AN OBSERVATIONAL AND NUMERICAL STUDY OF A REGIONAL-SCALE DOWNSLOPE FLOW IN NORTHERN ARIZONA

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Abstract: During the month-long METCRAX field campaign in northern Arizona near Winslow in October 2006, observed wind profiles uncovered a frequent presence of a near- surface wind maximum on nights with relatively quiescent synoptic conditions. The development of this flow usually began shortly after sunset with a shift from disorganized wind directions accompanying weak winds in late afternoon to a more steady southwesterly flow which continued through the night. The month-long observations from various measurement platforms are used to characterize the structure and evolution of this flow and numerical model simulations using the RAMS model are used to help identify the forcing mechanisms. The model results, which compared reasonably well with the observations, suggest that this low-level wind maximum represents a regional-scale downslope flow developed over the Coconino Plateau that slopes up towards southwest of the observational site near Winslow.

Keywords: *regional scale downslope flow, thermally driven circulation, terrain-induced flow.*

1. INTRODUCTION

The month long Meteor Crater Experiment or METCRAX in October of 2006 provided a unique opportunity of intense observations in a region of highly complex orography. While the main focus of the field campaign was to study the microclimate inside the Meteor Crater and majority of instruments were deployed inside the crater, the measurements made outside the crater that were designed to document the background conditions for the crater uncovered a diurnal circulation that is relatively unknown to this region. Under conditions of weak synoptic winds, the observed near surface wind profiles from METCRAX meteorological towers and a SODAR consistently showed a wind direction shift around sunset from more or less disorganized wind direction with weak winds in the afternoon to a more organized southwesterly flow. Accompanying this direction shift, there was usually an increase in wind speed that continued through the night, making it difficult to operate tethered balloons at night to characterize the structure of the cold air pools inside the crater (Whiteman et al. 2007, this volume). Upon further investigation of the topographic landscape a shallow southwest to northeast decline in elevation was noticed within the 40 km plateau immediate to the crater. It was then realized that this observed diurnal circulation is likely to be a downslope flow typically found in intermountain basins or on valley sidewalls. Due to the relatively large scale of the slope, downslope flows like those found in Horst et al. (1990) may not be representative of the same mechanical forces driving this regional scale circulation in Northern Arizona. Instead, these diurnal circulations may resemble the ‘regional drainage flow’ found nearly 100 km east of the Cascade Mountains in the Columbia Basin in Washington (Doran and Zhong 1993). Only a few studies on regional scale downslope flows have been found in the literature, and in each case the characteristics of the flow is highly dependent upon the surrounding topography. The METCRAX observations not only uncovered the existence and frequent occurrence of this regional scale wind phenomenon, but the month-long experiment also provided an unique opportunity for documenting its characteristics, the forcing mechanism, and its relationship with synoptic scale flows. This article will discuss the preliminary results from observational analysis and numerical modelling focusing on this regional scale downslope flow.

2. OBSERVED CHARACTERISTICS

The observational data from various measurement platforms were used to characterize the structure and evolution of this phenomenon. The data included 15 min-averaged vertical profiles of wind and temperature from near surface to approximately 350 m above from a sodar with radio acoustic sounding system (RASS), rawinsonde soundings launched every three hours between 3 pm to 9 am during seven Intensive Observational Periods (IOPs), hourly wind and temperature profiles from 100 m to more than 2000 m from a

915 MHz radar wind profiler/RASS, and surface weather data from three 10-m tower outside the crater. The locations of these instrument platforms are shown in Whiteman et al. (This volume).

The observations from all these platforms revealed frequent occurrences of this flow phenomenon during the month-long experiment when synoptic scale forcing is weak. Data from 22-23 October, or IOP5, are shown here to illustrate the typical behaviour of this circulation. Figure 1 shows time series of 2-m temperature and 10-m wind speed and direction from the three meteorological towers outside the crater. The ISFF and ISS sites were located about 2.5 SW and 5 km NNW of the crater, respectively, while the RIM site was located on the western rim of the crater. The topography of the region can be seen in Figure 3. The detailed locations of the sites and high resolution topography can be found in Whiteman et al. (this volume).

An abrupt reversal of wind direction from upslope (northeasterly) to downslope (southwesterly) occurred immediately following the sunset. A decrease in wind speed occurred during the period of transition, which is followed by a gradual increase of wind speed to its afternoon level or slightly higher. Stabilization to a more southwesterly direction occurs near midnight as the downslope flow remains steady until daybreak. The morning transition from southwesterly donwslope to northeasterly upslope occurred more gradually than the evening transition with upslope flows becoming well-established after 0900 MST.

Figure 2 shows the three hourly rawinsonde sounding profiles in the lowest 500 m from the afternoon of 22 Oct. to the morning of 23 of Oct. The soundings were launched from the ISS site. After sunset around 1800 MST, a shallow temperature inversion strengthened, which limited the mixing to near the surface. With the lack of turbulent mixing wind speeds were expected to decrease, but the speed in the lowest 50 m actually increased to near 4-5 m s^{-1} as the night continued. A directional shift can also be seen after 1800 MST from the northeasterly direction to a predominant southwesterly flow. This southwesterly wind direction extends from the surface to 300 m where an abrupt directional change back to the easterly large-scale flow aloft occurred. The maximum wind speed at night is generally found near the surface, as expected for downslope flows. This result rejects a hypothesis that the increase in wind speed may be associated with a nocturnal low-level jet resulting from inertial oscillation because the maximum wind speed of a LLJ normally occurs near the top of surface-based inversion which, in this case, was around 300 m. The daytime upslope winds only show a weak maximum around 100 m above ground.

3. PRELIMINARY MODEL RESULTS

High resolution numerical simulations were performed using the Regional Atmospheric Modelling System (RAMS, Pielke et al. 1992) to identify the forcing mechanisms for this regional scale flow. Four nested grids with a horizontal grid spacing of 32, 8, 2, and 0.5 km were used to resolve the complex topography of the region. The vertical grid spacing of each grid was 20 m adjacent to the surface, which is stretched to 500 m around model top near 10 km. To adequately define the topography of the region the 2000 U.S. Geological Survey dataset at 30s, or about 1 km resolution, was used for the innermost grid. The simulations were initialized using the NCEP 32-km operational Eta analysis, which was deemed sufficient due to the higher resolution and inclusion of the observed soundings.

The simulation was initialized at 0500 MST on 22 October, and continued for 24 hours to 0500 MST on 23 October. Though model parameters are still not finalized, preliminary results are encouraging. Figure 3 illustrates the model's depiction of the downslope flow at 0000 MST, 23 October. The three observational sites seem to correspond well to the simulation, as both the model and observations have a distinct southwesterly wind direction near the crater and moderate (4-6 m/s) wind speed. The transitional period from downslope to upslope takes on the characteristics of a front-like appearance, which have been similarly described by Papadopoulos (1999). These front-like patterns are easily depicted within the numerical model, but are difficult to confirm due to the limited number of the surface observations

4. DISCUSSIONS

The METCRAX campaign provided a unique opportunity of intense observations of flow and boundary layer structure over a gentle sloped region in Northern Arizona. These observations uncovered a diurnal circulation, similar to those seen in a valley or mountainside, but on a larger horizontal scale. Observations and numerical modelling have provided a glimpse of the forcing mechanisms driving this circulation, and early results do correspond well to previously observed slope flows on a regional scale.

This project is ongoing. Other IOPs as well as non-IOP days will be investigated to determine the interaction of the synoptic scale winds with this regional scale flow. Model parameters will continue to be tested for their impact on the thermally driven flows occurring over the sloped plateau. One test will detect if the nearby San Francisco Peak is significant to the thermally induced flow of the region. The humidity in the region varies considerable with changes in elevation and simulations will be performed to determine how this may affect the strength and transitions of the downslope flow. Finally, the interaction between the gentle slope and shallow basin and between this regional scale thermally driven flow and synoptic scale winds will be investigated. From this project a typical characterisation of regional scale slope flow is hoped to be developed, while detailing climatological observations of the large plateau in Northern Arizona.

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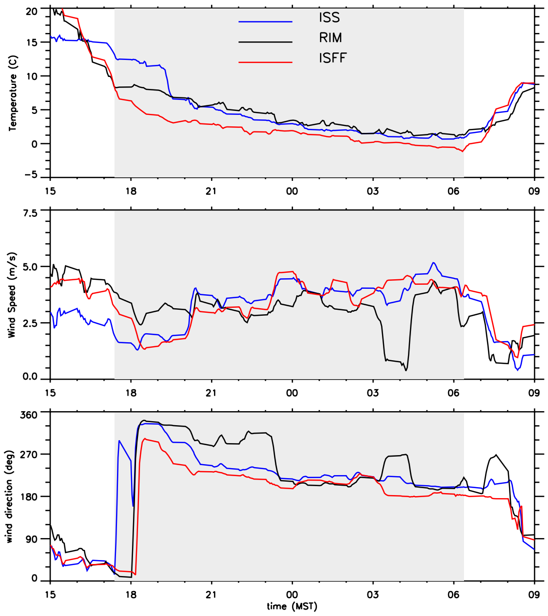

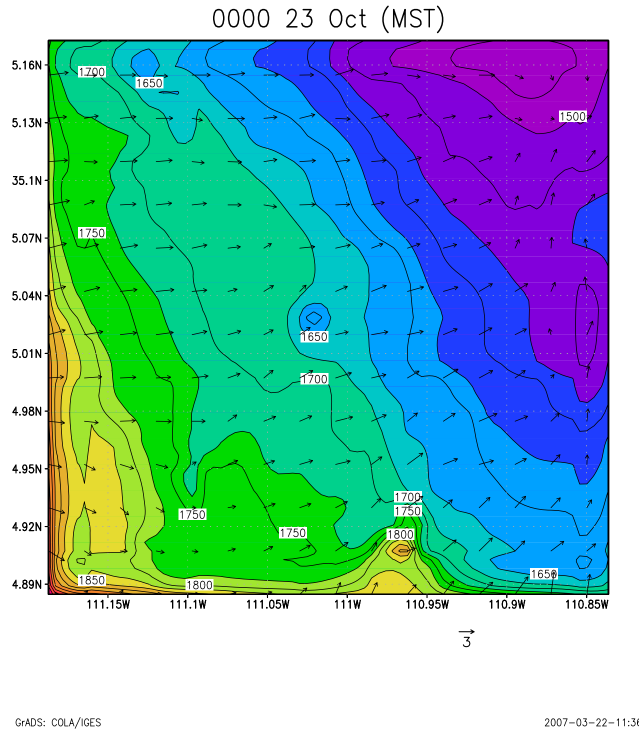

Figure 1: Time series of observed surface temperature, wind speed and direction from three surface meteorological stations for 22-23 October.

Figure 3. RAMS simulated surface wind fields at 0000 MST, 23 October, showing well-developed downslope flows on a regional scale.

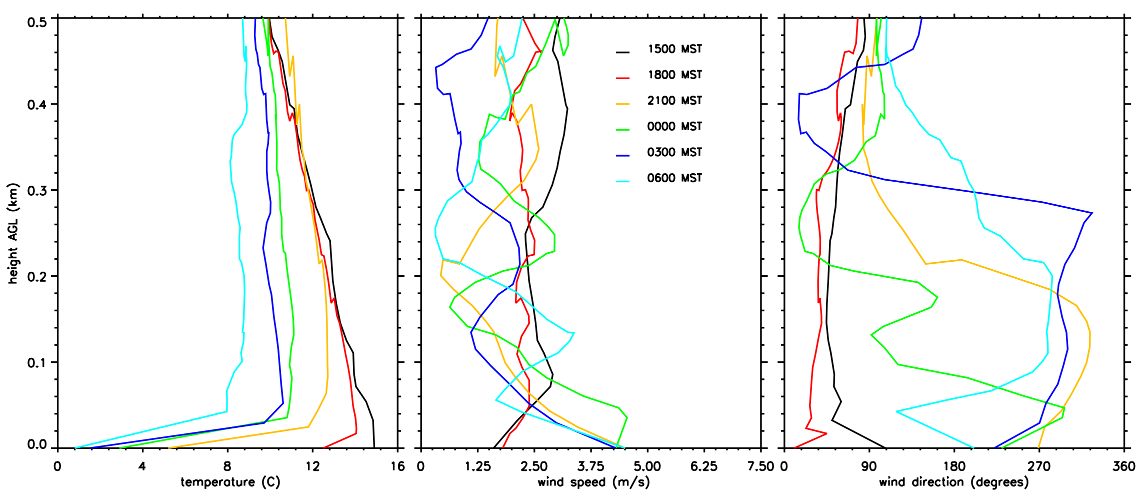

Figure 2. Rawinsonde soundings of temperature (left), wind speed (center), and wind direction (right) for IOP5, Oct. 22-23.