Representing interactions between radiation and Earth's surface in large-scale models

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4th ESA EO Summer School on Earth System Monitoring and Modelling
August 4-14, 2008, ESRIN
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Partitioning of Solar fluxes in Land Surface Canopies based on operational ESA and NASA products

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How do we model the absorbed fluxes in vegetation and soil ?

Correct partitioning between the flux that is absorbed :

1- in the vegetation layer $A_{veg} = 1 - ALB_{sfc} - A_{ground}$ (VIS+NIR)

2- in the background $A_{ground} = T_{veg}(1 - \alpha_{ground})$

Assessment of the fraction of solar radiant flux that is scattered (albedo) by, transmitted through and absorbed in the vegetation layer

Pinty etal., (2006): Journal of Geophysical Research, doi:10.1029/2005JD00595

What are the needs?

- Update/improve the current Land Surface schemes describing the radiation transfer processes in vegetation canopies

  see 2-stream model by Pinty et al. JGR (2006).

Requirements from a 2-stream model

- 3 (effective) state variables:

1. *Optical depth:* LAI — *amount of leaf material*
2. *single scattering albedo :*

   Leaf reflectance+ Leaf transmittance — *leaf color*
3. *asymmetry of the phase function*

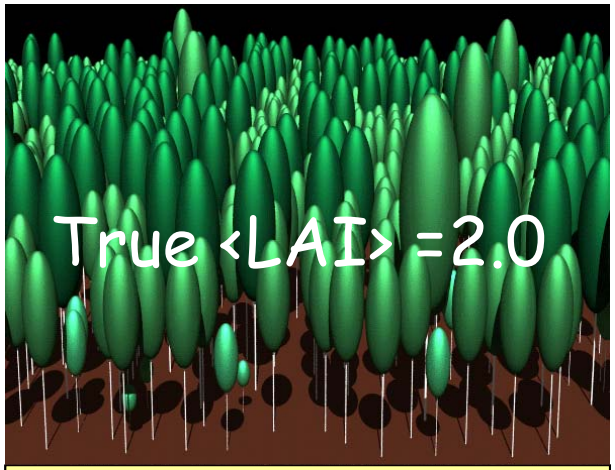
   Leaf reflectance/transmittance

- 2 boundary conditions:

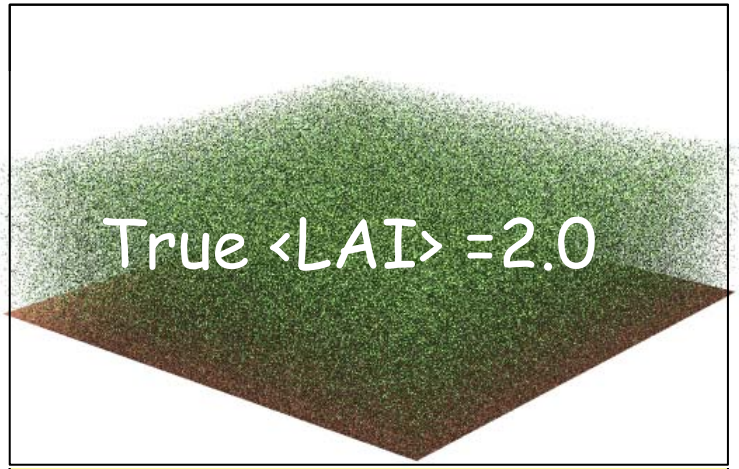
1. *Top: Direct and Diffuse atmospheric fluxes (known)*
2. *Bottom : Flux from background Albedo (unknown)* — *soil color*

Pinty etal., (2006): Journal of Geophysical Research, doi:10.1029/2005JD00595

The concept of effective LAI



3-D heterogeneous system



1-D system representation

Direct transmission at 30 degrees Sun zenith angle,

$$T_{3-D}^{direct}(< LAI >) = 0.596$$

Direct transmission at 30 degrees Sun zenith angle,

$$T_{1-D}^{direct}(< LAI >) = \exp\left(-\frac{< LAI >}{2\,\mu_0}\right) = 0.312$$

Effects induced by internal variability of LAI

What are the needs?

- Update/improve the current Land Surface schemes describing the radiation transfer processes in vegetation canopies

  see 2-stream model by Pinty et al. JGR (2006).

- Prepare for the ingestion/assimilation of RS flux products into Land Surface schemes

  Retrieve 2-stream model parameters from RS flux products

The core of the JRC-TIP

$$J(\mathbf{X}) = \frac{1}{2}\left[\left(M(\mathbf{X}) - \mathbf{d}\right)^T \mathbf{C}_d^{-1}\left(M(\mathbf{X}) - \mathbf{d}\right) + \left(\mathbf{X} - \mathbf{X}_{prior}\right)^T \mathbf{C}_{X_{prior}}^{-1}\left(\mathbf{X} - \mathbf{X}_{prior}\right)\right]$$

Model parameters

2-stream model

Uncertainty measurements

measurements

Uncertainty parameters

Parameter knowledge

- Computer optimized Adjoint and Hessian model of cost function from automatic differentiation technique
- Assume Gaussian theory
- Posterior uncertainties on retrieved parameters are estimated from the curvature of $J(\mathbf{X})$

Pinty etal., (2007): Journal of Geophysical Research, *doi:10.129/2006JD008105*

OUTPUTS: posterior knowledge

- PDFs of all 2-stream model parameters:

$$PDF(\mathbf{X}) \approx \exp\left(-\frac{1}{2}(\mathbf{X}-\mathbf{X}_{post})^T \mathbf{C}_{X_{post}}^{-1} (\mathbf{X}-\mathbf{X}_{post})\right)$$

a posteriori uncertainty covariance matrix

- Assessement of all fluxes predicted by the 2-stream model and their associated uncertainty:

$$\mathbf{C}_{post}^{Flux} = \mathbf{G}\mathbf{C}_{X_{post}}\mathbf{G}^T$$

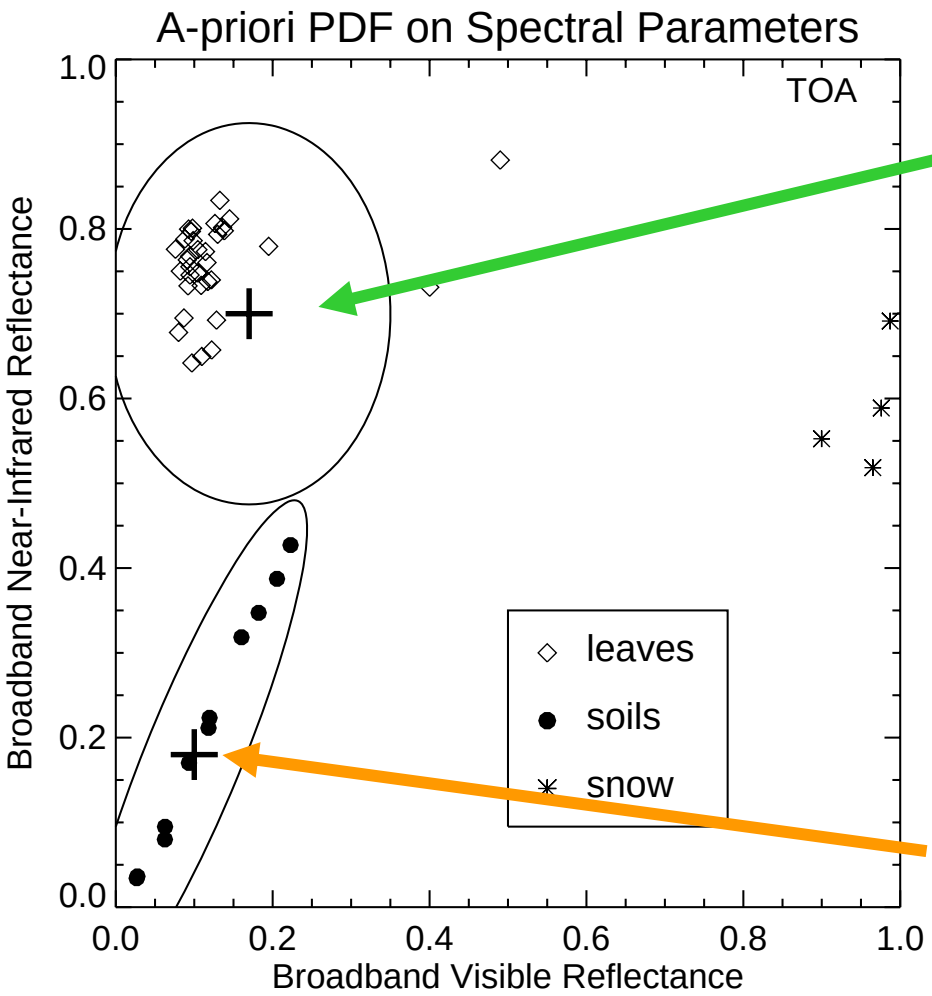
Pinty etal., (2007): Journal of Geophysical Research, *doi:10.129/2006JD008105*

Application results over selected EOS validation sites

Application with measurements set **d** limited to the visible and near-infrared broadband surface albedos, i.e.,

2 measurements and 7 model parameters to be retrieved

prior knowledge on model parameters

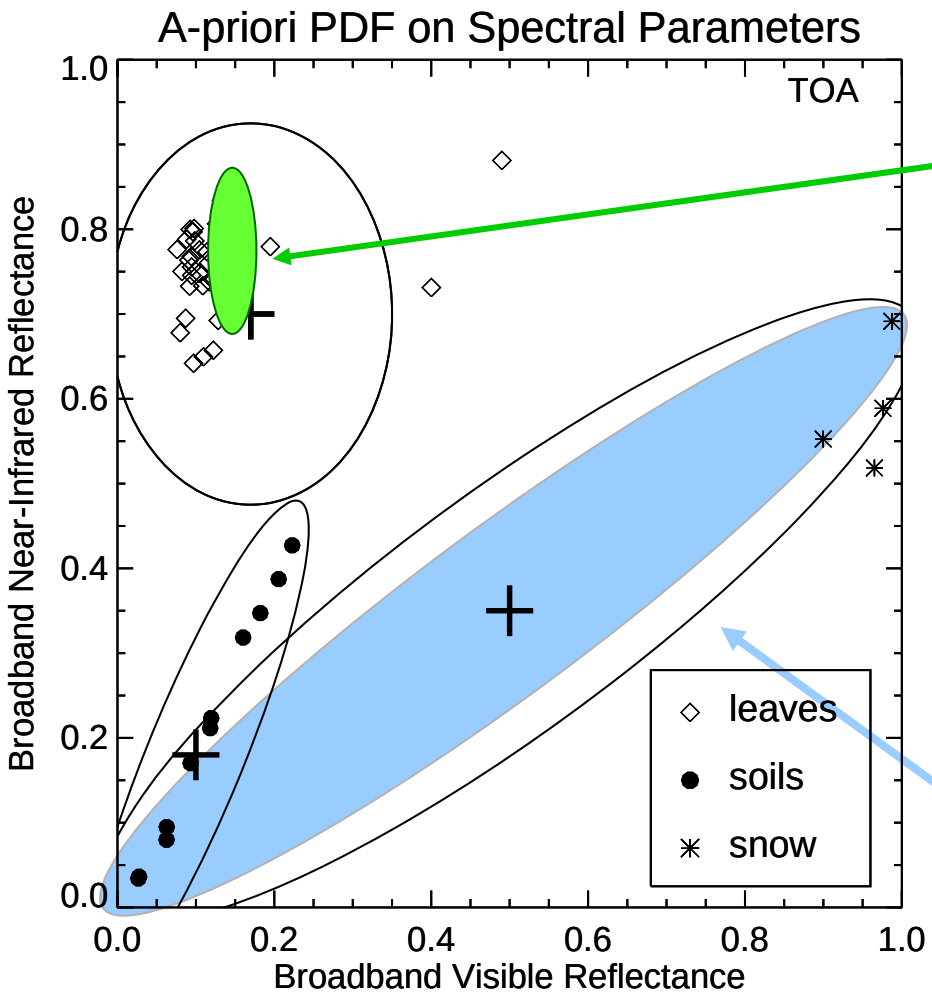


$$LAI_{prior} = 1.5$$

$$\sigma_{prior}(LAI) = 5.0$$

Pinty etal., (2007): Journal of Geophysical Research, doi:10.1029/2006JD008105

prior knowledge on model parameters



a priori 'green' leaves

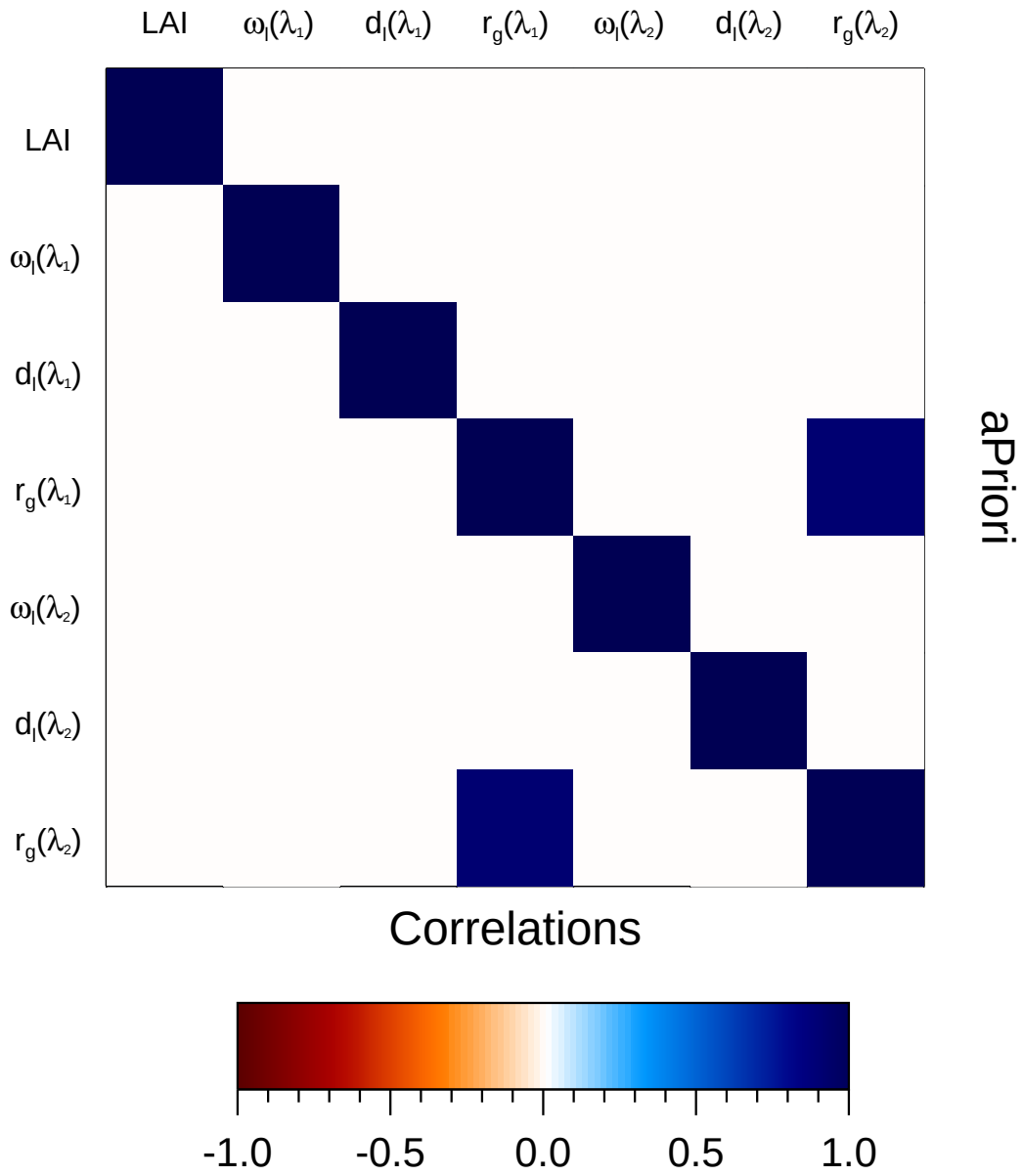
$$LAI_{prior} = 1.5$$

$$\sigma_{prior}(LAI) = 5.0$$

in case snow occurs

Pinty etal., (2007): Journal of Geophysical Research, *doi:10.129/2006JD008105*

a priori covariance matrix



Example of application results

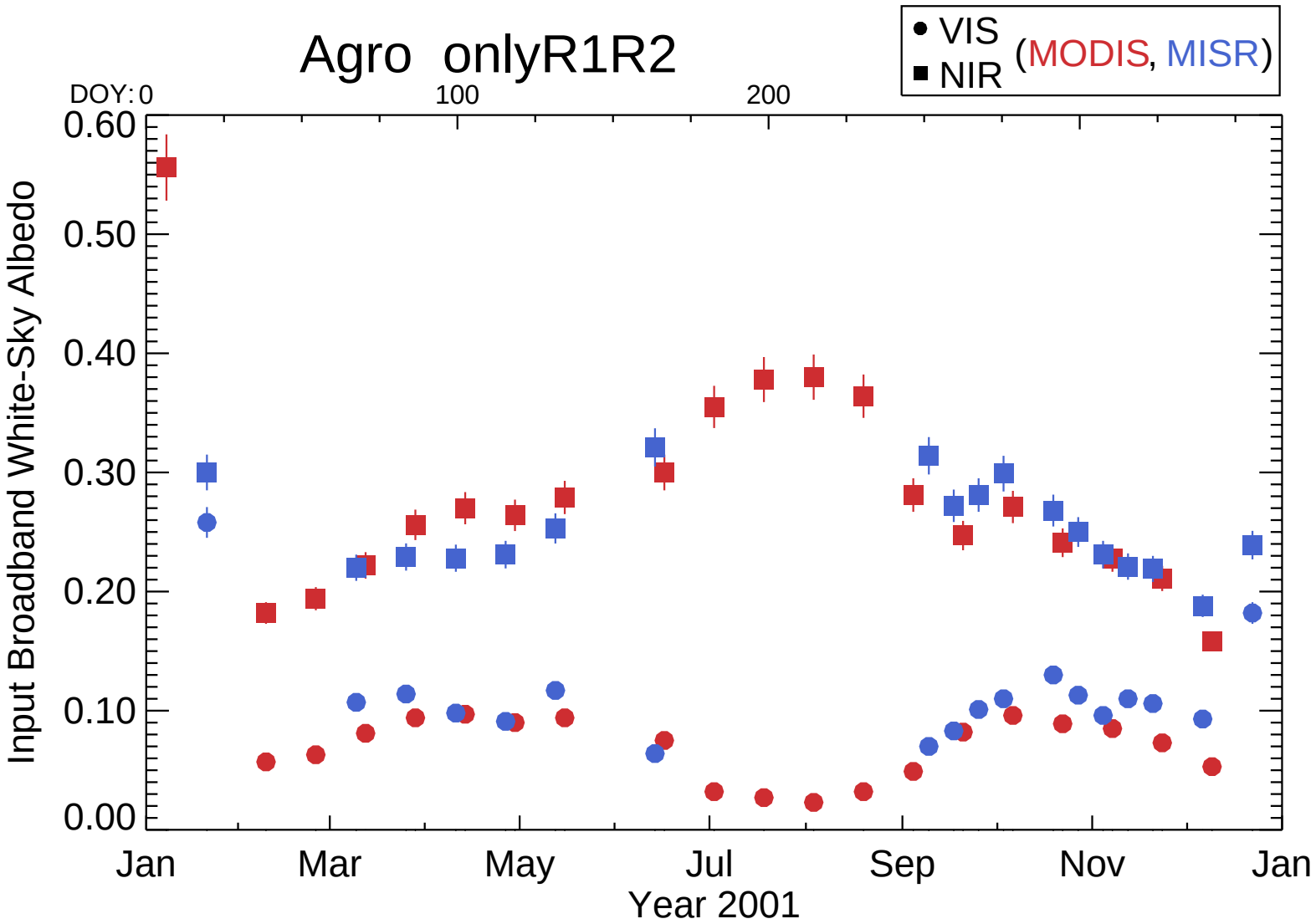
Site identification and characteristics

Dahra (Senegal)	15º 22' N 15º 26' W	Semi-arid grass savannah	Short and homogeneous over 1-2 km
AGRO (US)	40º 00' N 88º 17' W	Broadleaf crops and corn/soybean	Mixed vegetation with different land cover type
Konza (US)	39º 04' N 96º 33' W	Grassland, shrubland and cropland	Mixed vegetation with different land cover type
Mongu (Zambia)	15º 26' S 23º 15' E	Mixed shrubland and woodland	Intermediate height but low density vegetation

Pinty etal., (2007): Journal of Geophysical Research, *in pres*

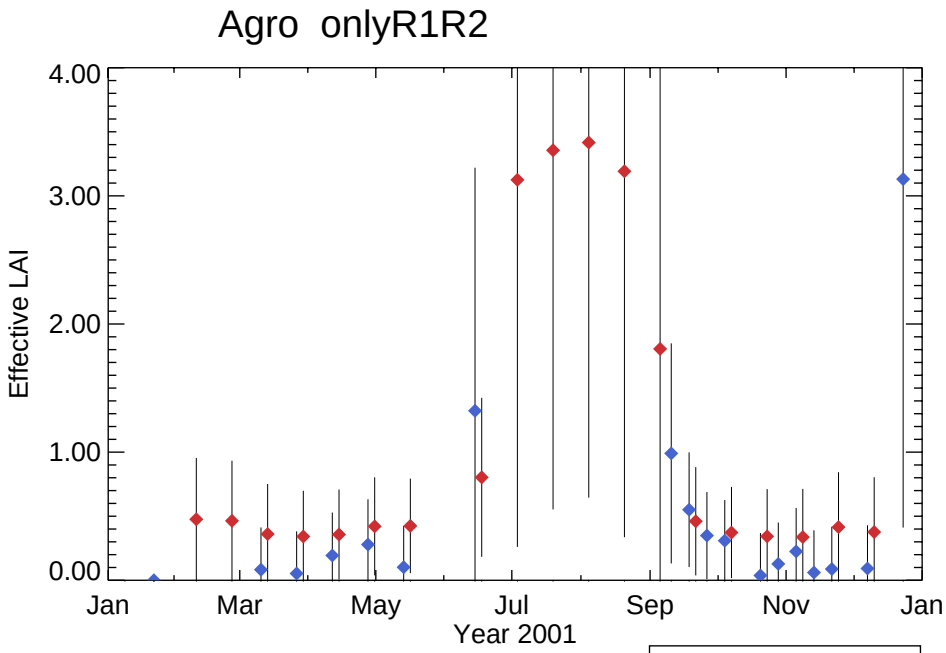

AGRO
BigFoot

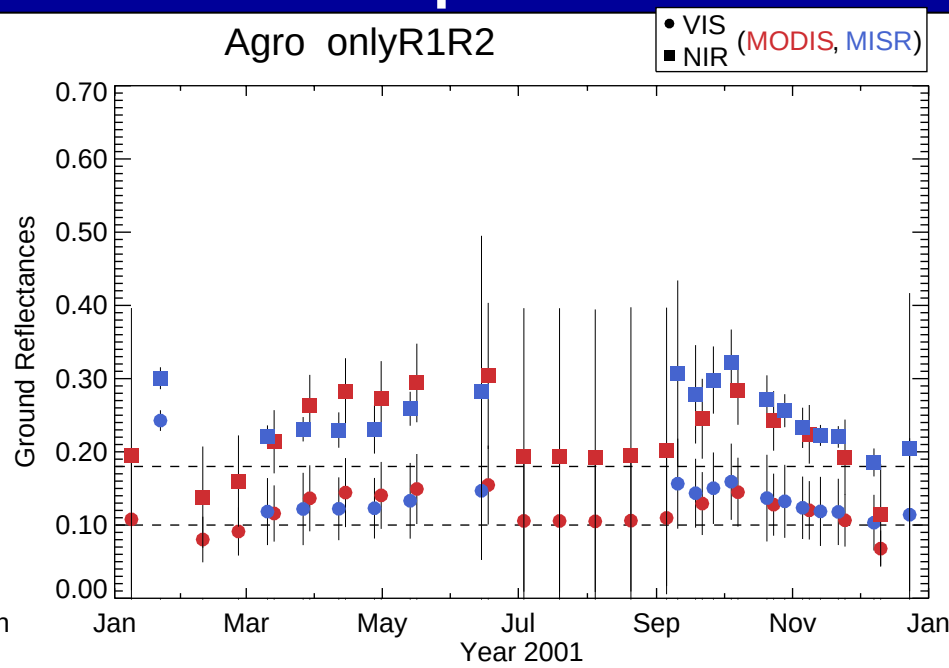
Application over AGRO: Measurements

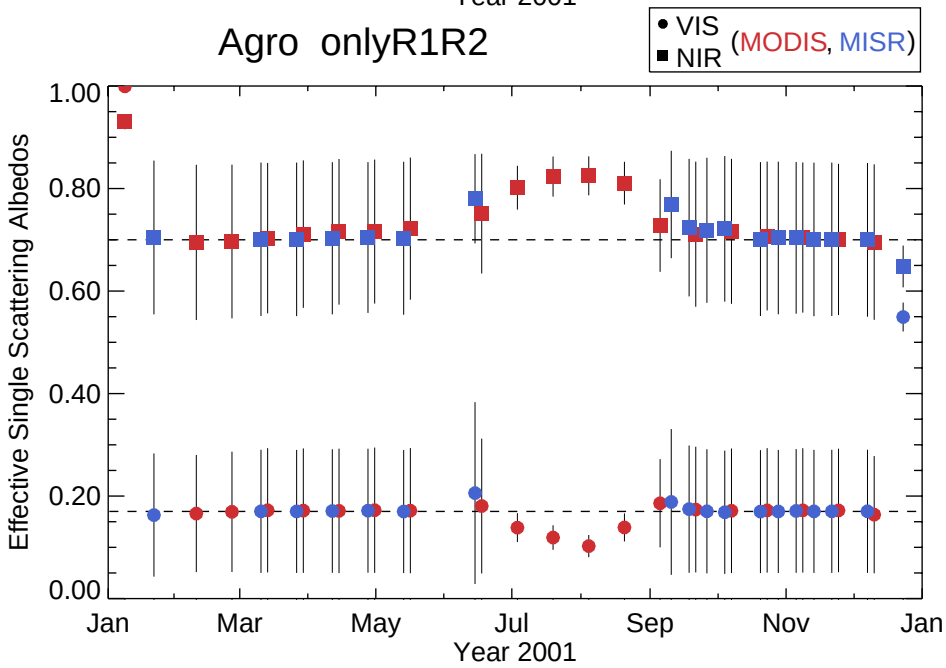


Pinty etal., (2007): Journal of Geophysical Research, *in pres*

Application over AGRO: model parameters





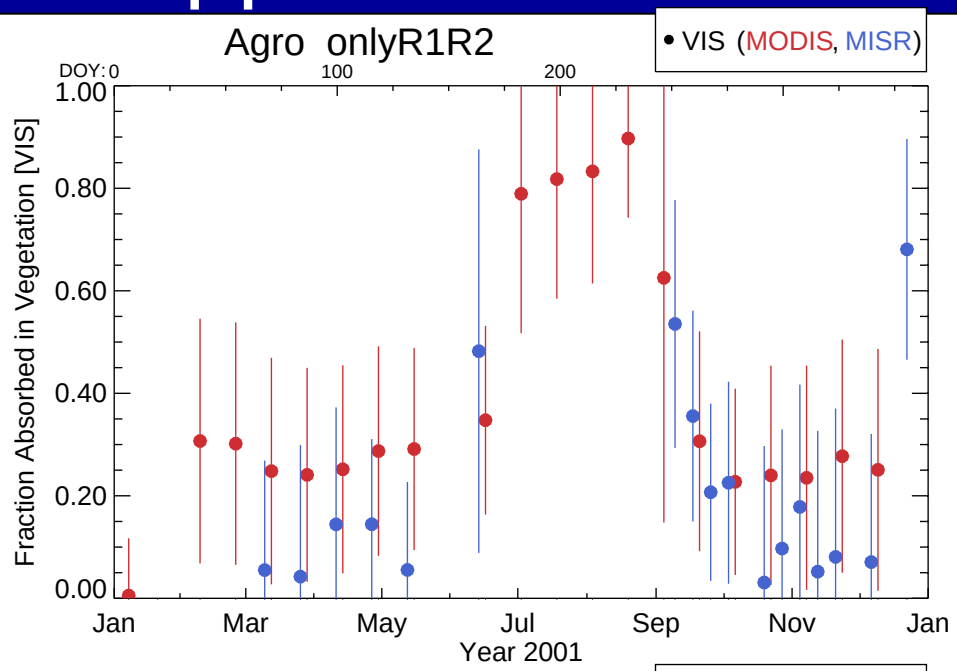


2-stream model parameters

Time-independent inversion

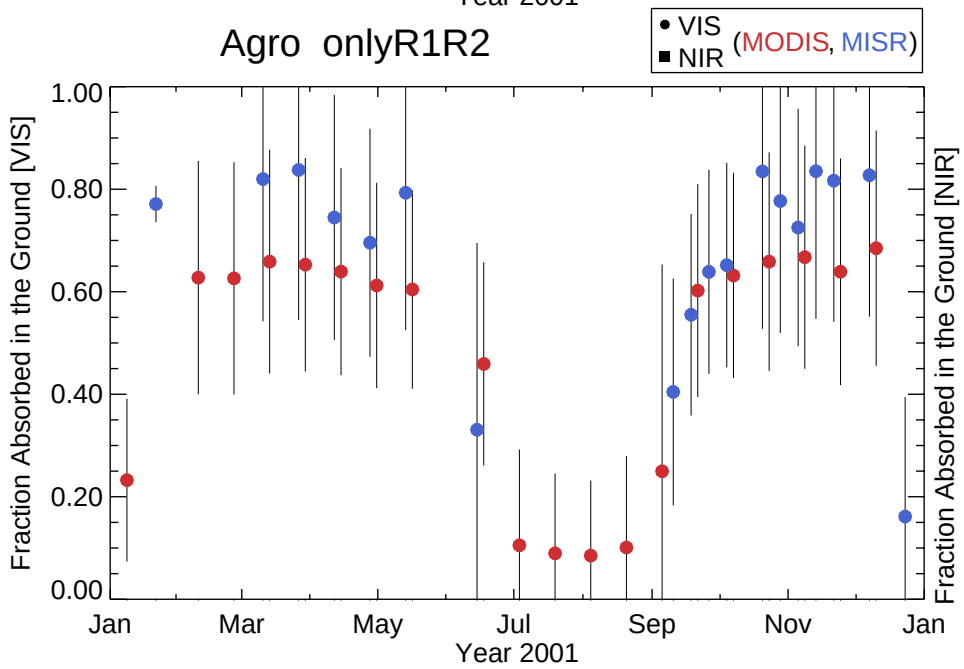
Pinty etal., (2007): Journal of Geophysical Research, *in pres*

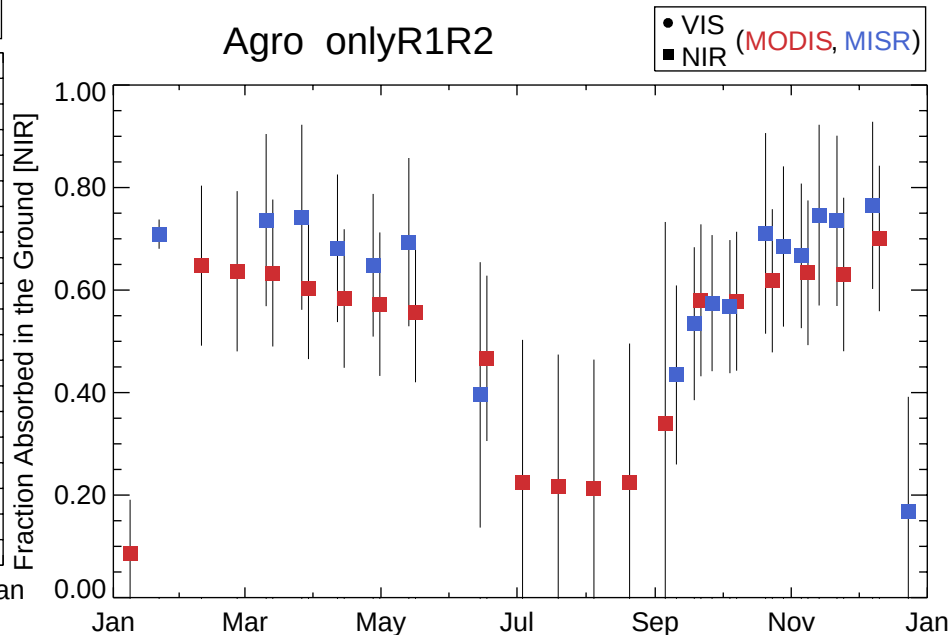
Application over AGRO: Radiant fluxes



2-stream model radiant fluxes

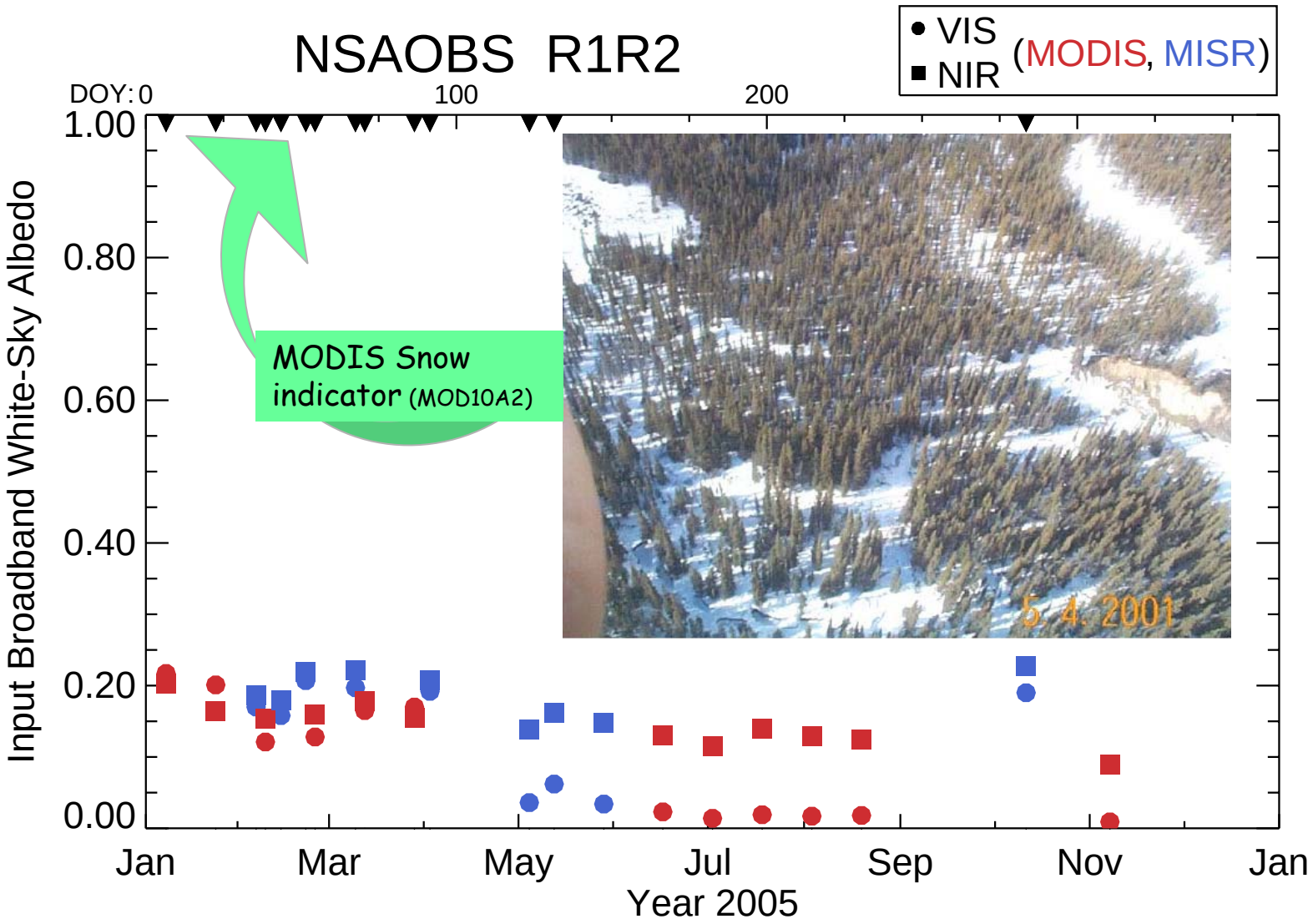
Time-independent inversion





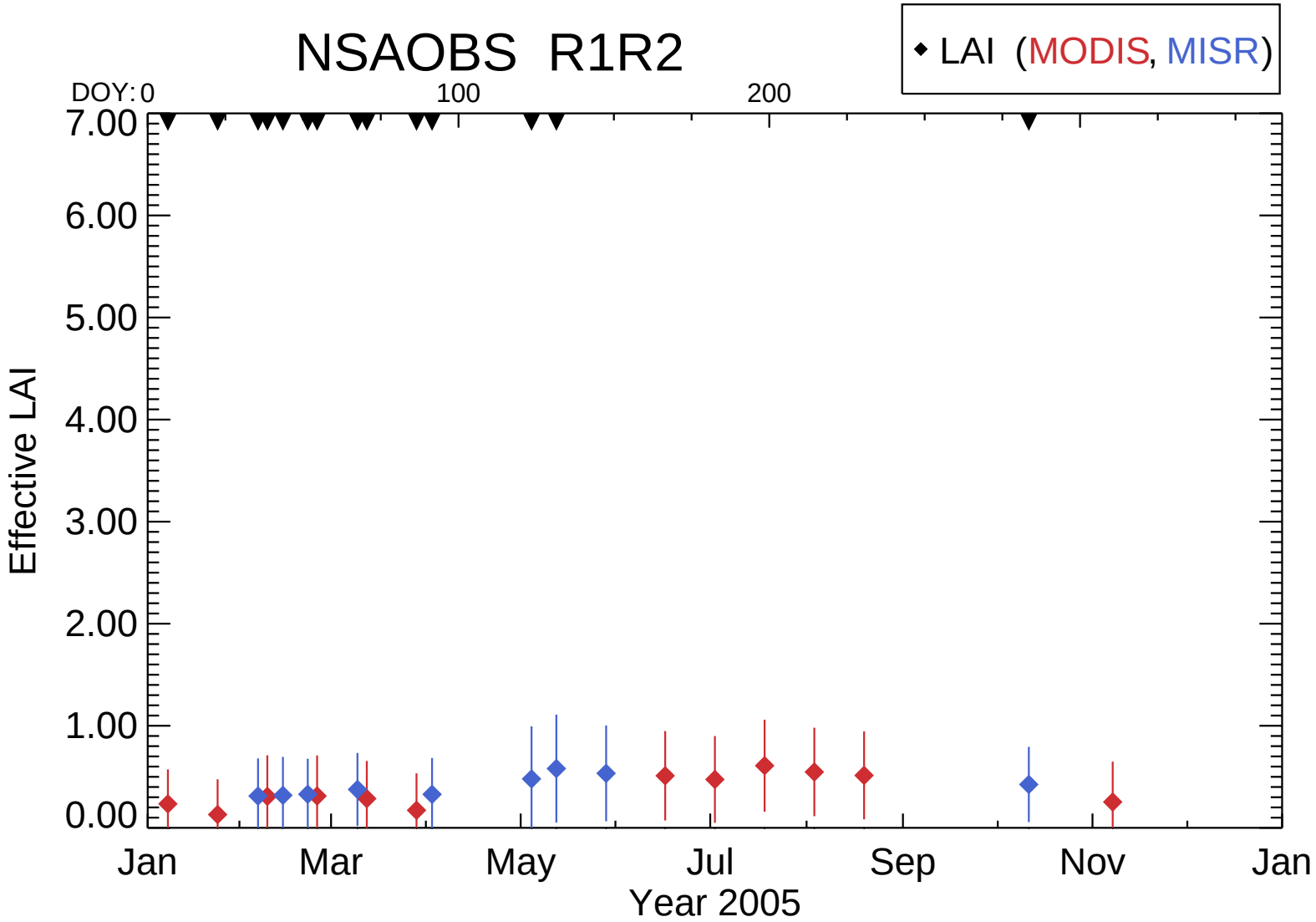
Application over BOREAS NSA-OBS

Application over BOREAS: Measurements

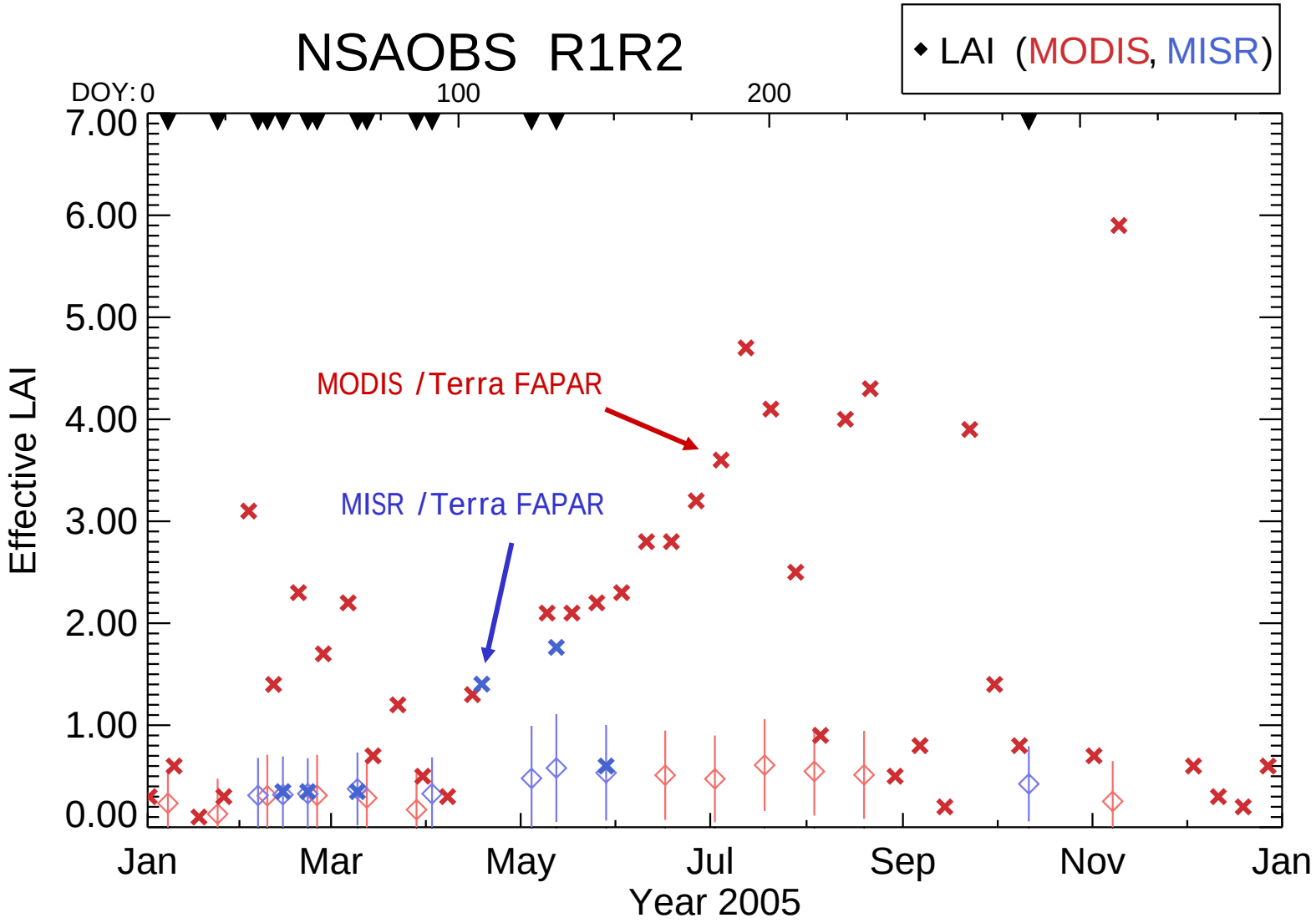


Specified uncertainty on BHRs is 5% relative

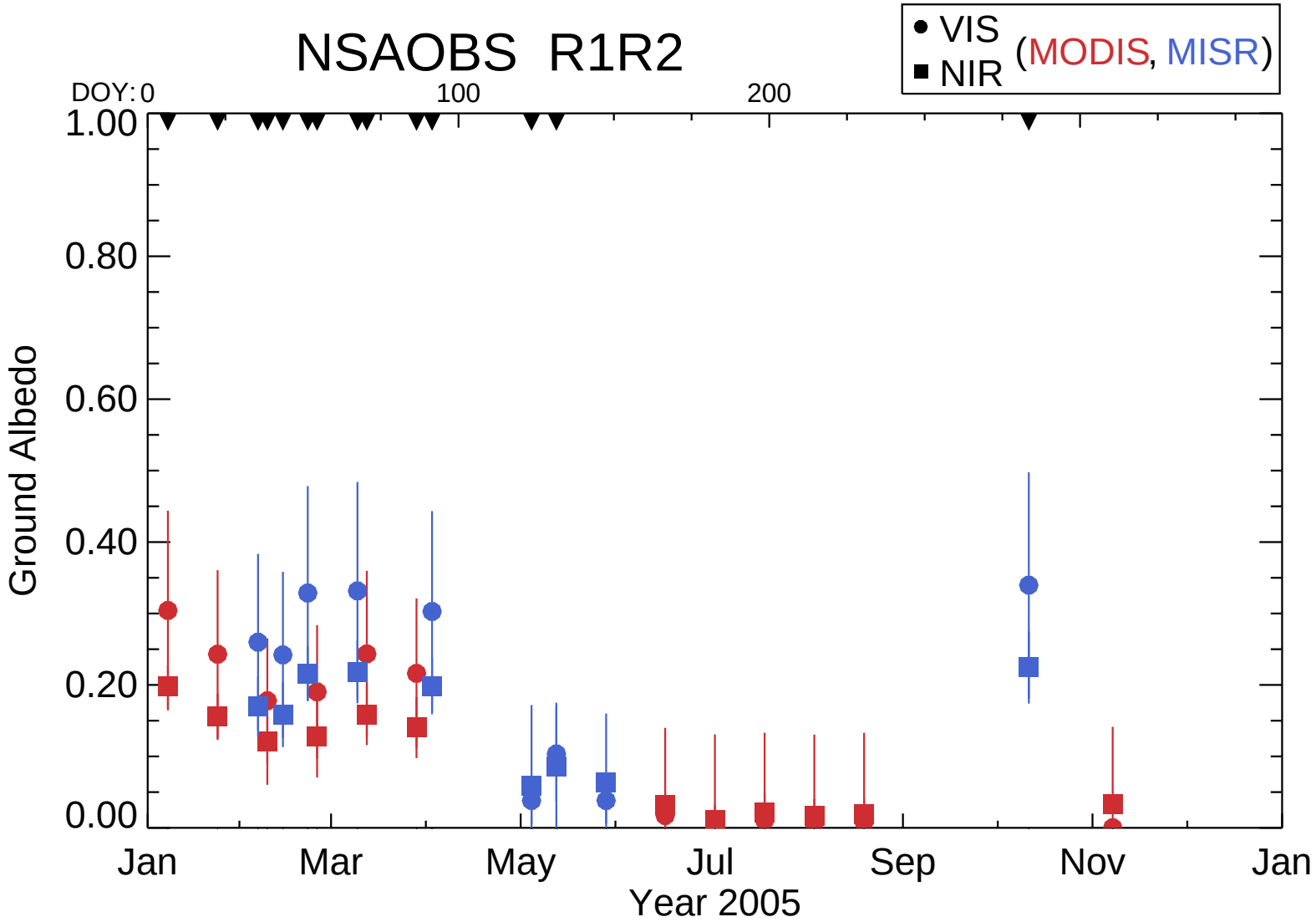
Application over NSAOBS: model parameters



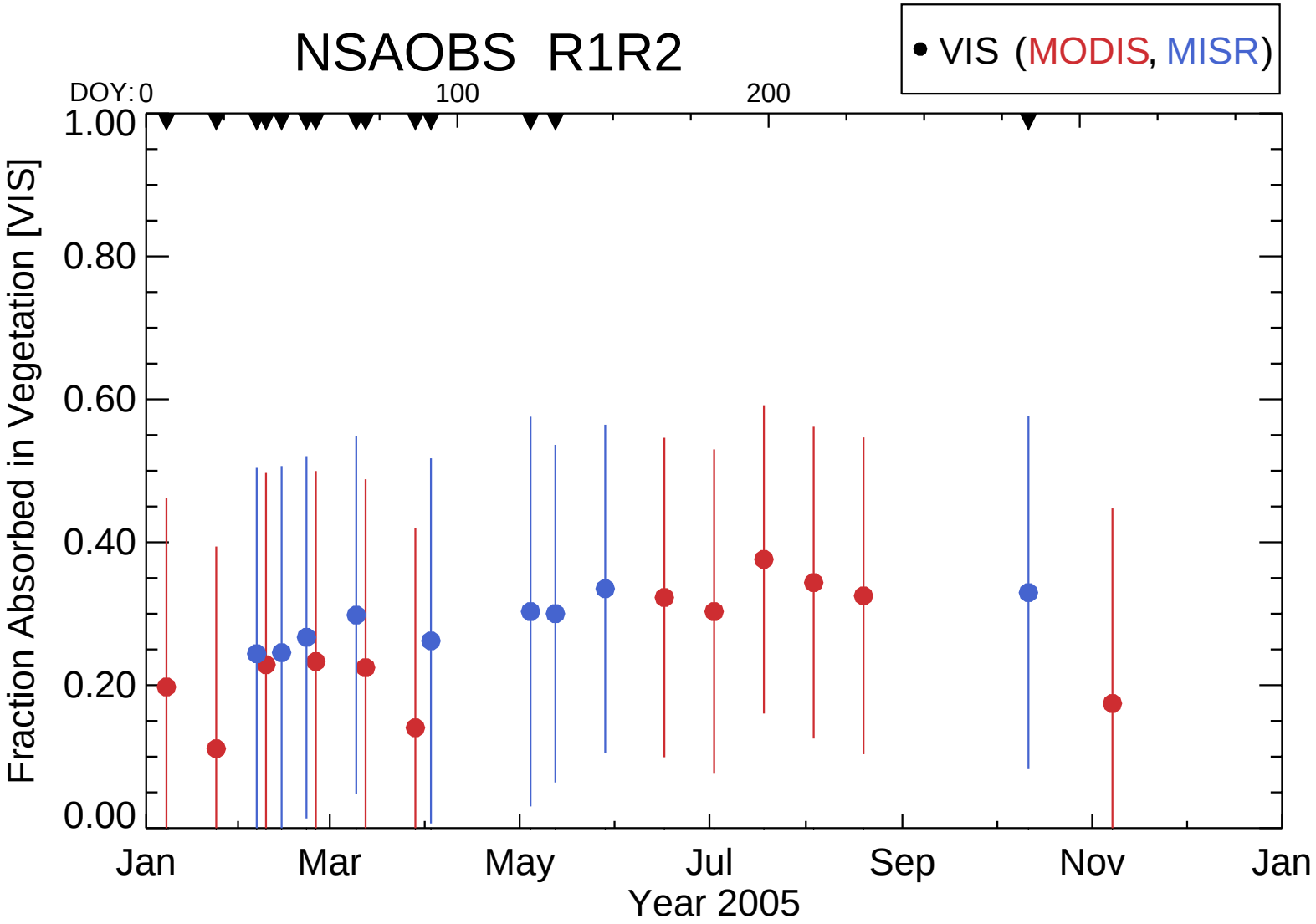
Application over NSAOBS: model parameters



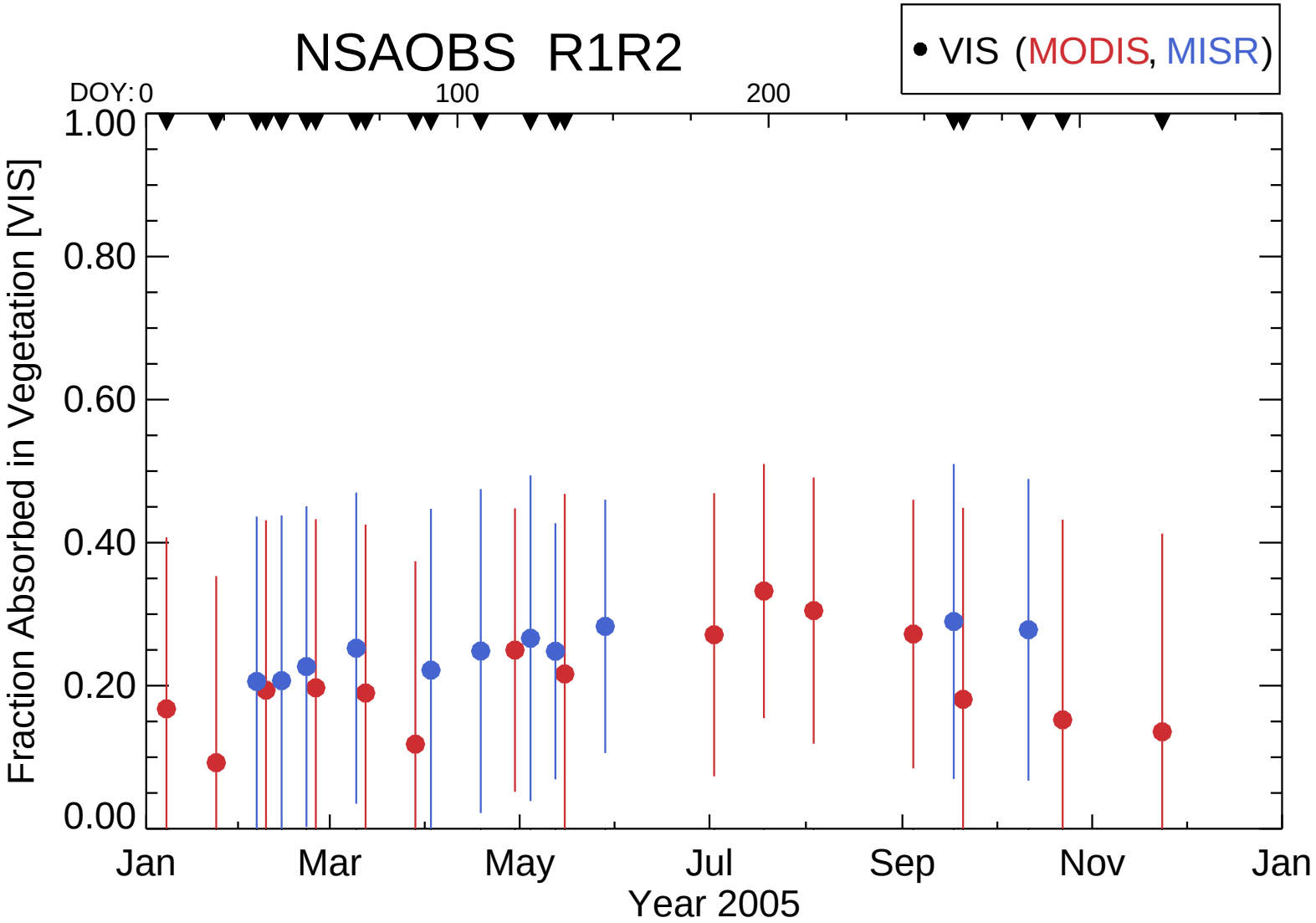
Application over NSAOBS: model parameters



Application over NSAOBS: radiant fluxes

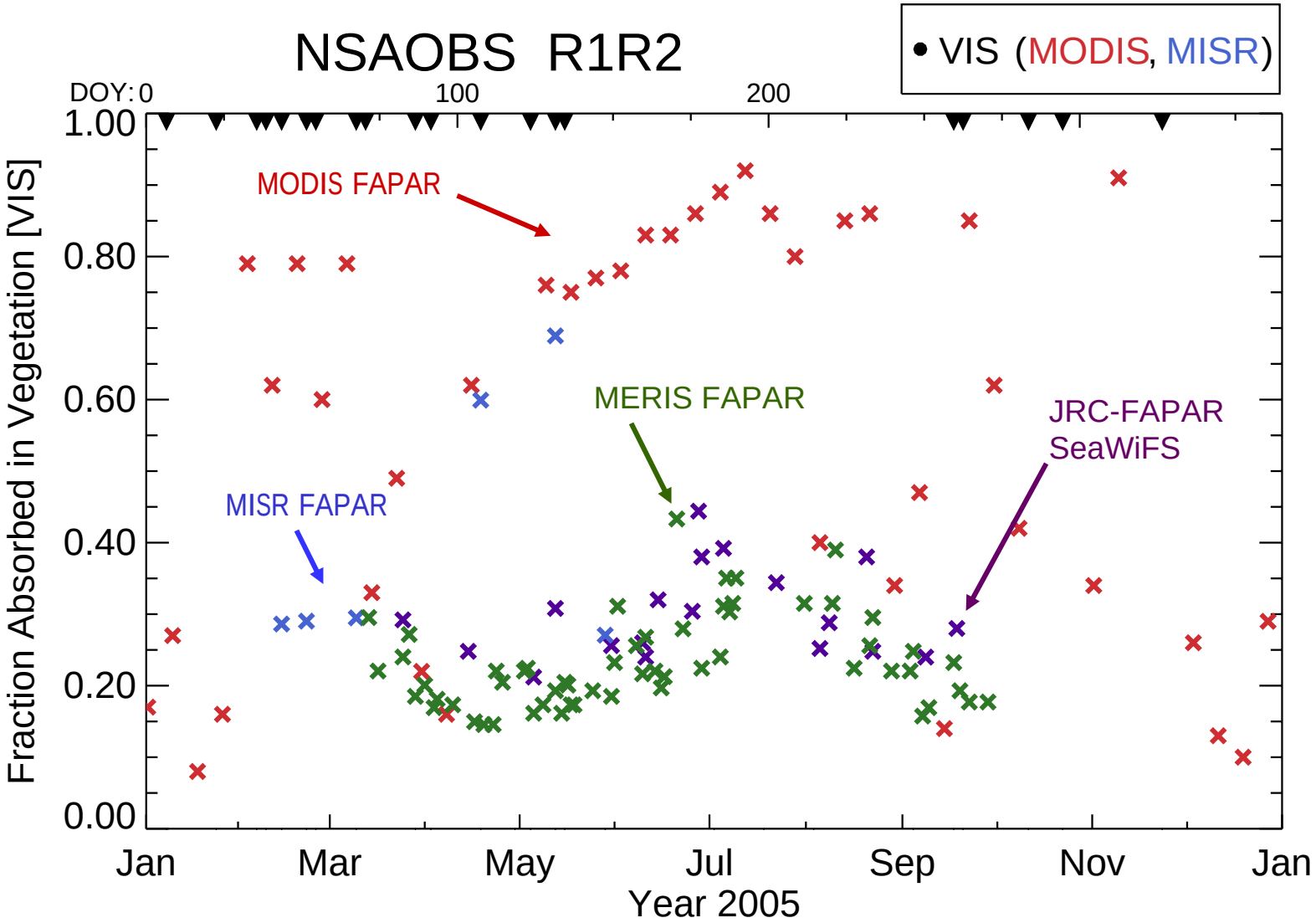


Application over NSAOBS: radiant fluxes



a priori 'green' leaves

Application over NSAOBS: radiant fluxes



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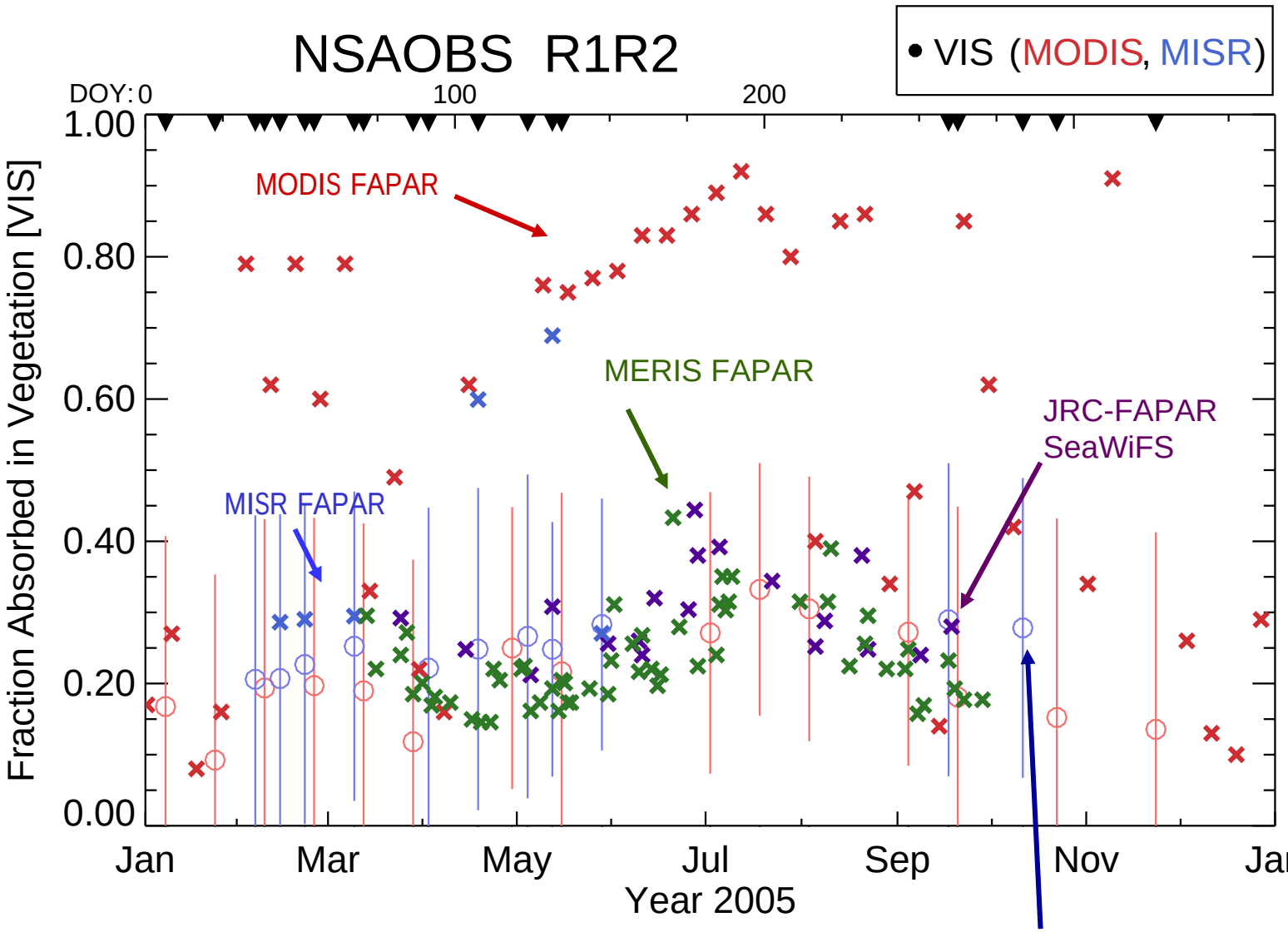


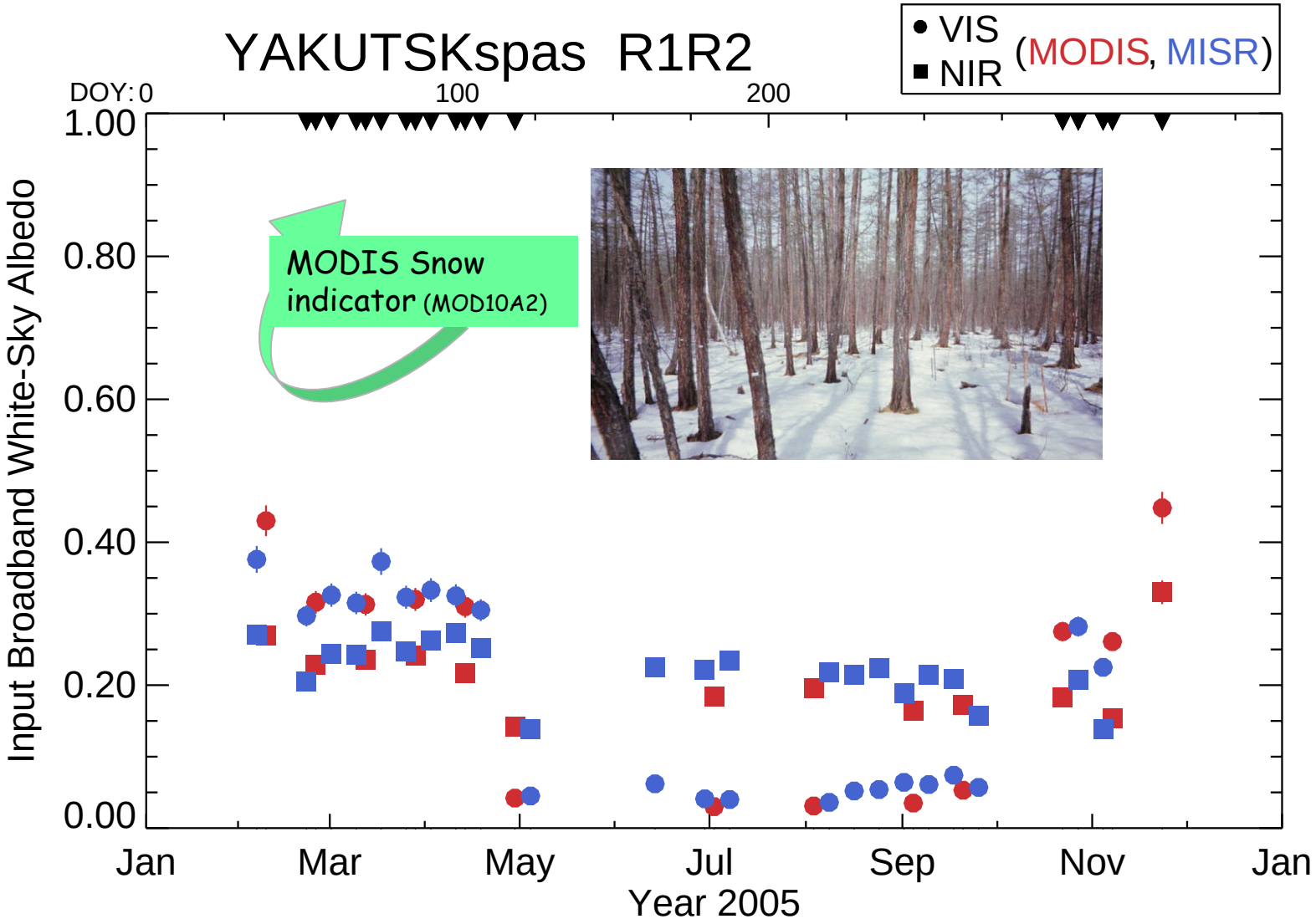
a priori 'green' leaves

our inversion based on TERRA albedos

Application over Yakustk Forest: a deciduous needle-leaf larch forest

Courtesy of Dr. R. Suzuki

Application over Yakutsk: Measurements



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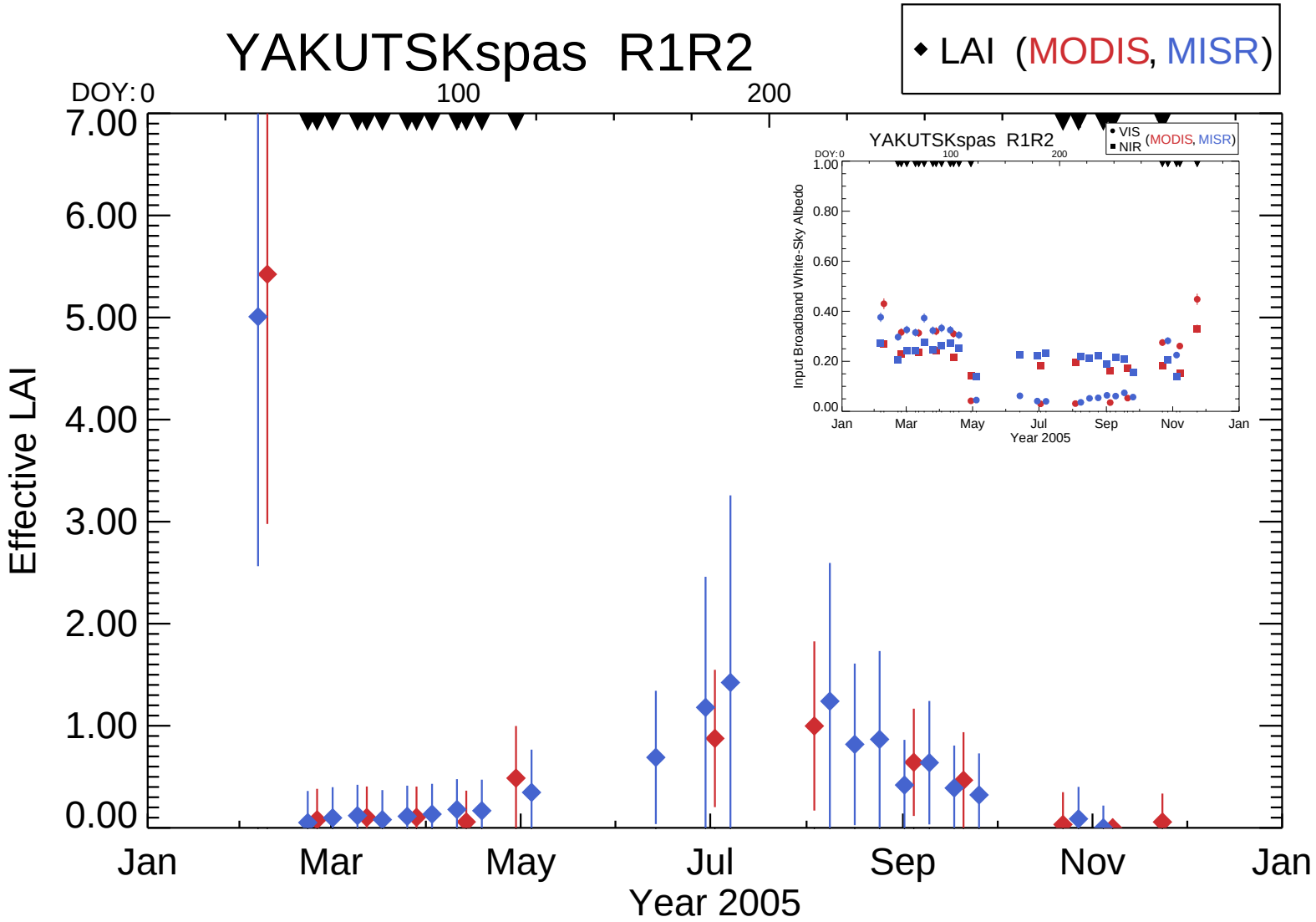

Pinty etal., (2008): Journal of Geophysical Research, doi:10.129/2007/JD009096

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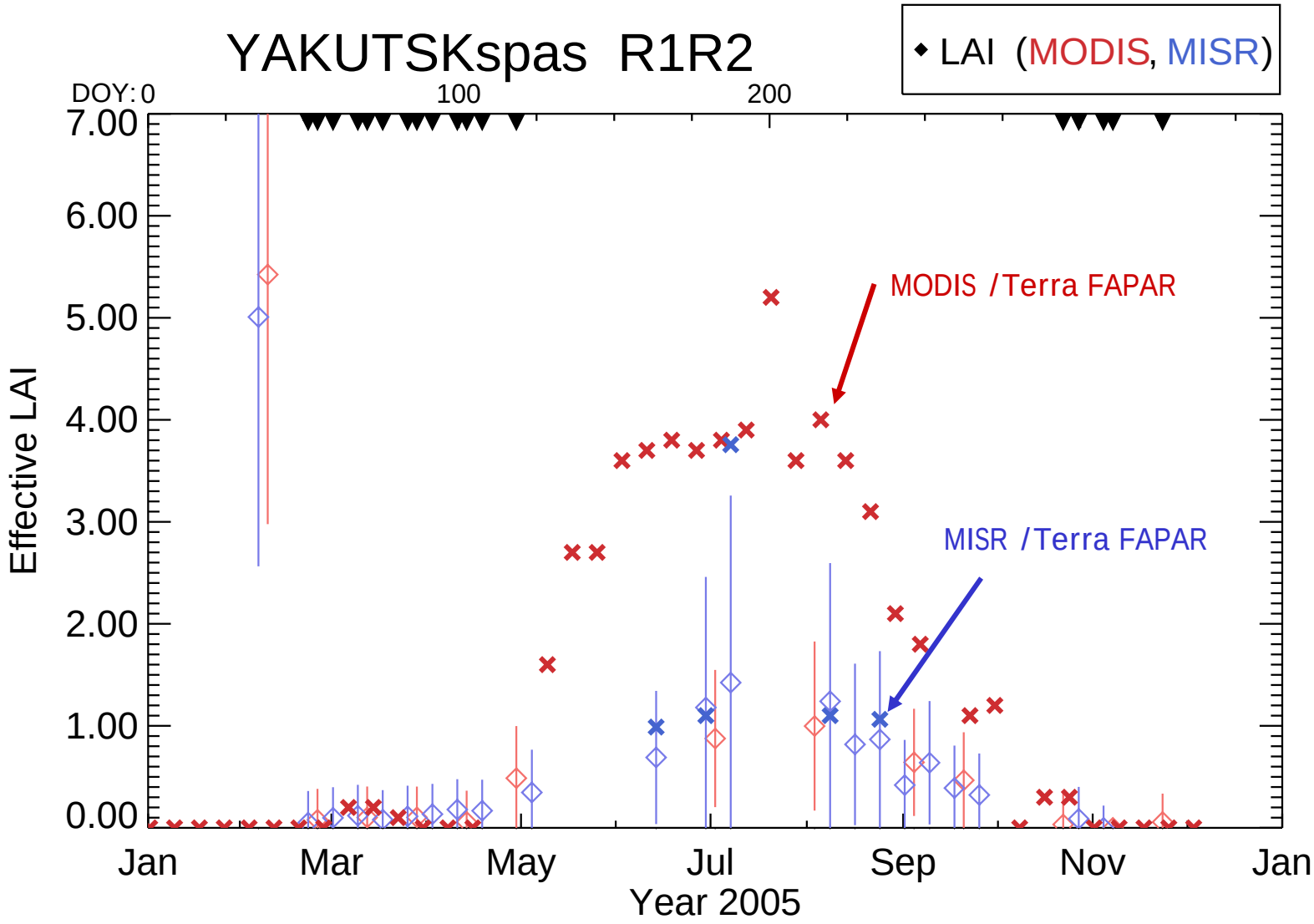

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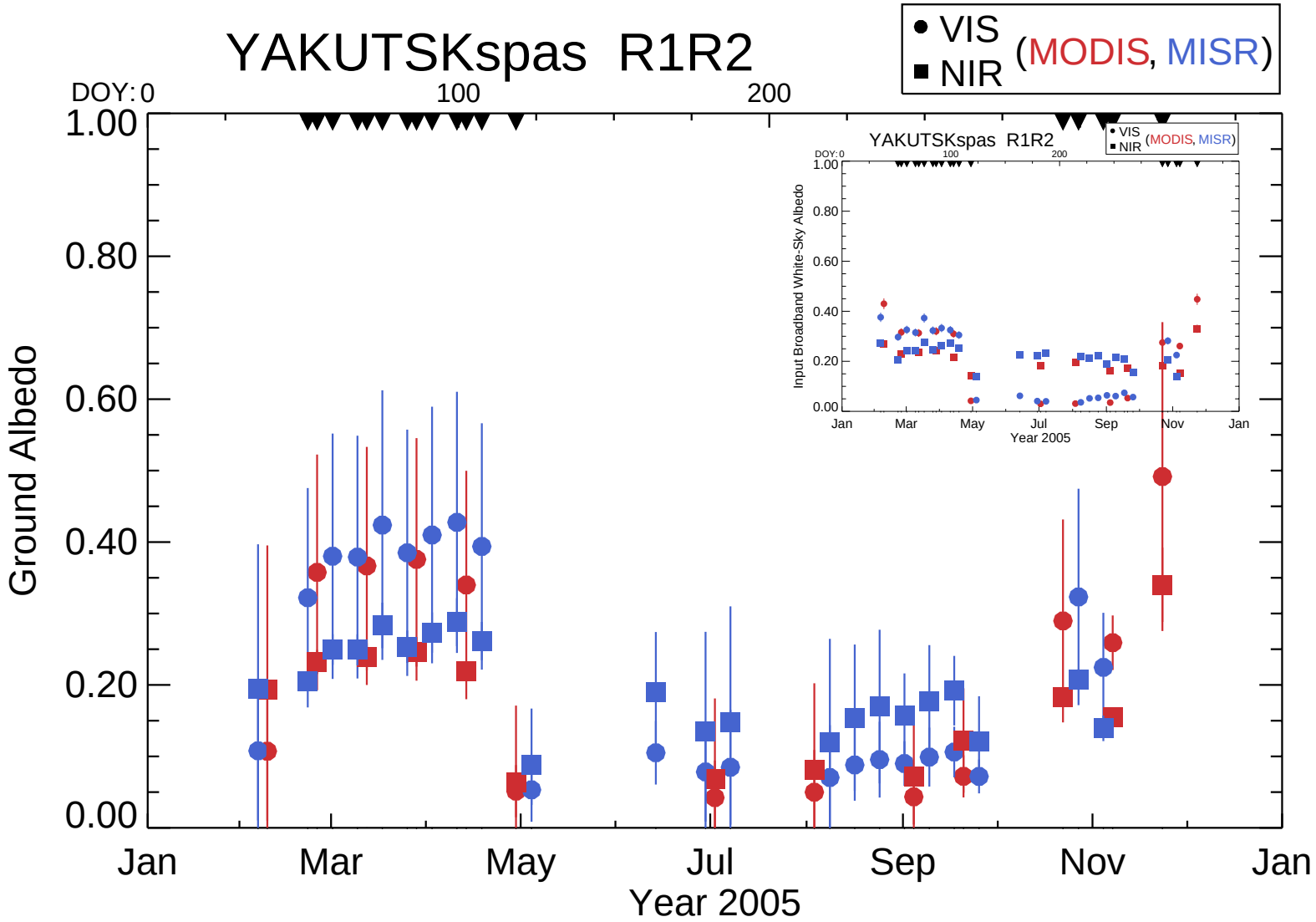

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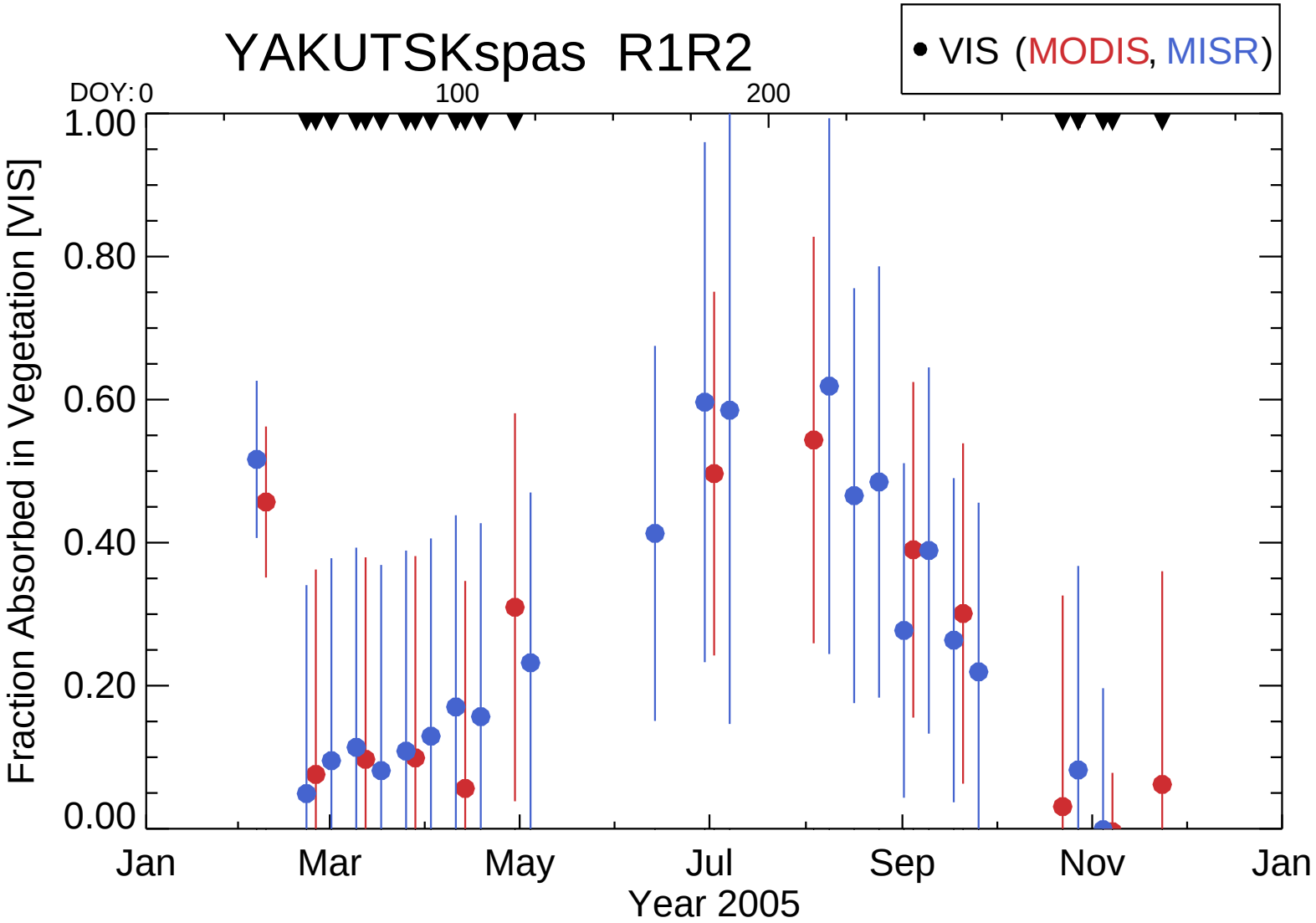

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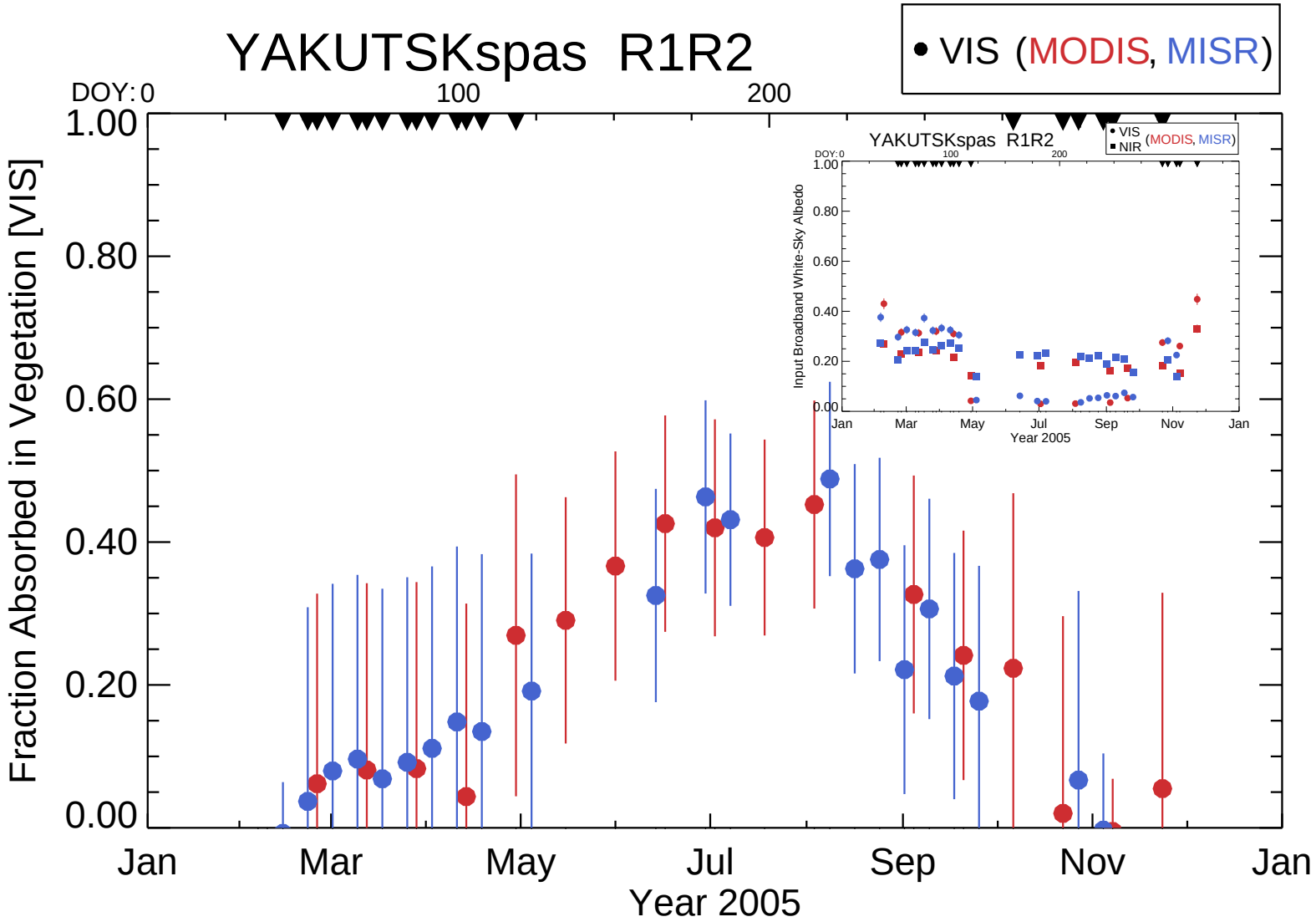

a priori 'green' leaves

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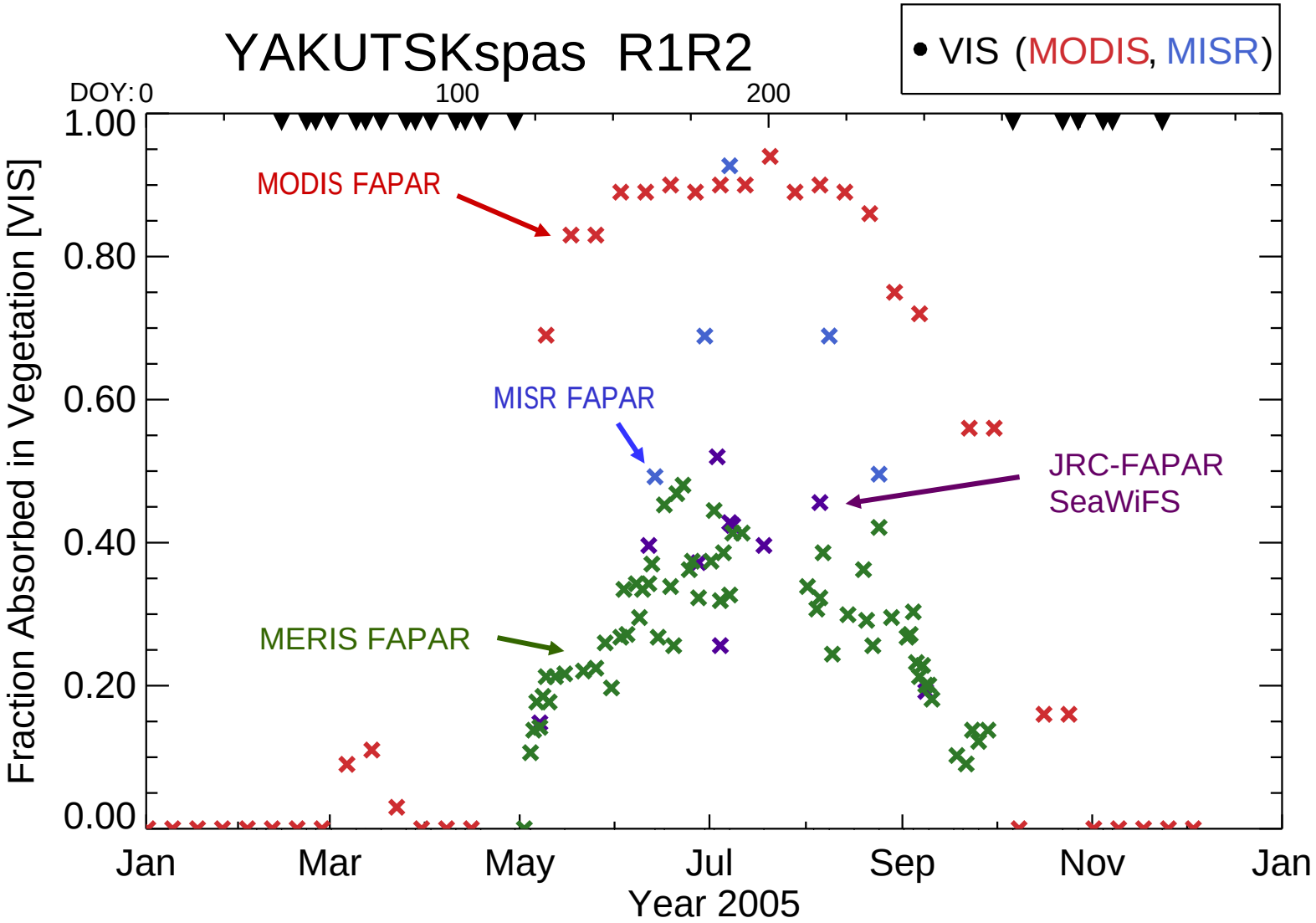

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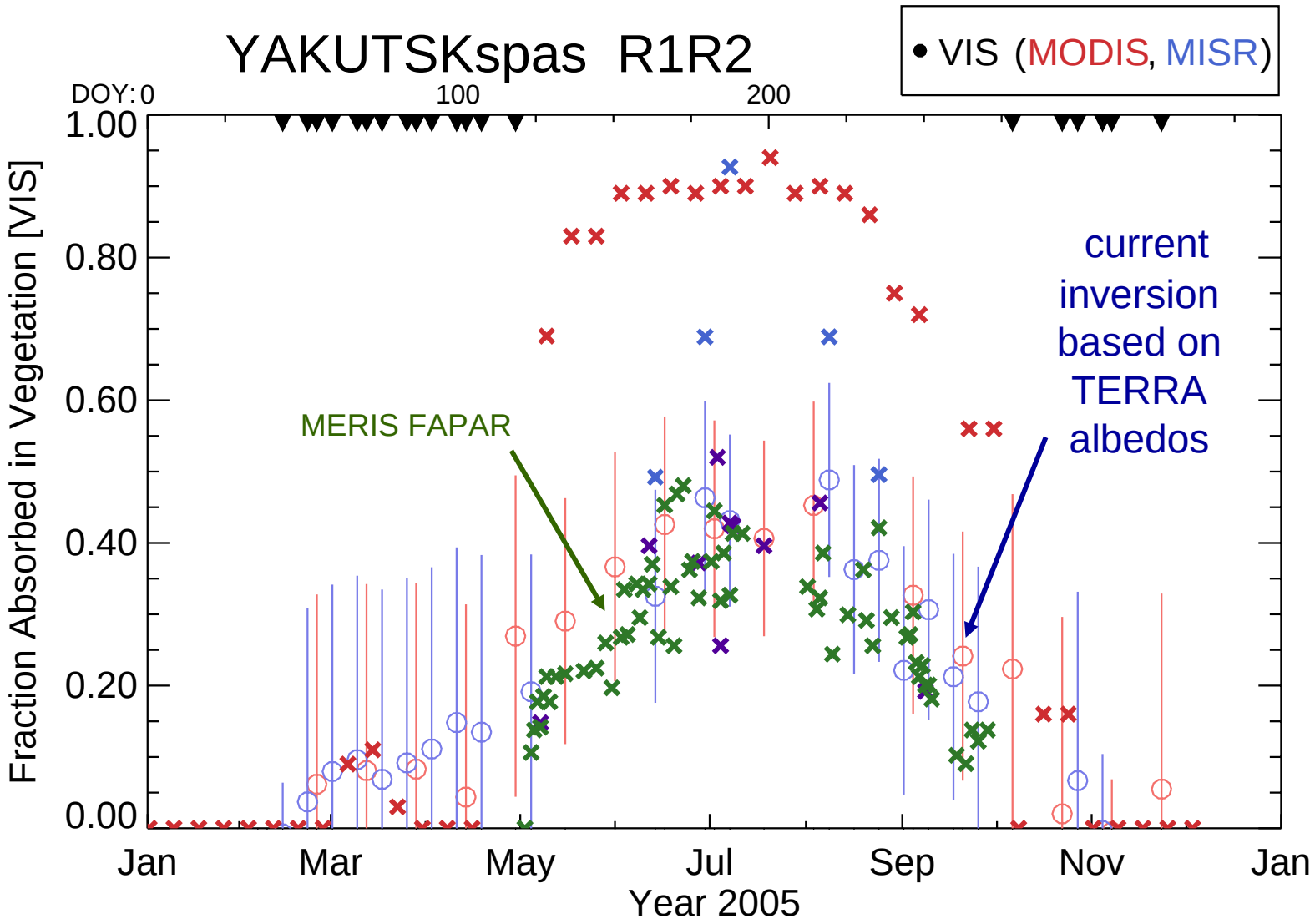

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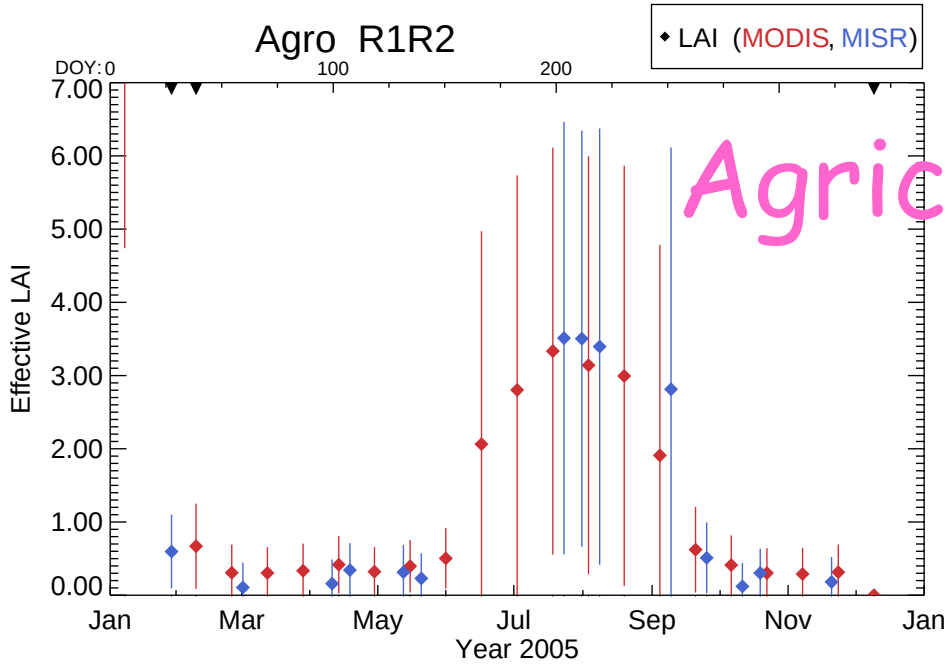
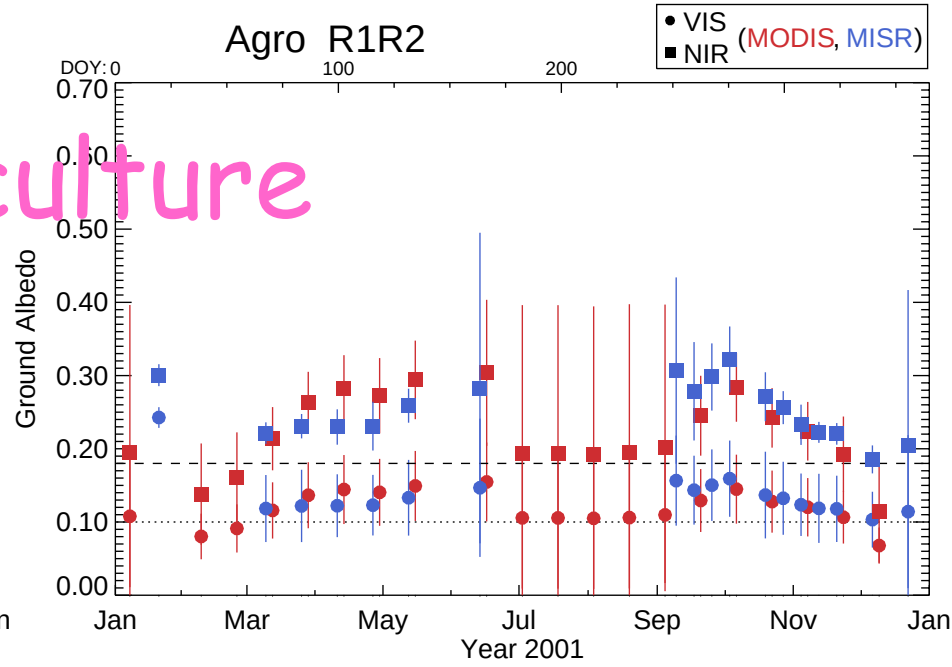
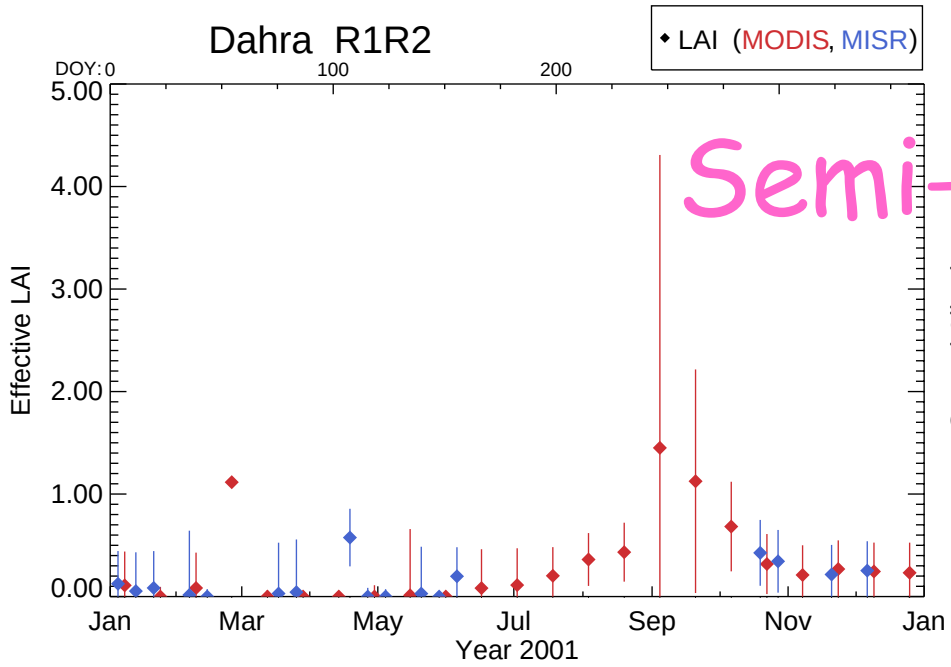
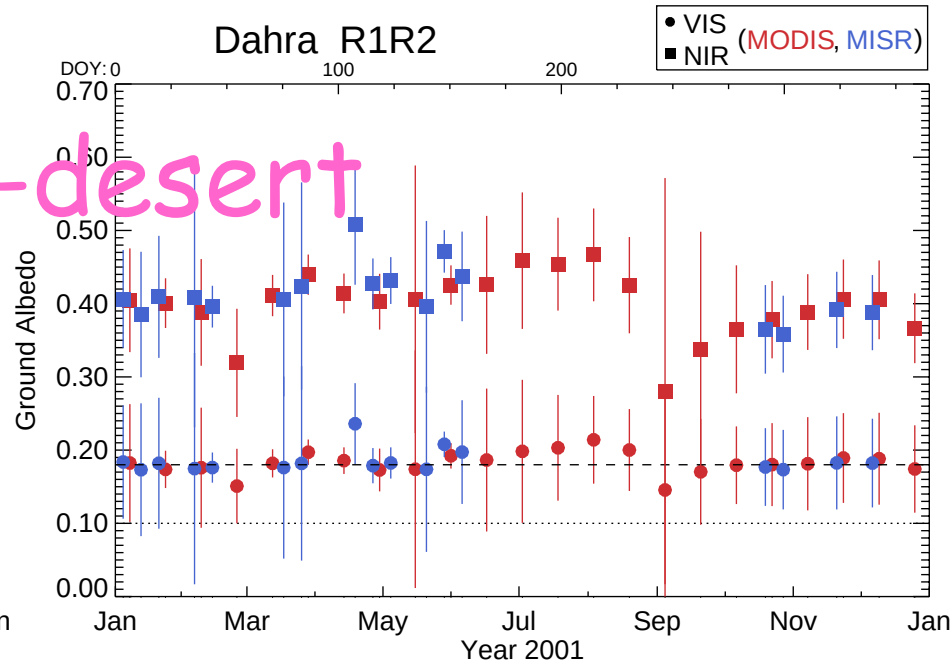


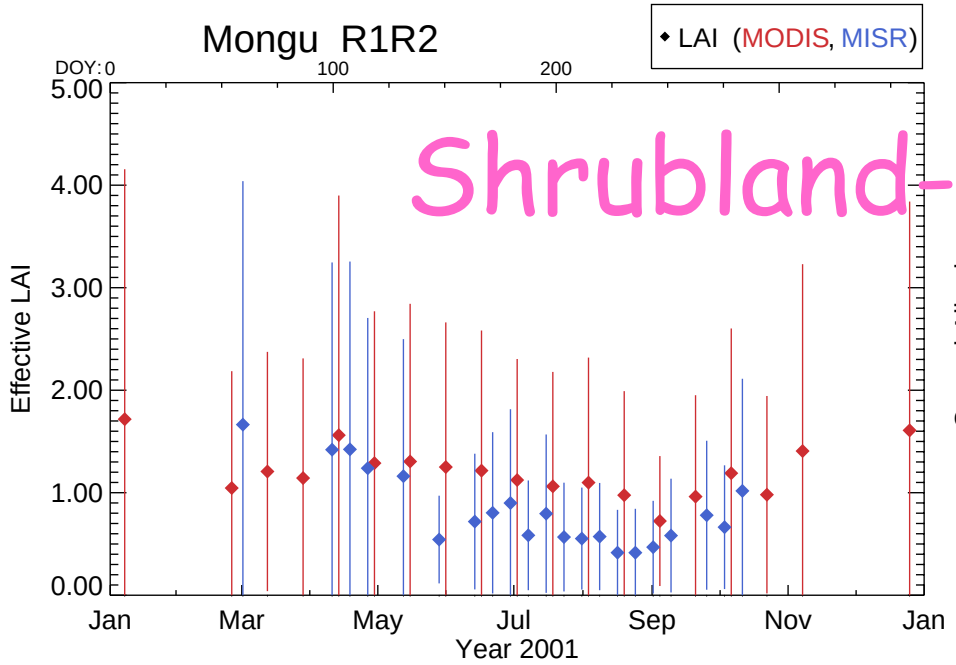


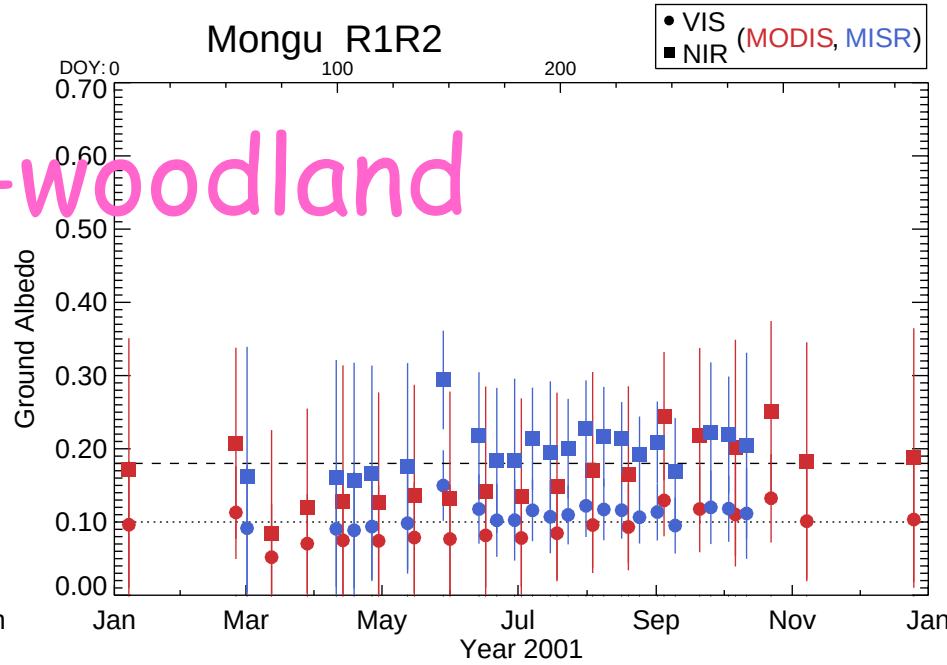
Agriculture



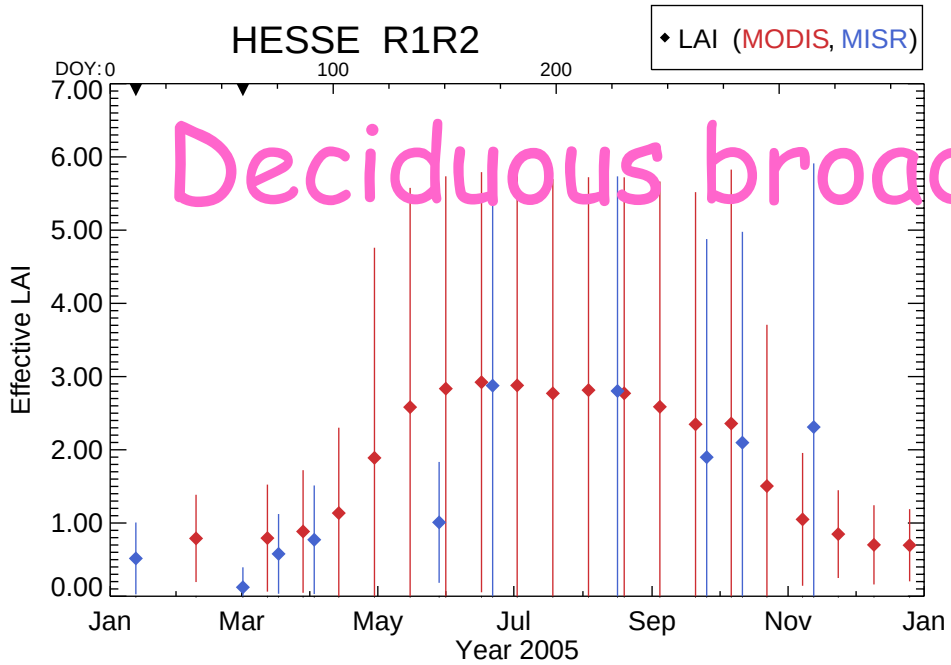


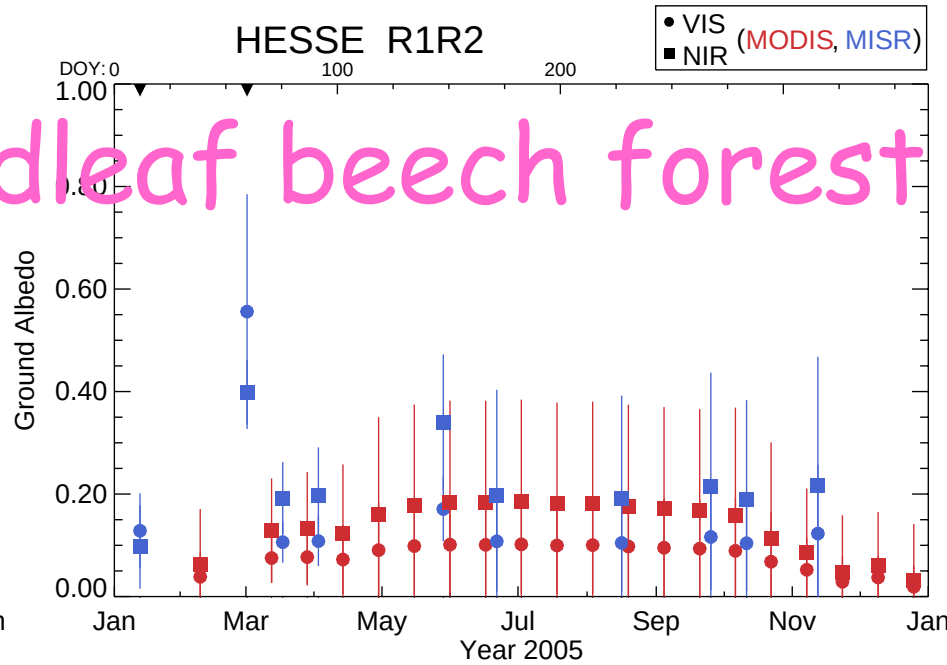
Semi-desert



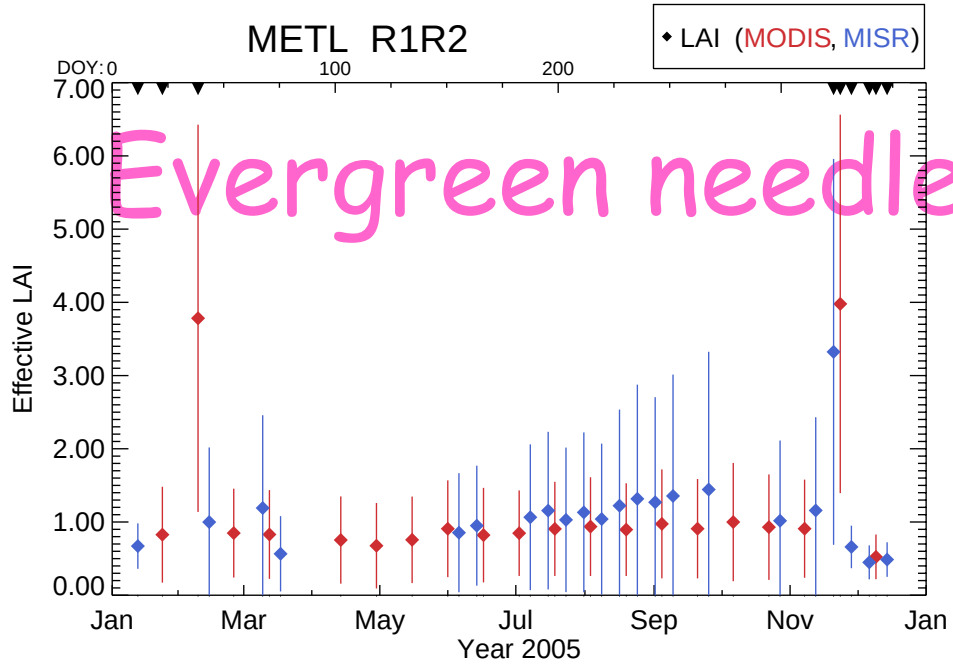


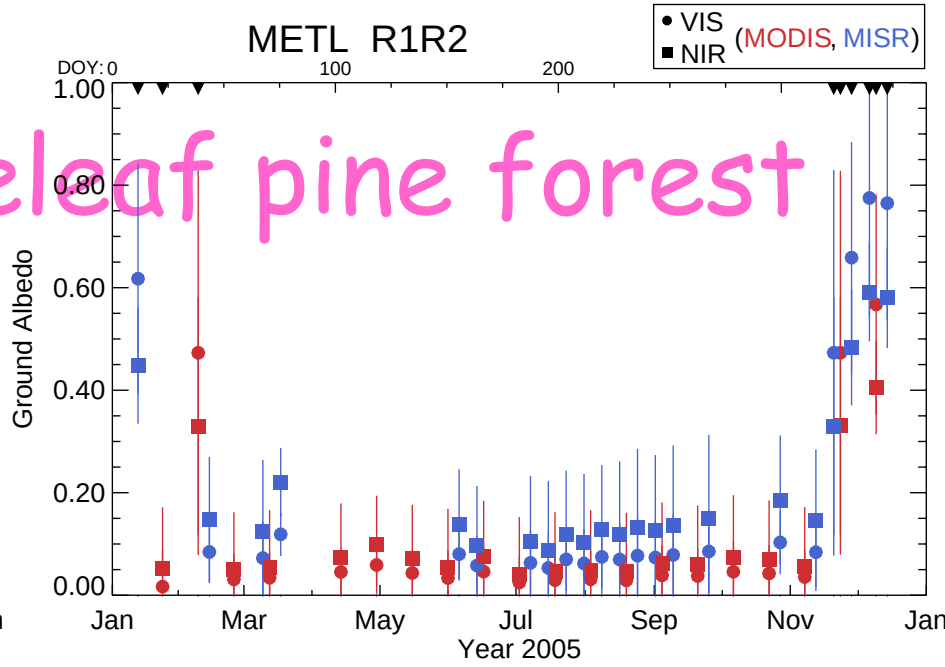
Shrubland-woodland



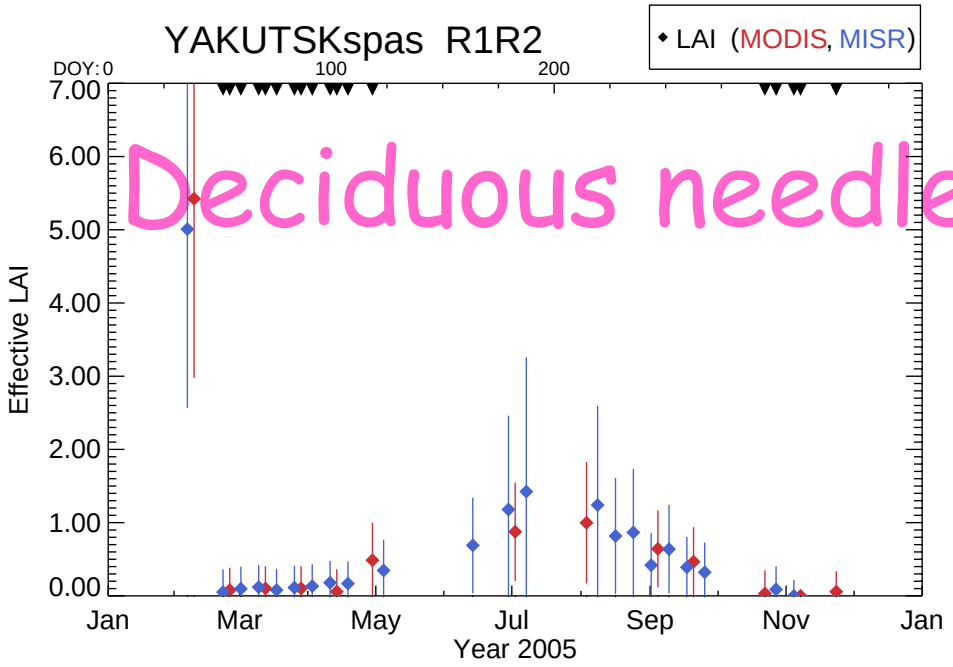


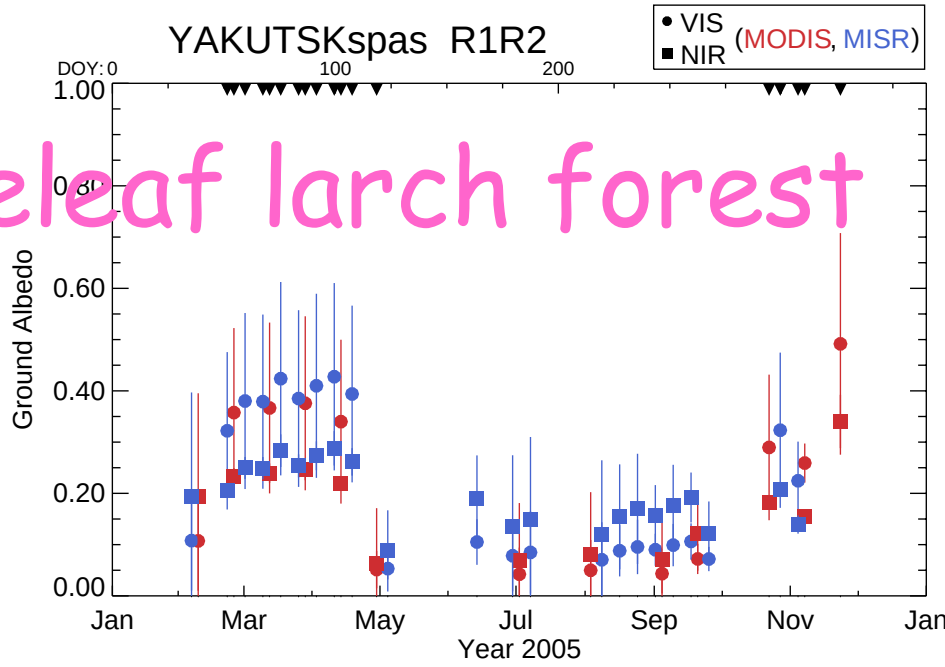
Deciduous broadleaf beech forest



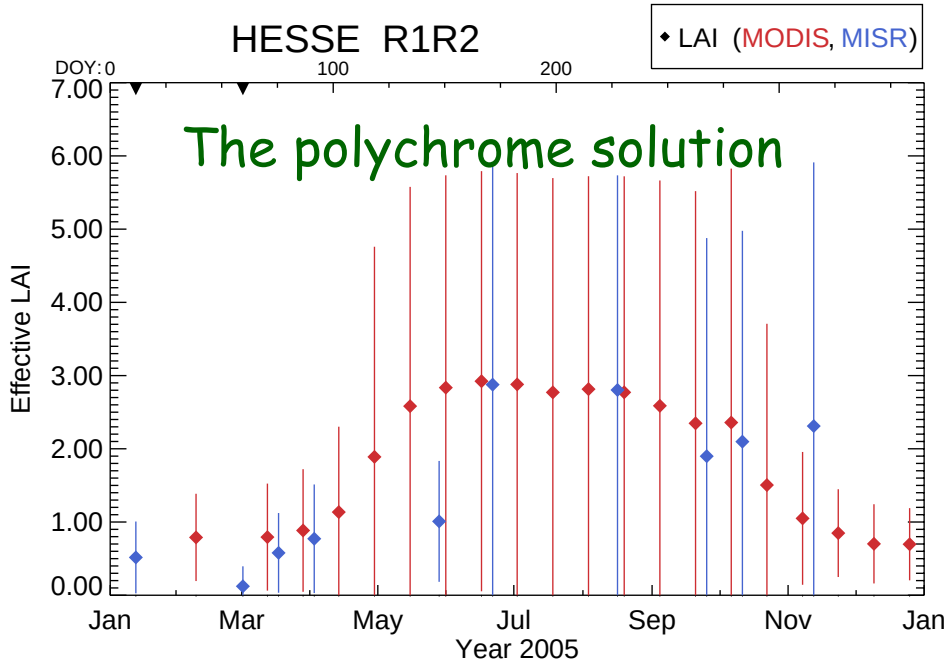


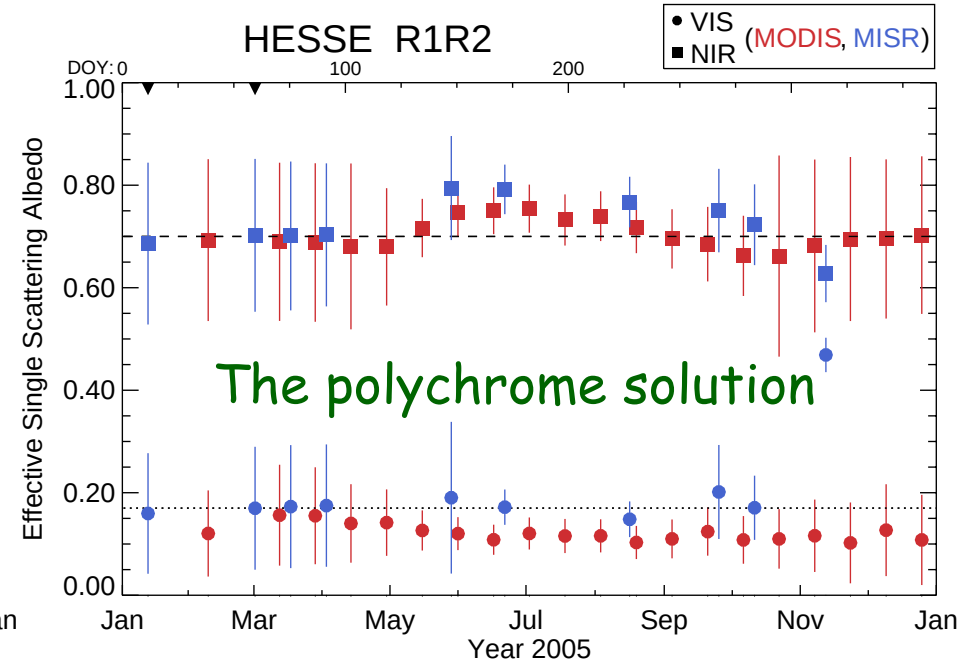
Evergreen needleleaf pine forest





Deciduous needleleaf larch forest


HESSE R1R2
LAI (MODIS, MISR)
DOY: 0
100
200
The polychrome solution
Effective LAI
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Jan
Mar
May
Jul
Sep
Nov
Jan
Year 2005


HESSE R1R2
VIS
NIR
(MODIS, MISR)
DOY: 0
100
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The polychrome solution
Effective Single Scattering Albedo
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0.80
0.60
0.40
0.20
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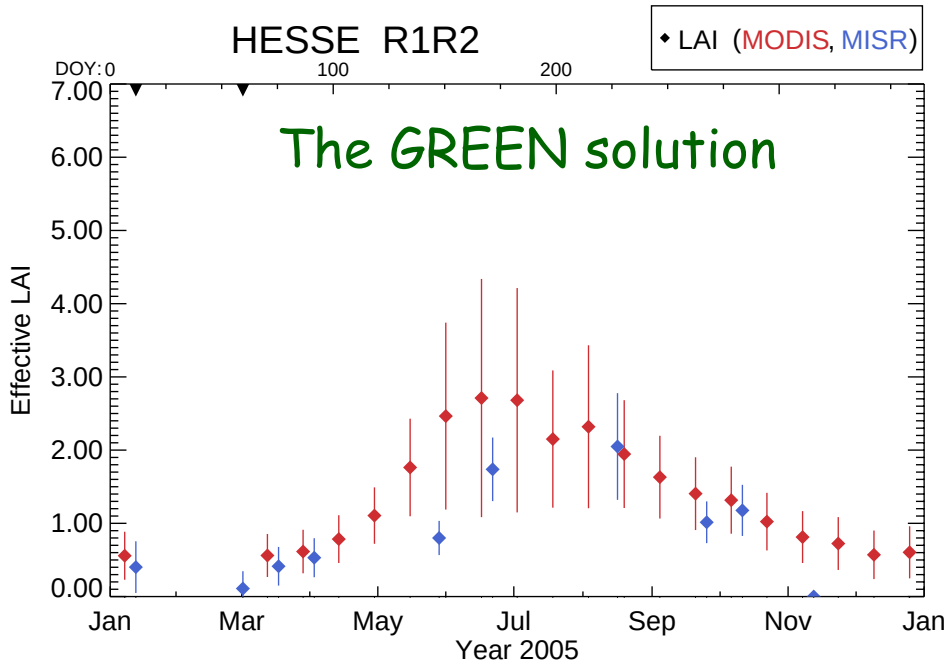
HESSE R1R2
LAI (MODIS, MISR)
DOY: 0
100
200
The GREEN solution
Effective LAI
7.00
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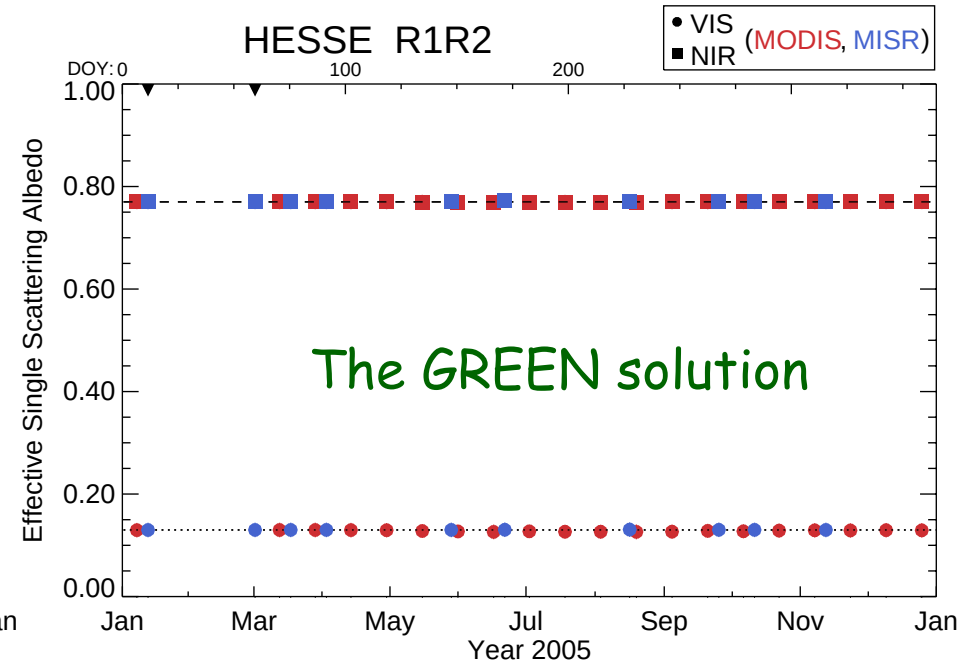
Year 2005


HESSE R1R2
VIS
NIR
(MODIS, MISR)
DOY: 0
100
200
The GREEN solution
Effective Single Scattering Albedo
1.00
0.80
0.60
0.40
0.20
0.00
Jan
Mar
May
Jul
Sep
Nov
Jan
Year 2005

Reducing uncertainties on model parameters and radiant fluxes

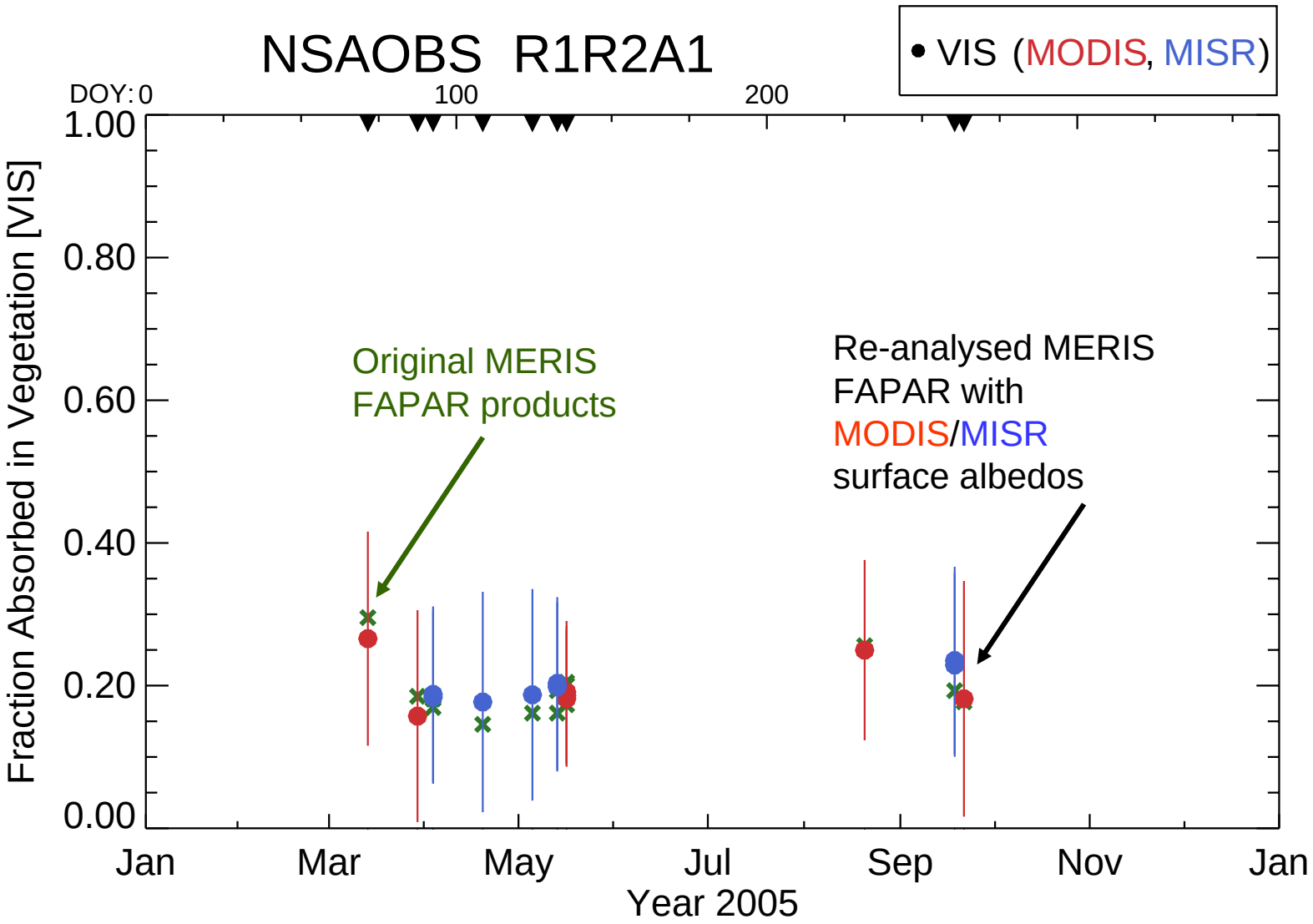
The large uncertainties on the retrievals, e.g. LAI and FAPAR, are mainly a direct consequence of :

1- Correlations between model parameters in relation with radiation transfer processes

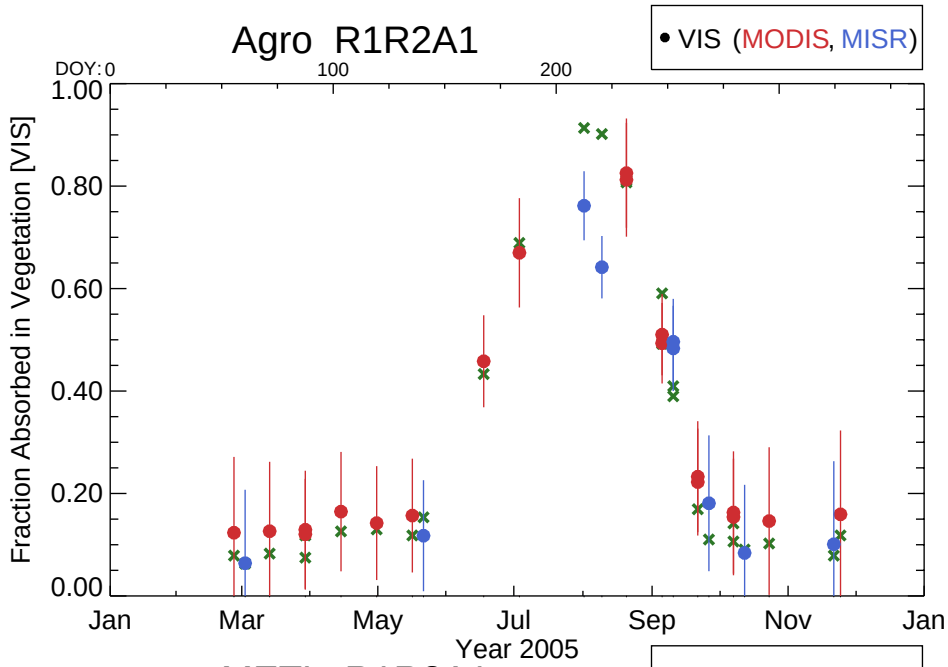
2- Limited a priori knowledge on model parameters and from available measurements

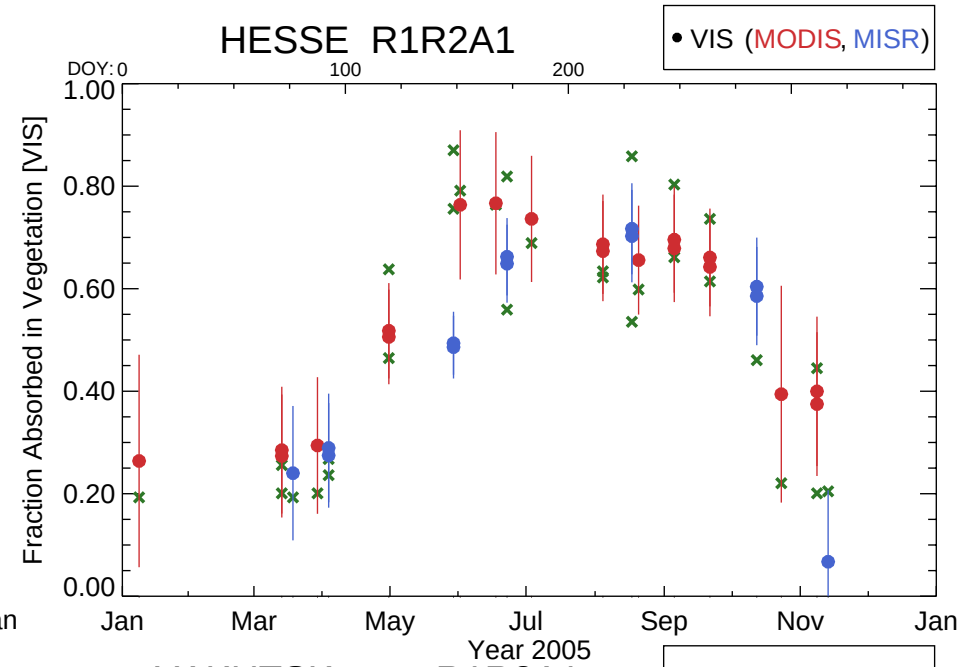
→ Add extra measurement(s)

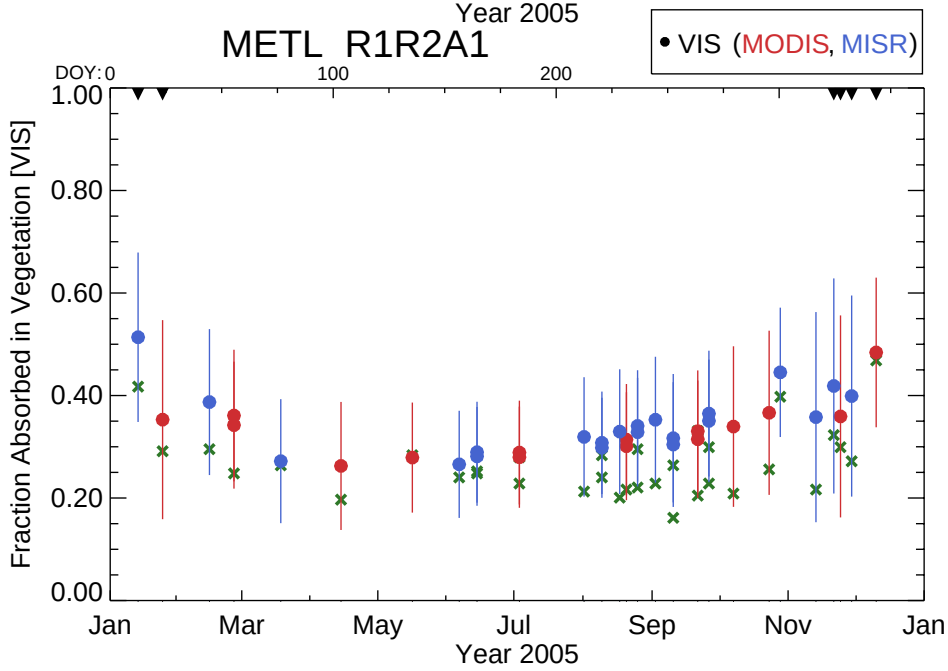
Application over NSAOBS: radiant fluxes

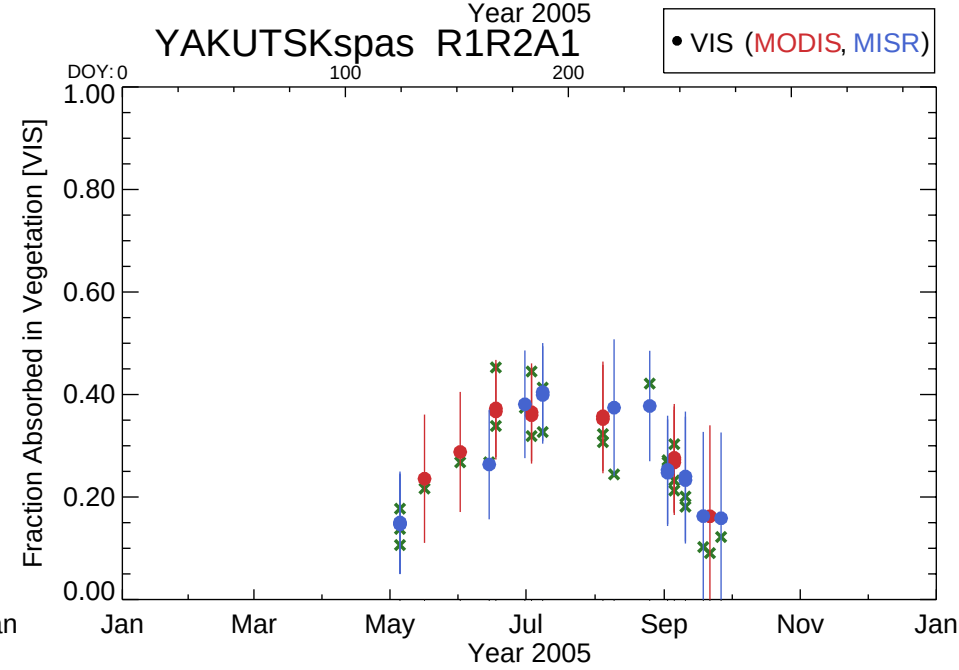


Assimilation of the MODIS and MISR surface albedos









Assimilation of the MODIS and MISR surface albedos

Concluding remarks

1. Computer efficient inversion package has been designed and tested : estimate of uncertainty on all retrievals

2. This integrated package can be used for various purposes : retrieval of parameters from RS products, validation of RS products, assimilation of RS products into Land surface schemes.

3. Capability to generate global surface model parameters ensuring full consistency with measured (uncorrelated) fluxes from various sources: spectral albedos from MODIS-MISR (and any other sources).

4. Estimating radiant fluxes and surface parameters in the presence of snow .