Cloud distributions over CONUS in recent two decades
-
Preliminary results of cloud climatological study combining MODIS and CONUS404 data

Trang Thuy Vo (tv0015@uah.edu)
The University of Alabama in Huntsville

-----
Lulin Xue
Sisi Chen
RAL, NCAR
Leiqiu Hu
The University of Alabama in Huntsville
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)

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

But, still, models have uncertainties…
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

(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

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
Definition of cloudy pixels

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

  ⇒ MODIS cloud screening algorithm faces most uncertainties in winter/nighttime (An and Wang 2015)

- **CONUS404**: Cloudy pixels: pixel with a maximum cloud fraction in a vertical column that are larger than 0.01 (1%)
Seasonality

MODIS

Cloud modis composite for month 1 at : Daytime

CONUS404

Total cloud CONUS404 composite for month 1 at : 20

MODIS - CONUS404

MODIS-CONUS404 cloud difference in Month 1 at : Daytime

Daytime
Seasonality

Cloud modis composite for month 1 at: Nighttime

Total cloud CONUS404 composite for month 1 at: 7

MODIS - CONUS404

MODIS-CONUS404 cloud difference in Month 1 at: Nighttime

MODIS-CONUS404 cloud difference in Month 5 at: Nighttime

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%)
Regional variance of cloud distribution MODIS/CONUS during the daytime:

- South East: strongest disagreement, particularly in summer daytime
- North West: strongest agreement

In spring, CONUS underestimates clouds in the northern US.
Regional variance of cloud distribution MODIS/CONUS404 during the nighttime

Nighttime:

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

Spring

Summer

Autumn

All clouds

Total cloud CONUS404 composite for month 1 at : 0

Total cloud CONUS404 composite for month 4 at : 0

Total cloud CONUS404 composite for month 7 at : 0

Total cloud CONUS404 composite for month 10 at : 0
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

[Image: Map showing areas with clear sky, non-precipitating clouds, and precipitating clouds]
Precipitating clouds

Cloud precip composite for month 1 at 0:00 UTC

Cloud precip composite for month 4 at 0:00 UTC

Cloud precip composite for month 7 at 0:00 UTC

Cloud precip composite for month 10 at 0:00 UTC

Winter

Spring

Summer

Autumn
Non-Precipitating clouds

Winter

Spring

Summer

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

Winter

Spring

Summer

Autumn
Winter

Cloud mid clouds composite for month 1 at : 00 UTC

Mid-level clouds

Spring

Cloud mid clouds composite for month 4 at : 00 UTC

Summer

Cloud mid clouds composite for month 7 at : 00 UTC

Autumn

Cloud mid clouds composite for month 10 at : 00 UTC
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-precipitation 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 uncertainties in CONUS404 (e.g., land cover, moisture level, aerosols) for each different cloud types

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