Comparison of convective clouds over the continental United States from satellite observations and cloud-resolving atmospheric models

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31 August 2013

Introduction

- Simulating convective clouds remains a major challenge in the climate modeling community
- Traditional GCMs cannot simulate convective clouds explicitly, and must use parameterizations
- Parameterizations have a number of limitations
- Recently, two alternate methodologies for simulating convection have emerged:
- Global Cloud Resolving Model (GCRM)
  - a Cloud Resolving Model extended globally
  - grid spacing of about a few kilometers
  - no convective parameterization
  - can represent the coarser features of larger convective clouds
  - example: Nonhydrostatic Icosahedral Atmospheric Model (NICAM)
- Multiscale Modeling Framework
  - attaches a local CRM to each GCM gridbox
  - CRM replaces convective parameterization and others
  - CRM is often 2D
  - CRMs in adjacent cells cannot communicate directly
  - less computationally expensive than GCRM
  - example: Superparameterized Community Atmospheric Model (SP-CAM)

Introduction (cont’d)

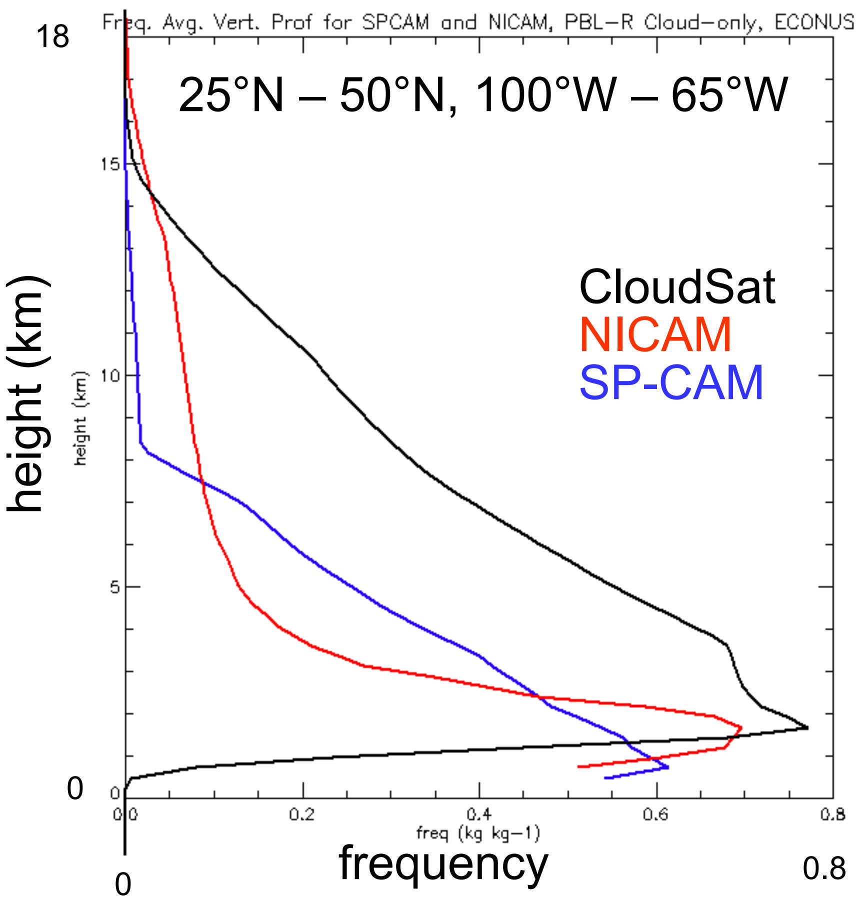
- Question: How well do GCRMs and MMFs represent convection?
  - still limited by microphysical and sub-grid scale parameterizations
  - can only represent coarser cloud processes
- This study seeks identify any major disagreements between observed and simulated convective clouds
- Particular focus – how well are the relationships between conv. clouds and the environment simulated?
- NICAM (7 km res.) and SP-CAM (ver. 4) are chosen to represent the GCRM and MMF
- CloudSat (W band polar-orbiting radar) is used to observe convective clouds
  - good for detecting convective clouds, not so good with thin ice clouds and very shallow clouds

Part 1: Mean cloud vertical growth

- Rationale:
  - The vertical growth of convective clouds determines the heating and moistening/ drying profiles, and where associated clouds form (e.g. anvils)
  - If models cannot simulate vertical growth realistically, then they cannot simulate the associated variables well
  - Recent satellites (e.g. CloudSat) can measure cloud depth directly and accurately, even with multiple cloud layers (no proxy measurements needed)
- Methodology: calculate the mean observed and simulated vertical profiles of convective clouds over the summertime (JJA) continental US (CONUS)
  - CONUS has vigorous summertime convection, and environmental observations are frequent and high quality
- Eastern CONUS is used to avoid mountains
- Model clouds are identified using simulated CloudSat radar reflectivity: cloudy pixel has refl. greater than -28dBZ
  - this allows a fairer comparison between obs. and models
- A convective cloud is identified as any cloud with a base in the planetary boundary layer (i.e. within 3000 m of the surface)
  - all other clouds are removed from results
- Observation time domain: JJA 2006-2010
- Model time domain: single JJA season
- SP-CAM cloud data are taken from the CRM-level, not GCM level

Mean vertical profiles – convective cloud-only

Mean vertical COF profile, ECONUS



- Cloud Occurrence Frequency (COF) vertical profile, normalized by number of clouds
  - shows when a conv. cloud forms, where it is, and how deep
- Observed COF maximizes at 1.8 km, decreases slowly to 4 km, then decreases steadily to 15 km
- 1.5 to 4 km region is probably shallow cumulus layer
- above 4 km is transition from shallow CU to CU congestus to DCC
- Both NICAM and SP-CAM do not produce deeper conv. clouds as often as observed
  - NICAM COF decreases exponentially with height
  - SP-CAM COF decreases to near-zero at 8 km
- Neither model produces a noticeable cumulus layer
- horiz. res. too low to represent shallow CU

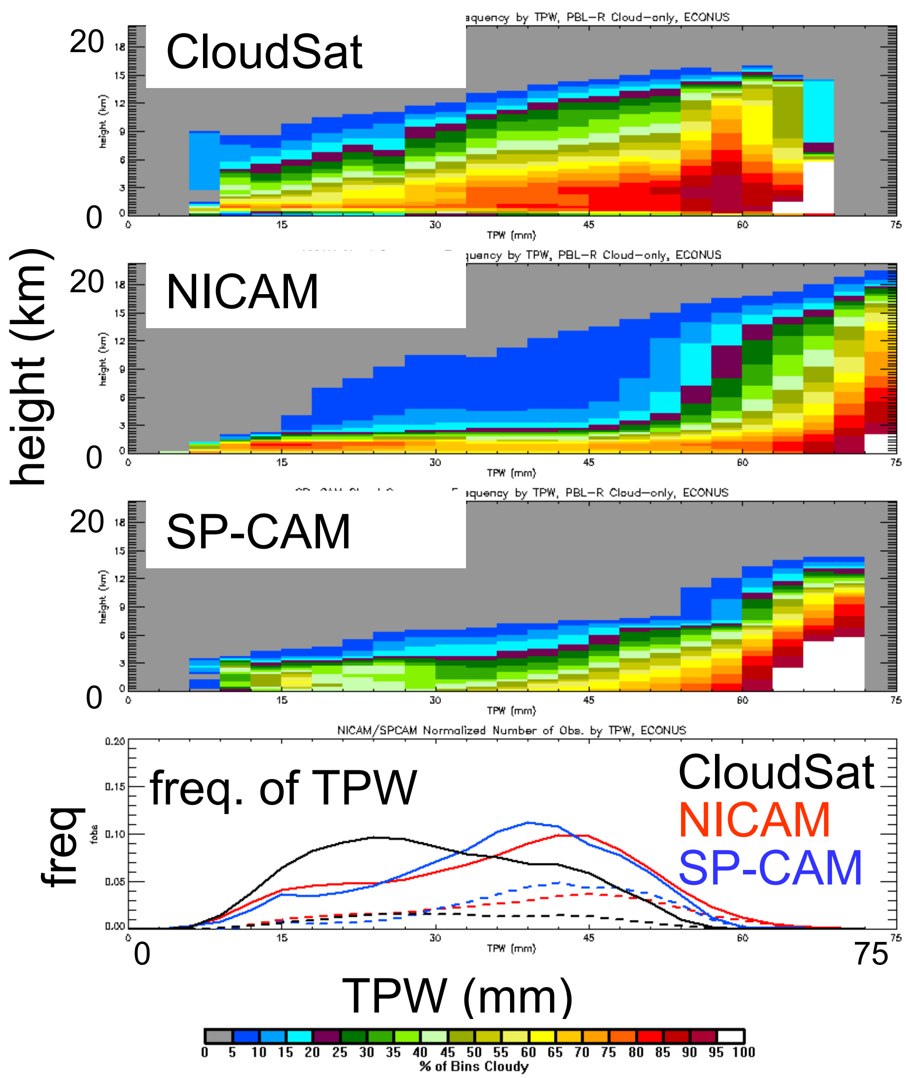
Part 2: Conditional Sampling of Mean Cloud Vertical Growth

- Conditional sampling: restricting the samples included in an analysis systematically using a related variable
- For example: sampling cloud properties according to an environmental variable (e.g. temperature)
- Conditional sampling can help reveal the relationship between clouds and the environments they form in
- This technique has been used frequently in studies of tropical deep convection
  - e.g. outgoing longwave radiation versus sea surface temperature
- This technique has gained interest recently as new datasets have become available
  - we can now use more direct measurements of cloud properties instead of proxies (OLR)
- In the past, CloudSat data have been used in conjunction with A-Train data to conditionally sample tropical convection
- This study will apply the same technique to CONUS convection

Part 2: Conditional Sampling of Mean Cloud Vertical Growth (cont’d)

- Methodology: conditionally sample the vertical COF profiles of conv. clouds according to large-scale environmental variables
  - “large-scale”: averaged over 100 km
- Three variables used: total precipitable water (TPW), surface air temperature (SAT), and 500 hPa vertical velocity (W500, averaged over 2° x 2 °)
  - only TPW will be discussed
- “Observations” of large-scale environment are taken from North American Regional Reanalysis
  - refinement of the NCEP/NCAR Reanalysis for CONUS

Mean vertical profiles sorted by TPW – convective cloud-only

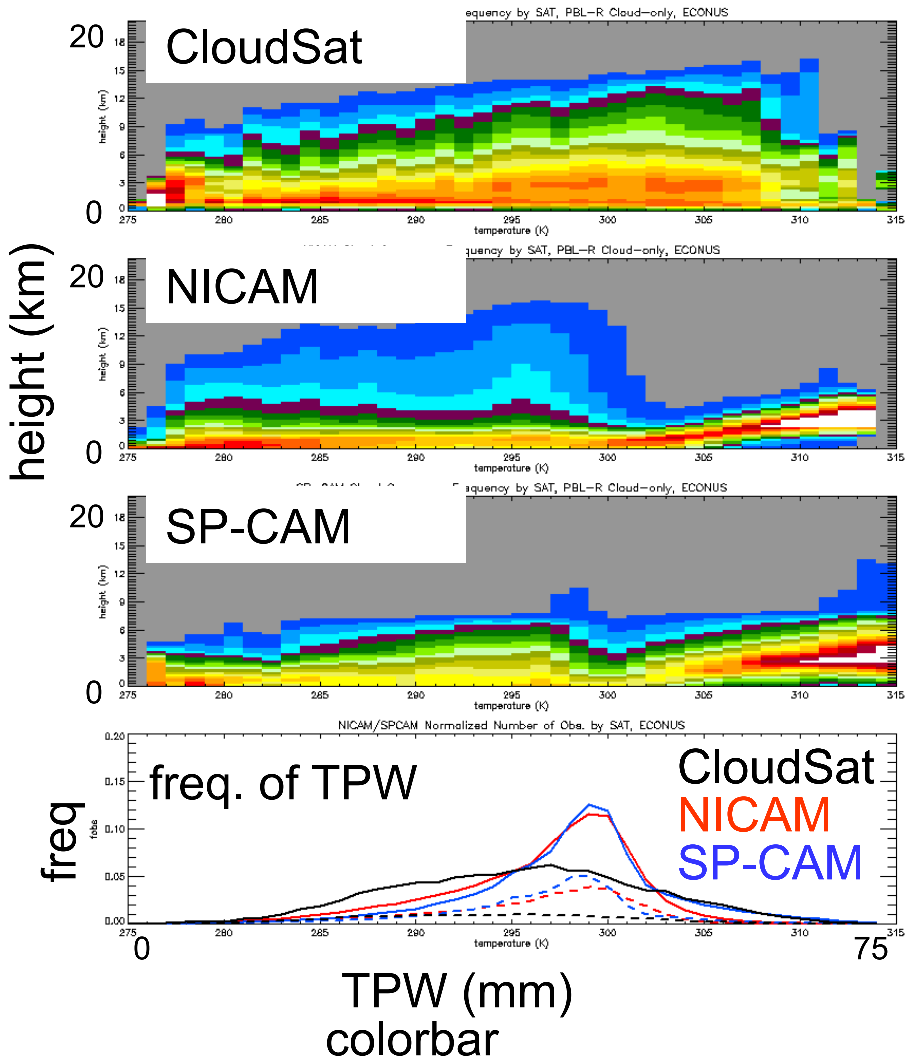


- The data in the preceding figure are now binned by TPW
- As observed TPW increases, observed conv. clouds grow deeper steadily
  - this is opposed to tropics, where clouds stay shallow until 50 mm
- NICAM does not develop clouds vertically until 55 mm
  - resembles tropics
- But clouds at high TPW are actually taller than observed
- **Conclusion: NICAM's lack of deeper conv. clouds occurs because clouds do not grow realistically in drier environments**
- SP-CAM does not grow clouds as tall as observed at any TPW
- SP-CAM also has a smaller discontinuity in growth at 60 mm
- **Conclusion: SP-CAM has a problem developing clouds vertically in all moisture conditions**
- **NICAM and SP-CAM produce shallower conv. clouds for different reasons**

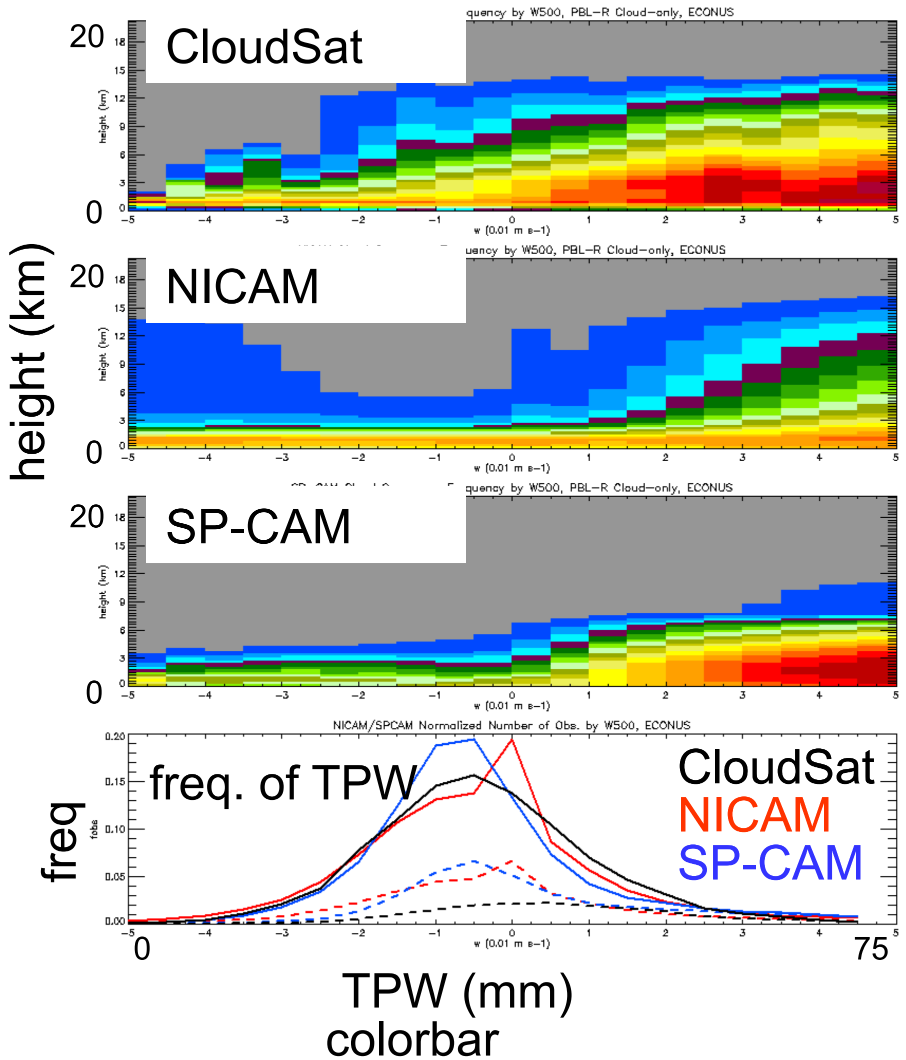
Conclusions and Future Work

- NICAM and SP-CAM do not produce deeper conv. clouds as frequently over the eastern US as observed
- Neither model fully reproduces the observed relationship between TPW and conv. cloud growth
  - NICAM has difficulty developing clouds vertically in drier environments, but has such no problem in humid environments
  - SP-CAM has difficulty developing clouds in any moisture environment
- The difference between the models in the response of conv. clouds to moisture suggests different reasons for their unrealistic behaviors
- Conditional sampling can reveal additional errors in model behavior that are not obvious from mean cloud property calculations alone
- This methodology is currently being applied to mature deep convective clouds to detect further disagreements between models and observations

Mean vertical profiles sorted by SAT



Mean vertical profiles sorted by W500



Data Sources - Observations

- CloudSat
  - 94 gHz radar, 1.1 km effective horiz. res, 250 m effective vertical res.
  - polar orbiting, overpasses at 1:30 AM and PM
  - detects thicker clouds, such as DCCs
- North American Regional Reanalysis
  - improved variant of the NCEP/NCAR Reanalysis
  - 32 km horiz. res., 6 hr temporal res.
  - used for non-cloud variables (e.g. TPW, SAT, W500)
- obs. data taken from JJA 2006-2010

Data Sources - Models

- Superparameterized Community Atmospheric Model (SP-CAM)
- multiscale modeling framework – uses multiple horizontal and temporal scales
- time domain is JJA, one year in early 21^{st} century
- cloud variables are taken from the cloud resolving model
- Nonhydrostatic Icosahedral Atmospheric Model(NICAM)
- global cloud resolving model
- 7 km horiz. res., 6 hr temporal res.
- time domain is JJA 2004

Introduction

- Simulating clouds remain one of the primary difficulties in climate modeling
- Convective clouds are particularly challenging
- much smaller than the typical GCM grid box
- sensitive to parameterization schemes (e.g. microphysics, sub-grid scale)
- The inability to simulate deep convective clouds realistically leads to multiple model errors
  - vertical temperature and moisture profiles
  - large-scale atmospheric features (e.g. MJO)
  - cloud radiative feedback
- This is not a trivial problem!
- Traditional GCMs have been limited to convective parameterization schemes to resolve this challenge

Why JJA CONUS?

- lots of vigorous convection during the summer
- observations are numerous and high quality
- extratropical continent is different from tropical oceans
- models may get tropics right but not extratropics
- it’s a region that hasn’t been thoroughly investigated with GCMs