Cloud distributions over CONUS in recent two decades

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Preliminary results of cloud climatological study combining MODIS and CONUS404 data

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Why it is important to understand cloud distribution in climate models?

- Clouds: a very sensitive and **uncertain** component of the climate system (Stephens et al 2005, Bony et al 2015)
- Climate model: important tool to understand climate evolution and predicting climate changes

⇩

- **Cloud distribution** should be understood and validated properly in climate models.

Which factors causing the cloud uncertainties in traditional climate models?

Source: *The COMET Program, UCAR.*

Recent **continental-scale convection-permitting modeling of current and future climate of CONUS (CONUS404)**
(Liu et al 2017)

But, still, models have uncertainties…

The unique of CONUS404

- More finer spatial resolution ⇒ able to capture hydrological cycle
- Permits **convection** and resolves mesoscale orography at 4-km grid spacing

⇒ address the changes in heavy precipitation and other extremes

As **clouds** are tightly coupled to hydrological cycles and radiative balance

understanding the uncertainties of **cloud distribution** in CONUS404 is a **key** to understand the model performance

improve model predictions

Research questions

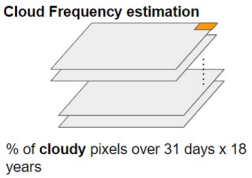
(1) Comparison of **cloud distribution** from MODIS/CONUS404 regionally and temporally

(2) Cloud climatology analysis across CONUS in recent 2 decades (2002 - 2020). What are seasonal and diurnal variations of **each cloud type** across CONUS?

Study domains and Methods

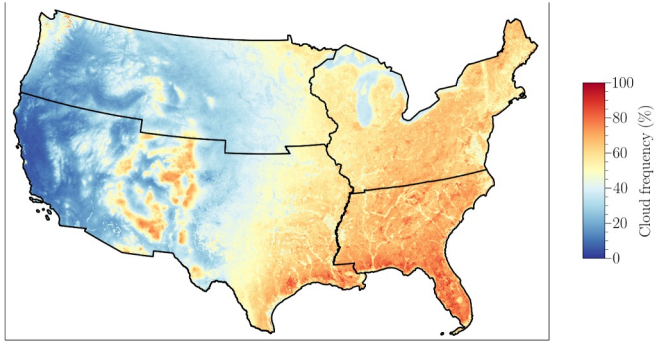
❖ **Dataset:**

1. **Satellite observations (Aqua MODIS Cloud mask layer (MYD35-L2)**
   - twice a day (~13:30 and 1:30 equator passing time),
   - 2002 - 2020
   - 1 km
2. **Long-term convection-permitting simulation (CONUS404)**
   - Hourly
   - 2002 - 2020
   - 4 km

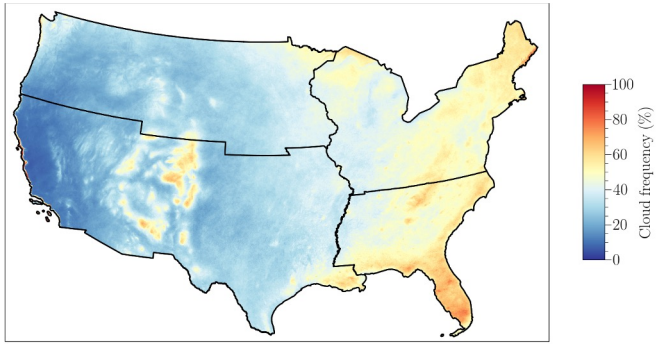


❖ **Cloud frequency (%):** percentage of days with cloudy pixels for a certain month within 18 years

MODIS



CONUS404

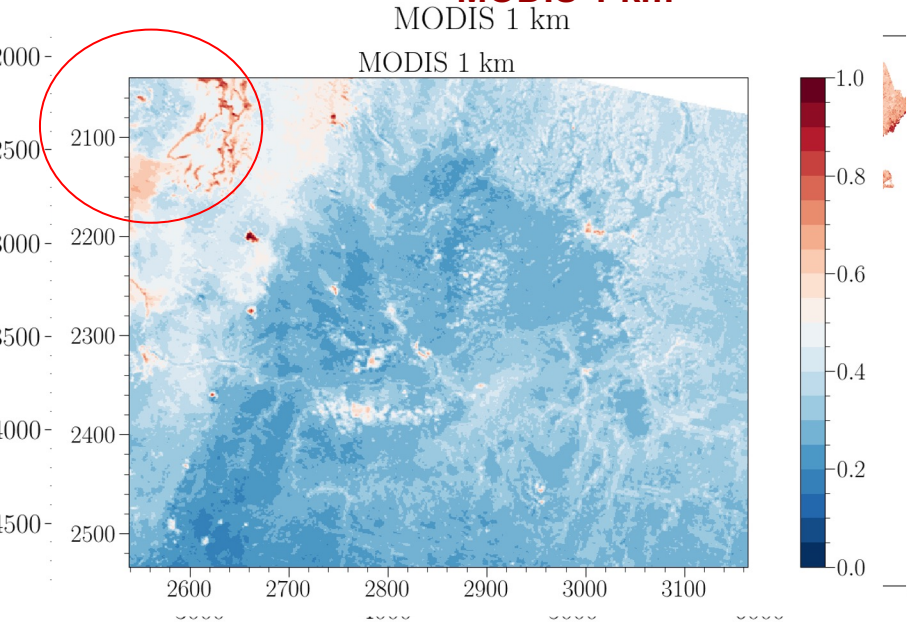


An example of **MODIS** (top) and **CONUS404** (bottom) composite cloud frequency maps for July **daytime**

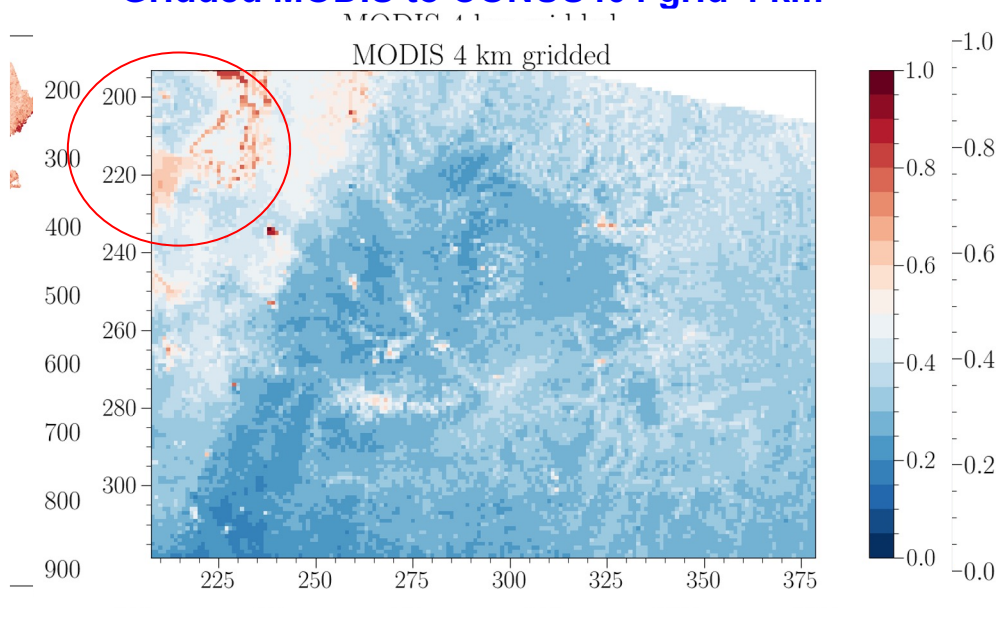
Study domains and Methods

- **Regridding MODIS grids to corrected CONUS404 grids**
  - Interpolation method: linear interpolation

MODIS 1 km



Gridded MODIS to CONUS404 grid 4 km



Study domains and Methods

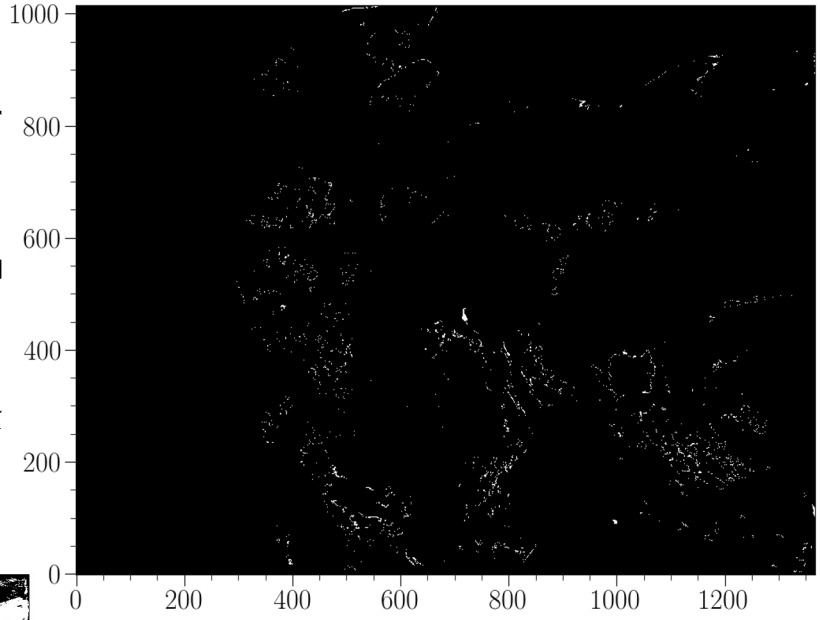
❖ Definition of cloudy pixels

- **MODIS:** pixels are classified as 'probably' and/or screening algorithm (Ackerman et al 1998)

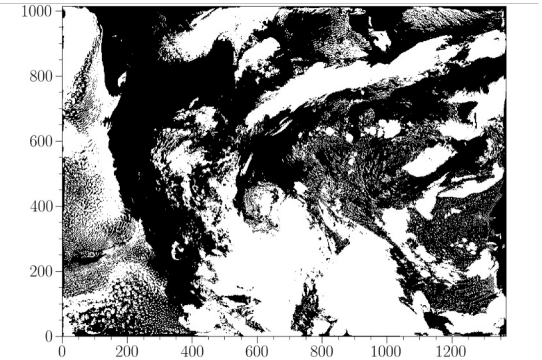
  ⇒ MODIS cloud screening algorithm faces most u Wang 2015)

- **CONUS404:** Cloudy pixels: pixel with a maximur larger than **0.01 (1%)**

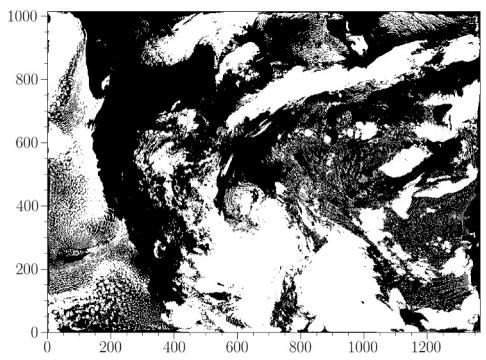
Difference between 5% - 1%

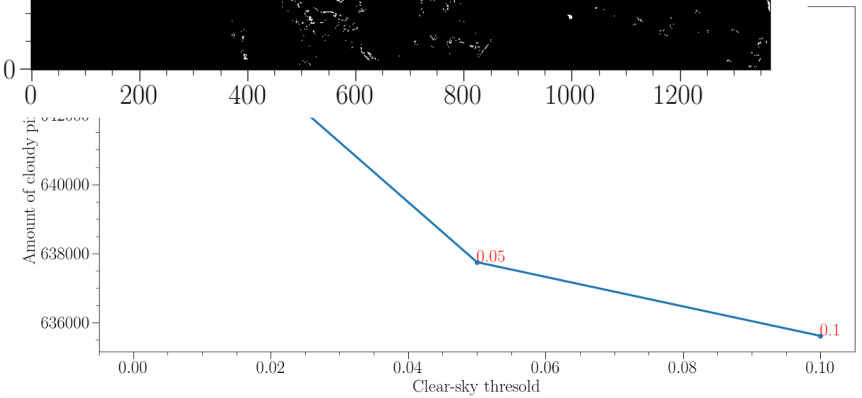


1%



5%



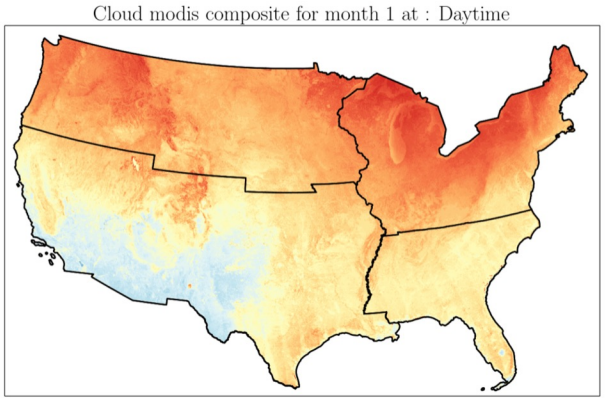


2013-07-15:20:00:00 UTC

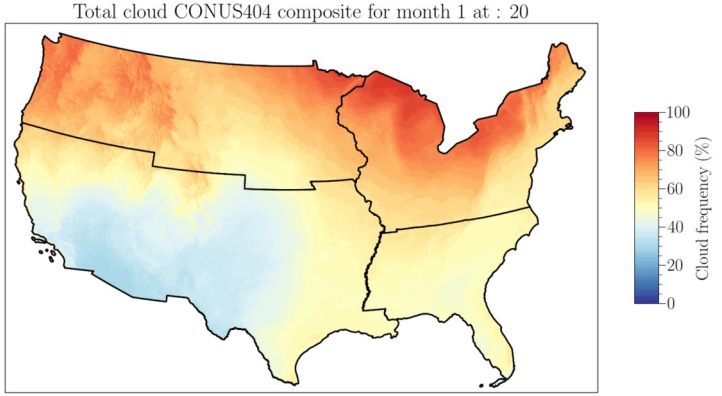
[0%, 0.1%, 1%, 5%, 10%]

Seasonality

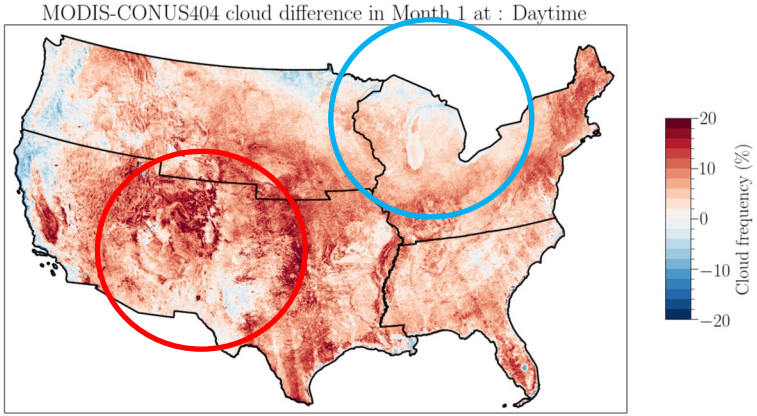
MODIS



CONUS404



MODIS - CONUS404

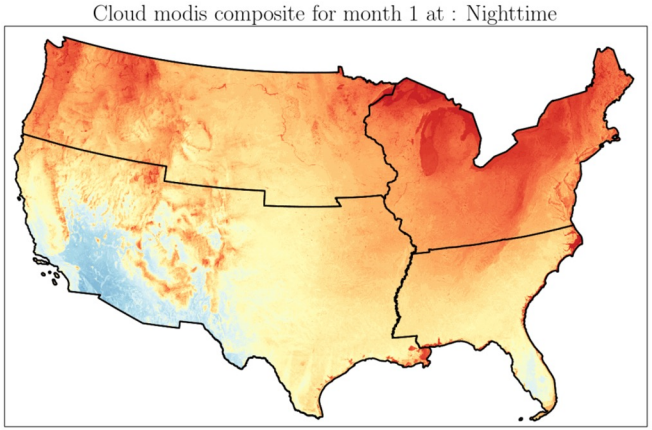


Daytime

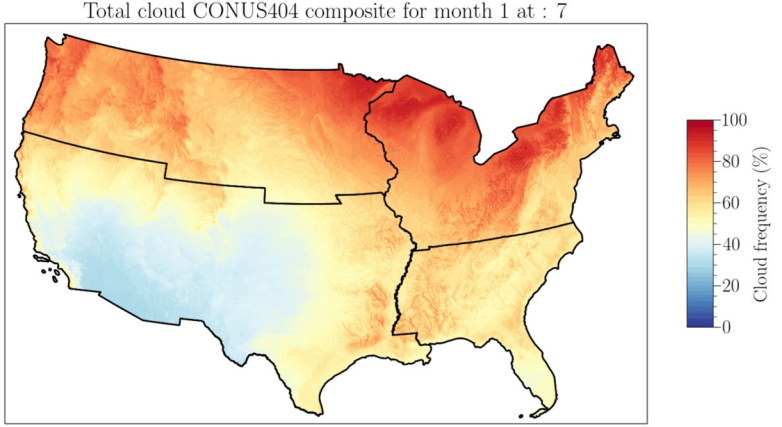
Seasonality

Nighttime

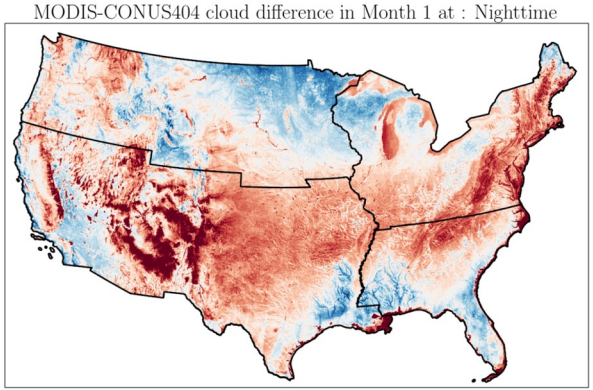
MODIS

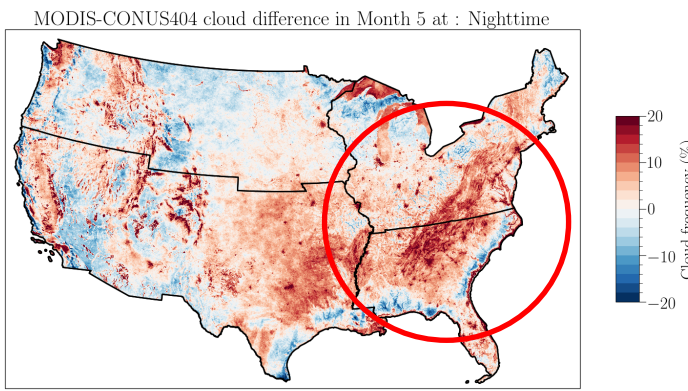


CONUS404



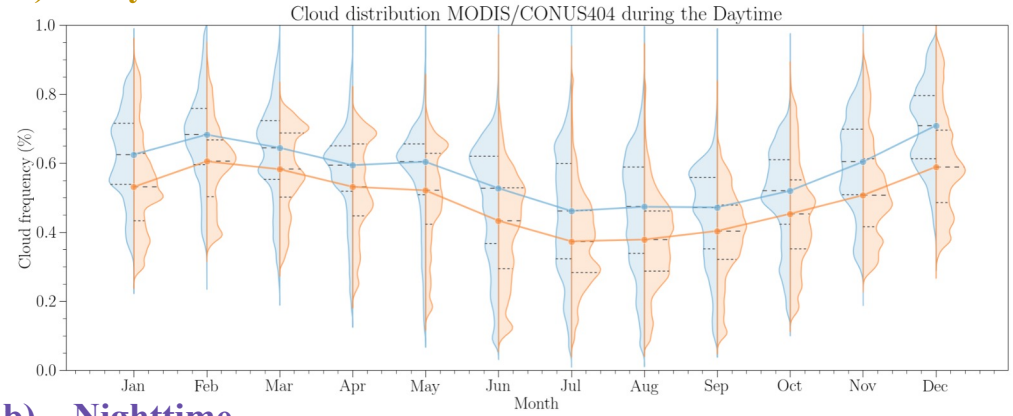
MODIS - CONUS404



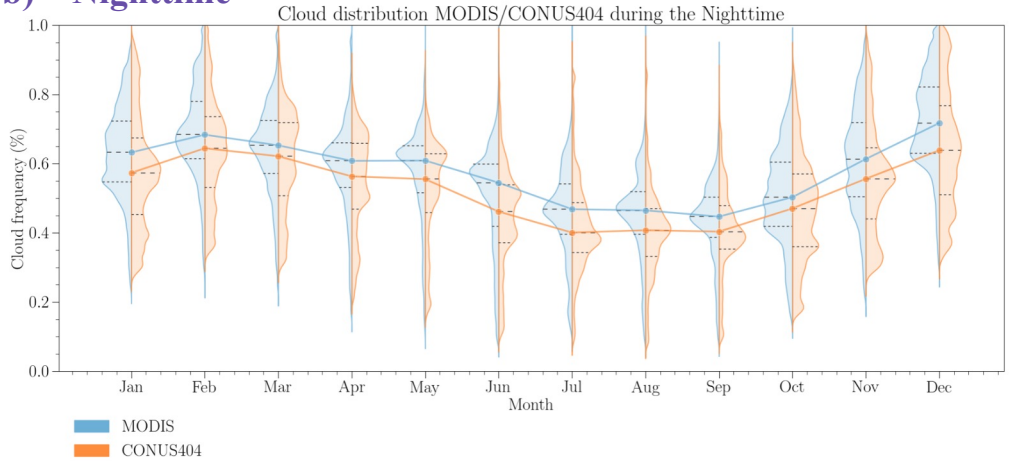


Cloud distribution MODIS/CONUS404

a) Daytime

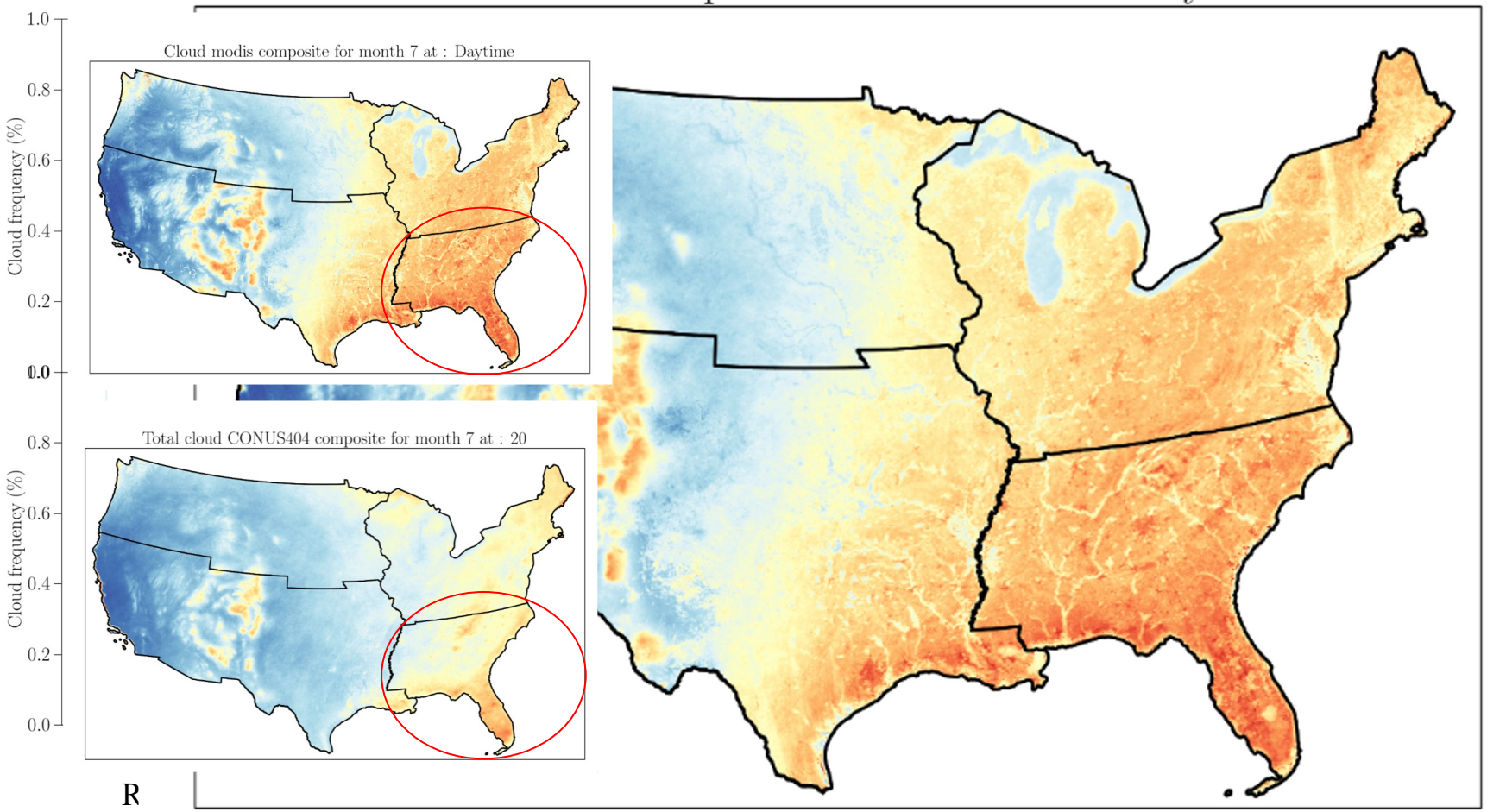


b) Nighttime



Seasonal variations of cloud distribution MODIS/CONUS404 during the (a) **daytime and** (b) **nighttime**

- CONUS404 underestimates clouds as compared to MODIS;
- **Diurnal**: daytime difference (7 - 12 %, median) is stronger than nighttime difference (4 - 6 %)
- **Seasonal:** daytime: strongest difference in December (~ 12%); Nighttime: in June (~ 6%)


Cloud modis composite for month 7 at : Daytime
Cloud frequency (%)
1.0
0.8
0.6
0.4
0.2
0.0
Cloud modis composite for month 7 at : Daytime
Total cloud CONUS404 composite for month 7 at : 20
Cloud frequency (%)
0.8
0.6
0.4
0.2
0.0

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NUS

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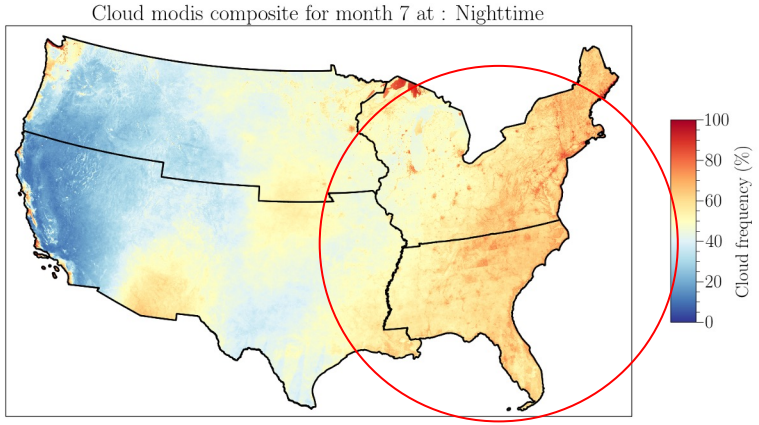
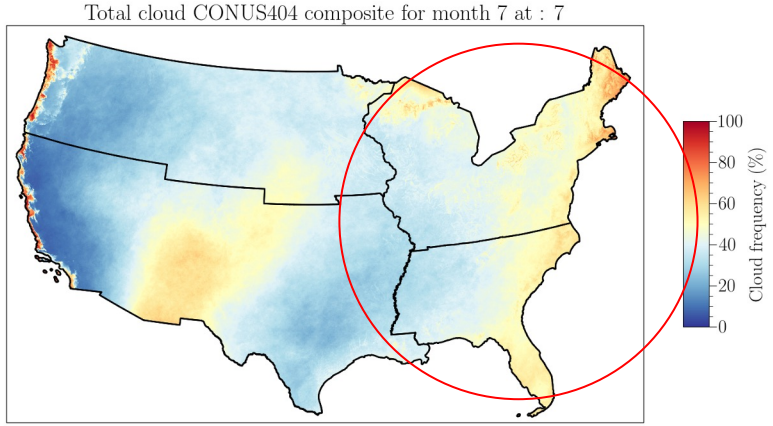
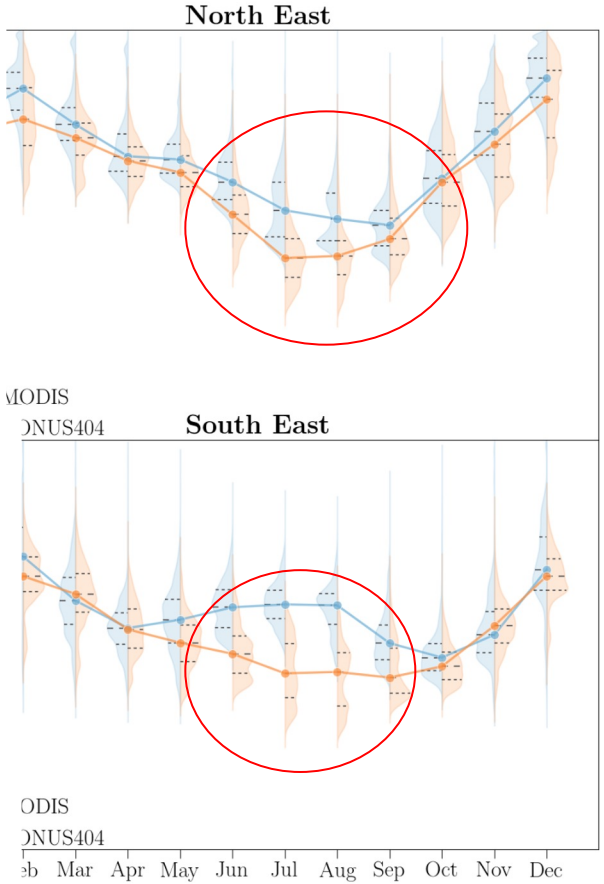
ariance / Nighttime







Nighttime:

- Overall, nighttime regional patterns show stronger **agreements**, except for South East
- CONUS404 overestimates in transition months (Mar, Nov) in South East

Regional variance of cloud distribution MODIS/CONUS404 during the **nighttime**

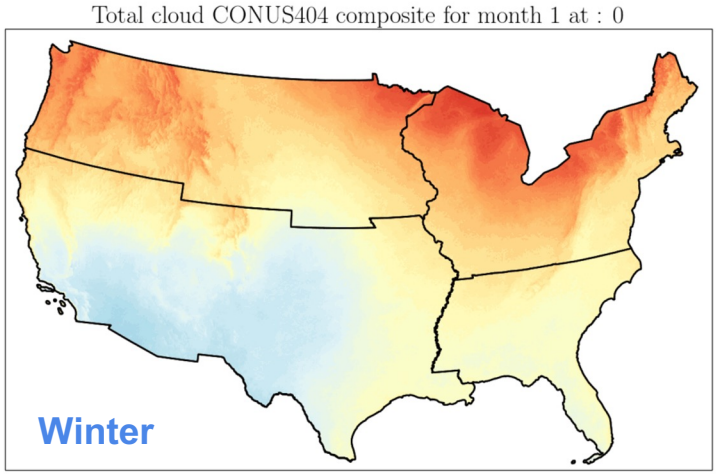
Part 1: By observing regional and temporal variance in MODIS/CONUS404 cloud distribution comparison

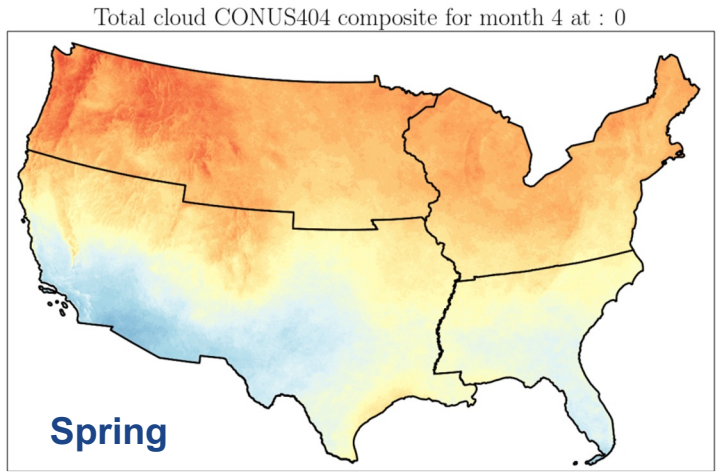
⇒ there are some underlying mechanisms causing such differences

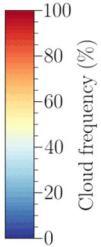
Part 2: Cloud climatology analysis of different cloud **types** using CONUS404 product

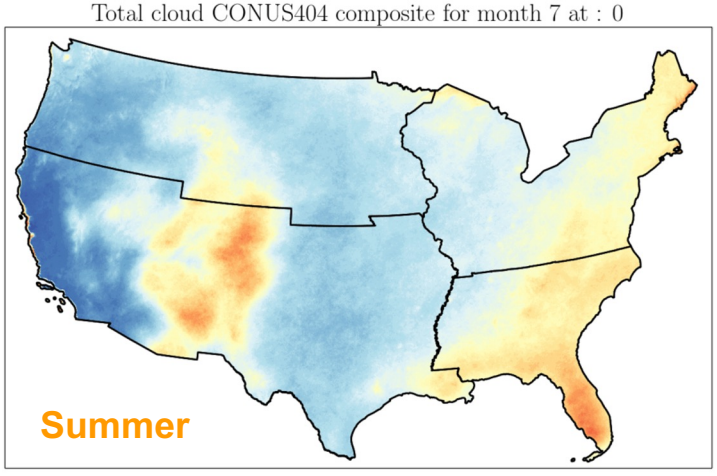
⇒ better understanding the physical mechanisms causing such different cloud patterns (as each cloud is relevant to different physical processes)

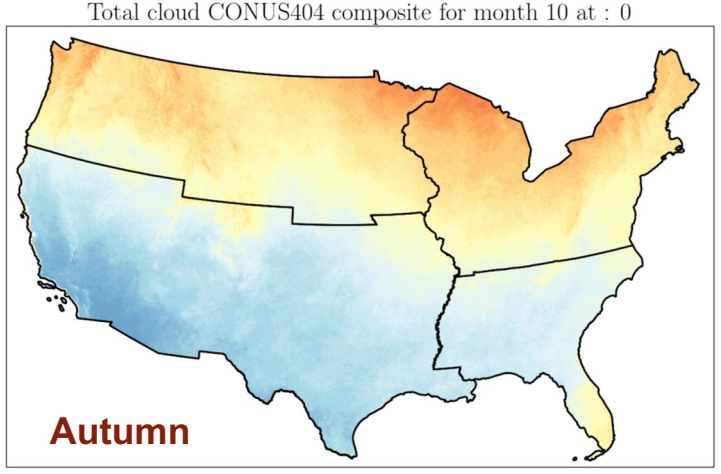
All clouds

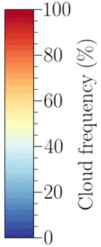

Total cloud CONUS404 composite for month 1 at : 0
Winter


Total cloud CONUS404 composite for month 4 at : 0
Spring

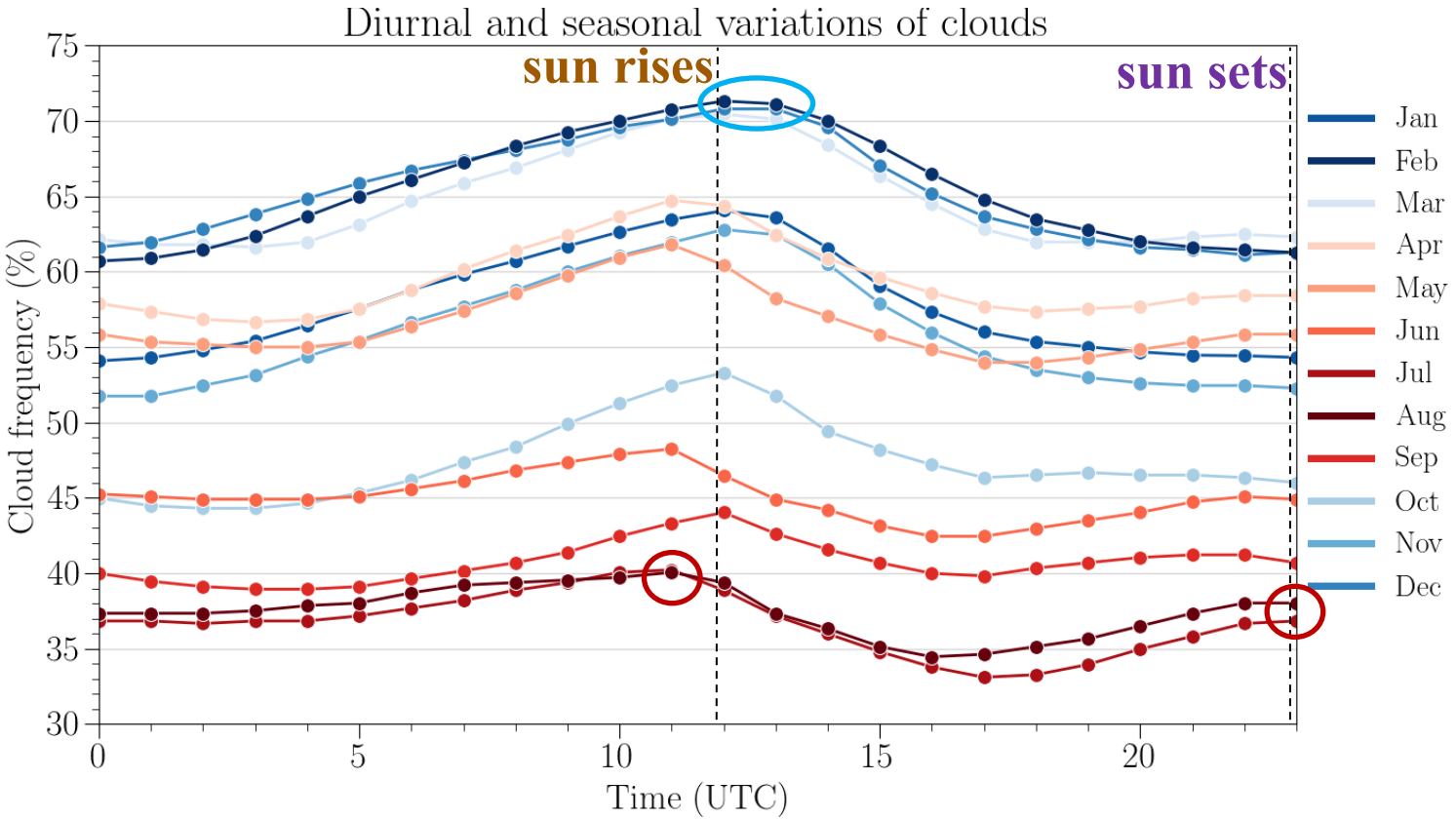

100
80
60
40
20
0
Cloud frequency (%)


Total cloud CONUS404 composite for month 7 at : 0
Summer


Total cloud CONUS404 composite for month 10 at : 0
Autumn


100
80
60
40
20
0
Cloud frequency (%)

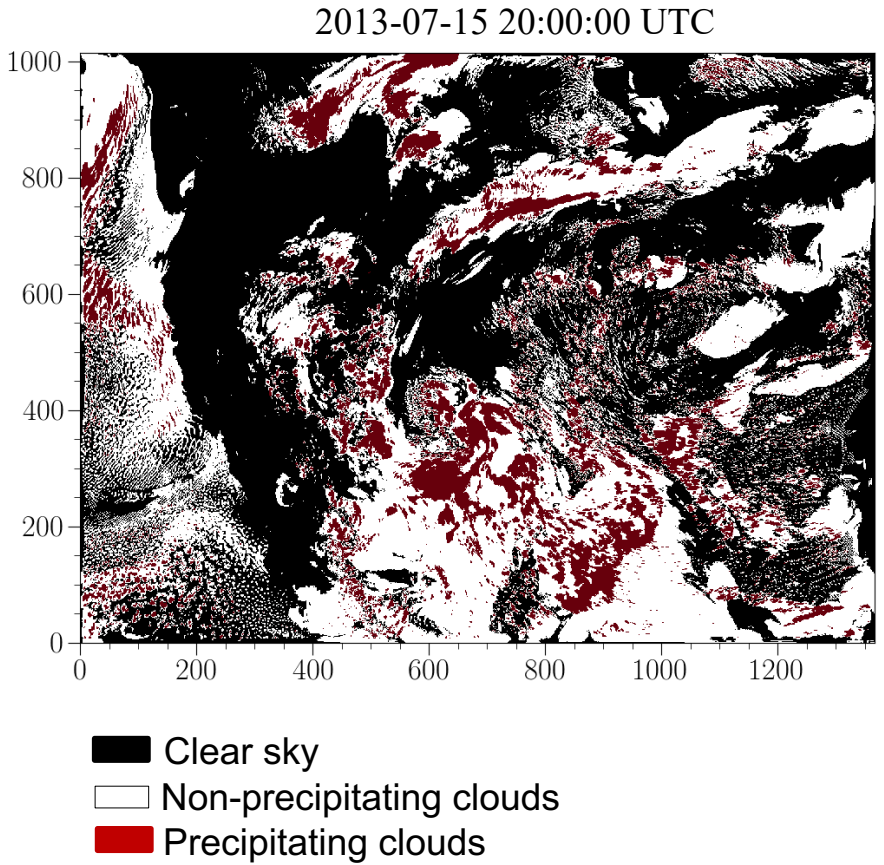
Diurnal and seasonal variations of clouds



- Strong **seasonality** of cloud diurnal cycle
- Diurnal: **double** peak clouds in summertime; **one** peak clouds in other seasons

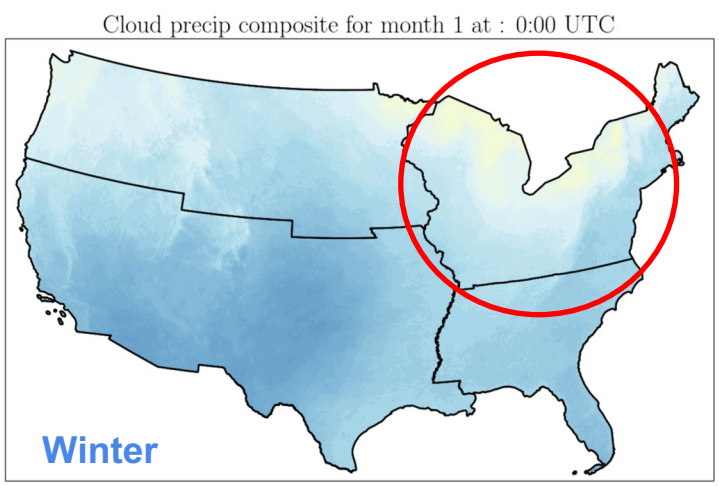
Precipitating / Non-precipitating cloud climatological analysis

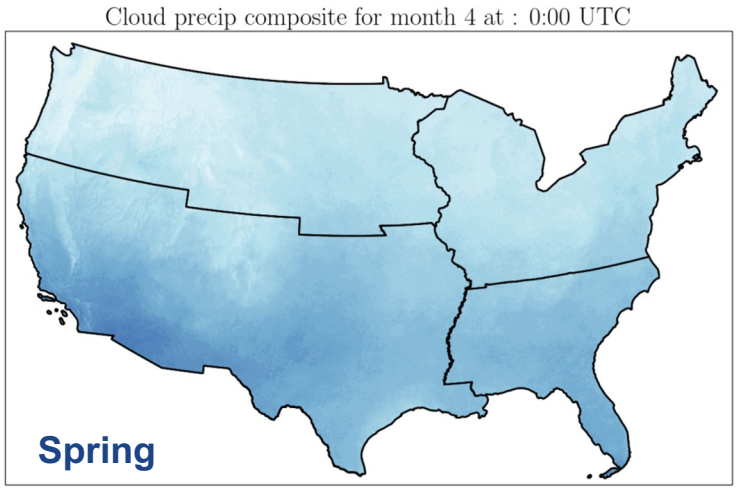
- **Precipitating clouds**: the maximum cloud fraction experienced the accumulated rainfall rate larger than 0.01 mm/hr
- **Non-precipitating clouds**: the maximum cloud fraction experienced the accumulated rainfall rate smaller than 0.01 mm/hr

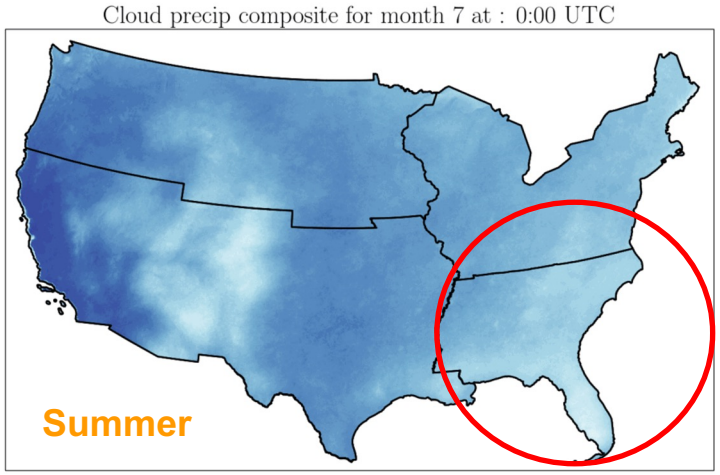


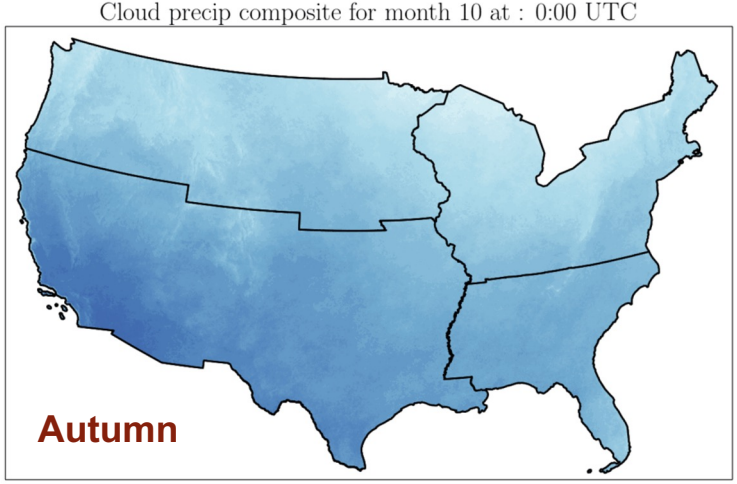
PREC_ACC_NC: ACCUMULATED GRID SCALE PRECIPITATION OVER PREC_ACC_DT PERIODS OF TIME

Precipitating clouds

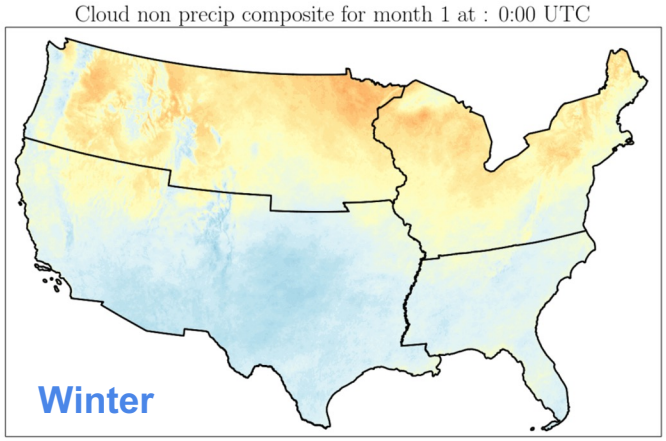


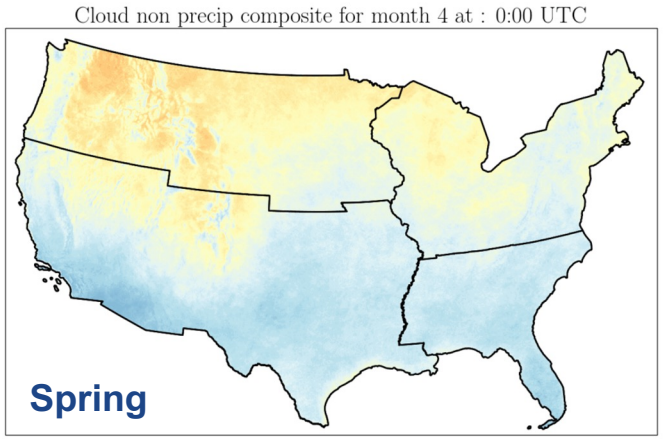


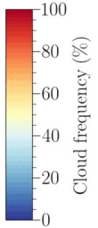


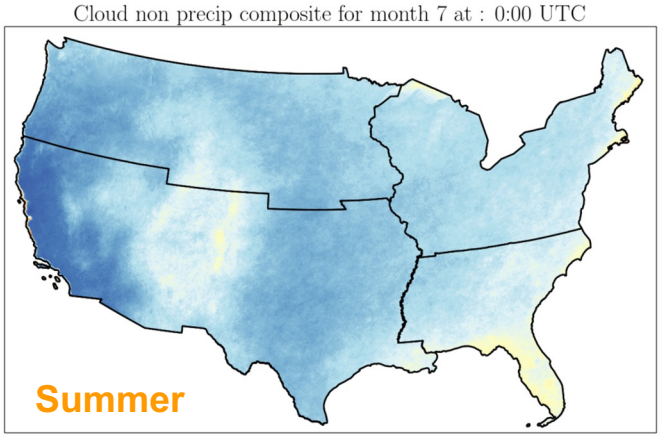


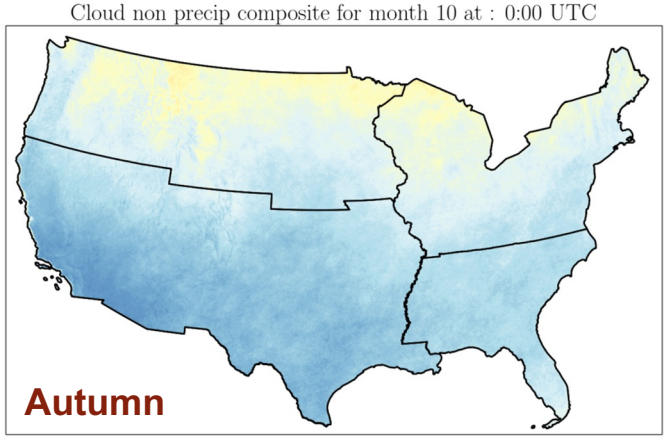
Non-Precipitating clouds

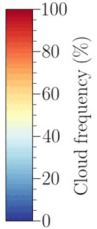


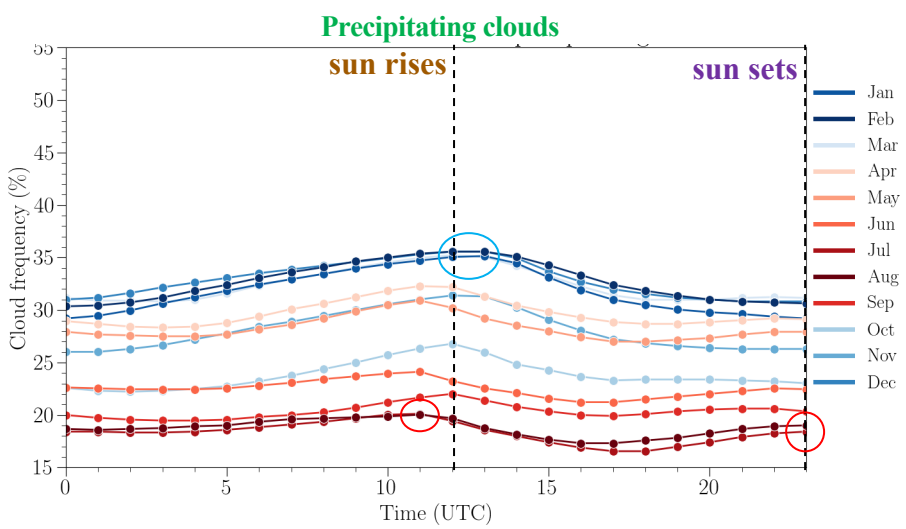


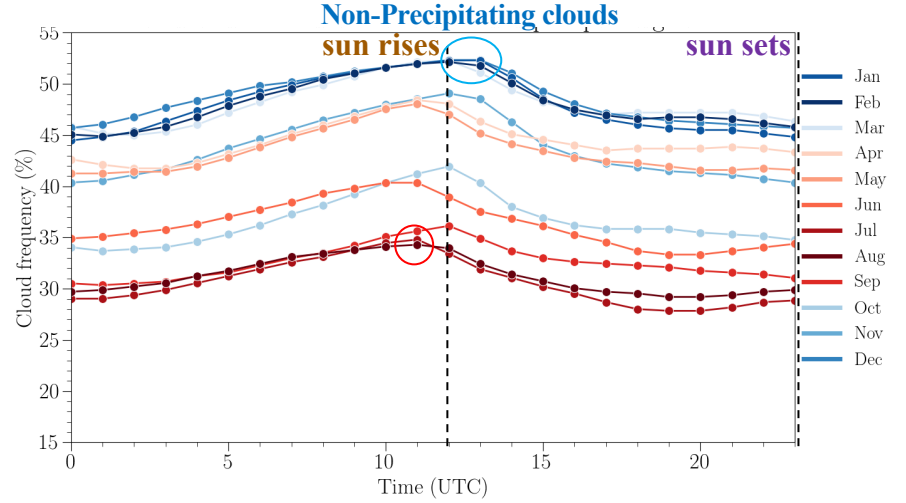












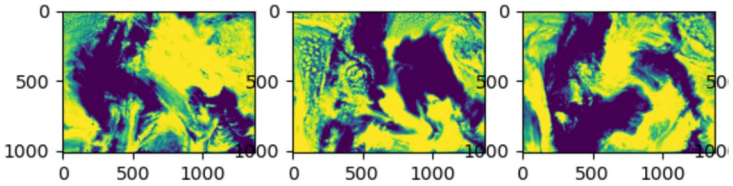
- Stronger frequencies of non-precipitating clouds
- Similar diurnal patterns

Low-mid-high cloud climatological analysis

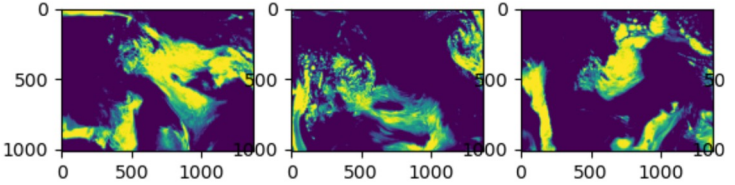
❖ Definition of different cloud type

- ➢ **Low-level clouds**: the maximum cloud fraction within a vertical height: 300 m to 2000 m
- ➢ **Mid-level clouds**: the maximum cloud fraction within a vertical height: 2000 m to 6000 m
- ➢ **High-level clouds**: the maximum cloud fraction with the vertical height larger than 6000 m

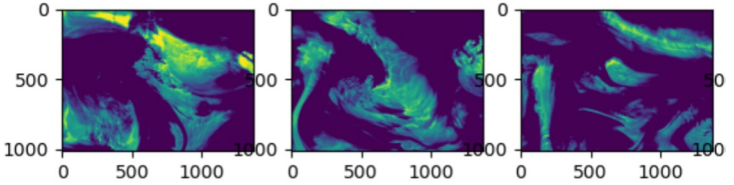
Low-level clouds



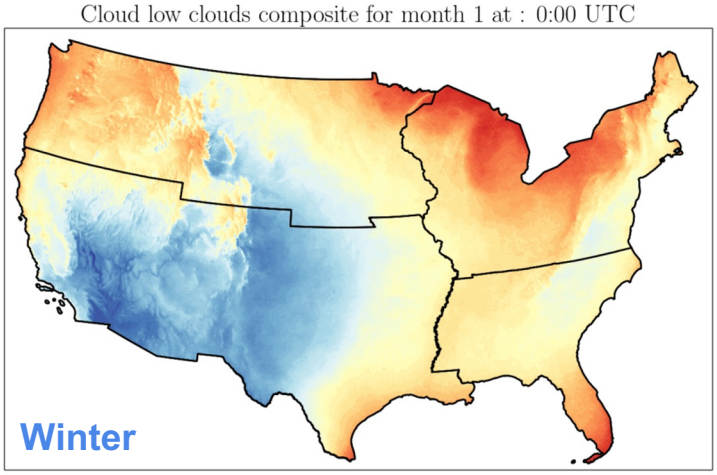
Mid-level clouds

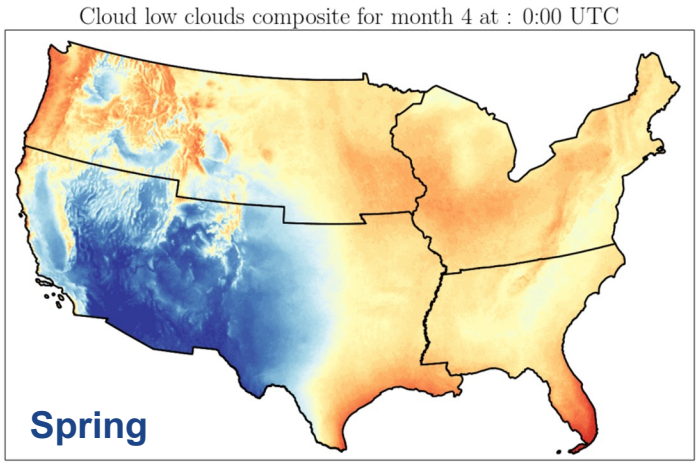


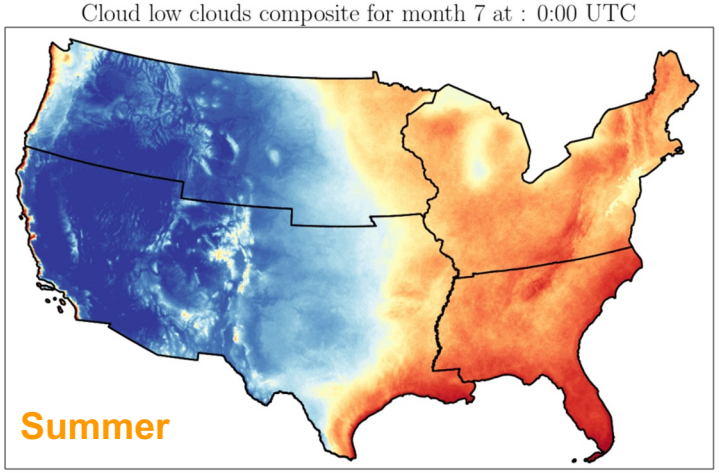
High-level clouds

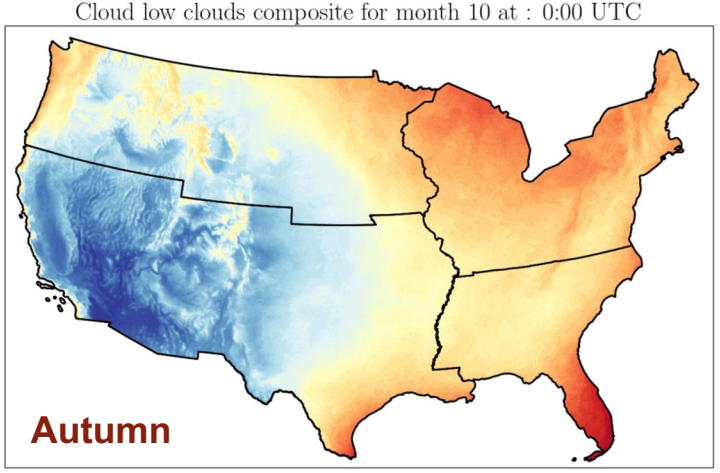


Low-level clouds

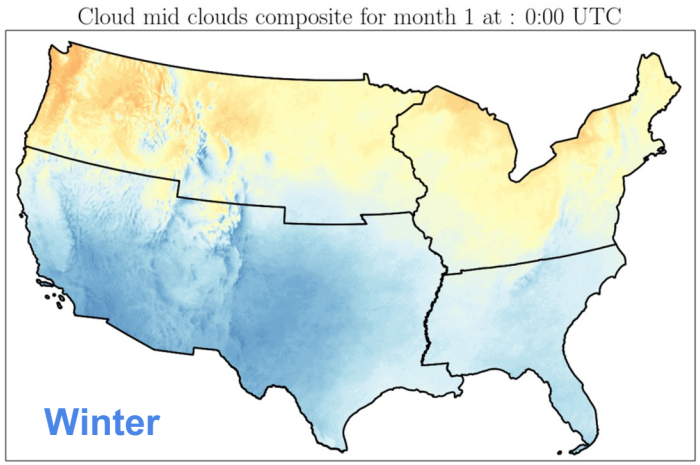


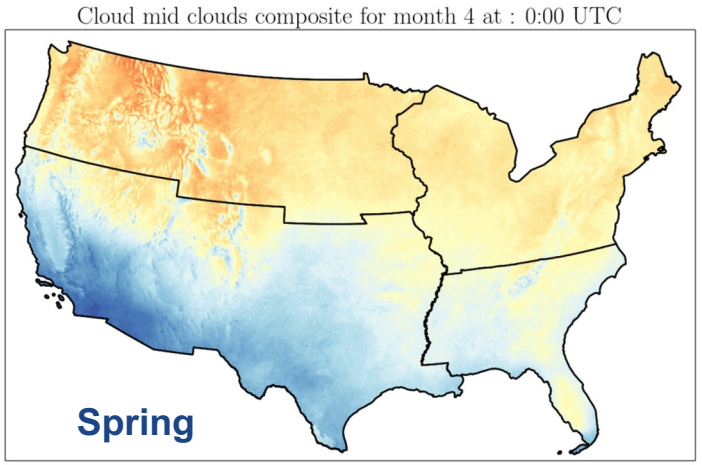


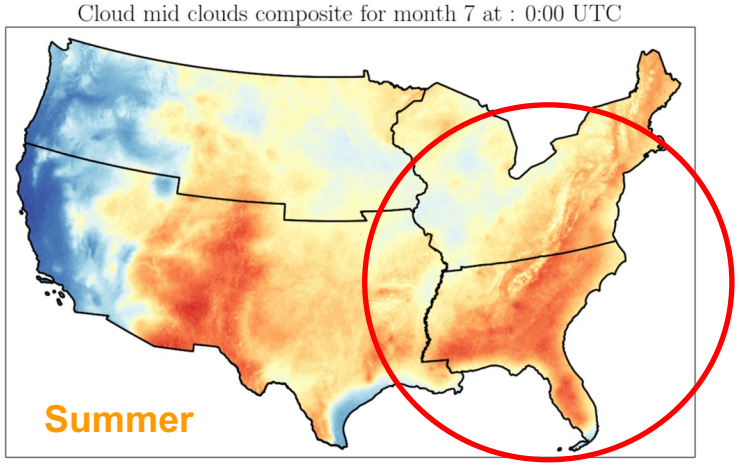


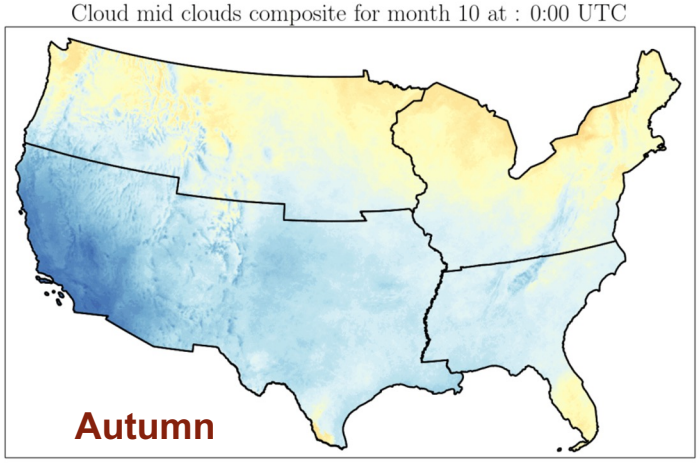


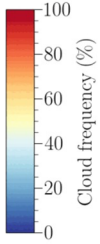
Mid-level clouds

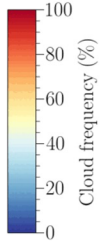




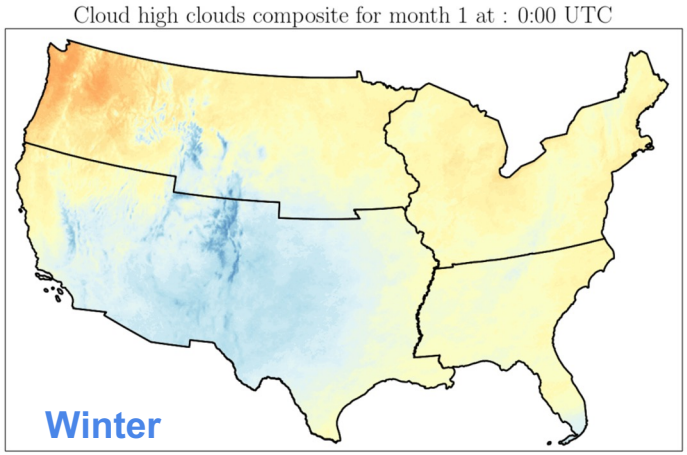


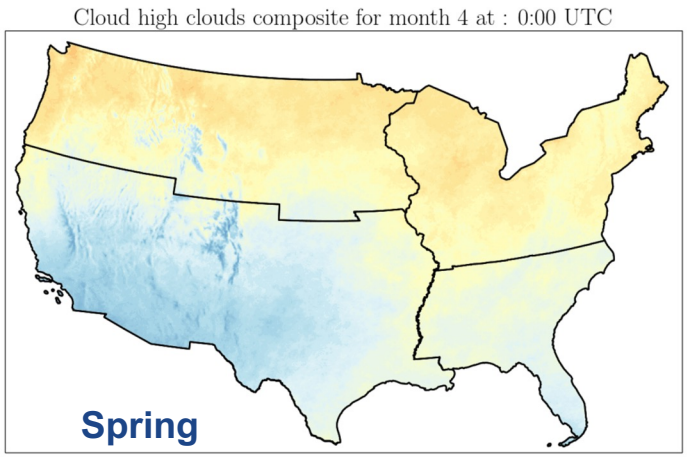


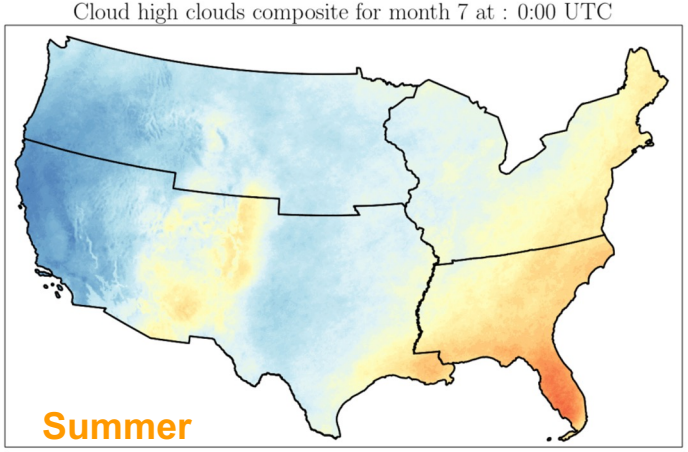


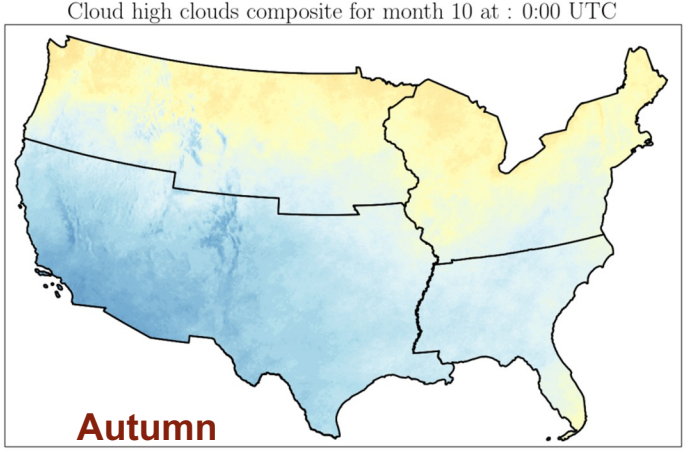


High-level clouds

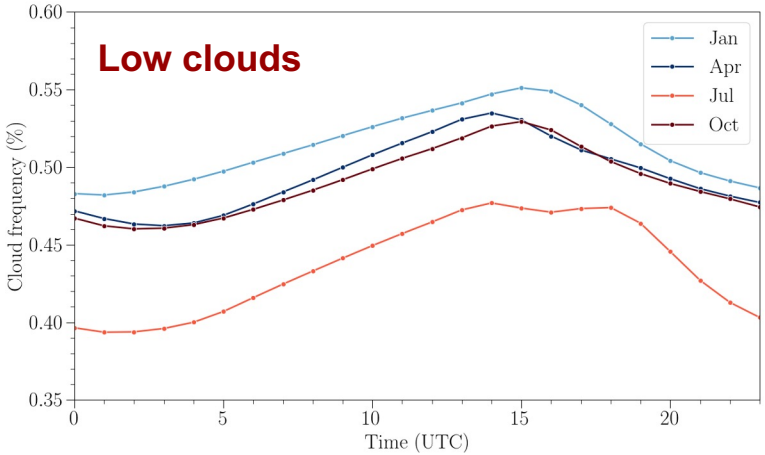


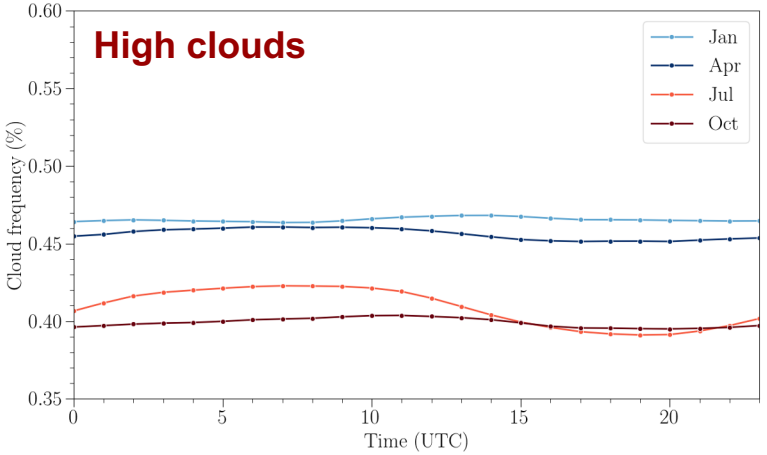


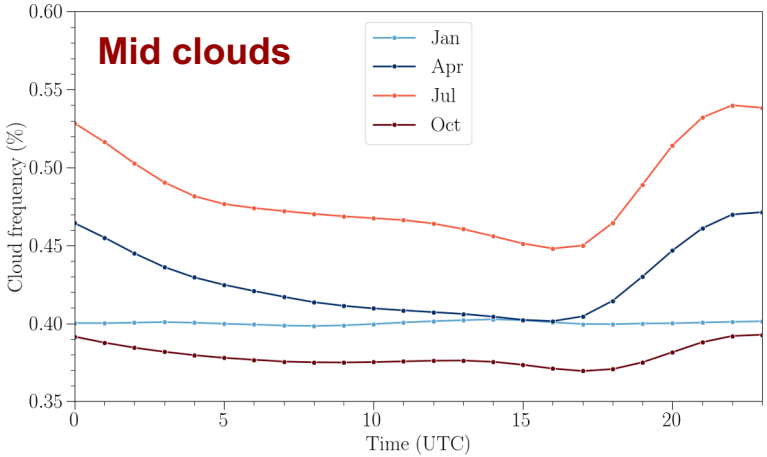




Diurnal and seasonal variations of low-mid-high clouds







- Diurnal cycle of low clouds is strongly coupled to the diurnal solar insolation
- Oppositely, the diurnal patterns of mid-level clouds are not following the diurnal solar insolation.
- Not much variations in high-level clouds

Take home messages

1. **MODIS/CONUS404 cloud distribution**

- CONUS404 underestimates clouds as compared to MODIS
- Daytime clouds show stronger disagreement as compared to nighttime clouds
- South East experienced the most disagreements, particularly in the summertime

2. **Cloud climatologies across CONUS**

- Strong seasonality of clouds across CONUS
- Double-peak clouds in summertime; one-peak in another seasons
- Smaller precipitating clouds magnitudes as compared to non-precipitationg clouds

Future research

- Integrate more sources of satellite observations with more detailed diurnal representation (e.g., GOES-16) to verify the certainties of diurnal cloud products from CONUS404

- Define the potential factors causing the cloud uncertaincies in CONUS404 (e.g., land cover, moisture level, aerosols) for each different cloud types

- Define another appropriate criteria for low-mid-high clouds analysis

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