What is the fate of detrained ice in the Tropical Western Pacific

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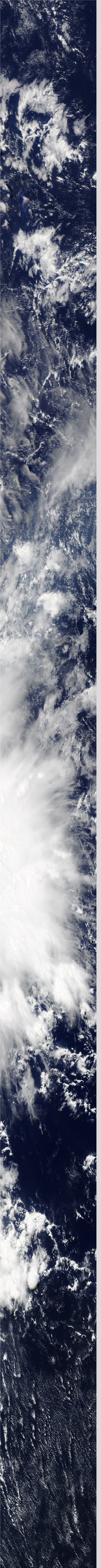
Abstract

Clouds in the tropical western Pacific are dominated by reflective deep convective cores with gradually thinning trailing anvil clouds, which play a crucial role in determining tropical cloud radiative effects. The microphysical controls of the thinning process and its changes when subjected to a future warmer climate are still very uncertain.We use the high resolution version of the Exascale Earth System Model (E3SM) to study the thinning process in present day and future climate. We apply Lagrangian forward trajectories starting at peaks of convective activity of the detected mesoscale convective systems (MCS) and track detrained ice crystals to better understand the processes controlling the transition of a thick detrained anvil cloud into a thin cirrus cloud. The trajectories are computed offline from the 1-hourly model-calculated velocity fields and ice crystal sedimentation velocities. The modeled MCS in present day climate have a comparable time evolution to those observed by Himawari geostationary satellite data, with an average lifetime of about 10-15 hours, which accounts only for the optically thick part of the cold cloud shield. However, E3SM fails to simulate the strongest storms, which is reflected by an underestimation of albedo and overestimation of outgoing longwave radiation. The analysis of ice sources (detrainment, vapor deposition, new nucleation events) and sinks (sublimation, aggregation, sedimentation) along trajectories highlights the crucial role of the balance between depositional growth and precipitation formation for the maintenance of aging anvil clouds. Interestingly, deposition of ice on detrained ice crystals contributes to the majority of the upper tropospheric ice mass. On the other hand, about 80% of the initial cloud mass is removed in the form of precipitation within the first 10 hours of the detrainment event, changing its radiative effect from net negative to net positive. The future climate simulation shows an increase in storm frequency and intensity, an increase in ice water content and albedo in convective cores and thick anvils. The trajectory calculations reveal a 15% decrease in cloud lifetime due to climate change, suggesting a decrease in thin high clouds due to a higher precipitation efficiency and a shift to more negative net cloud radiative effects.



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What did we do?

1. Tracked **Mesoscale convective systems (MCS)** in the Exascale Earth System Model (**E3SM**) at the horizontal resolution of 0.25° and evaluated it against **Himawari geostationary satellite data** for the Tropical Western Pacific
2. Computed **Lagrangian forward trajectories** starting at peaks of convective activity to better understand **the transition of a thick detrained anvil cloud into a thin cirrus cloud**

Why?

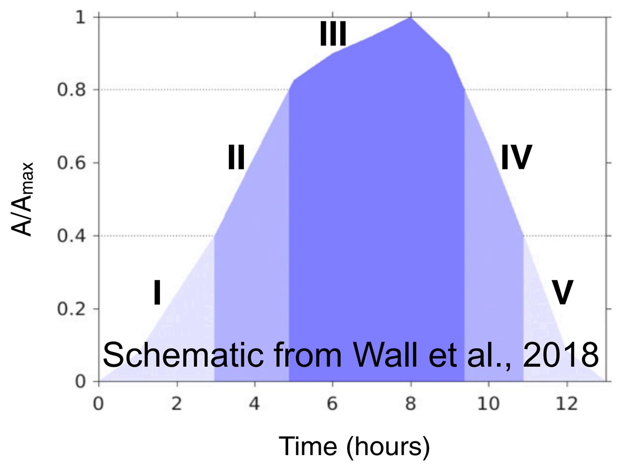
1. **Anvil clouds** are the **dominant cloud type in the Tropical Western Pacific** by both frequency and cloud radiative effects
2. It is unclear what controls the thinning of detrained anvil clouds and whether GCMs can simulate it in a satisfactory way

MCS tracking

Brightness-temperature based MCS tracking algorithm with 240 K "warm" threshold
(Fiolleau and Roca, 2013 , Wall et al., 2018)

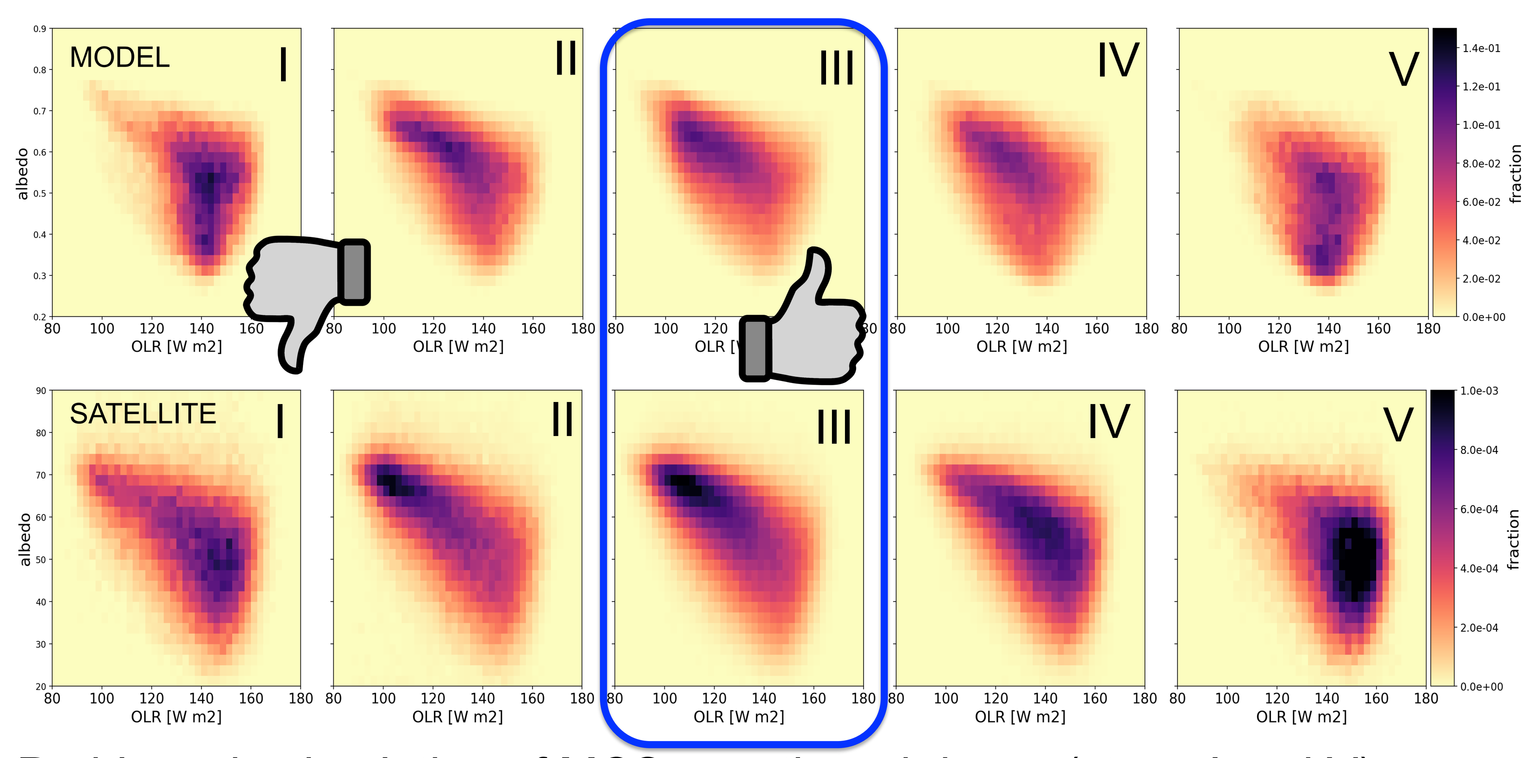
- Can detect only thick and intermediatly thick high ice cloud "shields"

Storms divided into 5 lifecycle stages based on their normalized surface area

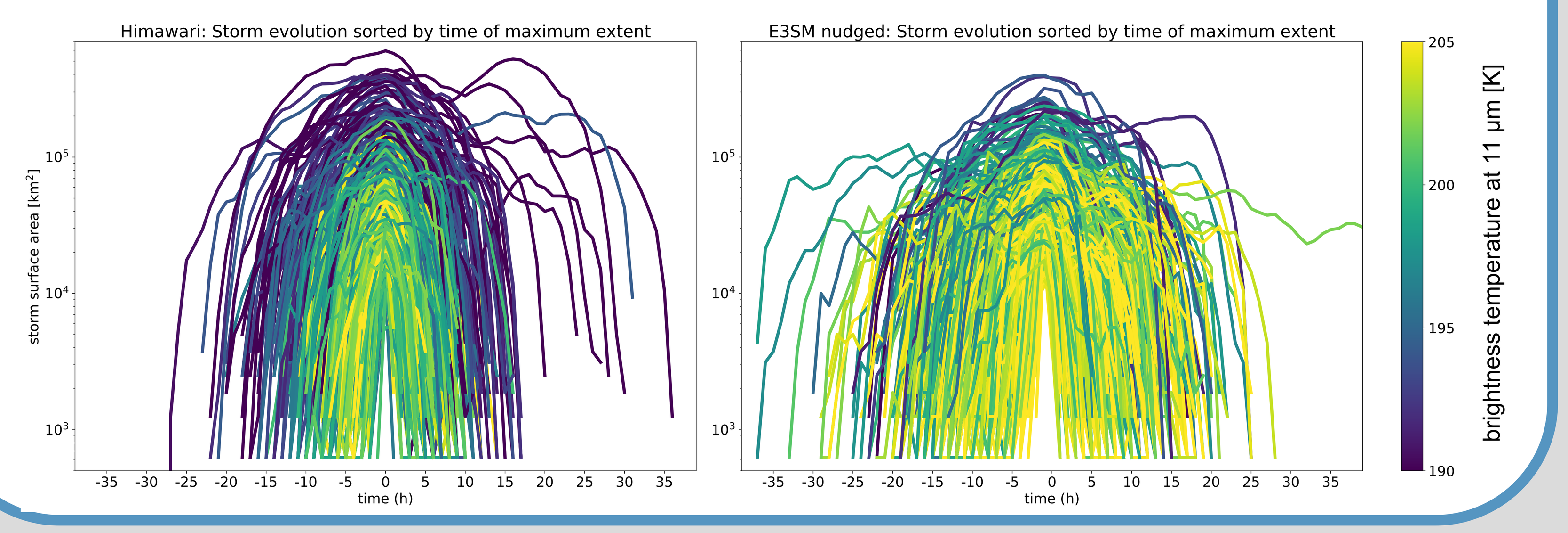


Schematic from Wall et al., 2018

Albedo – OLR histogram for each MCS stage

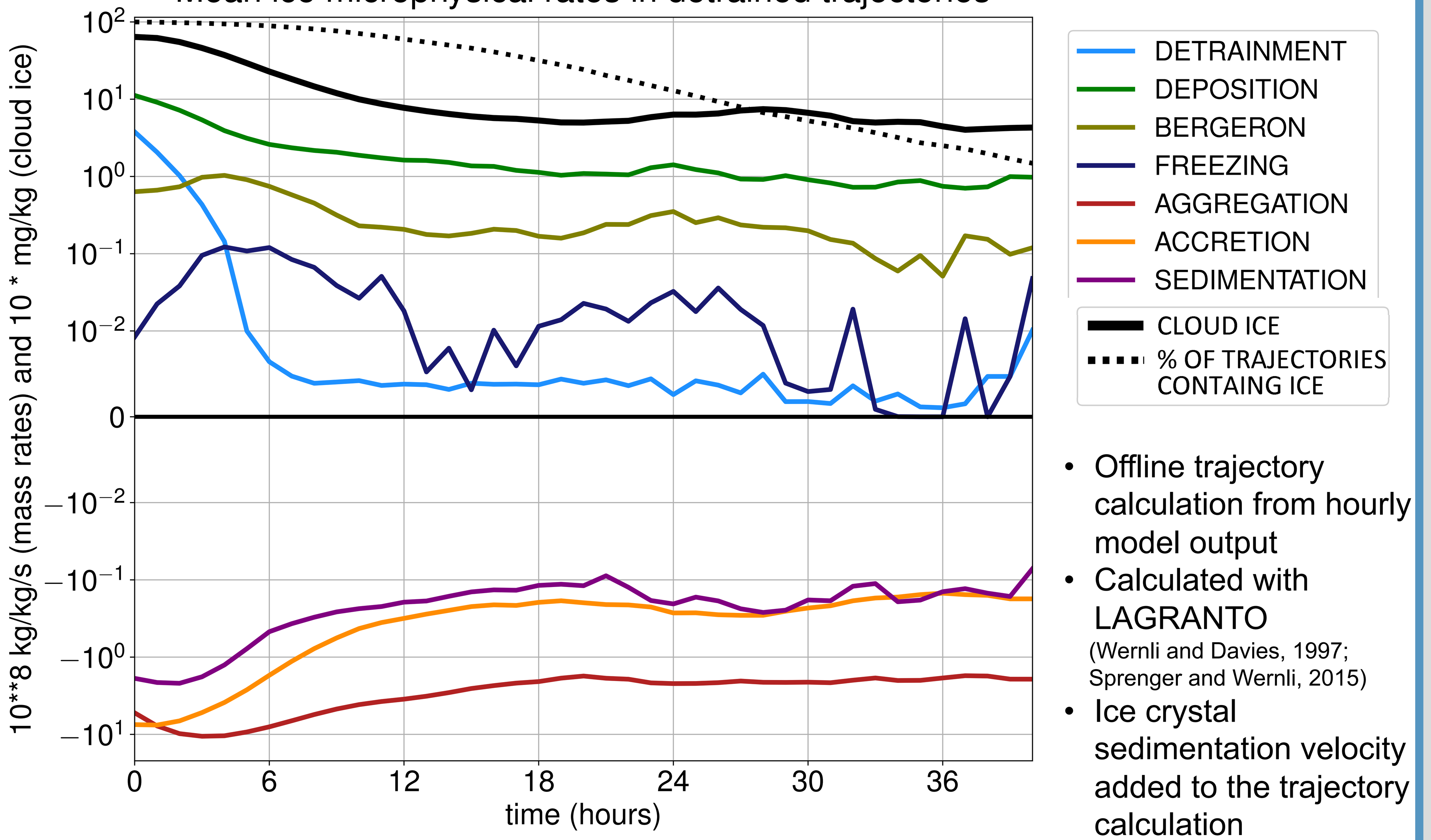


- Problems in simulation of MCS growth and decay (stage I and V)
- Peak of storm (stage III) simulated well, but with smaller albedo and OLR



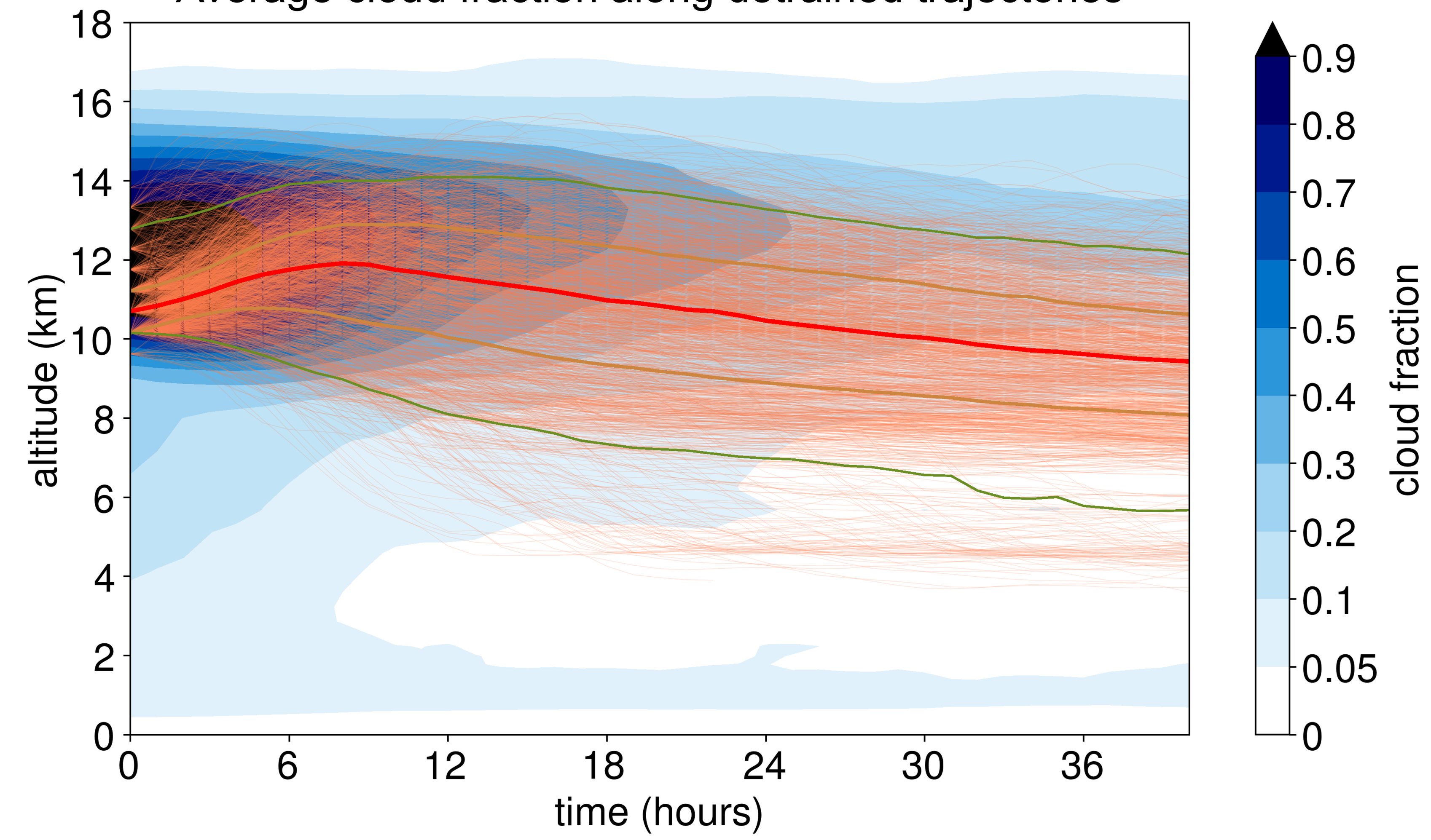
Cloud properties along detrained trajectories

Mean ice microphysical rates in detrained trajectories



- Offline trajectory calculation from hourly model output
- Calculated with LAGRANTO (Wernli and Davies, 1997; Sprenger and Wernli, 2015)
- Ice crystal sedimentation velocity added to the trajectory calculation

Average cloud fraction along detrained trajectories



Outlook

Can Lagrangian methods provide new insights into high cloud responses to global warming?

Compare hydrometeor tracking vs. air parcel tracking

Sensitivity to deep convective parameterization

Acknowledgements

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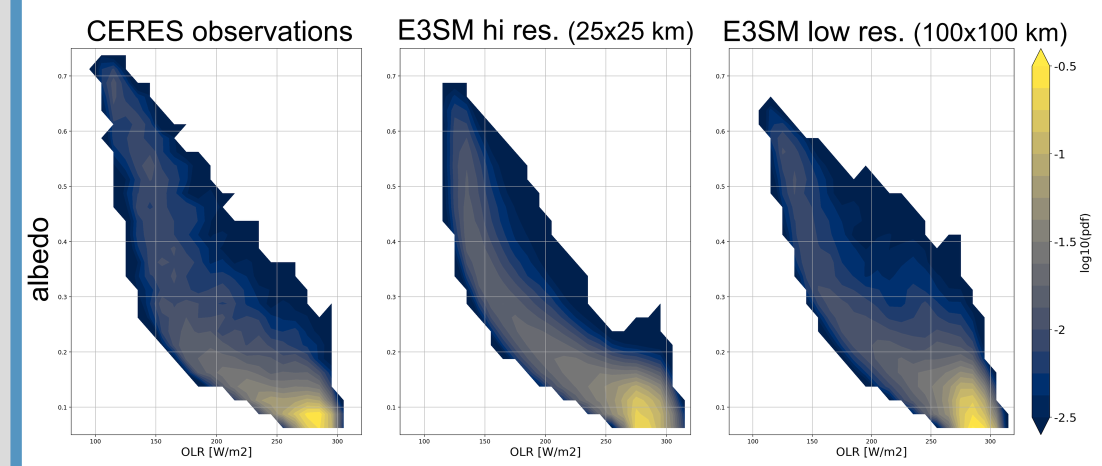
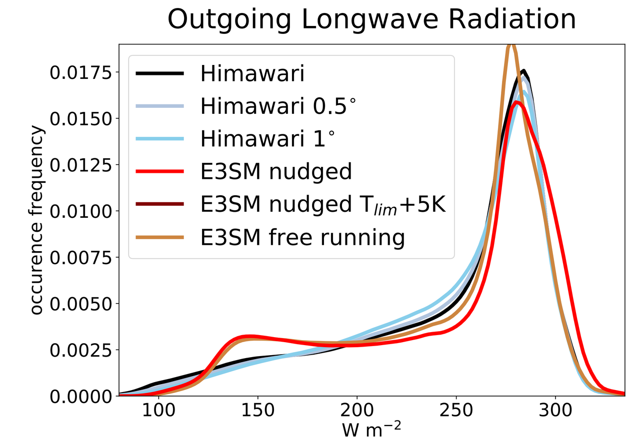
Conclusions

1. Deposition of vapor is the dominant source of ice in simulated ice clouds
2. Snow formation is the dominant sink of ice
3. E3SM represents well the climate in the Tropical Western Pacific

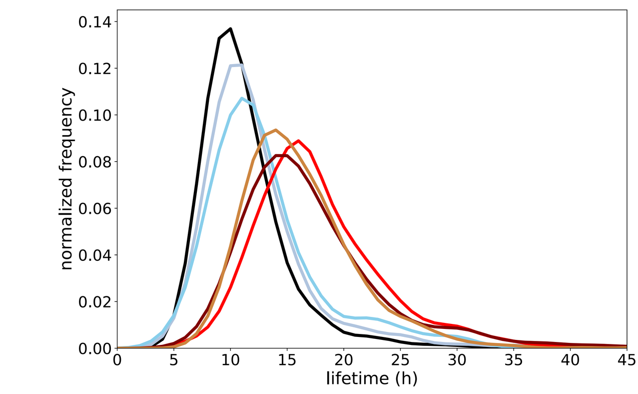
More E3SM model evaluation

The albedo-OLR distribution in E3SM matches well with CERES observations (ocean only, 12°S to 12°N, 150°E-170°E)





E3SM fails to simulate the strongest storms (with lowest OLR, highest precipitat. rates)



Simulated MCS evolution is comparable to observations, but MCS are too long-lived

MCS stage	Himawari (JJA 2016, 2500 tracked storms)	E3SM nudged (JJA 2016, 1400 tracked storms)	E3SM /Himawari fractional coverage [%]
I	2.5 h	3.7 h	6.5 / 6.0
II	1.8 h	3.1 h	21.0 / 16.7
III	3.2 h	5.3 h	49.5 / 51.4
IV	1.7 h	2.9 h	17.1 / 19.7
V	2.1 h	3.0 h	5.9 / 6.1
total	**11.3 h**	**18.2 h**	100 / 100
Mean maximum area [km^2]	4.6 x 10^4	5.5 x 10^4	/