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INTONATIONAL ANALYSIS AND PROSODIC ANNOTATION OF GREEK SPOKEN CORPORA

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1 INTRODUCTION

This paper provides an analysis of the prosodic and intonational structure of Greek within the autosegmental/metrical framework of intonational phonology (Pierrehumbert, 1981; Pierrehumbert & Beckman, 1988; Ladd, 1996), and presents Greek ToBI (henceforth GRToBI), a system for the annotation of Greek spoken corpora based on this analysis. Both the analysis and the annotation system have largely been developed on the basis of a corpus of spoken Greek, especially collected for this purpose, and including data from several speakers and a variety of styles (read text, news broadcasting, interviews, spontaneous speech). The linguistic variety analyzed—and the one for which GRToBI was conceived and designed—is Standard Greek as spoken in Athens. It is our hope that other varieties of Greek will be similarly analyzed, and that eventually GRToBI will be adapted for the annotation of corpora in those varieties as well.

2 STRESS AND RHYTHM

Greek is a stress accent language, described in traditional grammars as having "dynamic stress" (among others, Joseph & Philippaki-Warburton, 1987). Stress is acoustically manifested as either longer duration or higher amplitude of the stressed syllable (or both), making *total amplitude* the most robust cue to stress (Arvaniti, 1991; 2000).

Primary stress cannot be predicted from phonological structure, as there are no syllable weight distinctions in Greek and stress is not fixed. The main phonological limitation on the position of primary stress is that it must fall on one of the last three syllables of the word (Joseph & Philippaki-Warburton, 1987; Setatos, 1974). In all other aspects, stress placement

within this three-syllable window is largely determined by morphology (Drachman & Malikouti-Drachman 1999; Revithiadou, 1998). At the lexical level, there are no other stresses in addition to primary stress.

The presence of *postlexical* rhythmic stresses, on the other hand, is disputed. Malikouti-Drachman & Drachman (1981) and Nespor & Vogel (1989) suggest that rhythmic stresses appear regularly to remedy stress lapses in Greek. This claim, however, is not supported either by acoustic evidence or by the native speakers' intuition (see Arvaniti 1994, and references therein). Thus, we assume here that at the postlexical level, as well as lexically, there is only one stressed syllable per word.

There is one regular exception to this stipulation, however: content words stressed on the antepenult (or the penult) and followed by one (or two) enclitics acquire an additional stress two syllables to the right of their lexical stress; e.g.

(1) /ˈfernodas to mu/ > [ˌferno'dastomu] "bringing it to-me"

(2) /to teˈtraðio mu/ > [to teˌtraði'omu] "the notebook my."

For convenience, we will follow the practice of Greek grammarians and call the added stress of such sequences "enclitic stress," although it does not usually fall on the enclitic itself, as examples (1) and (2) show.

In contrast to words with enclitic stress, there are several polysyllabic function words in Greek which are normally uttered without stress, and thus form part of the following content word (with which they are syntactically, as well as prosodically, linked); e.g.

(3) /aˈpo noˈris/ > [apono'ris] "since early"

(4) /kaˈta to ˈspiti/ > [katato'spiti] "towards the house"

(5) /aˈna tin iˈfilio/ > [anatini'filio] "all-over the globe."

As shown in examples (4) and (6), some of these words in fact contrast with stressed homophones.

(6) /kaˈta tu ˈɣamu/ > [kaˈta tuˈɣamu] "against (the) marriage."

With respect to rhythm, Greek has been described as syllable-timed, though Dauer (1983) places it somewhere in the middle of the continuum she proposes between stress- and syllable-timing. Arvaniti (1994), however, points out that by Dauer's own criteria (1983;

1987) Greek should be a prototypical syllable-timed language, virtually devoid of stress; such a description, however, is not supported either by acoustic data (e.g. Arvaniti, 1991; 1992; 2000; Botinis, 1989), or the fact that Greek has several minimal pairs and triplets distinguished solely by stress placement. Instead, Arvaniti (1994) proposes that rhythm in Greek (as in all languages) is based on the alternation of strong and weak prosodic constituents. The difference between languages described as stress-timed, e.g. English, and languages described as syllable-timed, e.g. Greek, lies in the fact that the former have a strong tendency for keeping this alternation as even as possible, by using various strategies to eliminate stress clashes and lapses; in contrast, the latter seem to allow for less eurhythmic patterns, i.e. they tolerate clashes and lapses to a greater extent.

3 INTONATIONAL PHONOLOGY

For the intonational analysis of Greek we recognize three types of tonal events: *pitch accents*, which associate with stressed syllables, and two types of phrasal tones, *phrase accents* and *boundary tones*, which associate with the boundaries of intermediate and intonational phrases respectively. In contrast to stress, which as mentioned is lexically determined, the tones are morphemes that encode pragmatic information. Therefore, it is not expected that every stressed syllable will be accented (see also section 4.1).

3.1 The pitch accents

Greek has five pitch accents, L*+H, L+H*, H*+L, H* and L*. By far the most frequently used pitch accent is L*+H, which is the predominant choice for pre-nuclear accented syllables. Because of its distribution, L*+H has often been referred to as the "pre-nuclear" accent of Greek (Arvaniti, Ladd & Mennen, 1998; Baltazani & Jun, 1999). In our corpus, however, this accent was frequently attested in nuclear position, in calls, imperatives, negative declaratives and wh-questions.

Phonetically, the L*+H is manifested as a gradual rise from a trough (the L tone) to a peak (the H tone). In canonical conditions, that is if there are at least two unstressed syllables between consecutive L*+H accents, the L is aligned at the very beginning or slightly before the onset of the accented syllable, and the H at the beginning of the first post-accentual vowel (Arvaniti & Ladd, 1995; Arvaniti *et al*., 1998). The rather atypical alignment of the tones in the L*+H accent has given rise to a great deal of fluctuation in its description (see also Arvaniti, Ladd & Mennen, 2000, on the problems that the alignment of L*+H may pose for

the notion of starredness). In GRToBI this accent is analyzed as L*+H, because our corpus and the comparison of other quantitative data (Arvaniti *et al.* 1998; Arvaniti, Ladd & Mennen, ms.) showed that it is in contrast with another accent, which can be unambiguously described as L+H*.

As illustrated in Figure 1, in L+H* the H tone appears roughly in the middle of the accented vowel (Arvaniti *et al*., ms.), unlike L*+H which shows late alignment of the H tone. Furthermore, the two accents are functionally distinct, with L+H* often used to signal narrow focus, as illustrated in Figure 10 (Arvaniti *et al*., ms.; Baltazani & Jun, 1999; Botinis, 1998).

The two bitonal accents are in contrast with the monotonal H* accent. As can be seen in Figure 2, H* lacks the initial dip associated with the L tone of L+H* and L*+H. Rather, there is a declining plateau between the H tone of the last L*+H accent in the utterance and the nuclear H* (hence the use of the downstep diacritic, !, which however *does not* denote a distinct phonological category; for further details see sections 3.2 and 5.1). In Greek, this plateau does not exhibit the "sagging" posited by Pierrehumbert (1981) as a possible type of interpolation between successive H*s in American English. When H* is used as the nuclear accent in a declarative utterance, as in Figure 2, it signals broad focus, and thus contrasts with L+H*, which signals narrow focus in the same context.

In nuclear position in declaratives, the H* also contrasts with H*+L. From a pragmatic point of view, H*+L conveys a more nonchalant (or even wearied) attitude on the part of the speaker than H*. Phonetically, it is realized as a fall from high pitch, with the fall being completed by the end of the accented syllable. On this point, it is useful to compare the low stretch of the two contours shown in Figure 3, which illustrates the difference between H*+L and H*: as can be seen, when the pitch accent is H*+L the bottom of the speaker's voice is reached at the end of the accented syllable; in contrast, when the pitch accent is H*, this lowest F0 point is reached at the end of the first postnuclear syllable and the fall is realized in three discernible steps.

It should be noted that in an earlier version of GRToBI we had analyzed H*+L as !H* (Arvaniti & Baltazani, 2000). We have now revised our position, to bring the use of the downstep feature more in line with that in other ToBI systems, in which downstep—for obvious reasons—cannot be used utterance-initially (as we would be forced to do in Figure

3). Furthermore, it is clear that H* and H*+L are phonetically distinct, and thus analyzing H*+L as a "scaled down" version of H* is not well motivated. Finally, it appears that !H* is needed for cases of "scaled down" H* pitch accents, like the one shown in Figure 8. Despite these indications against our original analysis, it is not the case that the analysis of this accent as H*+L is entirely unproblematic; for example, it is not obvious why in Figure 3, H*+L is scaled lower than the utterance beginning. Clearly then the utterances in Figure 3 and similar isolated examples do not provide sufficient evidence on which to choose one alternative over the other. Rather controlled experiments are needed to provide a definitive solution to this problem.

Finally, the L* accent is typically realized as a low plateau, as shown in Figure 4. The L* appears as the nuclear accent before a "continuation rise" (Baltazani & Jun, 1999), in yes-no questions (Arvaniti *et al*., ms.; Baltazani & Jun, 1999) and in the calling contour we term "suspicious" (see Table 1).

3.2 Downstep and the phonetic realization of pitch accents

The descriptions presented above provide a sketch of the phonetic realization of the pitch accents under canonical conditions. However, pitch accents show significant contextual variability as regards both the scaling and the alignment of their targets, with tonal crowding and downstep being the main influences.

Concretely, L*+H and L* exhibit noticeable variability in contexts of tonal crowding, i.e. when several tones must be realized within a short segmental stretch. Previous research (Arvaniti, 1994; Arvaniti *et al*., 1998; 2000) and the data of our own corpus show that the speakers adopt mainly three strategies to cope with the tonal crowding of consecutive L*+H accents. Specifically, they may (a) undershoot the L tone of the second of the two L*+H accents; (b) realize the first accent earlier than normal and undershoot the second one (as illustrated in Figure 5); (c) realize the first accent earlier and the second one later than normal. Similarly, in cases of tonal crowding, L* accents are realized as rising from a low point, as in [mo'ro] in Figure 9.

There are two complementary explanations for the observed patterns. First, Greek favors the undershooting of all underlying tones to the truncation of some of them (for the distinction between undershooting and truncating languages, see Grice, D'Imperio, Savino & Avesani,

this volume; Ladd, 1996). It follows that L*+H, which requires at least two syllables for its canonical alignment, will be the accent most prone to undershoot. Second, it appears that in Greek the undershooting of L tones is preferred to the undershooting of H*s*. Support for this hypothesis comes from similar evidence on the undershooting of L% in Japanese (Venditti, this volume), which suggests that different realization constraints may apply to L and H targets universally. Regardless of the underlying reasons, and despite previous research on this issue, the realization of targets under tonal crowding is still not entirely understood; e.g. it is not clear whether the strategies mentioned above are a matter of the speaker's choice or depend on prosodic factors, such as phrasing and relative metrical strength.

Unlike tonal crowding, the investigation of downstep has been very limited in Greek. Our data, however, allow us to make certain observations. First, it is clear that in Greek downstep is *not* triggered by the presence of bitonal accents. The hypothesis linking downstep to bitonal accents was first advanced in Pierrehumbert (1980) for English, and was further refined and extended in Beckman & Pierrehumbert (1986), who took both English and Japanese data into account. This hypothesis (which has its origins in studies of tonal phonology in African languages) is often taken to reflect a universal tendency of tonal implementation (see e.g. Goldsmith's comments (1999:4); for evidence against the universality of the downstep trigger, see Yip (1996) and references therein). As mentioned, however, in Greek the most frequently attested pitch accent in prenuclear position is the bitonal L*+H. As most content words are accented in Greek, it is quite common to find long sentences with a series of L*+H accents, but no downstep, as illustrated in Figures 1 and 9. This lack of scaling interactions among tones in Greek is further supported by similar data from the scaling of phrase accents and boundary tones, discussed at some length in sections 3.3 and 3.4.

In addition, our corpus suggests that certain scaling differences probably reflect phonetic regularities, and thus need not be part of the phonological description of Greek intonation. We refer, in particular, to the widespread lower scaling of the nuclear accent relative to previous accents, illustrated here in Figures 2 and 5. One possible reason for this type of lower scaling could be *final lowering*, i.e. the progressive lowering of overall pitch range within the last 250 ms or so of an utterance (Liberman & Pierrehumbert, 1984). However, evidence like that presented in Figure 5—in which the nuclear L+H* accent is clearly downstepped relative to the previous pitch accents, but the following H% is fully scaled—

suggests that final lowering cannot be the only reason for the observed scaling effects. Although this type of "downstep" is regular and does not appear to have pragmatic significance—reasons for which we assume that it has no phonological bearing—it is clear that further research will be necessary before final conclusions about the role and operation of downstep in this and other contexts can be drawn.

3.3 The phrase accents

There are three types of phrase accent in Greek, H-, L- and !H-. The scaling of the H- and L- phrase accents does not appear to be influenced by the identity of neighboring tones. This contrasts with the situation observed in other languages, such as English and German, in which the scaling of phrase accents is influenced by preceding or following tones, resulting in upsteps and downsteps (Beckman & Ayers-Elam, 1997, and Pierrehumbert & Hirschberg, 1990, on American English; Grice & Benzmüller, 1995, on German). Because of this difference between Greek and other languages, falls or rises to mid pitch cannot be attributed to the upstepping or downstepping influence of a neighboring tone and are thus represented by !H-.

3.4 The boundary tones

Greek has three types of boundary tone, H%, L% and !H%. As with the phrase accents, !H% is used to represent a mid-pitch level, since phrase accents do not act as triggers of upstep or downstep in boundary tones. Notice, for example, that both L-H% and L-!H% are attested in Greek; that is, L- cannot be seen as the trigger of the downstep of !H% in the latter case, since it does not affect the scaling of H% in the former. Furthermore, no upstep of L% boundary tones due to a preceding H tone has been attested in the GRToBI corpus (see e.g. Figure 4).

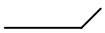
The three boundary tones combine with the phrase accents in eight different configurations that appear to have specific pragmatic functions. The possible phrase accent-boundary tone combinations and their typical usage are shown in Table 1.

The L-L% configuration is manifested as a low plateau at the end of an utterance, illustrated in Figures 2, 3, 9 and 10. The L-L% is preceded by L+H*, H* or !H* in declaratives, by L+H* in imperatives, and negative declaratives and by L*+H in wh-questions (Arvaniti and Ladd, ms.).

The L-H% is manifested phonetically as a dip and then a rise to a high F0 value. The L-H% is often found after a L+H* pitch accent, with the whole configuration (L+H* L-H%) suggesting a more "involved" type of continuation rise, that raises the expectations of the hearer about what is going to follow. An example of this "involved" rise is shown in Figure 5. The L-H% is preceded by L* in the "suspicious" calling contour mentioned in 3.1.

The H-L% configuration is used in yes-no questions, in which the nuclear accent is invariably L*. Most interestingly, the H- accent in this case, shows two distinct patterns of alignment, depending on the position of the nucleus (Arvaniti, in press; Arvaniti *et al*., ms.; Baltazani & Jun, 1999; Grice, Ladd & Arvaniti, in press). If the nucleus of the question is *not* on the final word of the utterance, the H- aligns with the stressed syllable of the final word. If the nucleus is on the final word, the H- and L% are realized at the right edge of the utterance. These two alignment patterns can be clearly observed in Figure 4.

Table 1: Possible combinations of phrase accent and boundary tone and their usage.

Configuration	***Schematic representation***	***Usage***
L-L%		declaratives, negative declaratives, imperatives, wh-questions
L-H%		"involved" continuation rise, "suspicious" calls
H-L%		yes-no questions, requesting calling contour
H-H%		continuation rise, questioning calling contour
L-!H%		"involved" wh-questions, negative declaratives showing reservation, requesting imperatives
H-!H%		stylized continuation rise
!H-!H%		stylized call, incredulous questions
!H-H%		polite stylized call

The H-H% configuration is manifested as a smooth rise to a high F0, as shown in Figure 6. It is typically preceded by a L* in both "continuation rises" and in the questioning calling contour. The L-!H% is found in wh-questions, requesting imperatives, and negative declaratives that show reservation. All these types of utterance have similar intonational structure: a L*+H or L+H* nucleus followed by a low plateau (a spreading L-), and a small rise (the !H%). As can be seen in Figure 7 that illustrates this contour, the !H% remains approximately in the middle of the speaker's range.

The stylized configurations—H-!H%, !H-!H%, !H-H%—are used less often than the rest and for a limited number of pragmatic purposes. The H-!H%, illustrated in Figure 8, is realized as a rise to a high plateau. Our corpus suggests that it is employed mostly when the speaker wants to hold the floor while preparing his/her next utterance, but s/he is unwilling to use a (filled) pause. The !H-!H% is the mirror image of H-!H%, that is a fall to the middle of the speaker's range; it is used in the *vocative chant* after L*+H, and also in incredulous questions after L+H*, as illustrated in Figure 1. Finally, the !H-H% is similar to !H-!H%. The difference between the two is the small rise at the end of the plateau in !H-H%, which makes the utterance sound more tentative or polite.

4 PROSODIC STRUCTURE

In the analysis adopted here, we assume that Greek has only three prosodic constituents at and above the word: the Prosodic Word, the Intermediate Phrase and the Intonational Phrase. As we show below, there is ample stress, tonal and sandhi evidence available for these three prosodic levels.

4.1 The Prosodic Word

A prosodic word (henceforth PrWd) consists of a content word and its clitics. The term "clitic," as used here, includes all items that in a given utterance lose their stress and form one PrWd with a host. In Greek this is the common fate of many function words, including disyllabic ones, which are not usually considered to be phonological clitics (see section 2).

As already discussed, a PrWd is expected to have only one stress; consequently it may bear only one pitch accent, though it is also possible for a PrWd not to be accented at all; this is, for example, the case with postnuclear PrWds (see Figure 10). PrWds with enclitic stress, on the other hand, may have two pitch accents, one on the lexically stressed syllable of the host and one on the syllable with enclitic stress (PrWds with enclitic stress may of course be de-accented; however, if they have only *one* pitch accent, this will necessarily fall on the syllable with enclitic stress).

In addition to stress and tonal cues, PrWds are the domain of at least eight types of sandhi, presented below. Some of these—stop-voicing, /n/-deletion, /s/-voicing, vowel degemination, and vowel deletion—have been reported in Kaisse (1985), Nespor & Vogel (1986) or

Condoravdi (1990), though their descriptions do not always match our data (see section 4.3). The other three rules emerged from our corpus.

- Stop-voicing after a word-final nasal (the nasal is usually deleted; if not, it assimilates for place of articulation to the stop); e.g. /tin ˈpoli/ > [tiˈboli] or [tiˈmboli] "the town, ACC".
- /n/-deletion before sonorants and fricatives; e.g. /ton laˈo/ > [tolaˈo] "the people, ACC".
- /s/-voicing before sonorants; e.g. /ˈʝos mu/ > [ˈʝozmu] "my son".
- degemination of identical consecutive vowels; /ta ˈatoma/ > [ˈtatoma] "the individuals".
- deletion of one of non-identical vowels; e.g. /to ˈatomo/ > [ˈtatomo] "the individual".
- /n/-resyllabification before a word-initial vowel; e.g. /ˈo.tan. ˈe.fta.se/ > [o.ta.ˈne.fta.se] "when s/he arrived"; in accented syllables /n/-resyllabification is evident from tonal alignment.
- degemination of identical consecutive consonants; e.g. /ˈʝos su/ > [ˈʝosu] "your son".
- diphthongization of non-identical vowels; e.g. /o. ˈi.ʎos/ > [ˈoi.ʎos] "the sun".

4.2 The intermediate phrase and the Intonational Phrase

The two levels of phrasing above the PrWd level are the intermediate and the intonational phrase (ip and IP respectively). An ip must include at least one pitch accent (i.e. there are no headless phrases in Greek), and is tonally demarcated by the presence of a phrase accent (H-, L- or !H-) at its right edge. An IP must include at least one ip and is tonally demarcated by the presence of a boundary tone (H%, L% or !H%) at its right edge.

There is abundant evidence for these two levels of phrasing in Greek. First, the tones associated with ip*s* show a simple F0 movement, such as a fall or a rise, unlike the right edges of IP*s* which often show more complex pitch configurations (see 3.4). In the cases where the pitch movement is of the same type (e.g. a rise), ips and IPs show a difference in scaling, as illustrated in Figure 6. This observation is supported by quantitative data: after the level of phrasing had been assigned independently of scaling and agreed upon by the authors, a systematic comparison was made of the difference (in Hz) between the lowest and highest F0 point in L* H- and L* H-H% configurations in the data of four speakers reading *The North Wind and the Sun*. The results showed that the H- was scaled closer to the preceding L* than the H-H% configuration by 30 Hz on average.

On the other hand, in IPs with complex final movement, such as a rise-fall, the two tones align independently, as noted, e.g., in the description of H-L% and L-!H% in section 3.4 and illustrated in Figures 4 and 7 respectively. This clearly shows that we are not dealing with bitonal boundary tones; if that were the case, then the individual tones would align together at the edge of the relevant phrase. Rather, in the L-!H% melody, we see that the L- spreads, while the !H% aligns with the last vowel of the utterance (Arvaniti & Ladd, ms.); in the H-L% melody the H- aligns with a stressed vowel, if one is available, while the L% always aligns with the last vowel (Arvaniti, in press; Arvaniti *et al.*, ms.).

Grice *et al.* (in press) reviewed these Greek data (as well as related data from German, Hungarian, Romanian, and English), and concluded that this behavior of phrase accents can be accounted for if we view phrase accents as phrasal tones with a secondary association to a specific tone bearing unit. This position does not of course account for the fact that phrase accents, in Greek at least, appear to always align at the edge of a non-final ip, and move to their secondary association site only when there is a boundary tone following. One possible reason for this difference between non-final and final ips is that in the former the delimitative function of the phrase accent takes priority, while in the latter, this function is assumed by the boundary tone and thus need not be fulfilled by the phrase accent itself (for a similar analysis along these lines, see Grice and Truckenbrodt, ms.)

In addition to the tonal evidence, our corpus suggests that at least some types of sandhi take place within ip boundaries but not across them. One such case of sandhi relates to vowel hiatus, which is resolved either by coalescence or by deletion within ip boundaries but not across them. On the other hand, Figure 6 illustrates another type of sandhi, consonant degemination, which does apply across an ip boundary (though not across IP boundaries). Finally, evidence for the two levels of phrasing comes from pauses: IPs, even non-final ones, may be followed by a lengthy pause, while pauses are rare after ips and always very short.

4.3 Sandhi and prosodic phrasing

Although in the prosodic analysis presented here we assume only three constituent levels, in previous analyses of the prosodic structure of Greek, additional levels have been postulated. Concretely, Nespor & Vogel (1986) propose that Greek prosodic structure includes the Clitic Group—the need for which has been generally disputed (e.g. Zec & Inkelas, 1991)—and three phrasal constituents, the Phonological Phrase, the Intonational Phrase and the

Phonological Utterance. An additional constituent, the Minimal Phrase, was later proposed by Condoravdi (1990).

Although a full discussion of these analyses is beyond the scope of this paper, it should be noted that whatever evidence there is for these additional constituents comes exclusively from sandhi. However, many of the sandhi phenomena used to support these analyses have not been reliably described and analyzed, resulting in disagreements between the phonological descriptions (e.g. Kaisse, 1985; Nespor & Vogel, 1986) and naturally occurring data (e.g. Fallon, 1994).

The examination of our own corpus allows to make the following observations regarding sandhi. First, several types of sandhi apply across larger constituents than has previously been suggested. The sequence [ˈotaˈxtips] in Figure 9 is a case in point: the adverb /ˈotan/ “then” loses its final /n/ before the verb /ˈxtipise/ “rang”, although /ˈotan/ and /ˈxtipise/ form separate PrWds (e.g. both remain stressed). According to Nespor & Vogel (1986) however, /n/-deletion before fricatives applies only within PrWd boundaries (to be precise within the Clitic Group, which corresponds to our PrWd). Similarly, the final /e/ of /ˈxtipise/ would be expected to delete within but not across a PrWd boundary. This example is not an isolated instance, and cannot be attributed to fast speech, as there is evidence that the utterance it is part of (and which was elicited under laboratory conditions) was rather carefully enunciated; this evidence comes from the words /ˈmalone/ and /tiˈlefono/ which are realized as such, rather than as [ˈmaɫne] and [ˈtlefono] respectively, as would be expected in fast casual speech.

Second, the application of some rules presented in Kaisse (1985) and Nespor & Vogel (1986) depends on the lexical items used, something rather unusual for postlexical rules (for a discussion see Arvaniti, 1991, and Malikouti-Drachman & Drachman, 1992, on the above-mentioned rule of /n/-deletion). Third, sandhi does not appear to be obligatory at any level; the speaker may choose to apply a particular rule, or may not. Finally, it appears that at least some of the rules involve gradient, rather than categorical, changes. This holds particularly true of /s/-voicing and vowel-deletion, both described in 4.1: in many instances of /s/-voicing, the /s/ is only partially voiced, while complete deletion of a vowel under hiatus appears to be very rare; in most cases, audible and (spectrographically) visible evidence of the “deleted” vowel remains in the signal. These findings are not surprising, as they agree entirely with

results reported in studies of similar phenomena in English and other languages (among several, Holst and Nolan, 1995; Zsiga, 1997; Ellis & Hardcastle, 1999). Nevertheless, they strongly suggest the necessity of empirically re-examining the phonological descriptions of Greek sandhi in particular, and of the reliability of sandhi as a phrasing marker more generally.

5 THE GRTOBI ANNOTATION SYSTEM

GRToBI has five tiers. The *Tone Tier* that gives the intonational analysis of the utterances; the *Prosodic Words Tier*, which is a fairly narrow phonetic transcription; the *Words Tier* that gives the text in romanization; the *Break Index Tier*, showing indices of cohesion; and finally a *Miscellaneous Tier* in which other information may be entered. Details on each tier are given below (for labeling conventions see Appendix I).

5.1 The Tone Tier

As mentioned, the Tone Tier presents the intonational structure of the utterance, using the analysis and criteria presented in section 3. In addition to the pitch accents, phrase accents and boundary tones described in that section, some diacritics are also used in the GRToBI annotation system. These are largely employed to provide a more detailed description of the phonetic realization of the pitch accents, in order to shed light on the relation between the phonological representation of accents and their context-dependent phonetic realization.

Concretely, L*+H pitch accents in tonal crowding contexts, in which as mentioned earlier their realization varies, are annotated using three diacritics: wL*+H (“w” for *weak*) is used when the L tone is undershot, as in [ˈmalonɛ] in Figure 9; >L*+H is used when the accent is realized *earlier* than typically expected, as in [ðaliˈða] in the same figure; and <L*+H is used when the accent is realized later than typically expected. Similarly, undershot L* accents, usually realized as a low *point* rather than a plateau, are annotated as wL* (see Figure 9).

Further, the downstep diacritic (!), may be used with any of the pitch accents with a H tone, if the transcriber feels that the accent is scaled lower than declination warrants. As mentioned in section 3, it is not clear what the role of downstep is in Greek, due to the limited research that has been conducted on this point. For this reason, we have decided to explicitly annotate downstep in the Tone Tier, even in cases in which we have reason to suspect that the presence of downstep is phonetically determined (as is the case with the scaling of nuclear

accents, illustrated with Figures 2 and 9). Explicit marking of downstep will facilitate further research, which can illuminate the scope and function of downstep.

5.2 The Prosodic Words Tier

The Prosodic Words Tier provides a detailed phonetic transcription of the utterances. Currently ASCII characters (with a fairly transparent relation to their IPA equivalents) are employed. We hope that in the future the information on this tier will be presented in IPA notation (for the current conventions see Appendix II).

In this tier, each PrWd constitutes one label. The aim of the PrWords Tier is to provide the users of the database with information about the actual pronunciation of the utterances. To this purpose the transcription is phonetic rather than phonological, that is, it encodes stress, allophonic variation, phone deletions, assimilations and sandhi in general.

This tier was deemed necessary for two reasons. First, it facilitates the analysis of sandhi and fast speech rules, which abound in Greek, by encoding their outcome. Second, it provides information about stress. This information cannot be deduced from the transliteration or from Greek spelling conventions, since Greek orthography marks stress only on polysyllabic words. In a given utterance, however, a monosyllabic content word will most likely be accented, while a disyllabic function word will often be cliticized. By coding and examining such cases we hope that a better understanding of the relation between stress and accent in Greek will emerge.

5.3 The Words Tier

At present the Words Tier provides a word-by-word romanization of the text, although our long-term goal is to present this information in Greek orthography. In the absence of a generally agreed system for the romanization of Greek, we have followed some of the more generally accepted conventions (such as *ch* for χ) and have devised means for transliterating the rest of the characters as transparently as possible. Our aim has been to represent each Greek letter and combination of letters with a unique roman character or set of characters, so that (a) searches of the Words Tier in the database yield unambiguous results and (b) the future algorithmic conversion to the Greek alphabet is possible. The full set of transliteration conventions can be found in Appendix III.

5.4 Break Index Tier

5.4.1 The Break indices

GRToBI uses four levels of break indices, 0, 1, 2 and 3. These levels correspond to a *subjective* sense of increasing disjuncture between words. By *word* here we mean any item that is separated by spaces in the orthography of Greek; *orthographic* words often form but part of a *prosodic* word. It should also be stressed that although the use of a particular index relies on the transcriber's judgment, indices correlate with specific stress, sandhi and tonal events (discussed in section 4), which the transcriber must take into consideration before reaching a decision.

BI 0 is used to mark boundaries within a sequence of orthographic words that show total cohesion of the type typically expected between items that form one PrWd. Thus, we assume that a sequence of orthographic words separated by BI 0 corresponds to a PrWd that has only one stressed syllable and may bear only one pitch accent. As noted, cases with two accents due to enclitic stress are also felt to form one PrWd. Because of this sense of cohesion, the boundaries between hosts and enclitics are labeled BI 0. However, little is as yet known of the intonational behavior of such sequences (but see Arvaniti, 1992; Botinis, 1998). Since this is still an open research question, we decided to flag the second accent in these cases by adding a label to it, namely "enclA" (for *enclitic accent*), as shown in Figure 8.

Although, as noted, several types of sandhi take place across a BI 0 boundary, its presence is not a necessary condition for BI 0 to be used (as it is in the American English ToBI for instance; Beckman & Ayers-Elam, 1997). For example, several forms of the Greek verbs include the proclitic particles, /θa/ or /na/; when the following verb stem begins with a consonant it is unlikely that sandhi will take place between the particle and the verb. However, native speakers feel that these particles cannot be conceived but as part of the verb form; for this reason, BI 0 is marked in such cases.

BI 1 marks boundaries between PrWds. Items separated by BI 1 should be stressed and carry at most one pitch accent each (two in cases of enclitic stress). In other words, a PrWrd will necessarily be stressed but may not be accented; for instance, in cases of early focus in an utterance, de-accenting of all PrWds following the nucleus is expected (Baltazani & Jun, 1999; Botinis, 1998), as illustrated in Figures 7 and 10. Although the absence of accent does not constitute evidence that a given stretch is *not* a PrWd, the presence of an accent should be

considered crucial for deciding that an item is a PrWd. Thus, when articles (which are normally proclitics) are accented, as often happens in media-speech (Arvaniti, 1997), then they are separated by BI 1 from the nouns that would normally be their hosts; they may also be flagged with "accdCL" (for *accented clitic*) in the Tone Tier.

BIs 2 and 3 mark ip*s* and IP*s* respectively[1]. The arguments for these two levels of phrasing and a description of the tonal and other prosodic cues that accompany each of them are presented in detail in section 4.2.

5.4.2 Diacritics for the Break Index Tier

In addition to the break indices, four diacritics are used to provide more detail on the prosodic structure of the annotated utterances: "s" for *sandhi*, "m" for *mismatch*, "p" for *pause* and "?" for *uncertainty*.

By far the most important diacritic for GRToBI is *s*, which is used to flag *all* instances of sandhi at all prosodic levels, independently of whether sandhi rules operating at this level have previously been described for Greek or not. We hope that by investigating a large corpus of spoken data thus marked, a better understanding of the possible environments for sandhi and of the prosodic constituents across which sandhi may apply can be reached. We anticipate that such research will have far reaching consequences in terms of the general understanding of the relation between sandhi, phrasing and prosodic structure.

The second diacritic is *m*, which should be used for cases of mismatch between the break index and the prosodic or tonal cues to this index. Concretely, this diacritic flags two types of mismatch depending on the break index it is associated with. The *m* diacritic is used with BI 0 to mark cases in which the context for sandhi at BI 0 exists but sandhi does not take place. For example, when a sequence such as /tin ˈkori/ "the daughter. ACC." is pronounced [tiˈgori] or [tiˈŋgori] then the boundary between /tin/ and /ˈkori/ is labeled *0s*; when the same sequence is pronounced [tin ˈkori] then it is labeled *0m*; in contrast, the sequence /i ˈkori/ "the daughter, NOM.", in which sandhi is not possible, is labeled simply *0*. The *m* diacritic is used with BI 1, 2 and 3, to mark cases in which the transcriber feels that a certain boundary is present, yet the

[1] It has been suggested to us that ip and IP BIs should be 3 and 4 respectively, instead of 2 and 3. This would make the system similar to that of English ToBI, which has an additional BI level, but not necessarily to other systems, such as Japanese ToBI (Venditti, this volume). We have decided not to follow the labeling conventions

tonal events that normally accompany this boundary are not in place. For example, when the transcriber feels that a sequence which does not end with a phrase accent nevertheless forms a separate ip, then the boundary between this and the following ip should be labeled *2m*.

Finally, *p* is used to mark pause at a given boundary, and *?* is used to mark uncertainty about the strength of a boundary. In cases of uncertainty the highest of the two possible candidates is marked, together with a matching analysis in the Tone Tier; if this is not possible (i.e. if the transcriber does not find the tonal cues that normally accompany a particular break index), then *m* should also accompany the break index label.

5.5 Miscellaneous Tier

The purpose of the Miscellaneous Tier is to encode information about the utterance that is beyond the scope of the other tiers, but may help the users in understanding the information encoded in those. Thus, comments such as disfluency, pitch-halving, or speaking rate are marked in this tier.

6 DISCUSSION AND CONCLUSION

In this paper we have presented a prosodic analysis of Greek, concentrating mostly on intonation and phrasing, but also dealing (albeit to a lesser extent) with stress and rhythm. It transpires from this analysis that the prosody of Greek is by and large understood, though certain issues remain unresolved. Among them are the phonology of downstep, the phonetic realization of accents under tonal crowding, and the phonological representation of the pitch accent currently analyzed as H*+L.

Despite these remaining questions, what emerges from this analysis is that the prosody of Greek has certain characteristics that merit further consideration. One of these relates to the phonological relevance and modeling of downstep. This issue has been extensively discussed in the literature (for a review, see Ladd, 1996), but it is still far from being understood. This is, after all, the reason why downstep is explicitly annotated in many ToBI systems, in contrast to the theoretical works on which these systems are based (e.g. Beckman & Pierrehumbert, 1986, and Pierrehumbert & Beckman, 1988). Yet, certain aspects of downstep are taken for granted, such as that downstep is triggered by bitonal accents. The Greek data

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of English ToBI, as the skipping of level 2 would make our annotation system less transparent.

clearly show that this is not a universal tendency, and point towards an analysis in which downstep is seen as an independent—rather than predictable—intonational feature.

A related issue is that of scaling influences among phrasal tones: in most intonational systems H- phrase accents upstep L% boundary tones, while L- phrase accents downstep H% boundary tones. Again, Greek does not exhibit this tendency. This means that the description of Greek intonation requires the use of a mid-level, namely the tones we analyze as !H- and !H%. This is problematical, given that the autosegmental/metrical framework is based on the assumption that intonational patterns can be adequately modeled using only two tones, H and L. However, if we were to limit ourselves to H and L for the description of Greek intonation, we would have to resort to an analysis in which the donwstepped patterns involve sequences of abstract L tones, which are not phonetically realized but serve to downstep others (as in Beckman & Pierrehumbert, 1986). Apart from the fact that such as analysis would be highly abstract and unmotivated, at present there appears to exist strong evidence against it, since non-downstepped L- H% sequences are attested in Greek.

A third point that emerges from the Greek data is the asymmetric behavior of phrase accents in final and non-final ips. As we have noted, phrase accents assume their secondary association only in the former case, and one possible interpretation of this behavior is that in non-final ip*s* phrase accents have to fulfill their delimitative function, something that is not necessary in final ip*s*. The issue of the secondary association of phrase accents is extensively discussed in Grice *et al.* (in press), but it is clear that the puzzle of the phrase accents' behavior is far from being completely solved. Data from more languages and possibly from the less common melodies of the languages already studied could provide a better understanding of this issue.

A final point that is worth commenting on is that of phrasing and the prosodic hierarchy. The hierarchy adopted in the GRToBI analysis is the one typically assumed in intonational phonology; at the same time it differs dramatically from the hierarchy assumed in prosodic phonology. The reason for the discrepancy may lie in the evidence used: in intonational studies evidence for phrasing comes mainly from tonal patterns, while work in prosodic phonology relies more heavily on sandhi. Greek in this respect may be quite unusual in having a large number of sandhi rules and requiring few levels to account for stress and intonational patterns, thereby bringing to the fore the asymmetries between the two

hierarchies. It is still uncertain whether the more elaborate prosodic structures that have been postulated in the past will turn out to be necessary. It this respect, however, it is clear that GRToBI can make a real contribution by providing natural data on sandhi, a phenomenon that is not easily amenable to laboratory testing. This holds also for other aspects of Greek prosody, such as downstep, which will certainly benefit mostly from the examination of prosodically annotated corpora like the GRToBI database.

To conclude, we hope that the prosodic analysis of Greek presented here will serve as the basis for further research, examining the outstanding problems that emerged during the preparation of GRToBI and indicated throughout the paper, as well as re-evaluating assumptions currently made in the cross-linguistic study of prosody.

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APPENDIX I: LABEL ALIGNMENT CONVENTIONS

- The labels for the L+H*, H* and H*+L pitch accents should be aligned with the highest non-spurious F0 point of the accented vowel.
- For the L* accent the lowest F0 point on the accented vowel should be chosen for alignment.
- For the L*+H pitch accent, for which the canonical alignment of both tones is outside the accented syllable, a reliable point early in the accented vowel should be used instead.
- Phrase accents should be aligned with the right boundary of the relevant ip.
- Phrase accent and boundary tone combinations should be aligned with the right boundary of the relevant IP.
- The *enclA* and *accdCL* labels should be placed above or below the relevant accent in the Tones Tier.
- The transcriptions in the PrWords Tier should be aligned with the right edge of the whole sequence of orthographic items that form one PrWd.
- Transliterated forms are aligned at the right edge of words.
- Break indices are aligned at the right edge of relevant constituents.

APPENDIX II: PHONETIC TRANSCRIPTION CONVENTIONS

IPA	**ASCII**	**IPA**	**ASCII**	**IPA**	**ASCII**
p	p	θ	th	ɲ / n̪	N / NN
t	t	ð	D	l / l̪	l / ll
k	k	s	s	r	r
c	c	z	z	ʎ / ʎ̪	L / LL
b / ᵐb	b / mb	ʃ	$	i	i
d / ⁿd	d / nd	ç	X	e	e
g / ᵑg	g /Ng	ʝ	j	ɐ	a
ɟ / ᶮɟ	J / NJ	x	x	o	o
β	B	ɣ	G	u	u
f	f	m / m̪	m / mm	y	y
v	v	n / n̪	n / nn		

In addition to the above symbols, the following conventions should be used:

- Noticeably centralized vowels should be transcribed as @.
- Noticeably nasalized vowels should be transcribed with a following ~; e.g. a~ for [ɐ̃].
- In cases of vowel coalescence, both vowels should be transcribed and joined by +; e.g. u+o for [o̯] resulting from a sequence of /u/ and /o/ (usually across a word boundary).
- Whispered vowels should be transcribed in brackets.
- Vowels that phonologically form separate syllables but are phonetically manifested as a rising diphthong (on the basis, e.g., of tonal alignment evidence), should be transcribed with the second vowel capitalized; stress should be placed before the diphthong.
- Stress should be marked before the consonant(s) of the stressed syllable, following IPA conventions. (At present we are agnostic as to syllabification, so we suggest that transcribers mark maximal onsets, unless tonal alignment or their own intuitions suggests otherwise.)

APPENDIX III: ROMANIZATION CONVENTIONS

GREEK	**Romanization**	**GREEK**	**Romanization**	**GREEK**	**Romanization**
α	a	ν	n	αι	ai
β	v	ξ	x	ει	ei
γ	g	ο	o	οι	oi
δ	d	π	p	ου	ou
ε	e	ρ	r	αυ	ay
ζ	z	σ	s	ευ	ey
η	h	τ	t	μπ	mp
θ	0	υ	y	ντ	nt
ι	i	φ	f	γγ / γκ	gg / gk
κ	k	χ	ch	τσ	ts
λ	l	ψ	ps	τζ	tz
μ	m	ω	w	ντζ	ntz

- When the grapheme combinations that usually represent one vowel (e.g., *αι*) represent two separate vowels, the graphemes are separated by fullstops; e.g. *a.i.d'oni* for *αϊδόνι*.
- Spellings with double graphemes are transliterated in the same way; e.g. *θάλασσα* is transliterated as *th'alassa*.
- In words with more than one syllable, stress is marked as an apostrophe before the stressed vowel. Monosyllables bear no stress mark in the Words Tier.
- Initials capitalized in Greek orthography should be transliterated with capital letters as well.

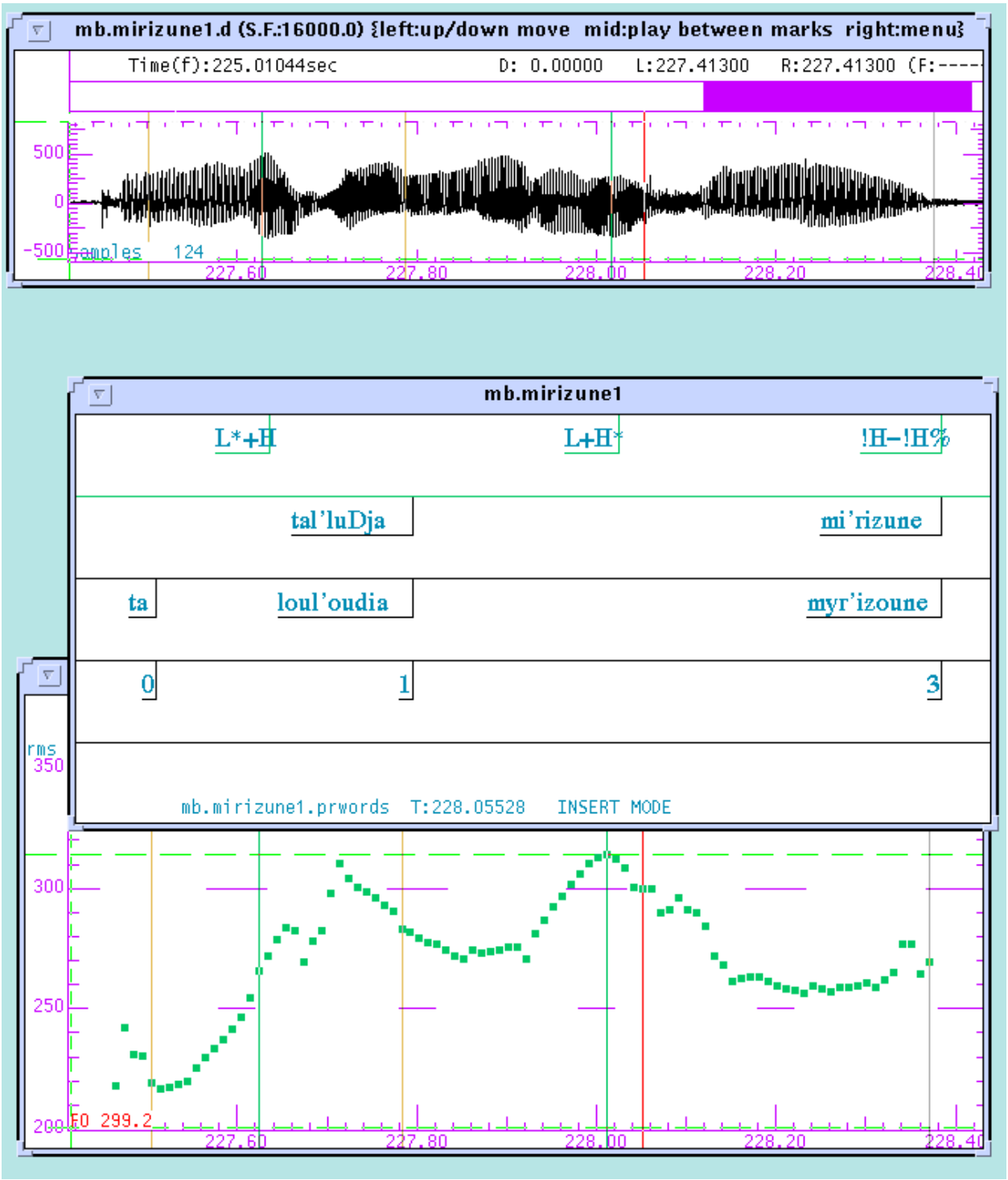

Figure 1: This example (gloss: "Do the flowers really smell?" *lit*. the flowers smell?) illustrates the different alignment of the H tone in L*+H (the accent on [l'ludia]) and L+H* (the accent on [mi'rizune]); in particular it shows how the H tone is aligned with the first postaccentual vowel in the former, but in the middle of the accented vowel in the latter. Further this figure shows a !H-!H% phrasal configuration, realized as a plateau in the middle of the speaker's range.

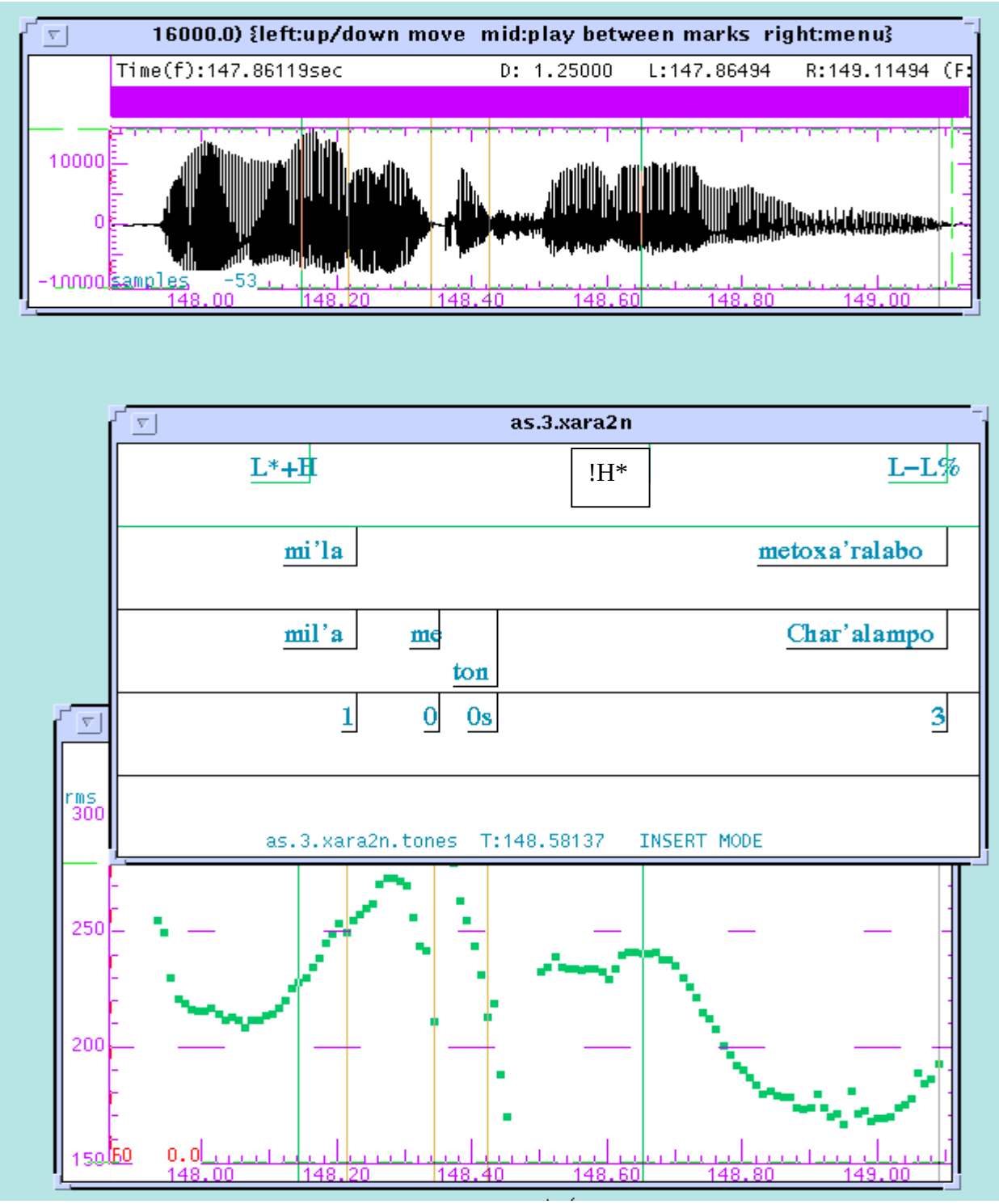

Figure 2: This example (gloss: "S/he is talking to Charalambos") shows a typical H* nuclear accent. Note the lack of a dip at the beginning of this accent; cf. the L+H* in Figure 1.

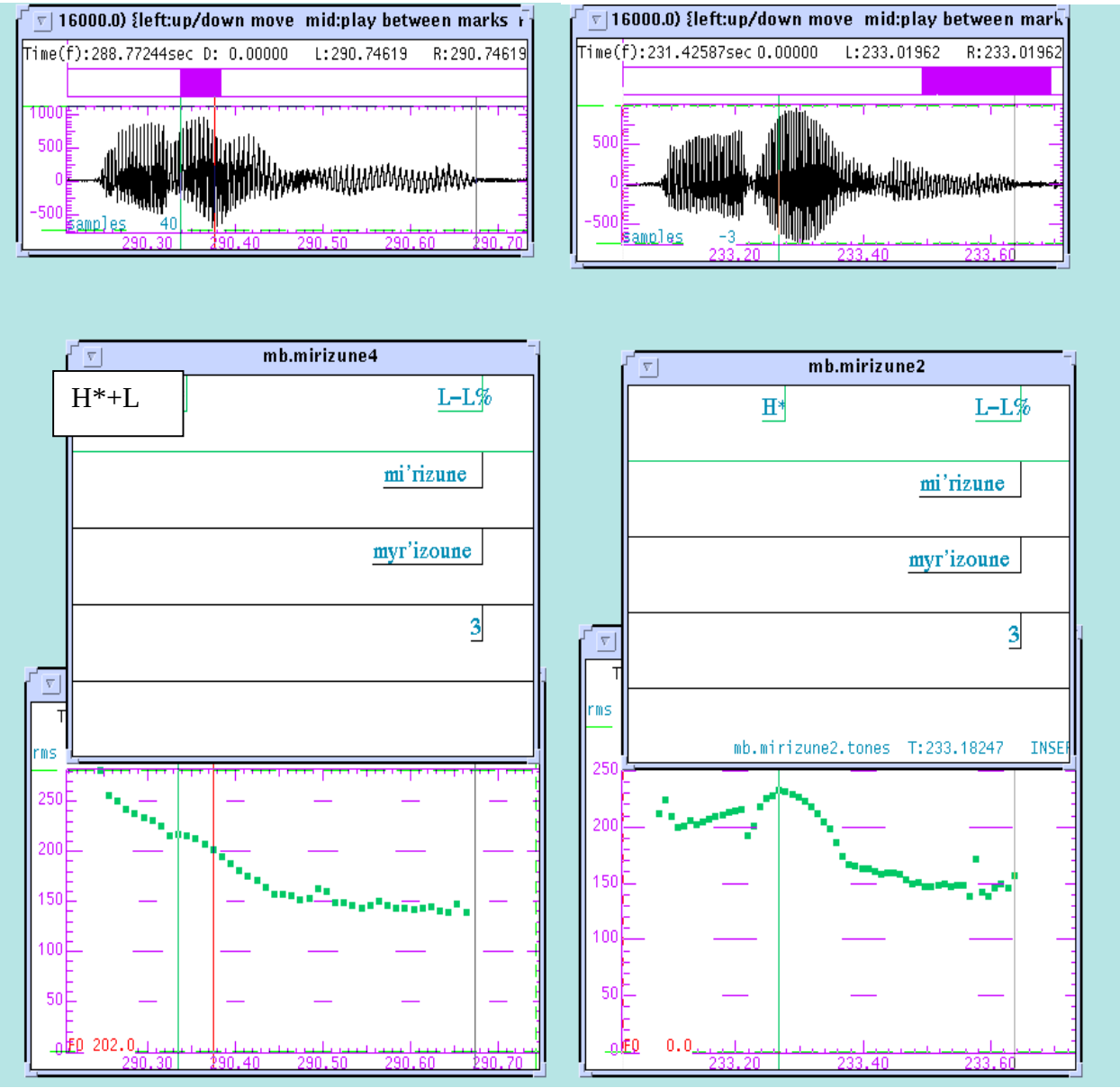

Figure 3: These two examples, (gloss (for both): "they smell"), illustrate the difference between H*+L (on the left) and H* (on the right) on a one word utterance. As can be seen the H*+L is falling throughout the accented syllable [ri], while the H* accent involves a shallow rise on the accented syllable.

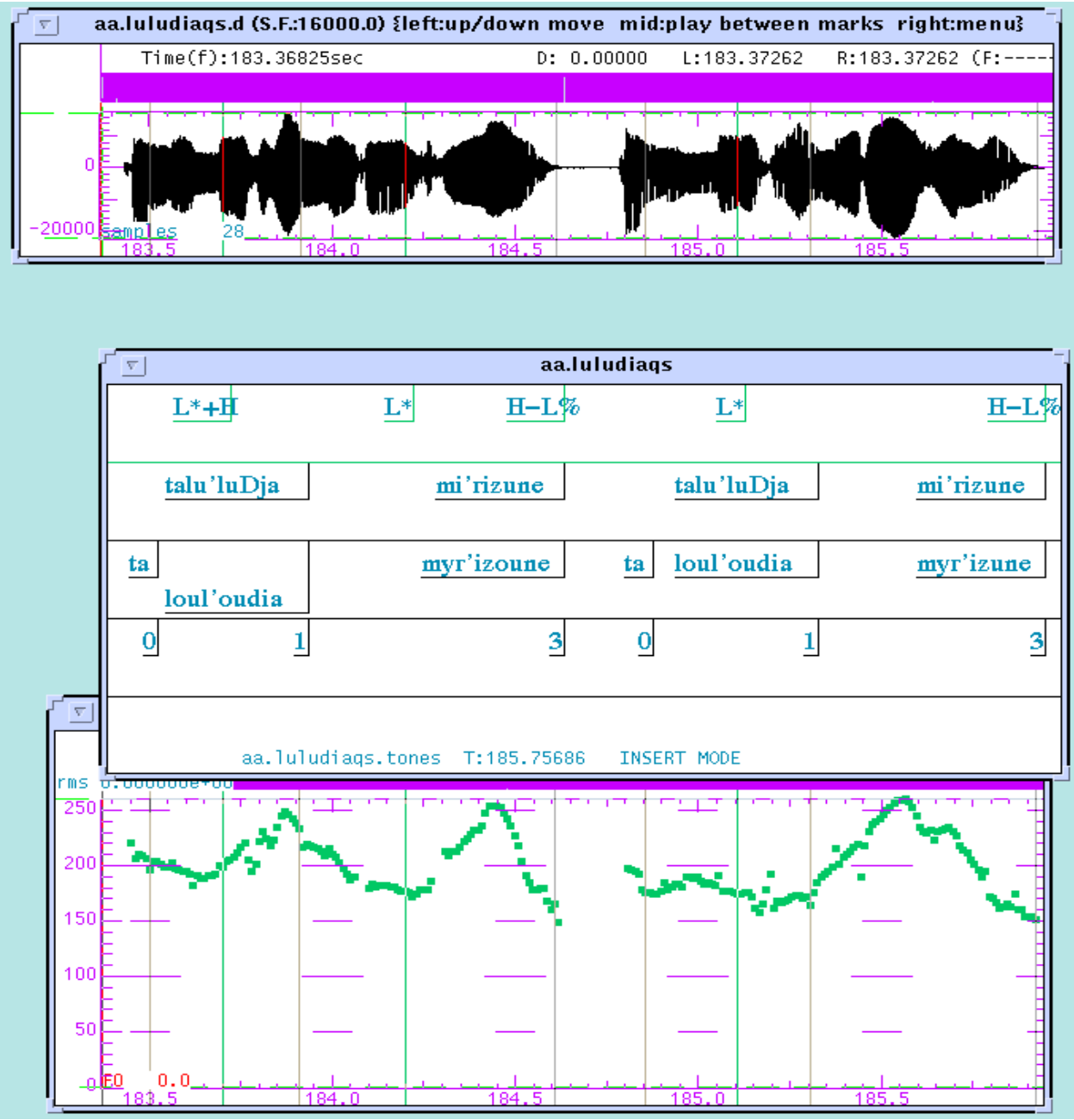

Figure 4: This illustration shows the same question twice (*lit.* the flowers smell), with focus on the word [mi'rizune] "they smell" on the left, and on the word [lu'luðia] "flowers" on the right (gloss: "Do the flowers SMELL?" and "Is it the FLOWERS that smell?" respectively). In both cases, the L* nucleus is realized as a low plateau with an additional dip in F0 on the accented syllable itself. Note also the different alignment of the H- in the two contours: as described in section 3.4, the H- aligns with the unstressed penultimate syllable [zu] in the question on the left (where the nucleus is on the final word), but with the stressed syllable [ri] in the question on the right (where the nucleus is early).

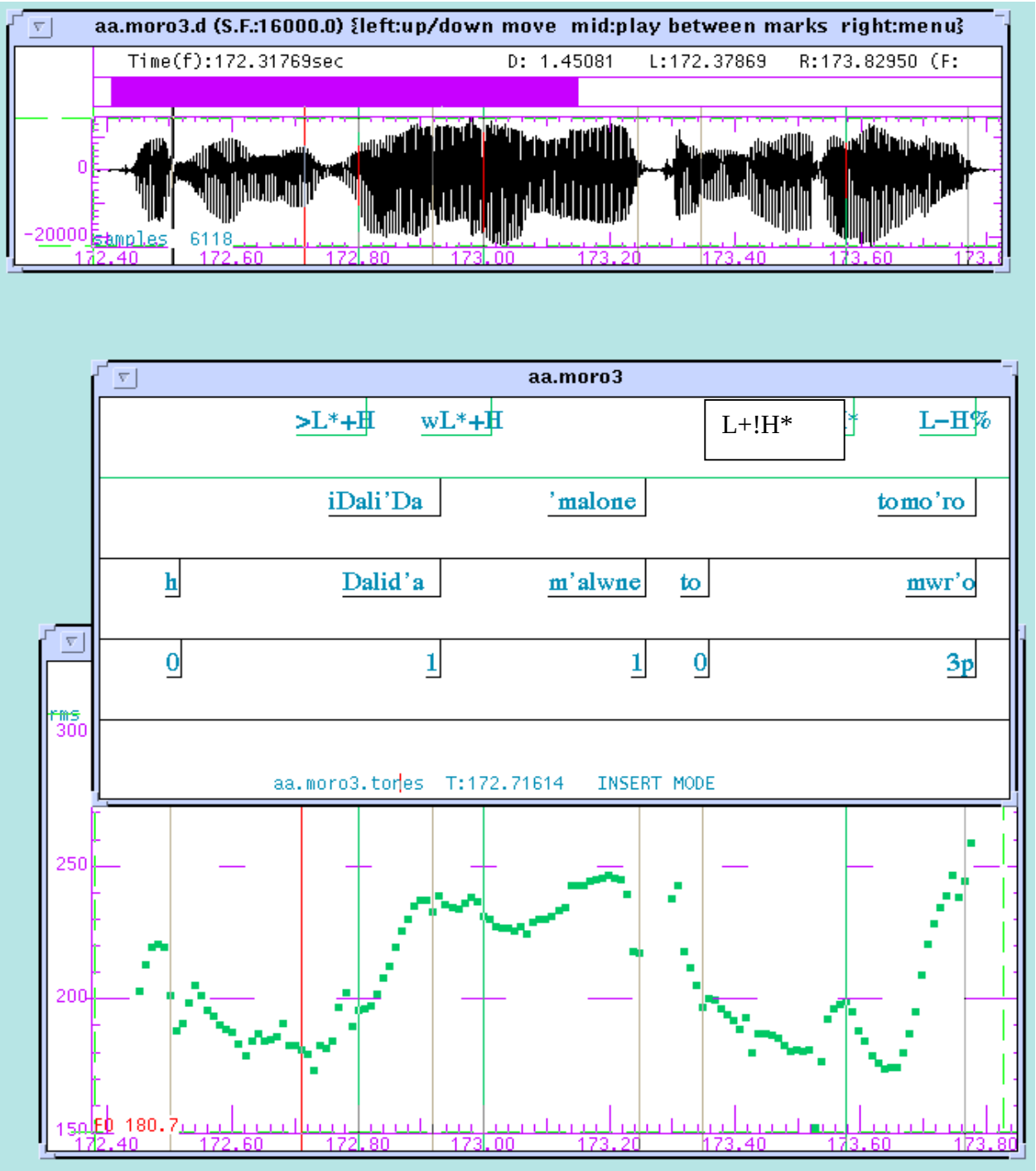

Figure 5: This example (gloss: "Dalida was scolding the baby [when she fainted]!") exemplifies the L-H% phrasal configuration, which is preceded in this case by a L+!H* accent on [mo'ro]. Note also the undershot (wL*+H) and early aligned (>L*+H) realizations of the two L*+H accents on ['malone] and [iðali'ða] respectively.

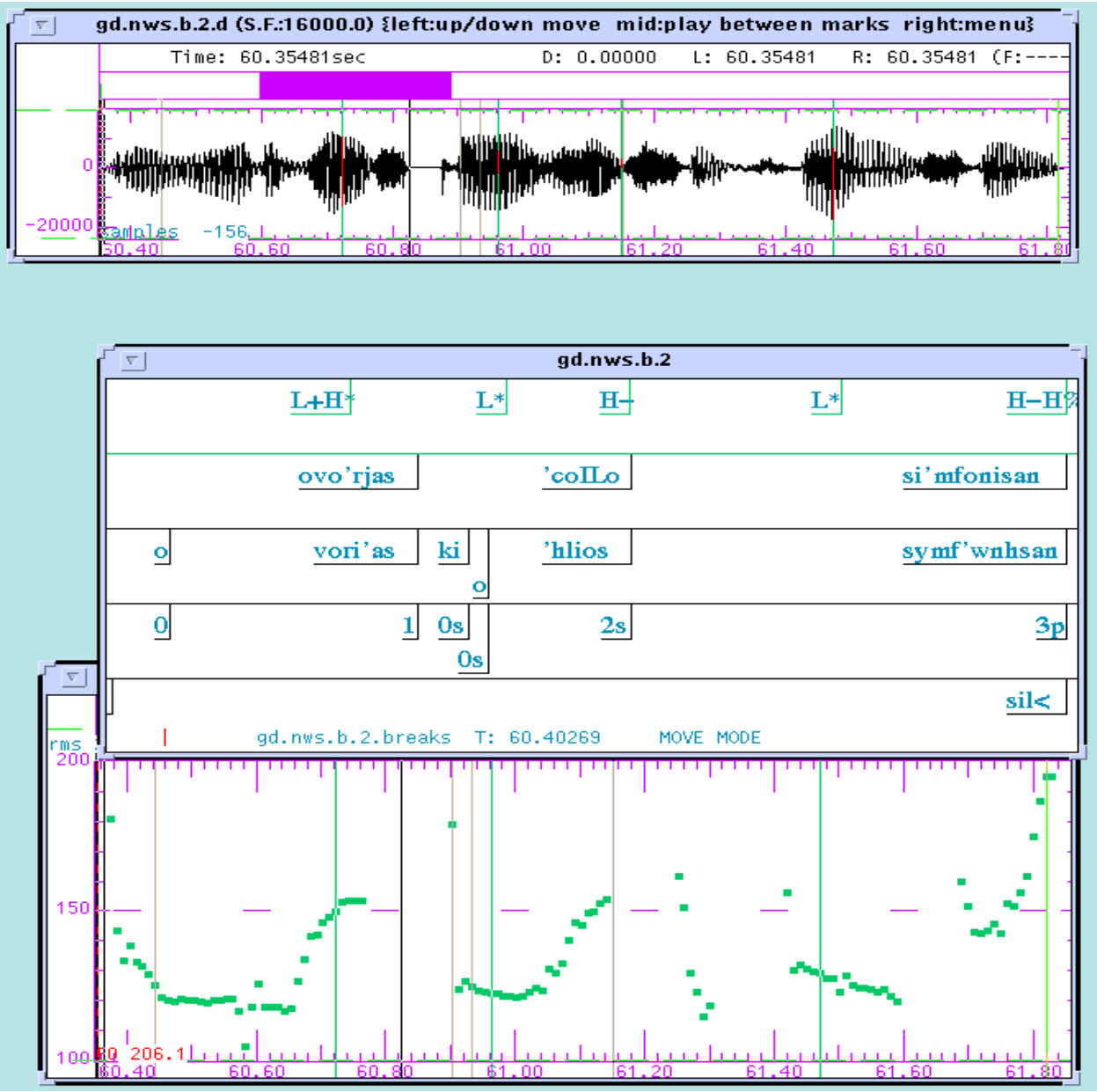

Figure 6: This example, (gloss: "The north wind and the sun agreed…"), illustrates the much higher scaling of H-H% relative to H-. Further the example shows the diphthongization of /o/ and /i/—pronounced as a rising diphthong—in /ke o ˈiʎos/ "and the sun"; this phrase is realized as one PrWd [ˈcoi.ʎos] as evidenced by the alignment of the L* with the whole syllable [coi]. Finally, this example illustrates consonant degemination across ip boundaries (the boundary labelled 2s): /ke o ˈiʎos sim'fonisan/ > [ˈcoiʎosiˈmfonisan].

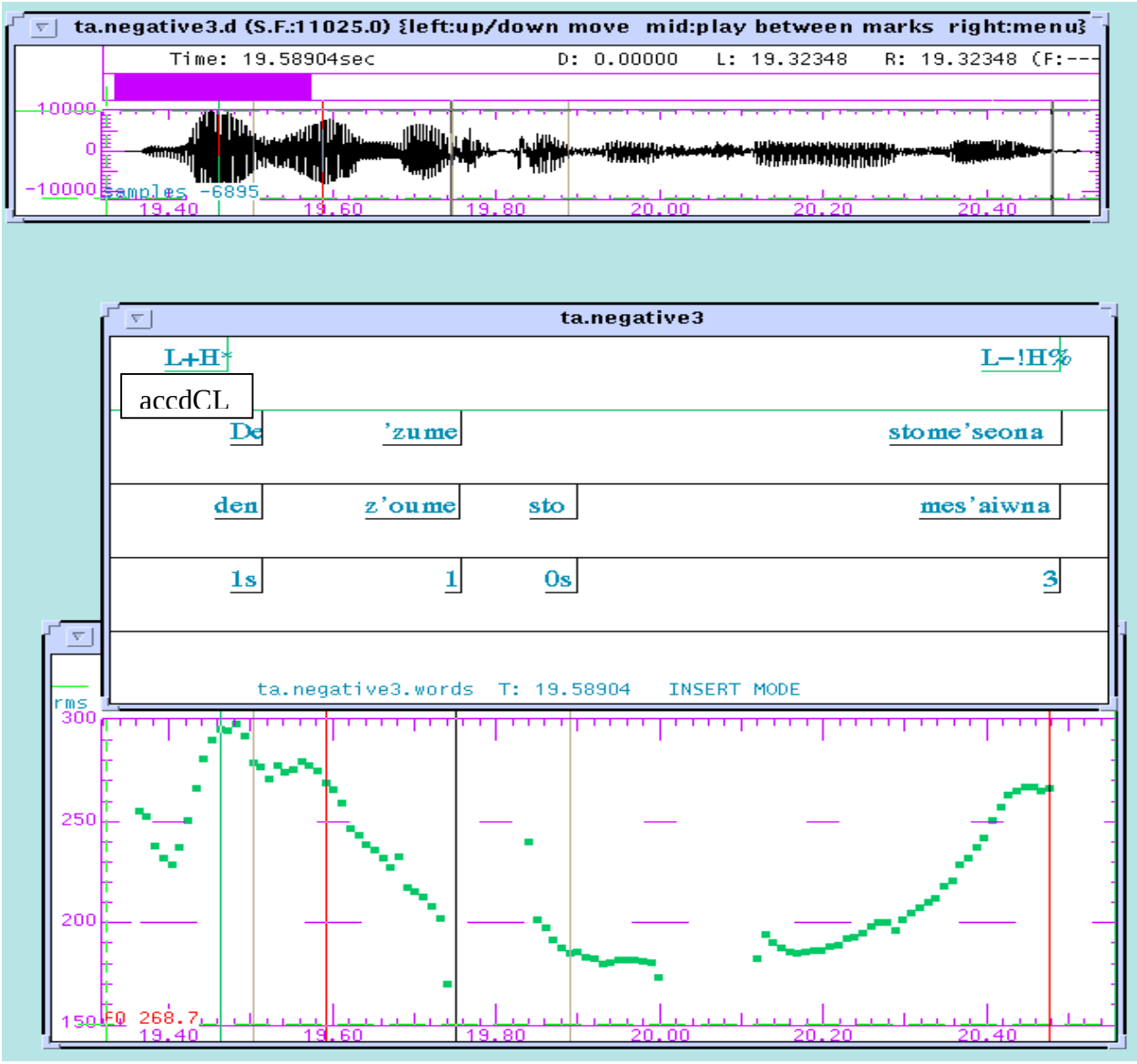

Figure 7: This example (gloss: "We do not live in the Middle Ages") illustrates the typical pattern of a negative declarative expressing reservation. Note that the negative particle /ðen/, which is considered a phonological clitic, carries the nuclear (and only) pitch accent of the utterance, and thus forms a separate PrWd from the de-accented verb ['zume] "we live"; yet, sandhi (/n/-deletion before the fricative [z]) does take place as well, although it is said to take place only within PrWd boundaries (Nespor & Vogel, 1986). The rest of the utterance is deaccented, with the L- spreading until after the last stressed syllable ([se] of [me'seona] "Middle Ages"). Finally, compare the scaling of the !H% (relative to that of the L+H* peak) to the scaling of the H- and H% tones in Figures 5, 6, and 9 (relative to the accentual Hs in those examples).

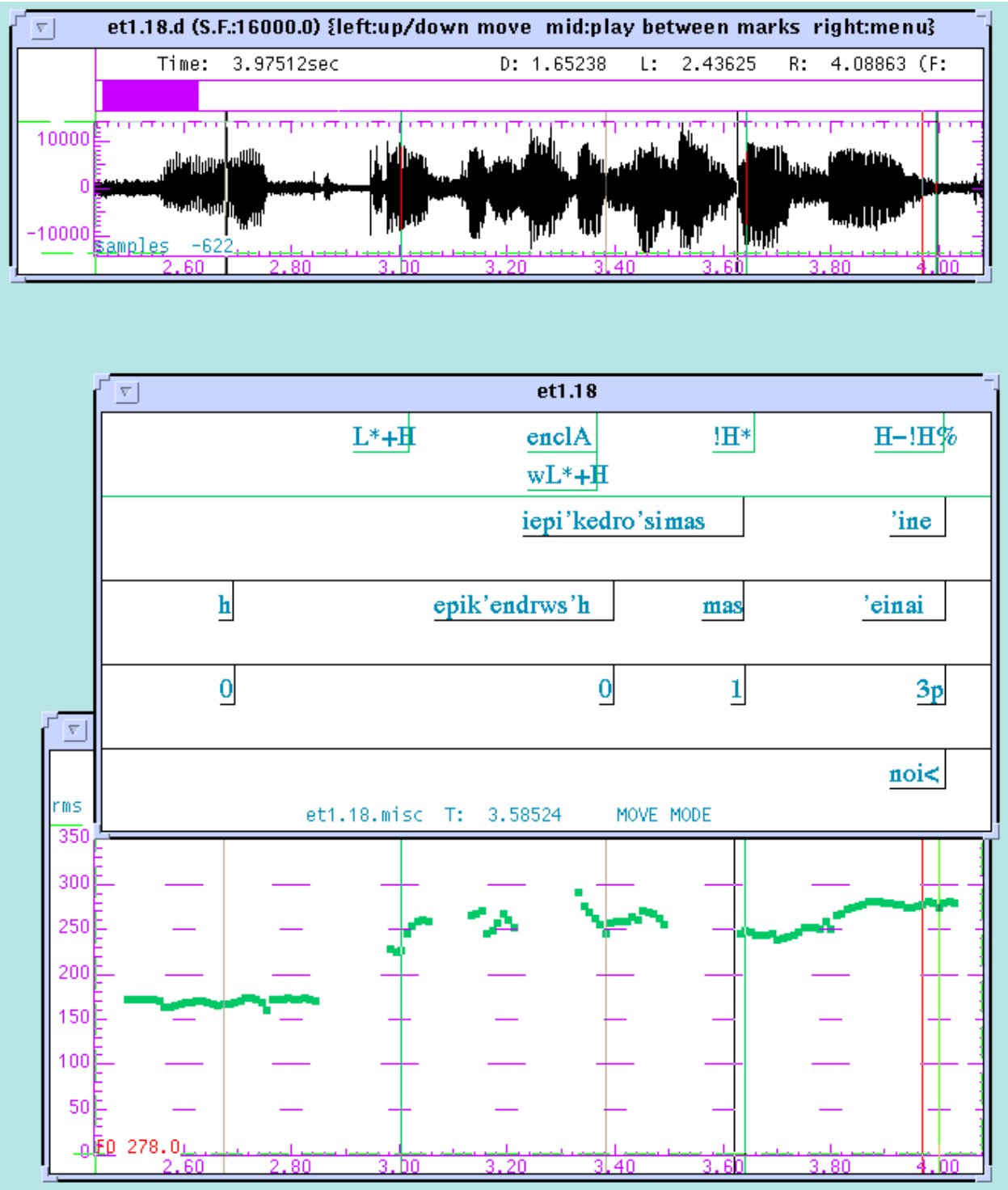

Figure 8: This example (gloss: "our focus is…") illustrates the stylized H-!H% configuration on the word ['ine] "is". Note also the presence of two accents on the word [epi'cedrosi] "focus," which here is followed by the enclitic [mas] "ours," and thus carries enclitic stress on its last syllable [si].

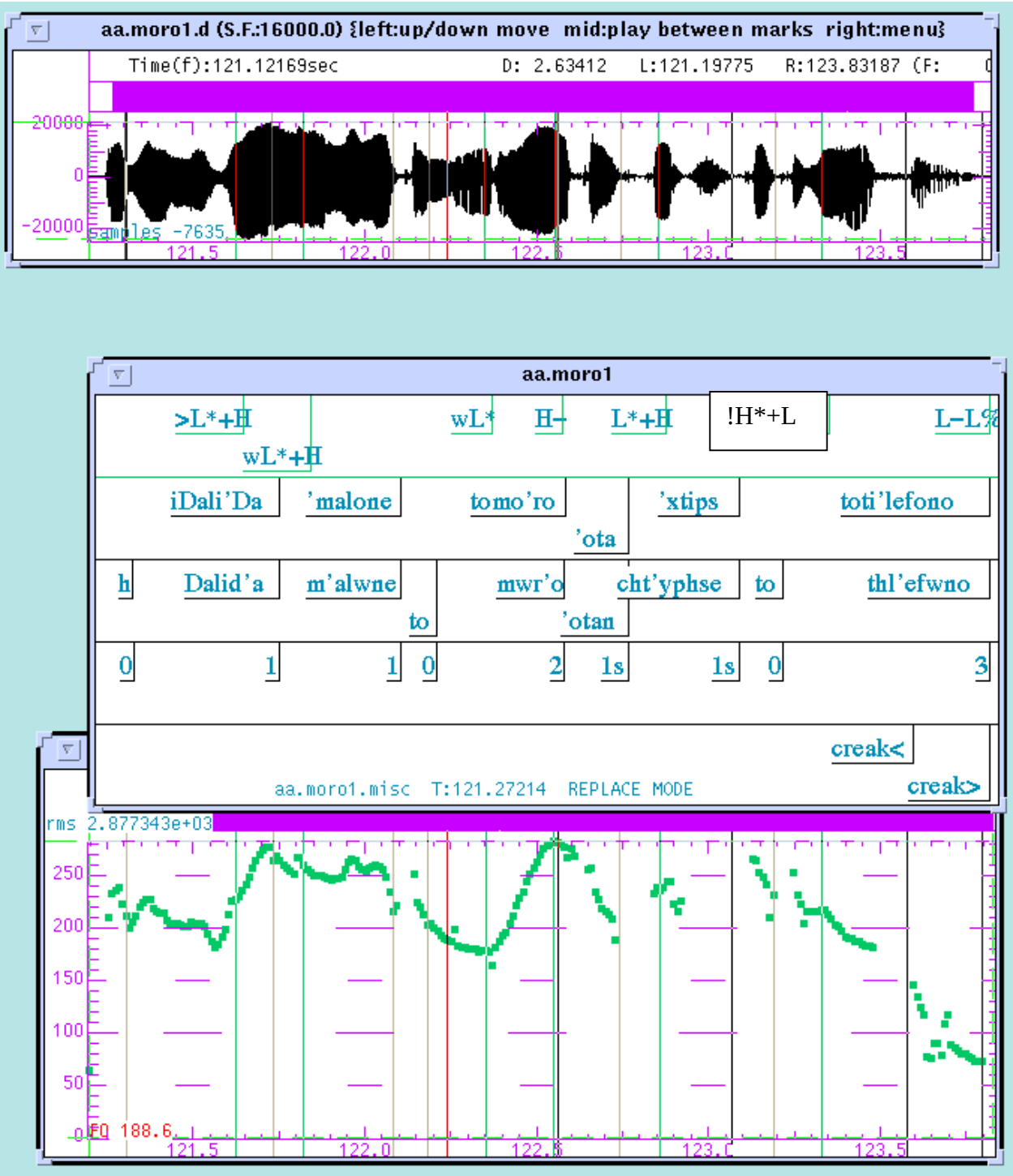

Figure 9: This example, (gloss: "Dalida was scolding the baby when the phone rang"), shows two different realizations of L*+H under tonal crowding, >L*+H which is realized earlier than it canonically would (the H tone is aligned with the accented vowel, instead of the first postaccentual vowel), and wL*+H, in which the L* tone is undershot, while the H shows the typical late alignment of H in L*+H accents. In this utterance there is also an undershot L* (wL*) on [mo'ro], realized as a rise from low pitch throughout the accented syllable (cf. the canonical L*s in Figure 6).

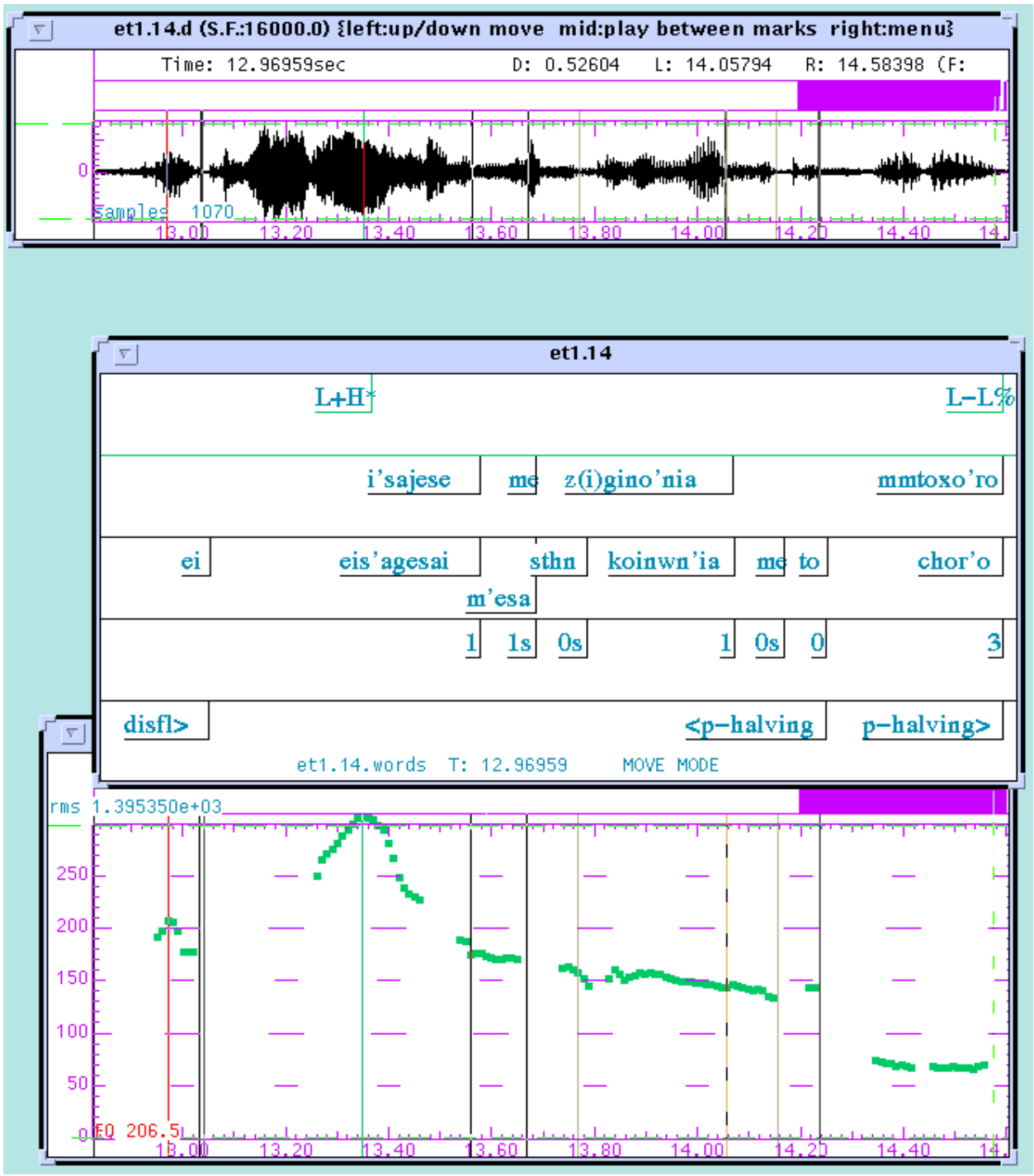

Figure 10: This example, (gloss: "[You] BECOME-PART of society through dance") illustrates de-accenting after early focus. Note also, the several instances of sandhi and fast speech rules. The phonological representation of the de-accented part of this utterance is /i'saɣese 'mesa stin kino'nia me to xo'ro/ and it would be expected to be realized, according to phonological descriptions, as [i'saʝese 'mesa stiɲɟino'nia metoxo'ro], rather than the actual [i'saʝese 'meziɟino'nia mṭoxo'ro].