Heating Effects of Supra-arcade Downflows (SADs) on Plasma above Solar Flare Arcades

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Abstract

We deliberately select three flares to investigate heating effects of SADs on the surrounding fan plasma. Prior work found in one flare that the plasma around SADs tends to heat up or stay the same temperature, accompanied by discernible signatures of adiabatic heating due to plasma compression and viscous heating due to viscous motions of plasma (Reeves et al, 2017). We extend this work to more flares and find that the heating effects of the SADs are also present in these events. The adiabatic heating is dominant over the viscous heating in each event. The adiabatic heating in the two M1.3 flares, being on the order of about 0.02-0.18 MK/s, is fairly comparable. In the more energetic X1.7 flare, the adiabatic heating is on the order of 0.02-0.3 MK/s, where we observe a more pronounced temperature increase during which dozens of SADs descend through the fan. As SADs constantly contribute to the heating of the surrounding fan plasma, the areas where SADs travel through tend to cool much slower than the areas without SADs. The cooling rate of areas without SADs descending through is ~ 1000 K/s and can be interpreted nicely by the cooling process of turbulence-dominant conduction followed by radiation, suggesting that the thermal conduction in fans is markedly suppressed by turbulent processes.

Introduction

Supra-arcade downflows (SADs) are downward-moving dark voids in solar flares. In the Atmospheric Imaging Assembly (AIA) on the Solar Dynamics Observatory (SDO), they are generally observed with the 131 Å channel, which is sensitive to plasma at about 10 MK. SADs are density depleted structures, and most SADs are cooler than the surrounding fan plasma. The speeds of SADs are ~ 100 km/s. Several studies have showed that SADs contribute to the heating of the surrounding fan plasma. Here, we further investigate heating effects of SADs on fan plasma in three flares (case A, 2011-10-22, M1.3; case B, 2015-06-18, M1.3; case C, 2012-01-27, X1.7) to ascertain if the scenario described in Reeves et al. (2017) holds for other events.

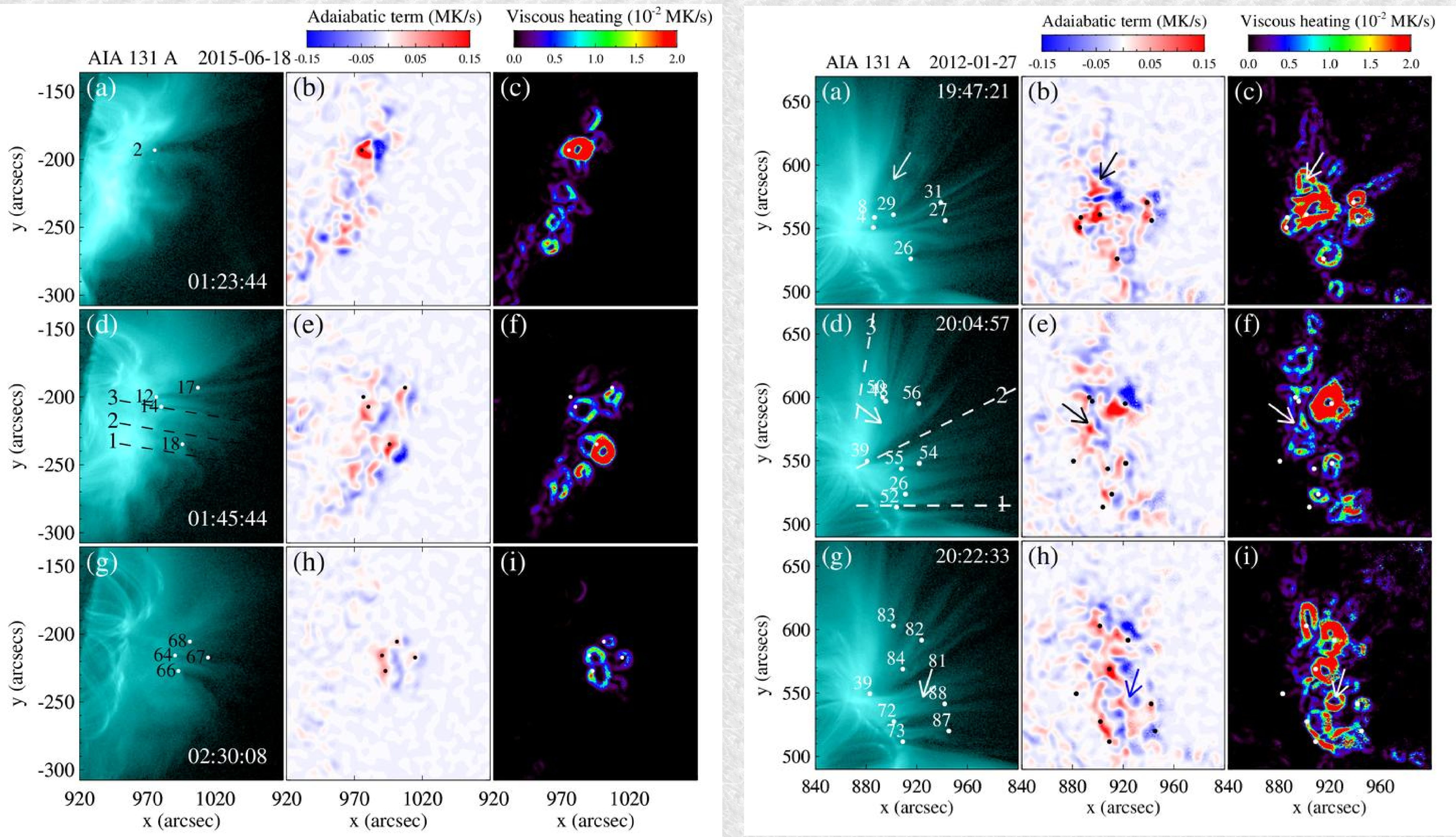

Fig1. Intensity in the SDO/AIA 131 A bandpass, the adiabatic term, and the viscous term for different times in cases B (left) and C (right), where dots and texts denote the heads and ID numbers of the SADs, respectively. Arrows indicate the bright downflows.

=> **Discernible signatures of the adiabatic and viscous terms around the SADs**

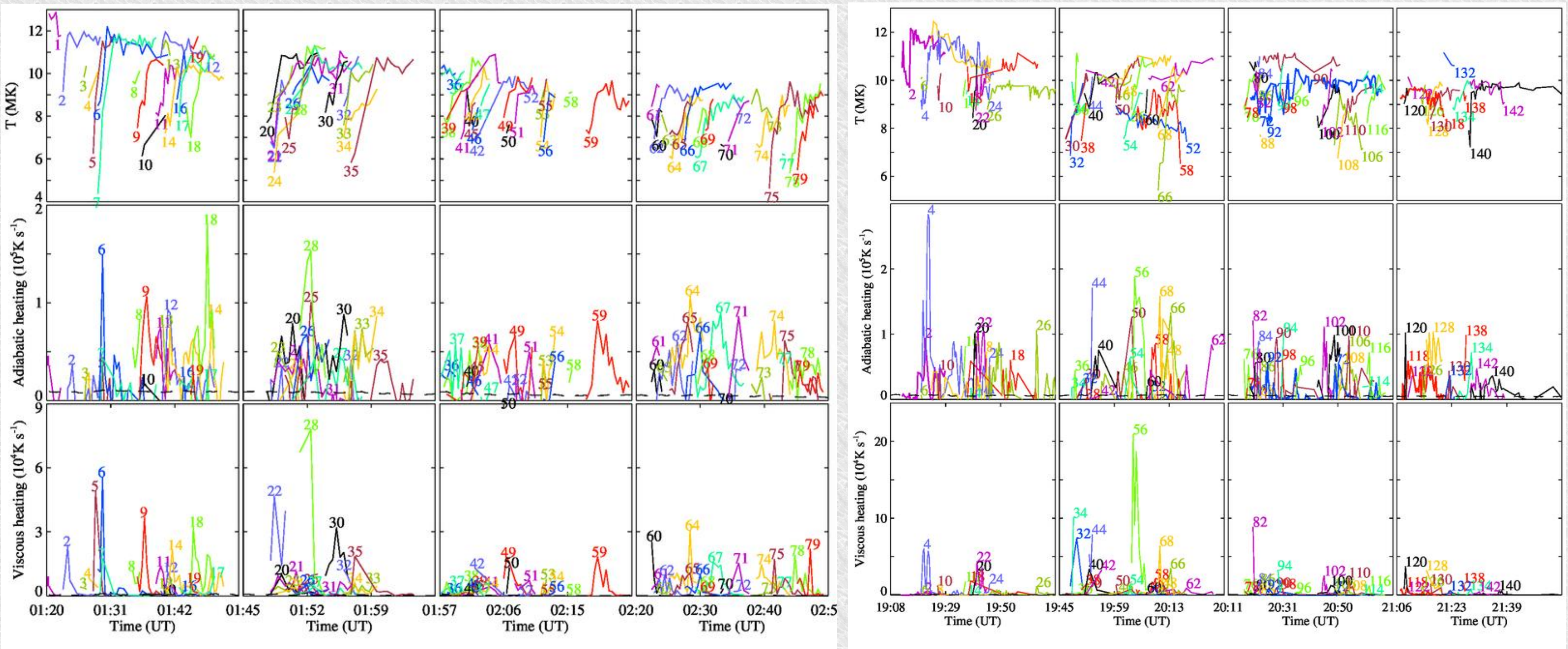

Fig. 2 Temperature (first row), the adiabatic heating (second row), and viscous heating (third row) as a function of time in cases B (left) and C (right), where each curve is for an individual SAD with ID number marking next to it, and dashed lines indicate the background levels.

=> **Temperature increases in each SAD, accompanied by distinct adiabatic and viscous heating. The highest temperature a SAD obtains decreases over time due to the overall plasma cooling in the fans.**

Summary

- The results are consistent with Reeves et al. (2017), namely, the plasma in front of the SADs tends to either stay the same temperature or heat up due to the adiabatic and viscous heating.
- Fan plasma without SADs cools through two main phases: collision-dominated conduction followed by radiation, suggesting that the thermal conduction in fans is suppressed by turbulent processes.

Methods

- The velocity results are derived from an optical flow calculation. The algorithm we use is the Gunner Farneback's algorithm.
- Constructing temperatures from differential emission measures (DEMs, Hannah & Kontar, 2012) .
- Calculating and visualizing the adiabatic and viscous terms from the MHD energy equation in terms of temperature.

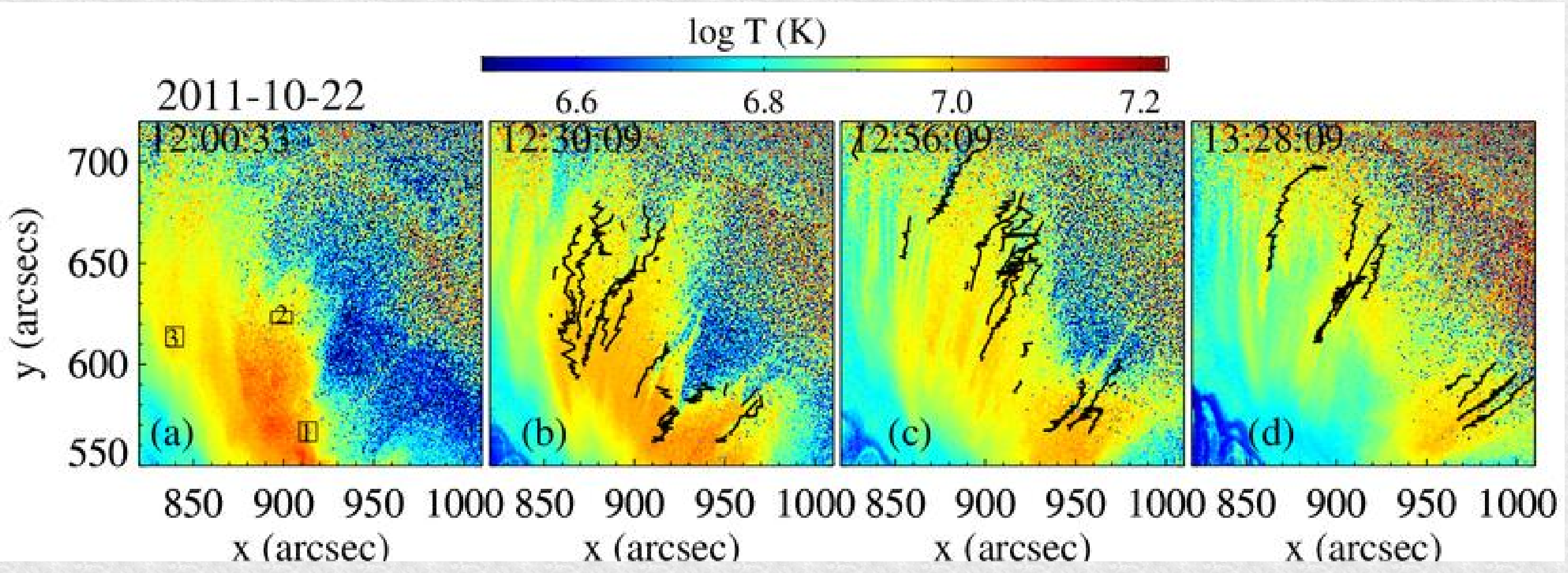

Fig 3. Distributions of temperature for several times in case A, where black curves indicate the moving tracks of SADs appearing between the times shown in the last panel and current panel.

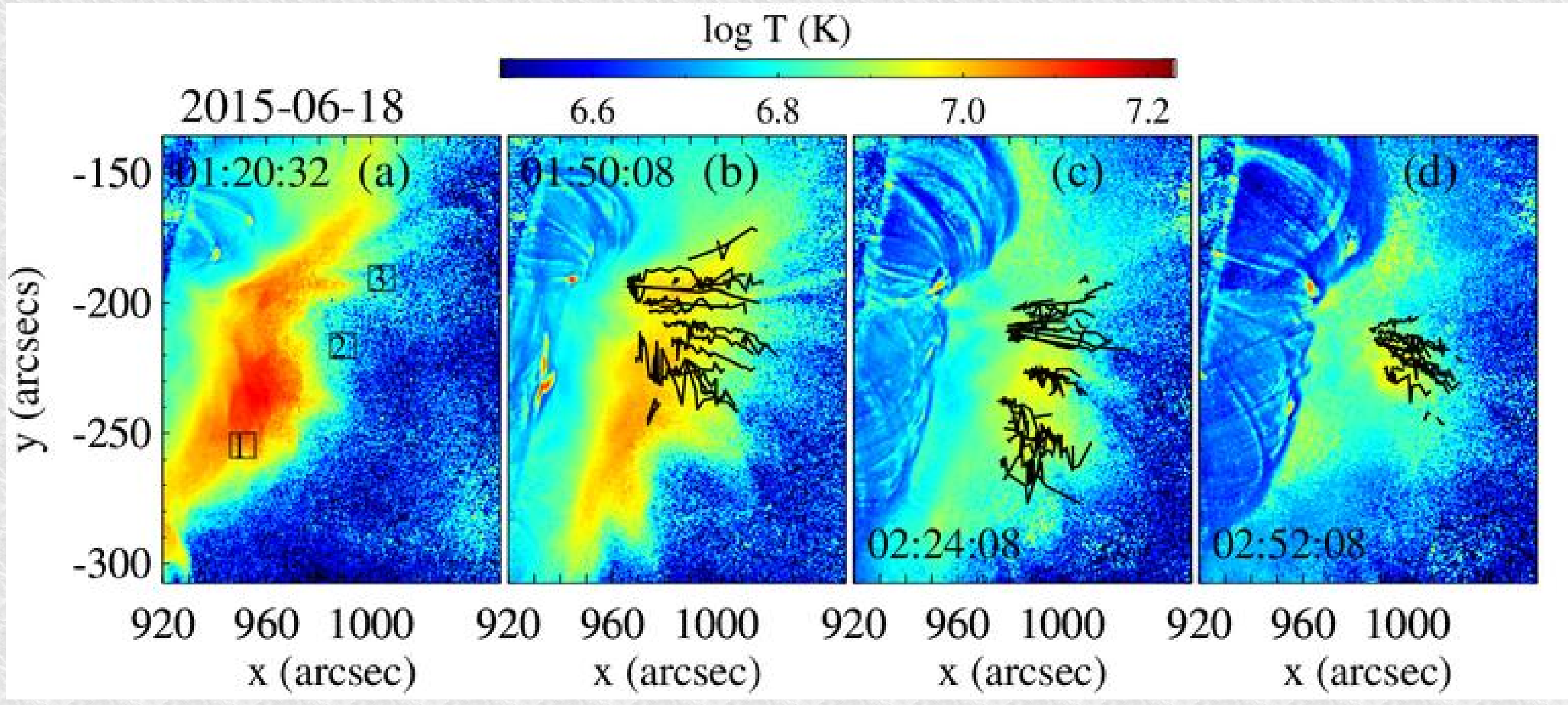

Fig 4. Same as fig. 3, but for case B.

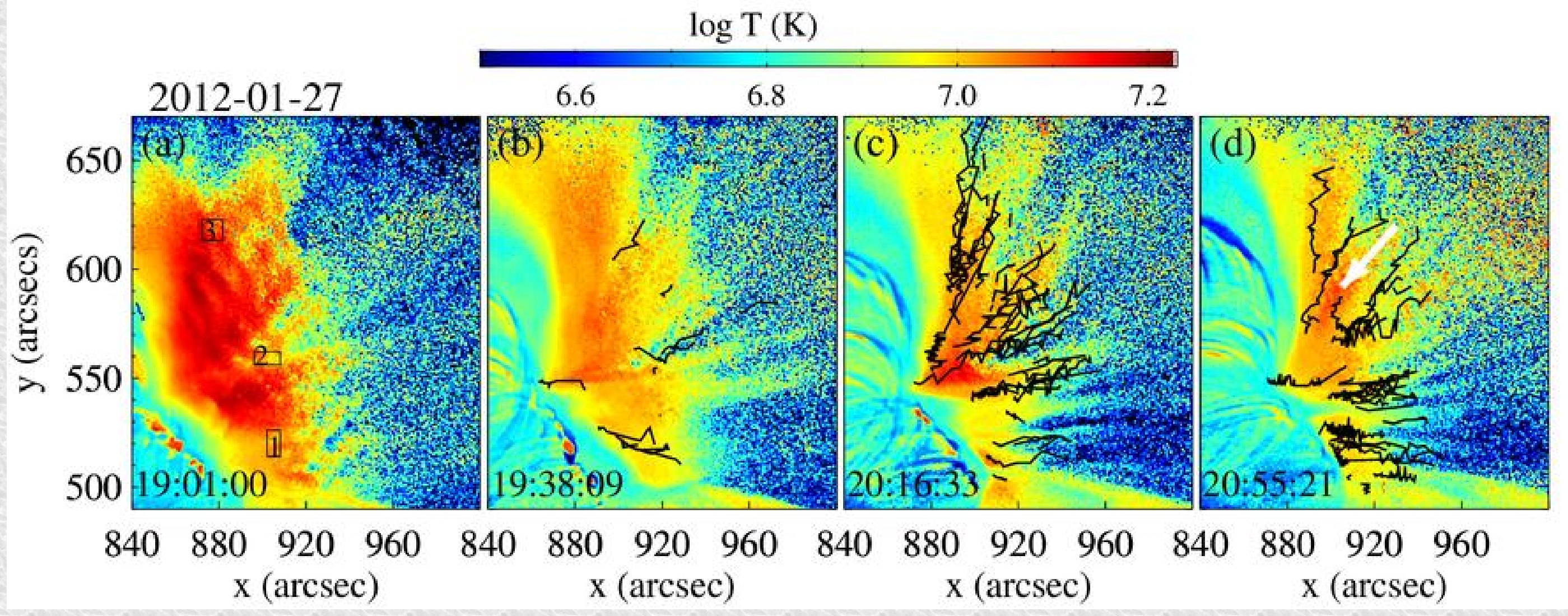

Fig 5. Same as fig. 3, but for case C.

Figs 3-5 => The plasma of higher temperature concentrates in areas where SADs frequently travel through.

Comparison with a Cooling model

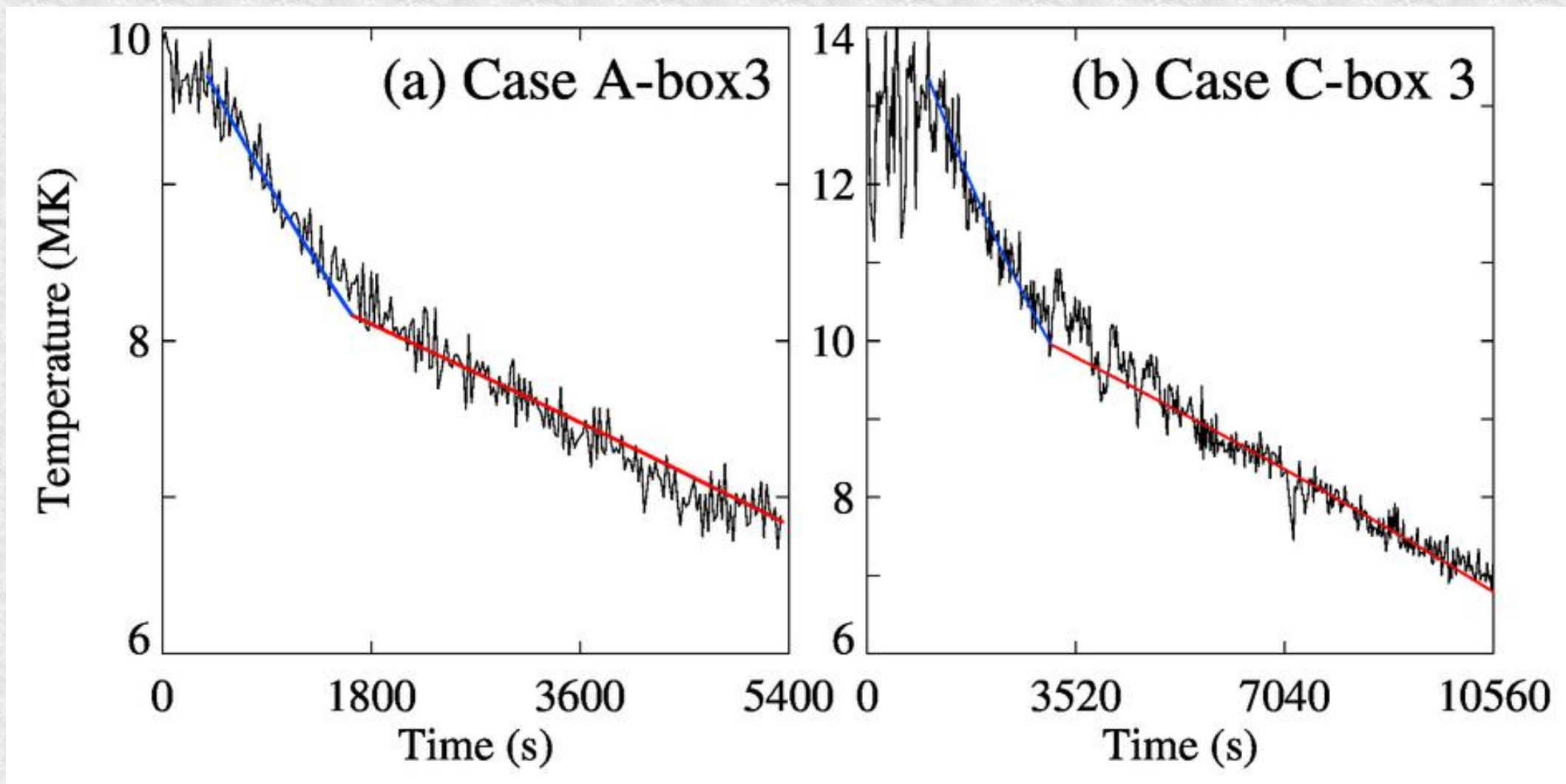

Fig. 3 Temperature evolution (black curves) after subtracting the effects of the adiabatic and viscous terms in box 3 of case A and box 3 of case C, where colored lines denote theoretical temperature evolution of cooling by turbulent conduction (blue lines) transitioning to radiation (red lines).

=> **The thermal conduction in fans is suppressed by turbulent processes**

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