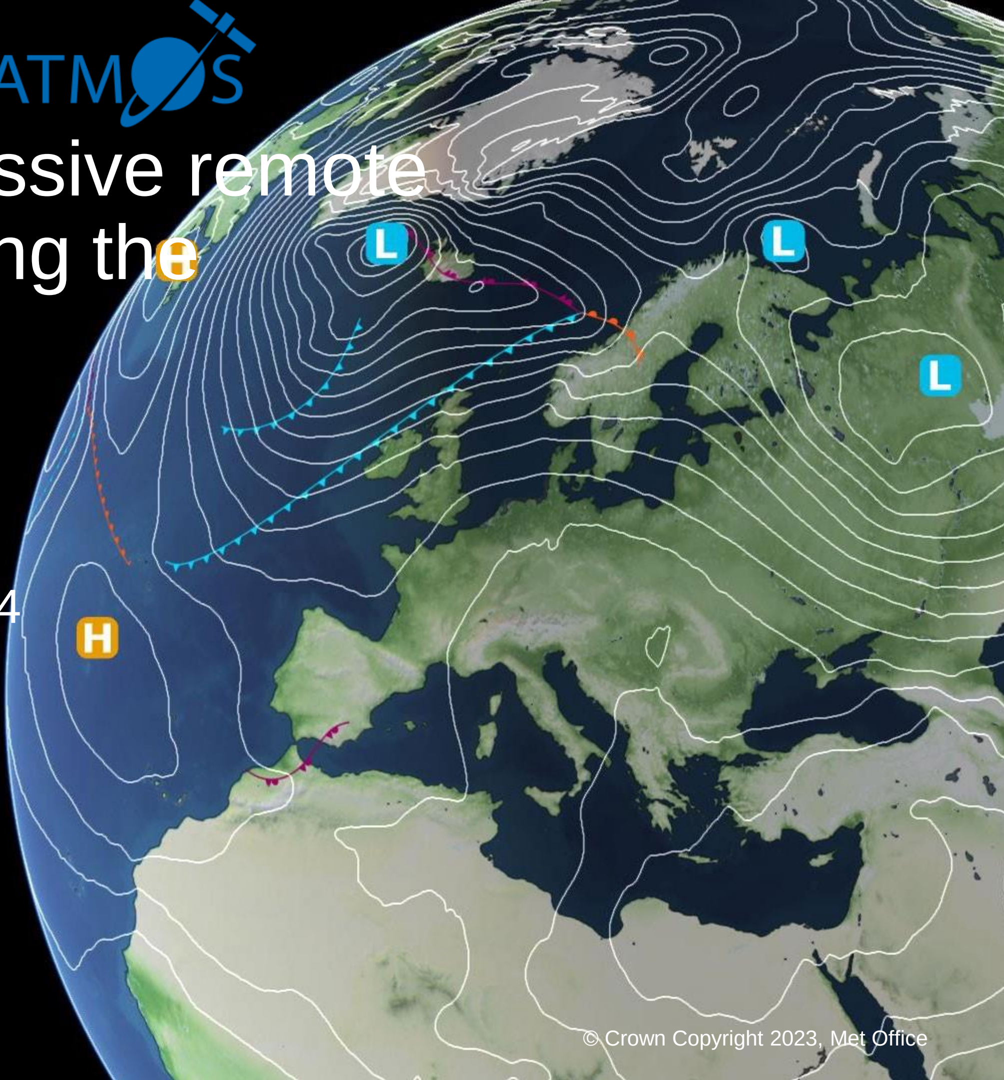
Combined active and passive remote sensing of ice cloud during the CCREST-M campaign

Stuart Fox, Anthony Baran, Julien Delanoë, Chris Walden, David Ashmore

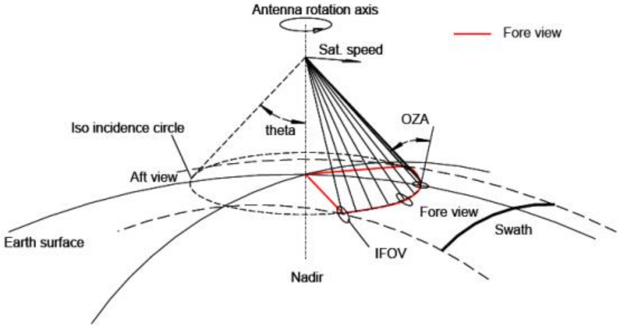
ARTS workshop, Kristineberg, May 2024



Passive submillimetre radiometry:
A new method for ice cloud remote sensing

EPS-SG Satellite B1 due to launch Dec 2025, carries Ice Cloud Imager (ICI)

Image: EUMETSAT

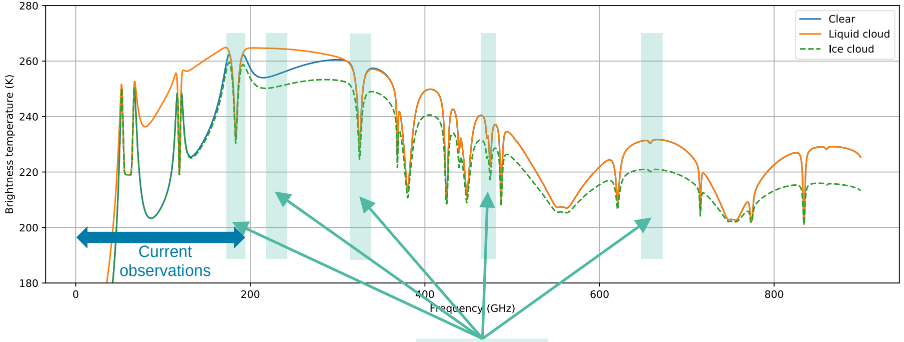


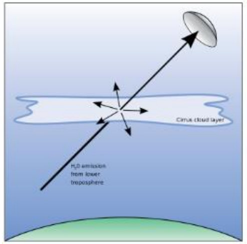
IR only sensitive to cloud top for optically thick clouds

Lidar/Radar have very limited spatial coverage

ICI retrieval products:

- Ice water path (column ice mass)
- Mean particle diameter
- Mass-mean cloud height





ICI bands

Retrieval Challenges

- Non-linear relationship between ice mass and brightness temperatures
- Non-Gaussian statistics
- Multiple-scattering (polarised) radiative transfer model required
- Complex and variable ice crystal shapes (and scattering properties)
- Uncertainties in ice size distribution

A decade of ISMAR observations

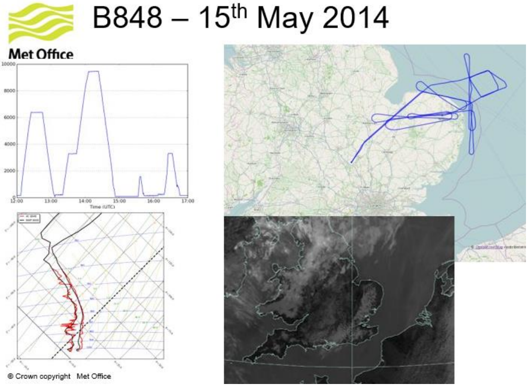
Met Office

ISMAR data processing and test flights

Stuart Fox, Stuart Rogers, Ian Rule, Robert King

ISMAR workshop, Kristineberg, 11-13 June 2014

© Crown copyright Met Office



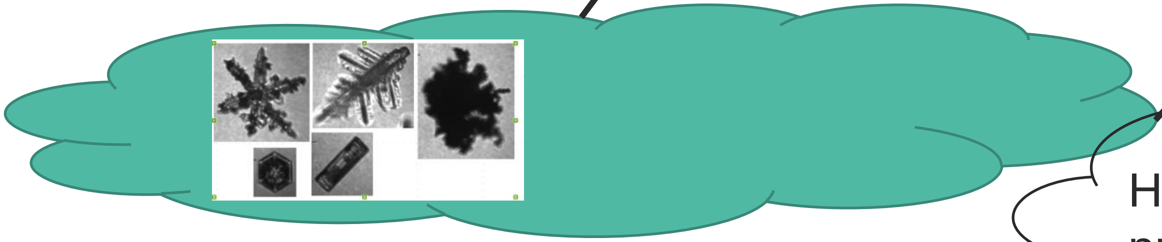
Met Office

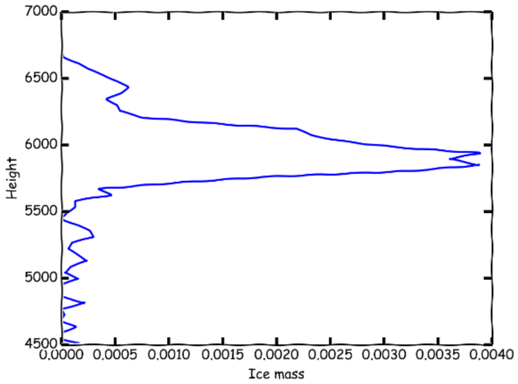
B848 – 15th May 2014

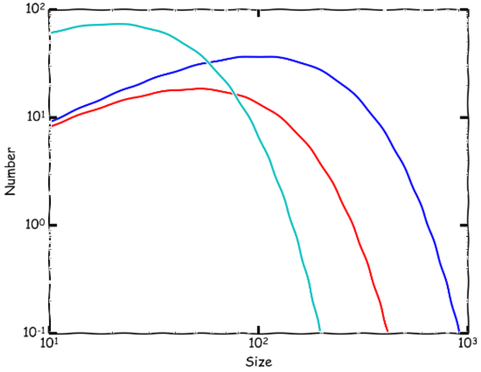
© Crown copyright Met Office

Kristineberg, 2014

The cloud problem







How do we determine cloud properties at time and location of ISMAR observations???

Some history

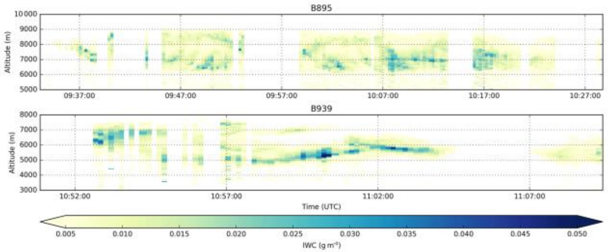
https://doi.org/10.5194/amt-12-1599-2019
© Author(s) 2019. This work is distributed under the Creative Commons Attribution 4.0 License.

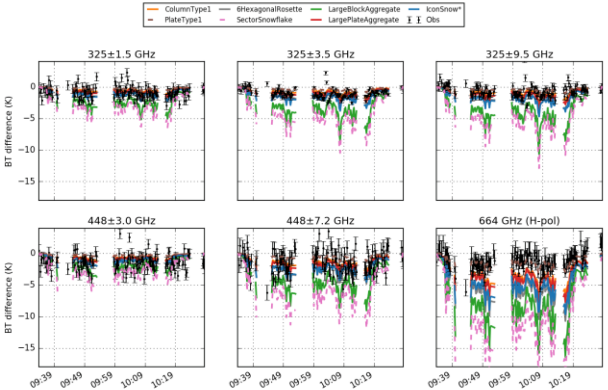
Article | Assets | Peer review | Metrics | Related articles

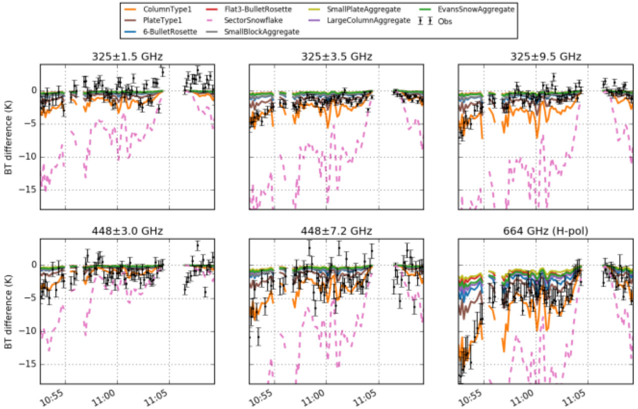
Research article | 12 Mar 2019

Airborne validation of radiative transfer modelling of ice clouds at millimetre and sub-millimetre wavelengths

Stuart Fox, Jana Mendrok, Patrick Eriksson, Robin Ekelund, Sebastian J. O'Shea, Keith N. Bower, Anthony J. Baran, R. Chawn Harlow, and Juliet C. Pickering







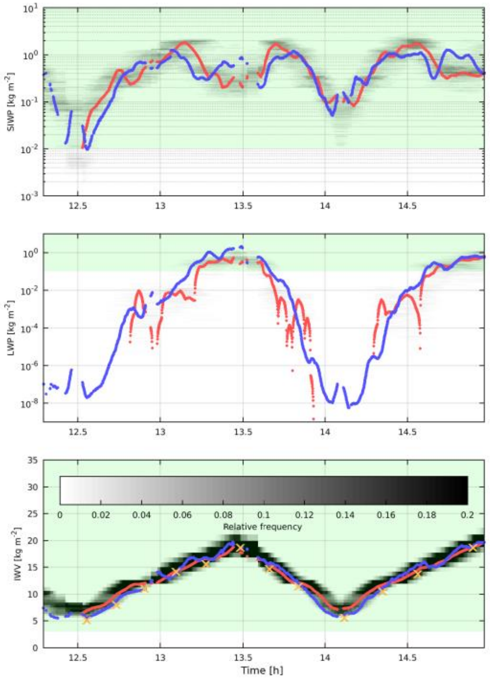
https://doi.org/10.5194/amt-11-611-2018
© Author(s) 2018. This work is distributed under the Creative Commons Attribution 3.0 License.

Article | Assets | Peer review | Metrics | Related articles

Research article | 01 Feb 2018

Retrieval of an ice water path over the ocean from ISMAR and MARSS millimeter and submillimeter brightness temperatures

Manfred Brath, Stuart Fox, Patrick Eriksson, R. Chawn Harlow, Martin Burgdorf, and Stefan A. Buehler



Met Office

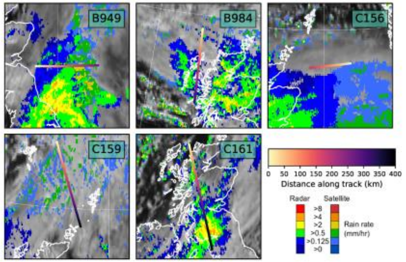
Open Access Article

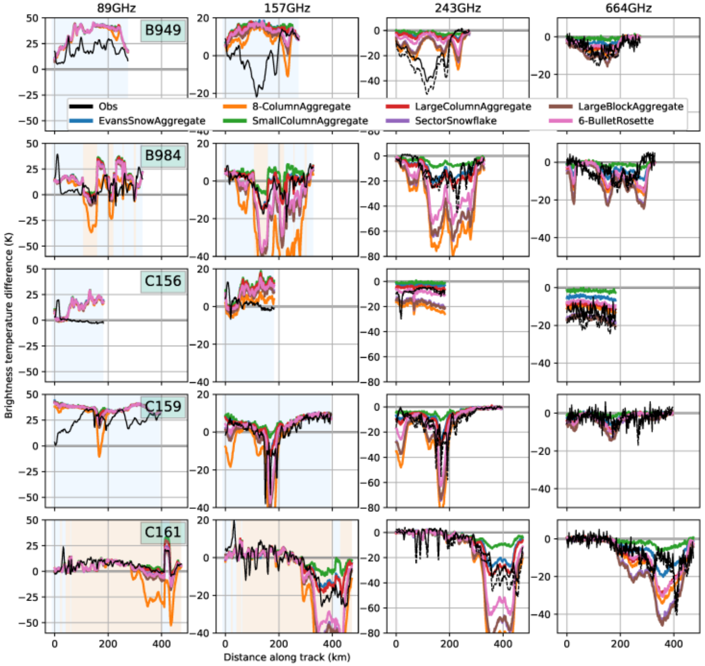
An Evaluation of Radiative Transfer Simulations of Cloudy Scenes from a Numerical Weather Prediction Model at Sub-Millimetre Frequencies Using Airborne Observations

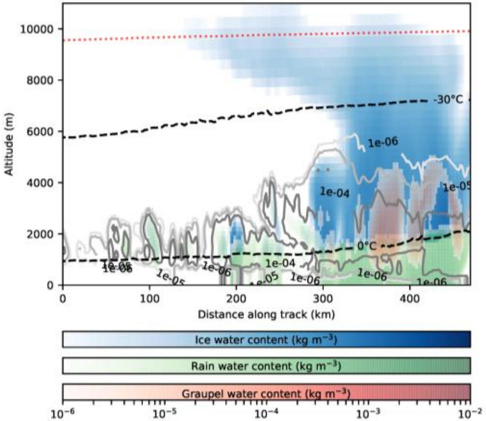
by **Stuart Fox**

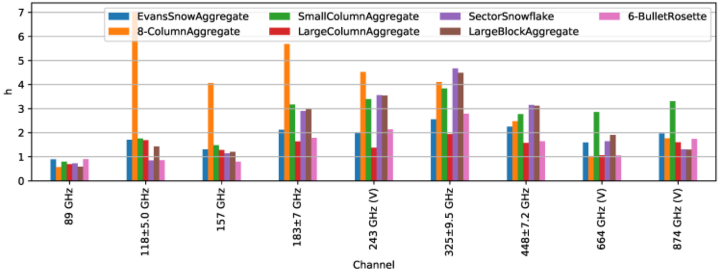
Met Office, FitzRoy Road, Exeter EX1 3PB, UK

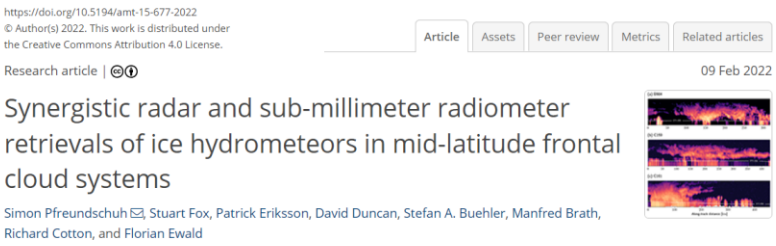
Remote Sens. **2020**, *12*(17), 2758; **https://doi.org/10.3390/rs12172758**











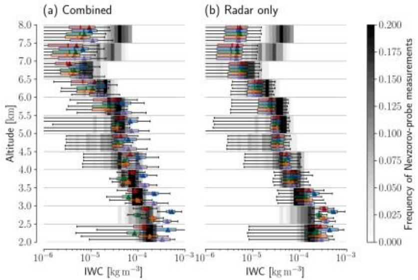
https://doi.org/10.5194/amt-15-677-2022

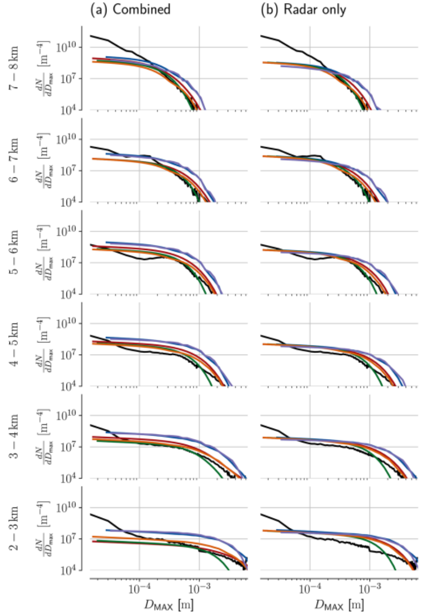
Article | Assets | Peer review | Metrics | Related articles

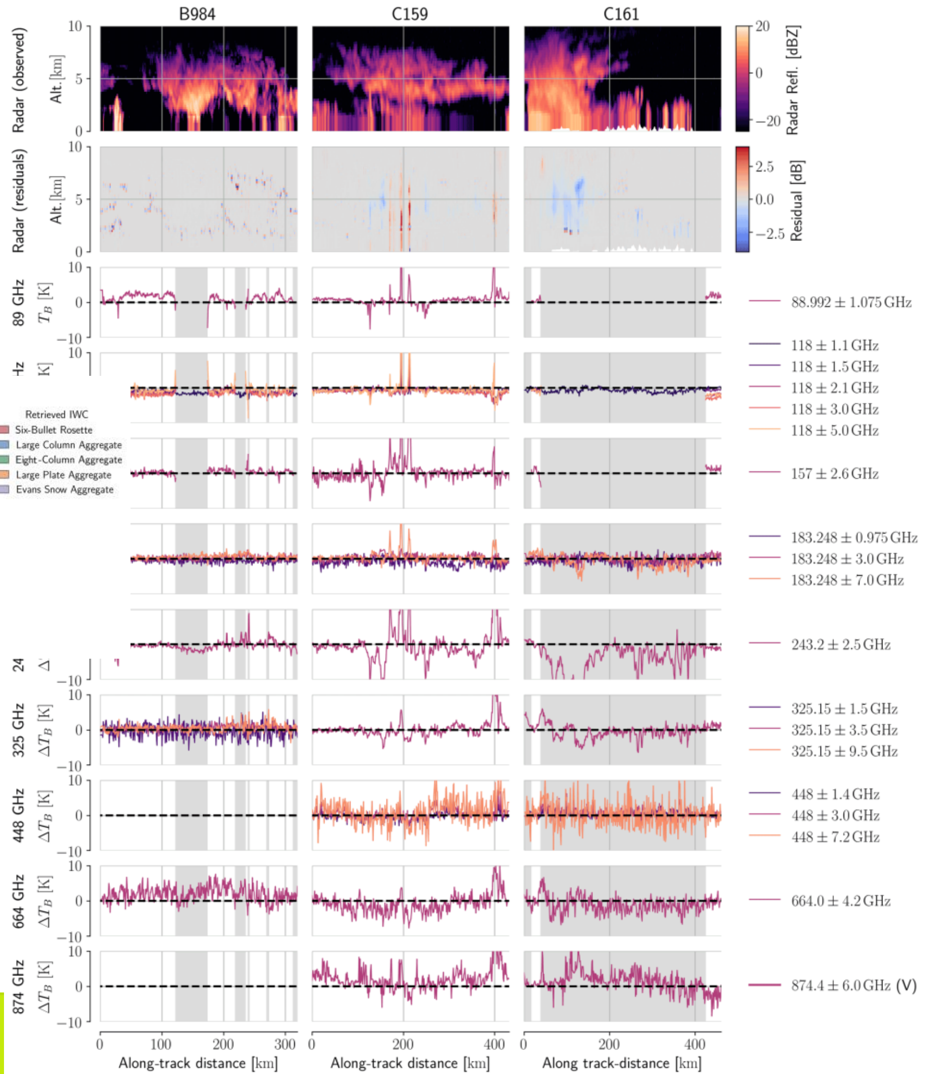
Research article | 09 Feb 2022

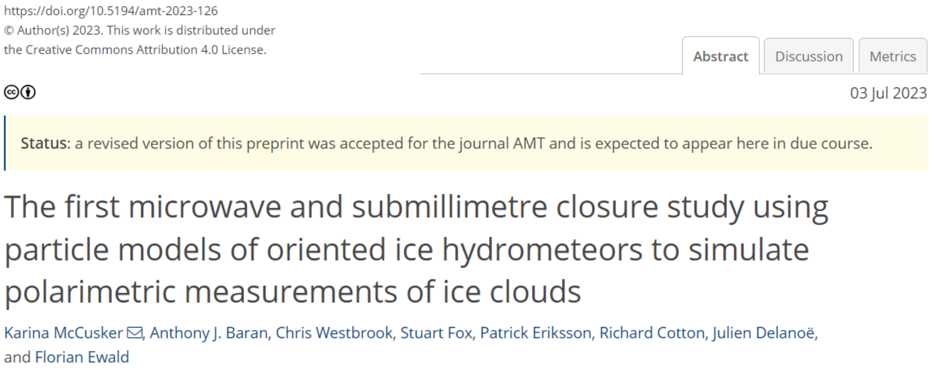
Synergistic radar and sub-millimeter radiometer retrievals of ice hydrometeors in mid-latitude frontal cloud systems

Simon Pfreundschuh, Stuart Fox, Patrick Eriksson, David Duncan, Stefan A. Buehler, Manfred Brath, Richard Cotton, and Florian Ewald









https://doi.org/10.5194/amt-2023-126

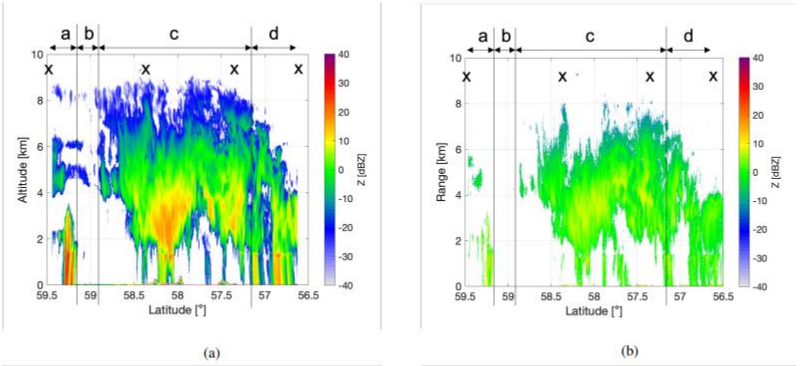
Abstract | Discussion | Metrics

03 Jul 2023

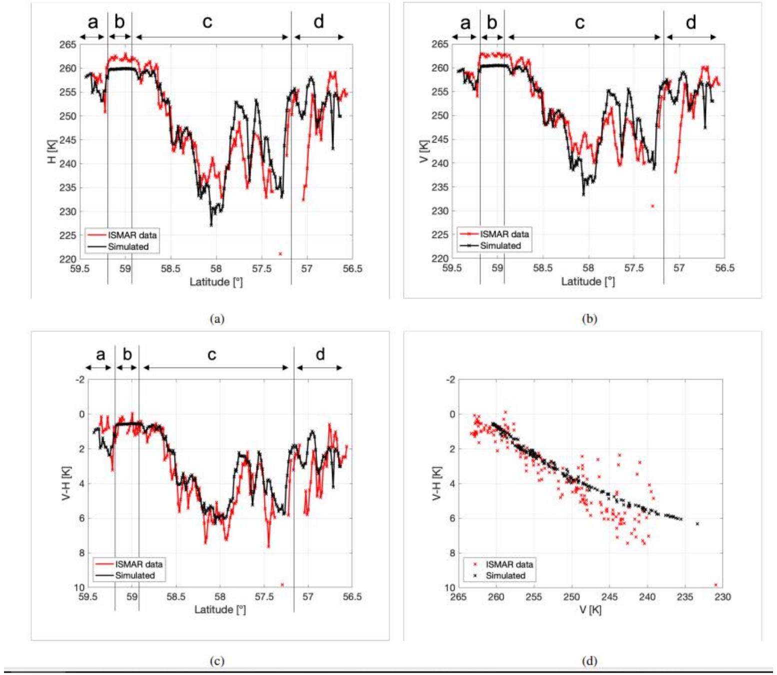
Status: a revised version of this preprint was accepted for the journal AMT and is expected to appear here in due course.

The first microwave and submillimetre closure study using particle models of oriented ice hydrometeors to simulate polarimetric measurements of ice clouds

Karina McCusker, Anthony J. Baran, Chris Westbrook, Stuart Fox, Patrick Eriksson, Richard Cotton, Julien Delanoë, and Florian Ewald



Radar reflectivity at 35 and 94 GHz



Observed and simulated BT and polarisation difference at 243GHz

- Knowledge of the vertical structure of ice clouds is essential to properly evaluate passive sub-mm forward models and retrievals
- Cloud radars can provide a strong constraint on the vertical structure of ice clouds
- Need to know both ice mass **and** size distribution

CCREST-M goals

- Simultaneous passive microwave/sub-mm and radar measurements of ice clouds
- Multi-frequency, (doppler) radar to better constrain size distribution
- Use to evaluate ice crystal scattering models and sub-mm radiative transfer simulations

© Claude DELHAYE / Safire / CNRS Images

If the radar will not come to the clouds, then the clouds must go to the radar…

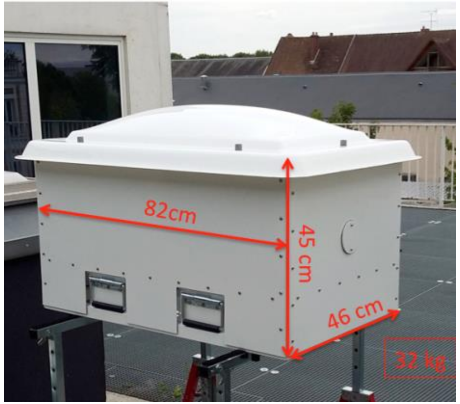
CCREST-M

Coordinated flights with FAAM aircraft and Chilbolton Atmospheric Observatory

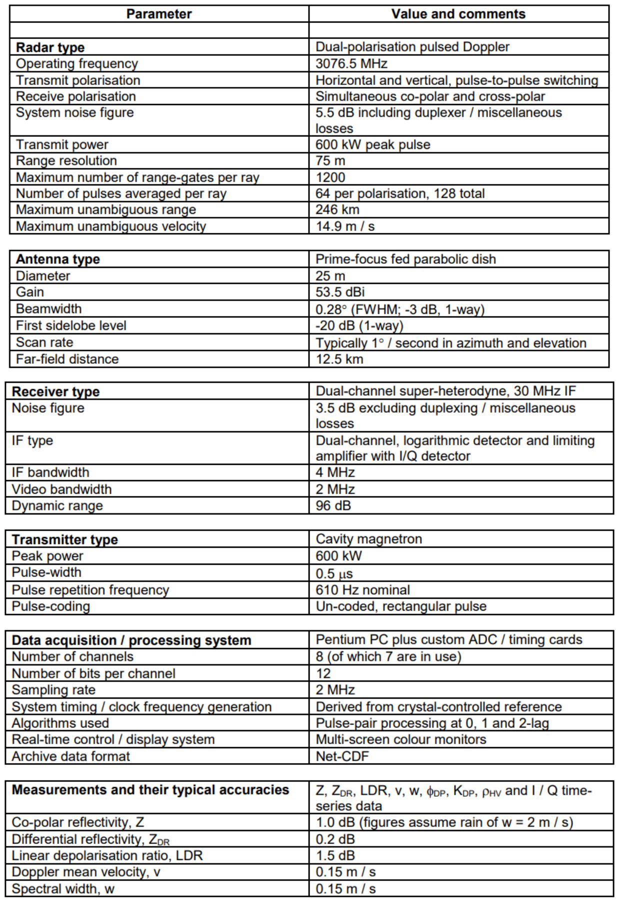
Copernicus 35GHz, vertical pointing

CAMRa 3GHz, scanning

Kepler 35GHz, scanning



mini-BASTA (LATMOS)
94 GHz, scanning



Parameter	Value and comments
Radar type	Dual-polarisation pulsed Doppler
Operating frequency	3076.5 MHz
Transmit polarisation	Horizontal and vertical, pulse-to-pulse switching
Receive polarisation	Simultaneous co-polar and cross-polar
System noise figure	5.5 dB including duplexer / miscellaneous losses
Transmit power	600 kW peak pulse
Range resolution	75 m
Maximum number of range-gates per ray	1200
Number of pulses averaged per ray	64 per polarisation, 128 total
Maximum unambiguous range	246 km
Maximum unambiguous velocity	14.9 m / s

Antenna type	Prime-focus fed parabolic dish
Diameter	25 m
Gain	53.5 dBi
Beamwidth	0.28° (FWHM; -3 dB, 1-way)
First sidelobe level	-20 dB (1-way)
Scan rate	Typically 1° / second in azimuth and elevation
Far-field distance	12.5 km

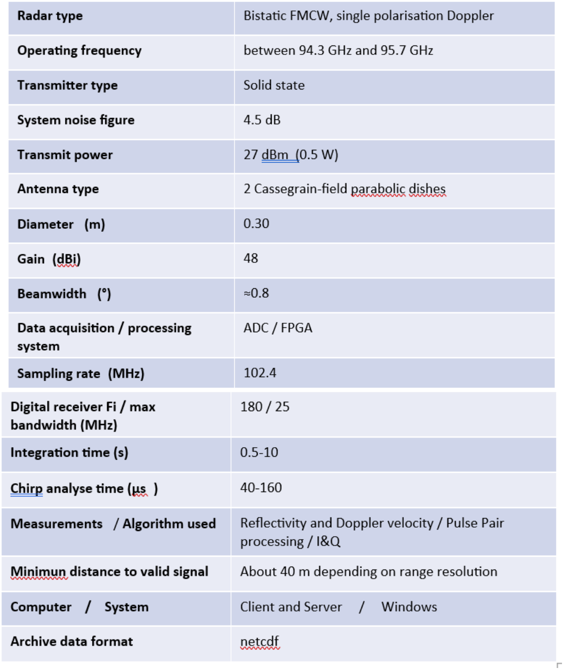
Receiver type	Dual-channel super-heterodyne, 30 MHz IF
Noise figure	3.5 dB excluding duplexing / miscellaneous losses
IF type	Dual-channel, logarithmic detector and limiting amplifier with I/Q detector
IF bandwidth	4 MHz
Video bandwidth	2 MHz
Dynamic range	96 dB

Transmitter type	Cavity magnetron
Peak power	600 kW
Pulse-width	0.5 μs
Pulse repetition frequency	610 Hz nominal
Pulse-coding	Un-coded, rectangular pulse

Data acquisition / processing system	Pentium PC plus custom ADC / timing cards
Number of channels	8 (of which 7 are in use)
Number of bits per channel	12
Sampling rate	2 MHz
System timing / clock frequency generation	Derived from crystal-controlled reference
Algorithms used	Pulse-pair processing at 0, 1 and 2-lag
Real-time control / display system	Multi-screen colour monitors
Archive data format	Net-CDF

Measurements and their typical accuracies	Z, Z_{DR}, LDR, v, w, ϕ_{DP}, K_{DP}, ρ_{HV} and I / Q time-series data
Co-polar reflectivity, Z	1.0 dB (figures assume rain of w = 2 m / s)
Differential reflectivity, Z_{DR}	0.2 dB
Linear depolarisation ratio, LDR	1.5 dB
Doppler mean velocity, v	0.15 m / s
Spectral width, w	0.15 m / s

Frequency: 35.1 GHz
Beamwidth: 0.58°
Antenna diameter: 1.0 m
Antenna gain: 49.2 dB
Peak power: nominally 30 kW
Average power: 30-60 W
Typical operating range: 22km (up to 40km with suitable choice of PRF and pulse width)
Azimuth scanning range: 0°-360°
Speed azimuth/elevation: 0°-20° per second (typically 1° per second)
Elevation scanning range: 0°-180°
Measurement gate length: 15-60 m (pulse width dependent)
Number of range gates: adjustable, maximum 800
Minimum gate spacing: 15 m
Pulse repetition frequency: 2.5-10 kHz depending on selected pulse width
Pulse width: 100-400 ns
Sensitivity: -53 dBZ (5 km range, 30 m range resolution and 10s time resolution, 1m antenna)
Polarization parameters: Linear polarization on transmit, co and cross polarized signals are received simultaneously. LDR, and co – cross – correlation can be computed.



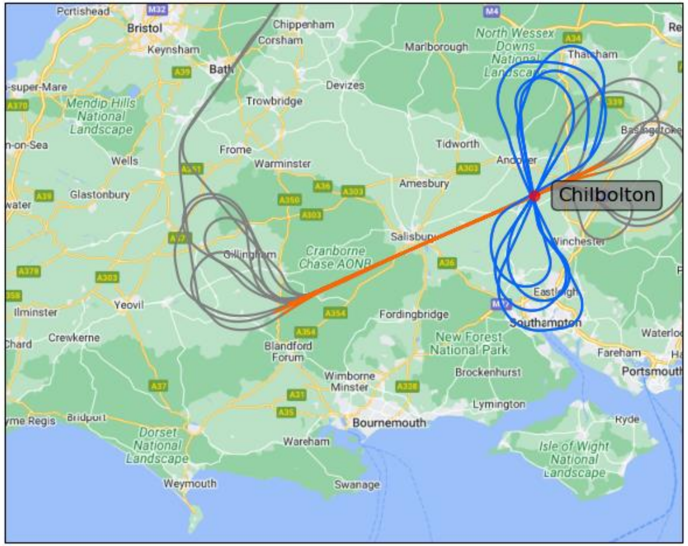
Radar type	Bistatic FMCW, single polarisation Doppler
Operating frequency	between 94.3 GHz and 95.7 GHz
Transmitter type	Solid state
System noise figure	4.5 dB
Transmit power	27 dBm (0.5 W)
Antenna type	2 Cassegrain-field parabolic dishes
Diameter (m)	0.30
Gain (dBi)	48
Beamwidth (°)	≈0.8
Data acquisition / processing system	ADC / FPGA
Sampling rate (MHz)	102.4
Digital receiver Fi / max bandwidth (MHz)	180 / 25
Integration time (s)	0.5-10
Chirp analyse time (μs)	40-160
Measurements / Algorithm used	Reflectivity and Doppler velocity / Pulse Pair processing / I&Q
Minimun distance to valid signal	About 40 m depending on range resolution
Computer / System	Client and Server / Windows
Archive data format	netcdf

5 Feb-27 March 2024

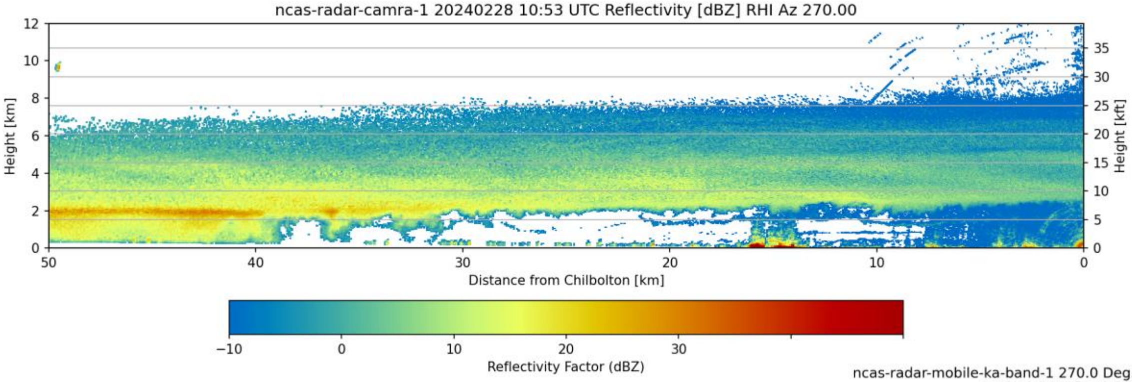
- Long time period to maximise the chance of good weather conditions
- Expected ~6 suitable cases during this period
- Actual 13 flights, of which ~9 were cases of interest

Airborne instrumentation:

- MARSS & ISMAR (microwave & sub-mm radiometers)
- Dropsondes (temperature/humidity profiles below aircraft)
- Lidar (355nm backscatter system)
- ARIES (hyperspectral infrared spectrometer)
- In-situ cloud microphysics (CDP, CIP-15, CIP-100, Nevzorov bulk water)

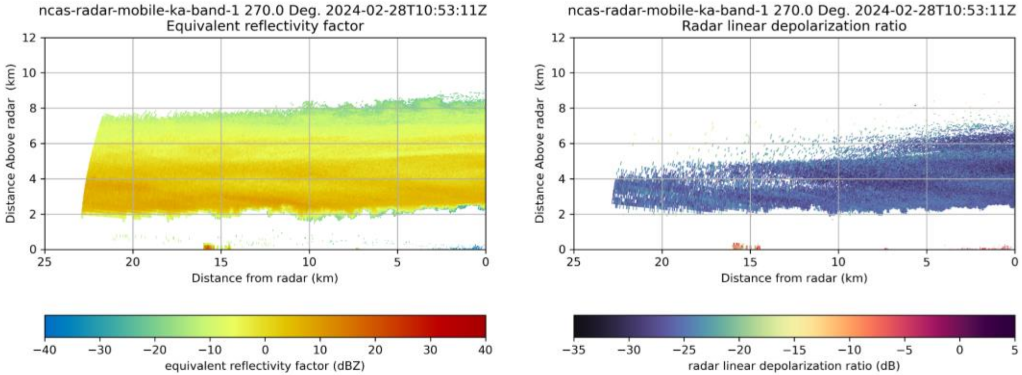


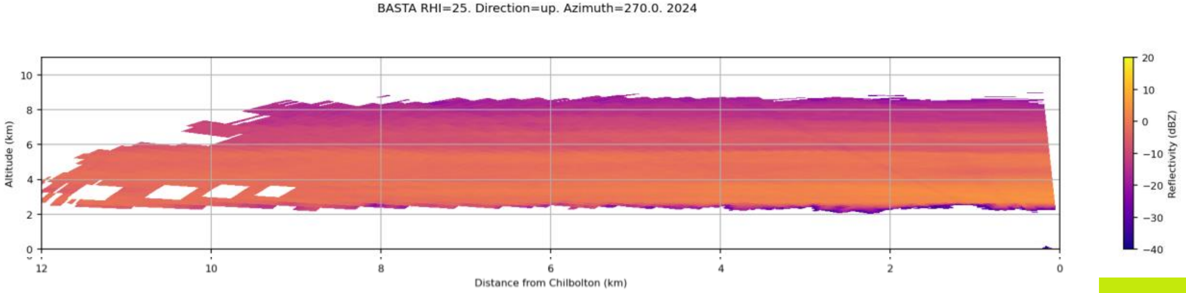
- Aircraft flying at max altitude (above cloud)
- Runs along radial (~50km), radars performing RHI scans
- “Figure-of-8” patterns for direct overpasses, radars pointing to zenith



CAMRa 3GHz

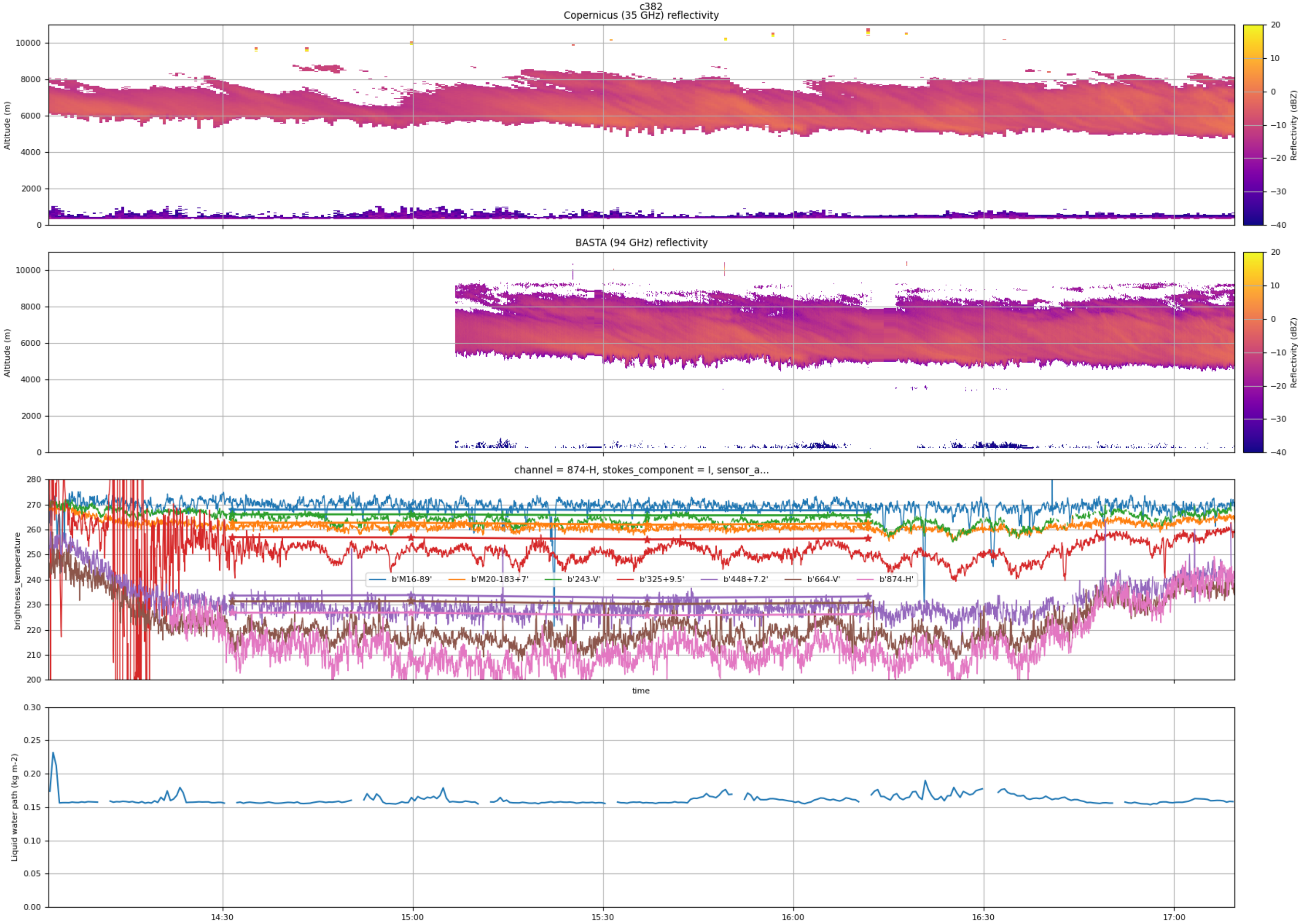
Kepler 35GHz



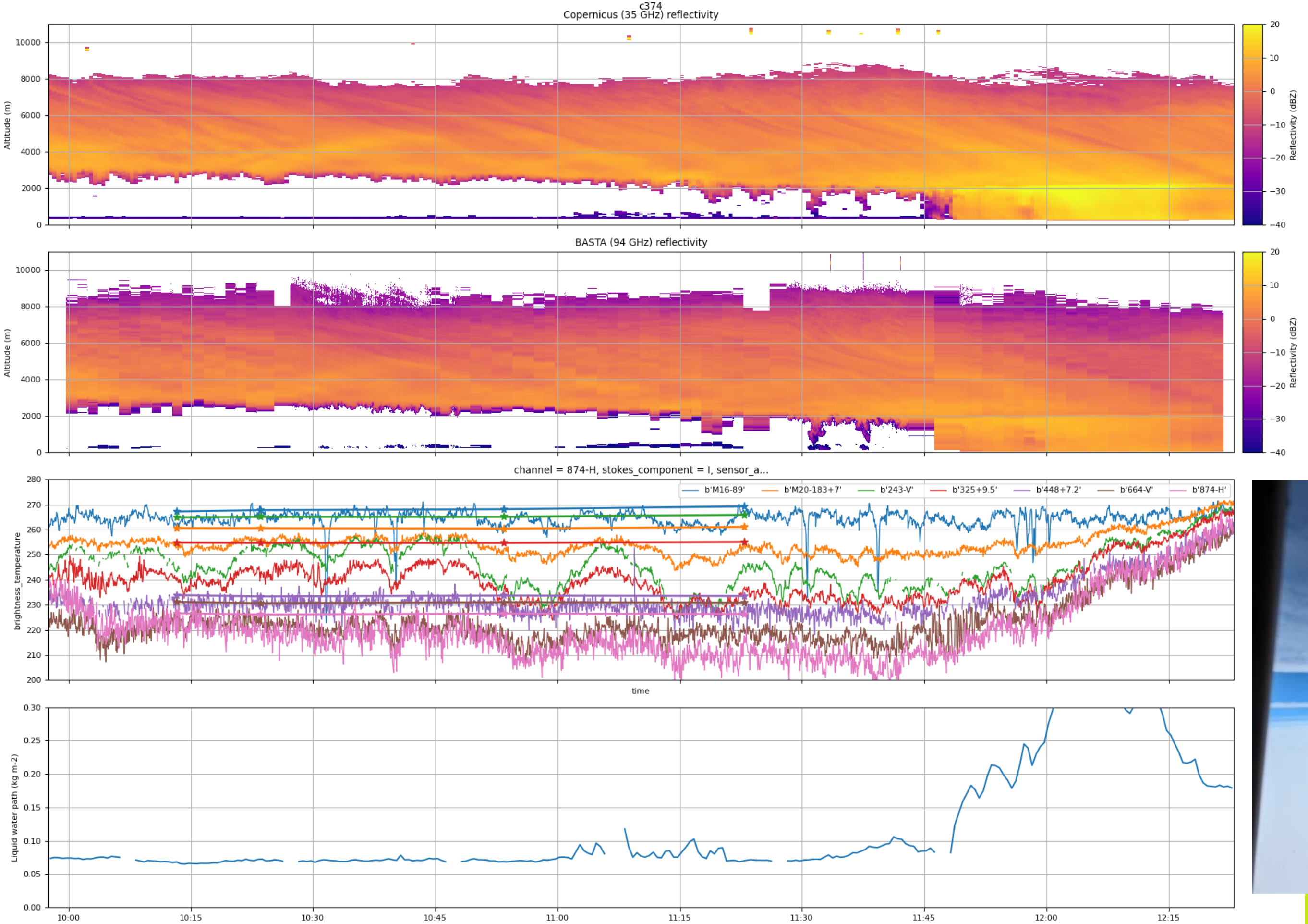


Mini-BASTA 94GHz

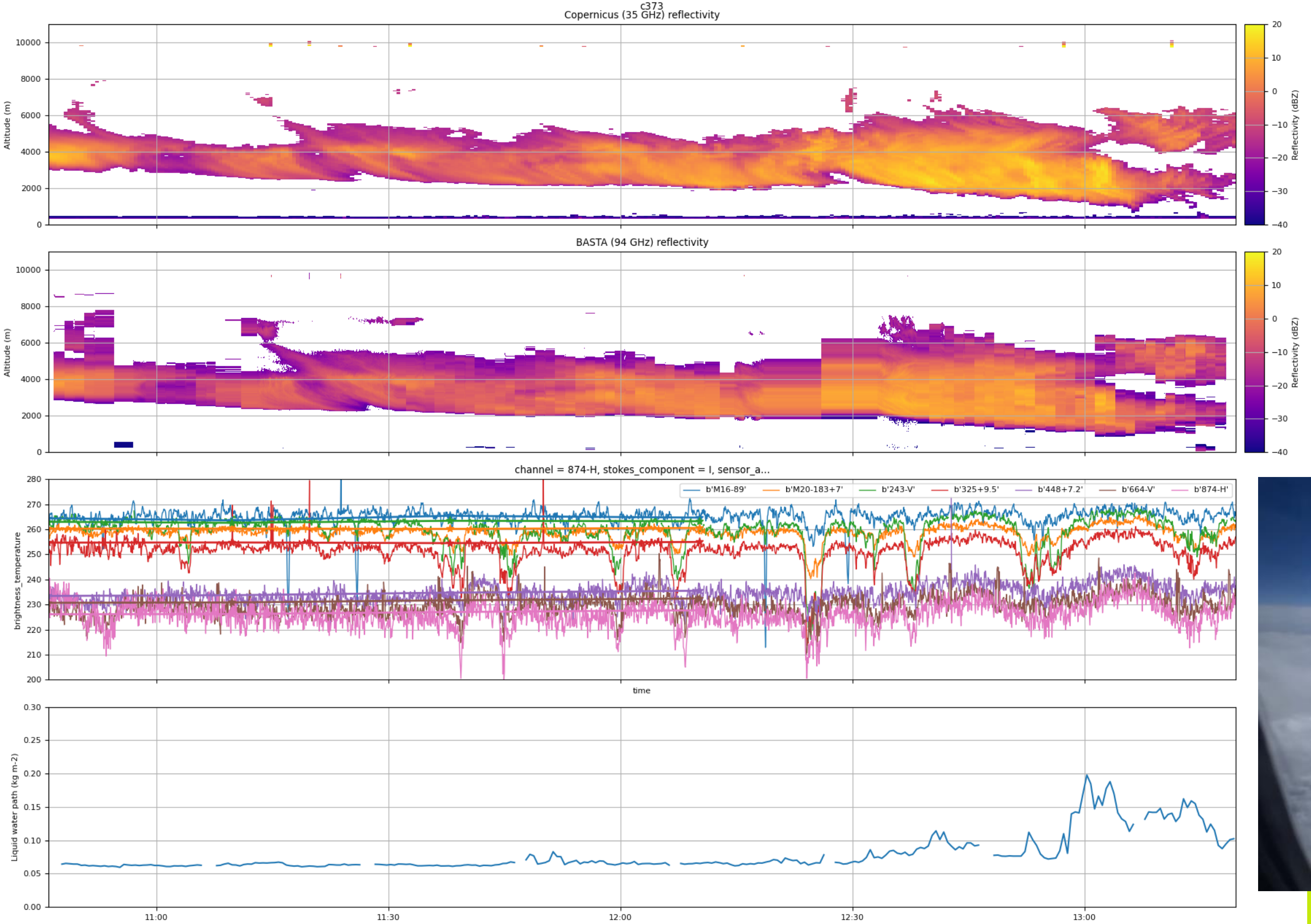
C382 – 25 March 2024



C374 – 28 February 2024



C373 – 28 February 2024



Planned work

- CCREST-M has produced a fairly unique dataset of multi-frequency radar and passive microwave/sub-mm observations of ice cloud
- Aim to use the data to evaluate ice crystal scattering models and radiative transfer simulations
- Initial focus is to develop retrieval of particle size distribution parameters from radar data
- Could also use radar data to provide “ground truth” of ice water path and cloud altitude to evaluate passive sub-mm retrievals
- Could be very interesting to combine with data from NASA IMPACTS campaign!