Preparing all-sky assimilation of MWI and ICI for weather forecasting

Alan Geer (ECMWF)

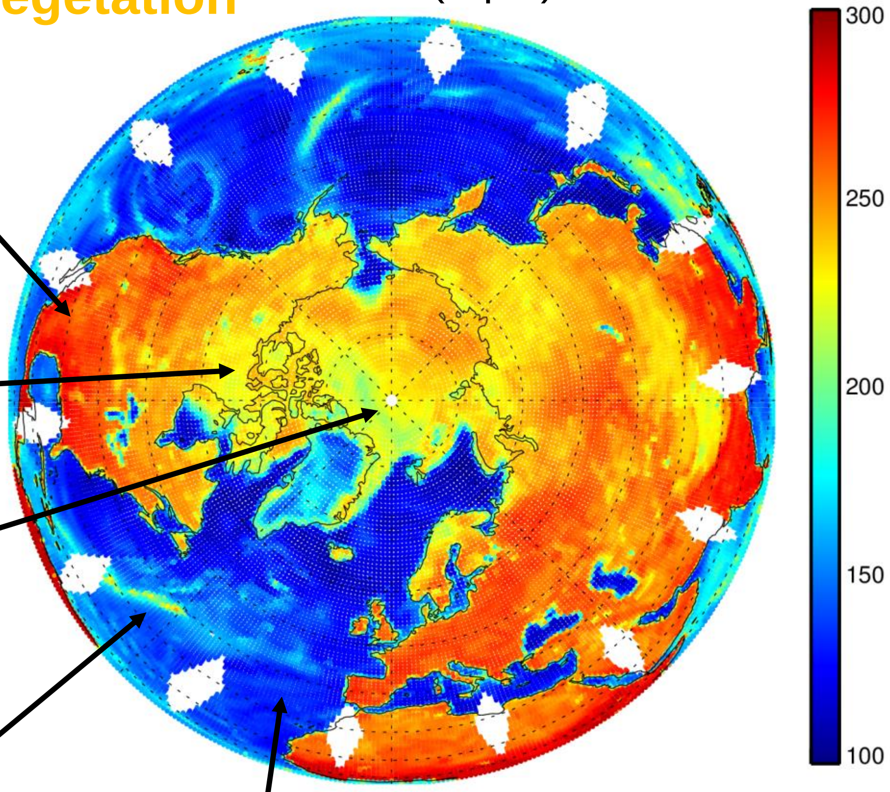
Thanks to:
Vinia Mattioli (EUMETSAT)
Vasileios Barlakas, Patrick Eriksson (Chalmers University)
Katrin Lonitz, Niels Bormann (ECMWF)

Motivation for MWI and ICI in numerical weather prediction (NWP)

Geophysical sensitivities in MWI and ICI radiances

land temperature, soil moisture, vegetation

19 GHz (h-pol)



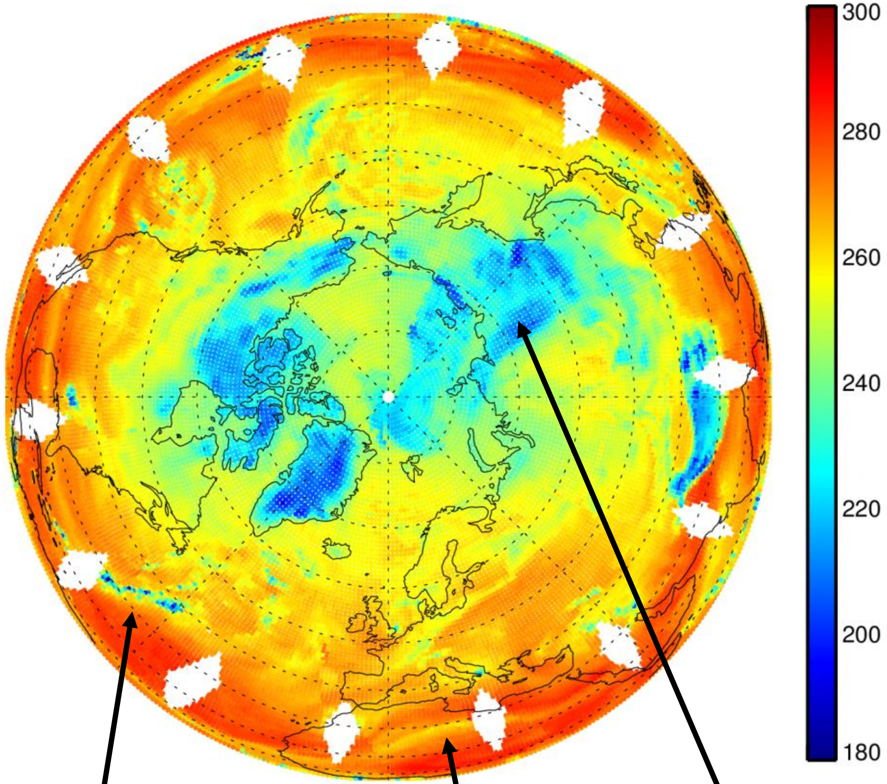
snow

sea ice

water vapour, cloud and rain

ocean temperature and surface roughness (wind)

183±7 GHz (h-pol)



Example SSMIS brightness temperatures [K] 6th Dec. 2019

extracted through direct radiance assimilation

assimilated indirectly through retrievals

not yet assimilated

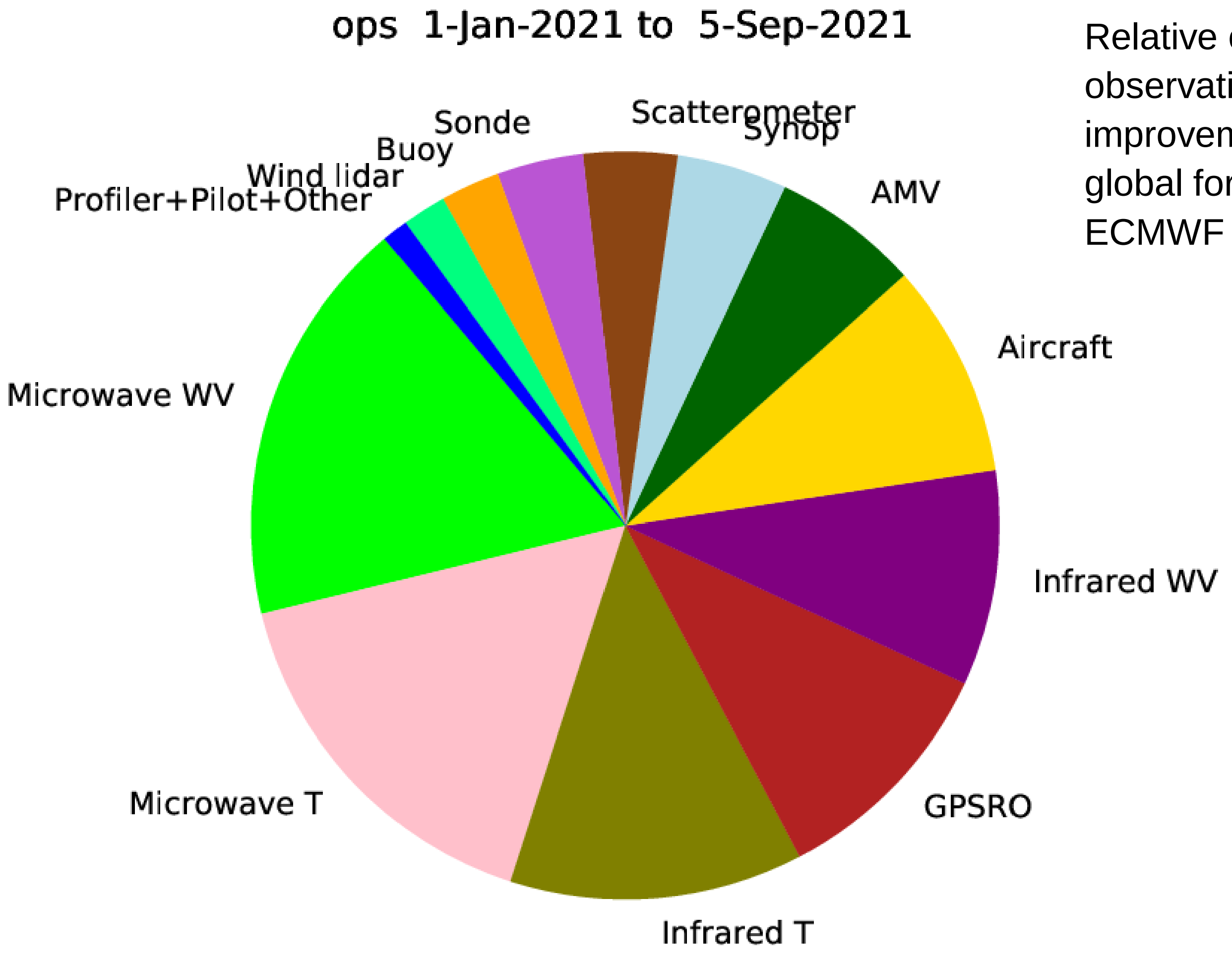
frozen hydrometeors

water vapour

snow “grain size” / surface reflection

NWP motivation 1: improved atmospheric initial conditions through all-sky radiance assimilation

Assimilation of radiances from 14 microwave sensors with window and humidity-sounding channels

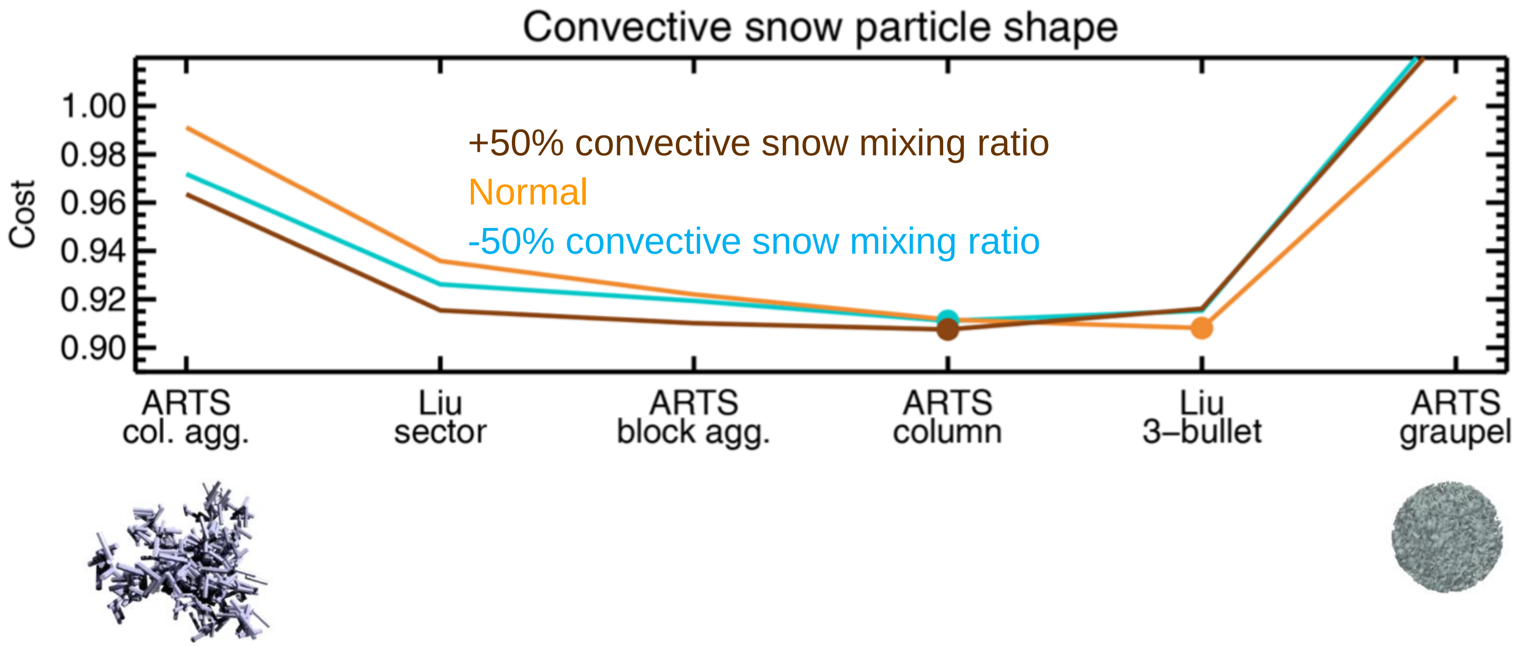


Relative contribution of observation types to improvement in 24h global forecast quality at ECMWF [%]

NWP motivation 2: improved cloud and precipitation modelling through parameter estimation

microwave radiances can help constrain many important microphysical parameters
(e.g. convective snow particle shape and size distribution)

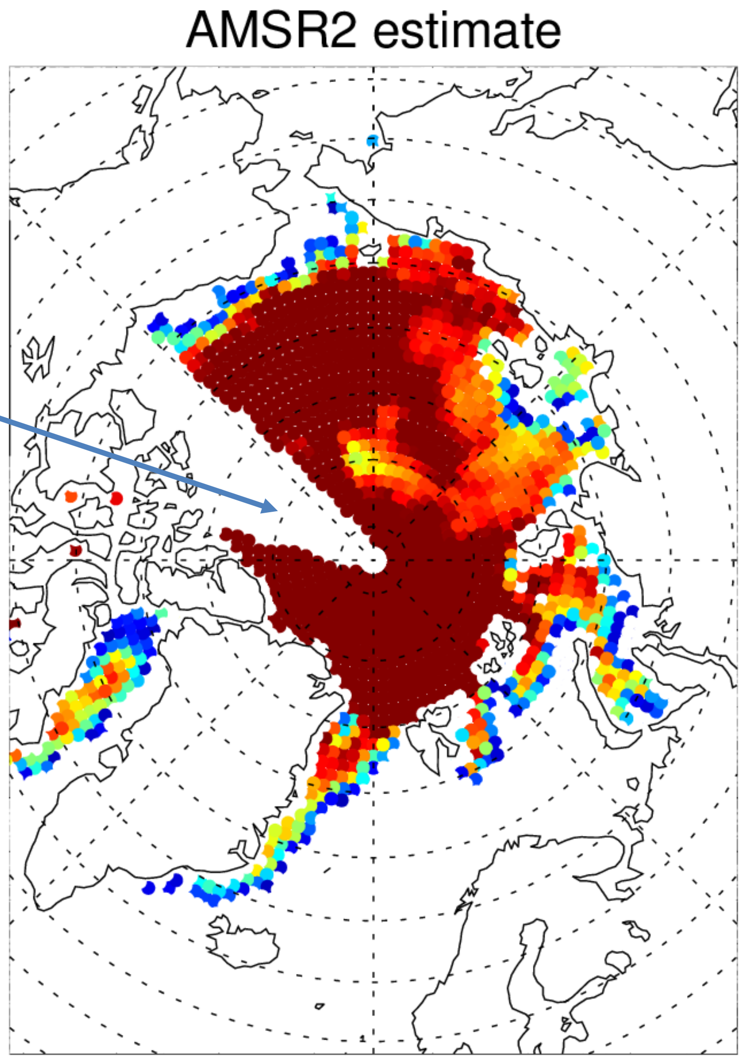
ECMWF vs. SSMIS 19 to 190 GHz cost function



RTTOV-SCATT v13.0 default physical parameter assumptions improved using simultaneous 6-parameter estimation (Geer, 2021, AMT, https://doi.org/10.5194/amt-14-5369-2021)
Particle shapes from the ARTS database (Eriksson et al., 2018, https://doi.org/10.5194/essd-10-1301-2018)

NWP motivation 3: improved earth system analysis through all-surface radiance assimilation

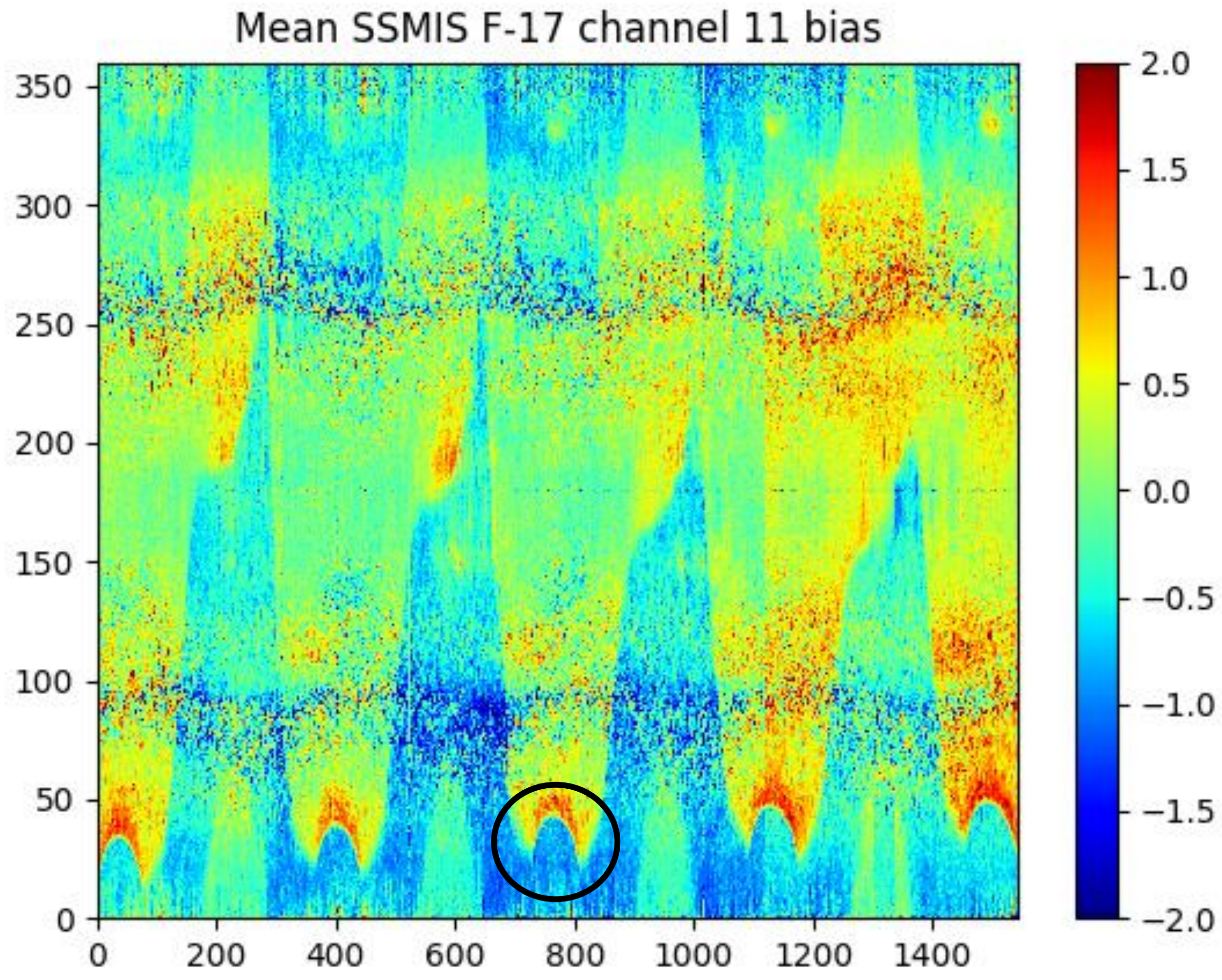
AMSR2 orbit not available in this 12h assimilation window



Simple sea-ice fraction estimate from 10 GHz AMSR2 observations, made as part of atmospheric DA

NWP motivation 4: a reference for calibration and monitoring

Angle through orbit



Day

All-sky observation minus NWP background [K]

NWP is very sensitive to changes in the relative calibration (e.g. through orbit, through time)

Preparing sub-mm radiative transfer (RTTOV)

ECMWF

A fast radiative transfer model for operational applications

EUMETSAT
NWP SAF
NUMERICAL WEATHER PREDICTION

News | Software | Monitoring | Support | Publications | Visiting Scientists | Training

RTTOV | Overview | RTTOV v13 | Documentation | Downloads | Bug fixes | Coefficients | Future Plans

Introduction

Current version: v13.0, November 2020

RTTOV (Radiative Transfer for TOVS) is a very fast radiative transfer model for passive visible, infrared and microwave downward-viewing satellite radiometers, spectrometers and interferometers. It is a FORTRAN 90 code for simulating satellite radiances, designed to be incorporated within user applications. The following paper gives an overview of the model and should be used when citing RTTOV:

Saunders, R., Hocking, J., Turner, E., Rayer, P., Rundle, D., Brunel, P., Vidot, J., Roquet, P., Matricardi, M., Geer, A., Bormann, N., and Lupu, C., 2018: An update on the RTTOV fast radiative transfer model (currently at version 12), Geosci. Model Dev., 11, 2717-2737, https://doi.org/10.5194/gmd-11-2717-2018.

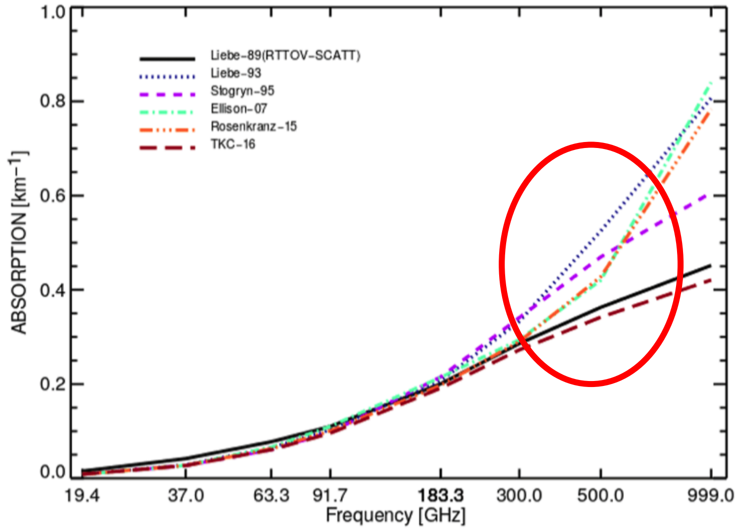
RTTOV Overview [hide]

https://nwp-saf.eumetsat.int/site/software/rttov/

Observation operator preparation: spectroscopy and water permittivity

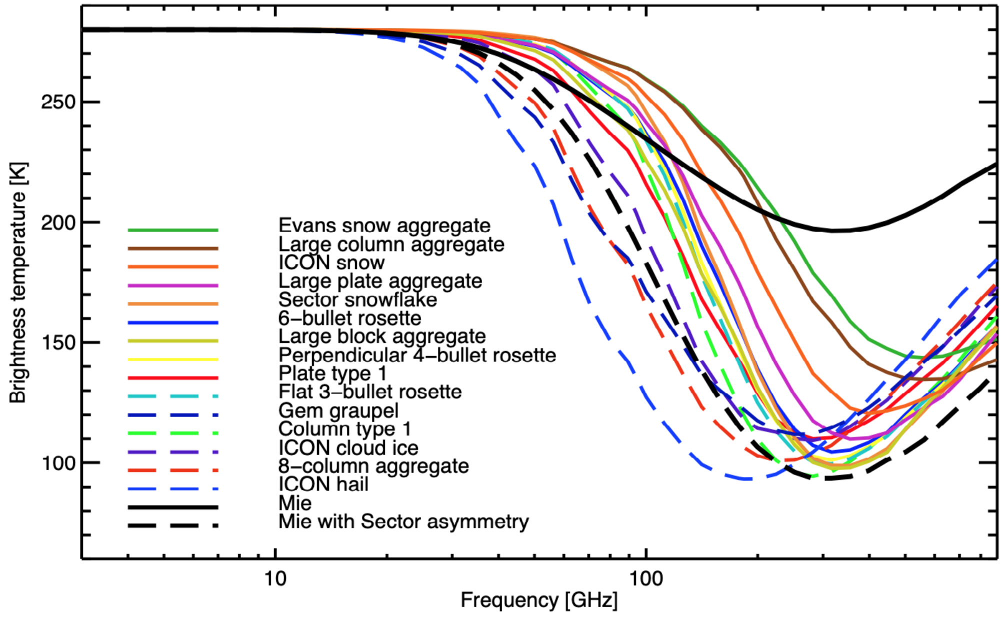
- Gas spectroscopy is mainly water vapour lines, oxygen & ozone lines, continuum
  - EUMETSAT workshop: Atmospheric Gas Absorption Knowledge in the Submillimeter: Modeling, Field Measurements, and Uncertainty Quantification, Mattioli et al., 2019, https://doi.org/10.1175/BAMS-D-19-0074.1
  - Reference model development: Turner and Saunders, 2019, Sub-millimetre Spectroscopy for AMSUTRAN. Part One: The Theoretical Basis, https://nwp-saf.eumetsat.int/publications/tech_reports/amsutran_1Thz_NWPSAF_report.pdf
  - Ongoing EUMETSAT-funded Met Office study: characterising bias and error in sub-mm spectroscopy using ISMAR (airborne microwave/sub-mm spectrometer)

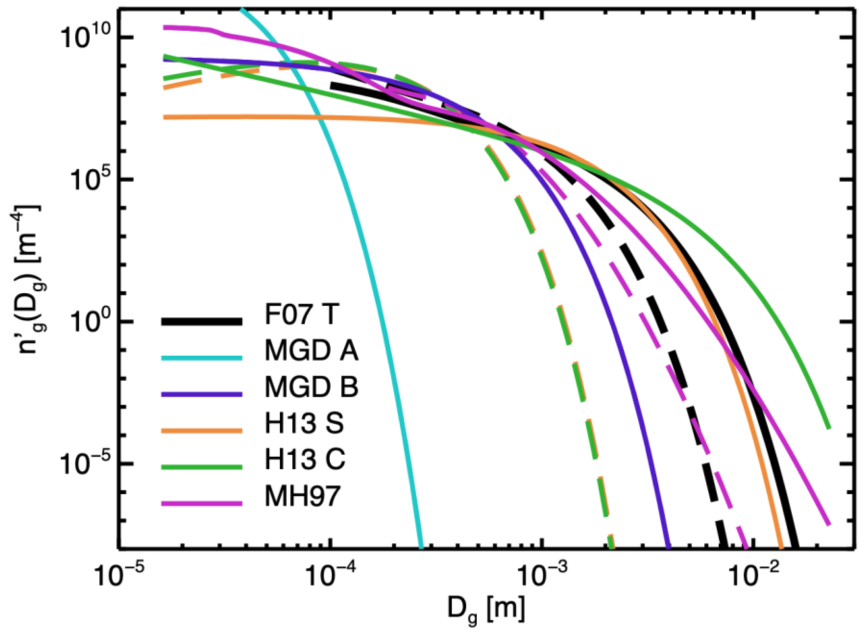
- Liquid cloud and rain (absorption and and scattering) depends on the permittivity model (equivalently refractive index)
  - Improved permittivity model, particularly for high frequencies (sub-mm) and supercooled clouds – Rosenkranz (2015, https://doi.org/10.1109/TGRS.2014.2339015)
  - Assessment in NWP by Lonitz and Geer (2019, https://doi.org/10.5194/amt-12-405-2019)



Observation operator preparation: frozen cloud and precipitation

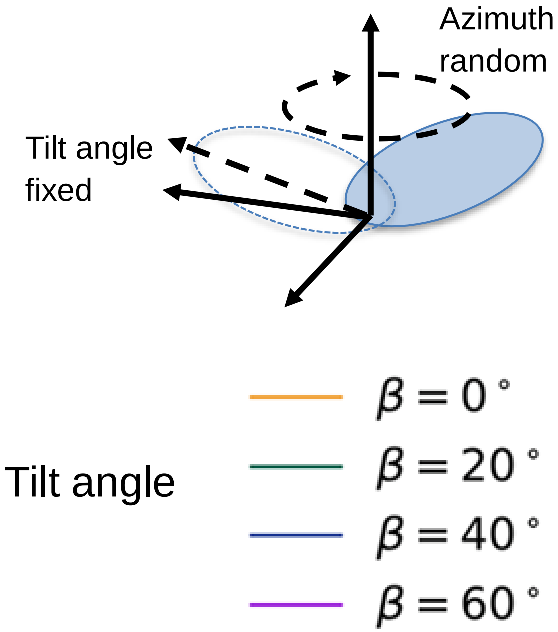
Particle shapes and size distributions
representing frozen particles from 1 to 884 GHz



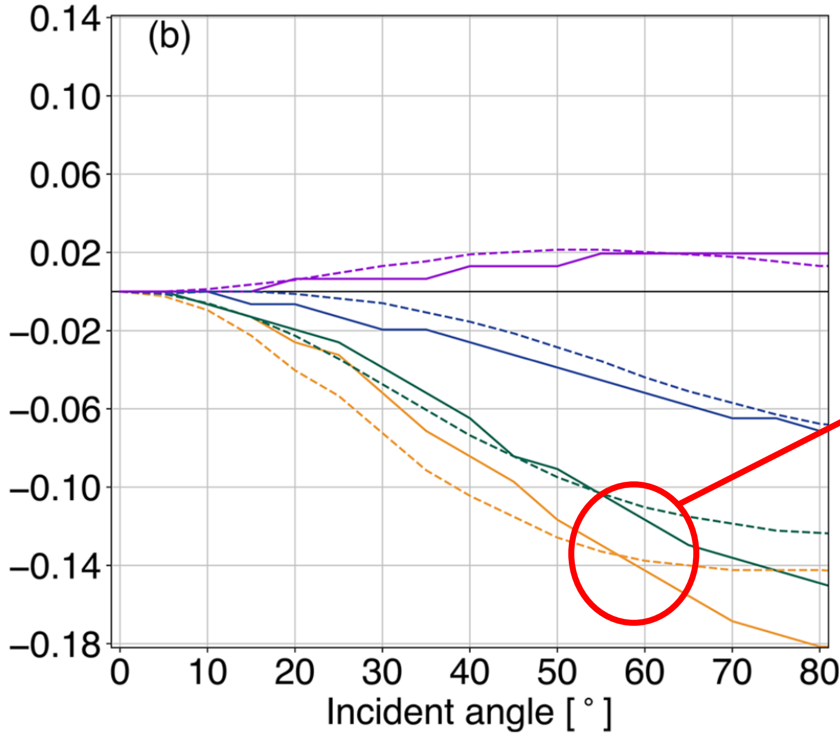


Particle shapes from the ARTS database (Eriksson et al., 2018, https://doi.org/10.5194/essd-10-1301-2018)
Bulk brightness temperature simulations, PSDs from Geer et al., 2021, https://doi.org/10.5194/gmd-2021-73

Representation of particle orientation and polarisation effects



Relative difference in extinction between vertical (v) and horizontal (h) polarisations



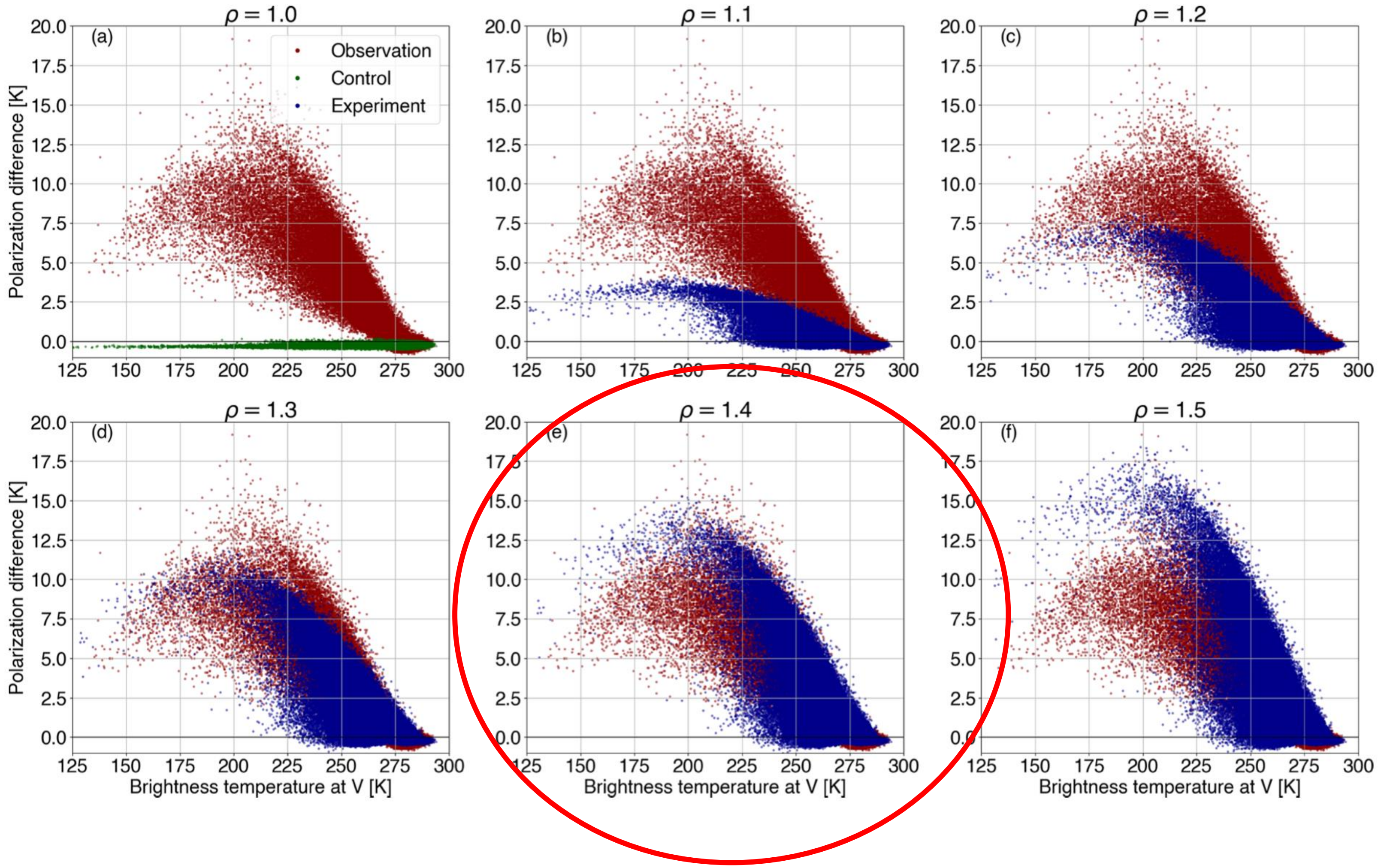
For preferentially horizontal particles, the extinction in h-polarised radiation is much stronger than v

Fig. 1, Barlakas et al., 2021, AMT, https://doi.org/10.5194/amt-14-3427-2021, showing optical properties of the azimuthal random orientation (ARO) large plate aggregate particle of Brath et al. (2020, AMT, https://doi.org/10.5194/amt-13-2309-2020) relative to the totally random orientation (TRO) original particle of Eriksson et al. (2018)

Particle orientation and polarisation effects in RTTOV

(Barlakas et al., 2021, AMT, https://doi.org/10.5194/amt-14-3427-2021)

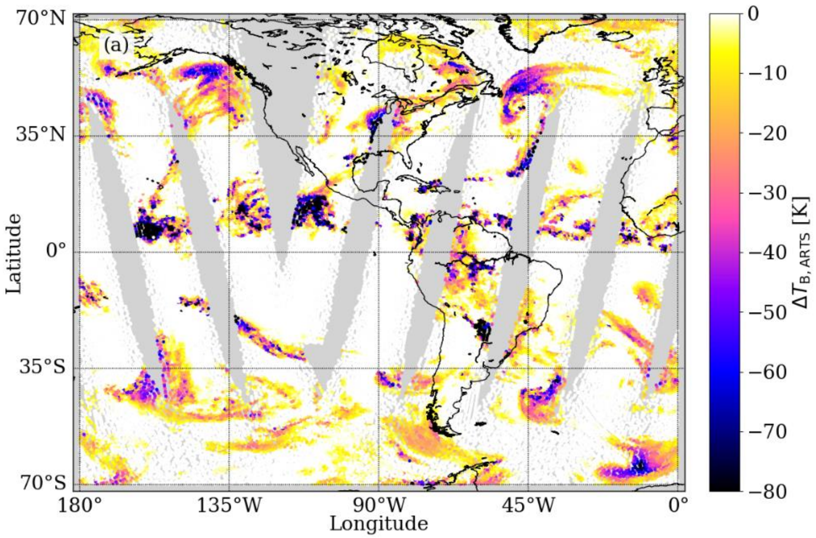
GMI 166 Ghz TBv – TBh as a function of TBv



Best polarisation ratio (ρ=1.4) found by parameter search using global GMI observations versus ECMWF-based RTTOV-SCATT simulations

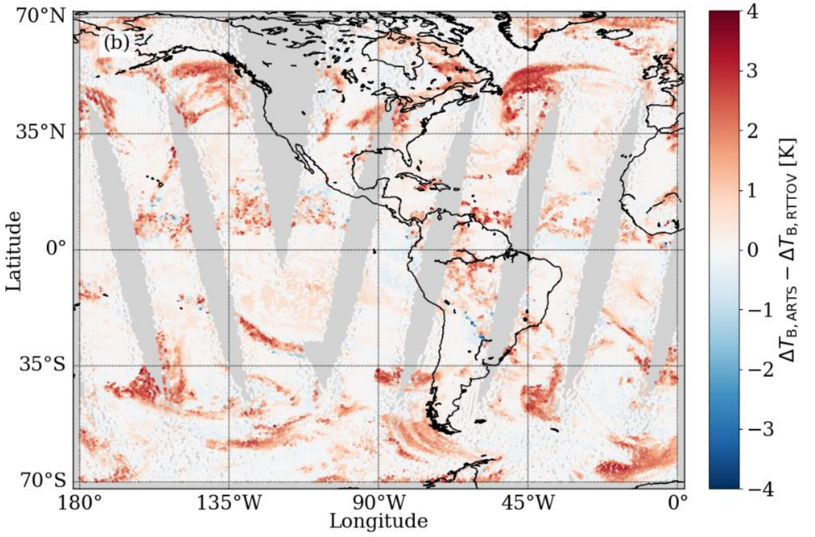
RTTOV vs. ARTS at sub-mm frequencies: focus on scattering solver

RTTOV-SCATT (delta-Eddington solver) compared to ARTS 36-stream discrete ordinate radiative transfer at 664±4.2 GHz



Hydrometeor impact on brightness temperature [K]

RTTOV-SCATT has errors but these are typically less than 10% of the observation error budget for data assimilation: accuracy should be sufficient for ICI



Difference RTTOV-SCATT minus ARTS [K]

Barlakas, Galligani, Geer and Eriksson, (2021, submitted to JQSRT): On the accuracy of RTTOV-SCATT for radiative transfer at all-sky microwave and submillimeter frequencies

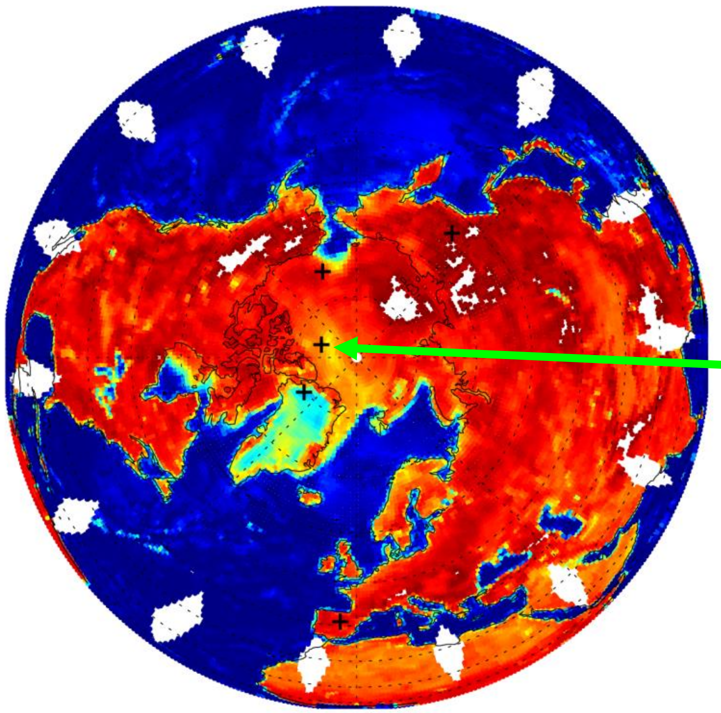
Observation operator preparation: surface interaction

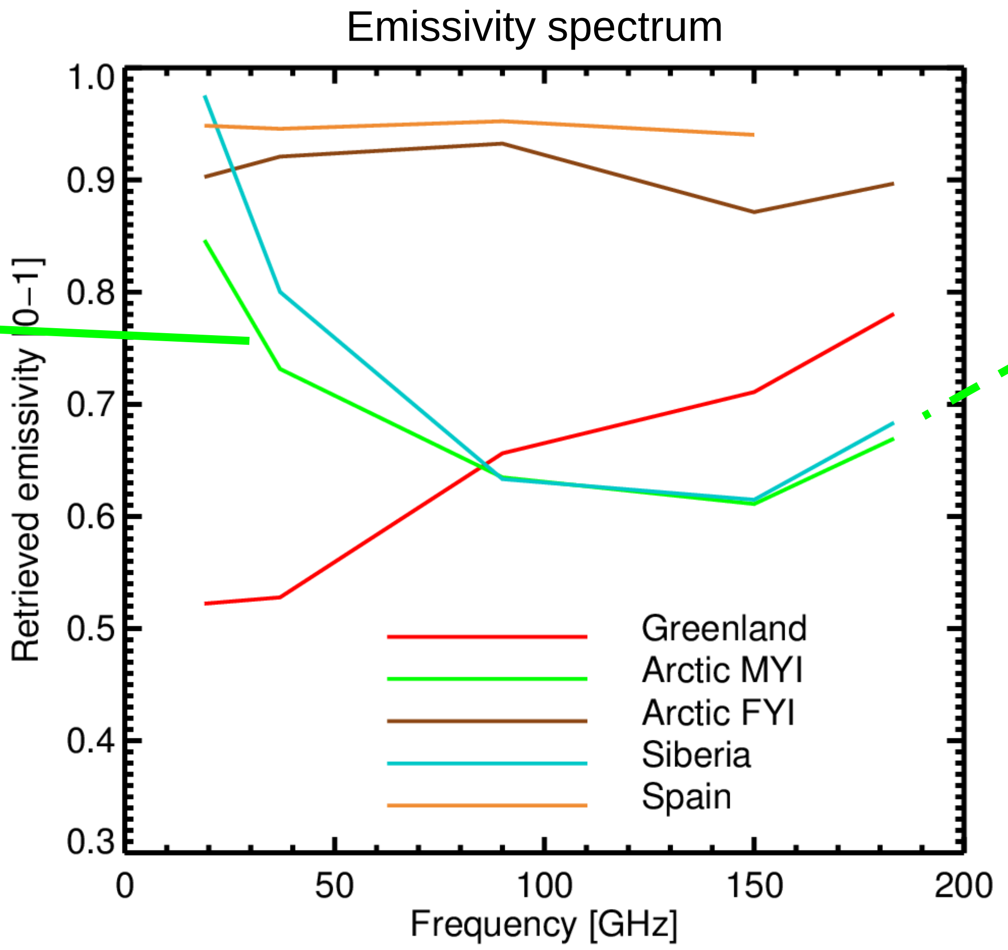
- Many ICI channels have some sensitivity to the surface at high latitudes and high altitudes
  - Sea surface emissivity
    - TESSEM - Sea-surface emissivity parametrization from microwaves to millimetre waves, Prigent et al., 2017, https://doi.org/10.1002/qj.2953)
    - PARMIO - A Reference Quality Model For Ocean Surface Emissivity And Backscatter From The Microwave To The Infrared https://www.issibern.ch/teams/oceansurfemiss/index.php/contents/
  - Sea-ice, snow and land surface emissivity
    - Atlas? Very difficult at ICI frequencies
    - Dynamic emissivity retrieval at lower frequencies (e.g. 10 – 100 GHz) with physical extrapolation to higher frequencies?

MWI and ICI together

Retrieved surface emissivity from DMSP-F17 SSMIS

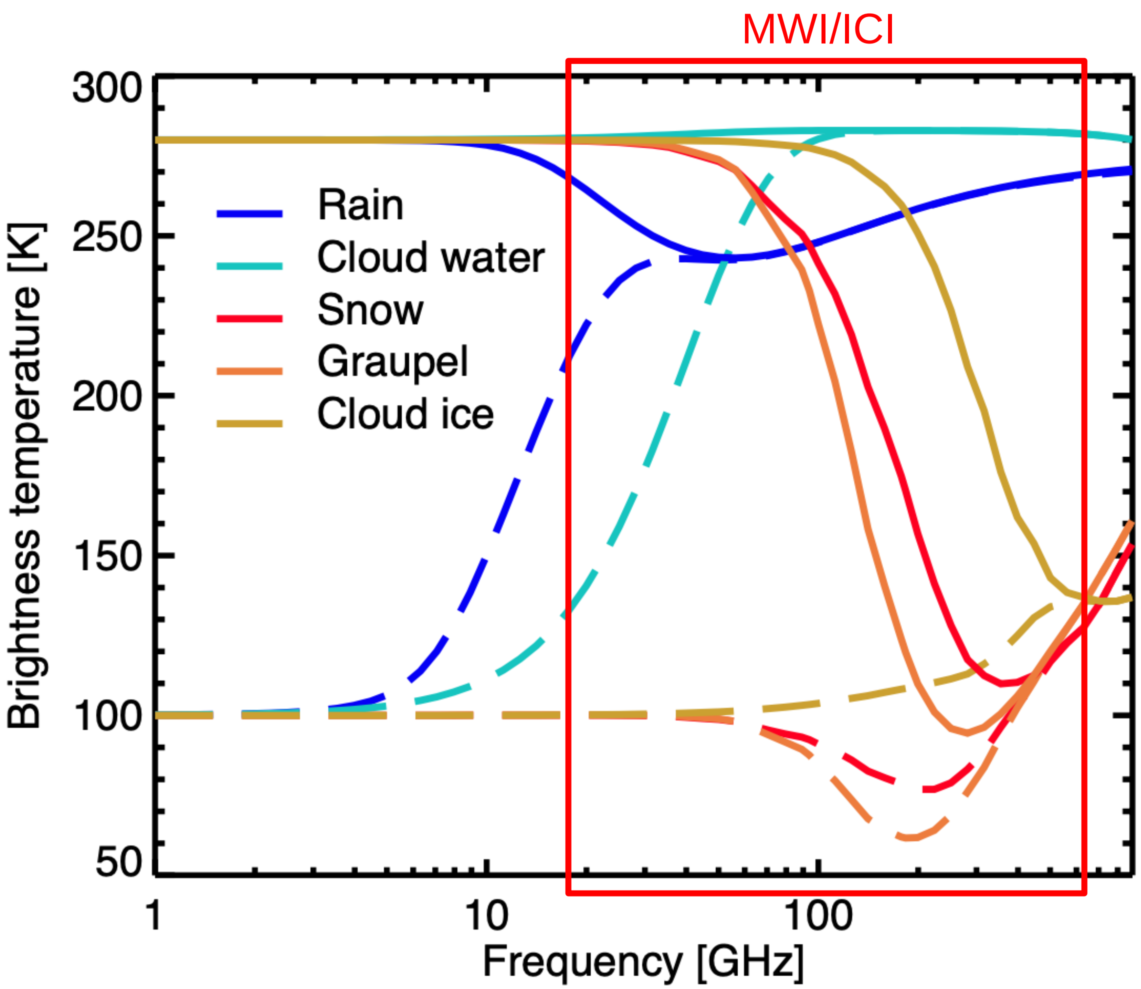
At 19 GHz (h-polarisation)





How to extrapolate to ICI frequencies?

Hydrometeor “spectra”



Over a warm / high-emissivity surface (e.g. land)

Use as much of the spectrum as possible to distinguish bulk particle composition, mass, shape, size, orientation

Over a cold / more reflective surface (e.g. ocean, highly scattering cloud)

Bulk brightness temperature simulations of homogenous cloud layer from Geer et al., 2021, https://doi.org/10.5194/gmd-2021-73

New scientific possibilities and questions for MWI and ICI

- Assimilate well-calibrated sounding channels:
  - Temperature channels (e.g. 50 GHz, 118 GHz) from a conical scanner
  - What is the impact of having so many humidity sounding channels? (8 at 183 GHz, 3 at 325 GHz, 3 at 448 GHz) Observation error correlation?
- First operational sub-mm mission:
  - Constrain the representation of smaller frozen particles in models
    - Ice cloud, anvil cloud, smaller snow and graupel particles
    - Ice particle orientation
- MWI-ICI combination – 19 to 664 GHz
  - Broad-frequency constraint of microphysical and microstructural representation of snow on ground and in the air.

Observation processing

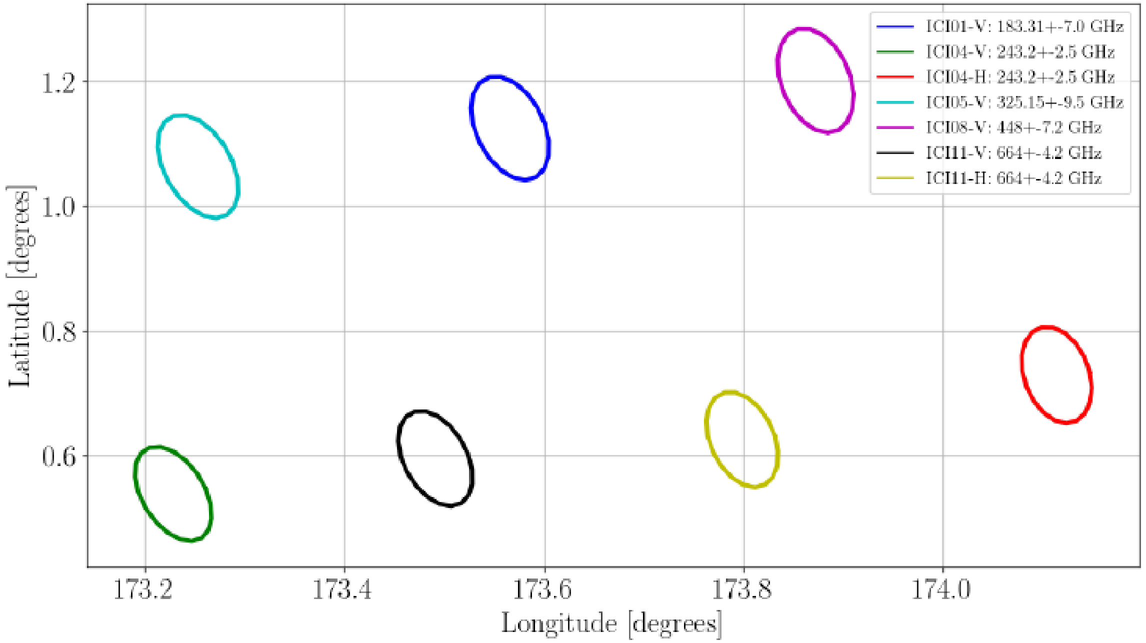
ECMWF

ICI Swath - about 800 samples per scan

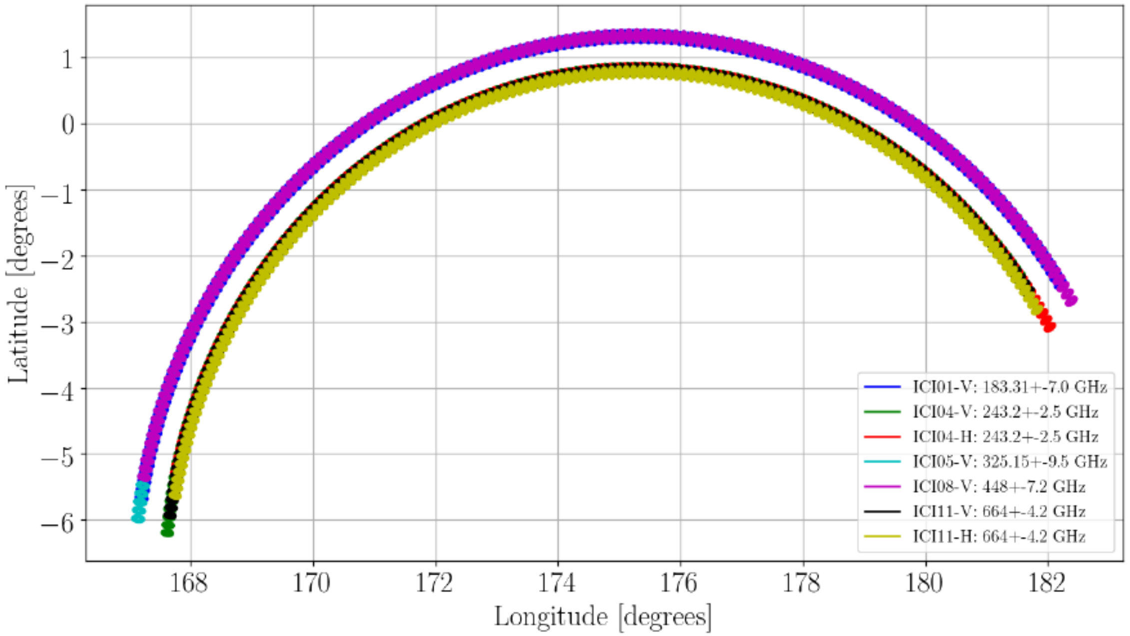
- **ICI: Conically scanning counterclockwise at 45 rpm. Incidence angles within 53°±2° . Observations acquired ± 65° in azimuth in the fore view (about 1700 km swath)**

ICI footprint: 16 km (ICI-1 to ICI-11);

Across-track footprint overlap 3-4x; spatial sampling ~2.7 km
Along-track footprint overlap ~ 40%; spatial sampling ~9 km



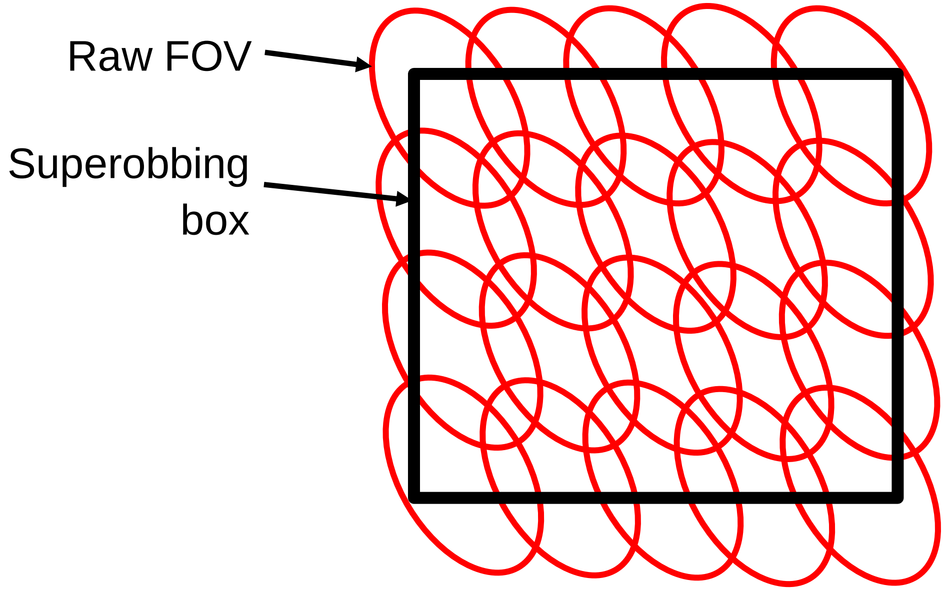
instantaneous, relative positions of -3-dB footprints on the geoid for ICI channels.

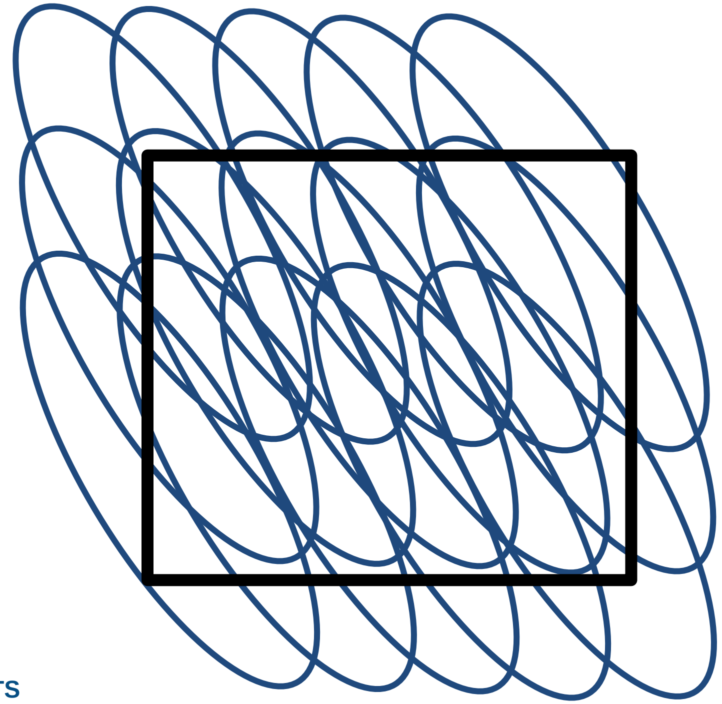


relative positions of -3-dB footprints on geoid for ICI channels of a complete scan.

Superobbing

- Superobbing: average all observations falling into an equal-area box on the earth's surface (e.g. 80 km by 80 km for all-sky assimilation at ECMWF). Why?
  - To colocate channels
  - Standardise the FOV across channels with varying footprint sizes
  - To match effective resolution of the forecast model (about 4x grid resolution; given the model is at ~8km resolution; this will need to be reduced in future)
  - To assimilate cloud features that are more predictable (spatial filtering)
  - Reduce data volume (large file sizes)
  - Avoid having to simulate horizontal observation error correlations
- Possibly superob MWI and ICI into one supersensor
  - Make surface emissivity, observation error, and inter-channel error correlations easier to deal with
  - Possibly use ECMWF in-house tool or NWP-SAF "MWIPP"





Summary

Summary: preparations for using MWI and ICI in weather forecasting

- Motivations:
  - better initial conditions
  - improved cloud and precipitation microphysics
  - earth system variables (e.g. snow, sea-ice)
  - cal/val and monitoring
- Radiative transfer preparations in RTTOV (particularly for sub-mm):
  - gas spectroscopy
  - cloud and precipitation modelling (liquid phase, ice phase, particle shape, size, particle orientation)
  - surface radiative transfer (ocean, sea-ice, snow, land)
- Possible timeline and plans at ECMWF
  - Start preparing the processing chain once the BUFR test data is available
  - Develop superobbing of MWI and ICI into one supersensor at around e.g. 40km resolution
  - Monitor MWI and ICI radiances soon after launch (2025)
  - Operational assimilation of MWI and ICI within 2025?