Causes and systematics of inundations of the Krasnodar territory on the Russian Black Sea coast

Response to the Comments of Reviewer 2

The authors greatly appreciate constructive comments of Anonymous Reviewer #2 that helped us to better focus and improve the paper.

Regarding specific comment 1 " Distinct items of contents are not well presented, i.e. " 2 Objectives of research" where the authors only did the description of the area".
We are very sorry for the translation and technical mistakes. This part initially was named "Objects of research", now we changed it into "Study area". Objectives of research are described in the abstract and the introduction parts and focus on the analysis of inundation situations on the Black Sea coast of the Krasnodar territory for the period from 1945 until 2013, definition of the main types, the analysis of synoptic factors of the formation of extreme rainfalls and rainfall floods, the analysis of the efficiency of the measures applied at the coast to mitigate inundations and their after-effects.

Regarding specific comment 2 "The organization of all content in the classic way" 1._ Introduction 2._ Material and Method 3._ Results and discussions 4._ Conclusions " will be better."
First part of the paper is organized in a classic way 1. Introduction, 2. Study area, 3. Hydrological data and methods of research. We provided separately section 4 to describe our classifications of inundations. Further results and discussions are then grouped into several sections: 5. Synoptic conditions of the formation of high floods, 6. Features and regularities of flood routing, 7. Temporal regularities of inundations 8. Geographical features and hazards of inundations 9. Countermeasures for inundations and their efficiency. 10. Conclusions.

Such division intentionally can better help to pick out different aspects concerning causes and systematics of inundations of the Krasnodar territory on the Russian Black Sea coast.

All technical corrections and suggestions regarding language improvement are incorporated into revised paper (see supplement file, the changes marked blue).
Main of them:
Abstract. We revised some paragraphs in the abstract according to reviewer#2 suggestions:

Page1. Old version: We analyse inundation situations on the Black Sea coast of the Krasnodar territory for the period from 1945 until 2013 and describe the main types of inundations at the coast.
New redaction: The inundation situations on the Black Sea coast of the Krasnodar territory for the period from 1945 until 2013 were analysed and the main types of inundations at the coast are described.

Page1. Old version: Assessments of seasonal and maximum flow of the Black Sea Coast Rivers for the period of hydrometric measurements describe regularities of change of the occurrence of inundations and their characteristics on the coastal terrain, within a year and on perennial time scale.
New redaction: Therefore, assessments of seasonal and maximum flow of the Black Sea Coast Rivers for the period for which hydrometric measurements describe regularities of change of the occurrence of inundations and their characteristics on the coastal terrain, within a year and on perennial time scale were done.

Page2. Old version: The seasonal distribution of small and moderately dangerous inundations reflects, on average, a water regime of two groups of rivers of the coast – to the north of the Tuapse River, and to the south. To the north of the Tuapse River, floods prevail from November until March (to 70 %).

They result from precipitation and winter snowmelt during frequent thaw periods. High waters in the cold season of the year often overlap with each other, forming a multipeak high water with 2–3 weeks in duration. In the summer and in early autumn a steady low flow is observed.

New redaction: The seasonal distribution of small and moderately dangerous inundations reflects, on average, a water regime of two groups of rivers of the coast – to the north and to the south of the Tuapse River. To the north of the Tuapse River, floods prevail from November until March (to 70 %) as a result of precipitation and winter snowmelt during frequent thaw periods. In winter, high waters often overlap to form a multi-peak high water of 2–3 weeks duration. In the summer and in early autumn we observe a steady low flow.

Page2. Old version: The annual flow cycle is mainly determined by strong winter and spring, and weak summer flows: Despite a characteristic distribution of floods and of water flow within a year, almost 71 % of all catastrophic and exceptional inundations took place in July - August (71 %) and in October - November (29 %). The characteristic features of dangerous floods are their rapid formation and propagation, a significant increase of water level (up to 5–7 m and more) and the multiple increase of water discharges.
An appreciable increase of the number of inundations in the period from the early 1970s until the early years of the 21th century was noted.
New redaction: The annual flow cycle is mainly determined by two seasons, winter/spring and summer, with strong and weak flows, respectively: almost 71 % of all catastrophic and exceptional inundations took place in July - August (71 %) and in October - November (29 %). The characteristic features of dangerous floods are their rapid formation and propagation, a significant increase of water level (up to 5–7 m and more) and the multiple increase of water discharges in comparison with low flow period. Analysis of the interannual changes of the number of inundations at the Black Sea coast of Krasnodar territory has shown some increase of the number of inundations in the period from the early 1970s until the early years of the 21th century.

Page3. Old version: Further, we provide an analysis of the efficiency of the measures applied at the coast to mitigate inundations and their after-effects.
New redaction: Further, an analysis of the efficiency of the measures applied at the coast to mitigate inundations and their after-effects are provided.

1) **Introduction.** We revised some paragraphs in the introduction according to reviewer#2 suggestions:

Page3. Old version: According to numerous data on the floods in the river mouths and in the coastal zones of European part of Russia (from the 18-20th century until 2013), collected by N. I. Alekseevsky et al. (2013), materials of A.A.Taratunin (2000) and other sources, the Black Sea coast of the Krasnodar territory is the most prone to this kind in Russia. In this rather small area, there were five catastrophic inundations during the last 10–20 years, which resulted in huge material damages and considerable human loss. Further nine high and a number of smaller inundations took place.
New redaction: According to numerous data on the inundations in the river mouths and in the coastal zones of the European part of Russia (from the 18-20th century until 2013), collected by the authors of this paper (Alexeevsky et al., 2013), materials of A.A.Taratunin (2000) and other sources, the Black Sea coast of the Krasnodar territory is the most effected coastal region in Russia. In this rather small area, there were five catastrophic inundations during the last 10–20 years, which resulted in huge material damages and considerable human loss. Further, nine large and a number of smaller inundations took place.

Page3. Old version: In general, there is a certain increase in the number and intensification of the magnitude of inundations. Which factors contribute to this impression? Is it the reaction to global and regional climate changes, the intensification of instabilities of the climate system, or the effectiveness of the existing system of forecasting inundations and flood prevention and the threat the floods pose to the settlements at the coast? What could be the operative prevention measures to minimise the potential damage, and which potential means are available to strengthen this system?

In general, there is a certain increase in the number and the magnitude of inundations. If it is so, which factors cause this trend? Is it the reaction to global and regional climate changes, the intensification of instabilities of the climate system? What is the effectiveness of the present-day system of inundation forecasts, prevention and of timely warning people about floods danger? Which potential means are available to strengthen this system?

Page4. Old version: a complex survey of inundations at the Black Sea coast of the Russian Federation practically is presently not available.
a complex survey of the inundation situation at the Black Sea coast of the Russian Federation practically has not been done until the present day.

Page4. Old version: Important elements of a scientific analysis are found in some works (Atlas, 2007; Barinov, 2009; Beljakova et al., 2013; Volosuhin, Tkachenko, 2013; Kononova, 2012; Magritsky et al., 2013; Dangerous hydrometeorological phenomena on the Caucasus, 1983; Panov et al., 2012; Sergin et al., 2001; Tkachenko, 2012), and in papers of the Kuban State Agriculture University. The second reason is the lack of high-quality data on inundations observed in the past, especially in the 20th century: the basic characteristics of inundations (areas submerged, their spatial extent, the intensity of their development and duration, of flooding height levels, water levels and discharges), and information on the magnitude and the structure of the estimated damage. The third reason is the continuing sparseness of necessary details and reliable long series of observational data.
New redaction: Important elements of a scientific analysis are found in some works (Barinov, 2009; Belyakova et al., 2013; Kononova, 2012; Magritsky et al., 2013; Panov et al., 2012; Sergin et al., 2001; Svanidze et al. 1983; Tkachenko, 2012; Volosuhin, Tkachenko, 2013), in the "Atlas of connatural and technogenic dangers and risks of emergencies of the Southern Federal district" (2007) and in papers of the Kuban State Agriculture University. Secondly, there is a lack of high-quality data on inundations observed in the past, especially in the 20th century: the basic characteristics of inundations (areas submerged, their spatial extent, the intensity of their development and duration, depths of flooding, water levels and discharges), information on the amount and the structure of the estimated damage. Thirdly, it is the lack of necessary details and reliable long series of observational data.

Page4. Old version: Probably the lack of necessary data, of detailed research, of a better understanding of factors and fundamental physics of the flood phenomenon, and knowledge of their key parameters is one of the reasons for the insufficient efficacy of measures applied at the coast to cope with inundations and their effects.
New redaction: Probably the lack of necessary data for detailed research and better understanding of factors and fundamental physics of the flood phenomenon and knowledge of key parameters is one of the reasons of the inefficiency of measures applied at the coast to cope with inundations and their effects.

2) We changes name of part 2 from "Objectives of research" into **Study area**, it was the translation and technical mistake

Page7. Old version: In total, 10 – 13 floods per year happen on average. The annual flow cycle is mainly determined by strong winter and spring, and weak summer flows:

New redaction: In total, 10 – 13 flood waves per year happen on average. The annual flood cycle mainly determines the inter-seasonal distribution of water flow

3) **Hydrological data and methods of research.** We revised some paragraphs in this part according to reviewer#2 suggestions:

Page8. Old version: The data are presented as averages (diurnal, 10-day diurnal, monthly and annual averages) water levels and water discharges, and by instantaneous maximum and minimum water discharges and levels. Secondly, numerous documentary data on inundations are collected. These data and information are part of the database.

New redaction: Firstly, the data are presented as average (diurnal, 10-day diurnal, monthly and annual) water levels and water discharges, Also data about momentary maximum, minimum water discharges and water levels are included in this database. Secondly, numerous documentary data on inundations are collected. These data are part of information from the electronic database

Page8. Old version: Thirdly, we used critical marks of the height and rise of water levels which, when exceeded, lead to flooding of flood plains. They are classified as unfavourable (UP) and dangerous (DP) for the population and economic activities. They are particular to each separate reach of a channel.

New redaction: Thirdly, we used critical marks of the height of water levels which, when exceeded, lead to flooding of floodplains ($H_{floodplain}$), to unfavourable (H_{UP}) and dangerous (H_{DP}) effects for the population and economic activities. They have unique values at each separate reach of a river channels.

Page8. Old version: along with regional criteria of dangerous precipitation. According to these criteria, rainfalls in the Tuapse and Sochi districts with an intensity of not less than 50 mm during no more than 1 hour (http://www.yugmeteo.donpac.ru/oj.jsp) are considered as heavy.

New redaction: and used regional criteria of the level of intensity and potential danger of precipitation. According to these criteria (http://www.yugmeteo.donpac.ru/oj.jsp), rainfalls in the Tuapse and Sochi districts with an intensity of not less than 50 mm (during no more than 1 hour) are considered as heavy.

Page8. Old version: The comparison of the documented events confirmed inundations to maximum water levels ($H_{\max}$) and peak discharges ($Q_{\max}$) at the gauges, with critical high-rise marks – $H_{floodplain}$, H_{UP}, H_{DP}, together with daily totals of precipitation at meteorological stations; critical values (or ranges of values) for these hydro-meteorological characteristics have been defined.

New redaction: We compared the documented events of inundations to maximum water levels ($H_{\max}$) and peak discharges ($Q_{\max}$) at the gauges with critical high-rise marks – $H_{floodplain}$, H_{UP}, H_{DP}, together with daily totals of precipitation at meteorological stations.

4) **Inundations and their types.** We revised some paragraphs in this part according to reviewer#2 suggestions:

Page10. Old version: Taking the formation processes and following the new classification, stated by Alekseevsky and Magritsky (2013), at the coast, there are some generic types of inundations, of natural origin.

New redaction: Taking the formation processes and following the new classification, stated by Alexeevsky and Magritsky (2013), at the coast there are some types of inundations.

Page10. Old version: The third type are the inundations due to storm surges and wind-wave surges, or inundations again of mixed type (№2) – a flood in a river coincides with a storm surge at the coast, i.e. in conditions of a back-water effect from a sea. These inundations are possible in river mouths at the coast. They are part of a group of coastal inundations.

New redaction: The next type of inundations are the inundations due to storm surges and wind-wave collapse. If flood in a river coincides with a storm surge at the coast, i.e. in conditions of a back-water effect from a sea, inundations of mixed type №2 occur. These inundations are possible in river mouths at the coast. They are part of a group of coastal inundations.

Page11. Old version: This classification is based on various qualitative and quantitative criteria ranging from frequency, value of excess of $H_{\max}$ over critical high-rise marks, the area of the terrain and number of the settlements (or basins) covered by the influence of inundations and their causes, or the amount of a direct material damage (as a rule at an approximate assessment) and threat for life.

New redaction: This classification is based on various qualitative and quantitative criteria. The most important are the frequency of floods, the value of the $H_{\max}$ excess over critical high-rise marks, the area of terrain and the number of the settlements (or basins) covered by the influence of inundations, the amount of a direct material damage (as a rule at an approximate assessment) and the threat for life.

5) **Synoptic conditions of the formation of high floods.** We revised some paragraphs in this part according to reviewer#2 suggestions and added additional explanations:

Page14. Old version: The horizontal scale of the polar low is approximately between 100 and 1000 km, that is, according to the Orlansky classification, a polar low is a phenomena of subsynoptic scale (the horizontal scale synoptic processes of more than 1000 km, and the same mesoscale processes of less than 100 km) (Markowsky and Richardson, 2002).
New redaction: The horizontal scale of the polar low is approximately between 100 and 1000 km. At least a dozen different length scale limits for the mesoscale have been defined since Ligda's article. According to this paper (Ligda, 1951), the first radar-detected precipitation area was a thunderstorm observed using a 10-cm radar in England on 20 February 1941. Organized atmospheric science research using radars was delayed until after World War II due to the importance of the relatively new technology to military interests and the secrecy surrounding radar development. The most popular definitions are those proposed by Orlanski (Orlanski, 1975) and Fujita (Fujita ,1981). Orlanski defined the mesoscale as ranging from 2 to 2000 km, with sub-classifications of meso-α, meso-β, and meso-γ scales referring to horizontal scales of 200–2000 km, 20 –200 km, and 2–20 km, respectively. Fujita (1981) proposed a much narrower range of length scales in his definition of the mesoscale, where the mesoscale ranged from 4 to 400 km, with sub-classifications of meso-α and meso-β scales referring to horizontal scales of 40 – 400 km and 4 – 40 km, respectively. According to these two classifications a polar low is a phenomena of subsynoptic scale (the horizontal scale synoptic processes of more than 1000 km, and the same mesoscale processes of less than 100 km) (Markowsky and Richardson, 2002).
Page15. Old version: A part of this precipitation has probably been seawater. On the western coast of the bay, there was no rain during this day.
New redaction: Most of the precipitations may be associated with the destruction of the tornado over the coast. Perhaps, it didn't even rain: sea water (drawn into the twister), flowed downs as a result of the destruction of the tornado. On the western coast of the bay, there was no rain during this day. This fact confirms a local phenomenon (which is characteristic of a tornado).
6 **Features and regularities of flood routing.** We revised some paragraphs in this part according to reviewer#2 suggestions:

Page15. Old version: On small rivers, a flood can therefore be observed almost simultaneously with powerful and destructive high floods. Waves of floods in the mountains and in foothills move with great speed.
New redaction: On small rivers, a flood can be observed almost momentary along the entire length of the channel. On the large rivers, such hydrological situation leads to the formation of especially high and destructive floods.
Flood waves in the mountains and foothills move with great speed.

Page18. Old version: Quite often floods transform in mudflows possessing greater destructive ability, and result in other hydro-morphological, economic and ecological adverse results. The main part of deposits accumulates first on the flood plain before arriving at the lower reaches and at the mouths of the Black Sea coastal rivers.
New redaction: Quite often floods transform in mudflows possessing even greater destructive ability, which lead to greater hydro-morphological changes, economic losses and ecological negative effects. The main part of deposits accumulates, firstly, on the flood plain in the lower reaches and at the mouths of the Black Sea coastal rivers.
7. **Temporal regularities of inundations.** We revised some paragraphs and added additional explanations in this part according to reviewer#2 suggestions:

Page20. Old version: On longer time scales, we can observe a nonlinear and statistically insignificant trend of the increase of the number of inundations and, hence, of the expected damage as given in (Fig.

8a). It mainly is caused by a noticeable increase of the number of inundations in the period from the beginning of 1970s until the first years of 21th century. This positive trend can be challenged, but the objective reasons for it, nevertheless, exist. First,

New redaction: At longer time scales, we can observe a nonlinear and statistically insignificant trend of the increase of the number of inundations and, hence, of the expected damage (Fig. 8a). It is caused by a noticeable increase of the number of inundations in the period from the beginning of 1970s until the first years of 21th century mainly. This positive trend can be challenged, but the objective reasons for it, nevertheless, exist. Firstly,

Page21. Old version: Evidence are the accumulation of the large volume of water in fish-breeding ponds and the headwater upstream of the bridge, the subsequent outbreak, the destruction of trees in the river basin; damage was caused to unlicensed residential buildings in a region of potential flooding and the untimely information of the population. Other anthropogenic factors had an influence, too.

New redaction: They are: 1. the accumulation of the large volume of water in fish-breeding ponds and the headwater upstream of the bridge, and its subsequent outbreak, 2. the destruction of trees in the river basin; 3. the location of residential buildings in an area of potential flooding, 4. the untimely information of the population.

Page22. Old version: Nevertheless, a number of scientists at present consider (Matveeva et al., 2013) that this tendency will continue. The data of the climate model ECHAM5/MPI-OM (scenario A2) highlight that during the summer season of 2046-2065 an intensive frontal region (one of the synoptic predictors of abundant precipitation) will be twice more often than in 1981-2000, and 3 times than in 1961-1980. For the winter season, we find a reverse relationship.

New redaction: Recent work supports the tendency we observe for the future (Matveeva et al., 2013). The data of the climate model ECHAM5/MPI-OM (scenario A2) have allowed to highlight that during the summer season of 2046-2065 an intensive frontal zone (one of the synoptic predictors of abundant precipitation) will be twice more often than in 1981-2000, and 3 times than in 1961-1980. For the winter season a reverse relationship is observed: in the conditions of the climate warming quantity of cases with intensive frontal zone will be less in 1.75 times and 1.4 times in comparison with 1981-2000 and 1961-1980 periods accordingly (Matveeva et al., 2013)

8. Geographical features and hazard of inundations. We revised some paragraphs and added additional explanations in this part according to reviewer#2 suggestions:

Page23. Old version: In addition, numerous artificial water bodies are potentially dangerous according to (Panov et al., 2012).In the Anapa area they very numerous, nearly 39 in number and with the total area of 3.5 km^2.

New redaction: In addition, numerous artificial water reservoirs (ponds) are potentially dangerous from the point of view of their possible outbreak. In the Anapa district such reservoirs are very numerous: nearly 39 in number and with the total area of 3.5 km^2 (Panov et al., 2012). The ponds are formed by dams on the rivers; these constructions usually are old and not robust. During the high flood the dam outbreak can increase the magnitude of event dramatically. For example, according our data such catastrophic flood took place on the river Durso in the summer of 2002.

Page23. Old version: During catastrophic inundations, the respective damage is high without depending necessarily on the dimensions of the terrain and the number of watersheds subjected to storm precipitation and rising water level in the rivers. The damage from the exceptional inundations in August 1991 was estimated at approximately 400 billion rbl. (or 680 mln. dollars, according to the official data of the Central Bank of the Russian Federation at exchange rates for different years), with 363 billion rbl. (615 million dollars) on the coast. The number of casualties reached about 40 people (including 11 people missing). The catastrophic inundation in August 2002 led to a damage of roughly 1.7 billion rbl. (54 million dollars) and casualties of ~60 (including missing people); in October 2010 there were damages of 2.5 billion rbl. (80 million dollars) and 24 deaths; in August 2012 some 1 billion rbl. (32 million dollars) and four people lost their lives. The exceptional inundation in July 2012 is not included in this list, as the main impact and the damage was in the Krasnodar territory, not at the Black Sea coast. During large inundations, human casualties also are possible; the size of direct material damage varies from several hundred thousand to several millions dollars, but, according to the available scarce data, has not exceeded 4 - 5 million dollars for the Black Sea coast rivers.

New redaction: During catastrophic inundations, the respective damage is huge without depending on the dimensions of the terrain and the number of watersheds subjected to storm precipitation and rising water level in the rivers. According to data of the electronic database «Inundations in the river mouths of the European part of Russia» (Alexeevsky et al., 2013) the damage from exceptional inundations in August, 1991 was estimated at approximately 400 million rbl. (or 680 mln. dollars, according to the official exchange rates of the Central Bank of the Russian Federation for different years), from which 363 million rbl. (615 million dollars) were attributed to the terrain of the coast. The number of casualties reached about 40 people, including 11 people missing. Inundations in August 2002 led to a damage roughly of 1.7 billion rbl. (54 million dollars) and casualties ~60 (including missing people); in October, 2010 – in 2.5 billion rbl. (80 million dollars) and 24 people dead; in August, 2012 – 1 billion rbl. (32 million dollars) and 4 people lost their lives. The exceptional inundation in July 2012 is not included in this list, as the main impact of the natural disaster and the damage was in the Krasnodar territory outside the Black Sea coast. During the big inundations, human casualties also are possible; the size of direct material damage varies from several hundred thousand to several millions dollars, but, according to the available scarce data, has not exceeded for the Black Sea coast rivers of 4-5 million dollars.

9 **Countermeasures for inundations and their efficiency** We revised some paragraphs in this part according to reviewer#2 suggestions:

Page26. Old version: Therefore, one important direction for safe and sustainable development of this area is and remains the implementation of various actions for a reduction of this hazard.

New redaction: Therefore, one important direction for safe and sustainable development of this area remains in the implementation of various actions for a reduction of this hazard.
Page27. Old version: Secondly, a clear understanding of the reasons, features and systematics of the origin and development of inundations and their adverse hydrologic-ecological, morphological, social, and economic consequences is necessary.
New redaction: For the next steps a clear understanding of the reasons, features and systematics of the origin and development of inundations and their adverse hydrologic-ecological, morphological, social, and economic consequences is necessary.

Page27. Old version: Thirdly, restrictions (by various means – from administrative measures to flexible flood insurance) are necessary for the processes of developing the territory to reduce its potential flooding hazard.
New redaction: Different restrictions (by various means – from administrative measures to flexible flood insurance) are necessary for the process of developing the territory in order to reduce its potential flooding hazard.

10. Conclusions

Page29. Old version: Extreme floods form rapidly and transit fast downhill.
New redaction: Extreme floods are formed and move down along the valley rapidly.

Also we checked bibliography and numeration in the picture 3.