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Short-Range Effects of Volcanic Aerosols on the Genesis and Intensity Change of Tropical Cyclones: Wukong (2018) and Cody (2022)

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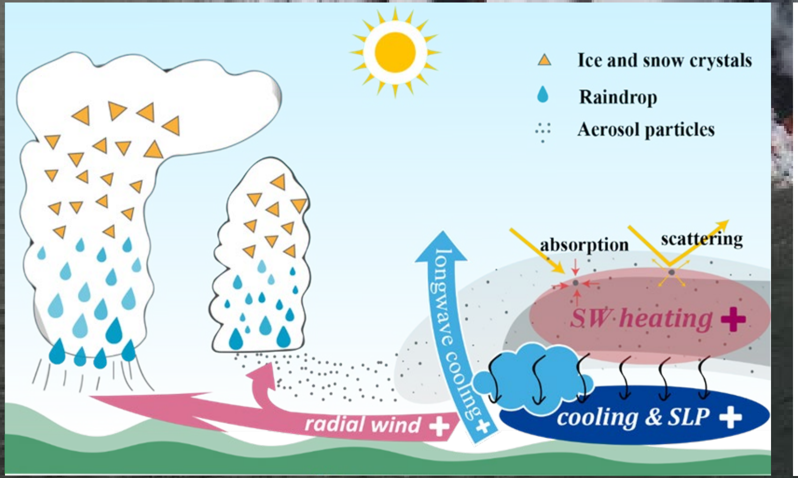
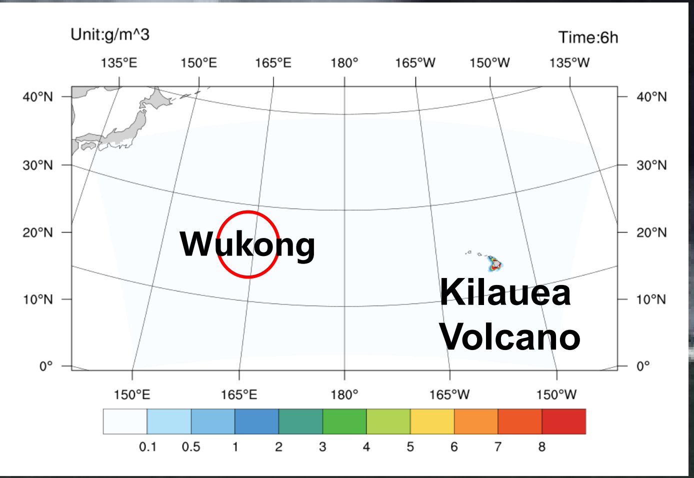
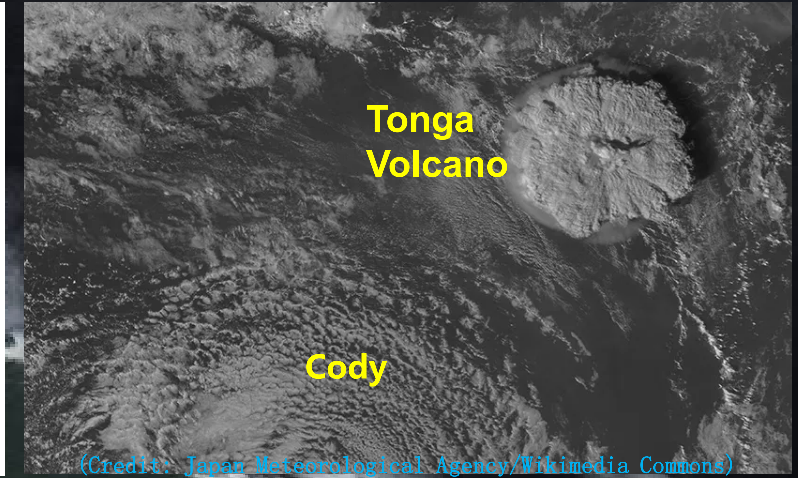
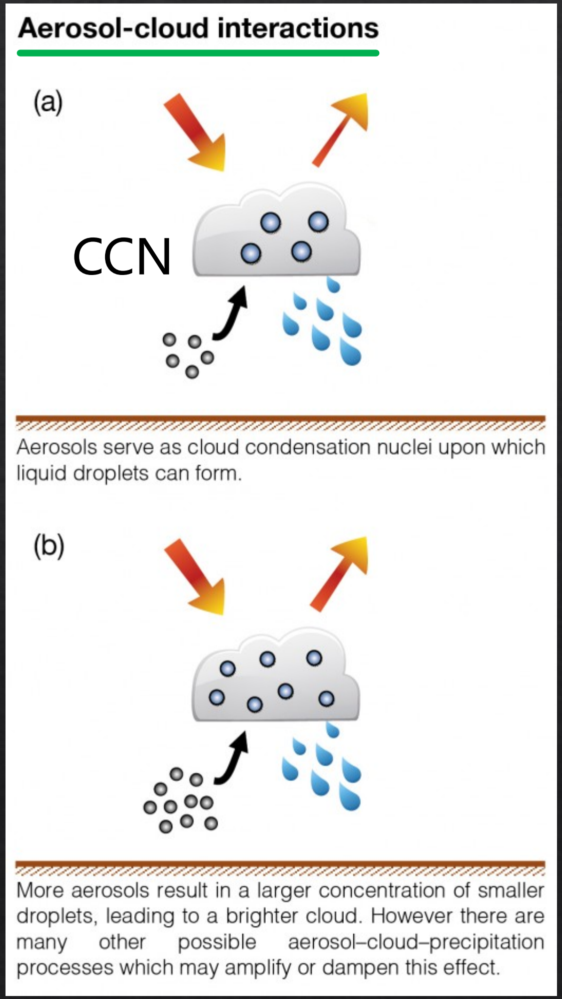
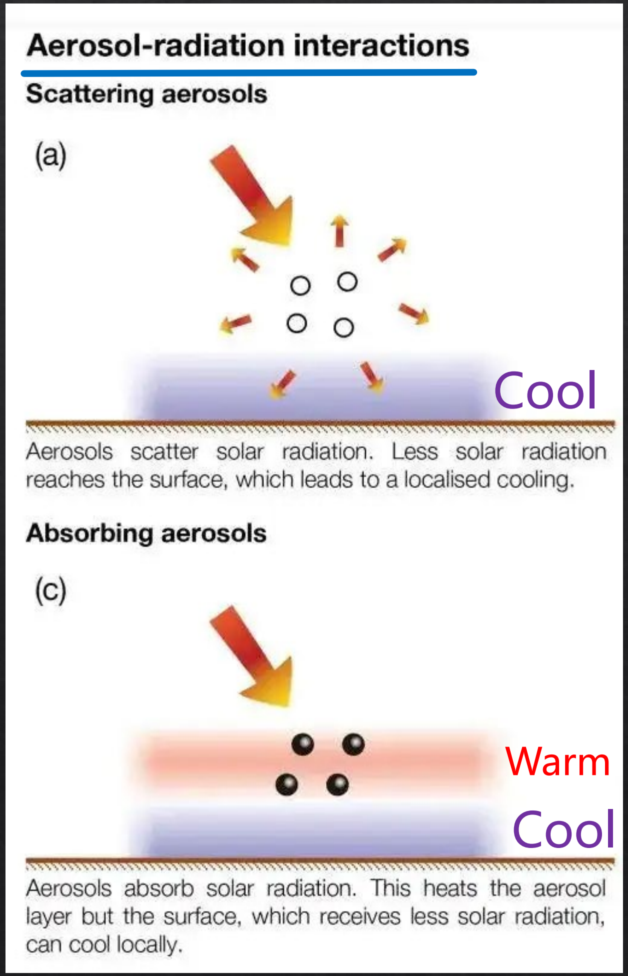






Backgrounds: Aerosol Effects





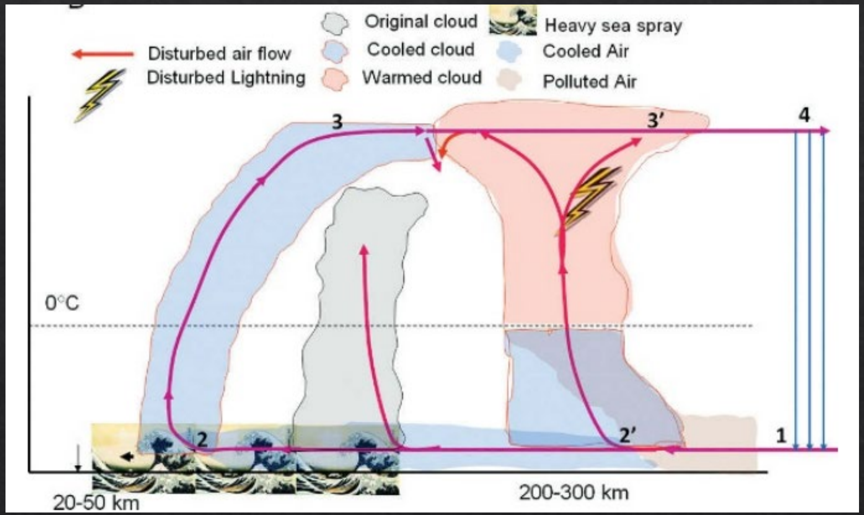
(credit: IPCC)

Backgrounds: Aerosol Long-term Effects on TC

- Sulfate aerosols from major volcanic eruptions reduce TC activity over the Atlantic by cooling the surface and subsurface waters of the tropical oceans (Evan, 2012; Guevara-Murua et al., 2015)
- A strong asymmetrical hemispheric cooling shifts ITCZ southward or northward, causing changes to the genesis potential indices and potential intensity of TC. (Camargo & Polvani, 2019)
- Volcanic eruptions lead to a redistribution of TC activity globally instead of an overall reduction (Pausata & Camargo, 2019; Yang et al., 2019)

Backgrounds: Aerosol Effects on Mature TC

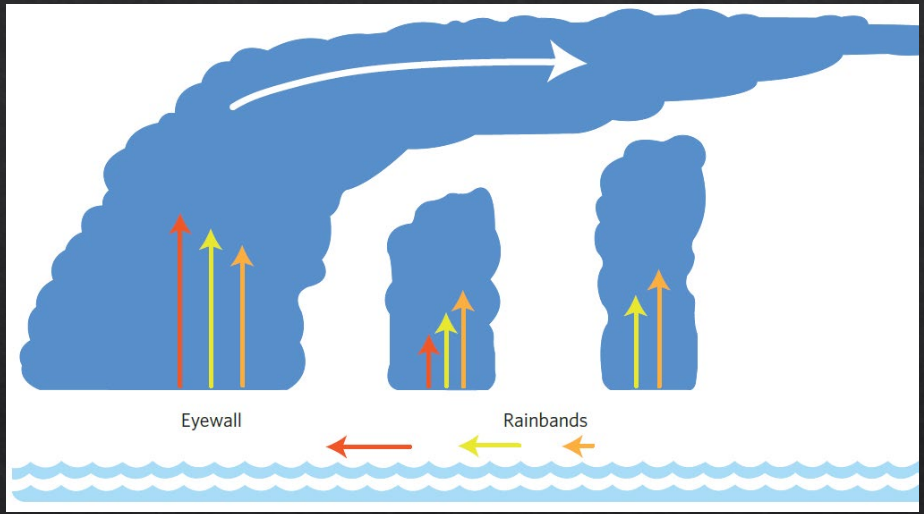
Aerosol–Cloud Effect



(Rosenfeld et al. 2012, *BAMS*)

- aerosols slow the formation of warm rain and cause invigoration of peripheral clouds, decreasing the inflow

Aerosol–Radiation Effect



(Wang et al. 2014, *Nature Climate Change*)

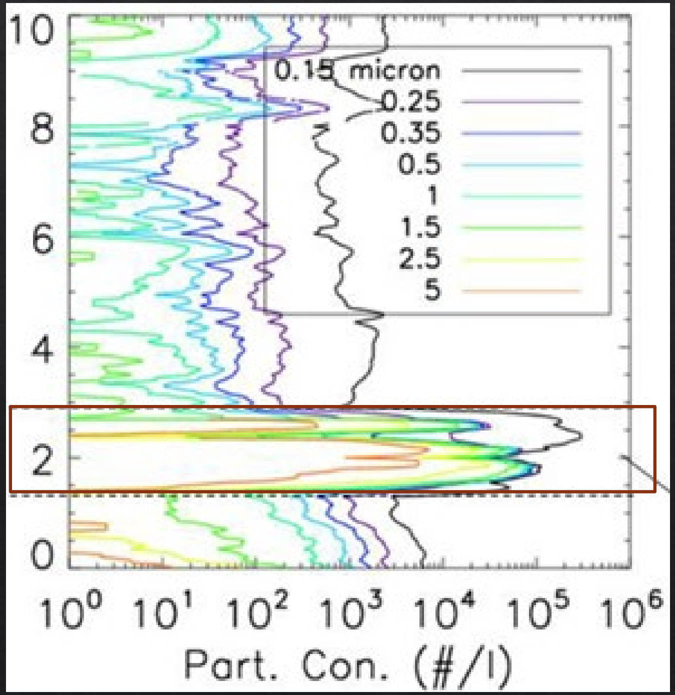
- convection is further enhanced in the rainband by lower-level radiative heating of absorbing aerosols

?

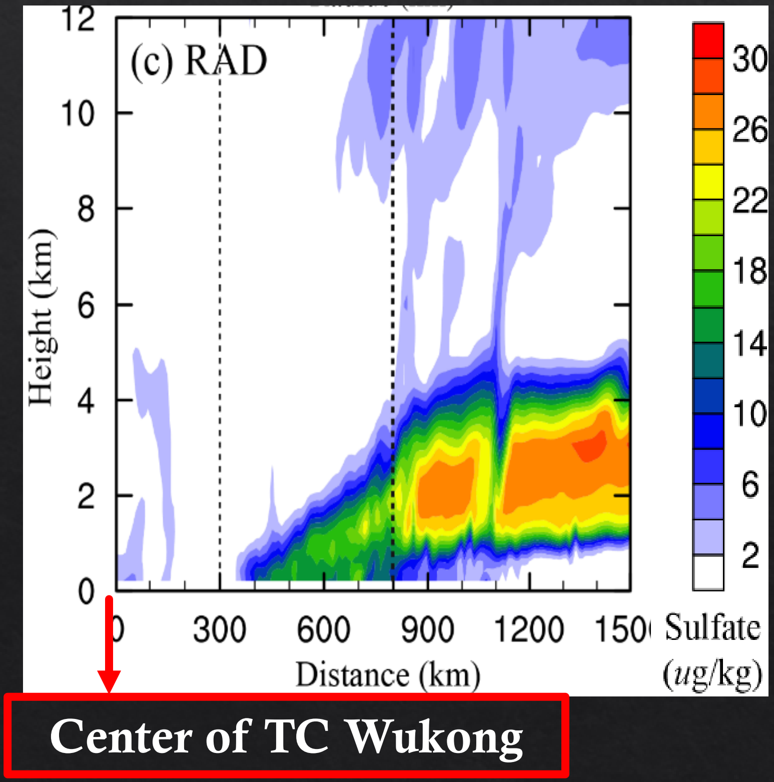
◇ **The radiative effect of light-absorbing aerosols reinforces the microphysical effect, leading to an even weaker intensity.**

Case of Pre-Tropical Storm Wukong (2018):

What are the microphysical and radiative effects of volcanic aerosols on tropical cyclogenesis (TCG) ?

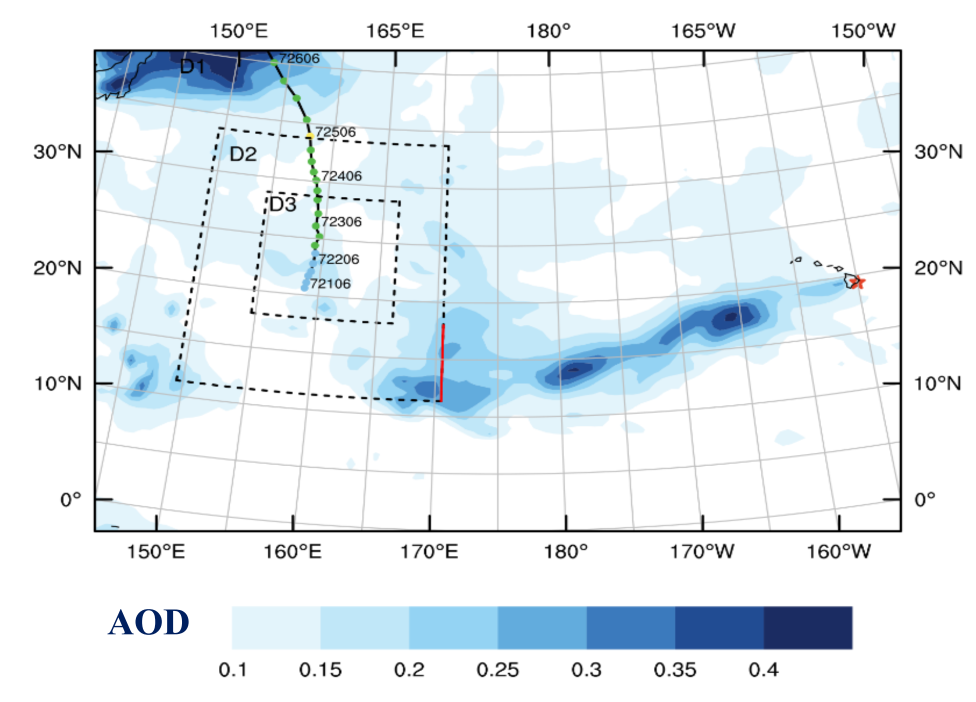


(Vernier et al. 2020, *BAMS*)



Experimental Design

AOD in 20–23 July 2018 from MERRA2



- Driver module of the aerosols: WRF-Chem-V3.9.1, MADE/SORGAM
- 3 km spacing； 44 levels
- RRTMG longwave and shortwave
- Double-moment microphysics scheme of Lin (1983)
- 24 μg m^{-3} sulfate distributed at heights of 1~4 km along the eastern boundary (red) of D2
- Other types of aerosols emission turned off

Experimental Design

Experiment	Aerosol–radiation effect (ARI)	Aerosol–cloud effect (ACI)
CLEAN	✘	✘
RAD	✓	✘
CLD	✘	✓
CTL	✓	✓

$$\text{ARI} = \text{RAD} - \text{CLEAN}$$

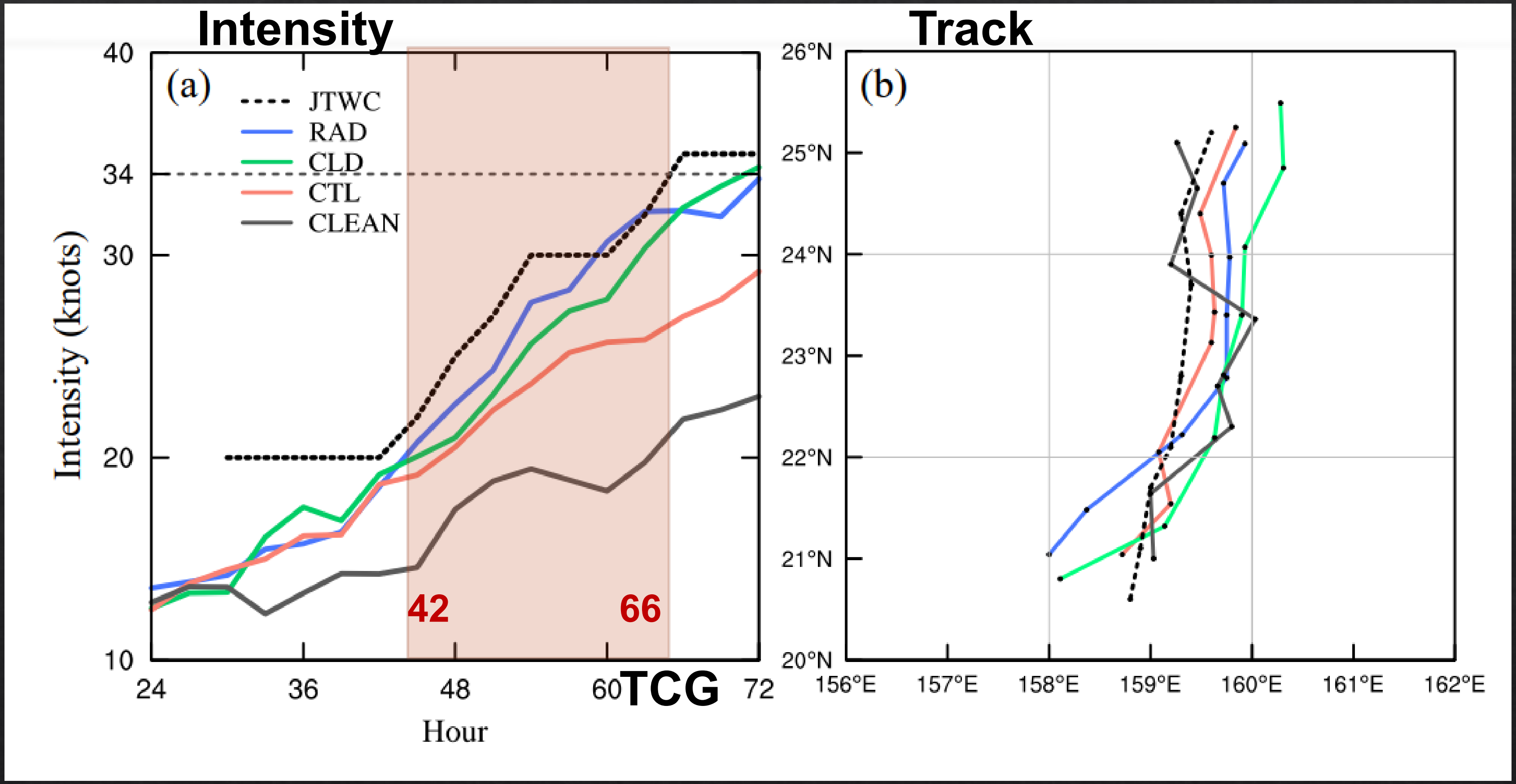
$$\text{ACI} = \text{CLD} - \text{CLEAN}$$

$$\text{Tot} = \text{CTL} - \text{CLEAN}$$

$$Nonlinear = \text{Tot} - \text{ACI} - \text{ARI}$$

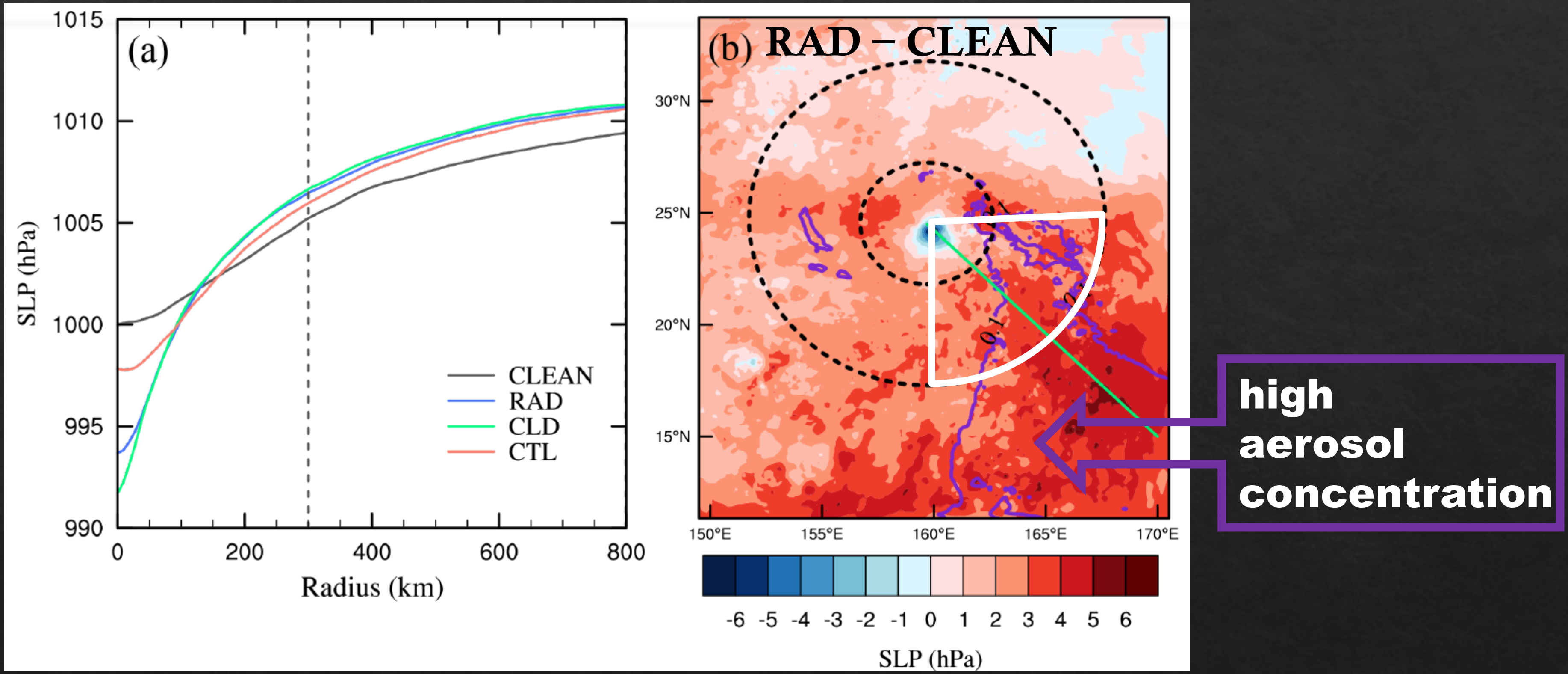
$$= \text{CTL} + \text{CLEAN} - \text{RAD} - \text{CLD}$$

Comparisons of TCG Processes



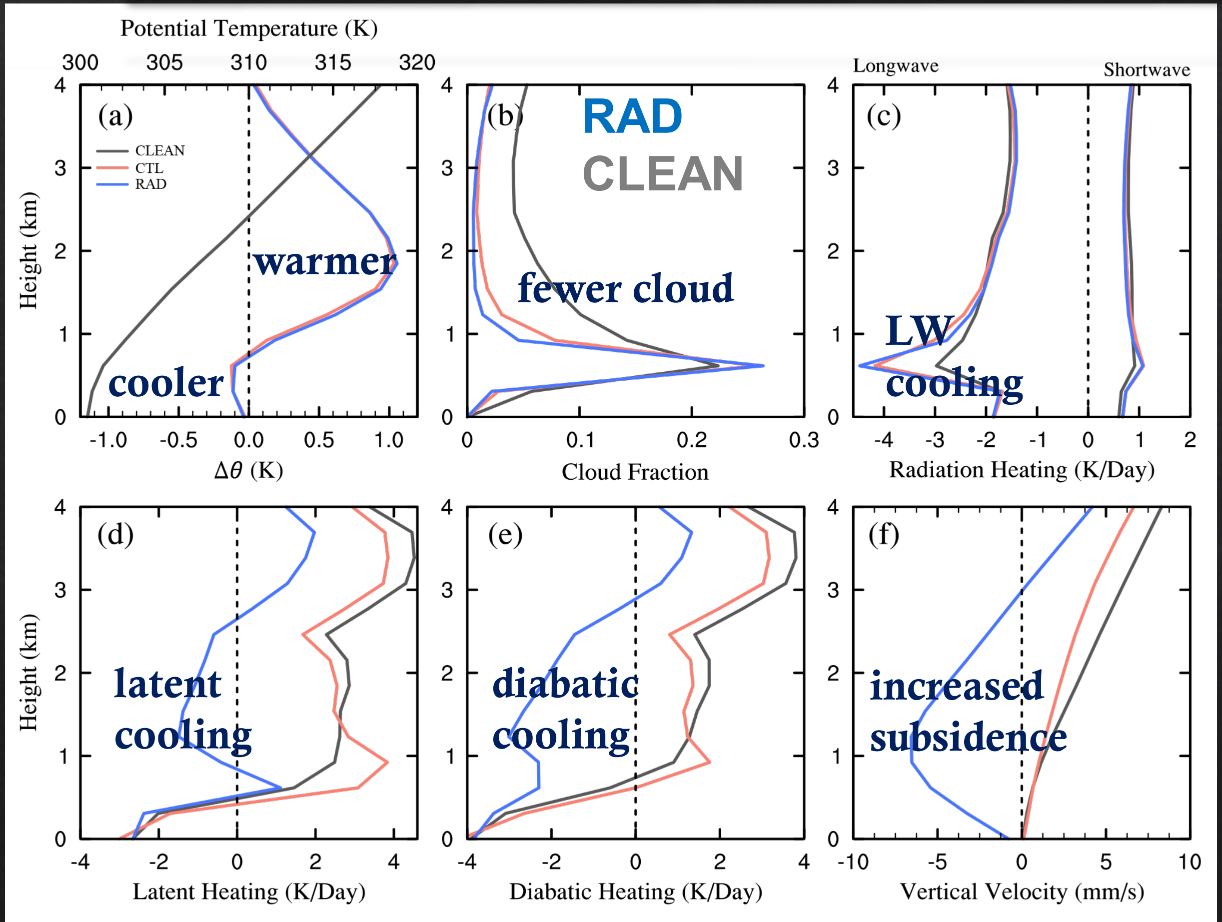
The TC genesis occurs earlier in RAD and CLD than in CTL and CLEAN. Why?

ARI Effects



ARI: increase of SLP in the TC environment, and radial SLP gradient

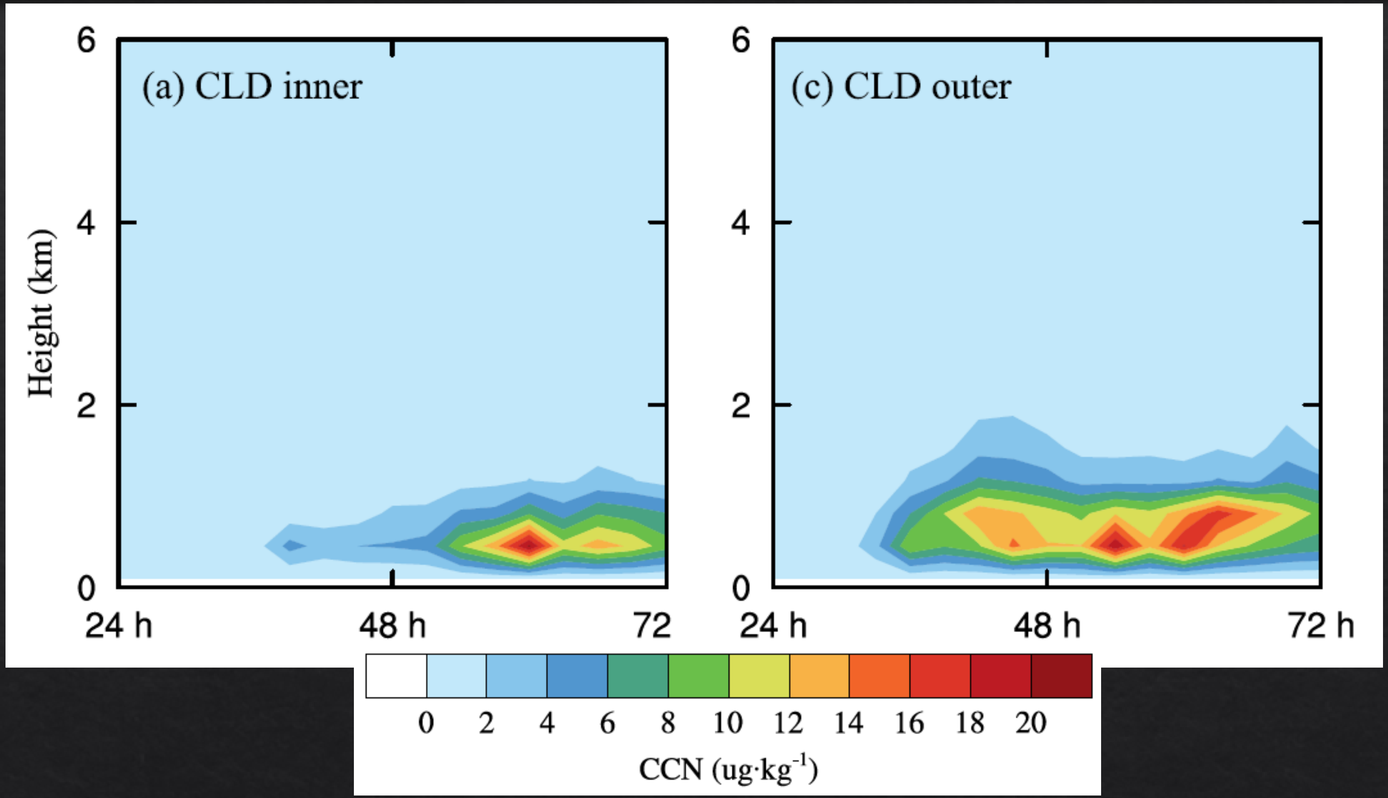
ARI Effects



Averaged profiles in high-concentration aerosol region (AOD > 0.2)

- ARI: enhanced solar shortwave heating → a warmer layer above 1 km → more stable low levels → reduced cloud cover → increased longwave radiative cooling
- the above positive feedback → suppress convection and latent heating → induced subsidence → increase SLP

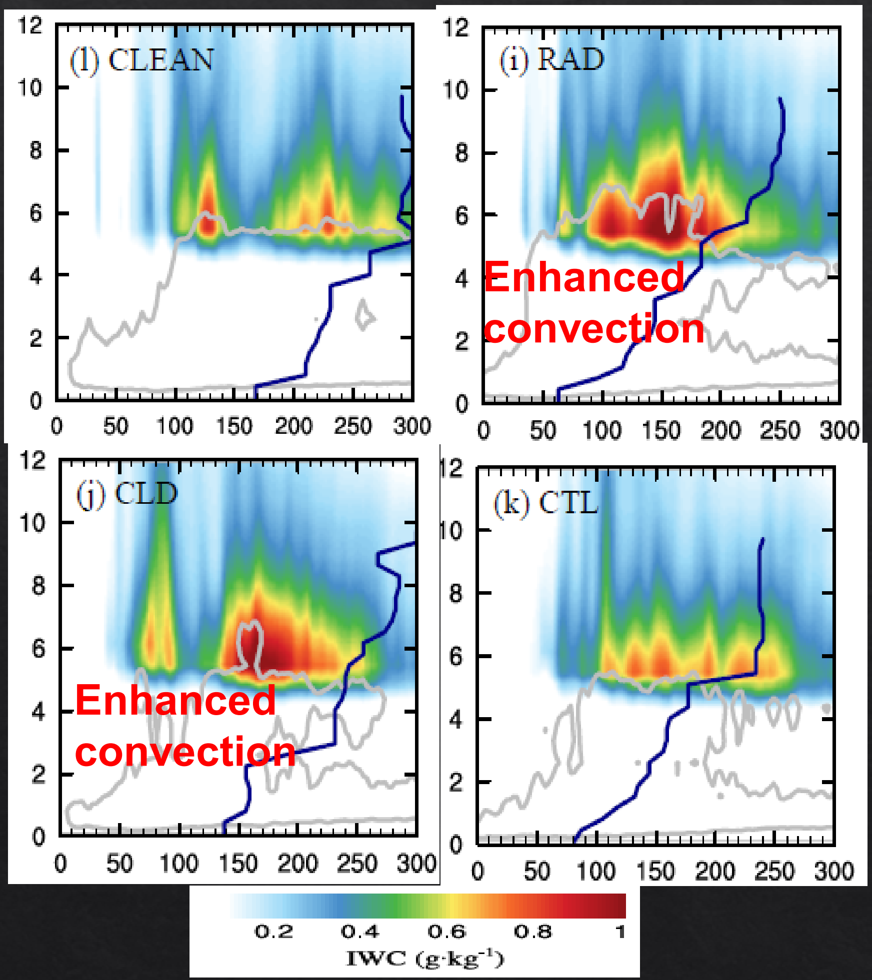
ACI Effects



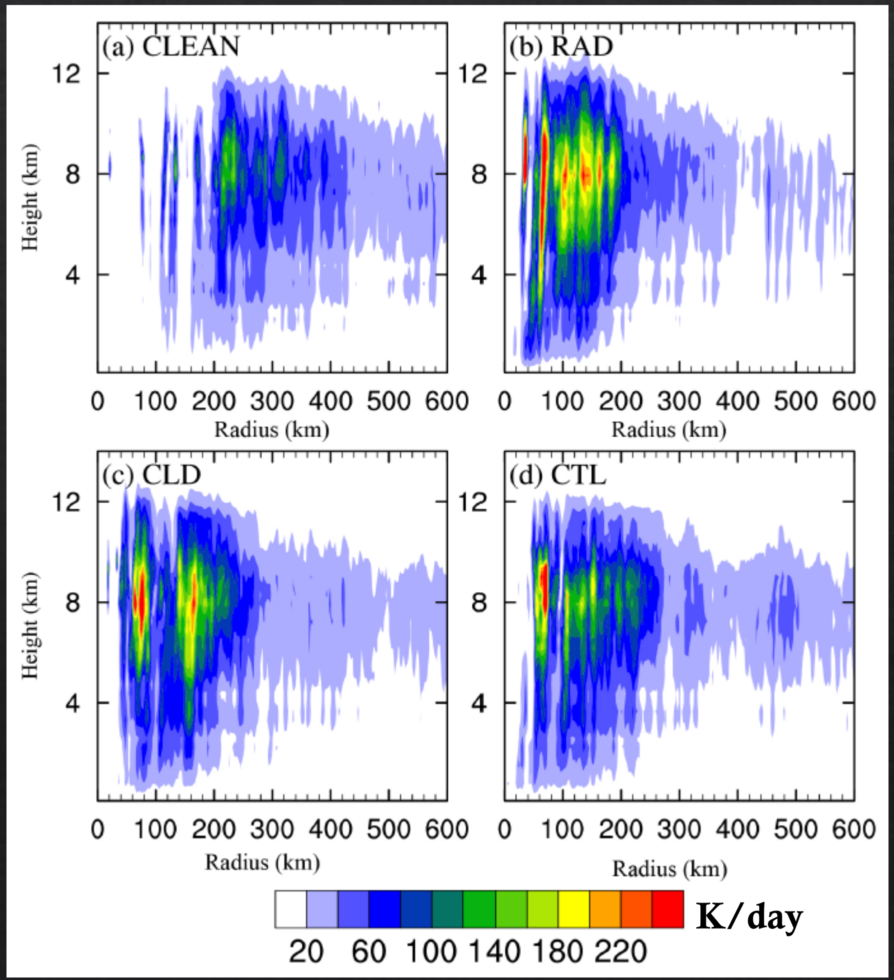
- ACI: The volcanic aerosols ingested by the storm circulation can invigorate convection in the storm's inner core by activating into CCNs

Comparison of ARI, ACI, and Total Effects

Liquid and ice water



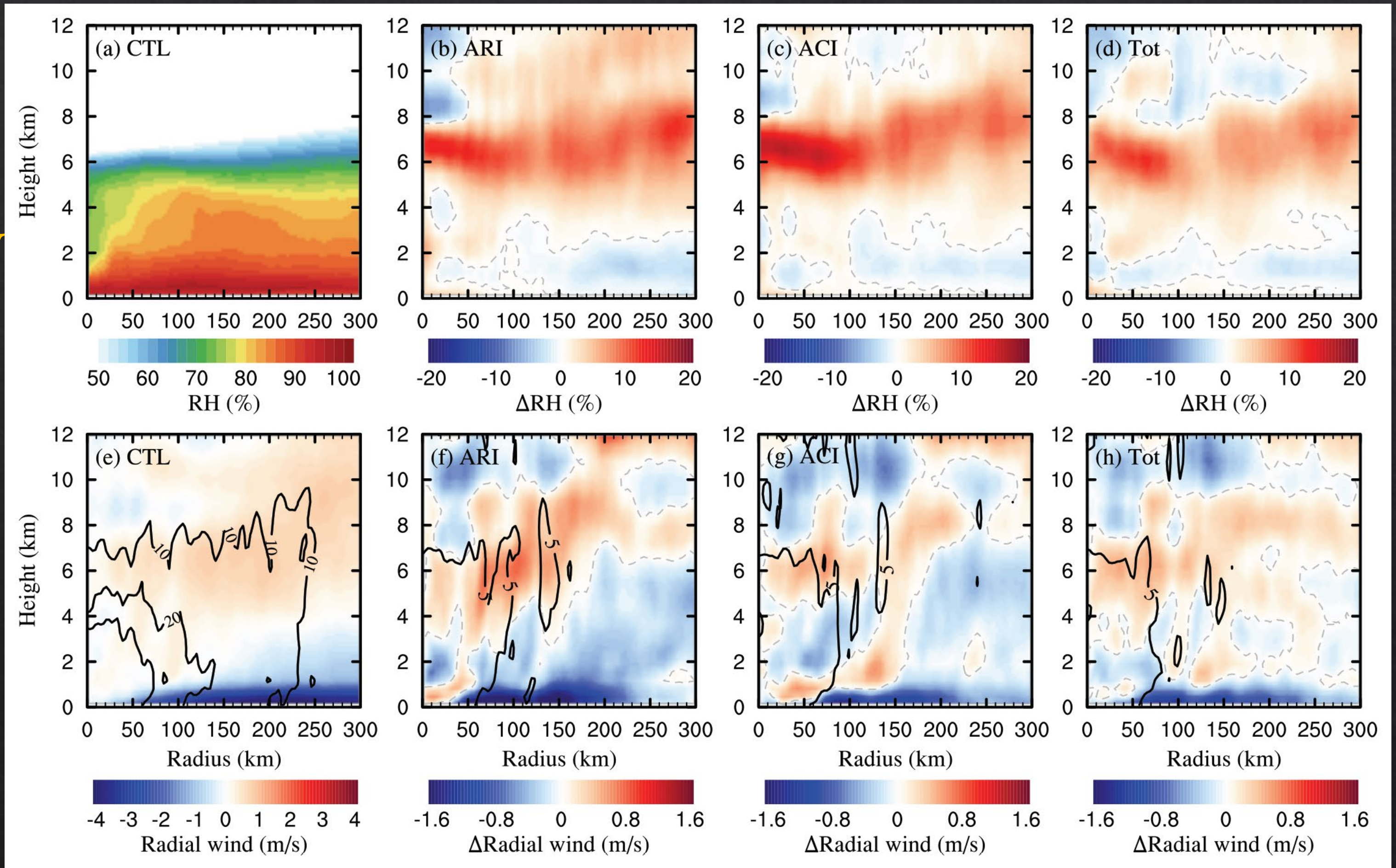
Diabatic heating



Comparison of ARI, ACI, and Total Effects

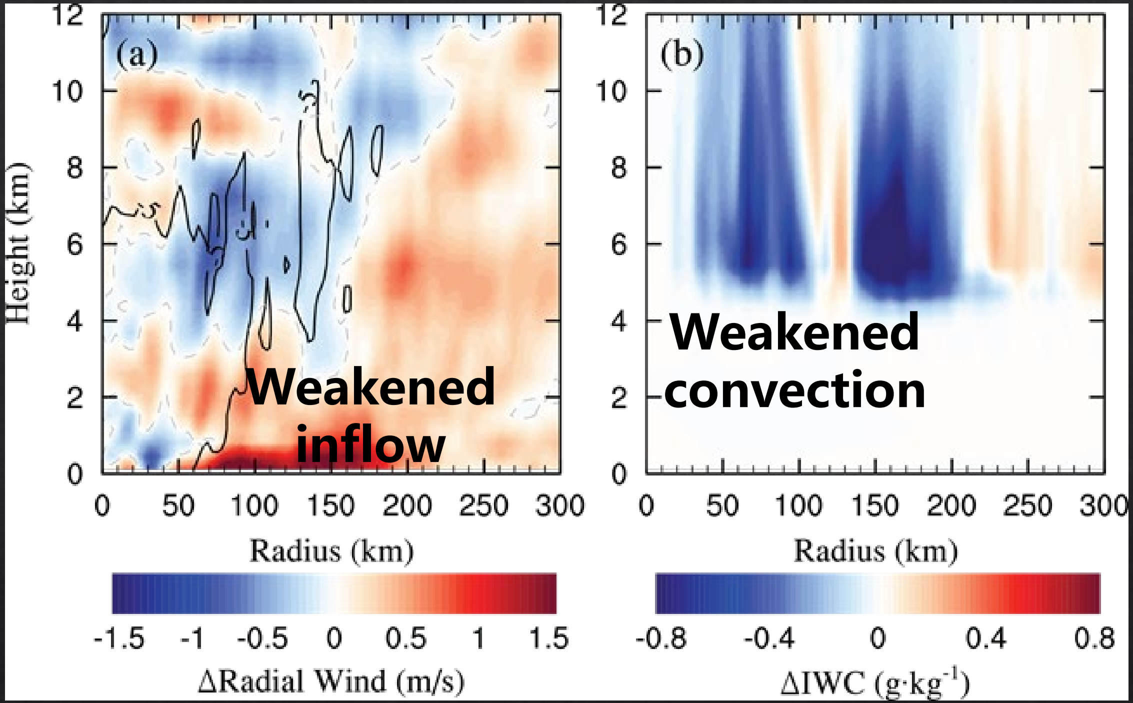
Relative humidity

Radial wind



Nonlinear Interaction between ARI and ACI

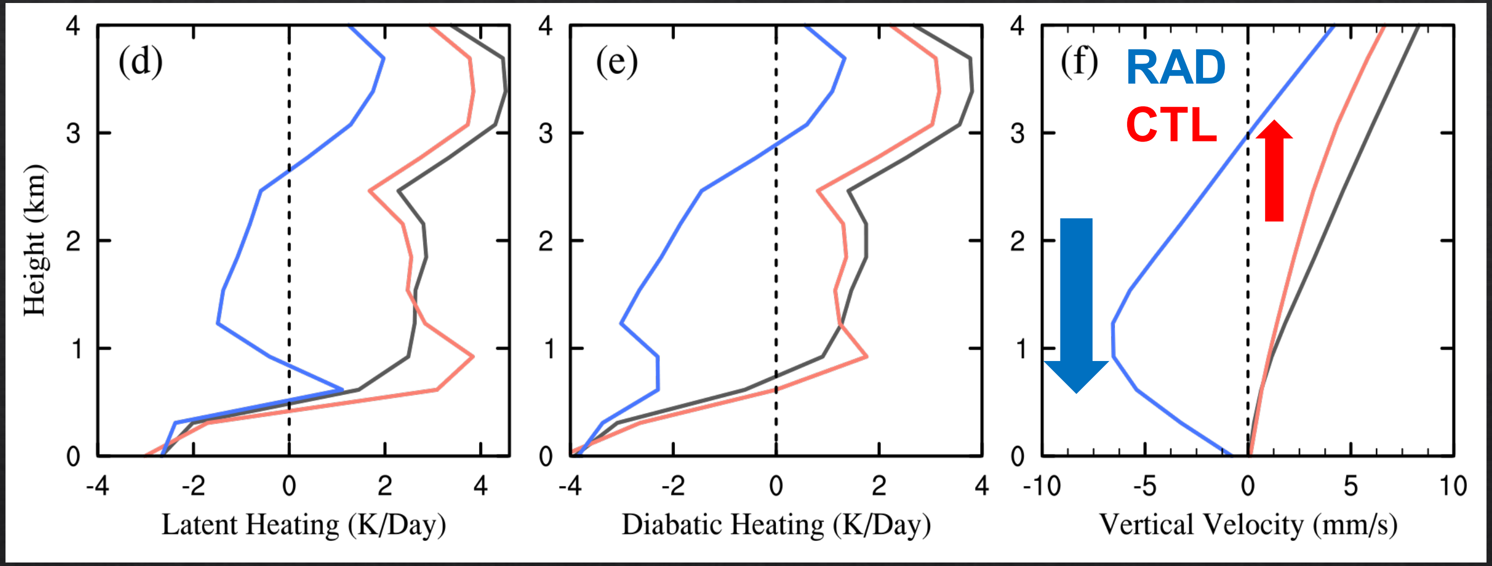
$$Nonlinear = \text{Tot} - \text{ACI} - \text{ARI}$$

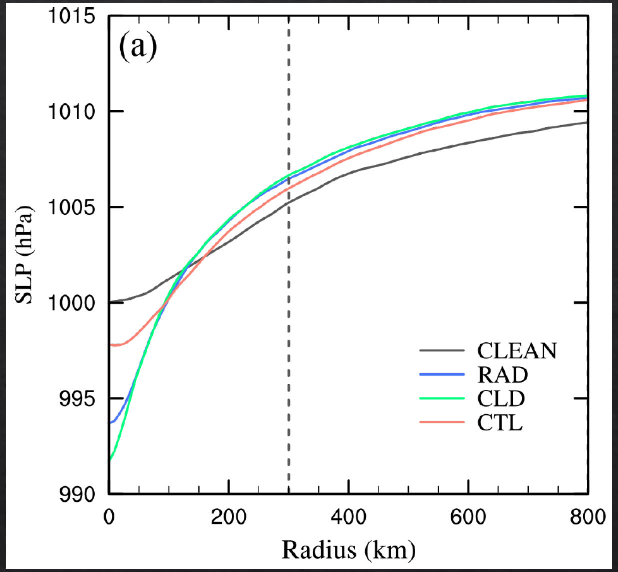


- It weakens the circulation and the inner-core convection of the TC

Why does Nonlinear Effect Occur?

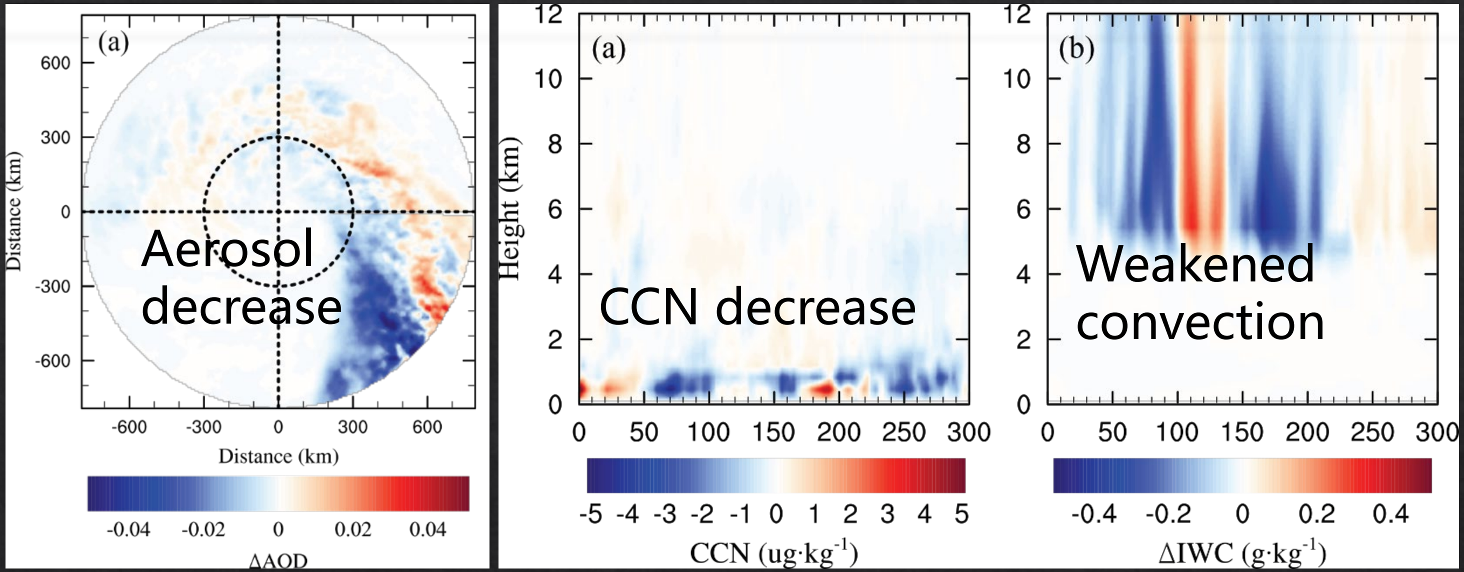
Tot − ARI = ACI + Nonlinear = CTL − RAD





- In CTL, ACI increases the latent heating and upward motion at low levels in the storm environment, partly offsets the positive contribution of pure ARI effect (e.g. downward motion) in RAD.

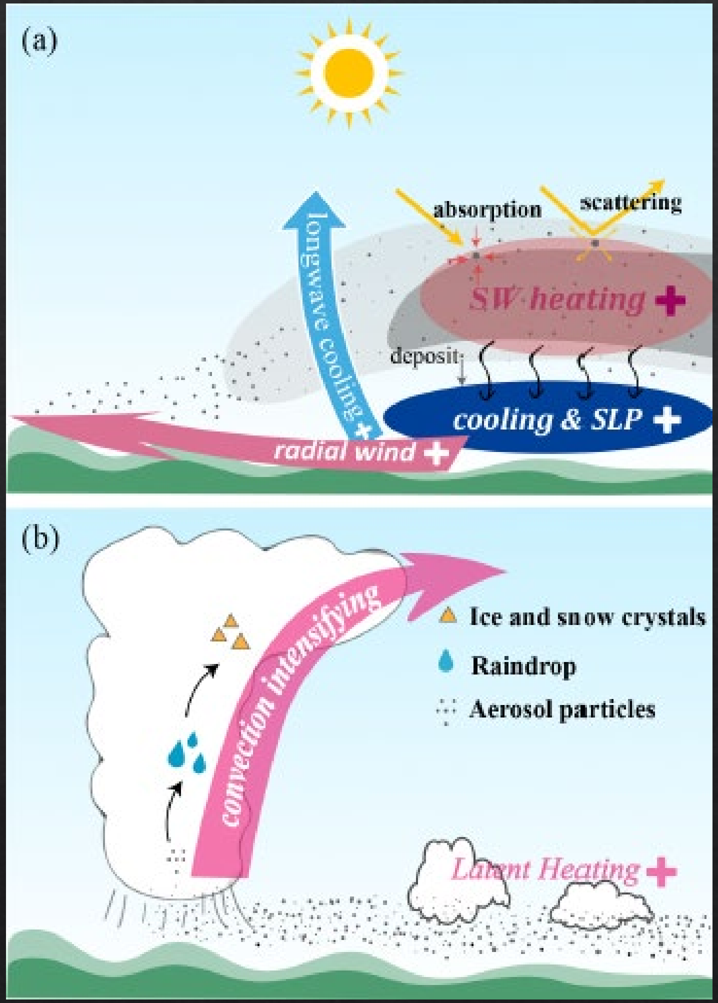
Why does Nonlinear Effect Occur?



$$\text{Tot} - \text{ACI} = \text{ARI} + \text{Nonlinear} = \text{CTL} - \text{CLD}$$

- In CTL, a part of volcanic aerosols in the storm environment are deposited. That might be the impact of the sinking motion caused by ARI effect.
- Therefore, aerosols and CCN decrease, which results in weakened convection in the inner core in CTL relative to CLD.

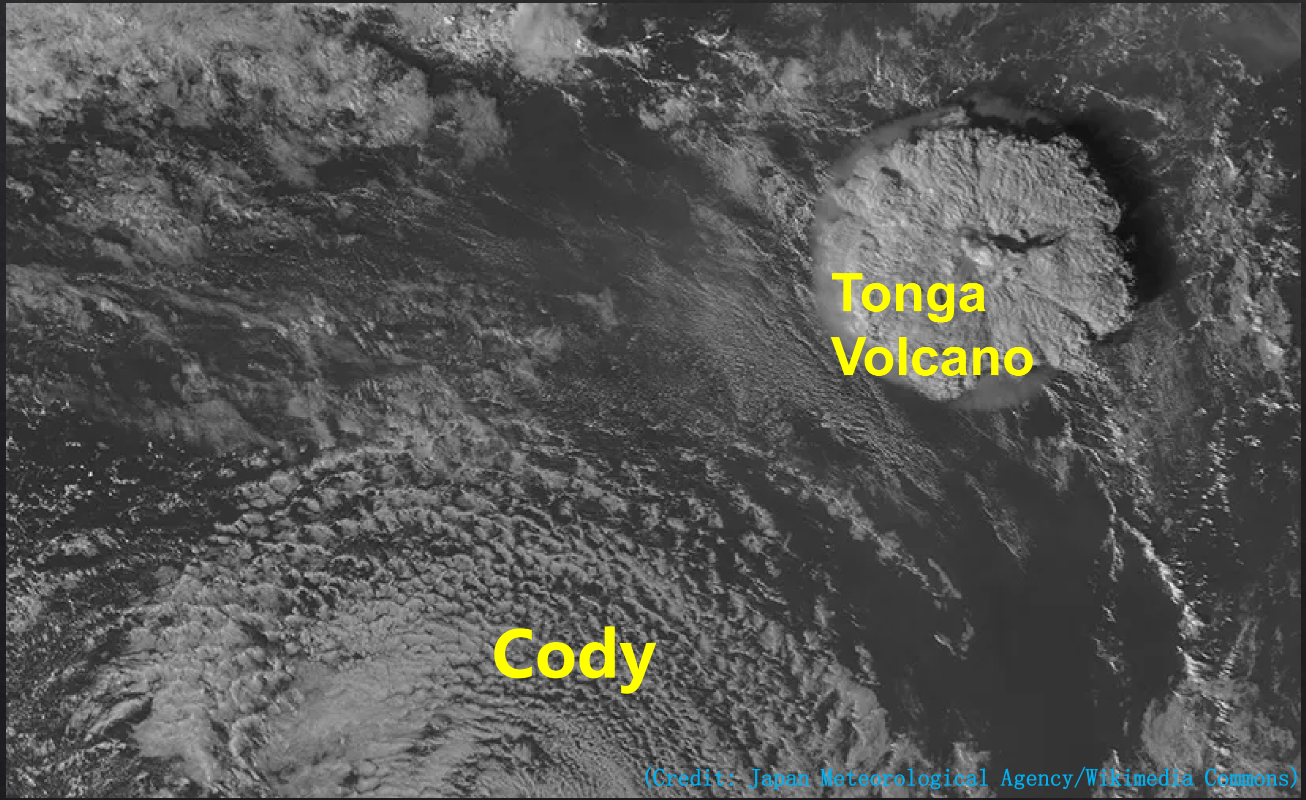
Effects of Aerosols on TCG



- Enhanced radiative cooling at low levels induced by aerosols advances TCG
- Microphysical effect of the aerosols invigorates convection in TC inner core so as to favor TCG
- The interaction between the above two effects offset partly their own positive contributions to TCG

Case of TC Cody (2022):

Could aerosols from Tongan volcanic eruption affect the intensity change in the decay stage?

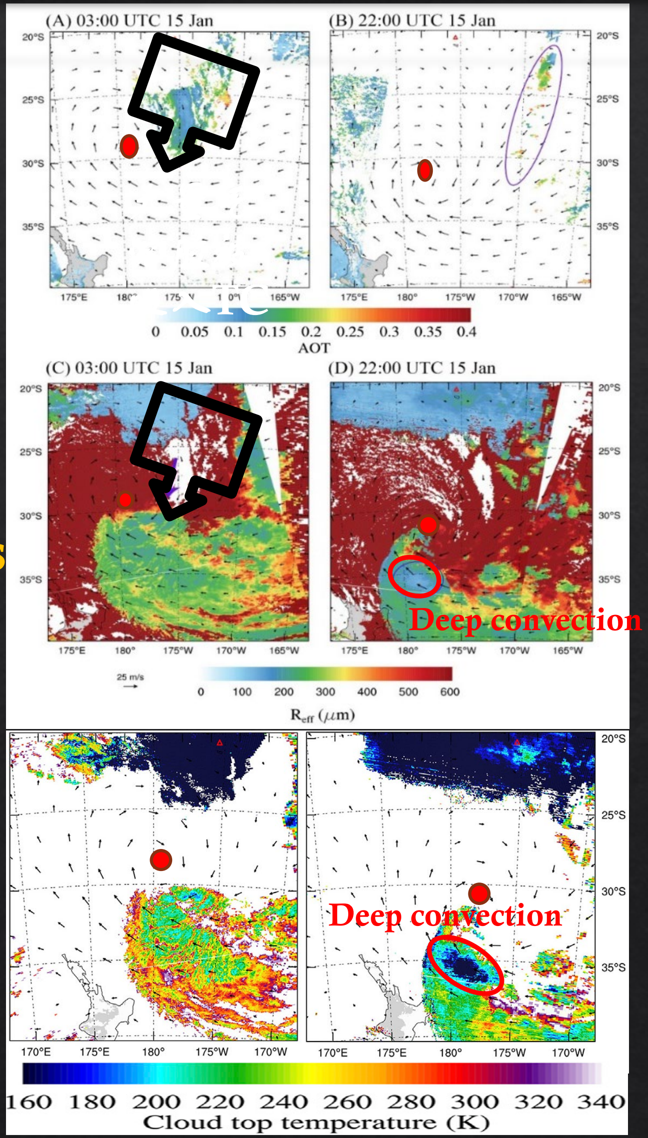


Satellite Observation of Aerosols and Cody's Cloud Development

Aerosol optical thickness

Cloud particle effective radius

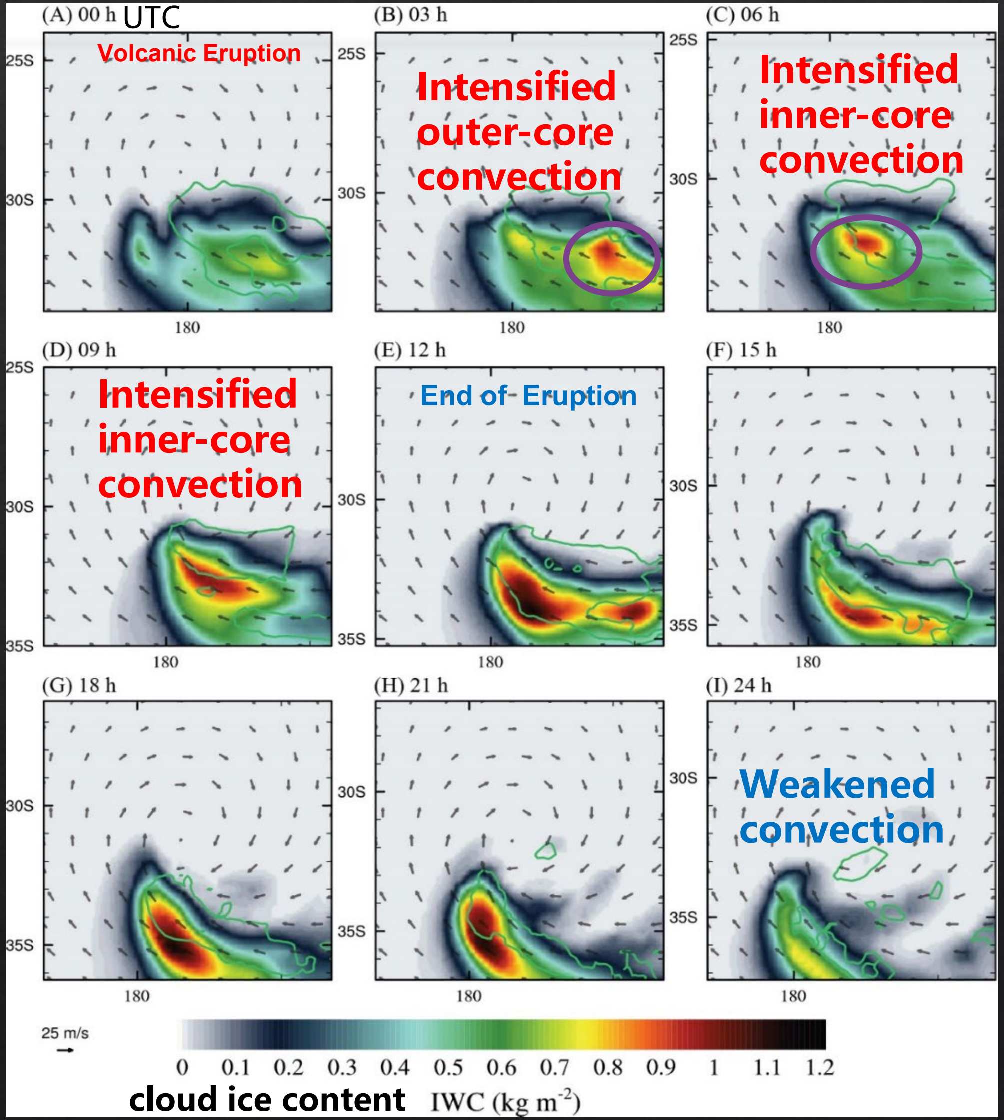
Cloud top temperature



- Large amount of volcanic aerosol into Cody's inner core after the volcanic eruption
- The effective cloud droplet radius decreased in the inner core
- Decreased cloud top temperature
- The deep convection was enhanced greatly by the aerosol−cloud effect

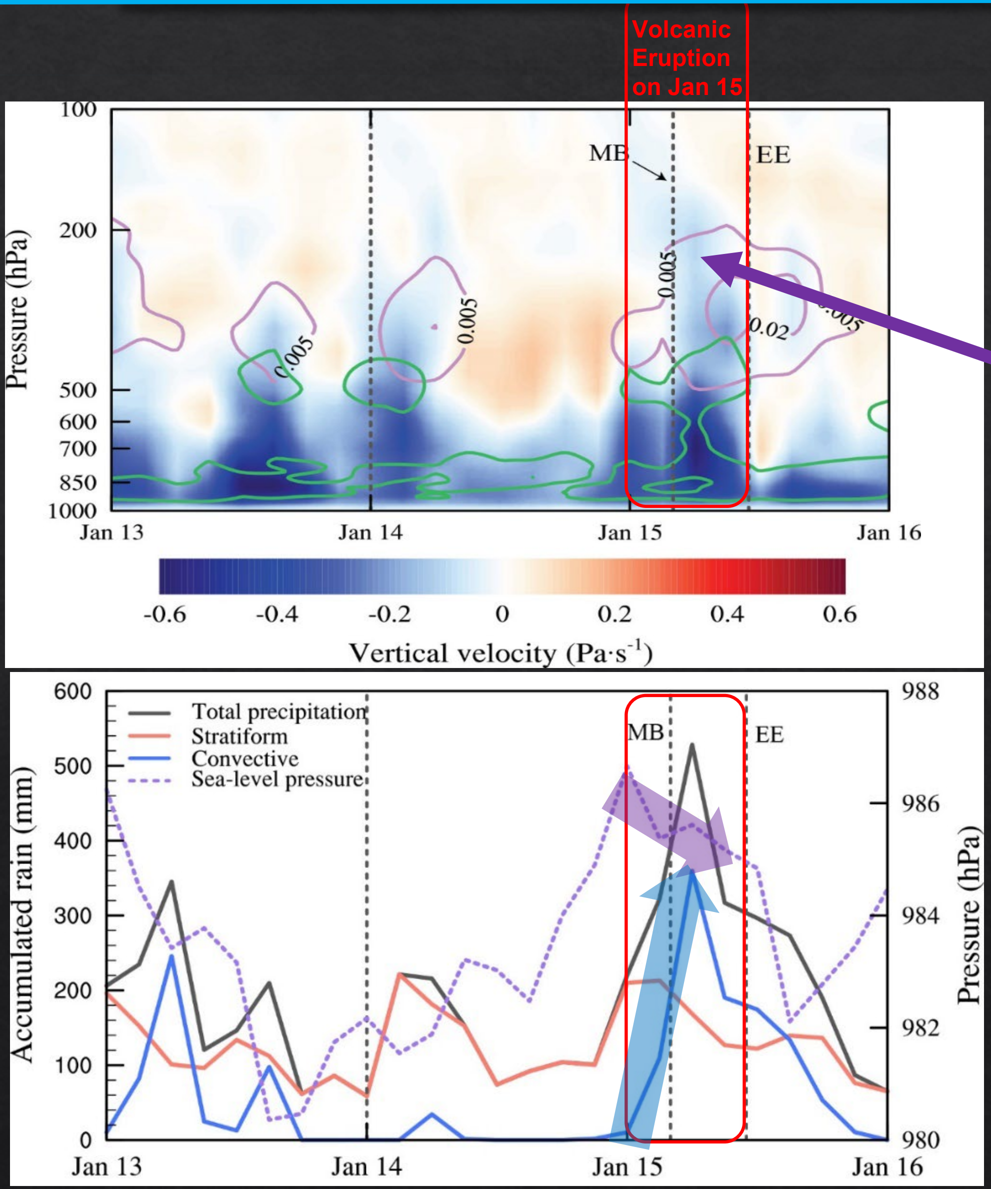
Evolution of Cloud Ice in Cody

January 15th



- Convection was enhanced after the volcanic eruption
- The inner core convection began to weaken with the cessation of volcanic eruption

Inner-core Convection and Intensity Change of Cody

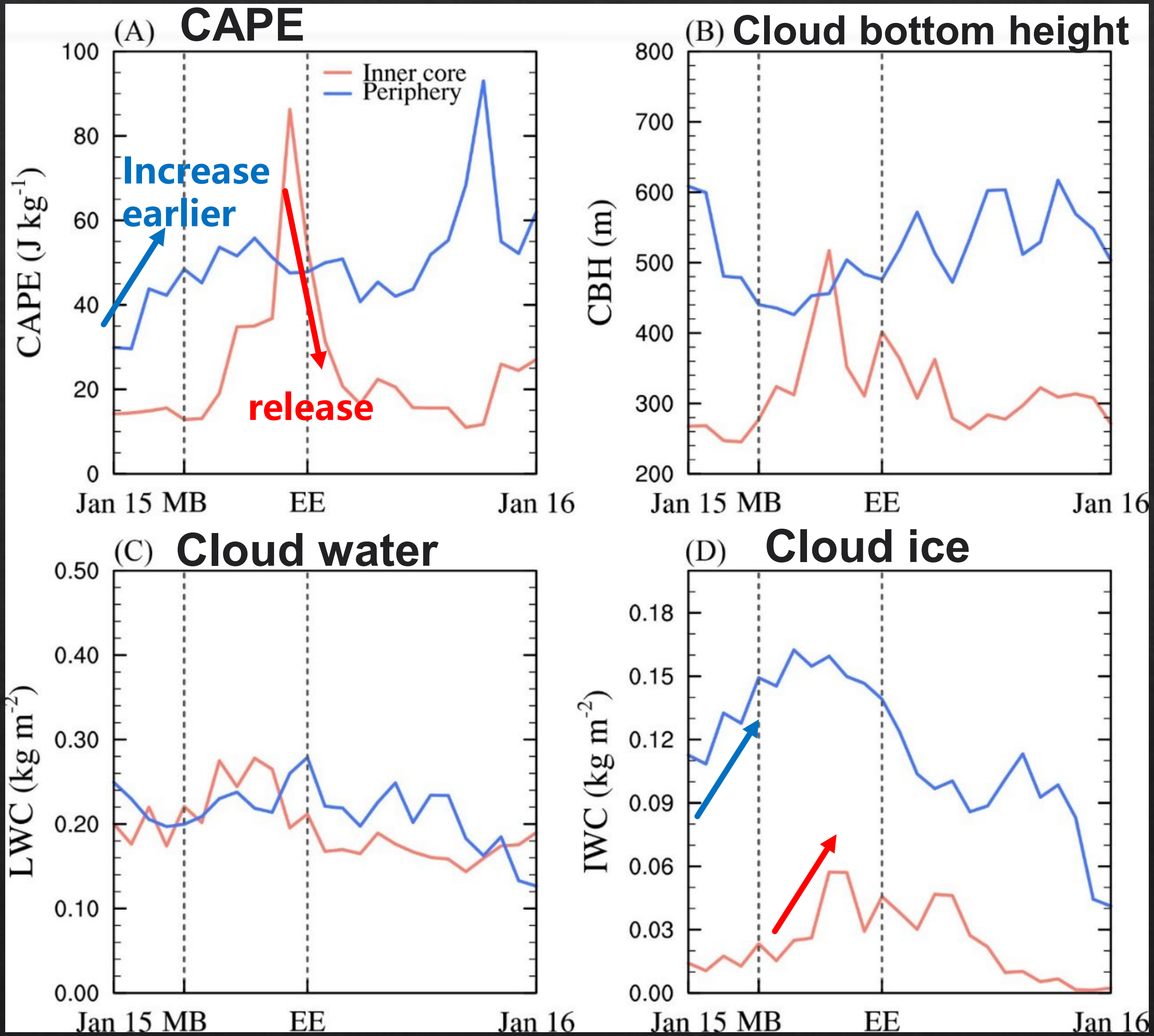


- Increased cloud ice and vertical updraft at the TC's inner-core after the volcanic eruption on Jan 15
- Increased convective precipitation
- Decreased minimal sea-level pressure

{ radius<150 km }

Cody intensifies after the volcanic eruption !

Convection and Clouds in Cody



Radius
- <150 km
- 200~300 km

- The outer-core convection was first enhanced at the beginning of the eruption, but the inner-core convection was strengthened after the main blast

Discussion and future work

- ARI and ACI effects, and their nonlinear interaction need to be considered.
- These effects on TC development could depend on the concentration, types (e.g. sea salt, dust, or anthropogenic aerosols) and position of aerosols, and TC's stage.
- Potential uncertainties can be examined by ensemble simulations.

References:

- Liu H., Tang X. and Gu J.-F. (2022): Effects of Volcanic Aerosols on the Genesis of Tropical Cyclone Wukong (2018). *J. Geophys. Res.: Atmos.*
- Liu H. and Tang X. (2022): Tongan Volcanic Eruption Intensifies Tropical Cyclone Cody (2022). *Front. Earth Sci.*