BOKU

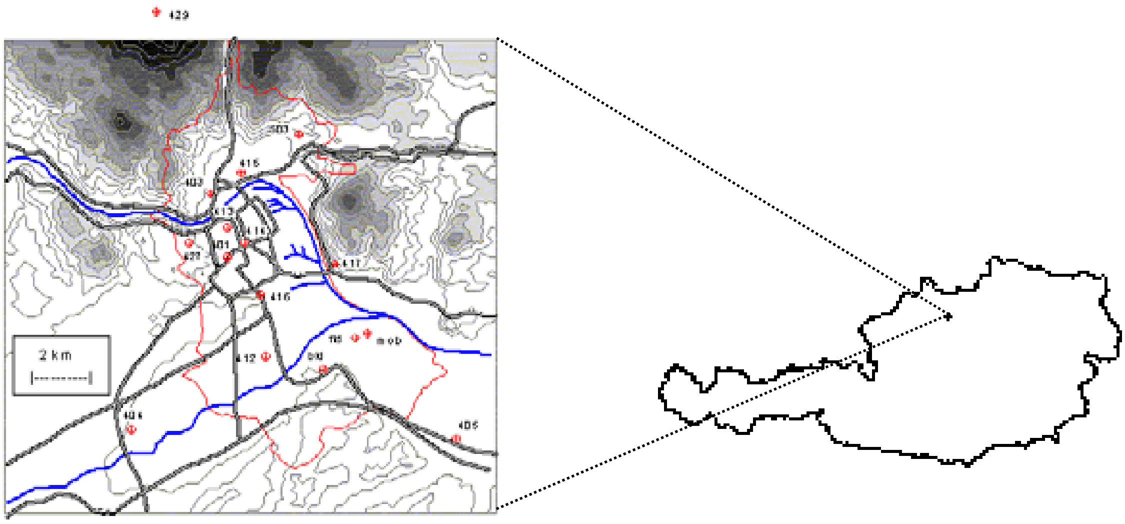
Universität für Bodenkultur Wien

Institut für Meteorologie

und Physik

Klimauntersuchung Linz - Basisstudie

Belüftungsrelevante Grundlagen



401: Hauserhof (auf dem Dach eines 40 m hohen Gebäudes, Innenstadt)
403: BH-Urfahr (Wohngebiet nördlich der Donau)
404: Traun (Wohngebiet)
405: Asten (Ländlicher Bereich)
412: Kleinmünchen (1500 m von der Industrie entfernt, südlich des Stadtzentrums, im Randbereich eines dichten Waldes)
413: Ursulinenhof (Nahe Stadtzentrum, Parkplatz)
414: ORF-Zentrum (2 km zur Industrie, Wohngebiet)
415: 24er-Turm (Nähe Autobahn)
416: Berufsschulzentrum (700 m von der Industrie entfernt, am Dach eines Gebäudes)
417: Steyregg (Weizenfeld, östlich der Stadt, starker Immissionseinfluss von der Industrie)
427: Freinberg (Turm 150 m hoch, Fußpunkt 380 m ü.d.M.)
429: Giselawarte (Wald, Messstelle 23 m über Grund)

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Anhänge

A) Lage und Charakteristik der Messstellen des Umweltmessnetzes

B) Chapter 5: Wind Patterns in Linz. Aus „Modelling of Pollutant Transport and Dispersion for Operational Use over Urban Area with Complex Terrain Surrounding“; Dissertation von Prabha T. V., 1996, Universität für Bodenkultur

C) Atmospheric de-coupling effects and their consequences for city ventilation. Mursch-Radlgruber, E., Prabha, T.V., 1996, Beitrag zur ICUC (International Conference on Urban Climatology, Essen).

1 Zusammenfassung

Durch eine ausführliche klimatologische Analyse des Datenmaterials der Umweltmessstellen konnten die grundlegenden Strukturen im Linzer Raum beschrieben werden. Dabei wurde

- einerseits von Korrelationen mit Wetterlagentypen ausgegangen und
- andererseits eine Typisierung der Strömungsstrukturen durch objektive diagnostische Analyse vorgenommen.

Beide Analysenmethoden zeigen klar, dass die Strömung mit Hauptrichtung aus Südsüdost zu den geringsten Windgeschwindigkeiten im Stadtbereich führten.

Die *Oberflächenstruktur* ist für die mittlere Belüftung des Stadtgebietes der *wesentlichste Parameter.* Durch eine Analyse der Oberflächenstruktur des gesamten Untersuchungsgebietes mit einem Geographischen Informationssystem konnten grundlegende Zusammenhänge zwischen der Struktur der Bebauung, dem Muster der Temperaturverteilung und der Lage im Gelände (z. B. Hanglage) erarbeitet werden. Aus den gefundenen Zusammenhängen ergab sich eine quantitative Darstellung der Temperaturverteilung zu verschiedenen Tages- und Jahreszeiten.

Neben den Grundlagenanalysen wurden noch die atmosphärischen Strukturen für die modellhafte Bearbeitung von Transportvorgängen aufbereitet und durch reale Fallstudien überprüft.

Mit den für die Analyse angewendeten einfachen Verfahren lassen sich bereits wesentliche Grundzüge für die Belüftungssituation im Stadtgebiet von Linz erkennen, obwohl es *für konkrete Maßnahmen* notwendig ist, noch *Detailstudien* durchzuführen. Es muss ebenfalls angemerkt werden, dass durch das Fehlen von Datenmaterial in manchen Bereichen größere Unsicherheiten gegeben sind.

Es kann daher empfohlen werden, auf der Basis dieser Analysen Detailuntersuchungen für konkrete Planungsaufgaben durchzuführen, bei denen Methoden für den kleinskaligen Bereich der Bebauung entwickelt und angewandt werden. Dabei ist in erster Linie eine Vertiefung des Verständnisses von

- Kaltluftbewegungen,
- Kaltluftlagerungen,
- Wechselwirkung der Hangbereiche mit der Wärmeinsel des Stadtbereiches

anzustreben. Da der vertikale Aufbau der bodennahen Atmosphäre der für die Ausbreitung von Schadstoffen wesentlichste Parameter ist, sollte die Datengrundlage durch Erhebung kontinuierlicher Profile mit modernen Fernerkundungsmethoden angestrebt werden. Dadurch sollte es möglich werden, für konkrete Planungsaufgaben die notwendigen Entscheidungshilfen für eine zukunftsorientierte Planung zu gewährleisten.

2 Einleitung und Problemstellung

In den letzten Jahren haben Stadtklimaanalysen immer größere Bedeutung erlangt. Dabei steht in erster Linie die Charakterisierung des städtischen Raumes im Hinblick auf

- Belastungen durch Luftverschmutzung
- hohe Temperaturen

im Mittelpunkt. Die von der klimatologischen Analyse wünschenswerten planerischen Hinweise haben vor allem die Aufgaben, die lufthygienische Situation zu verbessern. Ausschlaggebend für die lufthygienische Situation sind neben der Emissionssituation die klimatologischen Strukturen in erster Linie die Windverteilung und die Stabilitätsverhältnisse der Luftschichtungen. Erst dadurch ist eine Beurteilung von planerischen Maßnahmen möglich. Um diese Voraussetzungen zu schaffen wurde eine Basisanalyse des Datenmaterials der im Raum Linz installierten Stationen des o.ö. Luftgütemessnetzes durchgeführt. Ziel war die Beschreibung der für die Durchlüftung prägenden Strukturen anhand der Messdaten durch klimatologische Analysen einerseits und durch Modellbetrachtungen andererseits. Abbildung 1 zeigt den Großraum Linz mit den wesentlichen Oberflächenstrukturen.

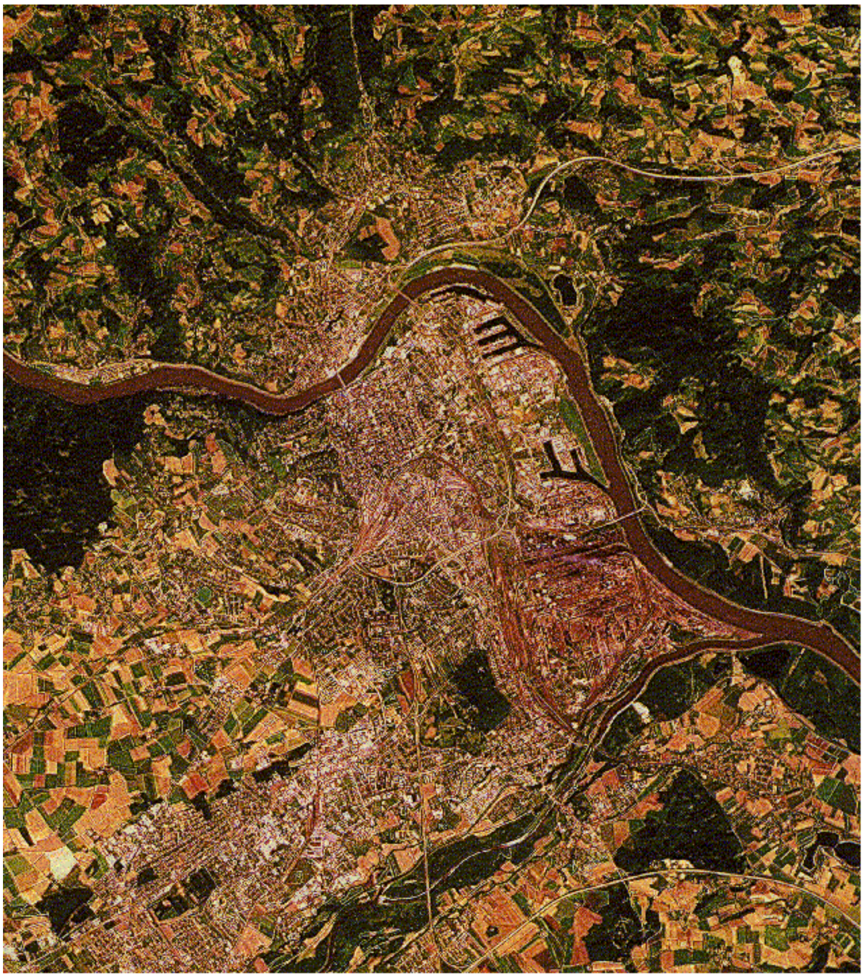


Abbildung 1: Satellitenbild von Linz mit Umgebung (NOAA Thematic Mapper)

3 Arbeitsprogramm und Analysenmethode

Die Untersuchung wurde in mehrere Abschnitte gegliedert.

1. Zuerst wurde das gesamte Datenmaterial des Luftgütemessnetzes von 1985 bis 1995 gesichtet und einer statistisch-klimatologischen Analyse im Hinblick auf markante Strömungsmuster unterzogen[1]. Dies lieferte die Basis für
2. weitere detaillierter Betrachtungen im Hinblick auf unterschiedliche Stadtbereiche und damit verbundene klimaökologische Wirkungen.
3. Gleichzeitig wurde eine Analyse der Oberflächenstrukturen von Topographie, Bebauung und Grünbereiche mit Hilfe eines Geographischen Informationssystems (GIS, IDRIS) durchgeführt um eine Datenbasis für die kleinräumige Interpretation zu schaffen.
4. Basierend auf diesem Datenmaterial wurden Modellrechnungen mit einem diagnostischen Strömungsmodell durchgeführt um Windströmungsstrukturen im Linzer Stadtgebiet bei unterschiedlichen übergeordneten Strömungssystemen (Einströmungen des Windes aus unterschiedlichen Richtungen in das Linzer Stadtgebiet) zu erhalten. Neben den unterschiedliche Strömungsrichtungen müssen auch noch die unterschiedliche thermischen Schichtungen der Luft beachtet werden.

Zusätzlich zu den Analysen des Datenmaterials der Luftgütemessstellen konnten in den Bereichen Bergern und Pichling Messungen über mehrere Monate mit zusätzlichen meteorologischen Stationen durchgeführt werden. Die Ergebnisse dieser speziellen Untersuchungen sind in eigenen Berichten zusammengefasst[2].

Im Rahmen dieses Projektes konnten eine Diplomarbeit[1] und eine Dissertation[3] abgeschlossen werden. Die Diplomarbeit ist als Bericht Nr. 1/95 des Amtes für Natur- und Umweltschutz in der Grünen Reihe erschienen. Die Dissertation ist als Bericht Nr. 1/97 erschienen. Ein Teil der Dissertation befindet sich als Anhang B in diesem Bericht.

Da das Material sehr umfangreich ist, konnten die Auswertungen nicht vollständig abgeschlossen werden. Derzeit sind noch mehrere Diplomarbeiten in Bearbeitung. Weiters entstanden mehrere Beiträge bei internationalen Tagungen[4], welche zu einer regen Diskussion führten und mit großem Interesse aufgenommen wurden (siehe Anhang C). Derzeit sind die Arbeiten in Linz Bestandteil des COST-Programmes SATURN, wodurch ein reger Austausch mit europäischen Wissenschaftern gegeben ist.

[1] [Hofko, 1994]

[2] [Mursch-Radlgruber 1995, 1997]

[3] [Prabha, 1996]

[4] [Mursch-Radlgruber, 1996, Prabha, 1994, 1996]

4 Grundsätzliches zu Transportmechanismen

Transport und Verdünnung von Luftschadstoffen in der bodennahen Luftschicht werden wesentlich durch die topographischen Gegebenheiten bestimmt. Dabei sind in erster Linie das thermische Verhalten des Talbereiches und seine Wechselwirkung mit der überlagerten mesoskalen[5] Strömung bzw. synoptischen[6] Strömung unter verschiedenen Wetterlagen von Bedeutung.

Typischerweise erzeugt die nächtliche Abkühlung im hügeligen oder bergigen Gelände eine Strömung, welche talauswärts gerichtet ist (-> Bergwind). Die Strömung ist gleichzeitig mit einer bodennahen Inversion[7] verbunden. Dabei kommt es zu einer starken Reduktion der *vertikalen* Durchmischungsaktivität der bodennahen Atmosphäre. Am Tag kommt es dagegen auf Grund der starken Erwärmung der Hänge und der Talatmosphäre zu einem Taleinwärtsströmen von Luftmassen (Talwind <-). Diese Strömung ist besonders intensiv während der Sommermonate. Ebenso ist diese durch die Sonnenstrahlung angetriebene Strömung meist sehr gut vertikal durchmischt.

Da wir uns bei der Frage der Ausbreitung von Abgasen in der bodennächsten Schicht befinden, sind die vertikalen Strukturen unter den für das Gebiet typischen Strömungssituationen von besonderer Bedeutung. Daher muss die Frage nach der Häufigkeit, der Mächtigkeit und der typischen Vertikalverteilung der Geschwindigkeit, Lufttemperatur und der Turbulenzaktivität dieser bodennahen Luftschichten am Standort beantwortet werden.

4.1 *Kaltluftströmungen*

Kaltluftströmung ist ein Ergebnis der nächtlichen Abkühlung der Erdoberfläche. Die kühlere, dichtere Luft, welche an den geneigten Hängen entsteht, bewegt sich ähnlich wie Wasser talwärts. Diese kalte Luft wird durch die Geländeformen geleitet und kanalisiert. Normalerweise hat diese Kaltluft eine Mächtigkeit bis knapp unter das Kammniveau der umgebenden Berge. Da sie jedoch sehr abhängig von der überlagerten Strömungsaktivität ist, kann die Mächtigkeit auch wesentlich geringer sein. Kaltluftströmungen sind immer verbunden mit einem Geschwindigkeitsmaximum im Talbereich und einem sehr deutlichen Minimum in Höhe der Obergrenze der Temperaturinversion. Häufig ist auch eine Verstärkung der Inversion im Bereich der maximalen Geschwindigkeit zu beobachten, wodurch die vertikale Durchmischung stark unterdrückt wird.

Durch diesen Mechanismus können Schadstoffe sehr effektiv in Bodennähe gehalten werden, was besonders für Bodenquellen, wie z. B. Deponien, von Bedeutung ist. Ebenso werden kleinstrukturelle Hindernisse, wie Baumstreifen oder Wälder, wichtig, da es durch diese zu Stagnationen und damit verbundene Luftschadstoffanreicherungen kommen kann.

[5] mikroskal: kleinräumig, mesoskal: mittelräumig, makroskal: großräumig

[6] Luftströmung aufgrund des Wettergeschehens

[7] Inversion = Temperaturumkehr, die Temperatur nimmt mit der Höhe zu!

4.2 *Verdünnung*

In jeder Diskussion über die Verdünnung von Schadstoffen in der Atmosphäre muss man zwischen Inversionsmächtigkeit und Durchmischungsschicht unterscheiden. Im Allgemeinen kann Mischung intermittierend in Zeit und Raum innerhalb einer Inversion beliebiger Mächtigkeit erfolgen. Die Inversionshöhe bedeutet daher nicht notwendig die Höhe der beteiligten Mischungsschicht. Ebenso kann Wind einen wesentlichen Effekt auf die Durchmischungsschicht haben. Besondere Situationen mit geringer Windgeschwindigkeit limitieren daher den Prozess der Verdünnung auf mehrere Arten:

1. Ein geringer Transport erhöht die Schadstoffkonzentrationen.
2. Eine schwache Scherung mit der Oberfläche reduziert die mechanisch verursachte Turbulenz und damit die Verdünnung.

Im Zusammenhang mit der nächtlichen Strahlungsabkühlung des Bodens und damit verbundener großer Stabilität sind daher Situationen mit geringen Windgeschwindigkeiten jene Schlüsselsituationen zur Beschreibung der höchsten Immissionsbelastungen.

Im Falle einer konvektiven Atmosphäre ist normalerweise der Boden wärmer als die darüberliegende Luft. Die dadurch induzierte Vertikalbewegung trägt wesentlich zur Luftschadstoff-Verdünnung bei. Dabei stellt die Sonneneinstrahlung den wesentlichen Antrieb für die verstärkte vertikale Durchmischung dar.

Um den Mischungsprozess während der Nacht beschreiben zu können, muss man zwischen statisch und dynamisch stabilen Situationen unterscheiden. Eine trockene Atmosphäre wird als statisch stabil betrachtet, wenn der Temperaturgradient mit der Höhe geringer als -0,98 °C/100m ist. Im Falle statischer Stabilität ist Arbeit notwendig um ein Volumselement vertikal zu bewegen. Der klassische Parameter, um die vertikale Durchmischungsfähigkeit unter statisch stabilen Bedingungen charakterisieren zu können, ist die Richardson-Zahl. Sie kann gem. Gleichung 1 bestimmt werden:

Gleichung 1: Bestimmung der Richardson-Zahl

$$Ri = (g / T_0)(\frac{(\Delta\Theta)(\Delta z)}{(\Delta U)^2 + (\Delta V)^2}) \qquad (1)$$

wobei $\Delta\Theta$ ist die Änderung der potentiellen Temperatur zwischen zwei Höhen (ΔZ), g=9,8m/s², T_0=mittlere Temperatur und ΔU und ΔV sind die Geschwindigkeitsdifferenzen zwischen zwei Höhen. Die Richardson-Zahl gibt den Widerstreit zwischen *statischer* Stabilität ($\Delta\Theta$) und der *vertikalen Durchmischung* durch Windscherung [$(\Delta U)^2+(\Delta V)^2$] an. Bei Werten von R_i >1,0 wird Turbulenz unterdrückt (Inversionen), im Bereich von 0,25 bis 1,0 kann Turbulenz existieren und bei Werten kleiner als 0,25 wird die Turbulenz dominant (konvektive Situationen).

Die Stabilitätsstruktur kommt wesentlich in der Standardabweichung der Horizontalgeschwindigkeitskomponenten zum Ausdruck. Ein wesentliches Charakteristikum der bodennahen Atmosphäre ist, dass bei geringen Windgeschwindigkeiten die Veränderlichkeit der Windrichtung dominant wird. Dies bewirkt, dass auch bei sehr geringen Windgeschwindigkeiten eine Verteilung der Schadstoffe in der Horizontalen erfolgt. Dabei wird jedoch der Schadstoff in Form von Ballen transportiert.

4.3 Typischer Tagesgang

Die Kombination aus Tageserwärmung und nächtlicher Auskühlung stellt das klassische Bild der atmosphärischen Grenzschicht dar (Abbildung 2).

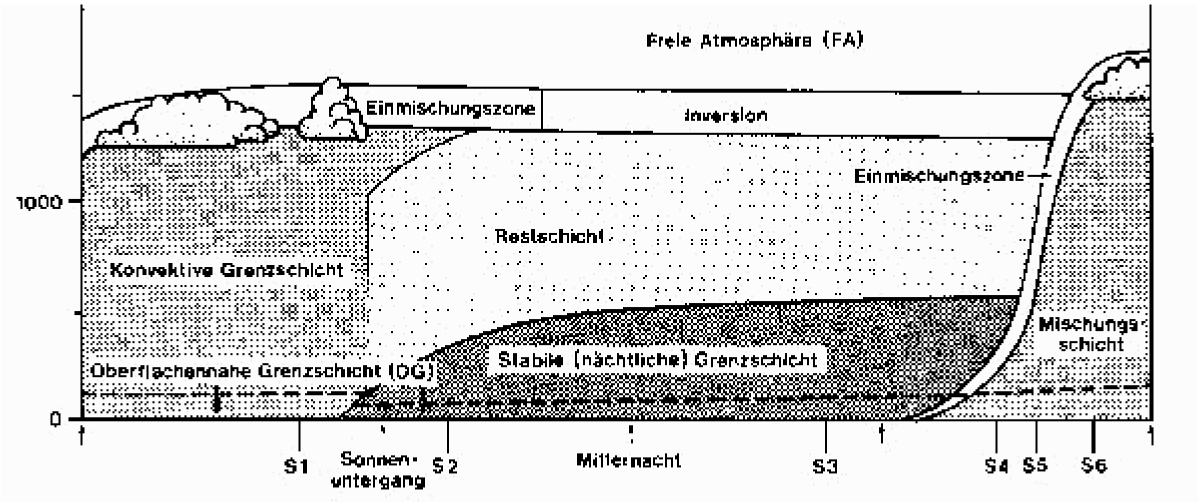


Abbildung 2: Die atmosphärische Grenzschicht während einer Hochdruckphase mit den drei wichtigsten Teilen: eine sehr turbulente Mischungsschicht (mixed layer), eine weniger turbulente Restschicht (residual layer) und eine nächtliche stabile Grenzschicht mit sporadischer Turbulenz (Nach Stull, 1988).

Dabei ist anzumerken, dass in topographisch komplexem Gelände, durch das tagesperiodische Wechseln zwischen Berg- und Talwind um die Zeit des Sonnenunterganges und Sonnenaufganges nicht nur der Turbulenzgrad der bodennahen Luftschicht und damit der Durchmischungsgrad geändert wird, sonder ganz wesentlich die Transportrichtung.

5 Material

5.1 Untersuchungsgebiet und verwendetes Datenmaterial

Das Untersuchungsgebiet stellt der Großraum Linz, eingebettet zwischen dem Mühlviertler Hügelland und dem Alpenvorland, dar. In Abbildung 3 ist die topographische Situation und die Lage der Stadt dargestellt. Prägend für diesen Raum sind die steilen Hänge des Mühlviertels mit dem sehr ausgeprägten Taleinschnitt des Haselgrabens, der Donauverlauf mit seinem Durchstich durch das Gelände im Westen und die niedrigen Geländetrassen im Süden. Es formt sich ein teilweise nach Südosten und Südwesten offenes Becken. Auch die Hügeltrasse im Süden hat eine nicht zu vernachlässigende Bedeutung für das klimatologische Geschehen.

Entsprechend der Lage des Stadtgebietes ist auch die Auswahl der Messstellen getroffen worden. Sie sind in Abbildung 3 eingetragen. Man kann sofort erkennen, dass im Umland einige Lücken offen bleiben. Dies ist eine Folge der Ausrichtung des Luftgütemessnetzes auf die dicht besiedelten Bereiche des Untersuchungsgebietes. Daraus ergeben sich in der Folge auch Konsequenzen für die räumliche Analyse, sodass in manchen Bereichen die angewandten objektiven Verfahren größere Unsicherheiten aufweisen.

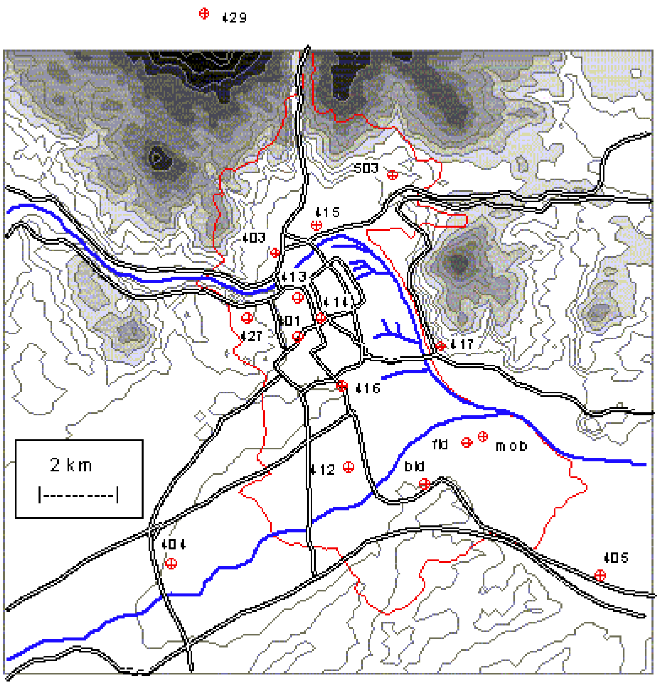


Abbildung 3: Gelände und Lage der Luftgütemessstationen im Untersuchungsgebiet. Die mittelstarke (rote) Linie zeigt die Stadtgrenze. Die Stationen 401 und 416 befinden sich auf Gebäuden. Zur Orientierung sind die größeren Straßen und die Donau dargestellt. Zusätzlich sind die drei Messpunkte der Intensivmessperiode 1995 (bld, fld, mob), südöstlich der Stadt im Bereich Pichling gelegen, eingetragen. Die Station 503 wurde in dieser Studie nicht verwendet.

Im Folgenden ist in Tabelle 1 eine Kurzbeschreibung der Stationen und der verwendeten Messgrößen nach Angaben des Amtes für Natur- und Umweltschutz wiedergegeben. Im Anhang A) ist eine Übersicht der Lage der Stationen im Stadtgebiet mit Stationsbeschreibungen angefügt.

Tabelle 1: Kurzbeschreibung der Umweltmessstellen und der verwendeten Messgrößen

Station Nr.	Stationsname	Meereshöhe in(m)	Höhe über Grund (m)	Parameter	Ortscharakterisierung (Umgebung)
401	Hauserhof	260	10	SO_2, Wind, Temperatur	Stadtzentrum auf einen 8-stöckigen Gebäude (40 m hoch)
403	BH-Urfahr	269	21	SO_2	Nördlich der Donau, Wohngebiet der Stadt
404	Traun	274	10	SO_2, Wind, Temperatur	Wohngebiet, ebenes Gelände
405	Asten	255	10	SO_2, Wind, Temperatur	Ländliches Gebiet mit Feldern und einem Friedhof, eben
412	Kleinmünchen	258	10	SO_2, Wind, Temperatur	Rand eines Waldes im Übergang zu Wohngebiet
413	Ursulinenhof	262	2	SO_2, Temperatur	Zentrum von Linz, Parkplatz
414	ORF-Zentrum	263	10	SO_2, Wind	Wohngebiet in der Stadt, 2 km zur Industrie
415	24er-Turm	255	10	SO_2, Wind, Temperatur	Nahe der Mühlkreisautobahn (10-20m), wenig Bebauung
416	Berufsschul-zentrum	274	31	SO_2, Wind, Temperatur, Strahlungsbilanz	Wohnareal nahe zu Industrie (700m entfernt), auf dem Dach einer Schule, auf Hang
417	Steyregg/Weih	335	10	SO_2, Wind, Temperatur	Feld auf Hang im Osten der Stadt, hügeliges Gelände
425	Freinberg-1	380	10	Temperatur	westlich von Linz, Park
426	Freinberg-2	380	90	Temperatur	westlich von Linz, Park
427	Freinberg-3	380	150	Wind, Temperatur	westlich von Linz, Park
428	Lichtenberg	700	2	Temperatur	Wald, auf Hang
429	Giselawarte	927	23	Wind, Temperatur	Wald, auf Hügelkuppe

5.2 *Gelände und Stadtstruktur*

Die Geländehöhe wurde für das Untersuchungsgebiet in einer Größe von 20 x 20km mit 10 m Auflösung von einer Karte im Maßstab 1:25.000 digitalisiert. Die Stadtstruktur wurde unter Verwendung der GIS- (Geographisches Informationssystem) Software IDRISI (IDRISI for Windows, 1995) aus dem in Abbildung 1 wiedergegebenen Satellitenbild erhoben. Dabei wurden Oberflächentypen klassifiziert, die sich nach Eigenschaften, wie Bebauungsdichte, Bebauungshöhe und Grünanteil (Art der Vegetation) richteten (Abbildung 4). Die unterschiedlichen strukturellen Gruppen wurden in Tabelle 2 zusammengestellt. Diesen Gruppen wurden in der Folge Rauigkeitseigenschaften in Form der Rauigkeitslänge[8] zugeordnet. Ebenfalls wurden für die Modellbetrachtungen diesen Kategorien Albedoeigenschaften[9] zugeordnet. Mir diesen Eigenschaften wird in der Folge wesentlich operiert, um durch Regressionsanalysen des Stationsdatenmaterials und der Topographie- (Höhe, Neigung) und Flächeneigenschaften zu flächige Analysen zu gelangen. Wie sich zeigt, ist diese Information bereits eine brauchbare Basis, um auf Aussagen der Belüftung schließen zu können.

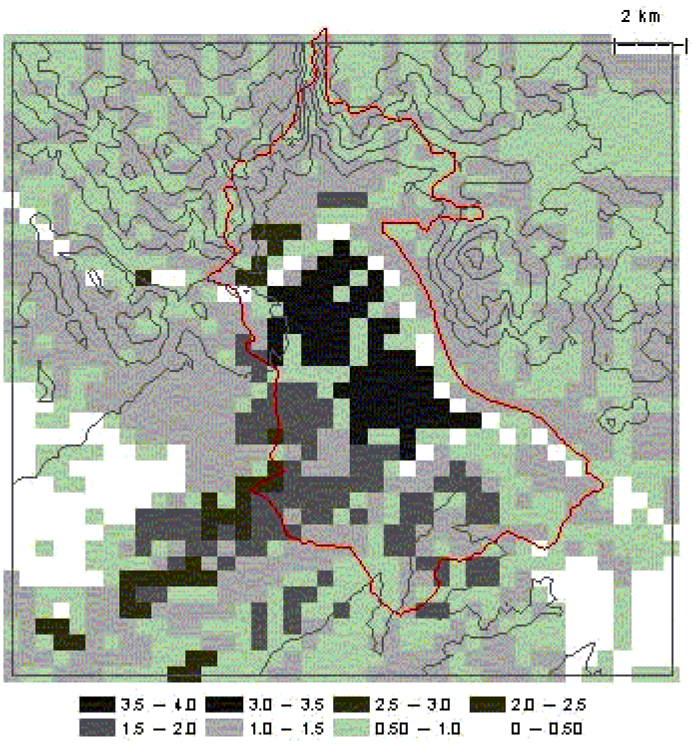


Abbildung 4: Oberflächenstruktur des Untersuchungsgebietes nach Rauigkeit klassifiziert

[8] [Wieringer, 1992]

[9] Albedo: Rückstreufähigkeit des weißen Lichts an unterschiedlichen Oberflächen

Tabelle 2: Strukturgruppen und Rauigkeitslängen

Nr.	Oberflächentyp	(z_0)
1	Gemischt, besteht aus isolierten Gebäuden, Bäumen, Büschen und Teilen landwirtschaftlicher Flächen, etc. auf hügeligen Gelände	0,75
2	Wasserflächen	0,001
3	Landwirtschaftliche Flächen auf ebenem Gelände, keine Hindernisse	0,06
4	Industriegelände, hohe Gebäude	3,7
5	Dichte Bebauung, Stadtzentrum, keine Bäume	3,2
6	Weniger dichte Bebauung, einige Bäume	2,0
7	Gebäude mit offenen Flächen und Bäumen	1,75
8	Gebäude mit einer großen Anzahl von Bäumen	1,1
9	Siedlung oder Dorf mit Ansammlung von Gebäuden	0,4
10	Dichter Wald	1,3
11	Stadtparks, Friedhöfe in der Stadt, etc.	1,2
12	Bahn, Autobahn, Straßen in der Stadt	0,5
13	Flugplätze	0,03

6 Durchlüftungsrelevante Grundstrukturen

6.1 Allgemeines

Wie die letzten Untersuchungen zeigten, dürften wesentliche Effekte auf das Strömungsgeschehen durch die Wechselwirkung des dicht verbauten Stadt- und Industriegebietes mit dem Umland gegeben sein. Dies zeigt sich bereits in der klimatologischen Auswertung des Luftgütemessnetzes, und besondere Hinweise finden sich in den Messungen zur Immissionsklimatologie des Planungegebietes Solar-City in Pichling im Südosten der Stadt.

Dabei wird durch die Überwärmung bebauter Strukturen eine bodennahe Strömung ins Stadtgebiet induziert (Flurwind), welche wesentlich zur Belüftung von Stadtquartieren beitragen kann. Andererseits ist in Linz die Situation wesentlich durch die topographische Gegebenheit der Mühlviertler Hänge und Täler, sowie des Donaudurchbruches geprägt. Diese können während so genannter Stagnationsperioden während der Nacht als Frischluftlieferanten wirksam werden. Dabei wird Kaltluft in Bodennähe in die bebauten Gebiete vordringen und dort zu einem Luftwechsel beitragen. Am Tag werden die südorientierten Hänge durch erhöhte Erwärmung während Strahlungswetterlagen ebenfalls eine aktive Rolle im Strömungsgeschehen des Stadtbereiches spielen.

Sieht man sich den Linzer Raum in einem Satellitenbild (siehe Abbildung 1, Seite4) an, so kann man bereits sehr deutlich die Stadtstruktur in der Bebauungsdichte (rötliche Färbung) erkennen. Durch die Geländegegebenheiten formt sich ein nach Süden offenes Becken, welches wesentlich verantwortlich für die große Anzahl von Stagnationsperioden (Abbildung 5) ist. Dabei sieht man sehr deutlich, dass die für eine schlechte Durchlüftung verantwortlichen

Fälle mit geringen Windgeschwindigkeiten (Calmen) am häufigsten bei stabilen Situationen auftreten. Dabei können im Gesamten ohne weiteres Häufigkeiten bis zu 40 % der Zeit auftreten.

Das heißt, man hat drei wesentliche Randbedingungen, welche die Durchlüftung prägen:

a) Oberflächenstruktur

b) Lage im Gelände

c) Lokalklimatische Charakteristika (vertikale Struktur der Luftschichtung, Produktivität von Kaltluft)

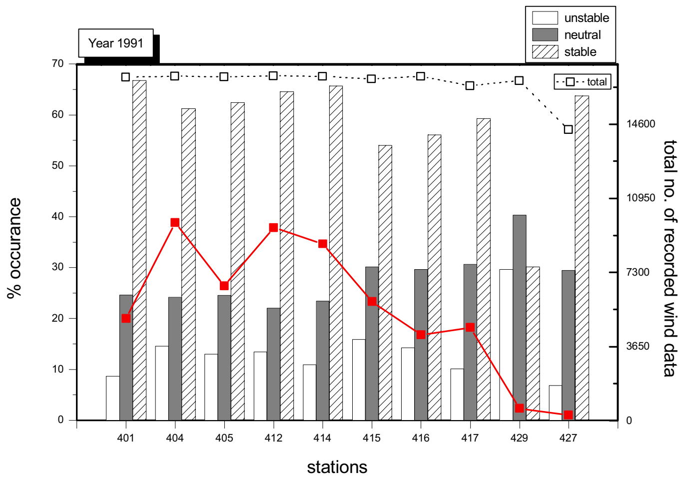


Abbildung 5: Häufigkeit des Auftretens von Calmen (Windgeschwindigkeit kleiner 0,5 m/s).

offene Quadrate: Summe der gemessenen Halbstunden-Mittelwerte an den einzelnen Stationen
volle Quadrate: prozentuelle Häufigkeit von Calmen pro Jahr an den einzelnen Stationen
Balken: prozentuelle Häufigkeit des Auftretens von instabilen, neutralen und stabilen Luftschichtungen an den einzelnen Stationen

In zwei Arbeiten wurde das klimatische Datenmaterial des Umweltmessnetzes bearbeitet[10]. Dabei wurde eine Durchsicht des gesamten Datenmaterials von 1981-1995 durchgeführt. In der Folge sind jedoch die Details aus den Jahren 1991, 1993 und 1995 erarbeitet worden. Es stand in erster Linie die Klassifikation der lokalklimatischen Strukturen abhängig von der Wetterlage und den Oberflächenstrukturen im Vordergrund der Betrachtung. Da in der Arbeit von Prabha (1996) die modellmäßige Beschreibung von Schadstofftransportvorgängen im Mittelpunkt stand, konnte die Bedeutung des Zusammenwirkens von Oberflächenstruktur, Lage im Gelände und lokalklimatischen Einflüssen für die Durchlüftung aufgezeigt werden. Dabei konnten bereits aus den Basis-Klimadaten der Luftgütemessstellen im Linzer Raum wesentliche Phänomene, wie z. B. Wärmeinsel, Kaltluftstagnation und -abkopplung, beschrieben werden.

[10] [Hofko, 1994, Prabha, 1996]

Betrachtet man die Durchlüftung oder den Luftwechsel von Stadtquartieren, so ist dies aus mehreren Gründen von Interesse. Einerseits ist diese Größe bedeutsam für die Verweildauer von Schadstoffen und damit auch für die Konzentration derselben in den Stadträumen, andererseits hat der Luftwechsel auch Bedeutung für die Wärmebelastung des Menschen.

Durch die Analyse der Oberflächenstruktur (Tabelle 2) und die Ableitung der für die Durchlüftung sehr wesentlichen Oberflächenrauigkeit, kann ein erster Einblick in die flächenhafte Verteilung des Durchlüftungspotentials gegeben werden (Abbildung 6). Man muss dabei beachten, dass in diese Darstellung noch keine klimatologische Information eingeht. Es besteht ein wesentlicher Unterschied, ob eine Fläche bestimmter Rauigkeit in einer windexponierten oder in einer geschützten Lage liegt. Dabei ist die Hanglage mit der Möglichkeit abfließender Kaltluft sehr von Bedeutung. Dies wiederum ist stark vom Potential zur Kaltluftproduktion abhängig.

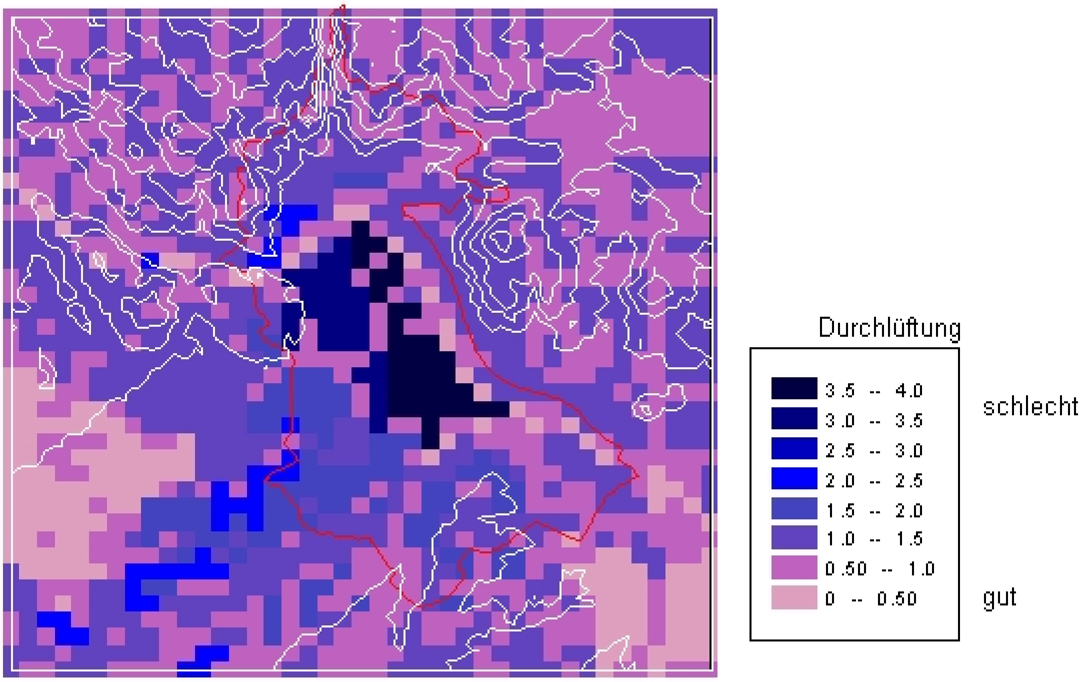


Abbildung 6: Stadtstruktur und Durchlüftungsbehinderung abgeleitet aus der Oberflächenstruktur

Dies bedeutet, dass für die kleinräumige Beurteilung einige wesentliche Größen (Kaltluftproduktion und -lagerung) genauer erhoben werden müssen. Für eine erste Charakterisierung des gesamten Raumes lässt sich jedoch einiges aus der Stadt- und Oberflächenstrukturanalyse (Abbildung 4) ablesen.

Man kann unschwer den dicht verbauten Stadtkern und die Industriebereiche erkennen. Weiters lassen sich auch die südlich gelegenen, flächig verbauten Vorstadtbereiche erkennen. Diese sind insofern von Bedeutung, da sie in Situationen mit Schwachwind die sich einstellenden Flurwinde beeinträchtigen. Dies konnte bereits in dem klimatologischen Datenmaterial nachgewiesen werden (siehe Anhang B Abschnitt 5.3). Jene Bereiche, die am wichtigsten sind, sind die Hangbereiche entlang der Mühlviertler Hänge, wobei der gesamte Bereich Urfahr als kritisch zu bewerten ist. Diese Bereiche sind auch jene, die bei den Modellberechnungen (Prabha, 1996, Mursch-Radlgruber, 1997) als am höchsten belastete Bereiche während Stagnationssituationen in Erscheinung treten. Bei diesen Stagnationslagen tritt sehr häufig eine leichte Strömung gegen die Mühlviertler Hänge ein. Dies offenbar verstärkt durch die Wechselwirkung der Hänge und des Stadtkernes (Wärmeinseleffekt). Ebenso stellt der Haselgraben einen beträchtlichen Frischluftlieferant (siehe auch Anhang B Abschnitt 5.2) während Stagnationslagen dar.

Die noch offenen Bereiche durch Bahntrassen oder größere zusammenhängende Grünbereiche sind ebenfalls von großer Bedeutung, da sie Leitfunktion für Luftmassen haben können. Dabei ist im Planungsprozess darauf zu achten, dass möglichst geringe Emissionen im Quellbereich dieser Luftleitbahnen sind.

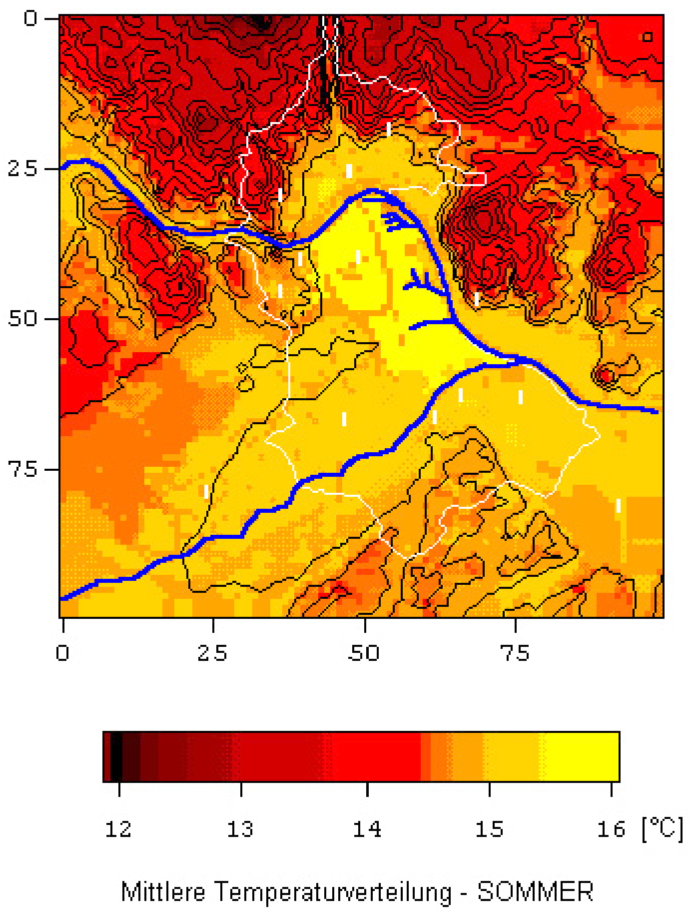
6.2 Regressionsanalyse der flächenhaften Verteilung von Temperatur und Kaltluft

Um Einblick in die Effekte der Verbauung und der Topographie auf die Temperaturverteilung und das thermische Verhalten zu bekommen, wurden die Daten aus dem Jahre 1991 einer Regressionsanalyse unterzogen. Dabei wurden mit den Stationsdaten des Winterhalbjahres (Monate 01-03 und 10-12) und des Sommerhalbjahres (Monate 04-09) eine multiple Regression gerechnet. Die erhaltenen Regressionskoeffizienten wurden dann zur Interpolation der Temperaturwerte in Bezug auf Lage der Station, Höhenlage und Oberflächencharakteristik verwendet. Der Interpolation wurde dass in der Oberflächenstrukturerhebung verwendete Raster von 200m zu Grunde gelegt. Dadurch ist es möglich, ein klimatologisches Verhalten der Lufttemperaturmittelwerte, der Minimalwerte und der Änderungen in der Fläche darzustellen.

In der Folge wurden die Ergebnisse für die mittleren Lufttemperaturen (Abbildung 7), der mittleren Minimumtemperatur (Abbildung 8) und der Lufttemperaturänderung währen der zweiten Nachthäfte (Abbildung 9) jeweils für das Winter- und Sommerhalbjahr dargestellt. Man sieht deutlich die teilweise beträchtlichen Unterschied zwischen den einzelnen Stadträumen untereinander und der Umgebung. Deutlich ist auch der Effekt der Höhenlage zu erkennen. Man sieht auch deutlich, dass die Oberflächenstruktur die dominante Randbedingung darstellt.

Durch die Regressionsanalyse der Stationsdaten gehen bereits indirekt die Strömungsverhältnisse in die Analyse ein, da die durch die Luftbewegung verursachten Effekte auf die Lufttemperatur in den Messdaten repräsentiert wird. Es ist natürlich schwierig eine repräsentative Auswahl der Situationen zu treffen, da diese wiederum einen Effekt auf die Aussage hat. Für detaillierte Analysen müssen konkrete Situationen in bestimmten Stadträumen gesondert untersucht werden, da dabei sehr kleinräumige Effekte oft dominant werden können.

Ein erster Ansatz wurde zur Demonstration durch die Analyse der Kaltluftentstehung auf Grund der Oberflächenstruktur und der Hangneigung durchgeführt. Dabei wurden jedoch keine Rauigkeitseffekte oder blockierende Effekte von Bebauungen und anderen Hindernissen berücksichtigt. In Abbildung 10 ist das Ergebnis dieser qualitativen Betrachtung dargestellt. Es erscheint unbedingt notwendig für konkrete Planungszusammenhänge Detailuntersuchungen mit verbesserten Analysewerkzeugen zur Kaltluftentstehung und Lagerung durchzuführen. Der Effekt der Kaltluftlagerung eventuelle Konsequenzen für die Belüftung von Stadtteilen konnte in ersten experimentellen Arbeiten (Mursch-Radlgruber, 1996, siehe auch Anhang C) dargestellt werden.



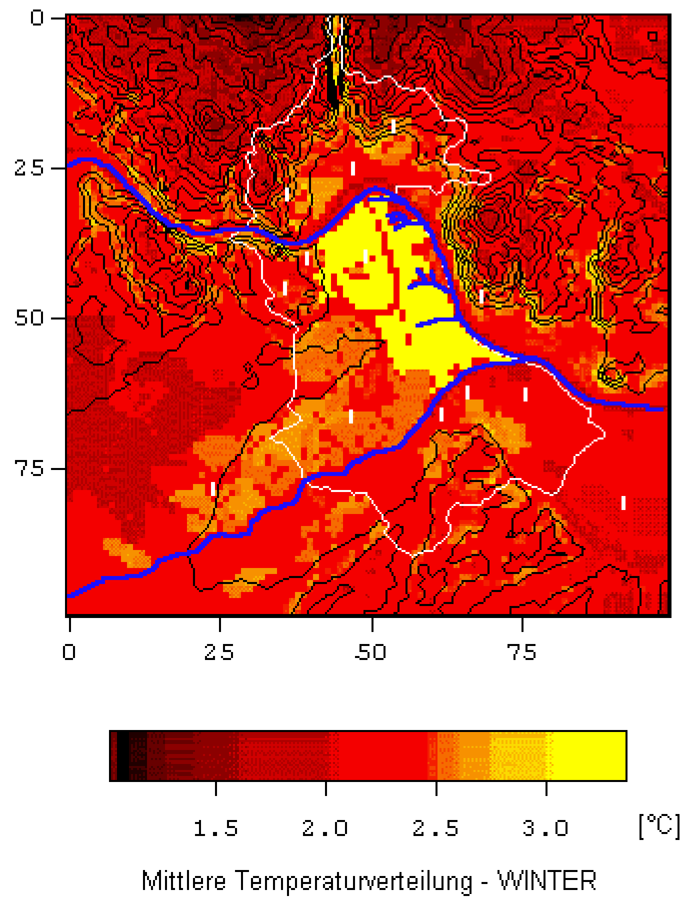
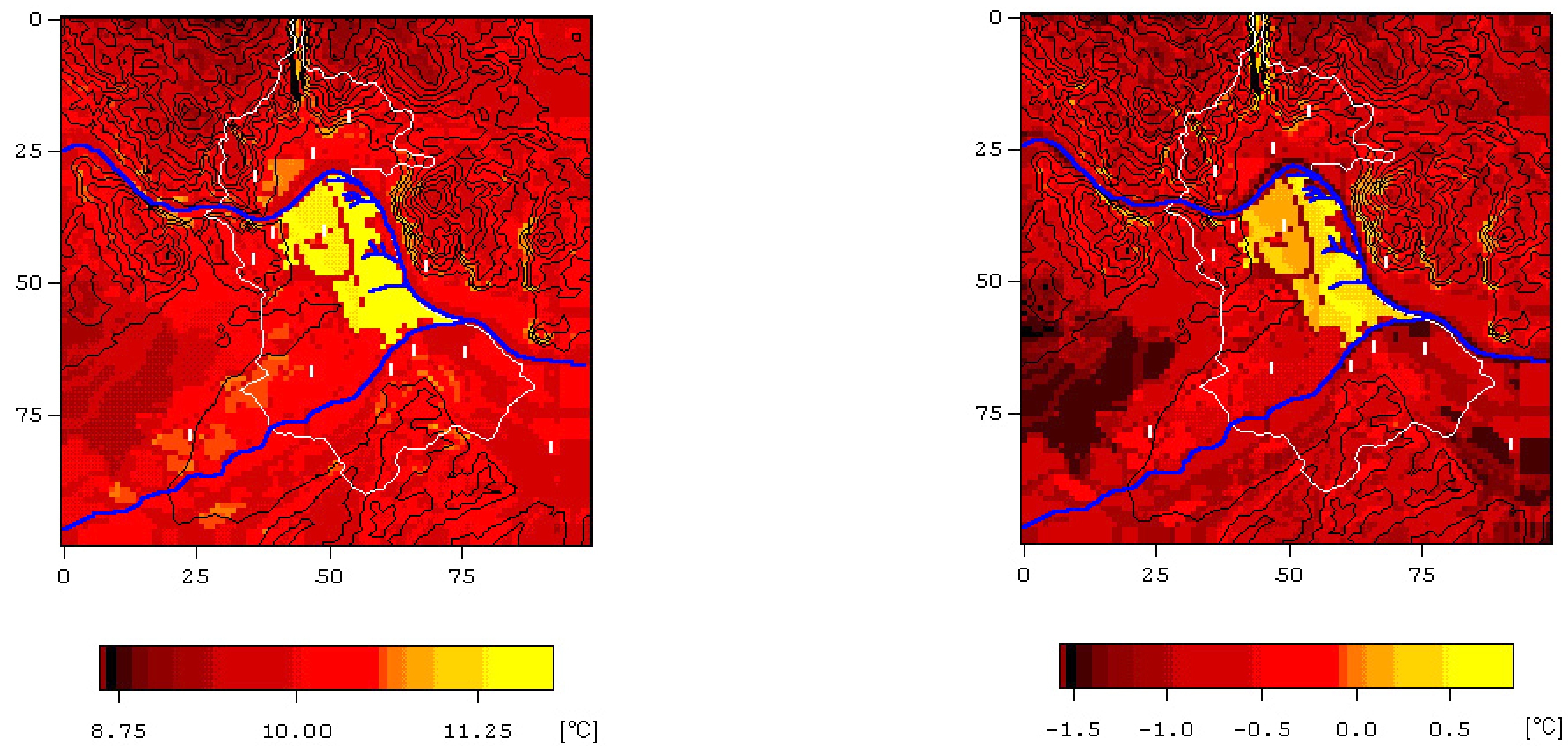


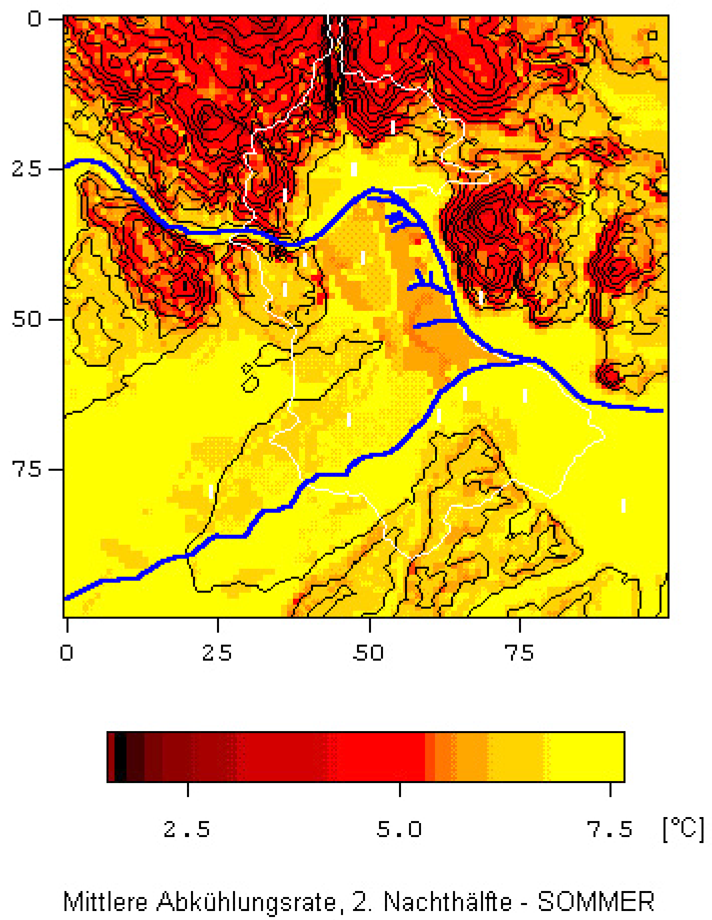
Abbildung 7: Mittlere Temperaturverteilung



Mittlere minimale Temperaturverteilung - SOMMER

Mittlere minimale Temperaturverteilung - WINTER

Abbildung 8: Mittlere Minimumtemperaturverteilung



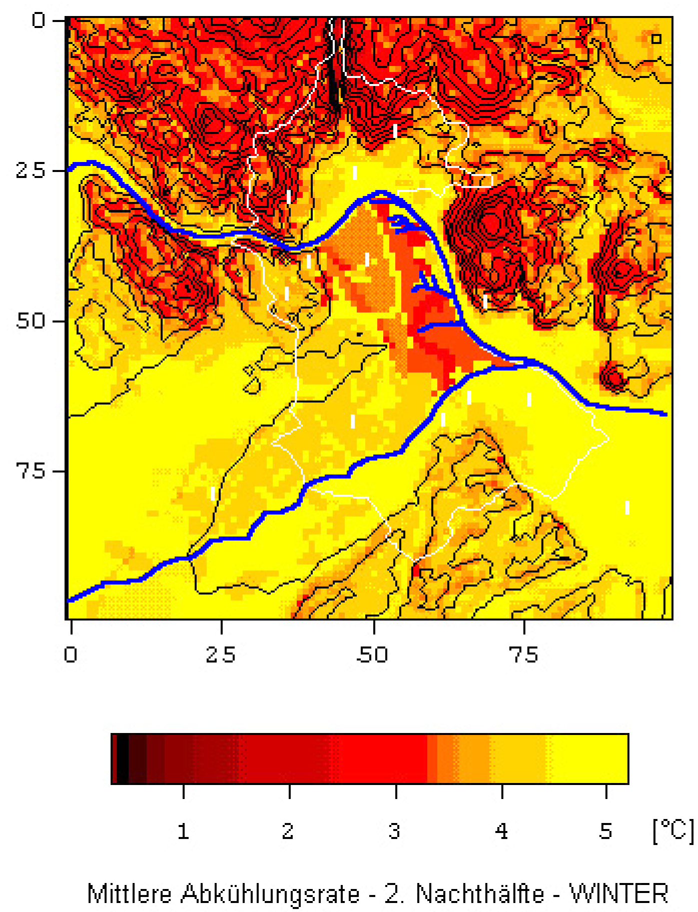


Abbildung 9: Mittler Verteilung der Abkühlungsrate der zweiten Nachthäfte (0:00 Uhr bis 6:00 Uhr)

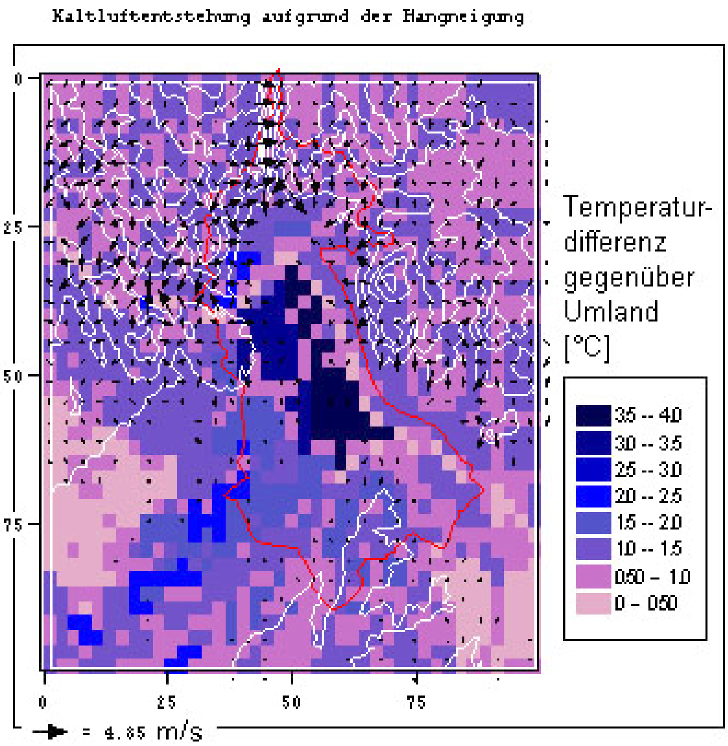


Abbildung 10: Kaltluftentstehung und Lagerung als Effekt der Oberflächenstruktur und Hangneigung

6.3 Strömungsstrukturen über der Stadt

Eine weitere wesentliche belüftungsrelevante Größe stellt die Luftströmung über der Baukörperstruktur der Stadt dar. Diese kann direkt aus den Messdaten des Stationsnetzes durch spezielle numerische Analyse mit einem diagnostischen Strömungsmodell (Prabha, 1996a) gewonnen werden. In der Arbeit von Hofko (1994) wurden die Stationsdaten durch betrachten der Relation mit der Wetterlagenklassifikation von Steinacker für den österreichischen Bereich einer Strukturanalyse unterzogen. Er konnte bereits die wesentlichen Strömungsstrukturen klassifizieren.

6.3.1.1.1 Wesentliche klimatologische Strukturen

Die wesentlichsten Strukturen sind die Häufigkeit der Windrichtungen bei den unterschiedlichen Bedingungen der Windgeschwindigkeit und der bodennahen Stabilität. In Abbildung 12 ist die Analyse der Windrichtungsverteilung bei unterschiedlichen Geschwindigkeitsklassen an den Umweltmessstellen dargestellt.

Dabei sieht man deutlich den Effekt durch die Topographie mit einer SO-Ablenkung im Stadtbereich. Weiters ist deutlich die Hauptausrichtung West-Ost zu erkennen. Ebenso kann man an der Station 24er-Turm im Bereich Urfahr die nächtlichen Strömungen aus dem Haselgraben erkennen. Für eine detailliertere Diskussion siehe auch Angang C) „Wind pattern in Linz“ (Prabha, 1996).

Diese Verteilung wird natürlich wesentlich mitgeprägt durch die thermischen Schichtungsbedingungen im Untersuchungsgebiet. Daher wurde eine Analyse nach Stabilitätsklassen durchgeführt (Abbildung 12). Für eine ausführliche Diskussion und weiterer markanter Besonderheiten sei wiederum auf Anhang B) verwiesen.

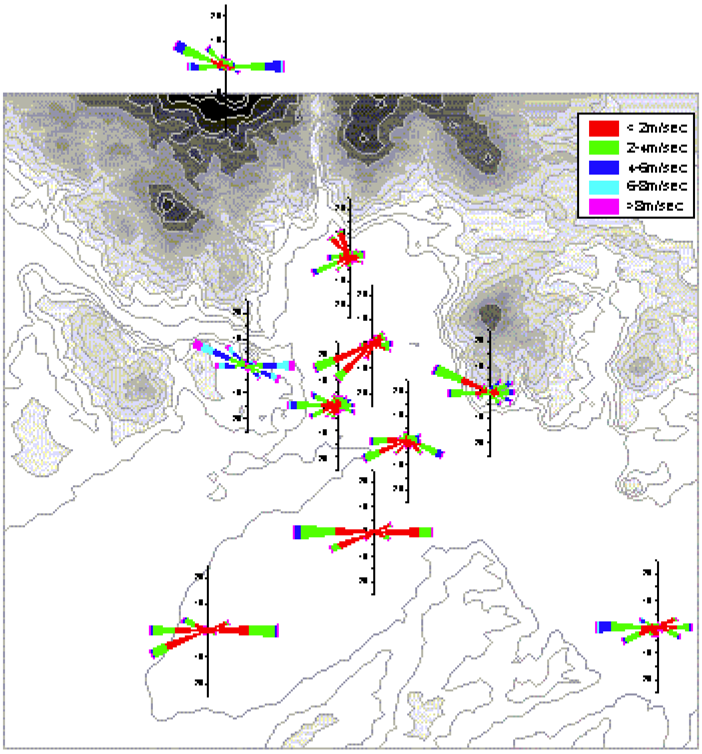


Abbildung 11: Windgeschwindigkeitsverteilung und Windgeschwindigkeitsklassen an einzelnen Messpunkten

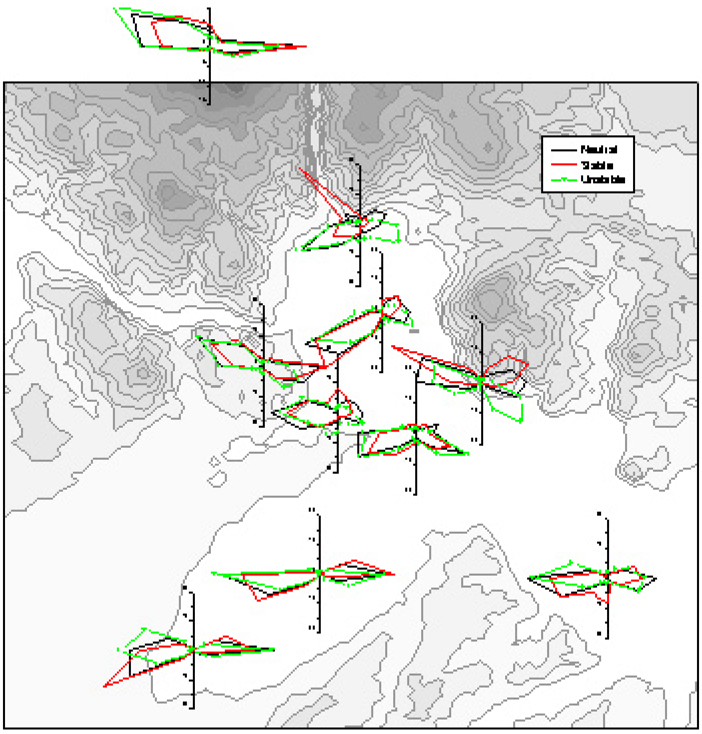


Abbildung 12: Häufigkeitsverteilung der Windrichtung bei unterschiedlicher Stabilität

6.4 Objektive Klassifikation durch diagnostische Analyse

Hier wurde nun versucht ein objektives Verfahren auf den Untersuchungsraum anzuwenden, um eine dreidimensionale Analyse zu erhalten. Dabei stellte sich heraus, dass einerseits das fehlende Datenmaterial aus einigen Bereichen des Untersuchungsraumes (z. B. Nordosten), und andererseits besonders die fehlenden Daten der vertikalen Verteilung von Wind und Temperatur, zu Ungenauigkeiten führten. Detailanalysen gingen in die Untersuchung des Schadstofftransportes während einiger Fallstudien zur Studie Pichling - Solar City (Prabha, 1996, Mursch-Radlgruber, 1997) ein.

Hier soll die Analyse der mittleren bodennahen (direkt oberhalb der Baukörper) Strömungsfelder zur Demonstration der wesentlichen horizontalen Strömungsverteilung dargestellt werden. Dabei wurden die diagnostizierten Strömungsfelder abhängig von der Windrichtung an der 150 m hohen Messstelle Freinberg klassifiziert.

Deutlich kann man die Topographischen Effekte durch Drehung der Windvektoren über dem Stadtzentrum erkennen. Besonders bei S- bis SO-Strömung kann noch eine deutliche Geschwindigkeitsreduktion festgestellt werden. Dies sind auch jene Lagen, bei denen Hochdruck vorherrscht und dadurch die Häufigkeit von Inversionen groß ist. Dabei werden einerseits die geringsten Windgeschwindigkeiten im Stadtbereich festgestellt und andererseits bekommt die mit der Kaltluftproduktion einhergehende Belüftung großen Stellenwert. Besonders bei SSO erscheint sogar im mittleren Strömungsbild eine Konvergenzzone mit vollständiger Stagnation über dem Stadtbereich. Man muss sich vor Augen halten, dass dies gemittelte Situationen aus einem gesamten Jahr darstellen. Die heißt, dass die Verteilung regelmäßige sich wiederholende Muster darstellen. Selbstverständlich ist in einzelnen Fällen eine Modifikation (Verstärkung oder Abschwächung einzelner Phänomene) durch thermische Forcierung gegeben. Auf einige Details wird ebenfalls in Anhang B) eingegangen.

Es erscheint sehr plausibel, dass das Schadstoffverteilung der großen Quellen oberhalb des Stadtkörpers durch diese mittleren Strömungsverteilungen gut beschrieben werden können. Es zeigt sich bei Modellrechnungen und Vergleichen mit den Immissionskonzentrationen an den Umweltmessstellen, dass der horizontale Transport mit diesem Ansatz gut beschrieben werden kann (Prabha, 1996a). Es zeigt sich jedoch auch, dass in kritischen Situationen (vor dem Durchgang einer Front, während Stagnationsperioden) das Fehlen kontinuierlicher Vertikalinformation über die Verteilung von Wind und Temperatur mit der Höhe zu großen Fehlern führen kann (Prabha, 1996b). Besonders das Fehlen kontinuierlicher Windprofile stellt unter diesen Bedingungen ohne moderne Fernerkundungsverfahren (SODAR, Mini-SODAR) ein fast unüberwindliches Hindernis dar.

Wind am Freinberg aus W

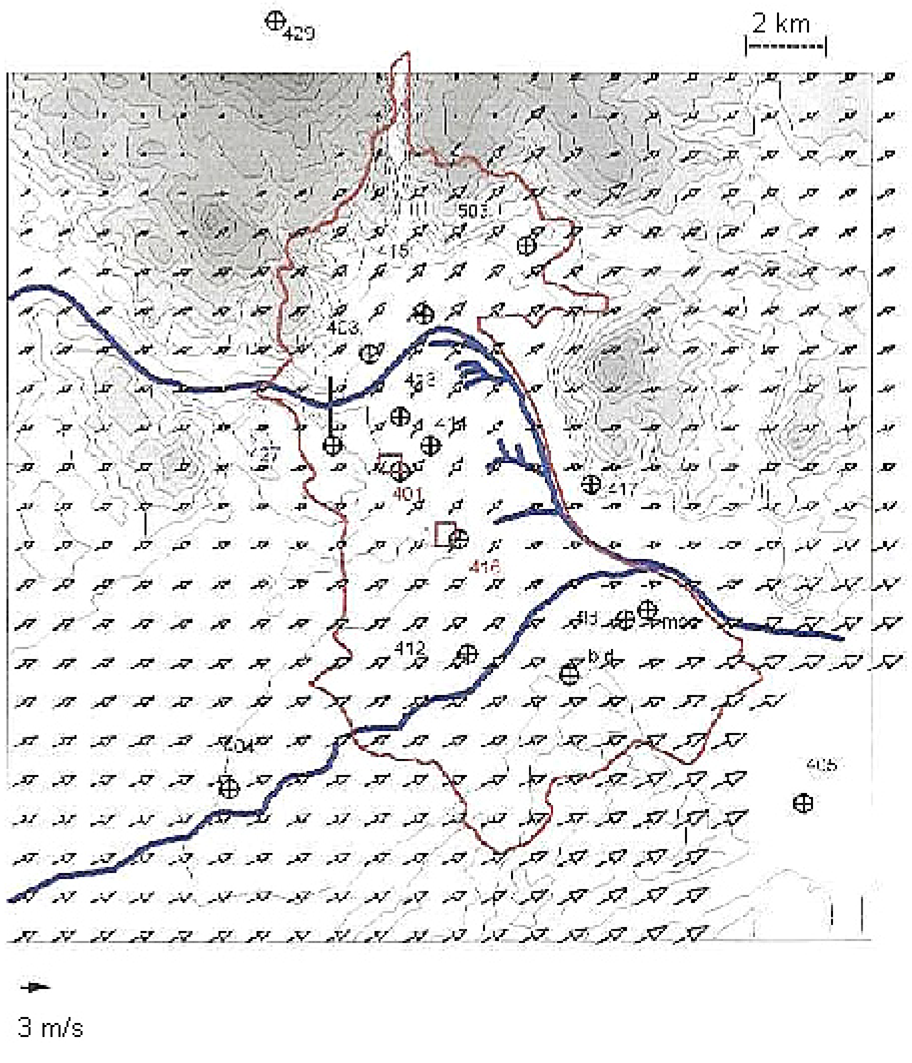


Abbildung 13: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus West

Wind am Freinberg aus WNW

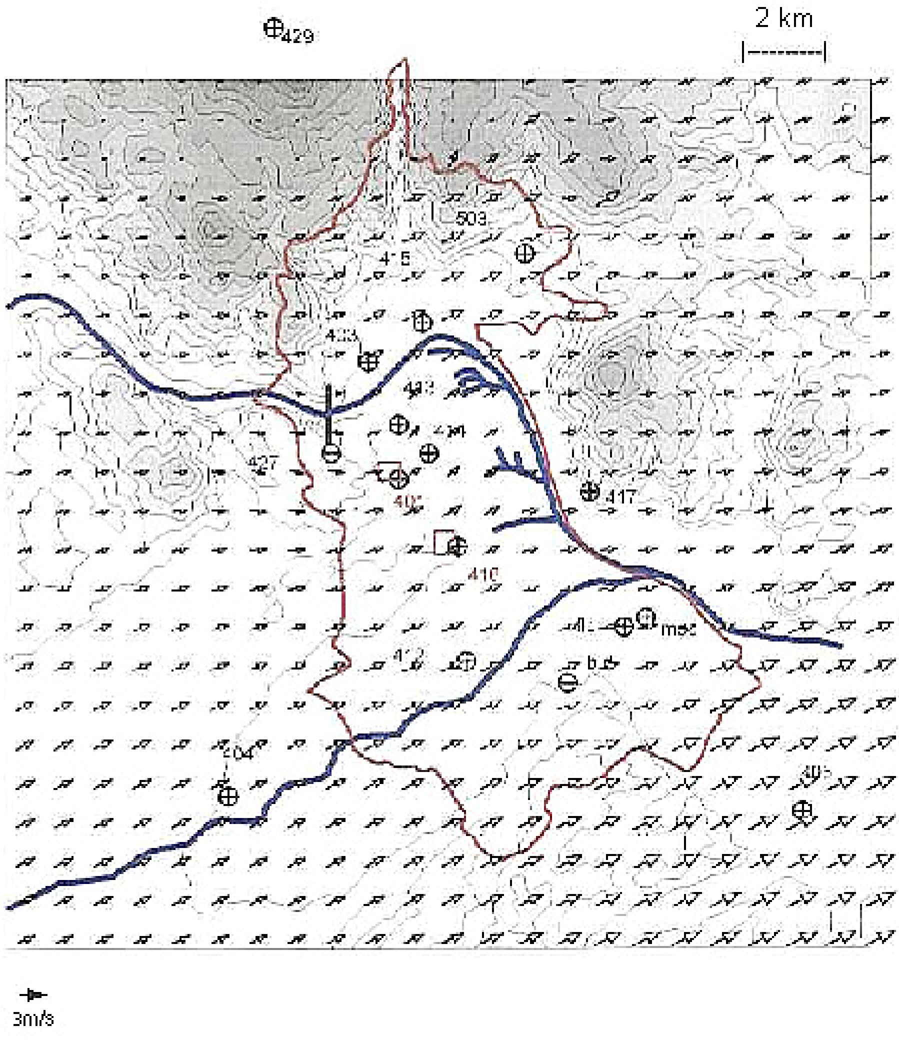


Abbildung 14: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

Wind am Freinberg aus NW

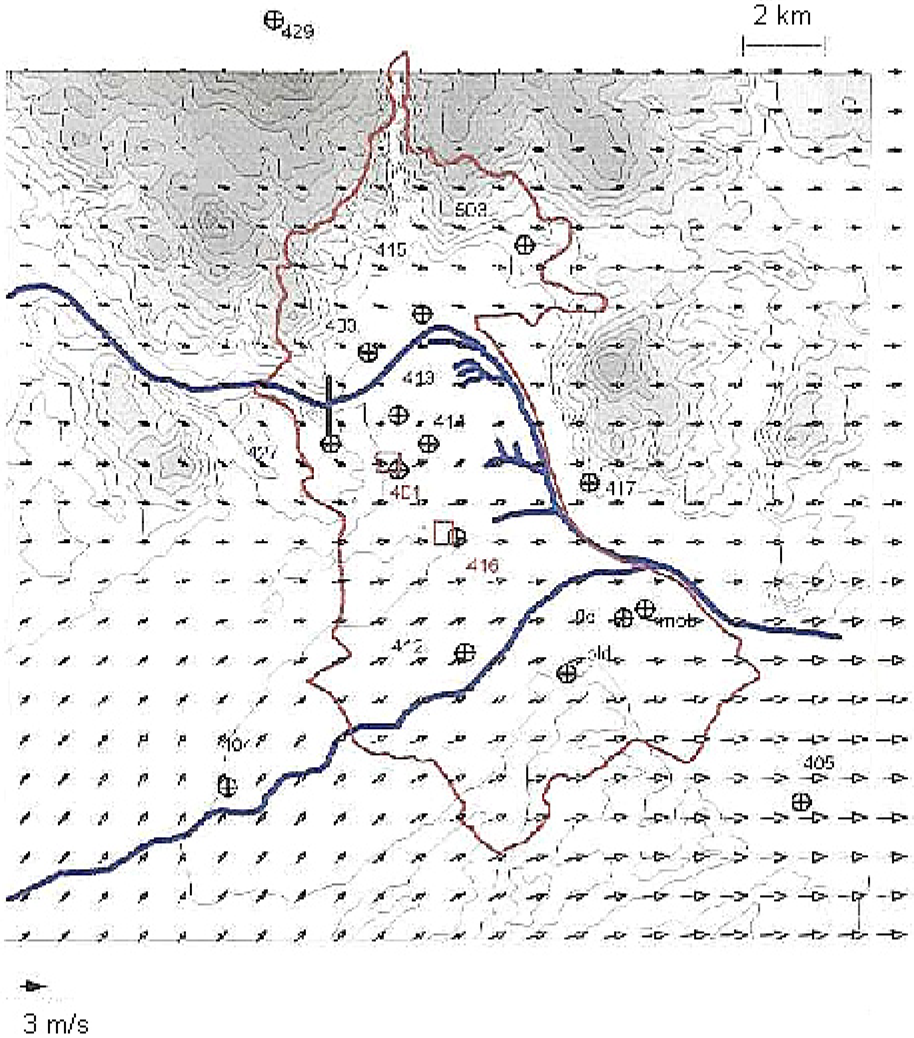


Abbildung 15: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

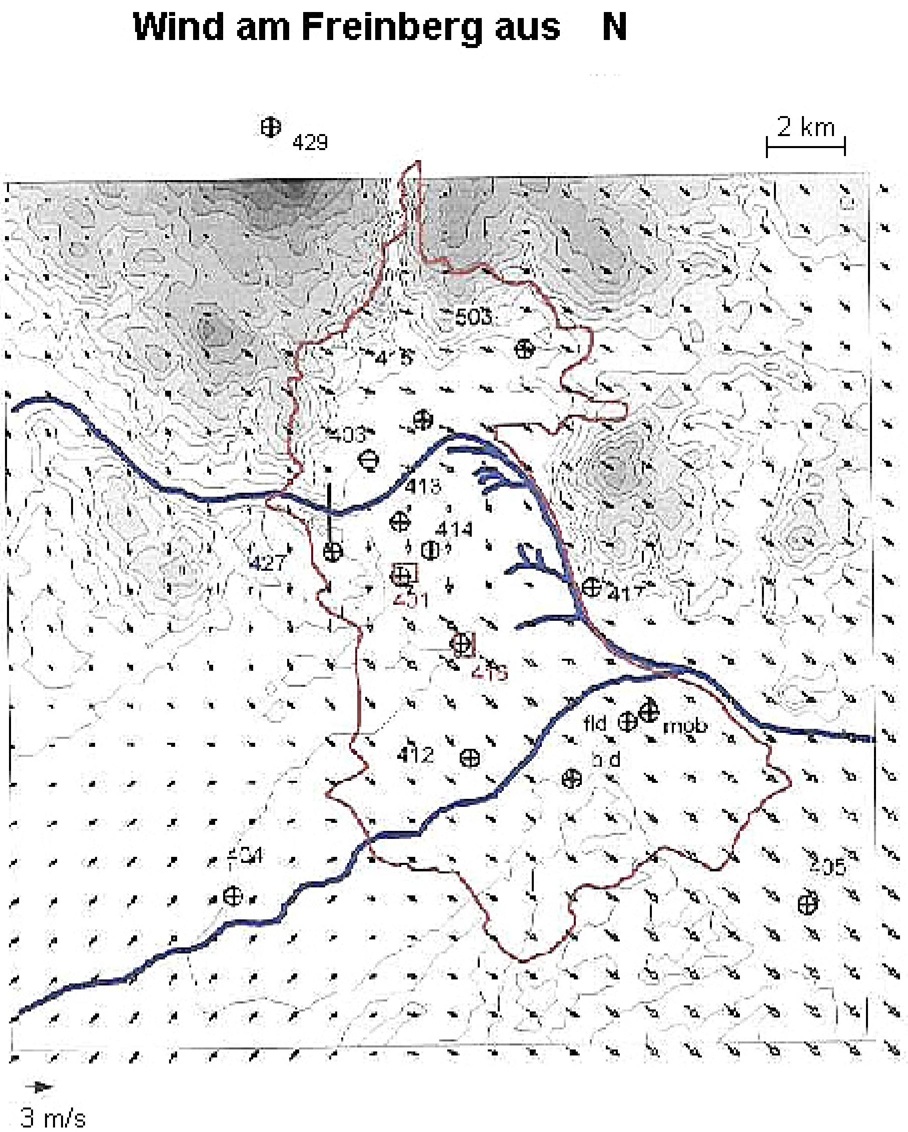


Abbildung 16: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Nord

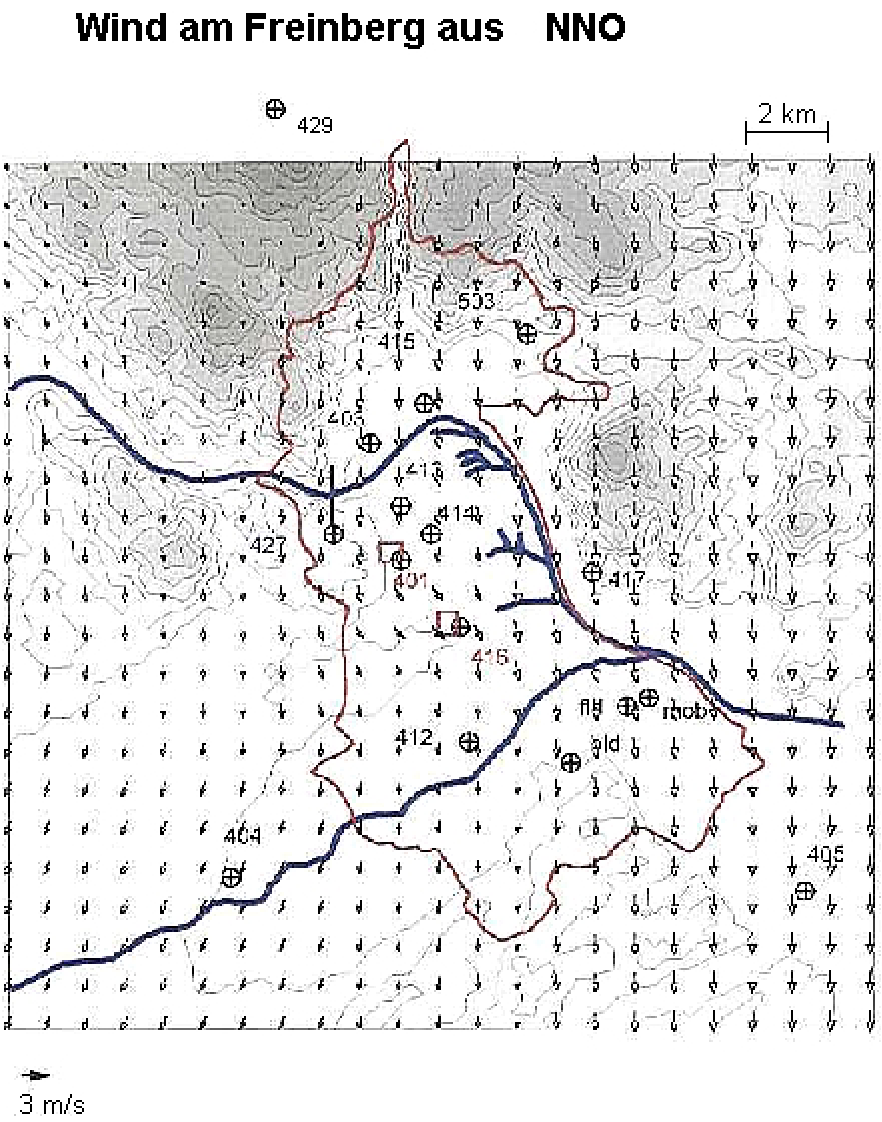


Abbildung 17: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus n Nordnordost

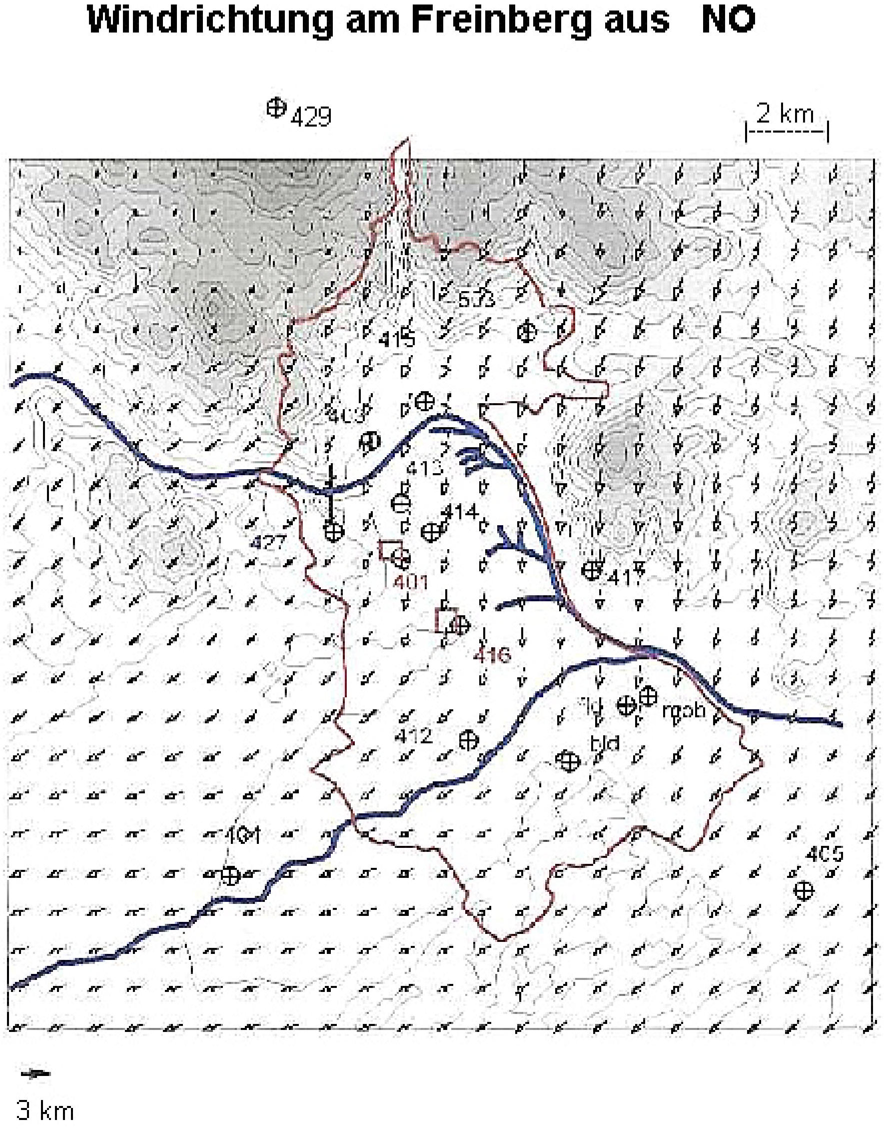


Abbildung 18: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Nordost

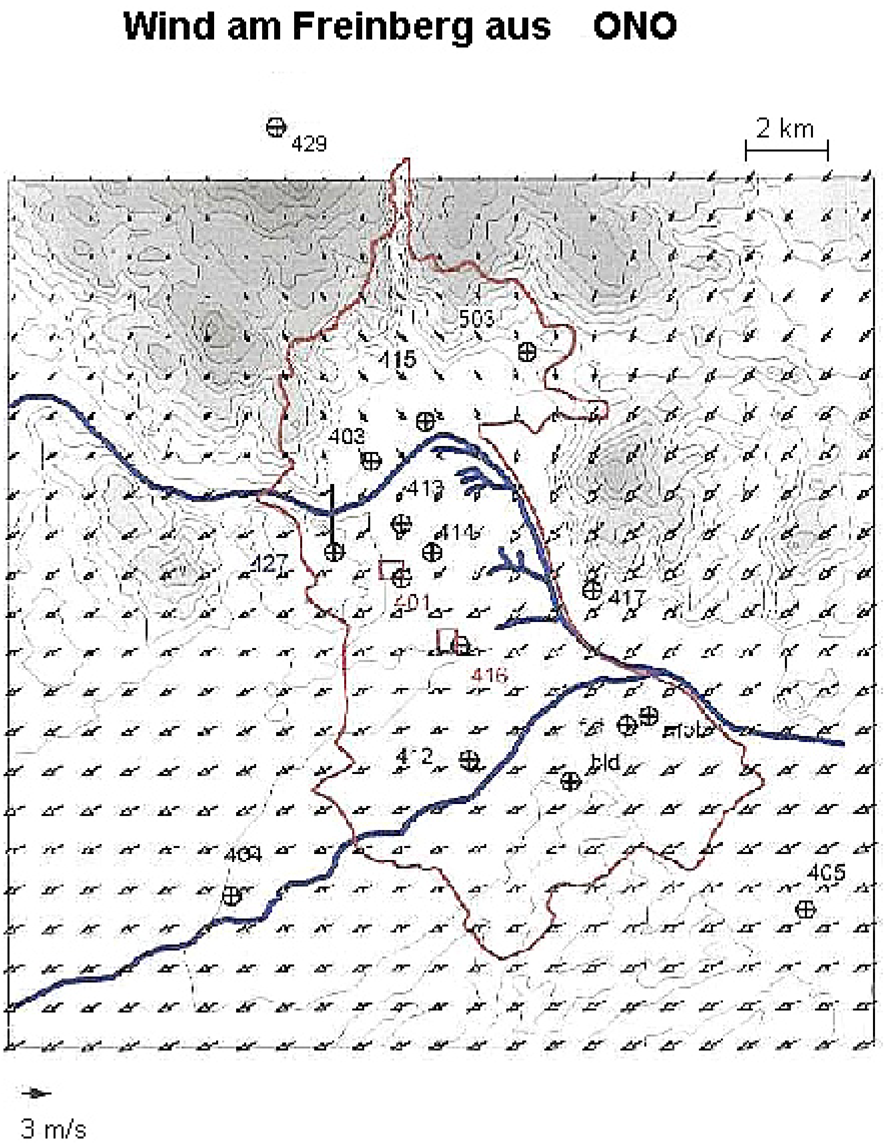


Abbildung 19: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

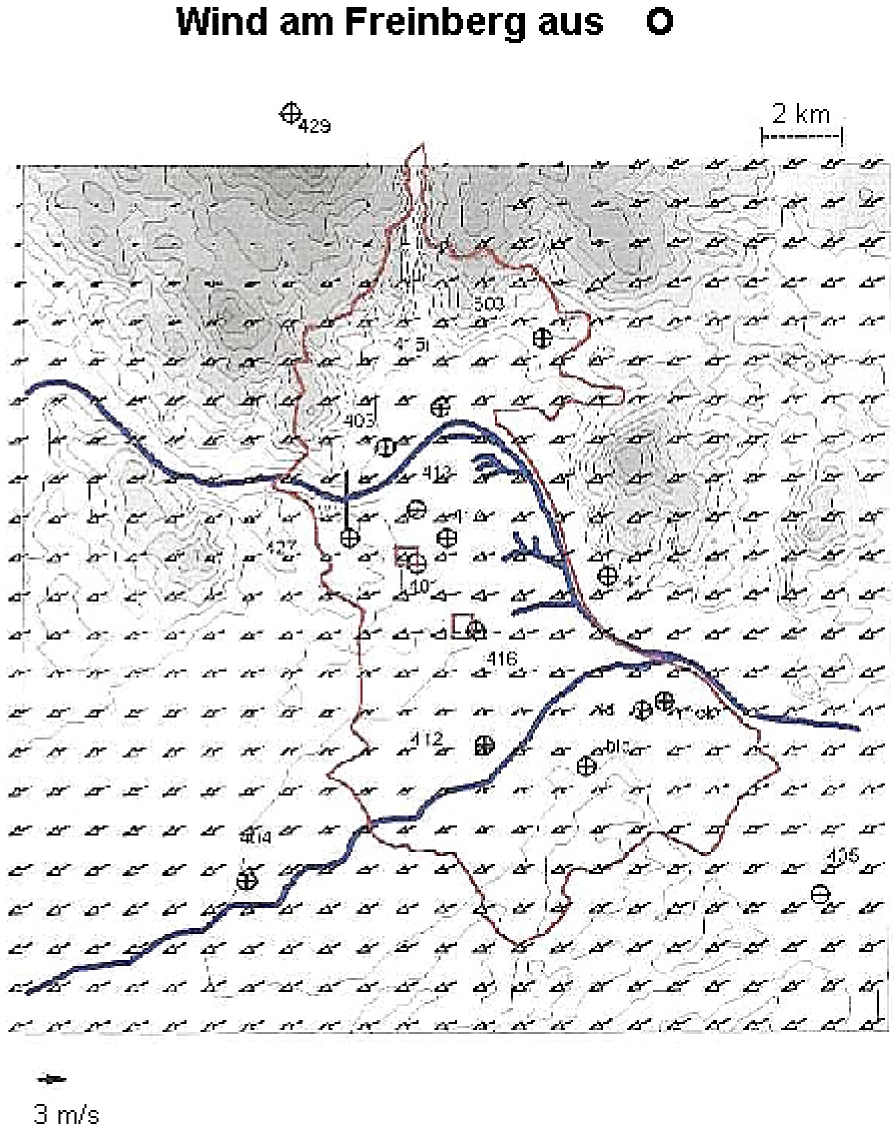


Abbildung 20: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Ost

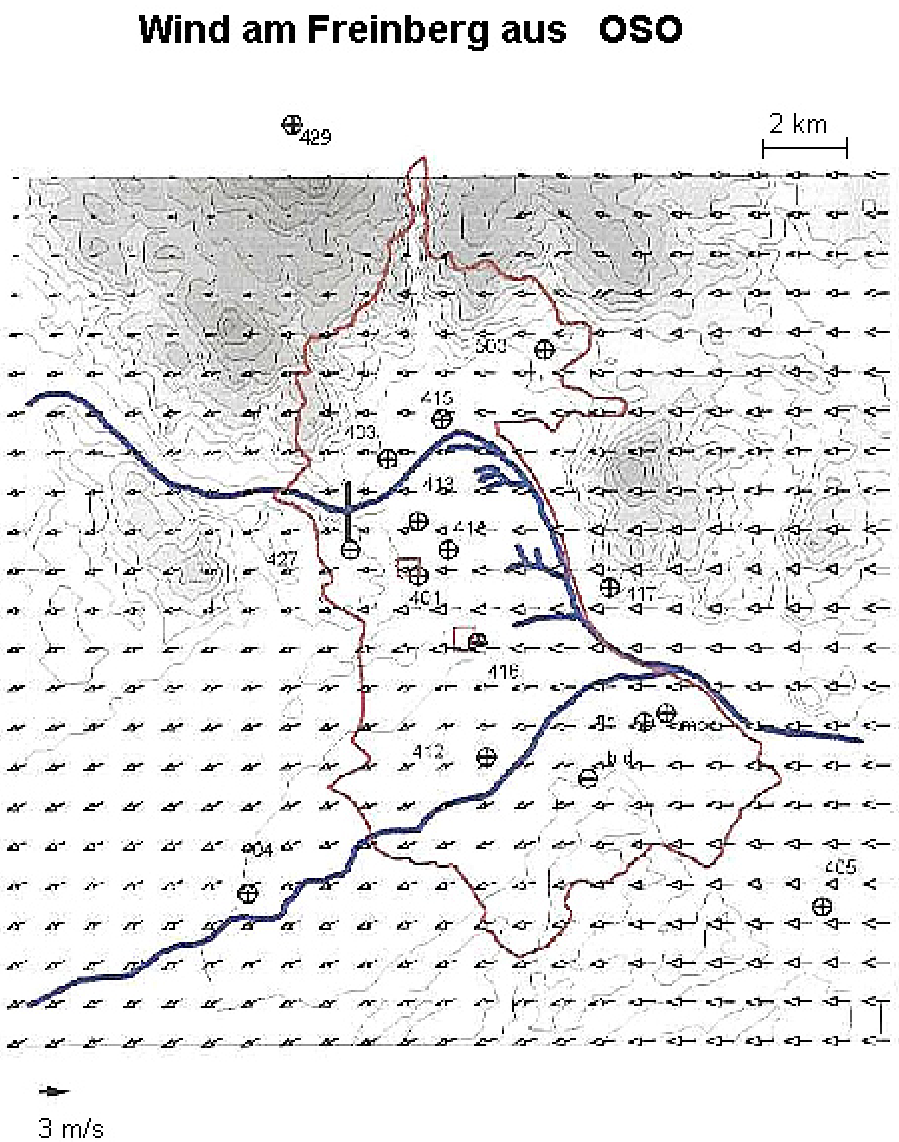


Abbildung 21: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Ostsüdost

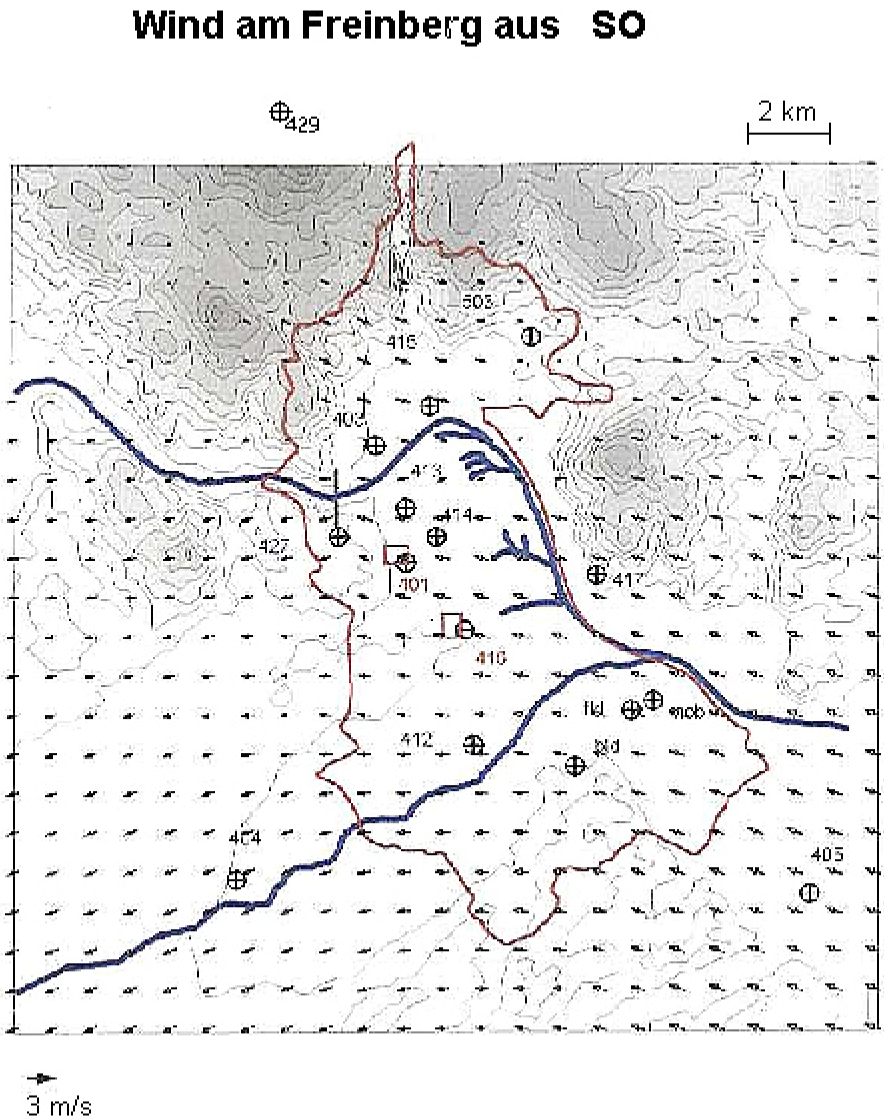


Abbildung 22: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

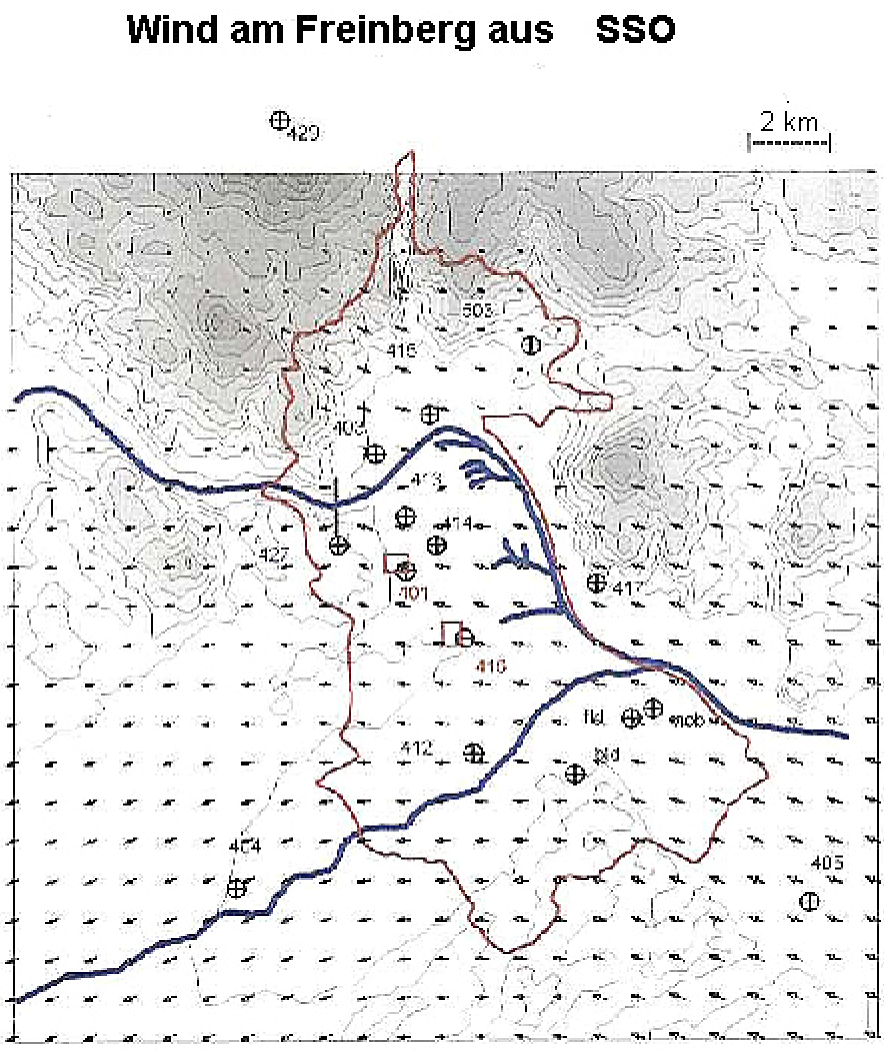


Abbildung 23: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

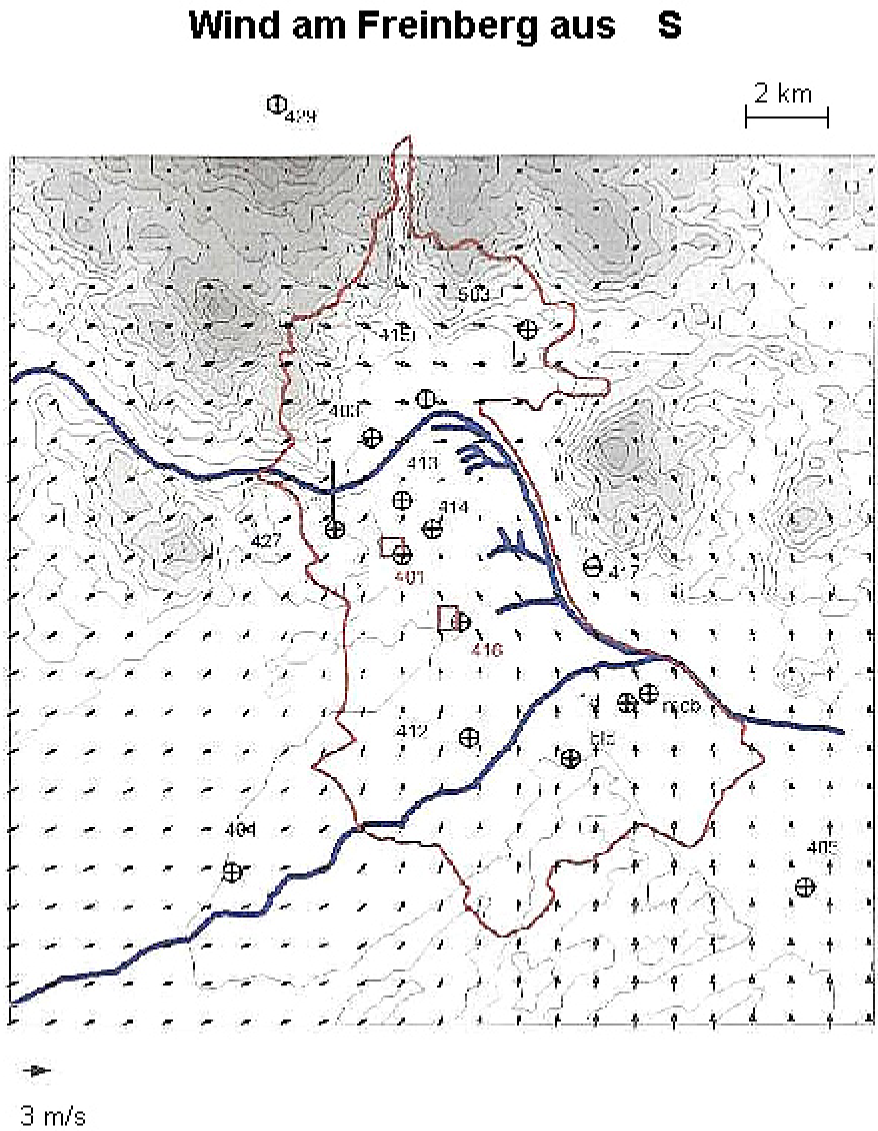


Abbildung 24: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Süd

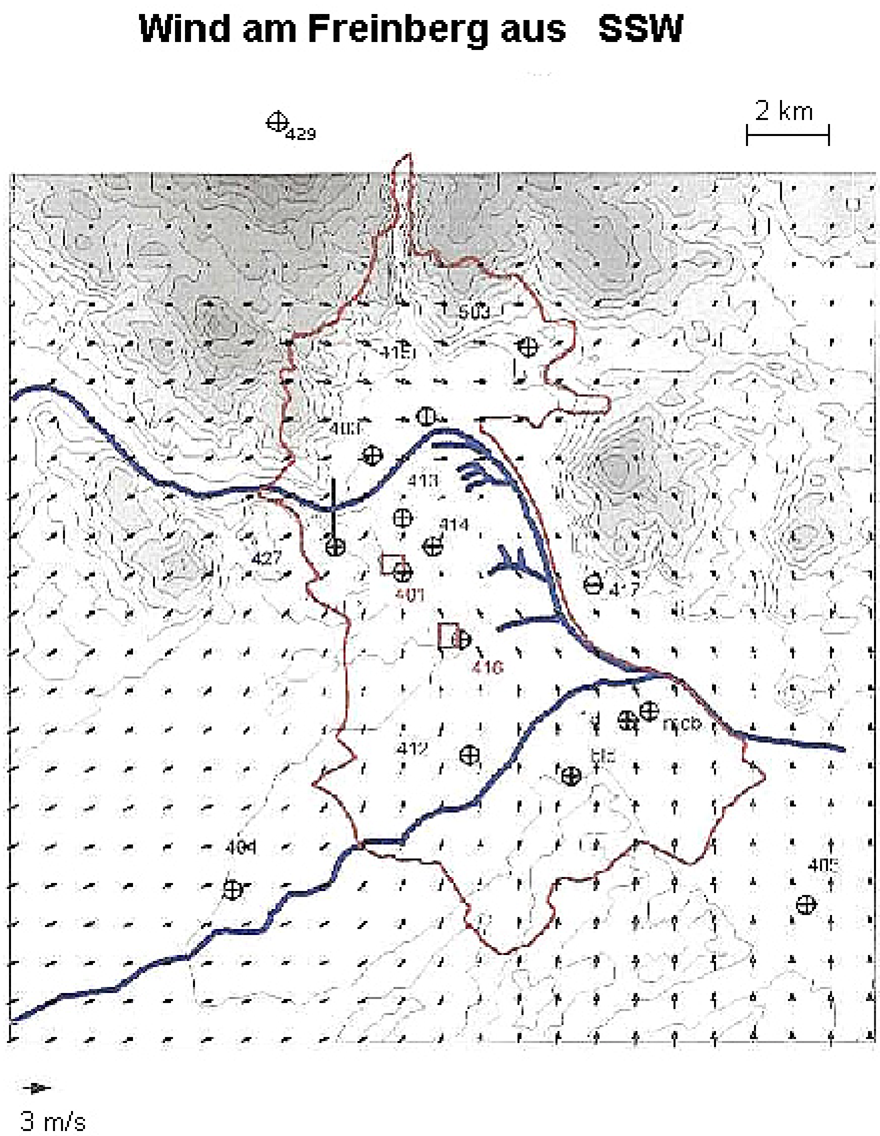


Abbildung 25: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Westnordwest

Wind am Freinberg aus SW

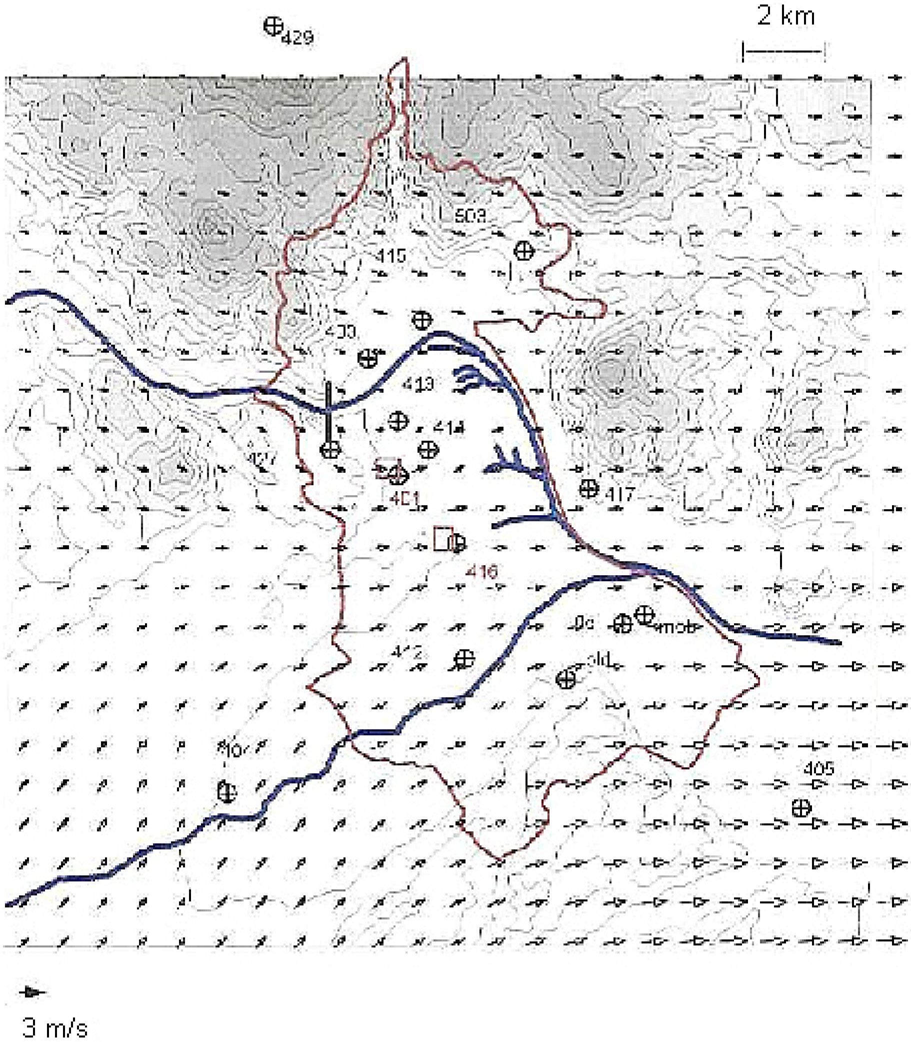


Abbildung 26: Windströmungsverhältnisse im Linzer Stadtgebiet bei einer an der Messstation Freinberg gemessenen Anströmung aus Südwest

6.5 *Inversionsstrukturen und Belüftung*

Wie schon im vorherigen Kapitel bemerkt, hat die thermische Schichtung der bodennahen Atmosphäre wesentlichen Einfluss auf das Strömungs- und Transportverhalten der bodennahen Luftschichten. Aus diesem Grund wurde eine systematische Analyse der Inversionstypen auf der Grundlage der Stationsdaten und der gemessenen Immissionskonzentration von SO_2, welcher als Tracer angenommen wurde, durchgeführt. Selbstverständlich sind durch die Höhenverteilung der Messstellen Grenzen für die Typisierung gegeben. Ebenfalls ist es möglich, dass wesentliche Strukturen nicht erfasst werden. Es zeigt sich jedoch, dass man dennoch eine Klassifizierung durchführen kann.

Es ergab sich eine Klassifikation von 8 unterschiedlichen Inversionstypen die in Abbildung 27 wiedergegeben sind. Durch die Auszählung der Fälle von SO_2-Konzentrationen > 0,01 mg/m³ sieht man sehr deutlich, dass die Fälle mit abgehobener Inversion und mit bodenaufliegender Inversion zu den Strukturen mit den größten Häufigkeiten zählen. Dies sind oft jene Fälle, die mit südöstlicher Strömung verbunden sind (siehe auch Anhang B).

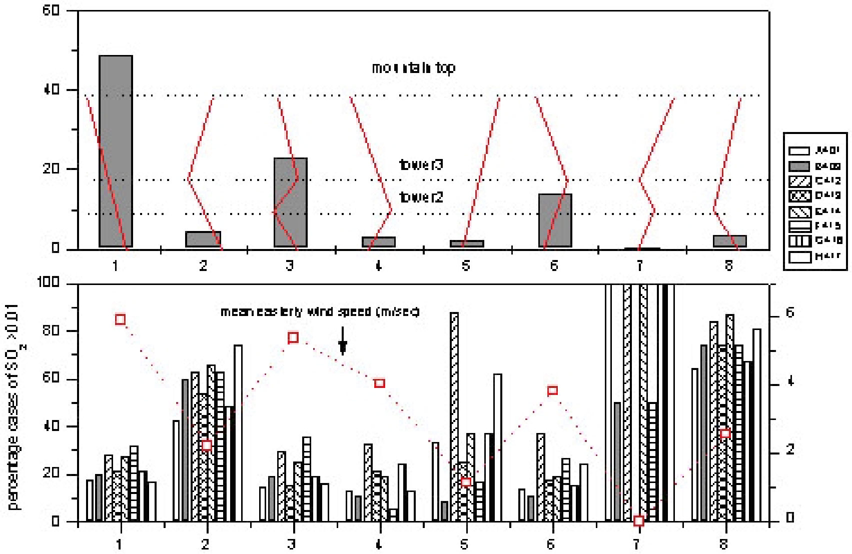


Abbildung 27: Häufigkeit unterschiedlicher vertikaler Temperaturstruktur und Häufigkeit korrespondierender Fälle mit SO_2-Konzentrationen > 0,01 mg/m³ und dem mittleren Wind

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Anhang A

Lage und Charakteristik der Linzer Luftgütemessstellen

[Aus dem Luftgütemessnetz des Amtes der o.ö. Landesregierung]

Anhang B

Chapter 5: Wind Patterns in Linz.

[Aus „Modelling of Pollutant Transport and Dispersion for Operational Use over Urban Area with Complex Terrain Surrounding“.

Dissertation von Thara Prabha an der Universität für Bodenkultur, Wien,1996]

5 WIND PATTERNS IN LINZ

A summary of the important features from the analysis of one year data (1991) for the study domain is presented in this chapter. Since major features of the flow during the years 1991 and 1993 considered here are the same and the availability of data in 1991 is more comprehensive, year 1991 is considered for this discussion. Initially a stability classification method is adopted by comparing four different methods used in this study. The statistics on the calm situations observed at differing stability and differing stations would deliver the knowledge of the specificity of the data used. Effort is in extracting the major mean flow patterns under differing stability conditions. An attempt is made to study the interaction between the ambient flow and the local flow regimes using the available data. This experience in the climatology is further used in the wind models in cases of no observations and to reduce the number of inputs to the models. The relevance of heat island in inducing circulations in Linz is also studied. The importance of these flow patterns in contributing to the pollution episodes is analyzed. Finally classification of major flow patterns is done with respect to the temperature profile over the city and relevant high pollution episodes are identified.

5.1 The data

The spatial coverage of the data in Linz is used to identify various units of the city that are less or more influenced by various factors like the terrain, local roughness effects, exposure to the free space, etc. Also it is important to know the role of the dynamical and thermal effects which play the most important role in the transport and diffusion of the pollutants out of the city. On one side when the thermally driven circulations try to ventilate parts of the city, the mechanical effects induced by the city structures would resist this. So the analysis of data for the year 1991 is done to understand the major flow patterns and to look into the differing problems of interest like the heat island, pollution episodes, ventilation of the parts of the city, etc. The calculation of stability is dealt in four different ways to find out validity of the approaches used for turbulence parameterization.

5.1.1 Determination of Stability : adopting a method

In this study, various methods have been adopted for finding the stability classification. Table 5.1 is used as the base for the classification to stable, unstable and neutral. From the table, Stability classes (2 and 3) are considered unstable, classes (4 and 5) are neutral and classes (6 and 7) are stable. Various methods are used with same number of data and their frequencies are compared.

Stability	Stability Class	Value of Monin-Obukhov length
Unstable	**2**	$-200 < L < 0$
Slightly Unstable	**3**	$-1000 < L < -200$
Neutral	**4**	$-1000 < L$ or $L > 1000$
Slightly Stable	**5**	
Medium Stable	**6**	$200 < L < 1000$
Strongly Stable	**7**	$0 < L < 200$

Table 5.1: Stability classification

5.1.1.1 Analytical solution for MO stability parameters

The method used here is based on the analytical formulations (Buyn, 1990) based on the Bulk Richardson number. The formulations are given in the Appendix B for stable and unstable classes. The Bulk Richardson number, a measure of the relative effects of convection and wind shear contributions to the diffusion, is calculated by using the mean potential temperature gradient with respect to height and the wind speed at the geometrical mean height(Z_m) using the wind profile. Since the measurement in the vertical at a single observing station is not available, the measurements at nearby stations are combined and used. The computations are done with Bulk Richardson number calculated for the layer above the city. The potential temperature gradient over the city is calculated by considering the measurements at Ursulinenhof (2 m), Freinberg tower level 50 m and 150 m. Temperature measurements at Hauserhof seem to be influenced by the heating of the roof as it is kept only 2 m above the roof and most of the time the temperature is quite higher than that at Ursulinenhof. Wind speeds from ORF-Zentrum (10 m), Hauserhof (50 m) and Freinberg tower level 150 m are used for the wind profile.

5.1.1.2 ÖNORM-M9440 -using Net Radiation

Using net radiation and wind speed at Berufsschule in the Austrian normal standard charts (Appendix A)

5.1.1.3 ÖNORM-M9440 - using lapse rate

Using lapse rate in the lowest 100m (measurements at Ursulinenhof (2 m), Freinberg tower level 50 m and 150 m are used to find this) and wind speed at Berufsschule are used with the Austrian normal standards charts (Appendix A)

5.1.1.4 Iterative Solution to MO - Similarity parameters

Net Radiation at Berufsschule is used along with the temperature at Ursulinenhof and wind speed at ORF-Zentrum. The estimates are done based on the scheme of (Holstag and Van Ulden, 1984) using an iterative scheme for unstable situation and during stable case Venketaram (1984) approach is used. The method is discussed in chapter 3.

Each of these approaches is applied for the whole year 1991 avoiding the cases of calm. Usefulness of this analysis is in finding the best method to parameterize the turbulent diffusion and in looking at the uncertainties associated with each. Fig. 5. 1 shows the percentage occurrence of each of the stability types (stable, unstable or neutral). There are notable differences in each of the four approaches. Neutral cases dominate for the calculations with ÖNORM 40 % (in case 2) and 50 % (in case 3). Same inputs of lapse rate are used in the Bulk Richardson no. approach and the ÖNORM. But in Bulk Richardson no. approach, the vertical shear of horizontal wind is also considered and more number of occurrences of unstable situation (≈ 50 %), nearly 40 % of stable and only 10 % of neutral are noted. Whereas the ÖNORM approach shows quite reduced number of unstable case as it is more biased to the neutral class. Iterative solution using the net radiation estimates nearly 35 % unstable case, 22 % neutral and 43 % stable. Compared to the second approach, the neutral classes are less, unstable and stable classes are more.

The stable cases in all the four methods, except in the second case are more or less same. Differences are mainly in the number of unstable or neutral cases. In the Bulk Richardson no. approach, since the vertical wind shear and temperature gradient over the city are considered, we could expect it to be more correct. The assessment of the reliable estimate of turbulence variables requires the knowledge of the standard deviations of wind components.

The classification of different stabilities based on MO-length is also a topic of discussion in the present literature (Hanna, 1990). As friction velocity and Monin-Obukhov length are zero for the calm situations, none of the above approaches would give reasonable estimates of diffusion parameters. There are also free convective situations with non zero upward heat flux under calm cases that are to be treated with free convective scaling.

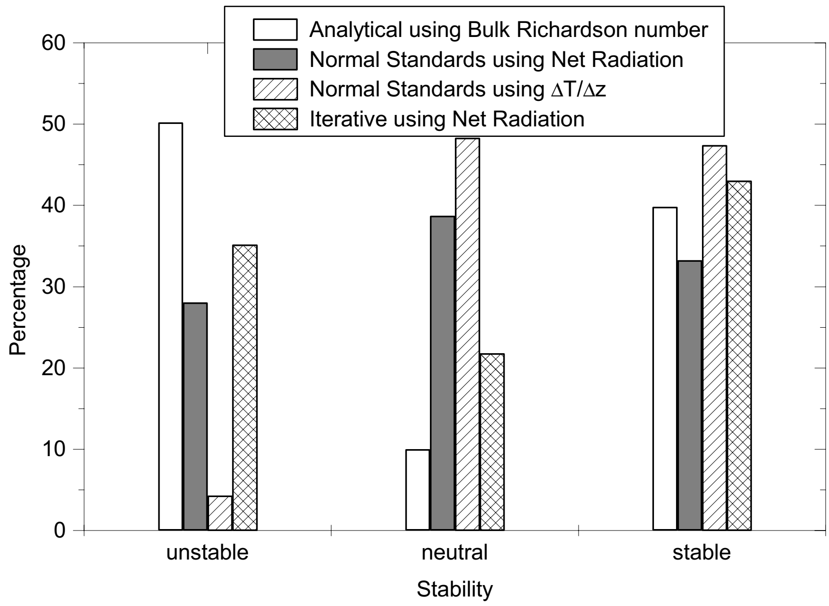


Fig. 5. 1: Frequency of stable/unstable/neutral cases for four different methods of stability calculations

From this analysis the second stability classification criteria based on the ÖENORM (Austrian Normal Standards-based on PGT classification) requires the least number of data and is comparable to the methods based on the iteration scheme and the Bulk Richardson number scheme. We could account for more number of cases for the classification of the flow types. So the stability classes for whole year are calculated using the net radiation and the wind speed at the station Berufsschule.

Percentage of occurrence of different stability classes for each half hour of the day is given in Fig. 5. 2. Around noon, 60 % of the cases were highly unstable, 20 % of the cases slightly unstable and 20 % neutral. Transition periods are dominant of neutral (60 %) and slightly or medium stable. During night, stable situation contributed ≈ 58 % and slightly and medium stable ≈ 20 percents. The inherent diurnal nature of the classification would also provide the information regarding the type of stability and the diurnal variation.

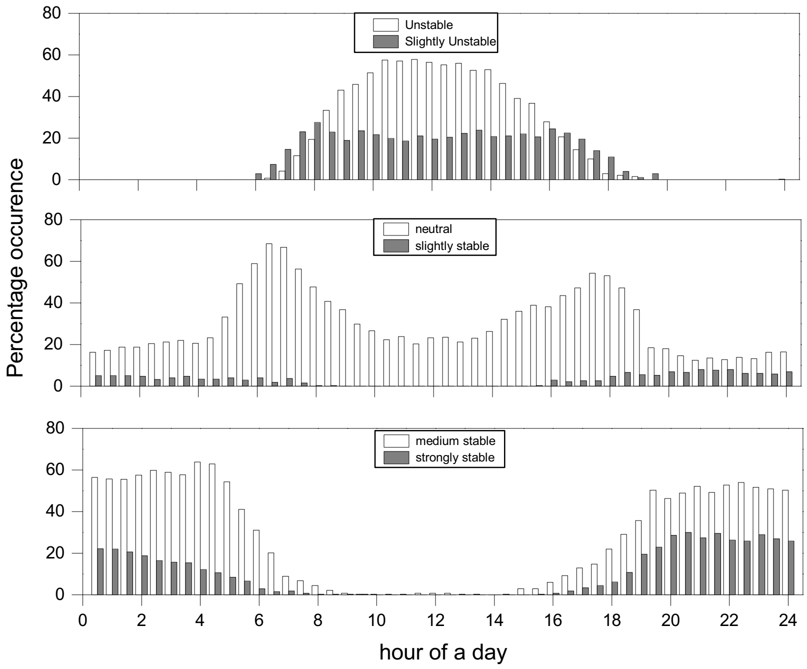


Fig. 5. 2: Diurnal pattern of the frequency distribution of different stability classes

5.1.2 Calm cases

The total numbers of data used from different stations are given in Fig. 5. 3. Wind observations at all the half hours are considered, omitting the bad and the missing data. For example, the wind observations at the 150m tower are missing for nearly 18 percent of the total period of 365*48 half hours. The percentage of total calm cases (wind speeds below 0.5 m/sec) at all wind observing sites is also shown. This gives a picture of the city effect at various parts of the city. Maximum percentage (≈ 40 %) of calms are observed at station Traun (404), which is situated at the south west of the study region in a suburban area in the big pre Alpine valley. About 38 – 39 % of calms are observed at Kleinmünchen (412) and ORF-Zentrum (414), which are at the city centre. The places close to the slopes show relatively lesser number of calms compared to Traun, Kleinmünchen and Asten. This could be attributed to the instability induced due to the drainage near the slopes. Relatively lesser number of calms are noticed at Hauserhof as measurements are taken over a high building (≈ 40 m). At 24er-Turm also less number of calms(≈ 20 %) are noticed due to the drainage from Haselgraben. Berufsschule is situated on a slope facing south and relatively suburban area. Station Steyregg (20 % calms) is also quite influenced by the topography and is situated at a higher elevation and at the edge of the hill.

The percentage occurrences of calm cases at all the stations at stable, unstable and neutral situations are also presented. This is done to get a first-hand knowledge of the response of the air movement to the local units of the city, like the areas of Dense buildings, more open spaces, forests, etc. under different stability cases. Also to assess how representative the wind observations are to the structural groups of the city. For all stations except the mountain station (429), the maximum percentage of calms occurred during the stable situations (i.e., mostly during night).

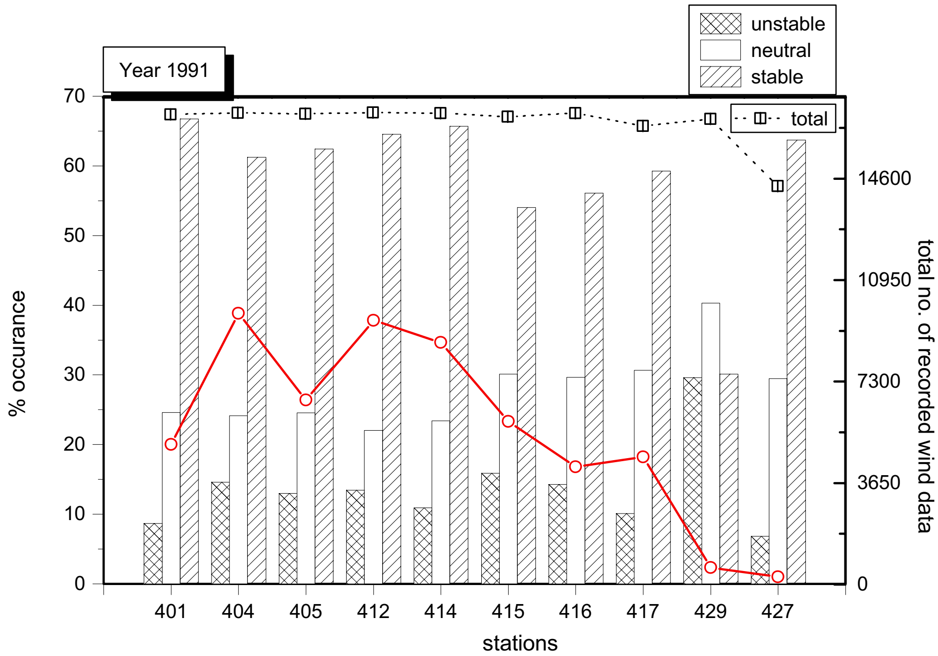


Fig. 5. 3: Percentage occurrence of calm cases. Total number of data (open square) used is scaled on right Y-axis and on left Y, percentage occurrence of calms (for the total case(shown as line with symbols) and for differing stability) are given.

For the stations in the city centre, the percentage of calms during stable cases exceeded 60 percent. Nearly 20 - 30 percent of the calms occurred during neutral case. During unstable case, 15 – 10 % of calms occurred at all the stations except at the mountain station were it increased to ≈ 30 %.

Calm situations during stable cases indicate the presence of negative heat flux with no shear. The sizes of the eddies become increasingly smaller, momentum is transferred from above and dissipation might occur. The dominant buoyancy flux drives the near surface atmosphere laminar, hindering the transport from above. Gravity waves also might form which would carry the fluxes of momentum, heat and pollution to other places. Whereas during the unstable case, a positive heat flux with no shear results in the free convective situations. The larger scale convective motions will introduce considerable horizontal motions. Under such situations, the fluctuations in the wind directions could be much higher leading to higher horizontal Dispersion and meandering. Thus the pollutants released at higher levels also contribute to the surface level pollution episodes. All these stagnating cases have severe consequences in one way or other.

The data are representative for different structural groups in the city and the role of the terrain induced circulations in ventilating the parts of the city is quite evident. This analysis clearly shows the indications of a heat island in the city qualitatively as the number of calms is a direct function of low ventilation at a particular unit of the city. The drainage winds play an important role in ventilating the regions near to the slopes there by reducing the number of calms. The low wind cases make it difficult to apply the theories of boundary layer research as most of them are developed for relatively moderate wind speeds.

5.2 Mean Wind Climate in Linz

The mean wind climate in Linz is analyzed first with respect to the synoptic scale flow and the topographical influences are further identified. In this section, analysis of the wind patterns at different stabilities is also looked at. The consideration of the diurnal changes in the wind direction will explore the origins of the thermally driven wind systems in and around Linz. The interaction between locally generated and ambient wind is further studied for differing stability to understand the complex flow patterns.

5.2.1 Interaction with the synoptic scale flow

The wind rose for a nearby mountain station (Feuerkogel at 1618m above sea level) is calculated using hourly observations of wind speed and direction from the National Meteorological Service and given in the Fig. 5. 4 (left). The west north-westerly - westerly is noticed in majority of the cases. On the right side of the diagram, the wind directions at the tower Freinberg and mountain station Feuerkogel are compared. There are four flow types with respect to the Feuerkogel. The north-westerly at the tower with easterly at Feuerkogel is the most dominant flow pattern. Coexistence of north westerly at both places is a dominant pattern. There exists two more distinct flow patterns over the city with respect to Feuerkogel. Majority of the easterly at the tower is associated with wide variety of wind directions at Feuerkogel. Opposing westerly wind at Feuerkogel is also a pattern of interest.

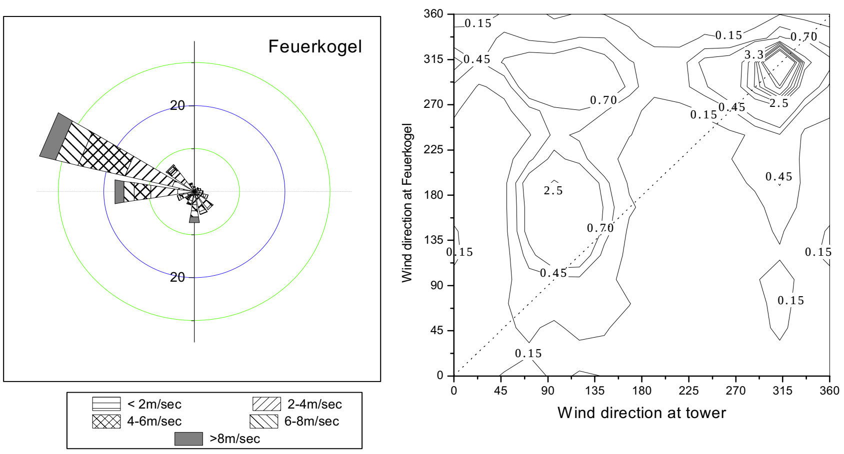


Fig. 5. 4: The wind rose diagram for Feuerkogel (left) and Comparison Feuerkogel wind directions with the wind directions at the Tower Freinberg-3

The geostrophic wind is calculated using the pressure observations of National Meteorological Service at various stations around Linz. It is done to find out the interaction between the flow patterns in the synoptic scale and local scale of concern. The stations considered are Salzburg, Hohe Warte (Vienna), Hörsching (Linz - Airport), and Litschau. Eight pressure values were available during the day and are linearly interpolated to have the values at every hour.

A regression equation for pressure(P) at a place relating it to the north-south (A) and east-west (B) gradients is used for the calculation of components of geostrophic wind. i.e.

$$P(x,y) = Ax + By + C$$

$$U_g = -\frac{1}{\rho f}\frac{\partial P}{\partial y} = -\frac{1}{\rho f}B$$

$$V_g = \frac{1}{\rho f}\frac{\partial P}{\partial x} = \frac{1}{\rho f}A$$

where $f = 2\Omega \sin\phi$, $\rho = 1.228\ \text{kg/m}^3$

The dominance of the east north-easterly to easterly or westerly was noted for the geostrophic wind. The calculated wind speeds are found to be higher possibly due to the selection of the stations. The selected stations are quite close for the geostrophic wind estimates. As geostrophic winds blow parallel to the isobars with high pressure on the right, we could expect the westerly geostrophic winds to be associated with low pressure to the north and high to the south. This would induce easterly surface winds. In the case of the easterly geostrophic winds, high pressure would be to the north and low to the south. This pressure gradient would introduce near surface westerly. Relative occurrence of wind directions at Freinberg tower for differing classes of geostrophic wind directions is checked to find out the relationships in Fig. 5. 5 (left).

Majority of cases showed opposing wind directions during the easterly wind at the tower and which is further cross checked with the radiosonde 2000 m level observation at Hohe Warte for the 00:00 hrs and 12:00 hrs. The majority of the cases showed good matching between the geostrophic wind directions and the radiosonde. Most frequent flow type was with westerly at the tower with easterly to NErly geostrophic wind (opposing winds). This suggests the geostrophic wind to be not always representative for the wind field in Linz. Representativity of the geostrophic winds over Linz is to be further studied to identify the cases where it is applicable by considering different synoptic flow patterns.

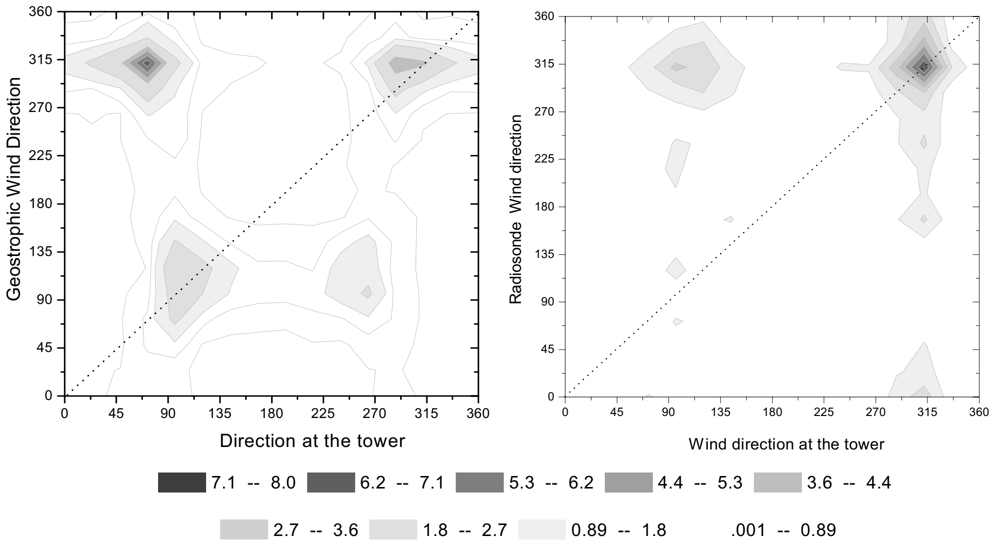


Fig. 5. 5: Comparisons of the geostrophic wind directions (on the left) and the radiosonde (on the left) wind directions at 2000 m (Hohe Warte) with the wind directions at the Tower Freinberg-3

The comparison of the wind directions at the tower and the radiosonde is given in the Fig. 5. 5 (right). The radiosonde observations (two timings; 12:00 hrs and 24:00 hrs) are used here. It is noted from the Fig. 5. 5 (right) that varying wind directions exist for the sonde for easterly/westerly case. Two major flow types can be identified as north-westerly at both the places (aiding) and opposite case with easterly at the tower with north-westerly at 2000 m level. The dominance of these opposing wind cases both in the radiosonde and geostrophic wind signify the importance of the local/mesoscale influences in Linz. This is also noted at the synoptic station Feuerkogel.

5.2.2 Influence of the Topography

The dominant wind systems over Linz are from west to north-westerly and from east to south-easterly. The wind rose for Linz in 1991 is given in Fig. 5. 6. Calms (wind speeds below 0.5 m/sec) are not considered as the directions at those wind speeds were kept as north (0 value) in the observations.

The main wind directions in the main valley are easterly or westerly. Giselawarte station depicts easterly dominance. These easterly winds are the main wind directions in the big valley between the Alps and the Böhmische Masse. Thus the easterly ambient winds noticed are already influenced in the mesoscale. Whereas during the westerly cases, north-westerly and westerly are the dominant directions. From north- west to westerly and south-east to easterly strong winds dominated at the tower Freinberg. This is quite parallel to the axis of the mountain ranges north of the city signifying the effect of channeling. Nearly the same feature is noticed at the mountain station (Giselawarte) except for the higher frequencies of easterly there. This signifies the effect of the local influences at the tower from the terrain surrounding the city. During west to south-westerly cases, the wind directions at mountain top could be taken as representative for the domain representative flow. During the easterly ambient flow in the valley, the wind field over the city is further modified due to the terrain and the city in a local scale. Thus we could expect a modified flow field above the city due to its closeness to the hills and with less modified flow field in the valley.

Steyregg is also at a higher elevation and the flow pattern is quite influenced by the topography during both the dominant wind directions. The station is situated at the edge of the Steyregg hill. The influence of the terrain under both the dominant wind directions is quite evident. The north-easterly to south-easterly situations are characterised by relatively high wind speeds. This would be a consequence of the gravity flows (down slope) and the decoupling effects over the city. All the directions north-easterly to south-easterly are observed there with wind speeds up to 2-6 m/s. Nearly 40 % of the total flow situations are from west-north-west to west.

The stations in the big valley like Asten, Traun and Kleinmünchen depict easterly or westerly maxima. South-westerly winds are the third dominant direction at these places. These wind directions match with the synoptic wind climatology of the main valley. These are the already channelled winds due to the big valley in the mesoscale. These stations are less influenced from the topography in the local scale. Strong westerly is also noticed seemed to be because of less number of obstacles unlike inside the city.

If we look at Hauserhof situated on a 40 m high building, westerly is the most dominant feature. Added to this south-westerly and north-westerly are equally dominant. Relatively reduced wind speeds are noted here. At Hauserhof, north-westerly to south-westerly dominated to 40 %. Most of the other wind directions are equally dominant. This station seemed to be influenced from the hills to the west. The frictional reduction would be responsible for the reduced wind speeds here. The station is more exposed at the eastern side to the city and thus the easterly ambient wind gets reduced due to the frictional drag due to the buildings in the city. The westerly winds also could get supported by the down slope winds from the hills to the west. The station depicts a mixed influence from the big valley, hills near by and the city. At Berufsschule similar influences are existent except that south-westerly and south-easterly dominate there. This is attributed to the gentle slope facing south. The wind speeds are reduced here also due to the frictional influences.

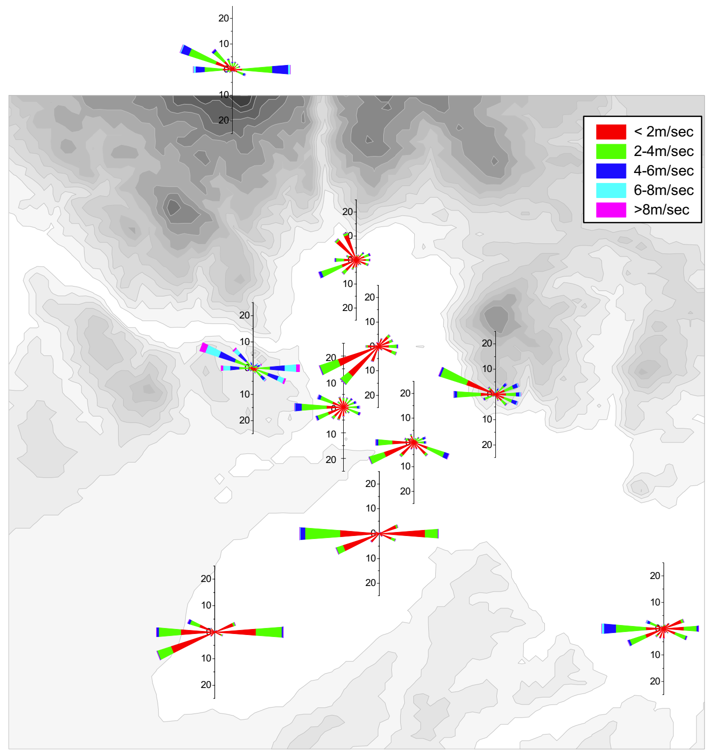


Fig. 5. 6: Wind rose for Linz. On the top of the plot, station Giselawarte (mountain station-429) is given.

At 24er-Turm, the drainage flow (mostly less than 2 m/s) from Haselgraben and the flow diversion along the Danube basin are the dominant features. ORF-Zentrum is also influenced by the Danube basin, where south-westerly contributed to nearly 40 %. The wind directions show a channeling around the Danube basin. The importance of this channeling feature in building up pollutant concentration inside the enclosed area of the city is one of the interesting aspect to be studied. The origins of these wind systems, are they mechanically driven or thermally driven, would increase the knowledge in quantifying this effect.

5.2.3 Influence of Stability

Frequency distribution of direction at all the stations for varying stability as mentioned in section (5.1.1) is classified and their frequency of occurrences is given in Fig. 5. 7. This clearly distinguishes the flow patterns introduced due to the topography.

During stable cases, the possible occurrences of the inversions and the suppression of the flow below would occur. This is due to the fact that the static stability above would introduce less influence. The flow field below would get separated with isolated unstable layer near the surface over the city. The near slope areas would be more stable. We could expect such situations be characterised by speed up at the solid lateral boundaries. The tendency of the air to move closely around the barriers during stable cases is clearly noticed. This is noted at Steyregg , ORF-Zentrum and 24er-Turm. Also the dominance of down slope (at Steyregg) and the valley flows (at 24er-Turm) are evident. The influence of the drainage is seen also at Hauserhof and at ORF-Zentrum. The northerly component at Hauserhof is specially noted during stable case as an indication of the strong drainage towards the inner part of the city. The frequency of such cases is quite low. Since the stable cases are concentrated during the night, we could say during night time the drainage flow systems are ventilating the nearby areas to the topographic barriers. Stations in the SE/SW sector of the domain (Asten, Traun, Kleinmünchen) also show the wind distributions that try to follow the terrain during stable situations with least differences. Station Asten also characterise a downslope flow from the mountain ranges to the south of the station. The wind at Freinberg and Giselawarte also show channeling more close to the topography with slight variations in the wind direction.

During the neutral situations, the topographic influences are less compared to the stable case. Neutral north-easterly flow at 24er-Turm is a distinct feature. This is also noted at ORF-Zentrum. The topographic influences are reduced at all the stations.

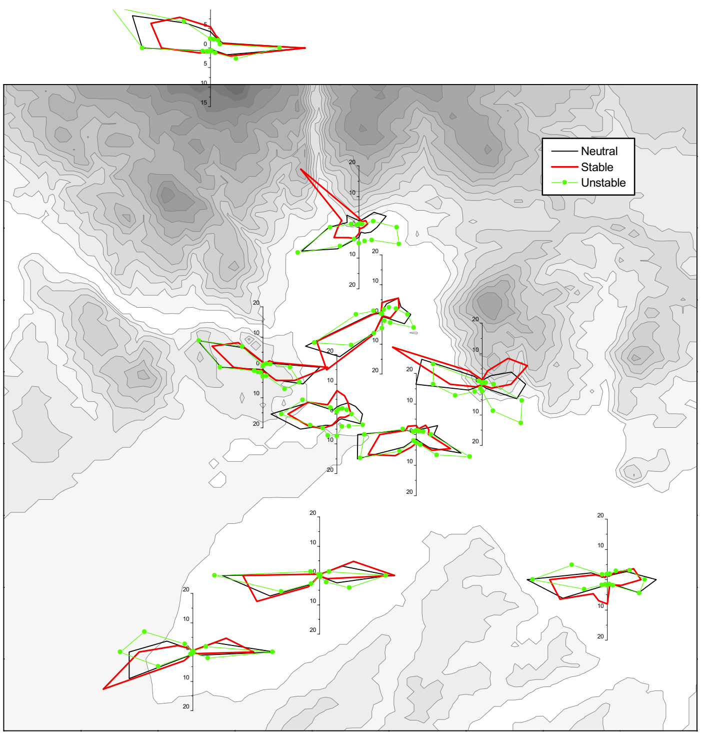


Fig. 5. 7: Distribution of direction at varying stability

The flow systems seem to follow the synoptic pattern during unstable cases. As a result of local mixing higher wind speeds are introduced, the heated slopes would also assist this. During unstable cases, the air is moving along the Danube basin indicating a circulation along the Danube in both the dominant directions that is consistent with the distribution at Steyregg. Similar indications are also seen at the ORF-Zentrum. As the unstable classes are concentrated only during the day, as the distributions at different stations inside the city reveal, we can expect the wind systems to follow the Danube basin with less effect from the topography. Also it can be noted that the westerly to north-westerly contribute to an anticyclonic vortex inside the city. The dominance of the south-westerly components at the stations „24er-Turm“ and „ORF-Zentrum“ during the unstable situation with westerly ambient wind is a clear indication for this fact. The easterly unstable cases characterise a cyclonic vortex inside the city. The origin of these vortex formations is not clearly understood. There could be two main aspects to look in to. Is it induced due to the interaction between the large-scale ambient and local effects of upslope directions when the slopes become more warmer (thermal induced) ? OR Is it a purely mechanically induced due to the aspect of the terrain ? Of course the effect of Danube river is another aspect embedded in these. This channeling along the Danube in other words the vortex formations do play a very important role in deciding the flow aloft. Thus the pollution dispersion too.

This analysis also gives a rough idea of the diurnal development of the flow systems. Further careful and detailed analysis is needed to look at the development and the decay of these wind systems. So the diurnal pattern of the wind directions at all the stations is studied.

5.2.4 Diurnal variations of wind direction

Frequency distribution of diurnal variation in wind directions at various stations is analyzed to understand the possible causes and air mass origins. This would also offer the possibility to put some light into the interactions of different scales(local, regional) as the diurnal cycle is the most important in those. (Fig. 5. 8a, Fig. 5. 8b, Fig. 5. 8c) show the diurnal patterns of frequency distributions. Before going into the details of the analysis, one should keep in mind that all the calm situations are excluded from this analysis. Since most of the calms occur generally during night, many of the night-time cases are not accounted for. Figure 5.3 gives an estimate of what percentage of data is treated for each station.

At Freinberg and Giselawarte, (Fig. 5. 8a) north westerly dominates during the day and Easterly dominates during night for 30 percent of the total occurrence. The same behavior is noticed for the year 1993 also at Giselawarte. This phenomenon is to be looked into as the mesoscale influences from the pre-alpine valley between the Alps and the Bömische Masse to North; in the Alpenvorland. This is an indication for the dominant mesoscale influence. The existence of such mesoscale diurnally changing wind systems in Alpenvorland is not documented. So this would be an interesting phenomenon to look into. A special feature of the easterly wind at the tower is noted here. The easterly wind changed to south easterly during the morning hours. Similar but opposite change in the direction distribution is noted during the sunset. This is an indication of the local effects at the tower. Since is located more close to the hills and the city itself, local effects would dominate during the transition periods.

If we look at the surface stations to the south-west of the city, Traun and Kleinmünchen (Fig. 5. 8) westerly is more dominant during night at Traun and during the day they are shifted more to the north. The city rural temperature differences (heat island intensity) would be a factor in contributing to the dominant westerly winds at this station during night. Easterly is also equally dominant though out the day and night for this station. Increased scatter in the distribution of the westerly winds by the late afternoon hours would be as a result of increased local mixing. The small valley of river Traun also influence this station. At Kleinmünchen, west to north-westerly dominate during the daytime and easterly dominate during the night-time. This is similar to the upper level flow. It should be noted that in the analysis of calm cases we noticed maximum of nearly 40 percent of calms at Kleinmünchen and Traun. So we lack a lot of cases to have an explanation for this aspect. At present it could be attributed to the mesoscale influence noted. At these stations, there are local influences that also play a good role in deciding the flow field especially during the night.

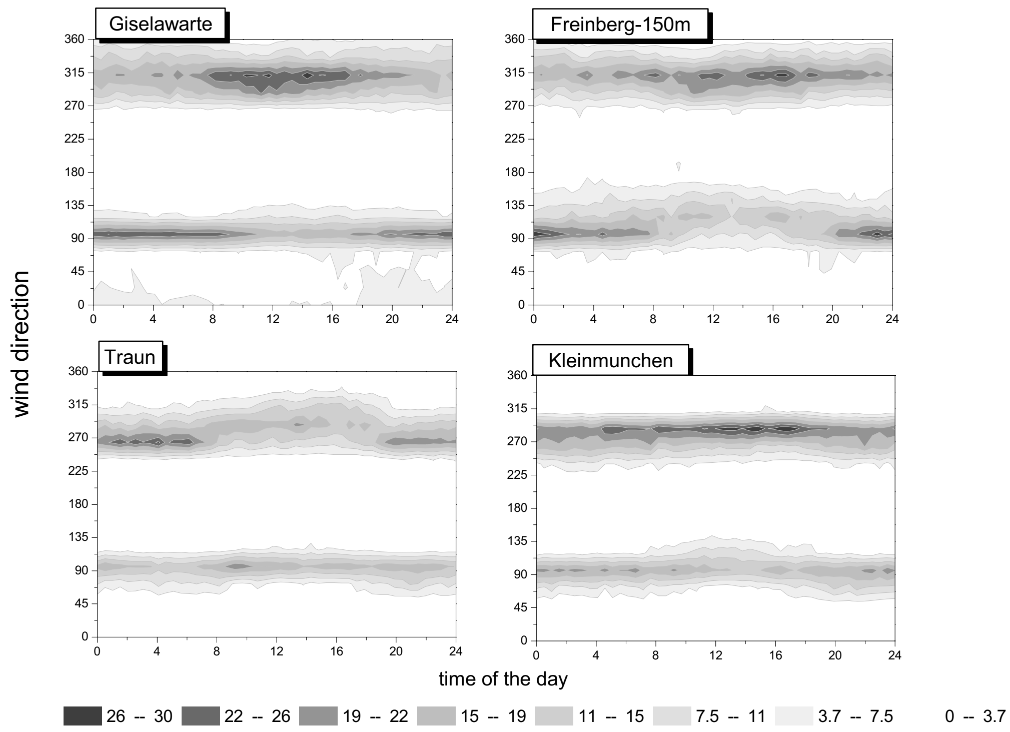


Fig. 5. 8: Diurnal variation of direction distribution for Giselawarte, Freinberg-3 (Tower), Traun and at Kleinmünchen

At Hauserhof, the dominant wind is from north to north-west through out the day. The easterly contribute only 10-15 percent during the day that shows a directional change as it is quite influenced by the Danube basin. This directional change is linked to the input of solar radiation. During the morning hours, the wind directions change more clockwise leading to south-easterly. This seems to be a result of the warming up of the slopes and the city effect is almost non-existent at this time. Then the interaction between the upslope and the ambient easterly wind would result in south-easterly winds. Since there is much difference in the sunrise timings during the year, there is a spread in this direction distribution (from 5:00 hrs to 10:00 hrs in the morning). By the afternoon hours, the flow around the Danube valley dominates as the temperature gradient between the slopes and the city diminishes. Unstable situation prevails and the topographic influences are reduced. By the evening hours till 20:00 hrs, the directions change to northerly or north-easterly. This is in relation to the cooling of the slopes and the thermally induced slope flow towards the city dominates. Since the city is warmer than the slopes and unstable during the first half of the night, the vertical motions persist over the city. This would increase the low level convergence thus the slope flow gets accelerated towards the city. It can be noticed in the Fig. 5. 9 that in the second half of the night, the frequency of the northerly or north-easterly flow towards the city is diminished. This could be associated with the development of a stable layer over the city and the dominance of frictional effects inside the city. Thus the city plays the role to resist the advance of the drainage. Since this station is located on 40 m high building, it gives an idea about the vertical extent of the thermally induced winds also. During daytime, we have noticed similar changes in the easterly wind directions at the tower with lesser changes than at Hauserhof. So we could expect the whole urban surface layer characteristics to be determined by the thermally induced flow systems and the city effect itself during clear sky situations.

In the case of ORF-Zentrum (Fig. 5. 9), westerly winds dominated and the easterly cases (10-15 %) showed a similar diurnal variation as at Hauserhof in wind direction. During the easterly cases, the changes in the wind directions are more clear and it's a dominant feature. The station seemed to be quite influenced by the Danube basin under easterly situation during the midday. Night time cases show the dominant north-easterly slope winds with maximum around 20:00 hrs. Later in the night, these wind systems were less frequent as in the earlier case.

At 24er-Turm (Fig. 5. 9) drainage flow from Haselgraben is the dominant feature during the night with maximum around 20:00 hrs. The existence of the drainage winds throughout the night till 800hrs in the morning is specially noted unlike in other stations like Hauserhof, ORF-Zentrum, where the drainage flow ceases in the middle of the night. It is also noted that the frequency of occurrence of drainage decreased in the second half of night. This establishes our assumption that the drainage is forced by the city effect in the first half of night and blocked later. We could expect the heat island created due to the city centre to assist the development of the stronger drainage in the first half of the night as the temperature gradients between the slopes and the city are larger during that period. But later in the night, frictional (dynamical effects) in the city centre would counteract and would resist the advance of the drainage well inside the city. This hypothesis could be analyzed with more care in the consideration of the heat island effect in a later section. Westerlies dominate during the day that would be in association with the upper level flow. Easterlies change direction during the course of the day. During the midday and afternoon hours, the wind systems are aligned parallel to the Danube basin.

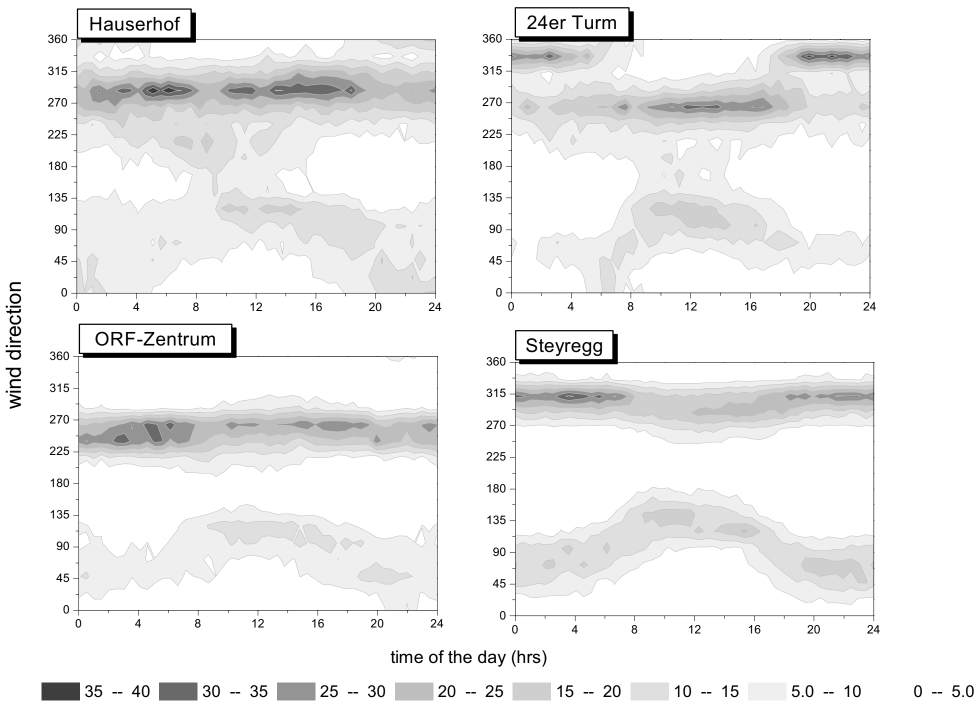


Fig. 5. 9: Diurnal variation of direction distribution for Hauserhof (a), 24er-Turm (b), ORF-Zentrum (c) and Steyregg (d)

At Steyregg also similar diurnal pattern is observed with more percentage of easterly and more distinct changes in the diurnal pattern signifying the importance of the drainage winds and the vortex formation in the Danube valley area of the inner city. north-westerly dominated during the night and the tendency to turn more westerly with the warming up of the slopes during the day is also noted. The development and decay of the slope flow are clearly noticed in the easterly case.

Maximum occurrences of the slope flow (nearly 20 %) at around 2000 hrs are a very good indication of the terrain effect over there.

Westerly is dominant during the day for most of the stations inside the city with majority of cases along the Danube. During the day this is the clear indication of the anticyclonic vortex formation in the Danube valley area of the city. Easterly cases depict the influence of the thermally induced flow systems. Instability seem to assist the flow along the Danube basin. These influences seemed to have a vertical extent at least up to 200m above the city.

At station Asten (Fig. 5. 10), north north-westerly and easterly are dominant during the day. During night, apart from these situations, the southerly to south-westerly winds contribute up to 10% of the cases. These could be the influence from the gentle mountain slopes to the south of Asten. A similar change in wind directions is noted during the easterly daytime cases with easterly turning more clockwise. Reverse changes are noted during the evening hours. The amplitude of these changes is less. Similar changes with less amplitude are also noted at other stations (Traun, Kleinmünchen) in the valley. This indicates that these changes in wind direction are occurring in a larger scale. Inside the city, these happen with larger amplitudes due to the complex nature of the surroundings and the city.

Easterly to south-easterly and westerly dominate during the day at Berufsschule (Fig. 5. 10). Dominance of westerly seemed to be associated with the dominant large-scale north-westerly wind above. The gentle slope at this station does have an influence at both the dominant ambient wind directions. Under easterly ambient winds, south-easterly winds are noted here due to this aspect. Also a downslope component is dominant for 10 % of the cases beginning nearly at 1600 hrs with maximum at 2000 hrs. This remained throughout the midnight with decreasing likelihood. This indicates the influence from the hills to the east of the city centre. This influence dominates the effect of downslope components from the north/north-west mountain ranges.

The features described above gave an over view of the diurnal patterns of the wind direction for various stations in and around the city. Under both the dominant wind direction situations, the diurnal patterns at most of the stations are quite different. The stations near to the mountains (i.e., inside the city), the effect of the Danube basin is more evident under the easterly cases with more channeling along the Danube basin. Also it is seen that the terrain induced flow towards the city from the slopes during night is a dominant phenomenon under easterly cases there by providing good ventilation of these areas. Under westerly flow, during day, the chances are to transport the pollutants out of the city by the wind systems along the Danube. Diurnal changes in wind directions are more with the easterly than the westerly cases.

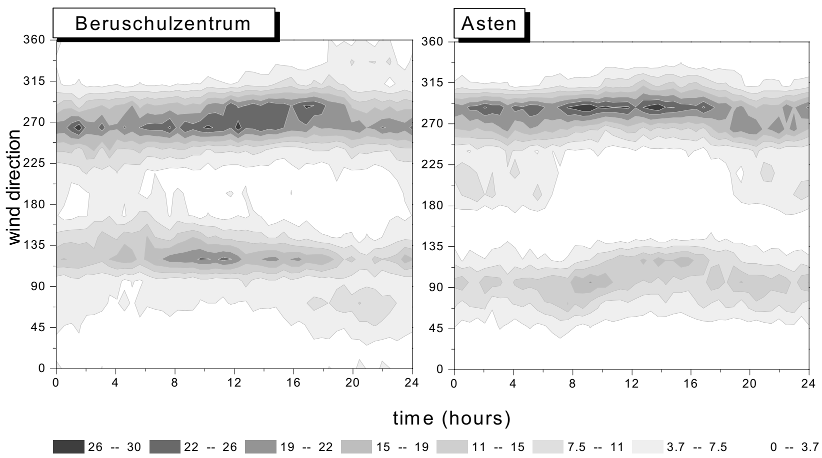


Fig. 5. 10: Diurnal variation of direction distribution for Berufsschule and Asten

5.2.5 Interaction with the 150m wind field over the city

Effects of flow above 150 m (Freinberg Tower) over the city's enclosed area to the surface observations are investigated by comparing the simultaneous occurrences of both the situations. Results of this analysis are presented for all the surface and mountain stations. The total number of occurrences of different wind directions at the stations is found for each wind direction class at the tower. This is done for all the three stability and for the total case. This analysis would offer the possibility to overhaul the complex interactions between the two levels in the vertical, i.e., the interactions between the ambient and the locally generated flow fields. In each of these plots, if the contours are below the diagonal of the plot frame, the wind is veering with height and if it is above the diagonal, wind is backing with height. In the case of Giselawarte this is reverse as the station is situated at a higher level than the tower. As in the case of other analysis related to the flow, the calm cases are not considered.

Hauserhof: If we compare the wind directions at Hauserhof and at the tower (Fig. 5. 11), the wind veers nearly 25° with height at mean situations possibly corresponding to the warm air advection over the city and the effect of the Danube valley. During the stable case differences are more under northerly to westerly winds at the tower. If we take this representative for the 50m wind field for enclosed area of the city, there are quite a few cases, this measurement would be affected by the wake of the individual building itself.

It could be that the drainage flow from the hills to the north is strong towards the city centre during such situations. This is seen during the cases of south-easterly or southerly wind at the tower. Another feature to be noted is the south-westerly neutral situations where there is not much difference between the wind directions at both the stations as the stations are more open to the flow from those directions. Wind speed at this station is quite important as there are a number of surface level pollutant sources and there are no other wind measurements inside the city that would deliver the information of the flow at 50m.

The stations more outside of the enclosed area of the city like Traun (Fig. 5. 12), Kleinmünchen (Fig. 5. 14) and Asten (

Fig. 5. 13) exhibit slightly different behavior. Stations Traun and Kleinmünchen show not much change in direction corresponding to the one at the tower, especially during the unstable and neutral cases. But in the case of Asten veering of wind with height up to 45° is noticed in all the cases.

During stable situation for varying wind directions at the tower, southerly winds are noticed at Asten. Nearly sixty percent of simultaneous occurrence of the easterly are noticed in the case of all the three stations. This indicates the pure synoptic influence from above and the good exposure of the tower to the eastern part of the domain.

Majority of the cases depicts a 20-40° veering at the tower compared to the wind directions at ORF-Zentrum (Fig. 5. 15) in the mean situation, which is found to increase with the westerly. During stable situations, apart from this feature, a well-marked number of cases are westerly at the station compared to the easterly and southerly to south-westerly at the tower. This is an indication of the terrain induced downslope winds from the hills to the north towards the city centre, during stable situations. Also for a range of westerly to north-westerly at the tower, stable westerly dominated at the surface station

Neutral situations show mostly same behavior as the unstable case except that the south-westerly are simultaneously noticed at the tower and at the station. This could be due to the fact that the stations are more open to the south-western sector.

24er-Turm: The drainage flow dominated in the mean situation for all the wind directions at the tower (Fig. 5. 16). Only 15 % of variations are seen during the stable situation apart from this dominant drainage from Haselgraben. Under south-easterly to south-westerly winds and northerly winds above, sixty percent of the cases depicts the dominance of drainage winds during stable case at this station.

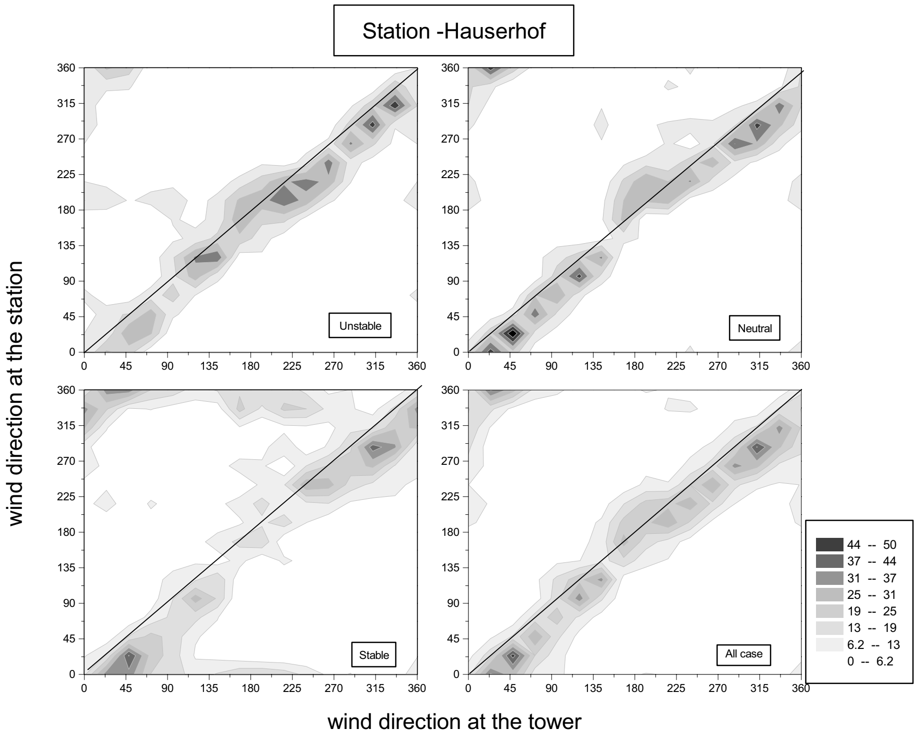


Fig. 5. 11: The comparison of wind directions at the station Hauserhof and at Tower for differing stability

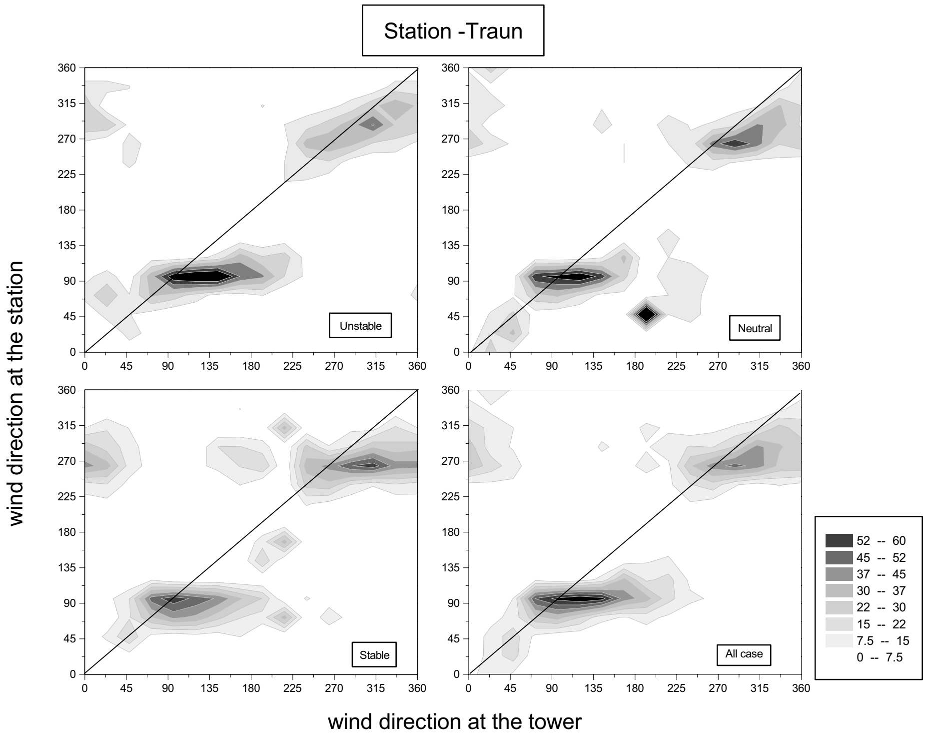


Fig. 5. 12: The comparison of wind directions at the station "Traun" and at Tower for differing stability

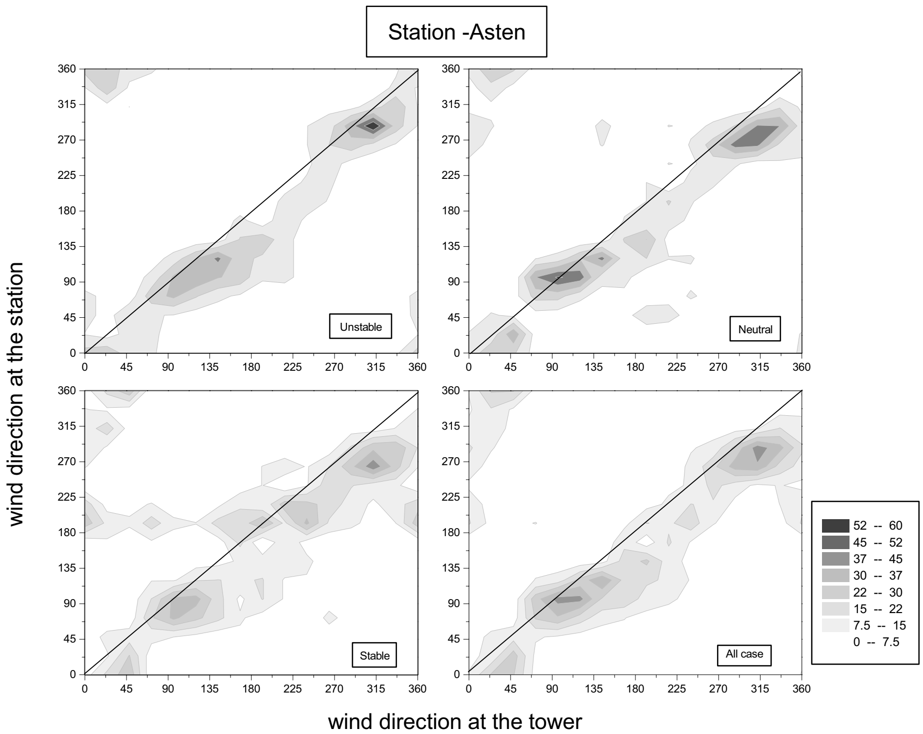


Fig. 5. 13: The comparison of wind directions at the station "Asten" and at Tower for differing stability

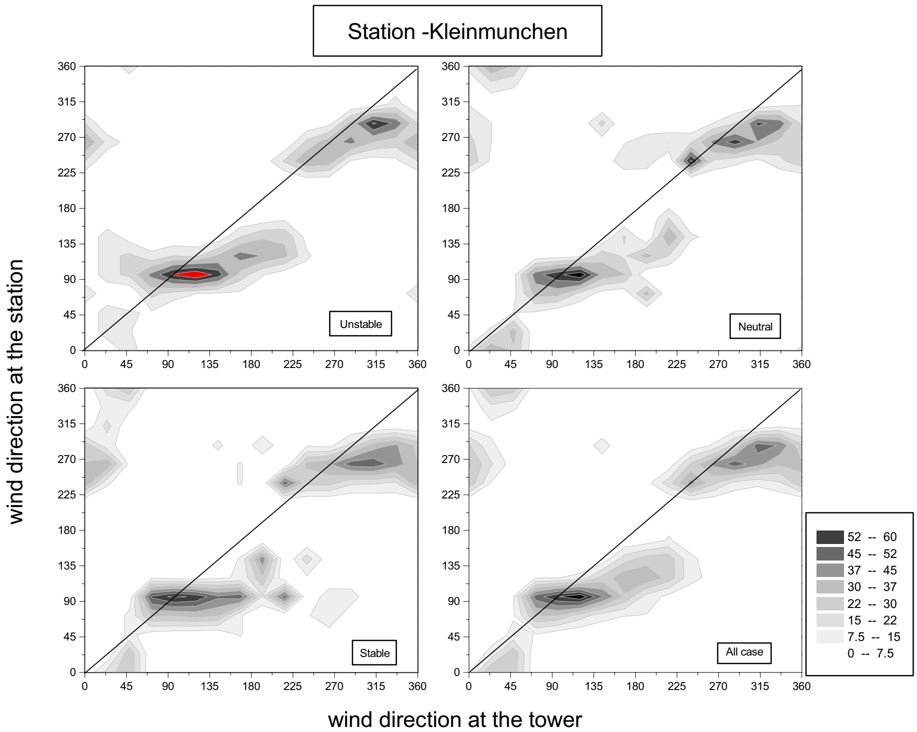


Fig. 5. 14: The comparison of wind directions at the station “Kleinmünchen” and at Tower for differing stability

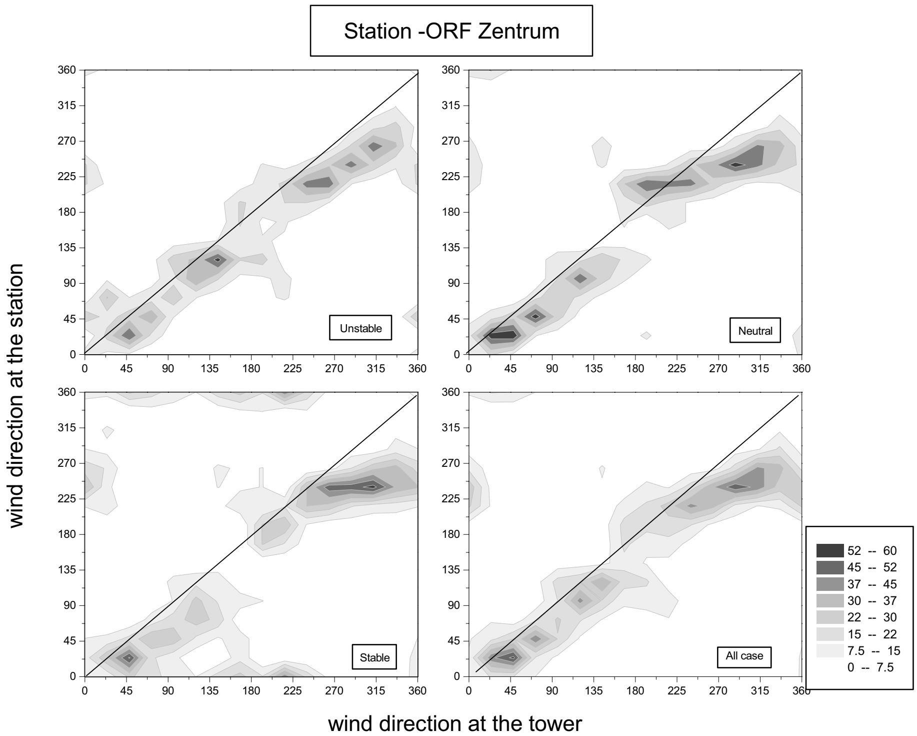


Fig. 5. 15: The comparison of wind directions at the station “ORF-Zentrum” and at Tower for differing stability

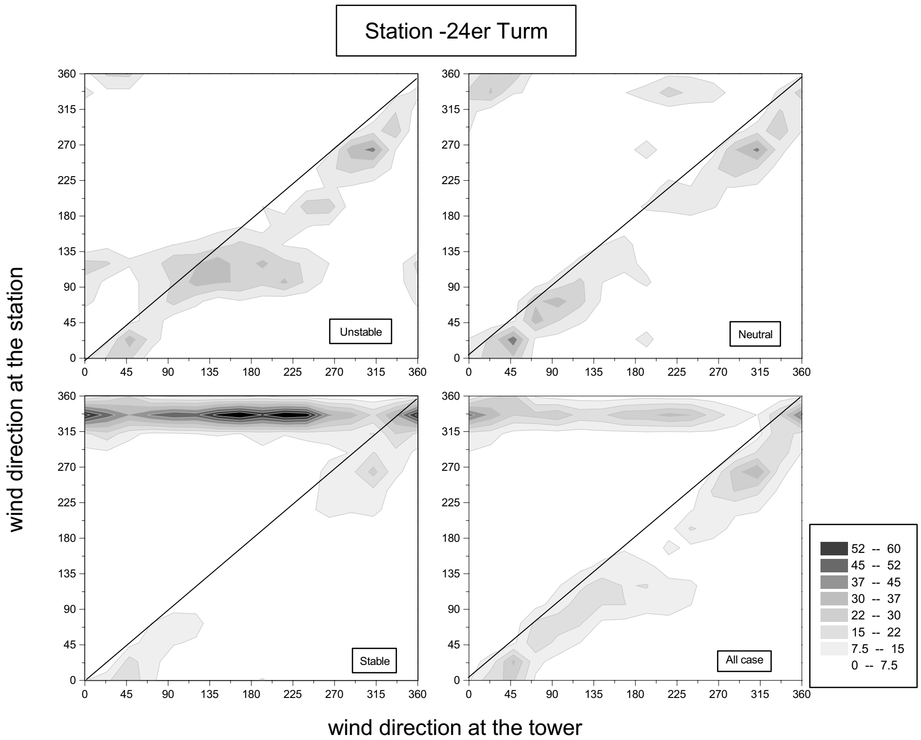


Fig. 5. 16: The comparison of wind directions at the station “24er-Turm” and at Tower for differing stability

Thus we can distinguish two wind patterns here one with a flow towards the mountain nearly 150m above the city and a drainage flow in the opposite direction towards the city from the slopes. This is a case with opposite ambient wind directions to the drainage. The stations ORF-Zentrum and Hauserhof also showed this kind of patterns under stable flow towards the hills. This indicates the influence of the drainage farther down to the city centre. This would be driven by the existence of larger volume of heated air over the city (less dense and low pressure) compared to the smaller volume of cooler air in the area of the Danube basin and Haselgraben. Thereby introducing a pressure gradient that could drive this drainage through out the night. This we have already seen in the case of diurnal pattern of the wind direction at 24er-Turm.

The main question here is the following. Whether the pollutants from the high level releases are carried along with the high level winds (quite below the crest of the hills) and bring back the pollutants to the city centre during the strong drainage ? This is an important problem to be addressed concerning the pollution levels inside the city. This would depend on the kinetic energy of the approach flow towards the hills. If there is enough KE (high wind speed) or if the heat flux from the city is quite high, it would rise over if not the implications in this respect are also to the forested hills where the deposition also might play a role. In the case of a strong stable layer aloft with the unstable near surface urban boundary layer, also pollutants could get trapped inside the well-mixed UBL. Then the vortex formations in the enclosed area of the city would contribute to high pollution episodes inside the city. The second wind pattern could be due to the synoptic influence where the northerly to north-westerly dominated both at 24er-Turm and at the tower. Neutral situations show 25° veering at the tower like the other stations in the city's enclosed area. Unstable case clearly shows that the wind direction at 24er-Turm is more influenced by the Danube basin. Wind directions are mostly between easterly and south-easterly for varying directions at the tower (easterly to south-westerly).

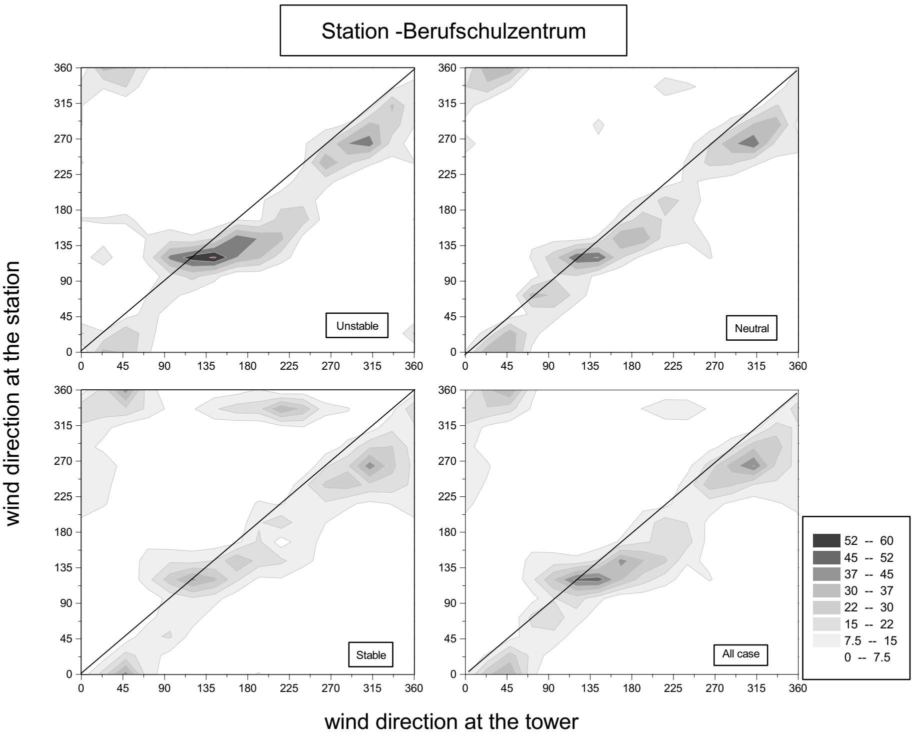


Fig. 5. 17: The comparison of wind directions at the station- Berufsschule and at Tower for differing stability

Berufsschule: In the mean case directional differences at Berufsschule and at the tower are up to 45 degrees (Fig. 5. 17). Apart from this, the downslope flow is a dominant feature of the stable case. But the influence from the overlying flow is the more significant one here. Effect of the Danube basin is also seen during the easterly south-easterly case. Under northerly to westerly winds at the tower, the backing of wind at Berufsschule is quite large.

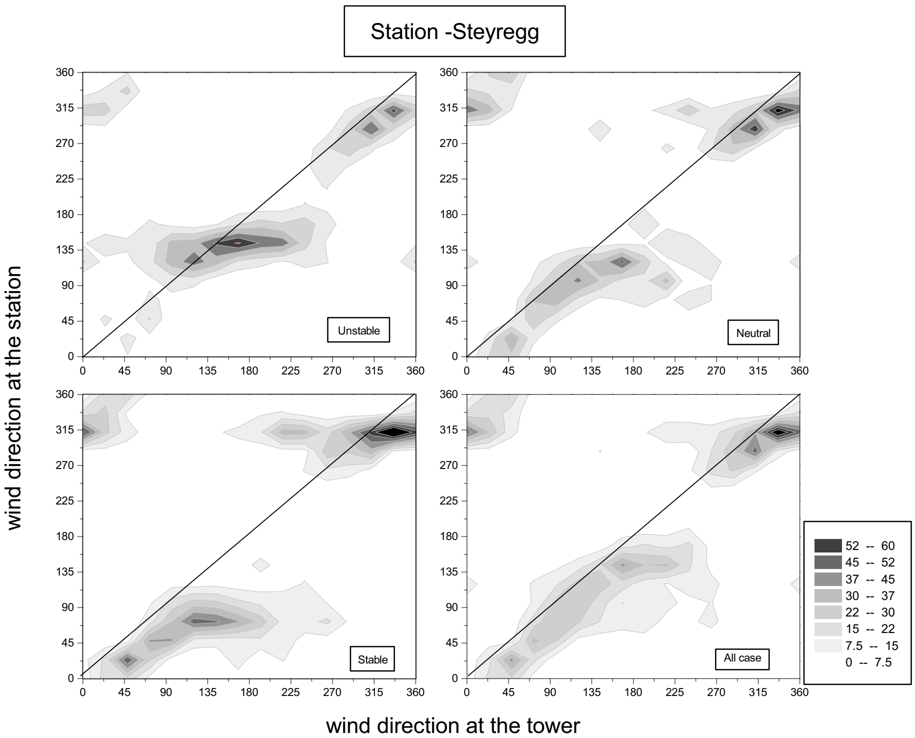


Fig. 5. 18: The comparison of wind directions at the station- Steyregg and at Tower for differing stability

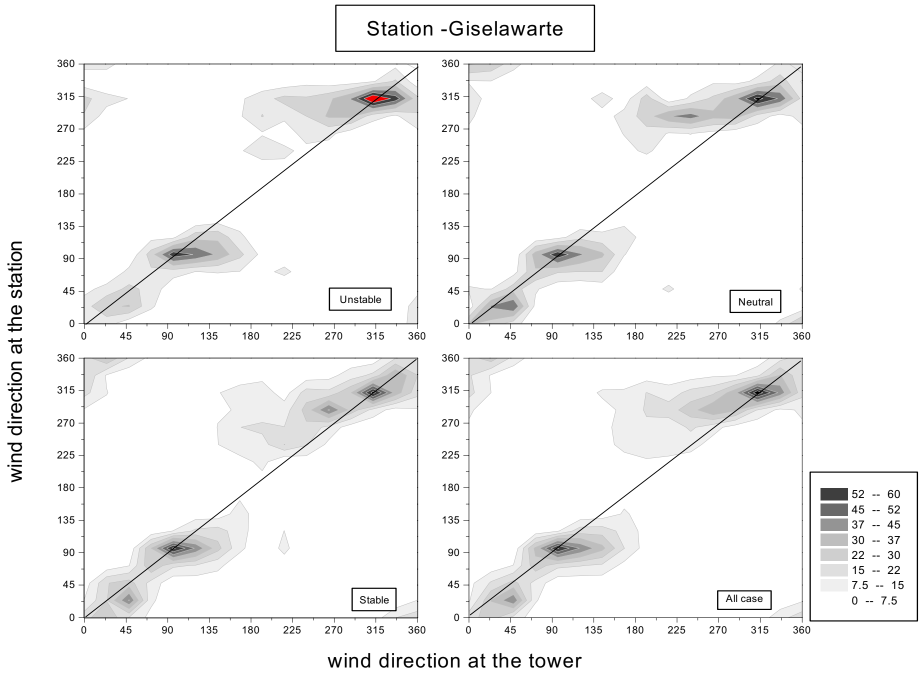


Fig. 5. 19: The comparison of wind directions at the station- Giselawarte and at Tower for differing stability

Steyregg: Veering of wind up to 90° with respect to this station is noticed at the tower for the mean situation (Fig. 5. 18). Easterly to north-easterly are dominant for the stable easterly to south-westerly flow at the tower. These would be attributed mainly by the downslope flow. During westerly to northerly flow at the tower, north-westerly were predominant for stable case. Neutral and unstable cases are characterised by flow around the hills along the Danube basin.

Giselawarte: The mean situation depicts strong correlation between the easterly and the north-westerly winds at top of the mountain and at the tower (Fig. 5. 19). Backing of wind at the tower indicates that the observation at Giselawarte is quite representative for the ambient flow under westerly to north-westerly flow and under easterly cases, the local influences dominated. Another aspect to be noted here is the channeling at the tower during both the major wind directions.

Regression relations are used to establish the interaction of the wind at the tower or the mountain top to the surface layer wind. The relations are developed for wind direction at the tower with those at Hauserhof and Traun. These are given in the table for varying stability class. The relation is $\mathrm{Dir}_{\mathrm{tower}} = a_0 + a_1 \mathrm{Dir}_{s1} + a_2 \mathrm{Dir}_{s2}$

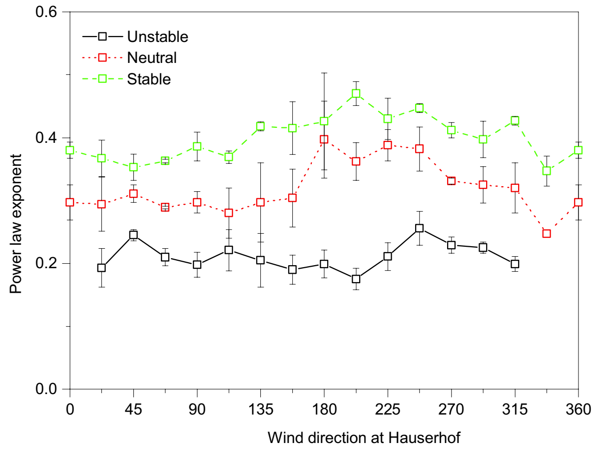


Fig. 5. 20: Mean power law exponents for differing wind directions at Hauserhof at stable, unstable and neutral cases. Standard deviations are also shown.

Stability class	a0	a1 s1=404	a2 s2=401	RMS Error
2	22.77958	0.41998	0.56353	18.57
3	13.33114	0.37976	0.64482	20.68
4	15.28652	0.40357	0.63033	26.67
5	11.82252	0.67690	0.37609	26.84
6	15.55326	0.67126	0.38606	31.06
7	29.92132	0.53236	0.47282	25.25

Stability class	a0	a1 s1=412	a2 s2=401	RMS Error
2	17.96381	0.56019	0.46227	17.75
3	9.31133	0.47364	0.58030	20.11
4	17.1078	0.28673	0.74041	28.49
5	16.74963	0.38876	0.6337	30.32
6	16.31957	0.73495	0.32547	30.58
7	37.03746	0.29366	0.67967	28.82

Stability class	a0	a1 s1=404	a2 s2=405	RMS Error
2	26.4066	0.94048	0.05406	21.56
3	24.57832	0.41602	0.56766	23.75
4	12.80496	0.47832	0.56682	30.78
5	5.26663	0.36848	0.71271	27.60
6	14.04308	0.50259	0.56766	31.80
7	21.09254	0.69978	0.34667	28.28

Table 5.2: The regression relations for the wind directions at the tower for differing stability accounting different stations.

Best relations are established for the unstable cases and for the combination of stations Hauserhof and Traun. During the unstable cases, the flow tries to be away from the influence of topography and the frictional effects to the flow field are reduced. The power law exponent (using the formula 1.7) used with the wind speeds at Hauserhof seemed to give better relations for the wind speeds at the tower. Variation of the power law exponent during differing stability and different wind directions at Hauserhof is shown in Fig. 5. 20. A larger value of the power indicates higher wind speeds at the tower compared to Hauserhof. The unstable case does not show much variation with different wind directions at Hauserhof. But the stable and neutral cases show higher power during the southerly to north-westerly at Hauserhof. This signifies a higher wind speed at the tower compared to Hauserhof. Reason for this aspect involves a number of important aspects. Hauserhof station is well exposed for the easterly/south-easterly cases. Due to this aspect, neutral and Unstable cases show more or less constant values of Power. But the stable case shows much variation as the frictional effects get more important at the lower levels with increasing stability. This also signifies the jet speed noticed during night at the tower. The effects of the hills to the south-west to north-west of Hauserhof also contribute to the reduction of the free stream wind over there.

5.3 Heat island Induced Circulations: Do they exist in Linz?

The heat island intensity is assessed for the parts of the city to study heat island effect induced circulations . Diurnal variation of wind speed and temperature difference between the station Asten and other stations are given in Fig. 5. 21. Heat island effect is quite clearly noticed at the stations inside the city. These are characterised by positive differences in temperature and low mean wind speeds. The wind speeds at the high altitude and the tower are demarked by the night time maxima in relation to the decreased mixing and the decoupling effects. Double maxima in wind speed at 24er-Turm is attributed to the drainage flow. The tower is characterised by higher wind speeds, nearly double that of the mountain top winds. It would be characteristic to the level of measurement and to the strong channeling effects along the sides of the barrier. It is noted that the maximum wind speeds inside the city are hardly above 4-6m/sec. This says that the role of local advection is quite less in disturbing the circulations induced by thermal inertia differences. The main influences could be from the cloudiness and the passage of frontal systems. Heat Island effect over the city of Linz is looked at in two different ways to have a proper index to relate the flow regime to the heat island intensity. First by looking at the extreme temperature differences between the stations in the city and the station Asten that is situated at agricultural land outside the city. The difference between the daily maximum and minimum temperature at each of the stations to that at Asten is computed for heating (JAN,FEB,MAR,OCT,NOV,DEC) and non heating (APR,MAY,JUN, JUL,AUG,SEPT) months.

This differentiation is used to avoid misinterpretation due to the role of artificial heat input to the city during Winter (heating months). The percentage number of days for each 0.5 °C difference is considered for the discussion and is given in Fig. 5. 22 and Fig. 5. 23. Same number of days is considered for all the stations.

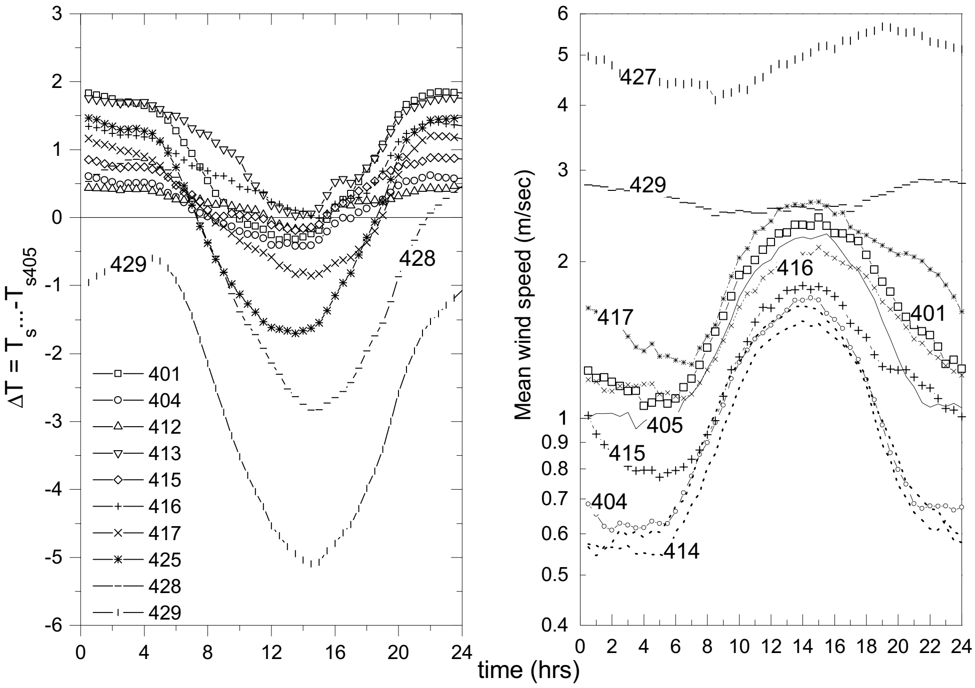


Fig. 5. 21: Mean diurnal variation of wind speed and the temperature difference between each of the stations and Asten (representative for the rural area).

During the Summer months (non heating months), both the maximum and minimum temperature differences' curves are not symmetrically distributed around zero. This means minimum temperatures show warming up trend and maximum temperature differences show cooler city compared to Asten. Obviously the maximum is taken representative for the day and minimum for the night. The cooler temperatures in the city during the day could be due to the following reasons. The first aspect is due to the thermal inertia differences. Inside the city, received energy is mainly used to heat the concrete surfaces and stored. This would contribute to the major part of partitioned energy, next to the sensible heat, during the day. Whereas at place like Asten the Sensible heat and the Latent heat flux would be the major part and would be more for same input of energy at both the places, which drives the atmosphere to be warmer over there during the day. Secondly due to the differences in the amount of direct solar radiation received inside the city, I.e., the city might receive less direct short wave radiation due to attenuation because of the rough urban complex or at the pollutant layer (aerosols) over the city.

During summer, the increased evaporation from the rivers or lakes also would assist the development of fog layers over the city (Wanner, 1984). Advection of air (and it's origin) over the city also would be another factor. The cooler atmospheres inside the city during the day compared to Asten is quite dominant at Hauserhof, Ursulinenhof, Steyregg and 24er-Turm. During night, i.e., if we consider the minimum temperature differences, temperatures at places like, Hauserhof and Ursulinenhof are warmer up to 1-4°C in reasonably significant percentage of days. This is the consequence of the release of the stored energy. Higher percentages at Hauserhof are attributed to the level of observation.

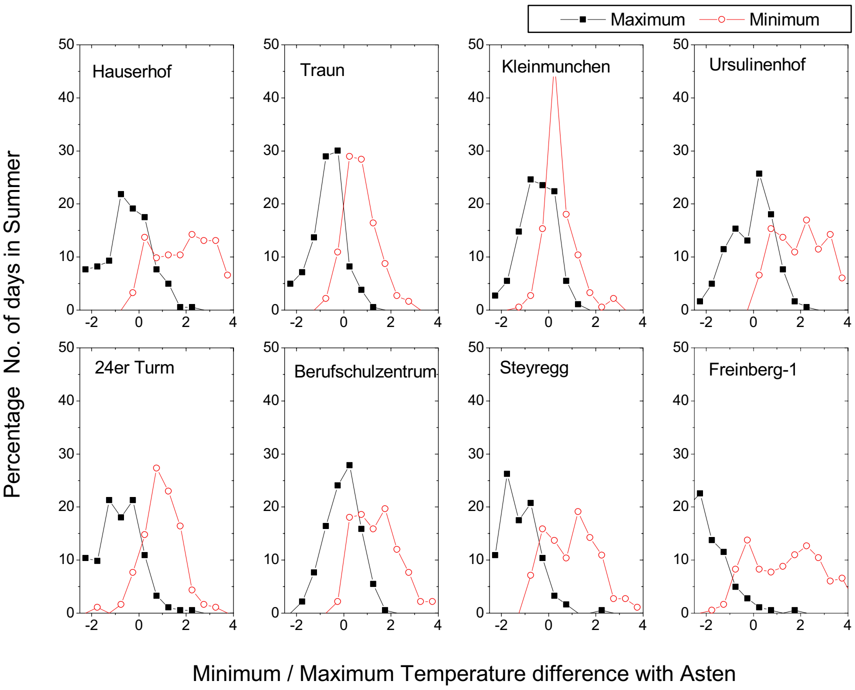


Fig. 5. 22: The frequency of the extremum temperature differences between the stations and Asten (rural station) during summer

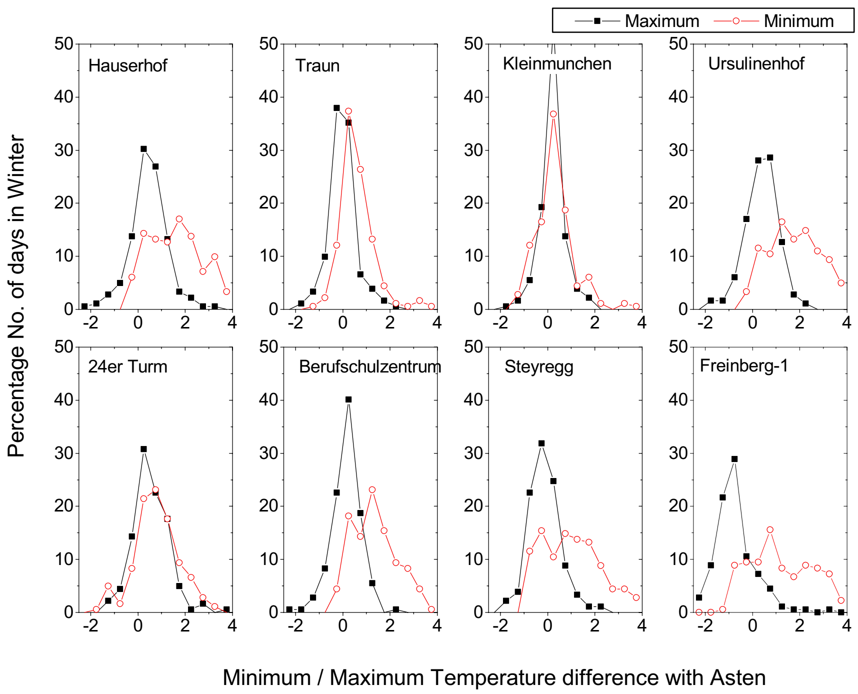


Fig. 5. 23: The frequency of the extremum temperature differences between the stations and Asten (rural station) during Winter

At Berufsschule and Steyregg these differences are up to positive 1-3°C. When we talk of Steyregg, it must be remembered that this station is situated at a higher elevation and we cannot attrib-

attribute the causes of high value of differences totally to the heat island (not that the day time maxima is also quite low). At 24er-Turm, this heat island intensity is up to 1-2°C rather reduced, possibly due to the cold air drainage from Haselgraben and there by the ventilation of this area. Also this station is near to the banks of Danube river. Above mentioned effects of heat island are noticed with low intensity (≤1°C) at Kleinmünchen and Traun. Temperature differences with Freinberg are also given which seems to be due to the differences in the elevation.

Winter period shows similar patterns in the minimum temperature differences. There is high heat island intensities at the stations inside the city. Maximum temperature at Hauserhof, Ursulinenhof and at 24er-Turm is more than that at Asten. This is possibly due to the differences in the thermal inertia and albedo and the water content and also the artificial heat input in the city. A careful measurement and analysis of the energy balance component would explore the causes. This also suggests the existence of the daytime heat island (≤2°C) at these places. Rest of the places shows a symmetric distribution suggesting random changes in the temperatures. There is not much change between the minimum temperature difference pattern of Summer and Winter.

Above analysis showed a mean situation and we cannot attribute all the positive anomalies to the heat island phenomena as there would be other causes like local advection or cloudiness that play an important role in the energy balance at a place there by changing air temperatures. Also the role of the thermally developed circulation in reducing the heat island intensity is to be assessed to study the ventilation at parts of the city. For this purpose, heat island is studied with cloudiness from Hörsching, wind speeds at the stations and air temperatures. Using the simple principle that the rate of change of temperature at a place is directly proportional to the net energy input to the different units of the system, proportionality constant being the thermal inertia or the specific heat of the different units in the system. Here system is quoted for the city and the units are different surface types or groups of structures. Heating (cooling) rates rather than the temperature differences are used. A comparative study of the heating (cooling) rates would deliver a more valuable information.

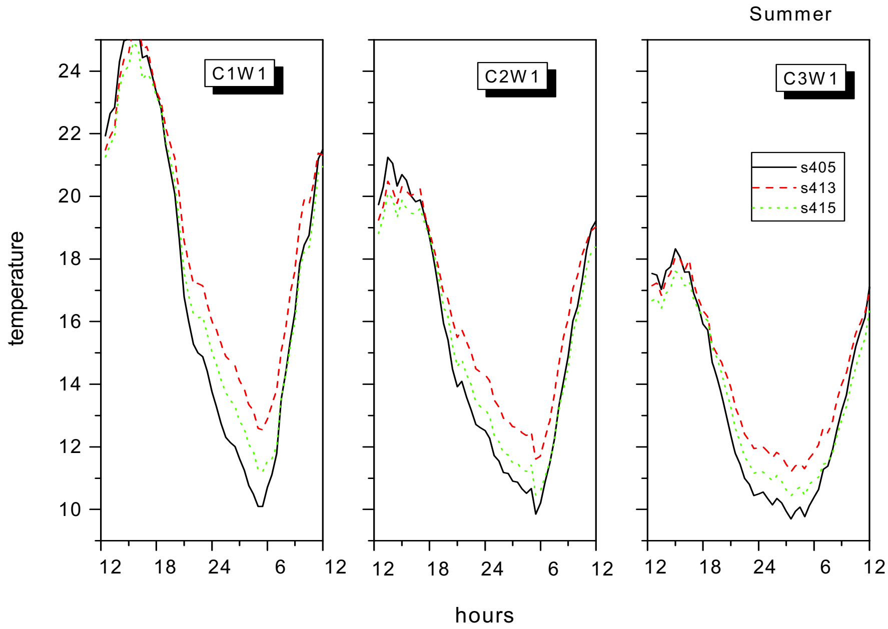
The mean temperatures from early afternoon to late night at Ursulinenhof (more representative to the city centre), 24er-Turm (representative for the city area influenced by the topography) and at Asten (representative for the rural area) are compared under differing cloudiness and low wind speed cases (Abbildung 24 for Summer and Abbildung 25 for Winter).

As seen in the Abbildung 22, for summer cases, Asten is warmer during the day and cooler during the night (up to 3°C compared to Ursulinenhof and up to 1°C compared to 24er-Turm).If we compare the cooling rates in the late afternoon to midnight, the following features could be noted.

- Cooling rate is more for Asten compared to Ursulinenhof and 24er-Turm.
- Ursulinenhof is warmest during night
- At 24er-Turm, the influence of drainage is driving the air cooler than Ursulinenhof. These features are common to all the cases shown in Fig. 5. 24 and Fig. 5. 24.
- Increased amount of cloudiness has a direct role in reducing the daytime maxima of temperature as the amount of solar radiation received at the surface decreases with increasing cloud amount. The winter case should be looked at with care as the number of days with good data was quite less
- The differences in the cooling rates could be related also to the thermal inertia differences as

$$C\frac{\partial T}{\partial t} = \text{Net energy input}$$

where C is the thermal inertia



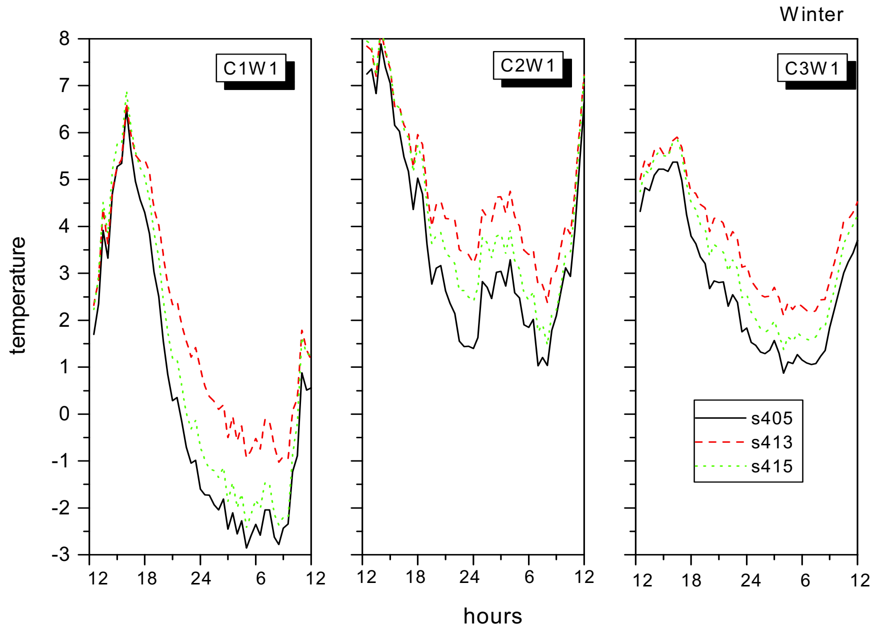


Fig. 5. 24 and Fig. 5. 25: The Mean Temperature variations at Asten (405), Ursulinenhof (413) and 24er-Turm (415) are presented. Winter and Summer case for clear days (c1w1), medium cloudy (c2w1) and cloudy (c3w1) and for low wind speeds.

The parts of the city like Ursulinenhof (urban) are characterised by larger thermal inertia (cooling slower) than the rural site (Asten) where cooling is faster. With increasing amount of cloudiness, the cooling rates also decreased. But the thermal inertia differences do exist. We could assign the differences in cooling rates to be an index for measure of the heat island intensity. The analysis using the extreme temperature differences would not deliver the real heat island intensity as the causes of all those extreme temperatures could not be attributed to heat island. But in the present analysis, the cases with heat island are classified to have less external influences. This concept could be used to define the parts of the city influenced by terrain, city effect or both. Thus the structural groups of the city could be classified based on this information.

Here our aim is to find out the role of heat island intensity in modifying the flow fields. A first step towards this aspect is explored with the help of the data classification based on the cloudiness and low wind speeds (less than 6m/sec over the domain). The westerly or easterly flow types are examined for 1800-2400 hrs in winter and summer. Frequencies of different flow patterns during easterly and westerly during winter and summer are shown in the Table 5.3 below. Importance of different flow types could be discussed here.

The occurrences of drainage situations are nearly 70 percent during summer easterly ambient flow and 17% of the drainage flow are strong towards the city centre. This is an important flow situation to be studied in detail. These are occurring during the cases of less synoptic/mesoscale influence and are characteristic of 1800-2400 hrs. The drainage wind at 24er-Turm generally exceeds 2m/s during such cases.

	Westerly		Easterly	
Type	Winter	Summer	Winter	Summer
a	43.3	52.75	57.5	69.81
b	1.04	4.84	4.2	17.03
c	26.77	18.79	26.96	17.78
d	26.51	13.02	36.96	20.37
e	6.03	3.62	17.14	10.0

Table 5.3: The frequency of different flow types during the cases of low wind and
a: Drainage occurrence,
b: Drainage influence to the city centre,
c: Occurrence of calms inside and nearby areas of the city,
d: calm at the city centre with convergence towards the city from the suburban areas (no drainage) and
e: calm inside the city with drainage and convergence from suburb towards the city.

The development and decay of these wind systems seemed to also connected with the amount of cloudiness. 43.47 % of these cases occurred during the clear, 34.78 % during medium cloudy, and 21.73 % during cloudy days of the easterly summer cases. This dependence could be attributed to the dominance of thermally driven circulation towards the city due the pressure differences between the city and the slopes. Fig. 5. 26 shows the variation of the temperature difference between the mountain top and at 24er-Turm for differing wind directions at 24er-Turm. The temperature gradient is found to be more during summer than winter. The drainage directions are characterised by lower temperature gradients, i.e., these are the cases of more stable situation.

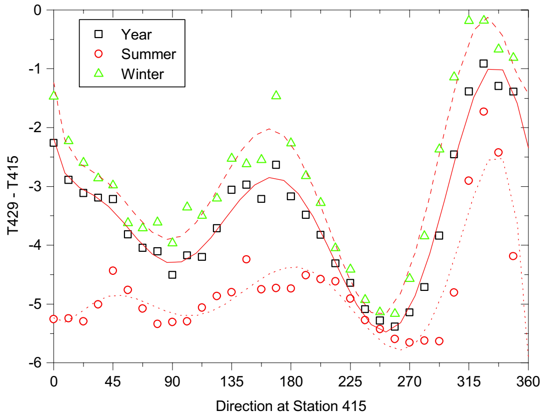


Fig. 5. 26: The variation of the temperature difference between the mountain top and 24er-Turm for differing wind directions at “24er-Turm”

But the higher differences in temperatures during summer (due to larger diurnal amplitude) suggest stronger thermal contrasts between the city and the mountain top. This relationship is true for the mountain slopes too. So increased thermal contrasts could drive a stronger drainage towards the city; the heat island intensity could intensify the drainage to be stronger into the city with less dense heated air over it. This situation is important in the aspect of air pollution transport inside the city as the ambient easterly flow would transport the pollutants released at higher levels towards hills and the increased drainage could bring back those to the city. But by midnight, the drainage is weakened towards the centre of the city as discussed in the section 5.2.4 due the dominance of the mechanical effects in the city. The temperature contrasts may increase between the areas of the city near to the slopes and the inner city during the course because of the cold air drainage.

During winter such flow situations seemed to be less; 4.84 % only. Out of that, 38.9 % for clear, 41.66 for medium cloudy and 19.44 for cloudy cases are also noticed. The situations with low wind field are quite less for the clear-medium cloudiness during this case. Type C is the total calm over the city up to 50 m. This signifies the existence of a stable heat island.

In the absence of drainage, the situation of calm inside the city with weak suburban flow towards the city centre is another prominent flow type. Here the effect of heat island is evident. But these are very weak. Another type of flow situation is with drainage and the city induced slow convergence to the city with calm inside the city. All these cases discussed here are quite important to be studied in detail to understand the interactions of the different flow regimes and it's consequences to the pollutant dispersion inside the city.

5.4 Strongly stable cases

We have seen in the earlier sections that the stable cases were characterised by winds following the barrier. To assess the strong channeling below the crest of the mountain range, and to see if there is a flow division, the strongly stable cases are considered to find the dividing streamline height using the Froude number concept (Fig. 5. 27). The idea is to examine the possible channeling effects under easterly cases.

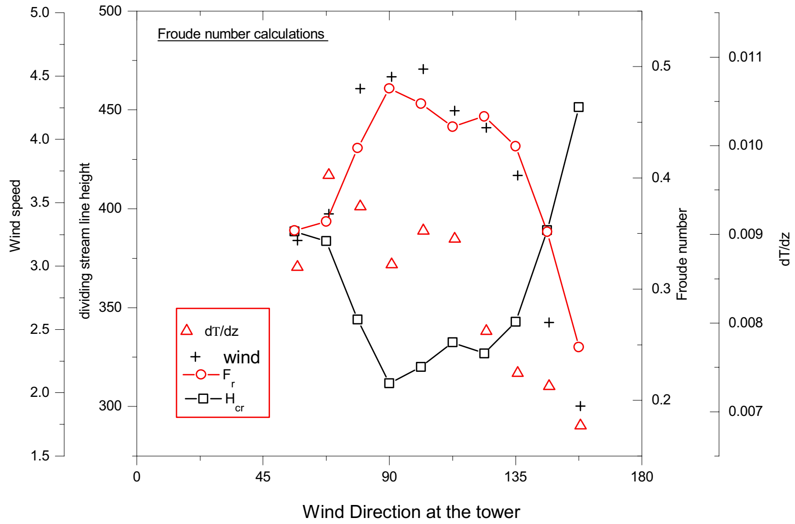


Fig. 5. 27: The Froude number, lapse rate, wind speed and the dividing streamline height for differing wind directions (approach flow towards the barrier)

The froude number is calculated using the extrapolated wind speed from the tower to a height above the mountain range and the temperature gradient over the city along with the barrier height of nearly 700 m. The calculated parameters are shown in Fig. 5. 27 for the easterly approach flow to the city. This gives the indications of a dividing height from 300-450 m above the city for the mean situation. This means during very stable cases, we could expect the flow diversion at 300-450 m above the city. This would contribute to larger lateral deviations to the flow.

5.5 Distribution of SO_2 as a tracer

The main sources of SO_2 in Linz are the Industries and the house heating. The role of these sources could be looked at with the mean distributions during the Summer and Winter months. Fig. 5. 28 shows the comparisons of the two cases. 'Hot' is April to September means and 'Cold' is the mean of rest of the months. There is a clear demarcation with higher values during the Winter months. It could a part be attributed to the area sources around and also to the possible higher number of inversions during winter.

Other features to be noted are higher concentrations for the south-easterly cases inside the city where Plume is directly over the city facing the hills. These are the situations where the easterly to south easterly winds contribute to the cyclonic vortex formation inside the city. Opposite wind directions also show higher concentrations during the drainage cases at 24er-Turm. This is a clear evidence of high pollution episodes related to the opposing flow situations as discussed earlier. Strong channeling along the Danube valley during easterly ambient winds seemed to carry the pollutants from the surface level towards ORF-Zentrum. Strong westerly situations show quite less number of worse cases as the pollutants are carried out of the city. Rural station Asten seemed to be more influenced from other sources than in Linz. Kleinmünchen and Traun are also less influenced by the sources from Linz.

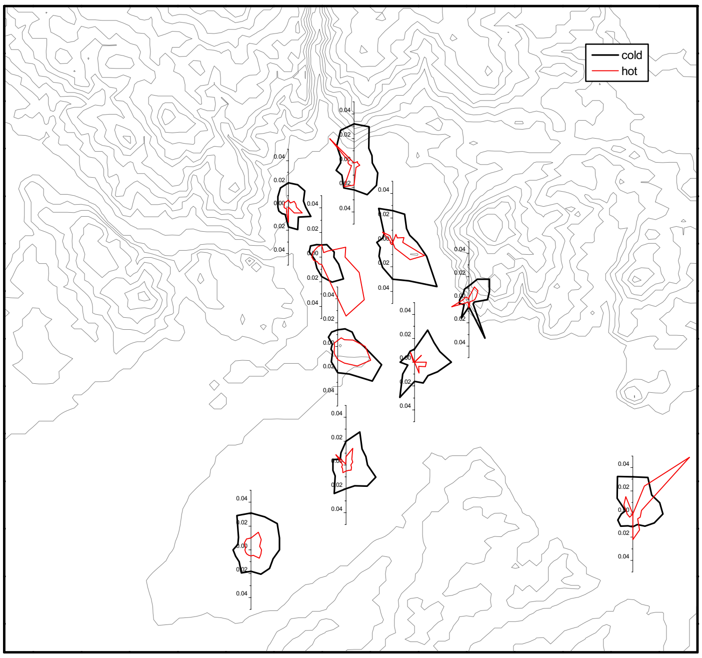


Fig. 5. 28: The distribution of mean SO_2 at all the stations for heating and non heating months

We have already noticed the discrepancy in adopting a method for the stability classification. Moreover we have missed a lot of cases in the analysis due to the large number of calm cases inside the city. Thus we would have missed to analyse some of the critical stations pertinent to the pollution episodes. To check the existence of severe pollution episodes inside the city under the easterly case with a stable layer aloft an unstable urban boundary layer a criteria is adopted for the flow classifications. This is based on the temperature profile over the city. Four temperature measurements are used for this. Temperature at Ursulinenhof is taken to be representative of surface level temperature. The measurements at the tower levels above 90 and 150 meters are taken to be the second and third level temperatures and the mountain top (Giselawarte) as the fourth point in the profile. This is a crude classification as the profile considered is quite influenced by the terrain and would not be quite representative for the elevations considered.

The percentage occurrence of each type of temperature profile is given in the Fig. 5. 29. Following designations could be assigned to each type.

1. Unstable
2. Thick Unstable surface layer with a stable layer aloft
3. Sandwiched stable layer in an unstable UBL
4. Stable surface layer with a residual mixed layer aloft
5. Stable
6. Thick stable surface layer with an unstable layer aloft
7. Sandwiched unstable layer in a stable UBL
8. Unstable surface layer with a strongly stable layer aloft

The easterly and the westerly flow situations deliver differing patterns of pollutant distributions in the above mentioned cases. Especially cases with overlying stable layers are characterised by more frequent episodes with higher concentrations of SO_2, and low mean wind speeds, compared to the other cases (shown in Fig. 5. 29).

These are the cases of low level mixing with less horizontal transport and the tracers released inside the unstable layer would get trapped inside the city as the overlying stable layer would hinder the diffusion of pollutants in the vertical. Also wind direction towards the barrier during the easterly situation would resist further lateral spread. But during the cases of flow divisions we could expect the standard deviations (spread) in the lateral directions to be higher (Hunt, 1990). Also it is noted that the opposing winds during the weak easterly with westerly at Giselawarte occurred during such cases with an overlying inversion indicating the presence of two flow regimes.

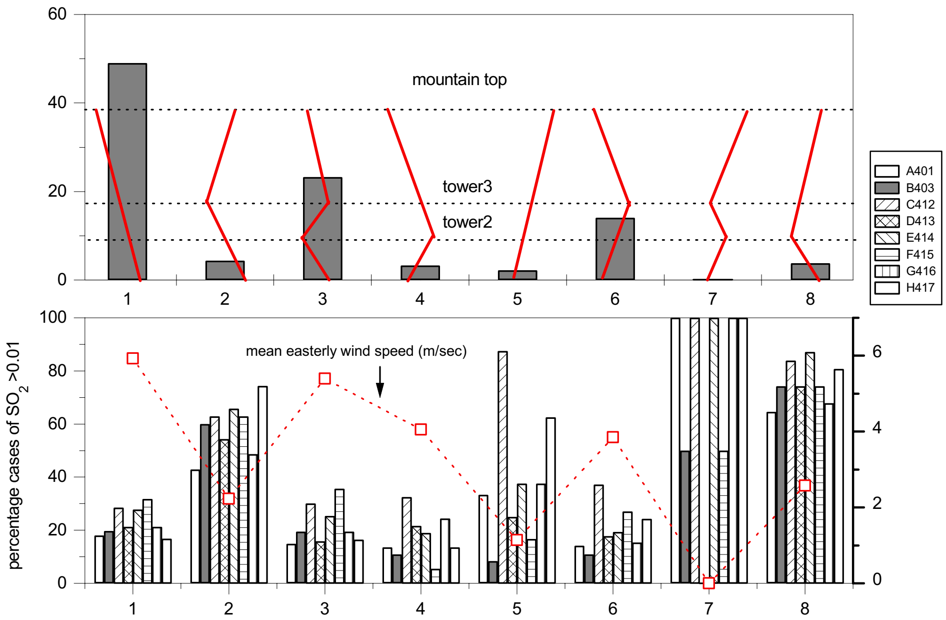


Fig. 5. 29: Frequency of different vertical temperature patterns and the corresponding frequency of cases with receptor point SO_2 concentrations exceeding 0.01 mg/m^3 and mean wind speed (open boxes).

Identification of such inversions with unstable layer over the city and it's inclusion in the models to parameterize the vertical diffusion would be possible only with the help of information of the flow and thermal structure in the vertical. The temperature pattern over the city as discussed earlier is used to classify different flow types. First as unstable or stable and then easterly (north-east to south-west) and westerly (south-west to north-east) with the following types.

1. Situations with drainage from Haselgraben
2. Opposing flow(winds at the tower and Giselawarte are in opposite directions)
3. Aiding flow(winds at the tower and Giselawarte are in same directions); here 1 and 2 cases are avoided

The main features of the flow patterns are discussed here.

a. Easterly at the tower, with Drainage:

During the unstable case, the flow pattern is characterised mainly with easterly winds (above 2m/sec) at the tower and Giselawarte with easterly to south-easterly or calms at the rural and sub-urban stations.

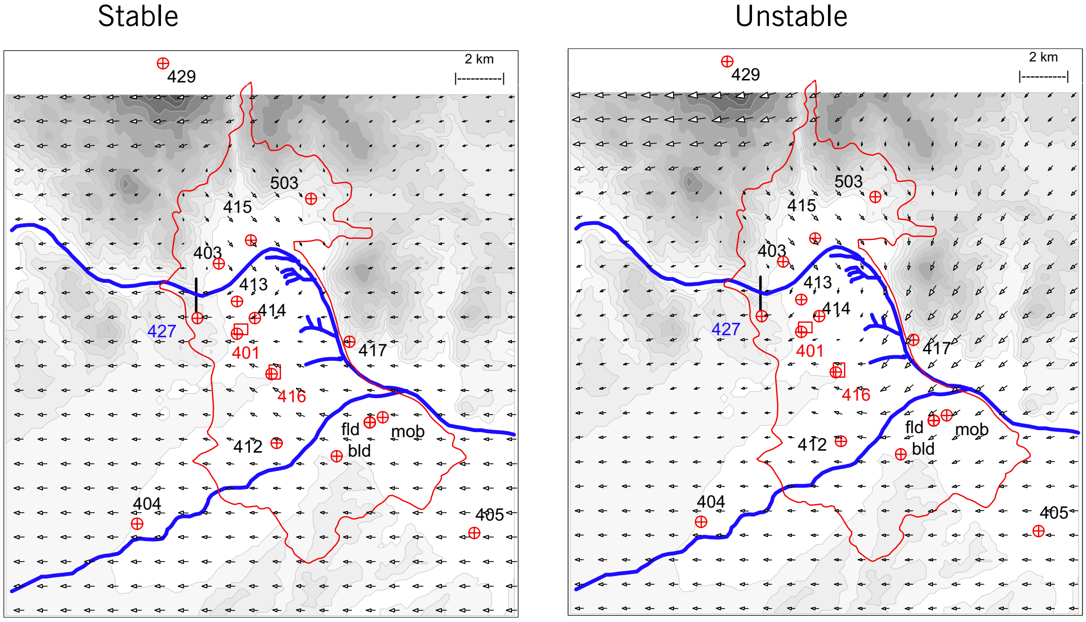


Fig. 5. 30: Mean prominent flow patterns near the surface with the drainage winds from Haselgraben and the easterly ambient wind at the tower. The most prominent wind directions and mean wind speeds for those cases are incorporated in the wind model to generate these wind fields. The vectors in both the diagrams are scaled to 3m/s

The drainage flow is dominant towards the centre of the city depending on the strength of the heat island. The majority of the drainage cases are characterised by calms inside the city centre in the second half of the night due to the mechanical effects induced by the city structures. Steyregg experienced strong channeling and north-easterly downslope flow. This case was discussed in the earlier section on heat island.

During the stable case with easterly winds at the tower and drainage at 24er-Turm, the drainage is not as strong towards the city centre compared to the unstable case (Fig. 5. 30). The comparison of the stable and unstable cases with drainage is a good indication that the heat island intensity is driving the drainage to be stronger in the unstable case over the city. Stable cases are characterised by either very low easterly or calm inside the city centre. Slope flows / the channeling at Steyregg is less strong than in the unstable case.

b. Easterly at the tower, opposing flow:

During unstable case, drainage from Haselgraben and the downslope from Steyregg are dominant. Southerly or north-westerly dominant at Hauserhof and at Berufsschule, effect of the gentle slope is quite evident. Calm cases are also equally dominant inside the city. Stable case is characterised by nearly the same flow pattern mainly with low wind speeds.

c. Easterly at the tower, aiding flow:

The easterly to south-easterly at the tower, Giselawarte and Steyregg are stronger and the wind speed at Hauserhof and Berufsschule are also stronger easterly winds. Inside the city, channeling along the Danube basin is quite evident. Calms are lesser than the earlier situations considered. In the stable case, strong south-easterly was the dominant at the tower, Steyregg and Asten. Flow pattern is quite the same as in the unstable case except for this dominant feature.

d. Westerly at the tower, drainage flow:

During unstable case, north-westerly at the tower is the most dominant wind direction and Hauserhof and Berufsschule and Steyregg also depict this feature with westerly in the suburban and rural stations.

Calms or very low south-westerly at the city centre is also noted. In the stable case, the stations inside the enclosed area of the city show south-westerly. Same is true for Asten, Traun and Kleinmünchen. Many cases of calms are also noticed. Drainage is not stronger than 2 m/s.

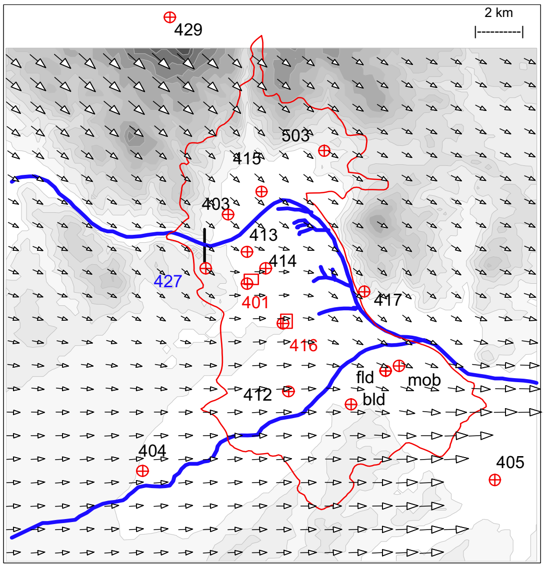


Fig. 5. 31: The surface wind pattern for the westerly with drainage flow

e. Westerly at the tower, opposing flow:

Weak drainage winds are noticed in the unstable and stable cases. Unstable case is characterised by channeling along the Danube. Majority of cases inside the city is characterised by north-easterly or south-easterly low winds depicting a complicated flow pattern. Stable case showed more well defined south-westerly flow with drainage occurrence at the stations in the city.

f. Westerly at the tower, aiding flow:

The strong westerly-north-westerly at the tower, Giselawarte and Steyregg present for the unstable case. The flow along the Danube with majority of low wind speed cases in the city centre. Stable cases are not stronger and near the slopes variable wind directions are noted.

The patterns (c) and (f) are the most dominant easterly and westerly cases respectively. Those unstable cases are characterised by less calms and we could expect the pollutants to be transported out of the city during such cases. But stagnating stable cases are quite dominant and are to be treated with care.

5.6 Discussion on the wind patterns in Linz

The analysis of one year (1991) data gave an overview of different flow patterns, their possible origins and the diurnal course as it is important in the local scale study. The low ambient wind cases pertinent to the high pollution episodes are analyzed in detail to understand the importance of complex flow patterns. Heat island intensity seemed to assist the drainage to be stronger towards the city during early hours in the night due to the pressure gradients developed due to the city effect and the cooling of the slopes. The receptor point SO_2 concentrations are used as a tracer to examine this and also different flow patterns are compared considering the temperature structure over the city.

The discrepancy in adopting a method to find the stability is one main problem faced in this study. Out of the four methods compared, Bulk Richardson number method seemed to be more correct. To validate this aspect, the classification based on the standard deviations of the wind direction and the temperature gradient could be adopted. In the data analysis, to accommodate maximum number of data, ÖNORM based on the net radiation and the wind speed is used which also dealt with the inherent diurnal variations.

The interaction of the local scale flow and the synoptic scale flow is analyzed using the geostrophic wind, radiosonde data and the data from Feuerkogel station. All this analysis showed a mesoscale influence in the study area. The diurnal variation of the wind directions at the stations situated at higher levels(Tower and Giselawarte) also showed a diurnal variability with maximum occurrence of the easterly during the night and westerly during the day. Whereas the synoptic mountain station does not characterise this feature. It was not found to be an isolated case during a particular year. Thus existence of a mesoscale flow system in the pre Alpine valley is suspected. Four distinct flow situations over Linz with respect to the geostrophic wind also need further study to identify the characteristics of each case with respect to the synoptic scale circulations. All these comparisons with the synoptic scale flow lead to the conclusion that the wind systems in Linz are more meso or locally influenced due to the terrain and the city structure.

The topographical influences are clearly identified at Giselawarte and at the tower with the channelled flow following the terrain. Especially the jet wind speeds noted at the tower seemed to be contributed mainly by the speed up from the channeling and the de coupling effects over the city. Station Steyregg situated at a higher elevation is influenced significantly from the topography. The surface level stations mainly influenced from the terrain are 24er-Turm, ORF-Zentrum and Hauserhof inside the city. The station Berufsschule experiences a slope effect. Stations in the main valley are less influenced except in the case of Asten where the mountains to the south of the station do have a role in having moderate number of southerly winds. To have a more clear picture of the topographic influences, wind distribution at differing stability is treated which lead to the following conclusions.

- During the unstable cases easterly winds contribute to a cyclonic vortex inside the city whereas westerly winds contributed an anticyclonic vortex due to the effect of the Danube basin.
- Stable situations are characterised by the flow adhering to the topography ; topographic influences were dominant.
- Especially the indications for advance of the drainage towards the city centre are noted at Hauserhof. This is a good indication for the horizontal extent and also for the depth of the drainage as the measurements at Hauserhof are taken over a building 40m high. This situation would deliver good ventilation of the city.
- Neutral flow showed the dominant north- easterlies at 24er-Turm
- The drainage winds at Asten are clearly noticed during the stable case.

The stability classification adopted also gave a good representation for the diurnal changes. This information along with the diurnal distribution of the wind direction clearly gave the idea of the development and decay of the thermally induced wind systems over Linz. The directional changes during easterly winds are found to be more compared to the westerly winds for the surface stations inside the city. This could be attributed to channeling around the Danube basin. The change in the easterly to south-easterly winds during morning hours is associated with the tendency of flow regime to be away from the influence of the terrain during the instability. This could be accomplished by the interaction of the upslope flow with the prevailing easterly winds. I.e., the upslope directions are south-easterly to south-westerly which gets added to the easterly flow in the parts of the city bounded by hills. Most interesting aspect is that this effect is noticed at the tower also. With respect to the problem of pollution distribution inside the city, this is an important situation. This phenomenon could lead to the enhancement of the first diurnal peak. Two important points to be noted are the following. This situation happens when the mixed layer is developing and there exists a stable layer aloft. Secondly, the south-easterly are towards the hills to the north of the city and could lead to plume impaction. This could lead to increase in lateral dispersion. The pollutants get trapped inside the unstable layer below well mixed. The stable layer aloft would block the vertical transport and diffusion. The only way out for the pollutants is through the horizontal transport and diffusion. In the surface levels this could be hindered as the surrounding hills obstruct the way out. It is noticed that such situation has caused increased levels of pollution inside the city. The Froude number calculations for the strongly stable cases show existence of a flow division around 300-450 m above the city. This leads to more lateral diversions to the flow. This signifies the importance of adopting the flow division in the wind model used in this study.

The diurnal variations of the mean wind speed at different stations are also considered to analyse the ventilation of the parts of the city. The secondary peaks in wind velocity observed for the stations Steyregg and 24er-Turm are the indications of the drainage flow. At Hauserhof also a small secondary peak is observed which could be attributed to both the drainage effects and also the speed up over the buildings.

In order to establish a relation between the surface level wind field and the one at 150m over the city, the simultaneous occurrences of wind directions during differing stability are studied. Hauserhof station gave similar wind directions as at the tower except during stable cases. These are the situations where the flow field inside the enclosed area of the city is mainly driven by the effects of the topography and the heat island. Whereas stations in the main valley like Traun Kleinmünchen and Asten showed two distinct flow regimes with respect to the tower. The regression relations established with the stations Traun and Hauserhof for the wind directions at the tower gave lesser RMS errors for the unstable situation compared to the stable case. Also the power law exponent for nent for the wind speeds at the tower using the wind from Hauserhof shows lesser variations with respect to differing direction during unstable case. This is mainly due to the dominant complexity of the flow pattern due to the city and the topographical effects with increasing stability.

The role of heat island induced circulation in Linz is studied. Heat island effect in Linz is looked at in three different ways. Namely, depending on the difference in temperature between the city stations and Asten, depending on maximum and minimum temperature in winter and summer, cooling rates for differing cloudiness and low wind situations. The increased percentages of the calm situations noticed at the centre of the city is an indirect indication of the heat island. More over a comparison of the mean wind speeds at different stations together with the temperature difference with the rural station Asten clarify this fact. The existence of the positive differences in temperature at Ursulinenhof with respect to Asten is seen through out the day suggesting the existence of warmer city in the mean situation. The effects during summer and winter are analyzed with the minimum and maximum temperatures. The major points to be noted from the analysis are the following.

- Large positive minimum temperatures (up to 4 °C) noticed during summer compared to winter indicating higher heat island intensity in summer. This could be a consequence of the higher input of solar energy and increased storage in the concrete buildings inside the city. This stored heat is released during the cooling phase of the city.
- Existence of day time heat island in winter attributed to the artificial heat input to the city.

Another approach adopted to identify the effect of the city is in terms of the cooling rates at different units of the city. This would deliver the isolated effect of heat island as the days with differing amount of cloudiness and low wind speed cases are treated separately. This classification offered the possibility to identify the topographical or heat island influences in different units of the city.

The drainage wind cases are isolated to classify different flow patterns associated with. One problem faced in the analysis of the flow patterns is large number of calm cases that were avoided. In this analysis the calms are also treated to explore the physical processes causing the same. The dominance of the strong drainage situations in summer is a direct consequence of the strong city-slope contrasts. Whereas the calm inside the city with weak drainage towards the city is dominant during winter. The comparison of the summer and winter time indicates the role of heat island in assisting the drainage. The coexistence of the calm in and around the city with drainage is also equally dominant as the earlier case. The heat island induced circulations are not stronger from the south-eastern south-western sector of the city as the horizontal temperature gradients are not very strong.

In presence of a stable layer over the city, the drainage winds are found to be weaker towards the city centre. And mostly calm are noted in the city centre during such cases with weak drainage winds in the city areas near to the slopes. But unstable urban boundary layer over the city characterised good ventilation of the city with strong drainage towards the city centre. These two situations are generally noted for clear sky situations with high pressure over Europe. Generally in the first half of the night, the drainage flow is stronger towards the city and is weakened towards the city in the second half of the night with the calm situations setting inside the city. This is also closely associated with the jet speeds noticed over the city. A hypothetical explanation for the role of city effect in assisting the drainage during the unstable case and blocking the drainage during stable case is discussed in the following paragraphs.

With the solar input cut off, the valley area would become cooler because of two reasons namely, less volume of air in the valley compared to that over the city and the thermal inertial differences. The thermal inertial differences lead to larger cooling rates near the slopes and inside the valley compared to the city centre. This leads to a horizontal temperature gradient between the city and the slopes. Also we could expect the formation of the stable layer in the valley and the nearby slopes (Fig. 5. 32). In the first half of the night, an unstable layer prevails over the city mainly because of the lower thermal inertia and thus lesser cooling of the city centre. This could lead to rising of unstable warm air and a vertical cell of circulation could form in the area between the city centre and the slopes. During the advance of the night, the city centre cools less and maintains almost a constant temperature. But gradually over laying layers in the city would become warmer as the heat is transferred up over the city. Meanwhile the city areas near to the slopes cool faster due to the drainage influence and the horizontal temperature gradient established would increase the low level convergence. There by the effect of the city induced circulation on the drainage would increase.

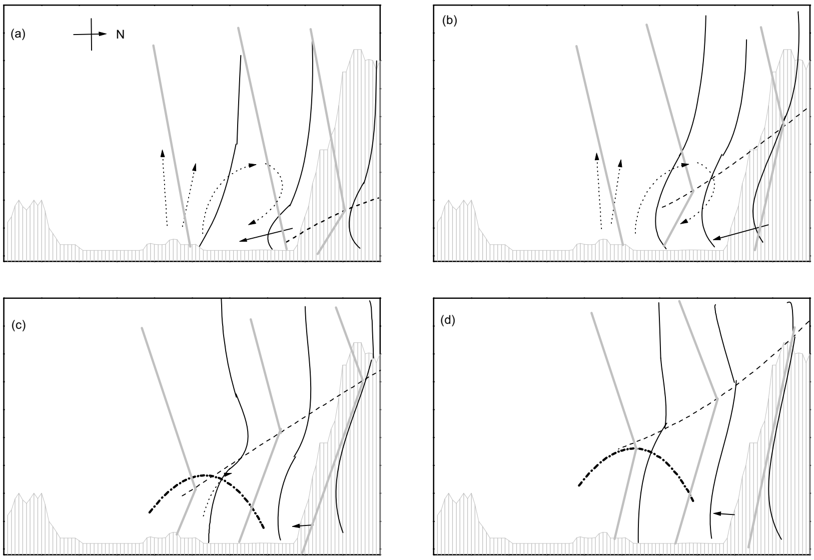


Fig. 5. 32: Hypothetical development of the Urban boundary layer over Linz during a clear night with low advective effects. Thick continuous lines are the temperature profiles, thin continuous lines are the velocity profiles thermal cell over the city is also shown in (a) and (b). The development of the stable layer is shown with dotted lines.

By the second half of the night, a stable layer gradually forms over the city (Fig. 5. 32c) . Above this layer instability prevails. Whereas the city areas near the slopes cool faster than the city centre and maintain a lower temperature than the city centre with a more deeper and stronger stable layer. The formation of the stable layer over the city centre would cease vertical advection as the eddies become more and more compressed and thus there is no supplementary energy from the vertical heat island cell to the drainage from the slopes. Thus the drainage towards the city is weakened. The eddies become smaller and smaller and dissipation would get more importance. Thus the frictional effects in the city decides the flow field. This leads to calm in the city whereas the horizontal temperature differences still exist to drive the drainage towards the city and gets weaker with the advance of the time. The areas of the city close to the slopes would get more ventilated through out the night. The formation of calm over the city extends up to a level forming a stable heat island. I.e., still there exists a temperature gradient between the city and the slopes with a stable temperature profile in the city that is not as stable as the one near the slopes.

Inside the stable heat island, a laminar layer might form because of no wind shear and thus the calm layer over the city gets decoupled from the unstable and more turbulent layer aloft. Whereas the overlying layer that is unstable would try to transfer momentum down but no heat. Since the laminar layer tries to block the transfer of momentum down, the wind shear increases in the intermediate layers between the stable(below) and unstable(above) layers. The increased wind shear generates turbulence in the upper layers whereas in the lower layers the turbulence is suppressed. These events could lead to the jet speeds over the city. This would also be contributing to the unusual jet speed noticed at 150m over the tower. Of course there are other factors as discussed earlier like the location that plays the major role in having high wind speed. The detailed analysis and validation of this hypothetical explanation depends very much on the availability of the vertical information.

This situation discussed in detail is of special concern to the pollution episodes inside the city. During the easterly south-easterly cases with the drainage being assisted by the city effect could bring the pollutants back to the city centre. Later the caesurae of the drainage and calm inside the city would give rise to the trapping of pollutants inside the city till morning hours. The During winter the existence of such situations could lead to the build up of pollutants inside the city from the house heating sources. Whereas the pollutants from the higher levels would get transported out of the city due to the jet speeds observed over the city.

Atmospheric de-coupling effects and their consequences for city ventilation.
Beitrag zur ICUC (International Conference on Urban Climatology,
Essen).
Erich Mursch-Radlgruber, Thara Prabha,
1996;

Atmospheric de-coupling effects and their consequences for city ventilation

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Abstract

The industrial city of Linz (213,000 inhabitants), with mainly steel and chemical industries, located in a basin bounded by hilly terrain often encounters the problems of high pollution levels in the build-up area. Under such situations, ventilation of parts of the city is of particular concern for city planning. First measurement campaign was carried out during summer 1995 to get a basic idea on some dominant features of the boundary layer structure under different forcing conditions. Since beginning of 1980´s an environmental observational network is routinely operated, which offers a database for the climatology and receptor point air pollution concentrations.

The analysis of the experimental data gave some insight into the strong effects of the city and the topography on the vertical structure of the boundary layer. Under clear sky conditions and certain mesoscale flow situations strong speedup effects directly above the buildings in presence of a strong inversion is often noticed. These are also favourable conditions for drainage flow on the slopes and valleys influencing the city from the North. In other parts of the city the air close to the surface is stagnating. A hypothetical model for the development of these situations is presented.

Key word Index : Decoupling effect, Heat island intensity, Hypothetical model

Introduction

This study is carried out on Linz, one of the industrial city of Austria which is situated in the surrounding of complex topography. The unique location and the orientation of the mountains play a special role in the interaction of the flow systems. Earlier study on the wind flow patterns in Linz by Weiss and Frenzel (1961) gave an introduction to the complexity of the problem. The role of terrain induced wind systems in ventilating parts of the city is of concern with respect to the air pollution transport and further planning in the city. The main problems to be considered in relation to the ventilation of the parts of the city are of different origin; thermally induced slope/valley winds, the circulations induced from the city and rural differences, very local influences due to the high rise buildings, channelled flow along the Danube valley, influence from the big open valley, etc. In defining the ventilation at parts of the city, proximity of these effects must be considered for different parts of the city. Since all these effects are interacting in different scales, an understanding of their interaction is necessary for deciding about the ventilation aspect. In the present study, utilizing the environmental observation network and a special measurement campaign, an attempt is made to understand the development and decay of the wind systems with respect to the stability of the urban boundary layer (UBL). In big cities, existence of a rural 'jet let' and its counterpart at a higher level over the city are documented in the early findings (Ackerman, 1974b; Bornstein et al., 1972). These were attributed to the weak flow accelerated due to the pressure gradient associated with the heat island. There is evidence that small city like in Linz heat island has definitely a role in the establishment phase of the down slope/valley winds to increase the strength of the drainage. With the weakening of instability over the city, drainage towards the centre of the city also weakens. Then a speed-up over the decoupled layer in the city is evident. A hypothetical model is suggested for these developments.

Location of the Study and Data

The location chosen for this study, the city of Linz, is situated nearly 200 km West of Vienna in Austria, the heart of Europe. Linz is one of the main industrial cities with 213,000 inhabitants. The city lies between Bömische Masse (to the North) and Kürnberg (to the South) in the Alpenvorland. Fig. 5. 33 shows the location of Linz in Austria and the surroundings of Linz along with the meteorological and air pollution monitoring stations. City limits are nearly in a flat terrain, except for the slops at the northern and western parts. The complex surrounding topography and the city effect complicate the problem of flow and dispersion of pollutants emitted from the industrial area. The valley of the Danube river taking its course through the city and the tributaries from North contribute to the drainage flow towards the city under cases of stable stratification. The prevailing ambient winds in the area are easterly or westerly to south-westerly. Close to the hills, channelled south-easterly and north-westerly are equally dominant.

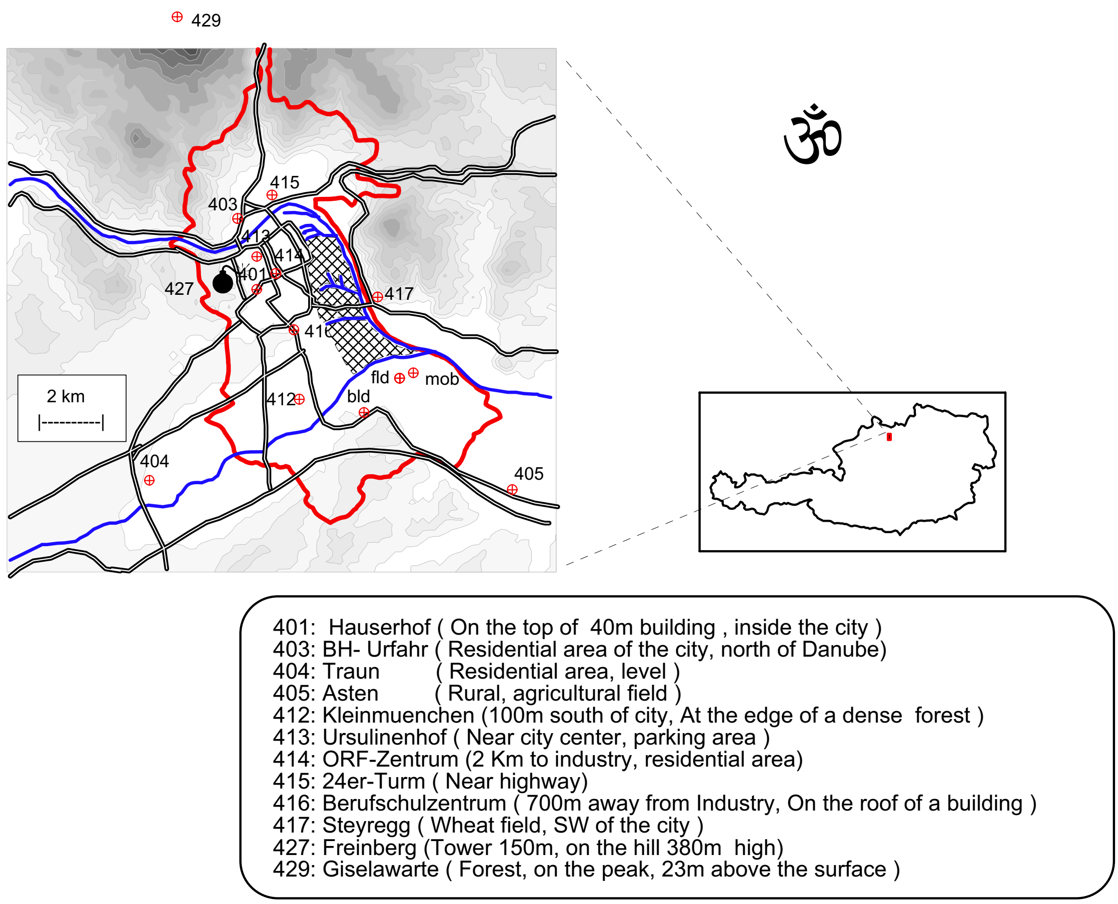

Fig. 5. 33: The location of Linz in Austria and network of the observing stations in Linz. The stations from the city administration are shown with numbers and the extra measurement network with the alphabets (bld - building top 60 m above, fld - field 10 m above and mob - mobile 10 m). The station “Giselawarte” (429) is shown outside the plot and is situated at the hill top (927m above sea level). At the tower “Freinberg” (427), three

levels (10 m, 90 m and 150 m) temperature and 150 m level wind velocity are measured. The stations "Berufsschule" (416) and "Hauserhof" (401) are situated at the tops of buildings. Station "Asten" (405) is representative for rural place. The difference in the grey shading gives the elevation(black – 900 m and white - less than 260 m). The heavy industrial area is marked with the shaded area.

The data used in this study are from the environmental network of stations from the city administration and the new measurement network in the south-western sector of the city. These measurements are made to decide further planning in that area. These measurements are carried out during the summer 1995. During this period, the Freinberg tower and Giselawarte were not operating. So the climatology of year 1991 is also considered for discussion. These data include the vertical temperature structure over the city and the wind shear. The receptor level SO_2 concentration from the monitoring network is also considered to identify the cases of high pollution episodes. The measurements of 1995 allow us to have the information about the suburban stability in the surface layer also as the wind and temperature measurements are made at 10 m (fld) and 60 m (bld) levels.

Statistical Analysis of the Ventilation Aspect

The spatial coverage of the data in Linz is used to identify parts of the city that are less or more influenced by various factors like the terrain, local roughness, exposure to the free space, etc. Also, it is important to know the role of the dynamical and thermal effects which play the most important role in the transport and diffusion of the pollutants out of the city. The thermally driven circulations try to ventilate parts of the city, the mechanical effects induced by the city structures resist this flow. The analysis of data for the year 1991 is done to understand the major flow patterns and to look into the ventilation of the parts of the city

The data are classified according to the stability classes derived using the net radiation and wind speed at the station Berufsschule (416). Among the total case 28.03 % unstable, 38.72 % neutral and 33.24% stable situations are noted. The dominance of neutral cases suggests the bias of the PGT classification towards the neutral case. A close look at the percentage of calm situations at different stations will give a first hand knowledge of the ventilation of different parts of the city. Fig. 5. 34 shows the percentage of total number of data, calms under the total and differing stabilities. The percentage of total data used give an idea of the total number of cases accounted for. At the tower Freinberg nearly 19 % of the data are missing and those situations are not considered whereas at other stations, 2-3 % of the cases are not considered.

The rural station Asten (405) shows (26 %) of calms. The stations Traun (404) and Kleinmünchen (412) showed maximum calm situations up to 38-39 %. These two stations are situated in moderately build-up area in the open valley bottom which is flat terrain. Here the topographically induced wind systems are of less importance. Whereas at the station ORF-Zentrum (414) situated inside the city with close buildings shows 35 % of calms which is directly attributed to the city effect. Hauserhof (401) shows 20 % of calms as the wind measurements are taken over a 40m tall building and are representative for the 50 m level wind speed over the city. At station Berufsschule (416) also wind measurements are done on the top of the buildings and show relatively lesser number of calms (17 %) compared to Hauserhof . This is due to the location of the stations, Berufsschule is situated on a gentle slope and the wind measurements are affected. The interesting aspect to be noted is the lesser number (23 %) of calms at the station 24er-Turm (415) which is situated inside the city but is very close to the Haselgraben, the steep valley to the North of the city centre. The downslope/valley winds dominate and play an important role in the ventilation of this part of the city. The station Steyregg (417) also shows lesser calms (18 %) due to the influence from the downslope winds and elevation of the place where the station is located (335m). All the stations except Giselawarte show maximum percentage (50-60 %) of calms during the stable situation and the least number of calms (10-15 %) during the unstable case. This statistic shows the importance of ventilation problem to be addressed in detail for different parts of the city.

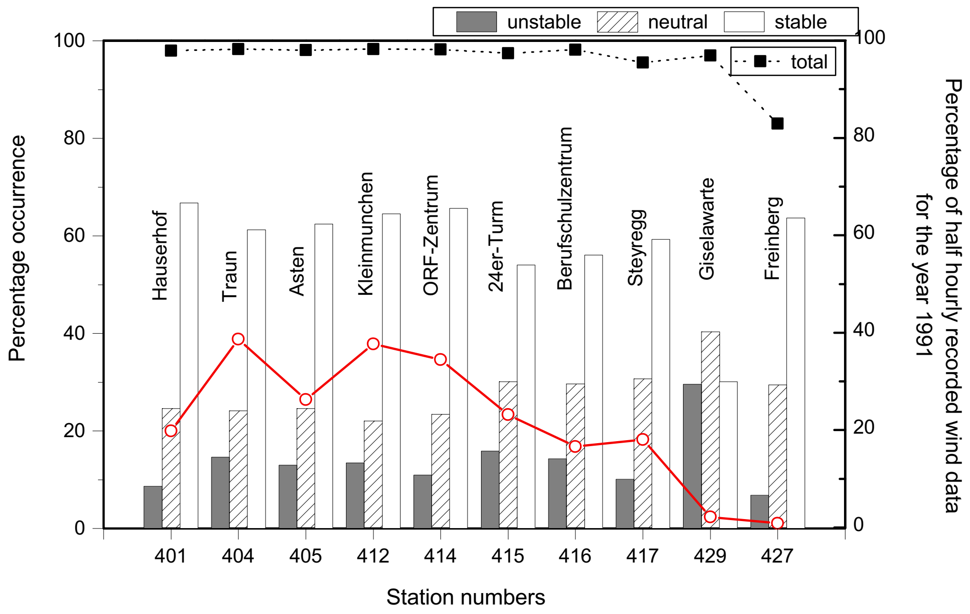

Fig. 5. 34: Percentage occurrence of calm cases. Total number of data (solid square) used is scaled on the right Y axis. On the left Y-axis, percentage occurrence of calms for the total case (shown as line with clear circles) and for differing stability are given.

Findings from the field measurements

Some of the findings from the measurement campaign during the summer of 1995 is used to explain the complex interactions of the wind systems with different origin. A considerable number of days during this campaign characterised a nocturnal wind maxima in the 60m level measurement in the suburban area (station -bld). The 10m level measurements in the suburban area (station -fld) did not show this acceleration. Thus it could not be considered as a consequence of the pure rural flow towards the city induced due to the city and rural temperature differences. This was generally associated with the strong stability in the suburban area and calms at the city centre. The occurrence of two such consecutive cases is shown in Fig. 5. 35. The data are for the 23rd May noon to 25th May 1995 noon. These are two cases with well-pronounced nocturnal maxima (3-4m/sec) in wind towards the city centre along with the strong drainage from the slopes. Similar acceleration of 1-2m/sec is also noted at Hauserhof representative for nearly 50 m over the city. These are northerly to north north-westerly from the Haselgraben. The station 24er-Turm also shows the downslope winds (~1m/s) throughout the night. Whereas 10m level (Station ORF-Zentrum) over the city characterises calm situations or weak north north-westerly drainage flow during this period. It is also noted from the Fig. 5. 35 that these accelerations also occurred in association with a strong stability in the suburban area, convergent situations over the city and established heat island intensity.

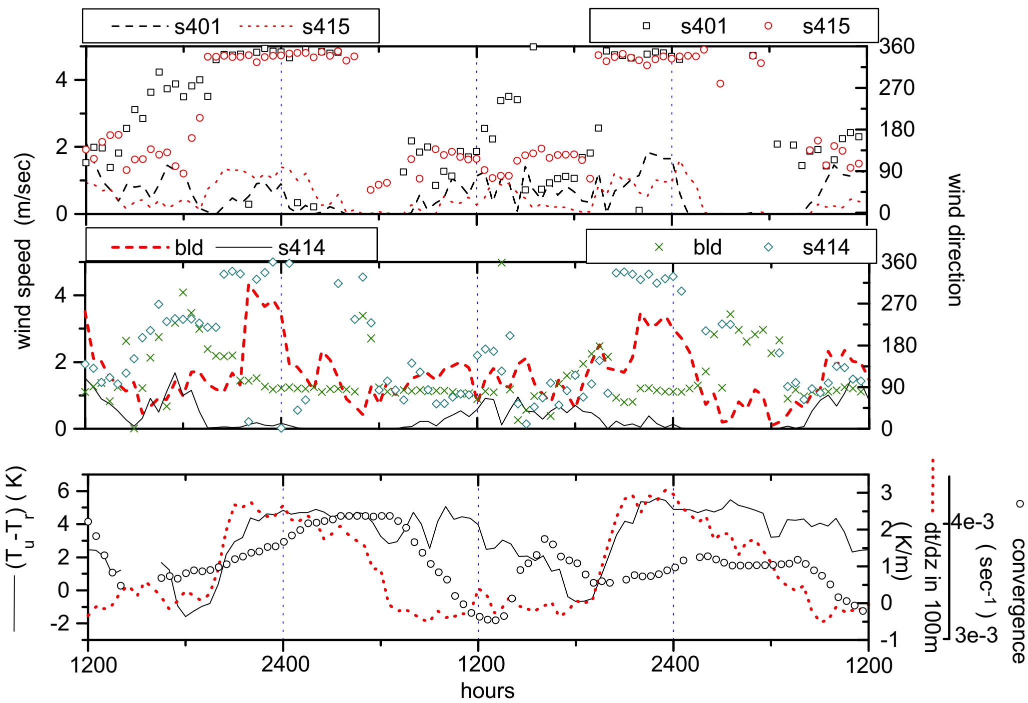

Fig. 5. 35: The temporal variation of wind speeds and directions at Hauserhof (401) and 24er-Turm (415) shown at the top, 60 m suburban (bld) and ORF-Zentrum (414) shown in the middle and the heat island intensity (T_u-T_r), lapse rate in 100 m of suburban area and convergence in the low levels over the city shown at the bottom figure.

The sequence of these complex interactions could be looked at as follows. With the sunset and the cooling of the slopes at the areas more close to the hills, the downslope flow develops. This part of the city cools faster as the volume of air occupied in the valleys are lesser compared to the larger volume of air over the city. These slopes are moreover covered by forests and the agricultural land unlike the city centre with more dense buildings. Thus the thermal inertia differences also contribute to this cooling differences. When this stable layer develops close to the slopes, city centre experience an unstable/neutral surface layer. We could assess this from the heat island intensity and the lapse rate both increasing during this phase. The heat island intensity establishes a horizontal temperature gradient with the city centre and the surroundings. The unstable air over the city would rise and to compensate for this, low-level convergence towards the city centre increases. This can be noted at the stations inside the city centre with the drainage winds reaching to the centre of the city. 50m level over the city also shows this effect. Thus a cold air pool develops in the city and development of a stable layer over the city would result. Above this cold air pool over the city, the flow gets accelerated towards the city. The considered case in Fig. 5. 35, at the beginning the slope flow is also driven by the low level convergence due to the vertical ascent over the city. Before midnight (at the time of wind maxima at 60 m in the suburb), the downslope wind at 24er-Turm gets weakened and the wind speed increases at Hauserhof .

These speed up features are very critical in assessing the impact from the industries as most of the sources are located at between 50-200 m above the surface. The area south-west of the industries where the measurements are made during 1995 (fld, mob, bld) is a sudden discontinuity in the roughness. This place is mostly agricultural fields and small villages. Thus more like a rural rather suburban nature. Thus the effect of the decoupling effect is noted in the boundary layer over this area. These speed up effects can be due to various factors like the effect of the decoupling over the city, skimming effects over the buildings and are to be studied in further detail. The lack of the wind velocity information at Freinberg tower and Giselawarte mountain station during the measurement campaign during 1995 made it difficult to assess the mesoscale influences if any exist in Linz. A climatological analysis of the data from 1991 utilised here to assess the importance of these effects.

Climatological relevance of the Problem

Frequency distribution of diurnal variation in wind directions at stations inside the city, tower Freinberg and Giselawarte is analyzed to understand the importance of the decoupling effects. This also offers the possibility to put some light into the interactions of different scales (local, regional) as the diurnal cycle is the most important in those. At Freinberg and Giselawarte, north westerly dominates during the day and Easterly dominates during night for 30 percent of the total occurrence. The same behavior is noticed for the year 1993 also. This phenomenon is to be looked into as the mesoscale influences from the pre-alpine valley between the Alps and the Bömische Masse to North; in the Alpenvorland. This is an indication for the dominant mesoscale influence. The existence of such mesoscale diurnally changing wind systems is not documented. This is an interesting phenomenon to investigate further with the help of a mesoscale meteorological model. The easterly wind changed to south easterly during the morning hours. Similar but opposite change in the direction distribution is noted during the sunset. This is an indication of the local effects at the tower. Since it is located more close to the hills and the city itself, local effects dominate during the transition periods.

At Hauserhof (Fig. 5. 36), the dominant wind is from north to north-west throughout the day. The easterly contribute only 10-15 percent during the day that shows a directional change as it is quite influenced by the Danube basin. This directional change is linked to the input of solar radiation. During the morning hours, the wind directions change more clockwise leading to south-easterly. This seems to be a result of the warming up of the slopes and the city effect is almost non-existent at this time. Then the interaction between the upslope and the ambient easterly wind results in south-easterly winds. Since there is much difference in the sunrise timings during the year, there is a spread in this direction distribution (from 5:00 hrs to 10:00 hrs in the morning). By the afternoon hours, the flow around the Danube valley dominates as the temperature gradient between the slopes and the city diminishes. Unstable situation prevails and the topographic influences are reduced. In the evening hours, till 20:00 hrs, the directions change to northerly or north-easterly. This is in relation to the cooling of the slopes and the thermally induced slope flow towards the city dominates. Since the city is warmer than the slopes and unstable during the first half of the night, the vertical motions persist over the city. This increases the low level convergence and the slope flow gets accelerated towards the city. It can be noticed in Fig. 5. 36 that in the second half of the night, the frequency of the northerly or north-easterly flow towards the city is diminished. This can be associated with the development of a stable layer over the city and the dominance of frictional effects inside the city. Thus the city plays the role to resist the advance of the drainage. Since this station is located on 40 m high building, it gives an idea about the vertical extent of the thermally induced winds also.

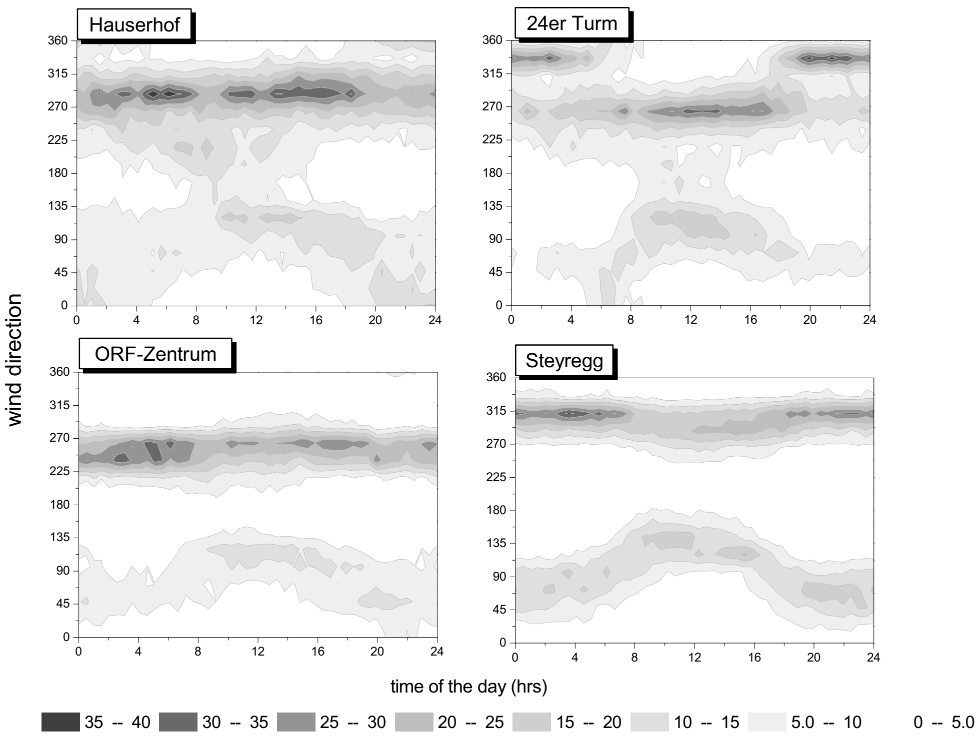

Fig. 5. 36: Diurnal variation of direction distribution for Hauserhof, 24er-Turm, ORF-Zentrum and Steyregg

In the case of ORF-Zentrum (Fig. 5. 36), westerly winds dominated and the easterly cases (10-15%) showed a similar diurnal variation as at Hauserhof in wind direction. During the easterly cases, the changes in the wind directions are greater and it's a dominant feature. The station seemed to be quite influenced by the Danube basin under easterly situation during midday. Night time cases show the dominant north-easterly slope winds with maximum around 20:00 hrs. Later in the night, these wind systems are less frequent as in the earlier case.

At 24er-Turm (Fig. 5. 36), drainage flow from Haselgraben is the dominant feature during the night with maximum around 2000 hrs. The existence of the drainage winds throughout the night and till 800 hrs in the morning, is specially noted unlike in other stations like Hauserhof and ORF-Zentrum, where the drainage flow ceases in the middle of the night. It is also noted that the frequency of occurrence of drainage decreased in the second half of night. This establishes our assumption that the drainage is forced by the city effect in the first half of night and blocked later. We can expect the heat island created due to the city centre to assist the development of the stronger drainage in the first half of the night, as the temperature gradients between the slopes and the city are larger during that period. But later in the night, frictional effects (dynamical effects) in the city centre counteract and resist the advance of the drainage well inside the city.

At Steyregg also, similar diurnal pattern is observed with more percentage of easterly and more distinct changes in the diurnal pattern. This signifies the importance of the drainage winds and the vortex formation in the Danube valley area of the inner city. North-westerly dominated during the night and the tendency to turn more westerly with the warming up of the slopes during the day is also noted. The development and decay of the slope flow are clearly noticed in the easterly case. Maximum occurrences of the slope flow (nearly 20%) at around 2000 hrs are a very good indication of the terrain effect over there. Thus the importance of these decoupling effects are noted at the stations inside the city for the climatology as well.

Hypothetical Model

The decoupling effect over the city is explained with the help of a hypothetical model by considering the boundary layer development over the city and the nearby slopes. With the solar input cut off, the valley area becomes cooler because of two reasons namely, less volume of air in the valley compared to that over the city and the thermal inertial differences. The thermal inertial differences lead to larger cooling rates near the slopes and inside the valley compared to the city centre. This leads to a horizontal temperature gradient between the city and the slopes. Also we can expect the formation of the stable layer in the valley and the nearby slopes (Fig. 5. 37a). In the first half of the night, an unstable layer prevails over the city mainly because of the lower thermal inertia and thus lesser cooling of the city centre. This can lead to rising of unstable warm air and a vertical cell of circulation can form in the area between the city centre and the slopes. During the advance of the night, the city centre cools less and maintains almost a constant temperature. But gradually overlaying layers in the city becomes warmer as the heat is transferred up over the city through radiative divergence. Meanwhile the city areas near to the slopes cool faster due to the drainage influence and the horizontal temperature gradient established increases the low level convergence. Thereby the effect of the city-induced circulation on the drainage increases.

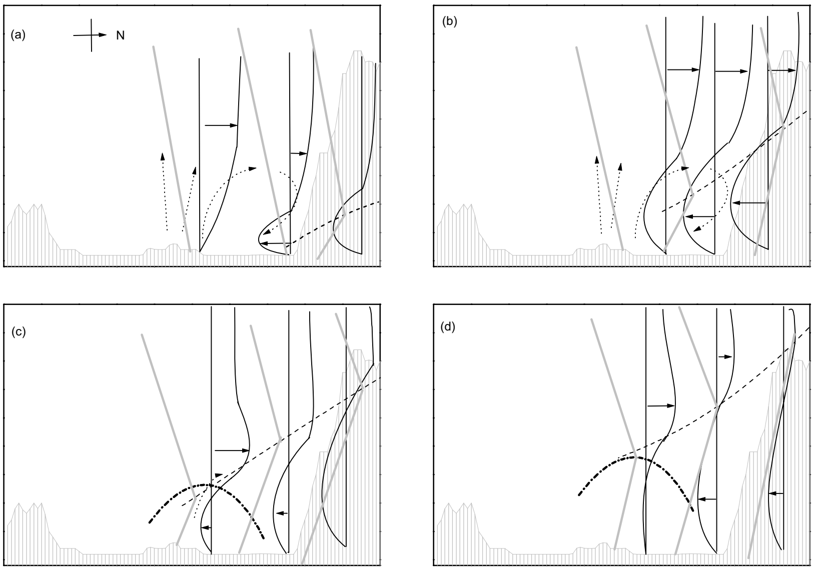

Fig. 5. 37: Hypothetical development of the Urban boundary layer over Linz during a clear night with low advective effects. Thick continuous lines are the temperature profiles, thin continuous lines are the velocity profiles thermal cell over the city is also shown in (a) and (b). The development of the stable layer is shown with dotted lines. The north-south cross-section of the city is shown in the background. The shaded portion gives the cross section of the topography.

By the second half of the night, a stable layer gradually forms over the city (Fig. 5. 37c) . Above this layer instability prevails. Whereas the city areas near the slopes cool faster than the city centre and maintains a lower temperature than the city centre with a deeper and stronger stable layer. The formation of the stable layer over the city centre ceases vertical advection as the eddies become more and more compressed and thus there is no supplementary energy from the vertical heat island cell to the drainage from the slopes. Thus the drainage towards the city is weakened. The eddies become smaller and smaller and dissipation gets more importance. Thus, the frictional effect in the city decides the flow field. This leads to calm in the city whereas the horizontal temperature differences still exist to drive the drainage towards the city but weaker with the advance of time. The areas of the city close to the slopes get more ventilated throughout the night. The formation of calm over the city extends up to a level forming a stable heat island. i.e., there still exists a temperature gradient between the city and the slopes with a less stable temperature profile in the city compared to that near the slopes.

Inside the stable heat island, a laminar layer might form because of no wind shear and thus the calm layer over the city gets decoupled from the unstable and more turbulent layer aloft. Whereas the overlying layer that is unstable tries to transfer momentum down but no heat. Since the laminar layer blocks the transfer of momentum down, the wind shear increases in the intermediate layers between the stable (below) and unstable (above) layers. The increased wind shear generates turbulence in the upper layers whereas in the lower layers the turbulence is suppressed. These events can lead to the jet speeds over the city. This also contributes to the unusual jet speed noticed at 150 m of the tower. Of course there are other factors, as discussed earlier, like the location, that plays the major role in having high wind speed at the tower. The detailed analysis and validation of this hypothetical explanation depends very much on the availability of the vertical information.

Conclusion

The decoupling effect over the city is an important aspect for the distribution of pollutants inside the city and the ventilation of parts of the city. The complex interactions between different aspects like the drainage winds, heat island, decoupling over the city should be studied further in detail. These first results and the drawn conclusions are to be verified with the help of a mesoscale meteorological model. In this direction, as a first step, a data base is being made from Linz and the intensive measurements will include the acoustic remote sensing technique with the help of mini SODAR. This will offer the possibility to study the urban boundary layer development in detail and the hypothetical model can be verified.

Acknowledgements

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