UDC 621.3.095

Anna Rudiakova, Yuliya Averyanova, Felix Yanovsky,
(National Aviation University, Ukraine)

Composite particlesmodel of doppler-polarimetricmeteorological radar signal

New wetness and iceness parameters were proposed to use in composite particles model of the doppler-polarimetric meteorological radar signal. This allows to simulate the mixed microstructure of clouds and precipitation with the possibility to tune the melting stage and set the mass density of dry subvolume. The model can be used to improve meteorological data interpretation and analysis of Doppler polarimetric meteorological radars.

Introduction

Information about the phase state of hydrometeors and precipitation is crucial for solving the range of meteorological tasks for aviation. It includes the detection of hail regions and dangerous icing-in-flight. The information also can be important for improving data interpretation and ambiguityavoidance when data analysis of modern and prospective meteorological radars.

The development of modern meteorological radars is aimed to combine the ability of the Doppler and Polarimetricmeasurementsmostly. This combination is succeeded in solving mentioned tasks as well as inatmosphericturbulencedetection [1-3]. The operation of Doppler and Polarimetric radars is connected with enhancement of obtained data that, in turn, requires the development of themodelsthatrelatereflectedradarsignalwithraindrops, snow, hail, icepellets, graupel, snowgrainsandothertypesofprecipitationandcloudconstituents. The model should be common enough to consider the real situation of the mixedmicrostructure of clouds and precipitationof many types. In this paper, the progress in model development is focused on combinationsofwater-air-icemixtureadditionallytotheraindrops.

Problem statement and solution

The mixture of ice-air or water-ice-air hydrometeors and their representation as the composite particles which consist of a surrounding media with given dielectric permittivity andsomeinternal inclusions withother permittivity were given in [4-6]. The Maxwell Garnet mixing theory was used to represent the effective dielectric permittivity of the composite particle. The two stages of sequential two-mixture calculations were used to achieve the effective permittivity of three-mixture particles. The model modification to the wet snow case using the direct one-stage account of air and ice inclusions in the water media was done in [7]. The drawback of the Maxwell Garnet mixing approach such as the non-symmetry according to the media and inclusions [8, 9], does not allow to realize the generalized tunable model for different types of cloud and precipitation constituents with an arbitrary water-ice-air mixture.

Bruggeman’s solution [8] is another approach that describes the multicomponent particle.Bruggeman’s solution solves the described above problem by selecting some appropriate “virtual” surrounding mediathat is true under the assumption that the combined fractional volume is unity.

We propose to modify Bruggeman’s mixing equationby introducing parameters of wetness $\xi : [0..1]$ and iceness $\zeta : [0..1]$. This should simplify the hydrometeor representation for modeling.

$$\sum_{i=1}^{3} f_i \frac{\varepsilon_i - \varepsilon_{eff}}{\varepsilon_i + 2\varepsilon_{eff}} = 0 \text{ ,assuming} \sum_{i=1}^{3} f_i = 1, \tag{1}$$

where ε_{eff} is the effective dielectric permittivity of the three-mixture particle; ε_i is corresponding relative permittivity of water ε_w, ice ε_{ice}, or air ε_{air}; f_i is the corresponding fractional volume of water f_w, ice f_{ice}, or air f_{air}.

The fractional volumes f_i can be represented using the wetness and iceness parameters bythe following way:

$$f_w = \xi, \tag{2}$$

$$f_{ice} = (1-\xi)\zeta, \tag{3}$$

$$f_{air} = (1-\xi)(1-\zeta). \tag{4}$$

After selecting the ξ and ζ, the effective permittivity of multicomponent particle can be calculated using the (1) and its radar cross section can be also determined.

In this approach, the wetness represents the melting stage of hydrometeor and varies from the zero value that corresponds to the completely dry stage, to the unitythat corresponds to the water drop.

The icenessreflects an ice fractionof the dry, ice-air,subvolume of a whole composite particle. Therefore, it gives one the simple way to select the mass density of the dry mixture. For example, hail can be represented by almostunity iceness, while snowflake contains a quite small fractional volume of ice.

The simulation of the dependence of iceness parameter on the corresponding spherical water drop size is shown in Fig. 1.

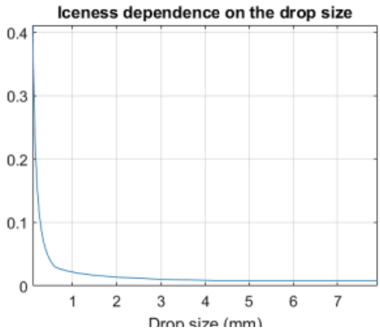

Fig. 1. Dependence of the iceness ζ on the water drop size.

It is possible to see the decreasing of the ice fractional volume with the drop size increasing. This corresponds to the appropriate mass density decreasing of biggest snowflakes.

The dependence represented in Fig.2 and Fig. 3 shows the result of Reflectivity dependence on wetnessand Differential Reflectivity dependence on wetnessthat weremodeled for the different melting conditions. In radar meteorology, the Differential Reflectivity is defined as

$$Z_{DR}= 10 \log (Z_{hh}/Z_{vv})=10 \log (P_{hh}/P_{vv})= 10 \log (\sigma_{hh}/\sigma_{vv})$$

where Zmeans radar reflectivity factor, P is average receivedpower, $\sigma$is RCS; the indexes h and v corresponds to the horizontal and vertical polarizations.

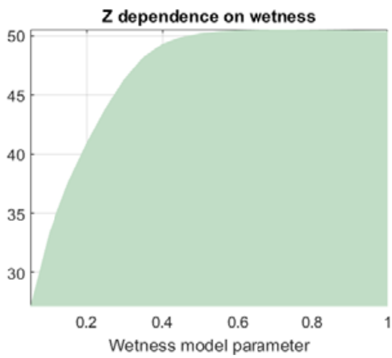

Fig. 2. Reflectivity dependence on wetness.

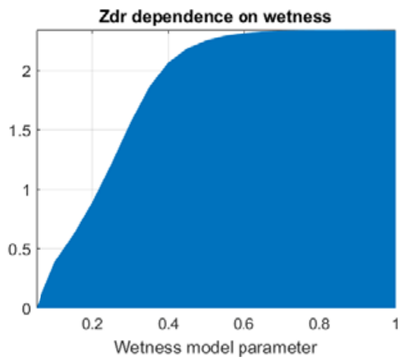

Fig. 3. Differential Reflectivity dependence on wetness.

Conclusions

New wetness and iceness parameters were proposedto use incomposite particlesmodel of the doppler-polarimetricmeteorological radar signal. This allows to simulate the mixed microstructure of clouds and precipitation with the possibility to tune the melting stage and set the mass density of dry subvolume. In this paper, the snow case enhancement of rain model was considered. Other mixed water-ice-air precipitation types can be easily added the same way.

The developed model can be used for modeling Doppler-polarimetric spectra of the radar signal reflected from different types of meteorological objects for improving meteorological data interpretation and analysis of Doppler and polarimetric meteorological radars.

References

1. Hongping Liuand V. Chandrasekar, "Classification of Hydrometeors Basedon Polarimetric Radar Measurements: Development of Fuzzy Logicand Neuro-Fuzzy Systems, and In Situ Verification," *Journal of Atmospheric & Oceanic Technology*, vol. 17, no. 2, pp. 140-164, February 2000.
2. F. J. Yanovsky, "Inferring microstructure and turbulence properties in rain through observations and simulations of signal spectr a measured with Doppler–polarimetric radars," In: Polarimetric Detection, Characterization, and Remote Sensing, M.I. Mishchenkoetal. (eds.), *NATO Science for Peace and Security Series C: Environmental Security*, Springer Science + Business Media B.V. 2011, pp. 501-542.
3. F.J. Yanovsky, C.M.H. Unal, H.W.J. Russchenberg, and L.P. Ligthart, "Doppler-polarimetric weatherradar: Returns from wide spread precipitation," *Telecommunications and Radio Engineering (English translation of Elektrosvyaz and Radiotekhnika),*Volume 66, Issue 8, pp. 715-727, 2007.
4. D.A. deWolf, H.W.J. Russchenberg, L.P. Ligthart, "Effective permittivity of ands cattering from wet snow and ice droplet sat weather radar wavelengths," IEEE Transactions on Antennas and Propagation, vol. 38, no. 9, pp. 1317-1325, September 1990.
5. H.W.J. Russchenberg, L.P. Ligthart, "Back scattering by and Propagation Through the Melting Layer of Precipitation: A New Polarimetric Model," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 34, no. 1, pp. 3-14, January 1996.
6. R. Meneghini, L. Liao, "Effective Dielectric Constants of Mixed-Phase Hydrometeors," *Journal of Atmospheric & Oceanic Technology*, vol. 17, no. 5, pp. 628-640, May 2000.
7. A.N. Rudiakova, F.J. Yanovsky, "The Doppler-polarimetric meteorological radar signal spectr a model enhancement for the snow case," *IEEE International Conference on Microwaves, Antennas, Communications and Electronic Systems (COMCAS 2017)*, November 2017, DOI: 10.1109/COMCAS.2017.8244827.
8. V. Markel, "Introduction to the Maxwell Garnett approximation: tutorial," *Journal of the Optical Society of America*, vol. 33, no. 7, pp. 1244-1256, 2016.
9. A. Sihvola, *Electromagnetic Mixing Formulas and Applications*, London, UK: The Institution of Engineeringand Technology, 1999.