Prosody: Speech Rhythms and Melodies

6. Generalising Pitch: Stylisation

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Summer School
Contemporary Phonology and Phonetics
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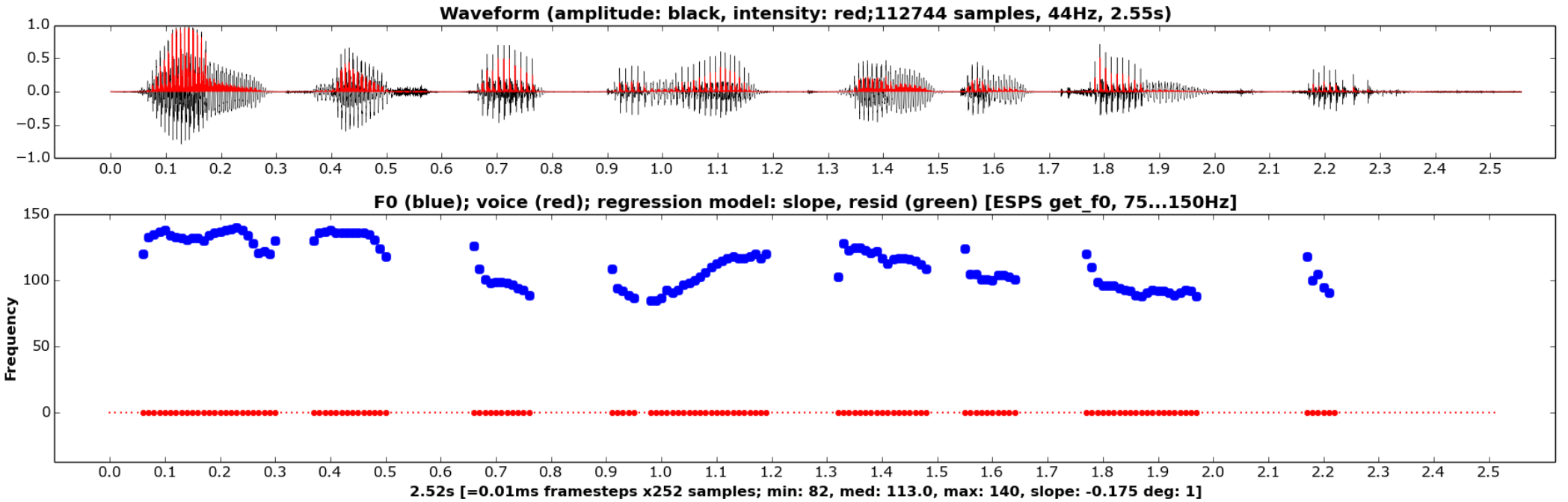
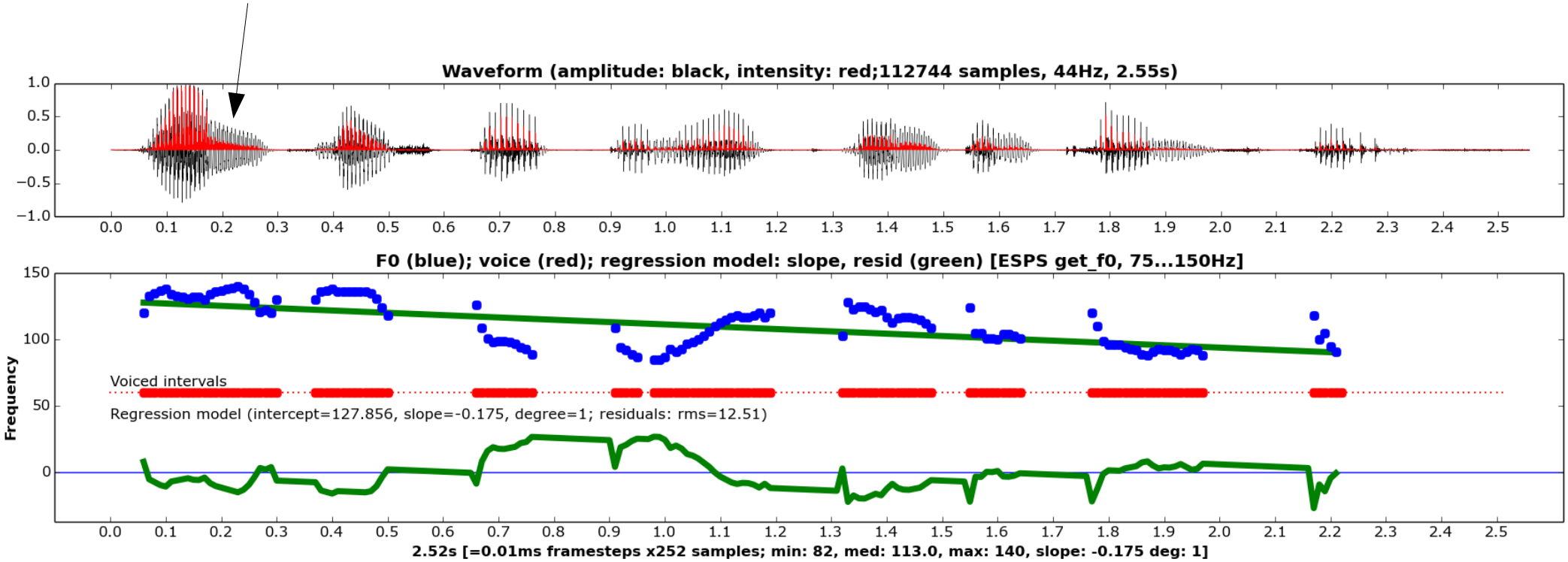
Revision: What exactly does this graph show?



Endlich gab der Nordwind den Kampf auf.

Phonetic correlates of phonological categories

amplitude; *intensity* = *f*(*amplitude*^{2}) → factor in stress, focus, contrast, emphasis



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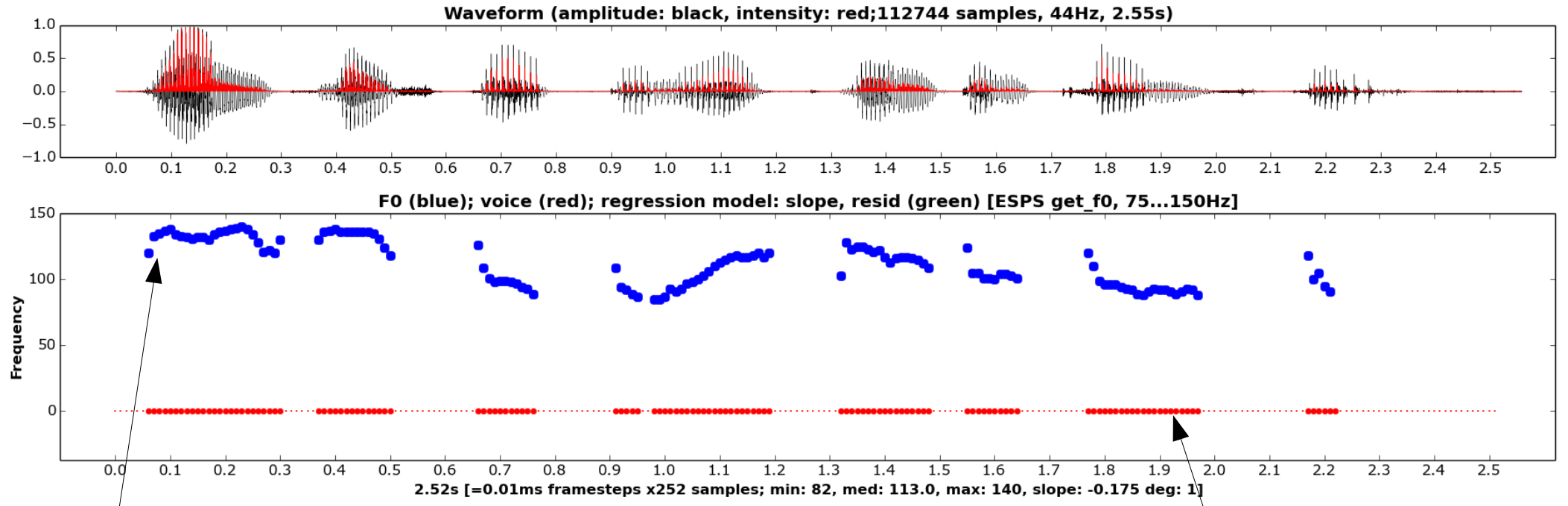
Representations of phonetic time functions

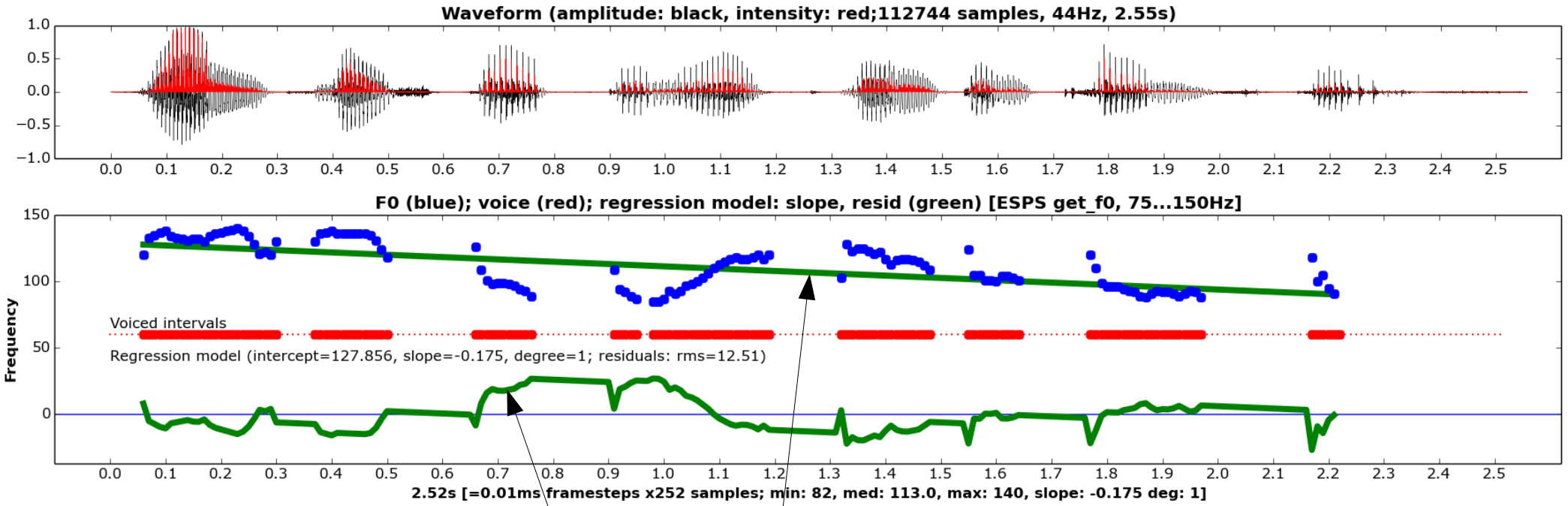


pitch track: fundamental frequency, f0

voicing

Endlich gab der Nordwind den Kampf auf.

Phonetic correlates of phonological categories



global downtrend model
→ declination model

pitch perturbation model → accent/tone and microprosody model

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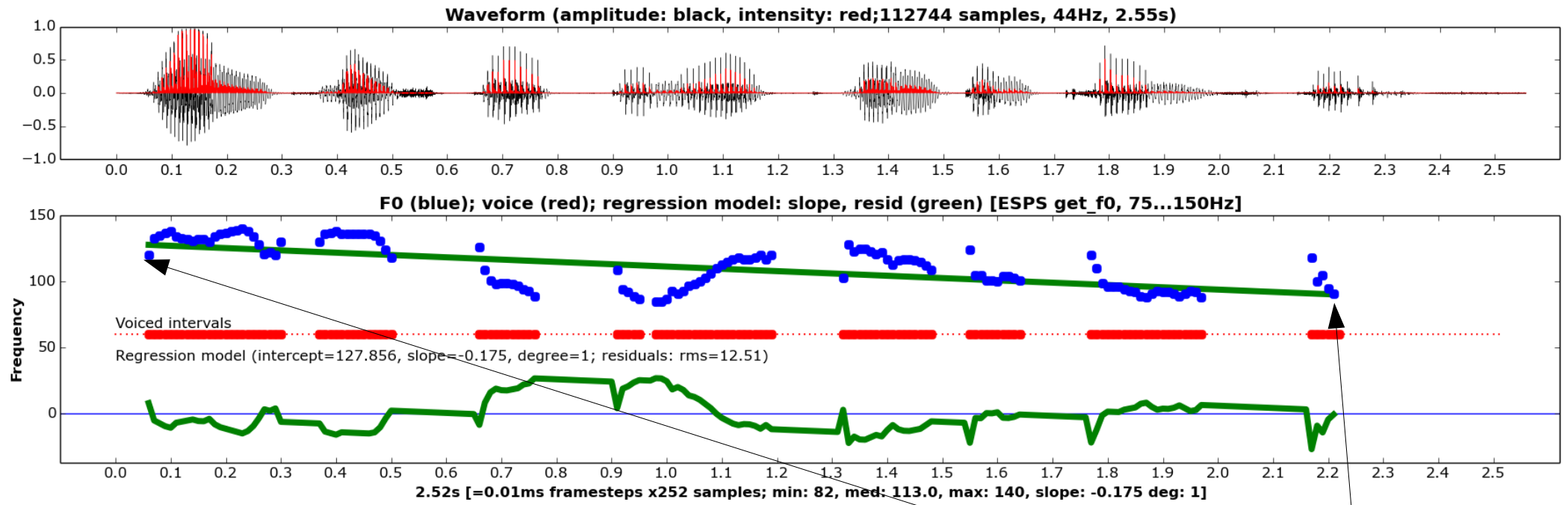
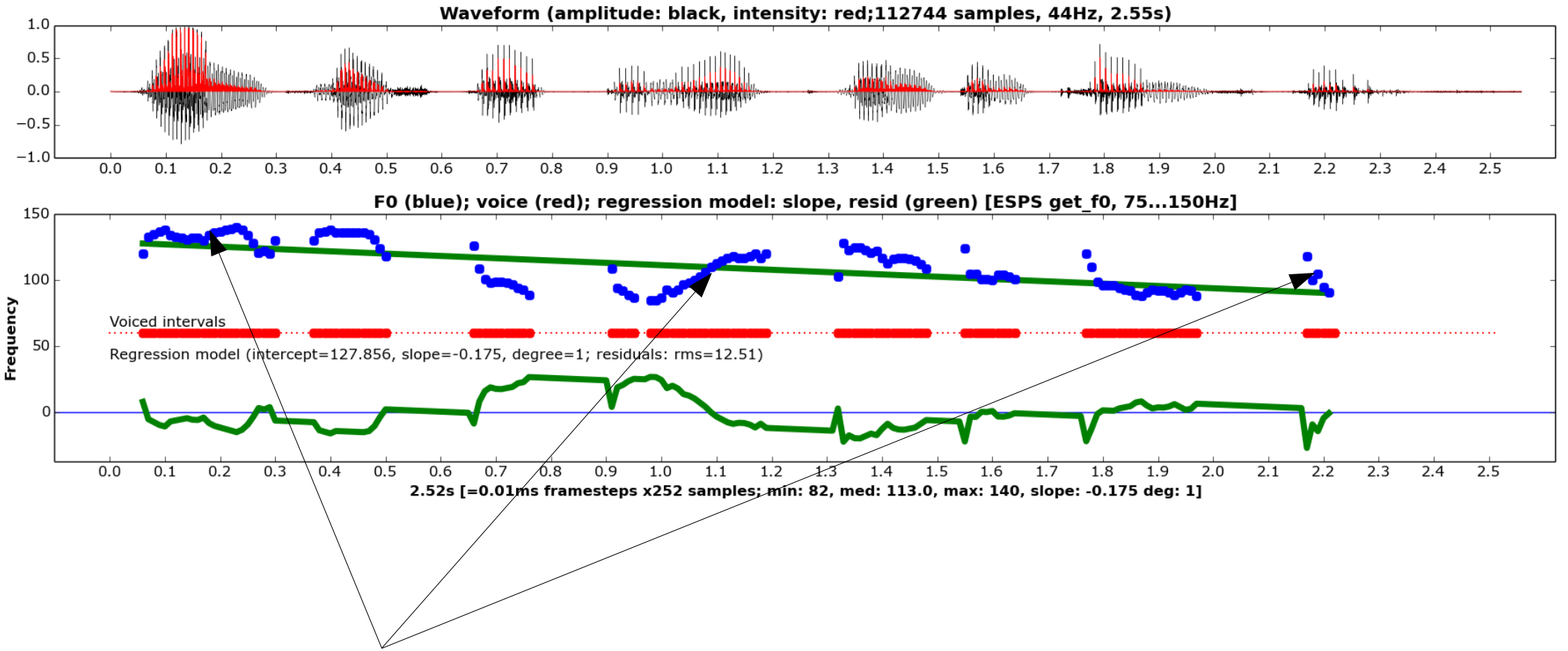
Phonetic correlates of phonological categories



initial & final pitch
→ boundary tone

Phonetic correlates of phonological categories



pitch deviations → local pitch accents (or tones)

Endlich gab der Nordwind den Kampf auf.

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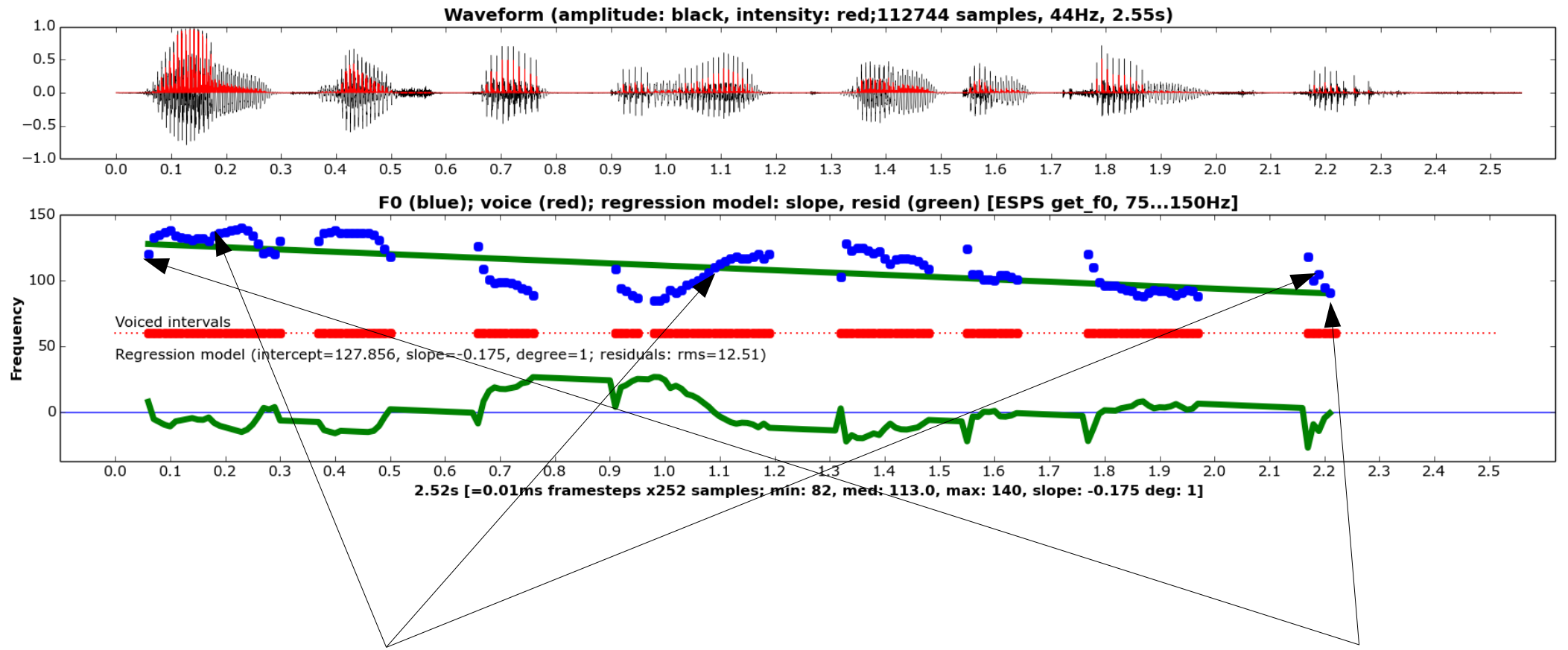

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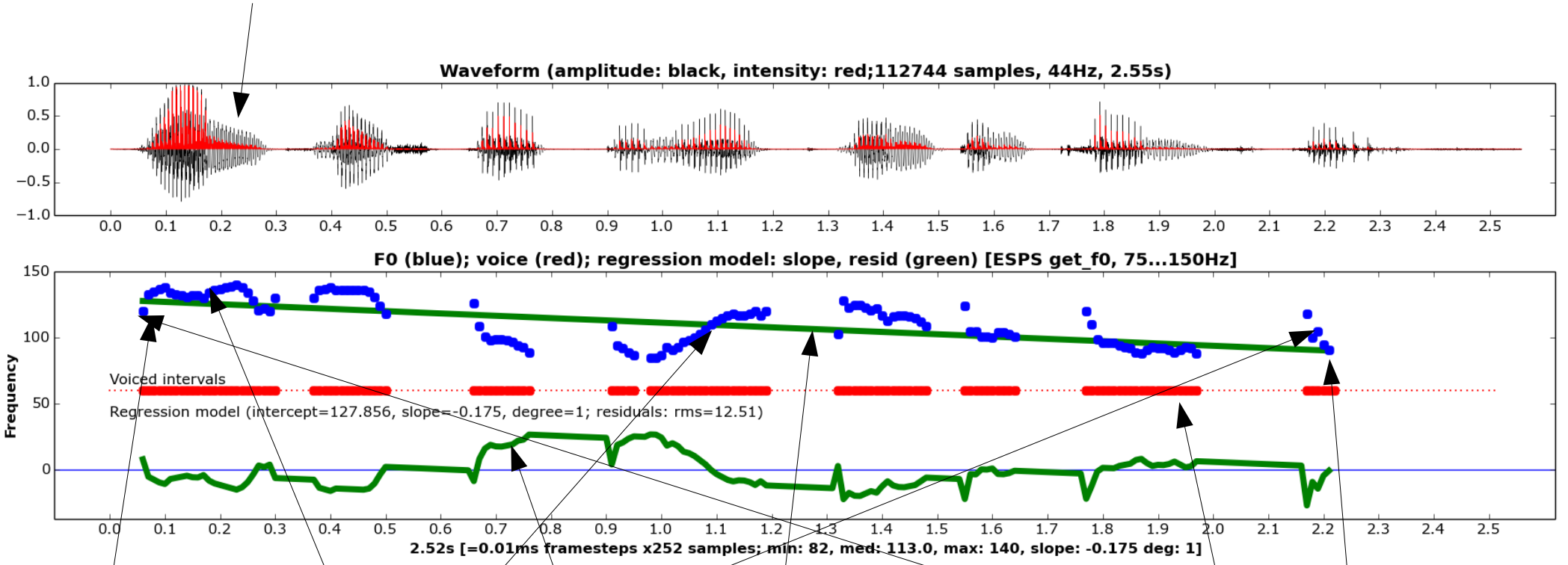

pitch track
f0

global downtrend model
→ declination model

voicing

pitch deviations → local pitch accents (or tones)

boundary tone

pitch perturbation model → accent/tone and microprosody model

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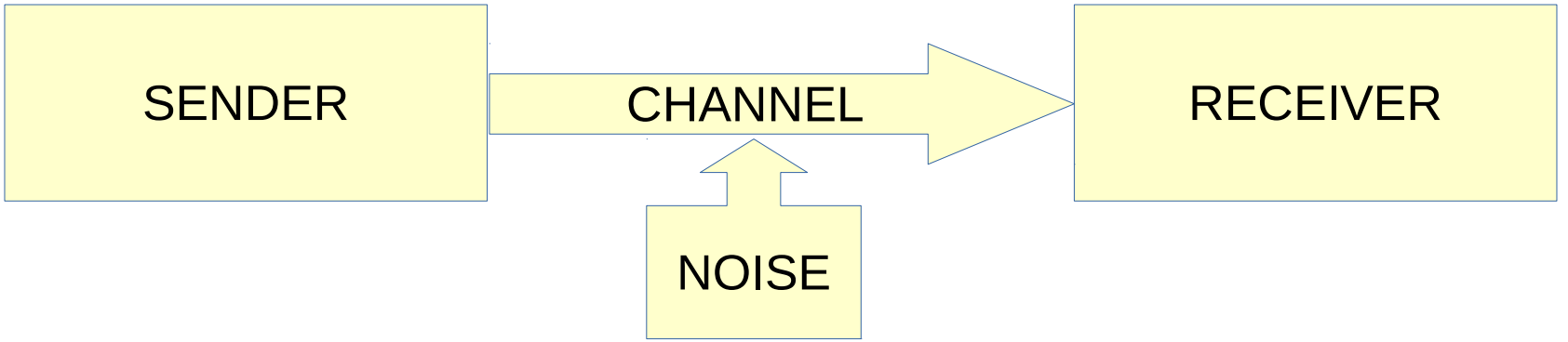
Phonetic interpretation: parameters and trajectories

- Phonetic domain parameters and trajectories
  - *melody*:
    - variation of fundamental frequency properties in time
  - *volume*:
    - variation of intensity properties in time
  - *duration*:
    - variation of unit duration properties in time
      - Note that *duration* has two temporal dimensions

- Phonological domains
  - structural and functional units and patterns

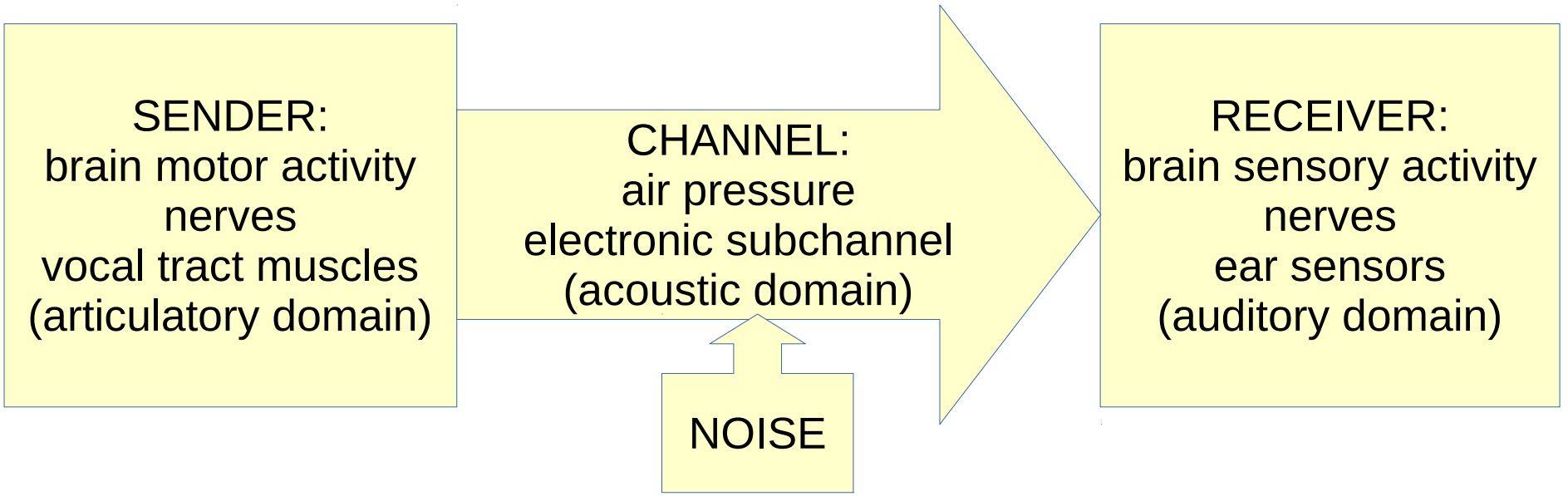
Phonetic interpretation: phases

- speaker, production, articulatory phonetics:
  - articulation rate - effort
- channel, acoustic phonetics:
  - fundamental frequency - intensity
- hearer, reception, auditory phonetics:
  - pitch - loudness



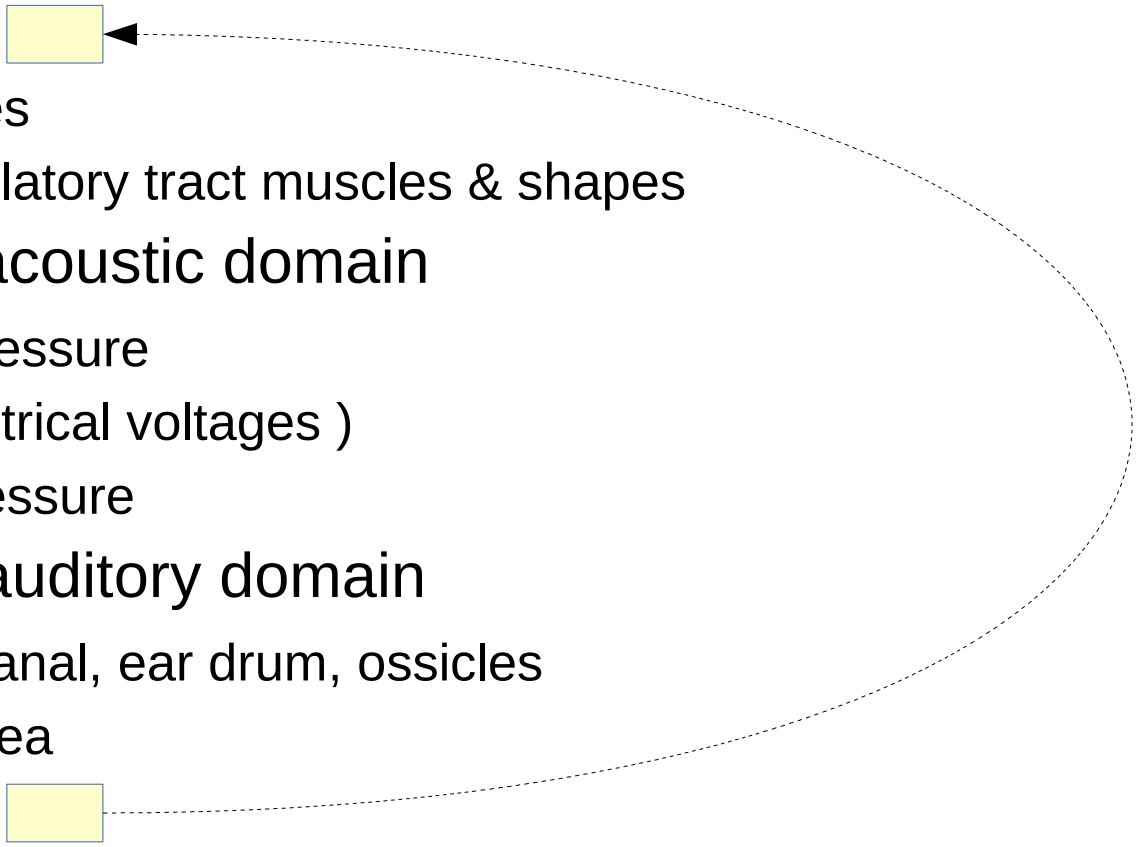
Forms of prosody: phases and subphases

- each of the phases has subphases:
  - → brain motor activity → nerves → vocal tract muscles
  - → air pressure → (electronic channel →) air pressure
  - → ear sensors – nerves – brain sensory activity



Phonetic interpretation: phases

- phonetic domains: information theoretic phases:
  - sender → channel → receiver
    - sender: articulatory domain
      - → brain
      - → nerves
      - → articulatory tract muscles & shapes
    - channel: acoustic domain
      - → air pressure
      - (→ electrical voltages)
      - → air pressure
    - receiver: auditory domain
      - → ear canal, ear drum, ossicles
      - → cochlea
      - → brain



Phonetic interpretation: methods

observations – measurements – models

Observations and measurements

- analysis methods:
  - observational methods
    - perceptual
      - quantitative measurements
      - interpretative judgments
    - instrumental
      - quantitative measurements + interpretative judgments
  - experimental methods
    - production
      - quantitative analysis of elicited corpus
      - quantitative analysis of authentic corpus
    - perception
      - quantitative analysis of same-different judgments, reaction times, ...

Observations and measurements

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    - perception
      - quantitative analysis of same-different judgments, reaction times, ...

From phonetic measurements to phonetic models

- First steps: collect data, extract F0
- Induce a prosodic model
- Evaluate prosodic model:
  - Method 1, machine learning:
    - use new data, predict goodness of fit of new data
  - Method 2, perception:
    - re-synthesise prosodic model
    - test results with perception experiments
      - same-different comparison
      - naturalness judgments
      - comprehensibility judgments

First steps: from waveform to F0

From waveform to F0

- Time domain methods
  - frequency = 1 / period
  - peak picking: intervals between peaks
  - intervals between zero crossing measurement
  - autocorrelation
- Frequency domain methods
  - overtone differences
  - spectral comb
  - cepstrum

Check Moebius slides

From phonetic measurements to phonetic models

From phonetic measurements to phonetic models

- Phonetic models:
  - smoothing models:
    - median smoothing
    - global regression
    - local regression (IPO)
  - segment models
    - voiced signal segments
    - quadratic interpolation between reference points
  - structured models
    - Fujisaki model
    - Liberman and Pierrehumbert model
    - Hirst model

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From phonetic measurements to phonetic models

- Phonetic stylisation models:
  - smoothing models:
    - median; global (Huber) and local (IPO) regression
  - segment models
    - voiced segment smoothing
    - quadratic spline segment interpolation (Hirst)
- F0 stylisation is the simplification of the F0 trajectory to remove
  - irrelevant properties
  - noise

First steps to stylisation: smoothing filters

Regression smoothing

F0 smoothing: general procedures

1. Identify voiced and unvoiced intervals, extract F0
2. Smoothing and 'stylisation' modelling procedures

Local sequencing procedures:

- level F0 sequences, e.g. based on median of a sequence: robotic!
- median smoothing:

  for each F0 (t_i) measurement :

  $F0_{smooth}$ (t_i) mean <F0 (t_i), …, F0 (t_n)>
- quadratic spline sequences
  - (Hirst)

Global reference plus accent/tone excursion procedures

- Regression: log, linear, quadratic, … ,
  - (Fujisaki, Pierrehumbert & Lieberman, Tilt model)

F0 smoothing: different approaches

- Smoothing by median filter:
  - the median of sequences of 3 measurements
- Smoothing by linear regression

$y = a_0 + a_1 x + \varepsilon$

- Smoothing by polynomial regression:

$y = a_0 + a_1 \cdot t + a_2 \cdot t^2 + a_3 t^3 + \ldots + a_0 t^n + \varepsilon$

- Smoothing by asymptotic descent, effectively log(x):

$F0(t_{t+1}) = m \cdot F0(t_i) + \varepsilon$, for $m < 0$

$a + F0(t_{i+1}) = a + m \cdot F0(t_i) + \varepsilon$, $m < 0$ non-zero asymptote

Smoothing: different approaches

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  $y = a_0 + a_1 x + \varepsilon$
- Smoothing by polynomial regression:

  $y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 x^3 + \ldots + a_0 x^n + \varepsilon$
- Smoothing by asymptotic descent:

  $y \in \langle x_1, \ldots, x_1 \rangle : x_i = m \cdot x_{i-1} + \varepsilon$

  $y \in \langle x_1, \ldots, x_1 \rangle : a + x_i = a + m \cdot x_{i-1} + \varepsilon$

Regression smoothing examples

1. Identify voiced intervals
2. Extract F0
3. Interpolate silent intervals
   - Simplified in the following examples:
     - 3rd quartile (75th percentile)
4. Calculate smoothing (declination / accent model)
   - Linear, quadratic etc. (polynomial) regression over interpolated F0 sequence
5. Calculate residuals (microprosody model):
   - Subtract regression values from F0 values

F0 smoothing: general procedures

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Global reference plus accent/tone excursion procedures

- Regression: log, linear, quadratic, … ,
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F0 smoothing: global procedures

F0 smoothing: procedure

1. Identify voiced and unvoiced intervals, extract F0
2. Smoothing and ‘stylisation’ modelling:
   - Local smoothing:
     - linear, median; quadratic spline (Hirst)
   - Global reference plus discrete deviant values for different accents or tones
     - Fujisaki model, Liberman & Pierrehumbert’s invariance model, Taylor’s ‘Tilt’ model
   - Global smoothing with regression:
     - log, linear, quadratic, polynomial of degree *n*

       (used for illustration in the following examples)

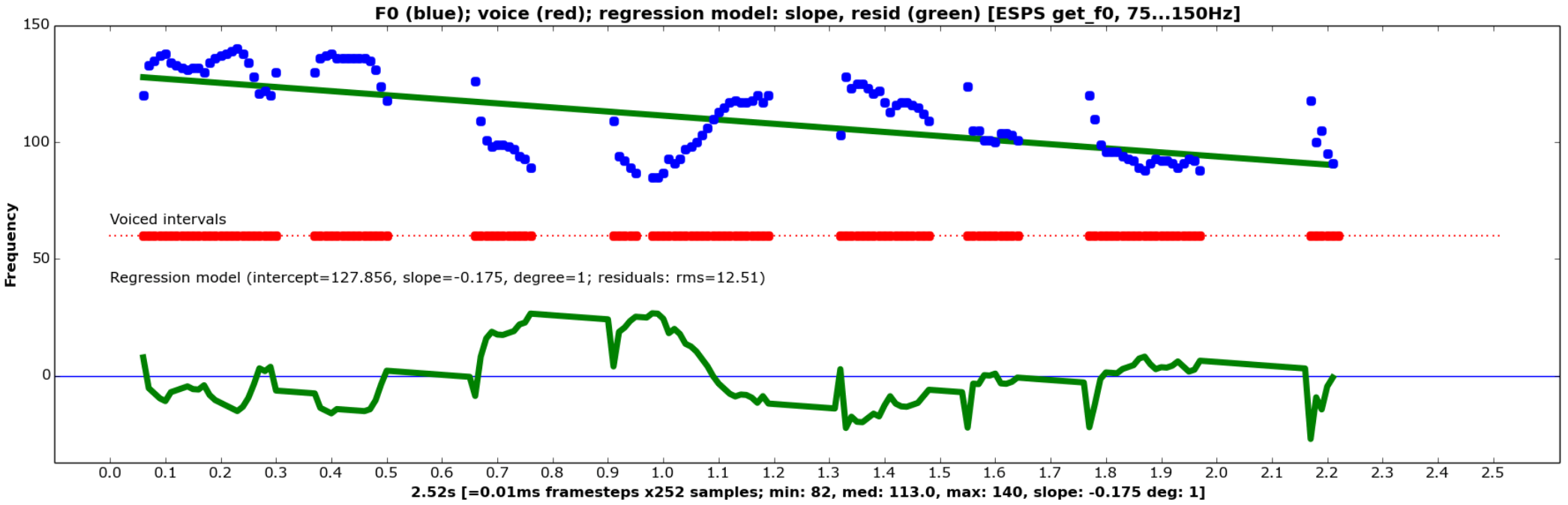
Smoothing: different approaches, different goals

- Smoothing by polynomial regression (degree *n)*:

$$y = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 x^3 + \ldots + a_0 x^n + \varepsilon$$

- Smoothing by linear regression (degree 1)

$$y = a_0 + a_1 x + \varepsilon$$



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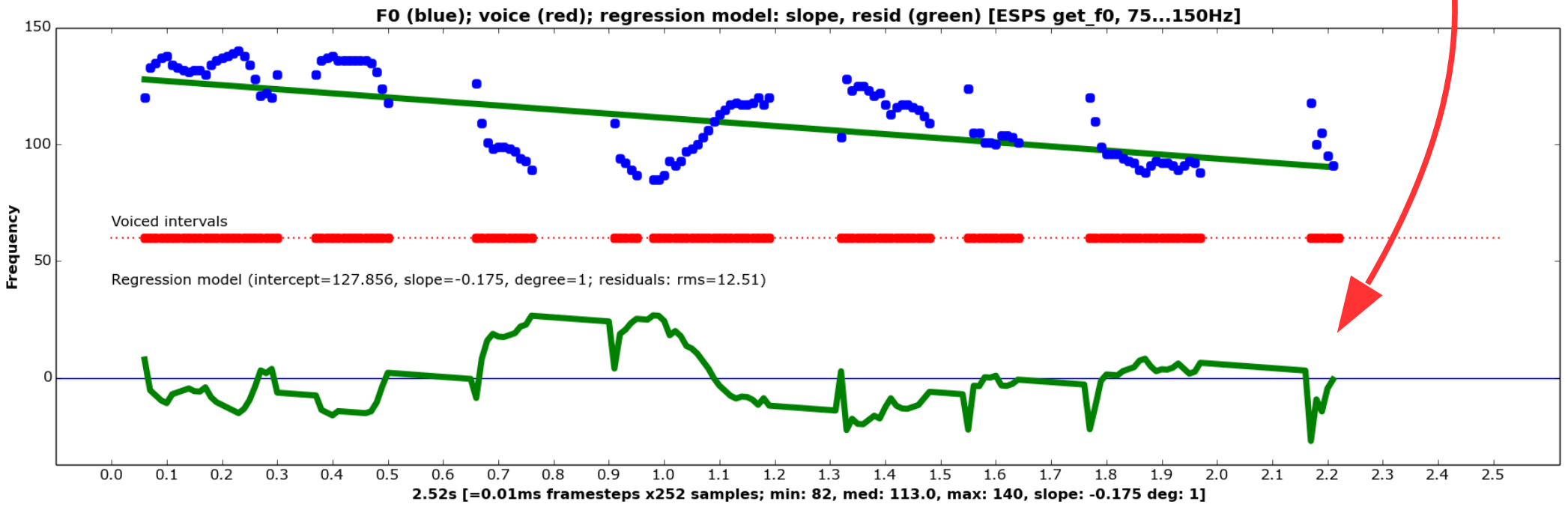
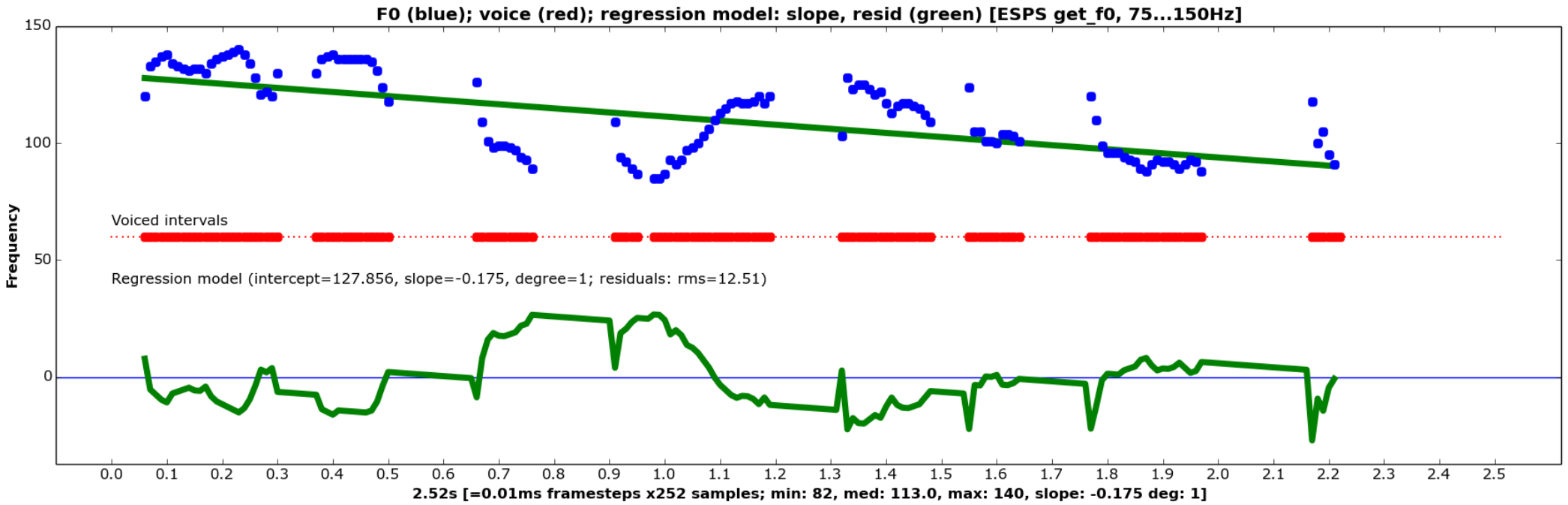
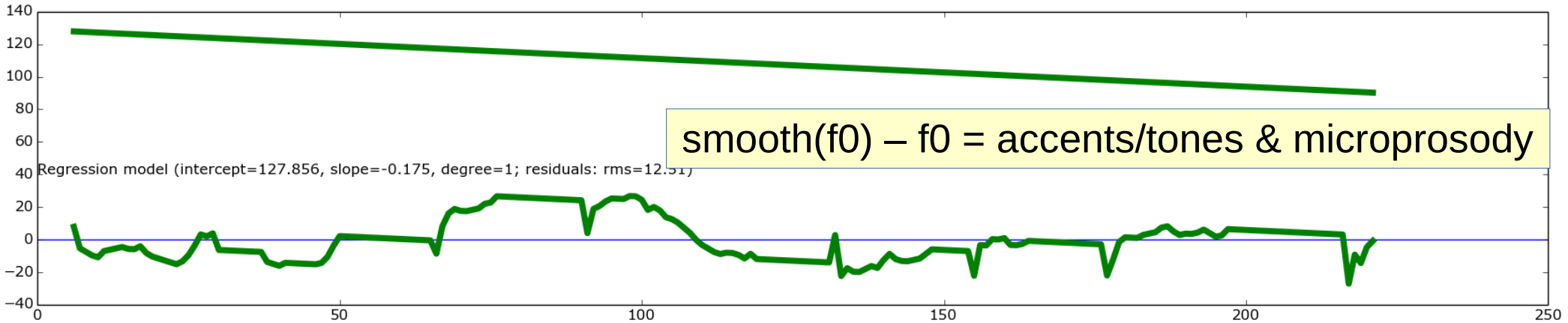


Global linear regression contour

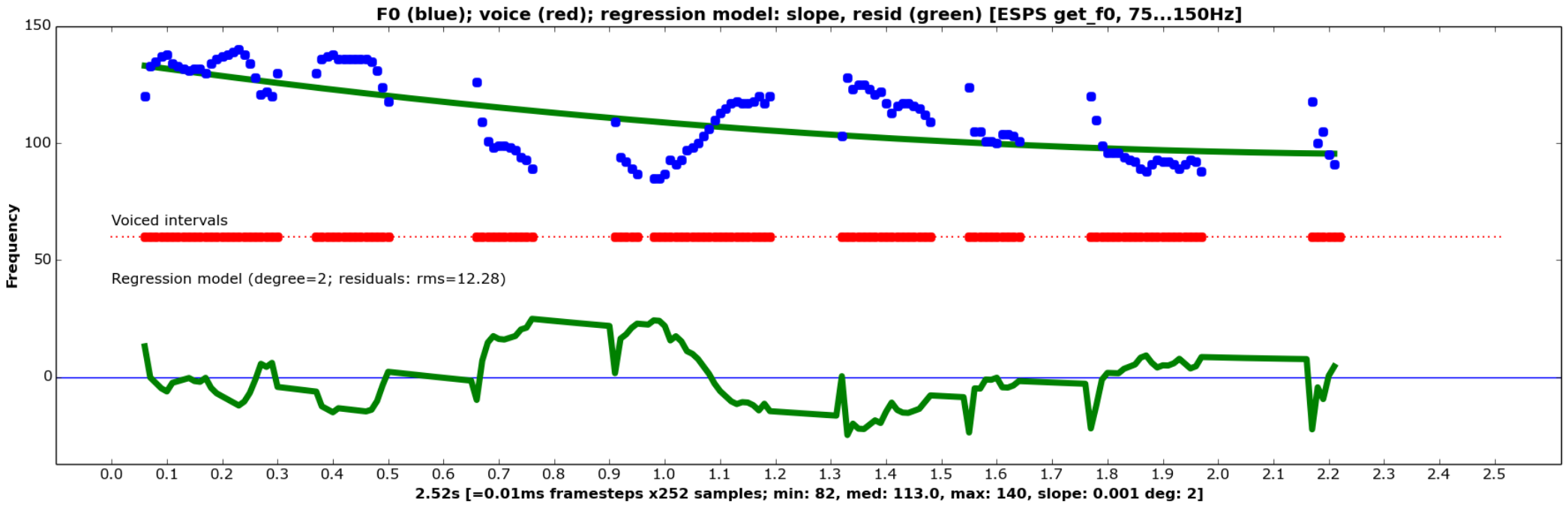


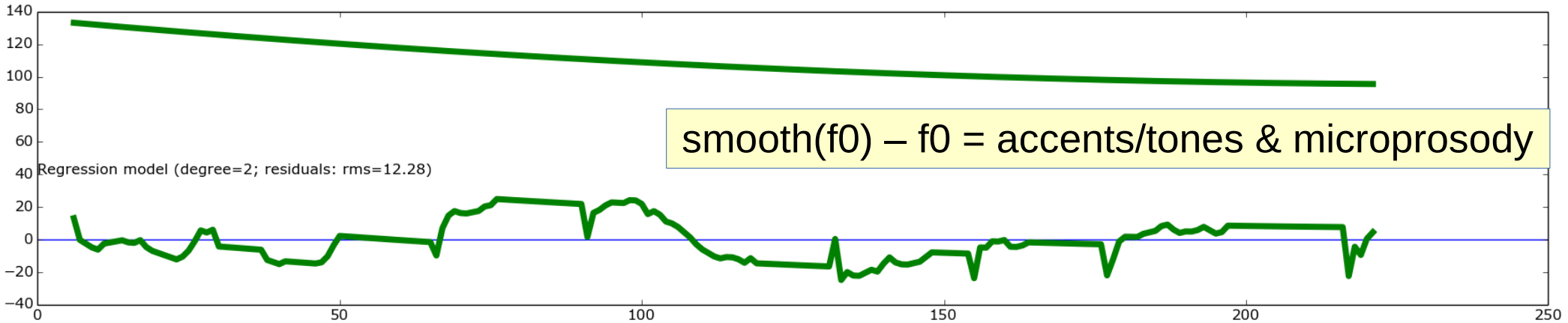


smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

Global quadratic regression contour

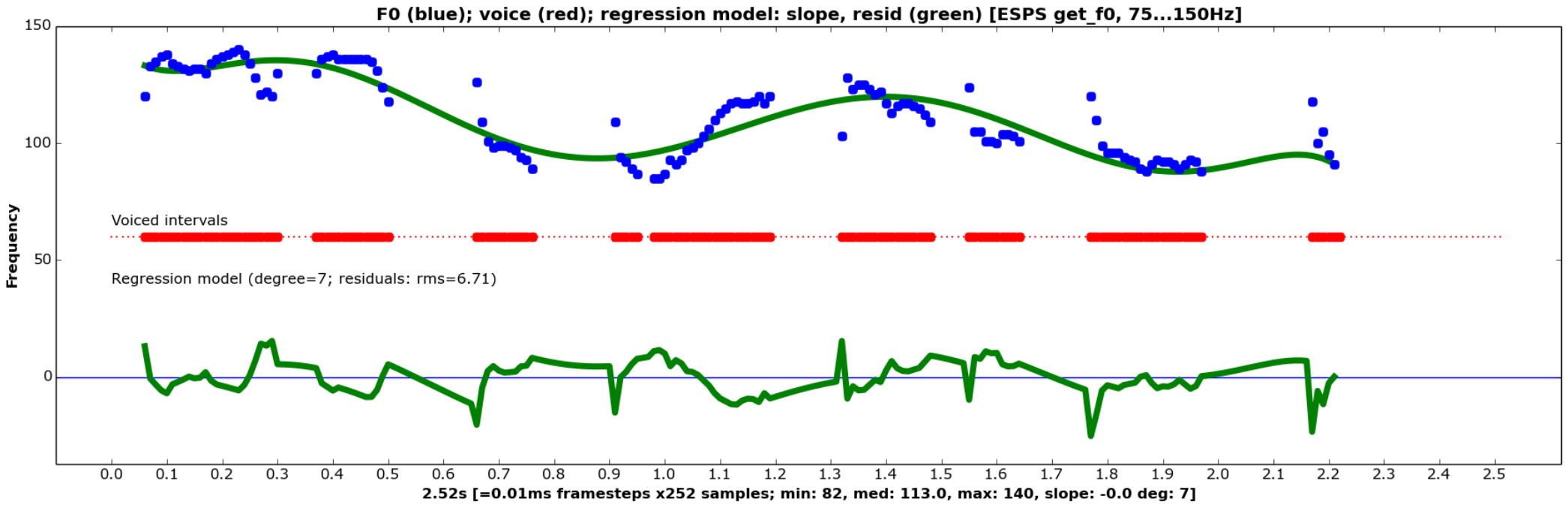


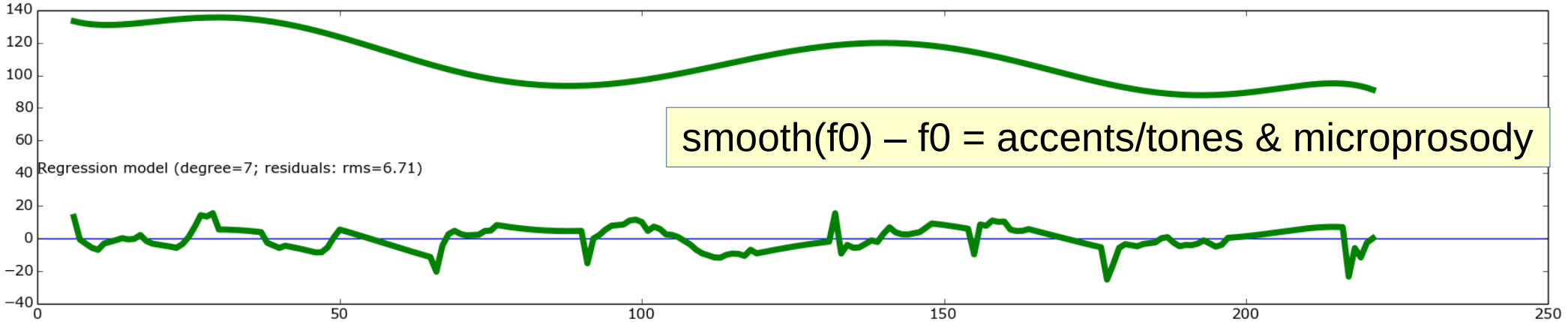


smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

Global regression contour, degree 7

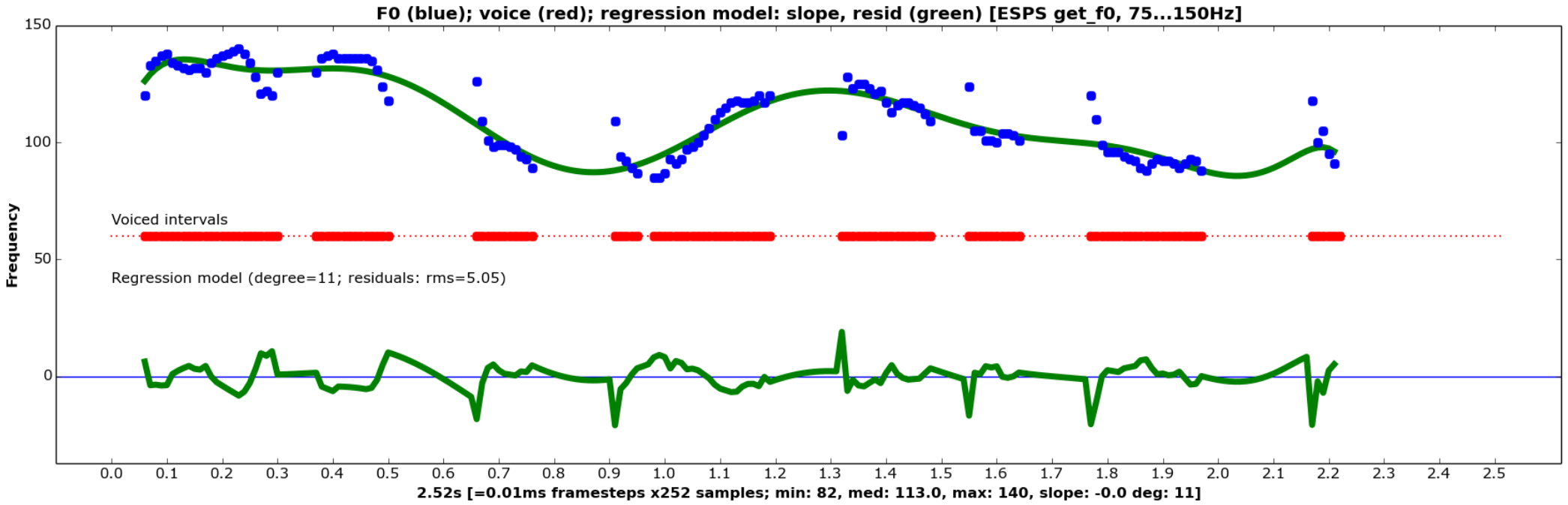


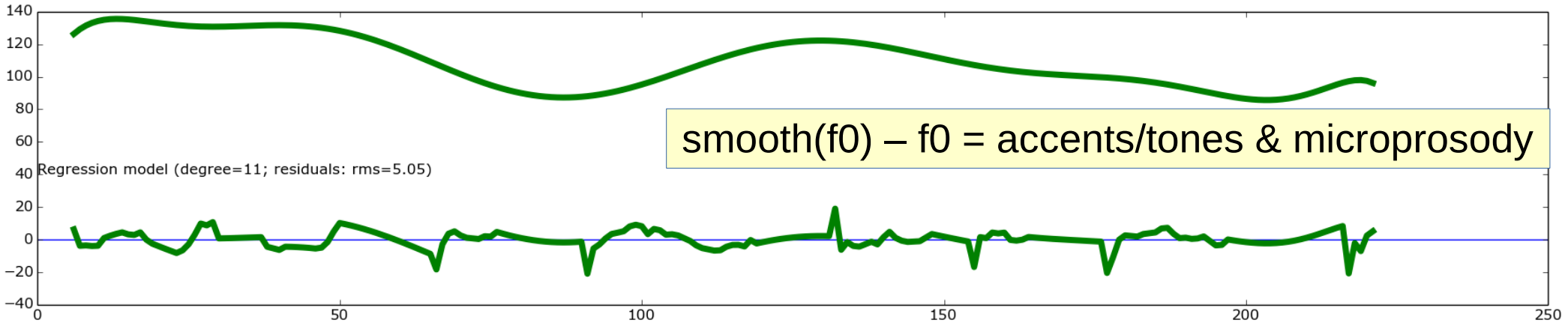


smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

Global regression contour, degree 11





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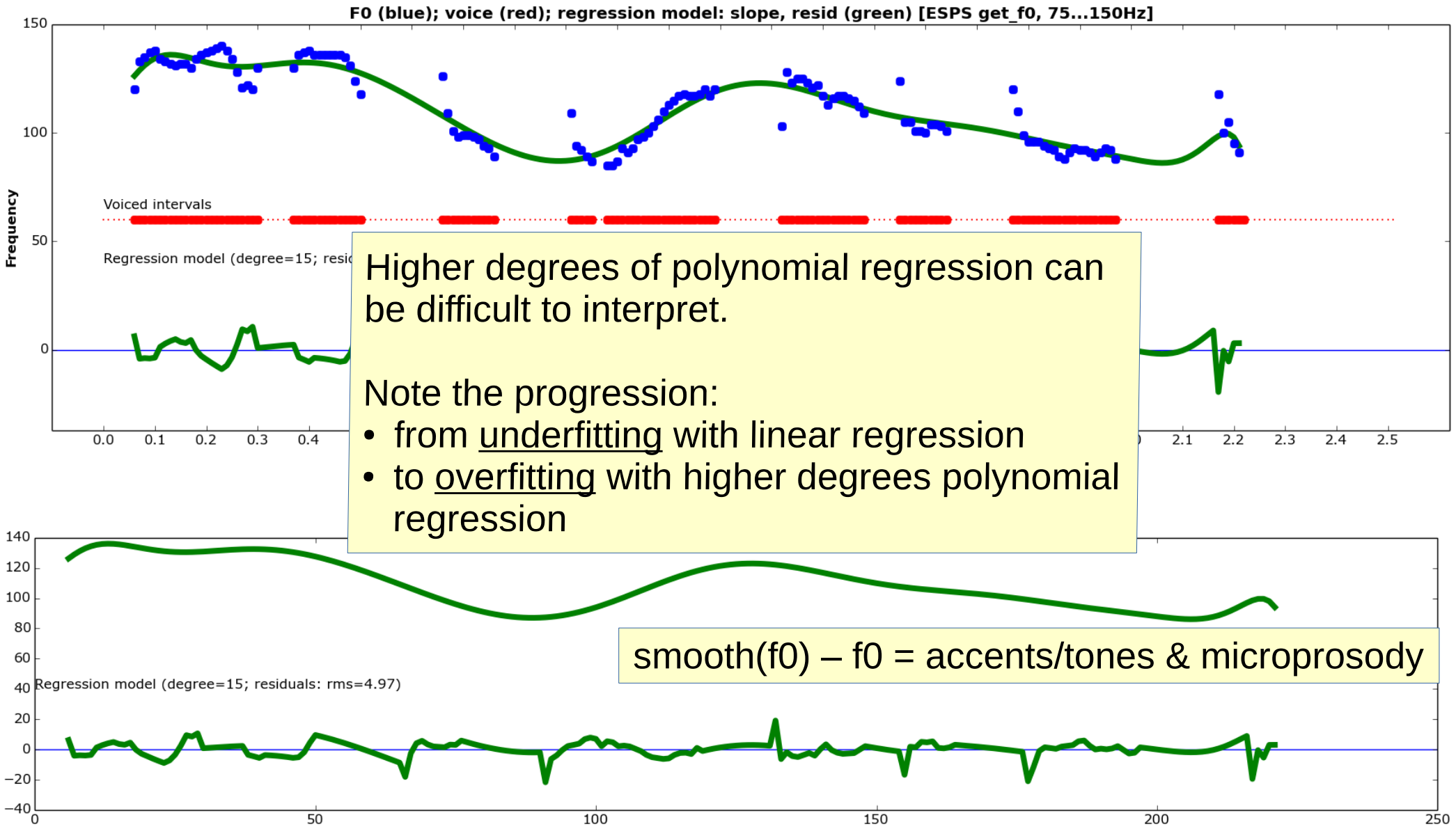
Endlich gab der Nordwind den Kampf auf.

Global regression contour, degree 15



Higher degrees of polynomial regression can be difficult to interpret.

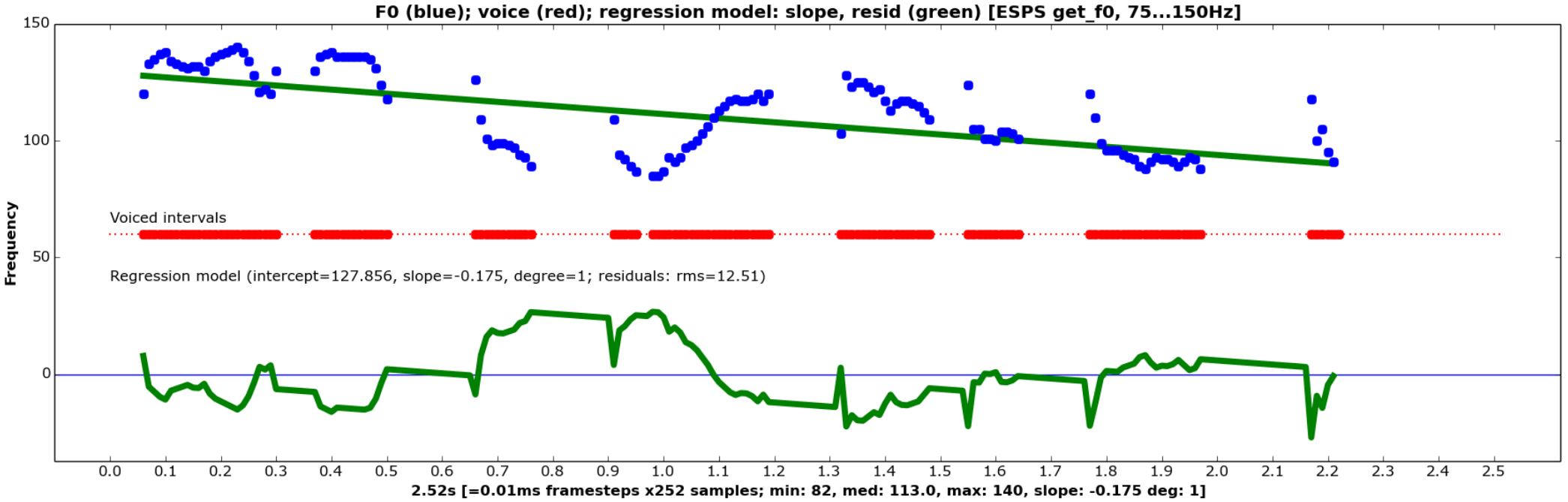
Note the progression:

- from underfitting with linear regression
- to overfitting with higher degrees polynomial regression

smooth(f0) – f0 = accents/tones & microprosody

Endlich gab der Nordwind den Kampf auf.

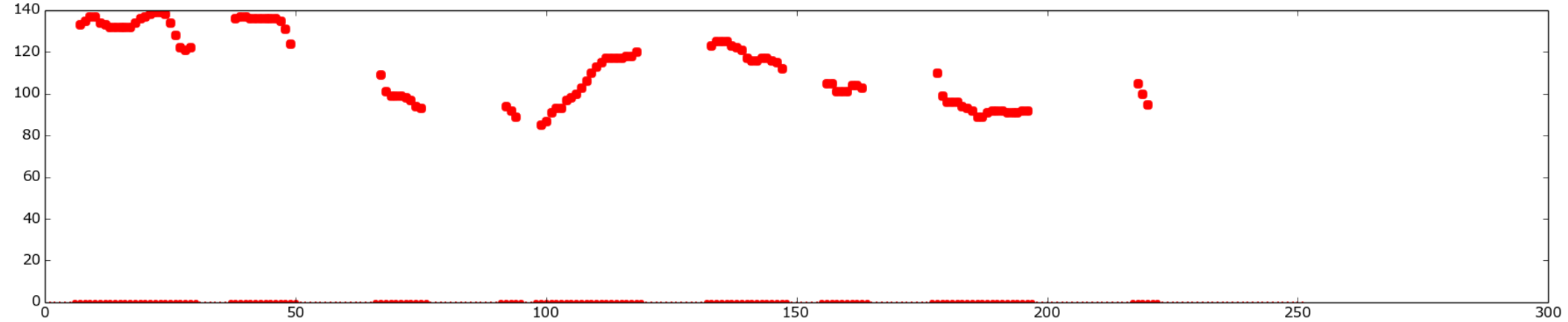
Global regression contours, up to degree 20



Endlich gab der Nordwind den Kampf auf.

F0 smoothing: local procedures

Simple median filter (scope: 3), often used



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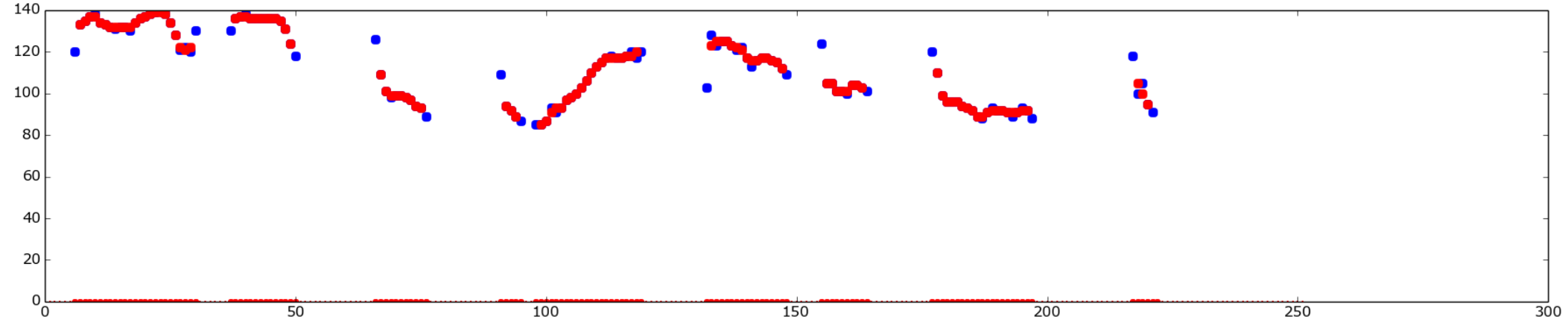
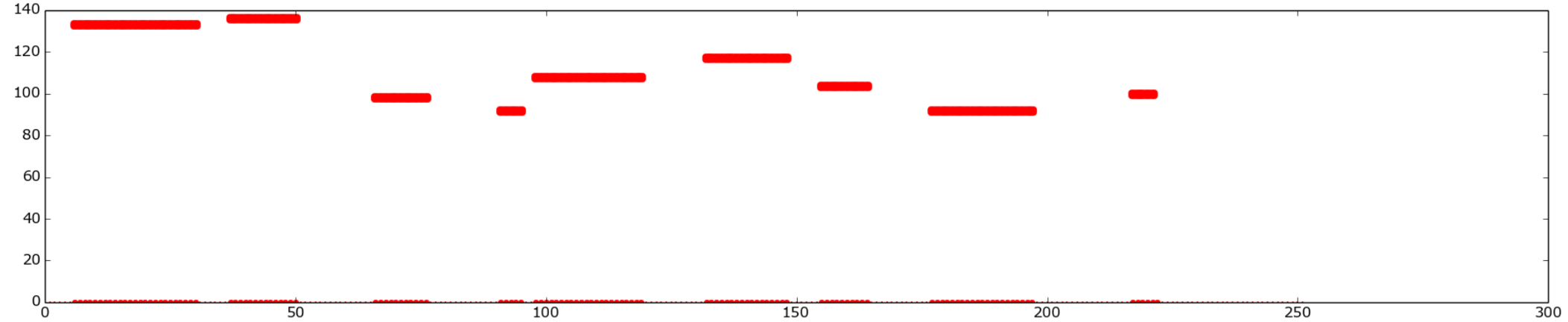


Each F0 value is normalised to the median F0 value of its immediate neighbours

Simple local median levelling filter – robotic!



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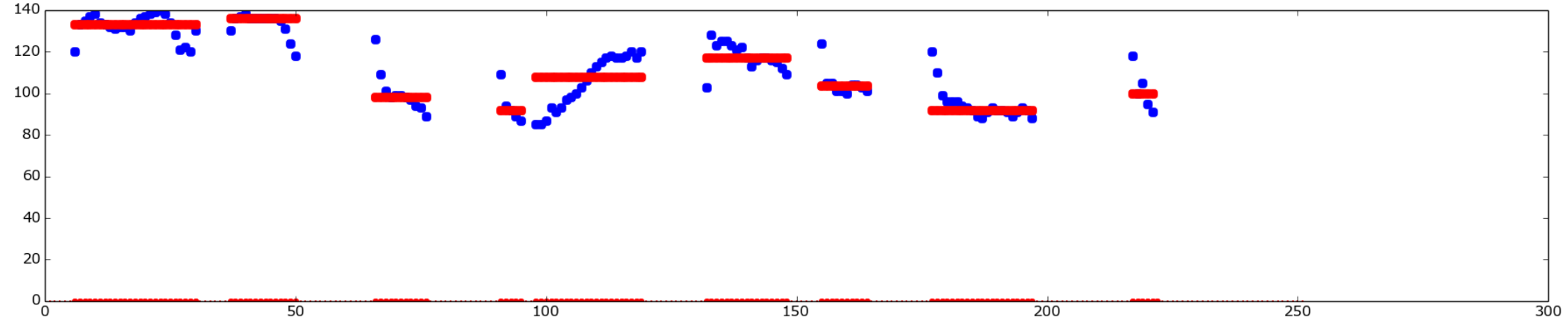
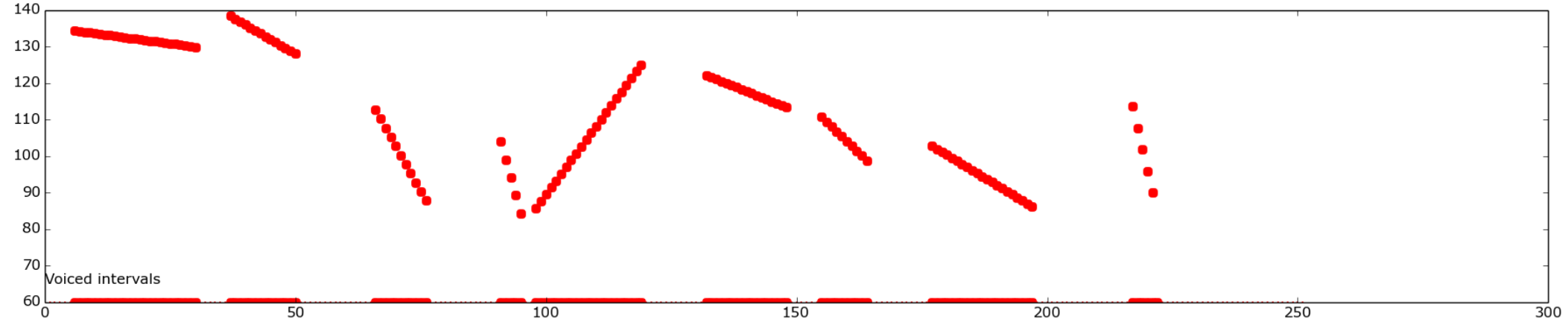


Each F0 value in a sequence is normalised to the median F0 value for the sequence

Local voicing regression contours, degree 1



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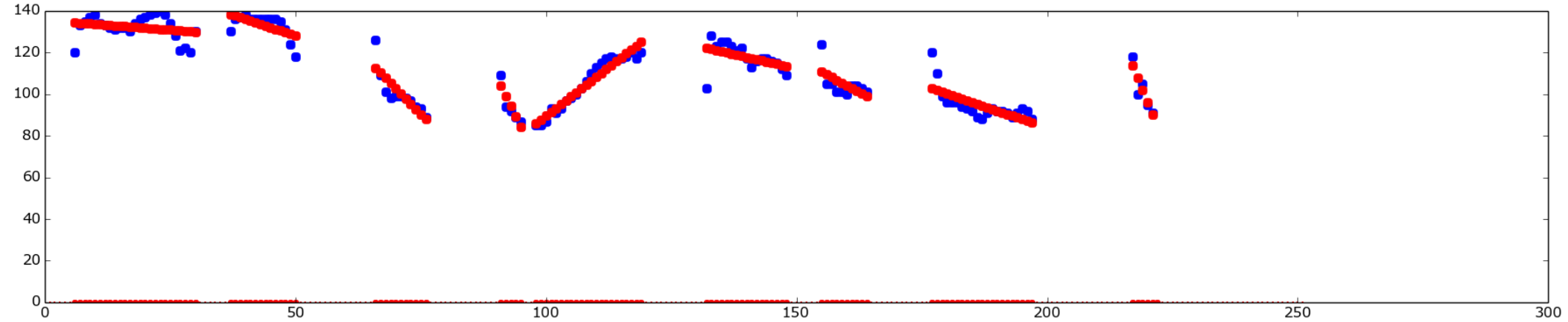
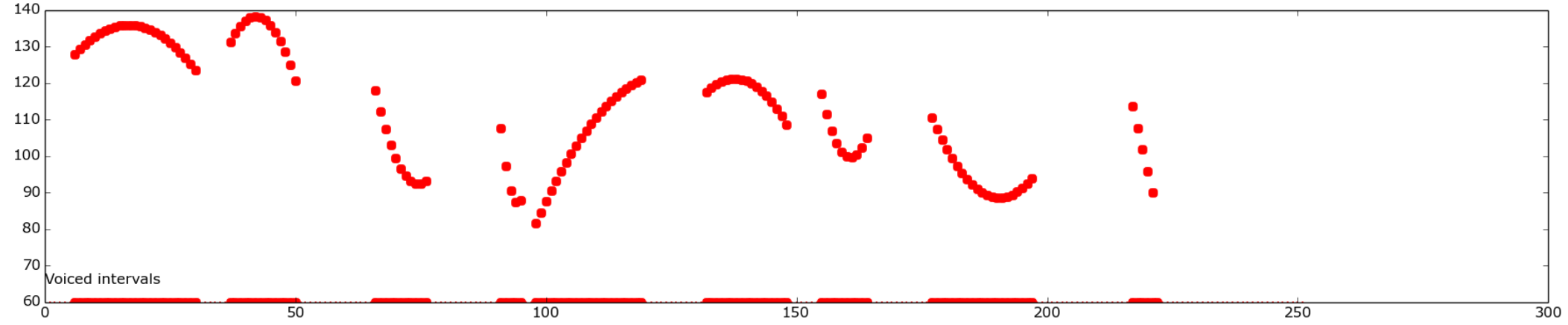


Local voicing regression contours, degree 2



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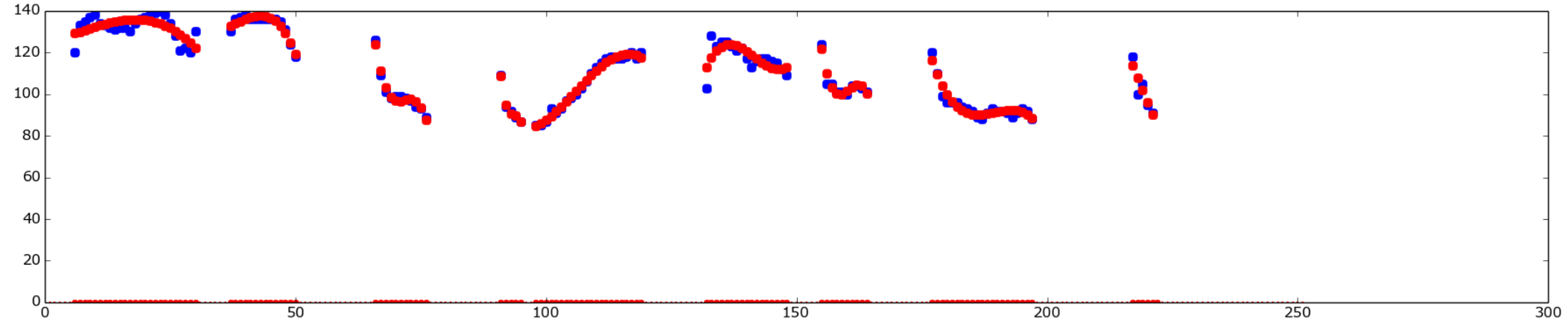
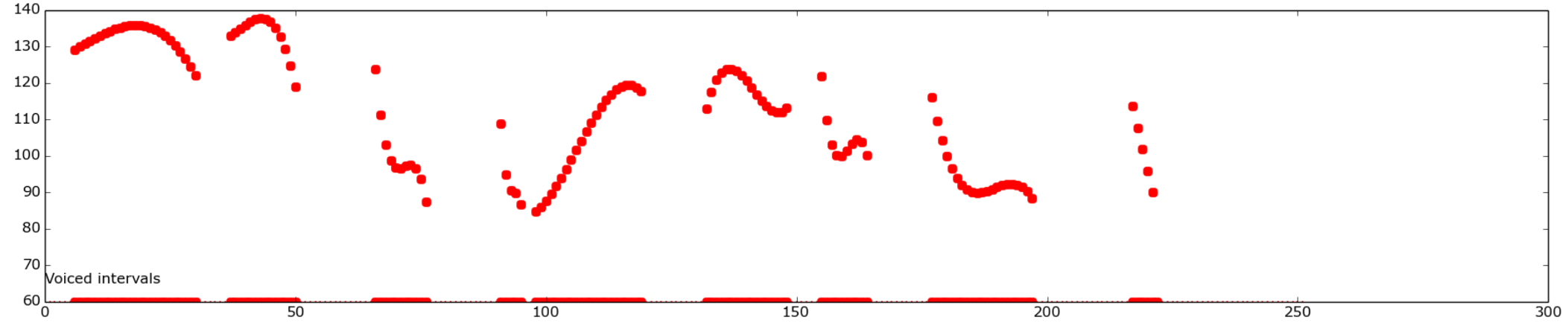


Local voicing regression contours, degree 3



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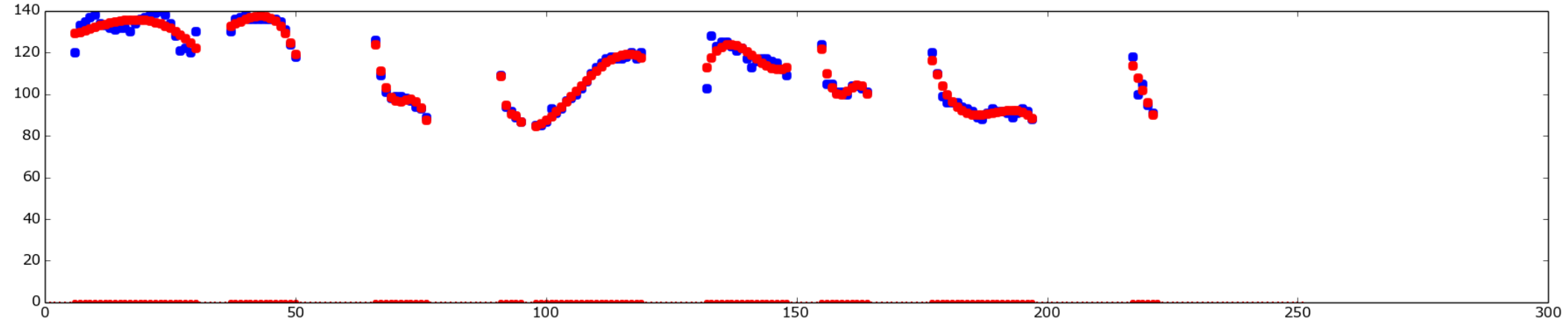
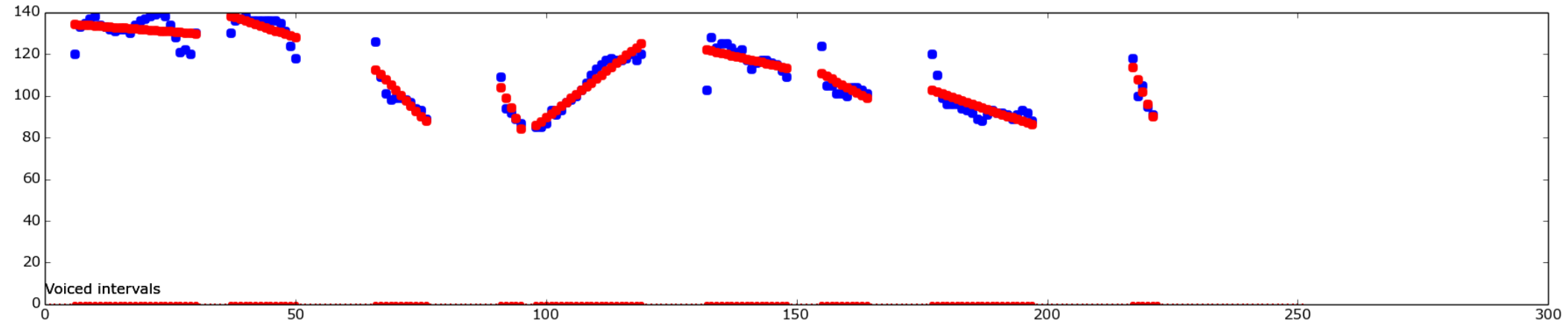


Local voicing regression contours (1...5)



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Models of f0 patterning: Hirst

- Intsint
- Momel
- ProZed

Hirst: quadratic spline - 'piecewise quadratic function'

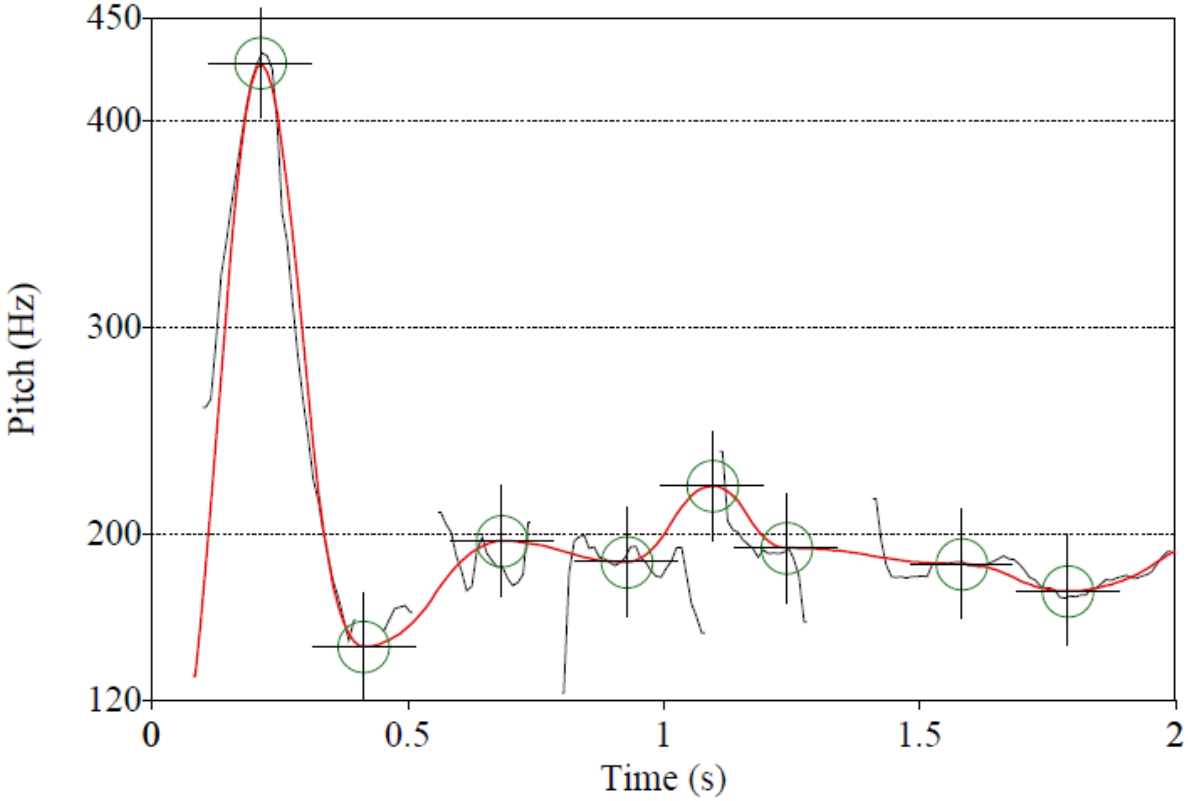


Fig. 6.7 Macromelodic profile (red) for a two-second extract from recording A01, defined as quadratic transitions between anchor points (green).

Hirst: quadratic spline - 'piecewise quadratic function'

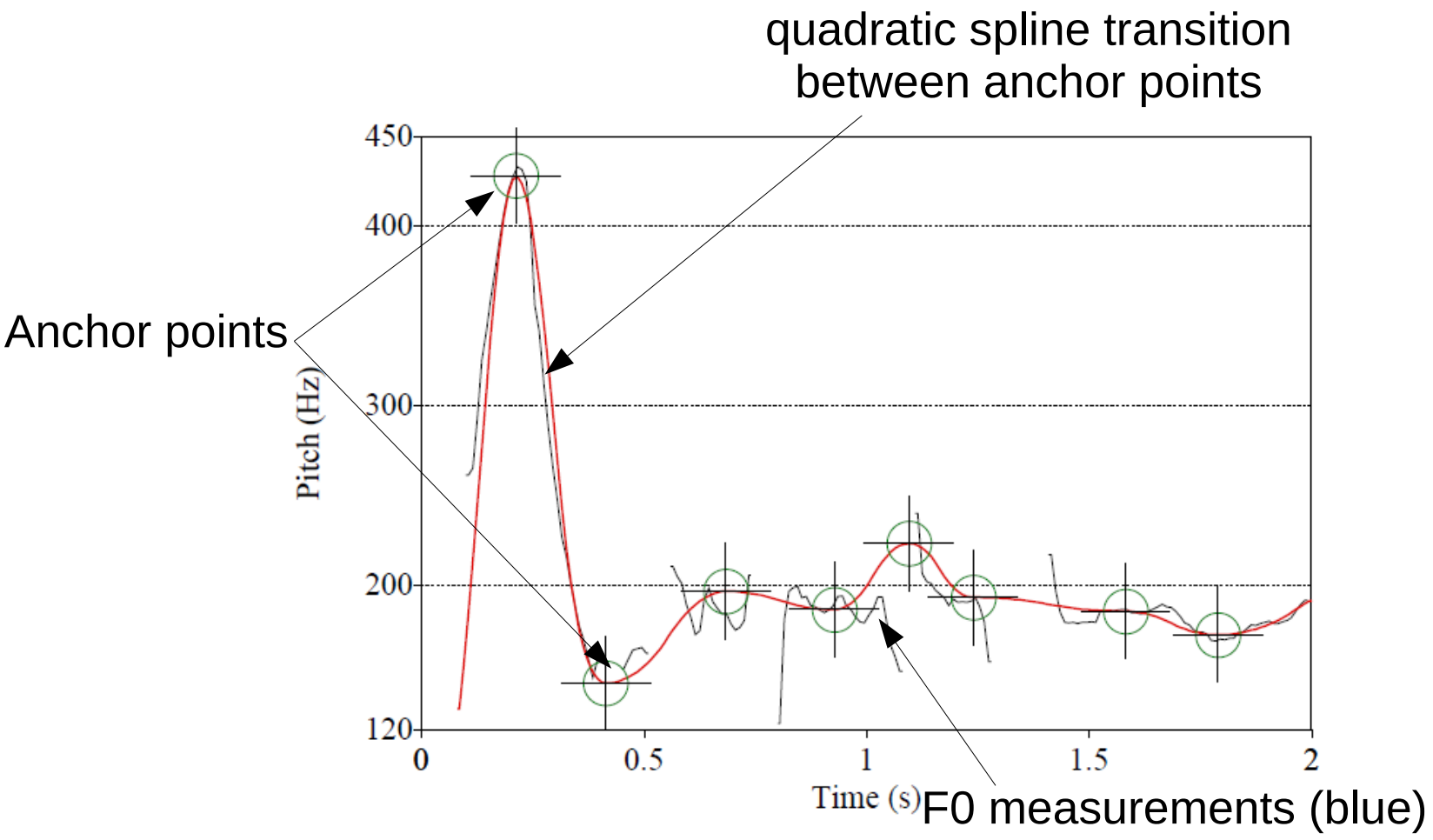
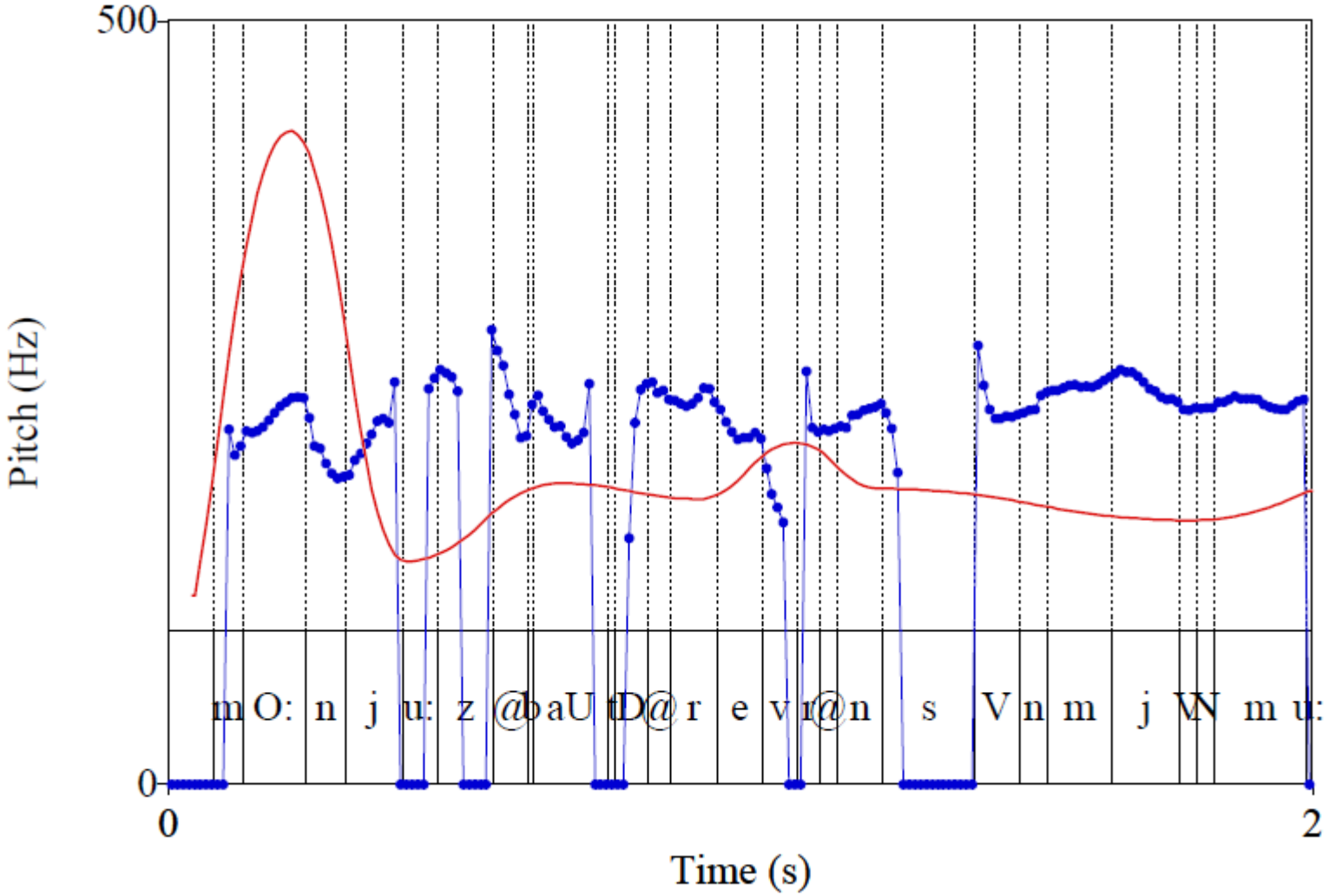


Fig. 6.7 Macromelodic profile (red) for a two-second extract from recording A01, defined as quadratic transitions between anchor points (green).

Hirst: micromelody = F0 / quadratic spline function

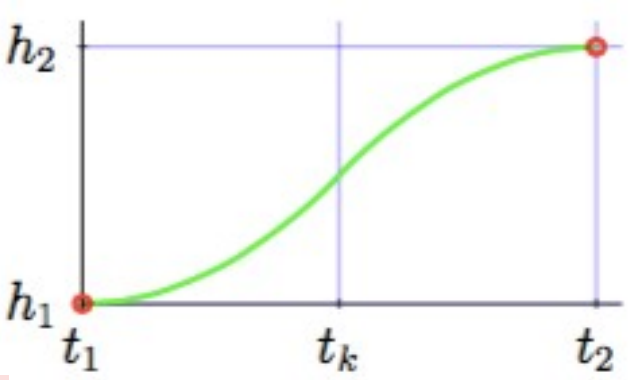


Macromelody (red), micromelody (blue): micromelody = F0 / spline model

Smoothing by local spline interpolation (Hirst)

Momel:
Quadratic splines:

- changing an anchor point only affects neighbouring transitions
- anchor points correspond to zeros on the first derivative of the spline
- the transition between two anchor points:
  - symmetrical
  - maximum slope at the spline "knot" - half way between two anchor points.



Hirst's f0 formulas:

$$t_i \in [t_1 \ldots t_k] : h_i = h_1 + \frac{(h_2 - h_1) \cdot (t_i - t_1)^2}{(t_k - t_1)(t_2 - t_1)}$$

$$t_i \in [t_k \ldots t_2] : h_i = h_2 + \frac{(h_1 - h_2) \cdot (t_i - t_2)^2}{(t_k - t_2)(t_1 - t_2)}$$

Cubic spline problem, so not used in Momel:

Changing one anchor point can affect the whole curve.

Many other methods ...

- Straight lines (IPO)
- Baseline + pulse modulation
- Gårding
- Grønnum (Thorsen)
- Asymptotic descent (Liberman & Pierrehumbert)
  - Tilt
- Spline sequence interpolation (Hirst)

Models of f0 patterning: Liberman & Pierrehumbert

Subtract the reference line from the F0 trajectory

Define the asymptotic declination line

Define the relation between focus and non-focus accent types

Define the relation between first pitch accent and reference line

Define final lowering

Models of f0 patterning: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$T(P) = P - r$

P and r in Hz

b. Downstep

$T(P_i) = s \cdot T(P_{i+1})$

where P_i is the F0 target in Hz of a step accent in position i, downstepped with respect to the previous accent target P_{i-1}

c. Answer-background relation

$T(P_A) = k \cdot T(P_B)$

where P_A is the F0 target in Hz of the A accent, and P_B the B accent

d. Relation of r to initial accent target

$r = f \cdot (P_0 - b)^e + d + b$

where P_0 is the target in Hz of the first pitch accent, and d, e, f, and b are constants

e. Final Lowering

$P \rightarrow r + l \cdot (P - r) / \_\_\_\_\$$

where $l < 1$

Modified transform for model 1

$T(P) = (1/l) \cdot (P - r)$

where $l < 1$ in final position, $l = 1$ otherwise

Model 1A

Substitute

$r = f \cdot (P_0)^e + d$

for equation (5d) in model 1.

Model 1B

Substitute

$r = f \cdot P_0 + d$

for equation (5d) in model 1.

Model 1C

Substitute

$P \rightarrow l \cdot P / \_\_\_\_\$$

for rule (5e) in model 1.

Models of f0 patterning: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$T(P) = P - r$

P and r in Hz

Subtract the reference line from the F0 trajectory

b. Downstep

$T(P_i) = s \cdot T(P_{i+1})$

where P_i is the F0 targ… tion i, down-stepped with respect to the previous accent target T_{i-1}

Define the asymptotic declination line

c. Answer-background relation

$T(P_A) = k \cdot T(P_B)$

where P_A is the F0 targ… the B accent

Define the relation between focus and non-focus accent types

d. Relation of r to initial accent target

$r = f \cdot (P_0 - b)^e + d + b$

where P_0 is the target i… are constants

Define the relation between first pitch accent and reference line

e. Final Lowering

$P \rightarrow r + l \cdot (P - r) / \_\_\_\_S$

where $l < 1$

for rule (5e) in model 1.

Define final lowering

Modified transform for model 1

…)

where $l < 1$ in final position, $l = 1$ otherwise

Model 1A

Substitute

$r = f \cdot (P_0)^e + d$

for equation (5d) in model 1.

d, e, f, and b

Model 1B

Substitute

$r = f \cdot P_0 + d$

for equation (5d) in model 1.

Models of f0 patterning: Liberman & Pierrehumbert

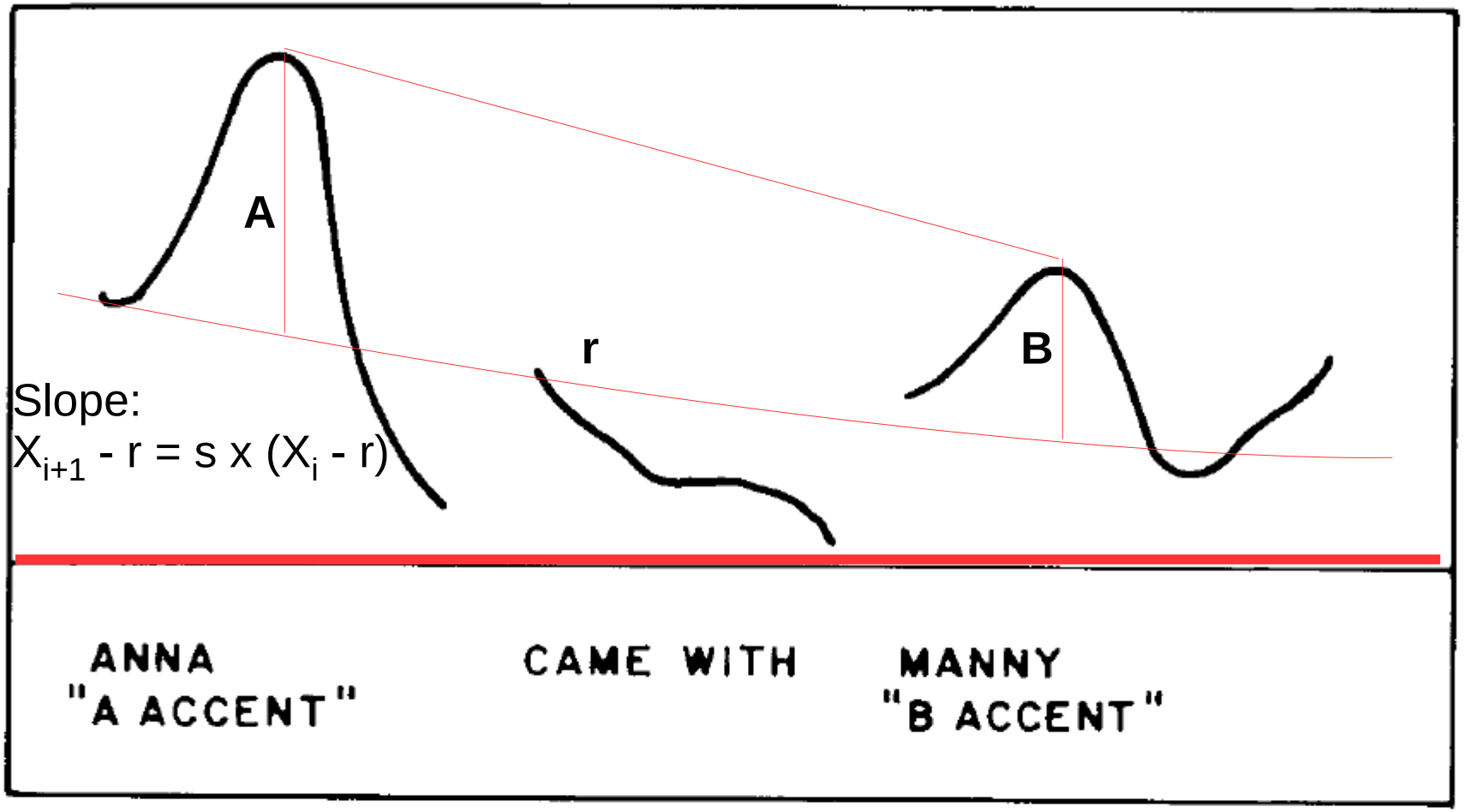


Figure 9
An F0 contour for *Anna came with Manny*, produced as a response to *What about Manny? Who came with him?*

Models of f0 patterning: Liberman & Pierrehumbert

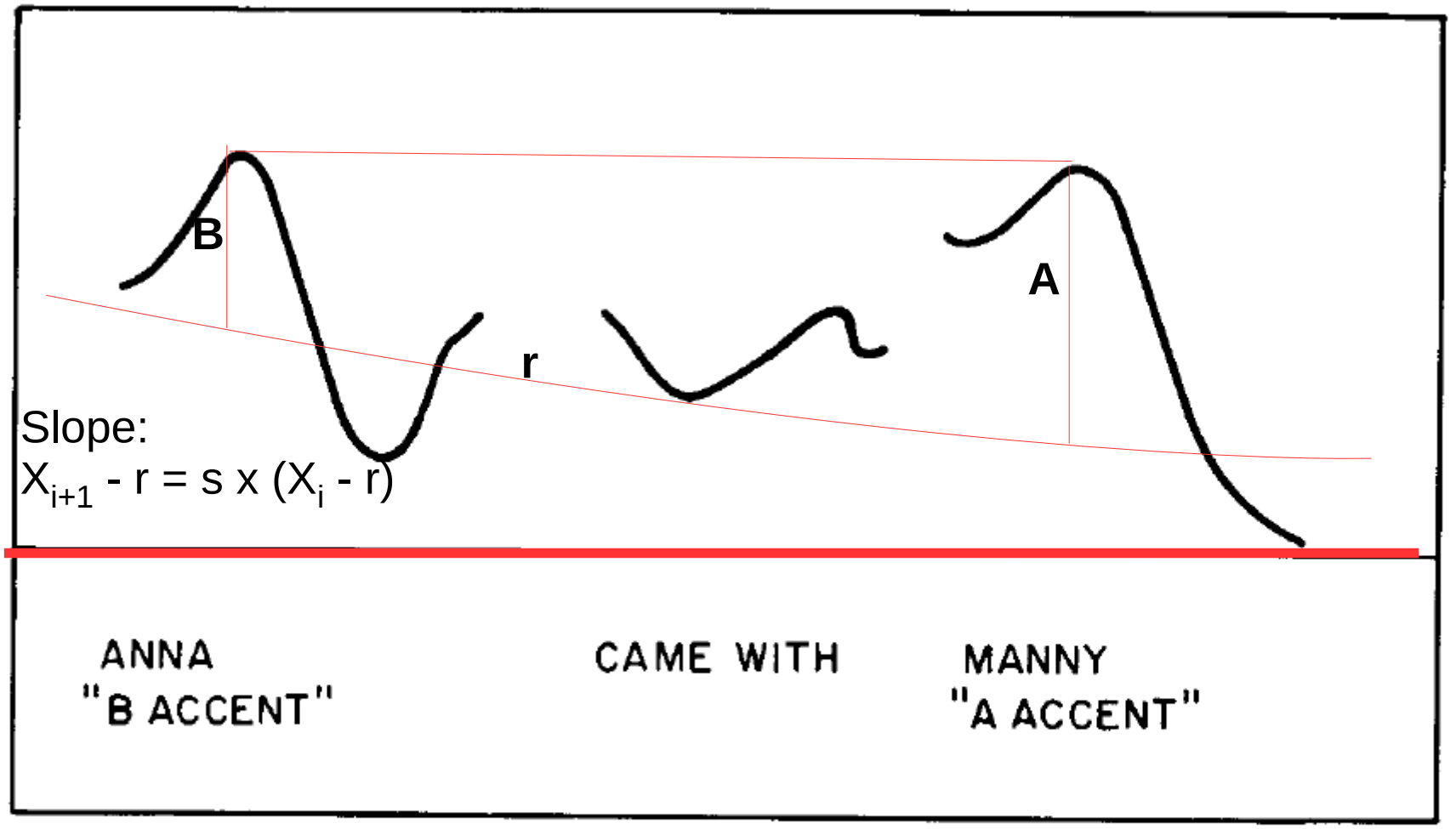


Figure 10
An F0 contour for *Anna came with Manny*, produced as a response to *What about Anna? Who did she come with?*

Models of f0 patterning: Liberman & Pierrehumbert

Model 1

a. General F0 transform

$T(P) = P - r$

P and r in Hz

Subtract the reference line

odified transform for model 1

$P) = (1/l) \cdot (P - r)$

where $l < 1$ in final position, $l = 1$ otherwise

b. Downstep

$T(P_i) = s \cdot T(P_{i+1})$

Define the asymptotic declination line

where P_i is the F0 target in Hz of a step accent in position i, downstepped with respect to the previous accent target P_{i-1}

c. Answer-background relation

$T(P_A) = k \cdot T(P_B)$

where P_A is the F0 target in the B accent

Define the relation between focus and non-focus accent types

lodel 1A

Substitute

d. Relation of r to initial accent

$r = f \cdot (P_0 - b)^e + d + b$

where P_0 is the target in Hz

are constants

$= f \cdot (P_0)^e + d$

r equation (5d) in model 1.

l, e, f, and *b*

Define the relation between first pitch accent and reference line

Model 1B

Model 1C

e. Final Lowering

$P \rightarrow r + l \cdot (P - r) / \_\_\_\_\$$

where $l < 1$

Su

P

Define final lowering

bstitute

$= f \cdot P_0 + d$

for rule (5e) in model 1.

for equation (5d) in model 1.

Models of f0 patterning: Liberman & Pierrehumbert

Model 1A

Substitute

$r = f \cdot (\mathrm{P}_0)^e + d$

for equation (5d) in model 1.

Model 1B

Substitute

$r = f \cdot \mathrm{P}_0 + d$

for equation (5d) in model 1.

Model 1C

Substitute

$\mathrm{P} \rightarrow l \cdot \mathrm{P} / \_\_\_\_\$$

for rule (5e) in model 1.

Modified transform for model 1

$\mathrm{T(P)} = (1/l) \cdot (\mathrm{P} - r)$

where $l < 1$ in final position, $l = 1$ otherwise

Model 2

Substitute

$\mathrm{T(P)} = \log((\mathrm{P} - b) / (r - b))$

for equation (5a) in model 1.

Models of f0 patterning: Liberman & Pierrehumbert

- Zero asymptote:
- X_i+1 = s x X_i
-
- X_i+1 - r = s x (X_i -r)
-
- F0 transform: converts measured F0 values into a new set of values that are assumed to behave in a simpler way - coser to underlying phonetic control parameters for intonation.
-
- Answer-background relation: taken to be constant ratio in transformed F0 values: k
-
- Downstep relation: taken to be constant ratio in transformed F0 values: s
-
- Lowering of F0 targets in utterance-final position; final lowering constant: l, utterance-final is bottom of entire system: b
-
- Transformed value of F0 target P depends on pitch range; reference level for each phrase: r
-
- Transformed value of P is its distance above r
-
- r constrained to remain is above final F0 value: b + d

Evaluation of stylised contours – 2 methods:

Difference between F0 and stylised contour

Difference between contours in perception test

From:
Demenko Grażyna, Wagner Agnieszka (2006). The Stylization of Intonation Contours. *Proceedings of Speech Prosody 3,* May 2-5, 2006, Dresden, Germany.

Evaluation of stylised contours: Demenko & Wagner

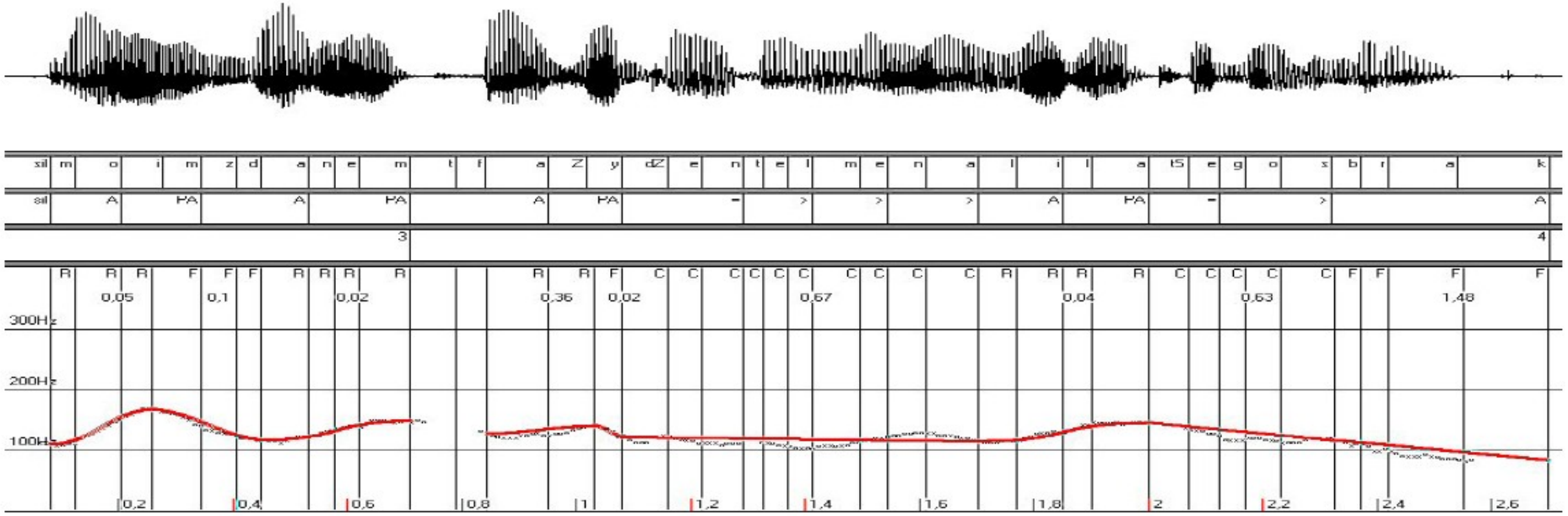


Figure 1: *Sentence:* In my opinion, the face of the lilac gentleman lacks something. *From top to bottom of the picture: waveform, .lab, .syl and .break tiers, and the stylization window. The original F0 contour is marked by dotted black line and the stylized F0 contour in red line.*

D&W 2006 stylisation model (SP3):

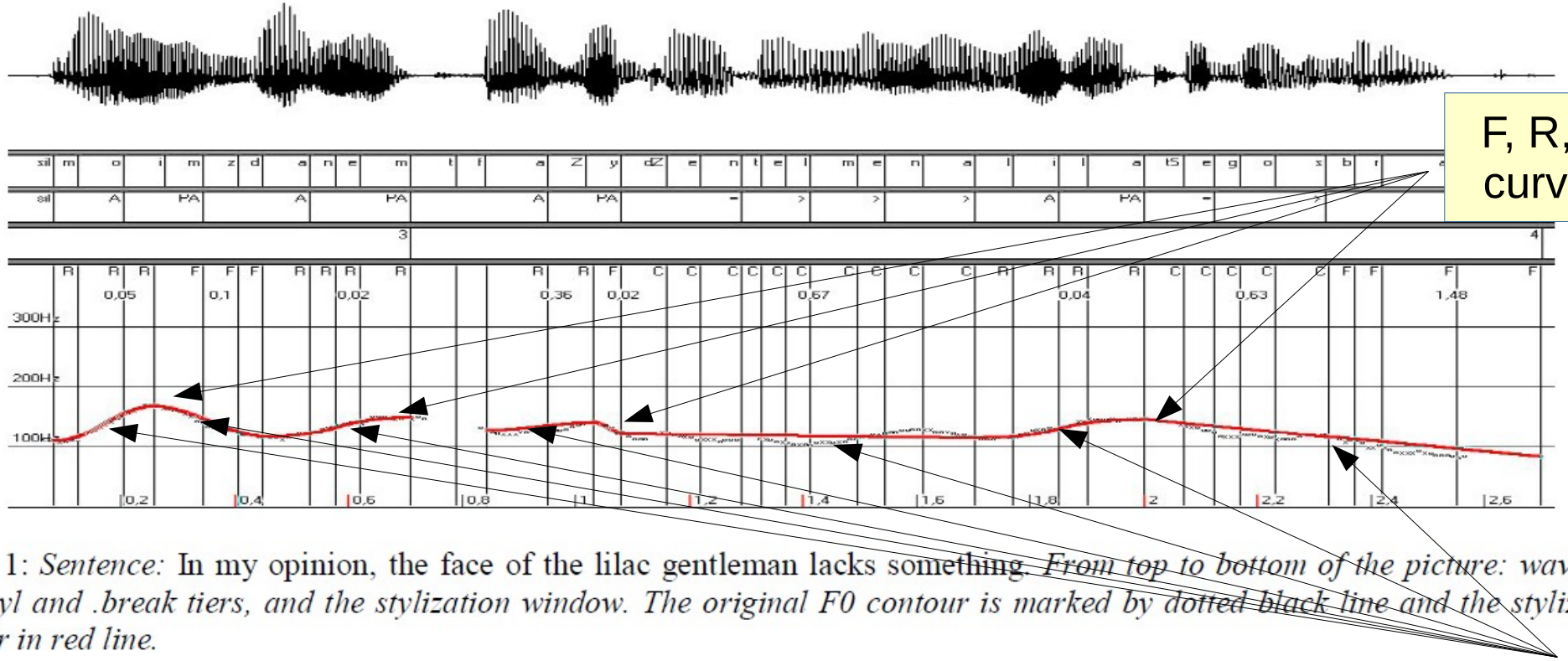
$IP \rightarrow IE^{+}$

$IE_i + SL_{i+1} + IE_{i+1}$

IP: Intonation Phrase
IE: Intonation Event
SL: Straight Line

$IE \in \{R, F, C\}$
IE parameters:
- slope
- Fp (F0 at start of event)
- range of F0 change
- shape coefficient of curve:
  $y = y^{\gamma}$ for $0<x<1$
  $y = 2-(2-x)y^{\gamma}$ for $1<x<2$

Evaluation of stylised contours: Demenko & Wagner



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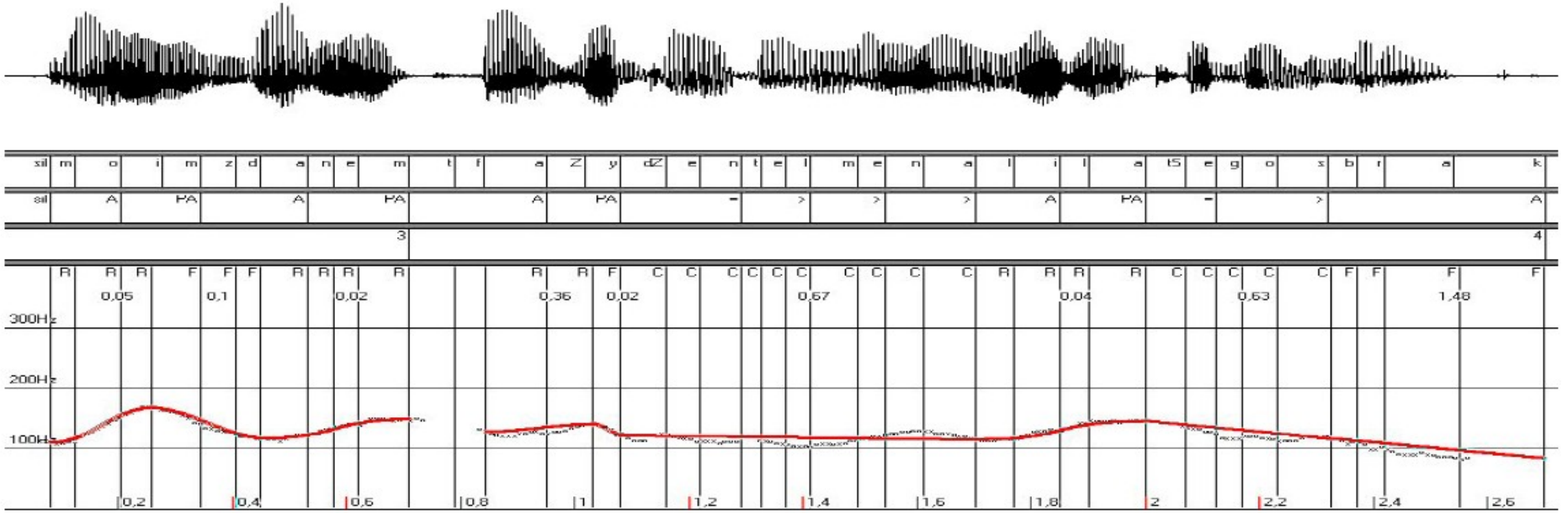


Evaluation 1: goodness of fit

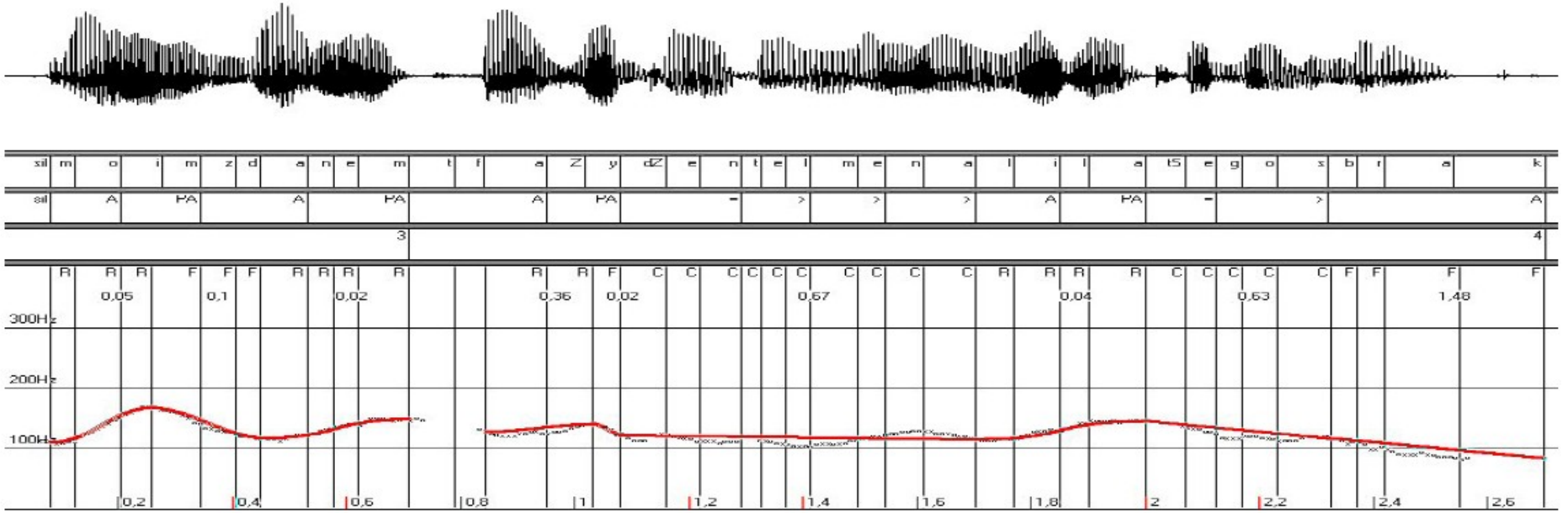
Compare F0 with stylised function with Normalised Mean Square Error:

$$NMSE(t) = \frac{\overline{(F_0(t_i) - Sty(t_i))^2}}{\overline{F_0(t)} \cdot \overline{Sty(t)}}$$

Accented syllable					
	Slope (Hz/s)	Fp (Hz)	Range (Hz)	bend	error
median	*58,51*	*112*	*14,2*	*1,51*	*0,01*
min	*-357,5*	*70,1*	*-96,8*	*1*	*0*
max	*401,7*	*176,7*	*93,7*	*9,549*	*0,64*
Post-accented syllable					
	Slope (Hz/s)	Fp (Hz)	Range (Hz)	bend	error
median	*-64,5*	*129*	*-13,1*	*1,05*	*0,001*
min	*-529,4*	*65*	*-135,6*	*1*	*0*
max	*364,7*	*208,5*	*86,6*	*9,549*	*0,25*

Table1. *The range of variability of parameters describing accented and post-accented syllables.*

Evaluation of stylised contours: Demenko & Wagner



Evaluation 2: perception test

1 (identical: F0 & Sty perceived as same)
2 (a bit different: small differences in pitch height (<10Hz) perceived between F0 & Sty (e.g. pitch too high at stylized phrase end), from microprosody, errors in F0 extraction or phone or syllable segmentation.
3 (very different: F0 & Sty differ significantly – different melody, from unrecognized accents (i.e. syllable accented but not labelled “A”; cf. also #2).
Subjects could listen as often as necessary.

Result:

n=400	**Test**
Score 1:	256
Score 2:	68
Score 3:	76

After revision of stylisation criteria, items with score 3 re-tested:
30% still with score 3.

From phonetic models to phonological models

Phonology: representation systems

- Reminder:
  - Tonetic
  - Conversation analysis
  - Levels
    - 4 levels + junctures: Pike
    - 2 levels + break indices: ToBI (Pierrehumbert)
  - Relations

http://mi.eng.cam.ac.uk/~pat40/examples.html

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  - Tonetic
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I will leave the details of relating phonetics and phonology to your own research!

http://mi.eng.cam.ac.uk/~pat40/examples.html

Rank-Interpretation Architecture of Language