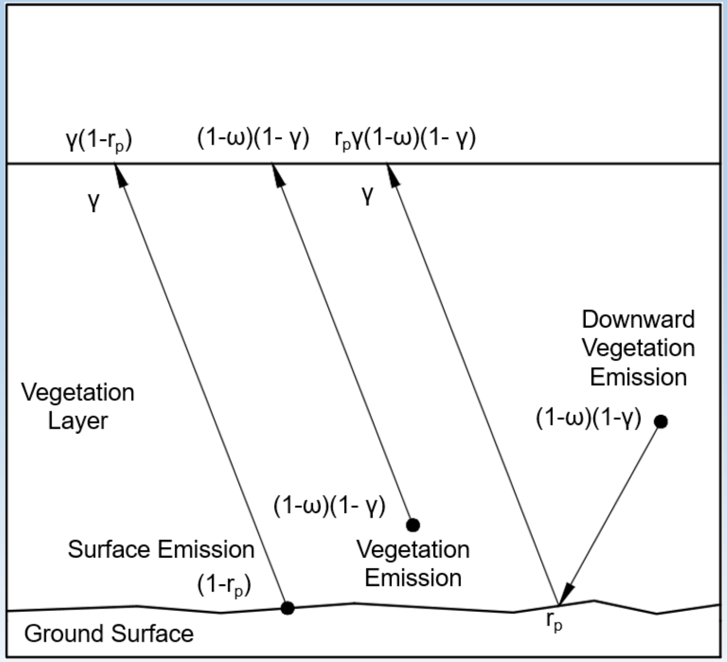
Radiometer-Based Surface Soil Moisture Including Higher-Order Soil-Canopy Interactions



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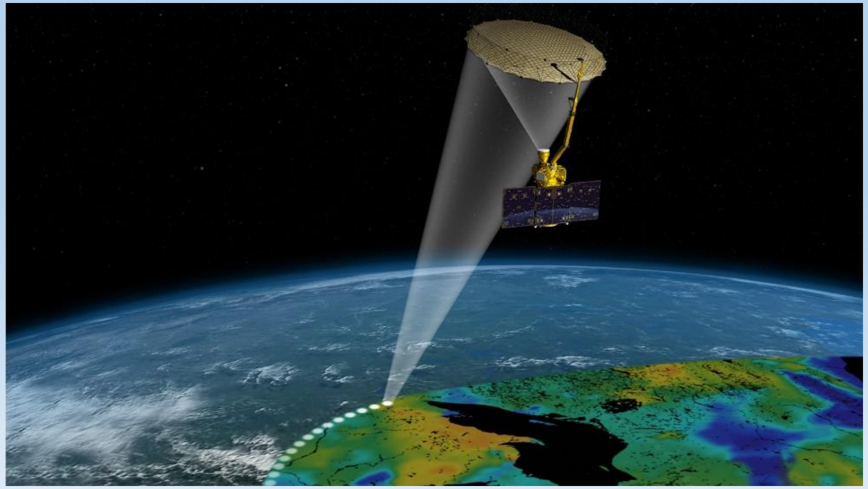


Background:

1. tau-omega is zero-th order radiative transfer model for opaque light vegetation over soil surface

2. Over more dense vegetation, more surface canopy interactions may be present

Questions:

1. How to include higher-order interactions in a retrieval algorithm?

2. Is the higher-order algorithm more (or less) sensitive to soil surface emission?

3. How do we estimate the parameter of the higher-order model (without more ancillary data inputs and assumptions)?

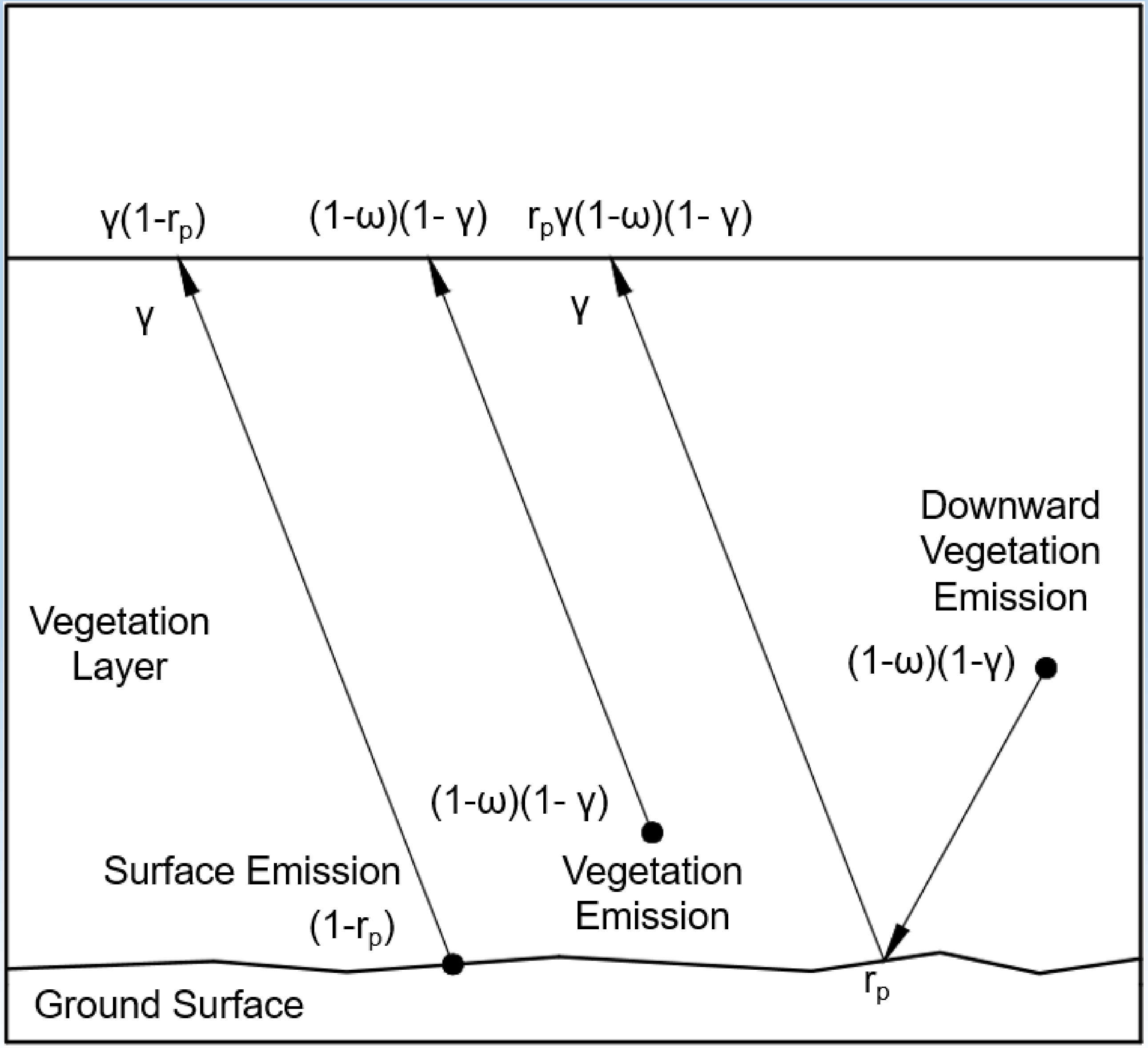
Address the three questions above and use a

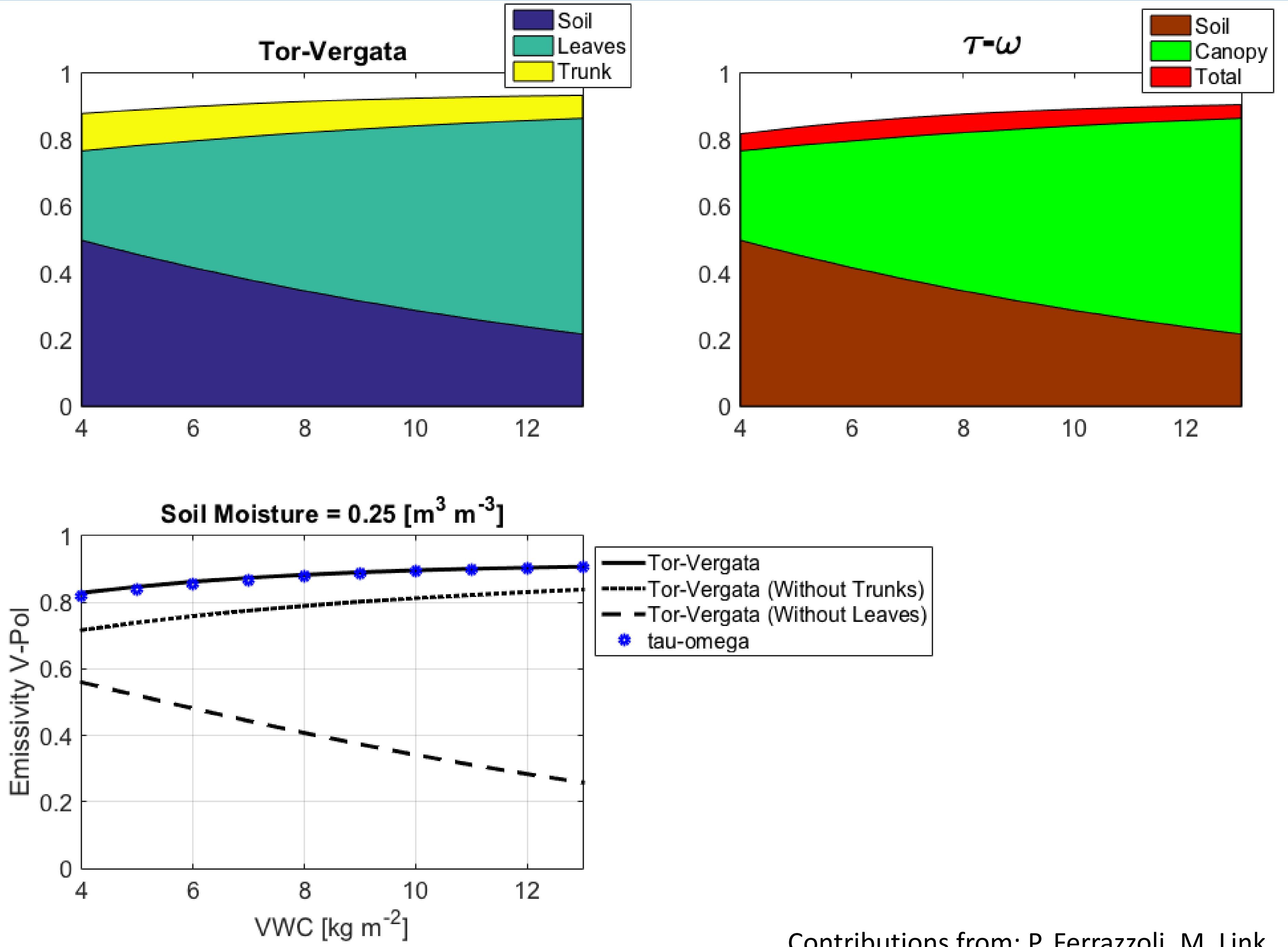
- dry tropical forest (woody vegetation with sharp seasonal phenology) and
- an agricultural

sites for demonstration.

$$\frac{T_B}{T} = \gamma(1 - r_p) + (1 - \omega)(1 - \gamma) + r_p\gamma(1 - \omega)(1 - \gamma)$$

tau-omega model





Contributions from: P. Ferrazzoli, M. Link

tau-omega model closely compares to numerical RT model for wide range of VWC

SMAP Single Channel Algorithm (SCA)

- Retrieves:
  - SM time series

- Using:
  - Land Cover Classification

Multi-Temporal Dual Channel Algorithm (MT-DCA)

- Retrieves:
  - SM, τ time series
  - single value of ω

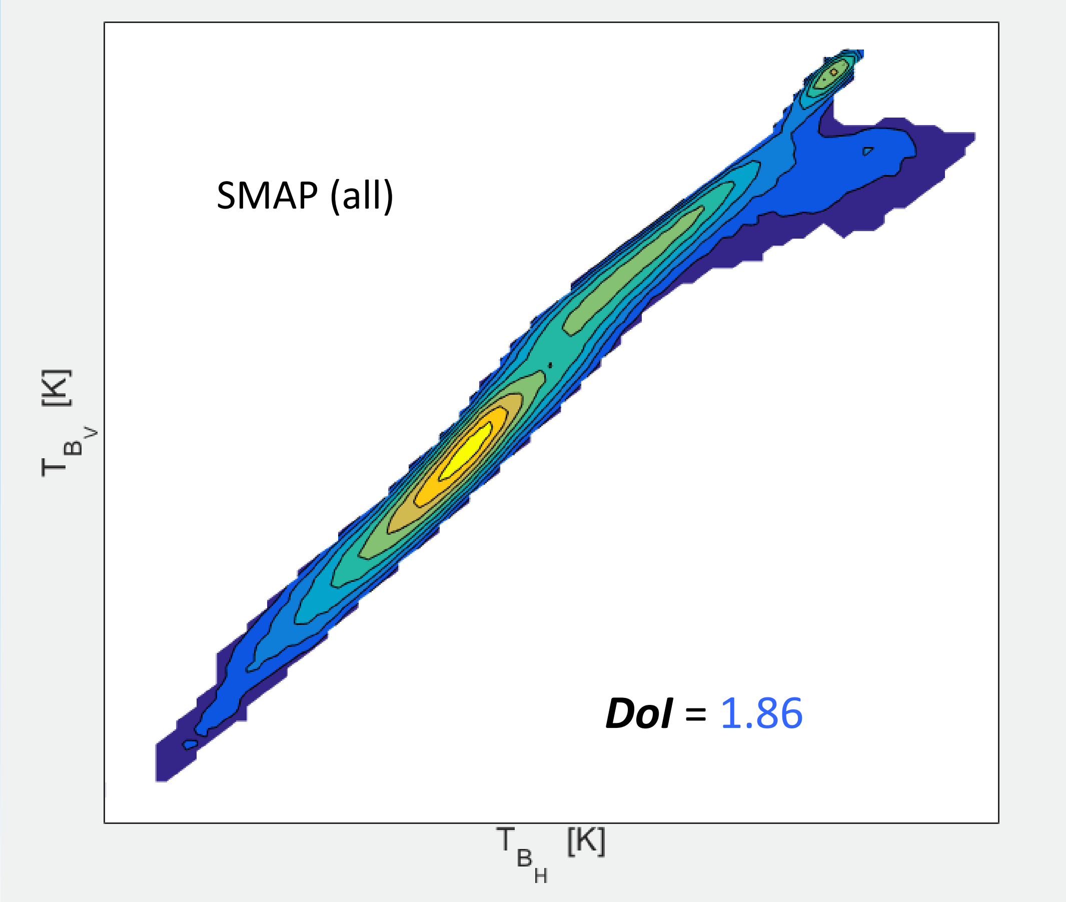
- Using:
  - Multiple passes
  - VWC about constant between passes

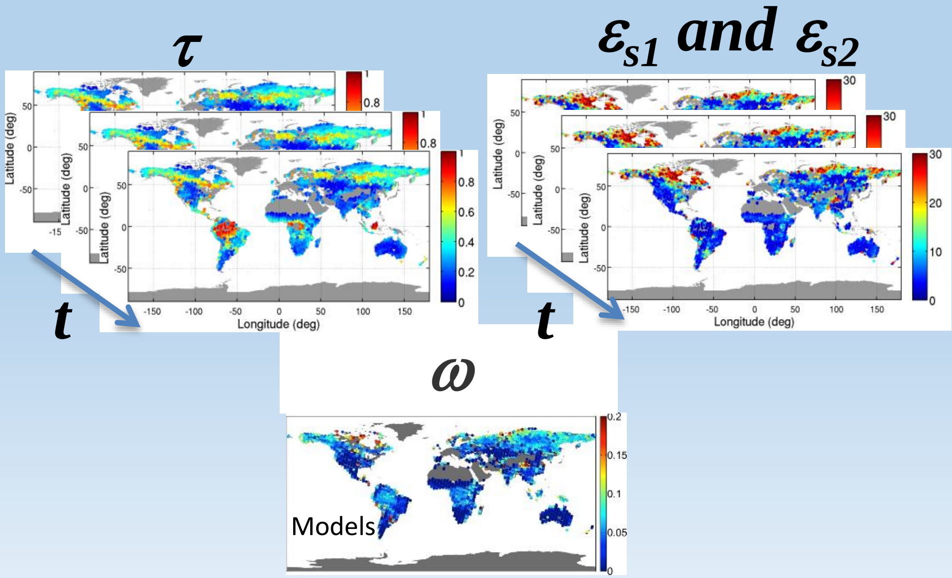
Konings et al. (2017) RSE

Retrieving Vegetation Parameters Without Relying on Optical Ancillary Data

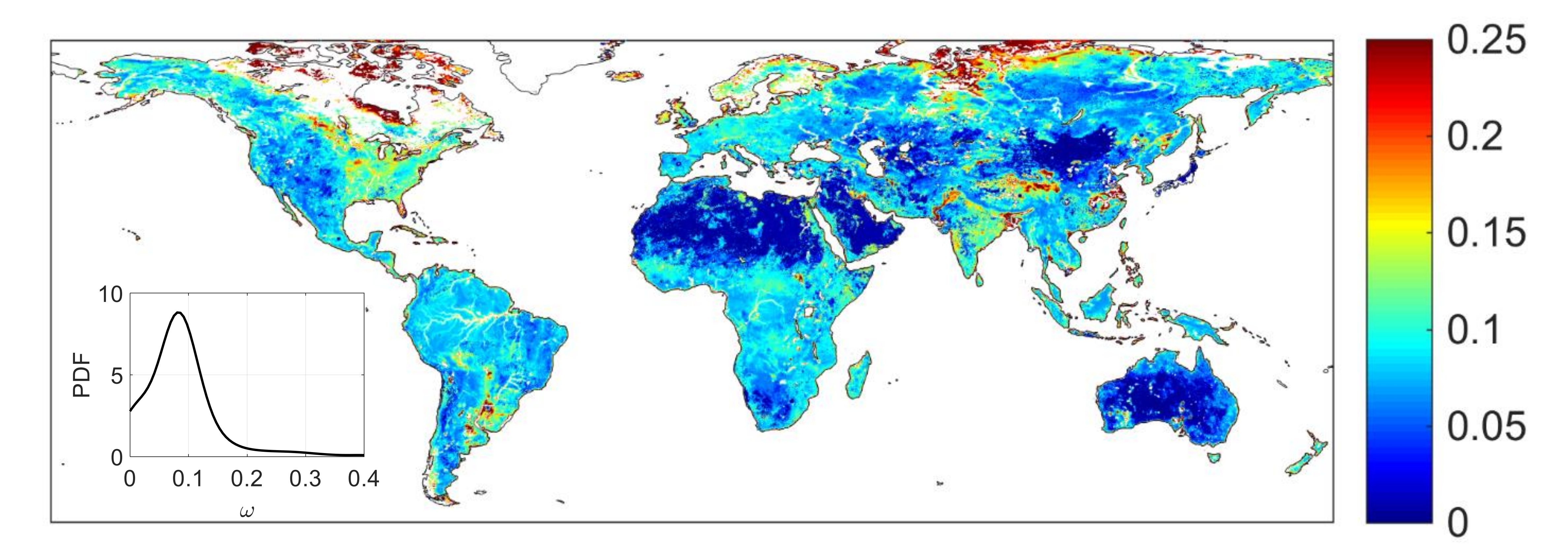
DoI: Konings, McColl, Piles, Entekhabi, 2015: How Many Parameters Can Be Maximally Estimated From a Set of Measurements? *GRSL* 12(5)

$$I(X;Y) = \int_Y \int_X p(x,y) \log\left(\frac{p(x,y)}{p(x)\,p(y)}\right) dx\,dy,$$





Multi-Temporal Dual Channel Algorithm (MT-DCA)



Global Effective Scattering Albedo Map (from SMAP data)

- Median = 0.08 (0.06, 0.10)
- Larger than used in SMAP & SMOS

Konings et al. (2017), RSE

Effective Scattering Albedo

Table 3
Values of the 'effective scattering albedo' (ω) as considered in current SMOS (Kerr et al., 2014; Kerr et al., 2012) and SMAP Level 2 & 3 retrieval algorithms (O'Neill et al., 2015) and retrieved in the recent studies of Konings et al. (2016) and for the SMAP Level 4 product (following De Lannoy et al., 2014).

Land cover type	'Effective scattering albedo' (ω)			
	SMOS algorithm (current, default)	SMAP L2 & 3 algorithm	Konings et al. (2016) (from Aquarius data)	SMAP L4 algorithm (from SMOS data)
Evergreen needleleaf forest	0.06–0.08[a]	0.050	0.05	0.12
Evergreen broadleaf forest	0.06–0.08[a]	0.050	0.05	0.08
Deciduous needleleaf forest	0.06–0.08[a]	0.050	0.06	0.12
Deciduous broadleaf forest	0.06–0.08[a]	0.050	0.03	0.10
Mixed forest	0.06–0.08[a]	0.050	0.05	0.12
Closed shrublands	0.00	0.050	0.03	0.14
Open shrublands	0.00	0.050	0.05	0.11
Woody savannas	0.00	0.050	0.04	0.13
Savannas	0.00	0.080	0.02	0.12
Grasslands	0.00	0.050	0.03	0.07
Croplands	0.00	0.050	0.04	0.12
Cropland/natural veg. mosaic	0.00	0.065	0.02	0.15
Barren or sparsely vegetated	0.00	0.000	–	–

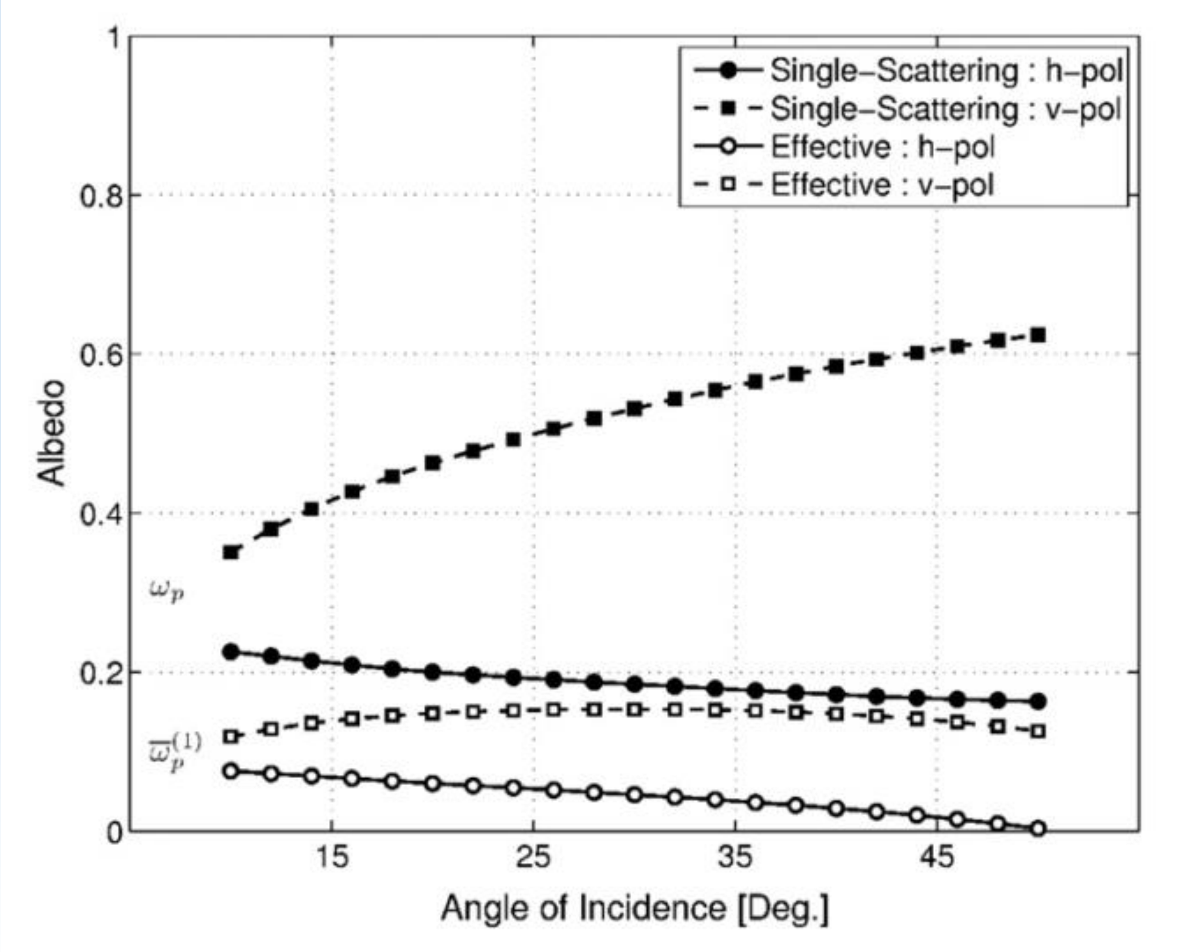
[a] ω = 0.08 over boreal forests, ω = 0.06 over the other forest types.

Wigneron et al. 2017

Effective Scattering Albedo: First Order Scattering

Kurum (2013) RSE

$$e_p^{(N)}(\theta) = \left[1-\gamma_p^2(\theta)R_{gp}(\theta)\right]-\bar{\omega}_p^{(N)}(\theta)\left[1+\gamma_p(\theta)R_{gp}(\theta)\right]\left[1-\gamma_p(\theta)\right]$$



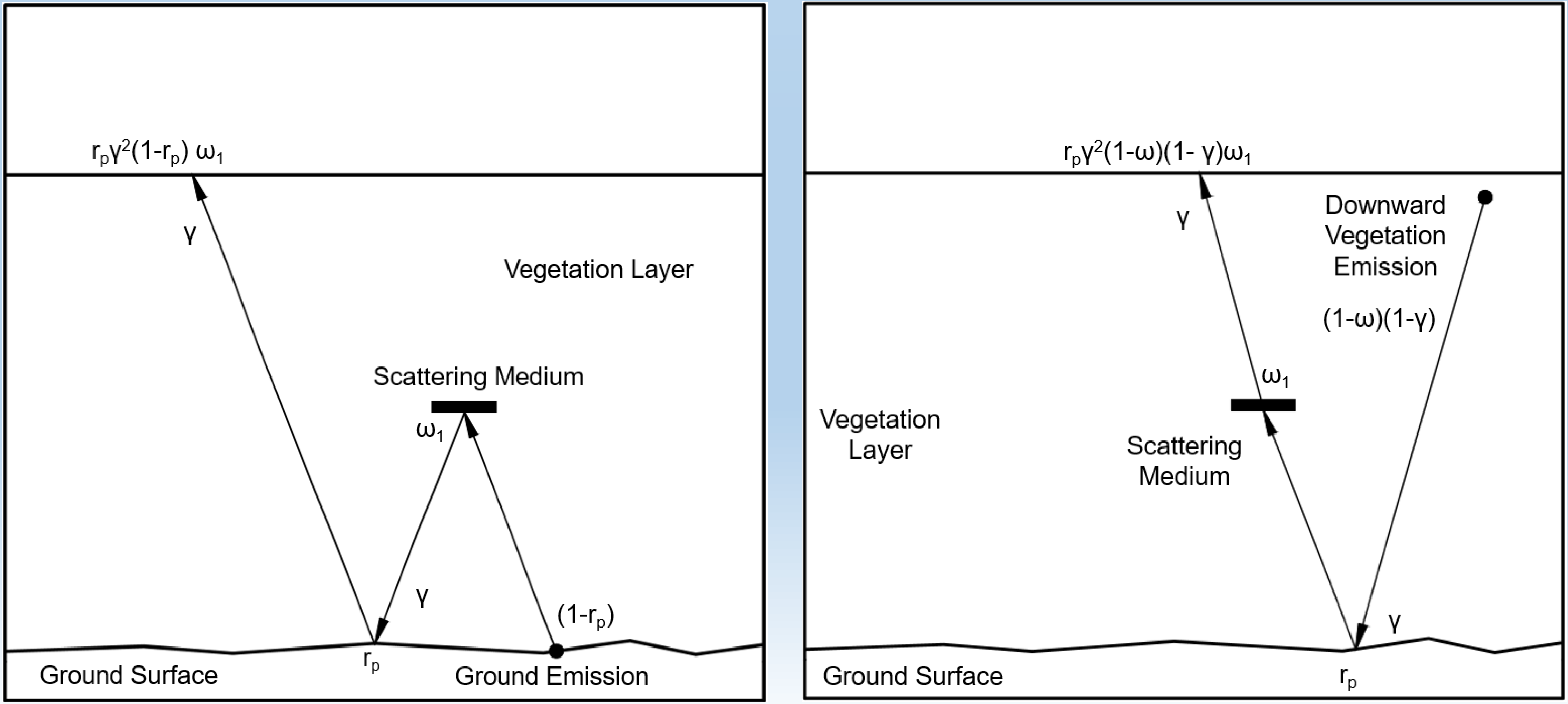
$$\bar{\omega}_p^{(N)}(\theta) = \omega_p(\theta) - \frac{\sum_{n=1}^{N}\Omega_p^{(n)}(\theta)}{\left[1+\gamma_p(\theta)R_{gp}(\theta)\right]\left[1-\gamma_p(\theta)\right]}.$$

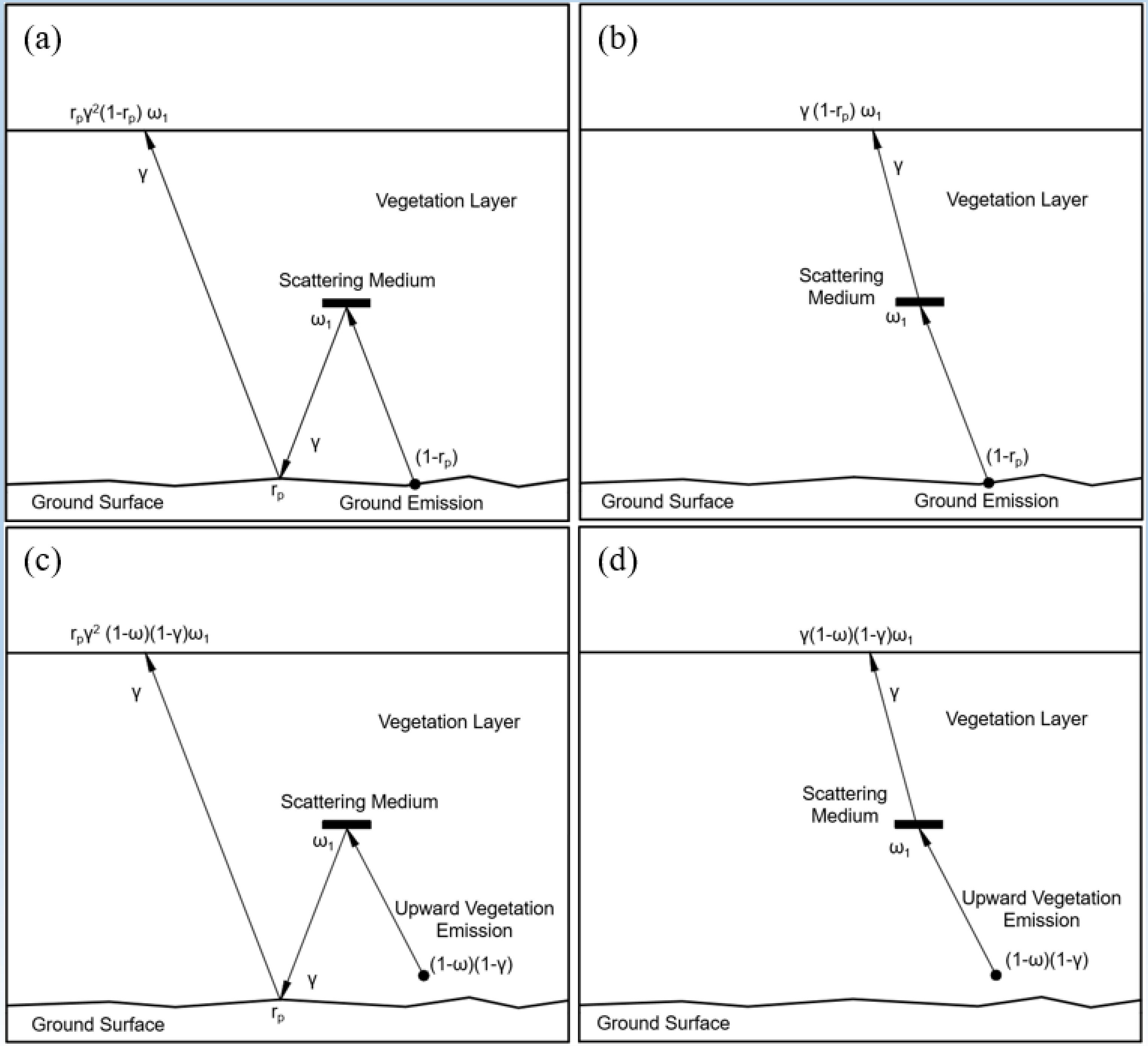
Accounting for first order scattering reduces single scattering albedo

Values estimated using forward model

Q1: How to include higher-order interactions in a retrieval algorithm?

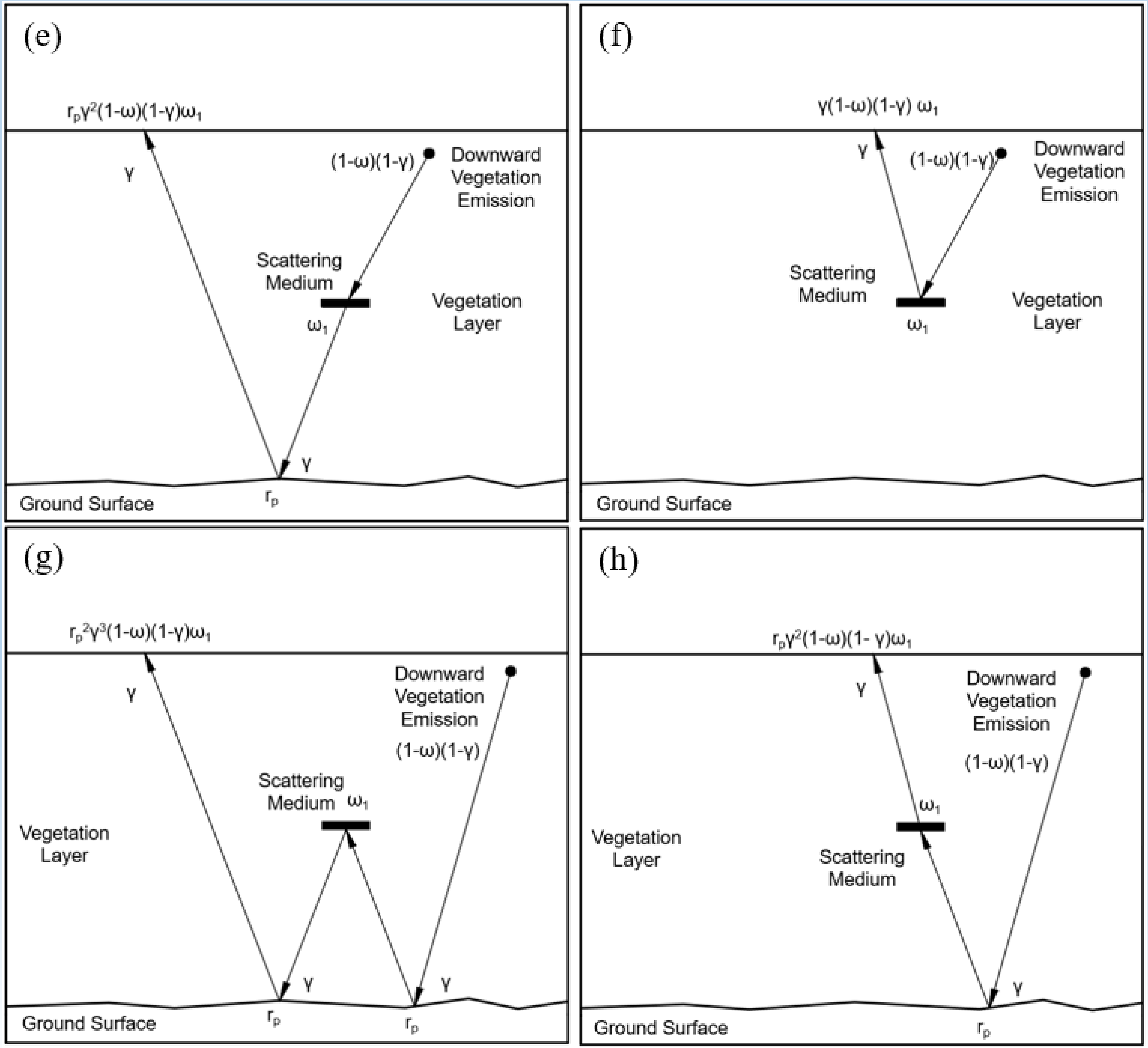
First Order Scattering Emission Pathways





Ground Emission

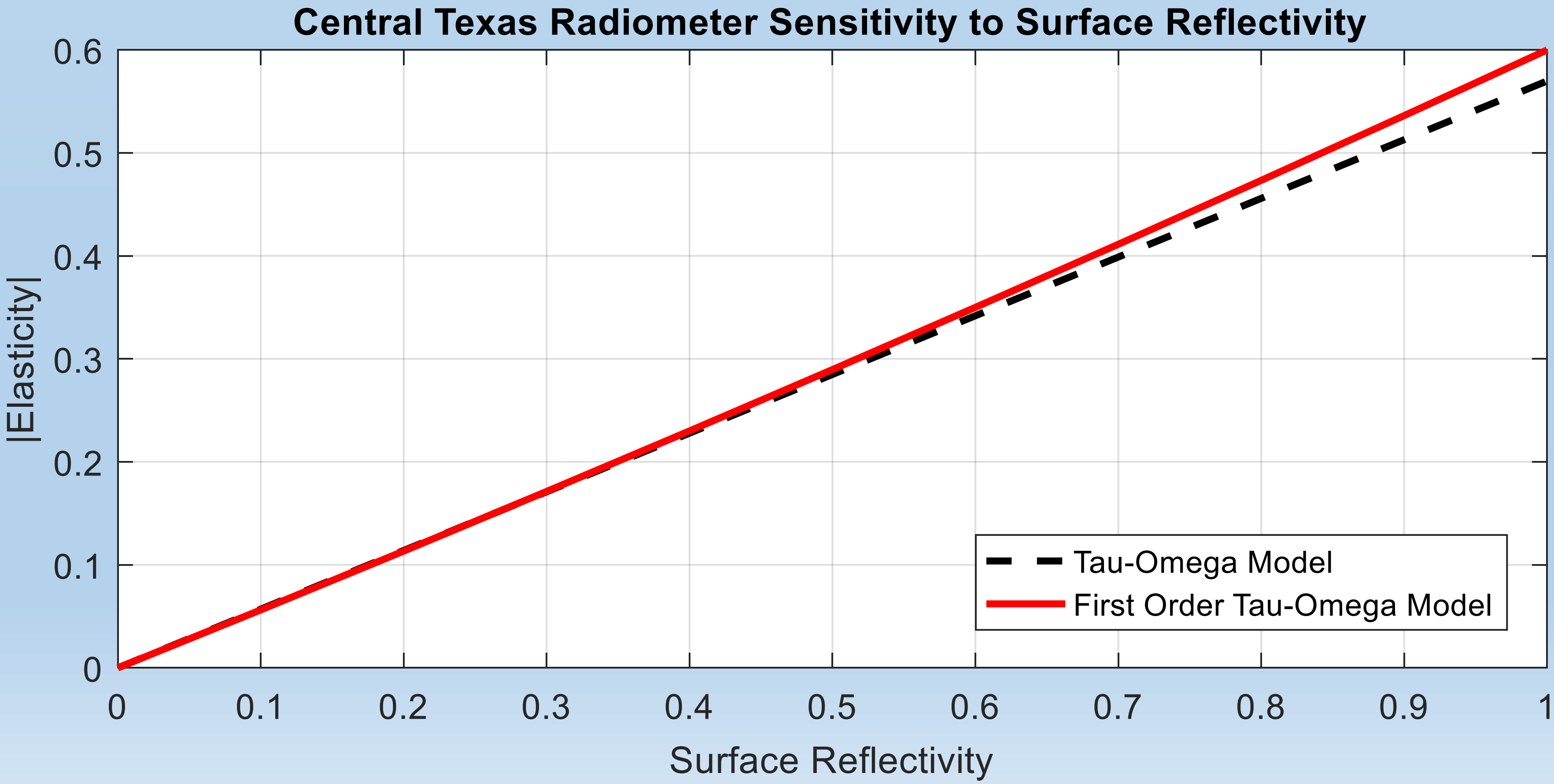
Upward Vegetation Emission



Downward Vegetation Emission

Downward Vegetation Emission with Surface Reflection

Q2: Is the higher-order algorithm more (or less) sensitive to soil surface emission?



Central Texas

$\omega_0 = 0.05$

$\omega_1 = 0.05$

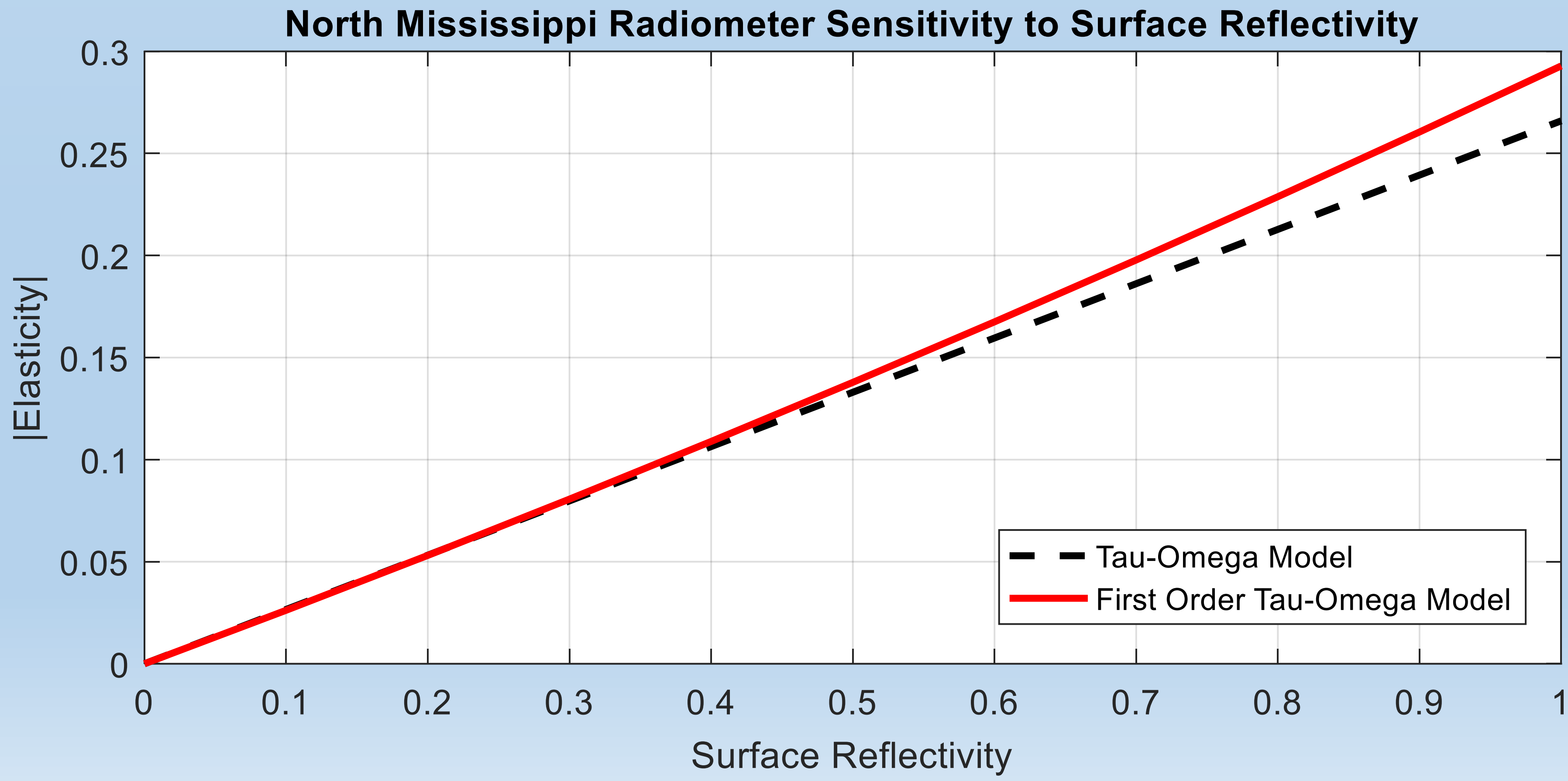
$\gamma = 0.73$

$\mathrm{h} = 0.16$

$$|Elasticity| = \left|\frac{r_p}{T_B}\frac{\partial T_B}{\partial r_p}\right|$$

$$SM = 0.25\ \frac{cm^3}{cm^3}$$

Q2: Is the higher-order algorithm more (or less) sensitive to soil surface emission?



N. Mississippi

$\omega_0 = 0.10$

$\omega_1 = 0.10$

$\gamma = 0.47$

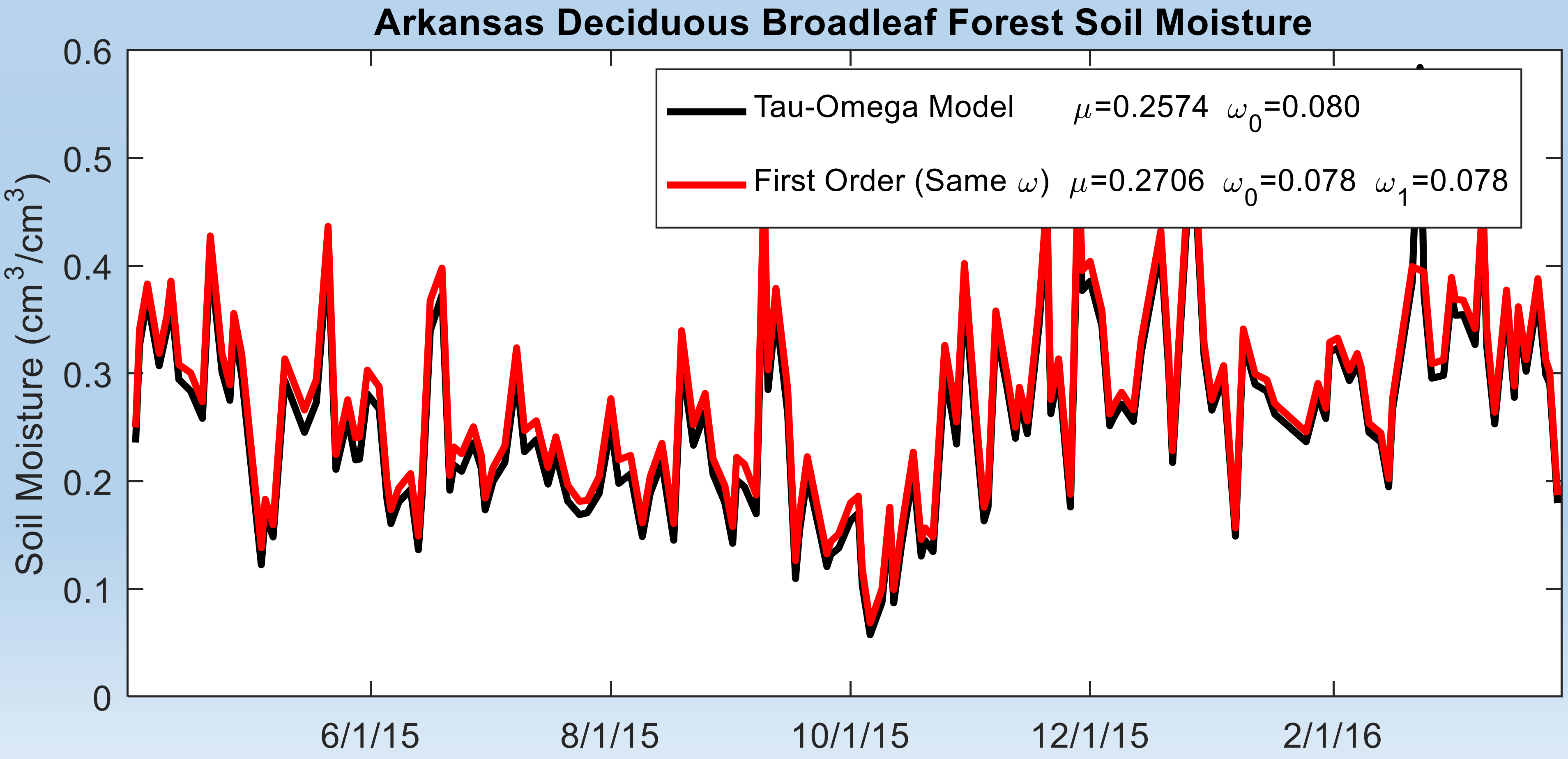
$\mathrm{h} = 0.13$

$$SM = 0.27 \ \frac{cm^3}{cm^3}$$

$$|Elasticity| = \left| \frac{r_p}{T_B} \frac{\partial T_B}{\partial r_p} \right|$$

Q3: How do we estimate the parameters of the higher-order model (without more ancillary data inputs and assumptions)?

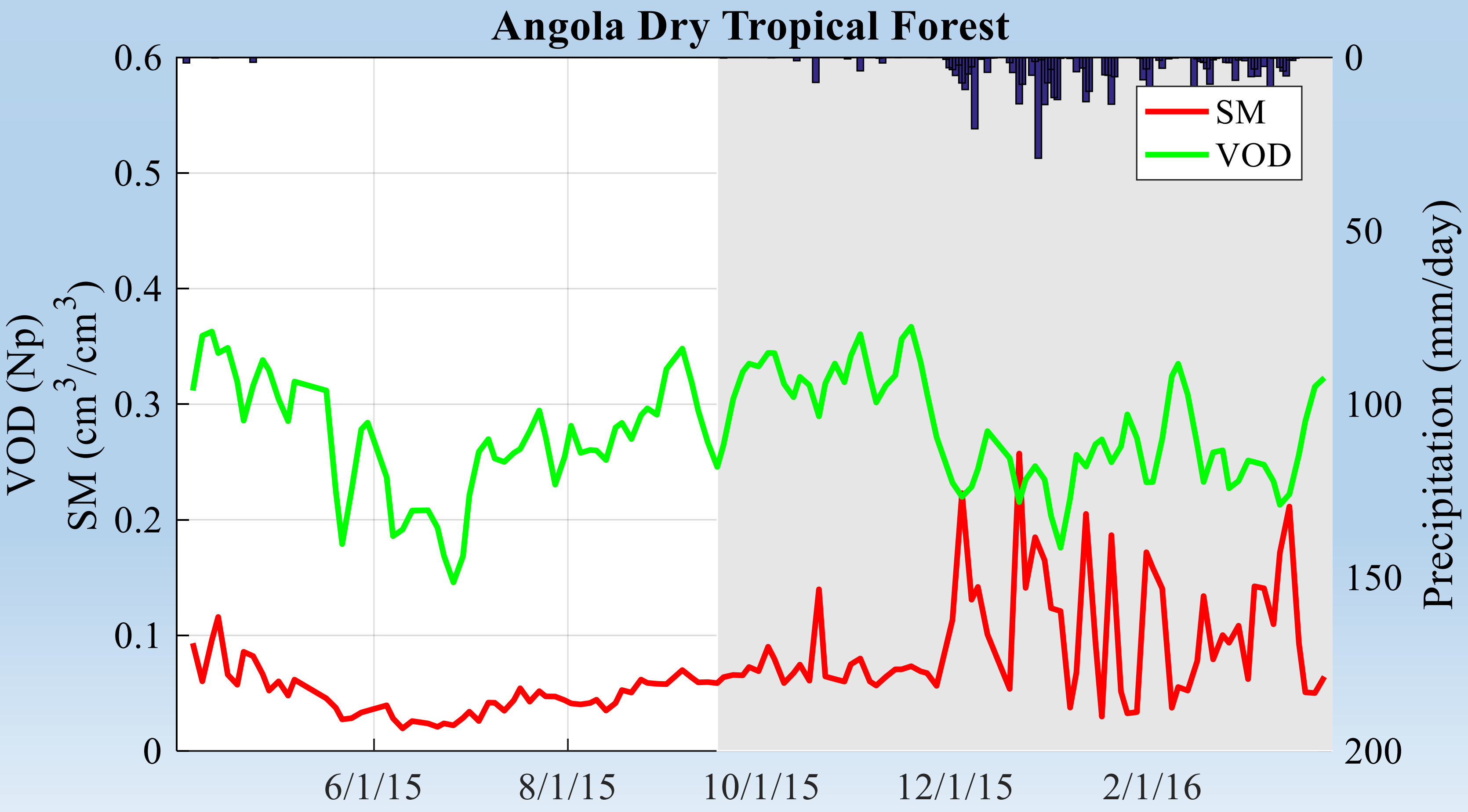
MT-DCA Soil Moisture and Vegetation Parameters Retrieval



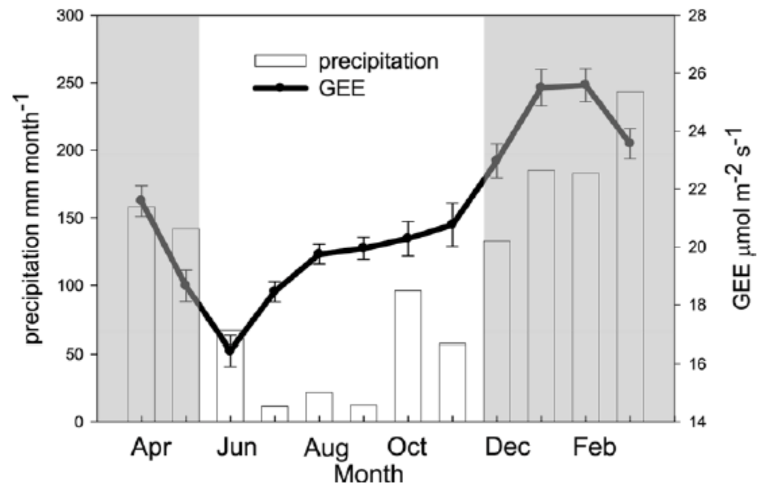
Effective Scattering albedo and scattering coefficient assumed equal

SM Bias: +0.013 cm^3/cm^3

Dry Tropical Forest Paradox



$\omega = 0.0875$

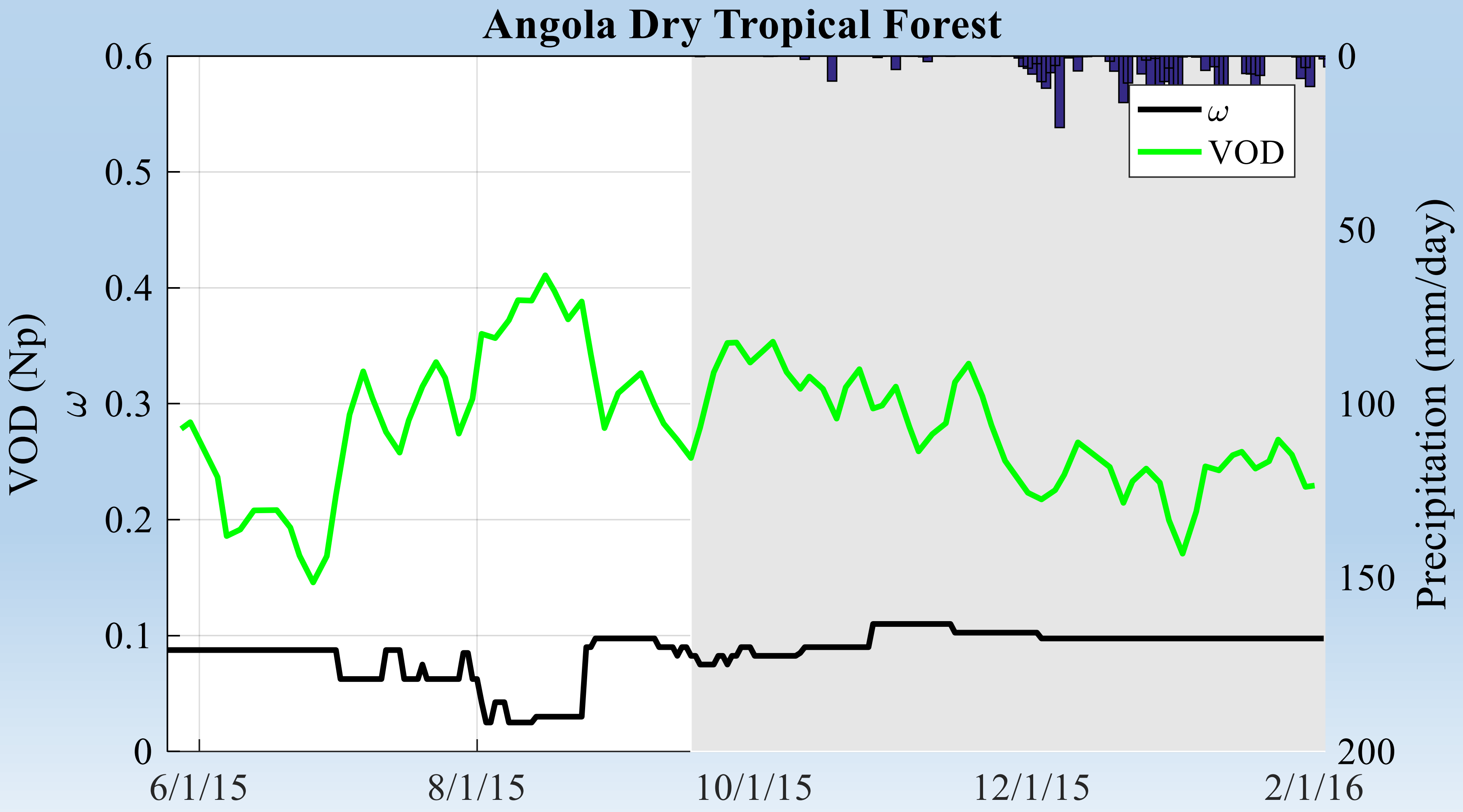


Doughty and Golden, 2008: Seasonal patterns of tropical forest LAI and CO2 exchange, *JGR-Biogeosciences*, vol. 113.

Flushing

Rivera et al., 2002: Increasing day-length induces spring flushing of tropical dry forest trees in the absence of rain. *Trees*, vol. 16.

Dry Tropical Forest Paradox



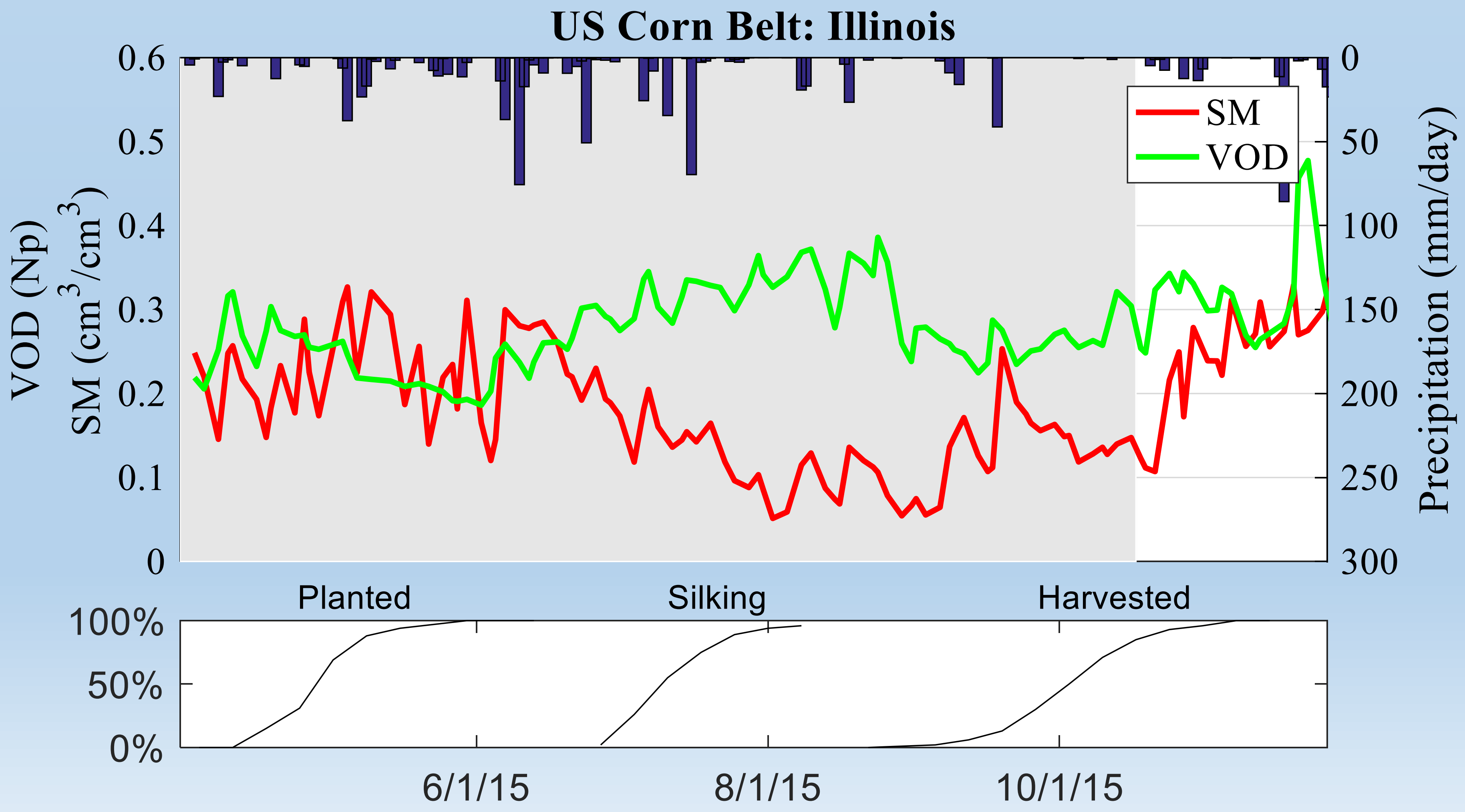
Dry Season:

SM ↓

VOD ↑

- Vegetation flushing
- Ecological Adaptation

Man-made Seasonality: Agriculture

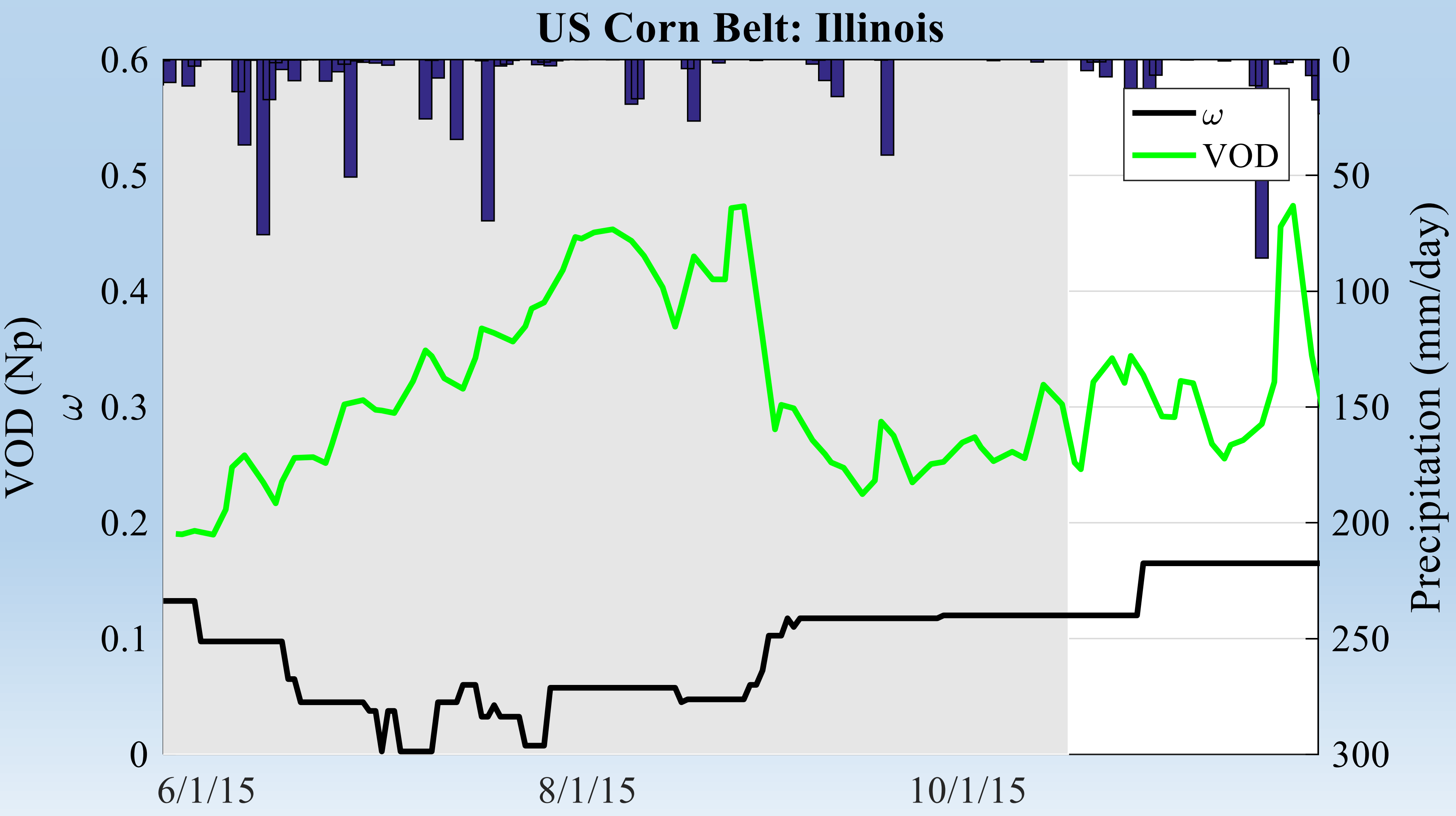


Illinois Growing Season:

1) Planting
2) VOD Increase
3) Harvest
4) SM Recovers

$\omega = 0.1175$

Man-made Seasonality: Agriculture



Illinois

Growing Season:

1) Seeding and Growth
2) Available SM Used
3) Harvest
4) SM Recovers

Summary

Q1: How to include higher-order interactions in a retrieval algorithm?

First-order interactions added to radiative transfer model

Q2: Is the higher-order algorithm more (or less) sensitive to soil surface emission?

First-order model is more sensitive to surface emissions because of interactions

Q3: How do we estimate the parameters of the higher-order model (without more ancillary data inputs and assumptions)?

MT-DCA framework is used to estimate vegetation parameters of the higher order model without reliance on problematic ancillary data and landuse classification

SMOS Effective Scattering Albedo

- SMOS-IC: Calibrated retrieved SM with in-situ SM to determine ω
- Low vegetation: ω ≠ 0

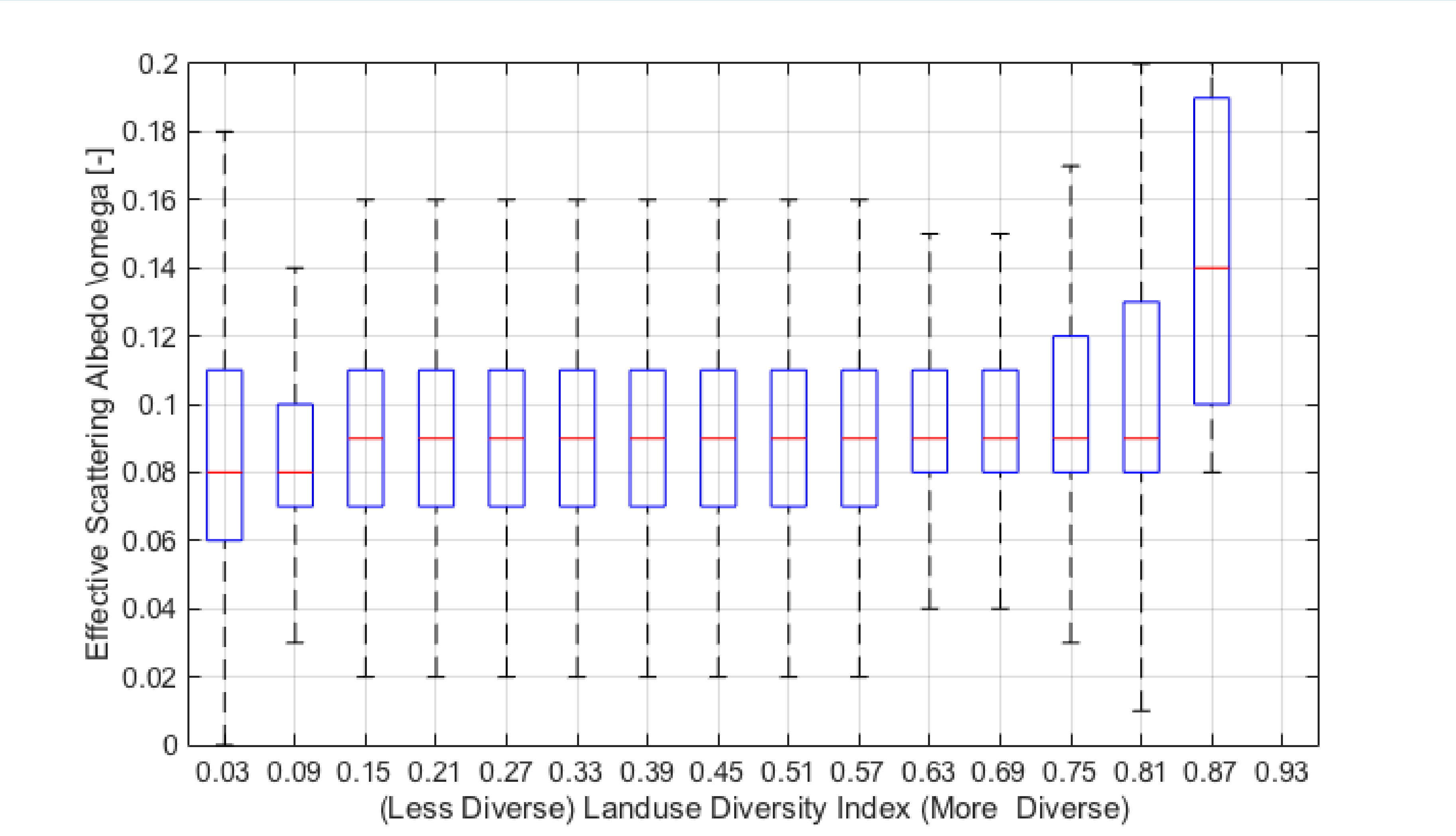
Class	ω (SMOS-IC)	ω (SMOSL3 V300)	H_R (SMOS-IC)	H_R (SMOSL3 V300)
1—Evergreen needle leaf forest	0.06	0.06–0.08 *	0.30	0.30
2—Evergreen broadleaf forest	0.06	0.06–0.08 *	0.30	0.30
3—Deciduous needle leaf forest	0.06	0.06–0.08 *	0.30	0.30
4—Deciduous broadleaf forest	0.06	0.06–0.08 *	0.30	0.30
5—Mixed forests	0.06	0.06–0.08 *	0.30	0.30
6—Closed shrublands	0.10	0.00	0.27	0.10
7—Open shrublands	0.08	0.00	0.17	0.10
8—Woody savannas	0.06	0.00	0.30	0.10
9—Savannas	0.10	0.00	0.23	0.10
10—Grasslands	0.10	0.00	0.12	0.10
11—Permanent wetland	0.10	0.00	0.19	0.10
12—Croplands	0.12	0.00	0.17	0.10
13—Urban and built-up	0.10	0.00	0.21	0.10
14—Cropland/Natural Vegetation'Mosaic	0.12	0.00	0.22	0.10
15—Snow and ice	0.10	0.00	0.12	0.10
16—Barren and sparsely vegetated	0.12	0.00	0.02	0.10

* ω = 0.08 over boreal forests, ω = 0.06 over other forest types.

MT-DCA median is 0.08 (closer to SMOS-IC)

Fernandez-Moran et al. 2017

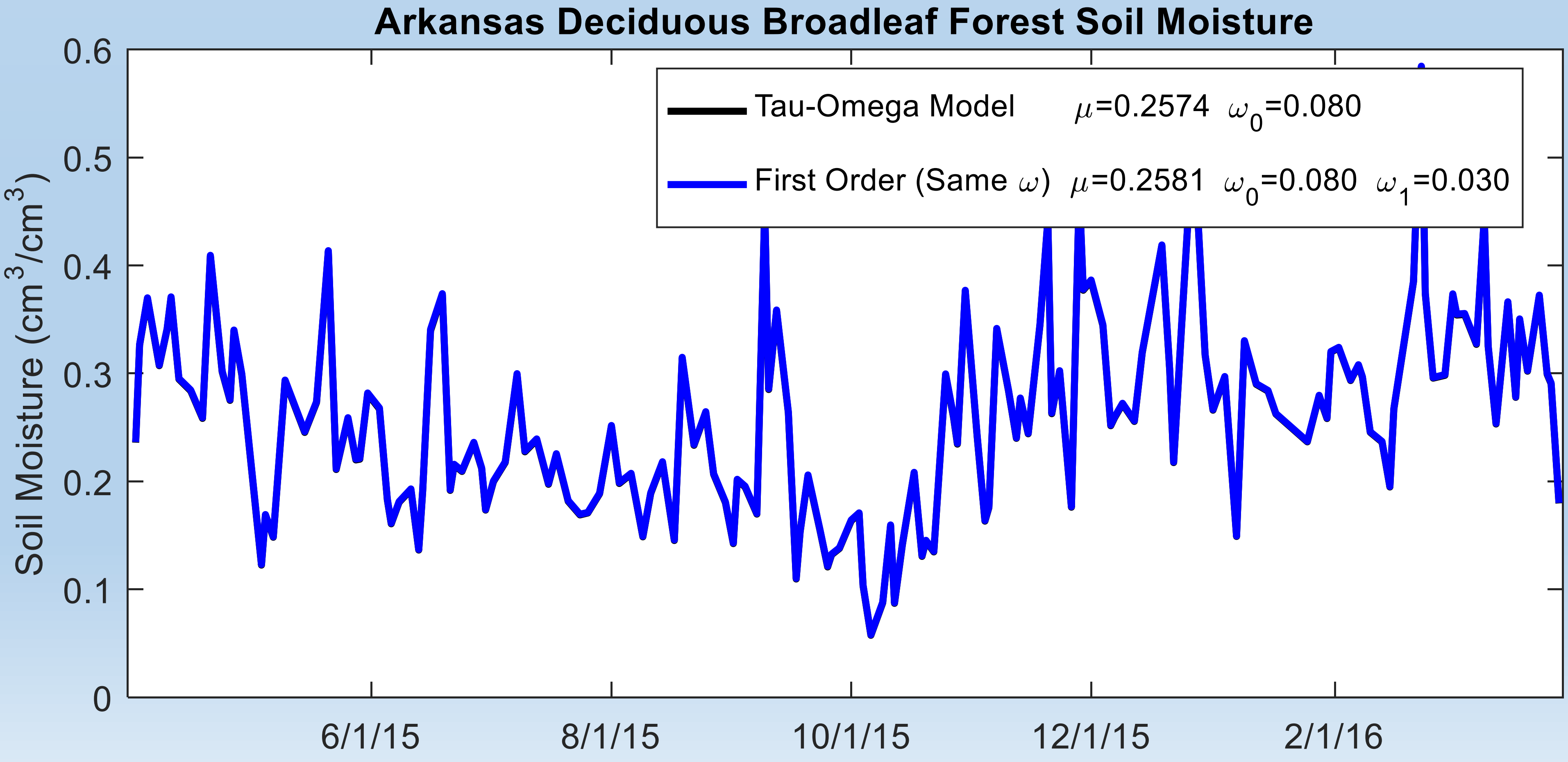
MT-DCA Effective Scattering Albedo



Upward shift in distribution of effective scattering albedo with increased heterogeneity

Konings et al. 2017

MT-DCA Soil Moisture Retrieval



Effective Scattering albedo assumed equal for tau-omega model and first order

SM Bias: +0.0007 cm^3/cm^3