Coupling of clouds, precipitation and land-surface processes in the climate over land

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Background references


• Betts, A. K., 2007: Coupling of water vapor convergence, clouds, precipitation and land-surface processes. *JGR* [submitted].
**Linking Weather and Climate…**

• Interactions of water are central to weather and climate *[phase changes and radiation interactions]*

• Global models are powerful tools for modeling interacting processes, but do they have the right “climate”?

• Evaluation against data is critical, but what matters?
Clouds are the crucial link in surface-atmosphere coupling

- Ocean timescales longer than over land
- Over land, cloud fields are a tightly coupled component; with daily impact on surface energy budget and evaporation
  - Partly linked to large-scale convergence
  - Partly linked locally to ‘soilwater’ which impacts evaporation, and LCL
Historical perspective

- For 20 years, ‘cloud radiative forcing’ has been a ‘challenge’; a ‘major source of uncertainty in climate modeling’
- Why? Seems odd because they are so easily observed!
- A quantitative framework, which links them to both surface and large-scale processes has been missing.
Why do surface coupled processes matter?

- Oceans: timescale of surface response longer, but clouds play major role
- Land: Cloud variability dominates surface energy balance on diurnal and daily timescales

- How does the coupled system work?
- How can we quantify the cloud fields?
- Use models to map links…
Consider the chain of processes involving water

SMI: soil moisture index \([0<\text{SMI}<1 \text{ as PWP}<\text{SM}<FC]\)

\(\alpha_{\text{cloud}}\): ‘cloud albedo’ viewed from surface
Data organized by

- $\alpha_{\text{cloud}}$: ‘cloud albedo’ viewed from surface – *measure of surface SW cloud forcing*

- $\text{SMI}$: soil moisture index
  
  $[0<\text{SMI}<1 \text{ as } \text{PWP}<\text{SM}<\text{FC}]$

- $P_{\text{LCL}}$: Lifting condensation level [in hPa]

- $\text{VIMC}$: Vertically integrated moisture convergence
Land-surface climate view

- Model “climate” is a 24-hr mean problem [with a superimposed diurnal cycle]
- Seasonal cycle is sequence of daily mean states + “synoptic noise”
- Spatial scale ≈ 900 km [at 10 m/s]
- Errors on these time- and space-scales cause drifts in model climate
How well are physical processes represented?

• Basin-scale assessment of ERA40 biases  
  [Betts et al. 2003a, 2003b, 2005; Betts 2007]

• FLUXNET data can assess both biases and the coupling of physical processes on the point scale  
  [Betts et al. 2006]
Compare ERA-40 with BERMS

- ECMWF reanalysis
- ERA-40 hourly time-series from single grid-box
- BERMS 30-min time-series from
  Old Aspen (OA)
  Old Black Spruce (OBS)
  Old Jack Pine (OJP)
- Daily Average
• Cloud ‘albedo’: $\alpha_{\text{cloud}} = 1 - \frac{SW_{\text{down}}}{SW_{\text{clear}}}$
Cloud albedo and LW comparison

ERA-40: low $\alpha_{\text{cloud}}$ [except summer]

$LW_{\text{net}}$ bias [winter]
\( \text{LW}_{\text{net}} \) on RH and \( \alpha_{\text{cloud}} \)

- Outgoing \( \text{LW}_{\text{net}} \) falls as RH and cloud cover increase
- Higher RH means lower LCL & depth of ML
- \( \text{LW} \) coupling same for BERMS and ERA-40
Mississippi: explore & evaluate

- $\alpha_{\text{cloud}}$: ISCCP as ‘truth’ [using ERA40 clear-sky]
- Precipitation: NCDC as ‘truth’
Cloud ‘albedo’: $\alpha_{\text{cloud}} = 1 - \frac{SW_{\text{netSRF}}}{SW_{\text{netSRF}} \text{ (clear)}}$

$SW_{\text{netSRF}} = (1 - \alpha_{\text{cloud}})(1 - \alpha_{\text{SRF}}) SW_{\text{dnSRF}} \text{ (clear)}}$
TOA and surface cloud albedos
- tightly related

- $\alpha_{\text{cloud}} = -\frac{\text{SWCF}_{SRF}}{\text{SW}_{\text{netSRF}}(\text{clear})}$
- $\alpha_{\text{TOA}} = -\frac{\text{SWCF}_{\text{TOA}}}{\text{SW}_{\text{dnTOA}}(\text{clear})}$
Seasonal cloud bias

- Systematic bias for all basins
- Largest negative in winter: -10%
- Bias from ISCCP and BERMS agree!
Seasonal precipitation bias

- ERA40 bias differs across basins
- Positive in winter:
- Large-scale precip. efficiency too high?
Daily $\alpha_{\text{cloud}}$ by season

- Winter low bias largest
- Scatter small
Coupling of soil moisture, LCL and precipitation

- LCL descends with increasing SMI-L1 and precip.
- Highly coupled
  - precipitation increases SMI-L1
  - wetter SMI increases evaporation from surface
  - falling precip. evaporates, lowering LCL
How does $\alpha_{\text{cloud}}$ depend on VIMC and $P_{\text{LCL}}$?

Missouri

Ohio-Tenn

ERA40

ISCCP
How does Precip. depend on VIMC and $P_{LCL}$?

Missouri

Ohio-Tenn

ERA40

NCDC
\( \alpha_{\text{cloud}} \), Precip. increase with SMI and VIMC

Missouri

Ohio-Tenn

\( \alpha_{\text{cloud}} \)  
Precipitation
Organize data by ‘surface cloud albedo’
How does Precip. depend on $\alpha_{\text{cloud}}$ and $P_{\text{LCL}}$?

Missouri

Ohio-Tenn

ERA40

ISCCP & NCDC
Surface cloud forcing has linear relation to $\alpha_{\text{cloud}}$

- Clear-sky $LW_{\text{net}}$ depends on $P_{LCL}$
- Cloud forcing does not
Compare SWCF/Precip

SWCF_{SRF}/Precip is less for ERA40 than observations
ERA-40/Satellite perspective on surface energy balance

SEB energy balance a ‘soluble problem’?

1) Surface cloud forcing/\(\alpha_{\text{cloud}}\) [visible]
2) EF from surface layer SMI [microwave], T
3) Vegetation a slower component [NDVI]
Net radiation variability depends mostly on $\alpha_{\text{cloud}}$

- $R_{\text{netSRF (clear)}}$ varies weakly
- $\text{CF}_{\text{SRF}}$ linear with $\alpha_{\text{cloud}}$
EF depends on T and SMI-L1

- EF increases with SMI
- Slope with $T \approx \text{'equilibrium evaporation'}$
Conclusions

• ERA-40 has low bias in effective surface cloud albedo, except in summer
• Moisture convergence, SMI and LCL linked to clouds and precipitation.
• Organize data by $\alpha_{\text{cloud}}$
  • SWCF$_{\text{SRF}}$/Precip is less for ERA40 than observations
• Split SEB into ….
  • $\alpha_{\text{cloud}}$ dependence of CF$_{\text{SRF}}$ $\rightarrow$ $R_{\text{net}}$
  • Evaporative fraction linked to T, SMI-L1
Model ‘climate’ evaluation

• Are observables coupled correctly in a model on the daily timescale?

• What are observables:
  – BL quantities: RH, LCL linked to SMI, precip
  – Clouds \([\alpha_{\text{cloud}}]\) determine surface and TOA SW and LW cloud forcing
  – Moisture convergence and precipitation
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