ISSUES IN BOUNDARY LAYER PARAMETRIZATION FOR LARGE SCALE MODELS
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(ECMWF)

• Boundary layer clouds
• Wind turning
• Momentum budget (heterogeneous terrain)

• With contributions from: Andy Brown, Sylvain Cheinet, Hans Hersbach, Martin Koehler, Andrew Orr
Recent implementation of Mass-flux/K-diffusion approach

**key ingredients:**

- moist conserved variables
- combined Mass-flux/K-diffusion solver
- cloud variability
- transition between stratocumulus and shallow convection
Results: Low cloud cover (new-old)

old: CY28R4    new PBL

T511
time=10d
n=140
2001 & 2004
Results: EPIC column extracted from 3D forecasts

![Graphs showing Liquid Water Path and WV Mixing Ratio over time.](image)

- **Liquid Water Path [g/m²]**
  - Local Time [October 2001 days]
  - Model Levels

- **WV Mixing Ratio [g/kg]**
  - Pressure [hPa]
  - Model Levels

Legend:
- red: old PBL
- green: new MK PBL
- blue: EPIC obs

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ARM SGP, number of cloudy hours in July 2003

Cloud radar

Model

Model lacks afternoon shallow cumulus

Sylvain Cheinet (2005)
ARM SGP, daily 36 hr back trajectories, July 2003

Cross section of model moisture and cloud cover for fair weather days in July 2003 (q: shaded; cc: contours at 0.01, 0.02, 0.05)
ARM SGP, surface fluxes (model/obs)

Monthly domain averaged diurnal cycle

West-East change of LE/H

Time evolution of LE and H for station C1
ARM SGP, 2m T/q, BL wind (model/obs)

28R1

28R1 +MO stable BL

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ARM SGP: Sensitivity to shallow convection

Cross section of model humidity difference for fair weather days in July 2003 (Effect of No Shallow Convection)

Cross section of model humidity difference for fair weather days in July 2003 (Effect of halving shallow convection mass flux over land)
Boundary layer cloud issues

• The switching algorithm is unsatisfactory. Unification between stratocumulus and shallow cumulus is desirable. What is the physical mechanism that controls the regime?

• Numerics of inversion handling

• Cloud top entrainment?

• Closure for shallow convection?

• Does a scheme have the correct feedbacks and how can we test this?

• What is the role of shallow convection in more complicated situations (cold air outflow, momentum transport)
Geostrophic drag law

\[
\frac{U_G}{u_*} = \frac{1}{\kappa} \ln\left( \frac{u_*}{f z_{om}} \right) - \frac{A}{\kappa} \quad \text{drag}
\]

\[
\frac{V_G}{u_*} = \frac{B}{\kappa} \quad \text{a-geostrophic angle}
\]
Operational verification of surface wind

A-geostrophic angle is too small
Operational verification of surface wind

Wind speed is too low during the day and too high at night
SST and surface wind over Eastern Tropical Pacific

Figure 2. The average SST measured by TMI over the 3-day time period 11–13 December 2001. The SST field was smoothed with a 2° by 2° loess smoother to remove small-scale noise from sampling errors in the short 3-day average. The vectors overlaid on the SST field are the QuikSCAT wind stresses on 12 December 2001, spatially and temporally smoothed as described in Section 3c. For clarity, the QuikSCAT stress vectors are displayed on a 2° grid. The white areas and missing wind stress vectors represent missing TMI or QuikSCAT data owing to persistent rain contamination during the 3-day averaging period or to land contamination in the antenna side lobes.
Relation between:
Downstream SST gradient and stress divergence,
Cross flow SST gradient and stress curl.

Figure 4. A schematic summary of the SST influence on low-level winds in the eastern tropical Pacific. The southeast tradewinds blow across the cuspy SST front on the north side of the cold tongue, represented here by the heavy black line. The wind stress magnitudes, represented by the lengths of the vectors, are relatively weak over the cold tongue and strong over the warmer water to the north. The wind stress divergence is strongest where the winds blow perpendicular to isotherms (i.e., parallel to the SST gradient), shown here as the stippled areas. The wind stress curl is strongest where the winds blow parallel to isotherms (i.e., perpendicular to the SST gradient), shown here as the hatched areas.
Figure 9b. The same as Figure 9a, except of wind stress divergence (color) and downwind SST gradient (contours) along 2°N. The downwind SST gradient contour interval is 0.25 °C per 100 km in all panels and the zero contours have been omitted for clarity.
Examples of ERA40 forecast veers

Brown et al. 2005

20020213 12Z+24

20020214 12Z+24

250m T and wind

Surface to 850 hPa veer

>27°
12°→27°
-12°→12°
-27°→-12°
<-27°

Backing on and behind cold front

Veering in warm sector of depression
Atlantic sonde stations

- SST, December 1987
Veering between surface (10m) and 850 hPa wind: comparison of 24 hour ERA40 forecast with 12Z sonde
Composite ERA40 results
(4 winters; Sable, Charlie, Lima and Mike combined)

- When sonde shows big veering, model veers less
- When model shows big veering, sonde veers more
  - Model definitely under-veers
- When sonde shows big backing, model backs less
- When model shows big backing, sonde veers are similar
  - Model probably under-backs

![Graph showing Composite ERA40 results](image-url)
Errors in ERA40 surface wind direction as \( f \) (surface wind direction)

- Southerly flow at Sable and Charlie likely to be associated with warm advection
  - Insufficient turning across boundary layer
  - Forecast surface wind veered relative to observed wind
- Northerly flow at Sable and Charlie likely to be associated with cold advection
  - Forecast wind direction errors become small, and possibly reverse (lack of backing across boundary layer)
  - Possible that plotting versus wind direction is not selective enough to pick out the strongest cold advection cases where lack of backing is most likely
Impact of resolution and model

- Qualitatively similar results in ECMWF T511 operational model and also in Met Office operational model

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Stable boundary layer diffusion

Diffusion coefficients based on Monin Obukhov similarity:

\[ w' \phi' = K \frac{\partial \phi}{\partial z} \]

\[ K = \left| \frac{\partial U}{\partial z} \right| l^2 f(Ri) \]

\[ Ri = \frac{g}{\theta} \frac{\partial \theta}{\partial z} \left| \frac{\partial U}{\partial z} \right|^{-2} \]
Impact of MOSBL on veers
(1 winter; Sable, Charlie, Lima and Mike combined)

- Typically increased 5° in stable cases
- Further weakening of mixing by reducing length scale from 150m to 50m gives further small increase
Wind direction from QuikSCAT
Wind direction

- Operational models underestimate a-geostrophic angle (what controls boundary layer veering?)
- Stable boundary layers do occur frequently over the ocean
- Real boundary layers are baroclinic (systematic LES simulations covering a wide range of baroclinicity may be helpful?)
T2-difference DJF (ensemble of 6 integrations)

Effect of MO-stability functions instead of LTG

Effect of reducing z0 over land by factor 10

Contours at 1, 3, 5, … K

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Effect of MO-stability functions

Forecast verification
500 hPa Geopotential

Anomaly correlation vs forecast
Area=N. Hem  Time=12  Mean over 32 cases
Date1=20040310 Date2=20040310

Forecast Day

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Surface drag, momentum budget

- Surface drag is controlled by boundary layer mixing and surface roughness length
- Less boundary layer mixing (e.g. in stable boundary layer) leads to less surface drag
- Surface drag (or effective roughness) over land is very uncertain due to terrain heterogeneity effects
Z0-table

4.5 ROUGHNESS LENGTH FOR MOMENTUM (Mafouf et al. 1995)

RVZ0M(1) = 0.15 JPRB  | Crops, Mixed Farming
RVZ0M(2) = 0.02 JPRB  | Short Grass
RVZ0M(3) = 2.00 JPRB  | Evergreen Needleleaf Trees
RVZ0M(4) = 2.00 JPRB  | Deciduous Needleleaf Trees
RVZ0M(5) = 2.00 JPRB  | Deciduous Broadleaf Trees
RVZ0M(6) = 4.00 JPRB  | Evergreen Broadleaf Trees
RVZ0M(7) = 0.10 JPRB  | Tall Grass
RVZ0M(8) = 0.013 JPRB | Desert # Masson et al.
RVZ0M(9) = 0.05 JPRB  | Tundra
RVZ0M(10) = 0.15 JPRB | Irrigated Crops # Crops type 1
RVZ0M(11) = 0.05 JPRB | Semidesert
RVZ0M(12) = 0.0013 JPRB | Ice Caps and Glaciers # Mason et al.
RVZ0M(13) = 0.05 JPRB | Bogs and Marshes
RVZ0M(14) = 0.0001 JPRB | Inland Water # Not used but needs value here
RVZ0M(15) = 0.0001 JPRB | Ocean # Not used but needs value here
RVZ0M(16) = 0.10 JPRB | Evergreen Shrubs
RVZ0M(17) = 0.10 JPRB | Deciduous Shrubs
RVZ0M(18) = 2.00 JPRB | Mixed Forest/woodland
RVZ0M(19) = 0.50 JPRB | Interrupted Forest # New value invented here
RVZ0M(20) = 0.02 JPRB | Water and Land Mixtures # Not used but needs value here
RVZ0M(0) = RVZ0M(8)  | # Bare soil value
z0

z0m; 1

z0m; eja1
CD-control

CD_48 12-fcts from 20040310 to 20040410 by 1; 1(28R1)
TOD+new z0 table

CD48-diff 0-12-hr from 20040310 to 20040410 by 1; eja1(TOD)/1(28R1)
CD-diff 12-fcts from 20040310 to 20040410 by 1; ejav(tod3)/1(28R1)
Zonal mean West-East turb. stress

Control
New z0-table

Zonal mean surf. press. error (step=24)

Control
New z0-table

Control
MO-stab.f.

Control
MO-stab.f.
Error tracking

Control

MO-stab.f.
500 hPa RMS error NH, 200403

Control
MO-stab.f.

500 hPa activity
Divided by Analysis activity
NH, 200403

Control
MO-stab.f.
500 hPa RMS error NH, 200403

Control
New z0-table

500 hPa activity Divided by Analysis activity NH, 200403

Control
New z0-table
Conclusions

• NWP is sensitive to surface drag. Drag is affected by vegetation roughness, orographic effects and stability.

• It is difficult to verify surface drag.

• Roughness lengths are derived from land use data sets, without considering heterogeneity. Results are uncertain.

Research topics

• Derive geometric land use parameters from satellite data

• Run high resolution canopy resolving models to “measure” effective roughness length and its interaction with stability

• Infer surface drag from synoptic development (variational techniques that minimize short range forecast errors?)