Using the surface energy balance to understand the Antarctic stable boundary layer.

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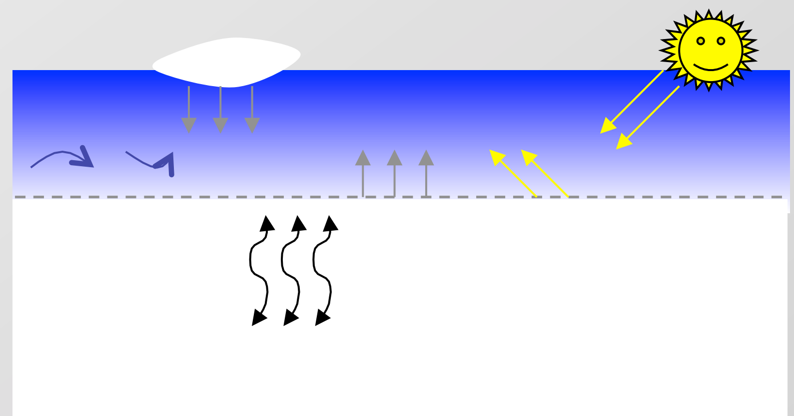
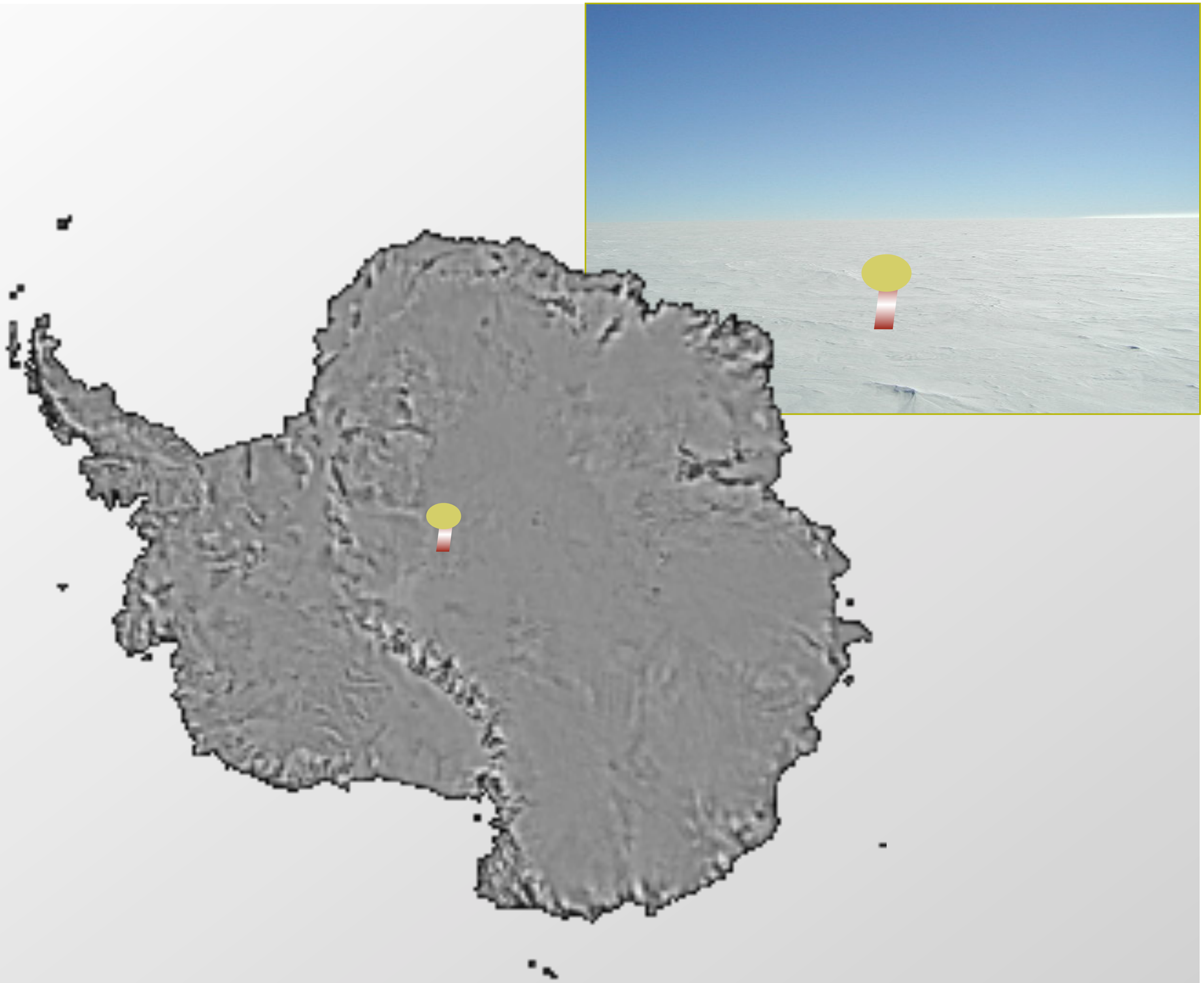
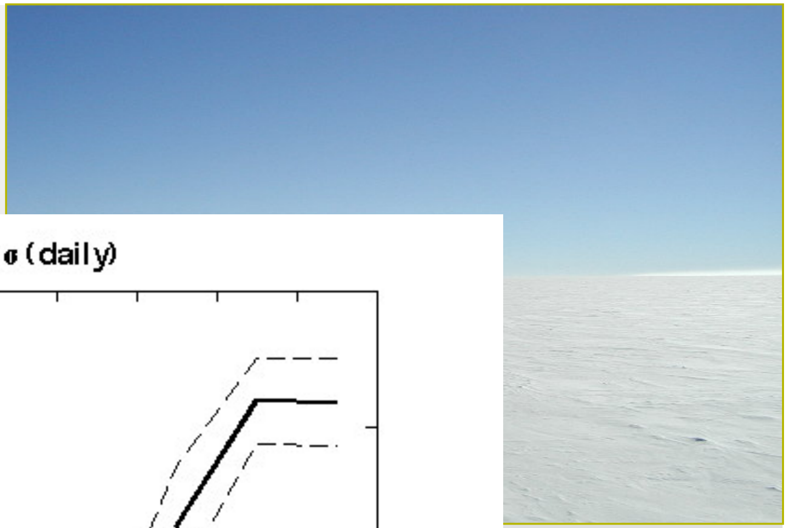
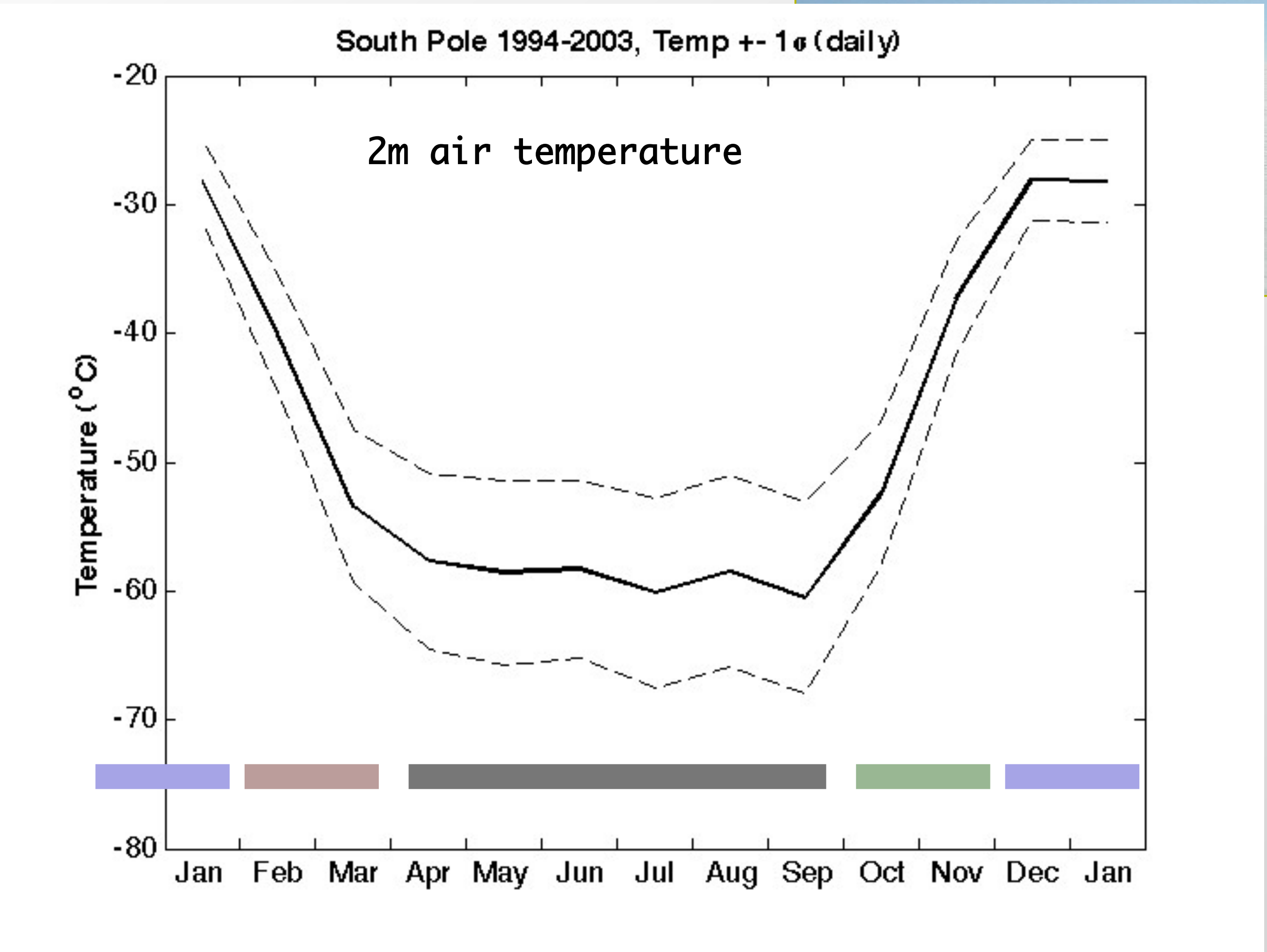


Session 5. Science using ground-based and satellite measurements
AMOMWF 2007, Rome, Italy.





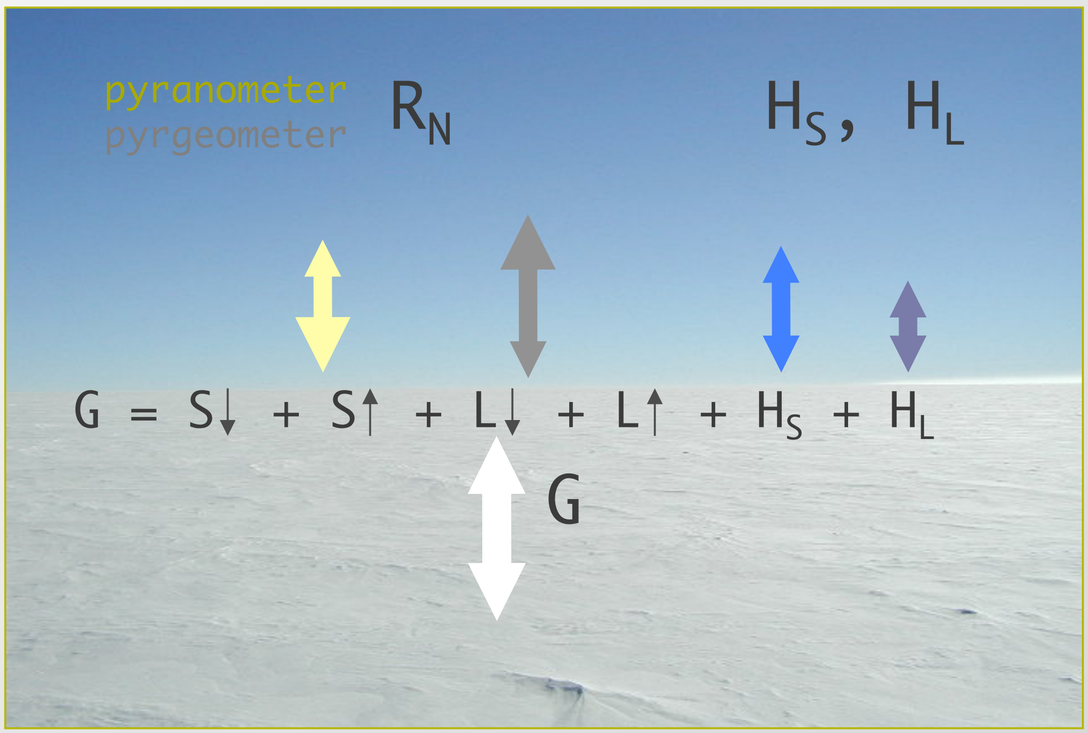

South Pole 1994-2003, Temp +- 1σ (daily)
2m air temperature
Temperature (°C)
-20
-30
-40
-50
-60
-70
-80
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan

net radiation — latent heat

$$G = R_N + H_S + H_L$$

subsurface heat — sensible heat

positive fluxes are directed downward



u_{10}, T_S, T_2, T_{2f}
Andreas (2002)

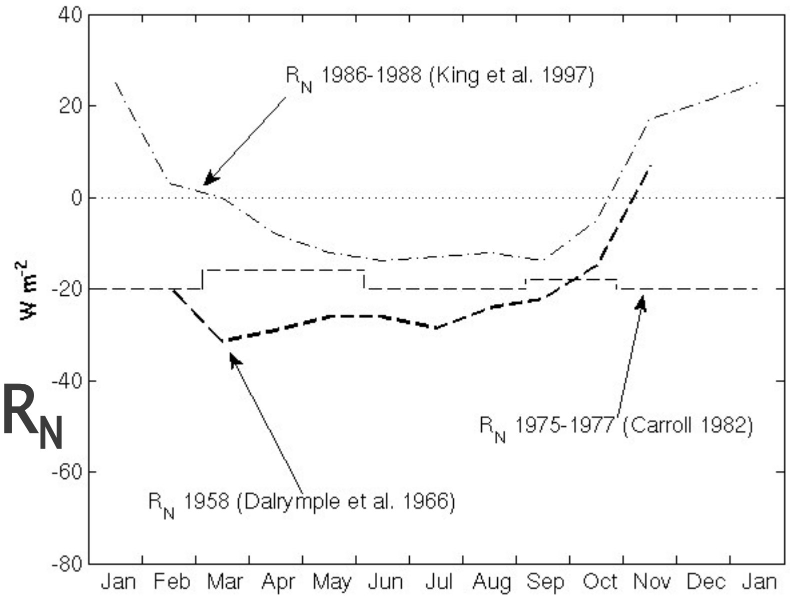
↑pyrgeometer --> T_{sfc}

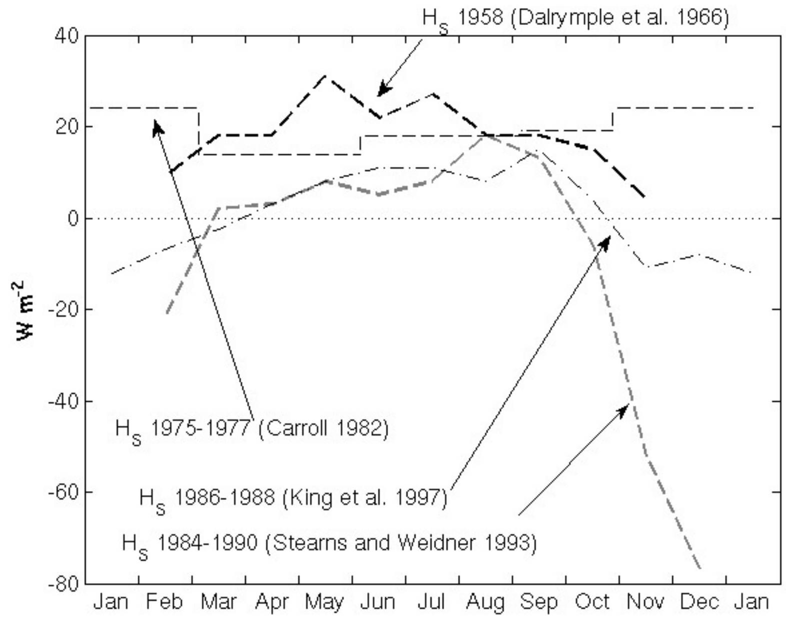
finite-volumes
numerical heat transfer model
Patankar (1982)

monthly means:
prior work

energy transfer over South Pole

R_N

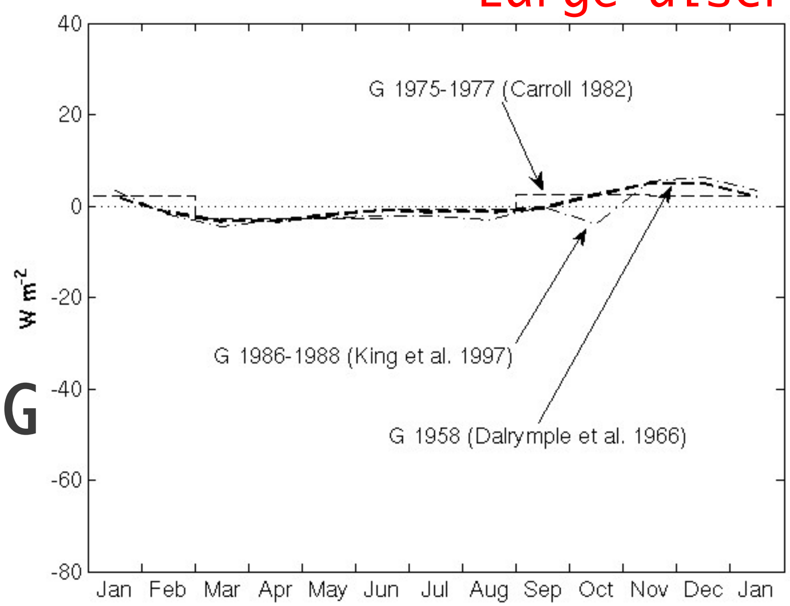


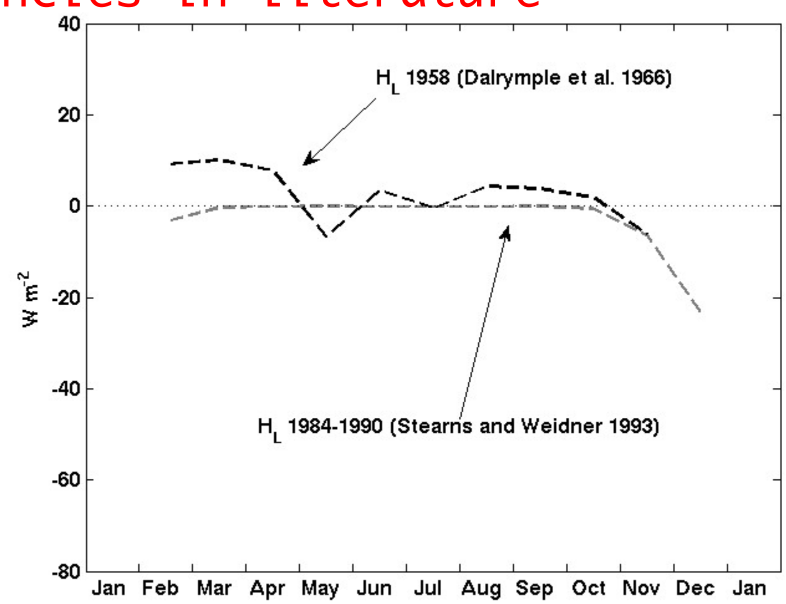


H_S

Large discrepancies in literature

G





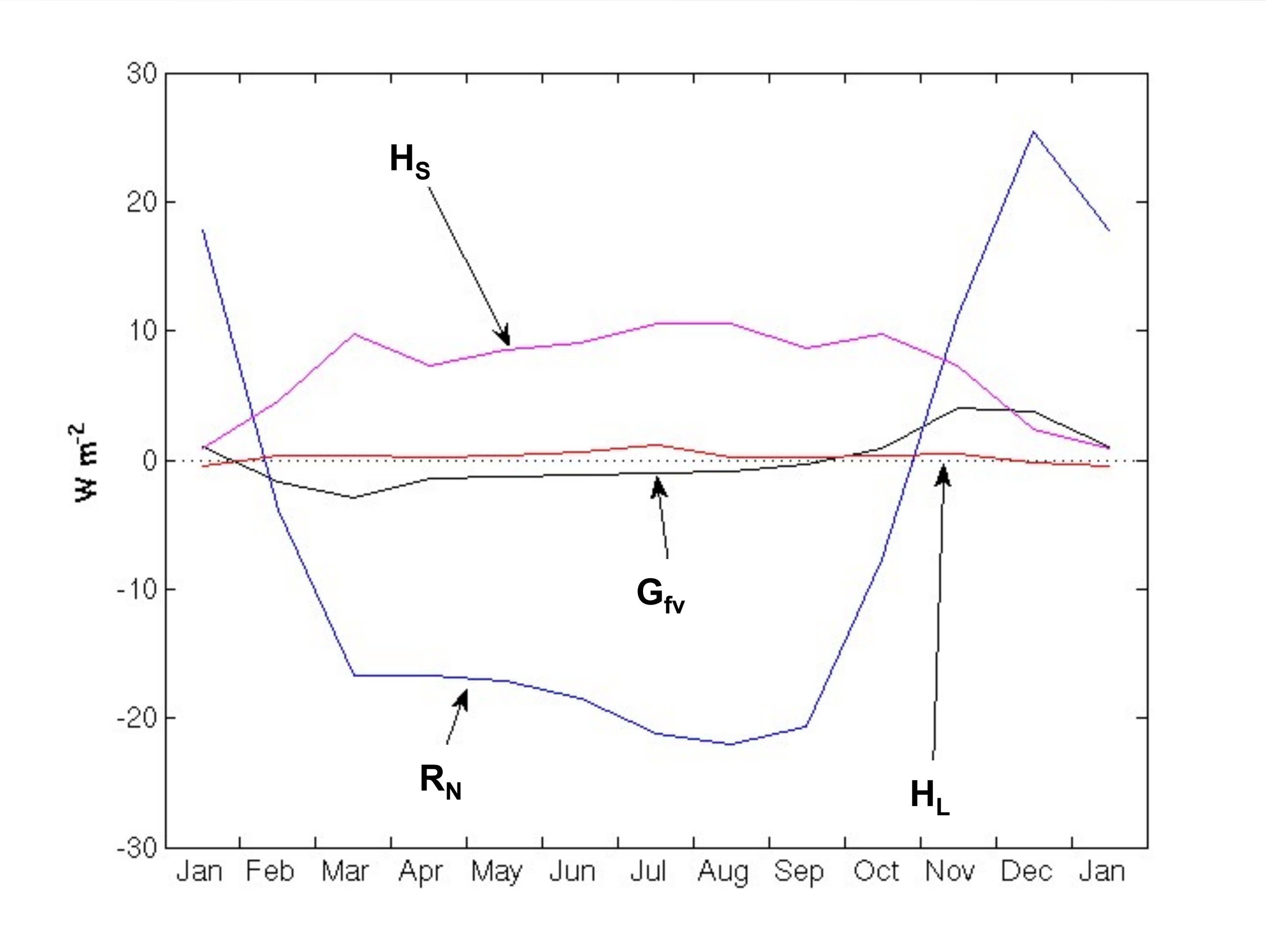
H_L

monthly means:

energy balance?

energy transfer over South Pole

$$G = R_N + H_S + H_L$$



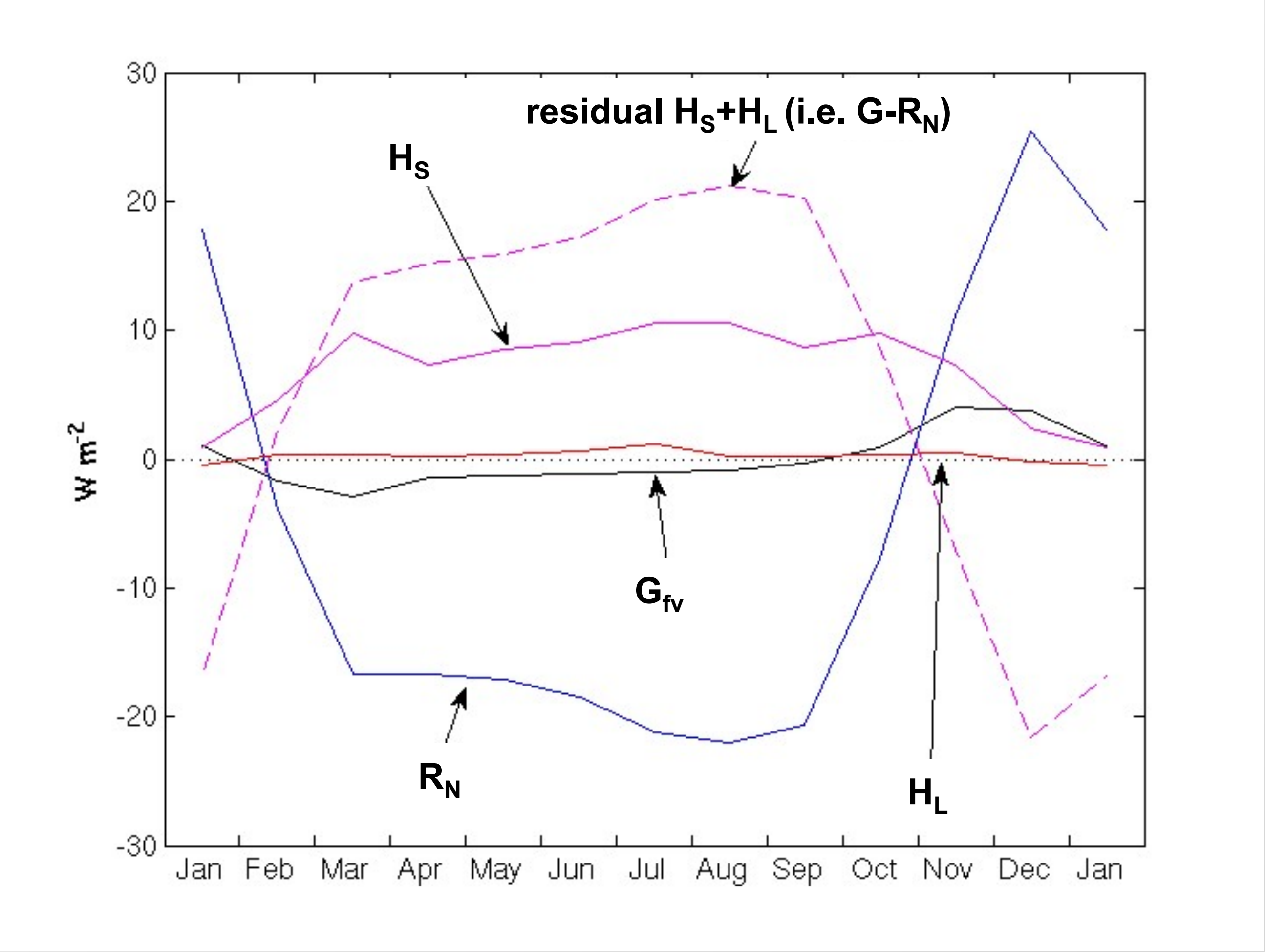
monthly means:

energy balance? *no.*

energy transfer over South Pole

$G = R_N + H_S + H_L$

$G - R_N = H_S + H_L$



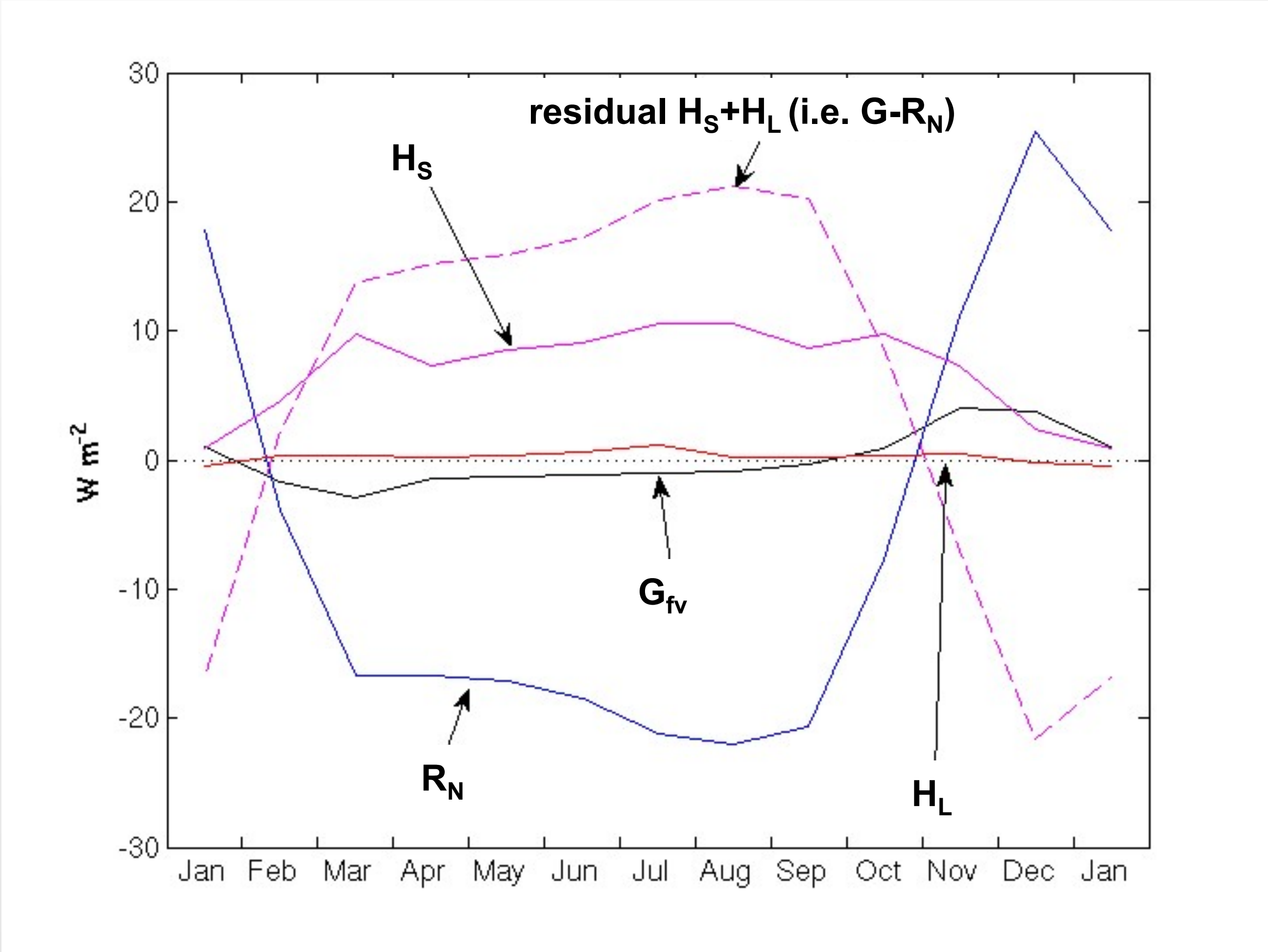
monthly means:

energy balance? *no.*

energy transfer over South Pole

$G = R_N + H_S + H_L$

$G - R_N = H_S + H_L$



H_S magnitude is underestimated by MO theory over South Pole, probably.

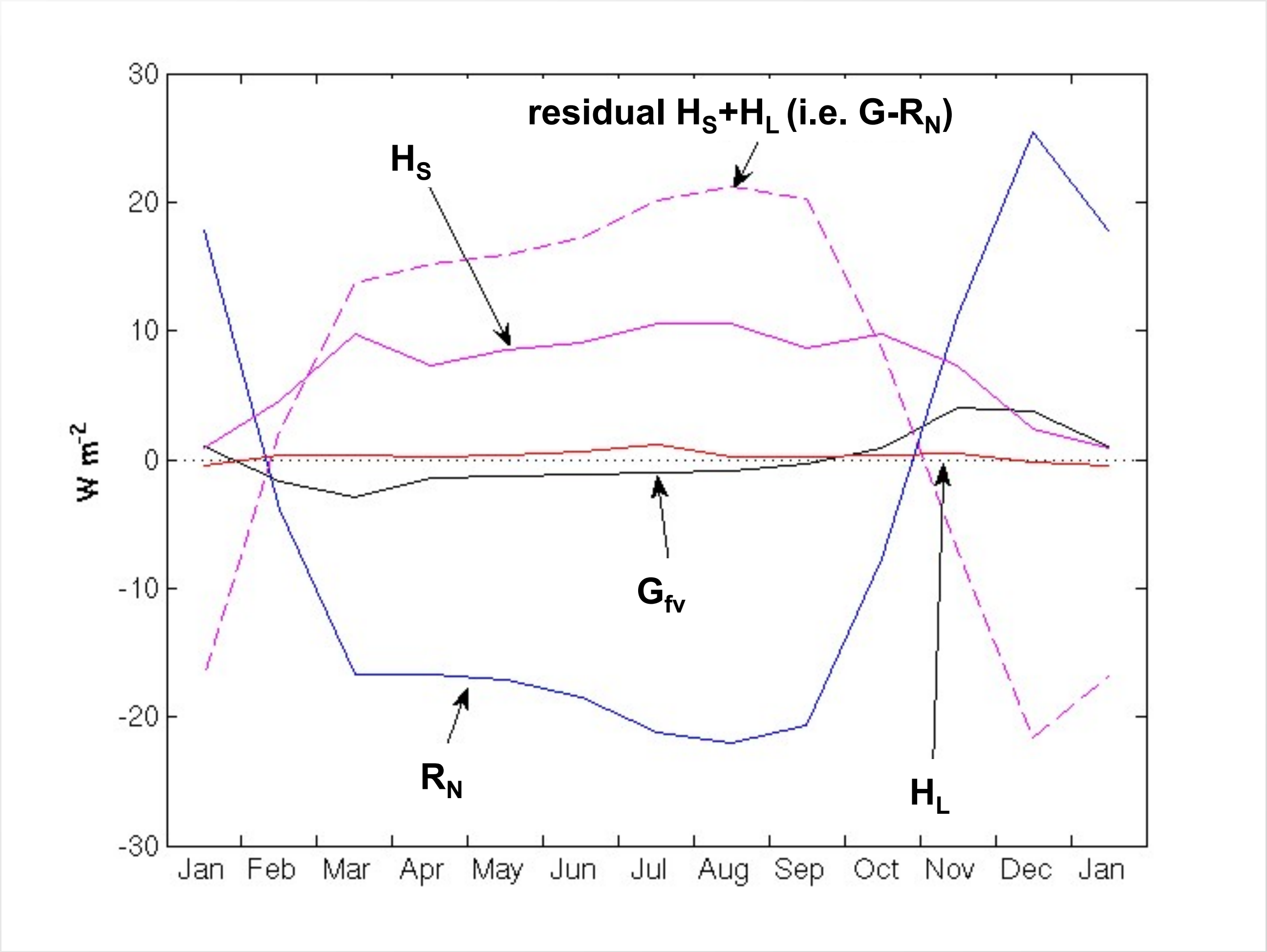
energy transfer over South Pole

$$G = R_N + H_S + H_L$$

$$G - R_N = H_S + H_L$$

monthly means:

energy balance? *no.*



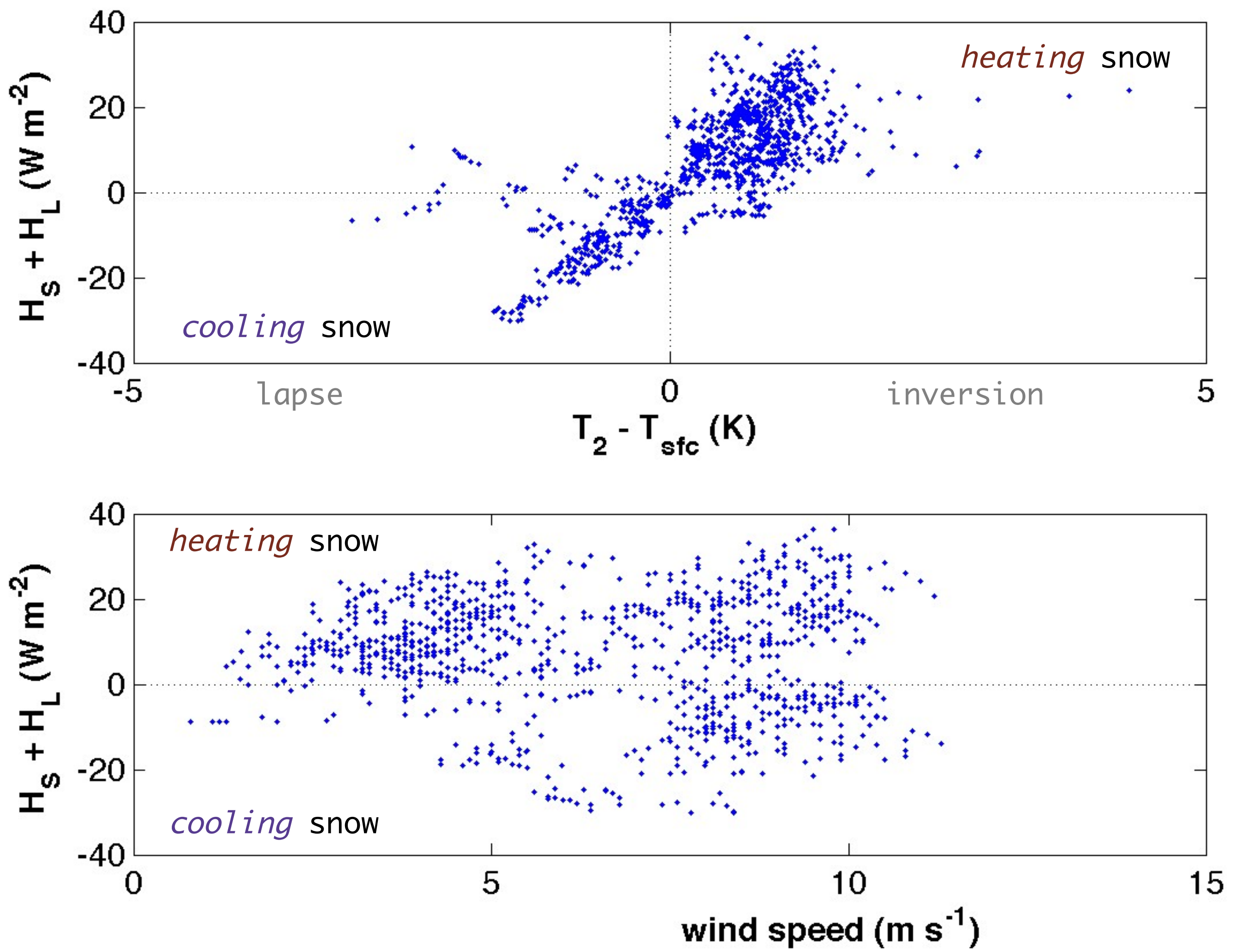
H_S is sensitive to skin-surface temperature derivation (from LUF).

stable boundary layer:
solution?

energy transfer over South Pole

$$G = R_N + H_S + H_L$$

$$G - R_N = H_S + H_L$$

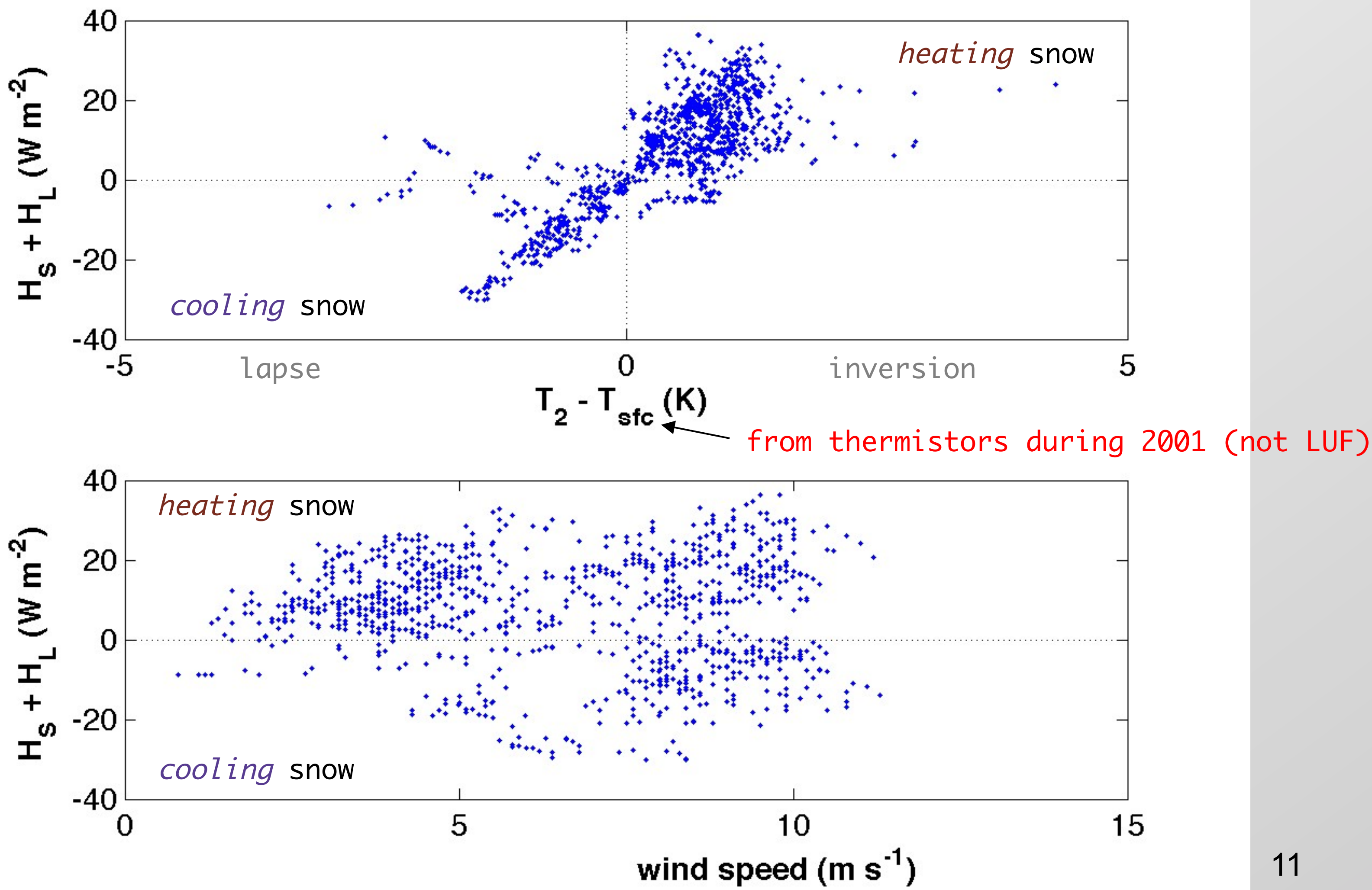


stable boundary layer:
solution?

energy transfer over South Pole

$$G = R_N + H_S + H_L$$

$$G - R_N = H_S + H_L$$



stable boundary layer:

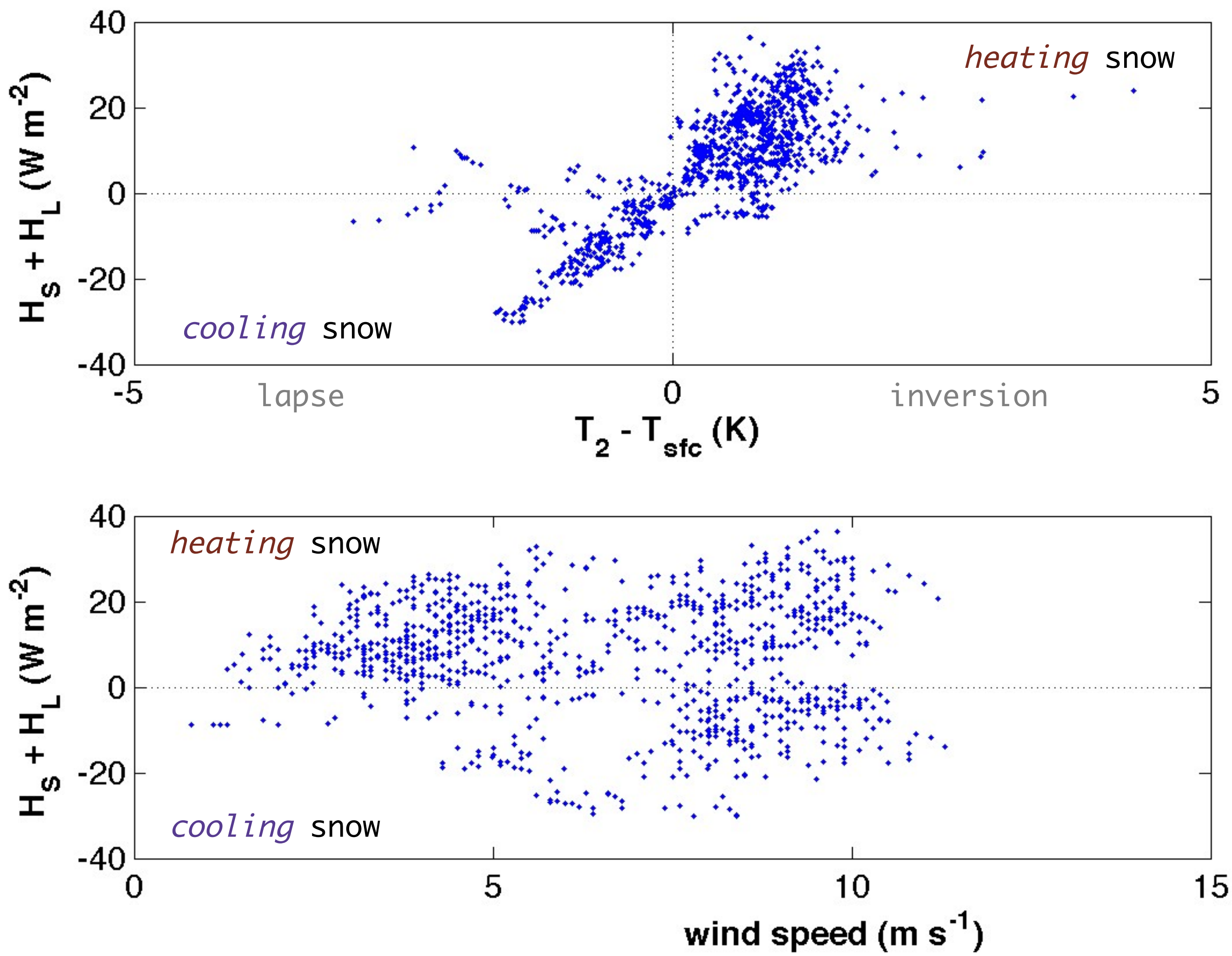
solution? *maybe.*

energy transfer over South Pole

$$G = R_N + H_S + H_L$$

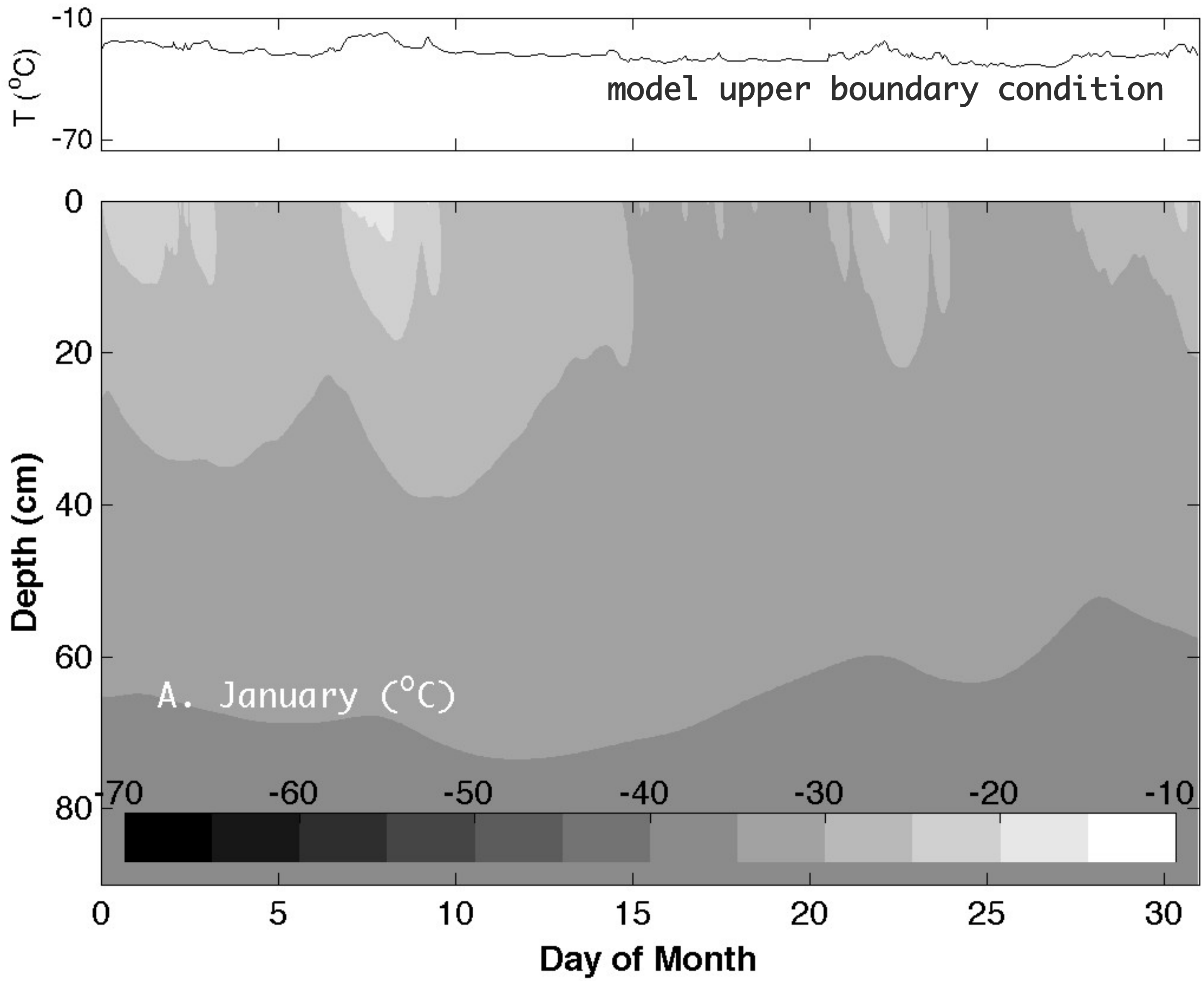
$$G - R_N = H_S + H_L$$

find emperical relationship between $G-R_N$, T_{inv}, ws, ...



short time scales:
subsurface temperatures

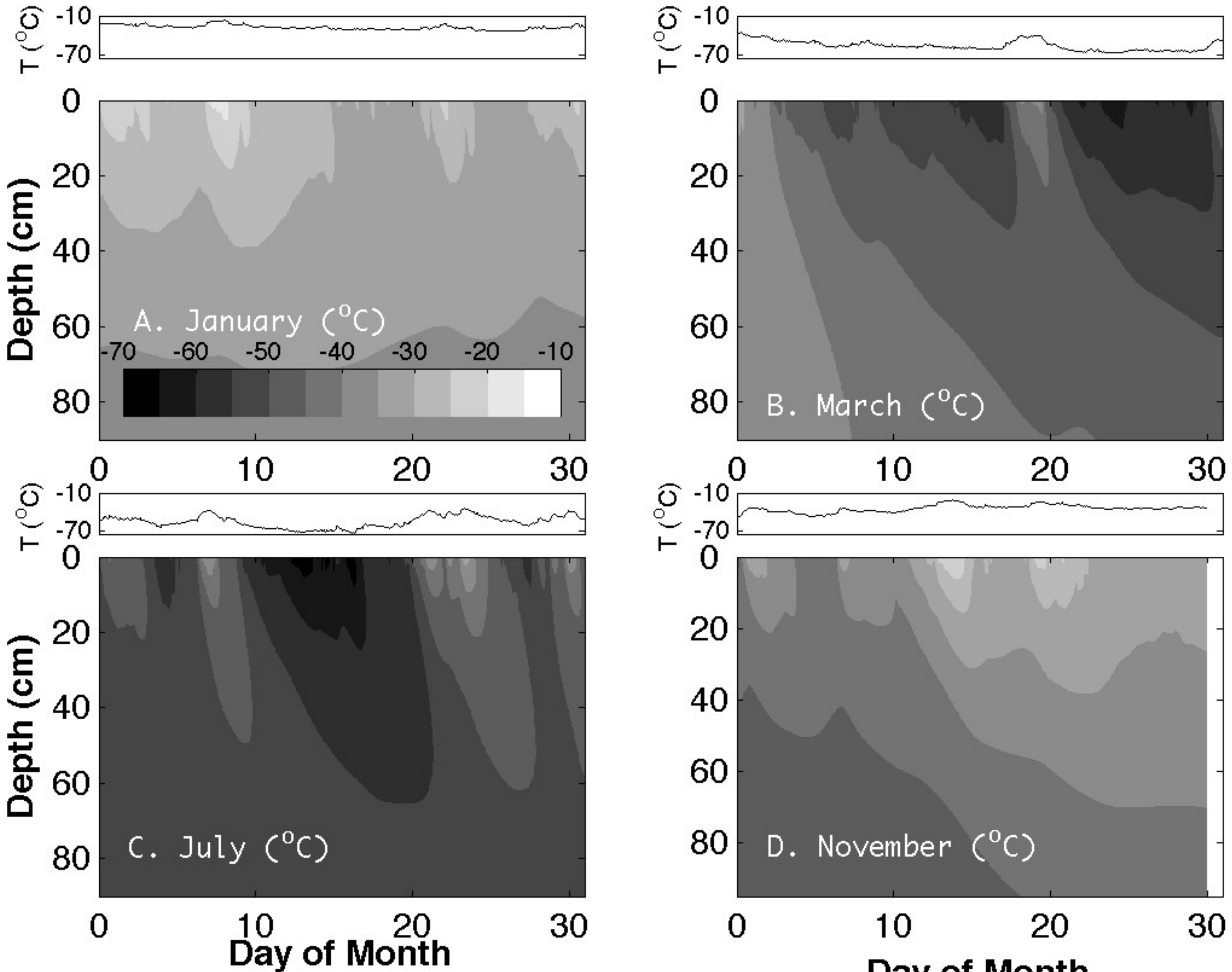
heat transfer in snow pack



short time scales:
subsurface temperatures

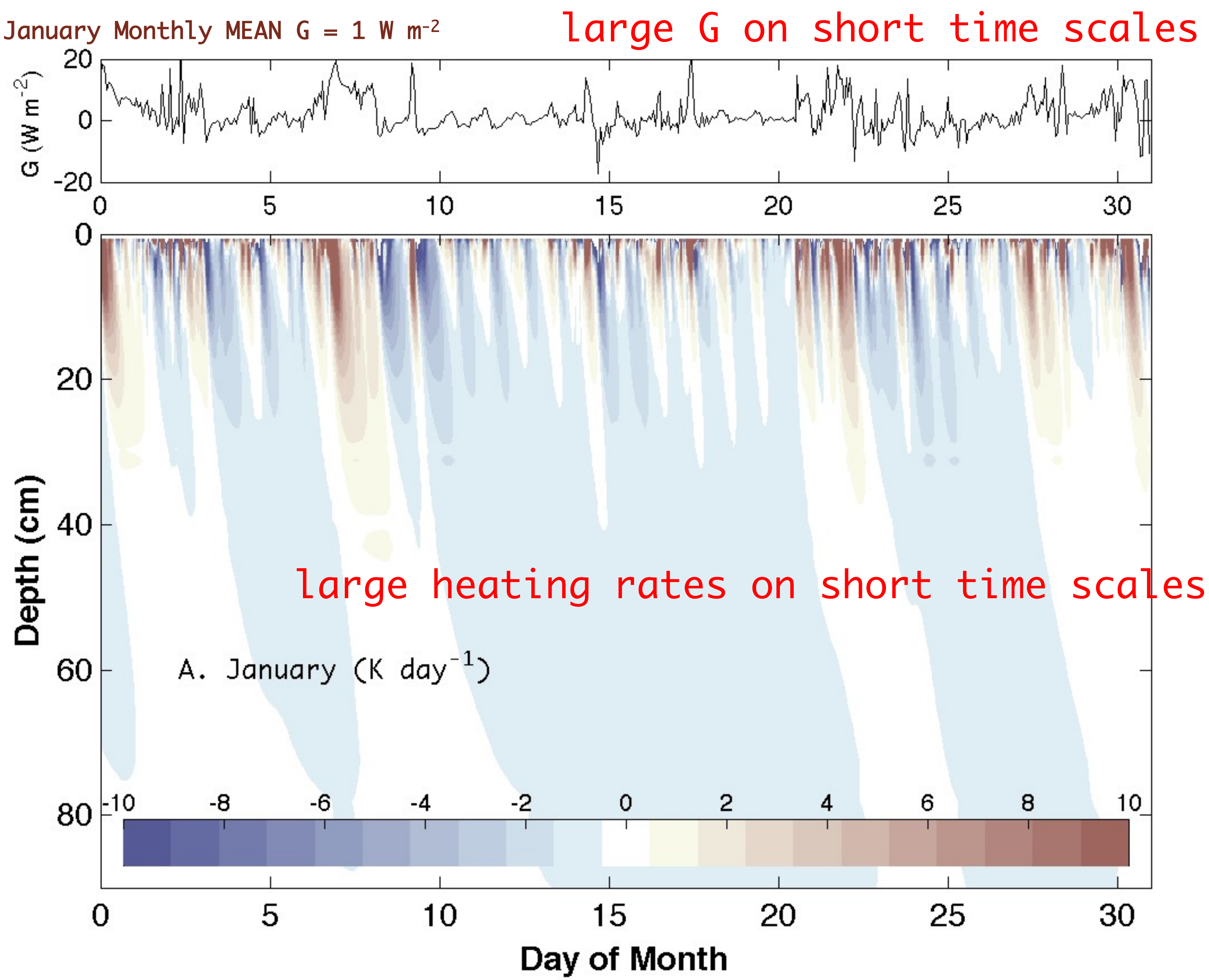
heat transfer in snow pack

high variability in subsurface temperatures during winter



short time scales:
subsurface heating rates

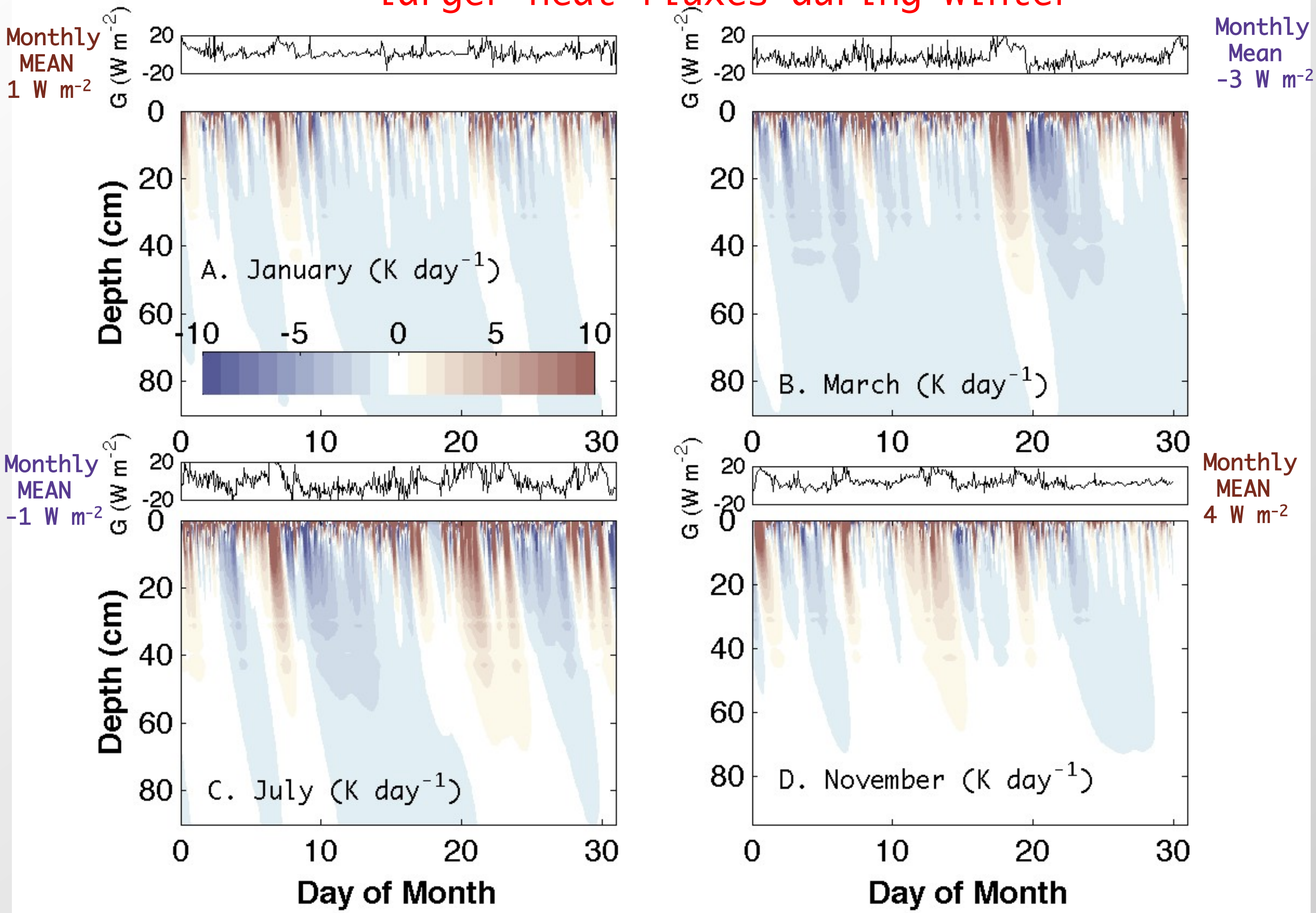
heat transfer in snow pack



short time scales:
subsurface heating rates

heat transfer in snow pack

larger heat fluxes during winter

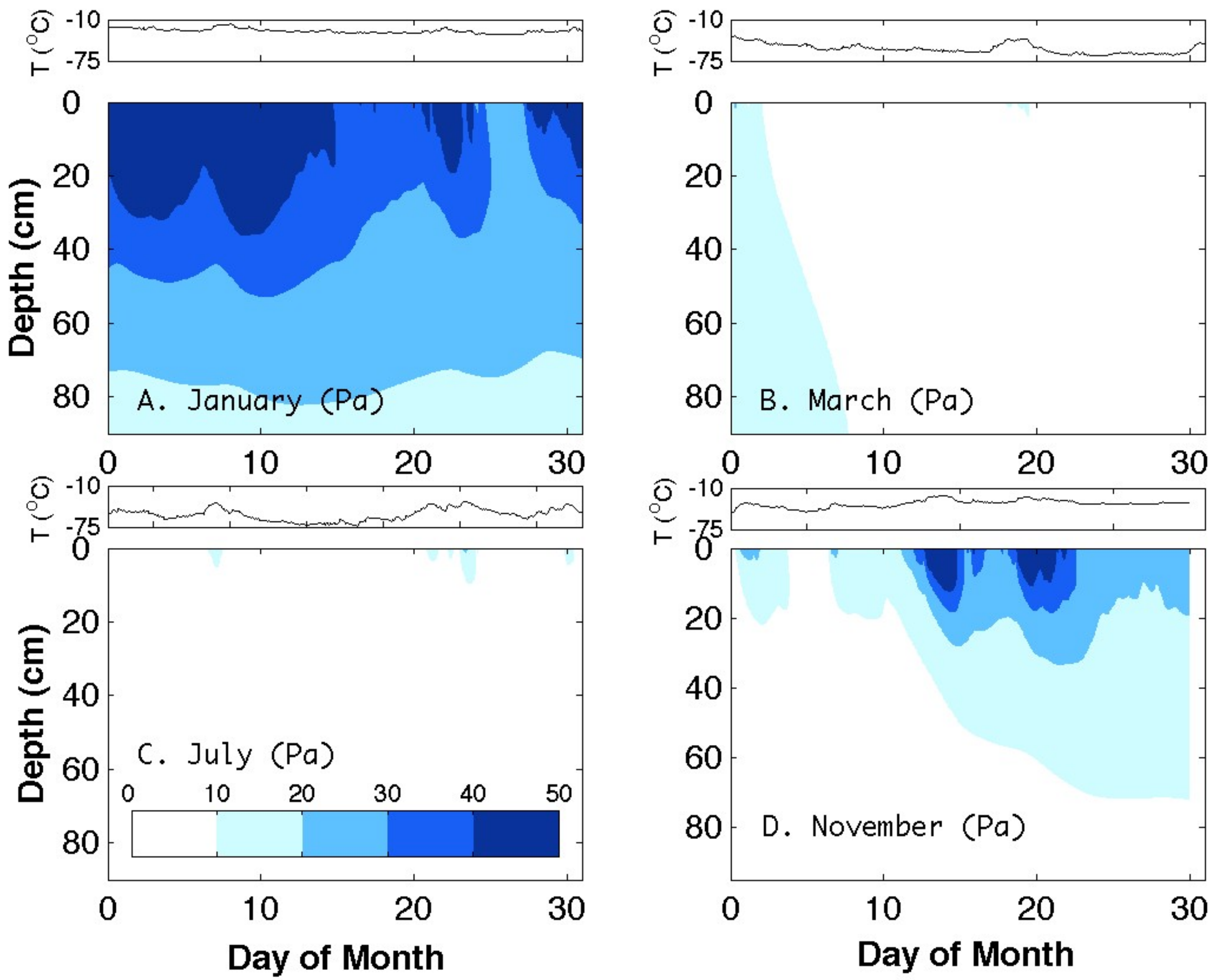


short time scales:

subsurface vapor pressures

heat transfer in snow pack

subsurface vapor pressures higher during summer



conclusions:

energy transfer over South Pole

$$G = R_N + H_S + H_L$$

No energy balance. H_S is probably larger in the monthly mean (by 10 W m^{-2}) than predicted by MO theory.

May be possible to develop emperical relationship for H_S+H_L.

No significant frost deposition at the South Pole.

Snow surface temperatures at the South Pole result in interface heat fluxes of up to 20 W m^{-2} on daily time scales.

Episodic sustained heating rates of greater than 10 K day^{-1} occur in the near-surface snow at South Pole.

Snow temperature gradients and heat fluxes important for depth hoar formation and $\delta^{18}O$ (or δD) fractionation.

acknowledgements:

Ed Waddington of UW for help with the finite-volume model.

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NSF Office of Polar Programs for general support and travel funds.

$$G = R_N + H_S + H_L$$

conclusions:

No energy balance. H_S is probably larger in the monthly mean (by 10 W m^{-2}) than predicted by MO theory.

No significant frost deposition at the South Pole.

Snow surface temperatures at the South Pole result in interface heat fluxes of up to 20 W m^{-2} on daily time scales.

Episodic sustained heating rates of up to 3 K day^{-1} occur in the near-surface snow at South Pole.

Heat plumes puncture deeper into the snow during winter than summer.

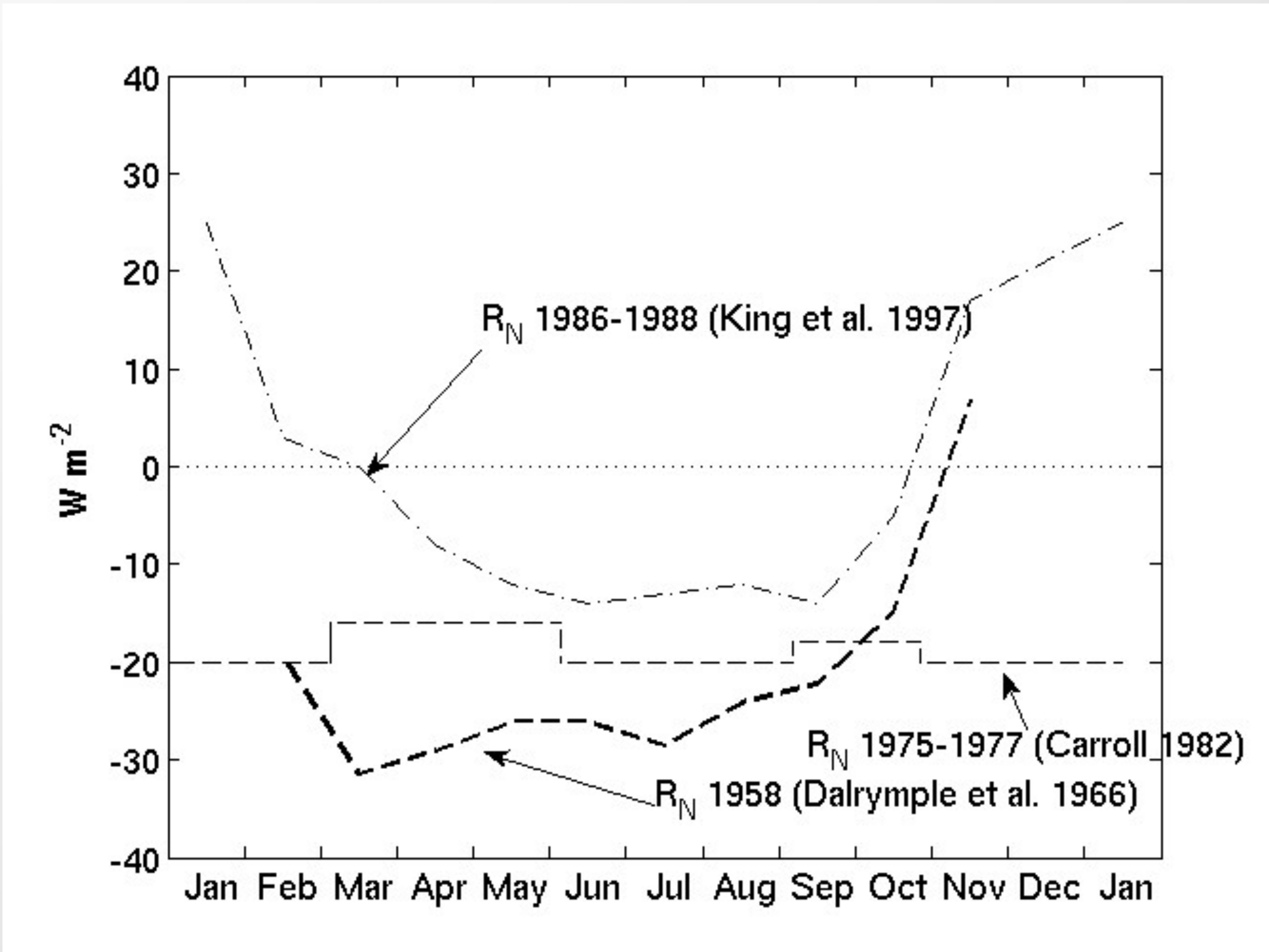
Snow temperature gradients and heat fluxes important for depth hoar formation and $^{18}O_2$ fractionation.

energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

prior work on R_N (net radiation)

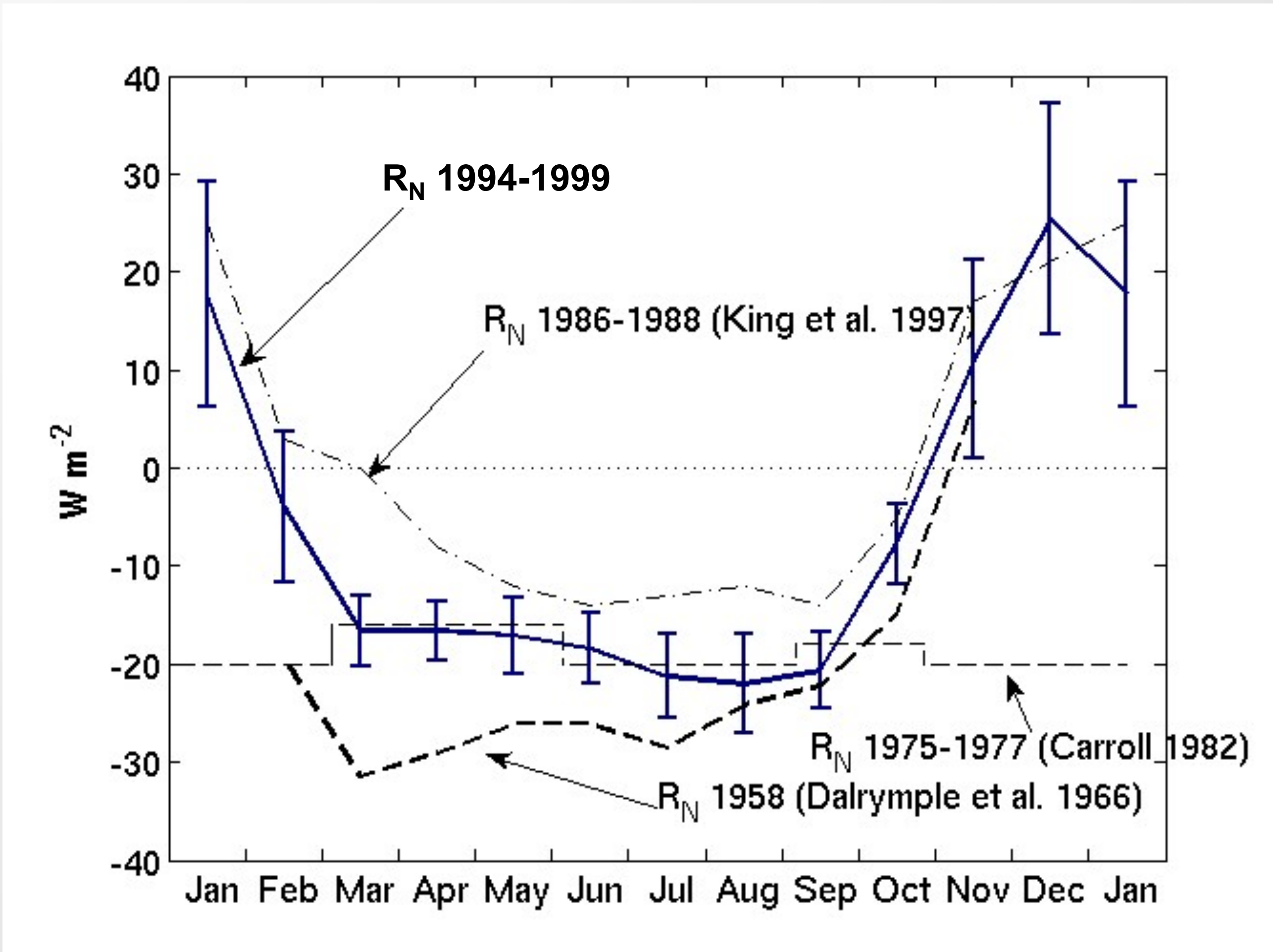


energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

R_N (net radiation)

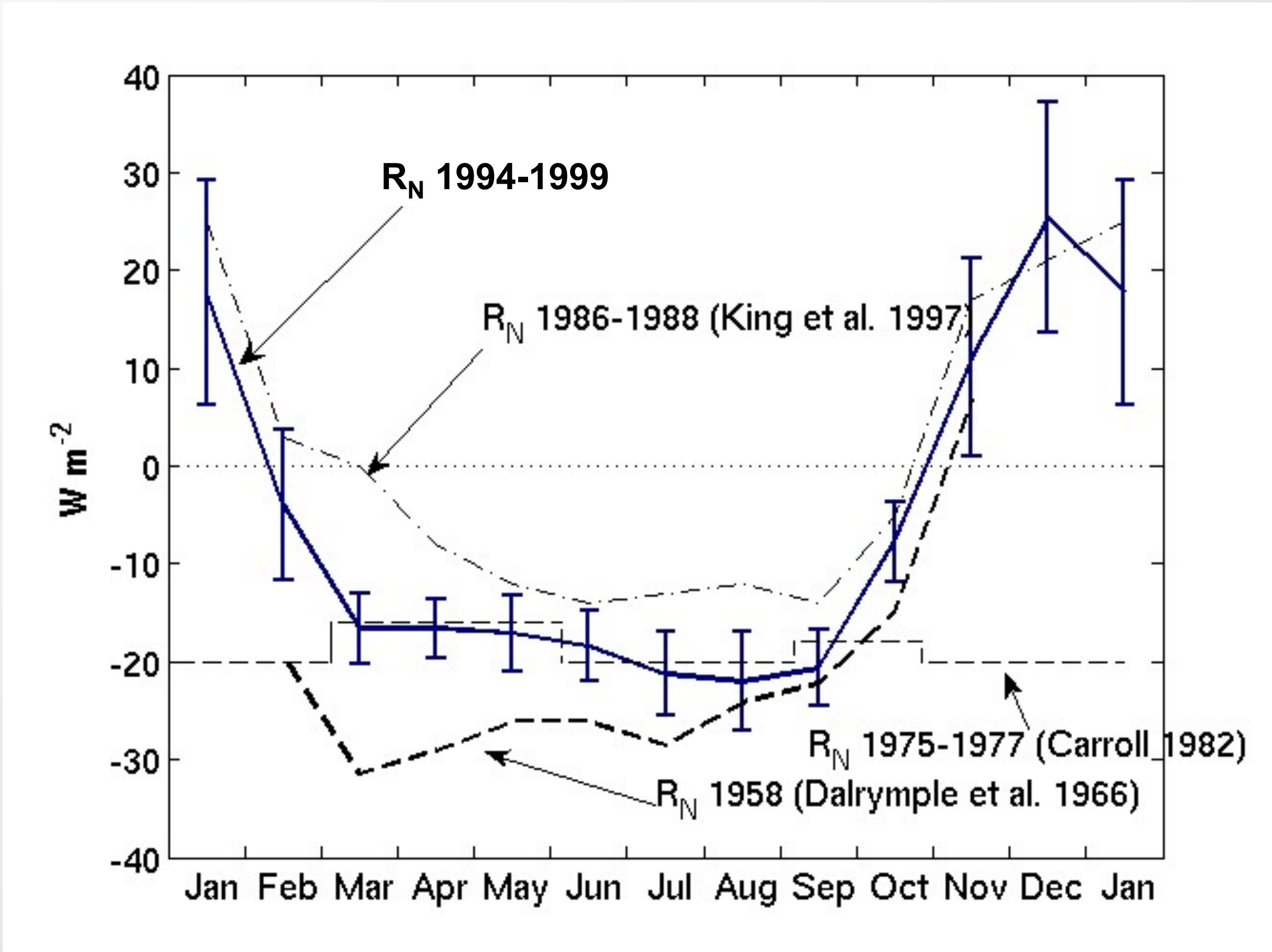


energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

R_N (net radiation)



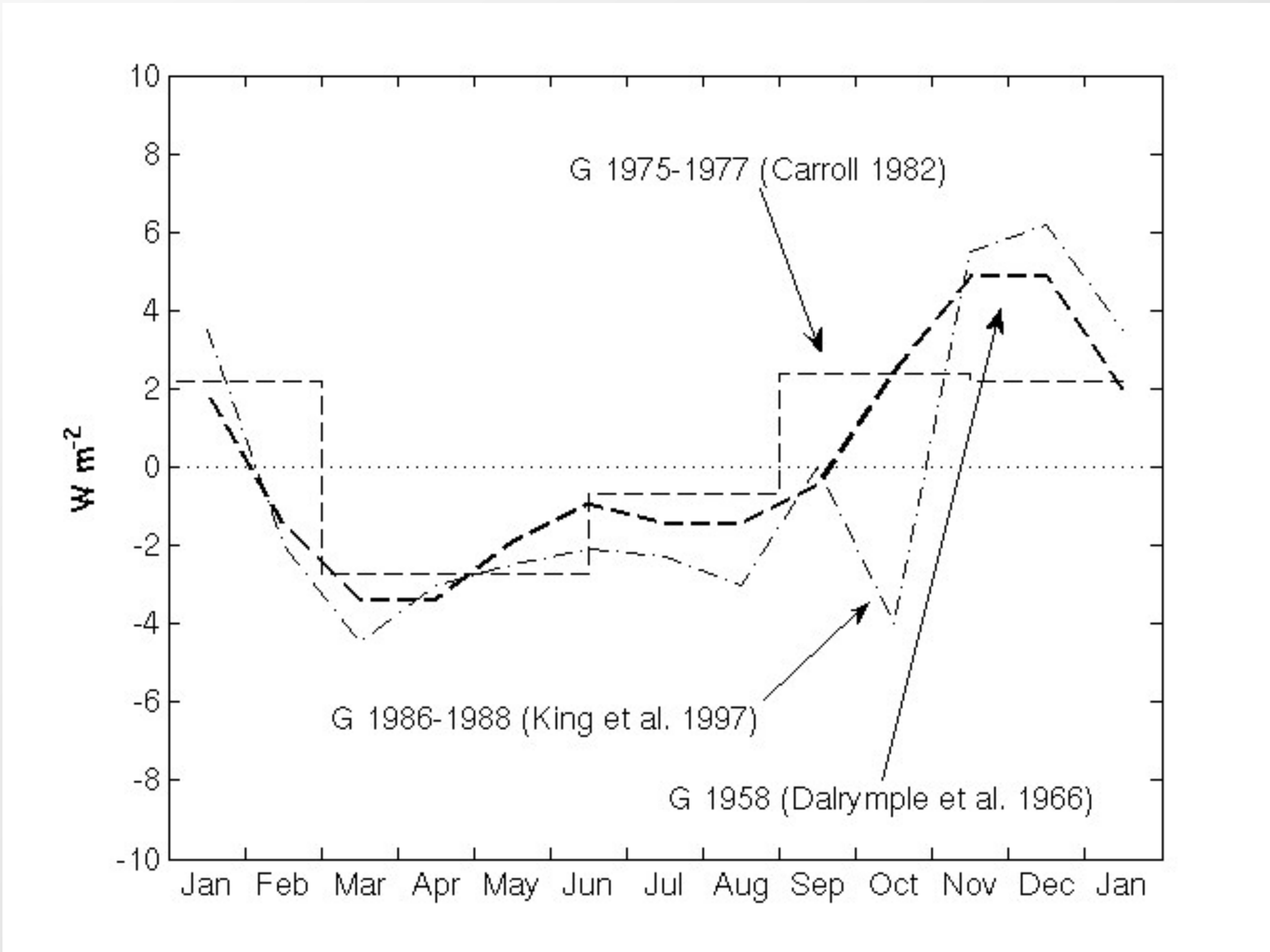
More interannual variability during Summer likely due to effect of clouds on solar radiation.

monthly means:

G (subsurface heat flux)

energy transfer over South Pole

$G = R_N + H_S + H_L$

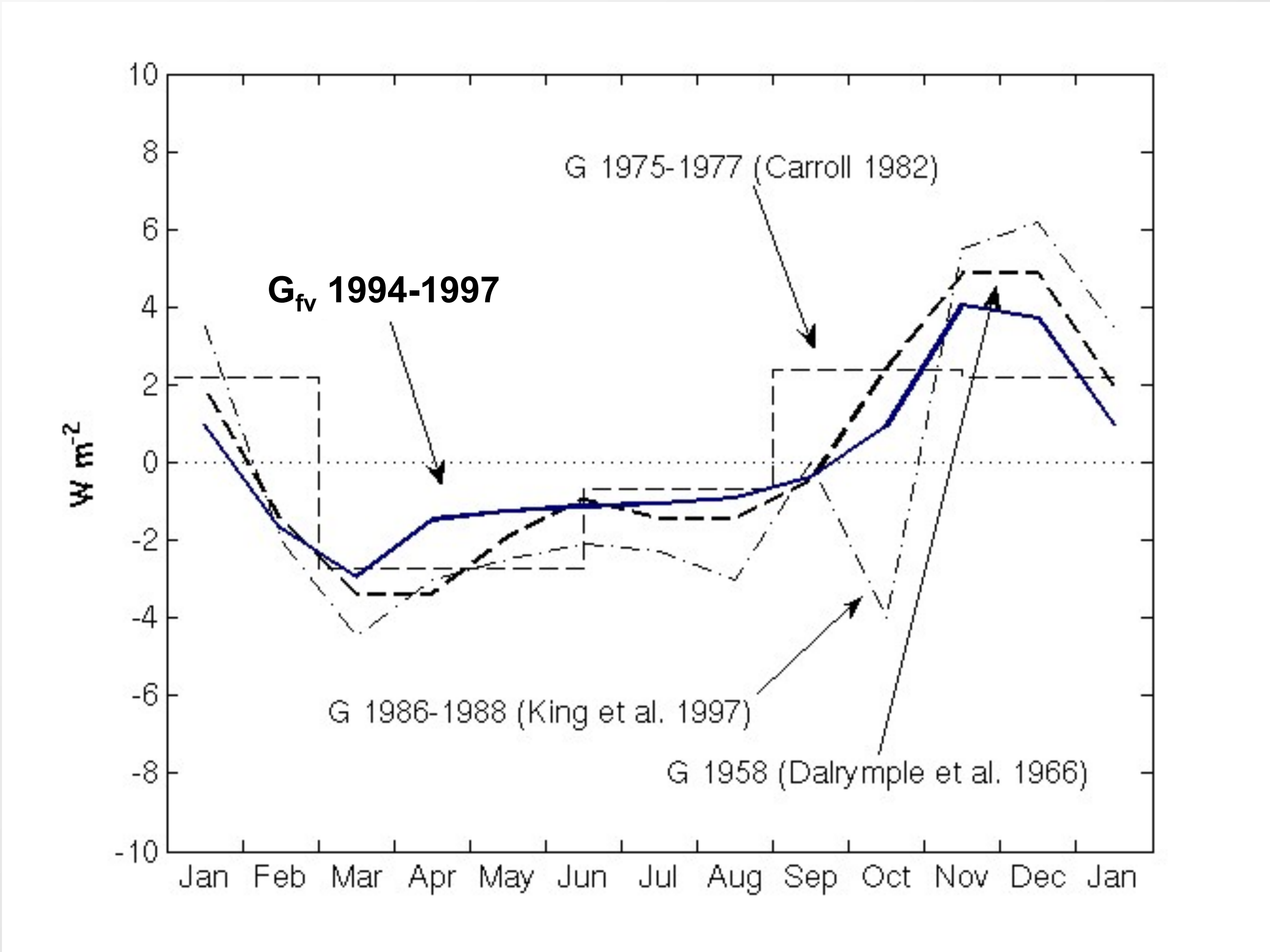


energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

G (subsurface heat flux)

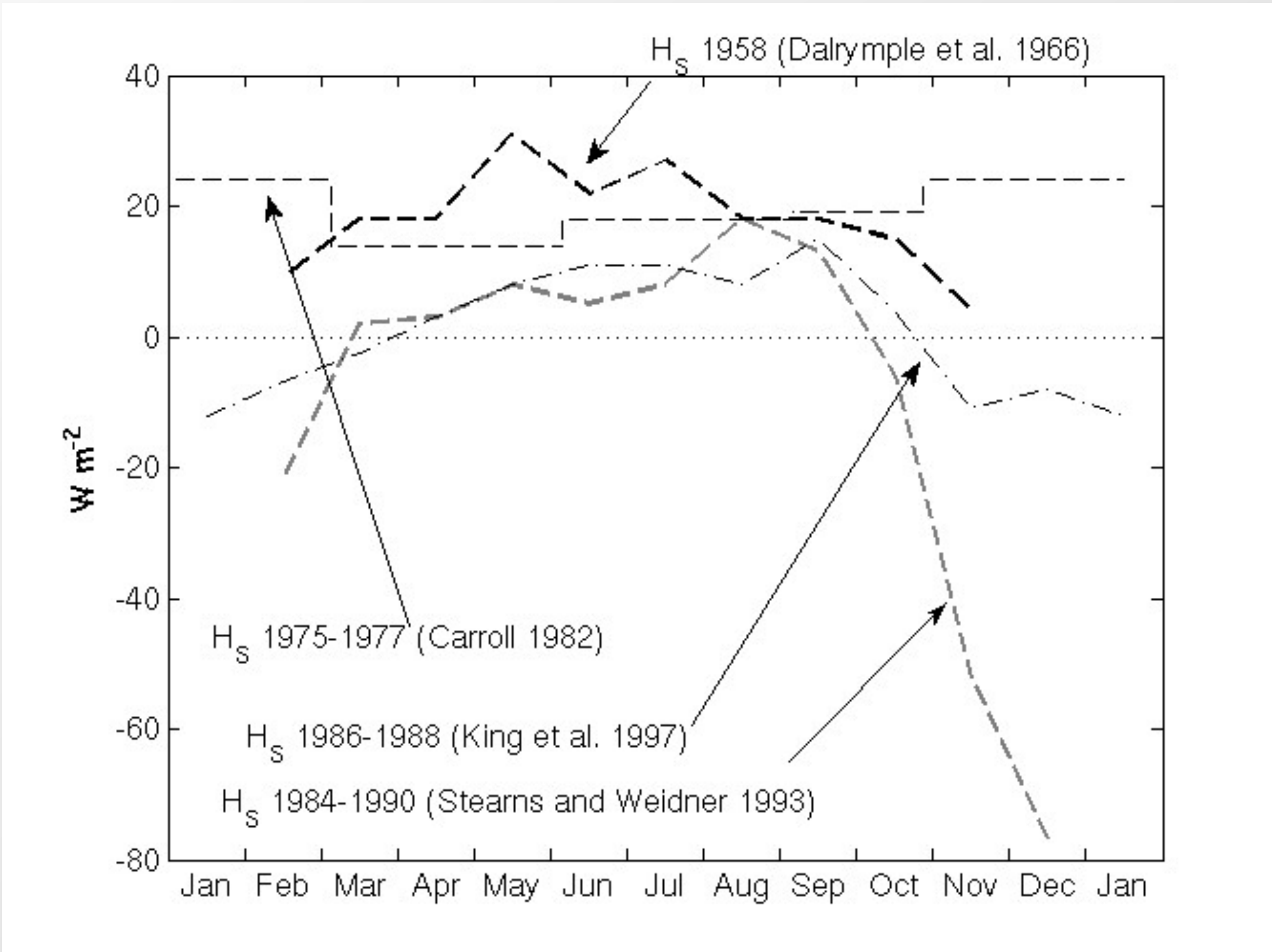


energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

prior work on H_S (sensible heat flux)

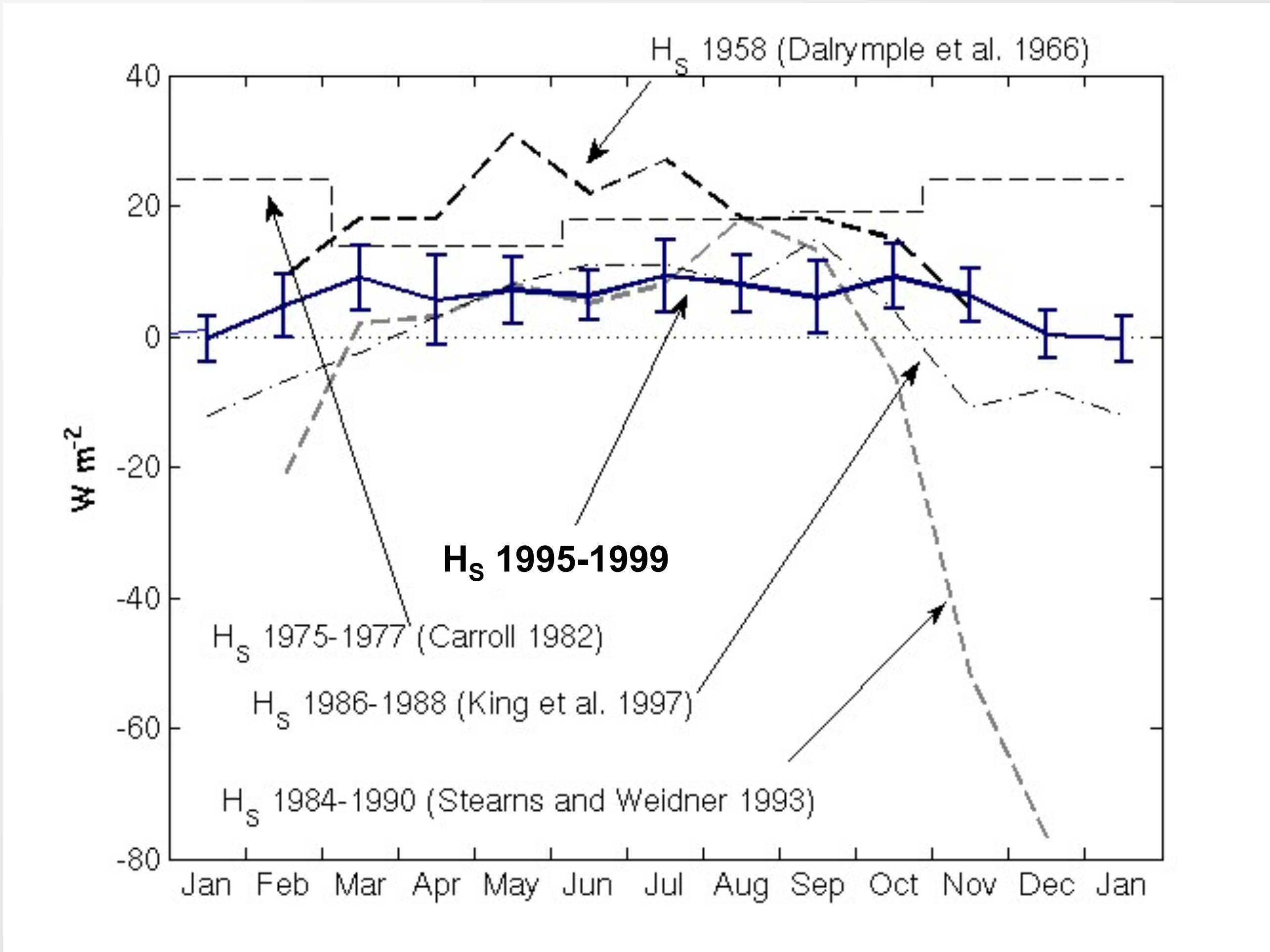


monthly means:

H_S (sensible heat flux)

energy transfer over South Pole

$G = R_N + H_S + H_L$

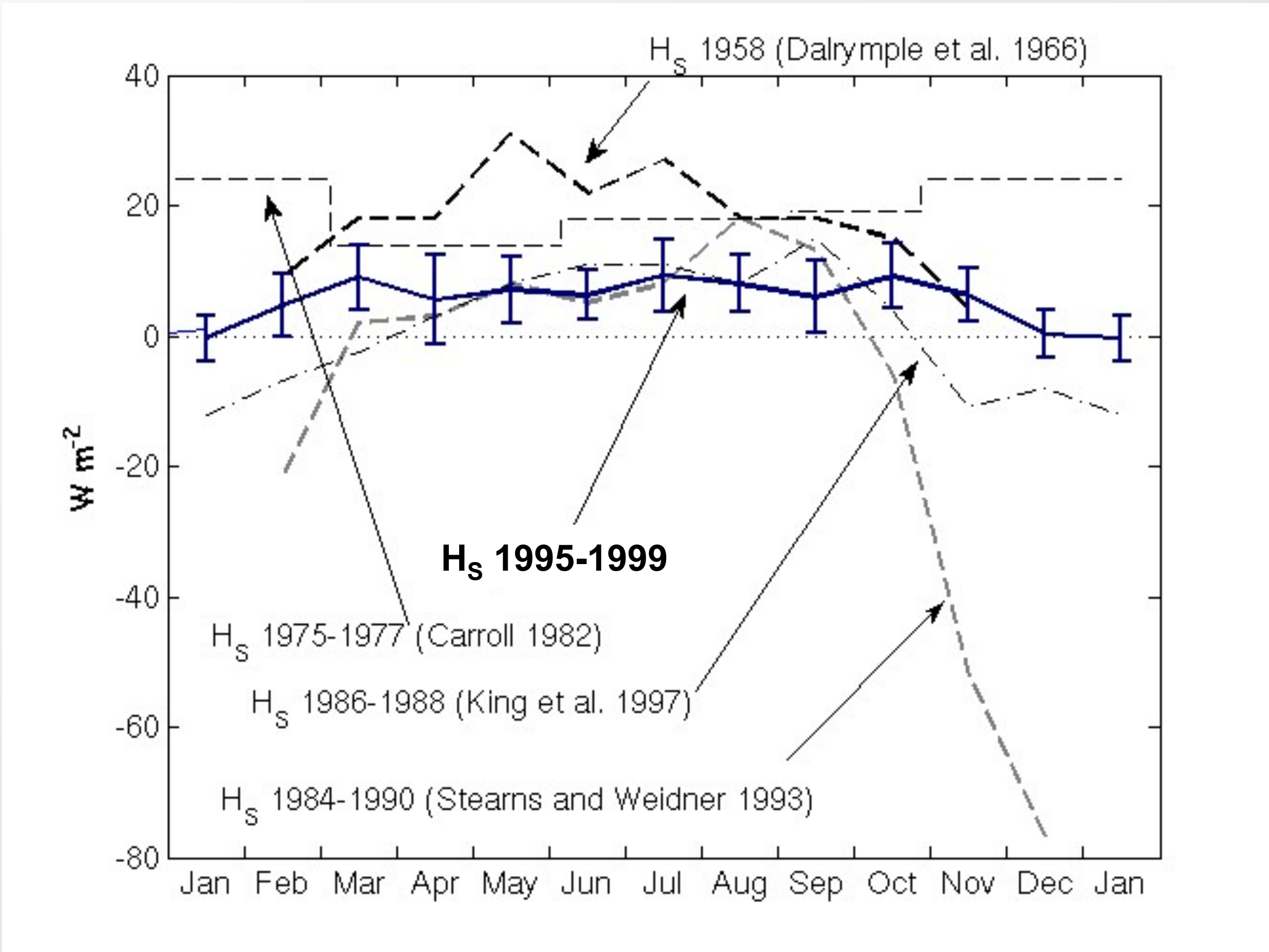


energy transfer over South Pole

$G = R_N + H_S + H_L$

monthly means:

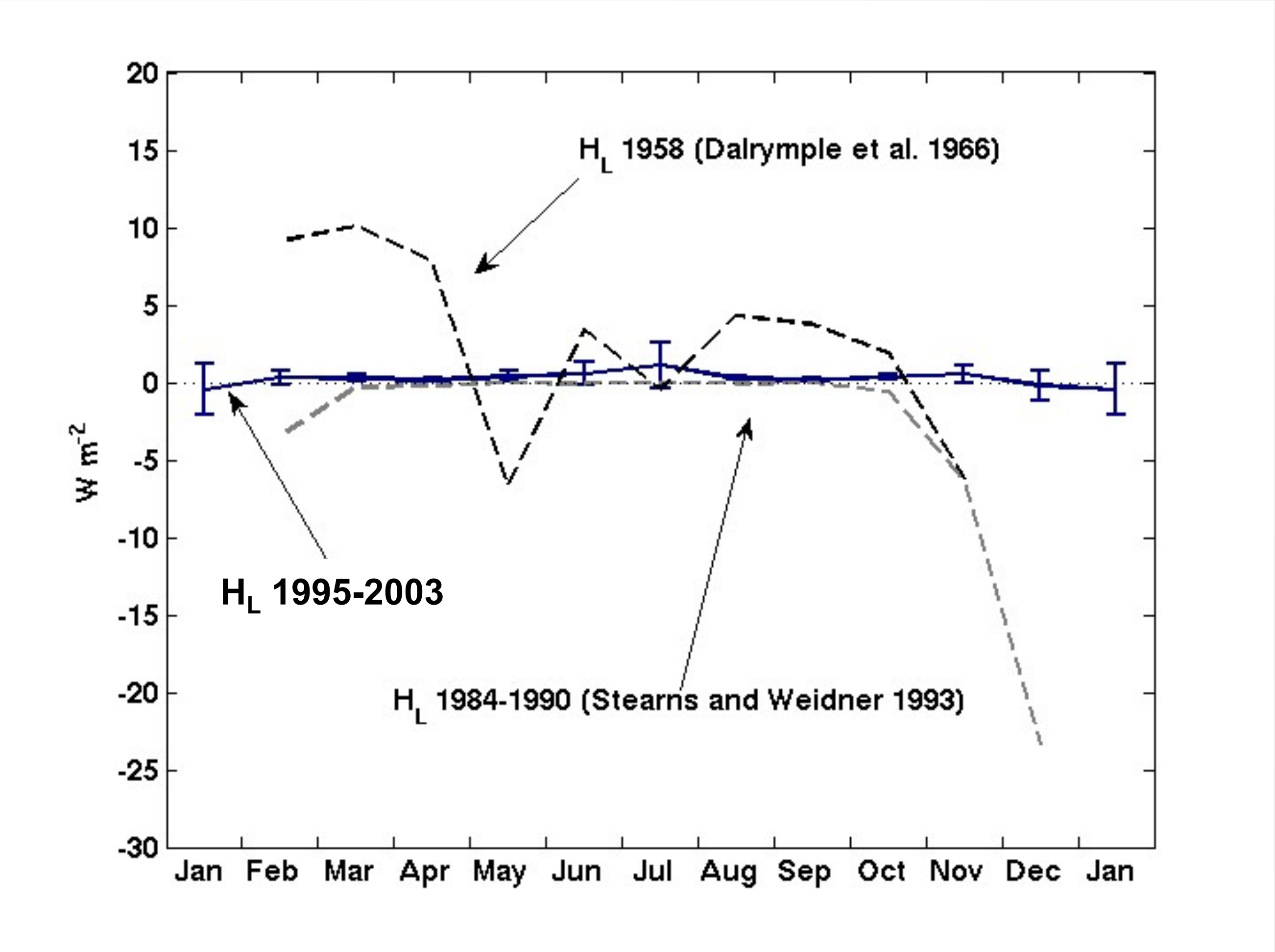
H_S (sensible heat flux)



monthly mean H_S from MO theory is almost always directed toward surface

monthly means:
H_L (latent heat flux)

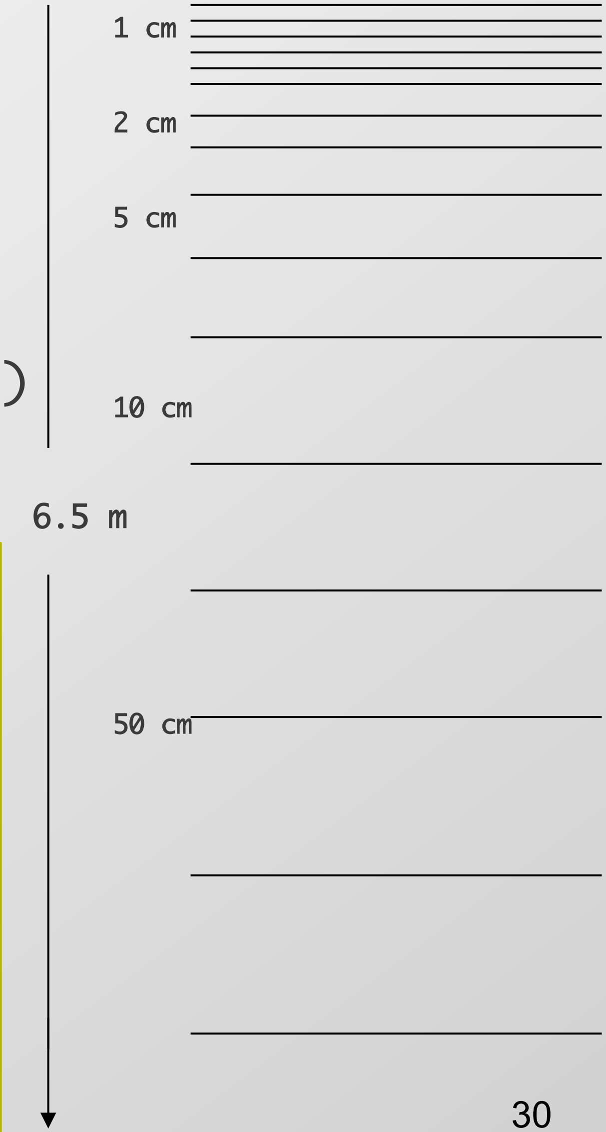
energy transfer over South Pole
$G = R_N + H_S + H_L$

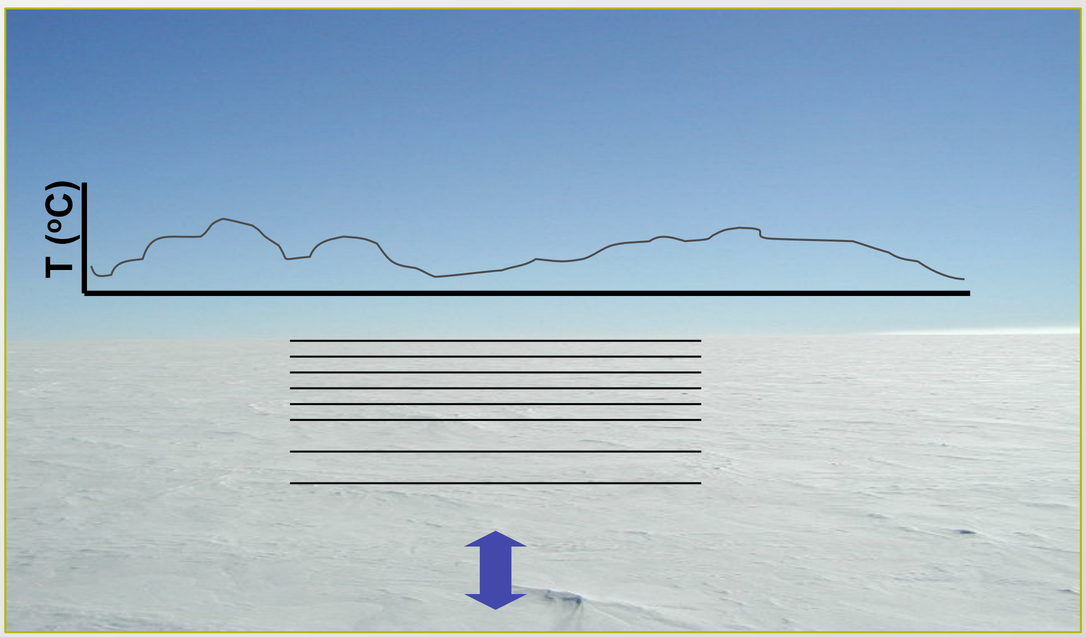


heat transfer model:

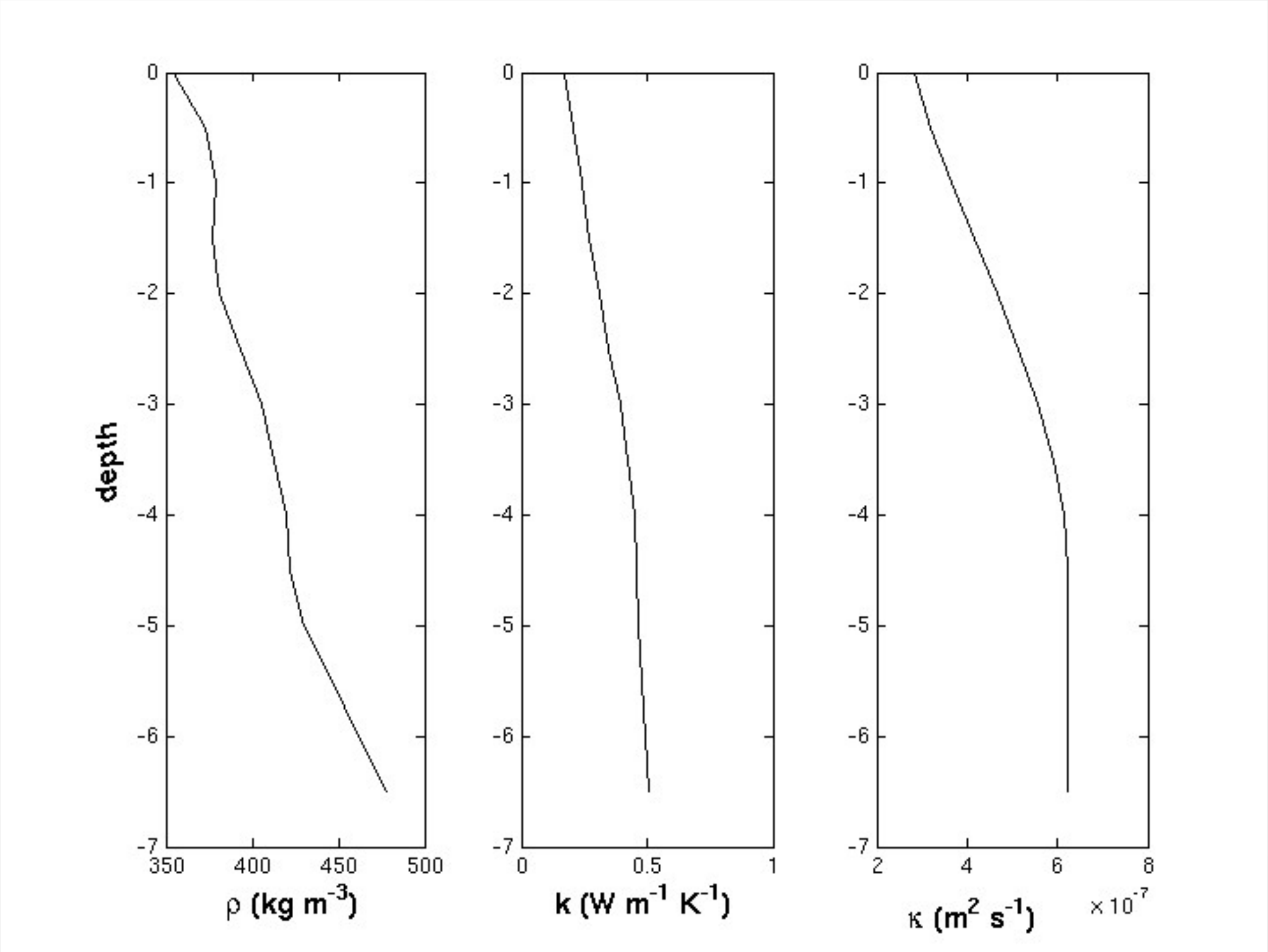
finite volumes (Patankar 1982)
variable levels
no accumulation (no advection)
no sources (solar, wind pumping, …)

boundary conditions:
top: variable surface T (1-3 min)
bottom: seasonal T gradient





G Model properties:
Dalrymple et al. (1966)



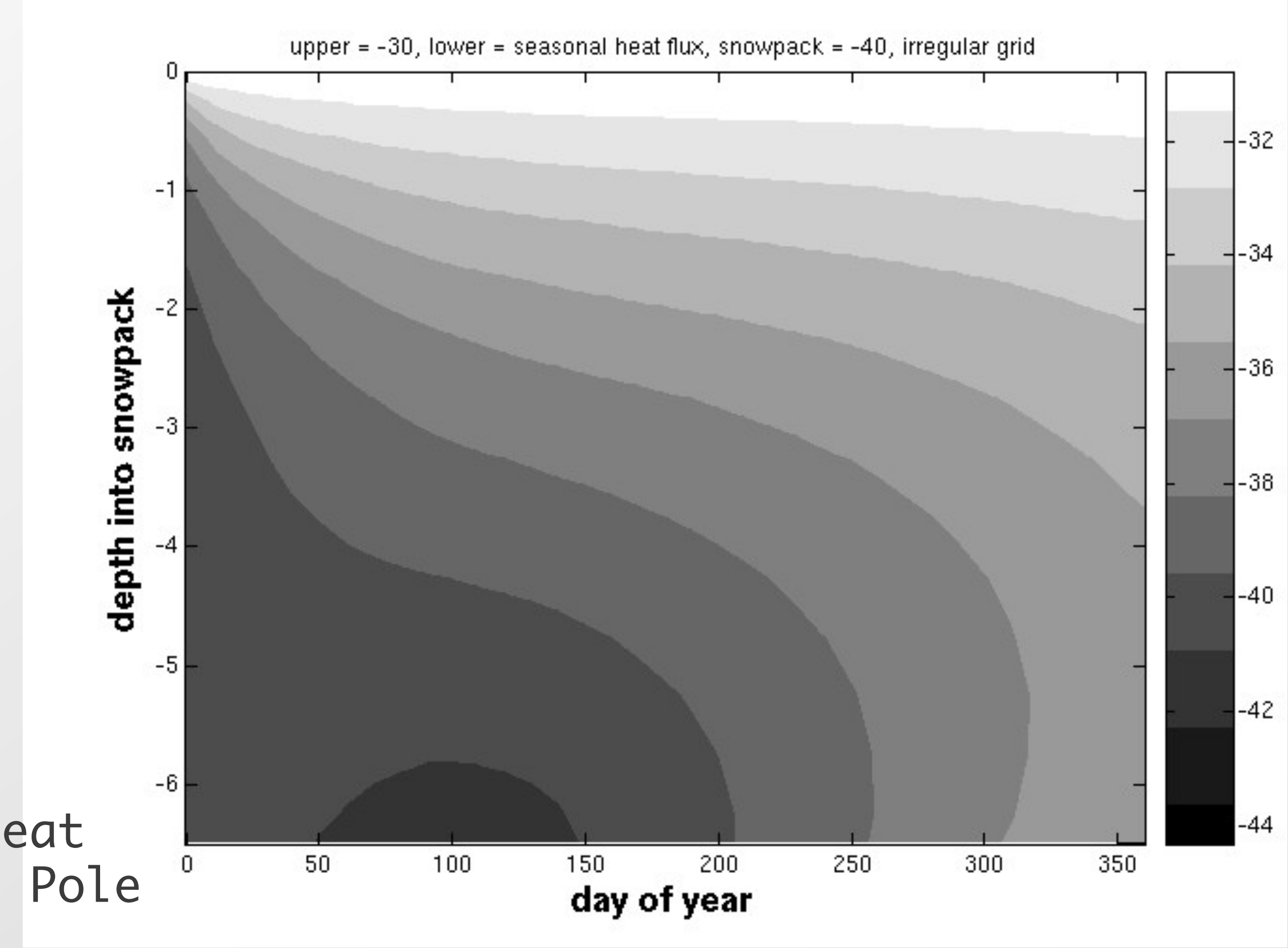
G Model validation:

Carslaw and Jaeger (1959)

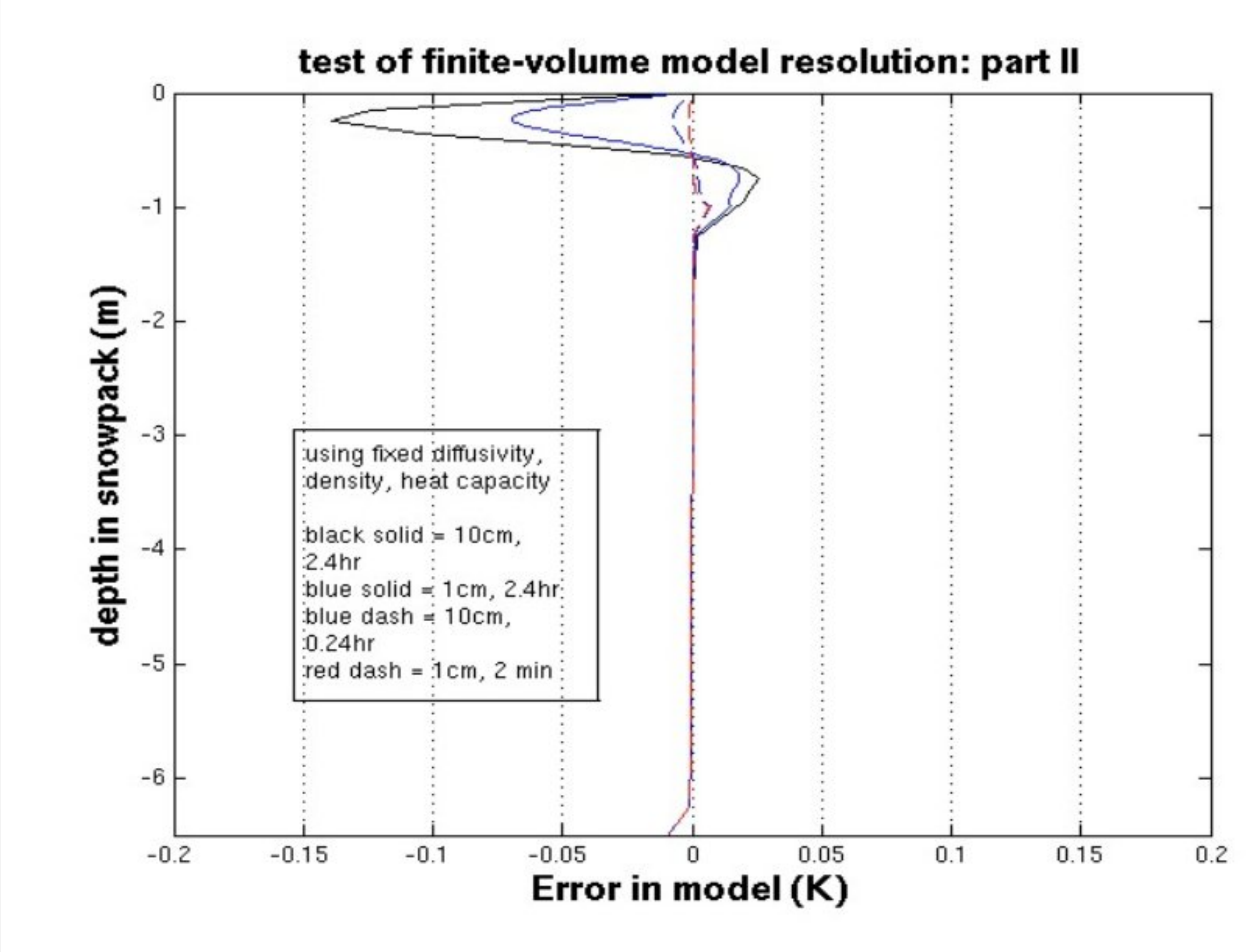
surface set
at −30°C

snow pack
set at −40°C

bottom set
to seasonal heat
flux at South Pole



G Model validation:
Carslaw and Jaeger (1959)



Effect of clouds on R_N: