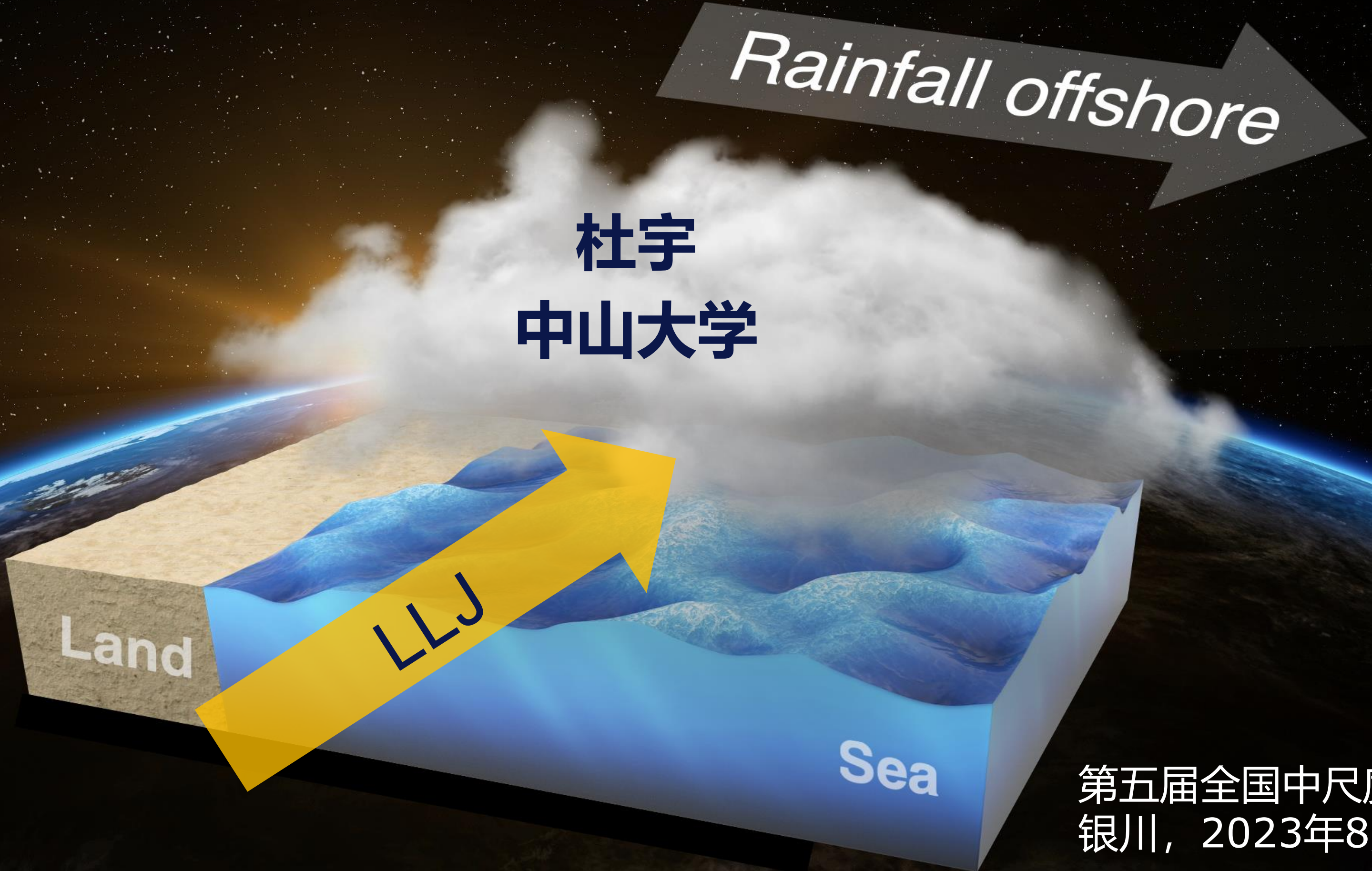
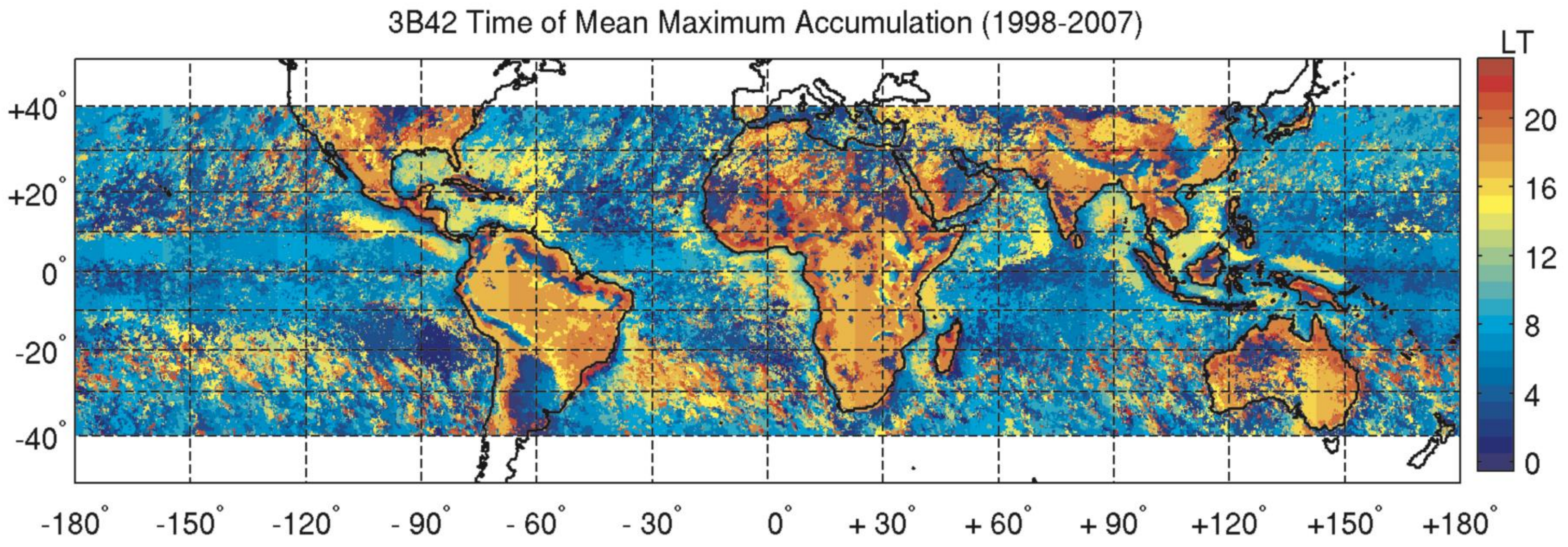
低空急流日变化的离岸传播



杜宇
中山大学

第五届全国中尺度气象论坛
银川，2023年8月10日

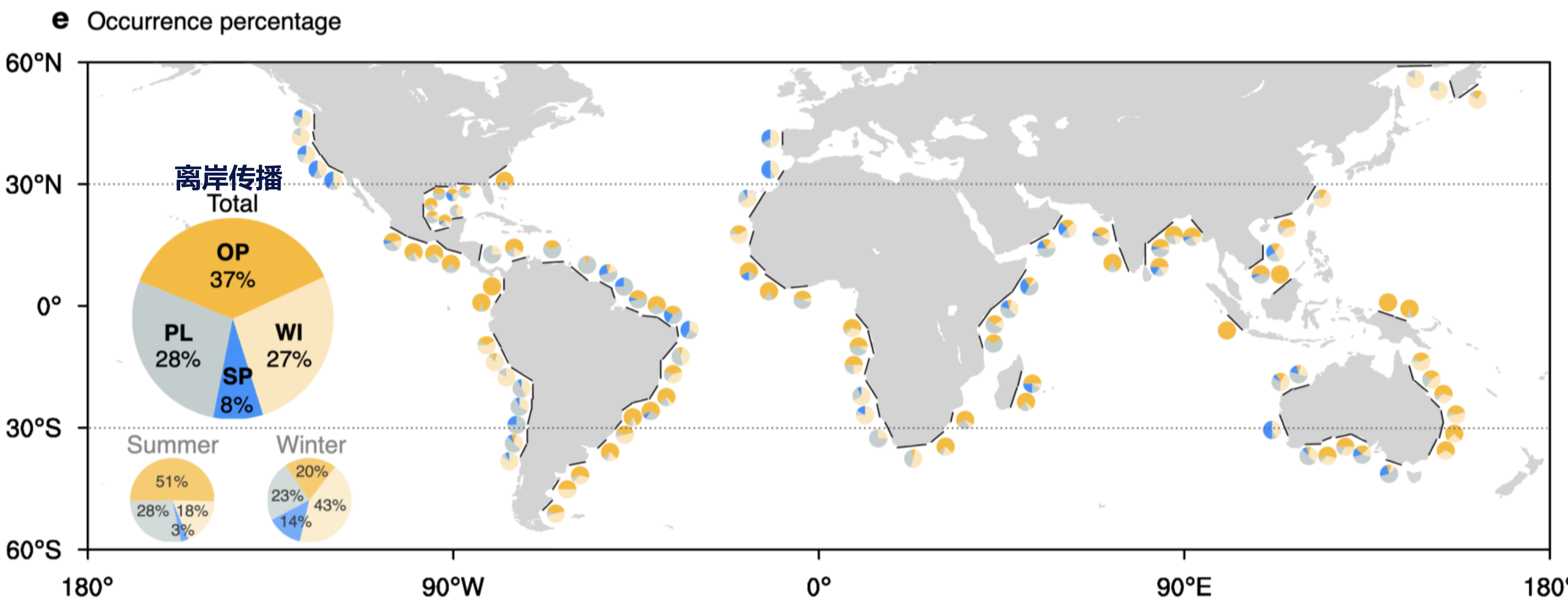
全球降水日变化



降水日变化的峰值时间

(Johnson 2010)

海岸降水日变化类型的全球分布



■ 全球海岸离岸传播占主导

(Fang and Du* 2022, Nature communications)

海陆差异激发的重力波

二维海陆风理论模型

$$\frac{\partial u}{\partial t} - fv = -\frac{\partial \phi}{\partial x} - \alpha u, \qquad (1)$$

$$\frac{\partial v}{\partial t} + fu = -\alpha v, \qquad (2)$$

$$\frac{\partial w}{\partial t} - b = -\frac{\partial \phi}{\partial z} - \alpha w, \qquad (3)$$

$$\frac{\partial b}{\partial t} + N^2 w = Q - \alpha b, \quad \text{and} \qquad (4)$$

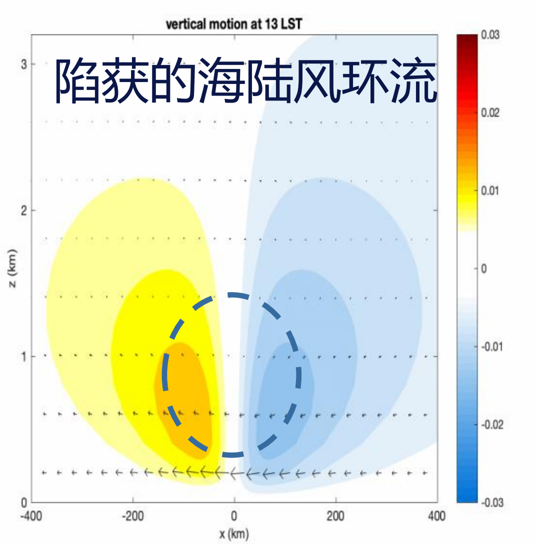
$$\frac{\partial u}{\partial x} + \frac{\partial w}{\partial z} = 0, \qquad (5)$$

解析解

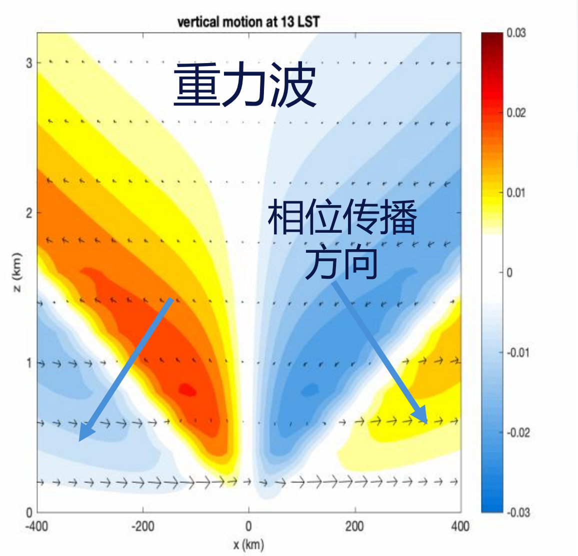
$$\hat{\psi} = \sqrt{\frac{\pi}{2}} \frac{Q_0}{\frac{f^2 - \sigma^2}{z_0^2} - (N^2 - \sigma^2)K^2} \times e^{-x_0|K|}\left[e^{-z/z_0} - e^{-\sqrt{(N^2-\sigma^2)/(f^2-\sigma^2)}\,\mathrm{sgn}(K)Kz}\right].$$

$$w = -\frac{\partial \psi}{\partial x} = \mathrm{Re}\left\{\frac{-i}{2\pi}\int_{-\infty}^{\infty} \hat{\psi} K e^{i(Kx-\omega t)} dK\right\}$$

高纬



低纬



填色：垂直速度

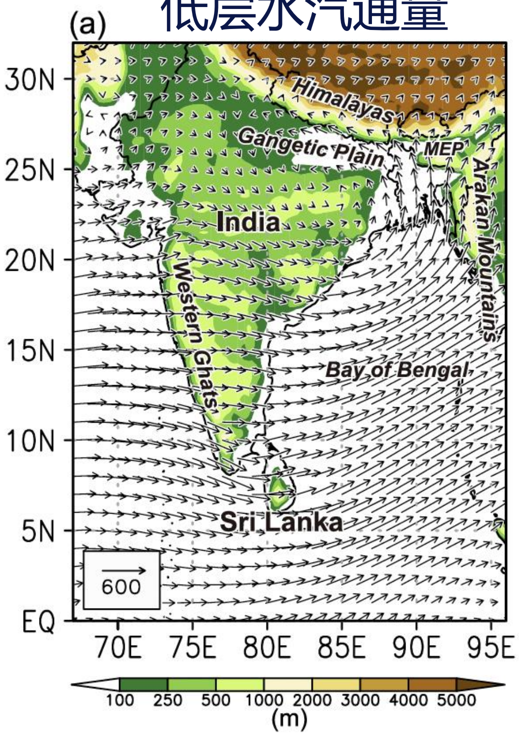
(Du and Rotunno 2015，2018，2019, JAS)

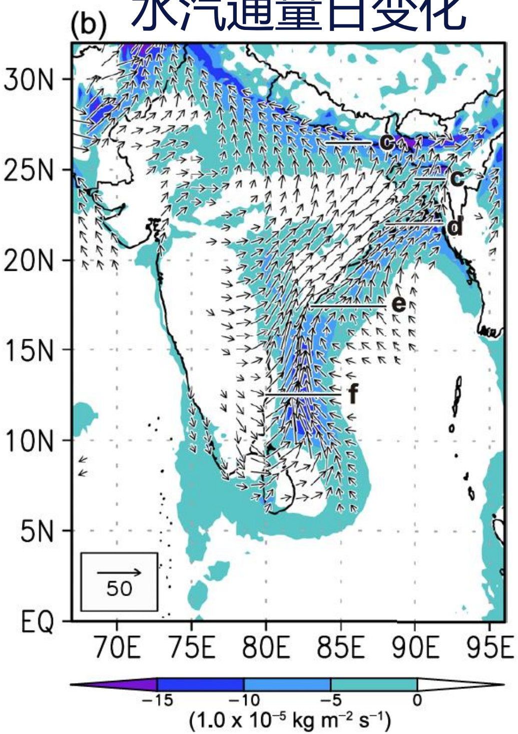
■ **海陆差异强迫激发的重力波 → 降水离岸传播**

科学问题

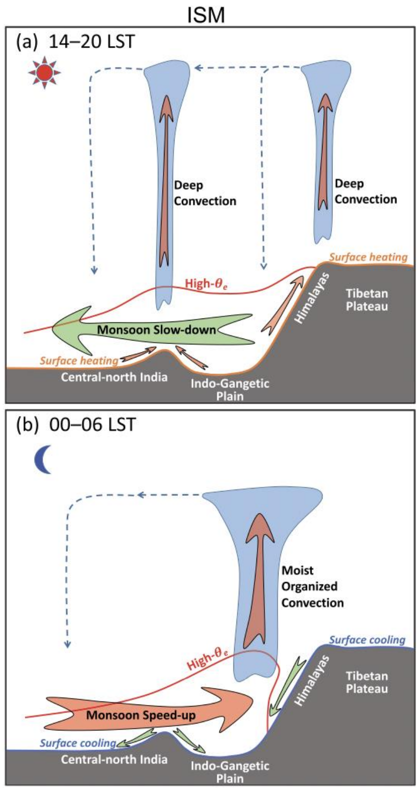
海上低层风场（低空急流）的日变化？离岸传播？

研究区域：孟加拉湾



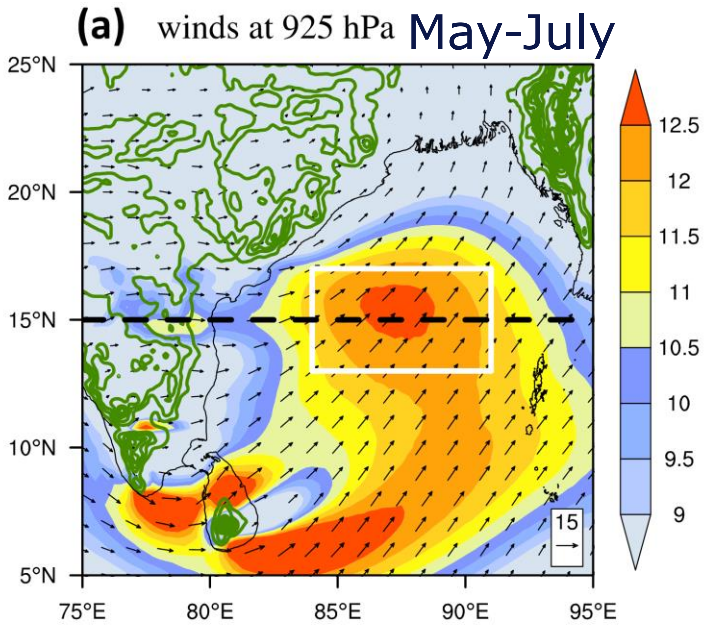


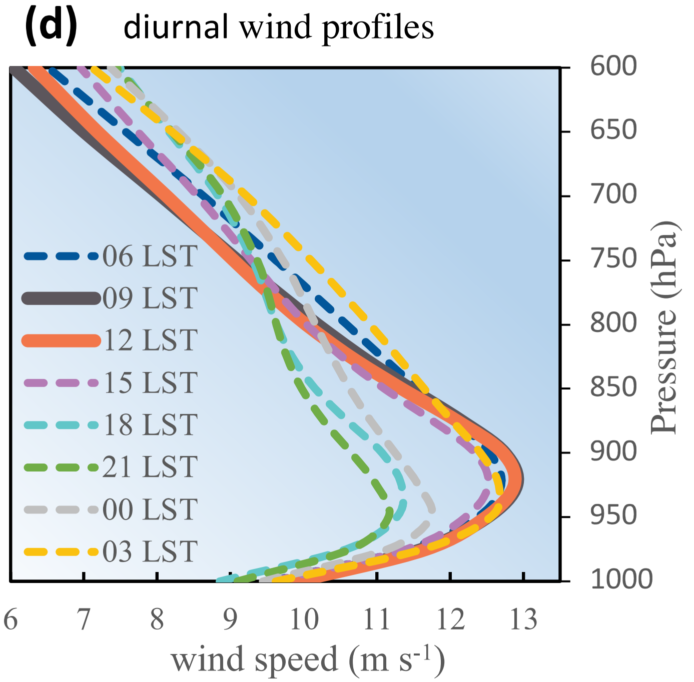
Fujinami et al. 2023



Chen 2020

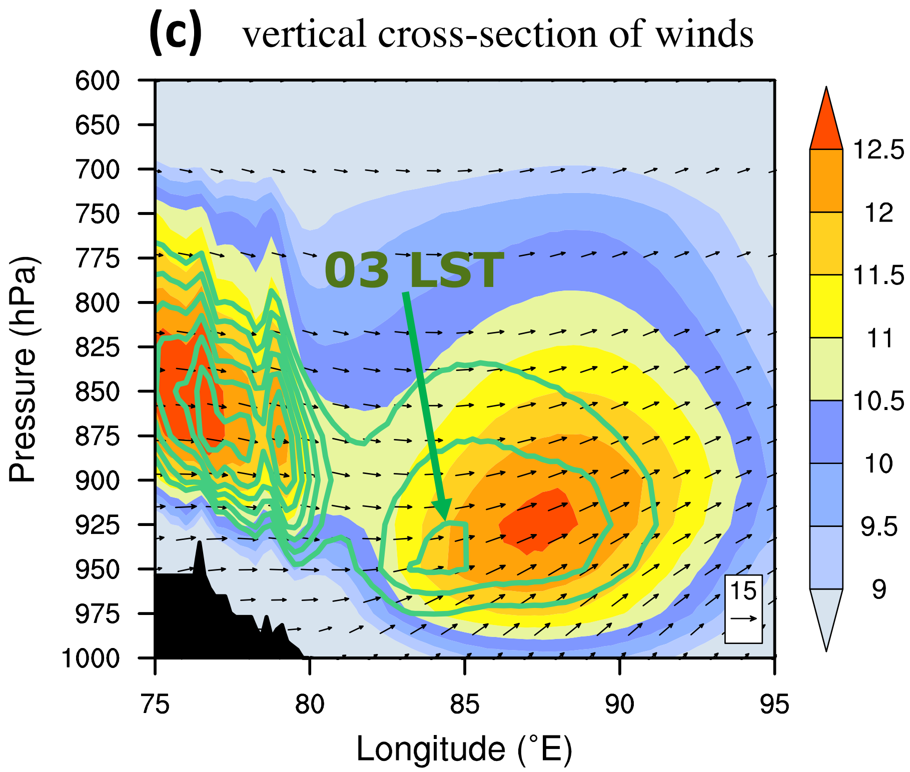
季风低空急流的时空分布





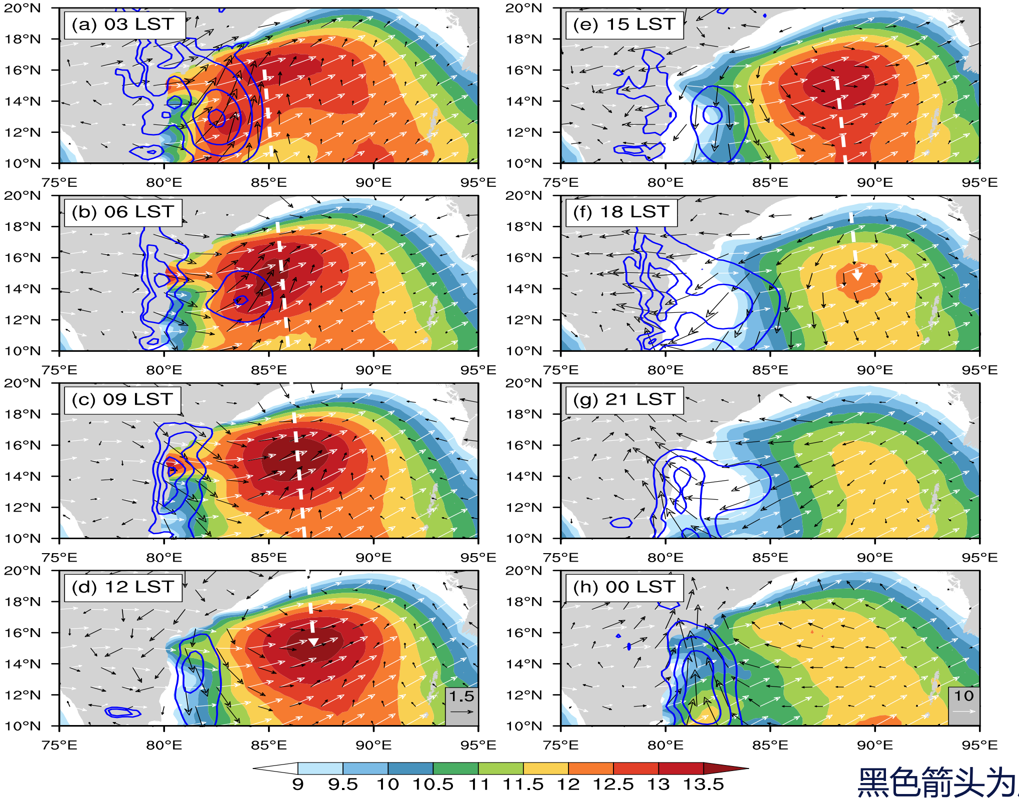
- 西南低空急流的风速核心位于孟加拉湾中部，峰值在**925hPa**
- 强度具有显著日变化，**上午最强**

季风低空急流的时空分布



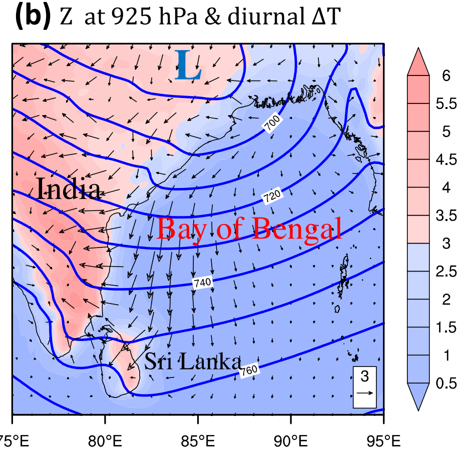
- 急流核的**位置**具有日变化
- 03LST急流核位置更靠近岸边

季风低空急流离岸传播



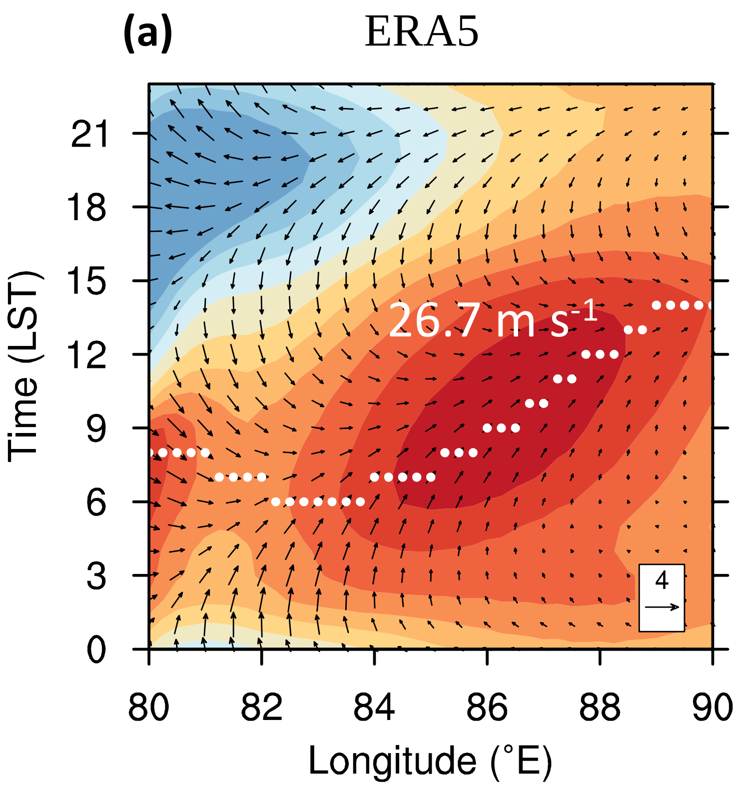
黑色箭头为风场日偏差

白天16LST-晚上04LST



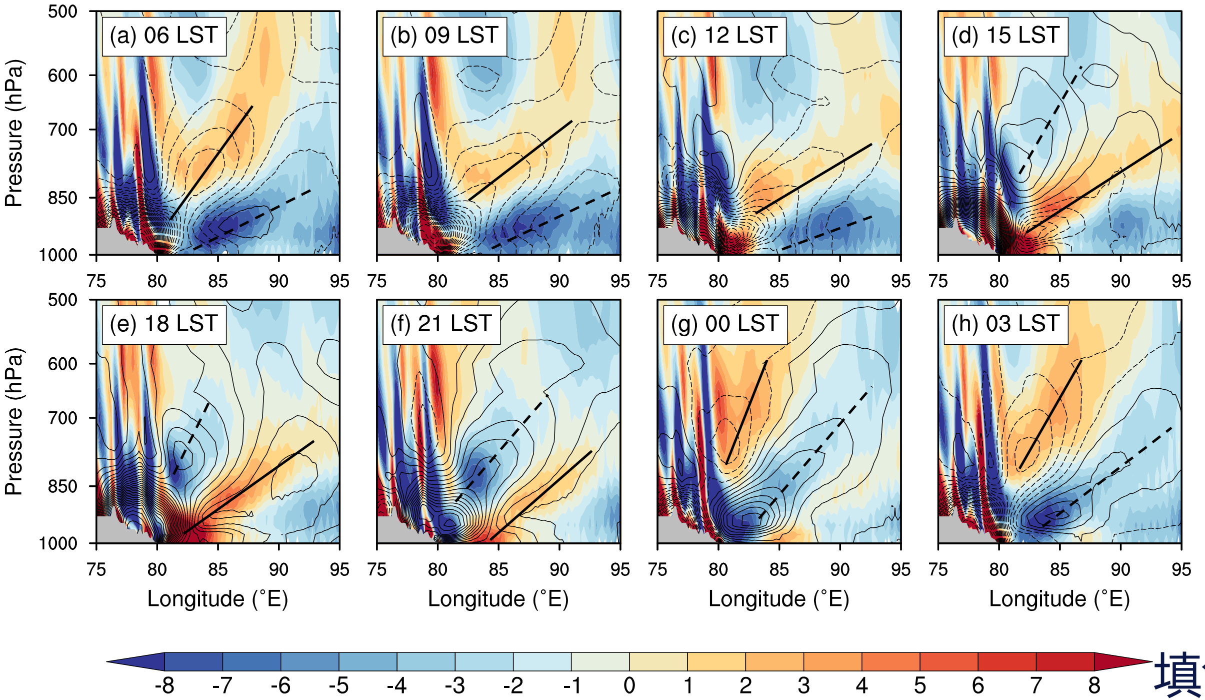
- 急流核的**位置日变化向离岸传播**
- 近岸**海陆风**显著，影响远岸范围大，且具有相位延迟（重力波？）

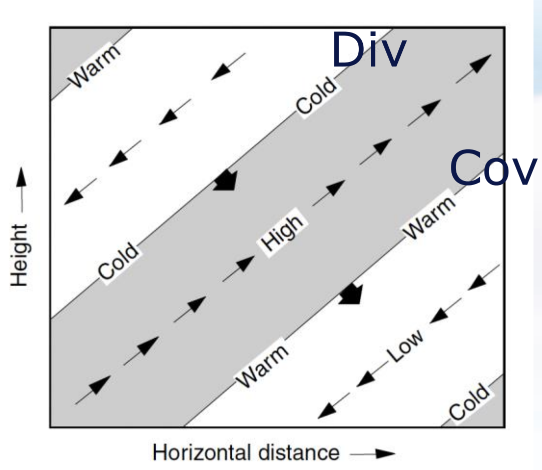
季风低空急流离岸传播的哈默图



- 近岸03-05LST -> 远岸 12-15 LST
- 急流离岸传播速度为**26.7 m s^{-1}**
- 传播距离为**600-800 km**

海陆热力差异激发的重力波结构





- 重力波**相位线**向离岸倾斜，并向下向离岸传播。
- 极化关系：温度和辐合**同相位**

填色：温度扰动
等值线：辐合辐散

考虑背景风的二维海陆风模型

模型

$$\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)u-fv=-\frac{\partial \phi}{\partial x}-\alpha u$$

$$\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)v+fu=-\alpha v$$

$$-b=-\frac{\partial \phi}{\partial z}$$

$$\left(\frac{\partial}{\partial t}+U\frac{\partial}{\partial x}\right)b+N^2w=Q-\alpha b$$

$$\frac{\partial u}{\partial x}+\frac{\partial w}{\partial z}=0.$$

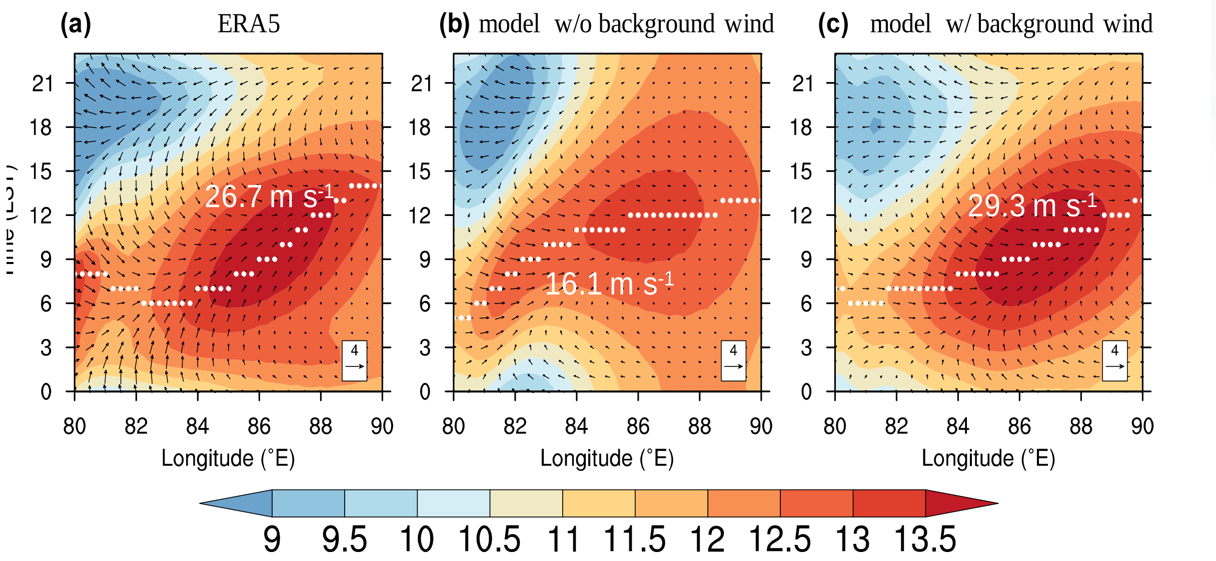
解析解

$$\psi = Re\left[\frac{1}{2\pi}\int_{-\infty}^{\infty}\hat{\psi}e^{i(kx-\omega t)}dk\right],$$

$$u=\frac{\partial \psi}{\partial z}=Re\left[\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{\partial \hat{\psi}}{\partial z}e^{i(kx-\omega t)}dk\right], \text{and}$$

$$v=Re\left[\frac{f}{i\omega-ikU-\alpha}\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{\partial \hat{\psi}}{\partial z}e^{i(kx-\omega t)}dk\right].$$

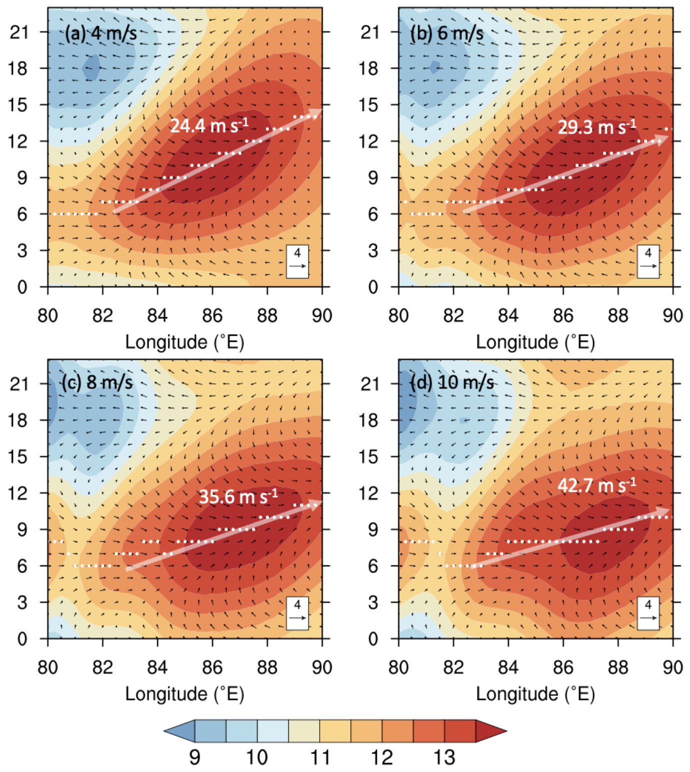
$$\hat{\psi}=\sqrt{\frac{\pi}{2}}\frac{Q_0}{\left[\frac{(f^2-\sigma^2)}{z_0^2}\right]-N^2k^2}e^{-x_0|k|}\left(e^{-z/z_0}-e^{-\sqrt{N^2/(f^2-\sigma^2)}\,\mathrm{sng}(k)kz}\right).$$



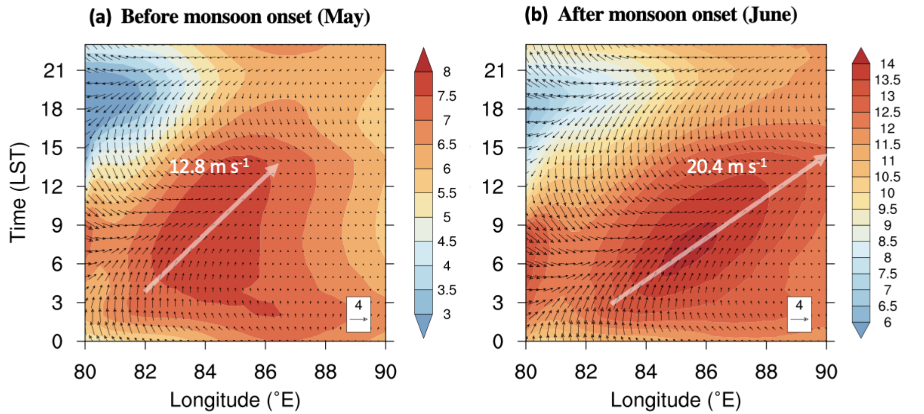
- 考虑背景风的二维海陆风模型能较好地模拟低空急流的**离岸传播**特征

背景风强度对传播的影响

理论模型



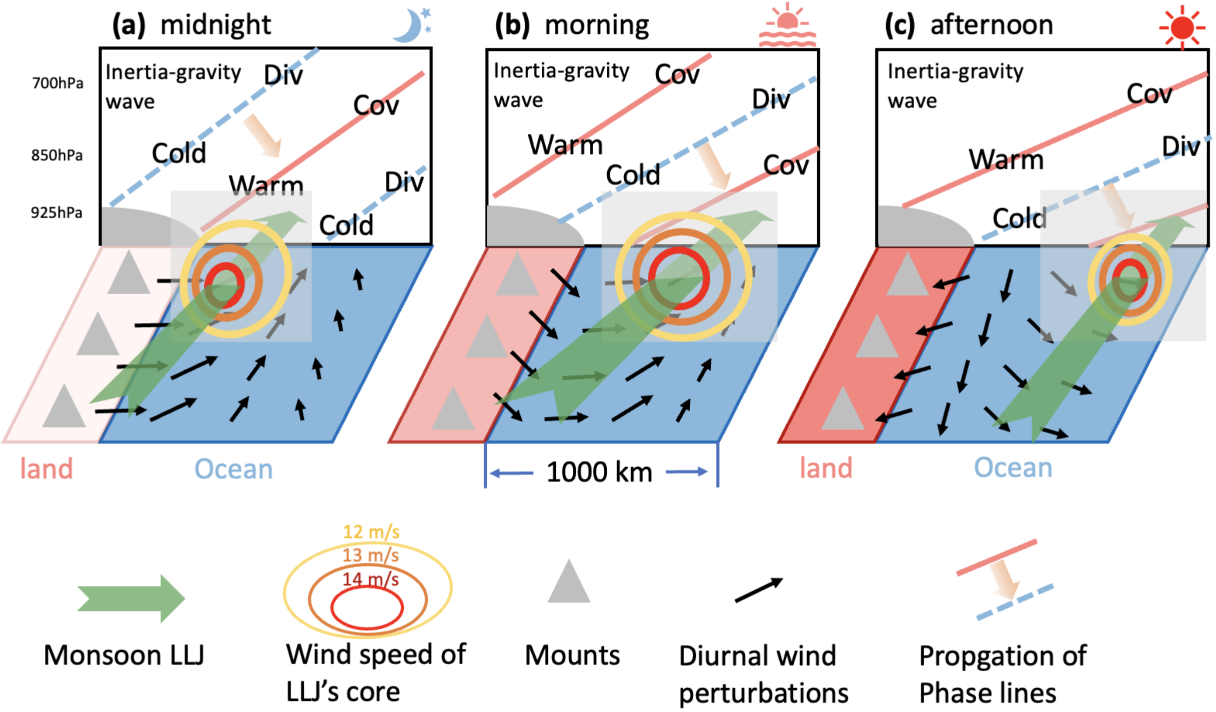
ERA5



1000-400hPa平均U：
0.4 m/s May
5.7 m/s June

- 离岸背景风导致低空急流离岸传播**更远距离**

总结：概念模型



Du, Y.#, 2023: Offshore Migration of Summer Monsoon Low-Level Jet on a Diurnal Scale, GRL (conditionally accept)