Report and Update on the Stable Boundary Layer Workshop, December 2012

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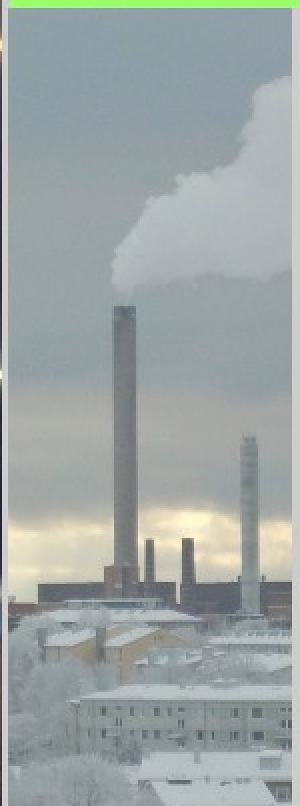
HIRLAM ASM and ALADIN Wk
Reykjavik 15-18 March 2013

Workshop on http://muscaten.ut.ee/Stable12

Parameterization of Stable Boundary Layer in Numerical Weather Prediction Models

Finnish Meteorological Insitute, Helsinki, December 3 - 5 2012



A workshop on "Parameterization of Stable Boundary Layer in Numerical Weather Prediction Models" was arranged in Helsinki on December 3 - 5, 2012.

Thank you for participation! Please find the presentations (pdf files) linked to the programme.

Workshop participants at 5 December 2012 inside the FMI building

Organisers

Nordic Network MUSCATEN. MUSCATEN is funded by the Nordic Research Board

PBL-PMES on "Atmospheric planetary boundary layers: physics, modelling and role in Earth system"(ERC Advanced Grant No. 227915, 2009-2013)

TEMPUS JEP-159352 QualiMET (Development of Qualification Framework in Meteorology, 2010-2013)

Russian Government Mega Grant "Interaction of the Atmosphere, Hydrosphere and Land Surface" (No. 11.G34.31.0048)

Forecasting SBL Weather

Modelling of SBL over snow and ice

Turbulence parametrisations

Air quality modelling in SBL

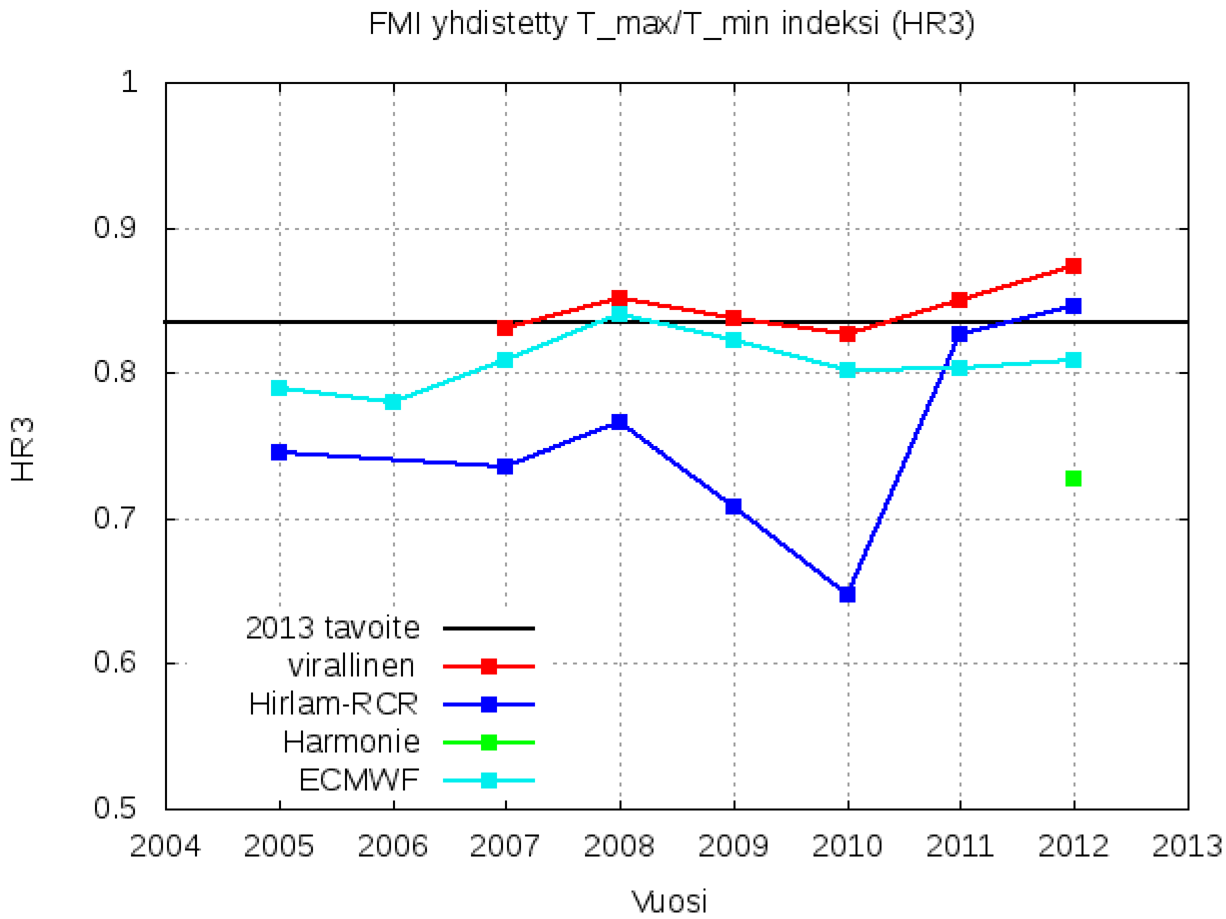
Suggested working groups:

WG-Oper: Problems and solutions for handling of SBL in operational NWP
Expected outcome: identification of main problems and suggestions for further work

WG-GABLS: Preparation of GABLS4 Antarctic experiment
Expected outcome: plans and perhaps data for the next phase of the experiment

WG-Turb: Ways to implement the new turbulence parametrisations into NWP models
Expected outcome: suggestions for the approach and code structures for AROME-ALARO and other models

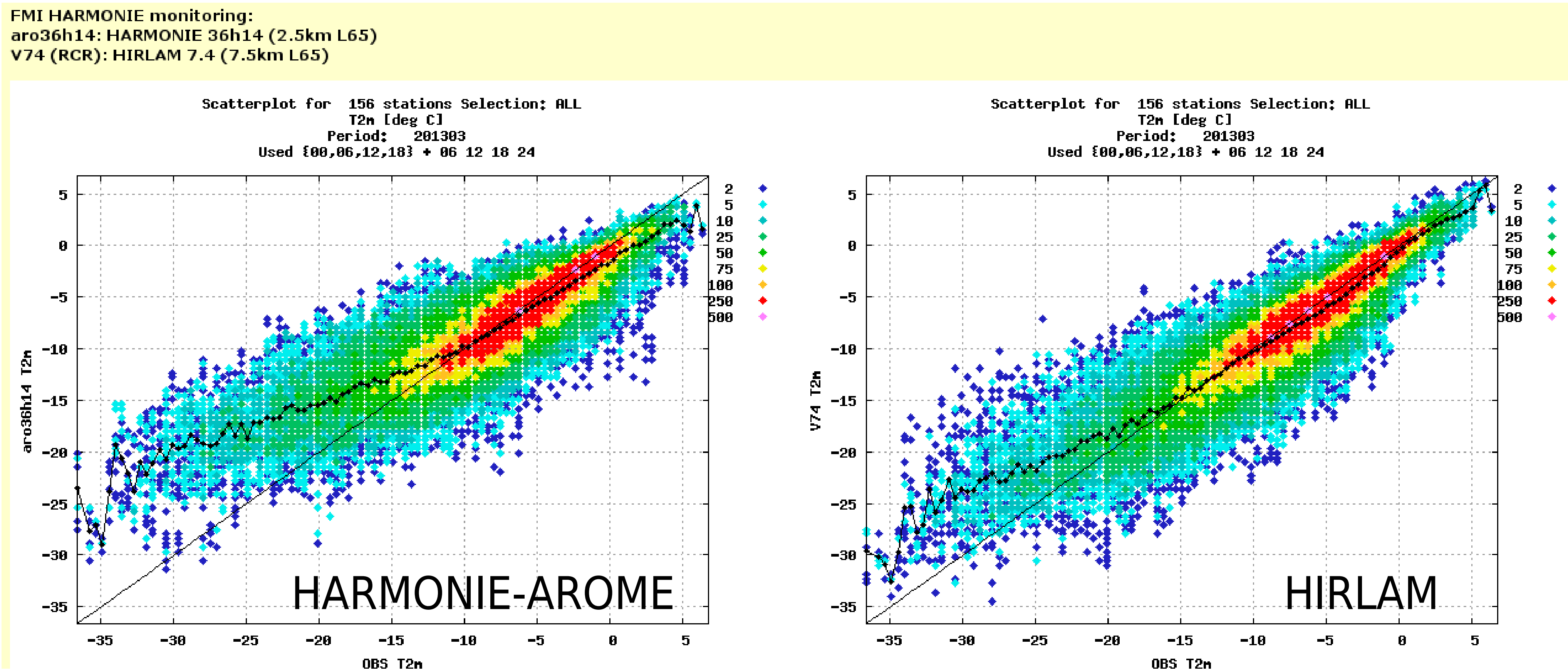
FMI T_{min}/T_{max} **index** – yearly mean hit rate



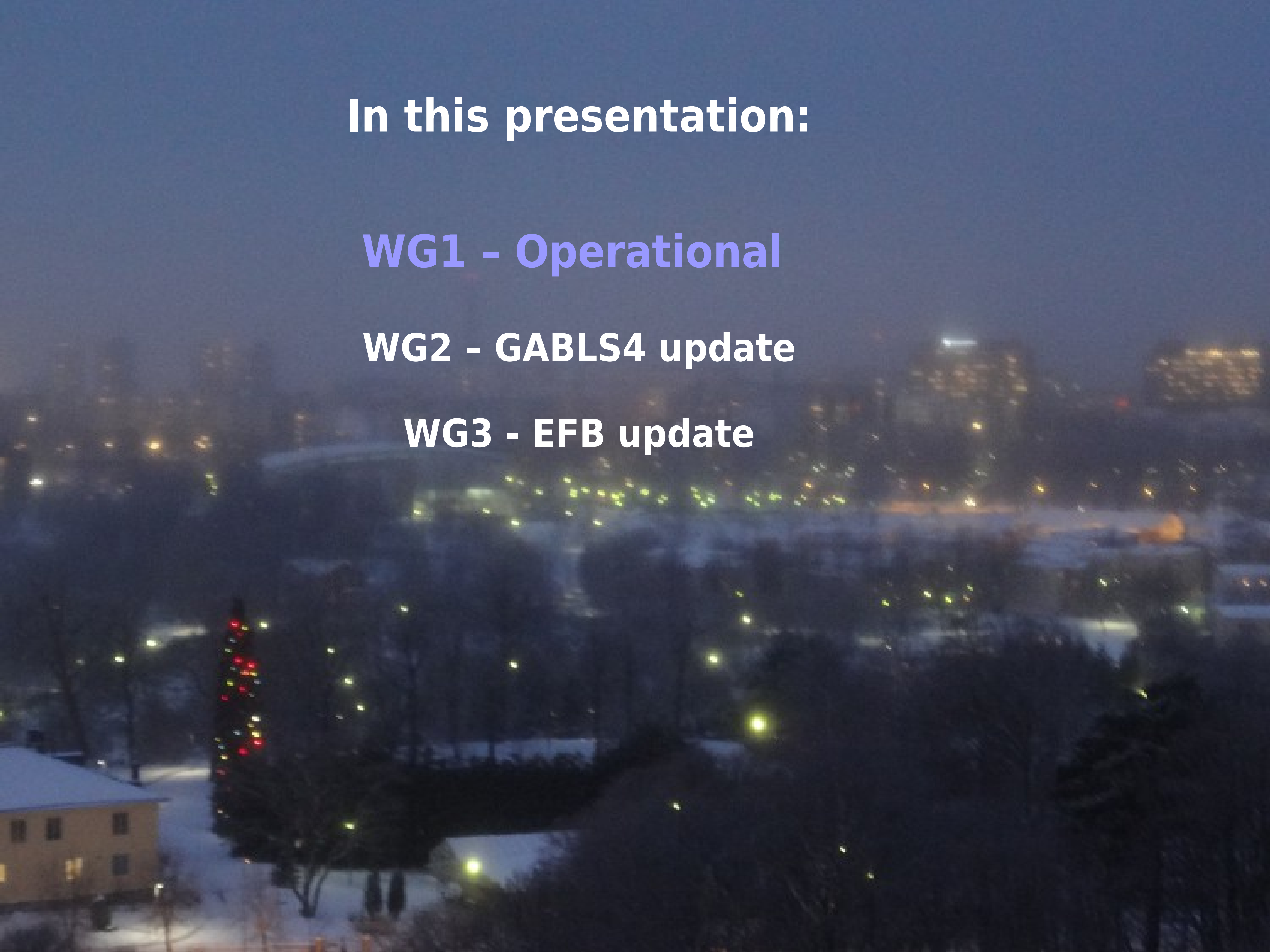
Based on forecasts v.s. observations over selected Finnish SYNOP stations

- T2m_max forecasts: 00UTC + 18h ja 12UTC + 30h
- T2m_min forecasts: 00UTC + 30h ja 12UTC + 18h

FMI HARMONIE-AROME compared to FMI HIRLAM, March 2013 T_{2m}



The classical Nordic Temperature Problem in AROME (not very bad, though)



In this presentation:

WG1 – Operational

WG2 – GABLS4 update

WG3 - EFB update

Main conclusions ECMWF/GABLS SBL workshop (Nov 2011)

- Uncertainty in the formulation of diffusion in stable situations remains high. Meso-scale variability and terrain heterogeneity are important
- *Use of Turbulent Energy equations to support the turbulence closure.*
- Large uncertainties on momentum budget in models. Impact of drag over land on the planetary scales. Intercomparison proposed.
- Biases in the LW downward radiation even in clear sky situations. Verification studies using e.g. BSRN were recommended.
- SBL is highly interactive with the underlying surface. Consider coupled system. LES should have at least simple surface energy balance.
- More diagnostic studies on behavior of the boundary layer and its interaction with the surface. More use of super-sites (CEOP, FLUXNET)
- For land surface : (i) shallow top soil to represent fast time scales, (ii) multi-layer snow scheme, (iii) use many observational sites to derive relevant model parameters, (iv) use DA techniques to "inverse" land surface parameters.
- *Define a new GABLS case for uniform snow*

WG – OPER

We do not need to list and solve all problems but concentrate on some?

Consistent treatment of momentum fluxes of different scales and origin

Forecast of (dissolution of) fog and visibility over different surfaces

Consistent treatment of cloud microphysics-radiation interactions

Proper handling of heterogeneity of the surface + under and above it

WG – OPER

Consistent treatment of momentum fluxes of different scales and origin

Suggestion:

Ensure consistent in scales derivation of the mean elevation and parameters needed for the parametrisations of subgrid-scale orogaphic momentum fluxes, based on high-resolution digital elevation data (SRTM and others).

Coordinate work already ongoing in HIRLAM, ALADIN, UKMO, COSMO . A working week on the finest scale modelling planned in HIRLAM, might start with the orography update and continue to provide fine-resolution estimate of orographic drag for comparison with global models?

WG – OPER

Forecast of (dissolution of) fog and visibility over different surfaces

Suggestion:

Arrange a model intercomparison of forecast visibility and cloud base (=diagnostic, post-processed), starting from an inventory of existing schemes and validation methods

WG – OPER

Consistent treatement of cloud microphysics-radiation interactions

> T_{2m}

Suggestion:

Ensure consistency between the assumptions concerning cloud particle size distribution in microphysics and radiation parametrizations

- For stable boundary layer: mostly fog and low level water and ice cloud

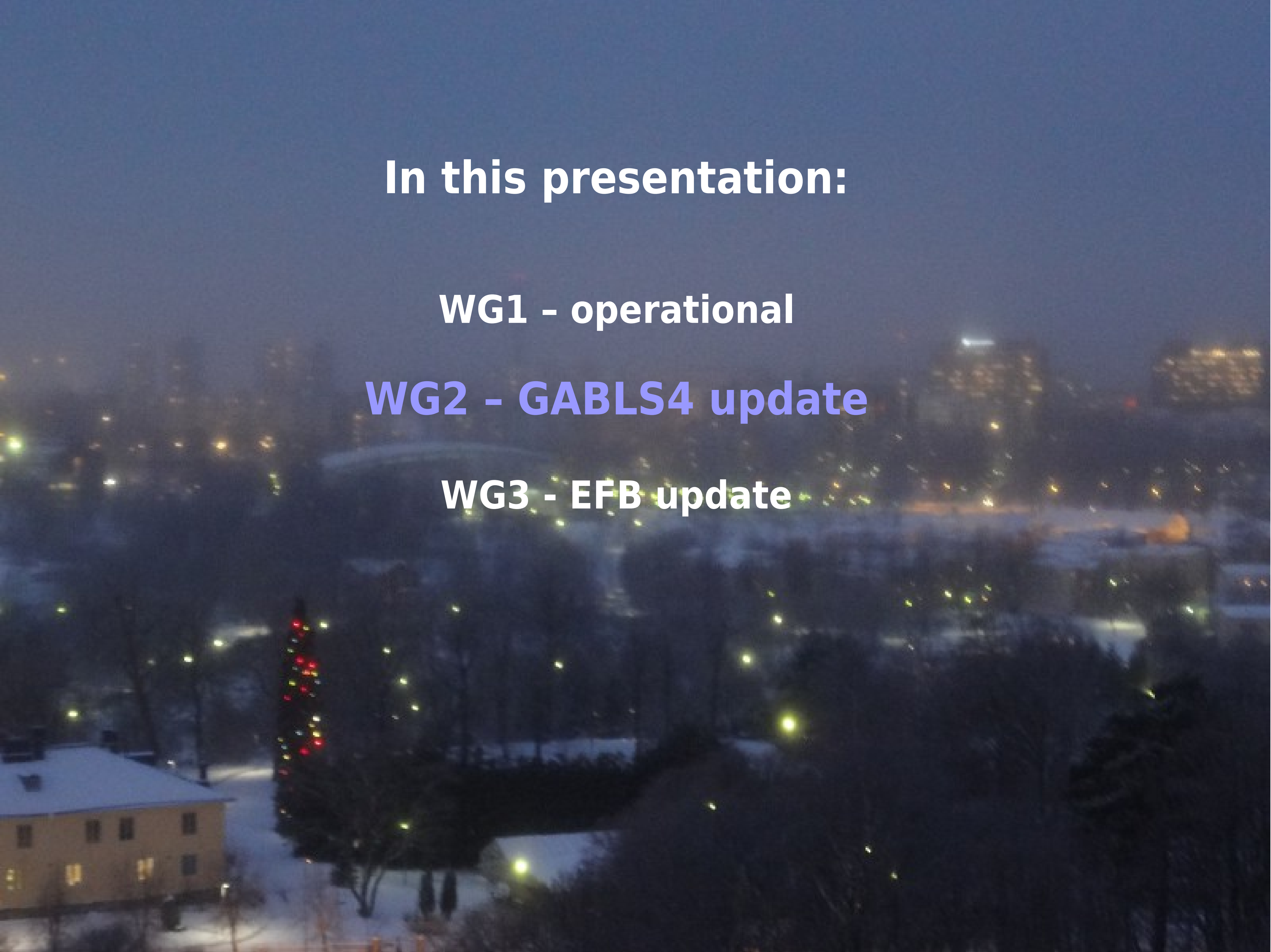
WG – OPER

> T_{2m}

Proper handling of heterogeneity of the surface + under and above it

Suggestion

Compare surface temperature and Under-surface profiles over different surfaces using advanced process models like CROCUS, HIGHTSI, …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Motivation

Numerical weather prediction and climate models continue to have large errors for stable boundary layers (SBL). To understand and to improve on this, so far three atmospheric boundary layer model inter-comparison studies have been organised within the Global Energy and Water Cycle Experiment (GEWEX) of the World Climate Research Programme (WCRP).

Previous GEWEX ABL Studies (GABLS)

have joined about 20 research groups to model:

- the SBL (GABLS1)
- the diurnal cycle (GABLS2, GABLS3), and
- the nocturnal low-level jet (GABLS3).

Timo Vihma, 2012

Conclusions from GABLS 1-3

- Diurnal cycles of temperature and wind continue to be a challenge for NWP and climate models

- inter-model scatter is large for all SBL variables

- sensitive processes in SBL include turbulent mixing, surface-interactions, and longwave radiation divergence

- GABLS experiments suggest that operational models typically overestimate mixing in SBL. This is supported by several 3D experiments and validation studies (Louis et al, 1982; Beare, 2007; Steeneveld et al, 2010; Lüpkes et al., 2010; Tastula and Vihma, 2011; Jakobson et al., 2012; Atlaskin and Vihma, 2012)

So far not addressed in GABLS

- long-lived very stable stratification
- ABL over polar regions with validation against observations

    Actual topic because of:
    - decrease of Arctic sea ice cover vs. increase in the Antarctic
    - collapse of Antarctic ice shelves
    - rapid melting of continental glaciers and permafrost

Timo Vihma, 2012

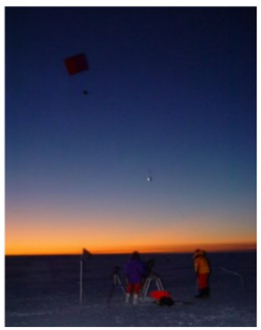
Timo Vihma, 2012

Plan for GABLS4

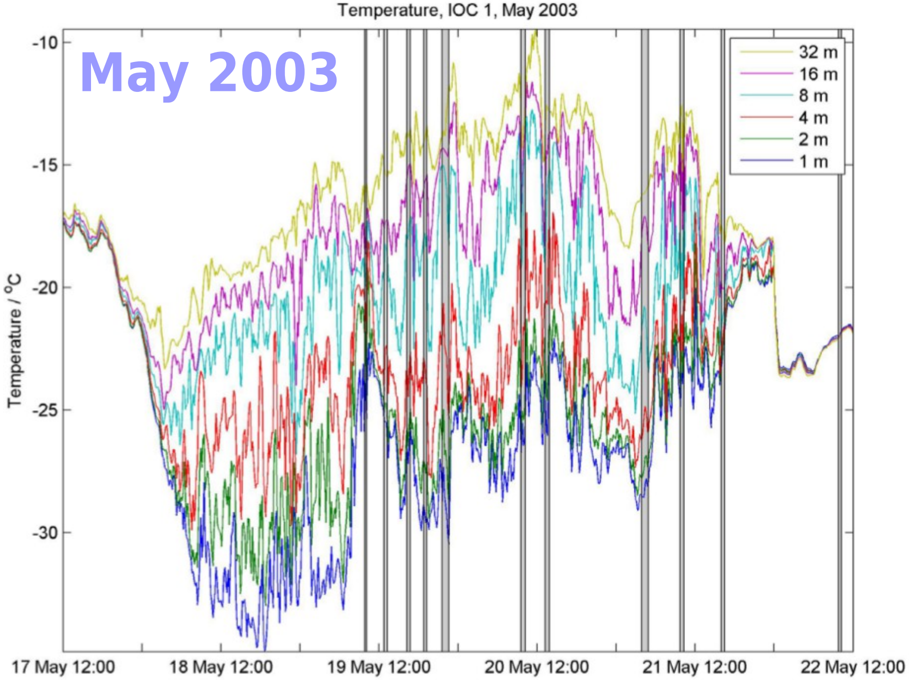
We explore the set-up of GABLS4 over the Brunt Ice Shelf, Antarctica, where the British Antarctic Survey carries out measurements at the Halley station

Halley

Halley station
75°35'S, 26°34'W, since 1956



Temperature, IOC 1, May 2003



Conclusions & Perspectives

- Several 3D experiments at 2.5km have been performed:
  - AROME physics with SURFEX and a specific option (Lglacier)
  - ARPEGE physics with the snow scheme used during the CONCORDIASI experiment or with the SURFEX scheme used in AROME
  - Number of vertical level 60 → 90
- Overestimation of low clouds:
  - Problem of the cloud scheme (PDF Function) ?
  - Underestimation of the mixing ?
  - Initial conditions ?
- Perspectives for 1D GABLS:
  - Create an "ensemble forcing"
  - Simplified the advection term
  - geostrophic wind forcing instead of wind advection ?
  - More comparison :surface fluxes, snow temperature (snow pack), TKE
- 1 year experiment in "Climate Mode "

Dome C

CNRS INSU Observer & comprendre

Workshop Stable Boundary Layer
3/5 dec 2012

METEO FRANCE Toujours un temps d'avance

IPEV Institut Polaire Français Paul Emile Victor

LGGE tower 45m

LGGE Laboratoire de Glaciologie et Géophysique de l'Environnement

GABLS4 plans over Halley and Dome C

Halley: (early) winter conditions

Research question: Evolution of very stable boundary layer starting from neutral conditions, with interaction of turbulence, longwave radiation, and heat conduction in snow

Challenges: At Halley, finding a case with mininum advection, katabatic winds and effects of sea is not easy: more suitable for 3D model comparisons

Dome C: summer conditions

Research question: Understanding stable boundary layer in conditions of strongly forced diurnal cycle over snow, with interaction of short- and long-wave radiation, turbulence, and heat conduction in snow

Advantages: More homogeneous environment than Halley, a lot of previous modelling done to support single-column experiments

GABLS4 plans over Halley and Dome C

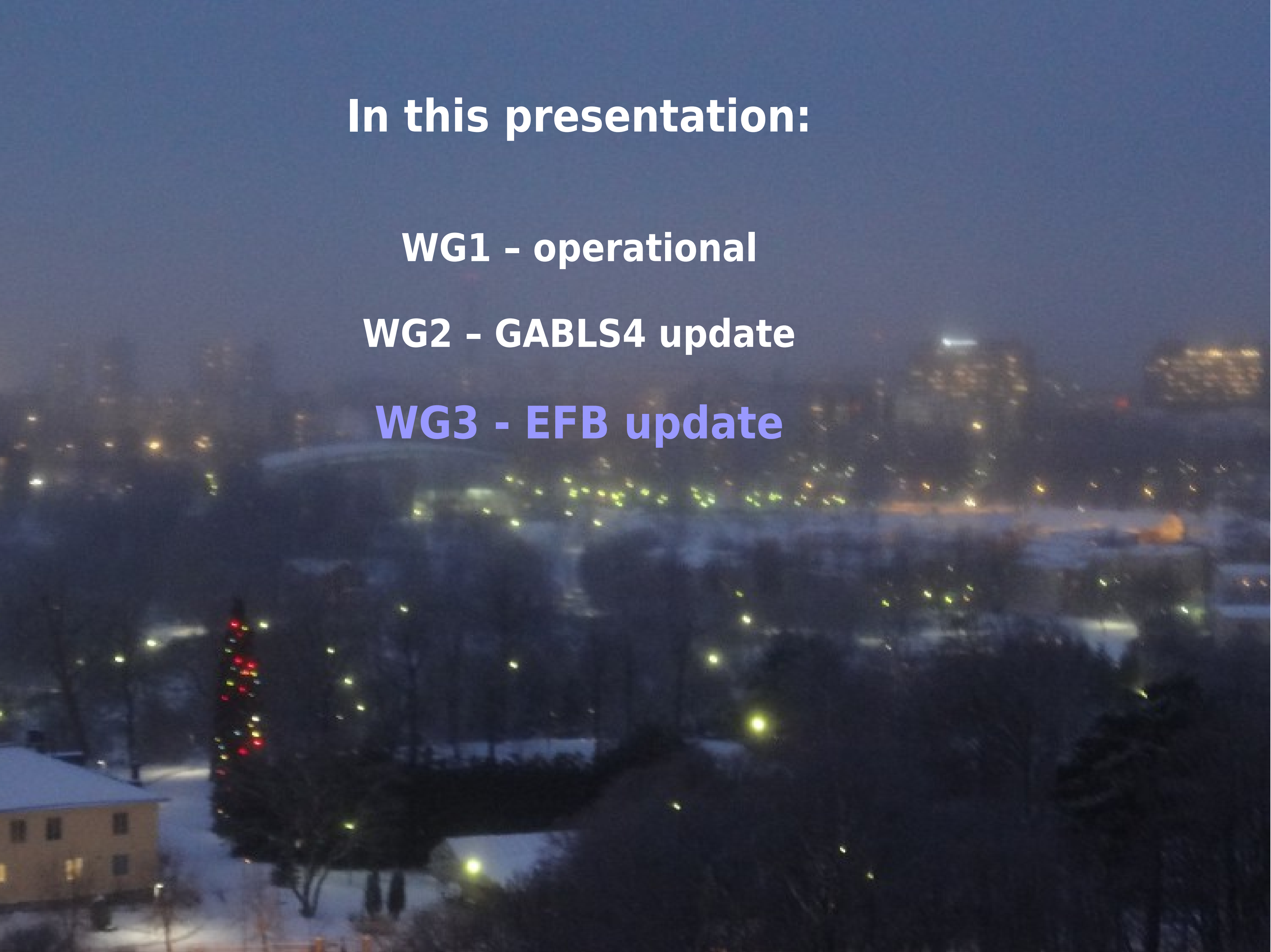
3D model experiments

ARPEGE – AROME
HIRLAM with ECMWF boundaries
Polar WRF with ECMWF boundaries
COAMPS
To understand advections, prepare input for 1D experiments, and compare 3D model results as such

Single-column model experiments

MUSC with ARPEGE – AROME
Polar WRF 1D
Duynkerke model
and others
To address the main research questions of PBL evolution, and to create a test case for development of NWP parametrisations

To be compared to LES results and detailed observations



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WG_turb: Goal

- **Implementation of EFB closure with:**
  - Two prognostic equations for turbulent energy:
    - Motivation: reliable stability parameter $\Pi = E_p / E_k$
    - Total energy + potential energy ?
    - Total energy + kinetic energy ?
    - Kinetic energy + potential energy ?
  - Prognostic turbulent time scale or length scale

Energy- & flux-budget (EFB) closure (2007-12)

Budget equations for major statistical moments

Turbulent kinetic energy (TKE) E_K

Turbulent potential energy (TPE) E_P

Vertical flux of temperature $F_z = <\theta w>$ [or buoyancy $(g/T)F_z$]

Vertical flux of momentum $\tau_{iz} = <u_i w>$ $(i = 1,2)$

Relaxation equation for the dissipation time scale $t_T = E_K/\varepsilon_K = l(E_K)^{-1/2}$

Accounting for TPE → vertical heat flux (that "killed" TKE in Kolmogorov type closures) **drops out from the equation for total turbulent energy (TTE = TKE + TPE)**

Heat-flux budget equation → imposes a limit on the vertical heat flux and assures **self-preservation of turbulence** → **no** Ri-**critical in the energetic sense**

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Disclosed two principally different regimes of stably stratified turbulence

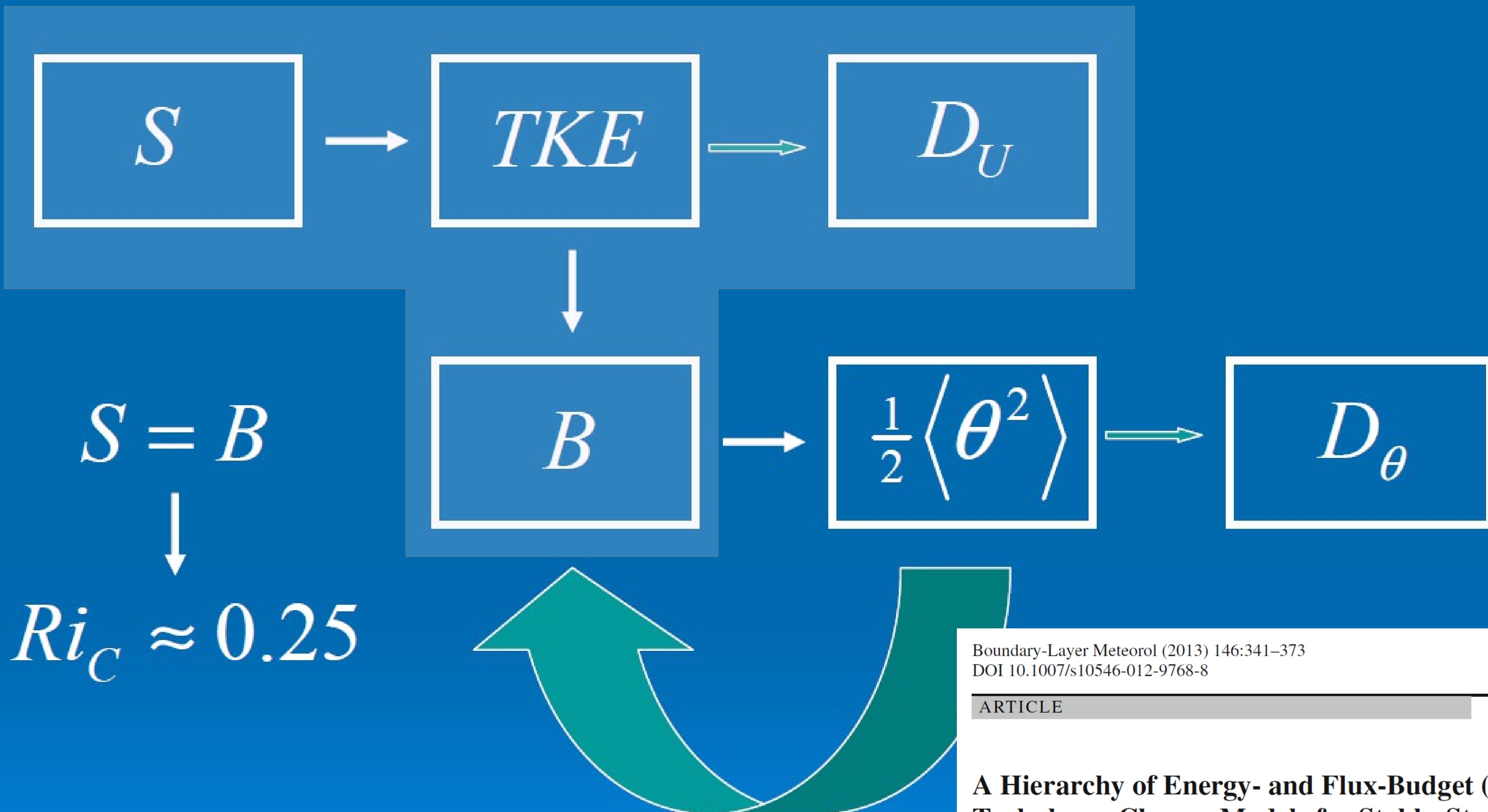
"Strong turbulence" in boundary layer flows with $K_M \sim K_H$ at $Ri < Ri_c$

"Weak turbulence" in the free atmosphere with $Pr_T = K_M / K_H \sim 4\, Ri$ at $Ri >> Ri_c$

MOS theory disregards weak turbulence at $z/L >> 1$ **and yields artefact** Ri_c

PBL height = the boundary between *strong*- and *weak-turbulence* regimes

Total Energy



Boundary-Layer Meteorol (2013) 146:341–373
DOI 10.1007/s10546-012-9768-8

ARTICLE

A Hierarchy of Energy- and Flux-Budget (EFB) Turbulence Closure Models for Stably-Stratified Geophysical Flows

S. S. Zilitinkevich · T. Elperin · N. Kleeorin · I. Rogachevskii · I. Esau

Nathan Kleeorin, 2013

With four prognostic equations (that will not change further in the document), that do not cause any solving problem. In the other equations, e, $\overline{\theta'^2}$, $\overline{\theta' q'}$ and $\overline{q'^2}$ will be supposed known !

$$\frac{\partial}{\partial t}(\overline{\theta'^2}) + U_k \frac{\partial}{\partial x_k}(\overline{\theta'^2}) = -\frac{\partial}{\partial x_k}\left(\overline{u'_k \theta'^2}\right) - 2\frac{\partial \Theta}{\partial x}\overline{\mathbf{u}'\theta'} - 2\frac{\partial \Theta}{\partial y}\overline{\mathbf{v}'\theta'} - 2\frac{\partial \Theta}{\partial z}\overline{\mathbf{w}'\theta'} - 2C_{\epsilon_\theta}\frac{\sqrt{e}}{L_\epsilon}\overline{\theta'^{\mathbf{2}}}$$

$$\frac{\partial}{\partial t}(\overline{q'^2}) + U_k \frac{\partial}{\partial x_k}(\overline{q'^2}) = -\frac{\partial}{\partial x_k}\left(\overline{u'_k q'^2}\right) - 2\frac{\partial Q}{\partial x}\overline{\mathbf{u}'\mathbf{q}'} - 2\frac{\partial Q}{\partial y}\overline{\mathbf{v}'\mathbf{q}'} - 2\frac{\partial Q}{\partial z}\overline{\mathbf{w}'\mathbf{q}'} - 2C_{\epsilon_q}\frac{\sqrt{e}}{L_\epsilon}\overline{\mathbf{q}'^{\mathbf{2}}}$$

$$\frac{\partial}{\partial t}(\overline{\theta' q'}) + U_k \frac{\partial}{\partial x_k}(\overline{\theta' q'}) = -\frac{\partial}{\partial x_k}\left(\overline{u'_k \theta' q'}\right) - \frac{\partial Q}{\partial x}\overline{\mathbf{u}'\theta'} - \frac{\partial Q}{\partial y}\overline{\mathbf{v}'\theta'} - \frac{\partial Q}{\partial z}\overline{\mathbf{w}'\theta'} - \frac{\partial \Theta}{\partial x}\overline{\mathbf{u}'\mathbf{q}'} - \frac{\partial \Theta}{\partial y}\overline{\mathbf{v}'\mathbf{q}'} - \frac{\partial \Theta}{\partial z}\overline{\mathbf{w}'\mathbf{q}'} - 2C_{\epsilon_{\theta q}}\frac{\sqrt{e}}{L_\epsilon}\overline{\theta'\mathbf{q}'}$$

$$\frac{\partial}{\partial t}(e) + U_k \frac{\partial}{\partial x_k}(e) = -\frac{\partial}{\partial x_k}\left(\overline{e' u'_k} + \overline{p' u'_k}\right) - \overline{u'_k u'_l}\frac{\partial U_k}{\partial x_l} + \beta_k \overline{u'_k \theta'_v} - \epsilon$$

Valery Masson for MNH/AROME, 2013

Code modifications based on cy38t1_op1:

- 3 GFL (YEFB1, YEFB2, YEFB2) added by Y. Bouteloup for 3 new prognostic variables (Ep or theta variance, humidity variance and covariance of theta and q)
- For the turbulence code used in ARPEGE, it seems feasible to implement the 4.2 proposal (Zilitinkevich et al 2012):
  - add Ep equation (eq88) (ACTURB and ACEVOLET)
  - Diagnose vertical component Ez with eq 92 (ACTURB)
  - Computes Km and Kh with eq 95 (ACTURB)
  - As a 1st step use the current mixing length (BL89)
- Minimum code modifications, still use the same algorithm for the tri-diag resolution and the flux computations.
- Probably less complex than the Valery's proposal for the AROME turbulence code
- Interesting to compare the two approaches on GABLS1 and GABLS3 but also with the modified TOUCAN (ALARO scheme)

'Dry case' target time-step organisation of TOUCANS

The resulting 'dry' scheme would then look like this:

1. computation of stability functions $\chi_3, \phi_3, T_h, F_{\overline{w'^2}}$, and F_ϵ from $\Pi^- = \frac{TPE^-}{e^-}[= \frac{C_p Ri_f}{1-Ri_f} \leftarrow$ cold start] [or at start for fast and dirty implementation: computation of Ri from Π^-]
2. computation of L, l_m from e^- and Π^-
3. computation of τ_ϵ, and K_E from l_m, e^-, and F_ϵ
4. computation of τ_{TTE}, and K_{TTE} from τ_ϵ, K_E, and Π^-
5. computation of $\tilde{e}$ from $\overline{w'\theta'}, \overline{w'u'}, \overline{w'v'}$, and τ_ϵ
6. computation of $\widetilde{TTE}$ from $\overline{w'u'}, \overline{w'v'}$, and τ_{TTE}
7. solver for prognostic TKE
8. solver for prognostic TTE and prognostic L for next time step if not diagnostic
9. computation of K_m, K'_h: $K_m = L_K C_K \sqrt{e^{(+)}}\chi_3(\Pi), \quad K'_h = L_K C_K C_3 \sqrt{e^{(+)}}\phi_Q(\Pi)$
10. local vertical diffusion solver with K_m, K'_h
11. non-local solver with additional TPE(=TTE-TKE) source term
12. no need anymore for a non local correction to the final value of TKE (and of TTE)

The main difference of TOUCANS with respect to other schemes is that the new TKE is computed first (with direct 'local' closure in the case of prognostic TKE only; with use of previous time step fluxes and present gradients in the case with prognostic TKE & TTE). The exchange coefficients follow (and they are used even in the fully prognostic scheme, because we want to differentiate SOMs from TOMs terms, the 'local' solving acting as preconditioning for the 'total' solving).

Jean-Francois Geleyn & Ivan Bastak-Duran for ALARO, 2013

Many colleagues have contributed to this presentation:

Eric Bazile, Valery Masson,
Francois Bouyssel, Jean-Francois Geleyn
Meteo France

Timo Vihma, Carl Fortelius,
Sergej Zilitinkevich
FMI

Nathan Kleeorin, Ben Gurion University

Thank YOU!