Institute for Space-Earth Environmental Research

NAGOYA UNIVERSITY

Precipitation and its variability in the high elevation area of the Nepal Himalayas

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Outline

- **HiPRECS:**
  In-situ observation project in the eastern Nepal Himalayas
- **Diurnal cycle** of precipitation:
  by land surface effects
  in higher elevations by the glacier
- **Heavy rainfall event**:
  by monsoon lows under typical ISO's influences
- Summary

Tsho Rolpa glacier lake and Trakarding Glacier in Rolwaling, eastern Nepal Himalayas ©Dr. Koji Fujita@NU

HiPRECS (**Hi**malaya **Prec**ipitation **S**tudy)

Hydrological cycle in the Himalayas:

- **Large amounts of summer precipitation** in the central-eastern Himalayas
- **Glaciers:** summer accumulation type
- **Head waters of major rivers and water resources**

Precipitation and its variability in summer:

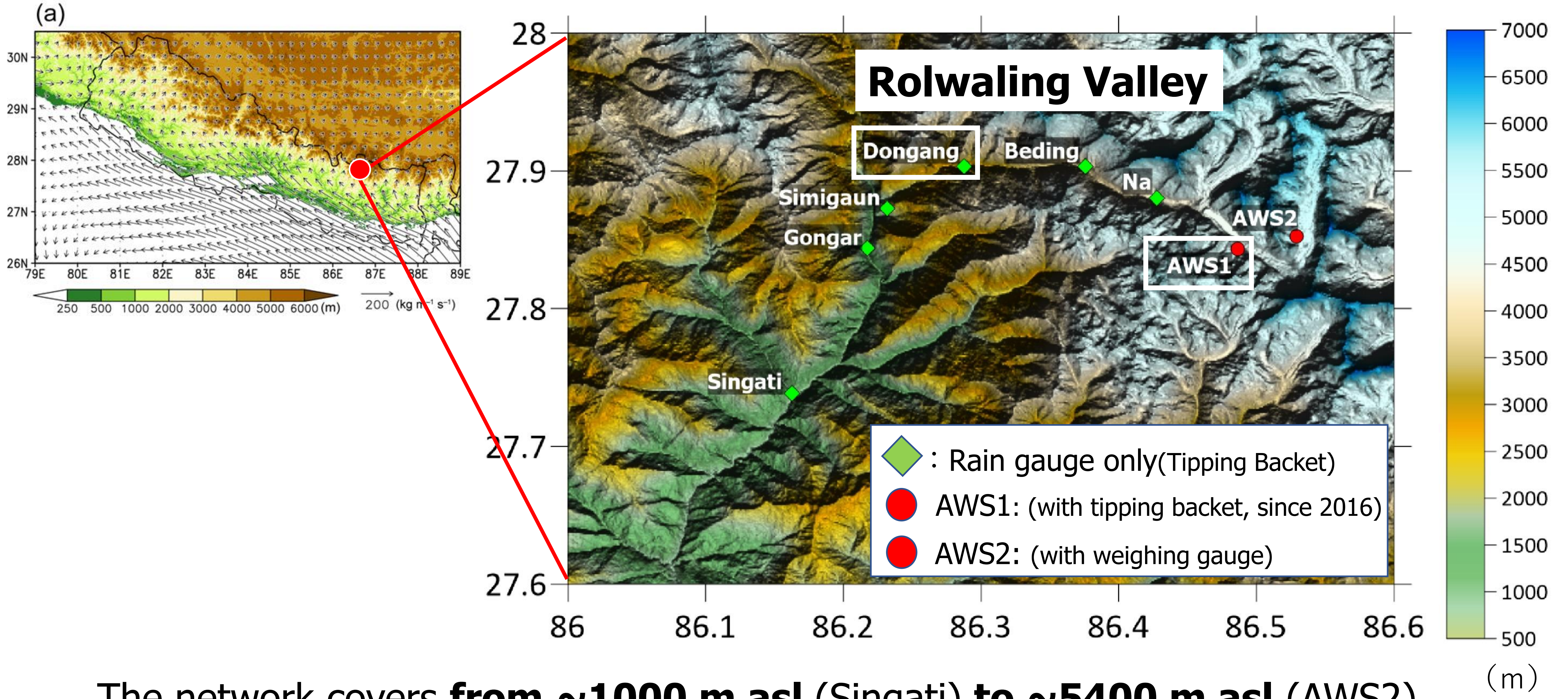
- essential element, but still poorly understood

HiPRECS (under AsiaPEX):

- An international joint research project between **Japan** and **Nepal** funded by JSPS-KAKENHI (PI:H. Fujinami, Period: **Oct. 2018 – Mar. 2023**, with **KU, NAST and ICIMOD**)
- To understand **summer precipitation and its variability** in the higher elevations of the Himalayas (e.g., around Rolwaling glacier and Ponkar glacier)
- By ***In-situ* observation** (rain gauges and AWSs), **satellites** (GPM-DPR, GPM-GMI, CloudSat-CPR and Meteosat), **EAR5** reanalysis and **Cloud resolving regional models** (CReSS, WRF and NHM)

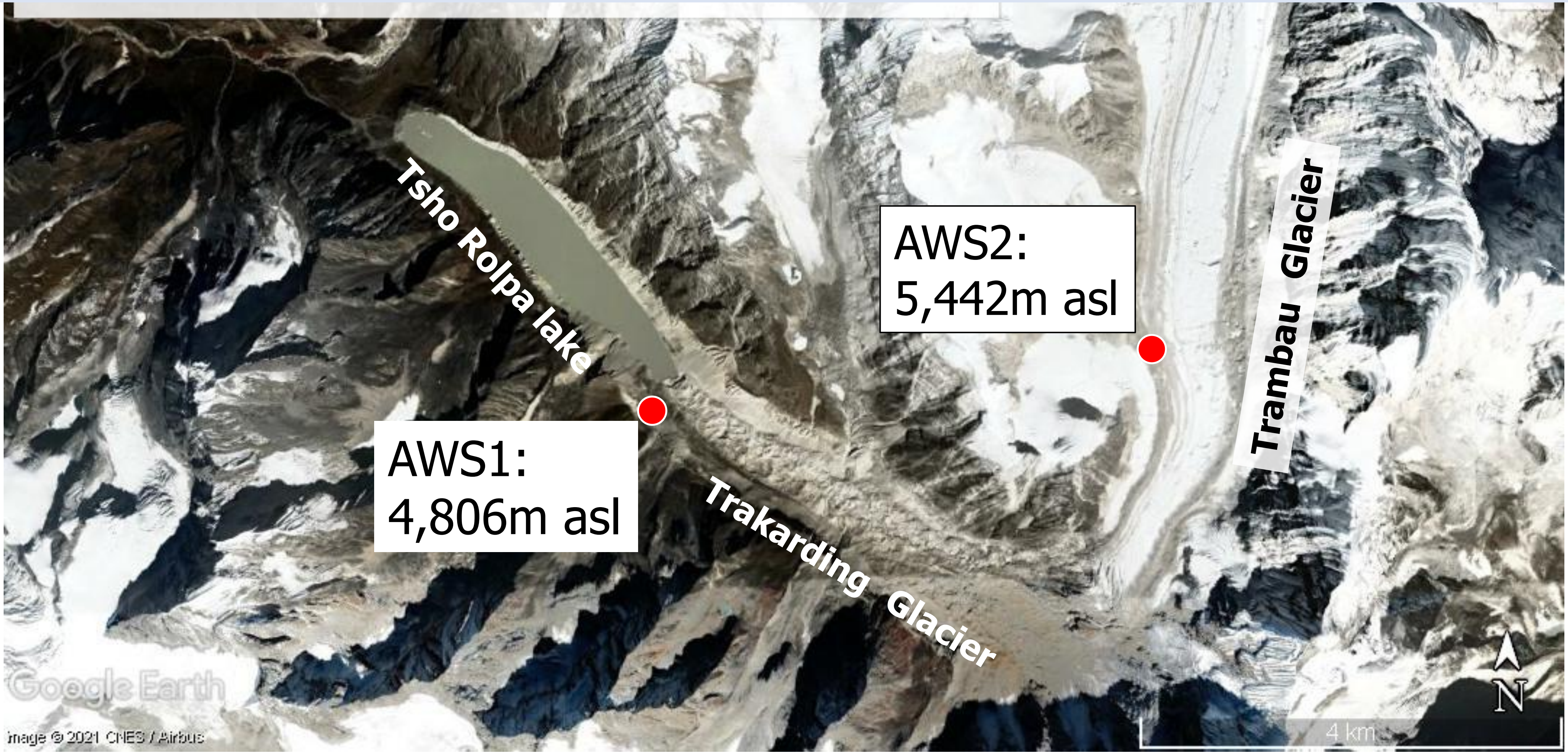
Rain gauge network along the Rolwaling Valley since 2019

in collaboration with JSPS-SNSF (PI:Prof. K. Fujita, Glaciologist)



The network covers **from ~1000 m asl** (Singati) **to ~5400 m asl** (AWS2).

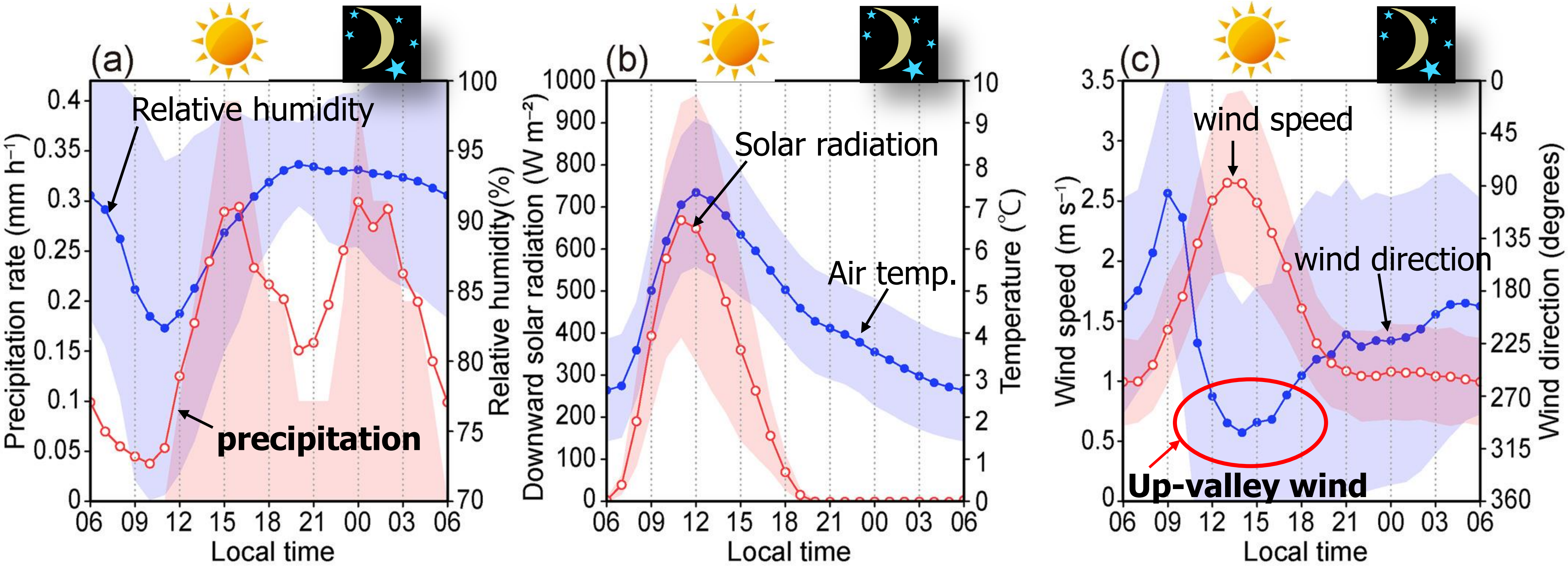
Tsho Rolpa glacier lake and Trakarding-Trambau glacier system



(©Google earth)

Diurnal cycle: Twice-daily maxima of precipitation

Observation at AWS1 3-year mean diurnal cycles (2016, 2017 and 2018)



(Fujinami et al. 2021, JGR atmos)

- **Daytime precipitation peak**:
  Up-valley flows induced by surface heating causes condensation along the slope.
- **Nighttime precipitation peak**:
  No signals in surface meteorological elements ➡ **Large-scale low-level monsoon flow**

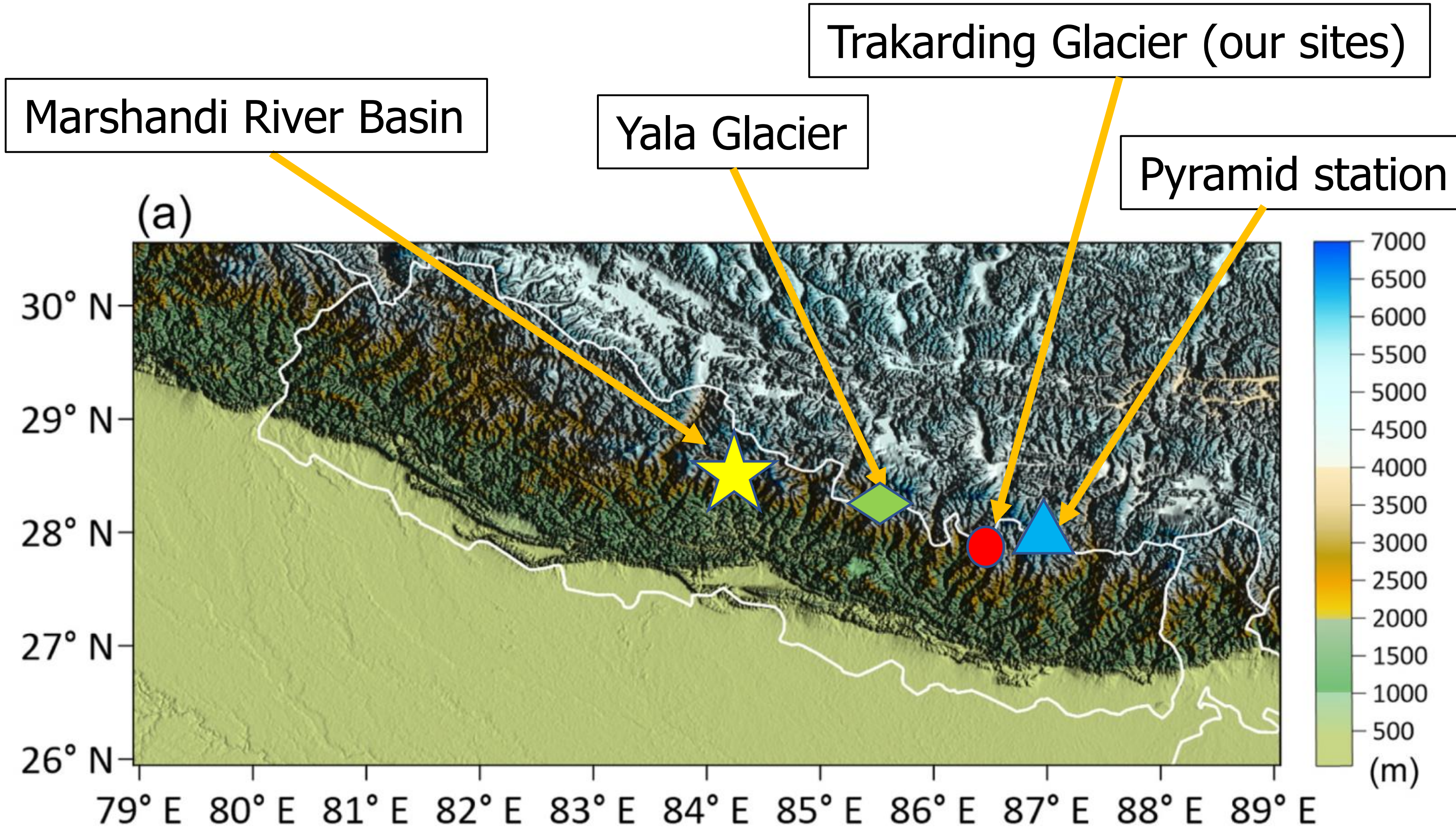
Twice-daily maxima of precipitation at higher elevations based on in situ observations

Marshandi River Basin:
- Barros et al. (2000, *GRL*); (2001, *Natural Hazards and Earth System Sciences*)

Pyramid station:
- Ueno et al. (2008, *MWR*), Yang et al. (2018, *IJOC*)

Yala glacier:
- Shea et al. (2015, *International Journal of Water Resources Development*)

Trakarding glacier:
- Fujinami et al. (2021, *JGR-Atmospheres*)

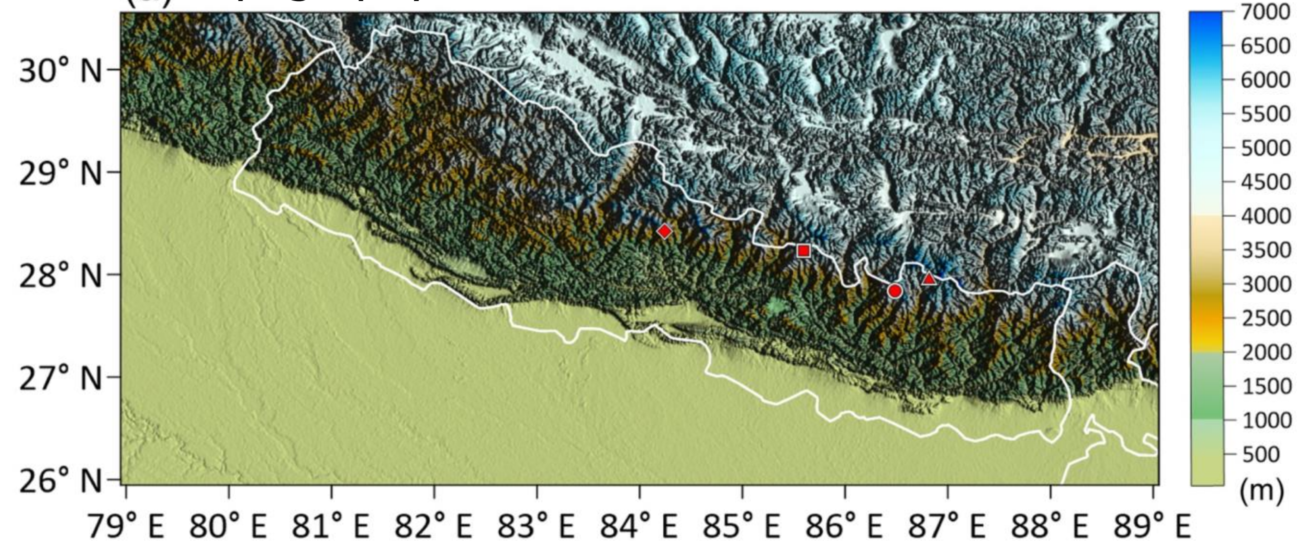


The similar diurnal cycle was reported in the past field experiments at the higher elevations.

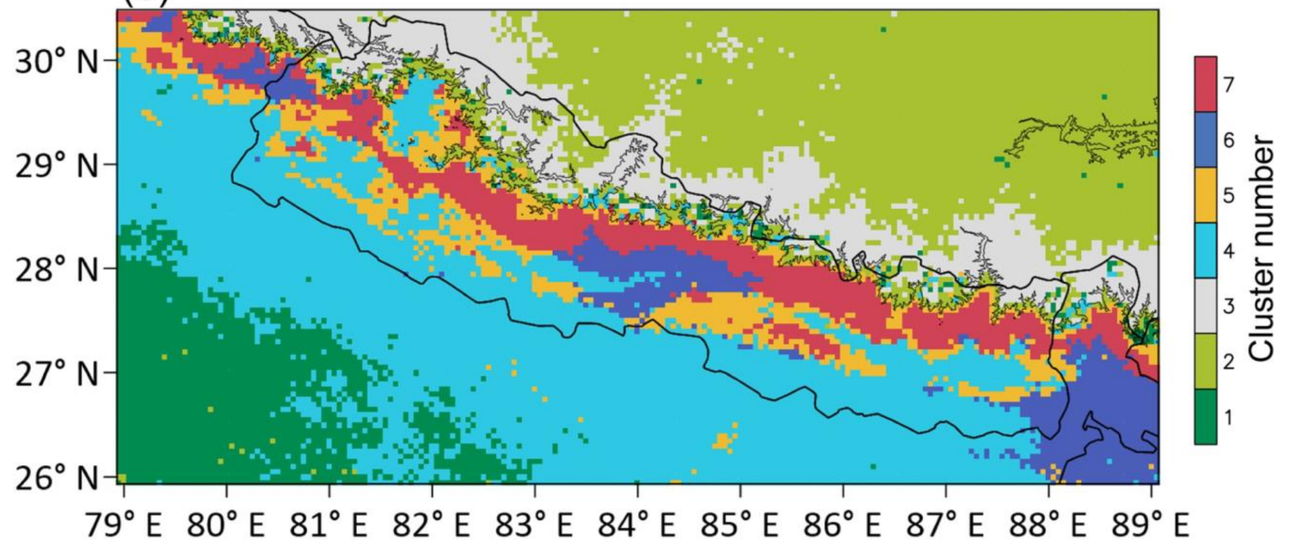
TRMM-PR Are the **twice-daily maxima** unique to the high-elevation area?

Cluster analysis of diurnal cycle of rainfall frequency based on **TRMM-PR(1998–2014)**

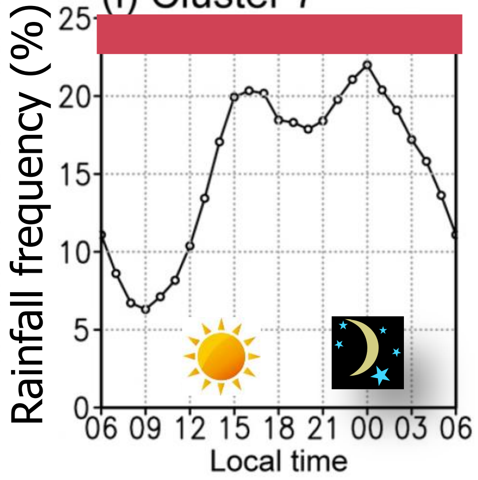
(a) Topography

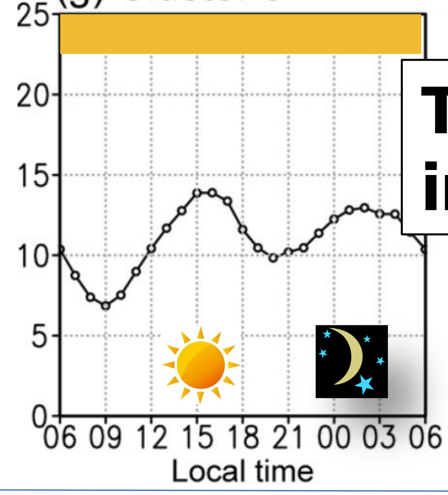


(b) Distribution of clusters



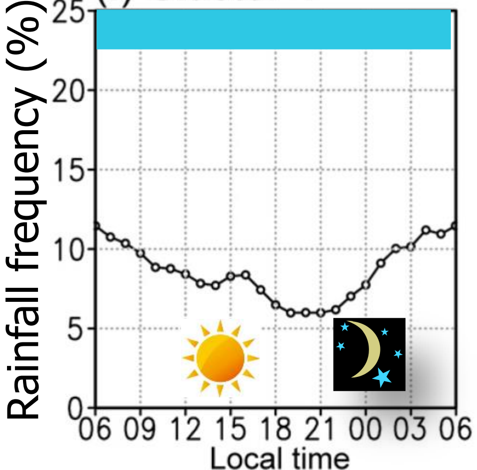
Higher elevations (>~1,500m asl): Cluster 5 & 7

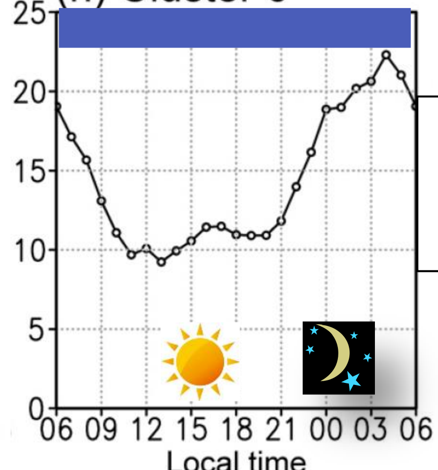




Two peaks in ☀ & ☾

Lower elevations (< ~1,500m asl):Cluster 4 & 6





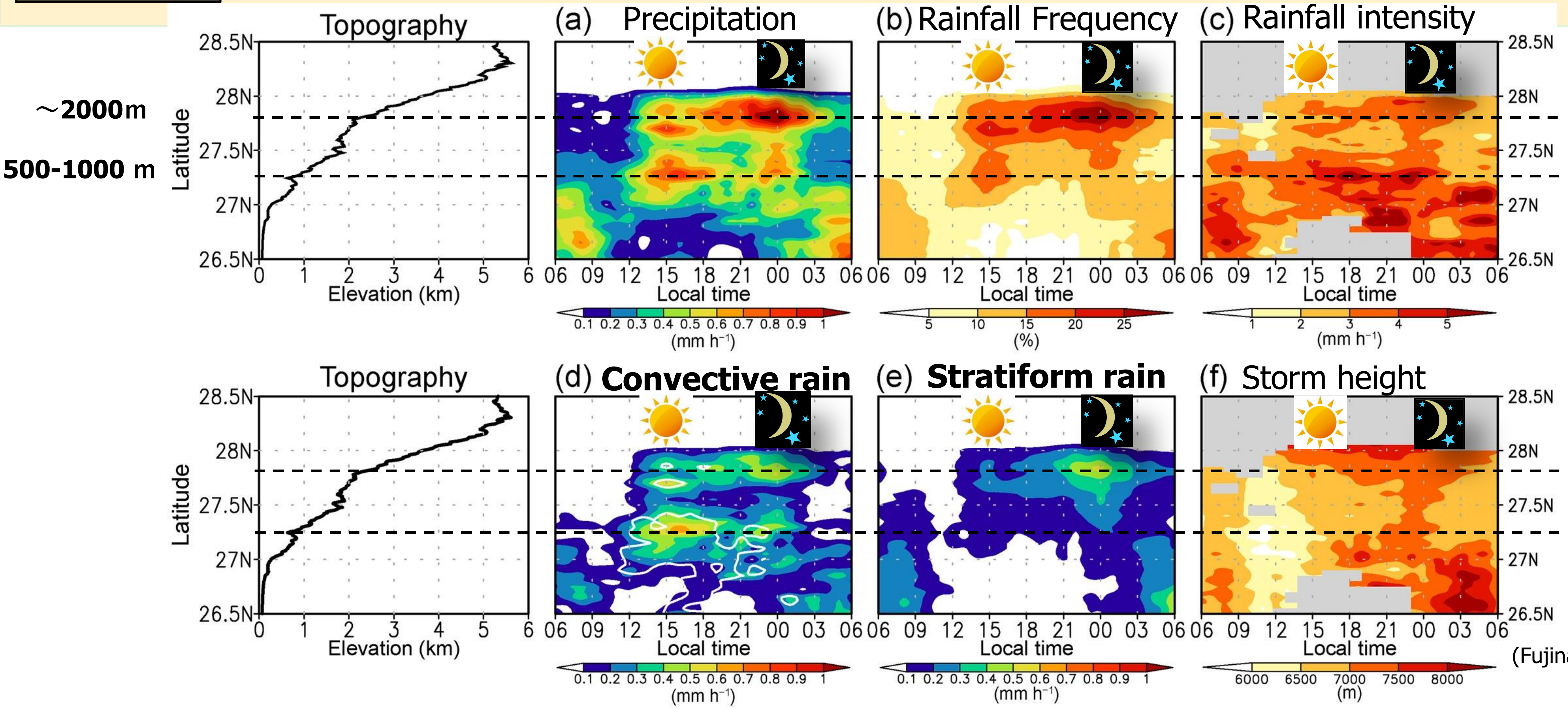
One peak only in ☾

(Fujinami et al., 2021)

Contrasting precipitation properties in the two peaks

TRMM-PR

Latitude-local time section (85.5–86.5E)



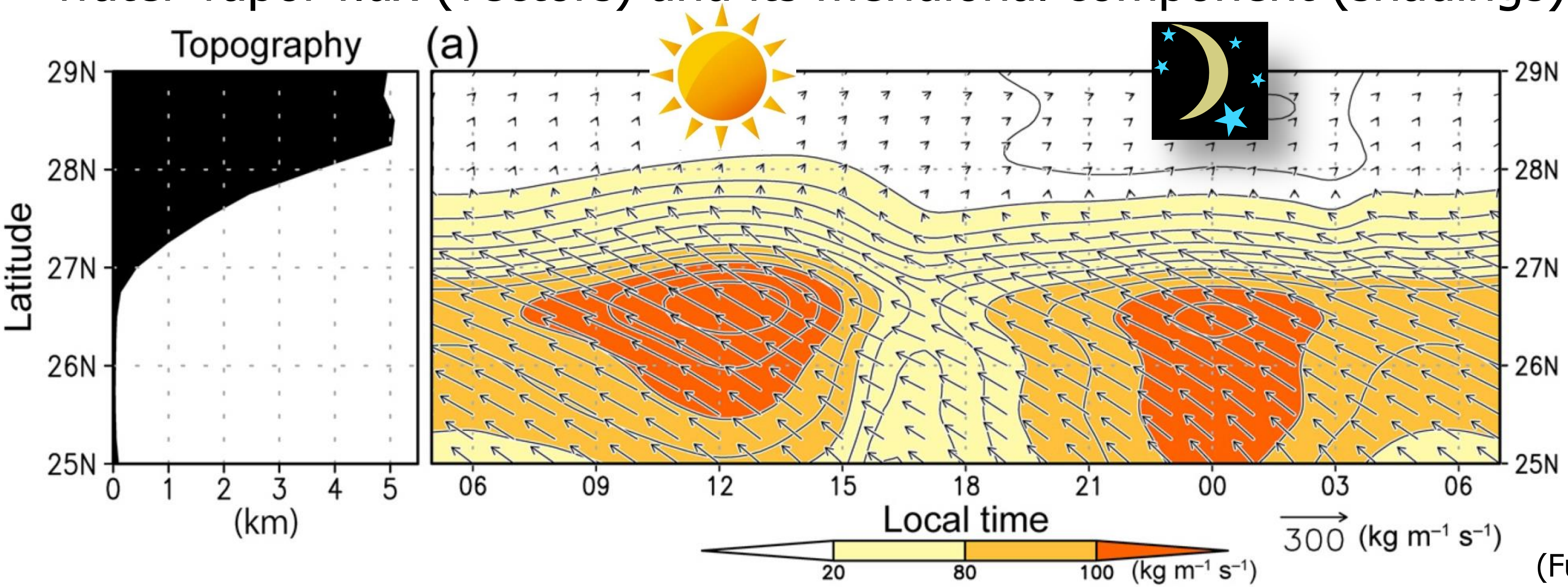
(Fujinami et al., 2021)

- **Daytime peak**: **convective-type** precipitation and **lower** rain-top height
- **Nighttime peak**: **stratiform-type** precipitation and **higher** rain-top height

Mechanism for driving the twice daily maxima of precipitation

ERA5

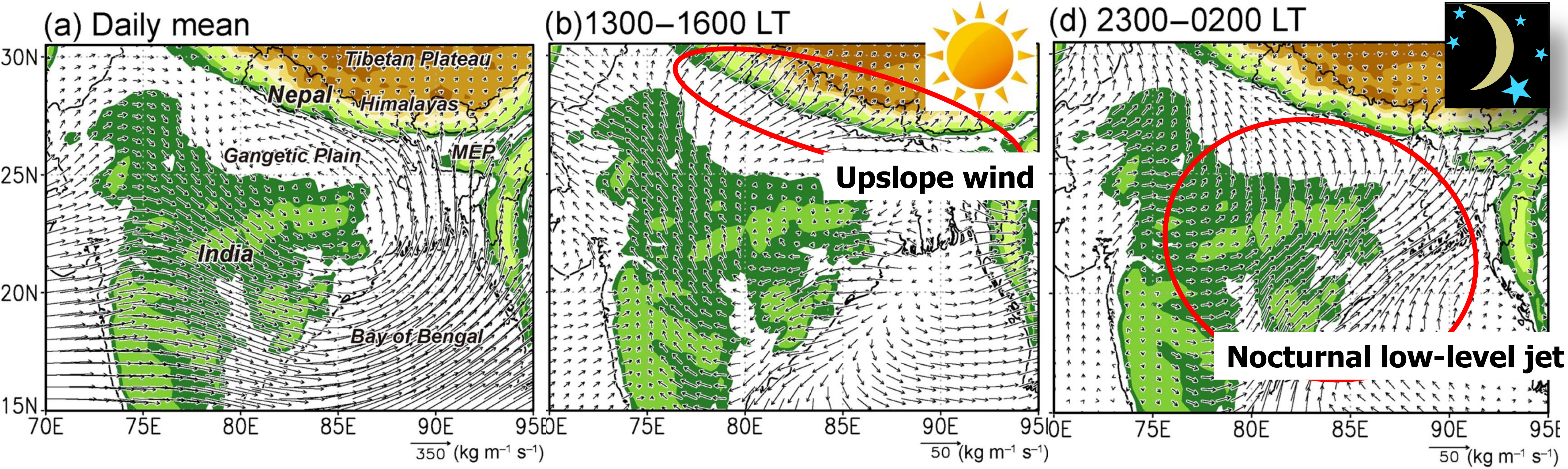
Latitude-local time cross section (85.5–86.5E)
water vapor flux (vectors) and its meridional component (shadings)



(Fujinami et al. 2021)

- The moisture flux strengthens twice a day during the day (12:00) and night (00:00).
- The timing corresponds to the twice-daily maxima of precipitation.

ERA5 Contrasting pattern of water vapor flux anomalies



(Fujinami et al. 2021)

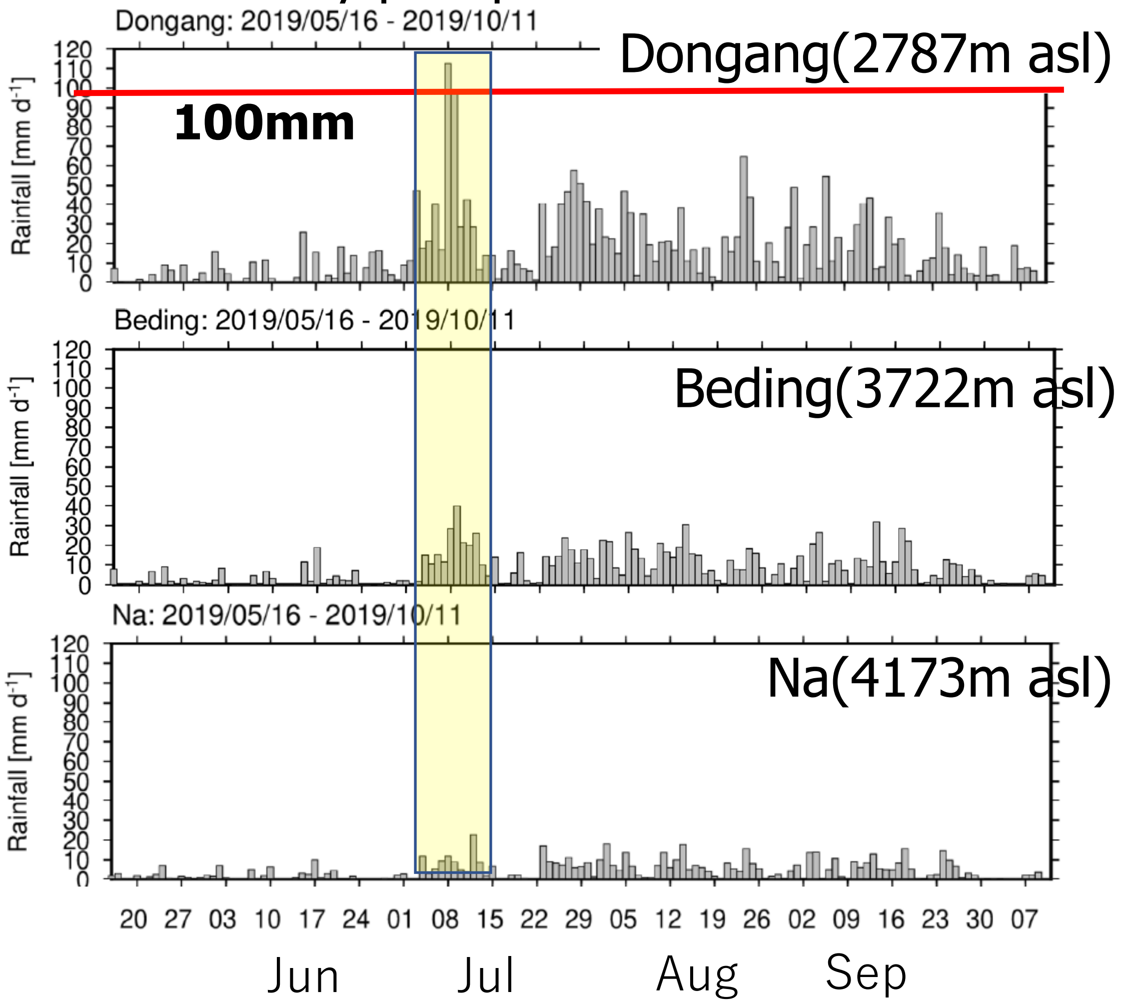
- **Daytime**: Southerly moisture flux anomalies (upslope flow) around the Himalayas; Strong upslope flow due to surface heating -> **convective-type rain**
- **Nighttime** : Large-scale moisture flux anomalies toward the southern slopes; Weak upslope flow and large-scale moisture flux convergence -> **stratiform-type rain**

A heavy rainfall event due to a monsoon low through multi-scale process

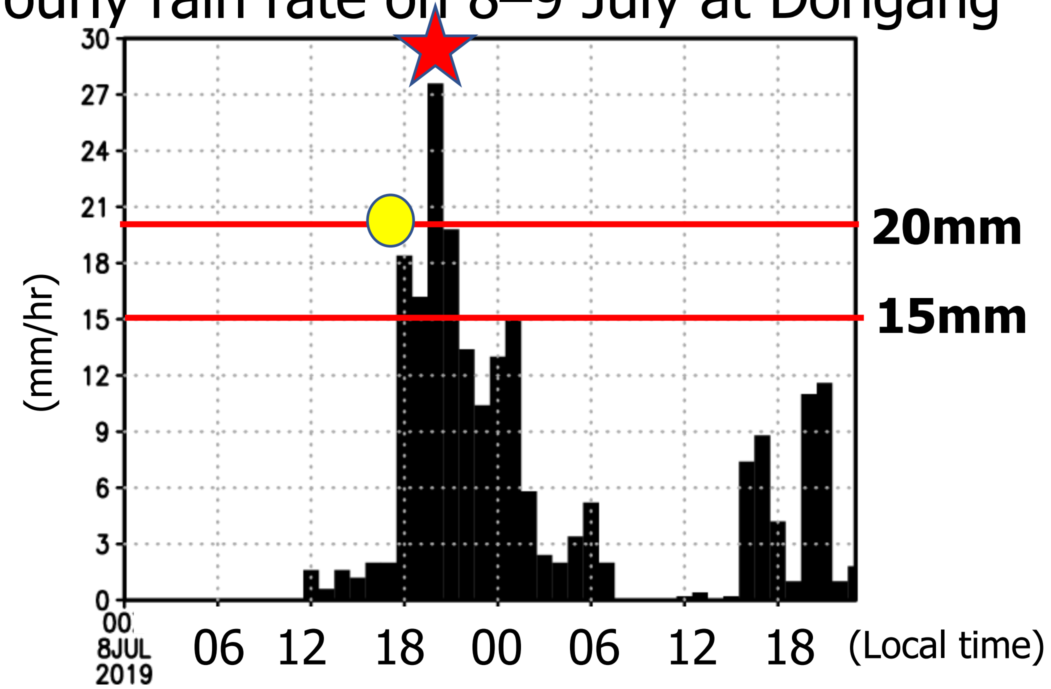
Observation at Dongang (2,800m asl)

A heavy rainfall event on 8–9 July 2019

Daily precipitation in 2019



Hourly rain rate on 8–9 July at Dongang

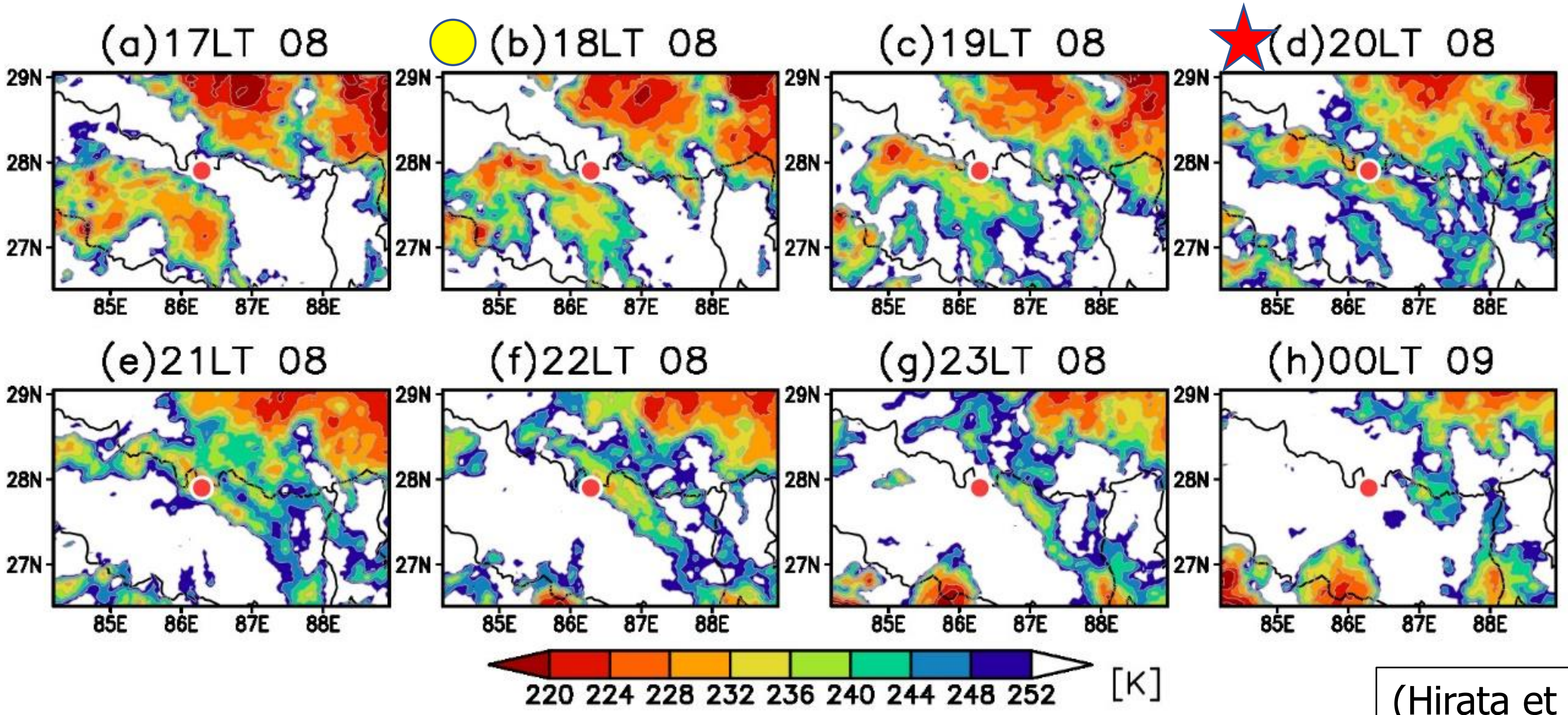


- High precipitation at Dongang (>200mm) and Beding (>60mm) during 8–9 July
- High rain intensity during 20:00–21:00 local time (>20mm/hr)

Cloud system during the heavy rainfall event

METEOSAT IODC

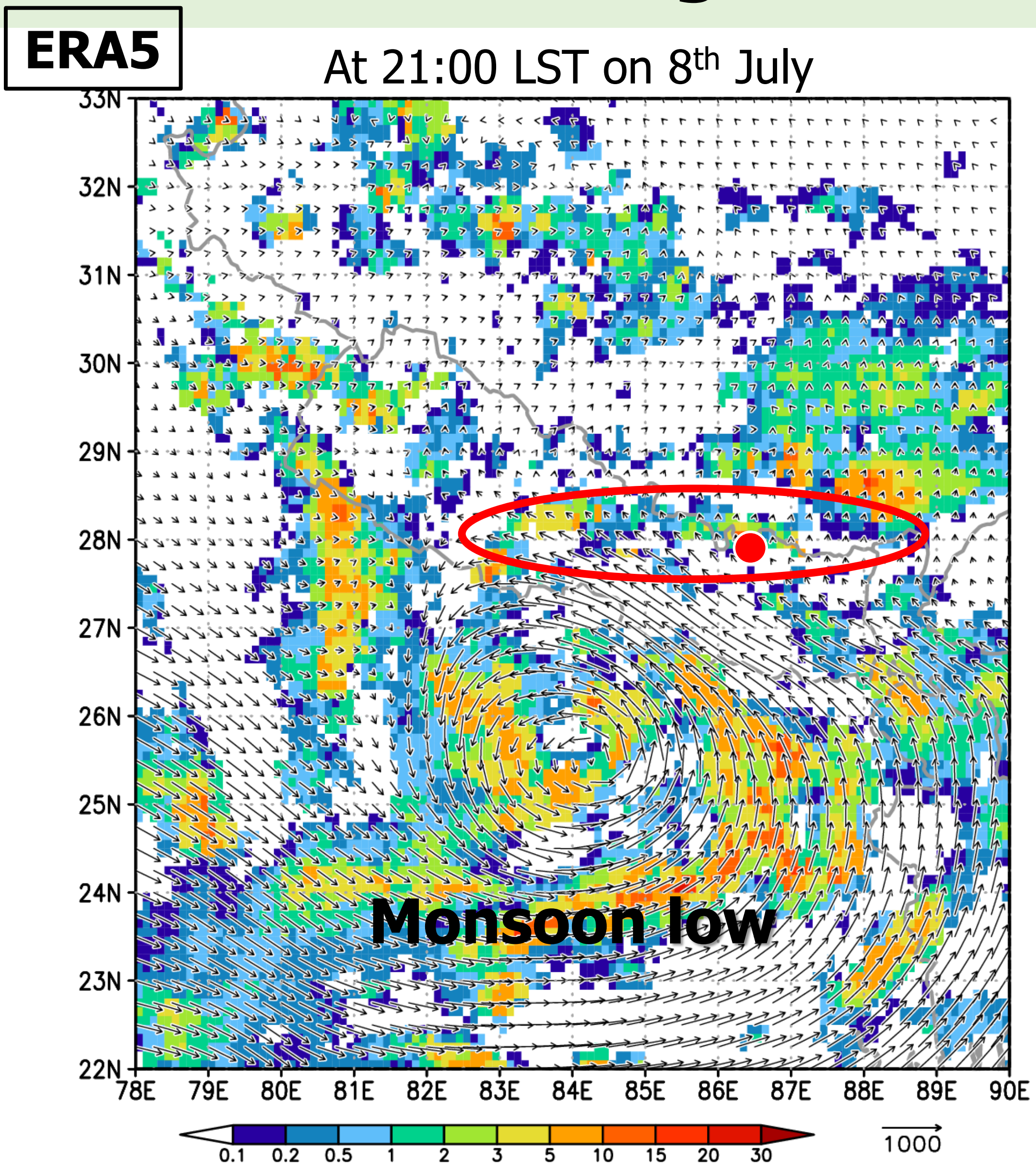
Hourly IR images from METEOSAT IODC



(Hirata et al., in prep)

- **Northward moving line-shaped cloud** band with **meso-scale systems**
- The cloud band passed over Dongang during the heavy rainfall event.

Synoptic-scale atmospheric circulation during the heavy rainfall event



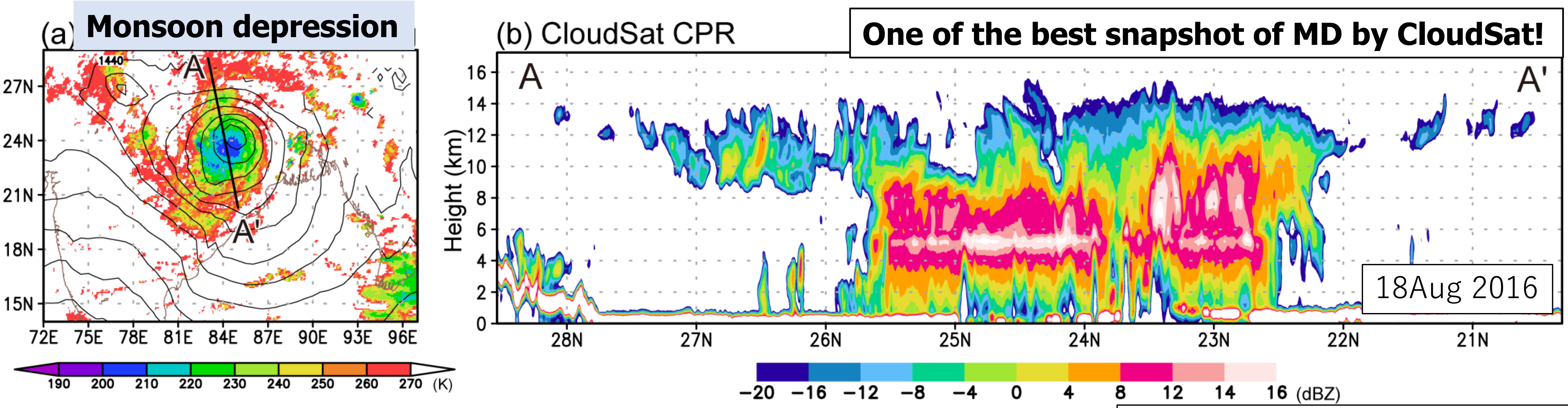
- **A monsoon low** by the Himalayas
- Large **southeasterly moisture transport** toward the Himalayan slopes
- The **Himalayan slopes** and the southeasterlies appear to cause the cloud/rain band.

Shadings: Rainfall (**IMERG**,mm/hr) 21:00 NPT 8July 2019,
Vectors: vertically integrated water vapor flux (**ERA5**)

Monsoon lows (low pressure system: LPS)

- **Effects of monsoon lows** (synoptic-scale disturbances over South Asia):
  - ➢ Onset of rainy season (e.g.,Barros and Lang 2003) and extreme rainfall (e.g.,Bohlinger et al. 2017)
  - ➢ to **moisten the (middle) troposphere** to the south of the Himalayas
  - ➢ to **enhance water vapor transport** toward the southern slopes
- **Locations of monsoon lows are spatially clustered by ISOs (BSISO and QBW).**

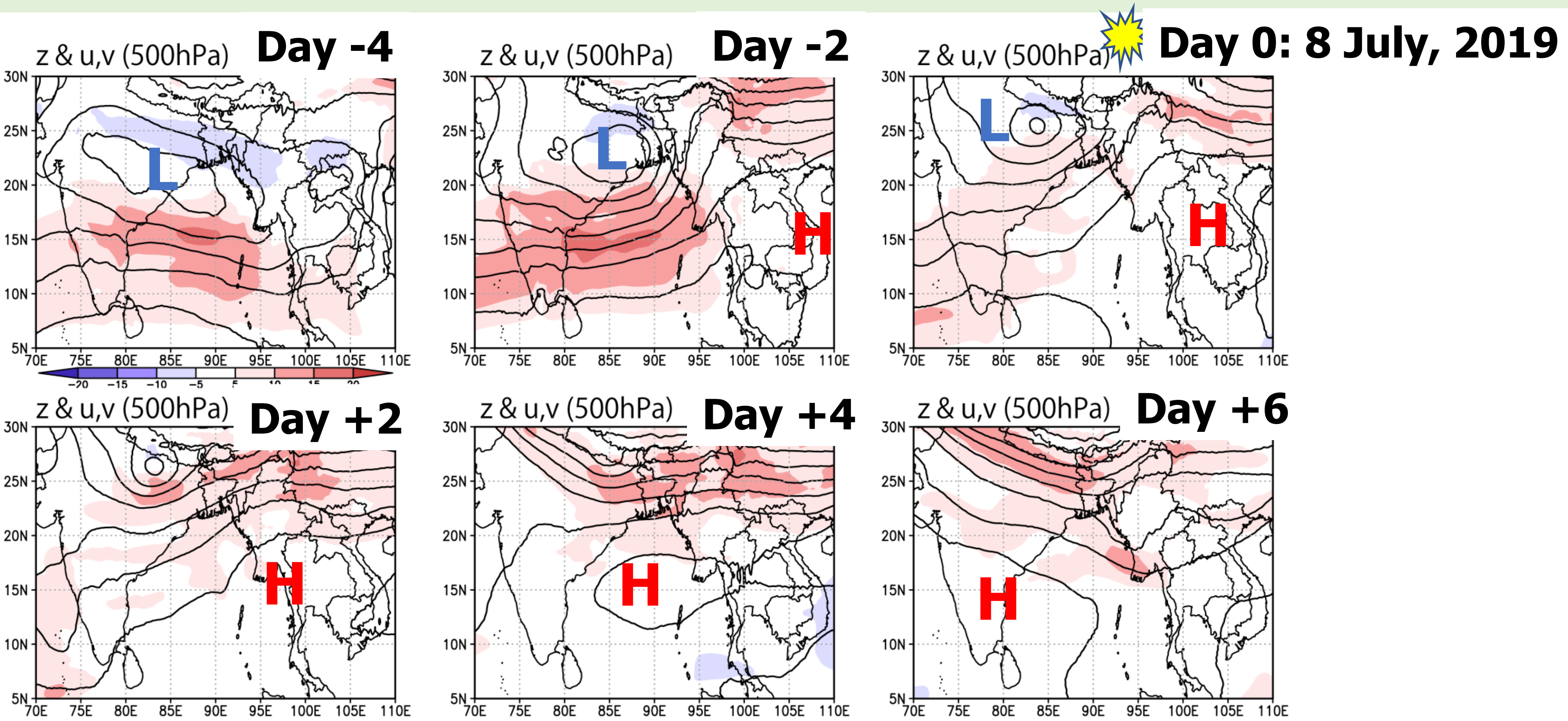
(e.g. Goswami et al. 2003; Hatsuzuka & Fujinami 2017)



(Fujinami et al. 2020, QJRMS)

Time sequence of geopotential height and zonal winds at 500 hPa

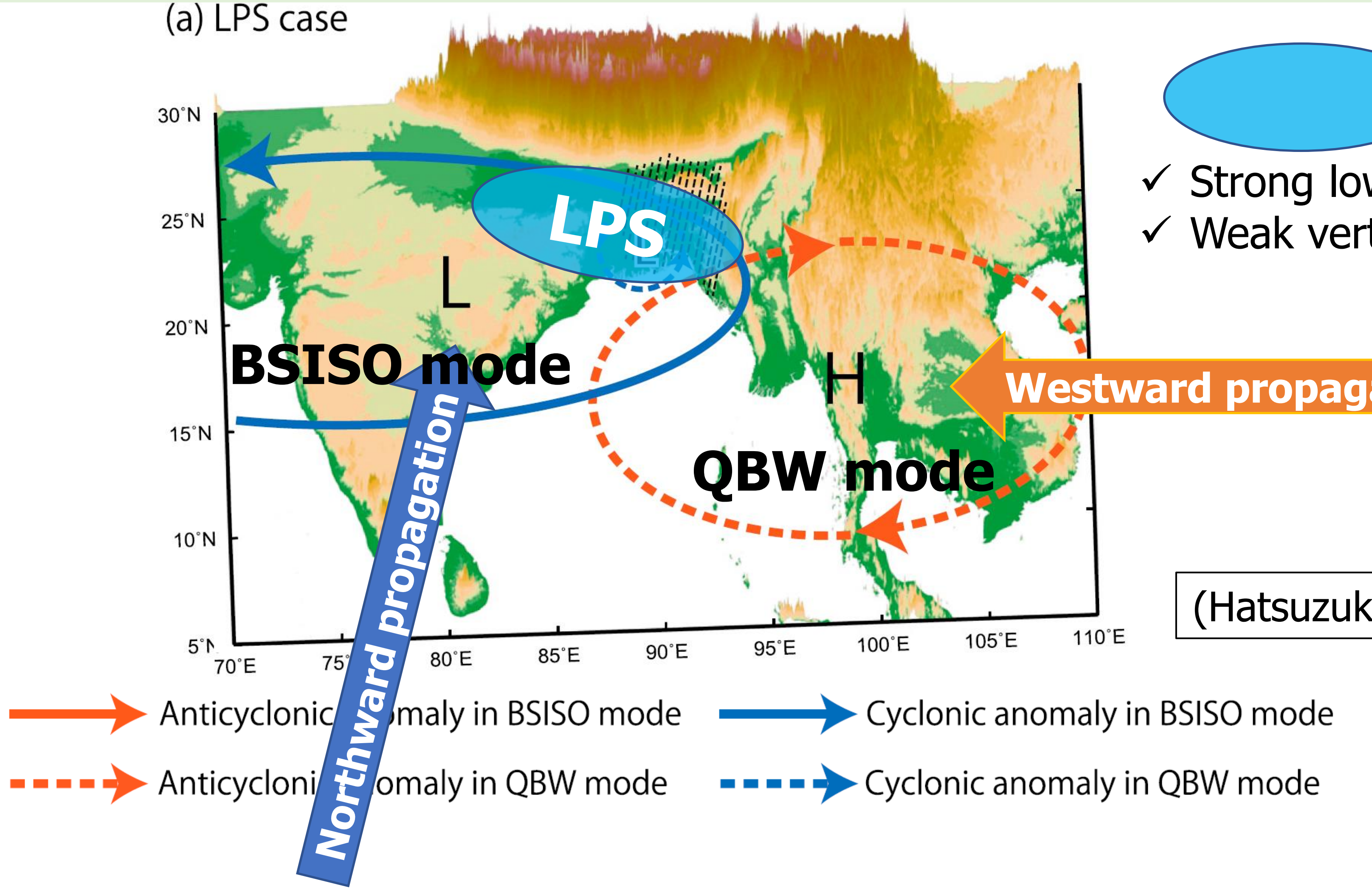
Red: westerlies
Blue: easterlies



- Westerlies move northward toward the Himalayas from day -4 to day 0.
- **Westward propagating high** over the BoB push them northward (**QBW mode**).

ISOs → low pressure system → Line-shaped cloud/rain band → Mesoscale convection

Relationship between ISOs (BSISO and QBW) and LPS over the Gangetic Plain



: Area with

- ✓ Strong low-level cyclonic wind shear
- ✓ Weak vertical wind shear

(Hatsuzuka and Fujinami 2017, JC)

- Enhancement of the low-level **cyclonic wind shear** over the Gangetic Plain
- A favorable environment for the genesis and the track of the LPS

Summary

In situ observation in the higher elevations of the Himalayas:

- Meteorological observations at elevations of >4,000 m asl over the Himalayas are still extremely scarce. They are essential to understand the **high mountain water cycle** with **glaciers (HiPRECS)**.

Diurnal cycle of precipitation:

- **Twice-daily precipitation maxima**, corresponding to day and night, occur widely across the higher elevations of Nepal Himalayas, including in the glacierized area.
- Upslope flows due to surface heating drive the daytime rainfall peak, and a monsoon nocturnal low-level jet creates the nighttime peak (**Land surface effects**).

The heavy rainfall event due to the multi-scale process:

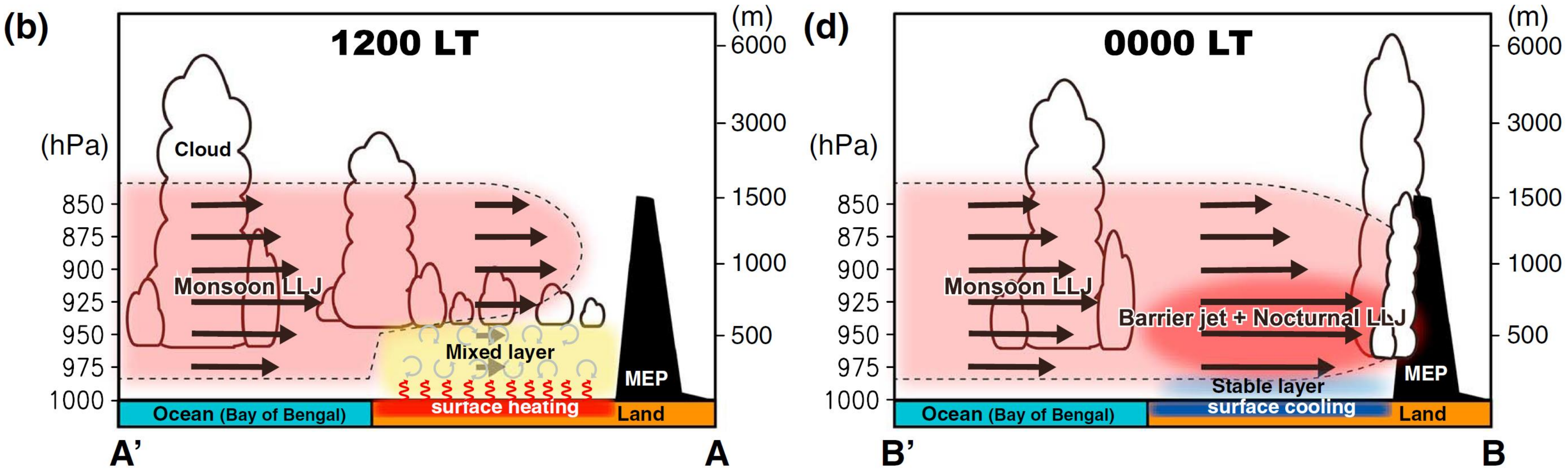
- **Multi-scale process** (ISOs, LPS, line-shaped rainband and meso-scale convection) led to the heavy rainfall event at Dongang (2,800 m) on 8–9 July, 2019.
- Understanding of multi-scale processes from the tropics to the mid-latitudes are needed to better understand precipitation variability in the Himalayas.


Thank you for your attention
@Karche in Rolwaling

Status of data acquisition in summer precipitation (May–October)

	2016	2017	2018	2019	2020	2021
Singati				○	○	○
Gongar				○	○	○
Simigaun				○	○	○
Dongang				○	○	○
Beding				○	○	○
Na				○	○	○
AWS1	○	○	○	N/A	○	○
AWS2					N/A	N/A

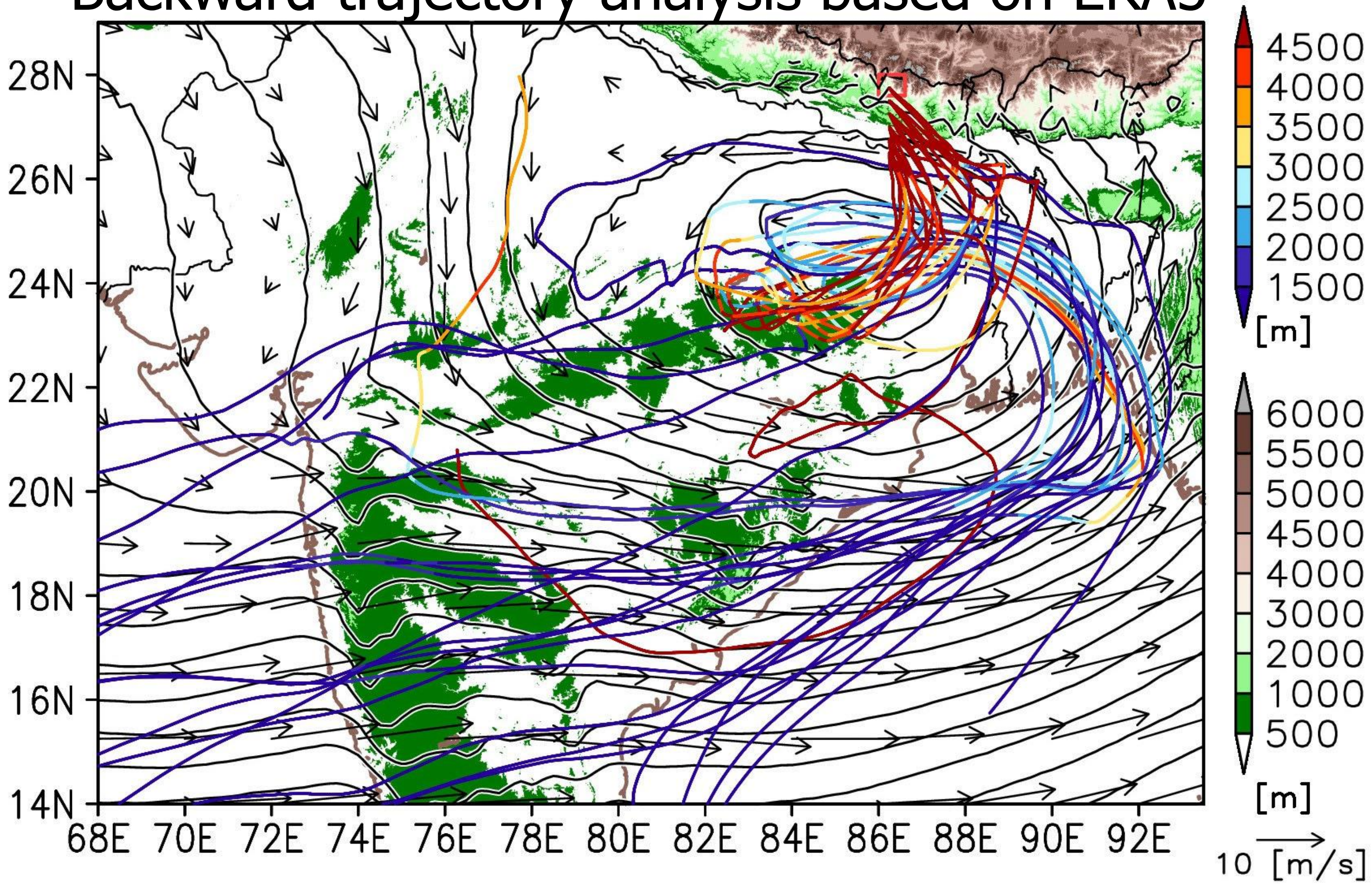
Effects of ABL process on the low-level horizontal winds



Fujinami et al. (2017, JGR Atmos)

How does the monsoon low transport the humid air into our observation site during the heavy rain event?

Backward trajectory analysis based on ERA5



The heights of the air parcels

(Hirata et al. 2022, to be submitted soon)

- Air parcels trapped in the monsoon low's circulation
- **Moisture transport** into the observation sites in the **middle troposphere**

Results

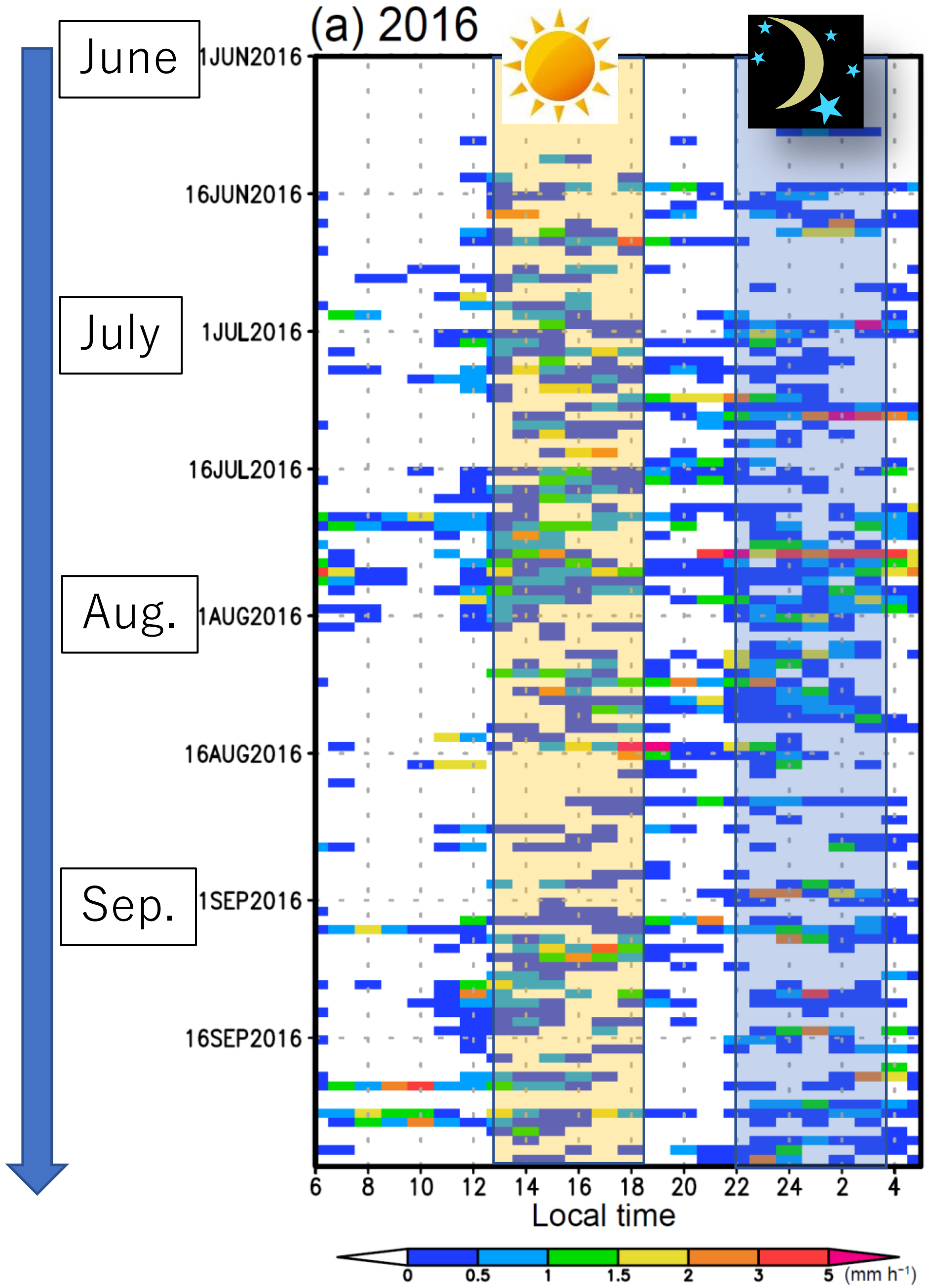
In-situ observations

- Precipitation in **daytime** and **nighttime**

- **Weak rainfall rate:**

Precipitation events with rainfall rates of **≤0.5 mm h^{-1}** account for **~60–70%** of all precipitation events.

Season-local time cross section



Data

- **Automatic Weather Station** (**AWS**) **at 4,806 m asl by Trakarding glacier in Rolwaling region, eastern Nepal (Fujita et al. 2021)**:
  - **Hourly** data, **2016–2018**, **June–September(JJAS)**
  - precipitation, air temperature, wind speed and direction, relative humidity and solar radiation
  - Precipitation: tipping bucket type with 0.1 mm resolution

- **TRMM-Precipitation Radar (PR) 2A25 v7:**
  - **Hourly** diurnal climatology (**1998–2014**, JJAS)
  - Near-surface rain, rain types and storm height
  - **0.05 $\times$ 0.05 grid**

- **ERA5 reanalysis:**
  - **Hourly** diurnal climatology (**1998–2014**, JJAS)
  - Meteorological elements: z, u, v, q and t
  - **0.25 $\times$ 0.25 grid**

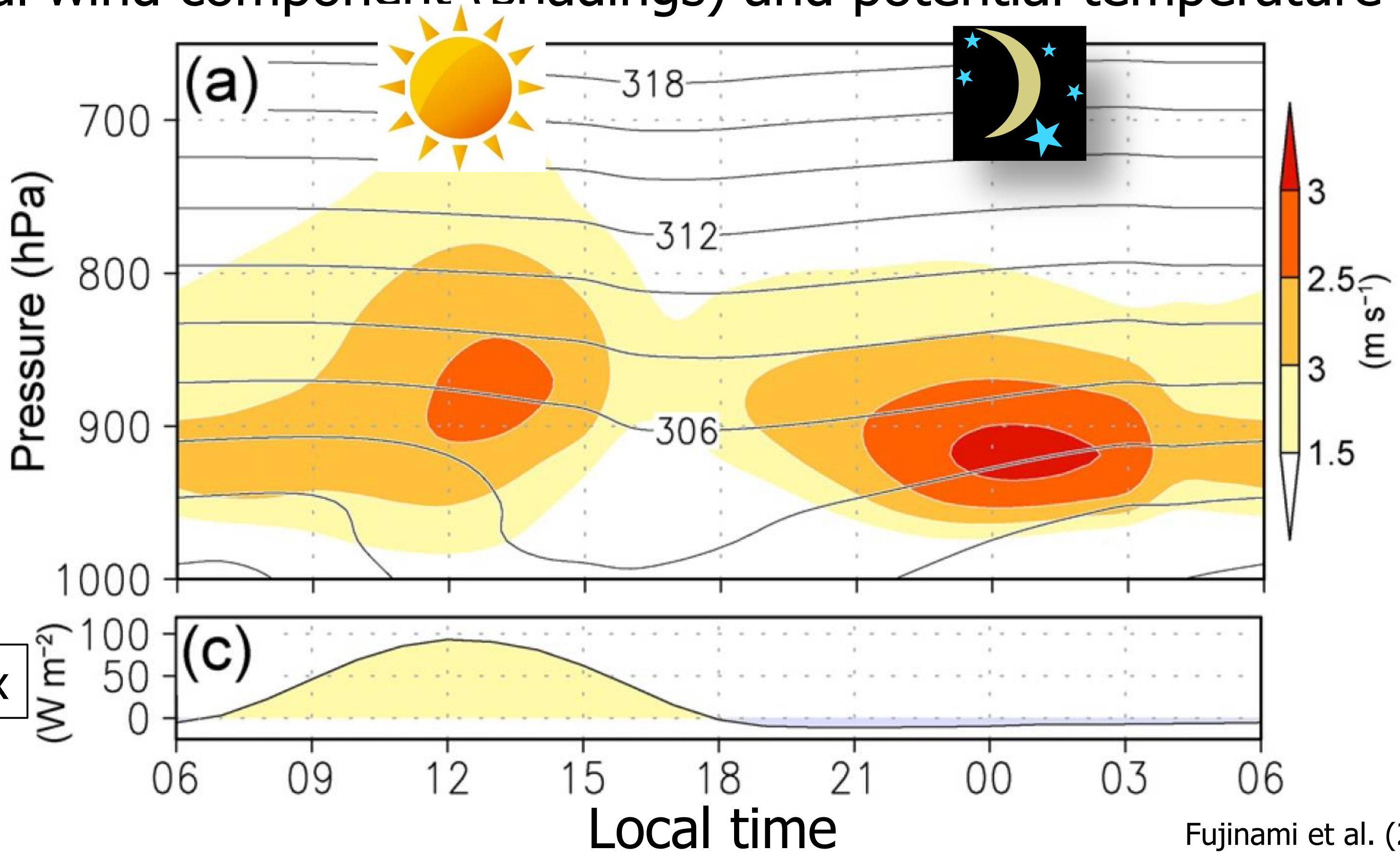
Diurnal cycle of horizontal winds due to the development of the ABL

ERA5

Vertical-local time cross-section over the windward plain:
meridional wind component (shadings) and potential temperature (contours)

Mean (85.5–86.5E)

Surface sensible heat flux



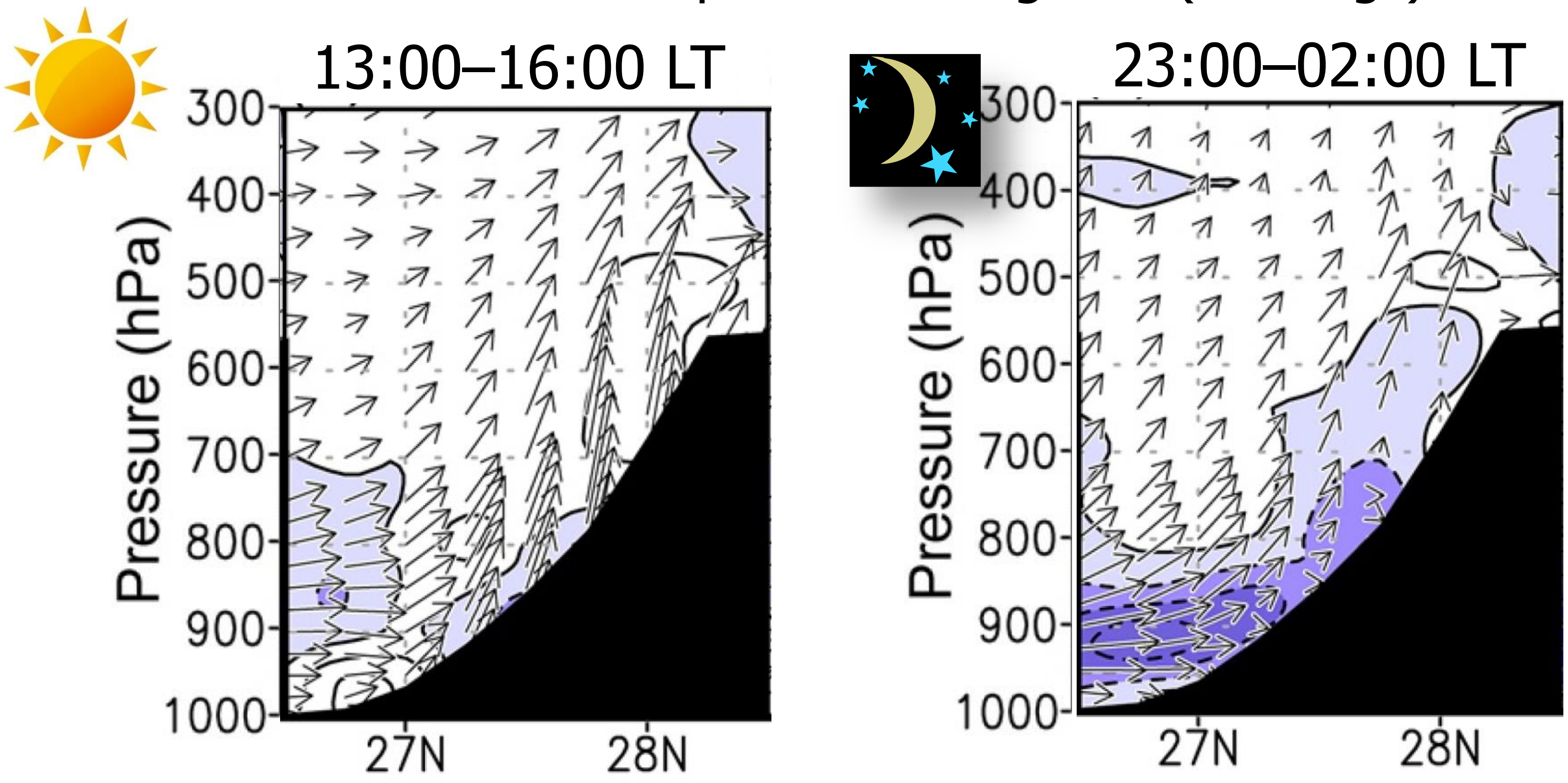
Fujinami et al. (2021)

- **Daytime**: Upslope flow over the slopes (**Anabatic winds over the slopes**)
- **Nighttime** : Acceleration of horizontal air flow (**Nocturnal jet over the plain**).

Contrasting vertical structure of meridional circulation

ERA5

Latitude-height cross-sections of meridional and vertical winds (vectors) and horizontal water vapor flux divergence (shadings)



Fujinami et al. (2021)

- **Daytime**: Strong **upslope flow along the slope surface** due to surface heating
- **Nighttime** : Weak upslope flow, the enhancement of southerlies below 850 hPa, **large-scale moisture flux convergence**.

Day lag composite of 850-hPa streamfunction , wind and OLR anomalies in day -4, -2 and 0

Quasi-biweekly (QBW) mode

Equatorial Rossby wave (n=1) as a key agent that regulates the low-level zonal wind on QBW time-scales

- Westward propagating double vortices
- Westward phase speed: ~6.5 m/s
- Zonal wavelength: ~6000-7000 Km
- The period of ERW ranges submonthly time-scales by nature

(Fujinami et al. 2014 *Clim. Dyn.*)