Toward Statistical Extension of CloudSat Curtain Observations to a Regional Swath

Steven D. Miller[1,2], John Forsythe[1,2], Rich Bankert[3], Manajit Sengupta[4], Phil Partain[1,2], Cristian Mitrescu, and Richard Austin[1]

[1] Colorado State University, Fort Collins, CO
[2] Cooperative Institute for Research in the Atmosphere (CIRA), Fort Collins, CO
[3] Naval Research Laboratory (NRL), Monterey, CA
[4] National Renewable Energy Laboratory (NREL), Golden, CO

DoD Center for Geosciences/Atmospheric Research at Colorado State University

Objectives

- Examine to what extent isolated, detailed observations of cloud vertical structure (water content) and geometric boundaries (top/base) can be ‘spread’ to surrounding regions.

- Demonstrate how cloud-type dependent statistics from active sensors (radar/lidar) can be applied to correct and augment passive sensor derived cloud parameters.

- Apply method to complex cloud scenes, and validate along the CloudSat/CALIPSO track.

Relevance and Interest

- There are several ways the operational community can potentially use CloudSat information.

  General Aviation: cloud ceilings, multi-layered cloud systems, cloud content for potential icing assessments

  DoD: aircraft launch and recovery operations, surveillance, TDAs, etc.

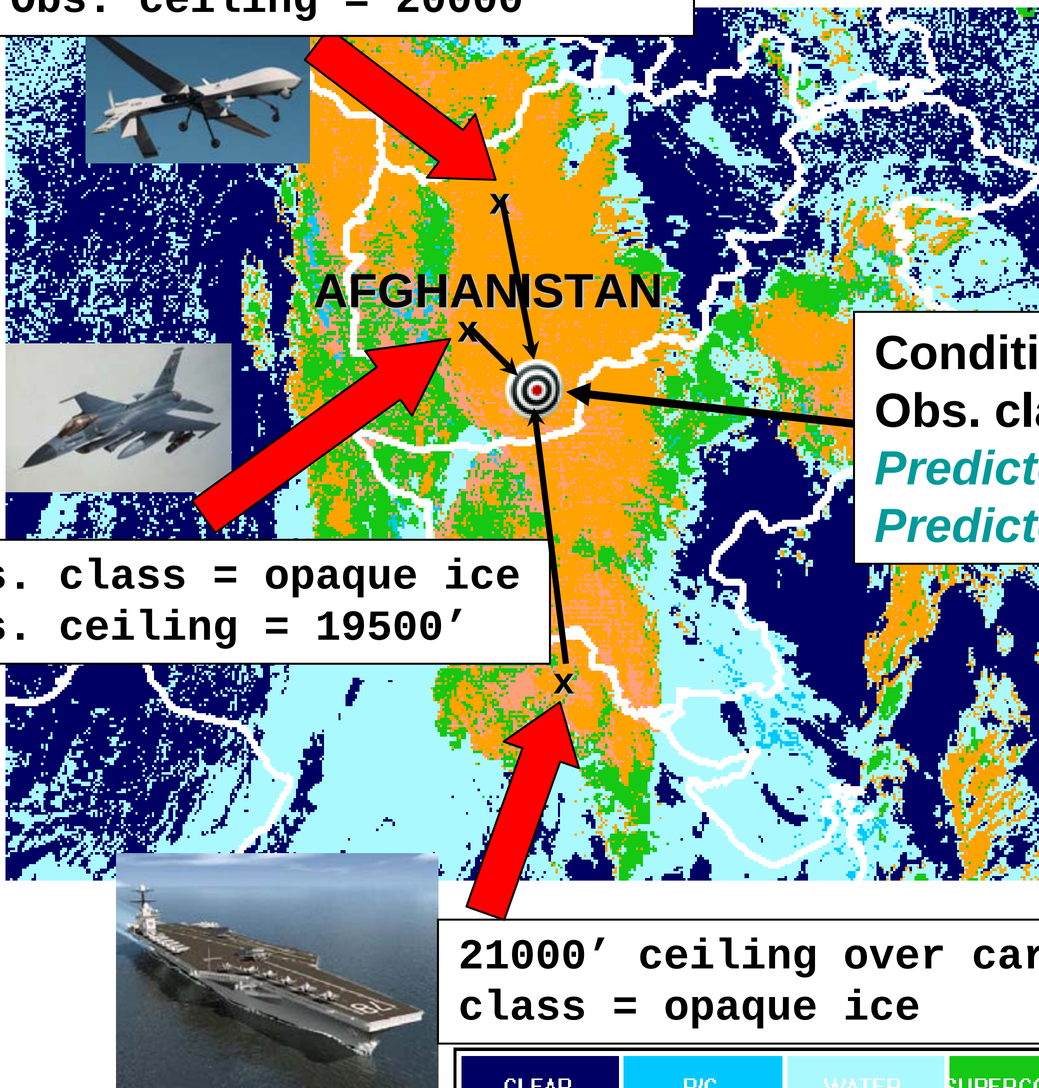
  U.S. Coast Guard: clear line-of-sight to surface below upper cloud deck.

- CloudSat provides a ‘first-look’ near real-time dataset (at ~3-6 hr latency) in support to these potential operational users, *but 2-D curtain slices are of limited use*.

- Members of the research community have also expressed an interest in techniques for extending CloudSat data into a regional domain (e.g., momentum flux calculations).

A DoD Conceptual Example

Obs. class = opaque ice
Obs. ceiling = 20000’



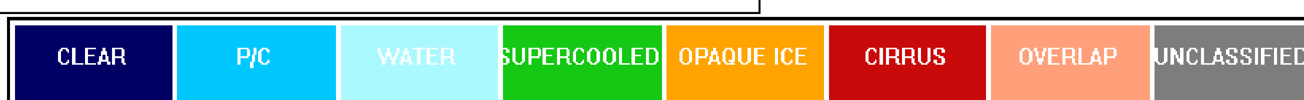
! Forecast models have difficulties predicting cloud cover (horizontal and vertical extent) and water content.

Conditions @ TARGET
Obs. class: opaque ice.
Predicted ceiling: 19750’
Predicted IWC profile also estimated.

Obs. class = opaque ice
Obs. ceiling = 19500’

CONCEPT: Take cloud observations in friendly areas, extend them into data-denied areas.

21000’ ceiling over carrier;
class = opaque ice



Rationale and Hypothesis

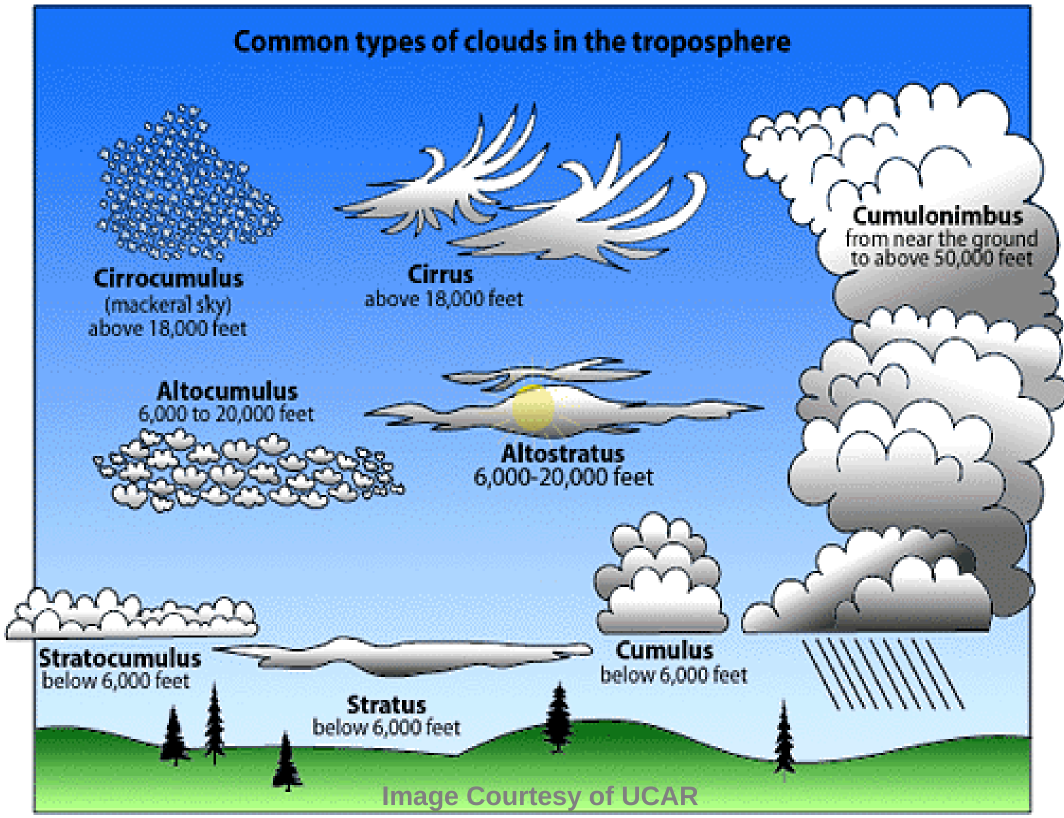
- The dynamics associated with cloud formation lead to characteristic vertical distributions of cloud occurrence and water content.
  - Clouds that form as a result of convective mechanisms tend to have base heights (ceilings) that are characteristic of the regional-scale environment (i.e., lifting/convective condensation levels).
  - Stratiform cloud boundaries defined by meso/synoptic-scale temperature and moisture structures.
- These characteristics may be captured statistically for clouds of similar type.

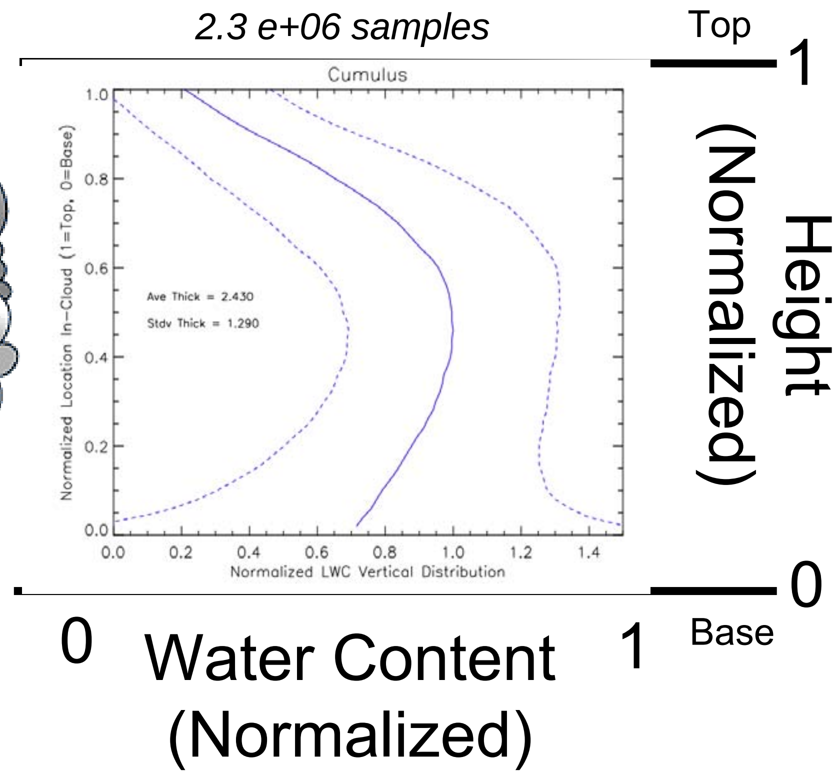
As such…

- A local vertical slice may provide useful proxy information about the surrounding cloud field.
- 'Curtain observations' from CloudSat/CALIPSO may be combined with temporally-matched conventional passive sensor swath data (2-D imager data; e.g., MODIS, GOES, MTSAT, MeteoSat).
- The goal is to estimate the geometric boundaries and internal water content structure of the topmost cloud layer (and in certain situations, two-layer cloud profiles detectable by passive techniques) by applying cloud-type dependent statistics to a region about the CloudSat/CALIPSO ground track

→ *This research seeks to determine to what extent these assumptions are valid for various cloud classifications.*

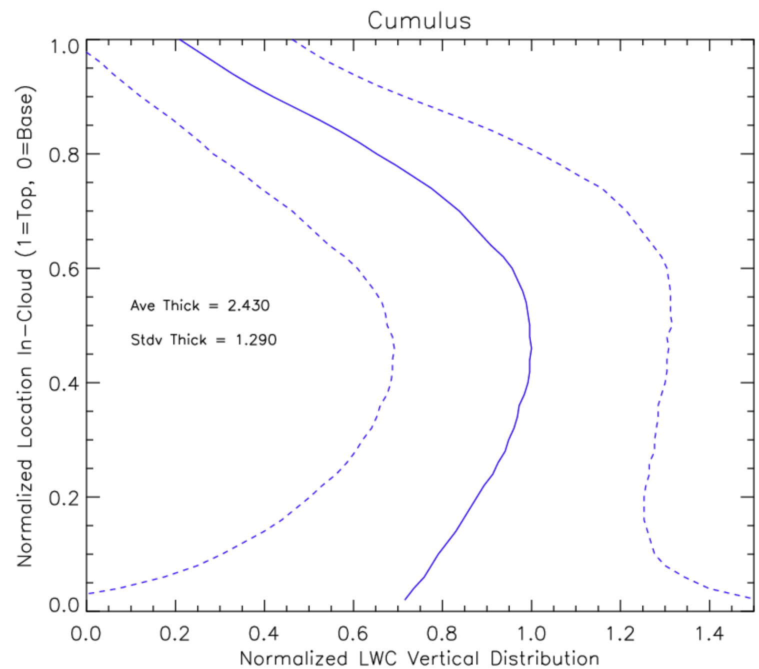
Water Content Vertical Structure





- Using CloudSat Level 2 Cloud Water Content (2B-CWC; R03) and Cloud Scenario Classification (2B-CLDCLASS) products, we computed liquid/ice water content (g/m^3) profiles for each cloud type.

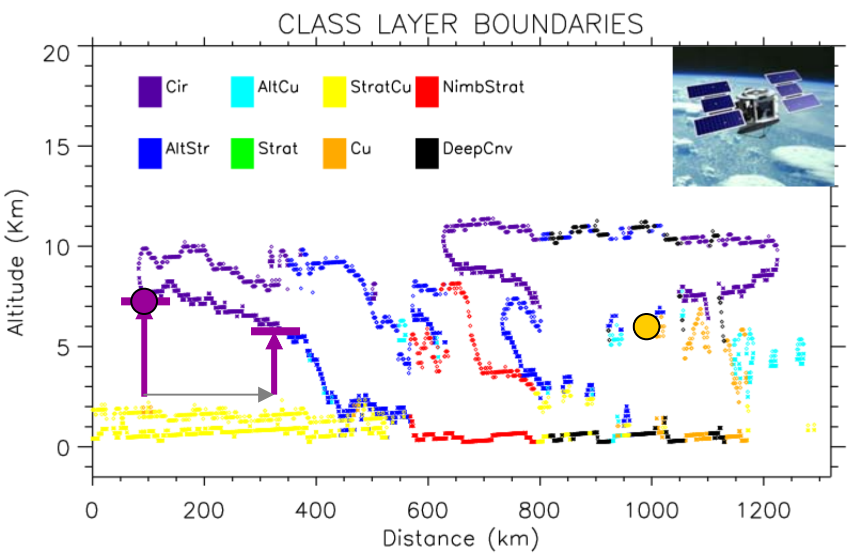
Vertical Structure Statistics

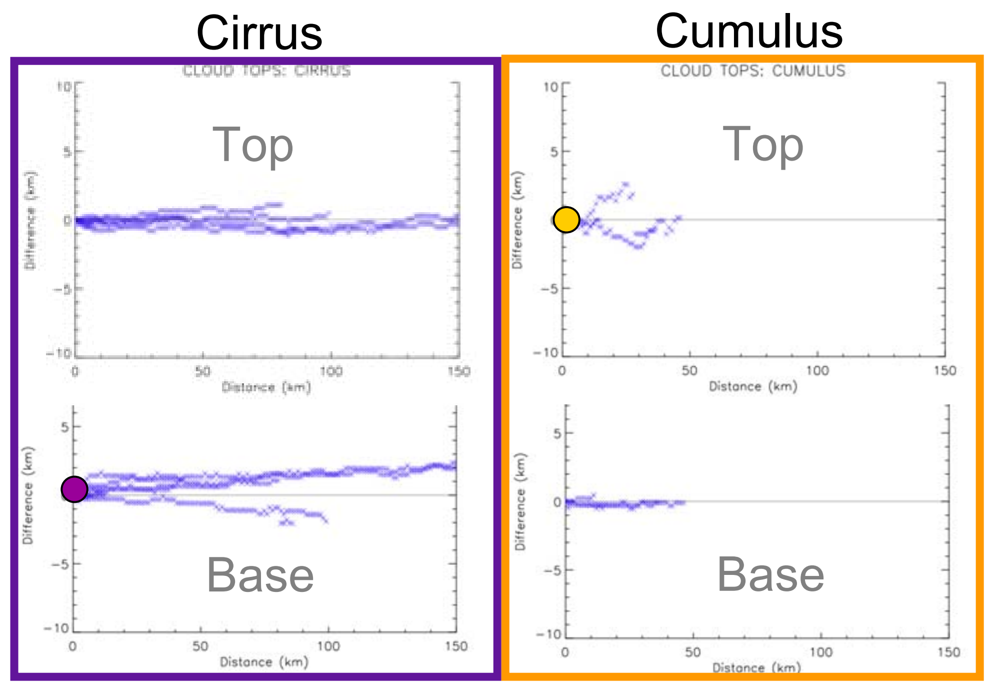


- Vertical structure consistent with expected LWC profiles of convective/stratiform types
  - *Cirrus*: growth of IWC in fall streaks prior to sublimation
  - *Cumulus*: growth of droplets in ascending air

→ We can apply these statistics to passive retrievals of single-layer integrated LWP/IWP.

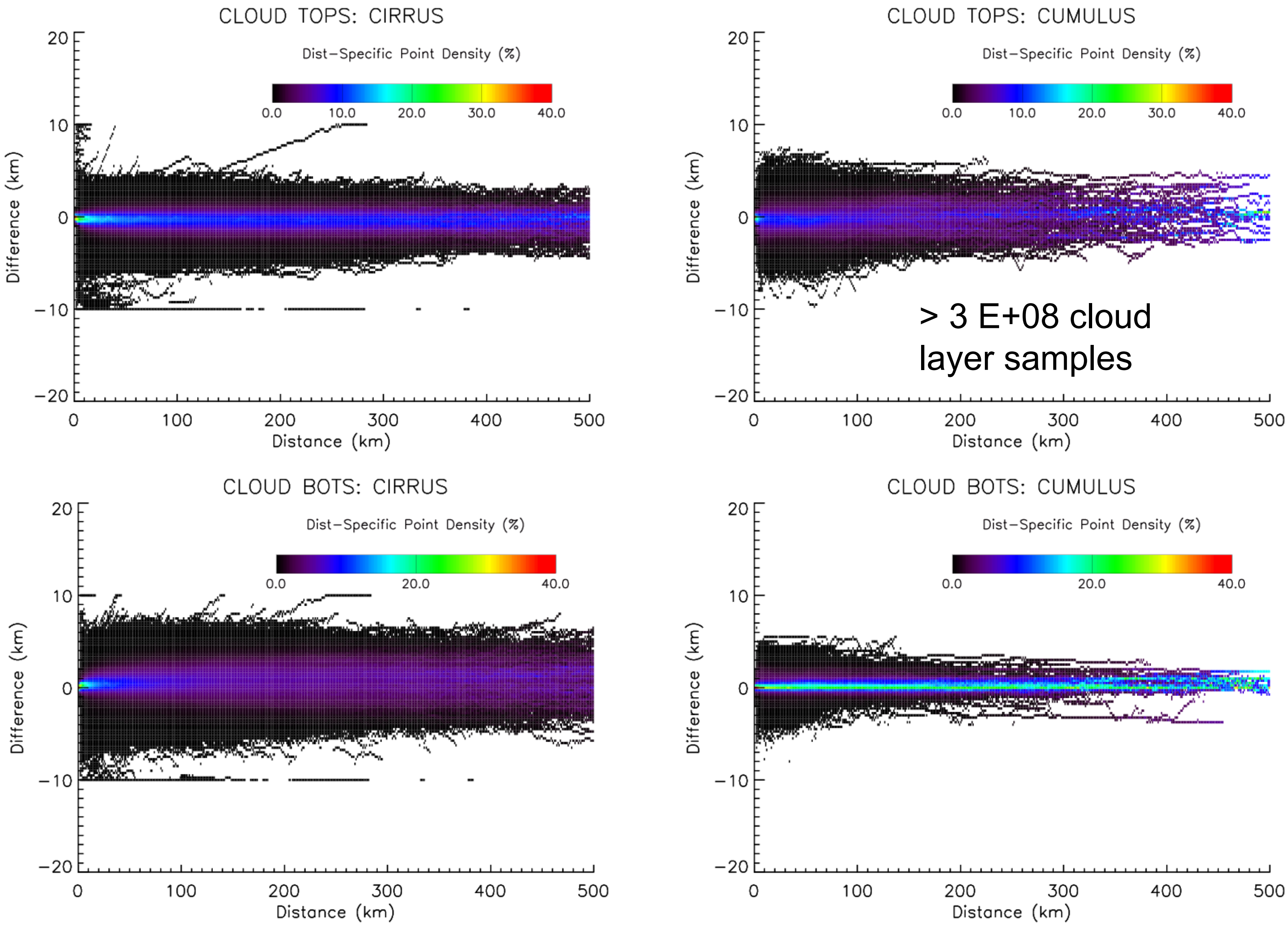
Geometric Profile: “Traces”





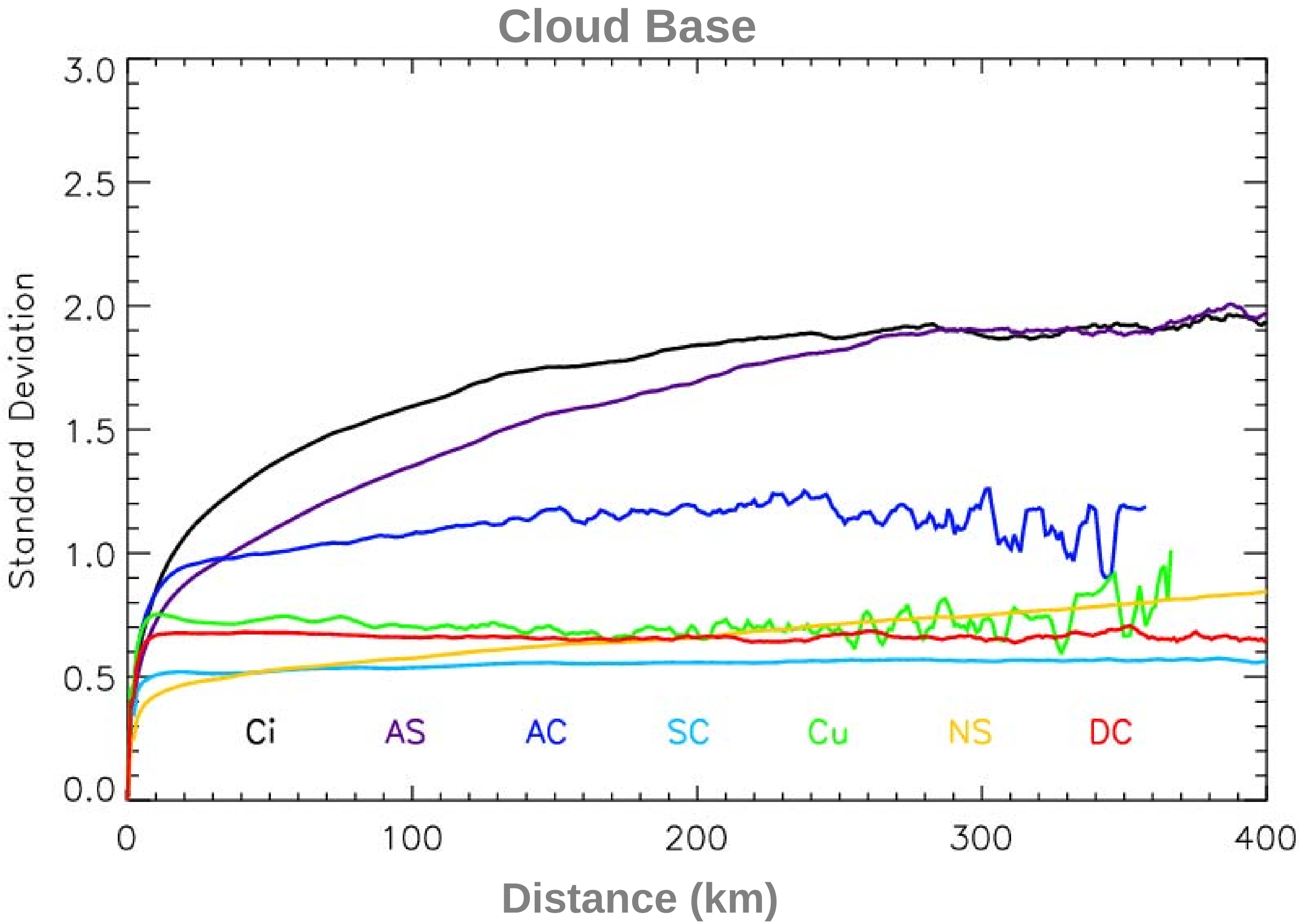
→Used Cloud Scenario Classification to compute departures in base/top height for contiguous cloud layers of a given cloud type, traced from a reference point.

2 Year Composite of “Traces”

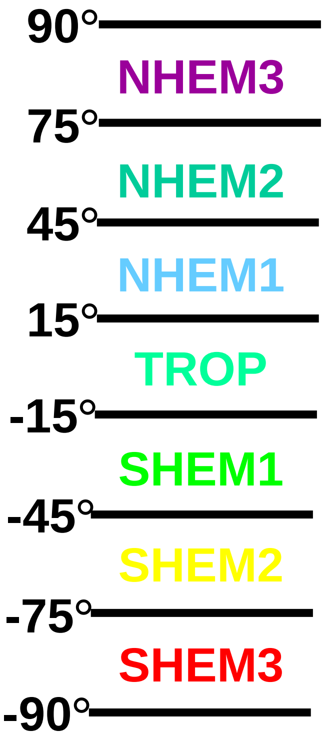


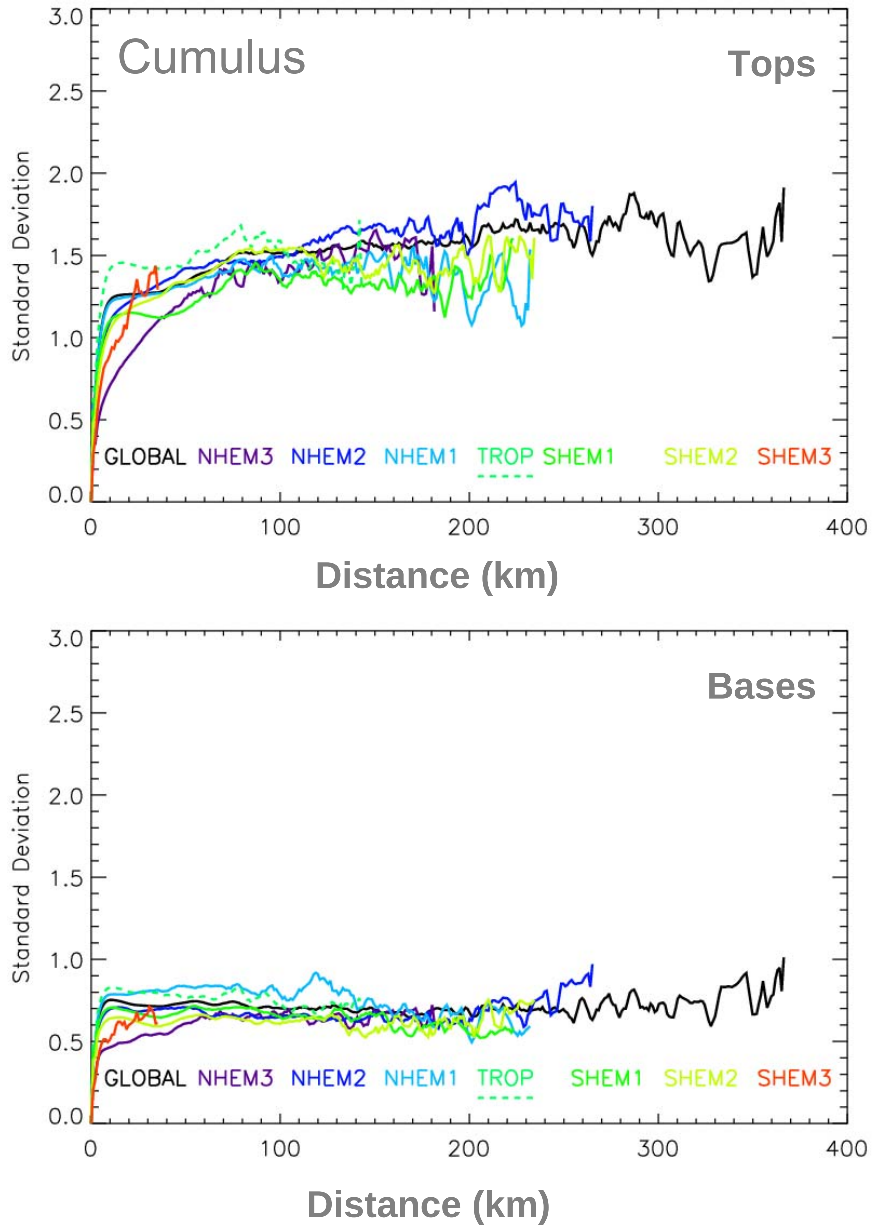
- Compute standard deviations as a function of distance.

Global Statistics on "Traces"

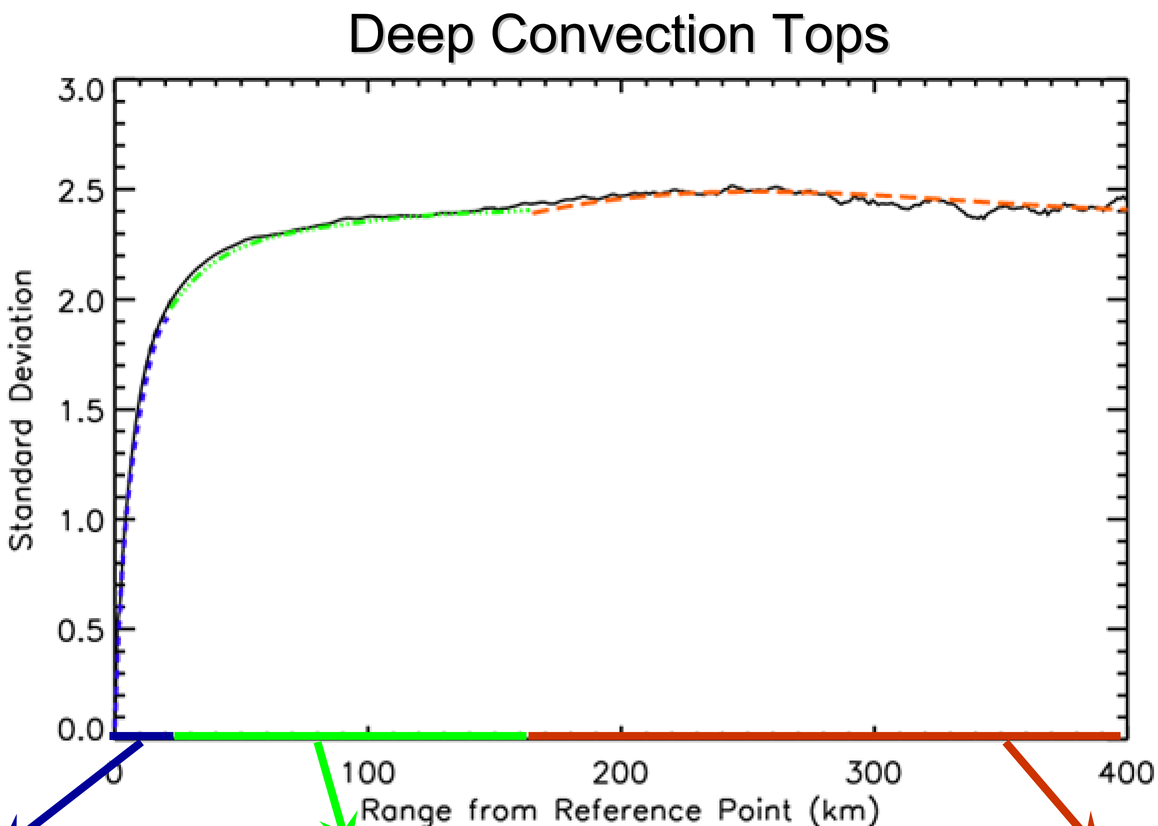


Zonal Statistics on "Traces"





Standard Deviation Fits

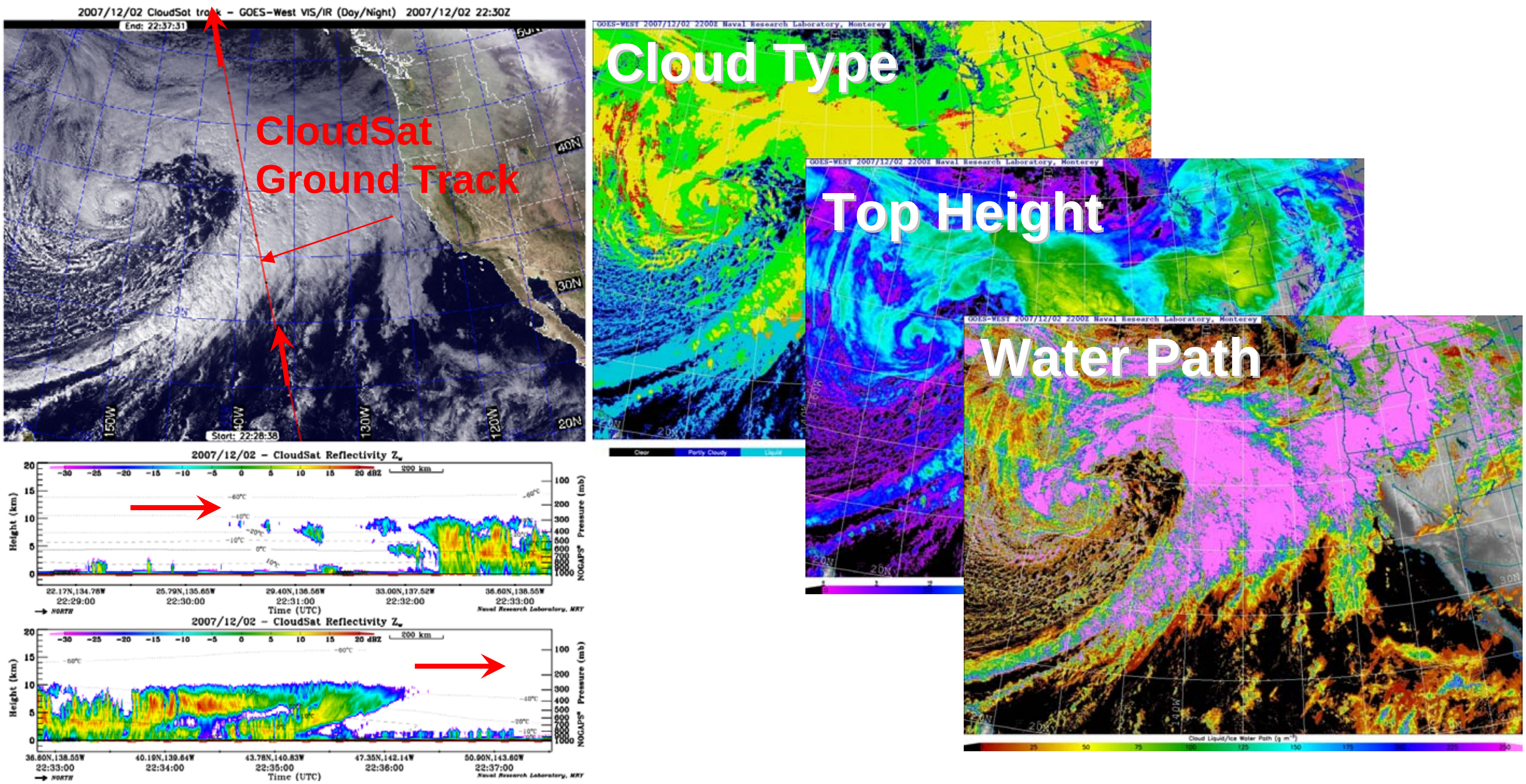


$$\delta(R) = \sum_{i=1}^{N_1} a_i R^i$$

$$\delta(R) = \sum_{i=1}^{N_2} b_i R^i$$

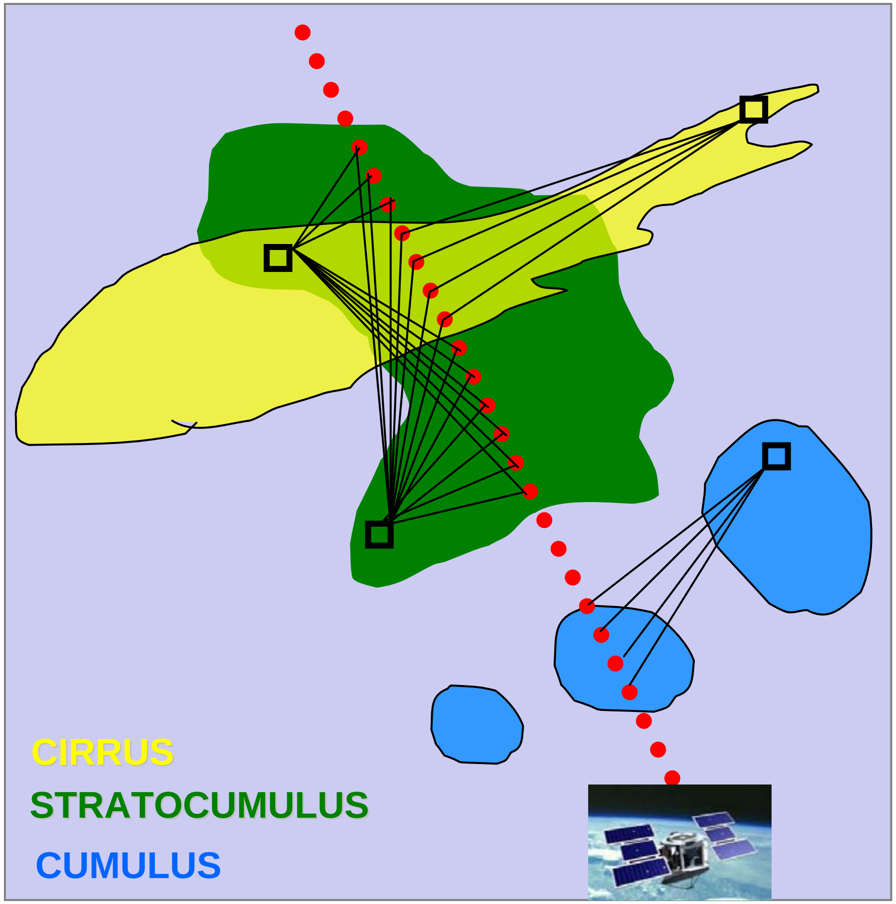
$$\delta(R) = \sum_{i=1}^{N_3} c_i R^i$$

Application to Swath Data



→ How can we use the type-dependent statistics to create a 'pseudo 3-D' version of the 2-D swath data?

Conceptual Application



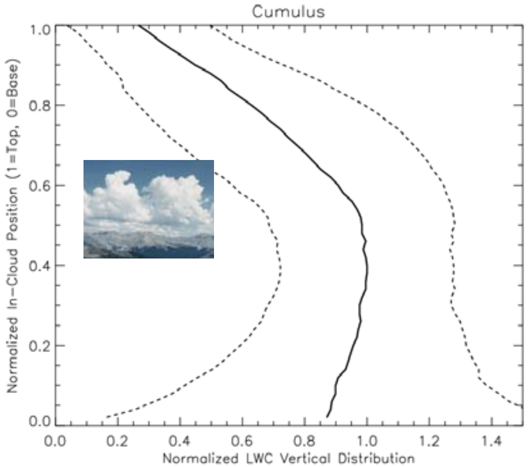
Cloud Type: ***Retrieved***

Liquid Water Path (LWP): ***Retrieved***

Estimate Cloud Top & Base Height:

$$Z = \sum_{n=1}^{N} \frac{z_n}{\delta_n^2(d_n)} \Bigg/ \sum_{n=1}^{N} \frac{1}{\delta_n^2(d_n)}$$

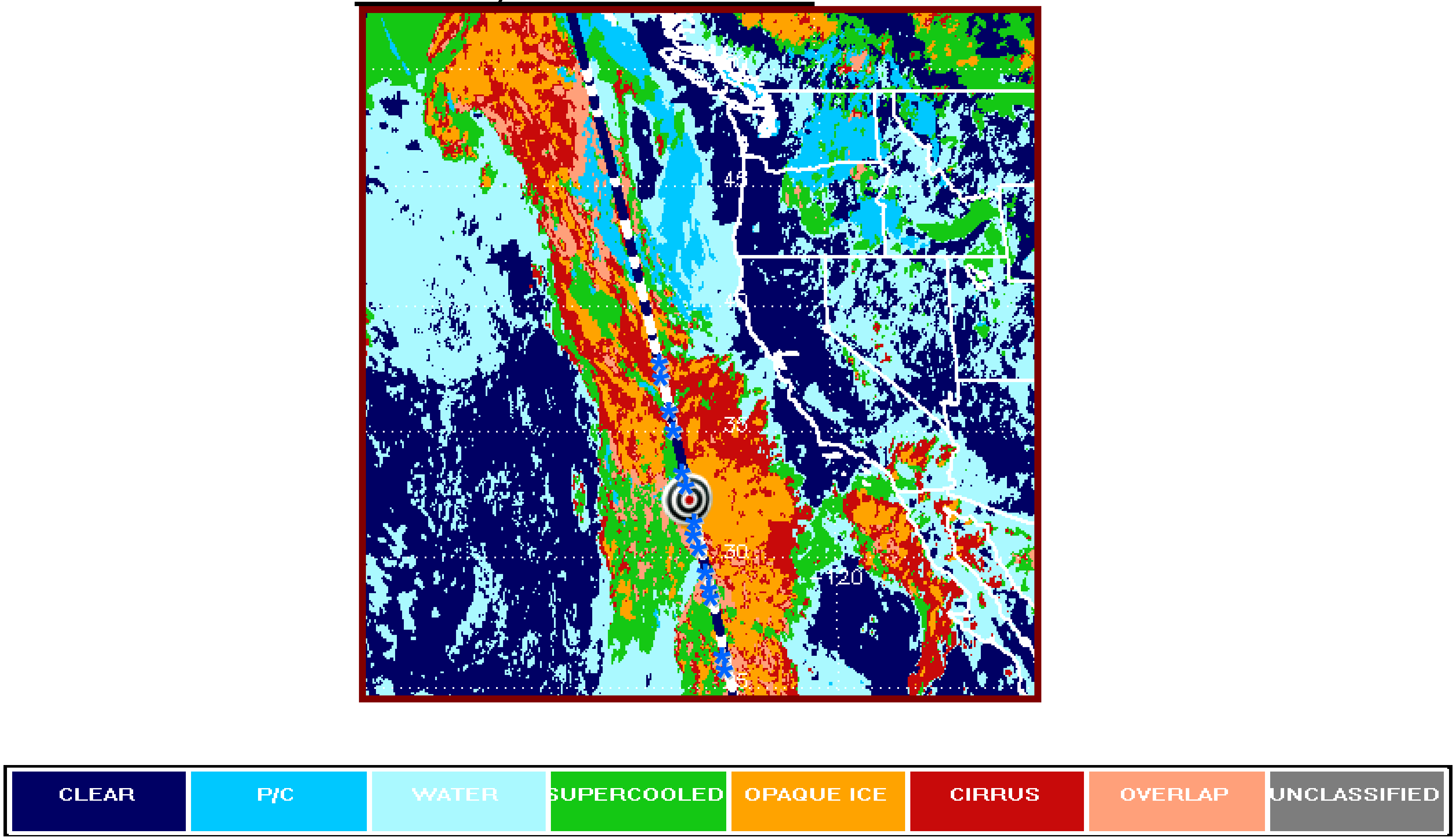
LWP distributed in between cloud Top and Base according to Cloud Type:

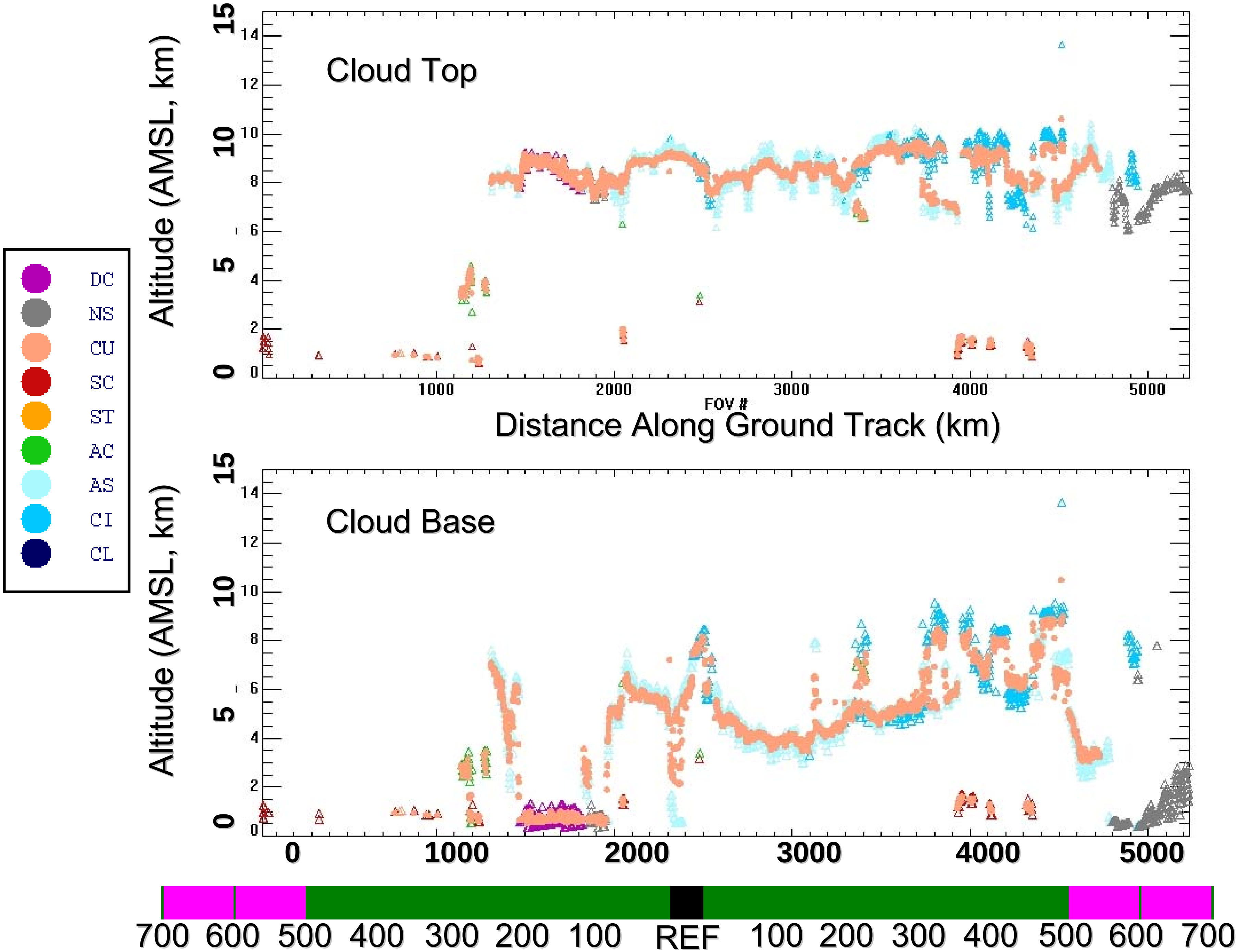


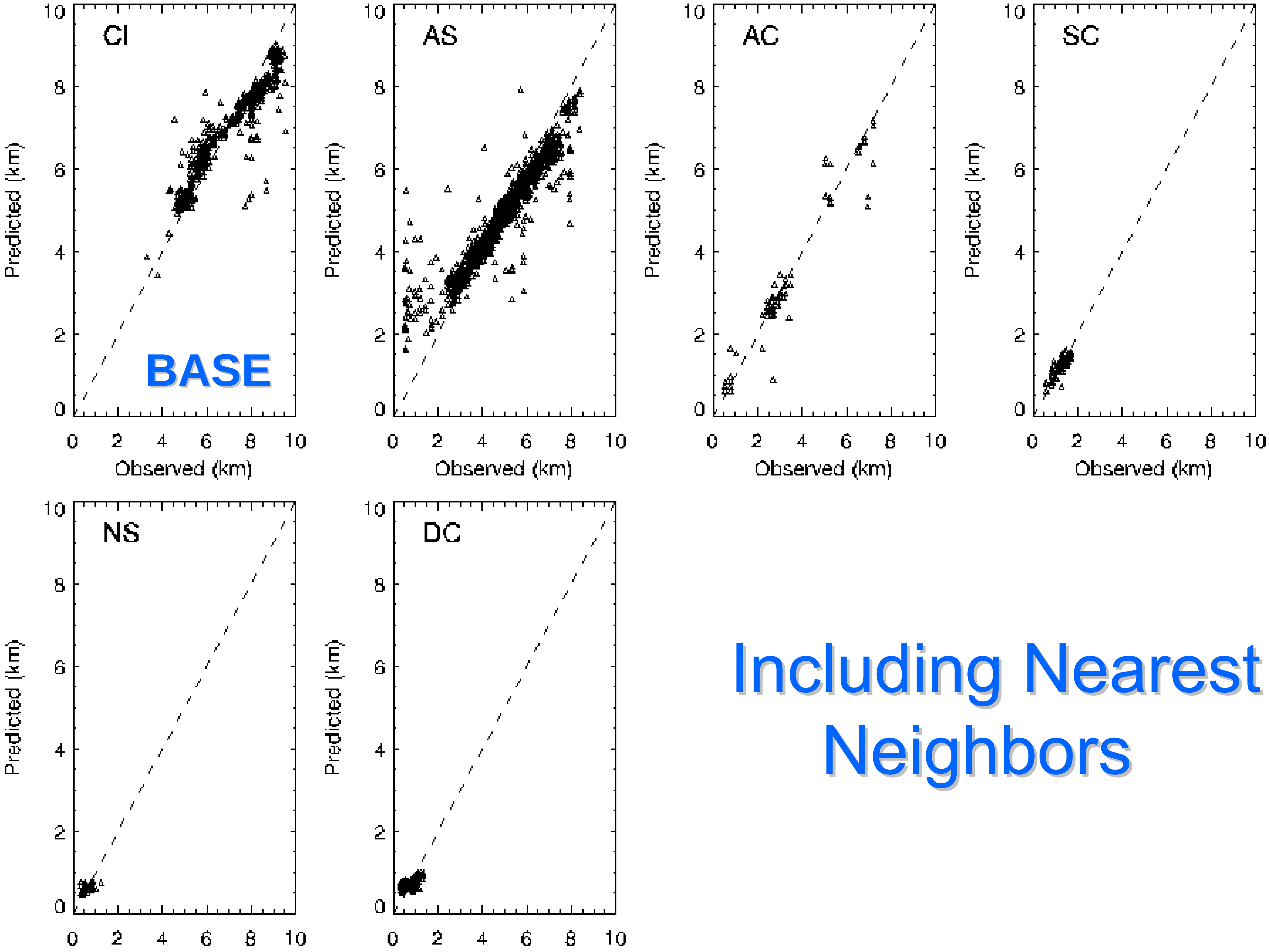
→ We illustrate this concept using along-track data.

Case Study: Eastern Pacific

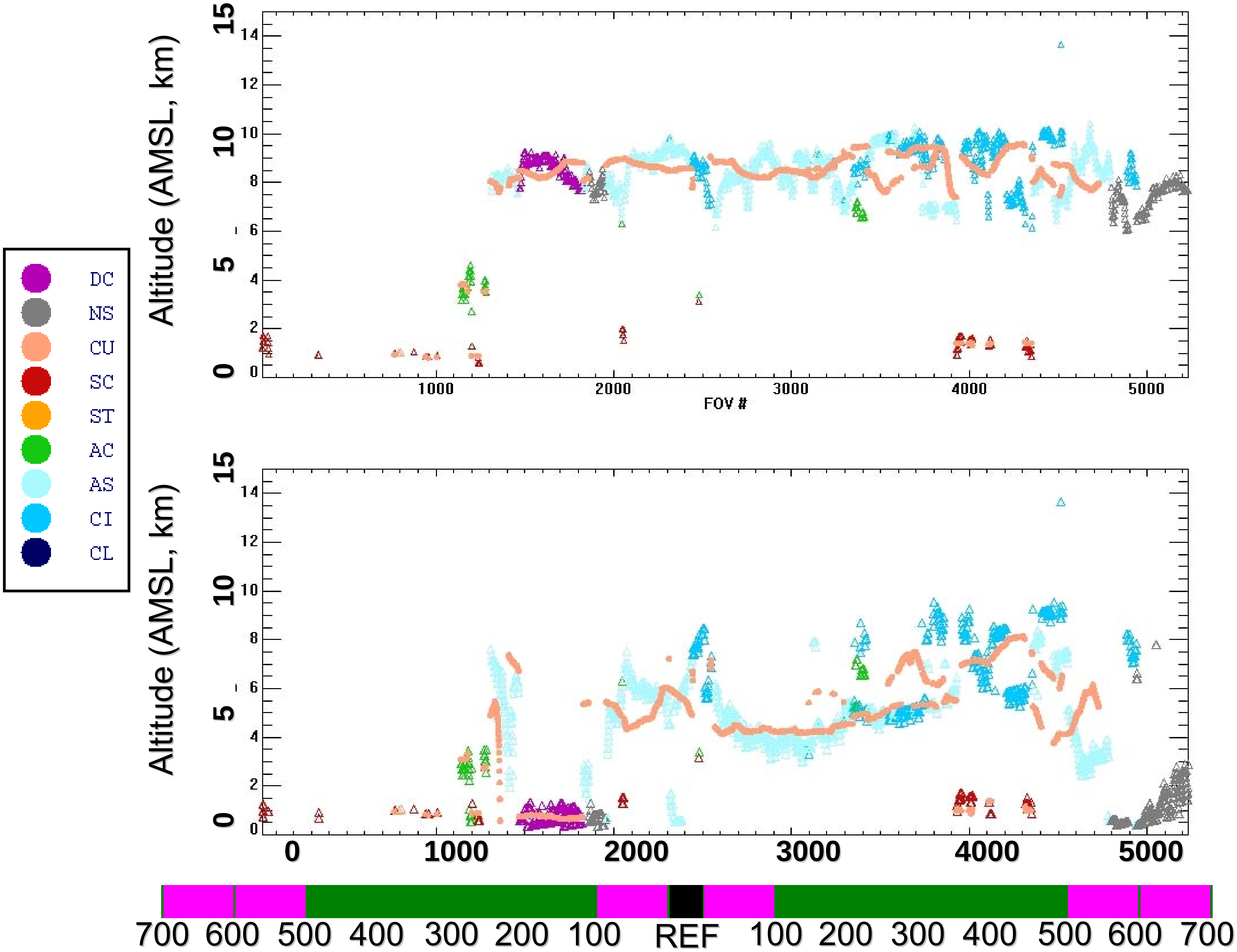
Jan. 20, 2009 2130 UTC



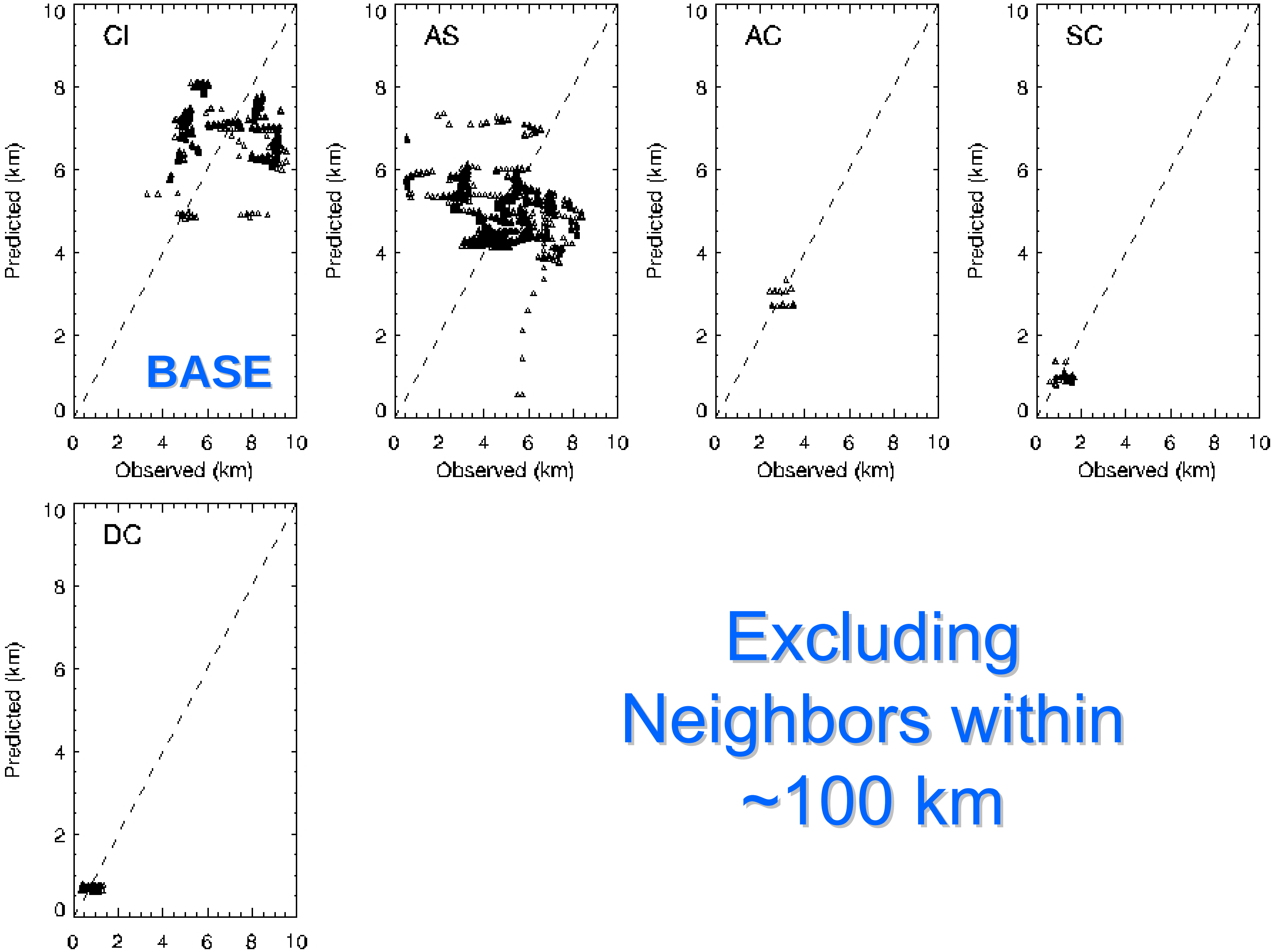

Cloud Top
Cloud Base
Altitude (AMSL, km)
Distance Along Ground Track (km)
FOV #
DC
NS
CU
SC
ST
AC
AS
CI
CL
700 600 500 400 300 200 100 REF 100 200 300 400 500 600 700



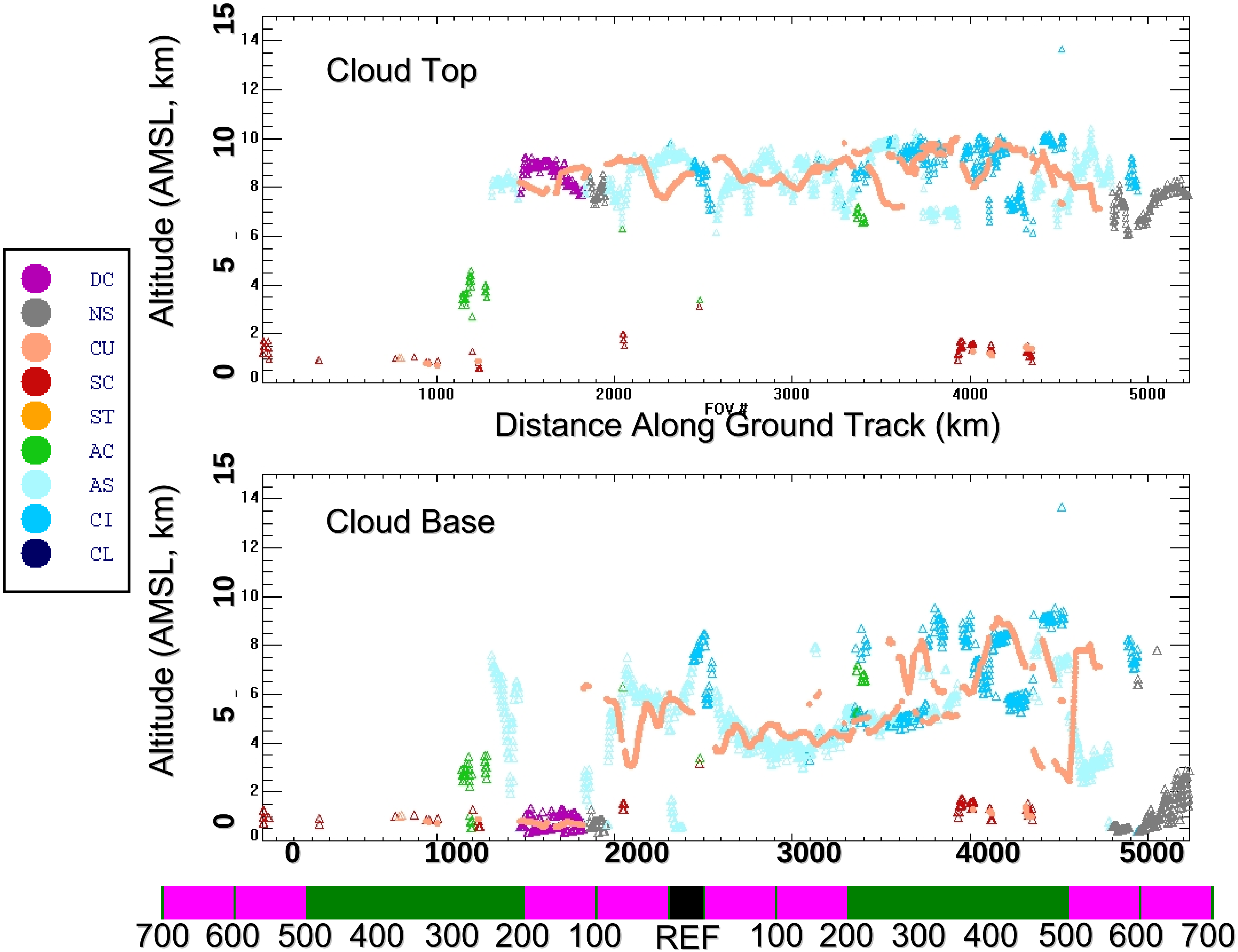
Including Nearest Neighbors



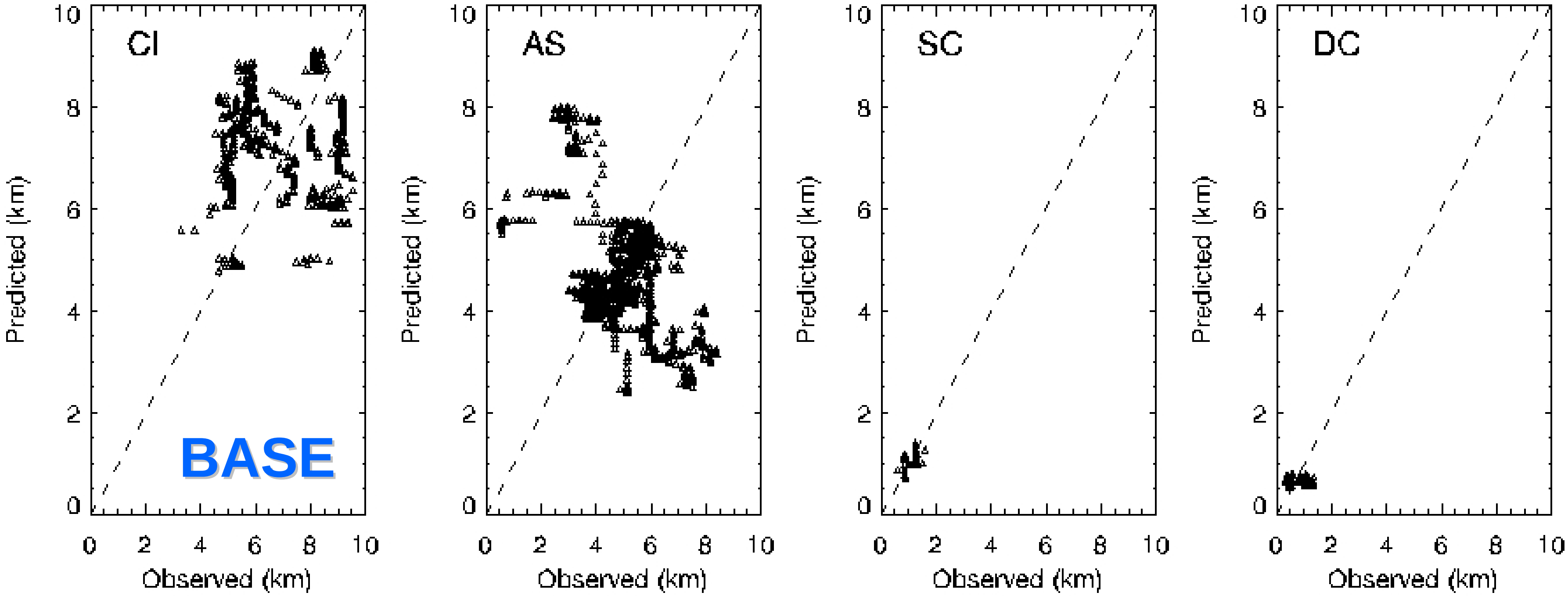
DC
NS
CU
SC
ST
AC
AS
CI
CL
Altitude (AMSL, km)
15
10
5
0
14
12
10
8
6
4
2
0
1000
2000
3000
4000
5000
FOV #
Altitude (AMSL, km)
0
1000
2000
3000
4000
5000
700 600 500 400 300 200 100 REF 100 200 300 400 500 600 700



Excluding Neighbors within ~100 km



Cloud Top
Altitude (AMSL, km)
15
10
5
0
14
12
10
8
6
4
2
0
1000
2000
3000
4000
5000
FOV #
Distance Along Ground Track (km)
Cloud Base
Altitude (AMSL, km)
15
10
5
0
14
12
10
8
6
4
2
0
0
1000
2000
3000
4000
5000
DC
NS
CU
SC
ST
AC
AS
CI
CL
700 600 500 400 300 200 100 REF 100 200 300 400 500 600 700



Excluding Neighbors within ~200 km

Next Steps

- Some cloud types (esp. altostratus, cirrus, and deep convection cloud tops) show strong zonal dependencies in standard deviation behavior → must examine this.
- Run statistics for contiguous and *non-contiguous* cloud layers.
- Time-matching between passive/active data important → use Aqua/MODIS.
- Extend statistics to 3 yr dataset and analyze seasonally.
- Off-track analysis—must reconcile cloud classification.

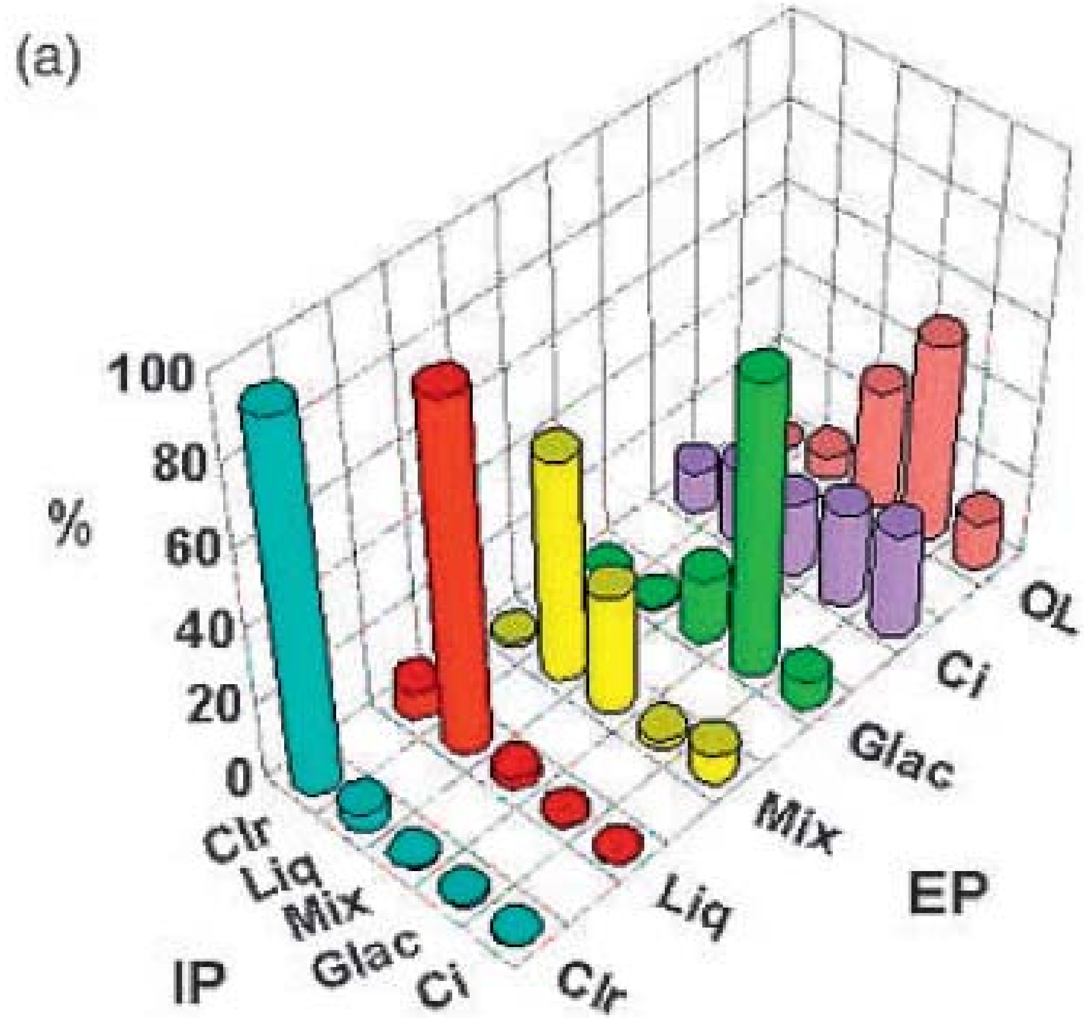
Liquid water
- Stratus (St)
- Stratocumulus (Sc)
- Cumulus (Cu)

Mixed phase/supercooled water
- Altocumulus (Ac)
- Altostratus (As)
- Cumulus congestus (CuC)

Glaciated
- Cirrocumulus (Cc)
- Cirrostratus (Cs)
- Cumulonimbus (Cb)
- CsAn

Clear (Clr)—not combined

Cirrus (Ci)—not combined



Bankert, R. L., C. Mitrescu, S. D. Miller, and R. H. Wade, 2009: ***Comparison of GOES cloud classification algorithms employing explicit and implicit physics***. J. Appl. Meteor., 48, 1411-1421.

→ A similar mapping must be done to relate CloudSat cloud types to those derived from passive swath data (MODIS/GOES/MSG/MTSAT)

Case 1: CloudSat Track more oblique to front

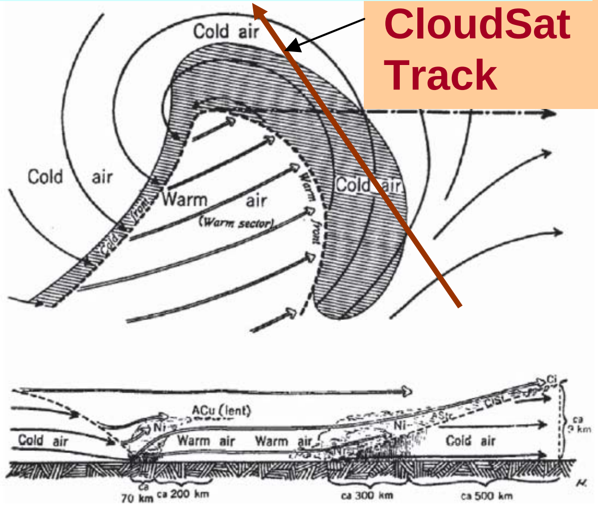


FIG. 1. Illustration of frontal clouds and precipitation in the Norwegian Cyclone Model, as conceptualized in Bjerknes and Solberg (1922).

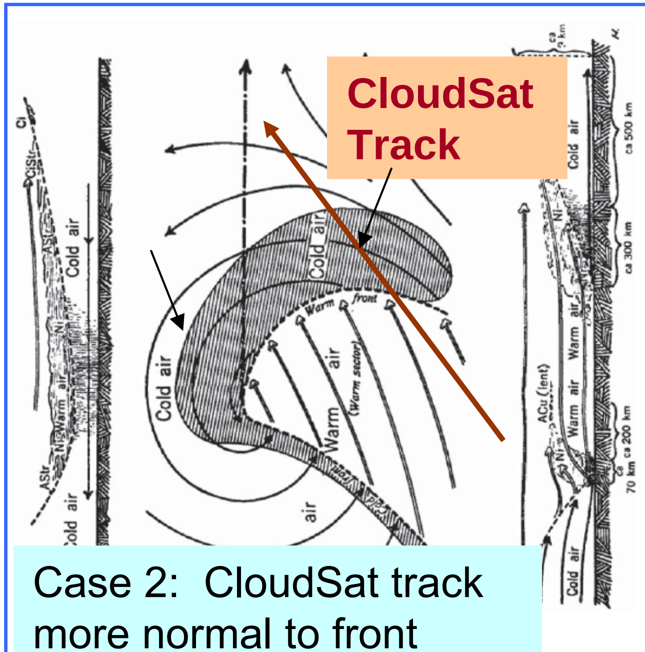
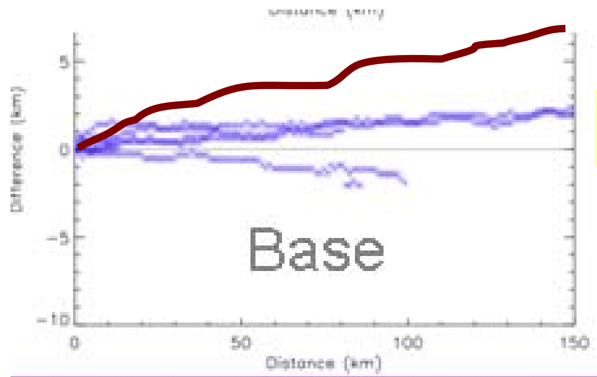


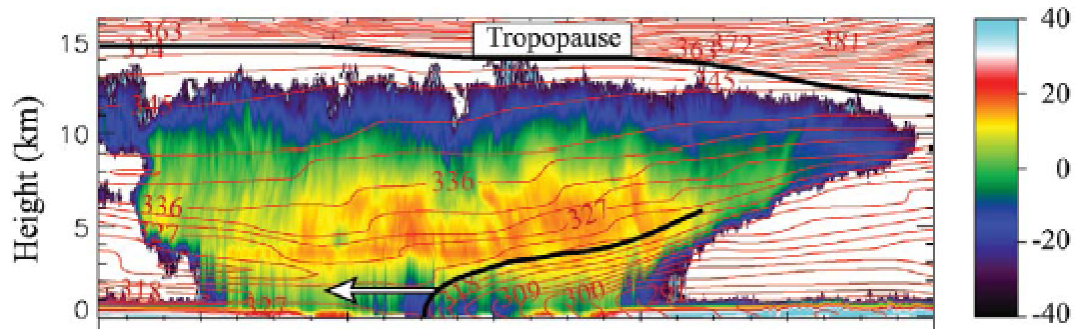
FIG. 1. Illustration of frontal clouds and precipitation in the Norwegian Cyclone Model, as conceptualized in Bjerknes and Solberg (1922).

Case 2: CloudSat track more normal to front

Are fronts oriented in a preferred direction with respect to CloudSat track? → Possible biases and/or truncations in current trace statistics.



Are there preferred directions where statistics are expected to perform better?



Base ~ roughly parallel to Θ_E surfaces

*Images adapted from Posselt, D. J., G. L. Stephens and M. Miller, 2008: CloudSat adding a new dimension to a classical view of extratropical cyclones. BAMS, **89**, 599 – 609.*

Summary

- A technique for providing vertically-resolved cloud information for the top-most layer(s) of passive imager swath data, based on cloud type dependent statistics from CloudSat/CALIPSO, is now in development.

- Early results show type-dependent structures in standard deviation that are consistent with our basic physical understanding of cloud dynamics/morphology.

- As the active datasets continue to grow, statistics for the stratified datasets will become increasingly robust.