# ARMS ocean emissivity model application

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A Reference Quality Model for Ocean Surface Emissivity and Backscatter from the Microwave to the Infrared
Bern, Switzerland, November 21, 2019

Outline

- Highlights on FengYun satellite program

- ARMS microwave ocean emissivity models

- Simulations vs observations

- Effects of surface emissions vs antenna emission

- Summary and Conclusions
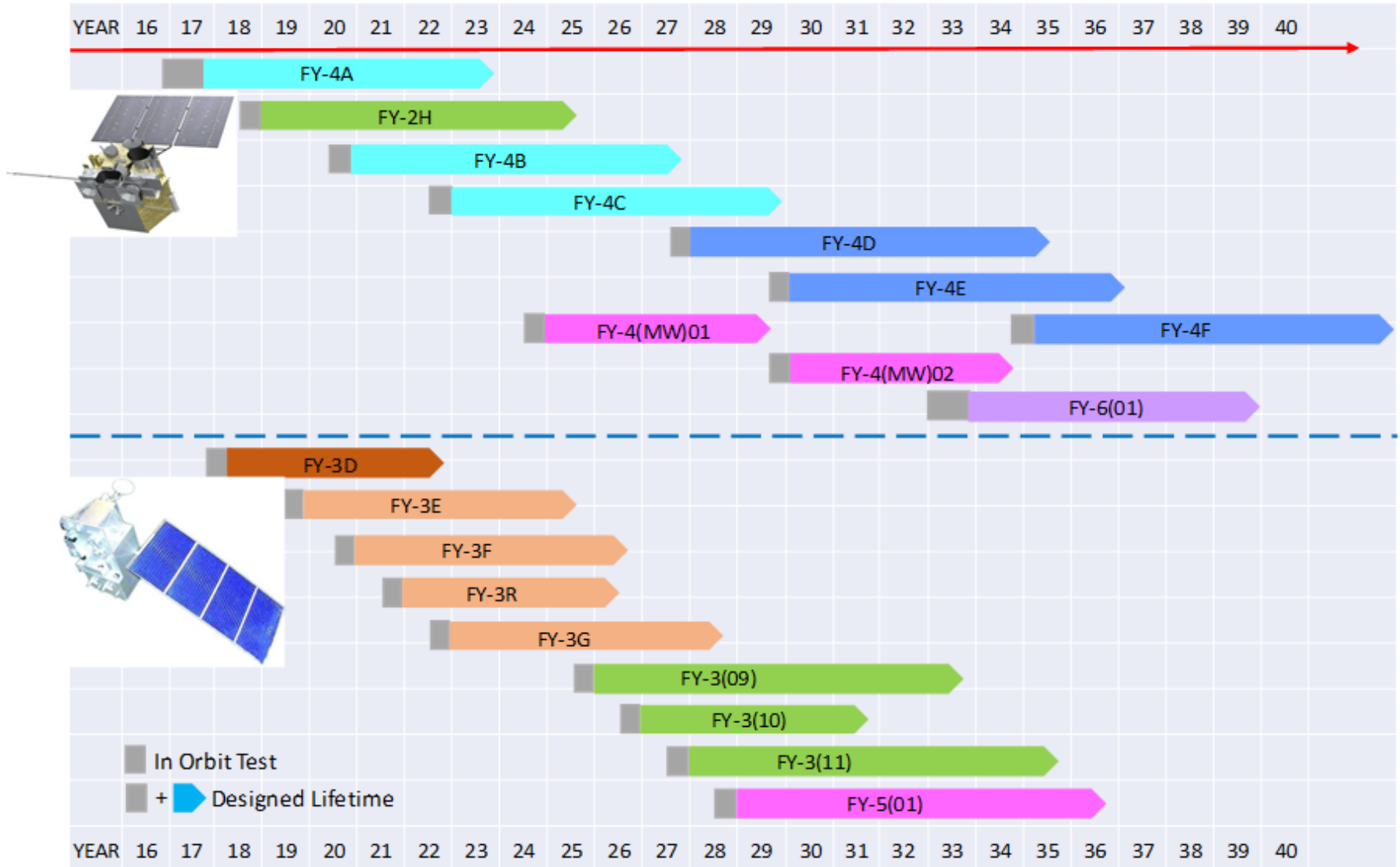
Fengyun Meteorological Satellite by 2030
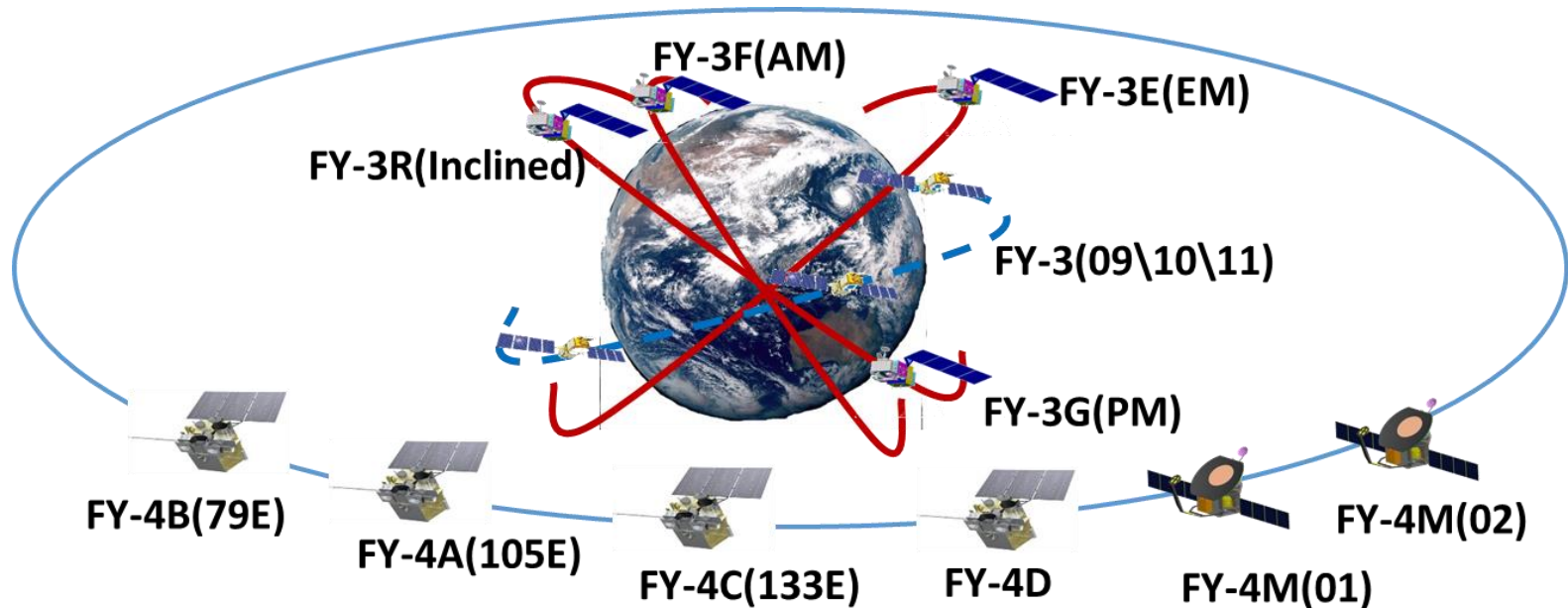
The LEO realizes the network of covering the EM, AM and PM satellite observation, and the time limit of global data updating has been raised from 6 hours to 3 hours. Fine detection of elements such as precipitation and greenhouse gas.
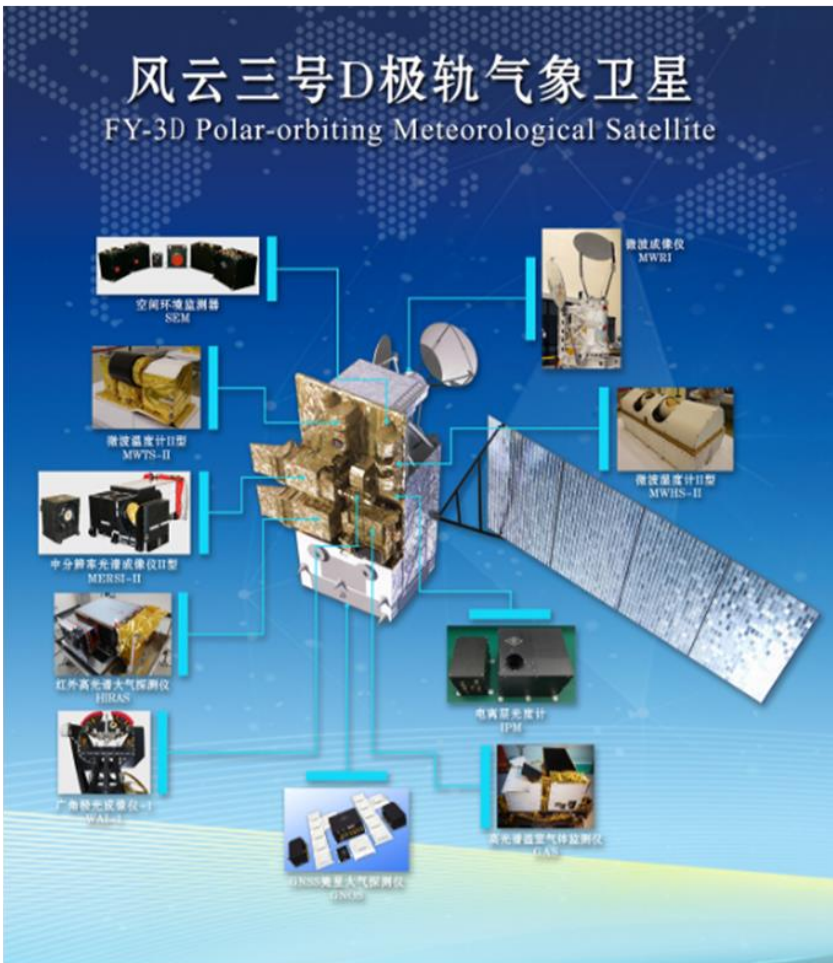
The new pattern of GEO observation: imaging, hyper-spectral and microwave sounding.

FY-4B: rapid scan(min), FY-4C: five minutes disk image, sounding abilities, whole disk lightening mapper.
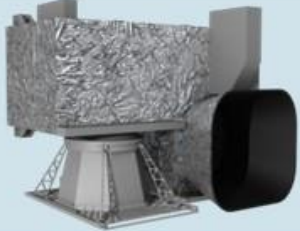
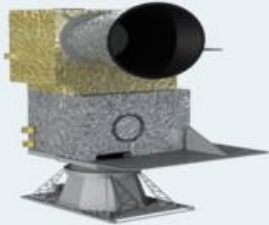# Fengyun Meteorological Satellite by 2040

FY-3D Polar-Orbiting Meteorological Satellite

风云三号D极轨气象卫星
FY-3D Polar-orbiting Meteorological Satellite

Payload Name	Channel Numbers with Spectral Coverage
MEdium Resolution Spectral Imager (MERSI-2)	25 (0.413 – 12 μm)
Hyperspectral InfraRed Atmospheric Sounder (HIRAS)	1370 (3.92 – 15.38 μm)
MicroWave Radiation Imager (MWRI)	10 (10.65 – 89 GHz)
MicroWave Temperature Sounder (MWTS-2)	13 (50.3 – 57.29 GHz)
MicroWave Humidity Sounder (MWHS-2)	15 (89.0 – 183.31 GHz)
GNSS Occultation Sounder (GNOS)	29 (--)
Greenhouse-gases Absorption Spectrometer (GAS)	5540 (0.75 – 2.38 μm)
Wide angle Aurora Imager (WAI)	1 (140 – 180 nm)
Ionospheric PhotoMeter (IPM)	3 (130 – 180 nm)
Space Environment Monitor (SEM)	25 (--)

■ **Four brand new instruments added (HIRAS, GAS, WAI, IPM)**

■ **One Successive instrument updated (MERSI-2)**

■ **All the successive Instruments performance are improved significantly**

FY-4A Geostationary Satellite

Instrument		Purposes
	AGRI: Advanced Geosynchronous Radiation Imager	14 -channel Earth images
	GIIRS : Geostationary Interferometric InfraRed Sounder	Clear-sky atmospheric temperature and humidity profiles
	LMI : Lightning Mapping Imager	Lightning distribution map in China area
	SEP: Space Environment Package	Space electric and magnetic environment information

Unique Aspects in FY Satellite Missions

- In its leo program, the operational satellite missions are often carrying some advanced instruments for new exploring the new sciences

- In geo and leo orbits, both high spectral IR and MW sounders are on board and allow for profiling atmospheric temperature and moisture under all weather conditions

- Both active and passive microwave instruments are deployed and allow for better profiling cloud and precipitation from operational missions

- Microwave imagers are flying on board FY satellites in both morning and afternoon orbits

- The missions in general provide critical supports to weather and climate applications as well as ecological and environment monitoring and assessments

Advanced Radiative Transfer Modeling System (ARMS)
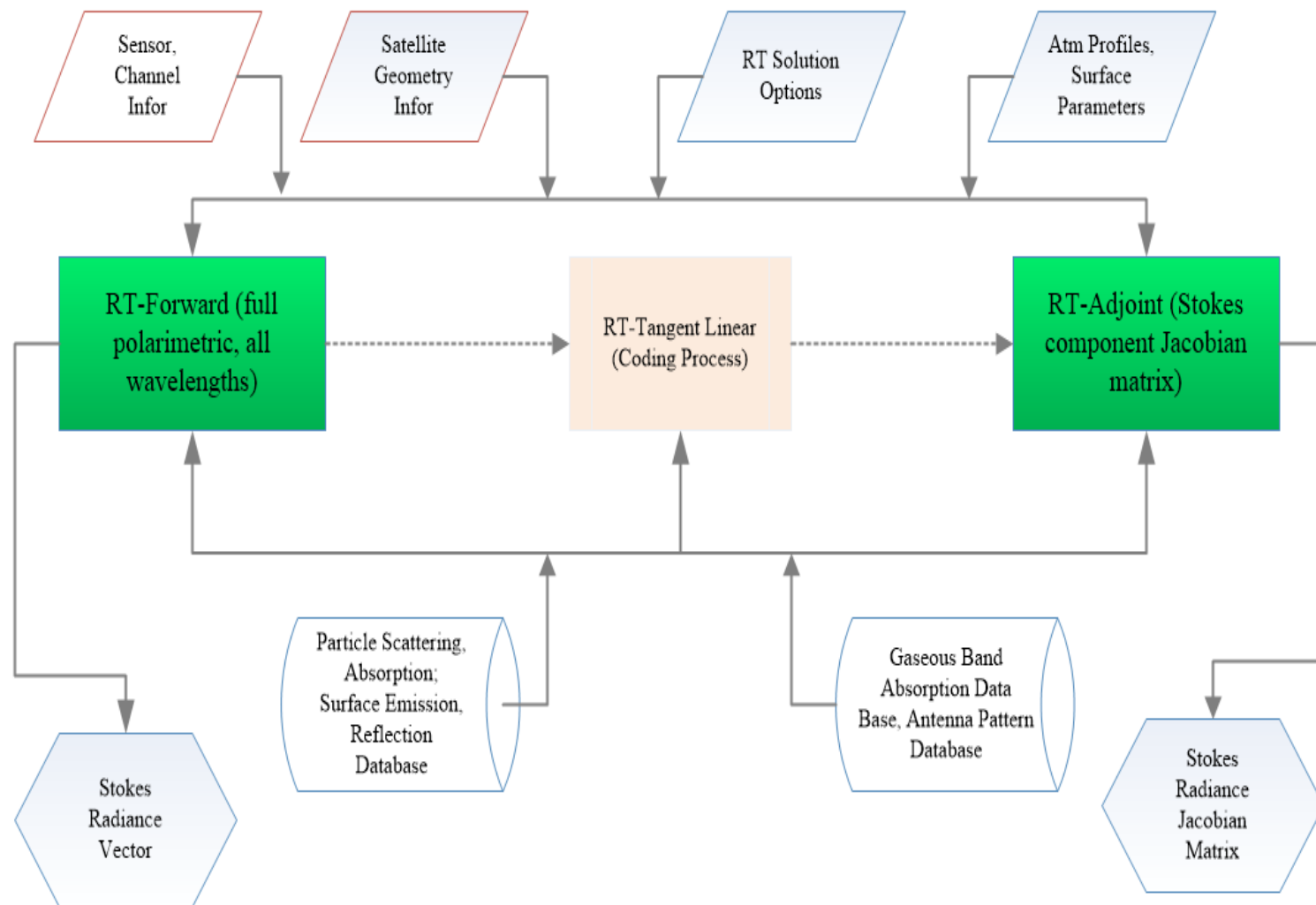
ARMS Supported Instruments

- FY-3A MWTS
- FY-3A MWHS
- FY-3B MWTS
- FY-3B MWHS
- FY-3C MWTS-2
- FY-3C-MWHS-2
- FY-3D MWTS-2
- FY-3D MWHS-2
- FY-3 B/C/D MWRI
- FY-3 B/C VIRR
- FY-3C MERSI
- FY-3C IRAS
- FY-3D MERSI-2
- FY-3D HIRAS
- FY-4A GIIRS
- FY-4A AGRI
- FY-4M GMIS

- NOAA 15 to 19 AMSU-A
- NOAA 18-19 MHS
- NOAA 18-19 HIRS
- NOAA 15-19 AVHRR
- SNPP/NOAA-20 ATMS
- SNPP/NOAA-20 CrIS
- SNPP/NOAA-20 VIIRS
- METOP-A to C IASI
- METOP-A to C IASI
- METOP-A to C AMSU-A
- METOP-A to C AVHRR
- JAXA AMSR2
- NASA GMI
- EOS Aqua AIRS
- EOS Terra/Aqua MODIS

ARMS Solvers

- Polarization Two-Stream Approximation (P2S)

- Advanced Doubling and Adding (ADA)

- Vector Doubling and Adding (VDA)

- DIScrete Oridinate Radiative Transfer (DISORT)

- Vector DIScrete Oridinate Radiative Transfer (VDISORT)

Definition of Radiative Transfer Model

$$\mu \frac{d\mathbf{I}(\tau,\mu,\phi)}{d\tau} = -\mathbf{I}(\tau,\mu,\phi) + \mathbf{J}(\tau,\mu,\phi) + \mathbf{S}(\tau,\mu,\phi,\mu_0,\phi_0)$$
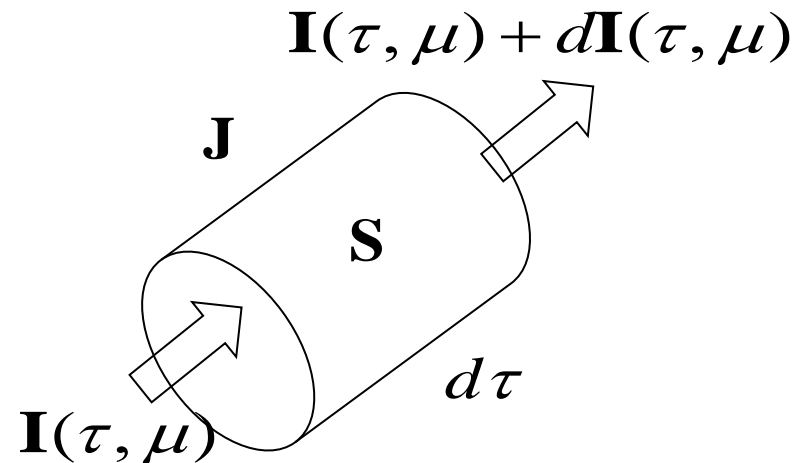
Extinction

Multiple scattering

Source: single scattering & thermal emission

$$\mathbf{I} = \left[I, Q, U, V \right]$$

or

$$\mathbf{I} = \left[I_r, I_l, U, V \right]$$

$$\mathbf{I}(\tau,\mu) + d\mathbf{I}(\tau,\mu)$$

$\mathbf{J}$

$\mathbf{S}$

$\mathbf{I}(\tau,\mu)$

$d\tau$

Source Terms and Multiple Scattering

Phase matrix

$$\mathbf{J} = \frac{\omega(\tau)}{4\pi} \int_0^{2\pi} \int_{-1}^{1} \mathbf{M}(\tau, \mu, \phi; \mu', \phi') \mathbf{I}(\tau, \mu', \phi') d\mu' d\phi'$$

$$\mathbf{S}(\tau, \mu, \phi, \mu_0, \phi_0) = (1 - \omega)B \begin{pmatrix} 1 \\ 0 \\ 0 \\ 0 \end{pmatrix} + \frac{\omega F_0}{4\pi} \exp(-\tau/\mu_0) \begin{pmatrix} M_{11}(\phi, \mu_0, \phi_0) \\ M_{12}(\phi, \mu_0, \phi_0) \\ M_{13}(\phi, \mu_0, \phi_0) \\ M_{14}(\phi, \mu_0, \phi_0) \end{pmatrix}$$

Radiative Transfer Solvers

- Discrete Ordinate Radiative Transfer (DISORT)

- Vector DISORT (VDISORT)

- Vector Double and Adding (VDA)

- Vector Matrix Operator (MO)

- Polarization Two Stream Approximation

ARMS Atmospheric Optics

- Fast atmospheric gaseous absorption models trained by LBLRTM

- Cloud and aerosol particle scattering LUT generated from Mie

- Cloud and aerosol particle scattering LUT from T-Matrix

Cloud Optical Property Library

Ice particle single-scattering property database

Spectrally Consistent Scattering, Absorption, and Polarization Properties of Atmospheric Ice Crystals at Wavelengths from 0.2 to 100 μm

PING YANG,* LEI BI,* BRYAN A. BAUM,[+] KUO-NAN LIOU,[#] GEORGE W. KATTAWAR,[@] MICHAEL I. MISHCHENKO,[&] AND BENJAMIN COLE*
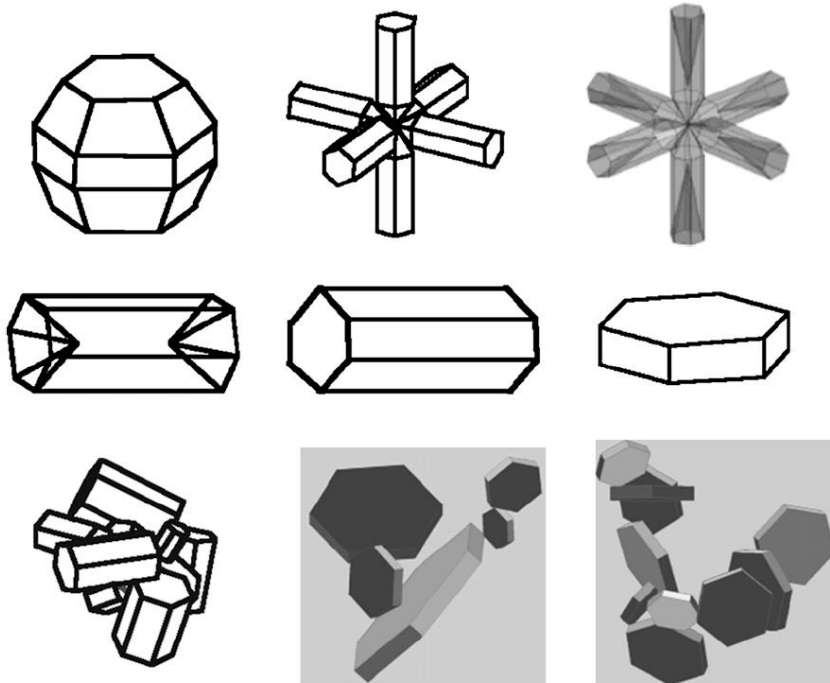
- Developed with the most accurate and state-of-the-art light scattering computation methods (T-Matrix *[Bi et al., 2014]* and IGOM *[Yang et al., 1996]*);
- Wide coverage of the spectrum from 0.2 to 100 um;
- Wide particle size range (maximum dimension) from 2~10^4 um;
- Complete scattering phase matrix with polarization
- Three degrees of ice surface roughness: Completely Smooth, Moderately Rough, Severely Rough;
- Extended to the microwave spectrum; temperature dependence considered;

Spectral Bulk Scattering Properties of Ice Clouds

$$r_{eff} = \frac{3}{2} \frac{\int_{r_{min}}^{r_{max}} V(r)n(r)dr}{\int_{r_{min}}^{r_{max}} A(r)n(r)dr},$$

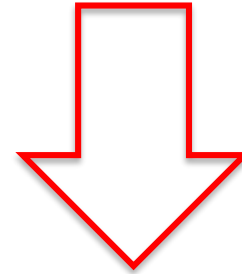Ice bulk optical properties as functions of effective radius R_{eff}

$$\overline{Q_{ext}} = \frac{\int_{r_{min}}^{r_{max}}[Q_{ext}(r)A(r)n(r)]dr}{\int_{r_{min}}^{r_{max}}[A(r)n(r)]dr},$$

$$\overline{Q_{sca}} = \frac{\int_{r_{min}}^{r_{max}}[Q_{sca}(r)A(r)n(r)]dr}{\int_{r_{min}}^{r_{max}}[A(r)n(r)]dr},$$

$$\overline{\omega} = \frac{\overline{Q_{sca}}}{\overline{Q_{ext}}},$$

$$\overline{g} = \frac{\int_{r_{min}}^{r_{max}}[g(r)A(r)Q_{sca}(r)n(r)]dr}{\int_{r_{min}}^{r_{max}}[Q_{sca}(r)A(r)n(r)]dr},$$

$$\overline{P(\theta)} = \frac{\int_{r_{min}}^{r_{max}}[P(\theta,r)Q_{sca}(r)A(r)n(r)]dr}{\int_{r_{min}}^{r_{max}}[Q_{sca}(r)A(r)n(r)]dr},$$

- Mass extinction coefficient
- Single-scattering albedo
- Asymmetry parameter
- Phase function Legendre expansion coefficient

Ice Cloud Scattering Properties
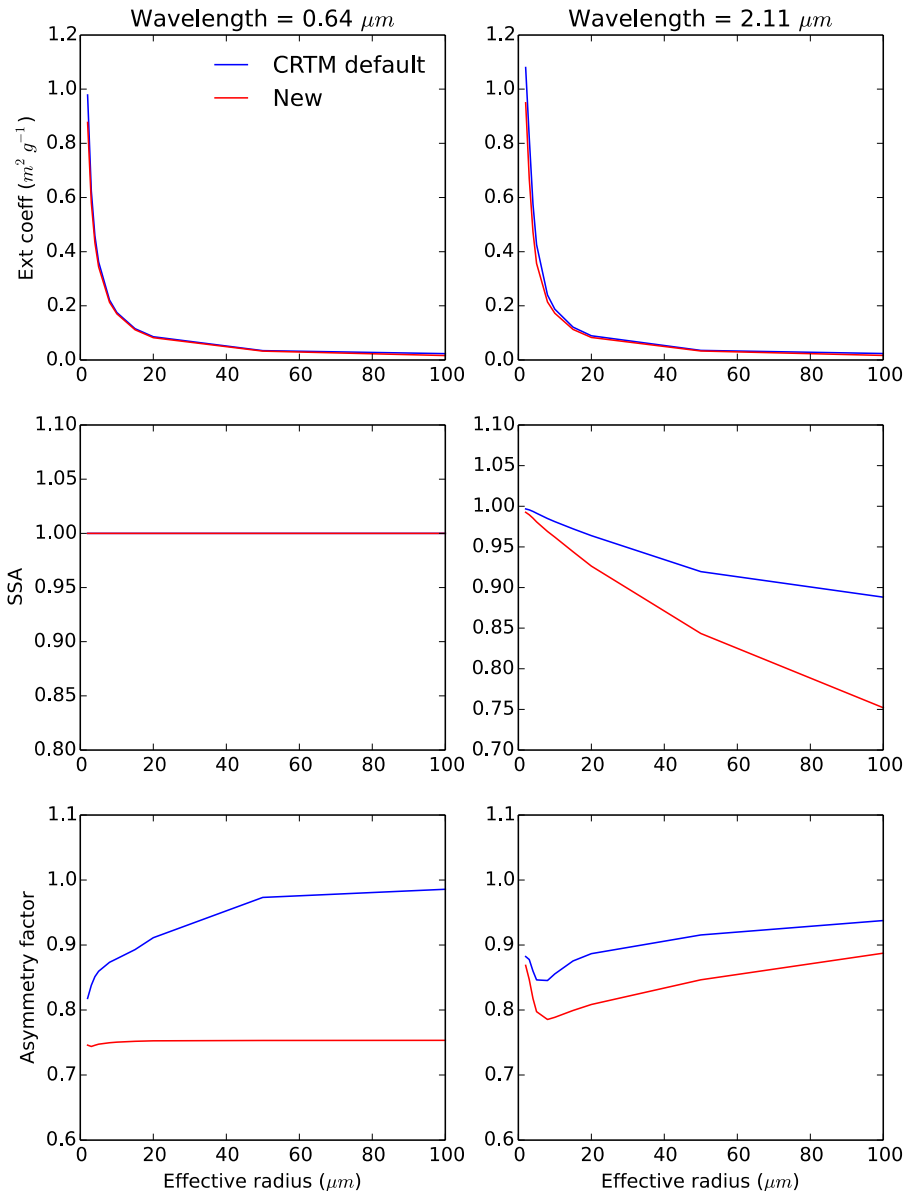
- Ice mass extinction coefficients:
  - Little difference
- The single-scattering albedo:
  - ~1 (0.64 μm wavelength)
  - Decreases with the increase of effective radius (2.11 μm wavelength)
- The asymmetry factor:
  - Shortwave (0.64 μm) ice cloud is almost independent to the effective size and remains constant around 0.75.
  - Conversely, the CRTM default ice cloud asymmetry factor has increasingly larger value with an increase in the effective radius.

Aerosol Scattering Database
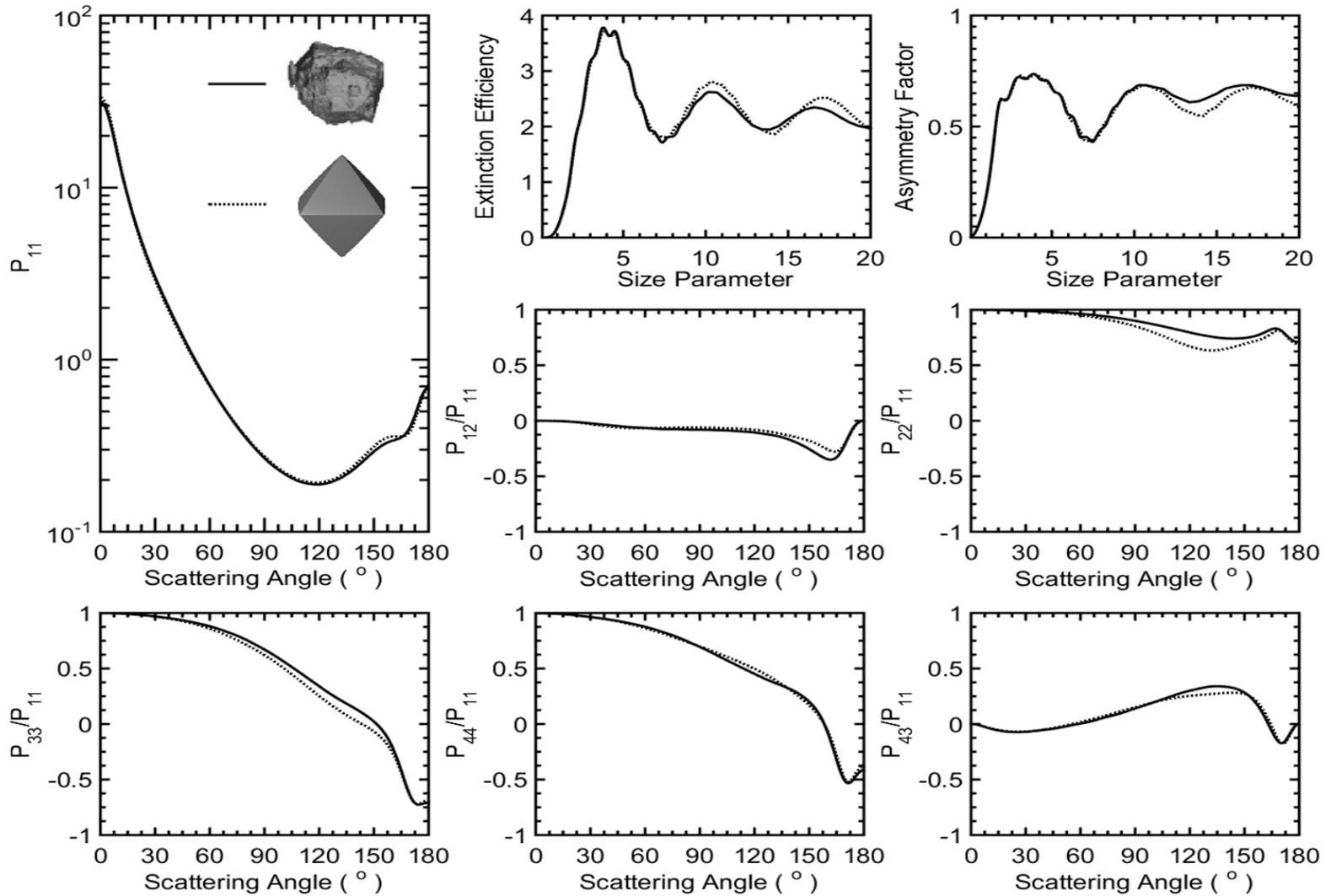
ARMS Surface Optics

- IR Ocean EM
    Wu-Smith-IR
- MW Ocean EM
    HSKS-EM
    FASTEM
- MW Land EM
    Advanced integral equation model (AIEM)
    Two stream analytic model
- Data Bases
    CNRW MW
    TELSEM MW
    UW IREMIS
    CAMEL IR

HSKS-Ocean Emissivity Model
(Hollinger-Stogryn-Klein and Swift)

- A rough surface without foam coverage: Hollinger, J. P., 1971, Passive microwave measurements of sea surface roughness, IEEE Trans on Geosci. Elec., GE-9, 165-169.

- Foam Reflectivity: Stogryn, A. 1972, A study of radiometric emission from a rough sea surface, NASA contractor report NASA, CR-2088.

- Calm water reflectivity: Klein and Swift, (1977 " emissivity for calm water" IEEE Trans. Antennas Propag., 25, 104-111.

HSKS-Ocean Emissivity Model

$$\Gamma_p = (1 - f_c)\Gamma_{p,foam-free} + f_c\Gamma_{p,foam}$$

Foam-free Reflectivity in H-Polarization due to wind roughness

$$tr = w(1.15\times10^{-1} + 3.8\times10^{-5}\times\theta^2)\sqrt{f\times10^{-9}}$$

$$\Gamma_{h,foam-free} = \Gamma_{h,calm} - tr/t_s$$

Foam-free Reflectivity in V-Polarization due to wind roughness

$$tr = w(1.17\times10^{-1} - 2.09\times10^{-3}\times exp(7.32\times10^{-2}\times\theta))\sqrt{f\times10^{-9}}$$

$$\Gamma_{v,foam-free} = \Gamma_{v,calm} - tr/t_s$$

Foam Reflectivity in H-Polarization

$$g = 1.0 - 1.748\times10^{-3}\theta - 7.336\times10^{-5}\times\theta^2 + 1.044\times10^{-7}\times\theta^3$$

$$\Gamma_{h,foam} = 1.0 - (208.0 + 1.29\times10^{-9}*f)/(t_s g)$$

Foam Reflectivity in V-Polarization

$$g = 1.0 - 9.946\times10^{-4}\times\theta + 3.218\times10^{-5}\times\theta^2 - 1.187\times10^{-6}\times\theta^3 + 7\times10^{-20}\times\theta^{10}$$

$$\Gamma_{v,foam} = 1.0 - (208.0 + 1.29\times10^{-9}*f)/(t_s g)$$

Refractivity or Emissivity for Calm Water Surface

For a specular surface, reflectivity can be calculated by Fresnel law:

$$\Gamma_{v,calm} = \frac{\varepsilon(f,\theta)\cos\theta - \sqrt{\varepsilon(f,\theta) - \sin^2\theta}}{\varepsilon(f,\theta)\cos\theta + \sqrt{\varepsilon(f,\theta) - \sin^2\theta}}$$

$$\Gamma_{h,calm} = \frac{\cos\theta - \sqrt{\varepsilon(f,\theta) - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon(f,\theta) - \sin^2\theta}}$$

sea surface
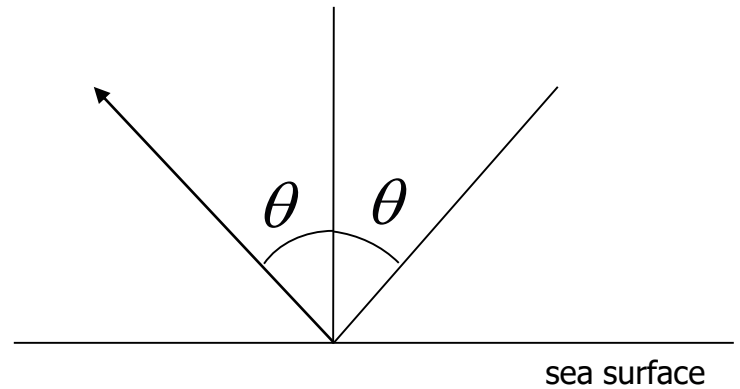
$\Gamma_p(f,\theta)$ Reflectivity f Frequency θ Local zenith angle

Foam Coverage

Foam is a mixture of air and water and has a higher emissivity than flat water

Foam coverage:

Stogryn, 1972

$$f_c = 7.75 \times 10^{-6} \left(\frac{V}{V_0} \right)^{3.231}$$

Monahan, 1986

$$f_c = 1.95 \times 10^{-5} u^{2.55}$$
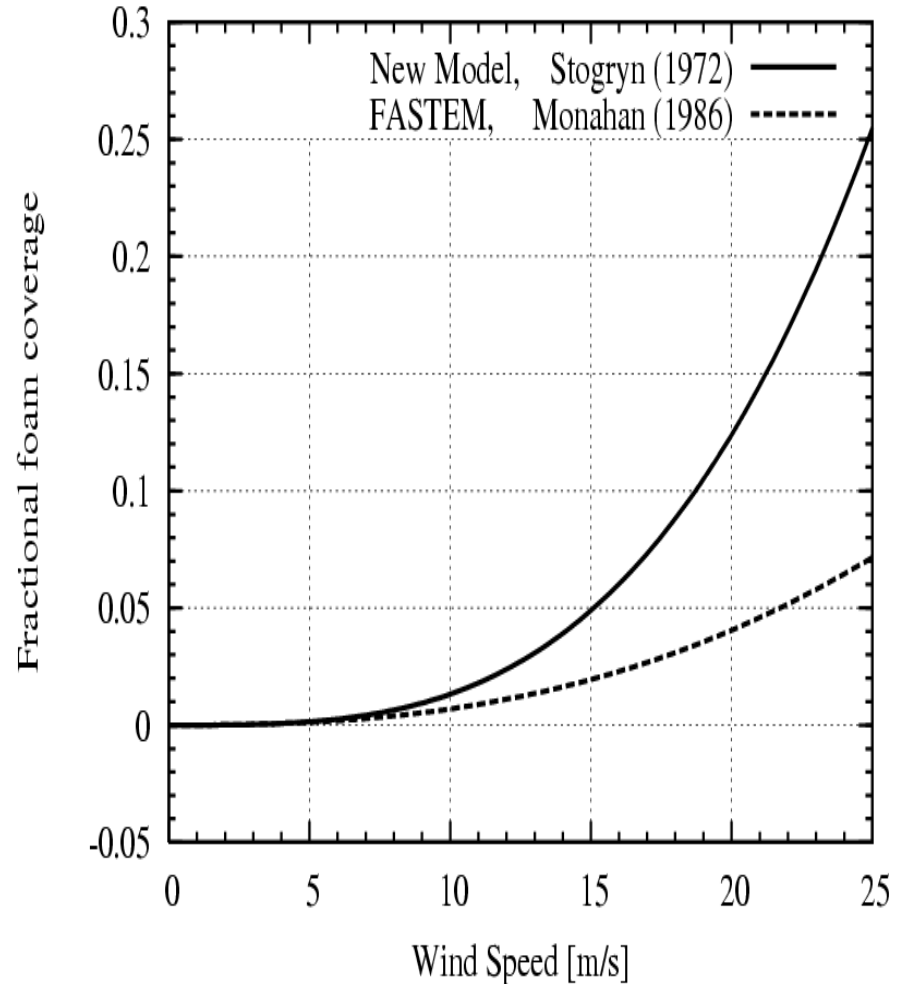
Foam Emissivity vs. Angle
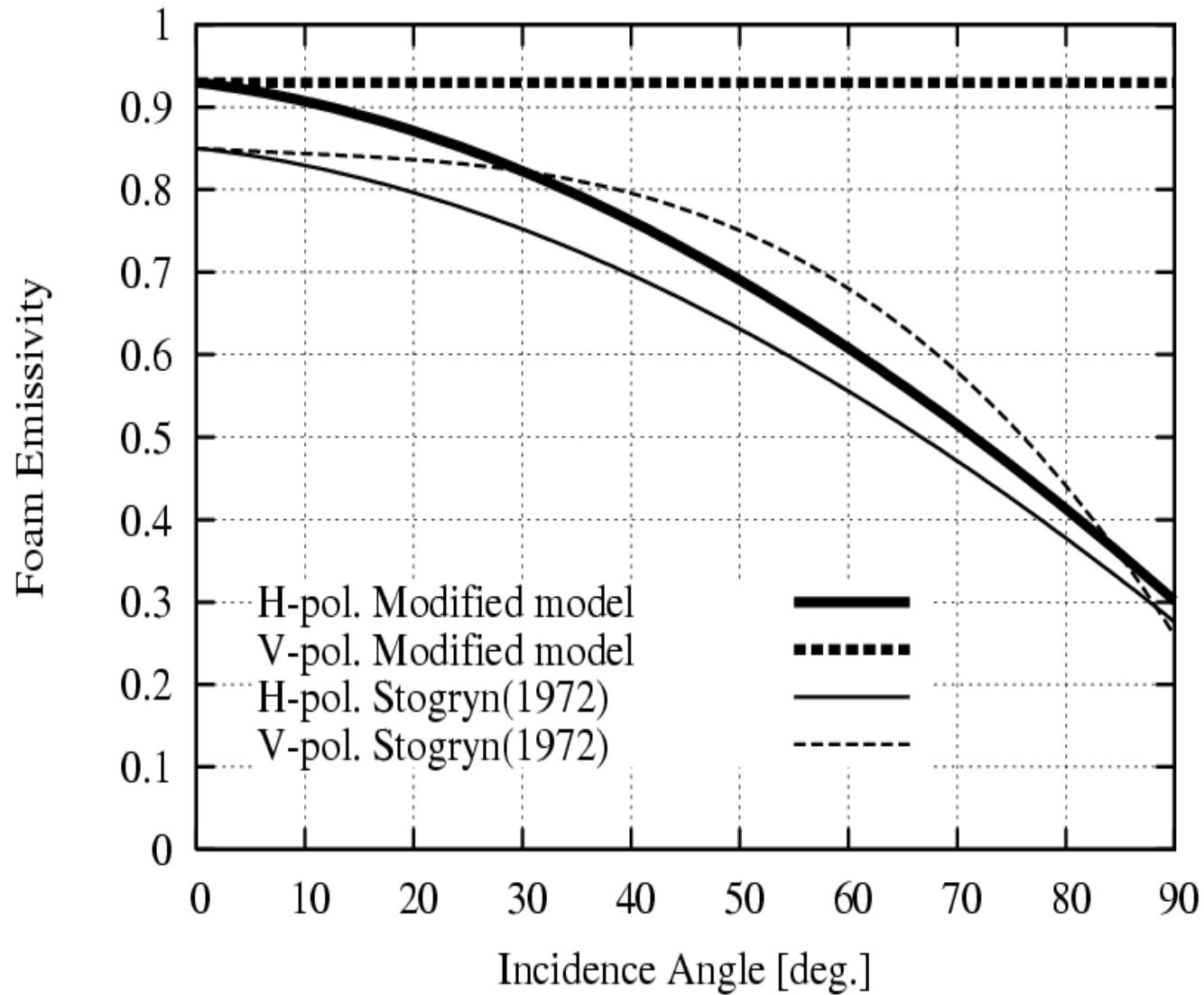
Two-Scale Ocean Emissivity Model
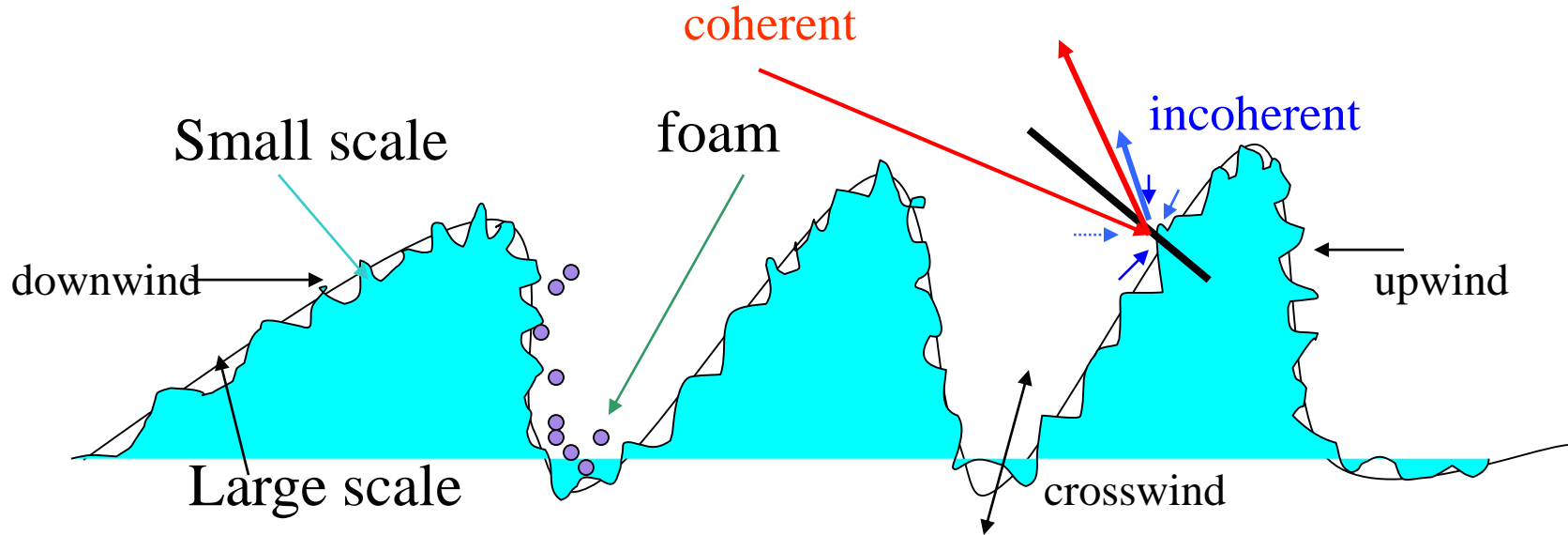
The large-scale roughness is dependent on the gravity waves and whereas the small irregularities is affected by capillary waves. There are coherent reflection and incoherent scattering associated with the waves in both scales

Surface MW BRDF Emissivity Model

Relationship of BRDF, Bistatic Coeffs and Emissivity

$$e_p(\vartheta_i, \varphi_i) = 1 - r_p(\vartheta_i, \varphi_i)$$

$$r_p(\vartheta_i, \varphi_i) = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi/2} (\sigma_{pp}(\vartheta_s, \varphi_s; \vartheta_i, \varphi_i) + \sigma_{qp}(\vartheta_s, \varphi_s; \vartheta_i, \varphi_i)) \frac{sin\vartheta_s}{cos\vartheta_i} d\vartheta_s \varphi_s$$

$$= \int_0^{2\pi} \int_0^{\pi/2} (\gamma_{pp}(\vartheta_s, \varphi_s; \vartheta_i, \varphi_i) + (\gamma_{qp}(\vartheta_s, \varphi_s; \vartheta_i, \varphi_i)) sin\vartheta_s d\vartheta_s \varphi_s$$

$$= r_p^{coherent}(\vartheta_i, \varphi_i) + r_p^{incoherent}(\vartheta_i, \varphi_i)$$

where p,q stands for polarization,   s for scattering,   i for incident

$$I_{stokes} = \begin{bmatrix} \langle |E_h|^2 \rangle \\ \langle |E_v|^2 \rangle \\ 2Re\langle E_v E_h^* \rangle \\ 2Im\langle E_v E_h^* \rangle \end{bmatrix} = c \begin{bmatrix} T_h \\ T_v \\ U \\ V \end{bmatrix}$$

$$\begin{bmatrix} r_h(\vartheta_i, \varphi_i) \\ r_v(\vartheta_i, \varphi_i) \\ r_U(\vartheta_i, \varphi_i) \\ r_V(\vartheta_i, \varphi_i) \end{bmatrix}^{coh} = \begin{bmatrix} \left|R_{hh}^{(0)}\right|^2 + 2Re(R_{hh}^{(0)} R_{hh}^{(2)*}) \\ \left|R_{vv}^{(0)}\right|^2 + 2Re(R_{vv}^{(0)} R_{vv}^{(2)*}) \\ 2Re(R_{hh}^{(0)*} R_{vh}^{(2)} + R_{vv}^{(0)} R_{hv}^{(2)*}) \\ 2IM(R_{hh}^{(0)*} R_{vh}^{2} + R_{vv}^{(0)} R_{hv}^{(2)*}) \end{bmatrix} \text{Yueh, 1997}$$

$$\begin{bmatrix} r_h(\vartheta_i, \varphi_i) \\ r_v(\vartheta_i, \varphi_i) \\ r_U(\vartheta_i, \varphi_i) \\ r_V(\vartheta_i, \varphi_i) \end{bmatrix}^{inc} = \int_0^{2\pi} \int_0^{\pi/2} \begin{bmatrix} R_{hh}^{(1)} R_{hh}^{(1)*} + R_{hv}^{(1)} R_{hv}^{(1)*} \\ R_{vv}^{(1)} R_{vv}^{(1)*} + R_{vh}^{(1)} R_{hv}^{(1)*} \\ 2Re(R_{vh}^{(1)} R_{hh}^{(1)*} + R_{vv}^{(1)} R_{hv}^{(1)*}) \\ 2Im(R_{vh}^{(1)} R_{hh}^{(1)*} + R_{vv}^{(1)} R_{hv}^{(1)*}) \end{bmatrix} sin\vartheta_s d\vartheta_s \varphi_s$$

where $R_{pq}^0 = R_{pq}^0(\vartheta_s, \varphi_s; \vartheta_i, \varphi_i)$ are SPM bistaic coefficents

There are several well-established methods for simulation of electromagnetic scattering from randomly rough surfaces

❑ **Kirchhoff Method (KM)** based on the assumption that the wavelength of the incident wave is much shorter than the horizontal variations of the surface so that the general solution can be regarded as the integration of local plane-boundary reflections.

Tangential Plane Approximation
*Stationary Phase Approximation and Geometric Optics (GO) (**FASTEM**)*
Scalar Approximation and Physical Optics (PO)

❑**Small Perturbation Method (SPM)** based on the assumption that the surface correlation length and its standard deviation are smaller than the wavelength (low frequencies).

❑**Composite Two-scale Model** based on the separation of both the surface and the EM wave into two distinct scales, e.g., Yueh et al., 1997

Water Permittivity Model

Debye (1929) model for pure water, the permitivity

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j2\pi f\tau}$$

Dissolved salt in water will be a good conductor and contributes to imaginary part

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_\infty}{1 + j2\pi f\tau} + j\frac{\alpha}{2\pi f\varepsilon_0}$$

For a better performance at higher frequency, it is found that double Debye is needed with

$$\varepsilon = \varepsilon_\infty + \frac{\varepsilon_s - \varepsilon_1}{1 + j2\pi f\tau_1} + \frac{\varepsilon_1 - \varepsilon_\infty}{1 + j2\pi f\tau_2} + j\frac{\alpha}{2\pi f\varepsilon_0}$$

ε_1 **is the permittivity at an intermediate frequency**

Water Permittivity vs. Frequency
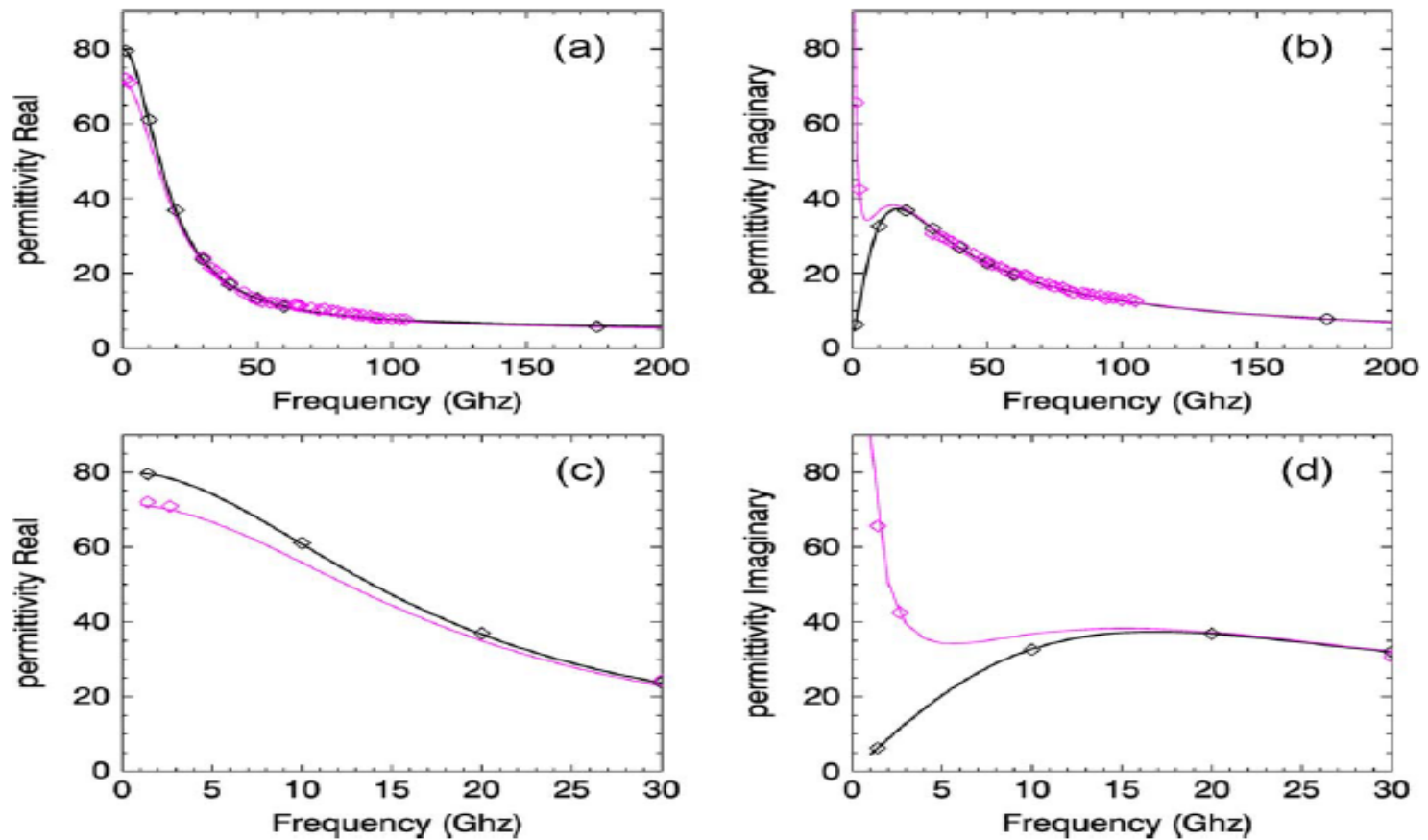
Fig. 1. Panels (a) and (b) represent the real and imaginary parts of the permittivity. Panels (c) and (d) are a zoom-in part for low frequencies. The black line is for fresh water, and the red line is for salt water. The water temperature is 25 °C. The salinity of sea water is 35‰. The solid lines represent the model results. The diamond symbols are for the measurements [12], [14], [18], [20]–[23].

Water Permittivity vs. Frequency
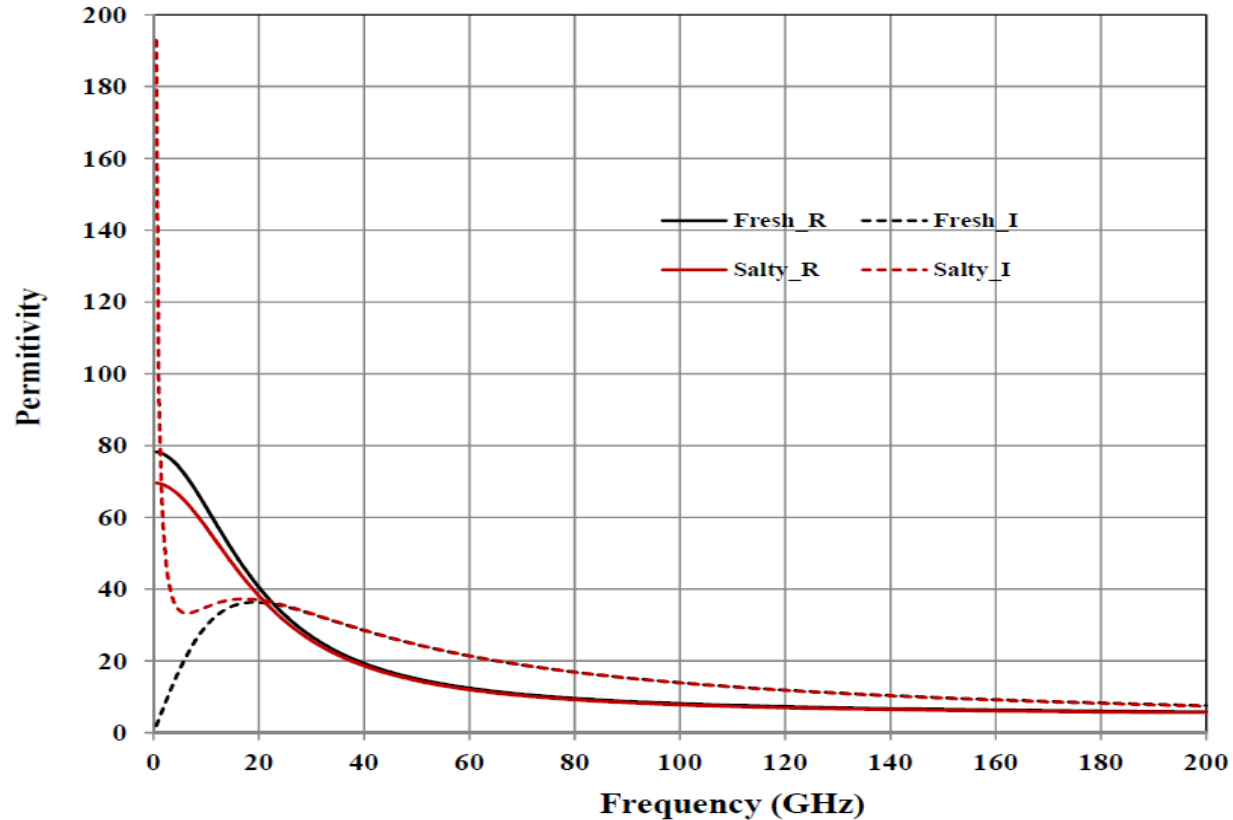
The permittivity model of Ellison (2003) is for a fixed salinity of 35‰. The permittivity model Black line for fresh water and red line for sea water. The symbol squares are measurements for fresh water (black) and sea water (red).

Comparison of Model Simulations with JPL WINDRAD Observations (theta=30°)

FASTEM6/5 and Two-Scale
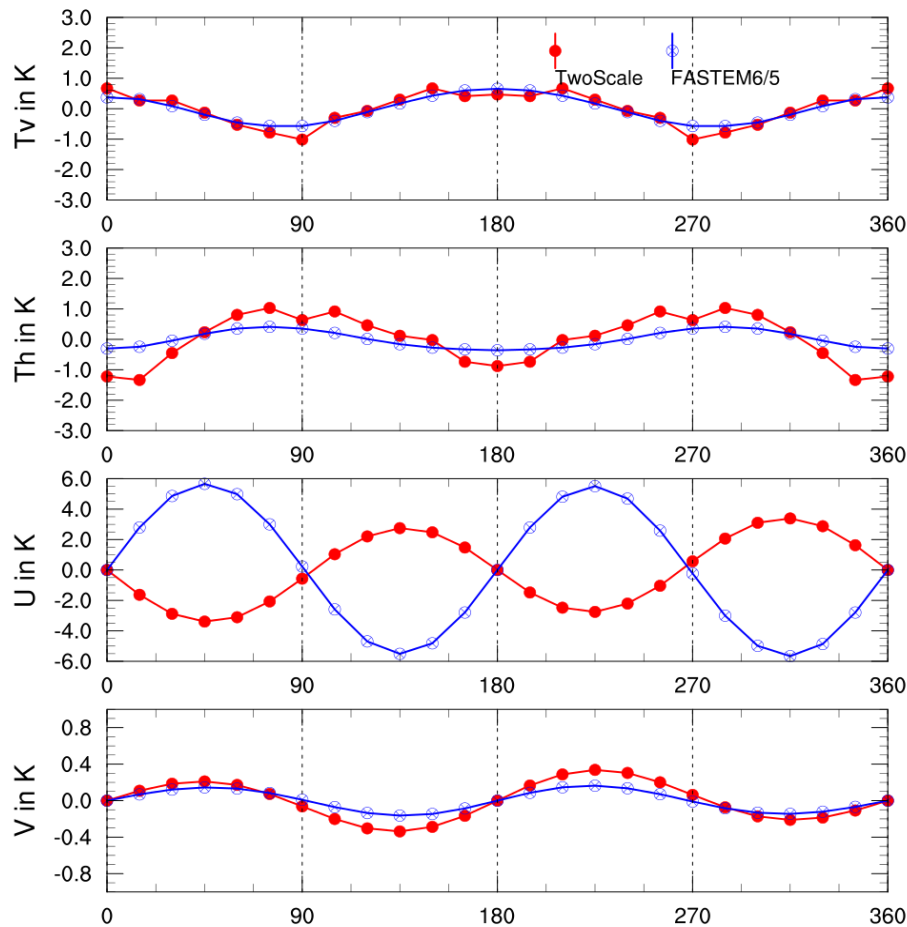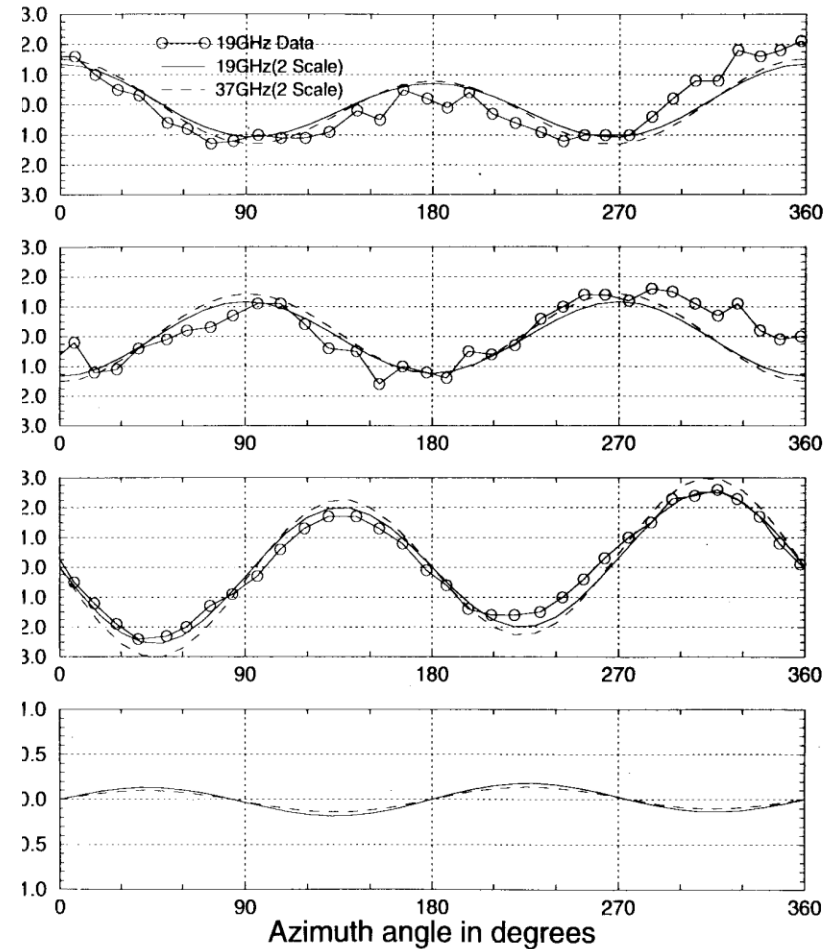
Yueh 1997

Two-Scale Ocean Emissivity Model vs. NRL Observations
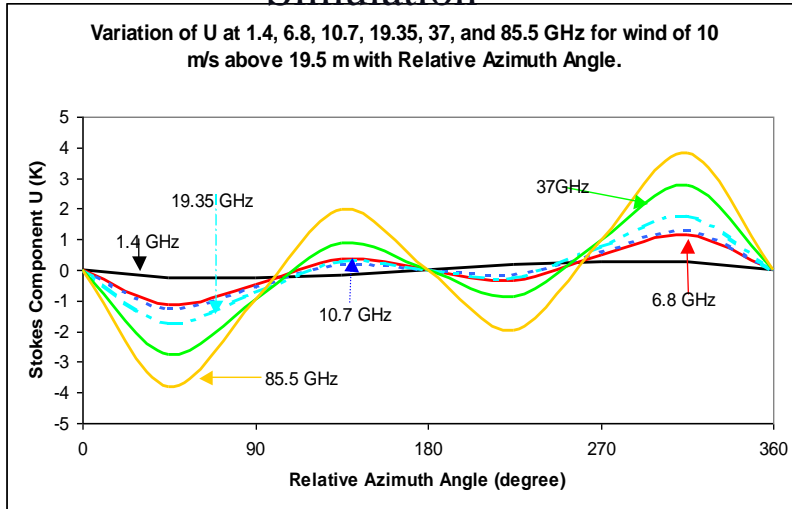
Simulation

Measurement

Two-Scale Ocean Emissivity Model vs. NRL Observations

Simulation

Measurement
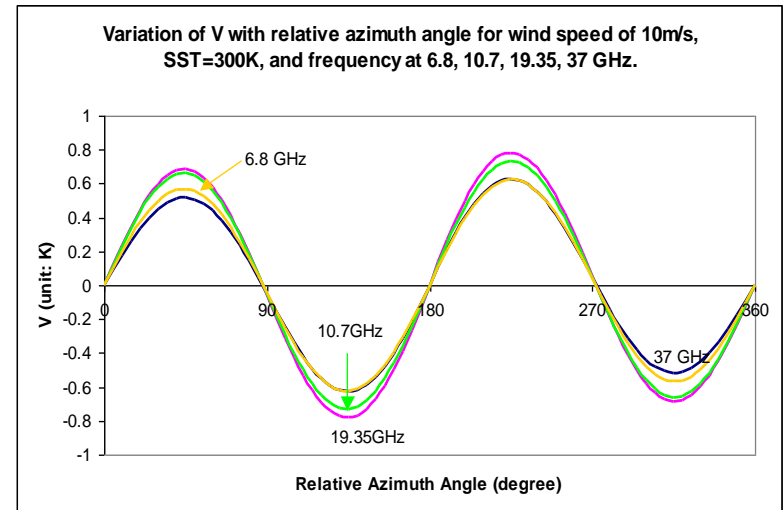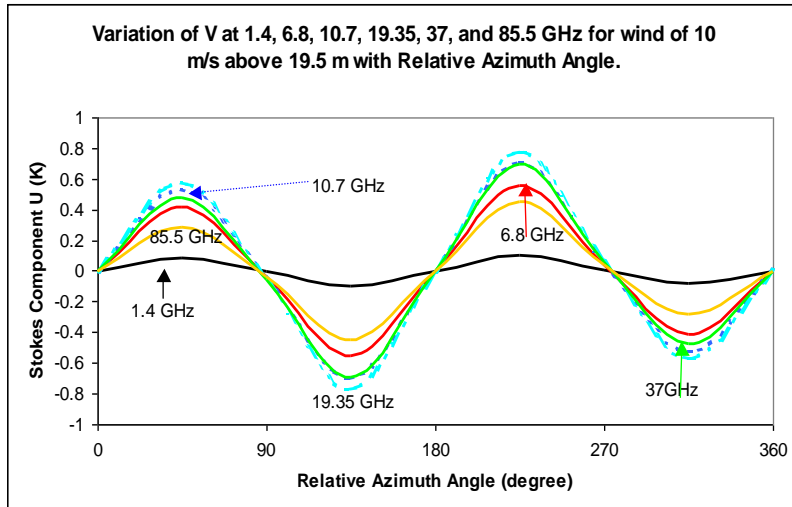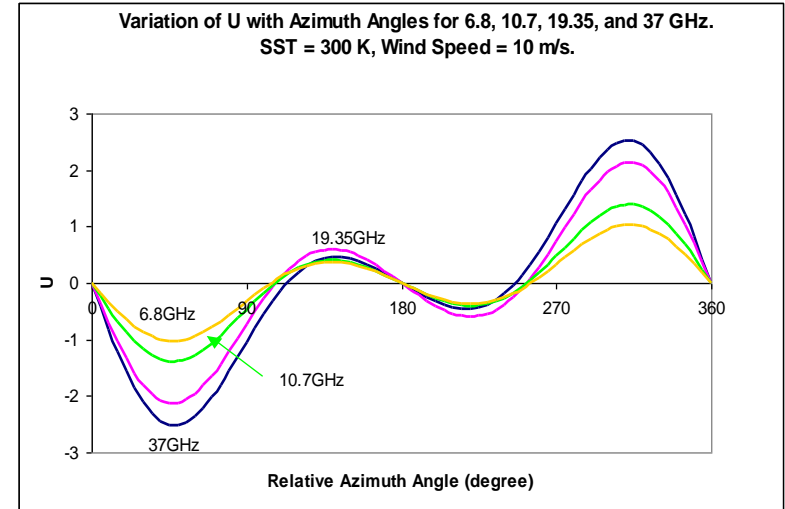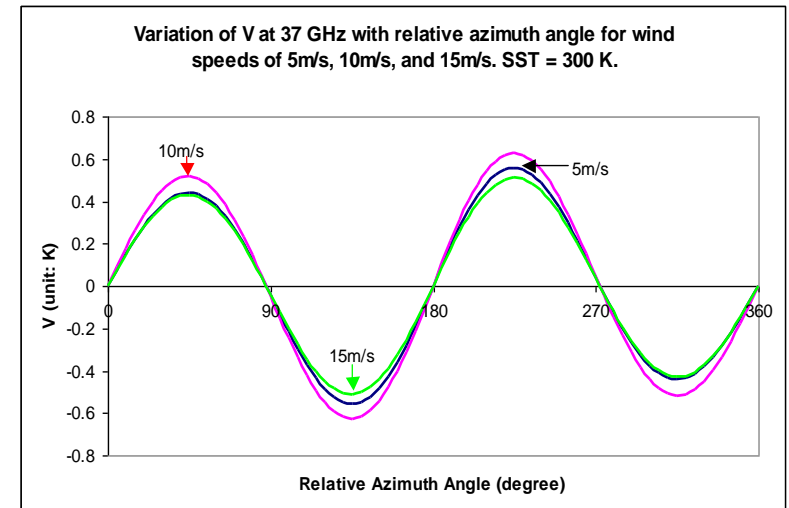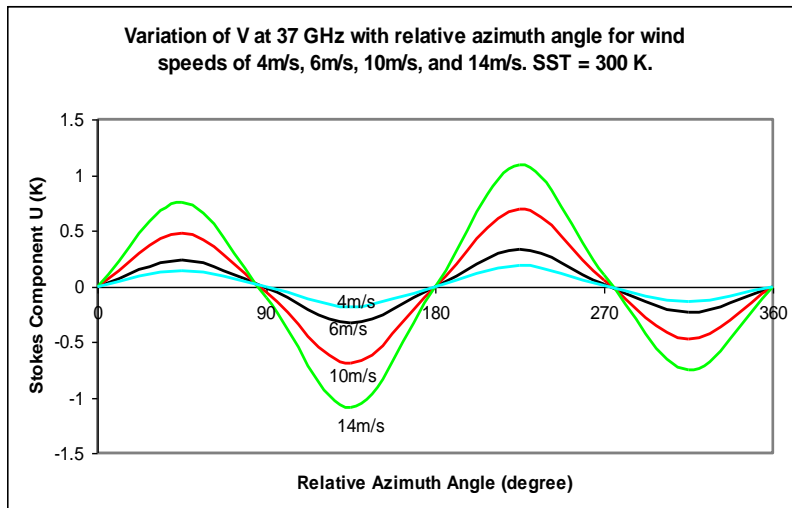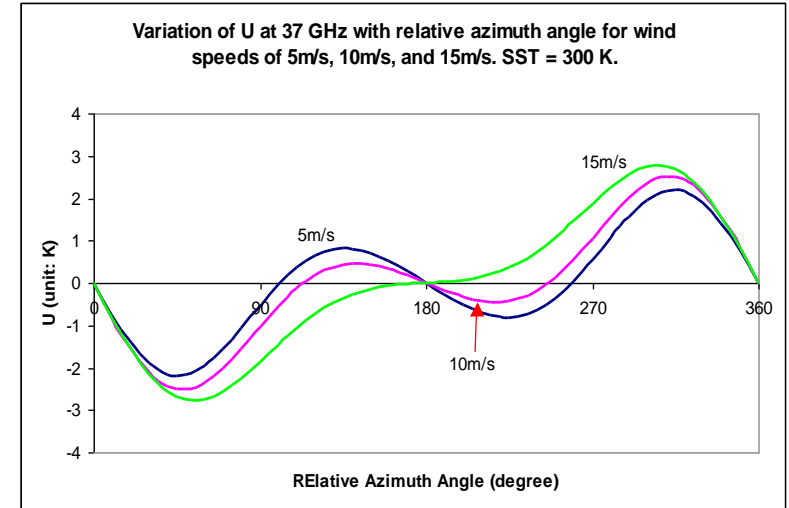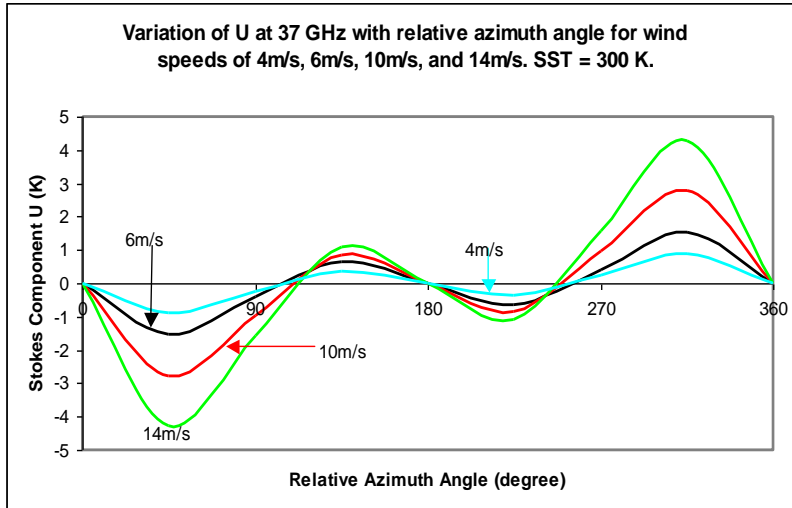
MWRI O-B 10.65H

MWRI O-B 10.65V

34

MWRI O-B 18.7H

MWRI O-B 18.7V

MWRI O-B 23.8H

MWRI O-B 23.8V

MWRI O-B 36.5H

MWRI O-B 36.5V
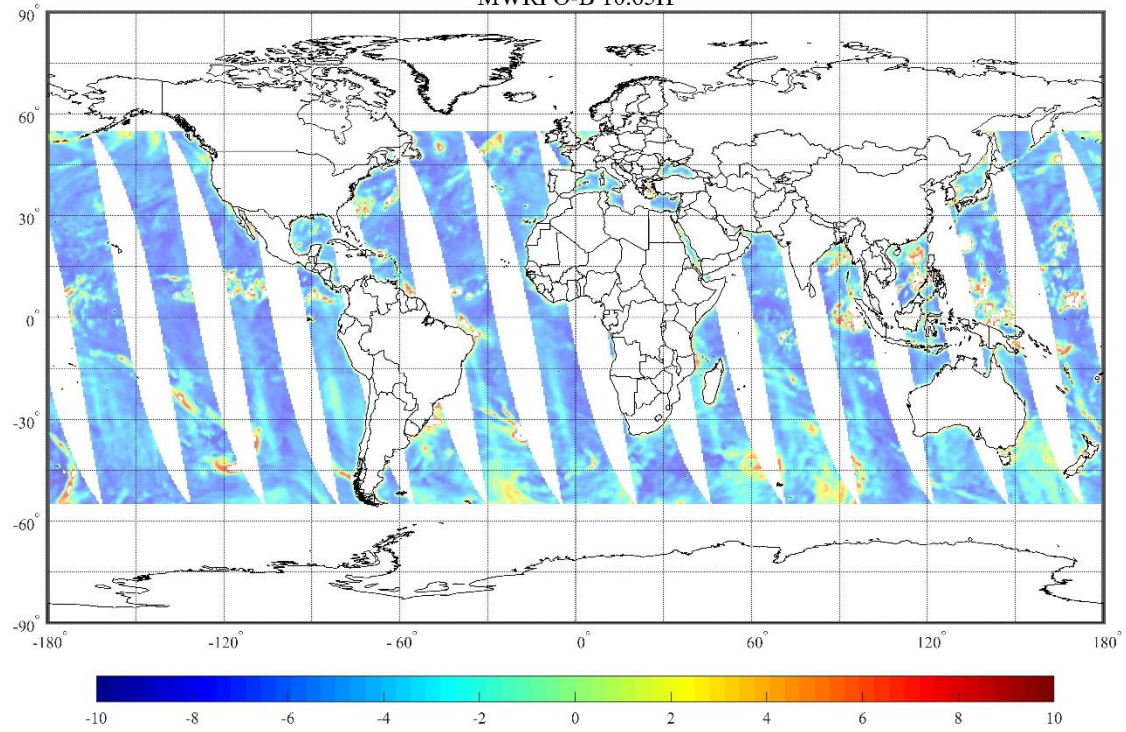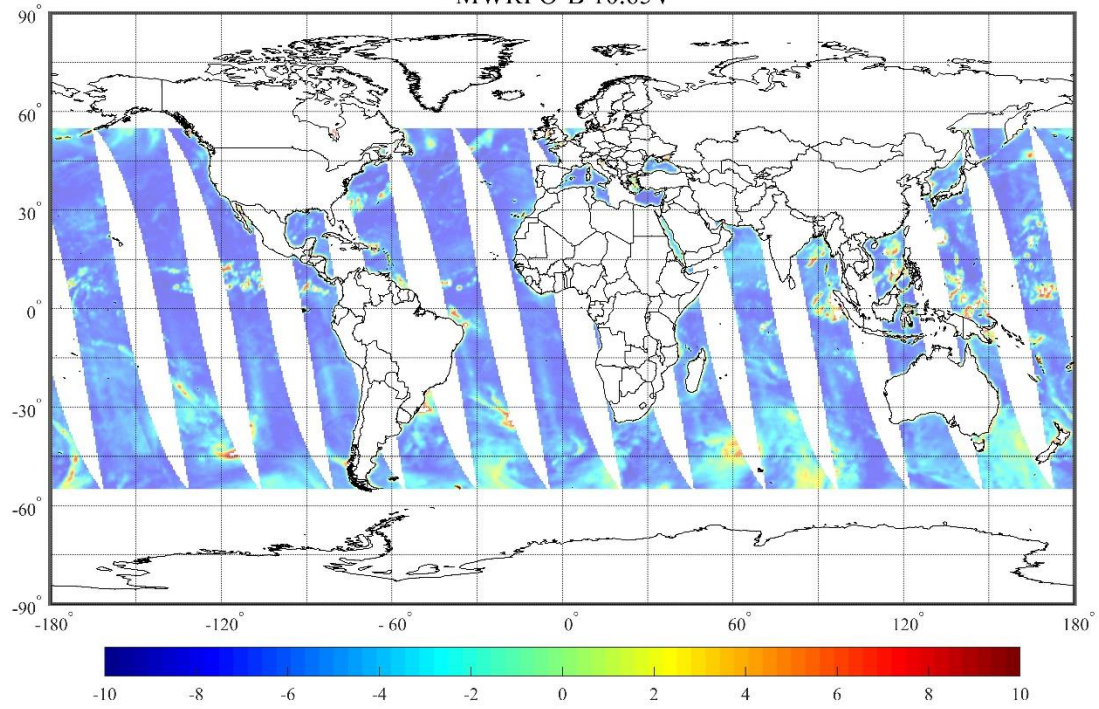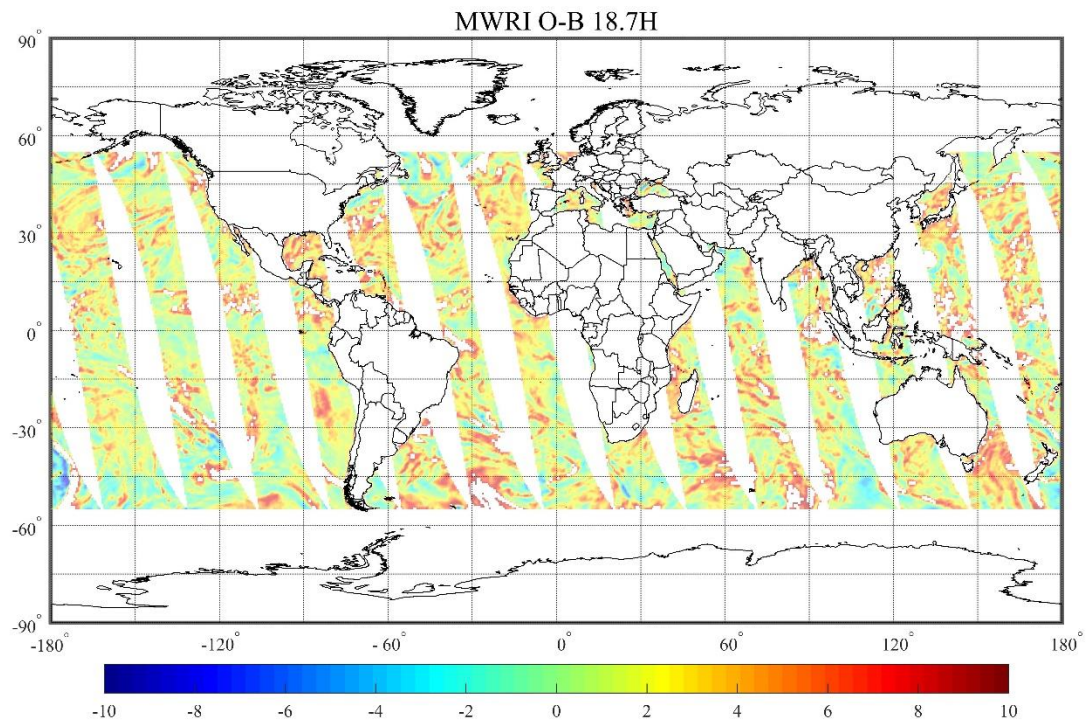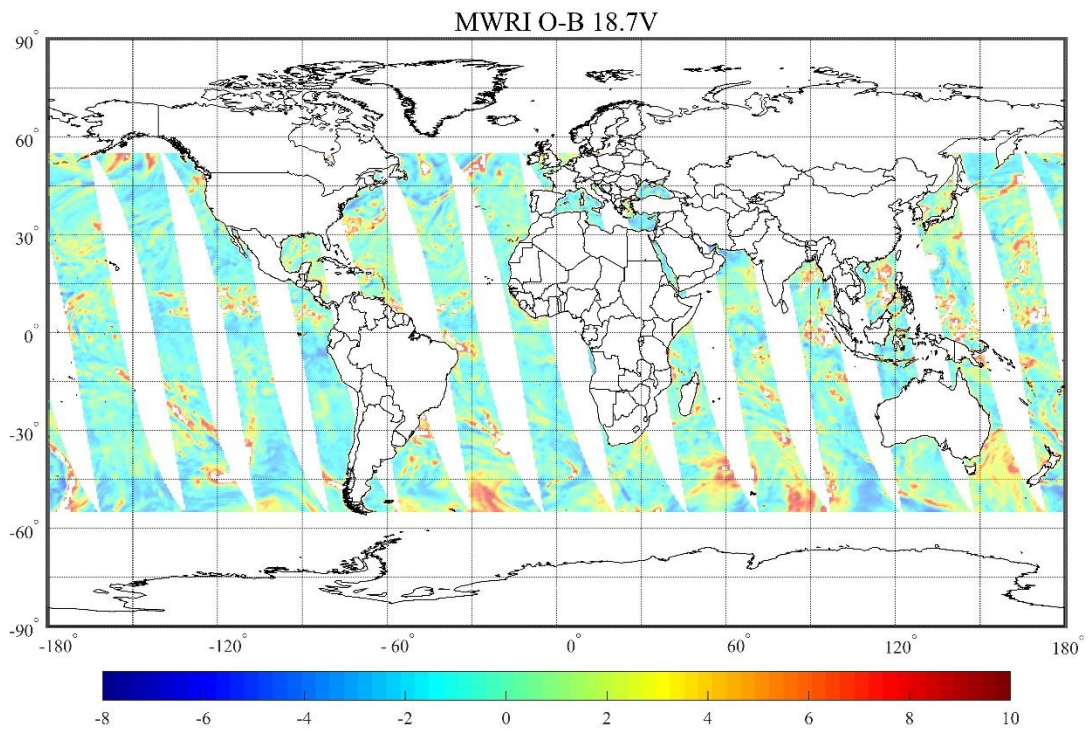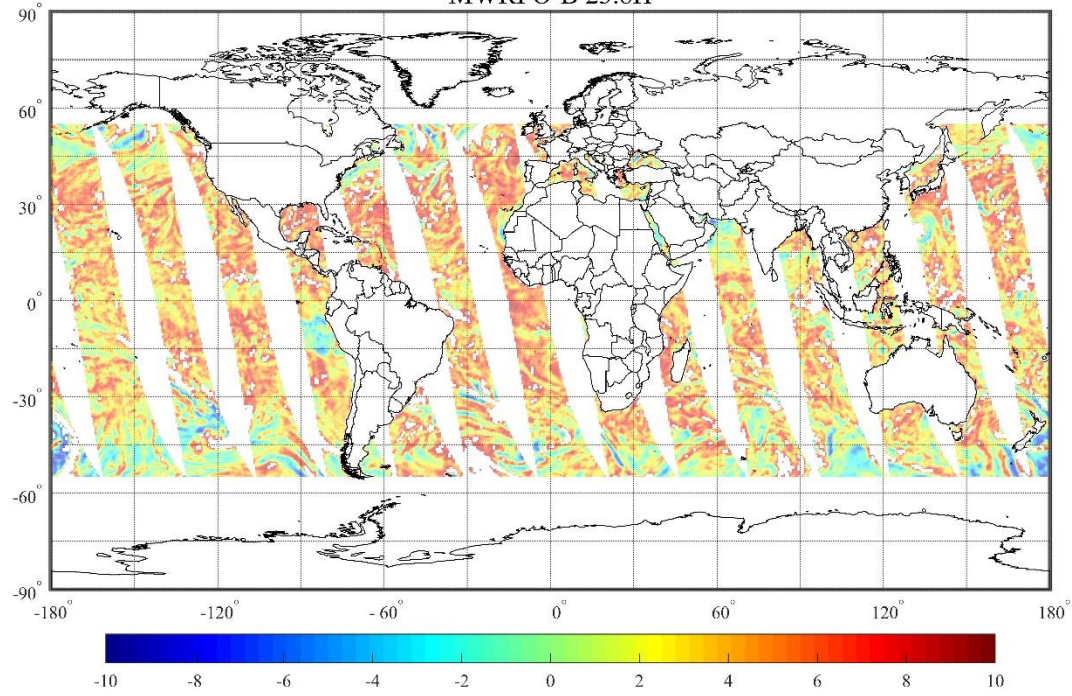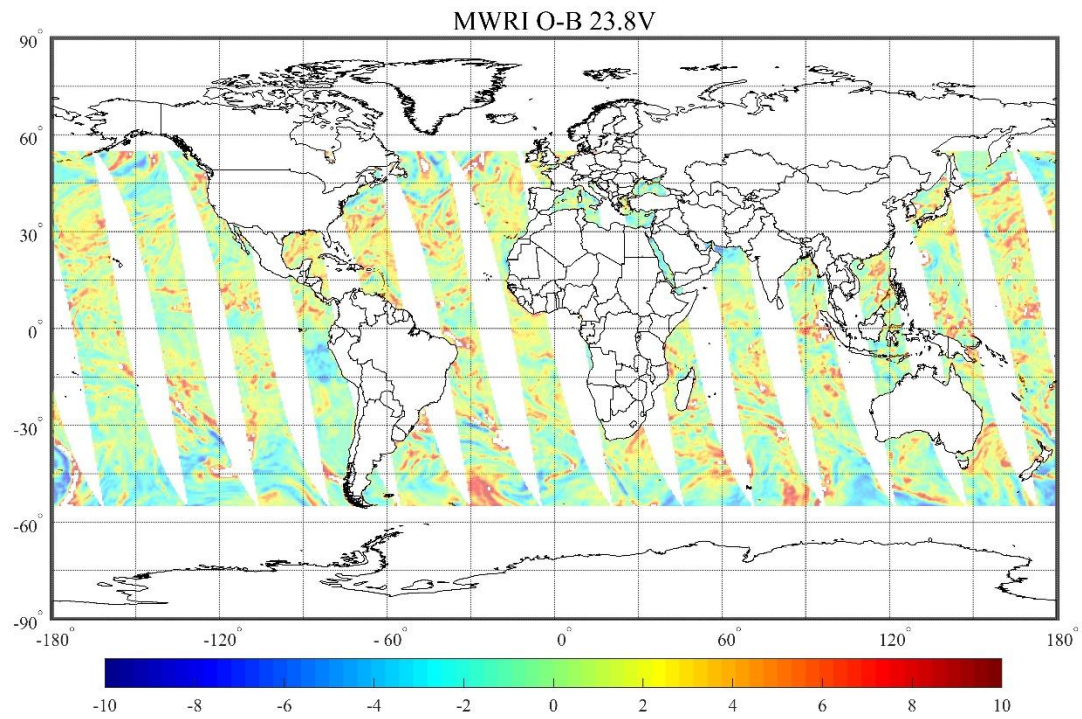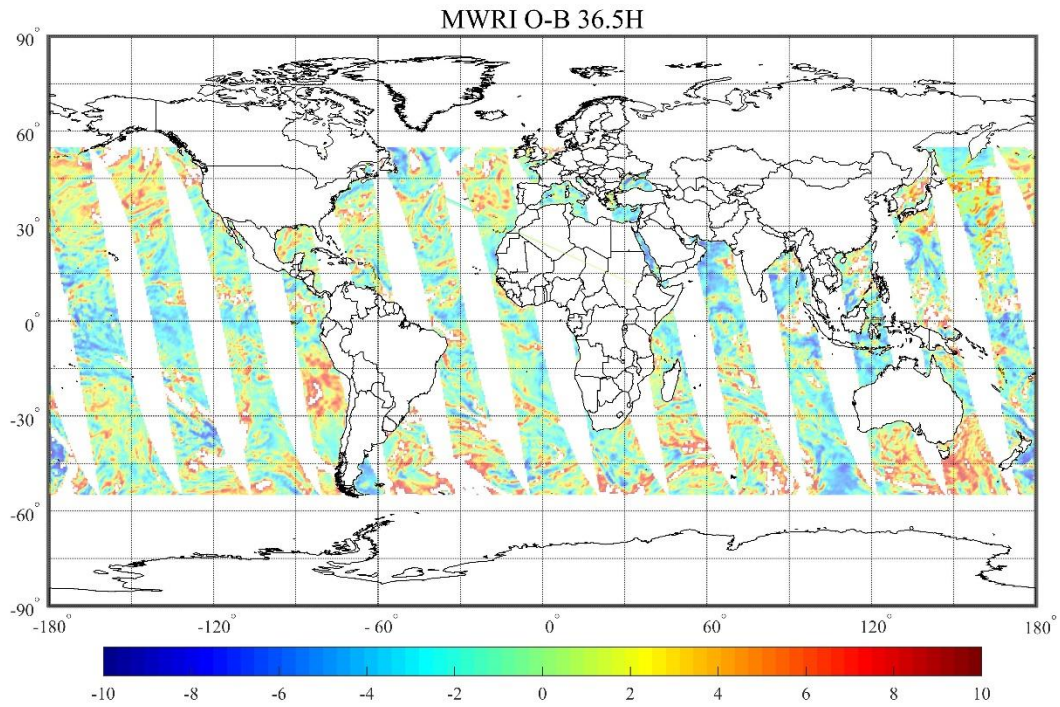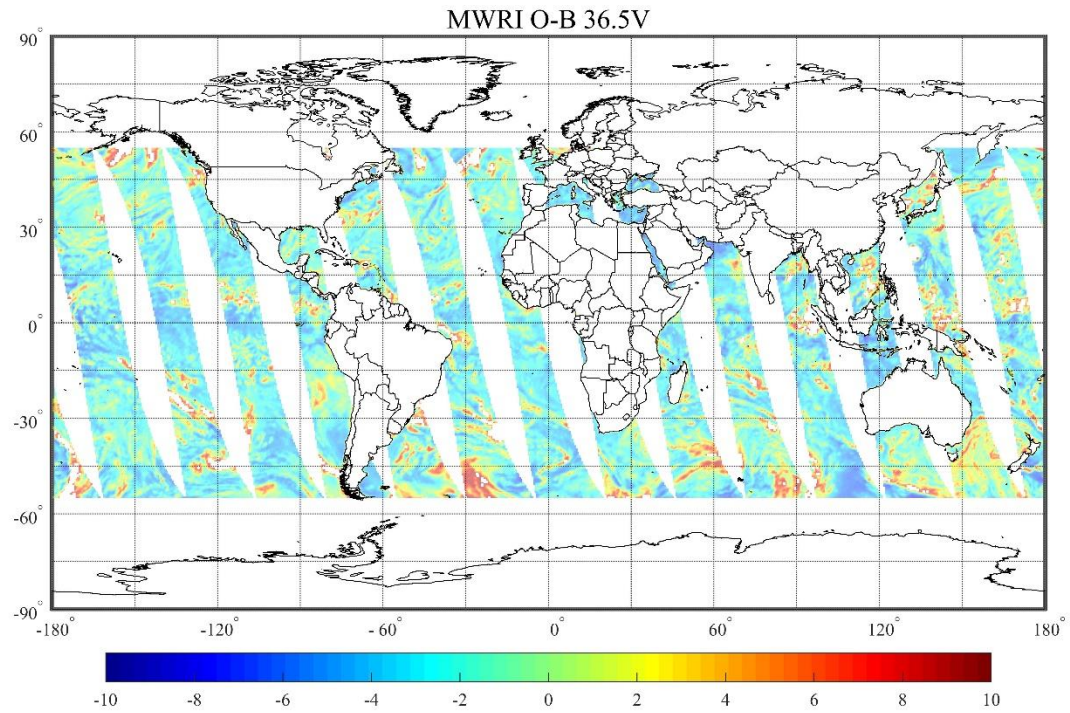
MWRI O-B 89.0H

MWRI O-B 89.0V

42
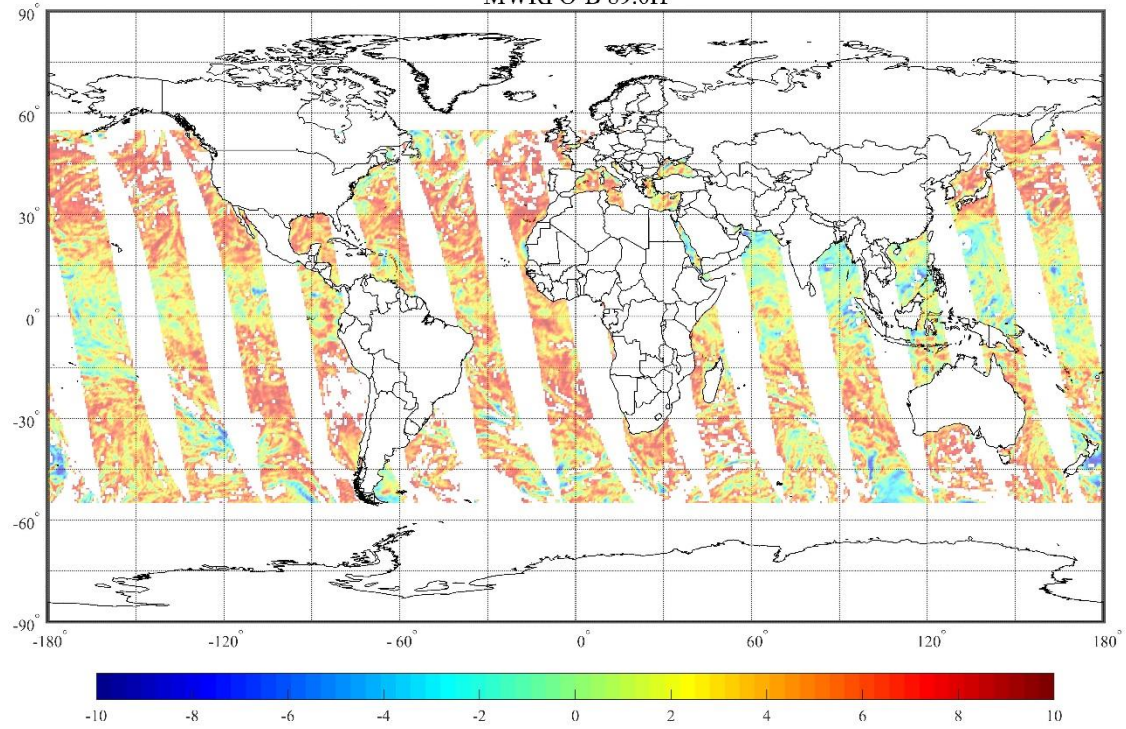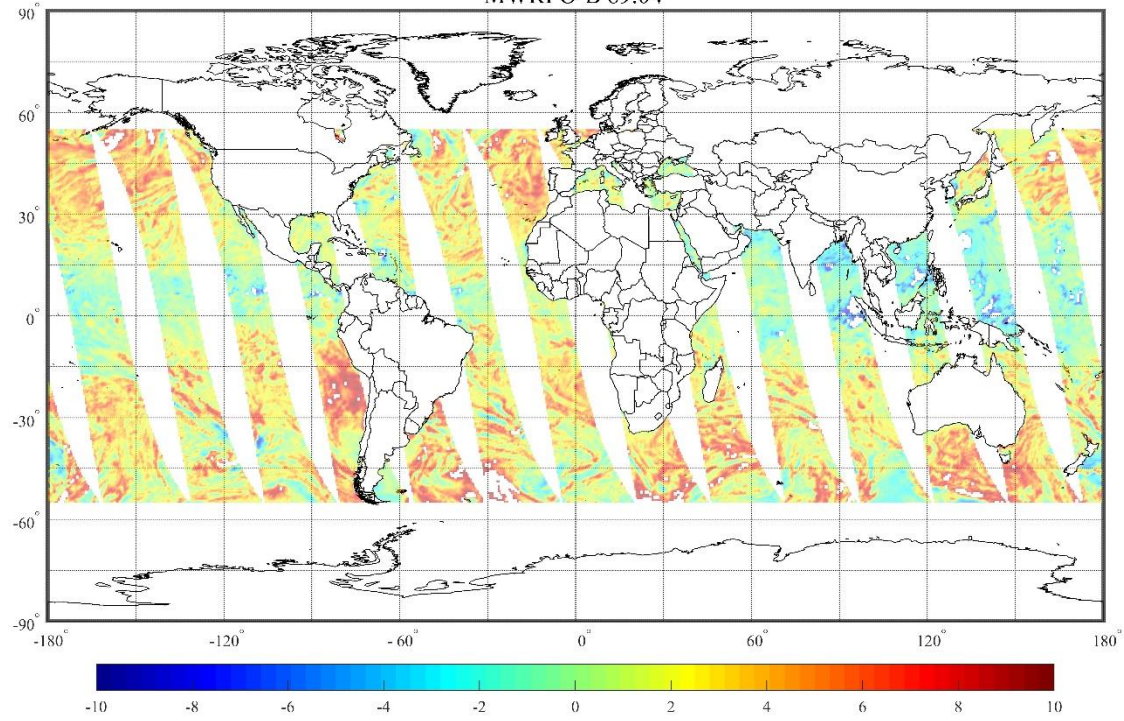
ATMS Reflector Emission and Its Effects on TDR

- Flat rotating reflector has an emission and affects the accuracy in computing the calibration target temperatures in two point calibration equations

- In the earth scene scanning, the antenna brightness temperature in the two-point calibration equation contains emission that must be further corrected

- Hagen-Rubens equation

$$\varepsilon_N = \sqrt{16\pi e_0 f / \sigma}$$

   0.0025 to 0.0065

- An algorithm is being developed for ATMS TDR correction
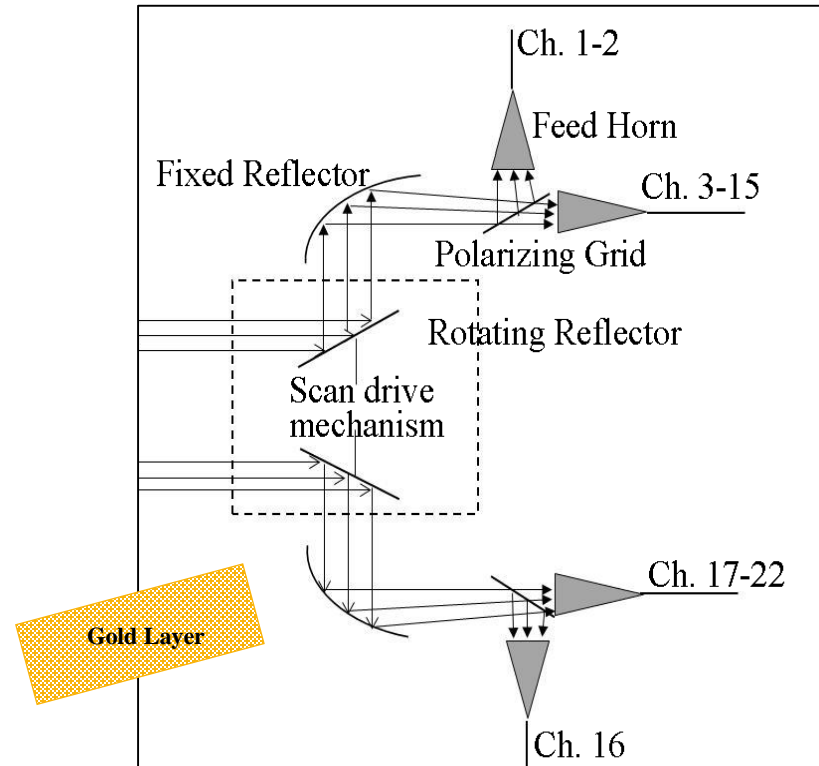
ATMS TDR Pitch-over Maneuver Data

ATMS TDR at Ch18 on February 20, 2012

Start maneuver
1815 UTC

B49 scan off earth view at
1826 UTC

B49 returns earth view
at 1848 UTC

End pitch
1858 UTC
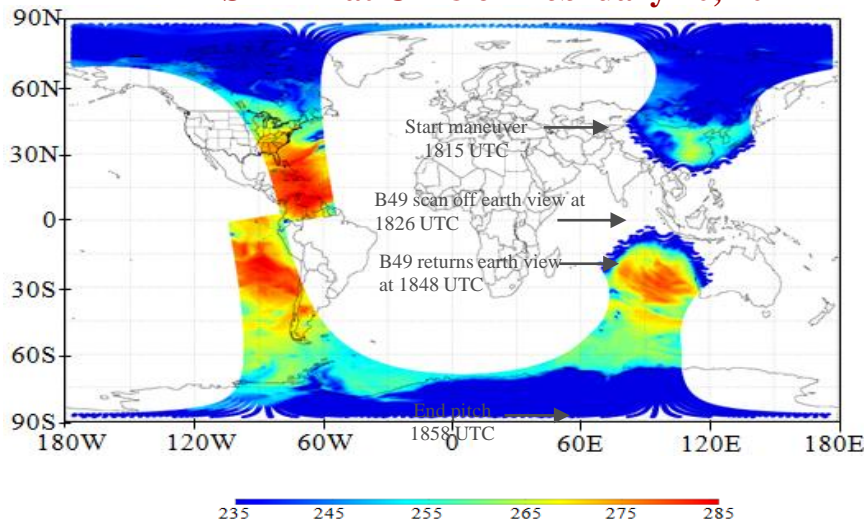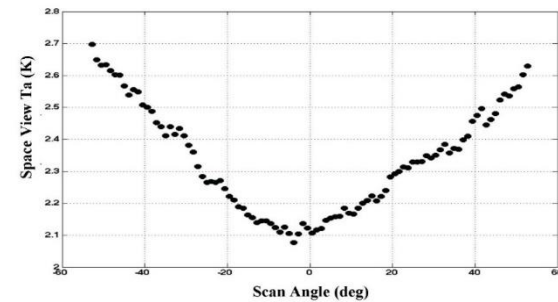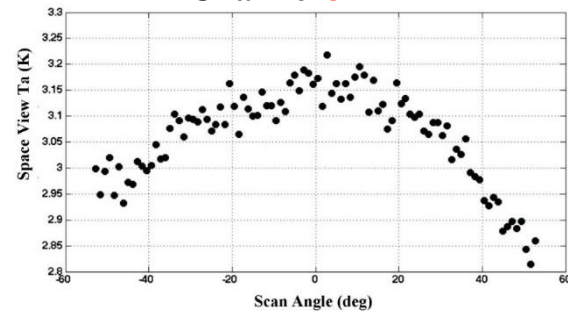
Channel 1

Channel 3

NPP ATMS pitch maneuver observations show channel related scan angle dependent feature, indicate the scan bias is not inherent feature of the scene
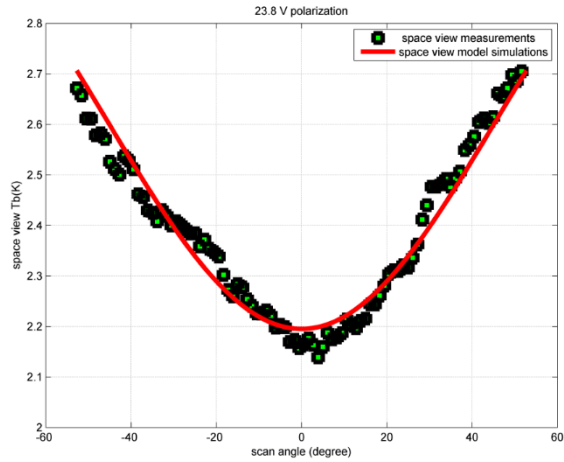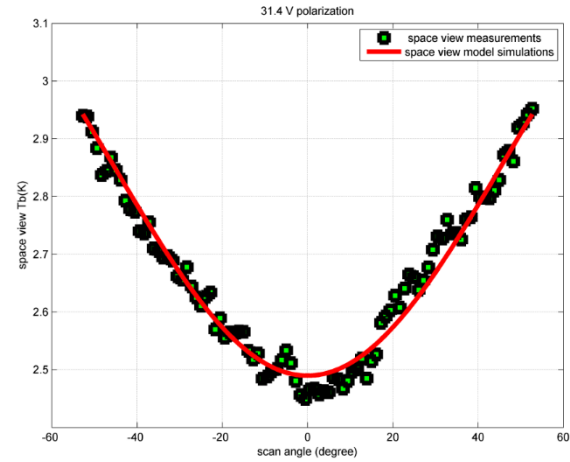
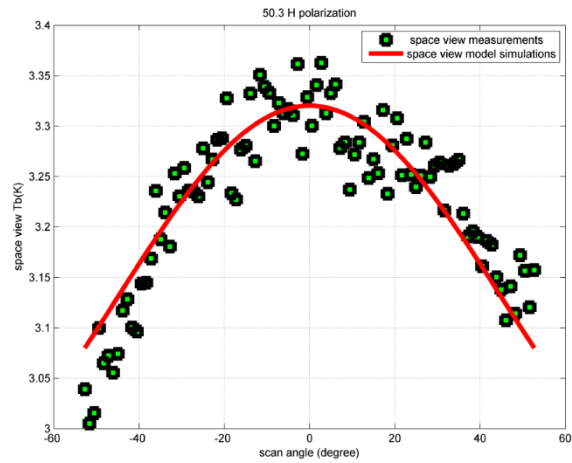# SNPP Pitch-Over Maneuver 20 Feb12
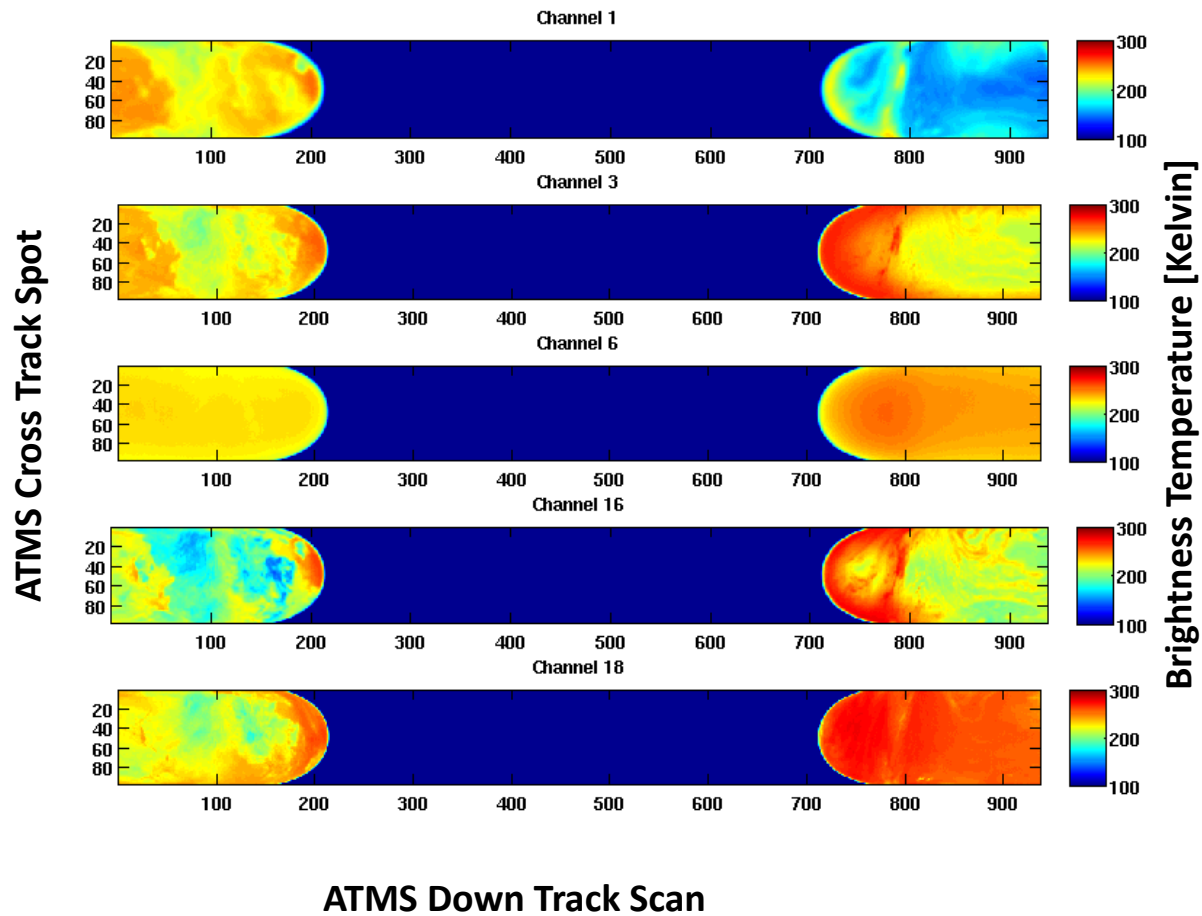
Pitch-Over Maneuver Data in Details

Channel 1
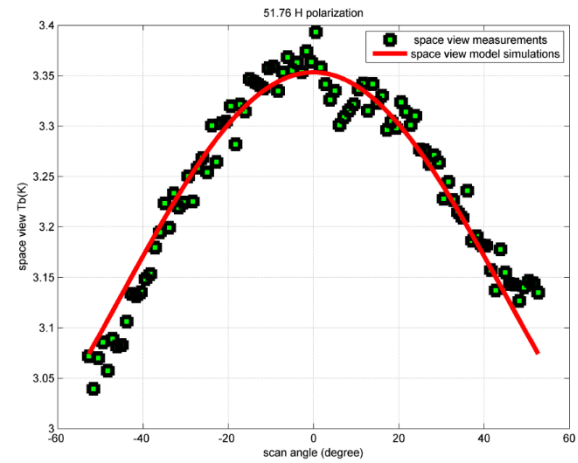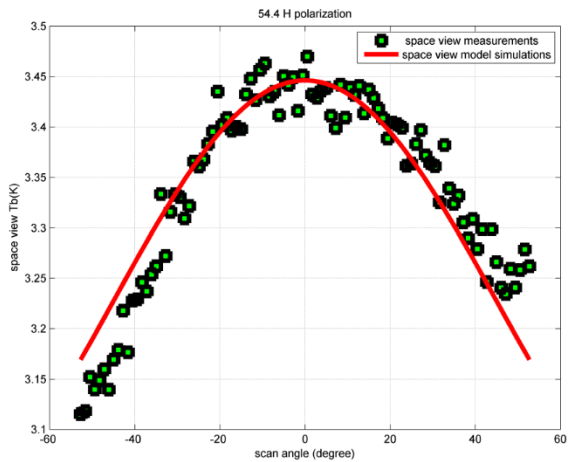
Channel 9

Channel 1

23.8 V polarization

- space view measurements
- space view model simulations

space view Tb(K)

scan angle (degree)

Channel 2

31.4 V polarization

- space view measurements
- space view model simulations

space view Tb(K)

scan angle (degree)

Channel 3

50.3 H polarization

- space view measurements
- space view model simulations

space view Tb(K)

scan angle (degree)

Channel 4

51.76 H polarization

- space view measurements
- space view model simulations

space view Tb(K)

scan angle (degree)

Channel 5

Channel 6

Channel 7

Channel 8

Channel 9

55.5 H polarization

Channel 10

57.29 H polarization

Channel 11

57f1 H polarization

Channel 12

57f2 H polarization

Channel 13

57f3 H polarization

- space view measurements
- space view model simulations

Channel 14

57f4 H polarization

- space view measurements
- space view model simulations

Channel 15

57f5 H polarization

- space view measurements
- space view model simulations

Channel 16

88.2 V polarization

- space view measurements
- space view model simulations

Channel 17

165.5 H polarization

- space view measurements
- space view model simulations

Channel 18

183.3f1 H polarization

- space view measurements
- space view model simulations

Channel 19

183.3f2 H polarization

- space view measurements
- space view model simulations

Channel 20

183.3f3 H polarization

- space view measurements
- space view model simulations

Channel 21

183.3f4 H polarization
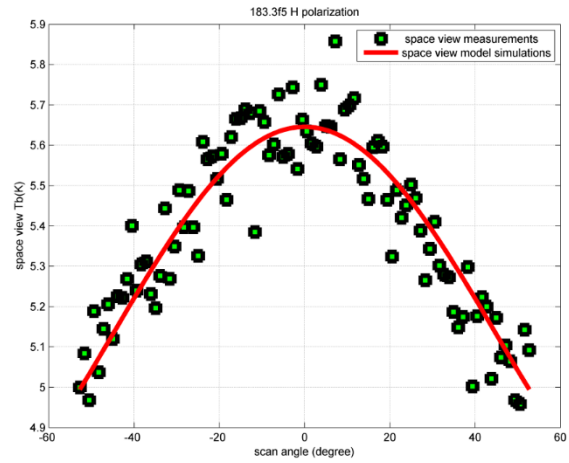

Channel 22

183.3f5 H polarization
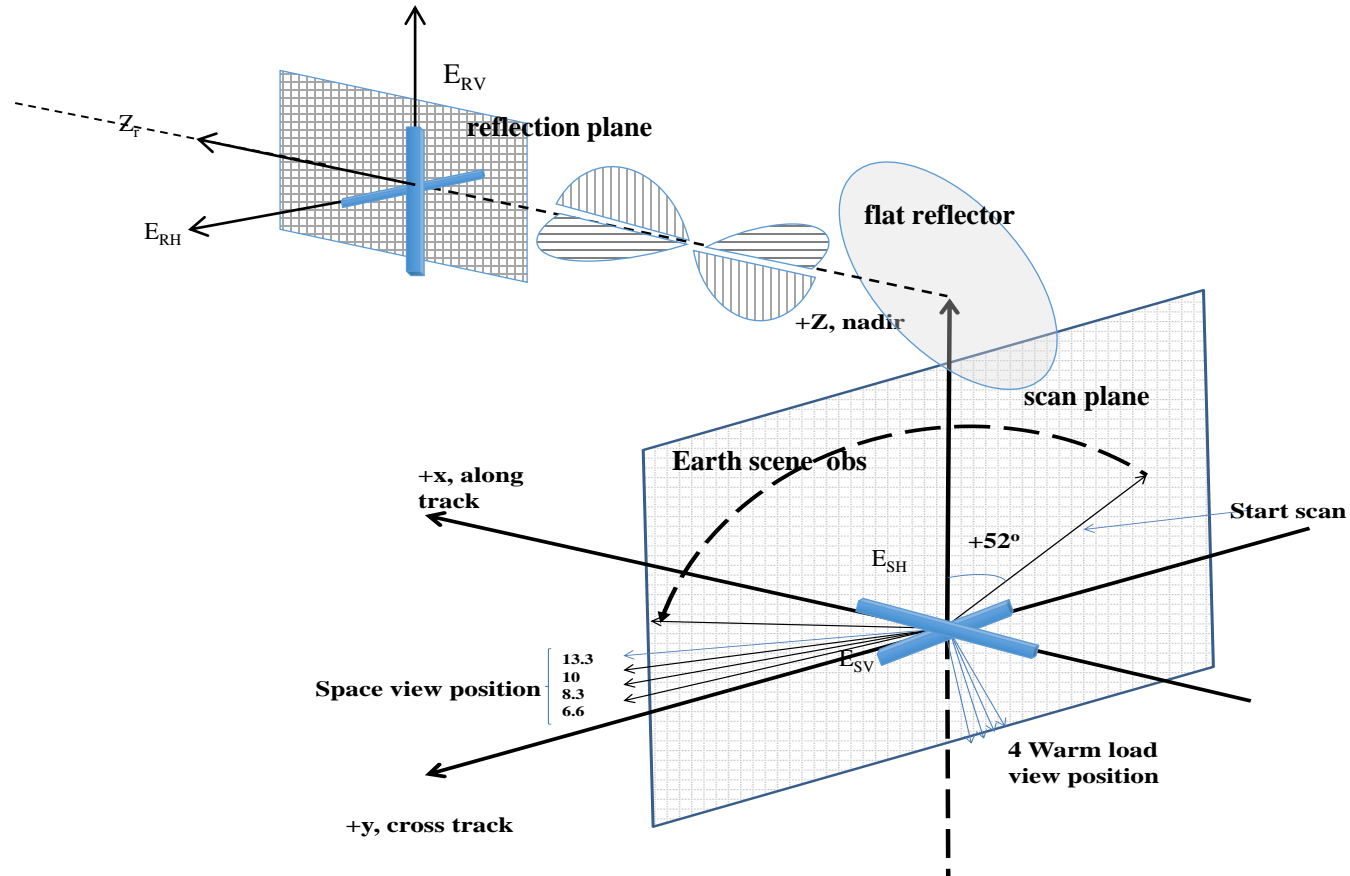
Flat Reflector Emissivity Model

Effects of ATMS Plane Reflector Emission on TOA Radiances

For Quasi-V (TDR):

$$R_{qv}^c = R_{qv} + \varepsilon_h\left(R_r - R_h\right) + \left[\varepsilon_v\left(R_r - R_v\right) - \varepsilon_h\left(R_r - R_h\right)\right]\sin^2\theta - \frac{R_3}{2}\left(1 - \varepsilon_h\right)^{3/2}\sin 2\theta$$

For Quasi-H (TDR):

$$R_{qh}^c = R_{qh} + \varepsilon_h\left(R_r - R_h\right) + \left[\varepsilon_v\left(R_r - R_v\right) - \varepsilon_h\left(R_r - R_h\right)\right]\cos^2\theta + \frac{R_3}{2}\left(1 - \varepsilon_h\right)^{3/2}\sin 2\theta$$
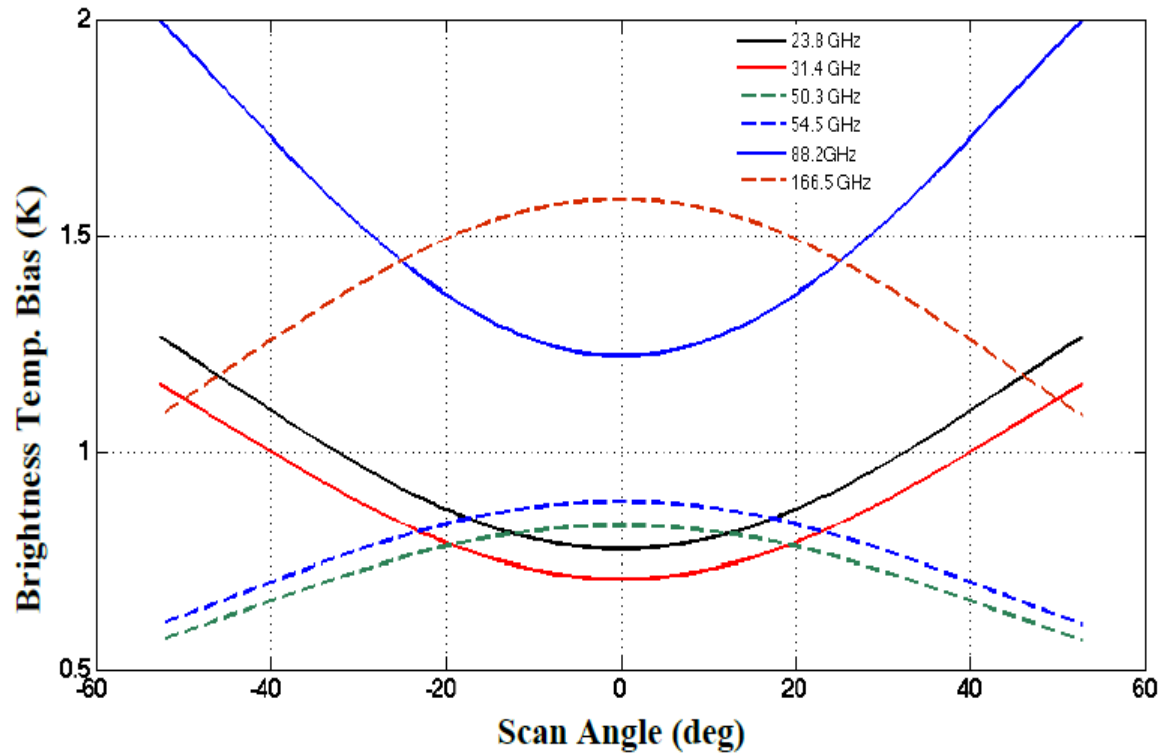
The second and third terms are the biases related to the reflector emission

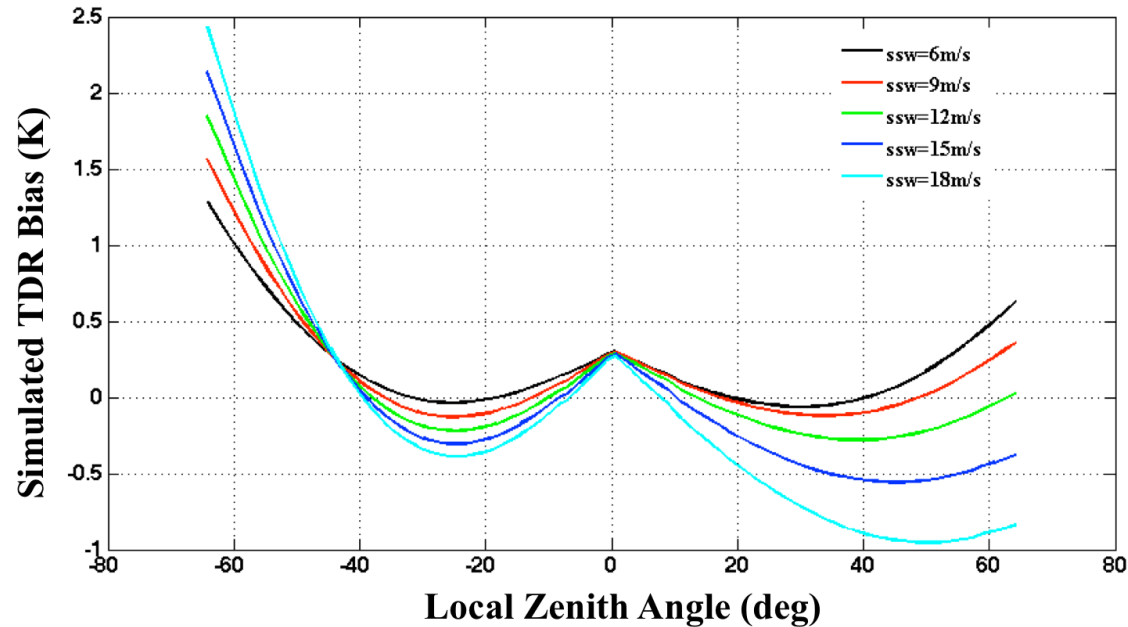*At an incident angle of 45 degree to the plane reflector, the Fresnel equation becomes*

$$\varepsilon_v = 2\varepsilon_h - \varepsilon_h^2$$

Weng and Yang, 2016, Remote Sensing

# The Cold Space Bias due to Reflector Emission

# Radiative Transfer Simulation Including ATMS Reflector Emission

- For polarized scene, the impact of reflector emission is dependent on the temperature difference between antenna reflector and V-pol scene
- The scan angle dependent feature in the error is mainly dominated by the third Stokes component of the scene radiation
- The simulated scan bias in TDR is consistent with those in real observations
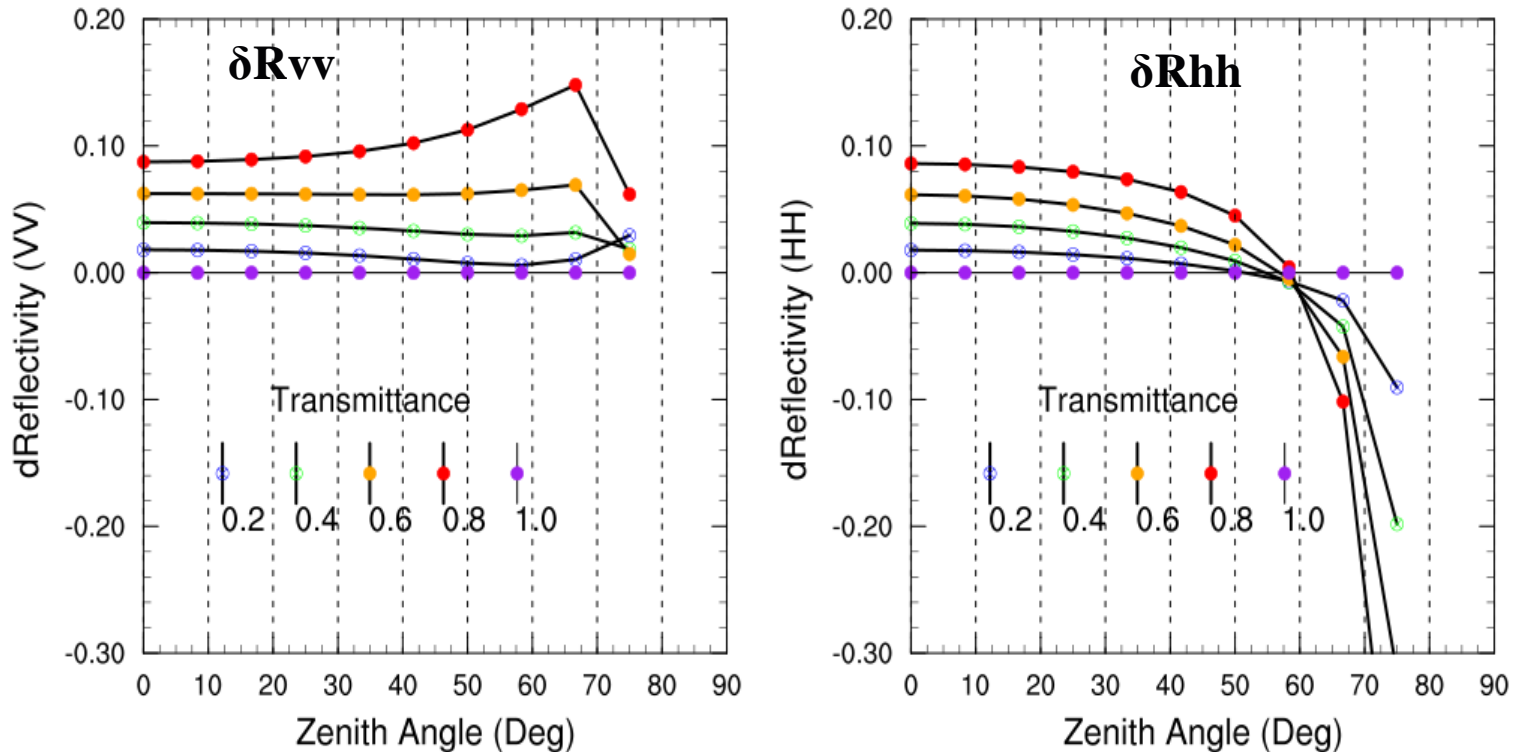
The Earth Scene Bias due to Reflector Emission

Effects of ATMS Plane Reflector Emission on Earth Scene Bias
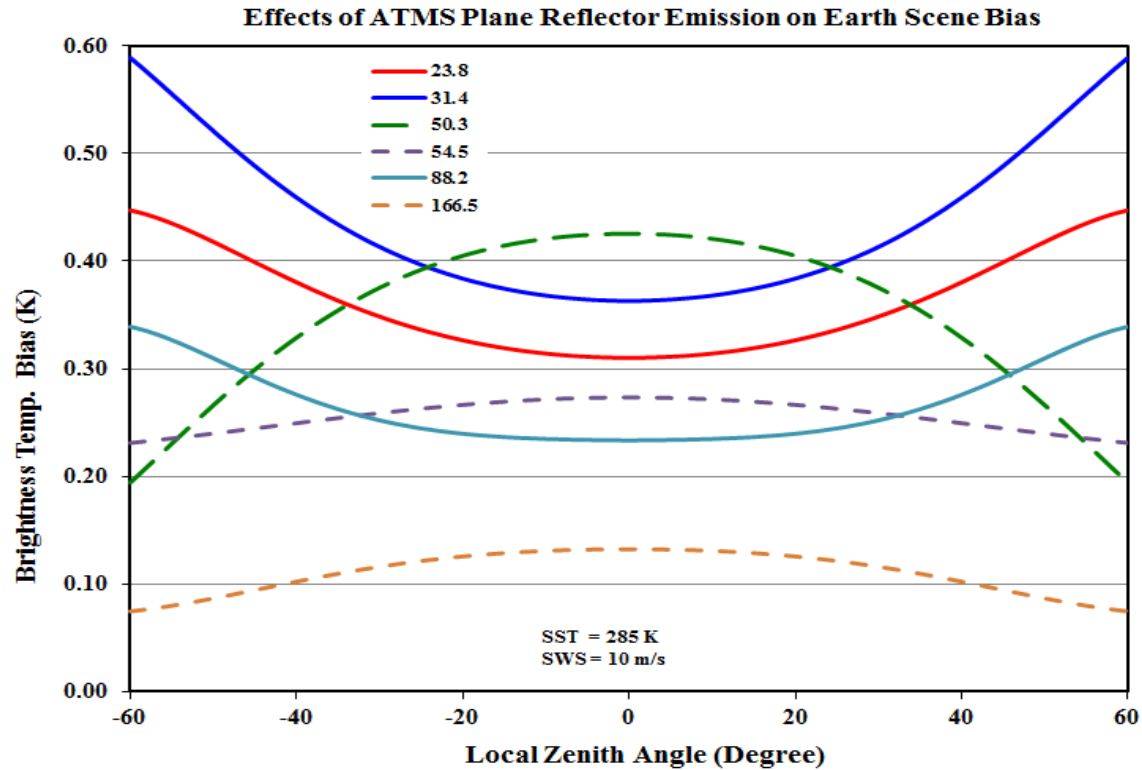
ATMS Scan Dependent O-B (TDR vs. SDR)
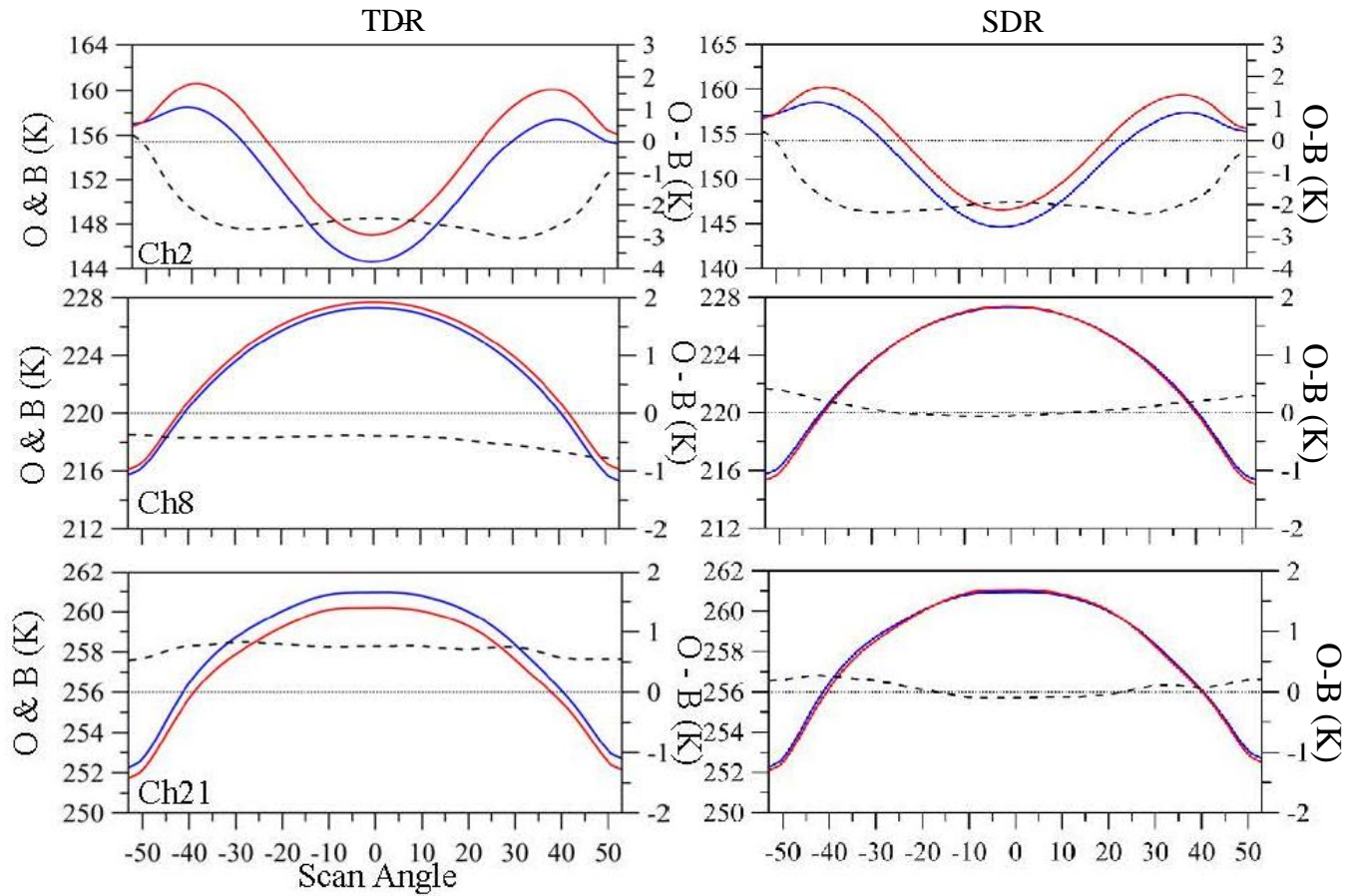
Reflection Correction in FASTEM6/5

FASTEM reflection correction ($\delta R(\tau) = R(\tau) - R(\tau=0)$) in terms of transmittance appears physically unreasonable. In general, one would expect larger reflection correction in more cloudy cases. FASTEM6/5 shows the opposite way. Correction for zenith >60° is also problematic.
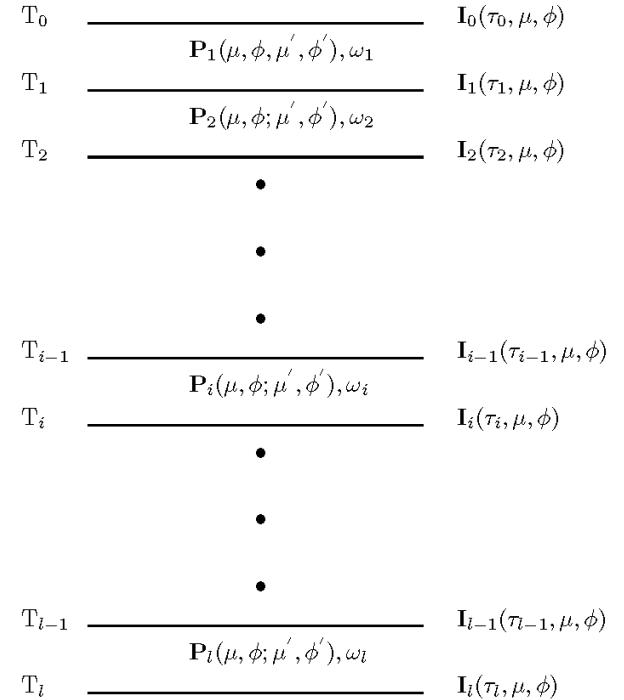
$$\mathbf{I} = \exp[\mathbf{A}(\tau - \tau_{l-1})]\mathbf{C_l} + \mathbf{S_l}$$

$$\mathbf{S_l} = \delta_{m0}\{B(\tau_{l-1})\Xi + \frac{B(\tau_{l-1}) - B(\tau_l)}{\tau_{l-1} - \tau_l}[\mathbf{A}_l^{-1}\Xi + (\tau - \tau_{l-1})\Xi]$$

$$+ \mu_0[\mu_0\mathbf{A}_l + \mathbf{E}]^{-1}\frac{\omega F_0}{\pi}\exp(-\tau/\mu_0)\Psi\}$$

$$\mathbf{I_l}(0) = \mathbf{I}_0$$

$$\mathbf{I_l}(\tau_{l-1}) = \mathbf{I_{l-1}}(\tau_{l-1})$$

$$\mathbf{I_L}(\tau_L) = \varepsilon B(T_s) + \mathbf{R}\mathbf{I_L}(\tau_L) + \mathbf{R}_0\frac{F_0}{\pi}exp(-\tau_L/\mu_0)\bar{\bar{\Xi}}$$

Summary and Conclusions

- The two-scale model has been used for training the fastem coefficients and produces the simulations in azimuth direction similar to the measurements.

- The 3rd and 4th Stokes emissivity from current FASTEM have a phase shift in azimuth direction. Some fix is required if it is used for a full polarimetric simulation

- FY MWRI simulations from using FASTEM have larger biases and the biases may be most likely caused by the instrument design and calibration uncertainty

- The correction to the fastem emissivity from atmospheric downwelling is a little bit odd.