



EUROPEAN COMMISSION
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RAdiative transfer **M**odel **I**ntercomparison (RAMI)

**J-L. Widlowski, M. Taberner, B. Pinty,
and the RAMI participants**

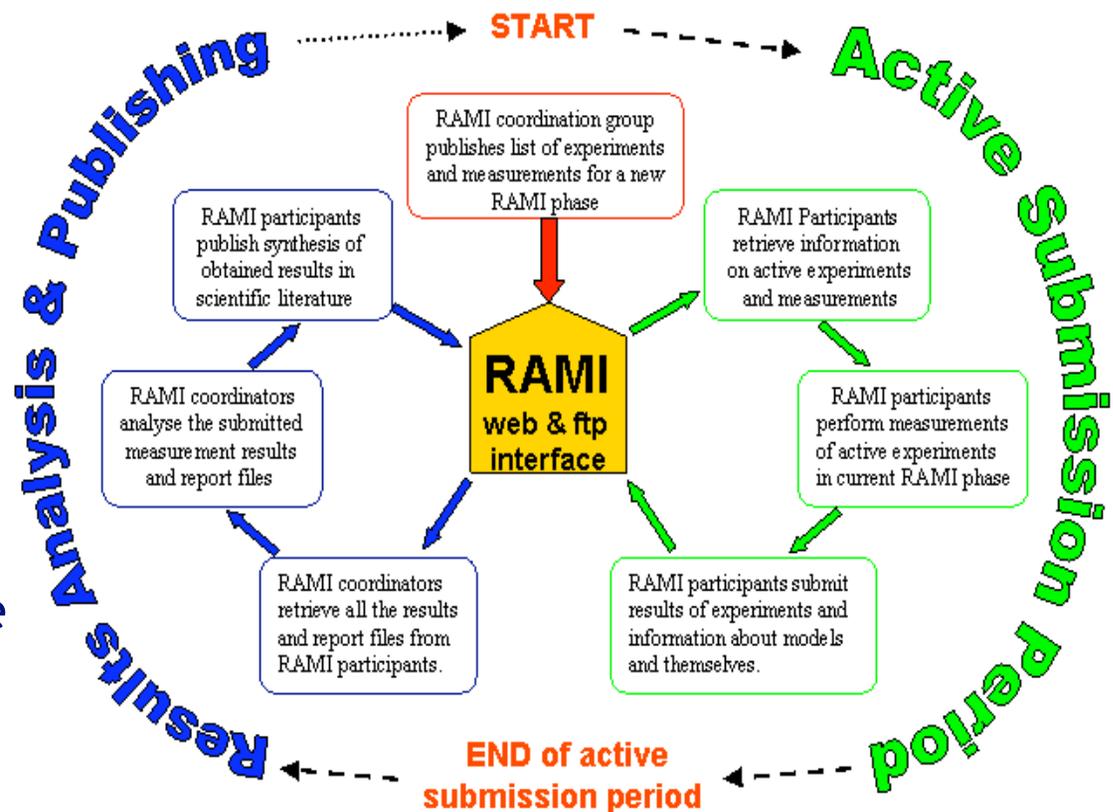
I3RC workshop, 11-14th October 2005, Kiel, Germany



RAdiative transfer Model Intercomparison (RAMI)

Functioning of RAMI:

- New phases held at 2-3 years interval:
 - publish test cases online
 - interact with participants
 - analyse submitted data
 - publish results online
 - inform science community
- Coordination currently with JRC, Italy.

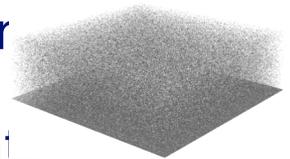
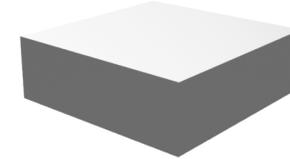
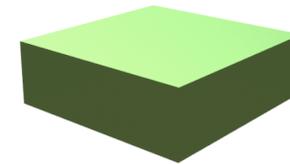




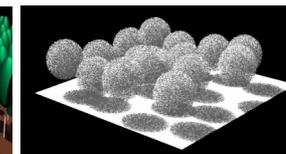
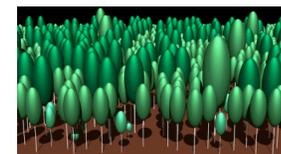
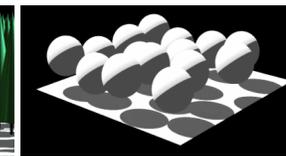
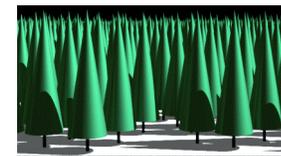
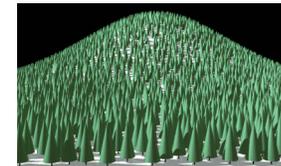
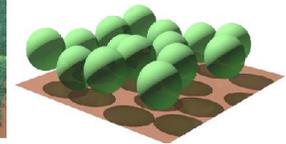
RAMI Phases

- **RAMI 1 (1999):**
 - Turbid medium and discrete
 - Solar domain + purist corner
 - 9 models (**HOM: 7**)
- **RAMI 2 (2002):**
 - Topography + true “zoom-in”
 - 13 models (**HOM: 9**)
- **RAMI 3 (2005):**
 - Birch and conifer scene (GO models)
 - Heterogeneous purist corner
 - Local transmission and horizontal flux measurement
 - ? Models (**HOM: 15**)

HOMogeneous



HETerogeneous





Measurement Types

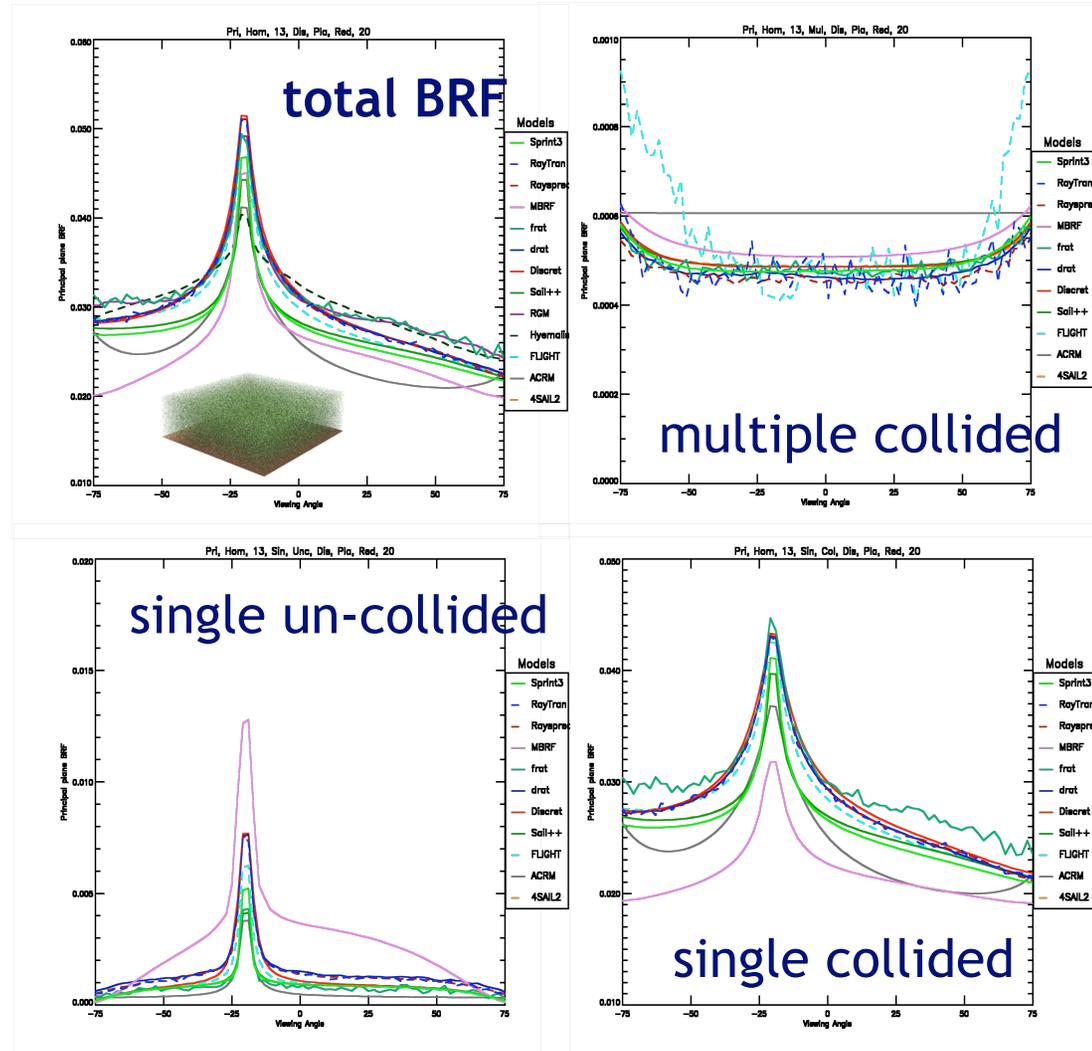
Measurements include

Flux quantities:

- Albedo
- Transmission
- Absorption

BRF quantities:

- Total BRF (PP+OP)
- BRF components
 - multiple collided
 - single un-collided (hit soil only once)
 - single collided





Model comparison in absence of a “truth”

Model self consistency:

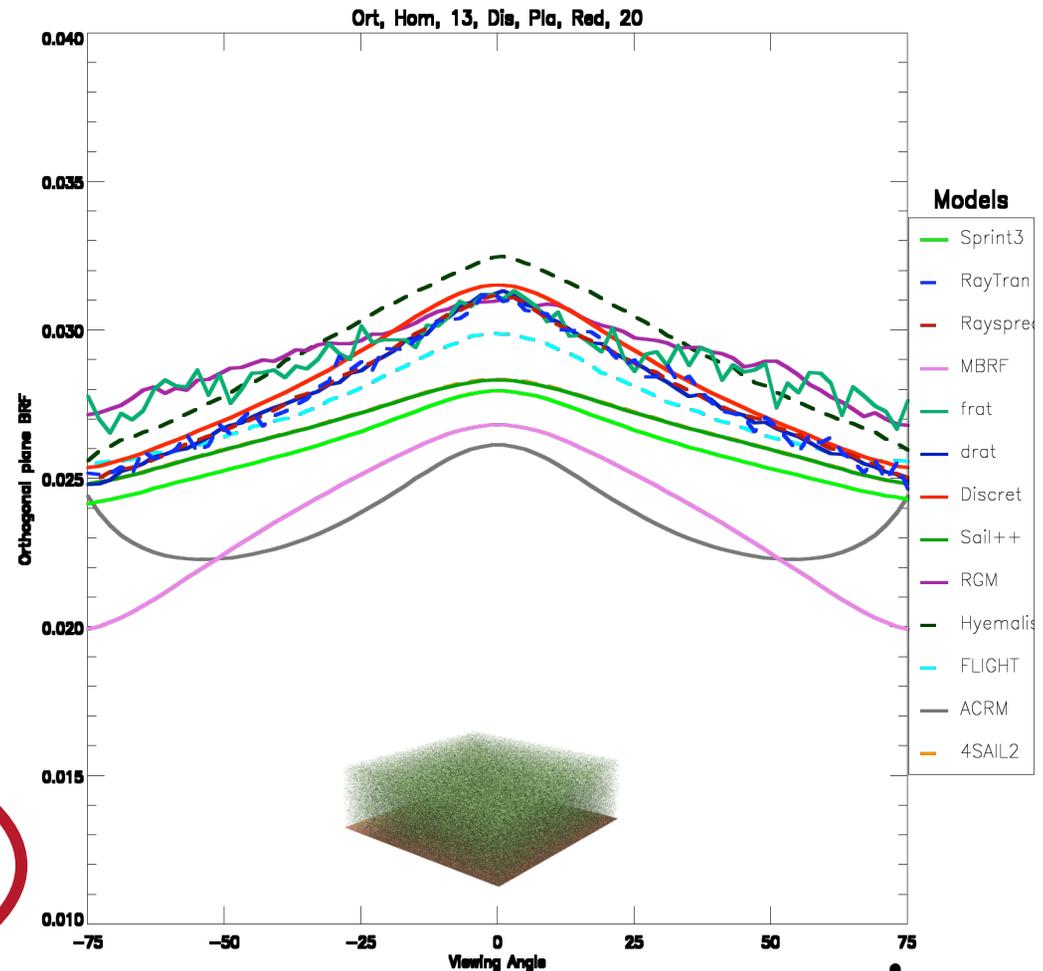
- Energy conservation
 - Fluxes: $1=A+R+(1-\alpha)T$
 - BRFs: $\text{total}=\text{co}+\text{uc}+\text{mlt}$
- Spectral rati:
 - $\frac{\text{uc}_{\text{red}}}{\text{uc}_{\text{NIR}}} = \frac{\alpha_{\text{red}}}{\alpha_{\text{NIR}}}$

Absolute model evaluation:

- Purist corner fluxes: A,R
- HOM TUR UNI: uc, co

Relative model evaluation:

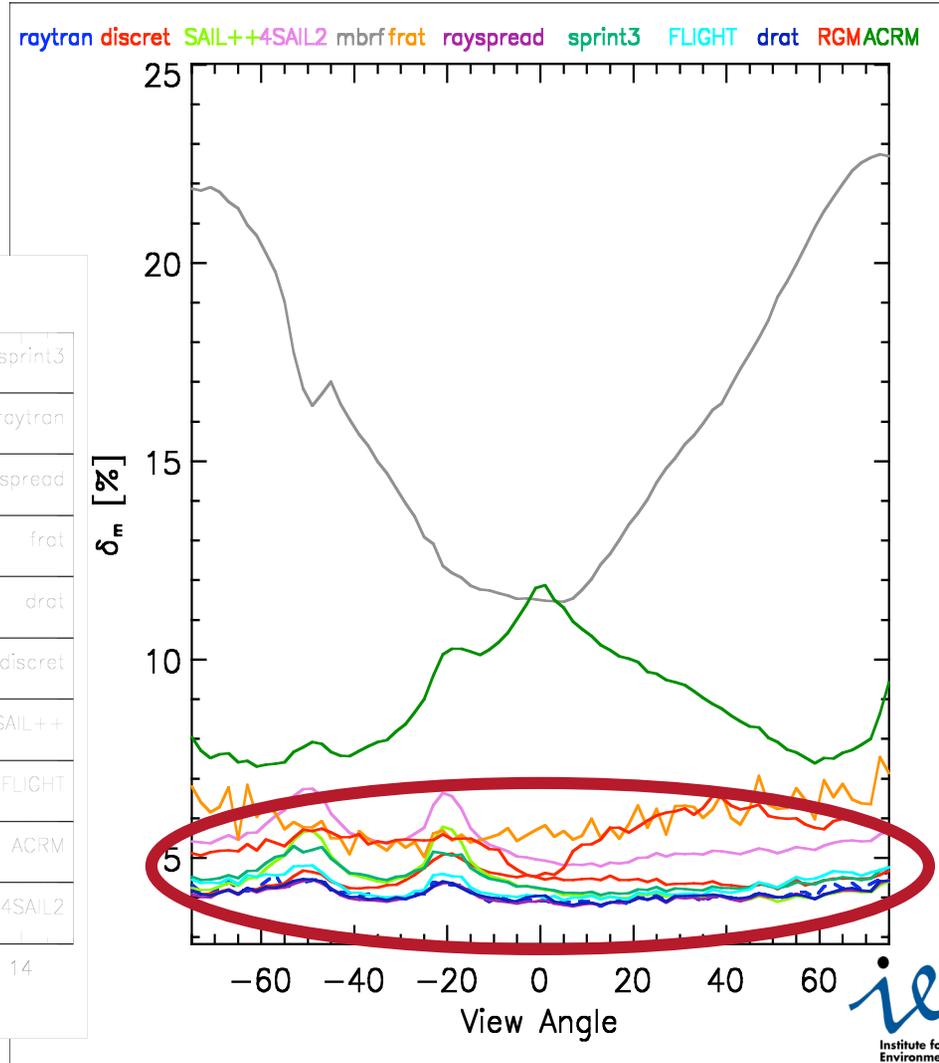
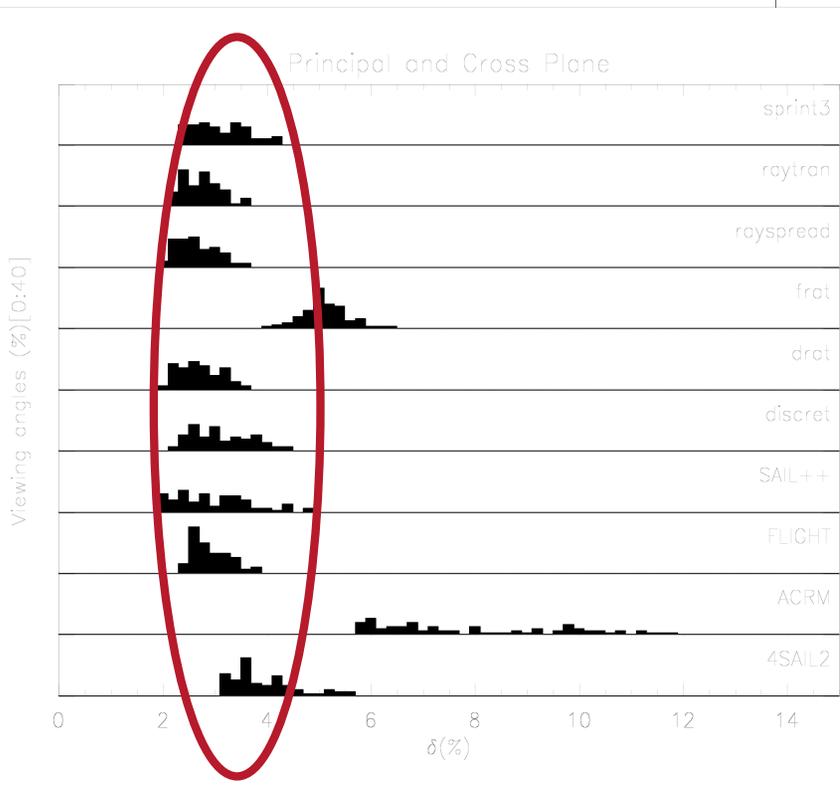
- Model dispersion: δ_m
- Model equivalence: X^2





Relative Intercomparison: BRF Dispersion

Evaluate how different any one model is with respect to all other models:





Relative Intercomparison: χ^2 statistics

Use χ^2 metric to identify how close RT models are to a credible BRF solution:

$$\chi^2(\lambda) = \frac{1}{N-1} \sum_{i=1}^{N_{\theta_0}} \sum_{s=1}^{N_{scenes}} \frac{\sum_{j=1}^{N_{\theta_0}} [\rho(i, s, j; \lambda) - \rho_{credible}(i, s, j; \lambda)]^2}{\sigma^2(i; \lambda)}$$

Credible BRF solution is derived from 3D Monte Carlo models:

$$\rho_{credible}(i, s, j; \lambda) = \langle \rho_{3D}(i, s, j; \lambda) \rangle$$

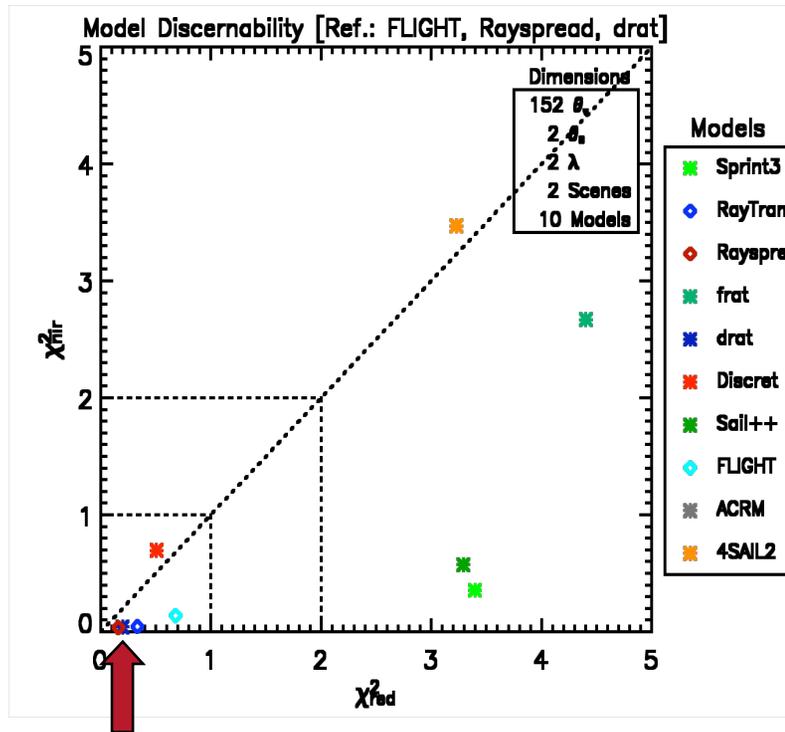
Simulation error is fraction f of credible BRF solution:

$$\sigma(i, \lambda) = f \langle \rho_{3D}(i, s, j; \lambda) \rangle$$



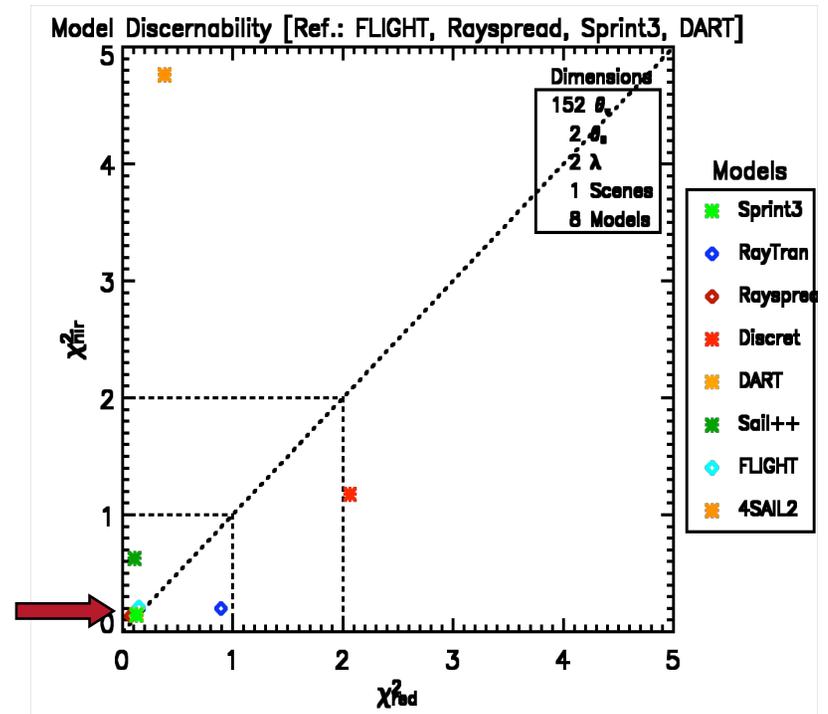
Relative Intercomparison: χ^2 statistics

Discrete



χ^2 uses $\sigma=0.025 \langle BRF \rangle_{3D}$

Turbid



χ^2 uses $\sigma=0.015 \langle BRF \rangle_{3D}$

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RAMI achievements so far...

- Established model intercomparison as community exercise,
- Fixed obvious model bugs and provided feedback on directions for potential RT model improvements,
- Documented spread of available RT models and reduction of spread from phase 1 to phase 2,
- Increased complexity of experiments (topography, zoom) and measurements (local transmission/BRF and horizontal fluxes),
- Augmented visibility (IRC, website) and participants list,
- Improved agreement between 3-D MC models (surrogate truth)

<http://rami-benchmark.jrc.it>



Where do we go from here?

Science questions should dominate any new experiments:

- What is the impact of canopy abstraction (on RT model output and accuracy of inversion algorithms)?
- How to validate remote sensing products (what field instruments and sampling schemes)?

Increasing number of structural scenarios from RAMI 1 → RAMI 3

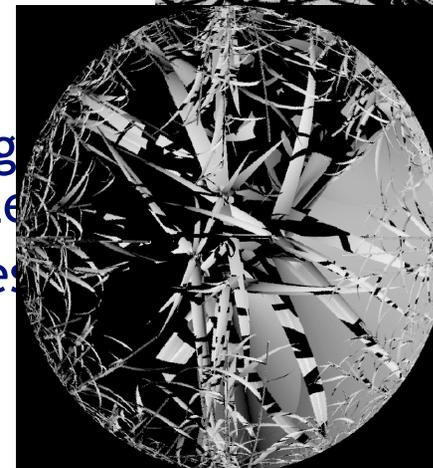
- Heavy on newcomers but necessary for comprehensive RT model evaluation! Can we ease this load?
- Reduce work of coordinators and enable continuous RT model checking - even in between RAMI phases.

Exploit very close agreement between 3-D MC models.



Landscape generation

- Generate explicit representations of selected field sites:
 - use available measurements and imagery.
 - sample different biomes (SAFARI, BO)
 - ideal scene size 250x250 to 500x500
- Generate structural abstractions of the same scenes.
- Apply dynamic measurements scenarios to these scenes:
 - reproduce measurements of existing instruments (TRAC, LICOR, fisheye lens)
 - provide new measurement strategies to specific campaigns.



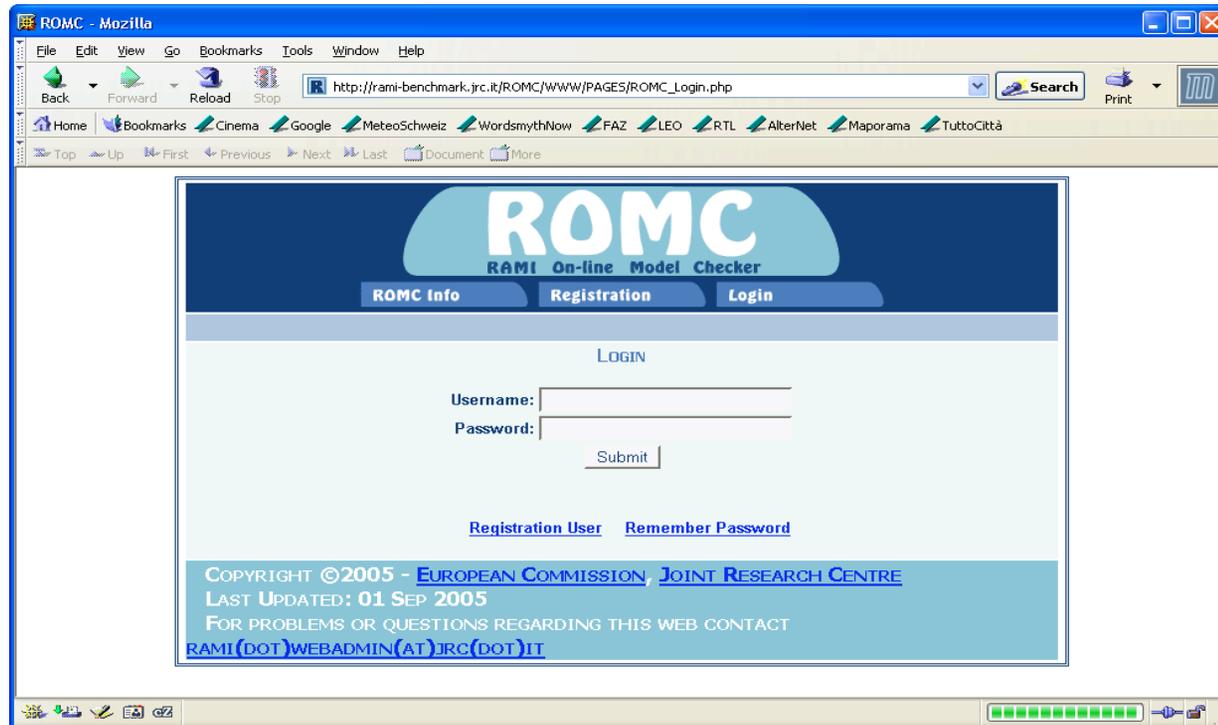
Courtesy of
P. Lewis &
M. Disney



The RAMI On-line Model Checker (ROMC)

The ROMC allows to check the performance of your RT model:

- quickly, online and at any time
- using a minimum set of test cases derived from RAMI
- against a “surrogate truth” derived from *credible* RAMI models





The RAMI On-line Model Checker (ROMC)

ROMC in a nutshell:

- To have access users must register (valid email address)
- Users may test up to 3 different models at once.
- To test their model users may choose between HOMOGENEOUS and/or HETEROGENEOUS (floating spheres) test cases.
- Measurements are the same as for RAMI exercises
- Users must submit their model simulations in RAMI format.
- Results will be shown graphically against the reference data set (with its uncertainty) or in terms of χ^2 statistics.
- Users may receive ROMC results as jpeg and ps files via email.
- Users may choose between **DEBUG** and **VALIDATE** mode



The RAMI On-line Model Checker (ROMC)

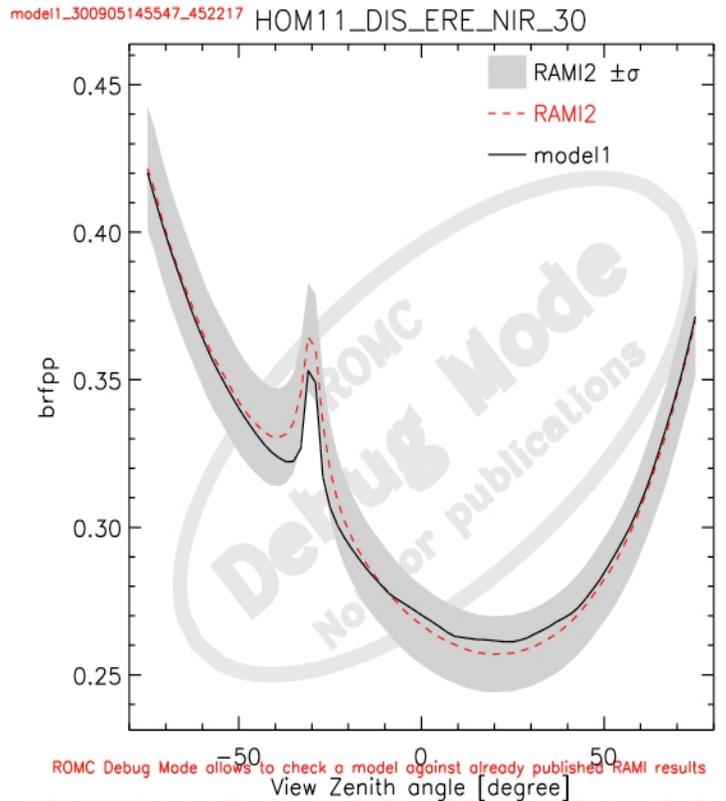
ROMC features 2 modes:

- **DEBUG mode**
 - Users choose from the set of existing RAMI experiments and measurements
 - Users may submit their simulation results repeatedly for the same test cases
 - Users may retrieve the ASCII file containing the reference data
 - DEBUG mode results do not qualify as model validation!
- **VALIDATE mode**
 - Users will be given a small set of experiments (similar to those in RAMI)
 - Once selected users may submit their simulations only once
 - Only graphical results files are available for download (jpeg and ps)
 - VALIDATE mode results may be used for model validation purposes.



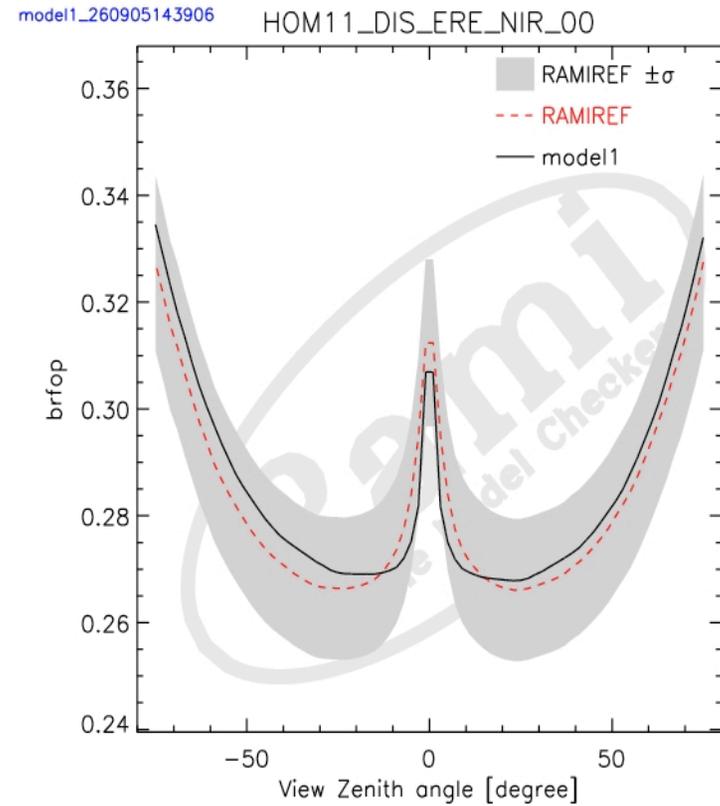
The RAMI On-line Model Checker (ROMC)

DEBUG mode



This graph is not a model quality certificate nor to be used in publications!

VALIDATE mode



RAMI On-line Model Checker - Institute for Environment and Sustainability



Common Data Repository

Need for accurate BRF/flux simulations over 3-D vegetation targets:

- improve the accuracy of retrieved state variables from multi-angular / multi-spectral remote sensing data.
- parameterise, correct and validate inversion schemes that are not based on 3-D RT models.
- evaluate instruments and measurement strategies that deliver inventory or ground 'truth' data in the field.
- perform case studies to assess the impact of structural parameters on reflectance anisotropy, e.g., crown shape, branches, etc.

RT simulations over detailed 3-D canopy targets require access to

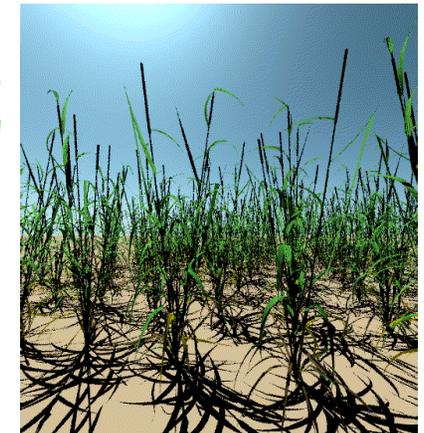
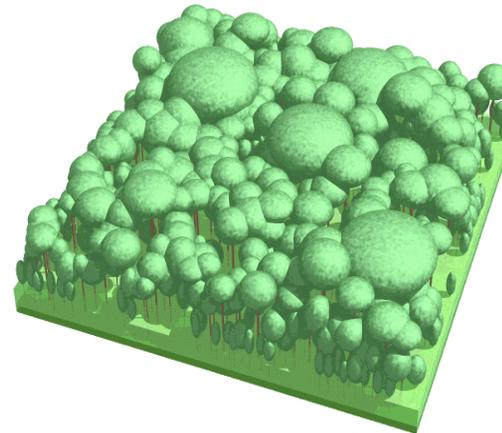
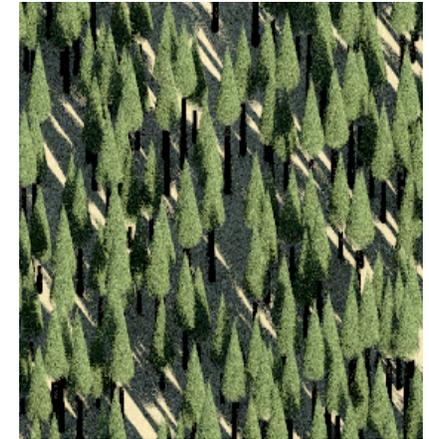
sufficient resources:

- Most 3-D RT codes are computationally heavy.
- Generation of canopy scenes is labour intensive and may require access to field data



Common Data Repository

- Individual 3-D RT modelling schools harbour the knowledge and expertise to represent certain plant architectures and communities.
- Individual 3-D RT modelling schools have acquired sufficient computer resources, and/or improved the speed of their 3-D models to meet the demands of in-house scientists and tasks.



Courtesy: M. Disney, Y. Govaerts, P. North, P. Lewis



Common Data Repository

Provided that the outputs (BRFs, fluxes, etc.) of a set of RT models are undiscernable (within some small level of uncertainty) amongst themselves then these RT models can be used interchangeably to generate a common data repository.

→ RAMI activity is a convenient platform:

- accepted community exercise
- expertise in model evaluation
- known file formatting and naming schemes

Entice 3-D Monte Carlo models to contribute to a publically available common data repository of accuracy assured BRF/Flux data.



RAMI and I3RC



...but it's time to put some meat on the bones!



APPENDIX



RAdiative transfer Model Intercomparison (RAMI)

Purpose of RAMI:

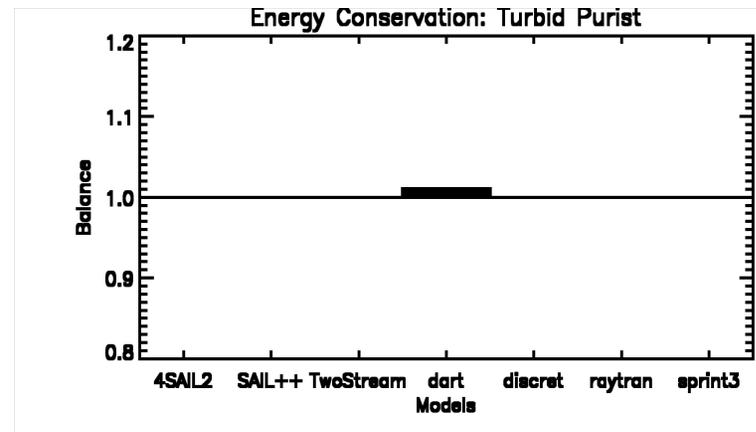
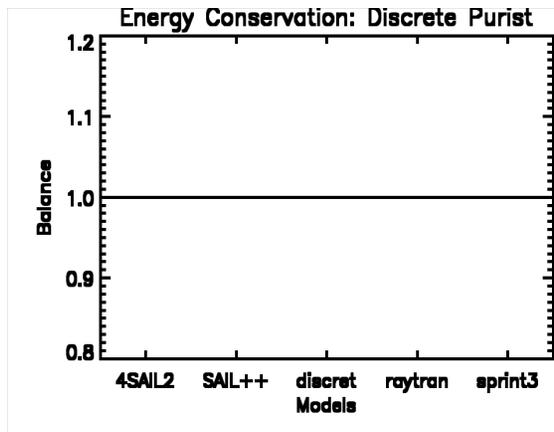
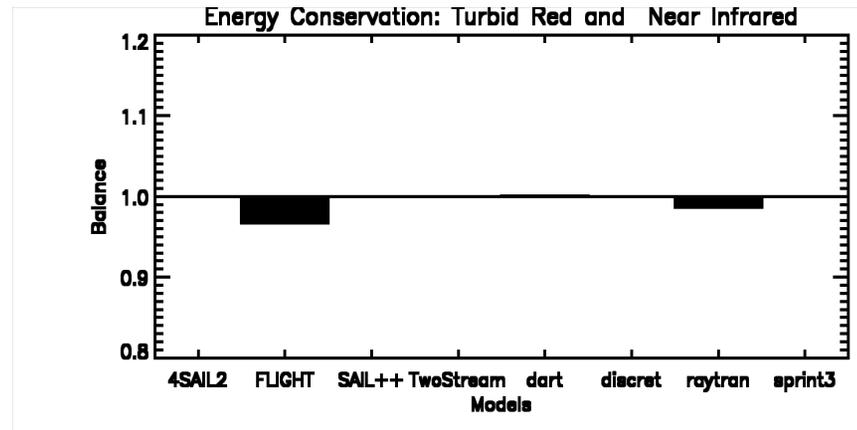
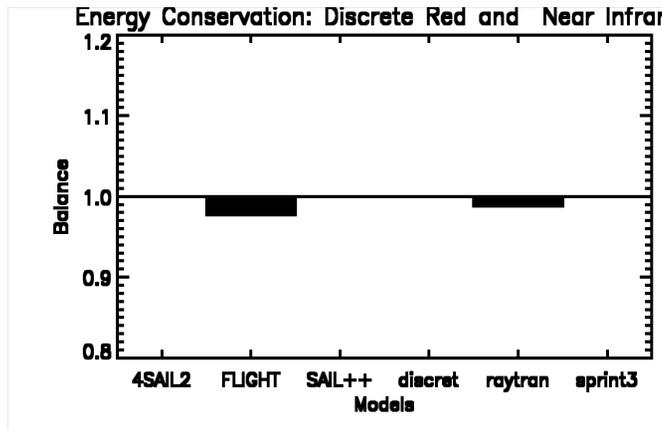
- To act as common platform for the impartial intercomparison, diagnosis and, ultimately, also validation of RT models.
- To document current uncertainties/errors among existing RT models over an as comprehensive as possible set of conditions.
- To serve as baseline protocol against which further RT model improvements and developments can be made.
- To foster the scientific debate in the modeling community.

<http://rami-benchmark.jrc.it>



Model Self Consistency: Flux quantities

Energy conservation requires that: $1=A+R+(1-\alpha)T$

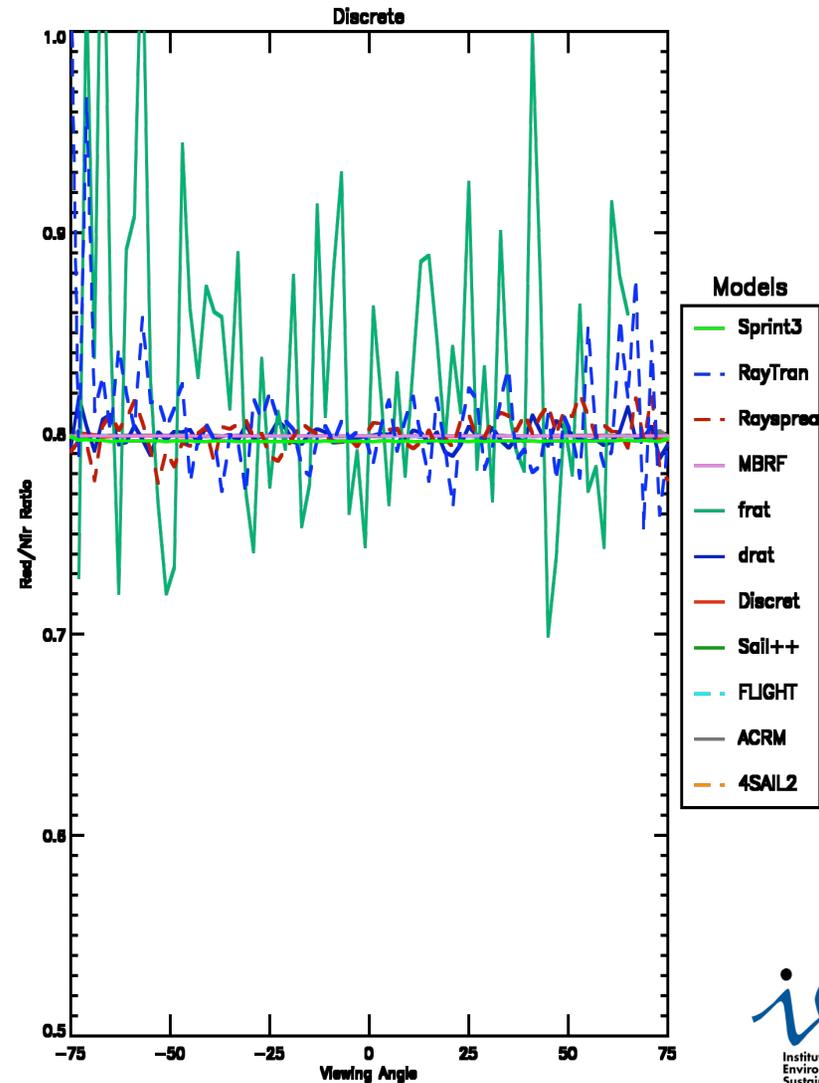




Model Self Consistency: BRF quantities

The spectral ratio of the single-uncollided in the red and NIR must be equal to the ratio of the soil albedos in these bands.

$$\frac{\rho_{sgl_uc}^{red}(\Omega_v; \Omega_0)}{\rho_{sgl_uc}^{NIR}(\Omega_v; \Omega_0)} = \frac{\alpha_{soil}^{red}}{\alpha_{soil}^{NIR}}$$

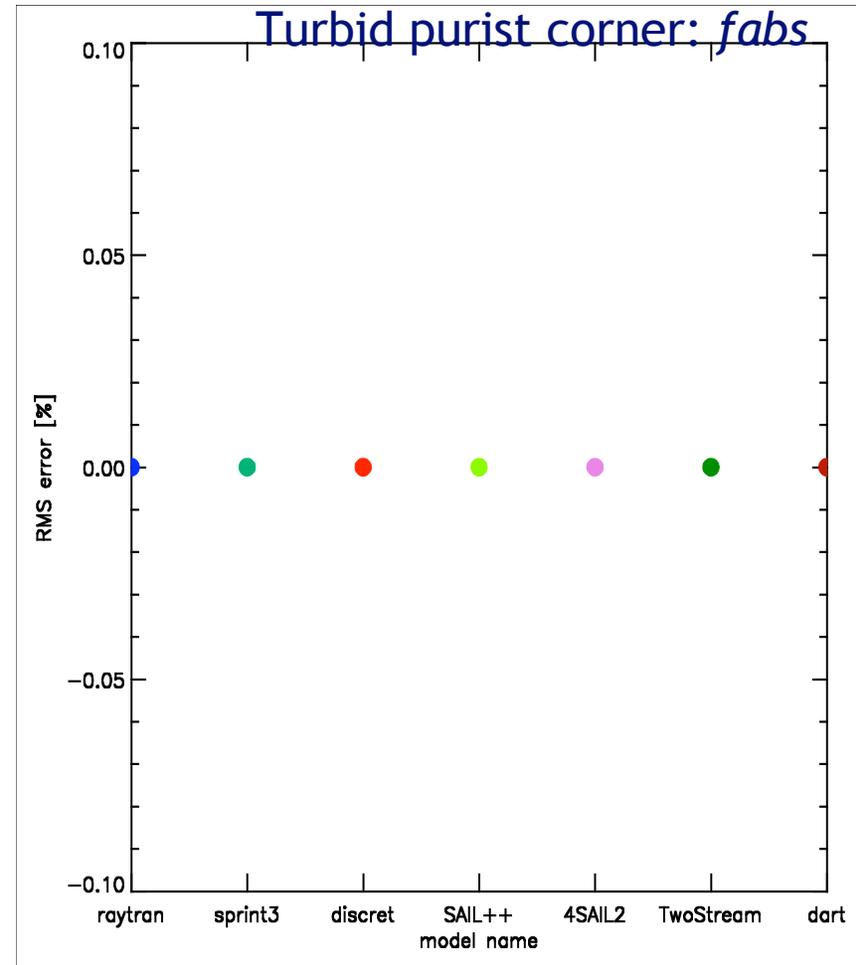




Absolute Model Evaluation: Flux quantities

Under conservative scattering conditions, *i.e.*, $r_L = t_L = 0.5$, $\alpha_{\text{soil}} = 1.0$, the surface leaving flux (DHR) is equal to 1.

Under conservative scattering conditions, *i.e.*, $r_L = t_L = 0.5$, $\alpha_{\text{soil}} = 1.0$, the absorbed flux is equal to 0.

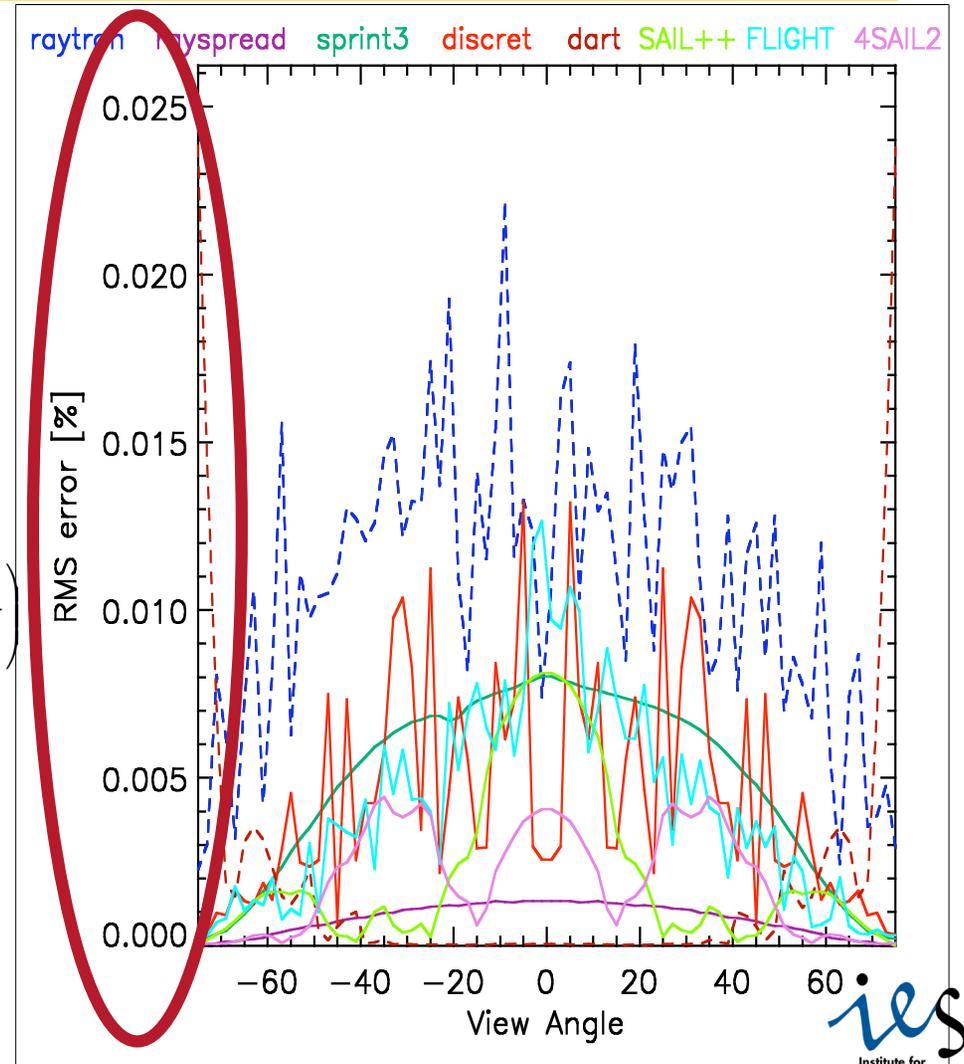




Absolute Model Evaluation: brf_uc_sgl

The *single-uncollided* (hit the soil once) BRF component in the case of a turbid medium canopy with a uniform LND overlying a Lambertian soil is

$$\rho_{sgl_uc}(\theta_v; \theta_0) = \exp\left(\frac{-0.5LAI}{|\mu_0|}\right) \cdot \alpha_{soil} \cdot \exp\left(\frac{-0.5LAI}{\mu_v}\right)$$





Absolute Model Evaluation: brf_co_sgl

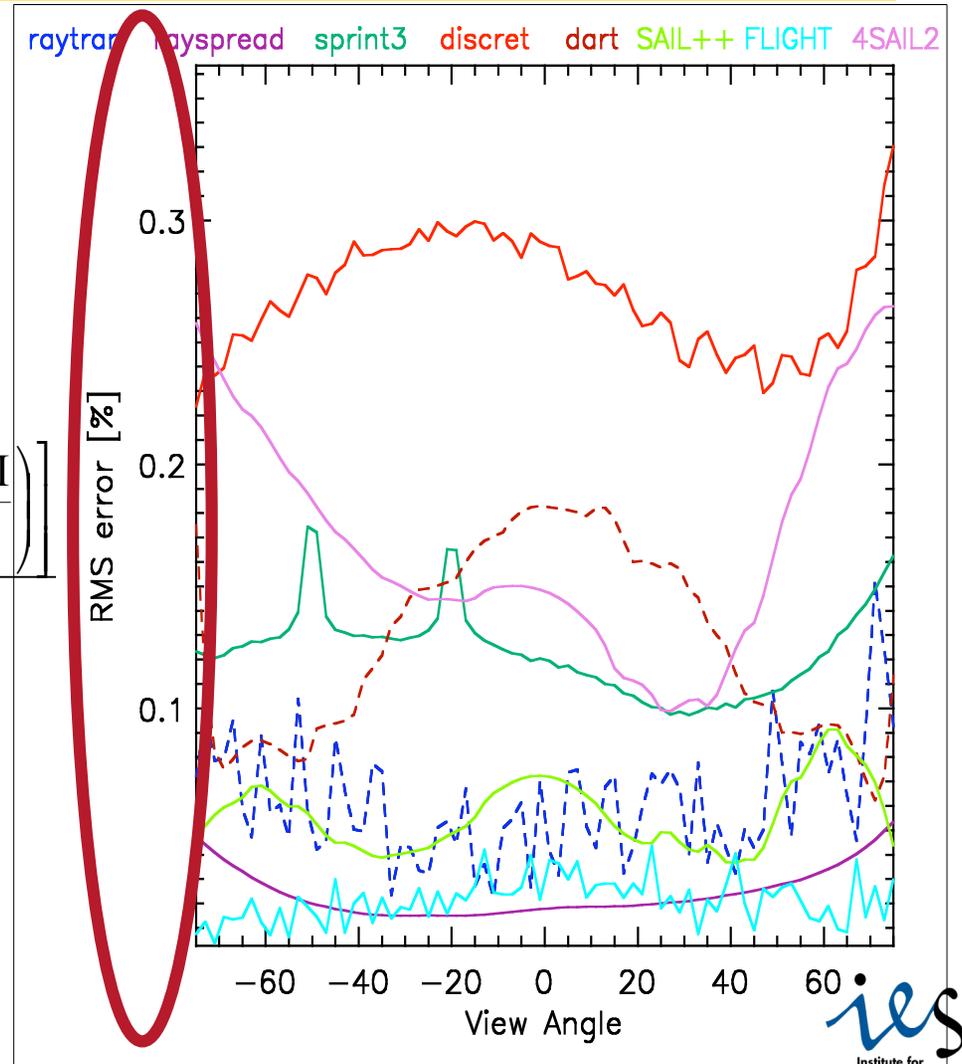
The single-collided (hit only leaves once) BRF component for a turbid medium canopy with a uniform LND overlying a Lambertian soil is:

$$\rho_{sgl} = \frac{\Gamma(\Omega_0 \rightarrow \Omega_v) \cdot \left[1 - \exp\left(\frac{-LAI}{2|\mu_0|} + \frac{-LAI}{2\mu_v}\right) \right]}{|\mu_0| + \mu_v}$$

where

$$\Gamma(\Omega_0 \rightarrow \Omega_v) = \frac{r_L + t_L}{3\pi} (\sin \beta - \beta \cos \beta) + \frac{t_L}{\pi} \cos \beta$$

$$\cos \beta = (\cos \theta_0 \cos \theta_v + \sin \theta_0 \sin \theta_v \cos \varphi)$$



Shultis and Myneni, 1988; Gobron et al, 1997



Model comparison in absence of a “truth”

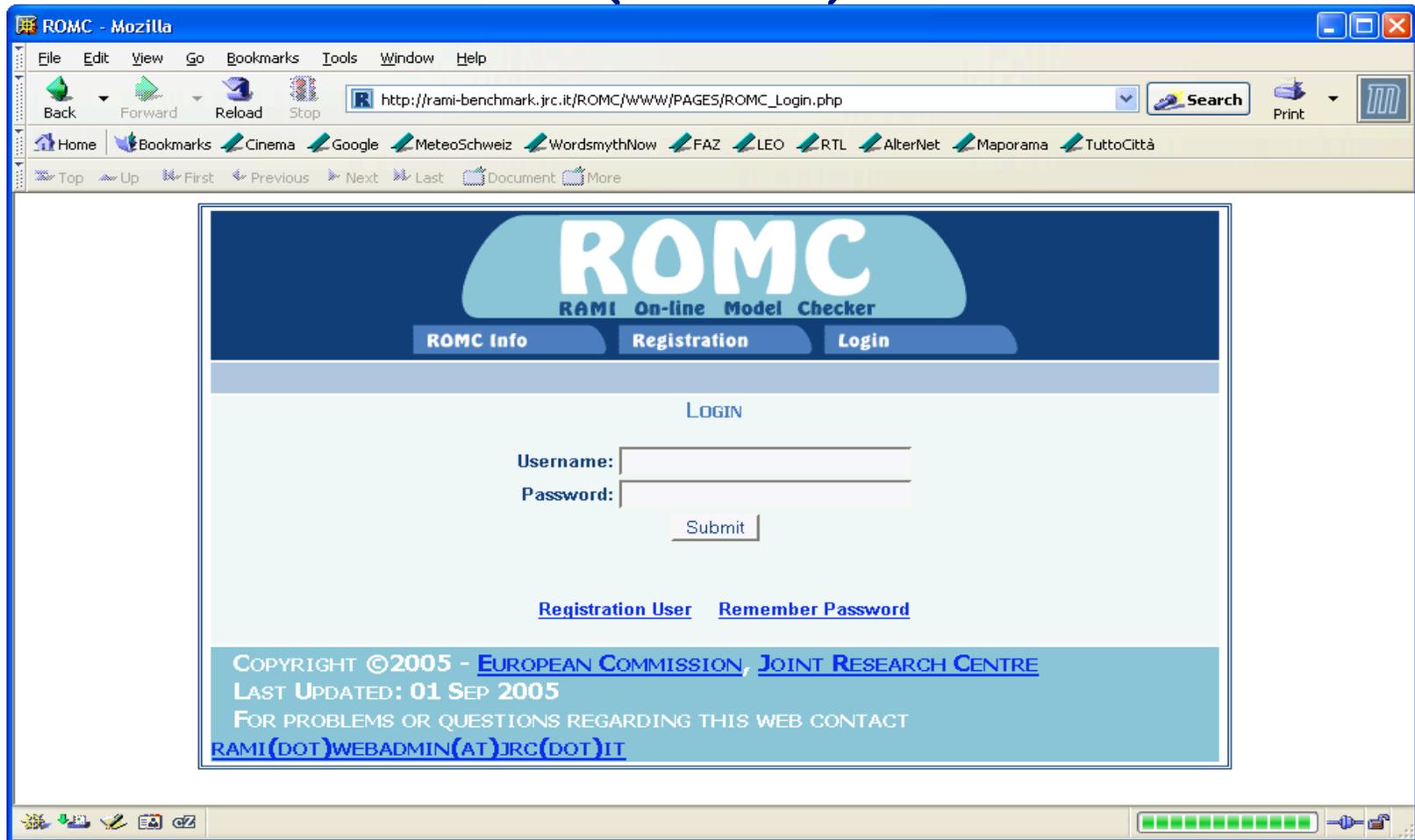
- Absolute “truth” is generally not available. Model results cannot be evaluated against an absolute reference “truth”.
- Model deviations with respect to an ensemble average are difficult to interpret in the presence of outliers.

but

- Model results can be compared *against each other* to document their relative differences.
- Model results can be compared over *ensembles* of test scenarios to establish trends/behaviours in their performance.
- Careful inspection/verification of an ensemble of model results may lead to the establishment of the “*most credible solutions*” as a surrogate for “Truth”



The RAMI On-line Model Checker (ROMC)





Model Certificates?

Advantages:

- Allow for better appreciation by other scientific communities
- give model owners a means of conveying the quality of their models.
- give potential model users/customers a means of estimating the quality of its output.
- create further impetus for RT model developers / owners to submit their model to a comprehensive validation procedure.

Unresolved issues:

- What criteria should be reflected (number of performed experiments and measurements, accuracy of results, nature of model)?
- If tied to RAMI: certificates expire for each phase, due to potential model development, new RAMI experiments and measurements. BUT previous RAMI results are available publically!



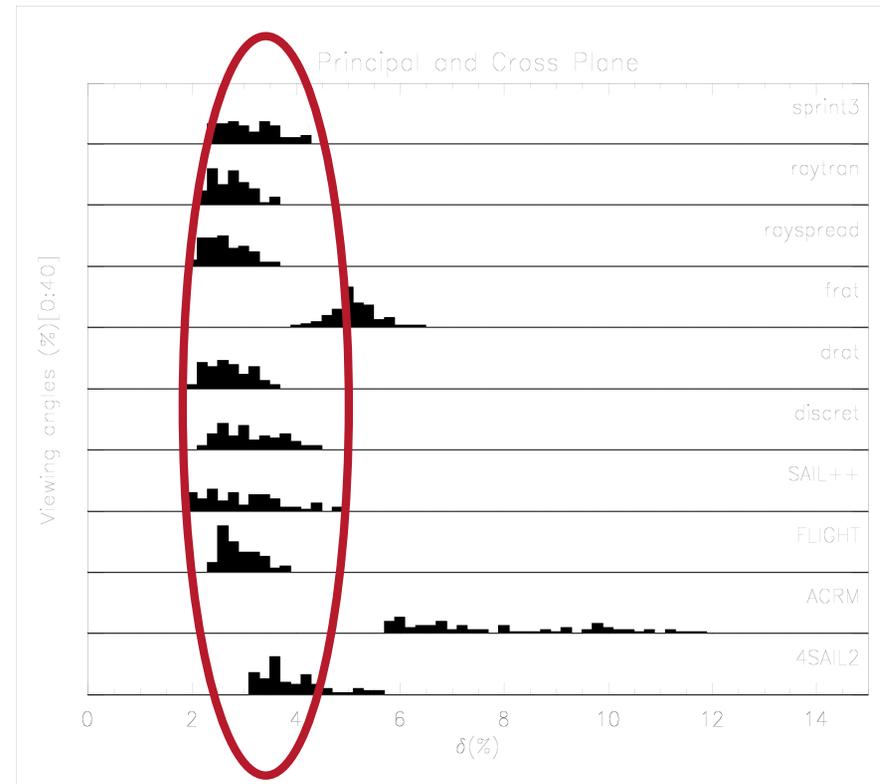
Relative Intercomparison: BRF Dispersion

Evaluate how different any one model is with respect to all other models:

$$\delta_m(\theta_v) = \frac{200}{N} \sum_{i=1}^{N_{\theta_0}} \sum_{s=1}^{N_{\text{scenes}}} \sum_{\lambda=1}^{N_{\lambda}} \sum_{k=1; k \neq m}^{N_{\text{models}}}$$

$$\frac{|\rho_m(\theta_v, i, s, \lambda) - \rho_k(\theta_v, i, s, \lambda)|}{|\rho_m(\theta_v, i, s, \lambda) + \rho_k(\theta_v, i, s, \lambda)|}$$

Histogram of $\delta_m(\theta_v)$ may be computed for the total BRF and the various BRF components

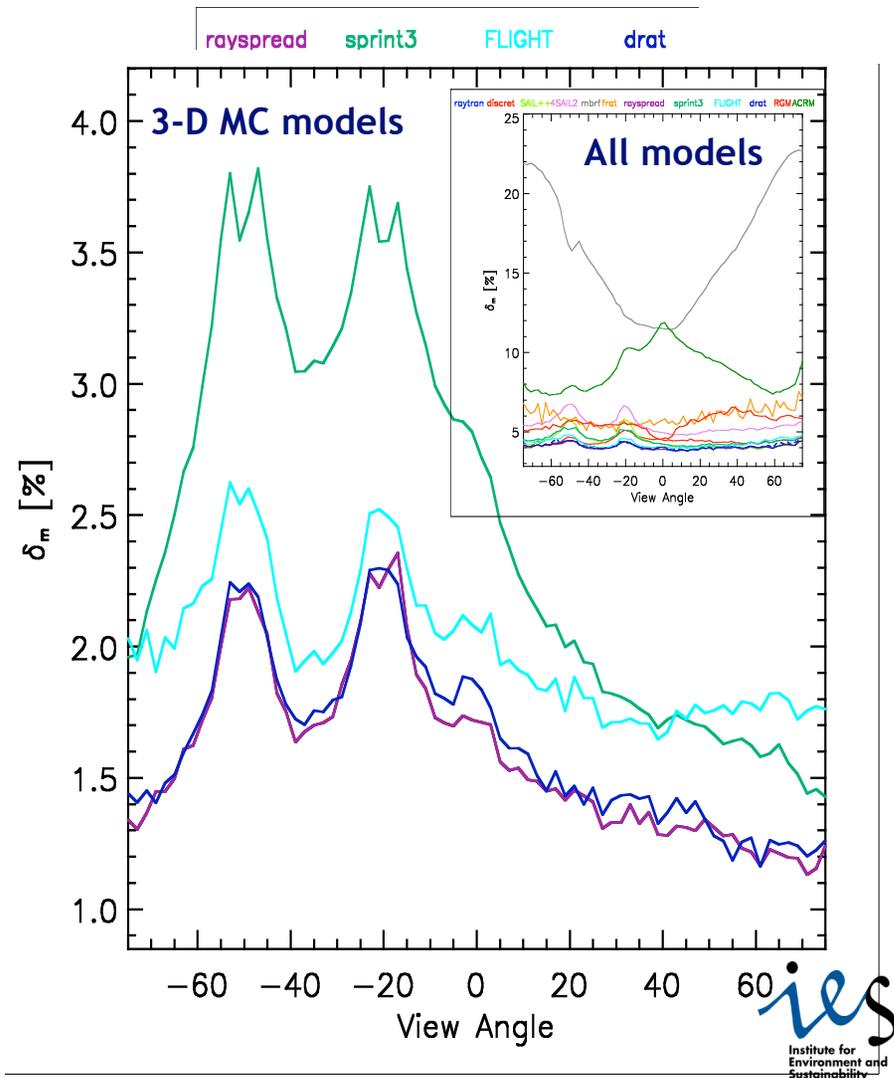




Relative Intercomparison: surrogate truth

In absence of *absolute truth* criteria, establish *surrogate truth* from ensemble of 3-D Monte Carlo models that:

- have performed all required experiments and measurements
- minimize RT assumptions and parameterisation shortcuts
- feature explicit input

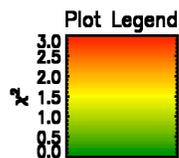




Participation & Performance

Discrete

	Model Discernability															
	4SAIL2	ACRM	FLIGHT	Hyemalis	RGM	Sail++	2-Stream	DART	Discret	drat	frat	MBRF	Rayspread	RayTran	Sprint3	
HOM11	Green	Grey	Green	Grey	Green	Green	Grey	Grey	Green	Green	Green	Red	Green	Green	Green	NR1
HOM12	Orange	Grey	Green	Grey	Yellow	Green	Grey	Grey	Green	Green	Green	Red	Green	Green	Green	NR1
HOM15	Red	Grey	Orange	Grey	Red	Green	Grey	Grey	Yellow	Green	Red	Red	Green	Green	Green	NR1
HOM0313	Red	Red	Green	Red	Red	Yellow	Grey	Grey	Green	Green	Red	Red	Green	Green	Yellow	Combined
HOM0313	Red	Red	Green	Grey	Green	Green	Grey	Grey	Green	Green	Orange	Red	Green	Green	Green	NIR
HOM0313	Red	Red	Green	Grey	Red	Red	Grey	Grey	Green	Green	Red	Red	Green	Green	Red	RED

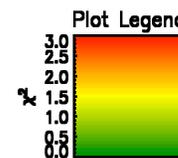


- χ^2 value > plot maximum.
- Incomplete Data
- No Data

χ^2 uses $\sigma=0.025 \langle \text{BRF} \rangle_{3D}$

Turbid

	Model Discernability															
	4SAIL2	ACRM	FLIGHT	Hyemalis	RGM	Sail++	2-Stream	DART	Discret	drat	frat	MBRF	Rayspread	RayTran	Sprint3	
HOM01	Yellow	Grey	Yellow	Grey	Grey	Green	Grey	Green	Green	Green	Grey	Red	Green	Green	Green	NR1
HOM02	Red	Grey	Orange	Grey	Grey	Green	Grey	Green	Green	Green	Grey	Red	Green	Green	Green	NR1
HOM05	Red	Grey	Red	Grey	Grey	Green	Grey	Orange	Yellow	Grey	Grey	Red	Green	Green	Green	NR1
HOM03	Orange	Green	Green	Grey	Grey	Green	Grey	Green	Yellow	Grey	Grey	Red	Green	Green	Green	Combined
HOM03	Red	Green	Green	Grey	Green	Grey	Grey	Green	Yellow	Grey	Grey	Red	Green	Green	Green	NIR
HOM03	Green	Grey	Green	Grey	Grey	Green	Grey	Green	Orange	Grey	Grey	Red	Green	Green	Green	RED



- χ^2 value > plot maximum.
- Incomplete Data
- No Data

χ^2 uses $\sigma=0.015 \langle \text{BRF} \rangle_{3D}$