

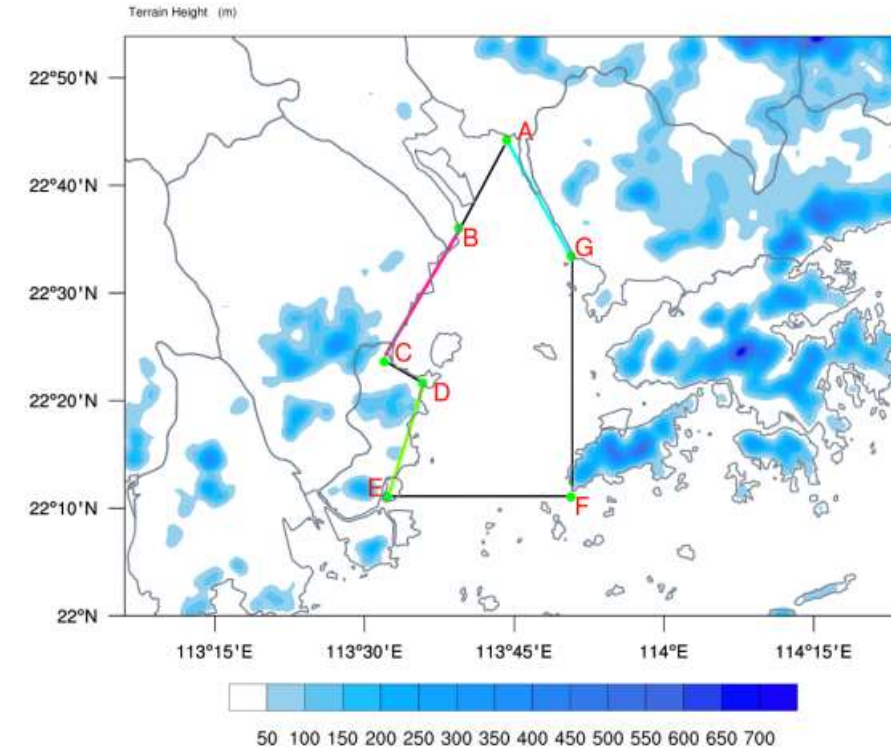
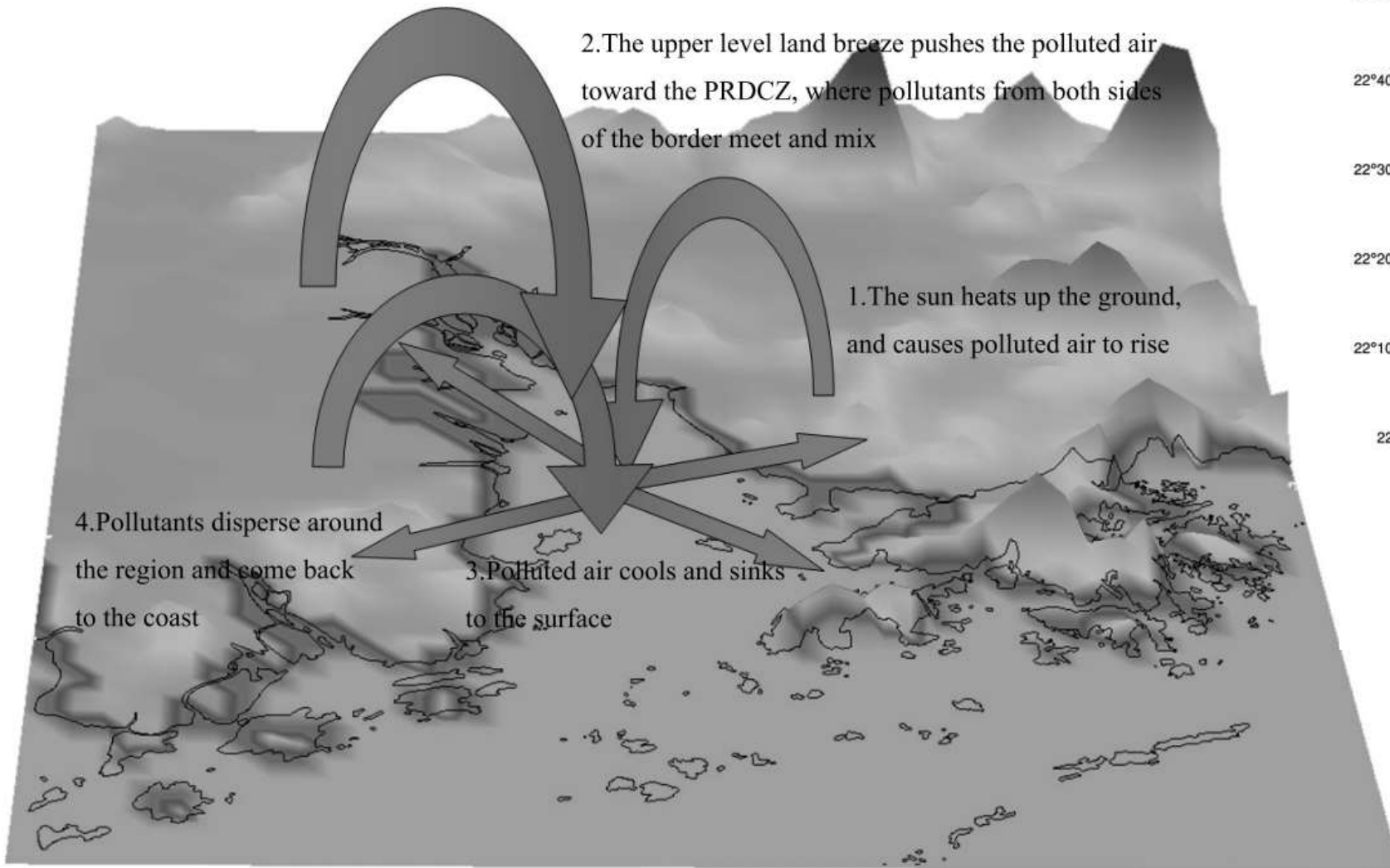
Characteristics of Sea Breeze in PRD Region and its Response to Urbanization

YOU Cheng, J. C. H. Fung, W. P. Tse

Division of Environment

Hong Kong University of Science and Technology

1. Introduction



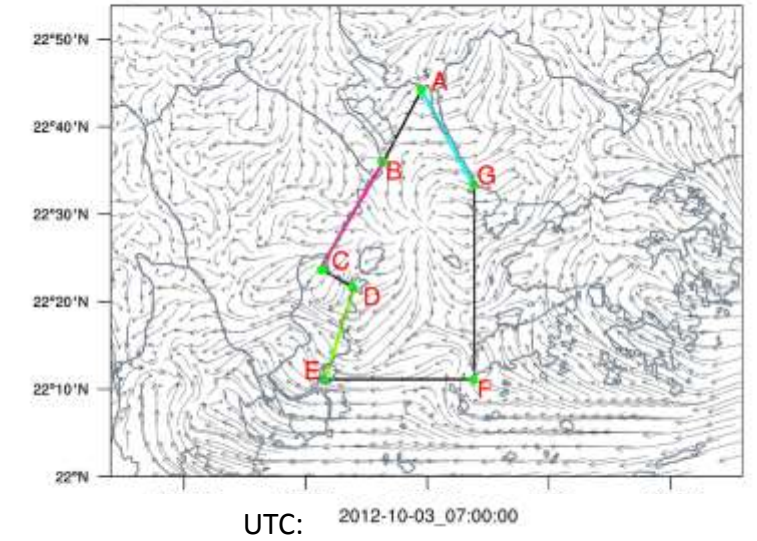
(Lo et al. 2006)

2. Methodology

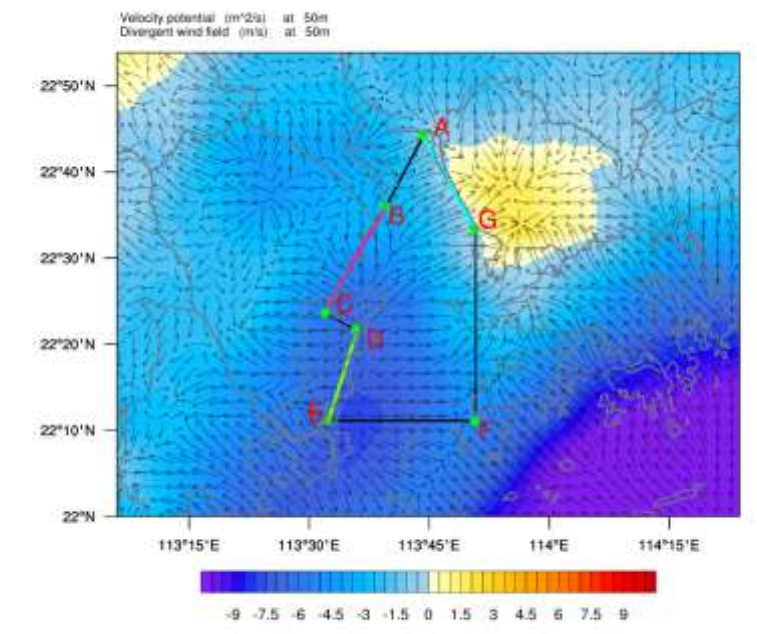
2.1. Wind Decomposition

$$\begin{array}{c} \mathbf{V}_O \\ \downarrow \\ \text{Original Velocity} \end{array} = \begin{array}{c} \text{Non-divergent Velocity} \\ \uparrow \\ \mathbf{V}_B \end{array} + \begin{array}{c} \mathbf{V}_D \\ \downarrow \\ \text{Divergent Velocity} \end{array}$$

\mathbf{V}_O



\mathbf{V}_D



2. Methodology

2.2. Criteria for Sea-breeze events

- Divergent center in Pearl River Estuary

$$\oint \vec{V} \cdot \vec{n} dl = \iint \nabla \cdot \vec{V} dS$$

$$flux = \frac{1}{N} \oint \vec{V} \cdot \vec{n} dl \text{ sides of polygon } ABCDEFG$$

1. It should be finished **in one day**;
2. When **surface solar energy** is **maximum**, it should have already appeared;
3. Requirements (1) (2) should be met at **four levels** (50m, 100m, 150m, 200m)

Original Wind Field

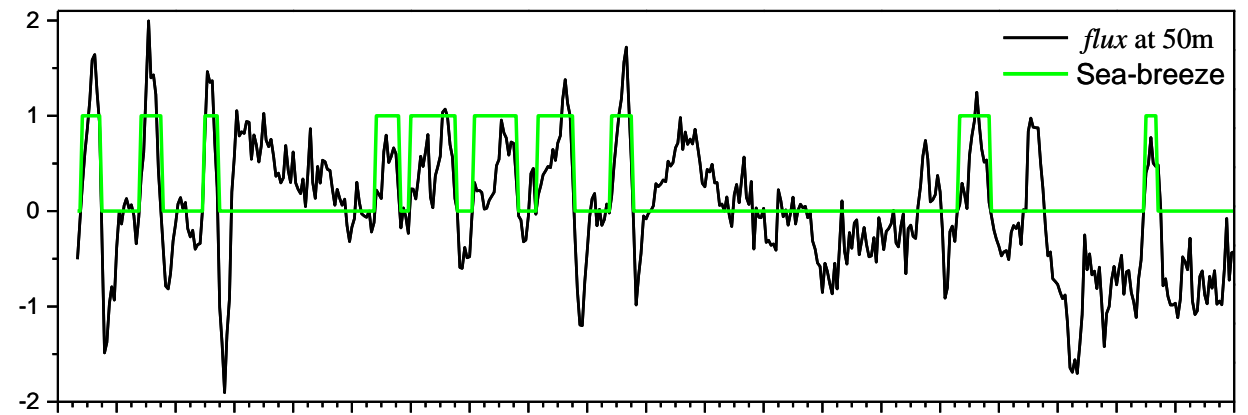
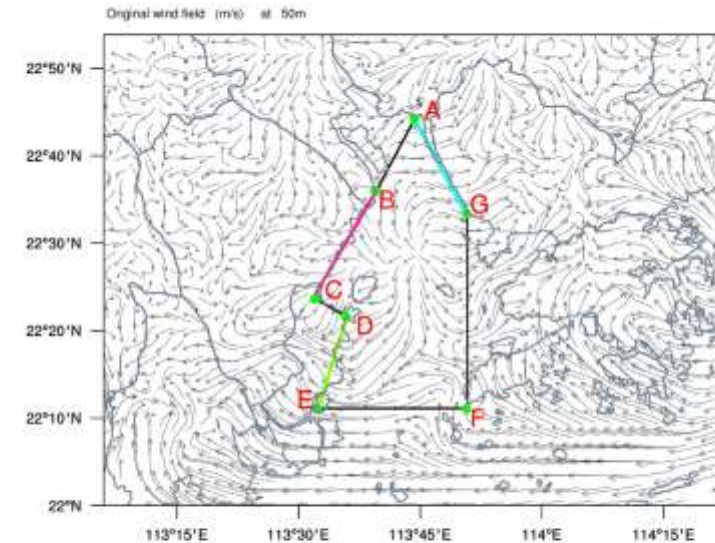


Figure. Time evolution of $flux$ at 50 m. Its unit is m/s . Green lines with value 1 indicate sea-breeze events. Major ticks symbolize 0:00 LT.

2. Methodology

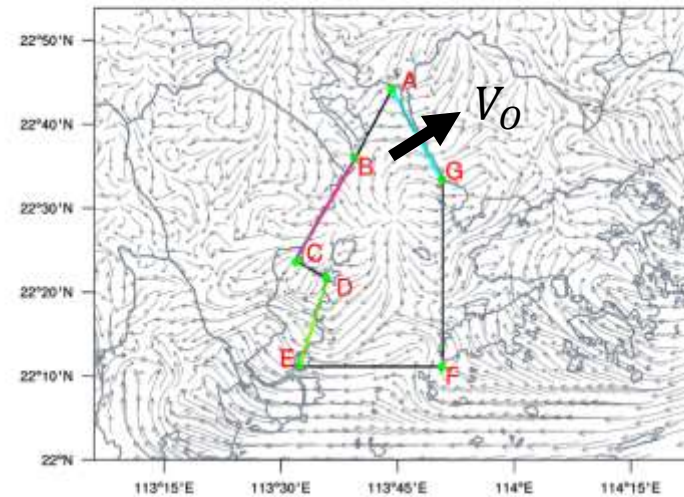
2.2. Criteria for Sea-breeze events

- Sea-breeze events along coasts

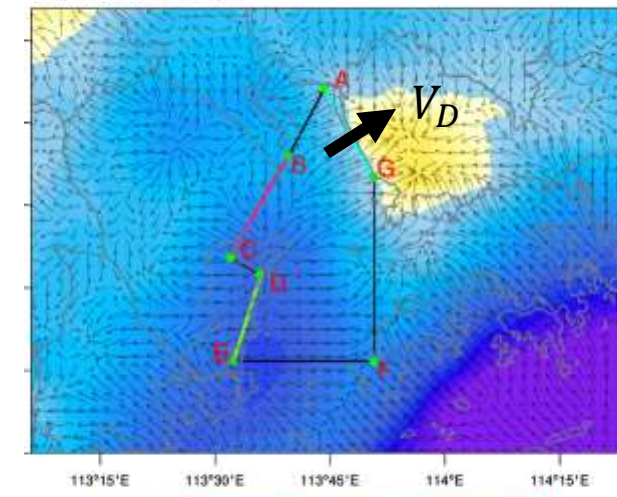
V_D : averaged normal divergent velocity at 50 m

V_O : averaged normal original velocity at 50 m

1. Sea breeze should start after **sunrise** ;
2. Sea-breeze events should be finished **in one day**;
3. when **surface solar energy** is **maximum**, they should have already happened.
4. Both V_D and V_O should be **positive**.



Original Wind Field



Divergent Wind Field

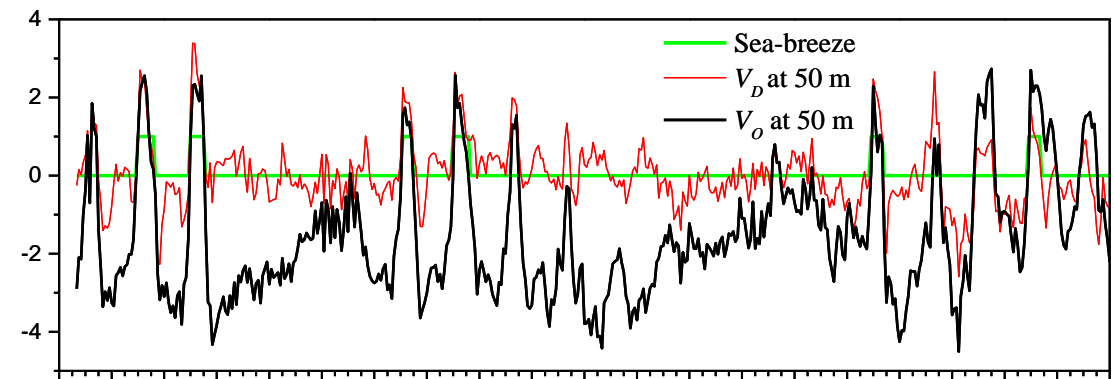
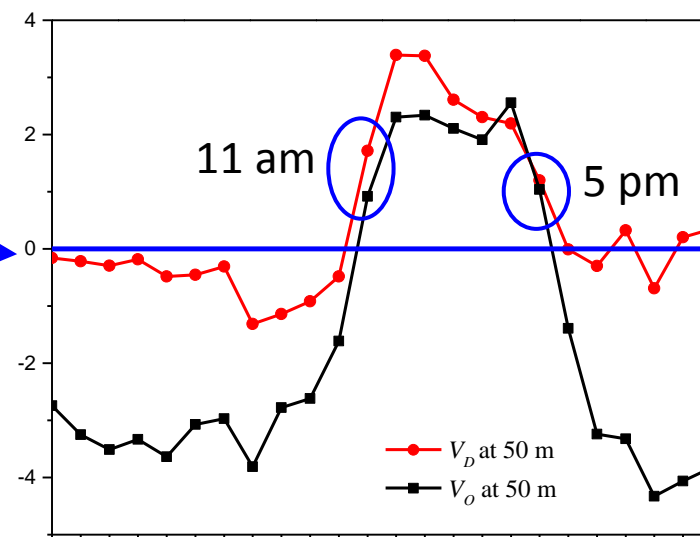
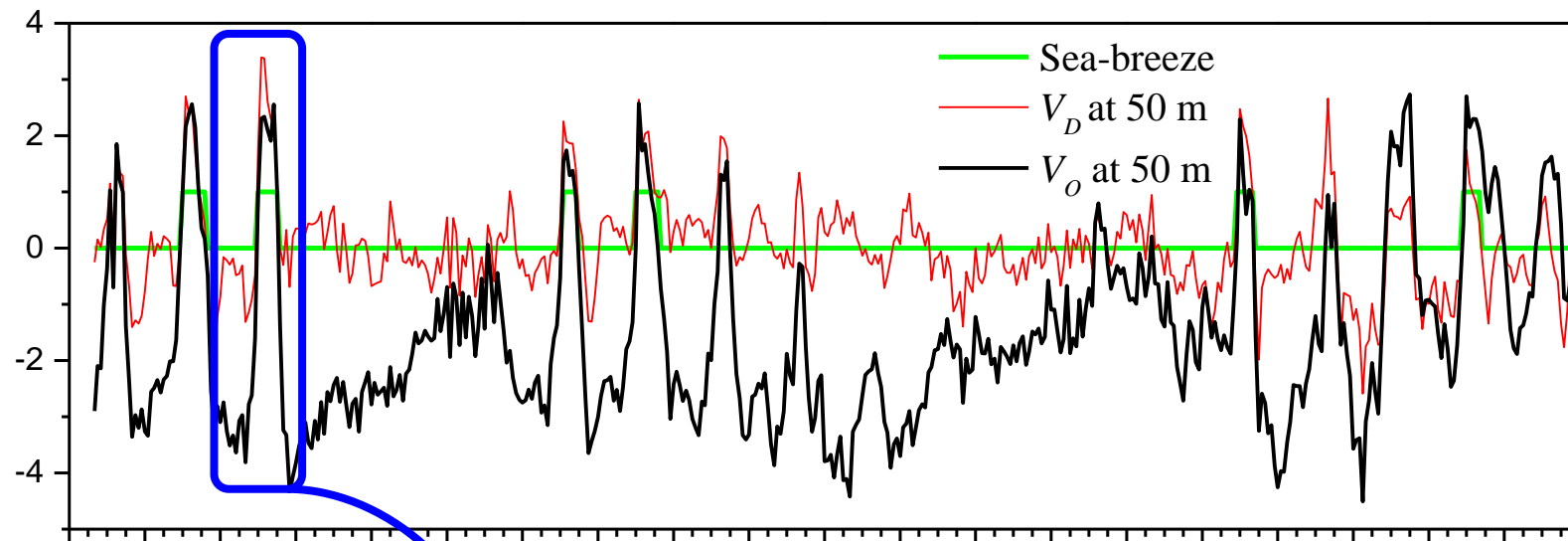


Figure. Time evolution of V_D and V_O at 50 m along coast AG. The units are m/s . Green lines with value 1 indicate sea-breeze events. Major ticks symbolize 0:00 LT.

2. Methodology



Start Time: the **first time** when V_D and V_O both greater than 0;

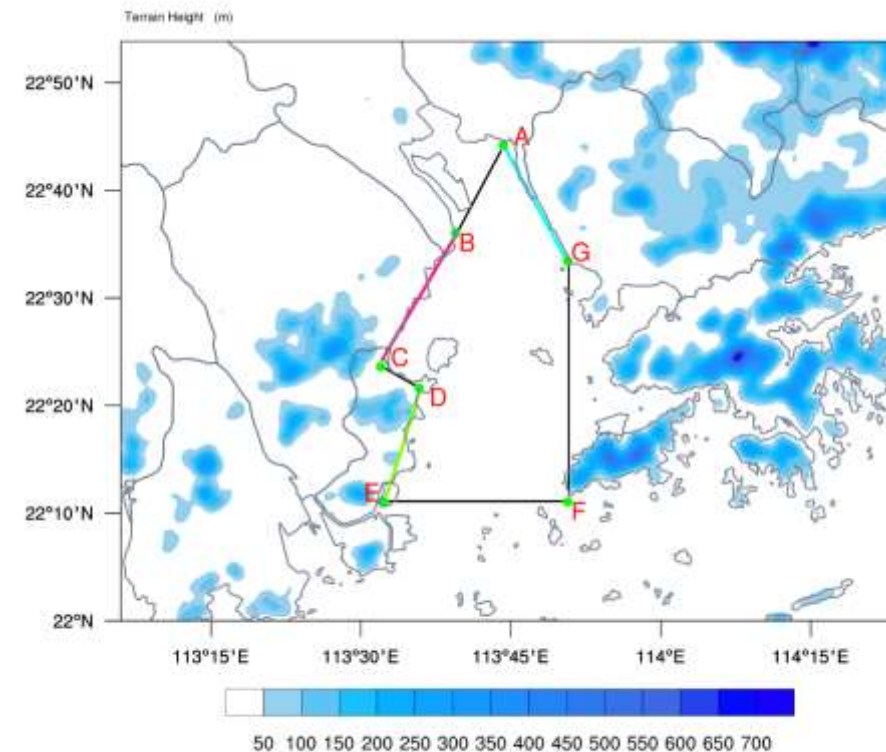
End Time: the **last time** when V_D and V_O both greater than 0;

Strength: **Averaged V_D** during one sea-breeze event.

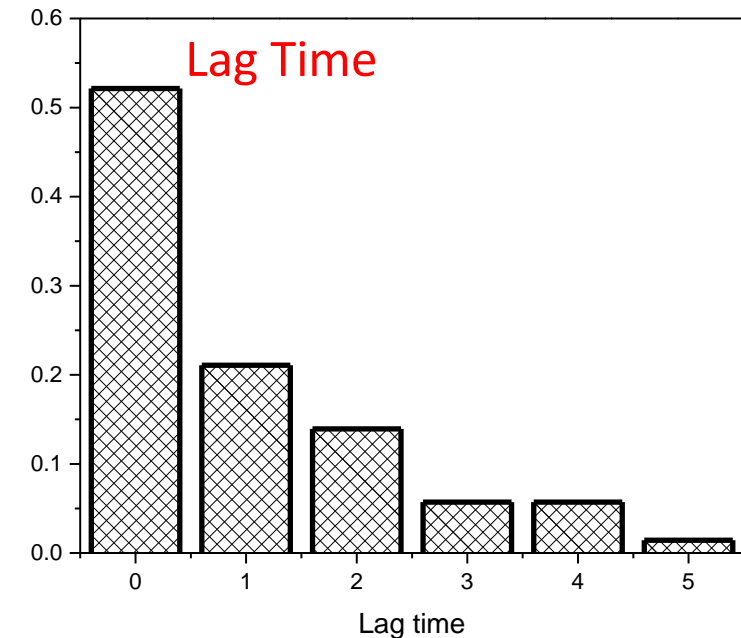
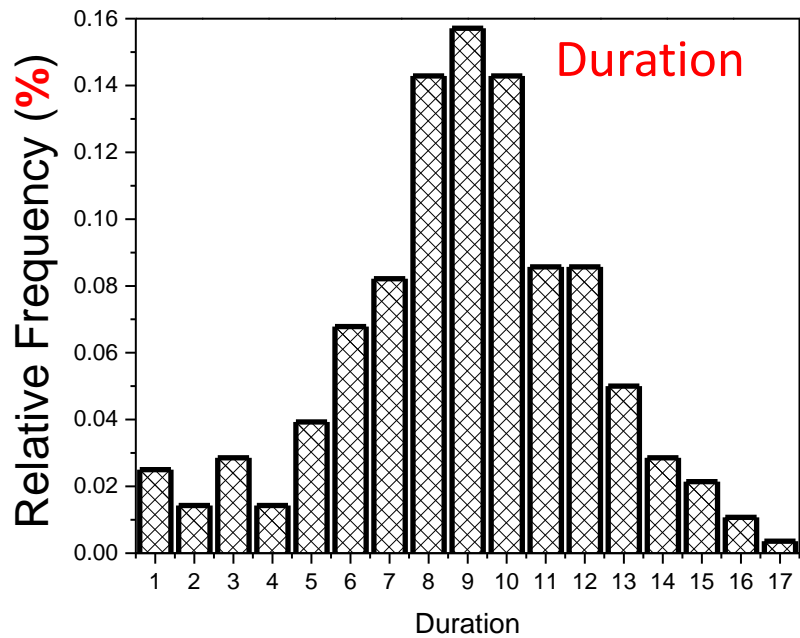
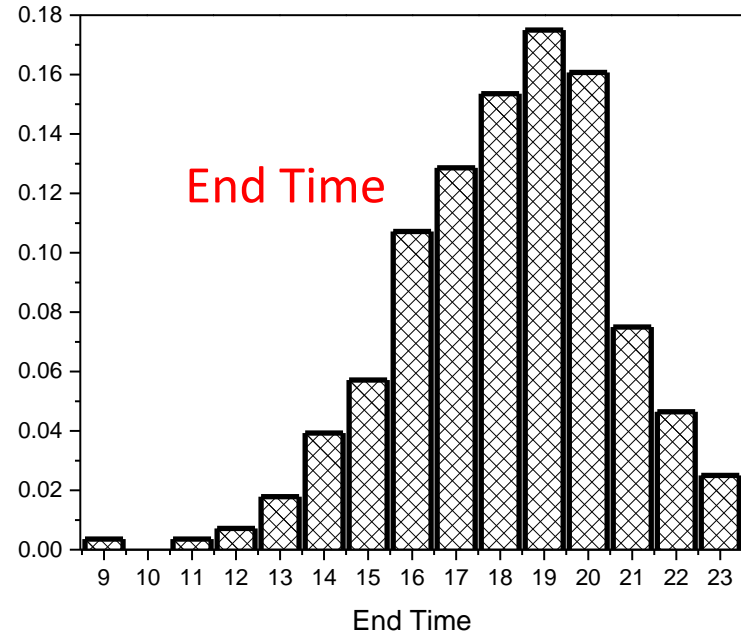
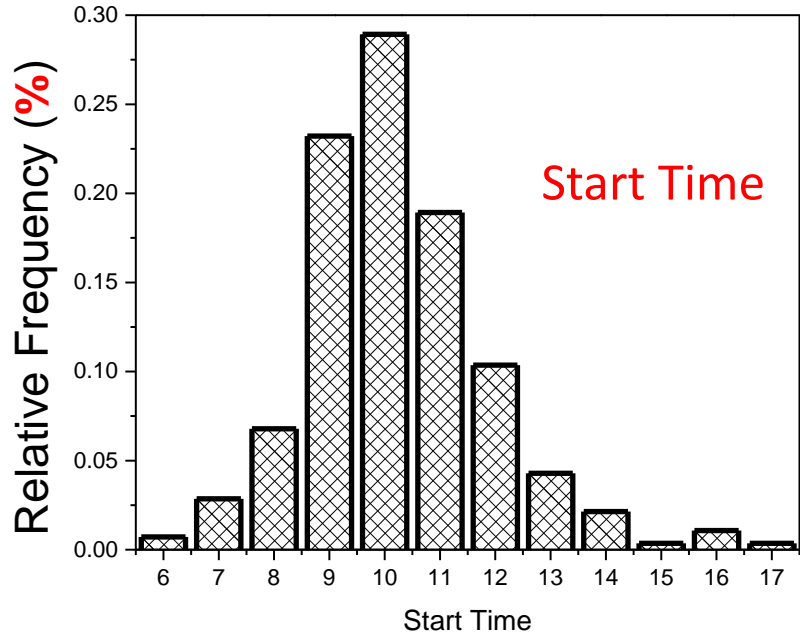
3. Statistical Results

Table. Yearly averaged strength, yearly averaged start/end time and number of sea-breeze events along each coasts in 2012.

	Coast AG	Coast BC	Coast DE
Number of Sea-breeze Events	114	70	96
Averaged Strength (m/s)	1.37	1.10	1.35
Start Time	10:30 am	10:10 am	10:00 am
End Time	18:11 pm	18:15 pm	18:06 pm

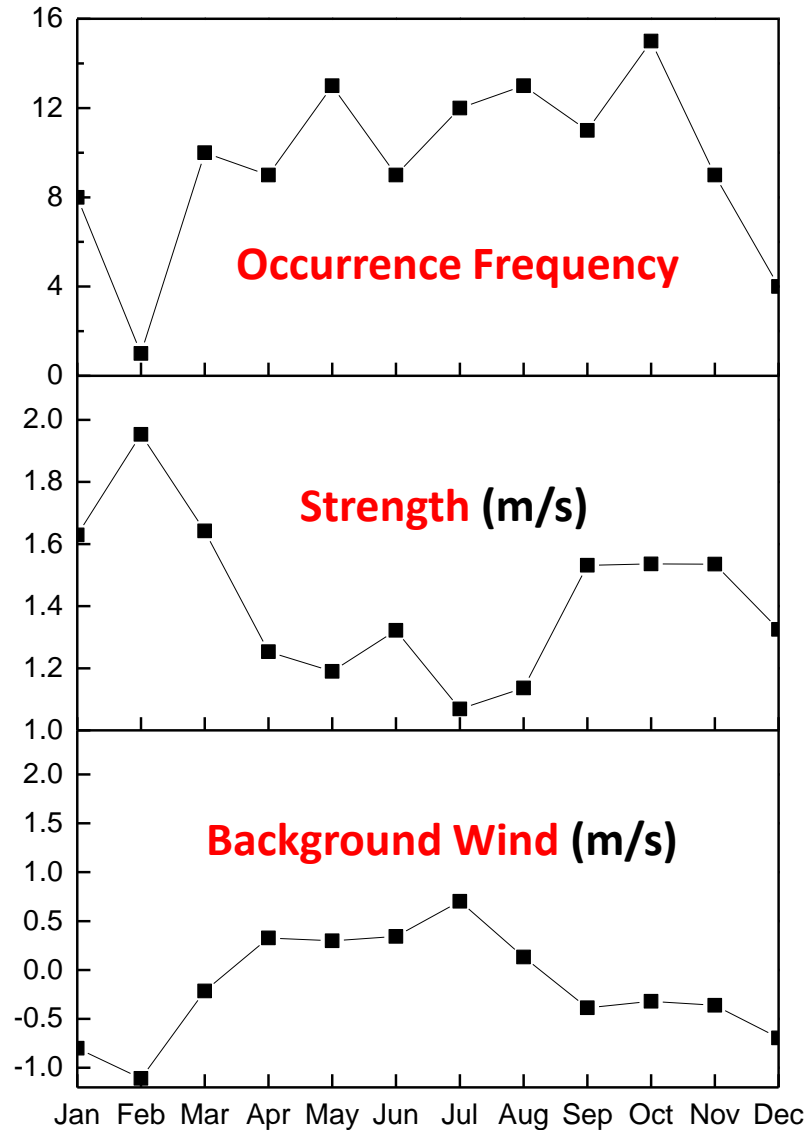


3.1 Start time, end time and duration of sea breeze events

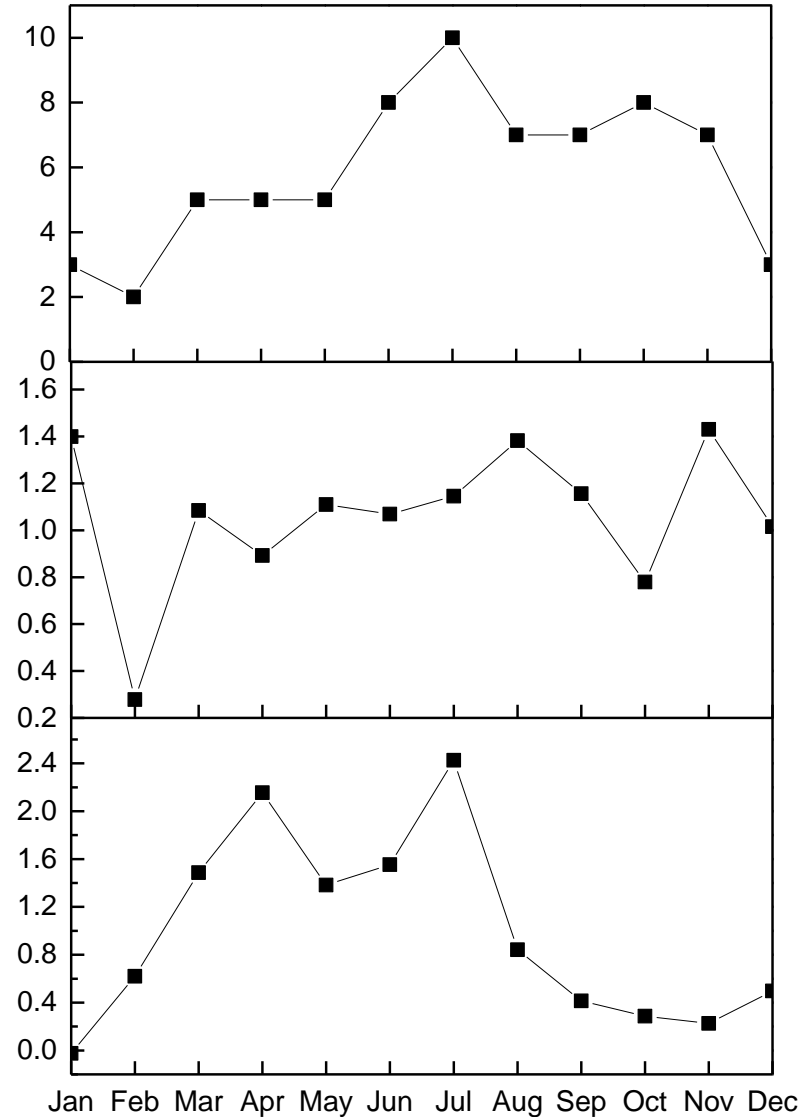


3.2. Monthly averaged strength, occurrence frequency and background wind

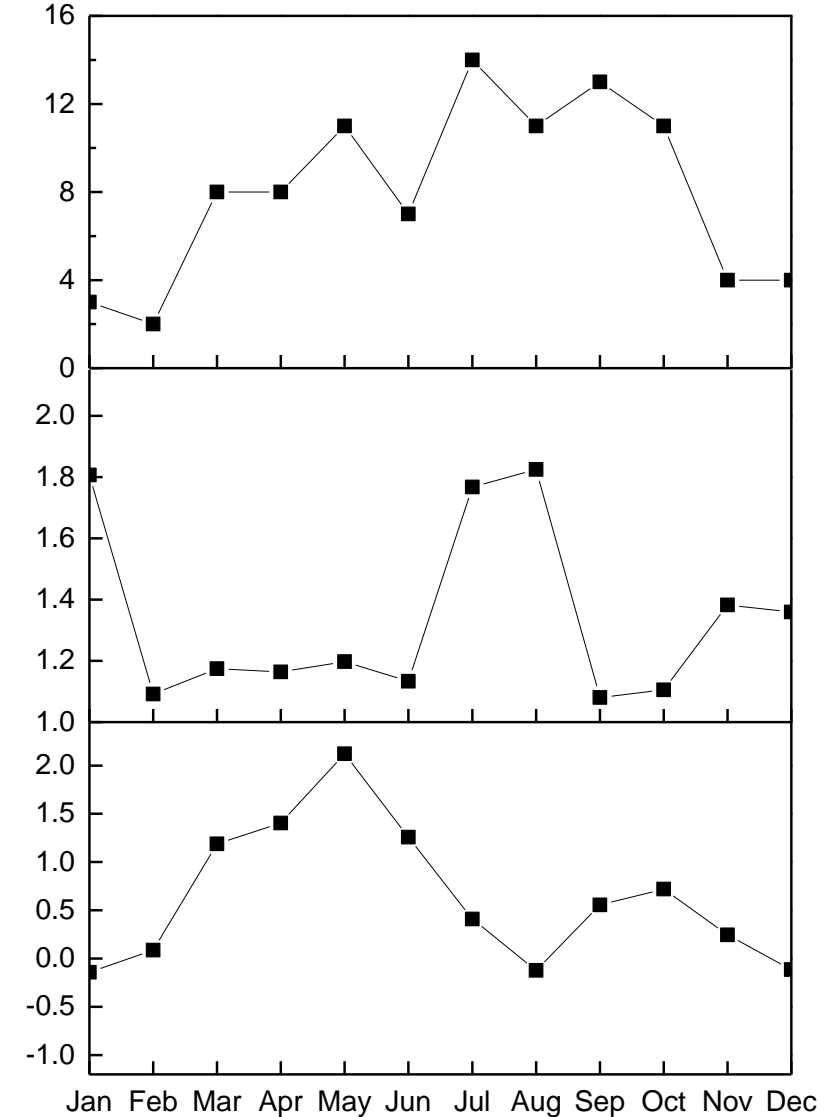
Coast AG



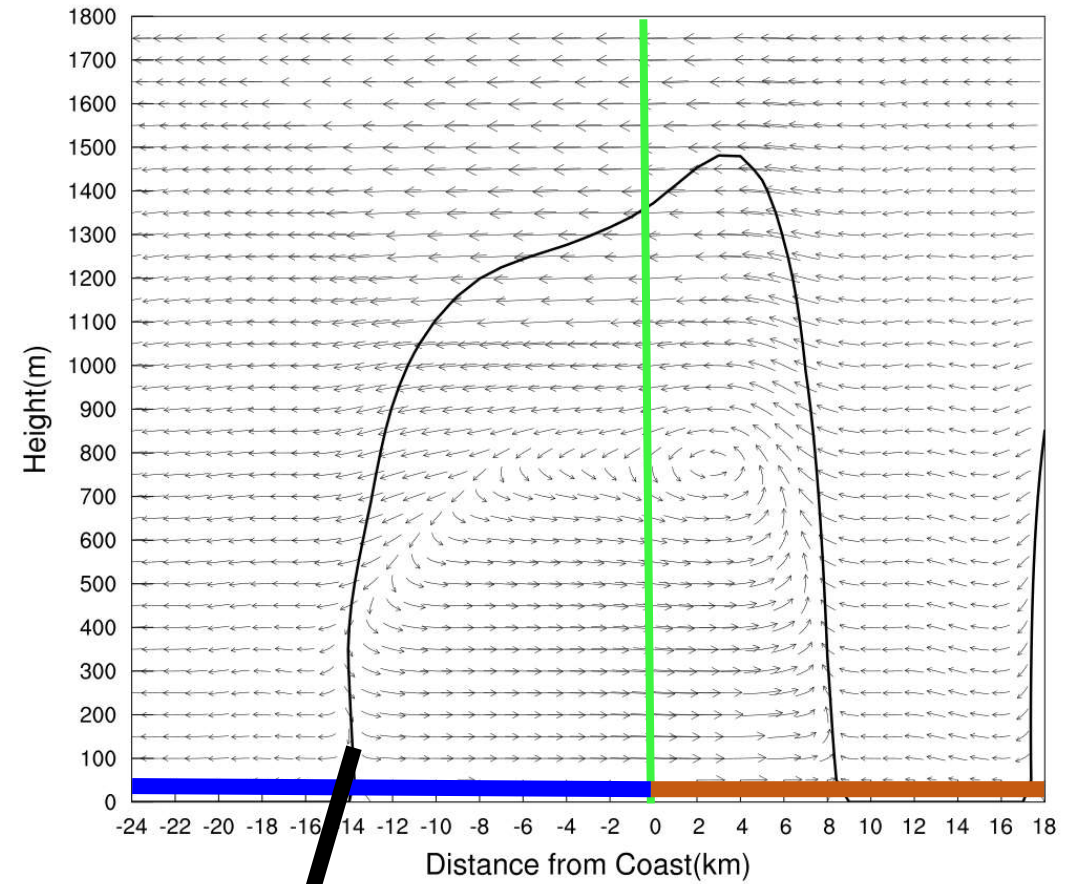
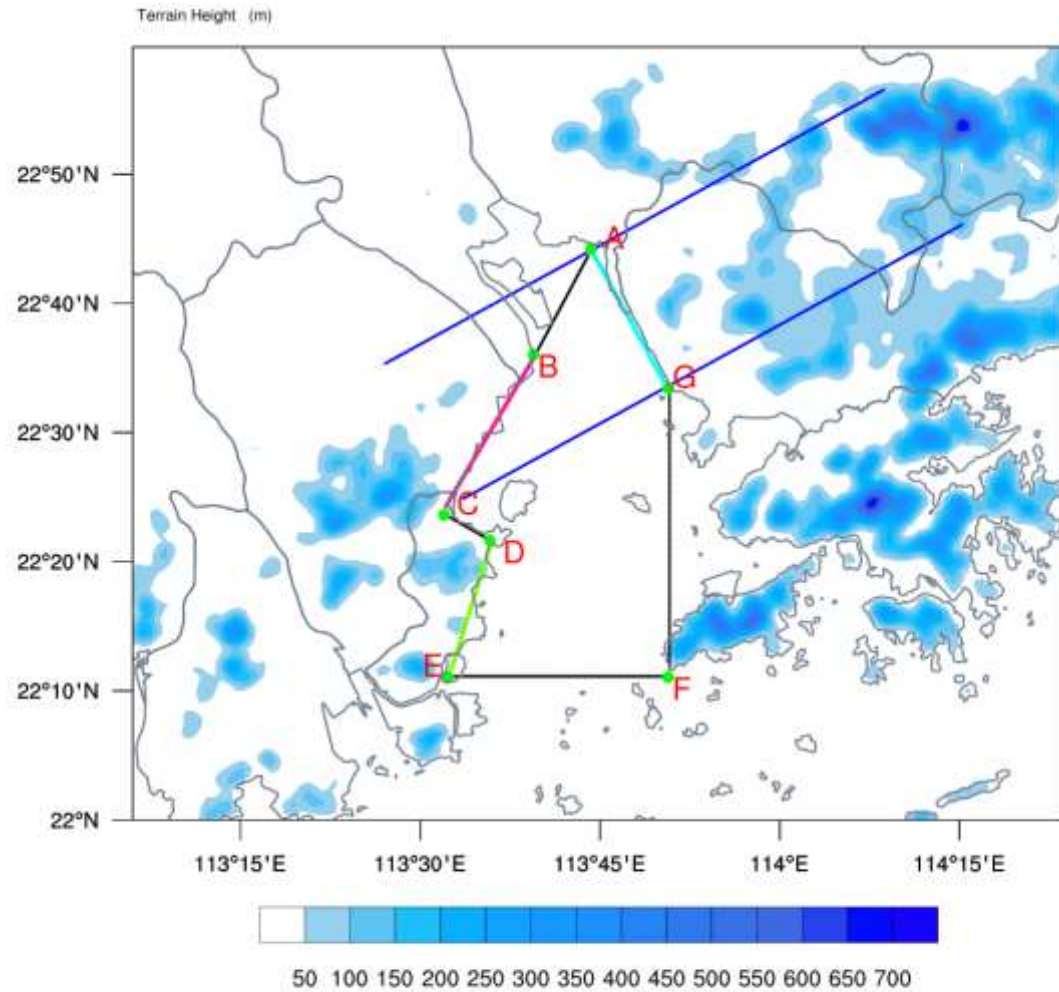
Coast BC



Coast DE

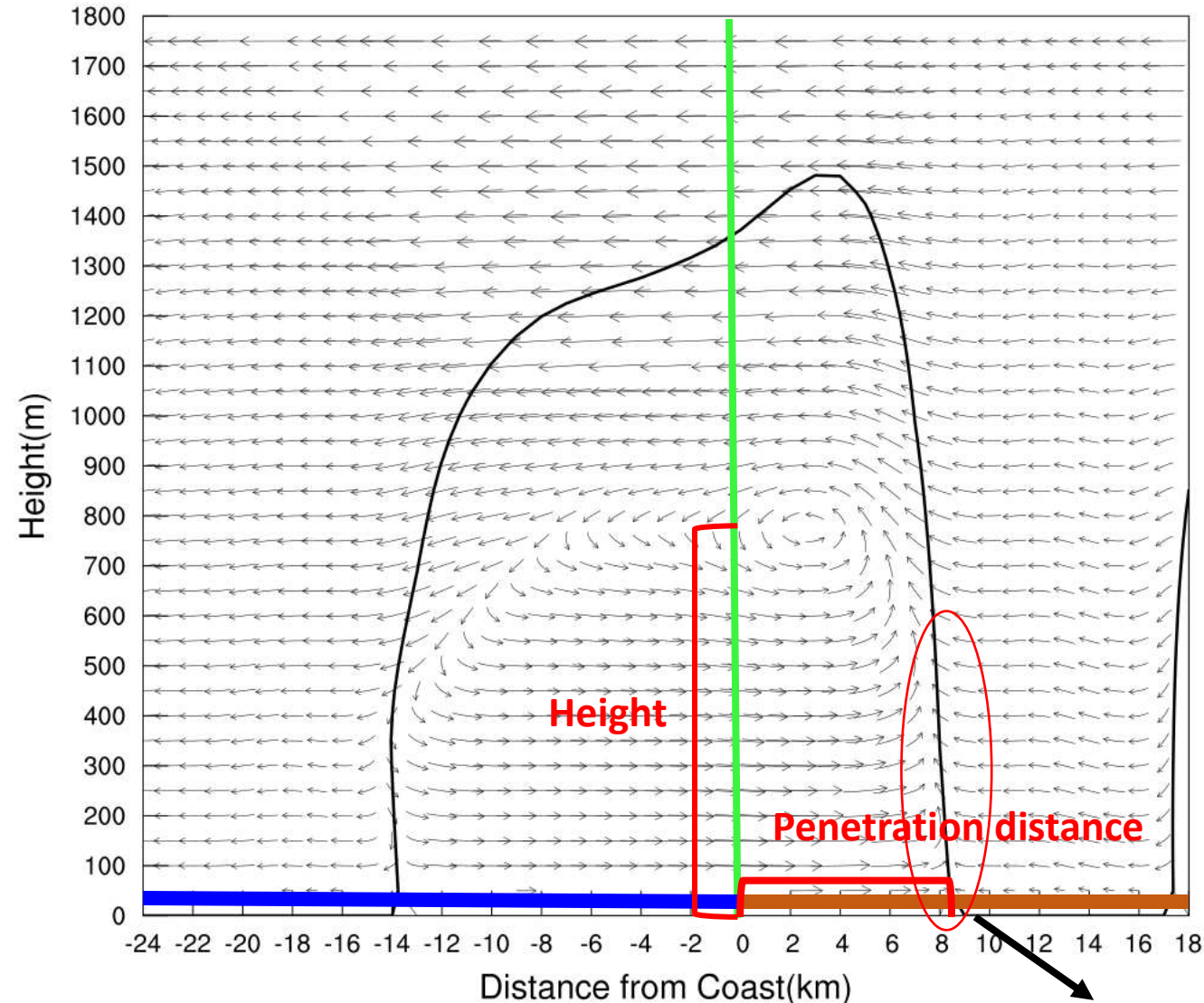


3.2. Characteristics of separable sea-breeze events



Stream function with value of 0

3.2. Characteristics of separable sea-breeze events



Definition of Separable Sea-breeze events

1. **Clear lateral boundary**;
2. Within the penetration distance, **inverse flow** can be found above the sea breeze everywhere.

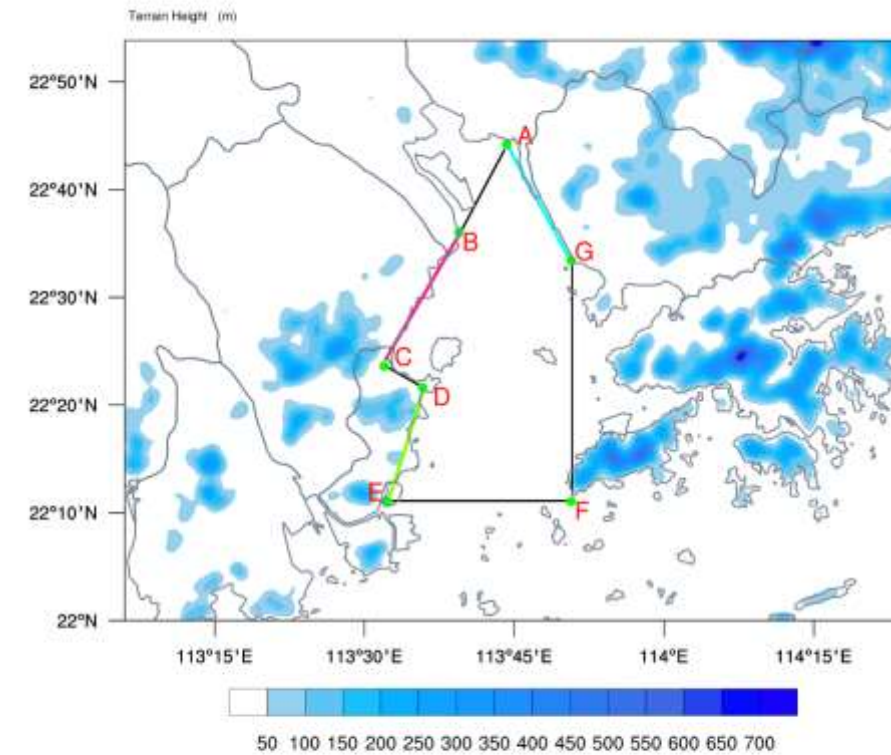
Pumping ability: Vertically Integrated inland velocity from the ground to the top of sea breeze above the coast

Convergent Zone

3.2. Characteristics of separable sea-breeze events

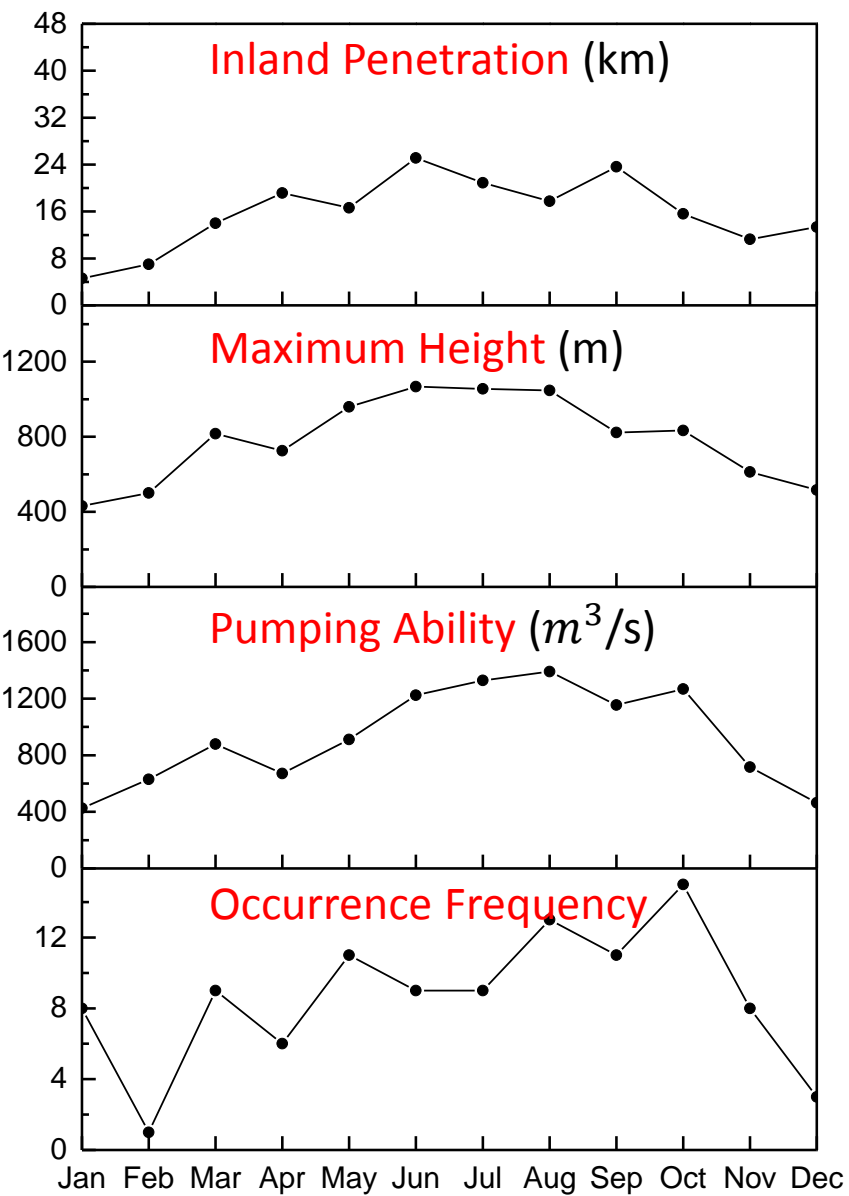
Table. Yearly averaged inland penetration distance, yearly averaged maximum height/pumping ability and number of separable sea-breeze events along each coasts in 2012.

	Coast AG	Coast BC	Coast DE
Number of Separable Cases	103 (114)	41 (70)	52 (96)
Inland Penetration (km)	17	30	26
Height (m)	707	730	706
Pumping ability (m^3/s)	1028	1150	1065

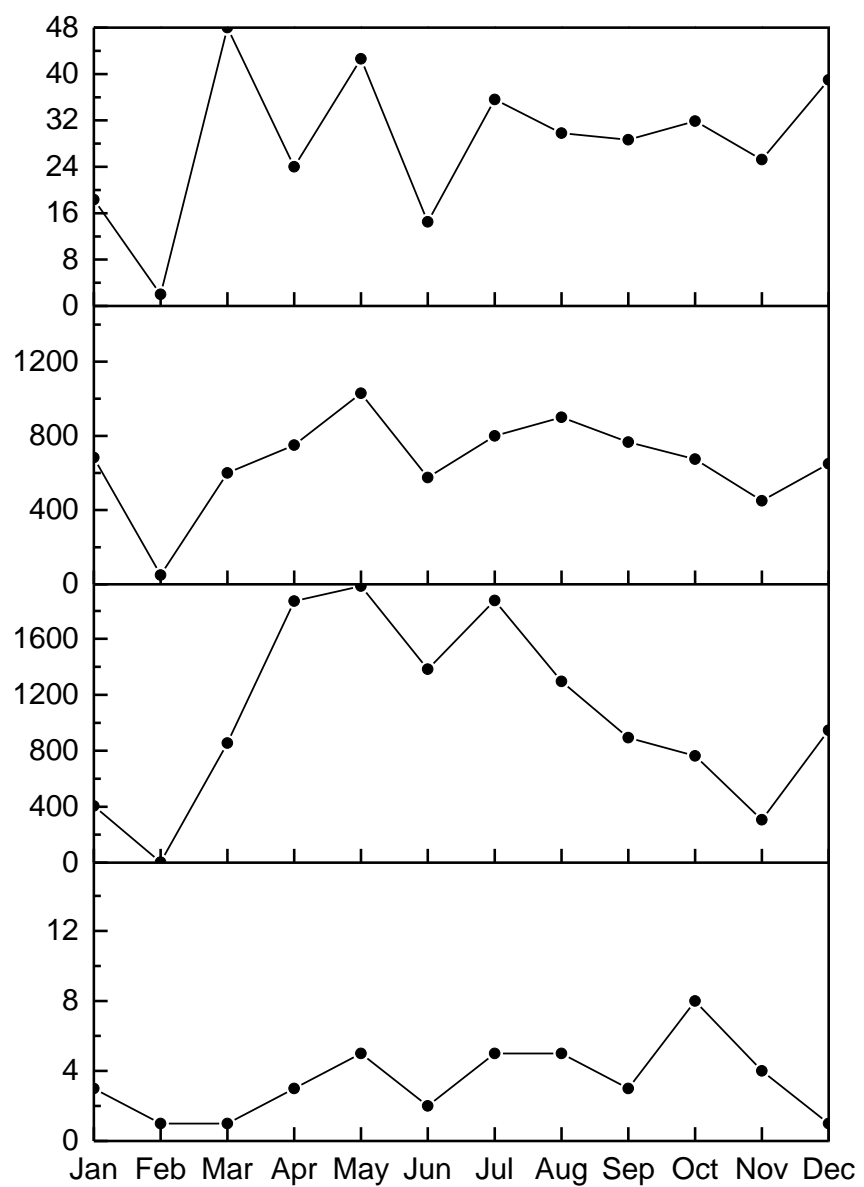


3.2. Characteristics of separable sea-breeze events

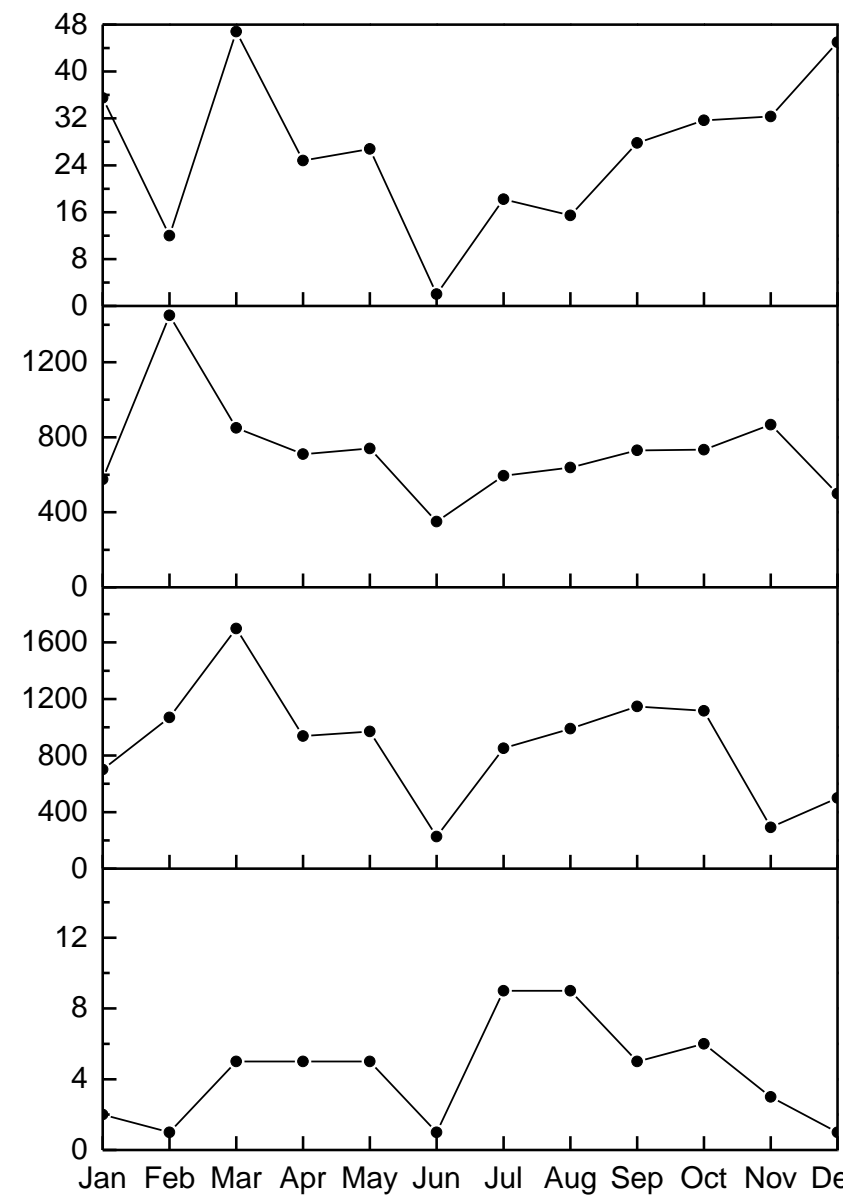
Coast AG



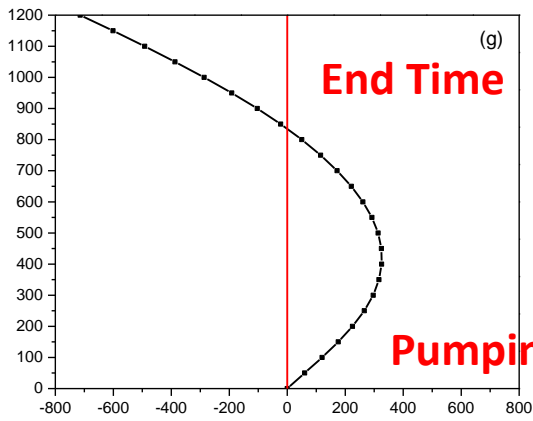
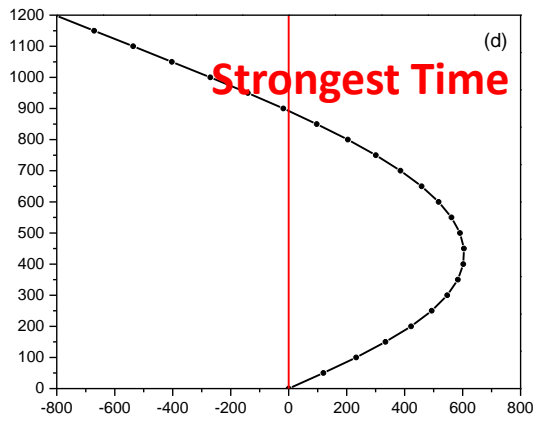
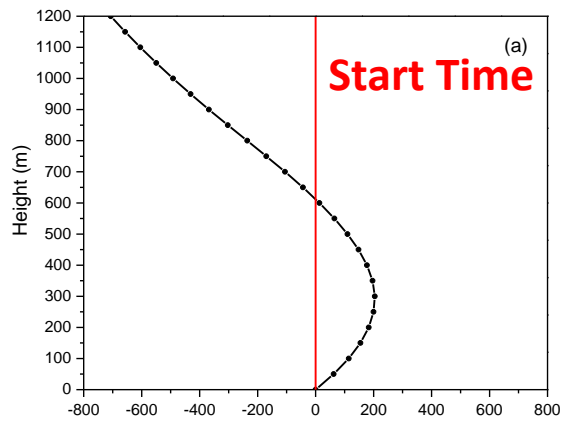
Coast BC



Coast DE

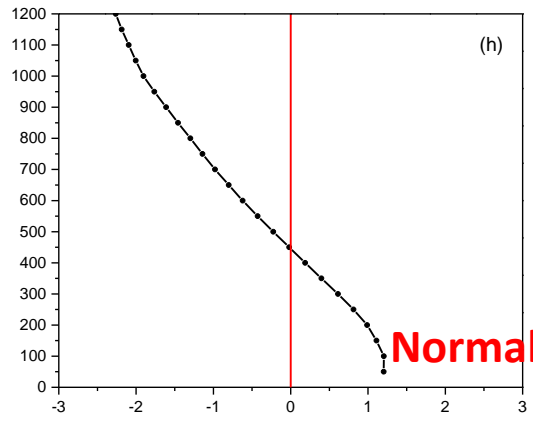
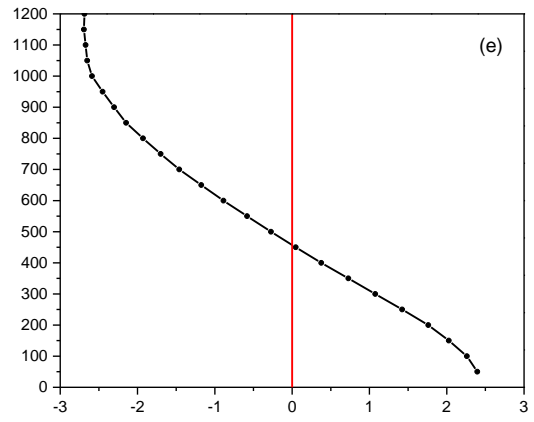
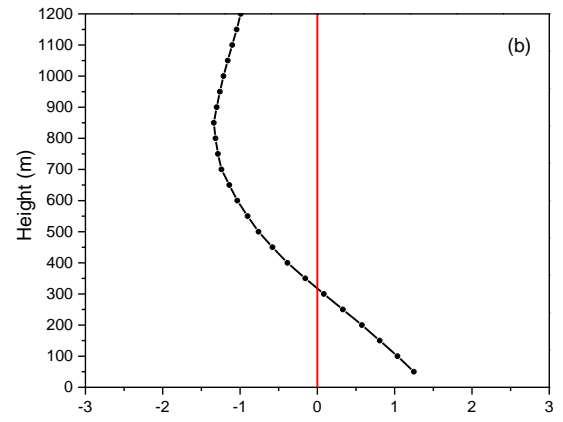


3.2. Characteristics of separable sea-breeze events

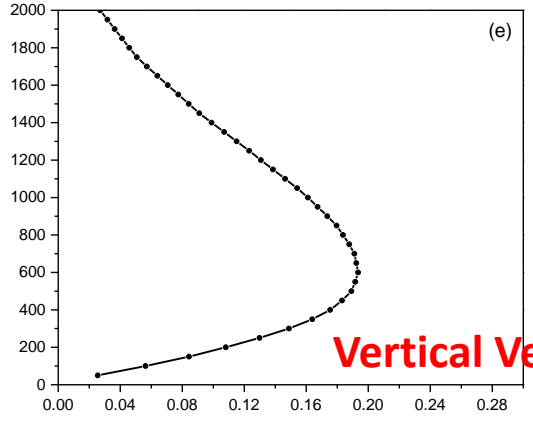
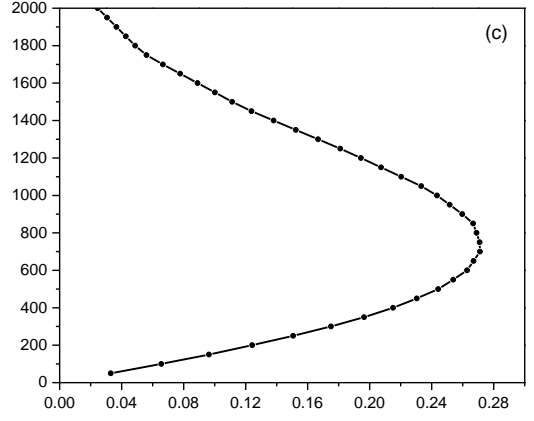
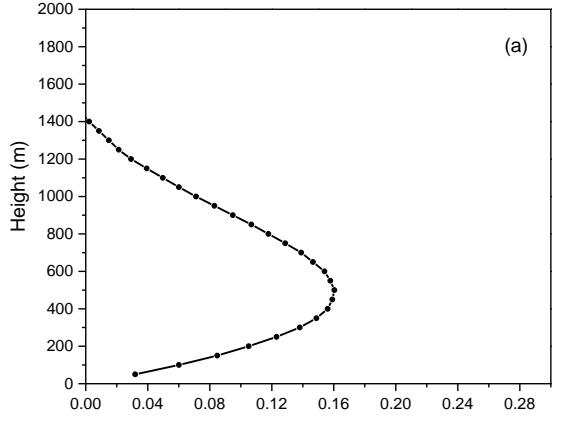


Coast AG

Pumping Ability (m^3/s)

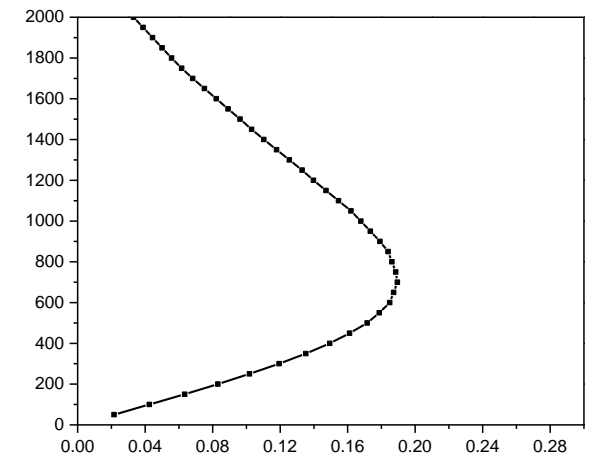
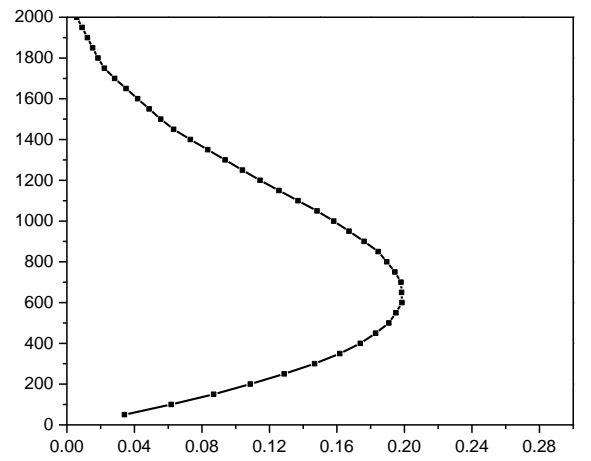
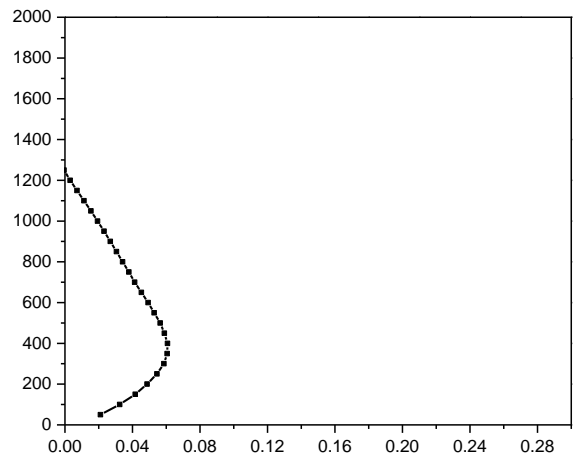
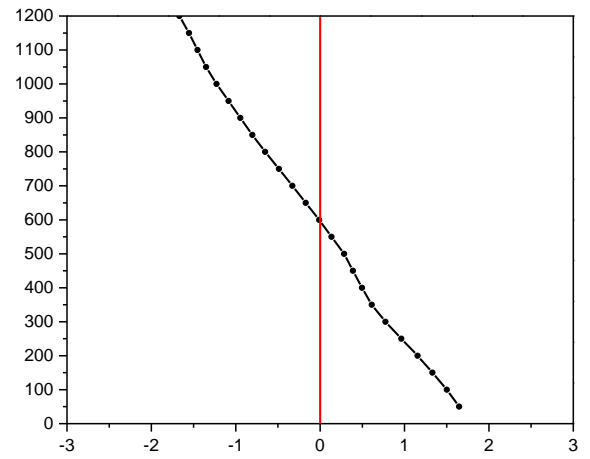
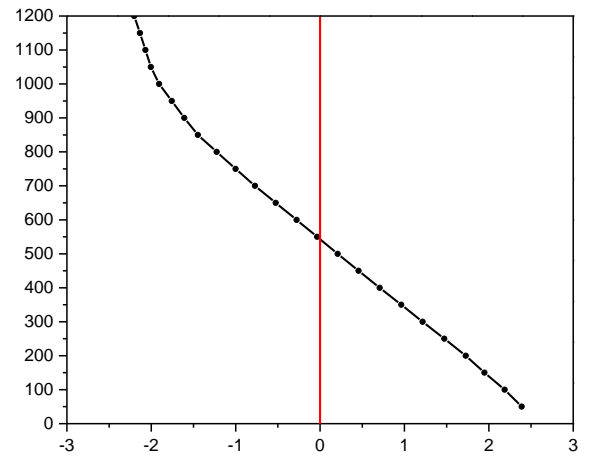
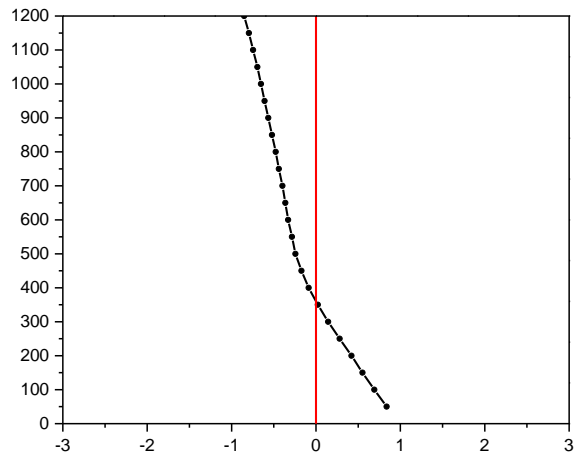
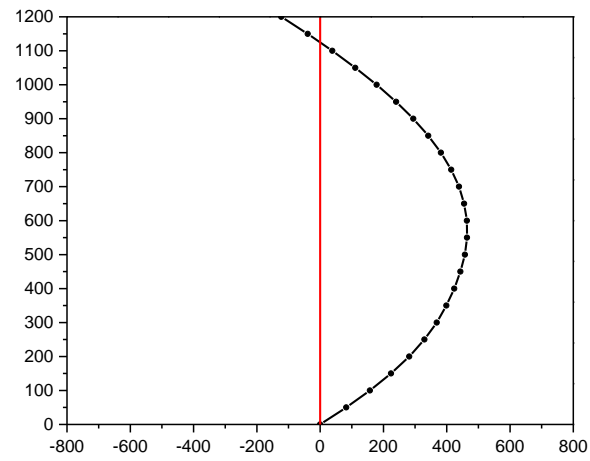
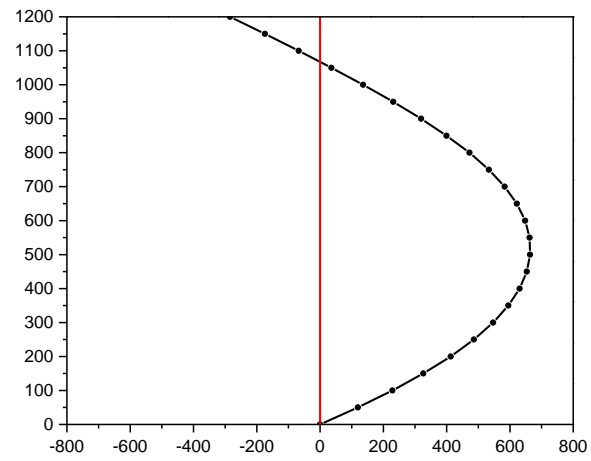
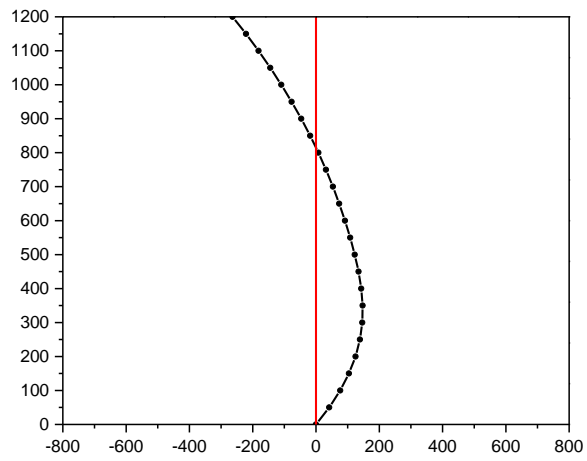


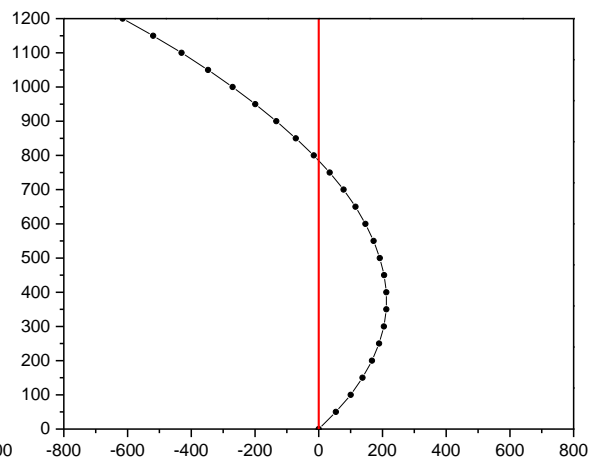
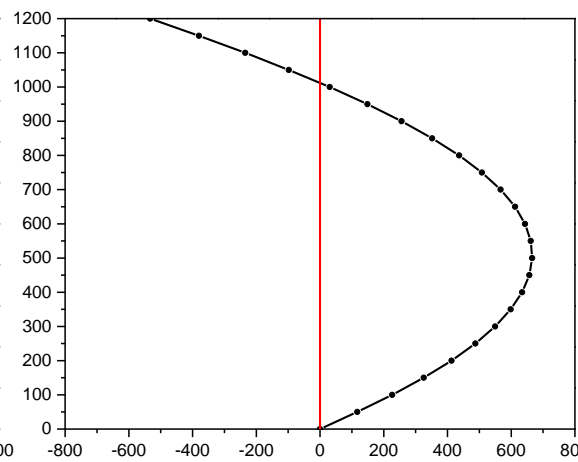
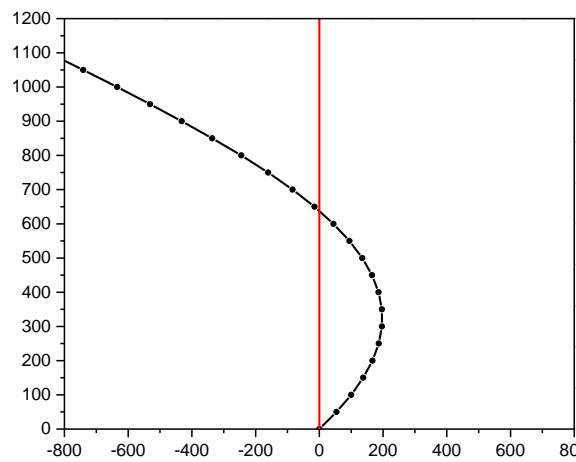
Normal Original Velocity (m/s)



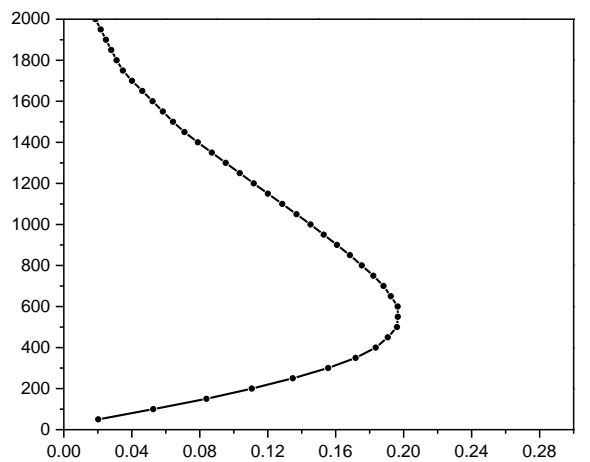
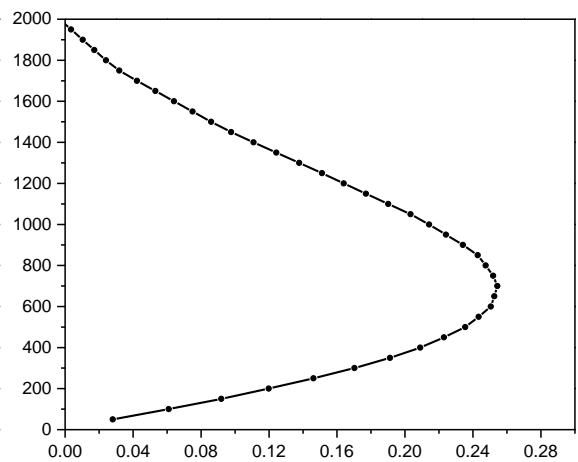
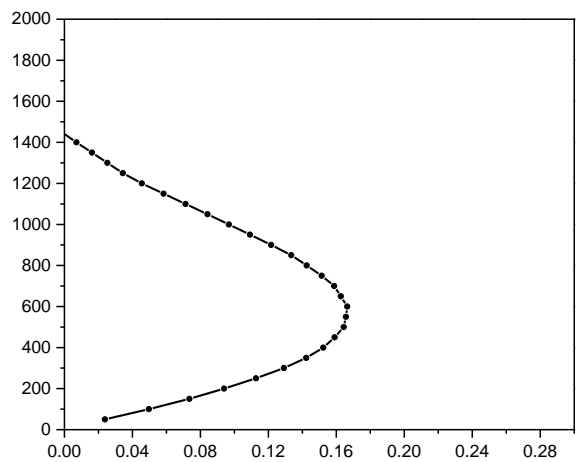
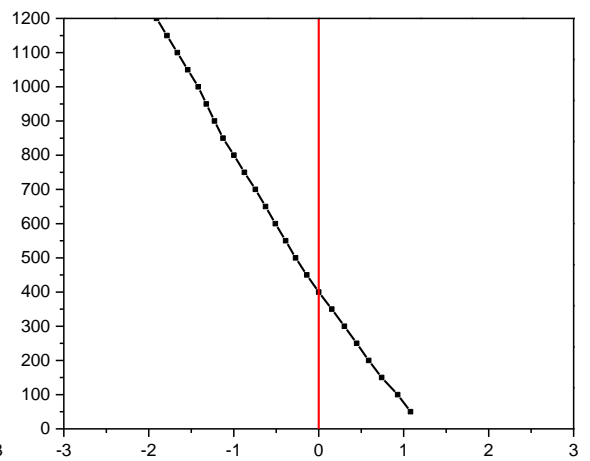
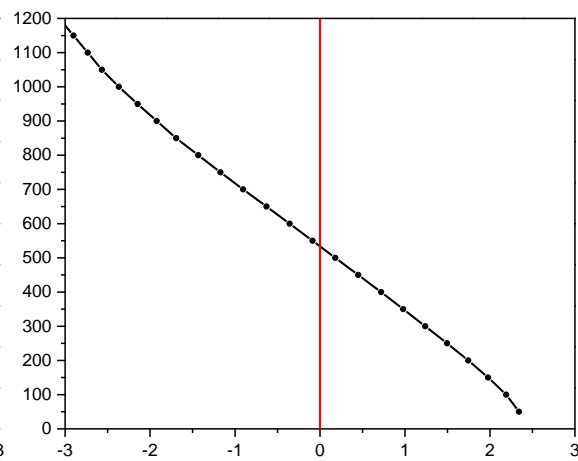
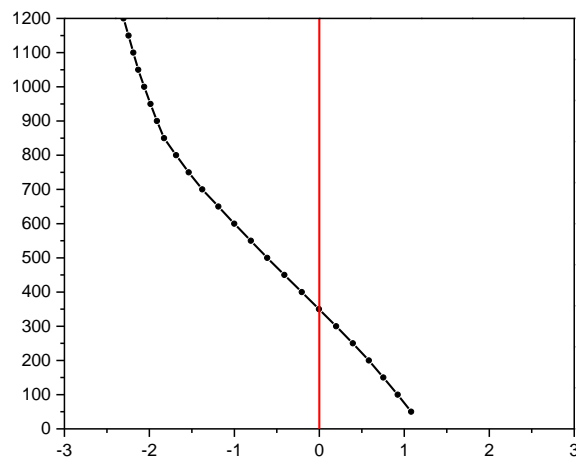
Vertical Velocity at Convergent Zone (m/s)

Coast BC





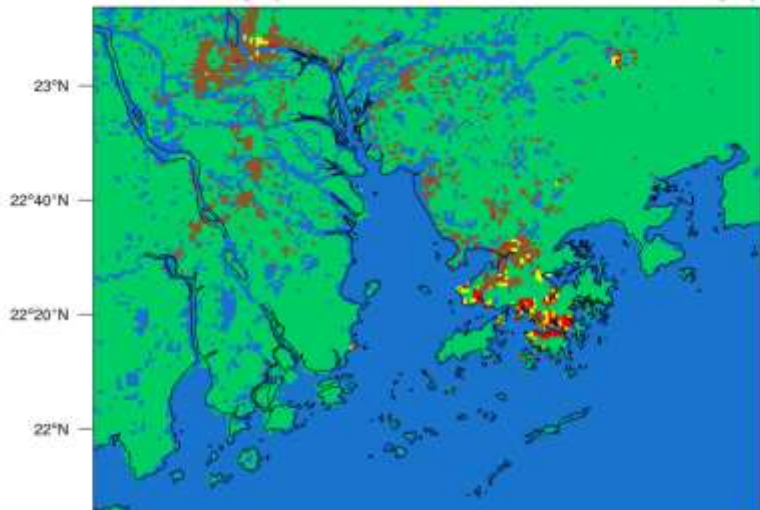
Coast DE



4. Effects of Urbanization on Sea-breeze

Classification of Landuse 1988

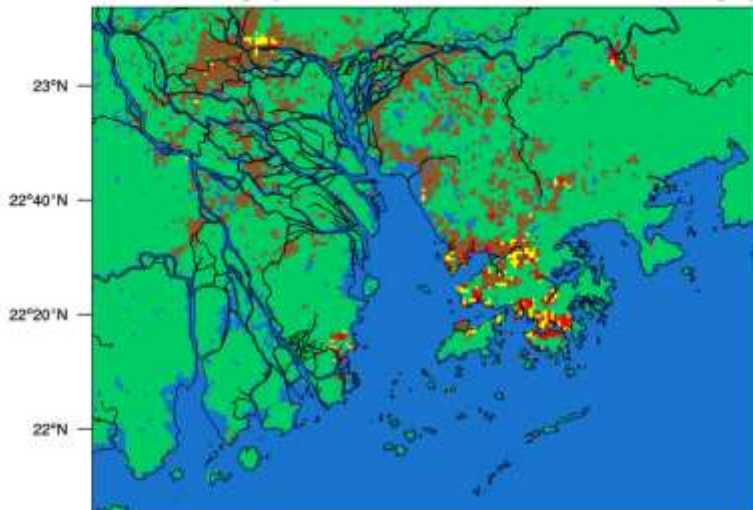
Dominant category category



Urban (Low-rise)
Mixed Tundra
Wooded Tundra
Urban (High-rise)
Barren or Sparse Vegetated
Wooded Wetland
Habitatless Wetland
Water Bodies
Mixed Forest
Evergreen Needleleaf Forest
Evergreen Broadleaf Forest
Deciduous Needleleaf Forest
Deciduous Broadleaf Forest
Savanna
Mead Shrubland/Cropland
Shrubland
Grassland
Cropland/Woodland Mosaic
Cropland/Grassland Mosaic
Mixed Dryland/Inglad/Cropland
Inglad/Cropland and Pasture
Dryland/Cropland and Pasture
Urban (Mid-rise)

Classification of Landuse 1999

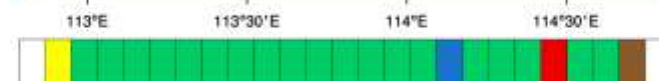
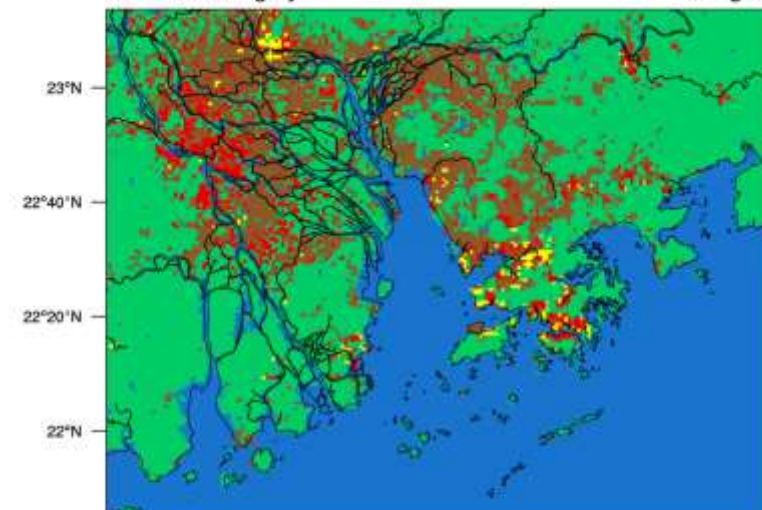
Dominant category category



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Grassland
Cropland/Woodland Mosaic
Cropland/Grassland Mosaic
Mixed Dryland/Inglad/Cropland
Inglad/Cropland and Pasture
Dryland/Cropland and Pasture
Urban (Mid-rise)

Classification of Landuse 2010

Dominant category category



Urban (Low-rise)
Mixed Tundra
Wooded Tundra
Urban (High-rise)
Barren or Sparse Vegetated
Wooded Wetland
Habitatless Wetland
Water Bodies
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Inglad/Cropland and Pasture
Dryland/Cropland and Pasture
Urban (Mid-rise)

4. Effects of Urbanization on Sea-breeze

Table. Characteristics of **all** sea-breeze events

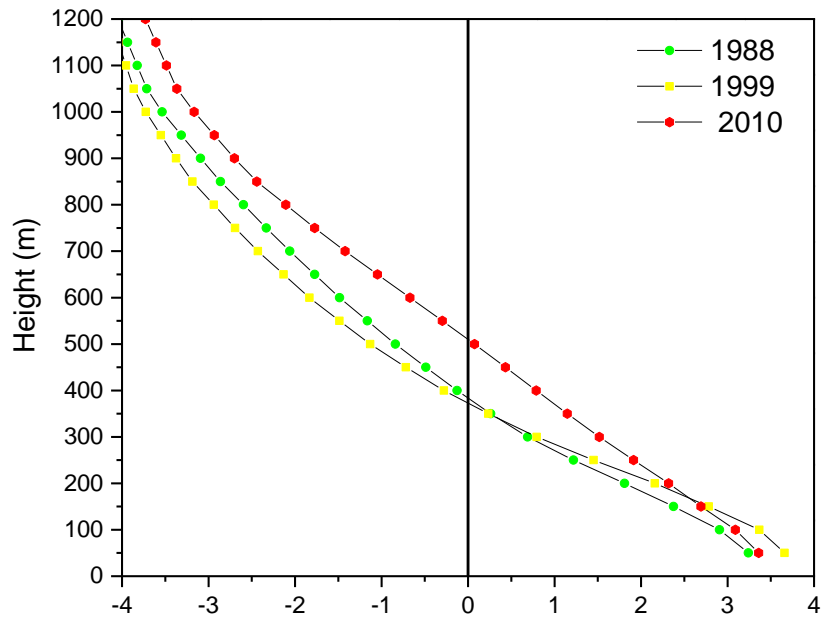
	1988	1999	2010
Start Time	11:30 am	10:55 am	10:50 am
End Time	17:20 pm	18:05 pm	17:50 pm
Duration (hour)	7 h	8 h 11 mins	8 h
Averaged Strength (m/s)	2.26	2.51	2.47

Table. Characteristics of **separable** sea-breeze events

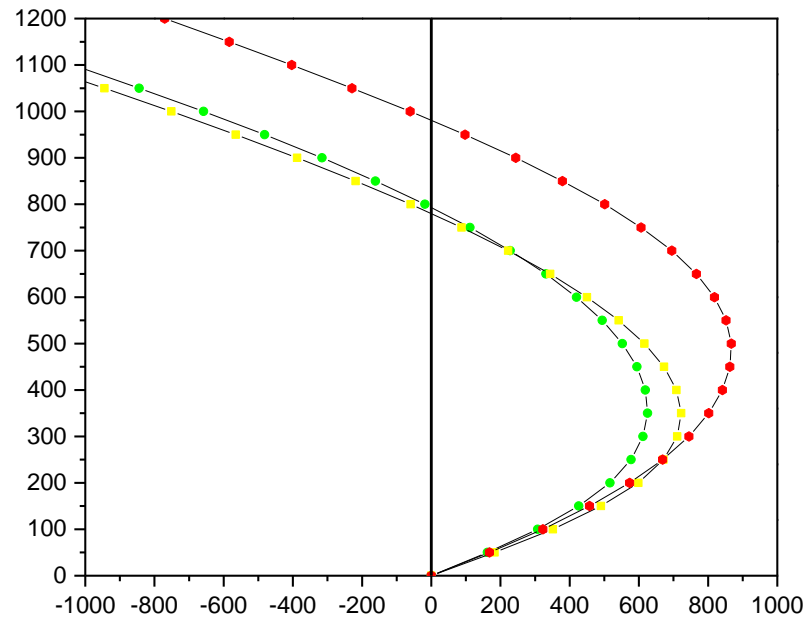
	1988	1999	2010
Number of separable cases	8 (11)	8 (11)	9 (11)
Inland Penetration distance (km)	16.1	15.3	15.6
Pumping Ability (m^3/s)	1003	1108	1223
Height (m)	506	544	617

4. Effects of Urbanization on Sea-breeze

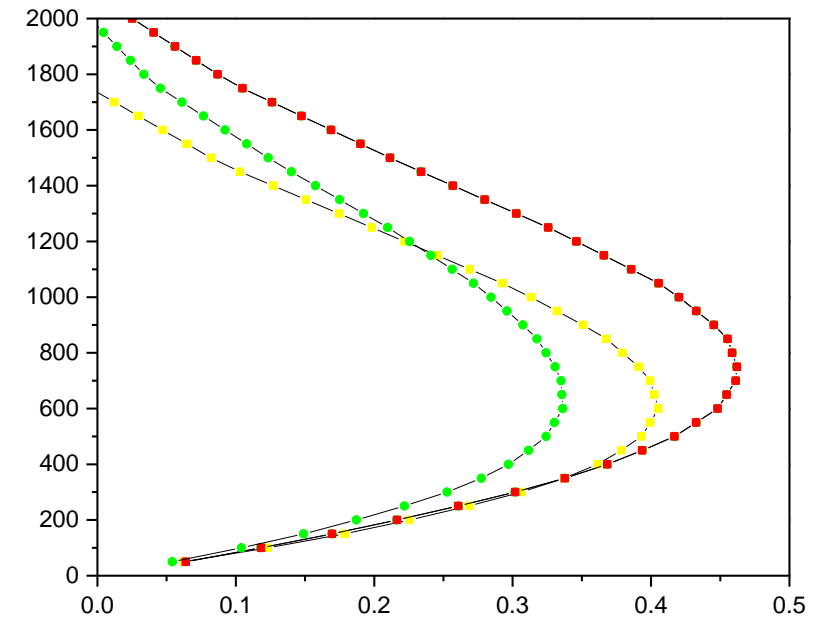
Normal Original Velocity (m/s)



Pumping Ability (m^3/s)



Vertical Velocity at Convergent Zone (m/s)



Thank You!

