Improving the Wind Gust Parameterization in COSMO-1

Christoph Heim
Guy de Morsier, Oliver Fuhrer, André Walser, Pirmin Kaufmann, Marco Arpagaus
The Problem

COSMO-1 underestimates strong wind gusts.
Choice of the Model behind the Parameterization

- Two general approaches to model wind gusts:
  - **Physical models**
    - Attempt to model vertical mixing of momentum
      + Should be generally valid
      + Promotes understanding of processes
      - No theoretical model applicable over complex topography
  - **Statistical models** (partially based on physical reasoning)
    - Use variables that are thought to be relevant and train statistical model.
      + More flexible because adjustable
      + Simple
      - Not generally valid

Our choice: Use statistical model allowing for physical model as predictors.
Simple linear model based on 2 predictors:
- model mean wind at 10m (WIND)
- transfer coefficient of momentum (TCM)

GUST = WIND + \alpha \cdot \sqrt{TCM} \cdot WIND
Physical Model (IFS, ICON)

- Complicated physical model based on Monin-Obukhov Similarity Theory.

Stable PBL:

\[ G_{10M} = V_{10M} + 7.71u_{tot}^* \]

Unstable PBL:

\[ G_{10M} = V_{10M} + 7.71u_{tot}^* \left( 1 - \frac{0.5}{12} \left( -\kappa H_{PBL} \frac{B}{u_{tot}^*} \right) \right)^{\frac{1}{3}} \]

Unfortunately, this does not work well in COSMO-1

\[ u_{tot}^* = \max(\sqrt{u_{stress}^2 + v_{stress}^2} + 2E^{-3}(H_{PBL}B)^3, 0.0001) \]

\[ B = \frac{g}{\rho} \left( -0.608 F_{Qv}^{sfc} - \frac{F_{H}^{sfc}}{T_{skin} c_p} \right) \]

\[ u_{stress} = \rho U_{l1} \sqrt{\max(0.1^2, U_{l1}^2 + V_{l1}^2)} \left( \frac{\kappa}{\log \left( 1 + \frac{\phi l1}{g z0} \right)} \right)^2 \]

\[ v_{stress} = \rho V_{l1} \sqrt{\max(0.1^2, U_{l1}^2 + V_{l1}^2)} \left( \frac{\kappa}{\log \left( 1 + \frac{\phi l1}{g z0} \right)} \right)^2 \]
How to calibrate?

- **Problem:**
  - Model also underestimates strong mean wind speeds.
  - This is the reason for the underestimated strong wind gusts.
How to calibrate?

- Gust parameterization can compensate for underestimated strong mean winds by choosing artificially high coefficients.

\[ \alpha = 7.2 \text{ (operational)} \]

\[ \text{GUST} = \text{WIND} + \alpha \times \sqrt{\text{TCM}} \times \text{WIND} \]

Calibration Goal:
Remove conditional bias while minimizing scattering and mean error.

- Doing so increases the scattering and mean error!

\[ \alpha = 10 \]
New Gust Parameterization

• Linear model based on a physical parameterization (Brasseur)
• Brasseur compares vertical profiles of stability and turbulence
• Linear model thus implicitly contains information from higher model levels!
New Gust Parameterization

\[ \text{GUST} = 1.62 \times \text{WIND} - 1.74 \times 10^{-3} \times \text{WIND} \times \text{BRA}_{\text{LB}} - 1.95 \times 10^{-5} \times \text{WIND} \times \text{BRA}_{\text{LB}}^2 - 1.25 \times 10^{-5} \times \text{WIND} \times \text{BRA}_{\text{LB}}^3 + 1.13 \times 10^{-2} \times \text{WIND} \times \text{BRA}_{\text{ES}} + 1.24 \times 10^{-2} \times \text{WIND} \times \text{BRA}_{\text{UB}} \]

Brasseur:
- Lower bound
- Estimate
- Upper bound
GUST = WIND + α * sqrt(TCM) * WIND

(operational)

α = 7.2

α = 10

new parameterization

RMSE 4.5
ME 2.6

RMSE 3.2
ME 0.4

reference MOD gust error vs OBS gust

MOD gust error vs OBS gust

reference MOD gust error vs OBS gust

MOD gust error vs OBS gust

RMSE 2.9
ME 0.3

MeteoSwiss
Storm Burglind/Eleanor 4 Jan 2018

**Old Parameterization**

\[ \text{ltype\_diag\_gusts} = 1 \]

**New Parameterization**

\[ \text{ltype\_diag\_gusts} = 5 \]
Limitations of New Parameterization

- New gust parameterization is a statistical model. Can be expected to work only within the domain of data used for training of coefficients. Everything else is extrapolation.

- Known cases of extrapolation (see next slides):
  - Lakes and Sea in winter
  - Very strong wind speeds
  - Different model resolutions
  - Different areas?

- Other problems:
  - Overestimated gusts in convective situations (?)
    - Frequency bias for strong gusts in summer (likely from convective situations) is already very high in \( \text{itype\_diag\_gusts}=1 \) but even higher in \( \text{itype\_diag\_gusts}=5 \). Probably due to a small amount of observation data for convective cells used in tuning.
Extrapolation – Lakes and Sea in Winter

- Gusts are overestimated over lakes (and the sea) in winter. Likely, relatively warm waters reduce stratification, increasing Brasseur gust estimates.
- This is not taken into account in the training of the linear model because (almost) no observations are available over water (extrapolation).
- Fix: Over water, combine new with old gust value. The relative contribution is proportional to the land fraction, with a minimum contribution of the new gust value.
Extrapolation – Very Strong Wind Speeds

\[ \text{GUST} = 1.62 \times \text{WIND} - 1.74 \times 10^{-3} \times \text{WIND} \times \text{BRA}_\text{LB} \]
\[- 1.95 \times 10^{-5} \times \text{WIND} \times (\text{BRA}_\text{LB})^2 \]
\[- 1.25 \times 10^{-5} \times \text{WIND} \times (\text{BRA}_\text{LB})^3 \]
\[+ 1.13 \times 10^{-2} \times \text{WIND} \times \text{BRA}_\text{ES} \]
\[+ 1.24 \times 10^{-2} \times \text{WIND} \times \text{BRA}_\text{UB} \]

- **Negative terms with power > 1.** For high values of lower bound of Brasseur bounding interval \( \text{BRA}_\text{LB} \) (≈ mean wind), the negative contribution of these terms increases strongly (!).

- **Training was performed with mean winds up to 25 m/s.** For stronger mean winds, linear model has to extrapolate and fails due to these terms.
- **Fix:**
  - Set 2 threshold values \( \text{thrs1} = 22 \text{ m/s} \) and \( \text{thrs2} = 25 \text{ m/s} \).

- If \( \text{mean\_wind} \leq \text{thrs1} \) (interpolation):
  - \( \text{Gust} = \text{gust from linear model (new parameterization)} \) \( (1) \)

- If \( \text{mean\_wind} > \text{thrs2} \) (extrapolation):
  - \( \text{Gust} = \text{mean\_wind} \times \text{gust\_factor} \) \( (\text{gust\_factor} = 1.9) \) \( (2) \)

- If \( \text{thrs1} < \text{mean\_wind} \leq \text{thrs2} \) (transition):
  - \( \text{Gust} = \text{linear transition between (1) and (2)}. \)
Extrapolation – Different Model Resolutions

- Wind gust parameterization is tuned for COSMO-1 of MeteoSwiss (Δx=1.1km).
- Was applied and verified also in COSMO-2 (Δx=2.2km). Improvement less consistent than for Δx=1.1km.
- Tests have neither been performed for lower (Δx > 2.2km) nor for higher (Δx < 1.1km) model resolutions.
Measurements: CH + Nearby Stations
Simulated Cases

• **Training**
  - 05.03.2017 - 07.03.2017 (Zeus)
  - 24.07.2017 - 25.07.2017 (storm in summer)
  - 03.01.2018 - 03.01.2018 (Burglind/Eleanor)
  - 16.01.2018 - 18.01.2018 (Friederike)
  - 01.03.2018 - 01.03.2018 (Föhn in Alpine valleys)
  - 29.04.2018 - 30.04.2018 (far-reaching Föhn)
  - 03.05.2018 - 04.05.2018 (Bise)
  - 30.05.2018 - 31.05.2018 (well simulated thunderstorms)

• **Choice of Parameterization**
  - 07.12.2017 - 16.12.2017 (10 winter days)
  - 21.06.2018 - 30.06.2018 (10 summer days)

• **Validation**
  - 04.01.2017 - 18.01.2017 (14 winter days)
  - 01.06.2018 - 14.06.2018 (14 summer days)
Summer: Thresholds 5 m/s, 12.5 m/s, 25 m/s

C1_107: itype_diag_gusts=1 (old)
C1_108: itype_diag_gusts=5 (new)
Winter: Thresholds 5 m/s, 12.5 m/s, 20 m/s

C1_107: itype_diag_gusts=1 (old)
C1_108: itype_diag_gusts=5 (new)

ETS

ETS 5 m/s

ETS 12.5 m/s

ETS 20 m/s
First operational verification results

Comparison with previous season

Old parametrization (DJF18/19)  New parametrization (MAM19)
First operational verification results
Comparison with previous year

Old parametrization (MAM18)  New parametrization (MAM19)

SMO-1 vs COSMO-E vs COSMO-7 vs HRES @ch for VMAX_10M &

COSMO-1 vs COSMO-E vs COSMO-7 vs HRES @ch for VMAX_10M6 & lt 13-24
Spatial Differences

New Parameterization

Gusts $\geq 12.5$ m/s

Gusts $\geq 20$ m/s
Summary

• New gust parameterization with calibrated linear model based on Brasseur estimates introduced Feb. 2019
• ETS for strong gusts was slightly better in validation periods
• Spring 2019: For strong gusts, the underestimation of the old parameterization is transformed to an overestimation of about the same magnitude
• Due to partially compensating errors at mountain stations, the effect at lowland stations is worse than the overall scores show
• Feedback of forecaster criticises this overestimation, as sensitive areas are mostly at lowlands (airports, lakes)
MeteoSwiss
Operation Center 1
CH-8058 Zurich-Airport
T +41 58 460 91 11
www.meteoswiss.ch

Meteosvizzera
Via ai Monti 146
CH-6605 Locarno-Monti
T +41 58 460 92 22
www.meteosvizzera.ch

MétéoSuisse
7bis, av. de la Paix
CH-1211 Genève 2
T +41 58 460 98 88
www.meteosuisse.ch

MétéoSuisse
Chemin de l'Aérologie
CH-1530 Payerne
T +41 58 460 94 44
www.meteosuisse.ch