Time Series Analysis On Snow Depth In the Alps

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Motivation

Understand and use SAFRAN CROCUS datasets

Learn about Time Series Forecasting

Find a model independent from weather forecast

Study snow depth during peak season

Novelty

Model based on HS data,

No meteorological feature

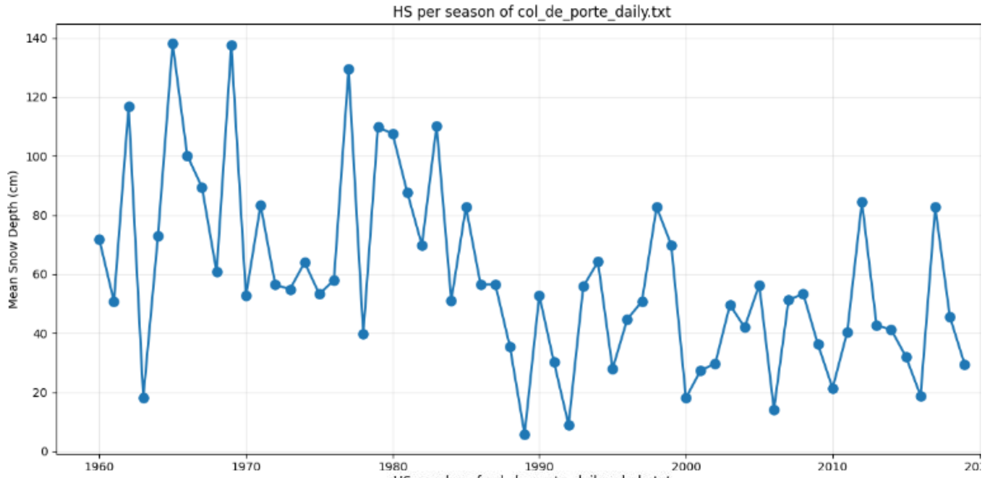
Model optimized for winter season in worldwide resorts

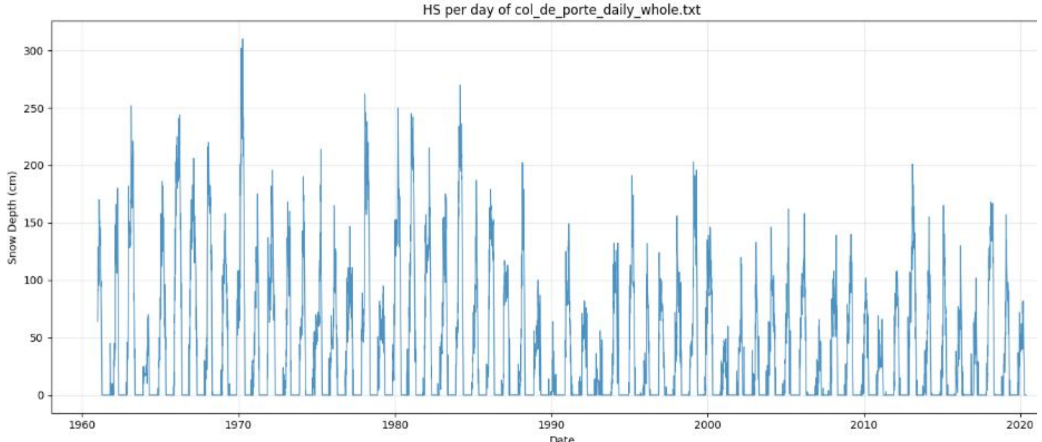
Use of a cross validation rolling method

Dataset

- **1975 => 2019**, 1 log/day, 212 day/year (Nov – May)
- Source: MeteoFrance's **SAFRAN-CROCUS** dataset
- Stations to study:
  - Les 2 Alpes: Highest, glacier ~**3000m**
  - Tignes: north-facing, stable snowpack ~**2600m**
  - Serre Chevalier: south-facing, unstable snowpack ~**2100m**
  - Col de Porte: Lowest, humid, perfect data source ~**1300m**

- Measurements are grid-generalized per station
- Processed Day Metrics : HS = > qc(HS) => **gapfill(qc(HS))**





Literature – Primary Data Source

Matiu, M., Crespi, A., Bertoldi, G., Carmagnola, C. M., Marty, C., Morin, S., Schöner, W., Cat Berro, D., Chiogna, G., De Gregorio, L., Kotlarski, S., Majone, B., Resch, G., Terzago, S., Valt, M., Beozzo, W., Cianfarra, P., Gouttevin, I., Marcolini, G., Notarnicola, C., Petitta, M., Scherrer, S. C., Strasser, U., Winkler, M., Zebisch, M., Cicogna, A., Cremonini, R., Debernardi, A., Faletto, M., Gaddo, M., Giovannini, L., Mercalli, L., Soubeyroux, J.-M., Sušnik, A., Trenti, A., Urbani, S., and Weilguni, V.: **Observed snow depth trends in the European Alps: 1971 to 2019**, The Cryosphere, 15, 1343–1382, https://doi.org/10.5194/tc-15-1343-2021, 2021.

Literature – Gap filling / Meaning

Use of the models Safran-Crocus-Mepra in operational avalanche forecasting, Coléou C* , Giraud G, Danielou Y, Dumas J-L, Gendre C, Pougatch E CEN, Météo France, Grenoble, France

Version 3.0 of the Crocus snowpack model, Matthieu Lafaysse1 , Marie Dumont1 , Basile De Fleurian1 , Mathieu Fructus1 , Rafife Nheili1 , Léo Viallon-Galinier1 , Matthieu Baron1 , Aaron Boone2 , Axel Bouchet1 , Julien Brondex1,4 , Carlo Carmagnola1 , Bertrand Cluzet1 , Kévin Fourteau1 , Ange Haddjeri1,4, Pascal Hagenmuller1 , Giulia Mazzotti1,4, Marie Minvielle2 , Samuel Morin1 , Louis Quéno1,5, Léon Roussel1 , Pierre Spandre1 , François Tuzet1 , and Vincent Vionnet1,3

Literature - Models

Aschauer, J., Bavay, M., Begert, M., and Marty, C.: **Comparing methods for gap filling in historical snow depth time series**, EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020–17211, https://doi.org/10.5194/egusphere-egu2020-17211, 2020.

Introduction to Time Series and Forecasting – Third Edition,

By Peter J. Brockwell Richard A. Davis, 2016

Durbin, James, and Siem Jan Koopman. 2012. **Time Series Analysis by State Space Methods: Second Edition.** Oxford University Press.

Work Done – Naïve Model

- Average of past Same Days:
  - NS(y, m, d) = $\frac{1}{y-1}\sum_{k=1}^{y-1} ds[k, m, d]$
  - NMAE = $\frac{MAE}{mean(HS\_after\_gapfill)}$
  - 2 Clear groups performance-wise: Stable/Unstable snowpack
- Note: 10 first years without cross-validation

Worst Accuracy

Best Accuracy

STATION NAME	MAE	NMAE
Tignes	30.822	0.395
Les 2 Alpes	48.345	0.404
Serre-Chevalier	25.076	0.82
Col de Porte	32.797	1.125

Work Done – (AR)(I)(MA) Model

- AR : Auto Regression – Past values
- I: Integration – Past trends
- MA: Moving Average – Past errors

- Stations with highest variance & non -stationarity need MA

- Limitations: Needs a seasonal parameter, lowest-order ARIMAs performed best

Worse Accuracy

Better Accuracy

STATION NAME	MAE	NMAE	p, d, q
Tignes	44.769	0.52	1, 0, 1
Les 2 Alpes	64.701	0.521	1, 0, 1
Serre-Chevalier	33.173	0.905	1, 0, 0
Col de Porte	42.711	0.946	1, 0, 0

Tested on p{0, 1, 2, 3}, d{0, 1, 2}, q{0, 1, 2, 3}

Work Done – (AR)(I)(MA) Model

- $AR_{m,d}$(p) = $C + \sum_{k=1}^{p} \Phi_k * ds[t-1]$
- $I_{m,d}$(d) = $\nabla^{d} * ds[t]$
- $MA_{m,d}$(q) = $C + \sum_{k=1}^{q} \theta_k * \varepsilon_{t-k}$
- Note: We add white noise shock

For every ARIMA member as ε_t

Worse Accuracy

Better Accuracy

STATION NAME	MAE	NMAE	p, d, q
Tignes	44.769	0.52	1, 0, 1
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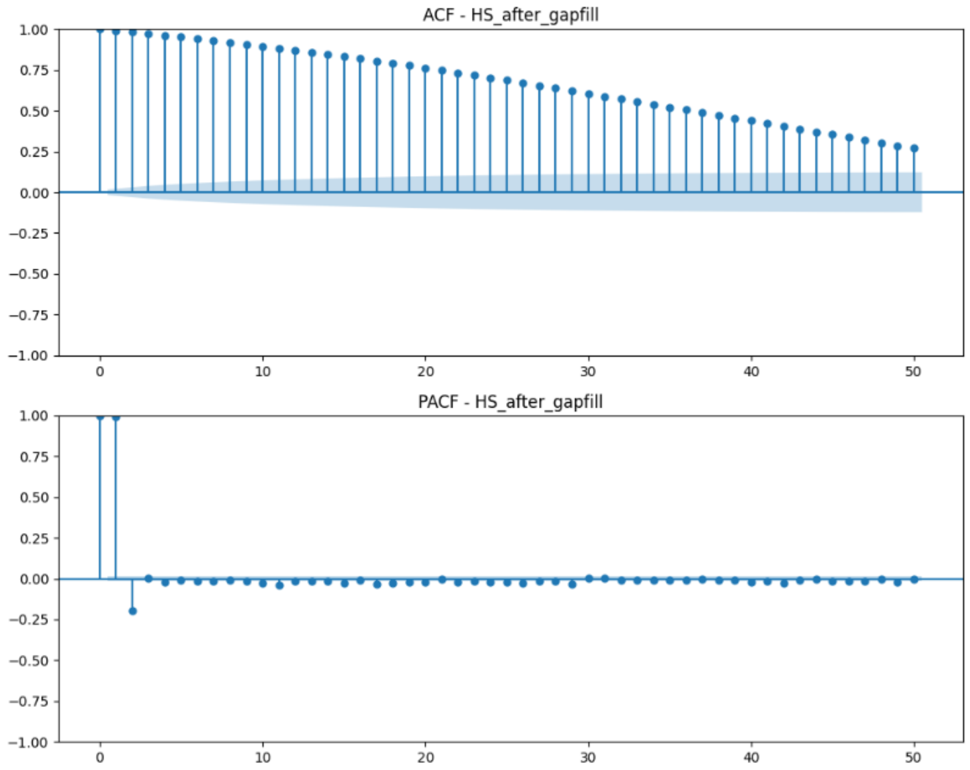
Work Done – (AR)(I)(MA) Model




```
ADF Statistic of col_de_porte_daily.txt : -12.037385978227787
p-value: 2.78284946105129e-22
Lags used: 28
Number of observations: 12615
Critical Value (1%): -3.431
Critical Value (5%): -2.862
Critical Value (10%): -2.567
```

Worse Accuracy

Better Accuracy

STATION NAME	MAE	NMAE	p, d, q
Tignes	44.769	0.52	1, 0, 1
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PACF stops at 2 => p = {1,2}
ACF(x) – ACF(x-1) <0.5 => q={0,1?}
ADF << Critical values & p~0 => d = 0

Work Done – Prophet Model

- Linear smoothing model by Meta
- Arguments tested:
  - Seasonality (custom – 212 VS **year**)
  - Fourier order [**5**;15]
  - Changepoint prior scale [**0.05**;0.5]
  - Seasonality mode (**add** VS mult)
- Default values are **bold**

Worse Accuracy

Better Accuracy

STATION NAME	MAE	NMAE	Args
Tignes	35.516	0.389	Default
Les 2 Alpes	52.951	0.396	Default
Serre-Chevalier	26.249	0.792	Seasonality
Col de Porte	34.219	0.847	Seasonality

CONCLUSION – What's next

https://github.com/PapayaSupreme/snow-depth-time-series-analysis-model

(S)ARIMA,

LSTM

Another, improved, custom model

Kaggle integration for bigger hyperparameters

Thank you for your time !

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