台東地區焚風現象之研究

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我出生於西元1984年的里約熱內盧，血液裡同時脈動著中華五千年的瑰麗與拉丁美洲的熱情與慵懶。我喜歡這個世界，儘管它還是有許多的不美好；我喜歡我自己，儘管這傢伙缺點還是不少。

幾乎有三分之二的高中生活都賠在「台東地區焚風現象之研究」上面了。從一年級某個秋天夜晚同學打來的電話到興奮地坐上往巴黎的法航班機，這個成本極低的研究真的讓我學了很多，很多。

得謝謝陳泰然教授、陳汝勤教授和曾世彬老師給我的概念和幫助、中央氣象局顏泰崇先生、陳正改先生和台灣省茶葉改良場台東分場鄭混元先生提供的資料與建中網路管理中心提供的設備。最後謝謝顏逸凡同學：沒有你，根本就不會有這件作品。

前言

焚風是台灣常見的一種局地性乾熱風。當溼熱的空氣受山嶺阻隔而被迫上升，絕熱冷卻使得水汽凝結成雲雨，降在迎風坡上，氣流越過山嶺後則下沉，因絕熱增溫而顯著地比當地空氣乾、熱，特以焚風稱之。（邱， 1983；郭及楊， 1982）

焚風也是許多農民深以為懼的天災。焚風強、乾而熱的特性會造成農作物的物理性傷害和脫水性乾害，例如1981年Ike（艾克）颱風在宜蘭誘發的焚風就讓當地數千公頃的稻田發生「白穗」而損失將近一億元；又如1996年台東茶區的焚風均在該年度春、夏茶季來襲，根據調查「8至40%茶芽受害，受害葉數達第三葉，葉片受害面積自20%至30%，葉尖、葉緣、葉柄及節間徑受害明顯，成乾枯狀有燒焦味；而且茶芽生長亦受抑制，新長出之茶芽出現受害徵狀以致茶菁品質降低」（鄭， 1997）。目前雖然可以用林木構築防風牆來保護作物，但畢竟成效有限，所減少的蒸發量僅20-30%；而迴避、危險分散或噴水灌水等方法又顯得太消極。然而為什麼焚風會帶給農民如此嚴重的災害和損失？如果能了解焚風的特性，是不是可以讓農民有更多的因應時間呢？

研究目的

(一)歸納並描述台東地區焚風發生前及發生時各種天氣現象變化的規律性。
(二)嘗試從整理出的規律性中發展出概略的焚風預報指標。

研究方法及步驟

(一)蒐集資料：包括台東縣鹿野茶區1994年至1998年間之焚風個案記錄、1994年至1998年台灣地區高雄、三地門、甲仙、尾寮山、表湖、奮起湖、日月潭、關子嶺(以上位於中央山脈南端西側迎風面，用以了解氣流過山前所在當地的氣壓及降雨量變化）、台東、花蓮、大武、成功、鹿野、池上、知本、綠島和蘭嶼（以上位於中央山脈南端東側背風面，用以了解焚風發生當地的天氣變化）等氣象測站之記錄（內容包括氣壓、氣溫、相對溼度、風向、風速和降雨量之逐日逐時資料）、測站分布圖和地形圖、1994年至1996年日本氣象廳所發布之地面天氣圖（每日兩張，各為格林威治時間0時與12時，1996年開始增為每日四張）。

(二)分析歸納：先由地面天氣圖觀察個案發生前約兩天的東亞天氣概況併以發生月份等資料將個案分類，其次分別研究不同類型個案發生前兩天內之各地氣壓、溫度、相對溼度、風向風速和雨量的變化。大部分「研究」的工作在試算表（Microsoft Excel）下進行：將蒐集到的逐時資料繪製為圖表，再比較不同個案相同氣象要素曲線走勢之異同。又風向在整個焚風發生的機制中十分重要；若是風向不正確，等於是把焚風最基本的要件「風」給去掉了。界定風向時必須考慮地形的因素，因為地形風有時會與大尺度的風向有180度的差別。為避免誤判，本研究採用高雄（台灣西南平原）、綠島和蘭嶼（台灣東岸離島）三個測站的風向資料作為風向分析的主要參考，另外再配合個案前兩到三天的地面天氣圖，就可以確定大尺度的風向概況是否符合焚風發生所需。比較之後便整理歸納出各氣象要素變化的規律性，並選擇個案「發生前」的顯著現象作為預報焚風的基礎。

分類

本研究包括1994年至1998年發生在台東地區的十三個個案。觀察天氣圖可將其個案分成兩類：

(一)颱風型

發生日期	焚 風 期 間	氣溫變幅（℃）	相對溼度變幅（%）	最大風速（m/s）	颱風名稱
8/7/94	20時-23時	23.5-35.9	90-34		Doug 道格
8/21/94	6時-12時	23-40.5	91-32		Fred 弗雷特
10/10/94	2時-14時	21-41	96-27		Seth 席斯
7/31-8/1/96	19時-1時	28-34	96-48	27.9	Herb 賀伯
8/18/97	2時-21時	26-36.5	88-37	31.9	Winnie 溫妮
10/16/98	9時-17時	26-30	93-48	24.5	Zeb 瑞伯

本型個案發生時台灣本島附近皆有颱風經過。

(二)鋒面型

發生日期	焚 風 期 間	氣溫變幅（℃）	相對溼度變幅（%）	最大風速（m/s）
4/14/95	6時-16時	20.5-38	93-34	
3/15/96	2時-12時	22-39	80-23	11.7
5/7/96	8時-16時	25-36	92-40	9.7
2/14/98	7時-15時	19-32.5	78-26	9.6
3/4-5/98	19時-10時	24-27	78-39	20.4
3/9/98	9時-17時	25-32.5	92-36	10.6
4/24/98	7時-16時	24-37.5	95-36	13.9

本研究以個案發生的日期為其命名，如發生在1996年7月31日和8月1日之間的個案稱為073196。十三個個案在各地的氣壓、氣溫、相對溼度、風向、風速和降雨量變化曲線請參見附錄之例圖。

颱風型個案

觀察颱風型焚風個案的結果如下（由於個案101698的Zeb颱風較特殊，將移至討論中說明）：

(一)由路徑圖可以發現這些颱風都經過台灣北方由東經120度、東經124度、北緯25度和北緯28度所圍成的矩形。通常焚風發生時，颱風中心也在這一塊區域內。除了Zeb近台後轉向東北方行進之外，其他颱風都是在台灣東方或東南方的海面而往西北方前進，屬於中央氣象局侵台颱風路徑分類裡的1、2和6。

(二)個案發生時颱風的中心最低氣壓在940hPa至970hPa的範圍裡。

(三)個案發生時，台東東南方外海的蘭嶼所測得的逐時風速多在15-25m/s的範圍，恰是颱風暴風圈邊緣區的水準。

(四)氣壓(圖一)：從個案發生前兩天開始繪製氣壓變化曲線，可以發現整個圖呈「漏斗狀」，東部幾個濱海測站和高雄的氣壓值從1000hPa到1005hPa的區間不斷下降，在到達「焚風日」上午的低點後回升，顯示颱風接近並遠離。最小值發生的時刻前後約三個小時的焚風效應影響最大。

(五)氣溫（圖二）：焚風如果開始在深夜，則當地的溫度急劇上升，隔日六七點時回到原值；其圖形呈現高而尖的金字塔狀，塔頂或有兩個。又如果發生當天凌晨或是日出時，則曲線變成了馬雅式的金字塔，通常在黃昏時焚風停止。西部測站在焚風發生前兩天的氣溫曲線大致上跟東部重疊(尾寮山的氣溫偏低約5℃)，焚風發生當天則失去日變化，平均維持在凌晨一時的溫度附近。

(六)相對濕度（圖三）：相對溼度的變化近似氣溫，只是上升和下降互換。台東和大武的溼度曲線在焚風開始後，往往在一小時之內遽降並維持最低值直到半天後回升為止(個案082194和101094中大武沒有完整的資料顯示相對溼度回升）。又大武相對溼度下降的時刻通常比台東要早，而台東又比成功和花蓮早。

(七)風速（圖四）：焚風發生前十二個小時或更早，中央山脈西邊的高雄風速會大幅增強；東部的蘭嶼和綠島風速遽增的時間不甚規則，但一定會增為之前的五倍以上。

(八)風向：個案發生前六個小時左右蘭嶼、綠島和高雄等平地測站的風向開始趨於穩定，多數是先由北風或北北東風開始漸漸轉向西北西或西方，此後一、兩個小時發生焚風，由此可見風是由台灣西南部逆時針方向翻越中央山脈；而在個案發生的現場，風向會先有一段不穩定期，之後才轉為焚風的標準風向。焚風發生時，如果風向突變或風速減緩，氣溫與相對溼度馬上會出現變化。

(九)降雨量（圖五）：西部測站大多符合理論出現降雨，尤其是在山區。

鋒面型個案

(一) 觀察天氣圖，將本型個案發生時台灣本島附近的天氣系統概述如下：

個案	個案發生台灣附近的天氣系統
041495	北方海面有滯留鋒和冷鋒，太平洋高壓中心在東北方海面
031596	北方海面有滯留鋒，太平洋高壓中心在東方海面
050796	低壓中心在日本東南方海面，冷鋒往西南方延伸
021498	滯留鋒停在東海南邊，太平洋高壓勢力強大
030498	冷鋒過境，溫帶氣旋中心在琉球附近
030998	日本南方、東海、廣東連續出現三個高壓，滯留鋒平行大陸東南沿海的海岸，太平洋高壓非常遙遠
042498	滯留鋒在台灣北方海面，呈震旦方向，高壓中心距離遙遠

（二）氣壓（圖六）：觀察個案發生前當地的氣壓記錄，可以發現每天都有完整的日變化（在 8-11 時和 21-23 時有最高值，而在 3-5 時和 15-18 時的時段中出現最低值），整體卻有下降的趨勢，極大、極小值平均下降 5-6hPa。又低點下降的幅度通常較高點來得大。

（三）氣溫（圖七）：溫度在我們所作的個案中也呈現每天規律的日變化，大約在凌晨 5、6點時到達最低點，而午後2、3點時則是一天中氣溫最高的時候。但是在我們將資料繪製成圖表後發現：在焚風發生前兩到三天的時間內，每日平均溫度與氣壓相反，有漸漸往上攀升的趨勢；每天最高溫與最低溫的差距愈來愈大，平均上升 65%。

（四）相對濕度（圖八）：相對溼度資料也有日變化。在一天之中，一般以清晨太陽還未出現時最高，下午 2 點至 4 點約為一天相對溼度最低的時候。這一點與之前兩項資料的日變化有著密切的關係，彼此互相牽連。而在處理個案中，我們也發現一些「地方性」的特色，例如：發生在台東的個案相對溼度的圖形往往呈漏斗狀，在焚風發生時溼度降至極低的狀態，但是經過較短時間（約 3 至 4 個鐘頭）即恢復至較正常的溼度。相對於台東測站，大武測站的溼度圖形常常出現斷層狀，即焚風發生時溼度急遽下降，之後需要極長的時間（有時長至一至兩天）恢復至一般的溼度。此一發現推測與地形有關，可以作為往後進一步研究的題材。

（五）風速（圖九）：繪製出風速變化曲線後，可以發現在焚風發生的四至六小時之前風速遽增，在高雄及綠島可增強至二或三倍，而蘭嶼的風速變化更是令人咋舌：大部分個案增強到至少 3 倍，最多出現 4 、 5 倍於平均風速的風。又綠島風速增強的時間較蘭嶼晚一至二小時。

（六）風向：個案發生前一兩個小時開始，風向會呈現非常穩定的狀態，有時候甚至連續六七個小時吹同一個方向的風。在焚風現象結束若干小時之後（視鋒面前緣的前進速率而定），風向會突然轉為北或東北方。

（七）降雨量（圖十）：西部測站大多符合理論出現降雨，尤其是在山區。

討論—颱風型個案

（一） 由於北半球的低氣壓逆時鐘旋轉，所以當颱風中心在台灣北方時，在其南方的環流恰好翻過中央山脈來到台東地區，而這樣的路徑符合焚風發生的條件。

(二) 根據關島JTWC的熱帶氣旋中心最低氣壓值與中心最大恆常風值回歸曲線關係圖，940hPa-970hPa的範圍代表「中等至較強的中度颱風」。當颱風的路徑符合颱風型個案結果(一)所述時，若強度不足，則其環流連翻越中央山脈都很吃力，遑論發生焚風；若該颱風強度太過，30kt（15m/s）暴風半徑依然完全籠罩台東，則當地仍是雨區，環流翻過山脈後沒有機會絕熱增溫。

(三) 由資料中可以發現個案發生當地離颱風中心約300公里，同時颱風的30kt（15m/s）暴風半徑也是300公里左右，所以焚風發生的地點多在雨勢已歇、空氣下沉的颱風邊緣區域。

(四) Zeb（瑞伯）颱風在本研究採用的六個個案中算是一個異類，不管是路徑、氣壓和暴風半徑都和其他不一樣。Zeb在菲律賓附近形成，受呂宋島地形影響減弱而轉向北方移動，經過台東近海時又往北北東方向前進。十月十六日晚間續往東偏並減弱為輕度颱風，此時颱風中心在宜蘭東北方外海，蘭嶼測得的風速平均在7.7m/s，颱風的位置和縮小了的暴風半徑恰好誘發了台東地區的焚風。

(五) 應用以上發現可以解釋1994年至1998年間為什麼其他颱風未在台東地區誘發焚風：

颱風名稱	日期	路徑分類	最強強度	原因
1994				
Tina	7/9-11	3	L	橫貫台灣本島帶來降雨
Yunya	7/19-20	8	W	路徑偏南
Caitlin	8/1-4	5	W	橫貫台灣本島帶來降雨
Gladys	8/30-9/ 2	2	M	疑似在大武發生焚風
1995				
Deanna	6/5-9	9	W	在台灣中部登陸，強度不足
Gary	7/29-31	9	W	路徑偏西
Helen	8/8-9	5	W	路徑偏南
Janis	8/22-24	1	W	路徑類似Winnie，強度卻不足
Kent	8/29-30	5	M	路徑偏南
Ryan	9/21-23	9	M	路徑類似Zeb，強度卻較大而帶來降雨
1996				
Cam	5/21-24	9	W	路徑偏南
Gloria	7/25-27	7	M	造成台中一帶的焚風，不在本研究討論範圍
Lisa	8/6-7	9	W	路徑偏西
Sally	9/6-8	5	M	路徑偏南
Zane	9/26-29	6	M	路徑偏東
Ernie	11/10-12	5	W	路徑偏南
1997				
Amber	*8/29	2	M	橫貫台灣本島帶來降雨
Cass	*8/30	未侵台	W	路徑偏東
Ivan	*10/21	未侵台	S	路徑偏南

颱風名稱	日期	路徑分類	最強強度	原因
1998				
Nichole	*7/10	5	W	路徑偏西
Otto	*8/4	2	W	橫貫台灣本島帶來降雨
Yanni	*9/28	4	W	路徑類似Zeb，強度卻不足
Babs	*10/27	5	M	路徑偏西

註：日期前有「*」者代表侵台或近台日期，其餘為存在期間。強度中W（weak）表輕度颱風，M（moderate）表中度，S（strong）則為強烈颱風。

(一) 焚風效應是隨著乾熱空氣團的移動而漸漸擴大的，因此氣流先到達處的氣溫和相對溼度必然變化得比後到達處早。由相對溼度「大武→台東→成功、花蓮」的變化順序足可證明風是由西南向東北吹送。

(二) 部分西部測站降雨零星或甚至沒有，經確認後發現這些測站的位置分布在山腳或是中央山脈以西的平原地區，山脊處的降水比較沒有辦法到達，但並不代表氣流過山留下的水汽沒有凝結。

討論—鋒面型個案

(一)鋒面型的個案集中在二至六月，大約是春初到夏初，在這一段時間東亞地區的天氣概況都差不多：亞洲大陸內部與太平洋上各有一個勢均力敵的高壓，東北亞一帶則通常會有溫帶氣旋產生，伴隨著暖鋒與劃過台灣北方海面的滯留鋒或冷鋒。對於這些徘徊在台灣北方的鋒面而言，台灣位在它們的暖區。在北半球鋒面暖區吹的是西南風，而在鋒面冷區則吹的則是東北風。若台灣東部地區發生焚風，則必須要有由西南方翻越中央山脈的空氣團受到造成焚風的乾濕絕熱增減溫的過程才行，因此推斷：台東地區要發生焚風，鋒面就必須在台灣的北方，使台灣位於鋒面前的暖區之中，而個案發生時的地面天氣圖也證明了這一點。

(二)由地面天氣圖可以發現個案發生前北方高氣壓不斷增強，使鋒面向南方逼近。這個現象反映在台灣地區附近氣壓鞍型場就是氣壓值不斷下降，但仍然保有日變化。氣壓的變化是鋒面型個案發生前一個相當重要的指標。

(三)氣溫在日變化間不斷升高，而相對溼度不斷降低的現象顯示出一個可能的情形：連續的好天氣。在每天太陽照射的白天中，輻射增溫現象可能因為連續的好天氣而出現加成的作用，使得後一天的太陽增溫比前一天更為明顯。如上所述，台灣在焚風發生之前一直是處於鋒面南方暖區，因此可能在太平洋高氣壓影響下出現連續多天的好天氣，而晴朗的天氣裡氣溫和相對溼度的變化會更為顯著，尤其是焚風發生時。

(四)在鋒面前方約一百至數百公里處由於前後方冷暖兩區的風向截然不同，會產生一種風速突然增強現象，稱之為「風變」。在鋒面南方所產生的風變，會使原本的西南風增強而足以翻越中央山脈，使焚風發生的可能性提高。在台灣本島西南方的高雄風速最先增強是理所當然；至於綠島比起蘭嶼距離高雄較近，前者風速增強的時間卻比後者稍晚，是因為風在從高雄往綠島的路上經歷了中央山脈的地形抬昇使得通過所需的時間變長，而這一點也是空氣團翻越中央山脈的一項間接證據。

(五)鋒面與風向突然的轉變有極大的關係。由地面天氣圖發現鋒面正好在風向改變時通過台灣上空，而鋒面北面冷區吹的是偏東北方的風，因此鋒面的接近與通過確實對台灣

的風向會造成影響。

(六) 部分西部測站降雨零星或甚至沒有，經確認後發現這些測站的位置分布在山腳或是中央山脈以西的平原地區，山脊處的降水比較沒有辦法到達，但並不代表氣流過山留下的水汽沒有凝結。

結論

(一)誘發台東地區焚風的颱風多由西南或南方經過東經120度、東經124度、北緯25度和北緯28度所圍成的矩形向東北或北方而去。通常焚風發生時，颱風中心也在這一塊區域內，且中心最低氣壓值在970hPa以下，颱風的30kt（15m/s）暴風半徑約在300公里左右。

(二)非颱風誘發的個案至少是由位於台灣北方海面的滯留鋒或冷鋒南下造成的。台灣位在鋒面前的暖區，因此大尺度的風向是西南風；當鋒面南下、風速增強，台東地區發生焚風的機會便大幅提高。

(三)在焚風發生前風向會漸趨穩定，保持在南到西南西的方向，同時風速也大幅增強。氣壓值則是在一至兩天前就開始出現不斷下降（颱風型）或在日變化中漸漸下降（鋒面型）的變化模式，可以作為預測焚風的一項指標。氣溫和相對溼度只有在焚風發生時才有明顯的變化，之前都沒有可循的模式以供歸納；氣溫在焚風發生時遽增、相對溼度驟降，都是和理論相同的結果，對研究沒有什麼幫助。

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(四)台灣電子地圖服務網（http://www.map.com.tw）

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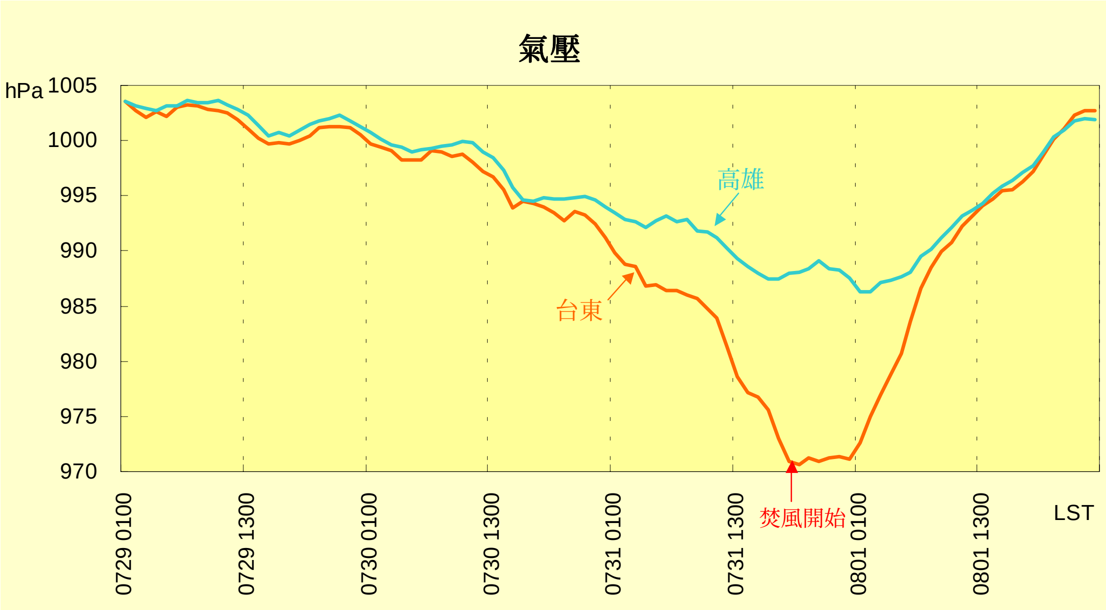
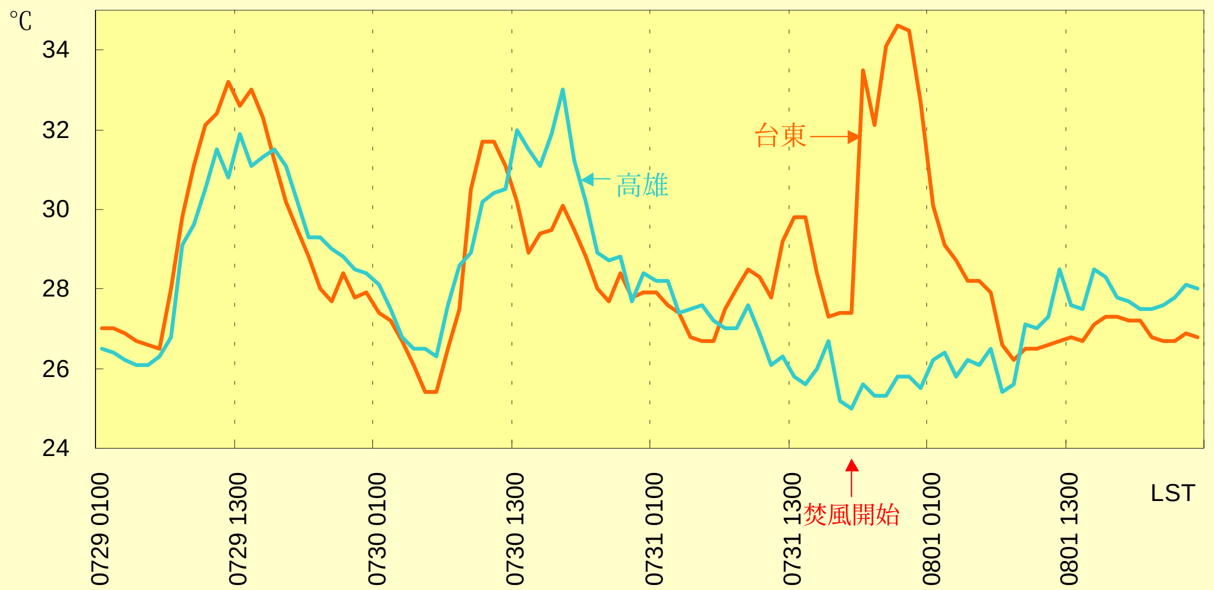
(六)Encyclopedia America（1997）

附錄



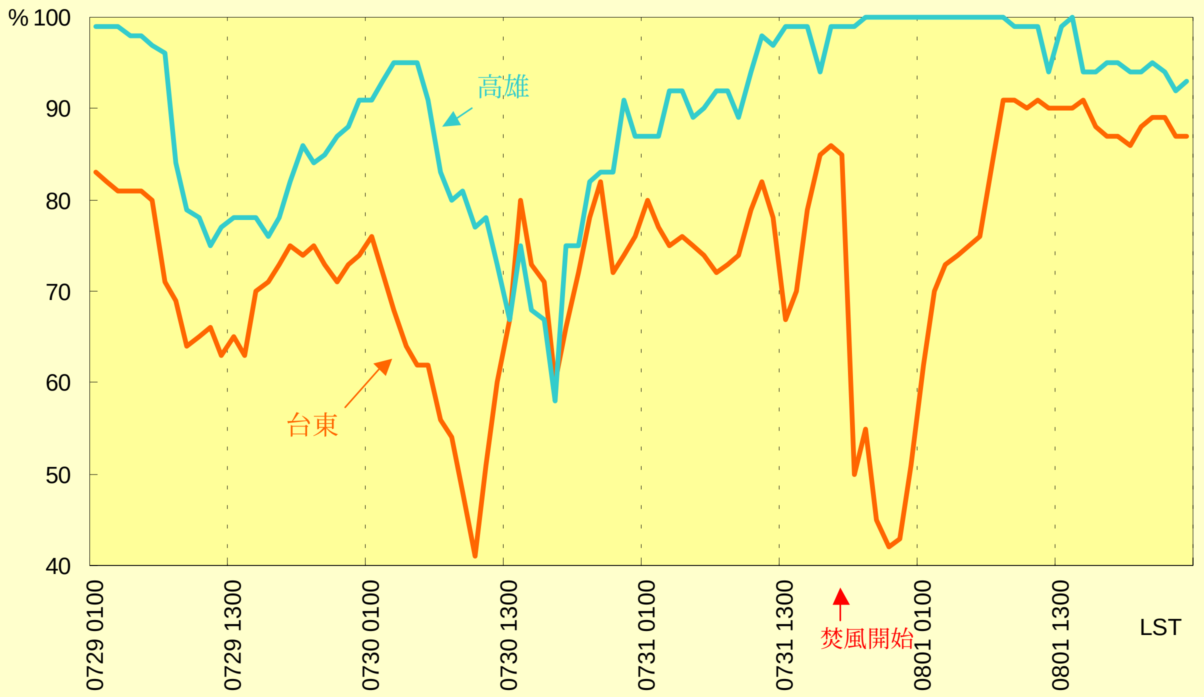
圖一 1996年7月29日至8月1日台東(橘線)與高雄(藍線)之氣壓逐時資料曲線

氣溫

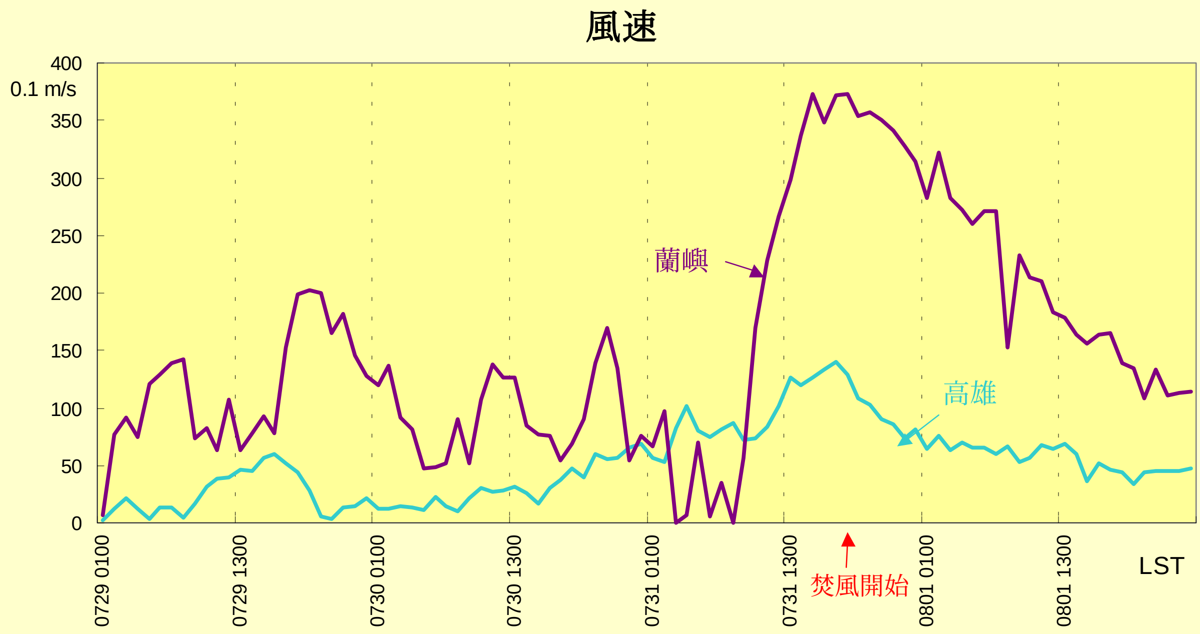


圖二 1996年7月29日至8月1日台東(橘線)與高雄(藍線)之氣溫逐時資料曲線

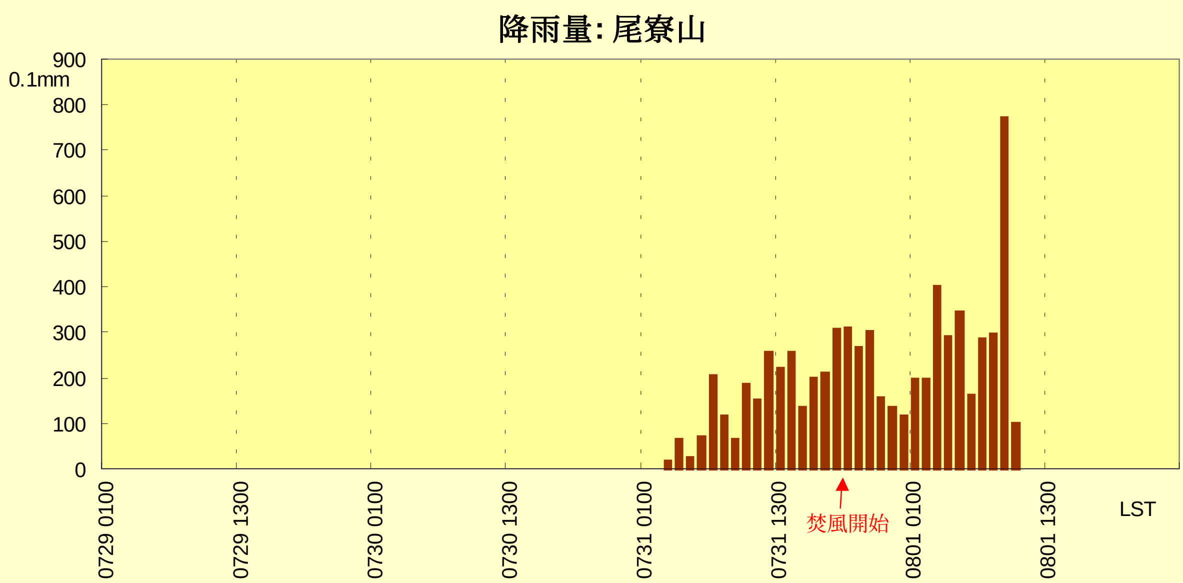
相對溼度



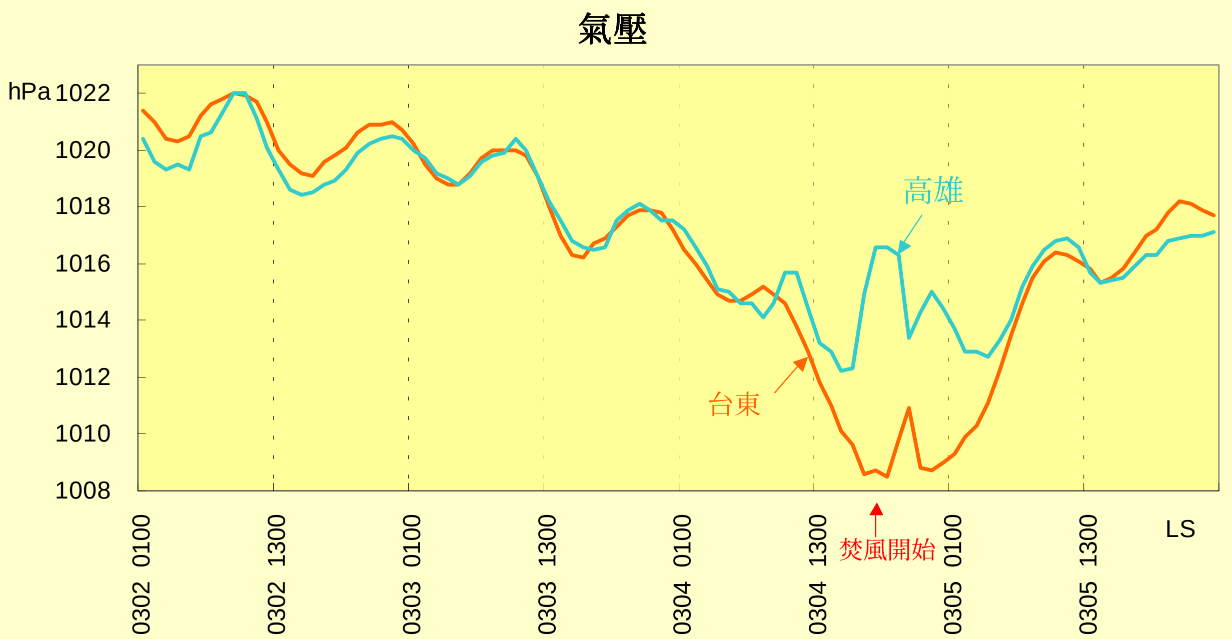
圖三 1996年7月29日至8月1日台東(橘線)與高雄(藍線)之相對溼度逐時資料曲線



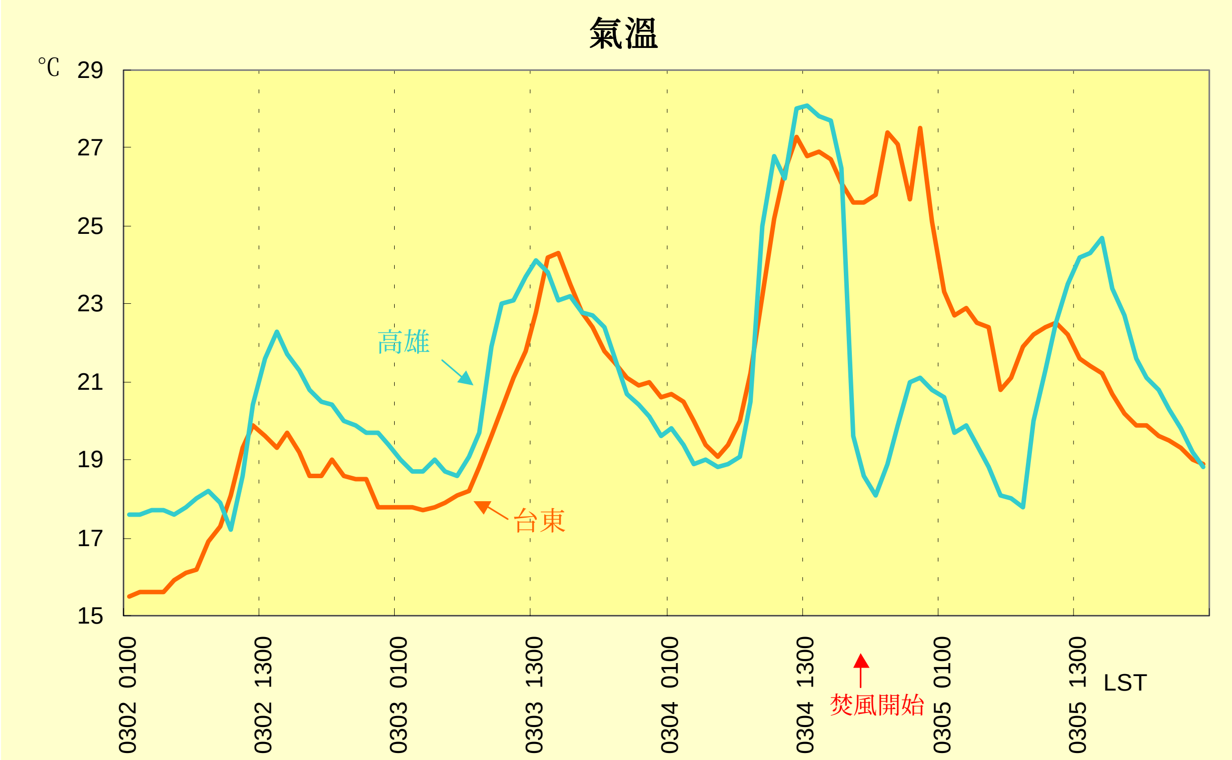
圖四 1996年7月29日至8月1日蘭嶼(紫線)與高雄(藍線)之風速逐時資料曲



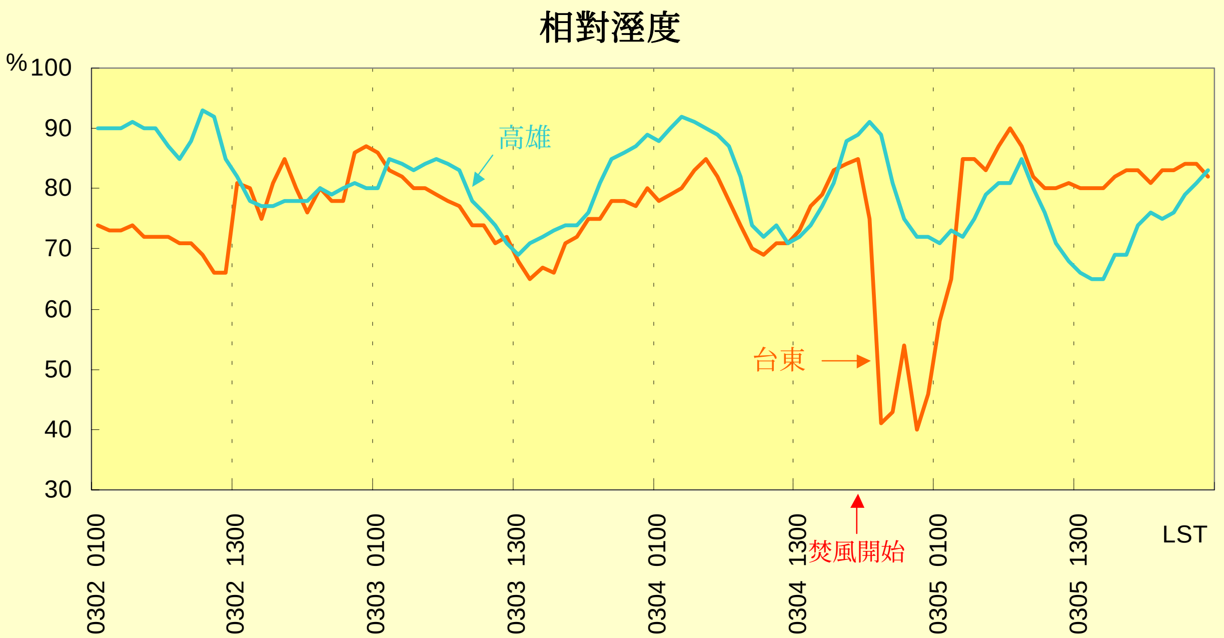
圖五 1996年7月29日至8月1日尾寮山之降雨量逐時資料



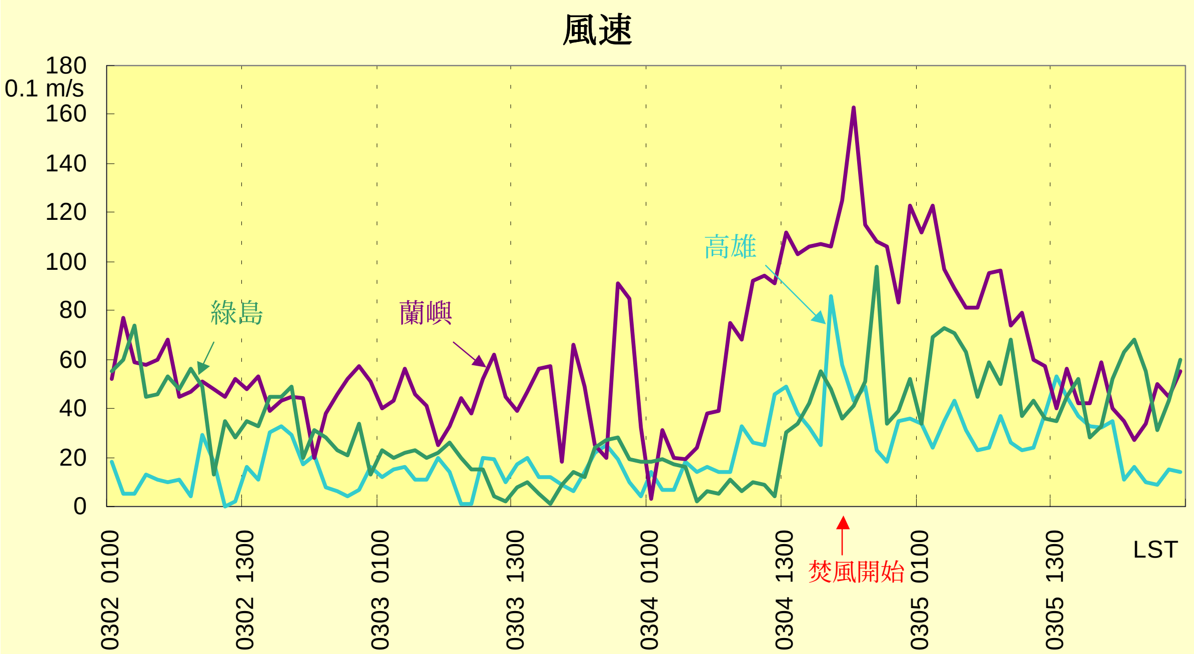
圖六 1998年3月2日至3月5日台東(橘線)與高雄(藍線)之氣壓逐時資料曲線



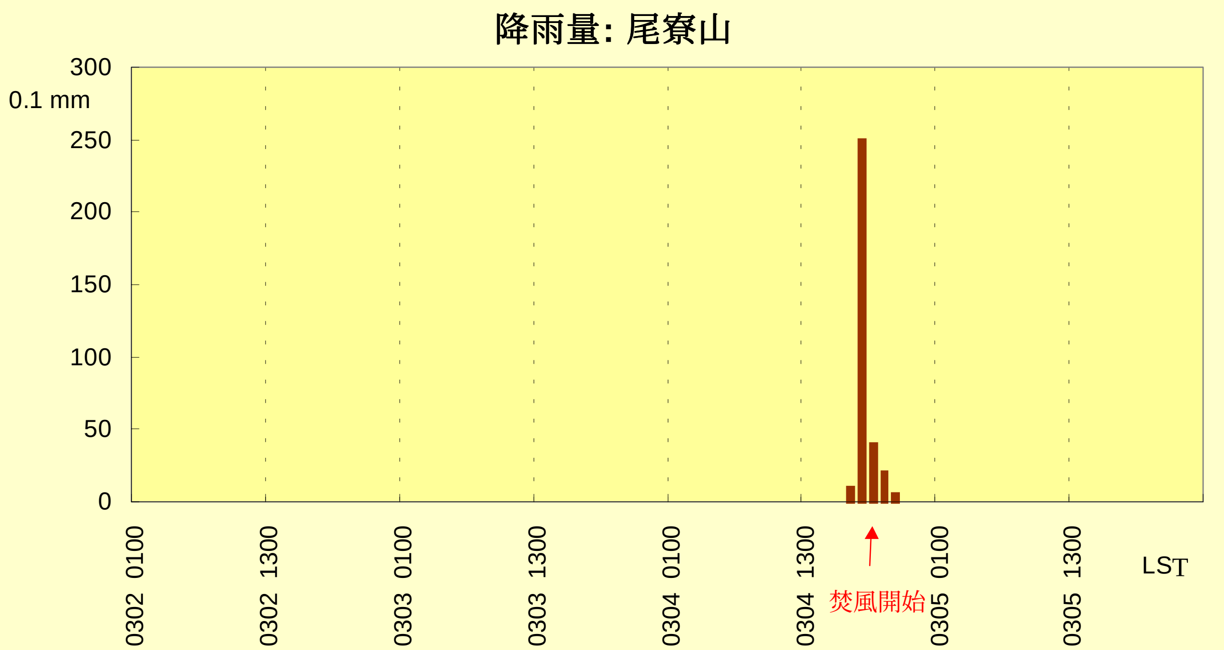
圖七 1998年3月2日至3月5日台東(橘線)與高雄(藍線)之氣溫逐時資料曲線



圖八 1998年3月2日至3月5日台東(橘線)與高雄(藍線)之相對溼度逐時資料曲線



圖九 1998年3月2日至月5日綠島(綠線), 蘭嶼(紫線)與高雄(藍線)之風速逐時資料曲線



圖十 1998年3月2日至3月5日尾寮山之降雨量逐時資料

Foehn in Eastern Taiwan

Introduction

Foehn is a regional warm and dry wind which is a common weather phenomenon in Taiwan. Foehn originates as follows: as the air is forced to rise over the windward mountain slopes, it cools because the pressure decreases and the air expands at higher altitudes. When the air is saturated, water vapor will condense to form cloud and cause precipitation. At the same time, the release of latent heat will occur. As the air flows over the mountain range and descends, it warms because the pressure increases and the air is compressed at lower altitudes. This warming, however, is greater than the cooling that occurred during the ascent because the latent heat was added to the air. Therefore, the leeside air is both warmer and drier than the one on the windward side. (Chou, 1963; Kuo and Young, 1982).

Many farmers fear for Foehn because its strong, dry and warm wind can bring physical injury and dehydration to crops. For example, the Foehn induced by typhoon 'Ike' on 1981 made several thousand hectares of rice field 'whitened' and plundered over NT$100 million (NT$28:US$1) from the farmers. Though we may plant some strong-wind-resistant trees around the fields to protect our crops, only 20-30% of total evaporation is decreased while other ways like avoidance, danger distribution and watering look rather passive. However, how does Foehn make farmers suffer like this? Will they have more time to prepare before the phenomenon occurs if we understand more of it?

Purpose

(1)To analyze and depict the regularity of different meteorological factors before and during the Foehn occurrence in Taitung County, Eastern Taiwan.

(2)Try to develop a rough index from the regularities we discovered to forecast Foehn.

Data Analysis and Procedures

(1)Data Collecting:

1.A report of Foehn occurrences from 1994 to 1998 (by Taiwan Tea Experiment Substation, Luyeh, Taitung)

2.Surface meteorological observation data (including hourly air pressure, air temperature, relative humidity, wind direction, wind speed and precipitation) from 8 stations on the windward west slope of Central Mountain Range in Taiwan and another 9 on the leeward side. The stations on the west are chosen in order to understand what had happened before the air rise over the mountain slope, and the east ones are used to present the characteristics of leeside air.

3.Topographic maps of Taiwan.

4.Asia Pacific surface weather maps and Japan GMS IR satellite imageries from 1994 to 1998 plotted by Central Weather Bureau of Japan (2 maps a day at 00 UTC and 12 UTC before 1996 and 4 maps a day after).

(2)Analysis

1.Classify Foehn cases by different synoptic weather patterns.

2.Analyze the variation of hourly air pressure, air temperature, relative humidity, wind speed and wind direction during the Foehn occurrence. Most the work is operated under Microsoft Excel.

3.Topographic winds are sometimes 180° different from the synoptic wind, so we choose Station Kaohsiung (Southwest Plain), Lanyu and Lutao (isles off the East Coast) to analyze the wind. These 3 stations are all far away from the mountains, so that the wind directions recorded there are out of terrain effect.

Classifying

13 Foehn cases found in Taitung County from 1994 to 1998 were classified with synoptic weather patterns into 2 types: (1) Typhoon Type: there were typhoons moving northward off the East Coast when Foehn occurred (2) Front Type: there was a stationery front or a cold front around East China Sea when Foehn occurred.

1) Typhoon Type

Date	Duration (LST)	Variation Range of Air Temperature (℃)	Variation Range of Relative Humidity (%)	Maximum Wind Speed (m/s)	Name of Typhoon
8/7/94	20-23	23.5-35.9	90-34		Doug
8/21/94	6-12	23-40.5	91-32		Fred
10/10/94	2-14	21-41	96-27		Seth
7/31-8/1/96	19-1	28-34	96-48	27.9	Herb
8/18/97	2-21	26-36.5	88-37	31.9	Winnie
10/16/98	9-17	26-30	93-48	24.5	Zeb

2) Front Type

Date	Duration (LST)	Variation Range of Air Temperature (℃)	Variation Range of Relative Humidity (%)	Maximum Wind Speed (m/s)
4/14/95	6-16	20.5-38	93-34	
3/15/96	2-12	22-39	80-23	11.7
5/7/96	8-16	25-36	92-40	9.7
2/14/98	7-15	19-32.5	78-26	9.6
3/4-5/98	19-10	24-27	78-39	20.4
3/9/98	9-17	25-32.5	92-36	10.6
4/24/98	7-16	24-37.5	95-36	13.9

We named these Foehn cases by the date it happened. For example, Case 073196 referred to the case happened from July 31 to August 1, 1996. For the example of detailed analysis results of air pressure, air temperature, relative humidity, etc, please refer to the last few pages of this report.

Foehn: Typhoon Type

When the Typhoon Type Foehn happened, we found that:

1)The centers of these typhoons all passed through a square area ranged from 120°E to 124°E, 25°N to 28°N. Despite typhoon 'Zeb' that turned northeastward after it encountered the island (Case 101698 will be discussed later in Chapter 7-4), all the other typhoons kept moving northwestward off the East or Southeast Coast. The lowest air pressures of typhoon centers were between 940-970 hPa during the Foehn occurrences.

2)During the Foehn occurrences, the observation of wind speed in Lanyu was 15-25 m/s, showing that Lanyu was right on the edge of the storm center.

3)Air Pressure (Fig. 1): The curves of air pressure variation during the Foehn occurrences look like a 'funnel'. The air pressure in Kaohsiung and other stations over East Coast kept decreasing from 1000-1005 hPa to the lowest point on 'Foehn Day', showing that the typhoons came closer; then it rose gradually, indicating that the typhoons went farther. Foehn was strongest 3 hours before/after the lowest air pressure was observed.

4)Air Temperature (Fig. 2): If foehn started at midnight, the air temperature would increase furiously and get back to the normal at 6 or 7 LST in the morning. There was a sharp peak, sometimes two peaks on the temperature curve. If Foehn began around sunrise and ended in the sunset, the curve would look like a Mayan pyramid. There was no obvious difference in temperature on both sides of the mountain before Foehn occurred, but the daily temperature variation in windward stations was not so obvious on Foehn Day as compared to normal days.

5)Relative Humidity (Fig. 3): The variation of relative humidity was opposite to air temperature. Relative humidity in Taitung and Tawu fell dramatically and maintained the minimum until its increase several hours later (there were not enough data to show when the relative humidity came back to normal in Tawu in Case 082194 and 101094).

6)Wind Speed (Fig. 4): Wind speed in Kaohsiung began to soar 12 hours before the Foehn occurrences. It is difficult to determine exactly the time when wind speed in Lanyu and Lutao started to rise, but the highest wind speed was almost four times stronger than the lowest.

7)Wind Direction: Wind direction became more predictable over plain or isle stations 6 hours before the occurrences; mostly it started as north or north-northeast wind, then turned counterclockwise gradually, and one or two hours later, the foehn occurred. We can prove that the wind crossed over the Central Mountain Range through an counterclockwise path with this phenomenon discovered. In the locale, there was an unstable period before the standard wind direction of foehn came. Air temperature and relative humidity responded immediately if wind direction or speed suddenly changed.

8)Precipitation (Fig. 5): There were rainfall records in most stations on the west slope of Central Mountain Range before the Foehn occurrences.

Foehn: Front Type

1)

Case	Synoptic weather pattern during the Foehn occurrences
041495	Stationery front and cold front on East China Sea, the center of Pacific high pressure field north-east of the island
031596	Stationery front on East China Sea, the center of Pacific high pressure field east of the island
050796	The center of low pressure field southeast of Japan, cold front extended southwestward
021498	Stationery front south of East China Sea, strong Pacific high pressure field
030498	Cold front passing through Taiwan, temperate zone cyclone near Ryukyu Islands
030998	Three center high pressure field in the south of Japan, on East China Sea and over Canton, stationery front parallel to Southeast Coast of Mainland China, Pacific high pressure field very far away
042498	Stationery front on East China Sea, Pacific high pressure field very far away

2)Air Pressure (Fig. 6): There was a diurnal variation in air pressure (highest at 8-11 LST and 21-23 LST, lowest point at 3-5 and 15-18 LST). When Foehn occurred, the highest point and the lowest point fell 5-6 hPa in average, and the latter usually reduced more than the former.

1)Air Temperature (Fig. 7): There was also a notable daily variation in air temperature. It reached the lowest point around dawn, and reached the highest around 14 or 15 LST. However, air temperature rose gradually before the Foehn occurrences; the difference between the maximum and minimum temperatures on Foehn Day was 65% higher than average in normal days.

2)Relative Humidity (Fig. 8): The highest value was before sunrise and the lowest was at 14-16 LST. We found some local relative humidity characteristics very interesting: the curves of Taitung look just like funnels, decreasing fast and increasing fast, but those in Tawu take a lot more time to recover. Terrain effect may play some role, but we need more study to proof it.

3)Wind Speed (Fig. 9): Wind speed doubled or trebled in Kaohsiung and Lutao 4-6 hours before the Foehn occurrences, but it trebled or quadrupled surprisingly in Lanyu even earlier.

4)Wind Direction: The wind became fairly stable 12 hours or earlier before the Foehn occurrences. Several hours (depending on how fast the front moving) after the foehn was over, the wind turned to north or northeast in a short time.

5)Precipitation (Fig. 10): There were rainfall records in most stations on the west slope of Central Mountain Range before the Foehn occurrences.

Discussion: Typhoon Type

1)Cyclonic storm has winds spinning counterclockwise about its center in the Northern Hemisphere, so if the typhoon center located near East China Sea, the high westerly or southwesterly surface winds could climb over the Central Mountain Range, descend in Eastern Taiwan and cause foehn.

2)According to the definition of tropical cyclone, the range of 940-970 hPa means ‘mild to strong moderate typhoons.’ If the path of typhoon fits the one narrated in Chapter 5-1 but its circulation is too weak to cross over the Central Mountain Range, Foehn will not happen; but if the circulation is too strong, it will rain both in western (windward) and eastern (leeward) slope of Central Mountain Range, and Foehn will not happen either.

3)The locales were usually 300 km away from the center of typhoon, while the storm radius of wind speed of 30kt (15m/s) was also around 300 km. It is believed that foehn often took place on the edge of the typhoons where the air sank.

4)Typhoon ‘Zeb’ is quite a weirdo among all the six cases of the type, no matter the path, the intensity or the storm radius. Zeb was formed near the Philippines, weakened and turned northward after it hit Luzon. He changed his direction again to north-northeast when moving along Taitung‘s coastline. Keeping turning eastward, his center came to the ocean northeast of Ilan County in the evening of October 16, 1998, when wind speed in Lanyu marked 7.7m/s in average. The location of Zeb and its shrunk storm circle were just right for inducing foehn in Eastern Taiwan.

5)The reasons why the other typhoons in 1994 to 1998 did not induce foehn in Taitung are unveiled by applying the discoveries above:

Name of Typhoon	Date	Strongest Intensity	Reason
1994			
Tina	7/9-11	L	Crossed over the island and brought precipitation
Yunya	7/19-20	W	Wrong path (too southerly)
Caitlin	8/1-4	W	Crossed over the island and brought precipitation
Gladys	8/30-9/2	M	Probably induced foehn in Tawu, but with not enough evidence
1995			
Deanna	6/5-9	W	Landed in the central part of the island with weak intensity
Gary	7/29-31	W	Wrong path (too westerly)
Helen	8/8-9	W	Wrong path (too southerly)
Janis	8/22-24	W	Path similar to Winnie's, but not strong enough
Kent	8/29-30	M	Wrong path (too southerly)
Ryan	9/21-23	M	Path similar to Zeb's, but with stronger intensity and brought precipitation
1996			
Cam	5/21-24	W	Wrong path (too southerly)
Gloria	7/25-27	M	Induced foehn on the west slope of Central Moun tain Range (not discussed in this study)
Lisa	8/6-7	W	Wrong path (too westerly)
Sally	9/6-8	M	Wrong path (too southerly)
Zane	9/26-29	M	Wrong path (too easterly)
Ernie	11/10-12	W	Wrong path (too southerly)
1997			
Amber	*8/29	M	Crossed over the island and brought precipitation
Cass	*8/30	W	Wrong path (too easterly)
Ivan	*10/21	S	Wrong path (too southerly)
1998			
Nichole	*7/10	W	Wrong path (too westerly)
Otto	*8/4	W	Crossed over the island and brought precipitation
Yanni	*9/28	W	Path similar to Zeb's, but not strong enough
Babs	*10/27	M	Wrong path (too westerly)

P.S. The stars (*) indicate the date when the typhoons invaded or approached Taiwan; other dates mean the life duration of typhoons.

7)The foehn effect expands as the warm and dry airflow moves, so the change of air pressure and relative humidity will first occur in the place that the air reaches earlier. The relative humidity variation order of 'Tawu→Taitung→Chengkung→Hualien' indicates that the wind moving from southwest to northeast.

8)Some stations on the west slope of Central Mountain Range had little or even no precipitation. After referring to the maps, I found that these stations are situated next to the mountain or on the Southwest Plain, where precipitation near the ridge was rather inaccessible. But this does not mean that water vapor did not condense when crossing over the mountain.

Discussion: Front Type

1)Front Type Foehn cases occurred from early spring to early summer (February to June). The cold and dry northeast monsoon in East Asia originates from the northern Asia continent in winter, and the warm and moist southwest monsoon comes from the tropical ocean such as the western Pacific and the South China Sea in summer. During spring to early summer, a transition phase occurs between the north-east and southwest monsoon and a front tends to form between a migratory high in the north and the subtropical high in the south. Taiwan is in the warmer area and has southwest wind blowing before the fronts approach southward. The wind might cross over the Central Mountain Range and induced Foehn. To sum up, if we want a foehn takes place in Taitung County, a front north to Taiwan is necessary. This conclusion is also proved by the surface weather maps.

2)The migratory high kept pushing the front southward and air pressure in Taiwan kept decreasing but the diurnal variation was still found. This phenomenon is a very important index before the Foehn occurrences.

3)The gradual increase of air temperature and decrease of relative humidity probably due to the sustained good weather. The effect of sun radiation heating might multiply due to the good weather, making the heating more and more obvious day by day. As narrated above, this kind of weather was possible because Taiwan was in the warm area before the fronts, and the subtropical high might influence the weather greatly. Besides, variations of various meteorological factors are more apparent in sunny days, especial when there is foehn.

4)Wind is stronger near the frontal zone. Since the fronts were moving southward, the southwest wind in the warm area eventually became strong enough to cross over the Central Mountain Range. Undoubtedly, wind speed in Kaohsiung shot up the earliest; but why did it increase in Lutao later than in Lanyu if Lutao was nearer to Kaohsiung? It is because the air encountered the mountain on its way to Lutao and was delayed. This is another proof of airflow's crossing over the Central Mountain Range.

5)Since there was northeast wind behind the fronts, a sudden change of wind direction was observed when the front passed Taiwan.

6)There was little or no rain on some stations over the west slope of Central Mountain Range. According to the topographic map, these stations are situated next to the mountain or over the Southwest Plain, where precipitation near the ridge was rather inaccessible. But this does not mean that water vapor did not condensed when crossing over the mountain.

Conclusion

1)The 13 Foehn cases found in Taitung County from 1994 to 1998 were classified with synoptic weather patterns into two types: (1) Typhoon Type: there were typhoons moving northward off the East Coast when Foehn occurred; (2) Front Type: there was a stationery front or a cold front around East China Sea when Foehn occurred.

2)When the Typhoon Type Foehn happened, the centers of these typhoons all passed through a square area ranged from 120°E to 124°E, 25°N to 28°N. The lowest air pressures of typhoon centers were between 940-970 hPa during Foehn occurrences and the storm radii of 30kt (15 m/s) were all about 300 km. Foehn usually occurred on the edge of a typhoon.

3)Front Type Foehn cases occurred from early spring to early summer (February to June). During this period, a transition phase occurs between the northeast and southwest monsoon and a front tends to form between a migratory high in the north and the subtropical high in the south. Taiwan was in the warmer area and there was southwest wind blowing before the fronts arrived. Since the fronts were moving southward, the southwest wind in the warmer area eventually became strong enough to cross over the Central Mountain Range and induced Foehn.

4)Wind direction became stable in south to west-southwest before the occurrences while wind speed rose rapidly. As an important index to predict foehn, the air pressure kept decreasing within two days before the occurrences (Typhoon Type) or fell gradually in daily variation (Front Type). The air temperature and the relative humidity changed obviously only during the occurrences. No traceable model for induction was available.

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6)http://lain.atm.ncu.edu.tw

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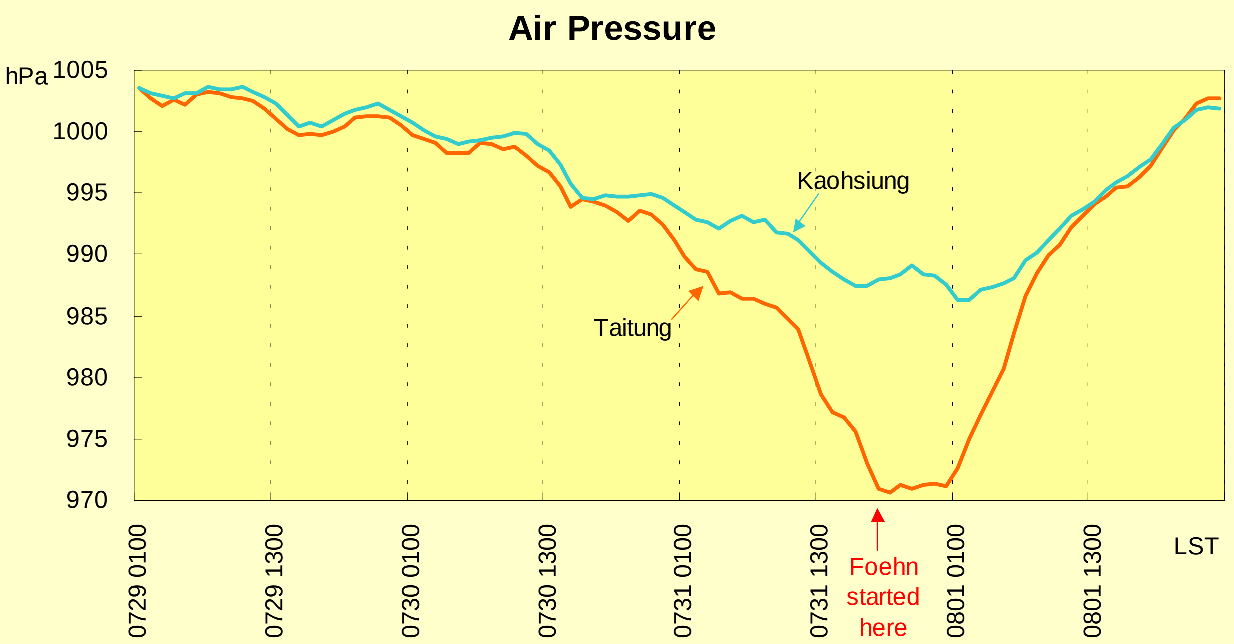

Fig. 1 Time series of surface air pressure at Taitung (orange line) and Kaohsiung (blue line) from July 29 to August 1, 1999

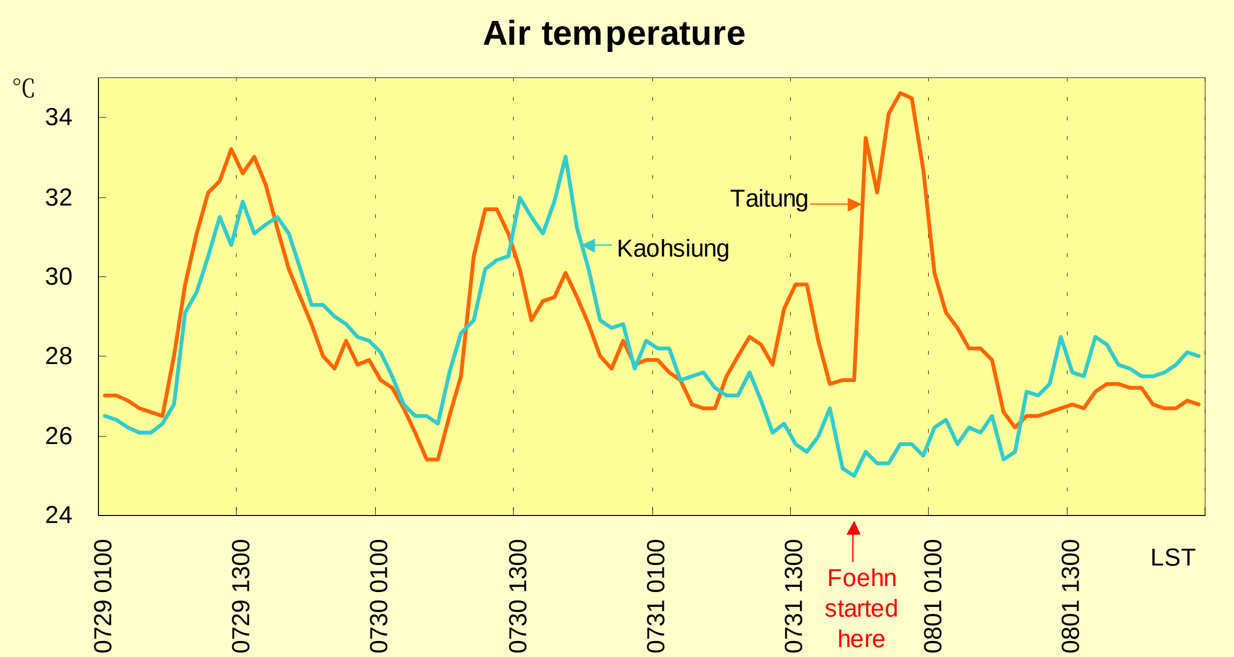

Fig. 2 Time series of surface air temperature at Taitung (orange line) and Kaohsiung (blue line) from July 29 to August 1, 1999

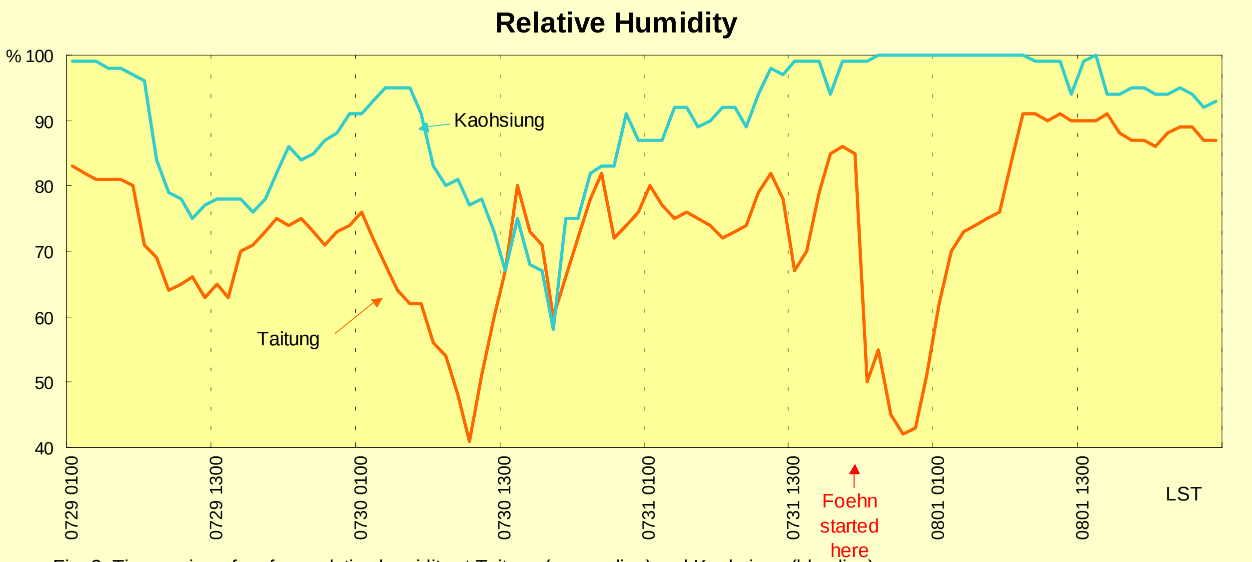

Fig. 3 Time series of surface relative humidity at Taitung (orange line) and Kaohsiung (blue line) from July 29 to August 1, 1999

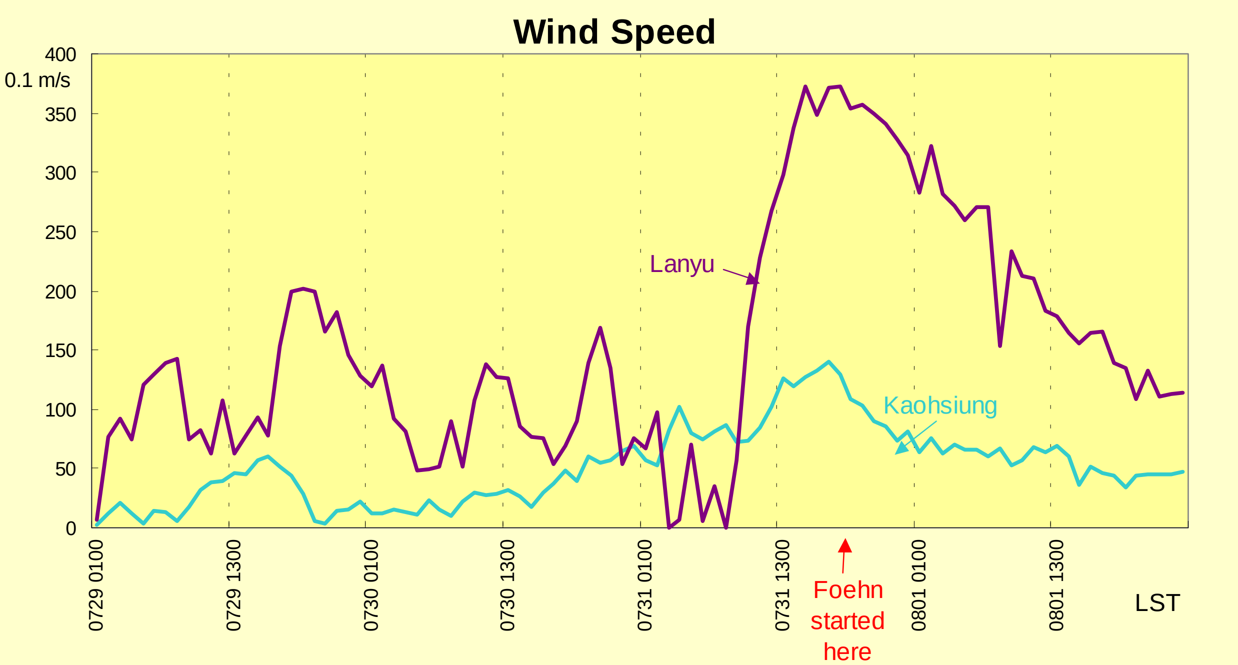

Fig. 4 Time series of surface wind speed at Lanyu (pueple line) and Kaohsiung (blue line) from July 29 to August 1, 1999

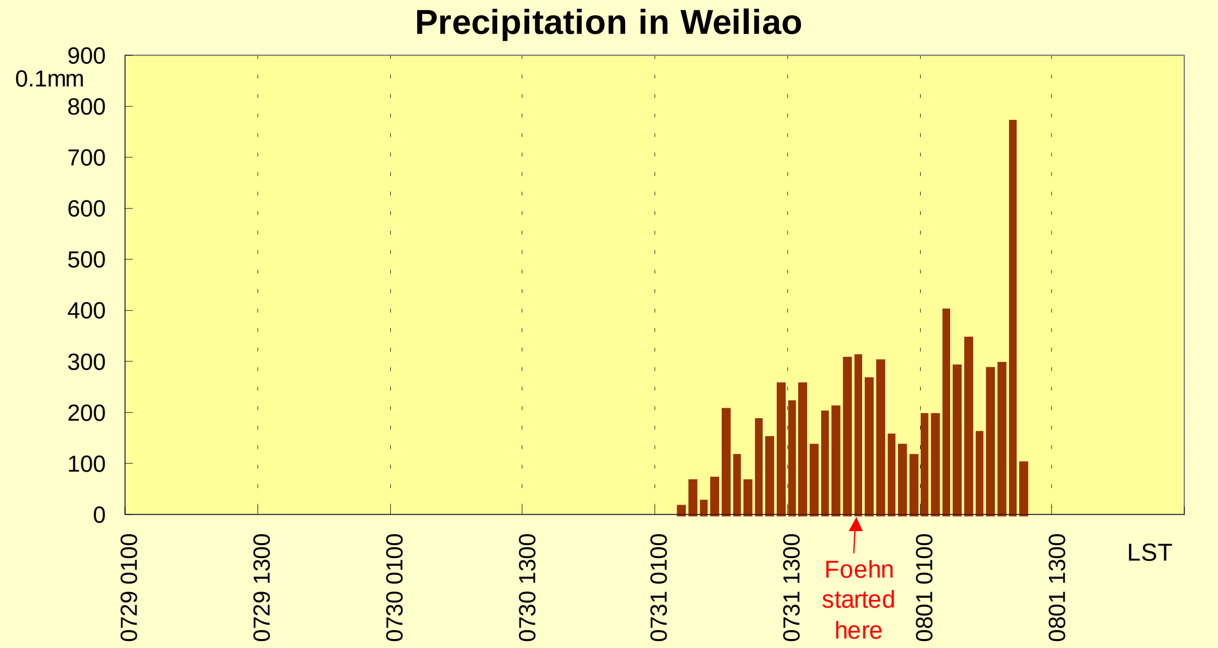

Fig. 5 Time series of precipitation in Weiliao from July 29 to August 1, 1996

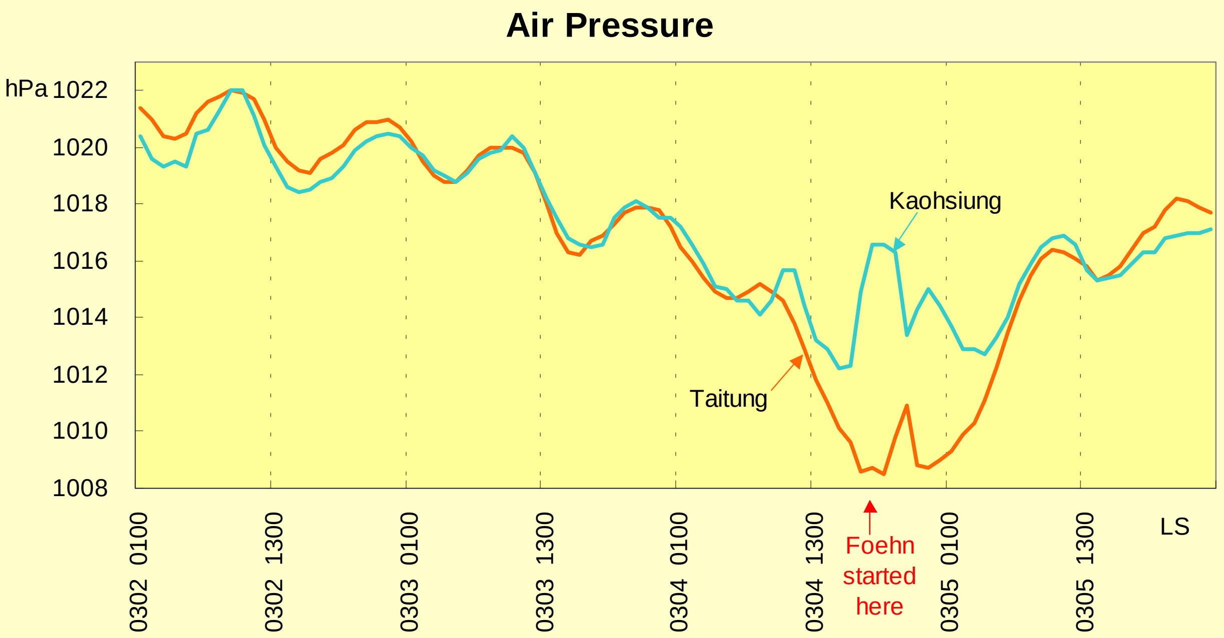

Fig. 6 Time series of surface air pressure in Taitung (orange line) and Kaohsiung (blue line) from March 2 to 5, 1998

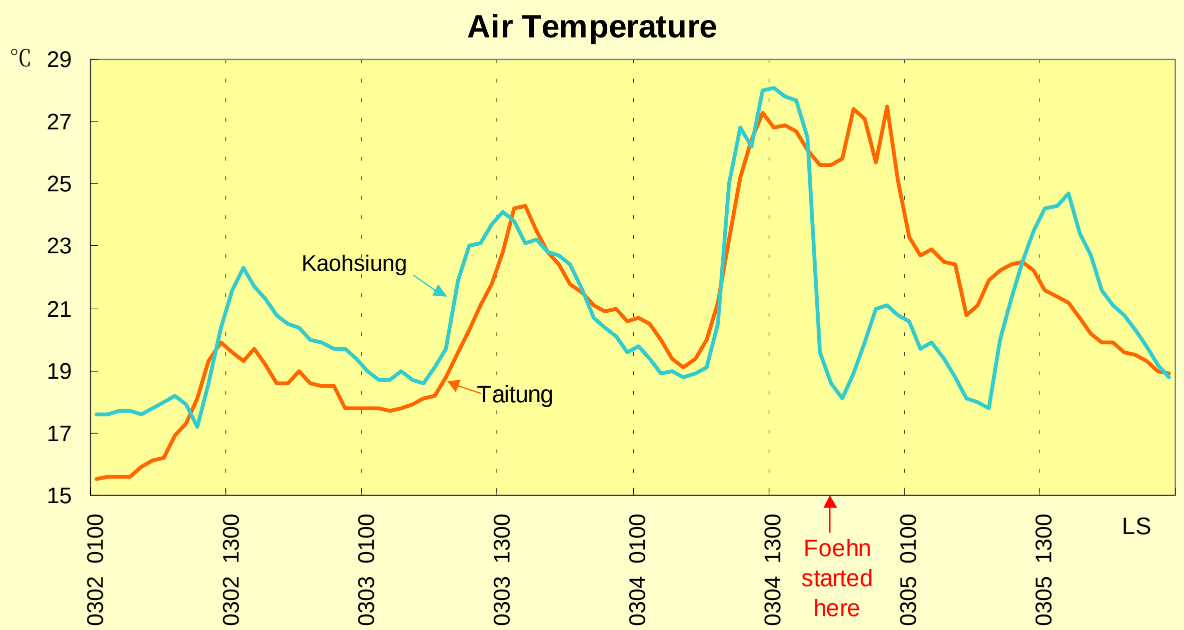

Fig. 7 Time series of surface air temperature in Taitung (orange line) and Kaohsiung (blue line) from March 2 to 5, 1998

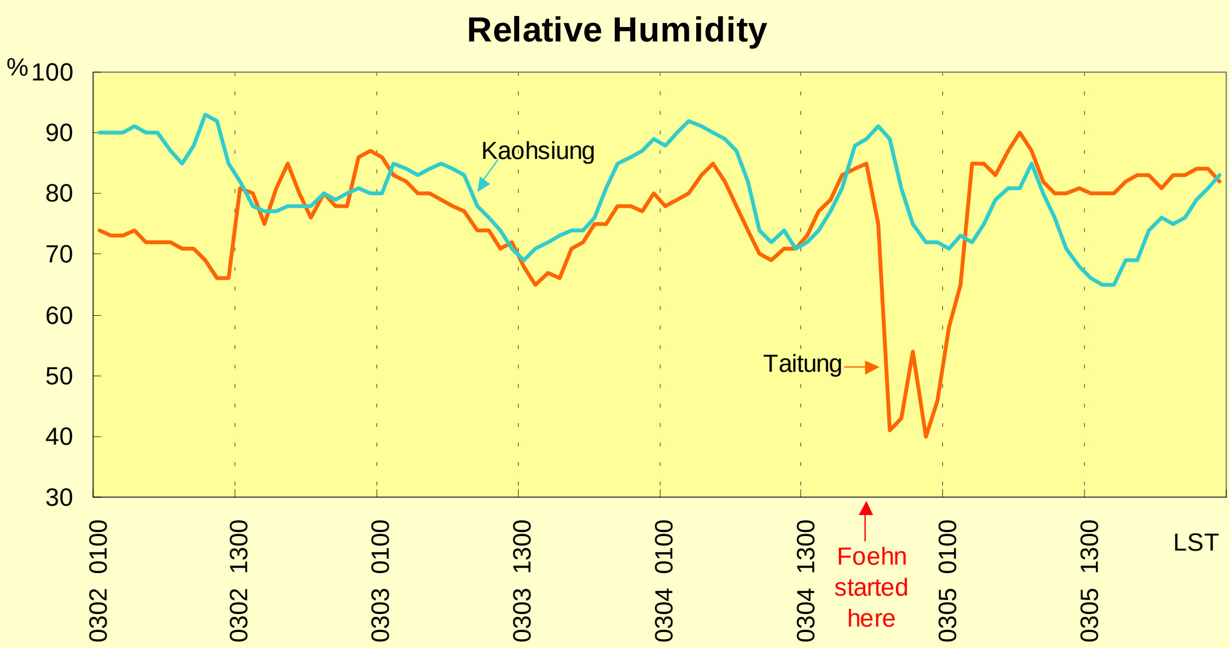

Fig. 8 Time series of surface relative humidity in Taitung (orange line) and Kaohsiung (blue line) from March 2 to 5, 1998

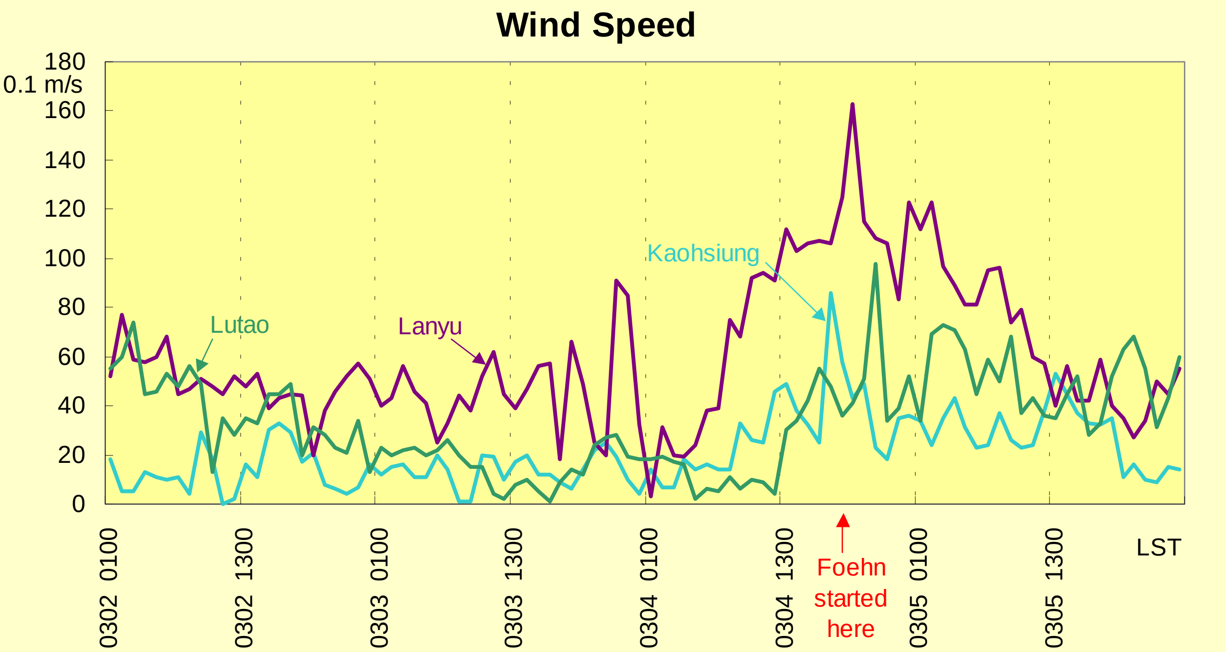

Fig. 9 Time series of surface wind speed in Lanyu (purple line), Lutao (green line) and Kaohsiung (blue line) from March 2 to 5, 1998

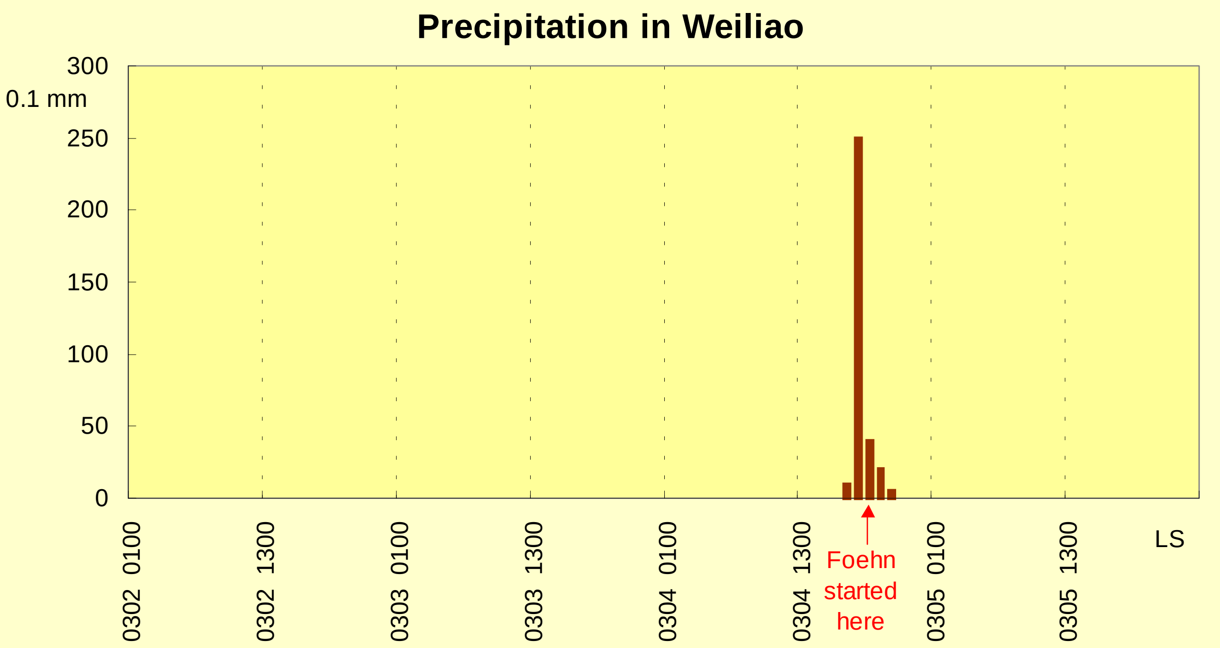

Fig. 10 Time series of precipitation in Weiliao from March 2 to 5, 1998