香港天文台
HONG KONG OBSERVATORY

Use and Interpretation of EPS Products

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Forecast Development Division

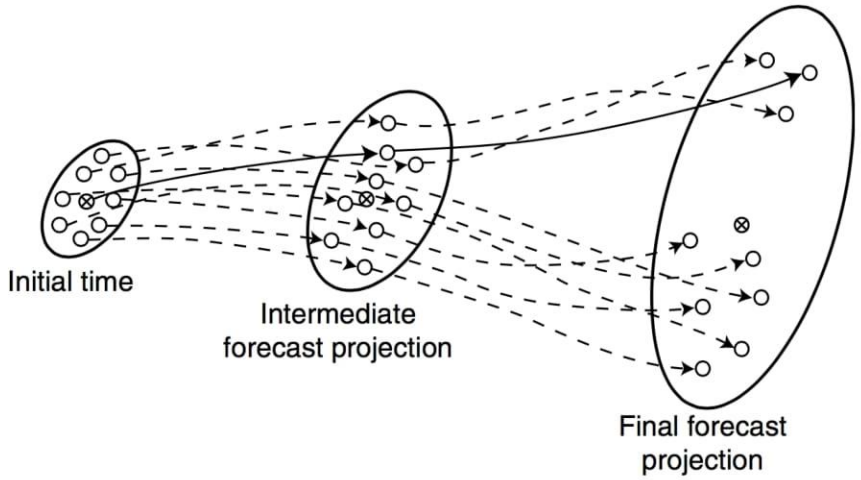
VCP Online Workshop on Development of Products from NWP Models and EPS for High-Impact Weather Forecasting

8-11 December 2020

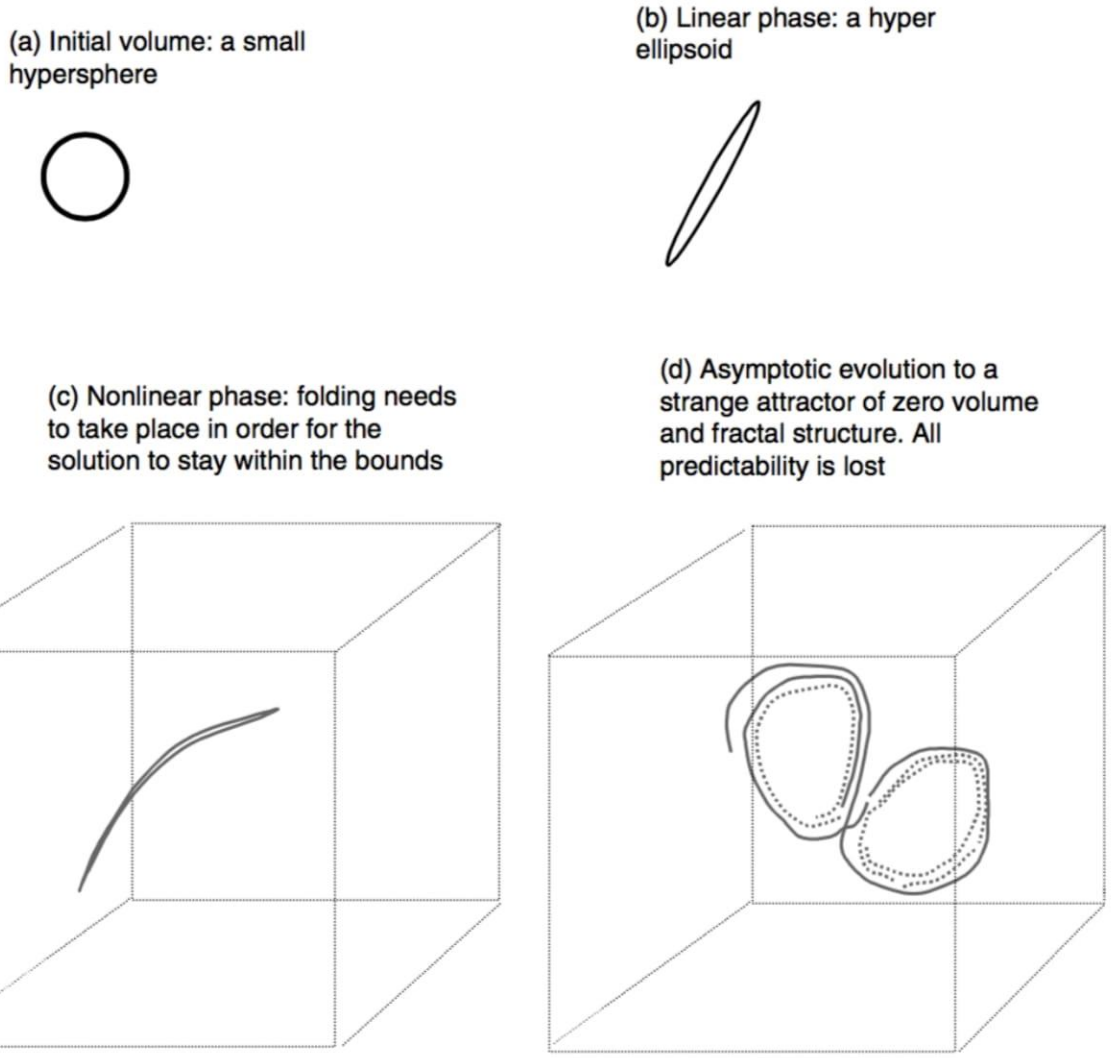
Ensemble prediction system

- Source of model errors:
  - initial conditions
  - incomplete representation of physical processes

- Repeat NWP model forecasts using slightly varied initial conditions (perturbation) or/and uncertainties in physical process (stochastic physics)



Kalnay (2003):



EPS Concept and Atmospheric Predictability

- Sampling of possible evolution of the atmosphere by integrating a set of simulations generated by perturbing initial conditions or model physics

- analysis errors typically dominating during the first few days or so;
  - analysis errors amplify most easily in the sensitive parts of the atmosphere (e.g. baroclinic zones); the errors then move downstream and amplify and thereby affect the large-scale flow;
  - to estimate the effect of possible initial analysis errors and the consequent uncertainty of the forecasts, small changes to the analysis are made, creating an ensemble of 50 different perturbations of initial states.

- model deficiencies are represented by stochastic processes in NWP model

- to save computational time, the 50 EPS members are run on a lower resolution version of the deterministic model (a.k.a. EPS Control)

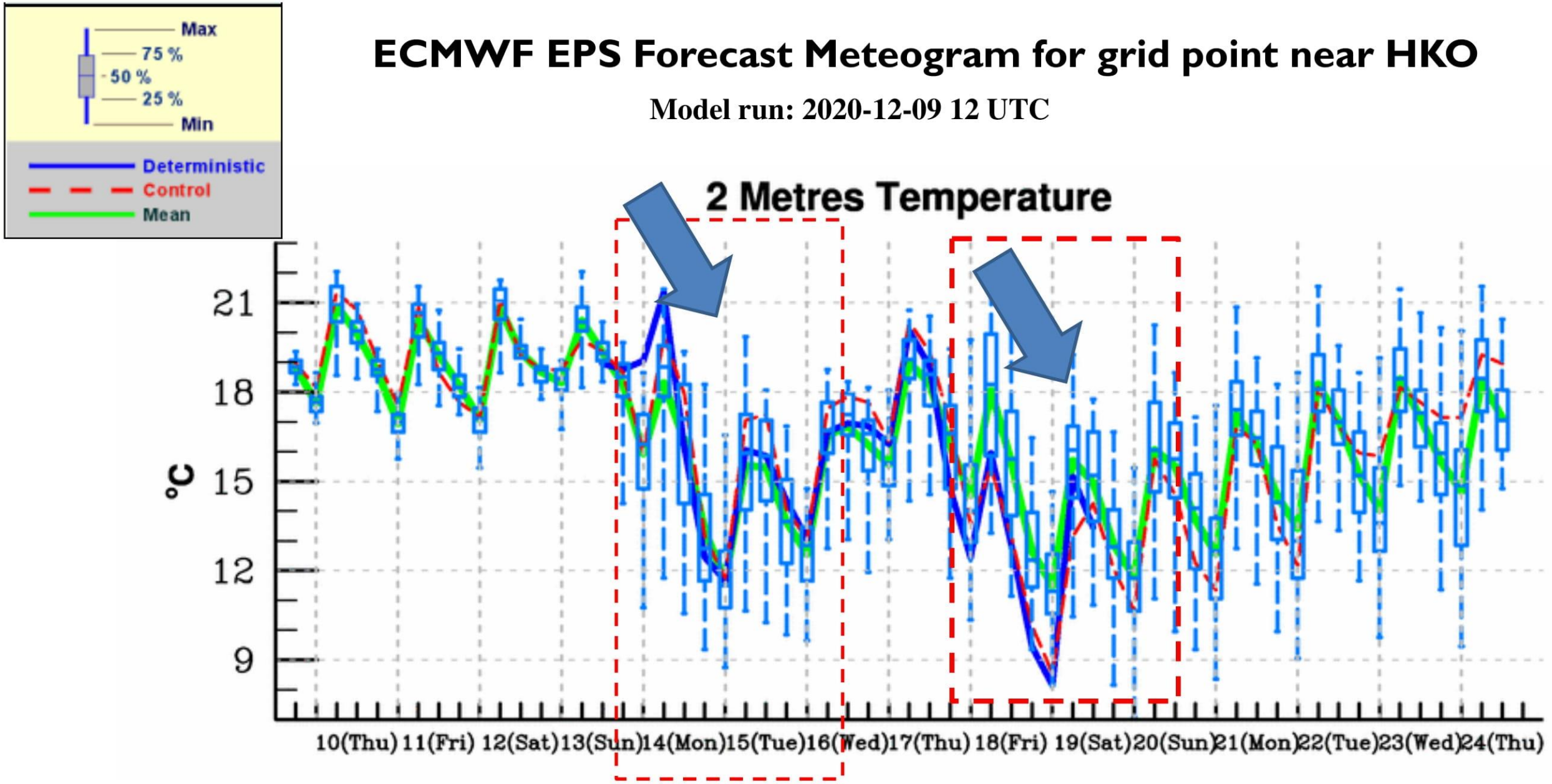
- Ensemble mean exhibits a better skill than a single, deterministic integration.
- Ensemble spread as an indicator for the predictability of forecast weather events

Using EPS

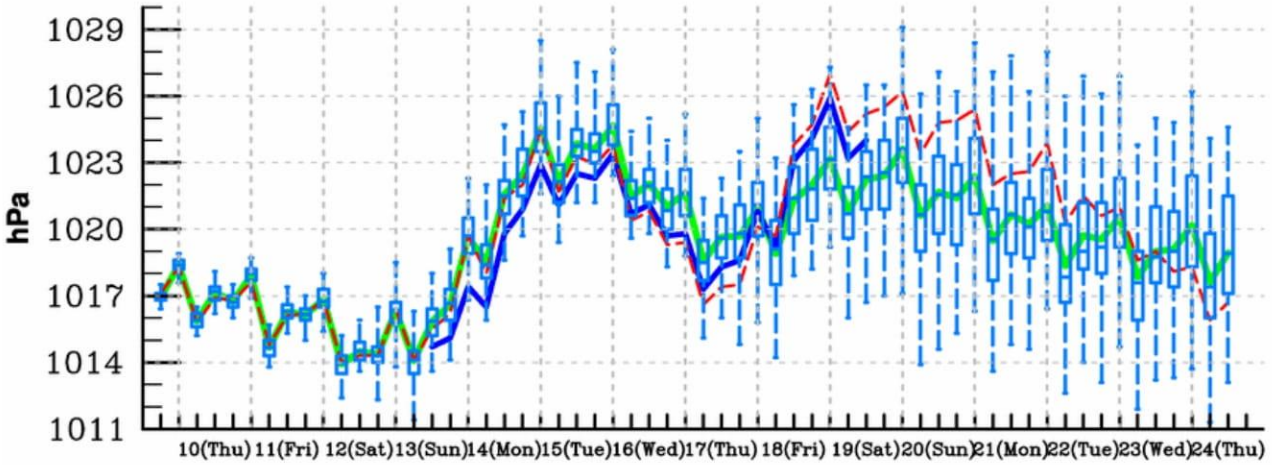
- Probabilistic forecast
- Alternative scenarios
  - Uncertainties from initial perturbation and physical processes
  - Worst scenario
- EPS guidance for significant convection forecast
- Extremity of weather
  - Extreme Forecast Index (EFI) and Shift of Tails (SoT)

ECMWF EPS Forecast Meteogram for grid point near HKO

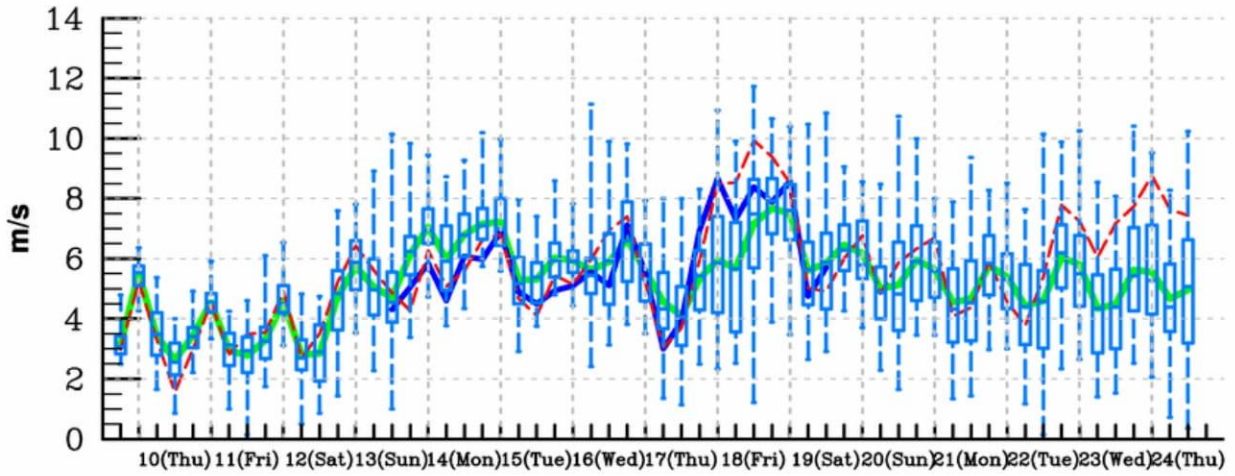
Model run: 2020-12-09 12 UTC



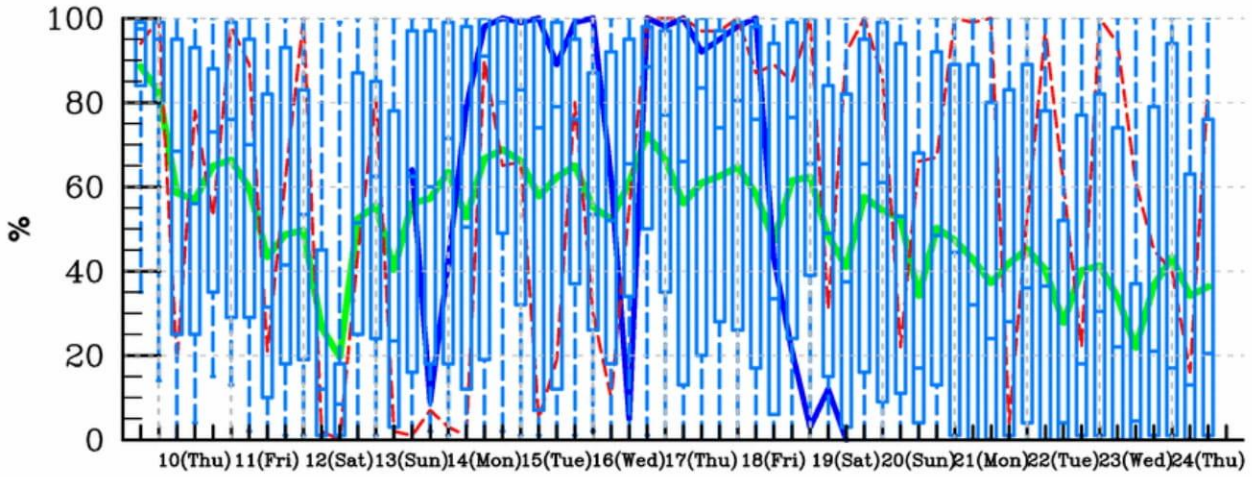
Mean Sea Level Pressure



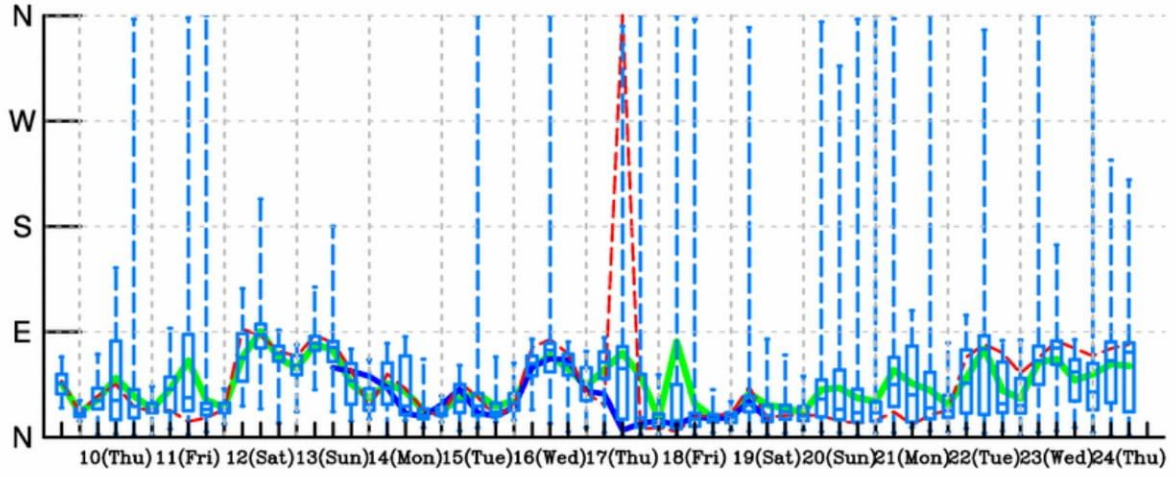
Derived Wind Speed



Total Cloud Cover



Derived Wind Direction



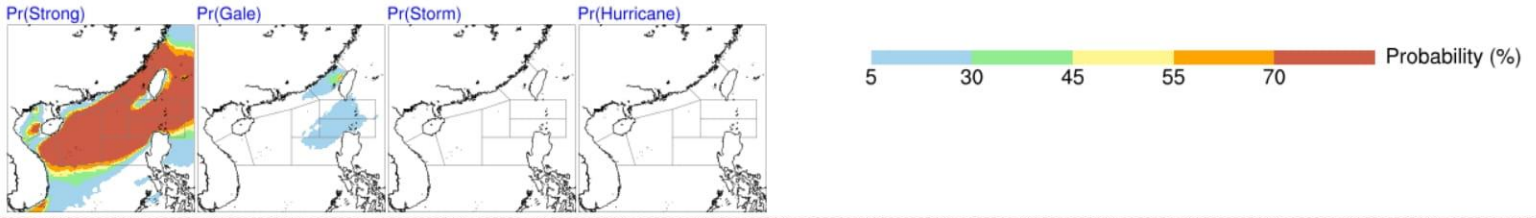
ECMWF EPS
Wind speed at 10m

2020-12-15 12:00 UTC (Tue)

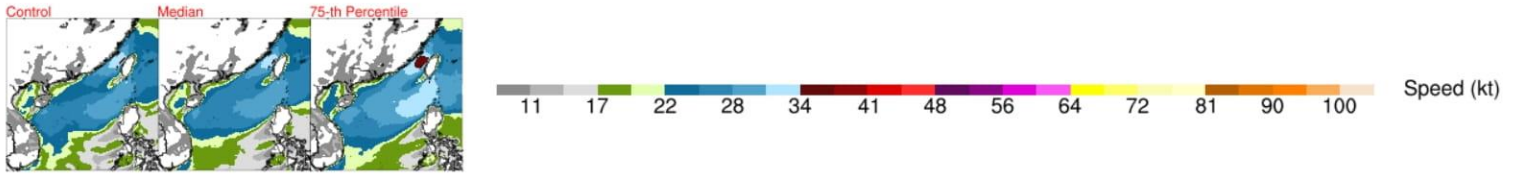
T+156 h forecast from
2020-12-09 00:00 UTC

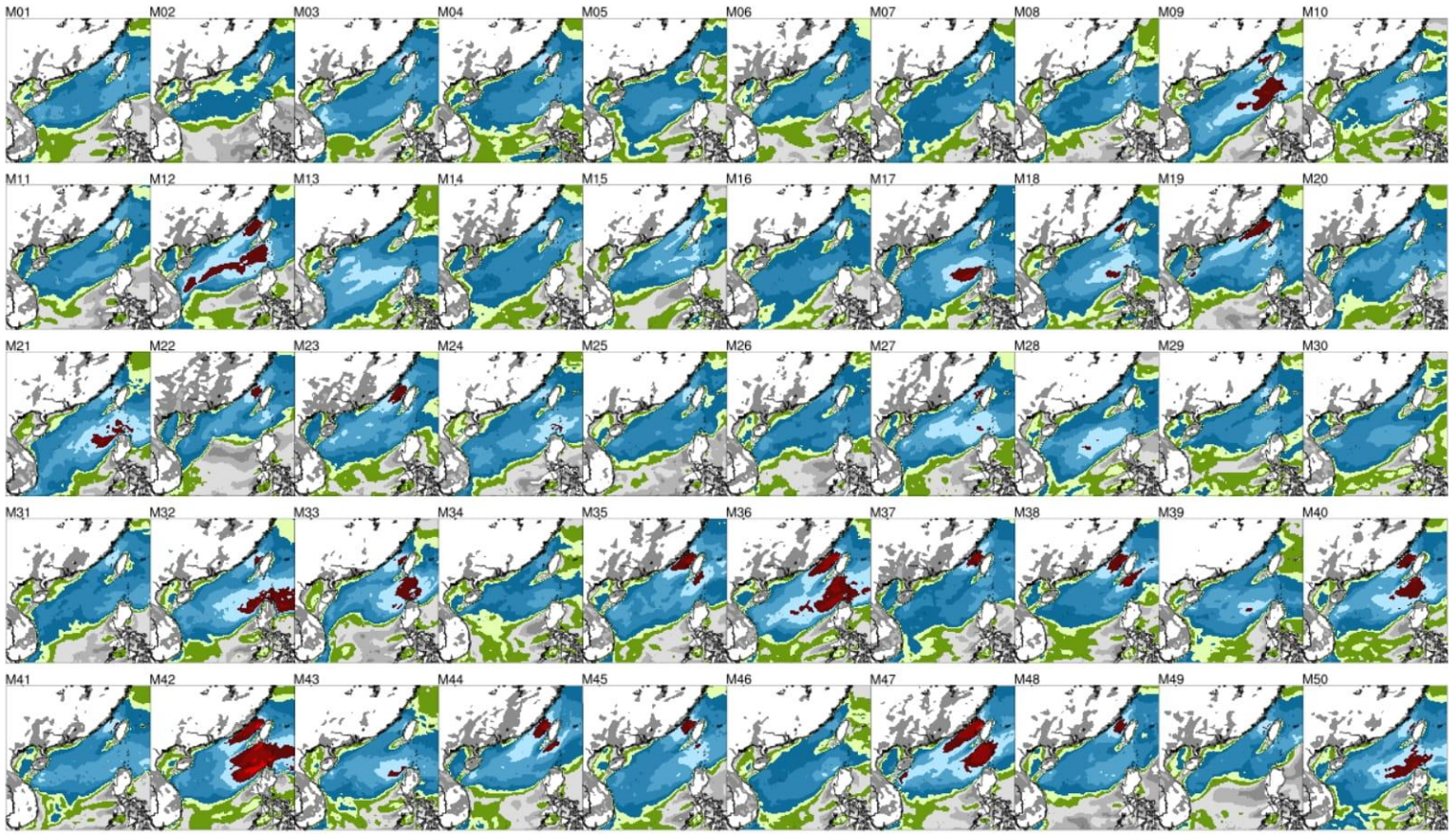
Probability of **10-m wind speed**

≥strong ≥ gale ≥ storm ≥ hurricane



Control	Median	75-th Percentile





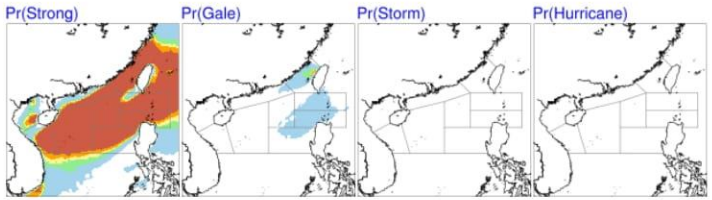
50 EPS Members

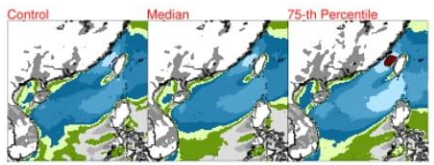
For Marine Weather Forecast and Warning

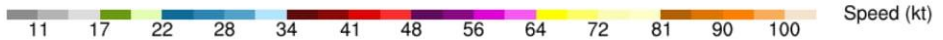
ECMWF EPS
Wind speed at 10m

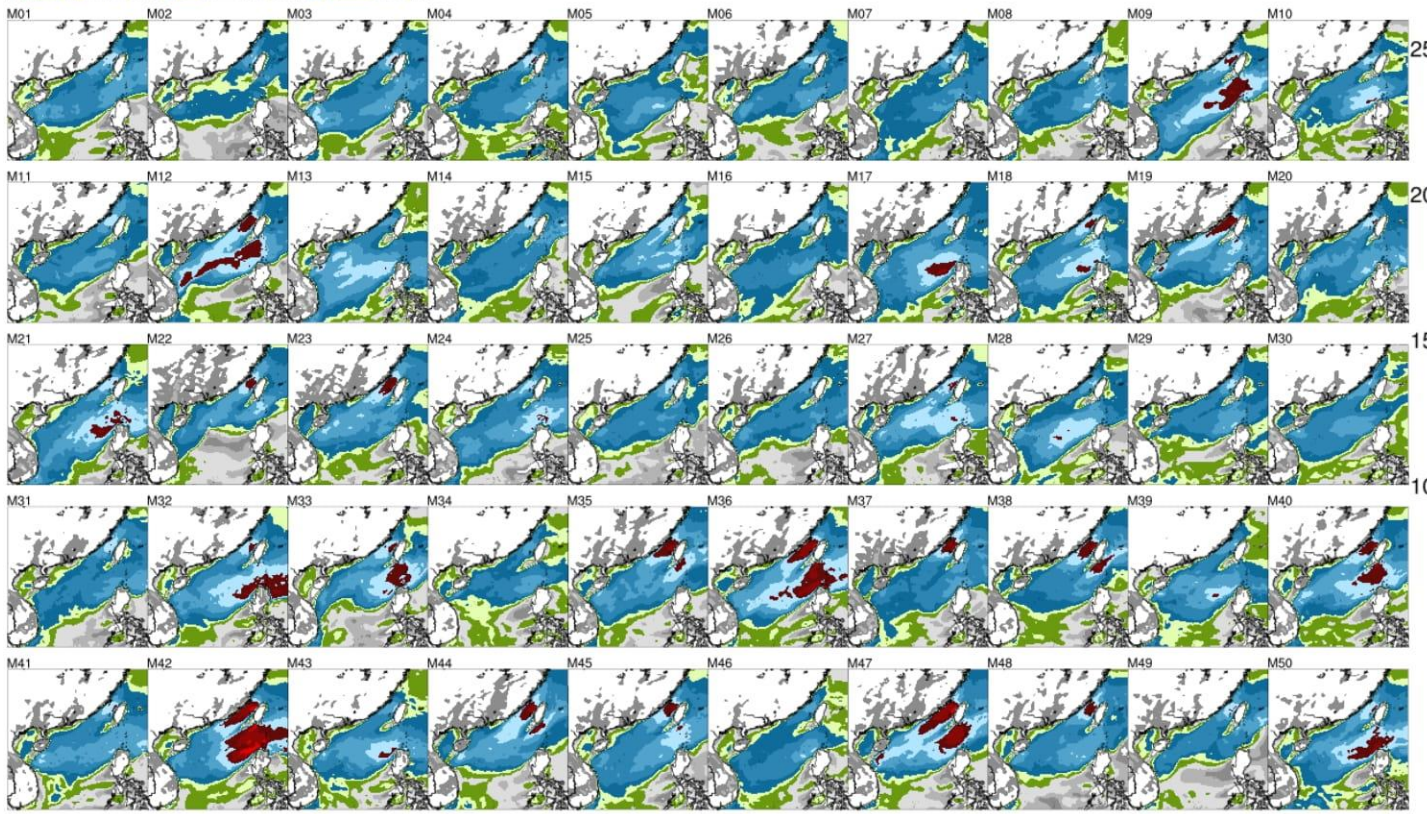
2020-12-15 12:00 UTC (Tue)

T+156 h forecast from
2020-12-09 00:00 UTC





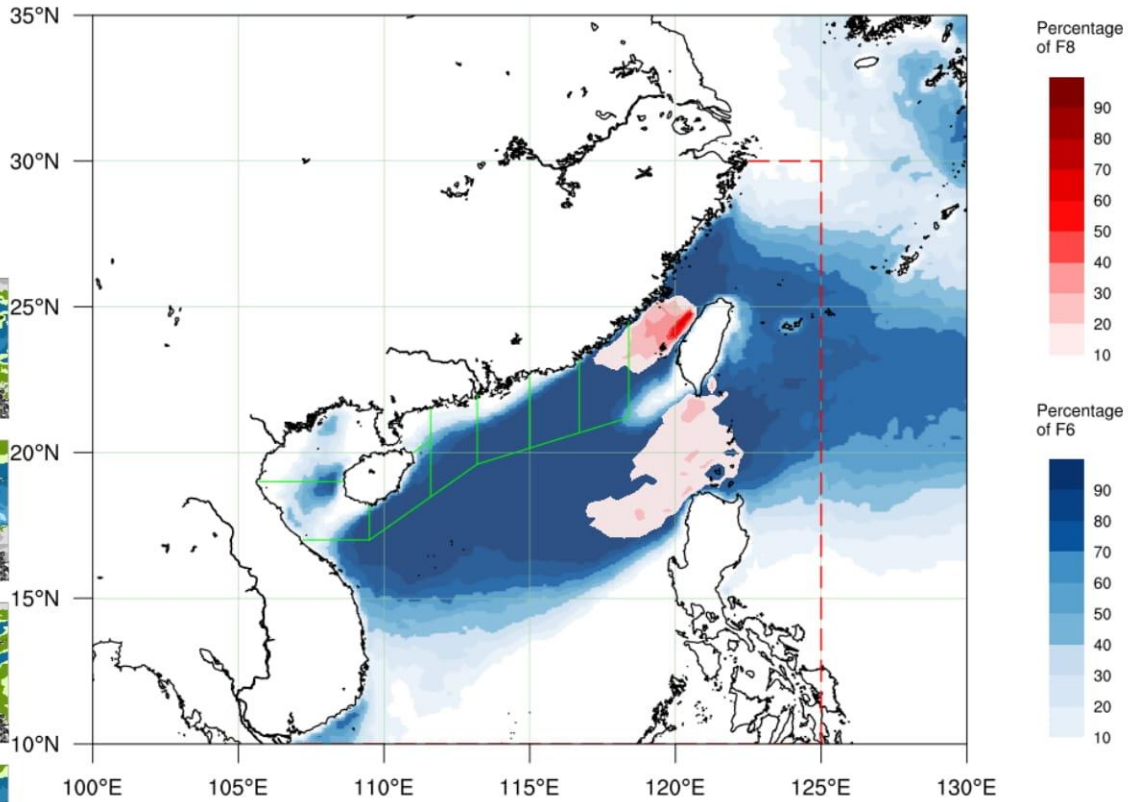




ECMWF EPS
Prob. of Strong Wind & Gales

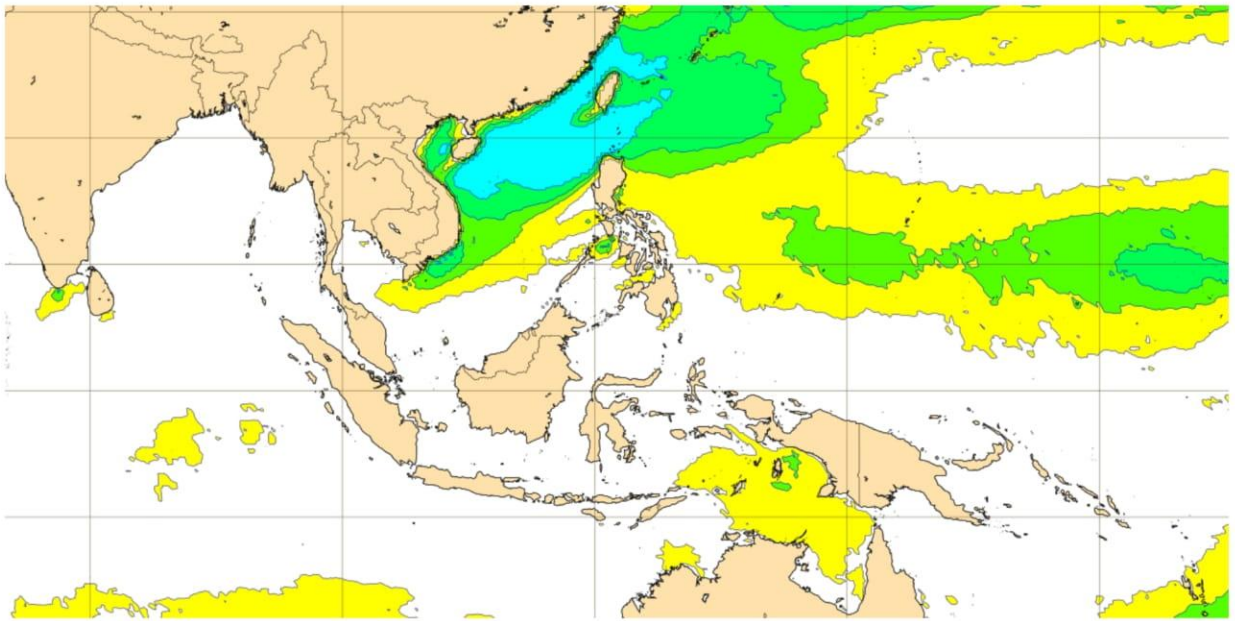
2020-12-15 12:00 UTC (TUE)

T+156 h forecast
Initialised at: 2020-12-09 00:00 UTC



Probabilities: 10m wind speed

Base time: Wed 09 Dec 2020 00 UTC, Valid time: Tue 15 Dec 2020 12 UTC, - T+156 h, Area : South East Asia & Indonesia, Threshold : > 10 m/s



Probability of 10 metre wind > 10 m/s (%)

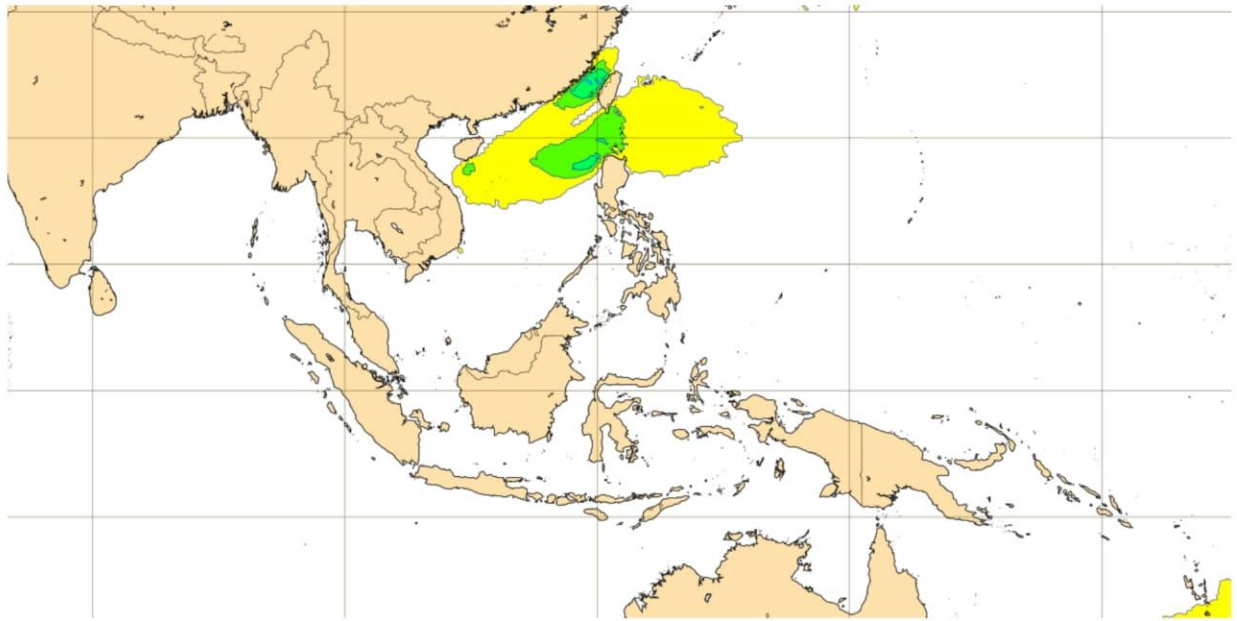
5 35 65 95 100%

cc

ECMWF

Probabilities: 10m wind speed

Base time: Wed 09 Dec 2020 00 UTC, Valid time: Tue 15 Dec 2020 12 UTC, - T+156 h, Area : South East Asia & Indonesia, Threshold : > 15 m/s



Probability of 10 metre wind > 15 m/s (%)

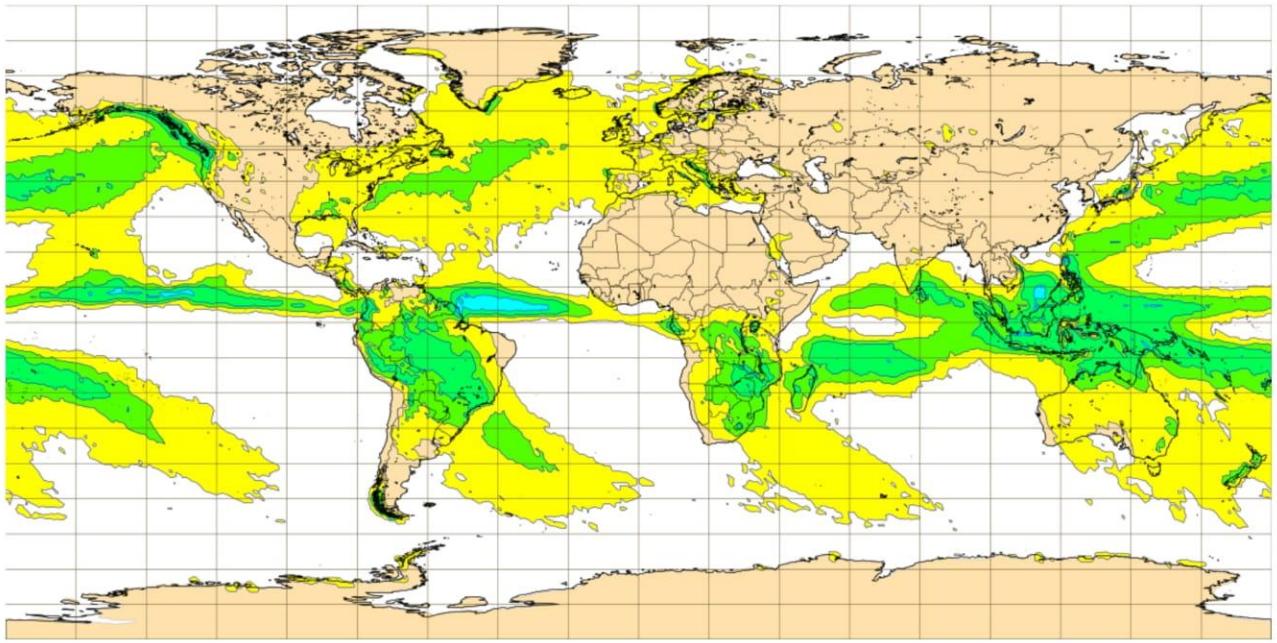
5 35 65 95 100%

cc

ECMWF

Probabilities (Day 10-15): total precipitation

Base time: Wed 09 Dec 2020 12 UTC, Valid time: Thu 24 Dec 2020 12 UTC, - T+360 h, Area : Global, Threshold : >5 mm

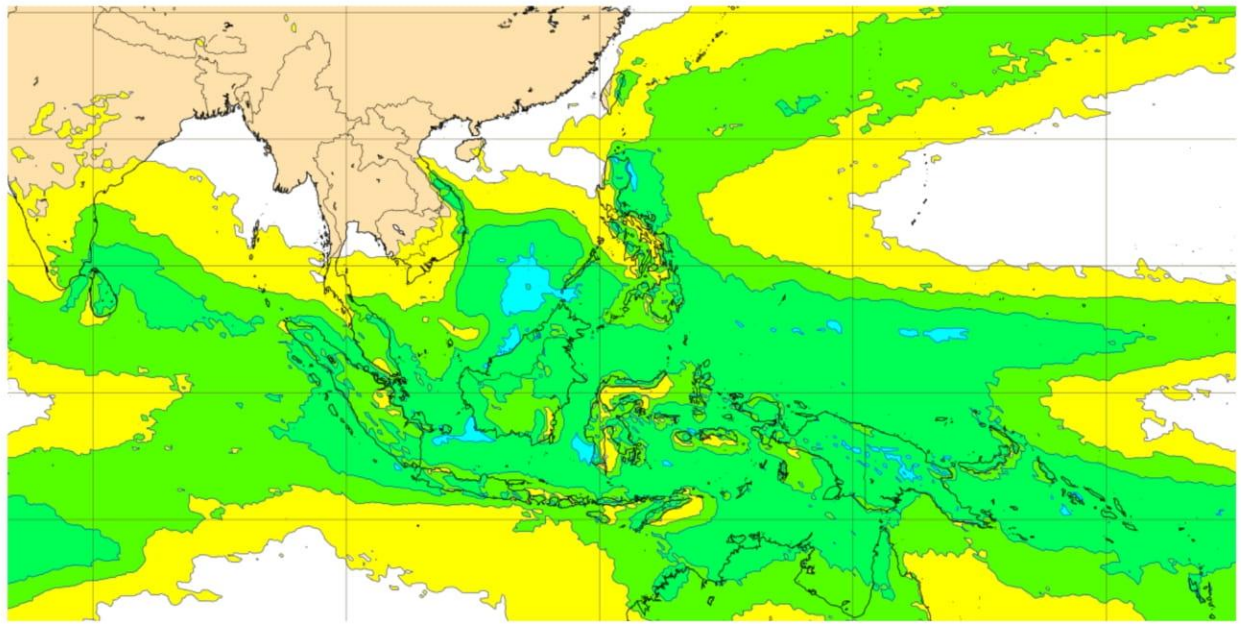


Total precipitation probability >5 mm (%)

5 35 65 95 100%

Probabilities (Day 10-15): total precipitation

Base time: Wed 09 Dec 2020 12 UTC, Valid time: Thu 24 Dec 2020 12 UTC, - T+360 h, Area : South East Asia & Indonesia, Threshold : >5 mm



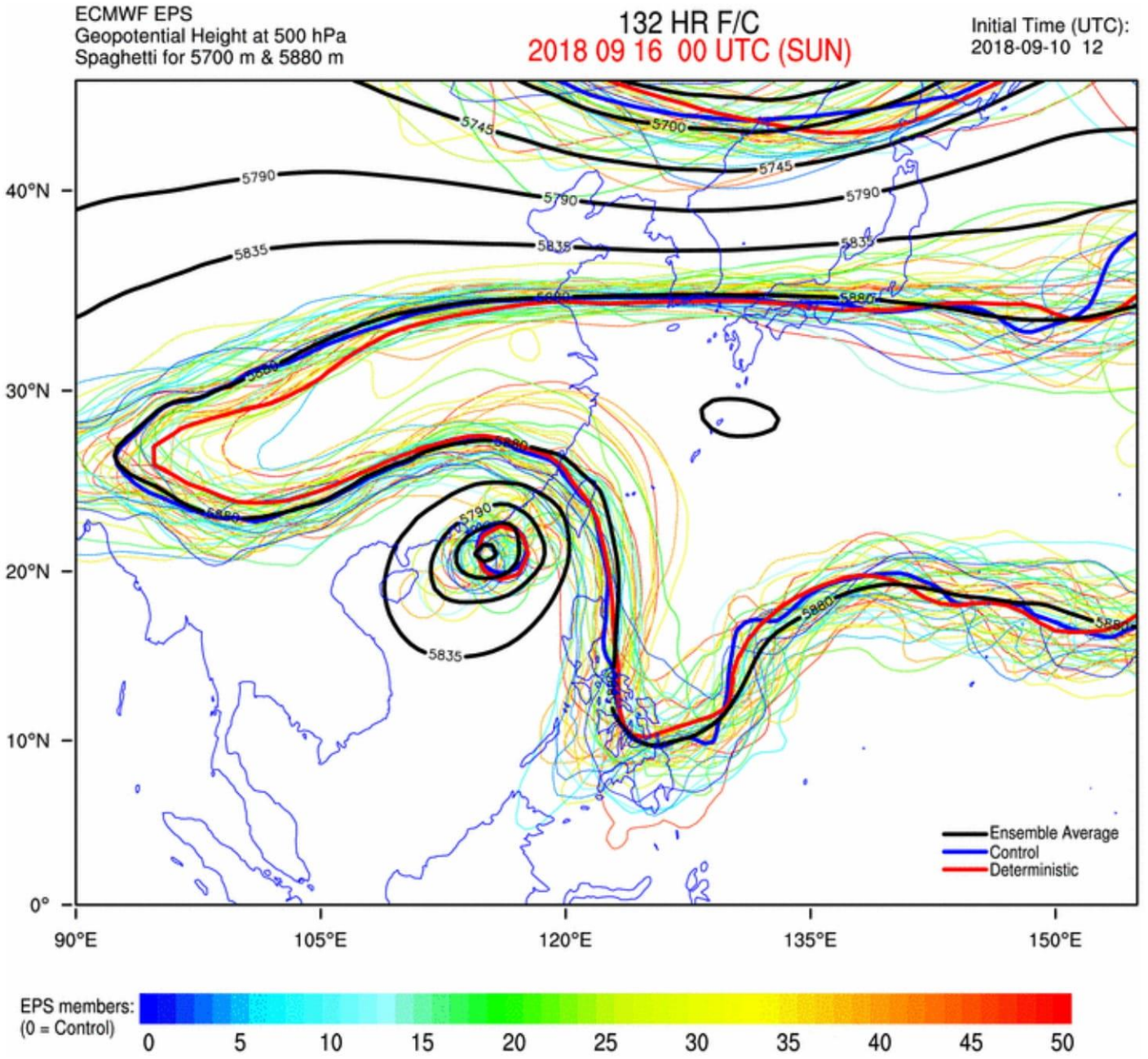
Total precipitation probability >5 mm (%)

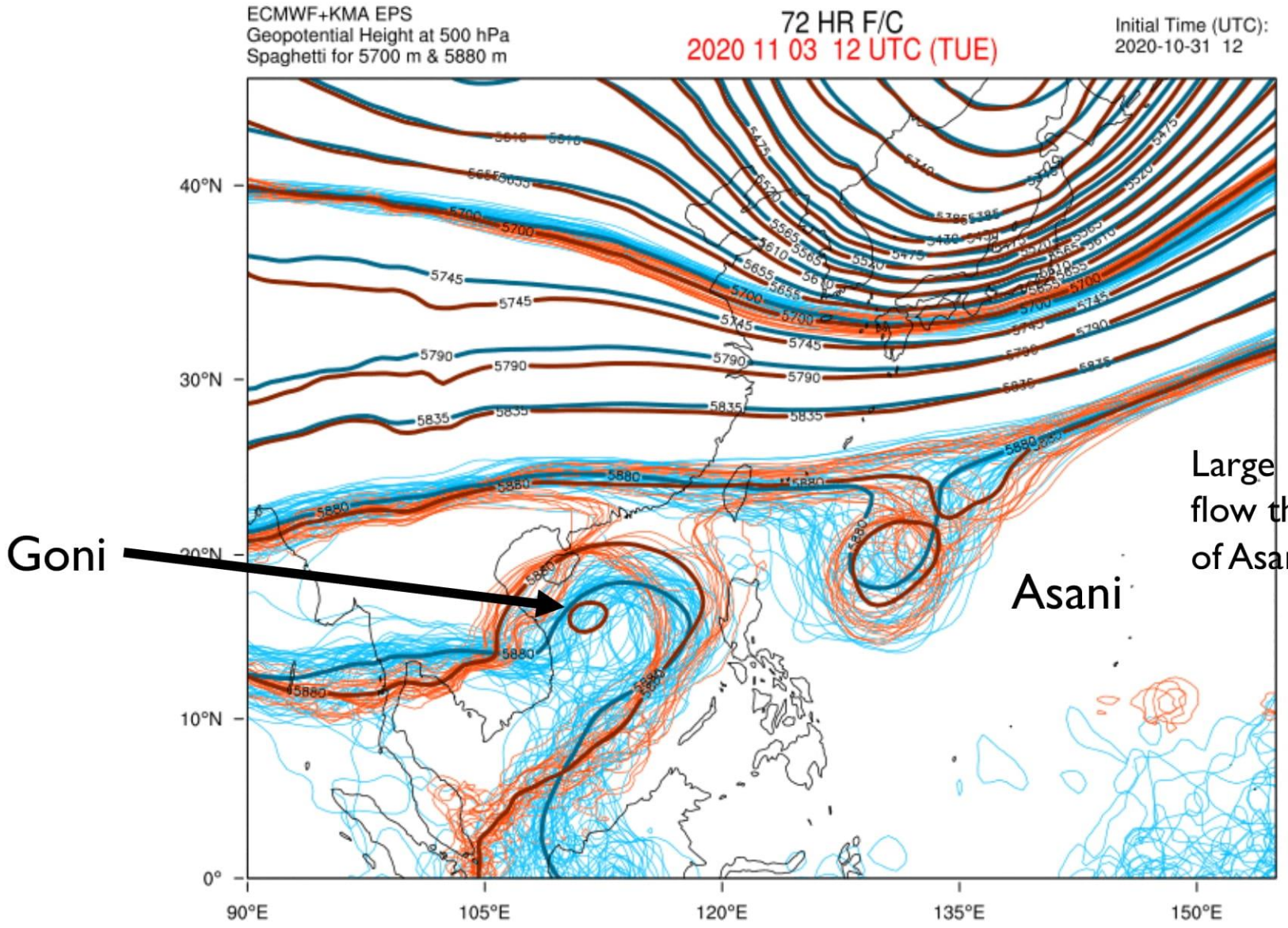
5 35 65 95 100%

Spaghetti plot of 500hPa GPH

Super Typhoon Mangkhut

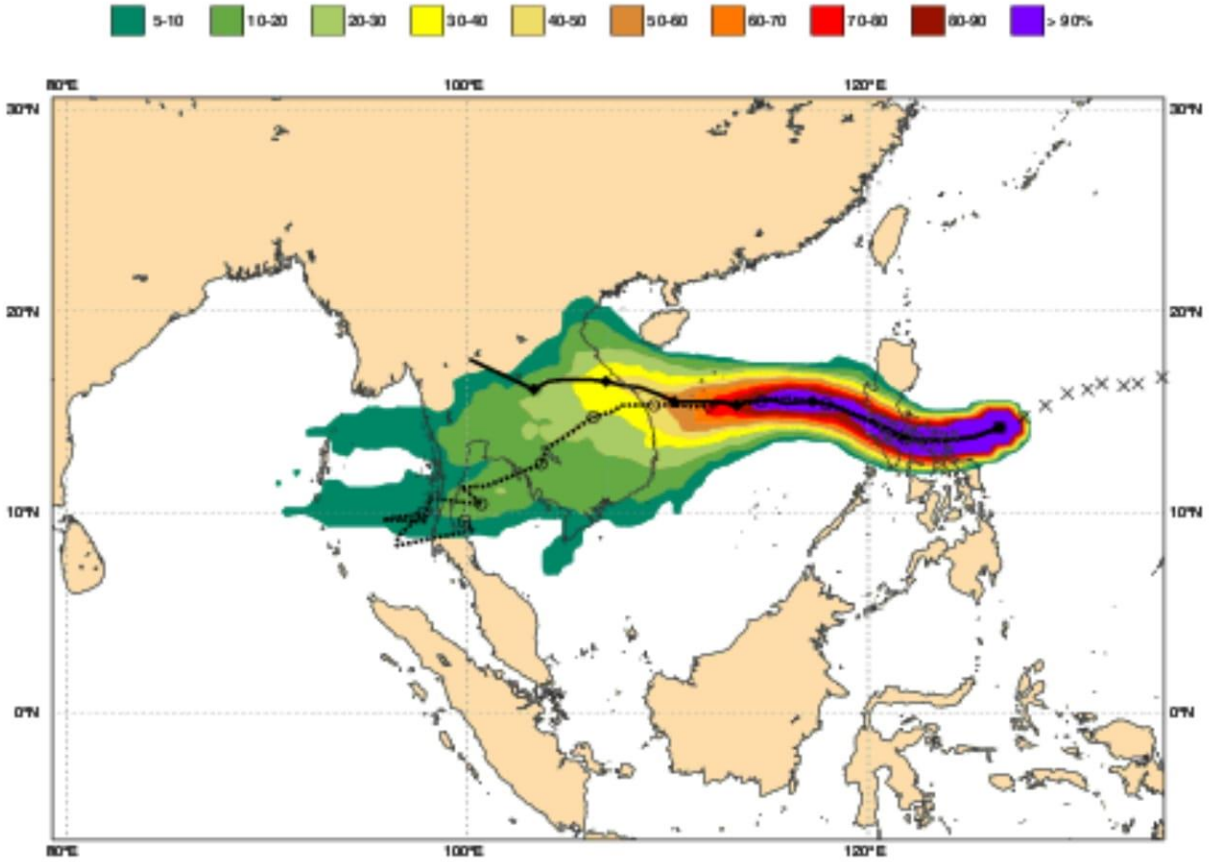
Uncertainties in storm motion under steering of subtropical ridge





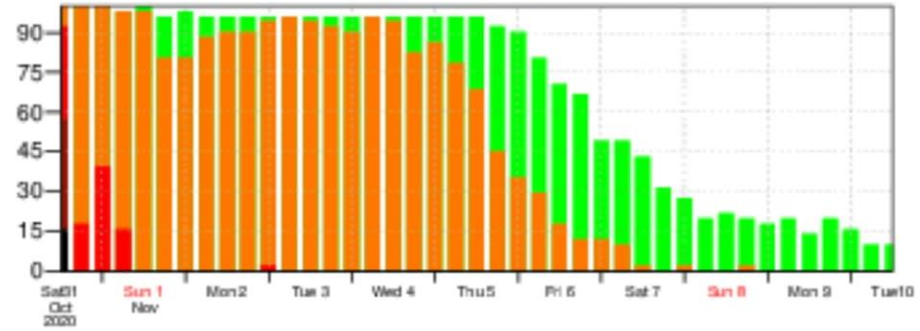
Large uncertainty in the steering flow that chance of recurvature of Asani could be likely (?)

Date 20201031 12 UTC @**ECMWF**
Probability that **GONI** will pass within 120 km radius during the next **240** hours
tracks: **solid**=HRES; **dot**=Ens Mean [reported minimum central pressure (hPa) **915**]

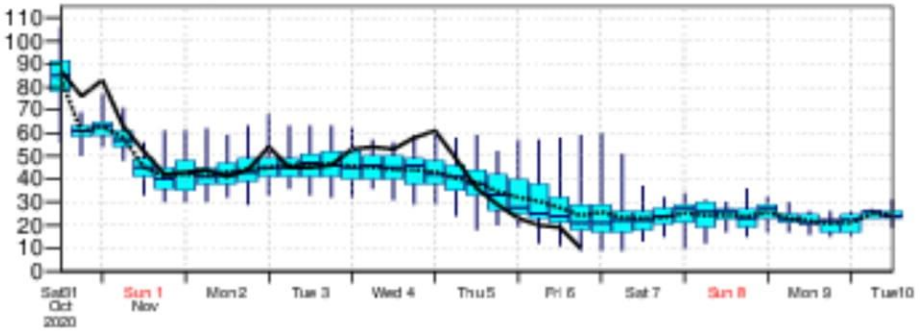


List of ensemble members numbers forecast Tropical Cyclone
Intensity category in colours: **TD**[up to 33] **TS**[34-63] **HR1**[64-82] **HR2**[83-95] **HR3**[> 95 kt]

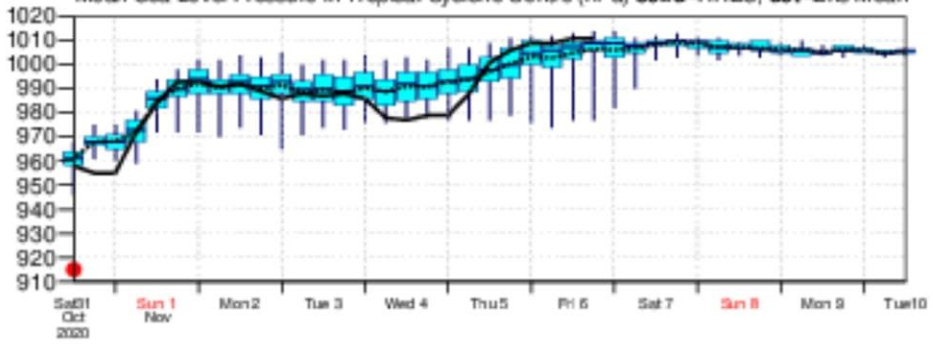
Probability (%) of Tropical Cyclone Intensity falling in each category
TD[up to 33] **TS** [34-63] **HR1**[64-82] **HR2** [83-95] **HR3** [> 95 kt]



10m Wind Speed (kt) **solid**=HRES; **dot**=Ens Mean



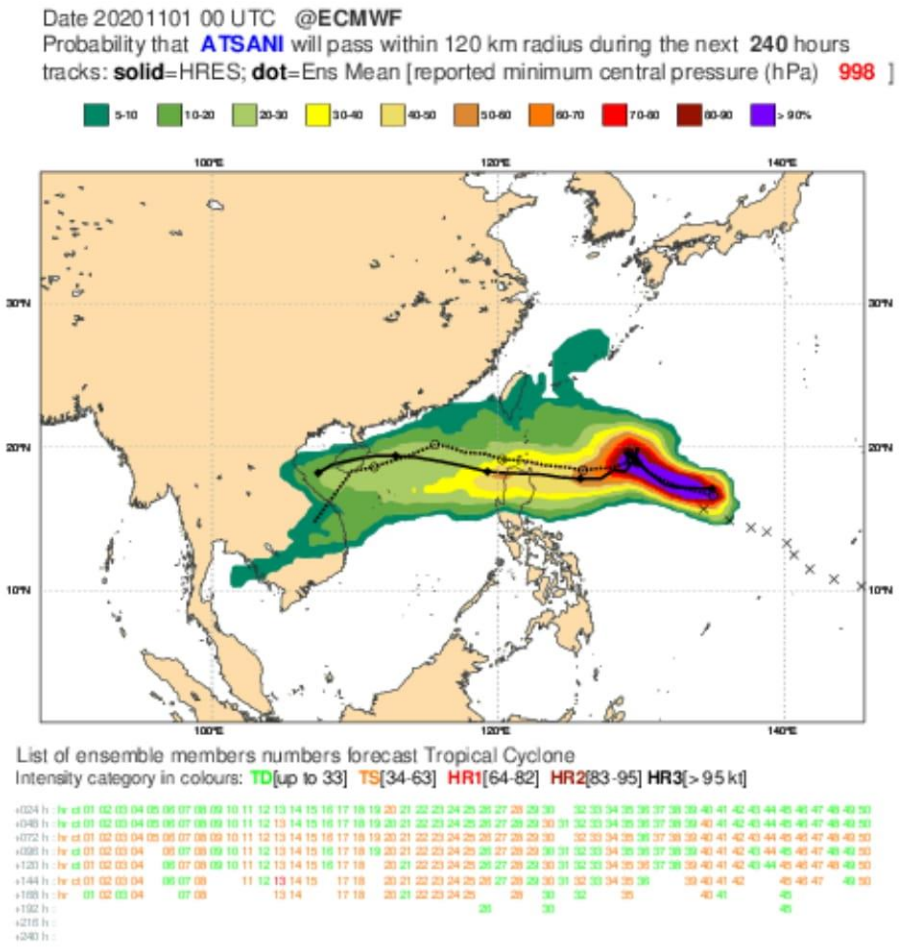
Mean Sea Level Pressure in Tropical Cyclone Centre (hPa) **solid**=HRES; **dot**=Ens Mean

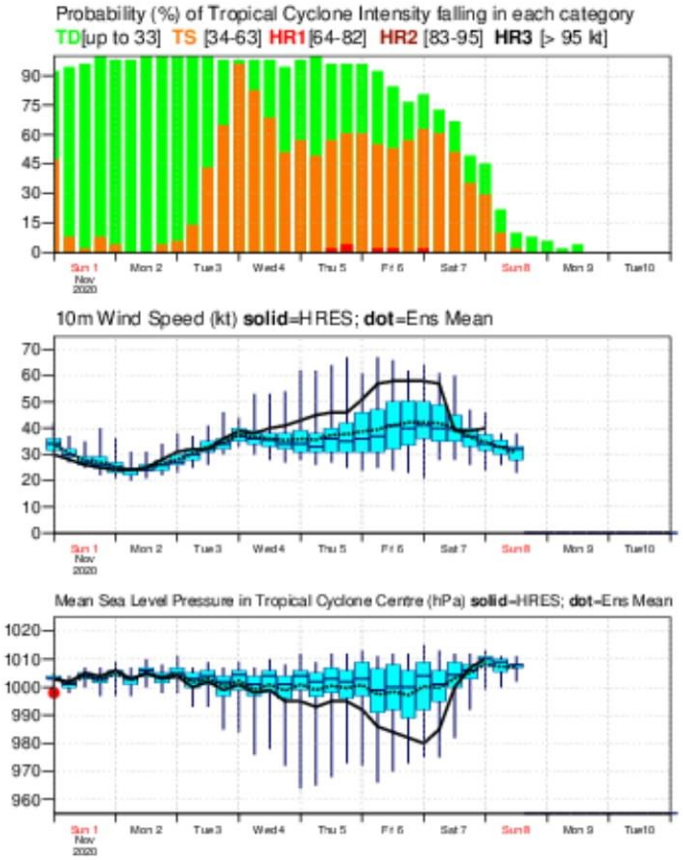


Strike Probability

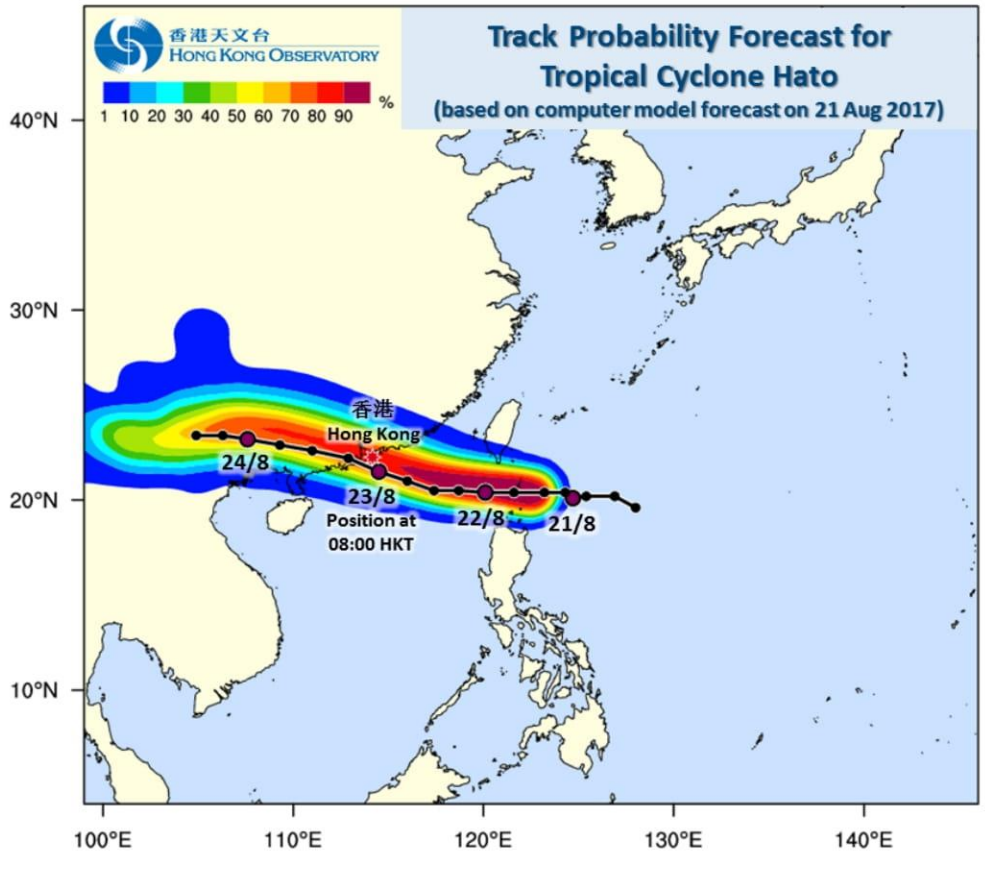
- Strike probability is defined as the proportion of members that predict that the tropical cyclone will pass within a 120 km radius of a given location at any time during the next 10 days (T+240 hours). In other words, the time dimension is integrated over the forecast range.

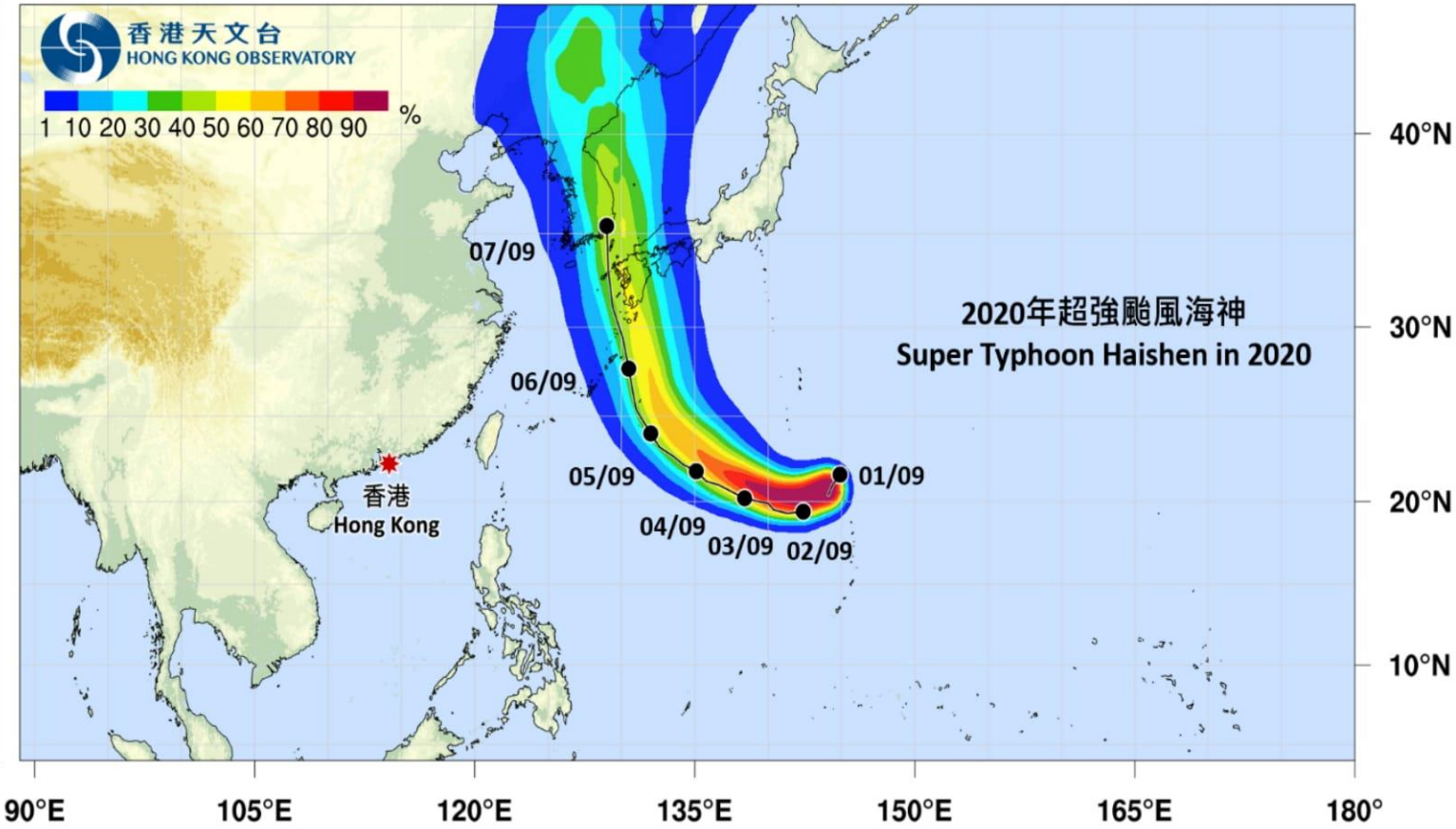
- This allows for a quick assessment of high-risk areas, regardless of the exact timing (Van der Grijn (2002) ECMWF Tech. Memo). A 60% probability at a specific location means that, within a circular area of 120 km, 60% of members have a tropical cyclone centre during the next 10 days.





Strike Probability Map vs Actual Track of TCs



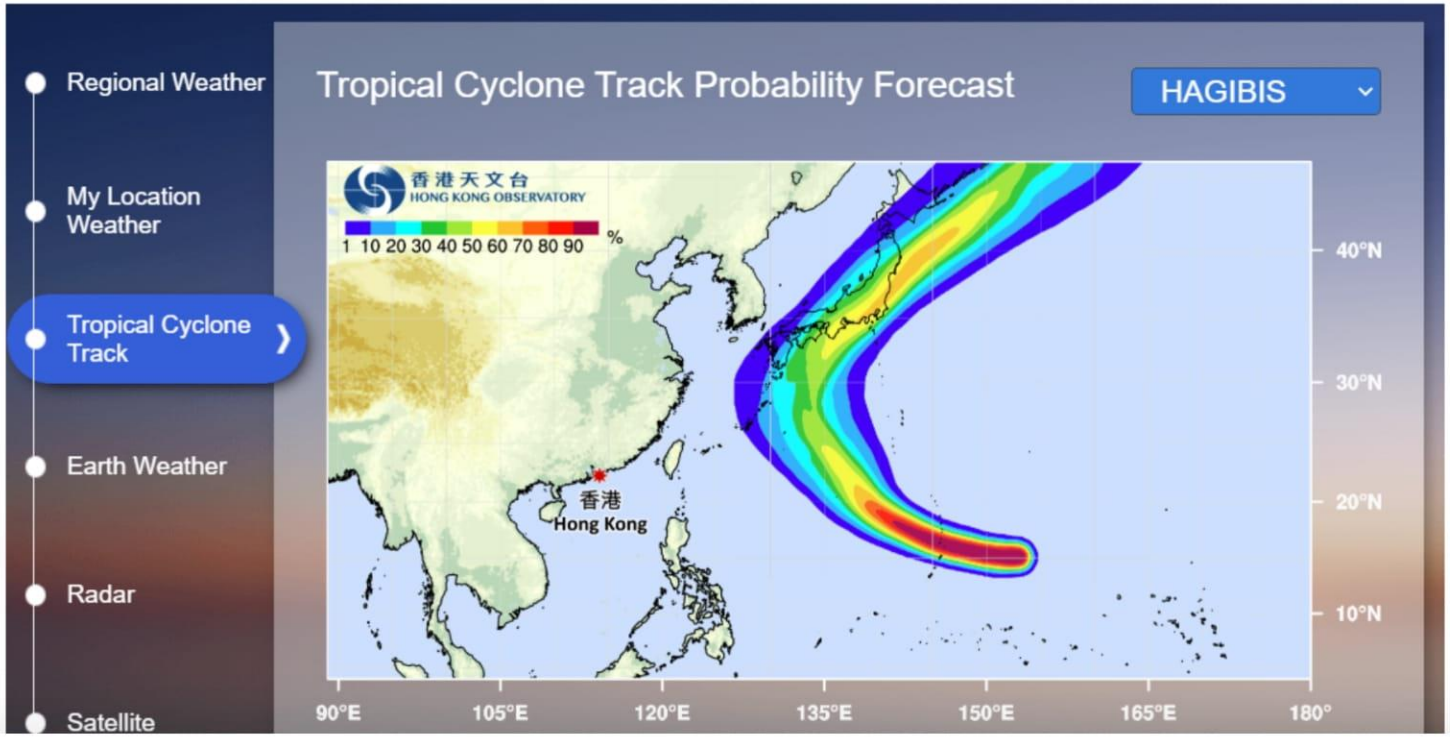


The Observatory Extends Tropical Cyclone Track Probability Forecast

28 July 2020

The Hong Kong Observatory (HKO) enhances its "Tropical Cyclone Track Probability Forecast" service today (28 July 2020). When a tropical cyclone is named in the western North Pacific between 140 degrees east longitude and 180 degrees east longitude, the "Tropical Cyclone Track Probability Forecast" webpage will provide a forecast within a few hours to show the probability of the tropical cyclone track in the coming nine days (Figure 1). This enables members of the public to appraise the trend of tropical cyclone movement and be better prepared.

The "Tropical Cyclone Track Probability Forecast" is automatically generated by computer using data from ensemble prediction system of weather models. The forecast will be updated once a day around noon. The public can get access to the "Tropical Cyclone Track Probability Forecast" from its website, HKO's homepage, or "MyObservatory" mobile app.



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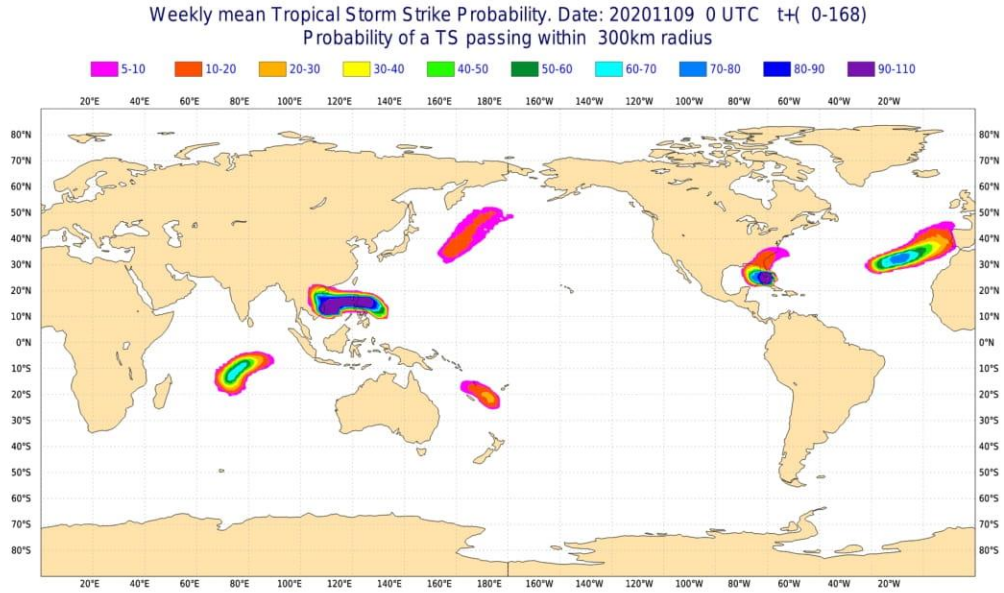
Extended range forecast charts from ECMWF website

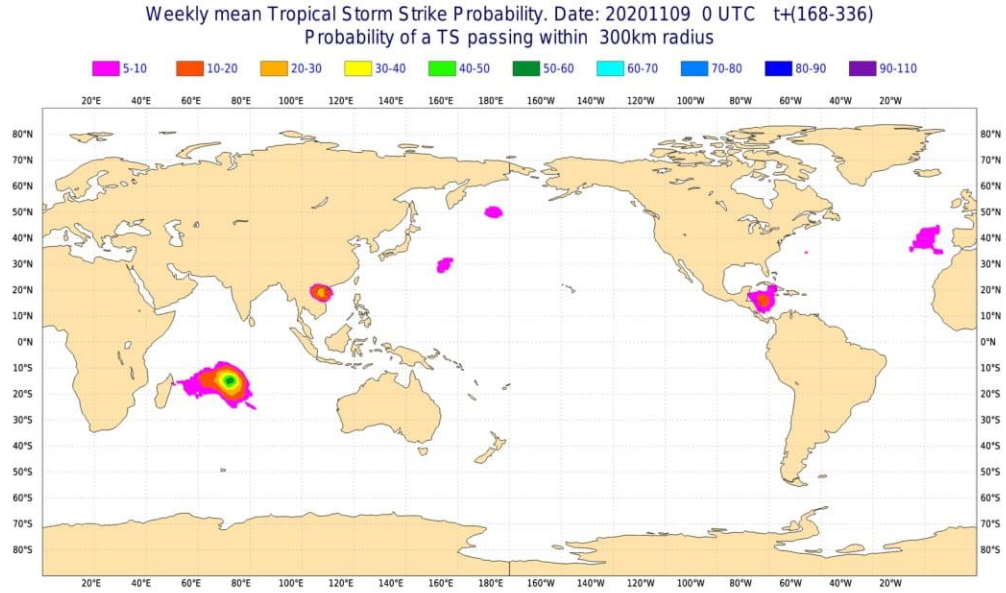
Tropical Storm Probabilities in next 4 weeks

Initial time:
9 Nov 2020

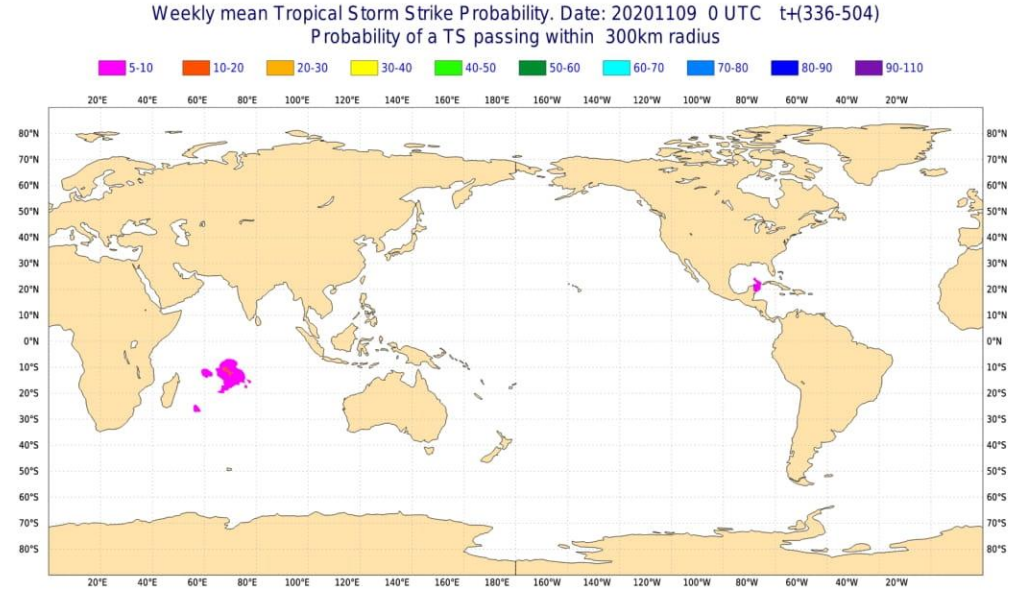
Base time: Mon 09 Nov 2020, Valid time: Sun 08 Nov 2020 - Sun 15 Nov 2020, - T+144 h, Area : Global, Step : 144, Intensity : Tropical storms, Parameter : Forecast



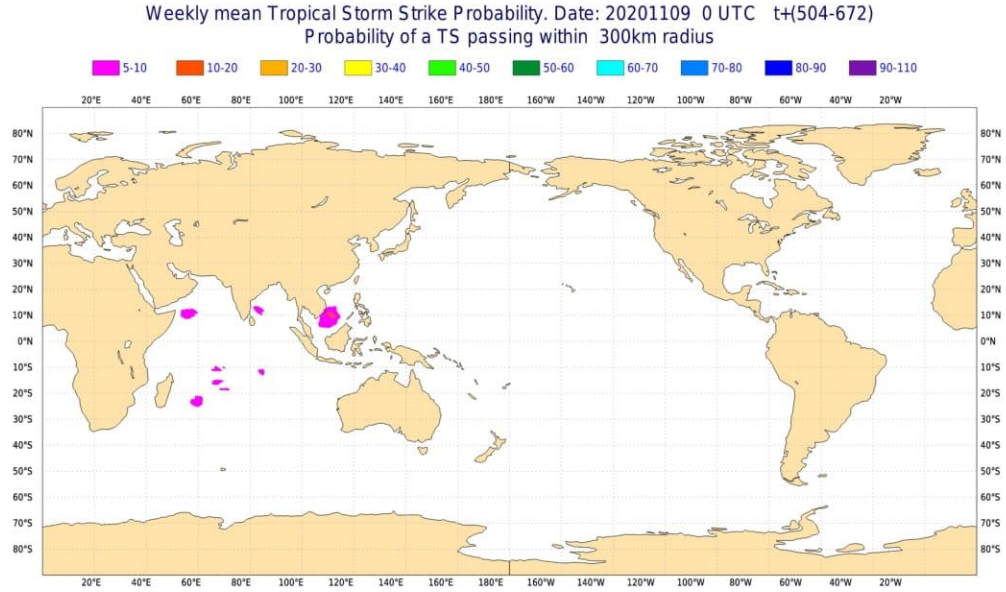
Base time: Mon 09 Nov 2020, Valid time: Sun 15 Nov 2020 - Sun 22 Nov 2020, - T+312 h, Area : Global, Step : 312, Intensity : Tropical storms, Parameter : Forecast



Base time: Mon 09 Nov 2020, Valid time: Sun 22 Nov 2020 - Sun 29 Nov 2020, - T+480 h, Area : Global, Step : 480, Intensity : Tropical storms, Parameter : Forecast



Base time: Mon 09 Nov 2020, Valid time: Sun 29 Nov 2020 - Sun 06 Dec 2020, - T+648 h, Area : Global, Step : 648, Intensity : Tropical storms, Parameter : Forecast

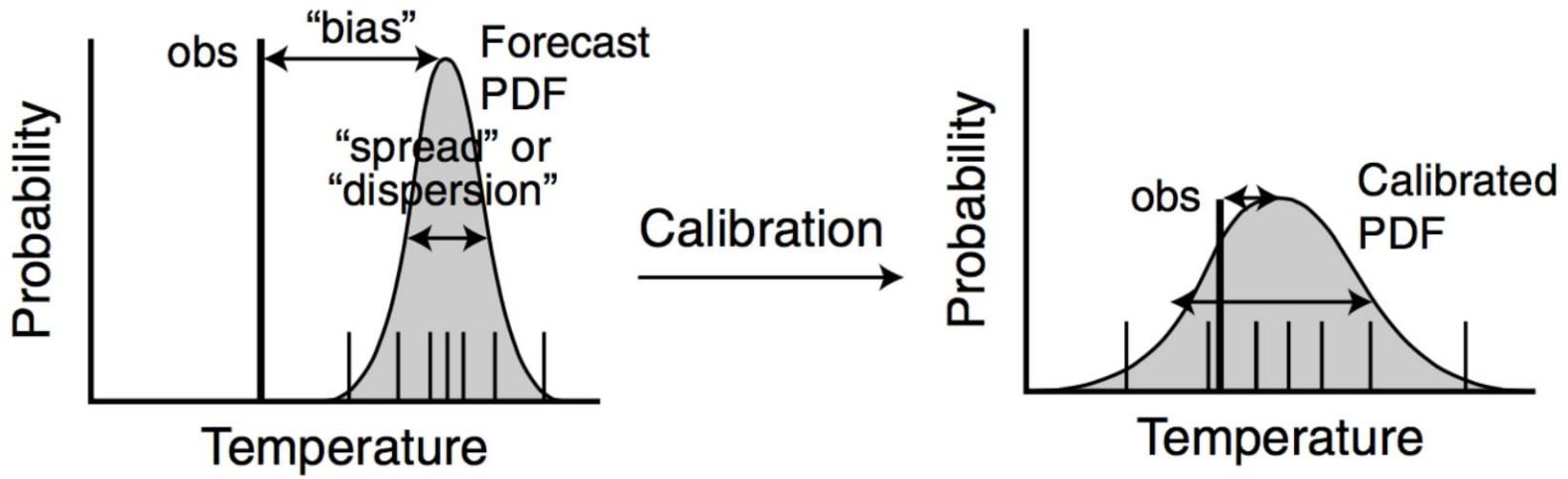


Post-processing of EPS

- Raw EPS forecasts are also subject to forecast bias and dispersion errors, i.e. uncalibrated
- Goal of calibration is to correct for such known model deficiencies, i.e. to construct predictions with statistical properties similar to the observations
- Statistical methods exist for post-processing ensembles

Calibration of ensembles

- Calibration of ensemble forecasts of weather and climate is a post-processing step to remove the bias from ensemble mean (1st moment) and higher moments that provides:
  - increased accuracy in ensemble mean,
  - improved estimates of the probabilities of extreme events, and
  - representation of ensemble spread in terms of quantitative measures of the uncertainty in the forecast of the ensemble mean



Warner (2011)

Bias correction

- Simple first order calibration a bias correction can be applied:

$$c = -\frac{1}{N}\sum_{i=1}^{N}\bar{e}_i + \frac{1}{N}\sum_{i=1}^{N}o_i$$

with: $\bar{e}_i$ = ensemble mean of the i^{th} forecast
o_i = value of i^{th} observation
N = number of observation-forecast pairs

- This correction is added to each ensemble member,
  - i.e. spread is not affected
- Particularly useful / successful at locations with features not resolved by model and causing significant bias
- Adaptive update of bias correction : Kalman filter

Non-homogeneous Gaussian Regression (NGR)

- distribution of the future state y_s of the temperature at location s is modelled as a Gaussian distribution with parameters depending on the M ensemble forecasts $\{f_{1s}; f_{2s}; \ldots; f_{Ms}\}$:

$$y_s | f_{1s}, \ldots, f_{Ms} \sim \mathcal{N}(a + b_1 f_{1s} + \ldots + b_M f_{Ms}, c + dS_s^2)$$

where $a, b_1, \ldots, b_M$ are regression coefficients, and S_s^2 is the ensemble variance

- To determine the coefficients $\{a; b_1, \ldots b_M; c; d\}$, minimise continuous ranked probability score (CRPS):

$$\mathrm{CRPS}(P, x_a) = \int_{-\infty}^{\infty} [P(x) - P_a(x)]^2 \, dx.$$

$$P(x) = \int_{-\infty}^{x} \rho(y) \, dy \quad \text{and} \quad P_a(x) = H(x - x_a)$$

$$H(x - x_a) = \begin{cases} 0 & \text{for} \quad x < x_a, \\ 1 & \text{for} \quad x \geq x_a. \end{cases}$$

CRPS expresses the distance between probabilistic forecast and the truth $\mathbf{x_a}$

- For Gaussian pdf (e.g. temperature and pressure), CRPS for training phase can be written as:

$$\mathrm{CRPS}_{\mathrm{train}} = \frac{1}{k} \sum_{i=1}^{k} (c + d\sigma_i^2)^{1/2} \times \left\{ Z_i [2\Phi(Z_i) - 1] + 2\phi(Z_i) - \frac{1}{\sqrt{\pi}} \right\}$$

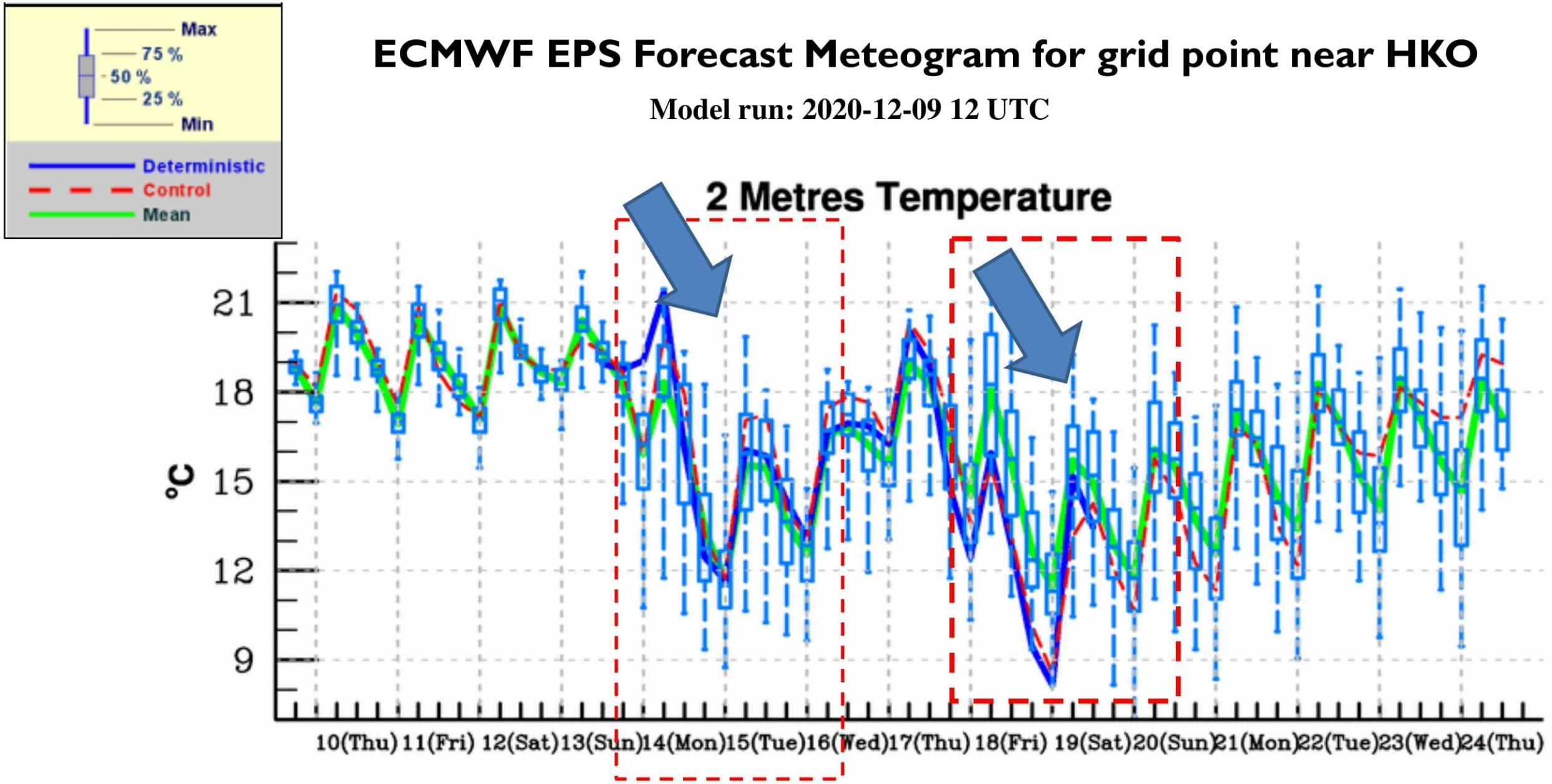
$$\text{with} \qquad Z_i = \frac{Y_i - (a + b\mu_i)}{(c + d\sigma_i^2)^{1/2}}.$$

Φ and φ denote the cumulative distribution function (CDF) and the PDF of the standard normal distribution (with $\mu = 0$, $\sigma^2 = 1$), respectively.

k is the number of days in the training sample and Y_i corresponds to the observation at day i.

ECMWF EPS Forecast Meteogram for grid point near HKO

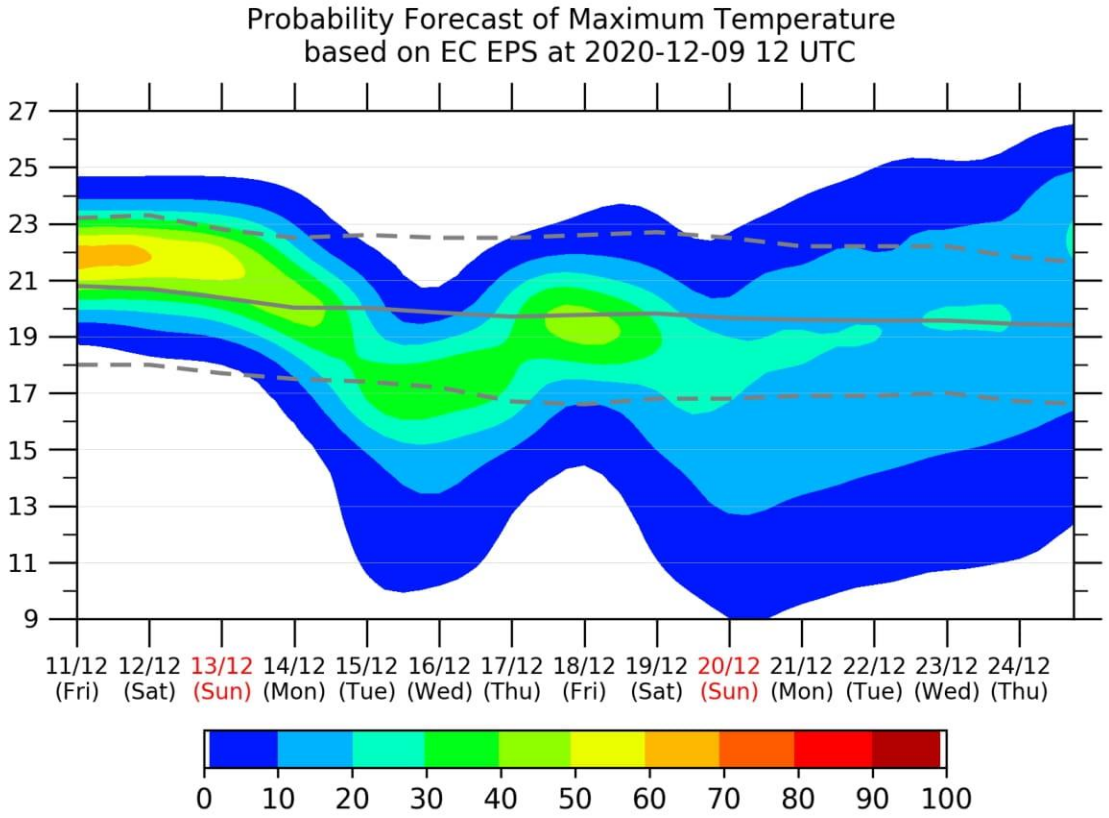
Model run: 2020-12-09 12 UTC



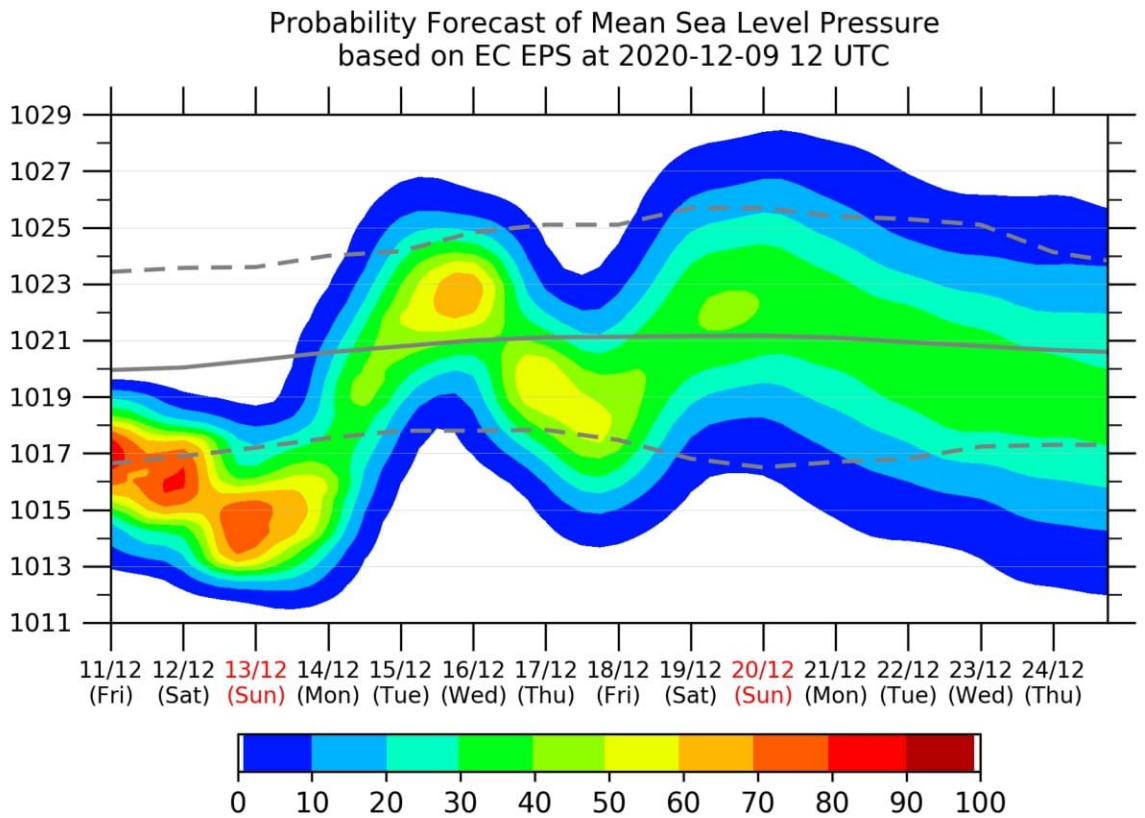
1. Trend of daily minimum temperature over Hong Kong (urban areas) in the next 2 weeks

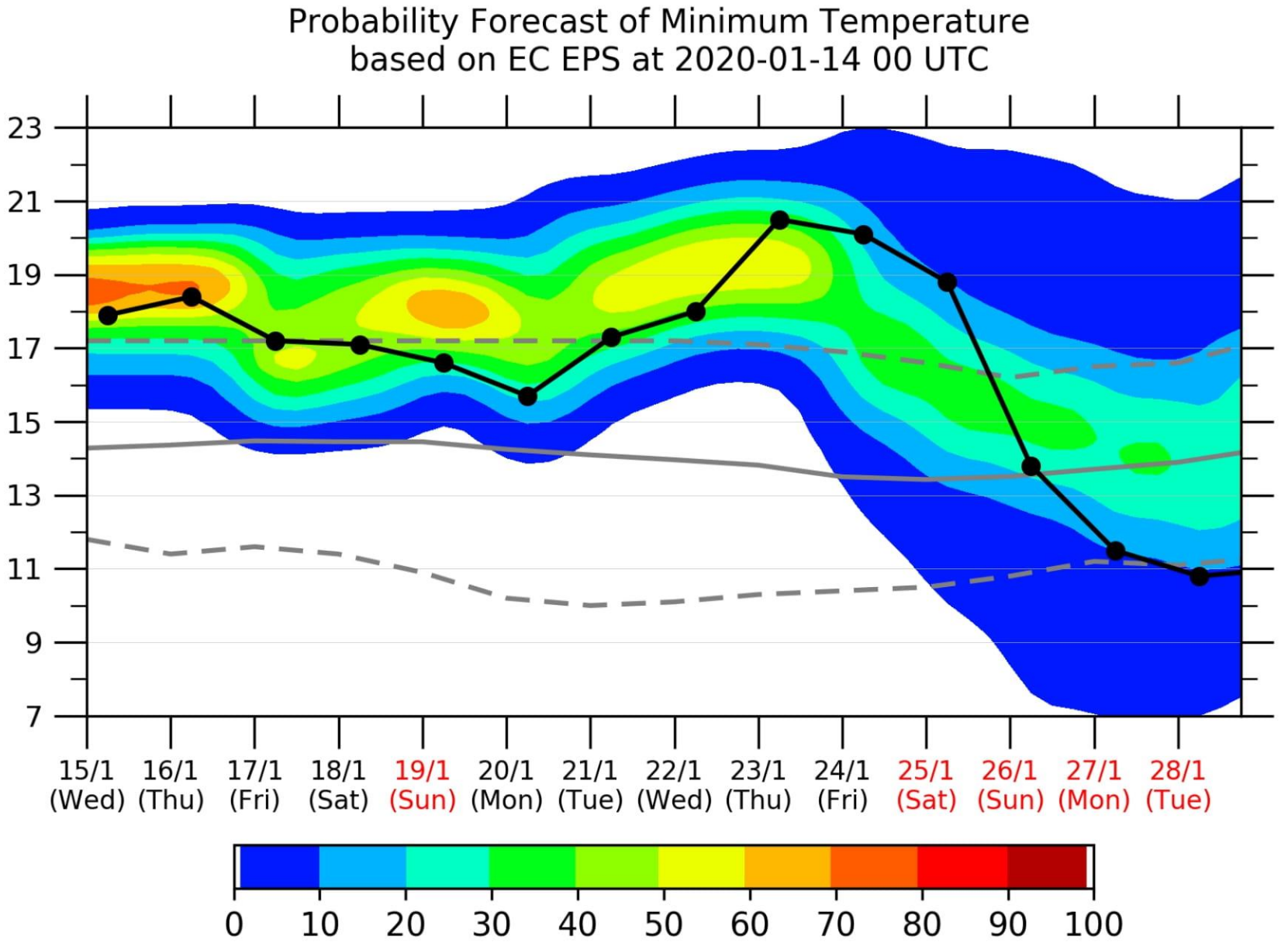
2. Probability of daily minimum temperature chance of abrupt temperature drop / cold weather

Maximum Temperature

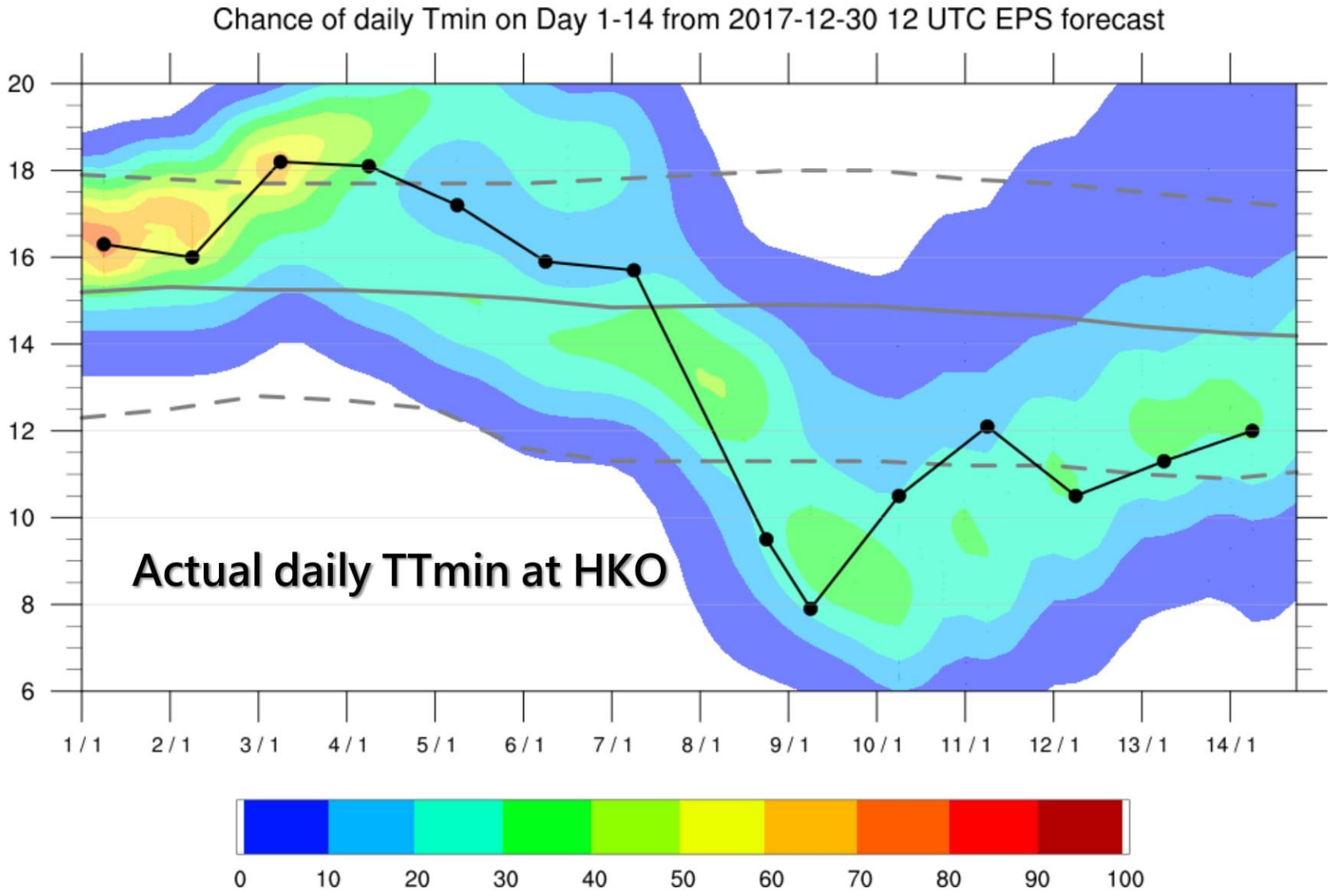


Mean Sea Level Pressure

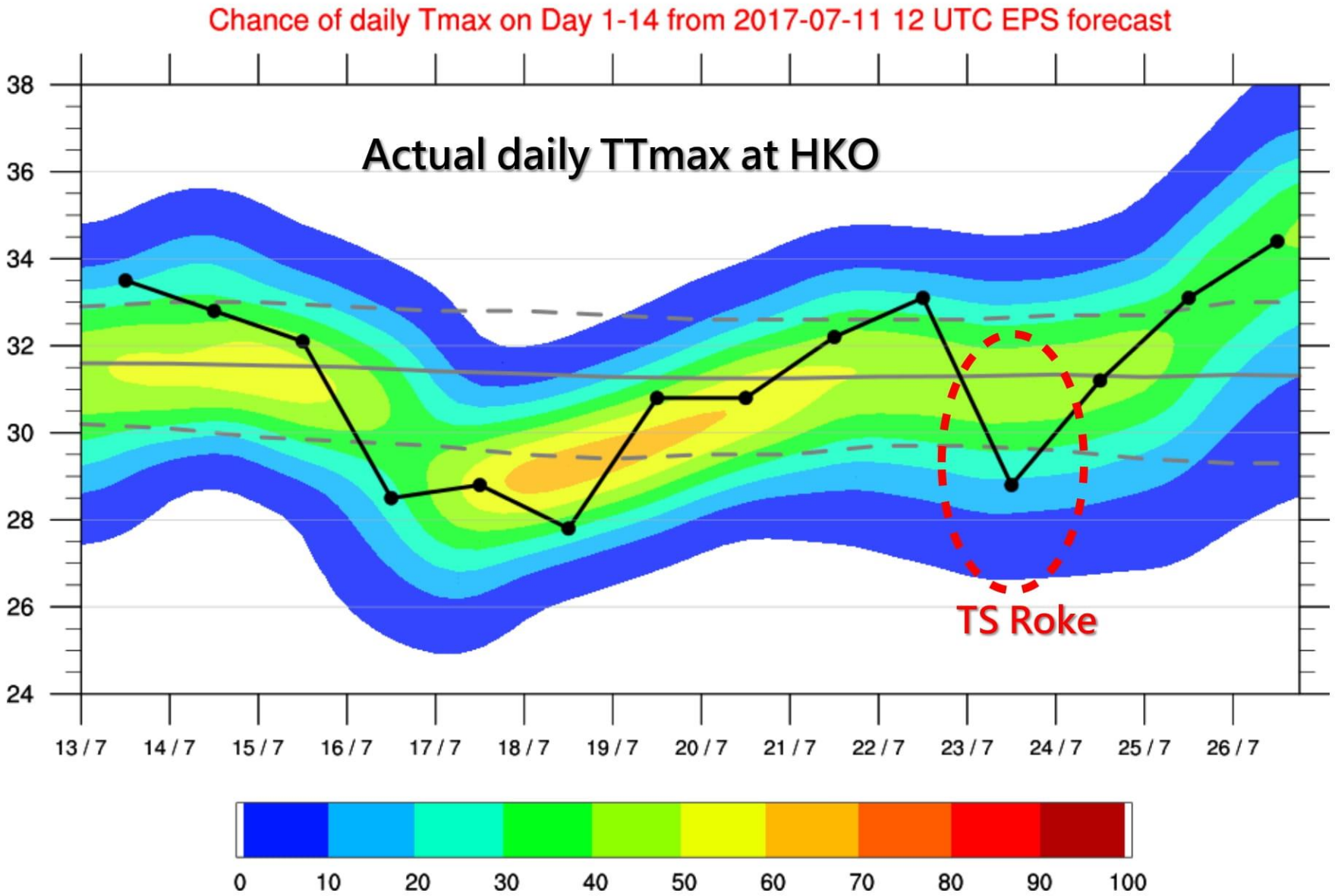



Probability Forecast of Minimum Temperature
based on EC EPS at 2020-01-14 00 UTC
23
21
19
17
15
13
11
9
7
15/1 (Wed)
16/1 (Thu)
17/1 (Fri)
18/1 (Sat)
19/1 (Sun)
20/1 (Mon)
21/1 (Tue)
22/1 (Wed)
23/1 (Thu)
24/1 (Fri)
25/1 (Sat)
26/1 (Sun)
27/1 (Mon)
28/1 (Tue)
0
10
20
30
40
50
60
70
80
90
100

Intense cold surge in early Jan 2018



Chance of daily maximum temperature



Calibration of PoP using logistic regression (LogR)

- Daily probability of precipitation (PoP) in Automatic Regional Weather Forecast

  – Pr { Precipitation >= some threshold η }
  – Direct Model Output (DMO)

For *N* EPS members in DMO,

$$\mathrm{PoP}_{\mathrm{DMO}}(\eta) = \frac{1}{N}\sum_{i=1}^{N} q_i$$

$$q_i = \begin{cases} 1 & \text{if } f_i \geq \eta \\ 0 & \text{if } f_i < \eta \end{cases}$$

where f_i is the total precipitation forecast of *i-th* member in EPS

- Formulation

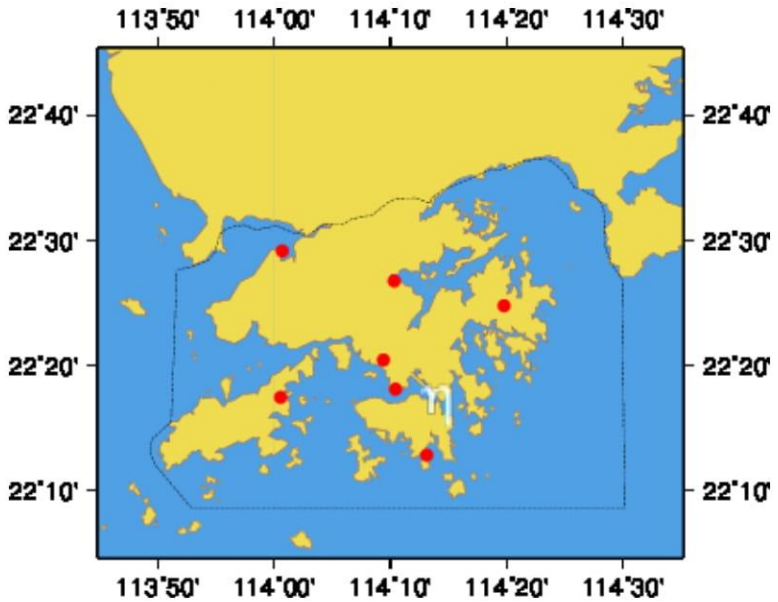
$$\mathrm{PoP}_{\mathrm{LogR}}(\eta) = \frac{1}{4\times 51}\sum_{i=1}^{4}\sum_{k=1}^{51}\frac{1}{1+\exp(-\beta_{0,i}-\beta_{1,i}f_{i,k}^{1/3}-\beta_{2,i}\delta_{i,k})}\ ,\eta = 0.05$$

$$\delta_{i,j} = \begin{cases} 1 & \text{if} \quad f_{i,j} = 0 \\ 0 & \text{otherwise} \end{cases}$$

η Threshold of precipitation (mm)

$\beta_{n,i}, \beta'_{n,i}$ Parameters of Logistic Regression

$f_{i,j}$ Precipitation amount forecast by EPS member



- Observed Rainfall:
  - Climatological averaged daily rainfall :
    - 0.05mm: <~50%
    - 10mm: ~15%
    - 20mm: ~10%
    - 50mm: ~5%

- Calibrate ECMWF EPS outputs for thresholds at 0.05 mm (rain/no rain) and 10 mm ("significant" rain day) with data from past 90 days

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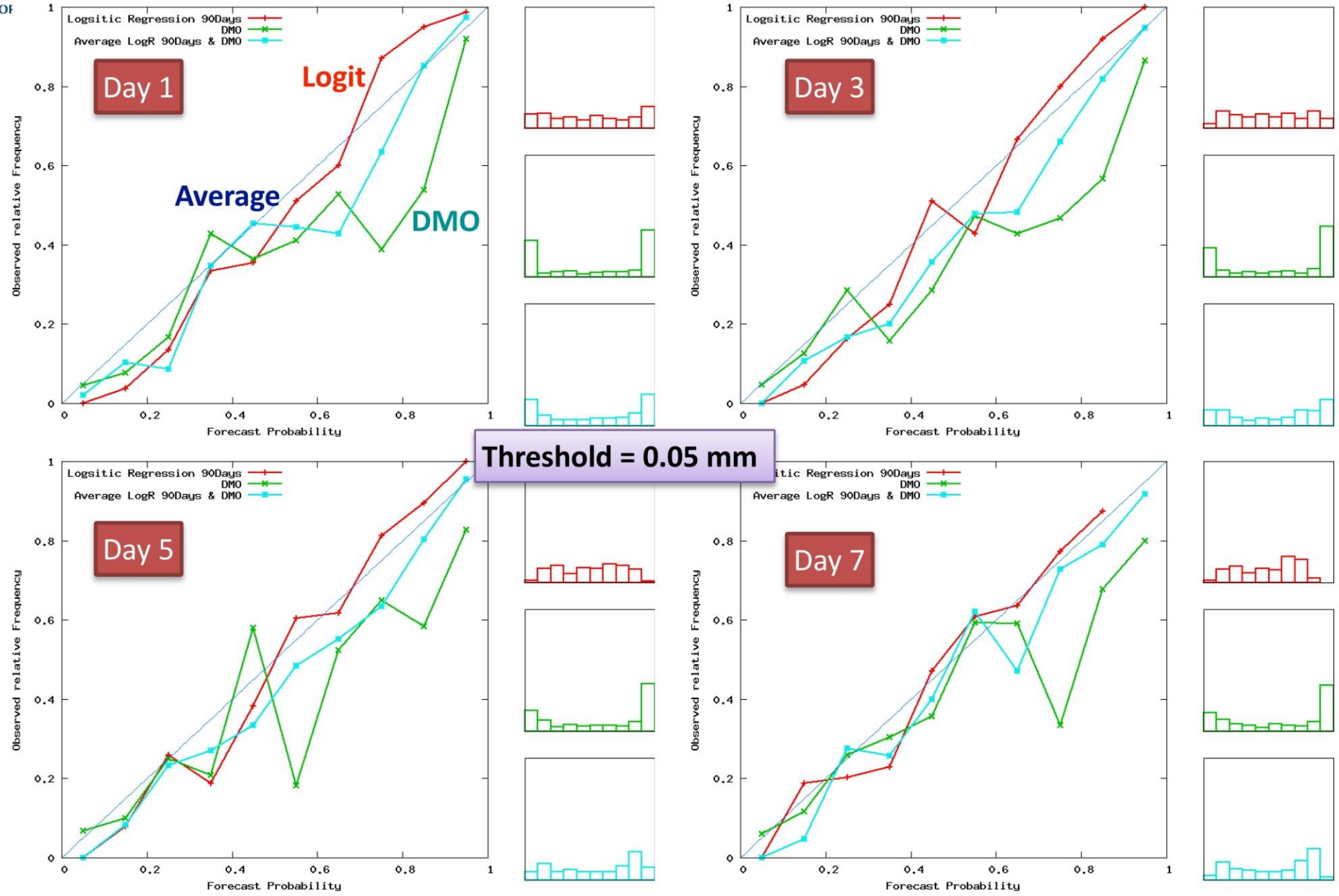

Threshold = 0.05 mm

EPS guidance for significant convective weather

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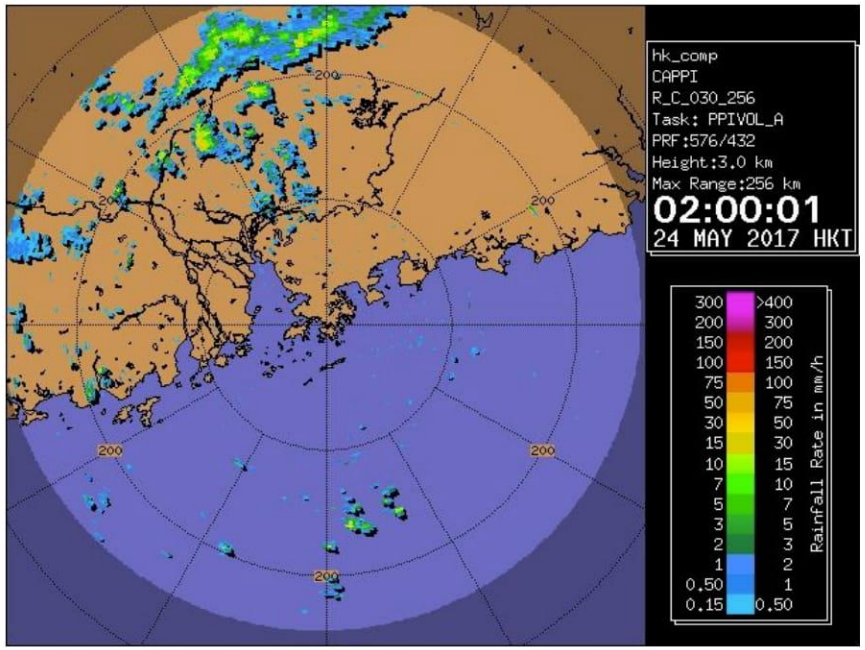
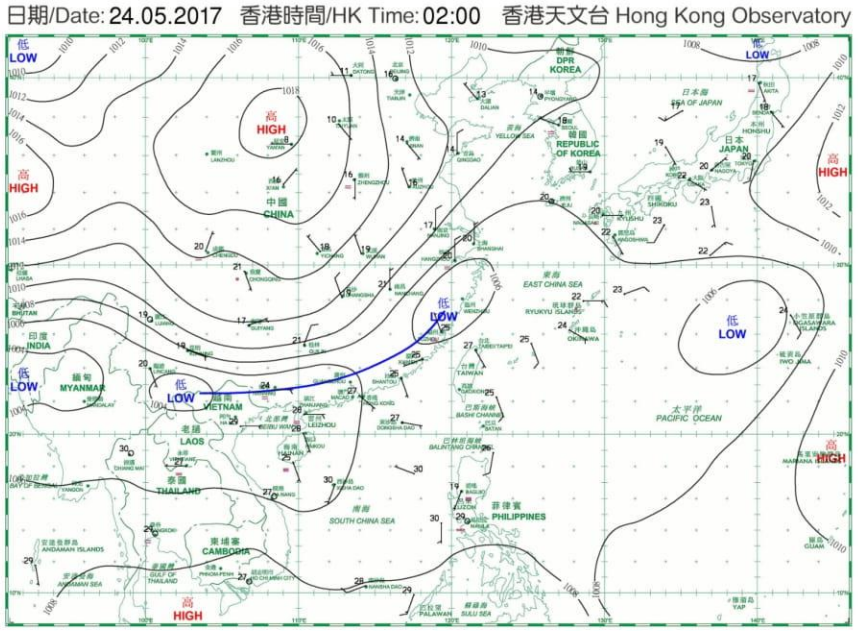
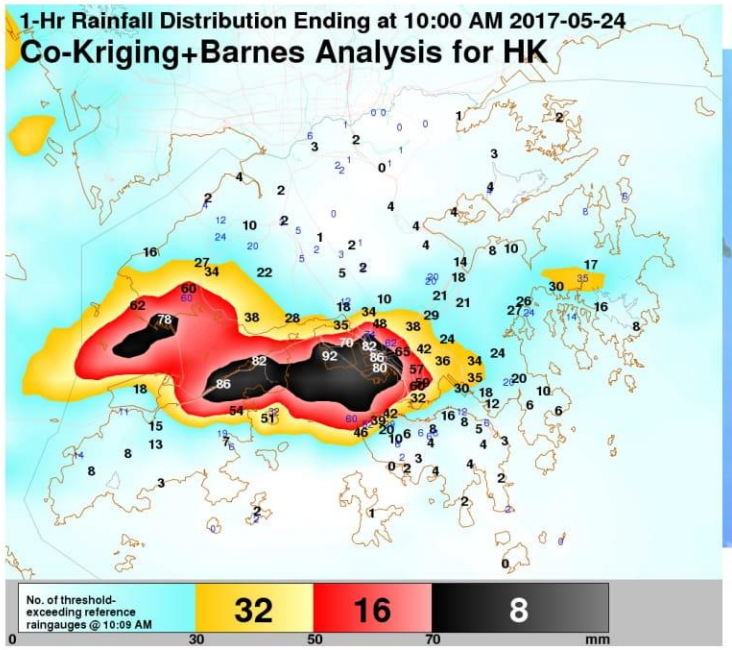
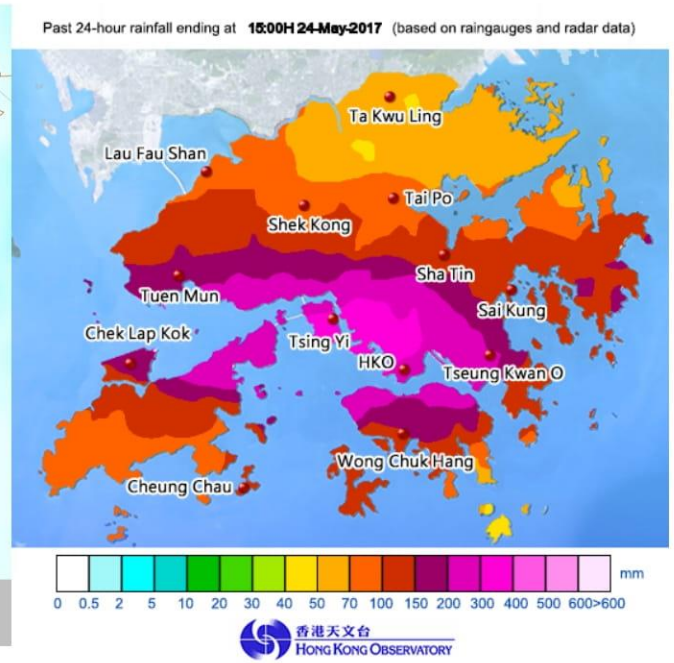
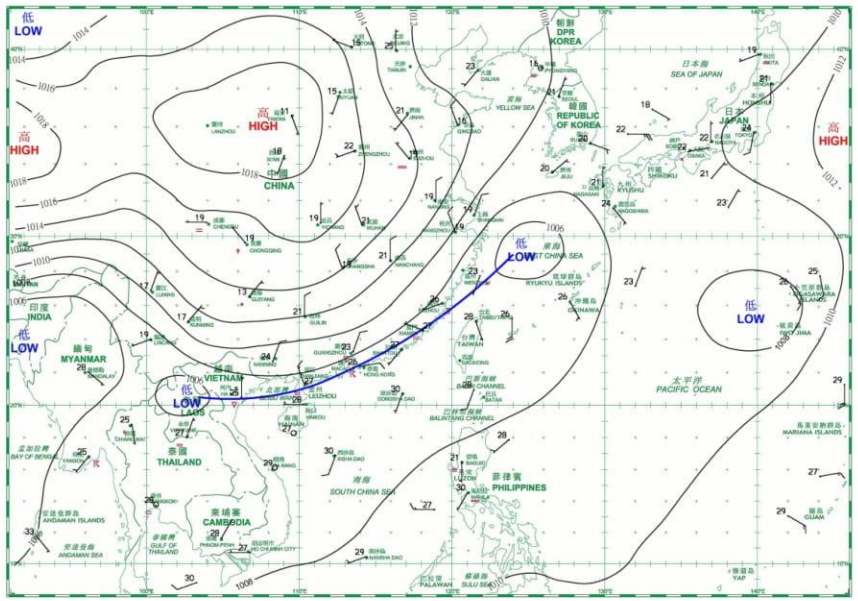
Black Rainstorm on 2017-05-24

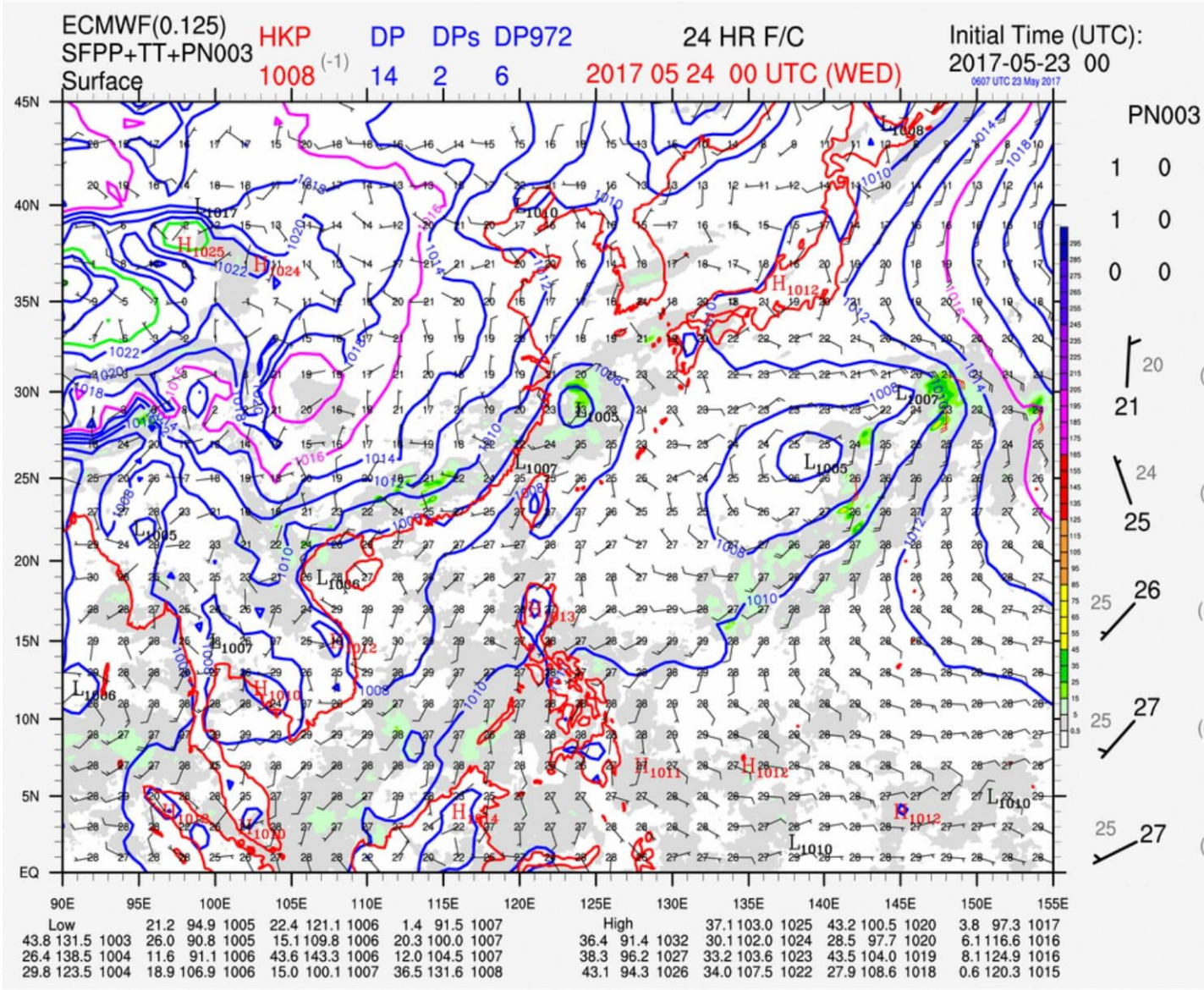


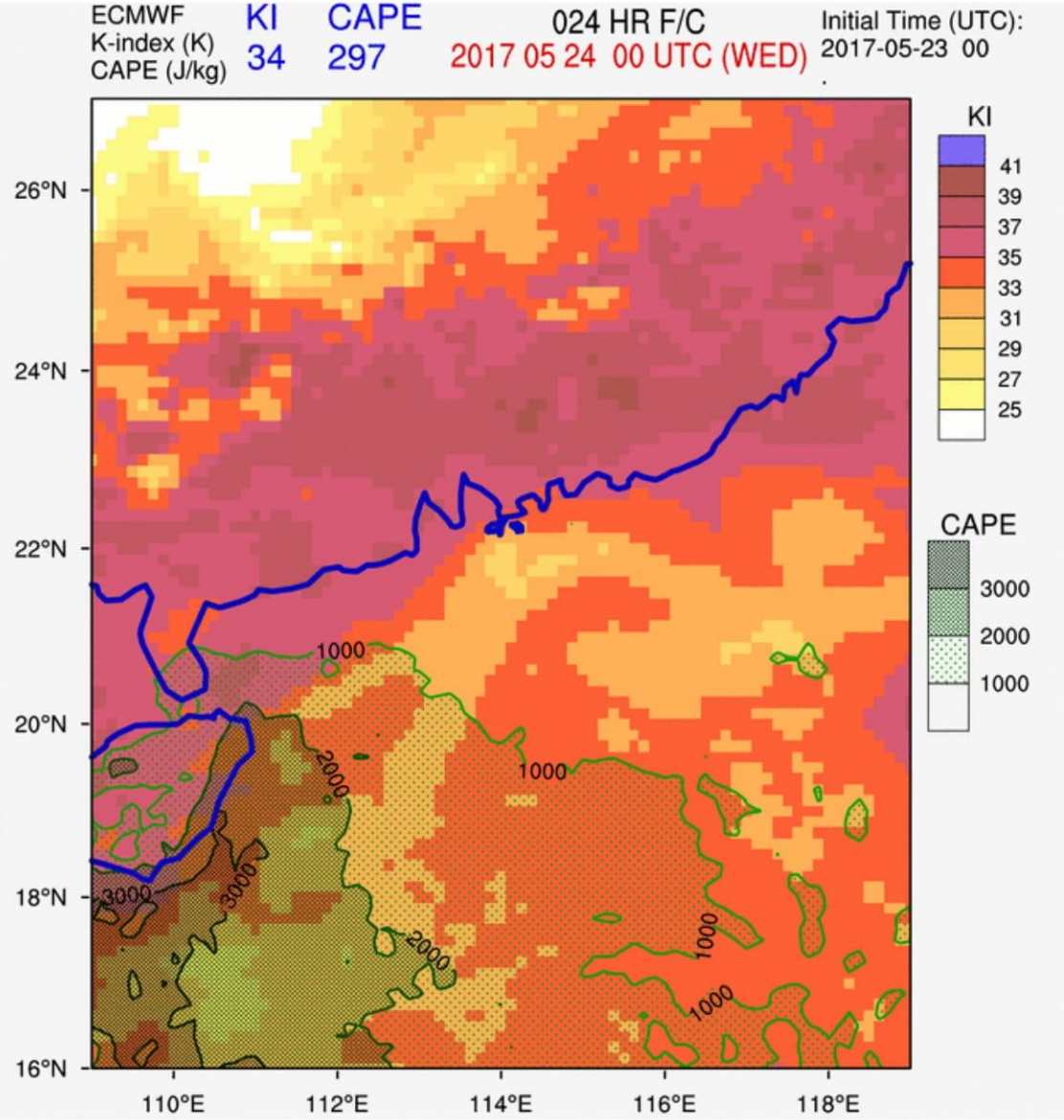


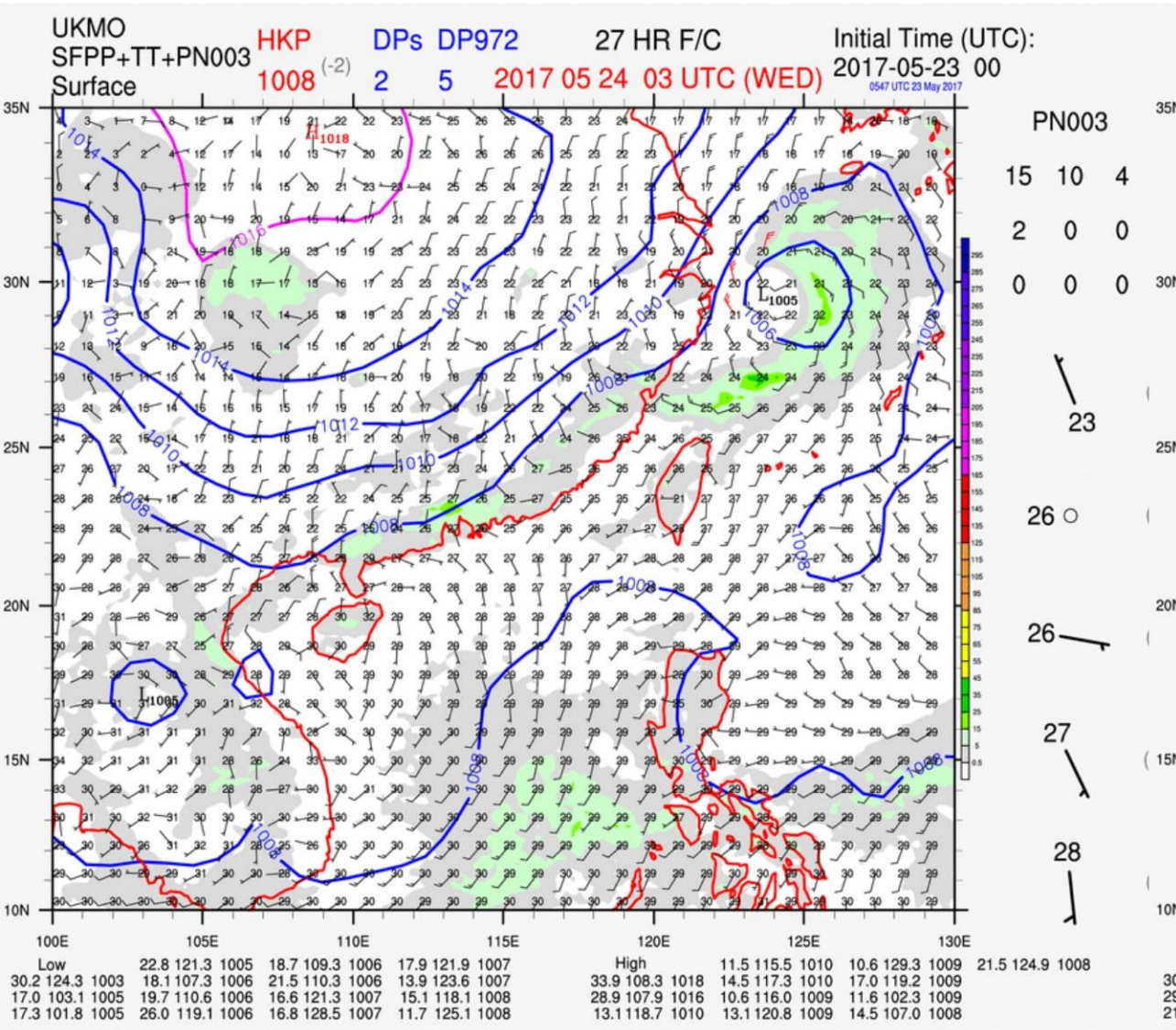







ECMWF(0.125)
SFPP+TT+PN003
Surface
HKP
1008 (-1)
DP
14
DPs
2
DP972
6
24 HR F/C
2017 05 24 00 UTC (WED)
Initial Time (UTC):
2017-05-23 00
0607 UTC 23 May 2017
PN003
1 0 0
1 0 0
0 0 0
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
90E
95E
100E
105E
110E
115E
120E
125E
130E
135E
140E
145E
150E
155E
Low
21.2 94.9 1005
26.0 90.8 1005
11.6 91.1 1006
18.9 106.9 1006
22.4 121.1 1006
15.1 109.8 1006
43.6 143.3 1006
15.0 100.1 1007
1.4 91.5 1007
20.3 100.0 1007
12.0 104.5 1007
36.5 131.6 1008
43.8 131.5 1003
26.4 138.5 1004
29.8 123.5 1004
High
37.1 103.0 1025
30.1 102.0 1024
33.2 103.6 1023
34.0 107.5 1022
43.2 100.5 1020
28.5 97.7 1020
43.5 104.0 1019
27.9 108.6 1018
3.8 97.3 1017
6.1 116.6 1016
8.1 124.9 1016
0.6 120.3 1015
36.4 91.4 1032
38.3 96.2 1027
43.1 94.3 1026


ECMWF
K-index (K)
CAPE (J/kg)
KI
34
CAPE
297
024 HR F/C
2017 05 24 00 UTC (WED)
Initial Time (UTC):
2017-05-23 00
KI
41
39
37
35
33
31
29
27
25
CAPE
3000
2000
1000
26°N
24°N
22°N
20°N
18°N
16°N
110°E
112°E
114°E
116°E
118°E


UKMO
SFPP+TT+PN003
Surface
HKP
1008 (-2)
DPs DP972
2 5
27 HR F/C
2017 05 24 03 UTC (WED)
Initial Time (UTC):
2017-05-23 00
0547 UTC 23 May 2017
PN003
15 10 4
2 0 0
0 0 0
23
26
27
28
35N
30N
25N
20N
15N
10N
100E
105E
110E
115E
120E
125E
130E
Low
30.2 124.3 1003
17.0 103.1 1005
17.3 101.8 1005
22.8 121.3 1005
18.1 107.3 1006
19.7 110.6 1006
26.0 119.1 1006
18.7 109.3 1006
21.5 110.3 1006
16.6 121.3 1007
16.8 128.5 1007
17.9 121.9 1007
13.9 123.6 1007
15.1 118.1 1008
11.7 125.1 1008
High
33.9 108.3 1018
28.9 107.9 1016
13.1 118.7 1010
11.5 115.5 1010
14.5 117.3 1010
10.6 116.0 1009
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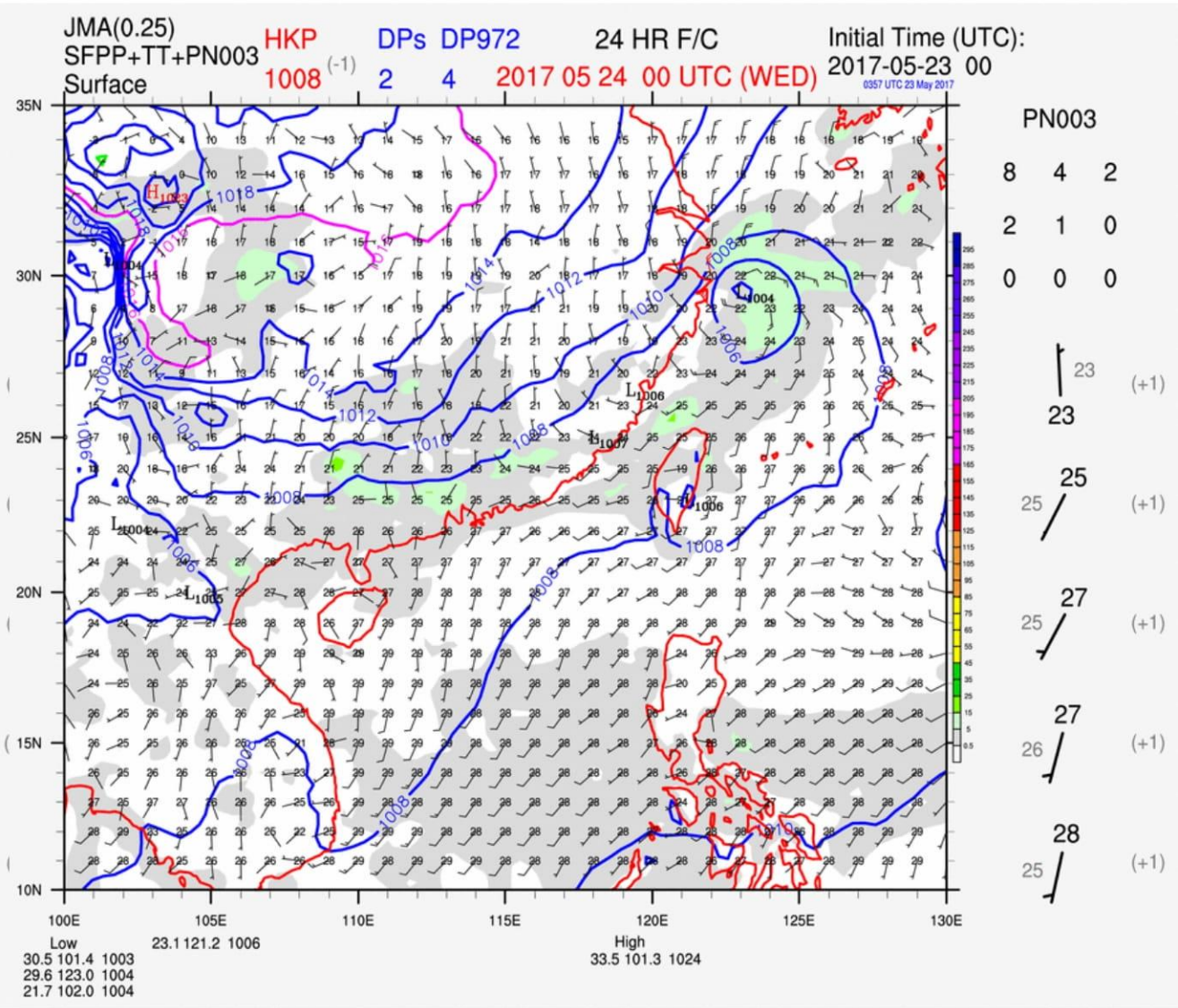
11.6 102.3 1009
14.5 107.0 1008
21.5 124.9 1008


JMA(0.25)
SFPP+TT+PN003
Surface
HKP
1008 (-1)
DPs DP972
2 4
24 HR F/C
2017 05 24 00 UTC (WED)
Initial Time (UTC):
2017-05-23 00
0357 UTC 23 May 2017
PN003
8 4 2
2 1 0
0 0 0
23 (+1)
23
25 (+1)
25
27 (+1)
27
26 (+1)
28
25 (+1)
35N
30N
25N
20N
15N
10N
100E
105E
110E
115E
120E
125E
130E
Low
30.5 101.4 1003
29.6 123.0 1004
21.7 102.0 1004
23.1 121.2 1006
High
33.5 101.3 1024

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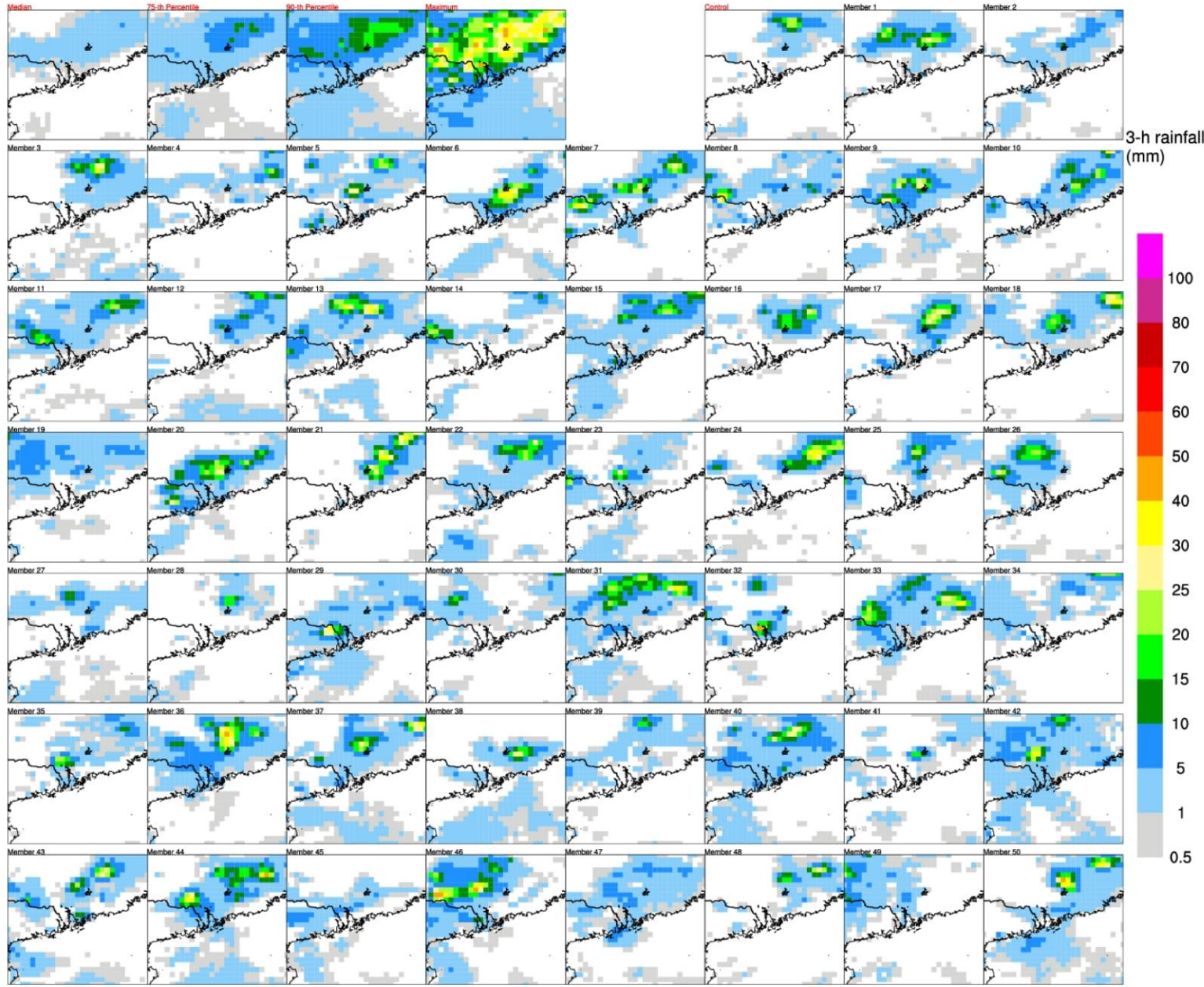
ECMWF EPS
3-h rainfall

2017-05-24 03:00 UTC (WED)

T+27 h forecast
Initialised at: 2017-05-23 00:00 UTC



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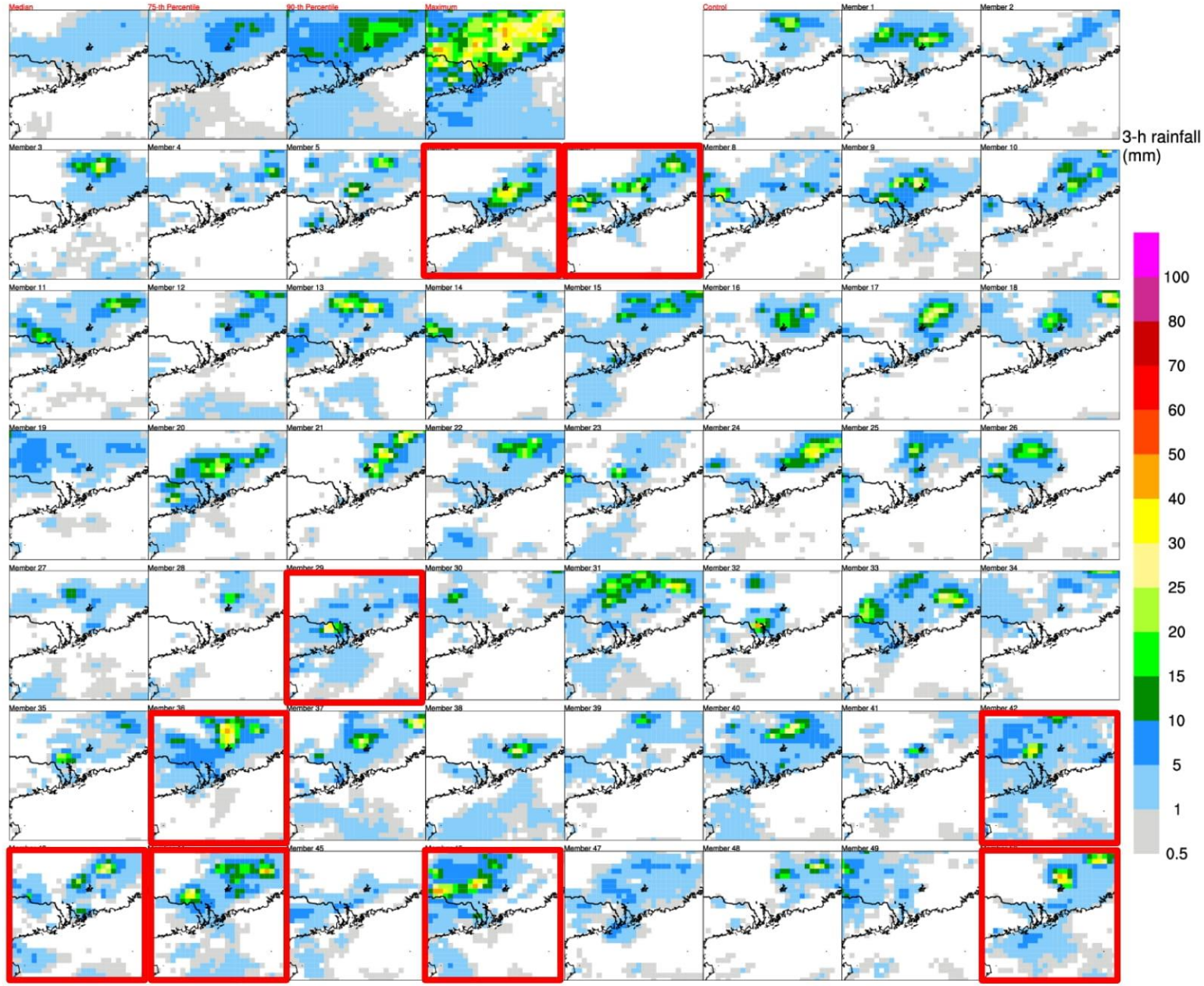
ECMWF EPS
3-h rainfall

2017-05-24 03:00 UTC (WED)

T+27 h forecast
Initialised at: 2017-05-23 00:00 UTC

Individual members showed sign of warm sector precipitation over GD coast but **too weak** in intensity



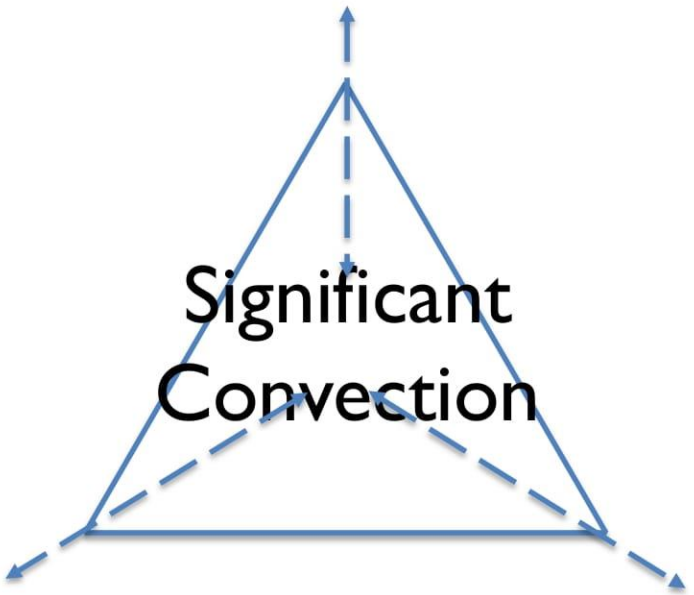
Question

- Can uncertainties in development be represented by NWP models - given that NWP models have different characteristics in resolving timing, initiation, mechanisms of development, etc ?

  - EPS encompass possible scenarios, as it should be designed like that (as revealed from success from TC track prediction)… at least from synoptic or sub-synoptic scale point of view

High-impact convective weather ingredients

Dynamics



Instability

Moisture

Uncertainty

Timing, Location and Physical mechanisms

Warm-season MCS, elevated thunderstorms and heavy rain (Moore et al. 2003):

https://journals.ametsoc.org/doi/abs/10.1175/1520-0434%282003%29018%3C0861%3ATEOWET%3E2.0.CO%3B2

- Favorable factors for elevated significant convections and heavy rain:
  - North-south **EPT gradient**
  - S - SW'ly **LLJ**
  - **Moisture convergence ridge** on 925 hPa (and/or 850 hPa)
  - Max. of +ve advection of EPT
  - Mid-tropospheric SW'ly flow

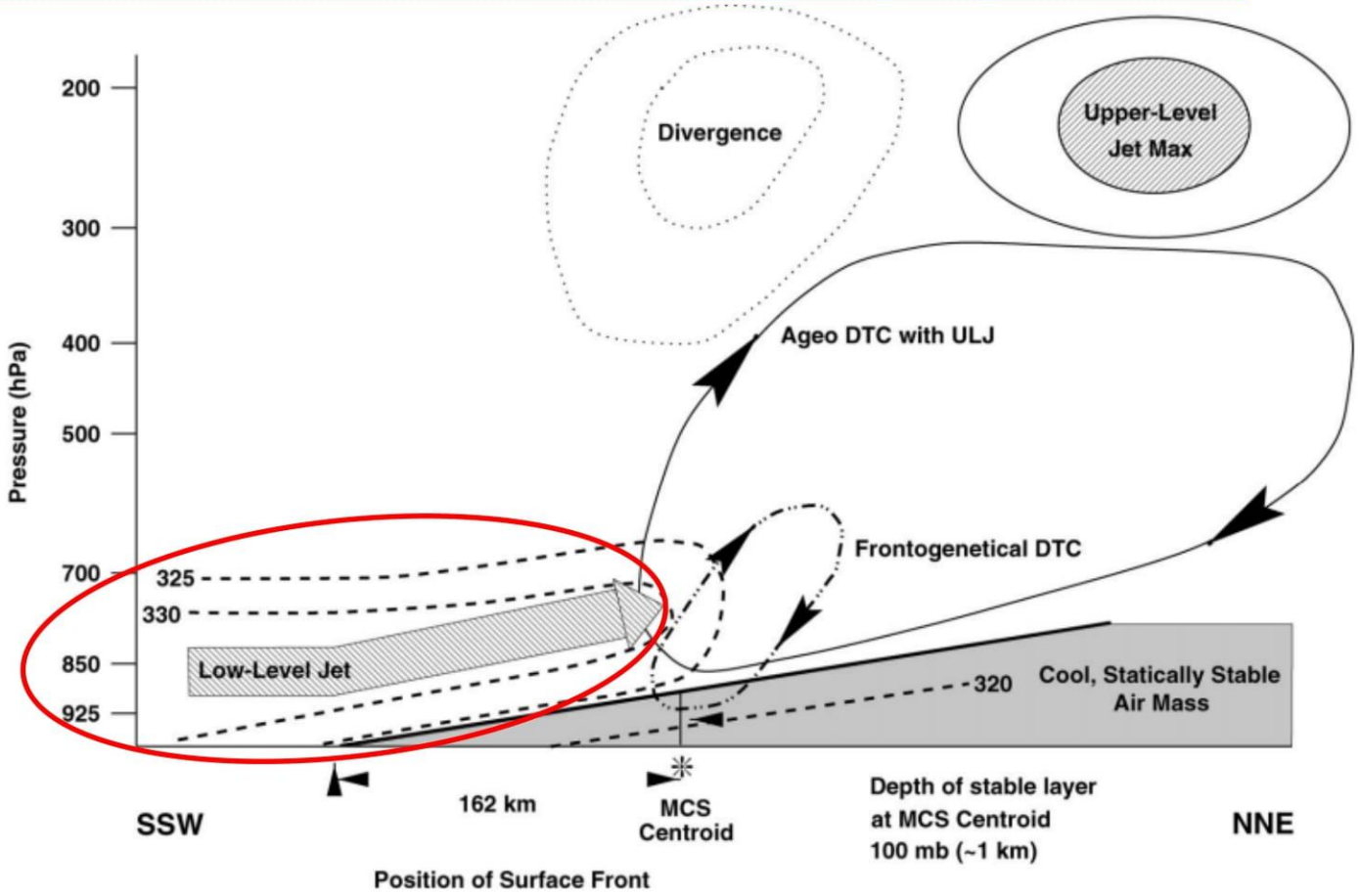
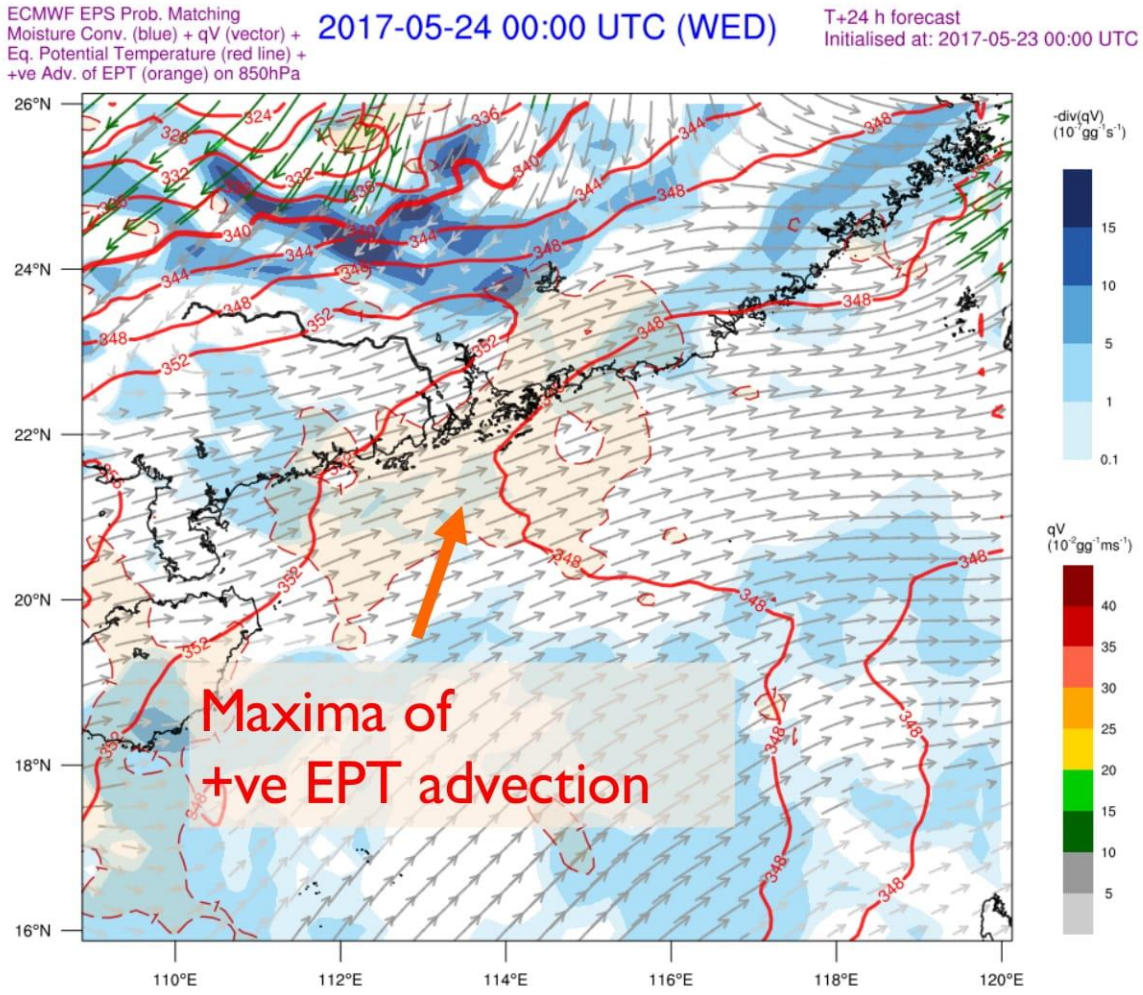


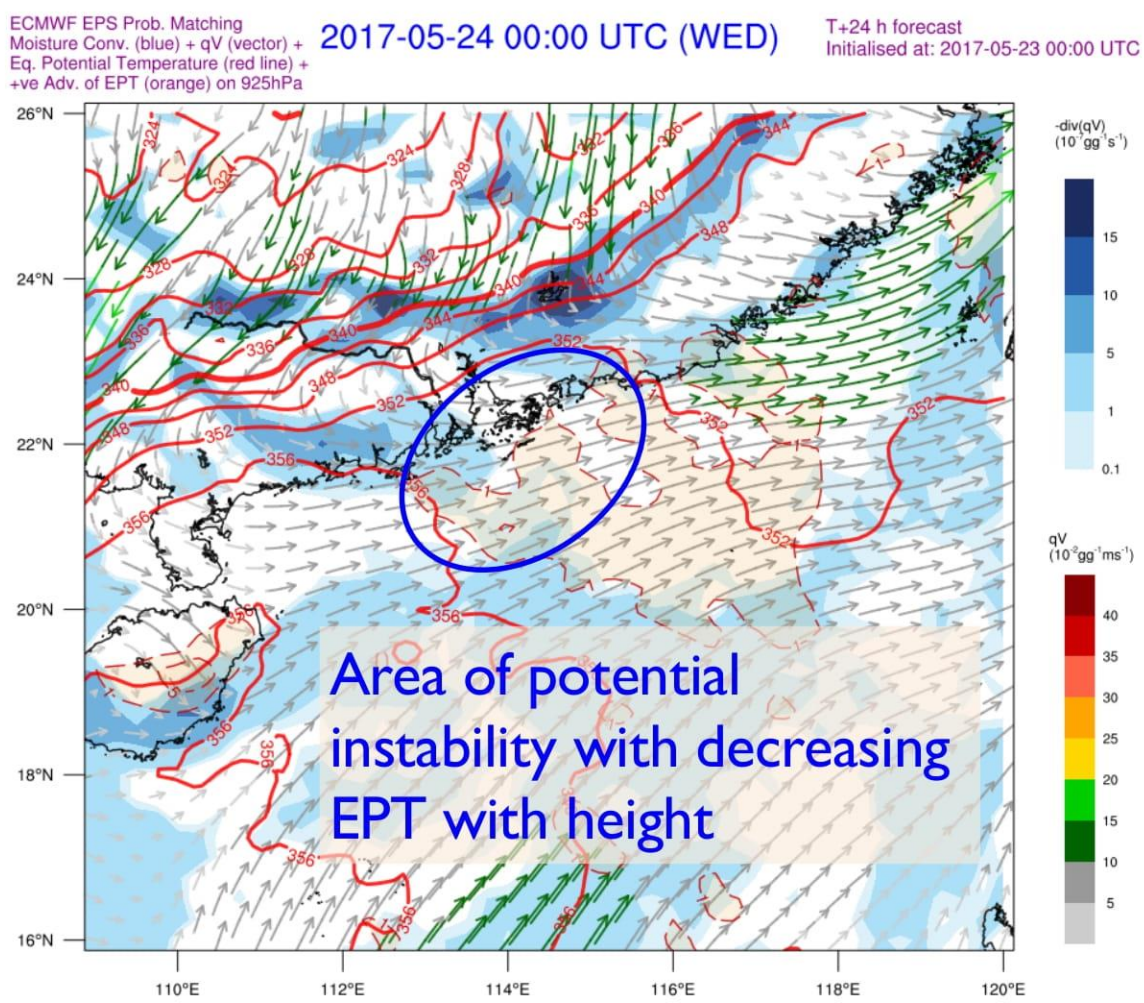
FIG. 14. Schematic cross-sectional view taken parallel to the LLJ across the frontal zone. Dashed lines represent typical θ_e values, the large stippled arrow represents the ascending LLJ, the thin dotted oval represents the ageostrophic direct thermal circulation associated with the upper-level jet streak, and the thick dashed oval represents the direct thermal circulation associated with the low-level frontogenetical forcing. The area aloft enclosed by dotted lines indicates upper-level divergence; the area aloft enclosed by solid lines denotes location of upper-level jet streak. Note that in this cross section the horizontal distance between the MCS and the location of the upper-level jet maximum is not to scale.

Warm-season MCS, elevated thunderstorms and heavy rain (Moore et al. 2003):
https://journals.ametsoc.org/doi/abs/10.1175/1520-0434%282003%29018%3C0861%3ATEOWET%3E2.0.CO%3B2

(A) Hint of favourable significant convection developments from diagnostics based on EC-EPS members

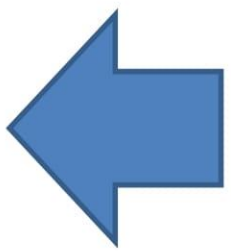
ECMWF EPS Prob. Matching
Moisture Conv. (blue) + qV (vector) +
Eq. Potential Temperature (red line) +
+ve Adv. of EPT (orange) on 925hPa





Leverage values of EPS

- Thunderstorm Potential (PoTS)
  - consider favourable parameters, based on local knowledge of weather hazard such as initiation and development of thunderstorms
    - stability parameters: K-index, CAPE
    - low-level jet (LLJ)
    - low-level moisture
    - low-level vorticity
    - upper-level divergence



Forecasters' wisdom and knowledge on suitable thresholds / weather patterns from experience and historical cases

  - frequency counts of above "ingredients" in each EPS member, every grid point, then take consensus (probability matching) to generate PoTS

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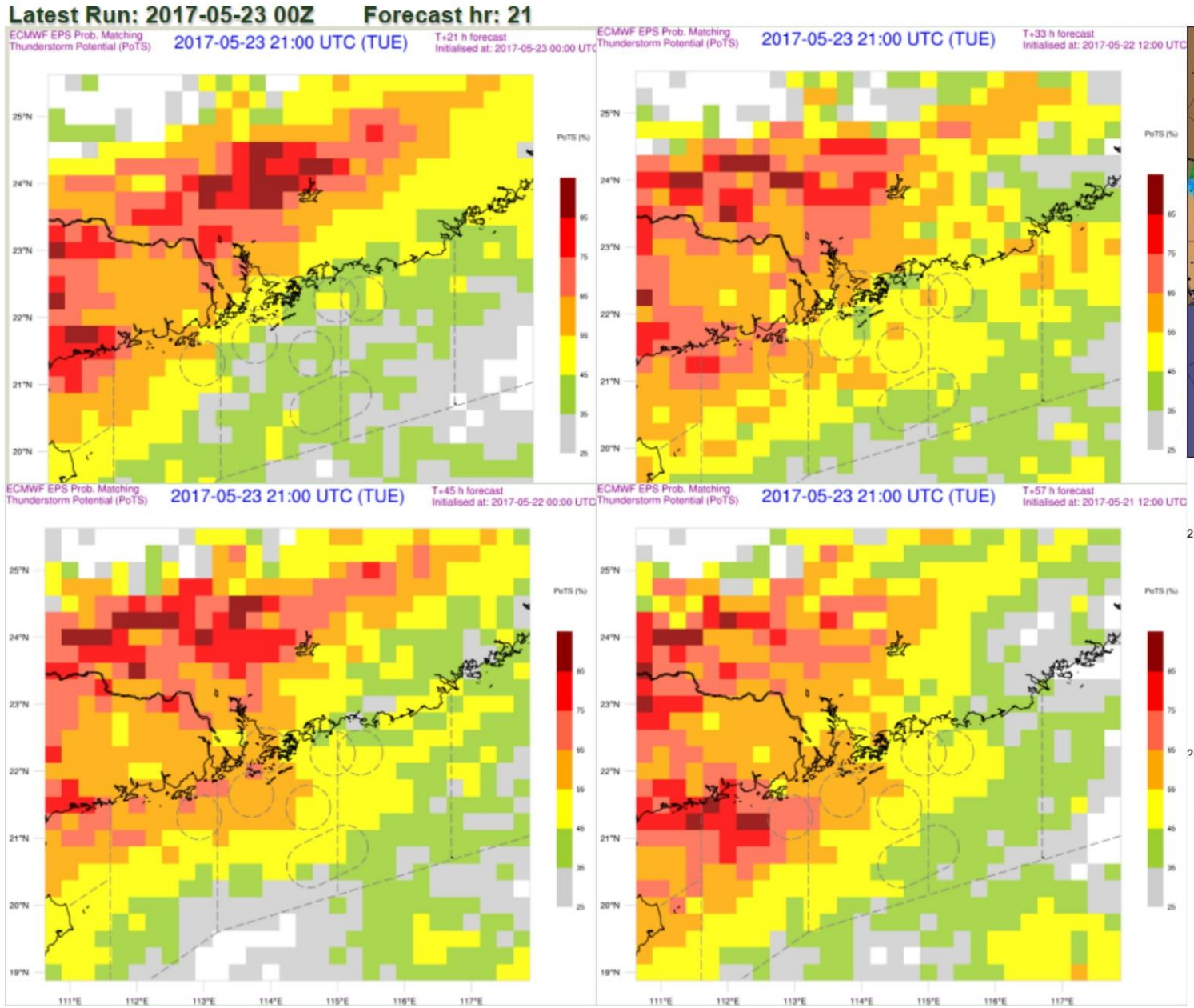
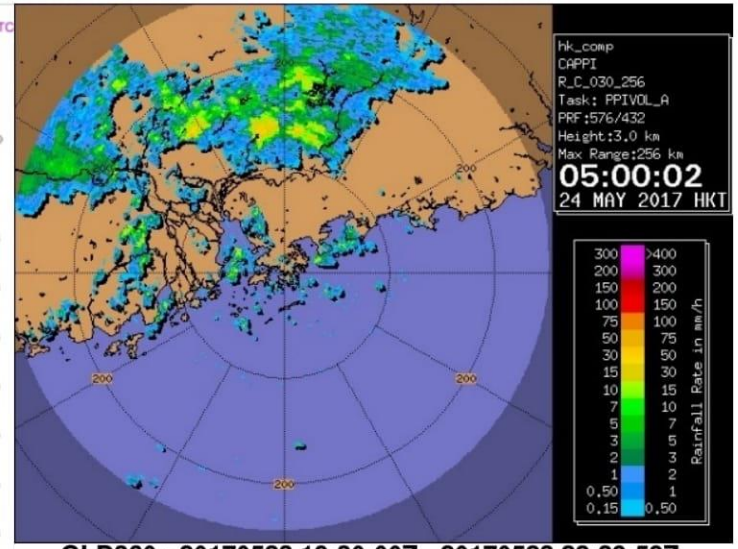
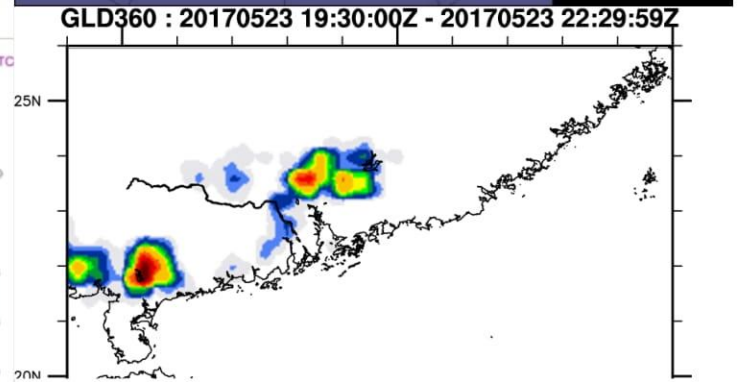
PoTS from recent 4 model runs of EPS forecast

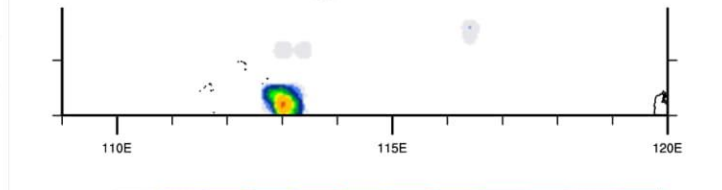
23/21Z

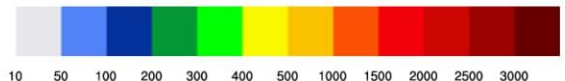






Global Lightning Data (GLD360) counts within 0.2x0.2 degree in 3 h time window





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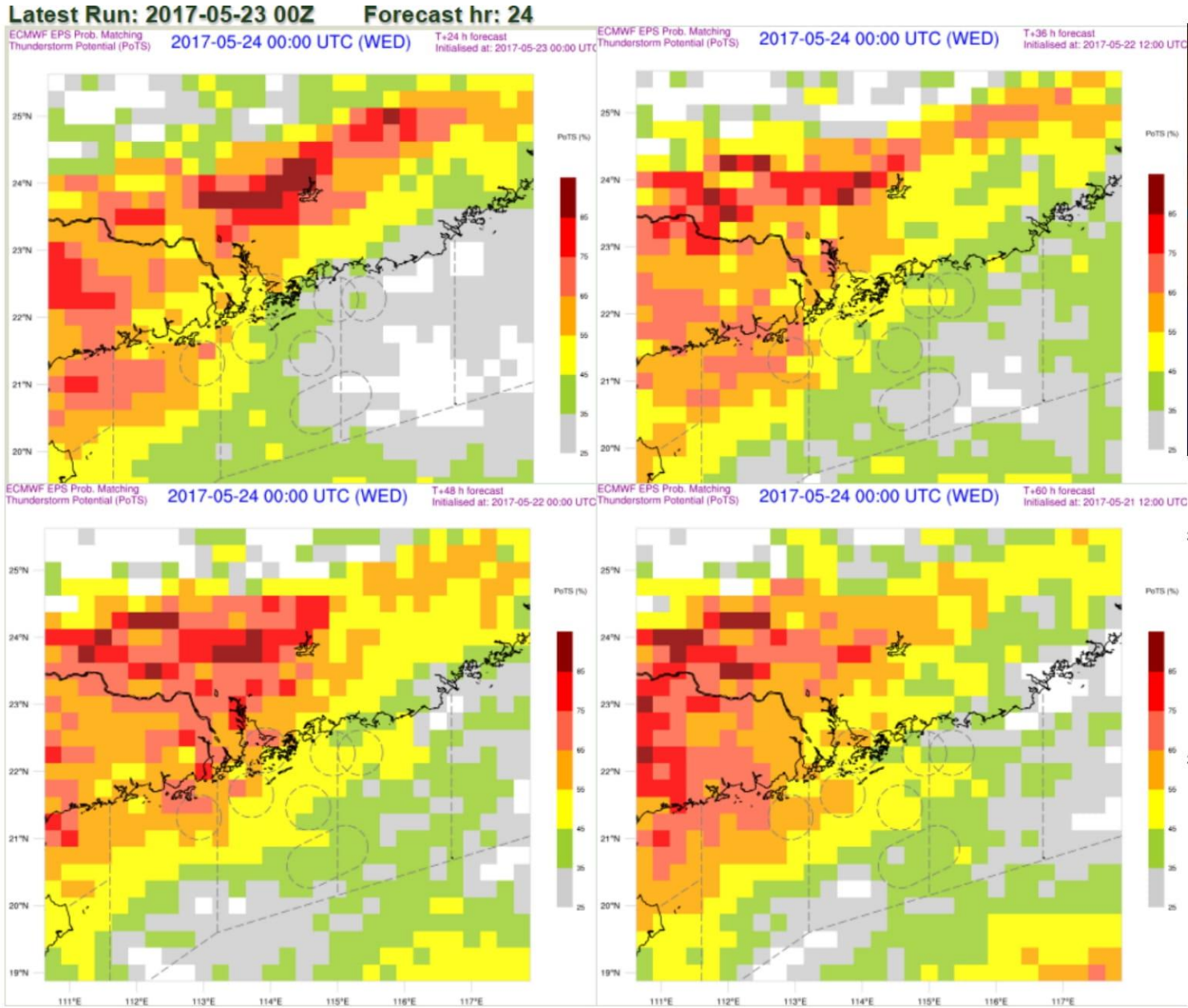
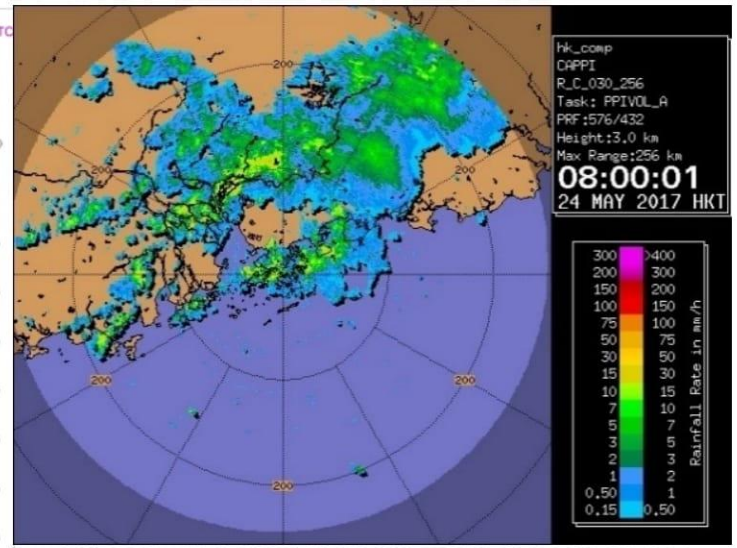
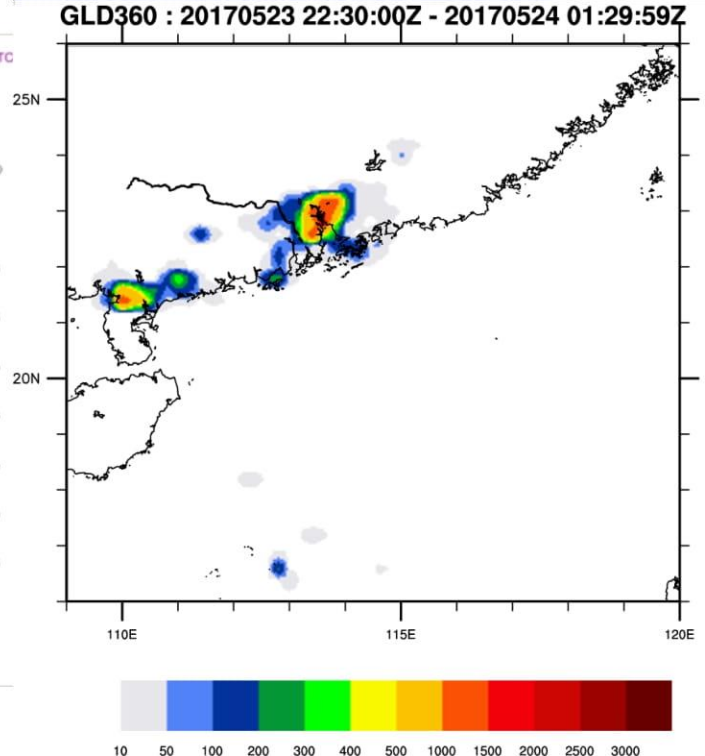
24/00 Z







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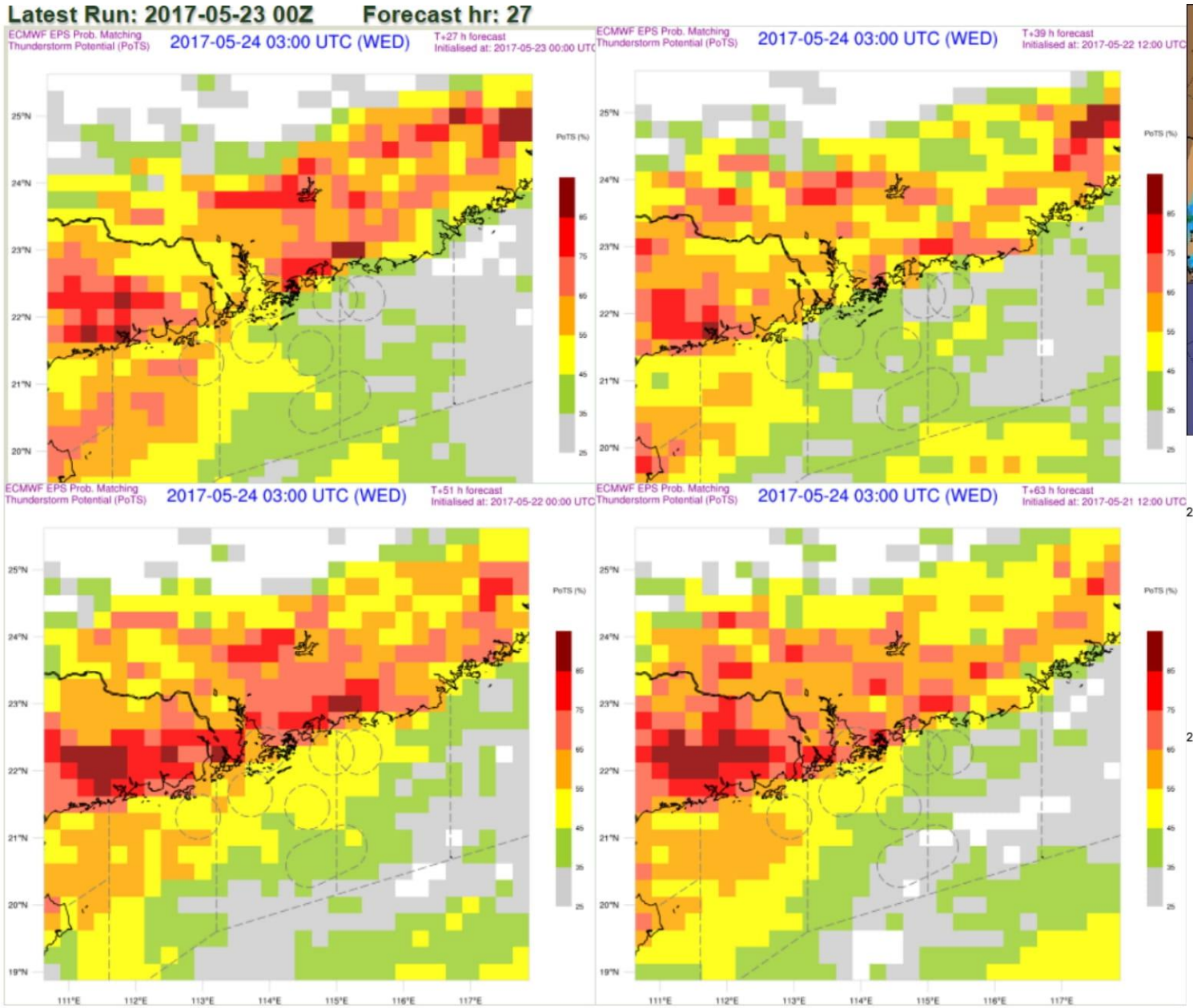
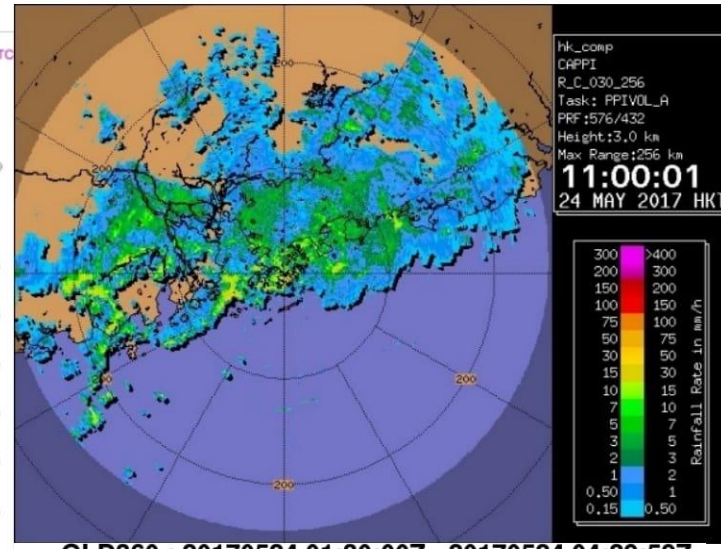
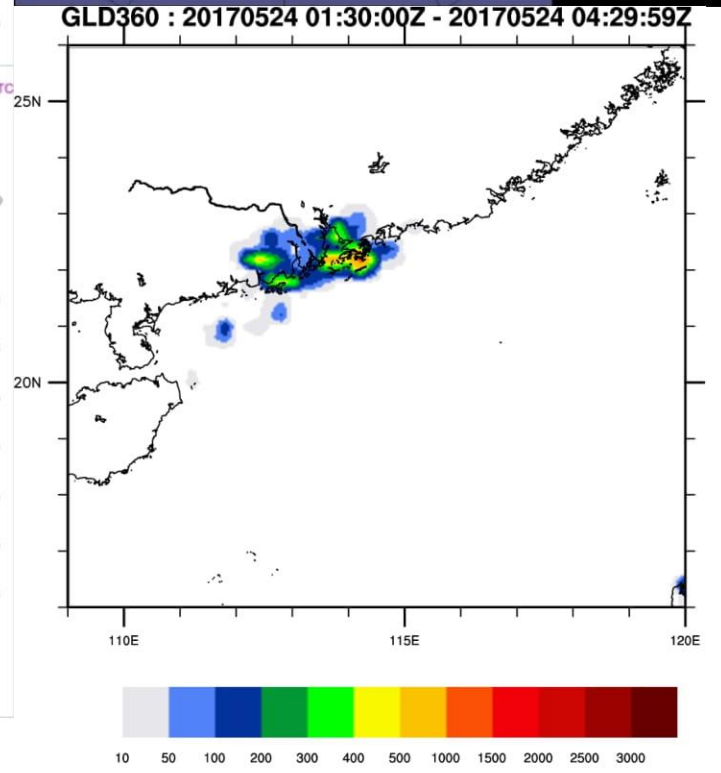
24/03 Z







Using ECMWF EPS in extreme weather forecast

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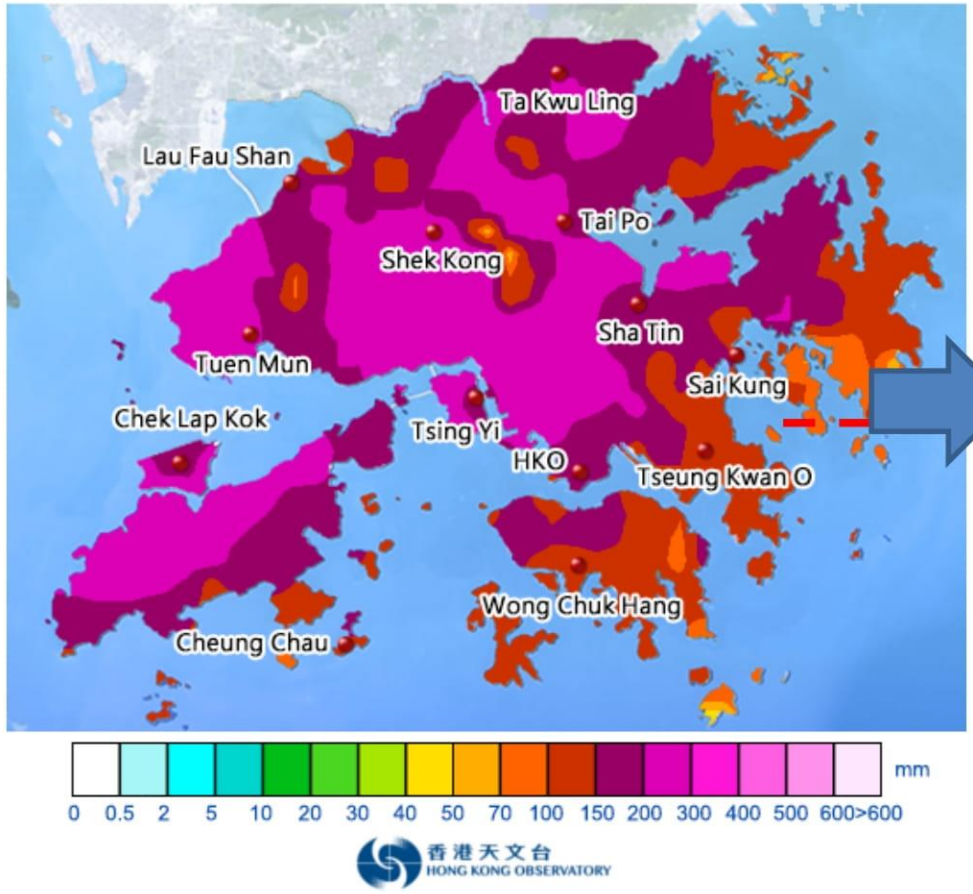
16 September 2018

HKO daily R/F: ~ 170 mm

Total rainfall on **16-Sep-2018** (based on raingauges and radar data)



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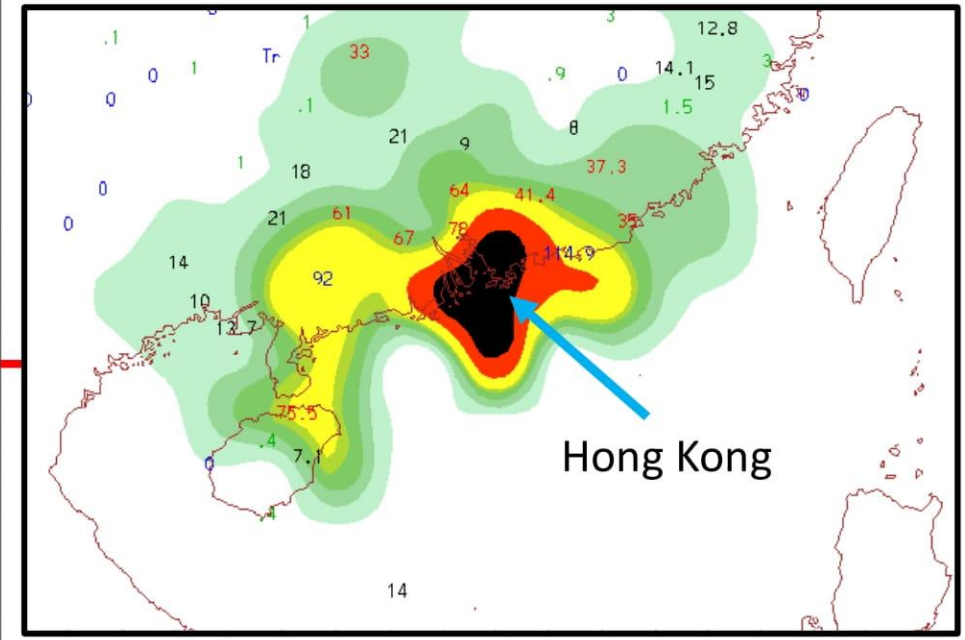
Highest Daily Total Rainfall (mm) at Hong Kong Observatory for September

Record Since: 1884.03.01, exclude 1940-1946

No	Rank	Total	Date of record
1	1	325.5	1965.09.27
2	2	276.0	1999.09.16
3	3	248.3	2006.09.13
4	4	245.2	1979.09.23
5	5	227.0	1996.09.14
6	6	223.9	1993.09.26
7	7	203.0	1962.09.01
8	8	202.2	1930.09.17
9	9	199.9	1957.09.22
10	10	199.3	1936.09.07
11	11	197.7	2013.09.05
12	12	190.3	2009.09.15
13	13	188.1	1970.09.09
14	14	178.8	2010.09.21
15	15	172.4	1983.09.09
16	16	170.5	1964.09.05
17	17	168.7	1949.09.08
18	18	162.8	2002.09.17
19	19	161.1	2002.09.15
20	20	153.9	1921.09.03
21	21	153.6	1953.09.27
22	22	150.5	1937.09.02
23	23	149.3	1948.09.22
24	24	148.7	1887.09.17
25	25	146.8	1894.09.25
26	26	145.2	1889.09.09
27	27	143.3	1910.09.03
28	28	141.9	1884.09.10
29	29	141.5	1926.09.21
30	30	141.2	1952.09.14
31	31	140.5	1907.09.15
32	32	135.8	1920.09.12
33	33	135.5	1918.09.21
34	34	133.7	1906.09.29
35	35	133.2	2001.09.01
36	36	132.5	1930.09.16

24-h R/F **80 – 110** **110 - 160** **> 160**



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Guidance from NWP models and Analogue Forecast System

Daily Rainfall Forecast 14/00 UTC F/C

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180914	0.1*	0.3*	0.2*	2.0*
20180915	0.0*	0.0*	143.6	0.5
20180916	-	-	211.4	74.4
20180917	-	-	84.5*	40.1*

Daily Rainfall Forecast 14/12 UTC F/C

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180914	1.8*	9.0*	0.1*	0.9*
20180915	8.3	52.6	2.1	0.5
20180916	22.4*	39.5*	102.6	86.0
20180917	-	-	24.6	39.5
20180918	-	-	4.0*	11.1*

Daily Rainfall Forecast 15/00 UTC F/C

HKT	Analogue TC RF		ECMWF	JMA
	analogue	1/2(anl+max anl)		
20180915	0.8*	88.0*	1.0*	0.0*
20180916	46.9	154.9	134.1	94.0
20180917	0.0*	43.7*	25.0	43.3
20180918	-	-	5.7*	22.5*

Run (UTC) \ Date (HKT)	20180914 (Fri)	20180915 (Sa)	20180916 (Sun)	20180917 (Mon)	20180918 (Tue)	201809
2018091212	No Rain	No Rain	V. Heavy	Heavy	Heavy	Li
2018091112	No Rain	No Rain	Extreme	Heavy	Light	Li
2018091012	No Rain	No Rain	V. Heavy	Heavy	Heavy	No
2018090912	No Rain	No Rain	Extreme	Heavy	Moderate	No
2018090812	No Rain	No Rain	Light	V. Heavy	Heavy	N
2018090712	Light	Light	No Rain	No Rain	N.A.	N
2018090612	Heavy	No Rain	No Rain	N.A.	N.A.	N
2018090512	No Rain	No Rain	N.A.	N.A.	N.A.	N
2018090412	V. Heavy	N.A.	N.A.	N.A.	N.A.	N

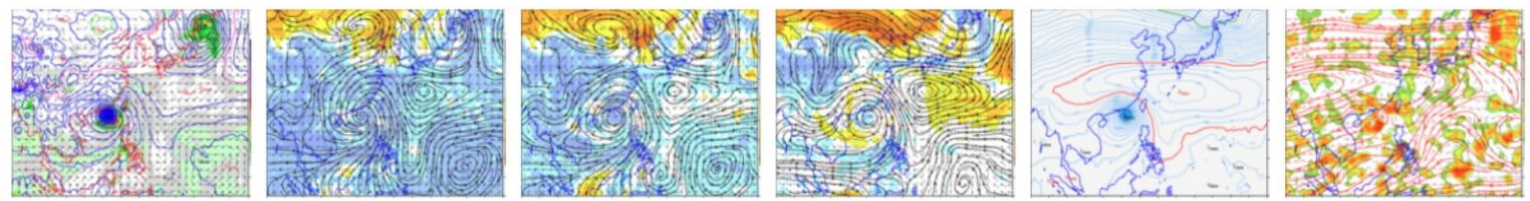
Analogs

Rank	Date	Score	Rain Category	Rain storm	RF (mm)	Max RF (mm/hr)	Min TT (ºC)	Max TT (ºC)	M
1	990916	4.54	[6] Extreme	[2] Red	222.1	73.3	24.7	28.4	

> 220 mm

Overview | Surface | 925 | 850 | 700 | 500 | 200 | Satellite

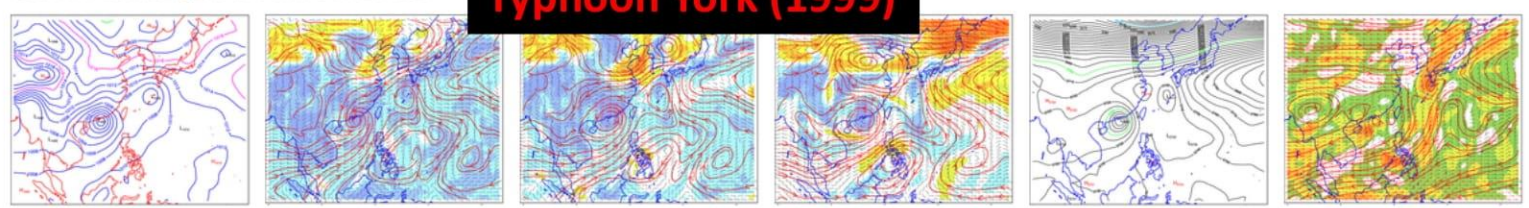
ECMWF Forecast for 2018091600Z



Surface 925 850 700 500 200

ECMWF Reanalysis for 1999091600Z

Typhoon York (1999)

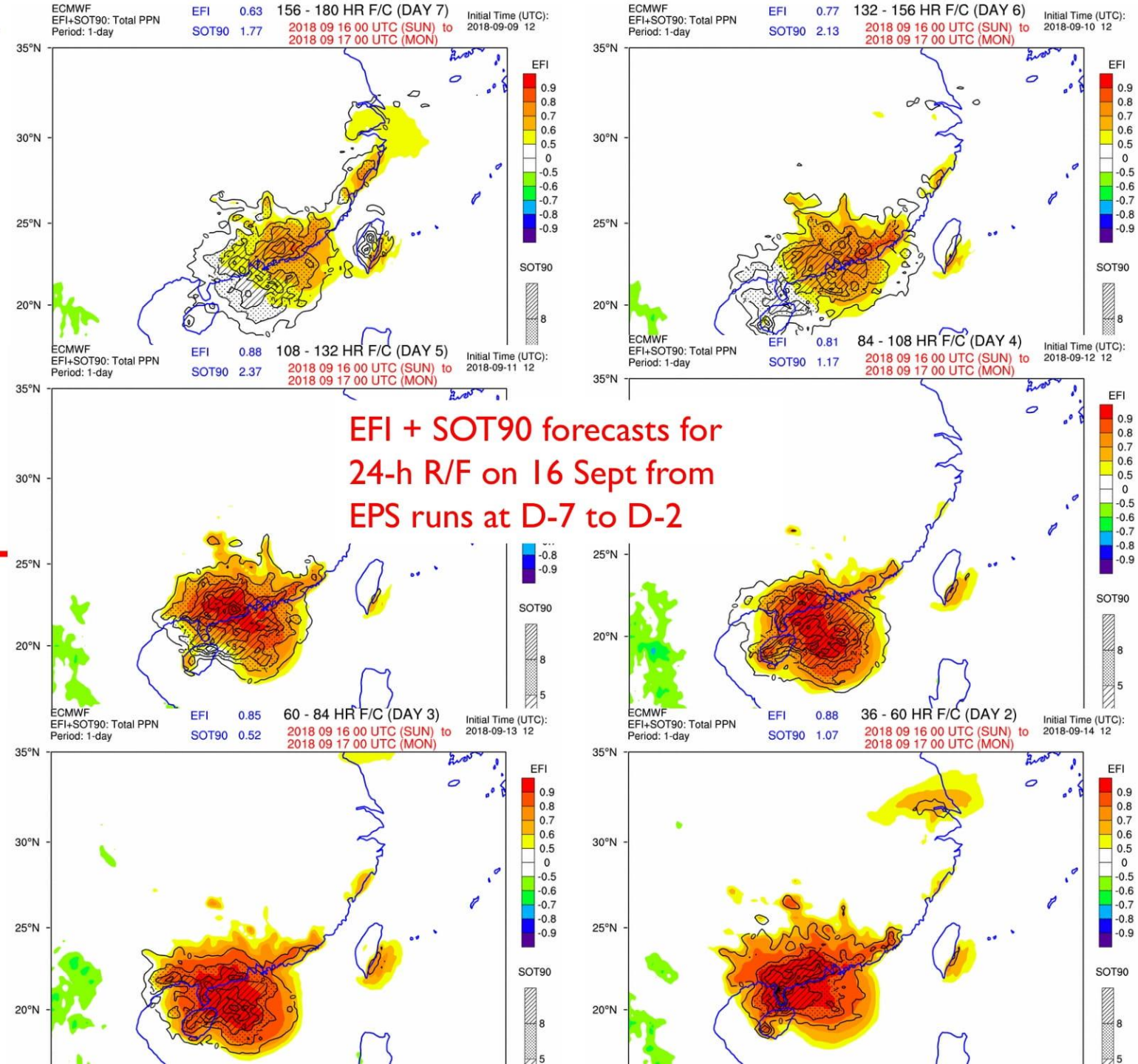


Surface 925 850 700 500 200

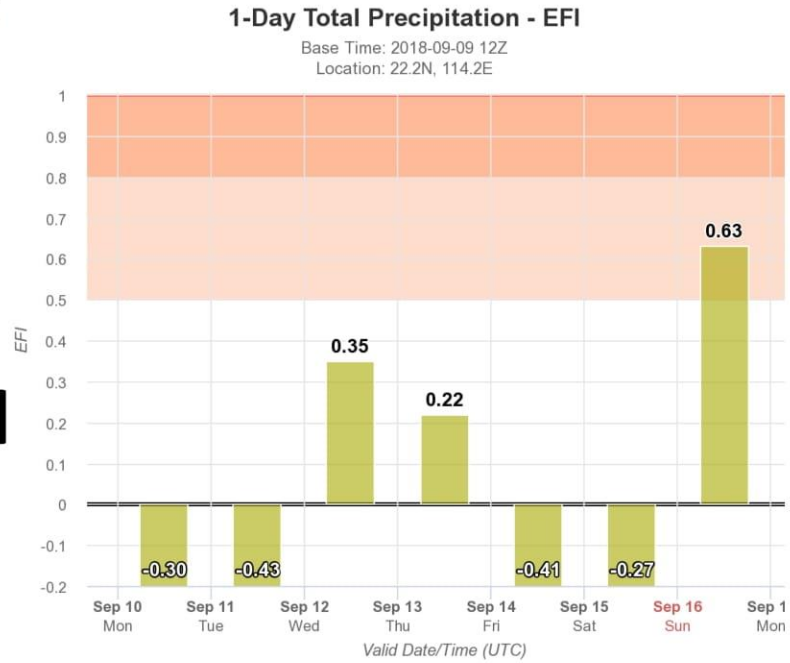
Highest Daily Total Rainfall (mm) at Hong Kong Observatory for September

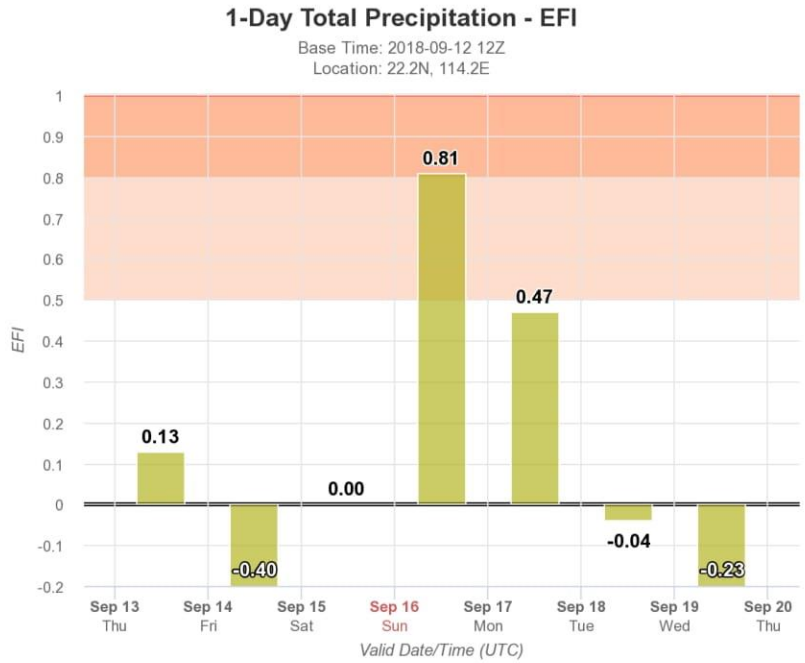
Record Since: 1884.03.01, exclude 1940-1946

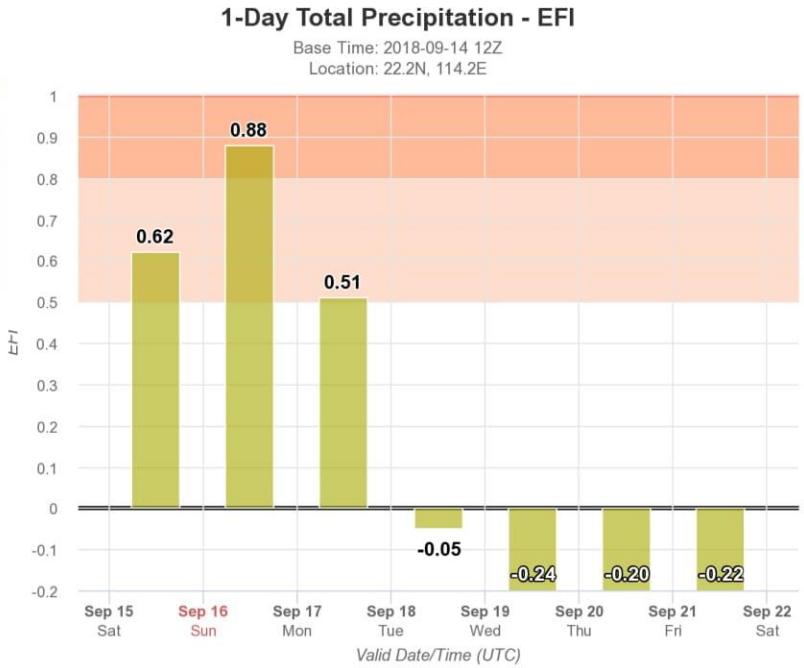
No	Rank	Total	Date of record
1	1	325.5	1965.09.27
2	2	276.0	1999.09.16
3	3	248.3	2006.09.13
4	4	245.2	1979.09.23
5	5	227.0	1996.09.14
6	6	223.9	1993.09.26
7	7	203.0	1962.09.01
8	8	202.2	1930.09.17
9	9	199.9	1957.09.22
10	10	199.3	1936.09.07
11	11	197.7	2013.09.05
12	12	190.3	2009.09.15
13	13	188.1	1970.09.09
14	14	178.8	2010.09.21
15	15	172.4	1983.09.09
16	16	170.5	1964.09.05
17	17	168.7	1949.09.08
18	18	162.8	2002.09.17
19	19	161.1	2002.09.15
20	20	153.9	1921.09.03
21	21	153.6	1953.09.27
22	22	150.5	1937.09.02
23	23	149.3	1948.09.22
24	24	148.7	1887.09.17
25	25	146.8	1894.09.25
26	26	145.2	1889.09.09
27	27	143.3	1910.09.03
28	28	141.9	1884.09.10
29	29	141.5	1926.09.21
30	30	141.2	1952.09.14
31	31	140.5	1907.09.15
32	32	135.8	1920.09.12
33	33	135.5	1918.09.21
34	34	133.7	1906.09.29
35	35	133.2	2001.09.01
36	36	132.5	1930.09.16



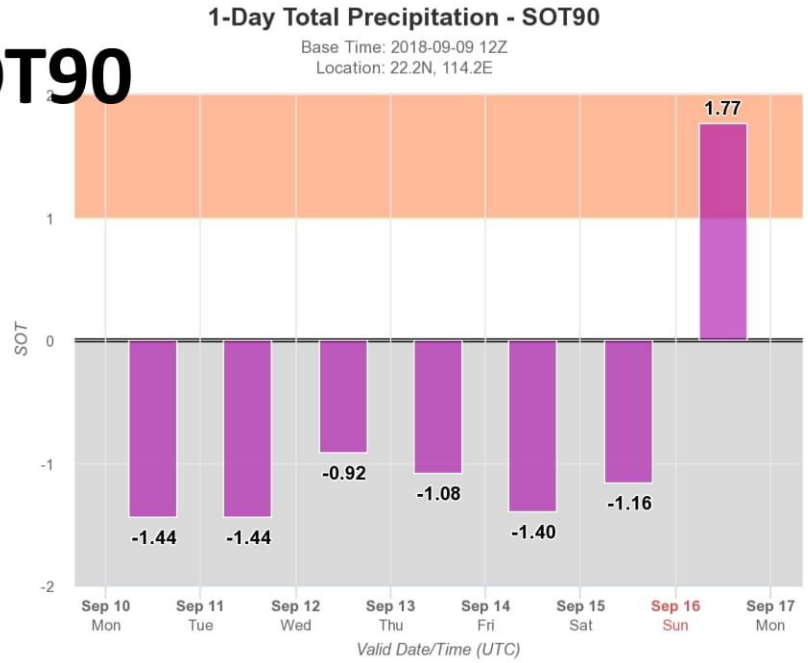
EFI

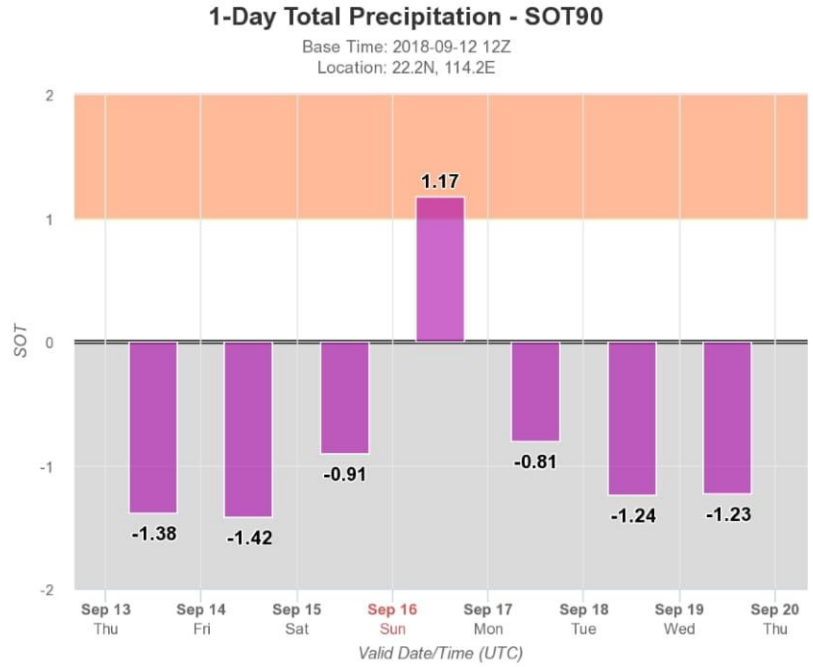

1-Day Total Precipitation - EFI
Base Time: 2018-09-09 12Z
Location: 22.2N, 114.2E
EFI
-0.30
-0.43
0.35
0.22
-0.41
-0.27
0.63
Sep 10 Mon
Sep 11 Tue
Sep 12 Wed
Sep 13 Thu
Sep 14 Fri
Sep 15 Sat
Sep 16 Sun
Sep 1 Mon
Valid Date/Time (UTC)

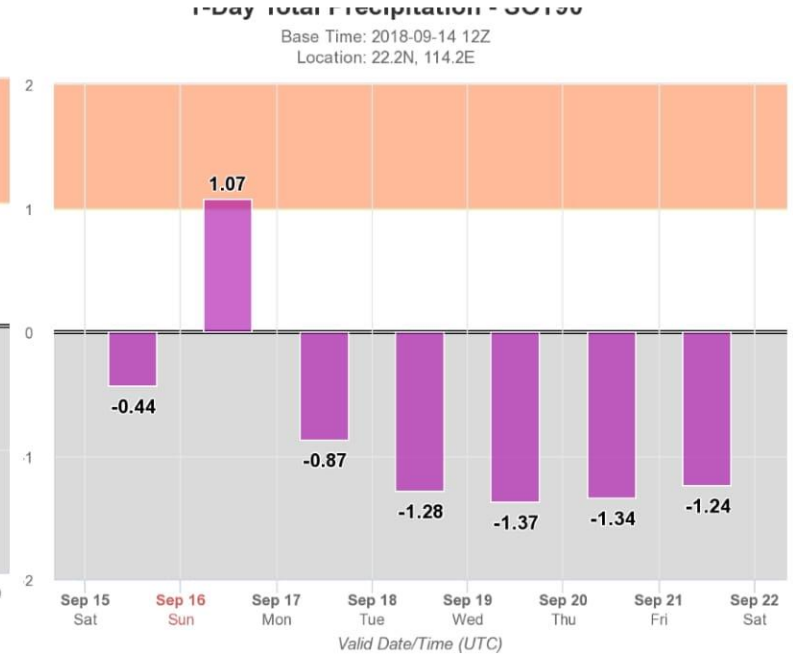

1-Day Total Precipitation - EFI
Base Time: 2018-09-12 12Z
Location: 22.2N, 114.2E
EFI
0.13
-0.40
0.00
0.81
0.47
-0.04
-0.23
Sep 13 Thu
Sep 14 Fri
Sep 15 Sat
Sep 16 Sun
Sep 17 Mon
Sep 18 Tue
Sep 19 Wed
Sep 20 Thu
Valid Date/Time (UTC)


1-Day Total Precipitation - EFI
Base Time: 2018-09-14 12Z
Location: 22.2N, 114.2E
EFI
0.62
0.88
0.51
-0.05
-0.24
-0.20
-0.22
Sep 15 Sat
Sep 16 Sun
Sep 17 Mon
Sep 18 Tue
Sep 19 Wed
Sep 20 Thu
Sep 21 Fri
Sep 22 Sat
Valid Date/Time (UTC)

SOT90


1-Day Total Precipitation - SOT90
Base Time: 2018-09-09 12Z
Location: 22.2N, 114.2E
SOT
-1.44
-1.44
-0.92
-1.08
-1.40
-1.16
1.77
Sep 10 Mon
Sep 11 Tue
Sep 12 Wed
Sep 13 Thu
Sep 14 Fri
Sep 15 Sat
Sep 16 Sun
Sep 17 Mon
Valid Date/Time (UTC)


1-Day Total Precipitation - SOT90
Base Time: 2018-09-12 12Z
Location: 22.2N, 114.2E
SOT
-1.38
-1.42
-0.91
-0.81
-1.24
-1.23
1.17
Sep 13 Thu
Sep 14 Fri
Sep 15 Sat
Sep 16 Sun
Sep 17 Mon
Sep 18 Tue
Sep 19 Wed
Sep 20 Thu
Valid Date/Time (UTC)


Base Time: 2018-09-14 12Z
Location: 22.2N, 114.2E
-0.44
-0.87
-1.28
-1.37
-1.34
-1.24
1.07
Sep 15 Sat
Sep 16 Sun
Sep 17 Mon
Sep 18 Tue
Sep 19 Wed
Sep 20 Thu
Sep 21 Fri
Sep 22 Sat
Valid Date/Time (UTC)

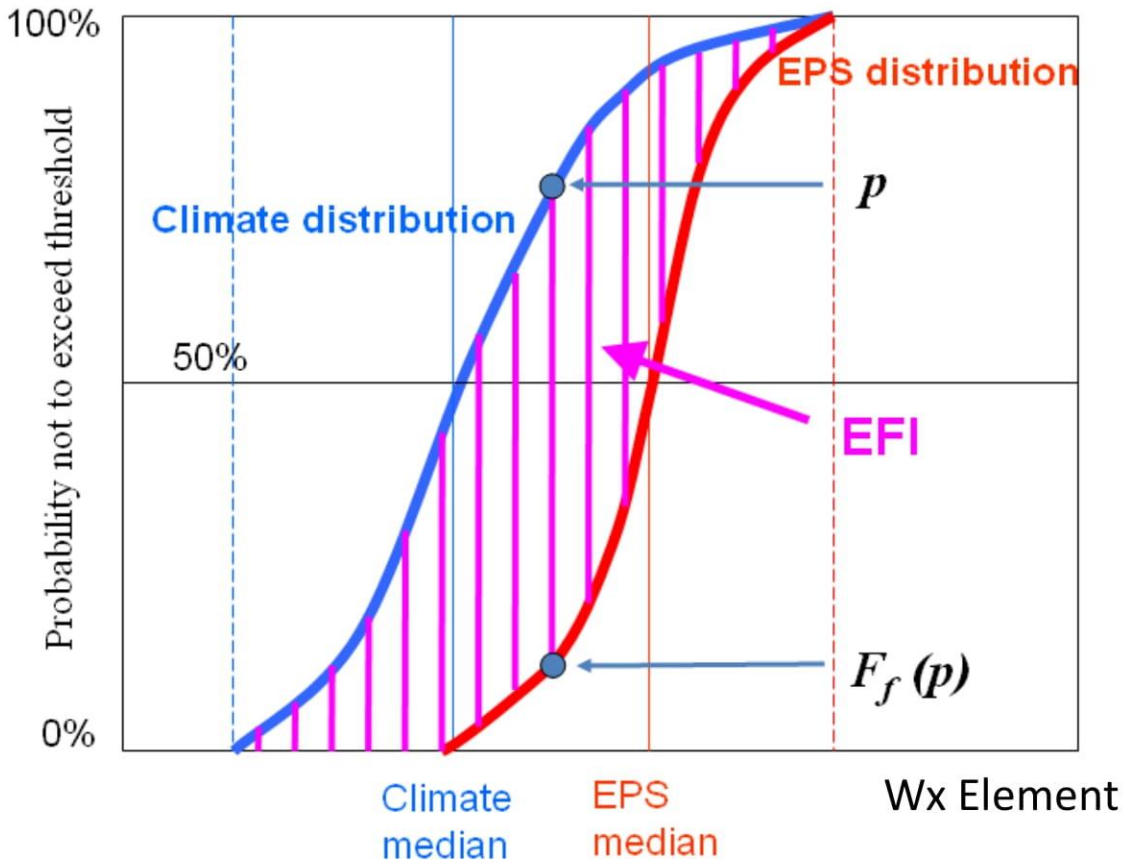
Extreme Forecast Index

$$EFI = \frac{2}{\pi}\int_0^1 \left(\frac{p - F_f(p)}{\sqrt{p(1-p)}}\right) dp$$

User guide to ECMWF forecast products:

"… EFI of 0.5 - 0.8 (irrespective of sign) can be generally regarded as indicator of "unusual" weather is likely and values above 0.8 representing "very unusual" or "extreme" weather"

EFI=+1 (-1) when all EPS members forecast values above (below) the absolute extremum in model climate (M-climate)



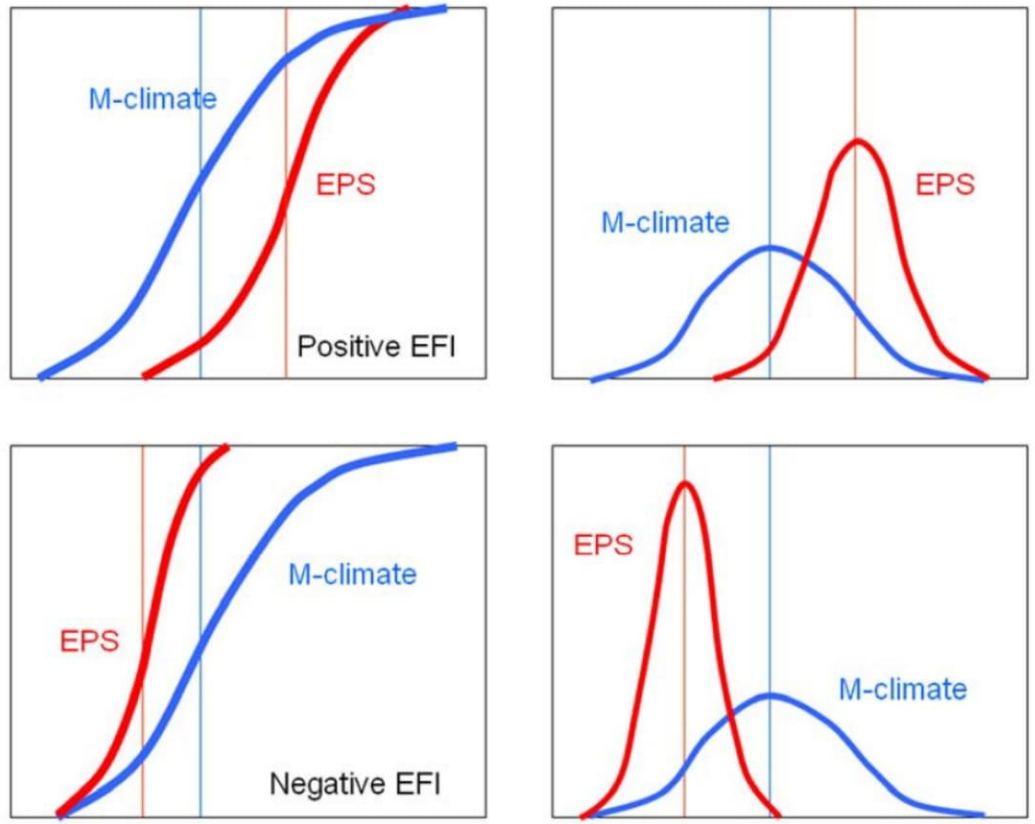


Figure 53: The EFI can have both negative and positive values: positive for positive anomalies (upper figures) and negative for negative anomalies (lower figures).

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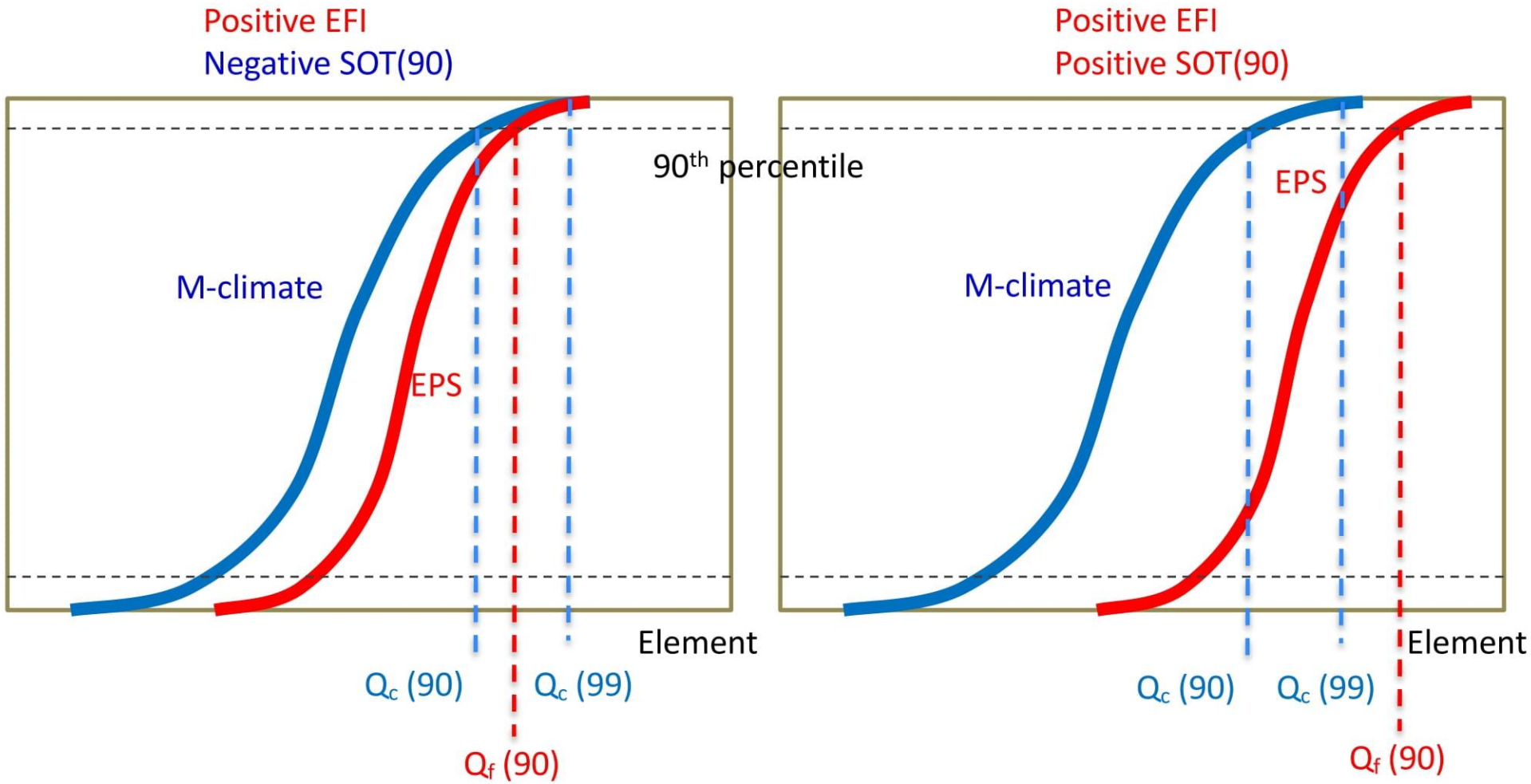
Shift of Tails (SOT)

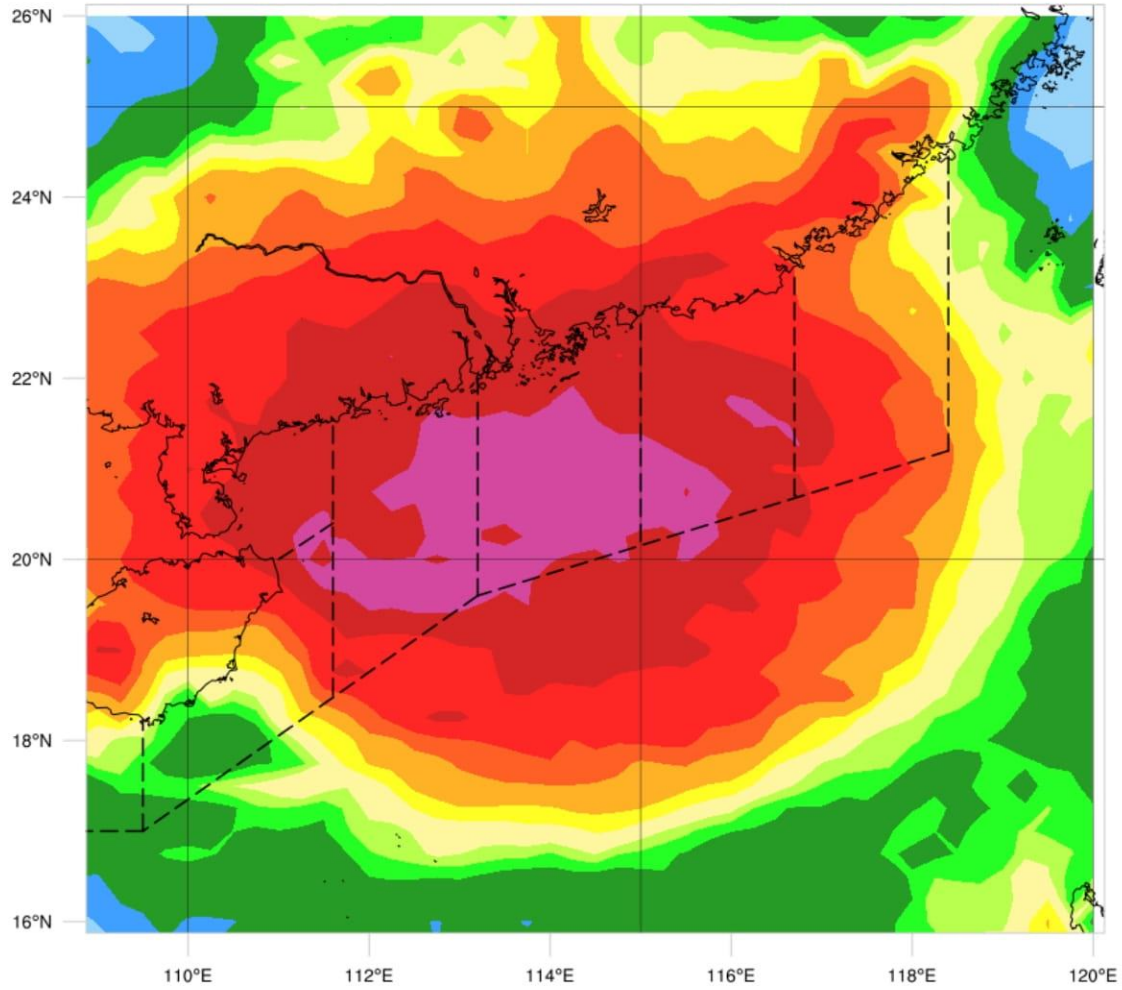
$$SOT(90) = -\frac{Q_f(90) - Q_c(99)}{Q_c(90) - Q_c(99)}$$

- SOT compliments EFI that defines how far the extreme members are above the M-climate
- Note SOT ~ 0 is quite common due to limited no. of ensemble members to construct the model climate and atmospheric variabilities represented by EPS

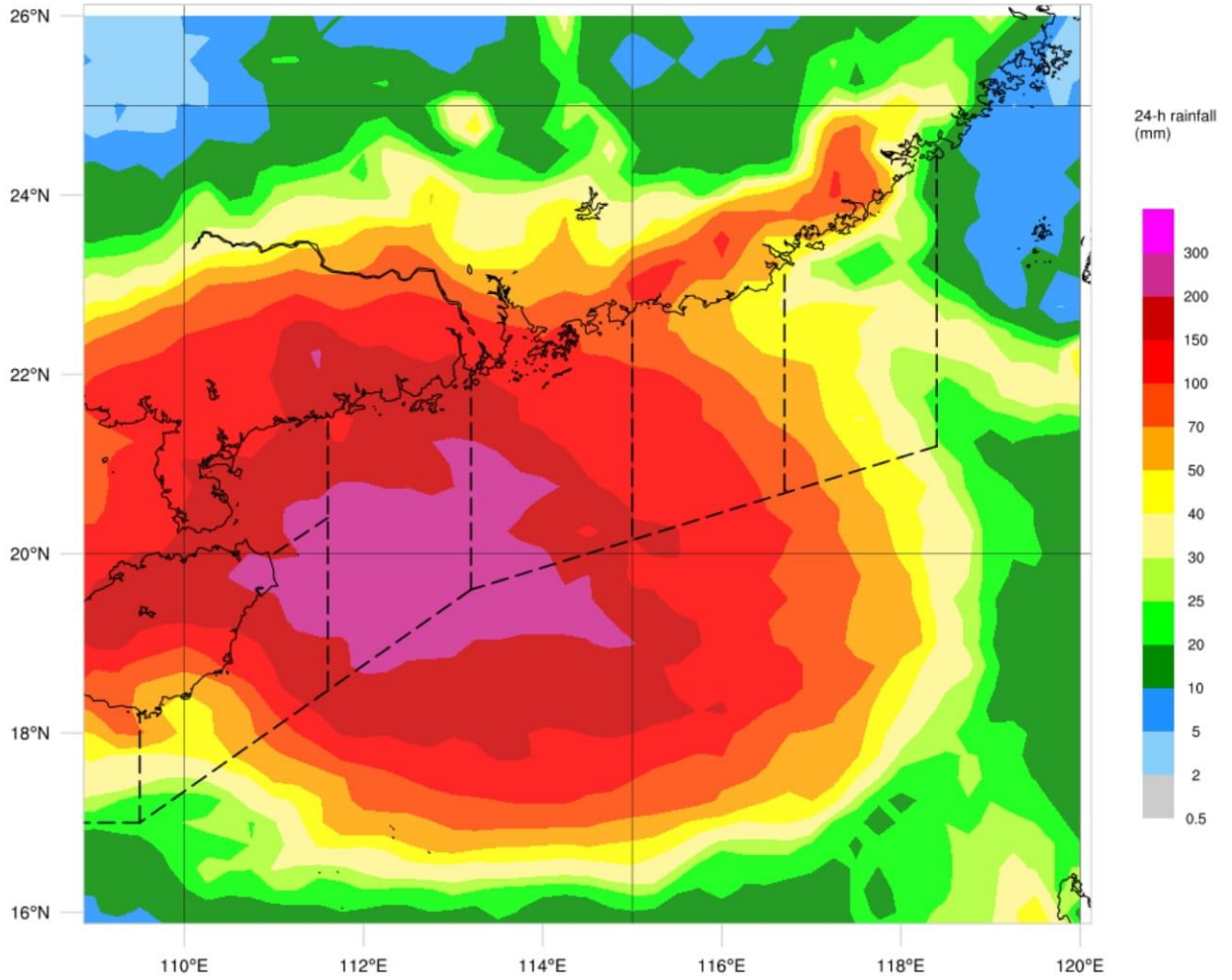


95th Percentile of 24-h R/F from ECMWF EPS

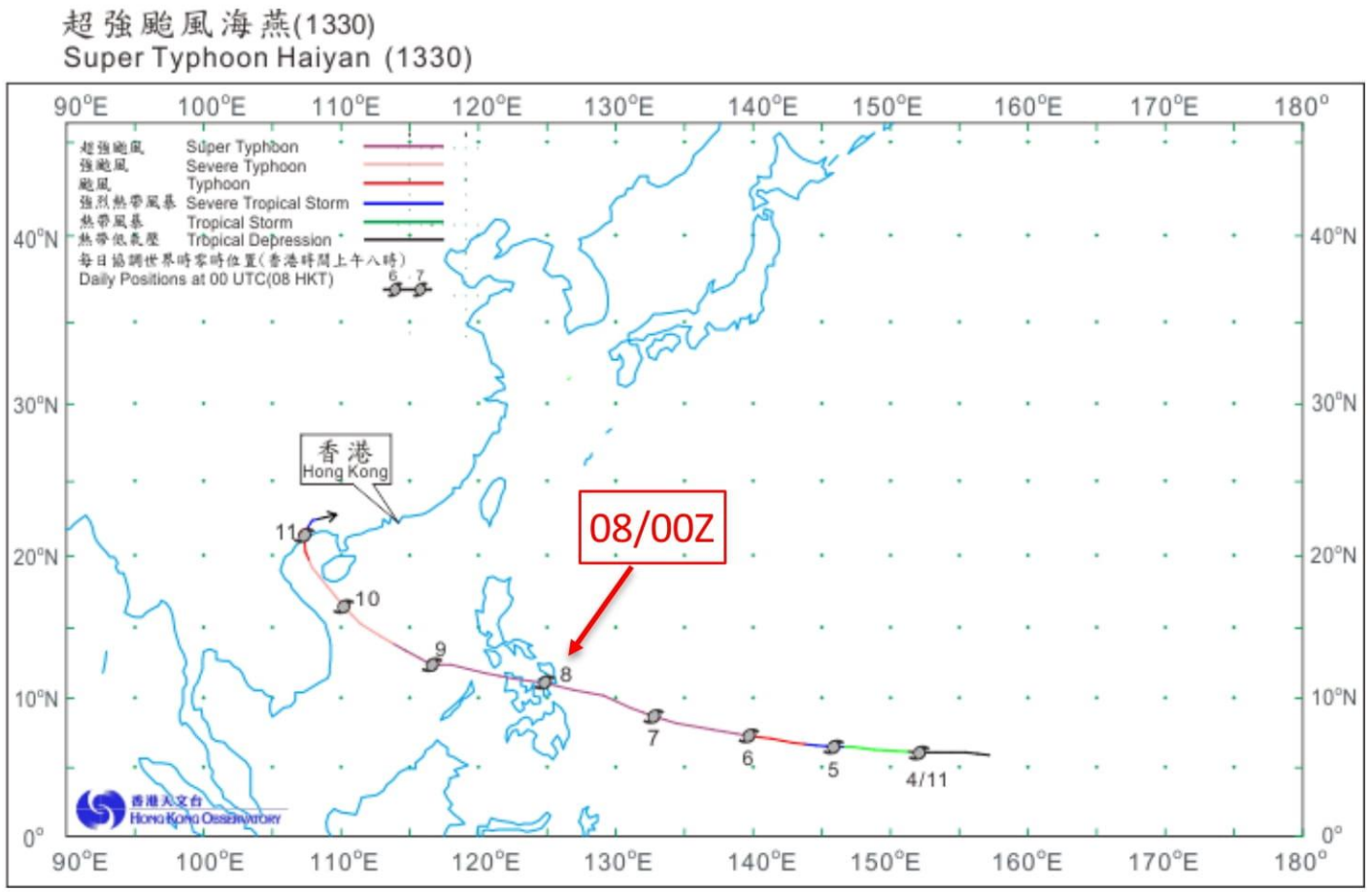
ECMWF EPS
95th Percentile of 24-h Rainfall
2018-09-16 18:00 UTC (SUN)
T+126 h forecast
Initialised at: 2018-09-11 12:00 UTC

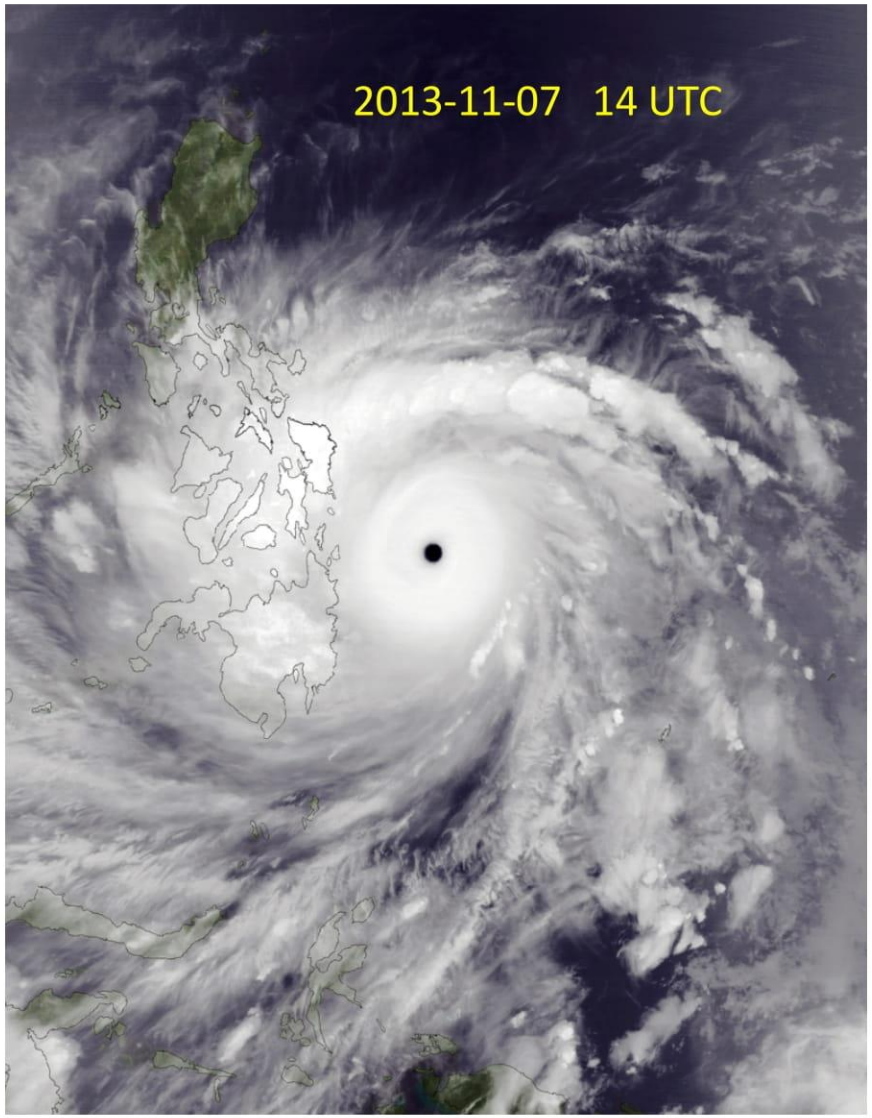


ECMWF EPS
95th Percentile of 24-h Rainfall
2018-09-16 18:00 UTC (SUN)
T+78 h forecast
Initialised at: 2018-09-13 12:00 UTC



Example 2 - Haiyan





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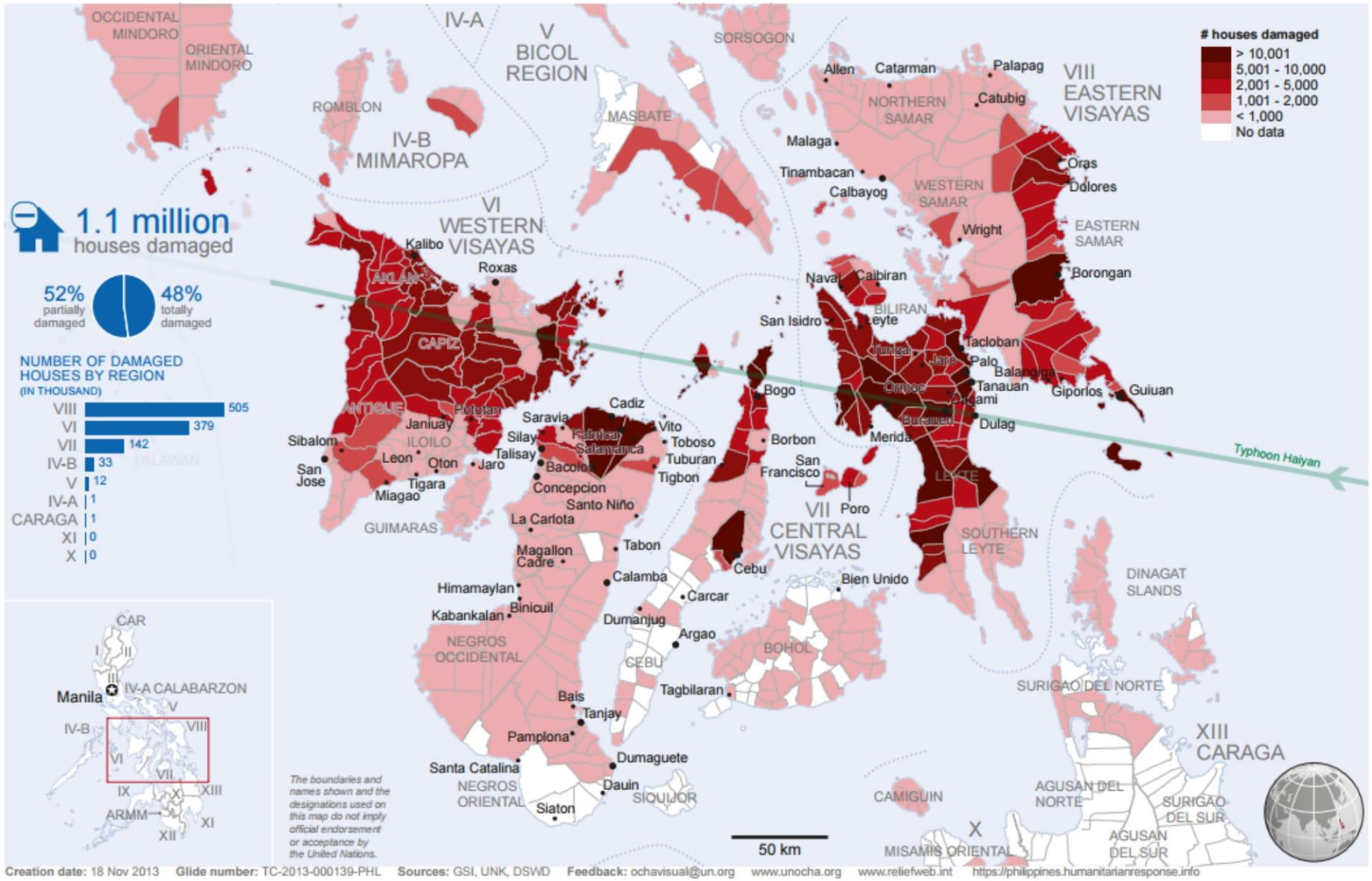
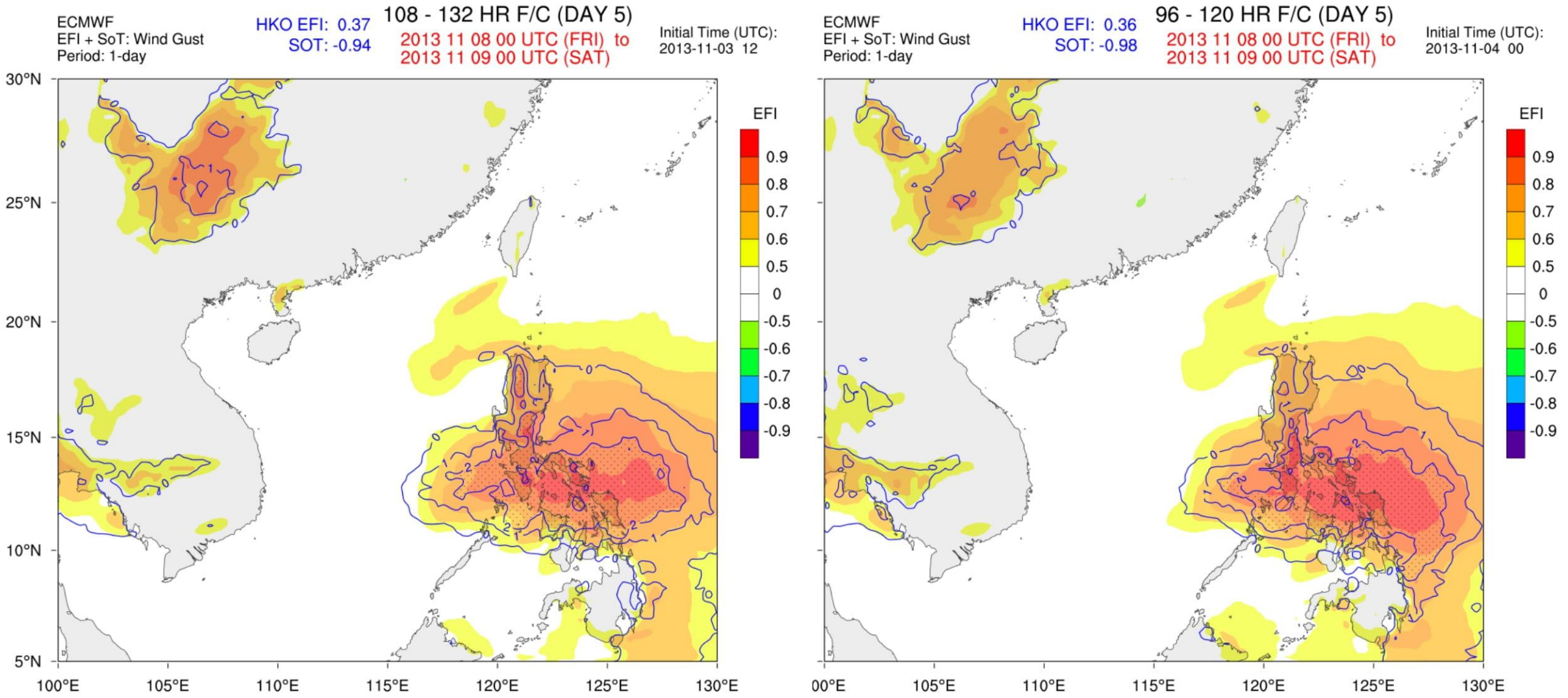
PHILIPPINES: Damaged houses (as of 18 Nov 2013 18:00 UTC+8)

OCHA

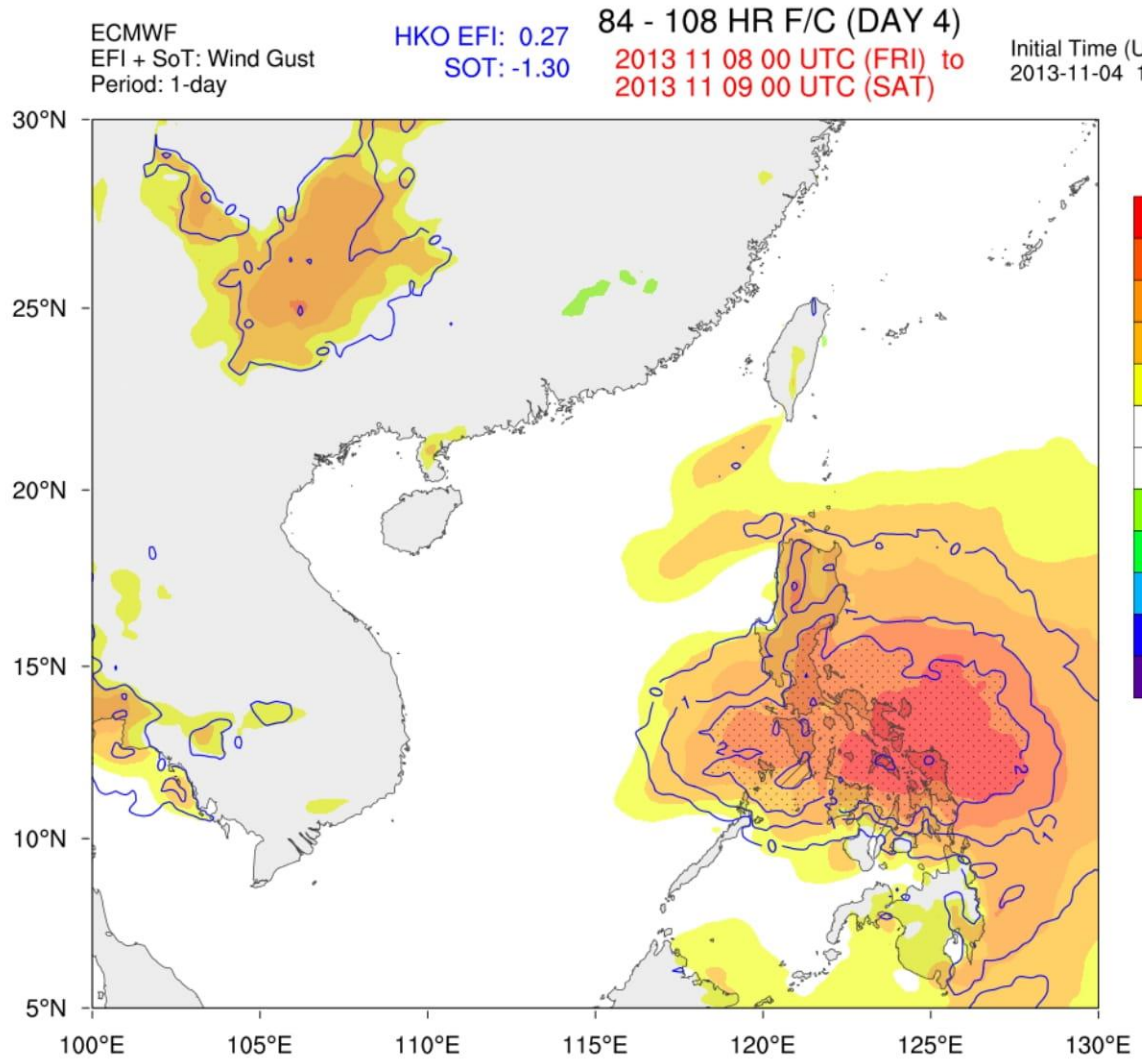


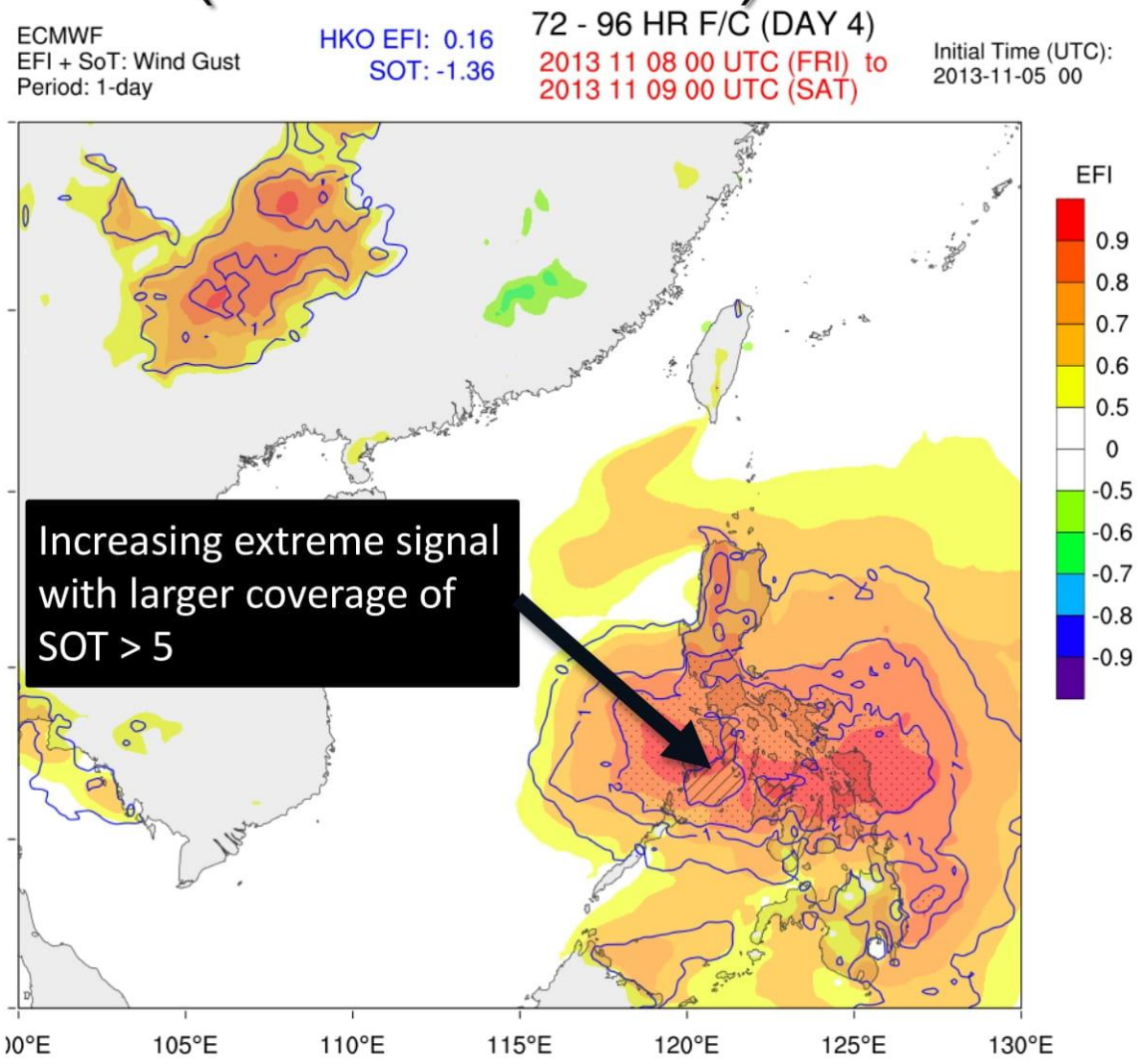
Creation date: 18 Nov 2013 **Glide number:** TC-2013-000139-PHL **Sources:** GSI, UNK, DSWD **Feedback:** ochavisual@un.org www.unocha.org www.reliefweb.int https://philippines.humanitarianresponse.info

EFI+SOT Wind Gust from 03/12Z and 04/00Z EPS runs

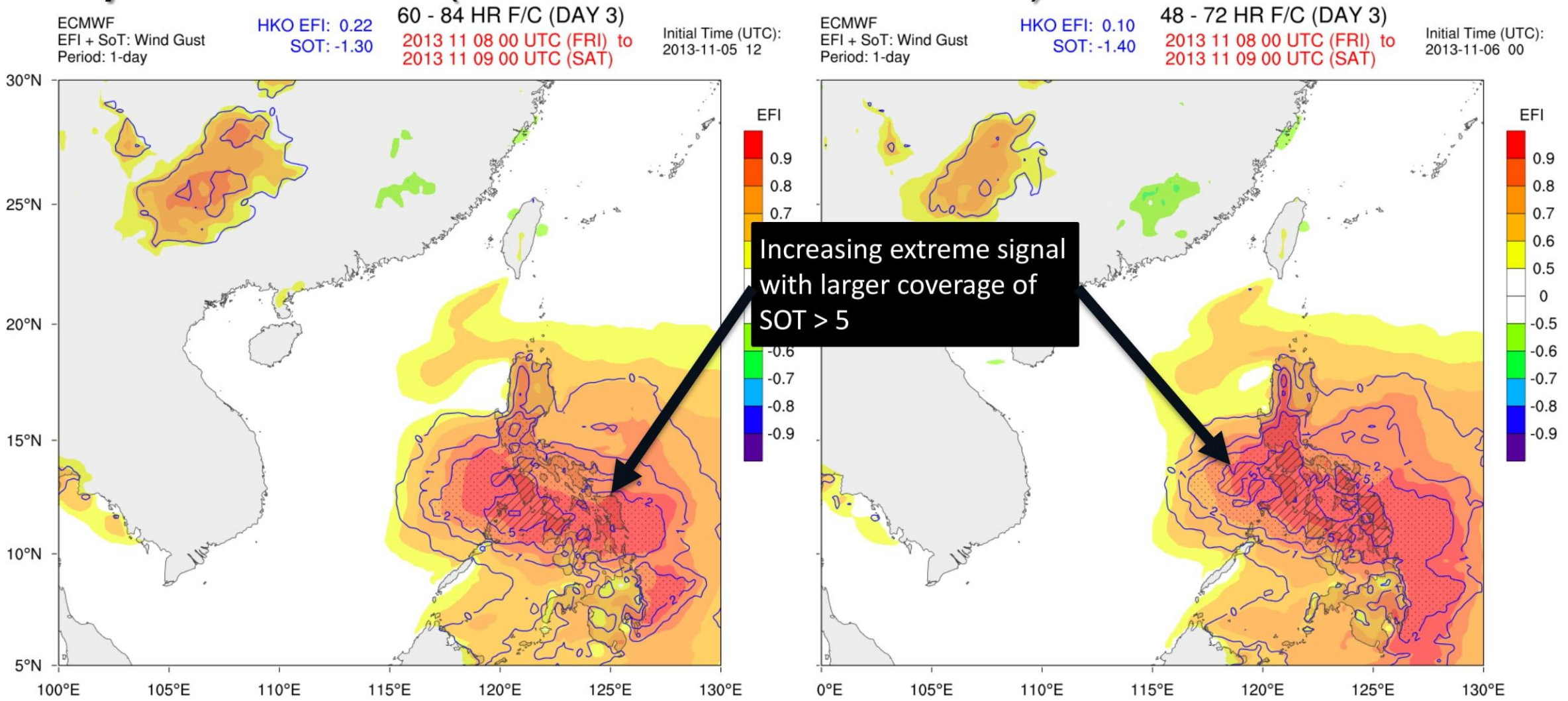


Day 4 forecasts of EFI+SOT Wind Gust (04/12 & 05/00Z)

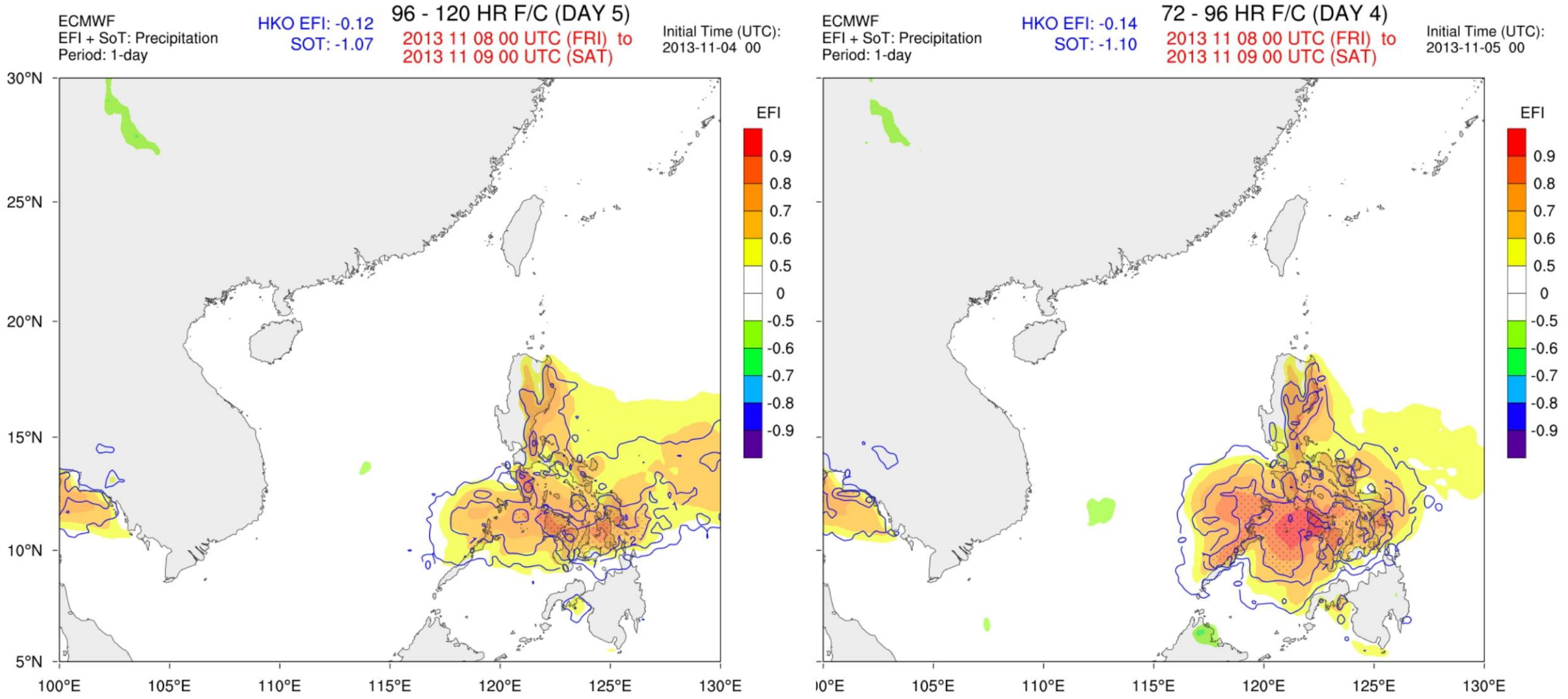




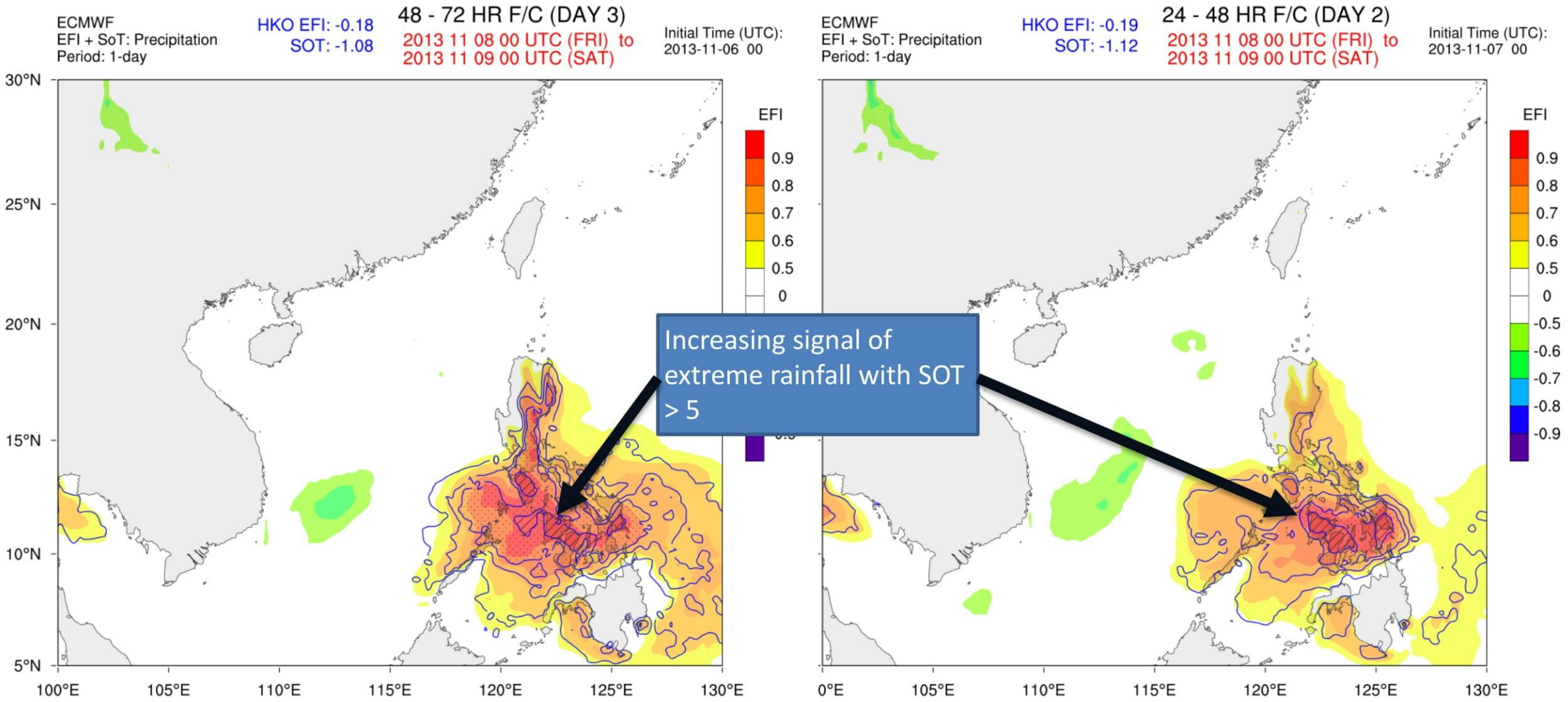
Day 3 Wind Gust (05/12 & 06/00 Z EPS runs)



EFI+SOT daily precipitation on 8 Nov (D+5 & D+4)



EFI+SOT daily precipitation on 8 Nov (D+3 & D+2)



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3.1 degree Celsius on 24 Jan 2016 (Sunday)

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The Government of the Hong Kong Special Administrative Region
Innovate with Science, Serve with Heart
London 20°C

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Very Cold Weather Afflicted Hong Kong

Sunday, 24th January 2016

[Mobile Version]

An intense cold surge is bringing very cold weather to Hong Kong today (24 January 2016). A rain band moved to the territory at 4 am and brought rain to the region. The rain also brought the temperature down further to 3 to 4 degrees in the urban area and a couple of degrees lower in the New Territories. The lowest temperature recorded at the Observatory this morning (up to 11 am) was 3.3 degrees, which is the ninth lowest on record and is also the lowest since 1957.

As the temperatures on high ground stayed below the freezing point, freezing rain and icing occurred. Meanwhile, temperatures around Hong Kong were also general on the low side. Some ice pellets aloft did not melt before reaching the ground and there was occasions of rain with small ice pellets.

The northerly winds associated with the intense cold surge will continue to affect Hong Kong. It will remain very cold tomorrow. Temperatures in the urban area will be in the region of 4 degrees while those in the northern part of the New Territories will be close to zero degree. Sub-zero temperatures are still expected on high ground. Cold weather will persist into Wednesday (27 January).

...ect in Hong Kong. People are advised to put on ...ntry winds in order to avoid adverse health ...icularly on icy road on high ground.

Icing on Tai Mo Shan

South China Morning Post | CHINA HK ASIA WORLD COMMENT BUSINESS TECH LIFE CULTURE SPORT WEEK IN AS

10 SHARES NOW READING Coldest day in 59 years unexpected: Hong Kong meteorologists describe forecast chal

Coldest day in 59 years unexpected: Hong Kong meteorologists describe forecast challenges as imperfect science

Observatory and other weather experts respond to criticism for underestimating the severity of the weekend cold snap

PUBLISHED : Monday, 25 January, 2016, 7:55pm
UPDATED : Tuesday, 26 January, 2016, 10:11am

Ernest Kao

10 SHARES

RELATED TOPICS
Hong Kong weather

Forecasts for extreme weather systems are never 100 per cent accurate and not simply the work of looking at statistics, local meteorologists emphasised.

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The point came as the Hong Kong Observatory was criticised on social media for underestimating the severity of the weekend cold snap.

Minimum temperatures Sunday dropped to 3.1 degrees on Sunday afternoon – more than five degrees lower than what was originally predicted and the city's lowest reading since 1957.

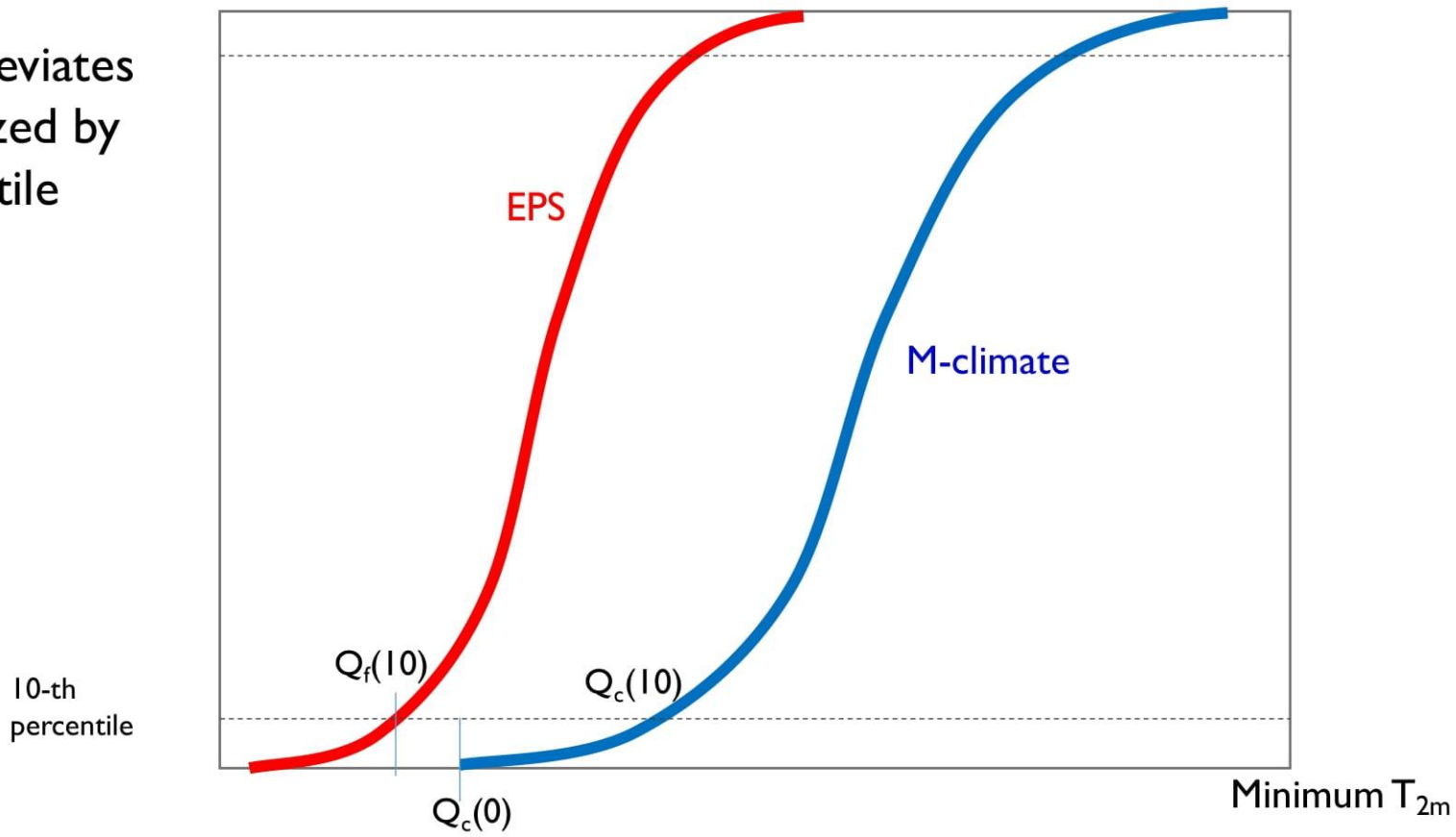
READ MORE: Hong Kong shivers through its coldest day since 1957: kindergartens, primary schools closed today →

Only last week, the Observatory stated that its grasp of Hong Kong weather was much better than overseas bodies or unofficial forecasters on the internet, as US and European-based systems indicated temperatures would be far lower than the

Shift of Tail (SOT)

$$SOT\_(10) = -\frac{Q_f(10) - Q_c(0)}{Q_c(10) - Q_c(0)}$$

Positiveness of SOT(10) indicating how far EPS deviates from M-climate normalized by the lowest 10-th percentile



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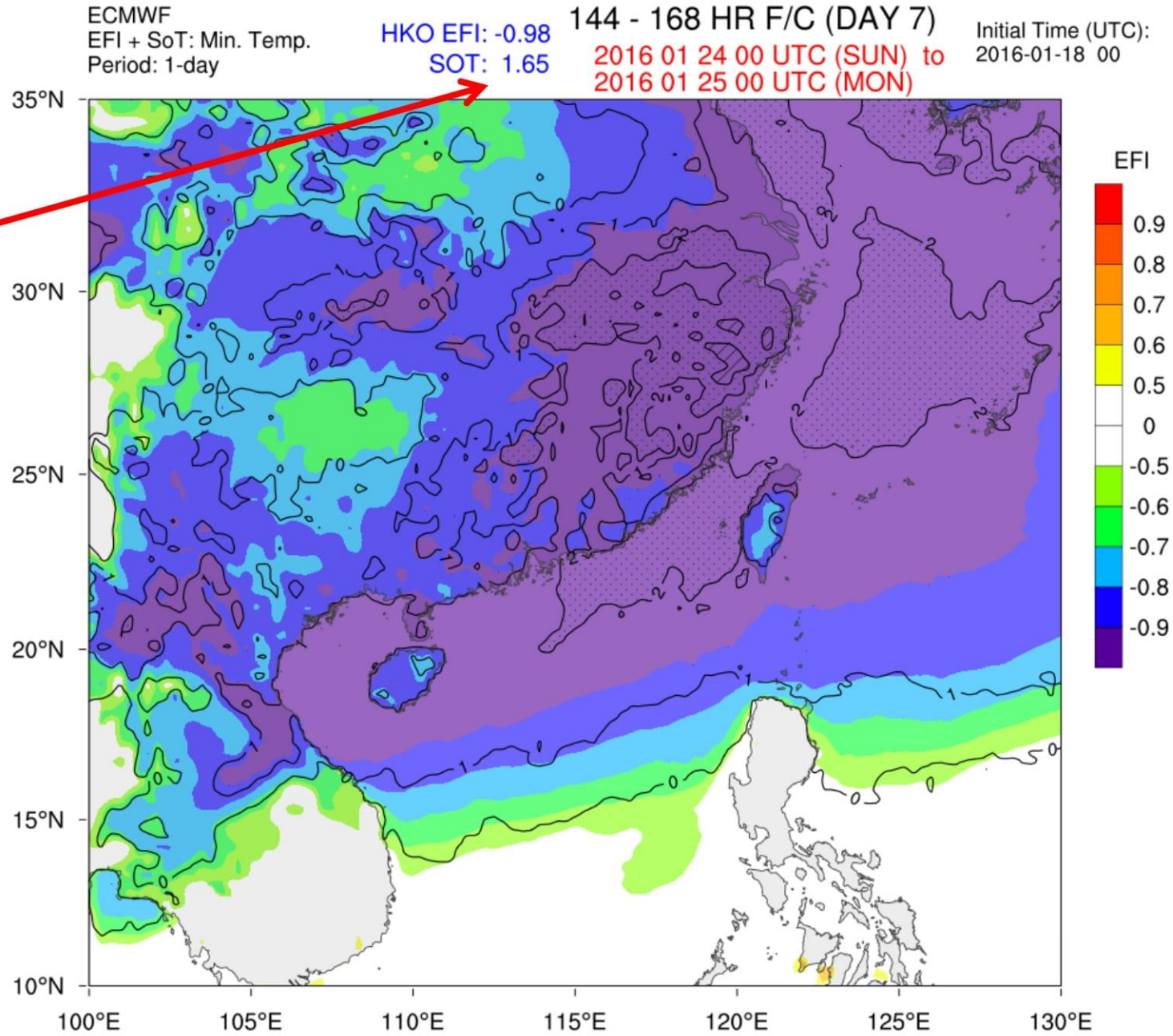
SoT(10) ~ 1.7 means that at least 10% of ensemble members are outside M-climate by about 1.7 times of Qc(1%)-Qc(10%) or more



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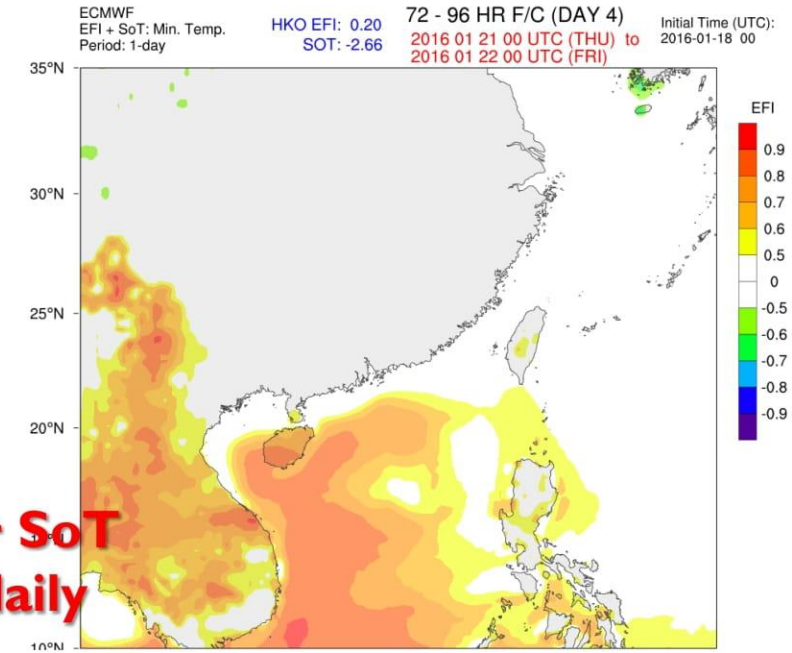
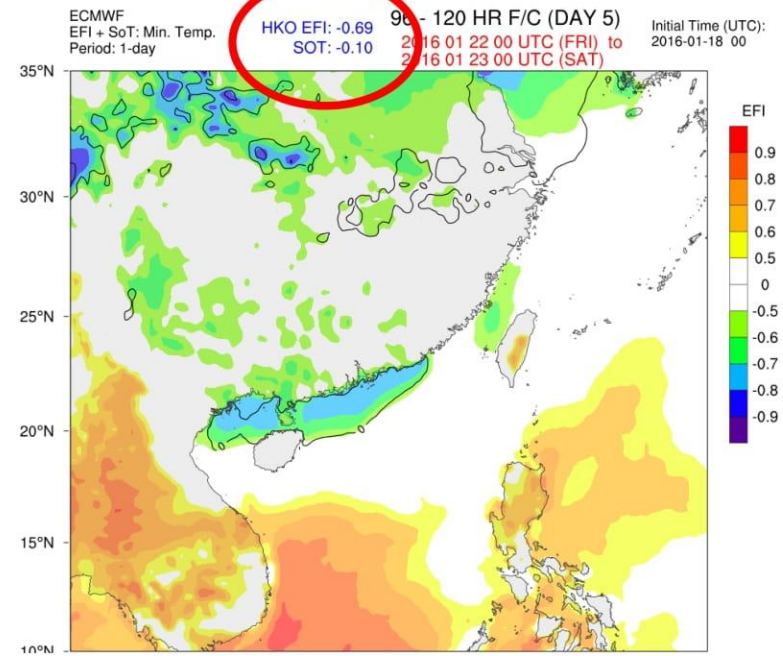
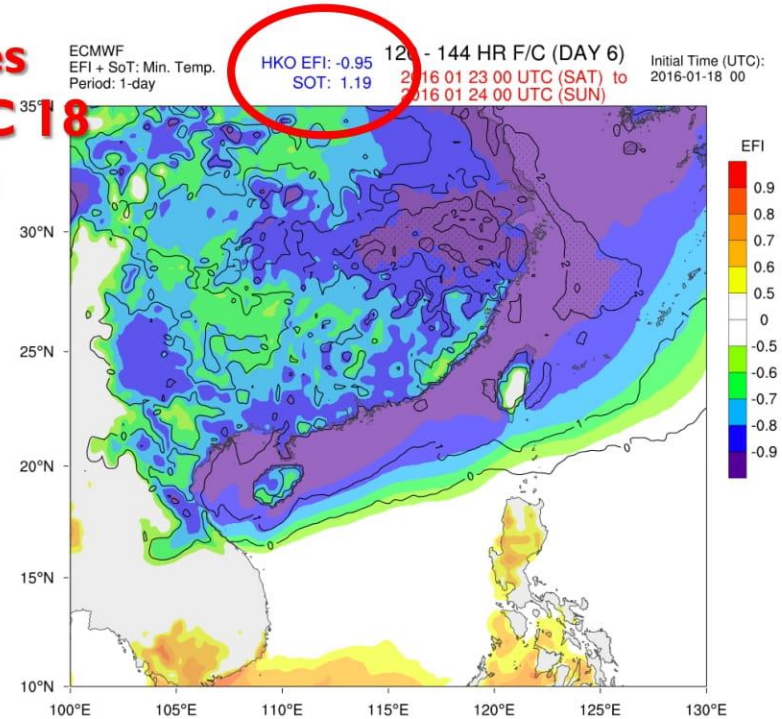
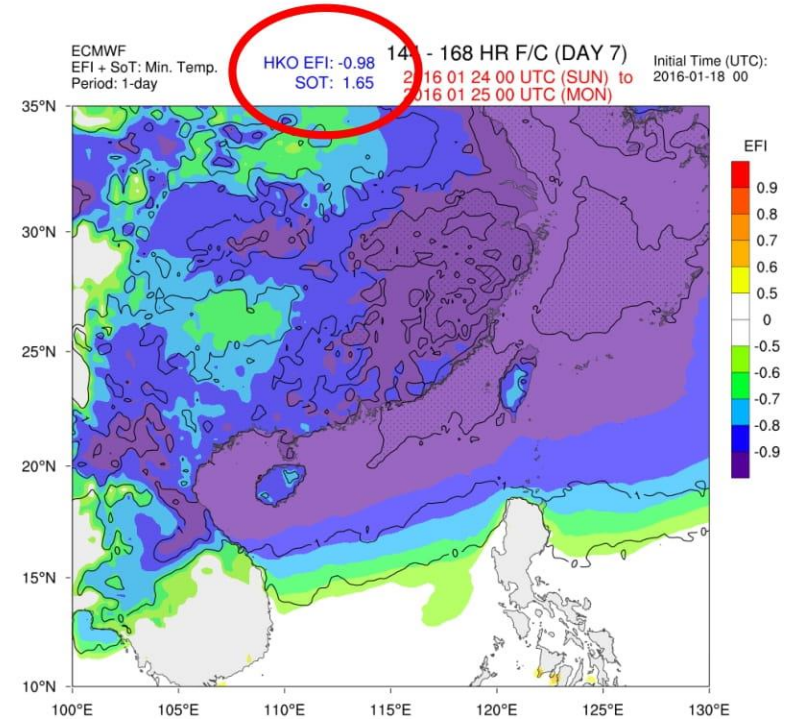
D4-D7 EFI + SoT of forecast daily minimum temperatures from 00 UTC 18 Jan 2016 run









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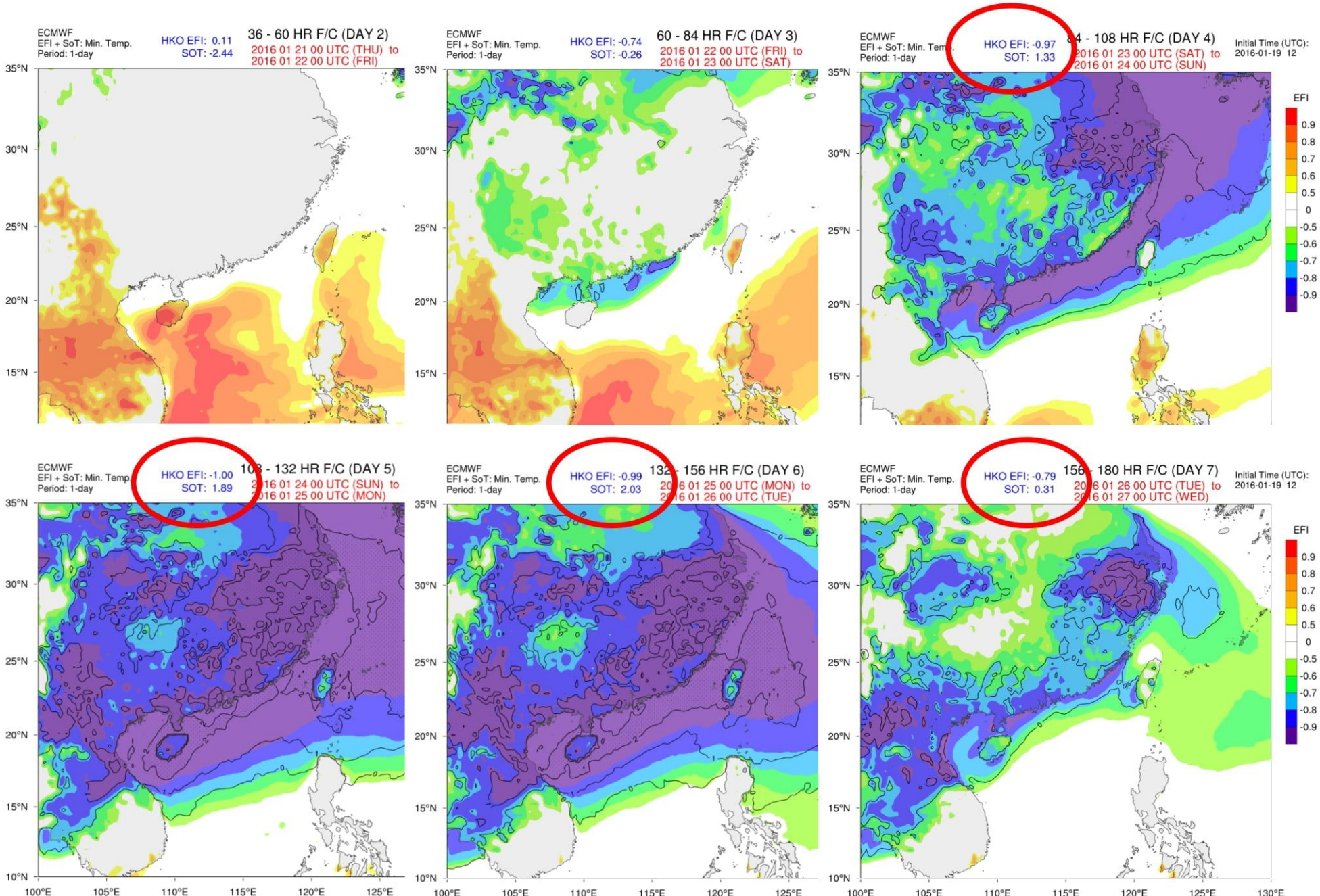
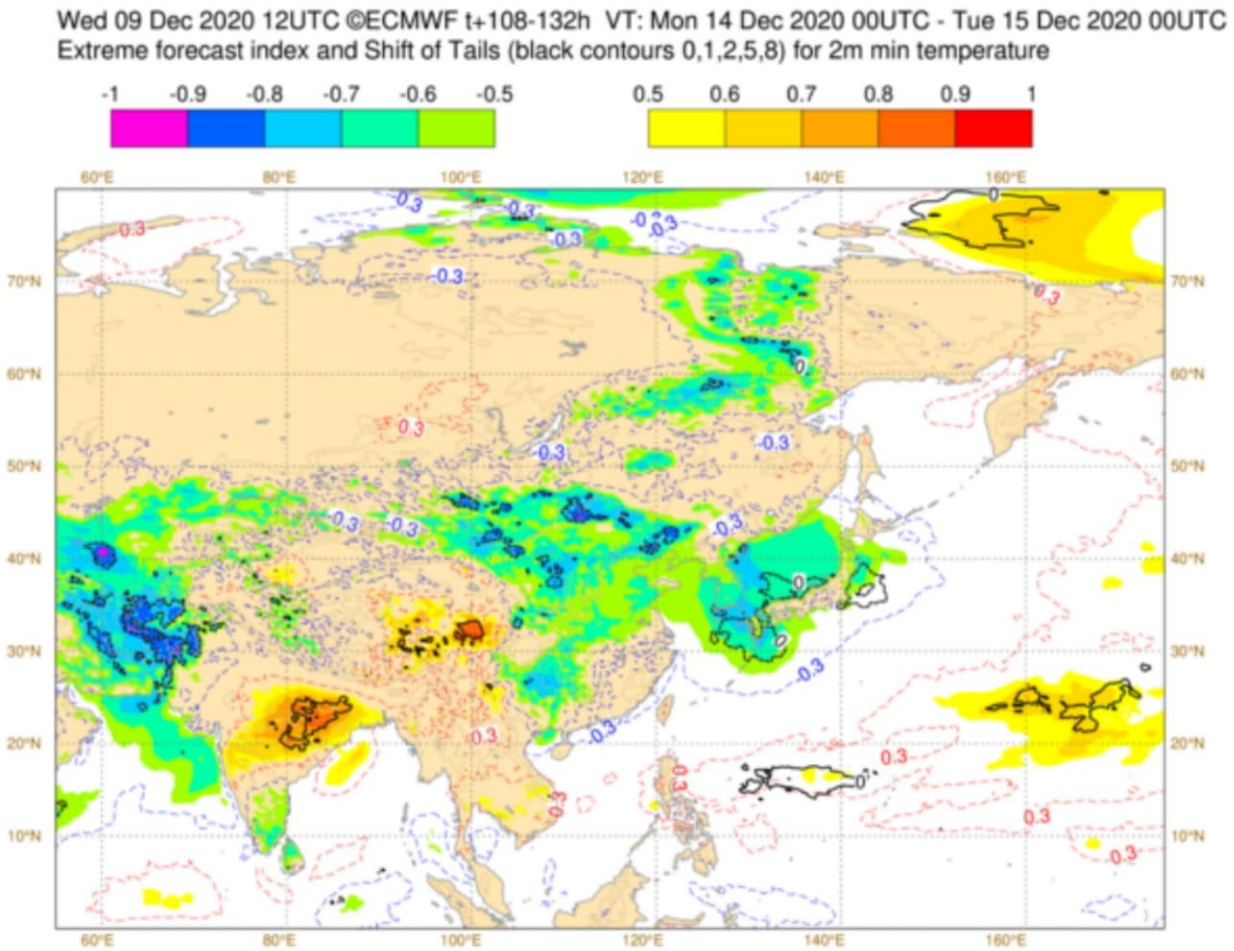
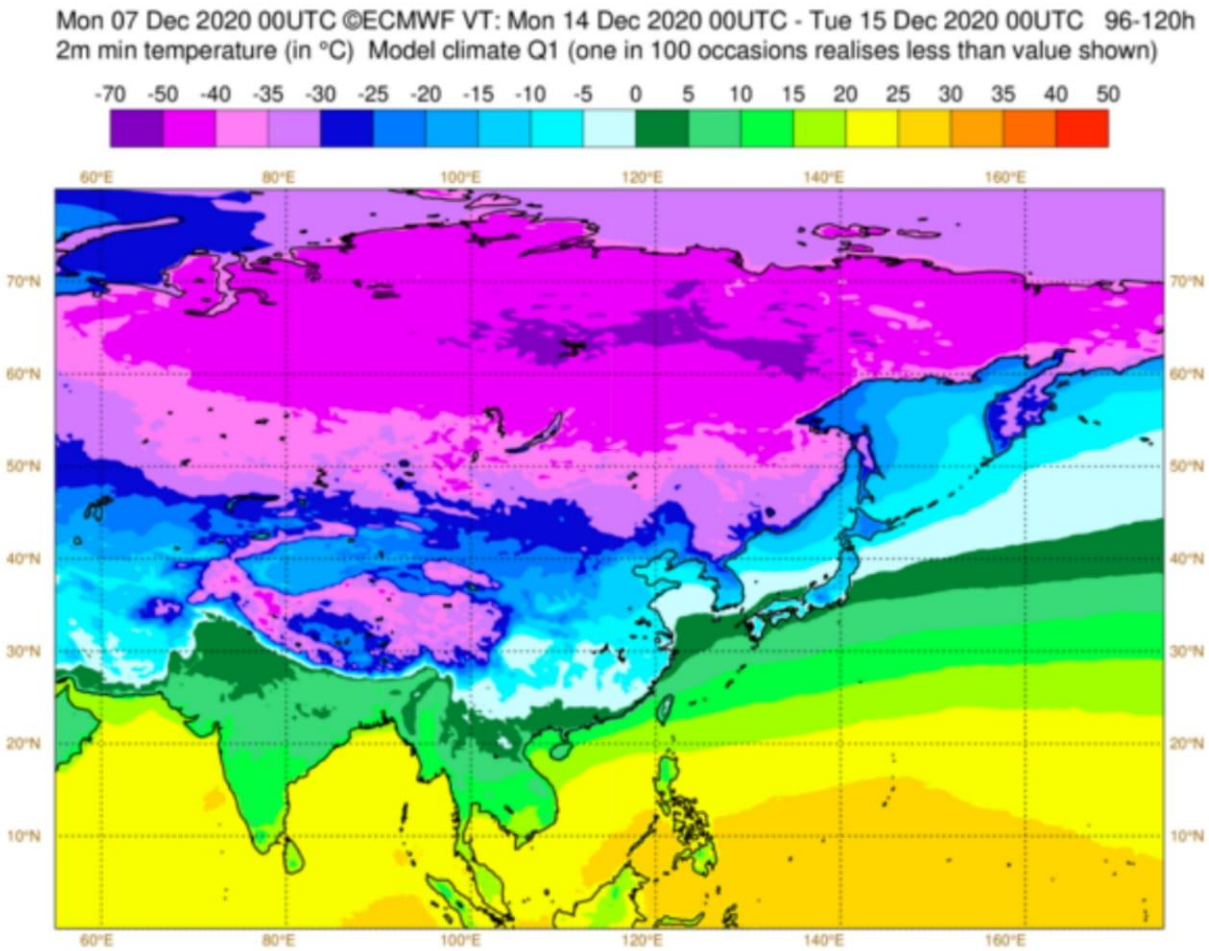
D2-D7 forecasts of EFI + SoT from 12 UTC run on 19 Jan 2016



EFI 2m minimum temperature

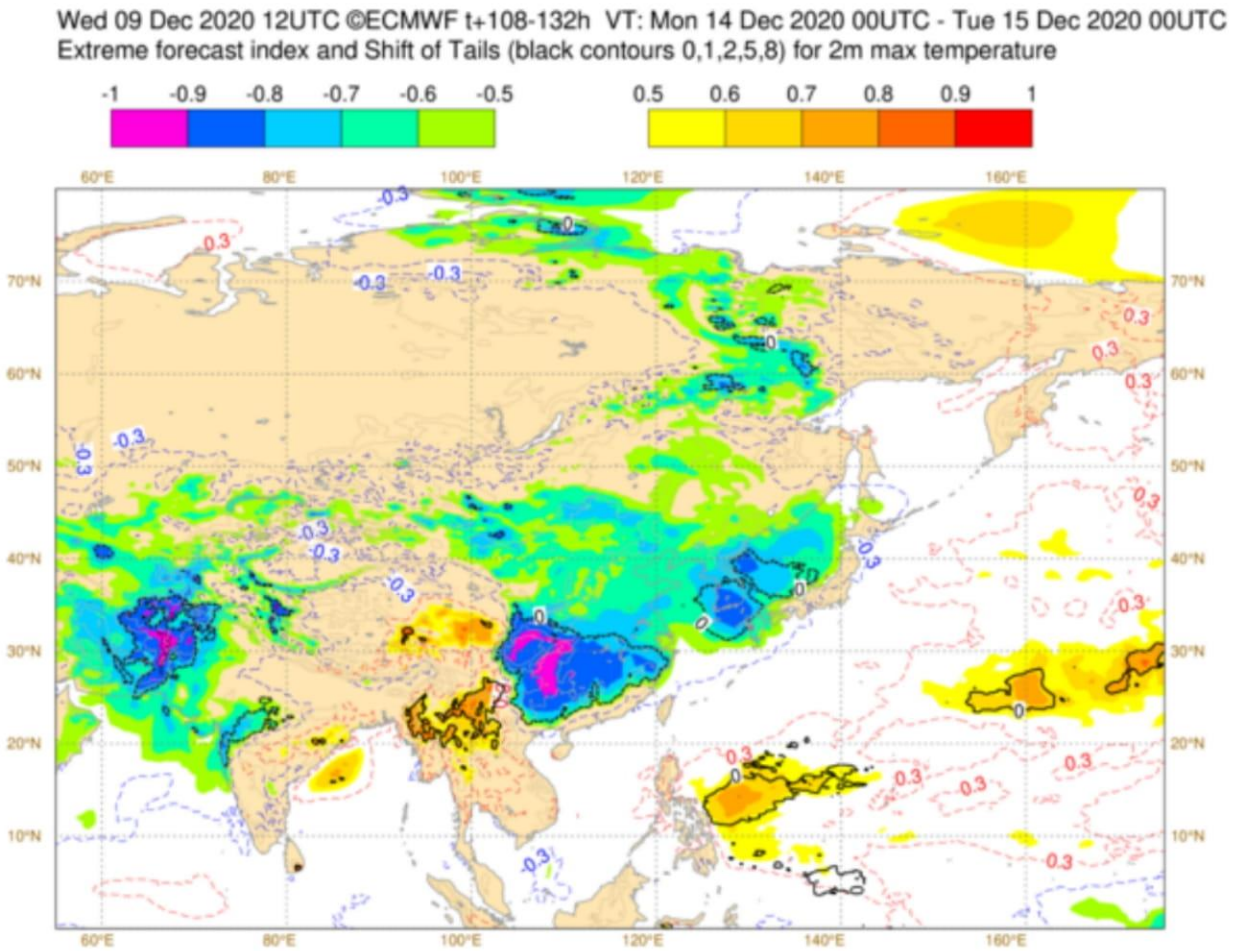
Base time: Wed 09 Dec 2020 12 UTC, Valid time: Wed 09 Dec 2020 12 UTC, - T+0 h, Area : Asia, Quantile : 1, Day : 5

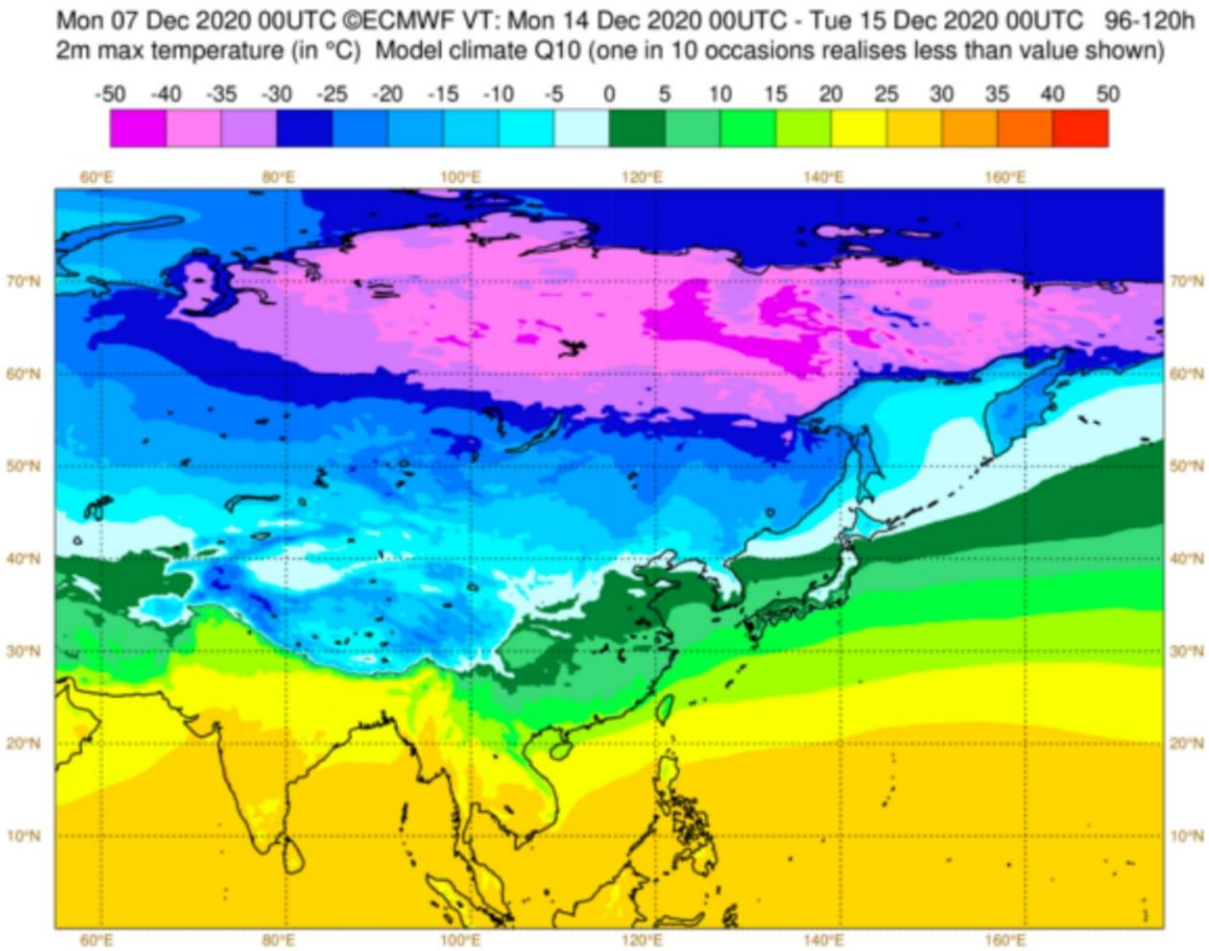




EFI 2m maximum temperature

Base time: Wed 09 Dec 2020 12 UTC, Valid time: Wed 09 Dec 2020 12 UTC, - T+0 h, Area : Asia, Quantile : 10, Day : 5

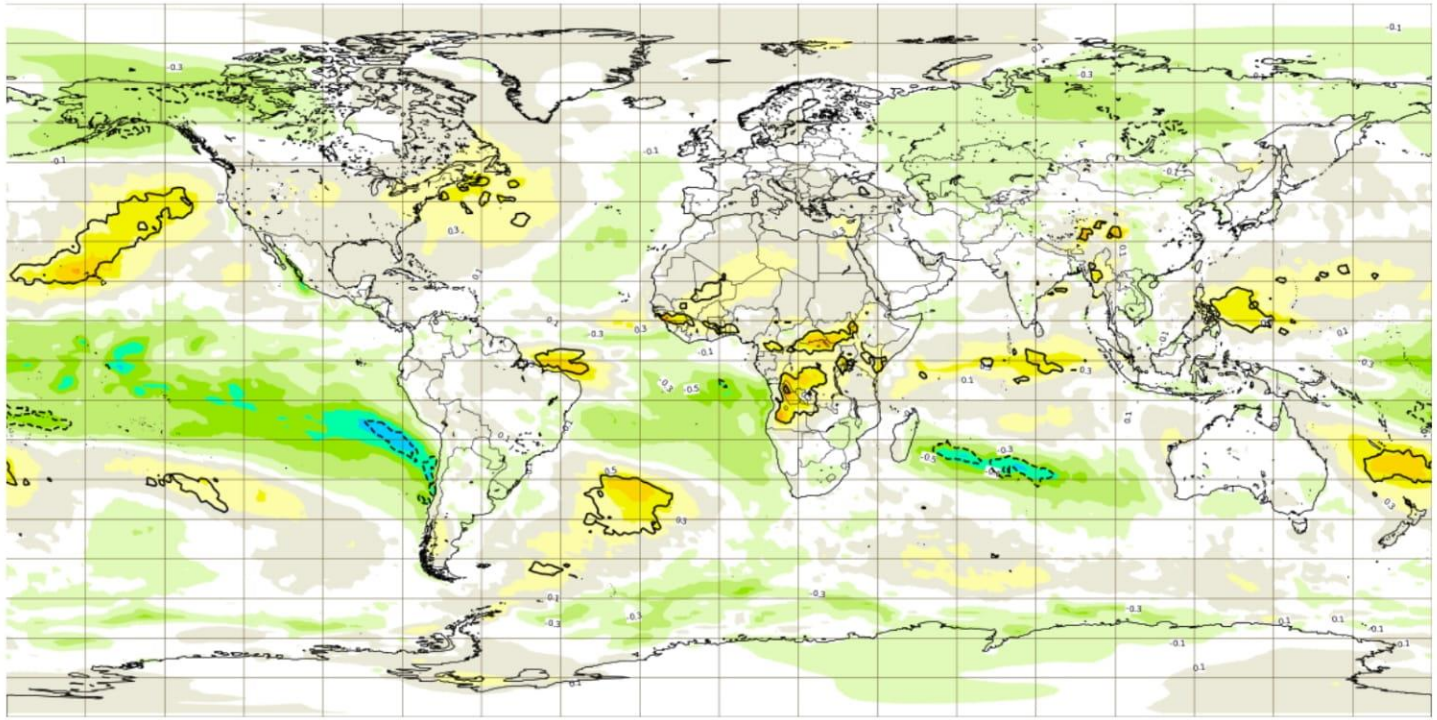




Weekly EFI 2m temperature forecast from ECMWF website

EFI 2m temperature over Extended range

Base time: Mon 07 Dec 2020, Valid time: Mon 21 Dec 2020 - Mon 28 Dec 2020, - T+504 h, Area : Global



Extended range: EFI for 2m temperature (efi_index)

-1 -0.9 -0.8 -0.7 -0.6 -0.5 -0.3 -0.1 0.1 0.3 0.5 0.6 0.7 0.8 0.9 1

Extended range: 2m temperature shift of tails (SOT) at quantile 10

Extended range: 2m temperature shift of tails (SOT) at quantile 90

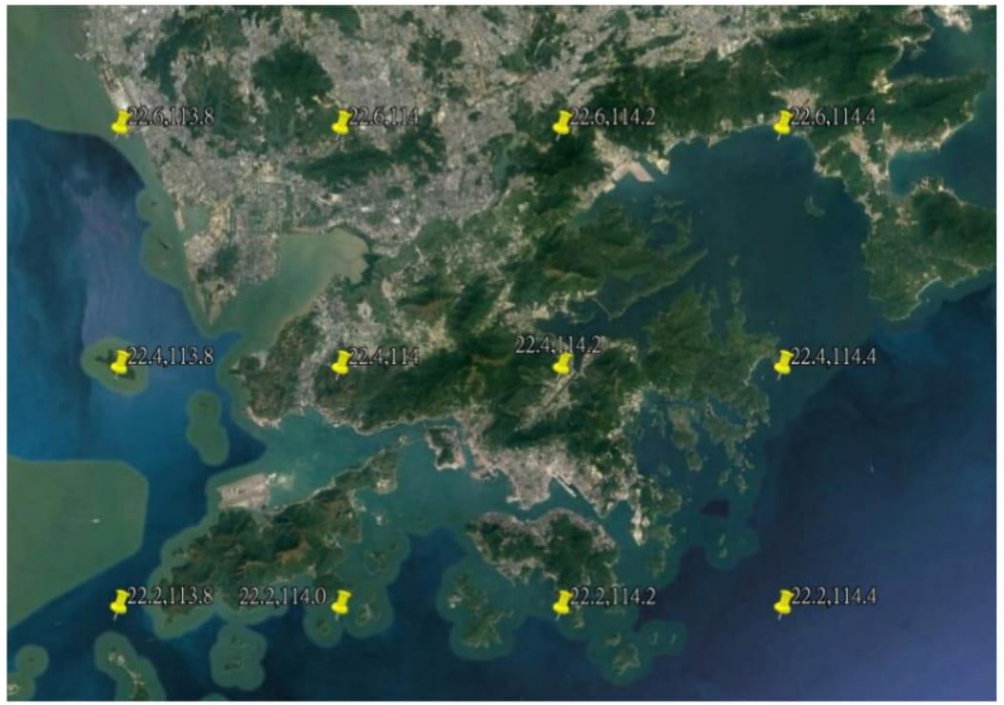
Using machine learning with EPS

Objective

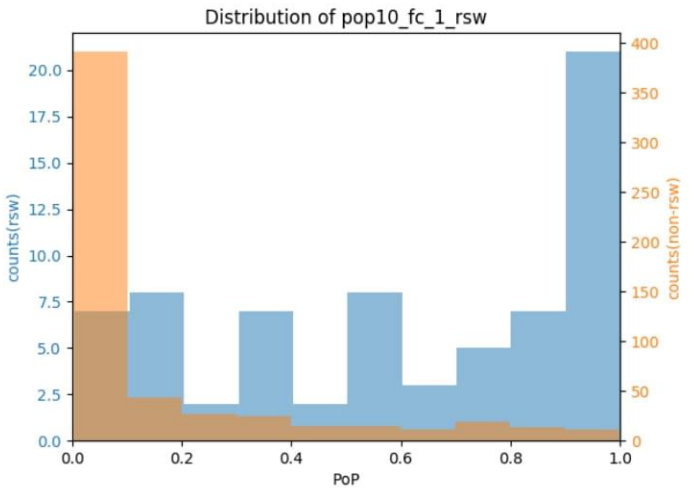
- Model output used: ECEPS, 51 members, 12 grid points around HK

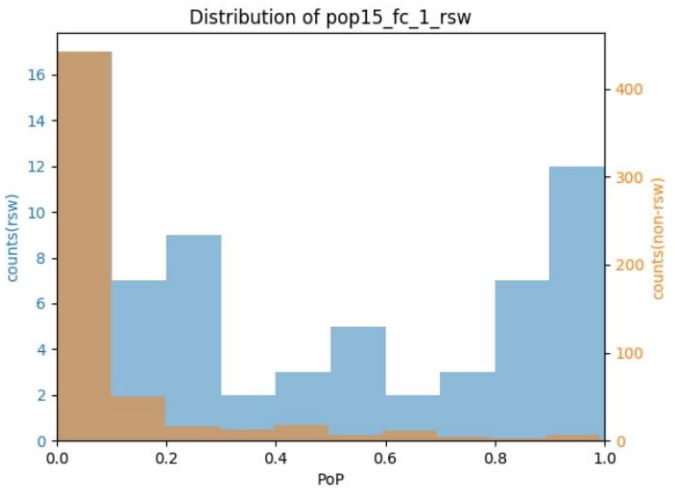
- Explore ECEPS PoP (spatial PoP around HK) to predict chance of Rainstorm Warning (RSW), i.e. >=30mm/h in Day+N forecast

- A classification problem in Machine Learning: classify it is RSW (class 1) or no RSW (class 0)



No sharp cut thresholds that can separate the 2 distributions → need more features to help in classification



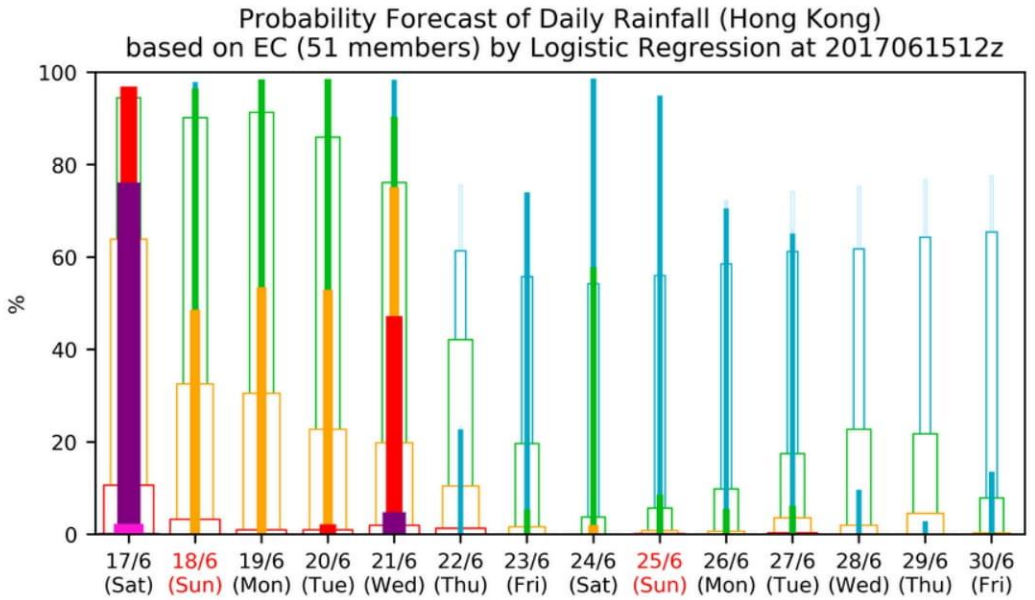


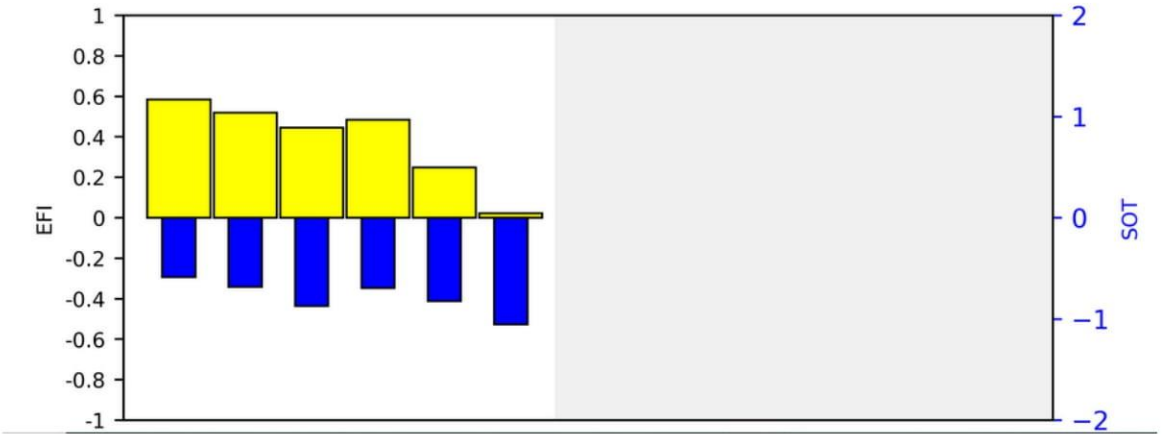
Feature space selection

- From experience, when there is significant rf, model $PoP_{>=10mm}$ and $PoP_{>=25mm}$ have some responses
- Also, both EFI and SOT have some skills in predicting extreme events
- Thus we select:

  $[PoP_{>=10mm}, PoP_{>=25mm}, EFI, SOT]$

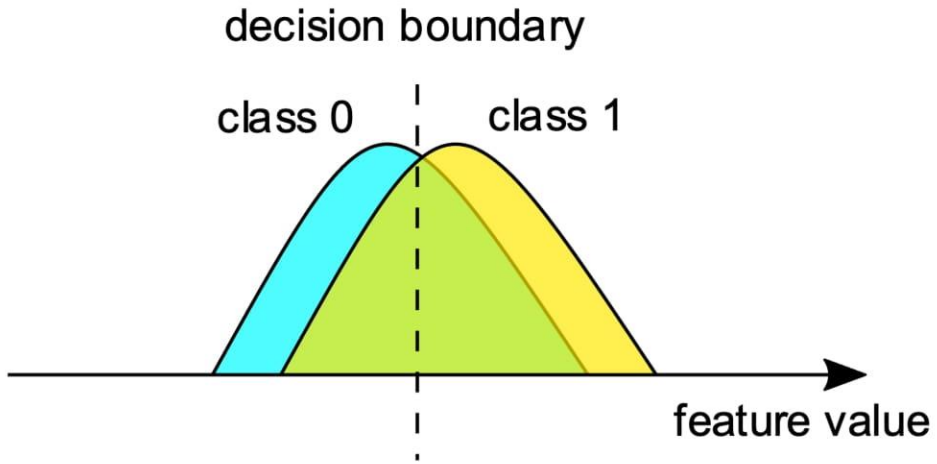
  as a 4-component feature vector to represent RSW and non-RSW dates in the 4D feature space.
- Classification problem: finding the decision boundary in the 4D space to separate RSW and non-RSW dates

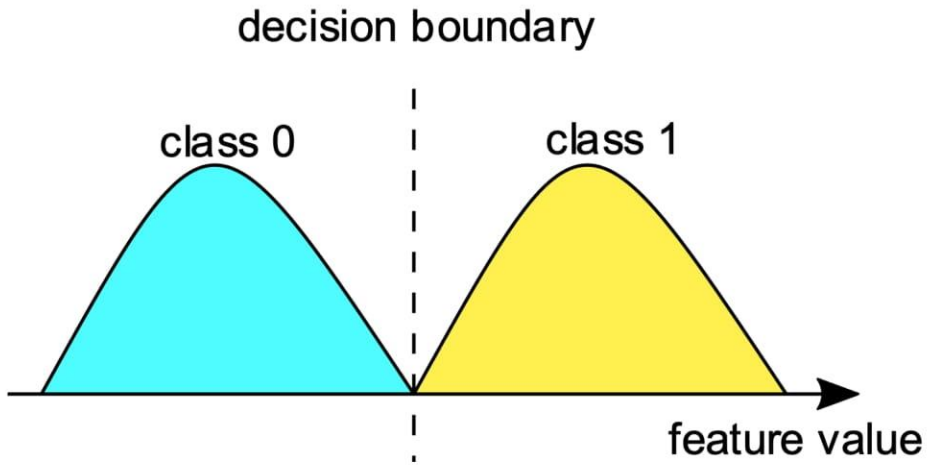




Feature space and decision boundary in classification

For "good features" in classification, the distributions for class 0 and class 1 should be as separate as possible.



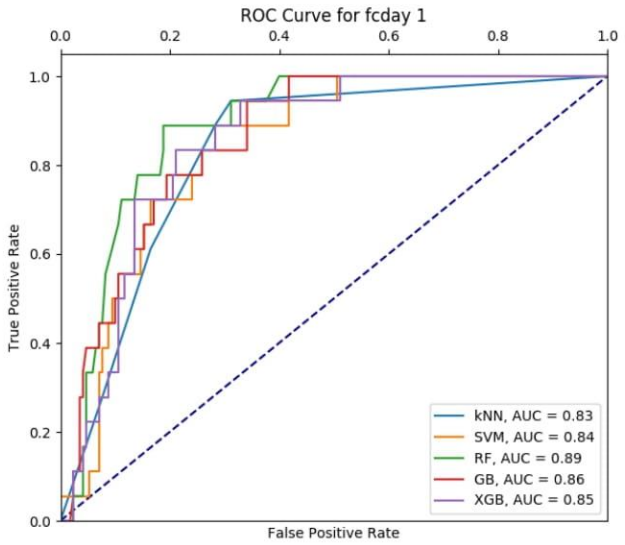


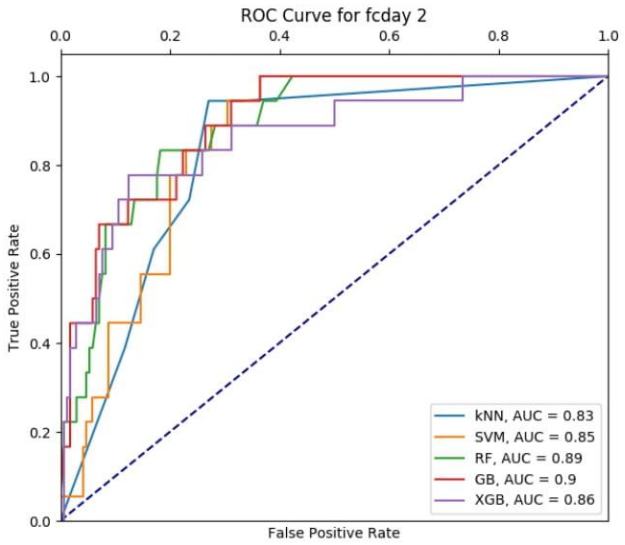
ML Models and Metrics used

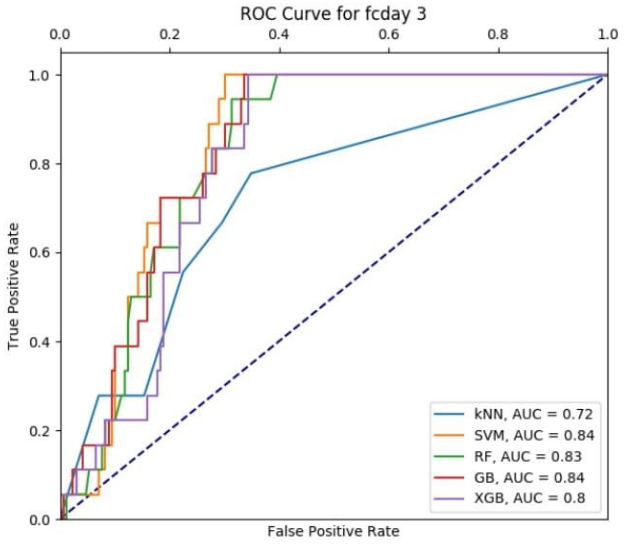
- We have tested 5 common binary classification models:
  - kNN (k-nearest neighbours)
  - SVM (support vector machine) linear kernel
  - RF (random forest)
  - GB (Gradient Boost)
  - XGB (Extreme Gradient boost)

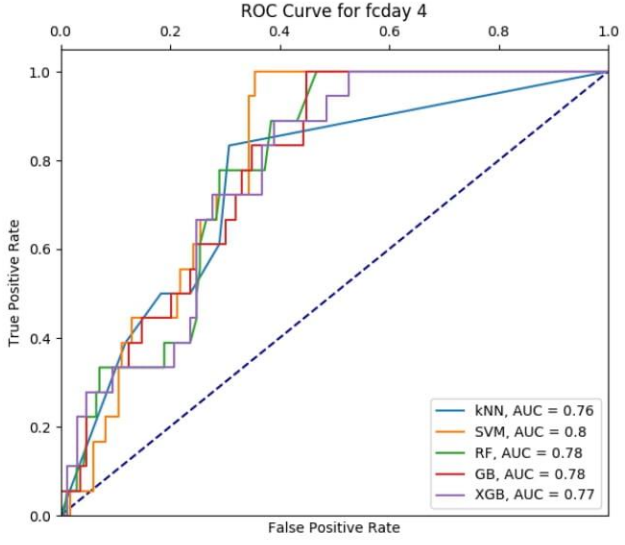
- Metrics used for verification
  - ROC curves
  - Confusion matrix (contingency table)
  - POD, FAR, CSI

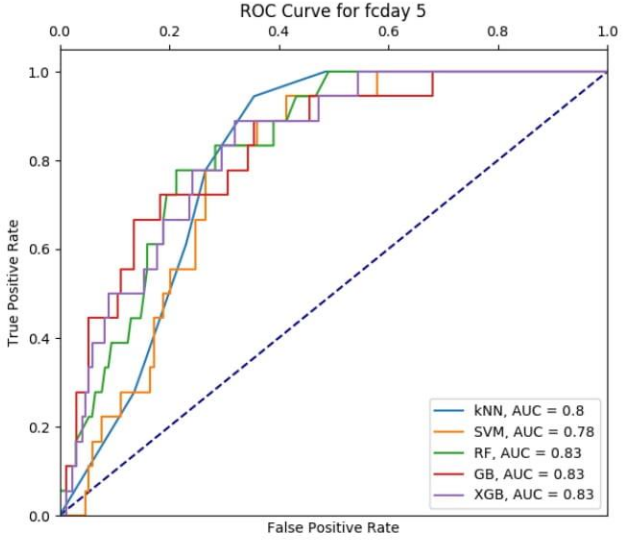
[PoP(10),PoP(25),EFI,SOT] (ROC curves, FC Day-1 to Day-6)

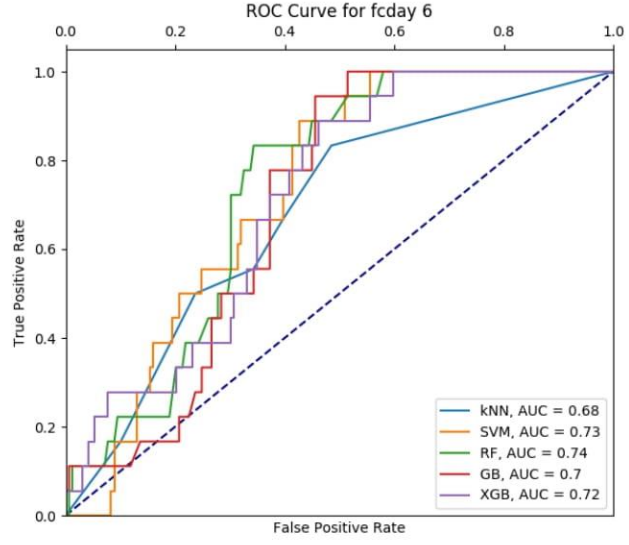












Using EPS

- Probabilistic forecast
  - Post-processing to calibrate ensemble mean and spread for improving performance
- Assessment of alternative scenarios
  - Uncertainties from initial perturbation and physical processes
  - Worst scenario
- EPS guidance for significant convection forecast
  - Leverage values from EPS members on predicting possible scenarios of dynamics and physical processes
- Extremity of weather
  - Extreme Forecast Index (EFI) and Shift of Tails (SoT)

- Q&A -