RAdiation transfer Model Intercomparison

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1 Introduction

1.1 ROMC/RAMI

The RAMI On-line Model Checker[1] (ROMC) allows you to evaluate the performance of a canopy reflectance model against a set of reference data obtained from 3-D radiation transfer models that, in

[1] http://romc.jrc.ec.europa.eu/

turn, were identified during the 3rd phase of the RAdiation transfer Model Intercomparison (RAMI) exercise.

The following sections will summarize the information collected on the ROMC website and the PYTHON scripts needed in order to create the RAMI 3 simulations and extract the data.

1.2 BRF

All remote sensing measurements [2] [3] [4] acquired from space or airborne imaging sensors in the solar domain turn out to be strongly dependent on the particular geometry of illumination and observation at the time these measurements were made. A similar situation occurs in the spectral domain: different measurement values are obtained when a target is observed in different spectral bands. The reflectance of a geophysical medium (at a particular wavelength) is thus dependent on both the orientation of the Sun and the orientation of the observer with respect to the target. Such a medium is called anisotropic, and the reflectance is characterized as bi-directional. By contrast, a perfectly reflecting, isotropic surface, i.e., a system that would reflect all incoming light equally in all directions, is called Lambertian.

The fundamental mathematical concept describing this anisotropic reflectance is the so-called Bidirectional Reflectance Distribution Function (BRDF). For practical reasons, the measured reflectance of a target is often normalized by the reflectance of a reference panel that is (ideally) a Lambertian surface, illuminated and observed under identical geometric conditions. The result of this normalisation is then called the Bi-directional Reflectance factor (BRF). For a polar plot of BRF values observed over a particular target click here .

Observations that lie in the same plane as the local vertical and the incoming direct solar radiation are referred to as BRFs in the here principal plane. Observations along a plane whose azimuth differs by $\pm$ 90 degrees to that of the principal plane are referred to as BRFs in the orthogonal (or cross) plane . If the direction of observation coincides with that of the direct solar illumination, no shadows are observed within the target and a BRF maximum known as the hot spot effect is observed.

Since the field of radiation transfer is rather technical, a precise terminology is used to designate the various reflectance concepts. The following papers provide detailed definitions on the terms employed here.

2 RAMI Scenes

There are two types of scenes in the RAMI 3 experiment:

Homogeneous : the properties of the scene can be considered independent of geographical location (horizontal spatial coordinates).

[2] Nicodemus, F. E., J. C. Richmond, J. J. Hsia, I. W. Ginsberg, and T. Limperis, (1977) *Geometrical Considerations and Nomenclature for Reflectance,* US Department of Commerce, National Bureau of Standards, NBS Monograph No. 160, Washington, DC.

[3] Martonchik, J. V., C. J. Bruegge, and A. Strahler (2000) *A Review of Reflectance Nomenclature Used in Remote Sensing*, Remote Sensing Reviews, 19, 9-20.

[4] Verstraete, Michel M. and Bernard Pinty (2000) *Environmental Information Extraction from Satellite Remote Sensing Data*, in Geophysical Monograph No. 114, Edited by P. Kasibhatla, M. Heiman, P. Rayner, N. Mahowald, R. Prinn, Ronald and D. Hartley, American Geophysical Union, Washington, D.C., p. 125-137.

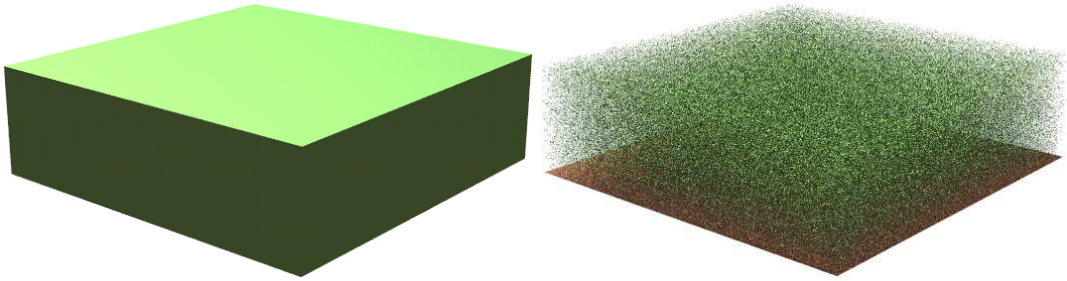
Heterogeneous : the properties of the scene are dependent on location.

2.1 Homogeneneous Scenes

There are two kinds of homogeneous scenes:

Turbid medium : a 'gas' of dimension-less particles representing the leaves (Fig. 1a).

Discrete scatterers : a large number of randomly distributed non overlapping disc-shaped objects representing the leaves (Fig. 1b).



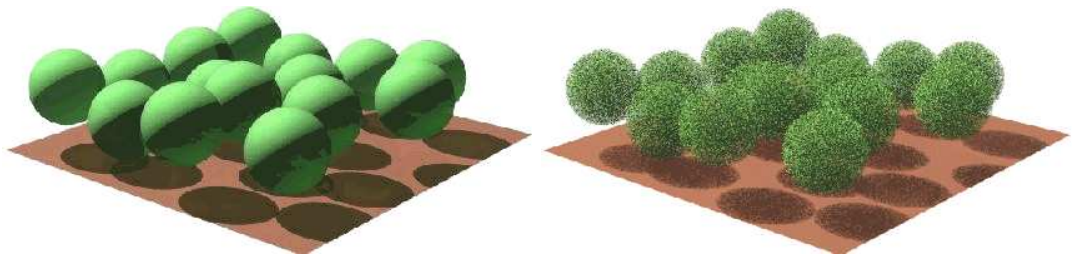
(a) (b)

Figure 1: (a) Homogeneous turbide scene. (b) Homogeneous scene with discrete scatterers.

2.2 Heterogeneous Scenes

The heterogeneous scenes can be divided into 4 categories:

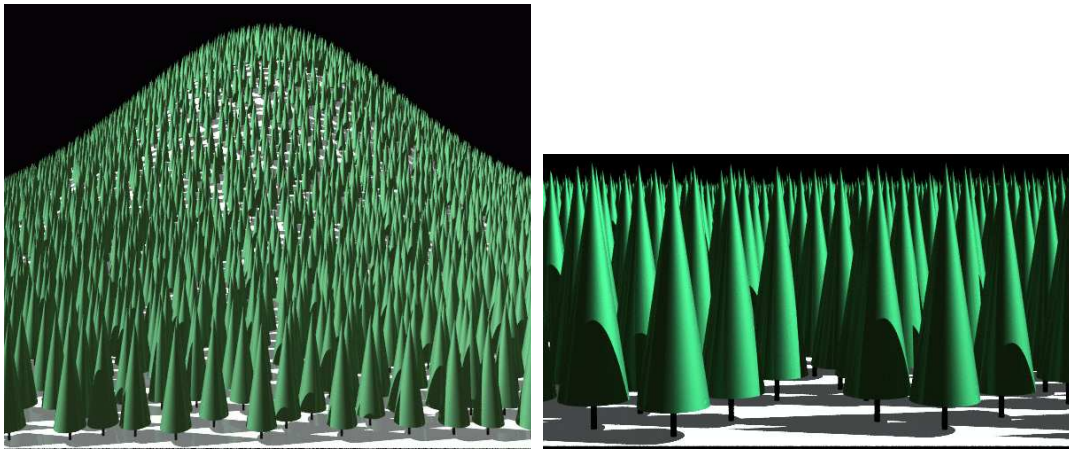
Floating spheres : multiple free-floating sphere-shaped volumes containing either discrete or turbid foliage representations (Fig. 2).



(a) (b)

Figure 2: (a) Heterogeneous turbide. (b) Heterogeneous with discrete scatterers.

Conifer forest : large spatial extend scenes featuring tree architectures and spectral properties that reflect those of typical coniferous forests, with or without topography (Fig. 3).

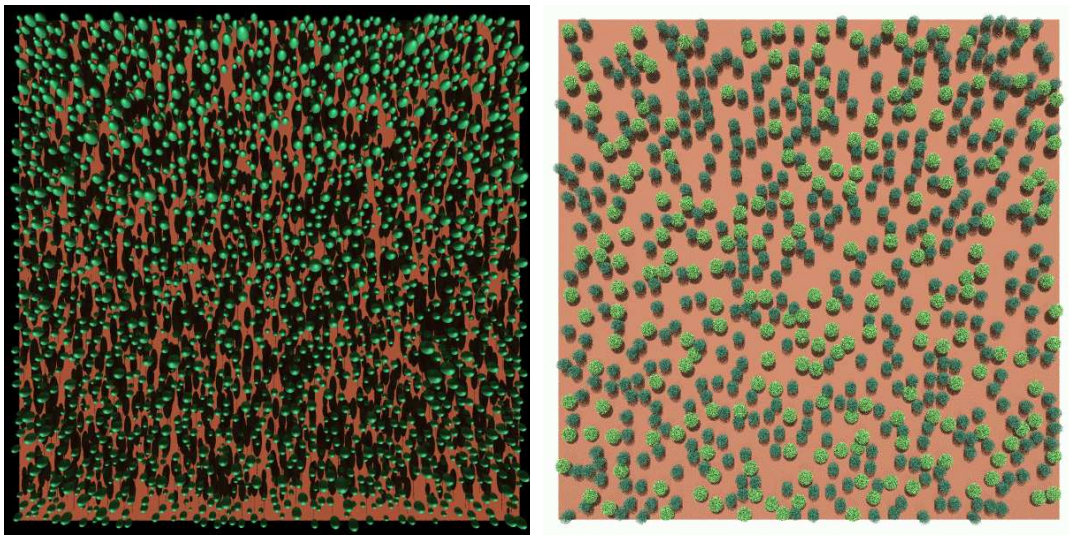


(a) (b)

Figure 3: Old growth coniferous forests (a) in the presence of an underlying topography. (b) in the absence of any underlying topography

Birch stand : spatially heterogeneous scenes resembling boreal birch stands (Fig. 4a).

Real zoom-in : large number of disc-shaped scatterers that are contained within a series of non-overlapping spherical and cylindrical volumes (Fig. 4b).



(a) (b)

Figure 4: (a) A large number of non-overlapping tree-like entities of different sizes and spectral properties. (b) Large number of disc-shaped scatterers that are contained within a series of non-overlapping spherical and cylindrical volumes.

2.3 Naming Conventions of RAMI Simulations

RAMI simulations are named with key identifiers that give the values of the different parameters of the simulation : leaf angle distribution (LAD), solar zenith angle (SZA),...

The table 1 gives the possible tags present in the RAMI simulation names.

Identifier tag	Tag meaning	Identifier tag	Tag meaning
HOMxx	HOMogeneous case	HETxx	HETerogeneous case
xx	Scene number xx	DIS	DIScrete scatterers
RED	RED wavelength (650 nm)	NIR	Near-InfraRed wavelength (860 nm)
UNI	UNIform LAD function	PLA	PLAnophile LAD function
ERE	EREctophile LAD function	yy	Value of the SZA in degrees

Table 1: Tags identifier and meaning of the RAMI experiments names.

2.4 Reflectances and Transmittances of Soil and Vegetation

There are 3 spectral bands simulated in the RAMI experiments:

1. Red.
2. Neaf infra-red (NIR).
3. Conservative scattering conditions (NR1).

The reflectance and transmittance values of the soil and the vegetation for each spectral bands are summarized in the table 2.

	NR1	RED	NIR
Leaf scatterer reflectance	0.5	0.0546	0.4957
Leaf scatterer transmittance	0.5	0.0149	0.4409
Soil reflectance	1	0.127	0.159

Table 2: Values of reflectances and transmittances for the three RAMI spectral bands.

2.5 Leaf Angle Distribution (LAD)

The spatial orientation of a leaf is described by the direction of its normal $\Omega_{\mathrm{L}}\left(\theta_{\mathrm{L}}, \phi_{\mathrm{L}}\right)$ to the upper surface, where θ_{L} is the inclination angle of the leaf normal, and ϕ_{L} is the azimuthal angle of the outward normal.

Consider a horizontally homogeneous leaf layer of unit thickness at height z, and let the sum of areas of all leaves (or parts thereof) whose normals fall within an incremental solid angle around the direction Ω_{L} be $\hat{g}_{\mathrm{L}}\left(z, \Omega_{\mathrm{L}}\right)$. Here all leaves are assumed to face upward, so that all leaf normals are confined to the upper hemisphere ($2\pi^{+}$), and $s_{\mathrm{L}}^{*}(z)$ is the total one sided area of all leaves in this horizontal layer.

The leaf-normal distribution (LND) function $g_{\mathrm{L}}(z,\Omega_{\mathrm{L}}) = \hat{g}_{\mathrm{L}}(z,\Omega_{\mathrm{L}})/s^*_{\mathrm{L}}(z)$, denotes the fraction of total leaf area in the horizontal layer of unit thickness at height z whose normals fall within unit solid angle around the direction Ω_{L}, and must satisfy the following normalization criterion:

$$\frac{1}{2\pi}\oint_{2\pi^+} g_{\mathrm{L}}\left(\Omega_{\mathrm{L}}\right)\, d\Omega_{\mathrm{L}} = \frac{1}{2\pi}\int_0^{2\pi} d\phi_{\mathrm{L}} \int_0^{\frac{\pi}{2}} g_{\mathrm{L}}\left(\theta_{\mathrm{L}},\phi_{\mathrm{L}}\right)\sin\theta_{\mathrm{L}} d\theta_{\mathrm{L}} = 1 \tag{1}$$

A variety of leaf angle distribution functions have been published in the literature. within ROMC, however, azimuthal invariance of the leaf normal distribution is assumed:

$$g^*_{\mathrm{L}}\left(\theta_{\mathrm{L}}\right) = g_{\mathrm{L}}\left(\theta_{\mathrm{L}}\right)\sin\theta_{\mathrm{L}} d\theta_{\mathrm{L}} \tag{2}$$

For the purpose of standardization and comparison the following formulae for g^*_{bun} are recommended (distributions from Bunnik [1978][5]) :

$$g^*_{\mathrm{bun}} = \frac{2}{\pi}\left(a_g + b_g\cos\left(2\,c_g\,\theta_{\mathrm{L}}\right)\right) + d_g\sin\theta_{\mathrm{L}} \tag{3}$$

The values of the parameters (a_g, b_g, c_g, d_g) for the different LAD are given in the table 3.

LAD	a_g	b_g	c_g	d_g
Planophile	1	1	1	0
Erectophile	1	-1	1	0
Uniform	0	0	0	1

Table 3: Values of parameters a_g, b_g, c_g and d_g for different LAD distributions used in RAMI experiments.

2.6 DART Parameters and Products

The general parameters of the DART RAMI simulations are given in the following section.

2.6.1 Input Parameters

The input parameters are set to improve the resolution without costing too much computer time. The table 4 gives the input parameters used in the RAMI simulations launched on a server.

Sun irradiance	1000	Nb of cell subdivisions (axial) for barycenters	5
Gauss-Seidel	∅	Nb of axial-subdivisions for scene illumination	10
Number of iterations	20	Repartition mode of illumination sub-centers	Semi-Random
Propagation treshold	0	Albedo treshold	0

Table 4: Summary of the input parameters of the DART simulations.

[5]Bunnik., N. J. J. (1978) *The Multispectral Reflectance of Shortwave Radiation of Agricultural Crops in Relation With Their Morphological and Optical Properties*, in Mededelingen Landbouwhogeschool, Wageningen, The Netherlands, 175 pages.

2.6.2 Required Products

The table 5 gives the necessary products to compute the ROMC results. Images are not needed thus not required in order to reduce computer time and memory.

Radiation budget products	✓	BRF/BTF Products	✓
Earth scene first order scattering	✓	All iterations products	∅
Extrapolation	✓	Mean BRF/BTF per image	✓
Images	∅	Radiance Products	∅
Hapke file Product	∅	Maximal zenith angle of images	25
Sensor plane images	∅	Horizontal plane image oversampling	1
Sensor plane image oversampling	1	Number of repetitive scenes	1
Airborne image	∅	OrthoImages (+ Irradiance, Exitance, Albedo)	∅

Table 5: Necessary products for the comparison with the ROMC.

3 Scripts for Creating and Launching Homogeneous Scenes

3.1 Method

There are 52 different homogeneous simulations in the RAMI 3 experiment for DART. Each simulation is based on a simple plot simulation with different key parameter values. In order to create,run and extract data from these simulations, PYTHON scripts will be used.

The method to get the results for the 52 simulations is as follows:

1. Create a core simulation with the DART input parameters and products.
2. For each RAMI simulation, create 3 simulations in order to compute the results asked by the ROMC (1^{st} order for vegetation only or soil only):
   (a) complete scene.
   (b) dark soil (reflectance, transmittance = 0).
   (c) dark vegetation.
3. Parse the simulations to modify the values of the key parameters (transmittance, LAI,...) using the names of the simulations.
4. Launch DART for the simulations.
5. Compute and extract the results for each simulation.

3.2 Required BRFs

There are 4 BRF required by the ROMC, in the solar plane (principal [pp]) and its perdendicular (opposite [op]):

1. The total BRF of the scene: BRFPP and BRFOP.
2. The BRF for single-scattered radiation collided by the leaves: BRFPP_CO_SGL and BRFOP_CO_SGL.

3. The BRF for single-scattered radiation collided by the soil: BRFPP_UC_SGL and BRFOP_UC_SGL.

4. The BRF for multiple-scattered radiation (two or more scattering events): BRFPP_MLT and BRFOP_MLT.

3.3 Results Formatting

The ROMC website processes the results in the following format: in table 6 for the header and table 7 for the body of results.

The viewing angles (from -75° to 75° in 2° steps) required by the ROMC are given the file Rami-Angles.py in radians.

Header line content	Number of rows	columns in file	Ratio of filtered rays
Header line format	integer	integer	real

Table 6: Header content of the results file.

Body lines content	SZA [rad]	VZA [rad][1]	SAA - VAA [rad][1]	BRF	Std. Dev. BRF[2]
Body lines format	real	real	real	real	real

Table 7: Body content of the results file.

BRF Bi-directional Reflectance factor. **SZA** Solar Zenith Angle.

SAA Solar Azimuth Angle. **VZA** Viewing Zenith Angle.

VAA Viewing Azimuth Angle (0 radians for backward scattering in the principal plane, i.e., the hot-spot location, PI radians for forward scattering in the principal plane. For the orthogonal plane: PI/2 and 3PI/2 radians.).

Ratio of filtered rays The number of rays that perform the measurement divided by the total number of incident rays (for ray-tracing RT models only).

Std. Dev. BRF Indication of the uncertainty in the BRF estimate as estimated from the radiative transfer model itself.

Real A real is defined as having 6 digits after the decimal point, e.g., 1.000000.

[1] if not defined set to -1.000000.

[2] if available, otherwise set to -1.000000.

3.4 Possible Parameters in RAMI Simulations

There are 52 homogeneous simulations in the ROMC that are variations of the same simple plot simulation. The names of the simulations contains values of key parameters of these simulations. These parameters are given in table 8, along with their possible values. The list of the 52 simulation names is given in the file RAMISimulations.txt.

Key parameters	Option call	Possible values
Leaf angle distribution	--LAD	ERE PLA UNI
Spectral band	--SpectralBand	NR1 NIR RED
Sun zenith angle	--SZA	0 20 30 50 60
Simulation number (→LAI)	--Number	1 2 3 5 11 12 13 15
Plot representation	--Turbid	TUR DIS

Table 8: Possible parameters in RAMI simulations, their possible values and option calls.

The option call gives the keys to add to the python scripts command described in 3.5.2 in order to choose what simulations to run.

For example, if the option --LAD ERE PLA was given, then only the simulations with erectophile and planophile LAD would be selected.

3.5 Python Scripts

There are 5 python scripts used to produce the ROMC files.

3.5.1 Arguments

Each of these scripts requires mandatory arguments as well as accepts optional ones, symbolized by the -- in front of the key command. The arguments given in table 8 are accepted by the 5 scripts.

RamiSimulationFolder: the relative path from the **simulations** folder of DART_LOCAL to the folder containing the **core** simulation.

RamiResultsFolder: the path to the folder where the results will be stored.

DartLocal or --DartLocal : if the DART_LOCAL path is not accessible by the scripts or to give a specific DART_LOCAL folder.

DartHome or --DartHome : if the DART_HOME path is not accessible by the scripts or to give a specific DART_HOME folder.

--dZ : the number of cells in the z-axis. This option is used when defining the parameters of the simulations.

--dXY : the number of cells in the x,y axes. This option is used when defining the parameters of the simulations.

3.5.2 Scripts Description

Each of the 5 scripts is designed to execute one task decribed below. The arguments are also given.

CreateRAMISimulations.py *RamiSimulationFolder* creates the chosen simulations. The option -r allows to overwrite existing simulations.

DefineSimulationsParameters.py *RamiSimulationFolder --dZ --dXY* modifies the xml files in the input folder according to the key values in the name of the simulations.

LaunchSimulations.py *RamiSimulationFolder* launches the different modules of DART.

ExtractRamiFiles.py *RamiSimulationFolder RamiResultsFolder* extracts the BRFs and write them in the Rami results folder.

SaveRomcPlots.py *RamiResultsFolder* creates pdf files ploting the BRF for each simulation.

3.5.3 Launching RAMI Simulations Summary

With the core simulation in the RamiSimulationFolder, the following commands will create, run and extract the information for the simulation HOM01_TUR_ERE_NR1_00.

python CreateRAMISimulations.py RamiSimulationFolder
--LAD ERE --Turbid TUR --SZA 0 --Number 1 --SpectralBand NR1 -r

python DefineSimulationsParameters.py RamiSimulationFolder
--LAD ERE --Turbid TUR --SZA 0 --Number 1 --SpectralBand NR1 --z 10 --xy 1

python LaunchSimulations.py RamiSimulationFolder
--LAD ERE --Turbid TUR --SZA 0 --Number 1 --SpectralBand NR1

python ExtractRamiFiles.py RamiSimulationFolder RomcResultsFolder
--LAD ERE --Turbid TUR --SZA 0 --Number 1 --SpectralBand NR1

python SaveRomcPlots.py RomcResultsFolder
--LAD ERE --Turbid TUR --SZA 0 --Number 1 --SpectralBand NR1

To create all 52 simulations, use theses commands instead:

python CreateRAMISimulations.py RamiSimulationFolder -r

python DefineSimulationsParameters.py RamiSimulationFolder --z 10 --xy 1

python LaunchSimulations.py RamiSimulationFolder

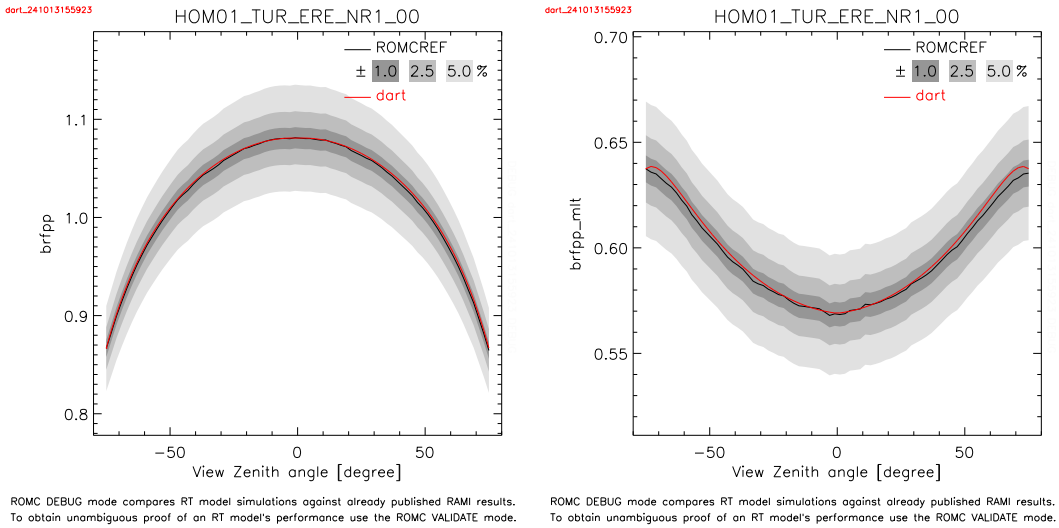
python ExtractRamiFiles.py RamiSimulationFolder RomcResultsFolder

python SaveRomcPlots.py RomcResultsFolder

Scripts readme files for windows and linux are provided in ReadmeWindows.txt ReadmeLinux.txt respectively.

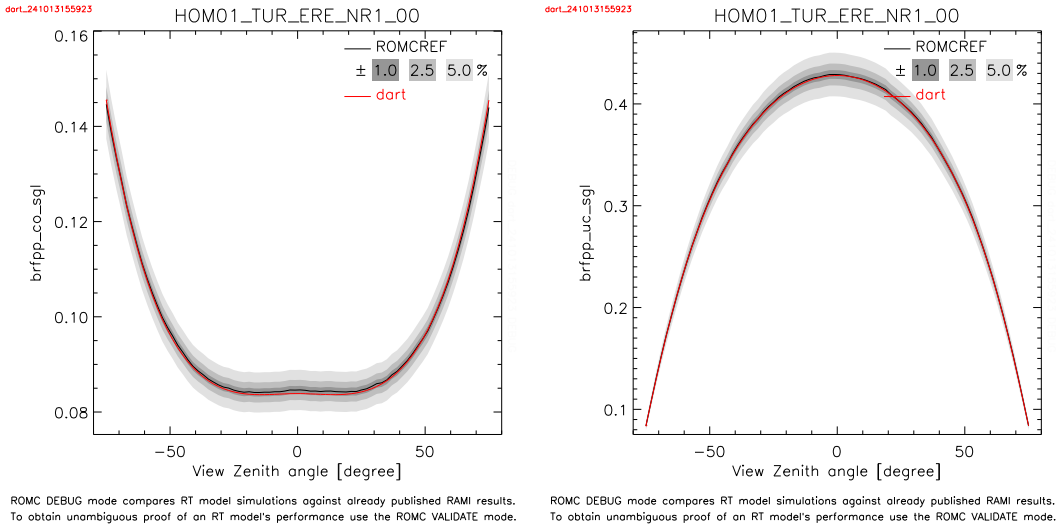
4 Sample Results Figures Provided by the ROMC

The ROMC website can create a comparison between the DART results and the 'true' results computed by the RAMI experiment. These comparisons for the 4 BRFs in the principal plane for the simulation HOM01_TUR_ERE_NR1_00 are given in Fig. 5 and 6.



(a) (b)

Figure 5: ROMC comparison for *HOM01_TUR_ERE_NR1_00.*(a)BRFPP.(b)BRFPP_MLT.



(a) (b)

Figure 6: ROMC comparison for *HOM01_TUR_ERE_NR1_00.*(a)BRFPP_CO_SGL.(b)BRFPP_UC_SGL.

4.1 SKILL

4.1.1 Definition

The SKILL of a model is an integrated indicator describing the overall closeness of the simulations of a model to the ROMC reference data set. The SKILL of a model is computed for every measurement type (BRFPP, BRFOP, FTRAN, brf1, FTRAN, etc.) provided that at least 3 flux (1 BRF) experiments were performed for this measurement type. A skill metric should behave as follows:

- Assuming identical dataset means then for any given variance the skill score increases with increasing correlation,
- Assuming identical dataset means then for any given correlation the skill score increases as the modelled variance approaches the variance of the ROMC reference dataset.
- For any given variance and correlation the skill score increases as the mean of the modelled dataset approaches that of the ROMC reference dataset, and

The ROMC skill scores are defined from zero (least skillful) to 100 (most skillful). More specifically:

$$\text{SKILL} = 100S \tag{4}$$

where S is a metric that evaluates the impact of 1) pattern similarity (correlation), 2) data variability (variance) and 3) differences between the mean of the data. S was defined by adapting equation 5 of Karl. E. Taylor[6] to account for datasets that have identical correlation and variance but that are offset by some fixed value. S is given by:

$$S = \frac{16\,(1+R)^4}{(\hat{x}_{\text{usr}} + 1/\hat{x}_{\text{usr}})^2\,(\hat{\sigma}_{\text{usr}} + 1/\hat{\sigma}_{\text{usr}})^2\,(1+R_0)^4} \tag{5}$$

Here R is the correlation coefficient between N datapoints of the users dataset (X^{usr}) and the ROMC reference dataset (X^{ref}). R is defined as:

$$R = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(X_i^{\text{usr}} - \overline{X}^{\text{usr}}\right)\left(X_i^{\text{ref}} - \overline{X}^{\text{ref}}\right)}{\sigma_{\text{usr}} \times \sigma_{\text{ref}}} \tag{6}$$

$\hat{\sigma}$ is the standard deviation of the users dataset (σ_{usr}) normalised by that of the ROMC reference dataset (σ_{ref}). $\hat{X}$ is the mean of the users dataset ($\overline{X}_{\text{usr}}$) normalised by the mean of the ROMC reference dataset ($\overline{X}_{\text{ref}}$).

$$\hat{\sigma}_{\text{usr}} = \sigma_{\text{usr}}/\sigma_{\text{ref}} \tag{7}$$

$$\hat{X}_{\text{usr}} = \overline{X}_{\text{usr}}/\overline{X}_{\text{ref}} \tag{8}$$

4.1.2 DART Skill for 30 Homogeneous Turbid Scenes

The skill of DART has been computed for the 30 homogeneous turbid scenes with dZ=100 and dXY=10. The results are given in the table 9.

[6] *Summarizing multiple aspects of model performance in a single diagram*, Journal of Geophysical Research,Vol 106, No. D7, pages 7183-7192, April 2006

Measurement	BRFOP				BRFPP			
	TOTAL	CO_SGL	MLT	UC_SGL	TOTAL	CO_SGL	MLT	UC_SGL
Skill	92.812	94.278	96.074	99.874	99.481	99.334	97.341	99.873

Table 9: Sample skill results of 30 homogeneous turbid scenes for DART.