# Using EnKF to probe the middle atmosphere with infra-sound waves

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# Outline

**1. Ensemble DA systems**

**2. The problem**

**3. DA for this case**

  **3.1. A perfect scenario**

  **3.2. The real case**

**4. Summary and future work**

# Ensemble DA systems

- Provide a natural estimate for uncertainty.
- DA can be performed as a filter or as a smoother. Different flavours.
- Ensemble reanalysis products becoming more popular.
- The weak constraint problem can be simulated by using different model errors / physics / parameters in different ensemble members.

# The ARISE project


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## ARISE Project

- Private eRoom
- Concept
- Design Study Activities
- Partners
- Meetings
- Links
- Opportunities

## Technologies


## ARISE Project

The ARISE2 project is a collaborative infrastructure Design Study project (2015-2018) funded by the H2020 European Commission. It includes 24 institutes and universities, belonging to 10 European member states, 3 associated countries, 1 international organization and 3 African countries.

> more on the Arise European project

## Technologies

**Infrasound** IMS network and European infrasound network (atmospheric waves and inversions in the stratosphere).
**LIDAR** of the NDACC network (stratospheric wind and temperature).
The project will also use complementary stations including **radars, wind radiometers and ionospheric sounders. It also use satellite observations.**

> more about technologies

## Highlights

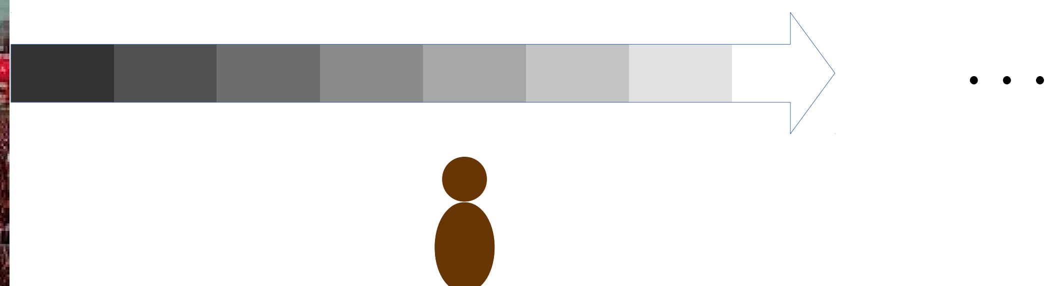
**ARISE meetings**

Thanks to the ARISE support by the French MRSEI ANR program, the following ARISE meetings were organized to ensure the project continuation:

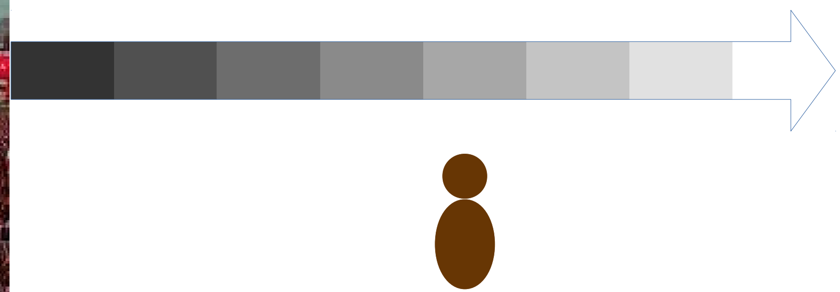
- January 24-25, 2019 : Paris (France), organized by Versailles University (UVSQ) and CEA
- April 10, 2019 Vienna (Austria) during the EGU2019 meeting
- June 5-6, 2019 Budapest (Hungaria) organized by CSFK
- September 10-11 Paris (France) organized by

# Sound propagation

Waves propagate away from the source and they suffer attenuation:

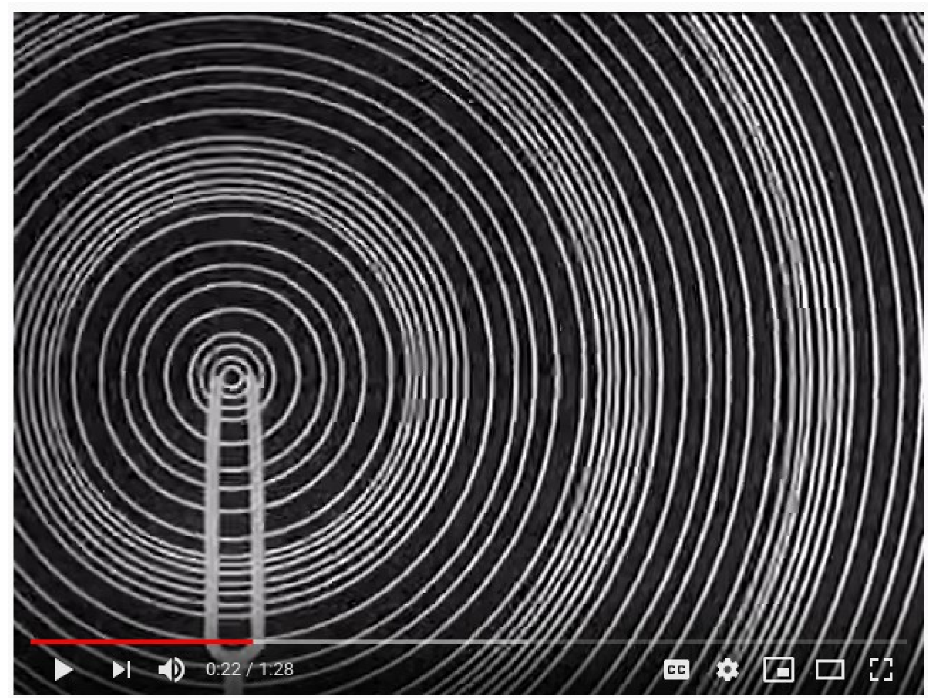


# Sound propagation

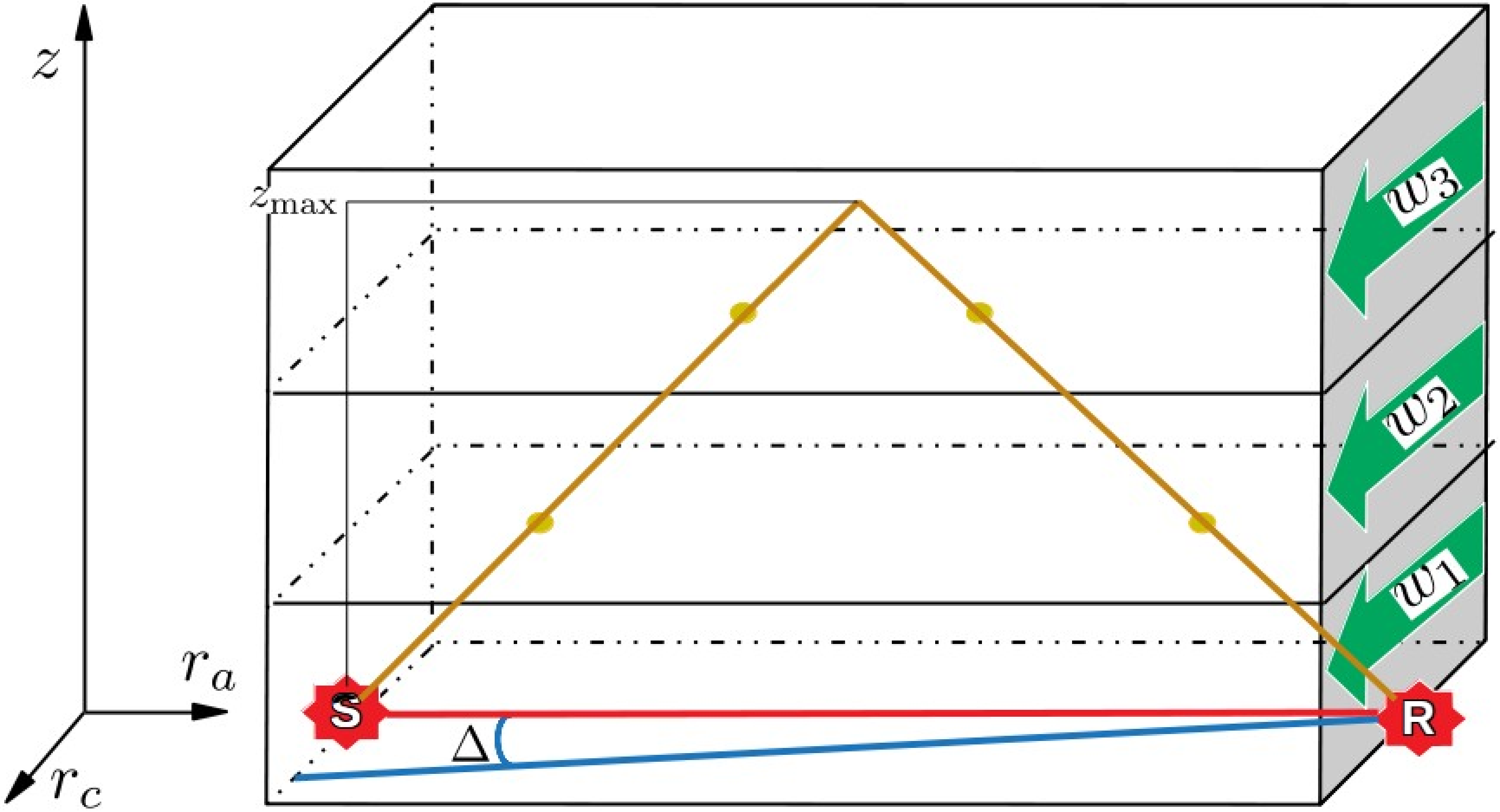


. . .

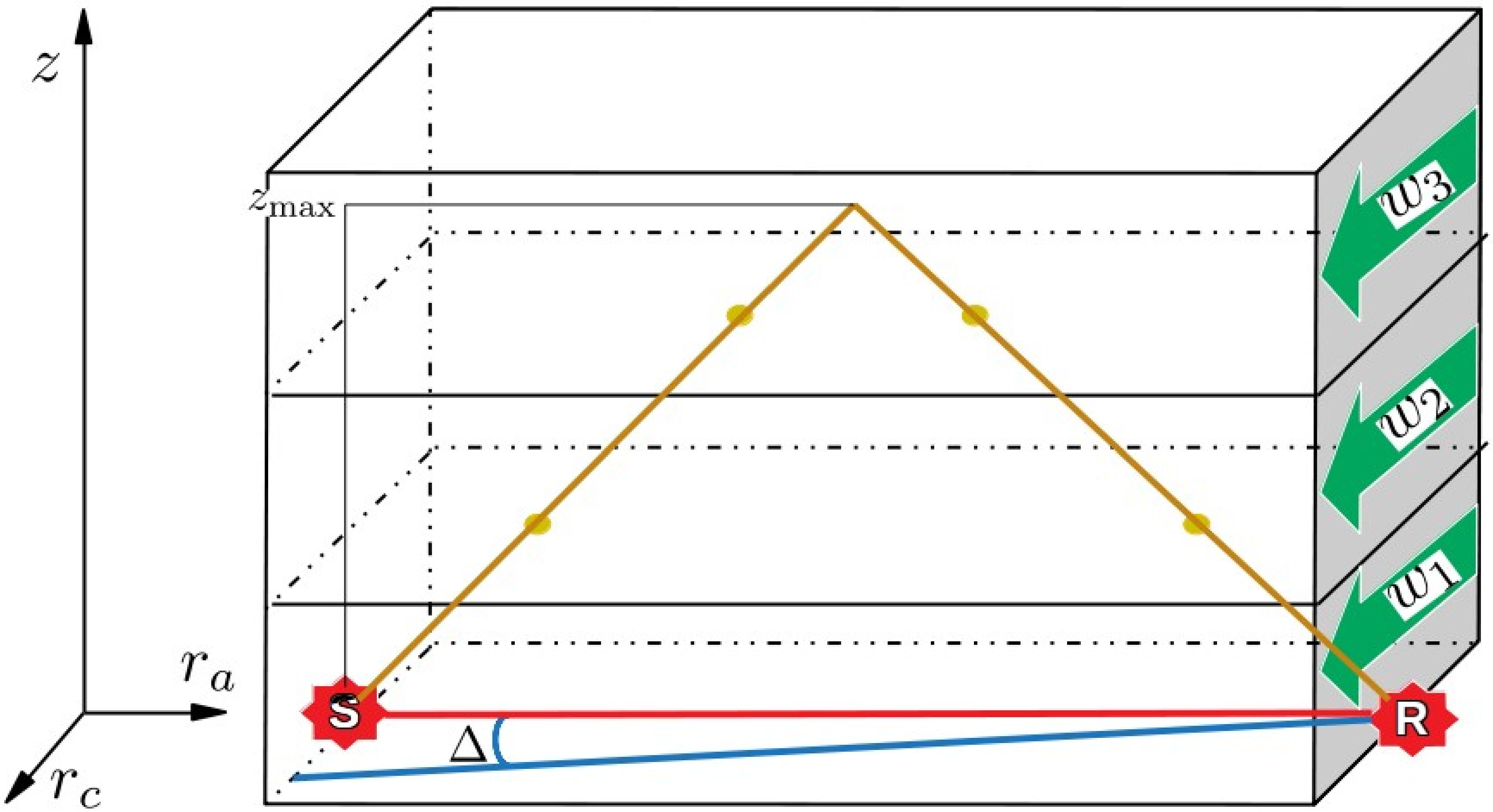
Don’t forget other directions.



# Refraction and reflection

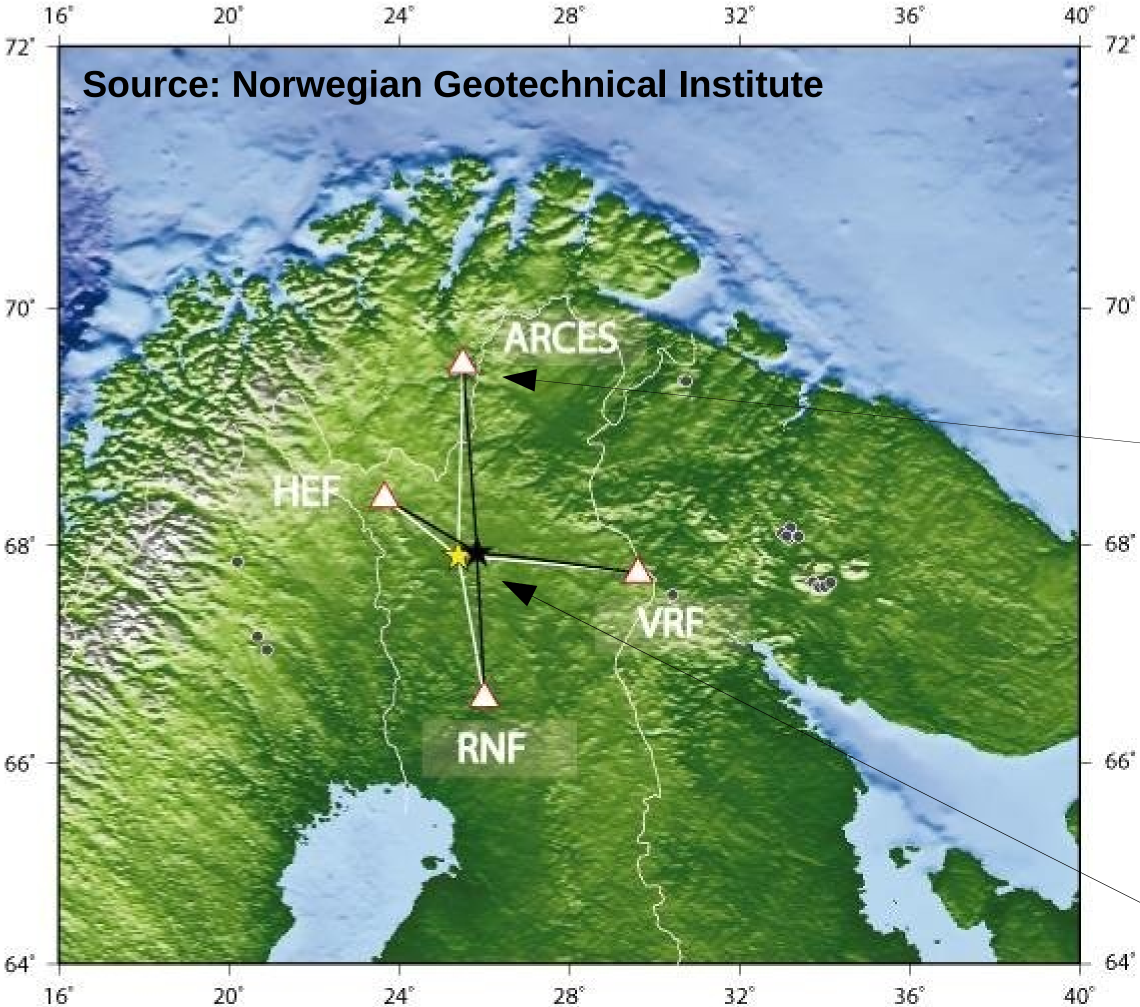


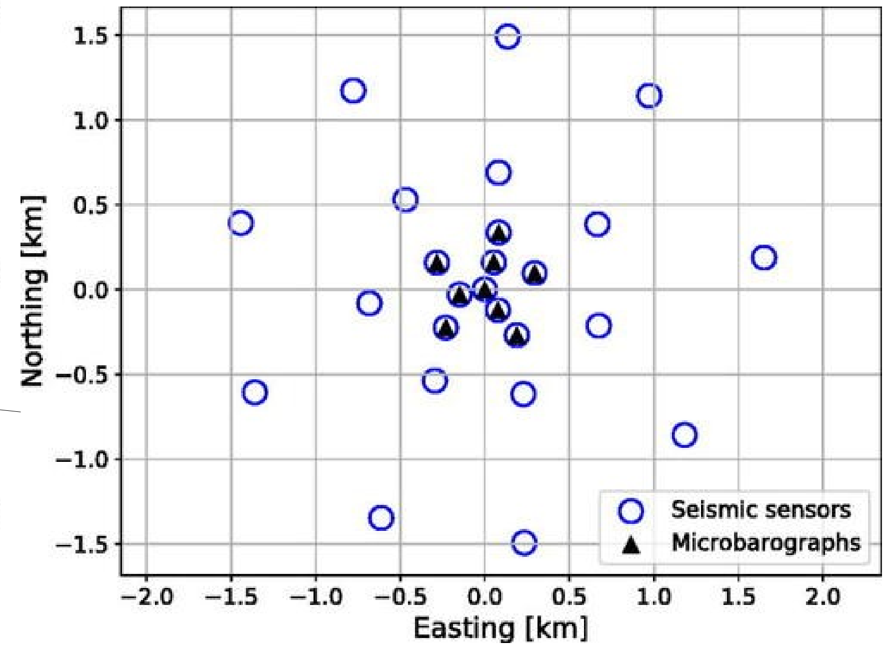
# Refraction and reflection




The cross-wind can shift the **apparent direction for** the wave source.

# Ammunition explosions in Finland

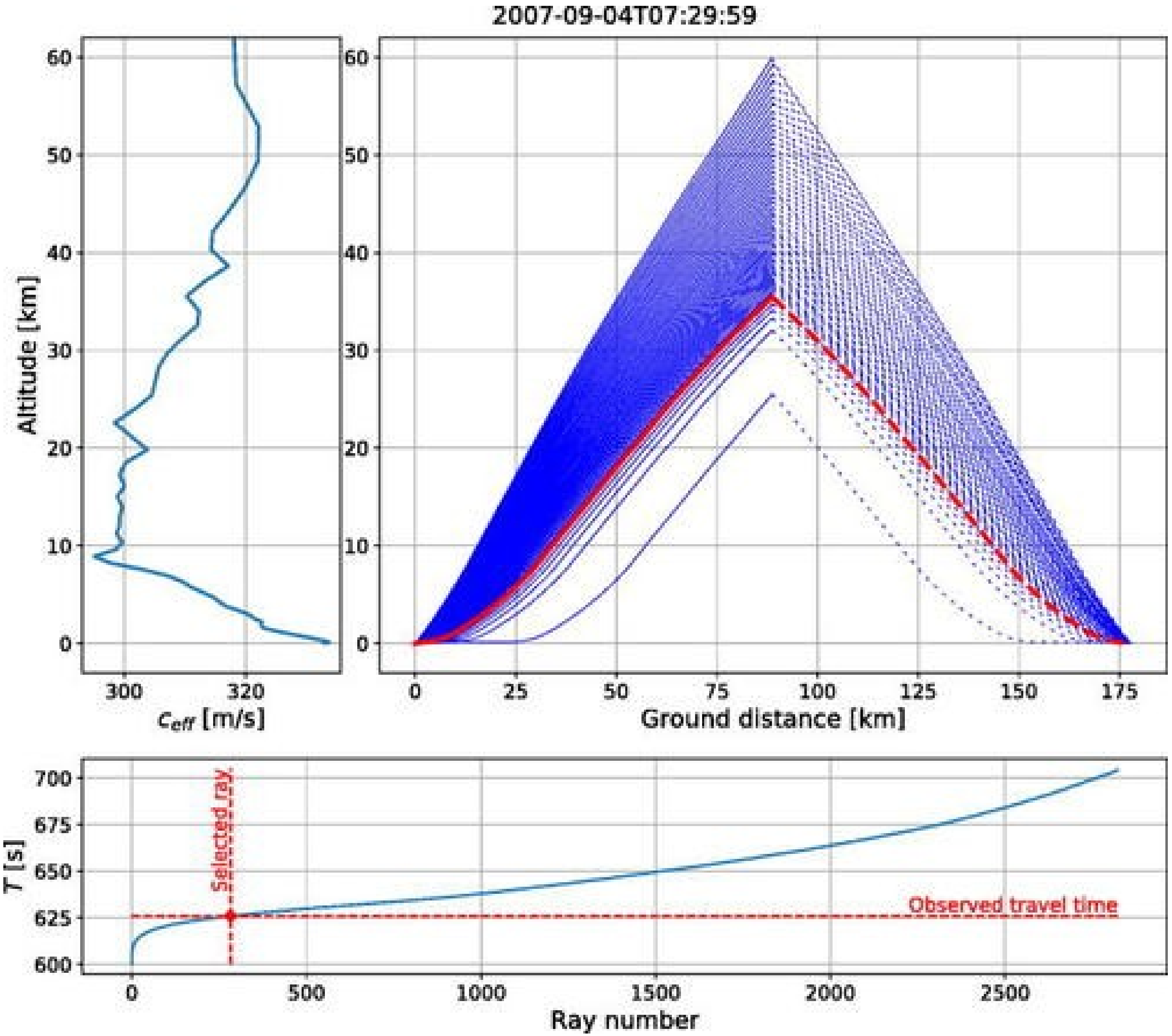



From Blixt et al 2019.

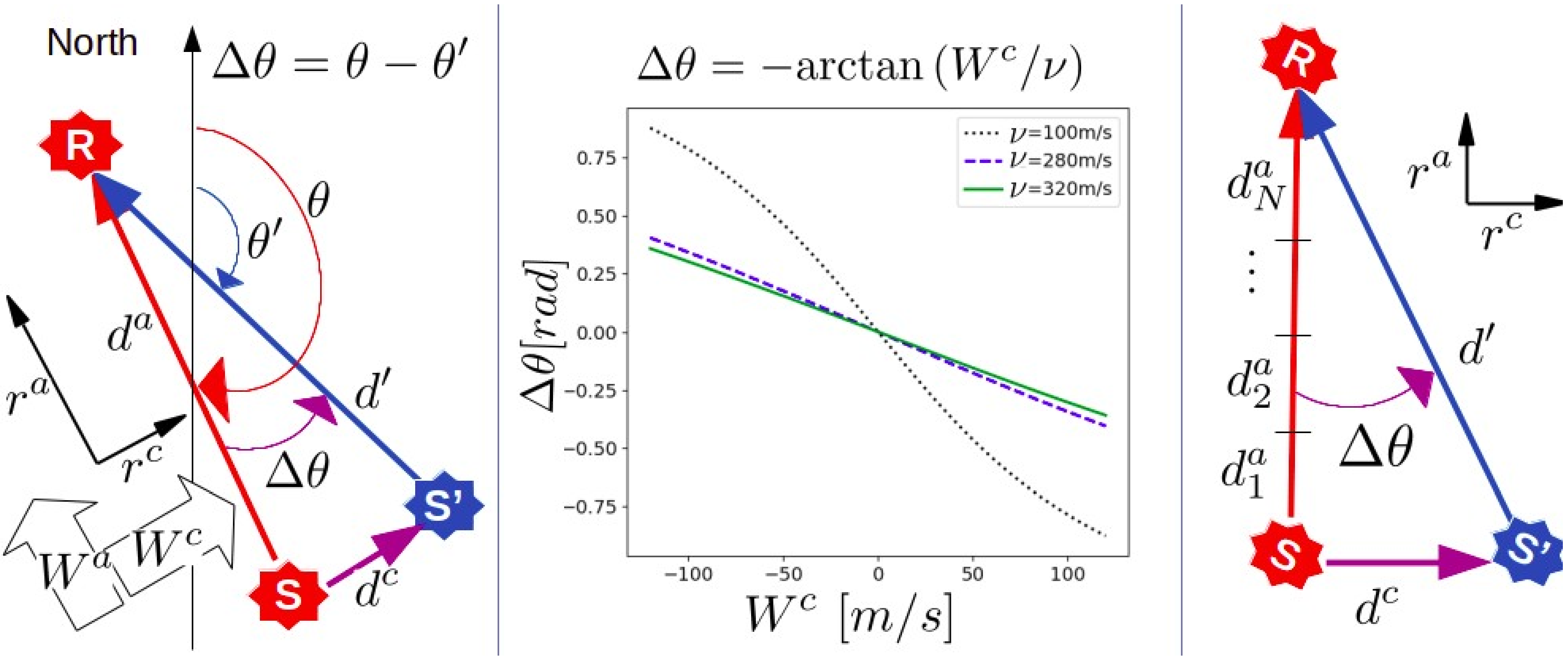
Hukkakero ammunition site.

# Travelled paths (reconstruction)




**From Blixt et al 2019.**

# The geometry of the problem

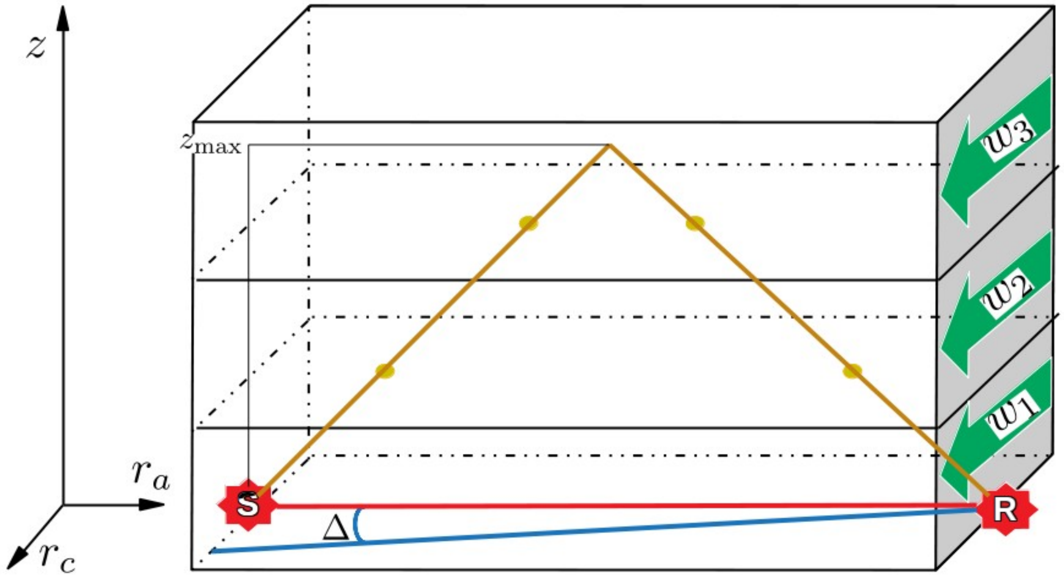



$$\Delta\theta = \arctan\left(\frac{w^c}{\nu}\right) + \eta$$

What is the effective wind?

# The “effective” wind

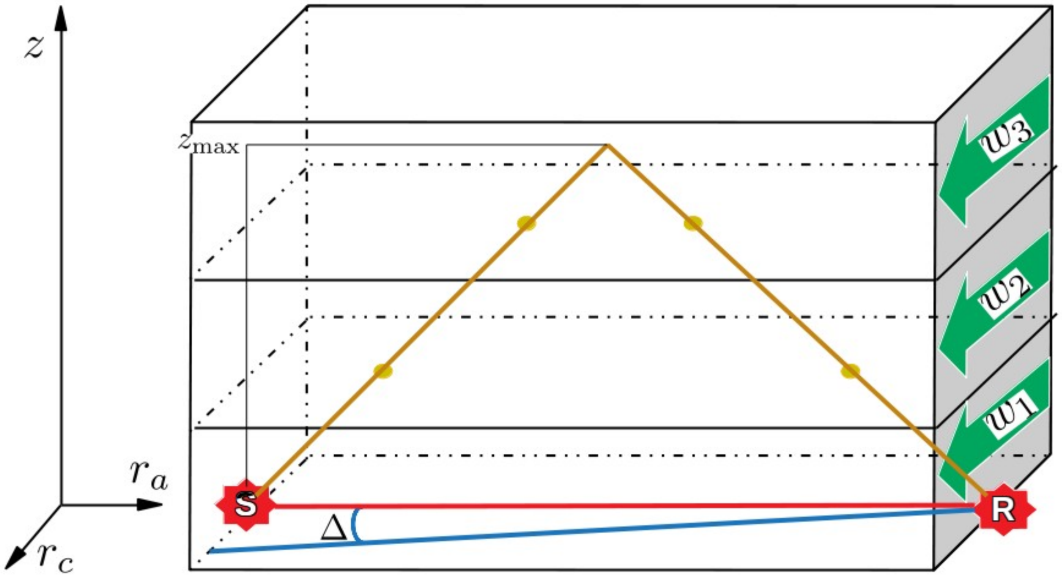
$$\Delta\theta = \arctan\left(\frac{w^c}{\nu}\right) + \eta$$



# The “effective” wind

$$\Delta\theta = \arctan\left(\frac{w_e}{\nu}\right) + \eta$$

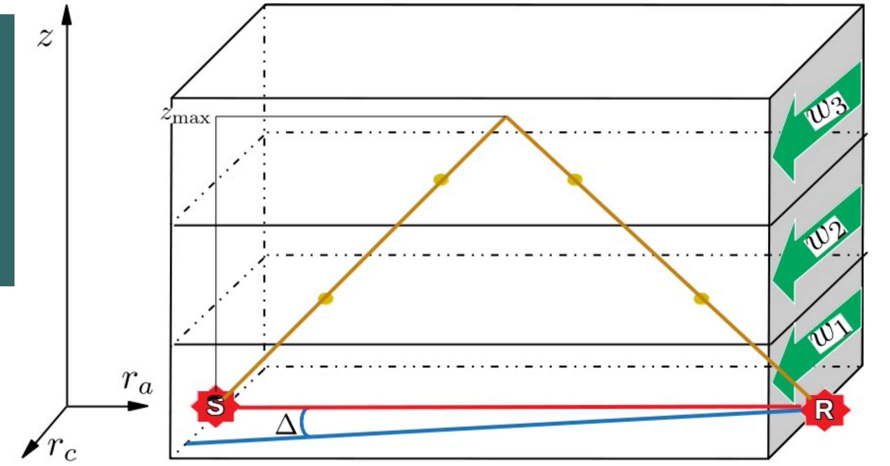
$$w_e = \int_0^{z_{\max}} \alpha(z) w_c(z) z,$$



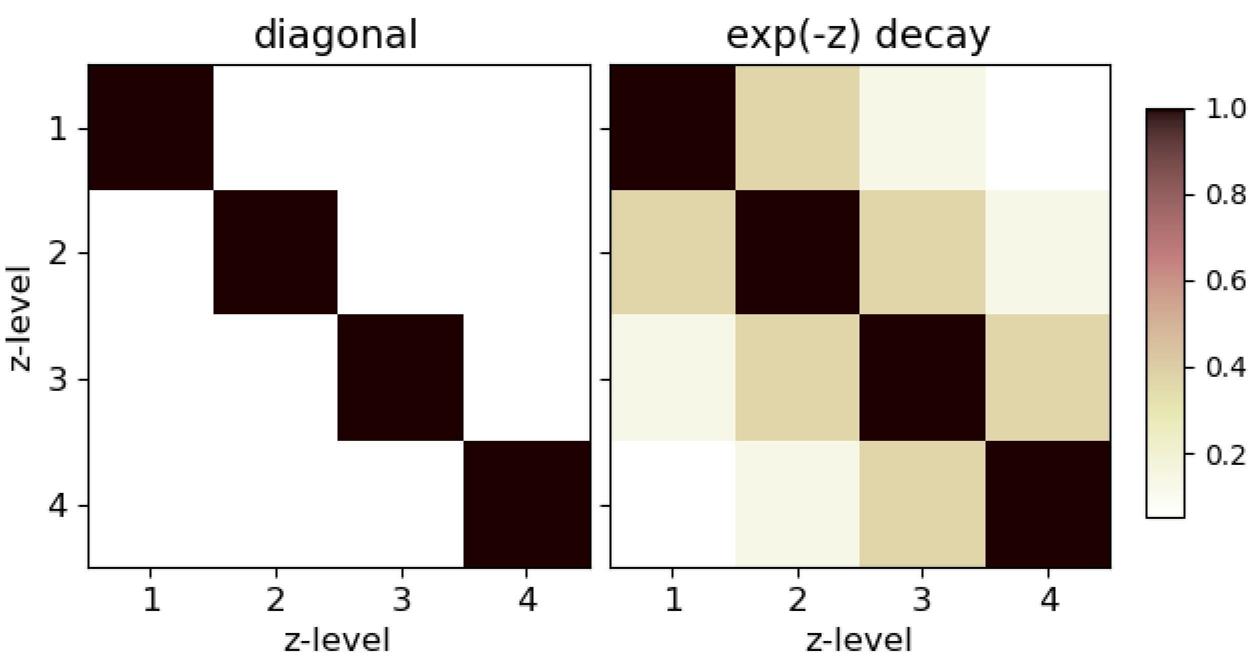

$$\mathbf{w} = \begin{bmatrix} w_1 & w_2 & \cdots & w_{N_z} \end{bmatrix}^{\mathbf{T}}$$

$$w_e = \boldsymbol{\alpha}^{\mathbf{T}}\mathbf{w} = \sum_{j=1}^{N_z} \alpha_j w_j,$$

# Simple case

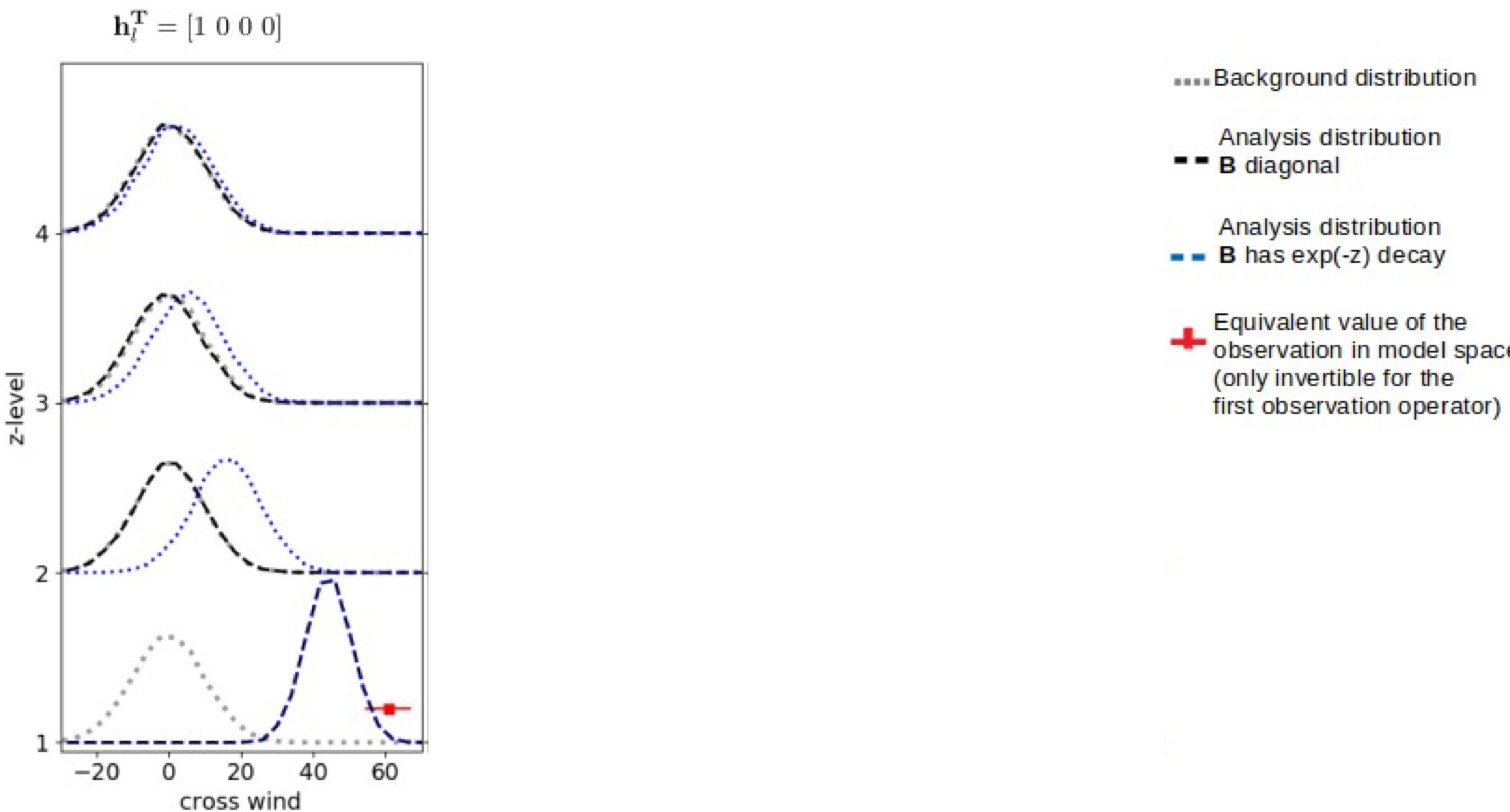



4 layers
10,000 ensemble members
1 given observation at the lowest level



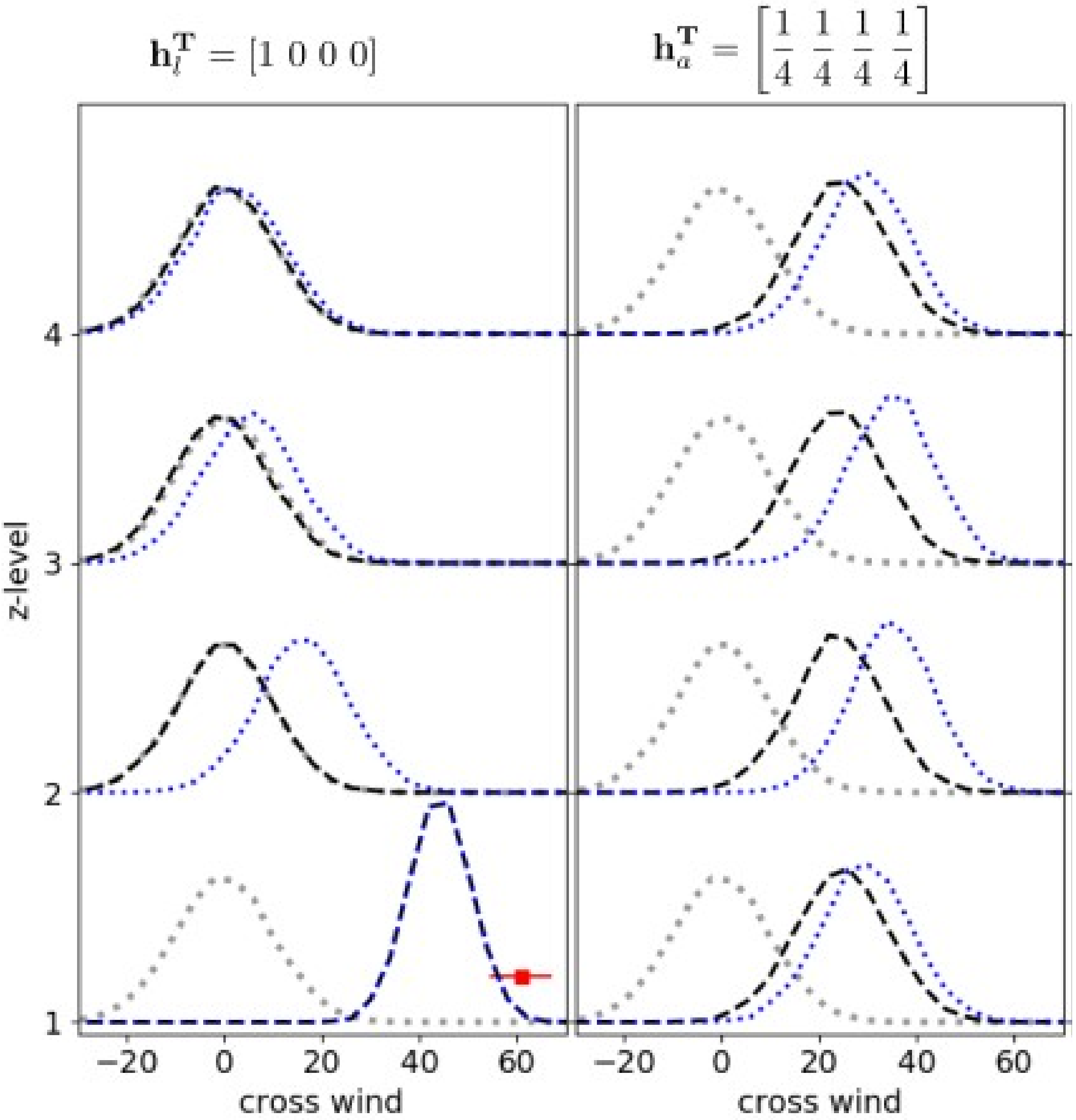

2 prescribed
covariance matrices

# Simple case

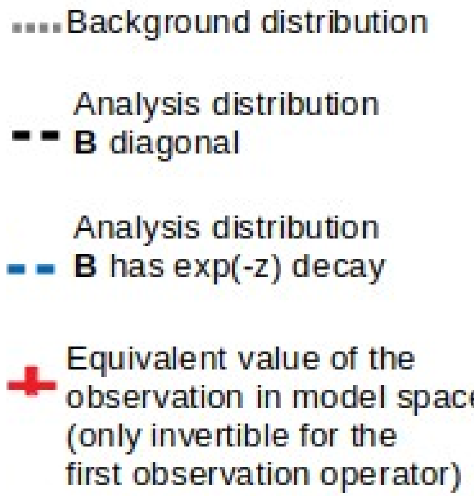


$\mathbf{h}_l^{\mathrm{T}} = [1\ 0\ 0\ 0]$
z-level
cross wind
−20
0
20
40
60
1
2
3
4
Background distribution
Analysis distribution
**B** diagonal
Analysis distribution
**B** has exp(-z) decay
Equivalent value of the
observation in model space
(only invertible for the
first observation operator)

# Simple case



$\mathbf{h}_l^{\mathbf{T}} = [1\ 0\ 0\ 0]$
$\mathbf{h}_a^{\mathbf{T}} = \left[\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\right]$
z-level
4
3
2
1
−20
0
20
40
60
cross wind
cross wind

Background distribution
Analysis distribution
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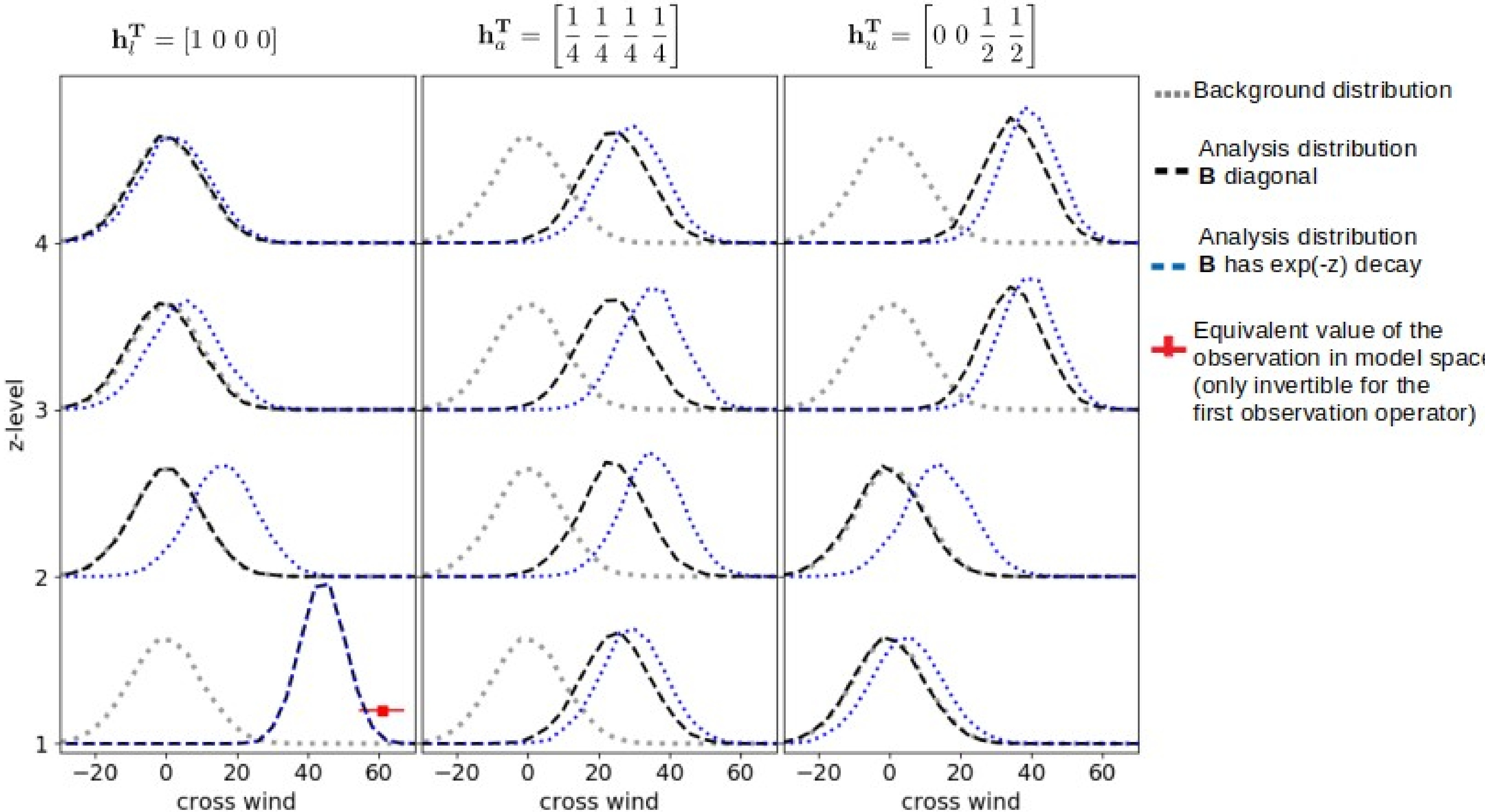
# Simple case

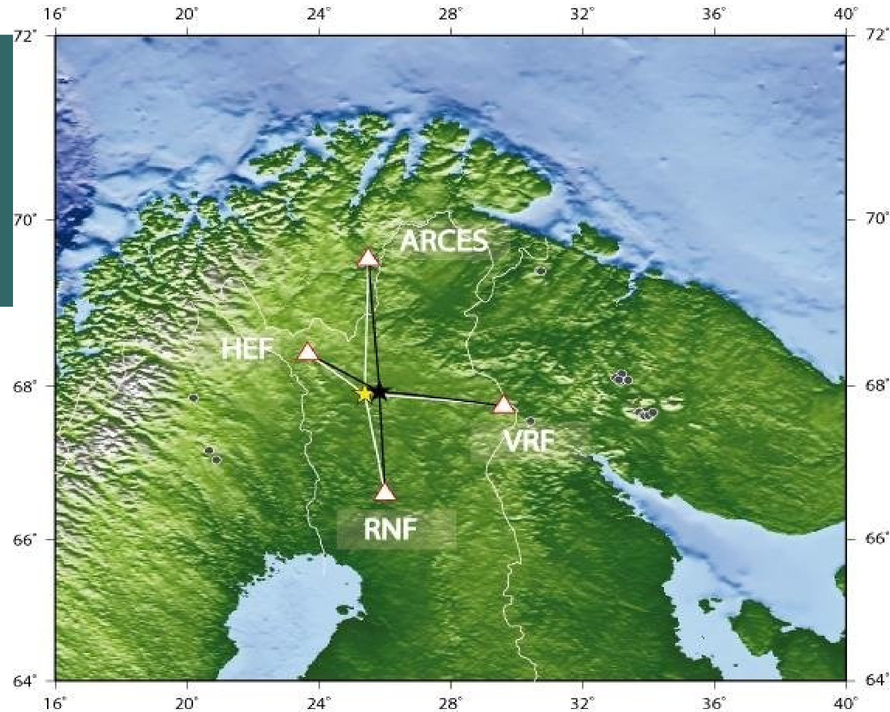


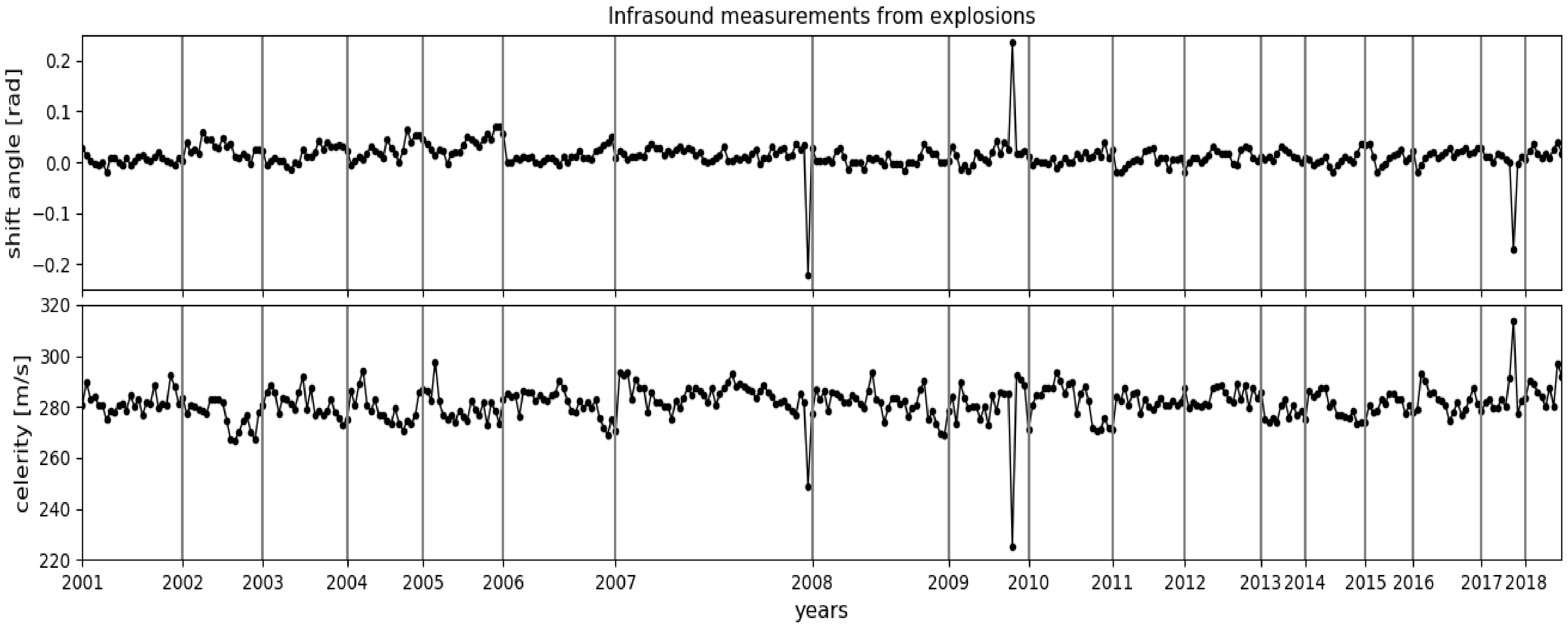
$\mathbf{h}_l^{\mathbf{T}} = [1\ 0\ 0\ 0]$
$\mathbf{h}_a^{\mathbf{T}} = \left[\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}\right]$
$\mathbf{h}_u^{\mathbf{T}} = \left[0\ 0\ \frac{1}{2}\ \frac{1}{2}\right]$
Background distribution
Analysis distribution **B** diagonal
Analysis distribution **B** has exp(-z) decay
Equivalent value of the observation in model space (only invertible for the first observation operator)
z-level
cross wind
cross wind
cross wind

# Real case

For the real case I have 18 years of explosions.

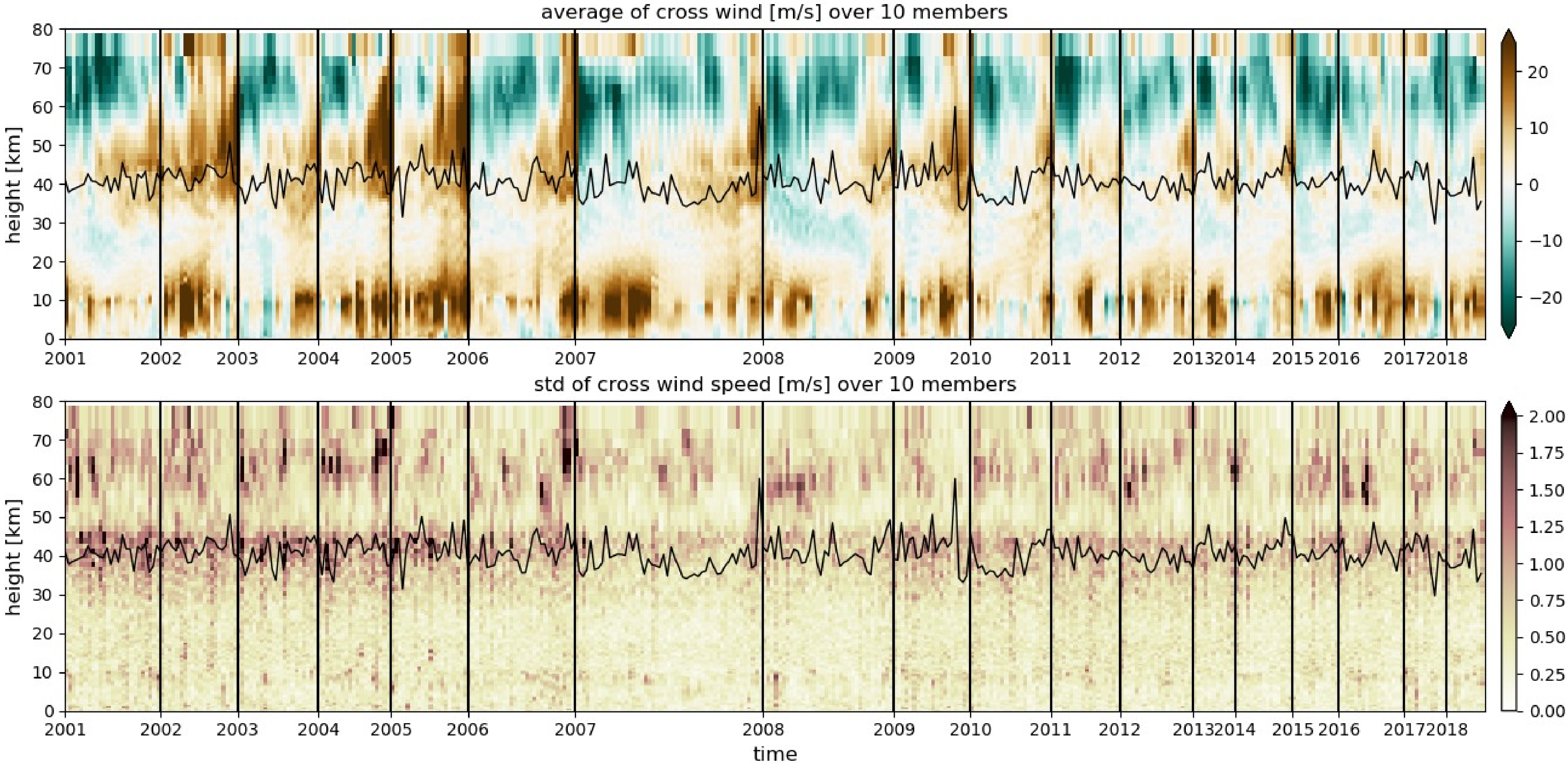
I know the perfect location of the source and receivers, and the shift angle is measured.



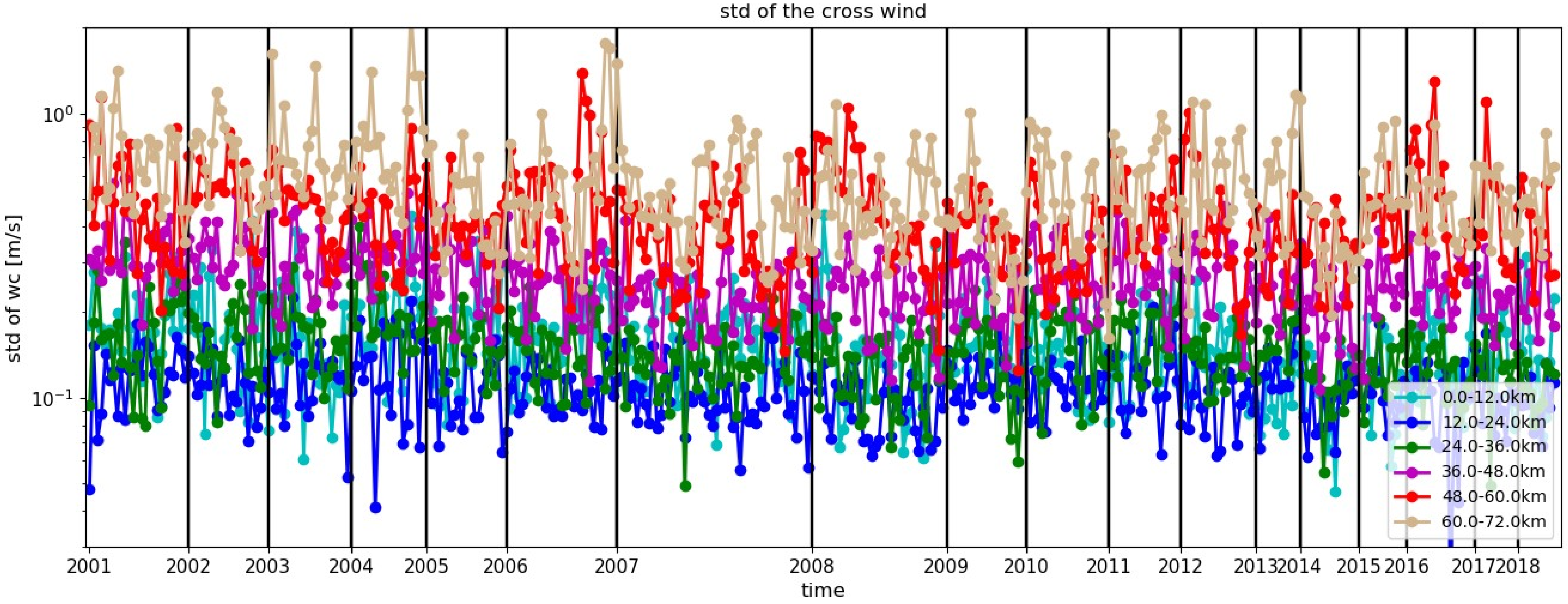
# Background values

ERA-5 winds. 10 ensemble members, 127 vertical levels.

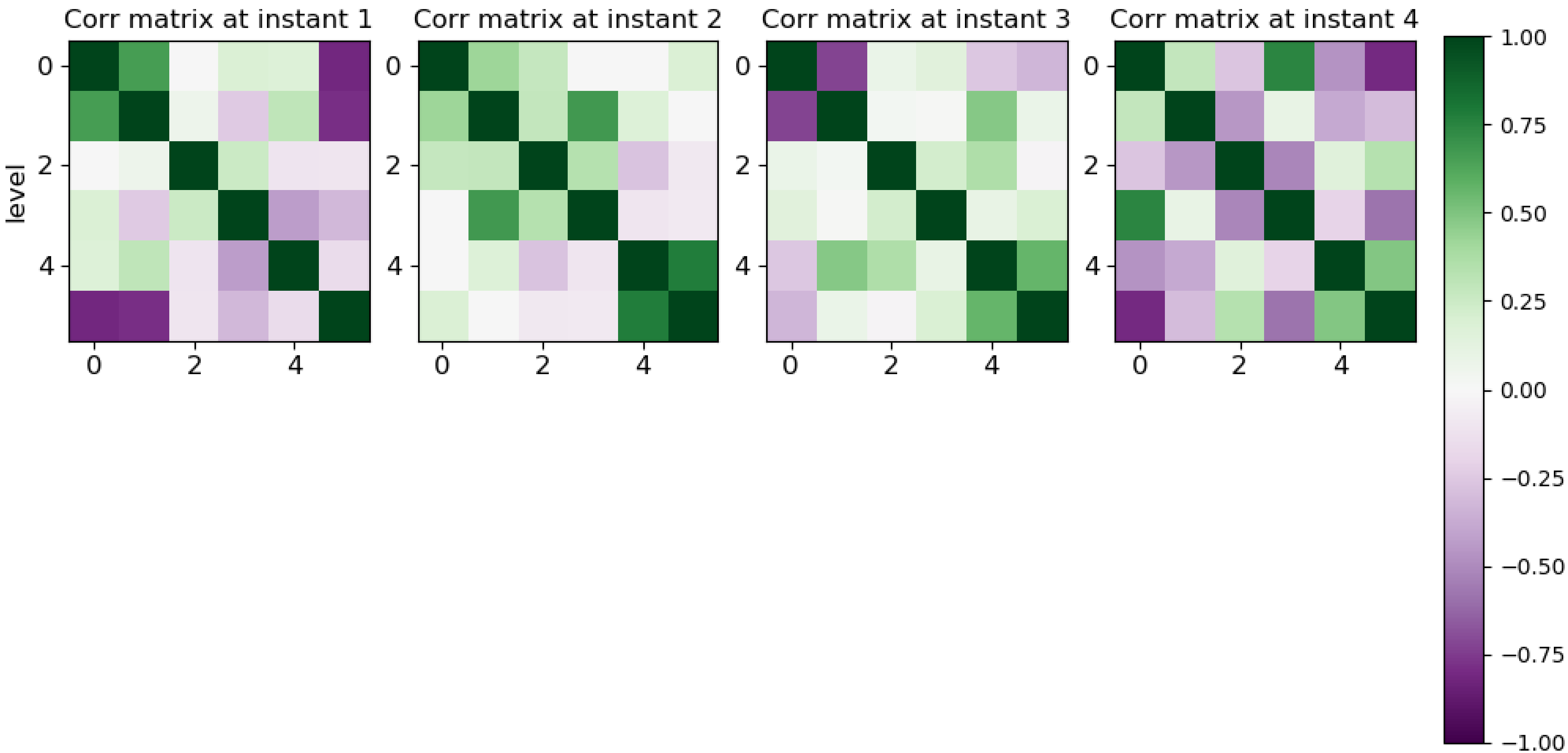


# Problem reduction

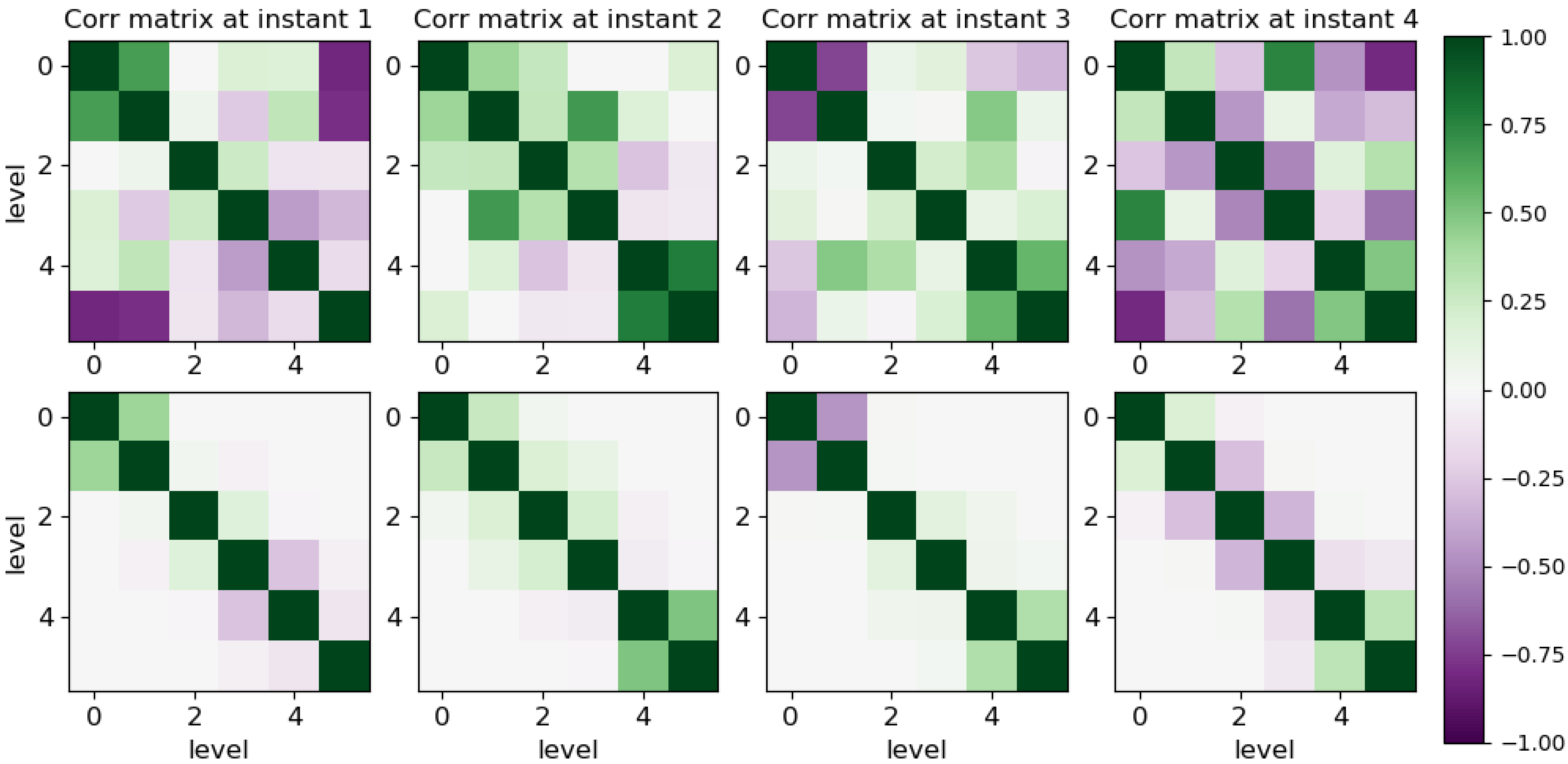
We reduce the problem to 6 ‘distinctive’ vertical layers.



# Raw covariances (noisy)

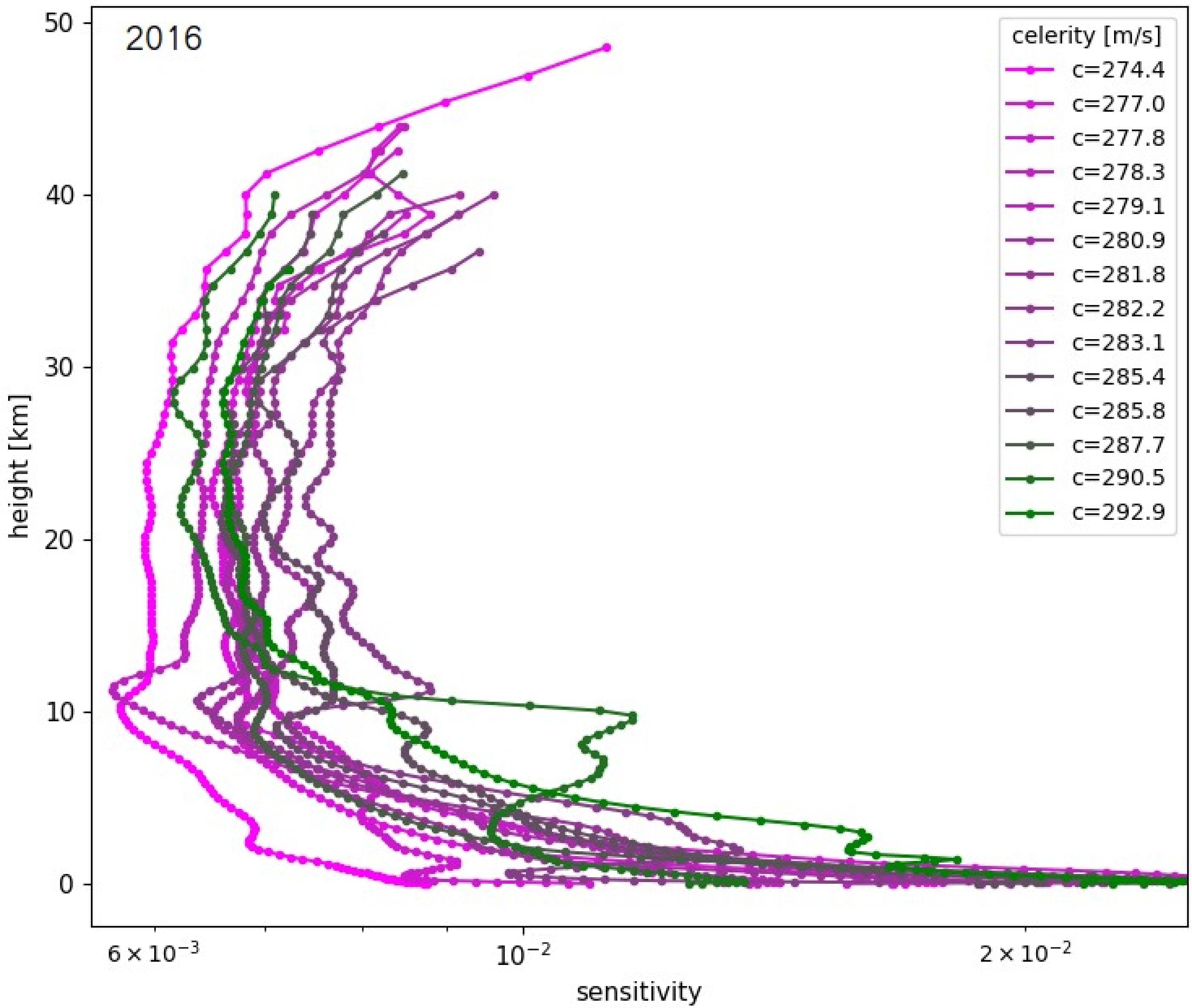


# Localised covariances




$$\mathbf{P} \to \mathbf{C} \circ \mathbf{P}$$

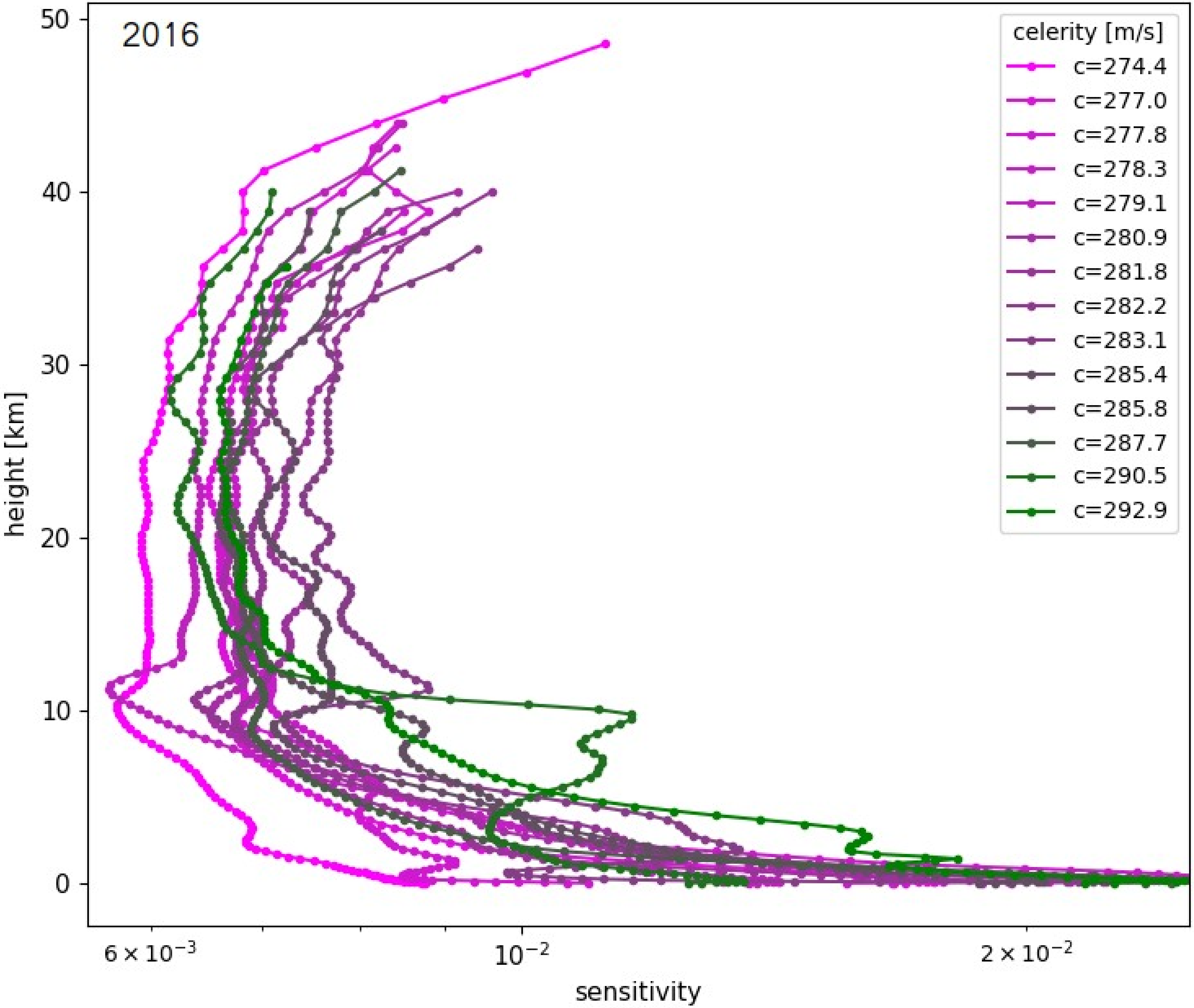
# Vertical penetration and sensitivity




Using a ray-tracing method used by Nasholm and Blixt.

Requires a model...

# Vertical penetration and sensitivity

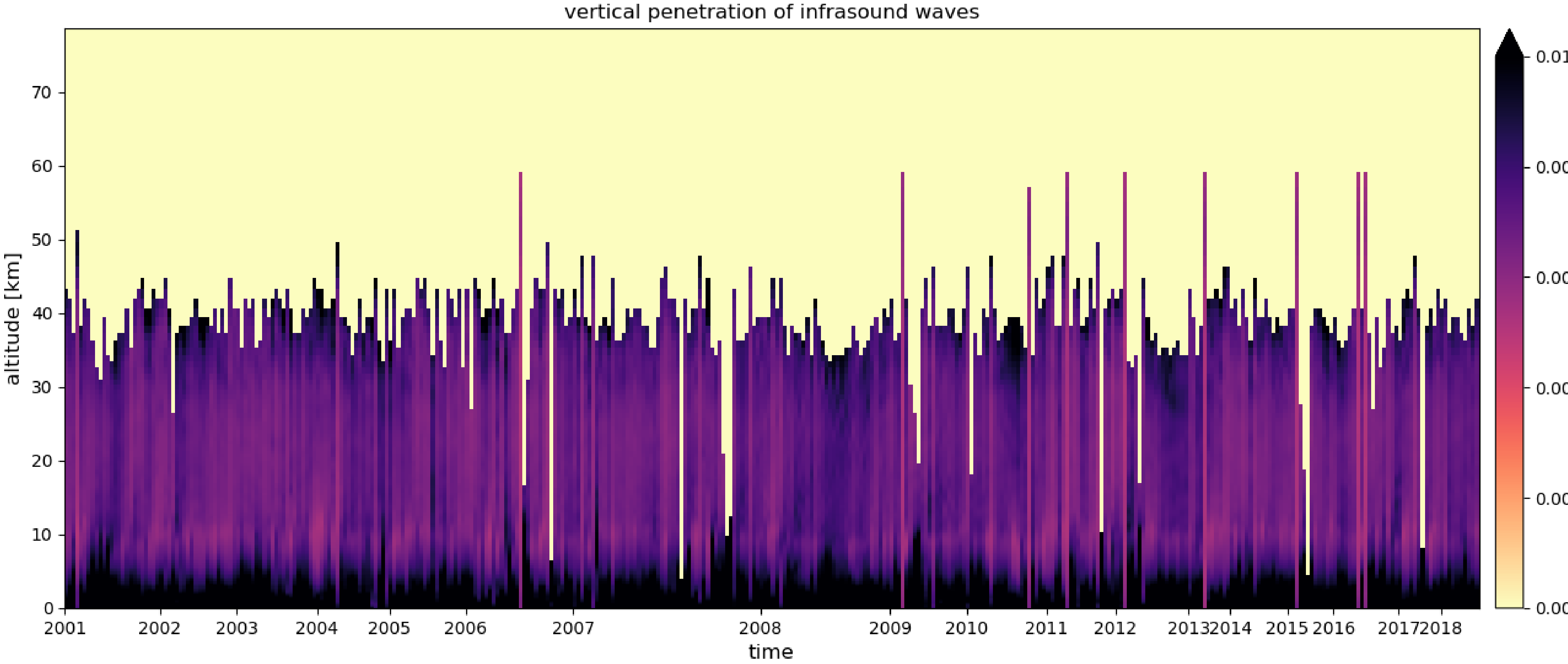



Using a ray-tracing method used by Nasholm and Blixt.

Requires a model...

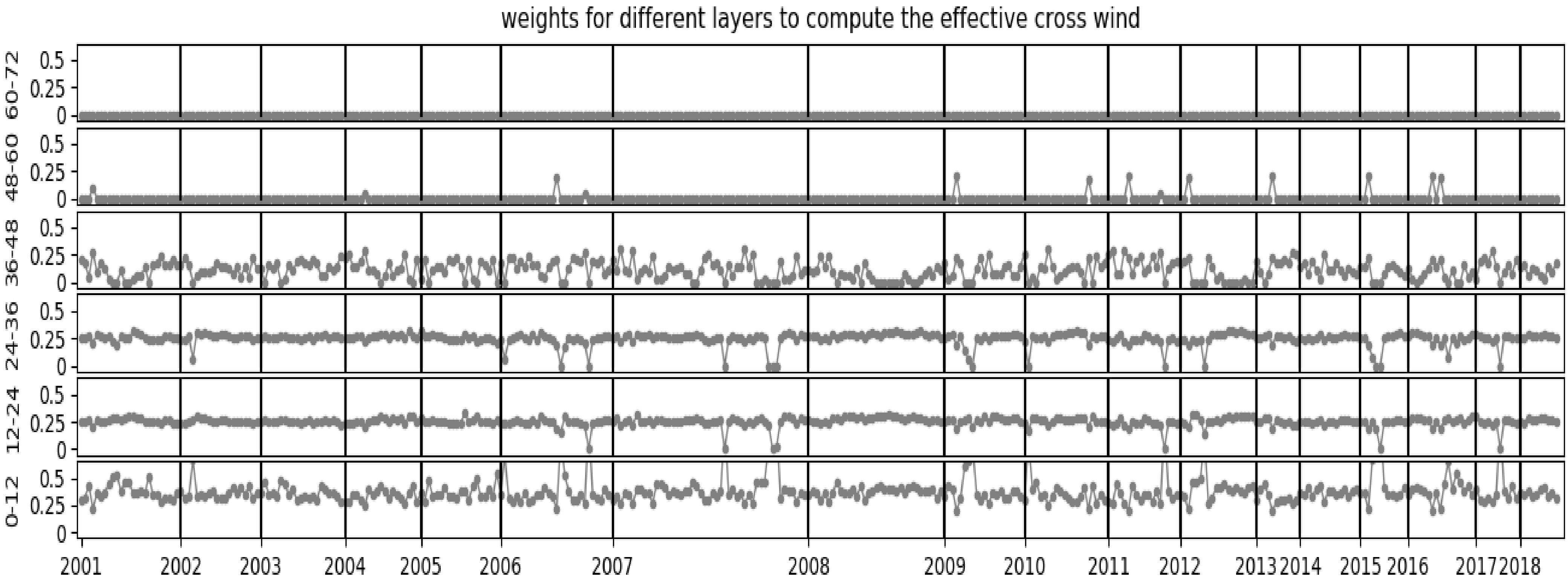
Danger of in-breeding.

# Vertical penetration and sensitivity

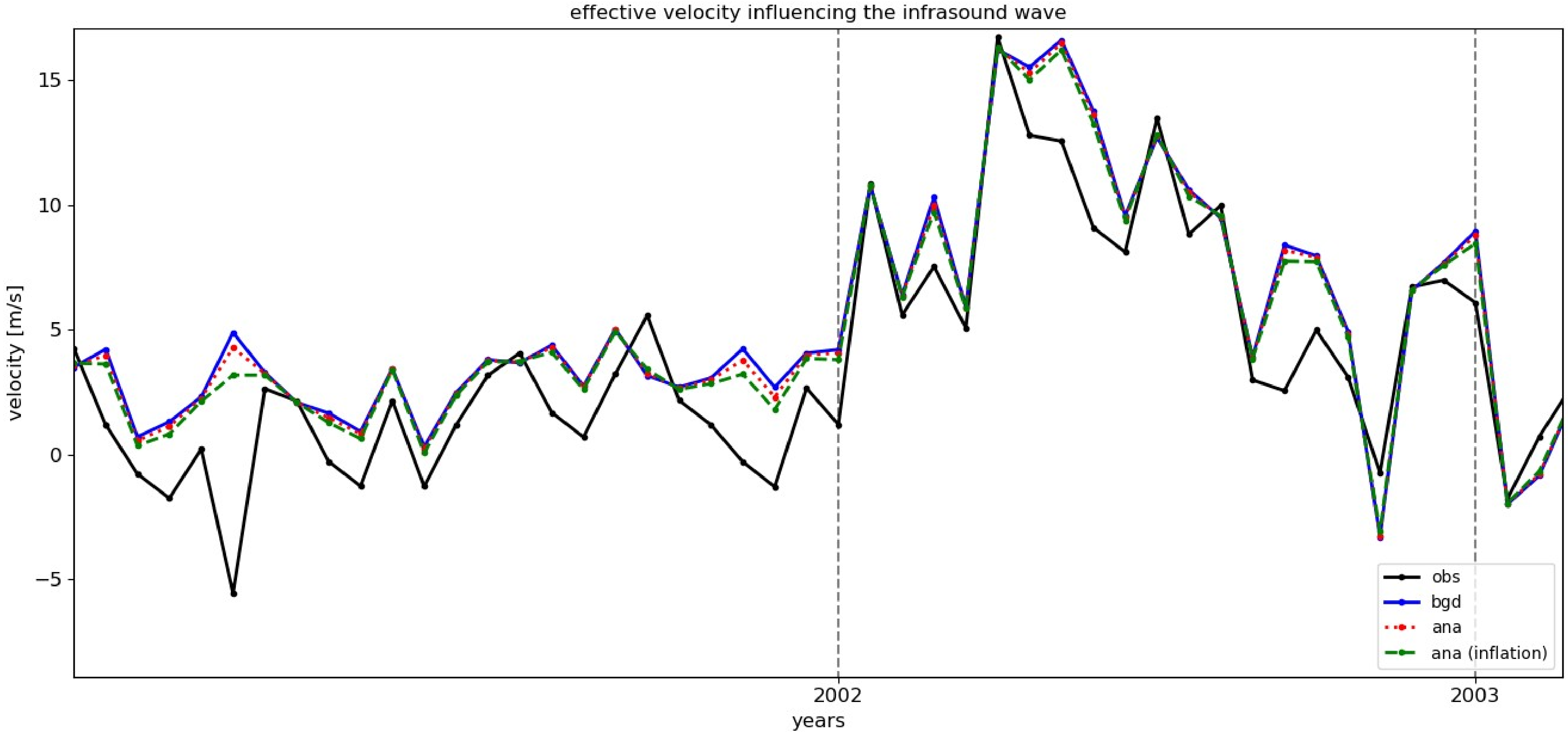


# Time-dependent weights

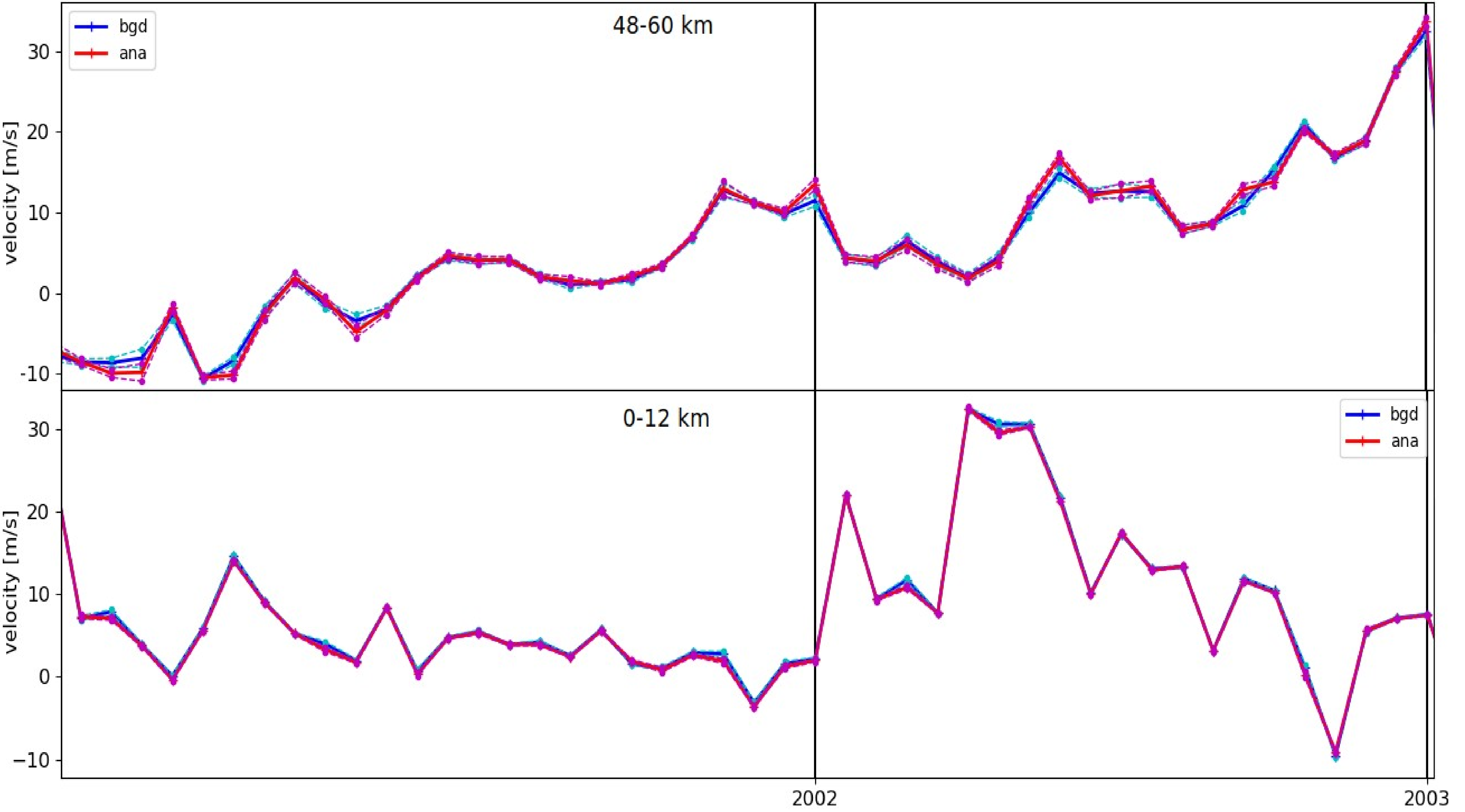
$$w_e = \boldsymbol{\alpha}^{\mathbf{T}}\mathbf{w} = \sum_{j=1}^{N_z} \alpha_j w_j,$$



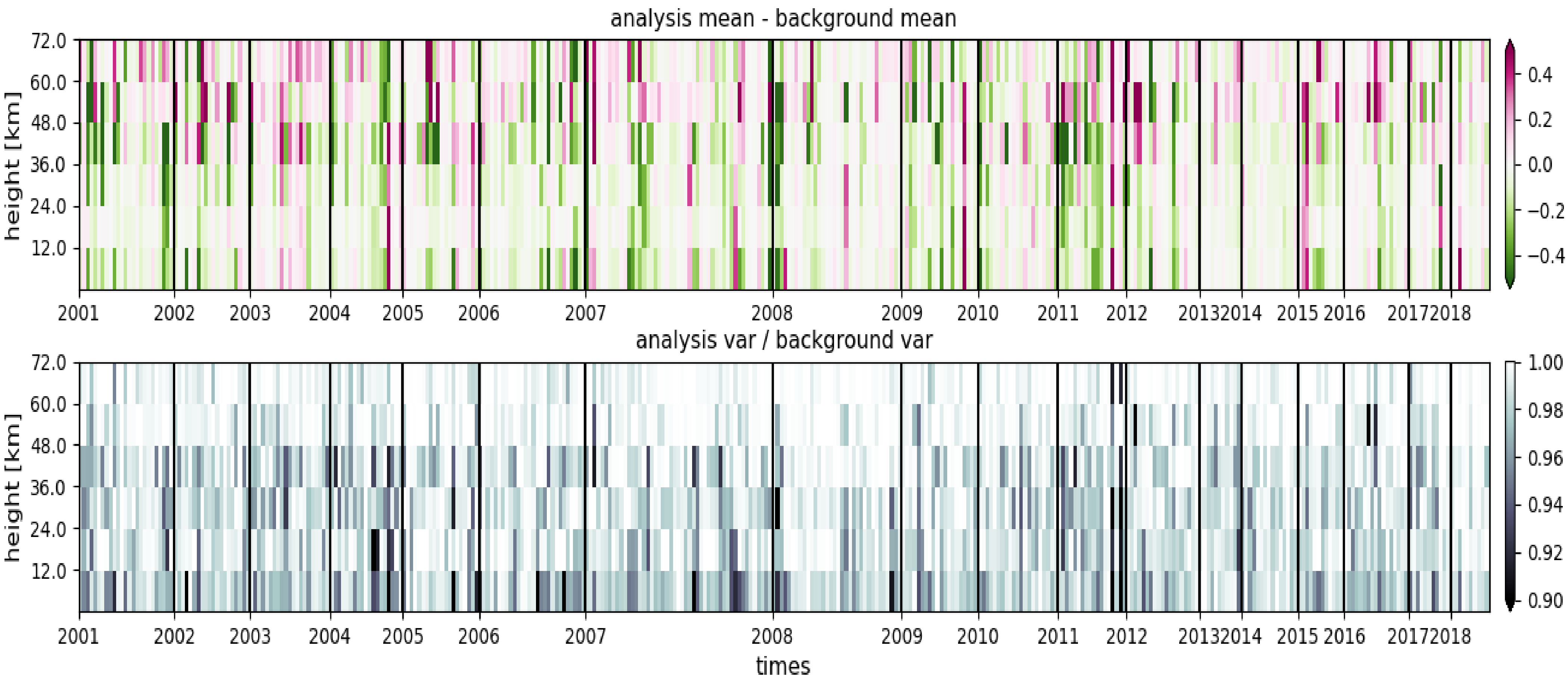
# Results: effective wind



# Results: analysis in 2 layers



# Diagnostics




Top: analysis-background difference for the mean.
Bottom: analysis/bacground ratio for the standard deviation.

# Outline

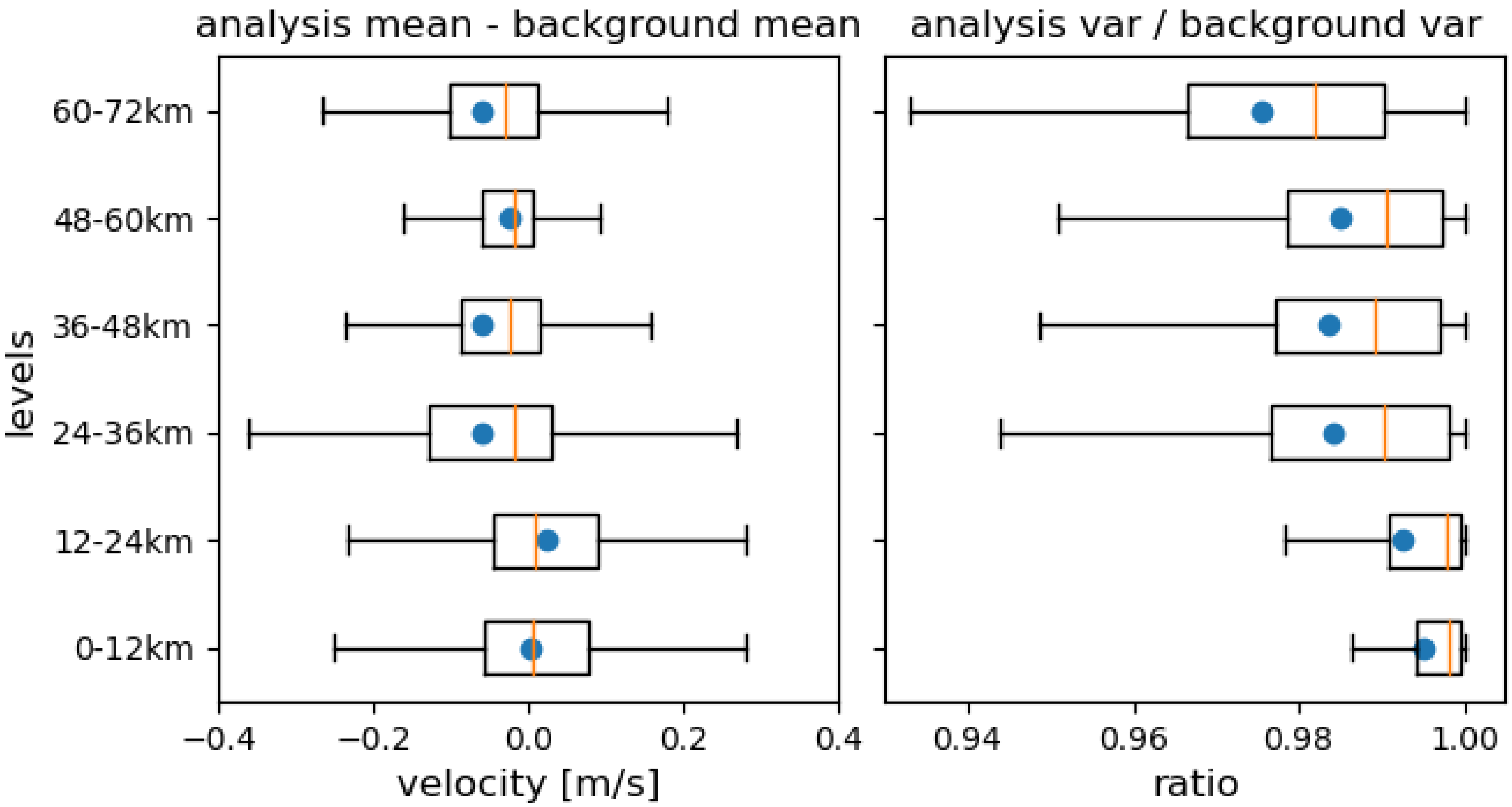
1. Some basics of data assimilation

2. The problem

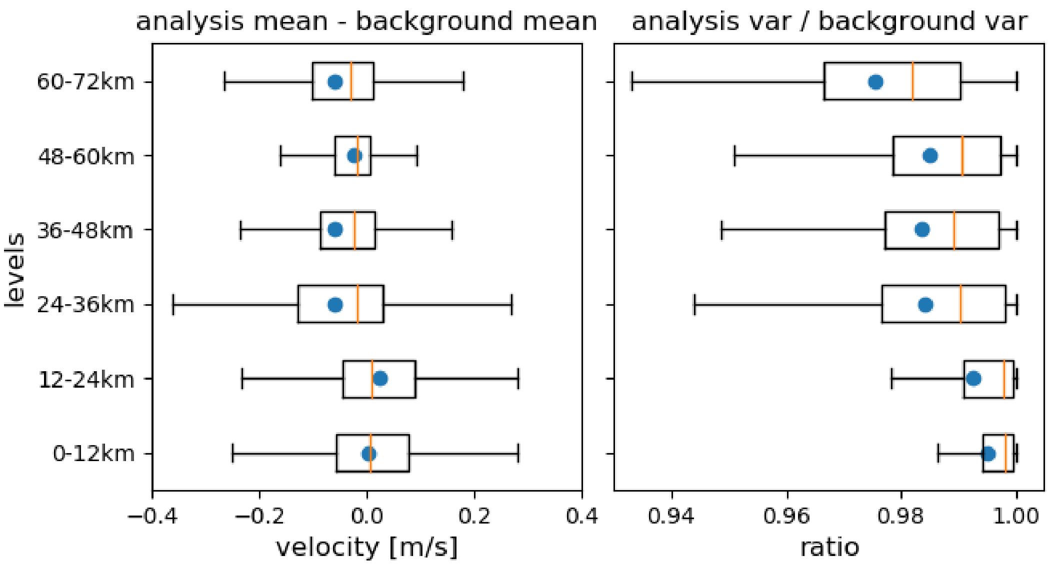
3. DA for this case
    3.1. A perfect scenario
    3.2. The real case

**4. Summary and future work**

# Summary: impacts



# Comments




- Assimilating infra-sound waves to constrain winds is possible.

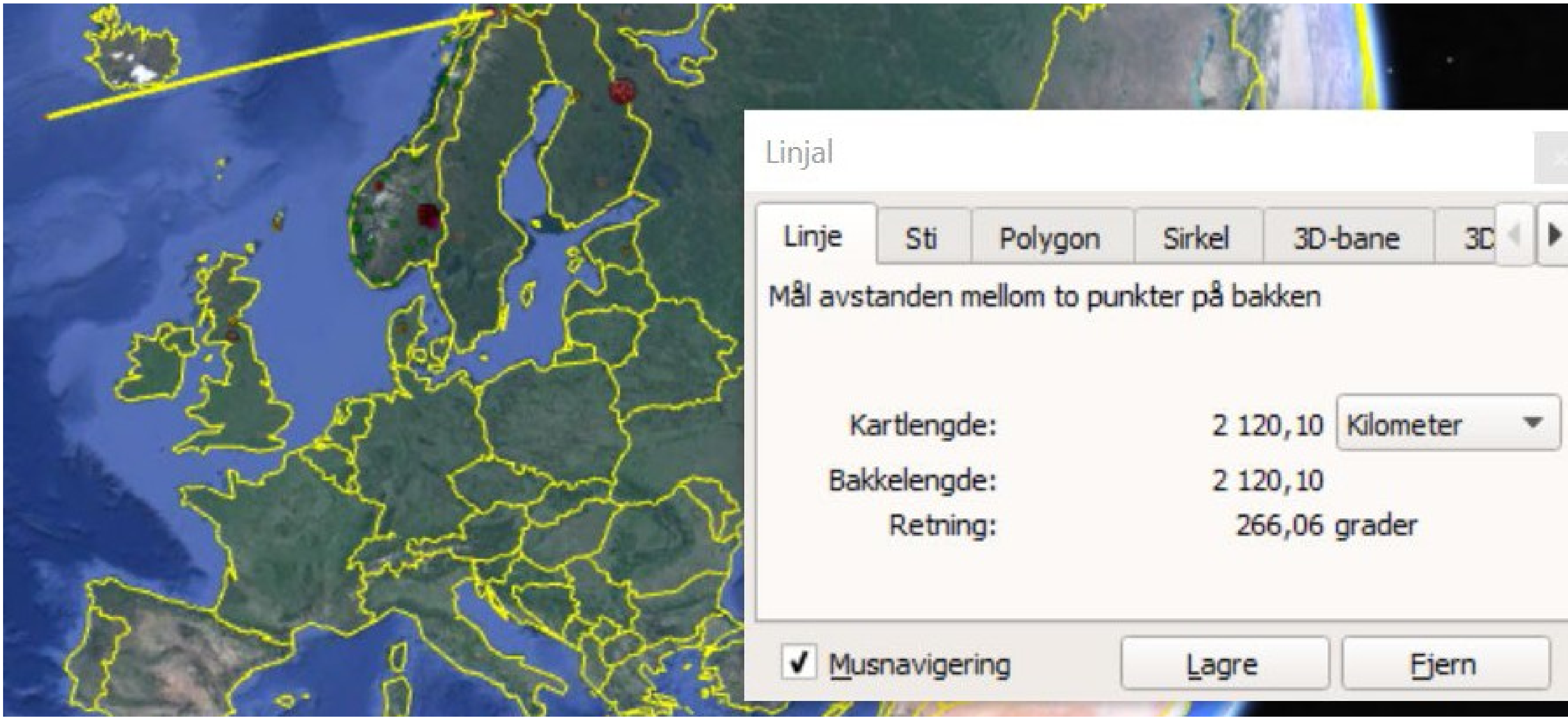
- We did not verify the analysis. Against what? Independent observations, another reanalysis? AEOLUS.

- When experimenting with inflation the impact was larger. Is it necessary?

- Analyse diagnostic quantities.

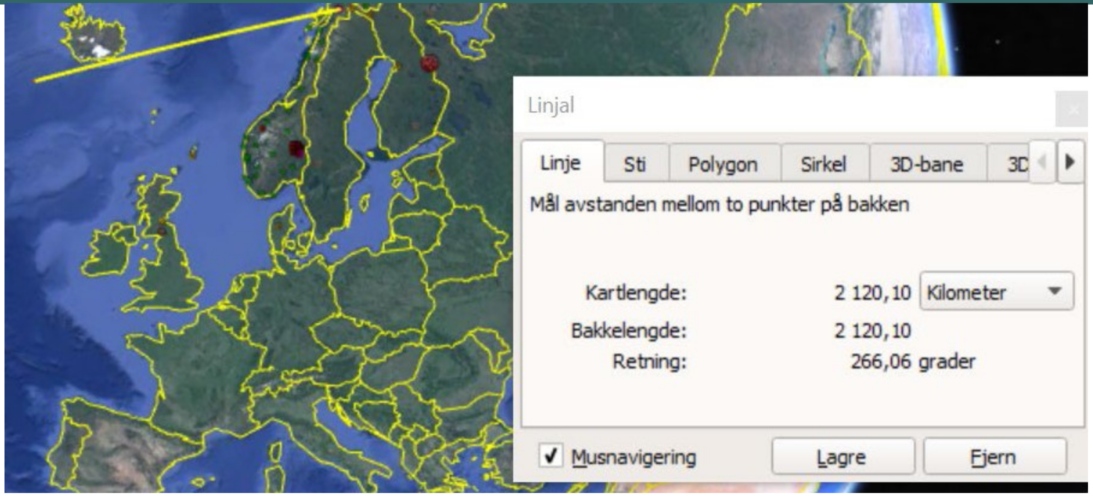
- The problem was relatively straightforward.

# The next problem




Assimilation of infra-sound waves naturally and continuosly generated: **ARISE 3**.

# Comments




- The problem is more challenging.

- Exact position of the source is unknown.
  Hence celerity is uncertain.
  Also the path is not clear.
  The ray-tracing procedure is not that easy.

- When applied to forecasts it should have more impact.

- Longer distance travelled but also higher penetration.