Global Perspective on the Plane-parallel Nature of Oceanic Water Clouds Using Data Synergy From MISR and MODIS

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Motivation

Application of the plane-parallel assumption

The plane-parallel assumption is ubiquitously used for solving the inverse and forward radiative transfer problems of clouds.

Clouds are assumed to be plane-parallel homogeneous in the horizontal direction and even in the vertical direction.

The assumption makes the inverse problems solvable and the forward radiative transfer calculation fast.

Motivation

problems of using the plane-parallel assumption
in the forward radiative transfer calculations

At the scale comparable to the GCM-grid:

Grid cloud albedo calculated from the averaged cloud properties is biased high as compared to the averaged albedo calculated from independent pixels.

(e.g., $\Delta\beta$=0.02-0.3, derived with cloud properties retrieved from AVHRR by *Oreopoulos and Davies (1998)* and $\Delta\beta$=~0.03, derived with cloud properties retrieved from MODIS by *Oreopoulos et al. (2007)*).

At the smaller scales:

Radiative transfer model simulations show that the domain averaged albedo/flux biases range from the marginal to severe, depending on which cloud fields are examined and the assumptions used in the simulations, e.g., cloud resolution, domain size, SZA.

(*Cahalan, 1994; Barker, 1996; Fu et al., 2000; Zuidema and Evans,1998; O'Hirok and Gautier 1998; Cole et al., 2005; Kato et al., 2006*).

Motivation

problems of using the plane-parallel assumption
in the retrieving of cloud optical thickness

Retrieving at nadir for overhead Sun

$\tau_{retrieval} < \tau_{truth}$ (e.g., *Davies, 1978; Zuidema and Evans, 1998; Várnai and Marshak, 2003*; Kato et. al., 2006; *Kato and Marshak, 2009*).

Retrieving at nadir for oblique Sun

$\tau_{retrieval}$ increases with the increasing of SZA (e.g., *Loeb and Davies, 1996 (30% error); Zuidema and Evans, 1998; Kato et al., 2006).*

Retrieving in oblique views for oblique Sun

$\tau_{retrieval}$ depends on the relative azimuth angle. But inconsistencies are found among literatures.

	Forward-scattering direction	**Backward scattering direction**
Kobayashi, 1993; Loeb et al., 1998; Loeb and Coakley, 1998	↘	↗
Várnai and Marshak, 2007	↗	↗
Kato et al., 2006	↘	↘

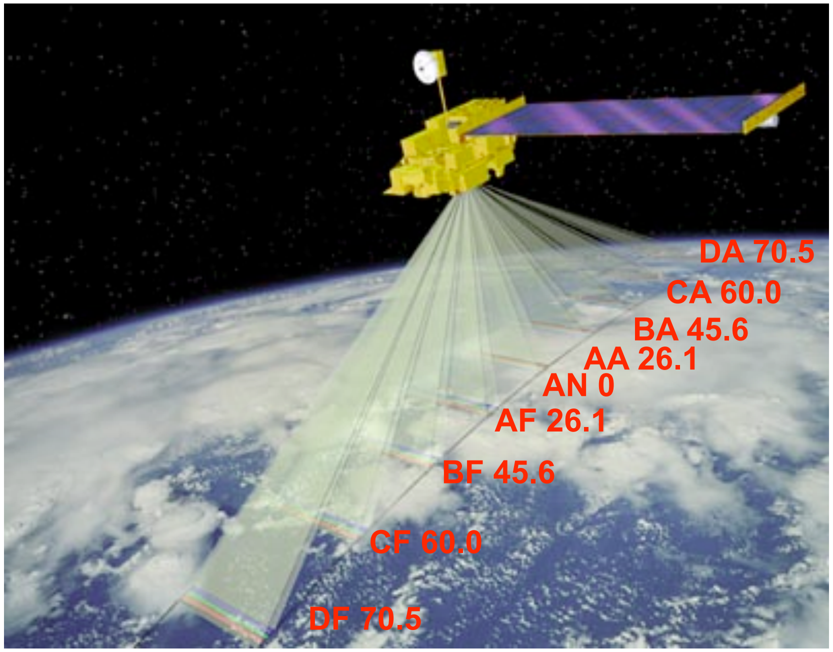
Motivation

How often and to what degree the plane-parallel assumption is valid for any given application requirement for real clouds on a global scale? Is there a way to identify cloud heterogeneity conditions under which the valid application of the assumption occurs?

How will the 1-D retrieved τ change with view-angle over the globe and to what extent?

Data fusion

MISR



(http://www-misr.jpl.nasa.gov/mission/miview1.html)

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MODIS

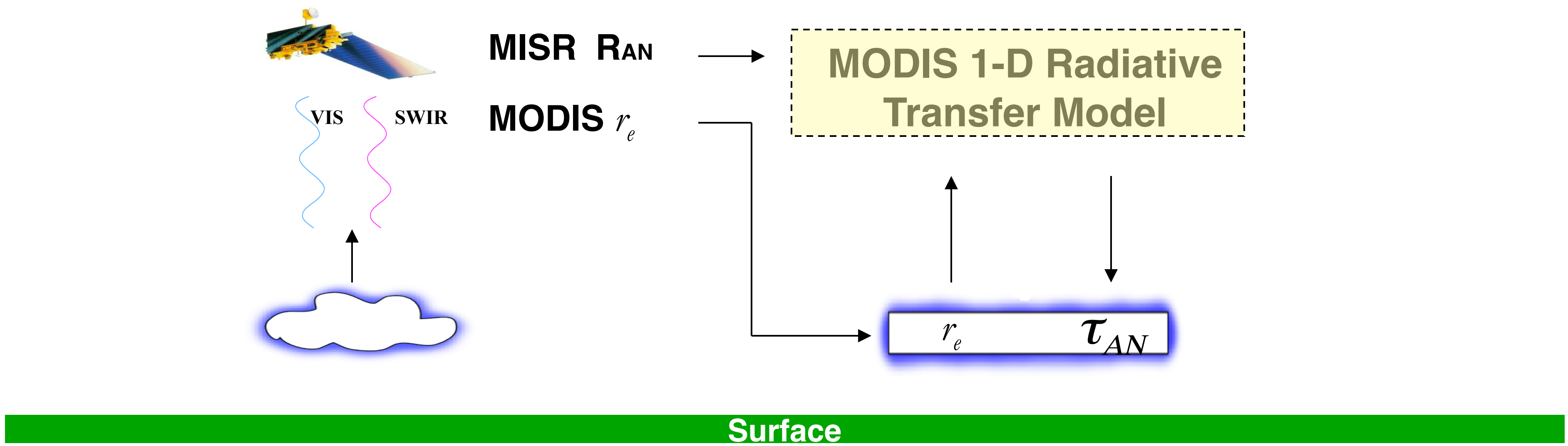
- cloud optical thickness
- cloud effective radii
- cloud phase

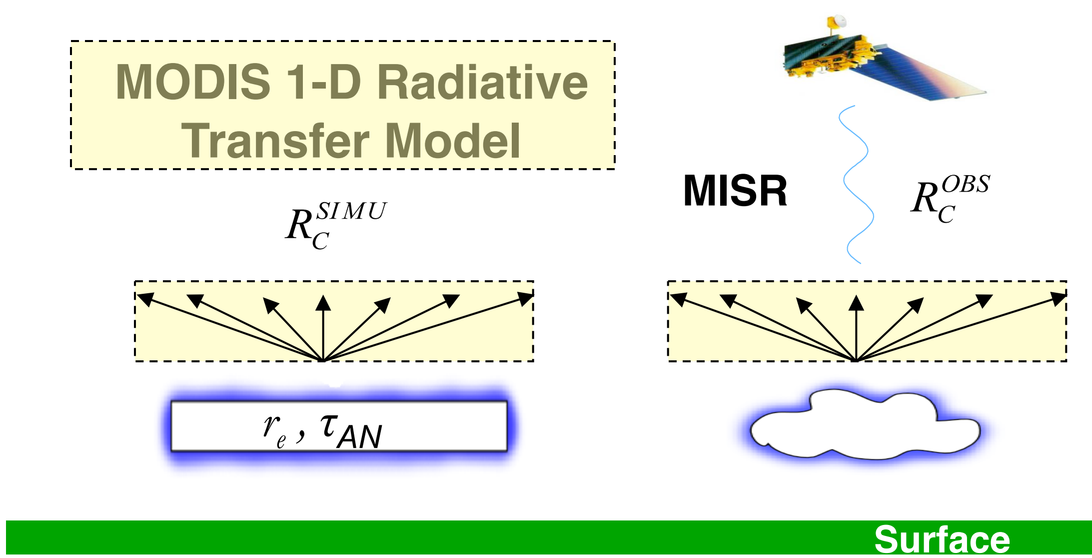
fusion is done at the cloud top

The applicability of the plane-parallel assumption through cloud view-angle consistency

Extracted from an article by *Liang et al.* [2009, GRL]
and a paper in preparation for submission titled "*A global view on the plane-parallel nature of oceanic water clouds*"

Approach #1



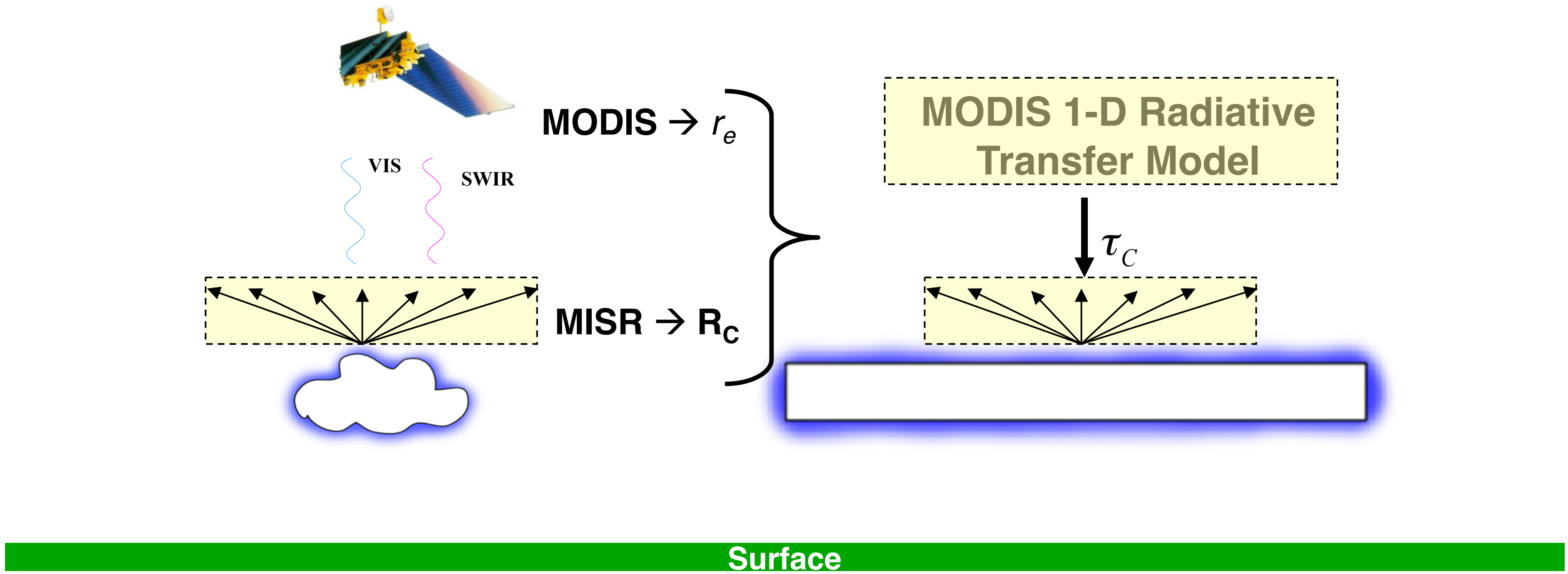


$$R_C^{SIMU} \quad R_C^{OBS} \quad \rightarrow \quad \delta_C = \frac{R_C^{OBS} - R_C^{SIMU}}{R_C^{OBS}}$$

Across the 7 cameras

$$m_{BRF} = \sqrt{\frac{1}{7}\sum_{C=1}^{7} \delta_C^{\,2}} \times 100\%$$

Approach #2



Across 7 cameras, normalized variation of τ_C

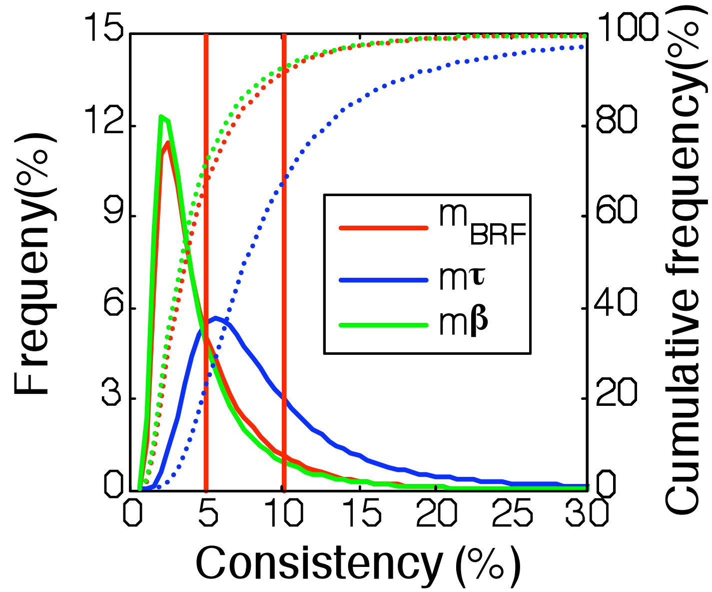
$$m_\tau = \frac{1}{\langle \tau_C \rangle} \sqrt{\frac{1}{7-1} \sum_C \left(\tau_C - \langle \tau_C \rangle \right)^2} \times 100\%$$

Can also use LWP or spherical albedo

View-angle consistency passing rates

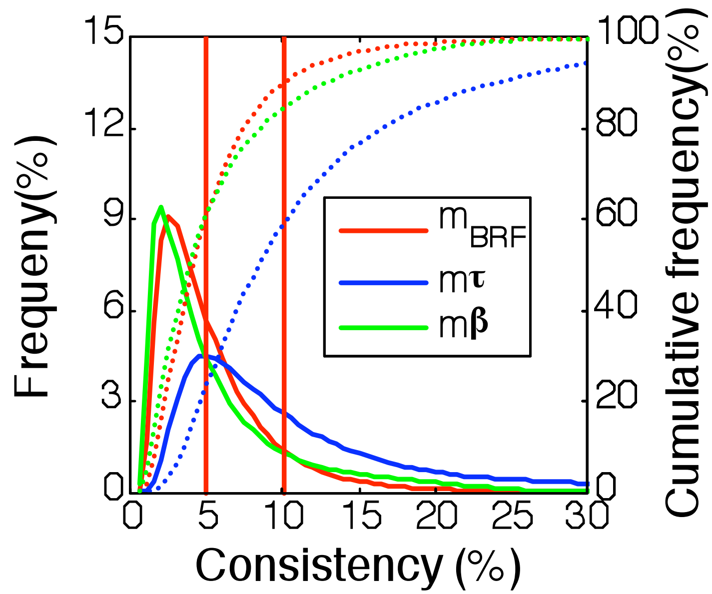
January

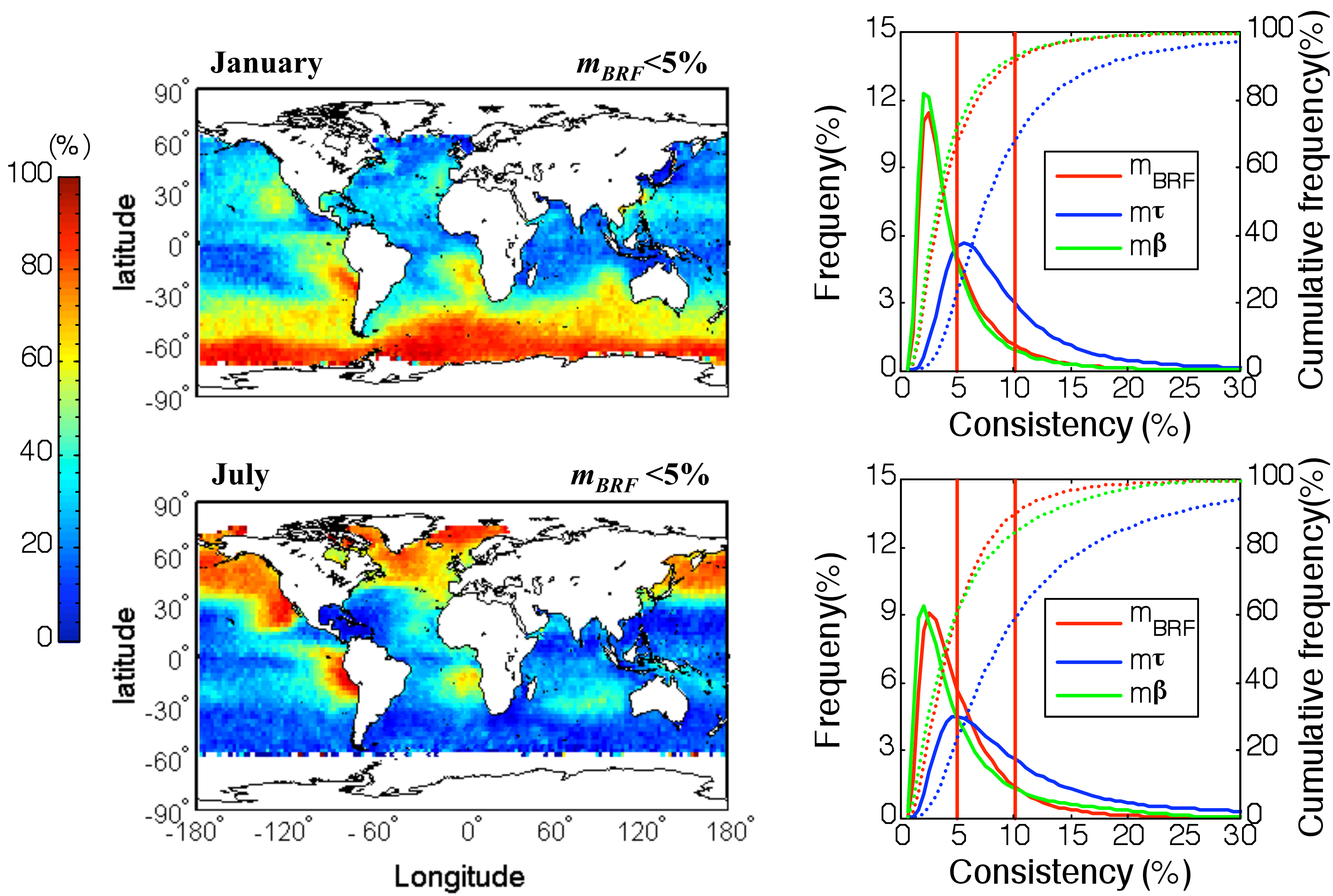
Passing rate threshold	5%	10%
m_{BRF}	68	92
m_{τ}	23	68
m_{β}	72	93



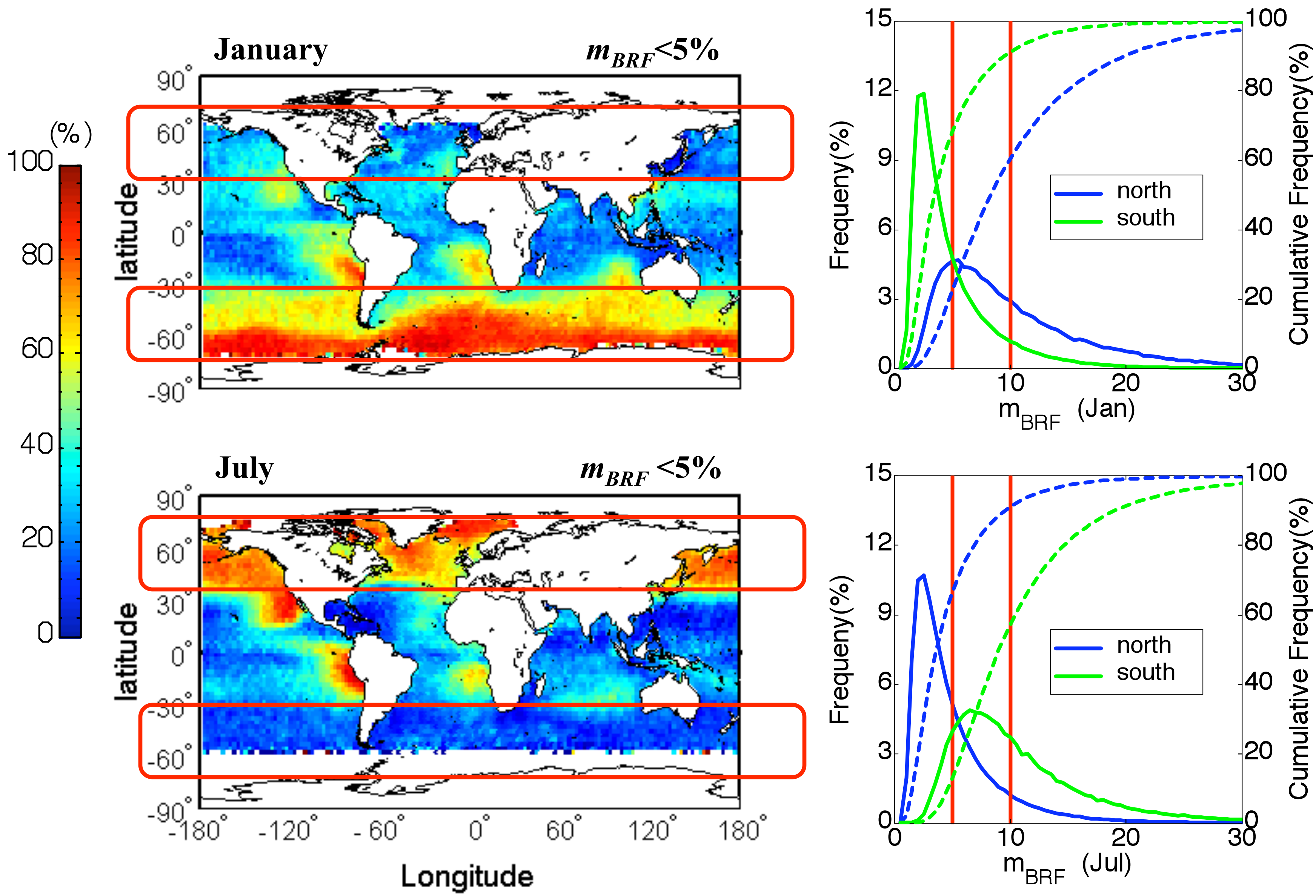
July

Passing rate threshold	5%	10%
m_{BRF}	61	90
m_{τ}	24	59
m_{β}	61	85



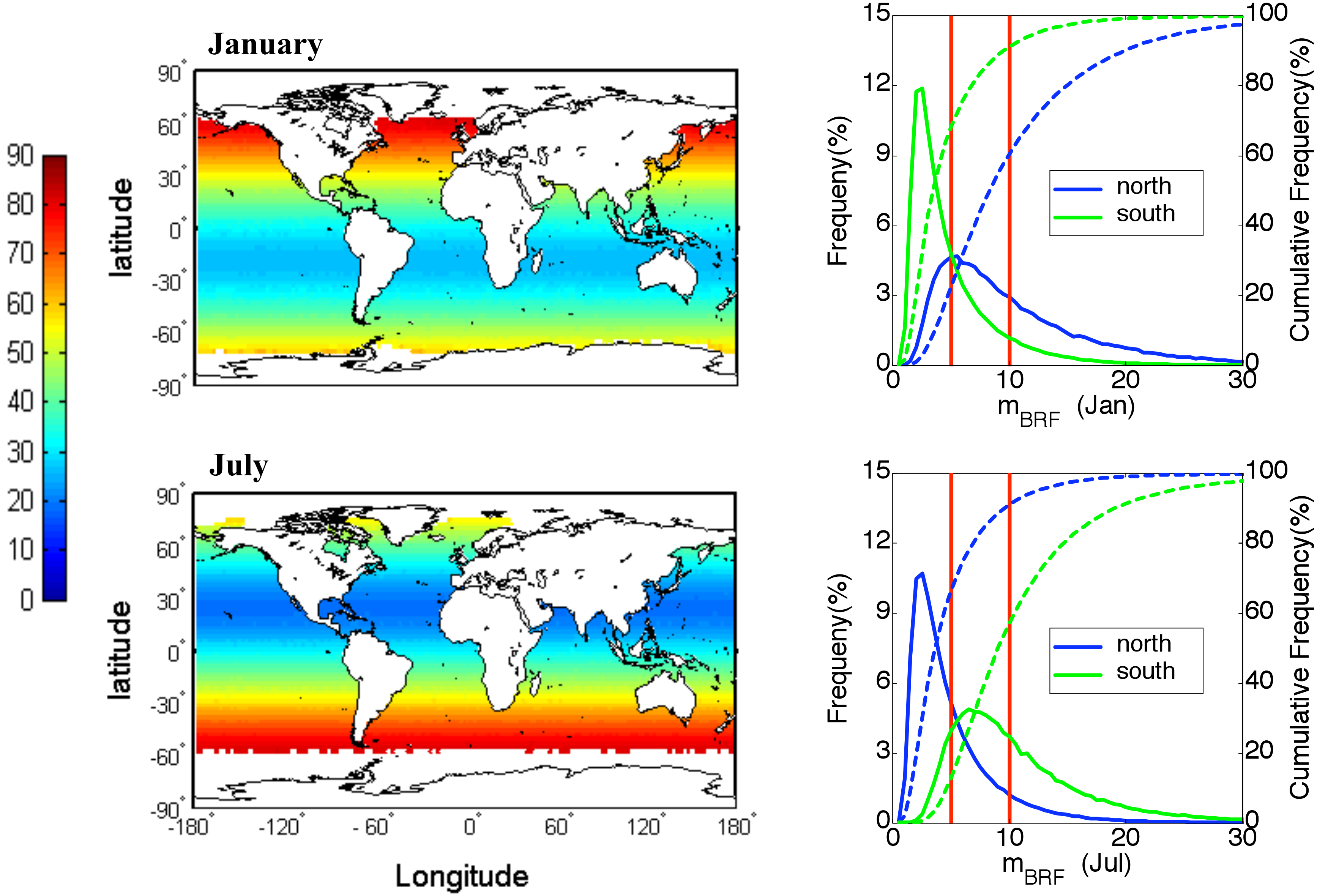


January
m_{BRF}<5%
July
m_{BRF} <5%
(%)
latitude
Longitude
Frequency(%)
Cumulative frequency(%)
Consistency (%)
m_{BRF}
$m\tau$
$m\beta$



January
m_{BRF}<5%
July
m_{BRF} <5%
(%)
100
80
60
40
20
0
90°
60°
30°
0°
-30°
-60°
-90°
latitude
-180°
-120°
- 60°
0°
60°
120°
180°
Longitude
Frequeny(%)
Cumulative Frequency(%)
north
south
m_{BRF} (Jan)
m_{BRF} (Jul)
15
12
9
6
3
0
10
20
30
100
80
60
40
20

Solar zenith angle dependence



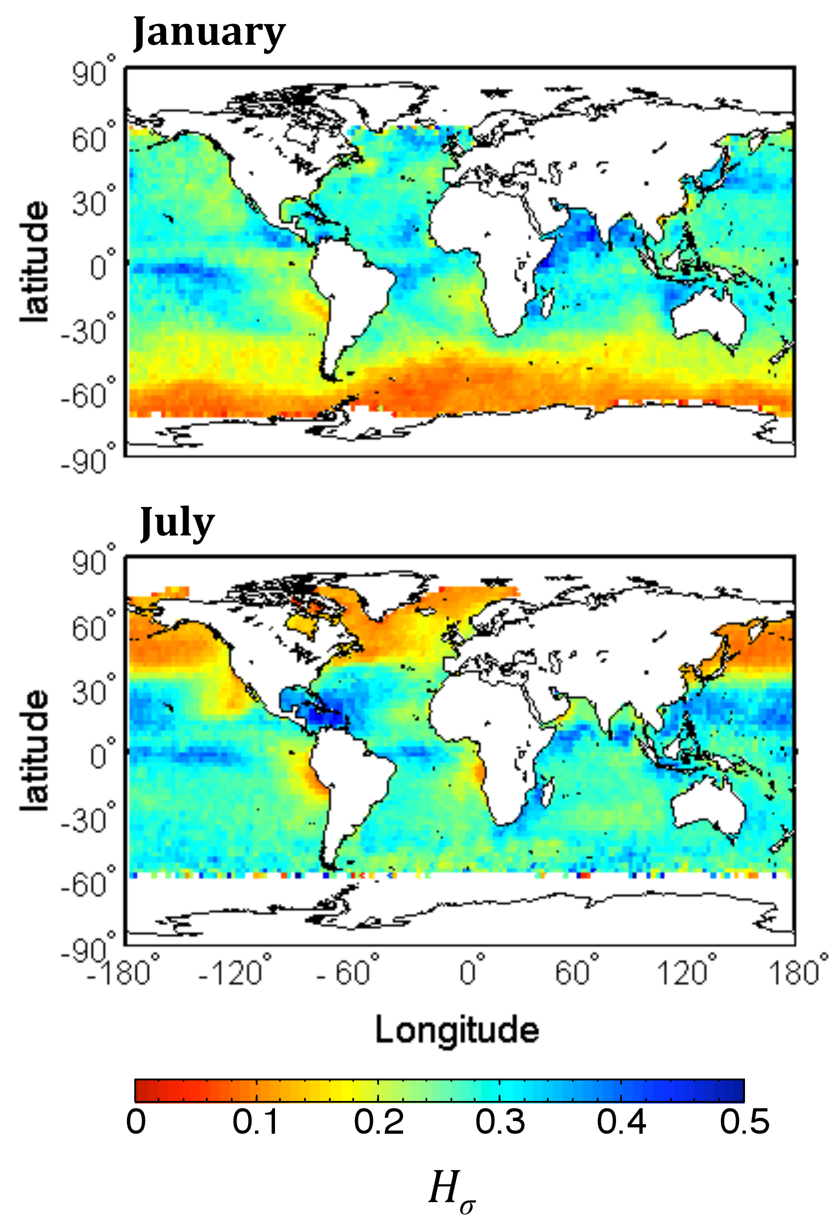
Angular consistency versus spatial heterogeneity

$$H_\sigma = \frac{\sigma}{\overline{R}}$$

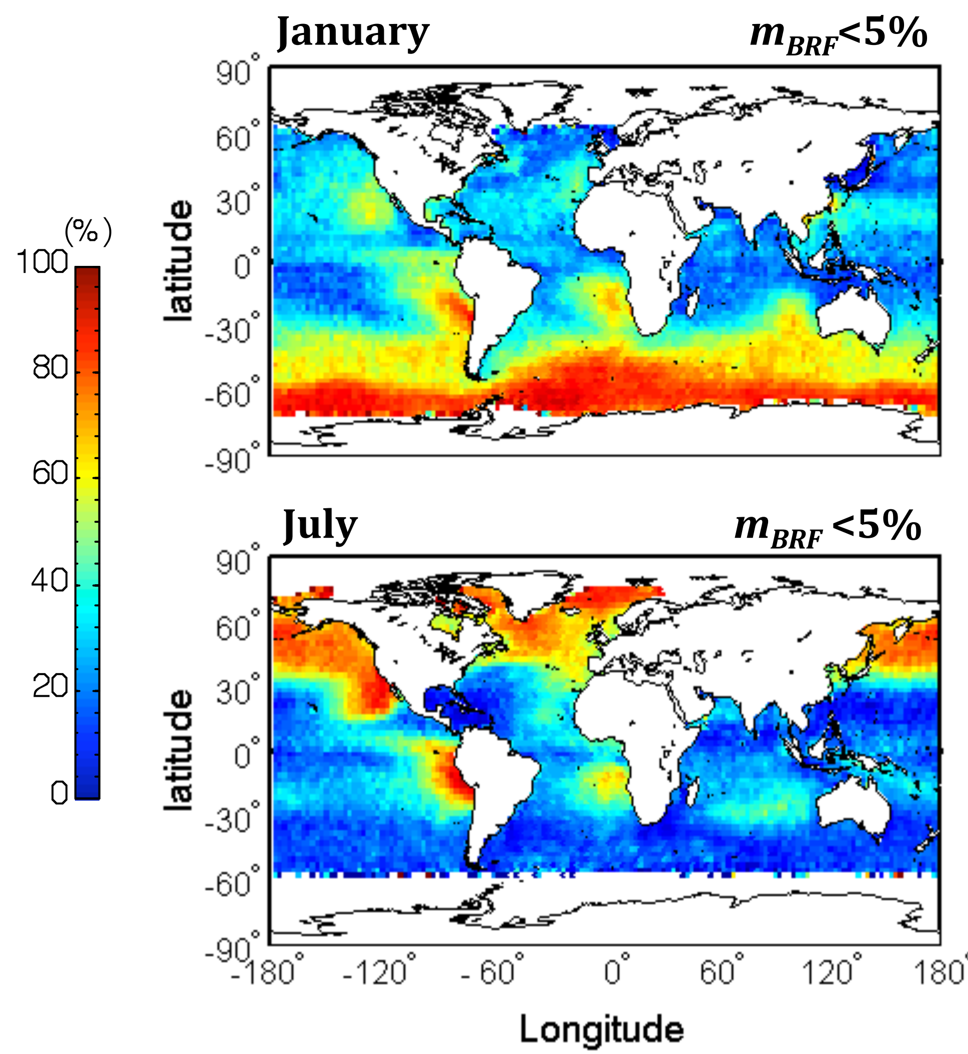
R = nadir red-channel BRF

$\overline{R}$ = mean R over 3 x 3 km^2

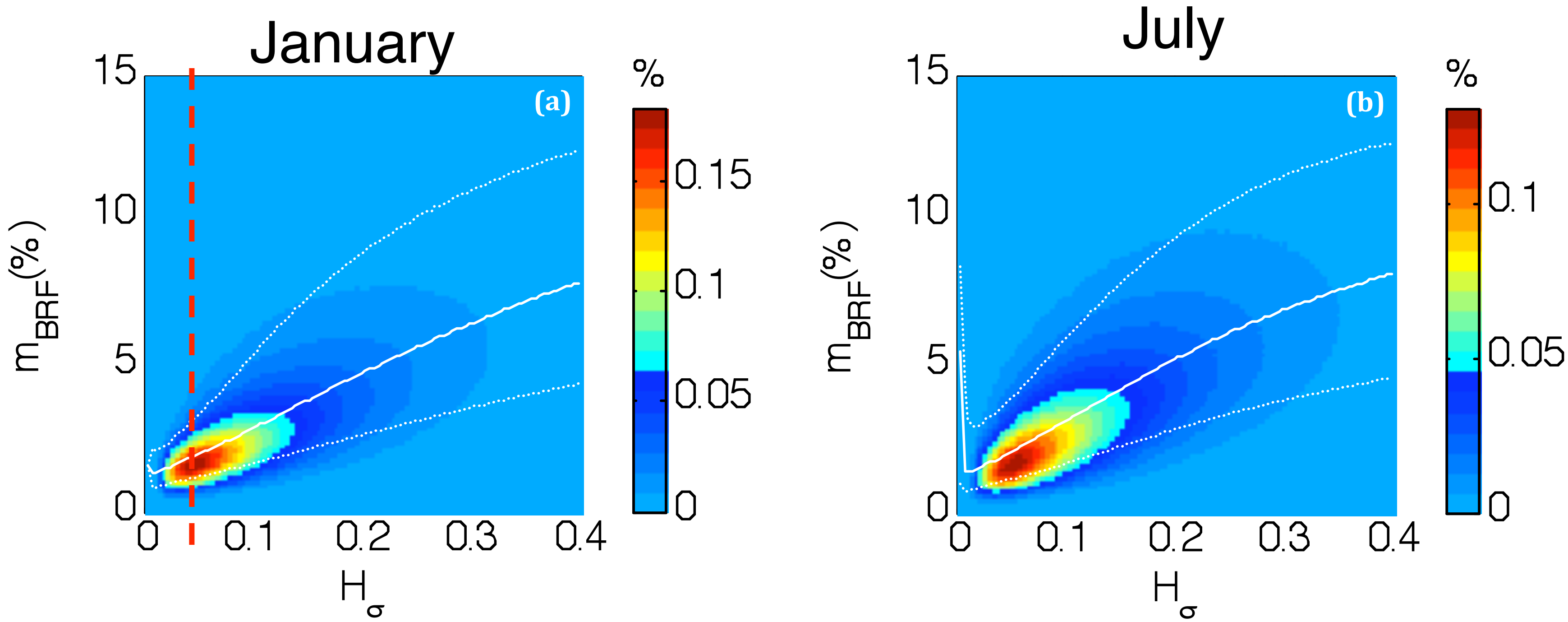
σ = standard deviation of R



Angular consistency versus spatial heterogeneity



Angular consistency versus spatial heterogeneity



Requiring 99% of retrievals to be angularly consistent in BRF to within 5% of their plane-parallel value, retrievals should be performed only on pixels where $H\sigma < 0.036$; ~ 14.4% of cloudy pixels met this criteria.

Viewing zenith angle dependence of cloud optical thickness

extracted from a paper in preparation for submission titled "*A global analysis on the view-angle dependence of plane-parallel oceanic water cloud optical thickness using data synergy from MISR and MODIS*"

Why MISR?

MISR can observe individual clouds at multi-angles near simultaneously. Examination can be done at the same time for the same SZA over the same scene.

- ✔ no latitudinal invariant assumption
- ✔ no seasonal invariant assumption
- ✔ consistent in cloudy scene identification
- ✔ small pixel size expansion

Data analysis

- Data were binned into 2.5º-latitude bins to characterize regional differences.

- View-angle dependence of 1-D retrieved τ was examined for large SZAs and VZAs and for various degrees of cloud optical thicknesses and cloud heterogeneities.

- Comparisons to the past studies were made.

Summary

- For the first time, we present the PDFs of cloud view-angle consistency to characterize the applicability of the plane-parallel assumption from globally representative observations. The regional distributions of view-angle consistency shows large spatial variation and SZA dependence.

- Relating the cloud view-angle consistency to the cloud spatial heterogeneity (H_σ) allows us to identify, with a prescribed confidence level, which MODIS microphysical retrieval and associated retrieval uncertainty within the MISR swath meet the plane-parallel assumption to within any desired range in view-angle consistency.

Summary

- **Our analysis of view-angle dependence of 1-D retrieved τconfirmed many τ-VZA relationships found in previous studies, while revealing additional complexities in the τ-VZA relationship by examining the data at large SZAs and VZAs and stratifying the data by cloud optical thickness and spatial heterogeneity.**

- **To fully understand the complex τ-VZA relationships requires to consider**
  1. **various 3-D radiative transfer pathways,**
  2. **increased viewing of more cloud-sides with viewing obliquity,**
  3. **relative azimuth angle between sun and view,**
  4. **concavity change in reflectance-τ non-linear relationship with view-angle, and**
  5. **other non-3-D radiative transfer effects.**

Questions?