A-Train Observations of Maritime Storm Track Cloud Systems: Comparing the Southern Ocean against the North Pacific and Atlantic

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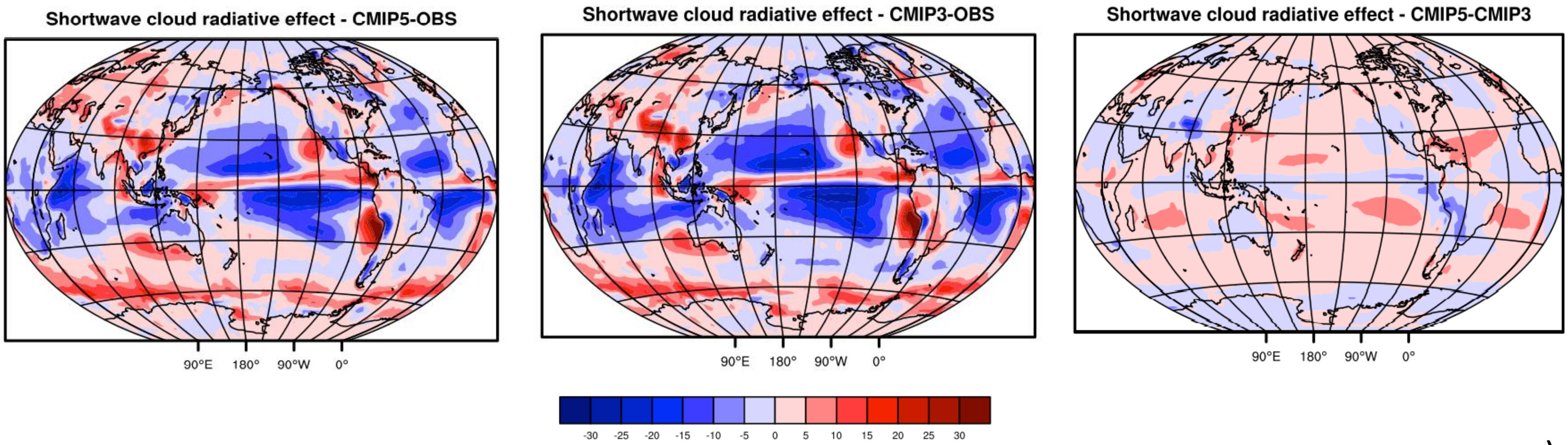
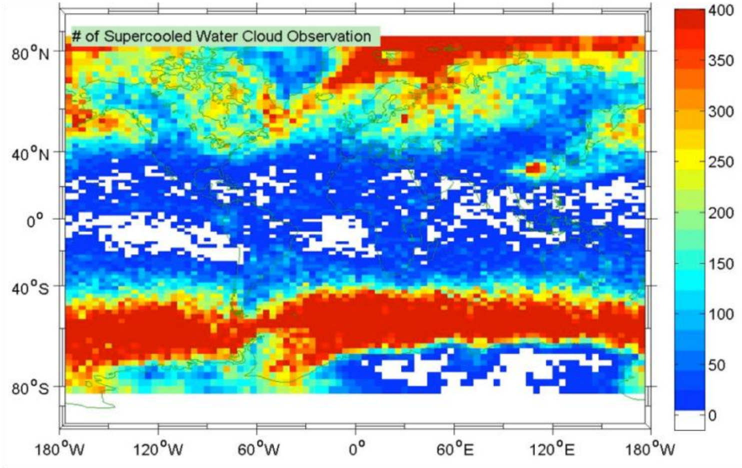
Challenges

Trenberth and Fasullo (2010) find that “disproportionately large biases exist in both the reanalysis and global coupled models” over the Southern Ocean (SO) which are “directly linked to the simulation of clouds in this region.” Moreover, they find a “remarkably strong relationship between the projected changes in clouds/climate and the simulated current-day cloud error.”

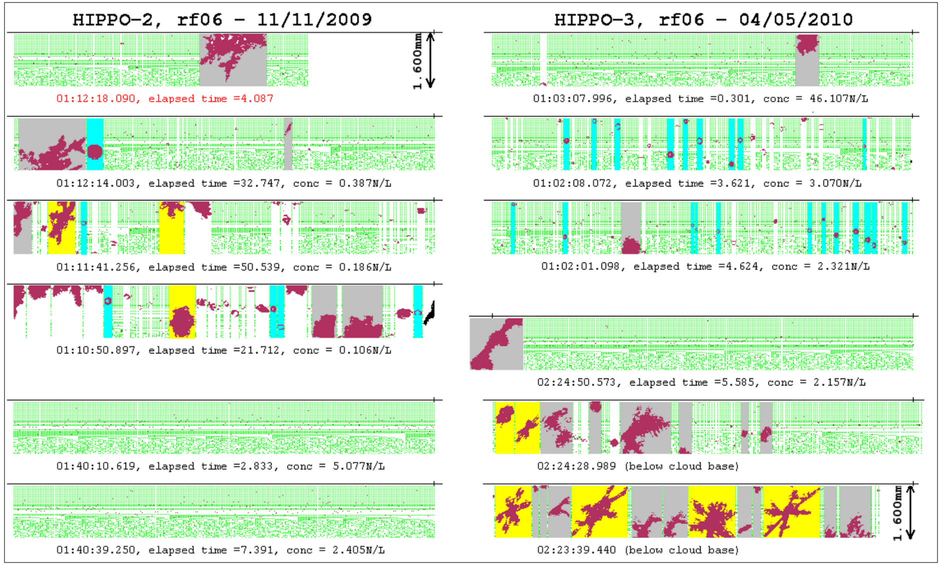


(from Jacob et al. WGNE workshop 2013)

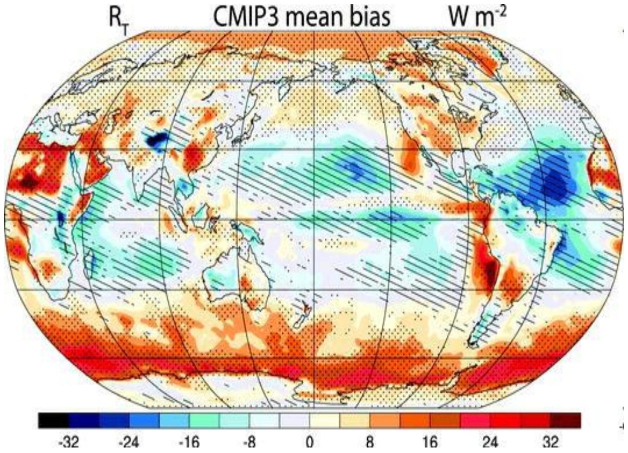
No major breakthroughs from CMIP3 to CMIP5!



Hu et al. (JGR 2010)



Chubb et al. (GRL 2013)



Trenberth and Fasullo (J. Climate 2010)

A lot of supercooled liquid water (SLW) over the Southern Ocean!

A high degree of similarity between the distribution of SLW over the SO and that of the mean bias of the SW radiation!

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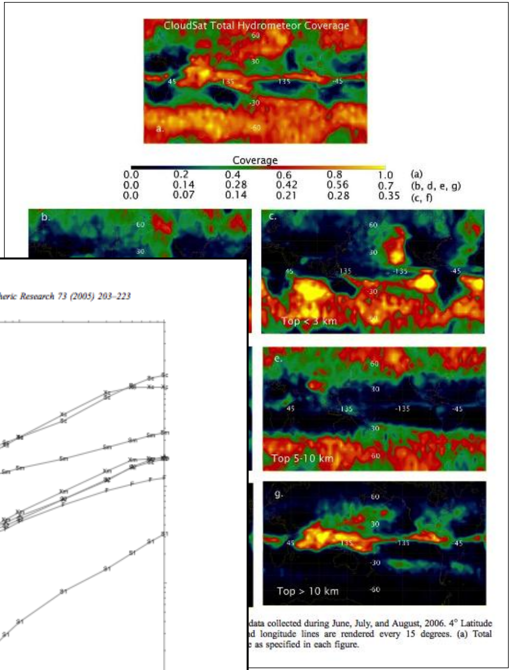
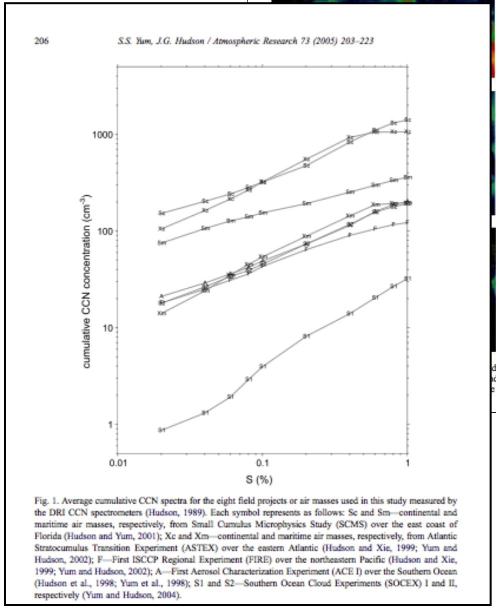
What’s the unique about the Southern Ocean environment?

- It has the highest fractional cloud cover in the world (e.g. Mace et al., JGR 2007).
- Annual averaged, it has the strongest winds and largest waves (Murphy et al. 1998).
- The air is highly pristine, particularly during winter (Yum and Hudson, 2005).
- Heavy sea spray.

Nevertheless, Mace (JGR, 2010) demonstrated that “there is a high degree of similarity in cloud occurrence statistics, cloud properties, and the radiative effects of the clouds” when comparing a region over the Southern Ocean to that of the North Atlantic using a merged A-Train product.





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Potential challenges in Mace (2010) analysis

- Cloud mask from merged CloudSat and CALIPSO
- Radar reflectivity from CloudSat
- Liquid water path derived from AMSR-E
- Cloud optical depth from MODIS
- Top-of-atmosphere (TOA) fluxes from Clouds and the Earth's Radiant Energy System (CERES)

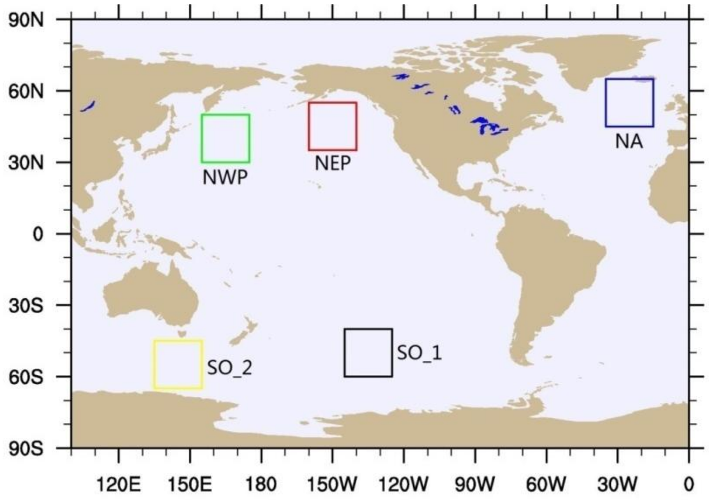
No cloud microphysics inputs from CALIPSO.

CloudSat cloud microphysics retrievals are temperature dependent.

Cloud integrated properties are from passive remote sensors only.

Properties and contribution of liquid/mixed phase clouds within the lower troposphere could be very uncertain!

Are there intrinsic/essential differences between the cloud nature over the NH and SH storm tracks?



With the application of both the individual (CloudSat/CALIPSO/MODIS) and the A-train merged products DARDAR-MASK (Delanoë et al. 2009).

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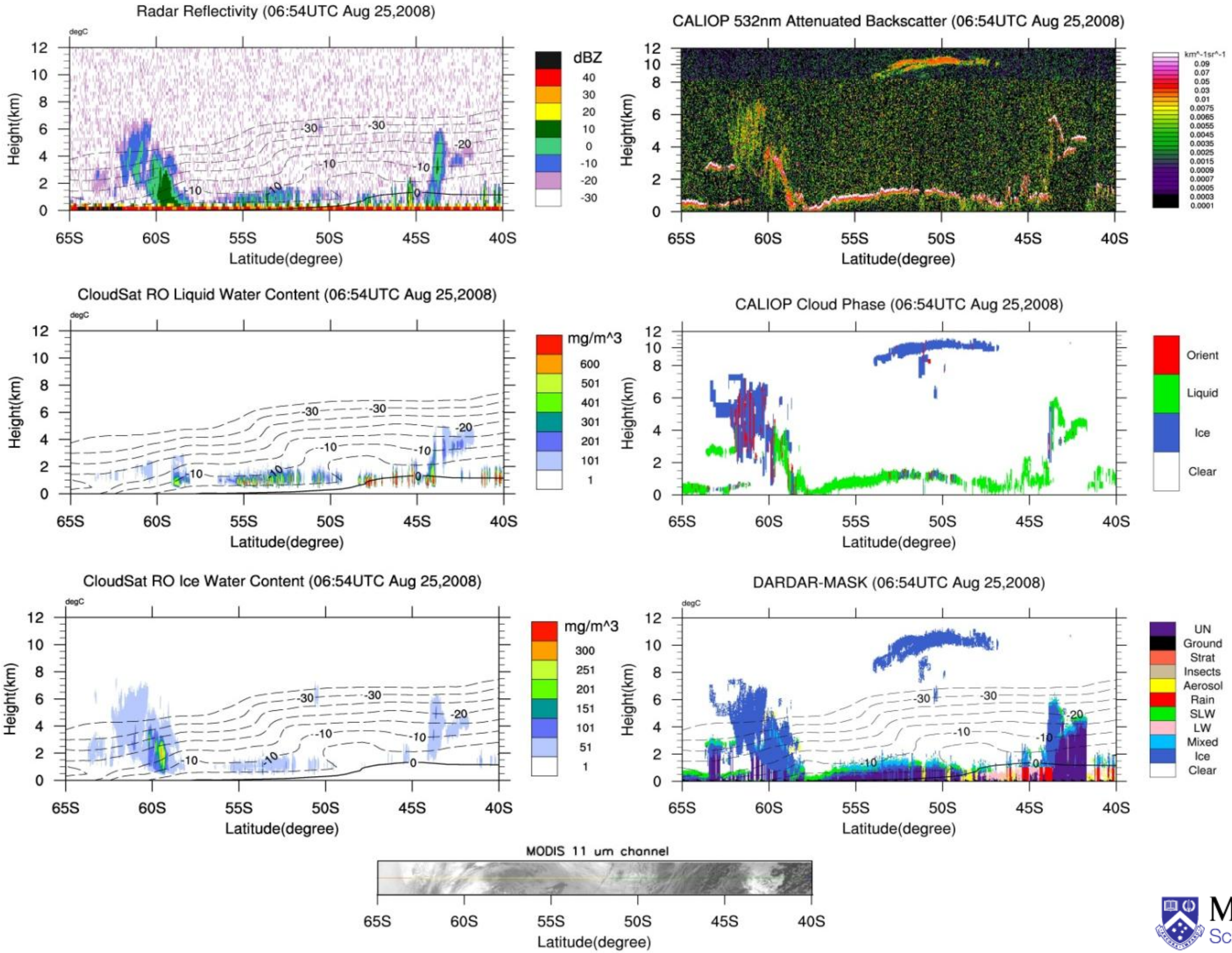

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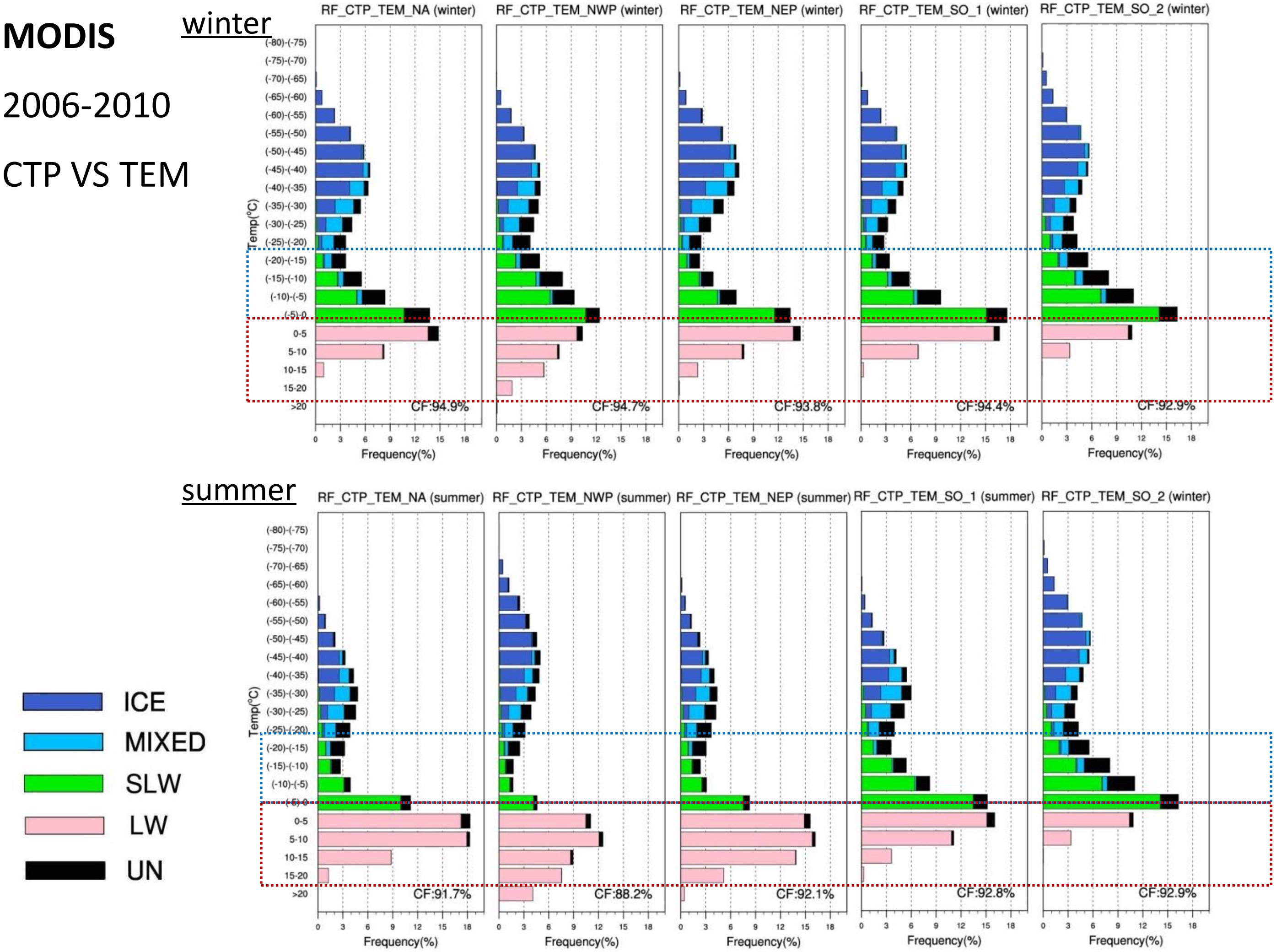
MODIS

2006-2010

CTP VS TEM



- Cloud Fractions (CFs) are comparable over the 5 regions
- Bimodal distribution (minimum between -15 and -25C).
- Temperature 0 and -20C dominated by SLW and, to a less extent, UN.
- Large seasonal cycle over NA, NWP and NEP. SO clouds only display a week seasonality.
- The SO storm tracks are exclusively covered by SLW CTs all year round, while significant increase of warm CTs are found over the NH storm tracks.

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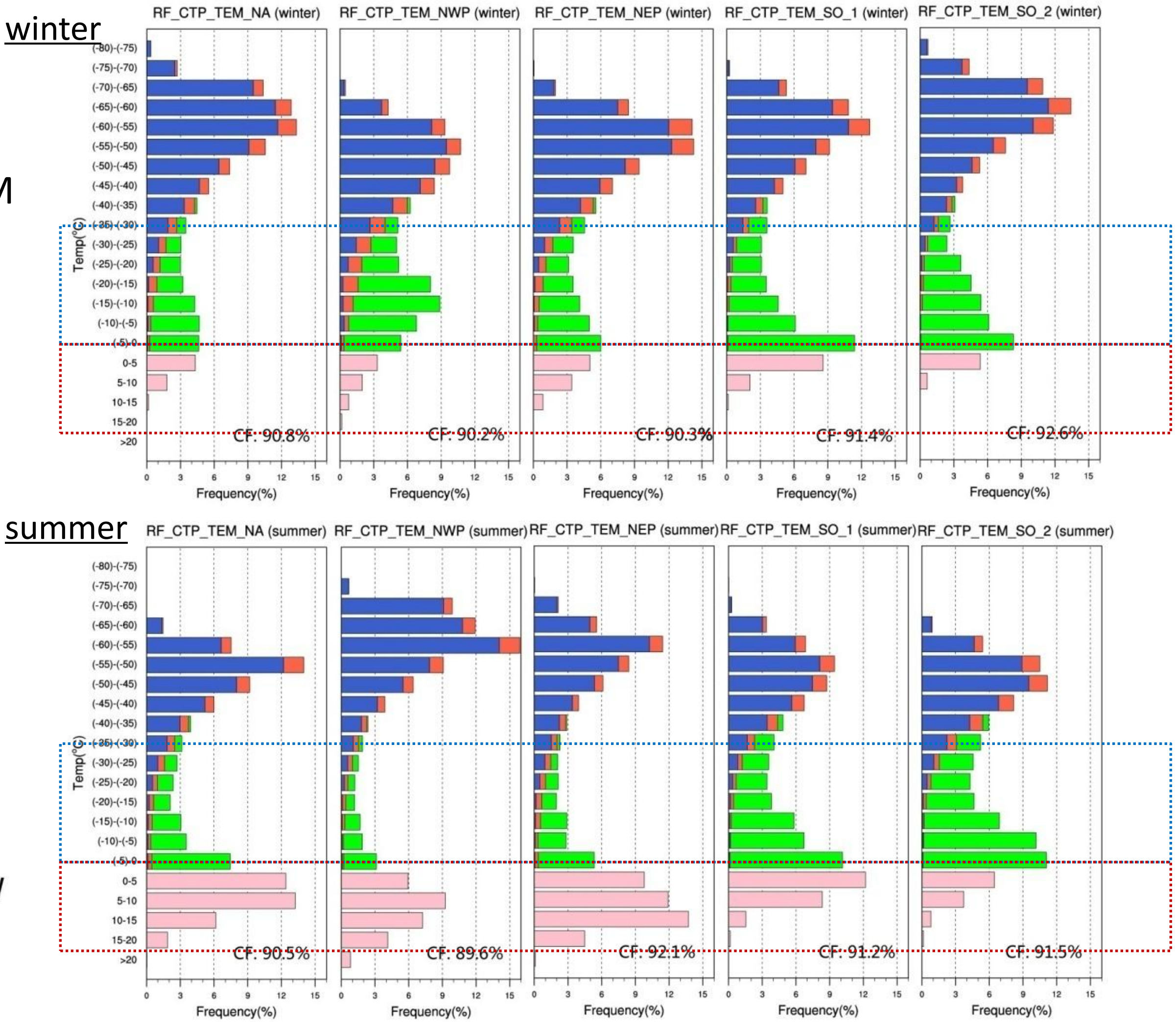
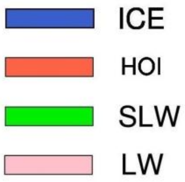
CALIPSO

2006-2010

CTP VS TEM





- Cloud Fractions (CFs) are comparable over the 5 regions
- Bimodal distribution (minimum between -15 and -25C).
- Temperature 0 and -20C dominated by SLW (down to -30C over the SO). ICE CTs are rarely found above -25C. Substantially more ICE CTs are between -30 and -70C.
- Large seasonal cycle over the NH storm tracks, particularly NWP.
- The SO regions are exclusively covered by SLW CTs all year round, while significant increase of warm CTs are found over the NH storm tracks.
- In summertime, more ICE CTs (cirrus) over NWP; and more SLW (possibly mid-level) CTs over the SO.

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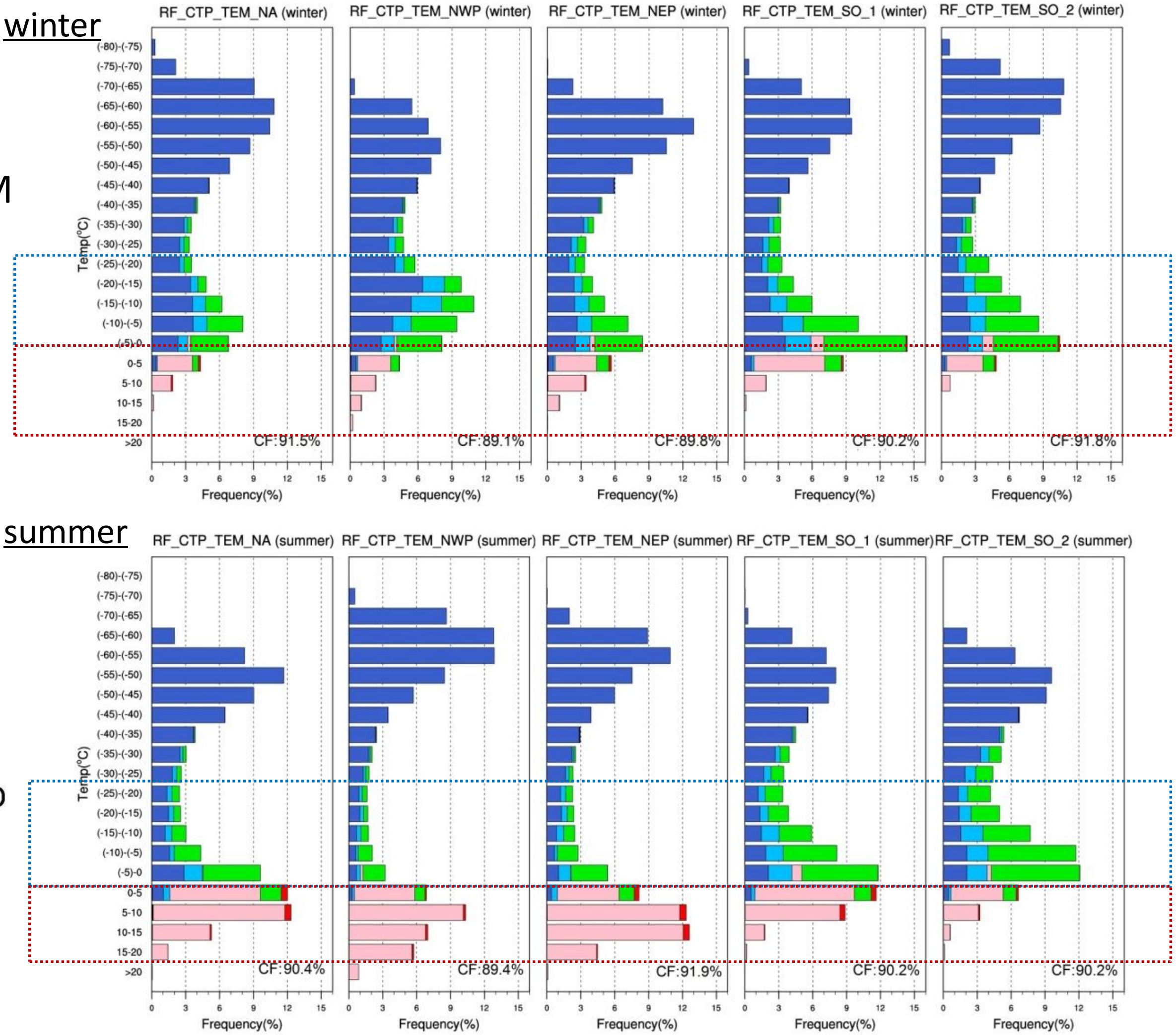
DARDAR

2006-2010

CTP VS TEM



- Cloud-top distributions across the temperatures are consistent with CALIPSO climatologies over the 5 regions.
- Compared to CALIPSO and MODIS, substantially more ICE and MIXED phase CTs are recorded between 0 and -25C.
- Large seasonal cycle over the NH storm tracks, particularly NWP.
- The SO regions are exclusively covered by SLW CTs all year round, while significant increase of warm CTs are found over the NH storm tracks.
- In summertime, more ICE CTs (cirrus) over NWP; and more SLW (possibly mid-level) CTs over the SO.

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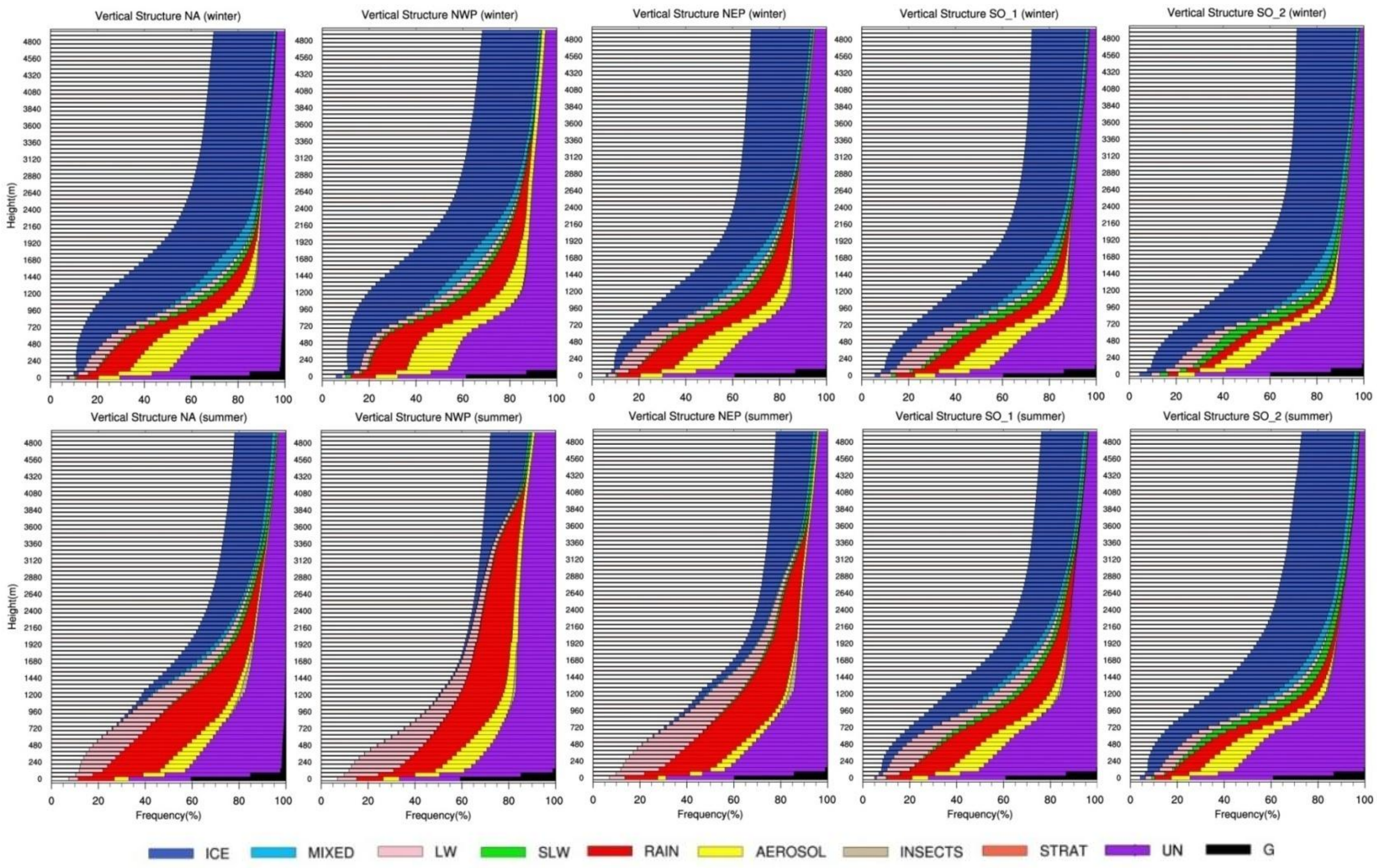
Vertical structures seen by DARDAR-MASK



- Cloud vertical structures display a large (weak) seasonal variation over the NA, NWP and NA (SO).
- The bulk of clouds are thicker over NA and NWP during wintertime.
- Substantial increase of RAIN class during summer over NA, NWP and NEP.
- The inability of CPR in the lowest km seems to have biased the vertical structure of the profiles (notice the sharp change in curvature at 720 and 960m).

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Problems:

Definition of clouds and cloud thermodynamic phase is not unique.

Definition differs among observations

MODIS: passive radiometer (vertically integrated information; not sensitive to optically thin clouds, e.g. cirrus)

CloudSat : Active cloud profiling radar (Rayleigh ap… proportional … dominated by ice particles due to their large diameter).

CALIPSO: 532/1064nm lidar (backscattered intensity appro. proportional to the square of particle diameter; signals dominated by liquid droplets due to their large number concentration).

Definition differs among retrieval algorithms

MODIS: a function of the brightness temperature difference between 8.5- and 11-µm channels.

CALIPSO (Hu et al.2009)

Pro: depolarisation ~ sphericity (ice vs. liquid) …ould be good).

…hole layer.

depolarisation is too noisy

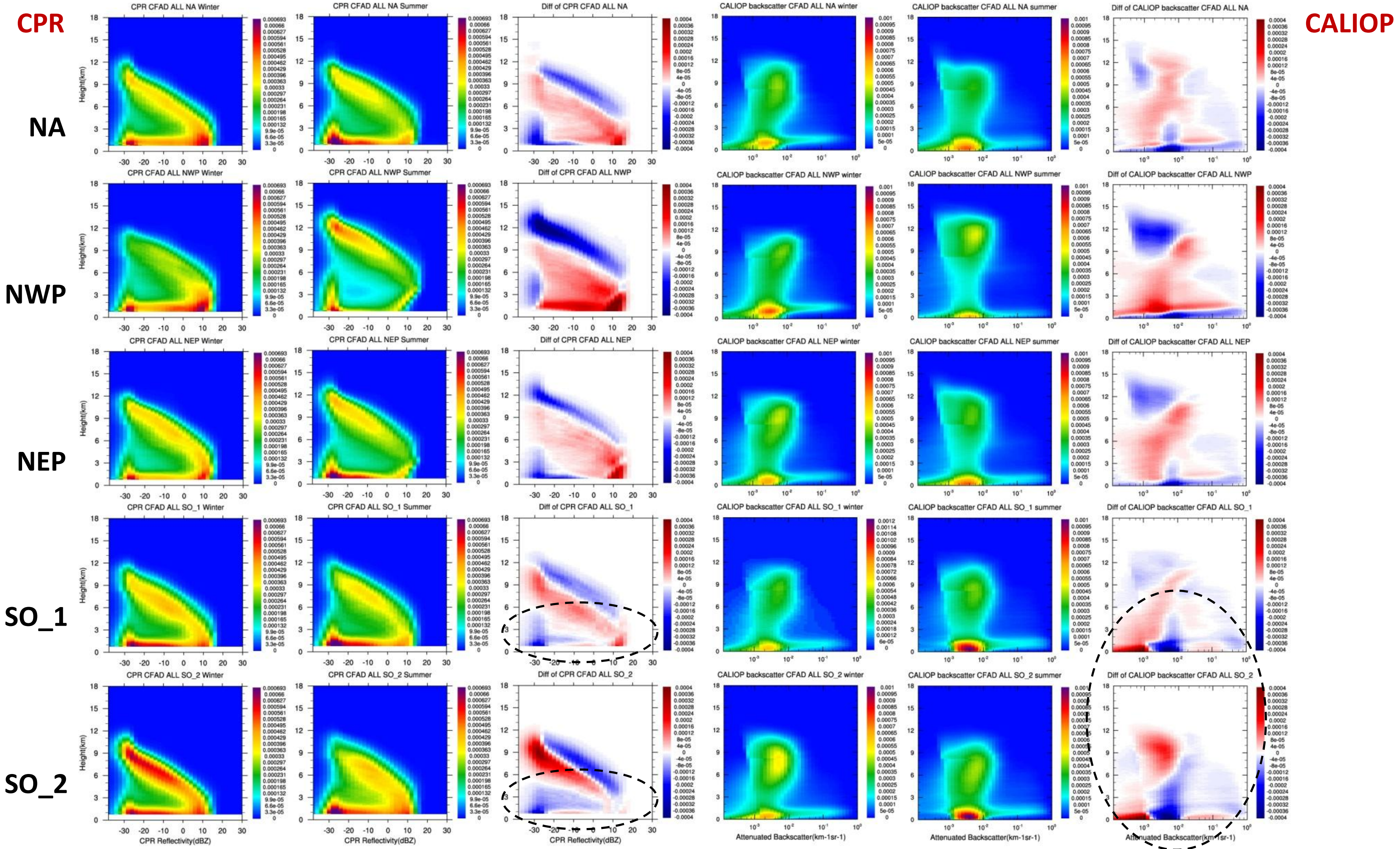
cannot determine mixed phase.

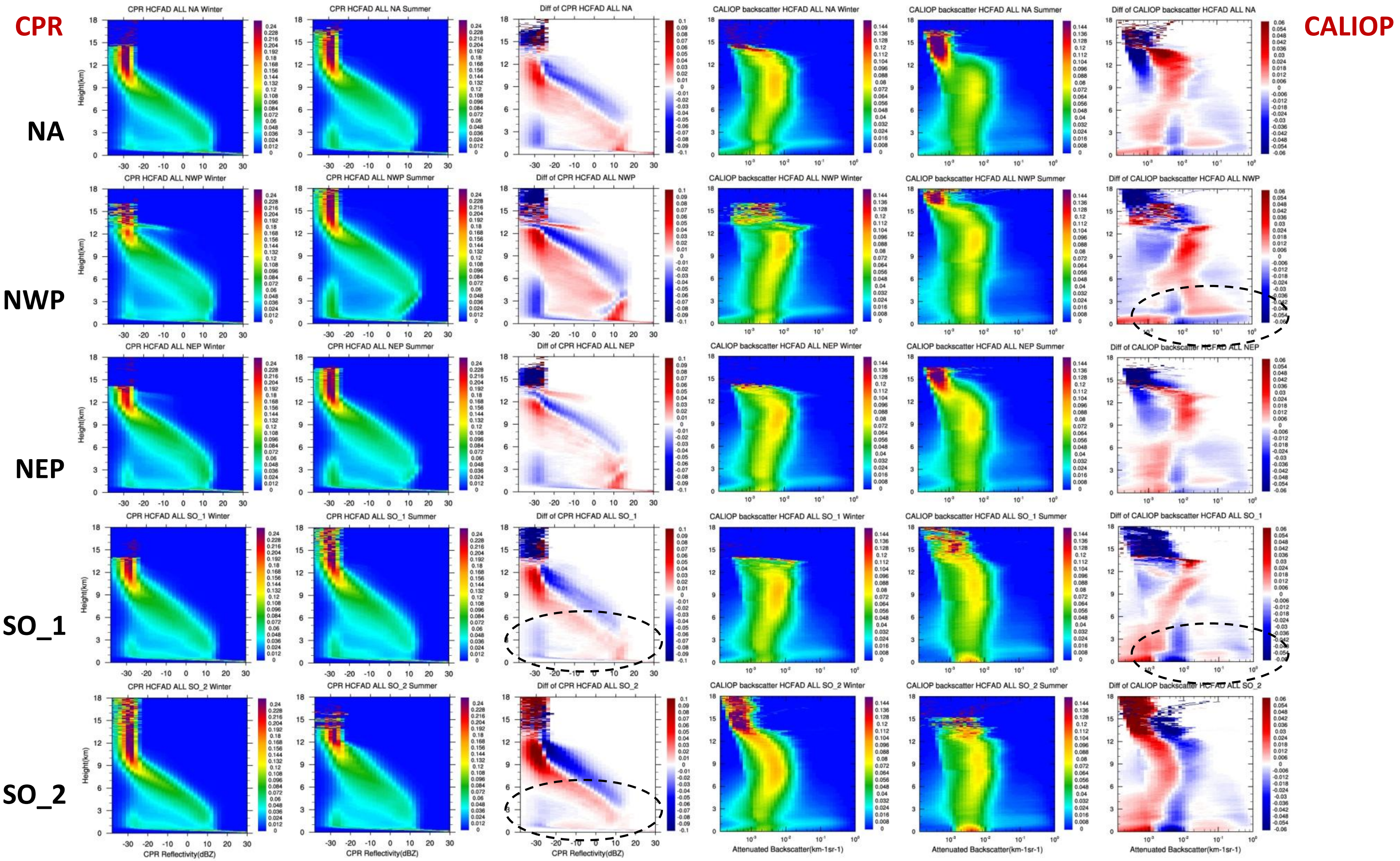
DARDAR (Delanoë et al. 2009):

Pro: combination of radar and lidar (provide vertical distribution of cloud properties).

Con: assumption of attenuated backscatter ß

Apart from the retrievals, it is also important to examine the raw signals obtained by individual instruments!

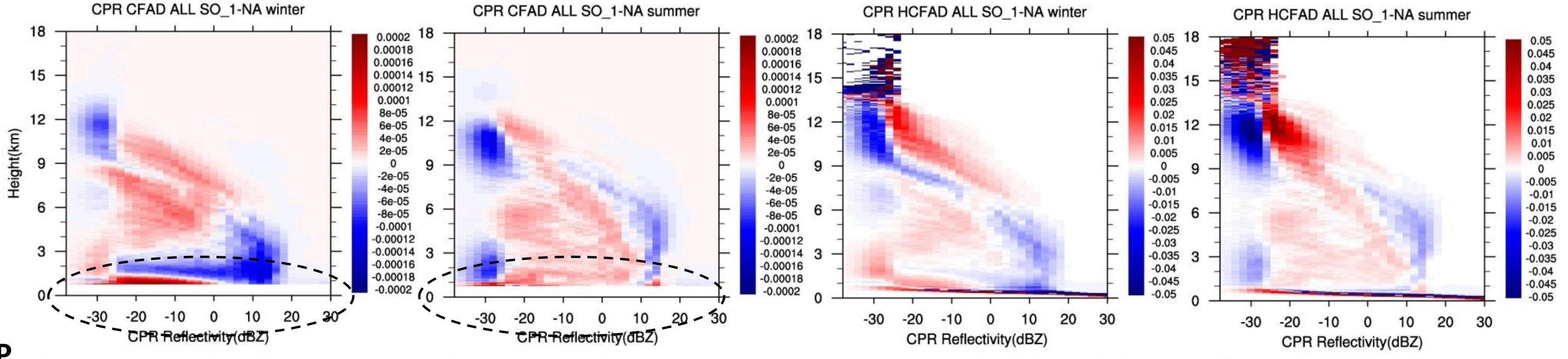

CPR
CALIOP
NA
NWP
NEP
SO_1
SO_2
CPR CFAD ALL NA Winter
CPR CFAD ALL NA Summer
Diff of CPR CFAD ALL NA
CALIOP backscatter CFAD ALL NA winter
CALIOP backscatter CFAD ALL NA summer
Diff of CALIOP backscatter CFAD ALL NA
CPR CFAD ALL NWP Winter
CPR CFAD ALL NWP Summer
Diff of CPR CFAD ALL NWP
CALIOP backscatter CFAD ALL NWP winter
CALIOP backscatter CFAD ALL NWP summer
Diff of CALIOP backscatter CFAD ALL NWP
CPR CFAD ALL NEP Winter
CPR CFAD ALL NEP Summer
Diff of CPR CFAD ALL NEP
CALIOP backscatter CFAD ALL NEP winter
CALIOP backscatter CFAD ALL NEP summer
Diff of CALIOP backscatter CFAD ALL NEP
CPR CFAD ALL SO_1 Winter
CPR CFAD ALL SO_1 Summer
Diff of CPR CFAD ALL SO_1
CALIOP backscatter CFAD ALL SO_1 winter
CALIOP backscatter CFAD ALL SO_1 summer
Diff of CALIOP backscatter CFAD ALL SO_1
CPR CFAD ALL SO_2 Winter
CPR CFAD ALL SO_2 Summer
Diff of CPR CFAD ALL SO_2
CALIOP backscatter CFAD ALL SO_2 winter
CALIOP backscatter CFAD ALL SO_2 summer
Diff of CALIOP backscatter CFAD ALL SO_2
Height(km)
CPR Reflectivity(dBZ)
Attenuated Backscatter(km-1sr-1)


CPR
CALIOP
NA
NWP
NEP
SO_1
SO_2
CPR HCFAD ALL NA Winter
CPR HCFAD ALL NA Summer
Diff of CPR HCFAD ALL NA
CALIOP backscatter HCFAD ALL NA Winter
CALIOP backscatter HCFAD ALL NA Summer
Diff of CALIOP backscatter HCFAD ALL NA
CPR HCFAD ALL NWP Winter
CPR HCFAD ALL NWP Summer
Diff of CPR HCFAD ALL NWP
CALIOP backscatter HCFAD ALL NWP Winter
CALIOP backscatter HCFAD ALL NWP Summer
Diff of CALIOP backscatter HCFAD ALL NWP
CPR HCFAD ALL NEP Winter
CPR HCFAD ALL NEP Summer
Diff of CPR HCFAD ALL NEP
CALIOP backscatter HCFAD ALL NEP Winter
CALIOP backscatter HCFAD ALL NEP Summer
Diff of CALIOP backscatter HCFAD ALL NEP
CPR HCFAD ALL SO_1 Winter
CPR HCFAD ALL SO_1 Summer
Diff of CPR HCFAD ALL SO_1
CALIOP backscatter HCFAD ALL SO_1 Winter
CALIOP backscatter HCFAD ALL SO_1 Summer
Diff of CALIOP backscatter HCFAD ALL SO_1
CPR HCFAD ALL SO_2 Winter
CPR HCFAD ALL SO_2 Summer
Diff of CPR HCFAD ALL SO_2
CALIOP backscatter HCFAD ALL SO_2 Winter
CALIOP backscatter HCFAD ALL SO_2 Summer
Diff of CALIOP backscatter HCFAD ALL SO_2
Height(km)
CPR Reflectivity(dBZ)
Attenuated Backscatter(km-1sr-1)

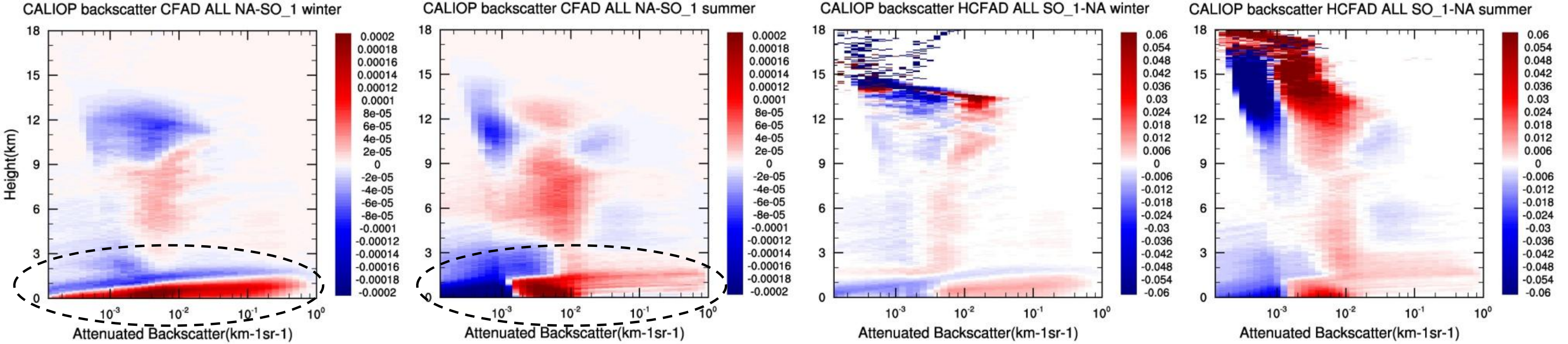
Comparison between the SO and NA (SO_1 minus NA)

CFAD **HCFAD**

CPR



CALIOP



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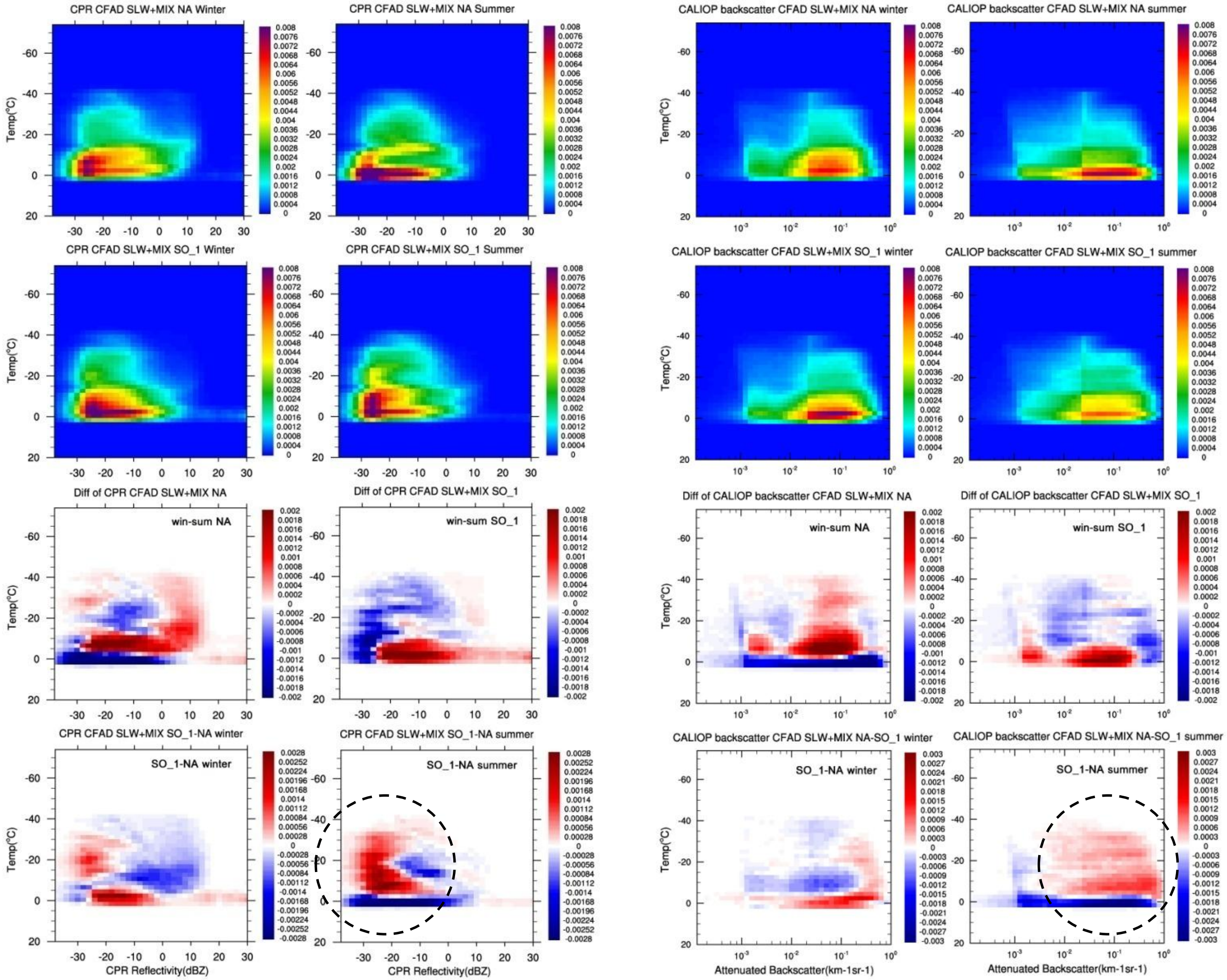
CPR

CALIOP



Most significant difference happens in summertime!

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Conclusion:

- The 4-yr climatology study using both individual and an A-Train merged products shows that fractional cloud covers are comparable over the NH and SH storm tracks, but the cloud structure and thermodynamic phase composition are very different.

- Cloud properties along the NH (SH) storm tracks display a strong (weak) seasonality. The NH storm tracks are featured by more glaciated clouds (associated with frequent frontal passages) during winter, and substantial increase of warm liquid clouds and rain during summer.

- The SO clouds are dominated by low/mid-altitude clouds all year round. Most of these clouds contain a large amount of SLW, which is not as frequently found over the NH storm tracks. This suggests that he boundary layer processes play an important role in the SO clouds systems.

- CloudSat observations have significant limitations in detecting SLW clouds and low-altitude warm clouds (below 1km), particularly over the SO. This shortcoming might result in considerable underestimate of the liquid clouds occurrence and their impacts on radiation budget.

- CALIPSO observations offer critical insights to understanding cloud microphysical and radiative properties, which could not be derived confidently by passive remote sensors. The lack of using CALIPSO inputs in studying cloud microphysics (e.g. Mace 2010) might bias our understanding of the storm track cloud systems.