Confidence and Communication Preferences on Weather Forecasts among University Students in Spain

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ABSTRACT: Weather forecasts affect many persons' lives and are used by the general public on a daily basis. However, they are not perfect, and there is an uncertainty associated with the current weather forecasts; users should be aware of this uncertainty. Previous research analyzes the perceptions, uses, and interpretations of uncertainty of Spanish undergraduate students. This study continues with this research line, but we investigate the degree of confidence and communication preferences of students enrolled in three meteorology-related subjects taught at two universities in Spain. We evaluated to what extent students trust in the current weather forecasts and analyzed how students are aware of the uncertainty associated with the forecasts considering different lead times. In addition, we assessed how students value the forecast of several weather elements as well as the students' preferences for deterministic versus nondeterministic forecasts under two weather situations, with different degree of complexity in the forecast communication. A Google Form questionnaire was developed to address these issues. The survey was conducted in 2018/19, and 101 participants anonymously filled out the survey. Participants were enrolled in three different subjects taught in the degree in marine sciences at the University of Alicante and the degrees in environmental sciences and physics at the University of Valencia. Results show that students have a well-formed opinion of weather forecasts, both for confidence and in relation to the trend found in the current weather forecasts toward less accurate forecasts for larger lead times. For students' preferences for deterministic versus nondeterministic forecasts, a significant majority of participants prefer weather forecasts that incorporate some uncertainty; a minority prefer single-valued (deterministic) forecasts. In comparing our results with those found in previous studies in different countries and contexts, similar outcomes are observed in general, but some differences are highlighted as well.

KEYWORDS: Atmosphere; Social Science; Europe; Forecasting; Numerical weather prediction/forecasting; Operational forecasting; Communications/decision-making; Education

1. Introduction

Earth's atmosphere is a dynamic system with a limited predictability. For this reason, weather forecasts have some uncertainty (Morss et al. 2008; Sivle et al. 2014). These forecasts are based on numerical models that allow for predicting the atmosphere's evolution on a given time period. The development of this kind of model has continuously improved forecasts over time, and this could give the impression that in the future it will be possible to reach perfect forecasts (O'Hanrahan and Sweeney 2013). However, although the physical background of these models, the set of equations, and the initial conditions to solve them are each time more detailed and better known, they have an intrinsic uncertainty that cannot be removed (Doyle et al. 2019).

Previous studies have included weather forecasts in classroom contexts with the aim of improving the meteorological educational process (Morss and Zhang 2008). This has provided students with firsthand experiences that aim to clearly visualize the theoretical concepts addressed in the lectures (Bond and Mass 2009; Schultz et al. 2013, 2015). Considering the easy access to weather forecasts, and the increasing interest among the general audience, they can be used by students for a better understanding of different atmospheric processes (Suess et al. 2013; Gómez Doménech et al. 2016). In this sense, Schultz et al. (2015) have pointed out how the weather forecasts used in the classroom stimulate critical thinking, involving the application, analysis, synthesis, and evaluation levels of Bloom's taxonomy. Bloom's taxonomy (Bloom 1956) is a way to organize levels of students' expertise and uses a multitiered scale to express the level of expertise required to achieve different measurable students' outcomes. These cited levels belong to the highest levels of expertise in Bloom's Taxonomy of Educational Objectives for Knowledge-Based Goals (Armstrong 2010). In the particular case of the University of Alicante, Spain, the weather forecasts have been used in the lectures on "introduction to meteorology" in the marine sciences curriculum. They have proven to be a valuable tool for visualizing and interpreting the concepts previously studied from a theoretical viewpoint (Gómez Doménech et al. 2016; Gómez Doménech and Molina Palacios 2018).

However, in some cases, the use of numerical models to address complex concepts of meteorology have revealed certain difficulties of students in order to correctly interpret the uncertainties of the forecasts (Gómez Doménech and Molina Palacios 2018). Scientists use models to represent different aspects of the world and interpret the models' outcomes (Giere 2004). For that reason, when using atmospheric

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models and the weather forecasts obtained from them, it must be made clear that such models are not perfect and that some degree of uncertainty is expected. In fact, forecasts that provide some uncertainty estimations are more in line with the current scientific understanding of future weather conditions (Joslyn and Savelli 2010). The expression of uncertainty metrics is a standard practice within the scientific community that produces measurements of a physical quantity. Uncertainty is used in this regard to assess the reliability of a measure and compare it with other measurements (Kuonen et al. 2019). In addition, forecasts with uncertainty estimates are also potentially useful to everyday decision-making processes (Bostrom et al. 2016; Taylor et al. 2019; Su et al. 2021). Uncertainty arises even within groups of people, and the way they talk to each other is critical to know whether personal or individual ideas are heard and taken up by the group. In this sense, from a linguistic point of view, people modalize assertions when communicating information, including certainty or probability of a statement into an otherwise emphatic statement of fact. This is done, for instance, by using statements like "I think the answer might be X." The equivalent emphatic or unhedged statement would be "I think the answer is X" (Brookes et al. 2021).

There is a large body of research focused on the perception and use of uncertainty in weather and decision-making as well as on the effective communication of uncertainty and probability information (see, e.g., Sherman-Morris 2005; Morss et al. 2008; Lazo et al. 2009; Joslyn and Savelli 2010; Morss et al. 2010; Ramos et al. 2010; Demuth et al. 2011; Parker et al. 2011; Joslyn and LeClerc 2012; O'Hanrahan and Sweeney 2013; Savelli and Joslyn 2013; Abraham et al. 2015; Kox et al. 2015; LeClerc and Joslyn 2015; Marimo et al. 2015; Zabini et al. 2015; Bostrom et al. 2016; Morss et al. 2016; Grounds et al. 2017; Kox and Thieken 2017; Grounds and Joslyn 2018; Keul et al. 2018; Losee and Joslyn 2018; Doyle et al. 2019; Fundel et al. 2019; Kuonen et al. 2019; Taylor et al. 2019; Fleischhut et al. 2020; Gómez et al. 2021; Joslyn and Savelli 2021). These studies generally agree that members of the public have well-founded intuitions about uncertainty on a practical level. For instance, people understand that forecasts are not perfect and that some degree of uncertainty is expected. Moreover, members of the public understand that forecast accuracy decreases as lead time of the prediction increases, even when uncertainty does not appear explicitly in the corresponding forecast. In this regard, people given uncertainty forecasts are able to understand and use probability information, taking better precautionary weather-related decisions and having more forecast trust than those who received a deterministic forecast. Therefore, nonexpert end users could benefit from reliable uncertainty estimates (Joslyn and Savelli 2021). In their comprehensive literature review, Doyle et al. (2019) highlighted that the issue of communicating uncertainty, scientific uncertainty, and model uncertainty has grown rapidly in the last decades. This study showed that scientists must first understand decision-maker needs regarding the communication of the decision-relevant uncertainties. Following this argument, Fundel et al. (2019) encouraged scientists, developers, and end-users to engage in interdisciplinary collaborations to make a better use of the available forecasts in daily life and apply them in decision-making processes. In fact, they emphasized the need of promoting the use of probabilistic weather forecasts to make informed decisions. This statement of including uncertainty information in forecast communication has also been highlighted in related research (Roulston et al. 2006; Joslyn and Savelli 2010; Hirschberg et al. 2011; Joslyn and LeClerc 2012; Ramos et al. 2013; Joslyn and Grounds 2015; Grounds et al. 2017; Kox and Thieken 2017; Taylor et al. 2019; Fleischhut et al. 2020; Joslyn and Savelli 2021; Rosen et al. 2021). Taking into account that more weather forecasts' uncertainty information is becoming available to the general public, learning how uncertainty information is processed and interpreted by people in different and specific backgrounds is crucial (Kox et al. 2015; Keul et al. 2018). Taylor et al. (2019) also emphasized the importance of conducting country-specific research in this sense. In the context of the current work, we present Spanish students' preexisting concepts related to the forecast uncertainty and their knowledge and processing of weather forecasts, with the intention of contributing to the existing literature in a region where no previous related research on these topics has yet been performed. In this respect, we must highlight that understanding uncertainty is essential to hold an informed view of the nature of science in general (Rosen et al. 2021; Woitkowski et al. 2021), and on the nature of atmospheric models and weather forecasts in particular.

Considering all of these issues, the aim of this paper is to perform an exploratory analysis to assess to what extent students enrolled in subjects related to meteorology are aware of the uncertainty of weather forecasts, focused on different key weather elements and lead times. To achieve this main goal, the following specific objectives have been defined: 1) to evaluate students' trust on the accuracy of forecasts; 2) to analyze whether students are aware of the uncertainties of the forecasts, and on the fact that uncertainty increases as long as the time interval increases; 3) to find out how students value forecasts of different weather elements over different time ranges; and 4) to assess to what extent students want and consider important to report uncertainty information, as compared with presenting the same information as a single-value forecast, that is, to assess the students' preferences for a probabilistic forecast versus a deterministic one. This latter point has been applied to two different conditions: a simple given weather situation and a more complex scenario. To this end, a survey has been used including questions developed in previous studies to analyze these same issues on the general public (Morss et al. 2008; O'Hanrahan and Sweeney 2013; Abraham et al. 2015; Kox et al. 2015; Zabini et al. 2015). Therefore, the current study continues the research line started in the previous study conducted in Spain and focused on the perceptions, uses, and interpretations of uncertainty by undergraduate students (Gómez et al. 2021). In this preceding work, questions regarding the perception of uncertainty in deterministic forecasts, uses of forecasts in hypothetical decision-making scenarios, and interpretations of probability-of-precipitation (PoP) forecasts were addressed among students pursuing the degree in marine sciences or in geography and territory

TABLE 1. Number of participants in relation to the total number of students that were asked to respond to the survey in the current study by subject and academic year when each subject is taught in the corresponding university degree.

Subject and degree	Year	No. of students
Introduction to meteorology (degree in marine sciences—UA)	Fourth	17/17
Meteorology and climatology (degree in environmental sciences—UV)	Second	52/66
Atmospheric physics (degree in physics—UV)	Second	32/44

planning taught at the University of Alicante. The present study, in contrast, focuses the attention on the confidence and communication preferences in relation to weather forecasts reported by students enrolled in meteorology and atmospheric physics courses taught at the University of Alicante and the University of Valencia (Spain).

The paper is organized as follows. Section 2 presents the data and method used in the current study. Section 3 presents the results found. Section 4 includes the discussion of results and some final remarks.

2. Data and methods

A total of 101 individuals of the 127 enrolled in the degree in marine sciences [University of Alicante (UA)] and in the degrees in environmental sciences and physics [University of Valencia (UV)] have participated in the current work. The study design was based on the application of a nonexperimental quantitative method, and an exploratory and descriptive design, through a survey. There are, thus, three different groups, as shown in Table 1. The first group corresponds to the optional subject "introduction to meteorology," taught in the fourth year of the degree in marine sciences at the UA; the second group corresponds to the compulsory subject "meteorology and climatology," taken in the second year of the degree in environmental sciences at the UV; while the third group corresponds to the subject "atmospheric physics," taught in the second year of the degree in physics at the UV. Although all groups corresponded to university students enrolled in the sciences, a separate analysis has been performed for each group to test possible differences related to the different levels (second and fourth years with different maturity levels), to the different nature of each degree (more similar results could be expected between marine and environmental sciences than each of them and physics), and to the different subjects taken before the meteorology-related courses. For example, students of "atmospheric physics" (subject placed at the fourth semester of physics degree) have a more solid background for dealing with probability, statistical tests, and uncertainties, since they have previously taken two classes on experimental physics (laboratory practices) and one on statistical methods; in addition, these students are more familiar with the use of models. On the other side, students of "meteorology and climatology" (subject placed at the third semester of environmental sciences degree) and "introduction to meteorology" have only followed a single general subject on statistics. "Introduction to meteorology" in the marine sciences degree is taken in the fourth year when students are expected to show a higher degree of reasoning.

A questionnaire directly focused on the research goals of the current study was used to gather student's information. The questions used in this questionnaire were drawn from previously published studies (Morss et al. 2008; O'Hanrahan and Sweeney 2013; Abraham et al. 2015; Zabini et al. 2015). These questions were adapted to the particular context of the study using Celsius instead of Fahrenheit as temperature units. Additionally, they were translated into Spanish in the same terms expressed in the mentioned works in order to allow direct comparison between findings.

The first question of the survey (Q1), related to the first objective of the current study, measures the frequency with which students feel they receive an inaccurate weather forecast. In this case, a four-point Likert scale is used: "very often," "often," "sometimes," and "rarely," together with two additional points: "I don't know" and "other." The second question (Q2) refers to the second objective of the current study, and shows the confidence that students have in these forecasts for different lead times: "less than a day," "1 day," "2 days," "3 days," "5 days," and "7 to 15 days," from the publication of the corresponding forecast. A specific and independent question was included to gather all this information separately. Besides, a five-point Likert scale is used related to the degree of confidence in the corresponding forecast for each of these periods: "very low," "low," "medium," "high," and "very high." Students' confidence in the accuracy of current weather forecasts is also analyzed (Q3), but in this case not focusing on the general weather forecasts, but considering different individual weather elements: temperature, humidity, wind, probability of precipitation, amount of precipitation, cloud cover, and radiation. Q3 addresses the third objective of the current study. In this case, once again, a five-point Likert scale is used on the degree of confidence in the forecast for each of the weather elements: "very low," "low," "medium," "high," and "very high." However, and as a difference with the second question, three forecast lead time ranges have been used in this case: 1, 3, and 7 days, following the study by Morss et al. (2008). In order to collect all this information separately, a specific and independent question was included, as indicated in Table 2. Since one of our goals is to study to what extent students are aware of the uncertainty inherent to the weather forecasts, we explored students' stated preferences for deterministic forecasts versus those expressing uncertainty in a weather situation related to daytime high temperatures forecast (Q4). In this case, we asked students how they prefer to receive the weather information, as a measure of the true value (e.g., "a maximum temperature of 25°C is forecasted for tomorrow") or reporting some sort of uncertainty using simple uncertainty communication

TABLE 2. Survey questions (Q) and possible answers used this study.

	Question	Possible answers
Q1	How often do you feel you experience inaccurate weather forecasts?	Multiple choice: "very often," "often," "sometimes," "rarely," "I don't know," and "other"
Q2	How much confidence do you have in weather forecasts for the times listed below? Forecasts for weather . . . "less than a day," "1 day," "2 days," "3 days," "5 days," and "7 to 15 days"	Multiple choice: "very low," "low," "medium," "high," and "very high" for each of these lead times
Q3	How much confidence do you have in forecasts of the weather elements listed below for forecasts of weather 1 day (24 h) from now? Forecasts for . . . "temperature," "humidity," "wind," "probability of precipitation," "amount of precipitation," "cloud cover," and "radiation"; repeat for forecasts of weather 3 days (72 h) from now and for forecasts of weather 7 days (168 h) from now	Multiple choice: "very low," "low," "medium," "high," and "very high" for each of these weather elements
Q4	Suppose you are consulting the weather forecast through two communication channels (A and B); the forecast according to channel A indicates a maximum temperature for tomorrow of 25°C, whereas channel B indicates a maximum temperature between 24° and 26°C; which way would you prefer to be given the weather forecast?	Multiple choice: "I prefer the way channel A gives the forecast," "I prefer the way channel B gives the forecast," "I like the way both channels give the forecast," "I don't like the way either channel gives the forecast," and "I don't know"
Q5	The high temperature for tomorrow will probably be 30°C. However, a cold front may move through during the day, in which case the high temperature tomorrow would only be 20°C; based on this weather scenario, for the options listed below, would you like the forecast given in this way? Students were presented with seven examples of how the forecast could be worded: Forecast 1: "The high temperature tomorrow will be 30°C." Forecast 2: "The high temperature tomorrow will most likely be 30°C, but it may be 20°C." Forecast 3: "The high temperature tomorrow will most likely be 30°C, but it may be 20°C, because a cold front may move through during the day." Forecast 4: "The high temperature tomorrow will be between 20° and 30°C." Forecast 5: "The high temperature tomorrow will be between 20° and 30°C, because a cold front may move through during the day." Forecast 6: "There is an 80% chance that the high temperature tomorrow will be 30°C and a 20% chance that the high temperature tomorrow will be 20°C." Forecast 7: "There is an 80% chance that the high temperature tomorrow will be 30°C and a 20% chance that the high temperature tomorrow will be 20°C, because a cold front may move through during the day."	Students were asked whether they liked the forecast presented in this manner (yes or no) for each option separately, i.e., not comparing each option with the others listed

formats (e.g., "a maximum temperature between 24° and 26°C is forecasted for tomorrow"). Finally, the last question (Q5) deals with the same goal as Q4, but examined students' preferences in a more complex scenario, when the uncertainty for a specific weather situation was briefly explained (Table 2). Both Q4 and Q5 are related to the fourth objective addressed in the current study.

The questionnaire was created using the Google Forms application. The link to the generated form was distributed by the faculty members of both universities, according to the different subjects indicated in Table 1. The link to access the form was described as "Weather forecasts confidence and communication." In addition, participants were informed that the information collected would remain anonymous. The study participants filled out the online survey and the results obtained were stored in a database for further processing. To analyze the responses received, the statistical computing environment R was used (R Core Team 2014).

Considering the research design of this study, a descriptive analysis of response frequencies and percentages was conducted. On the one hand, the nonparametric Kruskal–Wallis test was applied with the aim of evaluating whether the three independent groups indicated in Table 1 came from identical populations. On the other hand, the Mann–Whitney–Wilcoxon parametric test was applied so as to evaluate whether two independent samples come from identical populations, for instance, comparing the results obtained between two of the distinct subjects included in Table 1. These nonparametric tests were selected because the hypotheses necessary to apply the corresponding parametric tests were not fulfilled, for example, normality in the data distribution (Morss et al. 2010). To determine the smallest significance level at which the null

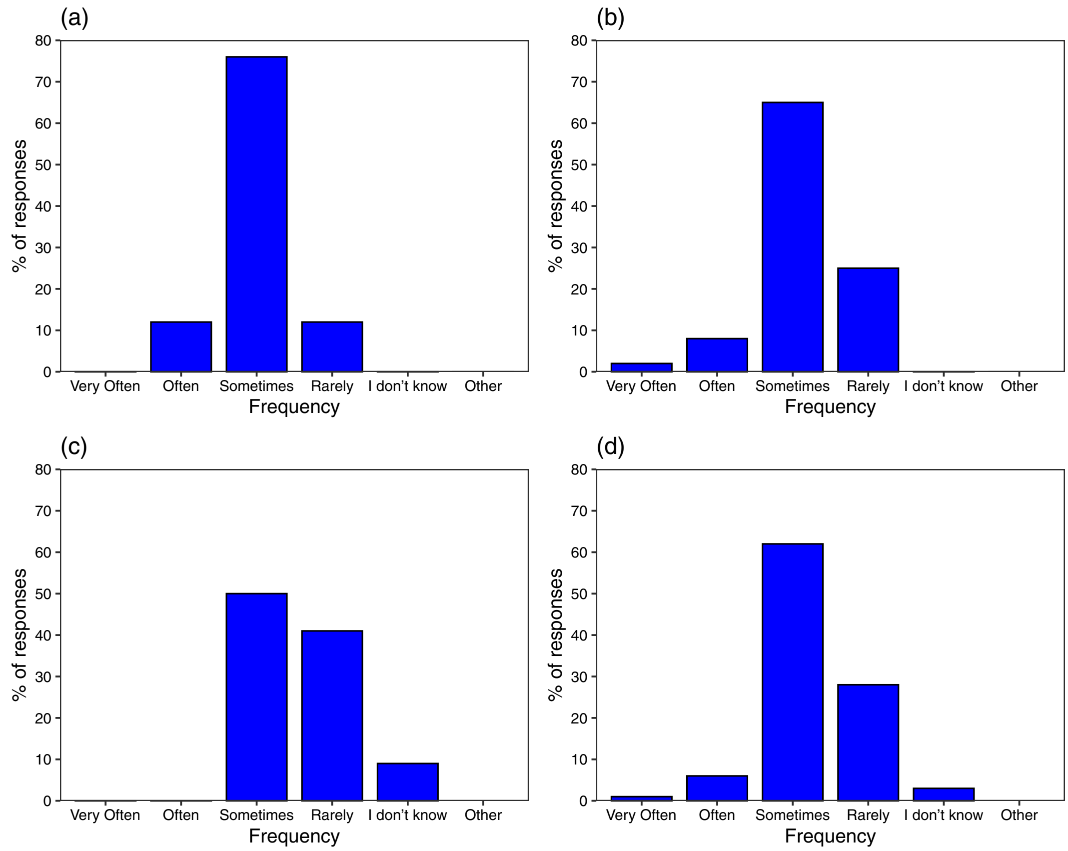

FIG. 1. Percentage of responses related to the frequency with which students perceived that weather forecasts were incorrect split into the different subjects evaluated in the current study: (a) "introduction to meteorology," (b) "meteorology and climatology," (c) "atmospheric physics," and (d) all data.

hypothesis (no relationship) can be rejected, the p value was taken. The null hypothesis was rejected if p value < 0.05 (Morss et al. 2010), taking into account a level of statistical significance of 5%, although in some cases the level of statistical significance obtained is higher (for instance, p value < 0.0001). Dividing the information provided by students enrolled in three meteorology-related subjects shown in Table 1 has permitted us to compare results of distinct cohorts in addition to consider the results found using all the responses provided by the students. Additionally, the Pearson chi-squared test is used in the discussion section to compare the results obtained in the current work with those found in previous related studies. The chi-squared tests whether the frequency distributions of two or more samples come from identical populations (Morss et al. 2010).

3. Results

a. *Students' confidence on the accuracy of weather forecasts*

Figure 1 shows the answers obtained for the question related to the confidence of students in weather forecasts (Q1). According to the answers, 62% of participants experienced inaccurate weather forecasts sometimes (Fig. 1d) and 28% experienced inaccurate forecasts rarely. At the other end, only 1% of participants felt that the forecasts were incorrect very often, and 7% of the recorded responses were obtained together for the "very often" and "often" levels in this question. Table 3 shows the frequency, over the total number of responses, with which students felt that weather forecasts are inaccurate. In this table, answers were divided according to the subject and degree of students.

TABLE 3. How often (%) students feel that weather forecasts are inaccurate, split by subject and degree.

	Rarely	Sometimes	Often
Introduction to meteorology (degree in marine sciences—UA)	12	76	12
Meteorology and climatology (degree in environmental sciences—UV)	25	65	8
Atmospheric physics (degree in physics—UV)	41	50	0

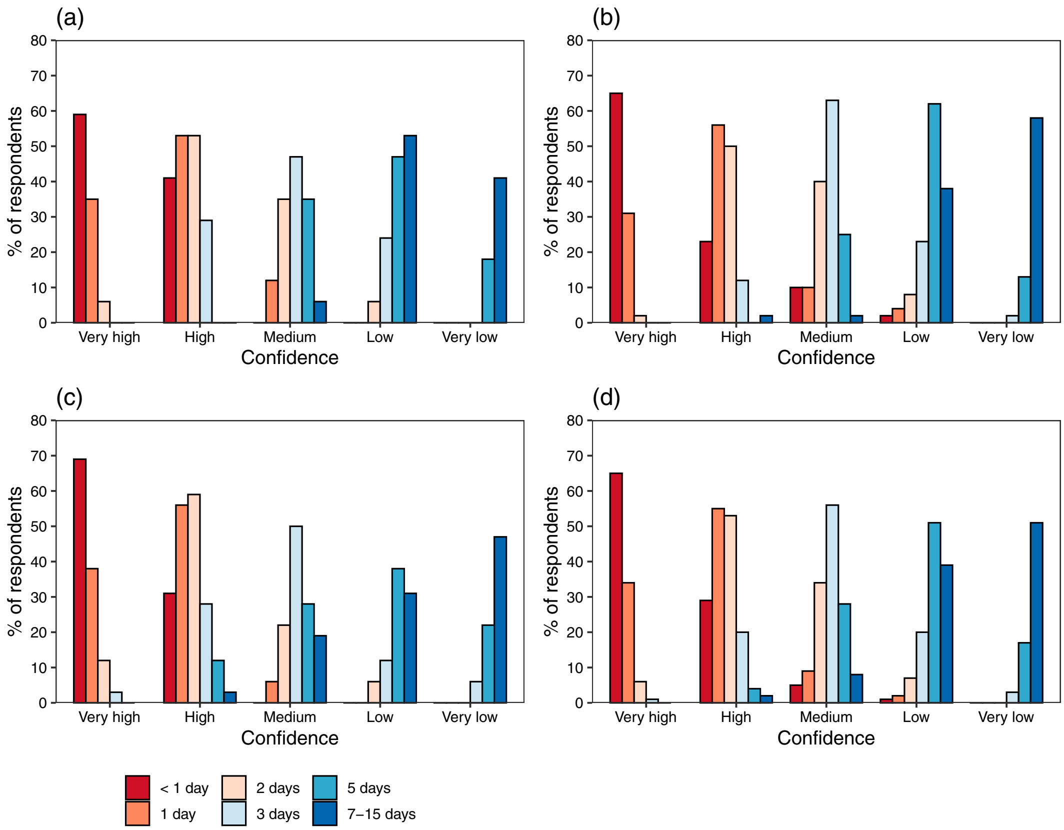

FIG. 2. Percentage of responses related to the confidence in weather forecasts for different lead times and students grouped by enrolled degree: (a) "introduction to meteorology," (b) "meteorology and climatology," (c) "atmospheric physics," and (d) all together.

A p value of 0.009 was obtained when the Kruskal–Wallis test was applied to answers to question Q1 to compare the results obtained in the three subjects. This result means that there is a significant difference among the results obtained for the different subjects separately. According to results shown in Fig. 1 and Table 3, the most repeated answer to incorrect forecast was "sometimes," followed by "rarely." The application of the Mann–Whitney–Wilcoxon to Q1 for the three different subjects shows that even though no significant differences are obtained between "introduction to meteorology" and "meteorology and climatology" (p value of 0.3), significant differences are obtained between "introduction to meteorology" and "atmospheric physics" as well as between "meteorology and climatology" and "atmospheric physics" (p value of 0.003 and 0.005, respectively). In this sense, the difference in the percentages of the "sometimes" and "rarely" choices was larger in the case of the subject "introduction to meteorology," followed by "meteorology and climatology," and finally "atmospheric physics," where the difference was only 9%. Table 3 shows that the percentage of the "sometimes" option decreased similarly, while "rarely" increased in the opposite direction. The results of Fig. 1 seem to indicate that students of the subject "atmospheric physics" are more confident about the accuracy of weather forecasts than the rest of students.

b. *Students' confidence in weather forecasts for different lead times*

The levels of confidence in forecasts reported by the participants were analyzed from the answers to the second question (Q2), see Fig. 2. In that case, 65% of the answers showed a very high level of confidence in forecasts for lead times lower than one day (Fig. 2d). In addition, 94% of the answers were selected as "very high" and "high." For 1-day forecasts, the confidence decreased from "very high" to "high" relative to the forecasts lead times of a few hours. The percentage of answers in the "high" confidence level was 89%. In addition, no answers were obtained with a "very low" confidence for forecasts with lead times lower than 2 days. Medium-high confidences were obtained for 2-day forecasts, with 89% of the answers in these levels. For 5-day forecasts, 51% of the answers corresponded to "low" confidence levels, while for forecasts with lead times of 7 days or higher, the confidence was "very low," with 51% of the answers. No significant differences were observed for the six forecast lead time intervals when comparing the answers obtained in the different subjects; p values of 0.7, 0.9, 0.9, 0.3, 0.6, and 0.6, were obtained

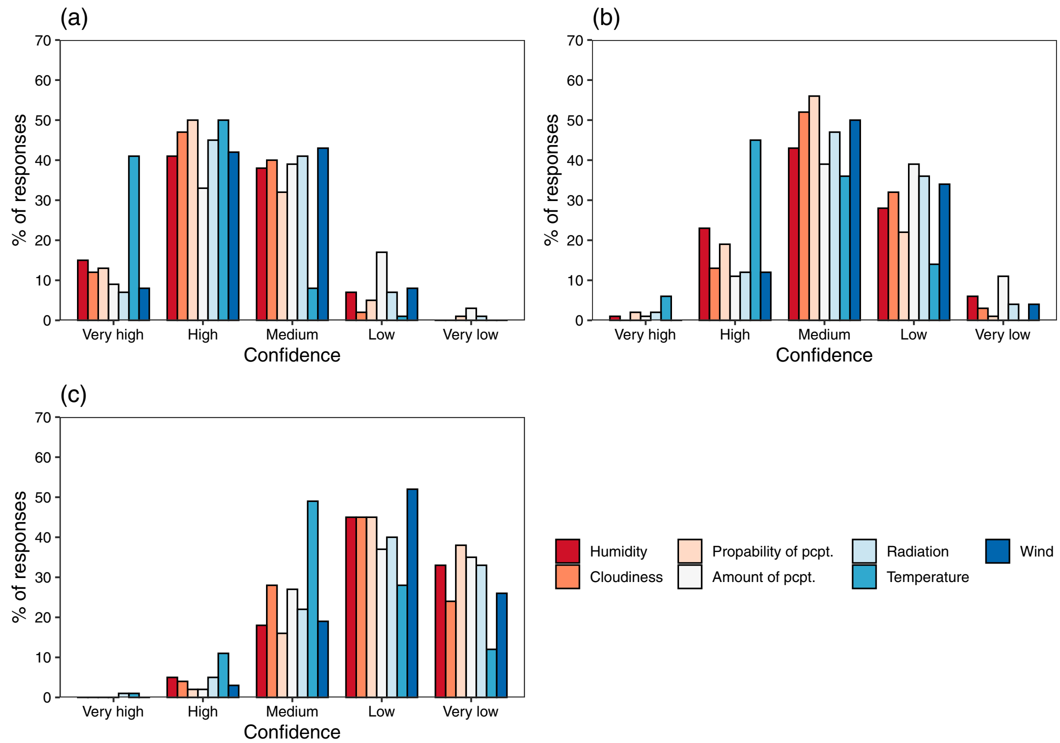

FIG. 3. Percentage of responses in relation to the confidence in the weather forecasts for different weather elements, taking into account all of the registered responses, and for different forecast lead times: (a) 1, (b) 3, and (c) 7 days.

when applying the Kruskal–Wallis test for forecast lead times of a few hours, 1, 2, 3, 5, and 7 days or more, respectively.

c. *Students' confidence in weather forecasts for different weather elements*

Figure 3 shows the results related to question Q3. Figure 3a shows the confidence in the forecast of the different weather elements considered, taking into account the 24-h weather forecasts. Figures 3b and 3c show the same but for 72-h and 7-day forecasts, respectively. As in the case of the general forecasts (Fig. 2), the confidence in the forecasts for the different weather elements decreases with the forecast lead time. Among the different variables included in Fig. 3, the confidence in the temperature forecast was high-very high for the 1-day forecast, and it was still high and medium for the 3- and 7-day forecasts, respectively. The amount of precipitation was the magnitude with the least confidence levels among students. However, the confidence levels for the probability of precipitation were high–medium, medium–low, low–very low for forecast lead times of 1, 3, and 7 days, respectively, corresponding to the top two choices for each forecast lead time.

d. *Students' preferences for communicating weather forecasts*

Figure 4 shows students' preferences for deterministic forecasts (single value) or forecasts that express uncertainty in a scenario of maximum temperatures. The preferred option in all cases is to report some measure of uncertainty. However, the percentage of students that selected channel B (the one expressing uncertainty) is 71%, 54%, and 44% for "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively. Students of "atmospheric physics" subject like the way both channels communicate the weather forecast, with 38% of the responses, similar to that found for "meteorology and climatology" (33%). This percentage decreases to 12% in the case of "introduction to meteorology." Only 2% of the "meteorology and climatology" students' responses do not show a well-formed opinion on the communication method they prefer. Combining those students who preferred the uncertainty forecast with those who liked both channels' forecasts, more than 80% of students prefer or are willing to receive this type of uncertainty information (83%, 87% and 82% of responses for "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively). Comparing the results obtained for these three related subjects, no significant differences are obtained between "introduction to meteorology" and "meteorology and climatology" (p value = 0.09 in the Mann–Whitney–Wilcoxon test), nor between "introduction to meteorology" and "atmospheric physics," and "meteorology and climatology" and "atmospheric physics" (p value of 0.21 and 0.81, respectively).

Figure 5 shows students' responses to question Q5. The first option was a maximum temperature forecast of 30°C, expressed as a deterministic forecast. The remaining six forecasts expressed uncertainty in some way and some of these

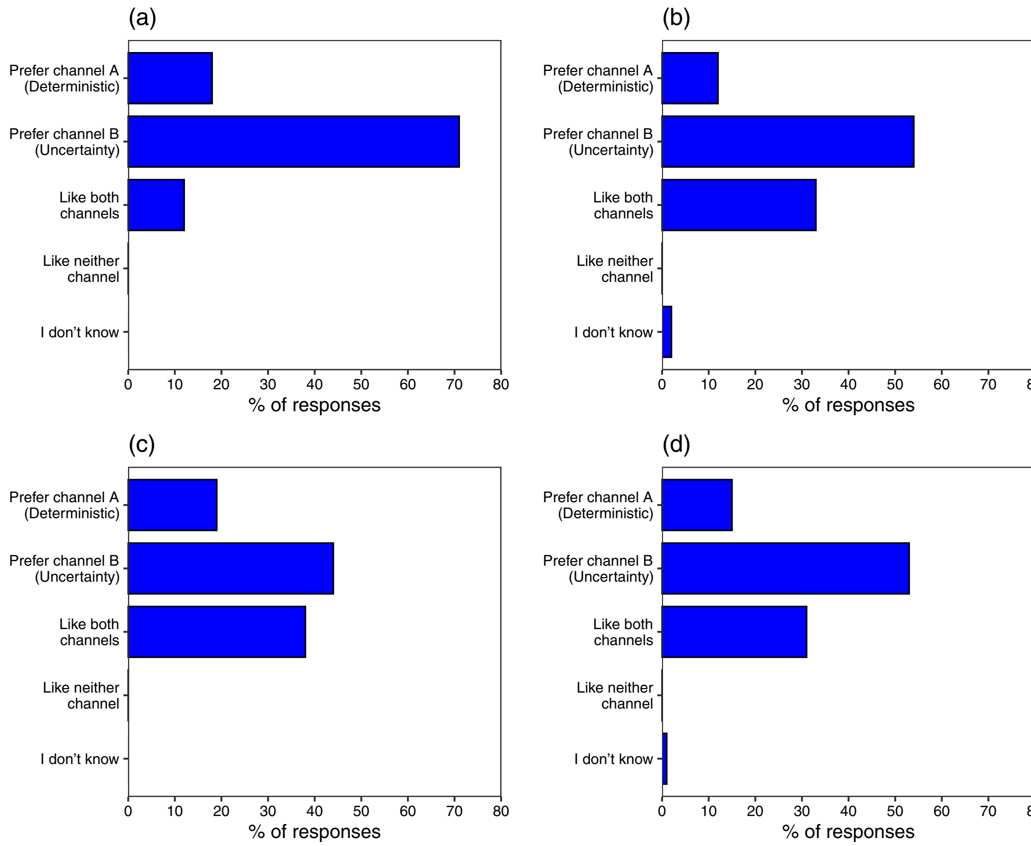

FIG. 4. Percentage of responses that preferred the way channel A gives the forecast (maximum temperature for tomorrow of 25°C; forecast is deterministic), preferred the way channel B gives the forecast (maximum temperature for tomorrow between 24° and 26°C; forecast expresses uncertainty), liked both channels, liked neither channel, or did not know: (a) "introduction to meteorology," (b) "meteorology and climatology," (c) "atmospheric physics," and (d) all data.

responses included an explanation of the corresponding weather situation as well; 18%, 25%, and 12% of students enrolled in "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively, prefer being given the forecast in the deterministic format. In addition, a similar distribution of responses is observed among the three subjects. Applying the Mann–Whitney–Wilcoxon test to the different forecast options included in question Q5, no significant differences have been found (p value > 0.05). Confronting the six forecasts that include uncertainty, the option that includes an explanation of the weather situation that a cold front may move through is the most preferred one (Fig. 5). Among all forecasts expressing uncertainty, students mainly preferred forecast 3: "The high temperature tomorrow will most likely be 30°C, but it may be 20°C, because a cold front may move through during the day" and forecast 5: "The high temperature tomorrow will be between 20° and 30°C, because a cold front may move through during the day"; 82% of students enrolled in "introduction to meteorology" preferred these two options. In the case of "meteorology and climatology," 81% and 71% of students preferred forecast 3 and forecast 5. Finally, 81% and 75% of "atmospheric physics" students preferred forecast 3 and forecast 5, respectively.

When the forecast is given as a probability percentage chance, lower differences are observed when comparing the forecast that explains the corresponding weather conditions (forecast 7) with the one that does not include this explanation (forecast 6). In this case, a difference between the affirmative responses of forecasts 6 and 7 of 12%, 17%, and 22% are found for "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively. These results contrast, for instance, with the difference between the affirmative responses of forecasts 2 and 3: 53%, 50%, and 37% for "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively. The application of the Mann–Whitney–Wilcoxon test does not show significant differences between forecasts 6 and 7 (p value = 0.49, 0.07, and 0.08 for "introduction to meteorology," "meteorology and climatology," and "atmospheric physics," respectively). However, significant differences arise between forecasts 2 and 3, and forecasts 4 and 5 (p value $<$ 0.05 in the Mann–Whitney–Wilcoxon test in the responses regarding all three subjects).

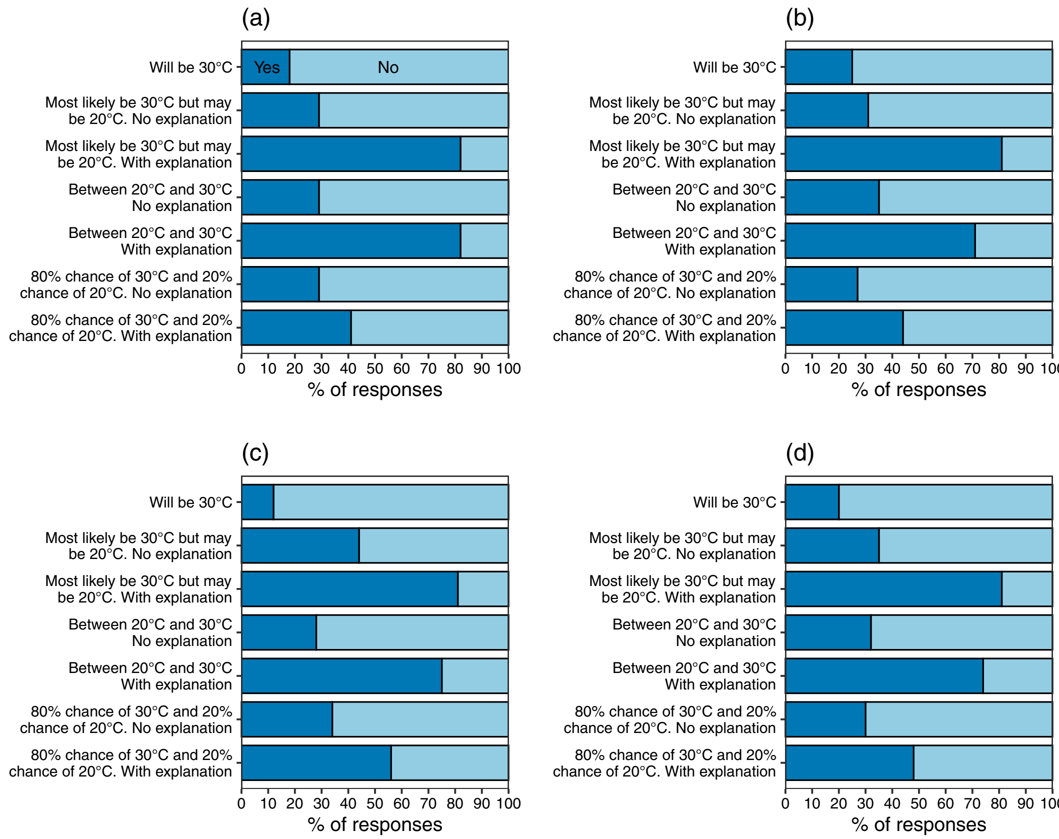

FIG. 5. Percent of responses that like the forecast being given in a deterministic format and additional six uncertainty formats, given the cold-frontal scenario presented in Table 2: (a) "introduction to meteorology," (b) "meteorology and climatology," (c) "atmospheric physics," and (d) all data. The six uncertainty forecast formats correspond to three different options for presenting the high daytime temperature, each of them presented with or without the explanation that a cold front may move through. Students could indicate whether they like (yes) or not (no) the different formats presented.

4. Discussion and summary

a. Students' confidence on the accuracy of weather forecasts

The first question (Q1) focuses on determining how often students experience that the meteorological forecasts are inaccurate, as already analyzed by O'Hanrahan and Sweeney (2013) among the Irish public. The results obtained in both studies show a similar distribution. The present work shows that 28% of the answers corresponded to students that consider the weather forecasts are "rarely" inaccurate, whereas the work of O'Hanrahan and Sweeney (2013) showed a 25% for the same question in a sample of 407 people. O'Hanrahan and Sweeney (2013) found that 46% of the answers corresponded to participants considering that the forecasts are inaccurate "sometimes," while here this percentage increases to 62%. If we analyze the answers on different subjects, "sometimes" is the most selected answer in all of them, but in the case of the subject "atmospheric physics," the answers "rarely" and "sometimes" have similar percentages (with a difference of only 9%). As all students are enrolled in the corresponding meteorology course for the first time, it seems that expertise does not explain the differences found among subjects for question Q1. Our experience as teachers shows us that the students enrolled in the "atmospheric physics" subject are usually more familiar with probabilities and uncertainties, since they had two previous related subjects in the physics degree, and three laboratories in which these topics were used, as well as with the use of mathematical models, since them were commonly used in most of the subjects pursued. This could be a plausible reason for the lower differences found between the "rarely" and "sometimes" answers in question Q1 in comparison with those found for "introduction to meteorology" and "meteorology and climatology." The results shown in Fig. 1c reduces the "sometimes" answers, relative to that displayed in Figs. 1a and 1b, in favor of the "rarely" answer. Therefore, it appears that "atmospheric physics" students, even though being aware of their limitations, are in general more confident in weather forecasts. Even though Morss et al. (2008) or Frick and Hegg (2011) concluded that a detailed understanding of meteorological definitions is not of preferential importance when

TABLE 4. How often (%) participants feel that weather forecasts are "rarely," "sometimes," or "often," and "very often" inaccurate (question Q1) in the study by O'Hanrahan and Sweeney (2013) and the current study.

Q1	O'Hanrahan and Sweeney (2013)	Current study
Rarely	25	28
Sometimes	46	62
Often and very often	25	7

dealing with uncertainty information, back in 1980, Murphy et al. (1980) concluded that meteorological education among the general public should be reinforced so as to improve people's knowledge regarding weather forecasts (Kox et al. 2015) as well as to avoid people underestimating the level of local risk indicated by severe weather warnings (Taylor et al. 2019). In this regard, Morss et al. (2008) also pointed out that understanding which uncertainty information is required and useful for users may help to identify which user education and outreach activities are needed to better communicate forecast uncertainty (National Research Council 2006). Besides, Gigerenzer et al. (2005) highlighted that communication of statistics in forecasts should be improved by means of providing a better education in statistics to the public. Based on the results found in the current study, it seems that a better education in statistics, as it is the case of "atmospheric physics" students, may be helpful to improve confidence on the accuracy of weather forecasts. Furthermore, it is not only a question of having a limited meteorological or statistical knowledge that produces misunderstandings of weather forecasts, but also how information is presented and communicated (Kox et al. 2015). Although different research studies address this issue (Mulder et al. 2020), more research is still needed in this regard and should also be conducted in the study region. In addition, the topic of the influence of an improved education in statistics regarding confidence and uncertainty information should be further investigated. This may be tested as well explaining probabilities, for instance, conveying probabilities in terms of relative frequencies (Fundel et al. 2019). According to O'Hanrahan and Sweeney (2013) a 25% of the Irish public considered that the weather forecasts are inaccurate "often" or "very often," whereas in the present work this percentage decreased to a 7% (Table 4). A chi-squared test shows significant differences in the responses obtained by O'Hanrahan and Sweeney (2013) and those found in the current work. According to Table 4, approximately the same percentage of responses increases the "sometimes" option and decreases the "often" and "very often" options in question Q1 comparing these two studies. Regarding how confident college students in the United States are in weather forecasts, Phan et al. (2018) found that 69.2% respondents were confident whereas 21.4% were neutral in relation to the level of confidence. Therefore, only 10% of participants were not confident in weather forecasts. If we consider the "often" and "very often" options as a measure of a poor confidence in weather forecasts in Q1, 7% of students were not confident at all. However, if we consider "sometimes" option in Q1 similar to "neutral" option in the study by Phan et al. (2018), a larger number of "sometimes" responses is found in the current study relative to the "neutral" option in Phan et al. (2018).

b. *Students' confidence in weather forecasts for different lead times*

In relation to the second question (Q2), results were in agreement with (Table 5) those found in other previous works (Morss et al. 2008; Lazo et al. 2009; Joslyn and Savelli 2010; Kox et al. 2015; Zabini et al. 2015; Kox and Thieken 2017; Phan et al. 2018). For instance, O'Hanrahan and Sweeney (2013) pointed out that 48% of the Irish public showed a very high level of confidence in the forecasts on a time scale lower than one day, whereas only 0.5% showed this same confidence in forecasts beyond 7 days ahead (only 2 answers out of a total of 407). In the current study, no students selected a very high level of confidence in the 7–15 days weather forecasts. Likewise, no answers were obtained for very low confidence levels for time scale forecasts lower than 24 h, and only one answer was given for a low confidence level, representing a 1% of all the answers. Instead, 51% of students showed a very low confidence level when the forecast lead time was set to be higher than 7 days. Thus, it is clear that the confidence in weather forecasts decreases when the lead time interval for those forecasts increases. In that sense, Morss et al. (2008), using a survey with more than 1400 answers, obtained a very high confidence in a forecast of several hours in 43% of the answers, whereas less than 2% showed a very low confidence in this time interval. In addition, approximately half of the answers showed a medium confidence in forecasts within 3 days, while a similar percentage answered very low confidence in a

TABLE 5. Comparison of the percentage (%) of participants that chose a very high level of confidence in weather forecasts for different lead times (question Q2) in the studies by Morss et al. (2008), Lazo et al. (2009), O'Hanrahan and Sweeney (2013), Zabini et al. (2015), and the current study.

Q2	Morss et al. (2008) and Lazo et al. (2009)	O'Hanrahan and Sweeney (2013)	Zabini et al. (2015)	Current study
<1 day	43	48	67	65
1 day	25	28	33	34
2 days	11	11	9	6
3 days	5	4	2	1
5 days	2	2	0	0
7–15 days	2	0.5	0	0

forecast period larger than 7 days. In this case, it is observed that 90% of the participants showed a decreasing confidence for increasing forecast lead time. These results have also been highlighted by Lazo et al. (2009) and Zabini et al. (2015). Likewise, participants in the study conducted by Joslyn and Savelli (2010) in Washington and Oregon (United States) expected more uncertainty at longer lead times, and Kuonen et al. (2019) showed that commercial fishermen in Oregon understood that forecast error is higher for longer lead times. In addition, Kox et al. (2015) and Kox and Thieken (2017) found that the confidence in 7-day forecasts was lower than the confidence in the 2-day forecasts, whereas Phan et al. (2018) showed a decay in the participants' confidence for longer lead times using 5- and 10-day forecasts. The trends observed in the present study are aligned to those found in these other works. This confirms the understanding of the students surveyed here regarding the uncertainty inherent to the weather forecasts, and of its general increase for higher time periods (National Research Council 2006), similarly to previous studies focused on the precision of weather forecasts (Vitart 2014).

In the light of the results included in Table 5, the very high confidence levels given by O'Hanrahan and Sweeney's (2013) respondents are similar to those in the Morss et al. (2008) survey for the different lead times evaluated. Zabini et al. (2015) found more similar results to those obtained in the current study. If we focus on the percentage of participants that selected a very high confidence level for less than and one day forecasts (Table 5), a difference of 2% and 3% is obtained comparing Morss et al. (2008) and O'Hanrahan and Sweeney (2013) surveys. Confronting the study by Zabini et al. (2015) and the current work, a difference of 2% and 1% is obtained for less than and one day forecasts lead times. However, differences around 20% are obtained when comparing the results shown by Zabini et al. (2015) and the current work and those previously found by Morss et al. (2008) and O'Hanrahan and Sweeney (2013). Considering the results shown in Table 5, similar percentages are found comparing the Italian public (Zabini et al. 2015) and the Spanish undergraduate student of the current study. Using a chi-squared test for the data presented in Table 5, no significant differences are obtained among the studies conducted by Morss et al. (2008) and Lazo et al. (2009), O'Hanrahan and Sweeney (2013), Zabini et al. (2015), and the current one, with the exception of the comparison of the results found by Morss et al. (2008) and those shown in the current study (p value = 0.02). Confronting the outcomes by Morss et al. (2008) and Zabini et al. (2015) a p value of 0.09 is obtained.

Table 6 displays the levels of confidence chosen by students for different forecast lead times (less than 1, 3, and 7–15 days) in relation to the students' perceptions of the accuracy of the corresponding forecast. It seems clear that there is a displacement in the "sometimes" and "rarely" confidence levels for the frequency with which students perceive inaccurate forecasts, ranging from higher confidence levels for shorter forecasts lead times to a lower confidence for longer lead times. Maybe students have longer lead times in mind when answering Q1, which evaluates the frequency of perceiving weather forecasts to be inaccurate, or maybe they think a forecast can be somewhat inaccurate but still have some confidence in the forecast. Another possibility could be that students evaluate Q1 considering forecasts as a whole, that is, having in mind different forecasts lead times and weather elements. However, further work is needed to discuss the results obtained for Q1 in light of the results found in Q2, as shown in Table 5, to assess these hypotheses.

TABLE 6. Students' responses (%) to question Q2 (less than 1, 3, and 7–15 days) based on students' responses to question Q1. Boldface type highlights the displacement in the percent of "sometimes" and "rarely" confidence responses for longer lead times.

	Q2				
Q1	Very high	High	Medium	Low	Very low
<1 day					
Very often	1	0	0	0	0
Often	4	0	2	0	0
Sometimes	***36***	***23***	3	1	0
Rarely	***24***	***4***	0	0	0
3 days					
Very often	0	0	1	0	0
Often	0	0	2	3	1
Sometimes	0	***10***	***38***	***13***	2
Rarely	1	***10***	***14***	***3***	0
7–15 days					
Very often	0	0	0	0	1
Often	0	0	0	1	5
Sometimes	0	1	4	***23***	***35***
Rarely	0	1	4	***12***	***11***

c. *Students' confidence in weather forecasts for different weather elements*

Morss et al. (2008) investigated the confidence of the general public in the forecast of temperature, probability of precipitation and amount of precipitation for lead time periods of 1, 3, and 7 days ahead. For all of them, the highest confidence was obtained for the temperature forecasts, whereas the lowest confidence was observed for the amount of precipitation forecasts, leaving the probability of precipitation with an intermediate confidence. In this case, it was also found that the confidence in the forecast of these three weather elements decreased for increasing lead time periods for the forecasts. For 1-day weather forecasts, Morss et al. (2008) found that 87% of respondents rated their confidence in temperature forecast as high or very high. The percentage of responses in this regard for precipitation chance and precipitation amount was 66% and 51%, respectively. Likewise, Kox et al. (2015) showed that their survey participants rated the confidence in a 2-day temperature forecast as high or very high with 89%, whereas 70% of respondents rated as high or very high the 2-day chance of precipitation forecasts. The confidence in the amount of precipitation forecasts decreased to 50%. Moreover, they found a displacement from high/very high confidence in 2-day forecasts to low/very low confidence in 7-day forecasts. In this latter case, the percentage of responses regarding temperature, precipitation chance and precipitation

TABLE 7. Comparison of the percentage (%) of participants that preferred the way channel A gives the forecast (maximum temperature for tomorrow of 25°C; forecast is deterministic), preferred the way channel B gives the forecast (maximum temperature for tomorrow between 24° and 26°C; forecast expresses uncertainty) and liked both channels in question Q4, according to Morss et al. (2008), O'Hanrahan and Sweeney (2013), Peachey et al. (2013), and the current study.

Q4	Morss et al. (2008)	O'Hanrahan and Sweeney (2013)	Peachey et al. (2013)	Current study
Channel A	22	13	14	15
Channel B	46	76	56	53
Both channels	28	7	20	31

amount forecasts was 26%, 15% and 7%, respectively. Similar outcomes were found by Kox and Thieken (2017) regarding confidence in weather forecasts among residents of Berlin; that is, survey participants correctly judged 2-day forecasts as more accurate than 7-day forecasts and they were more confidence in temperature forecasts than precipitation chance or amount of precipitation, which presents the lowest confidence comparing the three parameters. These results and the shown trends are similar to the ones obtained in the present work, as can be observed in Fig. 3. Considering all these results, it seems that confidence in precipitation forecasts addressing probabilities, such as precipitation chance, is higher than the confidence in forecasts addressing absolute values, that is, precipitation amount. Following the discussion of confidence in different weather elements forecasts, Joslyn and Savelli (2010) showed wider expectation ranges in the case of wind speed than for temperature forecasts. Moreover, their survey participants understood the impact of lead time in forecast expectation of temperature, precipitation, and wind speed. In this regard, expectation ranges of these weather elements for 3-day lead time forecasts were significantly larger than the corresponding next day forecasts. This latest forecast lead time is considered the most important (Demuth et al. 2011), whereas 2–3 and 4–7 days were rated higher in the United States and Poland, and India, respectively, in the cross-cultural study conducted by Keul et al. (2018). Regarding weather elements, Demuth et al. (2011) also pointed out that temperature and precipitation are the most relevant ones. Regarding the wind field, an intermediate confidence is found for this magnitude in the present work. The precision perceived by students in relation to these quantities agree with the results obtained in different studies related to real-time numerical weather prediction systems (Gómez et al. 2014). Morss et al. (2008) highlighted that members of the public have a clear understanding that the forecast of some weather elements tends to present a higher uncertainty than others.

d. *Students' preferences for communicating weather forecasts*

Comparing the results found in the current study for Q4 with those obtained in previous studies, Morss et al. (2008) reported that only 22% of respondents in the United States preferred the deterministic forecast, whereas more than 70% of respondents selected the probabilistic forecast or the one that likes how channels A and B present the weather forecast. In the study by O'Hanrahan and Sweeney (2013) in Ireland, 76% of respondents preferred the probabilistic forecast, while only 13% preferred the deterministic forecast. Combining those participants who preferred the uncertainty forecast with those who liked both channels' forecasts, O'Hanrahan and Sweeney (2013) found that 83% of students prefer or are willing to receive this type of uncertainty information. These results are similar to those obtained in the current study. In this line, Peachey et al. (2013) found that 70% of participants in their study (U.K. students) would prefer or were willing to receive the uncertainty forecast as compared with 20% that preferred the deterministic forecast alone. Merging all responses reported in the three degree subjects evaluated in the present study, 84% of students preferred to receive the forecast along with uncertainty information, whereas 15% preferred the single-value deterministic forecast. If we compare the results obtained by Peachey et al. (2013) with those found here, excluding "like neither channel" and "I don't know" options, a similar distribution of responses is found in the case of "introduction to meteorology." In this sense, the preferred option is channel B (forecast with uncertainty), followed by channel A (deterministic forecast) and like both channels. However, Fig. 4 shows that this is not the case for "meteorology and climatology" and "atmospheric physics" subjects. In this case, channel B is followed by the preference for both channels, with the channel A option being the one with lower number of responses. A comparison of the results obtained for preferences of channels A, B, or both is presented in Table 7. The application of a chi-square test to the data included in this table shows significant differences between the results found by O'Hanrahan and Sweeney (2013) and those obtained by Morss et al. (2008), Peachey et al. (2013), and the current work. In this regard, no significant differences are found between these three last studies (p value > 0.05). Kox et al. (2015) addressed the topic of weather forecasts communication through a single-choice question asking for the favored format users preferred to receive a 7-day forecast (establishing this lead time as a medium range weather forecast). The corresponding answer could be reported as single values, range of values, or probabilistic values, and 4%, 66%, and 30% of participants selected these three individual choices, respectively. These results are in agreement with those obtained in the 2005 study conducted by Customer Feedback Insight Group for NOAA (Kox et al. 2015). In this case, 10%, 59%, and 31% of the participants' responses were reported for single values, range of values and probabilistic values, respectively. Considering these results together with those obtained by Morss et al. (2008), O'Hanrahan and Sweeney (2013), and Peachey et al. (2013), as well as the present study, it seems that using a range of values is the preferred option for communicating weather forecasts among the distinct surveyed cohorts.

Regarding the use of probabilities in the communication of weather forecasts, O'Hanrahan and Sweeney (2013) found that 70% of the respondents accepted that the use of weather forecasts was not simply a way for weather forecasters to hedge their bets. This still leaves 30% of respondents thinking that they might. Considering these figures, we think that deterministic information should be kept when communicating weather forecasts as an alternative to providing uncertainty information given that probabilities increase confidence in weather forecasts (O'Hanrahan and Sweeney 2013). For instance, 85% of the participants in the study conducted by Kox et al. (2015) confirmed the need to keep deterministic information in contrast to 15% of respondents that thought they could work with probabilistic statements.

Regarding question Q5, Morss et al. (2008) found that 35% of the respondents liked being given the forecast in the deterministic format, whereas it was the least popular option in the cohort of the study by Peachey et al. (2013), with only 13% of participants liking this communication format. The results found in the current study are in agreement with those obtained by Peachey et al. (2013), with a lower percentage of responses for the deterministic format than those found by Morss et al. (2008) for the general public in the United States. Comparing the results obtained for question Q5 in the current study with those found by Morss et al. (2008) and Peachey et al. (2013), it seems that in all cases participants preferred the option that explained the corresponding weather situation, that is, that a cold front may move through, no matter how the forecast uncertainty is presented. Moreover, forecast 3: "The high temperature tomorrow will most likely be 30°C, but it may be 20°C, because a cold front may move through during the day" and forecast 5: "The high temperature tomorrow will be between 20° and 30°C, because a cold front may move through during the day," including the cold-frontal explanation, are the ones preferred by the U.S. public (Morss et al. 2008), with around 60% of affirmative responses, as well as by U.K. undergraduate Earth- and environmental-science students (Peachey et al. 2013), with 78% and 76% positive responses. The results found in the present study are in agreement with those previously found (Morss et al. 2008; Peachey et al. 2013), as shown in Table 8. As discussed in Morss et al. (2008), the obtained results seem to suggest that providing a simple explanation of the weather situation could be a way of communicating forecast uncertainty many people like, at least as a supplement to other uncertainty information (Peachey et al. 2013). However, Sivle and Aamodt (2019) suggested some recommendations for weather language usage. Applied to question Q5 in the current study, Sivle and Aamodt (2019) proposed that forecasts communicated to nonexperts should avoid technical terms that are difficult to understand. Here we use the term "cold front." It may be thought that many students may not be familiar with this term. But forecasts 3 and 5 are the ones preferred by students to communicate the corresponding weather forecast. As a cooling (cold front) is expressed in the statement in terms of temperatures: 30° to 20°C due to the passage of a cold front, it seems plausible that students recognize the general idea of the concept of a cold front. In any case, we must keep in mind that question Q5 is suggested as a general statement in contrast to an actual weather forecast in a real-life context. However, and considering questions Q4 and Q5, the majority of the students expressed a consistent preference for deterministic or uncertainty forecasts in both questions. This result might suggest that the majority of the students could prefer deterministic or uncertainty information across a range of situations. In this regard, further investigation of when and why students want deterministic versus uncertainty forecasts should be conducted in the future as people's preferences depend on the forecast situation and the format of the uncertainty information (Morss et al. 2008). Related to this point, an interesting question that should also be investigated in the future is to evaluate which way people talk about uncertainty in their daily life (Fundel et al. 2019).

TABLE 8. Comparison of the percentage (%) of participants that liked the forecast being given in a deterministic format (forecast 1) and additional six uncertainty formats (forecasts 2–7) in question Q5, given the cold-frontal scenario presented in Table 2, according to Morss et al. (2008), Peachey et al. (2013), and the current study.

Q5	Morss et al. (2008)	Peachey et al. (2013)	Current study
Forecast 1	35	13	20
Forecast 2	17	41	35
Forecast 3	60	78	81
Forecast 4	30	57	32
Forecast 5	58	76	74
Forecast 6	17	36	30
Forecast 7	32	67	48

Forecasts 3 and 5 were preferred more than forecast 7: "There is an 80% chance that the high temperature tomorrow will be 85°F and a 20% chance that the high temperature tomorrow will be 70°F, because a cold front may move through during the day" in Morss et al. (2008) as well as in the current study. In both cases, the percentage of affirmative responses in forecasts 3 or 5 is reduced by half relative to forecast 7 [from 60% to 30% in Morss et al. (2008) and from 80% to around 40% or even lower in the present study; Fig. 5]. However, these differences are less significant in Peachey et al. (2013), only around 10% (Table 8). It appears that forecasts communicated in percentage probabilities formats are not as much preferred as those expressed with a simpler uncertainty statement. A chi-square test using the data presented in Table 8 shows significant differences between the Morss et al. (2008) and Peachey et al. (2013) surveys as well as between Morss et al. (2008) and the current study (p value < 0.05), but not between Peachey et al. (2013) and the current study (p value = 0.15).

In the current study, forecast-7 responses are increased around 10% in "atmospheric physics" subject relative to "introduction to meteorology" and "meteorology and climatology" (Fig. 5). It may be though that undergraduate students in physics are more used to deal with probabilities and uncertainties. However, this difference of 10% is not translated in a significant difference between "atmospheric physics" and "introduction to meteorology" or "meteorology and climatology" from a statistical point of view. Comparing the two scenarios presented in questions Q4 and Q5, a significant majority of students preferred to receive the fairly simple uncertainty information tested. In addition, many students most preferred the uncertainty forecasts than the deterministic forecasts. Considering that given a deterministic forecast, members of the public expect a wide range of values, as described in the previous sections, expressing uncertainty as a predictive interval (range of values) has shown to improve user understanding and decision-making relative to point estimates (single value) (Grounds et al. 2017). Applied to different temperature forecasts, as it is the case of questions Q4 and Q5 in the current study, predictive intervals provide information regarding the reliability of the corresponding temperature forecast and improve user trust (Savelli and Joslyn 2013; Tak et al. 2015; Grounds et al. 2017; Joslyn and Savelli 2021). Moreover, Rosen et al. (2021) suggest that meteorologists use a combination of words and numbers to convey the probability of an outcome. Considering numbers, they give people an underlying sense of the probability whereas words help to contextualize the probability.

Considering the results found in the present work, students seem to accept that forecasts are not perfect. Moreover, students have a well-formed opinion and a well-founded knowledge of the weather forecasts, both in relation to the fact that longer-term forecasts are less accurate, and to the fact that inaccurate forecasts only appear sometimes or even rarely. Therefore, the results obtained here highlight the advantages acknowledged by students regarding weather forecasts. Understanding students' preexisting concepts related to the forecast uncertainty is important for designing and developing teaching and learning strategies devoted to establishing when and how provide additional uncertainty information when introducing or presenting weather forecasts in the classroom. In fact, understanding uncertainty is essential to hold an informed view of the nature of science (Woitkowski et al. 2021), and it is necessary to establish a certain knowledge. For instance, regarding laboratory courses, students must have a proper understanding of measurement and its related uncertainty in order to successfully complete an experiment. In this regard, a conceptual approach to learning measurement techniques must include the concept of uncertainty. The absence of some measure of uncertainty would reinforce the myth of the true value (Caussarieu and Tiberghien 2017). This is the classical approach related to a positivist view of science in which true values exist. However, the uncertainty approach is more related to the modeling approach. For that reason, when using atmospheric models and the weather forecasts obtained from them, it must be made clear that such models are not perfect and some degree of uncertainty is expected. From the three groups included in the current study, only the "atmospheric physics" group have previously been enrolled in an introductory laboratory course, named "Introduction to Experimental Physics," taught in the first year of the corresponding degree. Some of the outcomes of this subject are the following: establish uncertainty intervals for the measurements, express the physical quantities correctly and evaluate their uncertainties, and determining the accuracy of the results, among others. Regarding the field of linguistics, if not using emphatic statements of fact, people introduce different degrees of uncertainty into their statements through hedges and inflections. Concerning this issue among meteorologists and forecasters, the use of rank adjectives, such as "low," "medium," or "high," in forecast statements is essential to generate more consistent interpretations, both in relation to expressing the probability of an outcome as well as to communicate a rough sense of magnitude (Rosen et al. 2021). This is something that could be used here as well, as many participating students appear to be receptive to receive more forecast uncertainty information than that commonly provided to them now. In this regard, we could also bring our own expertise as professionals and educators in this area of study.

To conclude, previous studies (Morss et al. 2008; Peachey et al. 2013; Keul et al. 2018) have highlighted the need to further testing their results in other contexts. The current work, focused on Spanish undergraduate students enrolled in the sciences, spreads the previous research topics to other geographical regions by updating and reexamining previous findings. Consequently, the results presented here supplement and reinforce previous research studies regarding communication preferences of current weather forecasts as well as the confidence in them. We have been able to compare current outcomes with preexisting literature and to examine whether the same research questions are comparable among different contexts and cohorts, situations, number of participants, and so on. Moreover, the current study evaluates whether these questions have evolved and changed over time. Additionally, students' responses not only have been tackled and discussed as a whole, but also dividing the study cohort based on specific subjects related to meteorology and atmospheric physics. It has permitted us to have a broader idea of the results found and how they compare with previous studies related to the topic of this work, although we have to bear in mind the limitations of this comparison, considering that most previous works have been performed on the perceptions of the general public, whereas the present study focused on students that have a scientific background. Last, the present work focused on the confidence and communication in weather forecasts enhances and complements the previous results obtained regarding the perceptions, uses, and interpretations of uncertainty among undergraduate students in Spain (Gómez et al. 2021). However, both the previously mentioned studies and the current one showed communication preferences of weather forecasts when providing isolated pieces of hypothetical forecast information to participants through surveys. The obtained findings could be quite different when participants would be stated in the context of a specific channel, for example, TV news, or specific apps/web pages. Thus, future research in this sense will be the analysis of these kinds of questions, but looking at actual weather forecasts in specific contexts, for example, actual forecasts in the main national TV news, or forecasts from app/web services of the national meteorological agency, or even from international services, like that provided by the World Weather Information Service (WMO).

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