Data Fusion Between Microwave and Thermal Infrared Radiometer Data and Its Application to Skin Sea Surface Temperature, Wind Speed and Salinity Retrievals

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Abstract—Method for data fusion between Microwave Scanning Radiometer: MSR and Thermal Infrared Radiometer: TIR derived skin sea surface temperature: SSST, wind speed: WS and salinity is proposed. SSST can be estimated with MSR and TIR radiometer data. Although the contribution ocean depth to MSR and TIR radiometer data are different each other, SSST estimation can be refined through comparisons between MSR and TIR derived SSST. Also WS and salinity can be estimated with MSR data under the condition of the refined SSST. Simulation study results support the idea of the proposed data fusion method.

Keywords-data fusion; simulataneous estimation

I. INTRODUCTION

Microwave Scanning Radiometer: MSR onboard remote sensing satellites allow estimations of salinity, soil moisture, ocean wind speed, precipitable water, rainfall rate, air temperature (profile), atmospheric pressure, and Skin Sea Surface Temperature: SSST. On the other hands, Thermal Infrared Radiometer: TIR onboard remote sensing satellites allow estimations of SSST [1]. There are remote sensing satellites which carries both MSR and TIR radiometers such as Tropical Rainfall Measurement Mission: TRMM/VIRS (Visible to Thermal Infrared radiometer) and TMI (TRMM Microwave Imager) [2]. It is possible to improve estimation accuracy by using both radiometer data which is known as data fusion.

There are some atmospheric and ocean surface models in the microwave wavelength region. Therefore, it is possible to estimate at sensor brightness temperature (microwave radiometer) with the geophysical parameters. The real and the imaginary part of dielectric constant of the calm ocean surface is modeled with the SST, salinity (conductivity). From the dielectric constant, reflectance of the ocean surface is estimated together with the emissivity (Debue, 1929 [3]; Cole and Cole, 1941 [4]). There are some geometric optics ocean surface models (Cox and Munk, 1954 [5]; Wilheit and Chang, 1980 [6]). According to the Wilheit model, the slant angle against the averaged ocean surface is expressed by Gaussian distribution function.

There is a relation between ocean wind speed and the variance of the Gaussian distribution function as a function of the observation frequency. Meanwhile the influence due to foams, white caps on the emissivity estimation is expressed with the wind speed and the observation frequency so that the emissivity of the ocean surface and wind speed is estimated with the observation frequency simultaneously. Meanwhile, the atmospheric absorptions due to oxygen, water vapor and liquid water were well modeled (Waters, 1976 [7]). Then atmospheric attenuation and the radiation from the atmosphere can be estimated using the models. Thus the at-sensor-brightness temperature is estimated with the assumed geophysical parameters.

Sea surface temperature estimation methods with AMSR data are proposed and published [8] while ocean wind retrieval methods with AMSR data are also proposed and investigated [9]. Furthermore, water vapor and cloud liquid estimation methods with AMSR data are proposed and studied [10]. The conventional geophysical parameter estimation method is based on regressive analysis with a plenty of truth data and the corresponding microwave radiometer data [11].

Both radiometers observe same sea surface through same atmosphere. Also atmospheric model and sea surface model for both thermal infrared wavelength region and microwave wavelength region are known. Therefore, both radiometer data can be used for improvement of the estimation accuracy. One of the well known week points is sea surface emissivity model. As is mentioned above, surface emissivity depends on dielectric constant of the sea water as functions of sea surface temperature, salinity, etc., ocean wave shape distribution, foams (white caps appears when ocean wind is greater than 7 m/s), and so on.

The proposed method of data fusion between thermal infrared and microwave radiometers is eliminate influences due to emissivity changes by ocean winds based on the aforementioned models. Through simulation studies using Community Radiative Transfer Model: CRTM [12] of atmospheric code which covers from visible to microwave wavelength regions, it is found that the proposed data fusion is useful.

The following section describes the proposed data fusion method followed by simulation studies. Then conclusion is described together with some discussion.

II. PROPOSED METHOD

A. Process Flow of the Proposed Data Fusion Method

Process flow of the proposed data fusion method is shown in Figure 1. Assuming both of TIR and MSR radiometers are onboard same remote sensing satellite and observe the same sea surface through the same atmosphere.
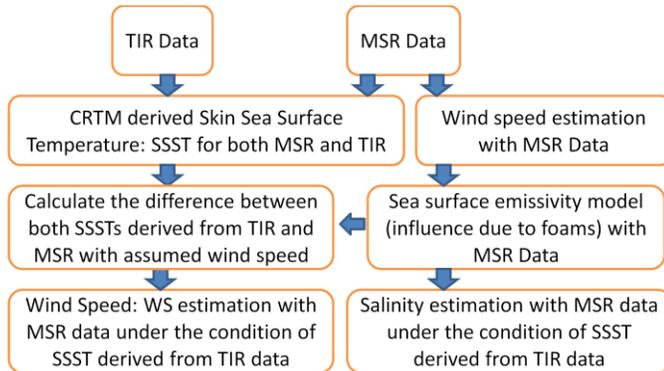

Fig. 1.   Process flow of the proposed data fusion method

B. Basic Idea of the Proposed Data Fusion Method

SSST is estimated with both TIR and MSR data separately. There is discrepancy between both SSST_TIR and SSST_MSR due to the fact that influences on emissivity due to ocean wind speed are difference between both. Emissivity in TIR wavelength region is affected by wind speed a little while that in microwave wavelength region is changed so much. Moreover emissivity in MSR wavelength region may change SSST and salinity (in relatively lower frequency below 10 GHz in particular). Therefore, such these influence might be possible to estimate by using the discrepancy between SSST_TIR and SSST_MSR. On the other hands, ocean wind speed can also be estimated with MSR data together with SSST. Therefore, wind speed can be refined using the discrepancy iteratively. Furthermore, salinity is estimated with estimated SSST as well as the refined wind speed.

C. Theoretical Background

Radiative transfer equation of MSR is expressed in equation (1).

$$I_\nu = \epsilon_\nu B_\nu(T_s)\tau_\nu(0, Z, \theta) + \int_0^z B_\nu(T(z))\frac{\partial \tau_\nu(z, Z, \theta)}{\partial z}dz$$
$$-(1 - \epsilon_\nu)\tau_\nu(0, Z, \theta)\int_0^Z B_\nu(T(z))\frac{\partial \tau_\nu(0, z, 0)}{\partial z}dz \quad (1)$$

The first term of equation (1) represent the contribution from the sea surface while the second term expressed the contribution from the atmosphere. The third term is the contribution from the reflected atmosphere and extraterrestrial contribution at the sea surface. In general, the first term is largest contribution followed by the second and the third term.

Sea surface reflectance for vertical and horizontal polarizations is expressed in equation (2) and (3), respectively.

$$\rho v = \left|\frac{\epsilon_r \cos\theta - \sqrt{\epsilon_r - \sin^2(\theta)}}{\epsilon_r \cos\theta + \sqrt{\epsilon_r - \sin^2(\theta)}}\right|^2 \quad (2)$$

$$\rho h = \left|\frac{\cos\theta - \sqrt{\epsilon_r - \sin^2(\theta)}}{\cos\theta + \sqrt{\epsilon_r - \sin^2(\theta)}}\right|^2 \quad (3)$$

where θ denotes observation angle, or incident angle. The sea surface reflectance is illustrated in Figure 2 as a function of incident angle. Meanwhile, sea surface emissivity in vertical and horizontal polarizations is represented in equation (4).

$$ev = 1 - \left|\frac{\epsilon_r \cos\theta - \sqrt{\epsilon_r - \sin^2(\theta)}}{\epsilon_r \cos\theta + \sqrt{\epsilon_r - \sin^2(\theta)}}\right|^2$$

$$eh = 1 - \left|\frac{\cos\theta - \sqrt{\epsilon_r - \sin^2(\theta)}}{\cos\theta + \sqrt{\epsilon_r - \sin^2(\theta)}}\right|^2 \quad (4)$$

Where ϵ_r denotes dielectric constant of sea water.

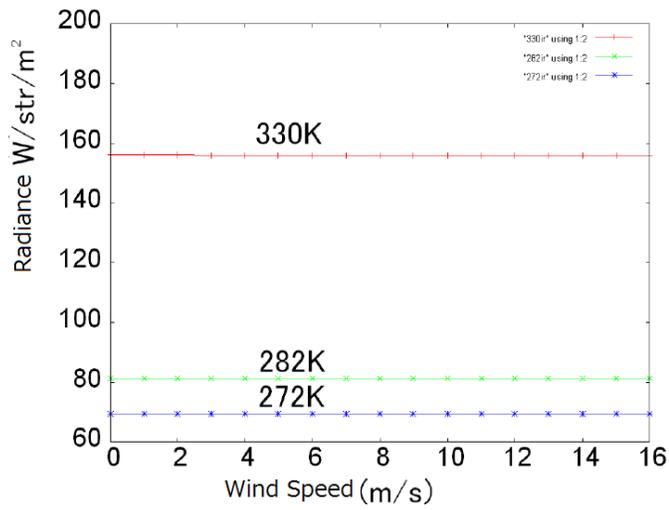Fig. 2.   Sea surface reflectance as a function of incident angle

III. SIMULATION STUDIES

A. Radiance

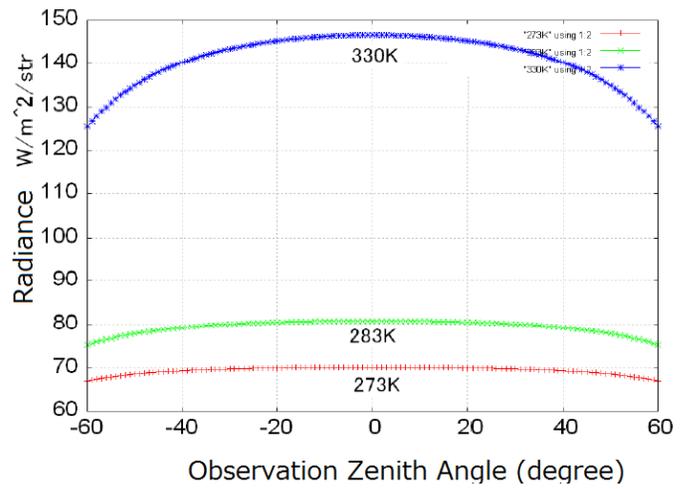Simulation parameters are set as follows,

1) Wavelength: 11 micrometer for TIR, 5GHz for MSR
2) Atmospheric condition: US standard atmosphere 1976
3) Observation target: sea surface with 272K, 282K, 330K of SSST
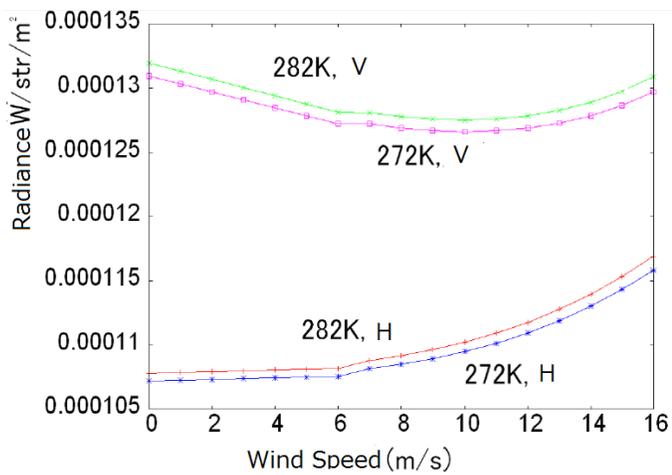*4) Observation zenith angle: 30 degree*

Figure 3 shows calculated radiance using CRTM atmospheric software code while Figure 4 shows the radiance as a function of observation zenith angle.
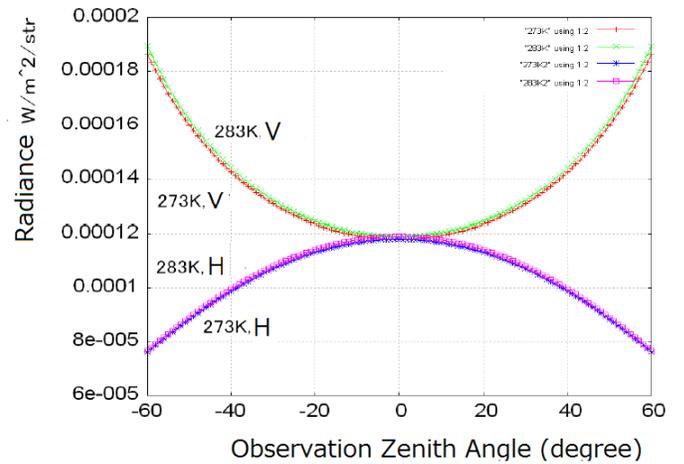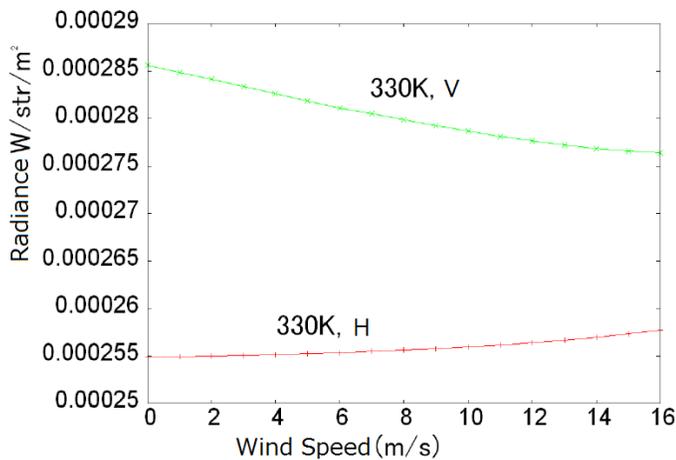
(a)TIR

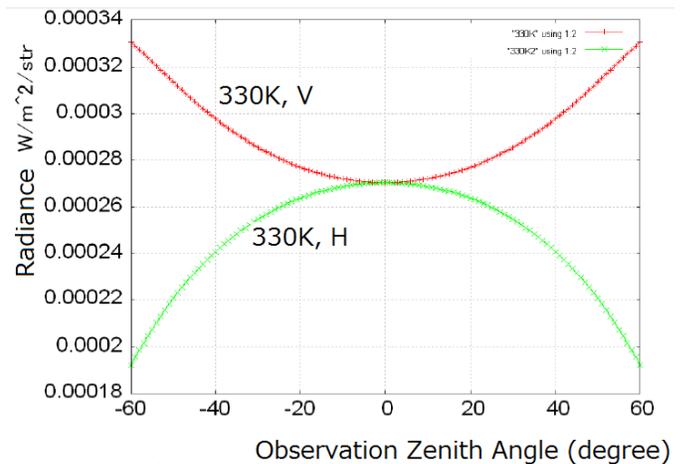
(a)TIR

(b)MSR1

(b)MSR1

(c)MSR2

(c)MSR2

Fig. 3.   Calculated radiance for TIR and MSR wavelength regions as a function of wind speed

Fig. 4.   Calculated radiance for TIR and MSR wavelength region as a function of observation zenith angle

TIR radiance at large observation zenith angle, limb darkening appears. Meanwhile, Figure 5 shows calculated radiance with the parameters of wind speed ranged from 0 to 16m/s.
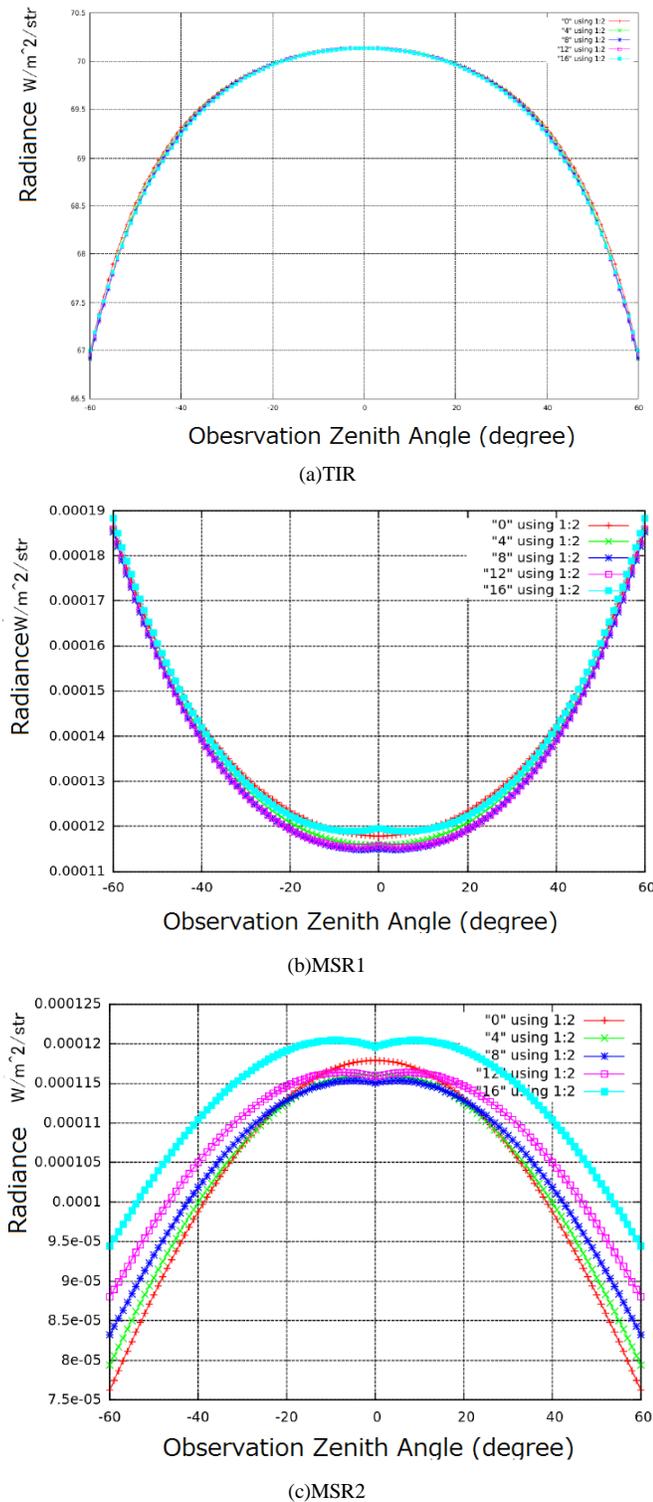
There is quite small difference among the calculated radiance for the different wind speed for TIR while that for MSR differ from each other, in particular for the 330K of sea surface temperature (Figure 5 (c)). The relations between observation zenith angle and radiance depend on SSST.

Figure 6 shows the calculated radiance for nadir viewing of observation zenith angle as a function of wind speed. The relations between wind speed and radiance depend on SSST.
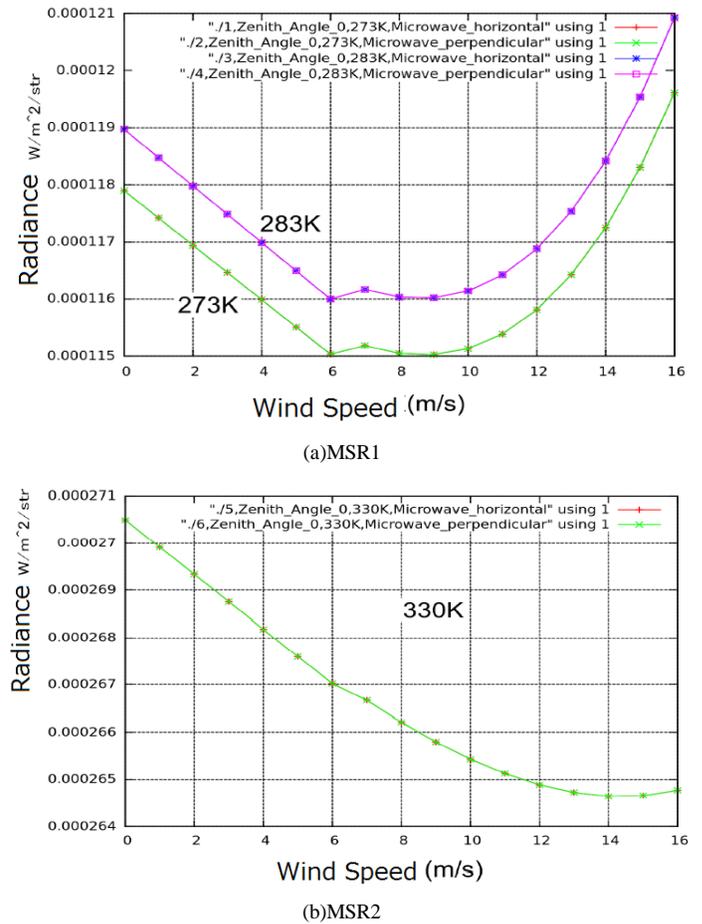

(a)TIR
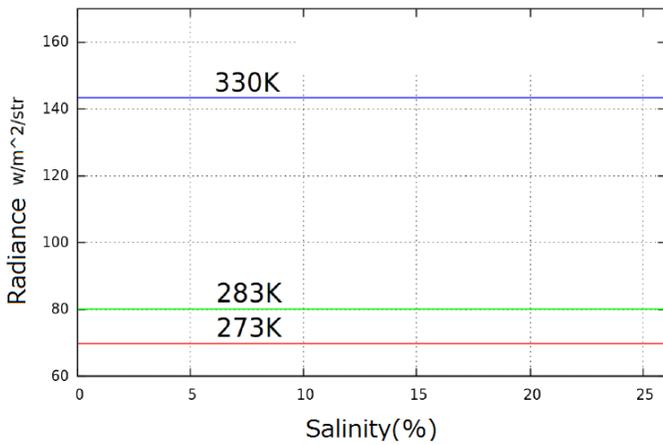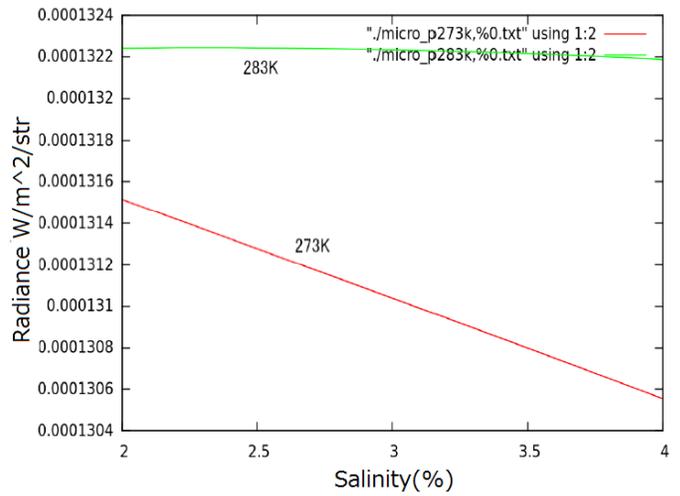

(a)MSR1

(b)MSR1

(b)MSR2

Fig. 6.   Calculated radiance for nadir viewing of observation zenith angle as a function of wind speed
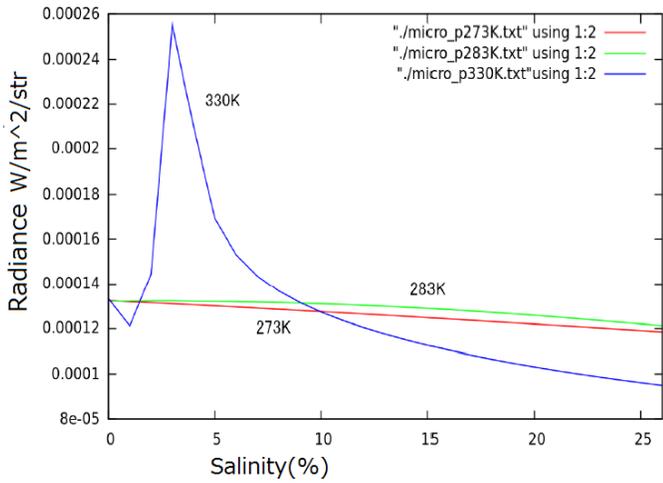
Meanwhile, Figure 7 shows calculated radiance as a function of salinity. It is obvious that there is no change of the calculated radiance for TIR while there is a relatively large change for MSR, in particular for vertical polarization.

(c)MSR2

Fig. 5.   Calculated radiance for TIR and MSR as parameters of wind speed ranged from 0 to 16 m/s
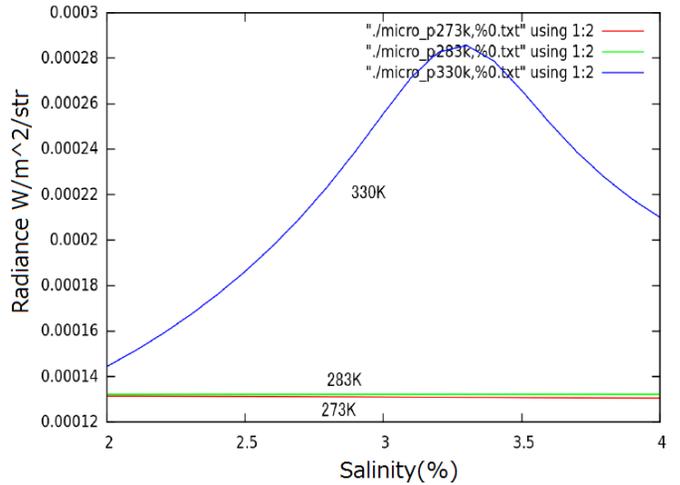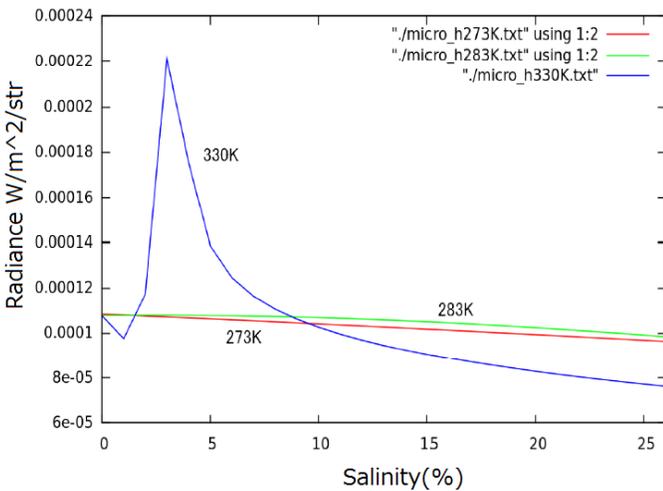
(a)TIR

(a)Vertical polarization for 273 and 283K of SSST

(b)Vertical polarization

(b)Vertical polarization for 273, 283, and 330 K of SSST
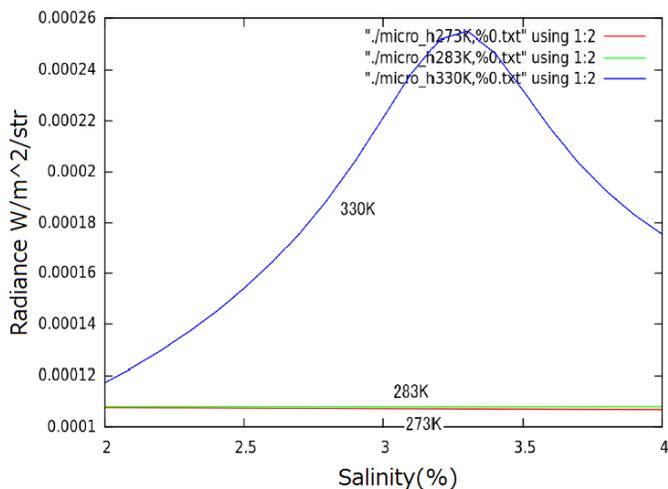

(c)Horizontal polarization

Fig. 7.   Calculated radiance as a function of salinity

(c)Horizontal polarization for 273, 283K of SSST

In more detail, calculated radiance for the salinity ranged from 2 to 4 % is shown in Figure 8.

(d)Horizontal polarization for 273, 283, 330K of SSST

Fig. 8.   Calculated radiance as a function of salinity

From these figure, it is found that salinity estimation is possible if the calculated radiance difference between horizontal and vertical polarization. Also it is promising that salinity is estimated for relatively large SSST, much greater than 330K.

IV.   CONCLUSION

Method for data fusion between Microwave Scanning Radiometer: MSR and Thermal Infrared Radiometer: TIR derived skin sea surface temperature: SSST, wind speed: WS and salinity is proposed. SSST can be estimated with MSR and TIR radiometer data. Although the contribution ocean depth to MSR and TIR radiometer data are different each other, SSST estimation can be refined through comparisons between MSR and TIR derived SSST. Also WS and salinity can be estimated with MSR data under the condition of the refined SSST. Simulation study results support the idea of the proposed data fusion method. In particular, SSST and WS can be estimated with refined SSST. Furthermore, it also is promising that salinity estimation with MSR data.

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