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ESTIMATION OF REGIONAL SNOW DEPTH CORRELATION SCALES AND IMPLICATIONS FOR GLOBAL SNOW ANALYSES

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OVERVIEW

- ❖ **STATISTICAL INTERPOLATION FOR SNOW DEPTH ANALYSIS**

- ❖ **NEW STUDY*** ***(Kongoli and Smith, Front. Earth Sci., 2023, volume 11)***
  - ❖ **Measured snow depth spatial correlations over North America**
  - ❖ **Fitted correlation functions and scale parameter estimates**
  - ❖ **Main findings**

- ❖ **IMPLICATIONS FOR OPERATIONAL SNOW DEPTH ANALYSIS**

** Modelling and estimation of snow depth spatial correlation structure from observations over North America"*

STATISTICAL/OPTIMAL INTERPOLATION FOR SNOW DEPTH

- **Introduced by Brasnett (1999)**

Brasnett, B., 1999. A global analysis of snow depth for numerical weather prediction. J. Appl. Meteor.,38,726-740.

- **Uses station-measured snow depth observations to generate daily gridded snow depth maps over the globe at 24 km resolution**

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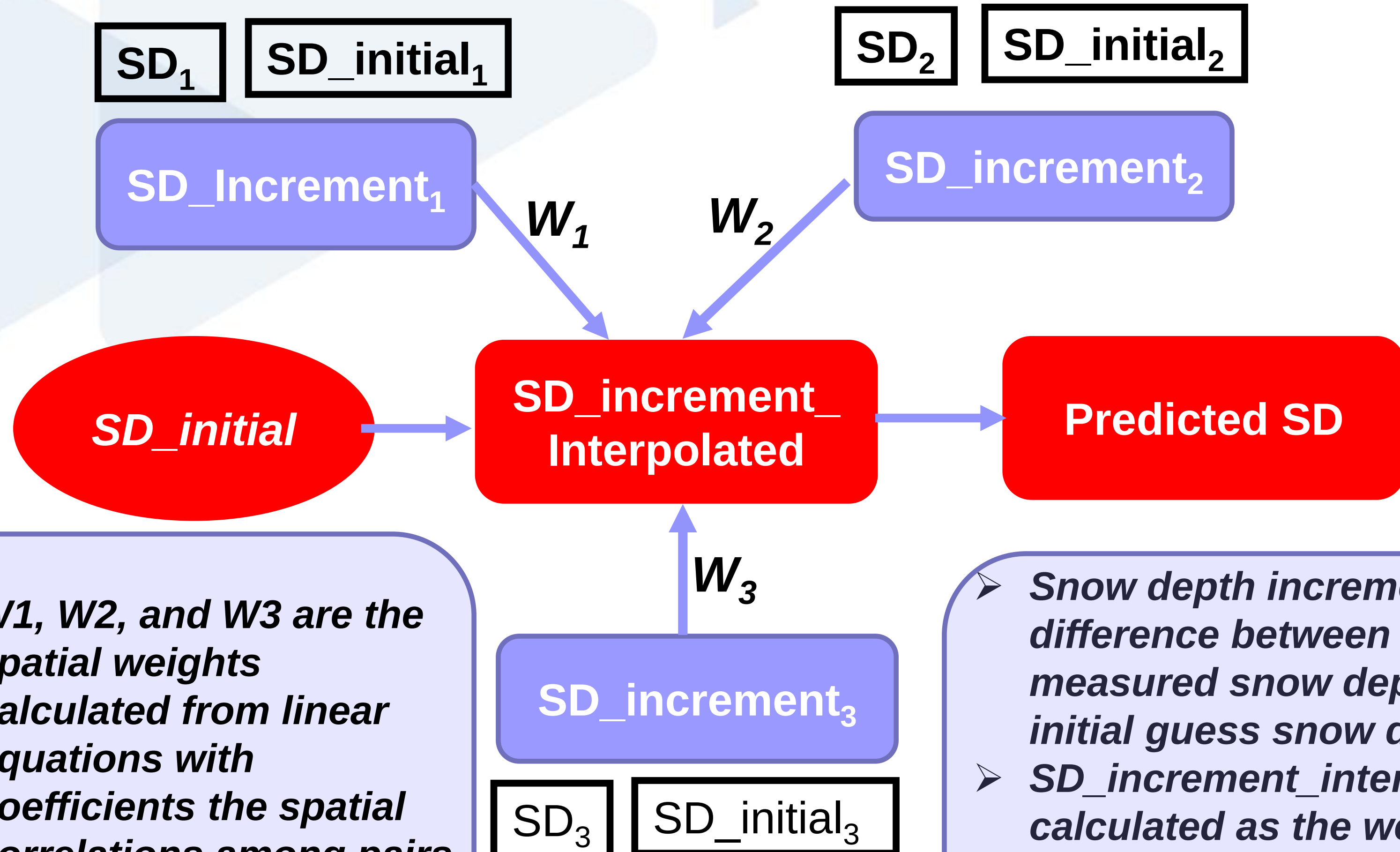
Kriging Interpolation Method*, *adapted for use in meteorology by L.S. Gandin, 1965. "*Objective Analysis of Meteorological Fields", Israel Program for Scientific Translation (from Russian).*

STATISTICAL/OPTIMAL INTERPOLATION FOR SNOW DEPTH (SD) EXAMPLE USING ONLY THREE MEASUREMETS



- ***W1, W2, and W3 are the spatial weights calculated from linear equations with coefficients the spatial correlations among pairs of stations/interpolation grid cell***

- ***Snow depth increment is the difference between the measured snow depth and an initial guess snow depth***
- ***SD_increment_interpolatedis calculated as the weighted average of the snow depth increments at stations 1,2, and 3.***

Snow Depth Optimal Interpolation (OI)

❖ **SD** increment *at analysis point k* Δ***SD$_k$*** is computed as the weighted average of observed increments Δ***SD$_i$*** surrounding *k*:

$$\Delta SD_k = \sum_{i=1}^{N} w_i \Delta SD_i$$

*ΔSD_i is the difference between the **observed SD** and the **first guess SD** at each observation point i [i = 1, N]*

❖The vector of optimum weights at ***k*** is computed by solving the set of N linear equations of the matrix form:

$$\underline{w} = (\underline{B} + \underline{O})^{-1}\underline{b}$$

$\underline{B}$ *is the correlation matrix of SD increments between all pairs of observations*

$\underline{b}$ *is the correlation vector of pairs of of observations and interpolation point k*

$\underline{O}$ *is the matrix of SD observational errors (normalized by the first guess SD error variance) between all pairs of observations*

Brasnett (1999) Increment Correlation Functions

❖ Correlation coefficients μ_{ij} between pairs of observations are computed as the product between the horizontal and vertical distance correlation functions:

$$\mu_{ij} = \alpha(r_{ij})\beta(\Delta z_{ij})$$

r_{ij} *is the horizontal separation distance between observations*

Δz_{ij} *is elevation (vertical) separation distance between observations*

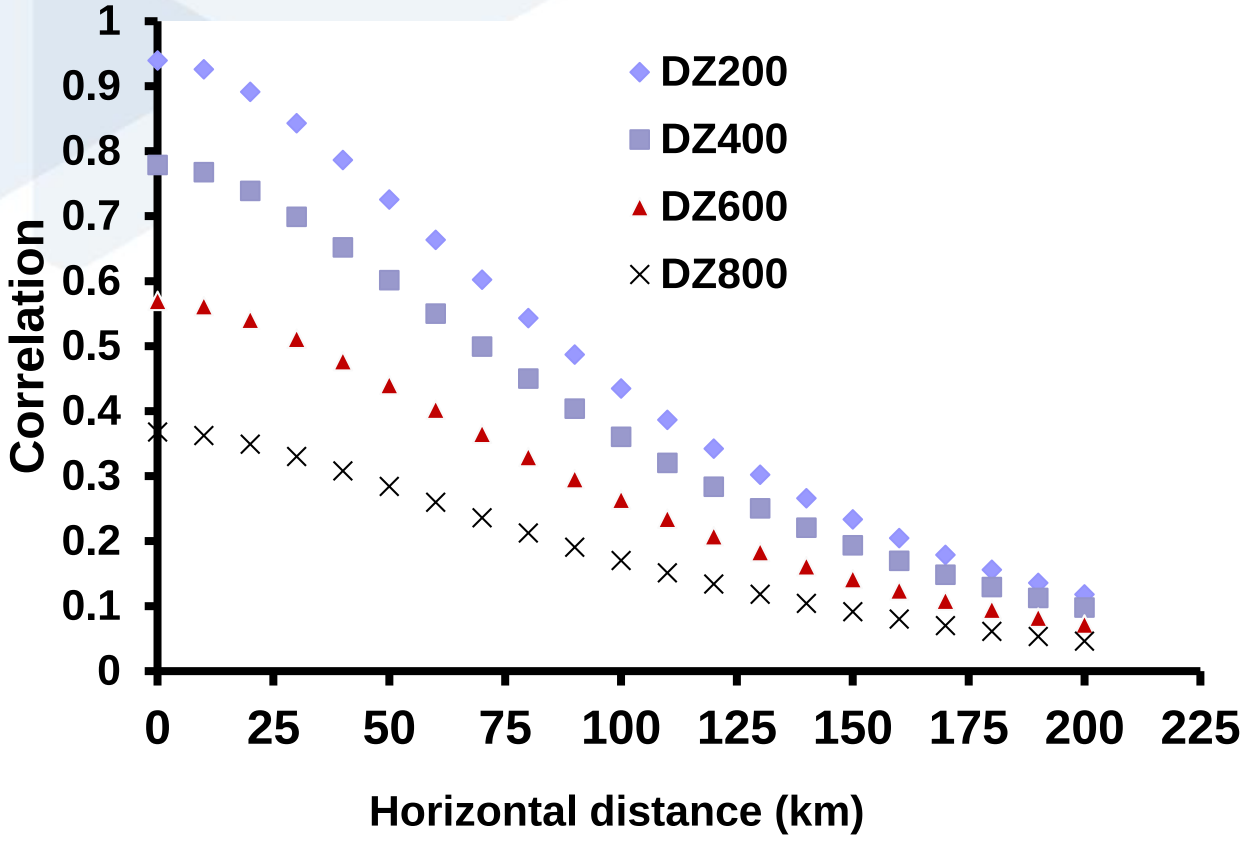
2nd order autoregressive correlation function for horiz. distance

$\alpha(r_{ij}) = (1 + cr_{ij}) \exp(-cr_{ij})$ $c = 0.018\ km^{-1}$ (*e-folding scale ≈ 120 km*)

Square exponential correlation function for vertical distance

$\beta(\Delta z_{ij}) = \exp(-(\Delta z_{ij}/h)^2)$ $h = 800\ m$ (*e-folding scale = 800 m*)

Plots of spatial correlations as a function of horizonal distance for several vertical distance values

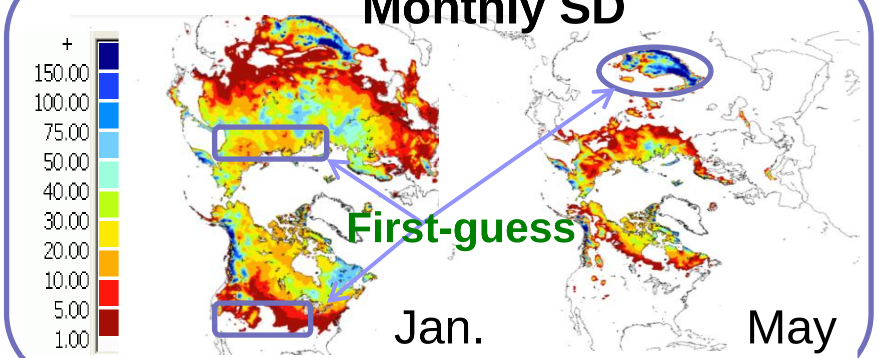


Canadian Meteorological Center (CMC) Brasnett 1999 J. Applied. Meteorol, Global Snow Depth Analysis

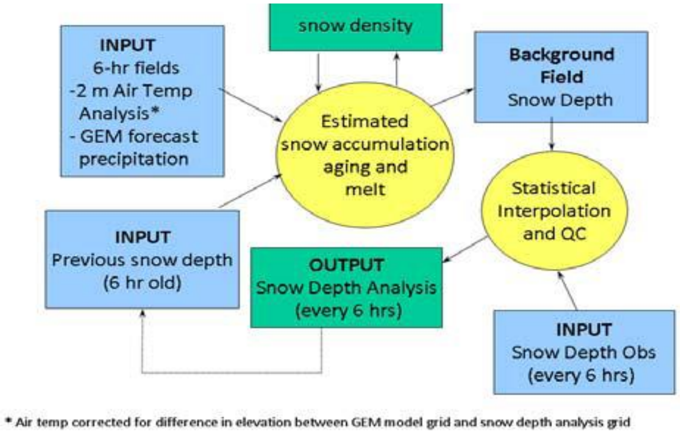
KEY FEATURES

- <u>2-D Optimal Interpolation</u> (OI) since March 1998, at 24-km & every 6 hours
- <u>Initial guess</u> - a simple snow accumulation and melt model using analyzed temperatures and forecast (six hour) precipitation from the CMC Global Environmental Multiscale (GEM) forecast
- <u>Driven by in-situ SD observations</u>; In regions where there are no SD observations, **analysis SD corresponds to the initial guess field.**

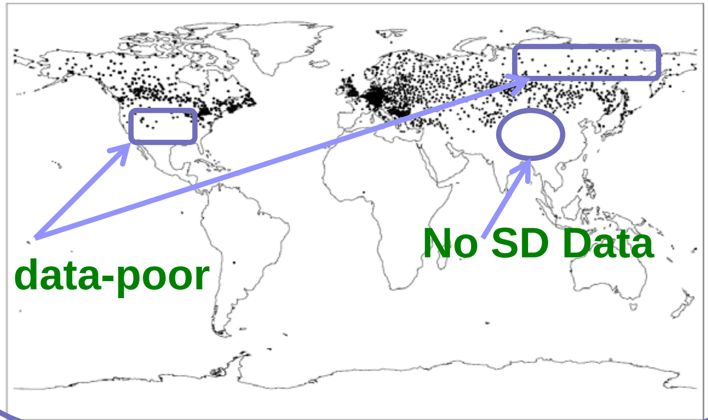
Monthly SD



Operational CMC SD Analysis Flowchart



SYNOP STATIONS



Motivation for estimating spatial correlation structure

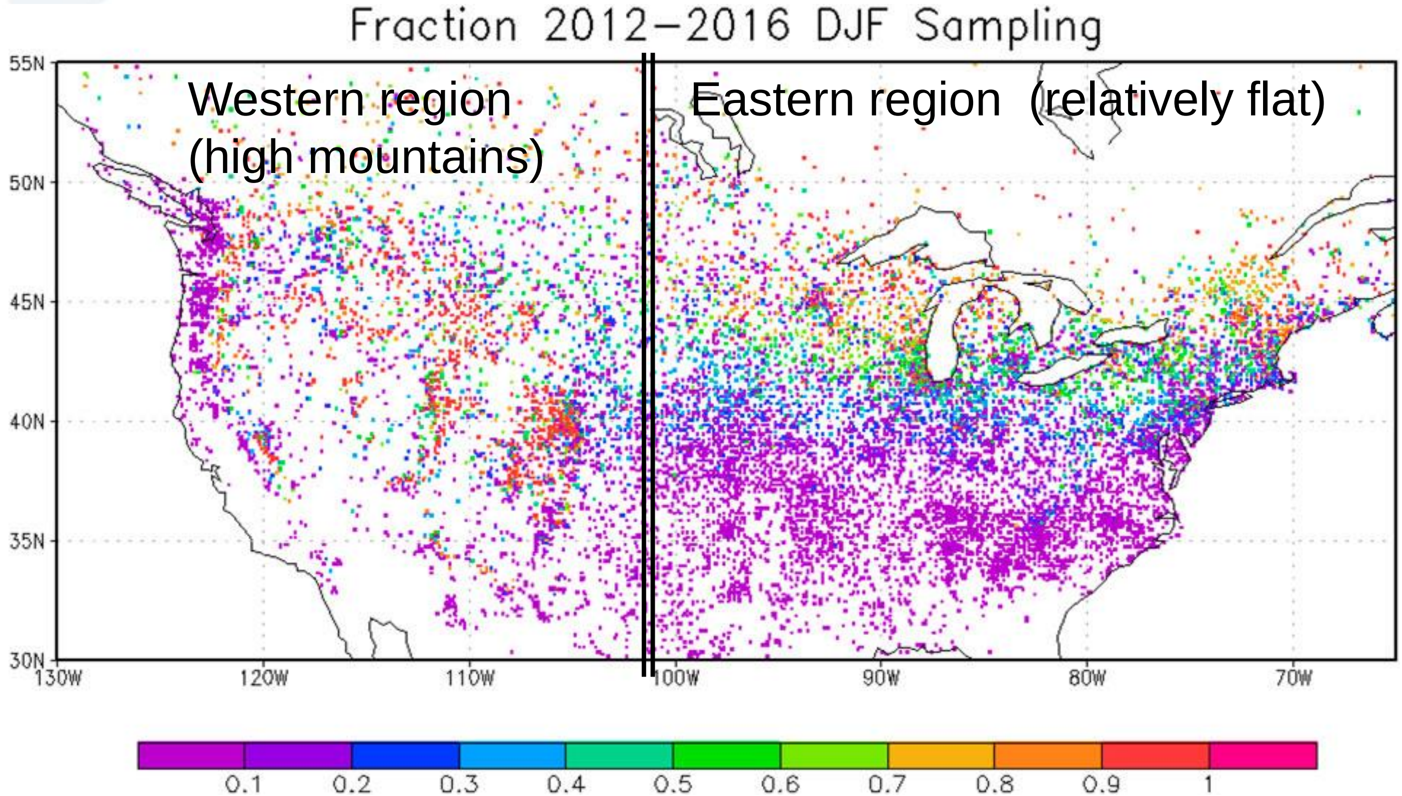
- No information provided of how well the correlation functions represent the structure of snow depth increments (*nowhere to be found in Gandin (1965) that the paper refers to)*
- *Method less beneficial over areas with stations separated by horizontal scales much larger than 120 km*

New Study:

- **1: Estimate spatial correlations of measured snow depth and daily snow depth increments**
- **2: Fit measured spatial correlations to modified Brasnett (1999) Equations to estimate correlation scale parameters**

1. Method for computing observed correlations

- Eastern (horizontal correlations) and western (vertical correlations) sub-regions. In-situ stations resampled onto 0.1 X 0.1^0 spatial grid. Binned horizontal correlations for 10 km from 0: 500 km range. Binned vertical correlations for 100 m from 0: 5000 m vertical range and restricted to adjacent grid cells.



2. Method for fitting binned correlations

- C1 is the autoregressive Brasnett equation – estimate ***α***
- C2 is similar to C1 but with an amplitude ***A***, which represents correlation when separation distance approaches zero– estimate both ***A and α***
- C3 is the exponential brasnett equation, estimate both ***A and α***

- ***Least square method using data of measured correlation (C) and corresponding distances (d)***

$$C_1 = (1 + d\alpha_1)\, exp\,(-d\alpha_1).$$

$$C_2 = A_2\,(1 + d\alpha_2)\, exp\,(-d\alpha_2).$$

$$C_3 = A_3\, exp\left(-(d\alpha_3)^2\right).$$

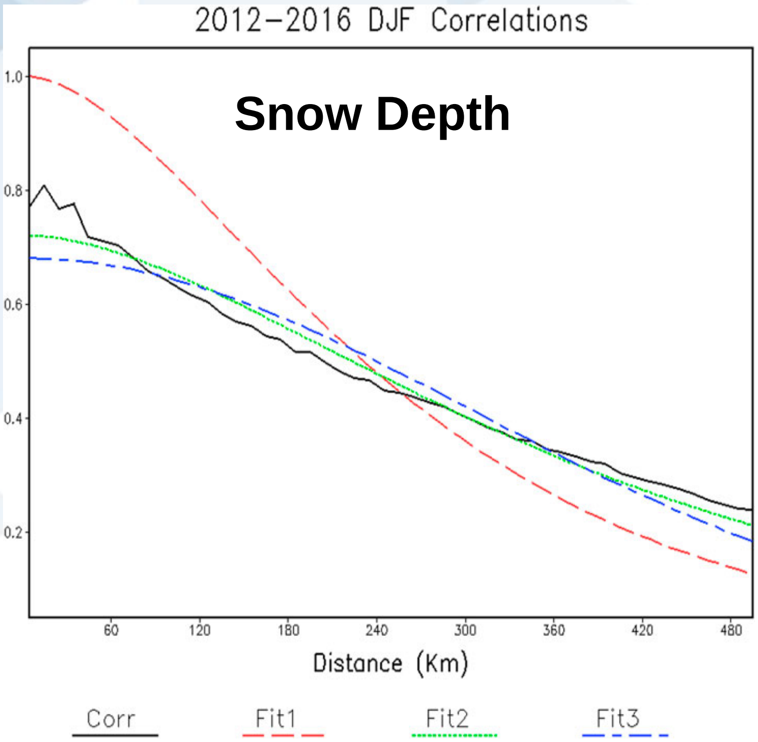
Main Findings

- **Large *horizontal e-folding scales of observed snow depth and daily increments, at 430 km and 370 km, respectively, when including an amplitude, which is less than 1 (0.5 for daily increments and 0.7 for full snow depth).***

- ***Without considering the amplitude, e-folding horizonal scales are severely underestimated and the fit is poor.***

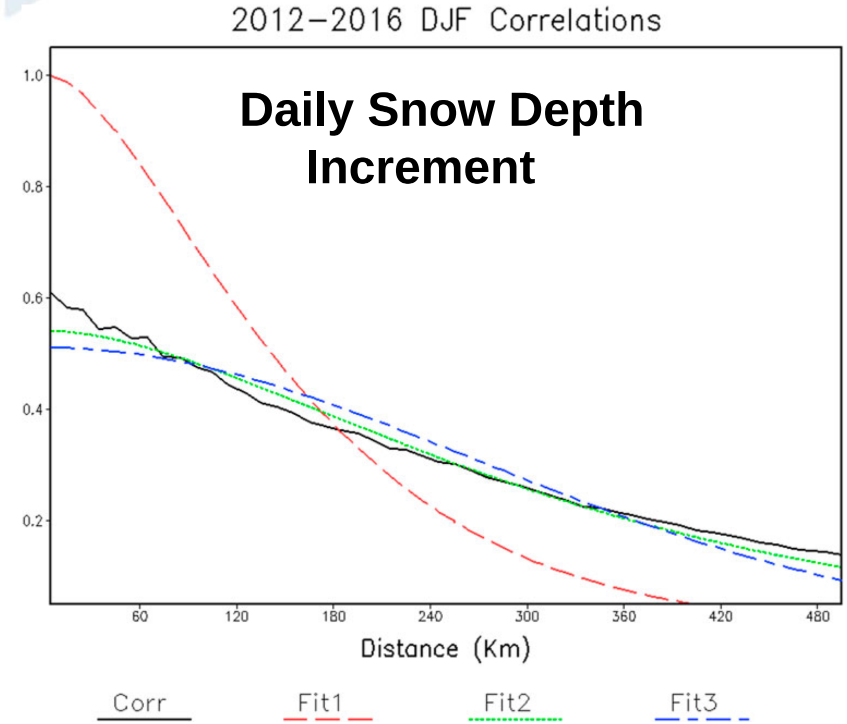
- ***Small vertical correlation of observed snow depth, at 460 m, but the vertical correlation of daily increments is much larger, at 1170 m***

Results: Spatial correlations for horizontal distance



	Scale	Amplitude	EFD	RMSE
Fit1	137.5	1.00[a]	295.6	0.13
Fit2	200.0	0.72	430.1	0.03
Fit3	431.4	0.68	431.4	0.04

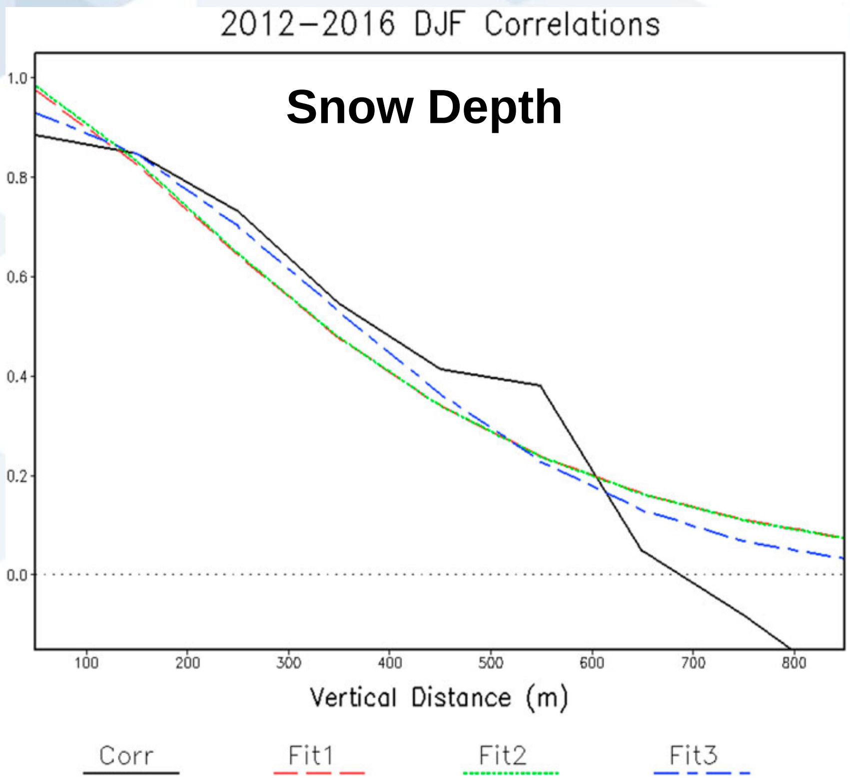
[a]Fixed a priori.



	Scale	Amplitude	EFD	RMSE
Fit1	84.6	1.00[a]	181.9	0.18
Fit2	170.2	0.54	365.9	0.02
Fit3	378.0	0.51	378.0	0.03

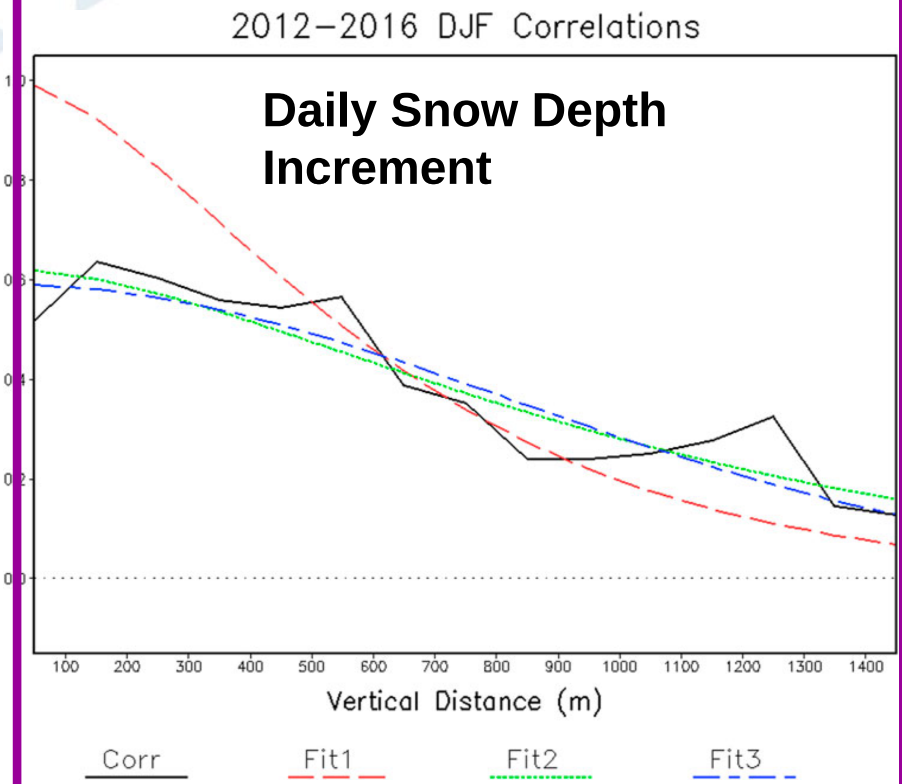
[a]Fixed atablef priori.

Results: Spatial correlations for vertical distance



	Scale	Amplitude	EFD	RMSE
Fit1	198.8	1.00[a]	427.5	0.14
Fit2	197.6	1.01	424.9	0.14
Fit3	461.1	0.94	461.1	0.12

[a]Fixed a priori.



	Scale	Amplitude	EFD	RMSE
Fit1	330.4	1.00[a]	710.4	0.18
Fit2	543.3	0.62	1,168.1	0.06
Fit3	1,166.7	0.59	1,166.7	0.06

[a]Fixed a priori.

Implications for operational snow depth analyses

- Horizontal correlation length scales of increments larger than 120 km need to be tested for improved predictions over poorly monitored areas.

- Vertical scales are more uncertain due to insufficient sampling over complex terrain and shorter vertical length scales.

- Interpolation of increments especially over complex terrain would be advantageous over full snow depth due to large scales and temporal consistency.

- Scales were assumed isotropic and fixed over the winter period, and need to be tested for seasonal adjustments.