A simple 1D numerical model for operational nowcasting of sea breeze at the HKIA

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Presented by P. CHEUNG

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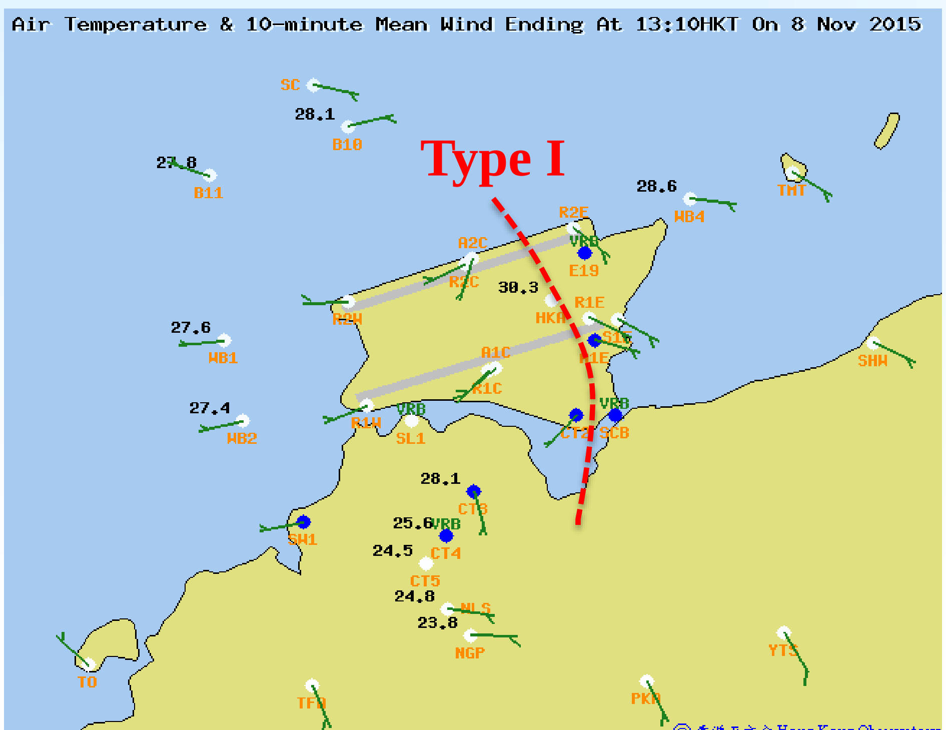
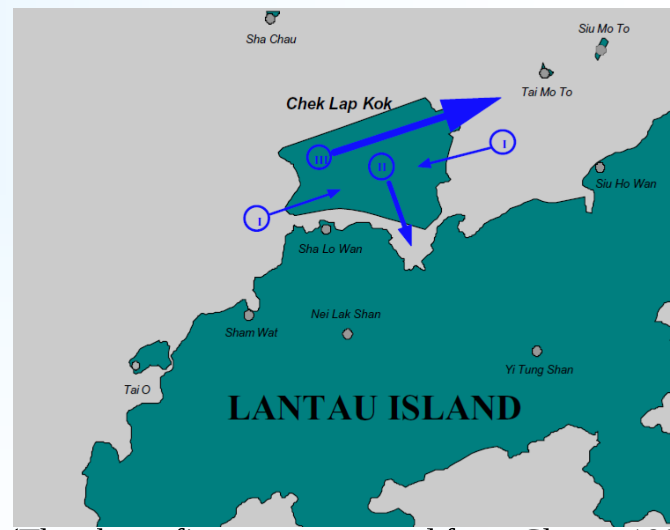
- Sea breeze at HKIA
  - Mostly westerlies in background easterlies (here, generally refers to winds with east-component)
  - Onset time depends strongly on east-component
  - Classification: Type I, II and III (Cheng, 1999)





(The above figure was sourced from Cheng, 1999)

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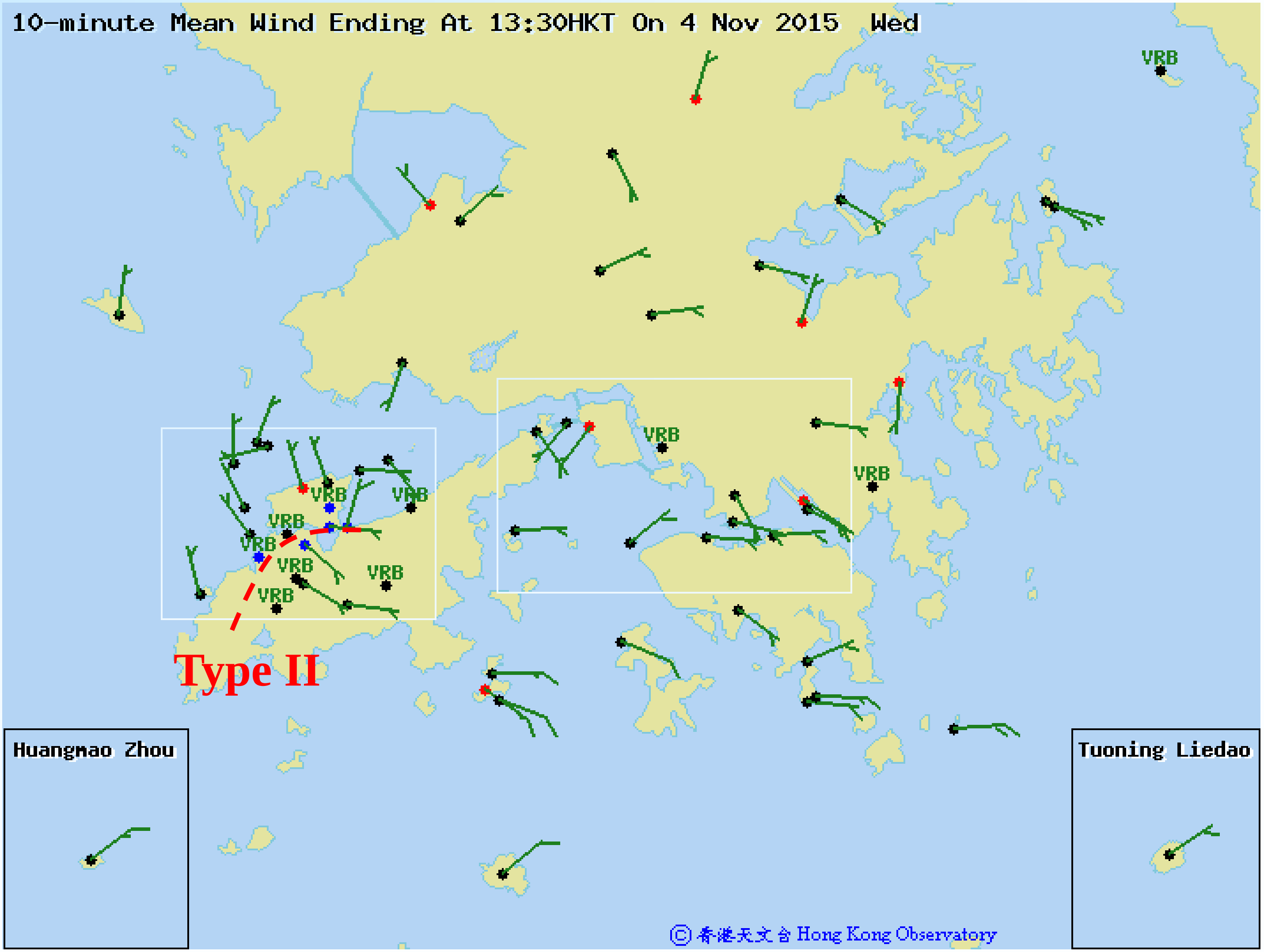

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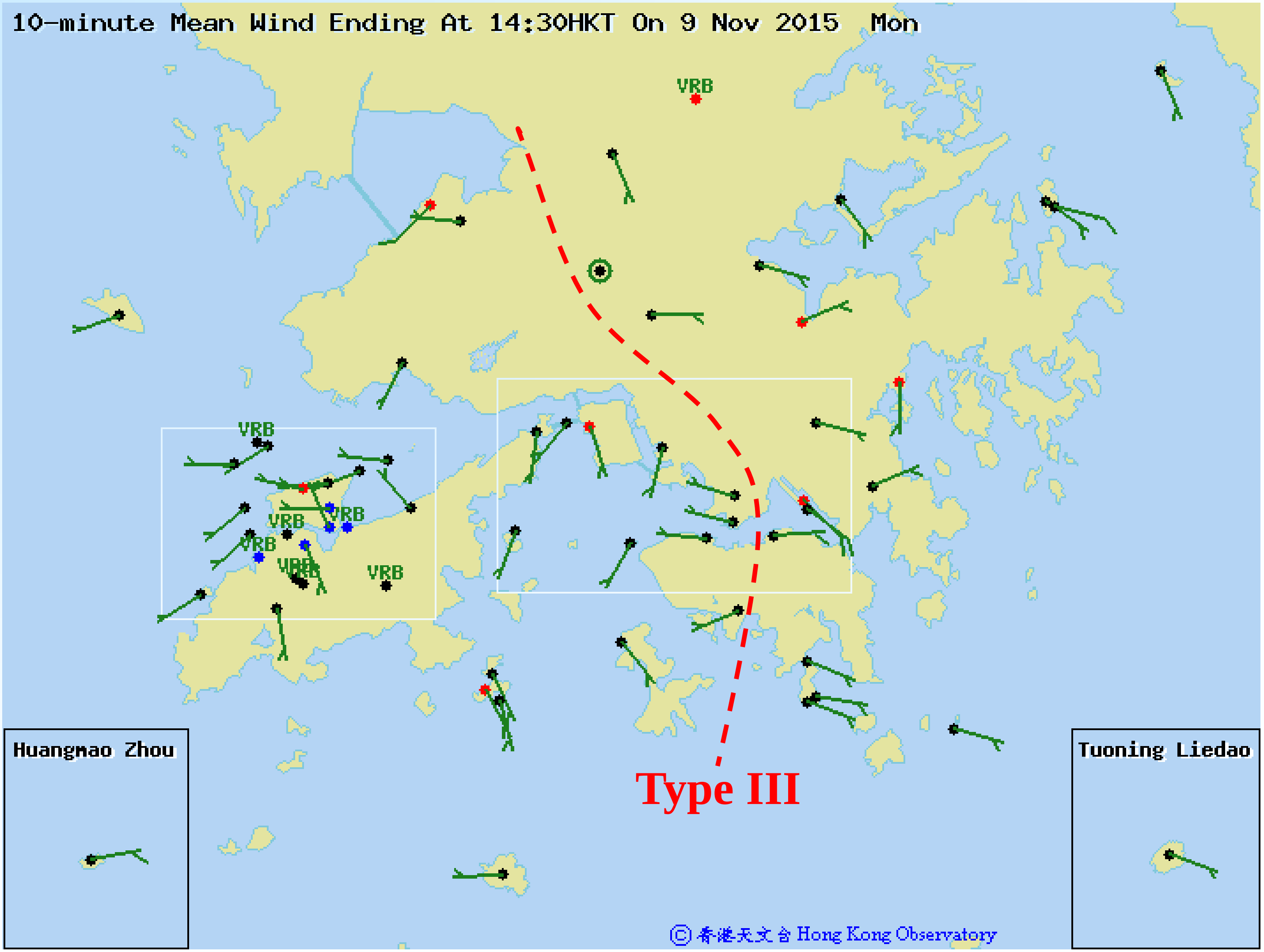

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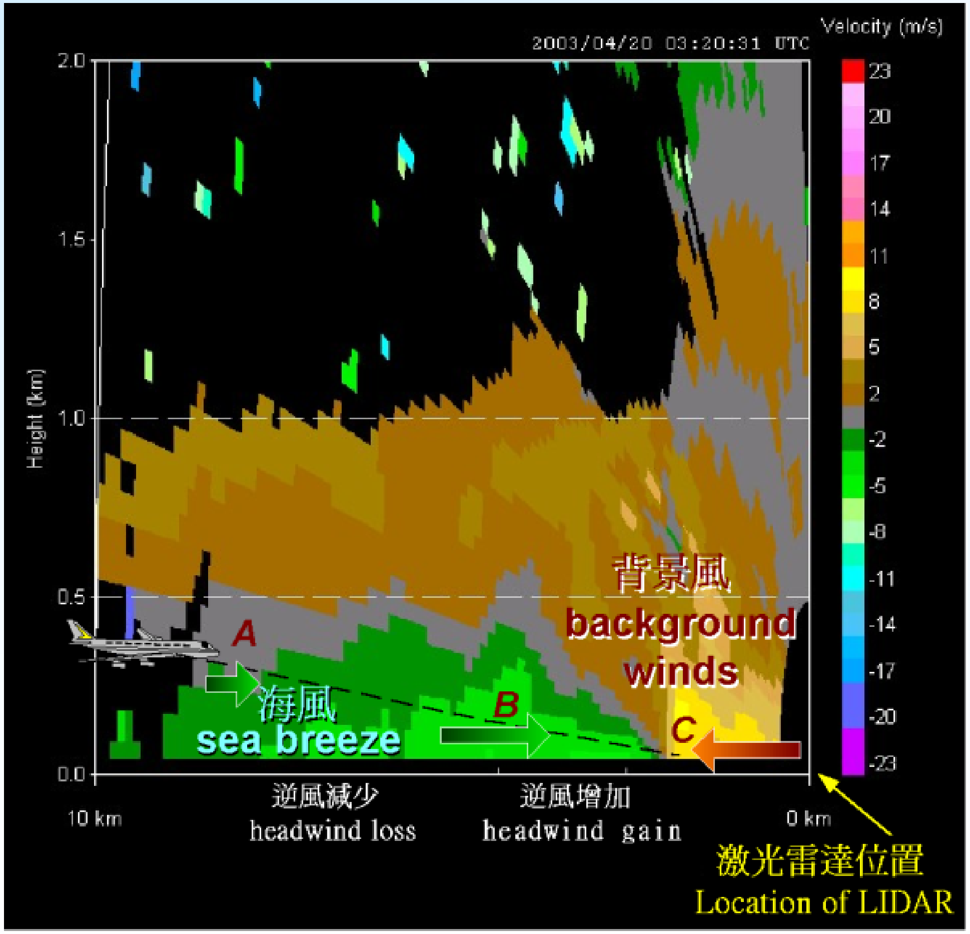
- Sea breeze at HKIA
  - Vertical cross section of sea breeze (sensed by LIDAR)



(Source: *Weather On Wings*, No.19, June 2003, Hong Kong Observatory)

Thickness of sea breeze behind intrusion head ~ 200-300m

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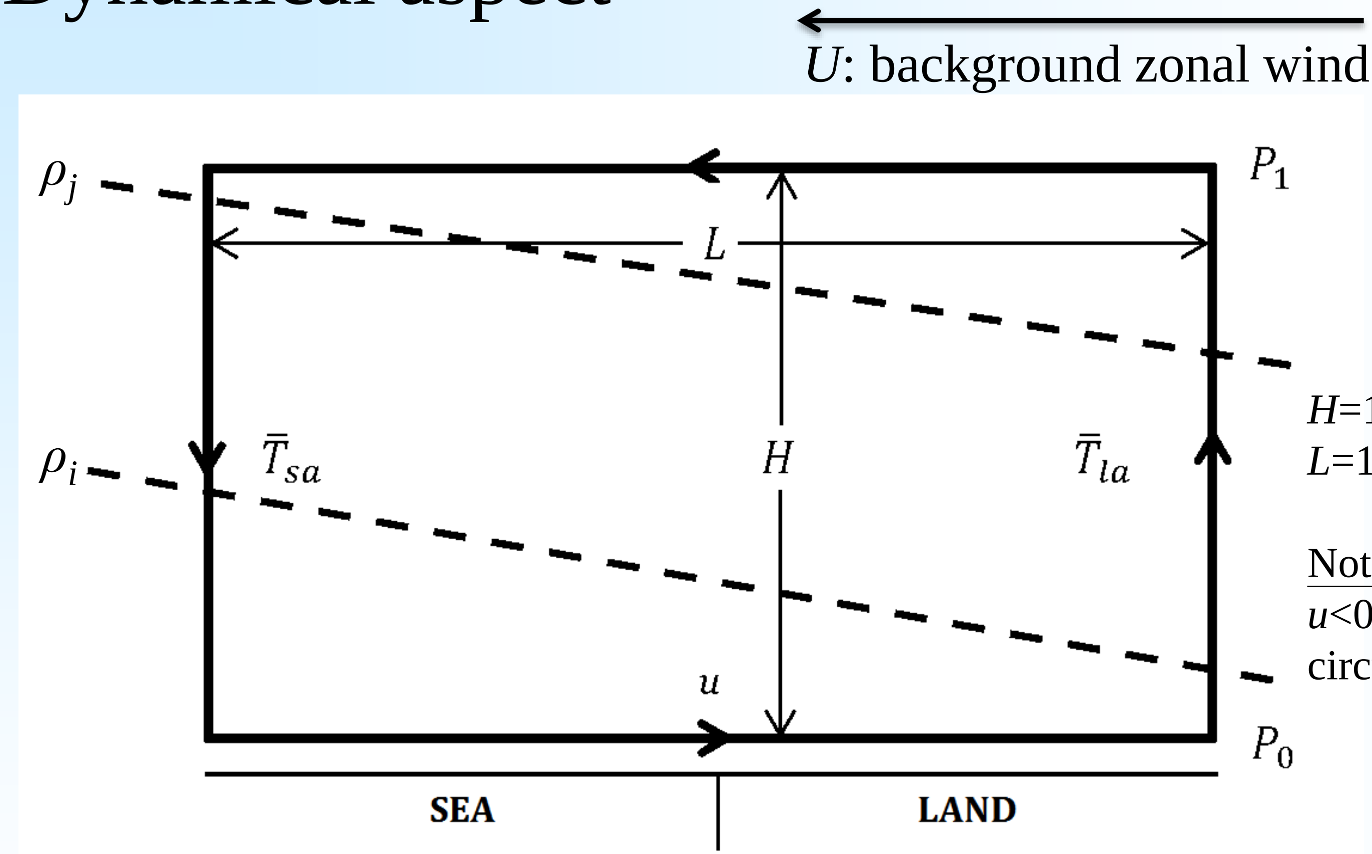
- Dynamical aspect



H=1,000m
L=10,000m (by tuning)

Notation:
u<0 for anticlockwise circulation

$$\frac{du}{dt} = -\frac{R\ln\left(\frac{P_0}{P_1}\right)}{2\,(H+L)}\,(\bar{T}_{la} - \bar{T}_{sa}) - ku$$

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- Iteration
  - Evolution of modelled circulation speed

$$u_n = u_{n-1} - \left[\frac{R \ln\left(\frac{P_0}{P_1}\right)}{2\,(H+L)} \underbrace{(\bar{T}_{la,n} - \bar{T}_{sa,n})} + k u_{n-1} \right] \Delta t$$

Land-sea differential of air temperature
(to be determined in consideration of
the **thermal aspect** of the model)

  - Evolution of modelled time (n^{th} step from base time)

$$t_n = t_b + n\Delta t$$

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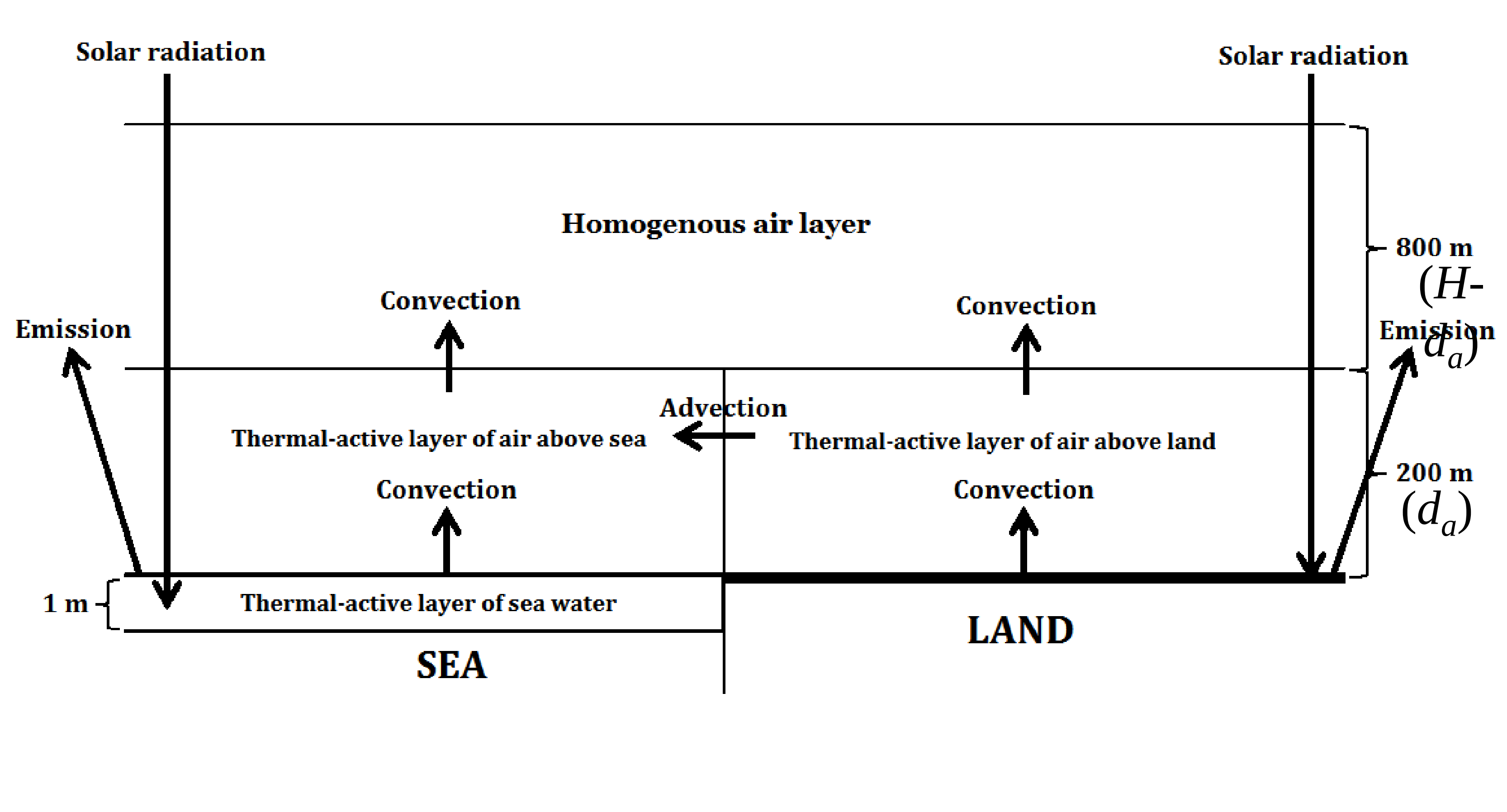
- Thermal aspect



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- Solar radiation flux

$$I(z,F) = 1.1 \cdot I_e \cdot 0.7^{X^{0.678}} \left[1 - 0.75\left(\frac{F}{8}\right)^{3.4}\right] \cos z$$

diffuse component

air mass effect (Meinel & Meinel, 1976)

effect of cloud cover, F (Kasten & Czeplak, 1980)

extraterrestrial solar radiation

solar zenith angle

where $X = \dfrac{1}{\cos z + 0.50572\,(96.07995^{o} - z)^{-1.6364}}$

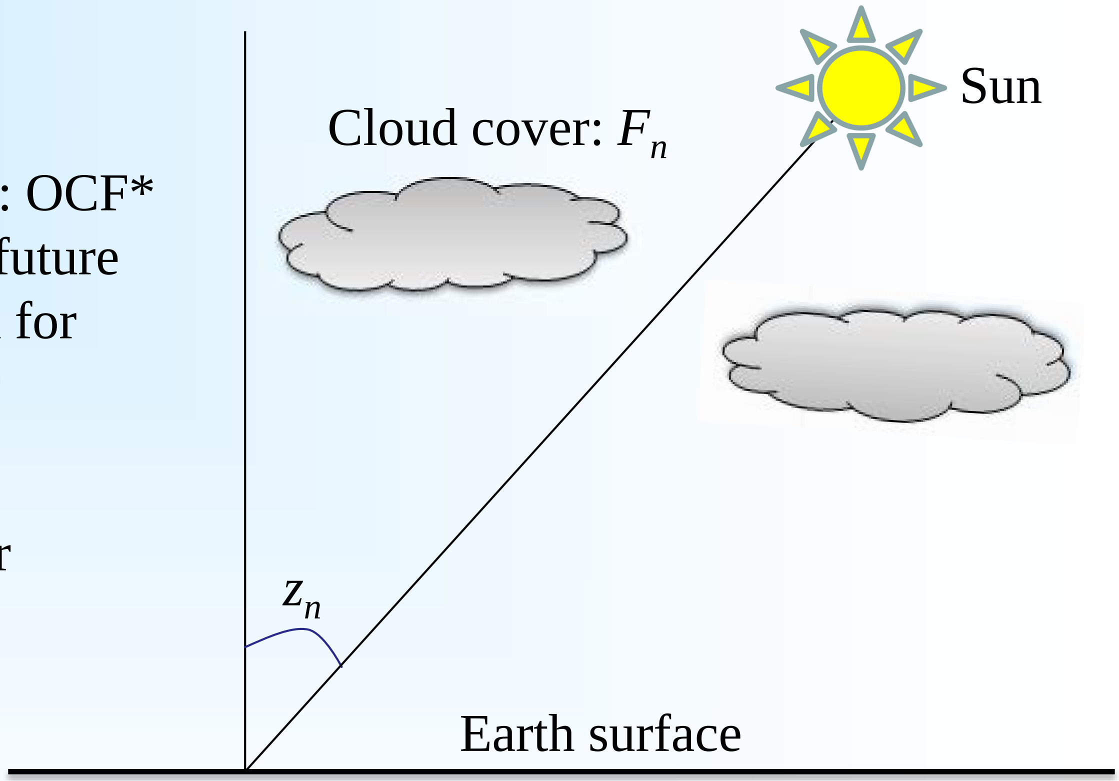
(Kasten & Young, 1989)

Solar radiation flux at n^{th} time step of a model run:

$$I_n = I(z_n, F_n)$$

Cloud cover: OCF* forecast for future hour / actual for present hour

Solar zenith angle computed for the modelled time (t_n) on given day of the year by astronomical formula



*Remarks: OCF stands for objective consensus forecast (Cheung, Leung and Tang, 2015).

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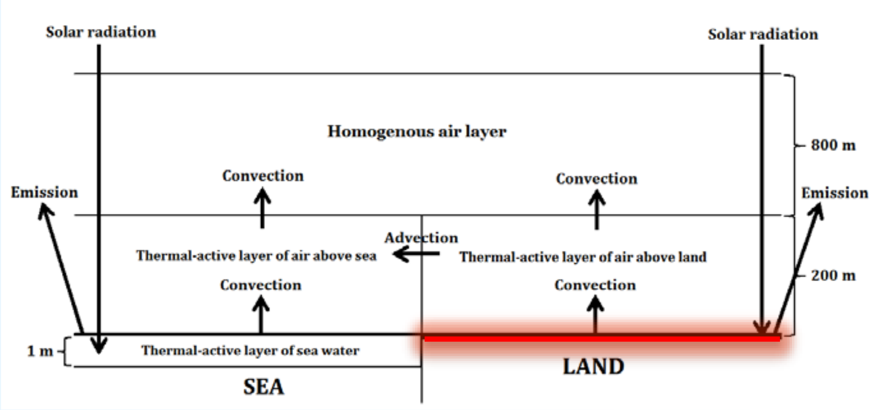
- Temperature of land surface
  - Surface of semi-infinite homogeneous slab

$$T_{l,n} = T_{l,n-1} + \frac{2q_{l,n}}{\kappa_l}\sqrt{\frac{\alpha_l \Delta t}{\pi}}$$

(Lienhard and Lienhard, 2008)



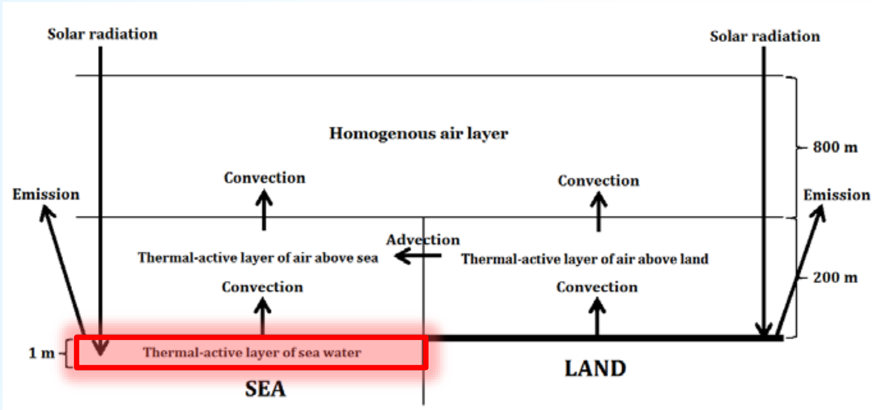
albedo effect — convective loss to air + drain to bulk of landmass

where
$$q_{l,n} = I_n(1-\beta_l) - h'_{la}\left(T_{l,n-1} - T_{la,n-1}\right) - e_l\sigma\left[(T_{l,n-1}+273.15)^4 - (T_{la,n-1}+273.15)^4\right]$$

radiative loss

- Temperature of sea surface
  - 1m thick homogeneous thermal-active layer

$$T_{s,n} = T_{s,n-1} + \frac{q_{s,n}}{c_s \rho_s d_s} \Delta t$$



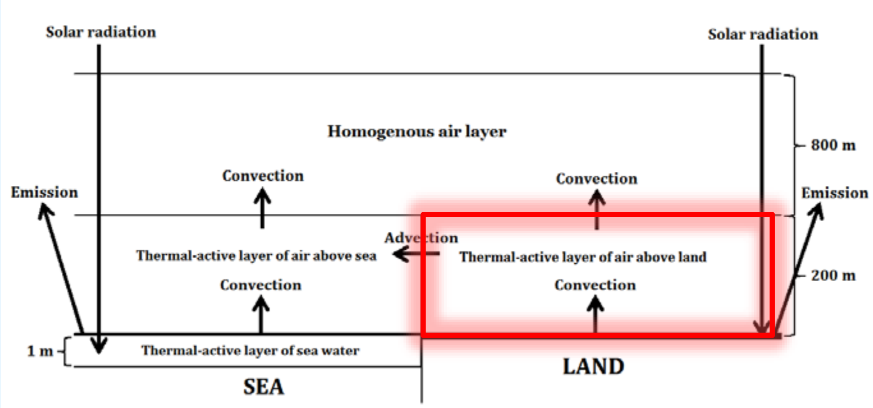
albedo effect — convective loss to air

where
$$q_{s,n} = I_n(1-\beta_s) - h_{sa}\left(T_{s,n-1} - T_{sa,n-1}\right) - e_s\sigma\left[(T_{s,n-1}+273.15)^4 - (T_{sa,n-1}+273.15)^4\right]$$

radiative loss

- Temperature of air on land
  - 200m thick homogeneous thermal-active layer

$$T_{la,n} = T_{la,n-1} + \frac{q_{la,n}}{c_a \rho_a d_a} \Delta t$$



heating due to convective loss from land surface

where $$q_{la,n} = h_{la}(T_{l,n} - T_{la,n-1}) - h_{au}(T_{la,n-1} - T_{u,n-1})$$

convective loss to upper air

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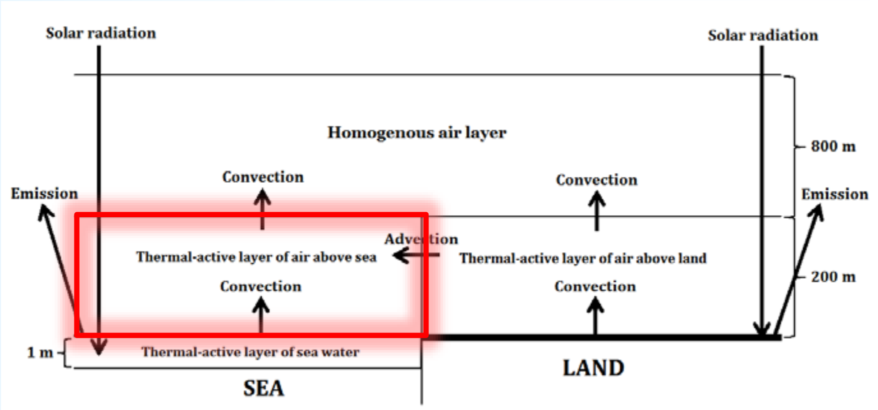
- Temperature of air on sea surface
  - [Similar to air on land]

$$T_{sa,n} = T_{sa,n-1} + \frac{q_{sa,n}}{c_a \rho_a d_a} \Delta t$$



heating due to convective loss from sea surface

where $$q_{sa,n} = h_{sa}\left(T_{s,n} - T_{sa,n-1}\right) - h_{au}\left(T_{sa,n-1} - T_{u,n-1}\right)$$

convective loss to upper air

- Effect of temperature advection
  - Temperature decrement of air on land (cold advection of sea breeze):

$$T_{la,n} \leftarrow T_{la,n} + \chi(u_{n-1})\left[\frac{u_{n-1}\Delta t}{L}(T_{la,n} - T_{sa,n})\right]$$

  - Temperature increment of air on sea surface (warm advection of land breeze):

$$T_{sa,n} \leftarrow T_{sa,n} + (\chi(u_{n-1}) - 1)\left[\frac{u_{n-1}\Delta t}{L}(T_{sa,n} - T_{la,n})\right]$$

where $\chi(u_{n-1}) \overset{\text{def}}{=} \begin{cases} 1 & \forall\, u_{n-1} < 0 \\ 0 & \forall\, u_{n-1} \geq 0 \end{cases}$

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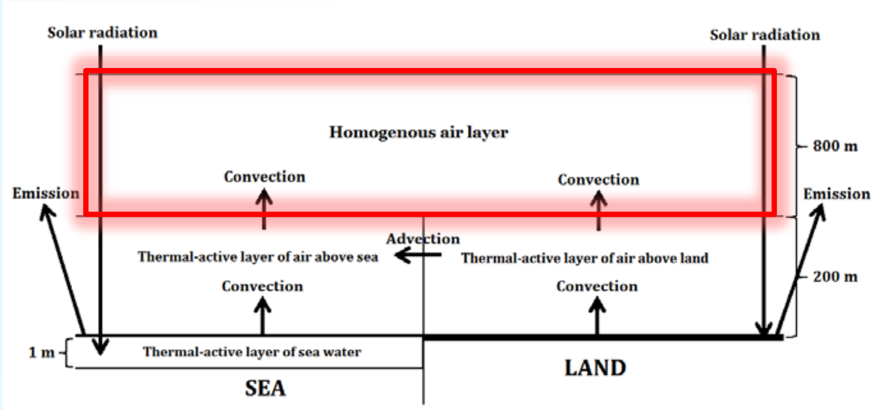
- Temperature of "upper" air
  - 800m thick homogeneous layer above thermal-active layer to top of circulation



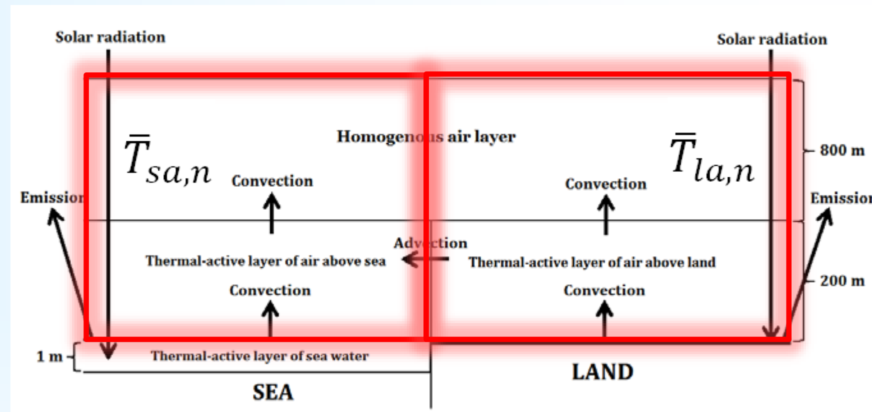
$$T_{u,n} = \left(\frac{T_{la,n} + T_{sa,n}}{2}\right) - \gamma\left(d_a + \frac{H - d_a}{2}\right)$$

Average of air on land and air on sea surface

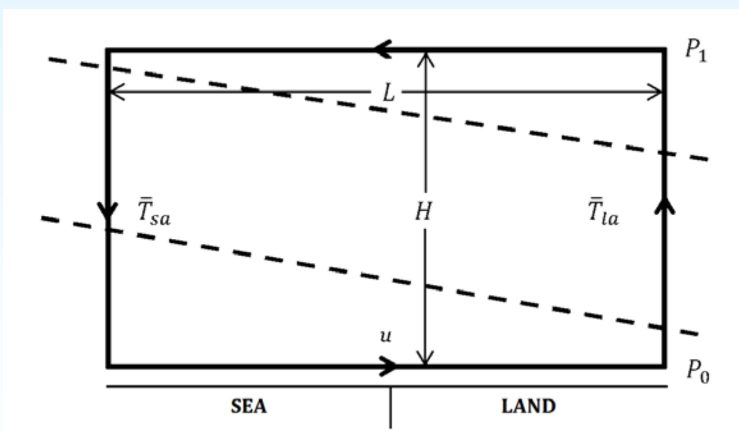
Reduced with height at fixed lapse rate, γ

- Land-sea differential in air temperatures
  - mean over the air column from surface to top of circulation

$$\bar{T}_{la,n} - \bar{T}_{sa,n} = (T_{la,n} - T_{sa,n}) \frac{d_a}{H}$$



Recall



$$u_n = u_{n-1} - \left[\frac{R \ln\left(\frac{P_0}{P_1}\right)}{2\,(H+L)} (\bar{T}_{la,n} - \bar{T}_{sa,n}) + k u_{n-1} \right] \Delta t$$

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- Supplementary exclusion tests
  - Westerly sea breeze is not expected to occur at HKIA if:
    - Background wind bearing north-component > 7m/s; or
    - Background wind bearing south-component > 2m/s; or
    - Winds on high ground bearing south-component > 8m/s

- Tuning [using 3 months of data] to obtain
  - Drag coefficient, linear: k=0.0001/s
  - Horizontal extent of circulation: L=10,000m
  - Heat transfer coefficient at land-air interface: $h'_{la} \approx h_{la}$=45W/m^{2}K
  - Heat transfer coefficient at sea-air interface: h_{sa}=5W/m^{2}K
  - Heat transfer coefficient between thermal-active air and "upper" air: h_{au}=5W/m^{2}K

- Initialization
  - Start with u_0=0m/s and latest observations at base time for other variables (apart from a few exceptions)
- Time step in iteration: Δt=300s
  - Model run half-hourly during 05-17H (not run if $U<0$ or westerlies at R2C at base time)
- Threshold for sea breeze occurrence: $u_n+U<-1$m/s
  - If threshold is not reached before modeled time 1730H, then westerly sea breeze is not expected to occur on that day.

- Webpage for displaying model input/output

Estimated sea breeze onset time

Estimated sea breeze onset time: 04 +/-1 UTC

* * *

Sea breeze onset/retreat time is estimated basing on the following data at 201511081000 (HKT):

BACKGROUND WIND (AWS)

Station	Direction (deg)	Speed (m/s)
WGL	061	5.8
R2C	VRB	2.1
CCB	078	5.1
TMT	111	3.0
R2E	071	3.8

Average (U,V): (3.3,0.8) m/s *[+ve for easterlies and northerlies]*

HIGH GROUND WIND (AWS)

Station	Direction (deg)	Speed (m/s)
NLS	114	8.1
YTS	139	9.0

Average J: -5.0 m/s *[+ve for northerlies]*

PRESSURE (AWS)

HKA (P_0): 1017.4 hPa

NLS (P_1): 935.1 hPa (est.)

TEMPERATURE (AWS)

HKIA (T_{HKIA}): 28.6°C

WB air (T_{wbt}): 27.7°C *[mean of WB1,2,5(WB3,4,8 as BU)]*

WB sea (T_{sst}): 26.6°C *[mean of WB1,2,5(WB3,4,8 as BU)]*

CLOUD COVER

SYNOP (O_h): 7 oktas

OCF from next hour till 17H (F_{h+1},F_{h+2},...): 4,4,4,4,3,3,2 oktas

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- Verification
  - 18 months "out-of-sample" data (not used in tuning)
  - Predicted vs actual for
    - Sea breeze occurrence on the day
    - Sea breeze onset hour (in case of predicted and actual occurrence)
  - Anemometer at the centre of northern runway as the reference point for actual

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- Result
  - Prediction sea breeze occurrence on the day
    - POD=0.69
    - FAR=0.30
    - CSI=0.53
    - Accuracy=0.78 (vs random predictions with forecast rate matching with “climatological” base rate: 0.53)

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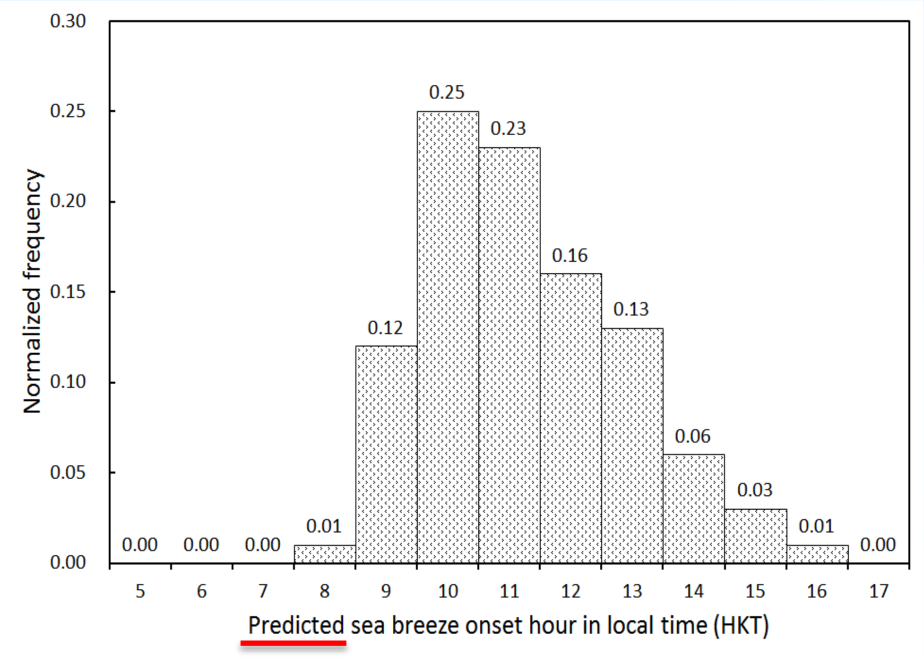
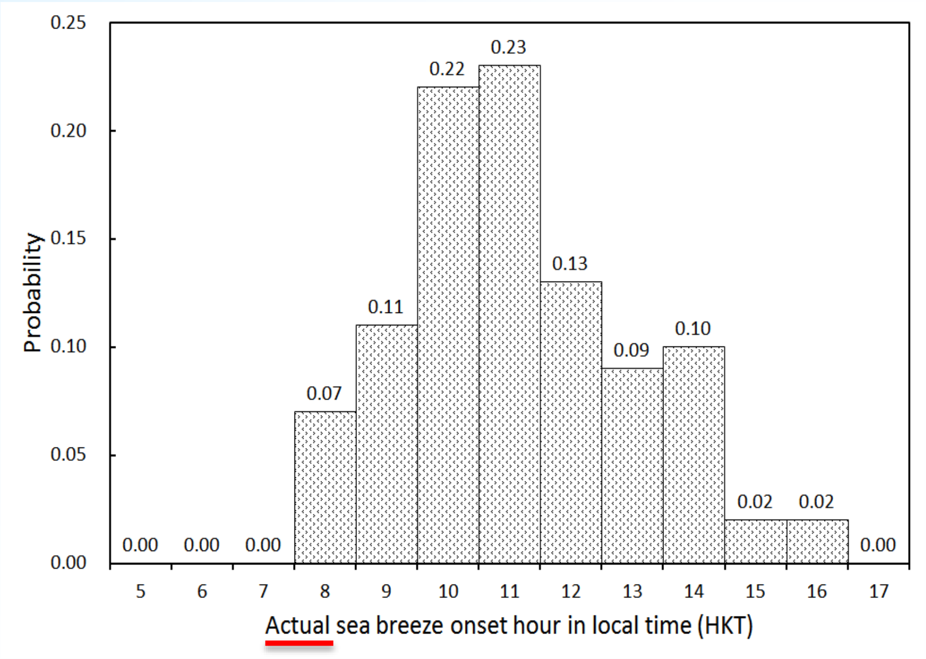
- Result
  - Prediction of sea breeze onset hour





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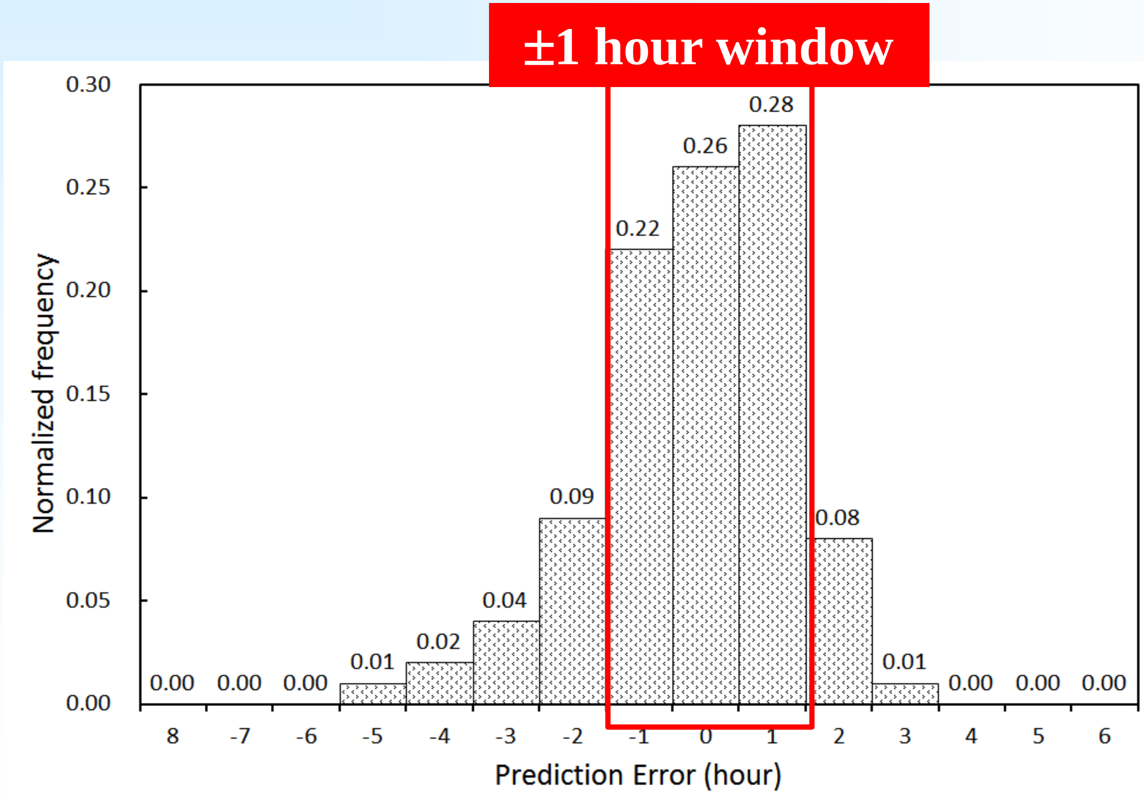
- Result
  - – Prediction of sea breeze onset hour
    - Overall accuracy: 0.76 (vs “climat”: 0.58)



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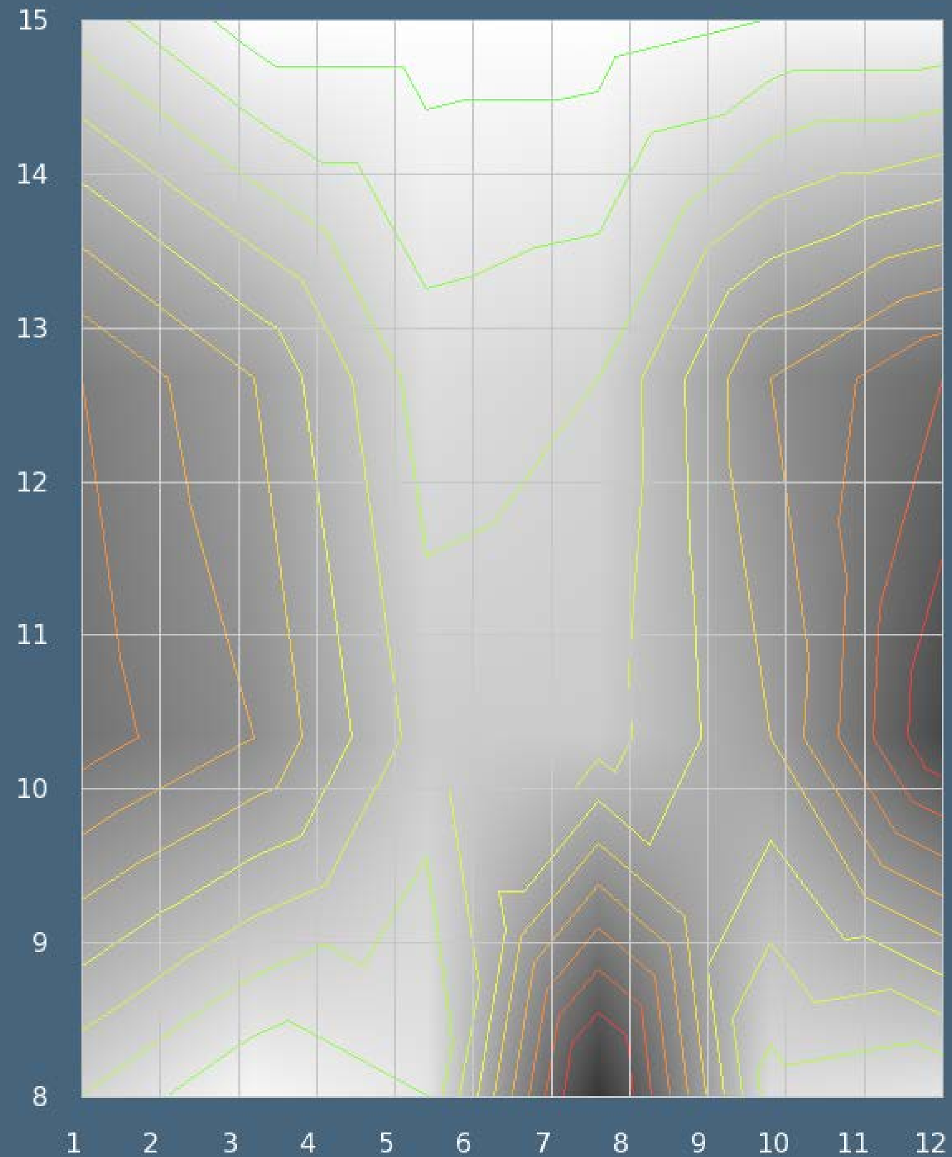
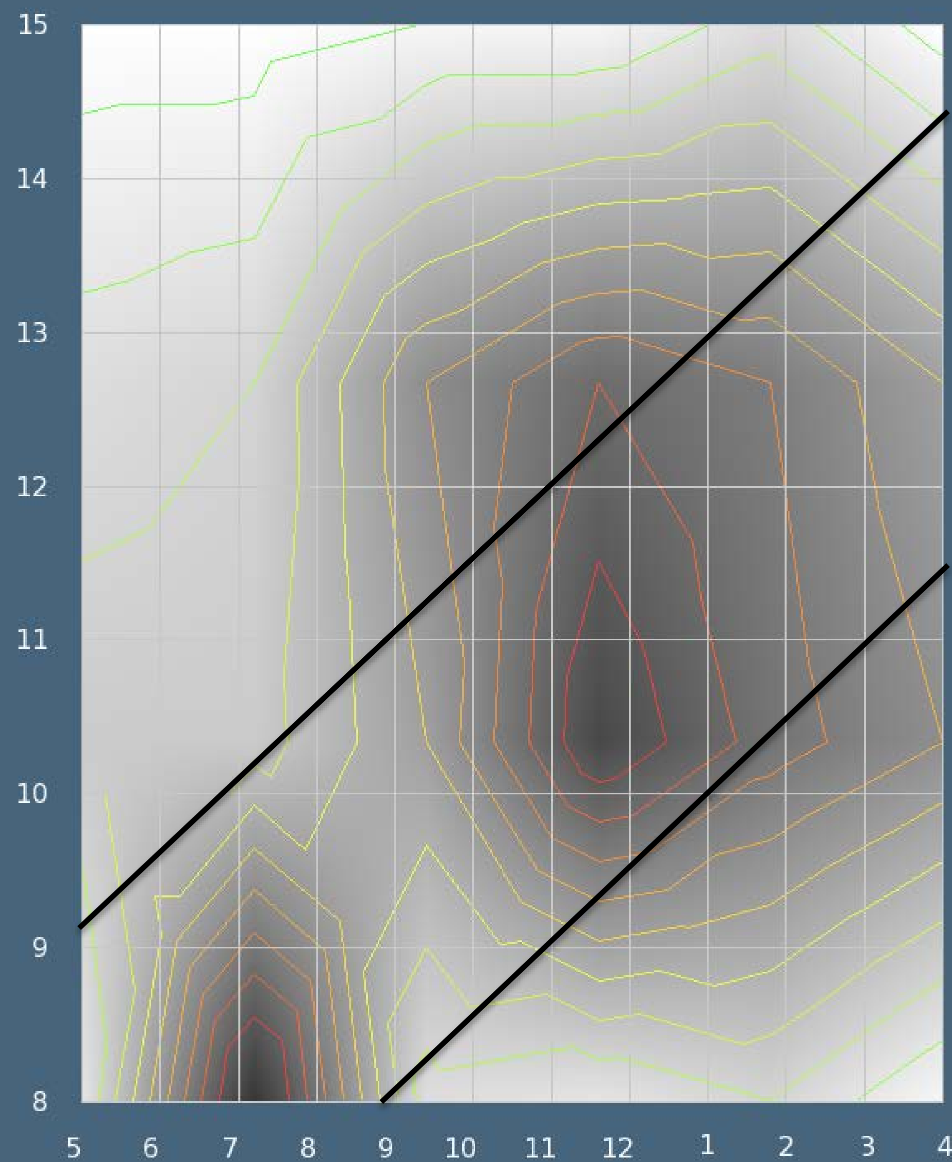
Seasonal onset distribution



Seabreeze onset Monthly distribution



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