Overview of the status of the PARMIO model

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Outline

- Overview of model features
- Details of model modules
- Enhancements for project PARMIO
- Code and Repository status
- Remaining issues

Overview of model features

- Model computes radiative parameters (Brightness/Apparent Temperatures, Normalized Radar Cross Section) over ocean surface as a function of environmental parameters and sensor specifications (e.g. incidence angle, frequency)
- Model components
  - Flat ocean surface : Fresnel reflection
  - Surface roughness : ocean waves of all scales through sea surface power spectrum and/or slope variance
  - Foam coverage and emission
  - Swell
  - Hydrodynamic modulation for upwind / downwind roughness asymmetry
  - Atmospheric model : limited to Standard US atmosphere vertical profile prescribed by surface parameters
- Inputs :

Sensor : Electromagnetic Wavelength, Earth incidence angle
Geophysical : Sea Surface Temperatures & Salinity, Wind speed & altitude, Atmospheric stability, Swell RMS height and peak wavelength
Model options : Two-scale cutoff wavenumber, Model for drag coefficient, slope variance, sea spectrum, foam emissivity and coverage fraction, sea water dielectric constant, EM model (Small Perturbations Method, 2-scale, GO)

- Outputs: Polarimetric (V, H, 3rd and 4th Stokes) radiative quantities (TB/NRCS) for smooth surface & induced by roughness, with / without foam, with / without atmosphere; Roughness-induced component is provided as harmonic coefficients of the azimuth angle vs wind direction (φ), e.g.

$$T_{b,rough} = T_0 + T_1 \cos\varphi + T_2 \cos 2\varphi$$

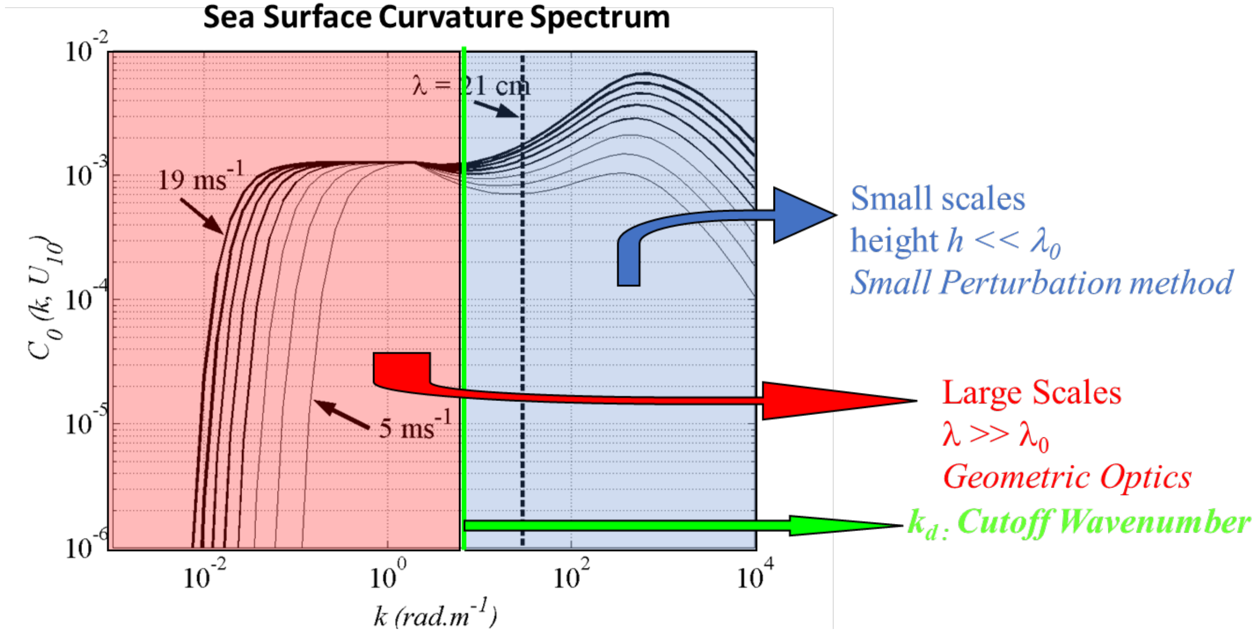
Details of model modules

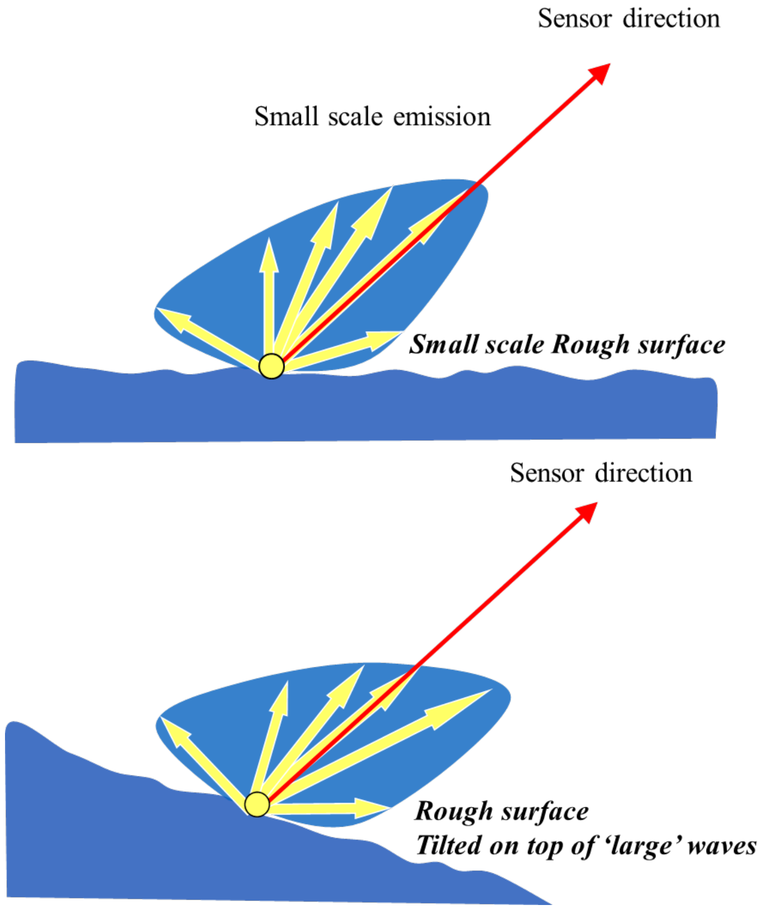
Sea water Dielectric Constant Models

- Klein & Swift 1977 : Developed from measurements at L- (1.4 GHz) and S-band (2.65 GHz); Used at 1.4 GHz (SSS) and 6 GHz (SST); Biased in cold waters (< 5degC) at both frequencies.
- Ellison et al. 1998 : Developed from measurements between 3 – 20 GHz + 23.8, 36.5, 89 GHz.
- Meissner et al. (2004, 2012, 2014): Adjusted / Validated on remote sensing data from 1.4 to 89 GHz.
- High frequency model from 28.8 to 449677 GHz (Stuart Newman).

Electromagnetic Models for Rough Surface

- Small Perturbation Method (SPM)
- GO (applicable at high MW and IR)
- 2-scale (adjustable cutoff)





Foam Coverage / Fraction Models

- Monahan & O'Muircheartaigh (1986) : commonly used model that depends on wind speed and atmospheric stability.
- Monahan & Lu (1990): distinguish different lifetime stages for foam bubles.
- WISE2001 : Empirical model from the WISE 2001 campaign (unpublished).
- Yin et al. (2016) : semi-empirical model, adjusted on SMOS observations at L-band. 5 parameterizations according to sea spectrum & wind product used. Requires consistent sea spectrum and foam emissivity models.

Foam Emissivity Models

- Stogryn (1972)
- Yin et al. (2016): Use multilayer model by Anguelova and Gaiser (2013). Same as coverage model, it is adjusted on SMOS observations, , 5 versions according to sea spectrum model and wind product used.
- Anguelova et al. (2022): multi-frequency tuned multilayer model (see later slide).

Swell

- Simple model from Durden and Vesecky (1985)
- Swell adds Gaussian spectrum to sea spectrum in the large wave doman => impact the model through large scales slope variances
- Adjustable parameters:
  - RMS height
  - Half power widths of swell Gaussian PDF along and across wind
  - Peak PDF swell along and across wind

Roughness Sea Surface Spectrum Models

- Durden and Vesecky (1985) [**DV**]: developed for radar at L-band, likely underestimates sensitivity to wind.

$\Rightarrow$ Spectrum amplitude is adjustable

$\Rightarrow$ Yueh (1997) model: multiplied DV model by 2

$\Rightarrow$ Yin et al. (2016) model : multiplied DV model by 1.25 and adjusted foam model

- Elfouhaily et al. (1998) : developed to be independent of remote sensing data. Good performance reported for C-band scatterometers. Includes wave development (inverse wave age is an input). Issue at L-band: loss of sensitivity to wind speed between 3 – 7 m/s.
- Slope Variance for large scales : computed from sea spectrum for k < kd or from Cox and Munk (1954) model

Drag Coefficient Models

- Used to Convert wind at a reference altitude (commonly 10 m) to other altitudes or to friction velocity used as input to sea spectrum models
- Cardone (1969), Charnock (1955), Donelan et al. (1993) (accounts for inverse wave age)

Enhancements for project PARMIO

- Stuart Newman : High frequency model for the dielectric constant of sea water for the IfraRed (covers 28.8 GHz -449677 GHz)

- Maggie Anguelova : Frequency tuned foam emissivity (Anguelova et al. 2022) that adjusts effective foam thickness (h_{fe}) and void fraction upper limits (v_{afv}, v_{afh}) at frequencies between 1.4 and 89 GHz
  - E. Dinnat modification : original code uses a "band" input that could take 6 discrete values (L, C, X, K, Ka, W)

  $\Rightarrow$ Possible to have inconsistent frequencies for rest of the model and the foam emissivity model

  $\Rightarrow$ Foam model usable only at 6 fixed frequencies f_1 = 1.4 Ghz, …, f_6 = 89 Ghz

  New code: uses the frequency f_0 used by the rest of the model and interpolates the tuned foam parameters (h_{fe} , v_{afv}, v_{afh}) from the 6 reference frequencies $f1$ -> $f6$ to f_0. If f_0 is out of the domain of the model, the closest boundary value is used.

Code and Repository status

- All team members contributions are included and merged, available on GitHub
- Code Improvements
  - Improved portability by fixing hardcoded paths to data files
  - Improved speed of foam models Yin et al. 2016 and Anguelova et al. 2022 (frequency tuned model)
  - Fixed multiple warnings and bugs
  - Added “inconsistency” warnings for some selection of models for foam emissivity and fraction
- Improvements to Documentation
  - Added list of folders and sub-folders wih content description
  - New expended header for main program
  - Cleaned up and translated (French -> English) all comments in main program
  - New header for all subroutines
  - Diagram of subroutines relationships

Remaining work

- Assess validity of atmospheric model for high frequencies IR
- Update NRCS / BRDF component to bring up to speed with TB
- Improve documentation of subroutines
- Muti-layer foam models (Anguelova et al. 2022, Yin et al. 2016) generate warning message

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