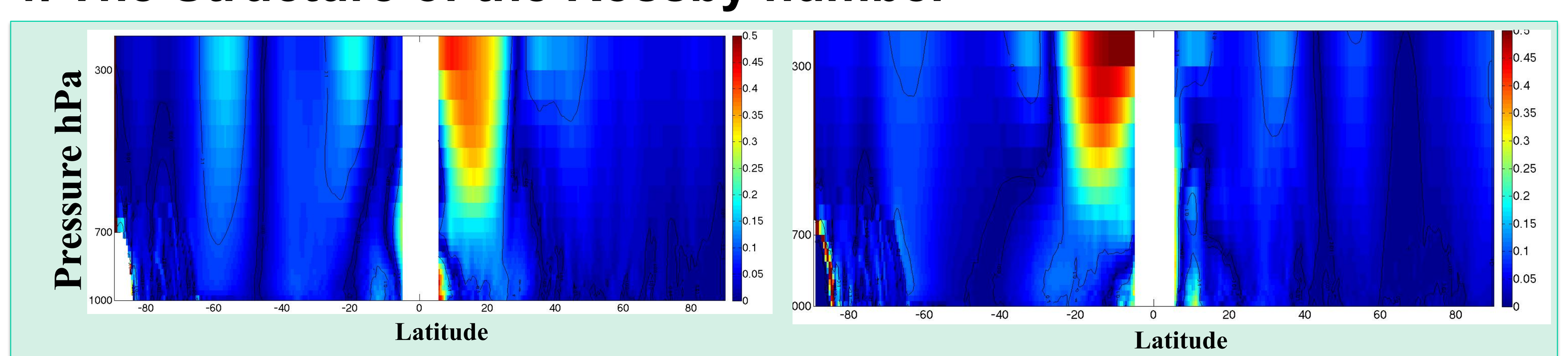



**Figure 3**: Zonal mean structure of the Rossby number averaged over all Januarys between 1979 and 2009 (left) and Julys (right). Monthly mean wind fields used for calculations. Values within 5° of equator not shown because of the blowup of 1/f near equator.

(3) $$Ro = \frac{|\varsigma|}{|f|} = \frac{\frac{1}{a\cos\phi}\frac{\partial v}{\partial \lambda} - \frac{1}{a\cos\phi}\frac{\partial (u\cos\phi)}{\partial \phi}}{2\Omega\sin\phi}$$

The Rossby Number in this study was calculated using the ratio between relative and planetary vorticity (3) in spherical coordinates.

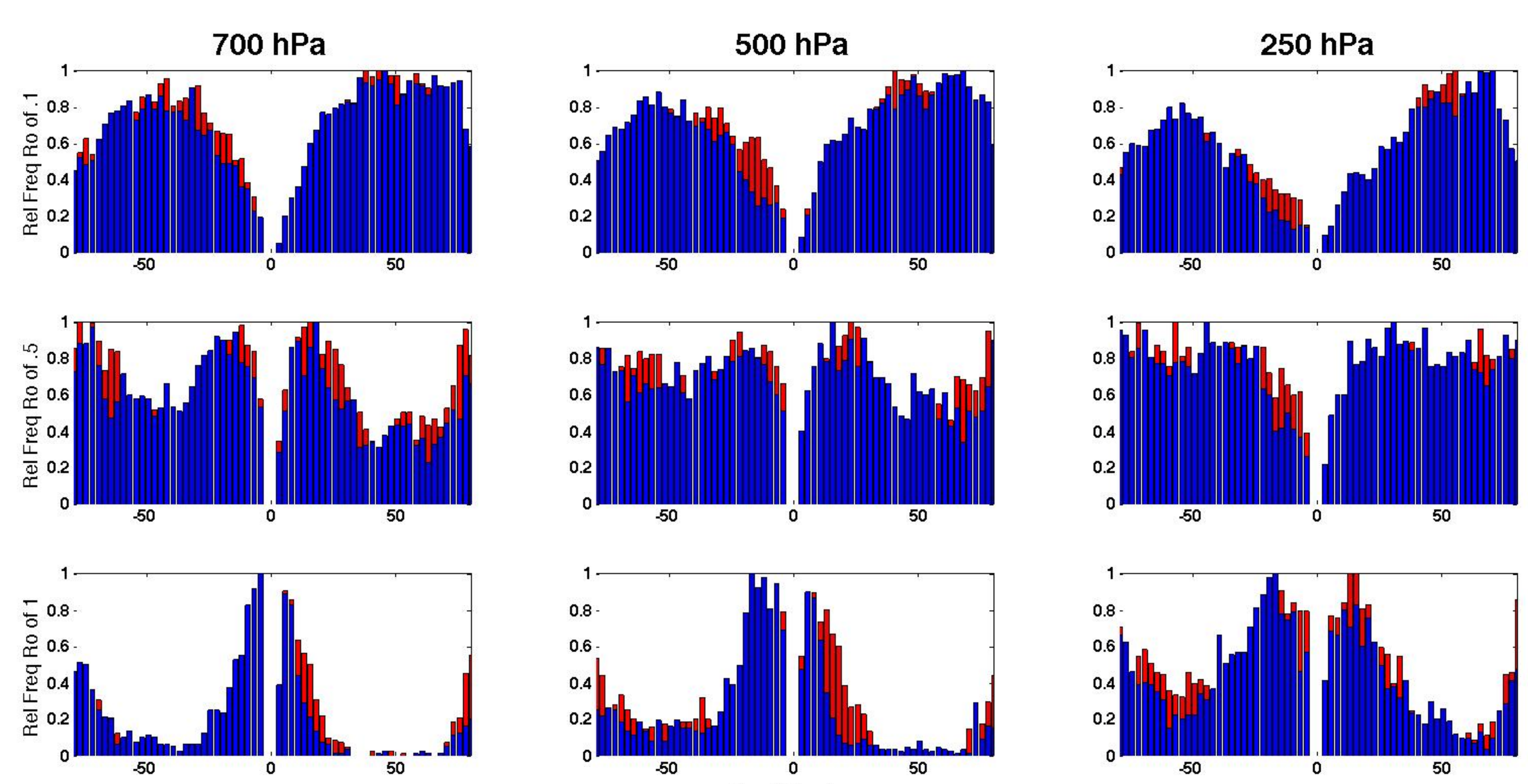



**Figure 4**: Rossby number relative frequency at a given latitude. Columns are all the same pressure, starting with 700 hPa on left, 500 hPa in middle, and 250 hPa on right. Rows are distributions for same significant Rossby number, .1 top, .5 middle, and 1 bottom. Rossby numbers were calculated using (3) from six hourly wind fields. January displayed in blue, July in red.

## 5) The Rossby number's dependence on scale

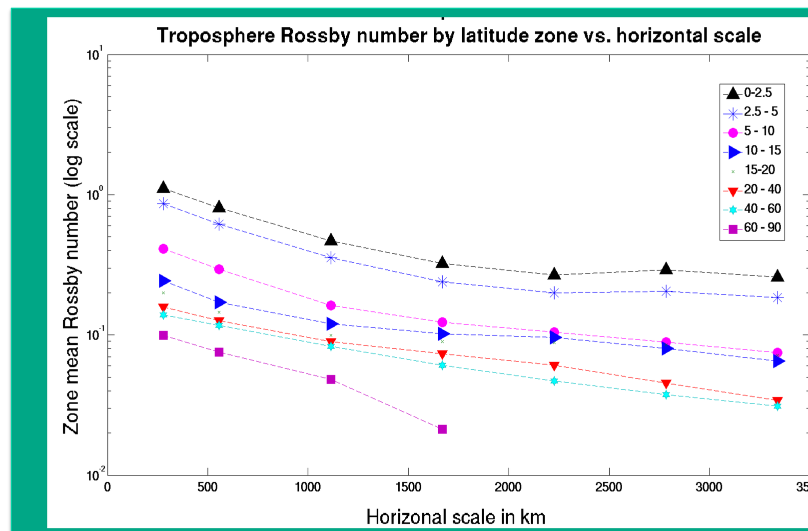



**Figure 5:** Median Rossby number by latitude. Six hourly wind fields from January 2009 used in equation (3).

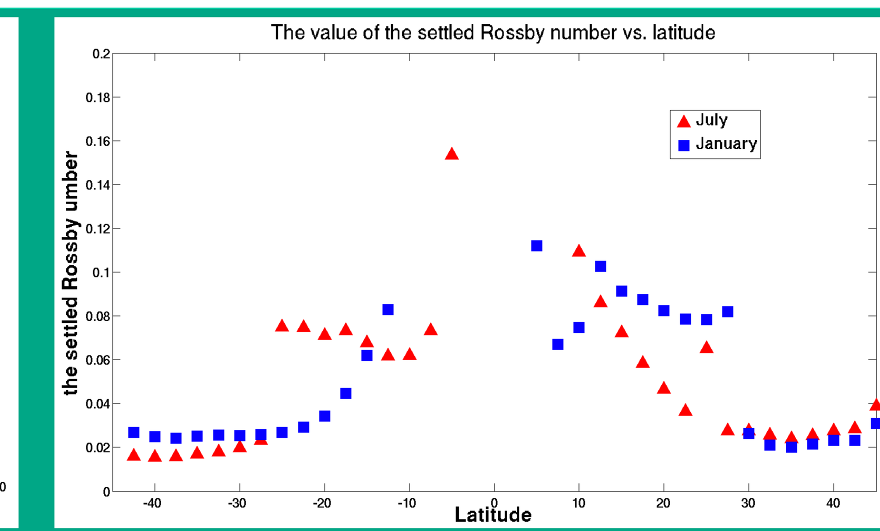


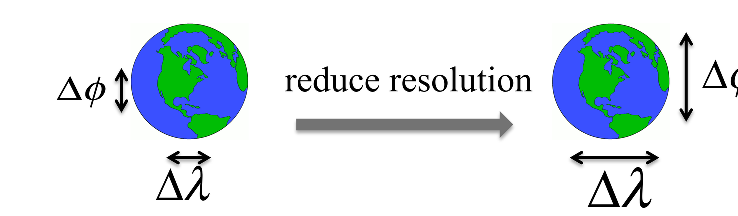

**Figure 6:** Typical settled Rossby number at a given latitude for the troposphere. Discontinuity clear around 30 degrees away from equator in winter hemisphere.

- The critical value of the Rossby numbers in figure 6 were calculated using eq. (4)

(4) $$\frac{d}{dL}Ro(L) = 0$$ L = horizontal scale (km)

- Method for increasing horizontal scale, increased distances in (5)

(5) $$\varsigma = \frac{1}{a\cos\phi}\frac{\Delta v}{\Delta \lambda} - \frac{1}{a\cos\phi}\frac{\Delta (u\cos\phi)}{\Delta \phi}$$



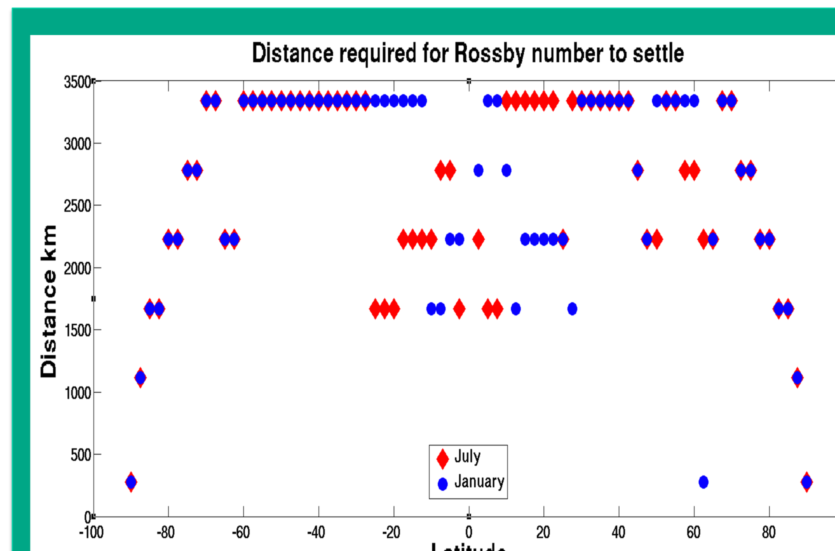




**Figure 7:** Distances required for Rossby number to settle. Distance calculated by finding the minimum of dRo/dlat.

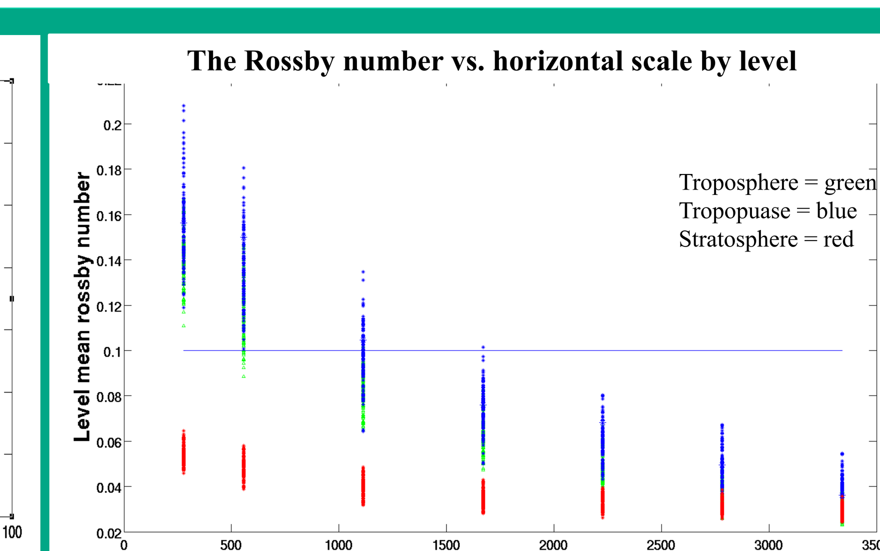



**Figure 8:** The Rossby number vs. horizontal scale. Each point is different six hour wind field calculation.

## 6) Conclusions

- The geostrophic wind approximation has a consistently high bias for predicting large wind speeds (figure 2). The geostrophic approximation holds very high accuracy to very low latitude (figure 1).
- There is no obvious connection between the Rossby number and the breakdown of the geostrophic wind approximation at low latitudes
- The Rossby number has a distinct structure (figures 3 and 4). Significant transitions in the Rossby number show potential for locating subtropical dry zones (figure 6).
- The Rossby number has a strong dependence on the horizontal scale of the wind field used to calculate it (figure 5). This dependence varies with latitude and can tell us the different distances of large scale dynamics as a function of latitude (figure 7).

This work has been supported by the National Science Foundation Science and Technology Center for Multi-Scale Modeling of Atmospheric Processes, managed by Colorado State University under cooperative agreement No. ATM-0425247.