Land-surface-atmosphere coupling

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Land-surface-atmosphere interaction

- Many interdependent processes
  - surface energy balance
  - shortwave and longwave fluxes
  - night-time boundary layer
  - role of water in the surface energy partition
  - vector methods
  - coupling between surface, boundary layer, precipitation
  - evaporation-precipitation feedback.
  - partition of moisture convergence into TCWV, cloud & precipitation
  - ratio of diabatic terms: cloud forcing to precipitation

- Adapted from papers of past 10-15 years
- *Many, many people have contributed*
- Reflect my idiosyncrasies; and many aspects of the ECMWF model
References


Themes

• Evaluating models with field data
• FIFE (grassland);
• BOREAS/BERMS (boreal forest)
• GEWEX (river basins)
• ERA-40 river basin & grid-point comparisons
• Diurnal, daily mean, annual cycle
• Land-surface climate
• SW and LW cloud radiative impacts
• Precipitation, evaporation, dynamics

– Talk is mostly Figures: Betts, A. K. (2009) for details
Surface Energy Balance

\[ R_{\text{net}} = \text{SW}_{\text{net}} + \text{LW}_{\text{net}} = H + \lambda E + G \]

- the split between surface processes and atmospheric processes
- the split between SW and LW processes
- the partition between clear-sky and cloud processes in the atmosphere
- the partition of the surface \( R_{\text{net}} \) into \( H \) and \( \lambda E \), which is controlled largely by the availability of water for evaporation and by vegetation
Clouds & Surface SW_{net}

SW_{net} = SW_{down} - SW_{up} = \left(1 - \alpha_{surf}\right)\left(1 - \alpha_{cloud}\right) SW_{down}(clear)

- **surface albedo**
  \[ \alpha_{surf} = \frac{SW_{up}}{SW_{down}} \]

- **effective cloud albedo** [per unit area surface]
  - scaled surface short-wave cloud forcing, SWCF
  \[ \text{SWCF} = SW_{down} - SW_{down}(clear) \]
  \[ \alpha_{cloud} = - \frac{\text{SWCF}}{SW_{down}(clear)} \]

[Betts and Viterbo, 2005; Betts, 2007]
Surface albedo

- Impact of landscape differences (forest/grass) on $R_{\text{net}}$ are large in spring
Impact of reducing boreal forest

$\alpha_{surf}$ from 0.8 to 0.2 (snow)

- Large systematic bias reduction;
- NH 850 hPa T forecast skill improved Feb. to mid-May
Winter climate transition

- Sun is low; and snow reflects sunlight, except where trees!
- $R_{\text{net}}$ low, sublimation small, clear sky, outgoing LW$_{\text{net}}$ large, gets colder
Aside

River basin archive

ERA-40 and ERA-Interim

Mackenzie  Mississippi  Amazon

Evaluation on river basin scale, starting from hourly archive
Effective Cloud albedo

- Transformation of SWCF to $\alpha_{\text{cloud}}$
- Large variability: 10% low bias in winter
Eff. Cloud albedo: ERA-40 data

- Transformation of SWCF to $\alpha_{\text{cloud}}$
- Seasonal cycle OK: small daily variability: biased???
Eff. Cloud albedo: ISCCP data

- Different clear-sky flux: Aerosol differences
- ERA-40 systematic high bias in $\alpha_{\text{cloud}} \approx +7\%$
- ISCCCP has more daily variability
• More dry season cloud over pasture
• Aerosol ‘gap’ in September burning season
Energy balance: forest and pasture

- In July, pasture has 8% higher surface albedo and 6% more cloud.
- Pasture LW\text{net} is greater (surface warmer, BL drier).
- Pasture R\text{net} ≈ 14% less than forest.

*BL cloud is surface coupled*
Tropics vs. mid-latitudes

- Amazon: reanalyses $\alpha_{\text{cloud}}$ biased high
- Mississippi: *low cloud in winter*
Longwave

Surface $\text{LW}_{\text{net}}$

- Point comparison: stratified by RH (LCL) & $\alpha_{\text{cloud}}$
- Quasilinear clear-sky and cloud greenhouse effects
- Amazon similar
Aside: Relation of RH to LCL

- $Z_{LCL}$ is $\text{fn}(T)$ but not $p$
- $P_{LCL}/p$ is weak $\text{fn}(T)$
Coupling of $LW_{\text{net}}$ with diurnal temperature range and NBL

Define *diurnal temperature range*

$$DTR = T_{\text{max}} - T_{\text{min}}$$

Scale by 24h mean $LW_{\text{net}}$

$$\Delta T_R = -\lambda_0 \ LW_{\text{net24}} \text{ where } \lambda_0 = 1/(4\sigma T^3)$$

$$T_{sc} = (T_2 - T_{24}) / \Delta T_R$$

$$DTR_{sc} = T_{\text{maxsc}} - T_{\text{minsc}} \approx 1 \text{ (Amazon)}$$

*Betts, JGR, 2006*
Mean diurnal cycle Madeira river

- DTR doubles in dry season (with \( LW_{\text{net}} \))
- \( \text{DTR}_{sc} \approx 1 \)
- \( \Delta T_{\text{Nsc}} = T_{\text{Nsc}} - T_{\text{mminsc}} \approx 0.9 \text{ DTR}_{sc} \)
\( LW_{\text{net}} \) and DTR – monthly mean data

- Mean \( LW_{\text{net}} \) and DTR correlated

\[ y = 1.76 + 0.159x \quad (R^2 = 0.80) \]

[Betts: JGR, 2006]
Spring climate transition

• **Before leaf-out**
  Little evaporation $\longrightarrow$ Dry atmosphere, low RH
  $\longrightarrow$ Deep dry BL
  $\longrightarrow$ Large outgoing $LW_{\text{net}}$
  $\longrightarrow$ Large DTR, warm days, cool nights

• **After leaf-out**
  Large evaporation $\longrightarrow$ Wet atmosphere, low cloudbase
  $\longrightarrow$ Small outgoing $LW_{\text{net}}$
  $\longrightarrow$ Reduced DTR, reduced $T_{\text{max}}$
Water availability & the surface energy partition

- FIFE grassland: partitioned by soil moisture
  - July & August; little cloud
- Evaporative fraction: \( EF = \frac{\lambda E}{\lambda E + H} \)
Diurnal cycle on vector diagrams

- $\Delta \xi_m / \Delta t = (F_s - F_i) / \rho \Delta Z_i$ where $\Delta \xi_m = \Delta (C_p \theta, \lambda Q)_m$
- $(H, \lambda E) = \Omega \Delta (C_p \theta, \lambda Q)$ where $\Omega = \rho \Delta Z_i / \Delta t$

Fluxes  vector  BL growth
Water availability, evaporation and LCL

Why is cloud-base is higher over land?

- ERA-15: SW-L1
- Boreal forest & moss
- Resistance to evaporation $\rightarrow$ RH drop and LCL rise
Land-surface-BL Coupling

- $\text{SMI-L1} = \frac{\text{SM} - 0.171}{0.323 - 0.171}$
- $P_{LCL}$ stratified by Precip. & SMI-L1 or EF
- Highly coupled system: only $P_{LCL}$ observable
Separating cloud and surface controls on the SEB and EF

- $R_{\text{net}}$ depends on cloud cover
- EF depends on $T$ and soil moisture
Cloud forcing to Precipitation

- SWCF/precip less in ERA-40 (0.48) than observed (0.74)
- Cloud radiative & diabatic forcing comparable
- And closely coupled on all timescales in atmosphere
Evaporation-precipitation feedback

- *Difference* in monthly mean forecast precip. (in mm/day) starting with wet and dry soils  
  
  [Beljaars et al. 1996]
Evaporation-precipitation feedback in ERA-40

- Two 120-day FX from May 1, 1987, initialized with wet and dry soils
- Memory lasts all summer
- E and P fall with dry soil
- E-P changes little; variability drops

[Betts 2004]

Is ERA-40 right?
Wet summers

- Both 2008 and 2009 were wet in Vermont!
- Direct fast evaporation off wet canopies
- Positive evaporation-precipitation feedback
Precipitation and cloud coupling to vertical motion in ERA-40 reanalysis

- Partition of moisture convergence into TCWV, \( \alpha_{\text{cloud}} \), and precipitation
- Note high bias of \( \alpha_{\text{cloud}} \) from ISCCP; while precip. generally low

[Betts and Viterbo, 2005]
Summary/Philosophy

• Look for relationships and information in the coupling of processes/observables
• Models have only *limited value* without deep understanding of the coupling of processes
• *Observations important for evaluation & to suggest processes that are simply missing*
• *Every model cycle* needs analysis of relationships, diurnal, daily mean and seasonal, for both wet and dry seasons (or disturbed/suppressed conditions) *against observations* for tropical and mid-latitude climate regimes
• A challenge: but tractable as both global, regional and point time-series datasets improve