P4

A numerical study of the impact of vegetation cover on cold-air pool formation in an idealized valley

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Introduction

- While a great deal is known about cold-air pool formation, maintenance, and erosion inside basins and valleys, and a number of numerical modeling studies have examined the impact of land cover on slope flows, relatively little is known of the impact of vegetation cover on cold-air pool evolution
- A better understanding of cold-air pool processes has relevance for air quality and aviation visibility prediction, as well as numerical model development (e.g., new parameterizations)
- Recently, the Advanced Regional Prediction System (ARPS) atmospheric model has been modified to allow simulation of flow through a multi-layer canopy (ARPS-CANOPY)
- In this study we use ARPS-CANOPY to examine the impact of vegetation cover along the sidewalls of an idealized valley on cold-air pool evolution

Madeira, Portugal

Credit: Thomas Hobbs, Wikimedia Commons

Planica Valley, Slovenia

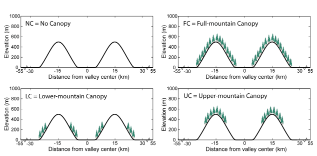
Credit: Markus Bernet, Wikimedia Commons

ARPS-CANOPY Model Summary

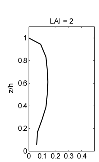
- Advanced Regional Prediction System (ARPS; Xue et al. 2000) Version 5.2.12
  - 3D atmospheric modeling system, with terrain-following coordinates
  - Designed to simulate microscale [O(10 m)] through regional scale [O(10^6 m)] flows
- Standard version of ARPS has been modified in the following ways:
  - Impact of drag forces on mean and turbulent flow through a vegetation canopy is accounted for via production and sink terms in the momentum and subgrid-scale (SGS) turbulent kinetic energy (TKE) equations [proportional to frontal area density (A_f): m^2 leaf area per m^3 canopy volume]
  - Attenuation of net radiation by vegetation elements is accounted for with a downward decaying net radiation profile inside the canopy, and by attenuating ground net radiation before it is passed to the ARPS soil model

Model Setup and Experiment Design

- 2D simulations with NX x NZ = 3683 x 83 grid points
- $\Delta x = 30$ m, $\Delta z = 2$ m up to z = 84 m, stretched from z = 84 m to top (z = 8 km)
- Mountain valley: Width = 30 km, Depth = 500 m, Sidewall slope = 5%
- Initial sounding: Neutral stratification; quiescent winds
- 18 m tall canopy (LAI** = 2) specified along mountain slopes (see figures below)
- Initialized at 2000 LST (~ 1 hr after sunset), run for 9 hours; mid-latitude location



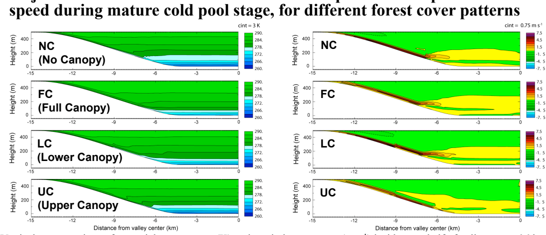
* Tree height exaggerated in schematic



** LAI: Leaf area index (m^2 leaf area per m^2 ground area)

Cold-Air Pool Sensitivity Overview

- **Objective: Examine vertical cross sections of potential temperature and wind speed during mature cold pool stage, for different forest cover patterns**

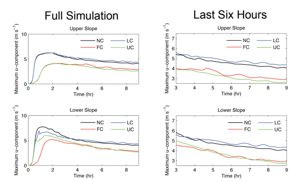


Vertical cross-sections of potential temperature (K) and u-wind component (m s^{-1}) inside west half of valley, at t = 06 hr.

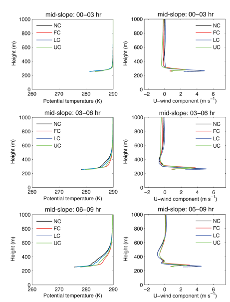
- Cold pool strength at t = 06 hr (coldest → warmest): NC, UC, LC, FC
- Case LC: Note the abrupt mid-slope deepening of the cold air and elevation of the drainage jet away from the surface (Opposite occurs for UC case)
- In almost all cases, drainage flow detaches from slope near z = 200 m. Exception is the UC case; drainage flow was detached as recently as t = 05 hr, but weak nature of jet leads to reattachment by t = 06 hr
- Note the very weak wind speeds inside the cold pool (isolated from slope flow)

Impact of Forest Cover on Slope Flows

- **Objective: Examine timeseries and profiles of u-wind component and potential temperature to investigate sensitivity of slope flows to forest cover**



Timeseries of maximum u-component of wind (u_{max}) along upper-half of slope (top panels) and lower-half of slope (bottom panels).

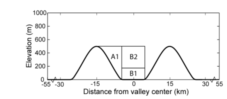


Vertical profiles of 3-hour mean potential temperature (left panels) and u-component of wind (right panels).

- Timeseries:
  - Upper slope u_{max} is insensitive to lower slope forest cover
  - Lower slope u_{max} is strongly influenced by upper slope vegetation
  - Lower slope u_{max} (strongest → weakest): NC, LC, UC, FC
- Profiles:
  - Mid-slope: canopy displaces jet from surface; sub-canopy maximum evident
  - Mid-slope: Two-layer thermal structure with surface inversion and deeper stable layer above (Note: air above inversion is colder in LC than UC)

Valley-Mean Cooling Rate Assessment

- **Objective: Examine sensitivity of valley cooling rate (VCR) to forest cover along valley sidewalls**



$$VCR = \left\{ \frac{\sum_{i=1}^{N}\left[\left(\frac{\partial\theta}{\partial t}\right)_i * (A)_i\right]}{(A)_{valley/zone}} \right\} = \left\{ \frac{\sum_{i=1}^{N}\left[\left(\frac{\partial\theta}{\partial t}\right)_i * (A)_i\right]}{\sum_{i=1}^{N}(A)_i} \right\}$$

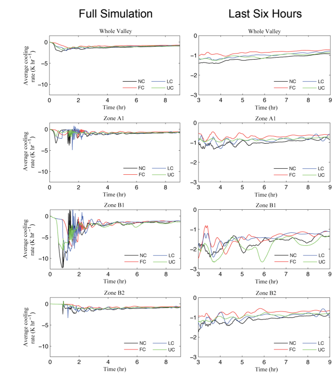
00-03 hr mean VCR

Case:	NC	FC	LC	UC
Valley	-1.514 (1)	-0.890 (4)	-1.231 (2)	-1.157 (3)
A1	-1.023 (1)	-0.619 (4)	-0.876 (2)	-0.766 (3)
B1	-3.852 (1)	-2.609 (4)	-3.083 (3)	-3.351 (2)
B2	-0.995 (1)	-0.381 (4)	-0.773 (2)	-0.573 (3)

03-09 hr mean VCR

Case:	NC	FC	LC	UC
Valley	-1.157 (1)	-0.848 (4)	-1.003 (3)	-1.044 (2)
A1	-1.005 (1)	-0.685 (4)	-0.872 (2)	-0.837 (3)
B1	-1.671 (2)	-1.437 (3)	-1.430 (4)	-1.831 (1)
B2	-1.104 (1)	-0.772 (4)	-0.966 (2)	-0.929 (3)

Time-averaged cooling rate (K/hr) for whole valley and individual zones, with rank indicated in parentheses.



Cooling rate (K/hr) timeseries for whole valley and individual zones.

- Strongest cooling occurs in zone B1 (lowest 1/3 of valley atmosphere)
- 00-03 hr mean zone B1 cooling (strongest → weakest): NC, UC, LC, FC
- 00-03 hr mean zone B2 cooling (strongest → weakest): NC, LC, UC, FC
- Strong oscillations between t = 01 and t = 03 hr indicative of gravity waves that develop as leading edges of cold pools collide in center (not shown)
- Differences in VCR between cases smallest during later part of night

Conclusions

- Sensitivity of cold-air pool and drainage flow characteristics to a forest canopy has been examined
- Overall valley cooling is reduced if sidewalls are partially or fully vegetated
- Forest cover yields weaker near-surface cooling and a weaker jet (elevated)
- Valley cooling strongest (weakest) in layer of valley atmosphere where, at the same elevation, sidewall slopes are bare (forest covered)
- Cold air drainage flows highly sensitive to forest cover farther upslope, but largely unaffected by forest cover farther downslope
- Additional work: (1) Explore sensitivity of valley cooling to canopy density and canopy vertical structure; (2) examine sensitivity to canopy characteristics under different background conditions (wind, stability); (3) consider asymmetric sidewall canopy cover; (4) extend to 3D simulations

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