Workshop on Diurnal cycles and the stable boundary layer
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Note:

The contributions in this document are also available from the ECMWF website:
http://www.ecmwf.int/publications/

Introduction and main conclusions

This workshop was part of the regular series of workshops organized by ECMWF to review the science in a particular area of research and to get advice from the community on how to proceed with model development. The topic of this workshop was on “stable boundary layers and diurnal cycles”, which has been a major subject of the GABLS project for about 10 years (here GABLS refers to the Gewex Atmospheric Boundary Layer study, see www.gewex.org). It was therefore important to organize this workshop together with GABLS and to review what has been learned and to decide how to proceed.

One of the reasons for having a workshop on stable boundary layers and diurnal cycles is that model output of near-surface weather parameters like temperature and wind is increasingly used by NWP users either with statistical post-processing or even directly. The diurnal cycles of temperature and wind are strongly influenced by small scale atmospheric processes in the stable boundary layer, in particular by turbulent diffusion, gravity waves and radiation, but also by the thermal coupling to the underlying soil through vegetation and snow. It appears that the large scale model performance is very sensitive to the details of the boundary layer formulation. Most large scale atmospheric models utilize rather diffusive boundary layer schemes resulting in stable boundary layers that are too thick, show too little wind turning, and underestimate the strength of the nocturnal jet. Climate projections show strong temperature signals at high latitudes which are affected by the above listed processes.

The workshop was divided into two parts: (i) two and a half days of oral and poster presentations covering the topics mentioned above, and (ii) one day of working group discussions followed by a plenary discussion session.

The presentations focused on all the physical aspects relevant for a realistic simulation of the stable boundary layer. The scientific issues were further discussed in the working groups covering: (i) processes, (ii) tools like LES and observations, (iii) parameterization schemes, and (iv) land surface interactions. The working groups were asked to make recommendations for large scale modellers and for further research in GABLS. The complete report on the working group discussions including recommendations is included in these proceedings.

A few of the main conclusions are:

- Uncertainty in the formulation of diffusion in stable situations remains high. No clear way forward was identified, but it is clear that the effects of meso-scale variability and terrain heterogeneity are important and need further study.
- It is well accepted now that the stable boundary layer is highly interactive with the underlying surface. It was therefore recommended to base further studies on the coupled system. Also for LES it was recommended to have at least a simple representation of the surface energy balance in future simulations.
- The uncertainty in the momentum budget is large in models. Sensitivity experiments show a direct impact of drag over land on the planetary scales. To diagnose this aspect further, a model inter-comparison study was proposed.
- Many models have biases in the long wave downward radiation even in clear sky situations. Verification studies using e.g. BSRN were recommended.

- More diagnostic studies of large scale models are needed to assess the behaviour of the boundary layer and its interaction with the surface. It was recommended to use super-sites (CEOP, FLUXNET) with a comprehensive set of observations e.g. in the context of the planned CORDEX-Europe initiative or possibly an “Arctic activity”.
- Large scale modellers should consider to move towards the use of Turbulent Energy equations to support the turbulence closure.
- Recommendations for the land surface include: (i) the use of a shallow top soil to represent fast time scales, (ii) the introduction of a multi-layer snow schemes to replace slab models, (iii) full exploitation of as many observational sites as possible to derive relevant model parameters, and (iv) the use of data assimilation techniques to "inverse model" land surface parameters.
- It was recommended to define a new GABLS case for uniform snow. This is a way of studying the interaction with the surface without having to deal with the complexity of heterogeneous terrain.

As organizers we would like to thank all participants for their excellent contributions. The guidance given by the working group discussions and the recommendations will be extremely helpful for the planning of further work at ECMWF and other centres, and for defining new activities in GABLS. Special thanks to Els Kooij-Connally, Rob Hine, and Anabel Bowen for skillfully preparing these proceedings.

The workshop organizers,

Anton Beljaars (ECMWF)

Bert Holtslag (U. Wageningen, co-chair GABLS)

Gunilla Svensson (U. Stockholm, co-chair GABLS)

Working Group Reports

WG 1: Physical mechanisms controlling stable conditions

Participants: J. Cuxart (Chair), P. Bechtold (Rapporteur), P. Anderson, S. Basu, F. Couvreux, D. McNider, D. Mironov, C. Nappo, C. Staquet, G.-J. Steeneveld, M. Udina, B. van der Wiel.

The main objective of this WG was to review the relevant science and make recommendations for future lines of research and development on the relevant physical processes in the Atmospheric Boundary Layer (ABL), within the general framework of developing the best possible representation of them in large scale models, like those used for numerical weather prediction or climate modeling.

The more detailed questions are:

i. Which processes need attention: turbulence, radiation, internal waves, meso-scale variability, terrain heterogeneity, other?

ii. What controls the evening transition?

iii. What is the physical background of the long tails in many parameterizations of turbulence (e.g. in the ECMWF model) and should there be a different treatment for land and ocean?

iv. Are momentum and heat transport different and, if so, why? Do waves make significant drag and at what scales?

Furthermore, GABLS would like to define high priority scientific questions that need study, and experimental and numerical configurations to address these questions.

Turbulence

The previous GABLS cases (1) have illustrated that weak to moderately stable stratification can be satisfactorily studied by Large-Eddy Simulations (LES) and that the one-dimensional operational and research parameterizations (at orders 1 and 1.5 in their majority) are able to capture the main features but with a large dispersion in key parameters such as the height of the nocturnal BL. Also the transition times in the morning and the evening are represented differently. Also a sensitivity was found to the treatment of the lower boundary condition and the dynamic forcing.

The more stable cases, with weak and not necessarily continuous turbulence, are still a subject that needs further study. An increased understanding is needed of the processes and their representation in large scale models. It is therefore advised to pay more attention to situations with strong stable stratification. These cases are normally observed when the synoptic forcing is weak (geostrophic wind below 5 m/s) and the surface cooling is large enough to generate a strong stratification close to the surface (2).

It is a matter of debate if the turbulence in this regime, very often sporadic or intermittent, is generated as the result of an internal process of the flow -such as the passage above the threshold of some critical value due to acceleration of flow decoupled from the ground, or some effect related to the internal waves - or due to some external forcing, probably related to the effects of heterogeneities -at different scales- in the surroundings of the point of interest. It is felt that it is probably a combination of both factors. (3)

This regime is usually misrepresented in models, because the parameterizations generate sustained turbulence (the MO formulae) instead of sporadic mixing events (that may be important) and this may be one of the reasons why the long-tails are used as a surrogate: to produce in an averaged and sustained manner the short-lived intense mixing events that happen in reality.

RECOMMENDATION: To study a case with strong stability, in which the effects of the terrain heterogeneity are minimized, in a way that the attention can be focused on the internal processes in the flow, such as the interplay between production by wind shear and destruction by negative buoyancy, and the role of the internal waves in the process (see below). An approach similar to the first GABLS case is suggested, making a case that could be simulated by LES and then run by a number of parameterizations.

A possibility is to build a case from the observations made in the Halley station of the British Antarctic Survey (BAS) in Antarctica, a site where studies on intermittent turbulence, radiation and internal waves have been carried out in recent campaigns. It would also be worth to see at what geostrophic wind the intermittent regime starts. BAS will inspect its database and see if it can propose a case suitable for the subjects mentioned above (4). Similar cases could be built from Weddelsee data (FMI).

Aims of such a study would be to see if LES can generate the observed (intermittent?) turbulence and to what point the parameterizations are able to reproduce this behavior or what changes should be made to represent the observations. Expected changes could include revision or elimination of similarity formulae in the surface layer or inclusion of extra features in the current parameterizations.

Internal (gravity) waves

Stable stratification can sustain internal gravity waves (IGW) up to the Brunt-Vaisala frequency (N). The presence of IGW's depends on factors that may generate them, locally or at distant locations. They may be generated by topographic obstacles, changes of surface roughness or even cold air areas acting as obstacles.

Waves may propagate for long distances or evanesce shortly after their formation. Therefore, their presence in one point does not necessarily respond to the meteorological conditions at this point (5) However, these local conditions put limits on what range of frequencies are possible (through the upper N-limit).

The ability of models to generate waves depends on their configuration. They may generate waves according to their explicit representation of the topography or other heterogeneities, but will miss any generated at subgrid scales. Exploration of real effects of IGWs is a necessity and still needs more experimental work in order to be able to develop suitable parameterizations for models.

It must be mentioned that other fields have more experience in the treatment of IGW, such as fluid dynamicists in water tanks or with DNS, especially in the phase of development of the wave and its eventual breaking, or oceanographers, that deal with waves propagating in the stably stratified ocean.

RECOMMENDATION: To review the literature from these communities.

IGW's transport momentum but not heat. Sporadic mixing can occur if the IGW breaks. However, a wave modifies locally the profiles of temperature and wind as it passes by. In consequence, IGW's could vary temporarily the Richardson number and allow for mixing in some phases of their propagation even without breaking.

It is agreed that more knowledge on IGW's in the stably stratified ABL is needed, also from statistical and climatological points of view. It is necessary to see if they are a quasi-permanent feature or just a sporadic occurrence. It is expected that the observations from the Halley Antarctic station can provide valuable information on this subject.

Radiation

In earlier boundary layer studies the effects of radiation were often neglected. However, it is widely acknowledged now that the effects of radiation are highly interactive and can not be ignored, especially in the stably stratified ABL and in the morning and evening transitions. In terms of surface energy budget, the radiation fluxes are by far the largest and the net radiation is often as uncertain as the other terms. Therefore, a numerical study that uses the energy budget as part of the surface boundary condition must take into account the net radiation term (6).

The vertical divergence of radiation is also a significant term, especially in very stable cases and in the evening transition, and close to the ground. This implies that it should be taken into account, either with the use of a detailed radiation scheme or, for idealized cases, with a simplified parametrization. For very stable cases, the nocturnal vertical divergence of radiation may even change sign close to the ground (warming in the first centimeters) and contribute significantly to cooling in the first meter above the surface. However, the vertical divergence of radiation is difficult to measure (although it has been done successfully in a few experiments), as it is at the limit of the resolution of the sensors, and very much affected by the local surface heterogeneities.(7)

The current approach is to run detailed radiation schemes (with vertical resolutions of the order of millimeters close to the surface) whose values can be compared with measurements for validation. The computed fluxes can be used as forcings for the single column models at lower resolutions and, since these very high vertical resolutions are out of reach for operational models, these effects should be parameterized.

RECOMMENDATION: In the idealized very stable case that may be constructed for an Antarctic station it is necessary to pay special attention to radiation e.g. by using detailed observations. Analysis of other recently gathered datasets is also recommended.
Finally, the effect of the net radiation seems to be dominant in the morning and evening transition periods and should not be ignored. (8)

Surface heterogeneity and topography

In flat conditions, surface heterogeneity is linked to thermal differences, normally resulting from the soil and vegetation variations. As discussed in the workshop, these differences generate variance of near-surface temperature which, in turn, is a positive term in the evolution equation for the temperature flux. Thus, thermal surface heterogeneities contribute to the generation of mixing of heat and opposes the formation of very strong stratification close to the ground. It is also a subject of current and further research to see how these heterogeneities shape the turbulence compared to homogeneous surfaces and to see how their effect could be parameterized. (9)

Topography affects the flow structure and generates associated pressure gradients that may locally induce areas more prone to turbulent mixing or to the formation of stagnant areas. If models are able to explicitly reproduce these effects, their turbulence schemes should be able to generate the corresponding associated turbulent fluxes, otherwise they should be parameterized, as seen in an example shown in the workshop (10).

Topography is also a generator of thermal gradients that may initiate thermally driven circulations, such as up- or down-slope flows or slope/plain or water/land circulations. Again these processes may be explicitly seen by models, otherwise they have to be parameterized. These circulations normally have the shape of a low-level jet, which is a structure that alters completely the characteristics of the layer near the surface, since it enhances mixing by wind shear and diminishes significantly the thermal stratification (11). To generate them, fine vertical resolution is necessary. The turbulence scheme and/or the numerical scheme must not overestimate the mixing, because it will wipe out these structures and will not be able to generate the appropriate vertical wind shear, leading to an incorrect representation of the near-the-surface mixing processes.

RECOMMENDATION: It is recommended that specific studies dealing with these aspects are undertaken, maybe using data of some recent experiments dealing with surface heterogeneities. It is clear that these studies should be made with coupled atmosphere-soil-vegetation schemes since these subsystems interact in a strongly non-linear manner.

Discussion on the specific ECMWF questions

Long tails over land. The working group concludes that the use of long-tails is an attempt to represent all the missing effects described above, such as subgrid heterogeneity and the corresponding temperature variance, low-level jets with associated shear-driven turbulence, small scale topographical variations or internal waves. Many of these effects take place on a very local scale and, therefore, should be locally addressed, perhaps through some point-specific statistically forcing fields. Long-tails generate a permanent mixing regardless of the local features (they are only function of the grid-scale vertical profiles) and may overestimate mixing in some cases and underestimate it in others. It is expected that, as these effects will be incorporated in models, long tails will have to be revised and, ideally, removed. Finally, if long tails are used in the surface layer and above, it may be sensible to modify them differently, depending on what the most important processes at every level are.

Long tails over the ocean. Over the ocean, heterogeneity is less than over land, except near land-sea discontinuities, but the effect of sea waves enhancing surface roughness has to be parameterized. It is recommended that functions over the sea are different from the ones over land since the reasons for using them are essentially different.

Morning and evening transitions. It is acknowledged that models behave very differently in these transition periods and that there is need for further understanding. Experimental and theoretical studies are under way, but still in a preliminary stage. Radiation and soil-vegetation processes play a prominent role when the wind is weak.

Momentum and heat mixing. It is recognized that the mixing efficiencies for momentum and heat may be significantly different. This could be taken into account by using a more complex system of equations (2nd order), a better treatment of the surface boundary conditions and/or through a parameterized turbulent Prandtl number. It is recommended that LES and experimental studies are looking into this issue to provide more insight on how to improve its parameterization. On the other hand, if internal waves prove to be ubiquitous, their contribution to momentum mixing could be very relevant and explain part of the different mixing efficiency.

(1): Holtslag, Svensson, Basu, Bosveld; (2): McNider, Van der Wiel; (3): Cuxart, Nappo, Mironov and Sullivan, Stoll; (4): Anderson; (5): Nappo; (6): Edwards, Bosveld, Mauritsen; (7): Edwards; (8): Bosveld, Svensson; (9): Mironov & Sullivan, Stoll, Cuxart; (10): Lock; (11): Cuxart.

WG2 Tools to support parametrization development

Participants: B. Beare (Chair), F. Di Giuseppe (Rapporteur), C. Ansorge, F. Beyrich, L. Caporaso, A. Ghelli, N. Harvey, C. Heret, R. Honnert, M. Khairoutdinov, T. Neves, R. Stoll, M. Tjernstrom, K. Walesby.

The discussion in this working group concentrated on new ways of combining Large-Eddy Simulation (LES), high resolution numerical weather prediction (NWP) and observations in order to inform parametrization development for the boundary layer (BL). After a discussion of the existing parametrization problems, observational datasets to address them were reviewed. The working group then focused on the key scientific questions and outlined the methodology required to answer them. Finally short and long term recommendations for ECMWF and GABLS were defined.

Existing parametrization problems

The table below lists key parametrization problems, and some of the strengths, weaknesses and challenges of addressing these problems with either LES or high resolution NWP.

Parameterization problem	LES	High resolution NWP
Polar clouds	Yes, through idealised initial conditions	Easier to force with analyses
Land surface BL coupling	Need to implement land-surface scheme	Land-surface scheme implemented
Very stable BL	Turbulence too weak for LES?	Easier to include orography.
Sub-grid heterogeneity	Yes, LES has been performed for LITFASS by University of Hannover	Revisit blending height
Radiation BL interaction	Yes, resolve sharp temperature gradient	Yes
Terra-incognita (grey zone) around 1 km horizontal grid length	Yes, but have to link to use of column schemes	Can be a problem at intermediate scales for convergence
Transitions (morning, evening)	Certainly needs investigation. Has been found critical in GALBS-2	Look at GABLS-2
Gravity waves	Non local, LES domain for sustainable waves too small.	Cannot address this problem

Observations to address parametrization problems

The table below lists existing observations available to address the parametrization problems and an assessment of the feasibility of future campaigns. It appears that much more data exists than is actually exploited by modellers.

Parameterization problem	Observation set	Future campaigns?
BL clouds	VOCALS DYCOMS-2 CHUVA ARM-super sites	It seems out of reach to propose a new field campaign For most of the critical parametrization issues data are already available either through the long term super sites (e.g. ARM) or through specific campaign as listed in this document. It is nevertheless emphasised that the data available are often not tailored for LES simulation and a substantial effort is required for their use by the LES community.
Land surface BL coupling/heterogeneity	BLLAST, LITFASS, CEOP, ARM. Also datasets exist of continuous surface observations collected by the regional model consortia (SRNWP-COSMO data pool).	
Very stable BL	CASES-99 TWA-ice Antarctica –Halley (ice shelf) Weddelsee	
Sub-grid heterogeneity	LITFASS	
Radiation BL interaction	CASES-99, Greenland, Wageningen	
Terra-incognita (grey zone)	HATS	
Transitions (morning, evening)	BLLAST, LITFASS	
Gravity waves	Antarctica-Halley	

Key science question and methodology

Given the challenges above, it was felt that the most feasible project for GABLS, involved answering the following scientific question: “What is the role of land surface coupling in the evolution of the stable boundary layer (SBL)?” To address this question, different aspects have to be considered. .

Observed case

The group identified the three scenarios of the very stable BL, the transitional BL and the heterogeneous BL, associated with the following observational data-sets:

- Evening transition boundary layer: BLLAST
- Very stable BL: Halley
- Heterogeneous BL: LITFASS

It was also noted that several other good observational sites are available for this purpose including: Cabauw, Cardington, CASES-99, ARM. Particularly, the continuous observations from Cabauw, Cardington, Lindenberg and ARM can provide a wider set of cases to choose from.

Observations for initialising and forcing LES

• Large scale forcing (Geostrophic wind, subsidence and tendencies) from reanalysis or regional models. For stable BL's, the geostrophic wind is particularly critical, but often difficult to diagnose.

• Geostrophic winds from radiosondes and wind profilers.

• Surface initialization (e.g. time series of surface parameters) from integrated measurements of soil and surface observations.

Land surface configurations

Since the range of LES models is familiar to many in GABLS, we focus here on the new issue of implementing the land surface schemes. The group felt that in order to draw in as many participants as possible into an inter-comparision, there needed to be a hierarchy of land surface models, for example:

- Full land surface schemes (preferably open sources as e.g. NOAH and JULES) with full radiation schemes.
- Surface energy balance with simplified radiation scheme (e.g. Edwards, GABLS-3), and soil transfer.
- For initial experimentation with LES, extremely simple surface energy balance formulations are preferable e.g. in the form of a few lines of code only.

RECOMMENDATIONS for ECMWF and GABLS

Short term:

- More interaction between the LES boundary layer and land-surface scientists.
- Form a working group to prepare a land-BL case. This should include a review of existing LES/Land surface work and observational sets. The work led by Raash at Hannover University on LITFASS could be a starting point.
- Diagnose Geostrophic wind for case studies.

Long term:

- Develop suites of well-documented benchmark cases to improve parameterization.
- Include regional model simulations.
- Develop better links with the climate modelling community.

WG3: Representation of stable conditions in large scale models

Participants: A. Lock (Chair), I. Sandu (Rapporteur), W. Angevine, V. Barras, E. Bazile, A. Cheng, T. Hara, M. Kleczek, T. Mauritsen, F. Pithan, B. Stensen, M. Sterk, G. Svensson, A. Zadra.

Level of complexity needed in large scale models

The group noted that operational centres are increasingly using some form of prognostic turbulence variable (such as TKE) in their vertical mixing parametrization (e.g. JMA, CMC, MeteoFrance, DWD) leaving, to the knowledge of those present, just ECMWF, Met Office and NCEP using first-order closures. In addition to allowing advection of turbulence by the resolved flow to be represented, such schemes also lead to a spatially smoother evolution that has been found to improve numerical stability characteristics. In the GABLS2 SCM inter-comparisons (Svensson et al, 2011) there was no obvious benefit for higher order closures over first order in simulating the boundary layer diurnal cycle. One key benefit noted though, is that prognostic turbulence allows a natural specification of the mixing length in the free troposphere (e.g. square root of energy divided by buoyancy frequency), something for which there is no current alternative (to the knowledge of those present) in a first order scheme.

Key areas of uncertainty

The group discussed the areas of uncertainty concerning the representation of stable conditions in large-scale models, and dwelt on the main questions on which further research is needed for making progress in this area:

1. As a general point, it was noted that many of the biases currently seen in models in stable boundary layers are not only caused by the representation of stable conditions, but are also related to the impact of cloud errors on the surface radiation budget, or to the representation of other processes or interactions such as the land/atmosphere coupling, or the orographic drag. So reducing the cloud errors and improving the representation of all the relevant processes and interactions remains a priority.
2. Heterogeneity is the main argument to justify the additional mixing used in large-scale models (e.g. by using "long tail" instead of "short tail" stability functions). However, such extra diffusion that accounts for unrepresented heterogeneity, is hard to quantify. Potential mechanisms affecting the additional diffusion are surface heterogeneity (topography, roughness and thermal characteristics), and the generation of local shear and partial cloudiness by meso-scale flow. There is no consensus on how these effects could/should be represented other than by increasing the turbulent diffusion everywhere.
3. Strongly stably conditions are characterized by intermittency. It is not clear how to represent mixing when it is dominated by isolated bursts, either when these are internal to the turbulence or when generated remotely and propagating.
4. The relative efficiency of mixing of heat, moisture, passive tracers and momentum is not well known. How do they vary as a function of stability? There were several qualitative examples given where enhanced scalar mixing (either CO2 or pollutants) over heat appeared to be beneficial but there is no direct observational evidence to justify it.

RECOMMENDATIONS:

1. Improve understanding of surface down-welling LW biases in clear skies:
    a. Is there a consistent reason for the nocturnal underestimation of the surface down-welling LW in GABLS3 for almost all SCM's? Is there a consistent bias above the boundary layer too? Can we understand the reasons for the initial differences between the models and with observations (which gases are included, assumptions about aerosols etc.)? How well do the schemes perform on selected cases from radiation inter-comparisons?
    b. Examine biases in GCM's compared to available surface sites (e.g. ARM and BSRN), both in case studies but also statistically – is there a systematic bias in the clear sky end of the distribution?
    c. It would be very beneficial to increase expertise in radiative transfer within GABLS3 and GCM surface analysis (e.g. via GASS).
2. Examine the vertical structure of the near surface temperature bias in GCM's:
    a. For example, do regions of cold screen T (at 2m) coincide with regions of strong lowest model level to surface T gradient? How accurate is the screen T interpolation in such regimes? MeteoFrance reported good improvements to screen T forecasts in light winds over snow from including a fine vertical grid and turbulence parametrization between the lowest model level and the surface (Masson and Seity, 2009) and the Met Office have also introduced a new screen diagnostic that takes into account radiative coupling in light winds.
    b. Do surface (radiative) skin T biases against satellites correlate with screen biases? Are satellite data available at high latitudes?
3. Momentum budget comparisons between GCM's were thought to be potentially very revealing. To spin up collaboration in this area it was suggested to start with simple fields and then develop more complex diagnostics in the future. A possible plan would be:
    a. Initially, how do surface stress, roughness length and bulk drag coefficient (e.g. calculated from surface stress and 850hPa wind) from different global models compare? This is already being evaluated for CMIP5 models (Gunilla Svensson) and she was willing to include additional models in her analysis.
    b. Consider whether initial tendency diagnostics could be used to identify regions of drift. Do different models show similar balances between sources of drag (large versus small scale orography versus turbulent drag)?
    c. Investigate ideas for evaluating sensitivities in the large scale circulation to changes in boundary layer parameters (such as less diffusive mixing).
4. There was a general request for more intelligent methods to evaluate the performance of boundary layer parametrizations, in addition to basic comparisons with site data, where the ability of a model to match observed sensitivities is evaluated (e.g. relationship between the drop in nighttime temperature and the decrease in boundary layer height (Betts) or surface wind angle versus SST gradient (Chelton)).

Future GABLS inter-comparison

1. It was felt there is still a lot to be learned from GABLS3:
   a. How different are the SCM's if the surface down-welling LW flux is specified and if different models are run with the same radiation scheme?
   b. What is the relative importance of the land surface?
   c. Are we any closer to being able to run LES of the diurnal cycle, with interactive radiation and land surface? Do they also underestimate LW fluxes?
2. The preferred option for a new GABLS case was to move into the very stable regime, for example revisiting GABLS1 with a simple surface scheme and to explore sensitivity to a range of different stabilities (neutral, weakly and strongly stable). It was thought it would be very interesting to include some form of passive scalar transport (see uncertainty 4, above).
3. It would be very useful if previous inter-comparison case datasets could be archived and made available for future analysis, e.g. via GASS.

WG4: Surface interaction

Participants: A. Verhoef (Chair), G. Balsamo (Rapporteur), P. Bauer, M. Best, F. Beyrich, G. Bonafe, F. Bosveld, S. Boussetta,.E. Dutra, M. Ek , J. Edwards, B. Holtslag, T. Kilpeläinen, P. Lemoigne, J. Lyndval, R. Santos, I. Trigo, P. L. Vidale.

The working group has followed the proposed questions and tried to answer with elements brought up by the working group members highlighting recommendations and priority.

What level of complexity is needed in the parametrization of the surface atmosphere interaction to obtain good temperature diurnal cycles and a good representation of surface drag?

The working group believes that understanding the coupling problems should be a first priority and deserves focus. The scales of relevance help to confine the problem (start from local scale). Using state-of-the-art coupled atmosphere/land models (e.g. including radiation schemes) reduce the risk of looking at land- and/or PBL-issues separately and too simplistically. Important questions are: where do we have the largest deficits and gaps in understanding i.e. vegetation (forest vs. grass), bare-soil, snow, water-bodies, ice? The coupling problems for day time and night time are not the same. The day time energy partitioning between sensible and latent heat fluxes is still highly uncertain and dependent on a number of parameters (e.g. vegetation, soil moisture) whereas at night the latent heat flux tends to be small and the partitioning between heat flux and ground heat flux is a major issue. Both day and night time coupling problems will require close collaboration between the GABLS and GLASS communities. This workshop had its main focus on the night time issues. For stable conditions it was suggested to start with a “simple” problem e.g. over a flat uniform snow surface to avoid the additional complexity of land heterogeneity.

Options for cases that can be run in a LSM-PBL coupled and uncoupled mode are: GABLS-2 or GABLS-3 provided it is revisited by PBL experts to identify problems, CHEAS tower in US, the Weddelsee dataset with 4-month observations over sea-ice (Tiina Kilpeläinen, FMI), and Antarctic data e.g. from Halley.

RECOMMENDATION:

It is recommended that Bert Holtslag/Gert-Jan Steeneveld (GABLS) and Martin/Mike (GLASS) coordinate a common experiment (possibly collecting and revisiting all GABLS cases) or propose an ensemble of cases (comparable for meteorological conditions).

PRIORITY: High.

What kind of data and diagnostics is available or required to analyze the relative importance of atmospheric and surface control on near surface cooling? Near Surface processes?

Data types to consider are:

1. Field data (Flux-towers, PBL profiles, vegetation and soil data).
2. Remote sensing data (that are accurate enough to inform about model errors), LST from Land-SAF, SMOS/ASCAT soil moisture products.

3. Re-analyses are a way to combine models and different types of observations. However, it can be a problem to estimate the land model error component in re-analyses. The study of GSWP2-AMMA products, and the consideration of accuracy of the forcing, are important to understand the limitations.

4. LANDFLUX data (mainly based on satellite data) are independent from re-analysis but have similar caveats as these products have complex error structures.

5. Smaller scales can be useful for process understanding but may not be optimal for GABLS/GLASS cases since interactions at larger scale are important as well.

RECOMMENDATION:

1. For GABLS to consider extremes in the cold-range: snow-cases in a polar region, light winds, stagnant situations in valleys (numerics can be an issue), and heterogeneous/ orographic cases.

2. To use an ensemble of cases with comparable meteorological conditions to estimate uncertainty.

PRIORITY: The priority for new GABLS cases of this type is medium. To define new cases that comply with both GABLS and GLASS requirements, should have high priority.

Can satellite skin temperature observations be used to constrain/optimize surface coupling parameters (e.g. in the ECMWF model: skin layer conductivity, roughness lengths, soil heat diffusion coefficients)? Are there other observations?

The presentations from Isabel Trigo and Anne Verhoef clearly demonstrated that observations can help to constrain uncertain model parameters. FLUXNET and CEOP contain a wealth of all-weather data over a wide range of climate regimes which can be further exploited. MSG-based LST is over a large domain but has the limitation of being reliable for clear-sky conditions only.

RECOMMENDATION: Compare more sophisticated canopy models (e.g. Vidale and Stockli, 2004) to the skin layer approach. It is believed that detailed canopy models can help the development of simplified models (in the same way as LES informs cloud parameterization). Observations of LST should be considered in this development process. Furthermore, canopy to soil coupling (as in the ECMWF model expressed by lambda-skin) should be considered together with increased vertical discretisation of soil, snow and also the PBL.

PRIORITY: The priority is high for the optimization of parameters on the basis of observations for current models, and medium for the use of more complex canopy-models, when they would be available in LSM's.

Can LES simulations be used to improve the understanding of the surface coupling?

LES stems from fluid-dynamics models that can run at high vertical and spatial resolutions and with some sub-grid processes (presentations by John Edwards and Rob Stoll). LES models are very useful for process studies but usually can run for short localized experiments only. Developments towards the inclusion of a LSM into LES are encouraged, maybe starting with bare-soil (including soil heat diffusion).

Radiation and turbulent coupling can be examined in great detail (with sub-second time-step) and local coupling (Rob Stoll's presentation) at the process level (eddy resolving) is very informative. Parameterization can be improved based on the findings with LES, but idealized cases demand careful interpretation of the results. Surface temperature and roughness heterogeneity seem relevant. These runs could be even more interesting if realistic scenarios (real landscape heterogeneity) could be considered together with simple LSM's.

RECOMMENDATION: Include more sophisticated canopy and soil models in LES (a hierarchy of canopy models exists, e.g. best, needed, and affordable) and for GABLS/GLASS community to start such an initiative.

PRIORITY: Medium.

Can other simulations or diagnostics be used to improve the understanding of the surface coupling?

It is felt that current literature is inconclusive at the higher PBL stability range and in the transient phases (therefore MO theory should be re-assessed in these cases).

In terms of diagnostics, the Koster Omega coupling strength index (as in GLACE-1) has a practical 0-1 range informing on the level of land-related predictability, but the caveats of being GCM model based only. In LoCO experiments, several metrics are explored and used in 1-D single column land-atmosphere experiments (c.f. Joe Santanello at NASA).

Can we obtain an observationally-based Omega-type diagnostic? Not exactly as in Koster's case, but definitely as in the LoCO case (Santanello et al., 2011, Santanello and Dirmeyer, 2011). It has to be confirmed whether such a diagnostic is applicable and useful for the stable PBL. If so, it can be applied to GABLS/GLASS experiments.

RECOMMENDATION: Avoid splitting day-time and night-time as separate problems as they influence each other and can lead to wrong interpretation

PRIORITY: High; it should be considered in all future experiments.

Single column experiments can be performed with boundary layer (BL) only (with specified surface condition), with land surface model only (LSM with specified near surface meteorology), and fully interactive. Running all three configurations will help disentangle questions about coupling. Because these simulations are cheap, they can easily be performed for a long period of time, provided that adequate atmospheric forcing and near surface meteorology is available.

The day time situation is dominated by the hydrological cycle for which prescribing a flux boundary condition may work well. For the stable case where the main process is thermodynamic in nature, flux boundary conditions do not work well. Some extra work has to be done to define a good hierarchy of experiments for the stable case.

Several institutes maintain column versions of their large scale model (UKMO, NCEP, DWD, MF, ECMWF) and can also derive the forcing (pressure gradient, advection, state variables) from their atmospheric analyses. A number of locations exist now with excellent long term observation programmes to support such work (e.g. ARM, CEOP, Cabauw, Lindenberg).

The strategy would be to run PBL and LSM first independently and then LSM/PBL coupled to identify problems using well established datasets (observed fluxes as in Cabauw, Lindenberg, etc.). GABLS and GLASS should work together to explore this?

Several issues were identified in relation to this experimental setup:

1. How strongly should the single column be coupled to the observed forcing (e.g. specify observed downward long wave radiation or leave to the radiation scheme)?
2. Specify observed geostrophic wind only, or also relax the state variables in the column towards observations?
3. What kind of observations are needed to have enough information about the processes?
4. There is an advantage in re-using old cases because good quality data and previous knowledge is available. However, long time series from Cabauw and Lindenberg are also attractive.

RECOMMENDATION: It is recommended that GABLS/GLASS encourage the preparation of long forcing data sets to be used by column meteorological modellers.

PRIORITY: High.

Convection resolving models coupled to a land surface scheme (~1 km scale, so not eddy resolving) are of interest to study the coupling strength between land and atmosphere, i.e. to what extent does the land surface contribute to atmospheric predictability? This is interesting because convection parameterization could alter feedbacks and the hydrological coupling can be examined in this configuration.

RECOMMENDATION: none.

Is the roughness length concept sufficient to represent the surface or is more complexity needed (canopy models or roughness dependent on stability)?

This question relates to the first question treated in this working group. It is very well possible that the concept is wrongly posed and that we need more complex canopy models. In the literature there are proposed sophistications which should be discussed in GLASS. GLASS should have a GABLS representative to make the link. Also Zoh is highly uncertain and varies with land use and canopy density (see e.g. Verhoef et al., 1997a). Optimizations are often targeted to improve diurnal cycle of T2m, rather than the skin temperature.

The skin temperature sensitivity to roughness length makes further investigation (in a careful manner) very important. Fluxes are both a GLASS and GABLS priority and it is not clear how to divide studies over GLASS and GABLS .

MF has a Surface Boundary Layer 1-D parameterization (6-layers) developed in the context of Urban applications. The benefit of this scheme was recently also shown for snow-cases (Patrick Lemoigne). This approach moves away from the bulk transfer method in the surface layer and runs the entire NWP model at higher vertical resolution with TKE closure (but cheaper as it considers boundary layer physics only). It does not represent the vegetation canopy explicitly.

RECOMMENDATION: Consider scheme developments and unification of stability function together with increased vertical discretisation of soil, snow and PBL layers.

PRIORITY: Medium.

How to represent interaction with land use heterogeneity and orography?

Statistical treatment (aggregated tiles) versus explicitly resolving heterogeneity, by increasing resolution of both atmosphere and land, is a way to explore the issues. High-resolution coupled runs could also be used to explore blending height issues. It is not clear how relevant the meso-scale advection terms in the surface BL are, and to what extent heterogeneity of the soil columns should be taken into account. If the tiling should include the soil columns, do they also exchange water and energy below ground?

It was suggested that for resolutions between 2km and 200km subgrid heterogeneity matters. At higher resolution it is believed that using tiles does not present an advantage. Case studies could be considered to study circulations due to heterogeneity (e.g. lakes breezes). Pielke has proposed a coherent meso-scale circulation parameterization to represent such effects.

Rob Stoll presented the side effects of a constant blending height. Inner-grid recirculation accounts for 10-15% of fluxes in low wind regimes (<5m/s). The basics are still subject to study in order to improve the understanding of the issue in simple cases.

Orography is also an important component of heterogeneity. Elevation bands can be used for snow but also vegetation and soil hydraulic regimes (see Walko et al. 2000, Gochis et al. 2009).

RECOMMENDATION: Study the effects of heterogeneity and a constant blending height. It should be considered that complexity in the treatment of heterogeneity should balance the verification material that we have available.

PRIORITY: Medium

Land and atmosphere (near-surface) are coupled, should the NWP Data Assimilation systems consider moving towards coupled-analysis?

This is still a nearly unexplored area of research. Coupled data assimilation could be studied in a 1D framework. The impact of coupling is unknown and is likely to depend on the length of the assimilation window (a few days). The current practice of using T2m to correct soil moisture can have a detrimental impact on the land variables e.g. on vegetation and hydrology.

The LDAS community is currently focusing on uncoupled data assimilation, with PILDAS as an inter-comparison project for such assimilation systems.

RECOMMENDATION: Investigate feasibility and relevance of coupling the land to the atmosphere in 1D data assimilation.

PRIORITY: Medium.