Improved Microwave Ocean Emissivity and Reflectivity Models Derived from the Two-scale Roughness Theory

Lingli He[1,2], Fuzhong Weng[3]

1 Chinese Academy of Meteorological Sciences, Beijing 100081, China

2 University of Chinese Academy of Sciences, Beijing 100049, China

3 CMA Earth System Modeling and Prediction Centre, Beijing 100081, China

E-mail: hllsat@163.com

Introduction

- **Physical/ accurate/ full polarimetric microwave ocean refection and emission models are important to:**
  - Atmosphere-ocean coupled radiative transfer modeling
  - Microwave instruments calibration
  - Satellite data assimilation in NWP models, for example

- **Microwave polarimetric ocean surface boundary conditions:**

$$\mathbf{I}(\mu,\varphi)=\mathbf{E}(\mu)S_t+\frac{1}{2\pi}\int_0^{2\pi}\int_0^{1}\mathbf{A}(\mu,\varphi;-\mu',\varphi')\mathbf{I}(-\mu',\varphi')\,\mu'\,\mathrm{d}\mu'\mathrm{d}\varphi'$$

Contribution	Emission	Reflection
Key quantity	$\mathbf{E}$, 4×1 emissivity vector	$\mathbf{A}$, 4×4 reflectivity matrix
Oder	Hundred Kelvin	several to tens of Kelvin
Existing models	FASTEM6, RSS, LOCEAN	Geometrical optics(GO)

- **Shortfalls of current reflection and emission models**

Model	Shortfalls
FASTEM6	not suitable for cold sea surface temperature(SST) and high ocean wind speeds
RSS	an empirical fit model limited to specific conditions
LOCEAN	only suitable for L-band.
GO	• only suitable for small incidence angle (<20°) and high frequency • only predict 8 elements of reflectivity matrix.
Summary	• Their applications are limited in specific conditions • No generic reflectivity matrix model exists that can calculate full 16 matrix elements.

- **Research purposes**
  - To develop generic full polarimetric microwave reflectivity matrix model and emissivity model which are suitable for a wide range of frequencies and wind speeds at various geometries.
  - Combined reflectivity matrix and emissivity vector at lower boundary condition improves ocean-atmospheric coupled RTM.

Model description

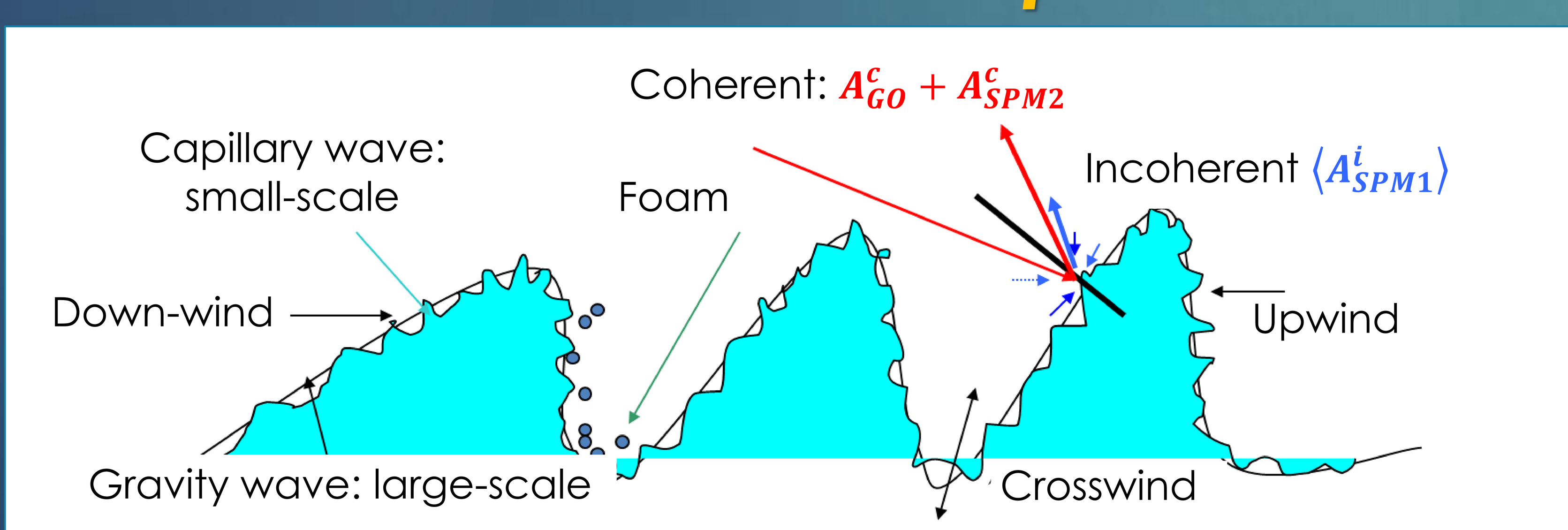

Fig.1 Two-scale concept diagram

SPM: small perturbation method.1 and 2 represent SPM first-order and second-order scattering solution, respectively.

- **Input :** SST, SSS, Wind speed, wind directon, frequency, geometry
- **Composition:**
  - Dielectric constant : Liu
  - Roughness Spectrum : 2*Durden and Vesekcy
  - Foam coverage : Monahan & O'Muircheartaigh, 1986
  - Foam emissivity : Stogryn, 1972
  - Cutoff wavenumber : Guissad and Sobieski, 1987
  - Hydrodynamic modulation : Reece, 1978
- **Bidirectional reflectance distribution function (BRDF)** : the ratio of the Scattered radiance to the incident irradiance.
- **Two-scale reflectivity matrix polarized BRDF (pBRDF):**

$$\mathbf{A}=A_{GO}^c+A_{SPM}^c+\langle \mathbf{A}_{SPM}^i\rangle$$

$$\mathbf{A}=\begin{pmatrix} A_{vvvv} & A_{vhvh} & \mathrm{Re}(A_{vhvv}) & \mathrm{Im}(A_{vhvv}) \\ A_{hvhv} & A_{hhhh} & \mathrm{Re}(A_{hhhv}) & \mathrm{Im}(A_{hhhv}) \\ 2\mathrm{Re}(A_{vvhv}) & 2\mathrm{Re}(A_{vhhh}) & \mathrm{Re}(A_{vvhh}+A_{vhhv}) & \mathrm{Im}(A_{hhvv}+A_{hvvh}) \\ 2\mathrm{Im}(A_{vvhv}) & 2\mathrm{Im}(A_{vhhh}) & \mathrm{Im}(A_{vvhh}+A_{vhhv} & \mathrm{Re}(A_{hhvv}-A_{hvvh}) \end{pmatrix}$$

Simulated results

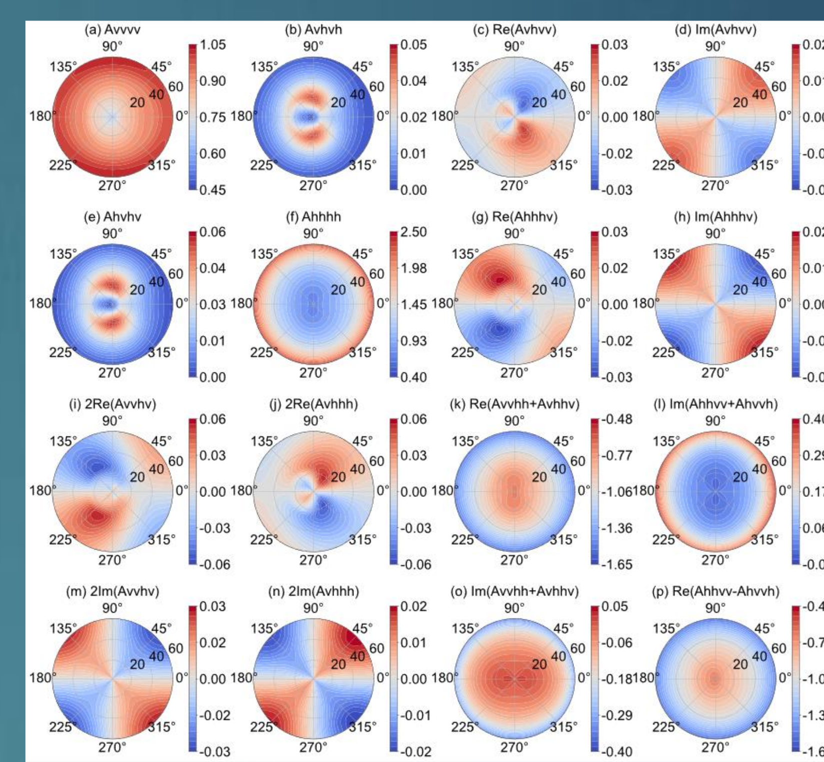

Fig.2 pBRDF in the specular direction ($\theta_i=\theta_s$, $\varphi_i=\varphi_s$) of 19 GHz, 10m/s, 285K, 35‰

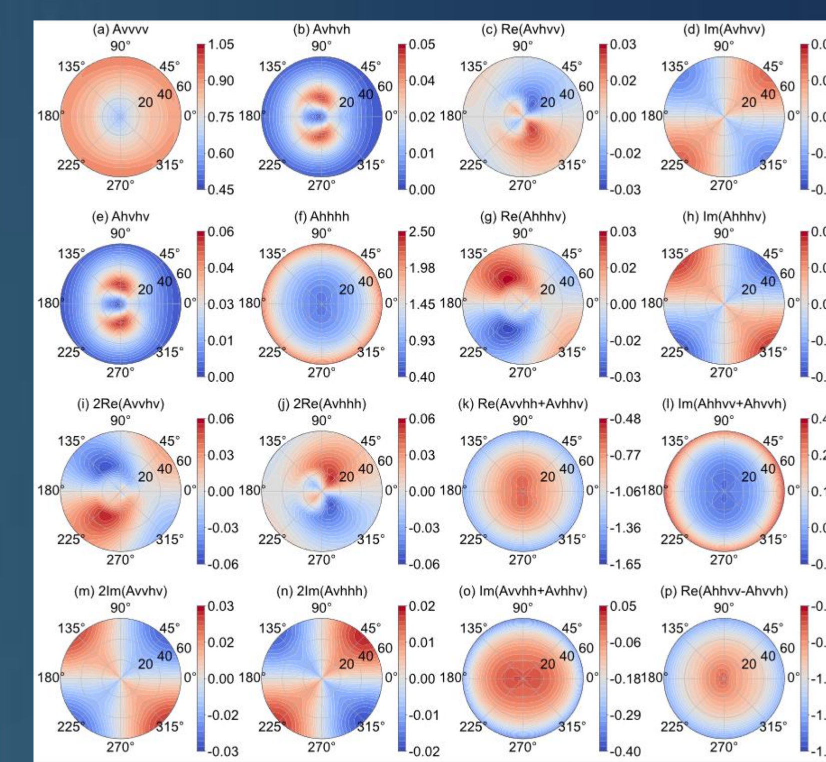

Fig.3 pBRDF in the specular direction ($\theta_i=\theta_s$, $\varphi_i=\varphi_s$) of 23 GHz, 10m/s, 285K, 35‰

- Fig. 2 and 3 shows that all elements of pBRDF are symmetric with respect to wind direction. 0°and 180°represents the upwind and downwind direction, respectively.
- All elements decrease with increasing frequency.

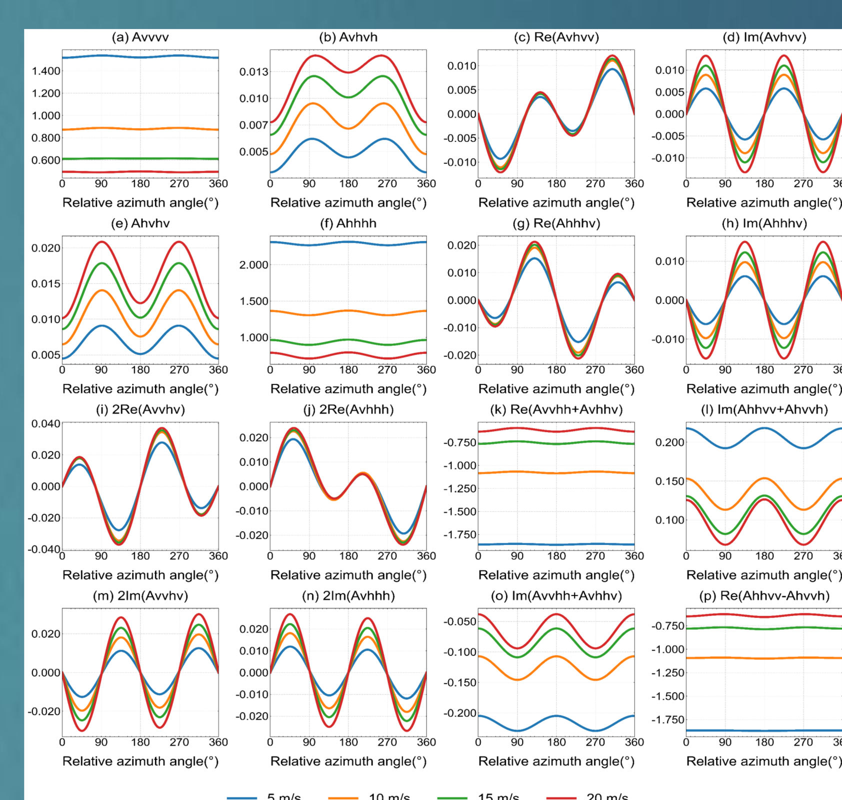

Fig.4 pBRDF under wind speeds of 5, 10, 15, 20 m/s as a function of relative azimuth angle in the specular direction ($\theta_i=\theta_s$, $\varphi_i=\varphi_s$) of 23 GHz, 285K, 35‰, scattering zenith angle is 45°

- As shown in the Fig.4, as wind speed increases, the harmonic amplitudes of some elements increase significantly and some decrease.
- The variation depends on the dominant processes of GO or Bragg scattering.

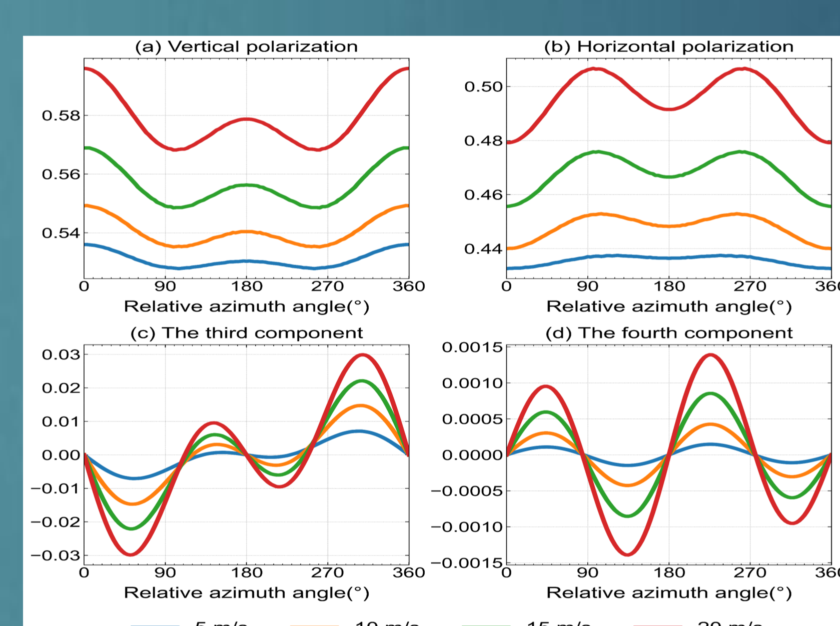

Fig.5 TSEM as a function of wind speed and relative azimuth angle of 37 GHz, 285K, 35‰, scattering zenith angle is 30°

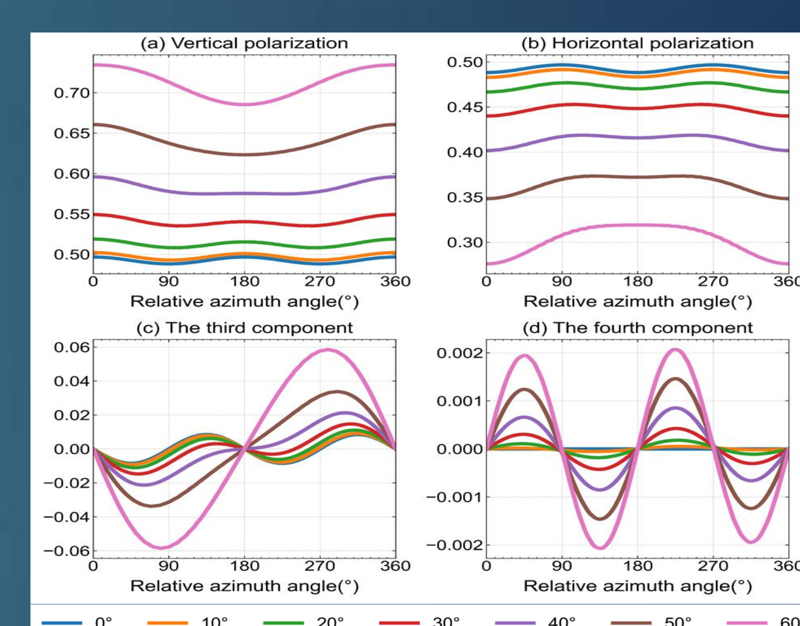

Fig.6 TSEM as a function of satellite zenith angle and relative azimuth angle of 37 GHz, 285K, 35‰, wind speed is 10 m/s.

- Fig.5 shows the TSEM which is the emissivity vector derived from pBRDF based on the Kirchhoff's law.
- TSEM have correct wind speed and direction dependences.
- Fig.6 shows a phase variation with satellite zenith angle .

Conclusions and next steps

- pBRDF and TSEM are suitable for a wide range of microwave frequencies and wind speeds at various observation angles.
- Next steps: 1)Expansion of the applications of reflectivity matrix model to active remote sensing. 2) Considerations of rain effect, multiple scattering and more accurate foam effect.

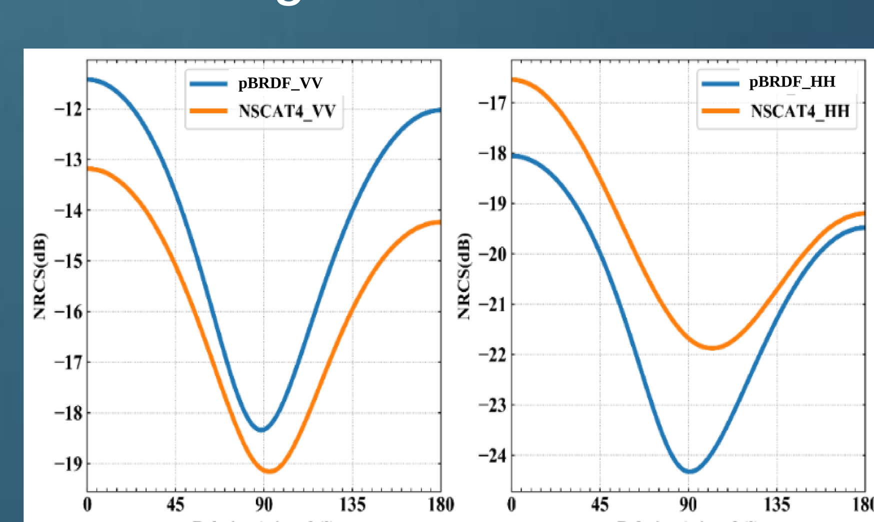

Fig.7 pBRDF in active remote sensing application. Compared with NSCAT4 GMF.

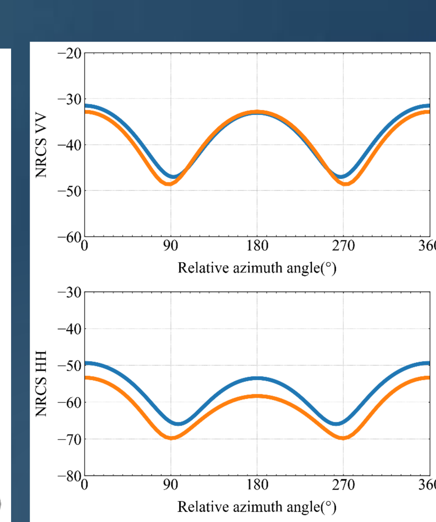

Fig.8 Compared with PARMIO.

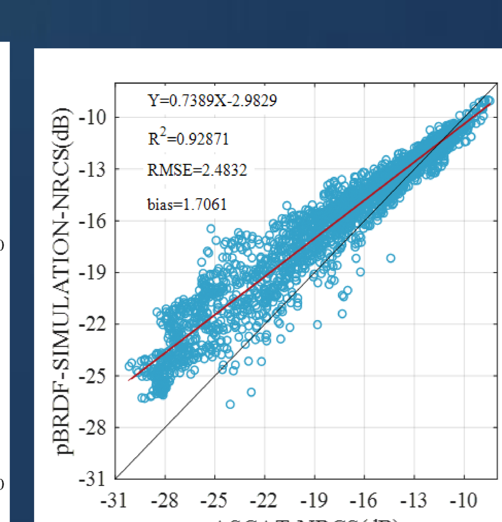

Fig.9 pBRDF simulate METOP-C ASCAT