High Resolution Numerical Modelling of a distinct extreme weather “Cold Surges” near Hong Kong region

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Outline

- ***Introduction to "Cold Surges"***

- ***General Synoptic pattern of North East Monsoon and advent of "Cold Surges"***

  Brief overview of the synoptic pattern in South China Sea
  Importance of Cold Surges and their impact to society: Recent Event
  Modelling Challenges associated with "Cold Surges"

- ***Case Study : Hong Kong "Cold Surge" event using Numerical Modelling Approach***

  Introduction to the Case Studies
  WRF Model Experimental Design & Configuration
  Model Performance & Evaluation
  Summary of Results

- ***Conclusions & Future Work***

1. Introduction to “Cold Surges”

Introduction to "*Cold Surges*"

- **Origin:**

  - *With the intensified pressure system over the SH, a strong pressure gradient is established between the SH and SCS. This result in outbreaks of cold air masses from East Asia land mass that intensifies the north easterly winds over the SCS*

- **Characteristics:**

  - *They are recognized as one of the distinct extreme weather events during the North East Monsoon. They are characterized by strong northeasterly winds, sharp temperature drop and increased surface pressure.*

- **Frequency of Occurrence:**

  - *They occur once or twice in a month and may continue to last from a few days to one week or even more. During their occurrence, they can cause heavy freezing precipitation and snowfall. The stronger and more intensified northerly surges further lead to strong convective activities over SCS.*

In Hong Kong these events are identified as "cold surges" or "Northerly Surges" !

Unique features of SCS

- **Biggest marginal seas in the world**: Circulation in this region is mostly driven by surface winds

- **Weather dominated by three major Monsoon System:** *Asian-Australian, East-Asian* and *Western- North Pacific* Monsoon systems.

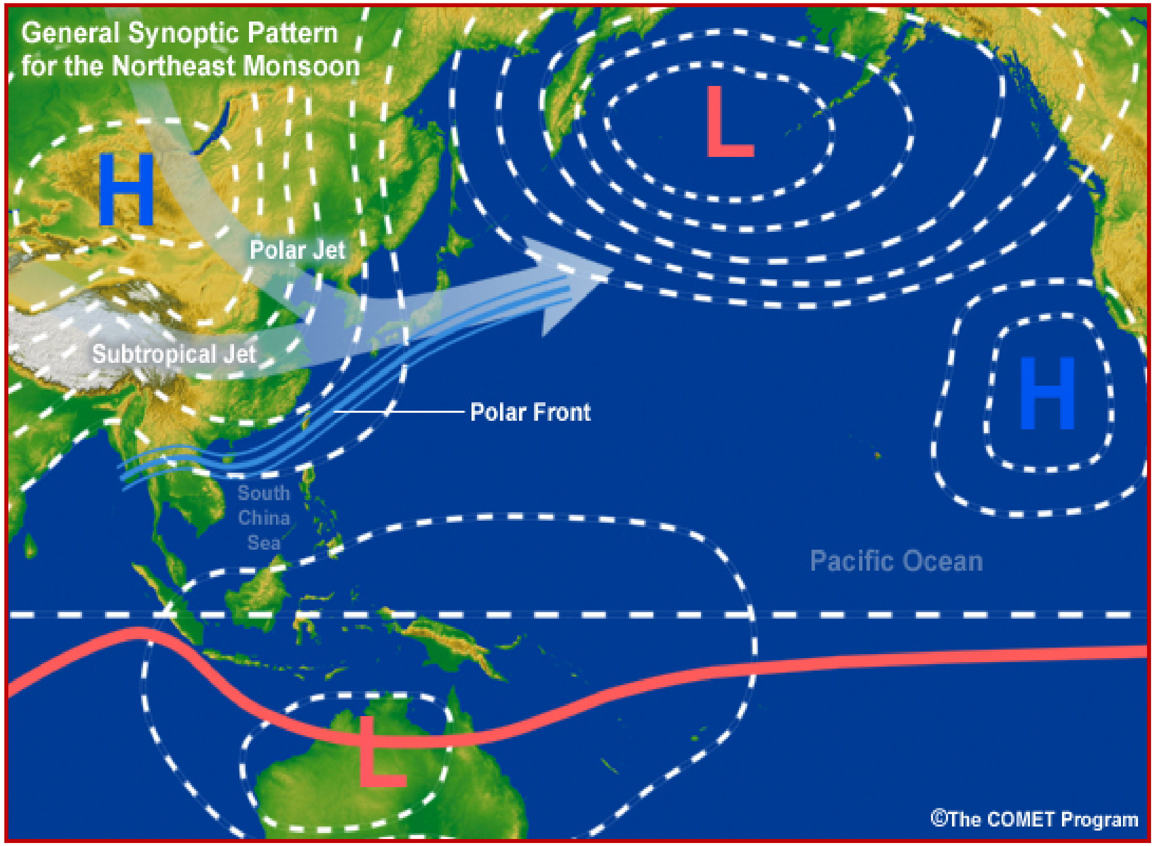
- **Most dominant Monsoon System**: East-Asian Monsoon System (SWM-Summer Monsoon & NEM-Winter Monsoon)

- **Most severe threat each year:** Intense and frequent weather systems as Strong Monsoonal winds, Tropical Cyclones and Fronts during NEM & SWM.

- **Understanding of Weather Extremes & Climate Variability**: A Major challenge for Scientific Community.

2. General synoptic pattern of NEM & Advent of “Cold Surges”

General synoptic pattern: NEM



Source: http://meted.ucar.edu

- NEM prevails from Nov-March (Dry, Rainy seasons & Cold surges)
- SCS under the influence of strong SH & active CSs
- Max strength in January & Min in April due to weakening of SH & AL
- Polar Jet most evident. Merging of Polar jet with subtropical jet

  -Very high wind speed EA

  -Cyclogenesis in SCS
- The SCS region is highly influenced by synoptic weather systems as TCs and fronts
- In April NEM coincides with movement of ITCZ

Interaction of cold surges & tropical Warm water: Cold Surge Vortex !

Severe Impact of of Cold Surges

- Cause *heavy rainfall and floods* in coastal areas of SCS.
- Considered to *strengthen cyclonic disturbances* north of Borneo coast.
- Cold Surge Vortex can result in *extreme rainfall events* in the coastal SCS region
- Associated with acute temperature drop and that has caused *immediate adverse effect on human health (Yang et al. 2009)*
- Cold surge in year 2008 (10 Jan-5 Feb): Resulted in *4 billion US dollar economic losses, damage of 11867 kilo hectares of crops and killed 129 people* in southeast china (DCAS/NCC/CMA 2008; Zhao et al 2008): *Asia-Pac J. Atmos. Sci. (2015)*

Major impact of 2008 Chinese Ice Storm

An unprecedented storm that inflicted direct economic losses exceeding U.S.$20 billion !

Categories		Description (destroyed or otherwise stated)	Source
Human life		129 dead, 1.7 million displaced	Zhao et al. (2008)
Infrastructure	Power grids	36,740 high-voltage transmission lines; 8,381 towers; 2,018 transformer stations	China Electricity Council (2008)
	Communication systems	35,000 telephone poles; 20,000 mobile phone base stations	News Office of the State Council (2008)
Food production	Agriculture	40% of the winter crops in China, 75 million livestock (mostly poultry)	Ministry of Agriculture (2008)
	Apiculture	30% of bee colonies in Zhejiang Province	Jin et al. (2008); Li and Wang (2008)
	Aquaculture	3.4 million pairs of broodstock, 0.42 million tons of fingerlings, 0.45 million tons of adult fish	Ministry of Agriculture (2008)
Forests		20 million hectares with >10% standing volume loss, 10% of national forest cover, 3% of national forest standing volume	Forest Resources Management Department (2008)
Wildlife		No systematic survey but dead wild animals widely seen in natural reserves	Song (2008); S. Wang et al. (2008)
Buildings		0.5 million collapsed, 1.7 million partial damage	Zhao et al. (2008)

Source: BAMS, Jan 2011

"An extreme event lasting days can undo socioeconomic and ecological structures decades in the making".

Modelling Challenges for Cold Surges in SCS

- **Circulation pattern** : Regional Weather near SCS is mostly dominated by the localized surface winds

- **Modelling localized Winds & Storms**: Modelling through GCMs tends to be spatially wider and less windy than observation.

  - Reasonable large weather pattern information
  - Poor localized weather information due to smoothening of land surface representation
  - Low temporal resolution to capture region specific mesoscale process

"Most severe weather occurs at the mesoscale, often forced by topography or coastlines, or are related to convection".

3. Numerical Modeling approach

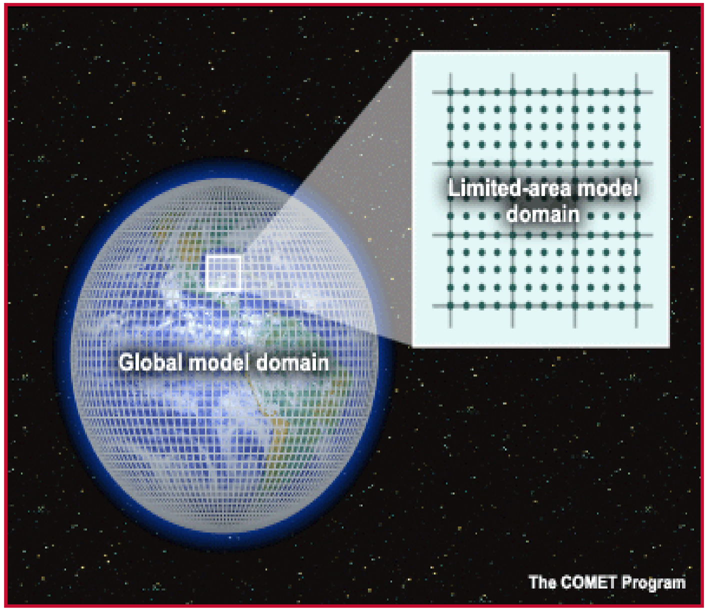
Dynamical Downscaling Technique

❖ **GCMs:**

-Based on well established physics & models
- Reproduces past weather & predicts future weather
- Wider grid spacing of approx. 100 km or more

(A major limitations in predicting mesoscale process !)

❖ **Dynamical Downscaling:**



Source: http://www.meted.ucar.edu/

- Reliable prediction of a Regional weather by Limited Area Model.
- Needs Initial & boundary conditions from GCMs.
- LAM includes components that influences the local weather.
- These LAMs run at varying horizontal resolution with grid spacing typically less than 30 km

Weather Research & Forecast Model (WRF)

- **Model:** Three dimensional regional *Numerical Weather Prediction*
- **Dynamical cores:** *Advanced Research WRF (ARW)* and *Non-Hydrostatic Mesoscale Model (NMM).*
- **Purpose:** Research in Atmospheric science & Real time forecast.
- **Developers:** *National Centre for Atmospheric Research, National Centre for Environmental Prediction, National Oceanic & Atmospheric Administration, University of Oklahoma, Forecast System Lab, Air Force Weather Agency*, and *Federal Aviation Administration.*

Important applications of WRF Model

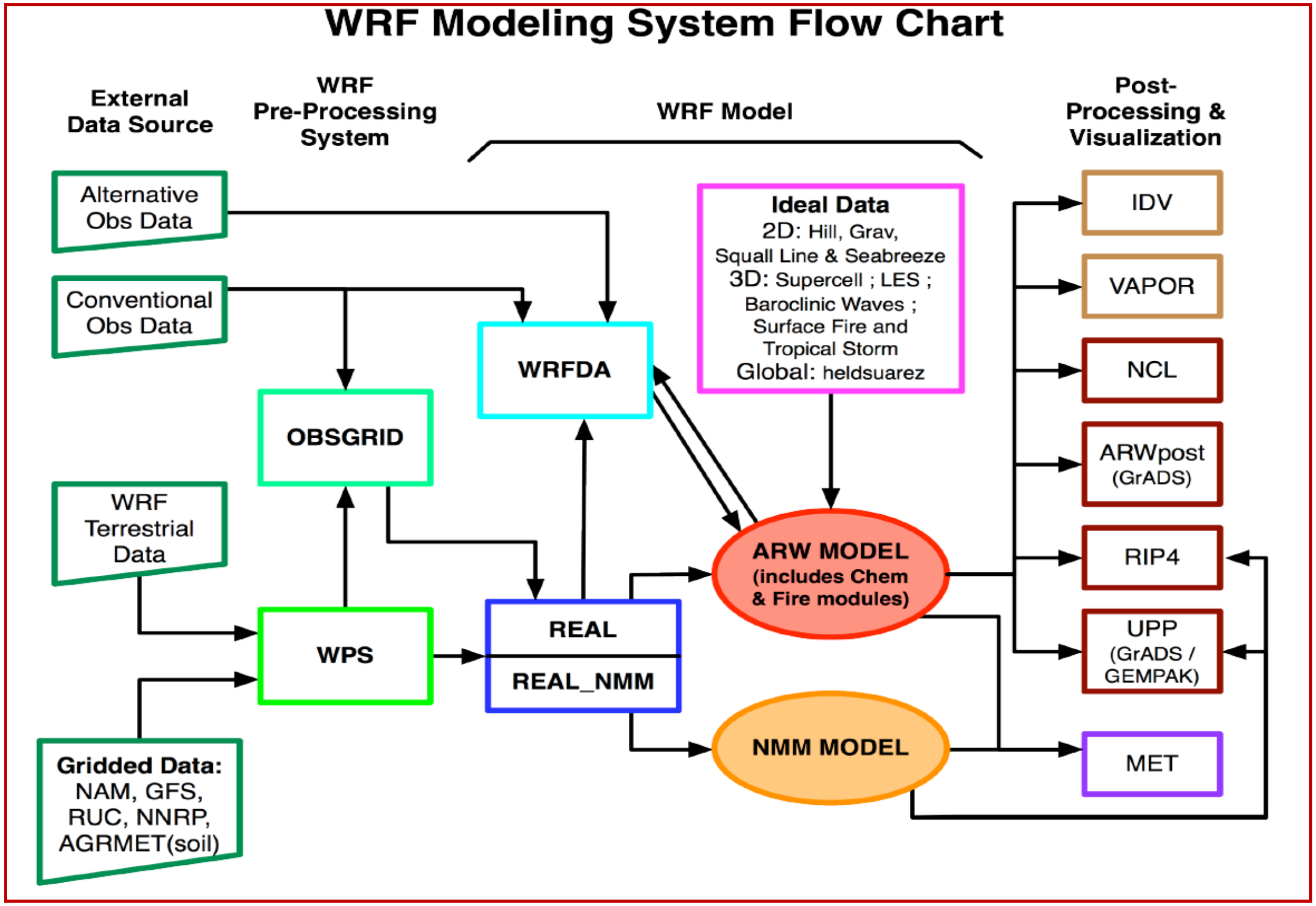
- WRF Model is considered to be suitable for a broad range of applications ranging from tens of meters to the global and includes the following:

  - Meteorological research & Real-time NWP
  - Data assimilation studies and development
  - Coupling with other earth system models

- WRF Model has been efficient in capturing the following Natural Hazards:

  - Modelling extreme rainfall, strong winds and surges from Tropical Cyclones (hurricanes/ typhoons/cyclones)
  - Monsoonal Winds, Flood (Rainfall), Droughts
  - Tornadoes, Hailstorms, Blizzards, Ice storms
  - Thunderstorms, Thermal extremes
  - Extra Tropical Cyclone (windstorm)

Structure of WRF Modelling System



Source: http://www2.mmm.ucar.edu/wrf/users/model.html

4. Case Study of “Cold Surges” Event near Hong Kong

Some Classical Definitions of Cold Surges

- A sudden drop in daily temperature is one of the key indications of a cold surge outbreak, and previous studies have used this as a main criterion of cold surge detection (Wang and Ding 2006; Ding et al. 2009).
- The most direct indicators of a cold surge occurrence over East Asia are the strengthening of the Siberian High and the subsequent abrupt surface temperature drop within 2 days (Zhang et al. 1997).
- In general, the cold surges are regarded as the only temperature decrease. In a case over East Asia, however, the definition of cold surges includes an amplification of the Siberian High (i.e., a sudden surface pressure change) as well as an abrupt temperature drop (e.g., Zhang et al., 1997a; Jeong and Ho, 2005; Park et al., 2011).
- An intense outflow causing a widespread outbreak of cold continental air, accompanied by strong northeasterly winds and sharp drops in surface temperature is called a “cold surge” (Wu and Chan 1995)

Criteria for identifying Cold Surges

- The Korea Meteorological Administration (KMA):

  - 1-day temperature drop of 10 ^{0}C as the cold surge criterion at their main observing station.
  - Ryoo et al. (2005) used a 2-day temperature fall larger than 7.5 ^{0}C for the whole of South Korea

- Chen et al. (2002) and Lu et al. (2007) selected the Pengehiayu station (25.63 N 122.07 E) in Taiwan as the reference point to define the criteria for cold surges:

  -The surface pressure increases at least 5 hPa,
  - surface temperature drops at least 4 ^{0}C,
  - and surface wind speeds increases at least 3 m/s in a 24-48 hour interval.

- A cold surge onset registered at HKO is defined to meet one of the following criteria:

  -Temperature drop during the past 24 hours exceeds 2 ^{0}C; or
  - Mean temperature during the next 6 hours is 2 ^{0}C or more less than the 24- hourly mean temperature recorded 30 hours ago.

Introduction to Case Study

- **Event being studied :** "Cold Surge" between 23-25 Jan 2016 near HK, between 24th Jan 2008 to 16th Feb 2008 and Cold front on 15th Dec 2009

- **Definition:** *Most distinct extreme weather events*. Widespread outbreak of *extremely cold continental air* that induces *extremely damaging frosts, snow, and ice storms*.

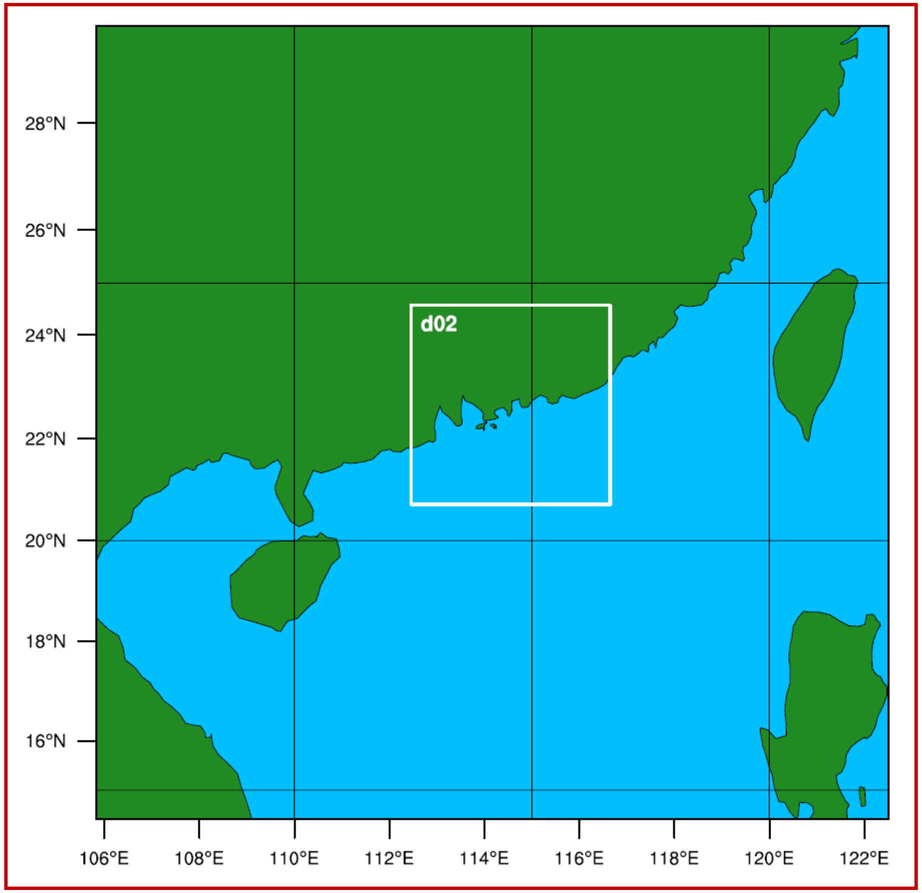
- **Past study:** Cold surges have been mostly studied using the observational meteorological data (e.g. Chen et al. (2004)).

- **Recent developments:** Study of the past events using *satellite data* (Alpers et al. 2015).

- **A new approach to study cold surge:** Cold Surge event near HK is analyzed using:

  -Reanalysis Data Set (ECMWF 75 x 75 km, FNL $1^0 \times 1^0$)
  -Satellite Data Product (ASCAT-25 km)
  -High Resolution WRF Model V3.7 at Spatial resolution of 9km & 3 km and Temporal resolution of 1 hr.

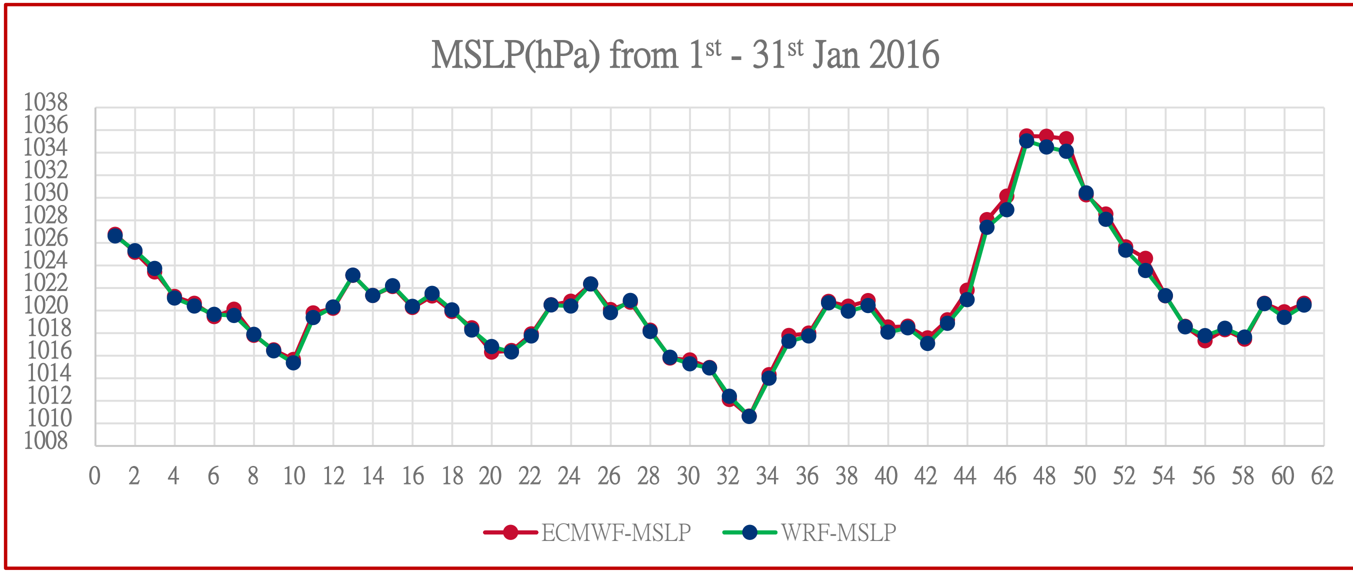
Model set up & Experimental design based on sensitivity experiments

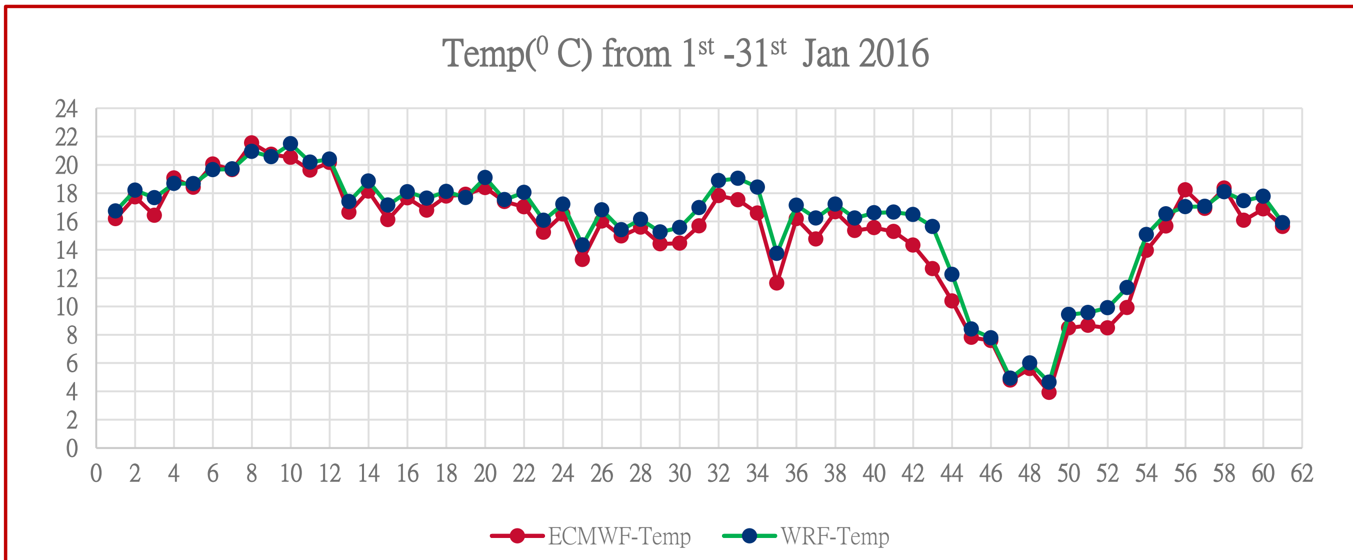


- **Domain: d01**-9km; **d02**-3Km
- **27** vertical levels; Top pressure level: **50hPa**
- **31 days** simulations from:
  - -Jan 1st 00:00 UTC to
  - -Jan 31st 00:00 UTC
- Model predictive skill tested

WRF Model domain centered at location of Hong Kong Observatory (22◦ 18’ 07’’ N; 114◦ 10’ 27’’ E)

Comparison of Model MSLP & Temp with ECMWF at HKO





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Model skill score in predicting weather over HKO

A. 12 hours predictive skill scores of MSLP over HKO for the period from 1st Jan -31st Jan 2016

	Mean sea level pressure (hPa)	Mean errors (hPa)	Root mean square errors errors (hPa)	Correlation coefficient
ECMWF	1020.828			
WRF	1020.640	-0.188	0.407	0.997

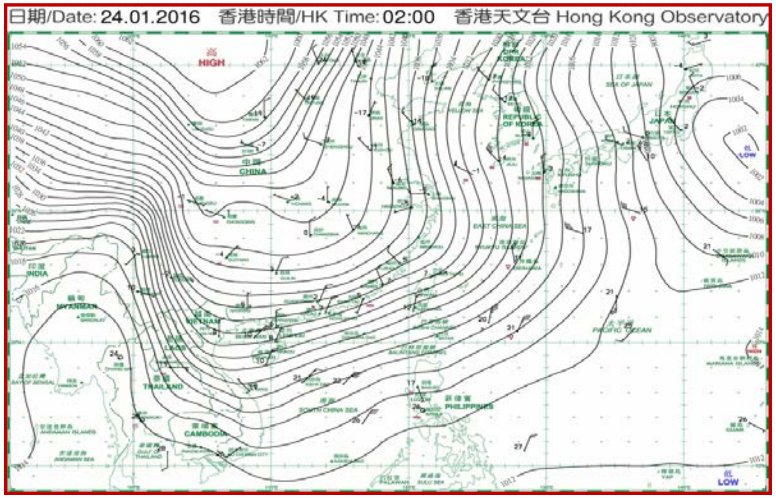
B. 12 hours predictive skill scores of Temp at 2m over HKO for the period from 1st Jan -31st Jan 2016

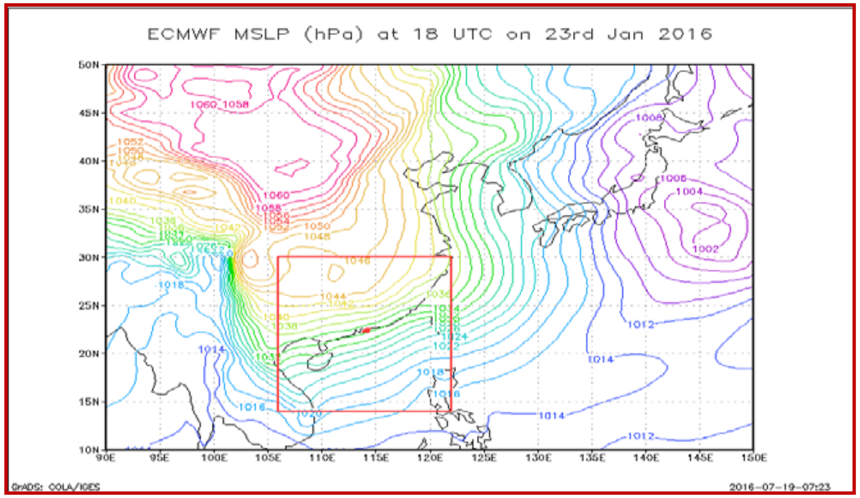
	Temp at 2 m (^{0}C)	Mean errors (^{0}C)	Root mean square errors errors (^{0}C)	Correlation coefficient
ECMWF	15.277			
WRF	16.029	0.752	1.027	0.984

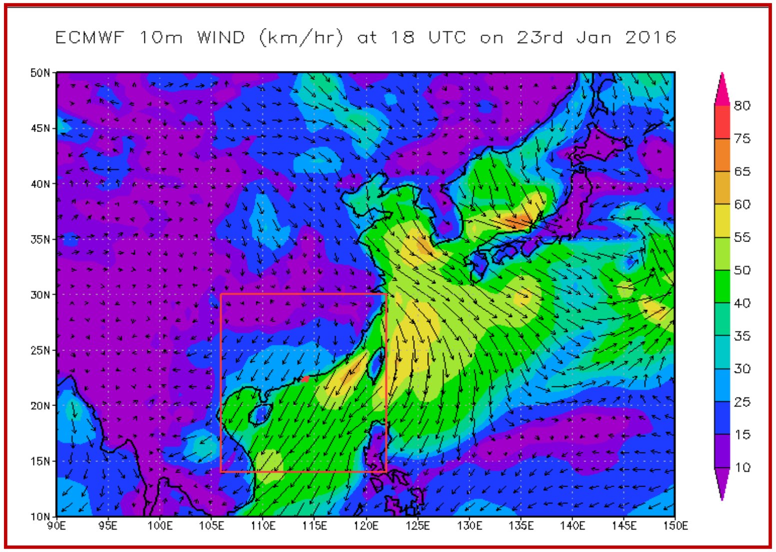
4.1 Case Study of “Cold Surges” Event 1 near Hong Kong

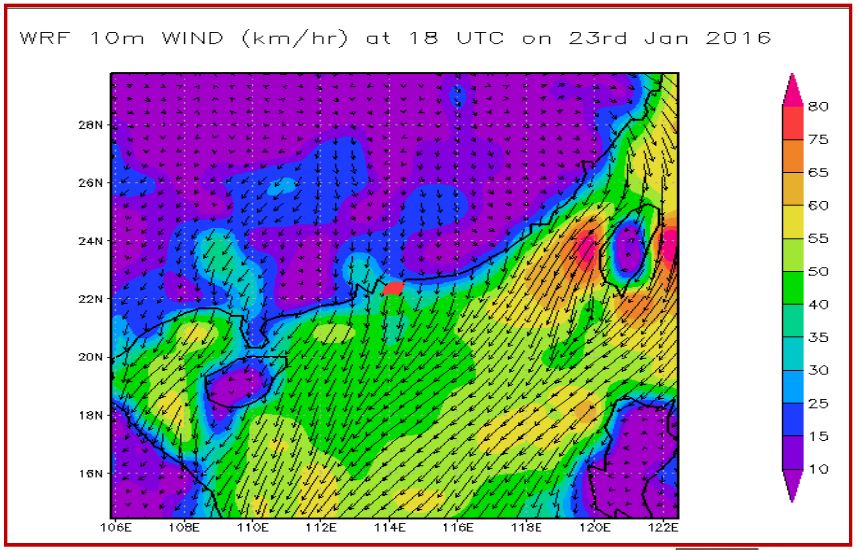
Event Occurrence Date	***: 24th Jan 2016***
Model Initialization Date	***: 23rdth Jan 18 UTC***
Model end run Date	***: 24th Jan 06 UTC***
Model predictability frequency	***: Hourly***

Comparison of Model analysis with HKO Weather Chart & Reanalysis Data on 23rd Jan 2016 at 18 UTC









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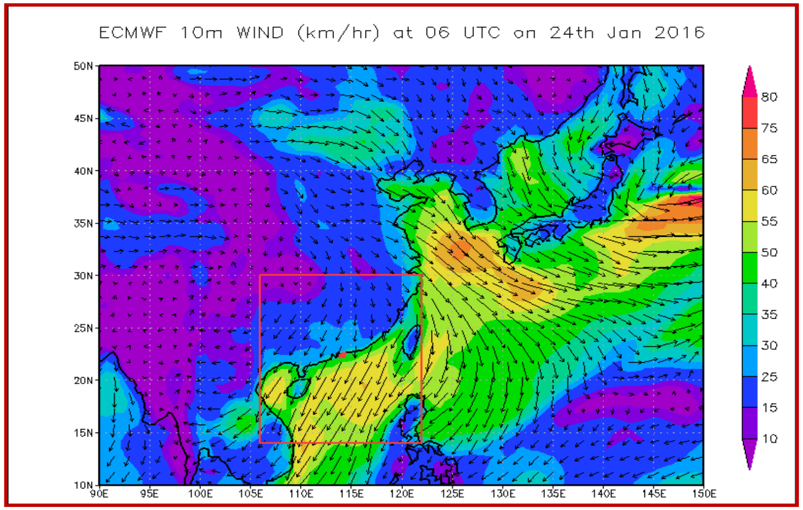
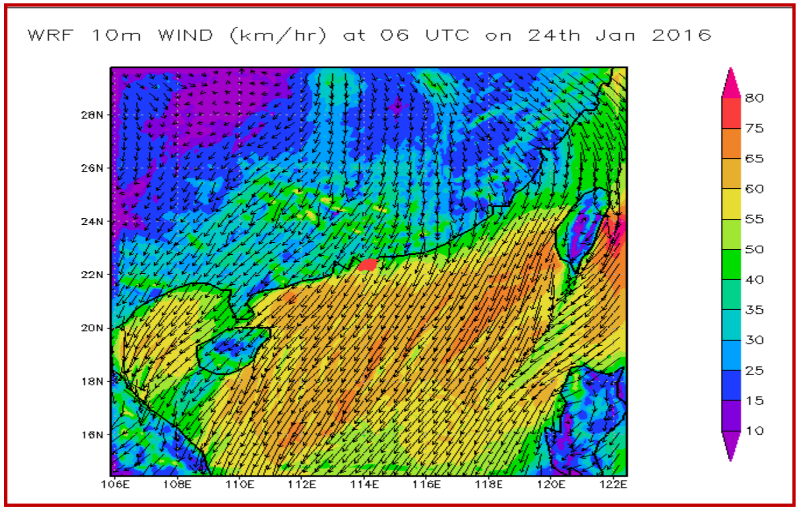
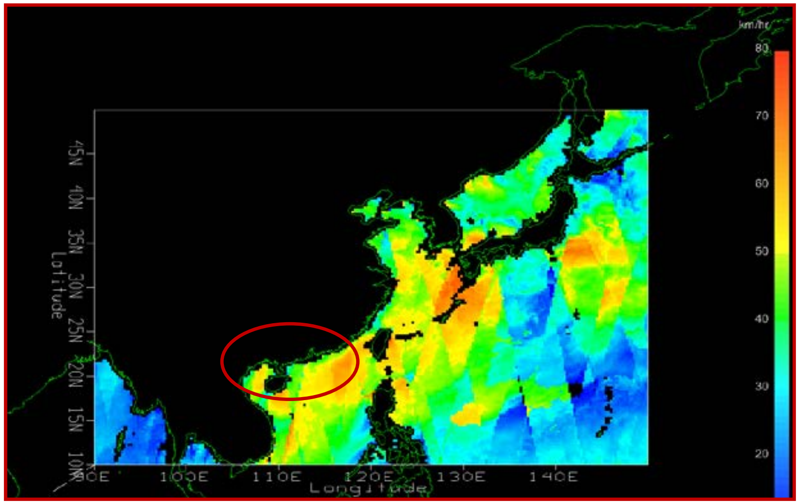
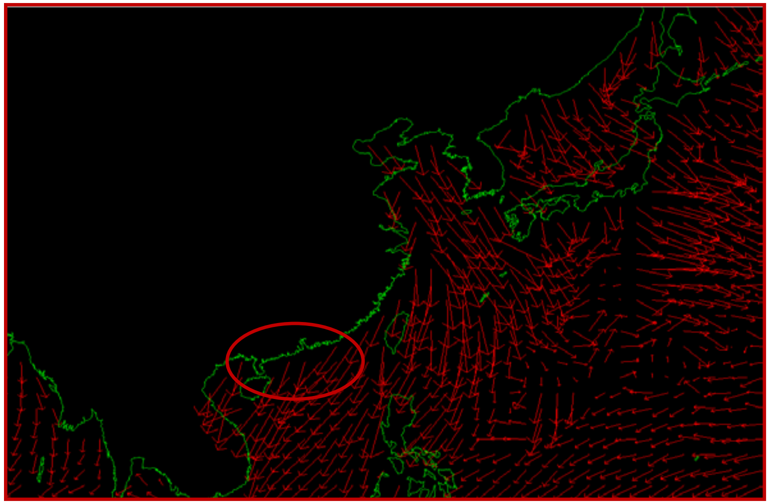
Comparison of Model prediction with ASCAT & Reanalysis Data on 24th Jan 2016 at 06 UTC





ASCAT winds at 12 UTC on 24th Jan 2016





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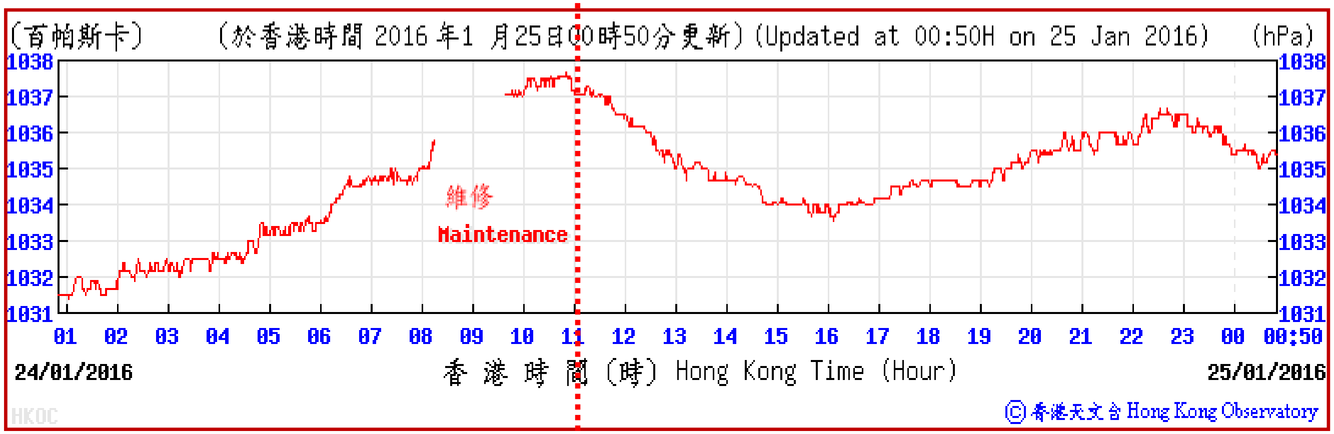
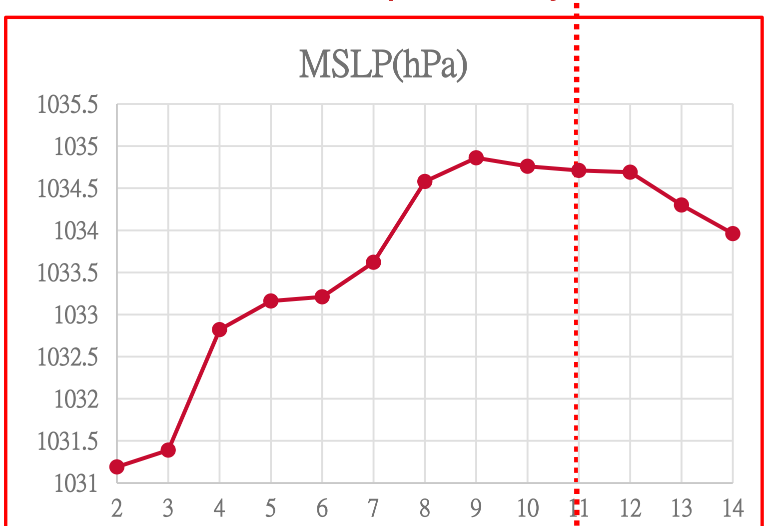
Observed & Predicted values at HKO (22 ⁰ 18′ 07″ N, 114° 10'27″ E) on 24th Jan 2016

Time Series of MSLP



- MSLP of **1037.7 hPa** was the *highest ever recorded pressure at HK Observatory.*

Time Series of 12 hr. MSLP prediction by WRF



Number	HK-Local	UTC
2	2:00 AM	18
3	3:00 AM	19
4	4:00 AM	20
5	5:00 AM	21
6	6:00 AM	22
7	7:00 AM	23
8	8:00 AM	0
9	9:00 AM	1
10	10:00 AM	2
11	11:00 AM	3
12	12:00 PM	4
13	1:00 PM	5
14	2:00 PM	6

- MSLP of **1034.81 hPa** predicted at HKO at 11 am on 24th Jan.

Source: http://www.weather.gov.hk

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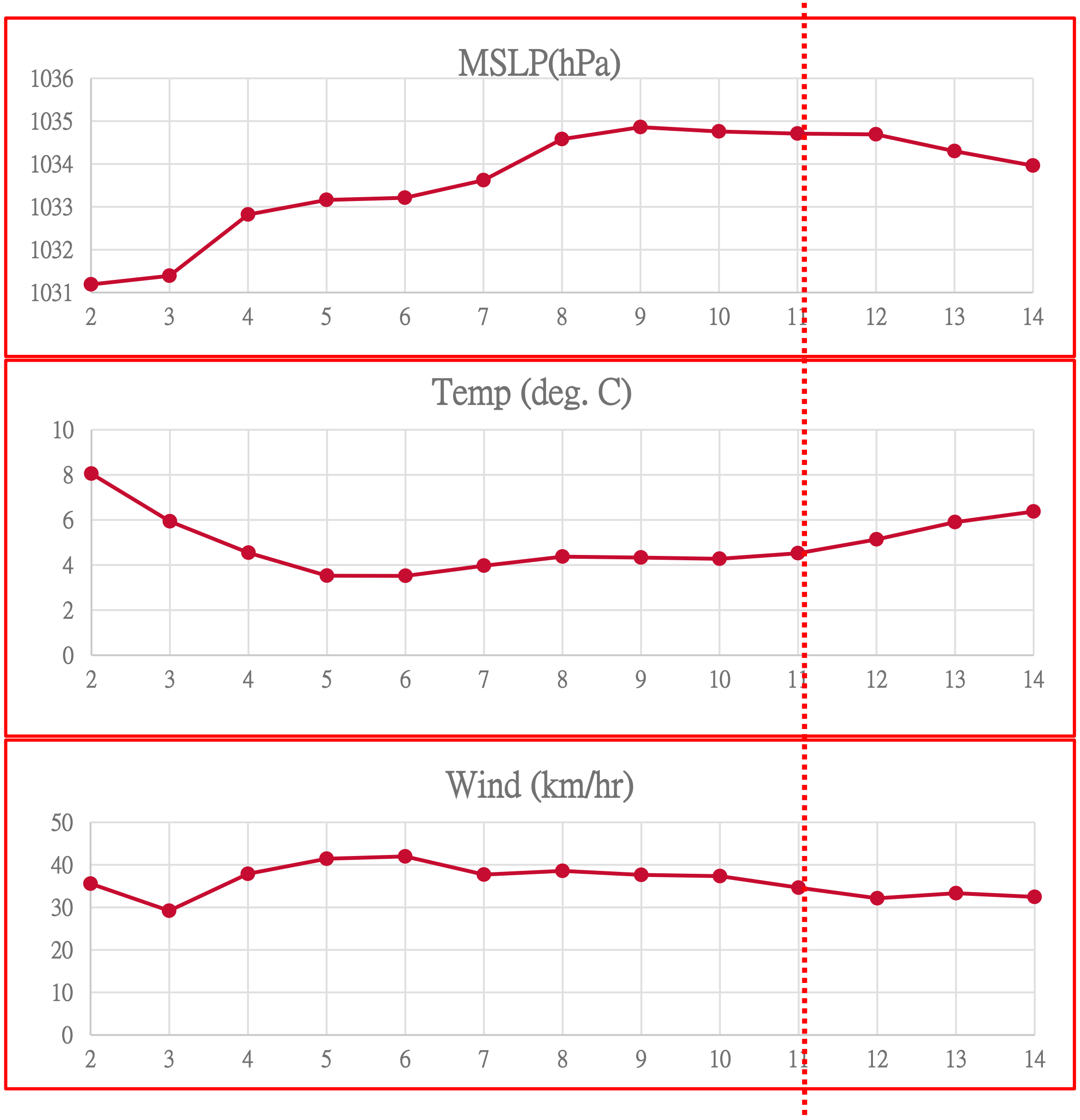
Predicted values at HKO (22 ⁰18′ 07″ N, 114° 10′27″ E) on 24th Jan 2016

Time Series of MSLP

Time Series of Temp

Time Series of Wind



Number	HK-Local	UTC
2	2:00 AM	18
3	3:00 AM	19
4	4:00 AM	20
5	5:00 AM	21
6	6:00 AM	22
7	7:00 AM	23
8	8:00 AM	0
9	9:00 AM	1
10	10:00 AM	2
11	11:00 AM	3
12	12:00 PM	4
13	1:00 PM	5
14	2:00 PM	6

- Lowest temp of **3.516 ^{0}C** predicted at 6 am on 24th Jan.
- Max MSLP of **1034.86 hPa** predicted at HKO at 9:am on 24th Jan.

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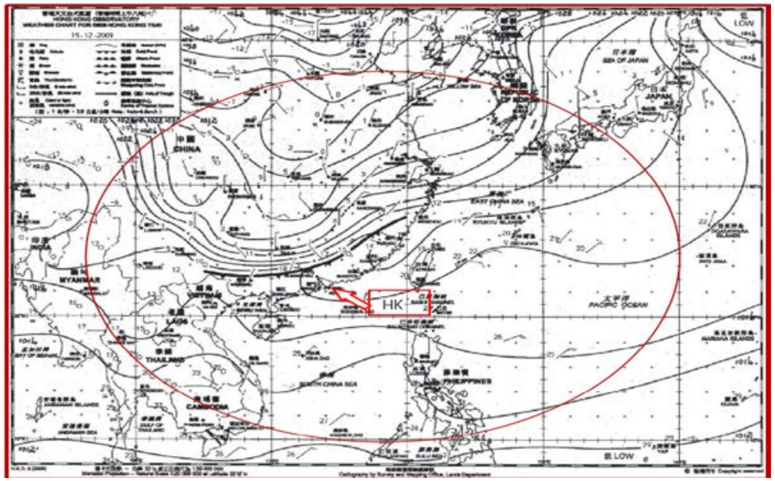
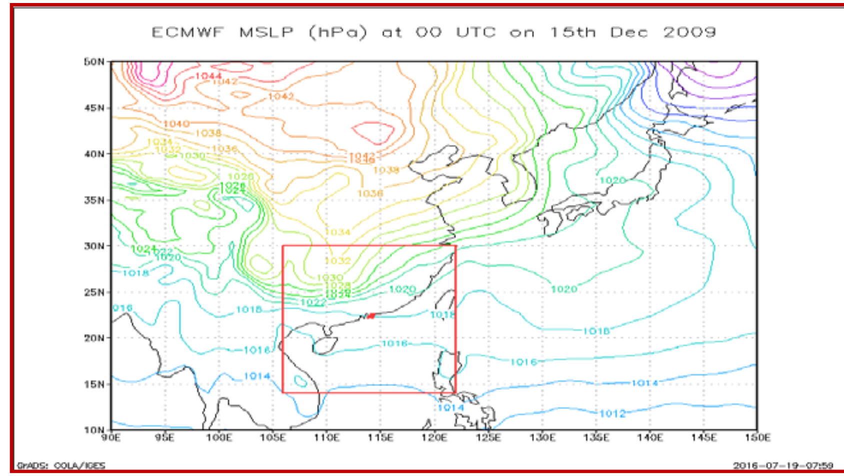
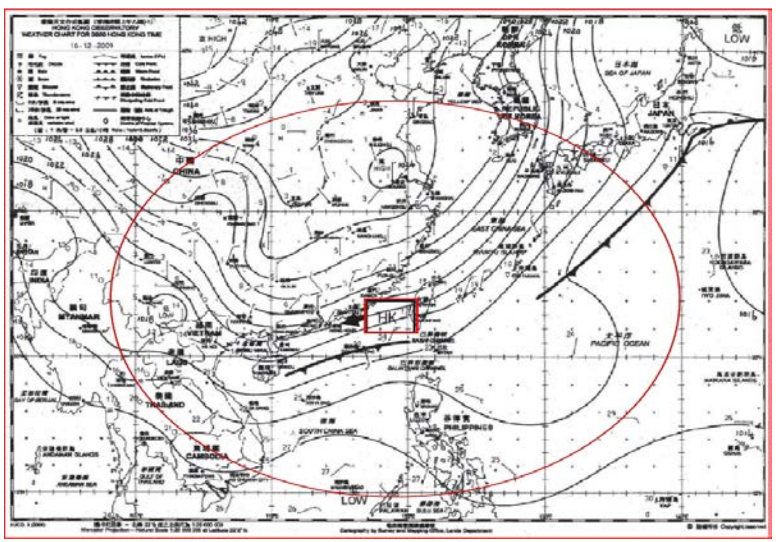
4.2 Case Study of "Cold Surges" Event 2 near Hong Kong

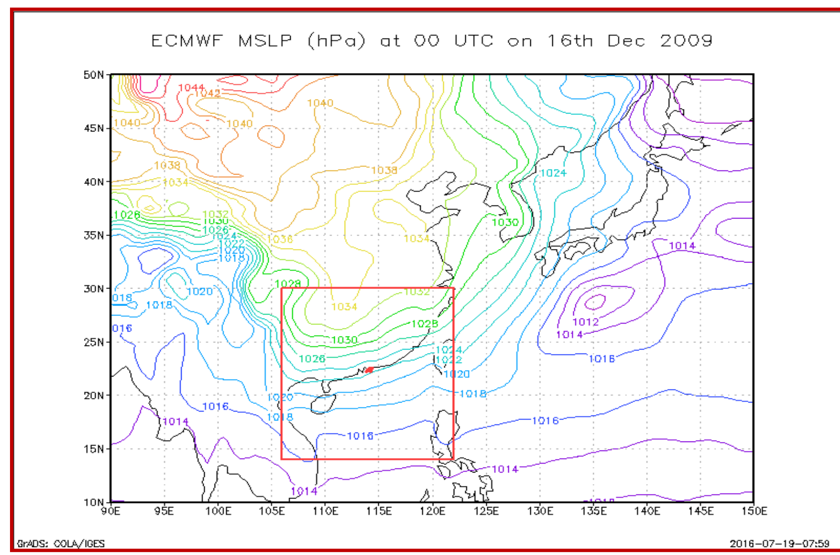
Event Occurrence Date : 15th Dec 2009
Model Initialization Date : 15th Dec 2009 at 06 UTC
Model end run Date : 15th Dec 18 UTC
Model predictability frequency : Hourly

Event description based on Synoptic Situation at 00 UTC of 15th Dec and 00 UTC of 16th Dec 2009









Weather Chart of South East Asia at 00 UTC on 16th Dec 2009 (reproduced from Alpers et al. (2012))

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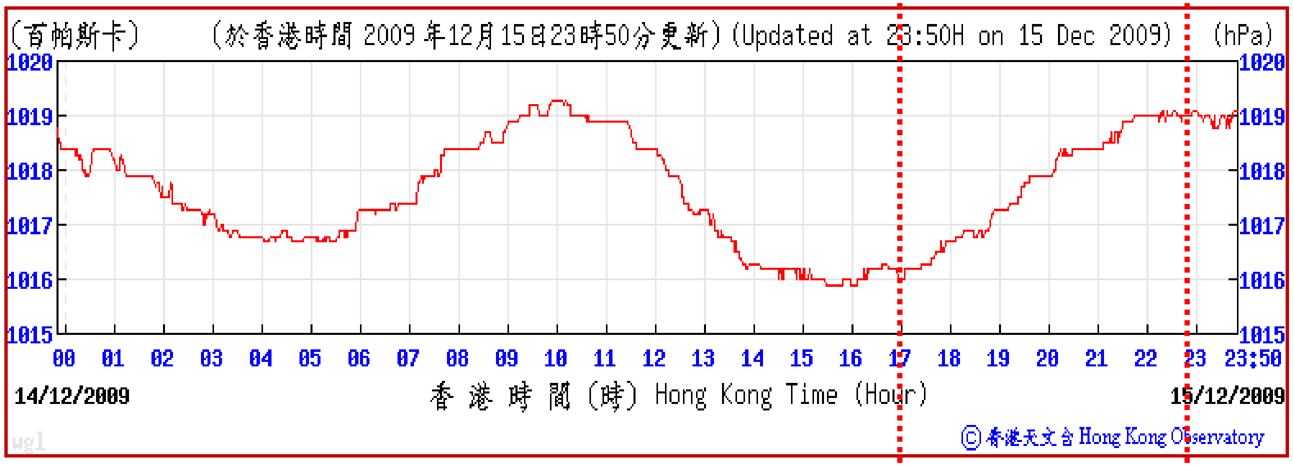
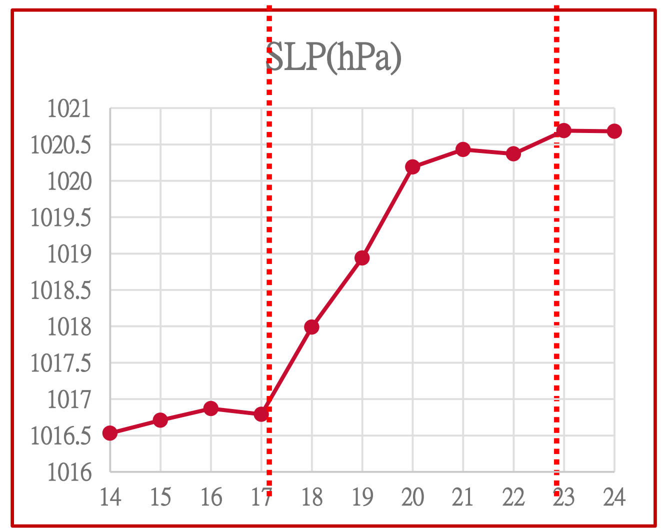
Observed & Predicted MSLP values at Waglan Island (22 0 10′ 56″ N, 1140 18′ 12″ E) on 15th Dec 2009



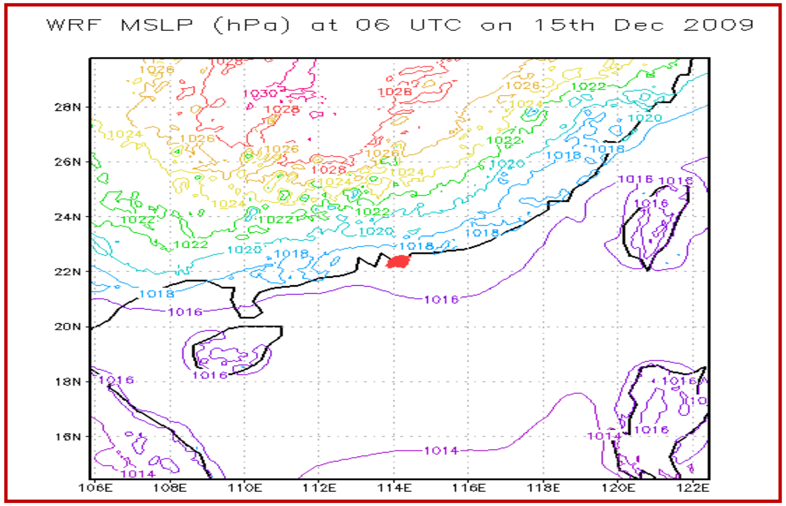
Number	HK-Local	UTC
14	2:00 PM	6
15	3:00 PM	7
16	4:00 PM	8
17	5:00 PM	9
18	6:00 PM	10
19	7:00 PM	11
20	8:00 PM	12
21	9:00 PM	13
22	10:00 PM	14
23	11:00 PM	15
24	12:00 AM	16



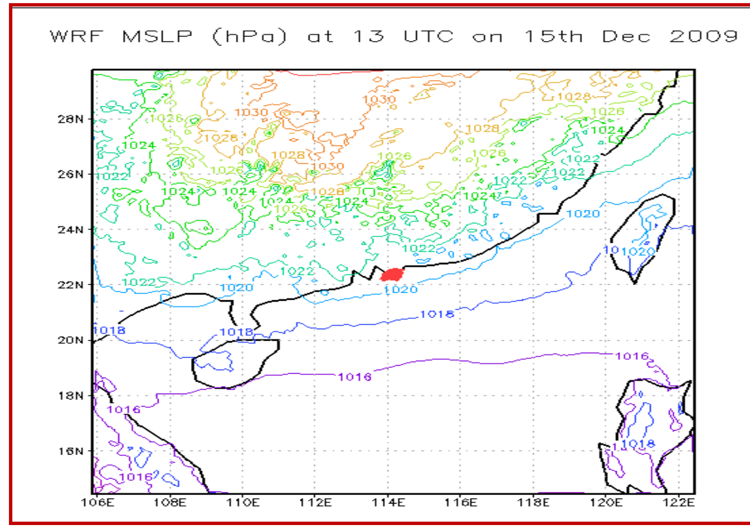
Source: http://www.weather.gov.hk

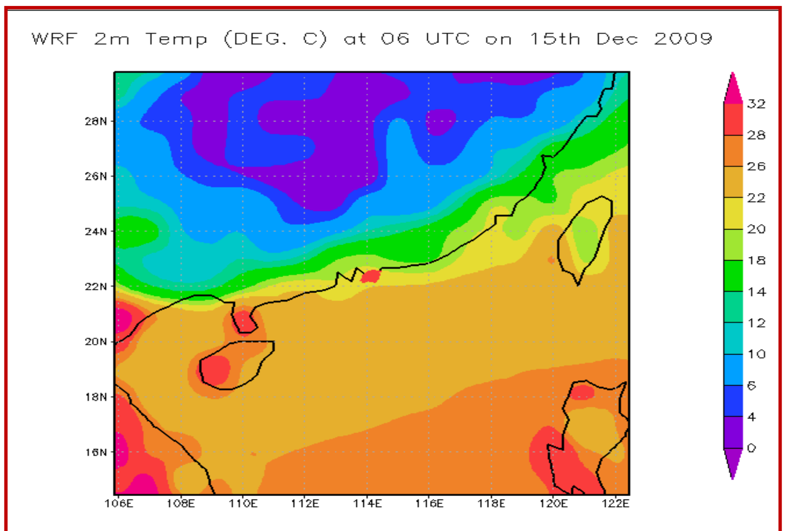
Surface Variables before and after the passage of Cold Front

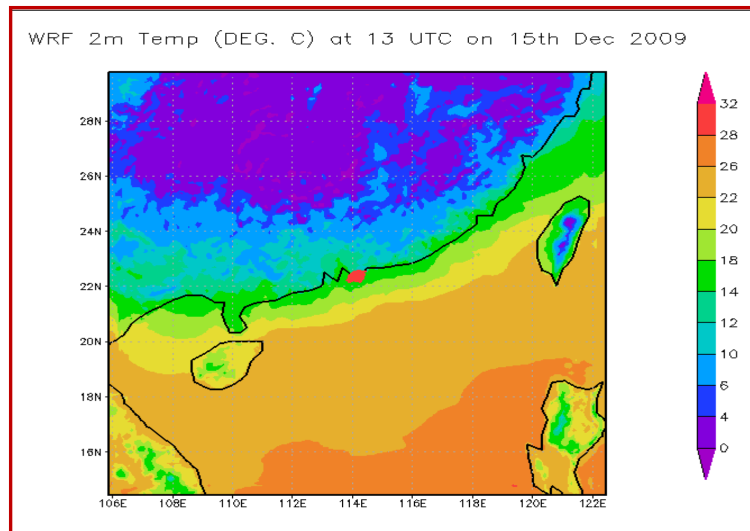
Before



After

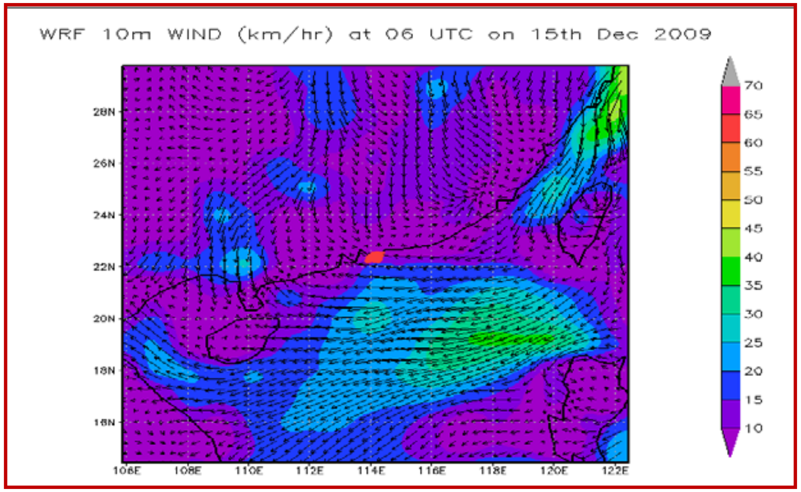




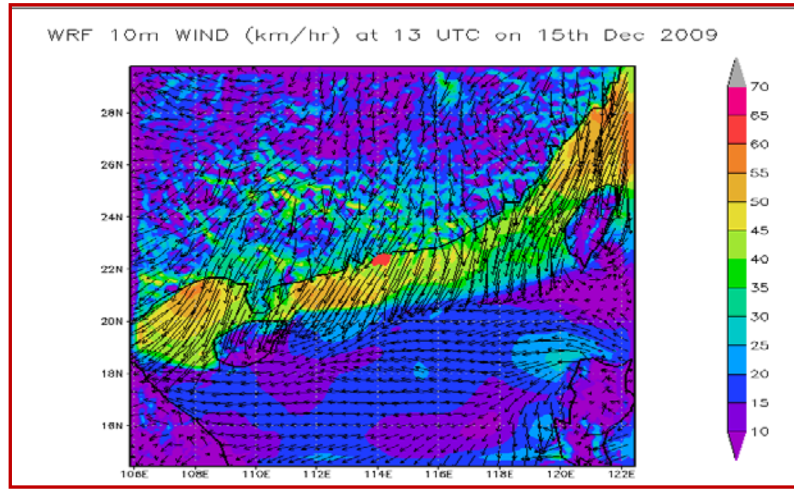


10 m & 850 hPa Winds before and after the passage of Cold Front

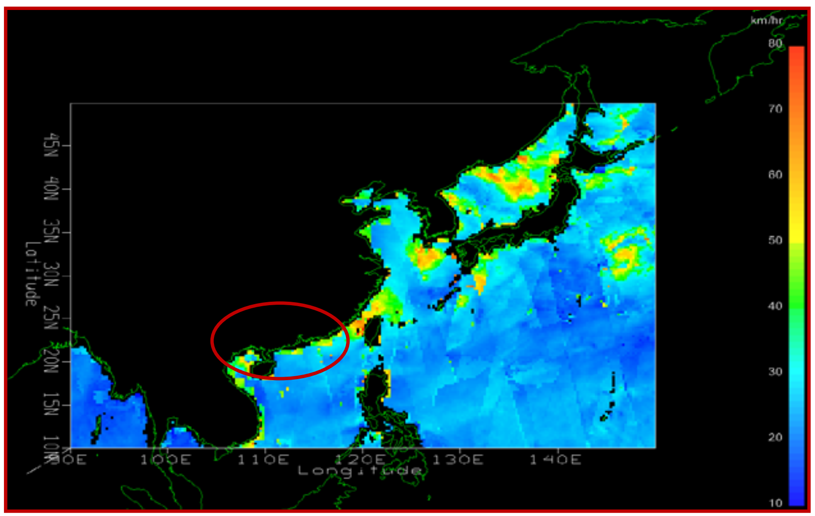
Before

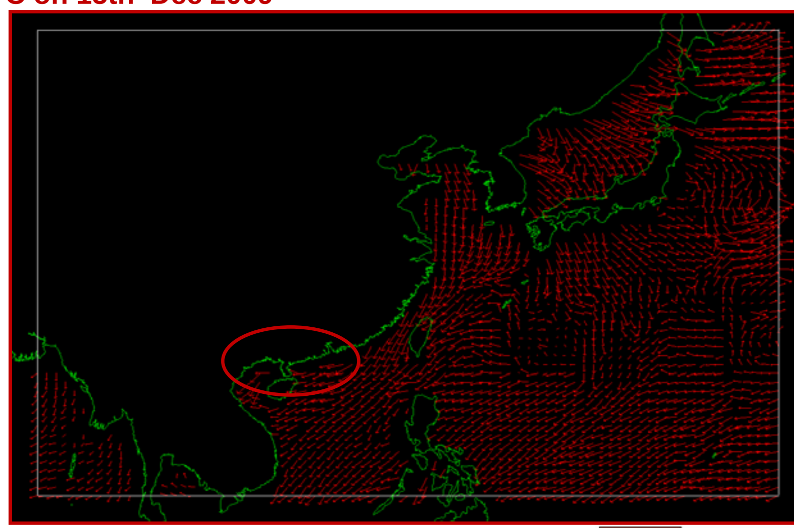


After



ASCAT winds at 12 UTC on 15th Dec 2009





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4.3 Case Study of "Cold Surges" Event 3 near Hong Kong

Event Occurrence Date	*: 24th Jan 2008-16th Feb 2008*
Model Initialization Date	*: 24th Jan 2008 at 00 UTC*
Model end run Date	*: 16th Feb 2008 at 00 UTC*
Model predictability frequency	*: 12 Hourly*

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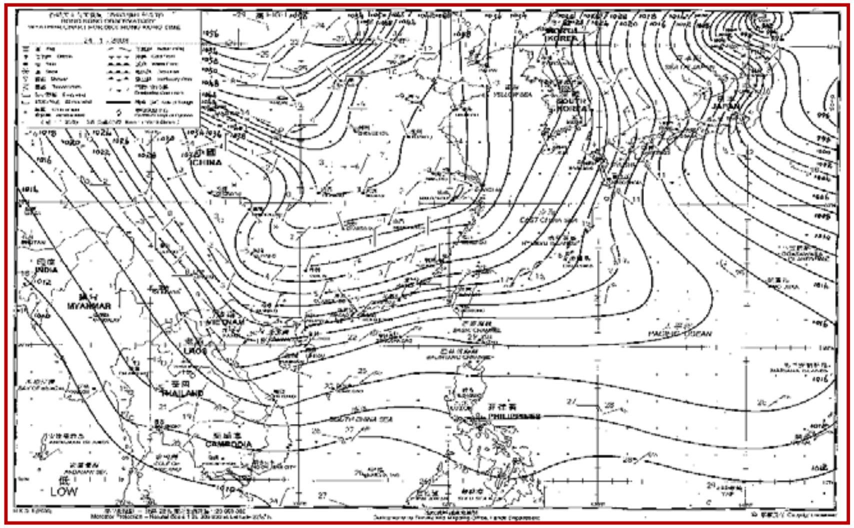
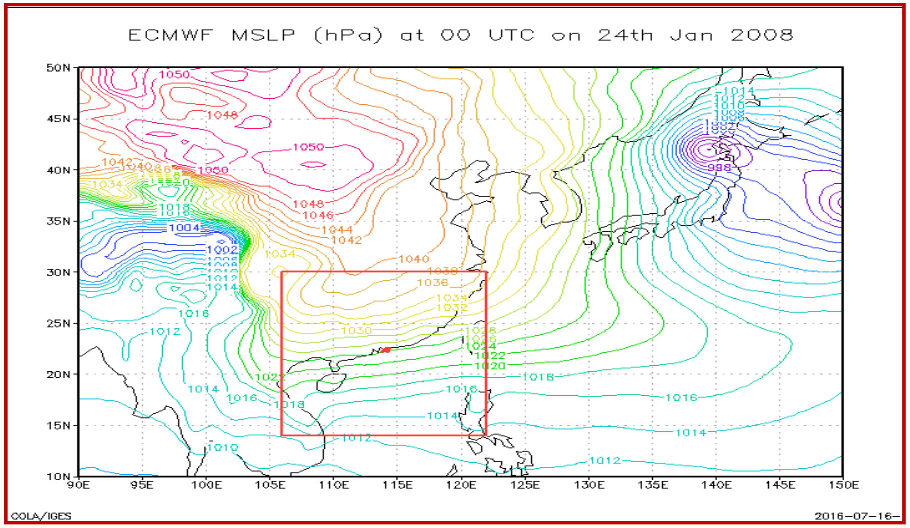
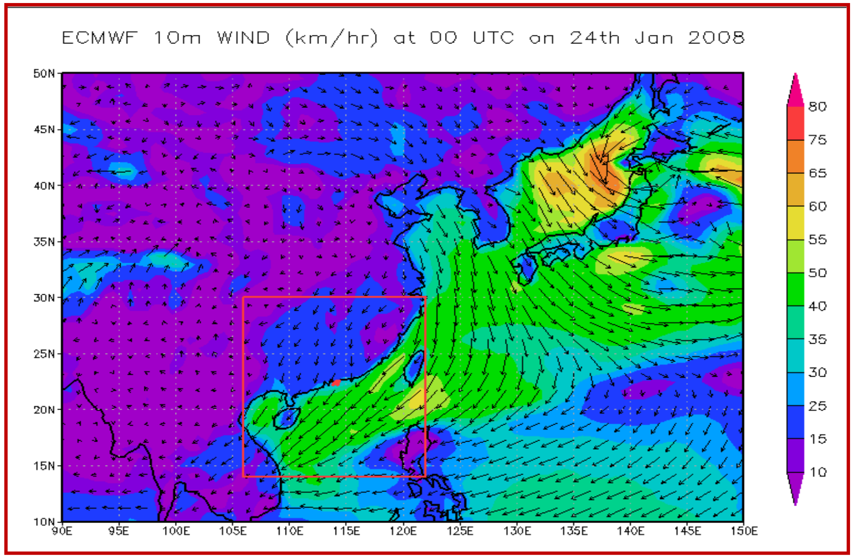
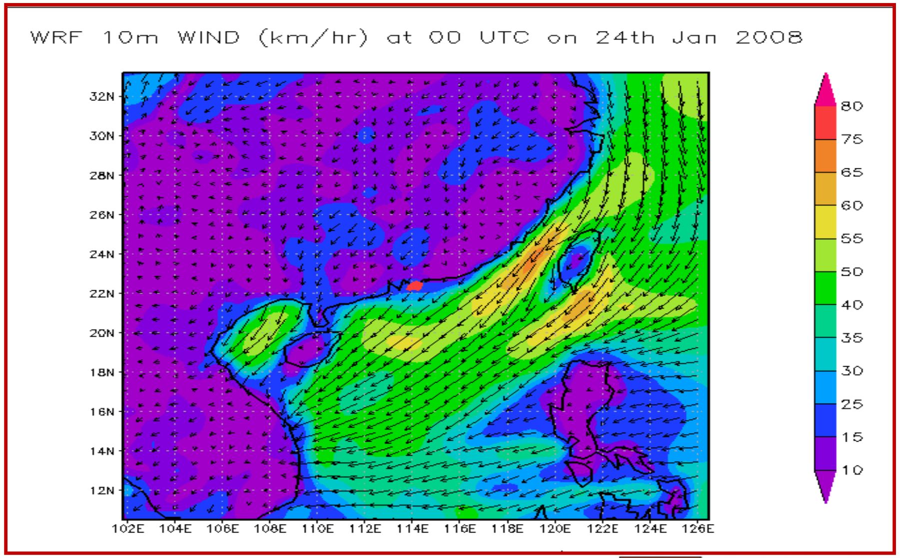
Comparison of Model analysis with HKO Weather Charts Synoptic features on 24th Jan 2008 at 00 UTC

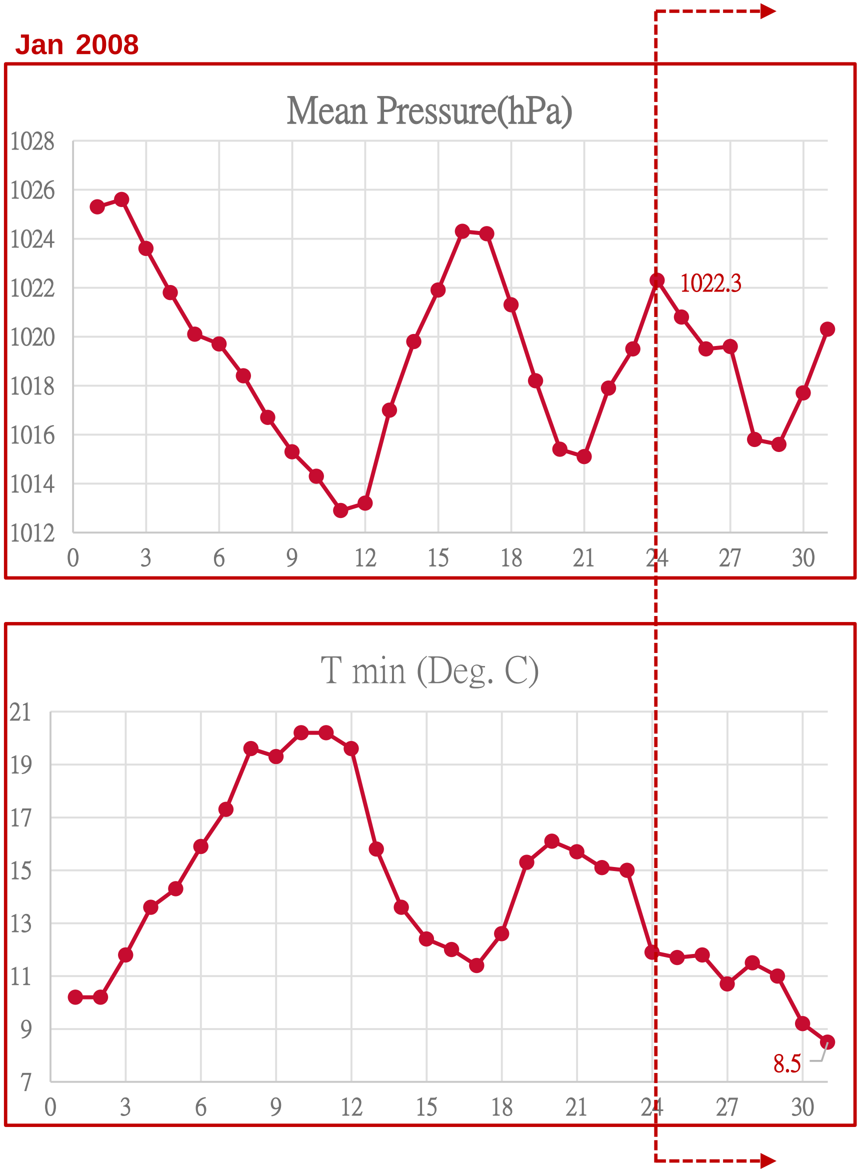


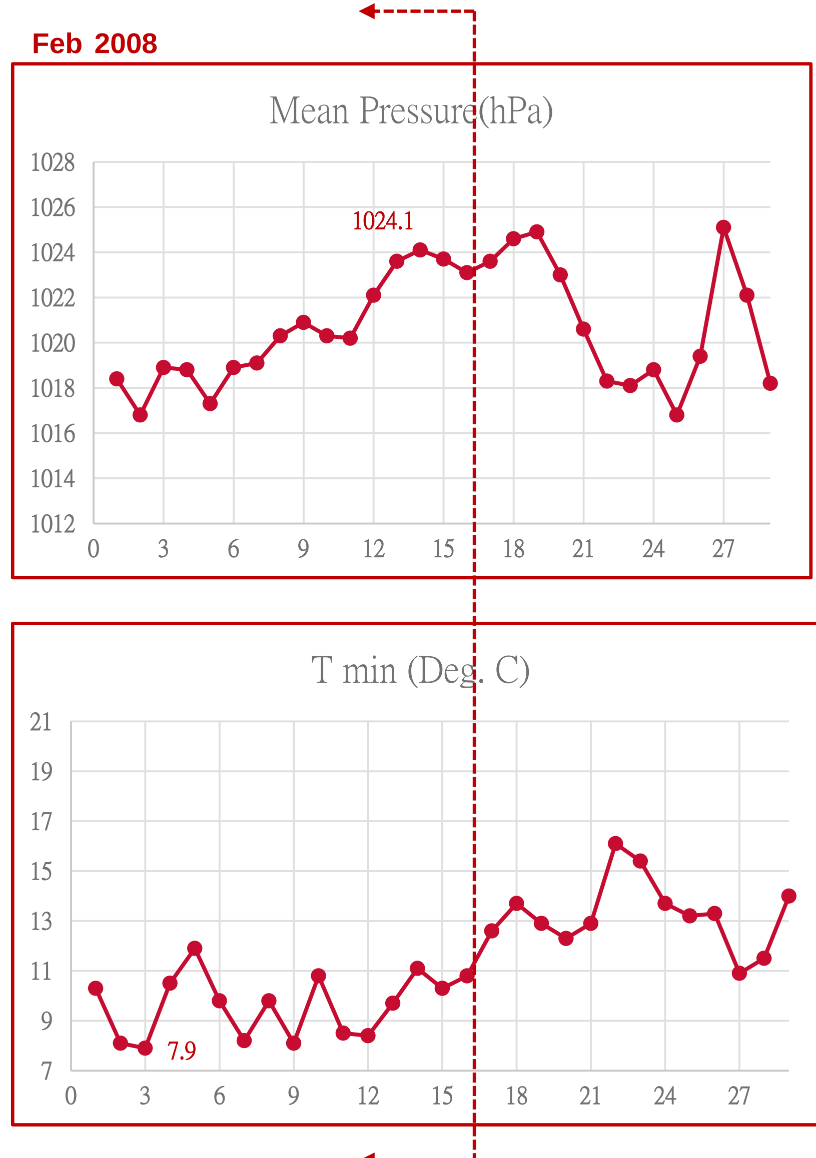






Daily data from HKO for the period Jan- Feb 2008





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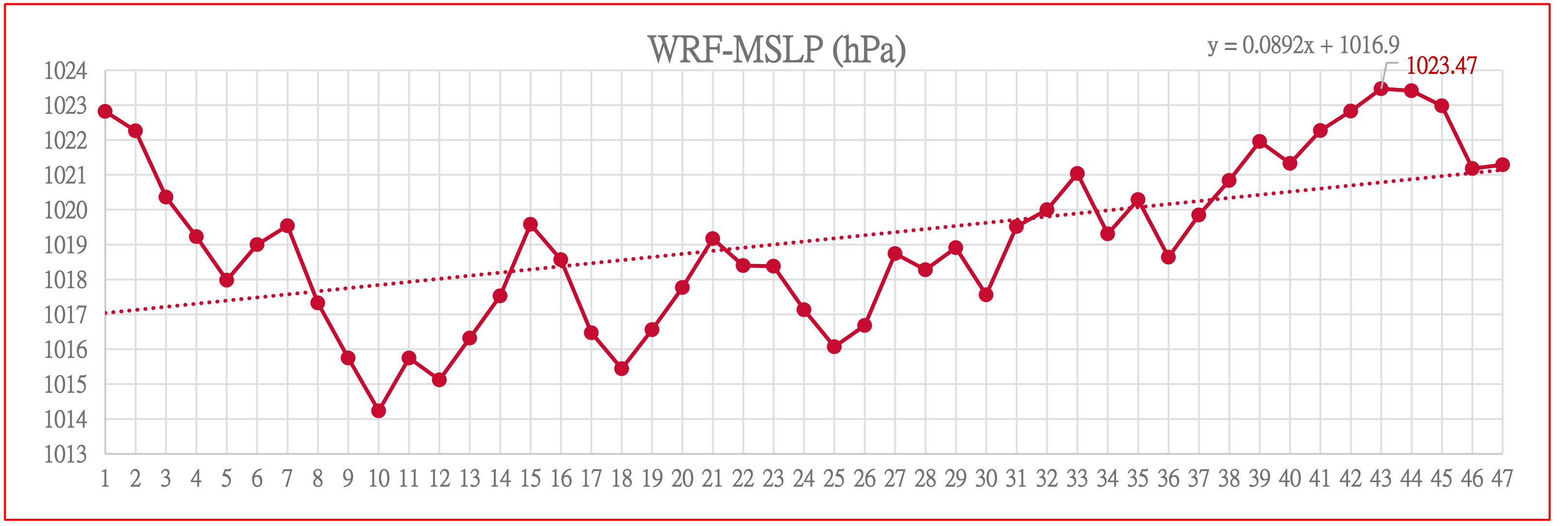
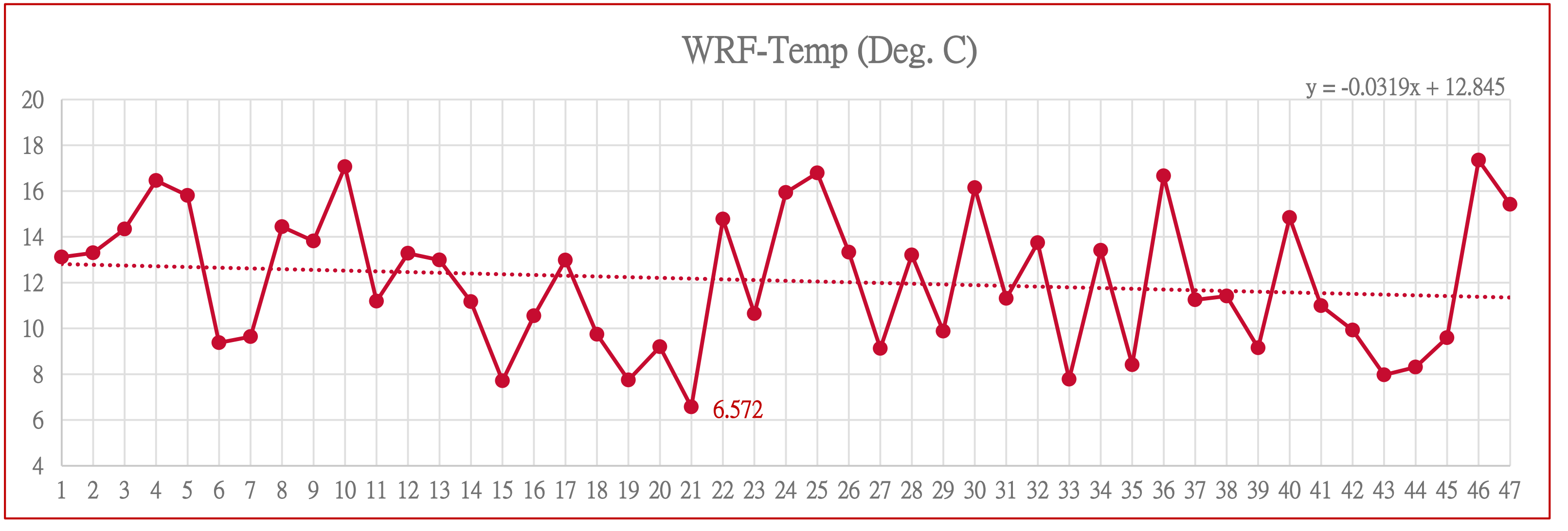
Model prediction from 24th Jan-16th Feb 2008





Summary of Case Studies

WRF Model performance was analyzed in capturing the meteorological phenomena associated with "Cold Surges" initially in a hind cast mode.

Four important conclusions are drawn from this case study as mentioned below:

- **Event-1(2016):** Model successfully predicted within 12 hrs. the occurrence of sudden increment in MSLP and the associated drop in Temperature. However, the Model underestimated the Max MSLP and could predict the peak value up to **1037.7 hPa** in comparison to reported value **of 1037.7 hPa**. The Model overestimated the Min temperature and the Min temp predicted was **3.56 ^{0}C**. in comparison to the reported values of **3.3 ^{0}C.**

- **Event-2(2009):** Model performed reasonably well in capturing the intensity and extent of local surface parameter variability during and after the passage of the cold front within 12 hrs. on 15th Dec at 06 UTC and 12 UTC.

- **Event-3(2008):** The model comparison with 12 hourly ECMWF data shows that it predicted well in capturing the extent of MSLP and associated temperature drop even in 24 days long spell.

- Our assumptions used in defining the WRF model physics are valid and the model spatial resolutions are sufficient to predict the cold surge occurrence within 12 hours.

Important Research Questions on understanding the extremity of "Cold Surges"

- The cold surge in 2008 has the Longest spell of 24 days in last 40 years. It is not clear till date, What has been the reason for a SH Pressure system to be stable for so long?

- Even if this system has been stable for so long, what lead this anticyclonic circulation pattern to be abnormal that reached such a new level of extremity?

- Suggestions on roles of La Nina, the north polar vortex and intrapersonal oscillation have been made but definitive answers has not been found.

- Do we need to reveal more on the SH Pressure system and AL Pressure system. Does their interaction brings huge and severe weather impacts over the coastal regions of SCS during NEM?

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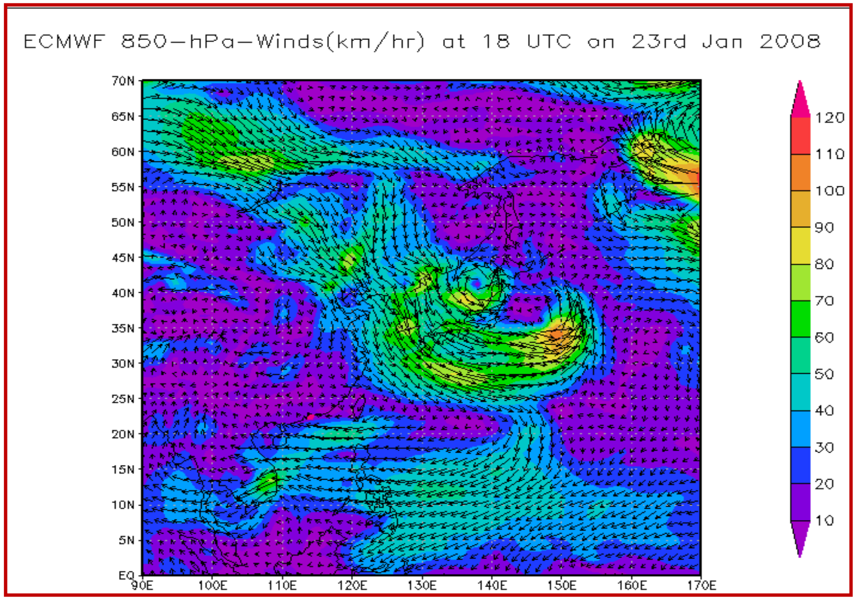
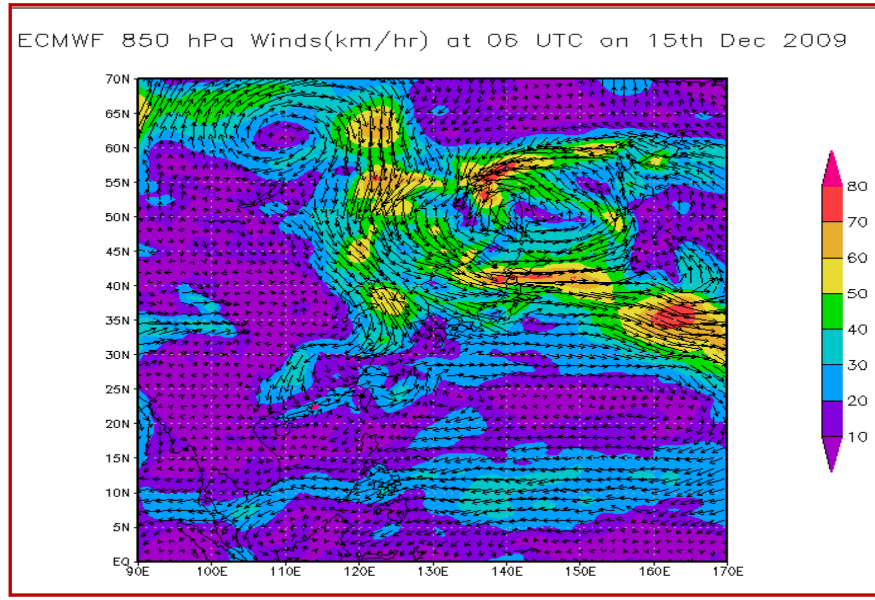
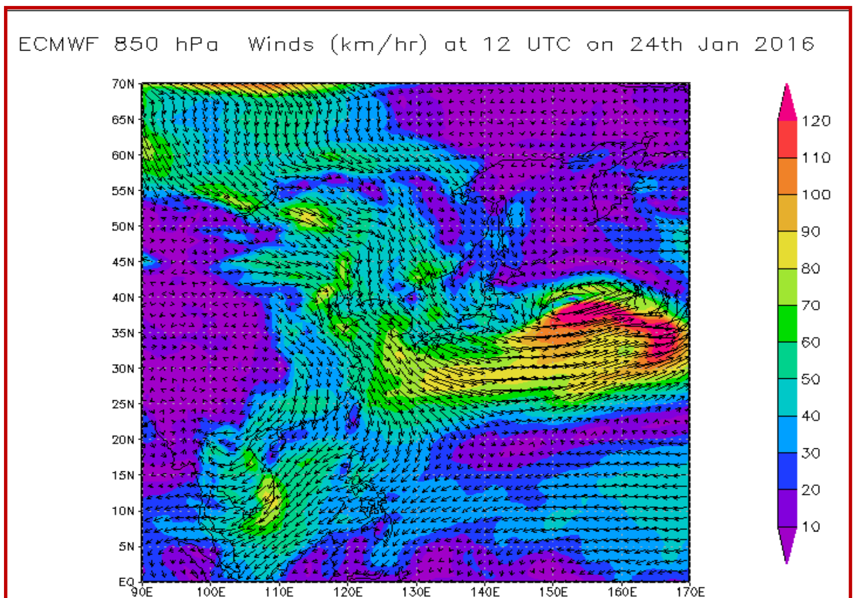
Preliminary Results on Cold Surge Occurrence







Year	Month	Max_MSLP	Min_MSLP
2016	Jan	1067.90	1041.31
2008	Jan	1063.09	1036.43
2008	Feb	1051.06	1036.74
2009	Dec	1059.20	1035.88

Future Work Plan

- Presently there is no definitive region specific triggering index on cold surges that can indicate about its intensity and extent and how long can they be effective?

- There is a immediate need of cold surge triggering index that can provide a reliable information for a specific region, likely to be impacted more by cold surges.

- In our preliminary research analysis (result not shown here), we have found (based on reanalysis data) that cold surge vortices are short lived and associated with tremendous energy. We also noticed that occurrence of these vortices brings huge severe weather impacts over the coastal regions of SCS.

- Formation of these cold surge vortex can be considered as an indication of intense weather system in SCS. What if these vortices though short lived but becomes more frequent in a month? What if these vortices develops tremendous energy to stay long ? If Yes, can these long lasting surge vortices have crucial role in the development of Tropical Cyclone during the winter season in SCS?

- We look forward to collaborating with Hong Kong Observatory in all our future research endeavours on “Cold Surges” in SCS!

Acknowledgement

- *WSN 16 Programme Committee, WMO/WWRP 4th International Symposium.*
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- *Mr. Roger Winder, LCC Communication Cube, NTU Singapore*
- *Prof Haresh Shah: Founder & Senior Advisor RMS, Inc. ; Senior Academic Advisor to the President, Nanyang Technological University, Singapore*

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Thank You !