Environment and Climate Change Canada | Environnement et Changement climatique Canada

Canada

EarthCARE radiative transfer simulation using A-Train satellite data

Zhipeng Qu[1], Jason Cole[1], Howard Barker[2], Meriem Kacimi[1]
Shannon Mason[3], Robin Hogan[3], Ben Courtier[4],

[1]: Environment and Climate Change Canada, Toronto, Ontario, Canada
[2]: Environment and Climate Change Canada, Victoria, British Columbia, Canada
[3]: European Centre for Medium-Range Weather Forecasts, Reading, United Kingdom
[4]: University of Leicester, Leicester, United Kingdom

ECMWF
EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

UNIVERSITY OF LEICESTER

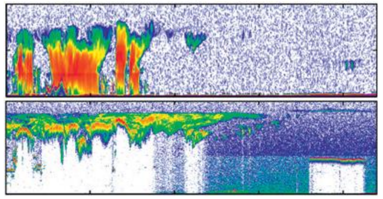
ESA-JAXA Pre-Launch EarthCARE Science and Validation Workshop, 13-17 November 2023 | ESA-ESRIN, Frascati (Rome), Italy

1. Background

Radiative closure assessment of EarthCARE mission, algorithm chart:

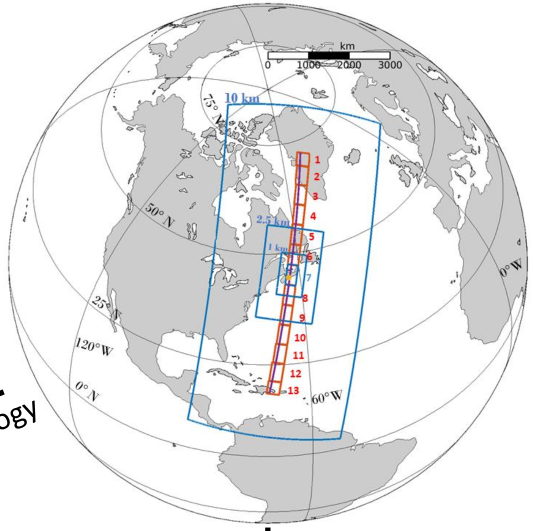
L2a products (CPR, ATLID, MSI)

CAPTIVATE→ ACM-CAP



RT[-1]: Cloud, aerosols, etc.

NWP simulated test frames



Halifax
Baja
Hawaii
(Qu et al. 2023
Donovan et al. 2023)
+
other test data

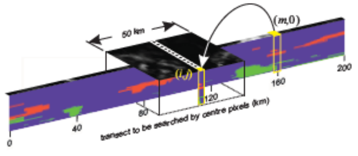
RT

Mason et al. 2023
Mroz et al. 2023
van Zadelhoff et al. 2023
etc.

Atmosphere conditions
Surface/trace gases climatology

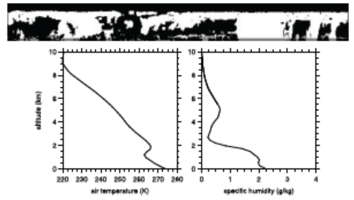
RT

ACM-3D



3D Scene Construction
Assessment Domain Selection

ACM-COM



Set-up of Atmosphere(s)

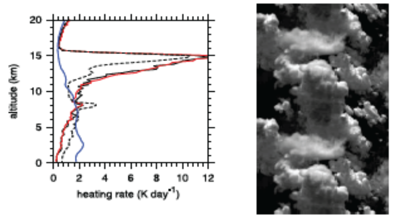
- Construct 3D scenes (~5 x 21 km) for ACM-RT
- Screen and sample assessment domains

Qu et al. 2023

- Create **L2a composite** atmosphere & surface properties
- Prepare data for ACM-RT, including **ACM-CAP**

Cole et al. 2023

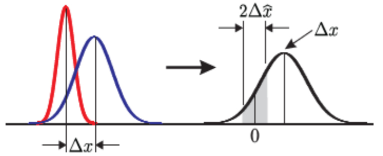
ACM-RT



1D and 3D Radiative Transfer

BBR'

ACMB-DF

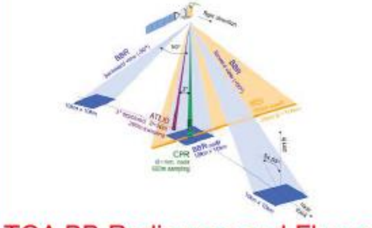


$$p_{\Delta\hat{x}} = \frac{1}{\sigma_p\sqrt{2\pi}}\int_{-\Delta\hat{x}}^{\Delta\hat{x}} \exp\left[-\frac{(x-\Delta x)^2}{2\sigma_p^2}\right] dx$$

Radiative Closure Assessment

BBR

BM-RAD & BMA-FLX



TOA BB Radiances and Fluxes

Velázquez Blázquez et al. 2023

- Perform 1D and 3D RT calculations (HR profiles)
- TOA radiances and fluxes to be used in ACMB-DF

Cole et al. 2023

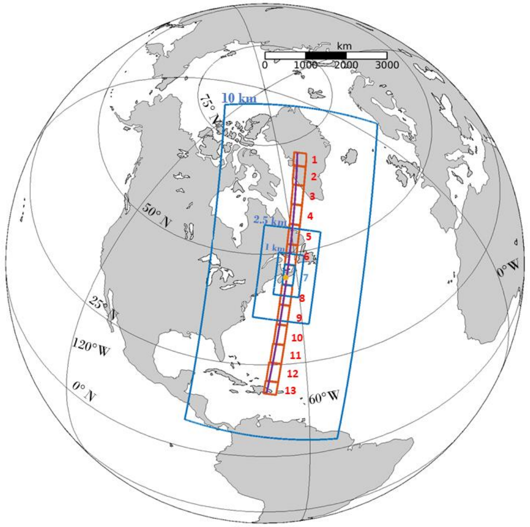
- Compare model radiances to BBR obs
- Compare model fluxes to BMA-FLX: $\Delta x < 10\ W\ m^{-2}$

Barker et al. 2023 (in preparation)

2. RT simulation based on A-Train data

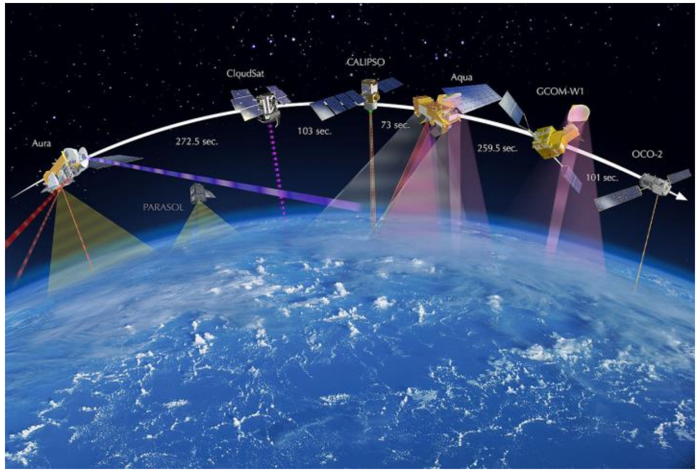
- **Different objectives at different stages of satellite algorithm development & validation**

NWP simulated test frames



- High resolution (250 m) for subgrid-scale variability
- 3D atmospheric scenes of cloud & aerosols (including off-nadir regions)
- Excellent for 3D RT simulation and assessment of its impact
- Reference truth available for verification
- Only fractions of orbits

Data from A-Train satellites

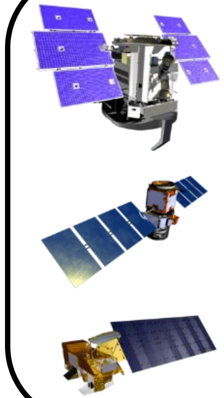


- Large number of orbit to test the robustness of satellite algorithm
- Real-world studies available
- Facilitates robust statistical analyses
- Lack reference truth
- Still allows for evaluation of 3D v. 1D RT?

3. Input data from A-Train satellites

- CCM-CAP: 260 orbits available: Jan 1 to Mar 13, 2007
- More orbits will be processed later
- Data will be available freely

A-Train Satellites



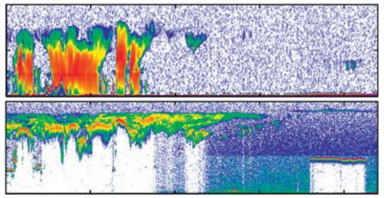
CloudSat

CALIPSO

MODIS (Aqua)

CAPTIVATE
Mason et al. 2023

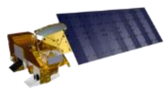
CCM-CAP



RT^{-1}: Cloud, aerosols, etc.

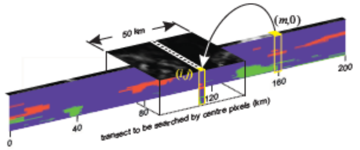
ERA5 &
Surface/trace gases
climatology

Radiances for scene construction



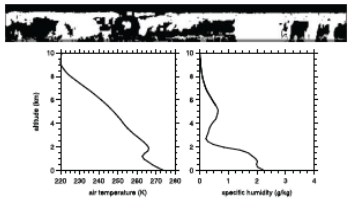
MODIS (Aqua)

ACM-3D



3D Scene Construction
Assessment Domain Selection

ACM-COM

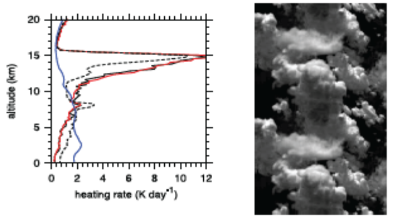


Set-up of Atmosphere(s)

- Construct 3D scenes (~5 x 21 km) for ACM-RT
- Screen and sample assessment domains

- Create **L2a composite** atmosphere & surface properties
- Prepare data for ACM-RT, including **ACM-CAP**

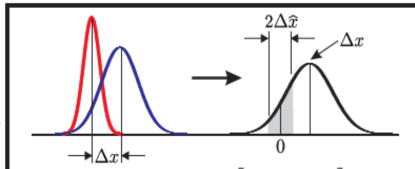
ACM-RT



1D and 3D Radiative Transfer

CERES CCCM’

ACMB-DF



$$p_{\Delta\hat{x}} = \frac{1}{\sigma_p\sqrt{2\pi}} \int_{-\Delta\hat{x}}^{\Delta\hat{x}} \exp\left[-\frac{(x-\Delta x)^2}{2\sigma_p^2}\right] dx$$

Radiative Closure Assessment

CERES CCCM

CERES CCCM

Integration of measurements:
- CALIPSO-CALIOP
- CloudSat-CPR
- CERES
- MODIS

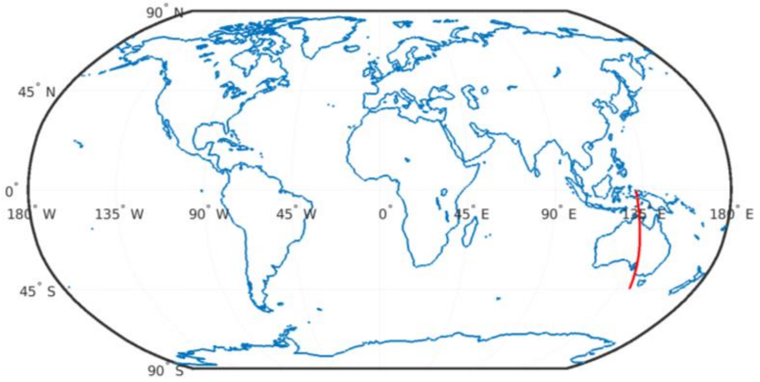
- Perform 1D and 3D RT calculations (HR profiles)
- TOA radiances and fluxes to be used in ACMB-DF

- Compare model radiances to BBR obs
- Compare model fluxes to BMA-FLX: $\Delta x < 10\ W\ m^{-2}$

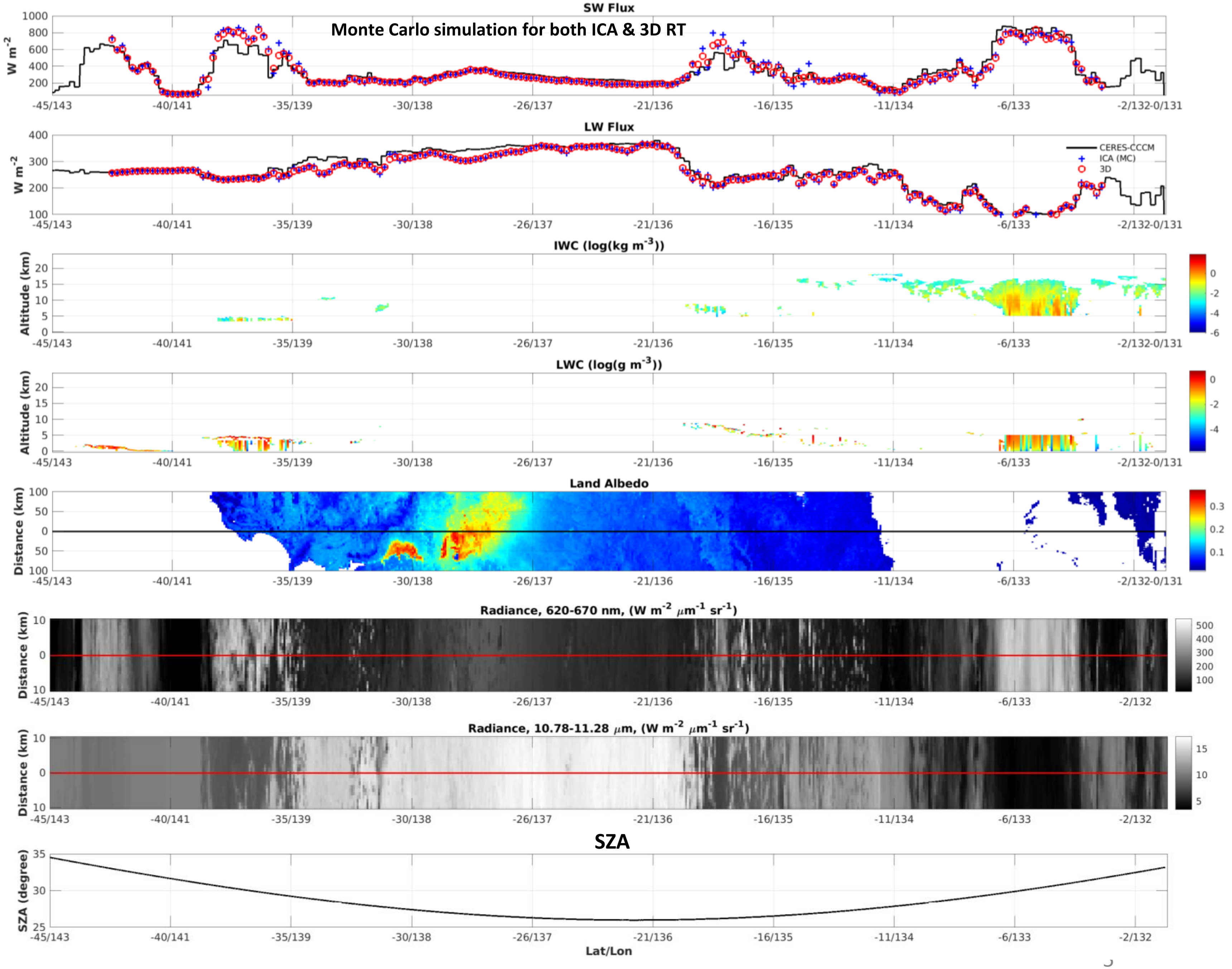
4. Case study (03609D)

Frame 03609D, 2007-01-01

- Large land area with clear sky (Australia)
- Deep convective system + broken clouds + mixed phase clouds + low liquid clouds
- Low solar zenith angle (SZA) conditions
- Good agreement (SW & LW) over deep convection
- Good agreement over ocean (cloudy or clear sky)
- Over-estimation of SW fluxes over mixed phase cloud (cloud properties?)
- Underestimation of LW fluxes over Australian desert (Surface T/type?)



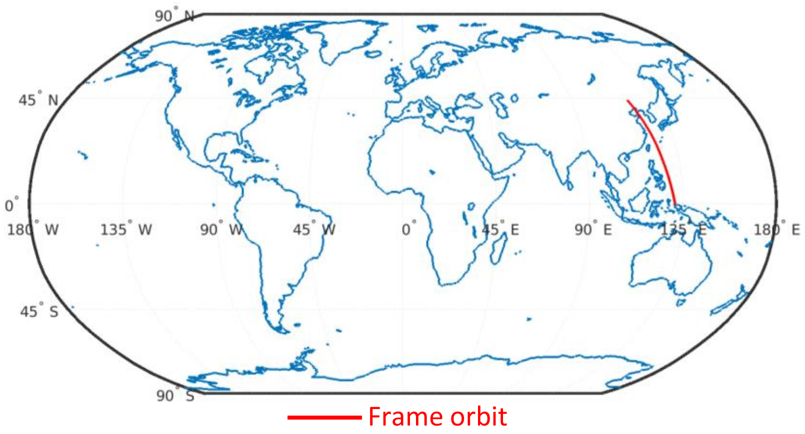
Frame orbit

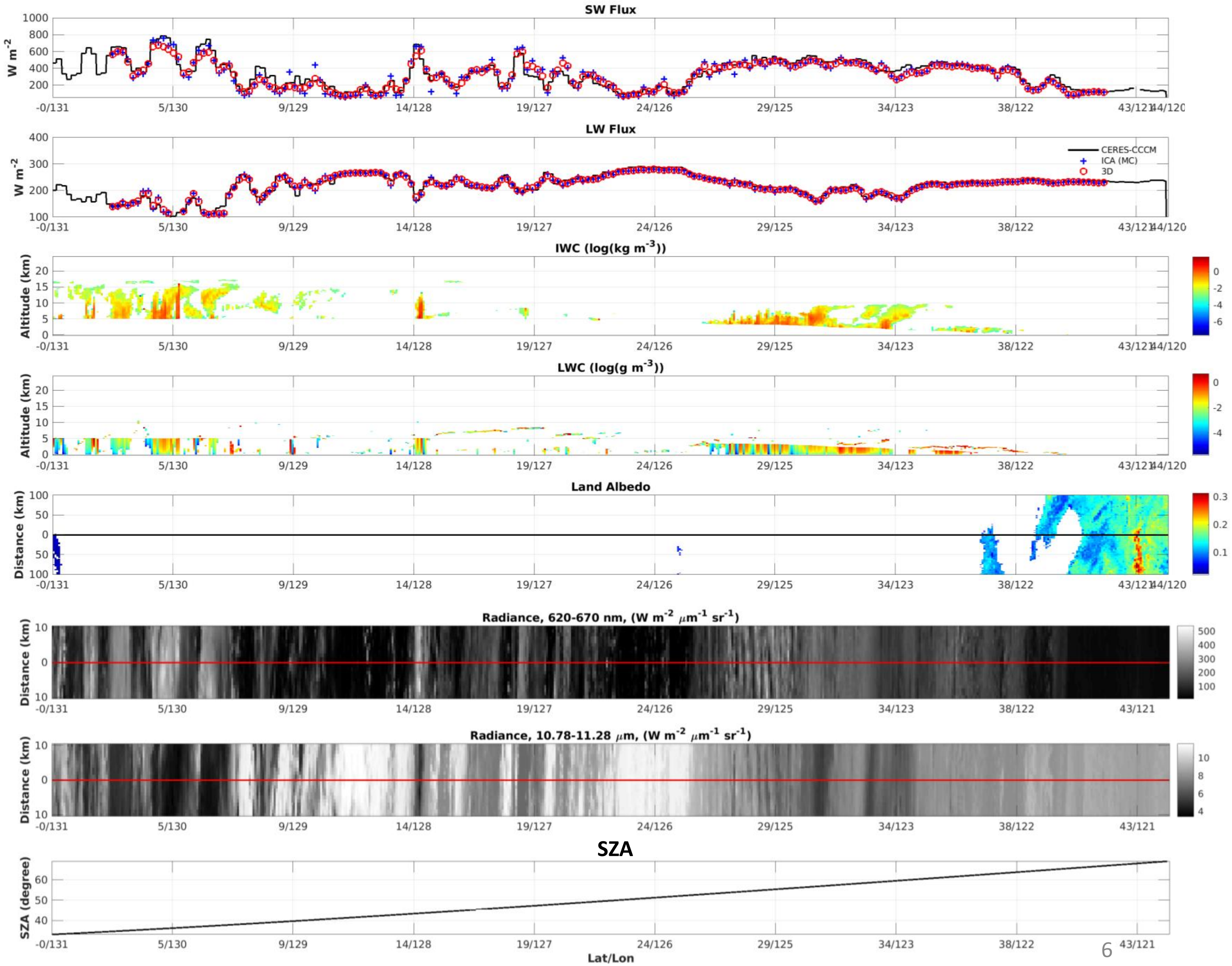


4. Case study (03609E)

Frame 03609E, 2007-01-01

- Mostly oceanic
- Multiple deep convective events + multilayer clouds + frontal system
- Larger SZA
- **Good agreement for most conditions!**
- ICA values (+) have more outliers than those of 3D RT (o)





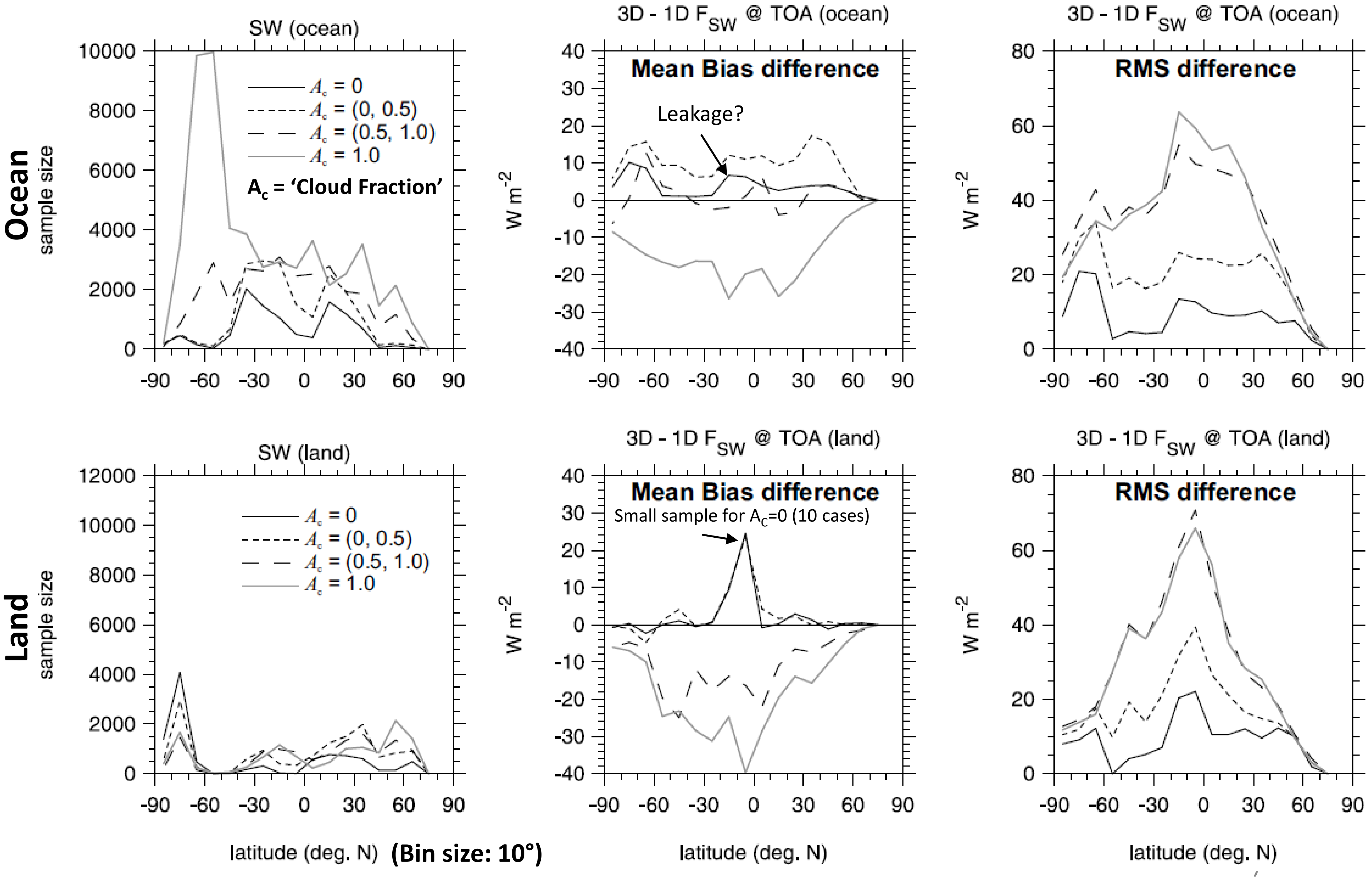
5. Statistics (Shortwave 3D -1D fluxes at TOA)

$A_c(1.0)$: large negative MB for overcast conditions over ocean & land (tropical region!): 3D effect of textured & convective cloud top with 'photon entrapment'?

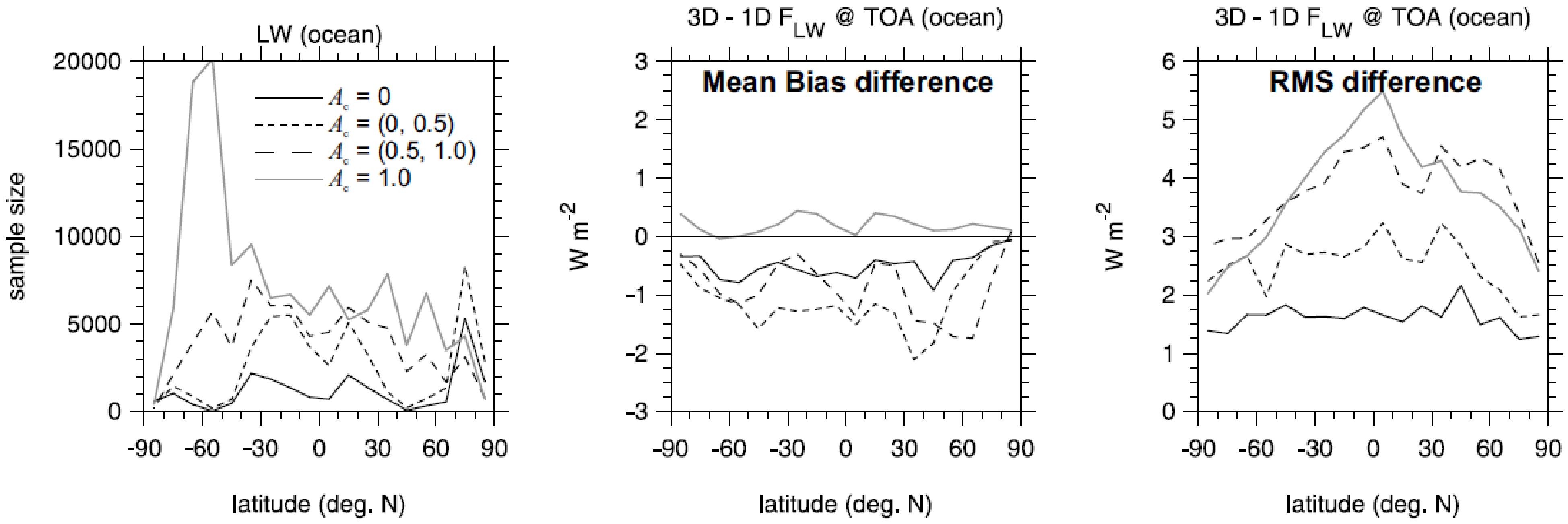
$A_c(0.5, 1.0)$: larger negative MB over land than over ocean: more convective over land for partially cloudy conditions?

$A_c(0)$: positive MB over ocean & land: leakage from clouds adjacent to the assessment domain? (over land, only 10 cases near -5°)

All: larger RMS for tropical region: more convective, textured, multi-layered clouds?



5. Statistics (Longwave 3D -1D fluxes at TOA)



Ocean:

- Both MB and RMS are small relative to SW
- Smaller MB for overcast conditions
- Larger MB for partially cloudy conditions (MB ~ -1 W m^{-2}, upwelling diffuse beam intercepted by cloud sides)
- Largest RMS for cloudier conditions (A_c > 0.5) in the tropical region

6. Conclusion and perspectives

Satellite based input data are used in EarthCARE radiative closure assessment processors for algorithm evaluation

- A-Train based synergetic retrievals of cloud & aerosols using CAPTIVATE algorithm from Jan 1 to Mar 13, 2007
  - 260 frames provided by ECMWF & ULeicester
- CERES CCCM upwelling SW & LW fluxes
- MODIS radiances for scene construction

3D – 1D fluxes:

- SW: larger differences for cloudier & more convective conditions (influence of turbulent cloud tops on RT fluxes?)
- SW: differences for tropical clear-sky conditions (influence of surrounding cloudy environment?)
- LW: differences are generally small for all cases (MBE < 2 W m^{-2}, RMSE < 5 W m^{-2})
- LW: larger differences for cloudier & more convective conditions (similar to SW case)

Perspectives:

- Further investigations of different causes of the discrepancy between ACM-RT fluxes and CERES CCCM fluxes
- Further evaluation of the impact of 3D RT w.r.t 1D ICA RT
- Simulate more frames to cover all seasons (at least a year)
- Continued improvement of the radiative closure assessment algorithm