Methods for characterizing meteors from infrasound signals

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Unterstützt von / Supported by
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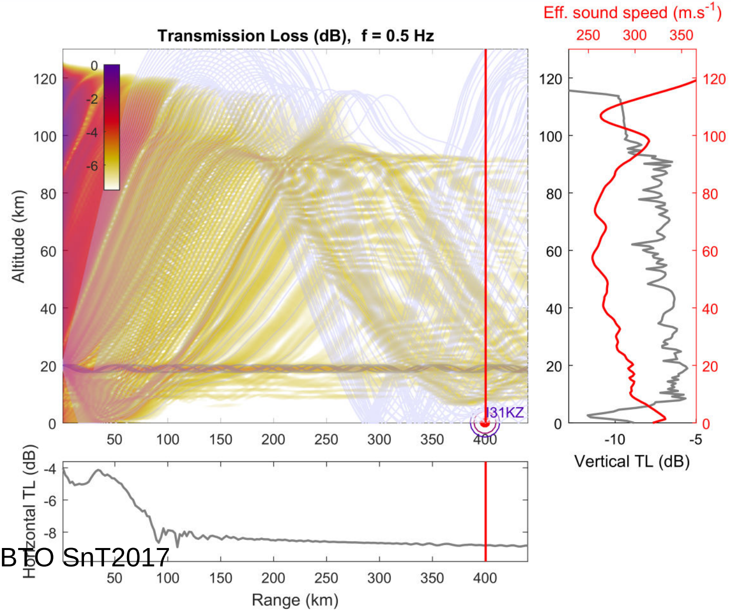
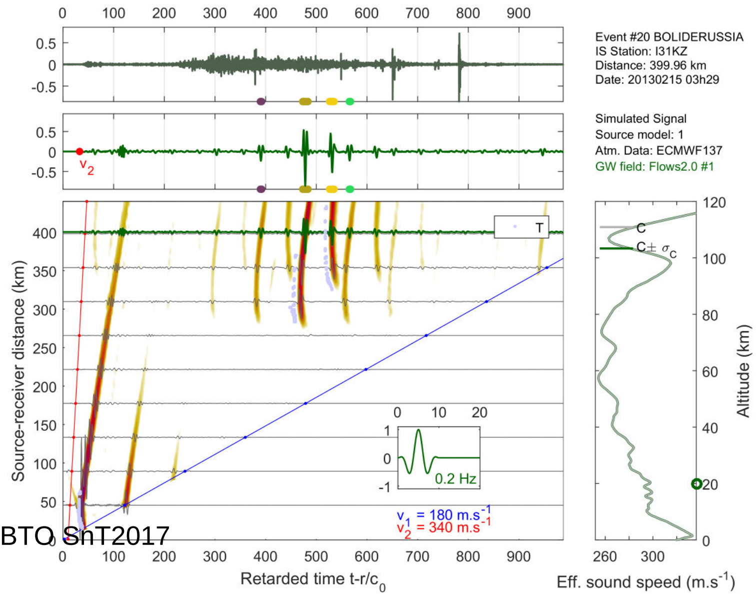
Outline

Introduction



Introduction



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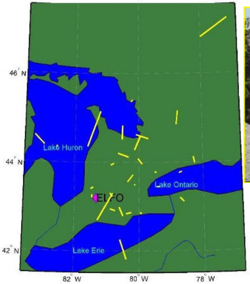
Motivation

ELFO Multistation Events: Spatial Distribution, 1-2011



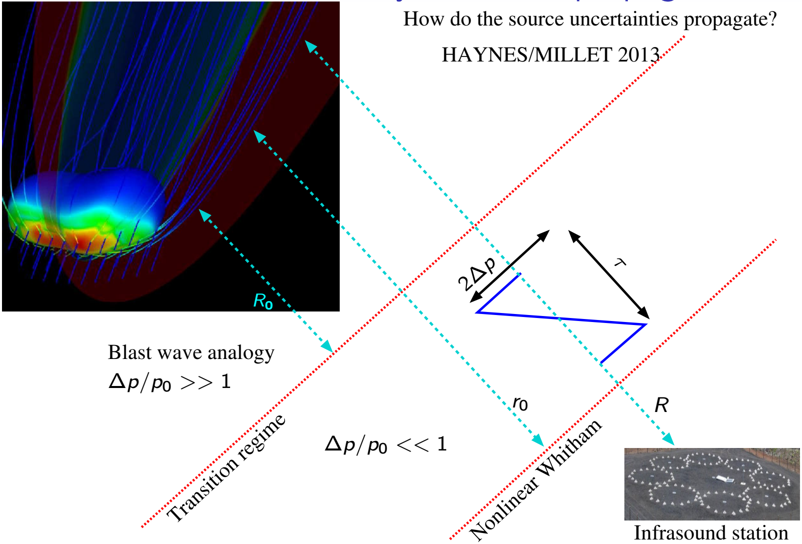
E. Silber
CTBT: Science and Technology 2013

CTBTO preparatory commission for the comprehensive nuclear-test-ban treaty organization
PREPARATORY COMMISSION

Atmospheric dynamics Research InfraStructure in Europe
ARISE

- Formulate a meteor-infrasound propagation model that involves a strong-weak nonlinear to linear regime through an anisothermal atmosphere that incorporates randomness from gravity waves phenomenon.
- Apply this model to characterize the event: Given a recorded signal 'energy' at a station, what is the source energy?
- Use model as prior to obtained data (e.g. SOMN).

N-wave model: weakly nonlinear propagation



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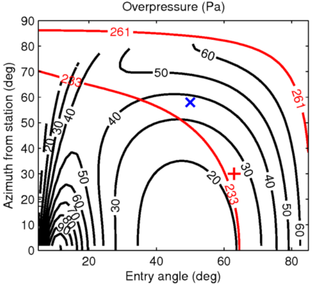
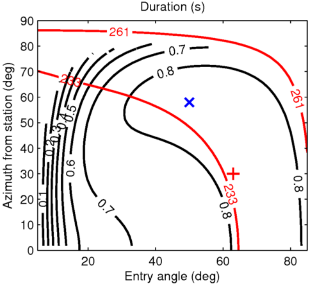
Example: Carancas Results (Isothermal case)



BAD AGREEMENT



GOOD AGREEMENT

All source parameters are fixed.

$\tau \approx 0.59$
$\Delta p \approx 0.85$

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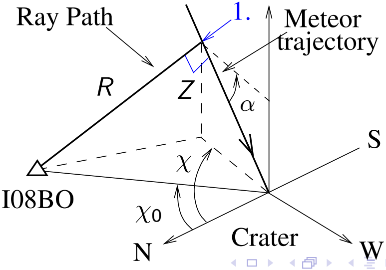
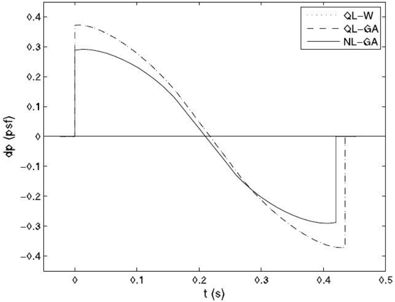


Range < 100 km: Weakly Nonlinear propagation...

... from 1D Euler equation

(a) Near-field perturbation



(b) Ground pressure signature

Approximation for the overpressure:

$$\frac{\Delta p(s)}{\Delta p(s_0)} = \frac{a_0(s)\rho_0(s)}{a_0(s_0)\rho_0(s_0)}$$

$$\frac{\Delta p(s)}{\Delta p(s_0)} = \sqrt{\frac{A(s_0)\rho_0(s)a_0(s)}{\rho_0(s_0)a_0(s_0)A(s)}}$$

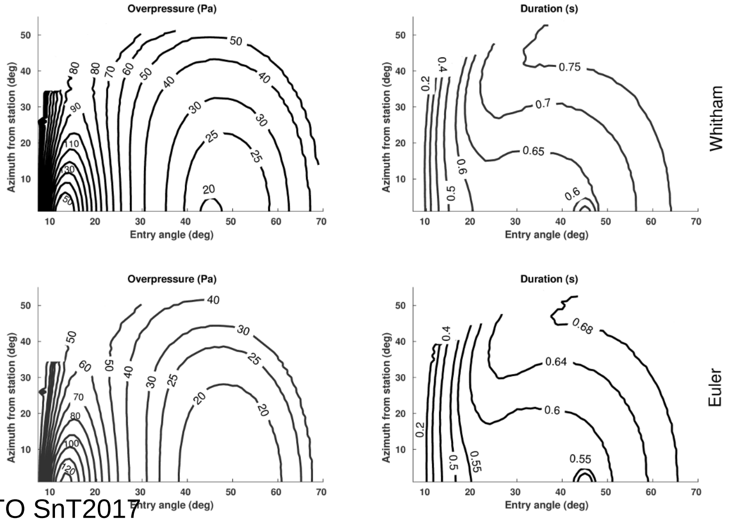
$$\frac{\Delta p(s)}{\Delta p(s_0)} = \frac{\Delta p(s)}{\Delta p(s_0)}(1+F(\Delta p(s_0), a_0, p_0, A))^{-1}$$

Berci (2012)

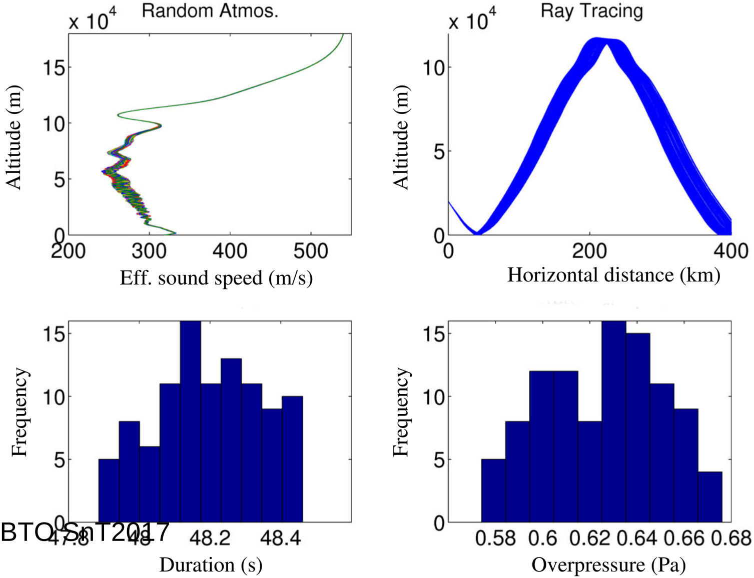
Whitham approximation for the rays

CTBTO SnT2017 $$\frac{dt}{ds} = \frac{1}{a_0(s)} - \frac{\gamma+1}{2\gamma a_0(s)}\frac{\Delta p(s)}{p_0(s)}.$$

Example: Carancas Results (Anisothermal case)



Chelyabinsk Example: I46RU (random atmosphere)



Energy Estimates

Propagation model to relate energy at point s_0, $Y(s_0)$, to energy at station $Y(s)$.

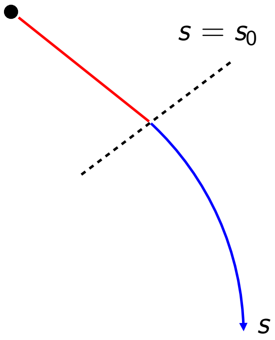
$$Y(s) = \left(\frac{a_0(s)}{2a_0(s_0)}\psi(s)\frac{\Delta p(s_0)}{p_0(s_0)}\tau(s_0)\right)^2 = \left(\frac{a_0(s)}{a_0(s_0)}\psi(s)\right)^2 Y(s_0),$$

$$\psi(s) = \frac{d\varphi(s)}{ds}\left(1 + \frac{\gamma+1}{2\gamma}\frac{\Delta p(s_0)}{p_0(s_0)s_0}\varphi(s)\right)^{-1}, \qquad \varphi = \int_{s_0}^{s}\frac{a_0(s_0)^2}{a_0(s')^2}\frac{\Delta p(s')}{\Delta p(s_0)}\,ds',$$

$$\frac{\Delta p}{p_0} = \frac{\sqrt{2}a_0(s)}{a_0(s_0)}\frac{\psi(s)}{\Phi}Y(s_0)^{1/4}$$

$$\tau = \sqrt{2}\Phi Y(s_0)^{1/4}$$

$$\Phi = \left(2k(s_0)\int_0^s \psi(s')\,ds'\right)^{1/2}$$



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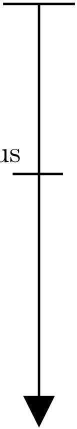
Energy Estimates

Source model: $\tau(s_0) \approx a_0(s_0)^{-1}\sqrt{X}, \quad s_0 \approx \sqrt{X}$

$\sqrt{X}$ blast wave radius



Propagation model: Relate X (source) to $Y(s)$ (station).

$$\psi(s) \sim \sqrt{W} a_0(s_0) a_0(s)^{-1} \tau(s_0) Y(s_0)^{-1/2} s_0 \quad (s >> \sqrt{X})$$

W is purely dependent on atmospheric conditions.

100 km

$$Y(s) = \left(\frac{a_0(s)}{a_0(s_0)}\psi(s)\right)^2 Y(s_0) \quad \Longrightarrow \quad Y(s) \approx WX^2 \quad s >> \sqrt{X}$$

Probabilistic model

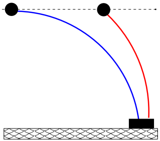
HAYNES/MILLET 2013

$X = exp(\theta(V_E, \rho_M, D, C_D)), \quad f_X = \lambda\, exp(-x\lambda) \quad \lambda > 0.$
Uncertainty propagation - Find characteristics at station from specified source locations in isothermal atmosphere.

HAYNES/MILLET 2017

Set $Y = y$, $X = (yW)^{-1/2}$. Inverse problem - Find energy estimates of source at unknown location in anisothermal random atmosphere model.

W is independent of source location



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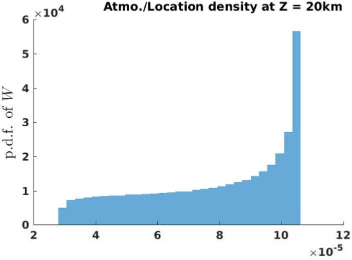
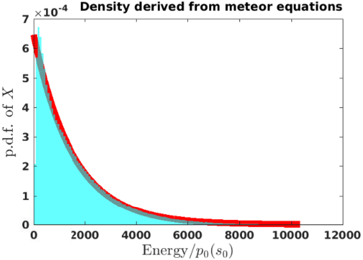
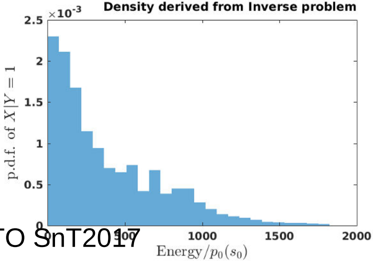
Carancas Example







Atmosphere is important in intermediate field.

Future work

- Quantify random contribution from gravity waves in propagation model.
- Strong/Weak nonlinear theory: Improve expressions for transition point s_0 and duration $\tau(s_0)$. Variation of s_0 by a factor of 10 results in energy variation by factor of 100.
- Inclusion of a linearity condition for nonlinear/linear propagation matching
- Apply model as a prior with data.