Jet Propulsion Laboratory
California Institute of Technology

# Dependence of CYGNSS Reflectivity on Vegetation Water Content and Surface Roughness

Simon Yueh, Rashmi Shah, Akiko Hayashi, Andreas Colliander, Xiaolan Xu, and Julian Chaubell

Jet Propulsion Laboratory, California Institute of Technology

**IEEE GNSS+R, May 20-22, 2019**

© 2019. California Institute of Technology.
Government sponsorship acknowledged.

# Objectives

Jet Propulsion Laboratory
California Institute of Technology

- Develop soil moisture (SM) retrieval algorithms using CYGNSS data along with ancillary datasets used by the SMAP mission processing system to produce a CYGNSS soil moisture product with the best consistency with the SMAP soil moisture;

- Leverage the established SMAP cal/val program to quantify the accuracy and spatial resolution of the CYGNSS products with error budget tables.

# Outline

Jet Propulsion Laboratory
California Institute of Technology

- SMAP-CYGNSS Matchup
- Vegetation Dependence
- Surface Roughness Dependence
- Summary

# CYGNSS-SMAP Match Up

Jet Propulsion Laboratory
California Institute of Technology

- CYGNSS data
  - Version 2.1
  - Level 1 data
  - Flags: Most of the quality flags are checked for
  - Excluding all Block IIF GPS s/c
- SMAP Data
  - SCAV Soil moisture < 5 $kg/m^2$
  - Gridded NDVI VWC
  - Surface roughness (baseline and DCA h)
- CYGNSS-SMAP data match up
  - Distance: within 15 km
  - Time: within 1 day

# CYGNSS Reflectivity Calculation

Jet Propulsion Laboratory
California Institute of Technology

- Assuming a radar equation for a coherent signal similar to [1]:

$$P_r^S = P_r - N = \Gamma(\theta)\frac{\lambda^2 P_t G_t G_r}{(4\pi)^2 (R_t + R_r)^2}$$

where

- $P_r^S$ is the received power reflected by the surface,
- $P_r$ is the peak power of the L1 DDM of reflected power,
- $N$ is the estimated noise floor,
- $P_t G_t$ is GPS Equivalent Isotropically Radiated Power (EIRP),
- $G_r$ is antenna gain towards the specular point,
- $R_t$ is the distance between transmitter and specular point,
- $R_r$ is the distance between receiver and specular point,
- $\Gamma(\theta)$ is the average reflectivity, and $\lambda$ is GPS wavelength (19 cm).

- Average reflectivity can then be computed:

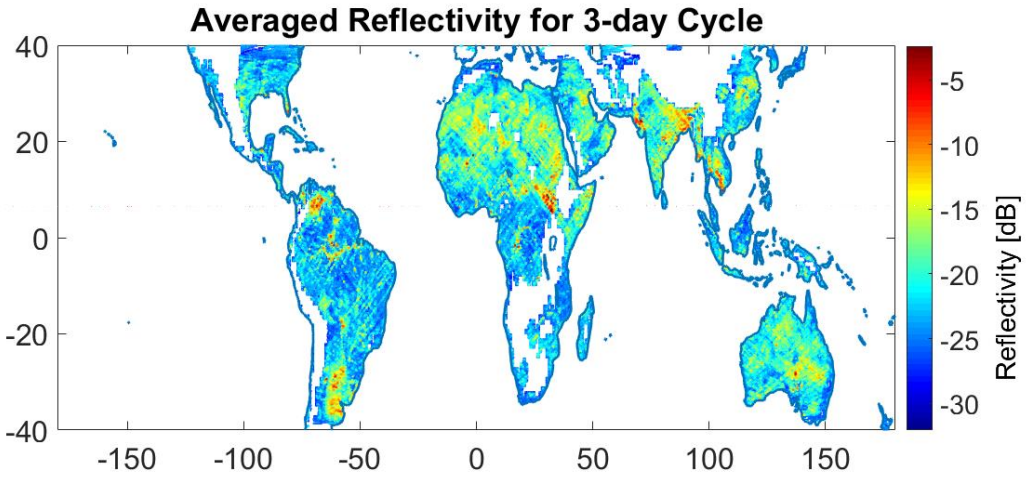
$$\Gamma(\theta) = \frac{(4\pi)^2 (P_r - N)(R_t + R_r)^2}{\lambda^2 P_t G_t G_r}$$

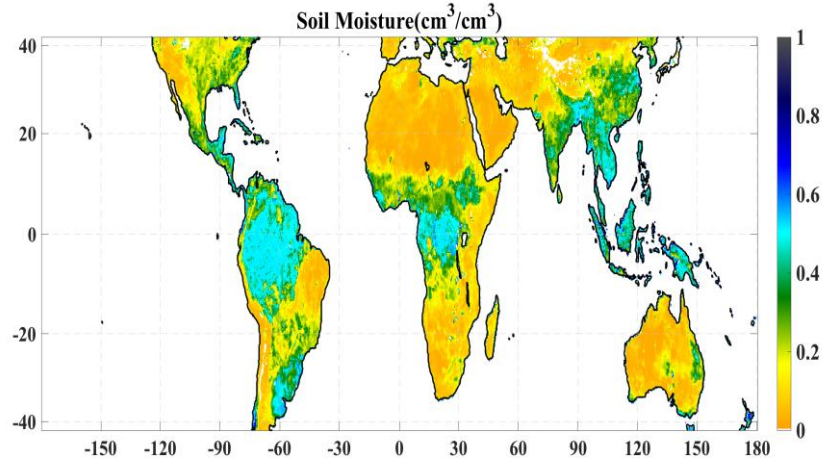
[1] Clarizia et al., 2018

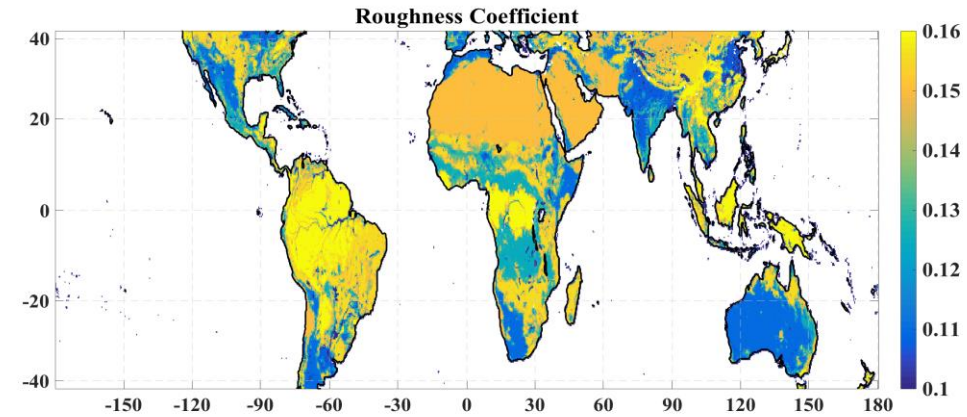
# CYGNSS Reflectivity

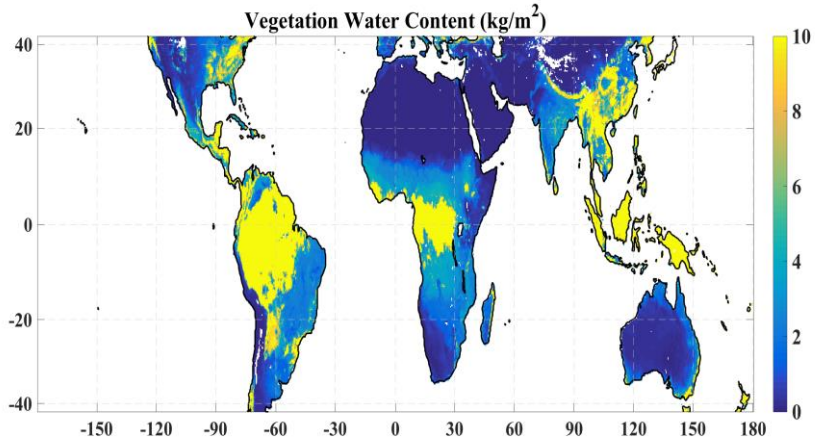
Jet Propulsion Laboratory
California Institute of Technology

## 3-day: Sept 30-Oct 2, 2017



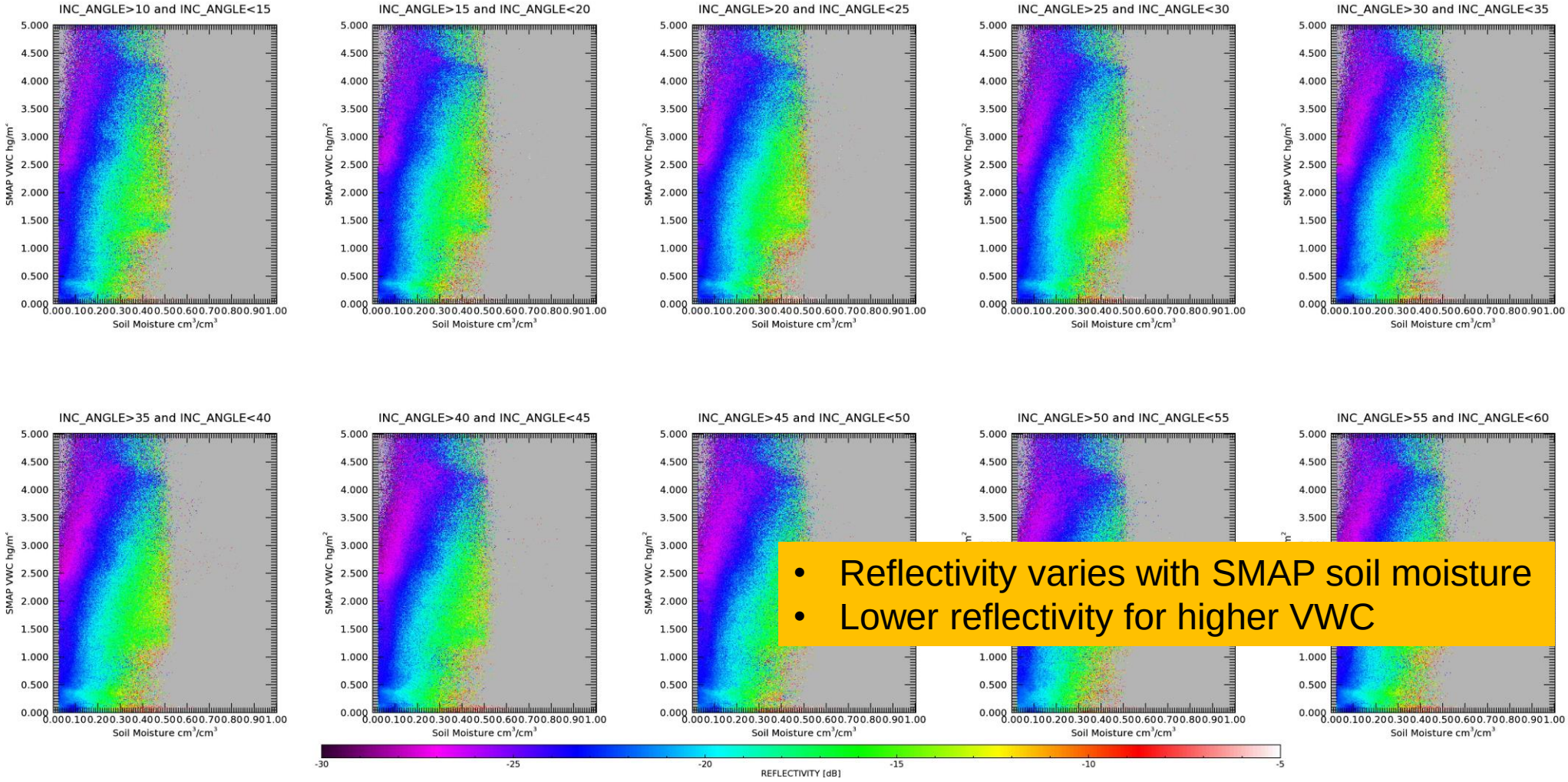



# CYGNSS Reflectivity vs. SMAP SM & VWC

Jet Propulsion Laboratory
California Institute of Technology

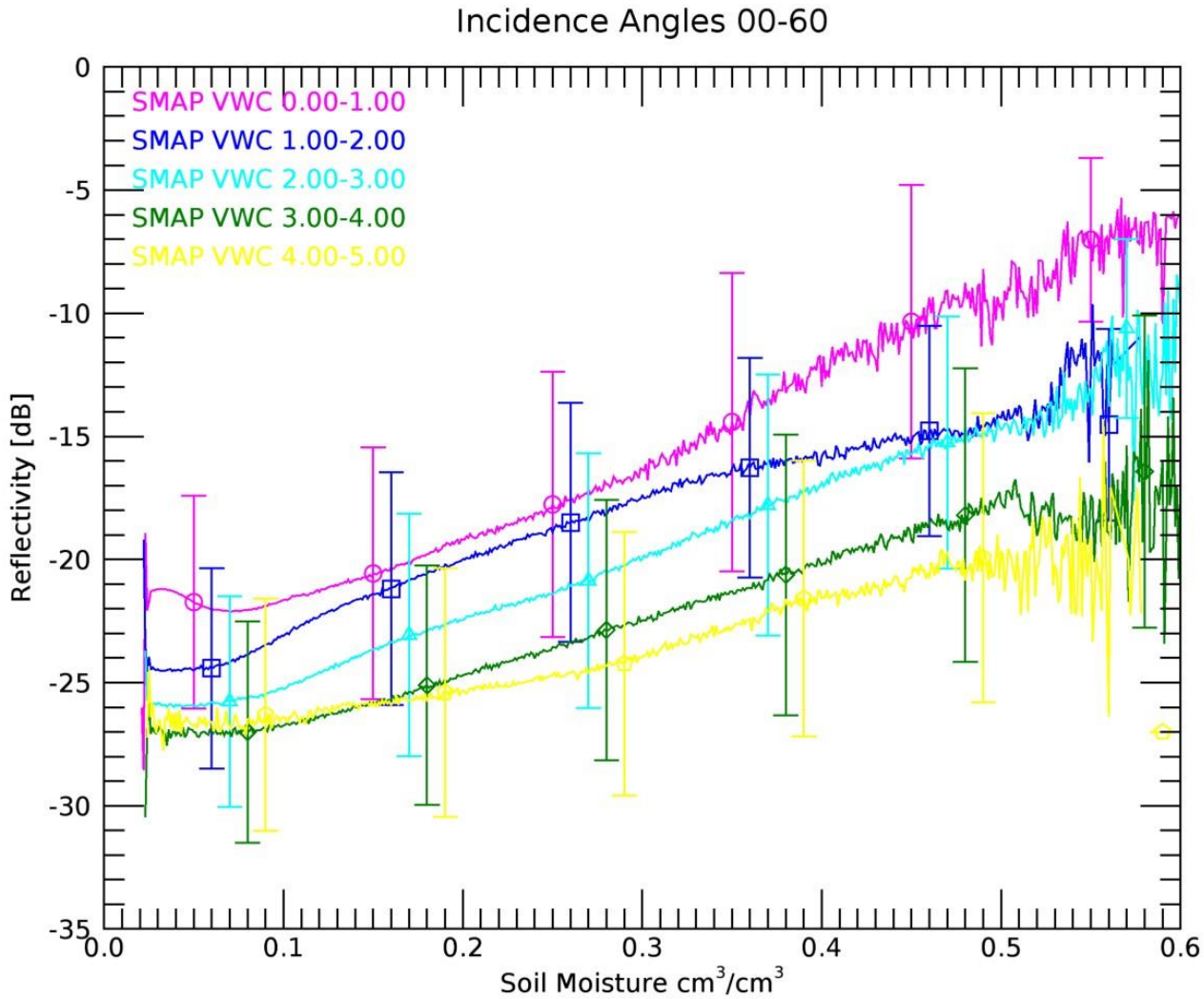
## Soil Moisture for Various Incidence Angles




- Reflectivity varies with SMAP soil moisture
- Lower reflectivity for higher VWC

# Effect of VWC & Soil Moisture

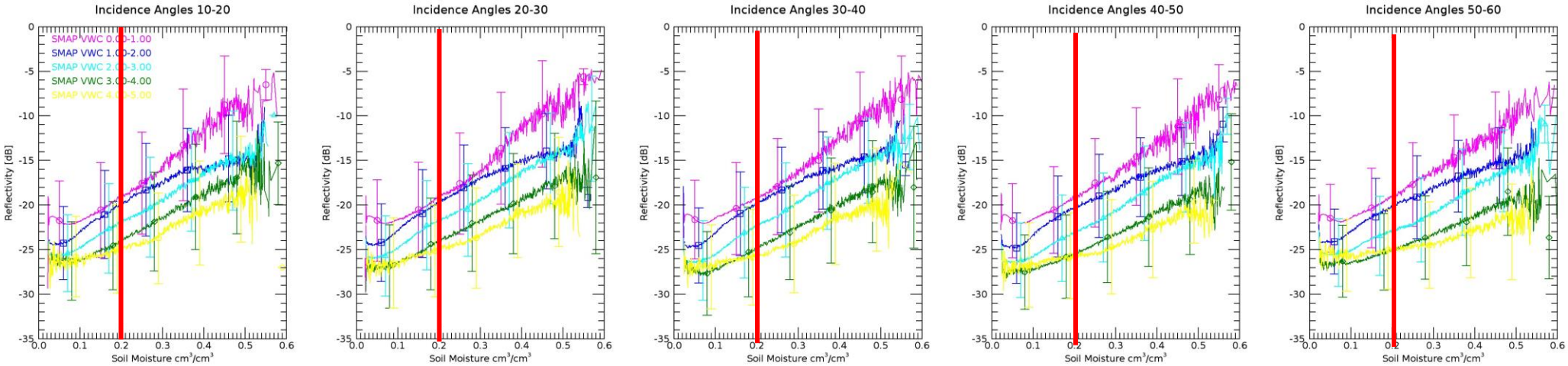
Jet Propulsion Laboratory
California Institute of Technology



# Effect of VWC & Incidence Angle

Jet Propulsion Laboratory
California Institute of Technology

Data are stratified into every 10 degrees in incidence angles




Similar features for all incidence angle bins.

# Dependence on VWC for SM of 0.2

Jet Propulsion Laboratory
California Institute of Technology

## Excellent linear dependence

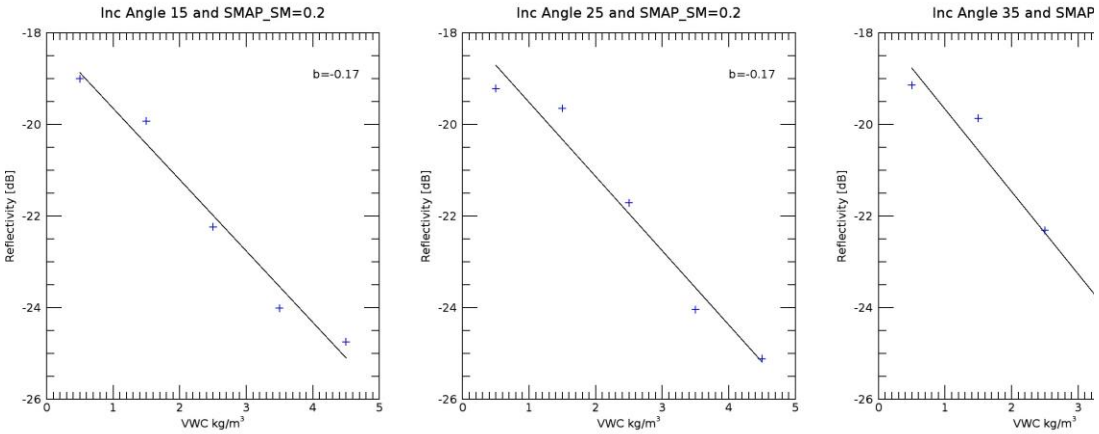
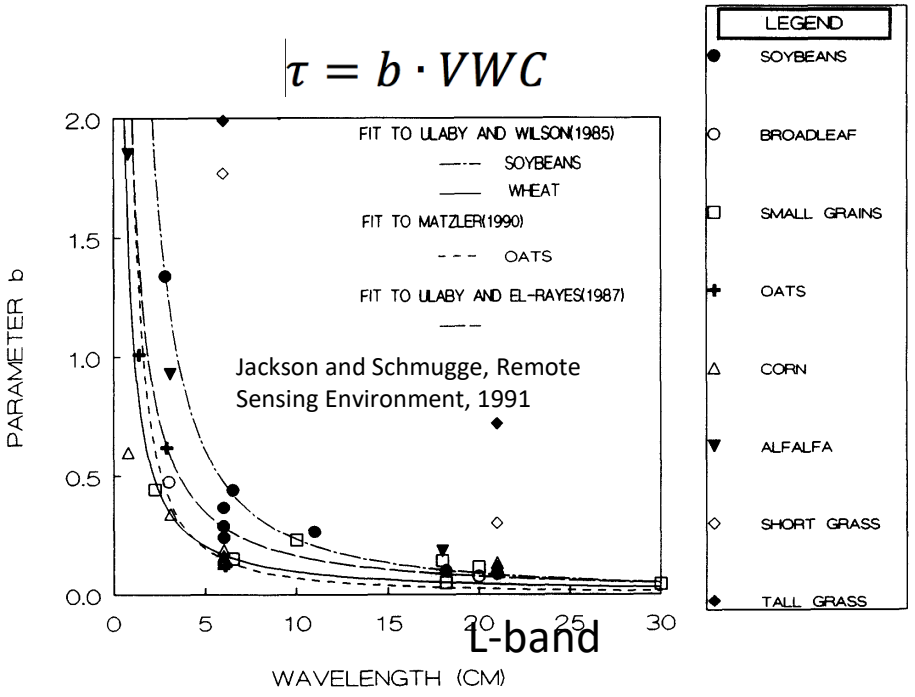



*Figure 4.* Summary of experimental data of the vegetation parameter $b$ as a function of wavelength for a variety of vegetation types.

$$\tau = b \cdot VWC$$




$$R_{\tau\theta} = \epsilon$$

## Linear Model for NDVI tau appears reasonable

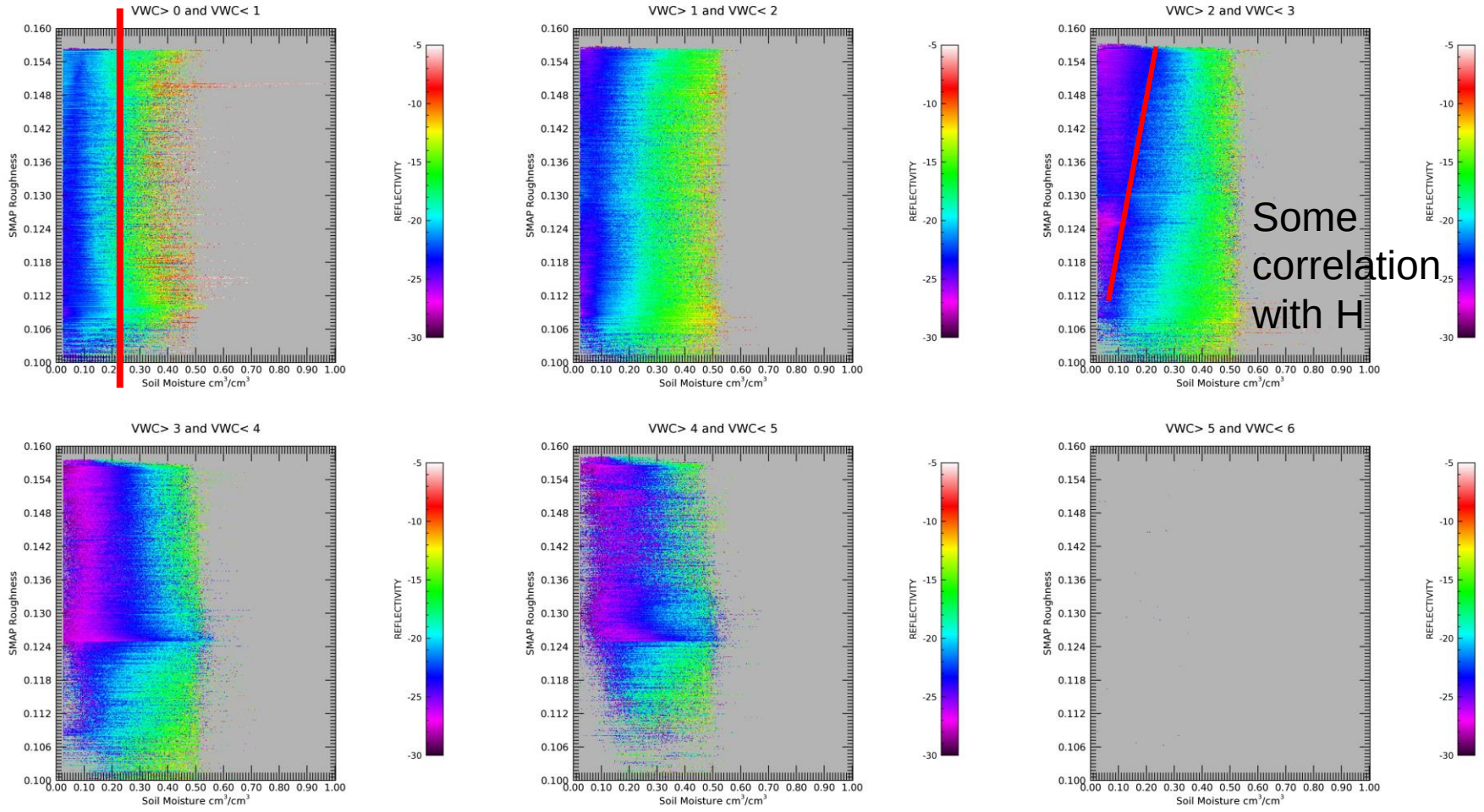
$$R_{\tau\theta} = -20log_{10}(e)\frac{VWC}{cos\theta}b + R_{\theta}$$

| | 10-20 | 20-30 | 30-40 | 40-50 | 50-60 | Average |
|---|---|---|---|---|---|---|
| b | 0.17 | 0.17 | 0.17 | 0.15 | 0.11 | 0.15 |

# CYGNSS Reflectivity vs. SMAP SM & Baseline Surface Roughness Ancillary

Jet Propulsion Laboratory
California Institute of Technology

No correlation with SMAP baseline surface roughness



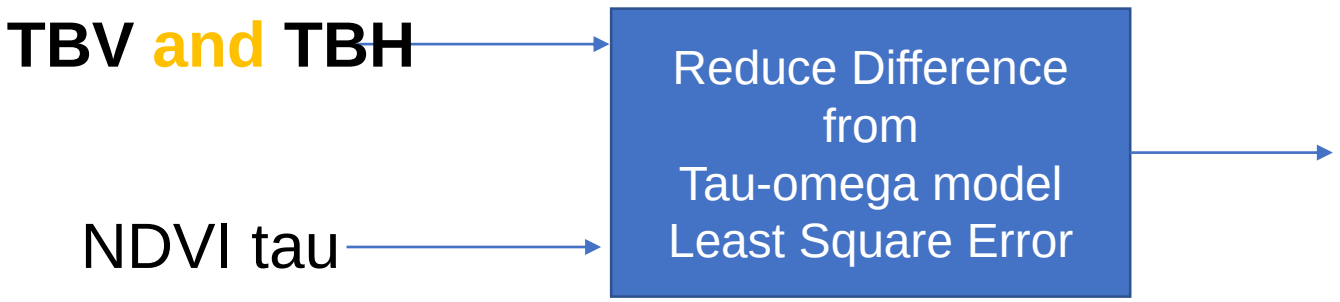
# Surface Roughness

## Derived from SMAP Dual-Pol Data

Jet Propulsion Laboratory
California Institute of Technology

- Use Dual Channel Algorithm: Retrieved soil moisture and h by letting tau = NDVI tau
- Include Q = 0.1771*h to represent polarization mixing
- Averaged h map on 3 and 9 km grids (NDVI tau threshold applied)

- Dual Channel Algorithm (DCA)

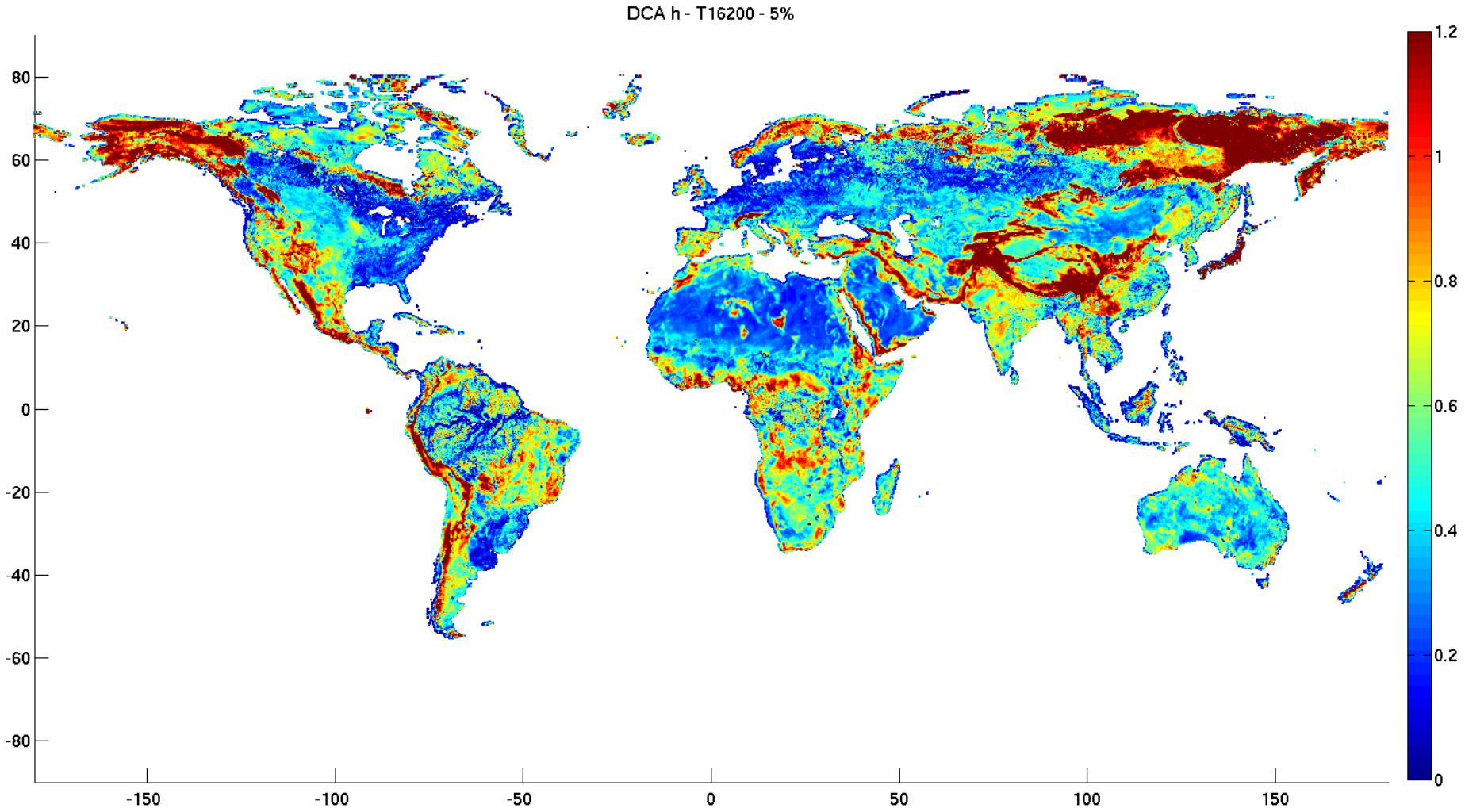



Soil moisture and Surface roughness

(Chaubell et al.)

# Surface Roughness
## From SMAP Dual Channel Algorithm

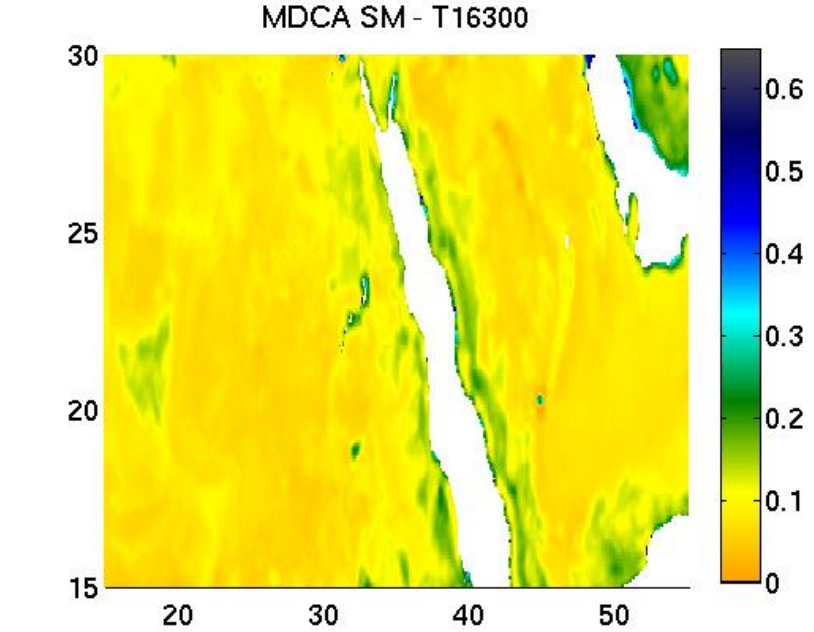
Jet Propulsion Laboratory
California Institute of Technology



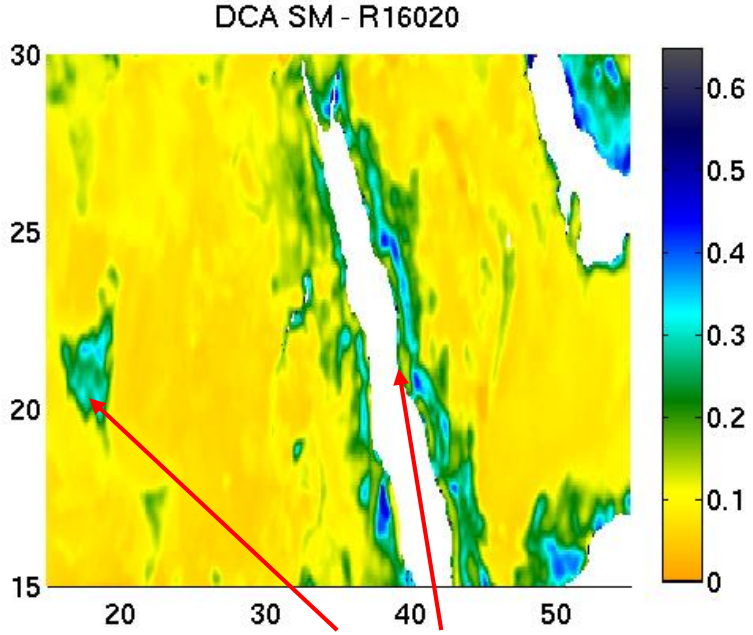
# DCA Surface Roughness Example

Jet Propulsion Laboratory
California Institute of Technology

**SMAP soil moisture using DCA surface roughness**



**SMAP soil moisture using baseline surface roughness**

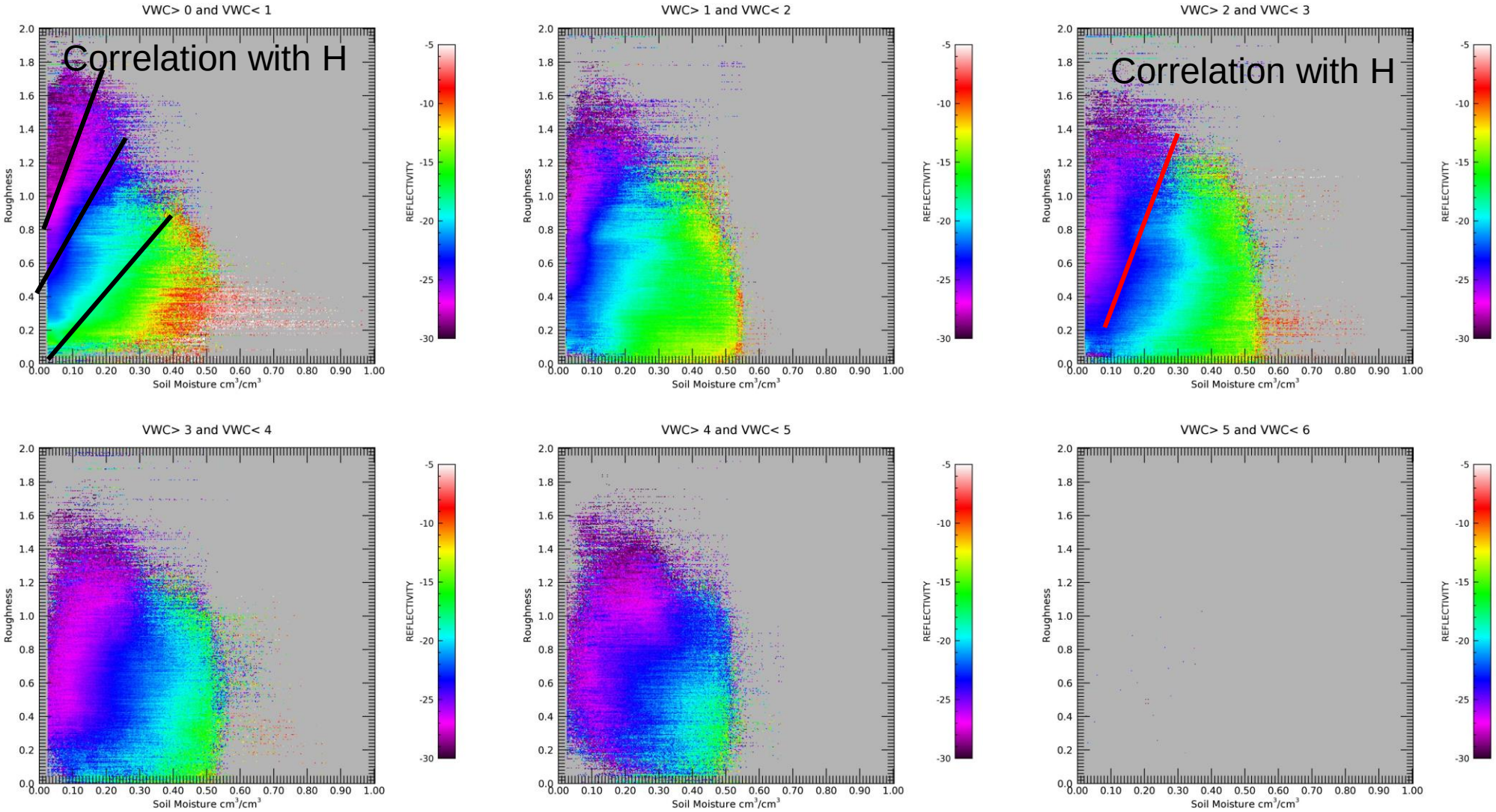



Artifacts related to topography

DCA Surface Roughness removes some artifacts due to topography from SMAP soil moisture retrieval

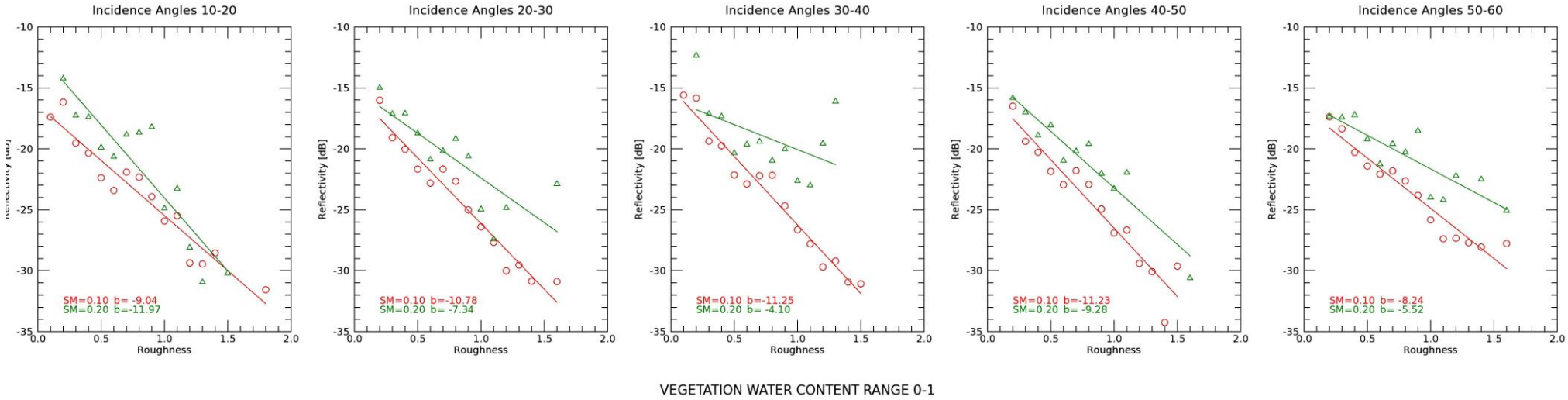
# CYGNSS Reflectivity vs. SMAP SM & DCA roughness (H)

Jet Propulsion Laboratory
California Institute of Technology



# Dependence of Reflectivity on Surface Roughness

Jet Propulsion Laboratory
California Institute of Technology




$$R_{h\theta} = e^{-aH} R_{\theta}$$

$$R_{h\theta} = -10\, log_{10}(e)\, a\, H\ + R_{\theta}$$

| Incidence Angle (deg) | Slope | a |
|---|---|---|
| 15 | -9.04 | 2.08 |
| 25 | -10.78 | 2.48 |
| 35 | -11.25 | 2.59 |
| 45 | -11.23 | 2.59 |
| 55 | -8.24 | 1.90 |

- No obvious dependence on incidence angle
  - Large scale random surface dominates?
- Linear dependence on h
- Non-Rayleigh – slope should be ~ $-(2kh\cos\theta)^2$

# CYGNSS Reflectivity vs. SMAP SM

Jet Propulsion Laboratory
California Institute of Technology

CYGNSS R

After compensation using SMAP soil moisture

$$\Delta R = R_{cygnss} - R_{\theta}$$

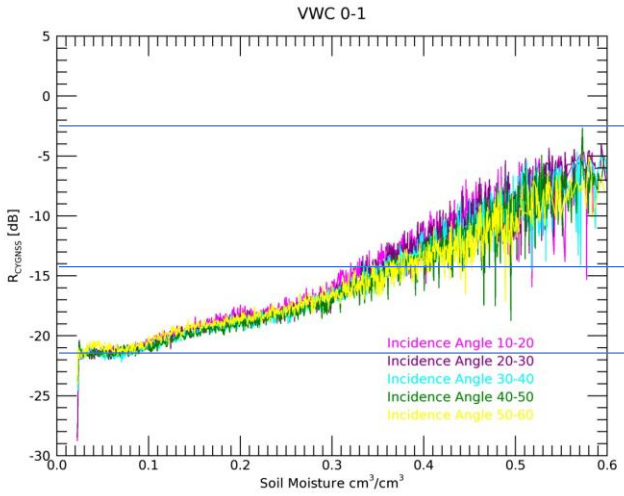
$R_{\theta}$: *Expected CYGNSS reflectivity using SMAP soil moisture and Mironov model*

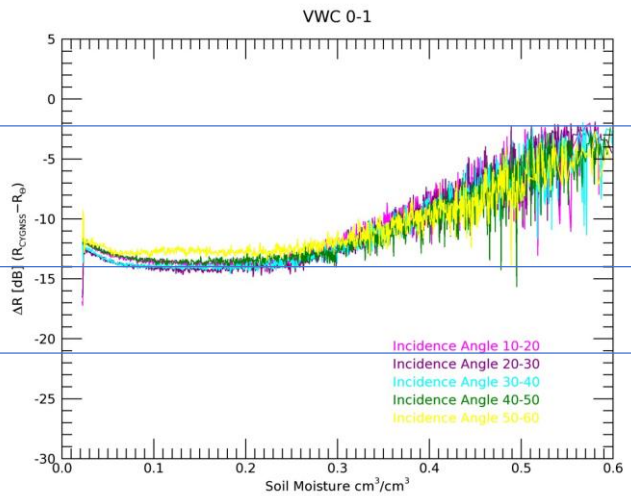
Compensation by SMAP soil moisture and roughness effects

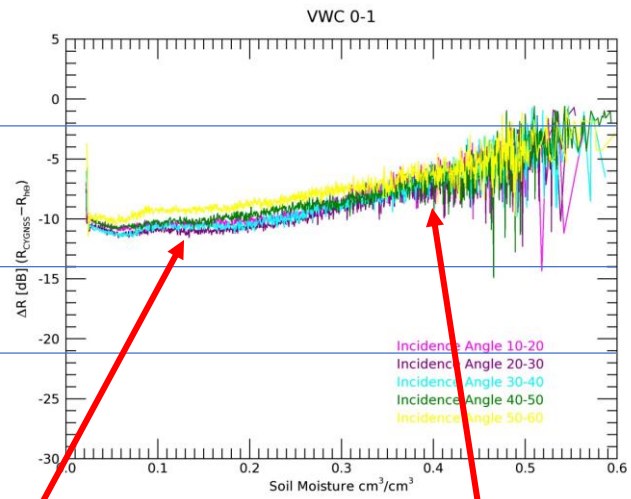
$$\Delta R = R_{cygnss} - R_{h\theta}$$

$$R_{h\theta} = -10\,log_{10}(e)\,a\,H\, + R_{\theta}$$

a=2.3




Reflectivity for soil moisture <0.2 can be largely flattened by using dielectric and roughness models

There is about 7 dB increase wrt soil moisture in the residual for moisture>0.2

# Summary

Jet Propulsion Laboratory
California Institute of Technology

- Characteristics of CYGNSS reflectivity reflect the change of SMAP soil moisture and NDVI-derived optical depth (tau).
- SMAP baseline surface roughness is inconsistent with CYGNSS reflectivity.
- CYGNSS reflectivity is correlated with SMAP DCA surface roughness.
- CYGNSS dependence on soil moisture cannot be fully modeled by the Mironov dielectric model and empirical SMAP surface roughness.
  - There is 7 dB residual for wet soil (>0.2 volumetric moisture).

Jet Propulsion Laboratory
California Institute of Technology

# Dependence of CYGNSS Reflectivity on Vegetation Water Content and Surface Roughness

Simon Yueh, Rashmi Shah, Akiko Hayashi, Andreas Colliander, Xiaolan Xu, and Julian Chaubell

Jet Propulsion Laboratory, California Institute of Technology

**IEEE GNSS+R, May 20-22, 2019**

© 2019. California Institute of Technology.
Government sponsorship acknowledged.