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Land Use Cloud Interaction Experiment (LUCIE): Preliminary results

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ABSTRACT

Tropical montane cloud forest ecosystems are sensitive to the processes that modulate orographic cloud base height. Impact of land use on cloud base height in the Monteverde region in Northern Costa Rica is examined using field observations and numerical modeling. Initial analyses show that lowland deforestation leads to upward migration of orographic cloud base.

1 INTRODUCTION

Tropical montane cloud forest (TMCF) ecosystems are characterized by frequent and prolonged immersion in orographic clouds. Interception of cloud water by vegetation is a significant source of moisture for the TMCF ecosystems, especially during the dry season. Recent studies show increases in the number of the dry season mist free days at the Monteverde cloud forest preserve, Costa Rica, during the past decades (Pounds et al., 1999). Coincident observations of amphibian population crashes and bird migration to higher elevations suggest that these increasing trends in mist free days have serious ecological consequences. Study by Still et al. (1999) link the increasing number of mist free days at Monteverde to a larger pattern of global climate change, in which increasing tropical sea surface temperatures lead to orographic cloud banks forming at higher elevations. Upward migration of orographic cloud banks at Monteverde, Costa Rica might explain the increase in the number of dry season mist free days. Numerical modeling and satellite observations (Lawton et al., 2001; Nair et al., 2003) suggest another possible mechanism for the upward migration of the orographic cloud banks, namely land use change in lowlands located upwind of orographic cloud formation sites. Land use, through modulation of the surface energy budget, modifies the thermodynamic properties of the lowland air masses that ultimately drive the orographic cloud formation. Lowlands upwind of Monteverde, Costa Rica are extensively deforested and in satellite imagery show differences in cloud formation compared to neighboring forested regions. Numerical model simulations also show increase in cloud base height in response to warmer, drier air over deforested areas.

Initial numerical model simulations (Lawton et al., 2001; Nair et al., 2003) assumed differences in soil water storage between forested and deforested areas, and used observations from forested and deforested sites in Amazon as a guide. In an effort to validate the findings of the preliminary work and to conduct more realistic numerical model simulations, a ground observation network has been established in the northern Costa Rican region. In addition, a field campaign, the Land Use Cloud Interaction Experiment (LUCIE), was conducted in the Northern Costa Rican region during a three week period in March of 2003. The high temporal resolution radiosonde data, ground observation network data and satellite data acquired during the LUCIE field experiment are being used along with numerical modeling to explore the influence of land use on cloud formation in the Northern Costa Rican region. This paper discusses preliminary findings from this analysis. The data used in this study is described in section 2 and a brief description of the analysis methodology is given in section 3. A brief description of preliminary findings is given in section 4 and the conclusions are listed in section 5.

2 DATA

2.1 Photographic observations of orographic cloud banks

Digital cameras, operated by ground observers at Monteverde, are used to photograph orographic cloud banks at regular intervals throughout the day. The photographic observations are used to estimate the orographic cloud base height

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2.2 Soil moisture observations

Automated, data logging, soil moisture sensor are used to measure soil moisture at multiple, paired pasture and forest sites in the Costa Rican lowlands upwind of Monteverde. The sensors measure volumetric soil moisture at 10cm, 50cm, and 100cm depths.

2.3 High temporal resolution radiosonde observations

During the LUCIE field campaign, two mobile National Center for Atmospheric Research GPS/Loran Atmospheric Sounding Systems (NCAR GLASS) were deployed in the Northern Costa Rican region during a three week period in March of 2003. These systems used radiosondes to measure the atmospheric thermodynamic and wind profiles at three hour intervals during the day for a series of paired sites. These paired sites included 1) coastal and interior locations 2) forested and deforested locations 3) Pacific and Caribbean locations.

2.4 Satellite data

Geostationary Operational Environmental Satellite 8 (GOES 8) data acquired at approximately half an hour intervals are used in this study.

3 METHODOLOGY

The main objective of the present study is to understand the impact of land use on convective and orographic cloud formation in the Northern Costa Rican region. Ideally an intensive observational field campaign would be used for this purpose. Due to historical and geographic constraints, the present study uses the Regional Atmospheric Modeling System (RAMS) to study the impact of land use on cloud formation. Observational data collected is mainly used for making the model simulations reasonably realistic, and for validating the model simulations. Note, however, that some of the observational data sets are useful in directly examining the validity main hypothesis of study: that deforestation leads to higher cloud base heights.

The Lifting Condensation Level (LCL), easily computed from atmospheric thermodynamic profiles measured by the radiosondes, is a valid surrogate for cloud base height. The diurnal evolution of LCL heights, computed from the radiosonde measurements over paired pasture-forest sites during the LUCIE field campaign are compared to examine the variations in cloud base height between these areas.

The RAMS is used to simulate the formation of orographic clouds in the Monteverde region for three land use scenarios: 1) a pristine landscape where the lowlands are forested; 2) current land use; and 3) lowlands deforested completely. These simulations utilize a nested grid structure with the outer grid of 100 x 40 points and spacing of 4 km covering the northern Costa Rican region and the finer inner grid of 100 x 42 points and 1km spacing covering the Monteverde region. In these simulations, the RAMS has identical initial conditions and lateral boundary forcing, derived from the National Center for Environmental Prediction (NCEP) reanalysis data sets and LUCIE observations. The RAMS was used to simulate the orographic cloud formation for a fifteen day time period spanning 1 March to 15 March 2003.

In prior studies (Lawton et al., 2001; Nair et al., 2003), consistent with observations from the Amazon, soil water storage was assumed to differ between over forested and deforested areas. However, soil moisture measurements from paired pasture-forests sites do not show significant soil moisture differences in upper one meter layer during the dry season. Nonetheless, compared to forests the pastures appeared water stressed during the dry season months, which suggests that trees have access to water deep in the soil which is unavailable to pasture grasses. In order to account for this effect, in the RAMS simulations trees are allowed access to deep soil layers that are effectively saturated.

The spatio-temporal distributions of the simulated orographic clouds are compared to GOES-8 satellite observations. The simulated orographic cloud base height for the three land use scenarios is also intercompared compared.

4 RESULTS

The LUCIE radiosonde observations show consistent differences in the LCL between the paired pasture-forest sites. The LCL heights over both these sites increases through the day, reaches a maximum in the afternoon, and then decreases. Figure 1 shows that during the day, the LCLs over the deforested areas are higher than over the forested areas.

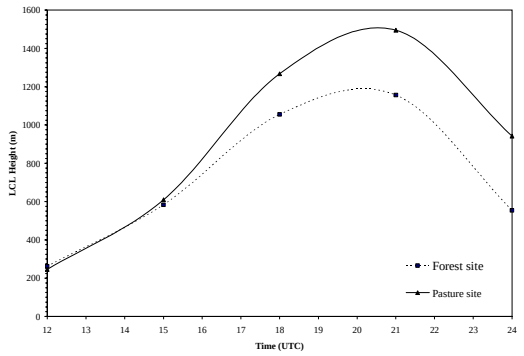

Figure 1. Diurnal variation of LCL heights computed from the thermodynamic profiles collected over the paired forest pasture sites on March 6-8 of 2003.

Spatial patterns of the RAMS simulated orographic cloud banks for the current land use scenario agree quite well with GOES-8 observations. Point to point comparison between the simulated clouds in the inner RAMS fine grid and the cloud mask derived from the 1 km GOES-8 show up to 90% agreement during the afternoon hours when the orographic cloud banks are well developed.

The diurnal evolution of the RAMS simulated cloud base heights, averaged over the fine grid, for the lowland and highland regions are shown in Figure 2. Note that the RAMS simulations show that in the afternoons the cloud base height is the lowest when the lowland areas are forested. The cloud base heights increase as the lowlands are progressively deforested. The diurnal pattern of the numerically simulated lowland cloud base height is qualitatively similar to the diurnal patterns of LCL derived from the LUCIE observations. However, note that the LCL heights are potential cloud base heights while Figure 2a shows the diurnal pattern of the actual simulated clouds in the lowlands. Thus the LCL patterns show gradual changes earlier during the day while the RAMS simulated cloud base height patterns show a sharp increase around 1500 UTC. Similarly later in the afternoon the LCL patterns (Figure 1) show a gradual decrease while the RAMS simulated cloud base height remain relatively constant. On average the RAMS simulations for the current land use scenarios agree with the morning photographic observations showing formation of orographic clouds at approximately 1400 m in the Monteverde region.

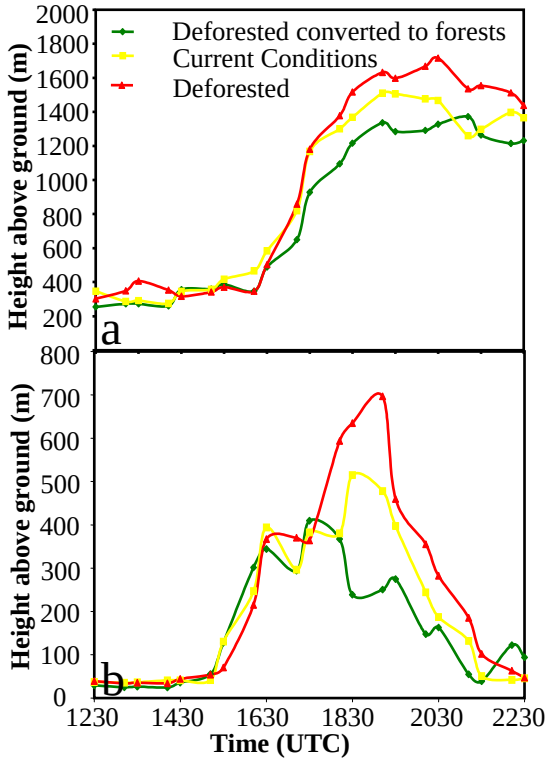

Figure 2. The domain averaged RAMS simulated cloud base heights for 3 March 2003 over a) lowlands; b) highlands

5 CONCLUSIONS

The radiosonde observations collected during the LUCIE field experiments show differences in LCL heights of 340m between the forested and deforested sites. The RAMS numerical model simulations show that the cloud base increases as the lowlands are progressively deforested. The RAMS simulated ogrographic cloud base heights agree with photographic observations of cloud base heights in the Monteverde region.

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