Analysis of the atmospheric heating process and its seasonal variation over the Tibetan Plateau using a land data assimilation system

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Introduction

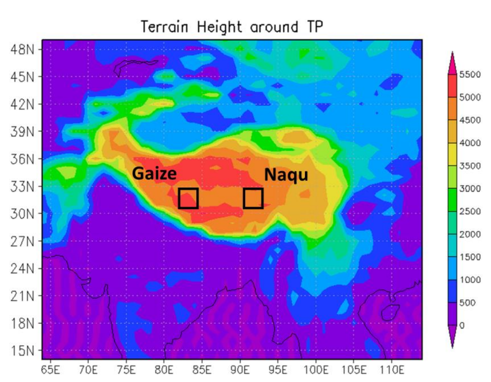
The atmospheric heating over the Tibetan Plateau (TP), located in the central Eurasian continent, has been shown to have **a strong influence on the formation of Asian Summer Monsoon (ASM)**. Previous studies indicated various heating components, including **sensible heat, latent heat and adiabatic heating**, as important sources for the total heating. However, the detail structure and quantitative understandings of the heating have not been obtained, and relationship between meso- and synoptic- scale processes has not been discussed enough in association with the heating.

This study investigated **the heating process and its seasonal variation in the premonsoon and mature monsoon seasons** of 2008 using **radiosonde data** and a land data assimilation system coupled with a mesoscale atmospheric model (**LDAS-A**), which assimilates microwave brightness temperature and accurately reproduces land and atmospheric states, and **gives a detail and overall picture of heating process over the TP**.

Data and Method

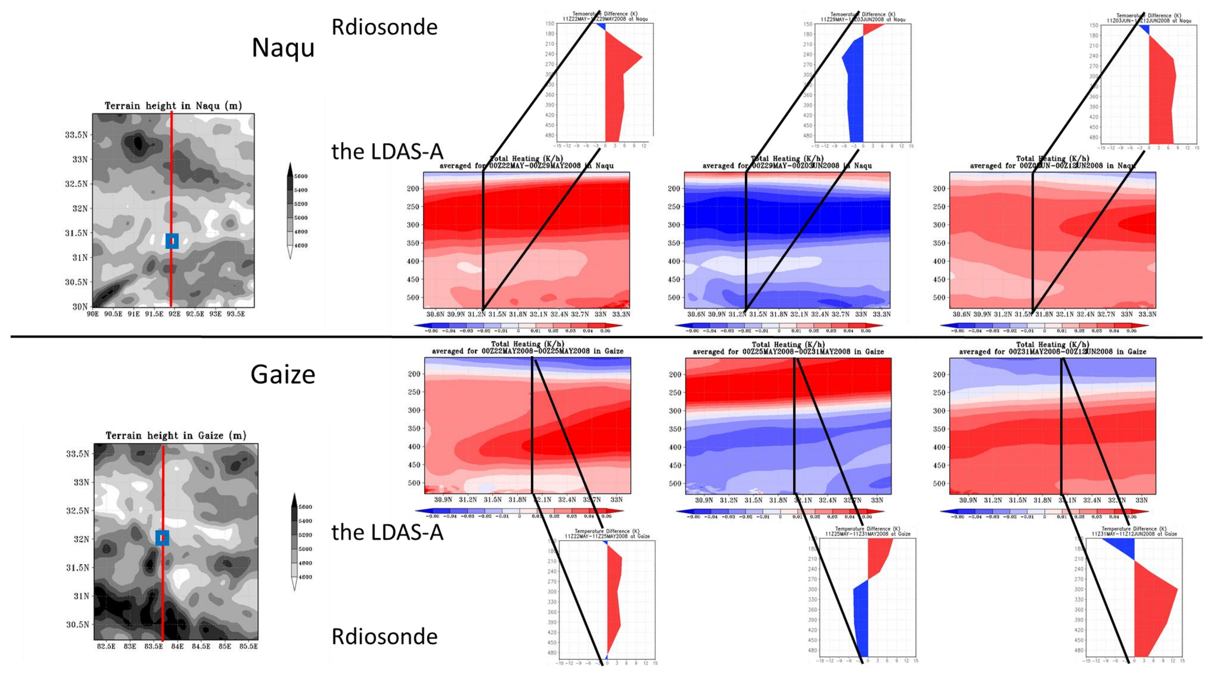
Radiosonde data

Fom 12 May to 12 June and from 7–16 July in 2008, radiosondes were launched from Gaize (32.18N, 84.03E) and from Naqu (31.29N, 92.04E) four times a day by the Japan International Co-operation Agency (JICA) project.



Land data assimilation system coupled with a mesoscale atmospheric model (LDAS-A)

The LDAS-A, developed by *Rasmy et al.* [2011], assimilates satellite microwave brightness temperature at lower frequency, which has high sensitivity to soil moisture in remote sensing. The LDAS-A accurately reproduces land and atmospheric states, and also atmospheric heating as shown below.



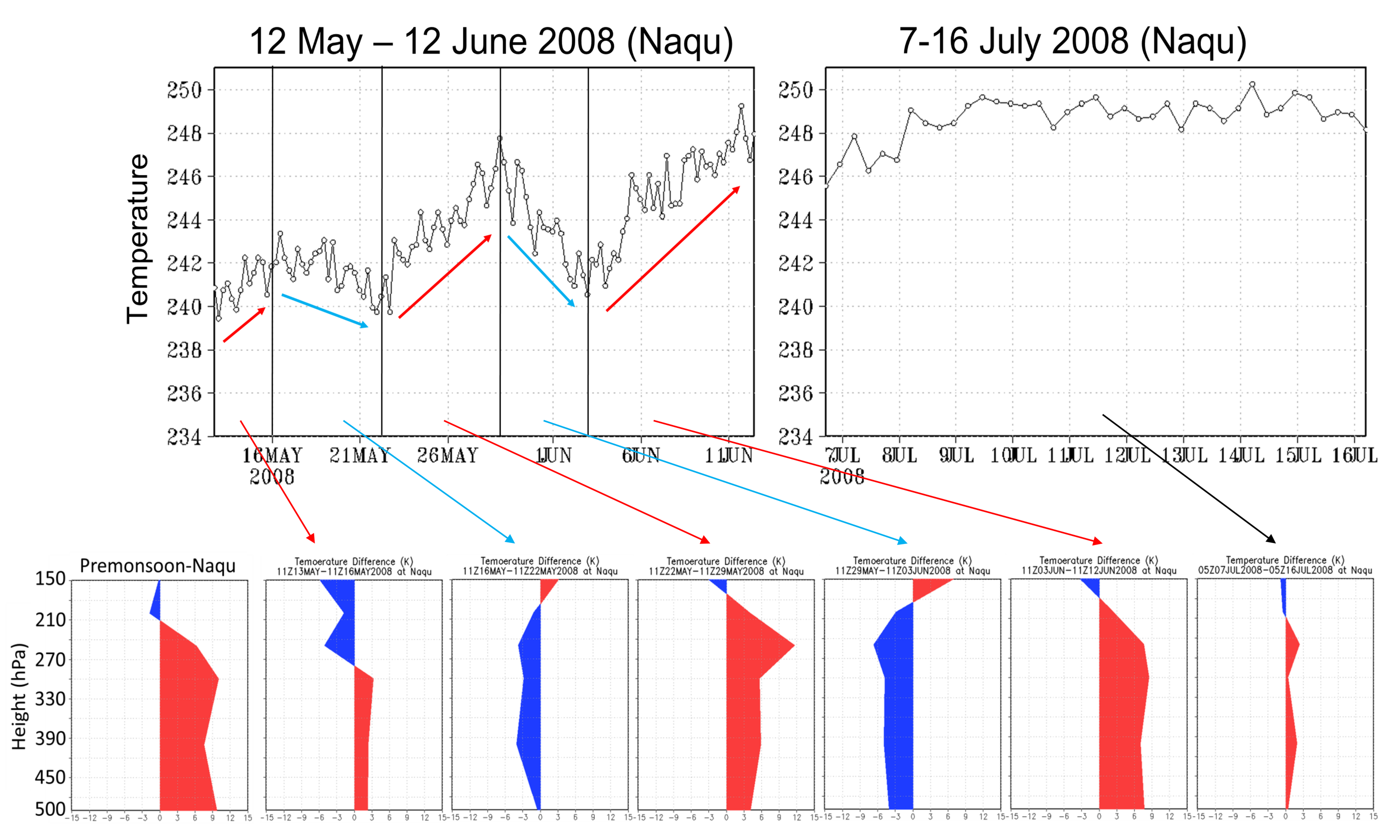
Comparison of the vertical profile of the heating obtained from radiosonde and the LDAS-A

Observed Vertical Profiles of Atmospheric Heating

Radiosonde data analysis shows that

- In the premonsoon season (PMS) (mid-May to mid-June), air temperature at 300 hPa follows a general increasing trend, but decreases occasionally, while in the mature monsoon season (July) it is relatively stable.
- In the PMS as a whole, the atmosphere is heated below 200 hPa and cooled above 200 hPa.
- When the vertical profiles of temperature change, which means heating amount, are shown individually in warming and cooling periods in the PMS, they are reversed.
- In the mature monsoon season (MMS), the vertical structure is similar to that in the PMS although the degree of temperature change is smaller.

Time series of air temperature at 300 hPa (upper figures)



The vertical profile of heating in each period (lower figures)

~ Questions arising from observational results ~

- What are the mechanisms of heating and cooling layer in warming and cooling periods in the PMS?
- And are the same mechanisms operating in the PMS and the MMS?

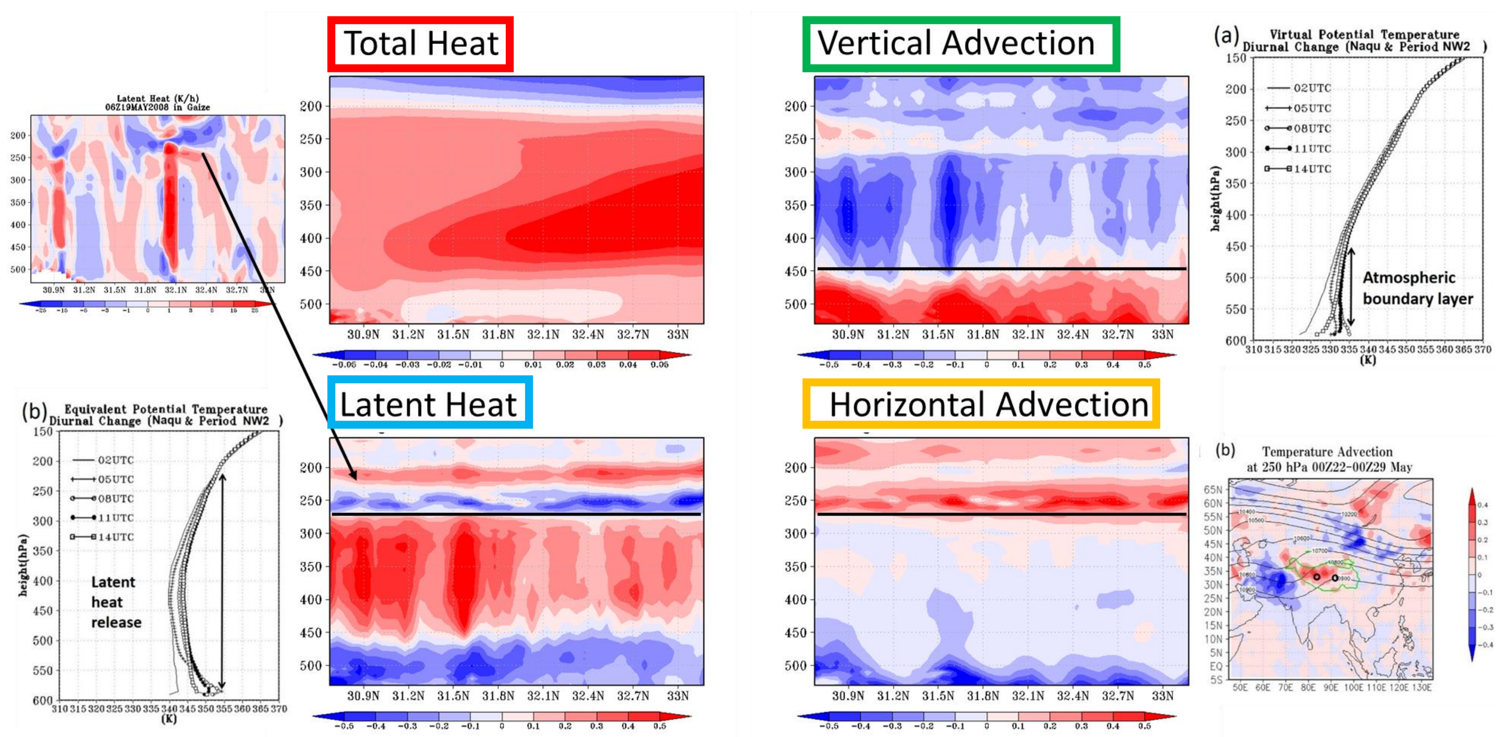
→ For a more detailed analysis of heating mechanisms, **a heat budget analysis** was conducted using the output from **the LDAS-A**. And the vertical structure of each heating component, **vertical advection, latent heat, and horizontal advection** was obtained.

Vertical Profiles of Atmospheric Heating from the LDAS-A

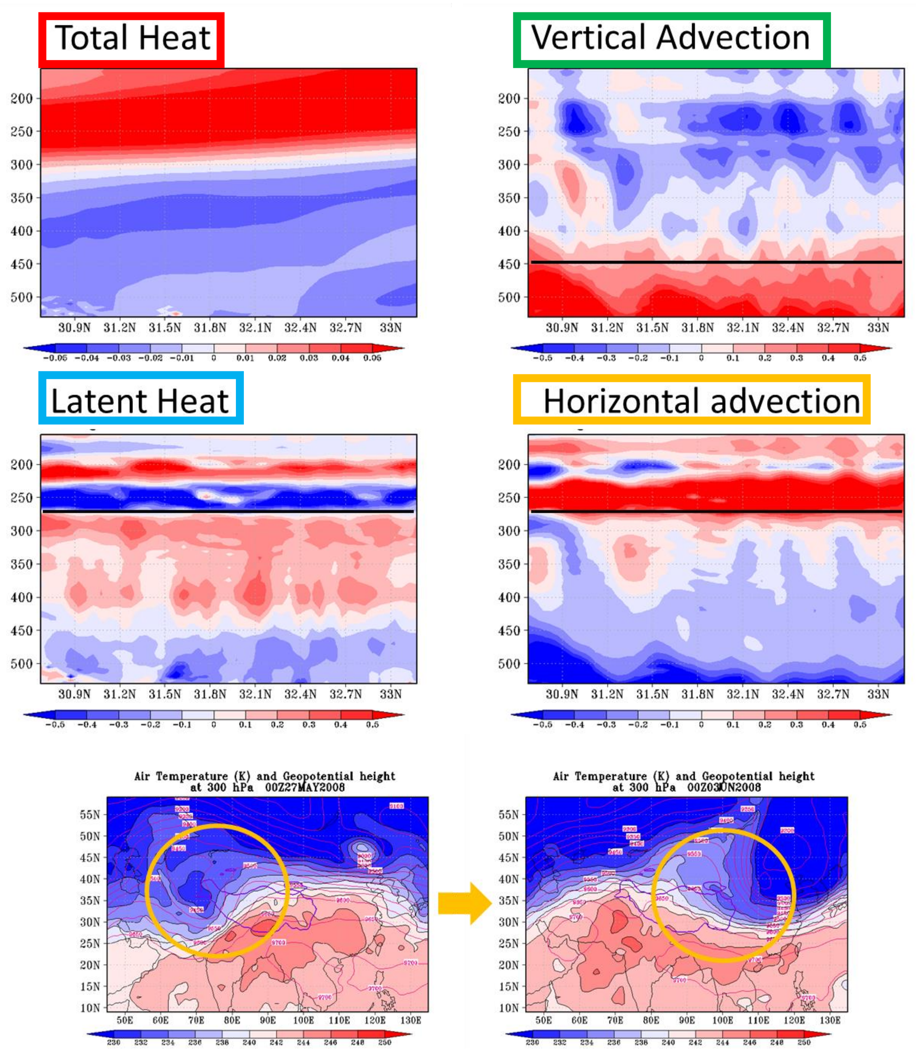
Heat budget equation

$$\boxed{\frac{\partial\theta}{\partial t}} = \boxed{-(u,v)\cdot\nabla\theta} \boxed{-\,\omega\frac{\partial\theta}{\partial p}} + \boxed{\frac{1}{C_p}\left(\frac{1000}{p}\right)^{\frac{R}{C_p}}(Q_l+Q_e+Q_r)}$$

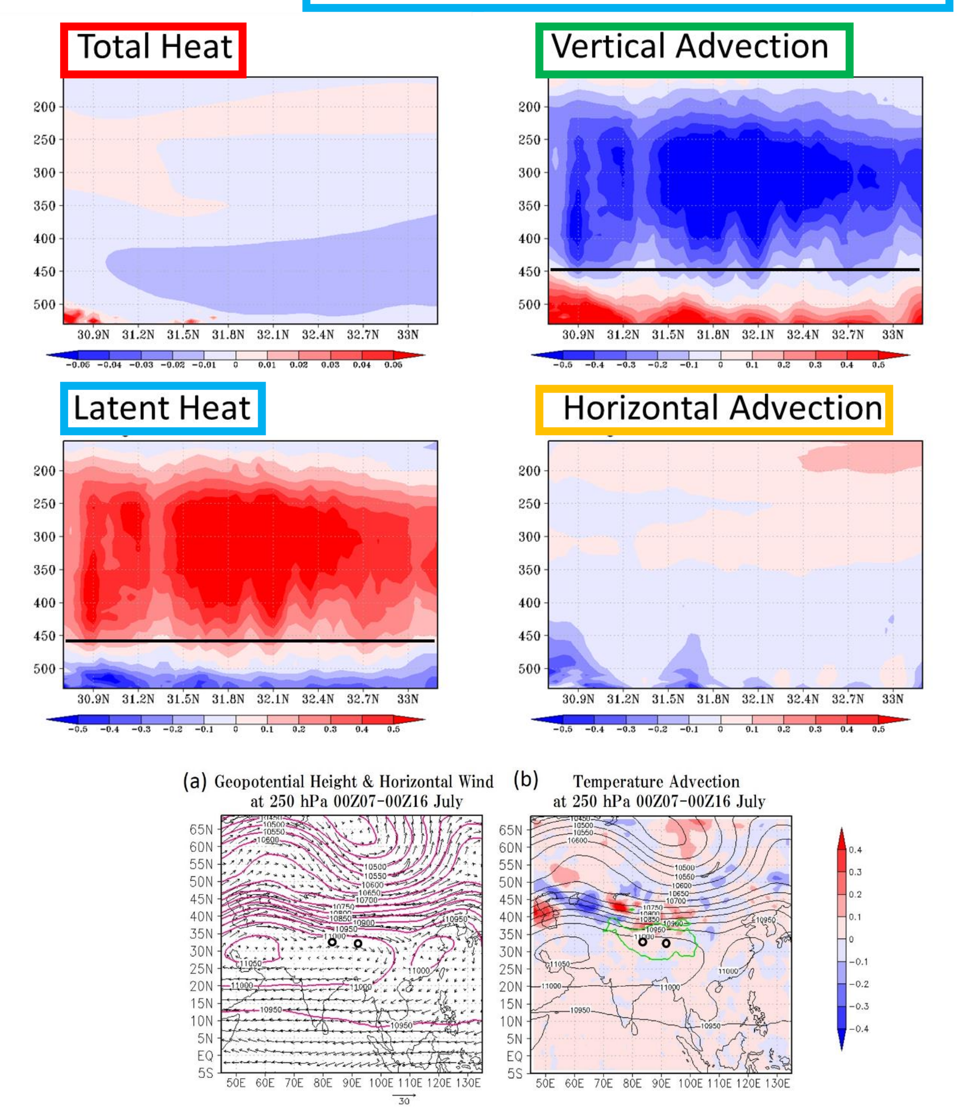
latitude-height cross sections of heating rate by each heat component in heat budget equation averaged over warming period (left), cooling period (middle) and mature monsoon season (right), and heating mechanisms



- The troposphere over the TP in warming periods was **divided into three vertical layers** in terms of the major heating process, sensible heat (SH) transport below 450 hPa, latent heat (LH) from 450–250 hPa, and horizontal advection (Hadv) above 250 hPa.
- The SH and LH are transported **by local convections** over the TP, because atmospheric boundary layer and unstable layer, which are estimated from the diurnal variations of potential temperature and equivalent potential temperature, correspond well to the heated layer
- The heat source for Hadv originated in **the southwest of the plateau**, related to a **synoptic-scale circulation** and southwesterly wind.
- In the upper layer, however, adiabatic **cooling** with ascending flow and **LH absorption** also contribute largely, so the net heating here is negative.



- In cooling periods, the vertical structure of each heat component is **similar to that in warming periods**, but the profile of total heat is **influenced by synoptic-scale situations of the westerly jet**, and reversed.



- In the mature monsoon season, **cumulus activities are much more active**, penetrating the middle layer.
- **Warm Hadv and latent cooling in the upper layer rapidly diminishes** at the same time as the formation of **the Tibetan Haigh**. The vertical profile of heat processes develops a **two-layered structure.**

The results of this study give a detail and overall picture of heating process over the TP in this season, indicating the importance of both heat from the surface of the TP and heat source outside of the plateau for total heating over the plateau. For more accurate prediction of the ASM, we may have to consider the role of the land surface of the TP and the heating due to it inside the model more seriously.

Reference
Seto, R., T. Koike, and M. Rasmy (2013), Analysis of the vertical structure of the atmospheric heating process and its seasonal variation over the Tibetan Plateau using a land data assimilation system, J. Geophys. Res. Atmos., 118, 12,403–12,421.
Rasmy M. et al. (2011), Development of a Satellite Land Data Assimilation System Coupled With a Mesoscale Model in the Tibetan Plateau. IEEE Trans. Geosci. Remote Sens., 49, 2847-2862.
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