Comparison of results from dispersion models for regulatory purposes based on Gaussian and Lagrangian algorithms: an evaluating literature study

9th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes

Garmisch-Partenkirchen, 01. - 04.06. 2004

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German Federal Office for Radiation Protection

(Bundesamt für Strahlenschutz, BfS)

Tasks

- radiation protection
- safety in nuclear engineering
- transportation and safekeeping of nuclear fuel
- radioactive waste disposal

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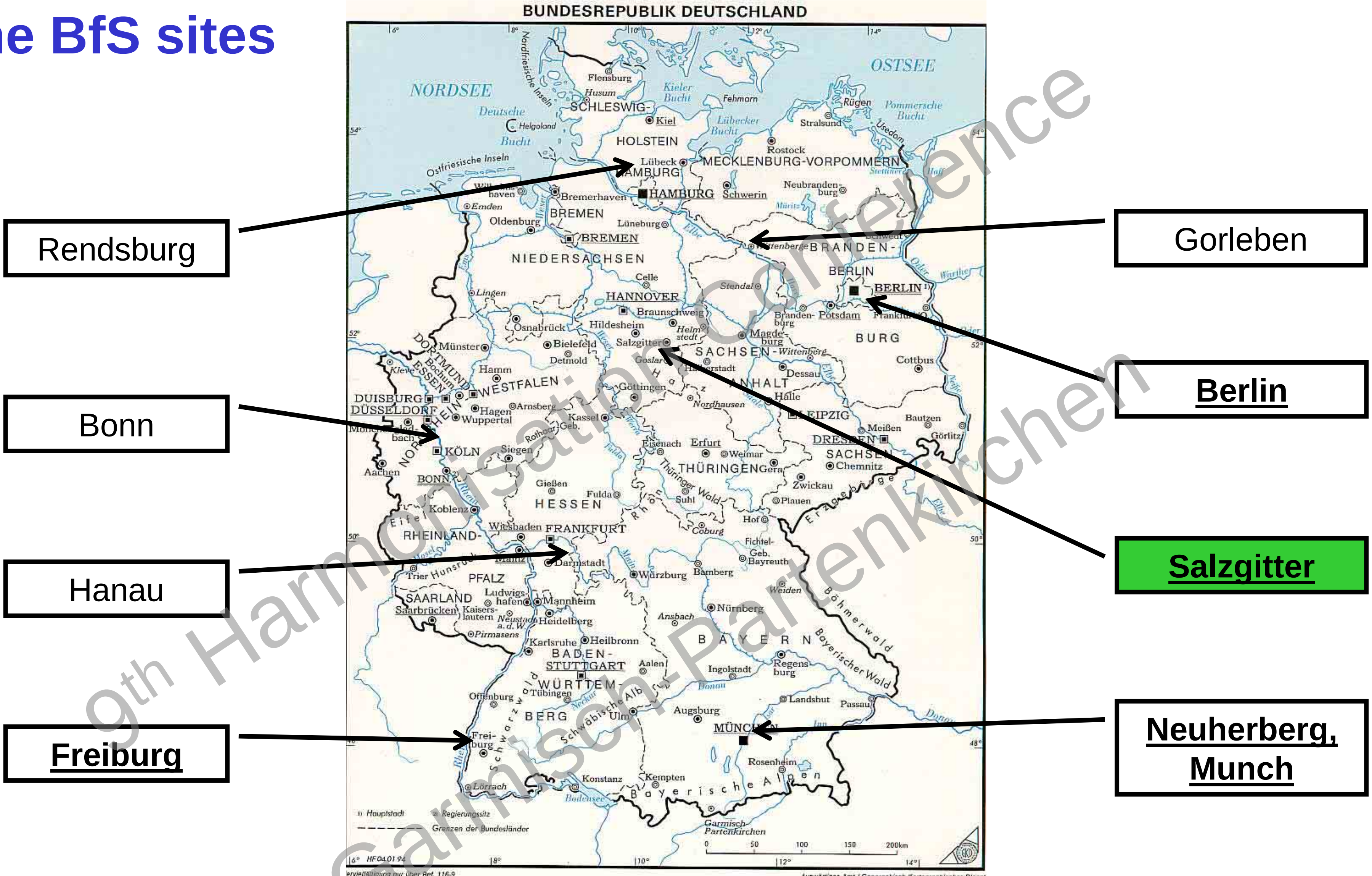
The BfS sites



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BfS has responsability for

nuclear power plants in the Federal Republic of Germany

- reactor in operation
- reactor shut down or shut down is decided

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BfS has responsability for

nuclear research reactors in the Federal Republic of Germany

- reactor in operation
- reactor shut down or shut down is decided
- reactor under construction

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BfS has responsability for

<u>supply and disposal of nuclear material</u> in the Federal Republic of Germany

- facility in operation
- facility shut down or shut down is in progress

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Computational procedures for radiation exposure after emission in the atmosphere

measurement, basic data

emission
meteorology
topography
orography

→

dispersion

preprocessors for determination of
u_* z_0 L_* z_H

Gaussian model
Gaussian puff model,
Lagrangian particel model,
Eulerian model

→

radioecology + emergency preparedness

models for radioecology and emergency preparedness

↓

data and graphics
for statements to radioecology
and emergency preparedness;
assessment of the radiation exposure

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Computational procedures for radiation exposure in Germany

legal procedures

- **AVV** (Technical guideline for computation of radiation exposure during normal operation)
- **SBG** (Technical guideline for computation of radiation exposure during emergencies)
- **expert systems (e.g. RODOS, ...)**

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Gaussian model in German legal procedures

Gaussian dispersion of concentration

(total reflection from surface)

$$\bar{c}(x, y, z) = \frac{Q_0}{2\pi \cdot u_x \cdot \sigma_y \sigma_z} \exp\left[-\frac{y^2}{2\sigma_y^2}\right] \cdot \left\{ \exp\left[-\frac{(z-H)^2}{2\sigma_z^2}\right] + \exp\left[-\frac{(z+H)^2}{2\sigma_z^2}\right] \right\}$$

- **$\bar{c}$:** **concentation**
- **Q_0:** **source strength**
- **σ_y, σ_z:** **dispersion parameters (variance of Gaussian distribution), measured or derived from $\sigma_{v,w}$**
- **u_x :** **medium transportation velocity**
- **H:** **height of plume axis (effective emission height)**
- **x, y, z:** **Cartesian coordinates of emision point, with y and z orthogonal to wind direction**

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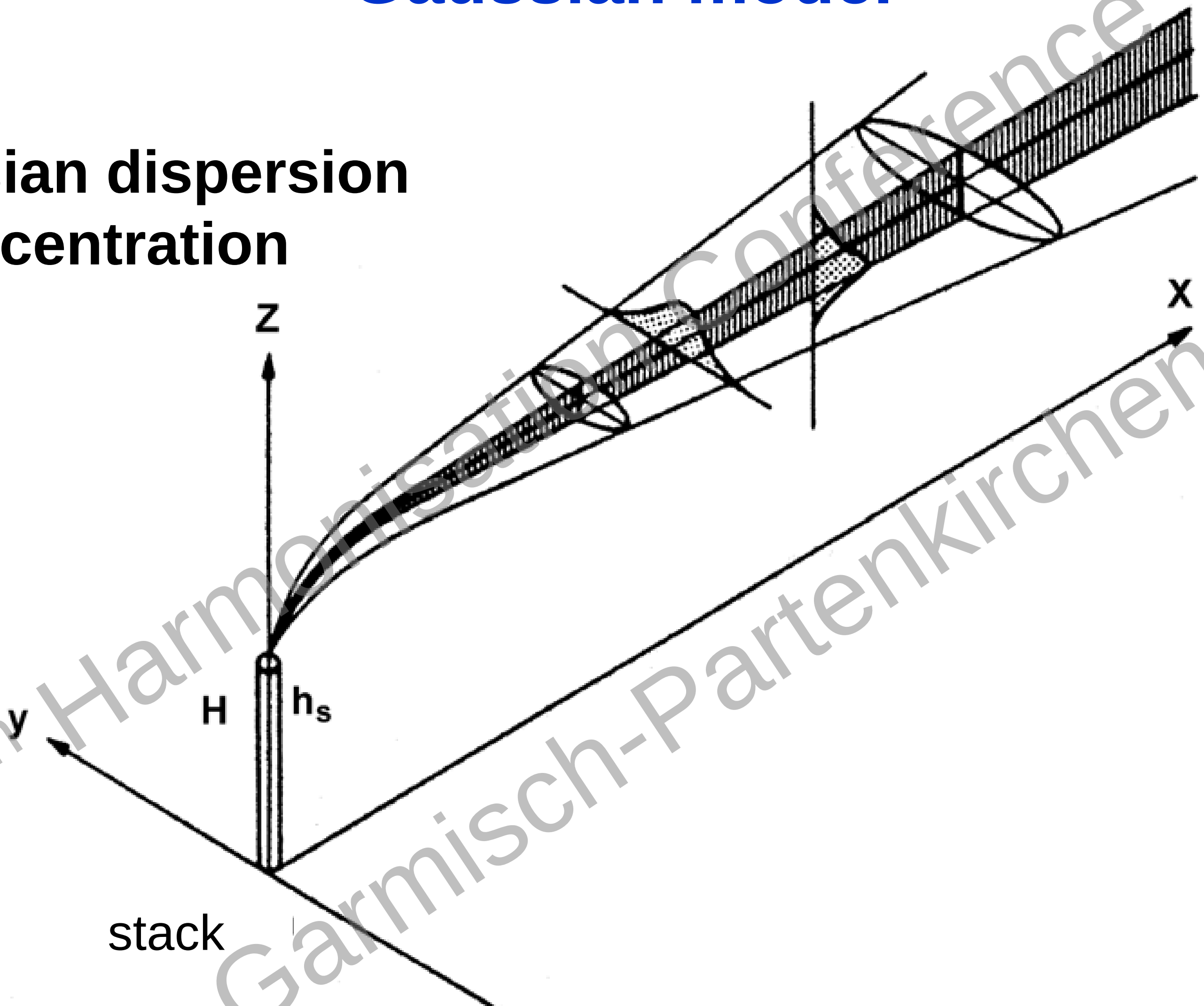
Gaussian model

Gaussian dispersion of concentration



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real dispersion conditions

differ a lot from Gaussian model assumptions

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Gaussian model

generally not considered:

- windprofile
- height dependance of windvector (Ekmann-spiral)
- windshear
- local / regional windsystems
- short term / explosive releases
- inhomogeneous surface roughness
- low inversions
- inhomogeneous / instationary turbulence
- low wind speed (high pressure area)

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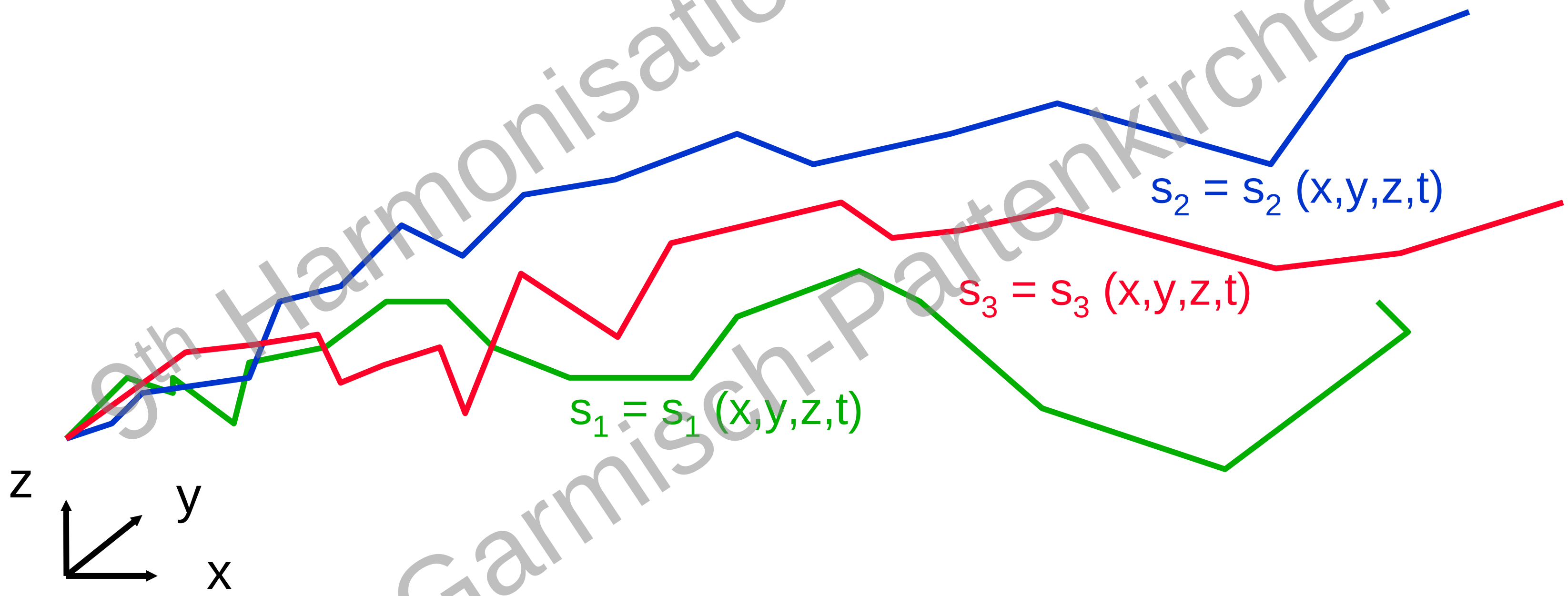
Possible alternative: Lagrangian model

particle model, consideration of (different) particle trajectories



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Lagrangian model, basic procedures

$$x_{n+1} = x_n + \Delta t \cdot (\overline{u}_n + u_n' + \hat{u}_n)$$

- **mean wind velocity**
  advection (large scale processes)
- **turbulent wind velocity**
  „directed" turbulence (~ Lagrangian correlation time)
  + stochastic turbulence
- **additional wind velocity**
  description of external processes (e.g. sedimentation, inhomogeneous turbulence)

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Lagrangian model

advantage / disadvantage

advantage

- **several meteorological and physical effects can be considered more intensively**

disadvantage

- **additional parameters necessary resp. available (L_*, u_*, z_0, d, T, turb. heat flux, turb. flux for momentum)**
- **air flow model necessary**
- **additional measurement data**

But : SODAR, diagn. / prognostic models

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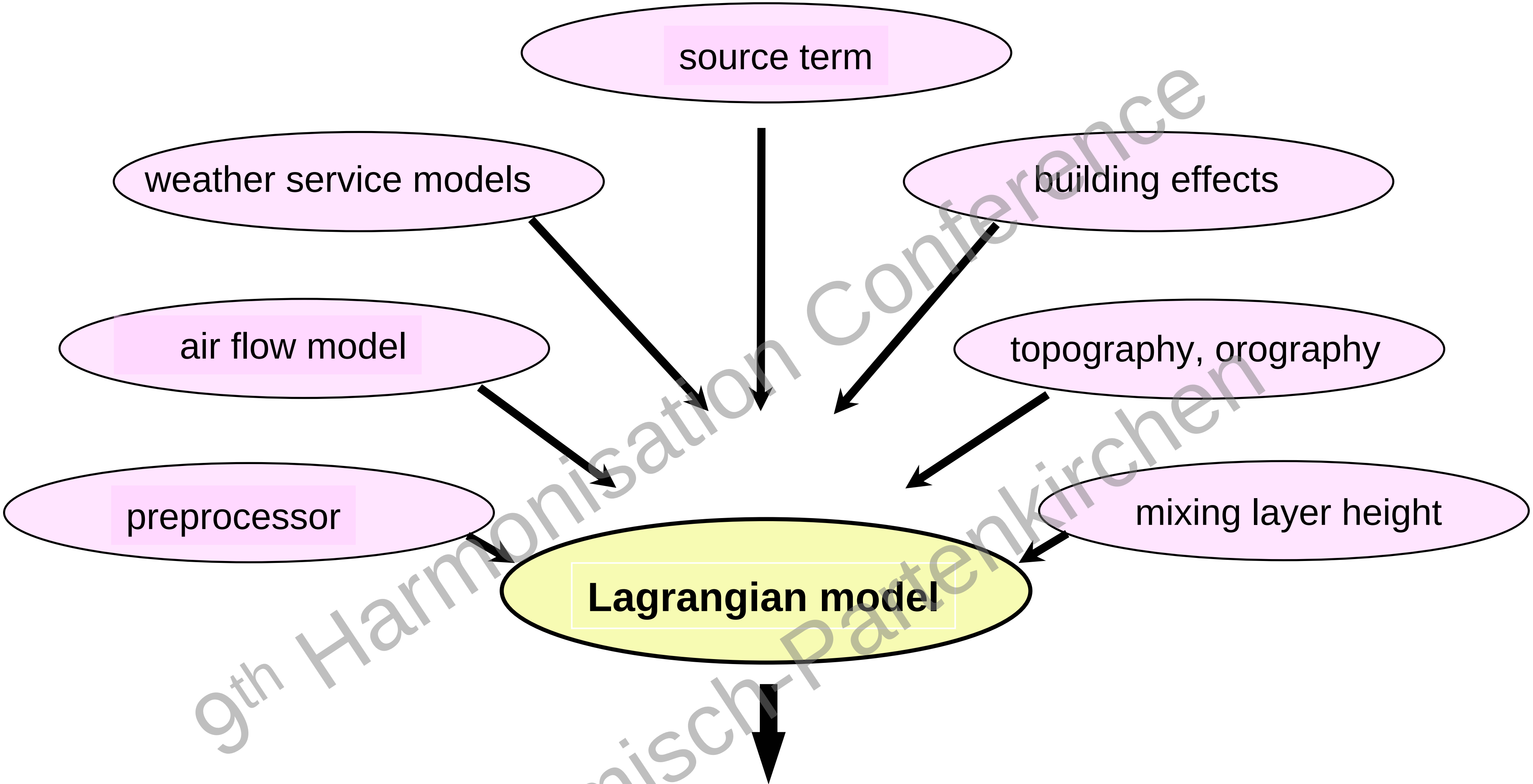

results close to reality
EURATOM Guidelines 96/29 !

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Gaussian model ⟷ Lagrangian model

GM | LPM

↓

Comparative considerations

(literature study)

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Comparative considerations (literature study)

[Glaab, 1986]

comparison of

German Clear Air Regulation(TA Luft) with Lagrangian model

- **flat terrain**
- **source distance up to 5000 m**
- **point sources in different heights**

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Comparative consideration

[Glaab, 1986]

isolines of

surface concentrations

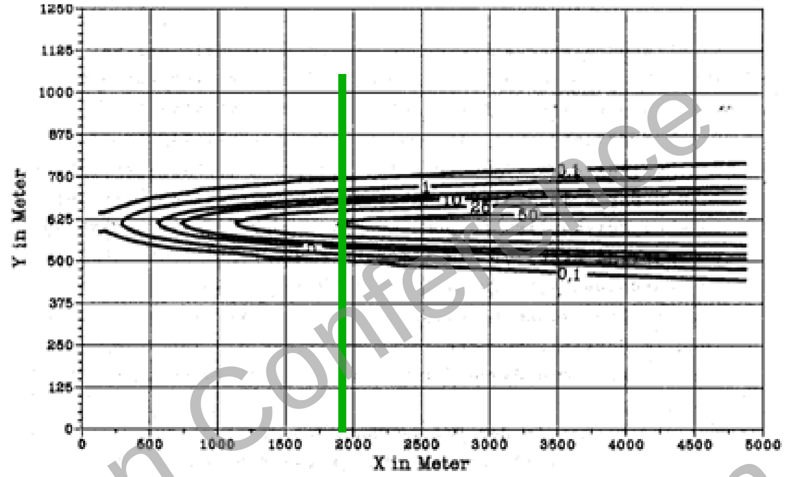
[μg/m³]

e.g. distance of

isoline 50 μg/m³

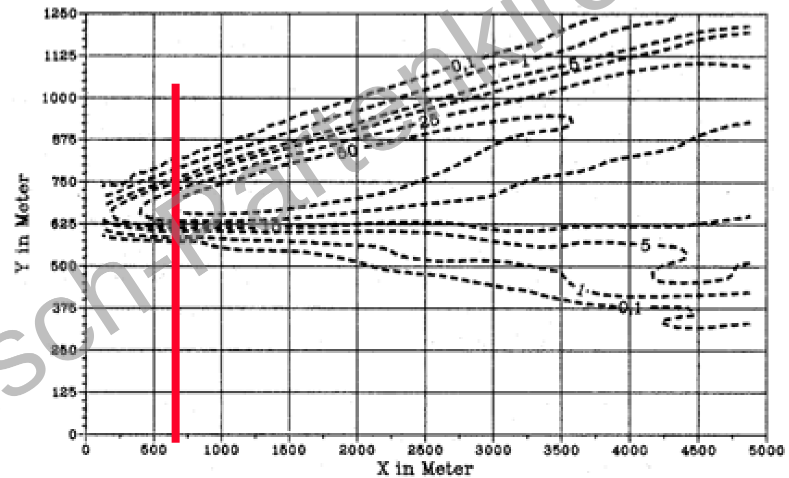
from source

source height 21 m



Gauß

figure 13a$_1$: surface concentrations in μg/m³ (dispersion class I, Gaussian method)



Lagrange

figure 13a$_2$: surface concentrations in μg/m³ (dispersion class I, particle model)

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Comparative consideration

[Glaab, 1986]

profiles along axis with max. surface concentrations

[µg/m³]

source height 21 m

stability

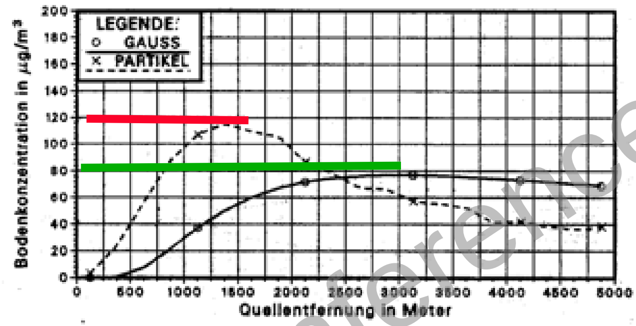

figure 14a : profiles along the axis of maximal surface concentration as a function of source distance (dispersion class I) ➔ **F**

I F

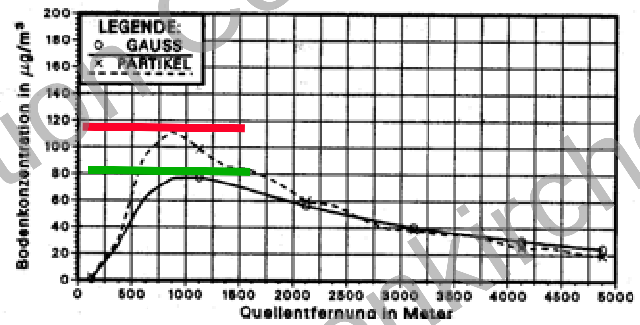

figure 14b : profiles along the axis of maximal surface concentration as a function of source distance (dispersion class II) ➔ **E**

II E

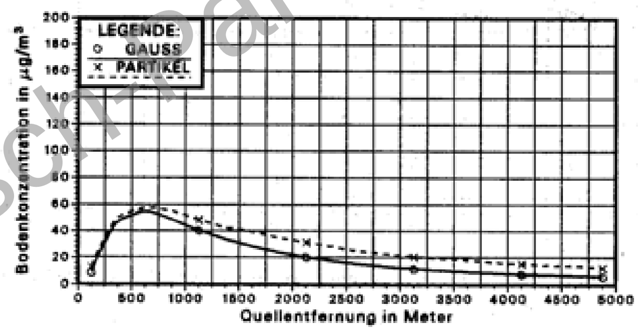

figure 14c : profiles along the axis of maximal surface concentration as a function of source distance (dispersion class III_1) ➔ **D**

III_1 D

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Comparative considerations
[Glaab, 1986]

general conclusions:
the Lagrangian model computes in

- **stable case**
  position of high concentrations closer to source,
  significant higher ground surface concentrations

- **unstable case**
  lower concentrations close to source
  higher values in greater distance

- **greater differences when sources are close to surface**

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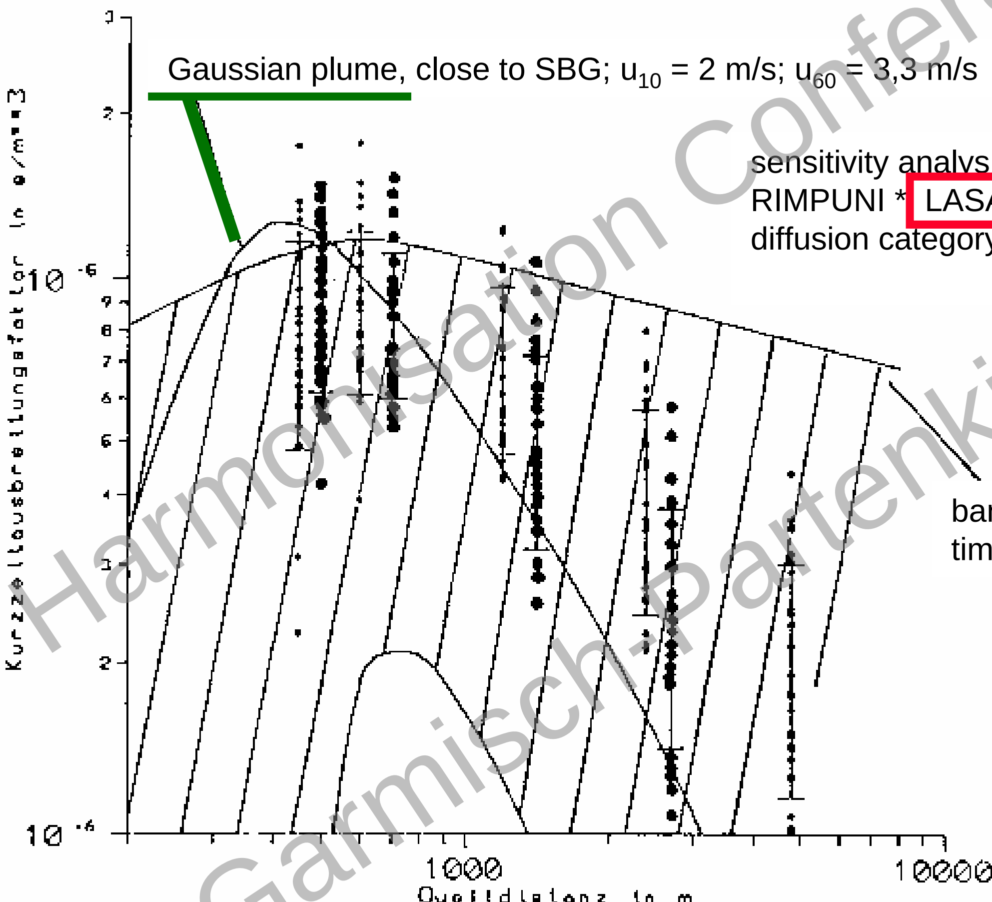
Comparative considerations (literature study)

[Martens et al 1993]

short time dispersion coefficient under the plume axis



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Comparative considerations (literature study)

[Martens et al 1993]

results:

- all models are practical to describe <u>average</u> conditions
- average parameters of boundary layer (like in GM) are not suited for consideration of individual cases
- parameters of boundary layer (u_*, L, z_0, m_H) like in LPM describe better the situation of stability than categories of diffusion

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Comparative consideration Gaussian and Lagrangian model

[Janicke, 2001 a]

comparison of

- **GuidelineTA Luft (AUSTAL 86 based on GM) with**
- **advanced model system**
  Lagrangian particle model LASAT

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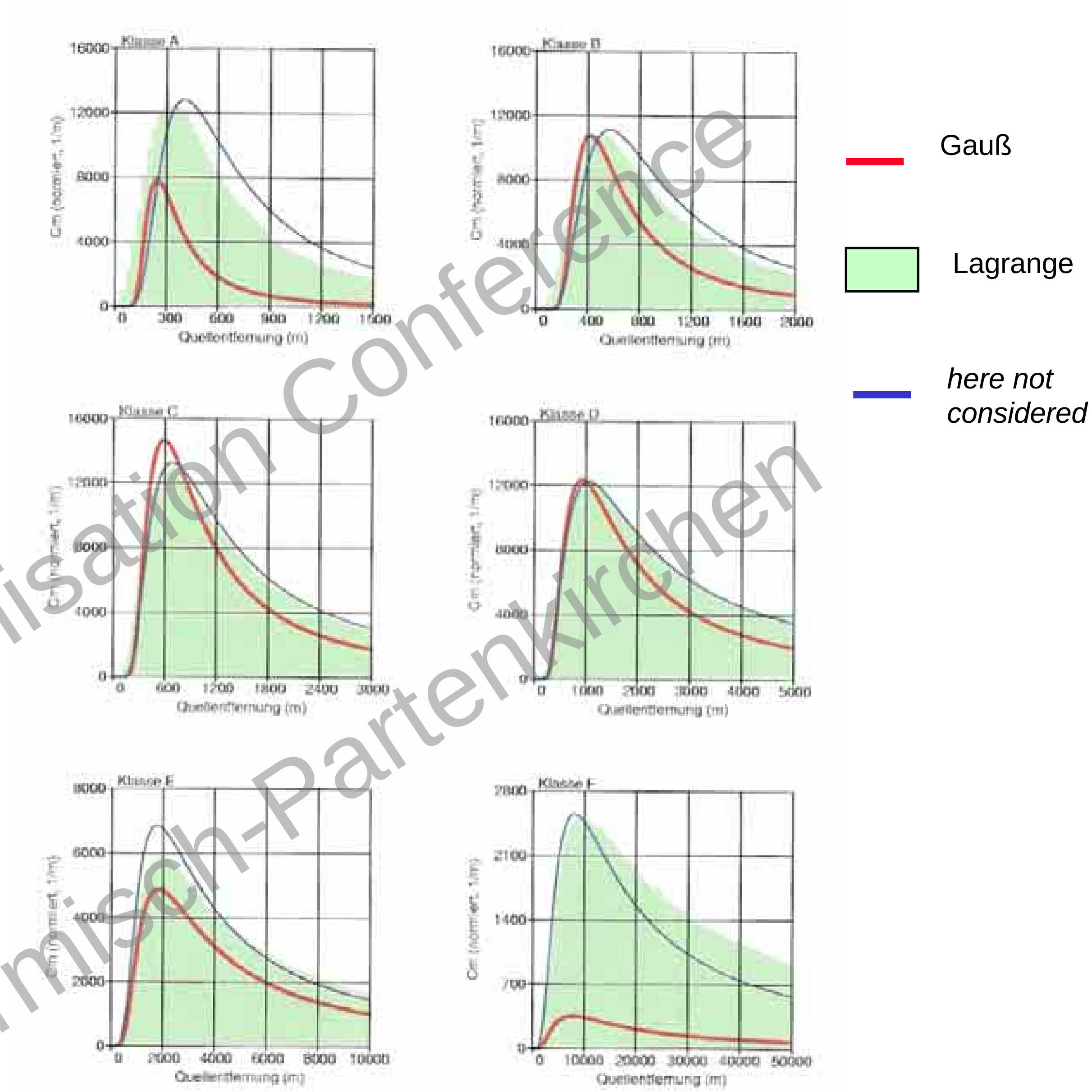
Comparative consideration

GM - LPM

[Janicke, 2001 a]



normalized
maximum concentration

source height 100 m

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Comparative consideration

[Janicke, 2001 a]

results:

- **it is possible to reproduce GFM results with LPM**
- **single situation: don‘t use Gaussian model**
- **longterm computations: Gaussian model is good for plain terrain and lifted sources**

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Comparative consideration

[Janicke, 2001 b]

Gaussian model (AUSTAL 86) and
Lagrangian model (AUSTAL 2000)

basis:

statistic of stability class	**1951 - 1969**
source heights	**100 m, (50 m) and 25 m**
roughness lengths	**1.5 m, 1.0 m and 0.5 m**

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Comparative consideration

[Janicke, 2001 b]

source height 100 m

AUSTAL86

J \ I	14	15	16	17	18	19	20	21	22
22	14	17	22	30	36	34	30	28	26
21	14	17	22	30	39	37	34	32	29
20	16	18	21	26	33	34	37	35	28
19	20	22	22	15	10	21	32	30	26
18	23	26	27	11	0	8	25	27	24
17	20	23	24	20	10	16	23	24	22
16	17	20	23	25	26	23	22	20	18
15	16	18	21	23	25	22	20	18	16
14	15	16	18	20	21	19	17	15	14

AUSTAL2000, $z_0 = 1.5\,\mathrm{m}$

J \ I	1	2	3	4	5	6	7	8	9
9	9	13	17	23	30	29	25	23	20
8	11	16	19	28	37	36	31	31	25
7	13	16	17	22	33	32	34	35	25
6	18	21	19	15	16	24	31	29	21
5	20	25	26	15	3	14	23	26	20
4	16	20	21	20	15	15	20	22	18
3	14	18	21	22	24	21	19	18	15
2	13	17	19	21	23	21	18	16	13
1	10	14	15	16	18	16	14	13	10

AUSTAL2000, $z_0 = 1.0\,\mathrm{m}$

J \ I	1	2	3	4	5	6	7	8	9
9	10	12	16	22	29	29	24	23	20
8	10	13	17	24	33	32	28	29	26
7	13	14	15	18	28	27	30	30	23
6	16	19	17	13	14	19	26	26	21
5	20	24	22	14	2	10	20	23	19
4	15	19	19	17	13	13	18	20	17
3	13	17	20	20	21	18	18	17	14
2	13	17	18	20	21	19	17	15	12
1	10	13	14	16	17	16	14	12	9

AUSTAL2000, $z_0 = 0.5\,\mathrm{m}$

J \ I	1	2	3	4	5	6	7	8	9
9	10	12	16	20	27	25	21	20	20
8	10	12	15	20	26	26	22	25	25
7	11	13	12	15	21	21	24	26	21
6	16	17	14	10	11	14	19	21	18
5	19	21	21	13	1	9	16	19	19
4	16	17	17	16	11	11	14	17	16
3	12	15	17	18	18	16	15	14	14
2	12	15	16	17	18	17	15	14	12
1	10	14	14	16	17	15	13	11	10

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Comparative consideration

[Janicke, 2001 b]

source height 25 m

AUSTAL86

J \ I	0	1	2	3	4	5	6	7	8
8	22	27	35	47	55	49	39	33	29
7	24	30	40	58	75	63	50	42	34
6	29	34	44	70	110	87	68	49	35
5	37	45	54	75	146	128	79	48	34
4	43	55	77	102	0	102	70	46	33
3	38	46	58	81	93	75	54	39	29
2	31	39	49	59	65	53	41	31	24
1	29	35	40	43	45	39	32	26	21
0	26	29	31	33	34	31	26	22	19

AUSTAL2000, $z_0 = 1.5\,m$

J \ I	1	2	3	4	5	6	7	8	9
9	22	41	51	72	90	74	53	45	33
8	35	57	79	121	154	117	90	76	46
7	40	67	97	161	247	172	132	90	48
6	60	98	130	204	408	273	159	91	48
5	73	129	200	305	332	265	145	88	47
4	57	98	144	229	260	182	111	76	41
3	44	81	122	148	160	121	88	57	34
2	44	71	86	92	104	87	65	48	30
1	38	43	51	52	60	47	39	34	20

AUSTAL2000, $z_0 = 1.0\,m$

J \ I	1	2	3	4	5	6	7	8	9
9	31	43	55	76	94	82	56	47	36
8	37	56	73	110	143	115	87	78	56
7	44	63	87	132	196	146	121	93	53
6	61	88	103	131	242	206	139	87	50
5	80	118	161	175	75	167	122	85	50
4	60	89	113	148	157	126	97	71	46
3	50	77	106	116	124	100	75	55	36
2	45	73	79	84	89	75	63	49	29
1	41	48	51	55	61	53	44	35	28

AUSTAL2000, $z_0 = 0.5\,m$

J \ I	1	2	3	4	5	6	7	8	9
9	28	36	44	61	76	70	55	46	39
8	30	36	49	73	102	86	66	63	52
7	32	42	50	79	124	98	89	73	48
6	48	56	57	61	105	116	92	60	44
5	52	73	85	76	14	76	77	59	42
4	40	52	61	75	68	63	62	51	40
3	32	48	61	67	73	60	52	41	30
2	34	47	50	51	57	50	45	37	30
1	33	38	38	44	42	38	34	31	27

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Comparative consideration

[Janicke, 2001 b]

results:

- **at source height 100 m: relative good similarity**
- **differences between GM and LPM increase with smaller source height**
- **single situations: partial considerable differences (z_0 !)**

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Comparative consideration

[Thehos et al, 1994]

Gaussian model (TA Luft) and air flow / Lagrangian model FITNAH / LPDM

basis:

statistic	**1944 single situations / 150 Cluster**
source heights	**75 m (computed with raised plume)**
areas	**Biebesheim, Kassel (cities in Germany)**

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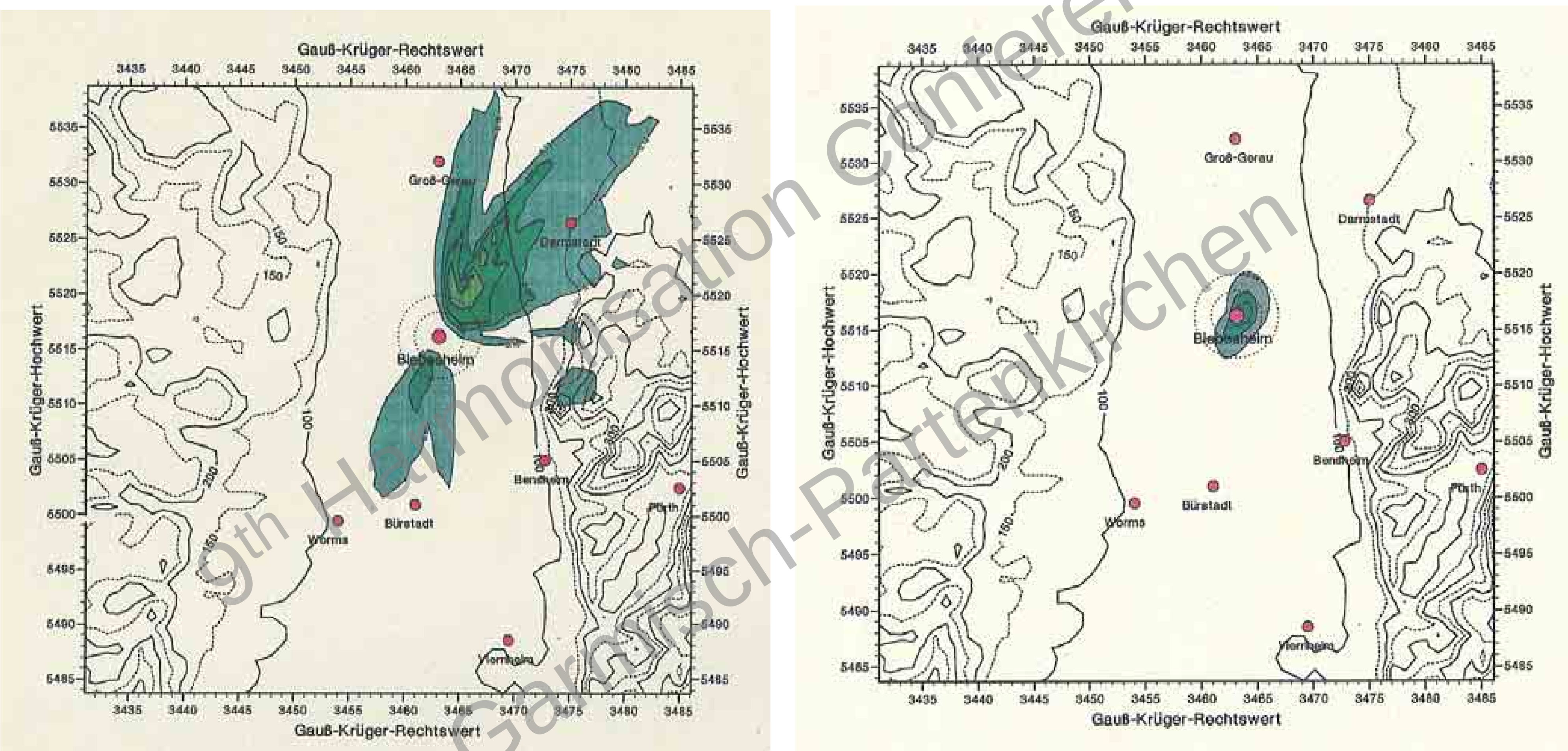
Comparative consideration [Thehos et al, 1994]

direct comparison homogeneous orography



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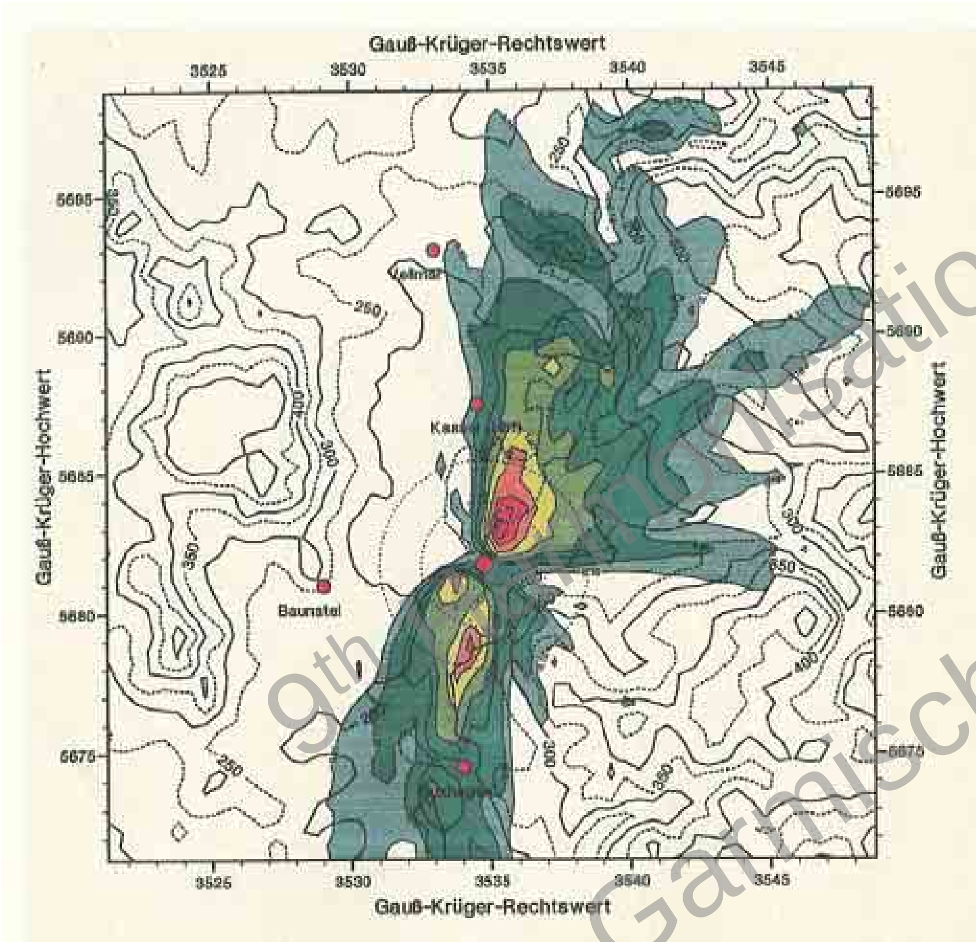
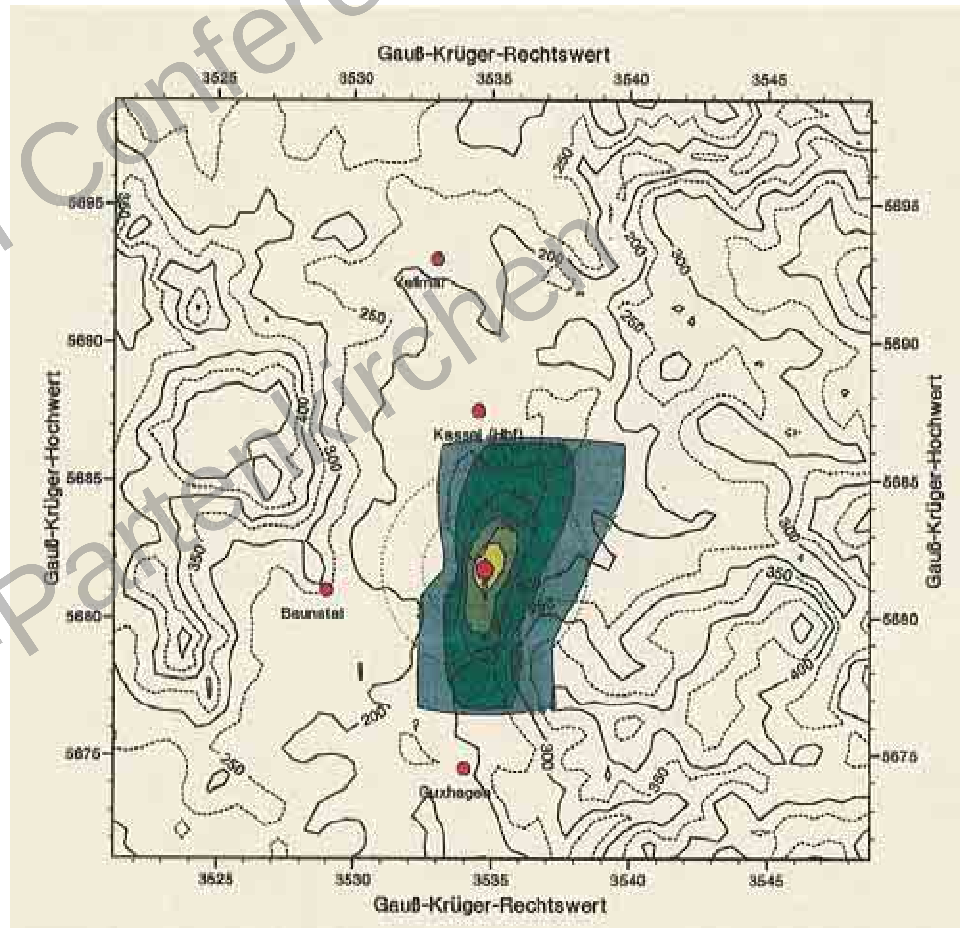
Comparative consideration [Thehos et al, 1994]

direct comparison structured orography





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Comparative consideration [Thehos et al, 1994]

results:

- **plain:** **height of maximum complies good; position of maximum at LPM farther**
- **not plain:** **great differences**

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Summary of the literature study

- **Gaussian models have partially severe constraints that can not be solved generally**

- **Gaussian models show especially deficits in situations with**
  - **instationarity (windfield, source)**
  - **orography**
  - **sources with low height**

- **Lagrangian models have greater significance because of their stronger physical contents**

- **Lagrangian models have been introduced in dispersion calculations in Germany for conventional pollutants**

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Summary

recommendation:

further examination of the
<u>introduction of Lagrangian models</u>
in regulation guidelines for radioactive pollutants
in Germany

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