A brief overview of hydrometeor scattering and surface modelling in ARTS

(microwaves to IR)

Patrick Eriksson

Department of Space, Earth and Environment
Chalmers University of Technology,
Gothenburg, Sweden

patrick.eriksson@chalmers.se

Surface

Workspace methods (WSMs) for describing the surface

Through surface_rtprop_agenda

- General methods
  - Unpolarized: surfaceBlackbody, surfaceFlatScalarReflectivity, surfaceLambertianSimple
  - Polarised, pre-set reflectivities: surfaceFlatRvRh
  - Polarised, n-based: surfaceFlatRefractiveIndex
  - Polarised, lookup: surfaceFlatReflectivity
    - Uses surface_reflectivity, that can be interpolated from Tensor6(f, stokes, stokes, ia, lat, lon)
    - Flat = only one downwelling direction
- Ocean
  - FASTEM
    - Don't use above ~250 GHz
  - TESSEM
- Land
  - TELSEM
    - Not strictly land, affected by water around coasts, rivers and lakes

Features and tricks

- Specular direction (specular_los) "tunable":
  - Standard choice is to consider surface topography
  - Assume horizontal surface (e.g. lakes)
  - Can be set to a fixed angle (e.g. 53° to approx. Lambertian)
  - Would be possible to use a Lambertian factor

- Emulate scalar radiative transfer (RT):
  - Recipe:
    - Run ARTS with stokes_dim = 1
    - Inside surface agenda, call surface WSM with stokes_dim ≥ 2
    - Call WSM surfaceMapToLinearPolarisation with "polarization angle"
    - And you get surface properties for e.g. H or V polarization
  - With this you can mimic a scalar solver, such as RTTOV!
    - Complements our aARO scheme (more later)

Representation of surface variables

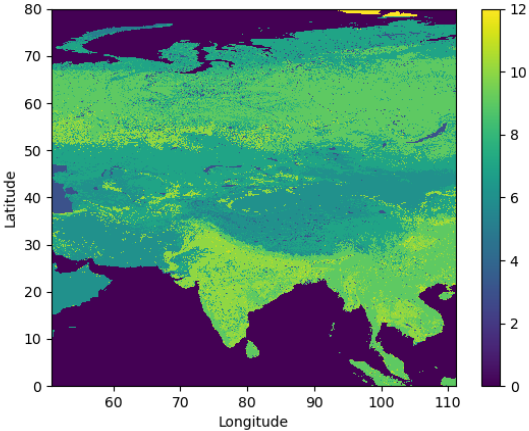
- z_surface is linked to main latitude and longitude grids
  - Bad choice!
  - There is also t_surface ...
- Other surface variables best provided as GriddedField2
  - That is, provided with dedicated lat and lon grids
  - Interpolated to point of interest by InterpGriddedField2ToPosition
- No pre-defined workspace variables for this
- You likely need to define variables for:
  - skin temperature and wind speed
  - wind direction (if using FASTEM)
- This works also for 1D and 2D
  - With lat_true and lon_true set properly

Recipe for working with surface types

- Create surface_type_mask with types coded as 0, 1, 2, . . .
- Fill surface_rtprop_agenda_array for each surface type
  - Append to the agenda, starting with setup for surface type 0
- Set surface_rtprop_agenda to contain surface_rtpropFromTypesNearest

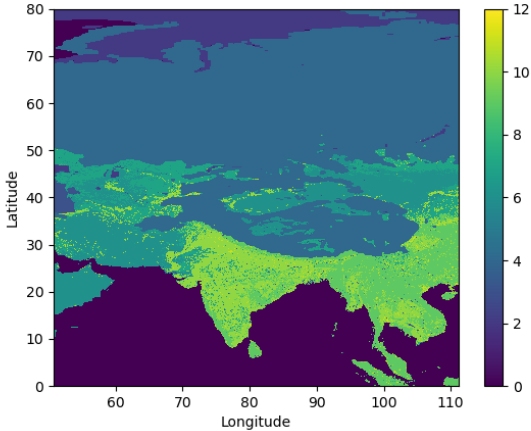
Example on surface type data

Static data



GLCNMO Land Cover v3

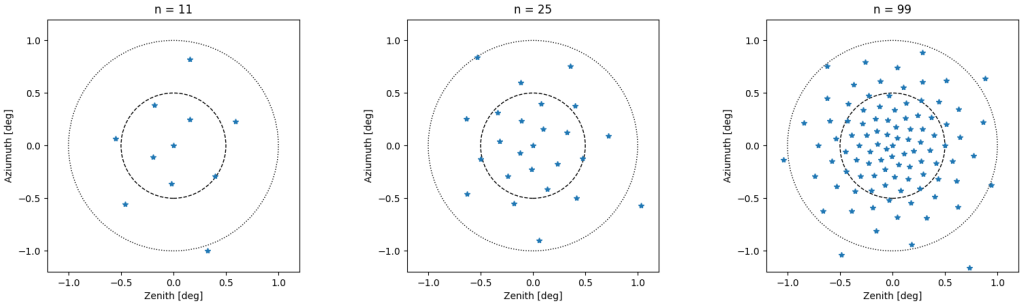
Snow and sea-ice added



From ERA5, Jan 2, 2015

"Footprint operator"

- There is also a start for a "footprint operator" scheme
  - That is, to derive the (weighted) average over the footprint
  - Activated by instead applying surface_rtpropFromTypesAverage
  - Contact Patrick if you want to test this beta feature
- You define the sample patters + weights
- An attempt to an equal-weight sampling scheme:



Hydrometeor scattering

Passive scattering solvers

- Monte Carlo (MC)
  - Only option for full 3D
- DOIT
  - Main option for 1D limb sounding
- DISORT
  - Limited to flat planet, 1D and scalar RT
  - Fastest and most robust solver
- RT4
  - Limited to flat planet and 1D
  - Slower and less robust (and can even cause Segmentation fault)
- Hybrid
  - Only option to retrieve hydrometeor properties with OEM
- Independent beam approximation (IBA)
  - Allows to run DOIT, DISORT and RT4 on local 1D inside 2D or 3D
  - Seems to remove systematic beam filling errors

Single scattering data

- ARTS' interface to T-matrix
- ARTS microwave scattering database
  - TRO: 35 habits
  - ARO: 2 habits
    - For ICI we use "aARO", similar to as implemented in RTTOV-SCATT
    - That is, separate V and H runs, using TRO data with scaled extinction
- UV-to-IR database by Yang&Bi now at hand in ARTS format
  - Wavelengths 0.2 to 99 μm
  - Nine habits, sizes 2 to 10 000 μm
  - Three levels of surface roughness
  - Some shapes common with ARTS TRO database
  - A aggregates have $b = 3$

Possible to streamline definition of particle models

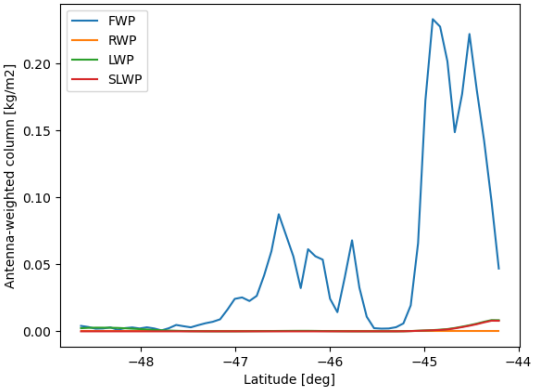
```
def scat_speciesAbelBoutle12(
    ws: Workspace,
    species: str,
    t_min: float = 265,
    t_max: float = 373,
) -> None:

    ws.Append(ws.scat_species, species)
    ws.ArrayOfStringSet(
        ws.pnd_agenda_input_names,
        (species),
    )
    ws.Append(
        ws.pnd_agenda_array_input_names,
        ws.pnd_agenda_input_names,
    )

    @arts_agenda(ws=ws, set_agenda=True)
    def ag(ws):
        ws.ScatSpeciesSizeMassInfo(
            species_index=ws.agenda_array_index,
            x_unit="dveq",
        )
        ws.Copy(ws.psd_size_grid, ws.scat_species_x)
        ws.Copy(ws.pnd_size_grid, ws.scat_species_x)
        ws.psdAbelBoutle12(t_min=t_min, t_max=t_max)
        ws.pndFromPsdBasic()

    ws.Append(ws.pnd_agenda_array, ag)
```

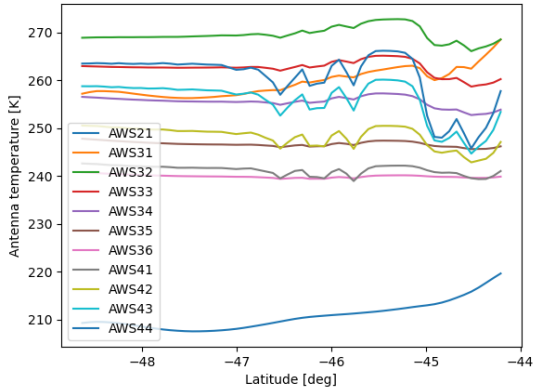
```
for species in ws.particle_bulkprop_names.value:
    if species == "RWC":
        ea.scat_speciesAbelBoutle12(
            ws,
            species
        )
        ea.scat_data_rawAppendStdHabit(
            ws,
            habit="LiquidSphere"
        )
    elif species == "SWC":
        ea.scat_speciesFieldEtAl07(
            ws,
            species,
            regime="TR"
        )
        ea.scat_data_rawAppendStdHabit(
            ws,
            habit="LargePlateAggregate",
            dmax_start=1e-4
        )
    else:
        raise ValueError(...
```

easy_arts

- Not an official ARTS package
- Developed at Chalmers for our own purposes
- Contains code for:
  - Working with surface types
  - Working with particle models
  - Importing data from standardized xarray/netcdf format
    - Automatic download/import from ERA5
  - Running DISORT and RT4 on 2D and 3D scenes (IBA)
  - Doing radar onion peeling
  - Inclusion of spectral and polarization responses
  - Band-averaging of abs_lookup
  - ...
- Can be shared on a "personal basis"
  - Mainly relevant for microwave meteorology sensors

AWS simulations based on CloudSat and ERA5





Outlook: V3, present plans

- Description of surface variables and types similar to present system
  - Also z_surface will have its own grids
  - All more user friendly
- Improved description of surfaces' EM properties ...
  - More consistent treatment between solvers needed
  - Introducing a full, general representation of the BDRF?
- Handling of scattering properties re-implemented from scratch
  - Easier to set up particle models
  - Possible to tabulate bulk properties, like RTTOV-SCATT
- Updates of scattering solvers
  - In-house implementation of DISORT (based on ??)
  - New version of DOIT in development
  - In-house implementation of RT4 on the wish list