Automated Tracking of Shallow Maritime Clouds on Geostationary Imagery to Extract Lifecycle Characteristics

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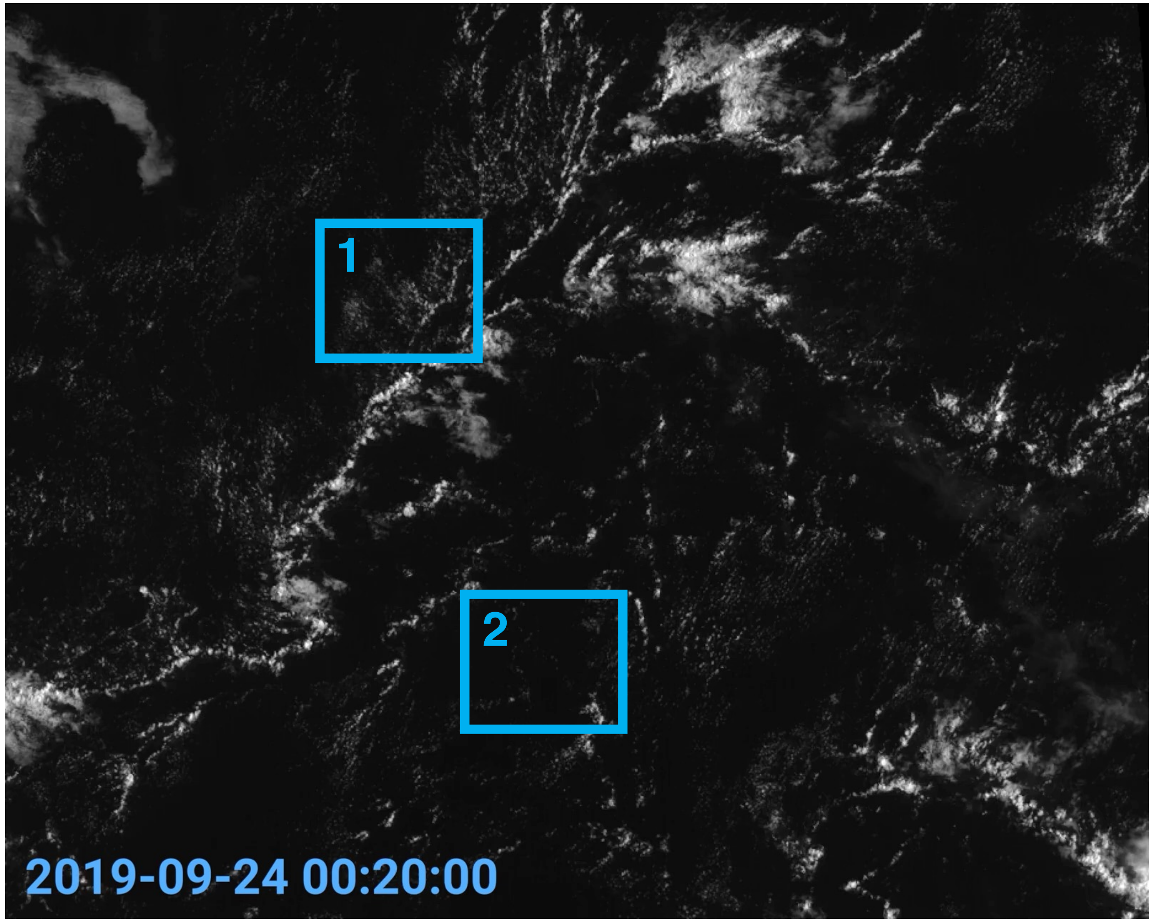
Outline

- Describe masking and tracking methods used to define cloud objects on hi-res geostationary imagery
- Apply the tool to a recent field campaign (NASA CAMP^{2}EX) to investigate the character of shallow clouds sampled and their lifecycles
- Describe strategy to define environments by “cloud-track ensembles” and differentiate apparent lifecycle properties
- Assess which types of clouds were sampled more than others throughout the tracked ensembles
- Touch on efforts to relate sampled environment parameters to each ensemble’s characteristics

Visual Example of Cloud Scales Involved

0.5-km Reflectance – Himawari-8 AHI
Rapid-scan (24 Sept 2019)



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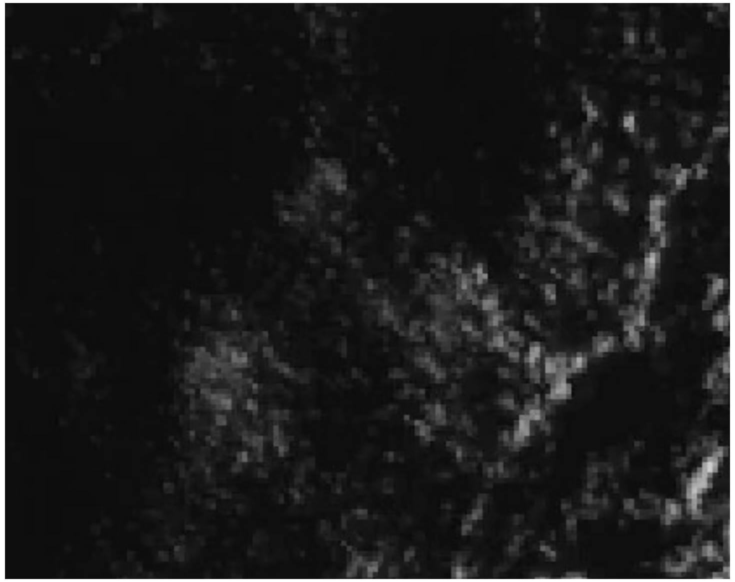

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How do we capture the time evolution of all these clouds?

Algorithm Approach – Segmentation

Cloud Identification and Masking

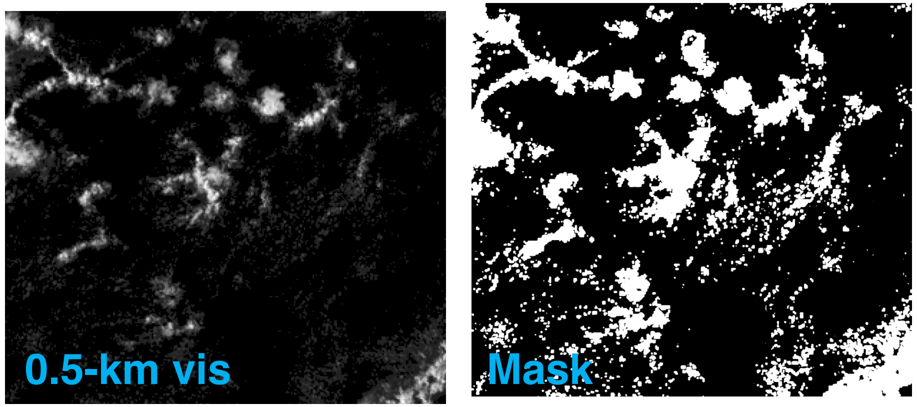
- A cloud mask is generated with a reflectance threshold at 0.5-km resolution and optimized for clouds of a general length scale:

  i. Transient "popcorn" cumulus with area < 25 km^2
  ii. Sustained "organized" cumulus with areas up to ~100 km^2

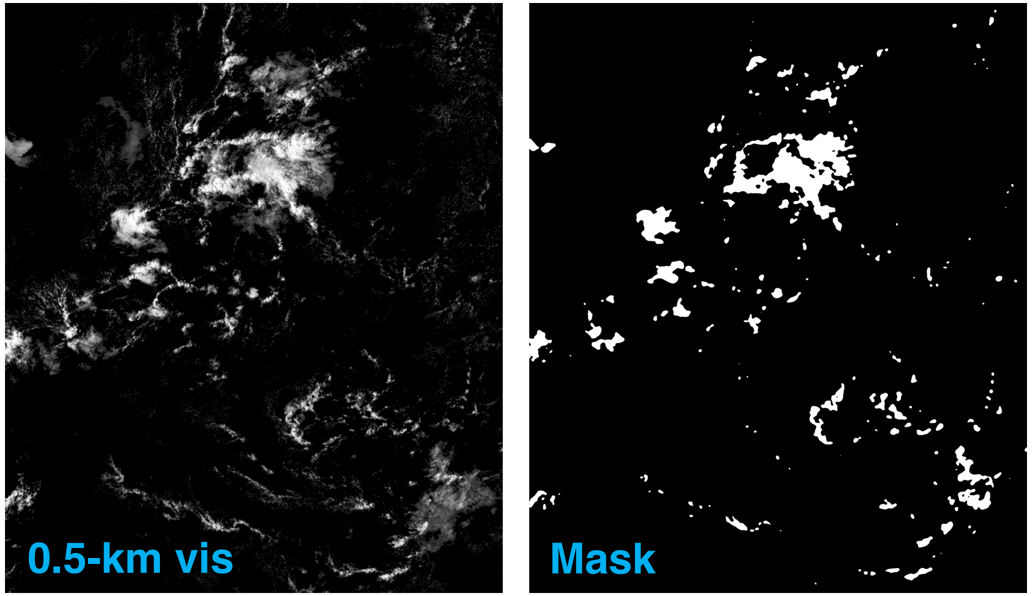
- The mask is binary, segmenting clouds from the background.
- A higher threshold detects organized cumulus better, particularly the reflectance extrema.
- One threshold isn't enough to create "trackable" frames:
  i. Noise Reduction w/ blurring filters
  ii. Cloud edge refinement

Complexity of the Approach

- Choosing the reflectance threshold:
  i. Low enough to capture birth and decay stages
  ii. High enough to remove background
  iii. Only works during daytime
- Mask processing time ~5-15 min/frame, with ~250 frames/day



Segmentation optimized for popcorn cumulus



Segmentation optimized for organized cumulus

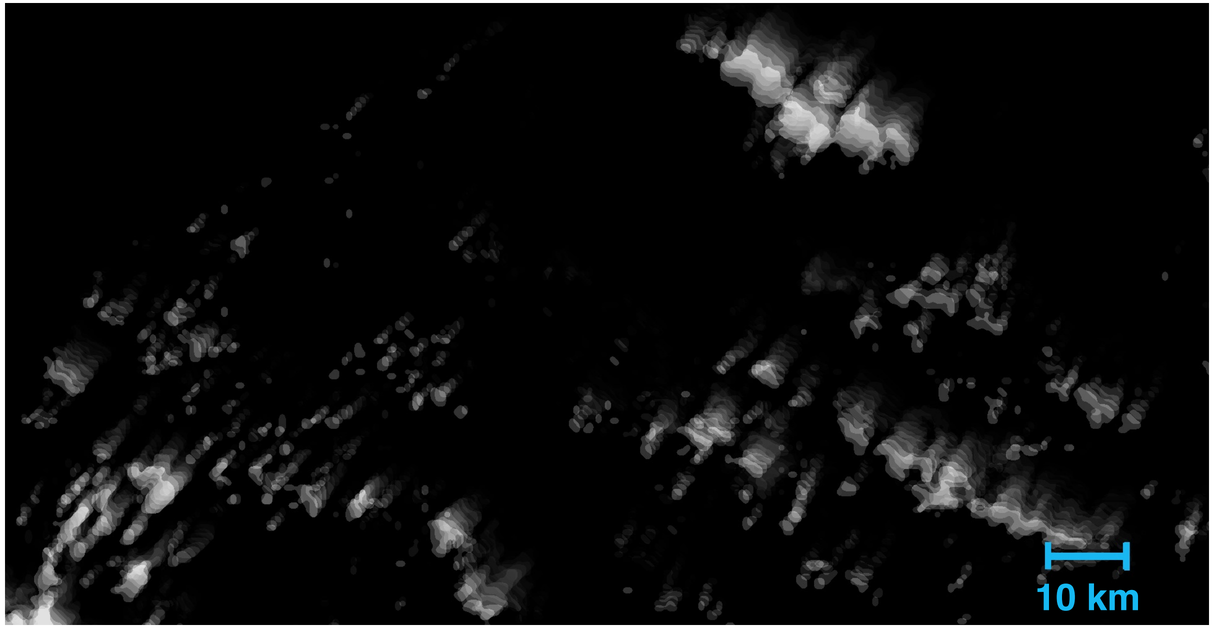
Algorithm Approach – Tracking

Components of a Cloud Track

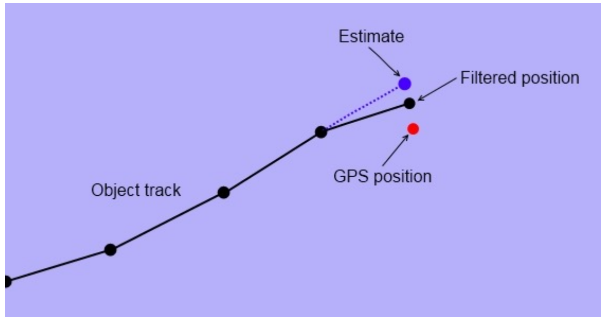
- Initial detection spawns a track
- Time-evolving centroid position and velocity
- Kalman filter
- Status of track on a frame: detected OR predicted
- Cloud boundary at ~ 0.5-km resolution
- Cloud area
- UTC time

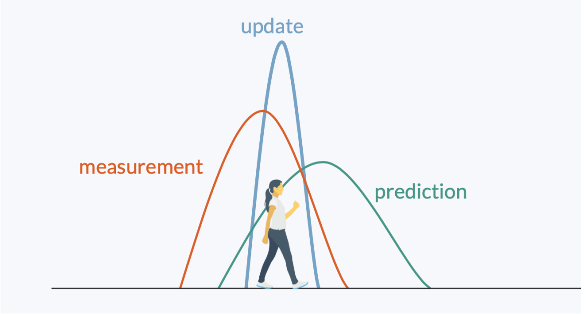
Kalman Filter

- Serves as a *motion model* for predicting an object's location on a successive frame
- Initialized with parameters estimating uncertainty in initial and evolving centroid positions
- Assumes constant velocity
- Issues encountered:
  i. Merging/splitting clouds shift centroid erratically from predicted position
  ii. New cloud forms near a tracked cloud and is mistaken for being the predicted position



30-minute time lapse of cloud mask (brighter areas = later time)





The Kalman filter tries to predict the path of an object but gets refined with successive detections of that object.

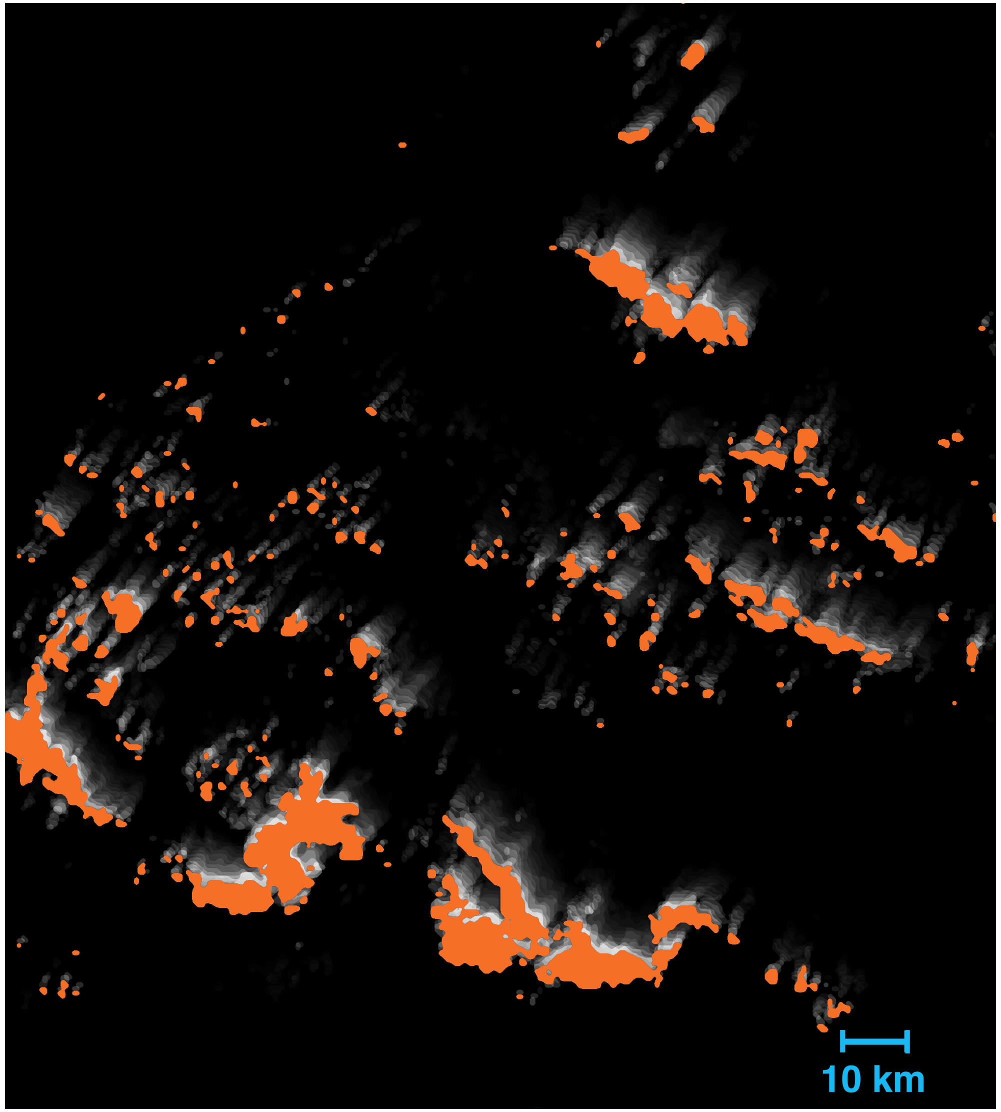
Algorithm Approach – Tracking

Assigning Detections to Tracks

- A successive frame starts with only cloud detections.
- Each detection is subject to a cost calculation, the likelihood it gets assigned to an active track.
- The cost depends on multiple factors:
    1. Variances between the detection and predicted centroid locations
    2. Overlap of objects from previous frame
    3. Apparent heading and its deviation from the estimated heading
- Minimal cost is necessary for matching a detection to an active track by Hungarian assignment.

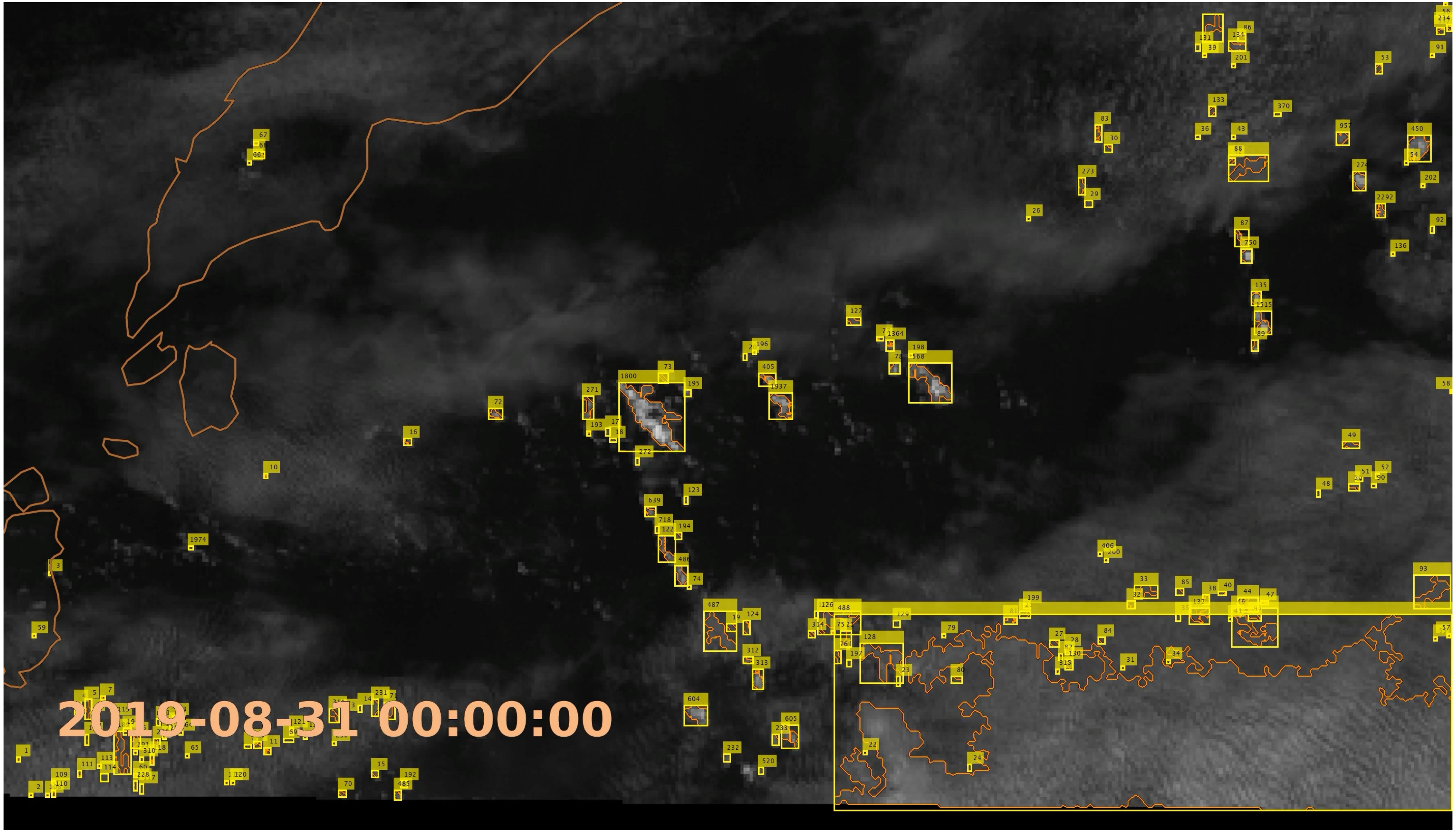
Complexity of the Approach

- Tracking on successive frames is a serial process, thus limiting options to parallelize code.
- Smaller spatial domain is one option but limits tracking to short-lived popcorn cumulus.



Cloud detections (orange) are matched with active tracks illustrated in the 30-minute time lapse

Example Output (SW Sulu Sea)

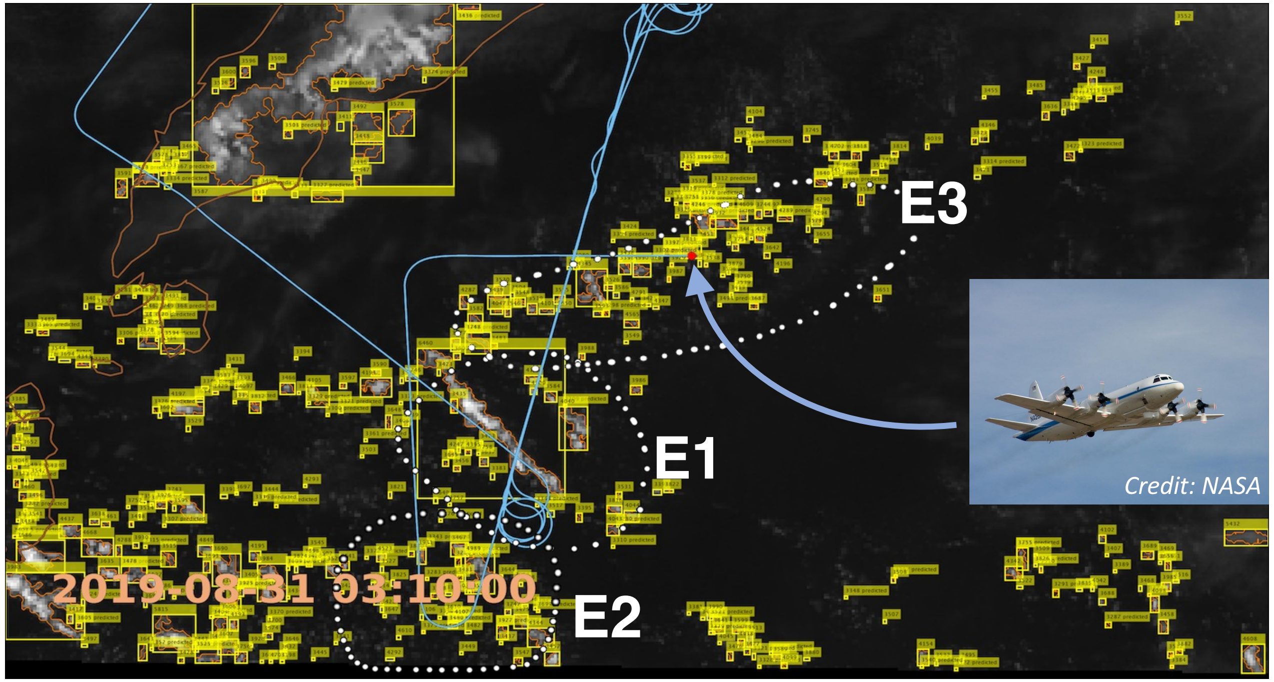


Partitioning Environments with Cloud-track Ensembles

- Lots going on! Thus, we focus on specific areas more closely related to the airborne (P-3B) field sampling.

- Creating an ensemble:
  1. Run tracker with masking optimized for the targeted phenomena
  2. Find where tracker is performing well and field sampling is available
  3. Draw region to initialize ensemble – any tracks passing through are included
  4. Search for cloud “systems” not captured well (i.e., multiple track IDs from splits/mergers) and manually link tracks. Up to 10 systems usually result.

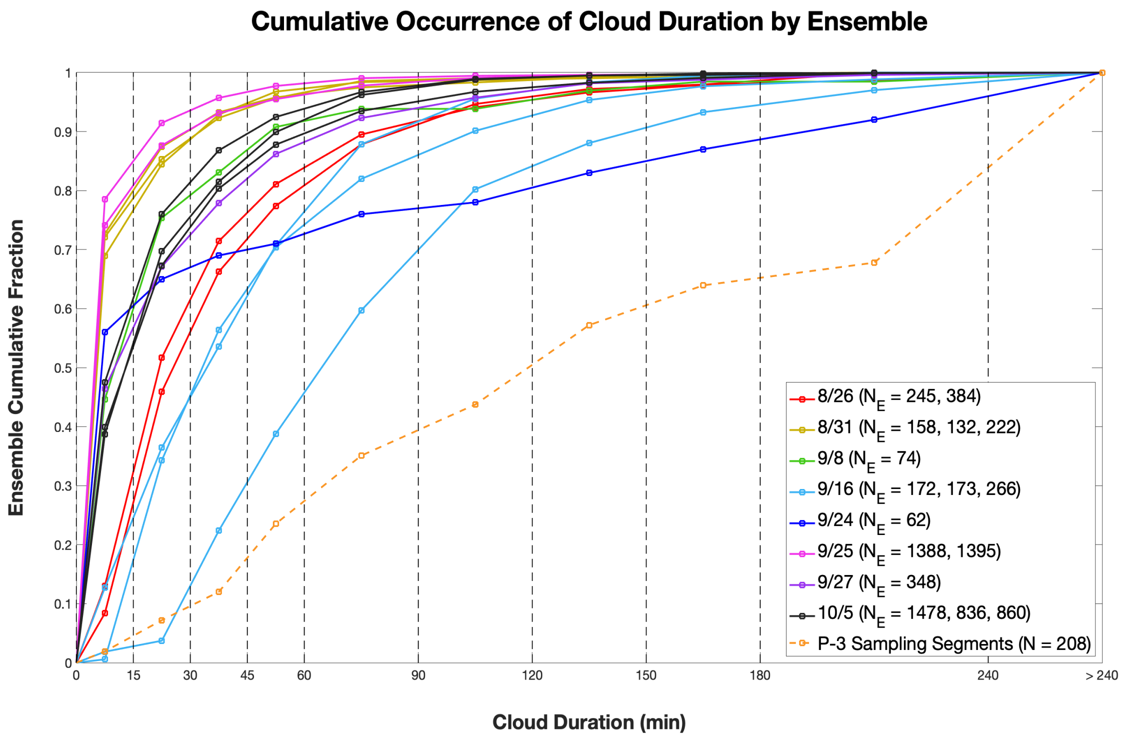
- 16 ensembles were selected from 8 dates over CAMP^{2}EX, with clouds classified by lifecycle parameters (duration, max area, max height)



Cloud tracks from 31 Aug 2019 with 3 ensembles defined (E1-E3)

Date	Total Ensembles	Sample Sizes N_E	Date	Total Ensembles	Sample Sizes N_E
Aug 26	2	245, 384	Sep 24	1	62
Aug 31	3	158, 132, 222	Sep 25	2	1388, 1395
Sep 08	1	74	Sep 27	1	348
Sep 16	3	172, 173, 266	Oct 04	3	1478, 836, 860

Observed Cloud Lifetimes and Overall Sampling

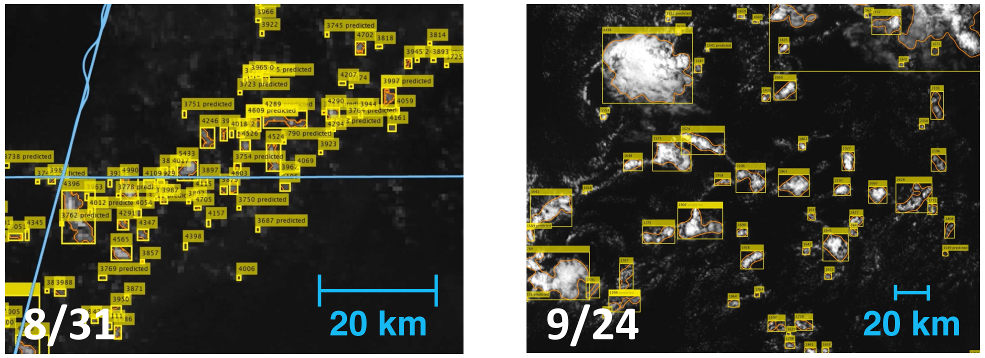


Cumulative Lifetime

- General exponential distributions describe the tracked lifetimes of cloud objects
- Majority of ensembles have roughly 2/3 of clouds lasting < 30 min
- Distributions with more long-lived clouds tend to have better environment dynamics (wind shear)

P-3 Sampling Segments

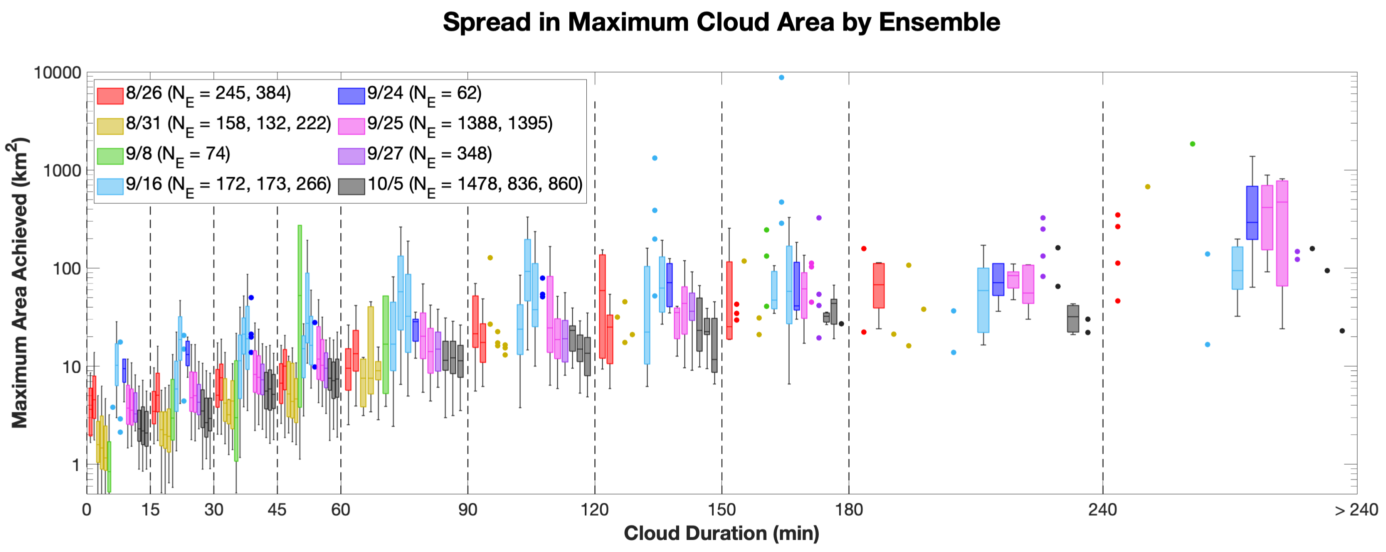
- P-3 *sampling segments* are flight legs that begin and end within a member cloud object
- More context on segments:
  - Represents any crossover of a tracked cloud
  - Doesn't account for P-3 altitude
  - Reduction of segments imposed when occurring near a cloud edge (e.g., spiral maneuver)
- Nearly half of segments cover clouds lasting more than 2 h, which only compose < 20% of any ensemble

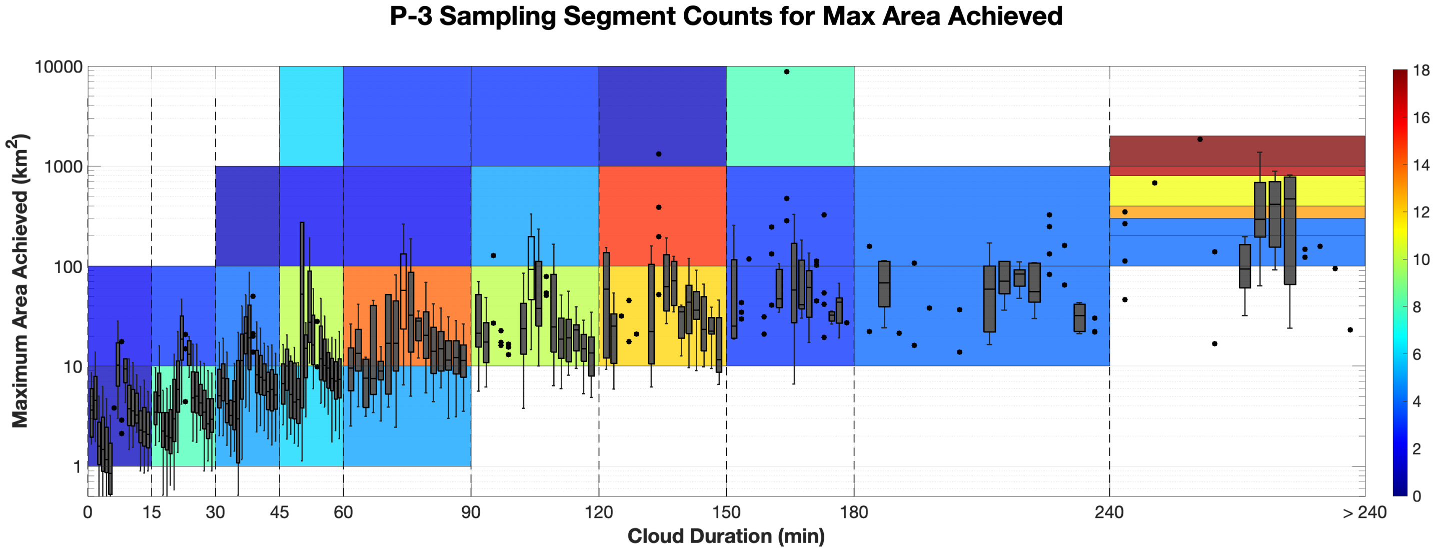


Ensembles with more short-lived clouds (e.g., 8/31 or 9/25) differ markedly in appearance from those with more long-lived clouds (e.g., 9/16 or 9/24).

Classifying Sampled Clouds with the Tracked Max Area

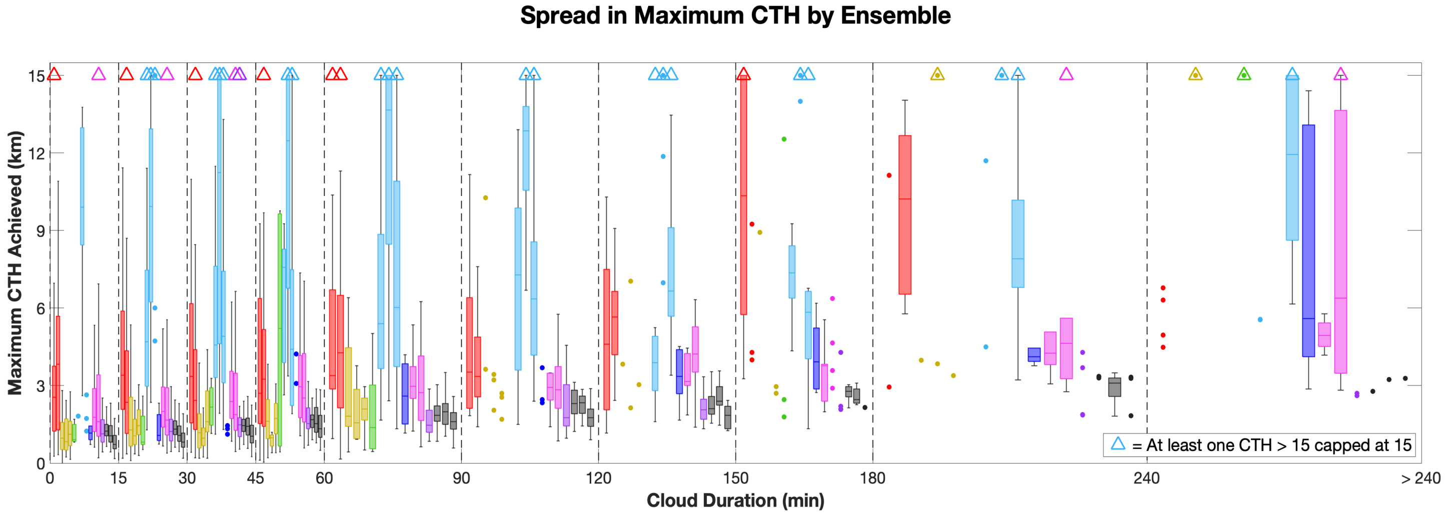
- Cloud area is logged at every time step, with max area analyzed as a "growth potential" for a given lifetime.
- The max area generally grows with increased lifetime but can plateau at > 2 h.
- Overlaying the sampling segments can estimate time spent on specific cloud classes.
- The cloud class "10's km^2 and 1-2.5 h" received significant sampling and matches well to the ensemble occurrences.
- The cloud class "~1000 km^2 and > 4 h" had much sampling but it doesn't occur often.



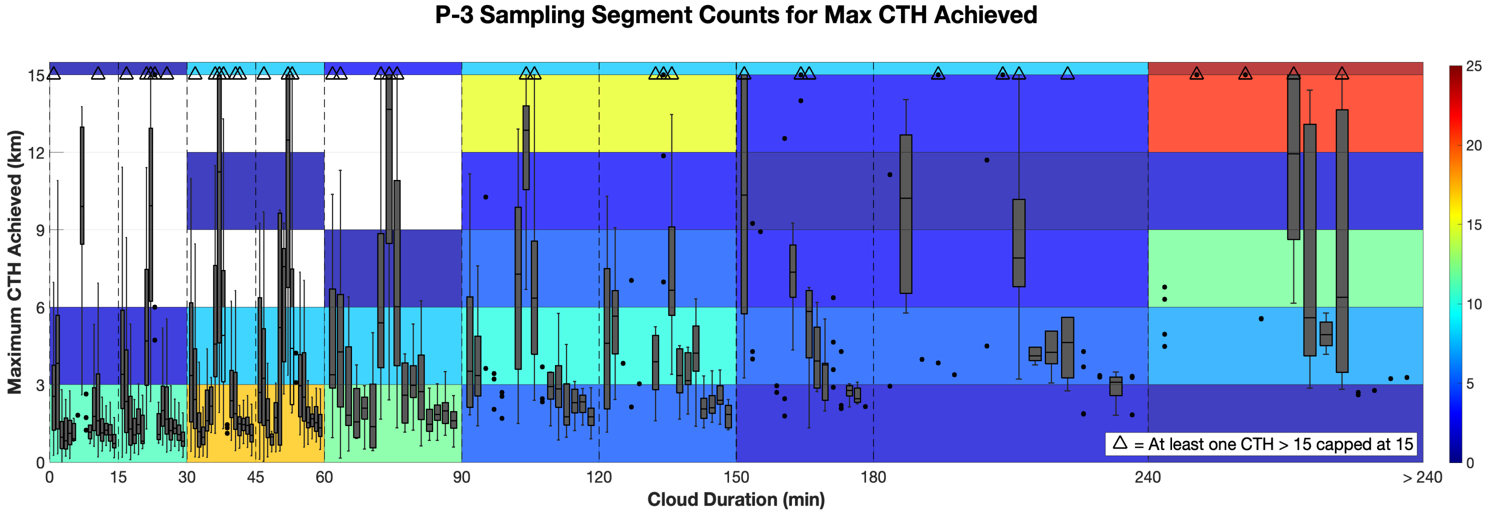


Classifying Sampled Clouds with the Tracked Max CTH

- Cloud-top heights (CTH) are logged at every time step:
  - Difference b/w background and minimum brightness temp (BT) at 11-micron
  - Divided by lapse rates defined for the time of year and latitude, as shown in (Baum et al, 2012)
  - Only works well for shallow clouds, w/ complications from thin cirrus



- CTH > 6 km regarded as "*reaching mid-troposphere or above*"
- Shallow clouds of < 3-km CTH and < 1.5 h received decent sampling
- Some ensembles (9/27 and 10/5) never reach > 3-km CTH despite long lifetime



Conclusions and Current Work

- Our tracking tool was built to study shallow clouds at the smallest resolvable scales – we welcome other methods that advance the bookkeeping.
- Cloud-track ensembles are useful to isolate environments and understand their influence on cloud evolution.
- The P-3 flights of CAMP^{2}EX tended to target clouds with enhanced organization and lifetime, rather than a typical ensemble "spectrum."
- Disentangling of individual cloud behaviors, involving growth/decay at random intervals, is necessary when aggregating IR data and finding relationships.