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The state of the atmosphere throughout the seasons: comparison of numerical weather prediction models for infrasound observations at regional distances

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P1.1-251

POSTER

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ABSTRACT

Infrasound signals from ARIANE-5 engine tests over two decades are investigated regarding the state of the atmosphere and the detectability at IMS infrasound station IS26

Since the year 2000 the German Aerospace Center (DLR) facility near Heilbronn, Germany, has conducted main engine tests of the European ARIANE-5 rocket. Infrasound signals from these tests have regularly been observed during the last two decades at IMS station IS26 at a range of about 320 km in easterly direction. While a majority of these tests produced signal observations when carried out during the winter season between October and April, there is an almost complete lack of observations during the summer season. When comparing numerical weather prediction models for summer and winter seasons, or times with detections or non-detections, then these models differ significantly in the sound speed profiles producing either a strong stratospheric duct or a lack thereof. This is also reflected by the effective sound speed ratio, mostly exceeding a value of 1 for detections and less than 1 for non-detections. However, a significant portion of profiles with non-detections, nearly a quarter or 20 out of 88 cases, show a sound speed profile that should enable infrasound signal observations. The reasons for the lack of observations are addressed in this study.

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INTRODUCTION

ARIANE engine tests at the P5 facility of DLR near Heilbronn form a repeatable source receiver setup over 20 years of various atmospheric conditions which are seen as the dominant factor for differences in observed signals at IMS station IS26

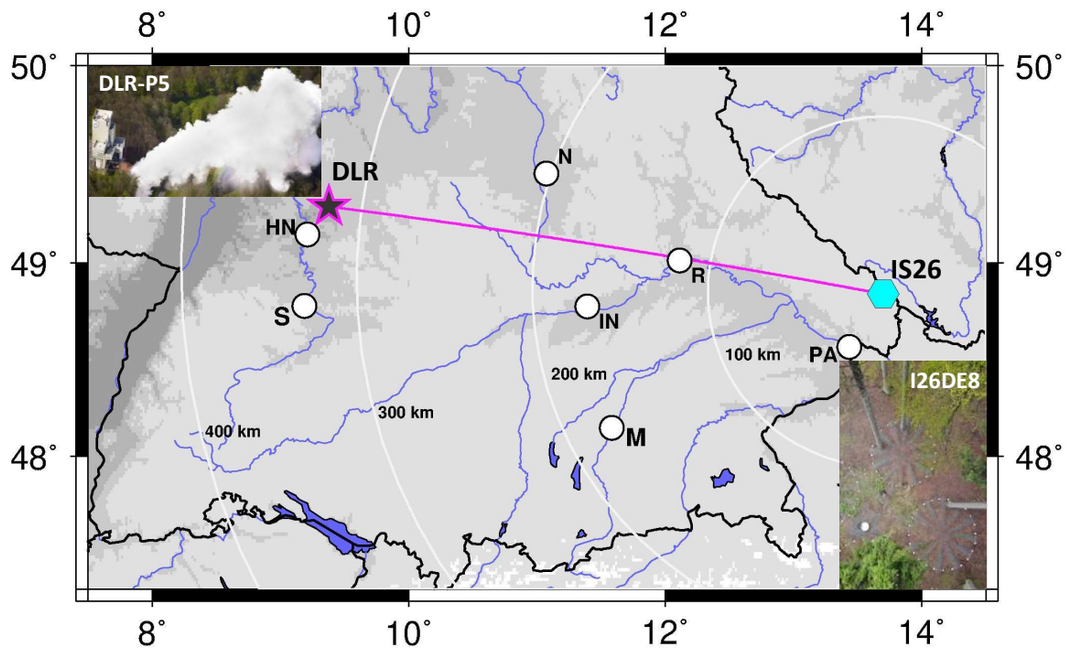
Ground Truth Data

Source: ARIANE5 engine tests conducted between 2000 and 2019 (20 yrs)

GT Source: 172 individual tests (159 of duration >10s)

Source-receiver range: 320km

Source-receiver azimuth: 99°



Labels in map: S - Stuttgart, HN – Heilbronn, N – Nuremberg, IN - Ingolstadt, M – Munich, R – Regensburg. PA –Passau

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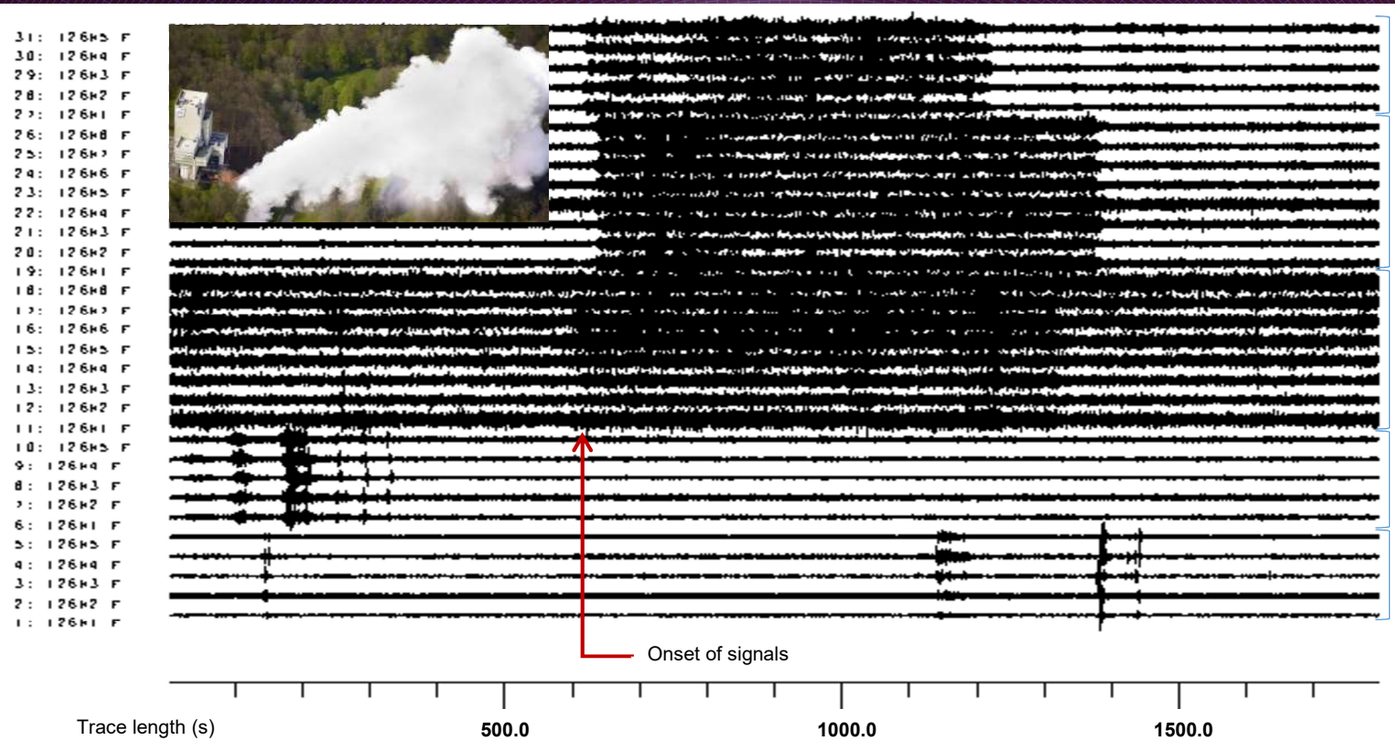
DATA EXAMPLES



Good signals

◀ *2000/04/23*

◀ *2013/02/14*

Fair to poor signals

◀ *2012/02/16*

No signals

◀ *2000/12/07*

◀ *2001/07/03*

Observations of ARIANE-5 infrasound signals at IS26 can range from good to fair/poor or are missing

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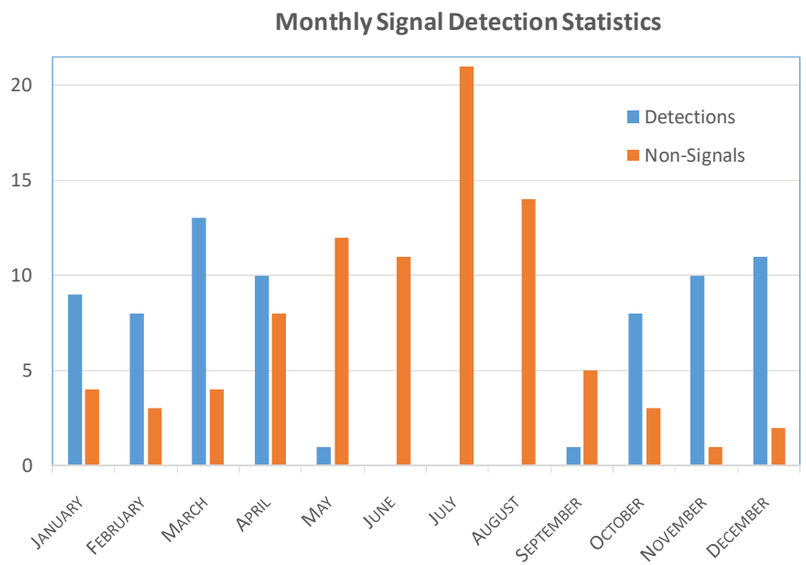
STATISTICS

Monthly Detection Statistics

Month	Det.		Non-Det.		Total
Jan	9	(69%)	4	(31%)	13
Feb	8	(73%)	3	(27%)	11
Mar	13	(76%)	4	(24%)	17
Apr	10	(56%)	8	(44%)	18
May	1	(8%)	12	(92%)	13
Jun	0	-	11	(100%)	11
Jul	0	-	21	(100%)	21
Aug	0	-	14	(100%)	14
Sep	1	(17%)	5	(83%)	6
Oct	8	(73%)	3	(27%)	11
Nov	10	(91%)	1	(9%)	11
Dec	11	(85%)	2	(15%)	13
Sum	71		88		159

- *Detections are observed in winter (Oct-Apr) except for two cases in summer (May-Sep).*
- *Winter detection rate is between 56% in Apr to 91% in Nov (average: 73%)*
- *Summer detection rate is only 3% (average) (and detections are absent for Jun-Aug).*
- *Detectability of signals is very stable in summer (i.e. non-detection), while more variable/random in winter.*

- *159 tests considered: distributed quite evenly with 11-18 tests/month over the 20 year time frame; maximum of 21 tests in July and minimum of 6 tests in September*
- *71 tests produced signal detections at IS26*



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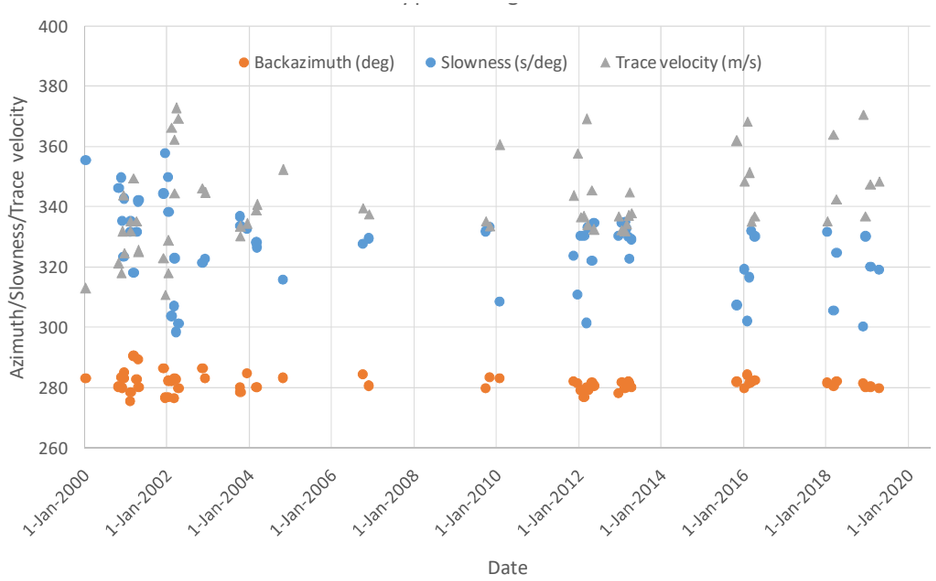
DATA ANALYSIS (1)



Data Analysis Results from Array Processing

- *Backazimuth scatters ±3.5° around theoretical value of 281°*
- *Slowness values (in s/deg) range from 300 to 360*
- *Equivalent trace velocity shows values between 320 and 370 m/s*
- *Array processing results more stable after upgrade from 5-element to 8-element array (Nov 2009)*

Array processing produces consistent results for the signals to be associated with the engines tests at the DLR testing facility at Lampoldshausen. Also, the obtained trace velocities strongly suggest stratosperic propagations of the acoustic waves between source and receiver.

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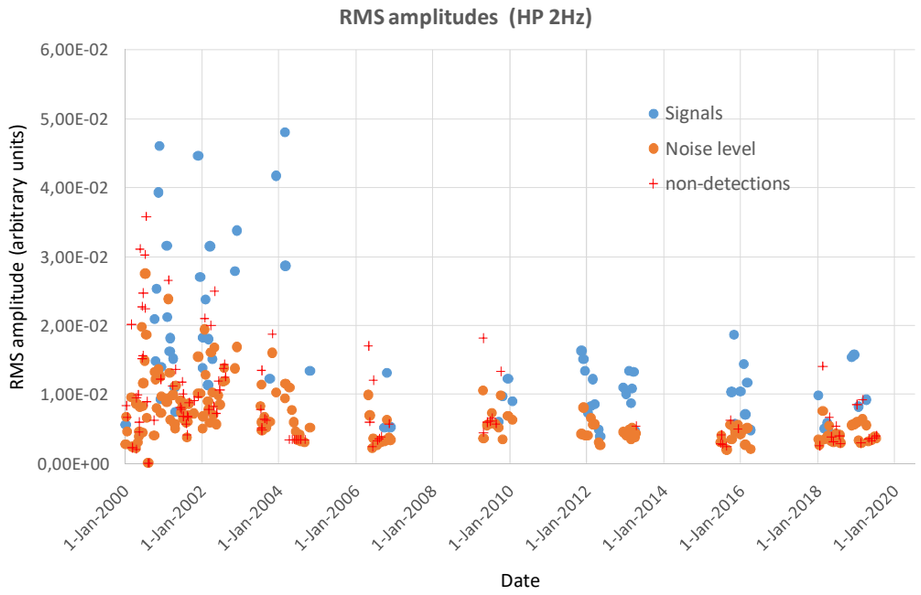
DATA ANALYSIS (2)



RMS Amplitude Levels at Element I26H1

For detections two RMS values are produced for the signal and the pre-signals noise level. For non-detections there is only one value given, representing the noise level within the expected signal window.

For non-detection cases the noise level is not consistently larger than for detection cases suggesting the lack of signal observation is not due to background noise .

The RMS amplitude values were determined from the waveform data of the reference element I26H1. Signal and noise levels show signal-to-noise ratios (SNR) from 1 to about 5, thus not separating the two populations clearly. Amplitudes of non-detections are within the noise levels, thus not clearly indicating increased background noise but lack of signals due to propagation conditions.

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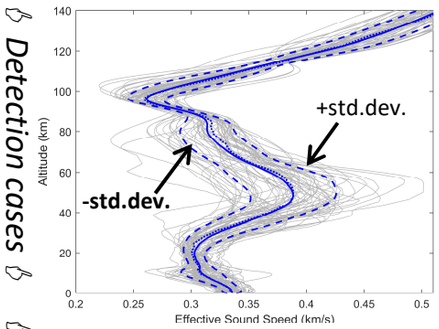
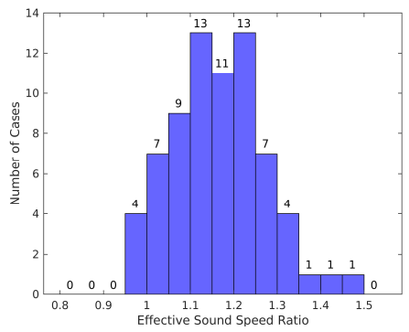
RESULTS (1)

ECMWF atmospheric profiles

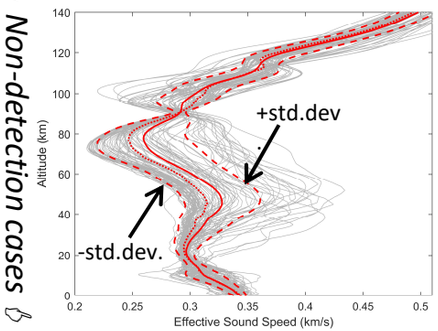
Histogram of v_{eff_ratio} of profiles

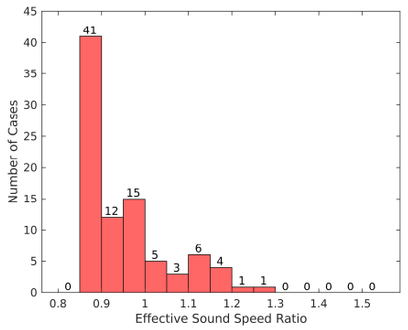
Detection cases





Non-detection cases





Numerical Weather Prediction Models (ECMWF)

- *ECMWF profiles for detections show a clear stratospheric duct; mean (solid) and median (dotted) curves show great similarity and produce an effective sound speed ratio (veff_ratio; here the max. ratio between effective sound speed at 30-70 km and in the lower 5 km) larger than 1*
- *Except for 4 profiles, all other 67 cases exhibit a veff_ratio >1*

- *Most ECMWF profiles for non-detections lack a stratospheric duct; mean (sold) and median (dotted) curves show larger differences with both showing effective sound speed ratios less than 1*
- *The (upper / +) standard deviation curve (dashed) produces a veff_ratio >1, as quite a larger number of profiles exhibit a stratospheric duct*
- *The histogram yields 20 cases of non-detections despite the existence of a stratospheric duct*

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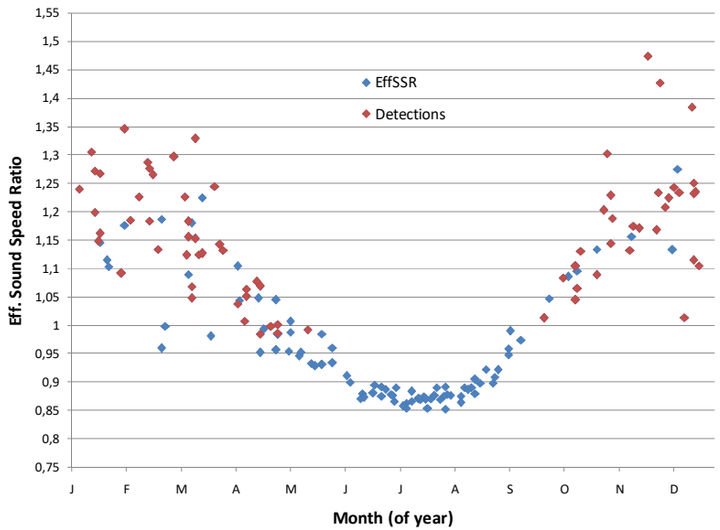
RESULTS (2)



Effective Sound Speed Ratios over the Seasons

- *veff_ratio for 159 tests*
- *Cases with detection are marked with red symbol*
- *Ratio is mostly above 1 from fall to spring equinox*
- *Ratio is smaller than 0.9 and quite stable between early Jun and late Aug*
- *Scatter is fairly high for cases with ratio above 0.95*
- *No obvious correlation of detections vs. non-detection with ratio (>1)*

The effective sound speed ratio (veff_ratio) changes characteristically over the seasons, being low in summer and high in winter (usually above 1). While detection occur mostly for veff_ratio >1, there are numerous cases where no signals were found in such cases.

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DISCUSSION (1)

	$v_{eff\text{-}ratio}>1.2$	$1.1<v_{eff\text{-}ratio}<1.2$	$1<v_{eff\text{-}ratio}<1.1$	$0.98<v_{eff\text{-}ratio}<1$	$v_{eff\text{-}ratio}<0.98$	Sum
Detection (A)	25 / 0	9 / 1*	0 / 2	-	-	34 / 3*
Detection (B)	4 / 0	1 / 6*	0 / 4*	- / 3	-	5 / 13[2]
Detection (C)	0 / 2*	1 / 5	1 / 6*	- / 1	-	2 / 14[2]
Non-detection	4 / 1	3 / 6*	0 / 6*	- / 9*	- / 59	7 / 81[3]
	36	32	19	13	59	159

Signal Quality

A – Good

B – Fair

C – Poor

**- SZ quest.*
*[2] - (2 x *)*
*[3] - (3 x *)*

Detections are classified in three different categories (good, fair, poor) (see "Data Examples")
The first number in a column represents cases without shadow zone (SZ) and the second with SZ

- *Of the 71 detections 41 are unambiguously predicted (from ECMWF model) while 30 are associated with SZs (among them 5 cases with questionable SZ)*
- *Giving cases with questionable SZ the benefit of doubt, 25 of 71 detections are not explained*
- *Of 20 non-detections 7 cases are associated with stratospheric ducting and without a SZ*

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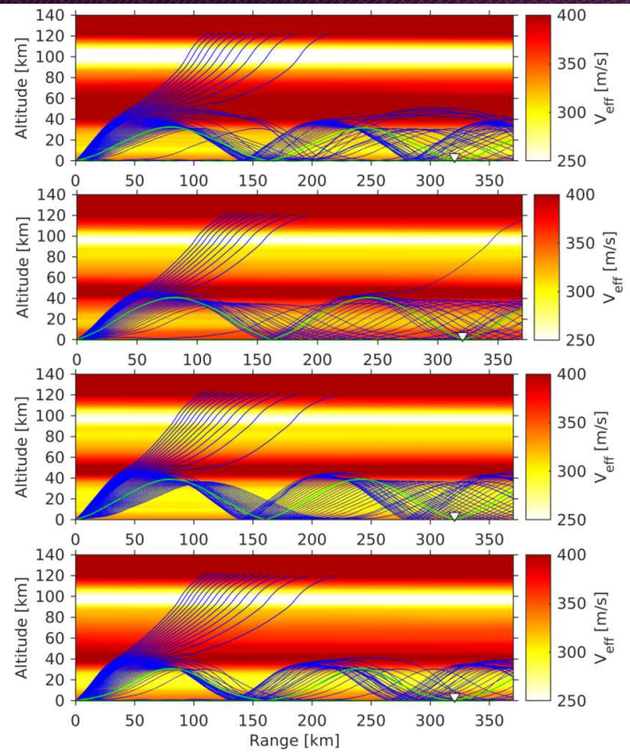
DISCUSSION (2)



◀2015/12/10

◀2000/03/09

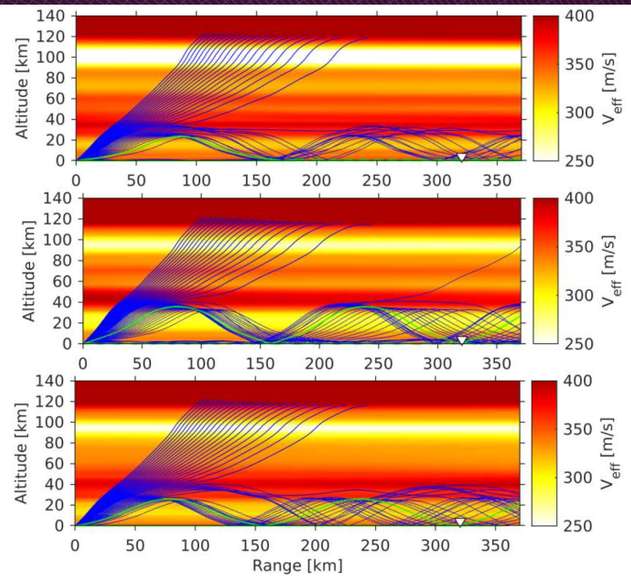
◀2002/03/15

◀2019/02/21

2018/01/22 ▶

2000/12/07 ▶

2000/01/21 ▶



- *For the 7 out of 20 cases with stratospheric duct an appropriate eigenray exists from source to receiver*
- *ECMWF model does not explain the lack of signal observation in these cases*

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CONCLUSIONS

- Over the past 20 years signals from rocket engine tests (ARIANE 5/ VULCAIN2) were carried out at 320 km from IS26 (from a backazimuth of 281°)
- Signals were observed at IS26 during the winter season (Oct-Apr) for 70% of the tests, while during the summer season (May –Sep) only 2 (3%) tests were detected.
- Array processing and signal duration (from ground truth data) confirmed the association of a test with the signal
- Amplitudes of the signals are consistent with increased levels prior to changes in the noise filtering system
- NWP models for detection cases clear indicate a stratospheric duct with effective sound speed ratios above 1
- For a significant number of non-detection cases the NWP model exhibits a stratospheric duct as well, but is often associated with a shadow zone.

↘

- In about two-thirds of the cases the NWP (ECMWF) is able to explain the presence or absence of a signal from an engine test
- For one-third of the detections, as well as the non-detections with stratospheric duct and absence of a shadow zone, the NWP model does not provide an adequate explanation.