



CEN/TC250/SC1

Eurocode 1 - Actions on structures

SC1.T6 Interdependence of climatic actions (wind, snow, thermal and atmospheric icing) and glass structure

Modelling of climatic action for Code implementation

Francesco Ricciardelli



WHO

Svend Ole HANSEN

(Svend Ole Hansen ApS, DK)

Filippo LANDI

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Jana MARKOVA

(Czech Technical University, CZ)

Harold McINNES

(Meteorologisk Institutt, NO)

Francesco RICCIARDELLI

(University of Campania, IT)

Nick MALAKATAS

Jens BRUNNER

WHAT

- Reduction in number of National Choices (NDPs)
- Enhanced ease of use
- Variability and interdependence of climatic actions: Probabilistic basis and load combination factors
- Structural glass structures: Snow loads, wind actions and thermal actions

			2019												2020												2021												2022						
	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	July	August	September	October	November	December	January	February	March	April	May	June	
Administrative (note: important for PTs) Phase 4																																													
Progress report by PT																																													
Half yearly progress report (interim report) including latest (as-is) draft(s) by PT																																													
PT Invoicing of Milestone 0 pre-financing																																													
PT Invoicing of labour costs (Milestones 2, 3 and 4)																																													
preparation of consolidated report to EC/EFTA by TC250 mgt. group																																													
external audit of consolidated report to EC/EFTA																																													
deadline submission of report to EC/EFTA by NEN and CEN																																													
EC/EFTA assesment of consolidated report																																													
Task specific (the schedule represents the deadlines for these tasks) - Phase 4																																													
Start of the Project Team																																													
General consultation activities in relation to the PT work																																													
Preparation of first Draft by PT																																													
preparation of background document(s) by PT																																													
Delivery of first Draft by PT to NEN																																													
Review of first Draft by SC or WG																																													
Preparation of Second Draft by PT, taking into account comments from SC or WG																																													
Delivery of second draft by PT to NEN																																													
review by SC or WG																																													
preparation of Final Draft by PT, taking into account comments from SC or WG																																													
Delivery of Final Draft by PT to NEN																																													
Commenting period for NSBs (Informal Enquiry)																																													
Preparation of Final document by PT, taking into account comments from NSBs																																													
Delivery of Background document(s) by PT to NEN																																													
Delivery of Final document by PT to NEN																																													
End of the Project Team																																													

RECIPIENTS: Code writers
(Semi-probabilistic people)

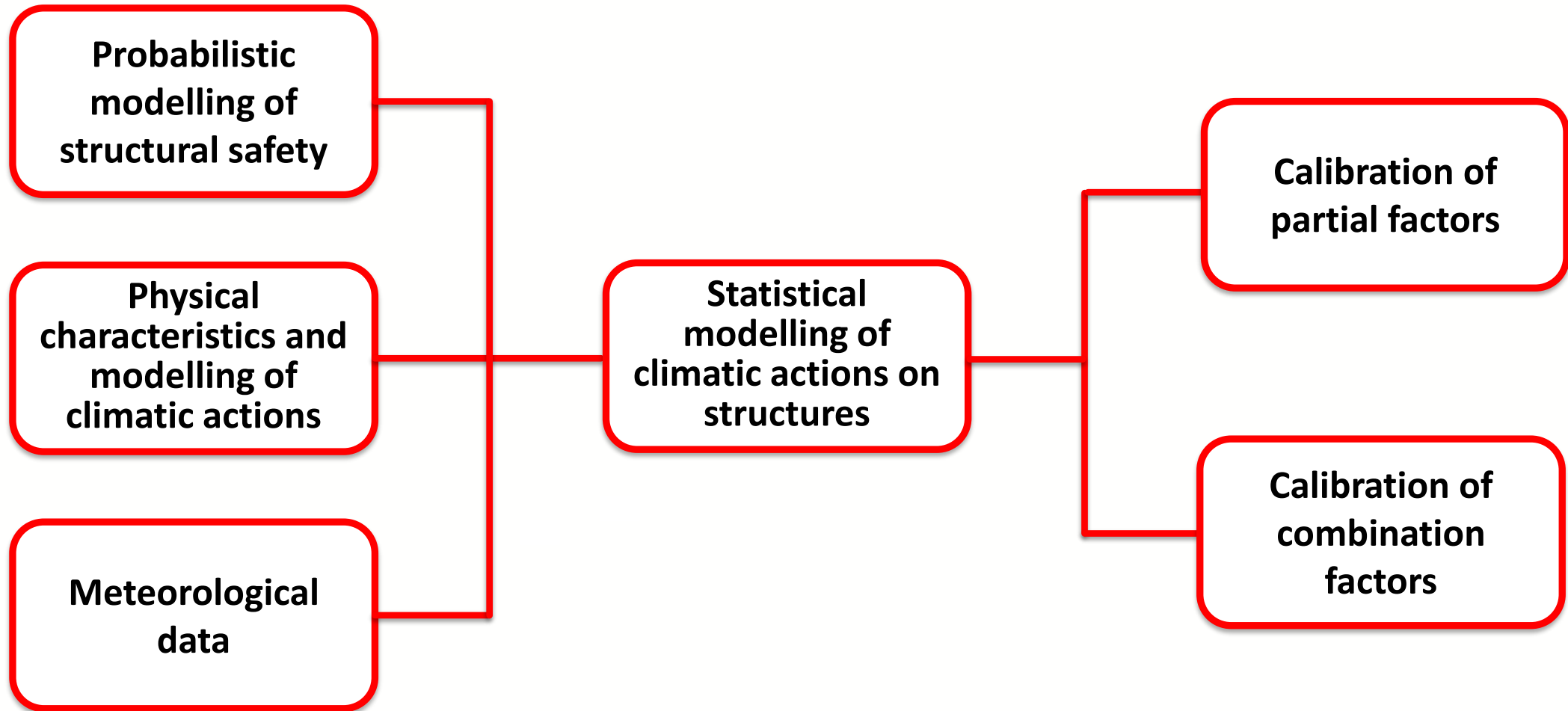
Project directors
(Reliability-based people)

SCOPE: Summarize physical aspects
of climatic actions and their
probabilistic modelling

Point out issues in the
calibration of γ and ψ factors
for climatic actions

**Probabilistic basis for determination of partial safety factors
and load combination factors**

BACKGROUND DOCUMENT



Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

- Brief history
- EN1990 implementation
- Calibration

1. Probabilistic modelling of structural safety

- 1.1. Background
- 1.2. Probability based code approaches
 - 1.2.1. *Ultimate Limit States*
 - 1.2.2. *Serviceability Limit States*
- 1.3. Calibration

2. Physical characteristics and modelling of climatic actions

- 2.1. Snow actions
 - 2.1.1. *Snow climate*
 - 2.1.2. *Wind exposure*
 - 2.1.3. *Thermal effects*
 - 2.1.4. *Shape of the roof structure*
 - 2.1.5. *Design criteria*
- 2.2. Wind actions
 - 2.2.1. *Atmospheric circulation*
 - 2.2.2. *The Atmospheric Boundary Layer*
 - 2.2.3. *Building aerodynamics*
 - 2.2.4. *Structural dynamics*
 - 2.2.5. *Design criteria*
- 2.3. Thermal actions
 - 2.3.1. *Climate characteristics*
 - 2.3.2. *Characteristics of construction works*
 - 2.3.3. *Surrounding environment*
 - 2.3.4. *Mechanism of temperature development*
 - 2.3.5. *Components of thermal actions*
 - 2.3.6. *Basic temperature components in Eurocode EN 1991-1-5*
 - 2.3.7. *Design criteria*

11 pages

Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

2. Physical characteristics and modelling of climatic actions

2.1. Snow actions

- 2.1.1. *Snow climate*
- 2.1.2. *Wind exposure*
- 2.1.3. *Thermal effects*
- 2.1.4. *Shape of the roof structure*
- 2.1.5. *Design criteria*

2.2. Wind actions

- 2.2.1. *Atmospheric circulation*
- 2.2.2. *The Atmospheric Boundary Layer*
- 2.2.3. *Building aerodynamics*
- 2.2.4. *Structural dynamics*
- 2.2.5. *Design criteria*

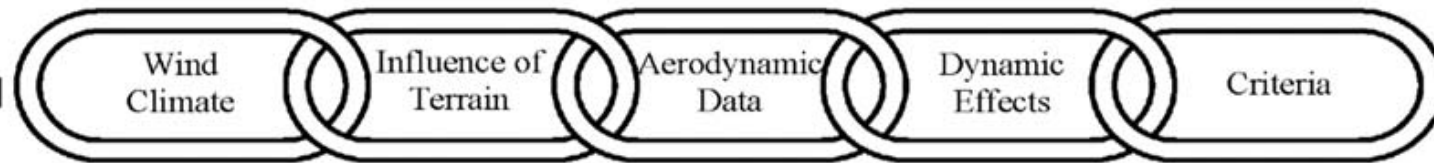
2.3. Thermal actions

- 2.3.1. *Climate characteristics*
- 2.3.2. *Characteristics of construction works*
- 2.3.3. *Surrounding environment*
- 2.3.4. *Mechanism of temperature development*
- 2.3.5. *Components of thermal actions*
- 2.3.6. *Basic temperature components in Eurocode EN 1991-1-5*
- 2.3.7. *Design criteria*
- 2.3.8. *Summary*

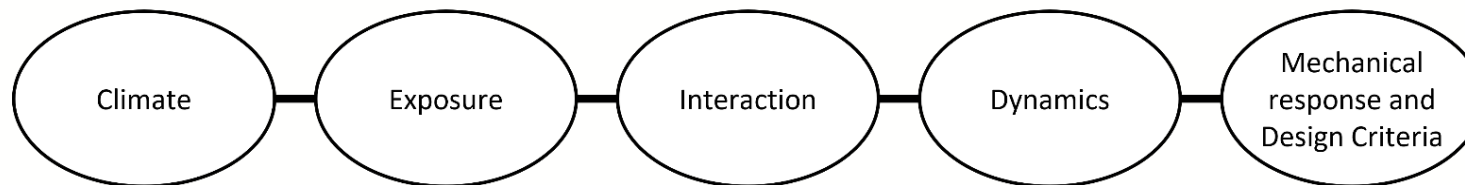
2.4. Atmospheric icing actions

- 2.4.1. *Precipitation icing (freezing rain)*
- 2.4.2. *In cloud icing*
- 2.4.3. *Summary on atmospheric icing*

WIND
LOADS &
EFFECTS



**The Alan G.
Davenport Wind
Loading Chain**

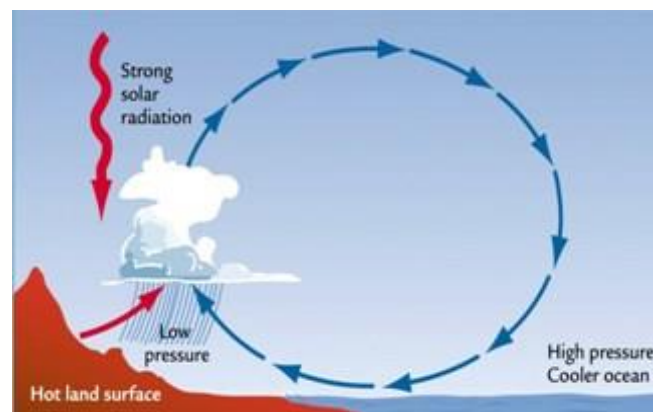
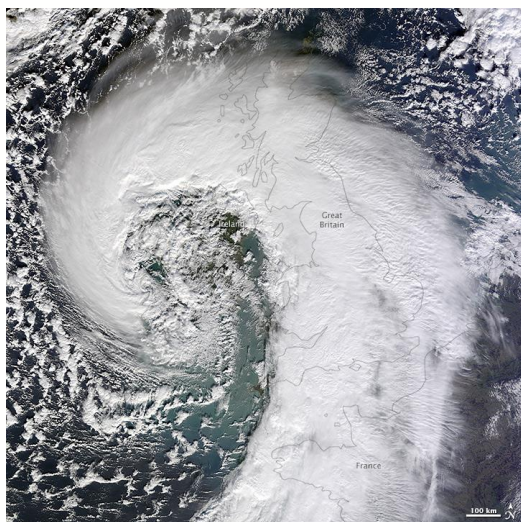
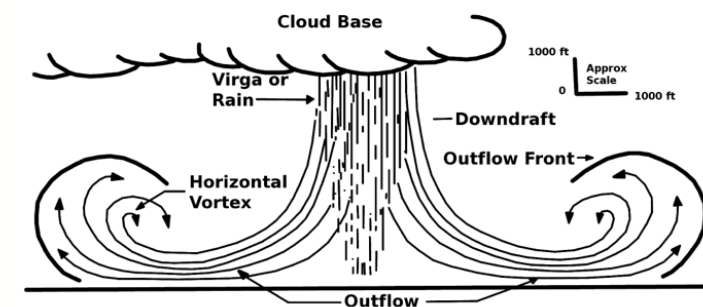
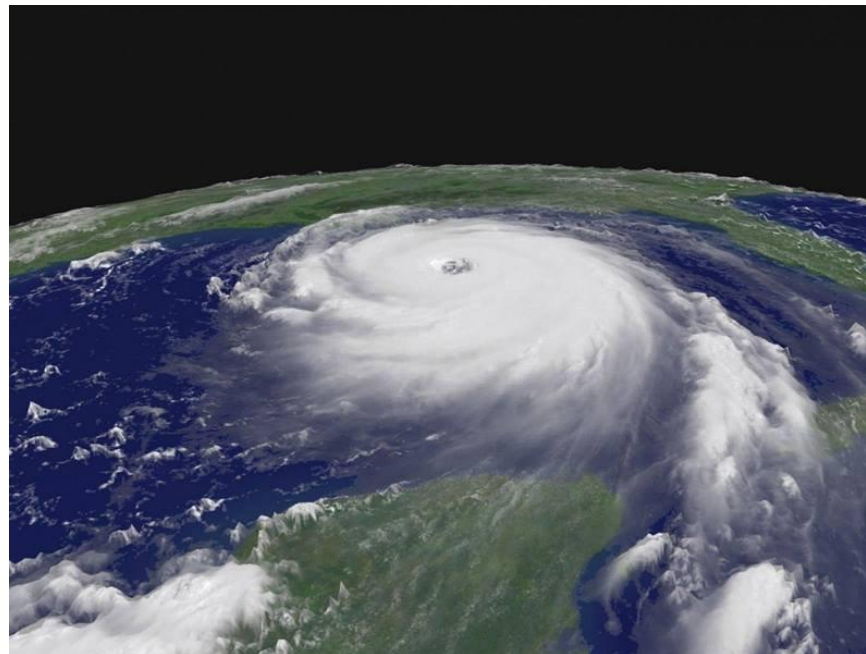
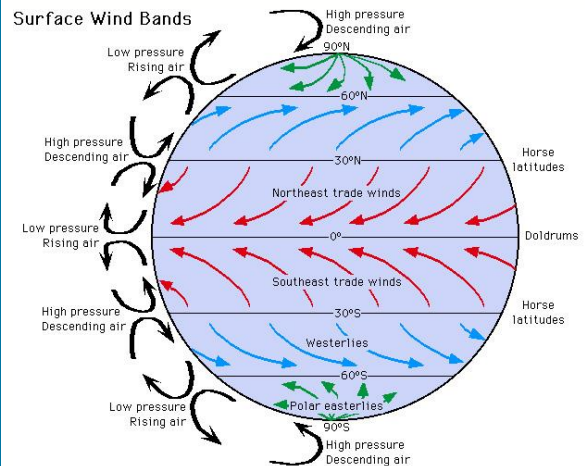


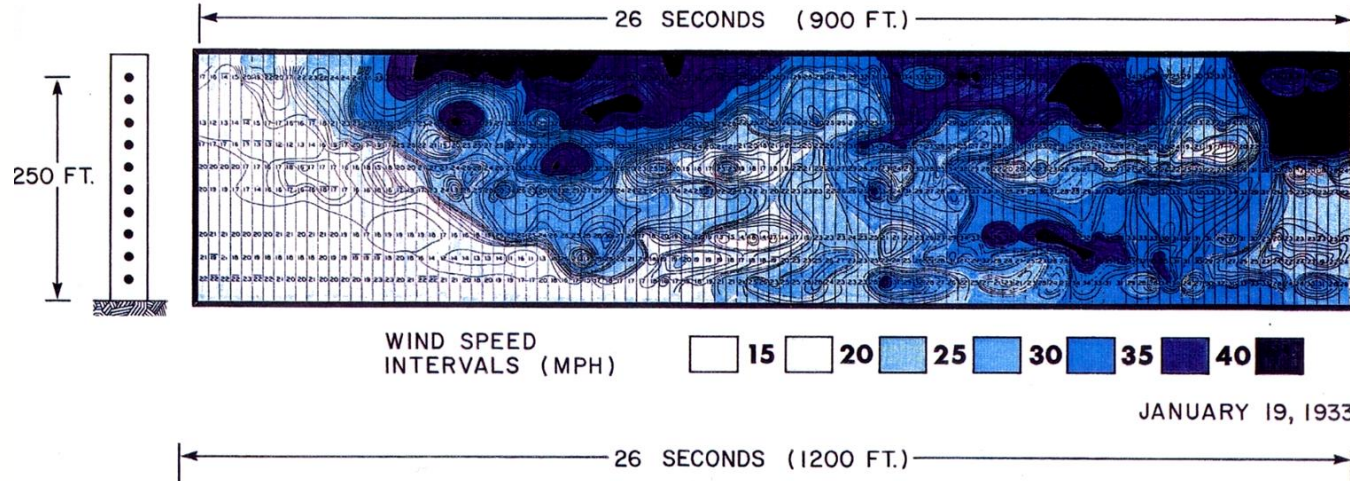
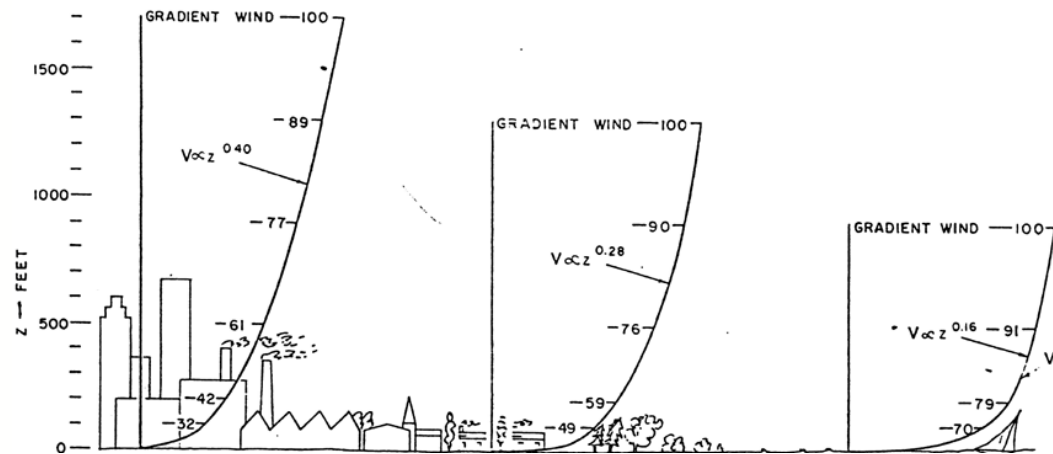
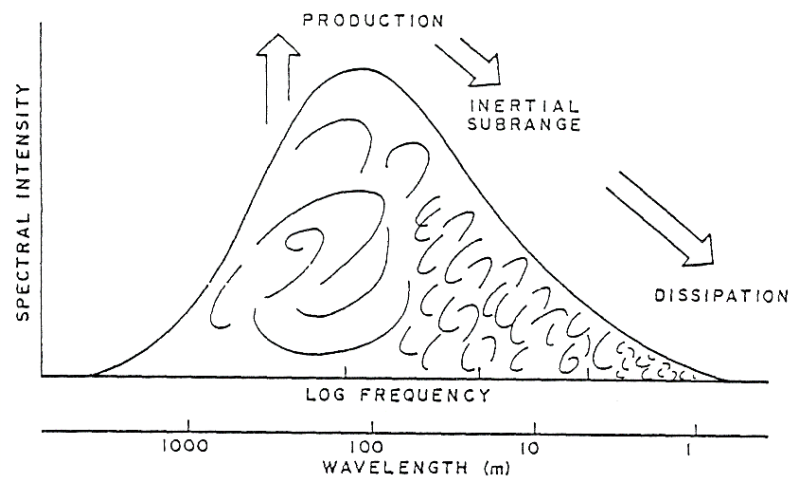
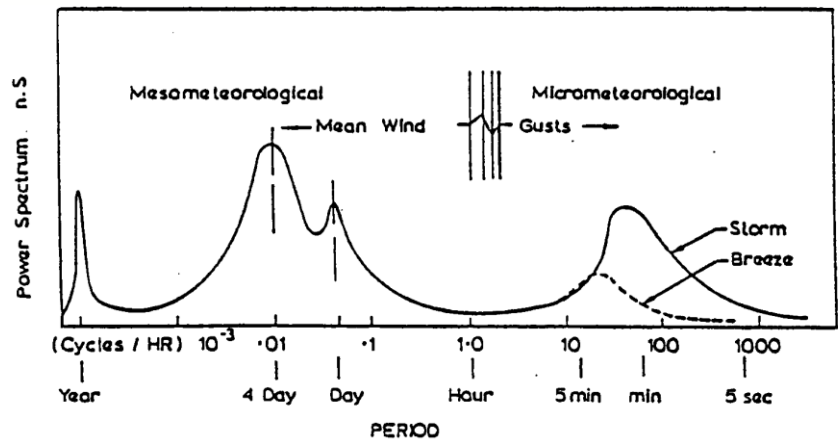
**Climatic Action
Loading Chain**

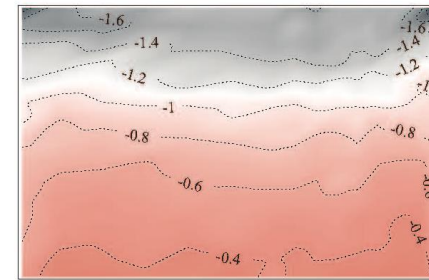
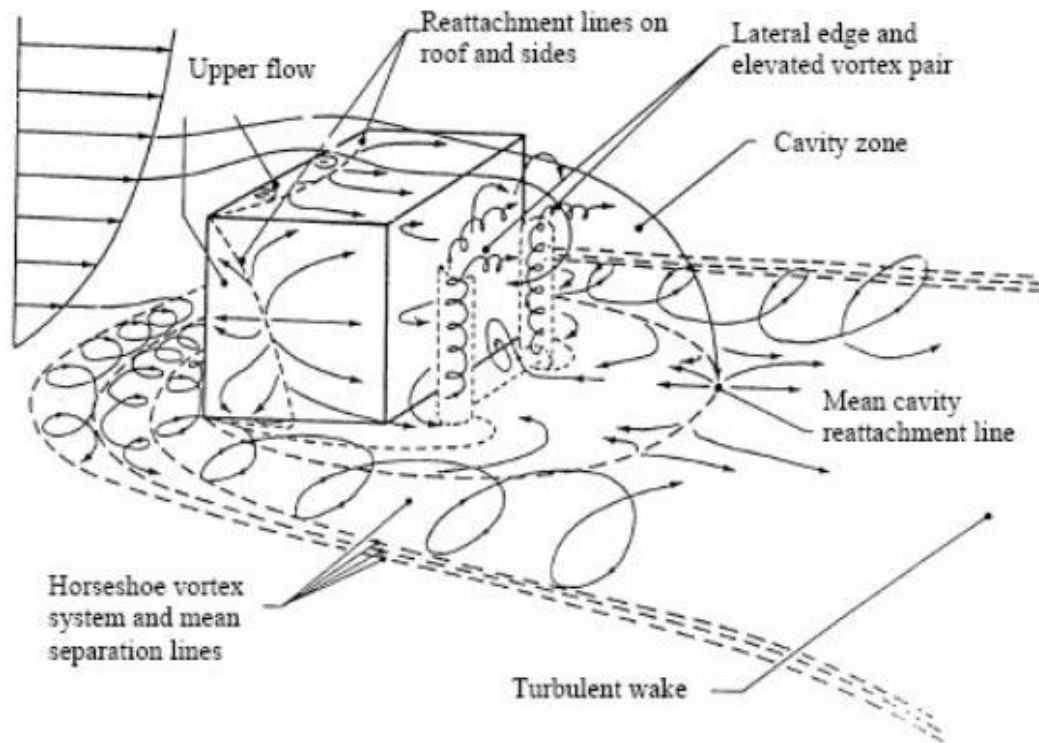
Climatic Action	Climatic Variable	Exposure Factor(s)	Interaction Factor(s)	Dynamic Factor
Snow Load	q_{sk}	c_e	$c_t \cdot \mu_i$	1
Wind Action	q_b	c_e c_s	c_p	c_d
Thermal Action	T_s	T_0 T_{out}	T_{in} T_{out}	1
Atmospheric Icing	$i_{b,o} \cdot c_{dir} \cdot c_{season}$	c_h	$c_{object} \cdot c_{orient}$	1



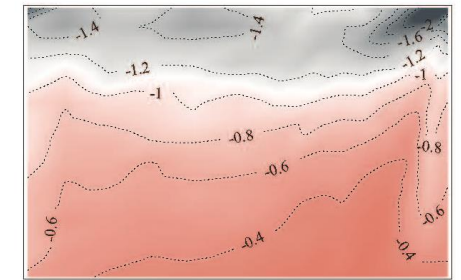
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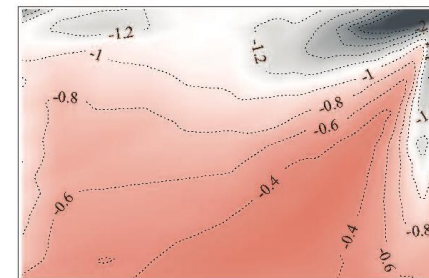




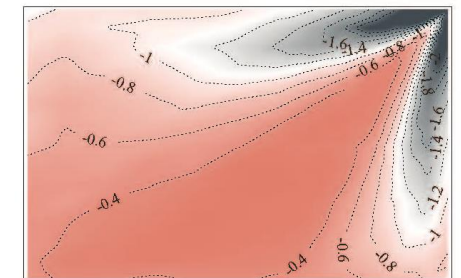
(a)



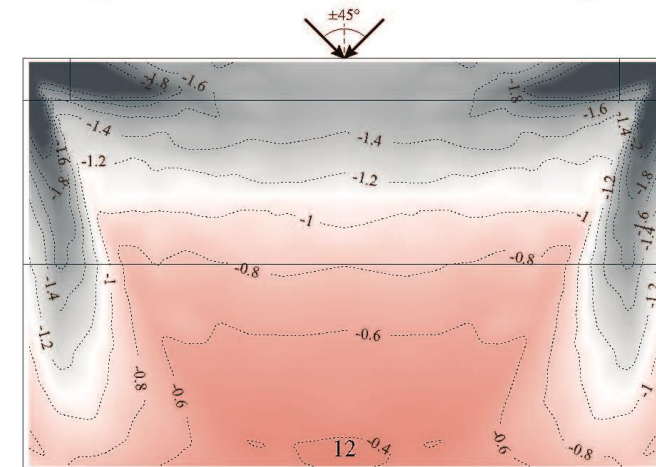
(b)



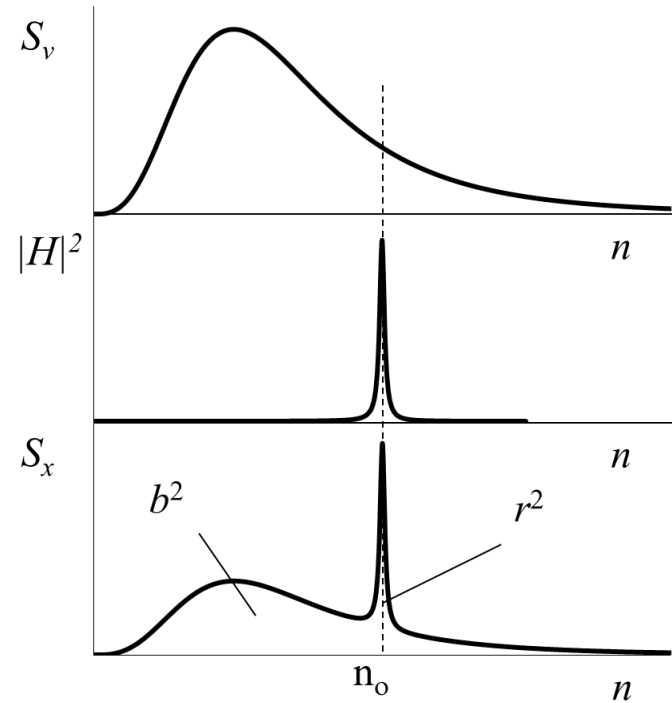
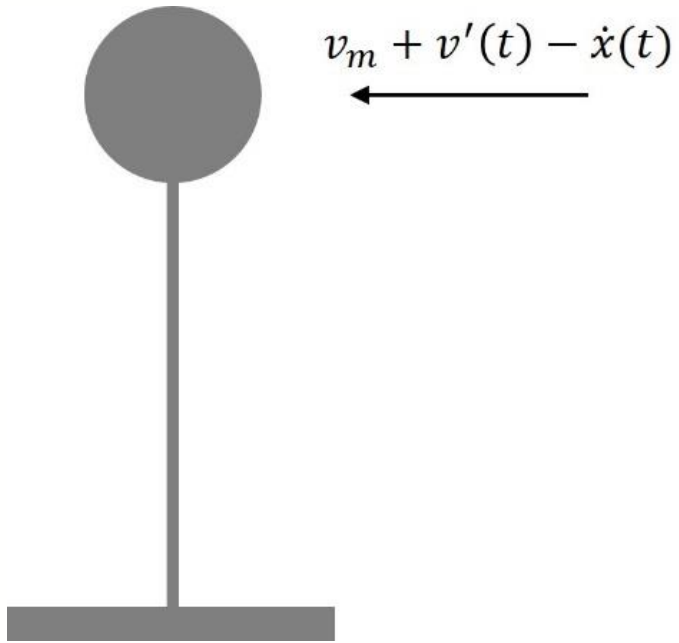
(c)



(d)



(e)



$$G_R = 1 + k \cdot \sqrt{4I_v^2 + \pi \frac{n_o}{v_m^2} S_v(n_o)}$$

$$p = q_b \cdot c_e \cdot c_p \cdot c_s c_d$$

$$c_e = c_{ABL} \cdot (1 + 7I_u)$$

$$c_s c_d = \frac{G_R}{1 + 7I_u}$$

Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

3. Meteorological data

3.1. Sources of meteorological data and availability

- 3.1.1. Conventional observations
- 3.1.2. Modelled data
- 3.1.3. Atmospheric icing
- 3.1.4. Summarizing words on meteorological data

3.2. Structure of meteorological data

- 3.2.1. Observations
- 3.2.2. Modelled data

3.3. Analysis of meteorological data and statistical models

- 3.3.1. *Snow data*
- 3.3.2. *Wind data*
- 3.3.3. *Temperature data*
- 3.3.4. *Atmospheric icing data*

3.4. Climatic zones of Europe

- 3.4.1. *Description of the Köppen – Geiger climate classes and subclasses*
- 3.4.2. *Climatic zones in Europe*
- 3.4.3. *Climatic zones and expected climatic loads*

3.5. Cross-correlation of climatic data

- 3.5.1. *Measures of extreme dependence*
- 3.5.2. *Interdependence of wind and snow*
- 3.5.3. *Interdependence of wind and temperature*
- 3.5.4. *Interdependence of snow and temperature*
- 3.5.5. *Interdependence of icing load with wind and temperature in Norway*
- 3.5.6. *Conclusions*

3.6. Future climate

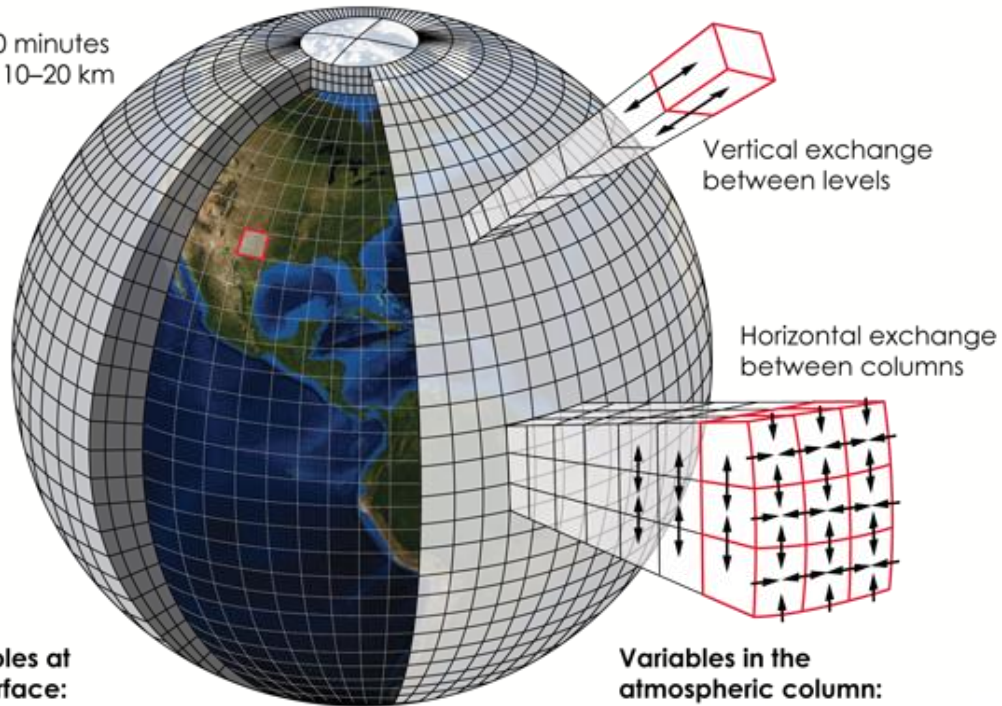
- 3.6.1. *Global climate change*
- 3.6.2. *Europe*
- 3.6.3. *Temperature*
- 3.6.4. *Summary and recommendation*

3.7. Examples

- 3.7.1. *Snow*
- 3.7.2. *Wind*
- 3.7.3. *Temperature*
- 3.7.4. *Icing*

Weather forecast modeling

Timestep 5–10 minutes
Grid spacing 10–20 km



Variables at the surface:

Temperature
Humidity
Pressure
Moisture fluxes
Heat fluxes
Radiation fluxes

Variables in the atmospheric column:

Wind vectors
Humidity
Clouds
Temperature
Height
Precipitation
Aerosols

Reanalysis and Hindcasting

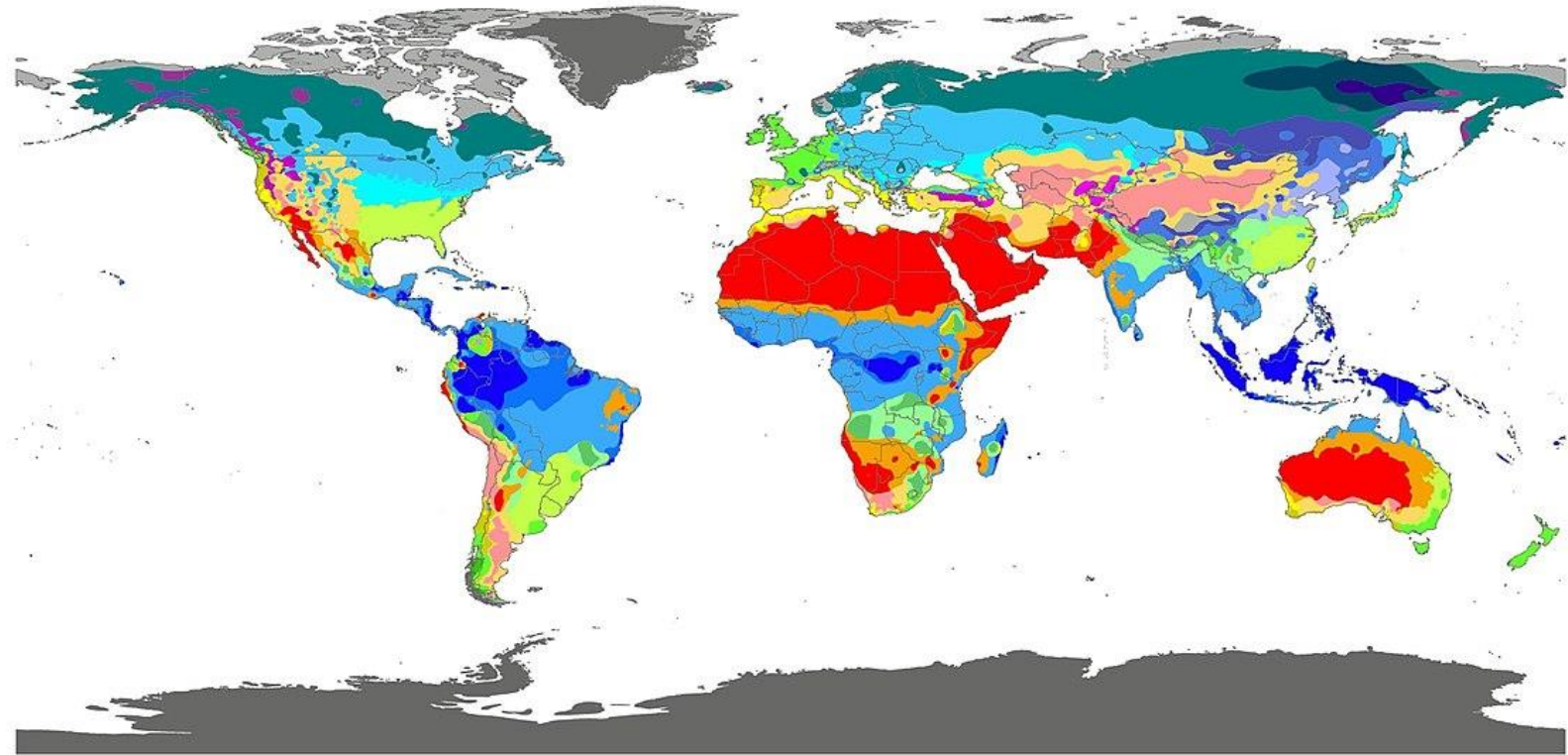
NWP model (basic equations)

- Equation of motion (wind)
- Continuity equation (mass conservation)
- First law of thermodynamics

Input to model
Surface observations
Radiosondes
Radar
Satellite data

Output from model
Forecast
Reanalysis
Resolution 0.5 to 30 km

World map of Köppen-Geiger climate classification



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MELBOURNE

Af	BWh	Csa	Cwa	Cfa	Dsa	Dwa	Dfa	ET
Am	BWk	Csb	Cwb	Cfb	Dsb	Dwb	Dfb	EF
Aw	BSh		Cwc	Cfc	Dsc	Dwc	Dfc	
	BSk				Dsd	Dwd	Dfd	

Contact : Murray C. Peel (mpeel@unimelb.edu.au) for further information

DATA SOURCE : GHCN v2.0 station data
Temperature (N = 4,844) and
Precipitation (N = 12,396)

PERIOD OF RECORD : All available

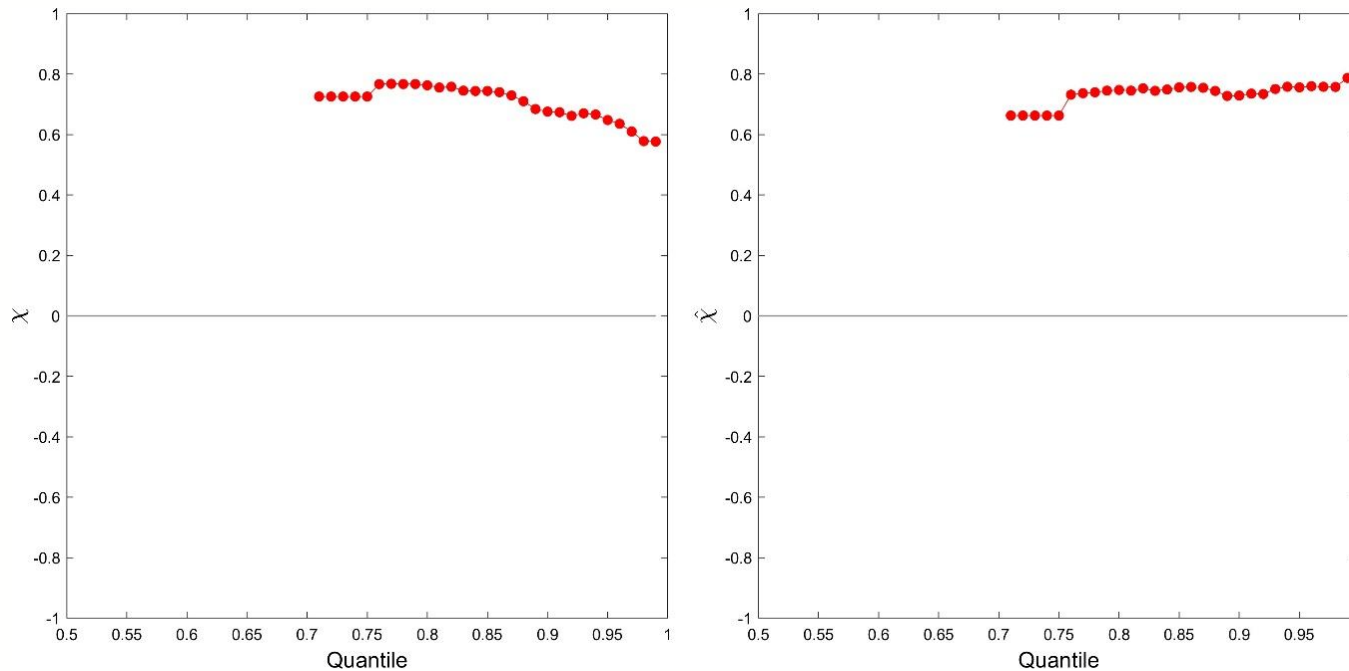
MIN LENGTH : ≥30 for each month.

RESOLUTION : 0.1 degree lat/long



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Correlation of climatic variables



$$\chi_p = \lim_{p \rightarrow 1} \Pr\{F_x(X) > p | F_y(Y) > p\}$$

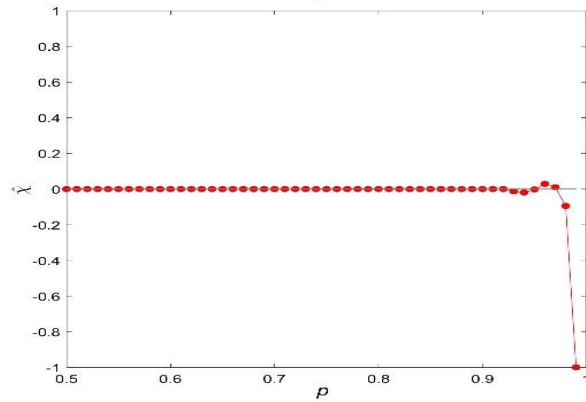
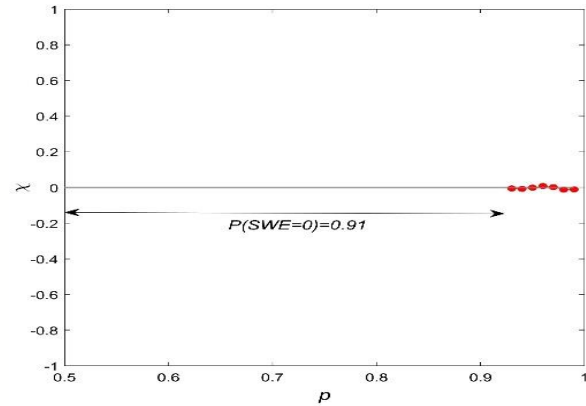
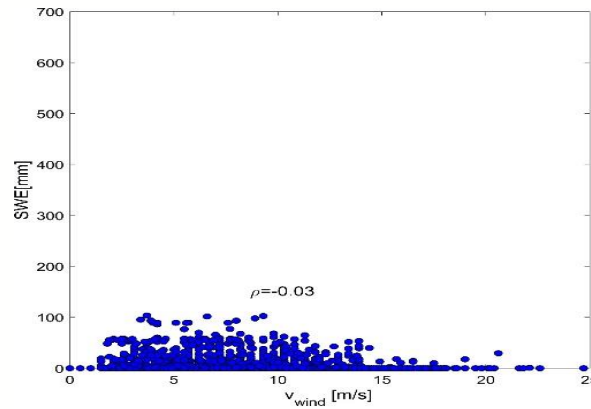
$$\chi(p) = 2 - \frac{\log(P(F_x(X) < p, F_y(Y) < p))}{\log(P(F_x(X) > p))}$$

$$\bar{\chi}(p) = \frac{2\log(P(F_x(X) > p))}{\log(P(F_x(X) > p, F_y(Y) > p))} - 1$$

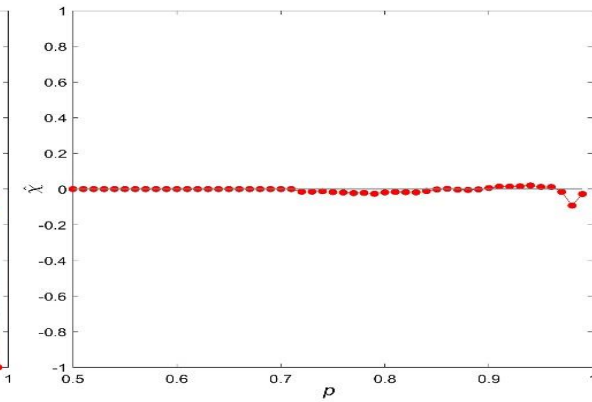
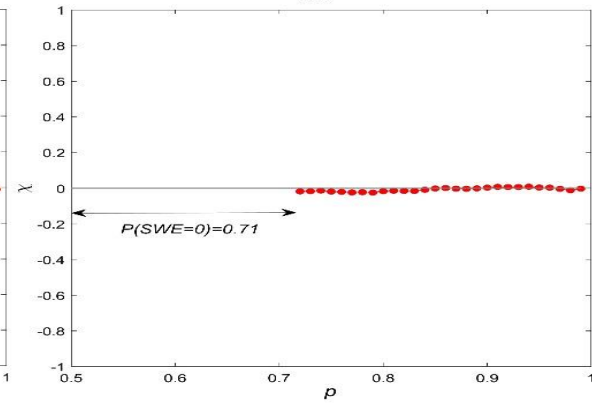
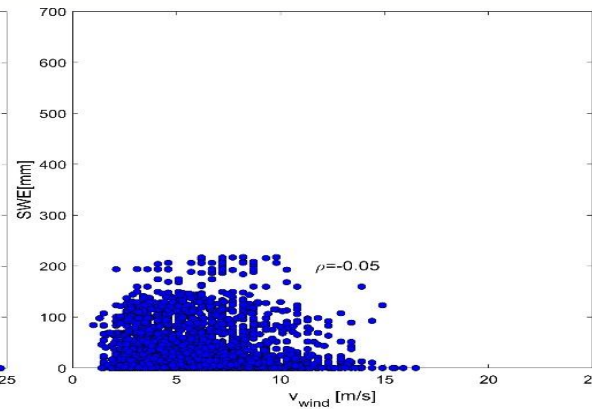
- $\chi > 0$ and $\bar{\chi} = 1$ asymptotically dependent variables with the increase of χ representing the increase in the strength of dependence;
- $\chi = 0$ and $\bar{\chi} < 1$ means asymptotic independence and the value of $\bar{\chi}$ determines the strength of dependence within this class;
- $\chi = 0$ and $\bar{\chi} = 0$ asymptotically independent variables;

Snow and Wind NORWAY

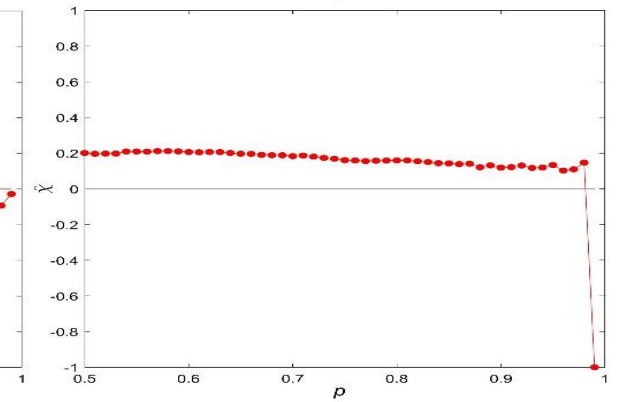
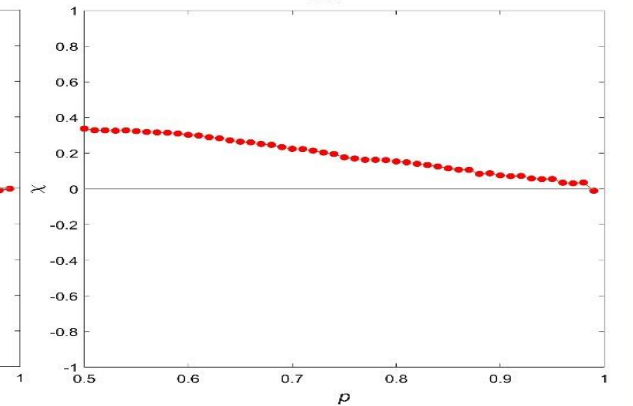
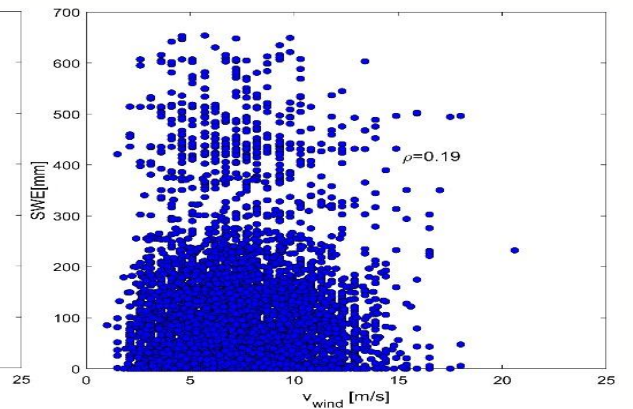
Bergen



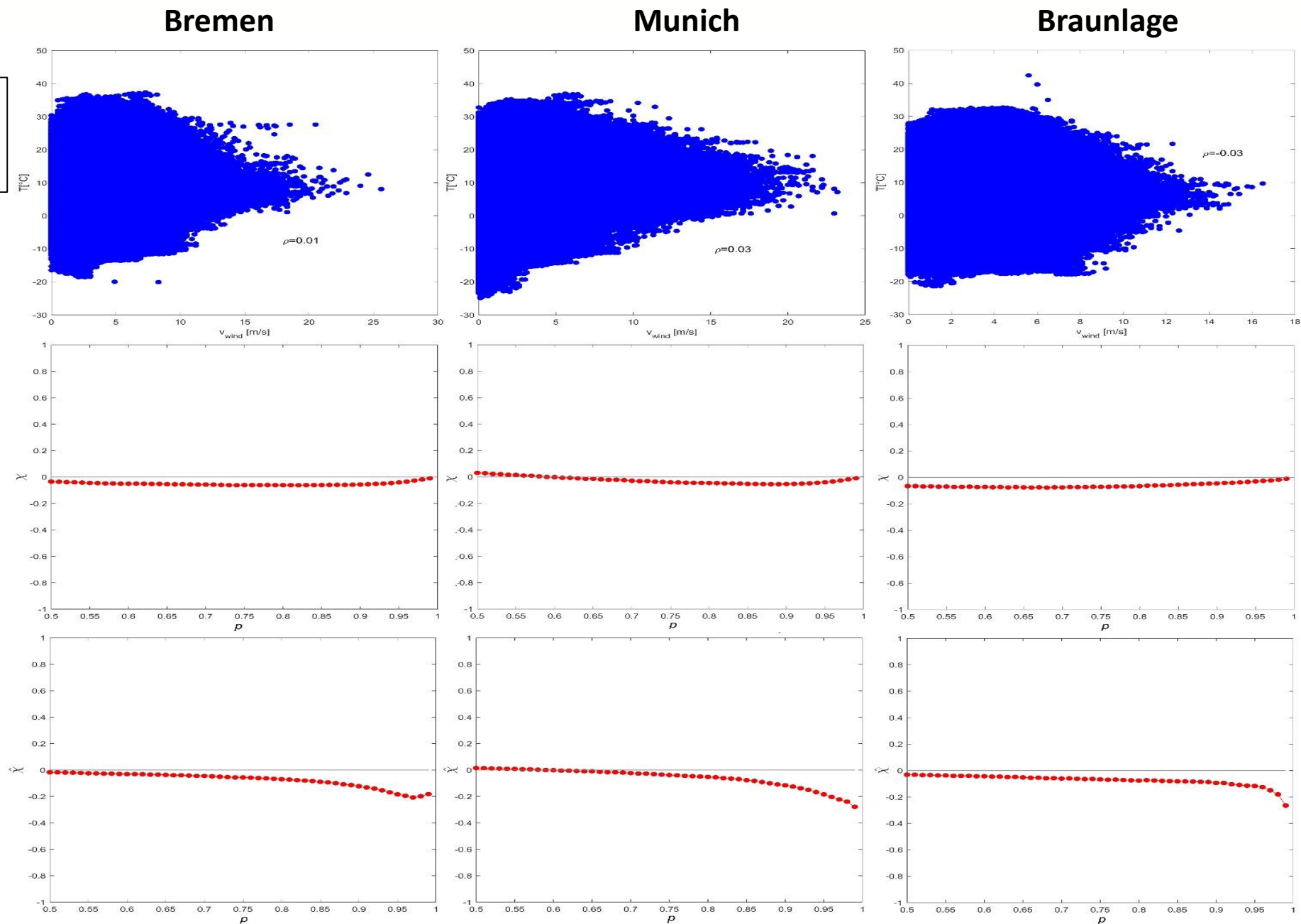
Oslo



Tromsø



Temperature and Wind GERMANY



Issues with climate changes

- Defining future climate
 - In relation to what “past climate”?
 - To what scale and with what degree of confidence?
- Does climate change impact on structures as it does on the environment?
- If so, how to account for it?

Table 3.7.5. Estimated return wind speeds for the Rome Ciampino Airport [m/s].

Return Period [years]	Fisher Tippett Type I			Method of Moments	Penultimate Type I Distribution		
	Gumbel	BLUE	Gringorten		Gumbel	BLUE	Gringorten
10	22.28	21.73	21.93	21.84	22.27	21.95	21.68
20	23.95	23.21	23.48	23.35	23.87	23.44	23.09
50	26.11	25.13	25.48	25.30	25.90	25.34	24.88
100	27.73	26.57	26.98	26.77	27.40	26.74	26.21
200	29.35	28.00	28.48	28.23	28.87	28.11	27.51
500	31.48	29.89	30.45	30.16	30.79	29.90	29.21
1000	33.08	31.32	31.94	31.62	32.22	31.24	30.48

Table 3.7.5. Estimated return wind speeds for the Rome Ciampino Airport [m/s] (cont'd).

Return Period [years]	GEV Distributions					
	PWM k= 0		PWM k= 1.5211		MLE k=0	MLE k=1.5211
	Gumbel	Gringorten	Gumbel	Gringorten		
10	21.36	22.44	21.62	21.81	20.87	20.40
20	21.85	23.89	22.44	23.29	21.93	21.20
50	22.26	25.71	23.27	25.20	23.20	22.08
100	22.45	27.05	23.75	26.63	24.08	22.65
200	22.59	28.36	24.15	28.06	24.89	23.14
500	22.70	30.05	24.57	29.94	25.89	23.70
1000	22.76	31.30	24.82	31.38	26.58	24.07

Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

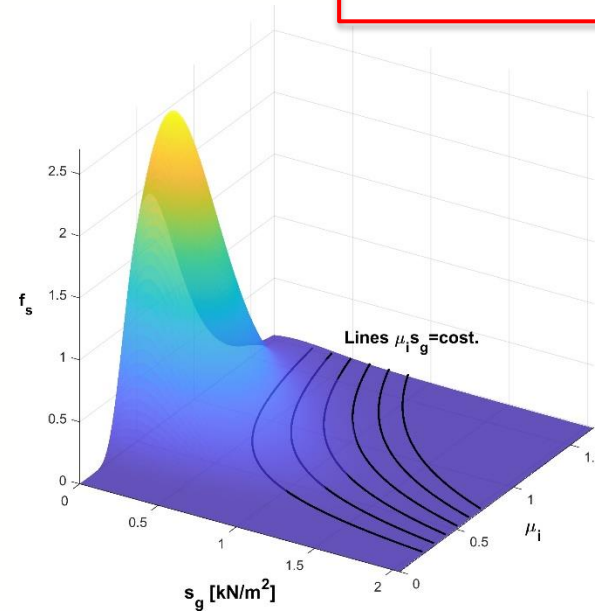
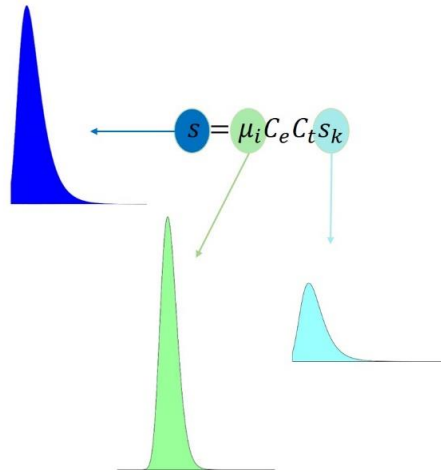
4. Statistical modelling of climatic actions on structures

- 4.1. General framework
- 4.2. Snow action
- 4.3. Wind action
- 4.4. Thermal actions
- 4.5. Atmospheric icing actions
- 4.6. Examples
 - 4.6.1. *Snow*
 - 4.6.2. *Wind*
 - 4.6.3. *Temperature*
 - 4.6.4. *Icing*

41 pages

Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT



4. Statistical modelling of climatic actions on structures

4.1. General framework

4.2. Snow action

4.3. Wind action

4.4. Thermal actions

4.5. Atmospheric icing actions

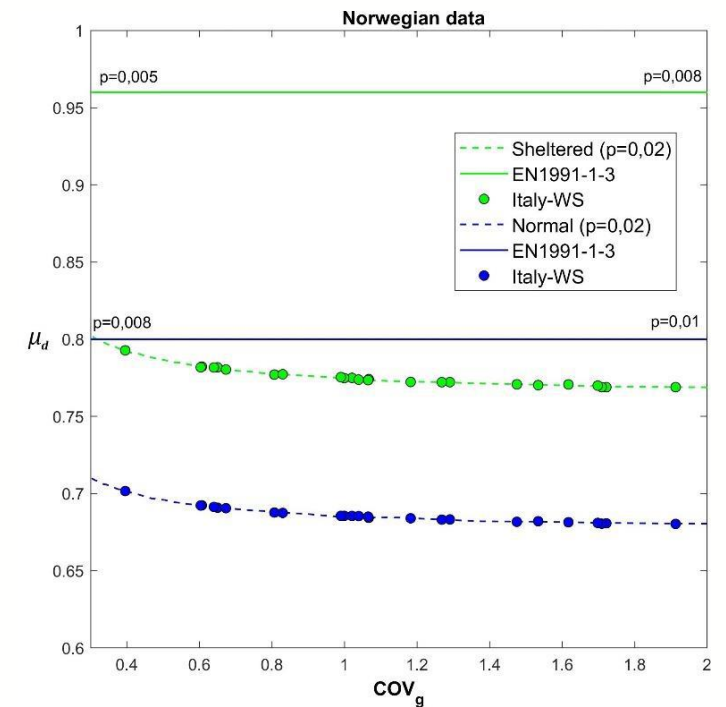
4.6. Examples

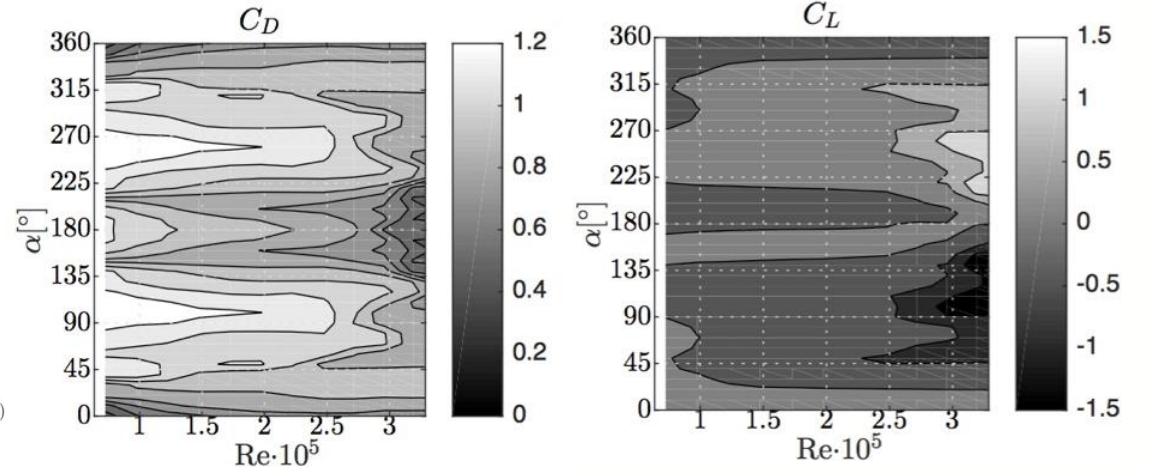
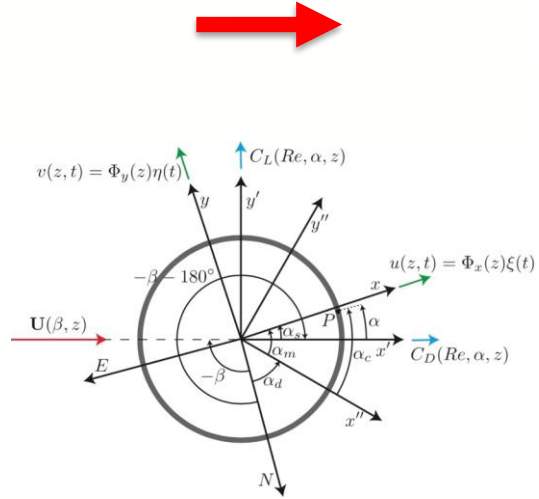
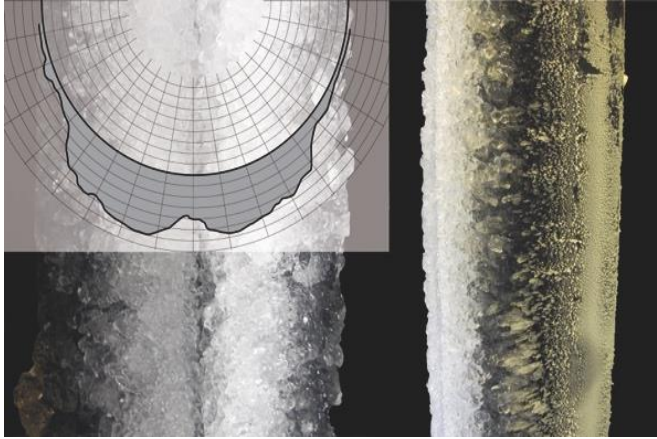
4.6.1. Snow

4.6.2. Wind

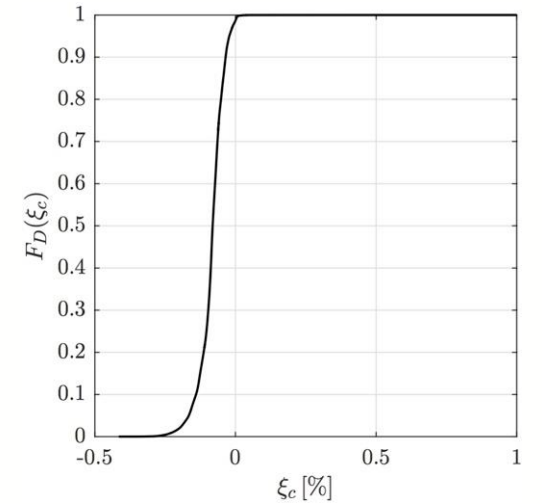
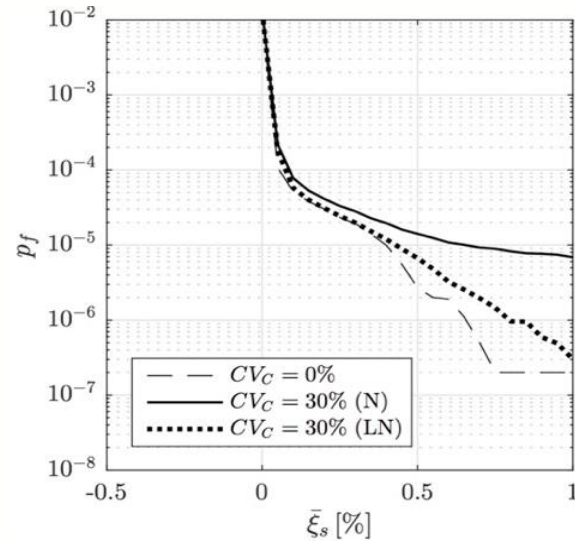
4.6.3. Temperature

4.6.4. Icing





$$f_D(\xi_c) = \int_0^{360^\circ} \int_0^{360^\circ} \int_0^\infty \int_{-\infty}^\infty \int_{-\infty}^\infty \int_0^\infty f_D(\xi_c | f_x, \kappa, \mathbf{C}, U, \alpha \alpha_s) df_x dk d\mathbf{C} dU(z_{ref}) d\alpha d\alpha_s$$



Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

62 pages

5. Calibration of partial factors

5.1. General framework

5.2. Snow action

5.2.1. *Sources of uncertainties and quantification*

5.2.2. *Probabilistic modelling of the action and combination with permanent actions*

5.2.3. *Calibration of partial factor for the action*

5.2.4. *Geographic aspects*

5.3. Wind action

5.3.1. *Sources of uncertainties and quantification*

5.3.2. *Probabilistic modelling of the action and combination with permanent actions*

5.3.3. *Calibration of partial factor for the action*

5.3.4. *Geographic aspects*

5.4. Thermal action

5.4.1. *Sources of uncertainties and quantification*

5.4.2. *Probabilistic modelling of the action and combination with permanent actions*

5.4.3. *Calibration of partial factor for the action*

5.4.4. *Geographic aspects*

5.5. Atmospheric icing action

5.5.1. *Sources of uncertainties and quantification*

5.5.2. *Probabilistic modelling of the action and combination with permanent actions*

5.5.3. *Calibration of partial factor for the action*

5.5.4. *Geographic aspects*

5.6. Examples

5.6.1. *Low rise building*

5.6.2. *Bridge*

5.6.3. *Guyed mast*

Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

$$w = \theta_w \cdot c_p \cdot c_g^2(z) \cdot c_r^2(z) \cdot c_0^2(z) \cdot q_b$$

5. Calibration of partial factors

5.1. General framework

5.2. Snow action

5.2.1. *Sources of uncertainties and quantification*

5.2.2. *Probabilistic modelling of the action and combination with permanent actions*

5.2.3. *Calibration of partial factor for the action*

5.2.4. *Geographic aspects*

5.3. Wind action

5.3.1. *Sources of uncertainties and quantification*

5.3.2. *Probabilistic modelling of the action and combination with permanent actions*

5.3.3. *Calibration of partial factor for the action*

5.3.4. *Geographic aspects*

5.4. Thermal action

5.4.1. *Sources of uncertainties and quantification*

5.4.2. *Probabilistic modelling of the action and combination with permanent actions*

5.4.3. *Calibration of partial factor for the action*

5.4.4. *Geographic aspects*

5.5. Atmospheric icing action

5.5.1. *Sources of uncertainties and quantification*

5.5.2. *Probabilistic modelling of the action and combination with permanent actions*

5.5.3. *Calibration of partial factor for the action*

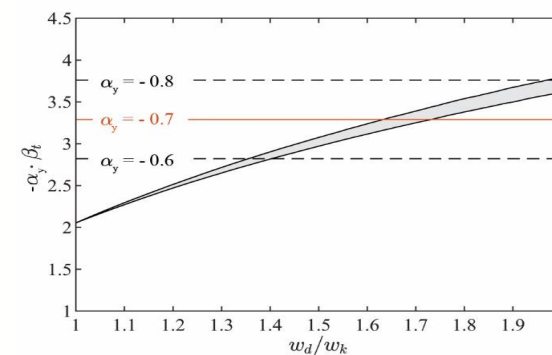
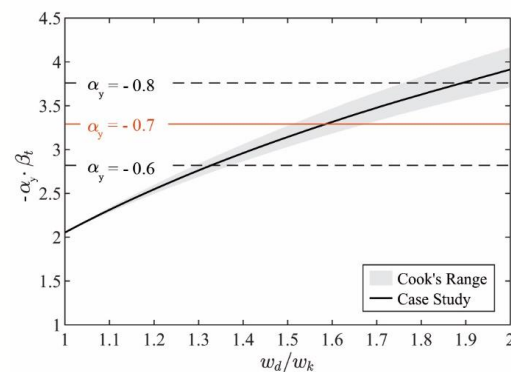
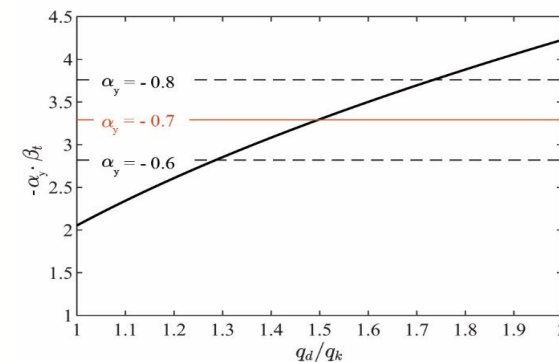
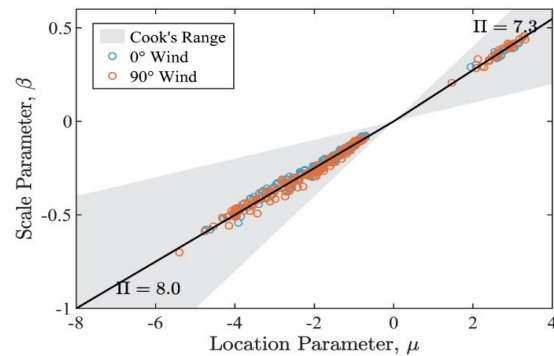
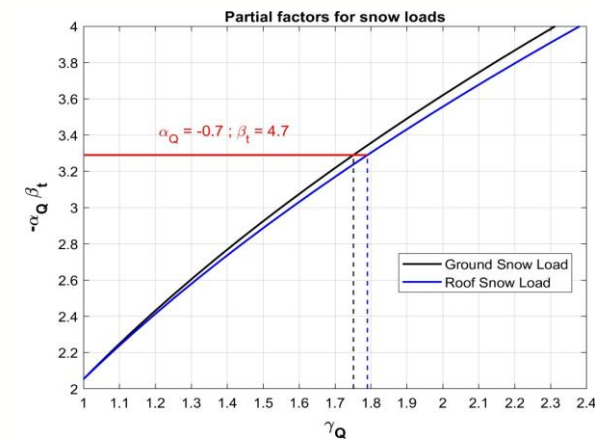
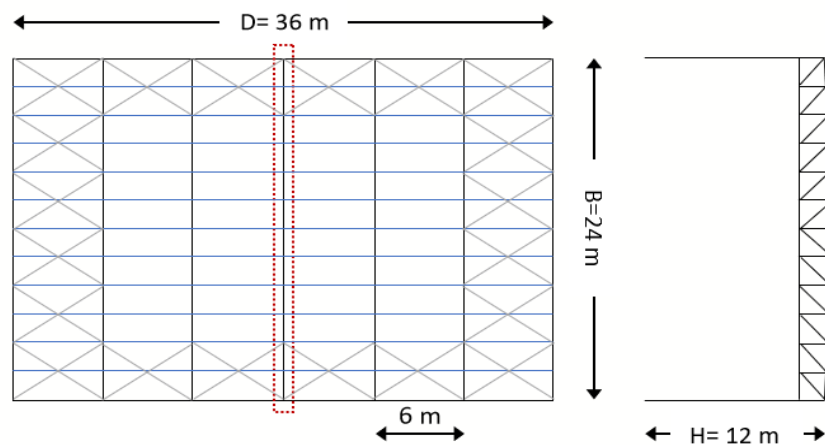
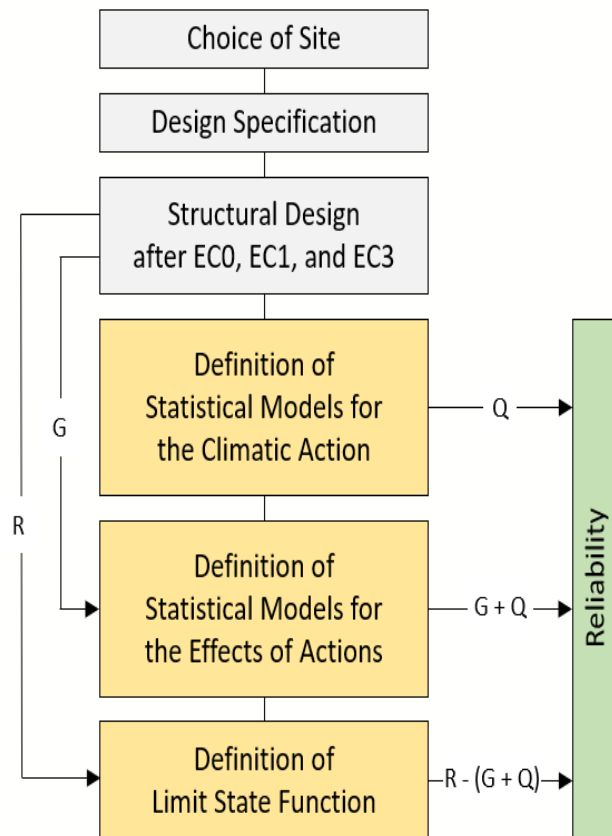
5.5.4. *Geographic aspects*

5.6. Examples

5.6.1. *Low rise building*

5.6.2. *Bridge*

5.6.3. *Guyed mast*



Probabilistic basis for determination of partial safety factors and load combination factors

BACKGROUND DOCUMENT

6. Calibration of combination factors

6.1. General framework

6.1.1. *Derivation of combination factor Ψ_0*

6.1.2. *Derivation of combination factors Ψ_1 and Ψ_2*

6.2. Combination factors for snow action

6.2.1. *Derivation of combination factor Ψ_0*

6.2.2. *Derivation of combination factors Ψ_1 and Ψ_2*

6.3. Combination factors for wind action

6.3.1. *Derivation of combination factor Ψ_0*

6.3.2. *Derivation of combination factors Ψ_1 and Ψ_2*

6.4. Combination factors for thermal action

6.4.1. *Interaction between thermal actions and other climate action*

6.4.2. *Derivation of combination factors*

6.5. Combination factors for atmospheric icing action

6.5.1. *Interaction between wind and ice loads*

6.5.2. *Combination of wind actions and ice loads*

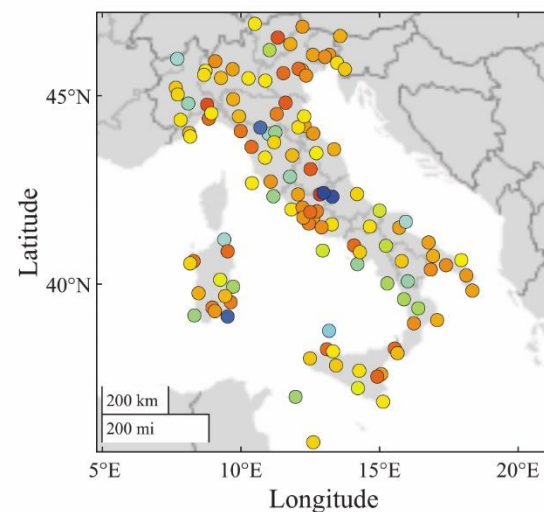
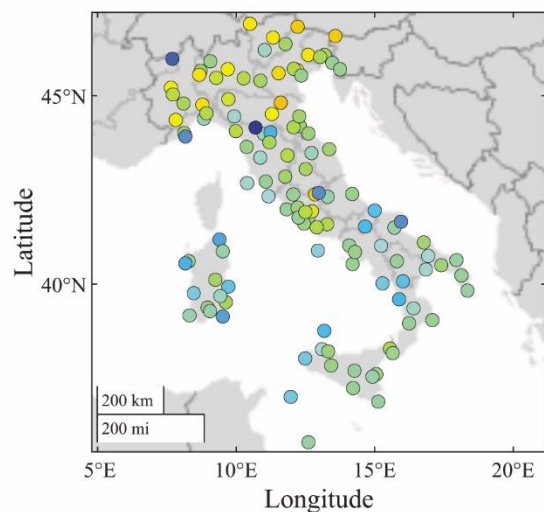
6.5.3. *Derivation of combination factor Ψ_0*

6.5.4. *Short summary*

30 pages

SCALE

SHAPE

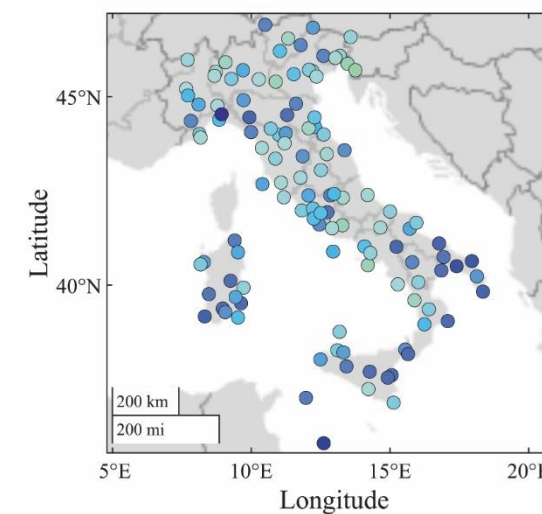
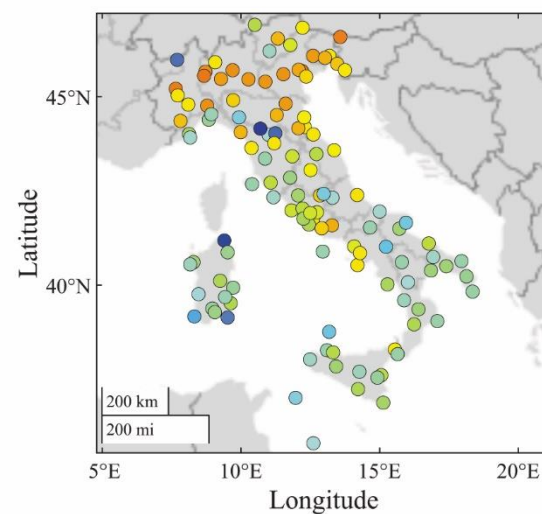


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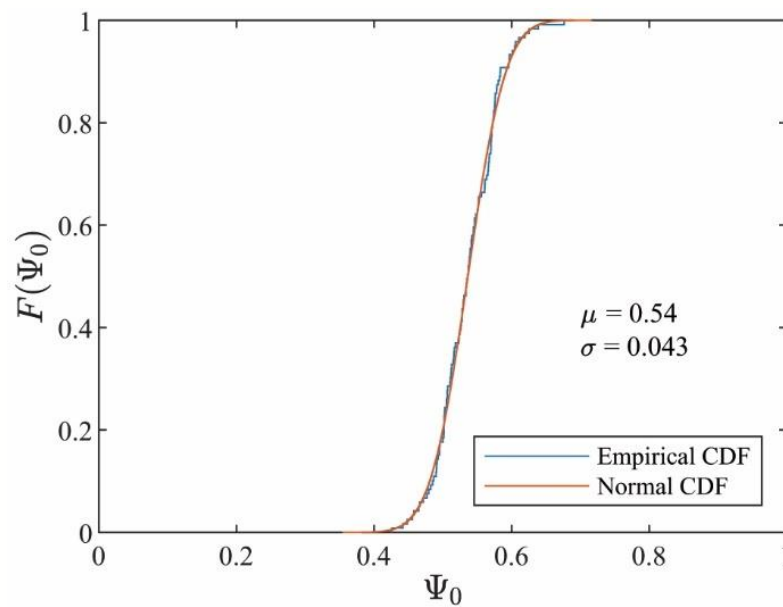
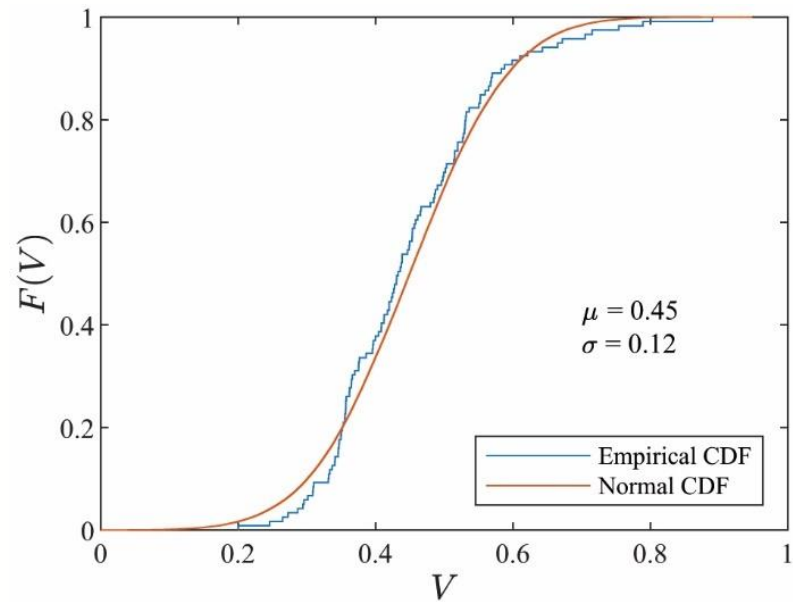
SCALE

SHAPE



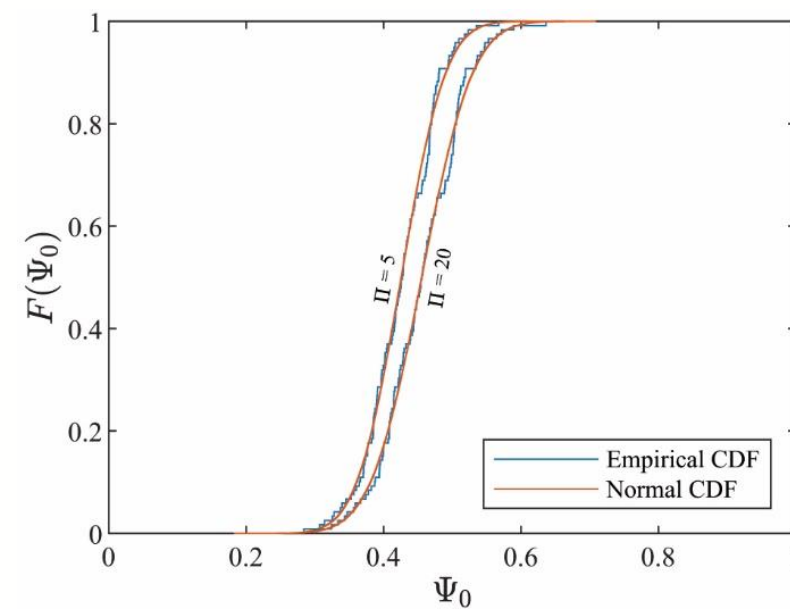
EXTREME VALUE





$$\Psi = 0.54$$

$$\Psi = 0.42 \div 0.46$$



Personal remarks (doubts)

- What degree of complexity in reliability calculations can be justified given the current level of uncertainty we have in the input variables?
- Where must we improve our input data?
- How to manage the discrepancies in Code factors when calibrated at the different levels?
- How broad a class of structures can be when the way the (climatic) action manifests itself rapidly changes from one structure to another?