Sea surface emissivity: Geometric optics models

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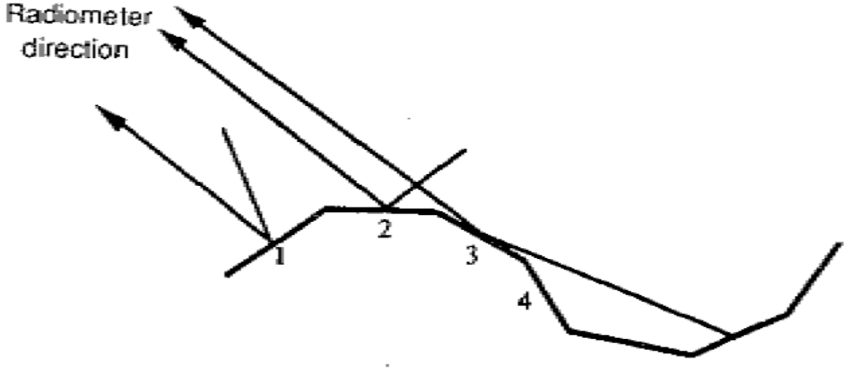
CNRS, LERMA, Observatoire de Paris,
Paris, France

Geometric optics models

The ocean surface is described as a collection of flat surfaces with a bi-directional slope distribution. Each facet reflects specularly the downwelling brightness temperature, following the Fresnel laws.



Fresnel laws apply to each facet:

$$R_h = \left| \frac{\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2$$

$$R_v = \left| \frac{\varepsilon\cos\theta - \sqrt{\varepsilon - \sin^2\theta}}{\varepsilon\cos\theta + \sqrt{\varepsilon - \sin^2\theta}} \right|^2$$

Requires:

- Statistics of the slope distribution
- Sea water dielectric properties
- Foam properties
- The downwelling radiation

Method applied to microwaves, as well as to infrared

Geometric optics models

Outline

Passive microwaves

Active microwaves

Infrared

The key input parameters:

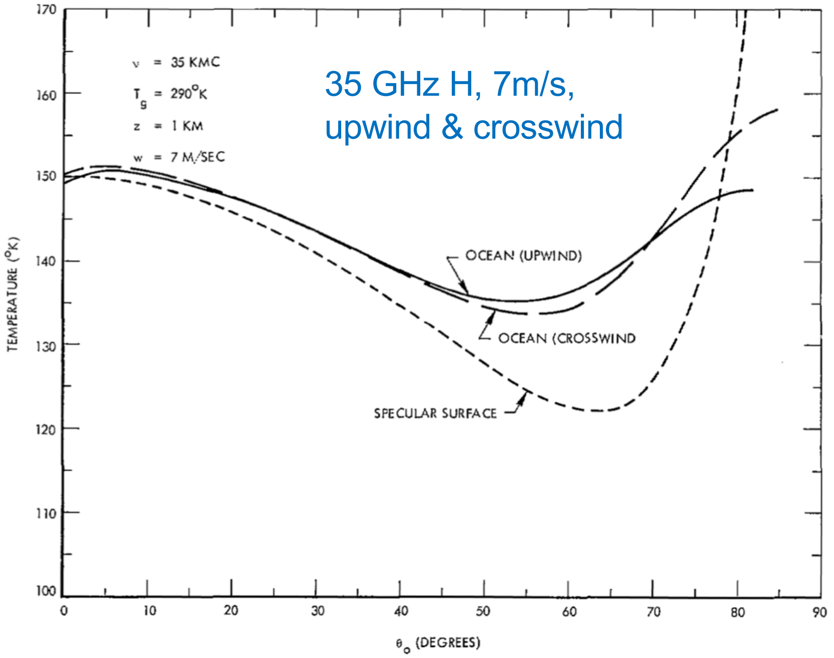
- Sea surface description
- Dielectric properties
- Foam
- Downwelling radiation

PASSIVE MICROWAVES

278 IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. AP-15, NO. 2, MARCH 1967

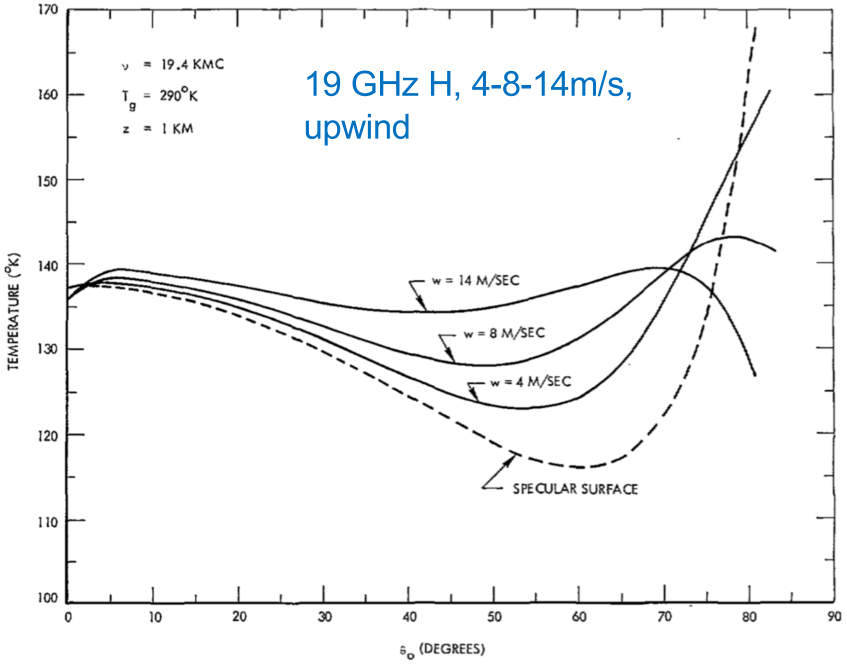
The Apparent Temperature of the Sea at Microwave Frequencies

A. STOGRYN



35 GHz H, 7m/s, upwind & crosswind

Fig. 2. Temperature of horizontally polarized radiation as a function of angle.



19 GHz H, 4-8-14m/s, upwind

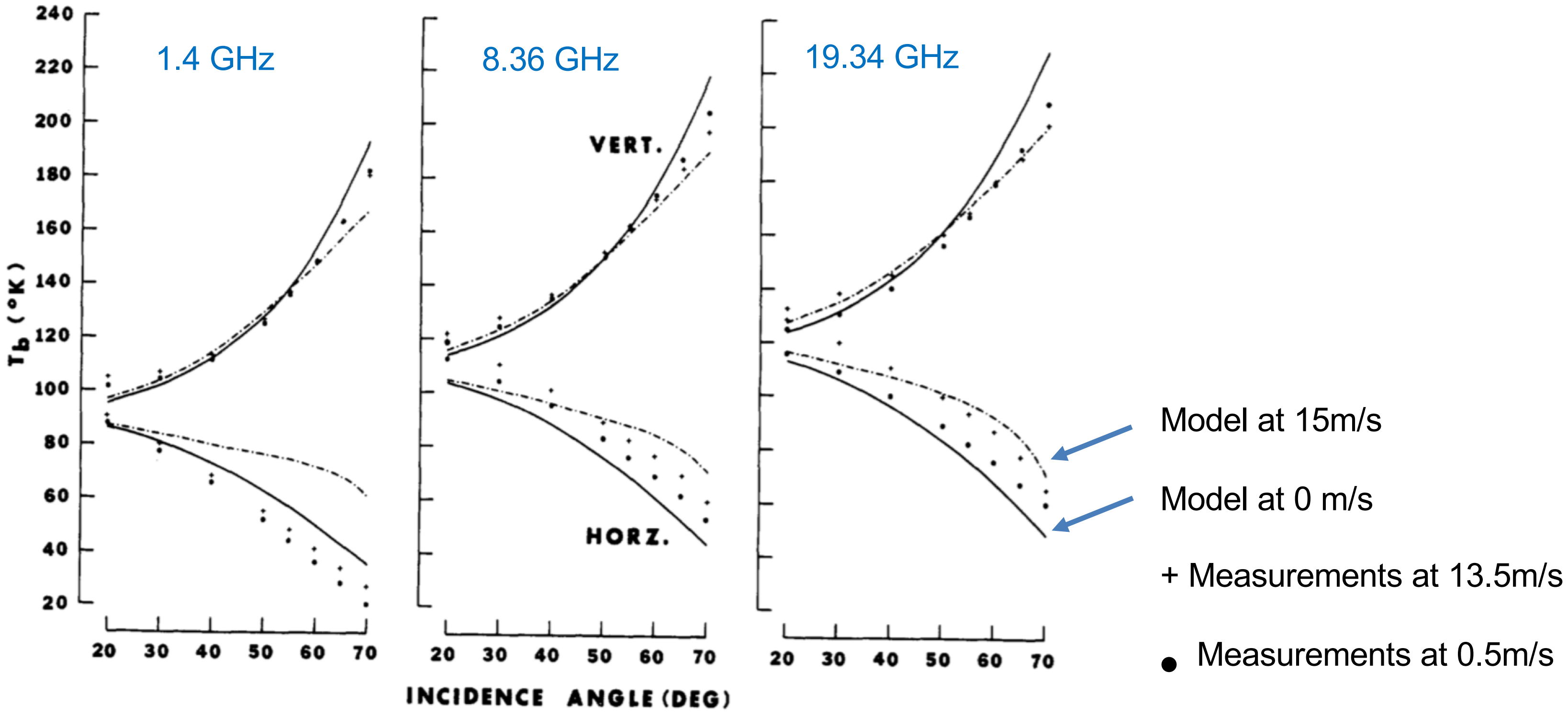
Fig. 3. Temperature of horizontally polarized radiation as a function of angle (upwind case).

Cox and Munk slope distribution (1954): almost gaussian, with small correction for skewness and peakness
The mean-square slopes depend linearly on the local wind speed.

IEEE TRANSACTIONS ON GEOSCIENCE ELECTRONICS, VOL. GE-9, NO. 3, JULY 1971 165

Passive Microwave Measurements of Sea Surface Roughness

JAMES P. HOLLINGER



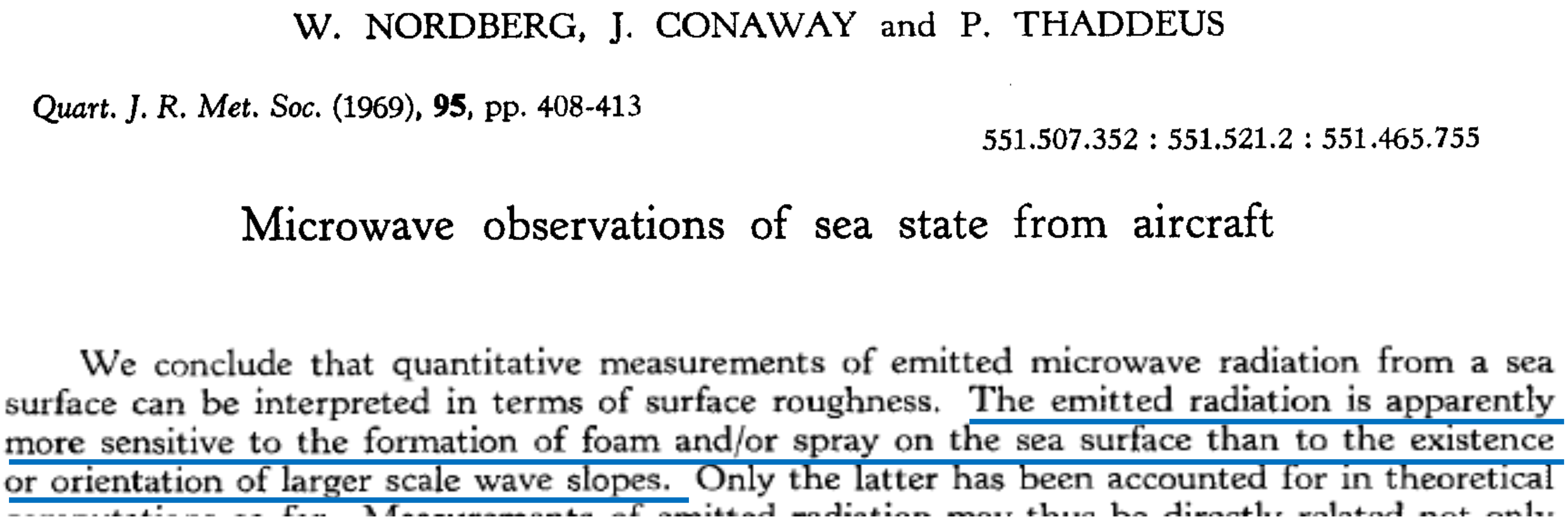
Model at 15m/s

Model at 0 m/s

+ Measurements at 13.5m/s

● Measurements at 0.5m/s

Measurements from a platform and comparison with Stogryn’s model.
Better fit when coefficients of 1/3, 1/2, and 2/3 are affected to the Cox and Munk slopes, for respectively 1.4, 8.36, and 19.34 GHz.



W. NORDBERG, J. CONAWAY and P. THADDEUS

Quart. J. R. Met. Soc. (1969), **95**, pp. 408-413

551.507.352 : 551.521.2 : 551.465.755

Microwave observations of sea state from aircraft

We conclude that quantitative measurements of emitted microwave radiation from a sea surface can be interpreted in terms of surface roughness. The emitted radiation is apparently more sensitive to the formation of foam and/or spray on the sea surface than to the existence or orientation of larger scale wave slopes. Only the latter has been accounted for in theoretical

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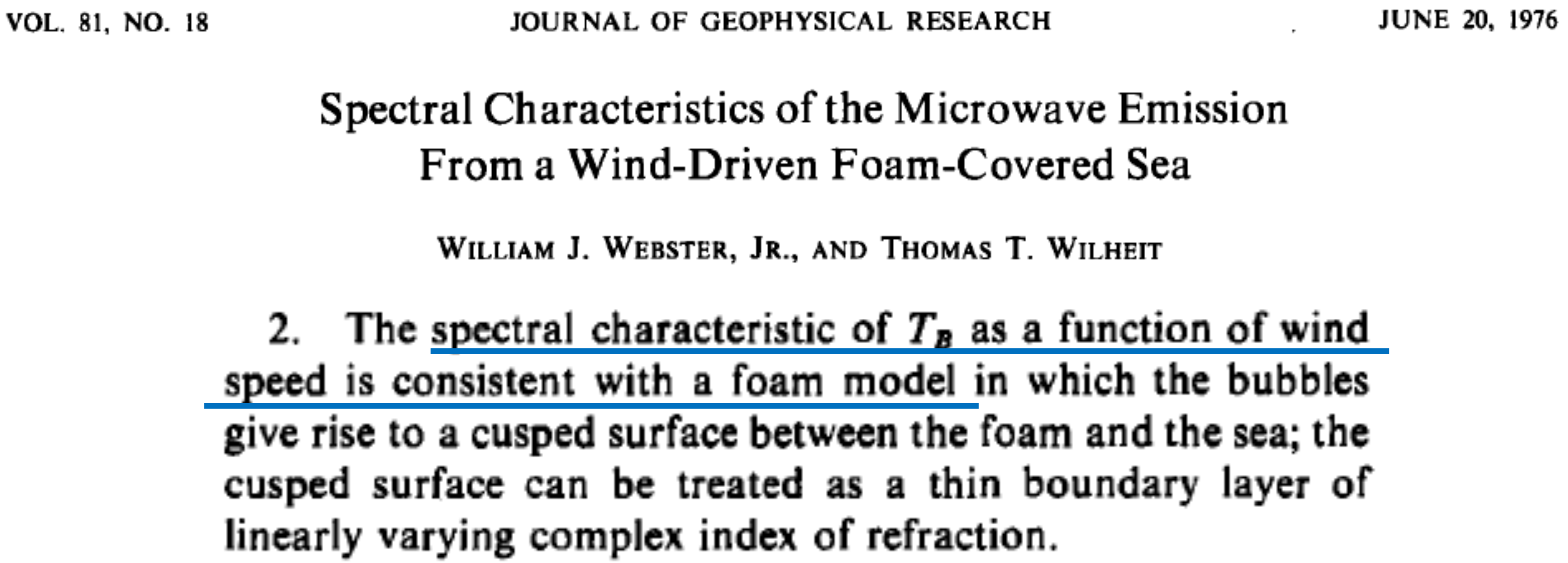


VOL. 81, NO. 18 JOURNAL OF GEOPHYSICAL RESEARCH JUNE 20, 1976

Spectral Characteristics of the Microwave Emission From a Wind-Driven Foam-Covered Sea

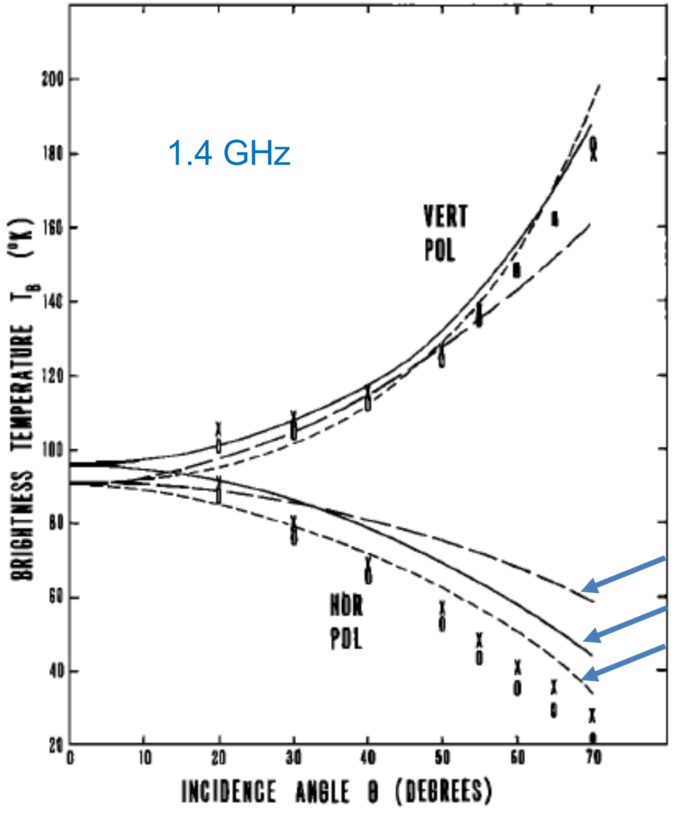
WILLIAM J. WEBSTER, JR., AND THOMAS T. WILHEIT

2. The spectral characteristic of T_B as a function of wind speed is consistent with a foam model in which the bubbles give rise to a cusped surface between the foam and the sea; the cusped surface can be treated as a thin boundary layer of linearly varying complex index of refraction.

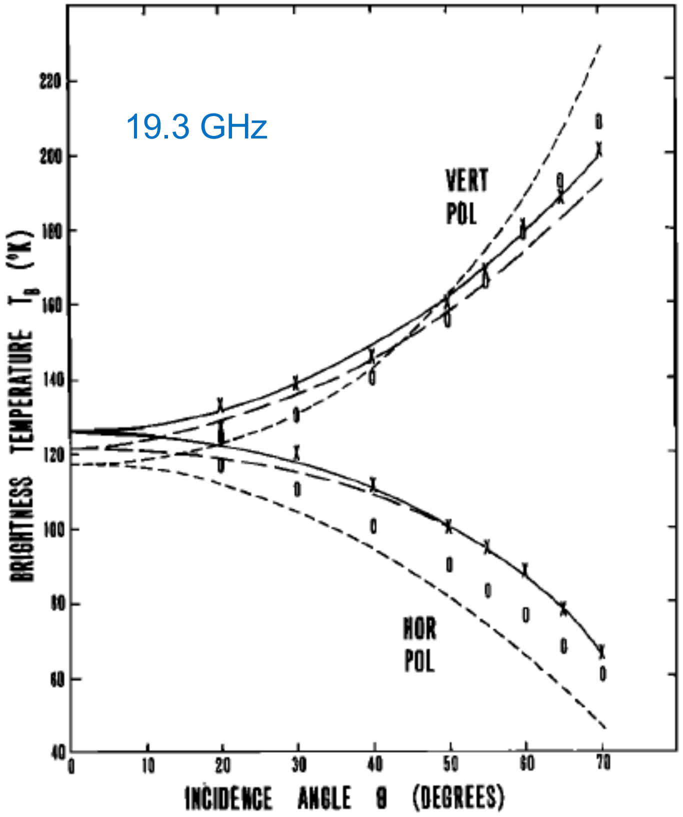
VOL. 80, NO. 24 JOURNAL OF GEOPHYSICAL RESEARCH AUGUST 20, 1975

A Two-Scale Scattering Model for Foam-Free Sea Microwave Brightness Temperatures

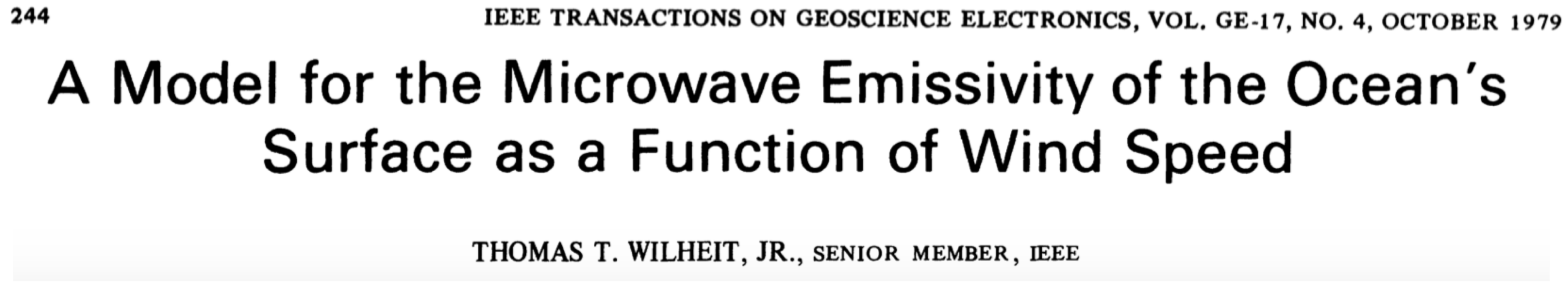
FRANK J. WENTZ



Geometric optics
Two-scale
Flat specular
x Measurements 13.5m/s
0 Measurements 0.5m/s



Small scale roughness superimposed on the large scale ones improves the fit to the observations, especially for low frequencies.



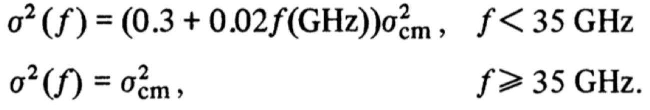
244 IEEE TRANSACTIONS ON GEOSCIENCE ELECTRONICS, VOL. GE-17, NO. 4, OCTOBER 1979

A Model for the Microwave Emissivity of the Ocean's Surface as a Function of Wind Speed

THOMAS T. WILHEIT, JR., SENIOR MEMBER, IEEE

A model to analyze the SMMR satellite observations.

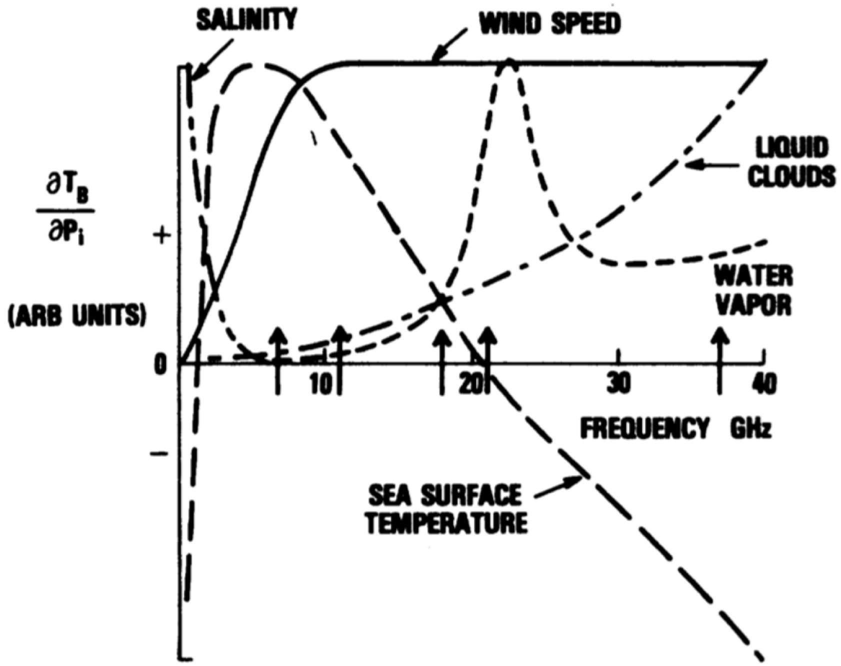
Includes foam contribution
A good fit is obtained when modifying the Cox and Munk variances.



$$\sigma^2(f) = (0.3 + 0.02f(\mathrm{GHz}))\sigma^2_{\mathrm{cm}}, \quad f < 35\ \mathrm{GHz}$$
$$\sigma^2(f) = \sigma^2_{\mathrm{cm}}, \quad f \geqslant 35\ \mathrm{GHz}.$$

Major limitations have been identified:
- no wind speed dependence in the model between 0 and 7m/s at nadir, especially problematic for the low frequencies.
- The treatement of foam without any polarization and viewing angle dependence.

However, for conical scanners (with incidence angles aroun 50°), and for frequencies above 30 GHz, should be suitable.

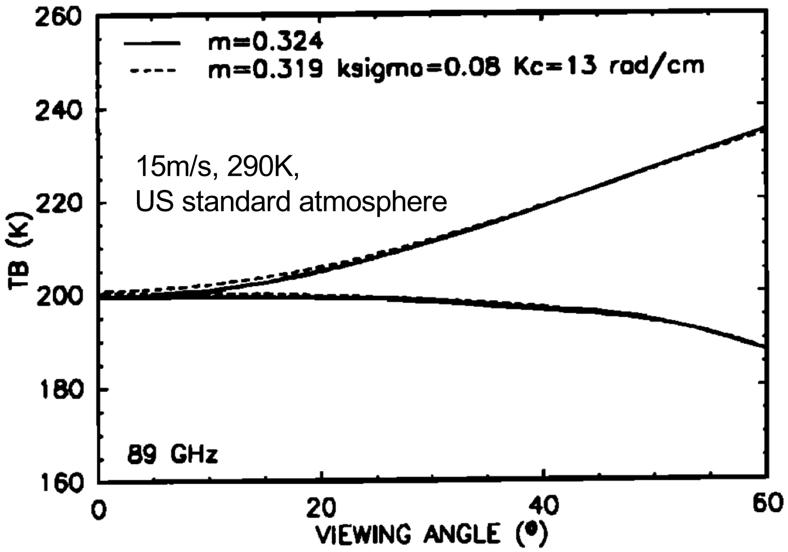


Developments for high frequencies

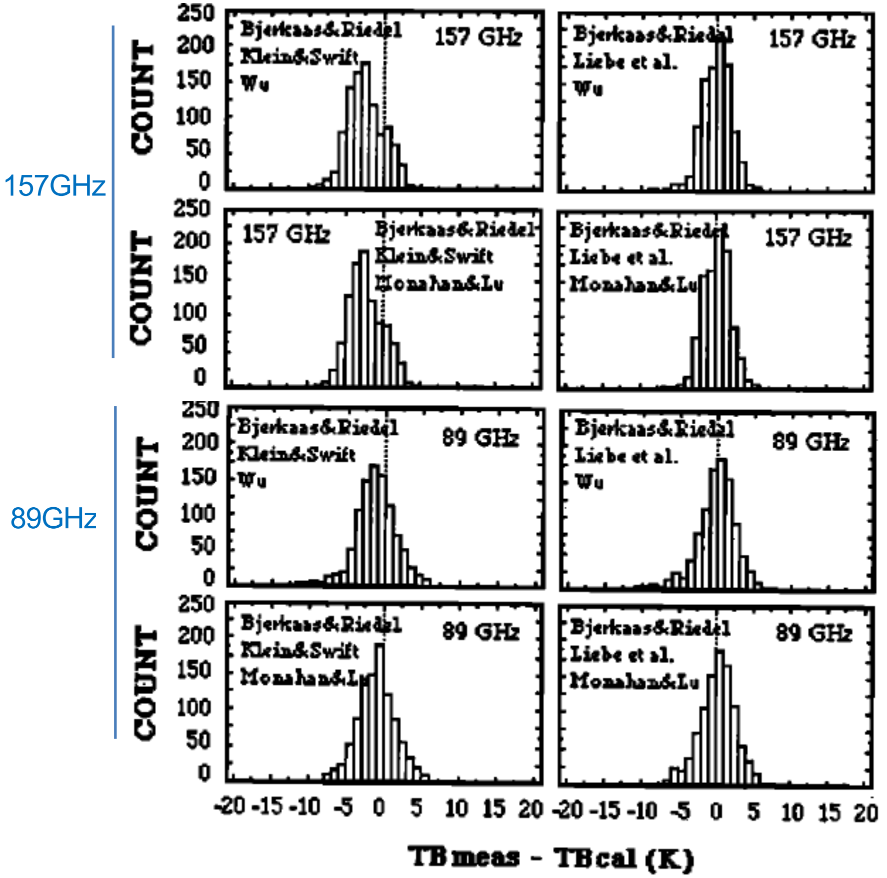
e.g., Prigent and Abba, 1990
Phalippou, QJRMS, 1996
Guillou et al., JGR, 1996

- Suitable for frequencies above 37 GHz. Below, usable using only a fraction of the Cox and Munk slope variances.
- Takes into account shadowing effects and multiple reflections
- Can handle the wind direction

Guillou et al., JGR, 1996



Comparison geometric optics and two scale model at 89GHz.



Difference between observations with the airborne MARS instrument and geometric optics simulations, with different hypotheses (slope ditribution, dielectric properties, foam)

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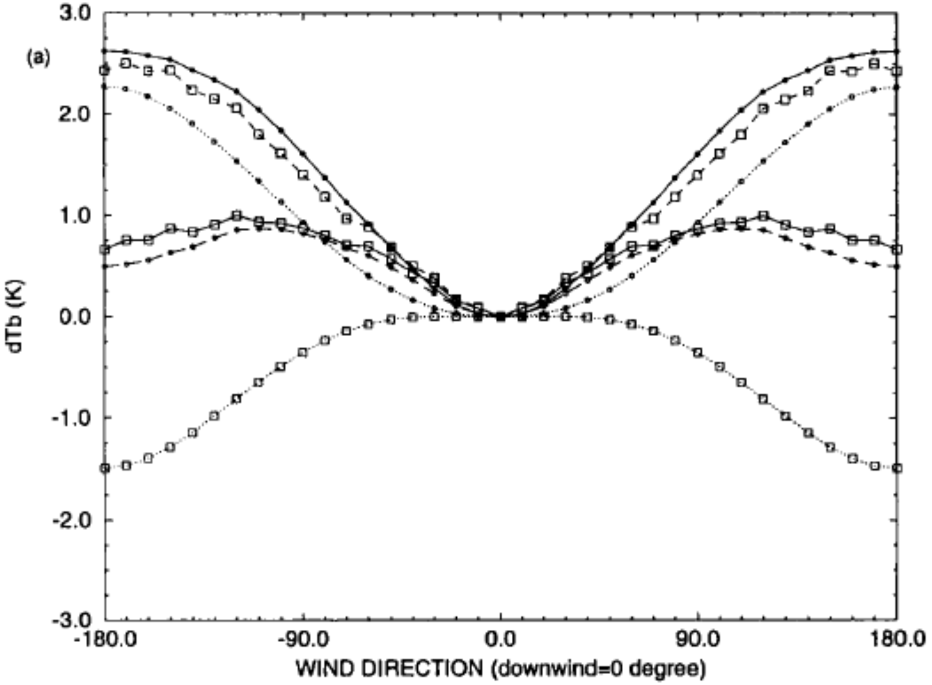


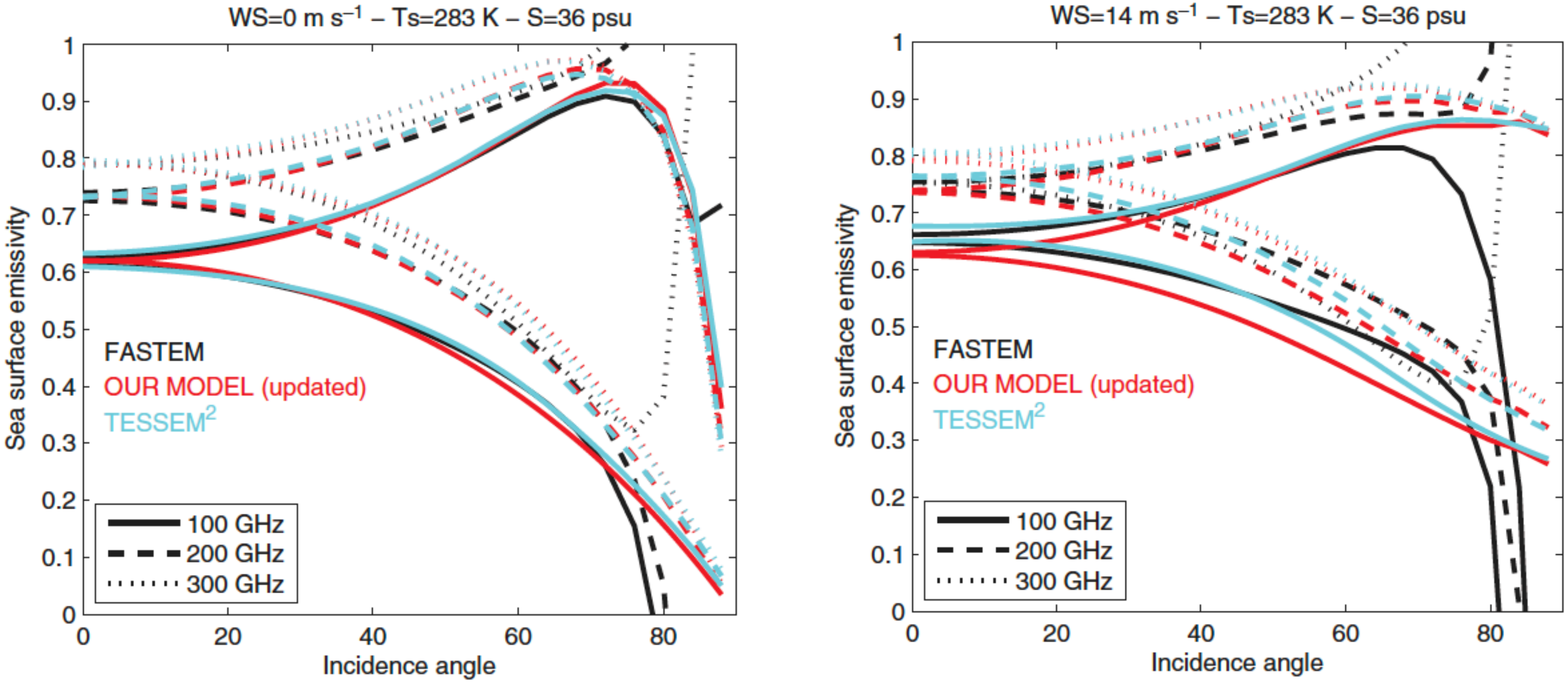
Phalippou, QJRMS, 1996

Figure 3. (a) Variation of 37 GHz brightness temperature (dT_b) as a function of wind direction for a 14 m s^{-1} wind speed. The downwelling radiation at nadir is used for multiple reflection (see text). The vertical and horizontal polarization are marked by dot and square symbols respectively. Dotted lines are for emission contribution, dashed lines are for scattering contribution, full line is for the total. Total precipitable water vapour = 14 kg m^{-2}, sea surface temperature = 290 K, no cloud.

Developments for high frequencies

TESSEM², Prigent et al., QJRMS, 2017

A fast model, especially designed for frequencies above 90 GHz and up to 700 GHz
It mimics FASTEM up to 200 GHz (*see Steve English presentation*) and up to 55 °, and a geometric optics model elsewhere.



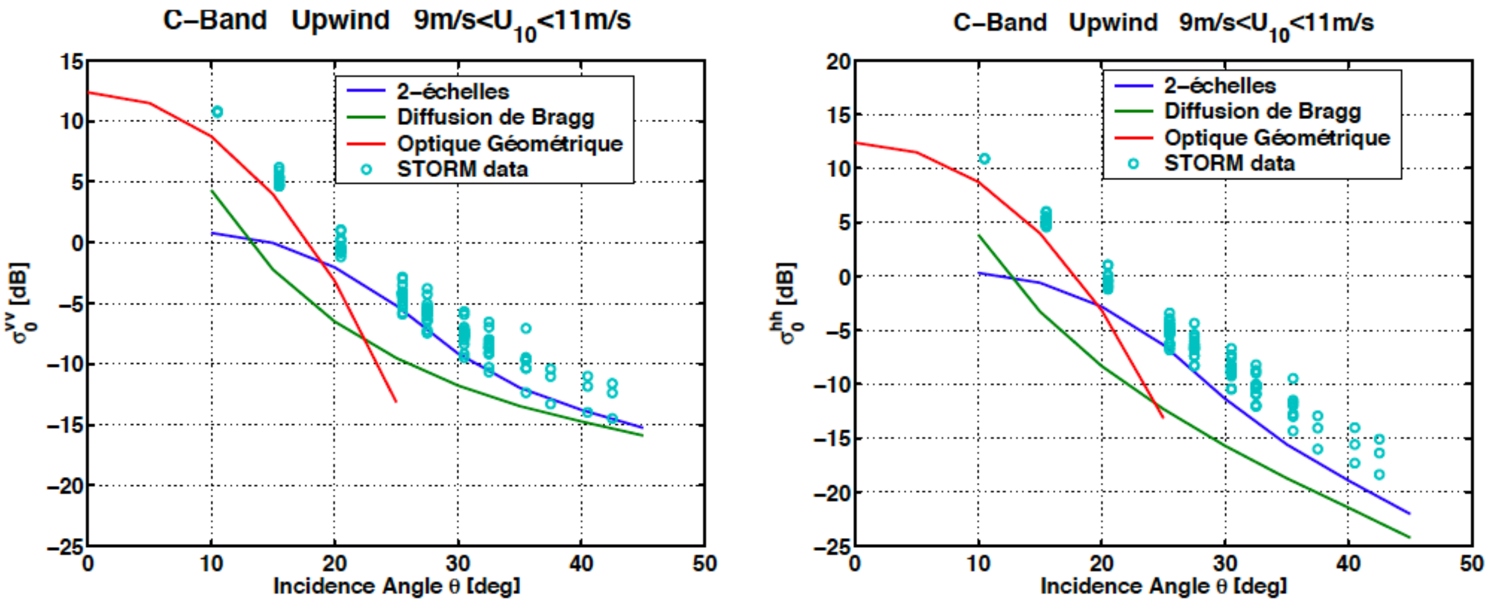
Only a practical tool, before something better is available!

ACTIVE MICROWAVES

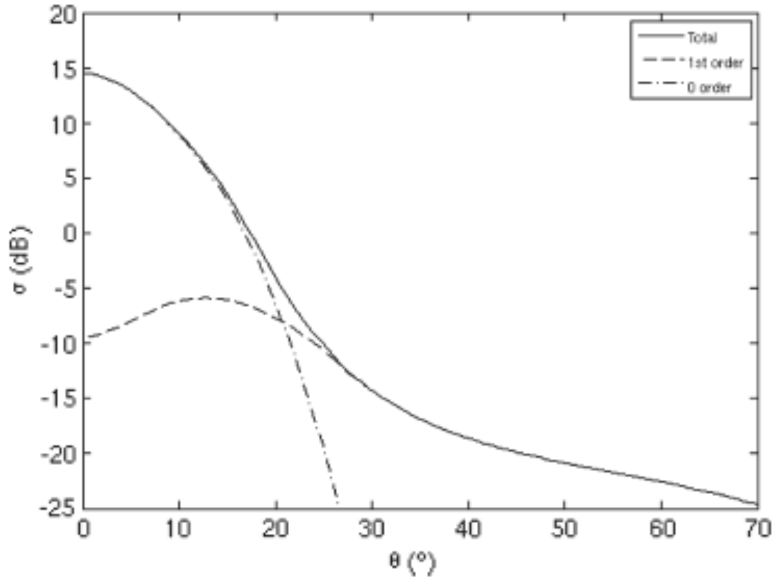
Geometric Optics

Valid only for the low incidence angles, roughly < 20°. Two-scale model necessary (*see Ad Stoffelen presentation this afternoon*)

Mouche, PhD, 2005



Nunziata et al., IEEE, 2009



INFRARED

Sea surface emissivity in the infrared

- For the analysis of surface-sensitive atmospheric sounders
- For accurate estimates of Sea Surface Temperature (SST)

SST requirements within 0.2K. This implies an accuracy of better than 0.5% in emissivity.

REMOTE SENSING OF ENVIRONMENT 24:313–329 (1988)

Emissivity of Pure and Sea Waters for the Model Sea Surface in the Infrared Window Regions

K. MASUDA, T. TAKASHIMA, AND Y. TAKAYAMA

Emissivity decreases slowly with increasing incidence angle

Little effect of the wind speed below 30° incidence angle, but large effect above 70°.

Little difference between pure water and sea water

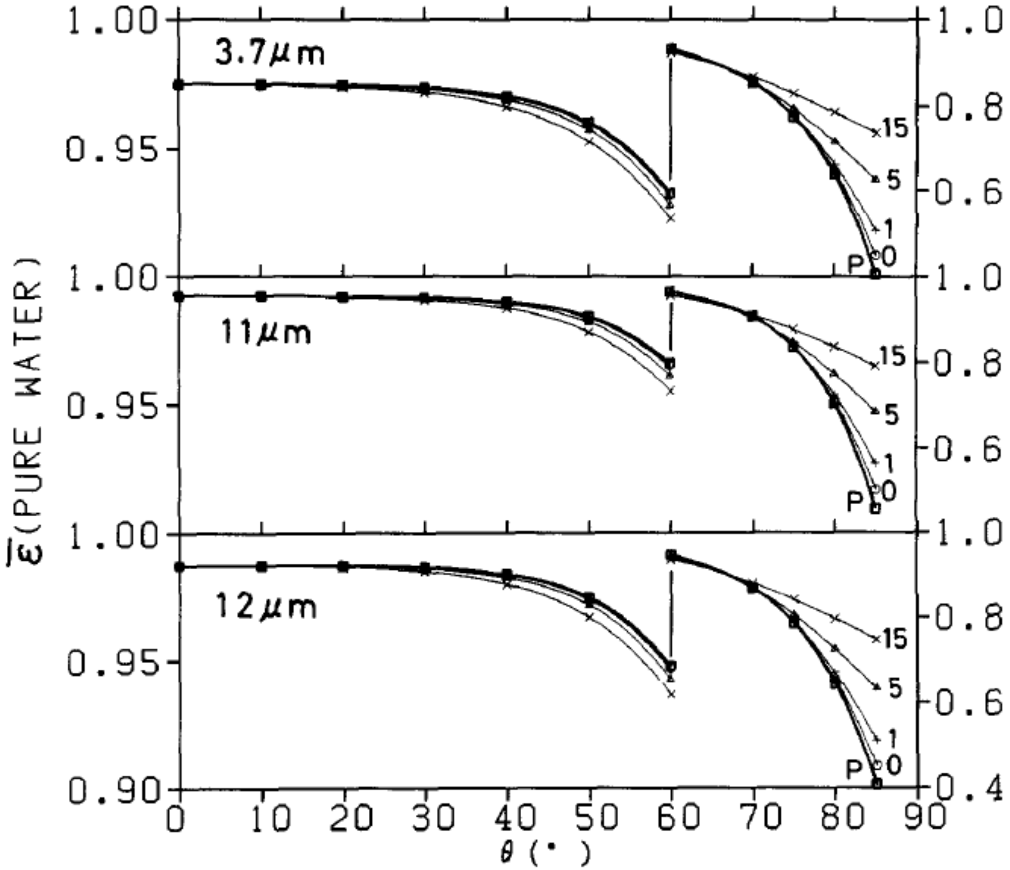


FIGURE 3. The average emissivities of pure water in three wavelength regions, 3.5–3.9, 10.5–11.5, and 11.5–12.5 μm. These are shown as a function of zenith angle of observed ratiation (θ). Plane surface (□); w = 0 (○), 1(+), 5 (△) and 15m/s (×). Central wavelengths are shown in figures. (The scale of ordinate is changed at $\theta = 60°$).

Applied optics, 1997

Emissivity of rough sea surface for 8–13 µm: modeling and verification

Xiangqian Wu and William L. Smith

Verification with observations

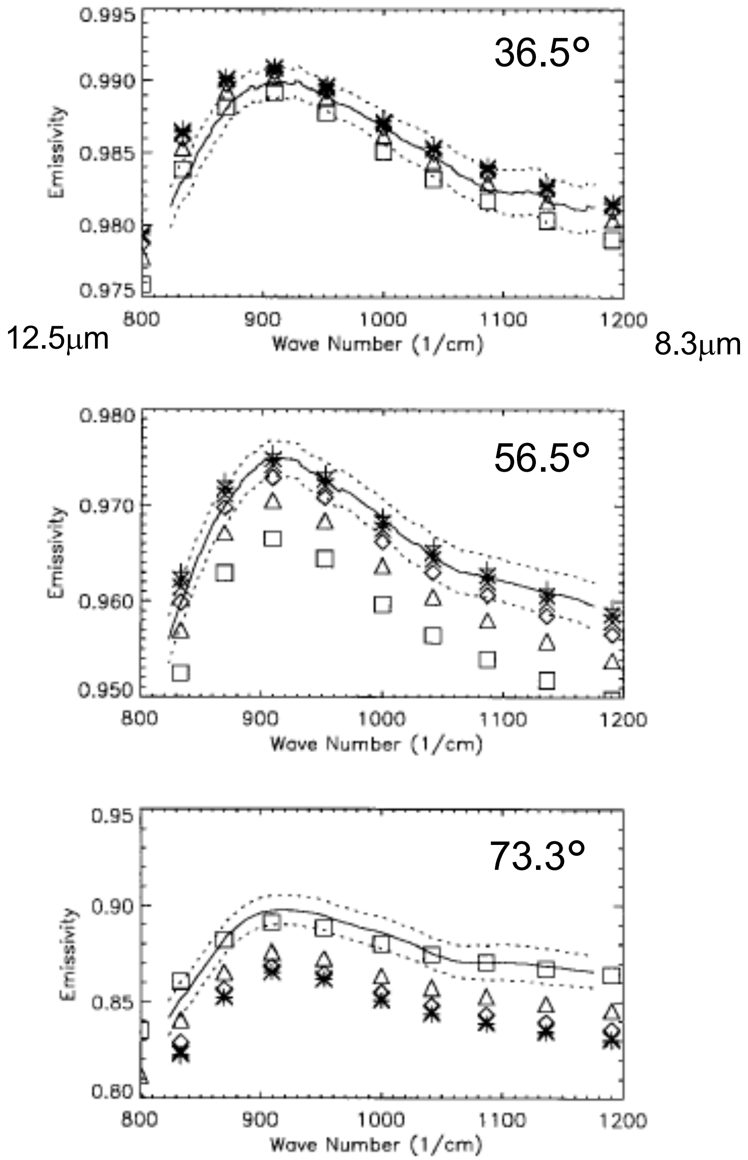


Fig. 3. Comparison of the computed and measured emissivity at 36.5° (upper), 56.5° (middle), and 73.5° (lower). Solid and dotted curves are the mean and standard deviation of the measured emissivity. Symbols mark the computed emissivity with Eq. (19) for wind speed of 0 (+), 1 (∗), 2 (×), 4 (◇), 8 (△), and 16 (□) m/s.

KEY INPUT PARAMETERS

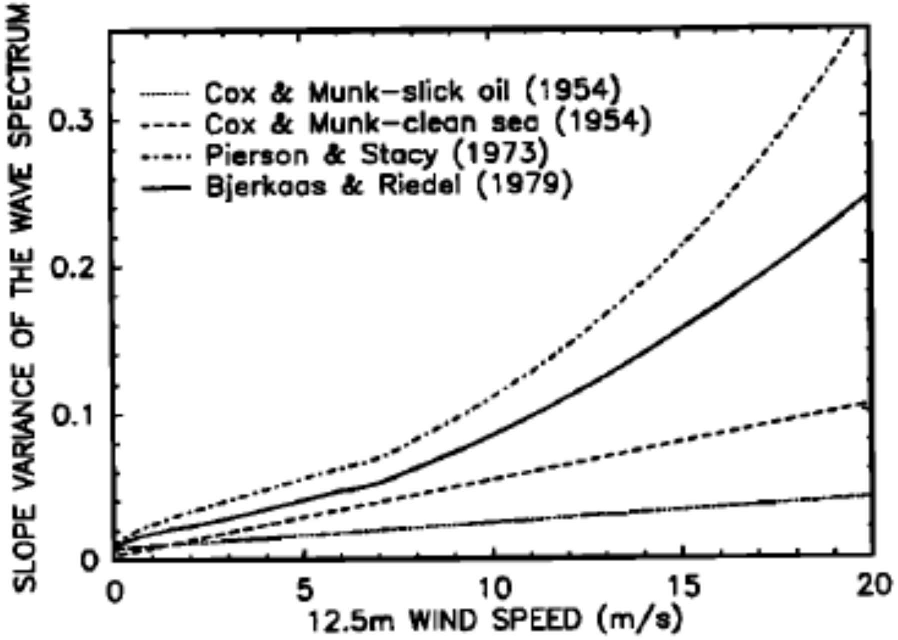
(regardless of frequency… and model types)

The sea surface description

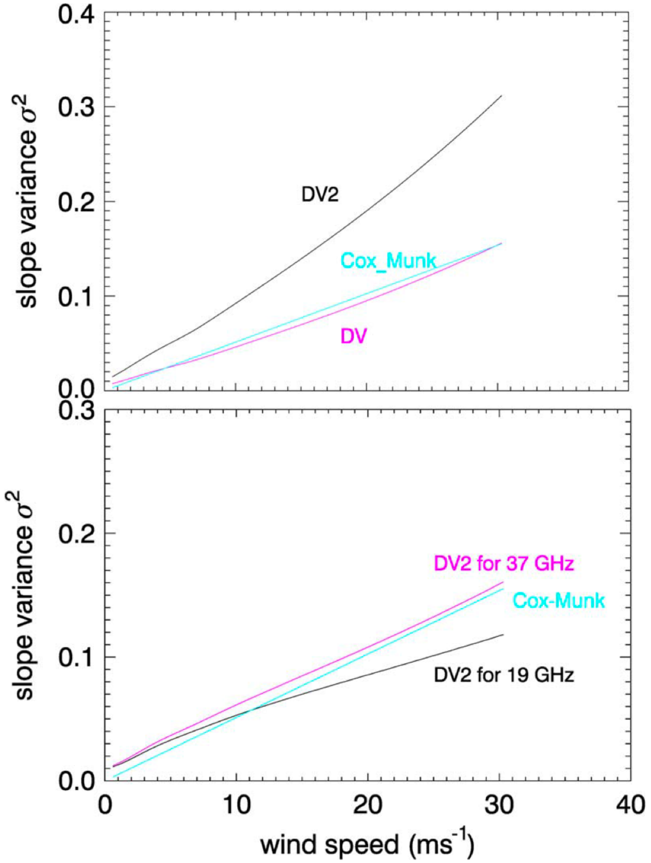
A key issue… not only for the geometric optics models… *Next talk by Simon Yueh*

The large scale roughness governed by the gravity forces (gravity waves)
The small scale roughness (capillary waves) governed by the surface tension
The cut-off wavenumber?

- Local wind speeds for fully developed seas. Fetch, duration, swell…??
- Rain effect on the surface?



Guillou et al., JGR, 1996



Liu et al., IEEE, 2011

The sea water dielectric properties in the infrared

Discussion led by Thomas Meissner tomorrow

Lack of measurements from the microwaves to the infrared

In the infrared

Wu and Smith, AO, 1997

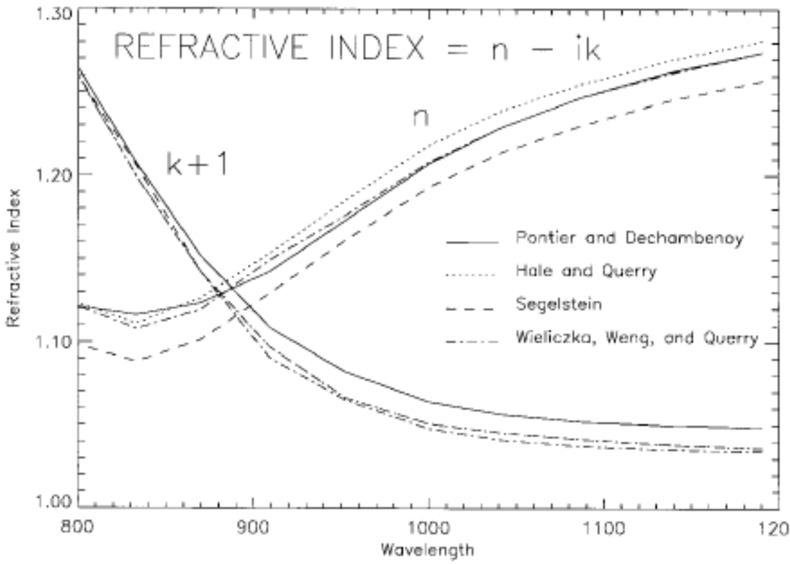
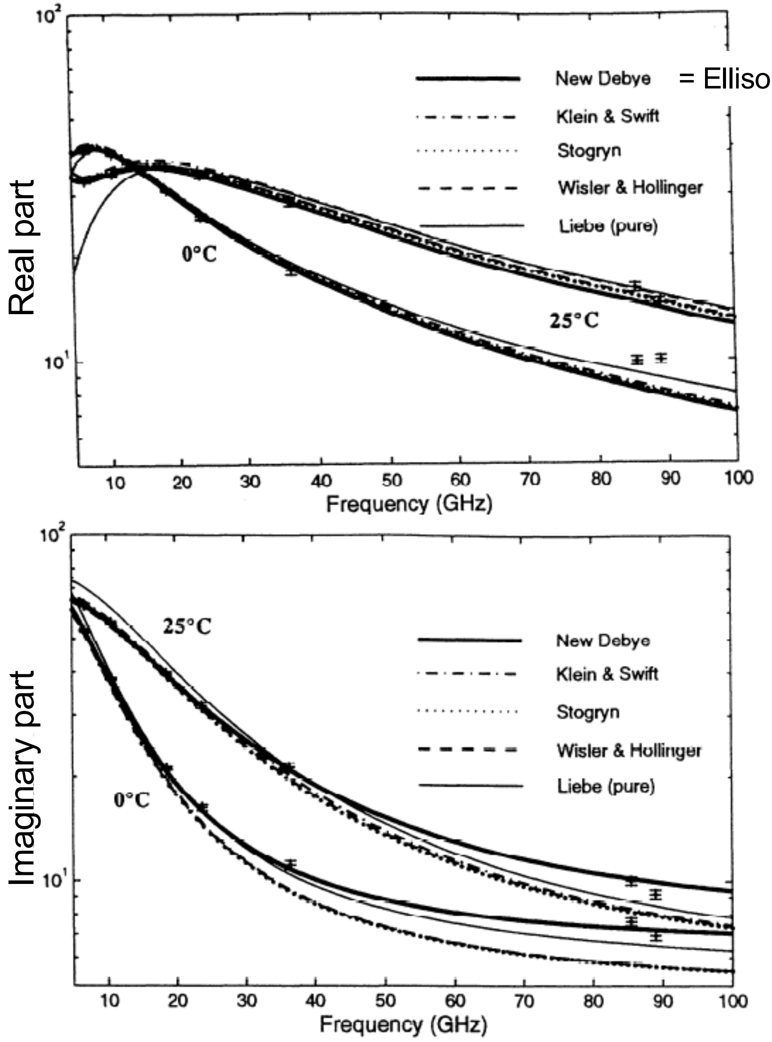


Fig. 8. Spectral variation of refractive indices obtained by various authors.

In the microwave

Guillou et al., RS, 1998

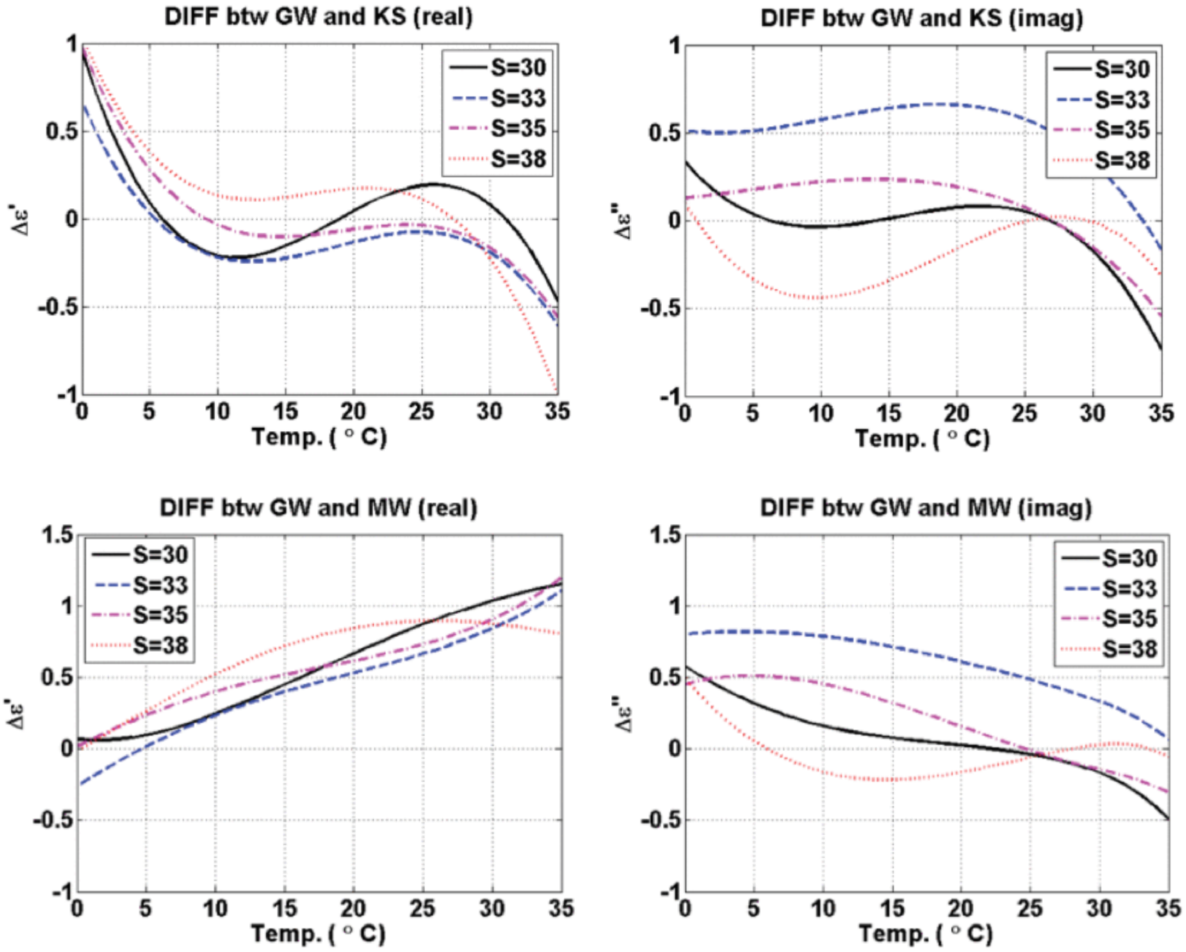


= Ellison et al.

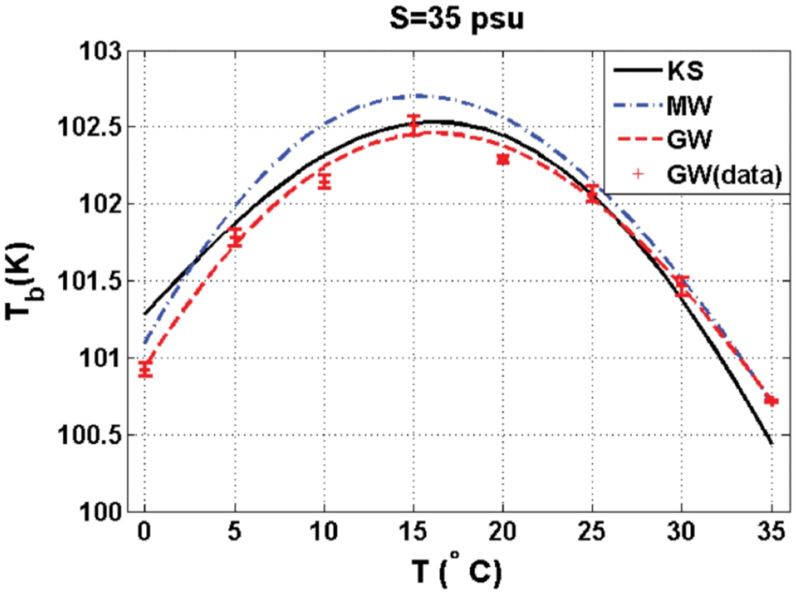
The sea water dielectric properties in the infrared

Discussion led by Thomas Meissner tomorrow

Particularly critical in the microwave at 1.4 GHz (L band), where high accuracy is required for salinity retrieval (better than 0.1K accuracy required).



Zhou et al., IEEE, 2017

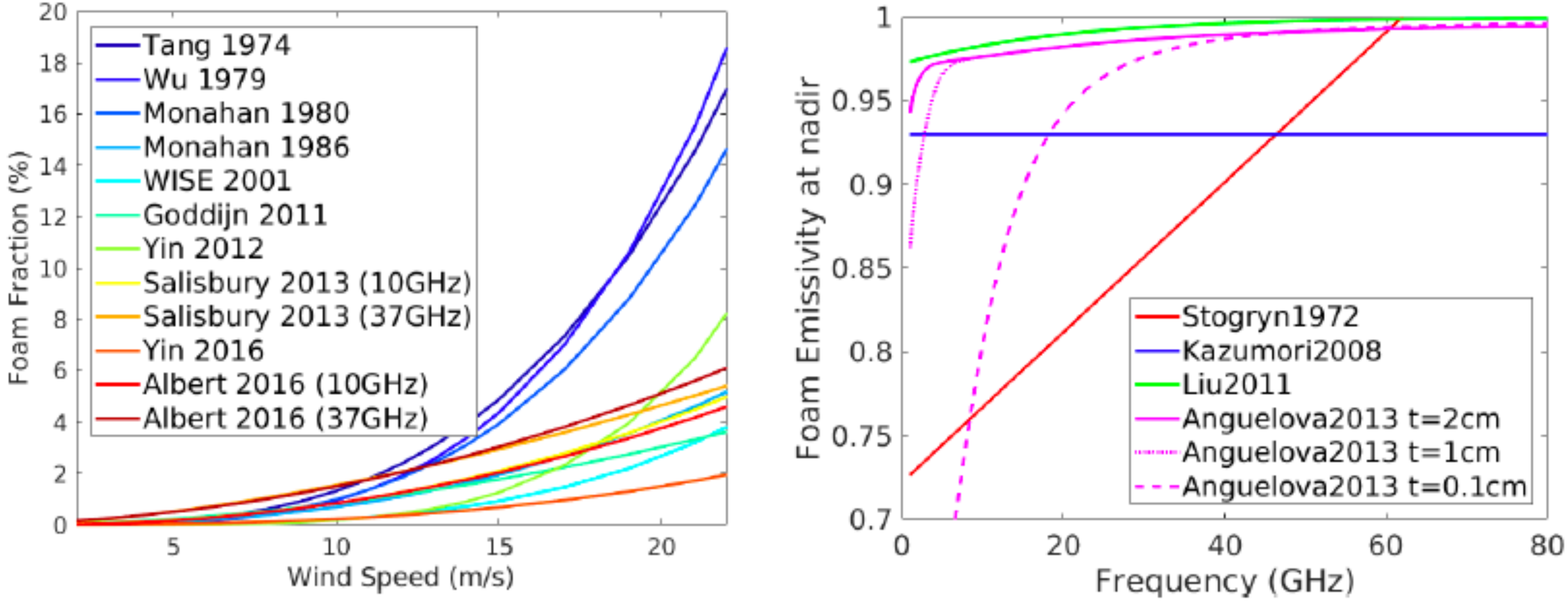


GW = George Washington University
KS = Klein and Swift
MW = Meissner and Wentz

The foam in the microwave (coverage and emissivity)

(in the infrared, sea emissivity high and foam emissivity as well, so little impact)

See presentation by Maggie Anguelova

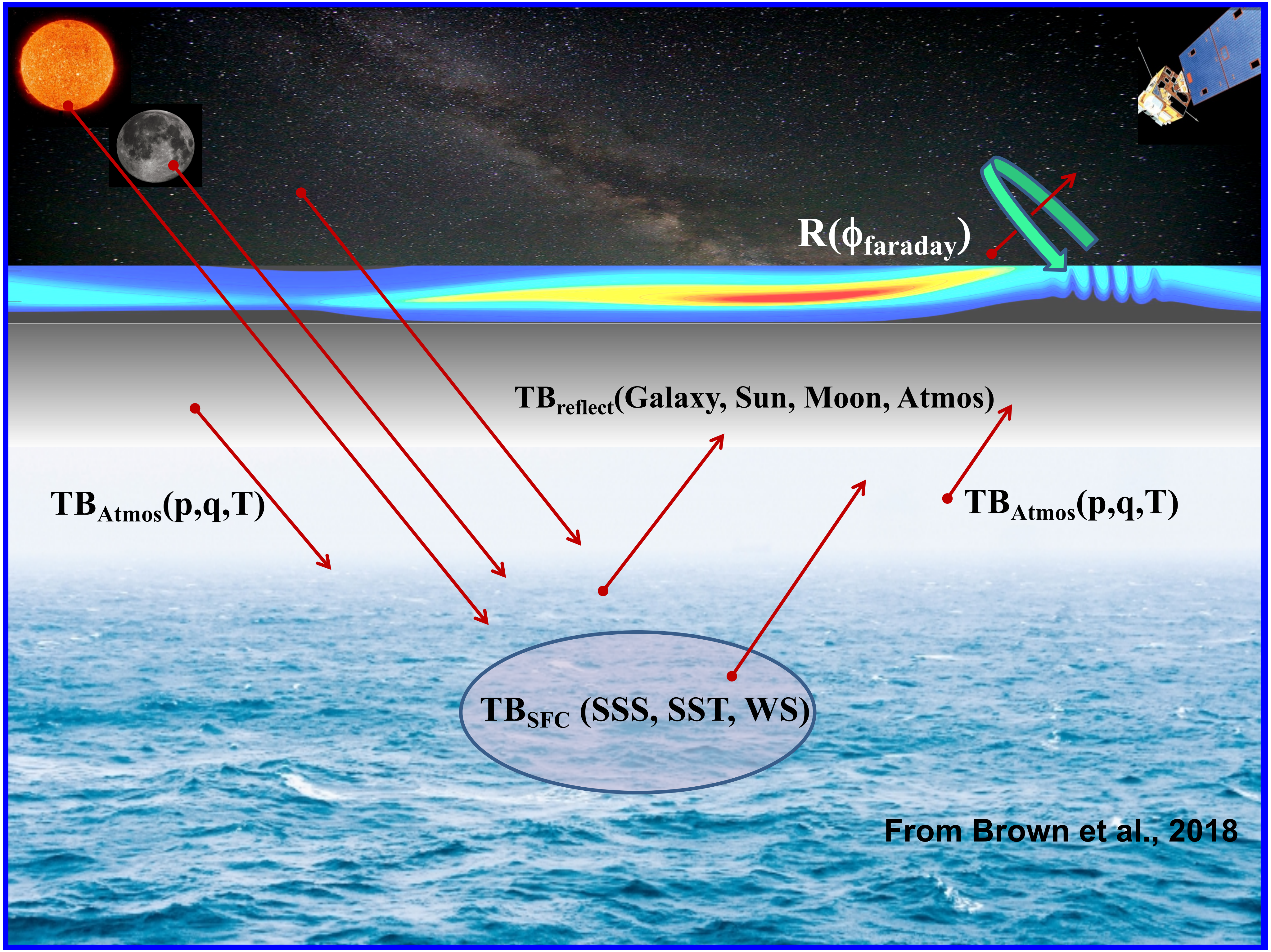


Kilic et al., JGR, 2019

The downelling radiation

Atmospheric and extra-terrestrial contributions

- Calculation of the atmospheric donwelling radiation with a radiative transfer model.
- Other contributions to account for (Galaxy, Sun..) ?
  Very critical at low frequencies (L-band)
- Including all directions or only the specular one?



$R(\phi_{faraday})$

$TB_{reflect}$(Galaxy, Sun, Moon, Atmos)

$TB_{Atmos}(p,q,T)$

$TB_{Atmos}(p,q,T)$

TB_{SFC} (SSS, SST, WS)

From Brown et al., 2018

The downelling radiation:

The extraterrestrial sources

Ho et al., INP, 2008

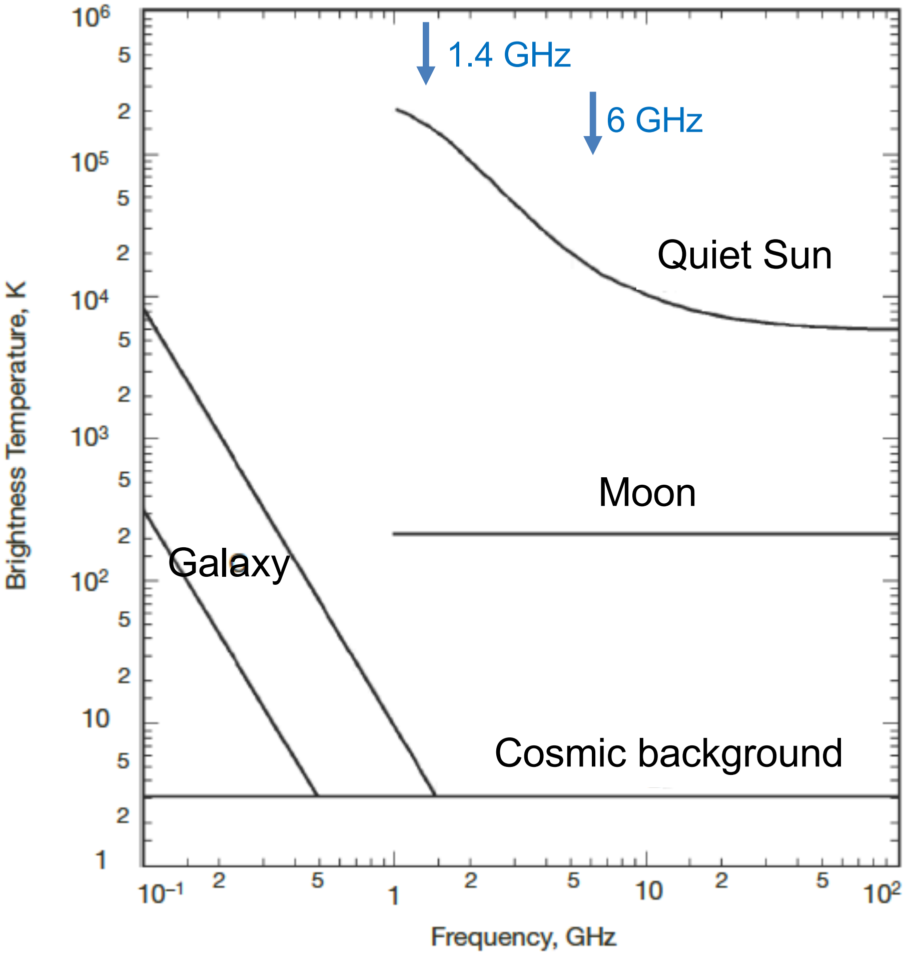


Figure 3. All noises from extraterrestrial sources. Line A is from a quiet Sun, while line B is from the Moon (all with 0.5-deg beamwidth diameter). Galactic noise (C, maximum to minimum) and cosmic background (D) are also shown. Lunar emission is independent of the frequency (figure after [7]).

CONCLUSION

Geometric optics models

- Suitable for passive microwave observations, above ~30GHz
- Not suitable for active microwave above ~15° incidence angles
- Suitable for infrared

- Requires a careful selection of the input parameters
  (sea surface description, dielectric properties, foam parameters,
  downwelling radiation)