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Transient versus quasi-stationary flavors of atmospheric rivers during East Asian summer monsoon

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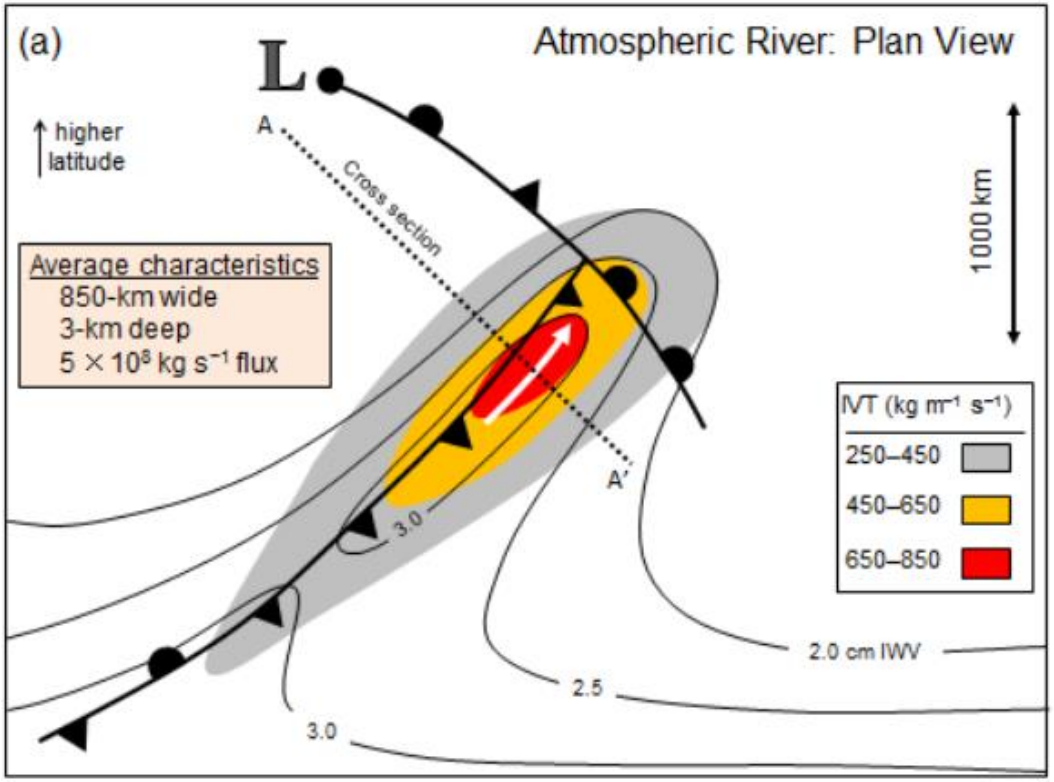
Outstanding Student & PhD candidate Presentation contest

What is the atmospheric river (AR)?



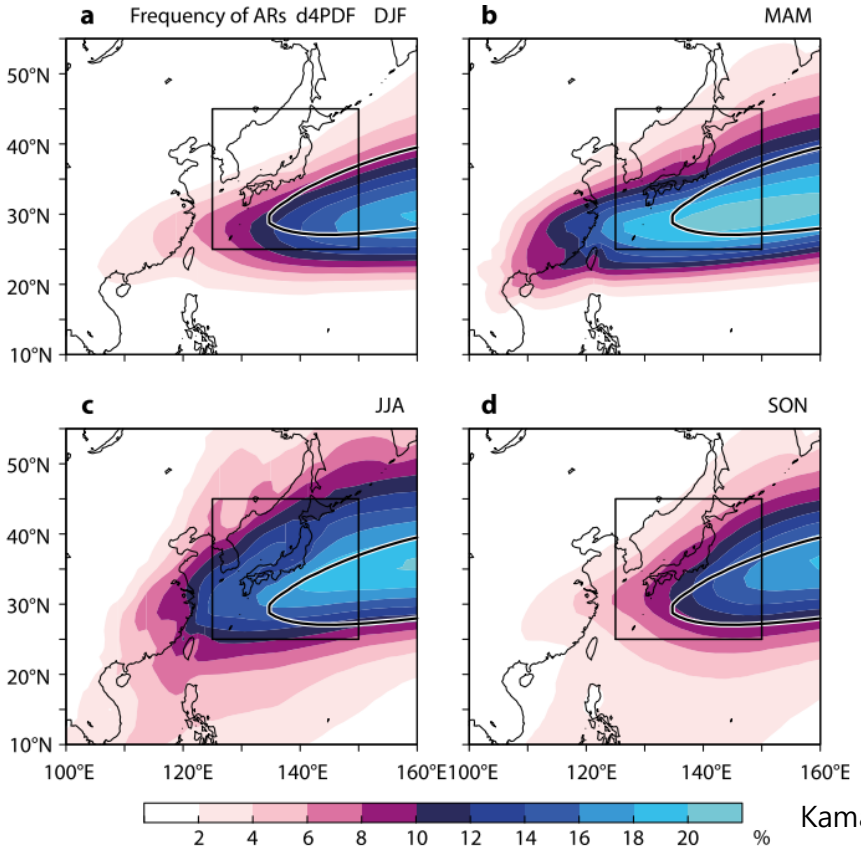
Ralph et al. (2018), AMS Glossary (2019)

AMS Glossary:

"A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone (ETC)"

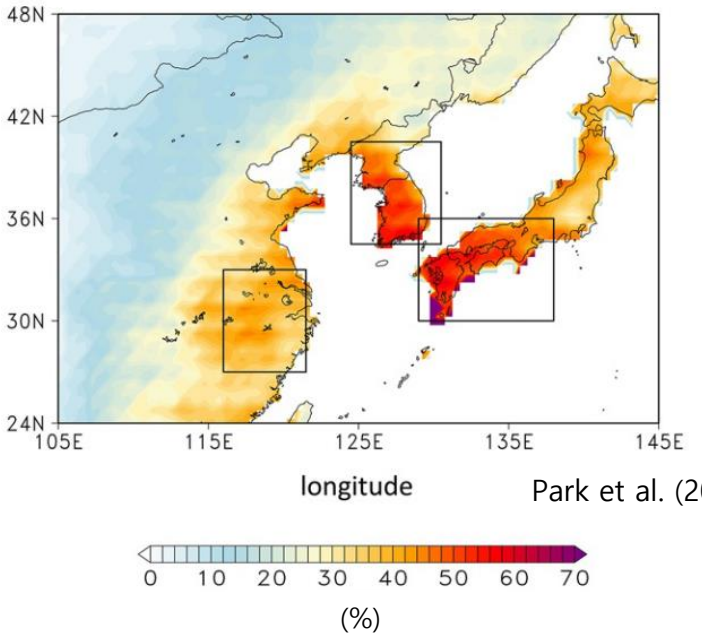
AR climatology in East Asia

AR frequency



Kamae et al. (2017)

AR-rainfall ratio in JJAS



Park et al. (2020)

- East Asia experiences frequent AR activity in summer (unlike the U.S. west coast where AR impacts are most pronounced in winter).
- ARs explain 40~60% of summer monsoon rainfall in East Asian coastal regions.

ARs in East Asian summer monsoon (EASM)

" The East Asian summer monsoon (EASM) is a period of *multi-scale* atmospheric circulations! "

- Although many previous studies have substantially contributed to the climatological scan of summertime ARs in East Asia, their underlying dynamics have yet to be explained.
- However, it is not conclusive whether the transiency and extratropical cyclone are the necessary conditions for the ARs.
- This issue is natural to be raised when considering the circulation characteristics of EASM (June–September; JJAS). As a midlatitude monsoon system, the East Asian summer monsoon is characterized not only by the slowly-varying monsoon flow along the WNPSH boundary (Ninomiya 1984; Ninomiya and Shibagaki 2007; Wang et al. 2001; Chen et al. 2004) but also by the baroclinic Rossby waves (Horinouchi 2014; Park et al.2015; Horinouchi et al. 2017; Park et al. 2021b).

- The classical AR definition may not fully explain the East Asian summer ARs.
- There might be **transient** and **quasi-stationary** flavors in the EASM ARs.

ARs in East Asian summer monsoon (EASM)

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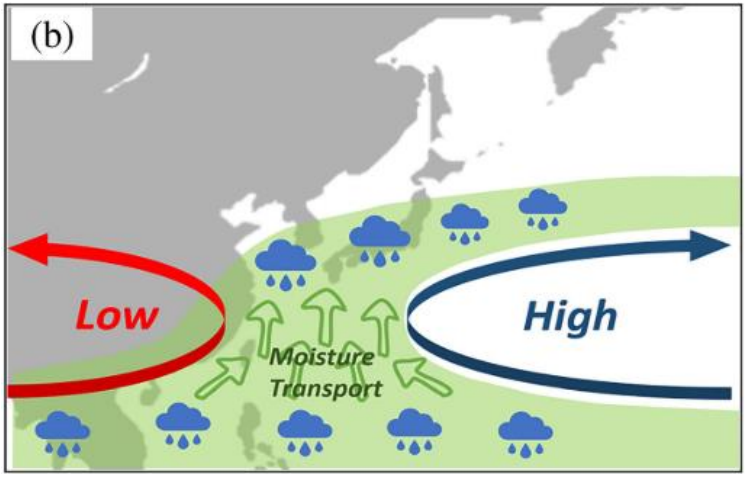
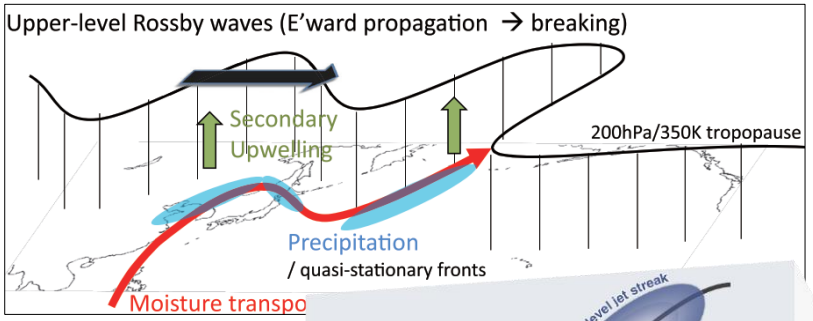
Monsoonal flow

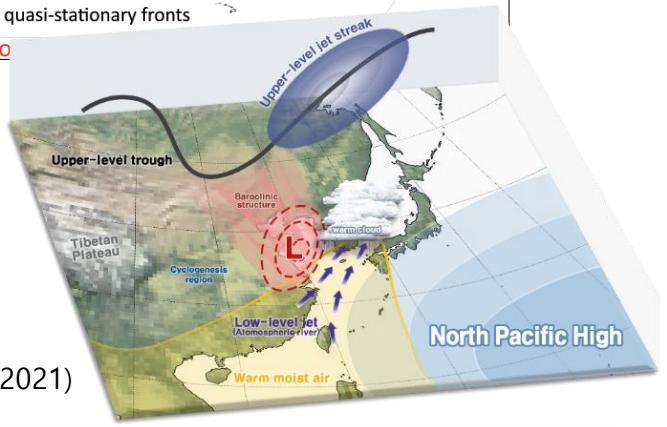


Son et al. (2020)

Baroclinic waves



Horinouchi (2014)



Park et al. (2021)

- The classical AR definition may not fully explain the East Asian summer ARs.
- There might be **transient** and **quasi-stationary** flavors in the EASM ARs.

Target of this study!

AR flavor metric

Time filtering of integrated water vapor transport (IVT) anomaly (IVTA)

$$\mathrm{IVT}(\mathbf{x},t) = \mathrm{IVT}_{\mathrm{Clim}}(\mathbf{x},t) + \mathrm{IVTA}_{\mathrm{HF}}(\mathbf{x},t) + \mathrm{IVTA}_{\mathrm{LF}}(\mathbf{x},t)$$

- 101-weights Lanczos filter
- 10-day cutoff period

AR-mean IVTA

$$\mathrm{IVTA}^{\mathrm{AR}} = \frac{\sum_{n=1}^{N}\{\mathrm{IVTA}_n|\cos\phi_n|\}}{\sum_{n=1}^{N}|\cos\phi_n|}$$

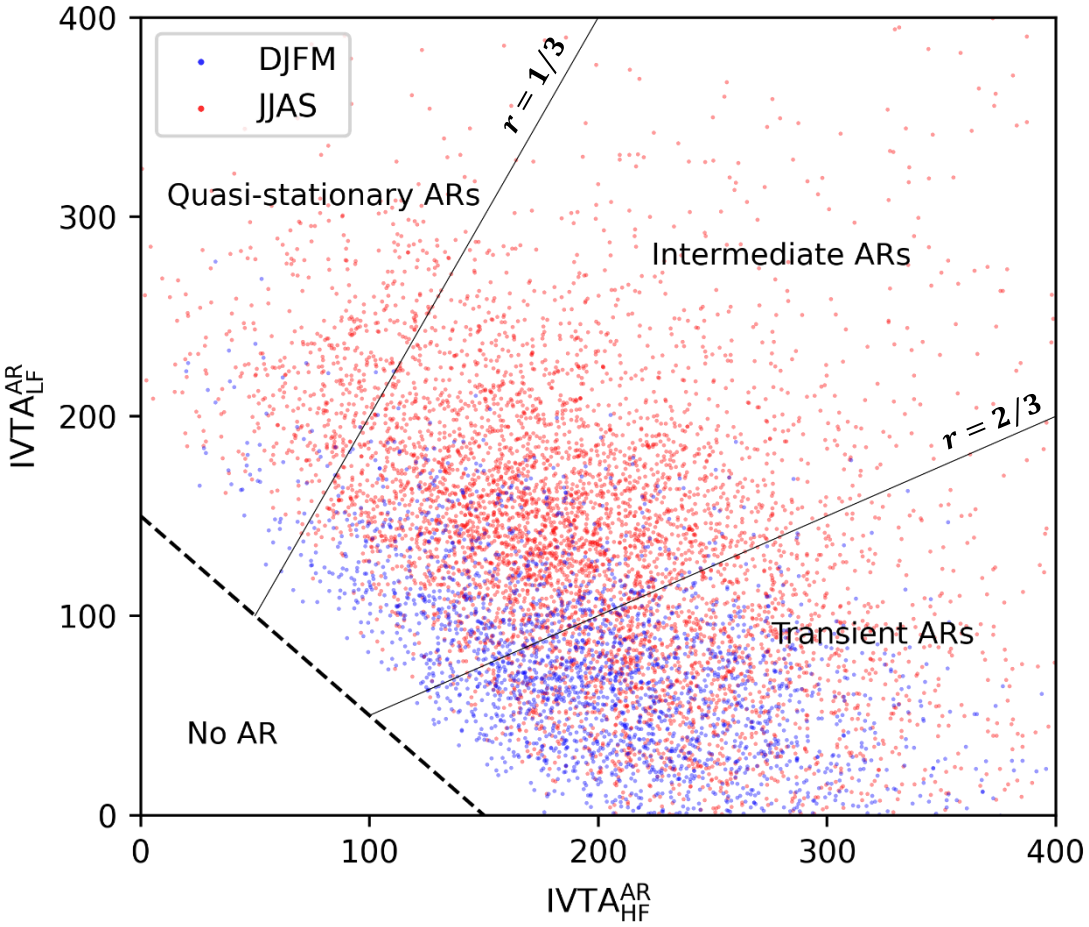
- N is the number of grid points occupied by AR
- ϕ_n and IVTA_n are the latitude and IVTA, respectively, at n^{th} grid point of AR

AR flavor metric

$$r = \frac{\mathrm{IVTA}_{\mathrm{HF}}^{\mathrm{AR}}}{\mathrm{IVTA}_{\mathrm{HF}}^{\mathrm{AR}} + \mathrm{IVTA}_{\mathrm{LF}}^{\mathrm{AR}}}$$ (ranging from 0 to 1)

- As r approaches 1, an AR is dominated by $\mathrm{IVTA}_{\mathrm{HF}}$ (fully **transient**).
- As r approaches 0, an AR is dominated by $\mathrm{IVTA}_{\mathrm{LF}}$ (fully **quasi-stationary**).
- If $r = 0.5$, an AR has an equal extent of transient and quasi-stationary flavors.

r in East Asia (JJAS vs DJFM)



1. **Transient ARs** ($r \geq 2/3$): **32.0%** in JJAS
2. **Intermediate ARs** ($1/3 < r < 2/3$): **58.6%** in JJAS
3. **Quasi-stationary ARs** ($r \leq 1/3$): **9.4%** in JJAS

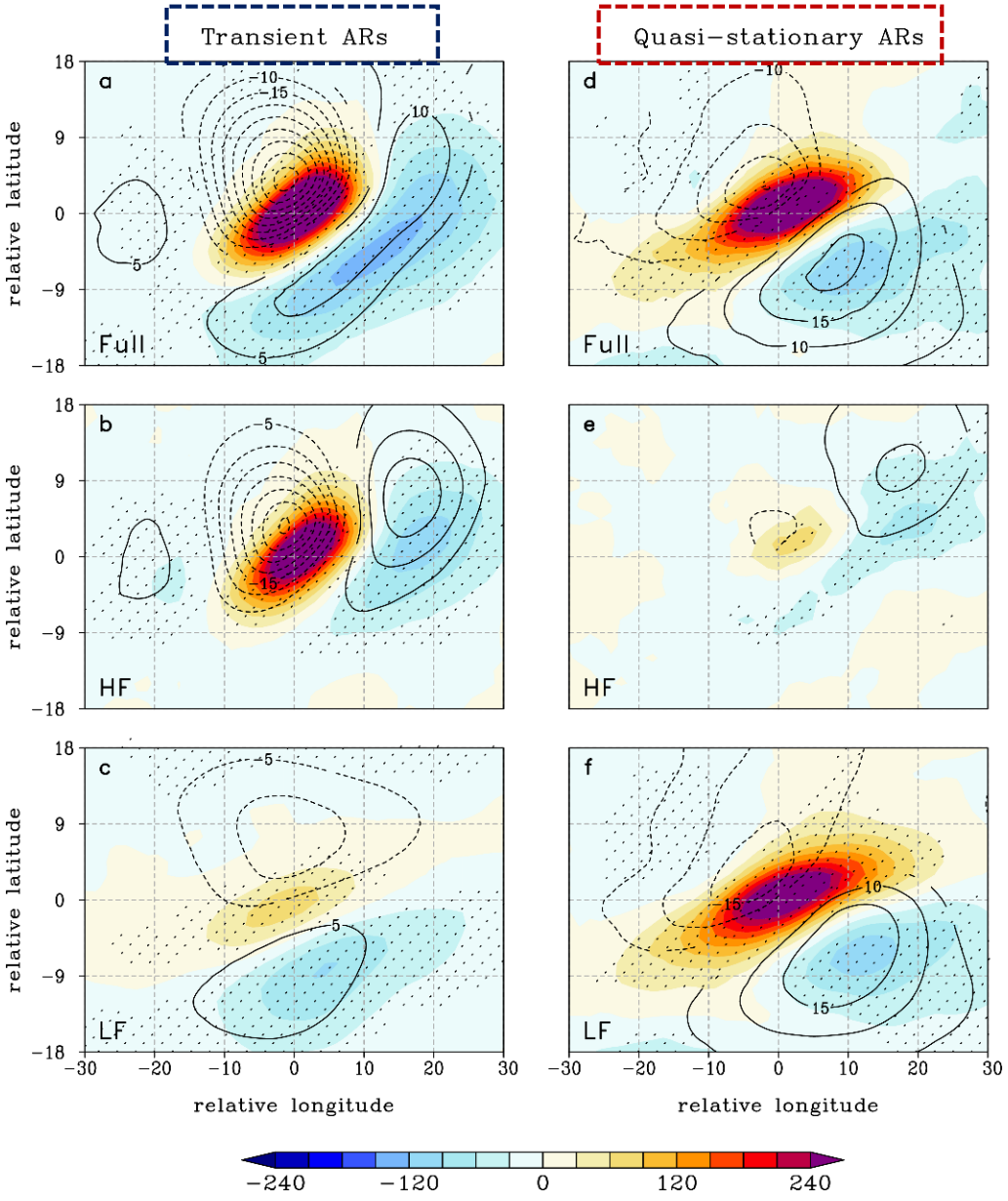
Hereafter, we mainly focus on the comparison of transient versus quasi-stationary ARs in JJAS.

Transient vs. quasi-stationary ARs in EASM

Full

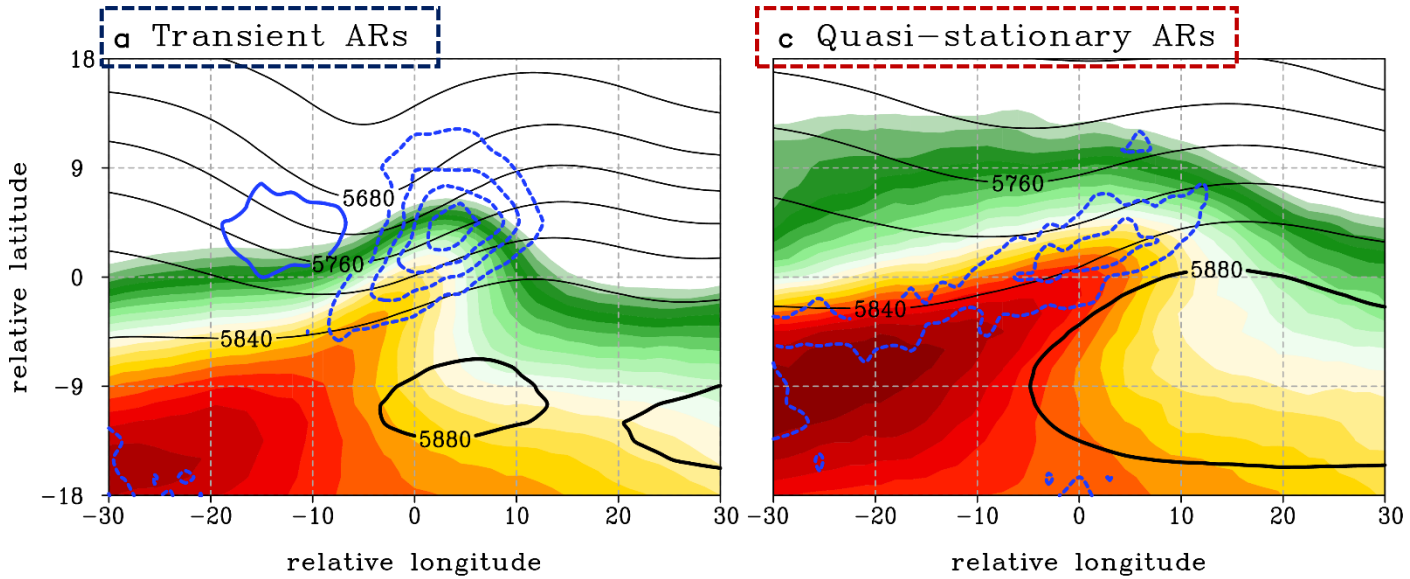
High frequency

Low frequency



- IVTA (shading, kg m^{-1} s^{-1})
- Z850 anomaly (contours, gpm)

Transient vs. quasi-stationary ARs in JJAS



- 850 (shading, K)
- ω500 (blue contours, Pa s^{-1})
- Z500 (black contours, gpm)

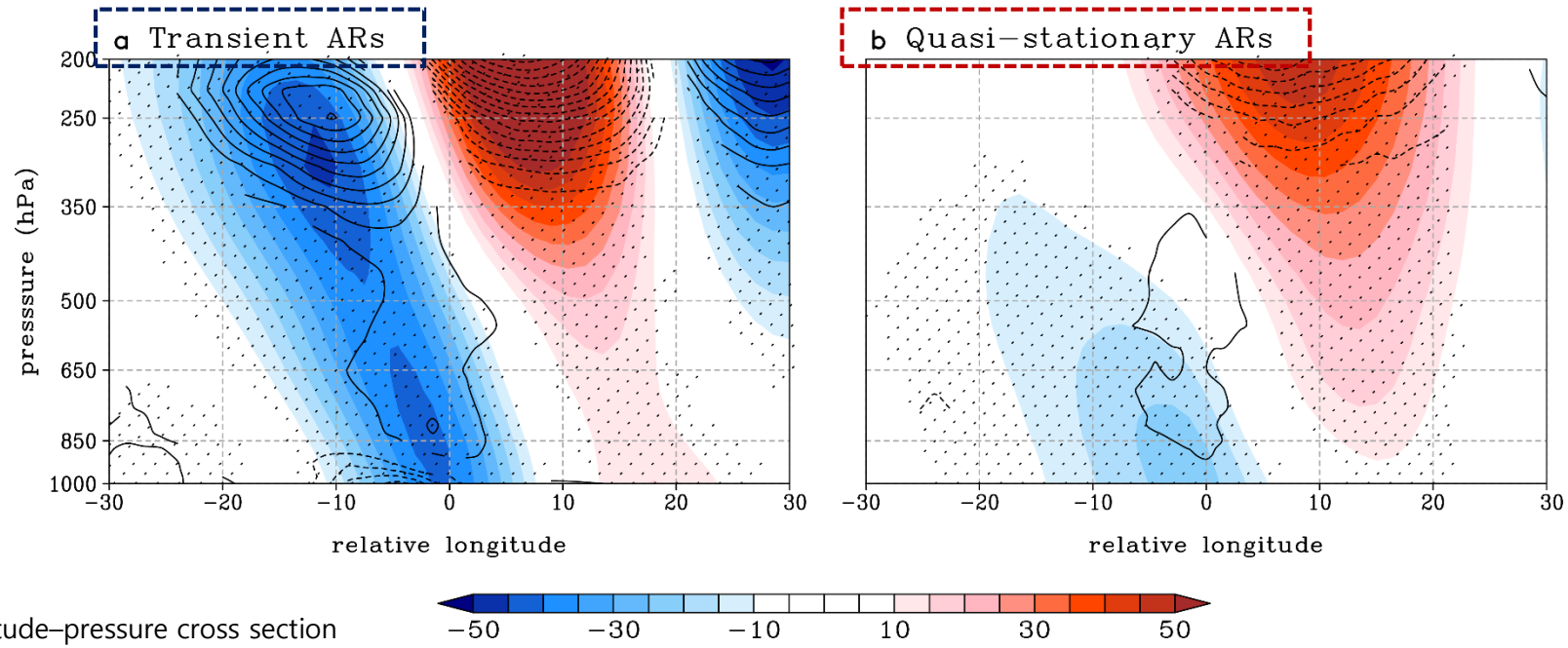
- Well defined trough in mid-troposphere
- Ascent to the right east of the trough
- Wave-like enhancement of the low-level θ_e

→ A typical circulation pattern of developing extratropical cyclone

- Weak undulation of 500-hPa flow
- Development of the WNPSH (5880-gpm line)
- Ascent along the monsoon frontal zone

→ A favorable circulation pattern for large-scale monsoon rainband

Transient vs. quasi-stationary ARs in JJAS



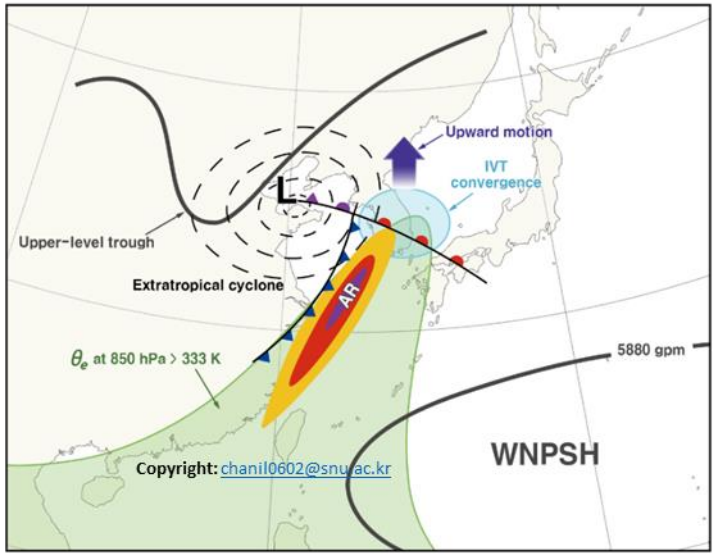
Longitude–pressure cross section
- Z anomaly (shading, gpm)
- PV anomaly (contours, 10^{-1} PVU)

- Baroclinic vertical structure
- Upper-level potential vorticity forcing

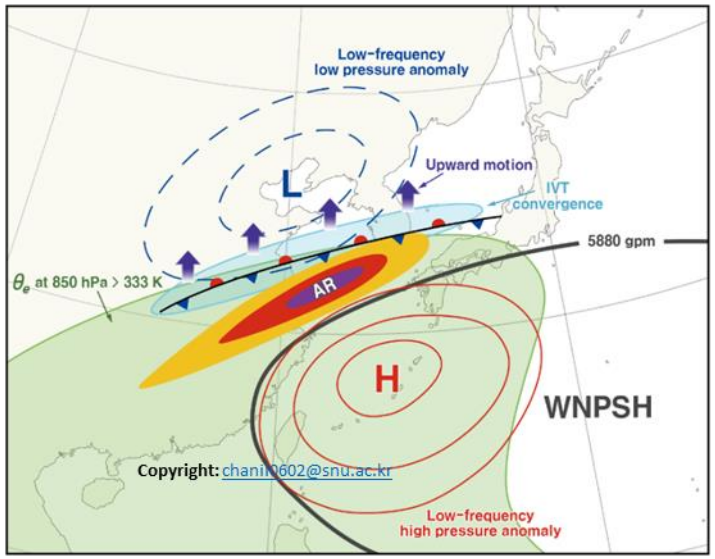
- No baroclinic vertical structure
- No upper-level potential vorticity forcing

Three types of East Asian summer ARs

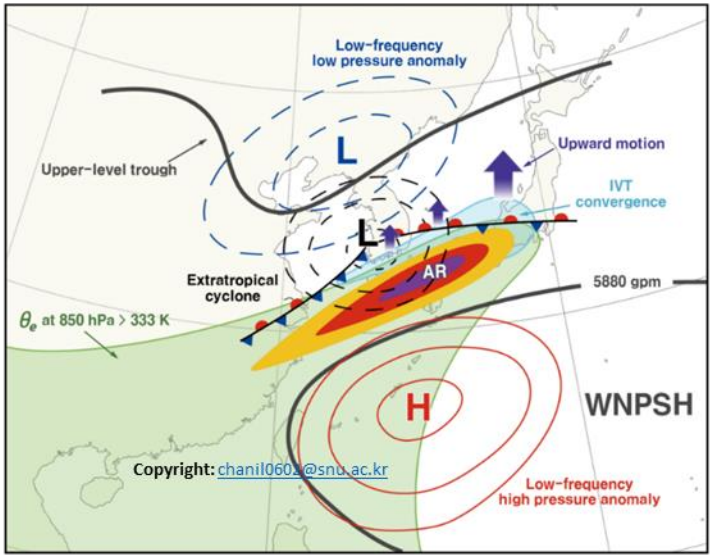
Transient ARs (32.0%)



Quasi-stationary ARs (9.4%)



Intermediate ARs (58.6%)



Papers in progress:

1) Park et al., 2022: Two flavors of atmospheric rivers in the North Pacific (under review).

2) Park et al., 2022: Disentangling the nature of East Asian atmospheric rivers in the summer monsoon period (to be submitted).

Summary

- The multi-scale nature of East Asian summer monsoon may complicate the behavior of ARs therein.
- To delineate this, the AR flavor metric (r) is applied to East Asian summer ARs.
- There are not only transient flavor but also quasi-stationary flavor in East Asian summer ARs.

- The East Asian summer ARs are categorized in to three types depending on r:
  1. **Transient ARs ($r \geq 2/3$):** occur by extratropical cyclone (similar to canonical ARs)
  2. **Intermediate ARs ($1/3 < r < 2/3$):** occur when transient cyclone travels along the frontal boundary between quasi-stationary low and high (confounding features)
  3. **Quasi-stationary ARs ($r \leq 1/3$):** develop along the frontal boundary between quasi-stationary low and high

- Many other of ARs (e.g., rainfall impacts, interannual variability, future change, etc.) may significantly differ depending on r. Maybe, future works on East Asian summer ARs need to take their two flavors into account.

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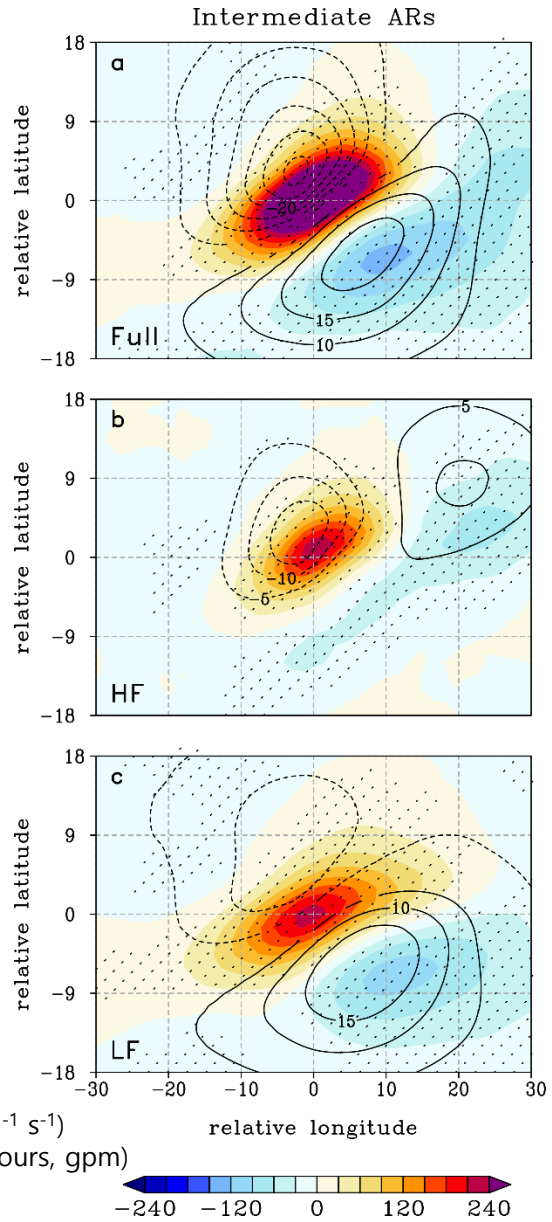
Intermediate ARs

Supplementary slides

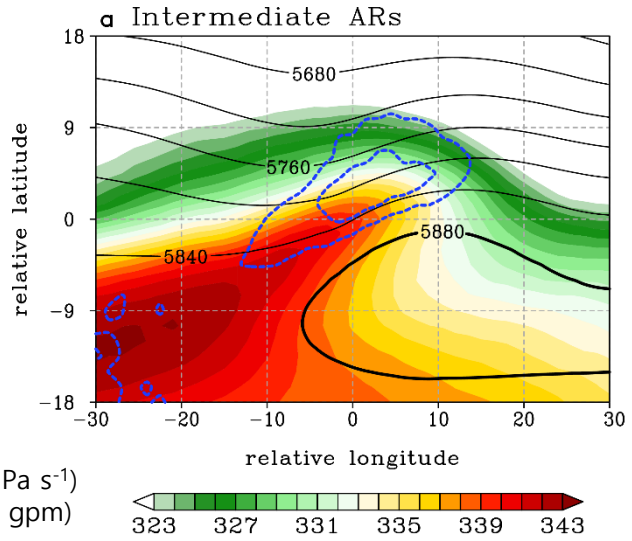
Full

High frequency

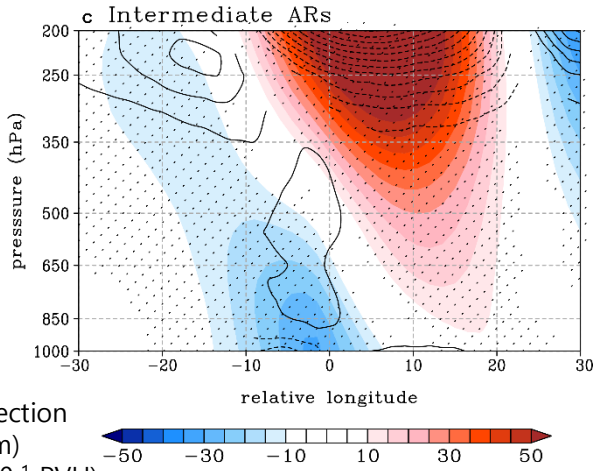
Low frequency



- IVTA (shading, kg m^{-1} s^{-1})
- Z850 anomaly (contours, gpm)



- 850 (shading, K)
- ω500 (blue contours, Pa s^{-1})
- Z500 (black contours, gpm)



Longitude–pressure cross section

- Z anomaly (shading, gpm)
- PV anomaly (contours, 10^{-1} PVU)

Automated AR detection

Supplementary slides

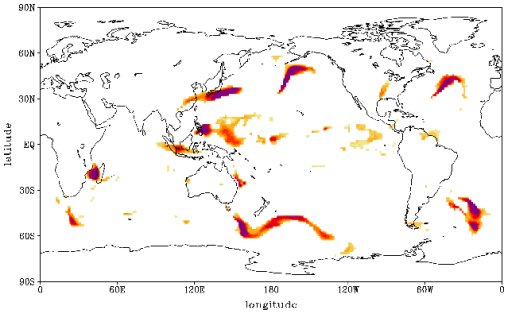
Repeat for $(n+1)^{th}$ time

Starts

IVT and IVTA fields at n^{th} time

Check 1: IVTA Threshold

Define the object as a collection of contiguous grid points with IVTA > 150 kg m^{-1} s^{-1}



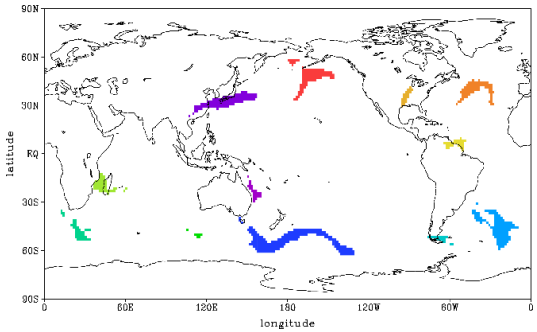
Check 2: Object's geometry

1. Filter out the object whose length to width ratio is less than 2
2. Filter out the object whose length is shorter than 2000 km

Check 3: Tropical object

Filter out the object whose centroid is equatorward from 10°N or 10°S and object-mean meridional **IVT** is smaller than 30% of object-mean zonal **IVT** in magnitude

The remained objects are ARs, and their catalog data are saved

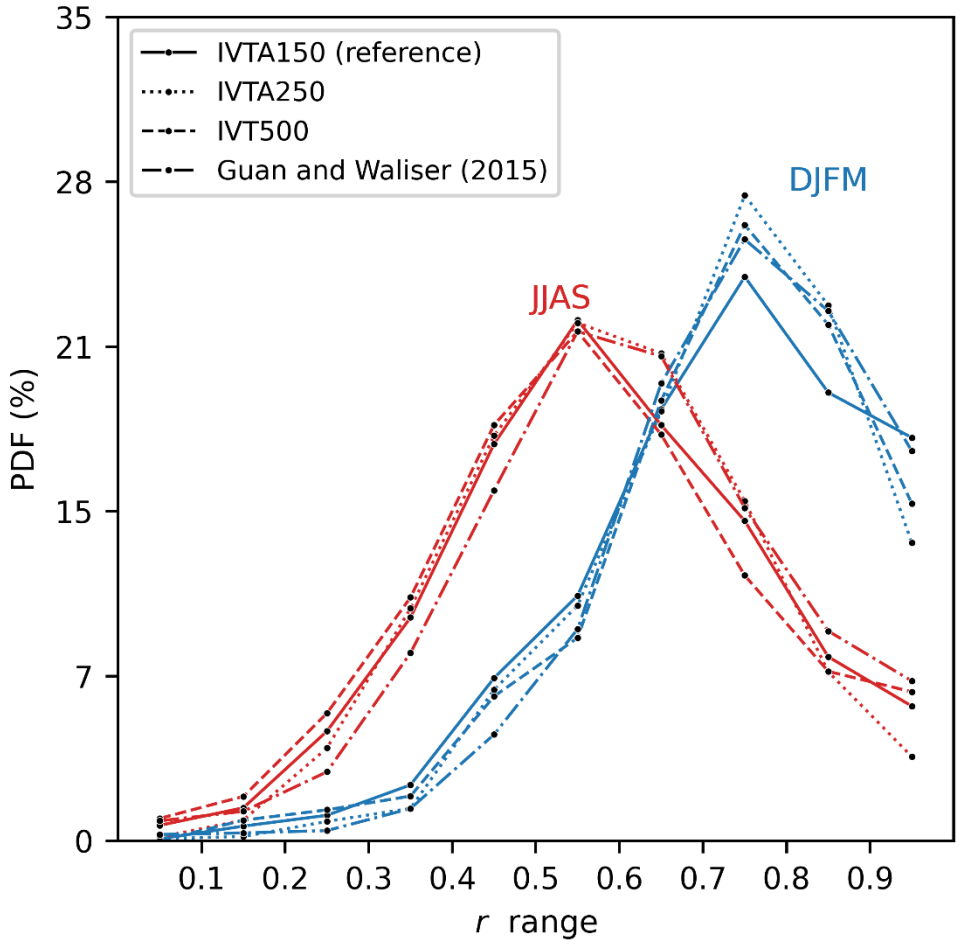


* Main body of the algorithm comes from Guan and Waliser (2015).

- The 42-years-long AR catalog (1979–2020) are produced using the algorithm of Park et al. (2021) with some modifications.
- A static threshold of integrated water vapor transport anomaly (IVTA) is used (**IVTA>150 kg m^{-1} s^{-1}**; ERA5 reanalysis)

Sensitivity to thresholds for AR detection

Supplementary slides



- The two flavors of East Asian ARs are robustly captured with different thresholds for AR detection.