Land-surface-atmosphere-climate coupling

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Ray Desjardins Session

AMS Conference on Atmospheric Biogeosciences

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FIFE research with Twin Otter

- Betts, A.K., R.L. Desjardins, J.I. MacPherson, and R.D. Kelly, 1990: Boundary Layer Heat and Moisture Budgets from FIFE. Boundary-Layer Meteorol., 50, 109-137.

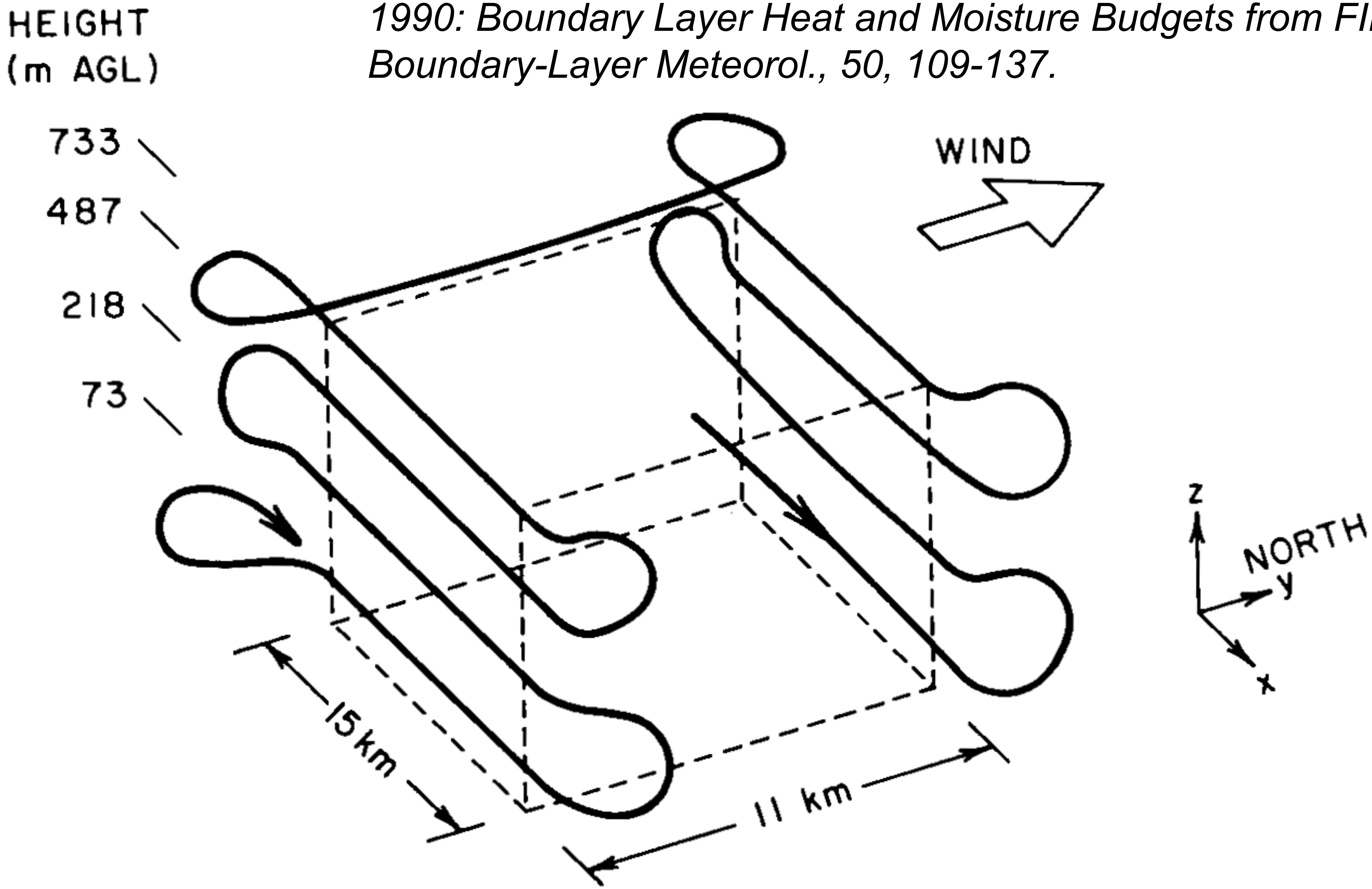
  - Aircraft stacks – FIFE may be one of the first experiments where such an exacting comparison between direct surface flux measurements, aircraft flux measurements and budget estimates could be made. Excellent time dependence from aircraft – consistent with but better than surface and sondes. Advection from stacks; fair. Showed aircraft fluxes were significant underestimates with 5km cutoff filter.
- Betts, A.K., R.L. Desjardins, and J.I. MacPherson, 1992: Budget analysis of the Boundary Layer grid flights during FIFE-1987. J. Geophys. Res., 97, 18533-18546.

  - Time dependence, advection, surface fluxes. With soundings for Inversion BR, vector budgets. ML model with closure gave high $A_R = 0.38$
- Betts, A.K., 1992: FIFE Atmospheric Boundary Layer Budget Methods. J. Geophys. Res., 97, 18523-18532.

  - Framework for 2-D heat and water budgets for time dependent BL– Santanello et al 2009 [Fig from JAMES 2010]
- Betts, A.K. and A. Beljaars, 1993: Estimation of effective roughness length for heat and momentum from FIFE data. Atmos. Res. 30, 251-261.

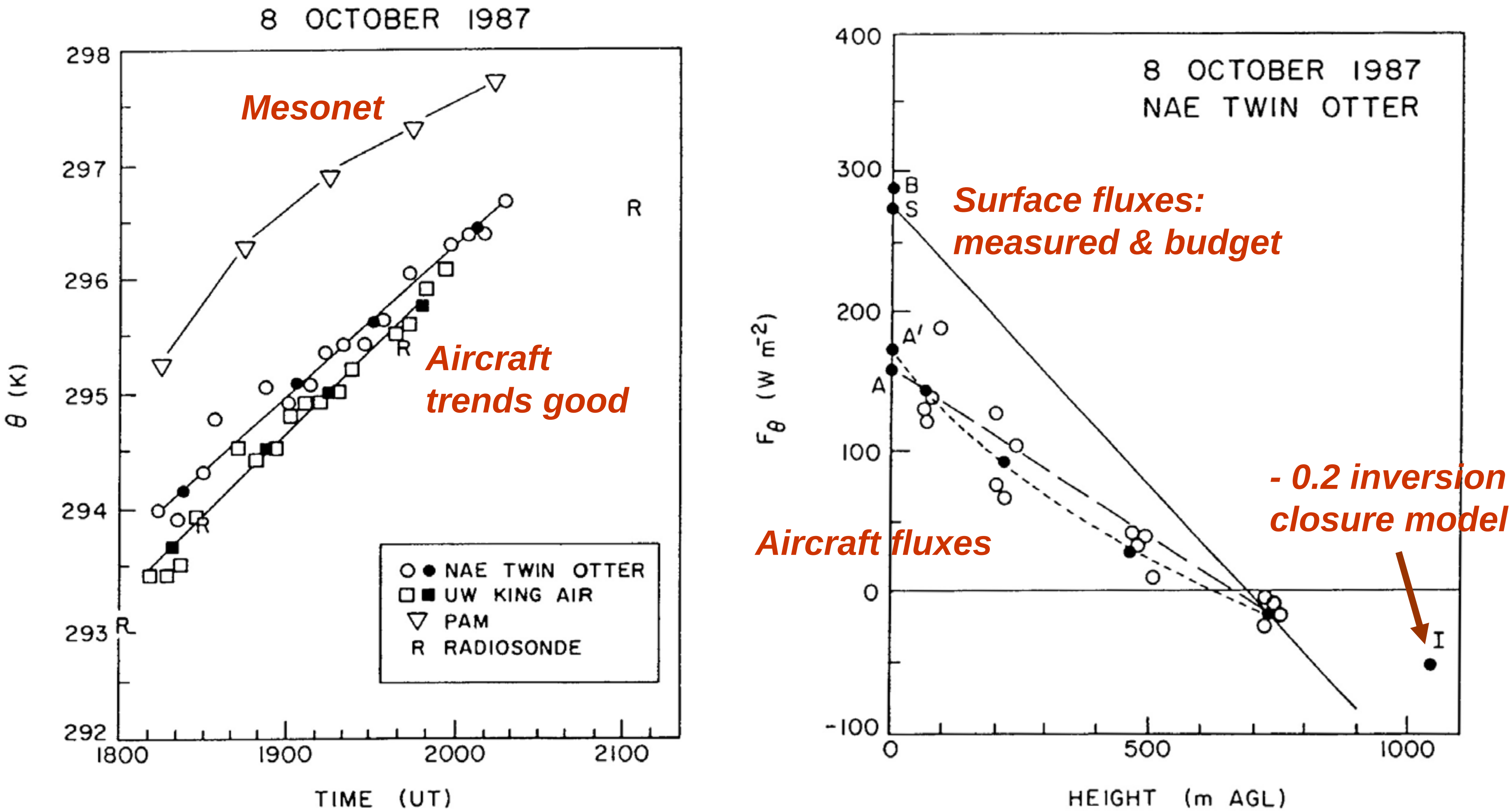
  - 30 TW flights at 100m: fit to Monin-Obukov; using mesonet T_{skin} data, and surface flux data

Betts, A.K., R.L. Desjardins, J.I. MacPherson, and R.D. Kelly, 1990: Boundary Layer Heat and Moisture Budgets from FIFE. Boundary-Layer Meteorol., 50, 109-137.



g. 1. Double stack flight pattern used by the NAE Twin Otter and UW King Air in heat an oisture budget studies over the FIFE site in 1987. The four levels and orientation illustrated appl specifically to flights on October 8. Different levels were used on other days.

Trends and budget of potential temperature



- *Betts et al. BLM, 1990*

Betts, A.K., R.L. Desjardins, and J.I. MacPherson, 1992: Budget analysis of the Boundary Layer grid flights during FIFE-1987. J. Geophys. Res., 97, 18533-18546.

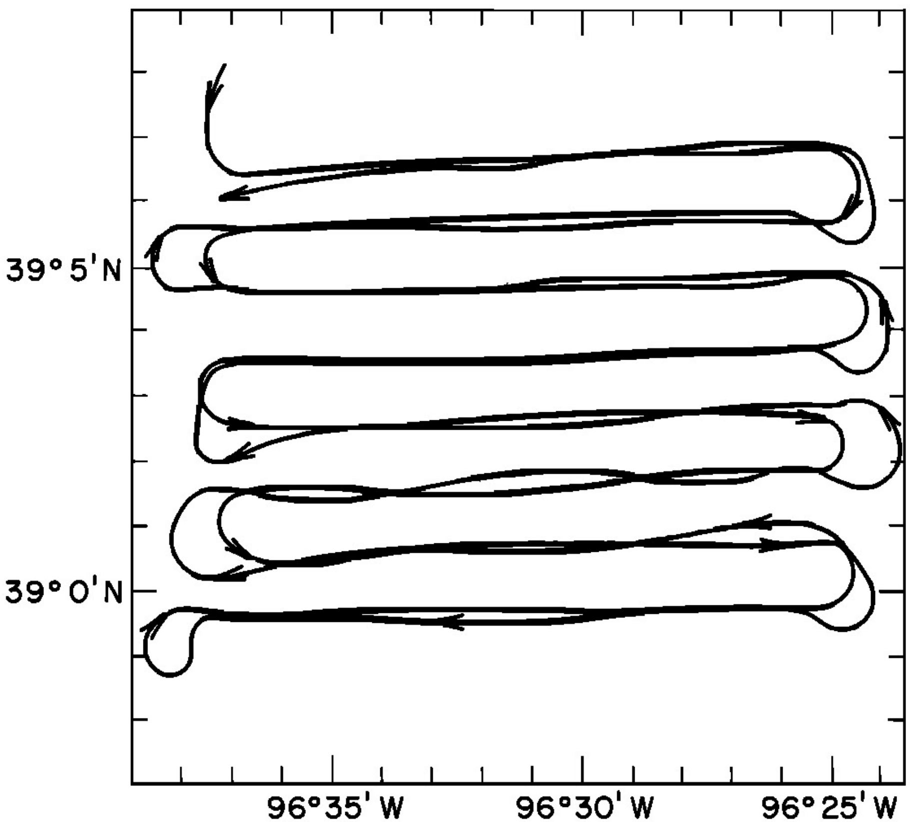


Fig. 1. Grid pattern flown by Canadian National Aeronautical Establishment (NAE) Twin Otter on July 11, 1987.

TABLE 1. Summary Data for Grid Flights

Flight	Date, 1987	Time, UTC	Mean Wind, deg/m s^{-1}	Inversion Height, m
July 11	11	1555–1728	192/13.3	830 ± 100
Aug. 15	23	1603–1741	192/8.6	740 ± 160
Aug. 15	24	2007–2146	188/11.6	800 ± 50
Oct. 7	34	1646–1826	344/6.7	780 ± 40
Oct. 7	35	2008–2147	350/4.5	1575 ± 50
Oct. 11	37	1714–1905	243/1.4	1000 ± 100
Oct. 12	39	1714–1900	291/1.5	540 ± 100
Oct. 13	40	1355–1556	195/10.1	230 ± 80

Large range of cases, flown cross-wind

Linear separation of time and N-S space derivatives

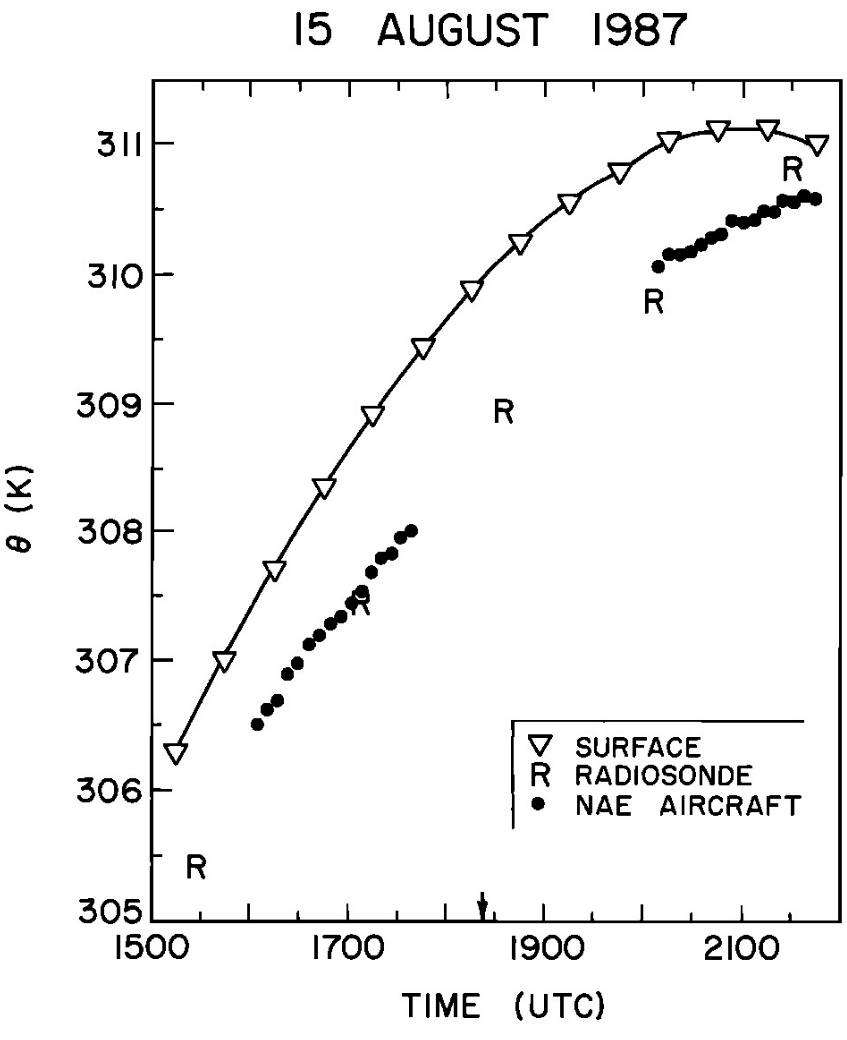
Budget method: inversion BR from sondes; surface fluxes measured

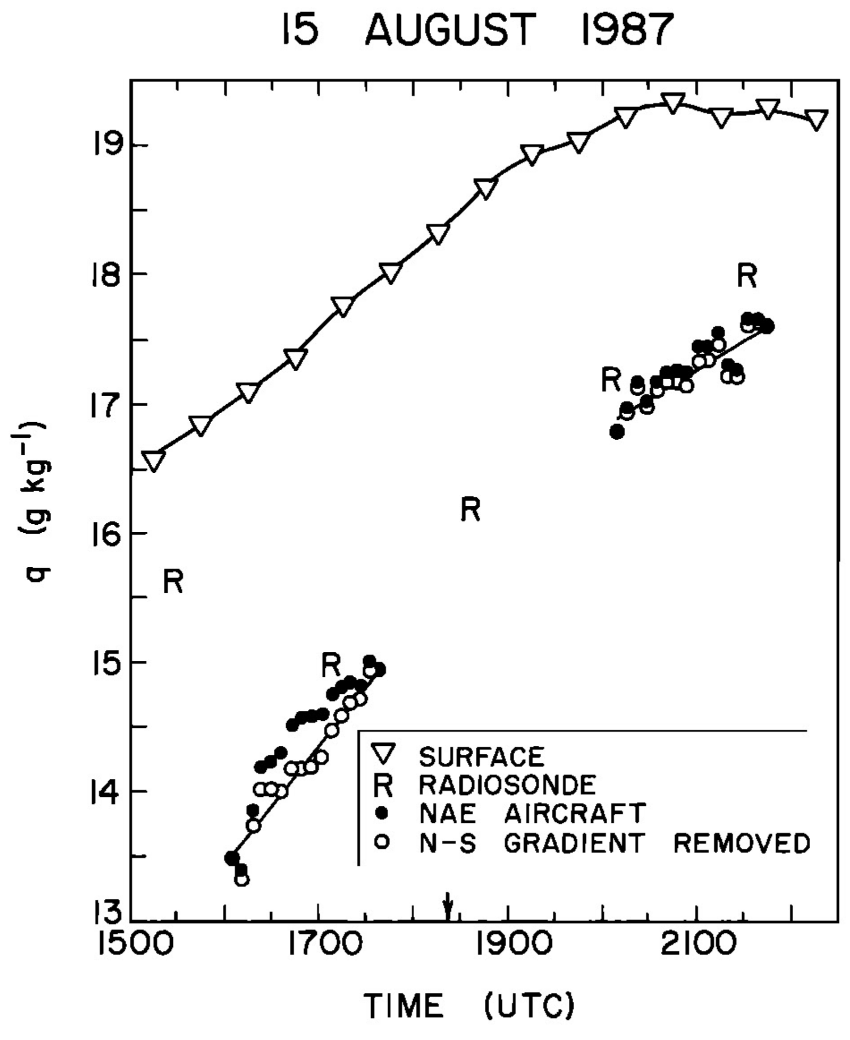
Improved aircraft flux data

ML model inversion closure A_R = - 0.38

Flown at 75-100m

Trends of θ and q

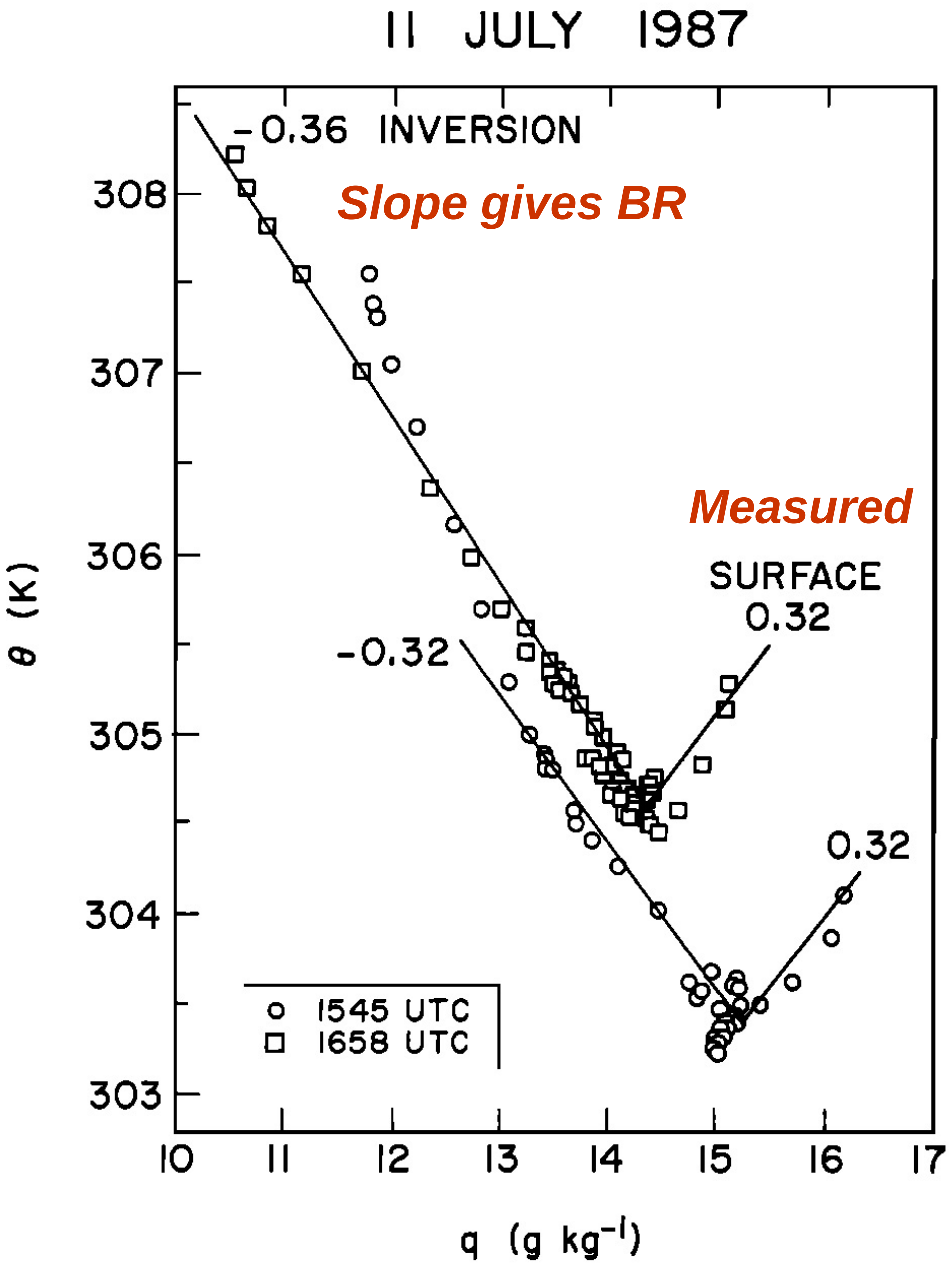




Aircraft define $\partial\theta/\partial t$, $\partial q/\partial t$ at 100m

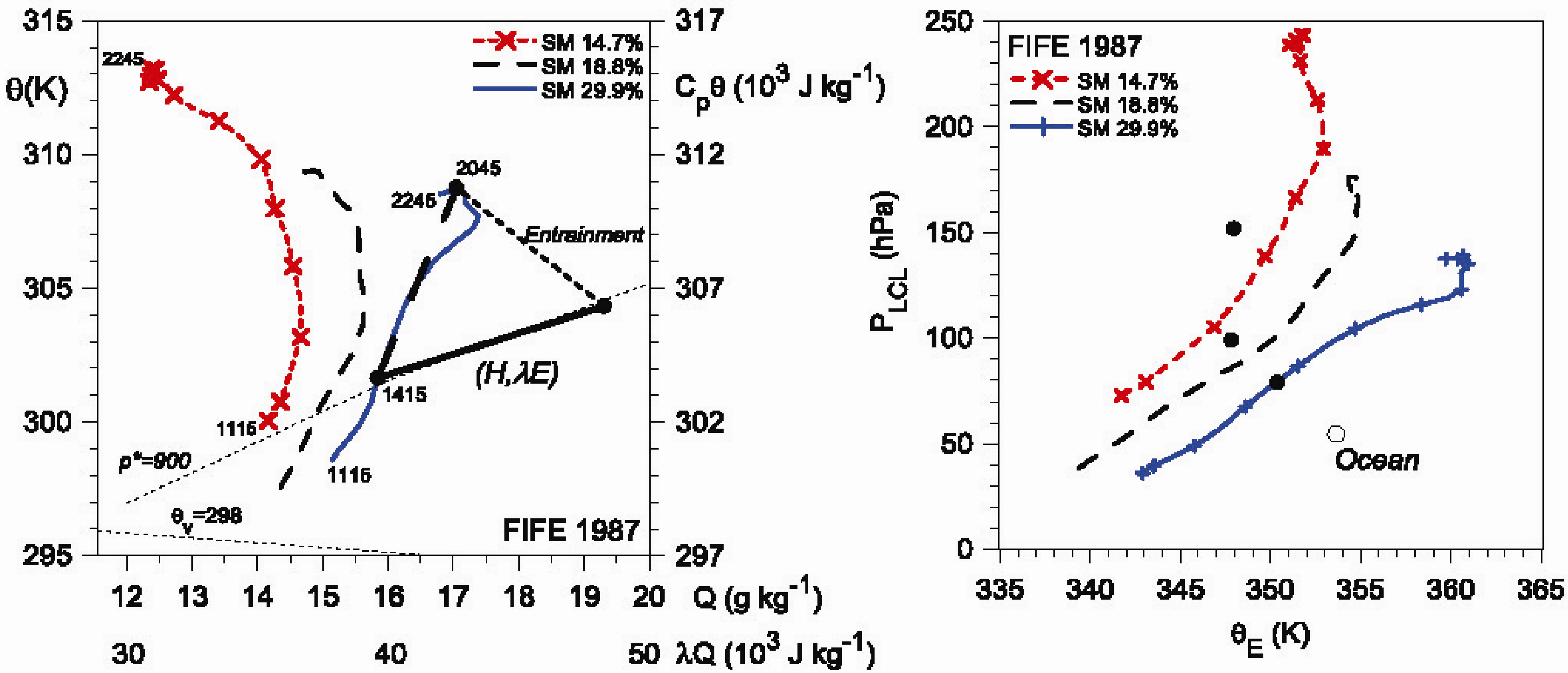
Inversion level flux constraint

- Surface fluxes: 14-site mean
- Inversion BR from sondes
- Inversion closure: A_R = -0.38 (mean)



FIFE Vector budgets

Land-surface-atmosphere coupling



. Daytime 2-m diurnal cycle for three FIFE composites, partition by soil moisture: (left) a (θ, Q) plot, showing v
5 to 2045 UTC, and (right) a (θ_E, P_{LCL}) plot.

- *Betts, A. K. (2009), Understanding land-surface-atmosphere coupling in observations and models. JAMES.* http://adv-model-earth-syst.org/index.php/JAMES/article/view/v1n4/JAMES.2009.1.4
- *Santanello et al. JHM 2009*

BOREAS Research - Twin Otter

- MacPherson, J. I. and A. K. Betts, 1997: Aircraft encounters with strong coherent vortices over the boreal forest. J. Geophys. Res., 102, 29231-29234.

  - Event 2 – 1234 LST on June 10: 11m/s updraft at 20m AGL in 2200m BL : soundings in paper: Show vortex and soundings

- Barr, A.G., A.K. Betts, R. Desjardins and J. I. MacPherson, 1997: Comparison of regional surface fluxes from boundary-layer budgets and aircraft measurements above boreal forest. J. Geophys. Res., 102, 29213-29218.

- Betts, A. K., R. Desjardins and D. Worth (2007): Impact of agriculture, forest and cloud feedback on the surface energy balance in BOREAS. Agric. Forest Meteorol., 142, 156-169, doi:10.1016/j.agrformet.2006.08.020 [Special book issue, "The Contribution of Agriculture to the State of Climate" Eds., R.L. Desjardins, M.V.K. Sivakumar, C. de Kimpe, ISSN 0168-1923, Elsevier, 2007] Comparative surface energy balance of grassland and forest in BOREAS, coupling of EF to clouds in model data.

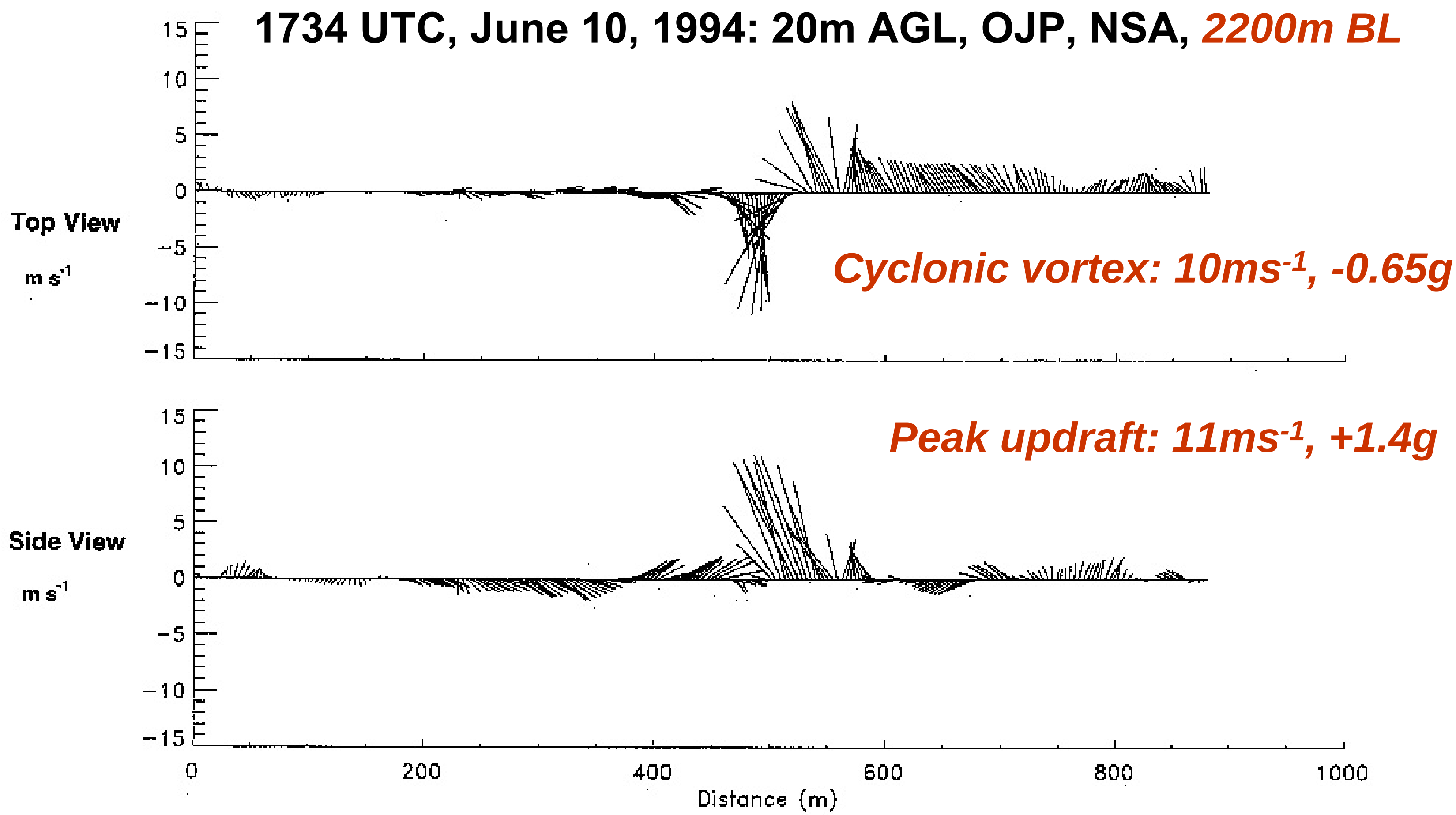
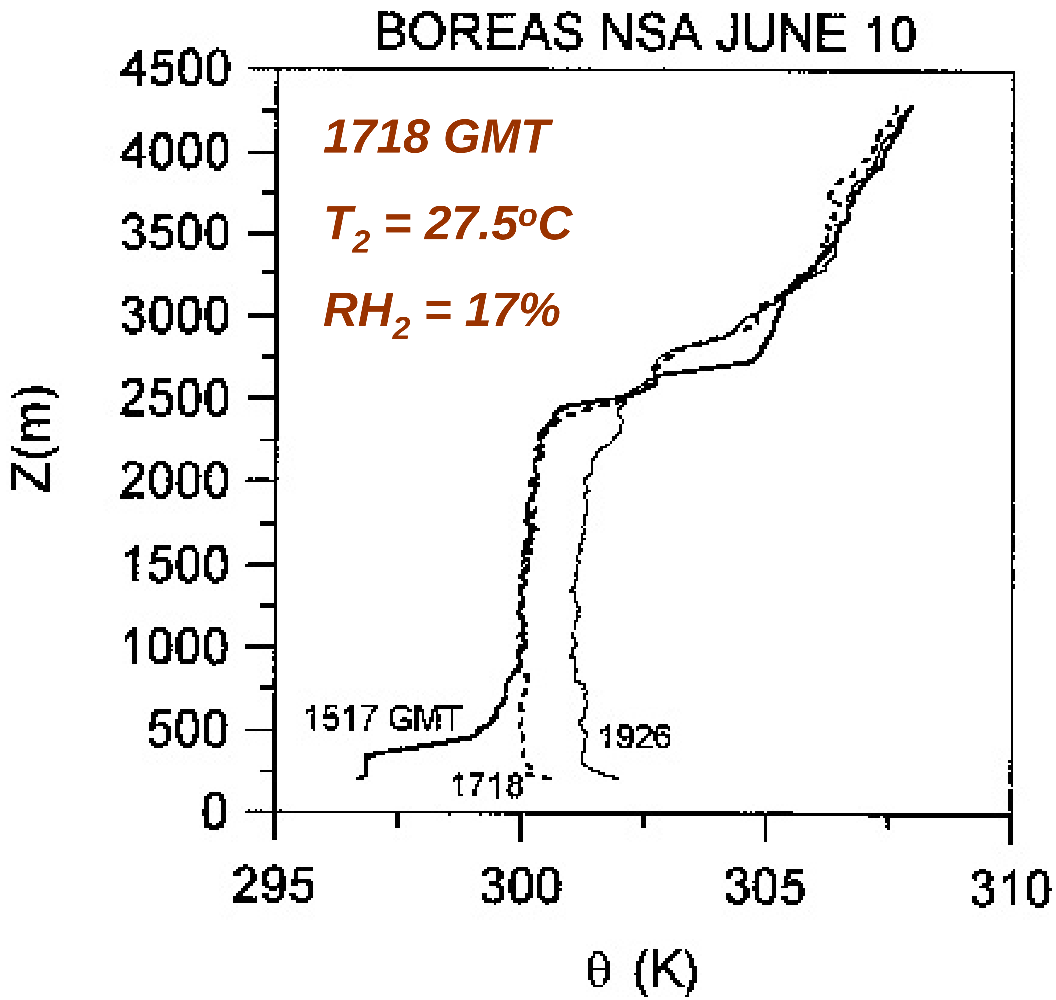


Figure 2. Plan and elevation views of wind vectors for gust event 2 relative to aircraft track (198°).

- *Leg mean R_n=546 Wm^{-2}; (H,λE)=(484,262) Wm^{-2}*
- *Peak (H,λE)=(16300,8750) Wm^{-2} ; CO_2= -48 mg $m^{-2}s^{-1}$*

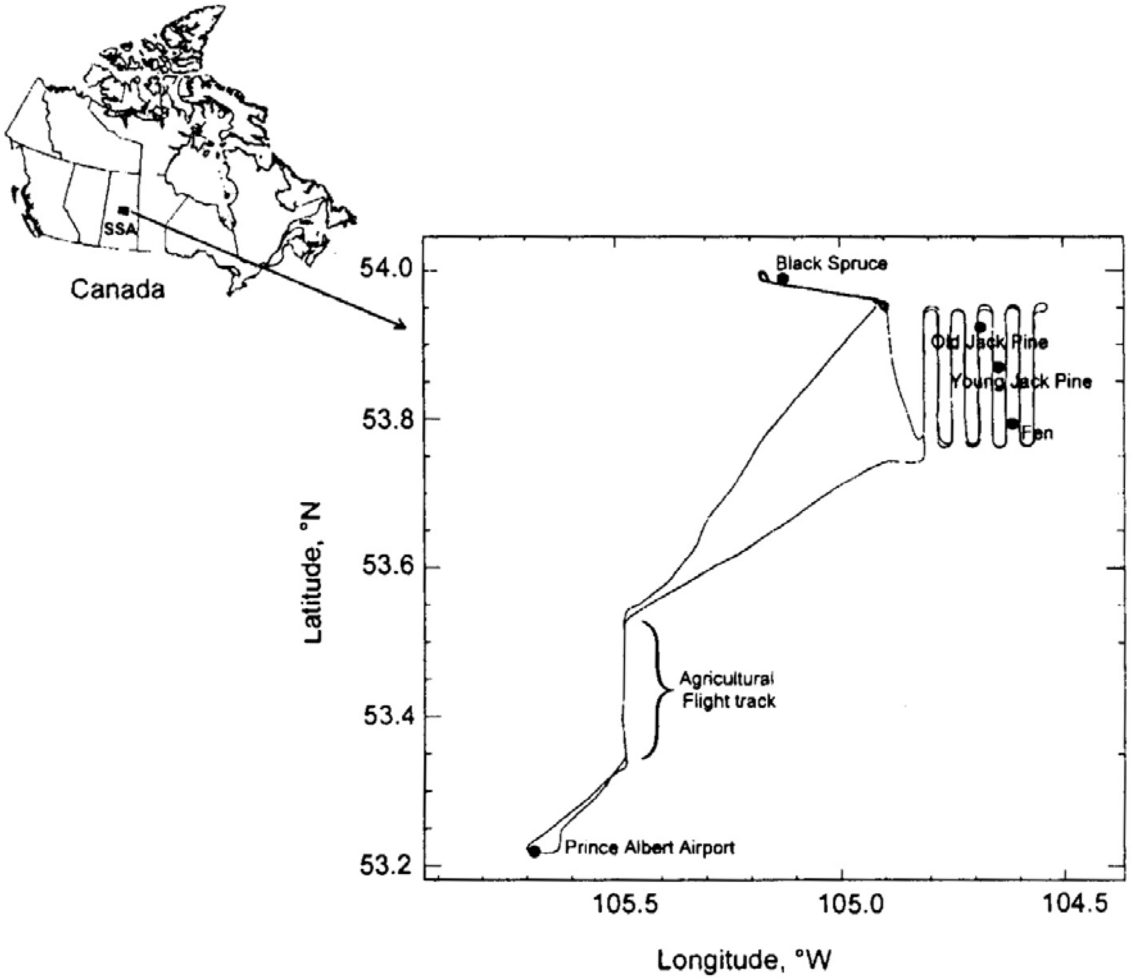
Deep Dry BLs in Boreal Spring

- Large diurnal range
- Cloud-free dry BL; surface RH = 17% [39% before dawn]
- Pre-existing deep BL
- Surface BR = 1.8
- Soil frozen till May 28 at 50-cm depth
- “Green Desert”



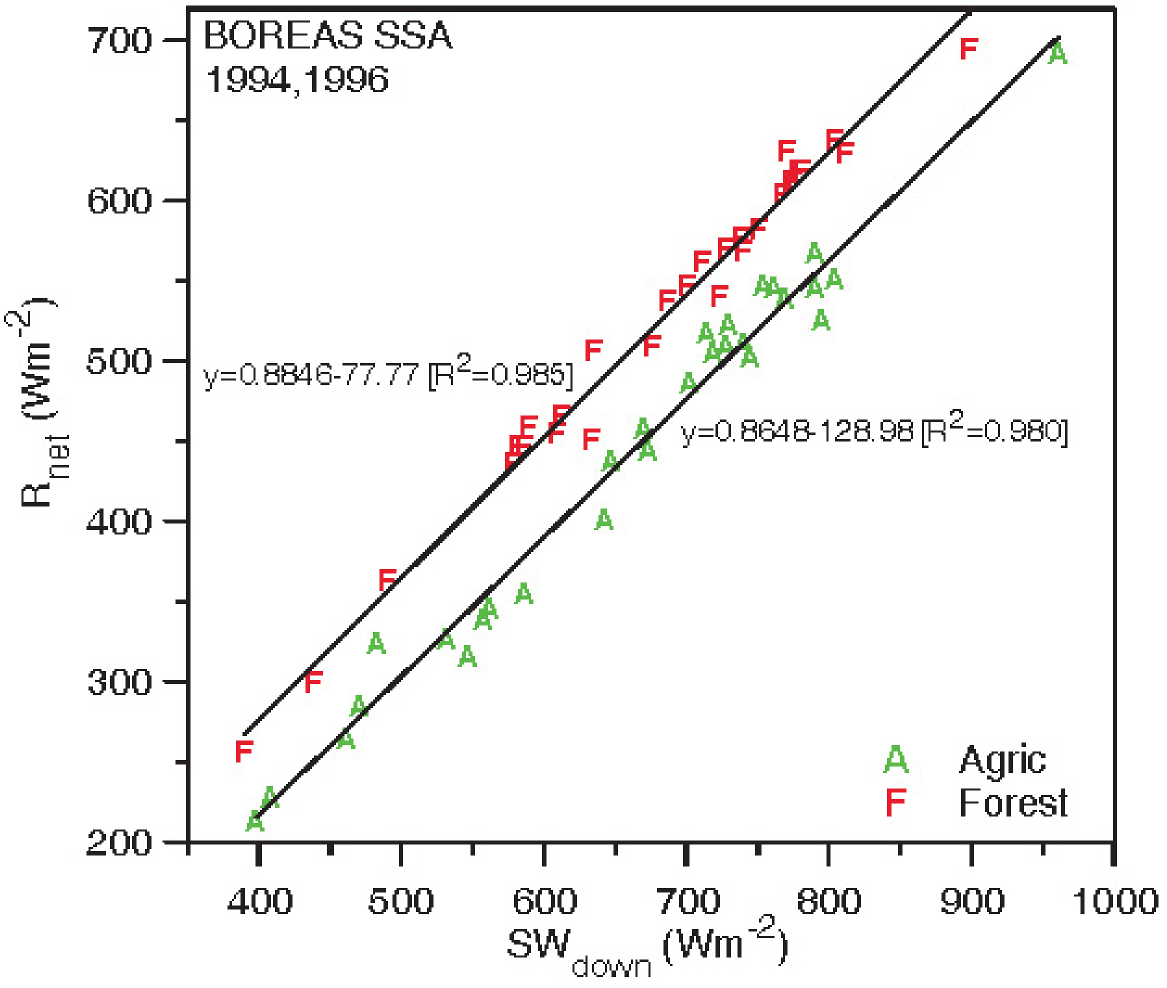
Impact of agriculture, forest and cloud feedback on the surface energy balance in BOREAS. Agric. For. Meteor., 142, 156-169

- Twin Otter flew enroute 'agricultural' flight track before every BOREAS SSA mission over forest
- **29 pairs**



Different Surface Energy Balance

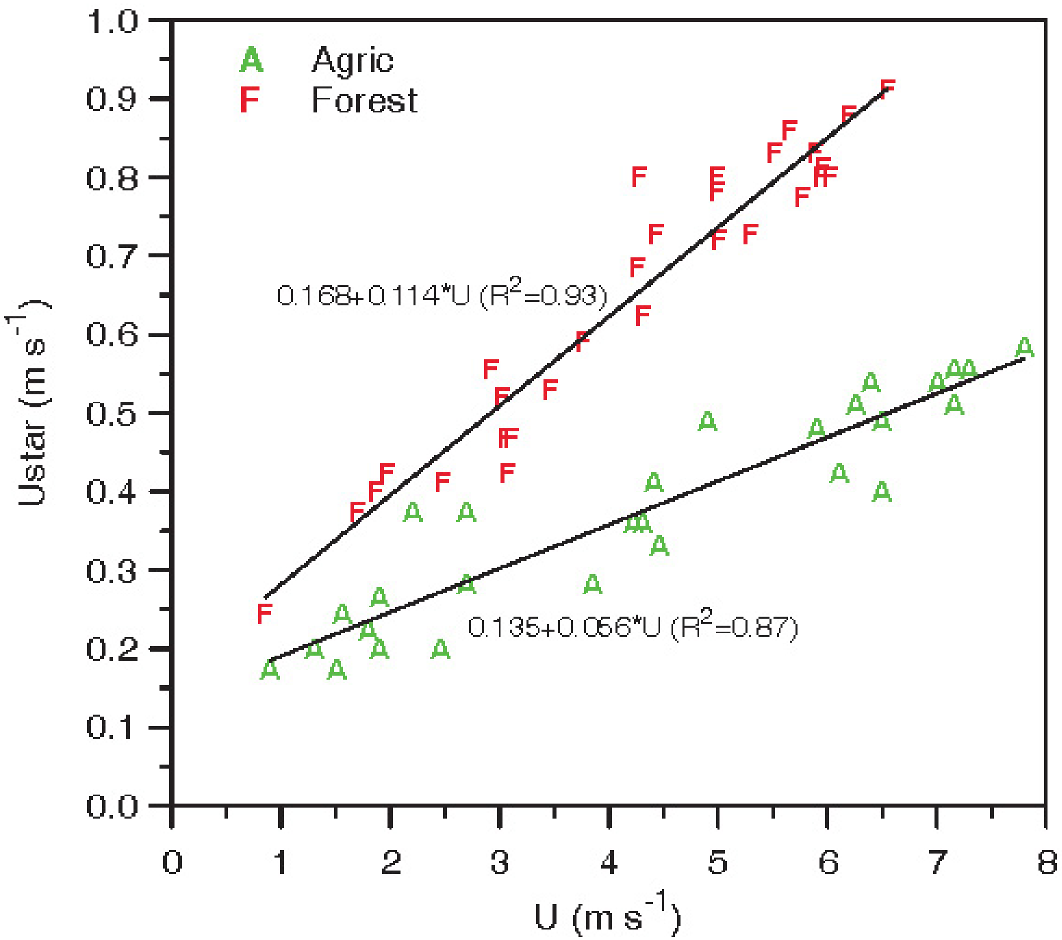
- R_{net} is 50 Wm^{-2} greater over forest, because of lower albedo and T_{skin}



Different roughness

- **Forest: z_{0m}=2m**
- **Agric: z_{0m}=0.2m**

- **U_{star}/U double over forest**



- **Daily means**
- **Spring Summer Fall**

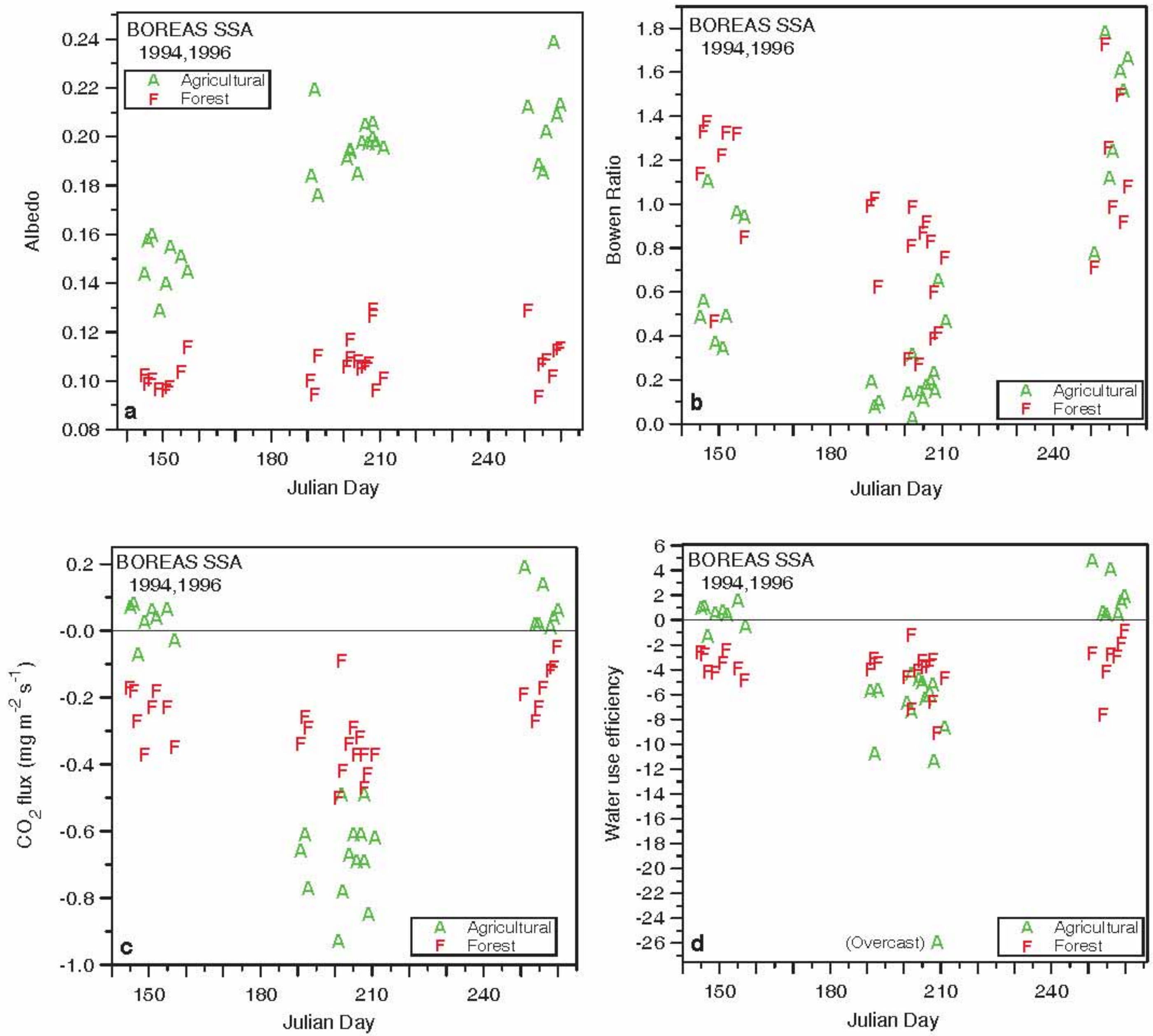


Figure 5. Comparison of forest and agricultural daily means for a) Albedo b) Bowen ratio c) CO_2 flux and d) Water use efficiency.

- **Seasonal Means**

- **Agriculture Forest BlackSpruce**

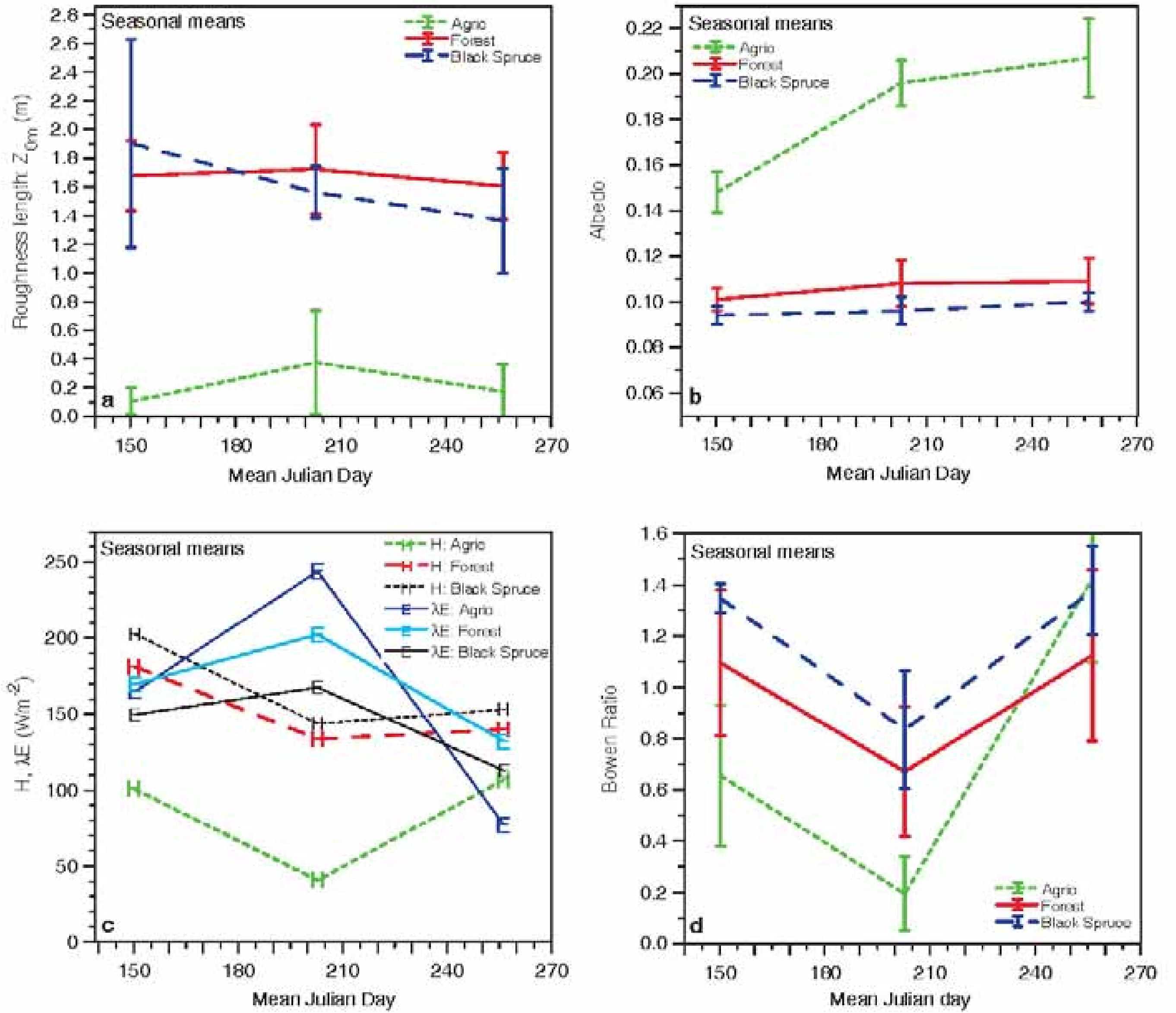
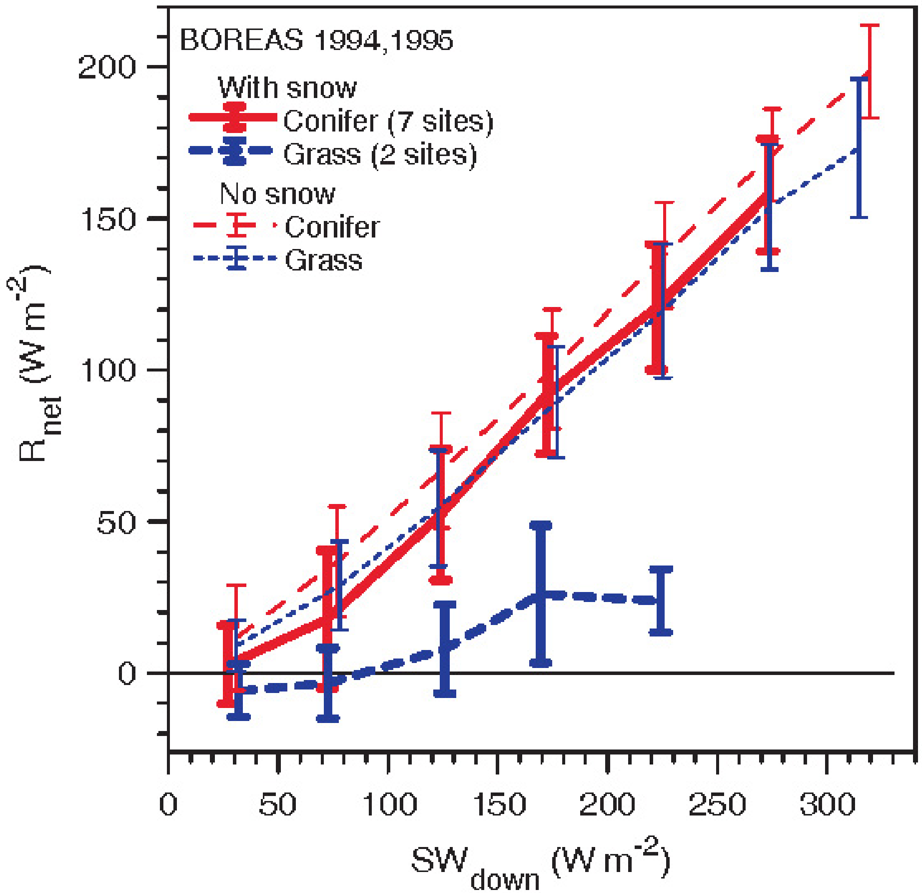
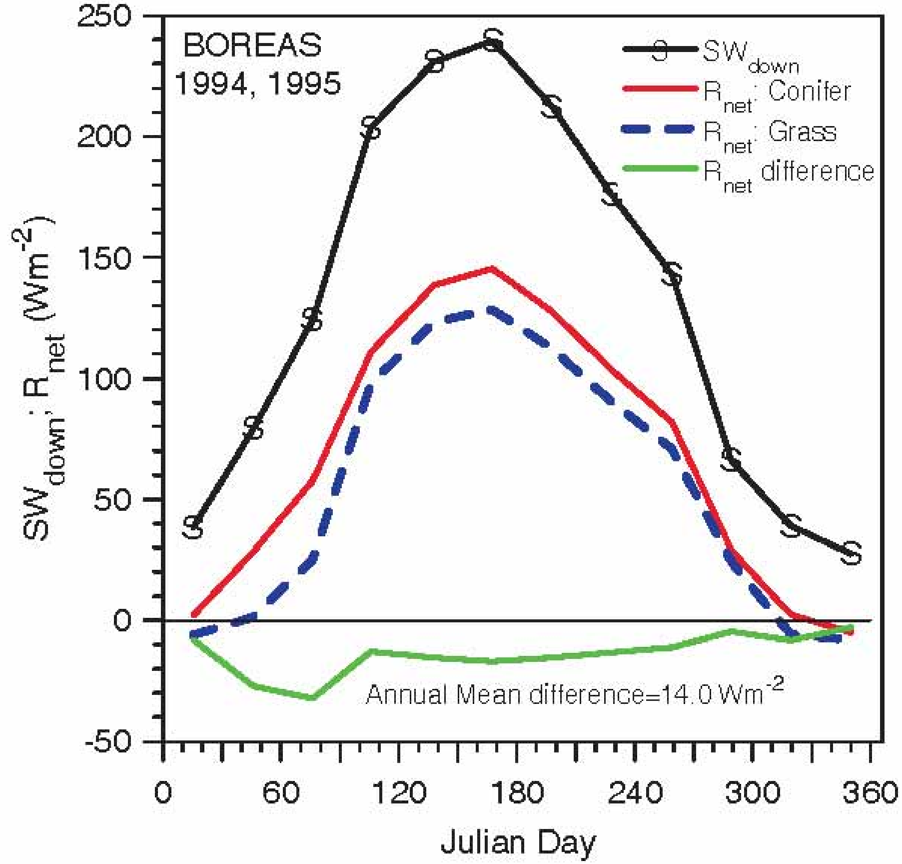


Figure 6. Seasonal means of a) Roughness length b) Albedo c) Sensible and latent heat and d) Bowen ratio.

Seasonal Climate Impact

Flux tower data

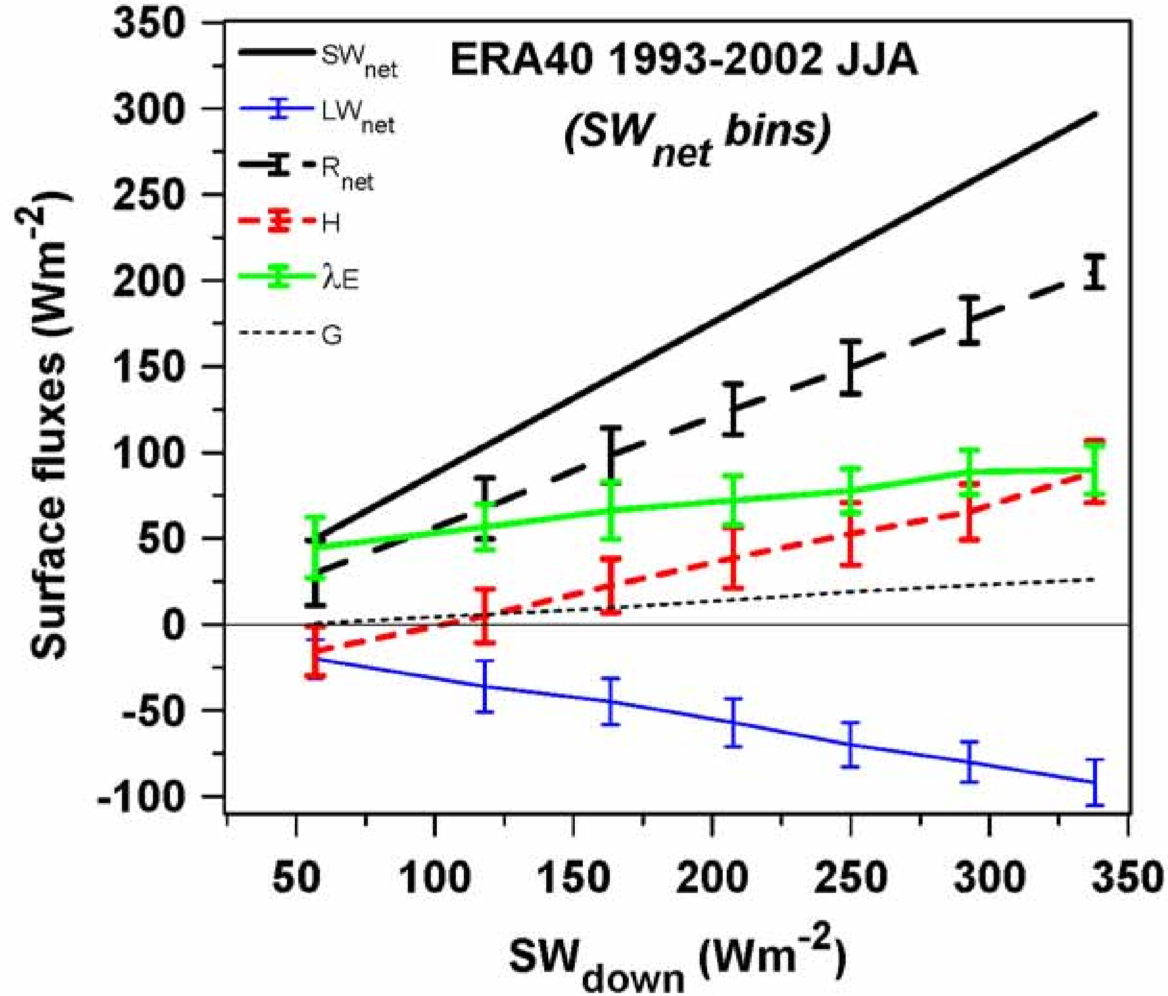




- **Snow impact** **Annual: -14 Wm^{-2}**

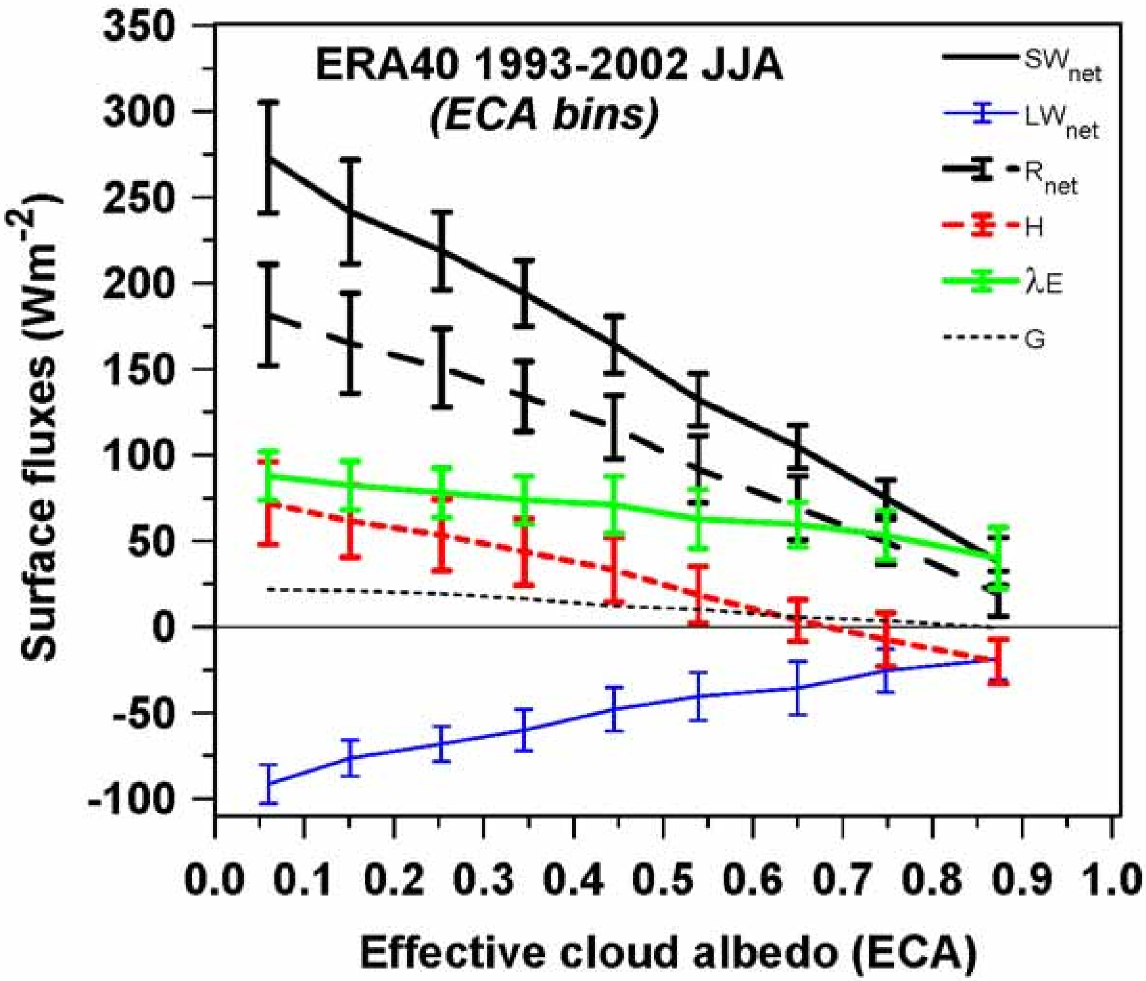
ERA-40 Surface Energy Balance
Binned by SW_{down} (Cloud Forcing: SWCF)

- Summer daily means
- Quasi-linear SW_{down}, SWCF
- λE variation small
- Model physics



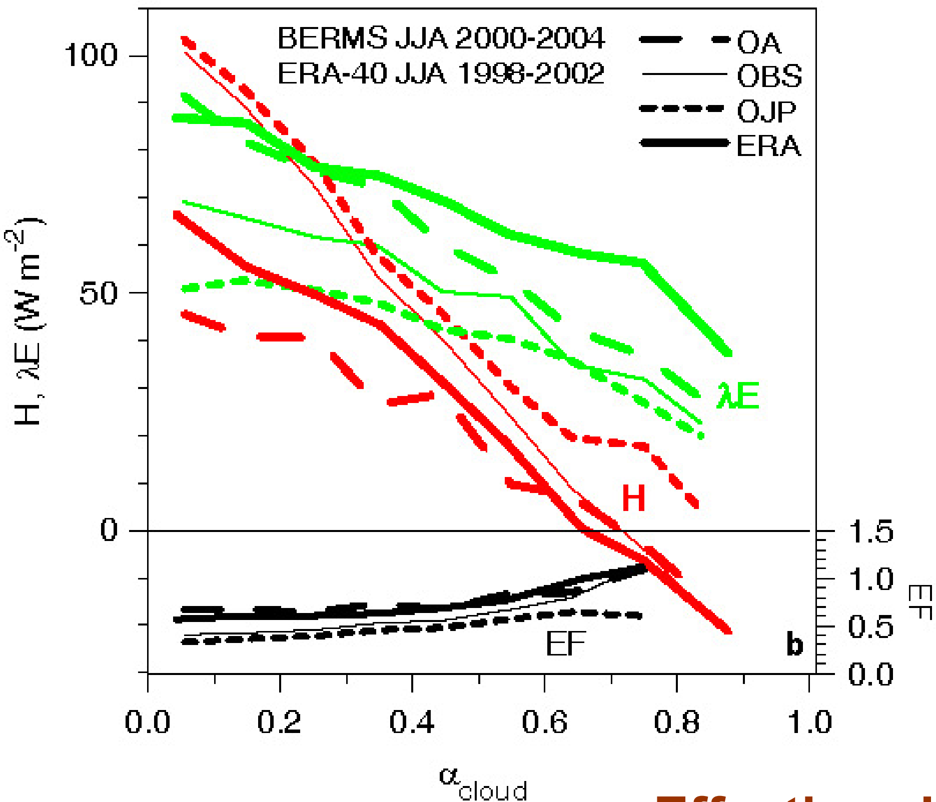
ERA-40 Surface Energy Balance
Stratified by Effective cloud albedo

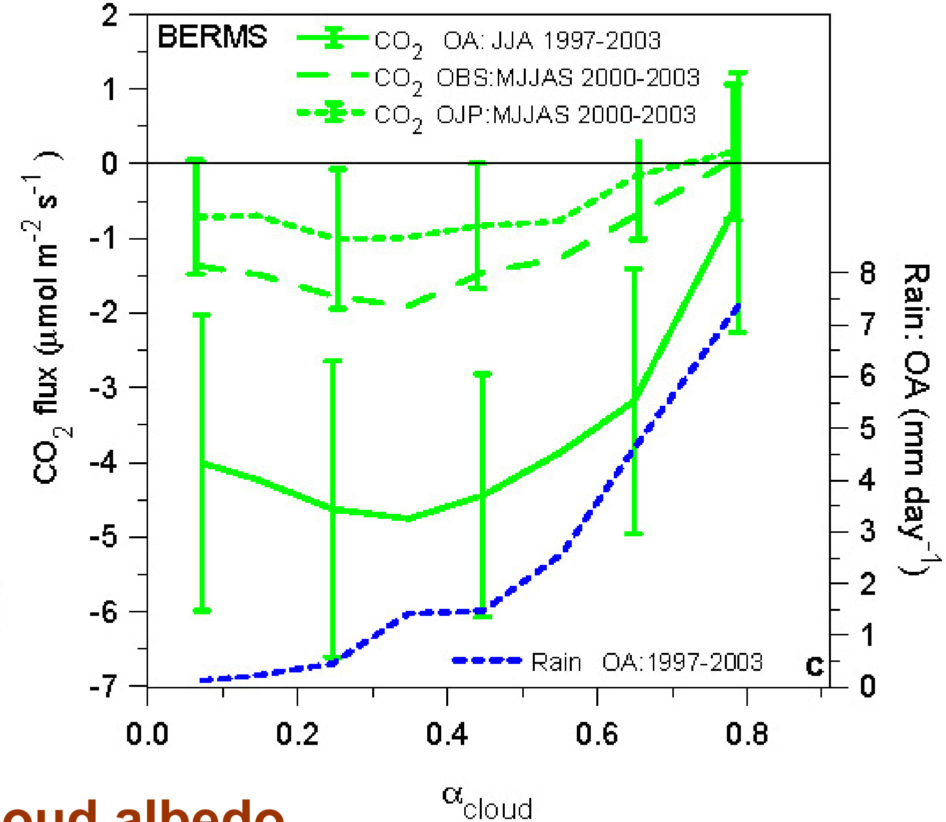
- **Transmitted fraction**
  FTSW
  $=SW_{down}/SW_{down}(clear)$
- **Effective cloud albedo**
  ECA
  =1- FTSW
  $= -SWCF/SW_{down}(clear)$
- **Where SW cloud forcing**
  SWCF
  $=SW_{down} - SW_{down}(clear)$
- **Similar picture**



Comparison with 3 BERMS sites

[Betts et al. 2006; Betts 2009]



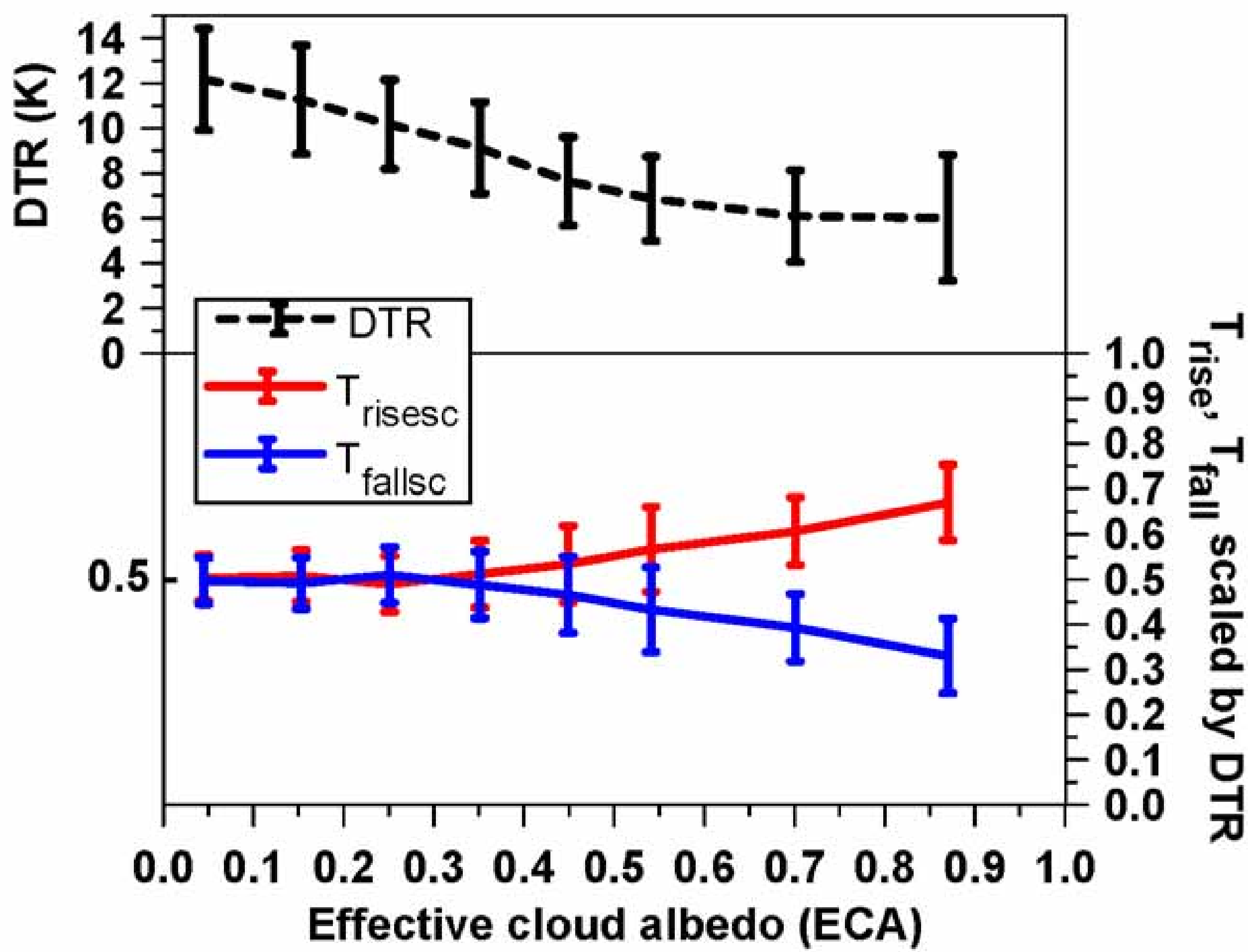


Effective cloud albedo

- **λE(*ERA-40)* high at wet cloudy end**
- **Net CO_2 flux peaks at ECA ~ 0.35**

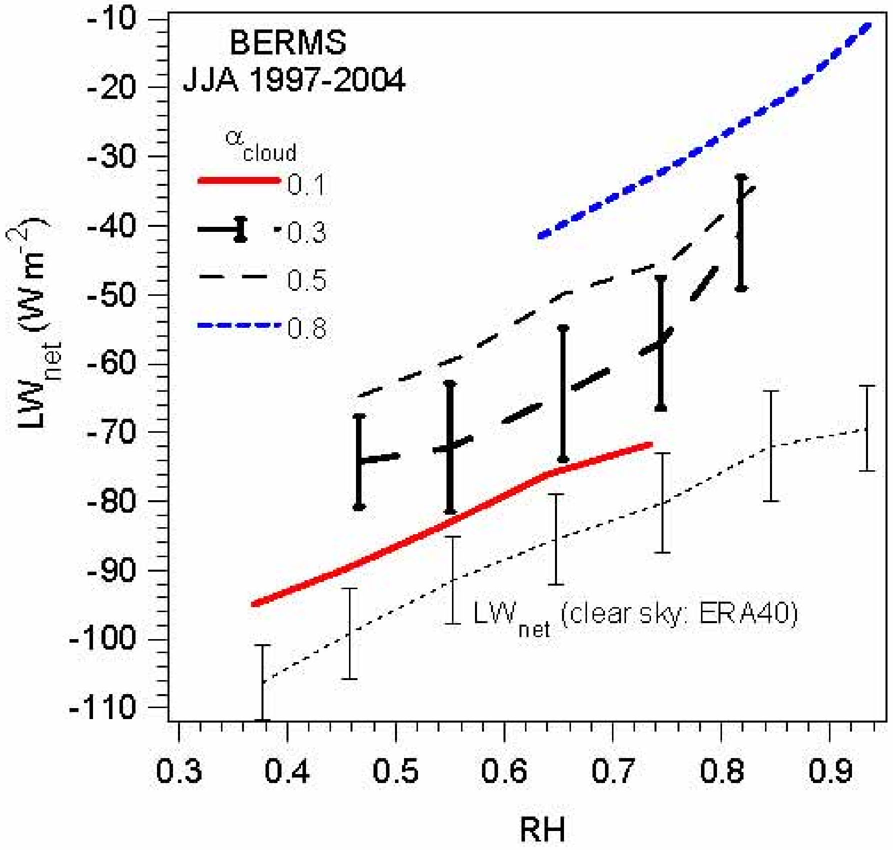
Diurnal Temperature Range

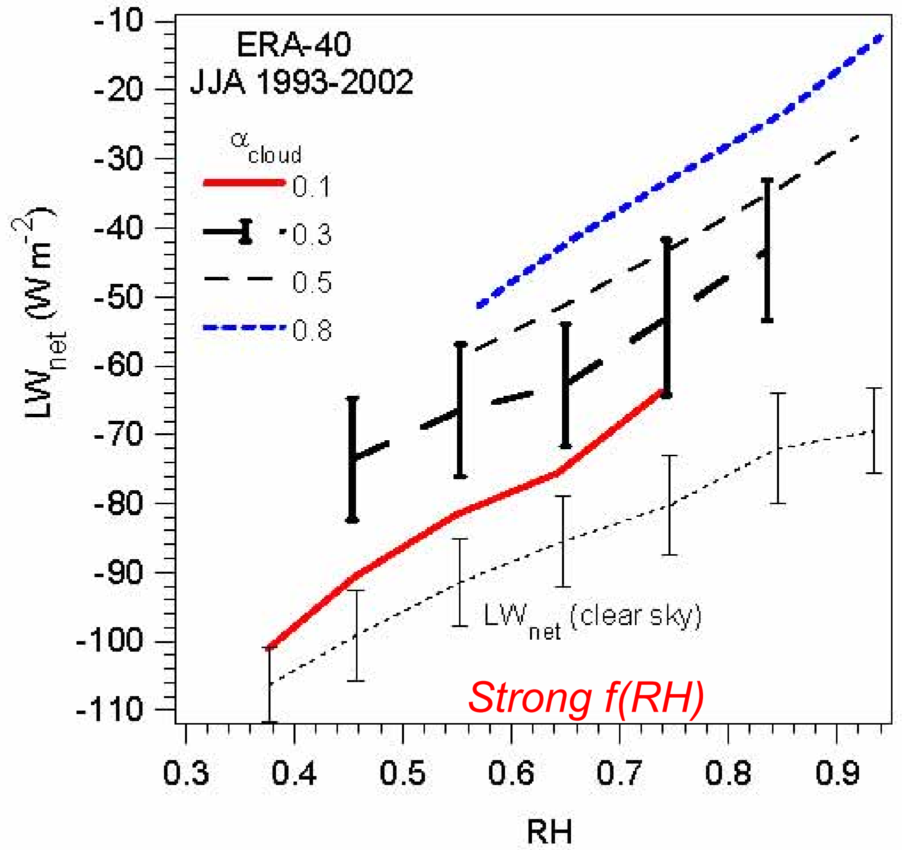
- ***Increasing cloud***: DTR falls
- T_{rise} and T_{fall} from T_{mean} become asymmetric
- Scaled $T_{rise} > T_{fall}$



ERA-40 JJA BERMS site

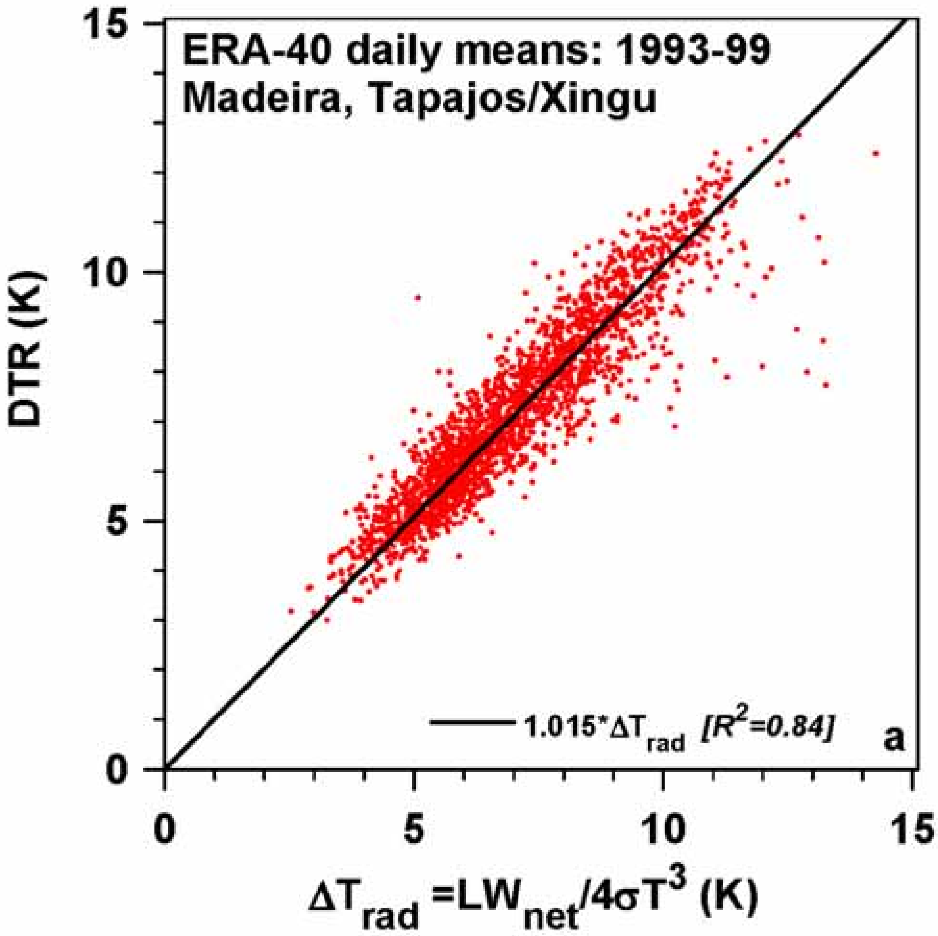
Net surface LW

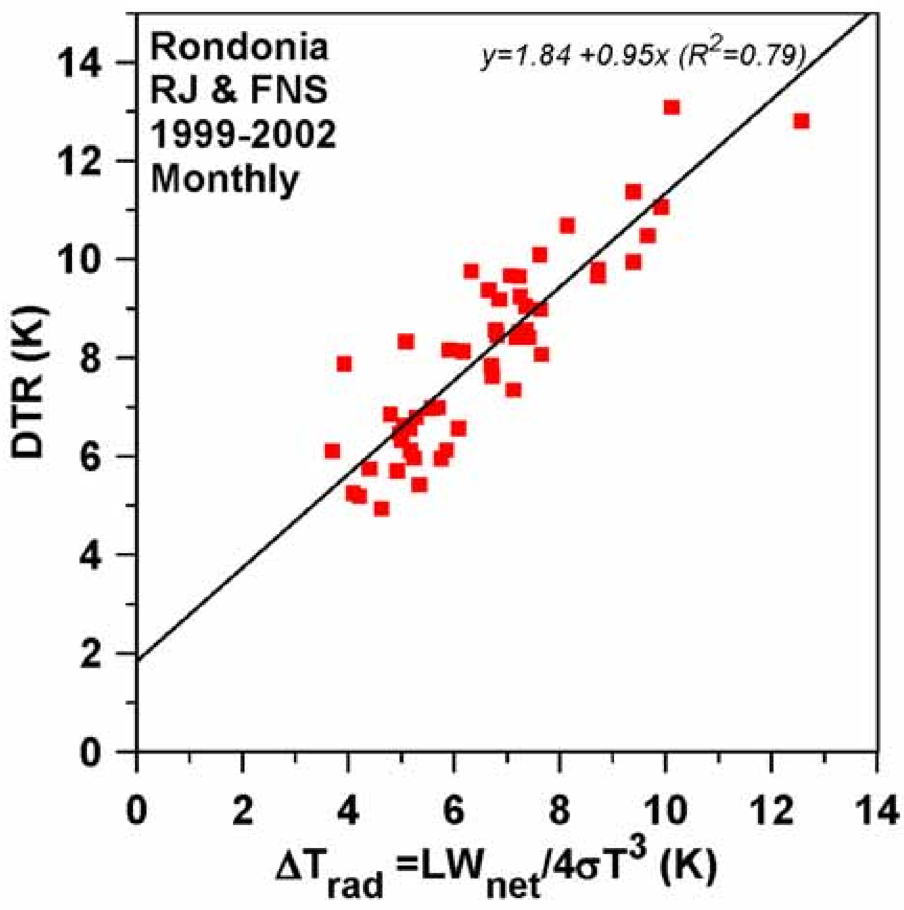




- **Point comparison: stratified by RH (LCL) & ECA (α_{cloud})**
- **Quasilinear clear-sky and cloud greenhouse effects**
- **But typically model RH and cloud distributions biased**

LW_{net} - Diurnal Temperature Range ERA-40 & Monthly Flux Tower data



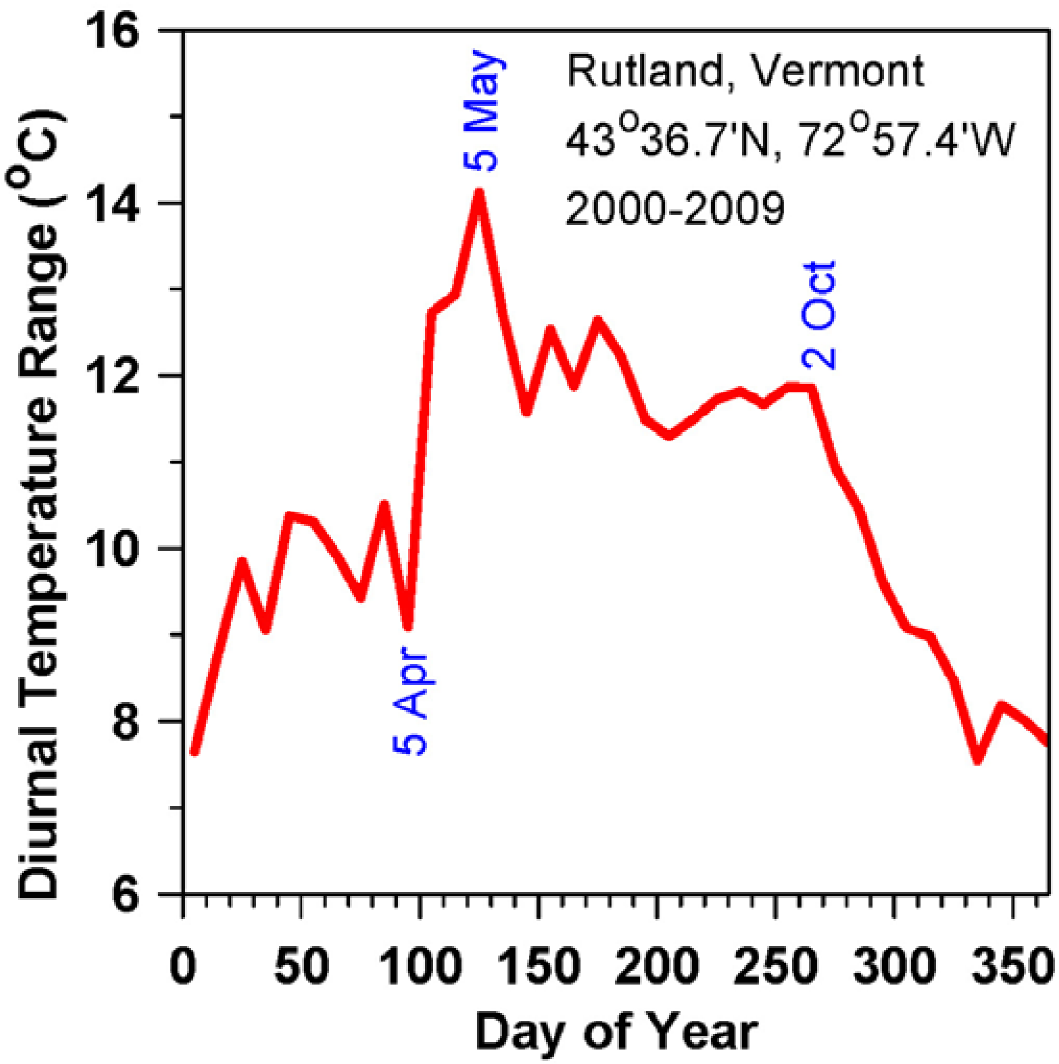


- **Mean LW_{net}, DTR well correlated**

[Betts: JGR, 2006; Betts and Silva Dias, 2010]

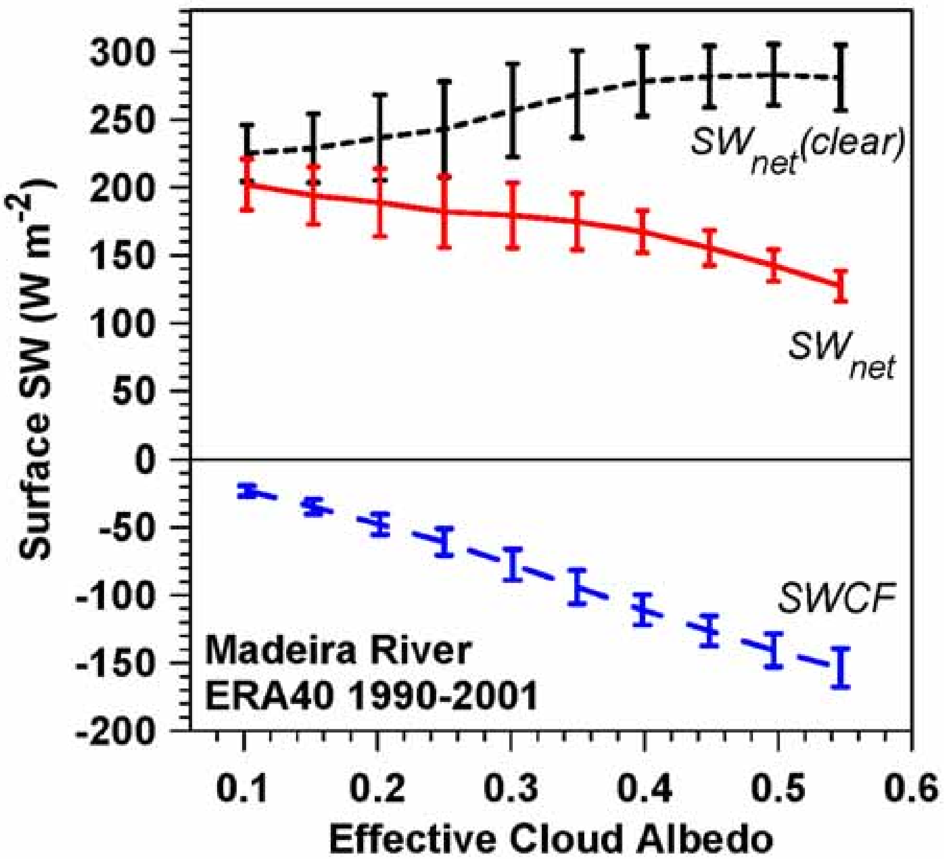
Annual cycle of Diurnal Temperature Range (DTR)

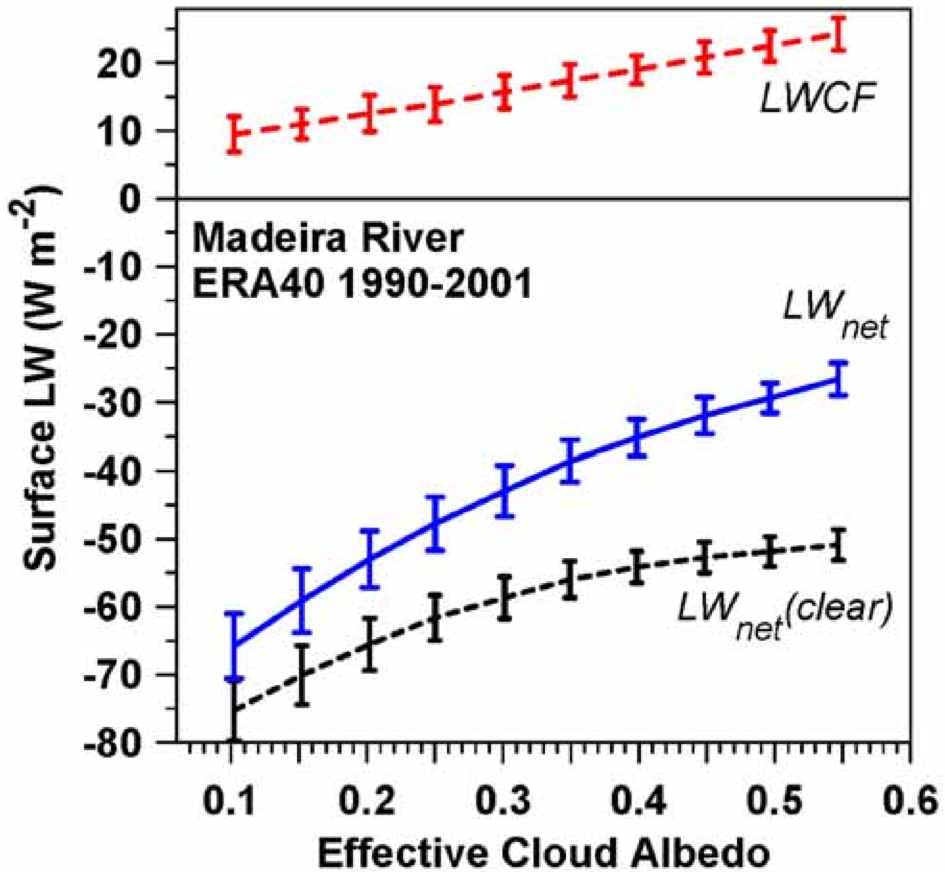
- **DTR increases sharply after 5 April, peaking at the time of forest leaf-out in the first week of May, and then falling as transpiration rapidly increases**



Betts, 2010

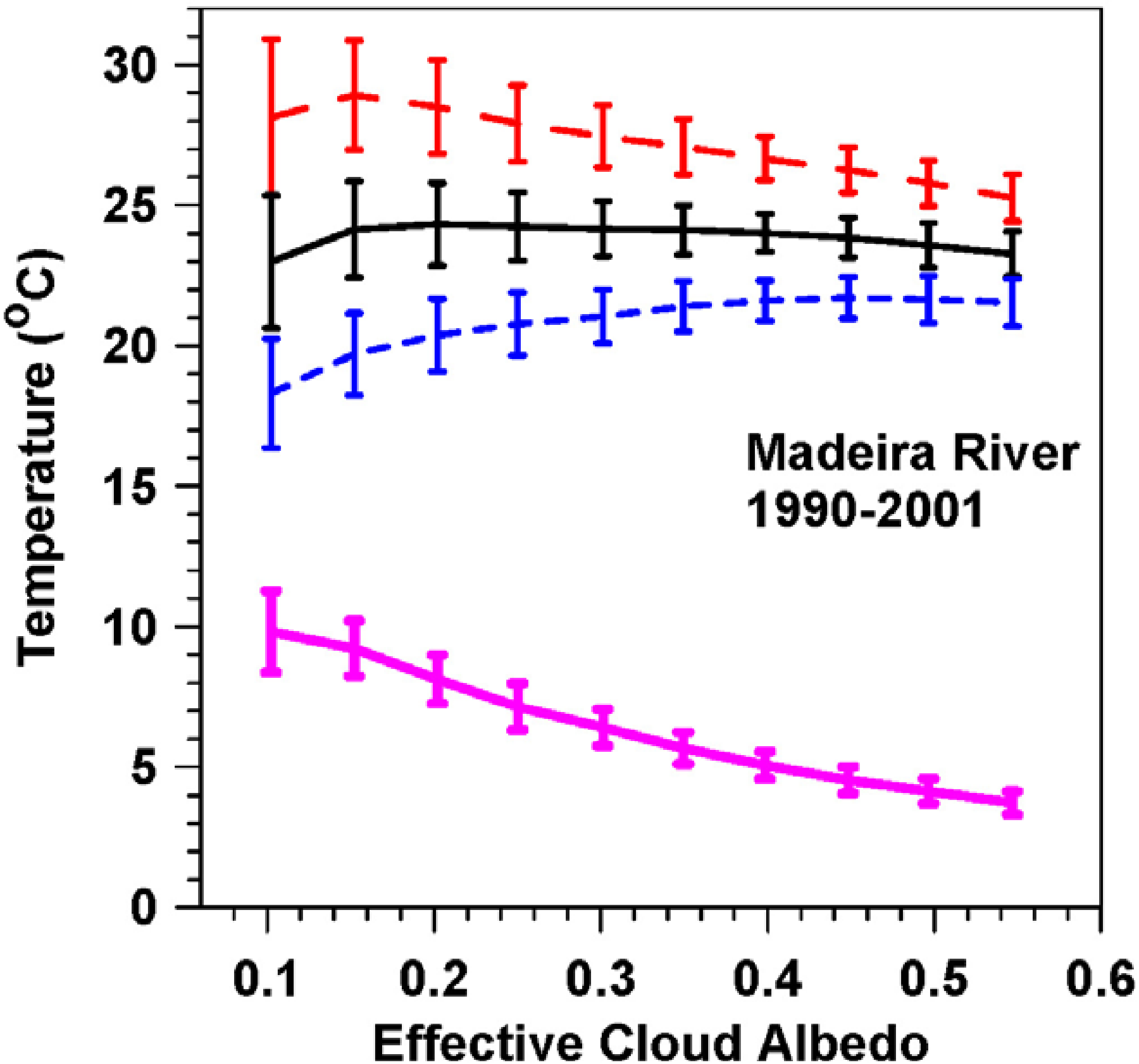
Shortwave and Longwave Cloud Forcing





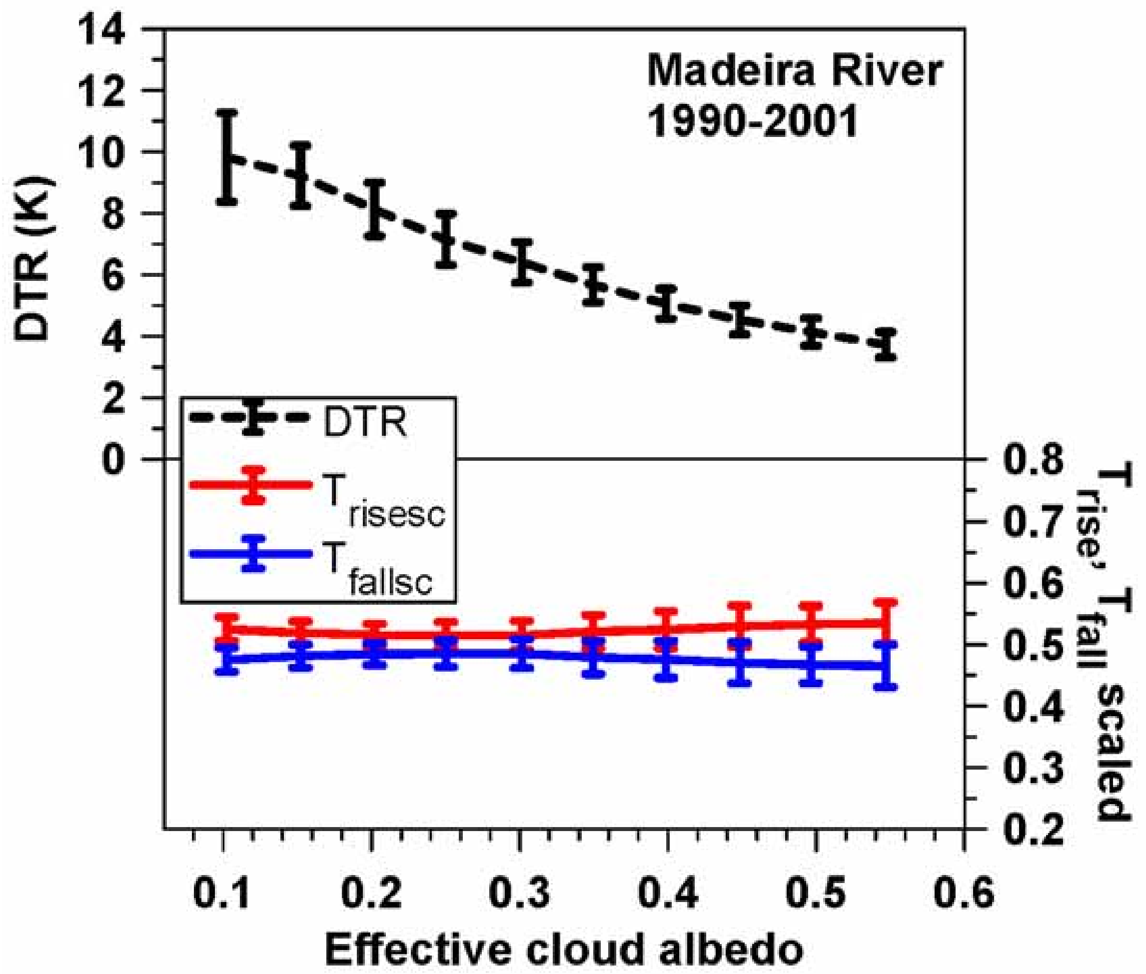
- Can we understand the role of cloud forcing on T_{max}, T_{min}?

T_{max}, T_{min}, T_{mean}, DTR



Diurnal Temperature Range

- ***Increasing cloud*: DTR falls**
- **Scaled T_{rise}>T_{fall}**
- T_{mean}< (T_{max}+T_{min})/2
- *(Zeng & Wang, 2012)*



ERA-40 Madeira River basin

Summary

- **High quality Canadian Twin Otter data pioneered many important studies of land surface-atmosphere coupling (just a few illustrated here)**
- **Community thanks Ray Desjardins and Ian McPherson for this invaluable research**