ARTS: overview with focus on ISMAR

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ARTS
The Atmospheric Radiative Transfer Simulator

radiativetransfer.org

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Outline

Short history

- Version 1
  - started 2000
  - “traditional” unpolarised 1D model
  - developed until $\approx$ 2005
  - still used for Odin-SMR operational processing

- Version 1.1/2.0
  - started 2002
  - version 2.0 released 2011
  - two main motivations
    - tomographic limb sounding inversions
    - microwave ice cloud observations

Scope

- Full polarisation (1-4 Stokes elements)
- 1D, 2D or 3D atmosphere
- All observation geometries covered
- Scattering of thermal emission
- Support practical retrievals
- Focus on microwave measurements
  - basic support for radio occultation
  - single scattering radar simulator
  - IR, at least clear-sky works fine

Key aspects

- Flexible
  - important for users
- Modular
  - important for developers
- Documented
  - important for all
- Maintained
  - important for users
- Open source
  - important for all

Outline

Main calculation steps

- Define/calculate gas absorption and surface properties
- Pencil beam monochromatic radiative transfer
  - ray tracing
  - integrate along propagation paths
- Inclusion of sensor characteristics
- Adopt to calibration scheme
  - set `iy_unit` to “RJBT” before calling `yCalc`

Calculation of absorption

- Line-by-line calculation based on
  - formats: HITRAN, JPL, LBLRTM and ARTS
  - line mixing can be considered (O2 @ 60 GHz)
- Absorption models and continua terms
  - gases: Liebe/Rosenkranz, CKD, HITRAN-CIA ...
  - liquid water: MPM93 and Ellison07
- On-the-fly or using lookup table
- All you need for ISMAR!?
- *Other features*
  - *Zeeman and Faraday rotation*
  - *other planets handled*

Surface radiative properties

- Upwelling radiation calculated as

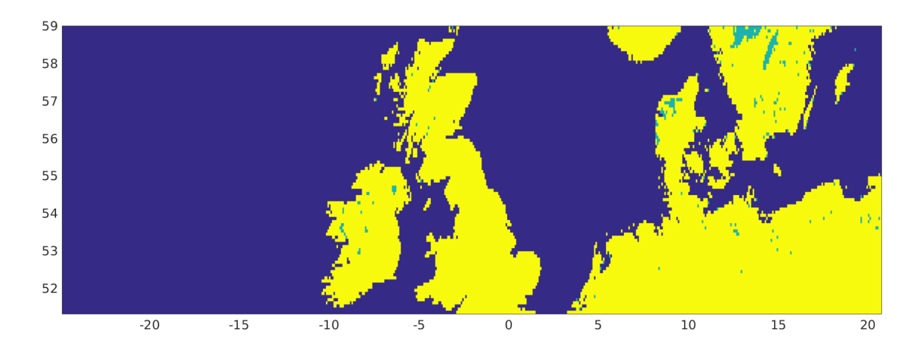
$$I_u = I_e + \sum_i R(\theta^i) I_d(\theta^i)$$

- Workspace methods for flat surface
  - constant or frequency varying scalar reflectivity, following given refractive index
- Lambertian surface
  - so far just a basic method
- FASTEM
  - don't use for incidence angles $> 80^\circ$ or above 400 GHz
- External data
  - possible to import and interpolate fields of R

- Output of EUMETSAT study should be implemented
  - What else could be needed for ISMAR?

The surface and 3D

- Possible to operate with surface types (land-sea mask)
- An example (with resolution actually used):



- A rough surface topography can be specified
  - Resolution follows the atmospheric lat and lon grids

Sensor characteristics

- Complete measurement vector calculated as

$$\mathbf{y} = [\mathbf{Hi}_1; \mathbf{Hi}_2; \ldots; \mathbf{Hi}_n]$$

- The response matrix **H** can include effects of
  - polarisation response, antenna pattern, sideband weighting, backend channel response, frequency interpolation . . .

- The approach assumes that **H** is identical for each view,
- but not valid for AMSU-A, ISMAR . . .
  - as polarisation response changes with viewing angle

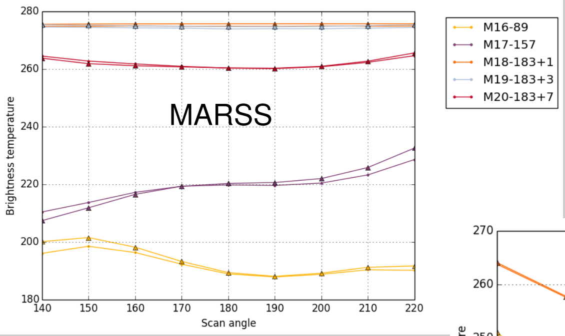
“Met MM system”

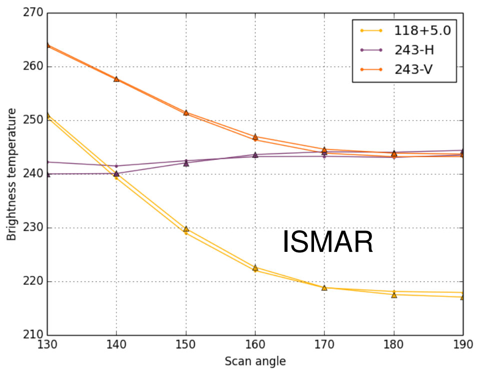
- Calculates **H** for a scan sequence
- DEIMOS, MARSS and ISMAR included

- Antenna response not yet handled
- Perfect balance between sideband assumed
- Rectangular channel response assumed
- Number of frequencies per passband can be set
- Scan positions to include can be selected

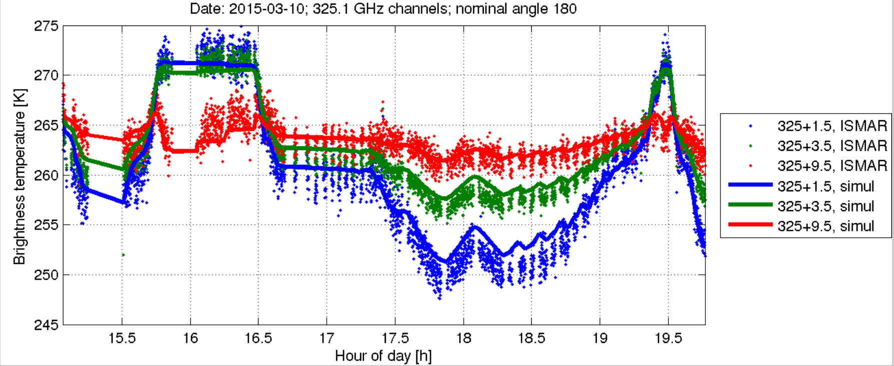
- Setting of `sensor_los`
  - zenith angle: direction of instruments reference direction (177° if no pitch or roll)
  - azimuth angle: direction of scan plane (flight direction of no roll)
- Use/mimic Atmlab’s `ismar_los.m`

Test of polarisation part
Flight B893, processing and figures by Stuart Fox





Simulation of complete flights
Flight B893, data close to nadir



- ERA-Interim (0.7°) with LWC considered (purely absorbing)
- 3D + Met-MM + surface set as:
  - ocean: FASTEM
  - lakes: FASTEM, with reduced wind speed (and zero salinity)
  - land: $r = 0.15$

OEM type retrievals

- Jacobian (weighting functions) provided for a number of atmospheric and sensor variables
- but not yet anything useful for surface reflectivity
  - something basic will be added soon

- Running OEM so far requires Atmlab
- but OEM inside ARTS is work in progress

Outline

Single scattering properties

- Must be provided in a ARTS specific format
- Horizontally aligned particles handled

- ARTS comes with Mishchenko's T-matrix code
  - probably less useful than expected
    (see Eriksson et al. AMT, 2015)

- Liu and Hong DDA databases are at hand in ARTS format
  - critical limitations of both databases
  - just total random orientation considered

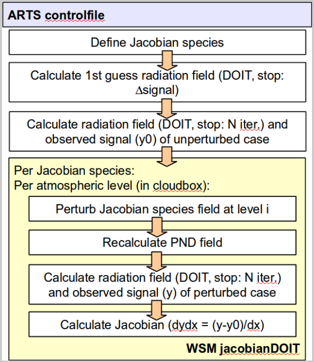
- A new DDA database has been started
  - more in presentation by Robin

Setting of particle number densities

- The core part is blind to particle type
- For each particle type you need to specify
  - single scattering
  - particle number density (PND) field [#/m3]
- The PND field can be set directly
- and now also based on hydrometeor profiles, combined with user-specified PSD:
  - `SWC-F07TR-Snow-*-*`

Solution methods

- Discrete Ordinate Iterative method (DOIT)
  - determines the complete radiation field in an iterative manner
  - 1D and 3D versions
  - required settings need some care
  - can provide weighting functions (very slow option)



- Monte Carlo (MC)
  - follows "photons" backwards in a random manner
  - only 3D
  - easy to use

- Both methods are fully polarised (vector RT)

- Present recommendation for ISMAR: DOIT-1D

Discussion

- Neither DOIT or MC is very fast! But sufficiently fast?
- If no, is there any option?

- Vector radiative transfer is required!
  - V and H radiation streams can not be treated separately when multiple scattering is significant

- Do we need 3D scattering calculations?
  - for ICI probably yes
  - less clear for ISMAR
- A master project on the subject has been started

Conclusions

- ARTS has the basic capabilities to handle ISMAR
- Main lack of data:
  - surface properties above 200 GHz
  - any single scattering data that are OK from 90 to 664 GHz?
  - single scattering data for horizontal alignment
- Do we need a faster scattering method?
  - should then be polarised
- Do we need to consider horizontal structures?
  - that is, scattering in 3D