Natural water thermal radiation at a 8 mm wavelength

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Abstract. The natural water thermal radiation in the temperature range of 30-85 degrees Celsius at a wavelength of 8 mm has been experimentally investigated. The measurements were carried out on an experimental installation with a radiometer as a receiver of thermal radiation with a sensitivity of 0.2 Kelvin. The water temperature was measured by a contact thermometer immersed in the water column. The dependence of the radio brightness temperature from the water thermodynamic temperature has been established. It was shown that the dependence of water radio brightness temperature from water thermodynamic temperature is non-linear, which corresponds to theoretical concepts. It was noted that the thermal radio emission is different sufficiently in the studied temperature ranges. In the thermodynamic temperature range of 30-50 degrees Celsius the gradient of the radio brightness temperature was about 0.15 Kelvin per degree Celsius, at 55-85 degrees - about 0.6 Kelvin per degree Celsius. It was shown, that the practical use of temperature dependences of water thermal radiation is possible for monitoring of water systems.
Keywords: water, experiment, temperature, thermal radiation.

1   Introduction

Water is a key element of any terrestrial systems, the basis of life on Earth. Physical methods of water research include measuring the intrinsic radio emission of water [1-2].

The water state dynamics are determined by heat and mass transfer on the surface of the water-air interface. The processes of absorption and emission of electromagnetic waves on the water surface significantly determine the air-water energy exchange.

Self thermal, electromagnetic in nature, emission of water depends on the own thermodynamic water temperature, measured in the water bulk or in water surface temperature layer.

Radio brightness temperature is the measure of water electromagnetic emission in a certain frequency range. It can be measured with high accuracy by radiometric methods. The information about dependence of the radio brightness temperature from the water thermodynamic temperature can be helpful for establishing the structure of the water, salt content, detection of impurities, and the presence of temperature, salinity, detection of impurities, and the presence of temperature heterogeneities. Radiometric methods make it possible to measure radio brightness temperature remotely [3].

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The intrinsic thermal radiation of water can be characterized by integral emissivity in a wide frequency range of electromagnetic radiation [4]. An important characteristic of thermal radiation is the spectral density of thermal radiation [5].

In this paper, the dependence of the intrinsic radio emission of water in the temperature range of 30-85 degrees Celsius on 8mm waves has been experimentally investigated.

2 Materials and Methods

2.1 Theory

The theory of water radio emission has been developed in [6-7]. Reflection and absorption of radiation by the water surface depends on the dielectric constant [8], temperature [9], and salinity [10] of the water. Salinity determines [11] the conductivity of water. Ionic conductivity determines the depth of the skin layer, which is the source of thermal radio emission.

For water-air boundary the brightness temperature T_{br} [12] depends from the water thermodynamic temperature T as

$$T_{br} = ET \qquad , \qquad (1)$$

where
E - emission coefficient.

If two media (air and water) cover a half-space each, for a normal wave incident, the emission coefficient is:

$$E = 1 - R \qquad , \qquad (2)$$

where

$$R = \left| (1 - \sqrt{\varepsilon})/(1 + \sqrt{\varepsilon}) \right| \qquad (3)$$

- Fresnel reflection coefficient,
ε -dielectric constant.

The dielectric constant ε is the function of several variables. The dielectric constant ε is expressed by the Debye equation [13]:

$$\varepsilon = \varepsilon_{hf} + (\varepsilon_{S} - \varepsilon_{hf})/(1 - i2\pi\nu\tau) + i\sigma/(2\pi\nu\varepsilon^{*}) \quad (4)$$

where
ν- frequency [14],
ε_{hf}- high-frequency dielectric constant,

ε_{S}- static dielectric constant,

τ-time of relaxation,

σ –conductivity,
ε^{*} - permittivity of free space.
The coefficients in (4) are empirical values [15].

2.2 Method

Research of the radiation-temperature dependence of natural water at a wavelength of λ= 8 mm in the temperature range t° =30÷85 °C with a 30x30 mm antenna aimed at the nadir were carried out.
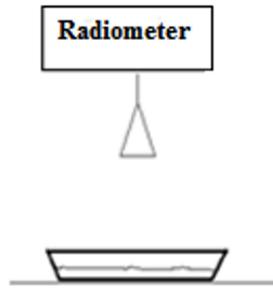
Fig. 1. The scheme of installation used in the experiments (compiled by the author).

Water was poured into a foam container. The water temperature was controlled after careful mixing. The zero level, relative to which the brightness temperature increment was calculated, was fixed by the brightness temperature of the water at ambient air temperature $t_{air} = 24\,^{O}C$.

The calibration was carried out using measurements of the temperature of a black body [16].

The temperature of the water poured into the container was regulated by adding hot water, mixing with cold water and by changing the temperature of the water during cooling. As a result, it was possible to carry out radio brightness measurements in a temperature range from 30 ° C to 85 °C.

The zero reference control was checked by the radio brightness temperature of the water at ambient temperature $t_{air} = 24\,^{O}C$.

3   Results

The measurement results in the temperature interval 30-50 ^{O}C are shown in the graph Fig.2, along the vertical axis of which radio brightness temperature are deposited

$$\Delta T_{br}(t^{O}C) = T_{br}(water,\, t^{O}C) - T_{br}(water,\, t = 25\,^{O}C).$$

Table 1. Thermodynamic temperature of water and deviation of the radio brightness temperature 29,9 -50,6 ^{O}C (compiled by the author).

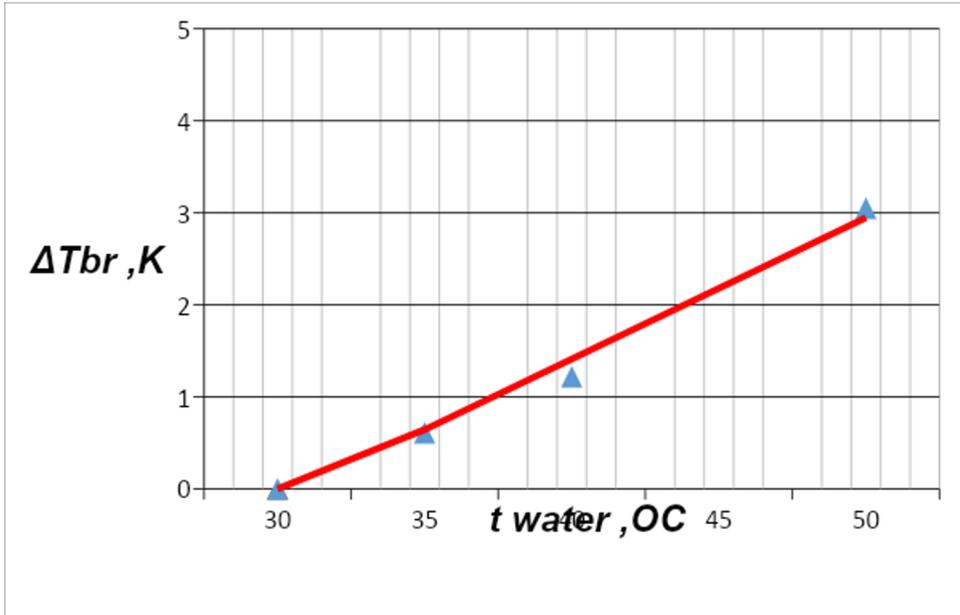| Thermodynamic temperature of water, $t_{water},\,^{O}C$	Deviation of the radio brightness temperature, K
29,9	0
35,5	0,6
40,3	1,2
50,6	3,0

Fig.2. Dependence of the deviation of the radio brightness temperature from the water thermodynamic temperature t_{water} = 30÷50 °C (compiled by the author).

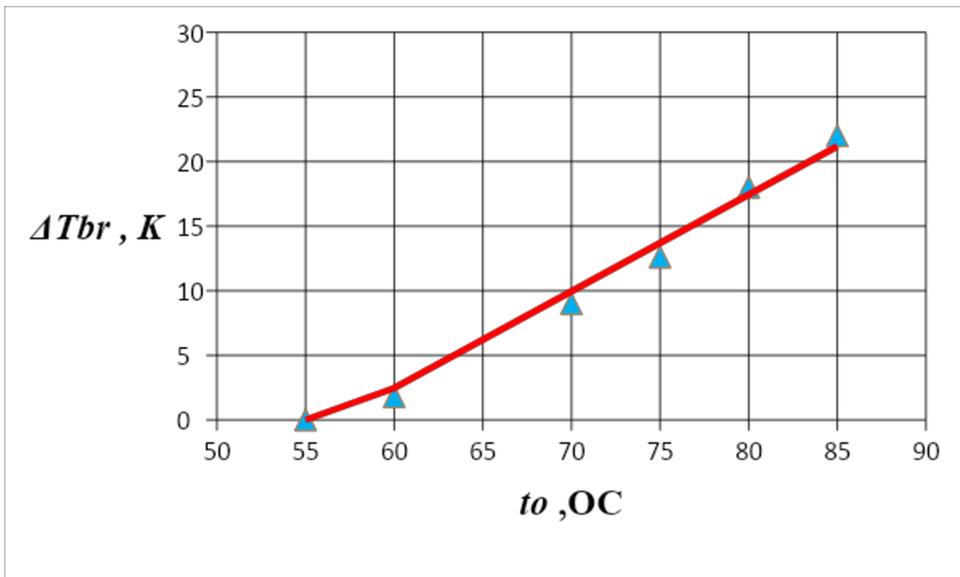**Fig.3.** Dependence of the deviation of the radio brightness temperature from the water thermodynamic temperature, t_{water} = 55÷85 ° C (compiled by the author).

Table 2. Thermodynamic temperature of water and deviation of the radio brightness temperature,

t_{water} = 55÷85 ° C (compiled by the author).

Thermodynamic temperature of water, t_{water}, ^{o}C	Deviation of the radio brightness temperature, K
55	0
60	1,8
70	9,0
75	12,6
80	18,2
85	21,8

4   Discussion

It can be seen from the graphs that the gradient of the radio brightness temperature differs significantly in the studied water temperature ranges. In the thermodynamic temperature range of 30-50 degrees Celsius, the gradient of the radio brightness temperature was about 0.15 Kelvin per degree Celsius, at 55-85 degrees - about 0.70 Kelvin per degree Celsius. This difference can be explained by the fact that a surface temperature film [17] forms on the air-water interface. The temperature of this film is mainly determined by the air temperature, if the temperature difference between water and air is small. The thickness of such water surface temperature film in our experiment conditions is estimated to be several millimeters [18].

Thermal electromagnetic waves are emitted by water from the skin layer mainly. The skin layer characterizes the depth of penetration of electromagnetic radiation into a conductive medium, which is natural water. The skin layer also determines the thickness of the water layer from which the thermal radiation emits. The thickness of the skin layer is determined by the wavelength of thermal radiation and the conductivity of natural water. The conductivity of natural water is determined by the presence and composition of impurities. The conductivity of natural water is ionic conductivity mainly. The thickness of the skin layer of natural water for waves with a length of 8 mm is several tenths of a millimeter.

The ratio of the thickness of the skin layer and the thickness of the water surface temperature film is an important parameter characterizing for the thermal radiation formation. For waves with a length of 8 mm, the thickness of the skin layer is much less than the thickness of the water temperature film. In this case, the spatial distribution of temperature in the water surface temperature film can be neglected and the temperature of the surface layer can be considered constant. The relative constancy of the water temperature in the skin layer and the small difference between the water temperature in the temperature film and the air temperature is probably the reason for the small change in the intensity of thermal radiation in the thermodynamic temperature range of 30-50 degrees Celsius.

In the thermodynamic temperature range of 50-85 degrees Celsius, the temperature of the surface temperature film is apparently determined mainly by the temperature in the volume

of water, which is expressed in thermal radiation intensity increase with an increase of water temperature.

5 Conclusions

The experiment demonstrates a significant difference in the intensity of water radio emission for water temperature close to and far from ambient air temperature. For water temperatures of 50-85 degrees Celsius, the gradient of the radio brightness temperature is several times higher than the gradient for the water temperature range of 30-50 degrees Celsius.

The sensitivity of the used equipment [19] makes it possible to record both small gradients of radio brightness temperature in the range of 30-50 degrees Celsius, and large ones for water temperatures of 50-85 degrees Celsius.

Dependences of the radio brightness temperature on the thermodynamic temperature, in general, correspond to the theoretical calculations performed using the Stogrin model. For 30-50 degrees Celsius range, the experimental values of the radio brightness temperature are slightly lower than the calculated values.

The dependence of the radio brightness temperature on the thermodynamic temperature of water can be used for the remote determination of the characteristics of aqueous solutions, such as permittivity [20] and ionic conductivity. The high sensitivity of the receiving equipment allows, in general, to record water radio brightness temperature with an accuracy of several tenths of Kelvin over a wide range of water thermodynamic temperatures.

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