Altitude and the distributional typology of language structure: ejectives and beyond

# 1.Introduction

In the context of the rise of cultural evolution, the present century has witnessed a surge of a strand of research which claims that human languages, like the human genome (e.g. Hancock et al. 2010, Jeong and Di Renzo 2014), are adaptive to their respective environments broadly construed (cf. Lupyan and Dale 2016, Dediu et al. 2017, and Benítez-Burraco and Moran 2018 for review). The relevant environmental niches to which languages are theorized to be adaptive to are of different kinds: they may be of a sociolinguistic kind – as when languages with many L2 learners respond to this role by evolving structures that increases their learnability by adults (see e.g. Thurston 1987, Trudgill 2011, Bentz and Winter 2012). They may be related to the medium in which language is transmitted. For instance, syntactically more complexly structured phrases and sentences tend to occur in the written rather than the oral medium, and more generally in languages with long traditions of writing and literacy (cf. Ong [1982] 2002). Finally, a particularly vibrant yet not entirely uncontroversial strand of research within this broader context pertains to the relationship between languages and the physical environment in which they are spoken (compare, for example, Regier et al. 2016, Bentz et al. 2018, and Urban 2018, 2020). That such research should be a topic that is in the news again would have seemed unlikely just a couple of decades ago, as it has been more or less banned from serious inquiry in the 20th century (cf. e.g. Sapir 1912). This is in large part in response to a preceding phase in which it blossomed in the 18th and 19th century. For example, in the context of so-called “climatic theory”, scholars of the times theorized a more or less direct relationship between languages and their respective environments and argued for various theories that range from the absurd (such as the idea that the perceived “harsh” sound of Swiss German results from the goiters of the Swiss that in turn are caused by the hard Swiss water – Egenolff [1735] 1978) to the moderately more plausible but speculative (e.g. the idea that “[T]he serrated close way of Speaking of Northern Nations, may be owing to their Reluctance to open their Mouth wide in cold Air, which must make their Language abound in Consonants; whereas from a contrary Cause, the Inhabitants of warmer Climates opening their Mouths, must form a softer Language, abounding in Vowels” Arbuthnot 1751: 153-154). In the 21st century, researchers have, often apparently unaware of their predecessors, begun to rediscover the relationship between language structure and physical environment as a serious topic of inquiry, and have posited dependencies between certain features of languages, in particular in phonology, that are sometimes surprisingly similar to what has been claimed in the 18th and 19th century (see Urban 2018 for extensive review of both phases in which such research flourished).

A facilitating role in the renaissance of the topic is played by the increasing availability of large linguistic databases that furnish comparative data across hundreds or even thousands of languages in readily accessible formats – though with the methodological danger of spurious correlations that arise only because of the vast possibilities of statistical hypothesis testing these databases allow (Roberts and Winters 2013; see now Roberts 2018 for an approach that mitigates that danger). Current approaches to linguistic typology are likewise conducive in paving the way towards the revival of this line of inquiry, i.e. typology has become less interested in the traditional goal of establishing linguistic types and (implicational) universals of language structure, but rather more towards understanding the geographical distributions of typological features and their determinants In the context of this reorientation, it is becoming increasingly clear that typological features, especially but not exclusively rare ones, are distributed unevenly across the globe and the task of linguistic typology in its current orientation is to explain why these are distributed the way they are (see Bickel 2007 for the programmatic statement).

This contribution fits squarely into this context. Concretely, we seek to shed additional light on the possible role of the geophysical environment in which languages are spoken on the sound structure of human languages, which has been a central arena of theorizing in both phases in which research on the language-environment interface flourished. Concretely, we put one major claim regarding a possible effect of the environment on language structure, that has been put forward recently, namely that so-called ejective consonants have a non-random distribution in the languages of the world that is governed by the altitude at which they are spoken (Everett 2013a), into a broader empirical and theoretical context. On the one hand, on the empirical side, we explore to what extent ejective consonants are the only class of sounds whose distribution can be theorized as depending on altitude. Concretely, we explore whether uvular consonants are distributed similarly in the languages of the world, as impressionistic evidence suggests; if so, this would constitute evidence that there is a broader patterns in the distributions not only of ejectives, but also other classes of rare and articulatorily costly sounds in the languages of the world. Everett (2013a) has suggested some possible ways in which ejectives may be adaptive in high-altitude environments that is based on the specific articulatory mechanism that are involve in producing them. Since uvulars do not share these, on the theoretical side, we relatedly explore whether an alternative explanation that is capable of accounting for the distribution of both classes of sounds feasible that, rather than assuming a direct impact of the environment on speaker behavior, rather posits an influence of the environment on social and economic behavior of people in high-altitude environments that then, indirectly, shapes linguistic distributions.

In the following section, we review in more detail the literature with which our contribution engages in dialogue and from which the goals of our analyses emerge. Then, in section three, we discuss the properties of the data on which we base our analyses, the results of which are presented in section four. On the basis of a large database of phonological inventories, we find that the evidence for altitude as a predicting factor is generally weak for both classes of sound, but slightly better for ejectives than for uvulars. However, a combination of a phylogenetic analysis of the development of both classes of sounds and a concomitant in-depth survey of the dedicated literature in historical linguistics suggests that for both classes of sounds, contrary to both alternative hypotheses, language contact is usually a major factor in generating the observed distributions of both classes of sounds. We discuss this finding and to what extent it can be reconciled with either of them in our final reflections in section 5.

# 2. Altitude and the distributional typology of language structure: ejectives and beyond

One prominent claim in the double context of the renewed interest in extralinguistic determinants on languages as adaptive systems – especially environmental influences on linguistic structure beyond the lexicon – and the reorientation of linguistic typology has been made by Everett (2013a). This study has raised considerable interest, but also controversy, especially because it makes the strong and explicit claim that there is a *direct* influence of the environment on language structure which is, as the author argues, not culturally mediated as is usually assumed in frameworks such as that of Regier et al. (2016) or Palmer et al. (2017).

The case pertains to ejective consonants. Relatively rare in the phonological systems of the languages of the world, ejective consonants are unlike the majority of consonants because they are produced using a non-pulmonic airflow mechanism. Due to the simultaneous closure of the glottis and a secondary closure in the buccal cavity (at either one of the usual places of articulation, though for reasons of articulatory effort most frequently at the velum) an amount of air is “trapped” in the part of the vocal tract between the two closures. Raising of the glottis due to muscular contraction, causes the local air pressure in the relevant part of the vocal tract to rise. This is often visible from the exterior by a characteristic movement of the Adam’s Apple. Upon sudden release of the closures, the air is released and the air pressure differential is rapidly equalized with an often salient acoustic effect that can be described impressionistically as a “pop”-like sound. To explore the distribution of ejective consonants, Everett (2013a) used data provided by the *World Atlas of Language Structures* (WALS, Maddieson 2011, now updated as Maddieson 2013a), reducing the information offered by Maddieson to a binary variable (presence vs. absence of ejectives). The dataset includes information on 567 languages and is based on the earlier UCLA Phonological Segment Inventory Database (UPSID; Maddieson 1984; Maddieson & Precoda 1990). Everett observed that ejectives tend to cluster in or near high-elevation regions of the world, including the Andes, the Caucasus, and the African Rift valley. Fig. 1. Shows the occurrence of ejective consonants in the most recent version of the PHOIBLE database (Moran and McCloy 2019), which includes the UPSID data but goes significantly beyond this seminal sample and currently has data on phonological inventories from 2186 distinct languages.

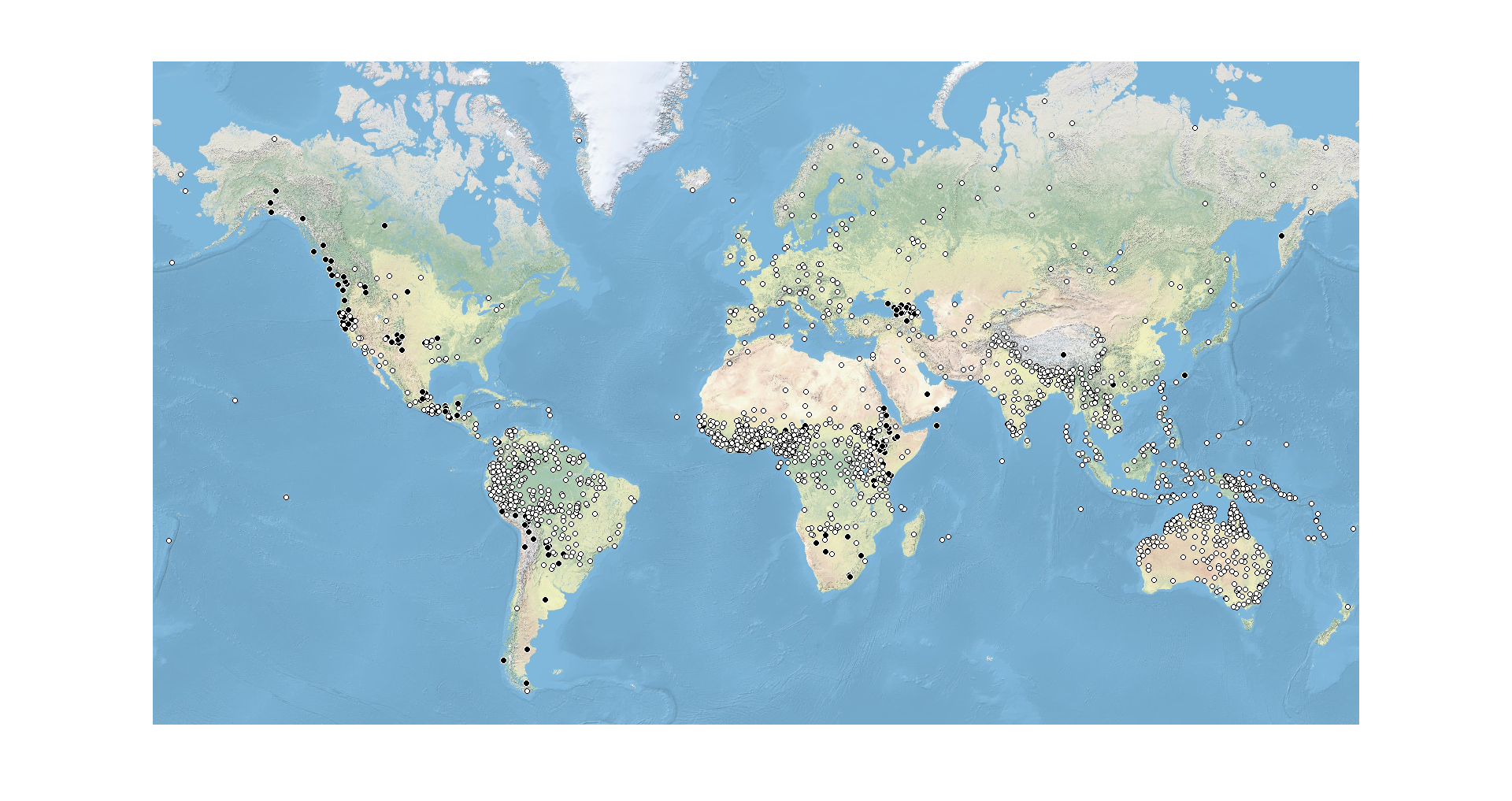


Fig. 1. Languages with ejective consonants in the PHOIBLE database.

Impressionistically, the distribution of ejectives according to PHOIBLE is quite similar as in WALS, with particularly salient hotspots in North America (in the Northwest and California, near the Rocky Mountains), Mesoamerica, the Andes in South America, the Ethiopian highlands in North Africa, and the Caucasus in Eurasia.

To assess whether the distribution of ejectives responds to elevation as the visual impression suggests, Everett (2013a) obtained geographic point coordinates (latitude and longitude) as provided by the WALS database. Points are mostly chosen such that they correspond to the center of the languages range, though for some languages idiosyncratic choices have been made (for instance, Russian appears to have been placed at the coordinates of Moscow). In turn, Everett used these coordinates to obtain a measure for the elevation associated with each language in the sample.

Descriptively, the result was that the mean elevation (as extracted on the basis of WALS coordinates) for languages with ejectives was 955 meters above sea level and that without them was at 631. To investigate further, Everett defined “high elevation zones”, i.e. regions “greater than 1500m in altitude, plus land within 200 km of such a region of high altitude.”[[1]](#footnote-1) The resulting 2 x 2 classification (presence vs. absence of ejective consonants and location of a language within such a “high elevation zone” vs. location outside) showed a statistically significant difference; later in the analysis, Everett (2013a) demonstrates that languages with ejectives that are outside high elevation zones thus defined are closer on average to such regions than those without.

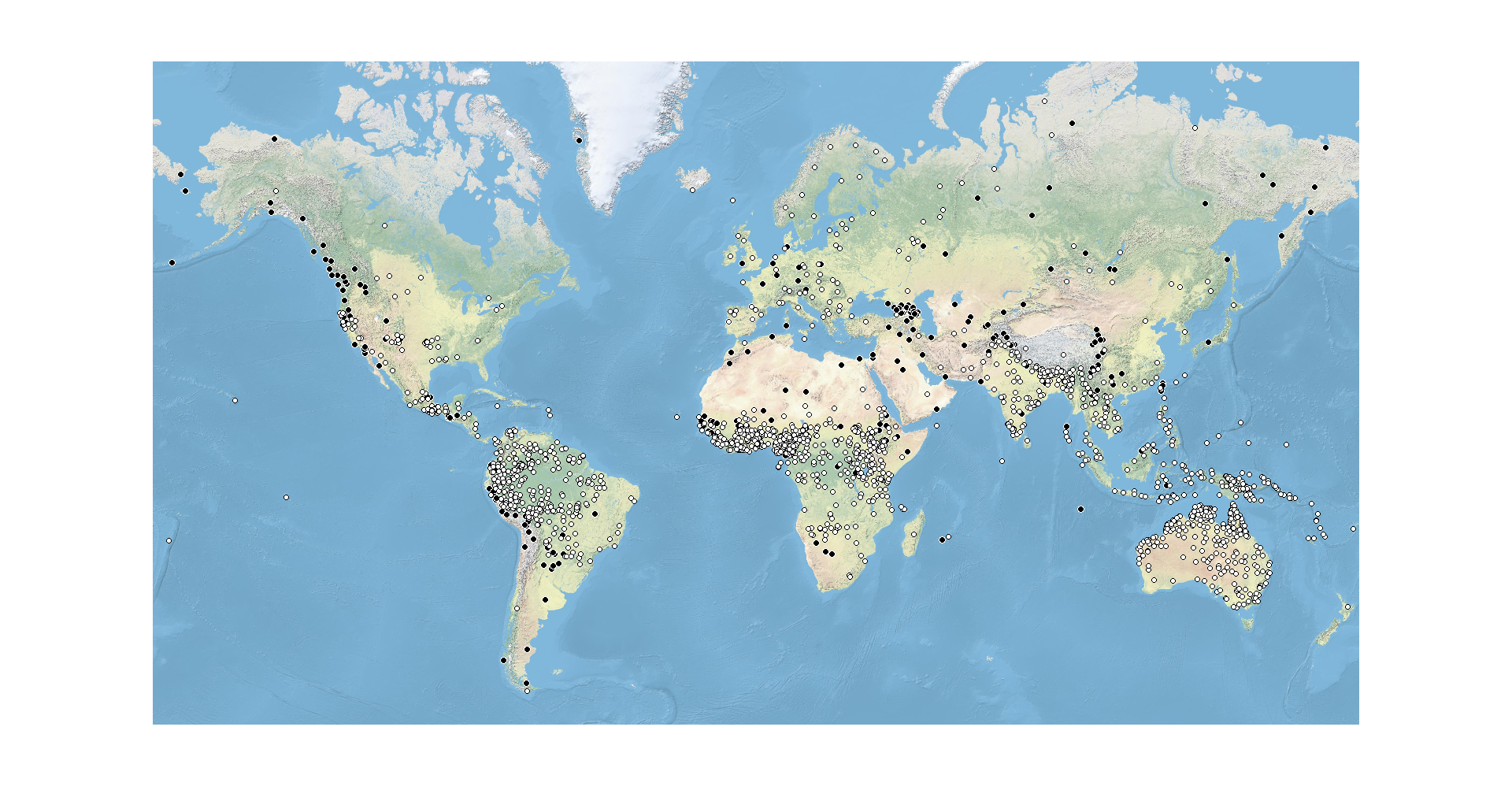
For quite some time, it has been recognized that both genealogical and areal biases must be taken into account when assessing typological distributions. Everett (2013a) does address the possibility that the distribution of ejectives and the impression that they tend to occur at higher altitudes may be influenced by particular language families. However, he outrightly dismisses the idea that genealogical biases might confound the results by observing that, in those regions where ejectives cluster together, it is always several language families that are represented and that contribute to the apparent pattern. Making the pioneering observation of large-scale areality in word order regularities, Dryer (1989) suggested that that a typological correlation can be considered genuine if it occurs in five of six so-called “macro areas” which have since then become a sort of widely applied quasi-standard in assessing areal effects in evaluations of typological distributions and correlations. Not situating his own analysis in this context explicitly, Everett offers a similar analysis by calculating the differences separately for Africa, Eurasia, South America and North America, noting that the expected differential occurs in Africa, Eurasia, and South America but not in North America (however, the difference is significant only for Africa as Everett 2013a’s Table 5 shows, but it does come out as significant throughout on the basis of a larger analysis informally offered in Everett 2013b; in both cases, no correction for multiple testing appears to have been carried out).

Everett (2013a) offers two different theories as to how the inclusion of ejective sounds in phonological inventories may be adaptive in high-altitude environments, without making a commitment whether either, both, or neither is really operative (cf. Everett 2013b). One possible factor that Everett discusses is related to a tradition in linguistics that emphasizes the competing motivations, especially in phonology, between minimizing articulatory effort and maximizing expressive possibilities (e.g. Martinet 1952). Given that ambient air pressure is undoubtedly lower in high-altitude environments than it is at or near sea level, the articulatory effort of ejectives, specifically the creation of the pressure differential that is necessary for their production, should be lower at high altitudes. This may be an incentive for speakers of languages in high-altitude environments to use this acoustically salient class of sounds. On the other hand, Everett hypothesizes, ejectives may also be adaptive in high-altitude environments because the non-pulmonic airflow that is involved in the production of ejectives may help to prevent desiccation, a significant problem in high-altitude environments due to generally lower air humidity (and the often limited availability of fresh water sources).

Evaluations of Everett’s (2013a) analysis and argument were quick to follow the original publication, though in the form of blogposts rather than contributions to peer-reviewed outlets. These responses have focused on replication of the association rather than in addressing the plausibility of the proposed mechanisms, and conclusions were divergent. While Roberts (2013) reports approaching the proposal with considerable skepticism, to his surprise he in fact found support for the statistical association of ejectives with altitudes, whereas Hammarström (2013), on the basis of a different statistical approach, could not replicate a significant association. Given the conflicting conclusions and the informal manner in which they have been published the question is, as of yet, neither conclusively confirmed nor conclusively rejected.

As evaluation has been mainly focused on methodological issues and the significance of the association itself, it is natural that the examination of the proposed explanatory theories and the evaluation of these against possible alternatives have been put aside.

While working on the typology of American languages (results now published in Urban et al. 2019) the first author noted casually and impressionistically that ejectives in the languages of Middle and South America tend to co-occur with another type of relatively rare and articulatory costly sound, namely uvulars, on which the questionnaire used for the Urban et al. (2019) also solicited information for the sampled languages. Checking the American situation against large-scale phonological databases beyond the narrow situation in Middle and South America, it becomes clear that, in fact, the distribution of uvulars seems highly similar to that of ejectives. Fig. 2. plots the location of languages with uvular consonants in the PHOIBLE database, giving a visual impression of this apparent distributional overlap.

Fig. 2. Languages with uvular consonants in the PHOIBLE database

In fact, on the basis of the initial visual impression one might be similarly inclined to suspect an elevation-dependent distribution of this class of sounds. The fit seems to be even “better” than that of ejectives, since “[t]he only major region of high elevation where languages with ejectives are absent is the large Tibetan plateau, along with adjacent regions of high altitude” (Everett 2013a), but uvulars actually are commonalso there (see discussion in section 4).

The impressionistically similar distribution of uvulars in geographical space, with hotspots of occurrence in high-altitude mountain areas of different areas of the world, if genuine and robust, would also invite the search for hypotheses that could account for the distribution of both classes of sounds and their apparent overlap. Since the articulation of uvulars, like most other consonants but unlike ejectives, involves pulmonic airflow, the explanations put forth by Everett (2013a) for the special case of ejectives, are unviable to explain a possible elevation-dependent distribution of uvulars in the languages of the world. However, if it can be corroborated, the similarities in distribution between both types of sounds suggest that some general factor is in play and governing them.

Mountain environments with their challenging topography are commonly thought of as having the effect of isolating human communities and limiting communication between them. This, in turn, is thought to influence the structural profiles of languages spoken in high-elevation environments, which in the absence of significant second language learning that would exert simplification pressures, are thought of as accumulating complex and more generally rare and hard to learn structures. This can happen either through the retention of such structures that are lost elsewhere or by their accumulation through diachronic change (cf. Urban 2020for review on language use and structure in mountain environments). Independently of Everett (2013a), Nichols (2013: 38) makes reference to precisely the classes of sounds of interest here when exemplifying this line of thought:

isolation favors (or at least does not disfavor) complexity, mountain geography favors isolation, and complexity of sound systems necessarily entails expansion along certain dimensions. Thus ejectives and uvulars can be found in mountain areas – not because harsh mountain geography deterministically causes language to add harsh consonant series (!), but because isolation favors complexity

However, what can legitimately count as “complex” segments? When operationalized as in McWhorter (2001), who equates “complexity” for practical purposes with cross-linguistic rarity, then both classes of sounds qualify (though the question of how to precisely define “cross-linguistically rare” remains). But also other possible manners of defining the controversial notion of complexity in language would lead to similar conclusions. For example, articulatory effort is undoubtedly high for ejectives. However, a greater articulatory effort of uvulars vis-à-vis other pulmonic stops, which has been suspected before (cf. e.g. Moulton 1983: 268), is now biomechanically also quantifiable precisely. In terms articulatory effort, uvulars (voiced and in CV syllables) are only exceeded by retroflex consonants (Lindblom et al. 2011: 79); and in fact, voicing is disproportionally more costly for back consonants, see Ohala [1997]2010: 666-667). Another possible piece of evidence for the marked status of uvulars is that, in situations of language death, where marked segments tend to merge with less marked ones in favor of the latter’s phonetic properties, uvular stops tend to merge with velars (Thomason 2015: 60-61).

An additional reason for thinking in this direction comes from Nikolaev and Grossman’s (2018) study on affricate-rich languages in Eurasia, whose distribution is strikingly similar to that of languages with ejectives and uvulars. All three tend to be found in mountain areas, i.e. affricate-rich languages especially in the Caucasus, the Hindu Kush, and the eastern Himalayas. Nikolaev and Grossman (2018: 574-576) also note that particularly rich inventories of affricates are typically dependent upon the presence of retroflex affricates. Since retroflex consonants, as just shown, are the only ones that exceed uvulars in articulatory effort in Lindblom et al.’s (2011) study, and since affricate rich languages have much the same distribution as uvulars and ejectives, the distribution of affricate-rich languages in Eurasia described by Nikolaev and Grossman would likewise be consistent with an account in terms of sociolinguistic behavior that is shaped by topography. That, in turn, shapes languages distributions, but inconsistent with direct environmental influences on language structure.[[2]](#footnote-2)

Under this hypothesis, then, the distribution of ejectives would turn out to be a special instance of a more general phenomenon that governs the distribution of (certain types of) complex segments in the languages of the world. Concomitantly, a theory that invokes the sociolinguistic dynamics of mountain areas would have greater explanatory power than Everett’s account by invoking a single principle that is capable of explaining both the distribution of cross-linguistically rare types of sounds that involve either pulmonic or non-pulmonic airflow. Such an account would be in line with the Boasian tradition, which assumes that the physical environment in which a language is spoken may shape the communicative needs and behavior of its speakers, and, if anything, these communicative needs and speech behavior, in turn, rather than the environment directly, shape the structure of languages (cf. Boas 1911 and Sapir 1912 for original statements and Regier et al. 2016 for a recent reappraisal in the context of the resurgence of research at the language-environment interface sketched in section 1). Thus, in contrast with Everett’s (2013a) reasoning, which explicitly argues for direct influence of environment on language structure, the influence of environment on language structure, if existent at all, would be at best indirect and, mediated through human behavior.

From this discussion, a twofold goal emerges for the present study. First, by formally reassessing the proposal of an altitude-based distribution of ejective consonants in the languages of the world, we seek to shed further light on this controversial proposal. At the same time, we offer several improvements in terms of the data used for the analysis and the procedures to arrive at sound results. Some of these improvements are due to reactions regarding the original article paper (e.g. Hammarström 2013, who questioned the validity of using the WALS data as the basis of statistical analysis), and others are brought up in the context of discussions of other research on the relationship between language and environment (e.g Hammarström 2016 on the necessity to control for genealogical and areal dependencies in the data in the same analysis rather than separately, or Collins 2016, who emphasizes the potentially significant role of language contact in shaping segment distributions). Yet another methodological improvement is the move away from using point coordinates as more or less arbitrarily chosen abstract representations of a language’s range. Instead, a methodological improvement is to use the most recent research in geolinguistics, which takes into account the range of languages into analysis (e.g. Pacheco Coelho et al. 2019, Hua et al. 2019). (Details of the analysis are described in the following section.) By reassessing the validity of the association between ejectives and altitude through a different dataset and different analytical techniques, we also contribute to a recent plea for robustness and incremental approaches in the assessment of the adaptive potential of human language (see Roberts 2018).

However, we also emphasize that our study is not meant as a mere critical re-evaluation of Everett (2013) in a narrow sense. By examining the distribution of uvular consonants in light of the same predictive parameter, i.e. altitude, and in the same overarching analytical framework, the main goal of our study is in fact is to identify the underlying causes for the distribution of certain sound classes. Generally, research in this area has focused on sophisticated assessments of the distributions of individual phonological features. While these studies give us a good indication of the degree to which the distribution of the linguistic features can be thought of as governed by properties of their surroundings, where there is still a long way to go is in coming up with linguistically and culturally plausible concrete pathways by which the environmental influences might actually find their way into language structure. At the same time, it is notable that analyses have, for the most part, focused on individual classes of segments or phonological properties such as sonority (Fought et al. 2004) and tone (Everett et al 2015, 2016a). As the preceding discussion of Everett’s (2013a) claim for an altitude-dependent distribution of ejectives shows, this runs the danger of not seeing broader patterns that might affect the distribution of several heterogeneous sound classes or phonological features – as is the case for ejectives and uvulars, for instance. However, the joint consideration of these might induce, indeed require, different and broader explanatory accounts, namely ones that are appropriate for explaining the distribution of all involved types of sounds. Thus, at the same time as reassessing the relationship between ejectives and consonants, we seek to discriminate between the original direct environmental explanation for the distribution of ejectives and an alternative one that is more general in nature, less direct, and based on sociolinguistic effects of geography on linguistic structure.

# 3. Data and coding

## 3.1. Phonological data

One of the aspects of Everett’s (2013a) study that is criticized by Hammarström (2013) is the use of the UPSID-based WALS data from Maddieson (2011), which as Hammarström (2013) notes, has not been designed for statistical evaluation. Hammarström (2013) recommends instead using either the World Phonotactics Database (Donohue et al. 2013) or PHOIBLE (Moran et al. 2012; Moran and McCloy 2019. Indeed, in a rejoinder to criticisms, Everett (2013b) provides summary statistics on the elevation of isolates and other analysis on the basis of data from the World Phonotactics Database. Since this source has in the meantime become unavailable, for our analyses in the present paper we use phonological data from the PHOIBLE database. The current version of PHOBLE (Moran and McCloy 2019) contains phonological inventories from 2,186 distinct languages. Some of these inventories were extracted from primary descriptions of the languages for the purposes of inclusion in PHOIBLE, but it also incorporates data from other, typically more regionally specialized, phonological inventory databases. Using PHOIBLE’s system of classifying segments in these inventories on the basis of distinctive features, we extracted the number of uvular and ejective segments in the inventories from the database. For uvulars, we have taken into account consonants of all manners of articulation (rather than just stops), and for ejectives, we have taken into account all places of articulation. We have excluded segments of both types that were annotated as being marginal in the language in the primary analysis. For our main analysis, we later converted these numbers into a binary variable that merely registers the presence or absence of uvular and ejective consonants per language, following in this regard the original study on ejectives by Everett (2013a). However, we also retained the original numeric counts in order to assess the relationship between elevation not only for the sheer presence or absence of both classes of sounds, but also the number of uvulars and ejectives in languages spoken at different elevations.

Given that PHOIBLE incorporates data from heterogeneous sources, the 2,186 PHOIBLE languages map onto a significantly larger number of 3,020 inventories from different sources. These often provide divergent accounts on the phonological inventories of the described languages. Therefore, a measure to avoid the inclusion of a single language more than once in the analysis, which would occur by a direct analysis of the PHOIBLE data, is necessary. Where for a given language (as represented by the ISO 639-3 code) more than one inventory from different sources is available, we have selected one on the basis of the following hierarchy of sources:

PH > GM > SAPHON > UZ > EA > ER > SPA > AA > RA > UPSID

This particular hierarchy was chosen because it maximizes the one-inventory per doculect principle, i.e. tertiary databases like SPA and UPSID often contain multiple references for “ single” languages, which were typologized by the source creators. This hierarchy also maximizes the inclusion of contrastive tone.

After selection of datasets according to this procedure, sometimes what remained in the highest-ranked source are data from more than one dialect of a given language, without a standard variety indicated. Where these did not differ with regard to the presence vs. absence of uvulars and ejectives, handling such cases was unproblematic, and the first listed dialect was kept while all others were removed from the datasets. In cases where different dialects of a language for which no standard variety was indicated differed with regard to the presence or absence of ejectives, all datasets were retained. This was the case only five times, namely for Kawarrang-Ogh Undjan, Western Balochi, Portuguese, and North Junín Quechua. The datasets are distinguished by modifying glottocodes (see Section 3.3) by an index (i.e. North Junín Quechua has the glottocode nort2980, and we distinguish the different datasets here as nort2980\_01, nort2980\_02, and nort2980\_03).

## 3.2. Elevation data

Another point of criticism which Everett (2013a) received pertained to the problematic use of point coordinates to represent the geographical location of languages. In response, Everett (2013b) has computed mean elevation of 100km and 500km ranges around dot coordinates to account or possible differences in slope and topography of the terrain surrounding the point coordinate representing the languages. Instead of relying on point coordinates, here, we do away entirely with reliance on more or less arbitrarily chosen point coordinates as the basis for obtaining information on the elevation of the region in which a language is spoken. Instead, …

## 3.3. Genealogical affiliations and areal breakdown

For modelling the effect of altitude on the distribution of ejective and uvular consonants while taking into account the genealogical structure of the world’s languages, we have relied on the Glottolog’s classification of the world’s languages (Hammarström et al. 2020), which tends to be conservative in accepting proposals for genealogical relations by insisting on documented evidence for form-meaning similarities that are explained in a least costly manner by inheritance from a common ancestor. The dataset underlying Glottolog assigns unique alphanumeric identifiers (“glottocodes”) to both languages and language families, but does not explicitly treat language isolates as singleton language families. For the purpose of our analysis, we have assigned these to pseudo-families called “isolate\_1,” “isolate\_2” etc. to reflect the fact that they, like language families, represent of genealogically independent lineages. Glottolog also retains some data for bookkeeping purposes, which are assigned to a pseudo-family with the glottocode “book1242”; we have removed these entries from the dataset, as Glottolog informs its users that for each such entry that it: “has been retired and is featured here only for bookkeeping purposes. Either the entry has been replaced with one or more accurate entries or it has been retired because it was based on a misunderstanding to begin with.”

While Glottolog provides a convenient and well-curated genealogical classification for controlling for inheritance, doing the same for contact-induced areality is generally more difficult and also for our present purposes specifically. Standardly accepted language area partitionings, such as that by Dryer (1989), are also implemented in WALS, or its recent modification by Hammarström and Donohue (2014). However, they are not ideal for our present purpose as they divide the world into macroareas that are large enough to contain several salient high-altitude zones and/or hotspots in the distribution of ejectives and/or uvulars. For instance, the Eurasian macroarea, as defined in these partitionings, would include the Alps, the Caucasus, the Hindu Kush, and the Himalayas. From a conceptual point of view, using this geographic partitioning for present purposes would entail an unspoken expectation that these major mountain ranges should behave alike, or can at least be treated analytically as behaving alike with regard to the distribution of uvulars and ejectives. However, there is in fact no robust reason to assume that simply because they are all located on the Eurasian landmass, this should be the case. We have therefore recognized the need for a more fine-grained partitioning in which high-elevation mountain regions are distributed more evenly across macroareas. Nevertheless, in order to retain a link with the extant literature, we have built on a partitioning that is based on Nichols’s (1992: 25-26) maximal differentiation of the world into areas. It has also been used by Urban (2012) for some analyses. Given that the PHOIBLE coverage is much denser than either Nichols’s (1992) and Urban’s (2012) language samples, instructions and criteria to separate areas from one another geographically had to be amended. Additionally, we did not make Nichols’s (1992) distinction between Western North America and Eastern North America and we also do not adopt Nichols’s (1992) Ancient Near East area because no languages of the ancient Near East are included in PHOIBLE. Instead, we introduced a new area called “Western Asia” into the partitioning, which is not included in any earlier analysis simply because there were few (or even no) languages from this part of the world in the respective samples. Building on this work, and modifying it to suit the purposes of the present research, we obtain a division of the world into eleven areas. Table 1 lists these areas, together with their conventional bounds from neighboring areas, where these require specification in the second column. The third column provides impressionistic and non-systematic information on some of the major mountain areas within these areas (where existent).

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| --- | --- | --- |
| Area | Comments | Major mountain areas |
| Europe | Includes the Caucasus and delimited from Northern Eurasia by its southern ranges and further north by the Ural mountains. Also includes Malta. | Alps, Caucasus |
| Northern Eurasia | Includes the Hindu Kush and the Himalayas; specifically, the Pakistani provinces of Gilgit and the Indian provinces of Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim, Arunachal Pradesh as well Nepal and Bhutan as a whole. Beyond, South & Southeast Asia begins. In the Southeast, Northern Eurasia is delimited from South & Southeast Asia by the national boundary of China. Also includes Japan. | Urals, Hindu Kush, Himalayas |
| South & Southeast Asia | See above, includes islands to the east of New Guinea | Southeast Asian Massif |
| Africa | Delimited by the Isthmus of Suez and including Cape Verde, Madagascar, and the Mascarene Islands. | Ethiopian Highlands |
| North America | Bounded in the south by the US-Mexico border | Rocky Mountains |
| Middle America | Bounded in the north by the US-Mexico border and in the south by the Panama-Colombia border | Central Mexican Highlands |
| South America | Bounded in the north by the Panama-Colombia border | Andes |
| Oceania | Melanesia, Micronesia (including all Islands at the longitude of New Guinea and further east), and Polynesia |  |
| Australia |  |  |
| New Guinea | The island of New Guinea narrowly. Islands to the east were assigned to Oceania. | New Guinea highlands |
| Western Asia | The Middle East and those parts of Pakistan not assigned to Northern Eurasia |  |

Table 1. The eleven macroareas used in this study to control for large-scale contact-induced areality.

When in doubt as to which macroarea a language should be assigned to (for instance in case of languages that are spoken both to the north and the south of the US-Mexico border), we have relied on the latitude and longitude coordinates as provided by Glottolog. This, of course, is ultimately arbitrary, but unlike using these coordinates *tout court*, only a very small number of languages are affected. This procedure relieves us from making ad-hoc arbitrary decisions that might bias the outcome by referring to decisions that have been made earlier. As a final note, we have bypassed the difficult decision of assigning Aleut (spoken on the Aleutian islands) and Kalaallisut (spoken on Greenland) to any of the macroareas by leaving them unassigned (a problem Nichols 1992 dealt with by not including Eskimo-Aleut languages into the survey in the first place).

# 4. Analyses

## 4.1. Descriptive statistics

We begin our discussion of the data by providing some basic descriptive statistics. The mean altitude of languages with uvulars in the subset of the PHOIBLE data that we analyzed is 1136.301 meters above sea level (masl) (median 623 masl). The mean of languages without uvulars is 590.1413 masl (median 306 masl). The mean of languages with ejectives is 1236.913 masl (median 1136 masl). And the mean of languages without this class of sound is 606.0188 masl (median 304.5 masl). Thus, languages with both types of sounds are on average consistently spoken at higher altitudes than those languages that lack them.

Next we assessed mean evaluation of languages with uvulars and ejectives and those without them separately by the macroareas defined in Section 3.3. Table 2 provides the mean values for the eleven macroareas defined for this study, together with the number of languages contributing to each cell.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Macroarea | Mean elevation of languages with uvulars | *n* | Mean elevation of languages without uvulars | *n* | Mean elevation of languages with ejectives | *n* | Mean elevation of languages without ejectives | *n* |
| Europe | 872.9118 | 35 | 342.4667 | 81 | 1388 | 21 | 310.1573 | 95 |
| Africa | 755.3889 | 54 | 678.2531 | 653 | 1474.833 | 61 | 609 | 646 |
| New Guinea | 2184 | 1 | 645.0137 | 75 | n/a | 0 | 665.8108 | 76 |
| South & Southeast Asia | 722.8571 | 15 | 476.2844 | 219 | n/a | 0 | 491.6267 | 234 |
| South America | 1776.526 | 38 | 441.9898 | 296 | 1459.083 | 24 | 527.6645 | 310 |
| Northern Eurasia | 1755.964 | 59 | 1868.656 | 92 | 1303.75 | 4 | 1840.723 | 147 |
| North America | 627.1765 | 35 | 743.8364 | 56 | 749.6739 | 46 | 645.3488 | 45 |
| Australia | n/a | 0 | 190.6528 | 312 | n/a | 0 | 190.6528 | 312 |
| Middle America | 1034.6923 | 13 | 995.1892 | 37 | 1219.333 | 15 | 913.8 | 35 |
| Oceania | n/a | 0 | 300.3889 | 38 | n/a | 0 | 300.3889 | 38 |
| Western Asia | 875.2143 | 16 | 1340.6 | 5 | 1182 | 4 | 948.5333 | 17 |

Table 2. Mean elevation of languages with and without uvulars and ejectives for the eleven macroareas defined for this study and the number of languages in each group.

First, the table reveals some properties of the dataset that are worth bearing in mind. In some of the macroareas, such as Australia and Oceania, both uvulars and ejective consonants are completely absent (see also Figs. 1 and 2). In addition, New Guinea and South and Southeast Asia host a very small number of languages with uvulars; none have ejectives (see also Figs. 1 and 2). It is interesting to note, incidentally, that the implicated macroregions are not randomly distributed but jointly identify a significant contiguous subpart of the world in which these sounds are rare or absent.

Where uvulars and ejectives occur more frequently, it is almost always the case that languages with uvulars and ejectives are spoken in regions with a higher mean elevation than those that do not, although the difference is minimal in some cases. The major anomaly is Northern Eurasia, where languages without uvulars and ejectives obtain higher mean values than those with them. Going against the general trend are also North America and Western Asia, though with regard to uvulars only.

By and large, the descriptive summary statistics largely replicate the results obtained by Everett (2013a, 2013b) for ejectives. Furthermore, the fact that the generalization that languages with ejectives are on average spoken at higher altitudes than languages without them holds better than the analogous generalization (violated also in North America and Western Asia) might suggest that the relationship between ejectives and altitude is stronger than that between uvulars.

Hhowever, it is necessary to analyze the situation in much more detail and from different angles to assess the robustness of this first impression. For further analysis beyond descriptive statistics, here we combine a rigorous quantitative statistical and phylogenetic approach on the basis of the large-scale comparative data from PHOIBLE (as recently exemplified in the relevant line of research by Everett et al. 2015, 2016a and Roberts 2018) with a more qualitative intra-family analysis on the distribution and diachrony of relevant sound classes (as exemplified recently by Nikolaev and Grossman 2018), based on the conviction that such a combination of quantitative and qualitative perspectives allow for deeper insights into the analyzed phenomena than one of them alone.

## 4.2. Modelling the presence of ejectives and uvulars as a function of elevation

We first approach the question if the probability of observing languages with ejective and uvular consonants in the PHOIBLE data (as modified according to the procedures described in Section 3.2.) is greater at higher elevations by a global overall analysis of all available data. For this global analysis, we employ Bayesian logistic mixed effects regression as implemented in the R package brms (Bürkner 2017, 2018a, 2018b), which uses the Stan programming language’s interface with the R statistical programming environment (Stan Development Team 2018). We have included elevation as computed according to the procedure described in Section 3.2. as a fixed effect after applying a log10-transformation.[[3]](#footnote-3)

Specifically in the context of research on linguistic adaptation to environmental givens, Hammarström (2016) emphasizes the importance of controlling simultaneously for possible confounds due to genealogical “horizontal” dependencies (language relatedness) and areal “lateral” dependencies (due to prolonged coexistence in neighboring areas and interactions of speakers that led to contact-induced similarities) within the same analytic procedure. As Hammarström (2016) shows, when performing separate analysis to address their possible effects, can lead to conclusions that may be unwarranted. We have therefore included both genealogical affiliation and geographical location as captured by the eleven macroareas defined in 3.3. as random effects into our mixed model and fitted random intercepts for both variables. Since it is conceivable that, depending on area, contact patterns in different mountain regions (on which see the survey in Urban 2020) have differing effects on the distribution of uvulars and ejectives, we considered it advisable to also fit random slopes for the macroareas that we are using to control for contact-induced areality. We did not include random slopes for the genealogical structure of the languages in the dataset because of the impossibility to fit these given the large number of small language families and isolates (see Jaeger 2011: 298-299 for discussion). However, since this data structure is also of potential concern for random intercepts, we later provide intra-family and intra-area assessments of variation in the presence of uvulars and ejectives to compare these with the results of the model. We have placed a weakly informative prior of SD = 2 on the fixed effect to be conservative and to not constrain the model too tightly (even though with large amounts of data the prior should not affect the posterior distribution significantly; see Vasishth et al. 2018: 149-150) and otherwise used default priors for the standard deviation of random effects and residual errors, which are constrained to positive values (Vasishth et al. 2018: 150). We ran the model in four chains, with 6,000 warmups and 8,000 iterations each and the drift parameter delta set to .99.

R̂ values of 1 for each parameter, effective sample size estimates, and a visual inspection of the chains indicated that both models had converged, and comparisons of plots of observed data with posterior predictive samples showed that the models fit the data well. For each increase in altitude by 1 meter, the probability of observing a uvular increased by 3.6% (95% CI [2.6%, 5.5%]). However, the posterior probability of the effect being chance is relatively high (*p* = .23). In contrast, for each increase in altitude by 1 meter the probability of observing an ejective increased by 6.7% [3.4%, 8.9%], and the posterior probability of the effect being due to chance is relatively low (*p* = .017). In other words, the Bayesian mixed effect logistic regression supports an effect of altitude on ejectives more than it does for uvulars. In an additional analysis, we also assessed whether results were different when the original numeric counts were used for analysis. Under both explanatory accounts mentioned in section two, one might indeed hypothesise that elevation should not only have an effect on whether uvulars and ejectives are present or absent in a language, but also on the number of distinct segments of both classes, with languages spoken at higher altitudes enriching their segment inventories with more sounds of both classes than languages spoken at lower elevations. Indeed, the plots in fig. 3 suggest that there might be a mild tendency for the number of both classes of sounds that are found in the languages of the world to increase with altitude, too.

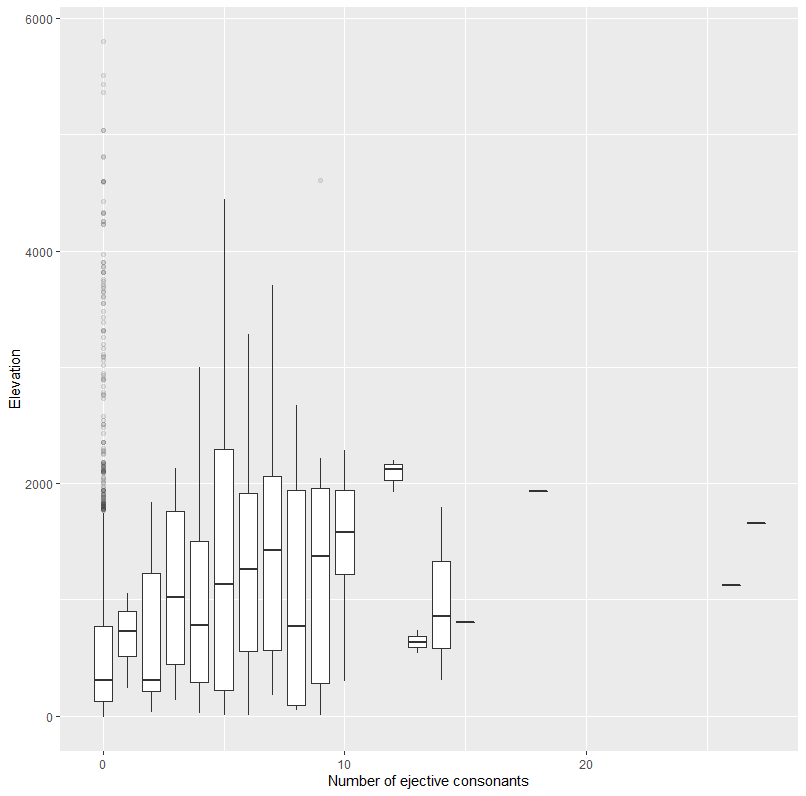
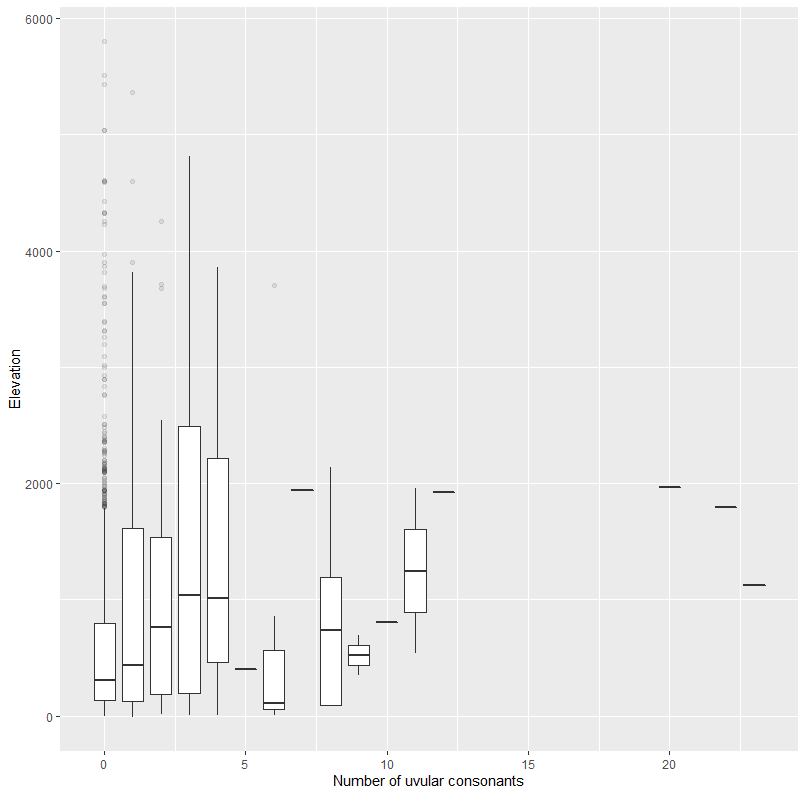


Fig. 3. Number of uvular consonants (left) and ejective consonants (right) in the PHOIBLE database as modified for this article.

To assess this more formally, we have built additional Bayesian mixed effect models, this time including the number of uvulars and ejectives rather than a binary classification as response but leaving other model parameters unchanged. Results of these ancillary models were similar to the main Bayesian mixed effects logistic regression in that the likelihood of observing ejective consonants increased moderately more strongly with altitude (3.5%, with a 95% confidence interval of [3.2%, 3.9%]) than did the probability of observing uvulars (3.3.%, with a 95% confidence internval of [3.1%, 3.5%]), and that the posterior probability of the effect being chance was low for the former (*p* = .0075) but high for the latter ( p = .17575).

As alluded to, the large number of isolates and small language families of the world, which are also present in PHOIBLE, is a concern for fitting random effects structures. We have therefore, in addition to the Bayesian logistic mixed effects regression, performed least squares regressions on the means of elevation and uvular and ejective proportions within macroareas and within language families. Bentz and Winter (2012: 8) suggest this additional analysis can be thought of as an analogue, in language typology, to a by-subjects and by-items treatment in a psycholinguistic experiment. For this additional analysis, we used the same macroarea breakdown described in Section 3.3. that is also included in the main model. For the intra-family analysis, we focused on language families that were represented in the PHOIBLE database by ten or more languages and in which either uvulars, ejectives, or both were actually attested, i.e. in Afroasiatic, Arawakan, Athabaskan-Eyak-Tlingit, Atlantic-Congo, Austronesian, Cariban, Dravidian, Indo-European, Mande, Mayan, Mongolic, Nakh-Daghestanian, Otomanguean, Quechuan, Salishan, Sino- Ta-Ne-Omotic, Tibetan, Tai-Kadai, Tupian, Turkic, Uralic, and Uto-Aztecan. Intra-area and intra-family means are plotted against altitude means in fig. 3.

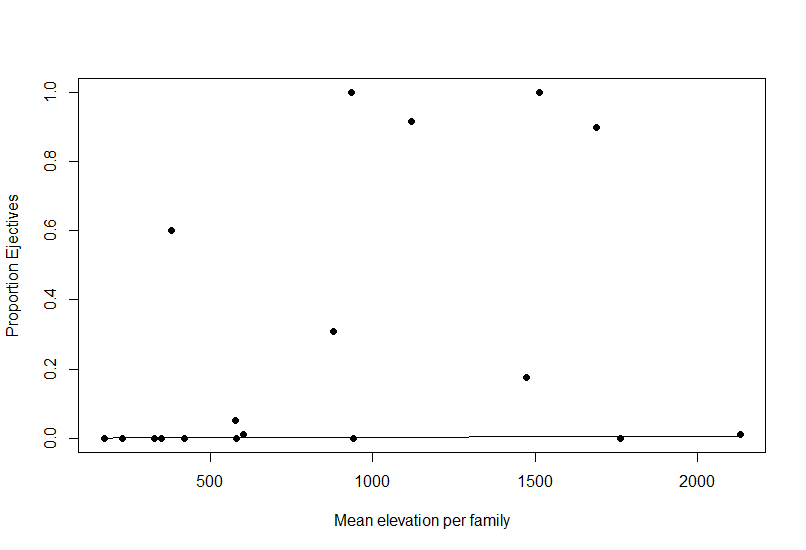
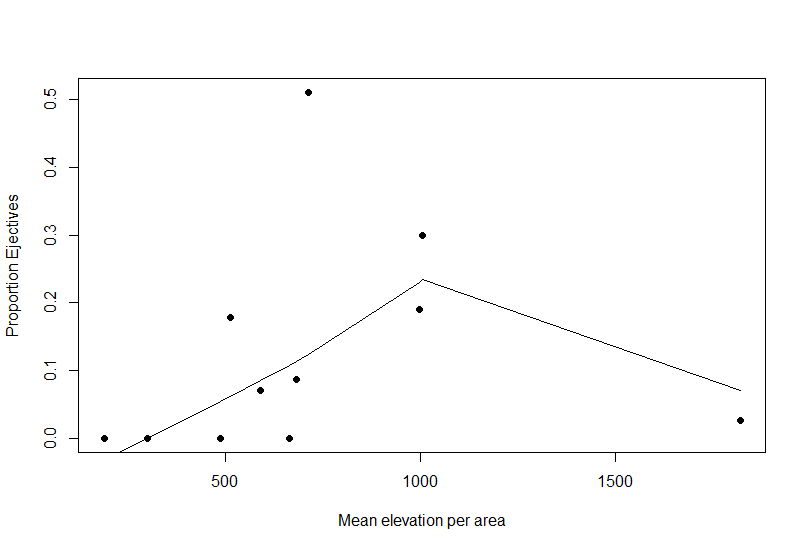
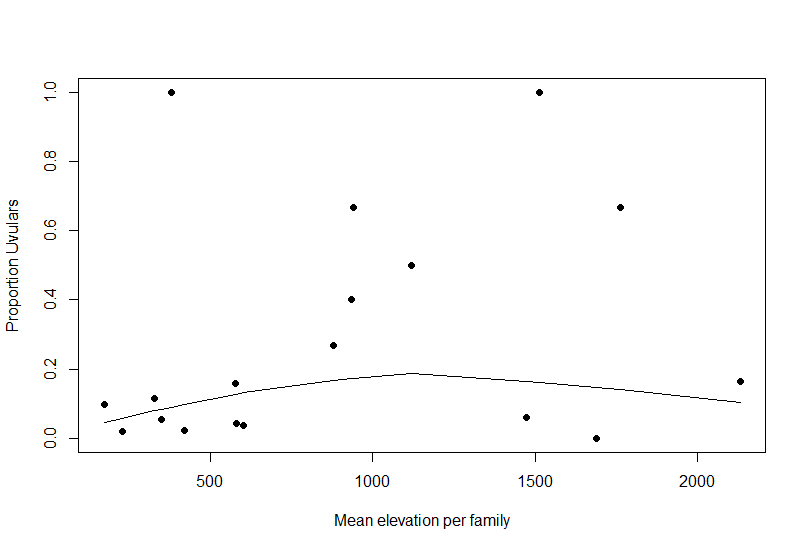
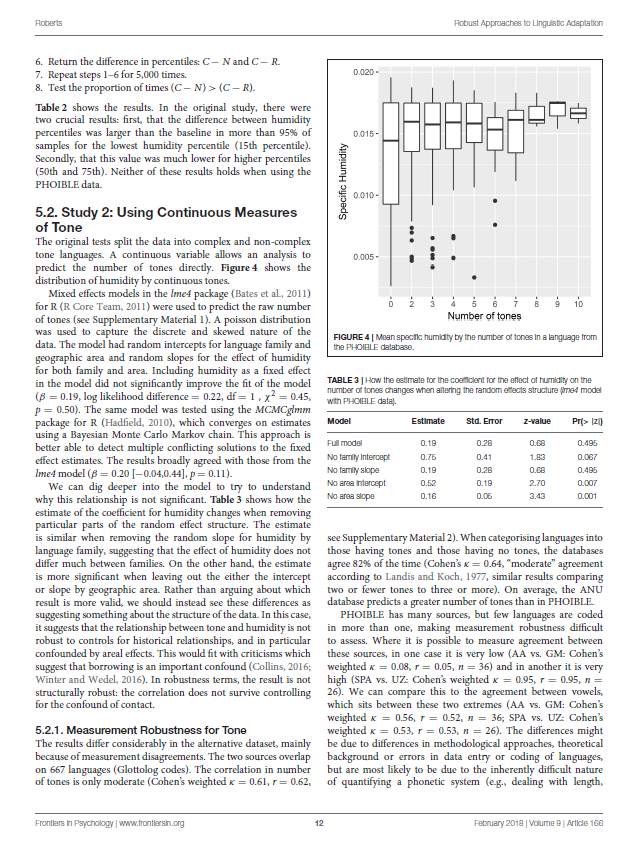


Fig. 3. Plots of intra-area and intra-family means for large language families with either uvulars or ejectives against altitude means; lines represent Lowess scatterplot smoothers.

Results of least square regressions were similar in that they have positive, but vanishingly small positive slopes. Moreover, with the only exception being the by-area treatment of uvulars which yielded a marginally significant result (p = 0.05829, Adjusted R2 = 0.2701), all analyses were insignificant and R2 values low, indicating that the fit to the data was poor. Generally, results for ejectives were not notably better than for uvulars, casting doubts on whether the conclusion that the distribution of ejectives is governed more significantly by altitude is robust.



## 4.2. Exploring the diachronic dynamics of ejectives and uvulars in language families

When modelling the distributions as in Section 4.1., we factor out genealogical information in order to abstract away from the vicissitudes of the phylogenetic histories of individual families. As Cathcart (2018: 1) points out, this does not make maximal use of the data because the evolutionary history of the traits of interest, which may allow for important insights into the genesis of the synchronically observable patterns, are artificially discarded. For instance, to decide whether any of the two alternative accounts for the observed distributions that have been sketched in Section 2 has merit, it is of significant interest whether ejectives and/or uvulars tend to *develop* within language families in high altitude environments -- or if they are *retained* there, but tend to be lost elsewhere (i.e. whether they are recessive in the sense of Nichols 2003, as is argued by Nikolaev and Grossman 2018 for retroflex affricatives). These diachronic perspectives are at the heart of recent research in distributional typology (Bickel 2011, 2015).

To assess the diachronic dynamics of both classes of sounds within language families, we chose to look at Indo-European and Sino-Tibetan -- two large and old language families of Eurasia. Members of these families are spoken across a multitude of different ecozones and altitudes, and given that in both cases several millennia have passed since their breakup from a common ancestor, there should have been ample opportunities for environmental effects on the structures of daughter languages to play out, if they exist.

Since we have reduced the PHOIBLE data to binary variables that simply register the presence vs. absence of uvulars and ejectives, we require a discrete variable model for phylogenetic reconstruction. We have used the phylogenies from Chang et al. (2015) for Indo-European and those from Zhang et al. (2019) for Sino-Tibetan. We have pruned these phylogenies to retain only those daughter languages that are represented in our dataset from PHOIBLE. This results in a phylogeny with 58 (75) tips (languages) for Indo-European and 39 (72) for Sino-Tibetan. In order to increase the coverage beyond the phonological inventories in PHOIBLE, we approached Harrold Hammarström and asked him to give us reports on those grammars in Glottolog that mention the presence of ejectives and uvulars. Hammarström has devised a data mining technique based on optical character recognition and regular expression searches, which identifies with some level of precision and recall, whether grammatical descriptions of a particular language contains or does not contain some linguistic feature. First we compared the results of this data mining technique with what we observe in PHOIBLE and the results were quite accurate. Given the accuracy, we extended our data set for the presence vs. absence of ejectives and uvulars to the full set of grammatical descriptions available for these two language families and we extended our language sample coverage to 75 languages in IE and 72 in ST.

First, we plot each phylogeny and the presence or absence of ejectives and uvulars, as shown in Fig. 4. Ejectives are exceedingly rare in both language families. In the subset of Sino-Tibetan languages that we analyze here, they are only found in Khams Tibetan. In the Indo-European languages we analyzed, they are restricted to Ossetic and eastern Armenian. Uvular consonants are somewhat more frequent in both families and approximately in line with the cross-linguistic mean proportion in Europe and Northern Eurasia (ca, 30% and 39% respectively). Note, however, they are distributed widely across the phylogenies of both families. Tikkanen (2008: 254) describes a velar:uvular contrast as a “macroareal feature extending from North Africa over southwestern Asia to large parts of (especially middle and southern) Central Asia and –discontinuously– some parts of north Asia (northwestern and northeastern Siberia) and even Southeast Asia (Khmer).”

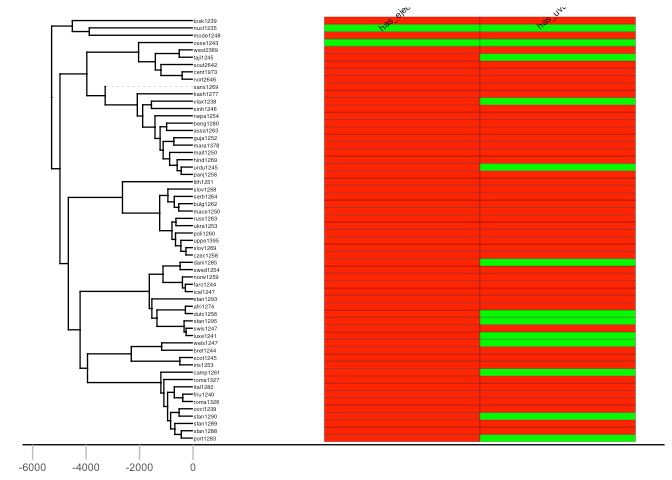
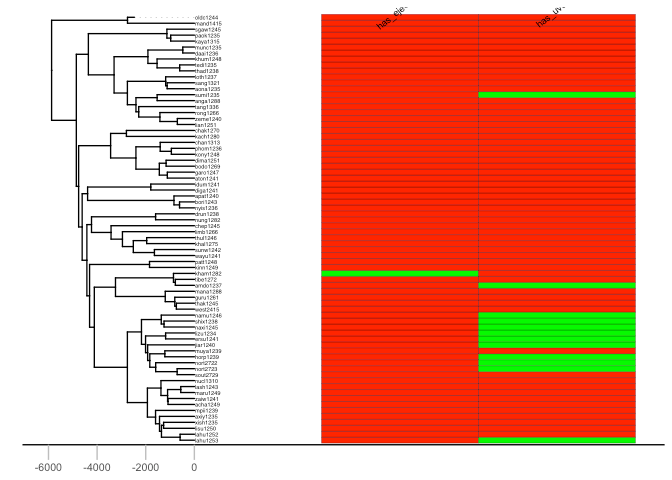
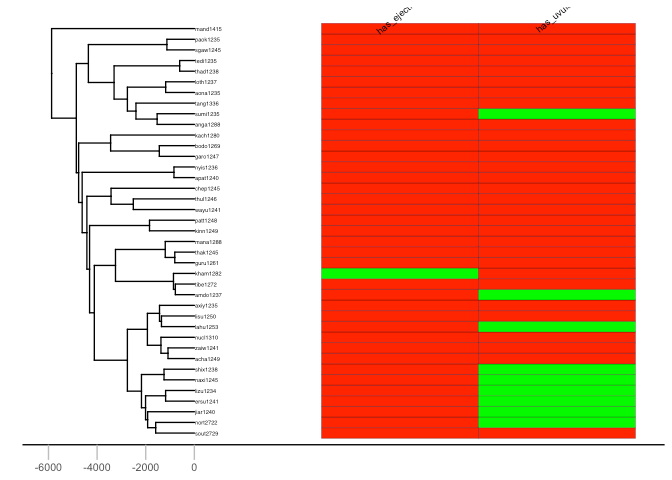
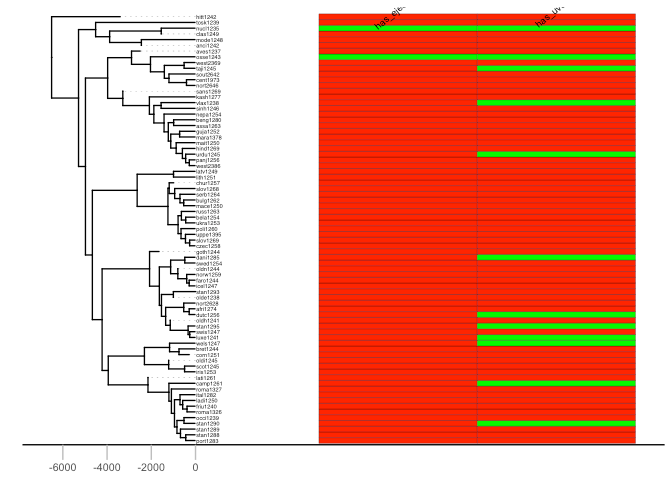


Fig. 4. Uvular and ejectives in Indo European (top) and Sino-Tibetan (bottom). Left hand plots represent the results of the analysis for the PHOIBLE data alone, right hand plots the results for the amended data by means of grammar mining.

Next, we generated stochastic character maps (Nielsen, 2002; Huelsenbeck et. al, 2003; Revell, 2012) using the make.simmap function from the R package phytools (Revell 2012) for an all rates different (ARD) model where q is set to empirical (maximum probability, full Bayesian MCMC) with 10 simulations on the ACQDIV phonology data. Stochastic character mapping …

As shown in Figures 5 and 6. show, neither trait is reconstructed far back in the respective phylogenies, though there is an interesting signal regarding uvulars in Sino-Tibetan which, on the basis of the phylogenetic reconstruction, appear to have been innovated at one point in a subgroup and then passed down to several present-day Sino-Tibetan languages.

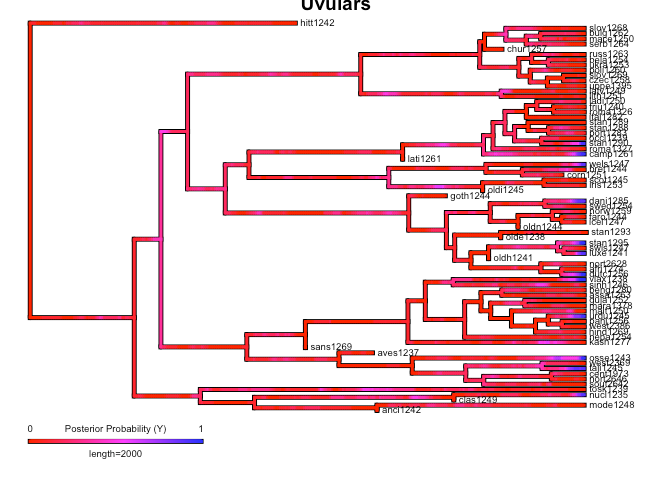
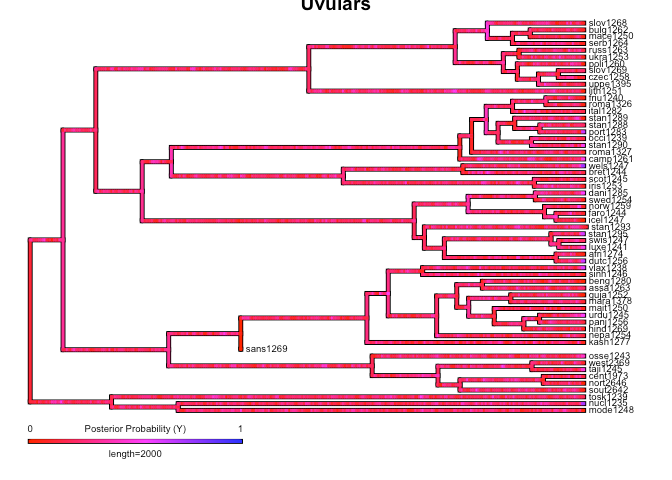
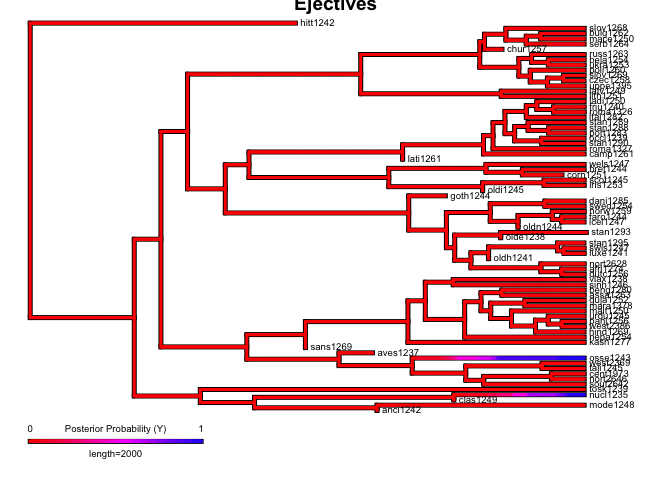
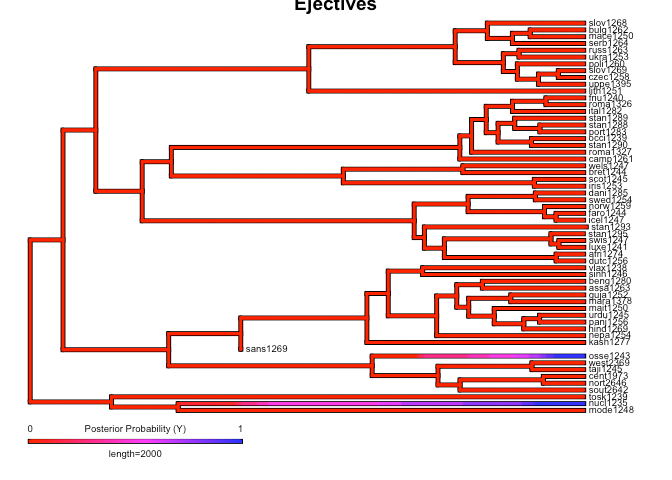


Fig. 5. Phylogenetic reconstruction of uvulars (top) and ejectives (bottom) in Indo-European. Left hand plots represent the results of the analysis for the PHOIBLE data alone, right hand plots the results for the amended data by means of grammar mining.

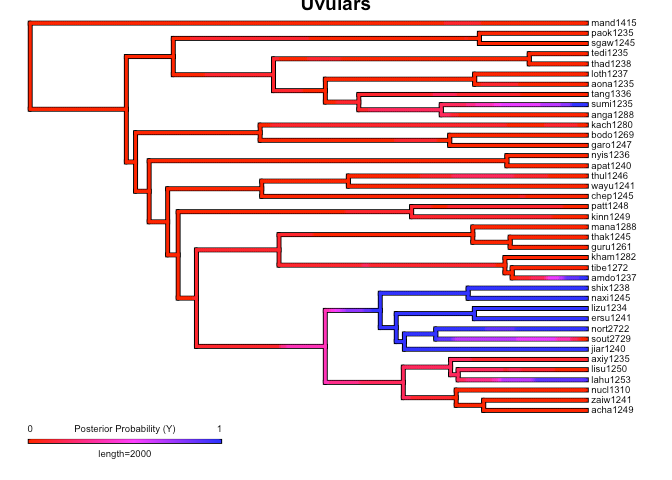
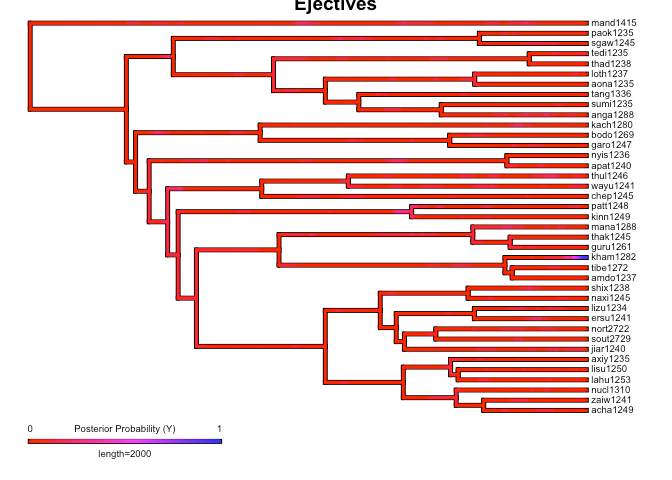
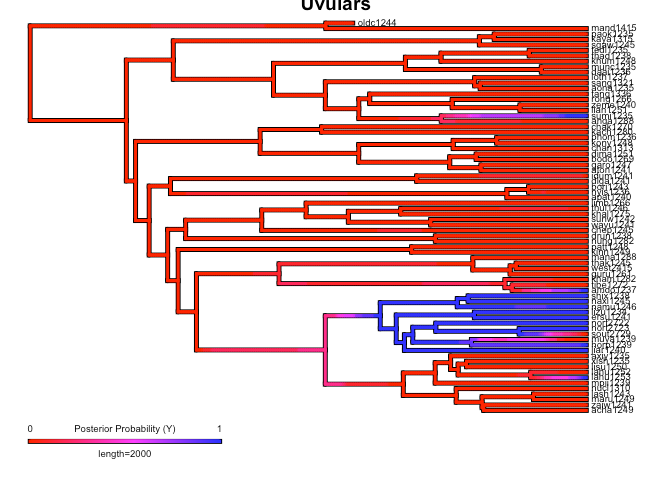
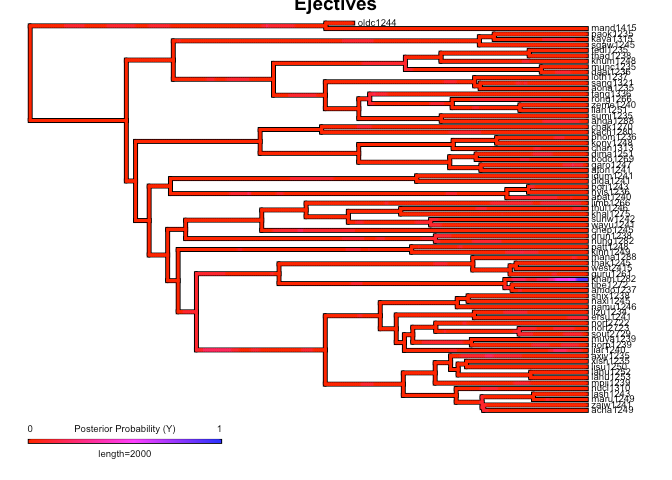


Fig. 6 Phylogenetic reconstruction of uvulars (top) and ejectives (bottom) in Sino-Tibetan. Left hand plots represent the results of the analysis for the PHOIBLE data alone, right hand plots the results for the amended data by means of grammar mining.

Next, we proceed by providing an interpretation of the phylogenies, taking into account also the pertinent published literature on the diachrony of the involved languages and language families.

As far as ejectives in Indo-European languages are concerned, their genesis is fairly well understood. The diachronic development of ejectives in Ossetic is usually attributed to contact with neighboring Nakh-Daghestanian languages of the Caucasus, which are rich in ejectives. In Ossetic, direct loans from Nakh-Daghestanian account for the ejectives in most language’s lexical items (Job and Schäfer 2006), but there is also regular sound change that gives rise to them and that likewise can plausibly be theorized to have been triggered by Nakh-Daghestanian influence (Thordarson 2009, Blevins 2017, Belyaev 2019). As far as we can ascertain, the majority opinion on ejectives in Armenian is that they are contact-induced, too, though there is an alternative theory that holds that they are instead directly inherited from proto-Indo-European, under the assumption of some version of glottalic theory (Gamkrelidze and Ivanov 1973, Hopper 1973, see Barrack 2002 for review). Interestingly, however, proponents of this alternative view argue that contact actually is involved. Instead of inducing the genesis of ejectives in Eastern Armenian, as was the case for Ossetic, in this case it is rather argued that their proximity “favored the preservation of a feature which was already present” (Kortlandt 1985: 190). Whatever took place, it was at a relatively high altitude environment in the North Caucasus.

Since ejectives are not a significant factor in Sino-Tibetan languages, we move on to a discussion to uvulars, again starting with Indo-European. To begin with, it is remarkable that among the Indo-European languages with this type of sound are exactly in Ossetic and Armenian. These languages, thus, do not only replicate one particular class of sounds of Caucasian languages, but rather have similar consonant inventories as Caucasian languages more generally, as Caucasian langauges are saliently characterized by rich systems of both ejectives and uvulars. Klimov (1965), Catford (1977) and Chiribka (2008) all noted that both ejectives and uvulars are areal features of the Caucasus; however, the wider proliferation of uvulars in Northern Eurasia has led Tuite (1999) to question the possibility of using these as area-defining features (see also Colarusso [1988]2016). Nevertheless, the uvular inventories of Caucasian languages is usually larger, by far, than those of other European languages (Chiribka 2008: 47-48). While the decision whether uvulars in the Caucasus can or cannot be considered a contact-induced areal feature is a matter for specialists to decide. Here, we wish to note that also in the mountains of the Hindu Kush, there are higher than expected frequencies of uvulars in Indo-European languages, when compared with the cross-linguistic average as represented in Maddieson’s (2013c) WALS chapter (Liljegren 2017: 121). Contact with the prestigious Persian language, which has a uvular, is a relevant factor for the occurrence of uvulars in Indo-Aryan languages of the Hindu Kush, where they occur in Perso-Arabic loanwords as a “prestige pronunciation” (Liljegren 2017: 121). Indeed in some but not all Indo-Aryan languages, uvulars have a somewhat marginal status. Note also that in other Indo-Aryan languages, the contrast between velar and uvular stops is not always strongly established (Tikkanen 2008: 253). However, as is the case with ejectives in Ossetic, they are more deeply entrenched in the phonological inventories of languages from the northern part of the Hindu Kush, where they are also found in native vocabulary (Liljegren 2017: 121). Tracing the history further back, the Persian uvular itself, while having internal sources, earlier received a major “boost” in frequency and functional load through the massive influx of Arabic loanwords (Bijankhan 2018). Here, we can trace aspects of the genesis of the areal-typological uvular belt from northwest Africa to Central Asia which Tikkanen (2008) describes to individual language contact events. Uvular consonants, especially rhotics, however, are also prominent in many languages of Europe. Again, the history of this phenomenon is contact-induced: uvular articulation of the rhotic originated in the Parisian dialect of French in the 17th century, and, as is the case for the Hindu Kush, spread as a prestige phenomenon from there; first to the metropolitan centers of other countries (and thereby across language boundaries) and from there further also to more rural areas(Trudgill 1974). While of course this literature review is selective, and there are cases including Turkic and Mongolic, where uvulars arose apparently entirely from internal sources through the phonologization of an originally allophonic variation in the context of back vowels that still persists in some languages (Tikkanen 2008). Note however, that the present-day distribution of uvulars is strongly influenced by areal factors, and language contact seems to have played a significant role in its genesis.[[4]](#footnote-4)

Finally, we explored the apparent phylogenetic signal in the diachronic development of uvulars in Sino-Tibetan; in particular, with a view to assessing whether it may have something to do with the environment in which diachronic development took place.[[5]](#footnote-5) In the PHOIBLE, uvular consonants are found in various places of the Sino-Tibetan phylogeny, and we will not trace their history within the entire family here in full detail. In a nutshell, it seems that uvular sounds can be reconstructed to the proto-language, but merged with other sounds in different branches at various points of time. For instance, Old Chinese still retained uvulars, but modern Chinese has lost them (Hill 2019: 32-33; 45). As far as the PHOIBLE data are concerned, however, there are two highland subgroups of Sino-Tibetan languages where they cluster together densely. These are Naic and Qiangic, which are hypothesized to form a common Na-Qiangic node together with Ersuic, where uvulars are also found (Michaud 2013: 13-14). Note however, Michaud (2013) admits that speculation is involved and even Qiangic itself is not universally accepted (Chirkova 2012). Uvulars are indeed reconstructed for proto-Naish (a subgroup of Naic, Jacques and Michaud 2011: 492), and they have also been used to characterize Qiangic (Chirkova 2012: 137) and might reconstruct to proto-Qiangic under the assumption that the group is valid (Hill 2009: 124). However, as Chirkova (2012: 147) also notes, they are also found outside Qiangic, including “in a number of Tibetan dialects spoken in the zone of distribution of Qiangic languages,” i.e. Eastern Tibet and adjacent parts of Sichuan and Yunnan. The pruned phylogeny for our phylogenetic study does not reflect that well because the Tibetan evidence is mostly removed from the phylogenetic analysis as relevant Tibetan languages are not included in the phylogeny by Zhang et al., (2019). Hill (2009: 124) makes similar observations regarding the geographical distribution of uvulars in Tibetan, noting that also other Sino-Tibetan languages in this region, as well as the Mongolian language Mongour, have uvulars. Hill says that, “[t]he region can be regarded as a uvular prone Sprachbund.” Tentatively, Hill states that uvulars could have emerged in the Tibetan and Mongolian languages of the region due to a Qiangic substrate, given that the class of sounds seems to be more well-entrenched in this group of languages. In sum, there is a phylogenetic signal in that several authors suggest the reconstructability of uvulars to low-level ancestors of local Sino-Tibetan subgroups,. However,the pattern of contact-induced emergence of uvulars that we have observed repeatedly elsewhere resurfaces at least equally prominently albeit here, as Hill (2009) suggests, possibly by a sub- rather than superstratum effect.

Now, even though it seems clear for some cases surveyed here that contact was the main driver for the diachronic development of ejectives and uvulars, could this perhaps be only the proximate reason, and could the ultimate reason why they were replicated through contact be an adaptation to high-altitude environments such as those of the Northern Caucasus and Eastern Tibet through language contact effects? Urban (2018) observed that the extant literature is often Janus-faced when it comes to this question. Where there is clear evidence for contact as the factor that generated the spread of phonological phenomena across language and language family borders, this is swiftly integrated into an account based on adaptation to environmental conditions by stating that relevant features may have spread through contact precisely because they are adaptive (e.g. Everett et al. 2016b: 86 in response to Collins 2016). However, note that Eastern Tibet, where some amount of convergence regarding uvulars seems to have taken place, is notably lower in elevation than Western Tibet and has a markedly different climate and vegetation. One would accordingly have expected that convergence would rather take place at the highest altitudes, if altitude were the driving factor. However, the language dynamics of altiplanos, such as the Tibetan Plateau, are usually different from mountain areas with a central crest (Nichols 2015). Therefore, the account that operates with the assumption that higher altitude induces sociolinguistic isolation does not necessarily apply straightforwardly for these. More generally, we observe the spread of uvulars at both high and low altitudes (i.e. in Europe), which is another reason for caution before adding another explanatory layer behind the contact-induced account (cf. Hammarström 2013 for similar reasoning). In sum, where uvular and ejectives were innovated contact, rather than sociolinguistic isolation, seems to be the decisive factor.

# 5. Discussion

In this contribution, we have examined the cross-linguistic distribution of two classes of sounds, ejectives and uvulars. We have sought to establish to what extent this distribution is predicted by environmental factors, concretely, the altitude of the area in which these languages are spoken. Our analyses were carried out in light of two competing hypotheses that may account for that distribution: the first, due to Everett (2013a), invokes the adaptive value of ejectives in high-altitude environments because of the reduced articulatory effort of these sounds and/or the advantage in preventing desiccation in the low ambient humidity. The second, alluded to by Nichols (2012), rather, operates on considerations having to do with sociolinguistic typology; specifically, sociolinguistic isolation (manifested e.g. by intra-community use of languages at the highest altitudes and little L2 learning) leads to the accruing of complex and marked language structures generally, a characterization that applies to both ejectives and uvulars.

Our analyses offer significant improvements in terms of the primary data, i.e. we use the broad cross-linguistic coverage of the PHOIBLE database to follow up on previous work by Everett (2013a, b) and a metric for altitude that avoids the simplistic use of more or less arbitrarily chosen point coordinates.

Roberts (2018) argues for a robustness approach to the analysis of adaptivity of languages to their environment. This entails, among other things, the test of pertinent hypotheses against different datasets and the use of different statistical methods to assess if, or to what extent, analyses converge on similar results. Rather than a single outcome, this yields a “space of results” that jointly gives an idea of the robustness of the tested hypothesis, which should ideally not be developed ad-hoc, but instead be based on already existing theoretical arguments and experimental evidence. Another hallmark of our approach is its reliance on incremental research: by testing already developed hypotheses on a different dataset against which they have not yet been evaluated, and by systematically comparing it with a conceptually different alternative that was not yet been evaluated statistically, our contribution fits squarely within this approach.

On this basis, a Bayesian mixed effects logistic regression showed that altitude has a larger effect on the probability of finding ejective consonants in a language than it does on uvulars, though by-area and by-family treatments did not allow us to replicate the overall stronger effect of altitude on the posterior probability of the mixed model. Given this result, we have modelled the phylogenetic evolution of both classes of sounds in two large families of Eurasia (Indo-European and Sino-Tibetan) and have couched the interpretation of our results of the phylogenetic analysis in a selective qualitative survey of the pertinent literature. This survey suggests a strong role of language contact in the diachronic development of ejectives in Indo-European and of uvulars in both Indo-European and Sino-Tibetan. This is a situation that is at odds with the scenario that would be predicted by the alternative explanation for the distribution, which instead of arguing for adaptiveness of linguistic structure to environmental givens, would consider elevation as a proxy to sociolinguistic isolation. Both ejectives and uvulars seem to be prone to spread across language boundaries in language contact situations. Maddieson (2013b) notes similar behavior for clicks and labiovelars: “the evolution or adoption of sounds of these two classes in the sound system of a language is strongly influenced by hearing these sounds in other languages spoken in the same area” and the same thus, seems to be true for the two classes of segments which we investigate here. Together with the weak predictive power of altitude on the distribution of uvulars in our Bayesian modelling, our result leads to increased doubt regarding the sociolinguistic isolation account, at least in the rather simplistic manner in which it is presently operationalized. But also ejectives have been shown to figure prominently as the targets of replication in contact situation – analogously to the case of Ossetic and, more controversially, Eastern Armenian, they are likely to have been transferred from Aymaran to Quechuan languages in southern Peru and Bolivia in a situation of intense language contact. This is not in principle incompatible with the idea that ejectives are adaptive in high-altitude environments as they may spread in language contact precisely because of their adaptive value. However, as we have noted, before accepting this idea fully, it would be necessary to specify the relationship between language contact and adaptiveness in a theoretical framework, as this relationship often remains blurry and ambiguous in extant work.[[6]](#footnote-6)

A final observation that remains to be reiterated is the striking co-occurrence of both classes of sounds which, in fact, was one of the motivating factors for us to consider sociolinguistic isolation as a possible alternative explanation that would account for the distribution of ejectives, but also other types of rare and articulatorily costly segments in the first place. In the case of Ossetic we have seen that this language has not simply evolved ejectives under Nakh-Daghestanian influence, but rather the same characteristic combination of ejectives and uvulars that is found in Nakh-Daghestanian (and Caucasian languages more generally). These cases are representative of a more common cross-linguistic pattern. PHOIBLE contains data from 248 different language families (including isolates as singleton families). Of these, only 68 (ca. 28%) feature uvular consonants, and only 65 (ca. 26%) ejective consonants, highlighting once more the relative rarity of both classes of speech sounds. There is no logical necessity that both classes of sounds should co-occur in the same languages and language families. However, the distribution of the sounds is strikingly correlated, with a Jaccard similarity coefficient of approximately .41 (computed using the jaccard.test function as implemented in the R package jaccard, Chung et al. 2018) Given the overall frequency of language families with the two classes of sounds, this is extremely unlikely the result of chance (p < .0000000001).

This suggests that there may actually be common underlying conditioning factors that govern the distributional typology of both classes of sounds and on which it is predicated.[[7]](#footnote-7). What these factors are, and in what terms (typological, sociolinguistic, diachronic, or a combination of these and/or other phenomena) they can be described, is an open and interesting question. Given the intricate entanglement of linguistic behavior, socioeconomic organization, environment and its topography and the cumulative effect that these factors have on language history and diachronic development, it might well be the interaction of several factors which, nevertheless, yields a striking clustering of ejectives and uvulars often in the same languages and language families. If elevation, either directly though adaptiveness, or indirectly as conducive to sociolinguistic isolation has a (limited) role to play, remains an area for further research to determine.

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1. For defining “high elevation zones” as those at 1,500 meters above sea level or greater, reference to Cohen and Small (1998) is made, but no rationale for the decision to include a 200km perimeter is initially given. [↑](#footnote-ref-1)
2. Everett (2013b) addresses a similar scenario which has been suggested to him in personal communication by unnamed third parties: “In addition, several readers suggested that the correlation may be due to the isolation of languages in mountains, which are somehow more likely to retain ‘odd’ sounds like ejectives due to reduced inter-linguistic contact. This would be an interesting finding in and of itself, and would offer strong evidence for an indirect influence of geography on phonology, but it too is transparently flawed. It does not explain why, for instance, implosives (which are about as common as ejectives), or any number of other sounds, do not correlate with high elevation.” Everett is, of course, right that implosives – always simply on the basis of a mere visual inspection of maps (e.g. Maddieson 2013) – appear to exhibit a quite different geographic patterning. However, since contrary to this outright dismissal, there is preliminary reason to think that “any number of other sounds” actually do correlate with high elevation, hence we consider this preliminary and subjective assessment as a sufficient incentive for further exploration. [↑](#footnote-ref-2)
3. This is because of an extreme left skew in the distribution of the altitudes at which languages are spoken – as human populations are typically much denser at low altitudes (Cohen and Small 1998) so is apparently language density. [↑](#footnote-ref-3)
4. Matras (2009: 270), furthermore, considers a uvular stop as an areal feature of present-day Anatolia. [↑](#footnote-ref-4)
5. One article which we unfortunately could not take into account in our evaluation is Liu (2010). [↑](#footnote-ref-5)
6. Moreover, regarding the Quechuan-Aymaran case, there is strong evidence that the factor that motivated the adoption of ejectives in Quechuan and that facilitated their spread through native Quechuan were iconic values associated with them locally (Mannheim and Newfield 1982, Mannheim 1991). Any argument that would seek to posit adaptiveness as a still more basic principle behind the diachronic developments would be faced with the challenge to factor this fact in. [↑](#footnote-ref-6)
7. This suggestion is also fueled by the striking absence or exceeding rarity of both classes of sounds in certain regions of the world such as New Guinea and Australia. [↑](#footnote-ref-7)