Frequency Angular Sounding (FAS) Technique

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IGF 2014

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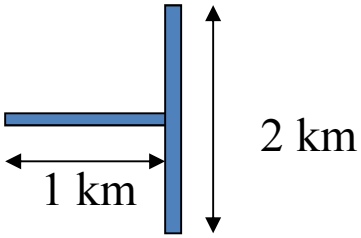
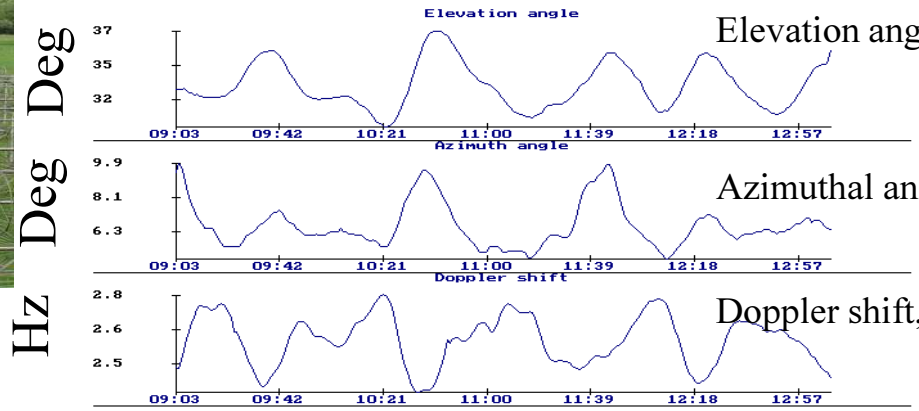
UTR-2 Phased Array

Array Dimensions



Example of oblique signal trajectory parameters (700 km radio path)



(May 1993)

∴ Signals from HF broadcasting or time-service stations can be used for monitoring TIDs.

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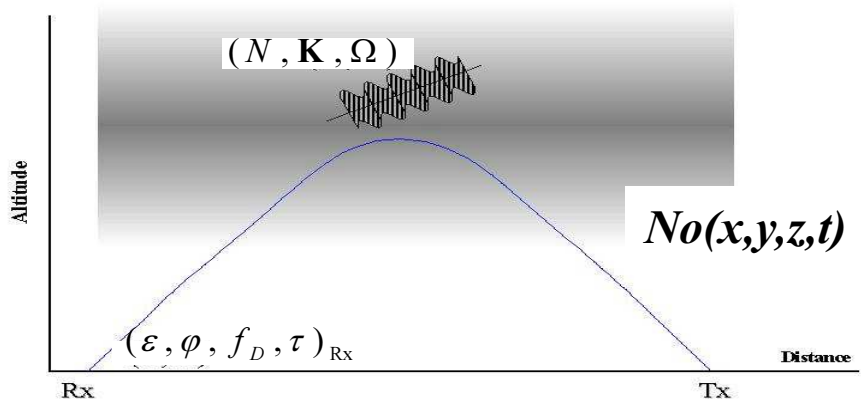
FAS principles

Measured signal parameters:
ε(t) elevation angle
φ(t) azimuthal angle
f_D(t) Doppler shift
τ(t) Signal delay (vert. sound.)



(DPS) (CHU,WWV, DPS, Rx=Tx)

Direct problem: $(N, \mathbf{K}, \Omega) \Rightarrow (\varepsilon, \varphi, f_D, \tau)_{Rx}$

Inverse problem: $(\varepsilon, \varphi, f_D, \tau)_{Rx} \Rightarrow (N, \mathbf{K}, \Omega)$

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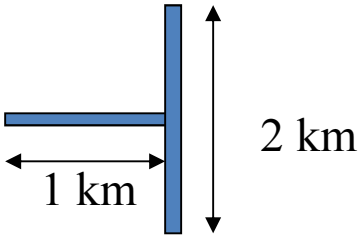

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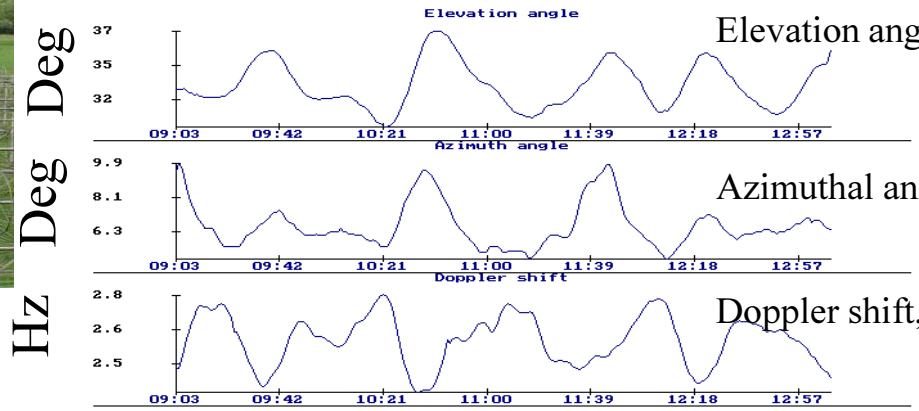

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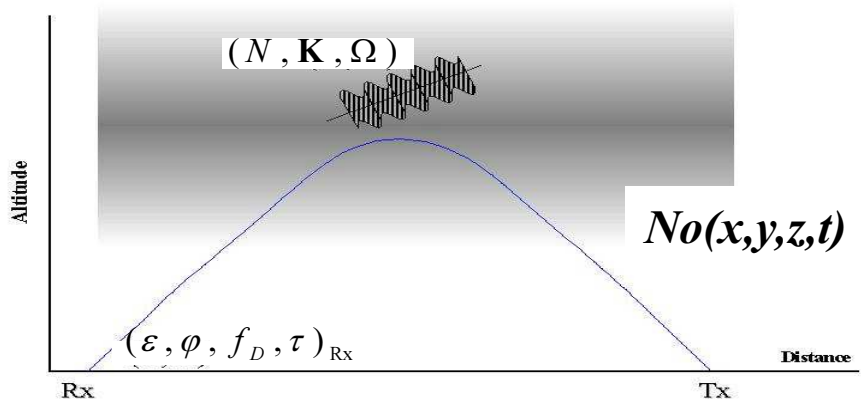

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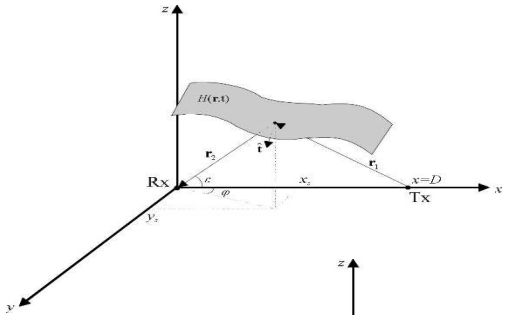
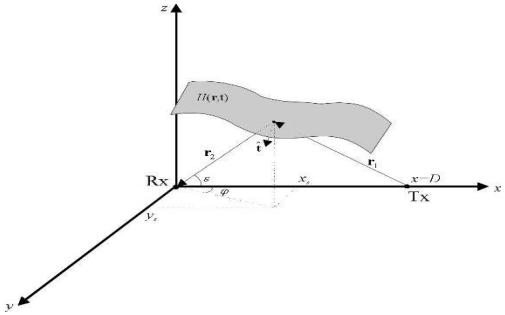
FAS: 3 approaches

1. Oblique



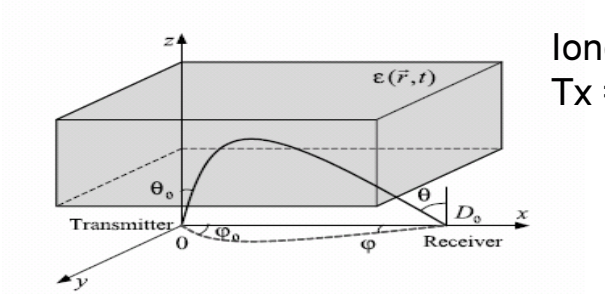
Perfectly reflecting surface is assumed.
Tx ≠ Rx

2. Vertical/Generalized



Perfectly reflecting surface is assumed.
Vertical case is ok

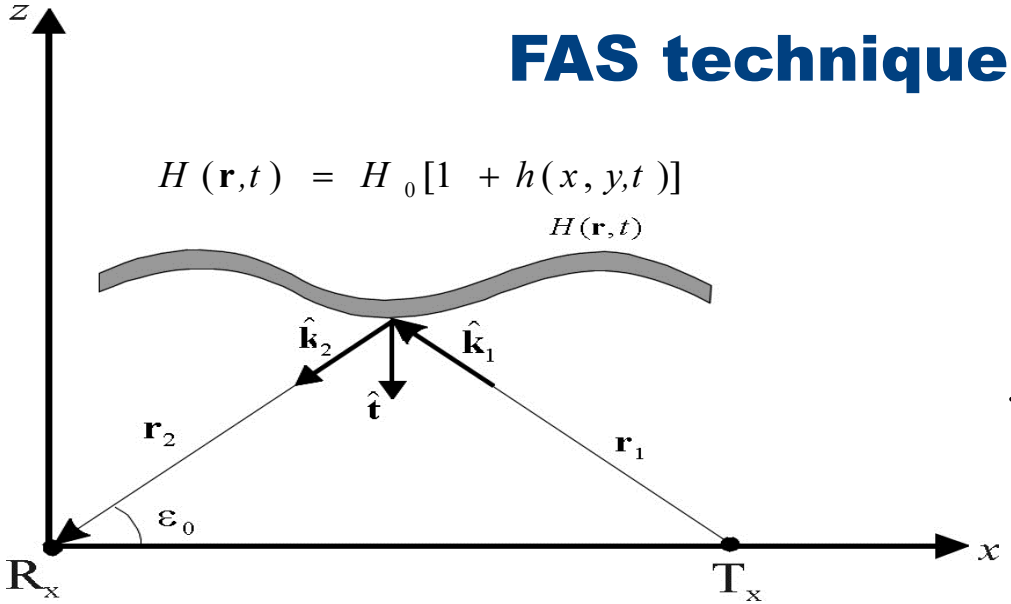
3. “3D density waves”



Ionospheric layer is assumed.
Tx ≠ Rx

FAS technique: approach

$$H(\mathbf{r},t) = H_0[1 + h(x,y,t)]$$



Perfectly reflecting surface model

Surface spectral representation:

$$h(x,y,t) = \int_{-\infty}^{\infty} N(\Omega) e^{i\Omega t} d\Omega \, e^{-iK(\Omega)(x\cos\theta(\Omega) + y\sin\theta(\Omega))}$$

$N(\Omega)$ – TID amplitude
$K(\Omega)$ – TID wavenumber
$\theta(\Omega)$ – TID direction of motion

Measured signal parameters:
$\varepsilon(t)$ elevation angle
$\varphi(t)$ azimuthal angle
$f_D(t)$ Doppler shift

Spectral representations:

$$\varepsilon(t) = \int_{-\infty}^{\infty} S_\varepsilon(\Omega) e^{i\Omega t} d\Omega$$

$$\varphi(t) = \int_{-\infty}^{\infty} S_\varphi(\Omega) e^{i\Omega t} d\Omega$$

$$f_D(t) = \int_{-\infty}^{\infty} S_F(\Omega) e^{i\Omega t} d\Omega$$

$$\boxed{\varepsilon(t), \varphi(t), f_D(t) \Leftrightarrow h(x,y,t)}$$

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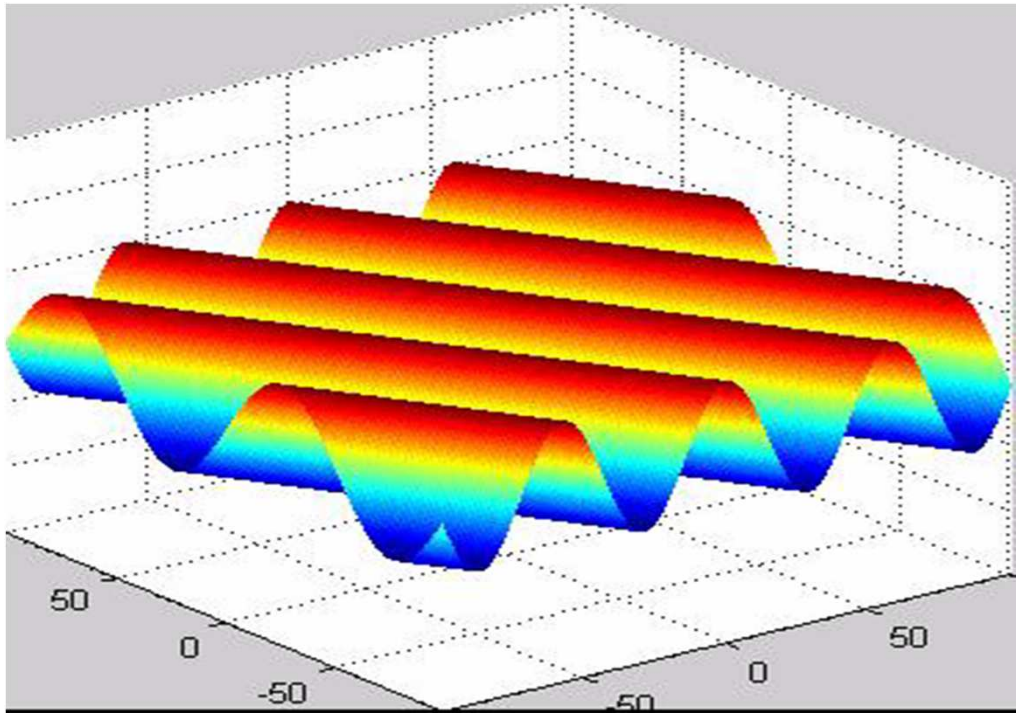
Surface model visualization



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Oblique FAS: cont.

With the use of the spectral representation, one gets solutions

Trajectory parameters spectra: (direct problem)

$$S_{\varepsilon}(\Omega) = N(\Omega)[\sin\ \varepsilon_0 \cos\ \varepsilon_0 - iH_0 K(\Omega)\cos\ \theta(\Omega)]$$

$$S_{\varphi}(\Omega) = iH_0 K(\Omega) N(\Omega) \tan\ \varepsilon_0 \sin\ \theta(\Omega)$$

$$S_F(\Omega) = -2iH_0 \Omega N(\Omega) \sin\ \varepsilon_0 / \lambda$$

Reflecting surface spectra: (inverse problem)

$$N(\Omega) = \frac{i\lambda S_F(\Omega)}{2H_0 \Omega \sin\ \varepsilon_0}$$

$$\tan\ \theta(\Omega) = -\frac{2H_0 \Omega\ \mathrm{Re}\ S_{\varphi}(\Omega)}{2H_0 \Omega\ \mathrm{Re}\ S_{\varepsilon}(\Omega) \tan\ \varepsilon_0 + \lambda\ \mathrm{Im}\ S_F(\Omega) \sin\ \varepsilon_0}$$

$$K(\Omega) = -\frac{2\Omega\ \mathrm{Im}\ S_{\varphi}(\Omega) \cos\ \varepsilon_0}{\lambda\ \mathrm{Im}\ S_F(\Omega) \sin\ \theta(\Omega)}$$

Measurements with FAS technique

Comparing TIDs parameters measured with DPS and ISR.

	Digisonde FAS				ISR		
Date	Velocity, m/s	Wavelength, km	Azimuth, deg		Velocity, m/s	Wavelength, km	Azimuth, deg
15.03.2001	341	655	117		305	585	102
16.03.2001	135	258	-80		156	274	-82

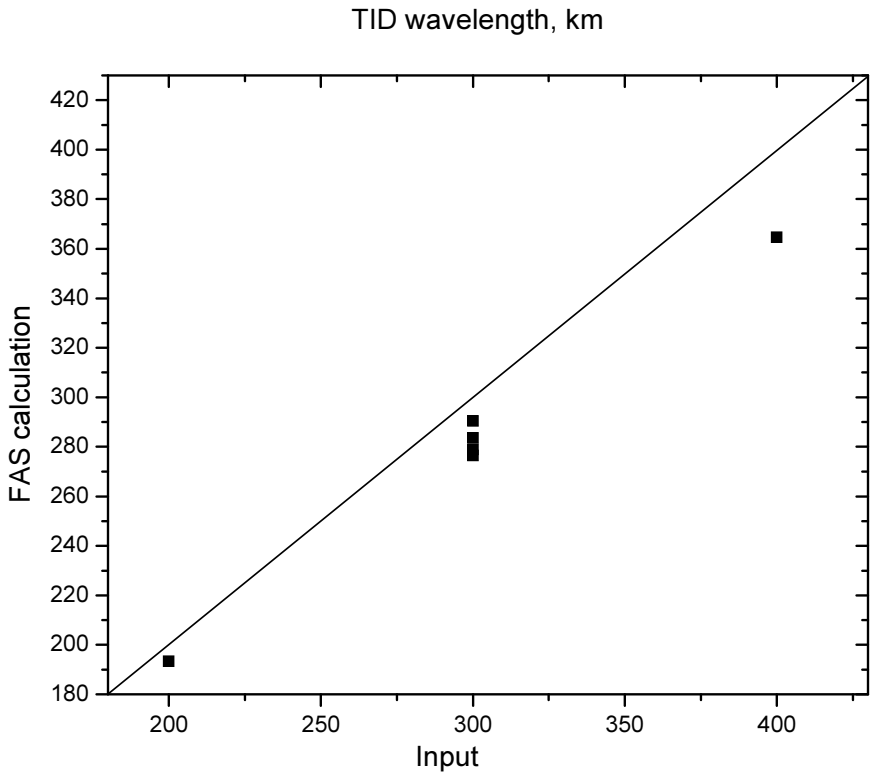
Comparison of the 30 min TID parameters obtained with FAS and ISR techniques for March 15, 2001 data

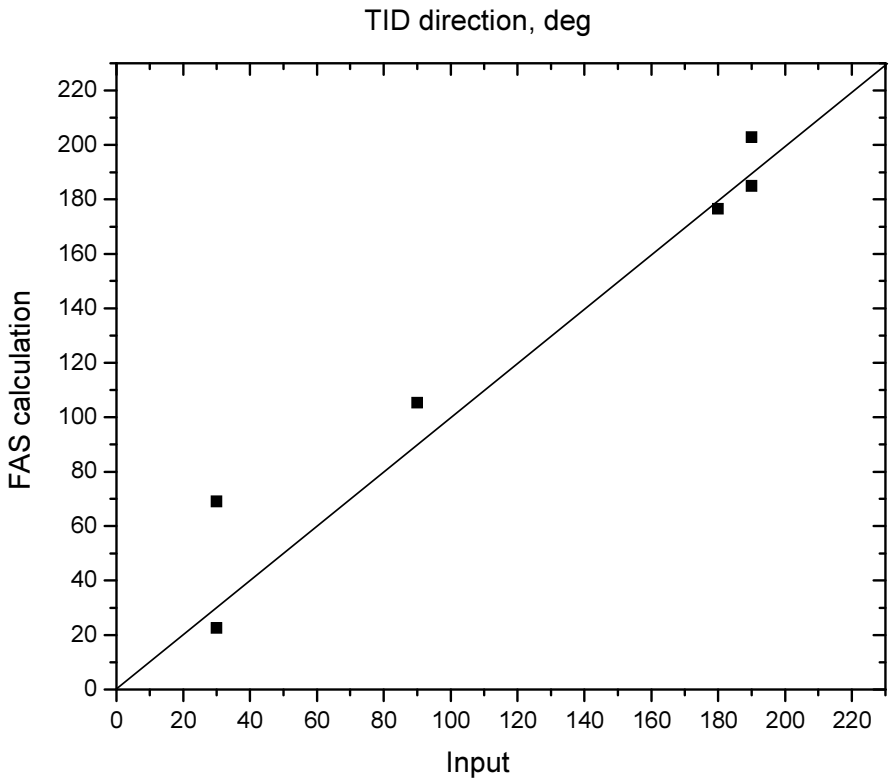
	Velocity, m/s	Wavelength, km	Propagation direction, deg	Amplitude,
ISR data	305	585	102	2.0 %
FAS (surface)	341	655	117	0.8 %
FAS (lower)	317	610	115	1.8 %

Simulation runs to test FAS accuracy

	Run1	Run2	Run3	Run4	Run5	Run6
Propagation						
fo, MHz	8.0	8.0	5.0	5.0	5.0	6.0
UT	17:00	17:00	5:00	5:00	5:00	7:00
Distance, km	324	651	651	651	651	853
TID parameters						
Period, min	30	30	30	30	20	30
Wavelength,km	300	300	300	400	200	300
Direction, deg	180	30	90	190	190	30
Amplitude, A	0.01	0.02	0.02	0.01	0.01	0.02

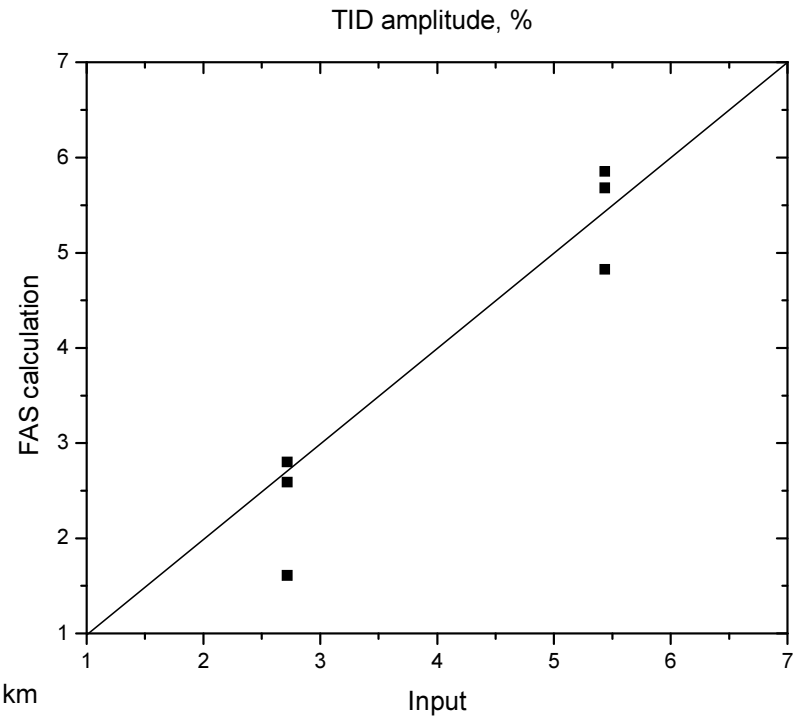
FAS accuracy test results

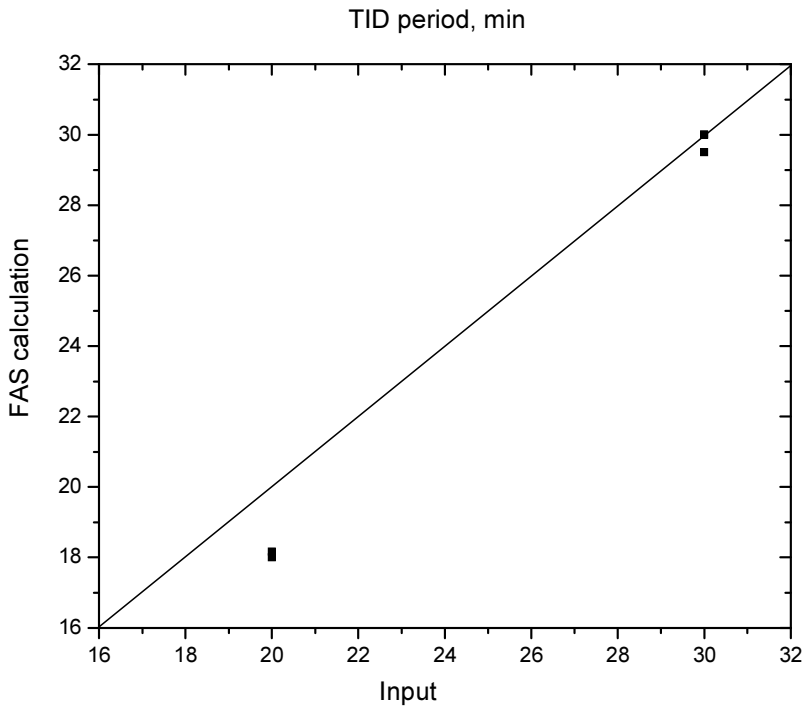




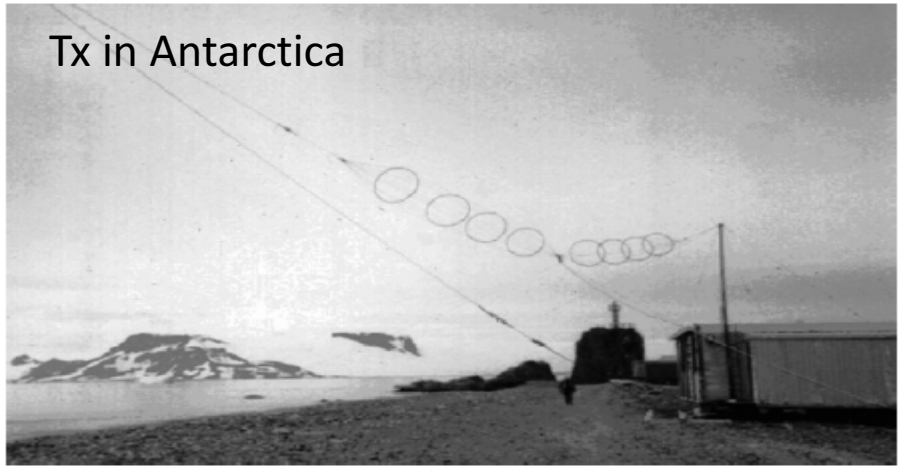
FAS accuracy test results (cont)

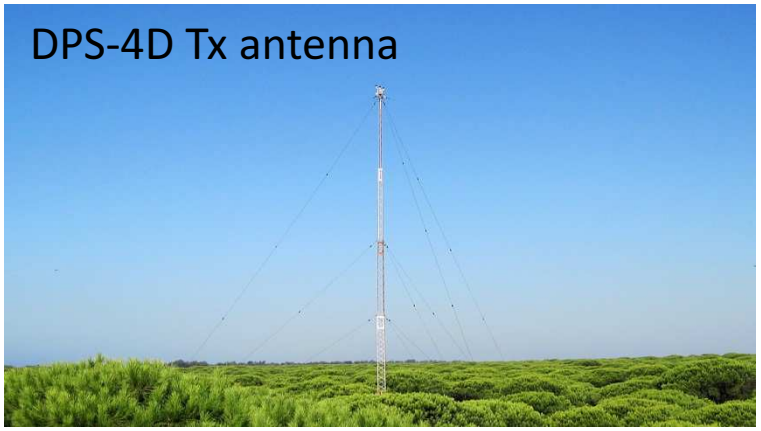
at 200 km

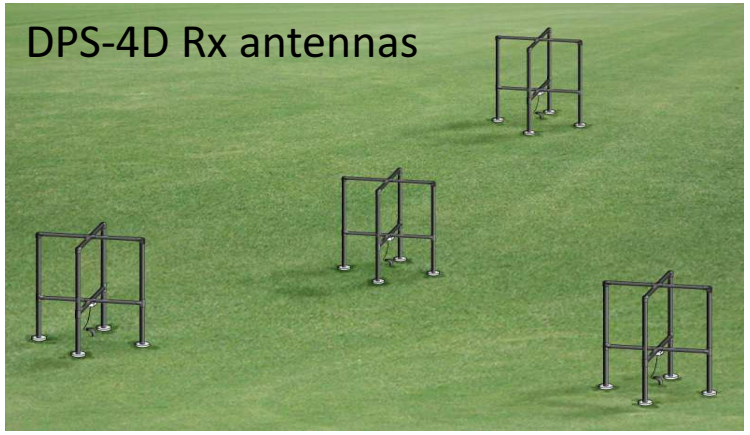




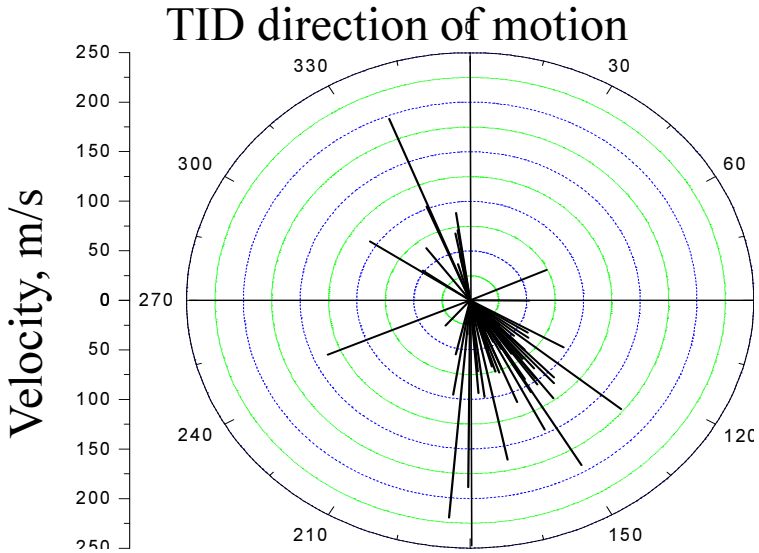
Experimental setups



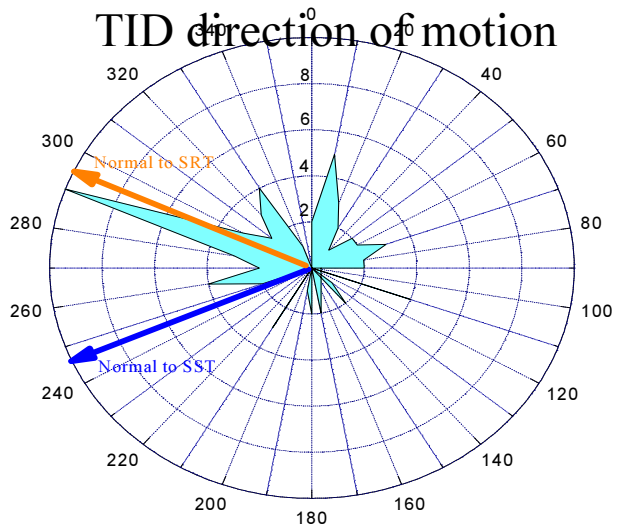




Measurements with FAS technique



Millstone Hill, November 2003
(geomagnetically disturbed period)



Antarctica, Feb-Mar 2004
(quiet period)

Histogram of TID azimuths. The orange and blue arrows are along the normal to the sunrise (SRT) and sunset (SST) terminators, respectively.

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FAS requirements

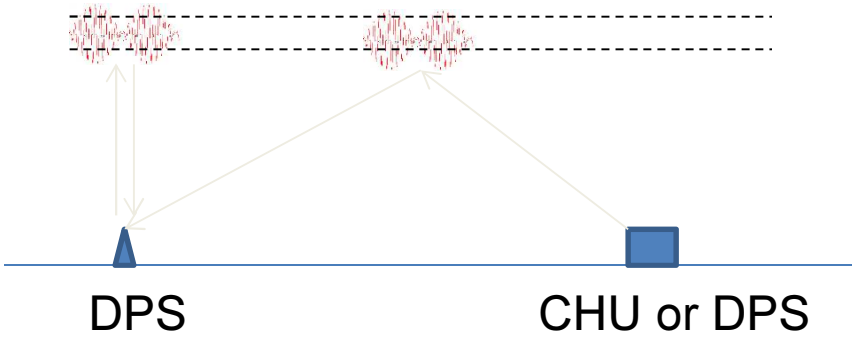
To measure continuously:

$\varepsilon(t)$ elevation angle

$\varphi(t)$ azimuthal angle

$f_D(t)$ Doppler shift

$\tau(t)$ Signal delay (vert. sound.)



Approximately:

Angles of arrival accuracy: ~1^0

Spectral resolution: 0.03-0.1Hz

Data taking rate: 1..10 min

Frequency stability: ~10^{-9} (for oblique sounding)

Conclusions and Recommendations

FS technique is capable of measuring TID parameters

FAS technique accuracy is about 10%

FAS technique can be integrated into DPS-4D systems.

We propose to establish Rapid-TID system of TID monitoring based on the FAS technique

Dalu
감사합니다
Gracias
Danke
Ευχαριστίες
THANK YOU
Obrigado
Köszönöm
Grazie
Спасибо
Dank
Tack
谢谢
Merci
ありがとう
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