GABLS4: an intercomparison case for 1D models to study the stable boundary layer at Dome-C on the Antarctic plateau

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Présentation faite par Eric Bazile pour le DICE workshop
(Exeter 14-16 octobre 2013)
Présentée par Yves Bouteloup à la réunion thématique DEPHY
(19 Novembre 2013)
GABLS4: an intercomparison case for 1D models to study the stable boundary layer at Dome-C on the Antarctic plateau?

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Outline

- Motivations
- Why Dome C on the Antarctic Plateau?
- Status of the 1D case
- Conclusions and perspectives
Motivations

• Under strongly stable stratification and depending on the parametrization used, GCM/NWP models still have an excess of mixing or strong decoupling with the surface \( \rightarrow \) warm or cold bias (Holtslag et al 2013)

• Some NWP models use a Turbulent Kinetic Energy (TKE) scheme such as ARPEGE, AROME, WRF, DWD, but under strong stable conditions the TKE is underestimated

• Following Galperin et al 2007 and Zilitinkevich et al 2008 turbulence survives for \( \text{Ri} \gg 1 \).

• Evaluate the Energy Flux Budget Closure (Zilitinkevitch et al, 2013)
Motivations

• 3 previous GABLS (GEWEX Atmospheric Boundary Study) case:
  • GABLS1 (Cuxart et al. 2006, BLM) ideal case only turbulence \((Ri \sim 0.25)\) Ts prescribed
  • GABLS2 (Svensson et al 2011, BLM) diurnal cycle \((Ri \sim 0.2/0.4)\) Ts prescribed
  • GABLS3 (Bosveld et al 2012, Ecmwf proceedings) composite case from Cabauw data : surface scheme with initial Bowen ratio \((Sh/Lh)\) with \((Ri \sim 0.4/0.6)\)

• GABLS4 : Stronger \(Ri > 1\), surface interaction, easier initialization only temperature, surface fluxes, TKE observed, 2 soundings per day ...
Observations: Antarctic Plateau Dome C / Concordia

- High frequency parameters (10 Hz) from 6 ultra-sonic anemometers: 3D Wind components and sonic temperature
- Low frequency parameters (30 min): air temperature (ventilated and not ventilated), relative humidity, wind speed and direction (*Young*)
- 1 minute solar radiation components
- Sub and surface temperatures
- Radiometer HAMSTRAD (P. Ricaud)
- RS (1 or 2 per day)

Thanks to Gert König Langlo (AWI for PMR, Bremerhaven, De), Christian Lanconelli (ISAC, Bologna, It), Andrea Pellegrini (ENEA, Roma, It), Eric Fossat (LUAN, Nice, Fr)
An homogeneous site?

LGGE tower 45m
December, 10-13th 2009

Temperatur (left)

Wind Speed (right)

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Temperature evolution (Mast data)

Sounding data (TEMP) available

$\frac{dT}{dz} = -12^\circ/18\text{m} \sim -650\text{K/km}$!
TKE at Dome C Antarctica 11/12 Dec2009

TKE computed from the Sonic by O. Traullé

TKE is underestimated at DomeC during night, although the surface temperature is well forecasted → underestimation of mixing
Large scale forcing

- **Forcing terms:** computed with several experiment done with a LAM at 2.5 km AROME (Seity et al, 2011) and with the ARPEGE physics. Time step=60s (SL) with 60 vertical levels and 45s with 90 vertical levels.

- Lateral boundary condition (LBC) from the operational ARPEGE analysis (4DVAR)

- Initial file (upper air and surface) for the LAM at 2.5km from ARPEGE analysis

- A re-analysis of the case with the last version of ARPEGE has started (V. Guidard) to provide better Lateral Boundary Conditions (LBC) for the LAM:
  - Stretched pole at Dome C: 10km
  - Improvement of the snow scheme
  - Using soundings at 00UTC and 12UTC (not used in the real time operational analysis in 2009) and all the levels of the sounding data
Temperature (Kelvin)

Rs Black line

Analyse oper red line

Guess B39G Blue line (V. Guidard) RS haute resolution avec ARPEGE a 10km pole sud

Analyse B39G Green line (V. Guidard) RS haute resolution avec ARPEGE a 10km pole sud (4DVAR partant du 9/12 à 0h)
Vent (m/s)

20091211 at 00UTC

WS DomeC Casse ARPEGE/ALADIN 20091211_00

20091211 at 12UTC

WS DomeC Casse ARPEGE/ALADIN 20091211_12

RS Black line

Analyse oper red line

Guess B39G Blue line (V. Guidard) RS haute resolution avec ARPEGE a 10km pole sud

Analyse B39G Green line (V. Guidard) RS haute resolution avec ARPEGE a 10km pole sud (4DVAR partant du 9/12 à 0h)

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How to compute the dynamical forcing for a 1D model?

- From a 3D experiment:
  - Classical method: from horizontal fields at different level → dependency to the grid, instantaneous output → requires some time and space filtering
  - DDH tool box available in ARPEGE/AROME: computes the budget for each variable. The DDH tool can be used for a single vertical profile or a “box” around the site: all the physical processes are diagnosed and the total tendency → the dynamical forcing can be deduced from:

\[
\frac{\partial T}{\partial t} = Dyn + \frac{\partial T}{\partial t}_{ray} \downarrow + \frac{\partial T}{\partial t}_{turb} \downarrow + \frac{\partial T}{\partial t}_{shall} \downarrow + \ldots
\]

Physics _ parameterizations

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METEO FRANCE
Toujours un temps d’avance
How to compute the dynamical forcing for a 1D model?

- In an ideal case, the dynamical term should be the same if we use different physics or options in the same model.

- Otherwise, it gives us an idea about the uncertainties for the 1D experiment.

- The choice of the forcing and the type (nudging, advection etc.) is a compromise between two goals: keep the model close to the observations and let them to develop physics bias!
The 1D Case

• Surface observation, sensible and latent heat flux, LW and SW fluxes (Christian Lanconelli ISAC CNR) TKE, and sounding data at 00 UTC and 12 UTC.

• Starting 11 Dec 2009 at 00UTC: Initial profile coming from the RS for T and Q, the wind is initialized with the geostrophic wind.

• Advection and geostrophic wind computed from a 2.5km model.

• Specific humidity advection every 12h: very small impact not really necessary.

• Temperature advection every 6 or 12h and geostrophic wind (profile every 6h/12h) and/or wind advection
**Impact of the atmospheric forcing**

- **Initv1**: wind and T advection
- **Initv2**: T advection and geos. Wind
- **Initv3**: T advection and geos. Wind from re-ana
- **Initv4**: New T advection and geos. Wind from initv2

2 physics: AROME and ARPEGE

Init v1: colder during night for both physics
**Impact of the atmospheric forcing**

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**Surf Temperature**

SCM-MUSC

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**Impact of the atmospheric forcing**

**Initv1**: wind and T advection

**Initv2**: T advection and geos. Wind

**Initv3**: T advection and geos. Wind from re-ana

**Initv4**: New T advection and geos. Wind from initv2

2 physics: AROME and ARPEGE

After 12 hours 3 groups:
- Init v1: SHF ~ 0 during night
- AROME with Initv2 and Initv4
- ARPEGE less sensitive between initv2, v3 and v4
December, 10-13th 2009

The SURFEX/CROCUS scheme will run driven by the observation → provide temperature profile to « replace » the missing data in the snow pack (E. Brun and O. Traullé)

Manual temperature observation at – 10cm
Conclusions & Perspectives

- Atmospheric forcing are almost defined.
- A new re-analysis with high vertical resolution of sounding will be done (end October).
- Impact of the atmospheric forcing on 2 physics has been studied → information about the impact of the uncertainties in the atmospheric forcing on the 1D results.

Perspectives:

- Description and the forcing will be available end of 2013.
- Two experiments:
  - One experiment with land/snow scheme interaction
  - One experiment with prescribed surface fluxes and Ts.
- Possible LES experiment using the same forcing and the prescribed surface fluxes. (H. Barral and F. Couvreux)
- Evaluate the Energy Flux Budget Closure (Zilitinkevitch et al, 2013)
Some weaknesses for $\text{Ri} >> 1$

• Following Galperin et al 2007 and Zilitinkevich et al 2008 turbulence survives for $\text{Ri} >> 1$. Is it the case with the TKE scheme?

\[ \text{Pr} = \frac{K_m}{K_h} \]
Some weaknesses ...

- With the 1D case (GABLS1 and GABLS3) and the 1D Model MUSC with the AROME and ARPEGE physics, we can verify the dependency of the Pr number vs Ri

\[ \text{Pr} = \frac{K_m}{K_h} = \frac{\alpha \theta \phi}{\alpha} \quad \text{with} \quad \alpha \theta = \phi. \]

\[ \phi = \frac{1}{C \cdot \beta \frac{L_m}{e_T} \frac{\partial \theta_{vl}}{\partial z}} + C \cdot \beta \frac{L_m}{e_T} \frac{\partial \theta_{vl}}{\partial z} \]

Assuming a stationary TKE without turbulent transport, it is possible to approximate Phi3 as a function of Ri (Cuxart 2000 eq 21). Moreover in cloudy case the impact is very detrimental!

\[ \text{TKE with } \phi = f(R_i) \]

E. Bazile et al (2011) (ECMWF Proceedings)
Energy Flux Budget Closure (Zilitinkevitch et al, 2013)

TPE : Turbulent Potential Energy  
\[ E_p = -\left( \frac{\beta}{\partial \theta} \right) \cdot \theta \]

\[
\frac{\partial E_p}{\partial t} = \text{advec} - \beta(\overline{w'\theta'}) - \frac{\partial \rho \overline{w' E_p'}}{\partial z} - c_p \cdot \frac{E_p'}{l}
\]

\[
\frac{\partial \epsilon_T}{\partial t} = \text{advec} + P_d + \beta(\overline{w'\theta'}) - \frac{\partial \rho \overline{w' \epsilon_T'}}{\partial z} - c_\epsilon \cdot \frac{\epsilon_T'}{l}
\]

The buoyancy flux appears with opposite signs and describes nothing but the energy exchange between TKE and TPE. For stable conditions and during transition in late afternoon the Buoyancy flux becomes negative and can be considered as an ultimate killer of turbulence (Zilitinkevitch et al, 2013)
Energy Flux Budget Closure (Zilitinkevitch et al, 2013)

![Graph showing energy flux budget closure](image)

**Fig. 3** The shares of the turbulent kinetic energy $E_K$: longitudinal $A_x = E_x/E_K$ (along the mean wind, red circles), transverse $A_y = E_y/E_K$ (green squares) and vertical $A_z = E_z/E_K$ (black triangles), after the Kalmykia-2007 field campaign of the A.M. Obukhov Institute of Atmospheric Physics of the Russian Academy of Sciences (courtesy of Rostislav Kouznetsov). The lines show our inter-component energy exchange model, Eq. 50, with $C_0 = 0.125$, $C_1 = 0.5$ and $C_2 = 0.72$, converted into $z/L$ dependences with the aid of Eq. 71
Energy Flux Budget Closure (Zilitinkevitch et al, 2013)

Partial EFB Closure in ARPEGE:
- new prognostic variable for Ep
- new computation for Km/Kh (anisotropy effect via Ez)

\[ K_M = \alpha_M \cdot l \cdot \sqrt{e_T} \quad \rightarrow \quad K_M = \cdot C_\tau \cdot E_z \cdot \frac{l}{\sqrt{e_T}} \]

\[ K_{\theta/q} = \alpha_\theta \cdot K_M \cdot \phi \quad \rightarrow \quad K_{\theta/q} = \cdot C_F \cdot E_z \cdot \frac{l}{\sqrt{e_T}} \cdot \left( -C_\theta \frac{E_p}{E_z} \right) \]