UNIVERSITY OF TRENTO - Italy
Department of Civil, Environmental and Mechanical Engineering

Comparative assessment of methods to retrieve fine-scale ABL structures from airborne measurements

L. Laiti[1], **D. Zardi**[1], M. de Franceschi[1,2], G. Rampanelli[1,3]

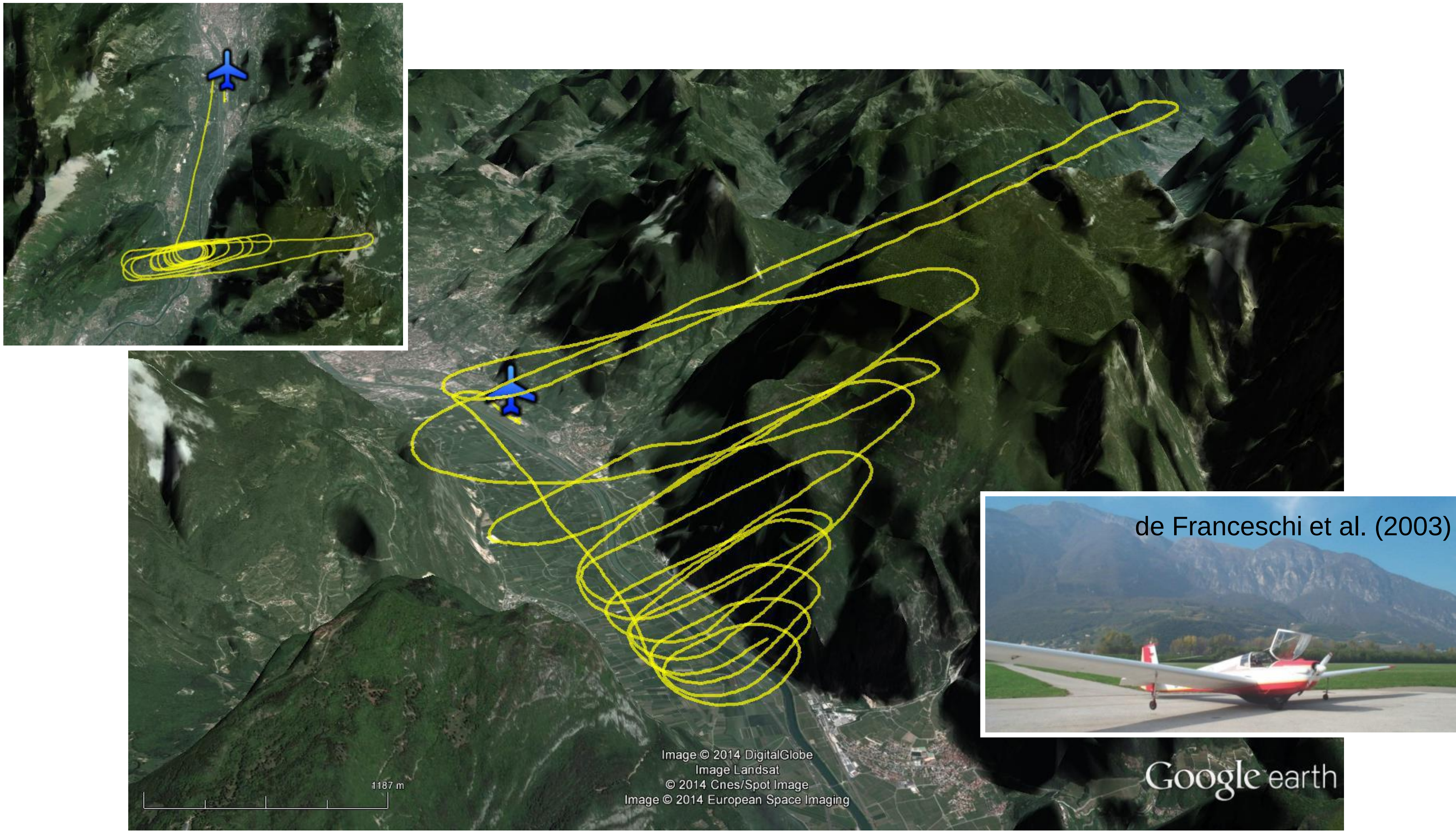
[1] Atmospheric Physics Group - Department of Civil, Environmental and Mechanical Engineering
University of Trento, Trento – Italy

corresponding author: lavinia.laiti@unitn.it

Outline of the talk

1. Airborne measurements of the ABL in a valley
2. The interpolation methods
3. Residual Kriging (RK)
4. Interpolation results
5. Objective cross validation
6. Modified cross validation
7. Conclusions

1. Airborne measurements of the ABL in a valley



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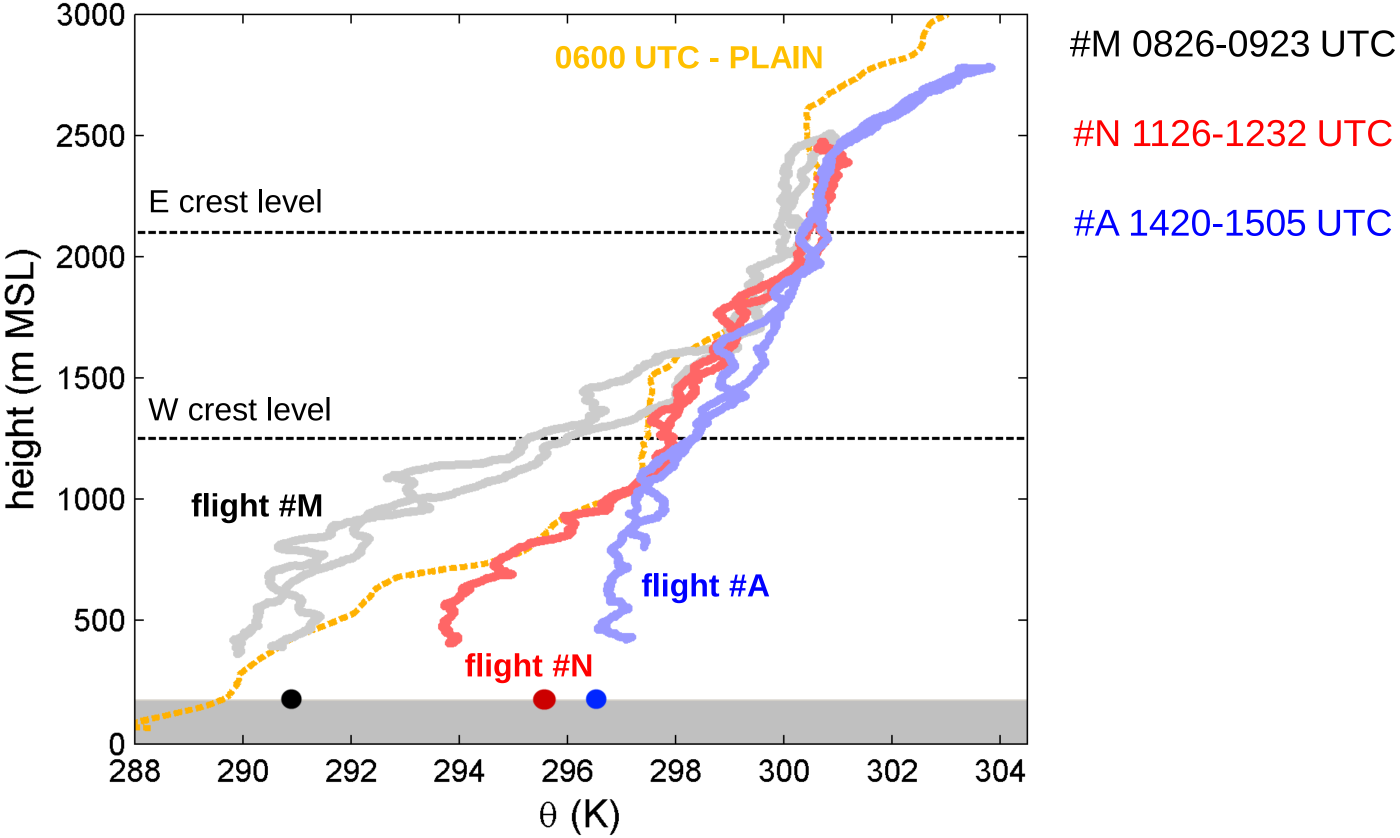

ABL vertical structure

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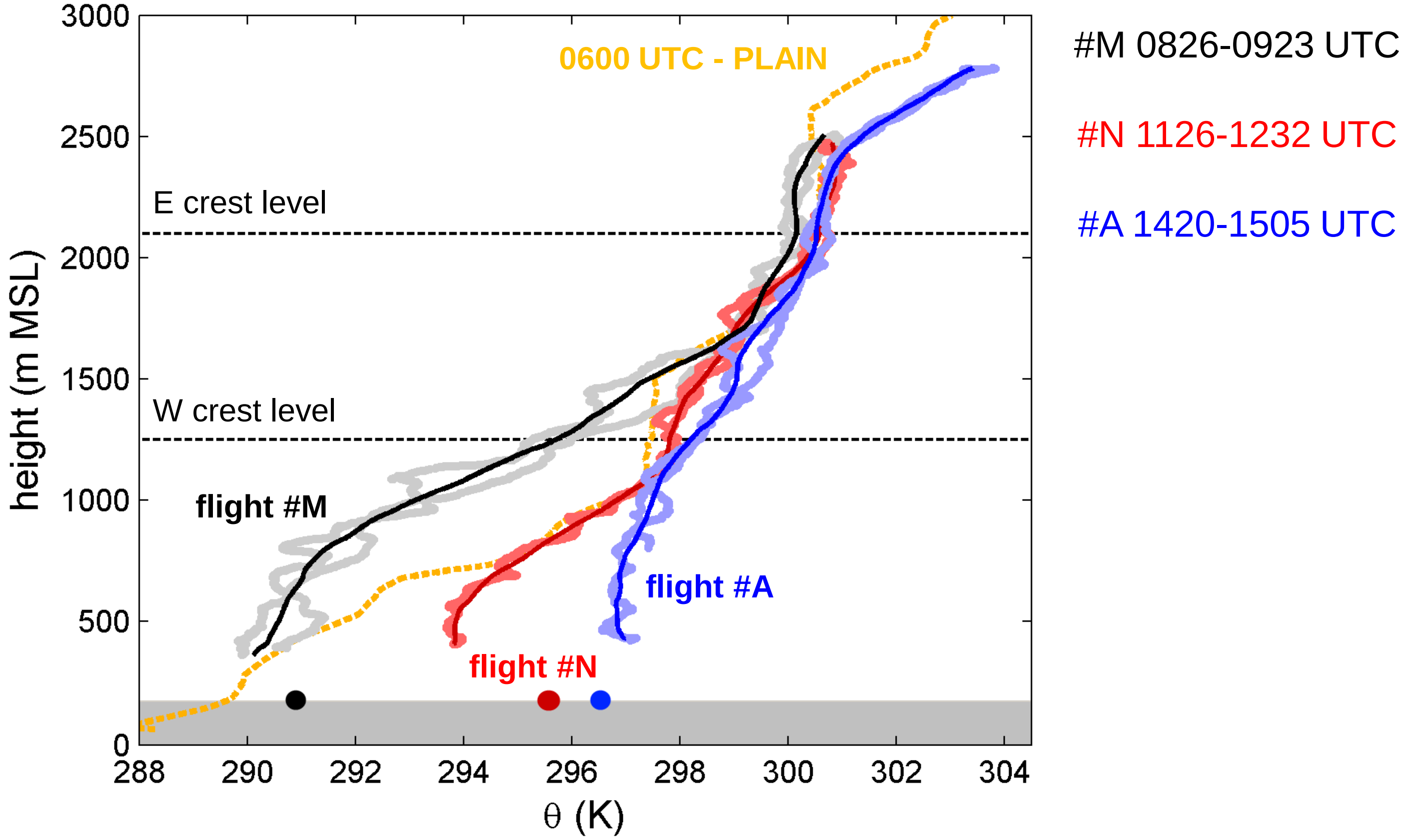

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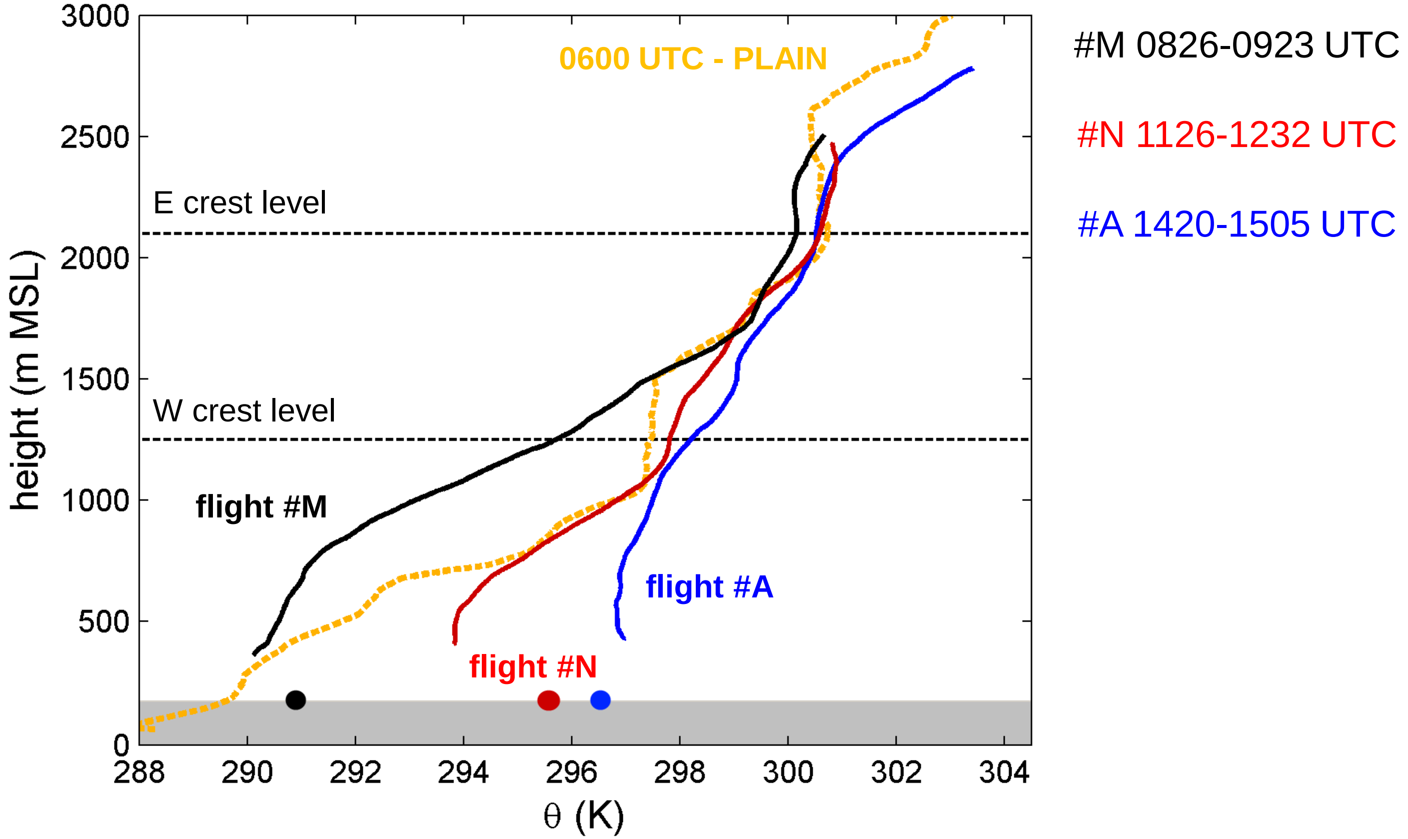

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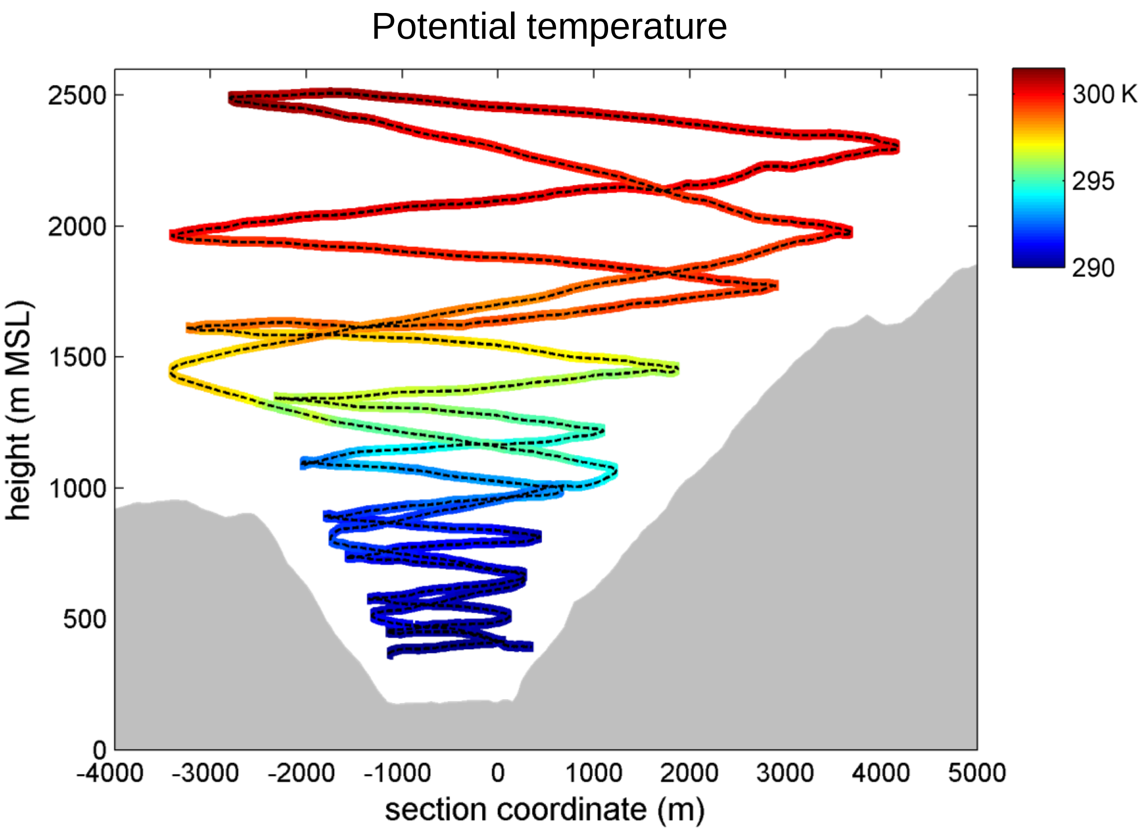
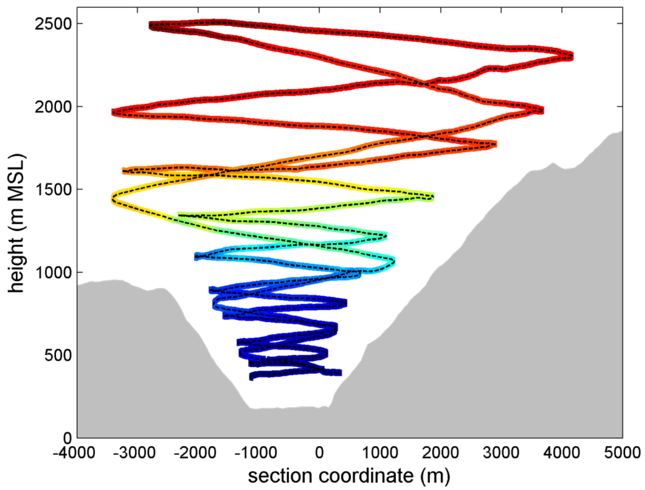
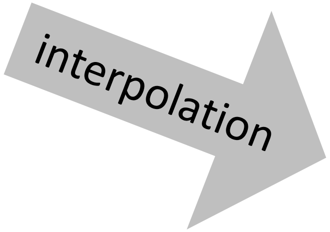


ABL fine-scale 2D/3D structure?

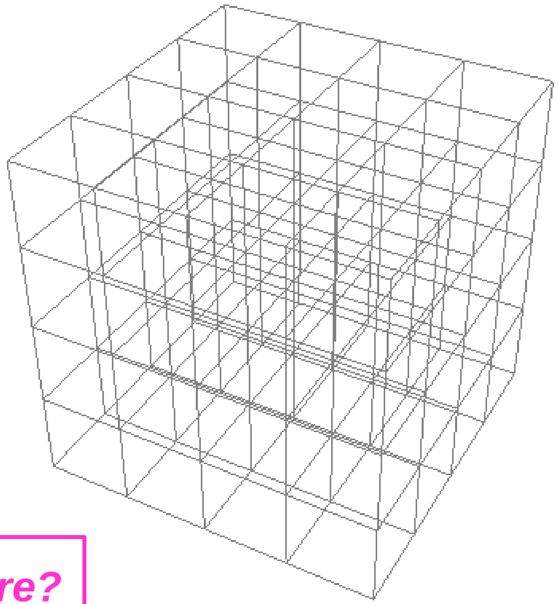
1. Airborne measurements of the ABL in a valley

flight trajectory





3D high-res regular grid



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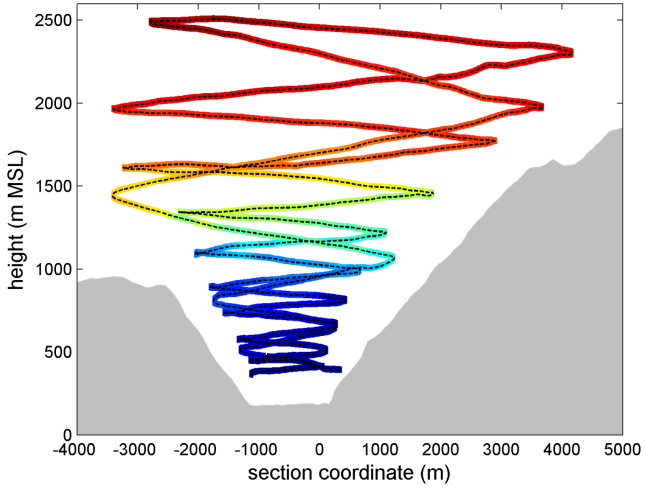

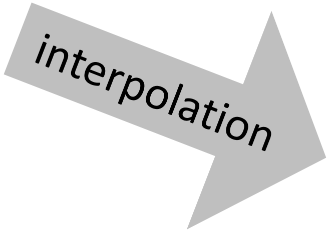

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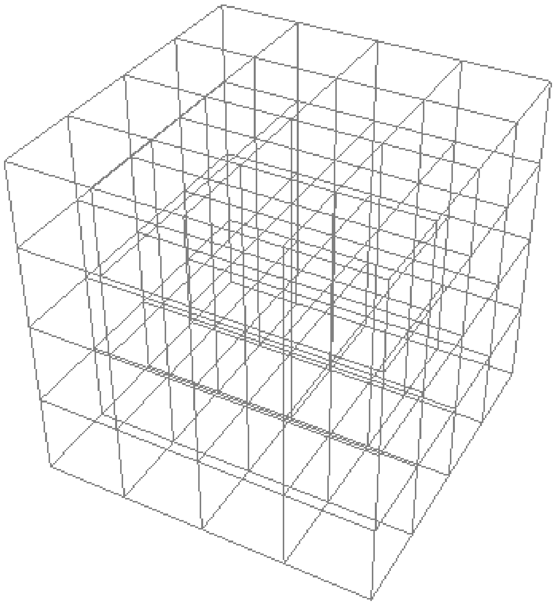


interpolation method?

2. The interpolation methods

Methods based on weighted averages: $\hat{\theta}(\mathbf{x}_g) = \sum_i \lambda_i \theta(\mathbf{x}_i)$ $\sum_i \lambda_i = 1$

- **Distance weighting**

Inverse Distance Weighting **IDW** *Egger (1983)*

$$\lambda_i = \frac{(r_i)^{-1}}{\sum_{j=1}^{N} (r_j)^{-1}} \quad \text{for } \mathbf{x}_i \neq \mathbf{x}_g$$

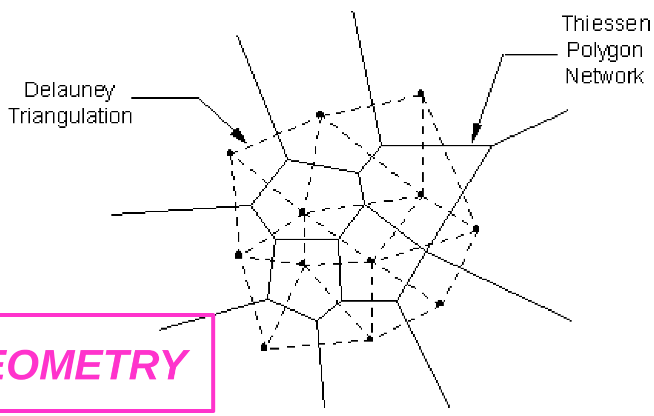
Exponentially-Weighted Inverse Squared Distance- **EWISD** *Hennemuth (1985)*

$$\lambda_i = \frac{\exp\left[-(r_i)^2\right]}{\sum_{j=1}^{N} \exp\left[-(r_j)^2\right]} \quad \text{for } \mathbf{x}_i \neq \mathbf{x}_g$$

GEOMETRY

- **Delaunay triangulation**

Natural Neighbors - **NN** *Weigel and Rotach (2004)*



GEOMETRY

- **Geostatistical methods**

Residual Kriging - **RK**

$$\sum_{j=1}^{N} \lambda_j \gamma(\mathbf{x}_i - \mathbf{x}_j) - q = \gamma(\mathbf{x}_g - \mathbf{x}_i)$$

γ = semivariogram function

GEOMETRY + COVARIANCE

3. Residual kriging (RK)

see Laiti et al. (2013) Atmos. Sci. Lett.

target variable = drift + residuals

$$\theta(\mathbf{x}_i) = \boxed{\mu(\mathbf{x}_i)} + \boxed{\delta(\mathbf{x}_i)}$$

residual approach

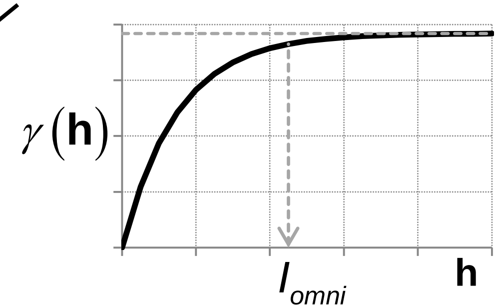
$$\boxed{\hat{\delta}(\mathbf{x}_g)} = \sum_i \lambda_i \cdot \delta(\mathbf{x}_i)$$

$$\boxed{\hat{\mu}(\mathbf{x}_g)}$$

extraction of pseudo-soundings by moving-window vertical average

interpolation by Ordinary Kriging (Cressie, 1993)

semivariogram $\gamma(\mathbf{h}) = \frac{1}{N_\mathbf{h}} \cdot \sum_{i=1}^{N_\mathbf{h}} \frac{1}{2} \cdot \left[\delta(\mathbf{x}_i) - \delta(\mathbf{x}_i + \mathbf{h})\right]^2$

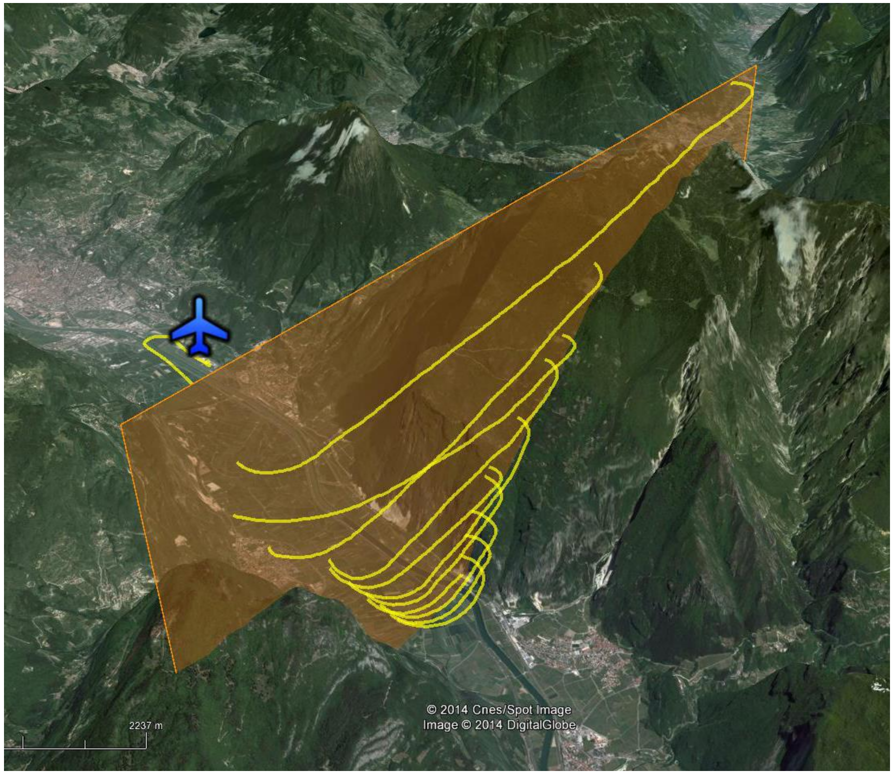


$$\hat{\theta}(\mathbf{x}_g) = \boxed{\hat{\mu}(\mathbf{x}_g)} + \boxed{\hat{\delta}(\mathbf{x}_g)}$$

byproduct: **variance of estimates** $\hat{\sigma}^2(\mathbf{x}_g) = \gamma(0) - \sum_i \lambda_i \cdot \gamma(\mathbf{x}_i - \mathbf{x}_g) + q$

4. Interpolation results

- interpolation grid: 50x50x50 m^3



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residual approach

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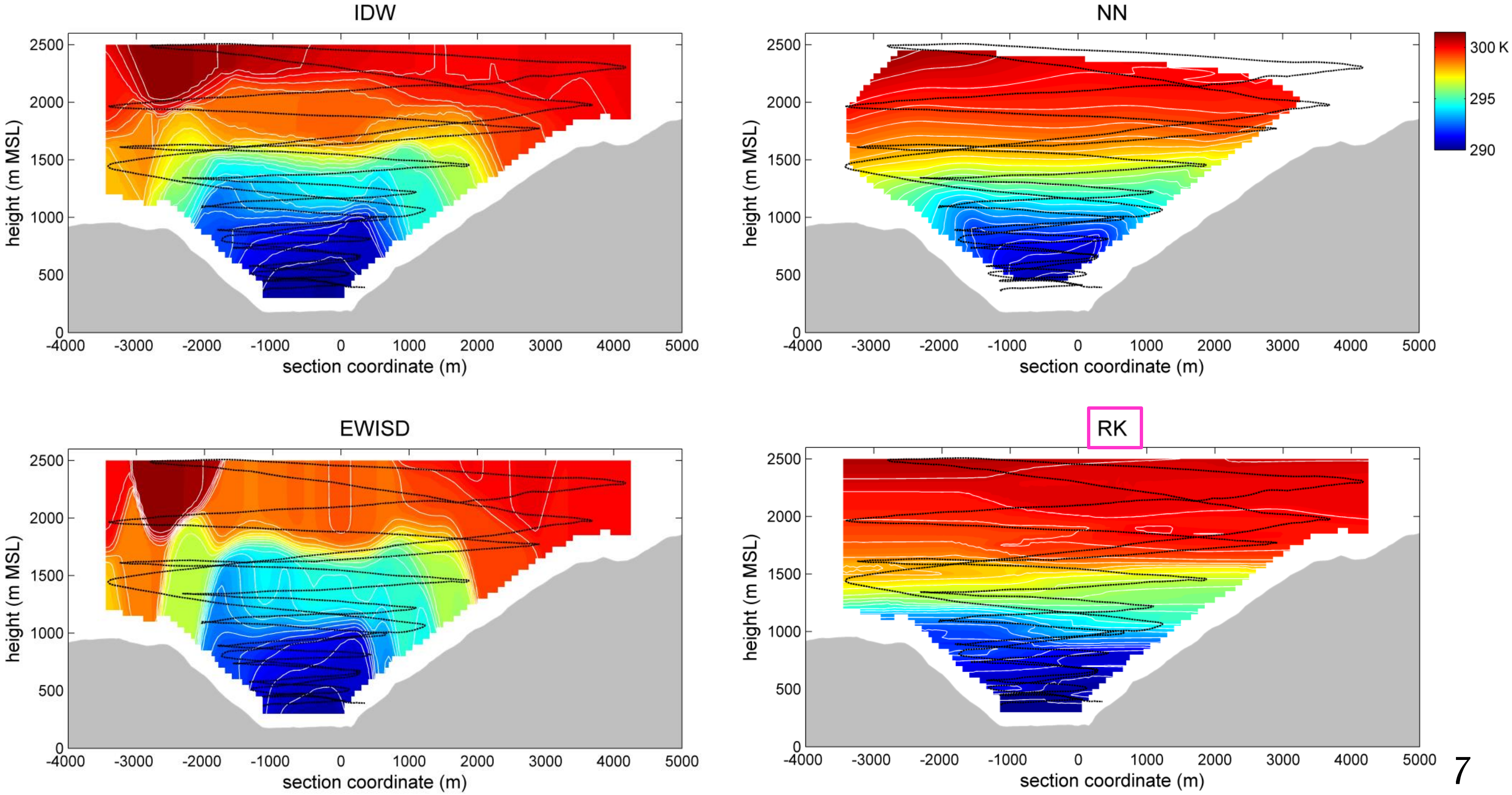

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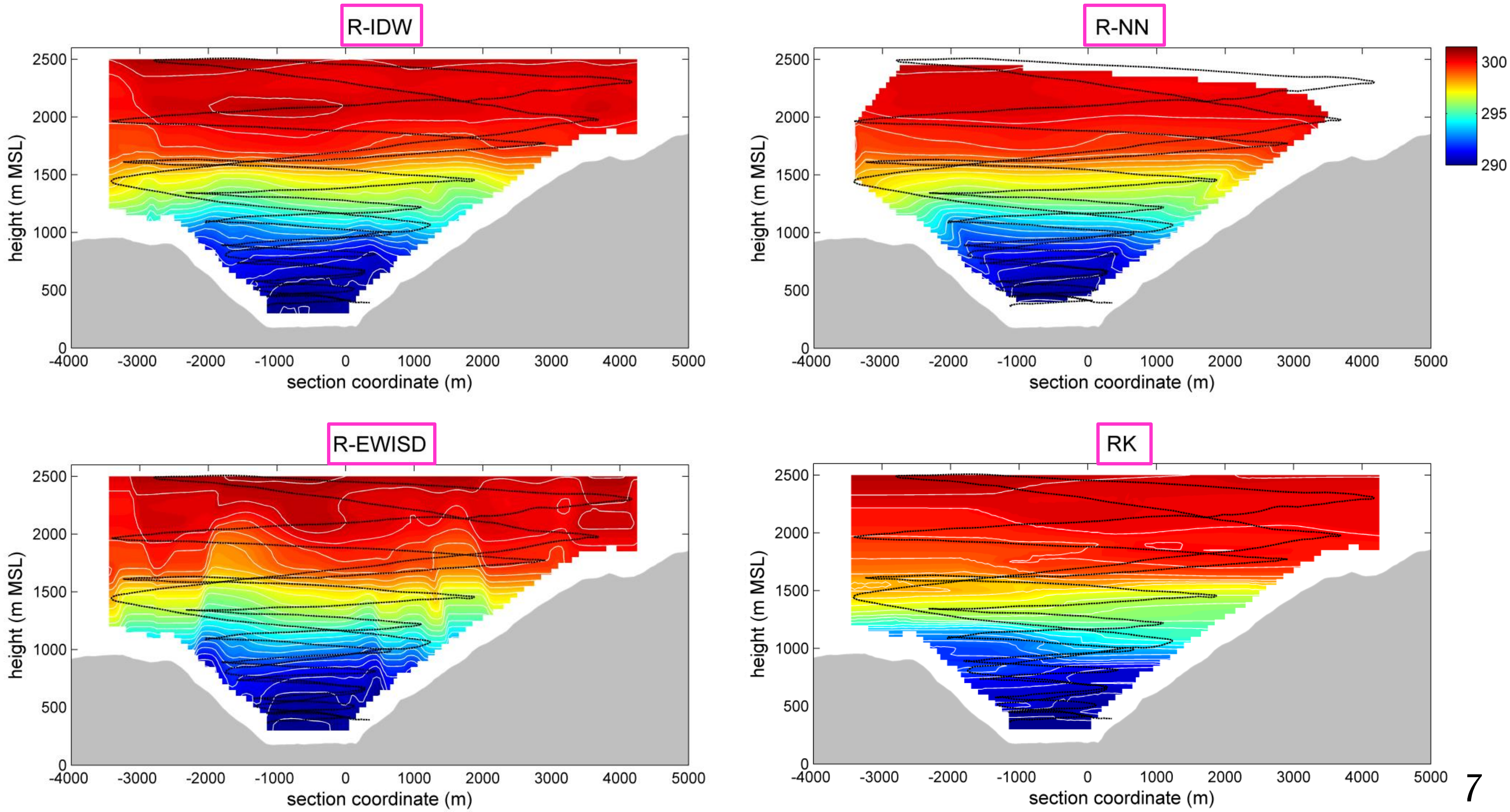
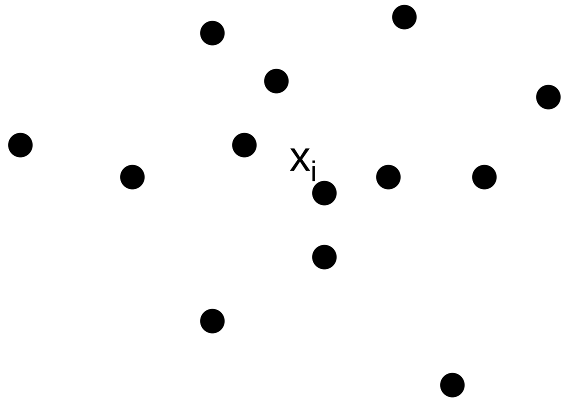


5. Objective cross validation

Leave One Out Cross Validation (LOOCV): exclusion of one observation at time



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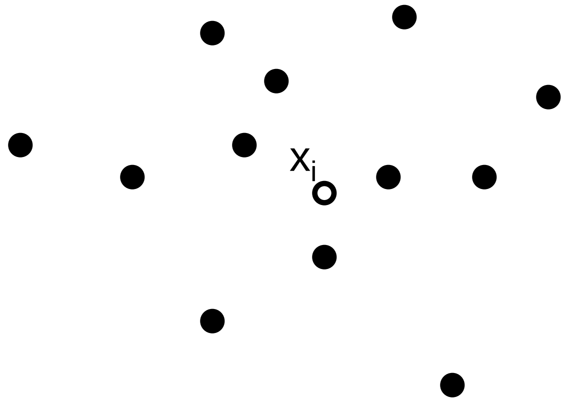

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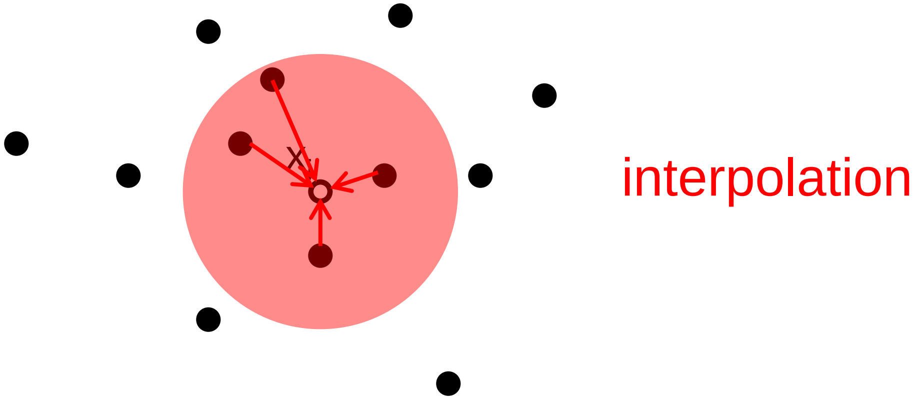

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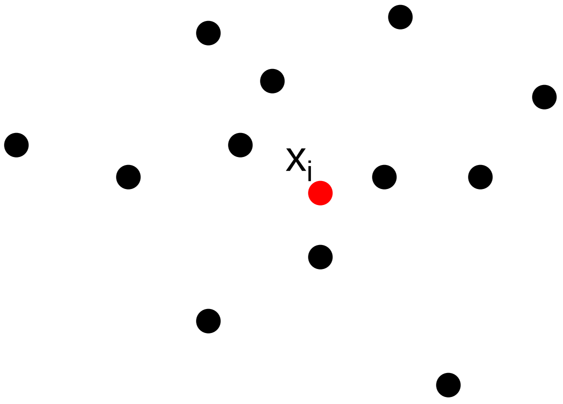
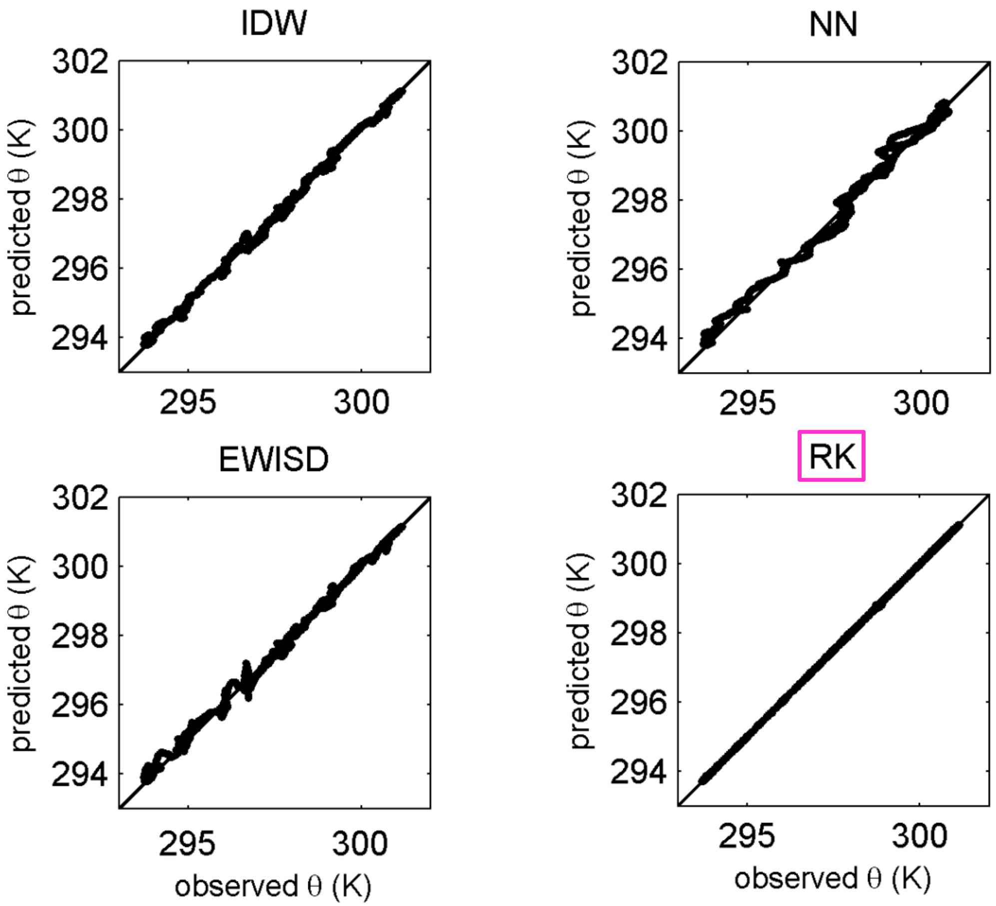


estimate error?

5. Objective cross validation

LOOCV

residual approach



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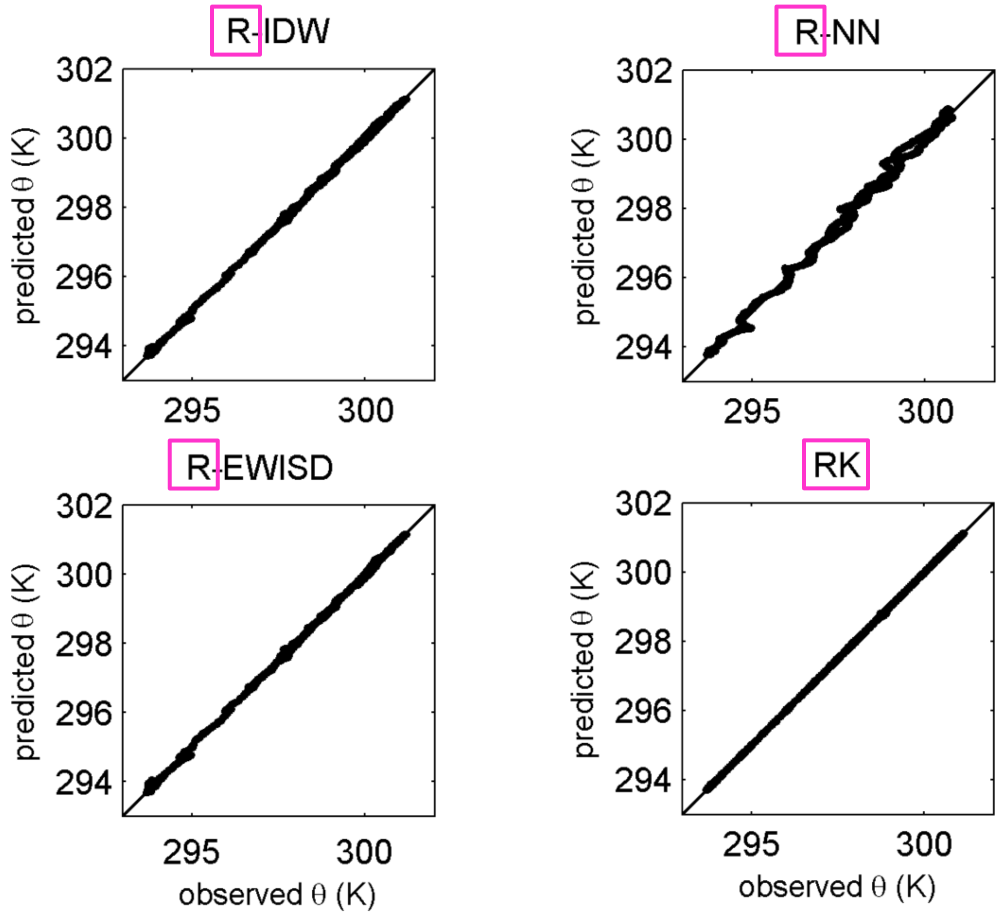
LOOCV

residual approach



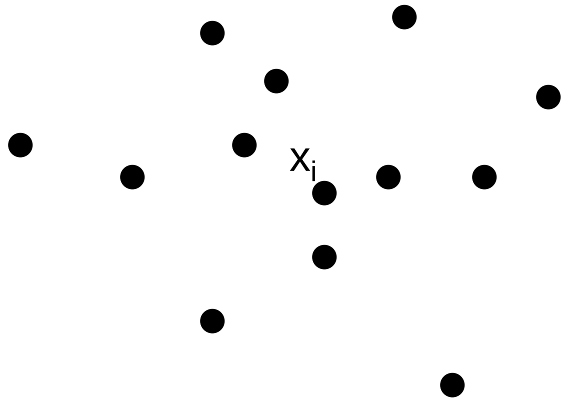
5. Objective cross validation

LOOCV

Method	MBE (K)	MAE (K)	RMSE (K)
IDW	-2.71E-02	1.49E-01	2.05E-01
EWISD	-8.90E-03	1.25E-01	1.93E-01
NN	-1.38E-01	3.27E-01	4.23E-01
R-IDW	-4.20E-04	1.02E-01	1.39E-01
R-EWISD	-8.05E-04	8.45E-02	1.29E-01
R-NN	-9.72E-02	2.63E-01	3.58E-01
RK	-5.90E-06	9.80E-03	2.26E-02

6. Modified cross validation

Modified LOOCV: exclusion of subsets of observations of increasing radius



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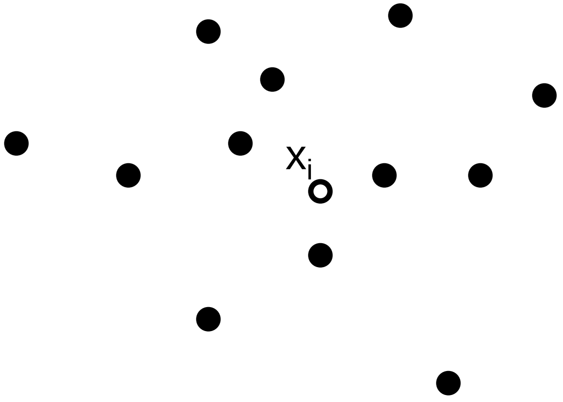

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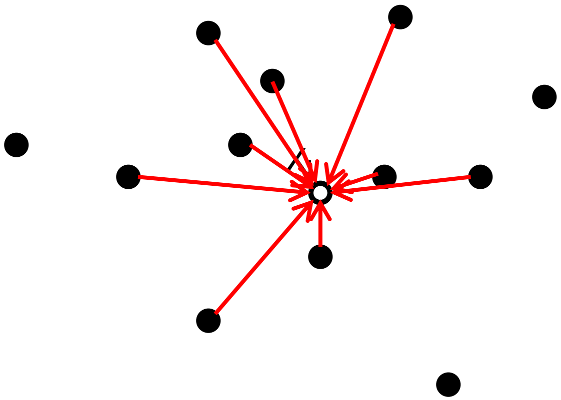

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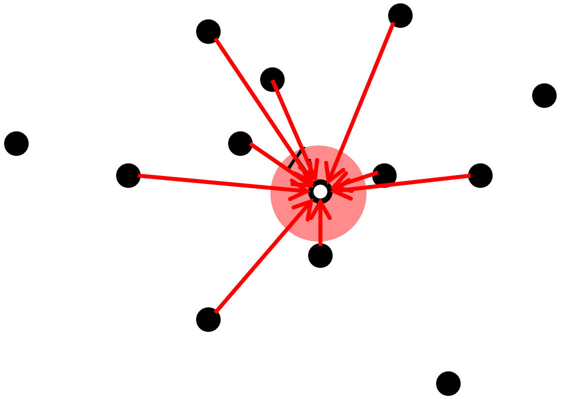

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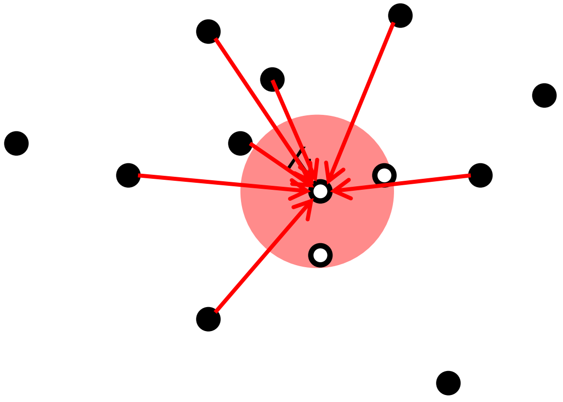

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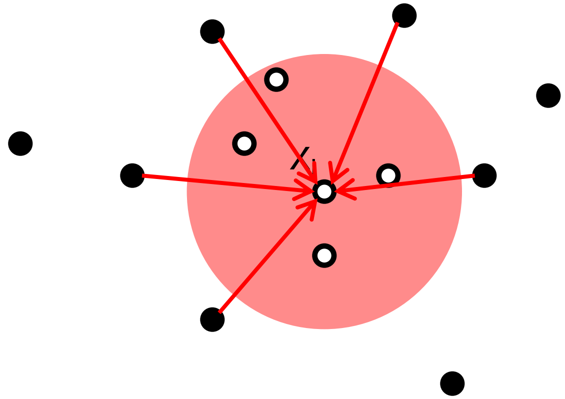

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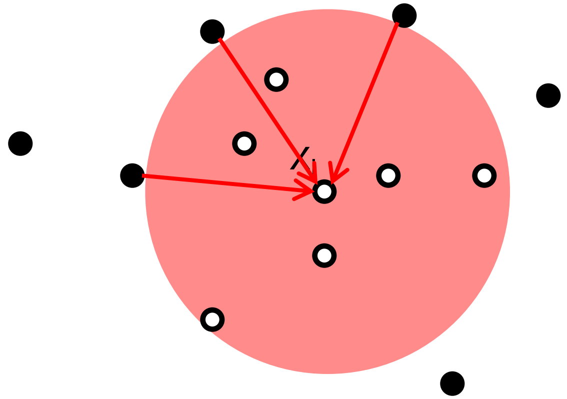


estimate error?

6. Modified cross validation

Modified LOOCV

flight #M

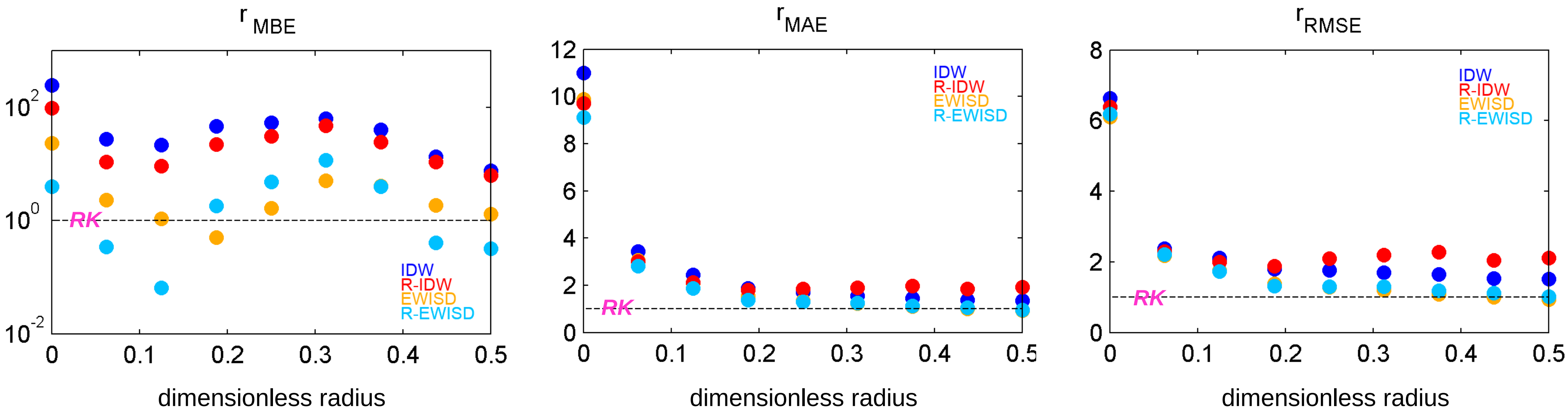
$$r_{MBE} = \frac{|MBE_{method}|}{|MBE_{RK}|}$$

$$r_{MAE} = \frac{MAE_{method}}{MAE_{RK}}$$

$$r_{RMSE} = \frac{RMSE_{method}}{RMSE_{RK}}$$

$$\text{dimensionless radius} = \frac{radius}{I_{omni}}$$

$$I_{omni} = \text{max distance of correlation}$$



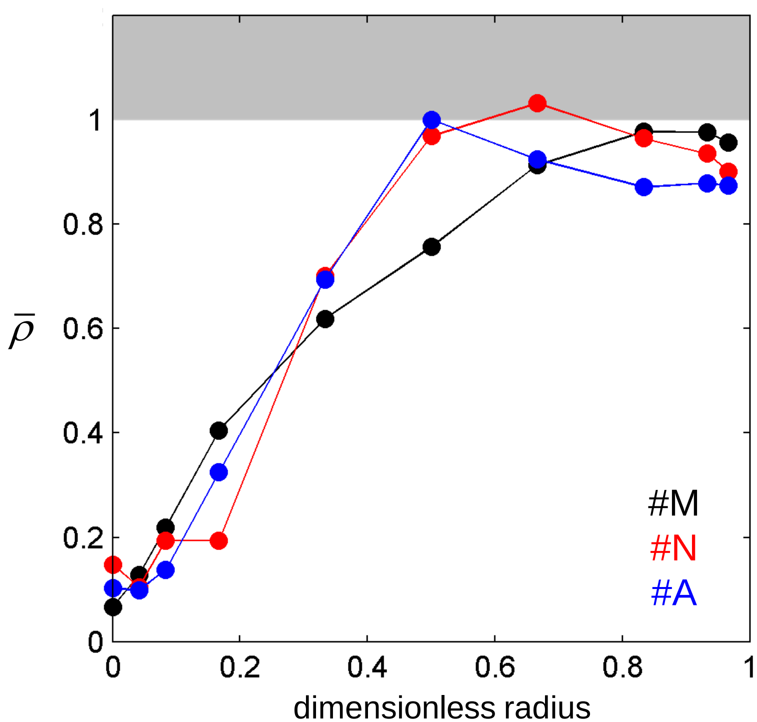
6. Modified cross validation

Is RK-predicted variance a good estimate of the interpolation error?

flight #M

$$\bar{\rho} = \frac{1}{N}\sum_{i=1}^{N}\rho(\mathbf{x}_i) = \frac{1}{N}\sum_{i=1}^{N}\frac{\left[\hat{\theta}(\mathbf{x}_i)-\theta(\mathbf{x}_i)\right]^2}{\boxed{\hat{\sigma}^2(\mathbf{x}_i)}}$$

RK estimate variance

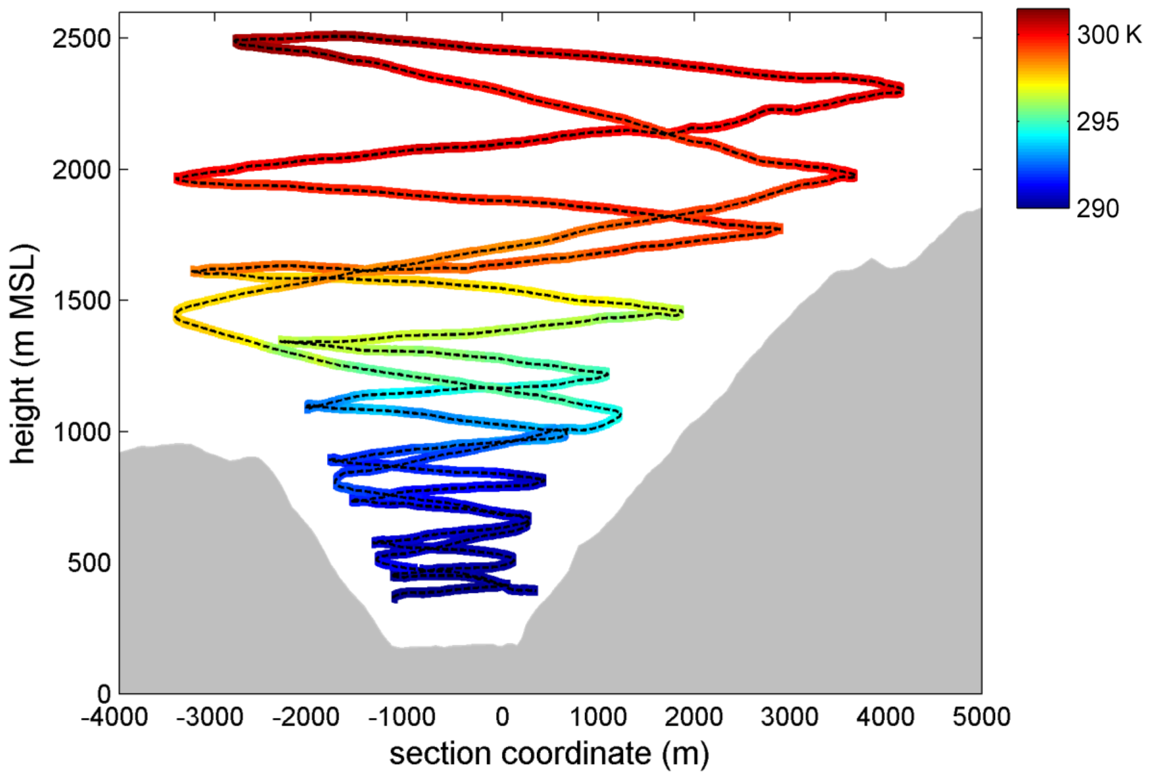


$$\text{dimensionless radius} = \frac{\textit{radius}}{I_{omni}}$$

I_{omni} = max distance of correlation

7. Conclusions

- The performances of 4 interpolation methods for the retrieval of fine-scale ABL structures from airborne measurements were compared



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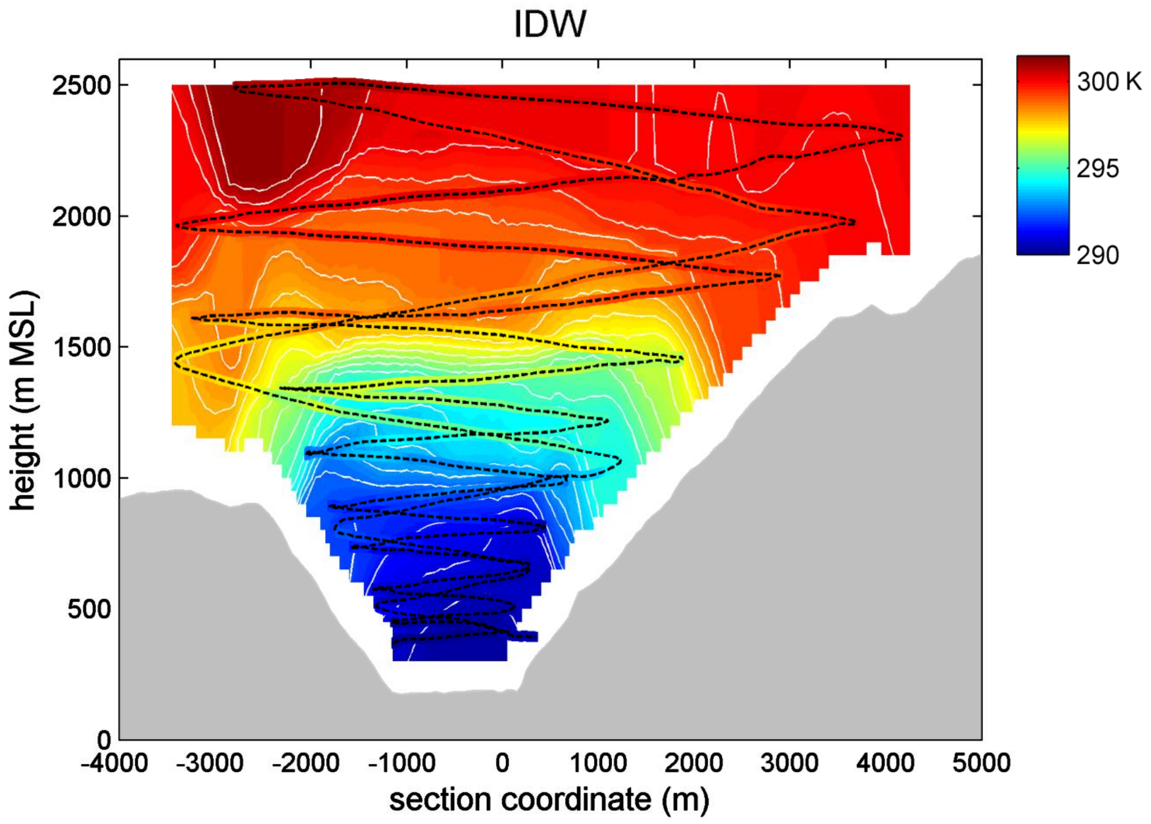

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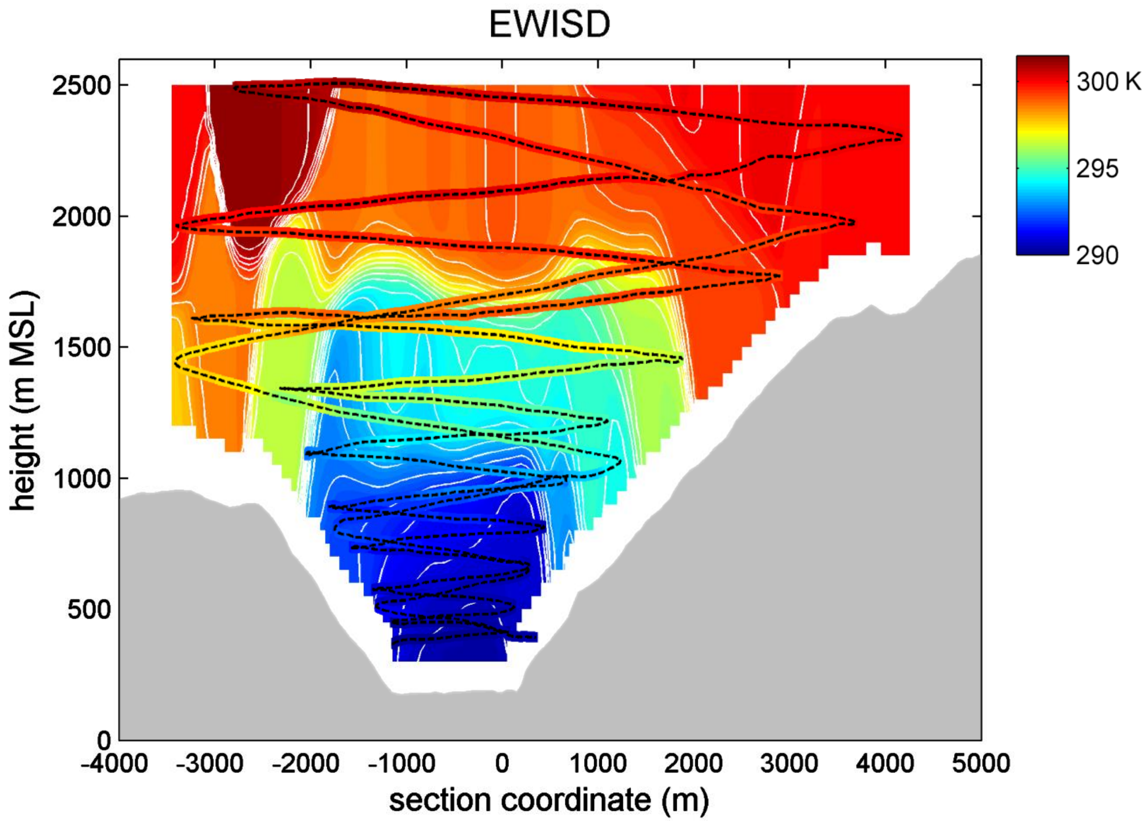

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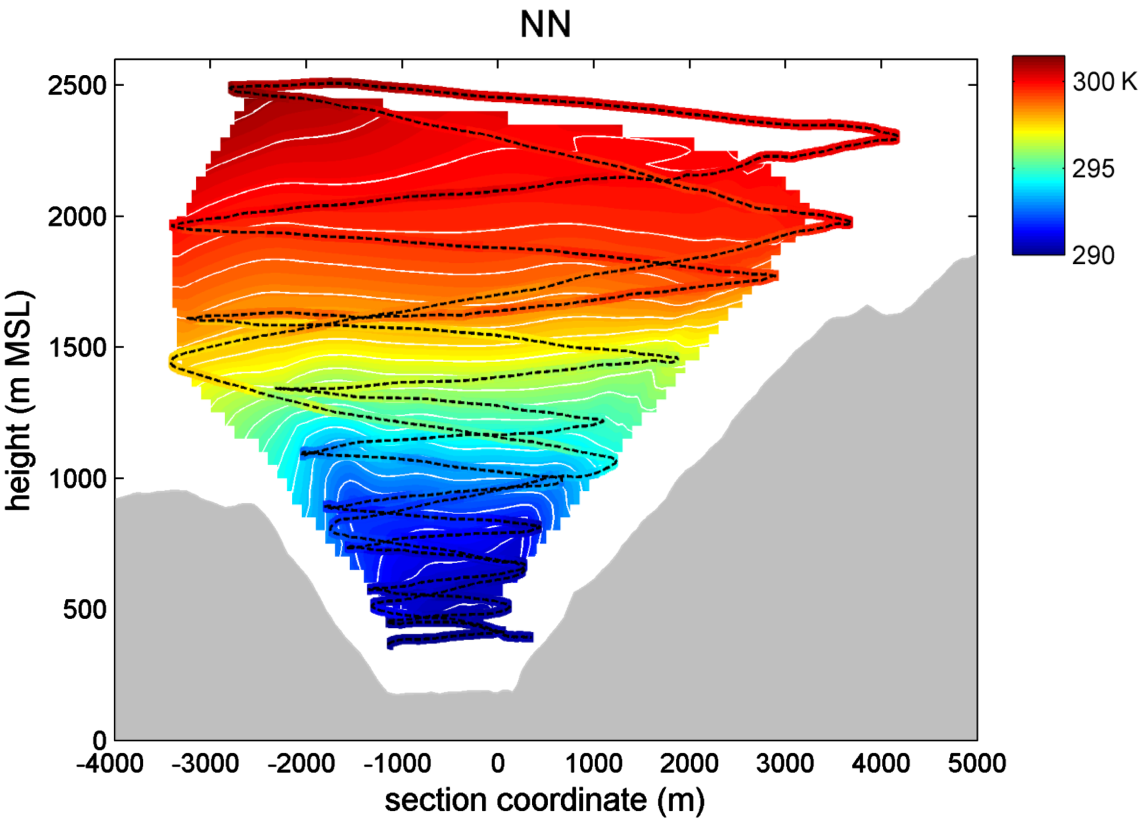

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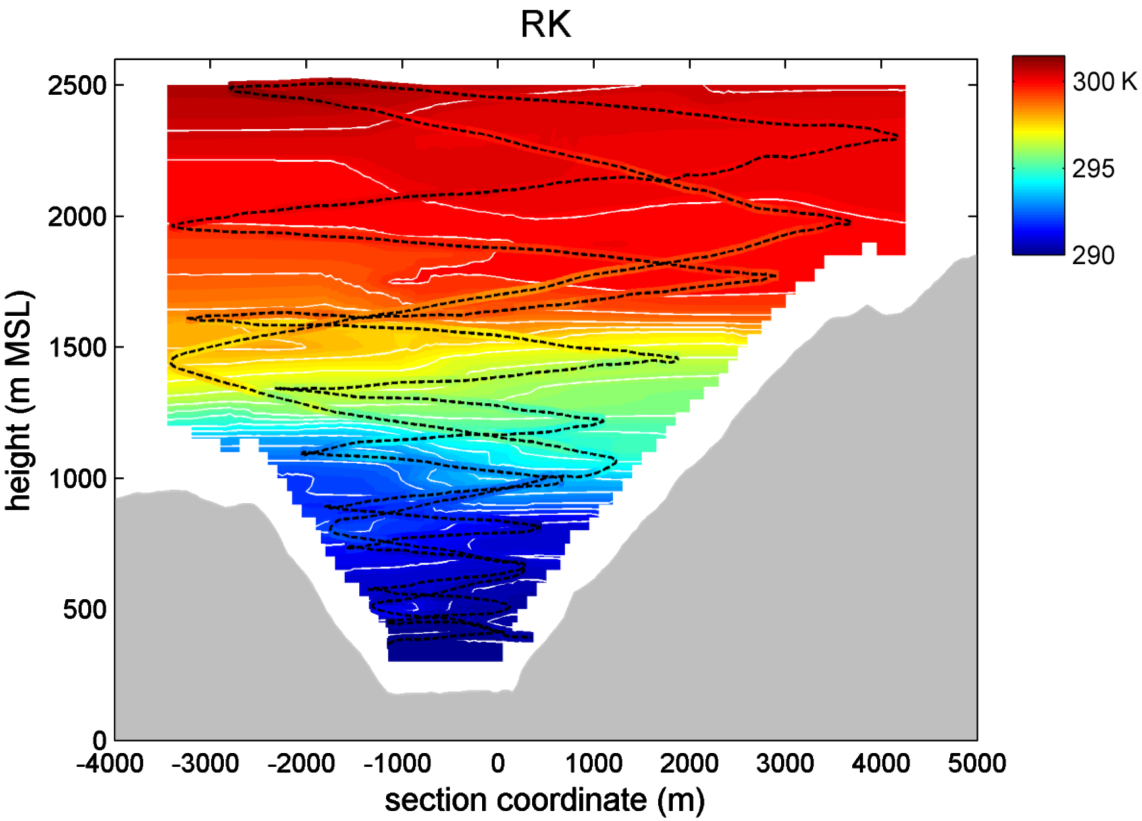

7. Conclusions

- The performances of 4 interpolation methods for the retrieval of fine-scale ABL structures from airborne measurements were compared

- LOOCV:
  - RK performs better than the other methods (IDW, EWISD, NN)
  - the residual approach improves the performance of all methods (especially IDW and EWISD)

- modified CV:
  - RK performs better than the other methods when observations are clustered (i.e. along a flight trajectory)
  - RK variance overestimates the interpolation error for distances shorter than ½ correlation range

- The interpolated fields provide an ideal benchmark for comparison with high-resolution numerical model output

The Adige Valley from Castel Beseno. www.gommoneclubverona.com

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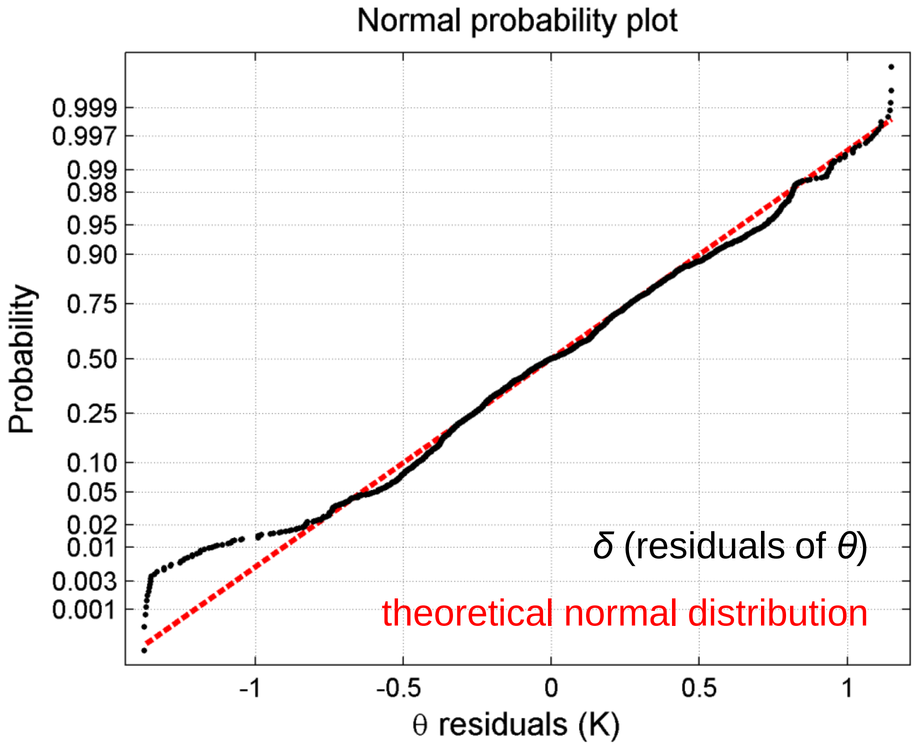
Remarks about kriging - 1

The target variable (i.e. θ residuals) must be normally distributed (random process)

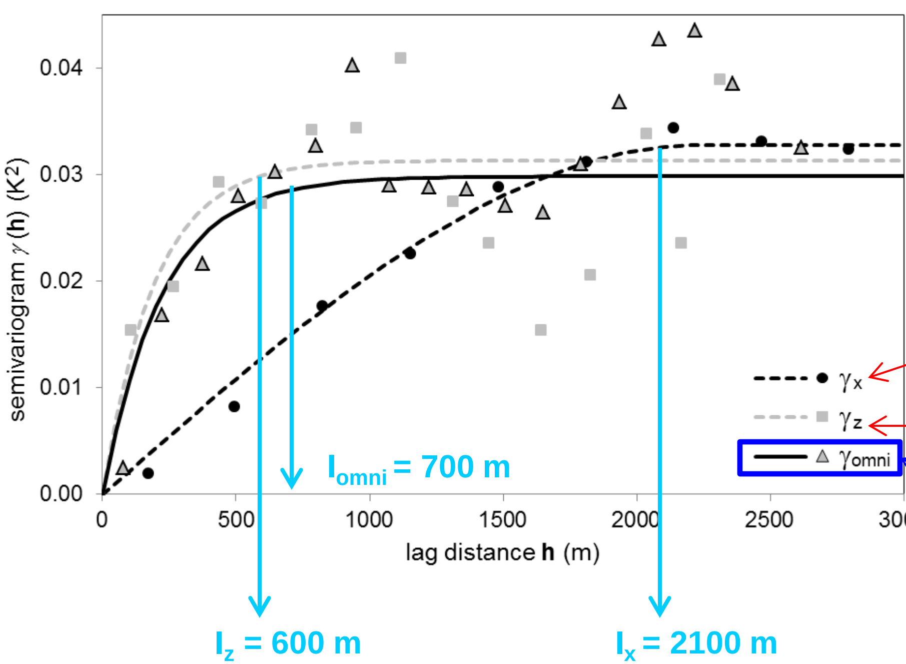


Remarks about kriging - 2

To deal with the anisotropy of the target field:

1. the directional semivariograms were estimated to get the anisotropy scales (semivariogram ranges, i.e. correlation ranges)
2. the spatial coordinates were rescaled by anisotropy ratios
3. the omnidirectional semivariogram was estimated and finally used in RK

$$\gamma\left(\mathbf{x}_i-\mathbf{x}_j\right)=\gamma\left(\mathbf{h}\right)=\frac{1}{N_{\mathbf{h}}}\sum_{i=1}^{N_{\mathbf{h}}}\frac{1}{2}\left[\delta\left(\mathbf{x}_i\right)-\delta\left(\mathbf{x}_i+\mathbf{h}\right)\right]^2$$



$$x' = \frac{x}{l_x}\cdot l_z$$

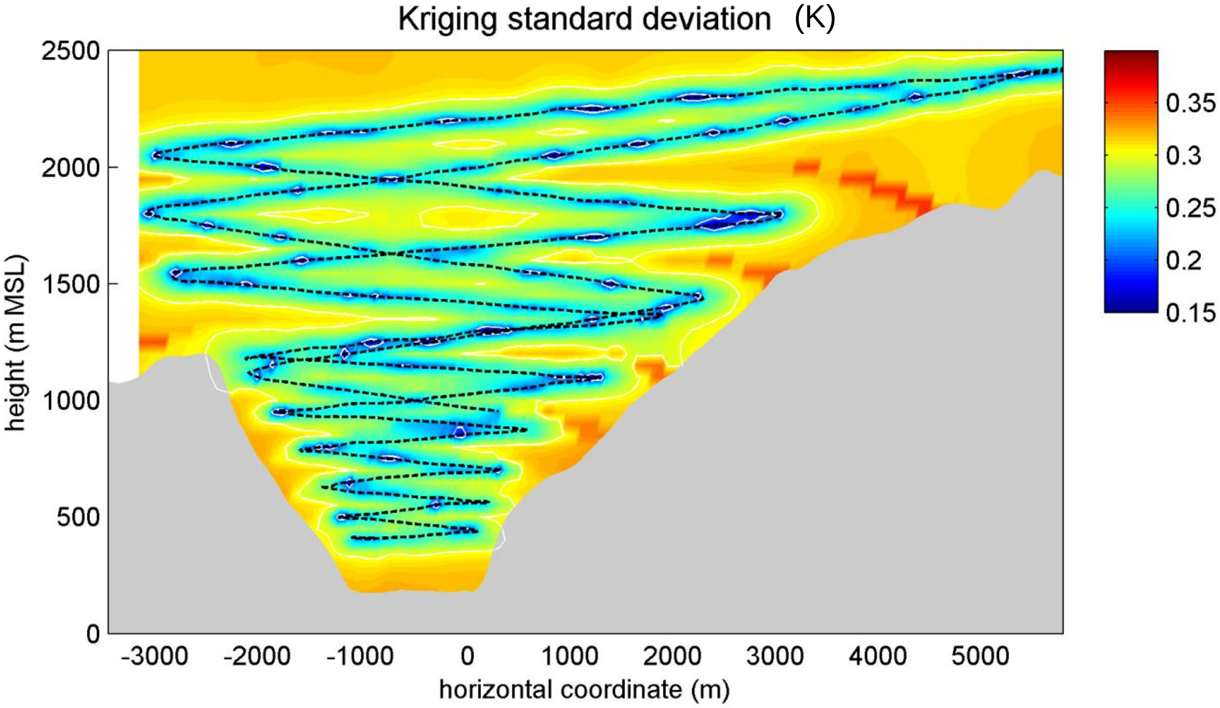
$$y' = \frac{y}{l_y}\cdot l_z$$

$$z' = z$$

Remarks about kriging - 3

Kriging also provides an estimate of the interpolation error, i.e. the kriging variance (or kriging standard deviation)

$$\hat{\sigma}^2\left(\mathbf{x}_g\right) = \gamma(0) - \sum_i \lambda_i \gamma\left(\mathbf{x}_i - \mathbf{x}_g\right) + q$$



6. Modified LOOCV results

Modified LOOCV: exclusion of subsets of observations of increasing radius

flight #M

$$\bar{\rho} = \frac{1}{N}\sum_{i=1}^{N}\rho(\mathbf{x}_i) = \frac{1}{N}\sum_{i=1}^{N}\frac{\left[\hat{\theta}(\mathbf{x}_i)-\theta(\mathbf{x}_i)\right]^2}{\boxed{\hat{\sigma}^2(\mathbf{x}_i)}}$$

$$\text{dimensionless radius} = \frac{radius}{I_{omni}}$$

RK estimate variance

$$I_{omni} = \text{max distance of correlation}$$