Towards a 3-Dimensional Model of Forest Heat Contributions to Snowpack Thermodynamics: Determining internal snowpack temperature responses to energy balance drivers in the Australian Alps

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Abstract

Research on modification to snowpacks as a result of forest disturbance has typically focused on spatiotemporal patterns of snow depth and snow water equivalent, snowpack energy fluxes, and melt/ablation characteristics. However, little work has been conducted on relationships between tree trunks and snowpack dynamics. Insight into drivers of internal snowpack thermodynamics around trees and their response to forest disturbance is crucial to understanding hydrological processes in forested regions of the cryosphere, especially as forest disturbance through climate change continues. This work investigates relationships between energy fluxes and thermodynamic patterns surrounding tree trunks and within the greater snowpacks of forest stands in the Snowy Mountains of the Australian Alps. Measurements of vertical and horizontal snowpack temperature profiles and sub-canopy energy fluxes were collected during the 2018 winter season in non-disturbed and fire-disturbed Eucalyptus pauciflora (Snow Gum) stands. Primary heat sources were identified for each measurement location in the snowpack through employing the Random Forest machine learning regression method. Preliminary results indicate that soil heat flux is the dominant control on snowpack temperature at all locations in the un-disturbed forest stand. However, outgoing longwave radiation is shown to be the prevalent driver at numerous locations within the fire-disturbed stand that are close to the snowpack surface and tree well. This work aims to develop the physical basis for a 3-dimensional thermodynamic model of snowpacks contained in forests that could be used in conjunction with existing 1-dimensional snowpack models to determine melt and variability.

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Tree Effects on Snowpack Energetics Experiment

1. Motivation

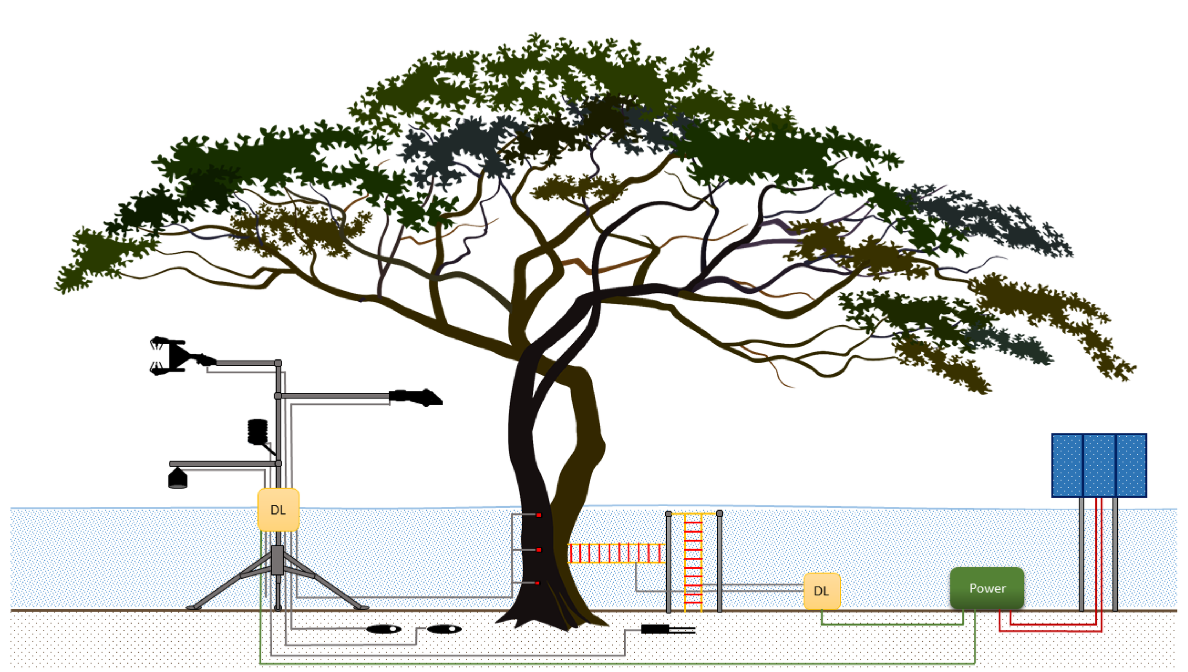
Increasing understanding of snowpack energy fluxes and thermodynamics will become more important as montane and boreal snowpacks develop marginal characteristics due to climate change[1].

Despite knowledge of the effects of forest stands on spatiotemporal patterns of snow depth and snow water equivalent, snowpack energy fluxes, and melt/ablation characteristics, impacts of forest stands and individual trees on snowpack thermodynamics has yet to be investigated.

The aim of this work is to identify relationships between energy fluxes and three-dimensional thermodynamic patterns surrounding tree trunks and within tree stands. The information obtained can be applied to improving snowpack melt and hydrological models within forested regions.

2. Methods

Thirty-minute measurements were obtained from snowpacks in undisturbed and fire-disturbed *Eucalyptus pauciflora* (Snow Gum) stands in Kosciuszko National Park, New South Wales, Australia from 1 June 2018 to 1 October 2018.



Snowpack Energy Fluxes: Sensible heat (H), latent heat (LE), shortwave (SW) and longwave radiation (LW), and soil heat (SHF) were collected via eddy covariance towers.

Snowpack Temperature: Two 100cm thermocouple ladders with measurements every 10cm were installed horizontally and vertically at each site. Horizontal ladders were attached to tree trunks and vertical ladders had the first measurement at 10cm above ground level (AGL).

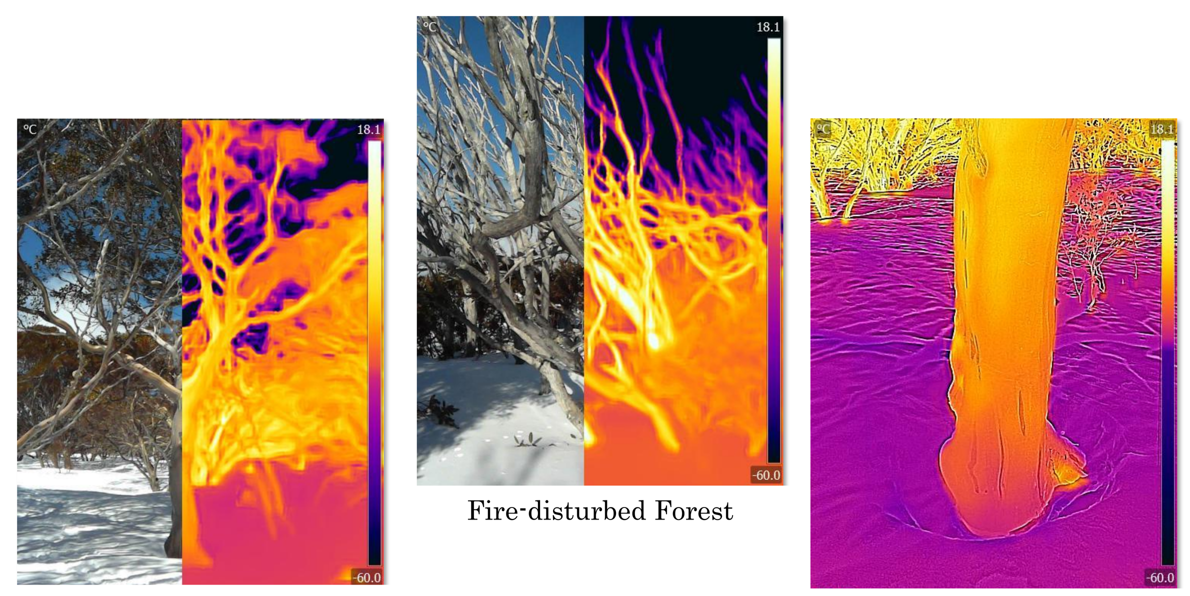
Tree Trunk Temperature: Three thermocouples were placed in tree trunks at 33cm, 66cm, and 99cm at each site.

Individual Thermocouple Temperature Models: A temperature change model was built for each thermocouple location in the snowpack using the measured energy fluxes with the Random Forest regression machine learning method[2].

*Measurements less than 80cm AGL were used for the fire-disturbed site as snowpack depth wasn't sufficient to use entire 100cm.

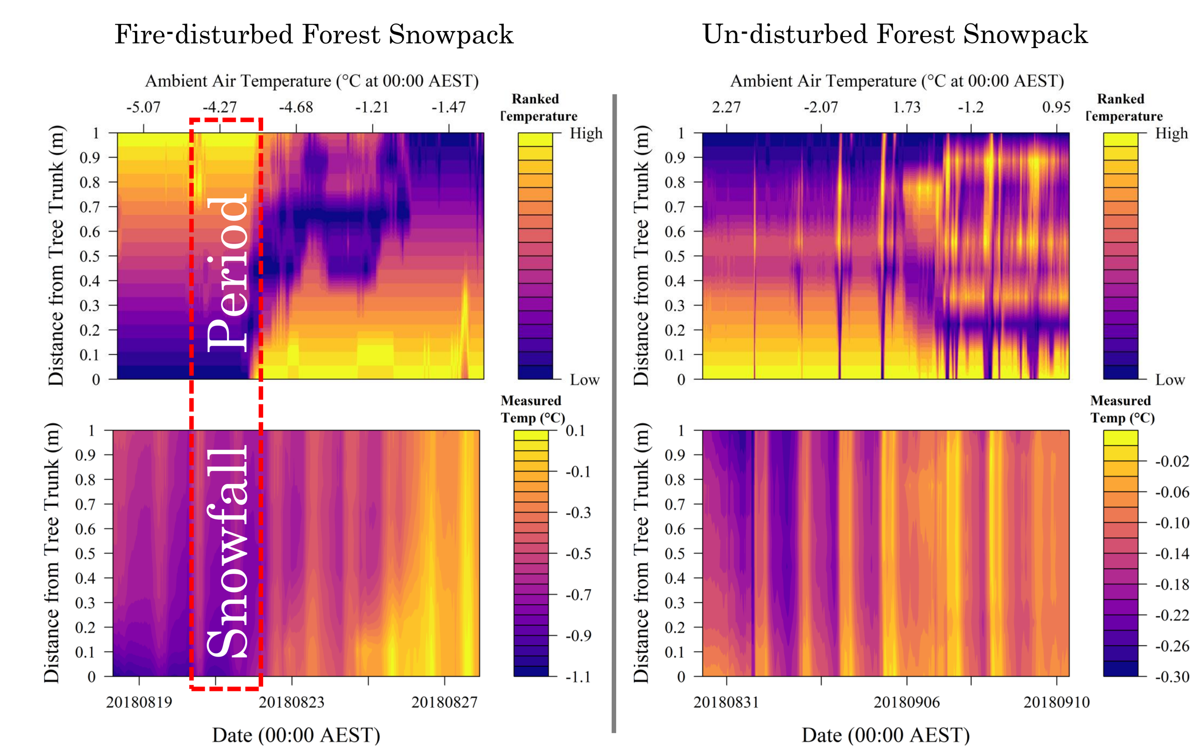
3. Tree Longwave Emission

- Maximum emission of LW occurs in the fire-disturbed *E. pauciflora* stands due to increased incoming shortwave radiation from a reduction in canopy.
- Equilibrium between tree and ambient air temperature occurs sooner within fire-disturbed tree stands.



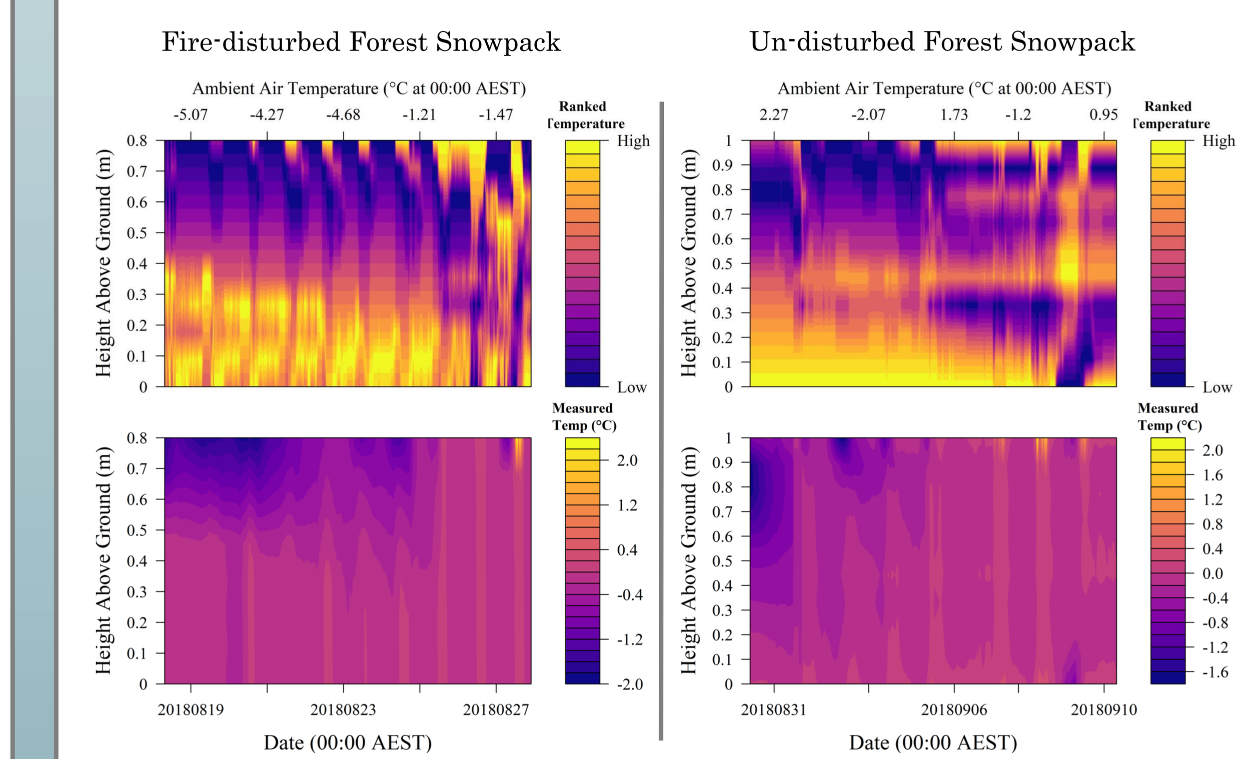
Un-disturbed Forest — Fire-disturbed Forest — Trunk-Snow Interaction

4. Horizontal Heat Transport



- Low temperatures are fully advected away from the tree trunk in the fire-disturbed forest snowpack in ~3 days.
- Greater temperature range is seen in the snowpack of the fire-disturbed forest, potentially as a result of tree well development and increased incoming shortwave.

5. Vertical Heat Transport

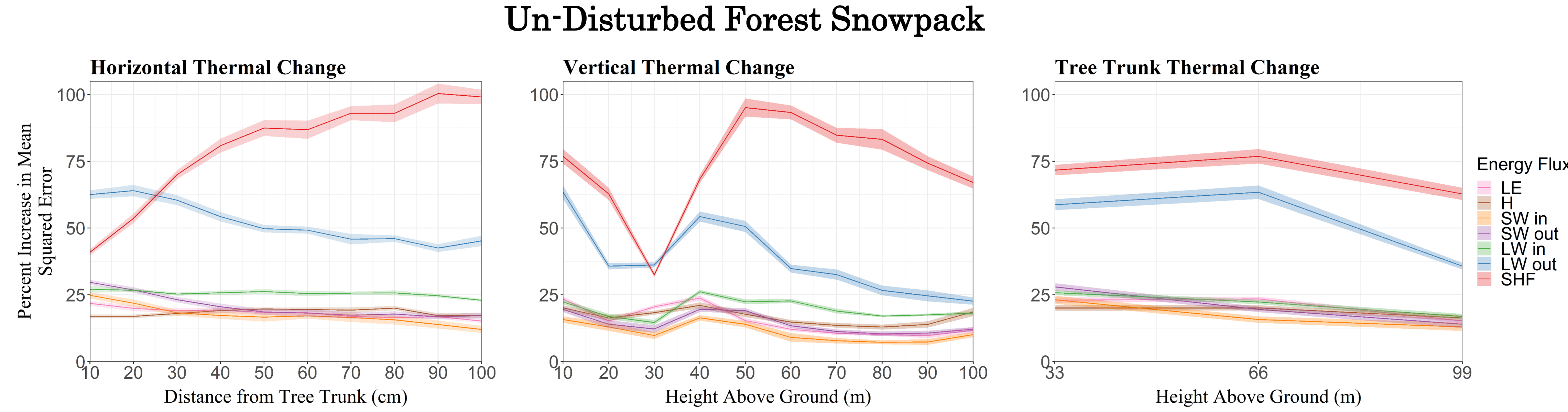


- Both snowpacks show warmer temperatures at ground level and surface with cooler temperatures in the middle.
- Snowpack in fire-disturbed forest shows greater temperature variability and diurnal signal than snowpack in un-disturbed forest.

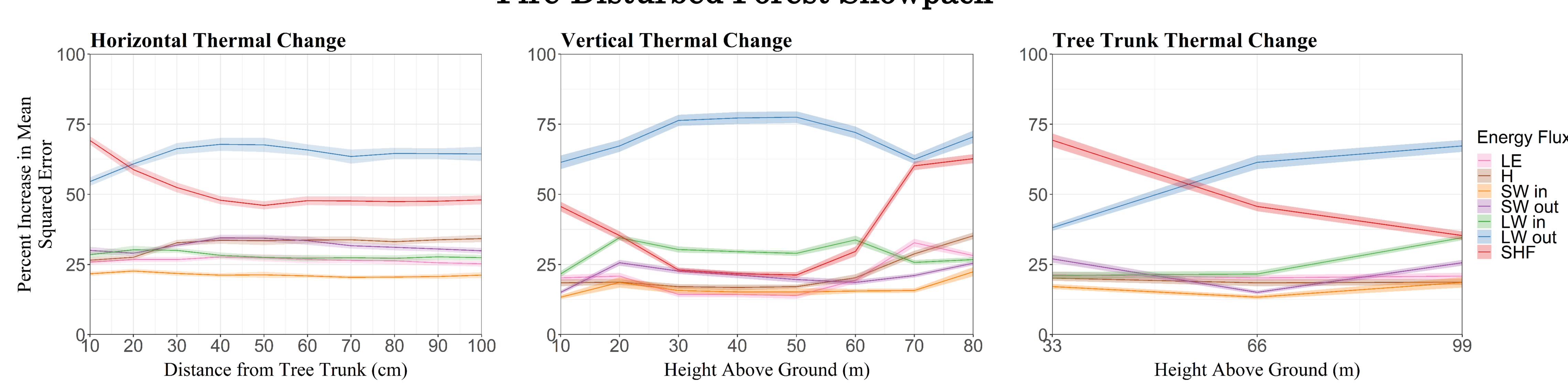
6. Drivers of Snowpack Thermal Change

The Random Forest regression method determines a variable's importance through measuring Mean Squared Error (MSE) values during random permutation of each variable. The variables responsible for the highest increase in MSE after permutation are considered most important to the regression model.

Un-Disturbed Forest Snowpack



Fire-Disturbed Forest Snowpack



- Soil heat flux is the dominant control on thermal change in the snowpack in the un-disturbed forest.
- Outgoing longwave radiation was determined to be the primary control on snowpack temperature for all but one snowpack thermocouple in the fire-disturbed forest and the two thermocouples closest to the tree in the un-disturbed forest.

7. Summary

Reduction of forest canopy at the fire-disturbed site had a significant influence on snowpack energy fluxes and heat transport through increased shortwave radiation and associated increased tree longwave emission. As such, five main conclusions are reached:

1. Removal of forest canopy increased snowpack temperature range horizontally from dead trees and vertically.
2. Mean snowpack temperature was 0.26°C lower in the fire-disturbed stand (-0.40°C) than in the un-disturbed stand (-0.14°C).
3. Advective fluxes (H & LE) had relatively little control on internal snowpack temperatures at all locations.
4. In addition to atmospheric influence, ground heat flux provides substantial control on snowpack temperature and associated melt.
5. Longwave radiation emitted from the fire-disturbed forest provides energy to develop tree wells earlier, but allows for reductions in snowpack temperature due to cooler ambient temperatures at night.

References

[1] Pachauri, R.K., et al., *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change.* 2014: IPCC.

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