Role of cloud liquid water in modulating the Arctic surface energy budget

Matthew Shupe and Ola Persson CIRES – University of Colorado and NOAA/ESRL

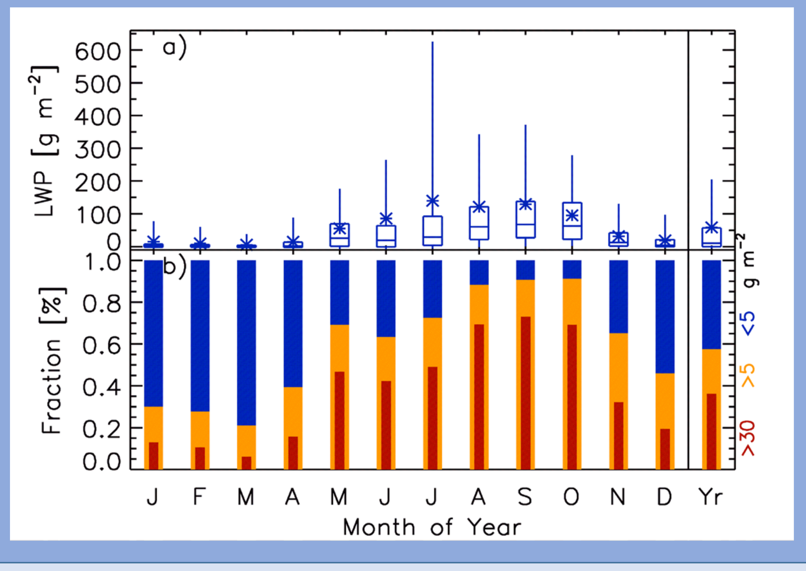
17 March 2015

1. Background

The **Surface Energy Budget (SEB)** is of great importance in the Arctic, where the surface consists largely of permafrost, sea-ice, and land ice. Perturbations to the SEB can lead to changes in surface and sub-surface temperatures and impact melting, thawing, and freezing processes. The fate of the Arctic cryosphere has profound regional and global implications related to climate-scale feedback processes (*sea-ice changes*), the potential release of greenhouse gases (*thawing permafrost*), changes in sea-level (*melting land ice*), and others. While the solar cycle and seasonal darkness largely control the seasonal evolution of the Arctic SEB, clouds also play a critical role. Here we focus specifically on the important influences of **liquid water clouds.**

2. Measurements and Methods

- All measurements are from the Barrow, Alaska ARM site for 2003-2014 (unless otherwise noted).
- Microwave radiometer-derived cloud liquid water path (LWP) from MWRRET
- Longwave & shortwave broadband radiation for up-, downwelling, and net (LWD,LWU,LWN,SWD,SWU,SWN) from QCRad
- Surface turbulent sensible and latent heat fluxes derived using a bulk flux approximation derived for Arctic conditions.
- Soil heat flux, temperature, and moisture are from the SEBS dataset (primary coverage in 2013-2014 only)
- Fluxes are positive in the downward direction (i.e., positive atmospheric fluxes heat the surface)



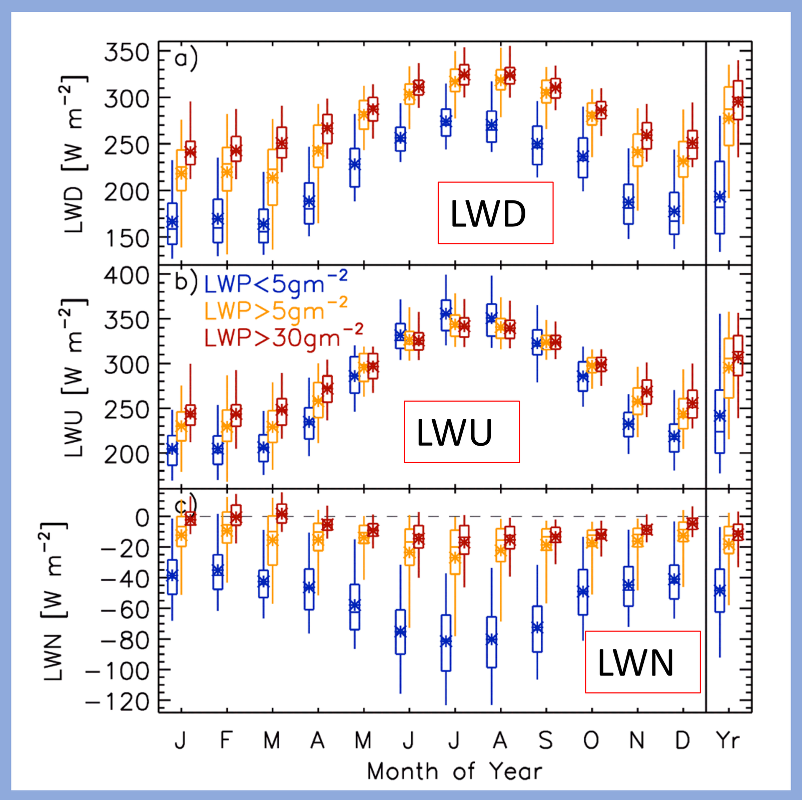
Liquid Water Classification. Liquid water is identified using a LWP threshold

1. **LWP < 5 g/m² = No Liquid (clear sky and/or ice clouds)**
2. **LWP > 5 g/m² = Liquid present (can also be ice)**
3. **LWP > 30 g/m² = Opaque liquid cloud (can also be ice)**

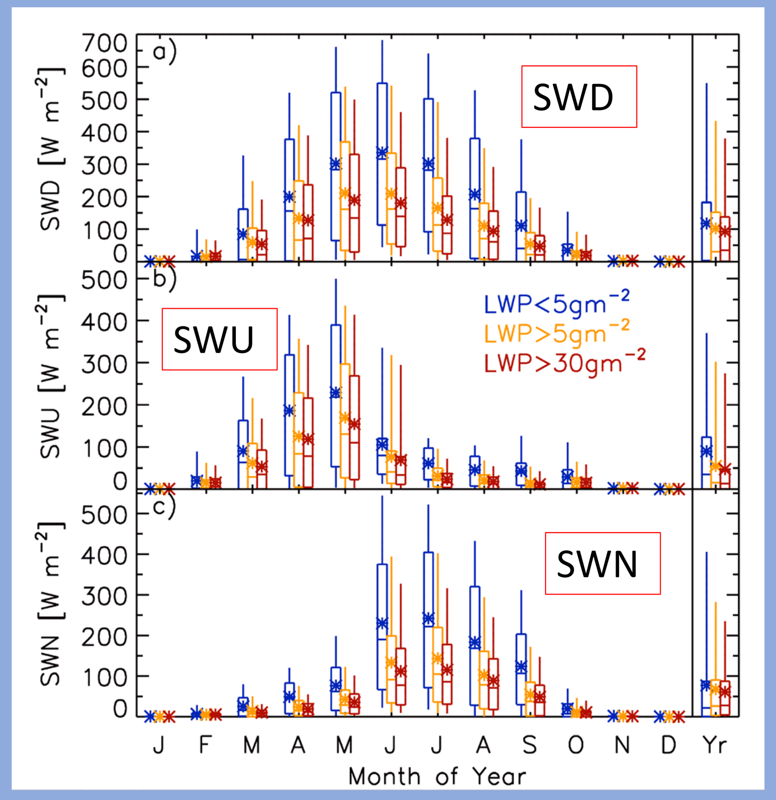
- Liquid water clouds occur 20-30% of the time in winter, increasing to about 90% of the time in summer (consistent with past work).
- Opaque clouds occur less than half of the time that liquid occurs in winter, but more than half of the time in summer.
- LWP statistics show a clear seasonal cycle with increased values in summer and fall relative to the rest of the year.

3. Atmospheric Flux Annual Cycle Summary

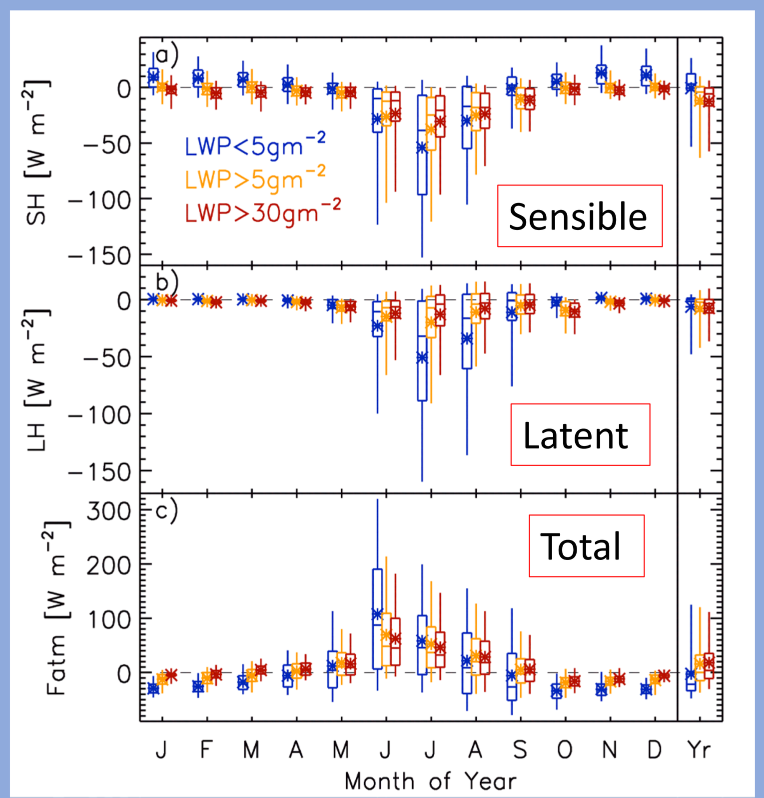
Longwave Radiation



Shortwave Radiation

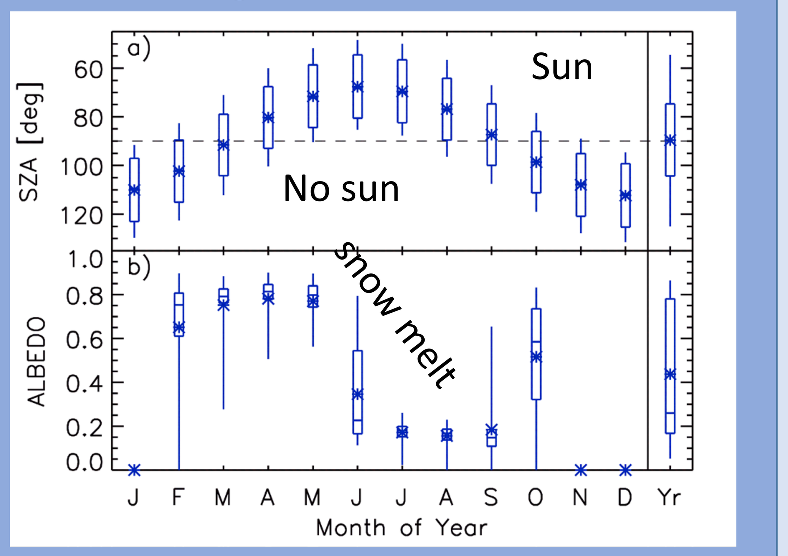


Turbulent and Total Atmos Fluxes

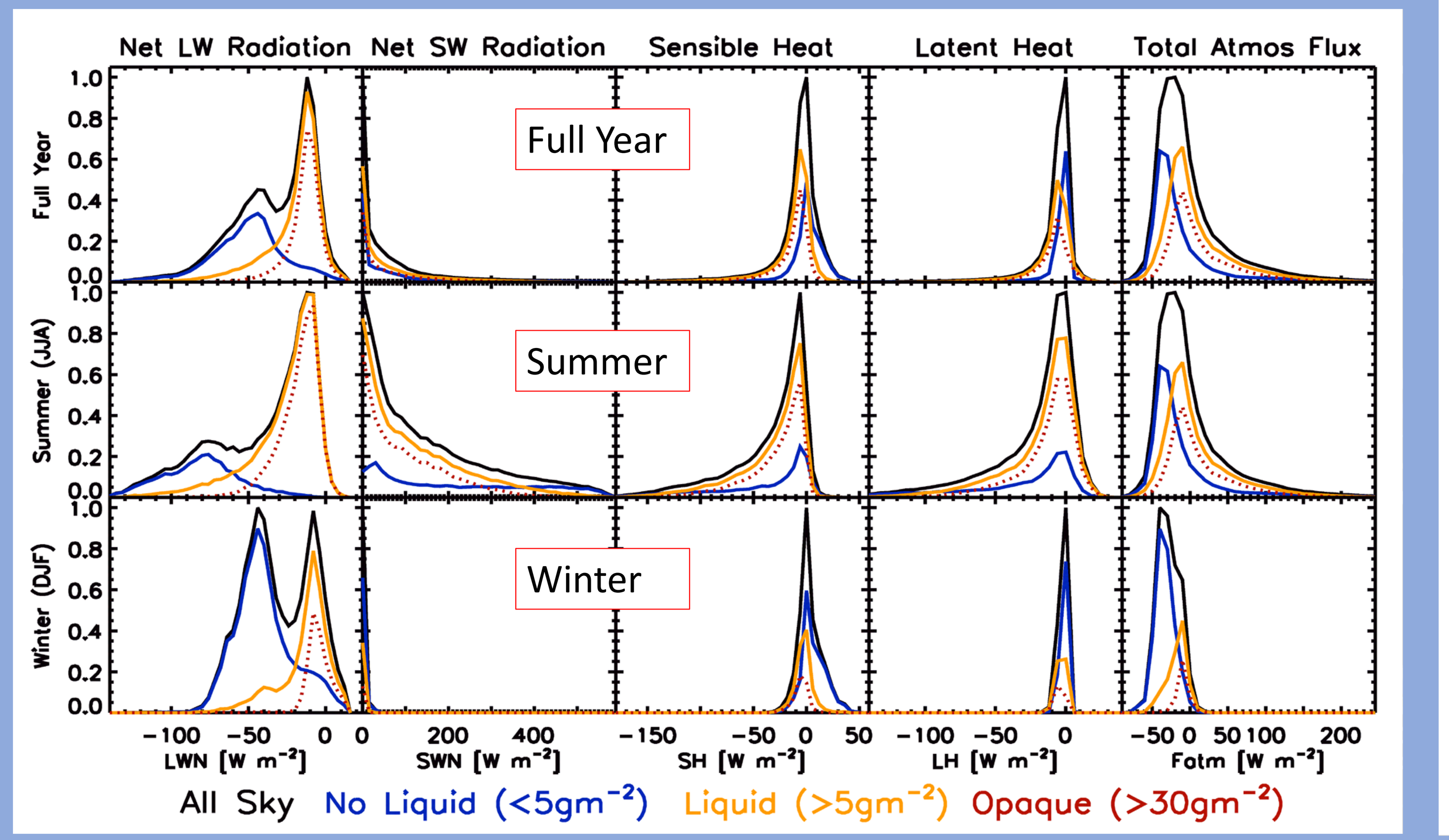


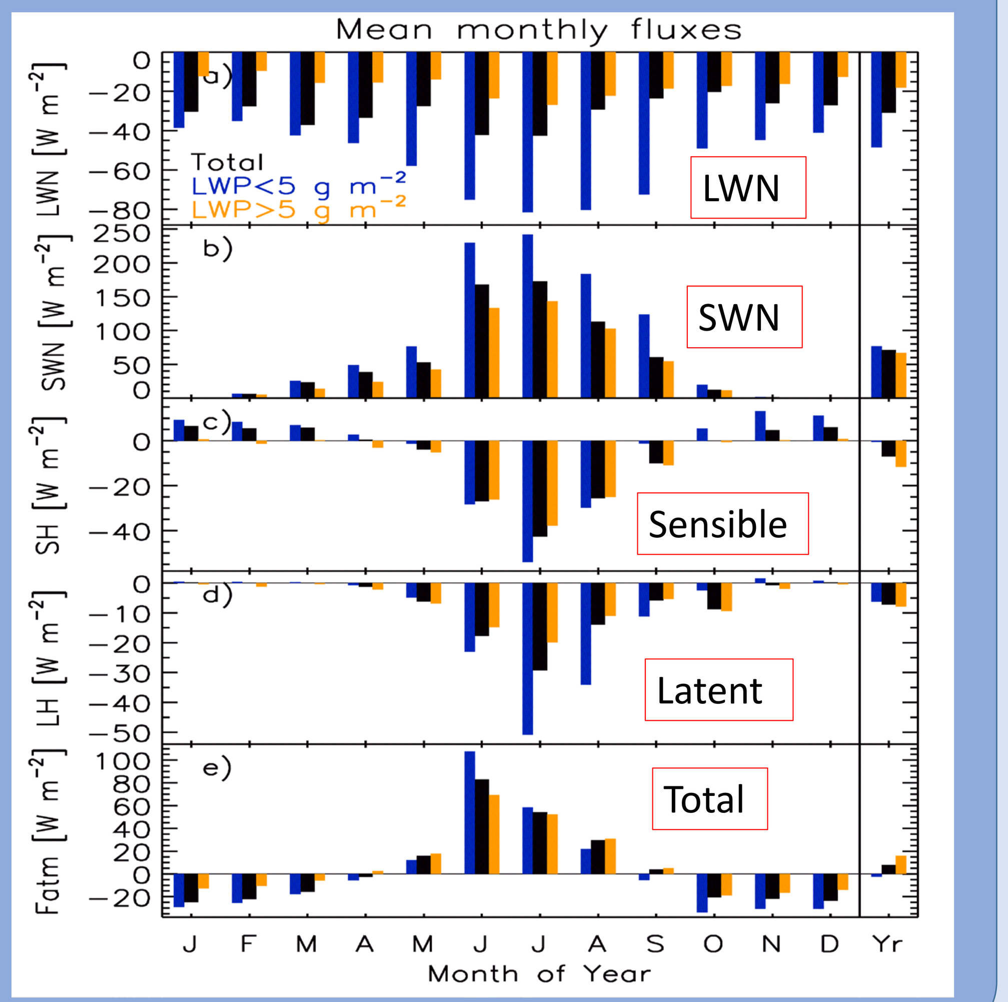
1. Enhanced LWD and LWU in summer due to temperature, moisture, and clouds
2. Decreased LWN in summer due to less atmospheric stability & weaker inversions
3. Bimodal LW states: Radiatively clear and opaque cloudy (=liquid cloud). The spread between states is largest in summer.
4. Enhanced SW in summer, but dramatic SWU transition in May-to-June as snow melts. Together these make a dramatic increase in SWN in June-September.
5. Turbulent fluxes generally cool the surface with a mid-summer maximum when temperatures are highest. Sensible heat flux weakly warms surface in winter when there are no liquid clouds due to strong surface-based temperature inversions.
6. Strongest net atmospheric surface warming in June due to strong increase in SWN. This warming is partially mitigated later in summer as turbulent surface cooling increases.
7. Liquid clouds dampen the annual cycle amplitude for all flux parameters, counteracting the solar cycle and surface temperature effects.

Sun Angle & Surface Albedo



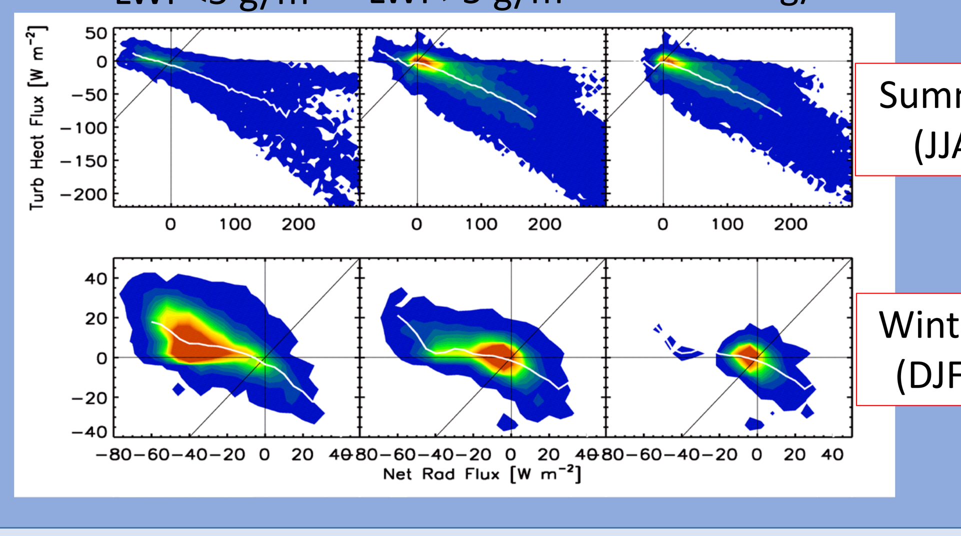
Summary of Contributions to Total Flux Terms and Distributions





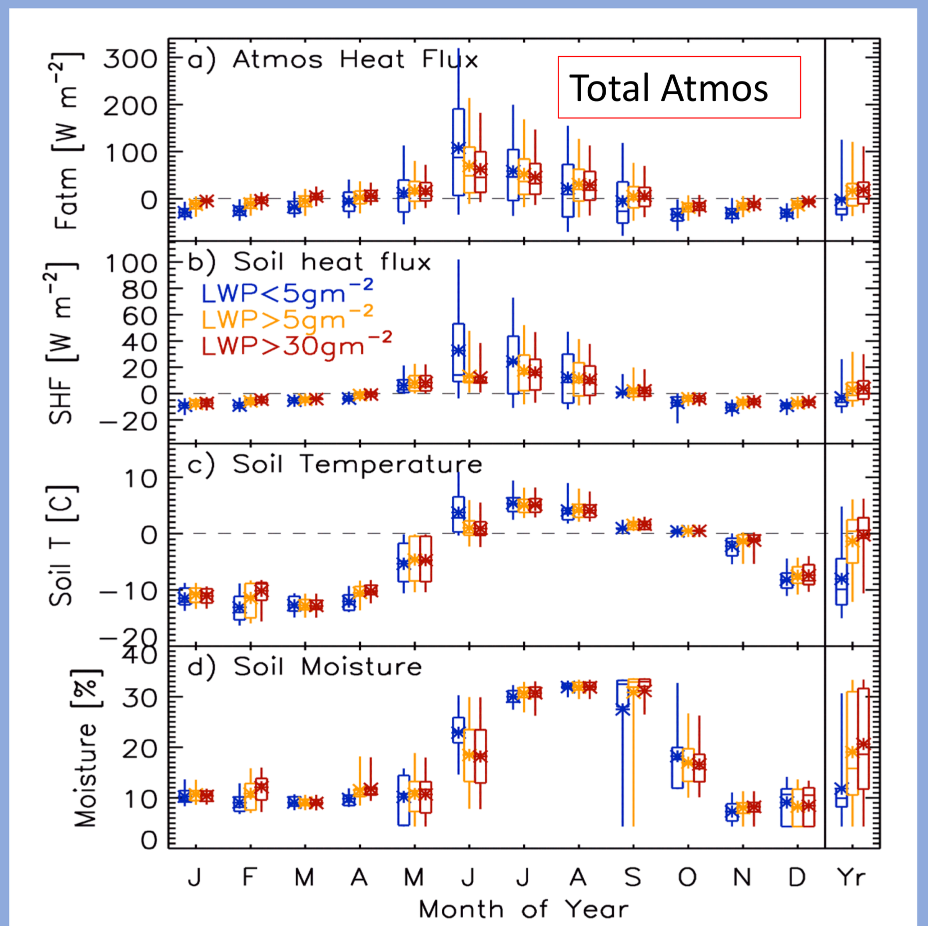
4. Turbulent Response to Radiative Forcing

Surface turbulent heat fluxes respond to perturbations caused by surface radiation. The simple case is in winter (bottom row) where surface LW cooling when liquid clouds are absent is partially offset by sensible heat warming. When liquid clouds are present, a near-neutral surface radiative flux forces little turbulent heat flux response at the surface. Summer (top row) is complicated by the large positive SW flux, which overwhelms the net LW flux and is partially offset by turbulent cooling of the surface.



5. Impact of Liquid Clouds on Surface and Sub-Surface

1. Total surface atmospheric heat flux is closely linked with conductive heat flux through soil and impacts soil temperature.
2. Quick sub-surface warming in spring as snow melts; slow autumn sub-surface cooling as atmospheric flux slowly decrease.
3. Most extreme seasonal heat fluxes are under skies that do not contain liquid water (i.e., radiatively clear days allow the sun to heat surface/soil in summer or the surface to efficiently cool in winter). Liquid clouds dampen seasonal effects.
4. Liquid clouds radiatively cool surface in June-Sept, but only lead to a net cooling of the surface and sub-surface in June & July due to compensating turbulent heat processes.



Estimated Liquid Cloud Forcing on all Fluxes

(Forcing relative to clear sky / ice-only cloud)

Max Forcing = Flux_liquid – Flux_no_liquid

Scaled Forcing = Max Forcing * Liquid Occurrence Fraction