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利用福衛三號氣溫數據觀測北半球平流層急劇增溫現象

得獎獎項

大會獎：一等獎

美國團隊正選代表：美國第 63 屆國際科技展覽會青少年科學獎

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關鍵字：福爾摩沙衛星三號、平流層急劇增溫現象

作者簡介

王顥蓁

我是王顥蓁，就讀台中女子高級中學三年級。我是個很樂觀的女孩，開心的面對明天，努力的從失敗中站起來，帶著微笑走著我認為適合我的路。我做事很直，一旦我決定一件事就會堅持做完，甚至希望它完美呈現。所以當我發現自己喜歡畫畫，我就跑去上繪畫課；喜歡研究，就順著學校的分組研究課投入。

此次參與國際科展的過程，我覺得每天的自己都在學習，不論先前有過多少不同的經驗，這又是一個新的開始、新的體驗：學習和隊友合作，一同在挫折中成長，學習去包容和自己不一樣的意見和想法，學著去發現自己的盲點然後盡可能的去修正……，雖然有時會因為找不到方向，或被太多瑣事困擾著，但努力經歷那些反而是這個過程中更有意義的收穫。從一開始誤打誤撞踏上這條路，到後來真的知道自己要什麼而追求，過程真的很充實。

最後，要謝謝指導我們的老師，還有總是給我們意見、鼓勵和讚美的教授們，他們的一句話、一句叮嚀總又讓我們充滿動力和力量，繼續向前邁進。

陳韻竹

我是台中女中三年級的陳韻竹。一開始做這份研究，老實說只是因為我和我的夥伴「必須」做出一份作業。在分組研究的過程中，我們也歷經了很多感覺上走不過的瓶頸，甚至從一開始選定的化學組轉到了現在的地球科學組。後來，在我們選定了「福爾摩沙衛星三號」之後，目標漸漸明朗，這個新興的科技讓我們見識到現在太空氣候觀測早已有了一個嶄新的、開闊的局面，也使我和我的夥伴一頭栽入這份研究報告之中。

如果說科展讓我們學習到最多的經驗，那必然是與夥伴的合作和互相包容，以及該怎麼把原本破破爛爛的報告書寫的完整、寫的能登「大雅之堂」。科展的體驗是一般高中生不會有的經驗，所以我很榮幸、也很慶幸自己能有這個機會，找一個能互相幫忙、討論研究的夥伴，一起完成一份從「零」開始的研究。沒有教科書、沒有考古題，更沒有「範本」，真正去探索一個全新的領域，是既新鮮又極富趣味的。可以說做科展是超出我升上高中前的「預設行程」，但同時也是我高中生活美麗的一頁。

最後，感謝一路上支持我的家人、老師還有很熱心的教授，以及在科展路上曾經助我一臂之力的所有人。

摘要

出於對溫度在人類的生活圈和地球各高度多樣的好奇,我們在本研究中,利用福衛三號的大氣溫度資料分析「北半球平流層急劇增溫現象(SSW)」這個特殊現象,發現:此現象明顯出現在冬末春初;高度方面,低空較不易觀察,而 30 公里以上高空受影響的程度較大;緯度方面,北緯 40 度以南的地區在 SSW 發生時降溫,幅度較小,而北緯 40 度以北升溫,幅度隨緯度增加而漸大。

同時,我們比較西元 2006 年~2010 年的資料,試著探討海陸差異和週期性,雖然海陸沒有顯著成果,但我們發現 SSW 在西元 2009 年為近年來高峰,且有類似週期性的變化;另外,我們也近一步對南半球做延伸探討,希望得到更完整的資訊。

經由此研究,我們不但更了解 SSW,也更確信福衛三號在未來極有可能成為新興的氣候變化觀測依據。

Abstract

Out of curiosity about temperature’s variety around the globe and the atmosphere, we used data from Formosa-Ⅲ to observe a special phenomenon which is entitled “Sudden Stratosphere Warming”. To begin with, we discovered that it obviously appears during late winter and early spring. In the aspect of altitude, it seems much easier to measure the unusual temperature increase above 30 kilometers in the atmosphere than below. As for the aspect of latitude, temperatures in the areas below 40˚N vary from those above, with the former decreasing slightly, and the latter increasing rapidly.

Meanwhile, we compared the data from 2006 to 2010 with one another, attempting to figure out the difference between sea and land, and also find out the cycle of SSW. However, we did not find concrete proof to the sea-land difference, but to our excitement, we found out that 2009 seems to be the most serious SSW year, and that SSW tends to form a half cycle within these years. Moreover, we took the Southern Hemisphere into discussion, and hope we get more complete data of it.

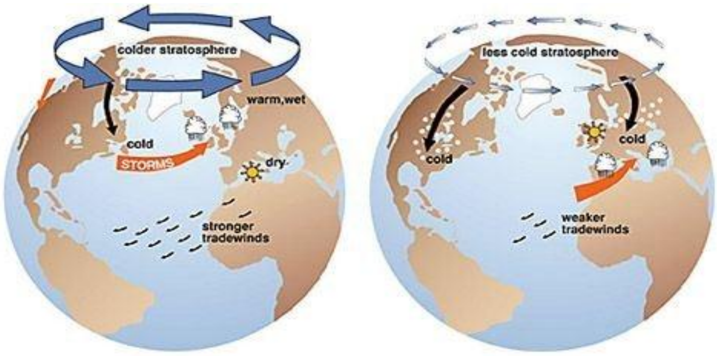
Through this project, we not only understand SSW more but also believe that the resource of our data, Formosa-Ⅲ, will play an important role in the future of climate observation.

壹、研究動機

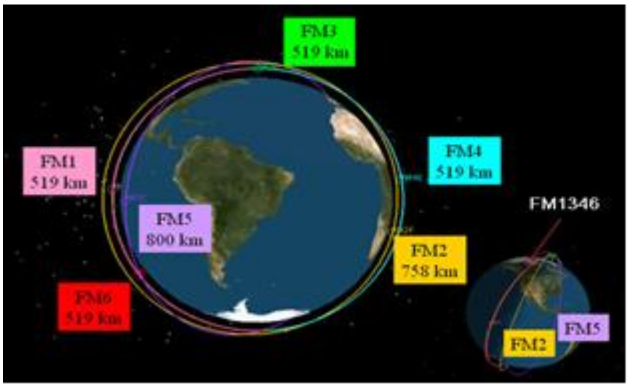
自古以來，劇烈的氣候變遷和自然災害總會造成生命財產損失，也對環境造成相當的破壞，尤其近年來的氣候異常，不只人類，生活在地球上各角落的動物亦受到波及，嚴重者甚至瀕臨絕種，因此科學家便致力於相關研究，希望能藉由對各個特殊機制和現象的進一步了解，達到預防或警報的作用。

西元 2010 年 2 月及 12 月，台灣經歷了幾次寒流，讓身處亞熱帶且不斷被告知溫室效應極為嚴重的我們對近年來溫度急劇變動感到不解，也同時對整個大氣的多樣性和一些例外的現象感到訝異和好奇。在高中地球科學課探討氣候變遷及大氣分層時，曾經提到一種特殊氣候現象稱為「北極震盪(Arctic oscillation，以下簡稱 AO)」,它導致了中低緯度嚴寒的冬天,影響我們所居住的對流層,因為好奇，我們更深入的去查資料,得知國家地理雜誌曾對 AO 之氣候特徵做一個相關報導，其中指出 AO 主要強調北半球高緯區的氣壓變動關係：當低壓強時，北極極地渦漩（Polar Vortex）變強，限制了極區的冷空氣向南吹，造成北美大陸產生暖冬之現象，而其他北半球地區也較往常溫度為高，此時稱之為「正相位時期」亦或是「暖相位時期」；反之，當低壓減弱，其四周的環流也跟著減弱，造成原本聚集在極圈的冷空氣向中低緯區擴散，使中、低緯度氣溫驟降，則 AO 呈「負相位（冷相位）時期」。從該專欄中，我們得知 AO 主要探討的是氣壓變動下地球上環流與溫度的相互關係，因此研究的一開始，我們想以溫度為觀察依據的角度切入此議題，並試圖觀察北半球在溫度方面的變動關係。但是當我們做出一系列北緯 60~90 度全年溫度曲線圖後，發現在對流層(低空)並沒有很明顯、規律的溫度起伏依據，故我們猜想應是觀測數據受到地面影響過大，但是意外地，我們發現平流層在年初有相對劇烈且異常的溫度振盪現象，因此我們更近一步針對此現象查資料，發現這個特殊的氣溫變動在學術上一般稱為「平流層急劇增溫現象(Sudden Stratosphere Warming, SSW)」。資料中也顯示，近年來 SSW 的出現頻率異常頻繁，在高緯區的異常現象尤為明顯：北緯 80~90 度極圈中心 30 公里高空的溫度比北緯 60 度為高。雖說 SSW 和 AO 似乎在某種程度上關係密切，但至今很少有人將 SSW 與 AO 的現象合併討論。

於是我們希望能針對這個發生在平流層的溫度急劇變動現象(SSW)做更進一步的研究，了解它影響高低緯區具體的時間及季節，並觀察 SSW 是否和 AO 一樣，在緯度方面也有類似的氣候變動關係，並且推展至北極震盪討論中較少出現的低緯度地區，觀察低緯是否也受 SSW 的影響。



圖（一）SSW 示意圖



圖（二）福衛三號運作示意圖

為了找尋適合探討 AO 及 SSW 的氣候觀測資料，我們搜尋了眾多觀測系統，最後選擇可以涵蓋全球大範圍海陸氣溫數據的福爾摩沙衛星三號。由於福衛相較其他觀測系統而言，得到的數據點分布較平均，較不受人為無法觀測等因素影響，且它提供的範圍、區域極為廣大，這種全球大範圍平均的氣溫數據，正適合我們用來研究北半球大範圍氣候變化及週期較長的北極震盪，於是我們選用福衛氣溫資料作為研究的來源，來探討近年來氣候震盪情形及其週期性。

一般而言，SSW、AO 主要影響的氣候特徵包括時間尺度和空間分布，在本次研究中，我們主要針對時間尺度與溫度震盪幅度進行探討，在週期方面將 SSW 與 AO 做初步的比較，雖然相關研究對 AO 的時間尺度認知上是屬於十年週期，而我們的資料收集僅自西元 2006 年～西元 2010 年共五年的時間(約莫半個週期)，我們仍希望能經由福衛資料的分析研究，檢視此研究方法的可行性，提供未來深入發展所需。

貳、研究目的

一、利用福衛三號大氣溫度分層資料探討西元 2006~2010 年期間，同緯度地區不同高度大氣溫度受「平流層急遽增溫現象 SSW」影響之變化，並挑選適當高度提供下述研究。

二、利用福衛三號西元 2006~2010 年間的資料，將 5 年曲線重疊於同一圖表，畫出 5 年大氣溫度隨時間的變化之曲線，討論不同年間，相同高度、不同緯度高低溫度震盪幅度變化情形，並找出各年間的曲線是否有週期性。

三、討論 SSW 影響之大氣溫度的震盪幅度是否因海、陸性質差異而有不同。

四、做出臭氧濃度依季節變化的曲線圖，並觀察其濃度是否與 SSW 有相關性。

五、以相同的作法做出南極的溫度曲線圖，觀察南半球溫度變化是否與北半球的 SSW 有相關；此外，結合北半球的增溫現象做熱對流探討。

參、研究設備及器材

一、福爾摩沙衛星三號：(以下簡稱福衛三號)

福衛三號於西元 2006 年 4 月 15 日從美國發射，為國家太空中心「第一期國家太空科技計畫」的第三個衛星。此計畫中一共發射了六顆微衛星，分別分佈於地球表面 700~800 公里高度之不同軌道中，並圍繞著地球運轉，組成涵蓋全球的低軌道微衛星星系來接收美國 24 顆全球定位衛星(GPS)所發出的訊號，提供全球大範圍、不分海陸即時的溫度資料。

二、使用軟體：Microsoft Excel、Microsoft Word、Matlab

肆、研究方法

一、利用 Matlab 將大氣溫度資料切割，選取其中北緯 60~90 度各高度的數據，作出溫度曲線變化圖，並用 Excel 將大氣溫度震幅量化，選取適宜觀察的高度範圍。

二、其次，把不同年間北緯 0~90 度的數據以每 10 度一個區間(依 0~10 度、20~30 度 … 80~90 度)，與選定的高度範圍，分別整理成大氣溫度震幅表格並作圖，可同時觀察大氣溫度震幅受高度的變化和緯度變化之影響。

三、以 Matlab 切割北緯 30~40^{o}、40~50^{o}、50~60^{o}、60~70^{o}、70~80^{o}、80~90^{o} 的海、陸範圍，作出西元 2006~2010 年全年以每日為單位重疊而成的大氣溫度變化曲線，並作出中位數，和第一、第三四分位數與前者相疊，藉此觀察海、陸性質差異對大氣溫度的影響。

四、做出臭氧濃度依季節變化的曲線圖，與先前的全年氣溫變化圖進行比照，觀察臭氧濃度是否與 SSW 有相關性。

五、用上述步驟(一)、(二)的方法，做出南緯 60~90^{o} 大氣溫度變化圖，並觀察是否在相同季節也有類似的增溫現象；此外，集中觀察西元 2009 年的大氣溫度變化，將南半球的高空大氣溫度以每 10 度緯度切割，觀察南半球大氣層是否有熱空氣的水平移動現象，以探討全地球表面的熱對流系統。

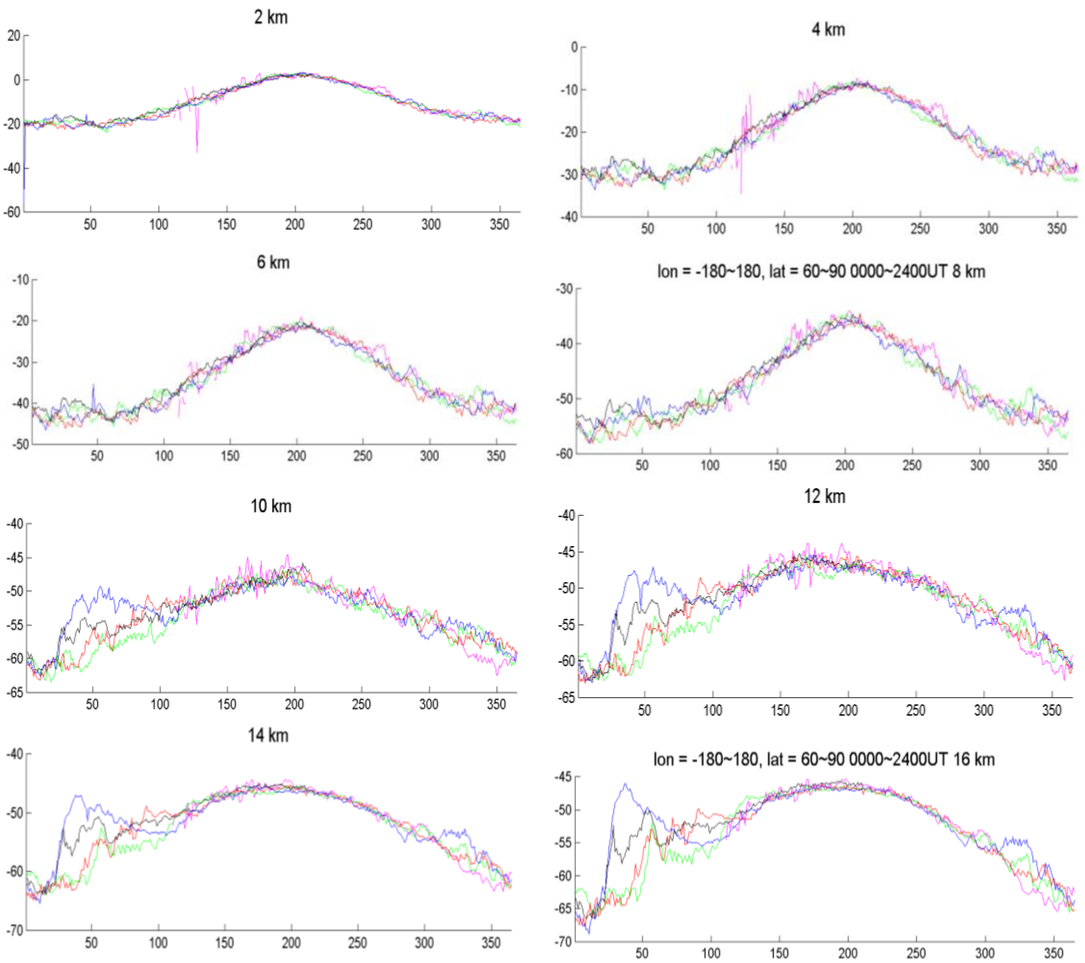
伍、研究過程與結果

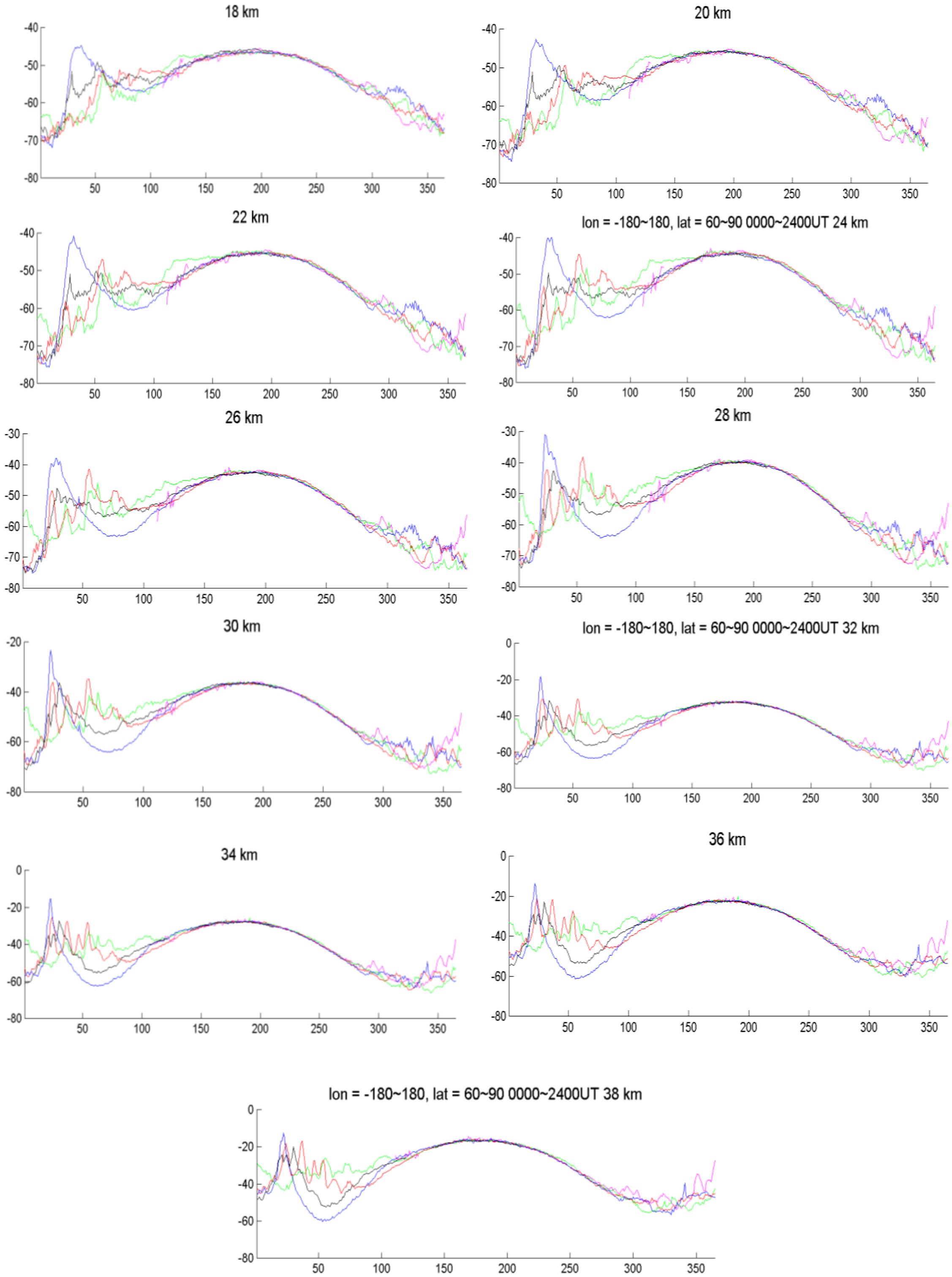
由於福衛是近年來發射的新興衛星，其資料僅包含西元 2006~2010 年共五年的數據，雖不足以涵蓋一般氣象科學中所提到的北極震盪 10 年週期，但我們嘗試在這五年中觀察有無類似北極震盪和平流層急劇增溫的相關現象。

一、北半球同一緯度地區，不同高度之氣溫觀察

我們試圖找出溫度變化最明顯的高度範圍，作為研究不同緯度時的固定高度。於是我們將西元 2006~2010 年北緯 60~90^{o} 依不同高度的逐日溫度變化作圖，得到結果如圖（三）所示：

其中桃紅線表 06 年、螢光綠線表 07 年、紅線表 08 年、藍線表 09 年、黑線表 10 年





圖（三）大氣溫度在西元 2006~2010 年各高度的年變化圖
範圍：北半球經度±180、北緯 60~90 度／時間：24hrs

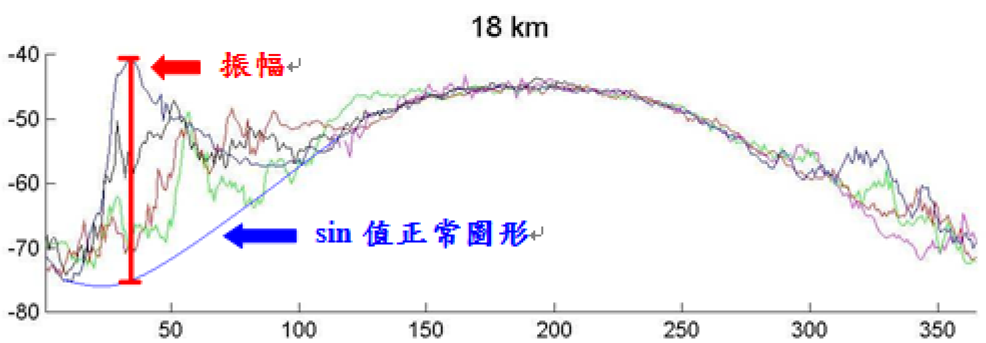
根據圖（三），我們發現不論夏季或冬季，低空溫度皆不穩定，我們推測在高度 2 至 12 公里間可能是因其地形、地表輻射、海陸比熱等因素干擾而使溫度變化不穩定，故較不易觀察增溫現象；而高度 14 公里以上

增溫現象漸為明顯，正屬於我們所研究的「平流層急劇增溫現象」的觀測範圍。

另外，我們觀察了夏季以及冬季的差異。若以春分(約第 80 天)和秋分(約第 264 天)為界線，可明顯看出夏季溫度的變化較冬季穩定，如夏至前後(約第 172 天)的四年溫度曲線幾乎重疊；相較於夏季，冬季可明顯看出受平流層急劇增溫現象(SSW)的影響而有大幅度增溫，若再將冬季以冬至(約第 355 天)為分界細分為秋末冬初和冬末春初，可經觀察得知在秋末冬初大氣溫度開始輕微的震盪，而溫度急遽上升達到最高峰值多在冬末春初之時，也就是 355 天之後，到隔年 80 天前，若以西元 2009 年（即溫度上升最為明顯的一年）為例，其溫度曲線在西元 2008 年年終開始振盪，而高峰固定出現在第 20 至第 50 天之間。

因為太陽輻射給地球的熱量在無其他外力考量下，影響地球呈現的溫度變化曲線應為正弦函數(sinθ 曲線)，故我們接著算出各高度的溫度最高點與 sin 值正常圖形的溫度位置之溫度差得其振幅，由於在圖（三）中可看出 2 至 12km 的溫度起伏較不穩定，故我們僅取平流層以上（約 14 公里至 38 公里）高空作數據量化；而且由於福衛是在西元 2006 年 4 月發射的衛星，故我們在作圖時發現圖中並沒有西元 2006 年前 120 天的溫度曲線，因此在以下數據整理及作圖中我們僅選取西元 2007 年到西元 2010 年為振幅觀測對象。

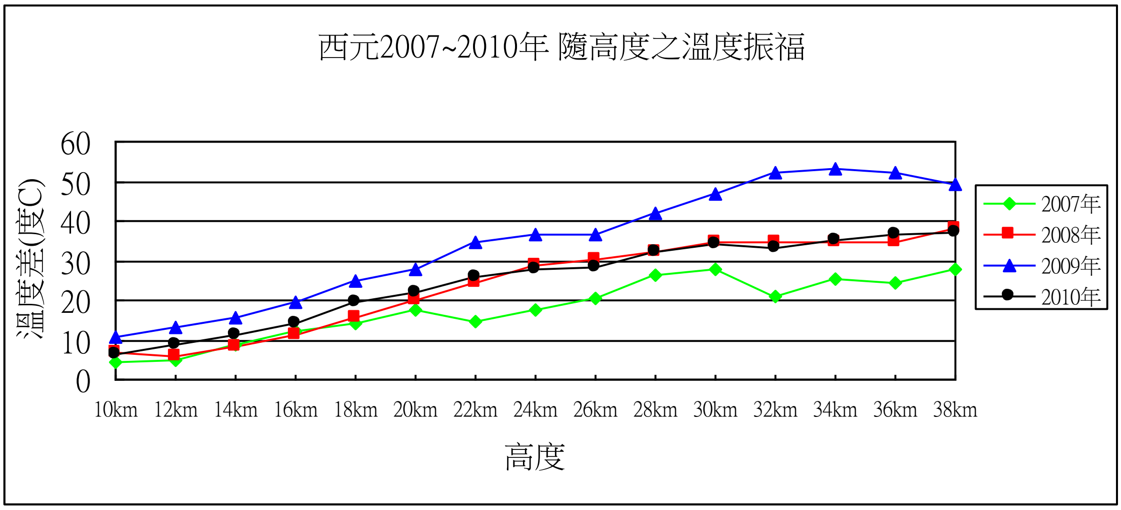
溫度振幅取得的方式以 18km 高度為例，如下圖（四），並整理成表（一）。



圖（四）溫度振幅取得的作圖方式（以高度 18 公里為例）

表（一）西元 2007~2010 年各高度及其溫度振福比較表

高度 年	14	16	18	20	22	24	26	28	30	32	34	36	38
2007	8.70	11.97	14.35	17.58	14.86	17.54	20.41	26.37	27.60	21.01	25.21	24.28	27.61
2008	8.39	11.18	15.50	19.85	24.40	28.99	30.05	32.14	34.50	34.75	34.62	34.69	37.88
2009	15.44	19.67	25.07	27.69	34.86	36.38	36.70	42.11	46.92	51.98	53.06	52.39	49.20
2010	6.48	8.87	11.08	14.06	19.62	22.02	25.87	27.72	28.10	32.36	34.22	32.93	35.13



圖（五）西元 2007~2010 年，北緯 60~90 度，高度及其溫度振幅折線圖

由表（一）及圖（五）中可看出 30km 以上高空為 SSW 造成溫度變化較明顯的範圍，因此，我們選擇 30~38km 範圍的溫度作為以下研究之依據。

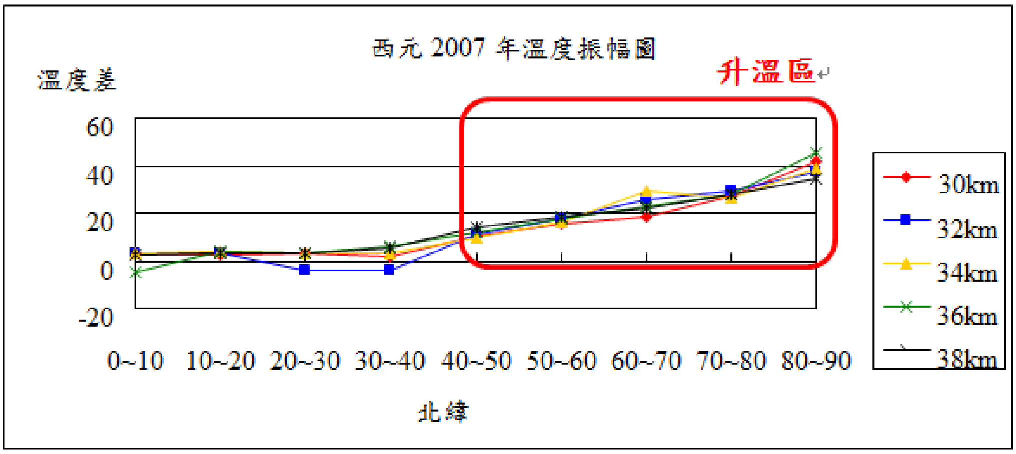
二、北半球同一高度範圍、不同緯度區間氣溫震盪幅度觀察：

接著，我們分別取西元 2007~2010 年、30~38km 高空範圍的數據，探討北半球各緯度地區受北極震盪影響之大小，依年份不同而作 4 張圖。

數據取得方式如上圖（四）所示，並將資料整理成表（二）～表（五）。

表（二）西元 2007 年，不同緯度、30 到 38 公里溫度振幅比較表 (溫度單位:℃)

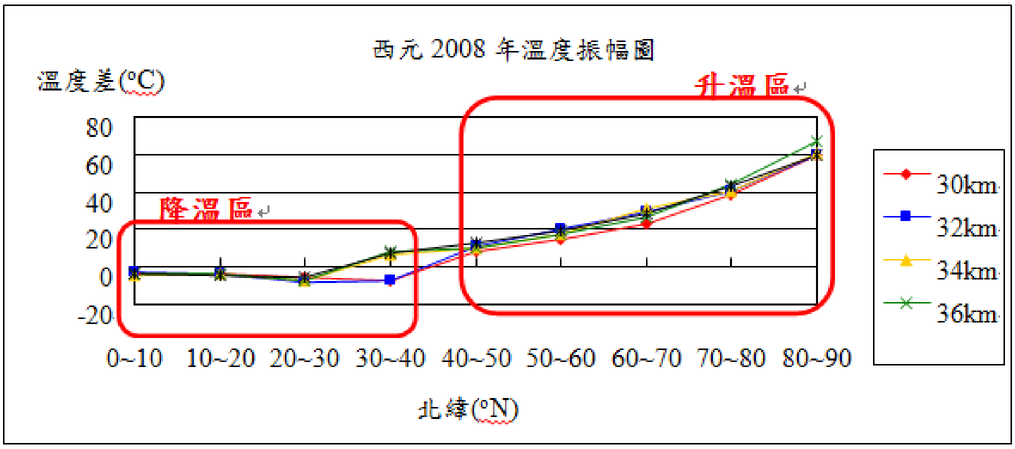
北緯(^{o}N)	0~10	10~20	20~30	30~40	40~50	50~60	60~70	70~80	80~90
30km	2.94	2.77	3.15	2.12	10.31	15.64	18.39	27.56	42.04
32km	3.405	3.44	-4.18	-3.97	11.60	17.63	25.73	29.45	37.78
34km	3.12	4.21	3.43	3.00	9.86	16.24	29.19	26.37	38.59
36km	-4.43	4.30	3.13	5.90	12.00	17.48	23.14	27.73	45.55
38km	2.66	2.93	3.58	5.23	13.87	18.67	22.52	28.34	34.80



圖（六）西元 2007 年，不同緯度 30~38 公里溫度變化

表（三）西元 2008 年，不同緯度、30 到 38 公里溫度振幅比較表 (溫度單位:℃)

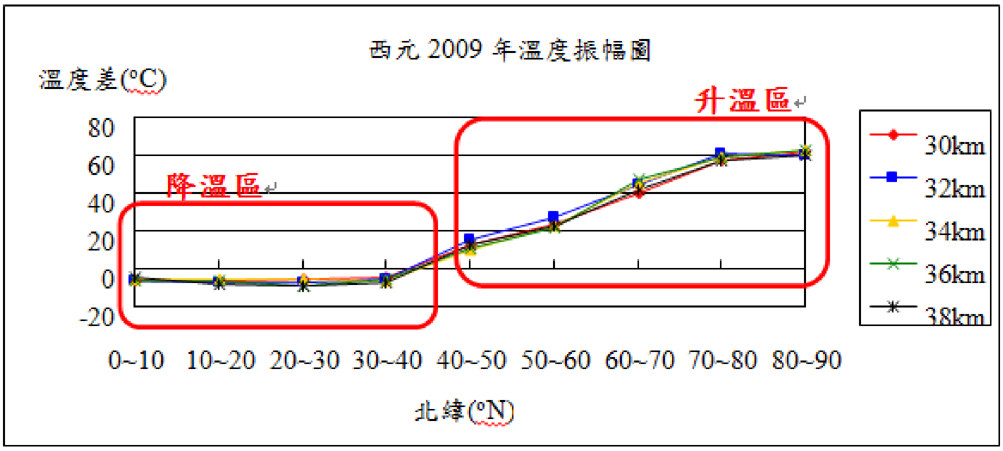
北緯(°N)	0~10	10~20	20~30	30~40	40~50	50~60	60~70	70~80	80~90
30km	-3.42	-3.19	-5.49	-6.82	8.12	15.32	23.10	39.02	59.39
32km	-2.70	-3.36	-7.79	-6.98	10.98	20.25	29.44	40.18	59.78
34km	-4.56	-3.59	-6.77	7.00	10.23	18.02	31.04	40.62	60.33
36km	-3.89	-3.64	-7.60	8.56	10.72	17.31	27.05	44.31	66.78
38km	-3.58	-4.67	-5.16	7.724	13.15	19.29	28.78	43.05	59.91



圖（七）西元 2008 年，不同緯度 30~38 公里溫度變化

表（四）西元 2009 年，不同緯度、30 到 38 公里溫度振幅比較表 (溫度單位:°C)

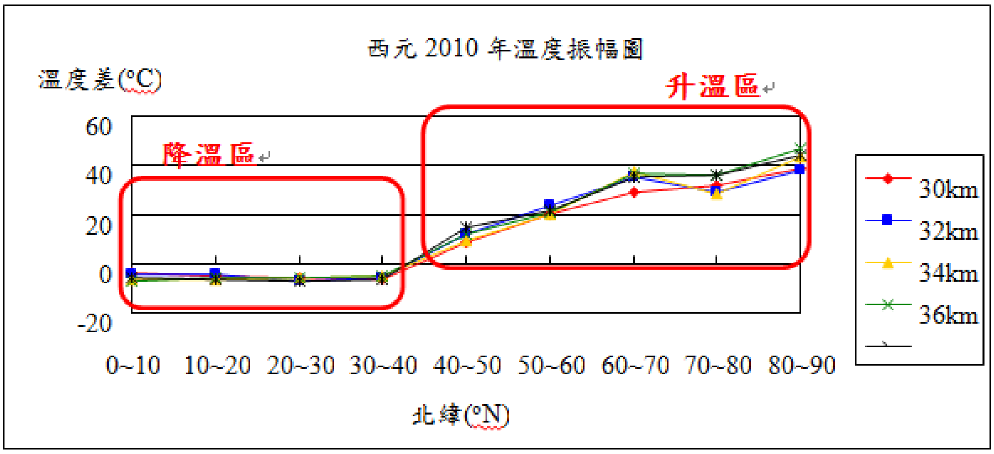
北緯(°N)	0~10	10~20	20~30	30~40	40~50	50~60	60~70	70~80	80~90
30km	-6.58	-6.54	-5.65	-4.18	12.35	23.95	39.61	57.27	61.63
32km	-6.49	-6.96	-7.46	-5.75	15.19	27.32	44.72	61.27	60.09
34km	-5.61	-5.38	-5.65	-6.2	10.23	23.10	45.82	59.51	62.58
36km	-6.26	-6.79	-8.70	-5.64	10.72	21.68	47.25	59.20	62.69
38km	-4.56	-8.40	-8.86	-7.42	12.34	22.51	42.00	57.40	67.84



圖（八）西元 2009 年，不同緯度 30~38 公里溫度變化

表（五）西元 2009 年，不同緯度、30 到 38 公里溫度振幅比較表 (溫度單位:℃)

北緯(ºN)	0~10	10~20	20~30	30~40	40~50	50~60	60~70	70~80	80~90
30km	-3.68	-4.97	-5.47	-6.18	8.469	20.04	29.47	32.21	38.57
32km	-4.40	-4.24	-7.21	-5.89	11.95	23.69	35.54	29.45	38.22
34km	-6.16	-6.43	-5.40	-4.9	9.49	20.56	37.32	28.86	43.47
36km	-7.13	-5.76	-5.88	-5.00	12.32	20.84	36.82	35.86	47.18
38km	-5.37	-6.26	-7.32	-6.20	14.75	21.58	35.07	35.87	44.05



圖（九）西元 2010 年，不同緯度 30~38 公里溫度變化

由表（二）～表（五）及圖（六）～圖（九）可知，高緯區受 SSW 影響，極圈環流減弱、冷空氣外流，故有增溫現象，且緯度越高，增溫幅度越大（如圖中的升溫區）；北緯 40 度以南的中低緯區則受北極震盪影響而降溫，而且溫度下降的幅度約莫在攝氏 10 度以內（如圖中的降溫區）。相較於高緯區的增溫現象，低緯區的溫度起伏較平緩。

觀察以上四年的溫度變化圖可得知，不論是哪一年，北緯 80~90 度的溫度差皆為最高值。另外較特殊的是，2009 年在北緯 70~80 度的溫度振幅比其他年高許多，其中 2009 年的溫度振幅比 2007 年高出 111.3%、比 2008 年高出 42.2%、比 2010 年高出 81.6%，大約比 2007~2010 四年平均值高出 46.7%。

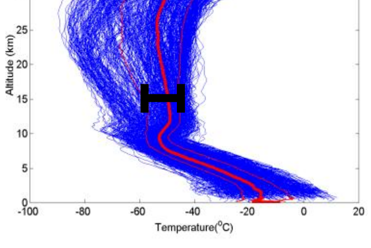
三、探討海、陸性質差異對上空大氣溫度造成的影響：

首先，我們試著以寬經度 10 度、長緯度 5 度切割出北半球不同緯度的海、陸區塊，取高度 2 公里到 38 公里的大氣溫度震盪幅度，作為以下氣溫數據選取的基準：自下頁開始，左側世界地圖為範圍選取的示意圖。

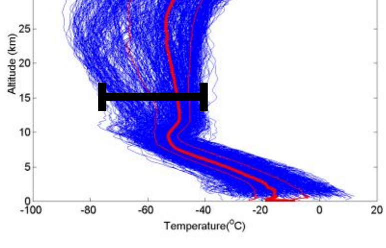
接著，我們利用 Matlab 依照不同區塊做出西元 2006~2010 年每日的溫度隨高度的變化圖，可得五年之每日溫度變化趨勢：自下頁開始，右側曲線圖表之。氣溫圖中，中央紅色粗線為中位數(50%)、左細紅線為第一四分位數(前 25%)、右細紅線為第三四分位數(後 25%)。

我們再以相同緯度，海、陸的第一及第三四分位數之間距，取出五年間平均溫度變化的範圍，依照不同緯度作圖，如圖（十六）、（二十四）、（三十二）、（三十八）、（四十八）、（五十六）；另外，同時以同緯度海、陸最高及最低溫差值，取出溫度變化極端值，依照不同緯度作圖，如圖（十七）、（二十五）、（三十三）、（三十七）、（四十九）、（五十七）。

作圖方法如下圖（十）、圖（十一）所示，以北緯 80~82.5 度的格陵蘭島氣溫圖，取高度 15km 溫度振幅作範例。



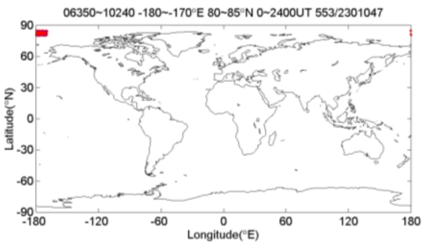
圖（十）、第一及第三四分位數溫度振幅測量



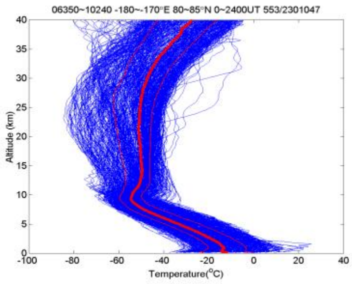
圖（十一）、極端值溫度振幅測量

（一）、北緯 80~85°N 溫度圖

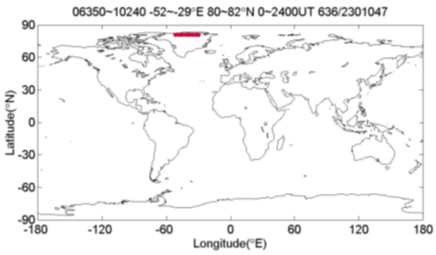
此緯區原先我們試著以寬經度 10 度、長緯度 5 度選取北半球 80~85 度的海、陸區塊，但切割後發現北緯 83 度以北缺乏陸地區塊，故僅取長緯度 2.5 度(即北緯 80~82.5 度)、寬經度 23 度的區間統計五年氣溫曲線。



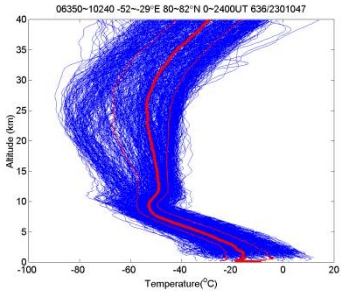
圖（十二）、太平洋觀測點選取



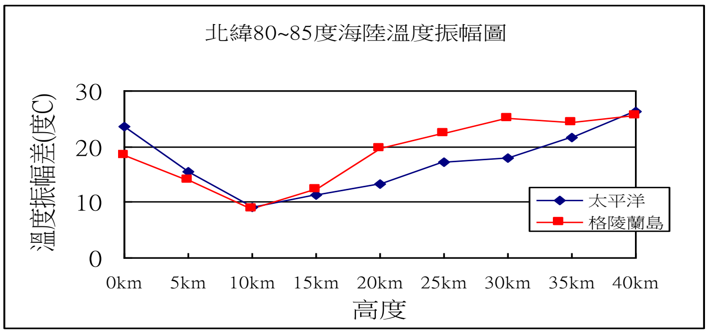
圖（十三）、太平洋氣溫圖



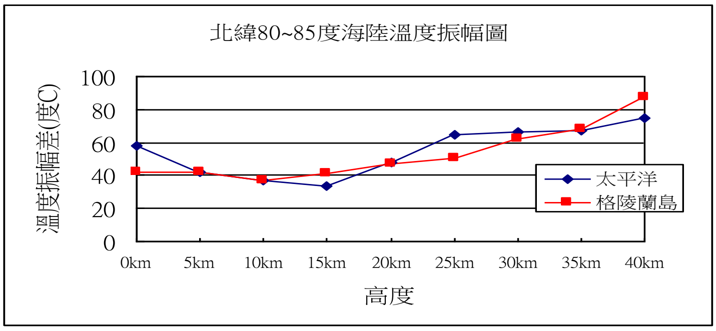
圖（十四）、格陵蘭島觀測點選取



圖（十五）、格陵蘭島氣溫圖



圖（十六）、西元 2006~2010 年、北緯 80~85 度，第一與第三四分位數的溫度震幅差作圖



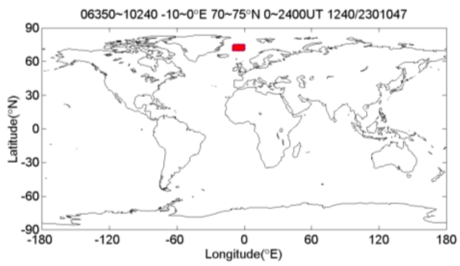
圖（十七）、西元 2006~2010 年、北緯 80~85 度，高低溫極端值的溫度震幅差作圖

由圖（十六），發現海、陸皆在高度 10 公里處達到溫度差的最小值，且當測量的高度範圍大於 10 公里時，陸地的溫度震幅差漸超越海洋，代表在北緯 80~85 度、10 公里以上的高空，就平均溫度而言，陸地是相對的不穩定。

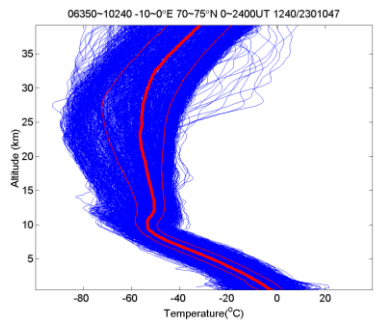
接著由圖（十七）也同樣可看出海陸在高度 10~15 公里處有較小的溫度震幅，正說明了高度 10~15 公里實為大氣中溫度較穩定的地區；但當高度達 20 公里以上，雖然海、陸的極端溫度震幅差皆有日益增大的趨勢，但自圖（十七）中看不出明顯的海陸差異。

（二）、北緯 70~75^{o}N 溫度圖

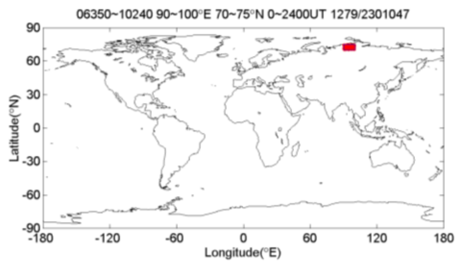
當我們把緯度範圍拉到北緯 70~75 度，可選取的陸地區塊增加，故我們在本次作圖中加入俄羅斯區塊一同觀察，目的是為確認相同緯度、不同經度範圍，是否會對陸地性質造成大幅度差異。



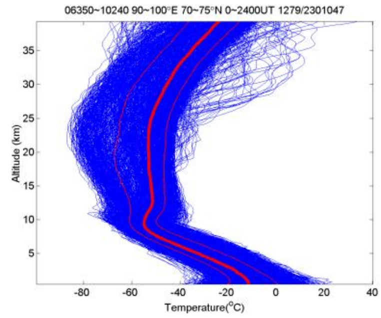
圖（十八）、大西洋觀測點選取



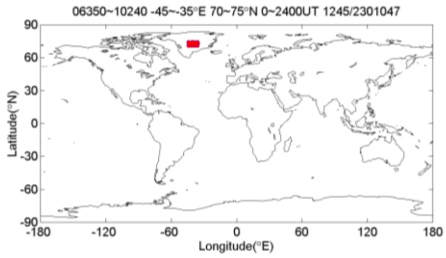
圖（十九）、大西洋氣溫圖

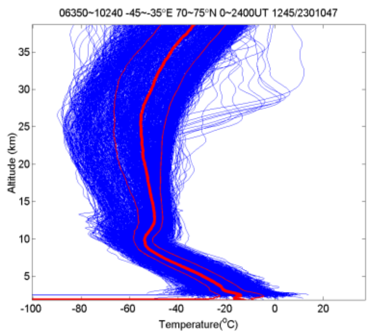


圖（二十）、俄羅斯觀測點選取

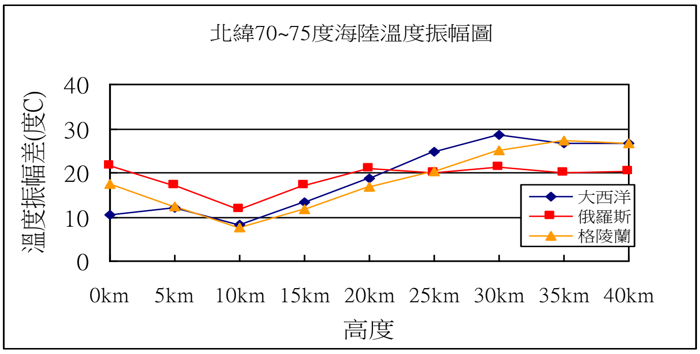


圖（二十一）、俄羅斯氣溫圖

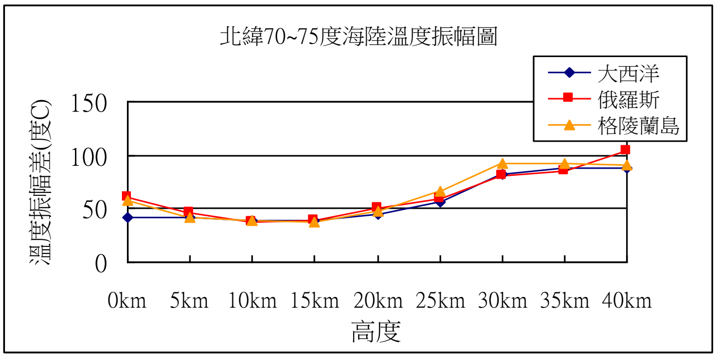




圖（二十二）、格陵蘭島觀測點選取　　圖（二十三）、格陵蘭島氣溫圖



圖（二十四）、西元 2006~2010 年、北緯 70~75 度，第一與第三四分位數的溫度差作圖

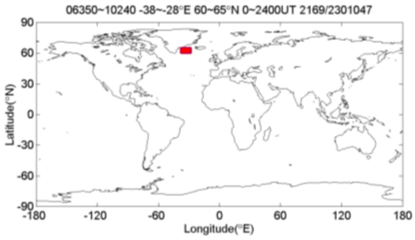


圖（二十五）、西元 2006~2010 年、北緯 70~75 度，高低溫極端值的溫度差作圖

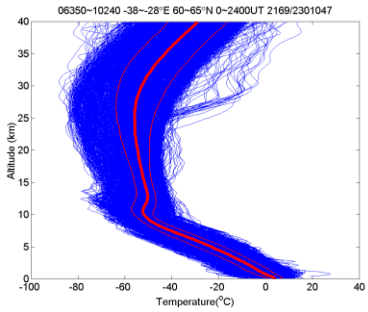
由圖（二十四）可看出平均溫度震幅差的最小值仍在高度 10 公里處。另外，我們自圖中亦可看出，雖然在高度 20 公里以下，兩個陸地區塊的溫度振幅差曲線略有同步現象，但兩者仍然相差了 5 度左右；而當高度上升至 25 公里以上，兩條曲線更加不穩定，因此能得知即使選取同一緯度的陸地區塊，兩者在溫度振幅差上仍有相當大的不同。

同樣地，由圖（二十五）也可看出在高度 5 公里以下，海的極端溫度振幅遠小於陸地；但高度 10 公里以上，海、陸差異則不明顯。

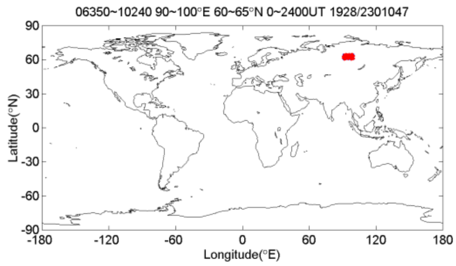
（三）、北緯 60~65^{o}N 溫度圖



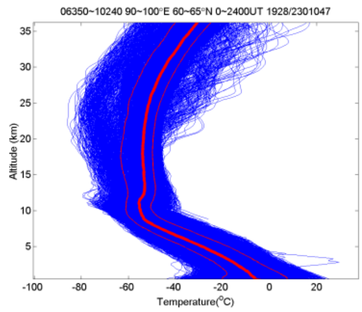
圖（二十六）、大西洋觀測點選取



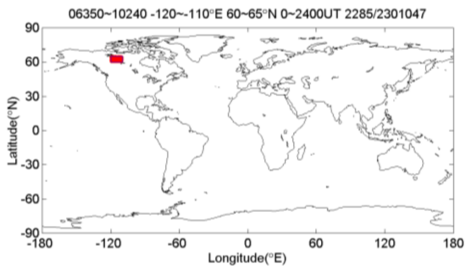
圖（二十七）、大西洋氣溫圖



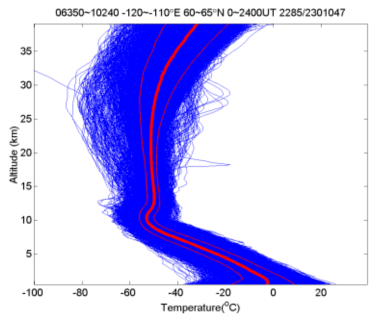
圖（二十八）、俄羅斯觀測點選取



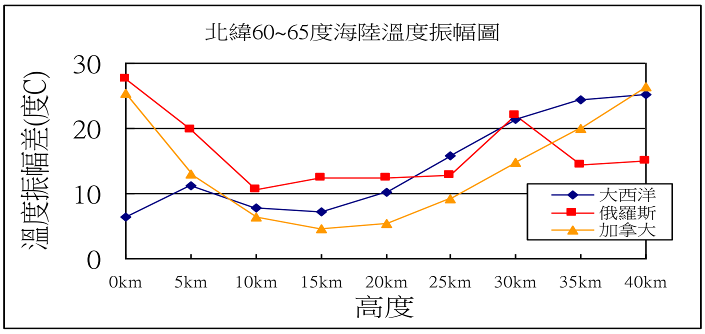
圖（二十九）、俄羅斯氣溫圖



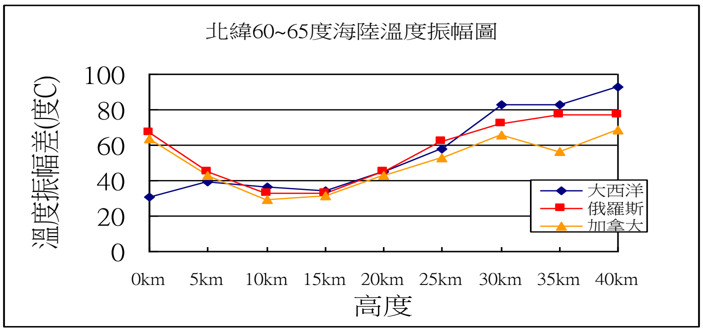
圖（三十）、加拿大觀測點選取



圖（三十一）、加拿大氣溫圖



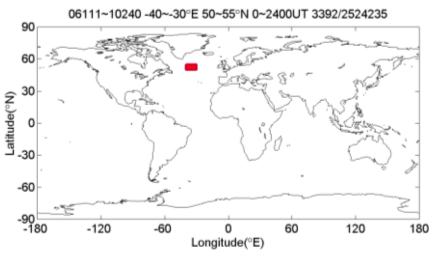
圖（三十二）、西元 2006~2010 年、北緯 60~65 度，第一與第三四分位數的溫度差作圖



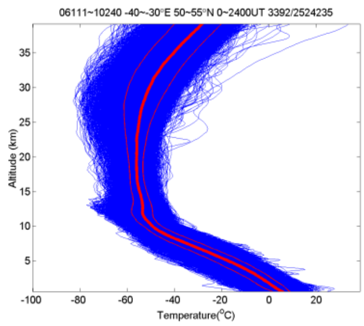
圖（三十三）、西元 2006~2010 年、北緯 60~65 度，高低溫極端值的溫度差作圖

由圖（三十二）可看出陸地在高度 5 公里以下的溫度振幅明顯高於海洋，且圖（三十三）的極端值溫度振幅也有類似現象；這說明了低空溫度在這三個海陸區塊中，以海洋區塊的溫度相對穩定，但高度 10 公里以上則沒有明顯的海陸差異。

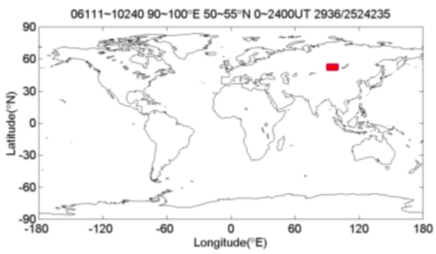
（四）、北緯 50~55^{o}N 溫度圖



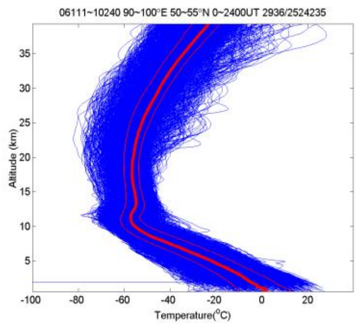
圖（三十四）、大西洋觀測點選取



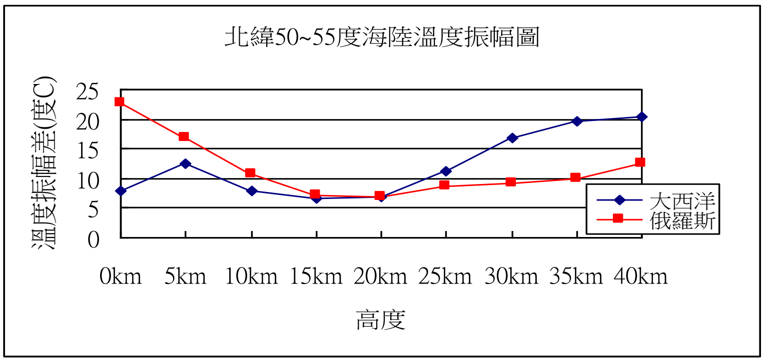
圖（三十五）、大西洋氣溫圖



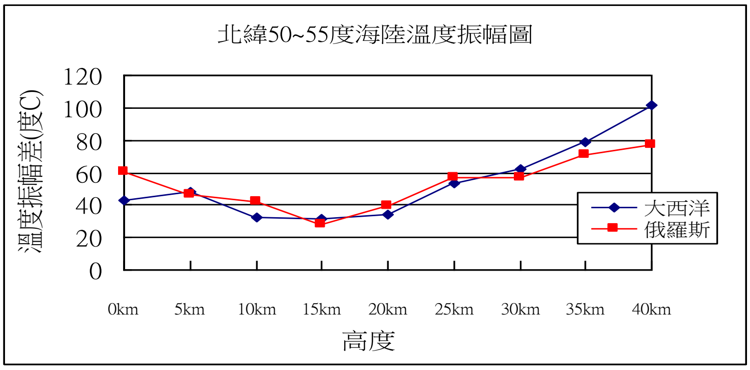
圖（三十六）、俄羅斯觀測點選取



圖（三十七）、俄羅斯氣溫圖



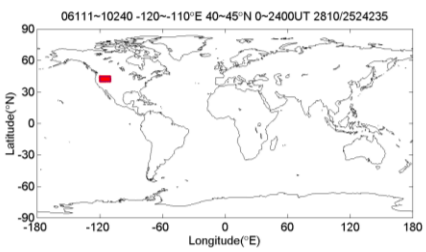
圖（三十八）、西元 2006~2010 年、北緯 50~55 度，第一與第三四分位數的溫度差作圖



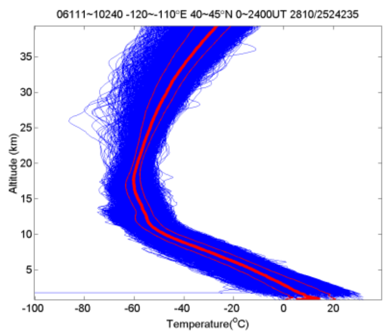
圖（三十九）、西元 2006~2010 年、北緯 50~55 度，高低溫極端值的溫度差作圖

由圖（三十八）、圖（三十九）看出在高度 5 公里以下，海洋的極端溫度振幅仍小於陸地，和前幾項觀察得到的結果雷同；值得一提的是，我們發現越往低緯度地區，海與陸的溫度振幅差越大，幾乎差距 15~20 度；但我們也同樣發現，我們所用來觀察 SSW 的高空並沒有因海、陸性質差異而有明顯不同。

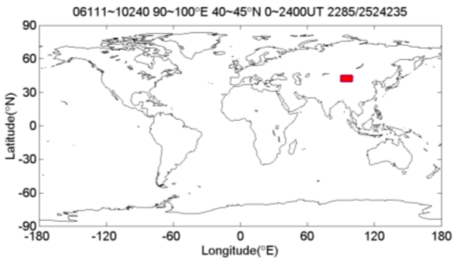
（五）、北緯 40~45°N 溫度圖



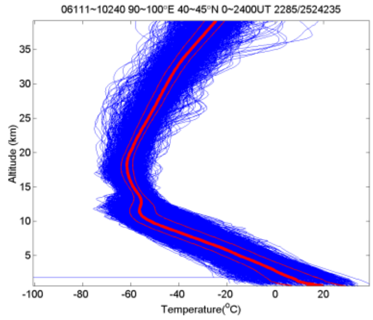
圖（四十）、美國觀測點選取



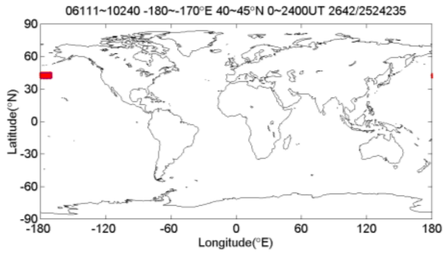
圖（四十一）、美國氣溫圖



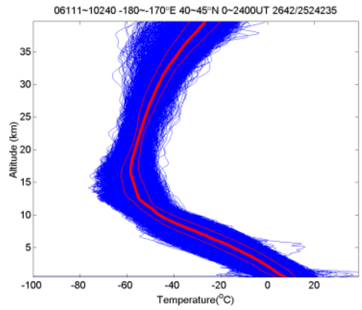
圖（四十二）、中國觀測點選取



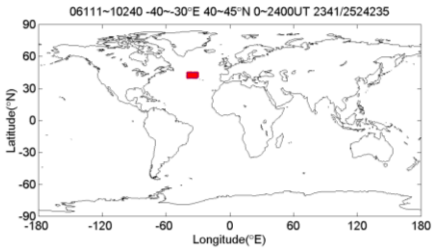
圖（四十三）、中國氣溫圖



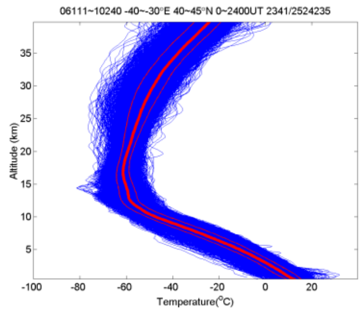
圖（四十四）、太平洋觀測點選取



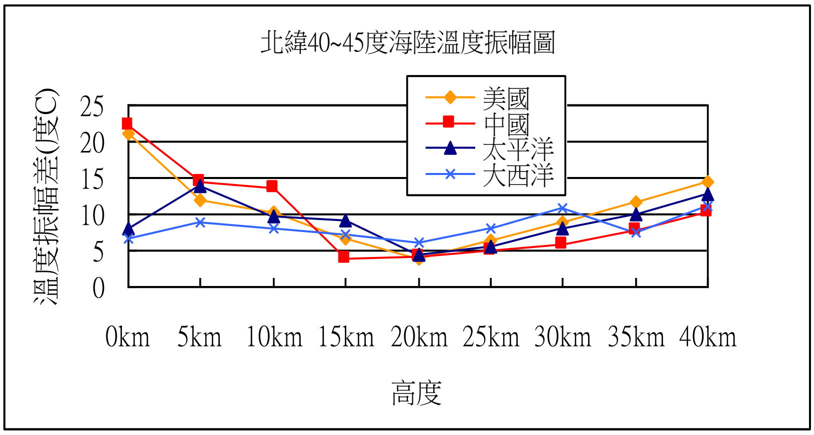
圖（四十五）、太平洋氣溫圖



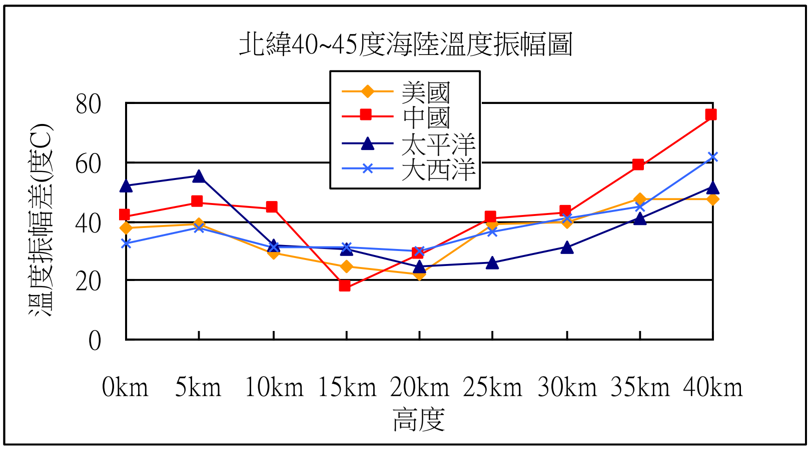
圖（四十六）、大西洋觀測點選取



圖（四十七）、大西洋氣溫圖



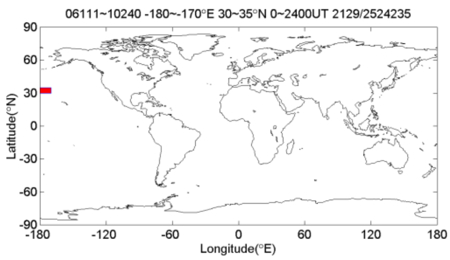
圖（四十八）、西元 2006~2010 年、北緯 40~45 度，第一與第三四分位數的溫度差作圖



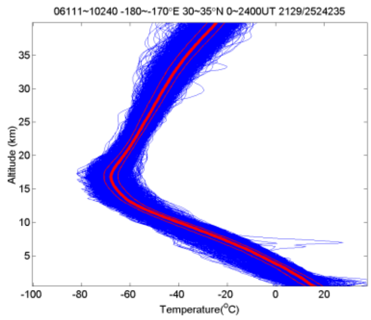
圖（四十九）、西元 2006~2010 年、北緯 40~45 度，高低溫極端值的溫度差作圖

從圖（四十八）可看出，高度 5 公里以下低空的海洋均溫相對穩定許多，陸地的溫度振幅明顯較大；而在圖（四十九）中，則沒有顯著的海陸差異。但我們從圖（四十八）觀察出的結論，與我們所研究 SSW 影響高空溫度震盪的結果並沒有直接的相關性。

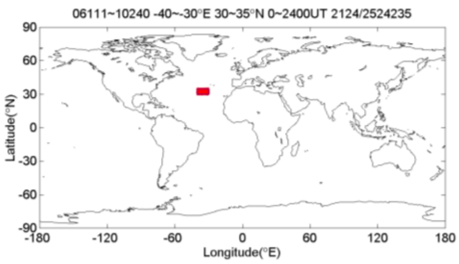
（六）、北緯 30~35^{o}N 溫度圖



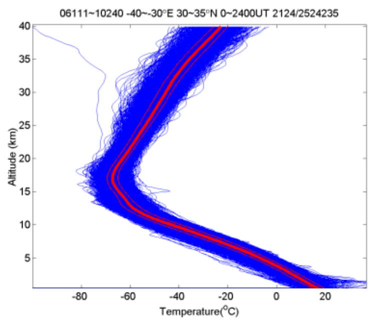
圖（五十）、太平洋觀測點選取



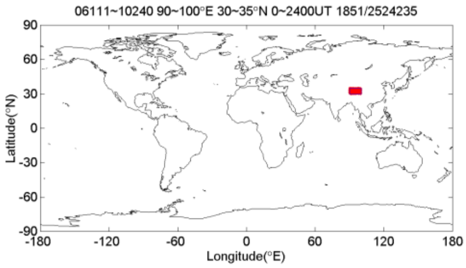
圖（五十一）、太平洋氣溫圖



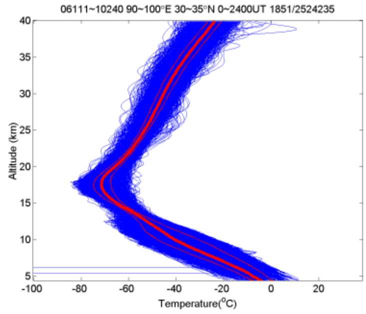
圖（五十二）、大西洋觀測點選取



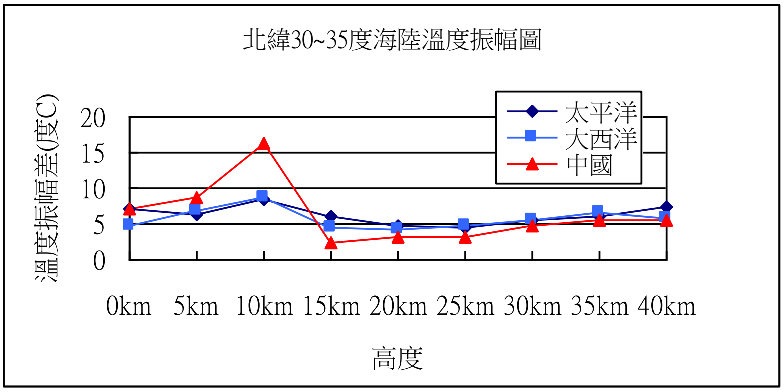
圖（五十三）、大西洋氣溫圖



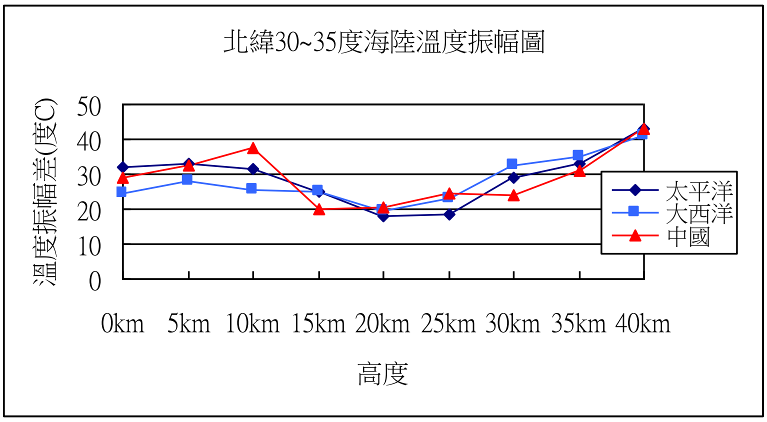
圖（五十四）、中國觀測點選



圖（五十五）、中國氣溫圖



圖（五十六）、西元 2006~2010 年、北緯 30~35 度，第一與第三四分位數的溫度差作圖

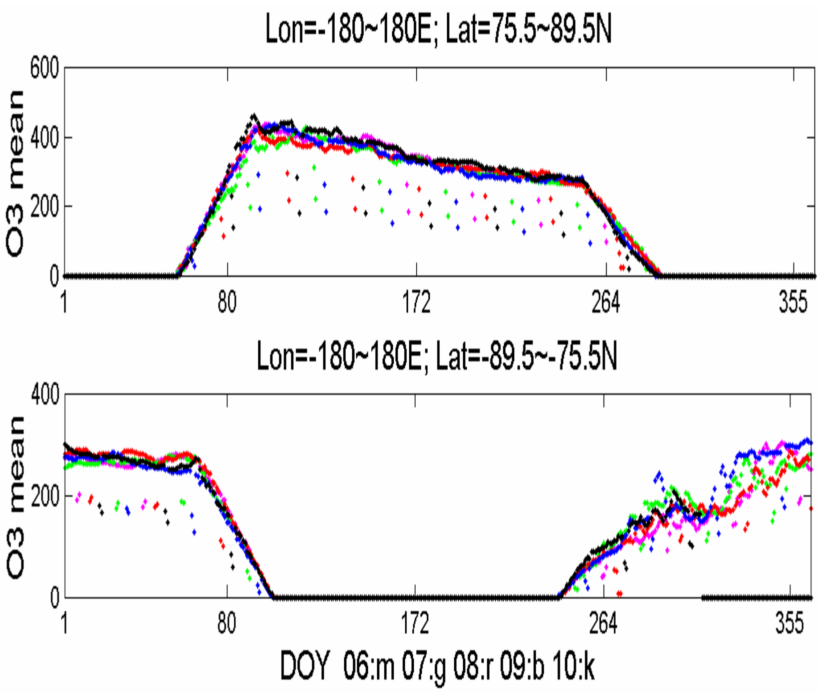


圖（五十七）、西元 2006~2010 年、北緯 30~35 度，高低溫極端值的溫度差作圖

最後，由圖（五十六）、圖（五十七）同樣地發現，我們所用來觀察的 SSW 高空溫度震盪並沒有因海、陸性質差異而有明顯不同。

四、探討臭氧濃度與 SSW 的相關性

有鑑於本研究的增溫現象發生在平流層，而臭氧層在平流層對溫度有相當大的影響，於是我們嘗試做出臭氧濃度圖隨季節變化圖觀察之：

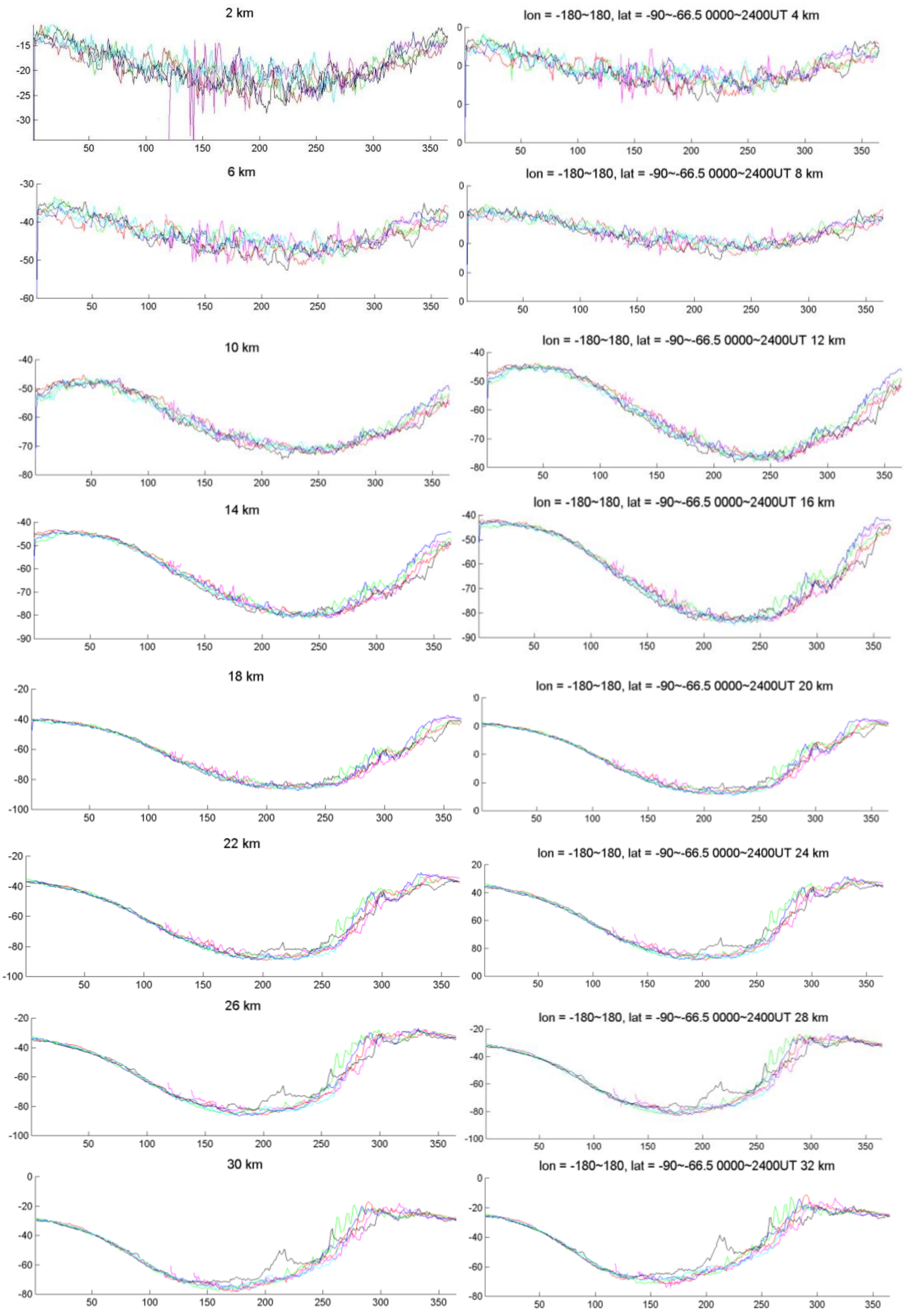


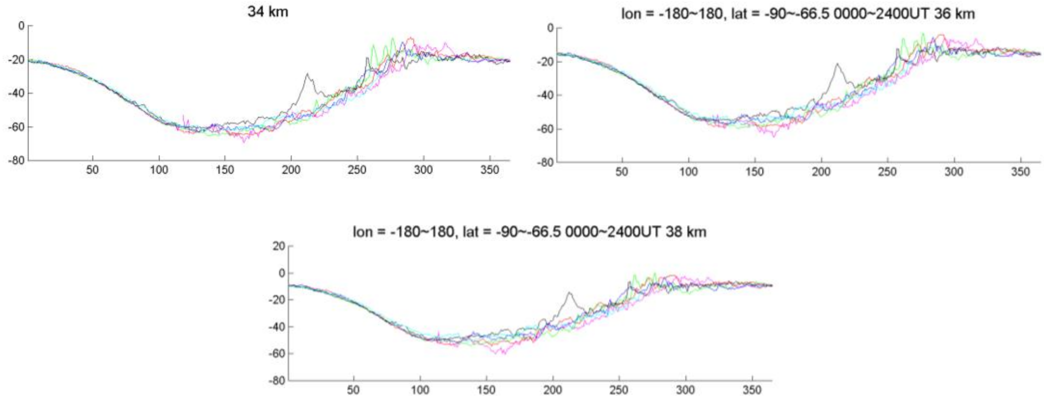
圖（五十八）、西元 2006~2010 年、南北緯 75.5~89.5 度臭氧濃度圖

由圖（五十八）可觀察到\，南北半球上空的臭氧是隨季節移動的，換言之，當北半球夏季北極圈臭氧濃度達極大值時，南半球的臭氧相對濃度極低（圖中顯示 0 表示濃度過低，福衛無法感應），北半球冬季則反之。將此結果與 SSW 的增溫現象比對，我們發現：當北半球年初正值增溫高峰時，臭氧濃度反而極低。一般認知裡，臭氧的存在應提升大氣溫度，但我們觀察到的結果卻正好相反，故我們推測北半球平流層的急劇增溫現象與臭氧濃度變化並無直接相關。

五、南半球的延伸探討

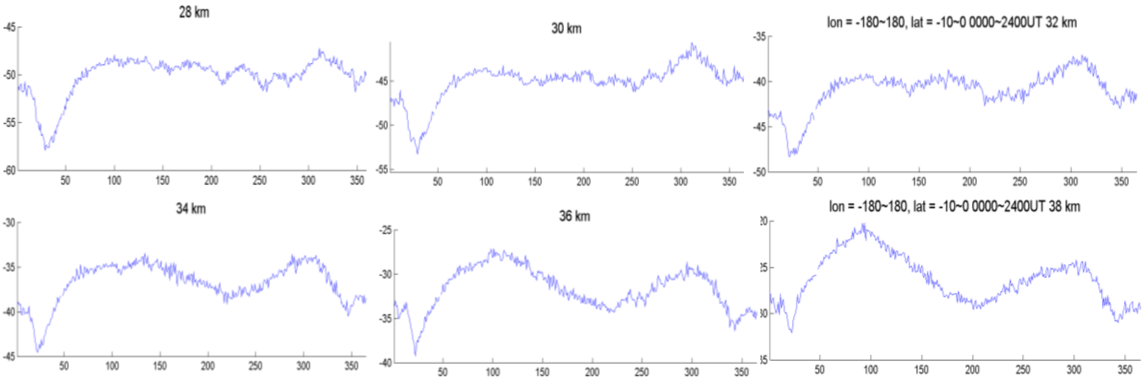
首先做出西元 2006~2011 年南緯 66.5 度~90 度的大氣溫度圖如下圖（五十九），由圖可看出南半球亦有增溫現象，且此現象的發生時間和北半球同一季節。



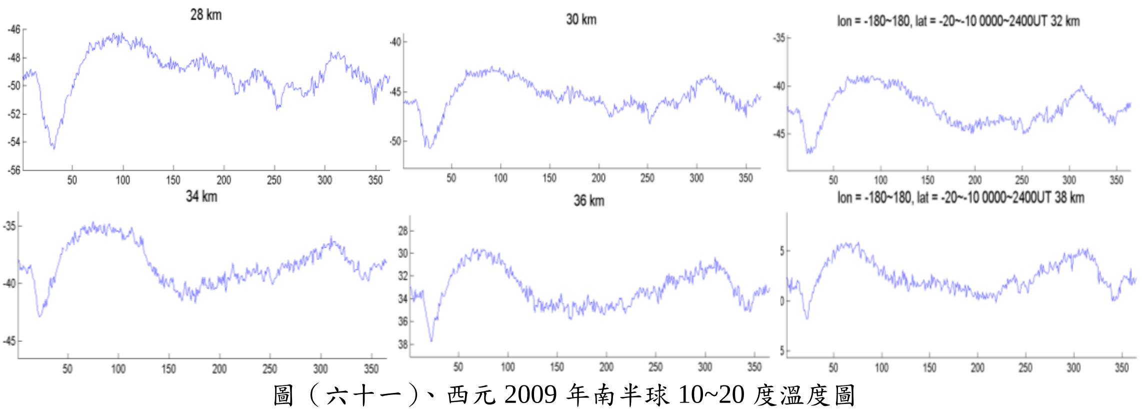


圖（五十九）、西元 2009 年南半球 66.5~90 度大氣溫度圖

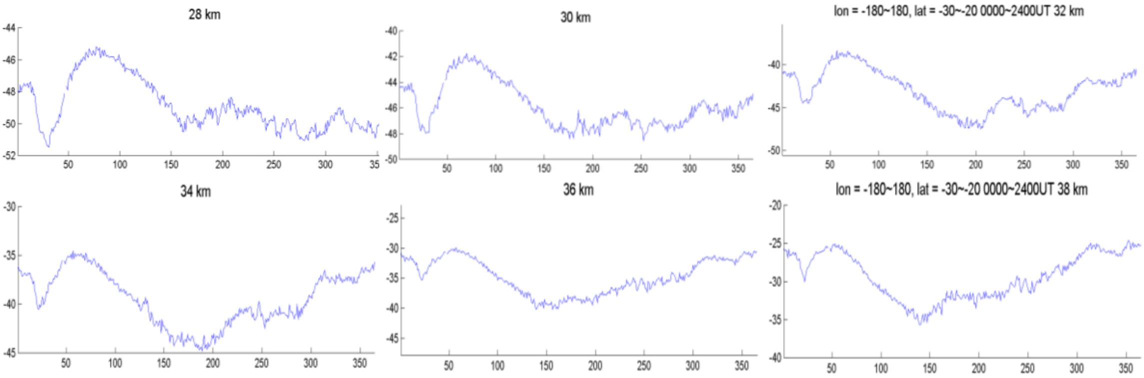
接著，我們選擇 SSW 最劇烈的西元 2009 年集中觀察，作出圖（六十）到圖（六十八）。從一系列的西元 2009 年大氣溫度圖可以看到：每年年初低緯區有急劇降溫，而高緯區年中則有類似 SSW 的增溫現象。



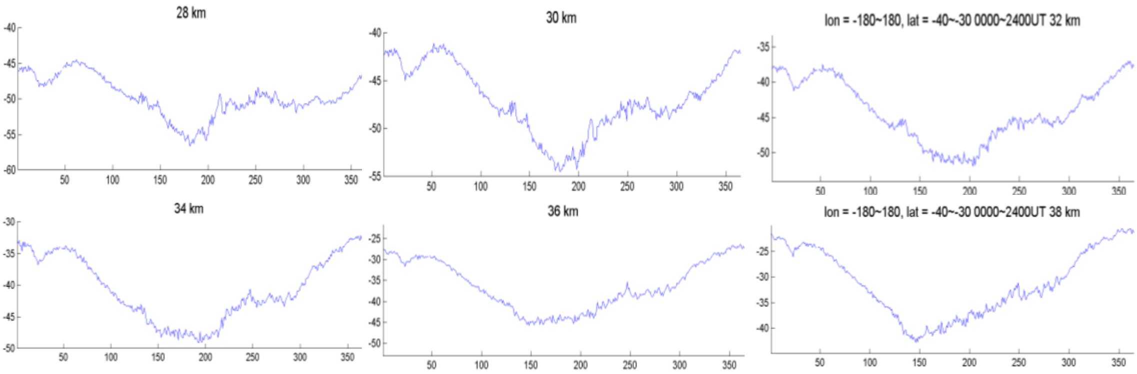
圖（六十）、西元 2009 年南半球 0~10 度溫度圖



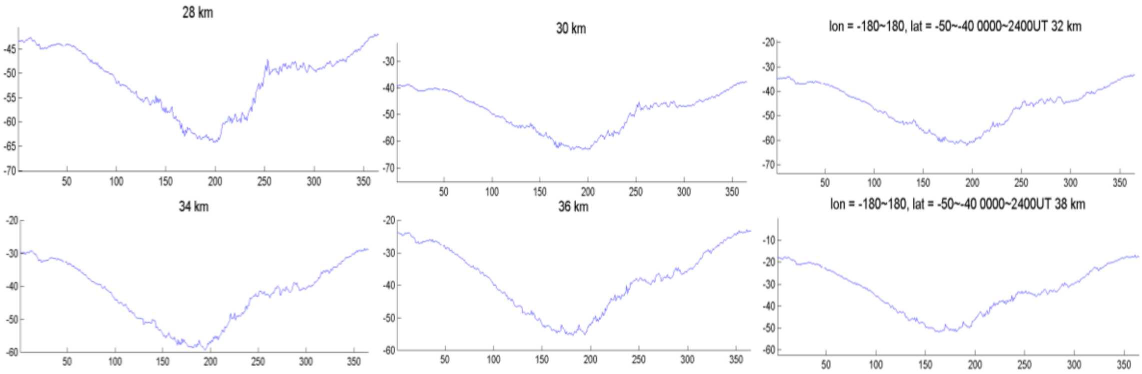
圖（六十一）、西元 2009 年南半球 10~20 度溫度圖



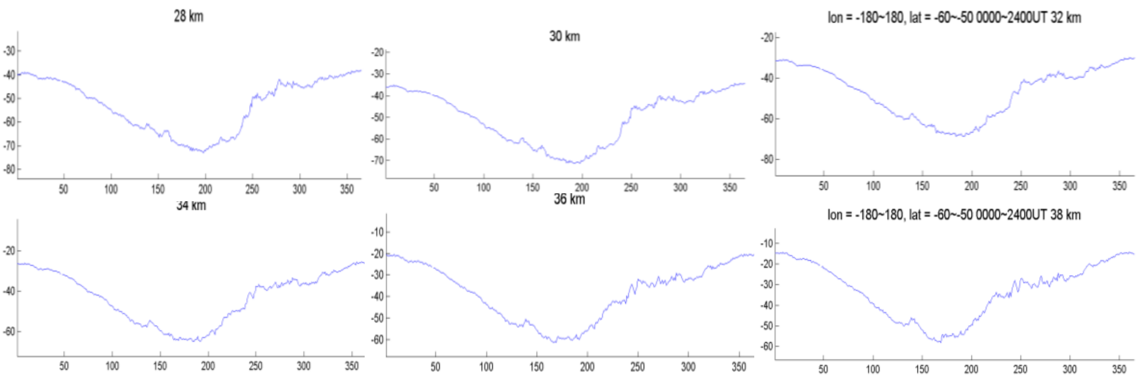
圖（六十二）、西元 2009 年南半球 20~30 度溫度圖



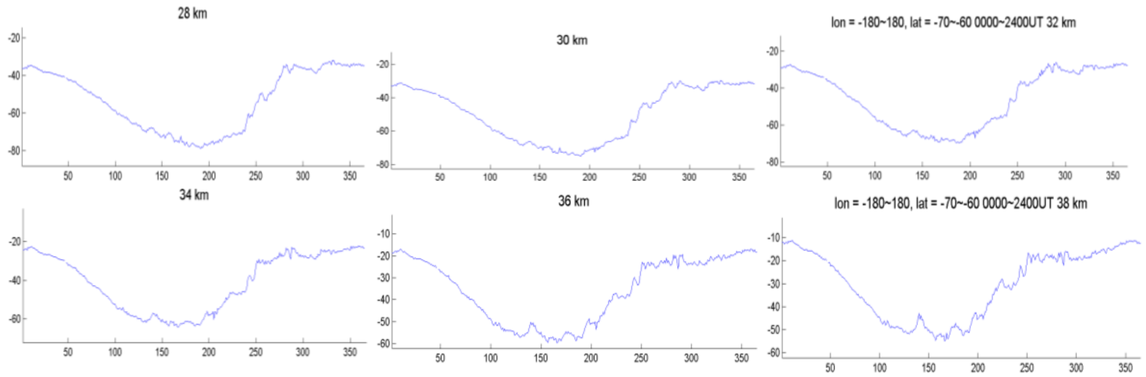
圖（六十三）、西元 2009 年南半球 30~40 度溫度圖



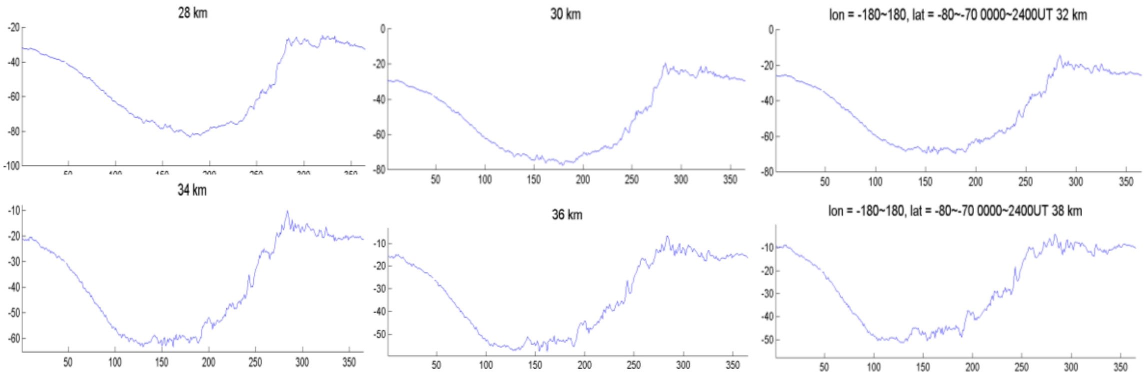
圖（六十四）、西元 2009 年南半球 40~50 度溫度圖



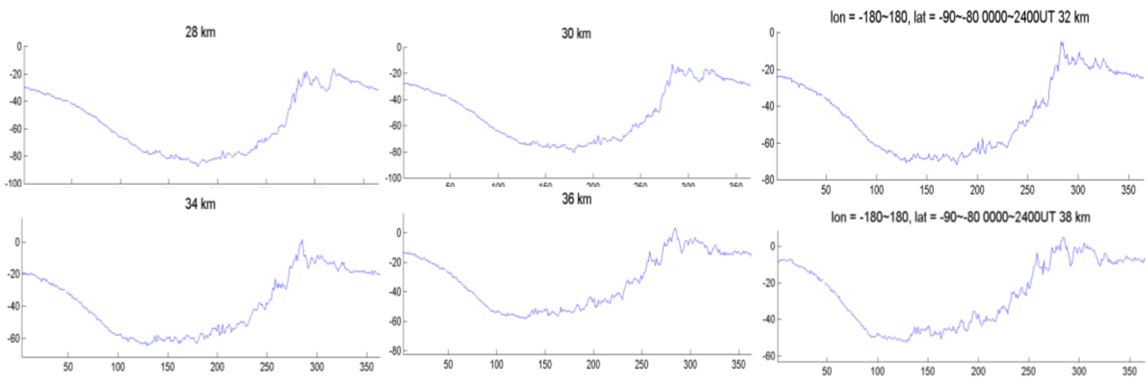
圖（六十五）、西元 2009 年南半球 50~60 度溫度圖



圖（六十六）、西元 2009 年南半球 60~70 度溫度圖



圖（六十七）、西元 2009 年南半球 70~80 度溫度圖



圖（六十八）、西元 2009 年南半球 80~90 度溫度圖

陸、討論

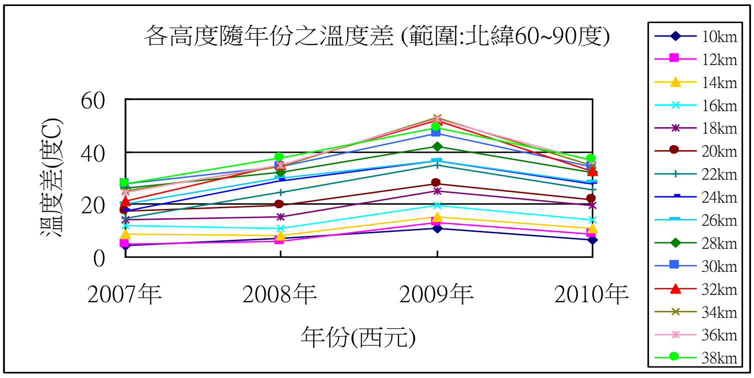
一、SSW 發生的時空間

（一）整理資料作出圖（三）並觀察後，可看出 SSW 明顯震盪多發生於當年年底冬至(約第 264 天)至隔年年初春分(約第 80 天)的區間內，而且其中最高峰大多出現在年初，另外，高峰出現的時間也會因觀測的高度不同而在天數上有細微差異：自圖（三）10 公里以及 12 公里可看出，低空的震盪高峰出現的時間較接近春季，約在第 50~60 天間；而當我們選取的觀測範圍越往高空，其震盪高峰出現的時間越接近第 25~30 天，特別在高度 28~38 公里處尤為明顯。

（二）由圖（三）可看出，高度較低(即高度 12 公里以下)的範圍在前 80 天溫度震盪不規律、沒有明顯的高峰，我們猜測可能是受低空水氣及對流層天氣變化的影響，導致多個高低起伏凌亂的波動，使我們難以測量何者是因北極震盪導致的溫度振幅，故此報告僅就 14 公里以上高空範圍的溫度變化作探討。我們從 14 公里開始將圖形數據量化觀察，並作出圖（五），由圖可看出同年度 30 公里以上的高空折線漸趨平緩，加上我們自地球科學的課程中得知平流層內受劇烈天氣變化的影響較小，故我們選取 30~38 公里的高度範圍來討論 SSW。

（三）我們觀察圖（五）的各年折線，可看出西元 2009 年北緯 60~90 度的平均溫度差明顯高於另外三年，且在 34km 達到高峰。此外，觀察圖（六）～圖（九）亦可發現，僅有西元 2009 年的溫度上升最高峰範圍為北緯 70~90 度，其餘三年的最高峰皆在北緯 80~90 度，這說明了西元 2009 年的 SSW 除了年平均溫度上升最劇烈，也同時導致了較大範圍的上升高峰。

（四）以各高度溫度隨年份變化的結果作圖得圖（六十九），可看出西元 2007 年至 2009 年溫度振幅漸增，而西元 2009 年後溫度振幅始降，形成部份週期的規律變化。我們推測 SSW 的發生可能有週期性，但此項推測必須有更長年份的觀察才能確定之。

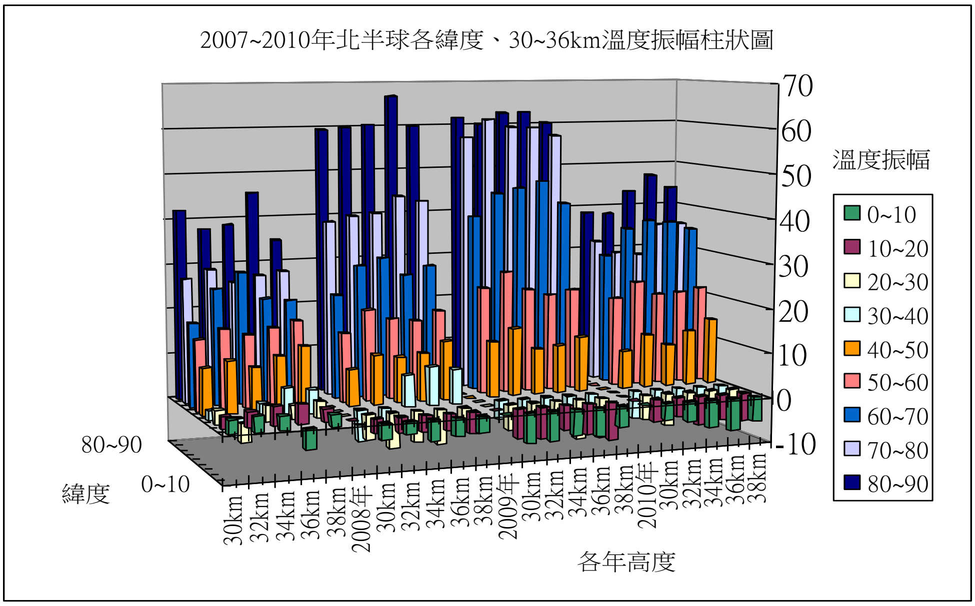


圖（六十九）、西元 2007~2010 年、北緯 60~90 度各高度增溫幅度變化圖

二、SSW 對不同緯區的影響

圖（七十）冷空氣分散示意圖

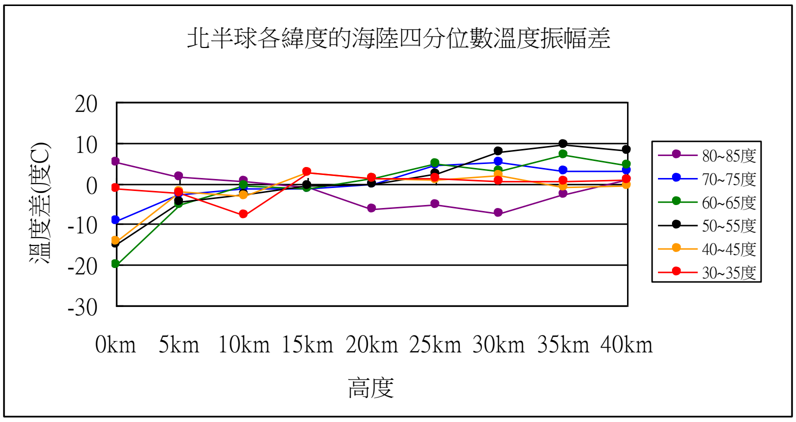
根據西元 2007~2010 年圖（六）～圖（九）以及圖（七十一）的作圖，我們觀察出從北緯 40 度開始，越接近北極中心其增溫現象越明顯，至北極高緯區增溫達極大。從這裡我們歸納出一個對此現象的推測：極區在每年年初的極地渦旋會減弱甚至消失，導致高緯區的冷空氣外流至中低緯度地區，造成高緯區增溫但低緯區降溫的現象，如圖(七十）所示。



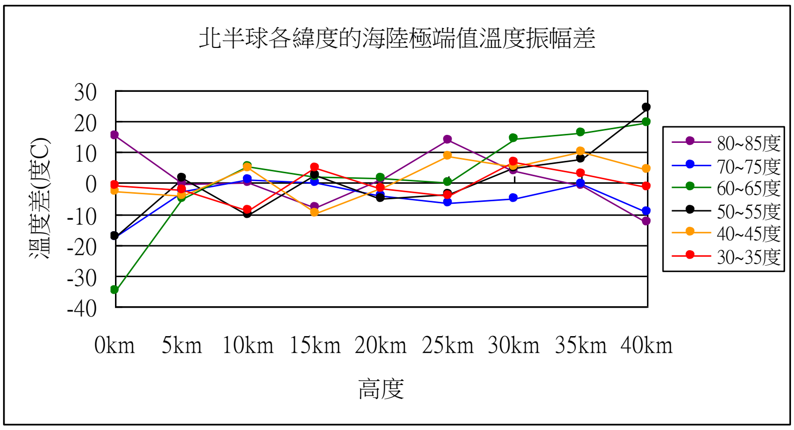
圖（七十一）、北半球 34~36km、各緯度地區溫度變化示意圖

三、SSW 對北半球海陸上空的影響比較

觀察圖（十二）～圖（五十七）的海陸溫度變化幅度圖，可看出北半球的溫度振動曲線，我們最後以各緯度海陸振幅的溫度差（即海洋溫度振幅減去陸地溫度振幅）作圖，得圖（七十二）、圖（七十三）如下。



圖（七十二）、西元 2006~2010 年，北半球各緯度的海陸四分位數溫度振幅差作圖



圖（七十三）、西元 2006~2010 年，北半球各緯度的海陸極端值溫度振幅差作圖

觀察圖（七十二）、（七十三），搭配數據及研究過程中第三項所做的觀察，我們發現海陸溫度振幅差值在 SSW 發生的高空呈現無規律的變化，並且在觀察緯度因素後發現，兩者之間並無顯著相關，故我們推測 SSW 造成的影響並不受限於海陸差異。

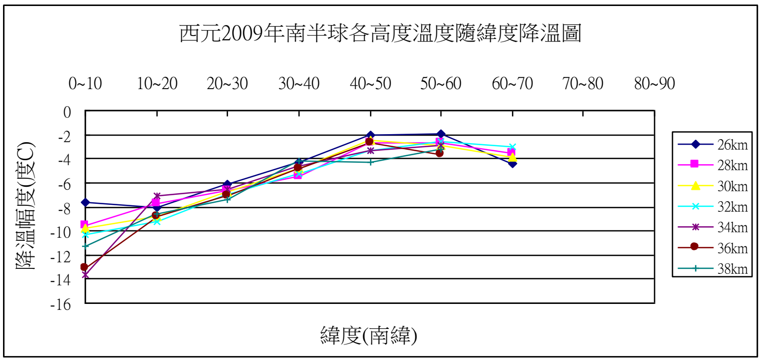
四、臭氧濃度對平流層增溫的影響探討

根據圖（五十八）的臭氧濃度圖所顯示的資訊，目前我們並沒有發現臭氧濃度的變化跟 SSW 有直接相關性。

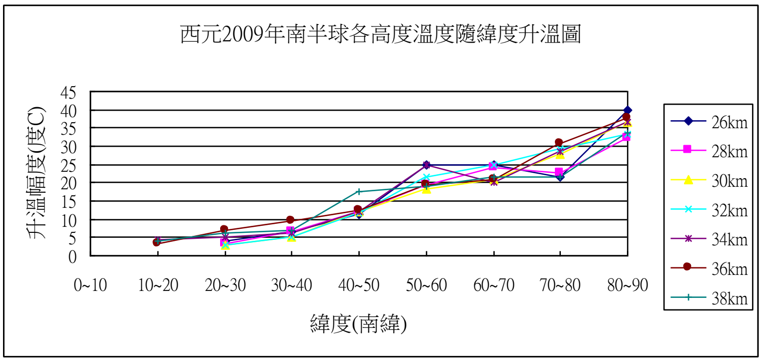
五、南、北半球熱對流探討

（一）首先由圖（五十九）可知，除了冬夏季節相反造成溫度曲線成反向變動外，南極圈內的增溫現象與北半球發生在相同的季節，即冬末春初之際。

（二）接著，將圖（六十）～圖（六十八）中西元 2009 年年初急劇降溫與年中降溫的溫度變化量化，製圖表如圖（七十四）、圖（七十五）。



圖（七十四）、西元 2009 年南半球各緯區年初降溫圖



圖（七十五）、西元 2009 年南半球各緯區年中升溫圖

由圖（六十）到圖（六十八）以及圖（七十四）、圖（七十五）可看出南半球在 SSW 劇烈的 2009 年亦有相對應的氣溫變化。首先是年初部分，西元 2009 年年初約一百天，也就是大約北半球發生急劇增溫的時段，南半球低緯區反而急劇降溫；而到了年中，相當於南半球冬末春初之際，則表現了類似北半球的 SSW 現象。以上兩個現象都值得好好探討，由同一時間的南

圖（七十六）
赤道熱源向高緯區流動圖

北半球大氣溫度增減，可以歸納出另一個可能的推測，也就是西元 2009 年南、北半球低緯區高空的熱，在某種大氣環流機制下飄送到了北半球的高緯區，這可以合理說明我們同時觀察到了南北半球低緯區都表現出降溫，而北半球高緯區急劇增溫的現象，換句話說，此時期極可能存在一個變化劇烈的大氣熱對流系統，推測其機制如圖（七十六）。

柒、結論

一、平流層急劇增溫現象發生的時空間：

（一）時間：每年冬末至隔年春初，且溫度曲線的高峰多集中在第 25~60 天。

（二）高度：低空較不易觀察 SSW，而 30~38km 的高空受影響之程度相差不大。

（三）西元 2009 年為 SSW 最劇烈的一年。

二、SSW 影響北半球的緯度範圍：北緯 40 度以北受 SSW 影響而升溫，且升溫幅度隨緯度增加而漸大；反之，北緯 40 度以南相對降溫，但降溫幅度較小。

三、SSW 發生在高空，應不受限於海陸差異。

四、臭氧濃度變化應與 SSW 無直接相關。

五、南北半球熱對流探討：

（一）南北半球高緯區均有急劇增溫的現象，但北半球溫度變化的幅度明顯高於南半球，且兩者的增溫現象均發生在冬末春初。

（二）西元 2009 年的南北半球低緯區的大氣溫度在年初均有顯著的降溫現象，推測此時南北半球赤道附近的熱在年初傳播到北半球高緯區，導致了北半球高緯區的急劇增溫現象。

捌、參考資料及其他

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Observing Sudden Stratosphere Warming by Using Data from FORMOSAT-3

Abstract

Sudden Stratosphere Warming (SSW) was first discovered in the mid-twentieth century. Since then, scientists have used many methods to observe it. To distinguish our research from former studies, temperature retrievals from the FORMOSAT-3/COSMIC(Constellation Observing System for Meteorology, Ionosphere, and Climate) radio occultation have been used to study SSWs' characteristics . The FORMOSAT-3/COSMIC is a collaborative satellite project conducted by the National Space Organization in Taiwan and the University Corporation for Atmospheric Research in the United States. It consists of six micro satellites launched in April 2006 that utilize the global positioning system radio-occultation limb sounding technique to provide high-precision temperature observations globally. There are between 1000-2500 global occultation profiles taken daily. The global sampling coverage and precision of this data set provides unique opportunities for study of SSW globally.

This study uses six years of temperature retrievals in the period, 4, 2006-1, 2012.Based on those data, we not only discuss the appearance and evolution of SSW occurred in the northern hemisphere, but we also investigate the characteristics of

SSW such as magnitude of temperature change, period of occurrence, latitudinal/longitudinal dependence and seasonality. It is discovered that SSW usually happens in the late autumn and winter of each year, and is especially obvious in late winter. In terms of latitude, the magnitude of temperature change in high latitude area above 40 degrees north was much stronger than below. Additionally, the evolution of selected SSW events will be investigated by using the global temperature distribution retrieved from the FORMOSAT-3/COSMIC.

Motivation

Feeling the unusual climate changes these years, including colder winters, hotter summers, blizzards, typhoons, hurricanes and storms that have caused disasters around the globe and taken thousands of lives, we decided to observe the mystery of the atmosphere.

During this research, the temperature aspect is especially focused on, as it seems to be the most noticeable part that humans can feel with climate change. It is also easier for people to understand or imagine how serious temperature increases or decreases can be. In the early days of this study, the troposphere was observed, with findings that the landscape seems to disturb the temperature in lower altitudes on a large scale. Therefore, we turned our focus to higher ones. Surprisingly, from the diagrams we made, in the stratosphere, there was a dramatic temperature increase. As this phenomenon was investigated deeper and deeper, we then found out that it occurs almost every year to different degrees. And after looking for information on the internet, we found out that the phenomenon we previously saw in our diagrams was entitled Sudden Stratosphere Warming, which is also known as SSW. In this study, we eventually decided to observe it by using equipment seldom employed in this field before, which is the satellite, FORMOSAT-3, and we also want to observe SSW through its temperature change over several years, between different latitudes and altitudes, in the hope of interpreting it in a way that hardly has anyone tried.(Schoeberl, 1978)

Background and Introduction

Sudden Stratosphere Warming (SSW) is one of the most highly-discussed issues today. (Mcguirk and Douglas, 1988; Mbatha et al, 2010; Harada et al, 2010; Scheiben et al, 2011) It was first found in mid-twentieth century (Scherhag, 1952), and since then, it has grabbed the attention of scholars from the atmospheric science field. In recent years, scientists have used many methods to observe it, calculate its cycle, and have tried to predict it through unusual omens, etc. (Limpasuvan et al, 2004) In most of the studies, they adopt data of the European Centre for Medium-range Weather Forecasts, sounding balloons from local weather stations, and radar systems to construct their studies. (Ratnam et al, 2004)Some of them put emphasis on defining the occurrence of SSW (Scherhag, 1952); others try to interpret how SSW propagates to the troposphere and influences the lower altitude(Nakagawa and Yamazaki, 2006), still others look into wind, current flow, temperature, planetary waves, polar vortex…etc. (Charlton and Polvani, 2007) However, their observations mainly focus on specific events occurring in the exact SSW year, which has already been indicated or found by other scholars. Therefore, in our research, we try a different method. We observe the temperature curves through years since 2006, the year when FORMOSAT-3 was launched, and measure the unusual temperature increase/ decrease, with no preconceived notion of the occurring year. We hope it could be possible to find out the exact SSW occurring year and its events directly by analyzing diagrams made from the temperature data of FORMOSAT-3. To distinguish our study from previous ones, we put emphasis on the advantage of using a satellite, whose observing scope ranges wider than that of traditional apparatus. **(Fig.1)** Moreover, since 1000-2500 global occultation profiles are taken per day, the more complete data maintains our observations with high accuracy even if we look into this phenomenon's evolution in the global scale by days. And also, FORMOSAT-3 offers us a great source in the vertical distribution of meteorological measurement.

All the advantages make it possible for us to discuss how temperature alters during SSW events by different matters thoroughly through latitude and altitude.

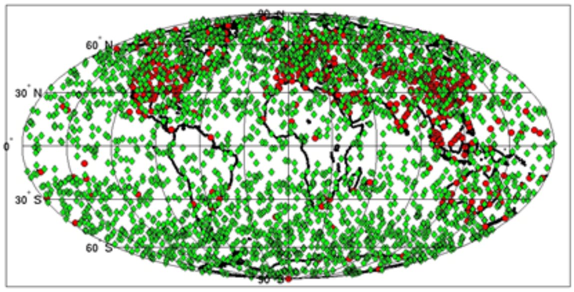


Fig.1 Occultation Location for FORMOSAT-3/COSMIC, 6 planes, 24hr, red dot: ground based observation, green dot: FORMOSAT-3

First of all, temperatures in different altitudes are measured and made into charts, and those in the higher troposphere and stratosphere are picked out separately to form a basis to indicate how SSW acts during these years in the aspect of height since 2006. Second, the aspect of latitude is discussed through charts, which illustrate the relationship between different years, different latitudes, and the alteration of temperature during SSW period. Moreover, temperature in the southern hemisphere is taken into consideration. Through the temperature curves and temperature maps, how SSW evolves, shapes and how heat shifts around the globe is discussed as completely as possible. Meanwhile, we compile data during these years, and focus on case by case study. Last but not least, vertical distributions of temperature within SSW areas and its surroundings are acquired from FORMOSAT-3. Data was then made into table and charts to see how SSW impacts these places differently according to their location and time/season.

Data Source

FORMOSAT-3 is a cooperation project between National Space Organization (NSPO) in Taiwan and University Corporation for Atmospheric Research (UCAR) in the U.S. In this project, six micro satellites were launched together in America on April fifteenth, 2006, and then separated in the outer space, moving around their own orbits **(Fig.2)**. Hence, they form a global observing system, providing over two thousand data around the globe per day. (Liou et al, 2007) This advantages of profiling both sea and land data just meet our need, as we prefer equal data around the globe to completely discuss SSW in a global scale in our research.

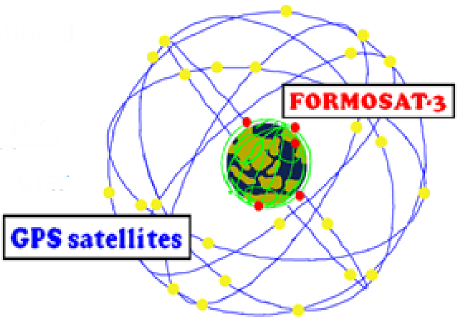


Fig. 2 Surrounding of 24 GPS and FORMOSAT-3

Moreover, the way how FORMOSAT-3 receives data is really different from other observing systems. This special technique is called “Occultation." The basic theory of it is that the GPS receiver on the micro-satellite receives the micro-signal sent by a satellite of global positioning system (GPS) in an unusual way. At the moment when the GPS satellite is about fall or rise on the verge of the horizon, the signal may be block by the atmosphere. And as we know, when light, sound/ acoustic waves, or electromagnetic wave travels, they may be refracted as they enter another medium. So here is quite the same. As GPS satellite, which is at the opposite side, is about to fall or rise on the verge of the horizon, the

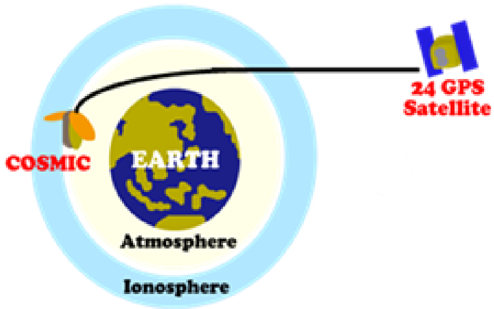


Fig. 3 Receiver receive signal from GPS satellite

signal sent by it would be refracted by the atmosphere covering the surface of the earth. **(Fig.3)**

Therefore, the wave of the signal will be refracted, and at the same time slow down. And since the refraction angle would differ between different contents, in this instant moment, scientist are able to calculate the atmospheric density, temperature, humidity/moisture, pressure, and total electronic content (TEC) by the refraction angle of that specific area. **(Fig. 4)** (Tsai et al, 2006; Hsu et al, 2009) Moreover, Fig.5 in the next page shows the detail procedure how scientists calculate all kinds of atmospheric products by using the refraction angle. And because the difference among each angle is small, the measurement must be precise. Therefore, when it comes to the quality and accuracy of this technique, the data from it is almost as accurate as that of sounding balloons. However, FORMOSAT-3 could collect data more widely. (Aragon-Angel et al, 2010)

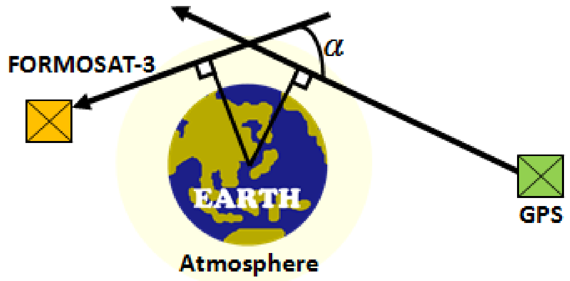


Fig.4 Bending angle(α)

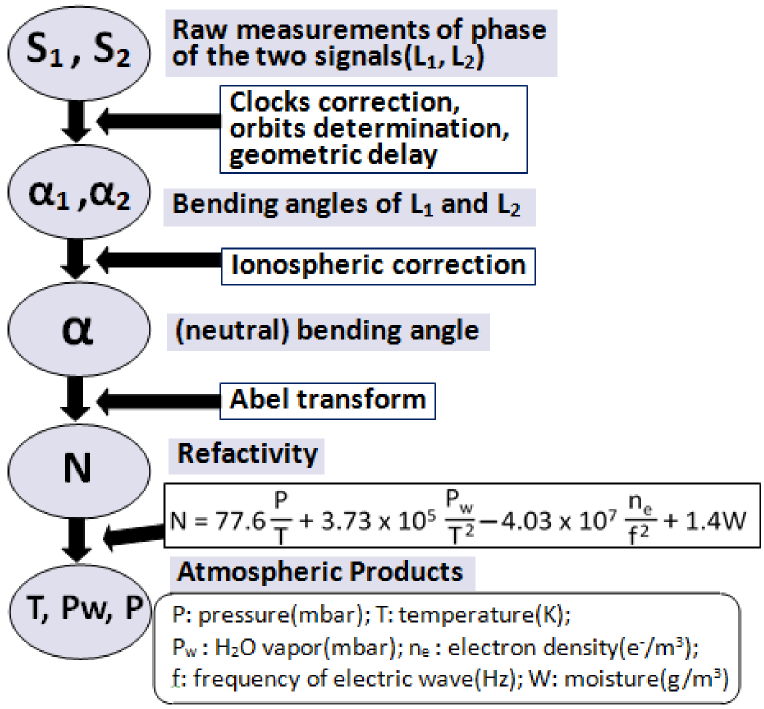


Fig. 5 Detail procedure of how atmospheric products are retrieved form refraction angles

Data & Analysis, Discussion

1. SSW at Different Altitudes

In this part, Matlab was used to separate temperatures within 66.5 °N to 90 °N, 180 °E-180 °W, 2006 to 2012, by their heights. A series of temperature figures were drawn from the height 2 kilometers to 38 kilometers every 2 kilometers to show how temperature rises and falls among different heights through the entire year **(Fig. 6)**.

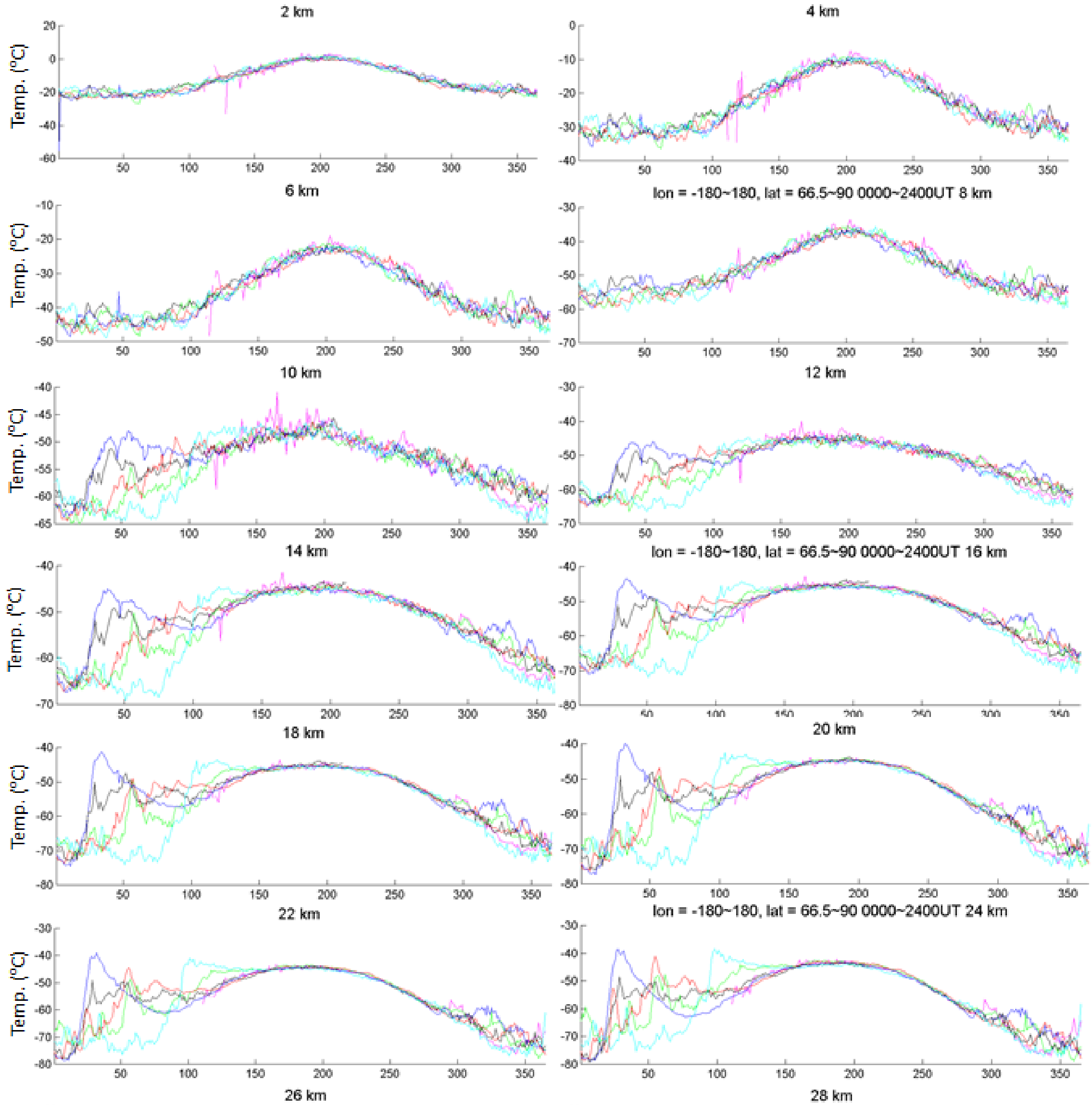


Fig. 6-1 Temperature curve from April 2006 to January

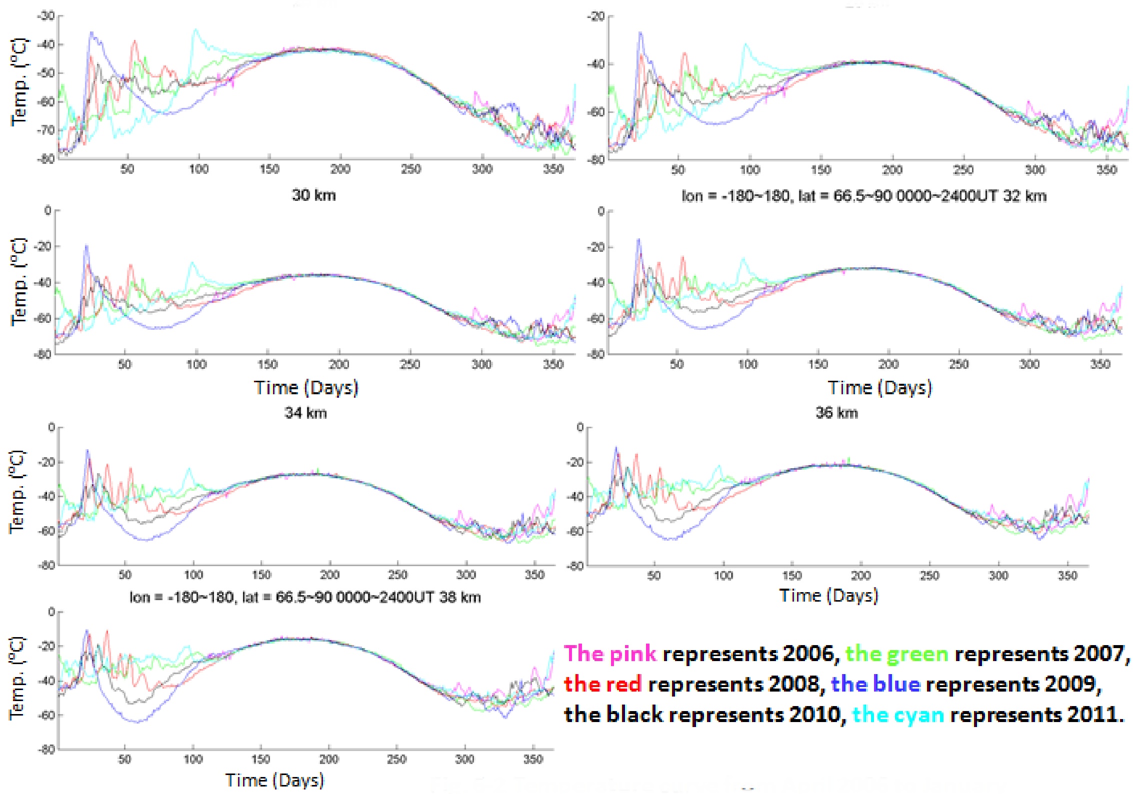


Fig. 6-2 Temperature curve from April 2006 to January

From **Fig.6** , because of the disturbance from low-altitude H_2O vapor, the observation of Formosa-III failed to collect accurate data, which makes temperature curves seem to fluctuate irregularly without forming any peaks at height below 10 kilometers. In contrast, at the beginning of every year above the height 10 kilometers, temperature increases obviously, which becomes a clue to SSW events. The obvious increases of temperature, namely SSW phenomenon, happen from the Winter Solstice (about 264^{th} day) to the Spring Equinox (about 80^{th} day) the next year. Besides, the peaks of temperature curves vary between years. For example, in 2008 (the red line), there are 4 peaks; however, in 2009 (the blue line), there is only one dramatic event.

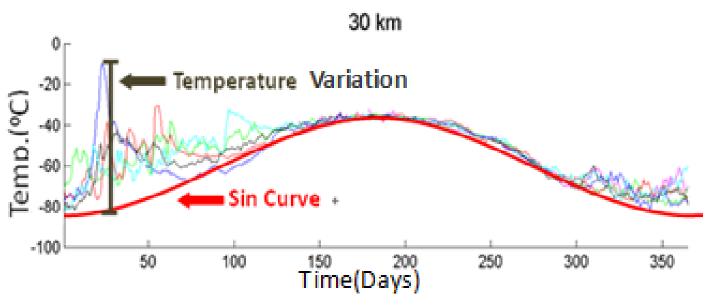


Fig.7 Example of how temperature variation is calculated

Next, to specifically illustrate the severity of SSW at each altitude, temperature variation is calculated as the way shown in **Fig.7.** Excel was also used to show the increase of temperature under the influence of height, **Chart.1** and **Fig.8**, with the x-axis representing "Altitude," and the y-axis, "Temperature Variation."

Chart. 1 Temperature variations at heights from 10km to 38km, from 2006 to 2011

Height / Years	10km	12km	14km	16km	18km	20km	22km	24km	26km	28km	30km	32km	34km	36km	38km
2007	8.70	8.70	8.70	11.97	14.35	17.58	14.86	17.54	20.41	26.37	27.60	21.01	25.21	24.28	27.61
2008	8.39	8.39	8.39	11.18	15.50	19.85	24.40	28.99	30.05	32.14	34.50	34.75	34.62	34.69	37.88
2009	15.44	15.44	15.44	19.67	25.07	27.69	34.86	36.38	36.70	42.11	46.92	51.98	53.06	52.39	49.20
2010	6.48	6.48	6.48	8.87	11.08	14.06	19.62	22.02	25.87	27.72	28.10	32.36	34.22	32.93	35.13
2011	5.75	7.78	11.55	14.07	14.45	16.84	19.91	21.94	26.87	29.36	30.29	32.77	31.9	38.89	35.44

According to **Fig.8**, it could be deduced that temperature variation could be better observed as it gets higher and higher. And heights above 28 kilometer have especially obvious increases.

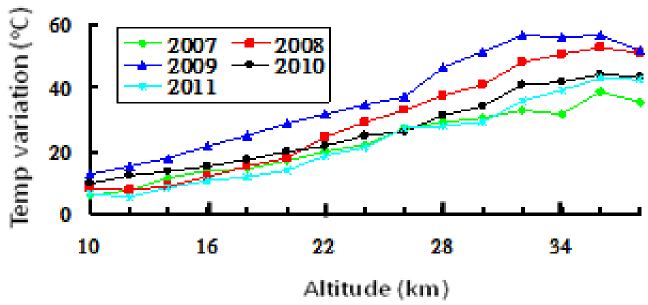


Fig. 8 Temperature variations at different altitudes

All in all, it is discovered in this part that temperature increase is more obvious at heights above 30 kilometers than below. Therefore, SSW in the range of 30 kilometers to 38 kilometers will be focused to discuss other matters in following research.

2. SSW at Different Latitudes

Data collected at higher altitudes, i.e., 30 kilometers to 38 kilometers, were used for detailed discussion, as is mentioned above.

Compared to the normal Sin curve, temperatures variations were measured every 5 degrees in latitude, and compiled in **Chart.2 –Chart.6**. Then temperature curves were drawn according to temperature variations, **Fig.9**, with the x-axis representing "North Latitude," and the y-axis, "Temperature Variation."

Chart. 2 Temperature variations at heights from 30km to 38km, for all latitude in 2007

(°N)	0-5	10~15	20-25	30~35	40-45	50~55	60-65	70~75	80-85
30km	-2.59	-2.61	-3.34	-4.74	6.11	12.46	13.84	24.58	26.33
32km	-2.37	-3.15	-2.97	-4.55	6.77	12.48	13.89	26.41	30.82
34km	-2.61	-3.37	-6.8	-4.33	6.96	11.97	17.74	25.26	31.16
36km	-1.65	-2.15	-3.02	-3.92	7.47	11.07	17.29	25.93	34.07
38km	-1.59	-4.08	-3	-4.87	7.92	12.25	19.09	25.68	43.63

Chart. 3 Temperature variations at heights from 30km to 38km, for all latitudes in 2008

(°N)	0-5	10~15	20-25	30~35	40-45	50~55	60-65	70~75	80-85
30km	1.63	-3.34	-6.62	-5.72	4.19	11.29	15.13	33.21	46.15
32km	-3.22	-4.8	-6.91	-6.57	7.03	13.09	16.2	36.96	55.08
34km	-5.57	-5.65	-6.96	-6.65	4.63	15.69	20.92	40.86	54.69
36km	-6.26	-5.47	-6.36	-5.11	6.83	16.69	21.34	44.25	58.04
38km	-7.42	-5.99	-6.65	-4.16	6.38	15.4	22.05	44.62	58.92

Chart. 4 Temperature variations at heights from 30km to 38km, for all latitudes in 2009

(°N)	0-5	10~15	20-25	30~35	40-45	50~55	60-65	70~75	80-85
30km	-7.41	-6.41	-6.17	-5.05	5.08	19.01	30.85	47.04	51.03
32km	-6.76	-7.76	-6.79	-4.62	7.87	20.26	29.24	49.02	58.03
34km	-7.48	-7.7	-6.8	-5.41	7.9	21.9	37.34	52.86	56.69
36km	-6.77	-5.92	-6.81	-5.8	6.76	19.67	39.47	52.25	56.15
38km	-7.37	-7.26	-8.55	-5.88	4.32	17.35	38.77	48.39	56.05

Chart. 5 Temperature variations at heights form 30km to 38km, for all latitudes in 2010

(°N)	0-5	10~15	20-25	30~35	40-45	50~55	60-65	70~75	80-85
30km	-3.53	-4.4	-5.27	-4.87	5.7	14.8	21.57	27.81	32.83
32km	-1.61	-5.87	-7.02	-6.06	6.14	15.56	24.95	32.3	35.08
34km	-2.78	-6.5	-8.5	-7.81	5.49	15.91	28.87	36.11	35.8
36km	-4.45	-5.87	-7.97	-6.9	5.7	18.38	29.1	37.52	38.8
38km	-7.42	-7.01	-6.93	-6.49	6.51	16.95	29.8	37.2	40.45

Chart. 6 Temperature variations at heights form 30km to 38km, for all latitudes in 2011

(°N)	0-5	10~15	20-25	30~35	40-45	50~55	60-65	70~75	80-85
30km	-3.24	-3.04	-2.63	-2.92	6.64	12.69	13.68	17.88	24.7
32km	-4.17	-5.55	-3.03	-2.17	8.86	14.77	15.99	22.23	32.79
34km	-5.95	-6.16	-3.25	-1.86	8.06	17.24	21.61	31.71	38.45
36km	-3.86	-6.1	-4.95	-1.88	8.82	16.69	23	35.59	43.53
38km	-5.13	-4.59	-4.93	-1.62	6.56	16.61	24.74	39.26	43.31

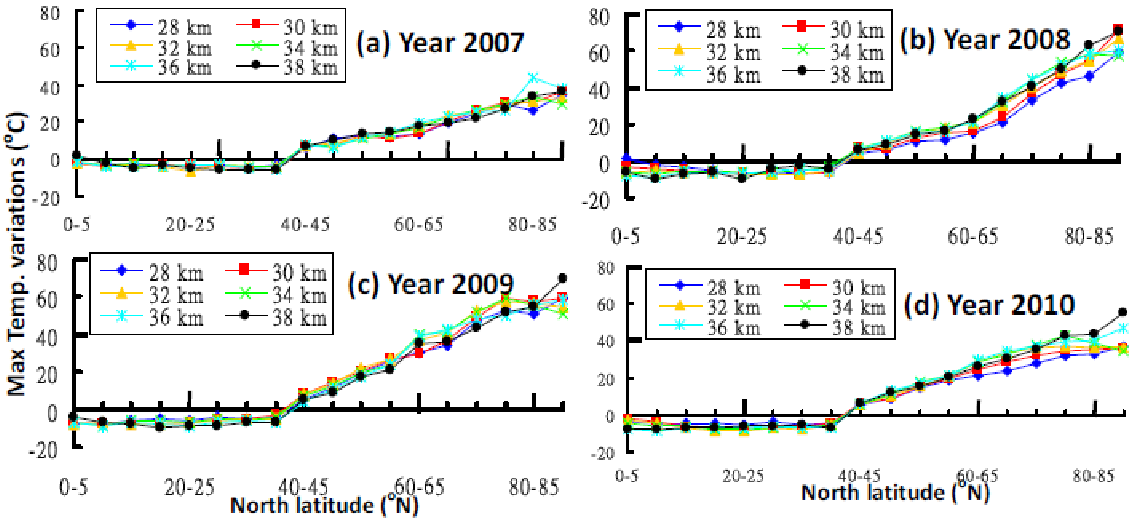


Fig.9-1 Temperature variations at different altitudes

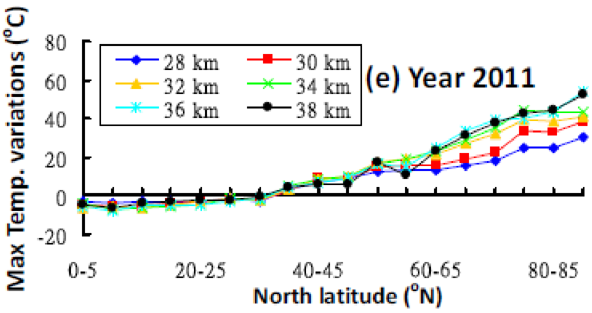


Fig.9-2 Temperature variations at different altitudes (2011)

According to **Fig.9**, as latitude increases, temperature increase becomes more obvious, and gets to its widest as the area of it reaches the center of the Arctic Circle. Moreover, among all the temperature increases, the two in 2008 and 2009, ranging from 85°N-90 °N, 180 °E-180 °W, are the most remarkable cases. Both of them come to their maximum by over passing regular temperature curve more than 70 degrees. However, at latitude below 40 degree north, temperature decreases slightly. To quantify this, we calculate the variation, and find that most of the decreases are 3-7 degrees fewer than normal, and even the most serious case in 2008, ranging 20°N-25 °N, 180 °E-180 °W, is only 9.462 degrees fewer compared to the regular.

Therefore, our first conjecture is hence as follow: the weakening or disappearance of the vortex in North Pole in the beginning of every year may causes the cold air to spread south from high-latitude regions, leading to the phenomenon of temperature increases in the Arctic and decreases in zones adjacent to the equator. And because the area in the low latitude is times bigger and wider than that in the higher latitude, the decrease could be slight since the cold air spread all over, which may possibly be diluted.

3. SSW between Years

This part could begin from **Fig.9-1** and **Fig.9-2** above. It could be found out in these two figures that there are noticeable differences between curves from 2006-2012. Increases in 2007, 2010, and 2011 tend to be lower than those in 2008 and 2009. In addition, the slope of temperature variation curves also differs between years, with 2007 slighter and smoother and 2009 sharper. Aside from this, it is also discovered that the influenced area in 2009 come to their temperature variation maximum from 70 °N to 90 °N. While in other years, only areas between 80 °N to 90 °N reach their maximum. These phenomena indicate that, among the observed years in this research, SSW influenced its surrounding most in 2009.

Besides, in a more detailed discussion, height 10 kilometers above the ground were mainly chosen, and a chart, **Fig.10**, was drawn to indicate how temperature variation of the area (66.5°N-90 °N, 180 °E-180 °W) changes during the SSW period in different years, since 2007 to 2012, with the x-axis representing “Years,” and the y-axis, “Temperature Variation.”

To begin with, temperature curves in **Fig.10** show that temperature variations in 2009 at each height are wider than those in other years. It is also likely for us to observe the aspect of cycle or the continuity between years from **Fig.10**. As it shows that the temperature variations become wider and wider from 2007 to 2009 and narrow down after 2009, we guess that the lines in **Fig.10** maybe could form a part of a cycle if the time scale continues for another 10 or 20 years. However, this supposition may be wrong, while SSW could possibly be a series of single events.

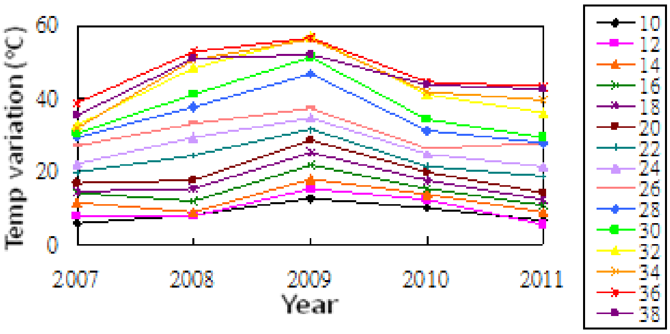


Fig.10 Temperature variations in different years

In short, it is assumed that SSW is periodic, but it takes further observation to verify this conjecture.

4. Further Discussion in the Southern Hemisphere

First, data from 66.5°S to 90°S, 180 °E-180 °W, were used for a series of diagrams to show if there is any similarity between northern and southern hemisphere. (**Fig.11**) The x-axis represents "Time(days)," and the y-axis represents "Temperature(°C)."

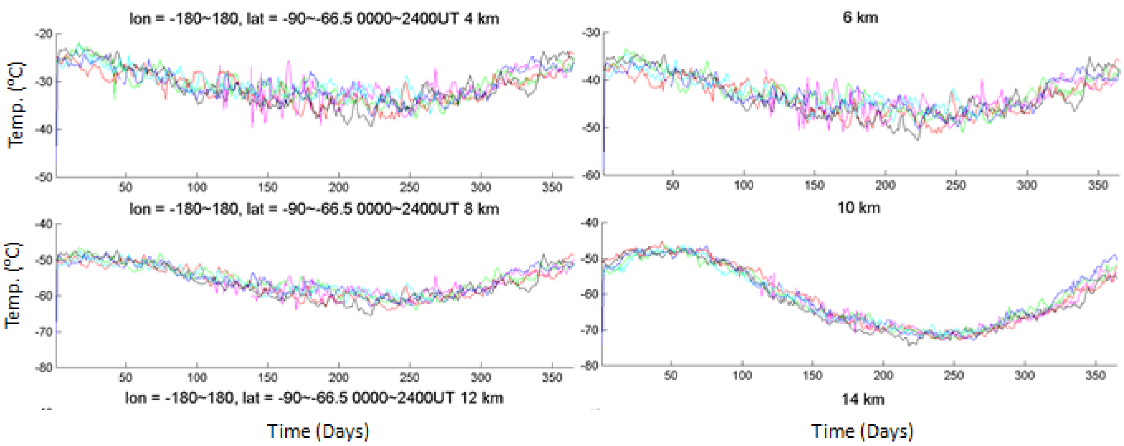


Fig. 11-1 Atmospheric temperature at 66.5-90°S, 4km-14km, from 2006 to 2012

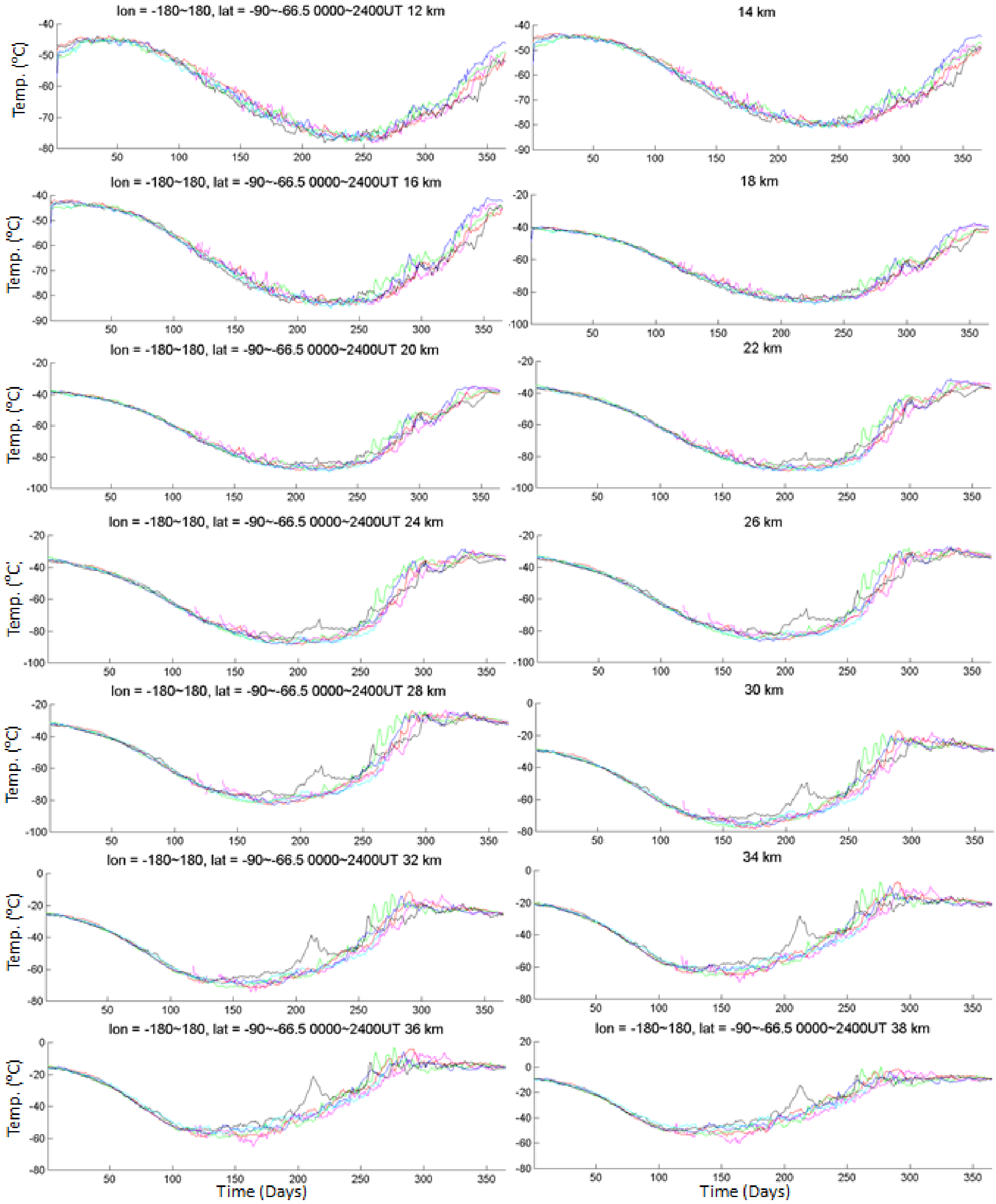


Fig. 11-2 Atmospheric temperature at 66.5-90°S, 4km-14km, from 2006 to 2012

Fig.11 indicates that temperature curves of high-latitude in northern hemisphere and the Antarctic region in the southern hemisphere seem to be up-side down because of the opposite seasons. And it could also be observed from **Fig.11** that there is a phenomenon, looking like SSW but not that drastic, happening in the south in the same seasons when SSW occurs in the north (from late winter to early spring).

Next, year 2009 is especially focused on since it is the year that SSW influences most in the northern hemisphere. Figures are drawn according to different latitudes (every 10 degrees) and different altitudes (every 2 km since 26km), **Fig.12 –Fig.18.** The x-axis represents "Time (days)," and the y-axis represents "Temperature(°C)."

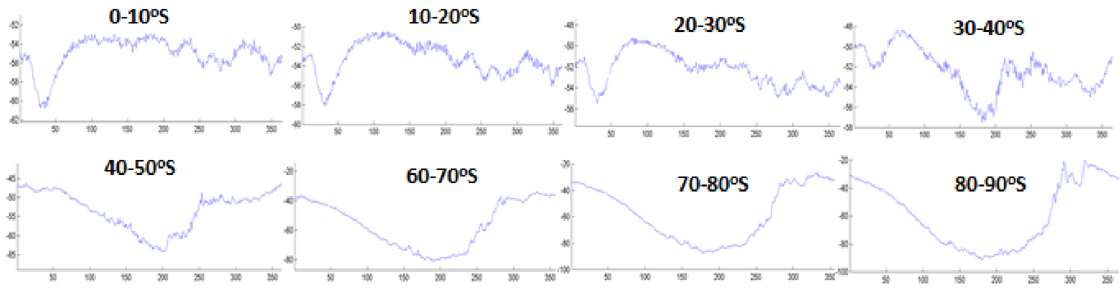


Fig. 12 Atmospheric temperature at 26km, 0-90°S (every 10 degrees), 2009

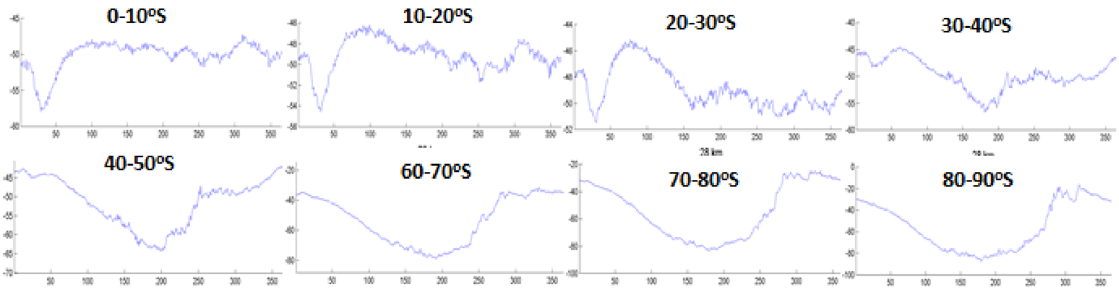


Fig. 13 Atmospheric temperature at 28km, 0-90°S (every 10 degrees), 2009

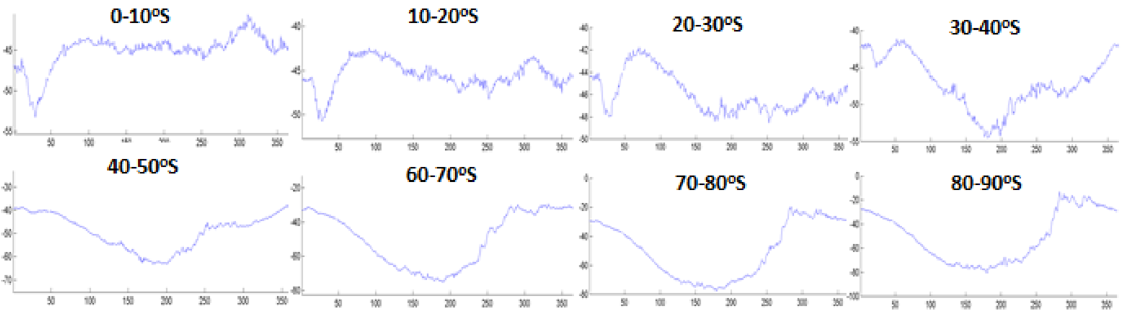


Fig. 14 Atmospheric temperature at 30km, 0-90°S (every 10 degrees), 2009

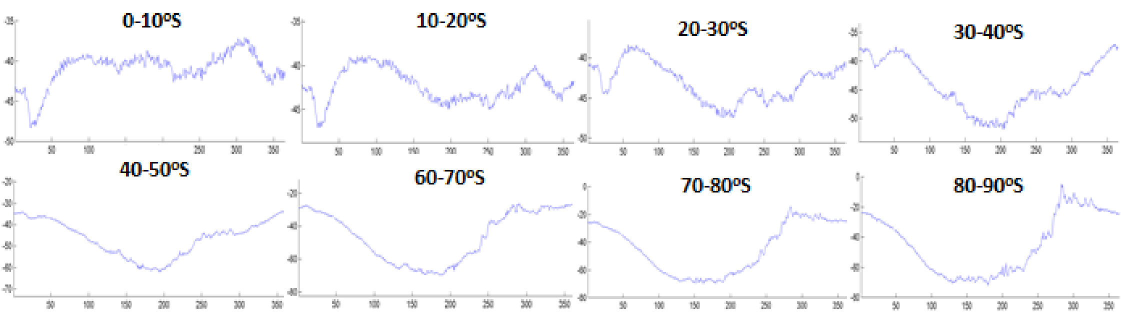


Fig. 15 Atmospheric temperature at 32km, 0-90°S (every 10 degrees), 2009

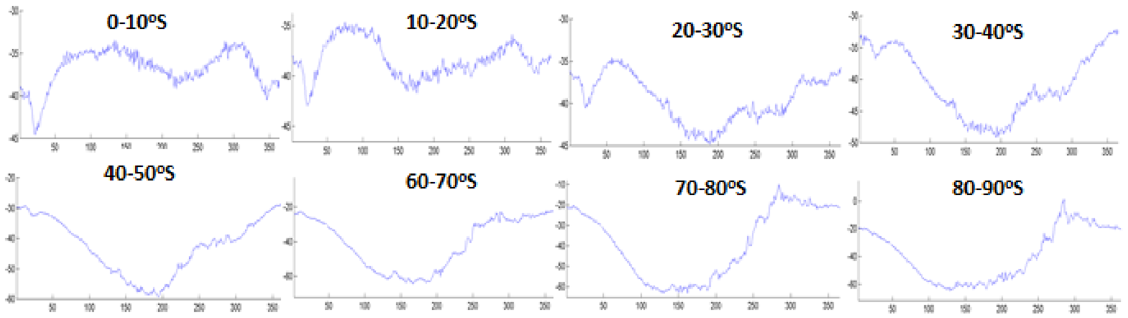


Fig. 16 Atmospheric temperature at 34km, 0-90°S (every 10 degrees), 2009

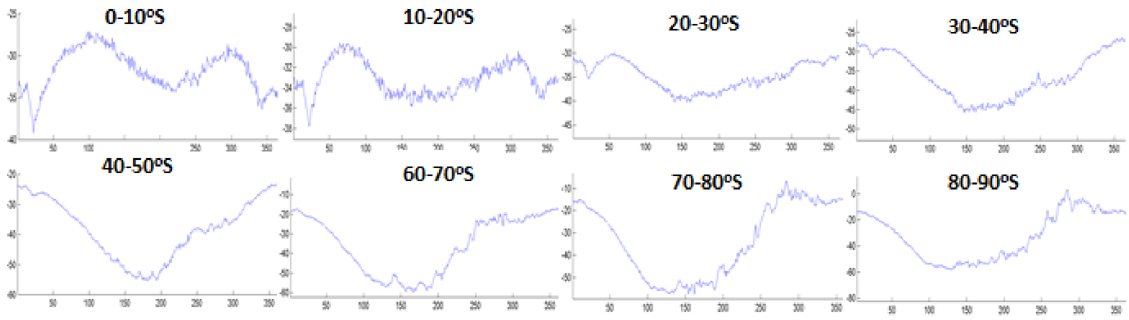


Fig. 17 Atmospheric temperature at 36km, 0-90°S (every 10 degrees), 2009

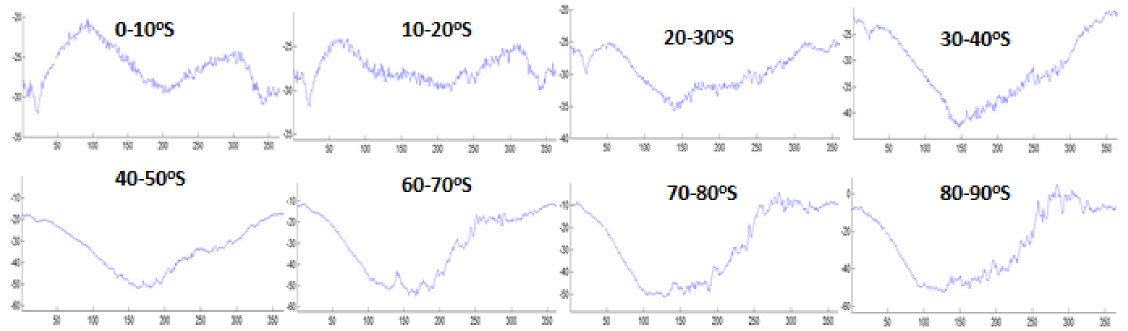


Fig. 18 Atmospheric temperature at 38km, 0-90°S (every 10 degrees), 2009

Then, the rapid decreases of temperature at low latitude in the beginning of 2009 (**Fig. 19(a)**) and increases of temperature at higher latitude in mid-2009 (**Fig.19 (b)**) were measured and presented in **Fig.20**. The x-axis represents "Latitude (°S)," and the y-axis represents "Temperature Variation Maximum (°C)."

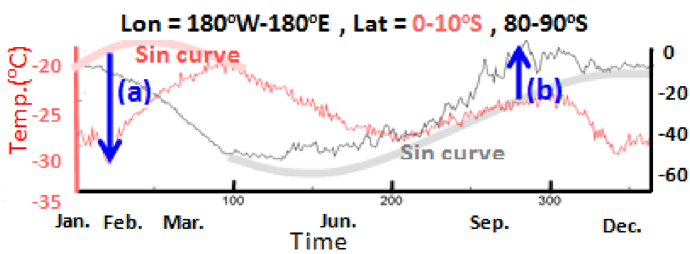


Fig. 19 Atmospheric temperature/ 2009, 38km, southern hemisphere

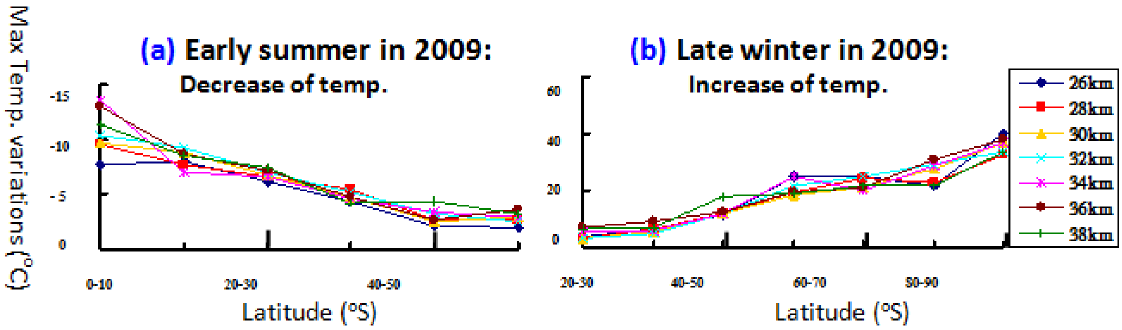


Fig.20 Max Temp. variations at different latitudes
(a)Early summer in 2009, and (b)Late winter in 2009

Fig. 20 shows that there are also corresponsive changes of temperature in southern hemisphere in SSW-obvious 2009. Within the first 100 days in 2009, during which SSW is most obvious in northern hemisphere, temperature in equatorial region of southern hemisphere decreases rapidly, though. And the most serious decrease of temperature could reach to 15 degrees lower than normal. In addition, during mid-2009's late winter to early spring, in the southern hemisphere, a phenomenon, likely the SSW, happens in the south. While the latitudes get higher and higher, the variations of temperature increase then become wider. It is therefore logical to make a supposition that there are some unknown atmospheric currents shifting the heat from equatorial region to high-latitude areas in northern hemisphere, which leads to SSW event.

5. The most noticeable SSW event (Case study)

To begin with, we calculate the entire temperature increasing events since 2007 to 2012.1, and name them by their happening years and appearing orders. For example, there are four apparent warming events during 2008; therefore, we named the four cases: 2008-A, 2008-B, 2008-C, and 2008-D. Exact happening time, influenced range, temperature increasing variation, lasting time, and whether the wind at Arctic reverse or not… etc. are all taken into consideration**.(Chart.7)**

Chart.7 Discussions about exact happening time, influenced range, temperature increasing variation, lasting time, and whether the wind at Arctic reverse or not

Cases	Happening time(Days)	Lasting time(Days)	Origination	Influenced range(Max)	Temp. Variation	Wind
2007-A	2006.315- 2006.325	11	126-146°W 53-62°N	42-171°W 50-75°N To 89°E-108°W 62-90°N	↑16°C	**W↓**
2007-B	2006.346.- 2006.352	7	77-109°E 30-48°N	79-166°E 55-78°N	↑22 °C	**W↓**
2007-C	2006.357- 2007.5	14	24-44°E 40-49°N	65°W-180°E 168-180°W 84-90°N	↑35 °C	**W↓**
2007-D	2007.7- 2007.10	4	44-62°E 43-57°N, 76-94°E 51-64°N	76-141°E 49-68°N To 98-177 °E 52-77 °N	↑27 °C	**W↓**
2007-E	2007.24- 2007.42	19	62-78 °E 25-45 °N	47-165 °E 51-71 °N To 12-79 °E 37-60 °N	↑30 °C	**W↓**
2007-F	2007.42- 2007.59	18	42-82 °W 54-67 °N	14-79 °W 53-80 °N To 43-67 °E 46-75 °N	↑34 °C	**E**
2007-G	2007.69- 2007.72	4	68-86 °E 46-56 °N	65-88 °E 45-76 °N	↑32 °C	**W↓**
(2007-H)	2007.89-	X	X	X	↑22 °C	**W↓**
2008-A	2008.13- 2008.27	15	10-44 °W 33-54 °N	47-83.9 °N 22-137 °E To 68-90 °N 180 °W-180 °E	↑34 °C	**W↓** **E**
2008-B	2008.28- 2008.39	12	56-81 °E 39-52 °N	20 °W-114 °E 40-81.5 °N To 130 °W-154 °E 56-90 °N	↑55 °C	**W↓** **E**
2008-C	2008.43- 2008.47	5	73-104 °E 28-41 °N	61-114 °E 37-81.4 °N	↑52 °C	**E**
2008-D	2008.48- 2008.56	9	11°W-41 °E 37-51 °N	36-82 °N 15 °W-75 °E To 53 °W-39 °E 39-67 °N	↑48 °C	**E**
2008-E	2008.66- 2008.76	11	86-98 °E 30-44 °N	21-102 °E 29-56 °N	↑31 °C	**E**

Cases	Happening time(Days)	Lasting time(Days)	Origination	Influenced range(Max)	Temp. Variation	Wind
2009-A	2009.17- 2009.32	16	60-89 °E 42-60 °N And 111-126 °E 53-60 °N	96 °W-114 °E 43-90 °N To 175 °W-127 °E 55-90 °N, 67-111 °E 38-76.6 °N	↑83 °C	**E**
2010-A	2009.326- 2009.345	20	46-69 °E 41-52 °N	26-146 °E 39-60 °N To 56-164 °E 56-68 °N	↑12 °C	**W↓**
2010-B	2010.13- 2010.36	24	21-77 °E 39-55 °N	7-122 °E 47-78.9 °N To 33 °W-73 °E 44-84.5 °N	↑47 °C	**W↓** **E**
2011-A	2010.335- 2010.337	3	80-102 °E 47-58 °N	71-115 °E 58-73 °N	↑20 °C	**W↓**
2011-B	2010.343- 2010.350	8	4-45 °E 41-60 °N	62°W-19 °E 29-52 °N	↑13 °C	**W↓**
2011-C	2010.362- 2011.8	11	42-61 °E 49°-59 °N	9 °W--129 °E 39-73.8 °N To 19-114 °E 61-90 °N And 9-90 °W 24-52 °N	↑23 °C	**W↓**
2011-D	2011.8- 2011.14	7	2 °W-15 °E 39-52 °N	21-85 °E 60-76.8 °N To 14-140 °E 61-78.6 °N	↑27 °C	**W↓**
2011-E	2011.15- 2011.18	4	36-55 °W 24-39 °N	19-94 °W 42-70 °N To 48-80 °W 45-72 °N	↑26 °C	**W↓**
2011-F	2011.25- 2011.33	9	90-129 °E 42-57 °N	46-82 °N 62-154 °E	↑24 °C	**W↓** **E**
2011-G	2011.36- 2011.37	2	126-139 °E 60-71 °N	34 °W-30 °E 81-85 °N	↑32 °C	**W↓**
2011-H	2011.42- 2011.48	7	70-89 °W 42-49 °N	25-89 °W 54-70 °N	↑31 °C	**W↓**
2011-I	2011.66- 2011.72	7	5-18 °E 77-80 °N	104 °W-60 °E 68-82 °N	↑39 °C	**W↓**

(Wind: E↓:eastern wind weaken/ W: eastern wind disappear, and western wind appear)

Besides, we draw a series of temperature distribution in global view during SSW occurrences from 28km to 38km above ground. While **Fig.21** stands for events happening in 2009, at the height 38km(for example), with the x-axis represents "Longitude (°E/ °W)," and the y-axis represents "Latitude (°N/ °S).

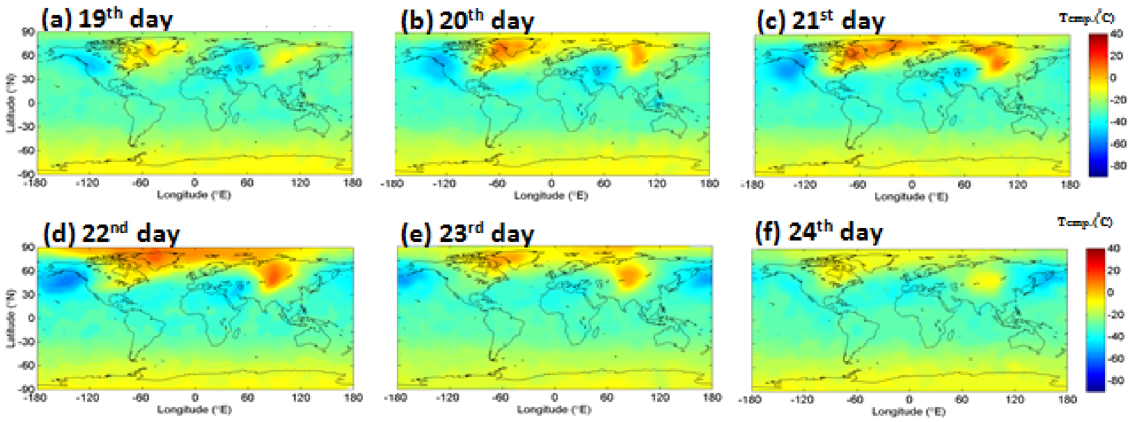


Fig.21 temperature distribution from 19th day to 24th day in 2009, 38-38.9km

Then, to observe influenced area and how SSW evloves, we cut the high latitude areas, put them together and make another figure, **Fig.22**.

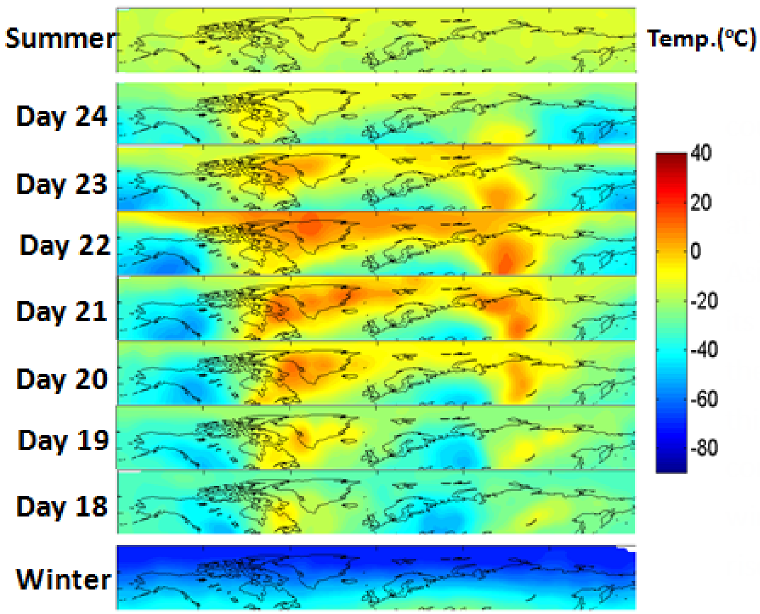


Fig.22 Evolution of temp. distribution during SSW event at 38km, 45-90°N, 2009

According to Fig.22, we could see that the case happening in 2009 started at Greenland and central Asia. At day 22, it came to its peak, which influenced the whole Arctic Circle. At this moment, temperature, comparing to the normal winter temperature figure, rise from -80°C to 20°C.

Therefore, we use the same way as we did in **Fig.22** and draw **Fig.23**, **Fig.24**, **Fig.25**, **Fig.26**, picking only obvious SSW events during these years.

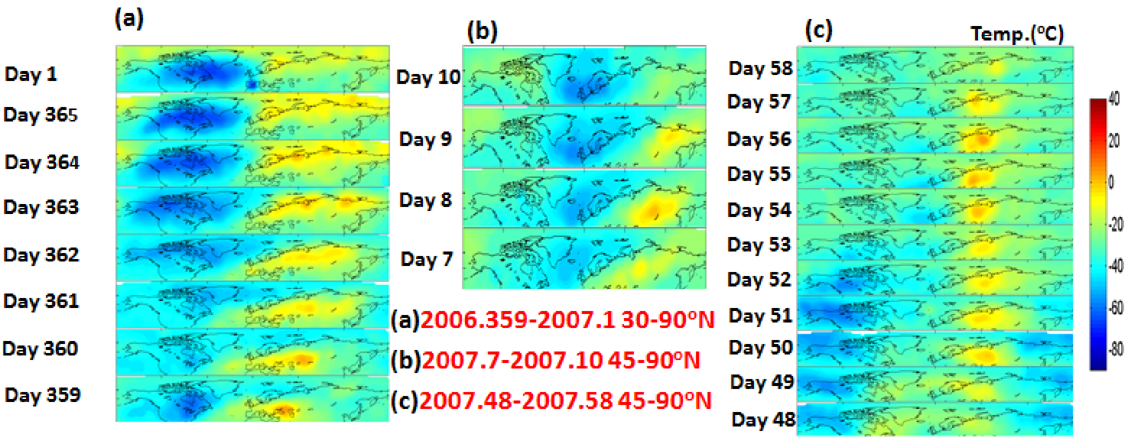


Fig.23 Evolution of temp. distribution during SSW event at 38km, 2006-2007

In **Fig.23**, we picked three obvious events during 2006 winter to 2007 spring. First, it could be found that SSW events do not have regular lasting time; instead, in 2006-2007, one of the events lasted for 4 days, but still some of them lasted for more than 10 days.

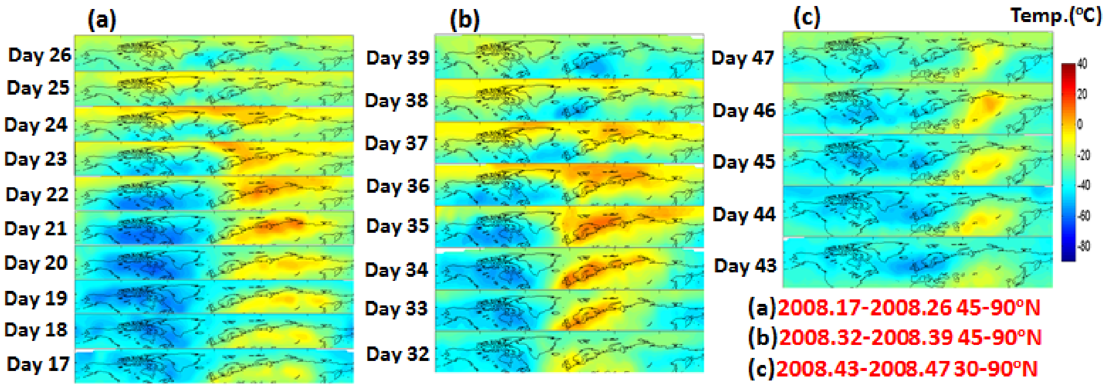


Fig.24-1 Evolution of temp. distribution during SSW event at 38km, 2007-2008

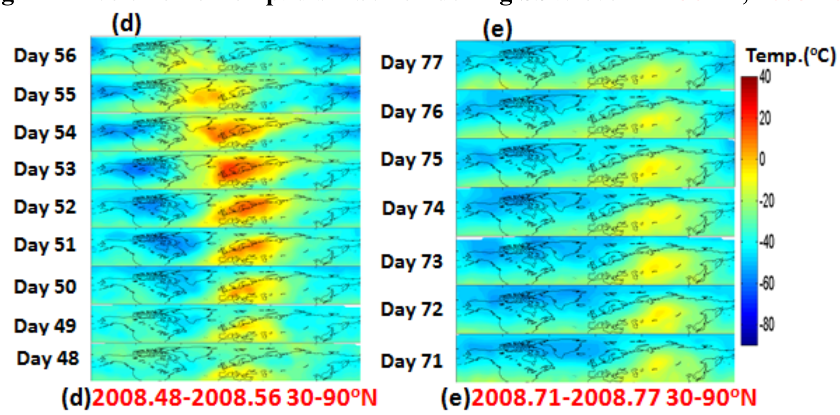
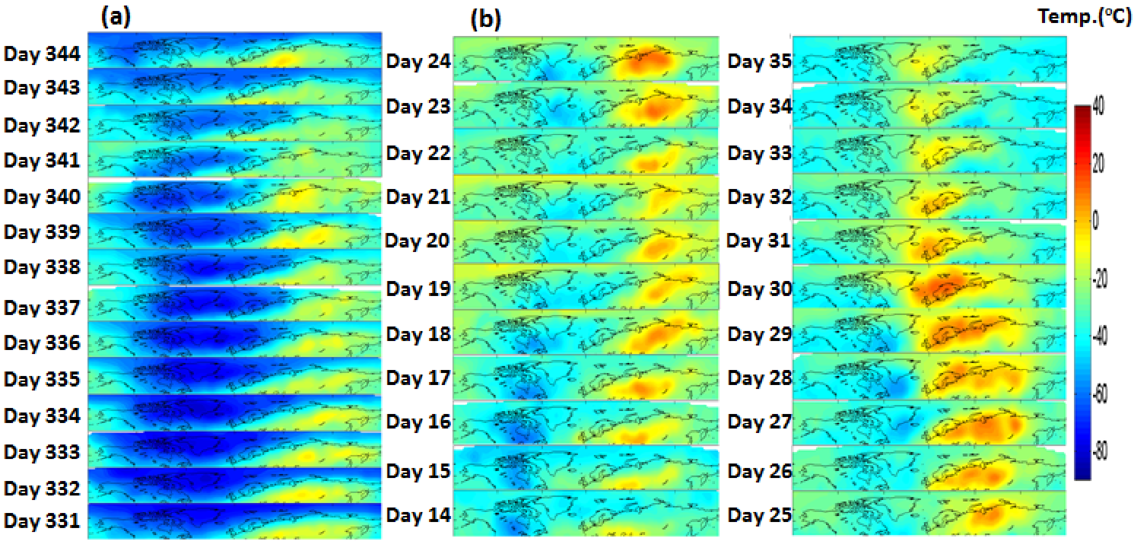


Fig.24-2 Evolution of temp. distribution during SSW event at 38km, 2007-2008



(a)2009.331-2009.344 30-90°N (b)2010.14-2010.35 45-90°N

Fig.25 Evolution of temp. distribution during SSW event at 38km, 2009-2010

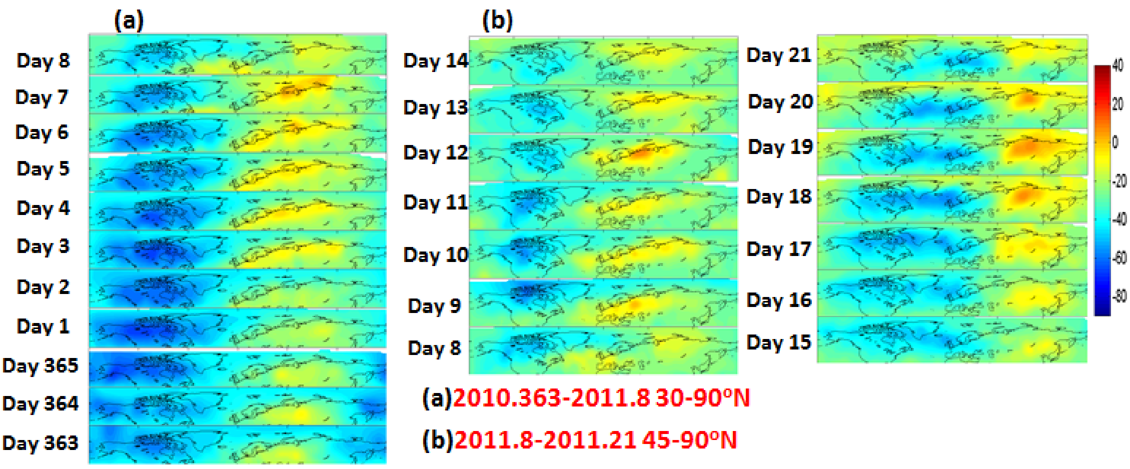


Fig.26 Evolution of temp. distribution during SSW event at 38km, 2010-2011

According to **Fig.24, Fig.25, Fig.26** , SSW mostly originated from Eurasia.and the temperature rose from -70°C to almost 20°C during the period. In contrast, Anglo-America tends to be low-temperature area, whose temperature stayed stably between -60°C to -40°C even when SSW occurred.

Last but not least, we picked some of the serious events and drew a series of figures using free bar(the range of the color bars below were chosen according to specific areas and time, so the color bars are different between one another). In this way, SSW could be better discussed, and the origin height of SSW could be also found. Follows are **Fig.27** and **Fig.28.**

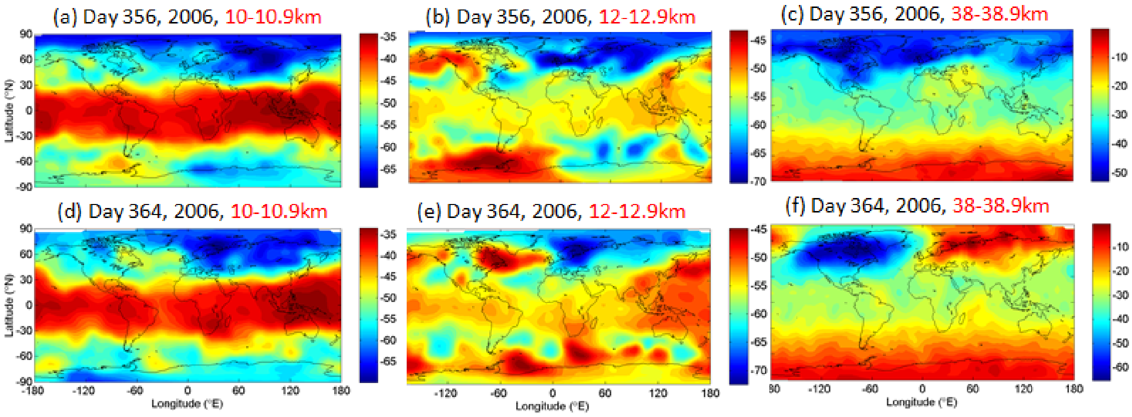


Fig.27 Temp. distribution during the origin of SSW:
(a), (b) and (c), and the peak of SSW: (d), (e) and (f), at 10, 12 and 38 km, 2006

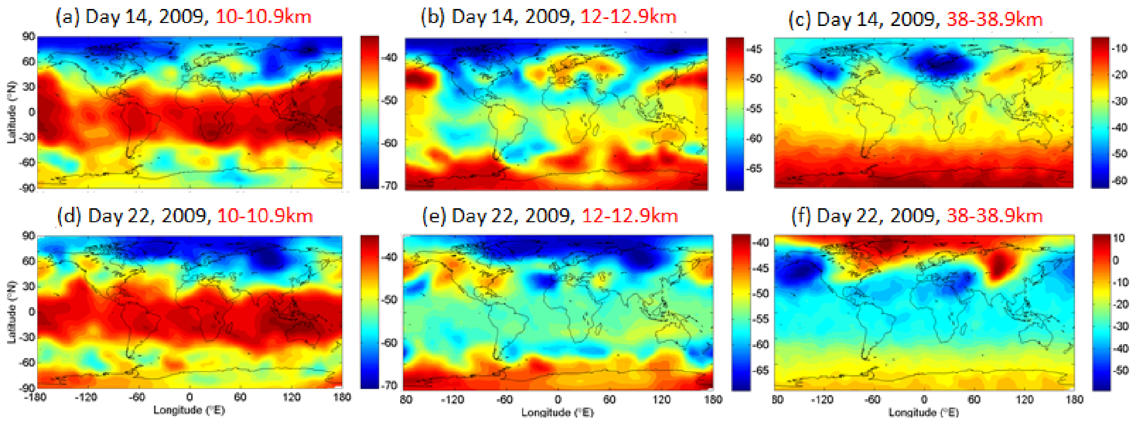


Fig.28 Temp. distribution during the origin of SSW:
(a), (b) and (c), and the peak of SSW: (d), (e) and (f), at 10, 12 and 38 km, 2009

It could be found out from **Fig.27** and **Fig.28** that at low altitude, temperature varies according to the region, as equatorial areas in high temperature and polar regions in low temperature. However, when it gets to stratosphere, temperature distributes according to seasons. For example, from the figures above, the northern hemisphere keeps in low temperature during its winter time.

Figures above also show the origin height of SSW. When the planetary wave, which contains energy and propagate from low to high altitude, reach the same velocity as the mean flow, the energy would then spread out, transform into thermal energy and heat the atmosphere(Schoeberl, 1978). Therefore, from **Fig.27** and **Fig.28**, it could be deduced that 10km may be where the two reach the same velocity since the temperature started to increase.

Conclusion

1. When and where SSW happens

(1) Period: SSW mainly happens from 350th day to 100th day next year every year, still few cases occuring in early winter and late spring. And the maximum of the temperature variation happens mostly during 25th to 60th day.

(2) Height: It's difficult to observe SSW in low altitude areas; however, there are apparent increases of temperature at heights from 30 kilometers to 38 kilometers. Moreover, 10km is also found to be the origin height that reveal the starting of SSW.

(3) If we define the severity of SSW by its temperature variation, the most noticeable event would be the one happening in 2009. But if we then compare all of the events' temperature variation to the wind, 2008 stands out because all of the events during that year not only had drastic temperature increase, but also caused the western wind to weaken and reverse.

2. The impact of SSW on the northern hemisphere:

Temperature increases in regions above 40 degrees north, and as it comes closer to the Arctic, the range of increases becomes more obvious; by contrast, temperature decreases in regions below 40 degrees north, but the range of temperature decrease is narrower.

3. Origination and Evolution of SSW

(1) Several SSWs originated from Central Asia and Siberia, and then spread to North Circle and Europe, and some even spread across mid-latitude(30-40 °N). Besides,

the obvious events in 2008 and 2009 both originated from Greenland(45-80°W, 60-75°N) and Siberia(89-97°E, 52-78°N), and evolved into a wide-ranged warming around the North Pole.

(2) SSW happens in high-latitude regions in both northern and southern hemispheres in the same seasons, from late winter to early spring, but temperature increase in northern hemisphere is far more conspicuous than that in southern hemisphere.

(3) Temperature rapidly decreases in both north and south equatorial region in the beginning of 2009. It suggests that during this period of time, heat may possible shift from equatorial region to high-latitude areas in northern hemisphere, and the shift of heat might leads to the occurrence of SSW events.

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評語

本研究希望利用分析福衛三號之平流層氣溫觀測數據來了解導致冬季高緯平流層快速增溫（SSW）的物理機制。福衛三號提供非常詳盡的四維時空大氣觀測數據。照理說，應該可以根據這些四維時空大氣觀測資料，找出造成導致冬季高緯平流層快速增溫的物理機制，也就是可能的因果關係。可是即使對專業的科學家而言，分析與展示四維時空觀測數據，仍是一個正在研究開發的技術。更何況對初次接觸這麼龐大之觀測資料的高中生而言，更是一個非常不容易的工作。如果這些學生們對 SSW 的可能物理機制，有一些了解，或許可以降低其分析資料的困難度。可是現有的 SSW 理論模式，多建立於早期資料不全的時代。因此即便學生們完全不依賴現有的 SSW 理論機制來分析觀測資料，仍是一個值得肯定的做法。

建議：

（一）本研究報告中，似乎將研究過程中嘗試過的研究結果，都羅列出來了。建議需要做一些取捨與刪減、或補強，讓分析結果的展現更精簡更有條理與邏輯性。例如 pages 15-23，同類型的研究成果，只需要展現一組，然後就可以用統計的方式，綜合展示不同地區的大氣溫度垂直分布情形。

（二）圖 59 之圖說有誤。

（三）第 3 頁倒數第 5 行：福衛三號不是國家太空中心的“第三個衛星”，是“第三個衛星計畫”。

（四）建議重寫中英摘要。若能寫得更專業更聚焦一些會比較好。

優點：

利用福衛三號衛星的觀測探討平流層之急劇增溫現象（SSW），為非常好的主題，資料為台灣學界之努力成果，可應用於全球性之重要議題。

缺點：

對於 SSW 現象的背景了解尚不夠，故在研究方向上並沒有很好的掌握到重點，

僅能就圖表中的現象做描述，討論也就無法較深入，此點較為可惜。

建議改進事項：

1、加強對 SSW 的基本了解，可幫助設定較好的研究與討論方向。

2、圖三可見較高處的 SSW 較早出現並漸向較低處傳播（以'09 為例），SSW 對對流層之影響為近年的研究重點之一。

3、P.11-20 的討論有些失焦，目的亦不明，應挑選'09 年事件前後，針對個案討論（NH 的，類似圖 60-68，會較佳也較有意義。