Sea breezes in along-shore flow: Idealised simulations and scaling

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1. Introduction

- Previous numerical studies have shown that the cross-shore component of the ambient wind strongly modulates the intensity and evolution of the sea breeze (Crosman and Horel 2010)
- The along-shore component has generally been considered of little importance; however, this may be a consequence of the ubiquitous use of 2D or quasi-2D simulations (infinite coastlines)
- We hypothesise that in the case of a finite-length coastline (e.g. a peninsula), the along-shore flow will play a much greater role due to the step-change in heating at the upstream coast
- This hypothesis is tested using idealised numerical simulations performed with the Met Office Unified Model

2. Model Configuration

- 600 x 300 km domain with 1 km grid spacing and 70 levels
- Fixed lateral boundary conditions (LBCs)
- Peninsula represented using a 400 x 100 km island to reduce discontinuities on the outflow boundary (Fig. 1)

3. Control simulation

- Sea breezes form on the north and south coasts (Fig. 2)
- Near the upstream coast, the sea breeze fronts (SBFs) form quasi-stationary arcs; further downstream they are straight, move inland and eventually collide
- Slight north–south asymmetries exist due to the Coriolis force

4. Sensitivity to wind speed and heat flux

- Four sensitivity tests performed with $U_g$ and $H_{max}$ increased and decreased by 50 %
- Both parameters strongly influence the evolution of the SBFS (Fig. 3)

5. Sea breeze scaling

- Based on the pure sea breeze scalings of Steyn (1998, 2003), Tijm (1999), and Porson et al. (2007), we let $v_{SBF} = v_{140}$ where

$$v_{x} = \left( \frac{\rho C_p T_0}{\beta v_s} \right)^{1/10}$$

is the scaling velocity, with $\beta$ the acceleration due to gravity, $v_s$ the time-integrated surface sensible heat flux, $\rho$ the air density [taken as 1.2 kg m$^{-3}$], $C_p$ the heat capacity of air at constant pressure, and $T_0$ a reference temperature (taken as the prescribed surface temperature)
- We then assume a linear relationship between the sea breeze velocity and the SBF velocity, of the form $v_{SBF} = \alpha v_{x}$
- The constants $\alpha$ and $\beta$ are determined through linear regression
- The integrated heat flux must be computed along the west-to-east trajectory defined by the background flow – at time $t$ and downstream distance $x$, it is given by

$$\tilde{H}(x,t) = \tilde{H}(x-\delta x,t-\delta t) + \frac{\delta t}{\delta x} \left[ \tilde{H}(x,t) - \tilde{H}(x-\delta x,t) \right]$$

where $\delta t$ is the time interval (set as 60 s), $\delta x = \delta U t$ is the space interval, and $\tilde{U}$ is the low-level along-shore flow speed (set as 0.85 $\tilde{U}_{SBF}$ through experimentation to minimise errors in $\tilde{H}_{SBF}$, see below)
- The SBF position $y_{SBF}$ can then be determined through integration, again along the trajectory defined by the background flow:

$$y_{SBF}(x,t) = y_{SBF}(x-\delta x,t-\delta t) + \frac{\delta t}{\delta x} \left[ y_{SBF}(x,t) - y_{SBF}(x-\delta x,t) \right]$$

This relation is able to predict the structure and inland movement of the SBFS remarkably well (Fig. 4), although it cannot capture the north/south asymmetries which are more pronounced with large $U_g$

6. Asymmetric peninsula

- Runs performed with south coast angled 15° w.r.t north coast
- With $\delta U = 10$ m s$^{-1}$ and $H_{max} = 200$ W m$^{-2}$, the south coast sea breeze is significantly weaker and the north coast SBF moves inland much more slowly and stalls around 20 km from the coast (Fig. 5)

- This is reminiscent of SBFS over the UK Southwest Peninsula under southwesterly flow which can initiate flash flood–producing quasi-stationary convective systems (Golding et al. 2005; Warren et al. 2014)

7. Conclusions

- The along-shore component of the ambient wind plays a significant role in sea breeze evolution over a peninsula (or elongated island)
- As the sea breeze moves inland it is advected downstream, resulting in quasi-stationary SBFS near the upstream end of the peninsula; these may provide a mechanisms for repeated convective initiation
- The evolution of the SBFS as a function of downstream distance is strongly influenced by both the wind speed and the surface heat flux
- A modified scaling for pure sea breezes reproduces this behaviour very well; however, it cannot represent asymmetries associated with the Coriolis force
- The evolution is notably changed when the peninsula is asymmetric
- Possible future work: modify the scaling to deal with a non-zero cross-shore flow component

References


43: 177–188.


