Testing the HBG model under strong stabilities of GABLS4

A SCM inter-comparison study using CCAM

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Outline

- The Huang-Bou-Zeid-Golaz (HBG) model (Huang et al., JAS, 2013)
  - GABLS
  - Local Richardson number similarity
  - The HBG model
- GABLS4 inter-comparison
  - GABLS4
  - Single column model (CCAM) and available schemes for SABL
  - Land surface model (CABLE)
- Results
  - Surface temperature
  - Surface sensible heat flux
  - Temperature at 42 m
  - Wind speed profile
- Conclusions

GABLS and LES runs

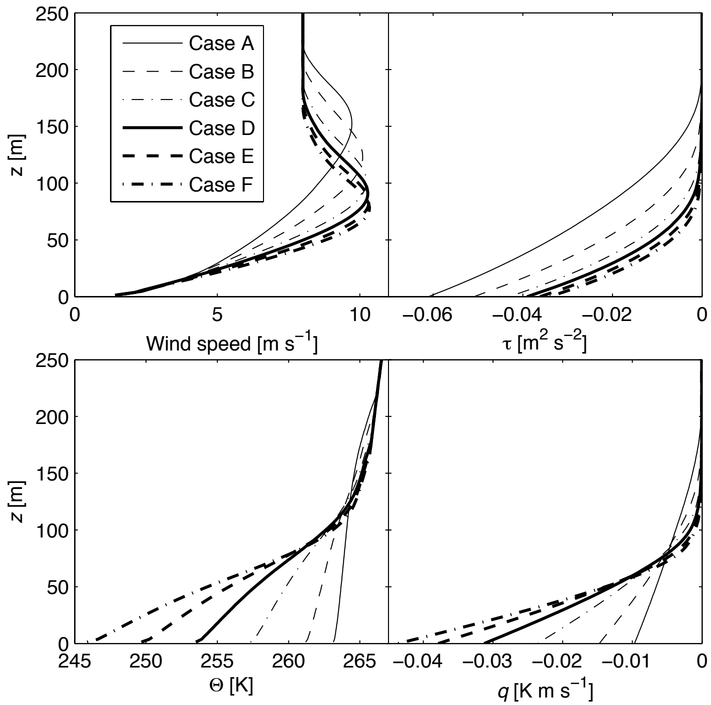
- Initial conditions
  - Geostrophic wind: U_g=8.0 m/s, V_g=0.0 m/s
  - Potential temperature: 265K up to 100m, then it increases at a rate of 0.01 K/m
- Boundary conditions
  - MOST wall model at surface and no stress and no penetration at the simulation domain top
  - Prescribed surface temperature with a constant decreasing rate of 0.25 K/h
  - Roughness length $z_{0m} = z_{0h} = 0.1$ m
- Higher stabilities
  - Increasing the surface cooling rate from 0.25K/h
  - **We also test much higher stabilities than GABLS, going up to 2.5K/h (Case A-F)**
- LES setup
  - Simulation domain
    - 162X162X160 grid points
    - 800X800X400 m^3
  - SGS model: Lagrangian scale-dependent dynamic (Bou-Zeid et al. *Phys. Fluids* 2005)
  - Courant-Friedrichs-Lewy (CFL) number is around 0.1
  - Total physical run time: 10 hours
  - Statistics were obtained with the results of the last three hour

CSIRO

TABLE 1. Mean boundary layer characteristics for stable ABL simulations with steady surface cooling rates.

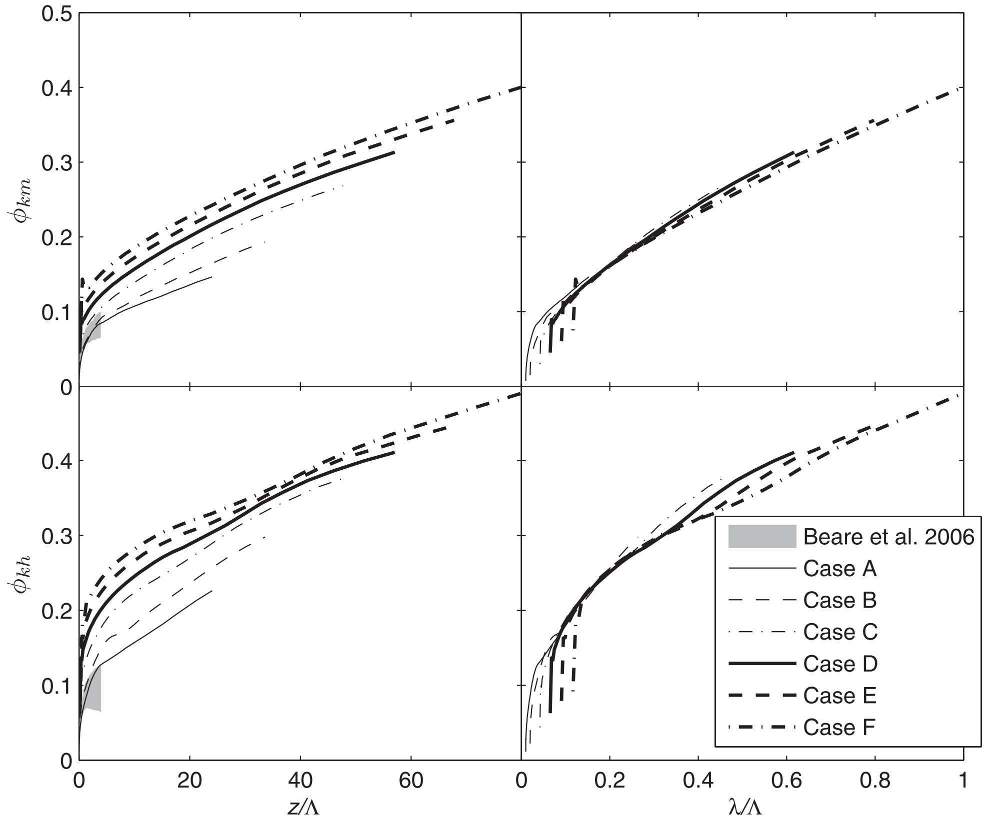
Case	Cooling rate (K h^{-1})	h (m)	u_* (m s^{-1})	θ_* (K)	$L_{MO}(z = 0)$ (m)	L_{OZ} (m)
A	0.25	158	0.247	0.0392	104	14.4
B	0.5	128	0.226	0.0653	51.9	8.15
C	1	106	0.208	0.114	24.8	4.31
D	1.5	94.5	0.198	0.158	15.9	2.88
E	2	86.9	0.190	0.199	11.5	2.11
F	2.5	81.5	0.184	0.237	8.93	1.65

[Huang and Bou-Zeid, JAS, 2013]



- With increasing stability:
  - Stronger wind speed peak, and vertical gradient of mean temperature
  - Lower low-level jet, and shallower boundary-layer
  - Decrease in surface momentum and increase in temperature flux

Local scaling theory



[Huang and Bou-Zeid, JAS, 2013]

- Dimensionless combinations of variables should be functions of z/Λ (Nieuwstadt 1984). **However…**
- Eddy diffusivities are *z*-less under strongly stable conditions.

$$\phi_{K_m} = K_m \Lambda^{-1} \tau^{-1/2}$$

$$\phi_{K_h} = K_h \Lambda^{-1} \tau^{-1/2}$$

$$\Lambda = -\tau^{3/2} \Theta (\kappa g q)^{-1}$$

Local Richardson number similarity

$$K_m = l_m^2 \left|\frac{\partial U}{\partial z}\right|,$$

$$l_m = l_N f_m^{1/2}\left(Ri_g\right)$$

$$\frac{1}{l_N} = \frac{1}{\kappa z} + \frac{1}{l_\infty},$$

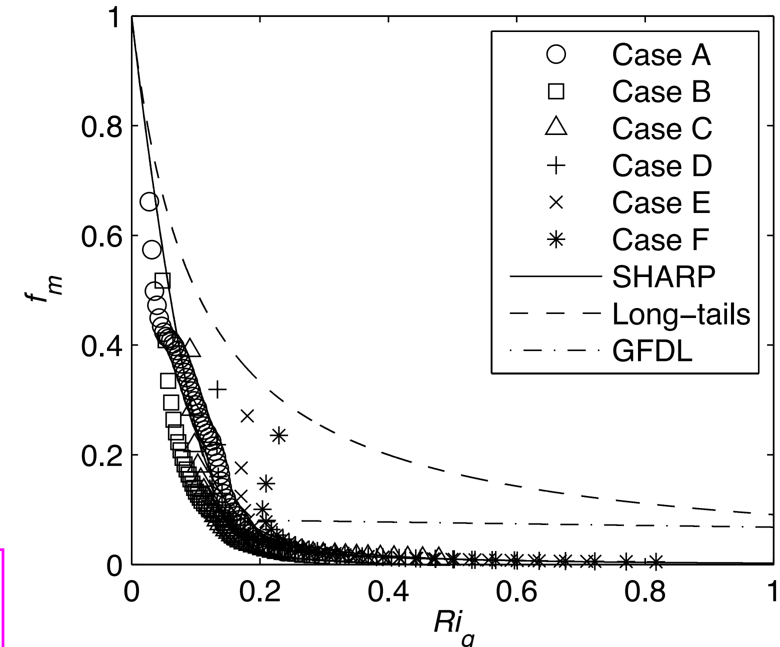
SHARP:

$$f_m\left(Ri_g\right) = \begin{cases} \left(1-5Ri_g\right)^2 & 0<Ri_g \le 0.1 \\ (20Ri_g)^{-2} & Ri_g > 0.1 \end{cases}$$

[Huang et al., JAS, 2013]

GFDL model:

$$f_m\left(Ri_g\right) = \begin{cases} \left(1\text{-}5Ri_g\right)^2 & 0<Ri_g \le 1/7 \\ \left(\dfrac{1-0.1Ri_g}{3.45}\right)^2 & 1/7<Ri_g \le 10 \\ 0 & Ri_g > 10 \end{cases}$$



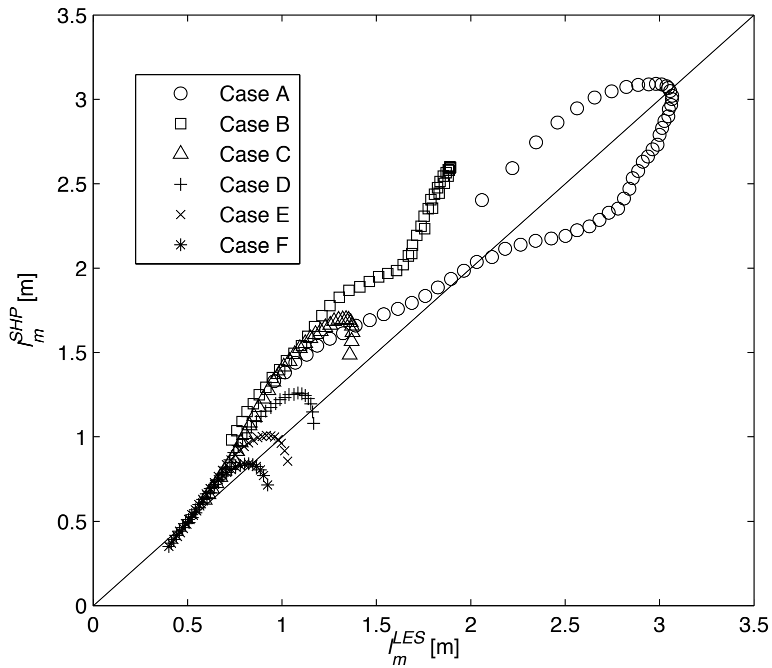
Long-tails:

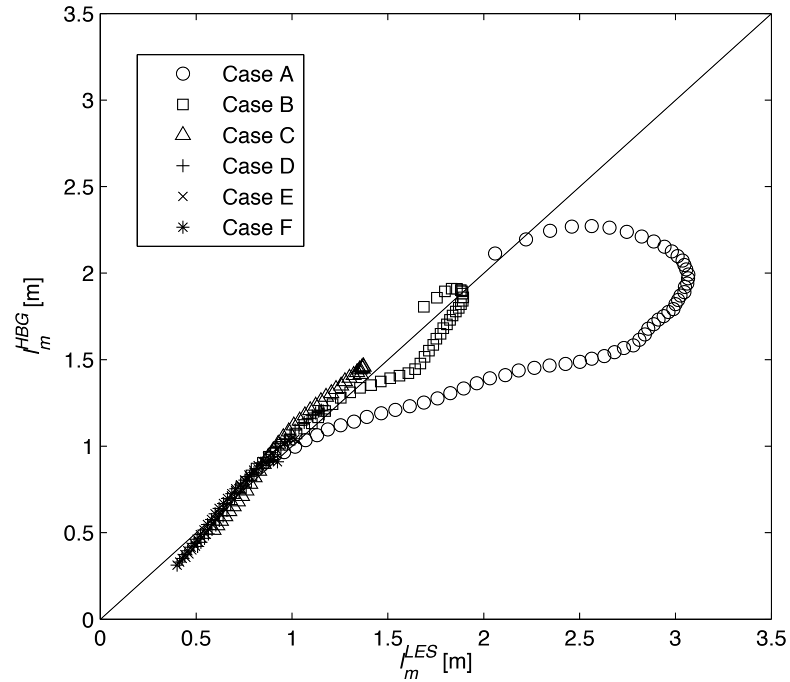
$$f_m\left(Ri_g\right) = \left(1+10Ri_g\right)^{-1} \qquad Ri_g > 0$$

The new model (HBG)

SHARP:

$$\frac{1}{l_m} = \frac{1}{l_N} + \frac{Ri_g}{\lambda} = \frac{1}{\kappa z} + \frac{1}{l_\infty} + \frac{Ri_g}{\lambda}$$

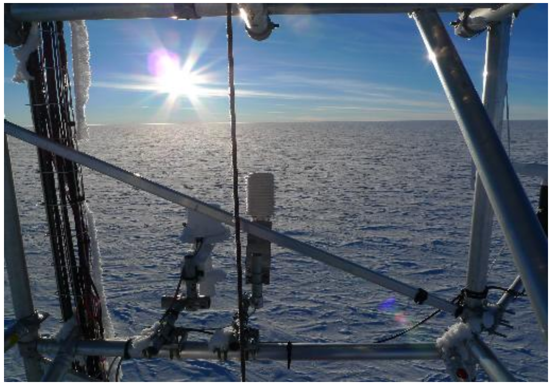




[Huang et al., JAS, 2013]

GABLS4 SCM/LSM inter-comparison

- Based on a real case on 11 Dec. 2009 under strong stability (Ri>1) at DomeC Antarctica
  - Stage 1b – Coupling of SCM with LSM, prescribed initial surface and soil conditions and atmospheric forcing
  - Stage 2 – Same as Stage 1b BUT the surface temperature is given
  - Stage 3 – idealized case: no radiation, no moisture, no prescribed atmospheric forcing, only prescribed surface temperature and constant geostrophic wind speed



From O. Traullé (left) and E. Brun (right)
http://www.cnrm-game-meteo.fr/aladin/meshtml/GABLS4/GABLS4.html

Single column model - CCAM

- CCAM: Cubic-Conformal Atmospheric Model developed by CSIRO
  - Support a variable-resolution global grid using Schmidt transformation
  - Three SABL schemes:
    - The HBG model

$$\frac{1}{l_m} = \frac{1}{\kappa z} + \frac{1}{l_\infty} + \frac{Ri_g}{\lambda}$$

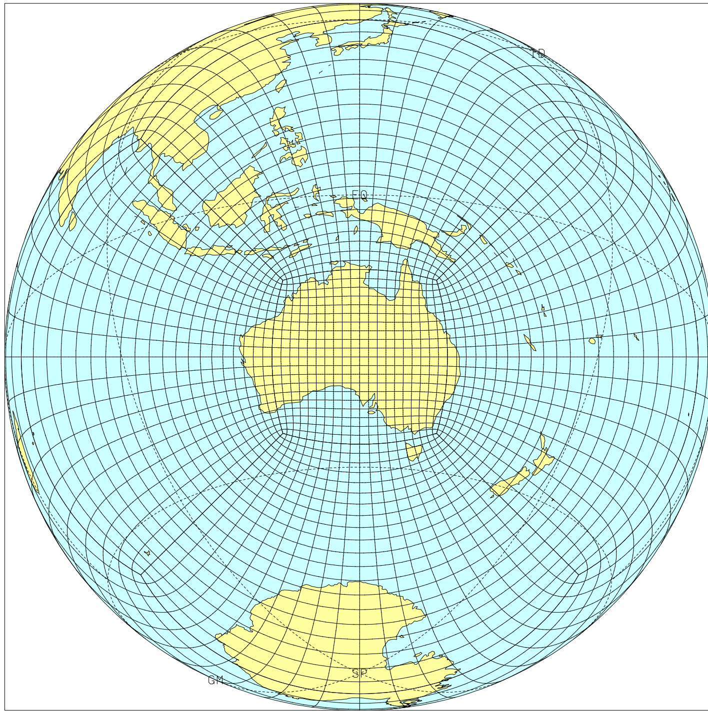
l_∞ = 9 m, λ = 0.45 m

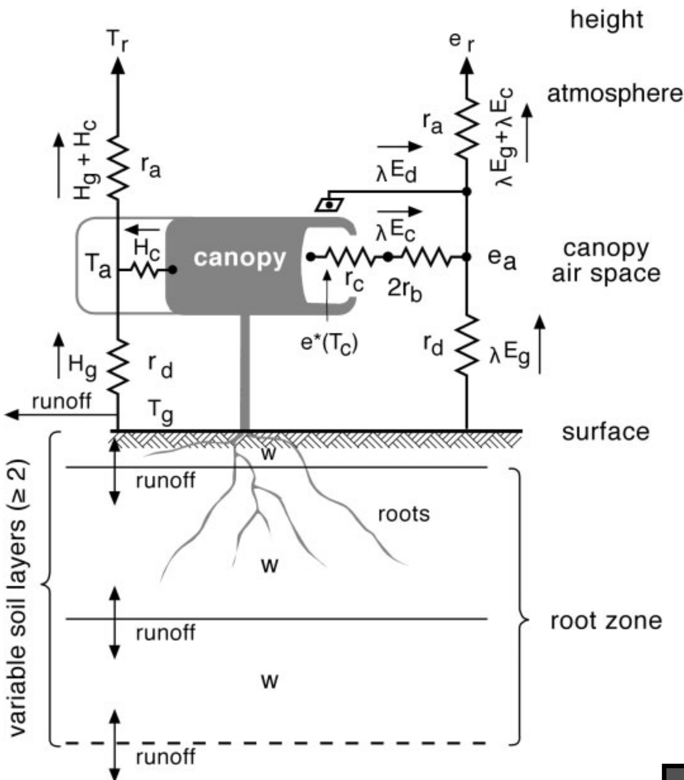
    - The Louis (1979) model (a long-tail type)

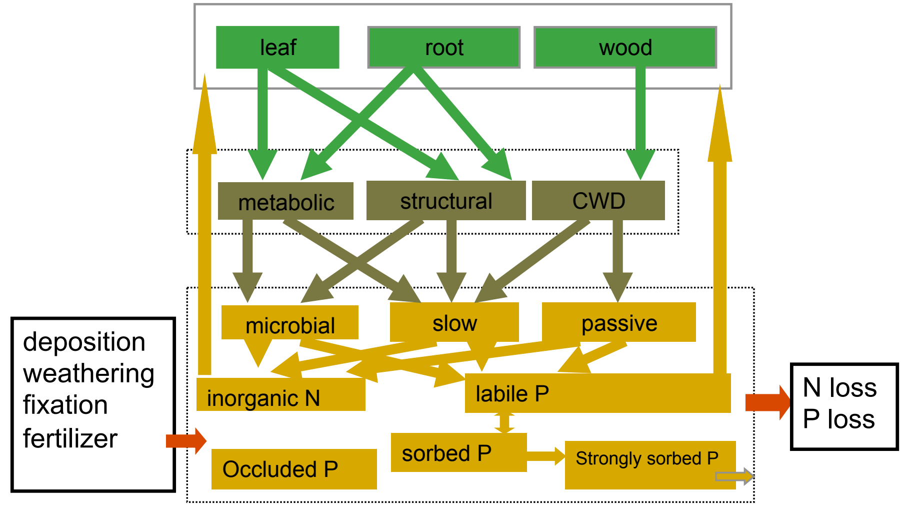
$$f_m(Ri_g) = (1 + 4.7Ri_g)^{-2}$$
$$l_\infty = 100\ m$$

    - A standard prognostic k-eps model
    - A modified Louis (1979) model

$$f_m(Ri_g) = (1 + 4.7Ri_g)^{-2}$$
$$l_\infty = 9\ m$$







Biophysics
(original CABLE)

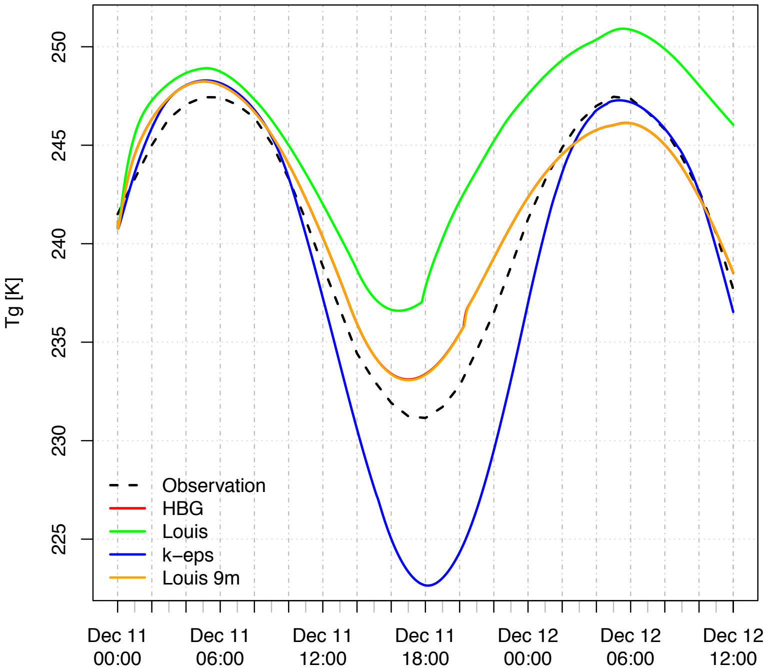
Biogeochemistry
(CASA-CNP)

CABLE
(current)

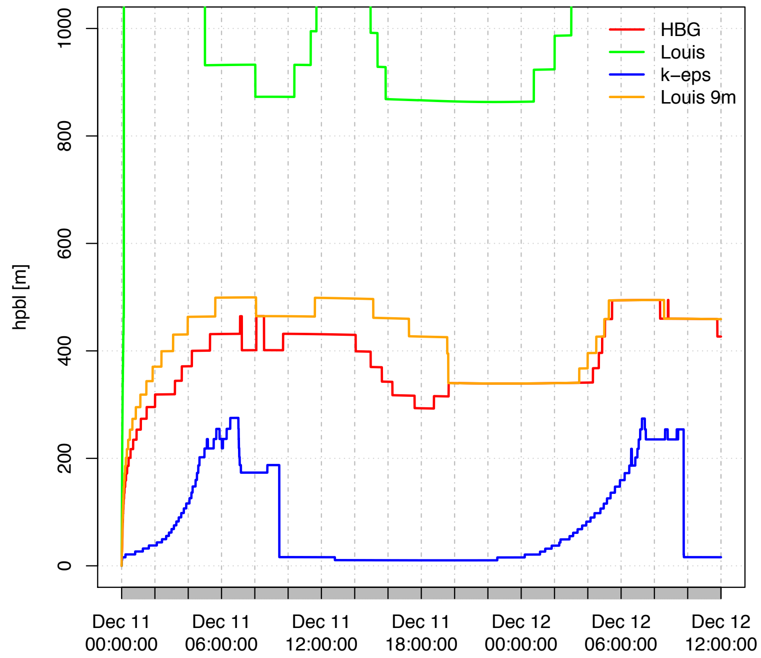
- Land surface model CABLE: Community Atmosphere Biosphere Land Exchange model developed by CSIRO and BOM
  - Biophysical component
    - Surface radiation transfer
    - Canopy turbulence
    - Two-leaf turbulence
    - Six soil and three snow layers
  - Biogeochemical component
  - Land use and land use change

Surface temperature

HPBL



Stage 1b

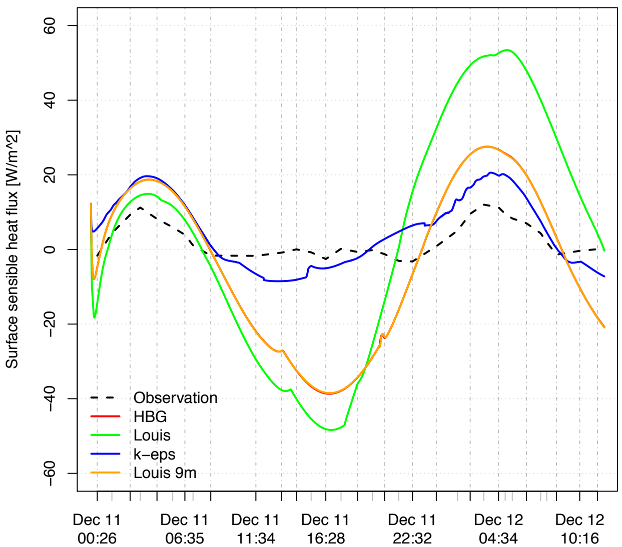


$$hpbl = h_{\tau=0.05\tau_s}/0.95$$

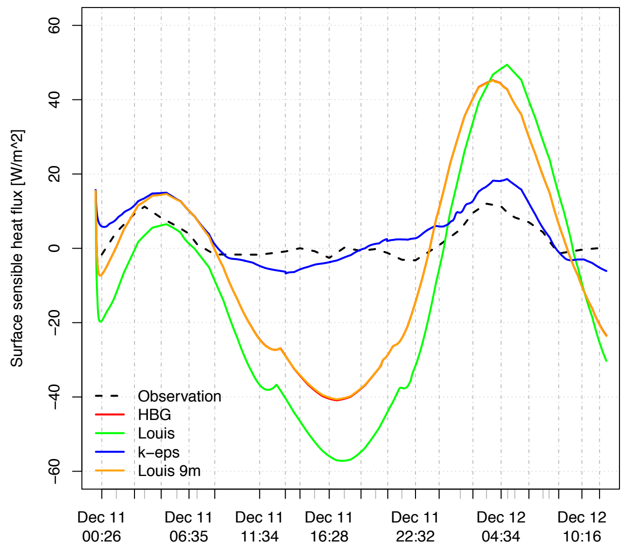
- K-eps scheme collapses during night
  - Low surface temperature
  - Shallow SABL
- Louis scheme
  - Overestimate surface temperature
  - Give spurious deep SABL
- HBG and Louis 9m perform similarly
  - Slightly shallower SABL for HBG

Surface sensible heat flux

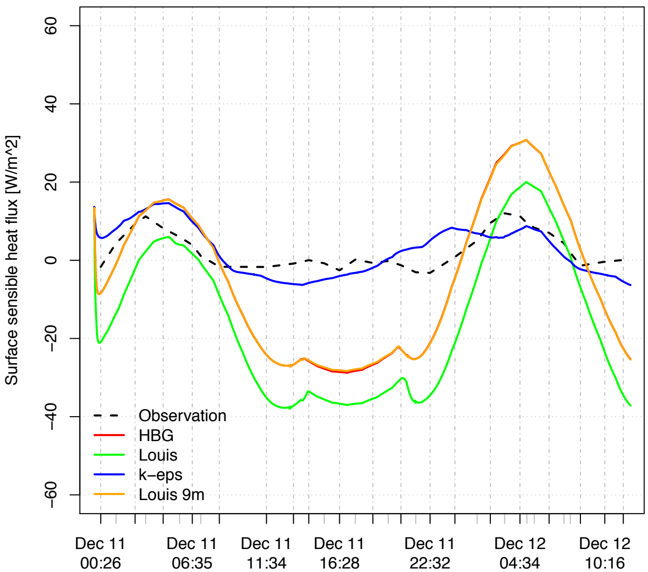
Stage 1b



Stage 2

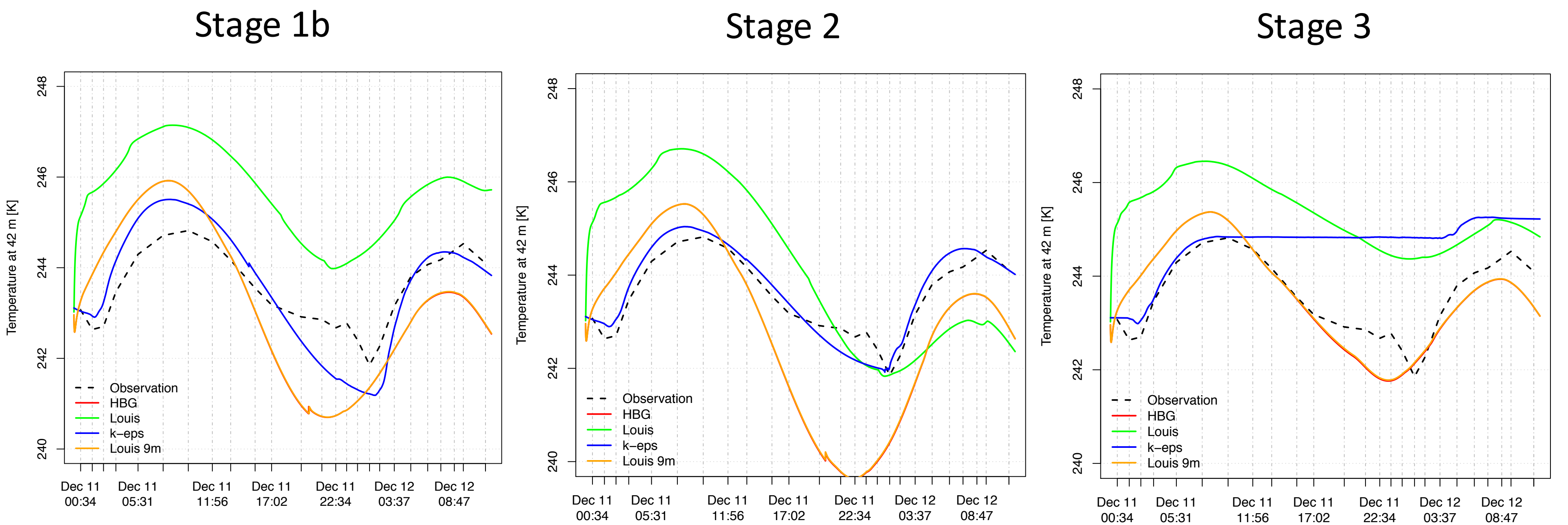


Stage 3



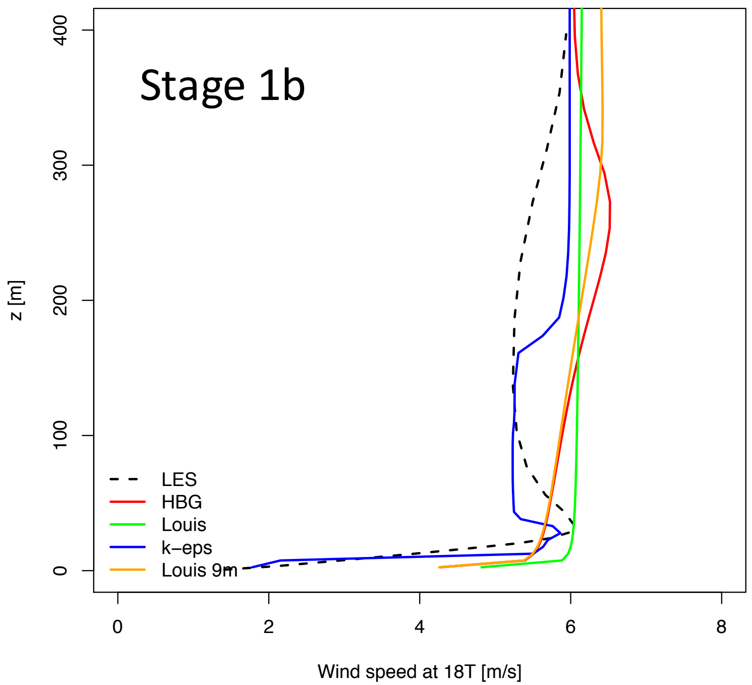
- Observation flux is actually at z = 7m – k-eps produces too little flux
- Louis scheme leads to more flux during night
- HBG and Louis 9m still perform similarly

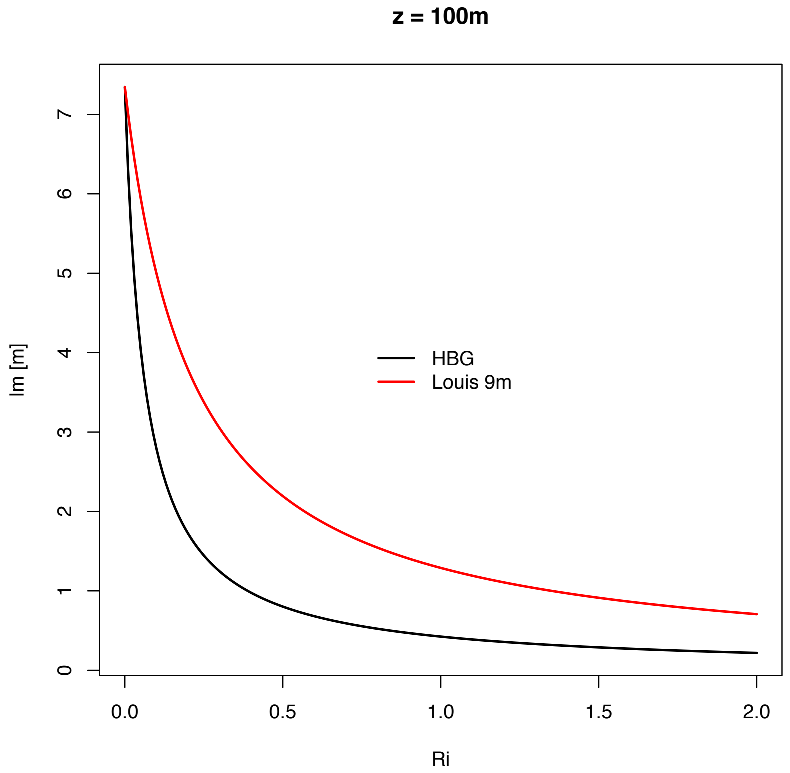
Temperature at 42 m



- Louis scheme overestimates temperature at 42m
- K-eps scheme
  - Best result for Stage 1&2
  - Constant temperature during night at Stage 3 as a result of a shallow SABL and no prescribed atmospheric forcing
- HBG and Louis 9m still perform similarly

Wind speed profile at 18T





- Louis scheme leads to fast wind speed increase at surface
- Relative to HBG, Louis 9m scheme causes a longer mixing length under strong stabilities
  - HBG produces a low-level jet while Louis 9m does not
  - Still needs investigation on the elevated low-level jet and wind speed near surface
- K-eps gives right LLJ but wrong shear at the top of SABL

Conclusions

- The HBG scheme has been tested under strong stabilities (Ri>1) using CSIRO-developed SCM (CCAM) and LSM (CABLE).
- The HBG scheme gives
  - The best overall result
  - Elevated LLJ
- The original Louis (1979) scheme leads to
  - Overestimated surface temperature
  - Spurious deep SABL
- The k-eps scheme could collapse under strong stabilities
  - Underestimated surface temperature
  - Too shallow SABL
  - Right LLJ
- Louis 9m
  - Similar to HBG
  - No LLJ simulated

Thank you

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