The Effects of Turbulent Mountain Stress (TMS) on the Boundary Layer in CAM

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Diurnal cycle in CAM4 and CAM5

- Aim is to compare the two very different PBL schemes
- CAM4 and CAM5 5-year climatological SST simulations
- Coupled to the land model which is the same in both simulations
- We analyse hourly output at locations with observations of turbulent fluxes
Flux stations used in the study
Annual cycle

Polar

Midlatitudes

Tropical Rainforest

2-m Temperature

Sensible heat flux

Latent heat flux

2-m Temperature

Sensible heat flux

Latent heat flux

CAM4

CAM5

JRA25

NCEP

ERA interim

CRU

Willmott & Matsuura
Diurnal cycle

Observed and simulated median monthly diurnal cycles

- Friction Velocity [m s⁻¹]
  - CAM4: 0.106
  - CAM5: 0.15
- Sensible Heat Flux [W m⁻²]
  - CAM4: 27.4
  - CAM5: 27.4
- Latent Heat Flux [W m⁻²]
  - CAM4: 23.7
  - CAM5: 23.9
- Wind Speed [m s⁻¹]
  - CAM4: 1.31
  - CAM5: 0.728
- Temperature [K]
  - CAM4: 2.77
  - CAM5: 2.97

Standard deviation (Normalized) vs. Correlation Coefficient

CAM4

CAM5
ARM SGP site

Data from January, February and March

Turbulent mountain stress
CLM and CAM interactions

**CAM4**
- CLM calculates turbulence fluxes at the surface
- Used as boundary conditions for the PBL scheme
- Same stability functions in CLM as in PBL scheme

**CAM5**
- CLM calculates turbulence fluxes at the surface
- TMS adds surface stress in CAM, thus a larger surface stress is used as boundary condition
- This extra drag reduces the wind speed in lowest layer
- Not the same stability functions in CLM, PBL and TMS
Turbulent Mountain Stress (TMS)

- Added to improve the general circulation
- Enhancement of the surface drag due to subgrid-scale terrain, basically increases surface roughness to \( z_{0\text{oro}} \)
- Applied when \( Ri < 1 \) based on function below

![Graph showing the relationship between Ri and a function output]

\[
\begin{align*}
\text{Graph:} & \\
\text{1} & \quad \text{0} \quad \text{1} \\
\text{Ri} & \\
\end{align*}
\]
Subgrid scale orographic drag

- Tropopause perturbed
- Generation of turbulence
  - Upper flow
  - Mountain waves
  - Sheltering effect
  - Formation of a regional wind
- Lower flow
  - Blocked flow
  - Deviated flow
- Generation of turbulence by shear

TMS

CLM
Subgrid scale orography

At SGP:

$\text{SGH30} = 23 \text{ m}$
Calculated $z_{0\_oro}$

At SGP:

$z_{0\_oro} = 1.7\,m$

$z_0 = 0.06\,m$
Neutral drag law

\[ u_*^2 = C_{DN} U_{ref}^2 \]

\[ U_{ref} = \frac{u_*}{k} \ln\left( \frac{z_{ref}}{z_0} \right) \]

\[ C_{DN} = \frac{k^2}{\ln\left( \frac{z_{ref}}{z_0} \right)^2} \]

Applied to the Southern Great Plains where

- \( z_0 = 0.06 \text{ m} \)
- \( z_{0\_oro} = 1.7 \text{ m} \)
- \( u^*_{CAM} \rightarrow U_{ref} \rightarrow u^*_{CLM} \)
Neutral drag coefficient for SGP

\[ C_{DN} = \frac{k^2}{\ln \left( \frac{z_{ref}}{z_0} \right)^2} \]

\( C_{DN} \) with \( z_0 = 0.06 \) m

\( C_{DN} \) with \( z_0 = 0.06 \) m and ref height for obs

\( C_{DN} \) with \( z_0 = 1.7 \) m
Wind speed is reduced...
Temperature gradients increase

More frequently stably stratified

More frequently unstable
Surface heat fluxes almost the same
Effect of turbulent mountain drag

TMS

No TMS

Near surface wind (m/s)

MIN = 0.04 MAX = 7.97

MIN = 0.02 MAX = 11.68

MIN = 0.11 MAX = 11.81

MIN = 0.11 MAX = 16.25

Track 5, CAM (December 2009)
Summary

• The Turbulent Mountain Stress is needed for CAM5 to have “enough” momentum extracted at the surface
• Climatological surface turbulent heat fluxes are similar in CAM4 and CAM5 even though the winds are much reduced in CAM5
• The model compensates the lower wind gradients with larger temperature gradients
• A more sophisticated parameterisation that does not interfere with the surface driven turbulence is preferable
• Problematic since there are no observational datasets to compare with...