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Observed Relationships between Cloud Fraction Trends of Shallow and Free-atmosphere Clouds

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Clouds play a critical role in the climate system by modifying incoming and outgoing radiation. In turn, clouds are affected by climatic changes. Cloud fraction (CF, the part of the sky covered by clouds) is one of the most reliable observed cloud properties and can be regarded as a good first approximation for cloud radiative effects.

Different types of clouds modify the energy budget and respond to climatic changes differently. Current climate models predict a negative trend in CF of shallow clouds (with low top height), which will further warm the climate by reducing the reflection of solar radiation. For other types of clouds, the predicted trend in CF has a net-zero radiative effect. The modeled results suffer from large variability and it contributes greatly to the uncertainty of climate projections. Therefore, observational constraints are badly needed.

Here, we divide the cloud records into three classes: total clouds (including all clouds), shallow clouds (with top pressure > 700 hPa), and free-atmosphere clouds (other than shallow). For each class, we decompose the general CF into two parts: one which is related to clouds' horizontal size (CF under cloudy conditions) and a second part, related to the frequency of occurrence (the ratio of cloudy days to all days). 17 years (2003-2019) of satellite observations (MODIS aboard Aqua) and reanalysis data (ERA5) are used in this work. Satellite records show significant regional CF trends. They show that: (1) the trend in shallow clouds' size dominates the trend in total CF, (2) there are opposite trends between the shallow and free-atmosphere clouds' occurrence, and (3) the trend in shallow clouds' occurrence compensate the trend in shallow clouds' size and lead to a weak trend in shallow CF. It can indicate the development of shallow clouds into free-atmosphere clouds and it can relate to an overlapping problem, where MODIS cannot detect shallow clouds under other clouds. Reanalysis data reveals that after considering a correction for the overlapping problem of cloudy layers, the observed opposite trends (point no. 2 above) are still detected, but to a smaller extent, indicating that this relationship in MODIS records is impacted by the clouds overlapping problem. This means that when considering a correction for the overlapping problem, larger local trends in shallow clouds' CF (point no. 3 above) are expected. Our findings provide new statistical relationships between clouds' trends by high-quality observational records and shows that the overlapping problem biases systemically the trends in cloud properties.