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Modeling a cold-air drainage event with a wireless sensor network

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Introduction:

Abstract

A wireless network of sensors was used to characterize a cold-air drainage event in the canyon surrounding the James Reserve. The flow of cold air at night and the first hours of sunrise have major ecological consequences by limiting the vegetation types to those tolerant of freeze and thaw cycles. A network of wireless sensors provides the opportunity to track this event in real time and fully characterize the cold air flow down the canyon, which may last 1.5 hours, and the pooling of cold air in low lying areas. By adjusting the spatial extent of the wireless sensors and the time interval between data capture, we can optimize the spatial and temporal extent of a sensor network and its ability to describe multiple cold-air drainage events.

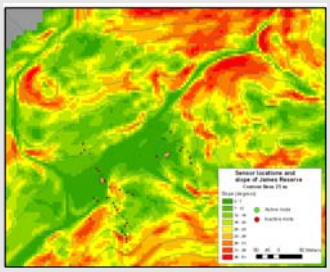
Cold-air drainage

- **Definition**
  Air layer near the ground cools faster and becomes denser than the air adjacent to a sloping surface. Cold air will move down-slope and accumulate in the valley or basin bottom.
- **Characteristics**
  Generally occurs in cycles; oscillations of 1.5 hours.
  Flow often between sunset and midnight, and coldest during early mourning.
  Cold-air flow only generated on clear nights with low wind speeds.
  A thermal belt and transitional zone with higher temperatures will occur above the cold-air pool.

Wireless sensor network

- **Spatial resolution**
  - Two transects were available with 11 wireless sensors (motes) each
  - First transect mote spacing was 25.1 ± 5 m.
  - Second transect mote spacing was 21.9 ± 8 m.
- **Temporal resolution**
  - Motes recorded data at 5 minute intervals (capable of finer resolution)

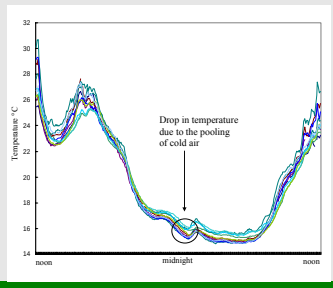
Cold–air drainage event at the James Reserve:



•Figure 1. The James Reserve is located in the San Jacinto Mountains CA, covering 29 acres (12 ha).

•Mixed hardwood and conifer forests are the dominant vegetation.

•Elevation and slope indicates that cold air forms in Northeast and drains toward the James Reserve.



•Figure 2. Multiple mote data from August 7 (noon) to 8 (noon), 2005. Cold-air event most notably occurred at 1 am and lasted 1.5 hours.

Geospatial modeling with wireless sensor data

Exploring the area

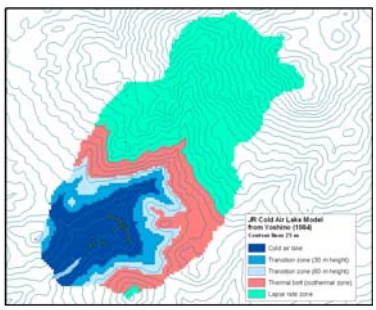


Figure 3. A model of the cold air lake that forms within the James Reserve following Yoshino (1984). The two transition zones (indicated in light blue) form just below a thermal belt of warm air, where cold air has drained away from the slopes. Areas above the thermal belt are progressively cooler with the increase in altitude, indicated as the lapse rate zone.

Exploring the data

Using the semivariogram to find the optimum distance

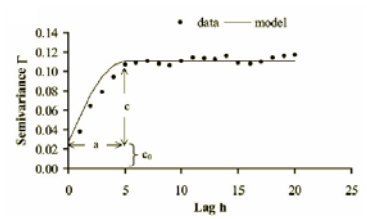


Figure 4. A spherical semivariogram showing range (a), sill (c), and nugget (c_o). The points represents data and the solid line represents the model fit. The lag is the separation distance between data points. The larger the semivariance, the less similar the data points.

•The sill (c) is the theoretical maximum variance.

•Range (a) shows the lag (distance) in which the sill is obtained.

•The nugget (c_o) reflects measurement error.

Results

Temporal optimum

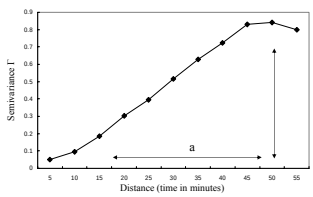


Figure 5. This semivariogram indicates from its range (a) that the optimum time interval for data capture is 50 minutes. To sample adequately it is advised to choose a time interval smaller than or equal to half the range.

Spatial optimum

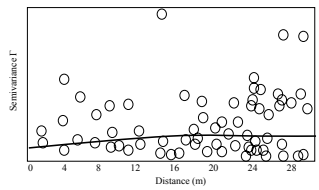


Figure 6. A semivariogram from all mote data (o) available from two transects in the James Reserve shows an optimal range of 18.8 m. Therefore in order to capture the functional properties of the landscape, motes should be spaced every 10 m.

Kriging geospatial model

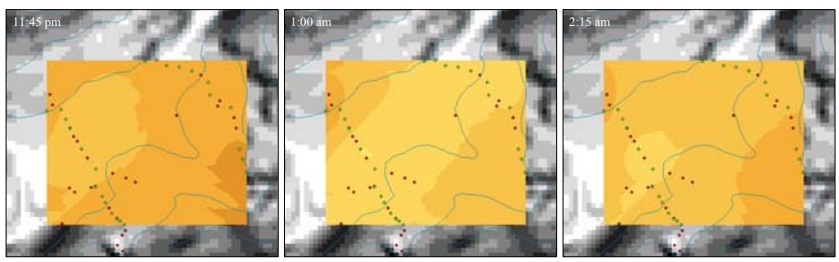


Figure 7. Kriging, a geospatial technique to interpolate data points based on the semivariogram, was used to produce these temperature maps of the James Reserve at three different time intervals, 11:45 pm, 1 am, and 2:15 am. The cold–air drainage pool was at its maximum volume in the basin at 1 am. Colored dots indicate the location of mote sensors along transects. Decreasing temperature is indicated with dark to lighter shades of brown. Lines are 25 contour intervals and the location of mote sensors are indicated by colored dots.

Future direction

- We recommend spacing mote sensors 10 m apart, based on semivariogram results.
- Data acquisition every 5 minutes can still be used to test the characterize a cold-air drainage event.
- Mote sensors deployed further up in elevation would be necessary to capture all the characteristics of the cold-air pool.
- Sensors along the cold air flow path would be necessary to model a cold-air drainage event as it happens.