What Drives Equatorial Boundary Layer Winds?

Marius Winkler | Juan Pedro Mellado, Tobias Kölling, Bjorn Stevens
“Along the equator, models fail to develop the eastern cold tongue, with SST gradients opposite to observations […].”

“Wind biases are thus likely a local and/or remote response to deficiencies in the atmospheric model physics.”

“[…], further investigation on the potential feedback of zonal winds on SST is needed to completely understand the role of the coupling between the ocean and the atmosphere […].”
ICON - ICOsahedral Nonhydrostatic

A. Non-hydrostatic model on global domains
B. Unstructured triangular grid
C. 5km resolution
D. 90 levels:
   • top at 75km with 400 m
   • bottom with 25m
E. 2-year simulation output: 01/2020 – 02/2022
Momentum Budget Analysis

Zonal:

\[
\frac{1}{\tau_{0,u}} \int_{0}^{h_{ABL}} dz \frac{\partial \tilde{u}}{\partial t} = \frac{1}{\tau_{0,u}} \left[ -\int_{0}^{h_{ABL}} dz \, \tilde{u} \nabla \tilde{u} + \int_{0}^{h_{ABL}} dz \, f \tilde{v} - \frac{1}{\rho} \int_{0}^{h_{ABL}} dz \, \frac{\partial \tilde{p}}{\partial x} - \frac{1}{\rho} \tau_{h,u} + \frac{1}{\rho} \tau_{0,u} \right]
\]

Top of the ABL at height \( h_{ABL} \)

\( \int_{0}^{h_{ABL}} dz \)

Ocean surface at height 0
Equatorial Boundary Layer Wind: Equatorial Atlantic

- Atlantic
- Indian Ocean

SLP anomaly - monthly mean: 05 / 2020

- Meridional Momentum Budget
- $20^\circ N$ to $10^\circ N$
- $10^S$ to $20^S$
- $20^N$ to $10^S$

Equatorial Atlantic

Motivation

Method

Results

Con. & Out.
Type 1/2: Zonal Wind Belt

Atlantic

Eastern Pacific

Indian Ocean
Type 1/2: Zonal Wind Belt

**Pressure Gradient Force vs. Turbulent Flux**

**Pressure Gradient Force vs. Advection Force**

**Pressure Gradient Force vs. Surface Drag**
Type 2/2: Cross Equatorial Winds

Atlantic: 
- Zonal mean of zonal wind: -1.7 m/s 
- Meridional mean of meridional wind: -1.5 m/s 
- Monthly mean: 09 / 2020

Indian Ocean: 
- Zonal mean of zonal wind: -4.6 m/s 
- Meridional mean of meridional wind 
- Monthly mean: 02 / 2020
Type 2/2: Cross Equatorial Winds

**Motivation**

- Type 2/2: Cross Equatorial Winds

**Model**

**Method**

**Results**

**Con. & Out.**

- Atlantic:
  - Zonal mean of zonal wind: 09/2020
  - Monthly mean: 09/2020
  - Zonal mean of zonal wind:
    - Monthly mean: 09/2020
    - Zonal mean of zonal wind: -1.7 m/s
  - Meridional mean of meridional wind:
    - Monthly mean: 02/2020
    - Meridional mean of meridional wind:
      - Monthly mean: 02/2020

- Indian Ocean:
  - Zonal mean of zonal wind:
    - Monthly mean: 02/2020
    - Zonal mean of zonal wind: -4.6 m/s
  - Meridional mean of meridional wind:
    - Monthly mean: 02/2020
    - Meridional mean of meridional wind:
      - Monthly mean: 02/2020

**Pressure Gradient Force vs. Surface Drag**

- Atlantic:
  - Zonal mean of zonal wind:
    - Monthly mean: 09/2020
    - Zonal mean of zonal wind: -1.7 m/s
  - Meridional mean of meridional wind:
    - Monthly mean: 02/2020
    - Meridional mean of meridional wind:
      - Monthly mean: 02/2020

**Pressure Gradient Force vs. Advection Force**

- Indian Ocean:
  - Zonal mean of zonal wind:
    - Monthly mean: 02/2020
    - Zonal mean of zonal wind: -4.6 m/s
  - Meridional mean of meridional wind:
    - Monthly mean: 02/2020
    - Meridional mean of meridional wind:
      - Monthly mean: 02/2020
A. We identify two types of equatorial boundary layer winds in ngc2009:

1) Zonal Wind Belt
2) Cross Equatorial Winds

<table>
<thead>
<tr>
<th>Wind Type</th>
<th>Atlantic</th>
<th>Indian Ocean</th>
<th>Eastern Pacific</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zonal Wind Belt:</td>
<td>Winter</td>
<td>Spring, Autumn</td>
<td>All year</td>
</tr>
<tr>
<td>Cross-Eq. Wind:</td>
<td>Spring, Summer, Autumn</td>
<td>Summer, Winter</td>
<td></td>
</tr>
</tbody>
</table>

B. Pressure gradient force dominates the wind balance.
Any Questions?
 ICON - ICOsahedral Nonhydrostatic

A. Non-hydrostatic model on global domains

B. Good conservation properties (mass and energy)

C. Unstructured grid originating from an icosahedron

D. R02B09: 5km (square root of mean cell area)

E. Total number of grids in R02B09: 20 971 520

F. 90 levels: top at 75km with 400 m, bottom with 25m

G. NextGEMS cycle 2 run:
   ➤ 2-year simulation output: 01/2020 – 02/2022

Hohenegger et al. (2022)