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Overview of Joint-Simulator development and application to GCMs

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Joint-Simulator
(Joint Simulator for Satellite Sensors)

- Simulate EarthCARE observations from Cloud Resolving Model (CRM) outputs.
  - ✓ Built on Satellite Data Simulator Unit (SDSU) (Masunaga et al. 2010, BAMS), specifically NASA Goddard-SDSU (NASA-open source http://opensource.gsfc.nasa.gov/projects/G-SDSU/index.php)
  - ✓ A suit of 1D plane-parallel simulators
  - ✓ Has an universal model interface that can be applied for various aerosol and cloud microphysical outputs

Main aims

- Validation and improvement of aerosol-cloud microphysical schemes in cloud resolving models (Hashino et al. 2013, 2016)
- Support for retrieval algorithm development

Joint-simulator available by registration; see https://sites.google.com/site/jointsimulator/
List of publications is also available in the site.

Sensor simulators

As of 2022 Feb

SDSU family

Blue: SDSU modules (http://precip.hyarc.nagoya-u.ac.jp/sdsu/index.html)
Green: NASA Goddard SDSU extension (http://opensource.gsfc.nasa.gov/projects/G-SDSU/index.php)
Orange: Joint-Simulator extension (https://sites.google.com/site/jointsimulator/home)

- Visible and infrared imager
  - RSTAR7 (Nakajima & Tanaka 1986, 1988)
    - Discrete-ordinate method/adding method
    - K-distribution table with HITRAN2004
- Broadband radiometer
  - CLIRAD (Chou and Suarez 1994, 1999; Chou et al. 2001)
    - delta-Eddington approximation/adding method (two stream)
    - K-distribution method with HITRAN1996
    - 21 bands
  - MSTRN-X (Sekiguchi and Nakajima 2008)
    - Discrete-ordinate method/adding method (two stream)
    - Correlated-k distribution method with HITRAN2004
    - 18, 29, or 37 bands.
  - RRTMG (Iacono et al. 2008)
    - Two-stream approximation and correlated-k approach.
    - 16 bands for longwave, 14 bands for shortwave.

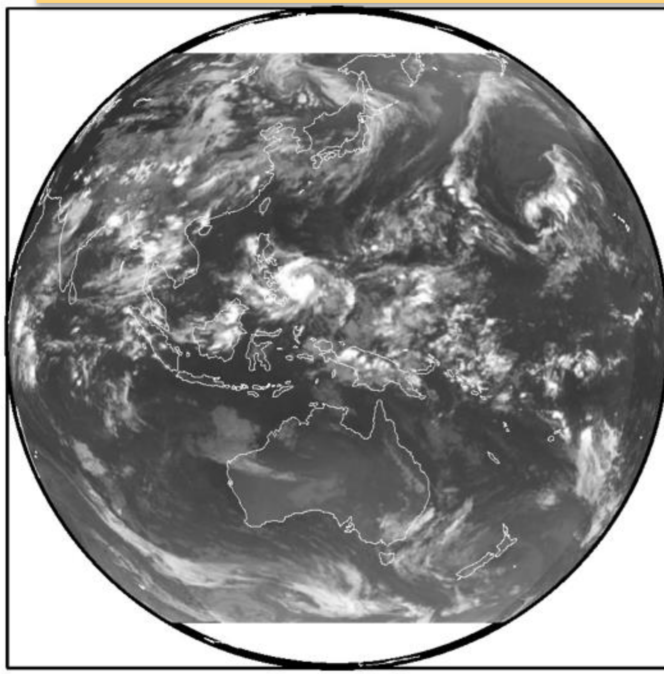
SDSU family

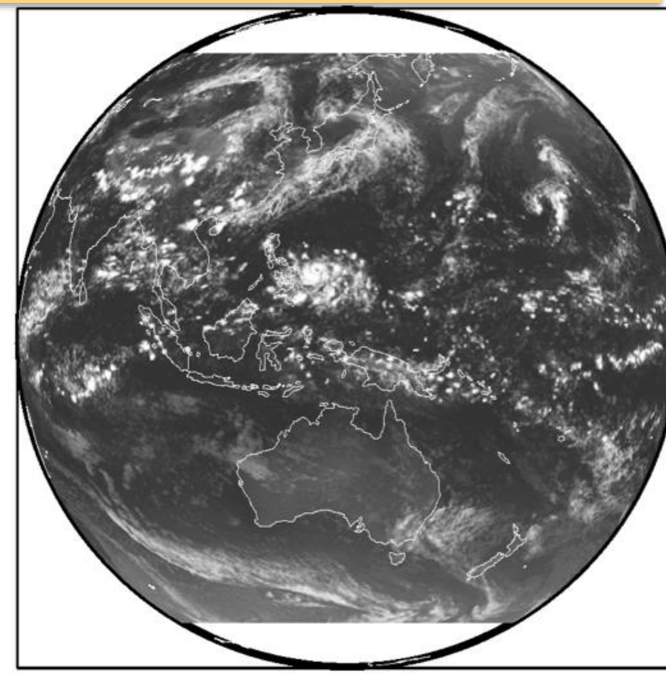
Blue: SDSU modules (http://precip.hyarc.nagoya-u.ac.jp/sdsu/index.html)
Green: NASA Goddard SDSU extension (http://opensource.gsfc.nasa.gov/projects/G-SDSU/index.php)
Orange: Joint-Simulator extension (https://sites.google.com/site/jointsimulator/home)

- Microwave radiometer and sounder
  - Kummerow (1993)
  - Liu (1998)
- Radar
  - Masunaga & Kummerow (2005)
  - EASE (Okamoto et al. 2007, 2008; Nishizawa et al. 2008)
  - POLARRIS-F (Matsui et al., 2019)
    - T-matrix method and Muller matrix
- Lidar
  - Matsui et al. (2009)
  - EASE

Auxiliary modules

- Field of view module
- Bright band module
  - Awaka et al. (1985)
- Subgrid module
  - Expand a grid column into subgrid columns.
  - Max-random overlap scheme (Jakob & Klein 1999)
  - PREC-SCOPS (Zhang et al. 2010)
- Statistics module
  - Generate joint histograms (CFAD)





Joint-Simulator is useful for quick, qualitative diagnosis of weather prediction.

Radar-lidar diagnosis for IWC and $R_{eff,m}$

- In the Arctic (65-80°N)

Observation Joint PDF

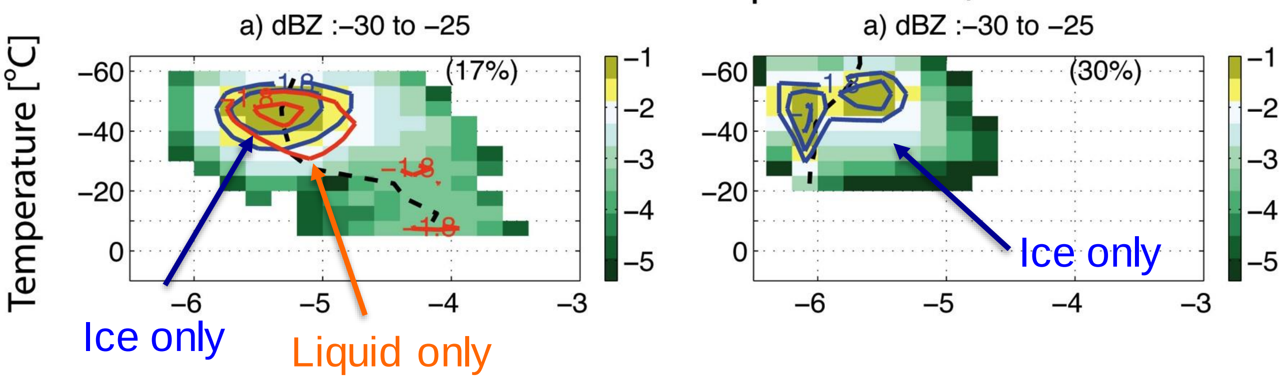
Simulation Joint PDF

Procedure for BETTER

1. Extract Z of similar values
2. Compare β

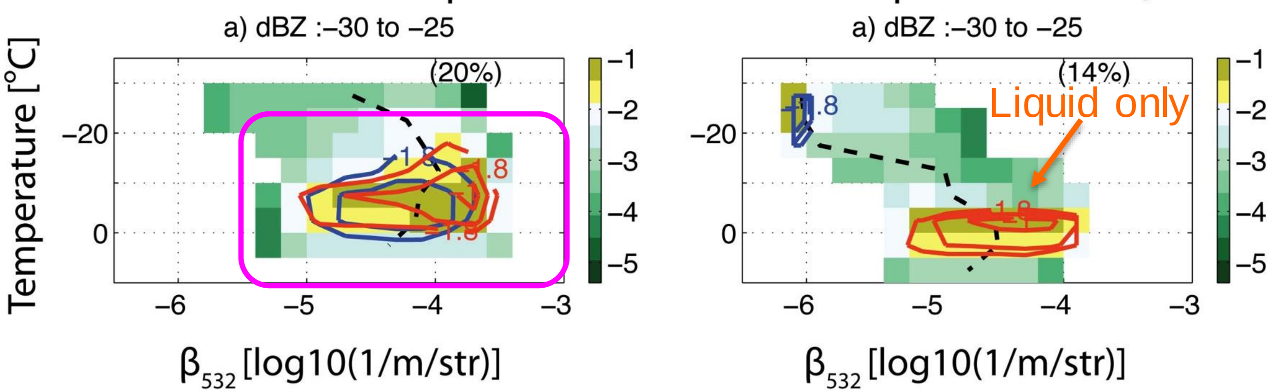
- If β is large, then IWC is large and $R_{eff,m}$ is small.

Hn ~ cirrus (cloud-top T < -28°C)



Cloud ice & snow: size is large and IWC is small,

Mn ~ Mixed-phase clouds (cloud-top T 0 ~ -28°C)

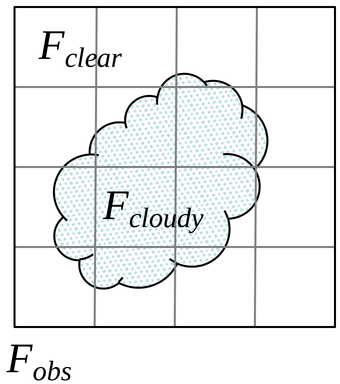


Lack of supercooled liquid in T < -10°C

Freezing of cloud droplets were not simulated.

Hashino et al. (2016)

Impacts of phase of cloud particles on radiation



Cloud Radiation Effects at surface

$$C = N(F_{cloudy} - F_{clear})$$

N: cloud fraction

Negative: surface cooling

Positive: surface heating

$$F_{cloudy} - F_{clear}$$

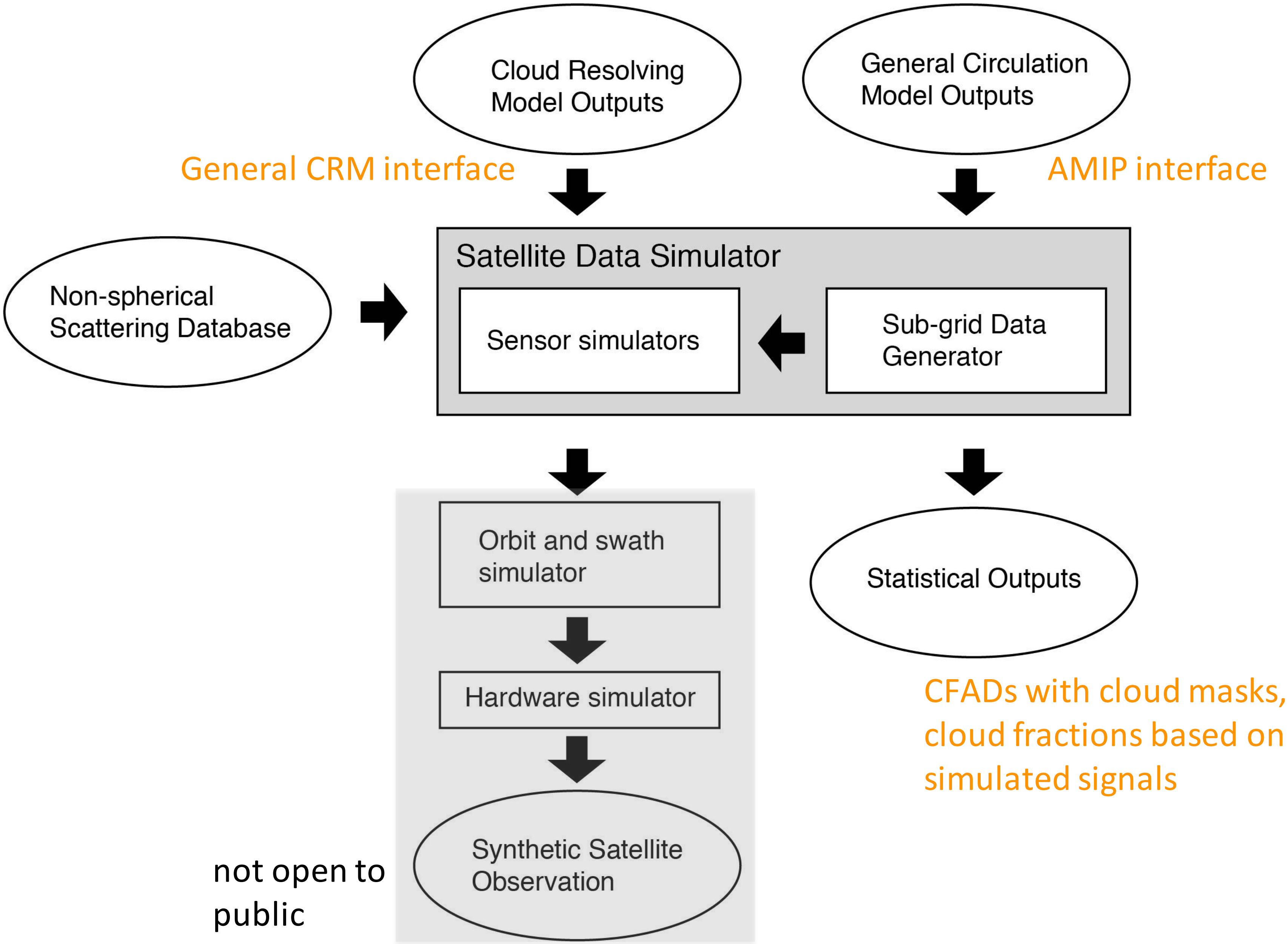
Downward Shortwave Radiation (W/m²)		High clouds (Hn)	Mixed-phase clouds (Mn)
Clouds containing liquid particles	OBS	-74	-146
	NICAM		-116
Ice-only clouds	OBS	-48	-130
	NICAM	-21	-25

Downward Longwave Radiation (W/m²)		High clouds (Hn)	Mixed-phase clouds (Mn)
Clouds containing liquid particles	OBS	40	65
	NICAM		47
Ice-only clouds	OBS	20	53
	NICAM	13	16

Diagnosis of IWC and effective radius is consistent with the bias of cloud radiative effects.
Evaluation of GCM clouds and precipitation has to be connected to radiation.

Hashino et al. (2016)

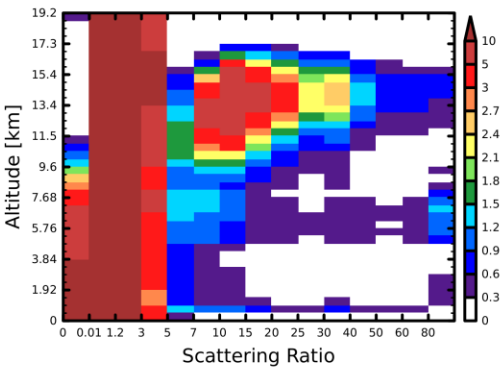
Joint-Simulator work flow



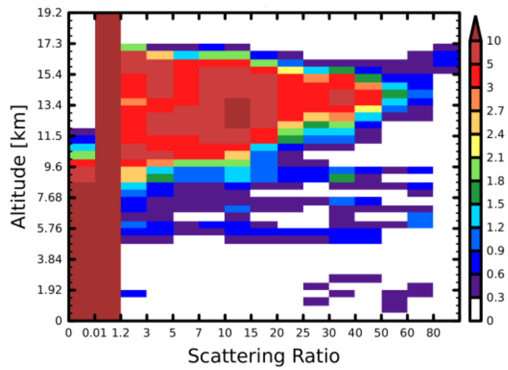
Comparison of COSP and J-SIM forward simulation

Tropical Western Pacific (5S-20N, 70-150E) 2008 June

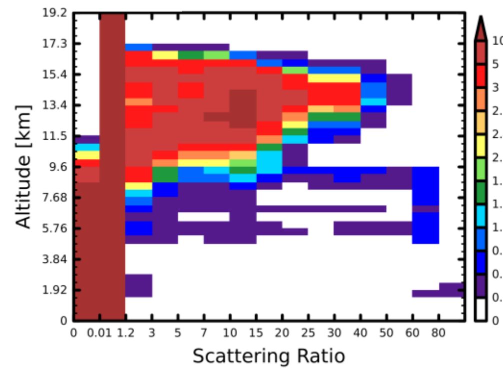
CALIPSO: OBS



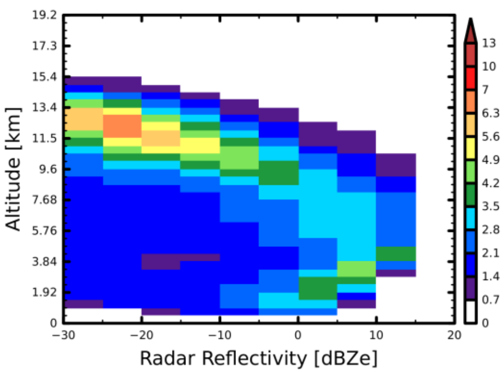
COSP



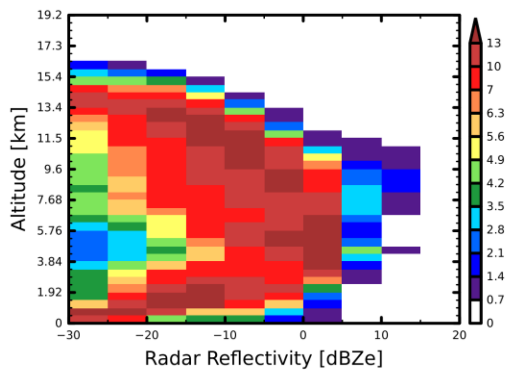
J-SIM



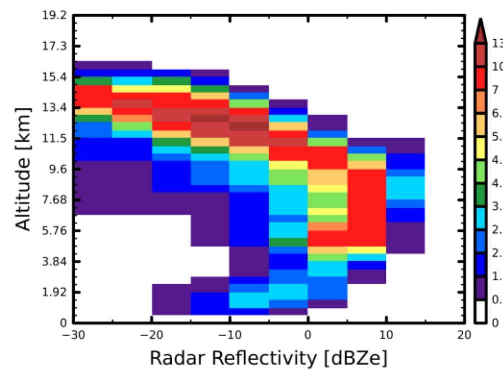
CloudSat: OBS



COSP



J-SIM



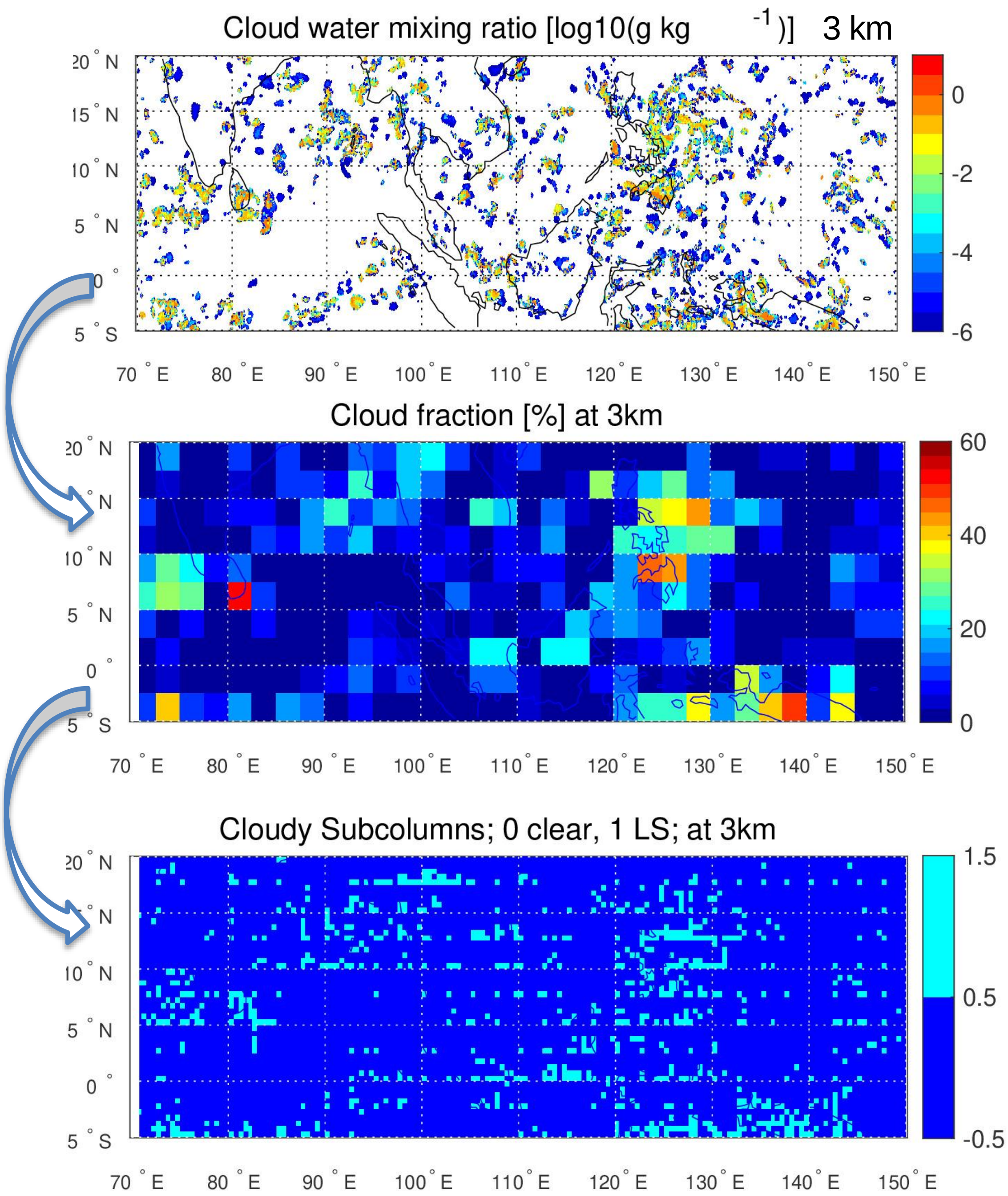
GCM applied: MRI ESM 2.0 AMIP from CMIP6

Settings:

- the same PSD and particle assumptions (COSP default)
- PREC-SCOPS introduced to J-SIM

Good agreement between COSP and J-SIM on Scattering ratio, some differences in Z.

NICAM NDW6



Evaluating uncertainty in the signal simulation for coarse GCM outputs

NICAM NSW & NDW6 simulation
g-level 9 data sets (δx~14 km)

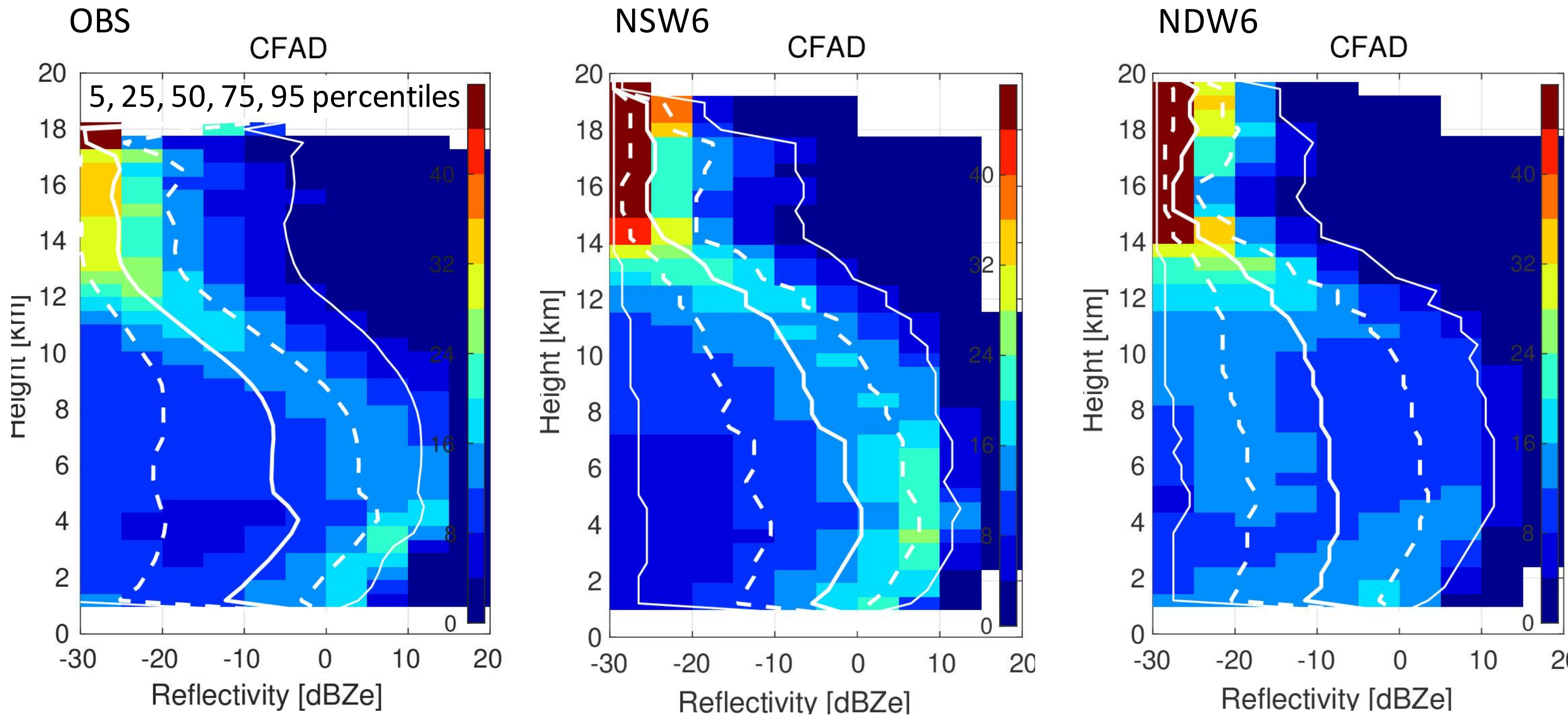
AMIP-like 2.5 x 2.5 degree lat-lon data

How does the sub-grid generation scheme affect the signal statistics?

Is it reasonable to use mean quantities (microphysics and dynamics) in the signal calculation?

CFAD of radar reflectivity

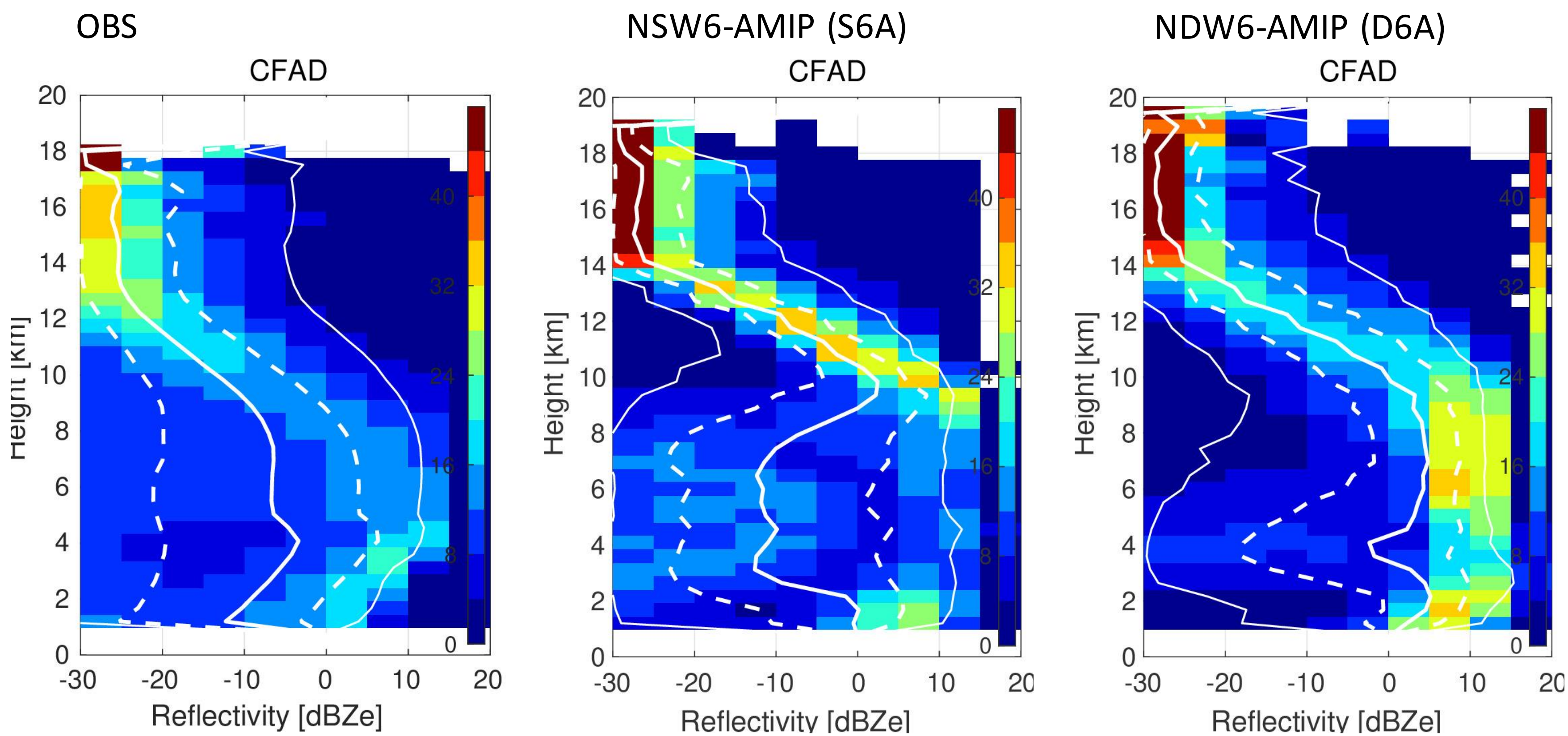
Tropical Western Pacific (5S-20N, 70-150E) 2008 June



NSW6 tends to overestimate below 5 km, but good agreement above 5 km.

NDW6 shows a good agreement of the percentiles, but shows a mode around –20 dBZ between 4 and 10 km.

CFAD of radar reflectivity over TWP; AMIP version



S6A & D6A: the median Z was increased in 10 – 14 km

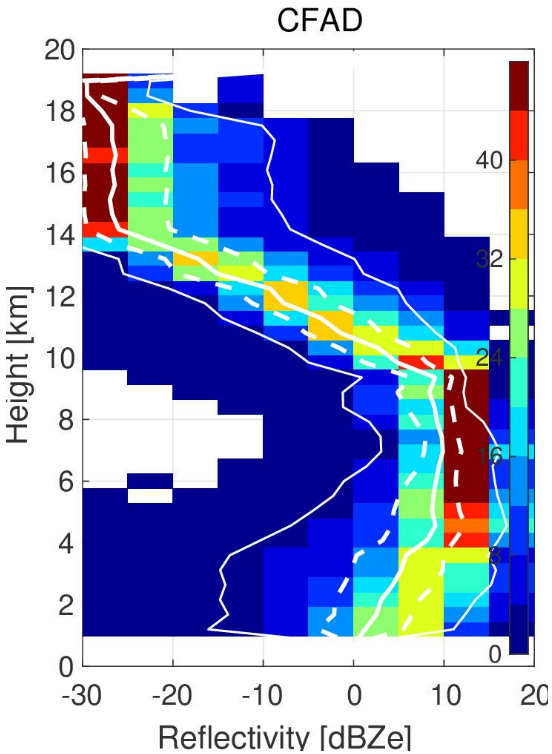
Very different behavior below 10 km

- S6A: large reduction of Z
- D6A: concentration of Z around 10 dBZ

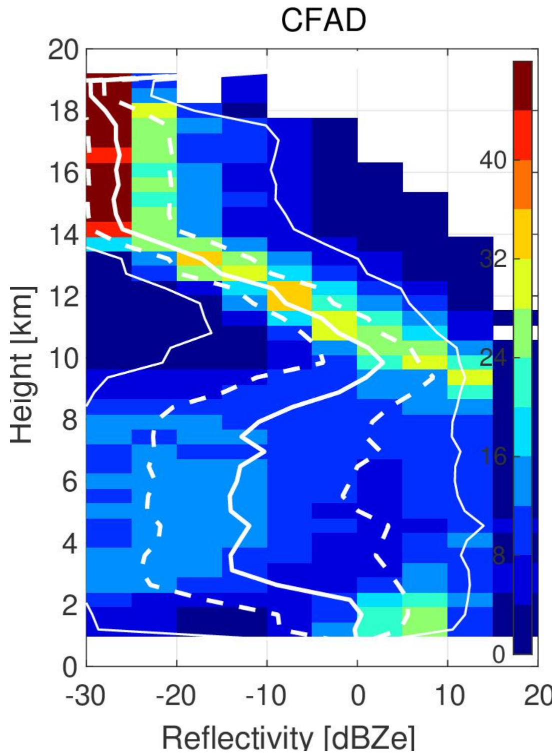
Nice separation of non-precipitating and precipitating signals are found below 4 km.

Dependence on precipitation fraction: S6A

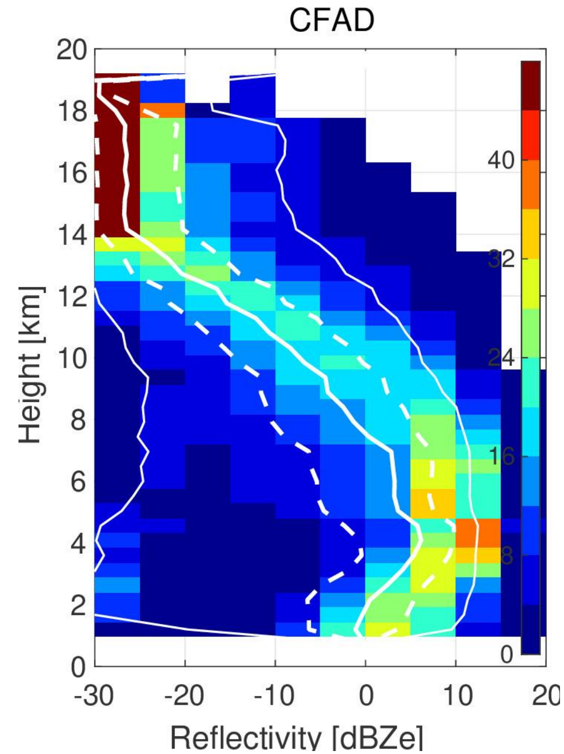
Assume precip particles are assumed to be cloud particles (LS-CLOUD)



Precip particles follow precip fraction generated by SCOPS (LS-SCOPS)

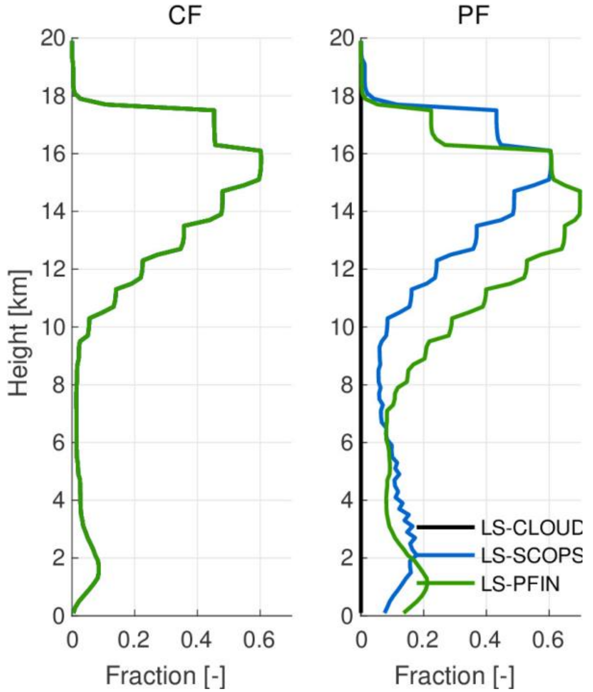


Precip particles follows precip fraction calculated from the original (LS-PFIN)

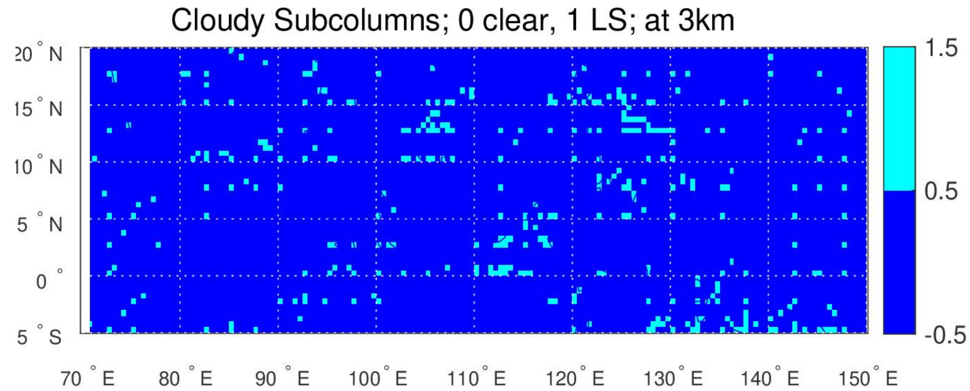


Precipitation fraction assumption has a large impact on CFAD!

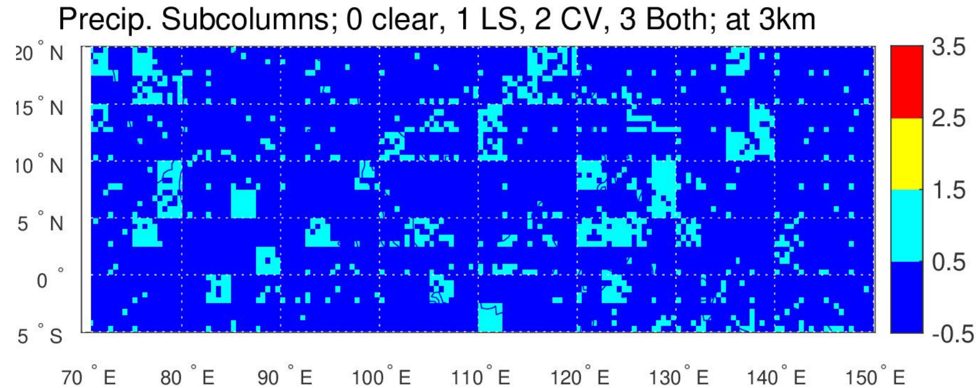
Cloud fraction and precipitation fraction over TWP: S6A



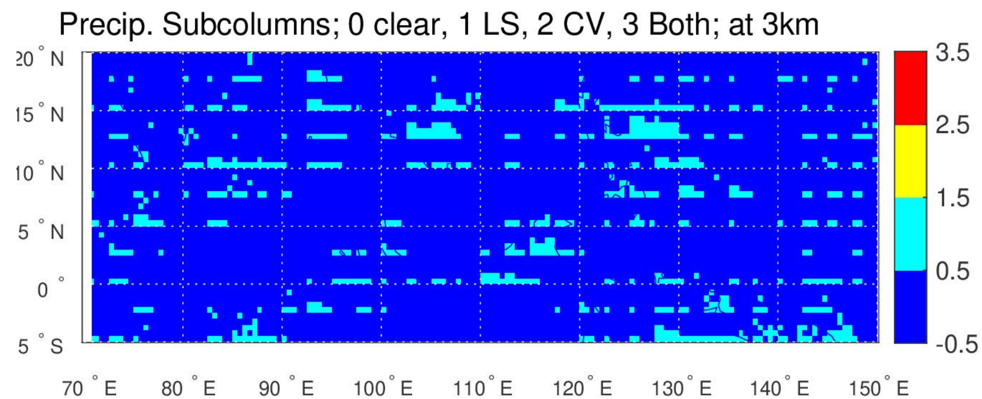
- The precipitation fraction generated by SCOPS is larger than the others in 2 – 6 km range.
- This is related to separation of cloud and precipitation particles in a grid box.



LS-SCOPS



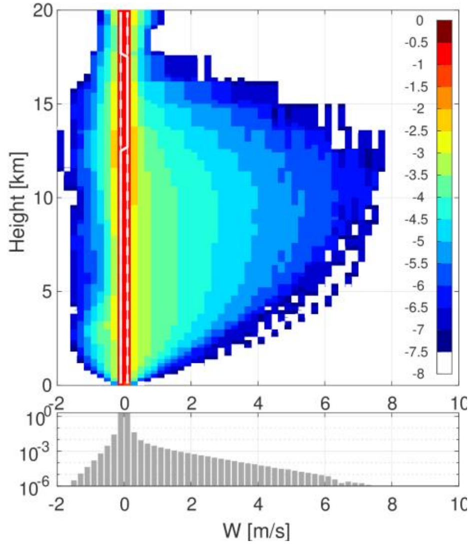
LS-PFIN



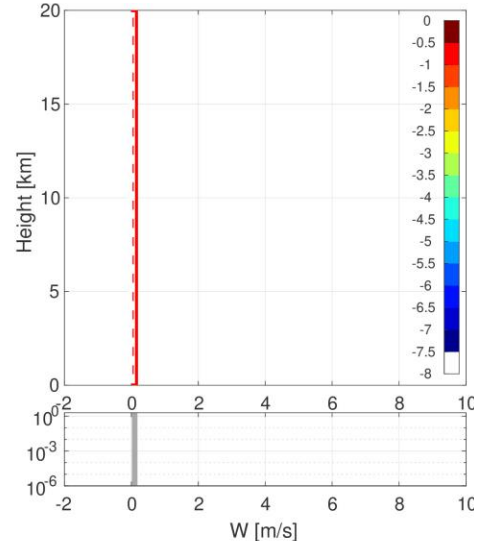
Doppler velocity useful?

W versus Height

NSW6

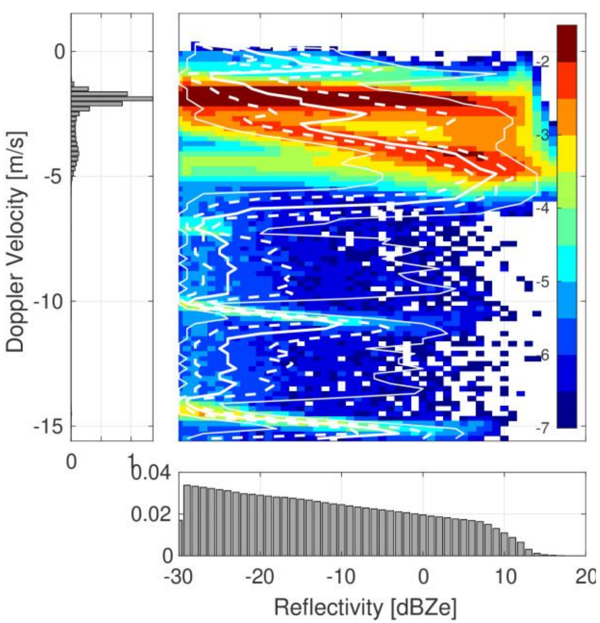


NSW6 AMIP

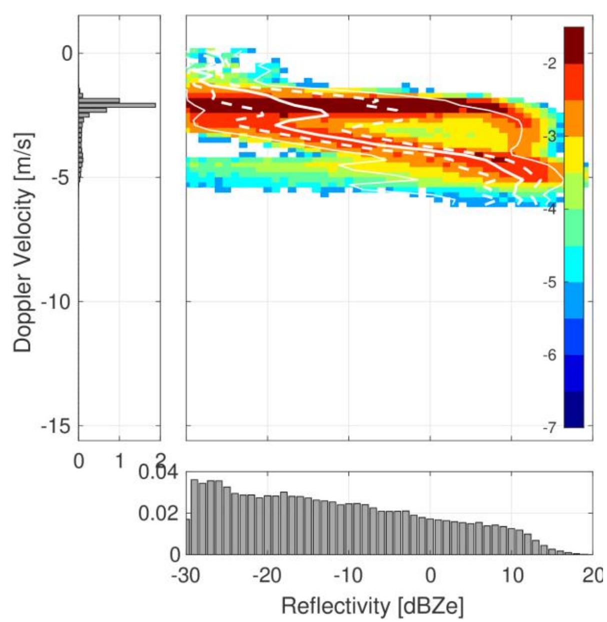


Ze versus Doppler velocity

NSW6



NSW6 AMIP



NSW6-AMIP: 2.5x2.5 grid-mean W is less than 0.2 m/s.

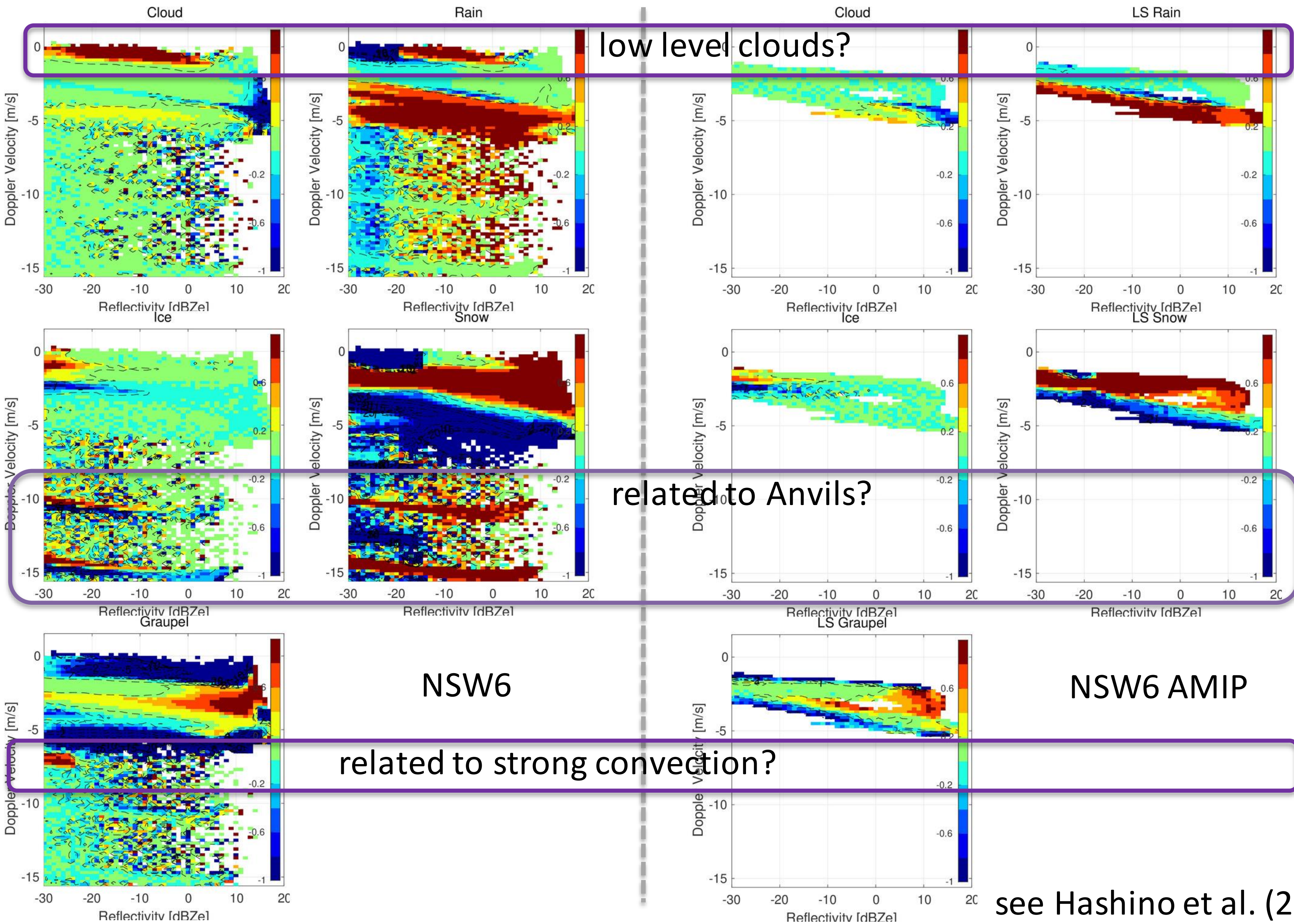
CMIP6 AMIP data sets do not have snap shots of vertical wind velocity.

How can we make association between sub-grid vertical motion and sub-grid clouds?

Marginal distributions of signals are similar.

The samples with large Doppler velocity magnitudes are not represented with AMIP version.

Separating contribution of hydrometeor categories



see Hashino et al. (2013)

Red: positive contribution to the signal; Blue: negative contribution

Summary

- Joint Simulator for Satellite Sensors (J-SIM) has been developed.
  - Simulate four sensors onboard EarthCARE and other major satellite sensors.
  - Supporting development of retrieval products (L1 swath data)
- New features include
  - ground-based polarimetric radars
  - AMIP interface for GCM outputs
  - PREC-SCOPS
  - COSP-like histograms for CALIPSO and CloudSat
- Uncertainty in forward simulation with coarse GCM outputs (preliminary)
  - AMIP-like simulation with NICAM outputs
    - Reflectivy increased or reduced
    - cloud and precipitation modes are seperated
    - precipitation fraction has a large impact on the CPR signals.
  - Doppler velocity information
    - Relationships beteween subgrid vertical motion and cloud/precip variables are necessary to capture convective systems.
    - Simulated large-scale cloud-precipitation systems may be evaluated.

Thank you for listening