ANALYSIS OF THE DIURNAL CYCLE OF CLOUD EFFECTS ON THE SURFACE RADIATION BUDGET OF THE CONTINENTAL USA SURFRAD NETWORK

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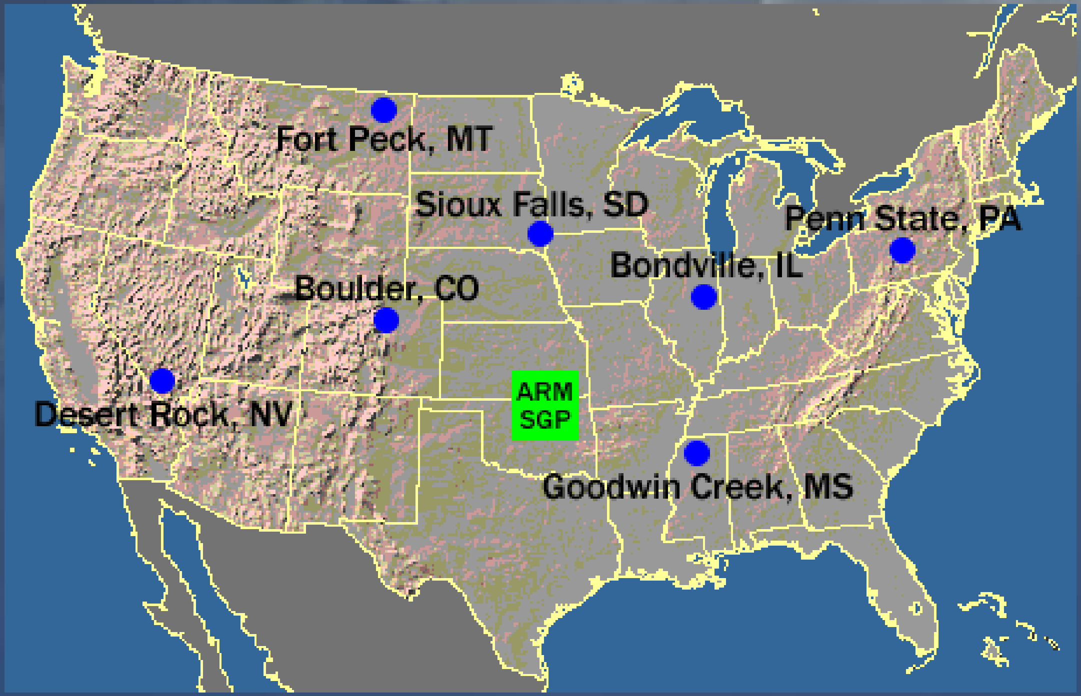
SURFRAD Network



Full surface net radiation budget and basic meteorological measurements

N → S

Code	Name	Latitude	Longitude	Elevation	Time Zone	Installed
FPK	Fort Peck, Montana	48.30783° N	105.10170° W	634 m	7 hours from UTC	Nov-94
SXF	Sioux Falls, South Dakota	43.73403° N	96.62328° W	473 m	6 hours from UTC	Jun-03
PSU	Penn. State Univ., Pennsylvania	40.72012° N	77.93085° W	376 m	5 hours from UTC	Jun-98
TBL	Table Mountain, Boulder, Colorado	40.12498° N	105.23680° W	1689 m	7 hours from UTC	Jul-95
BON	Bondville, Illinois	40.05192° N	88.37309° W	230 m	6 hours from UTC	Apr-94
DRA	Desert Rock, Nevada	36.62373° N	116.01947° W	1007 m	8 hours from UTC	Mar-98
GWN	Goodwin Creek, Mississippi	34.2547° N	89.8729° W	98 m	6 hours from UTC	Dec-94

Radiative Flux Analysis (RadFlux)

- Flux Analysis methodology
  - Time series analyses of surface broadband radiation and meteorological measurements (T/RH/Wspd)
    - Need at least 5-minute resolution
  - Detect clear (cloud free) sky occurrences
  - Use detected clear sky data to fit functions
  - Interpolate coefficients to produce continuous estimate of clear-sky irradiances
  - Use results to infer cloud effects on surface radiation and cloud properties

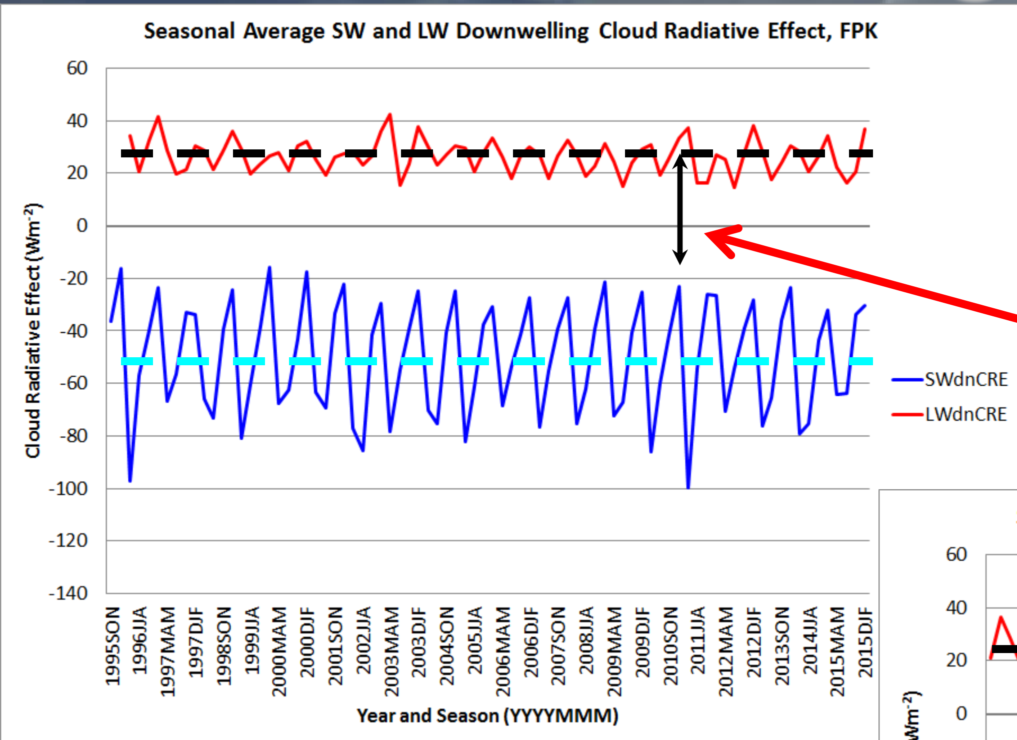
Cloud Radiative Effect and Forcing

- We define the difference between measured and clear-sky downwelling irradiance as the "downwelling cloud radiative effect" (CRE).
  - All-sky – Clear-sky
- We define the difference between measured and clear-sky net irradiance (up & down) as the "cloud radiative forcing" (CRF).
  - Alternately the CRE_{dn} - CRE_{up}
- With this convention, a positive number is an INCREASE in energy input to the surface caused by clouds, negative is a DECREASE.

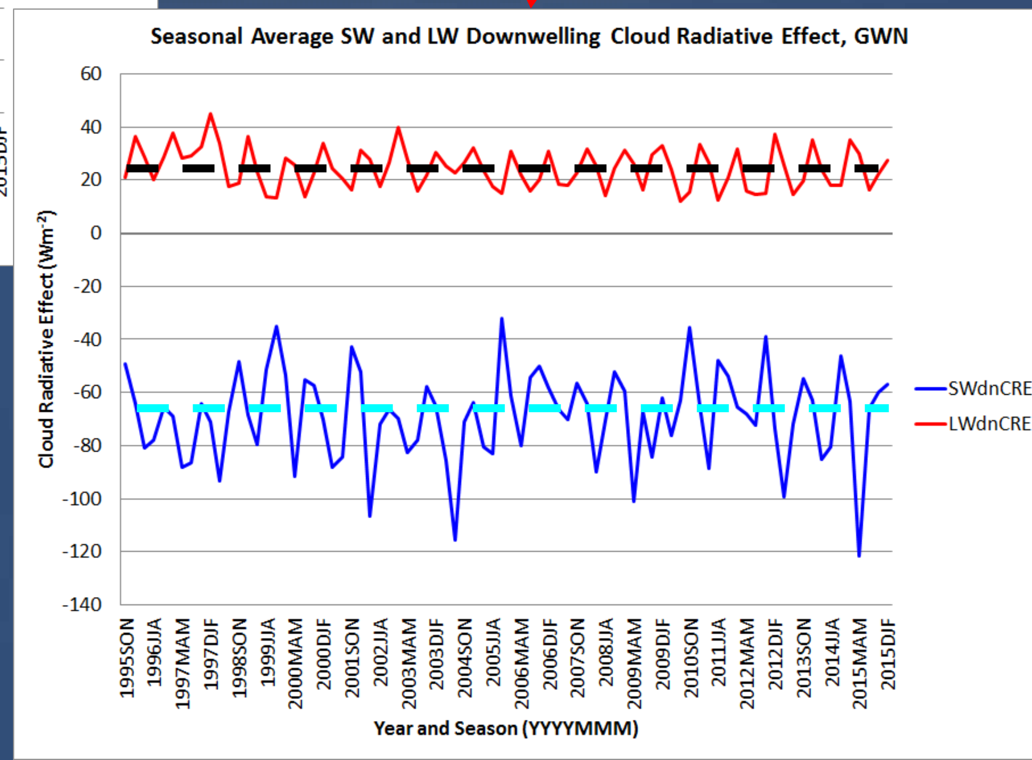
Seasonal Diurnal Analysis

- Seasons defined as:
  – Winter: December, January, February (DJF)
  – Spring: March, April, May (MAM)
  – Summer: June July, August (JJA)
  – Fall: September, October, November (SON)
- Diurnal Cycle calculated by:
  – For each season, take average in 15-minute bins across the 24-hour day based on local standard time
  – Total season average is then average of the average diurnal cycle

Seasonal Average CRE Example



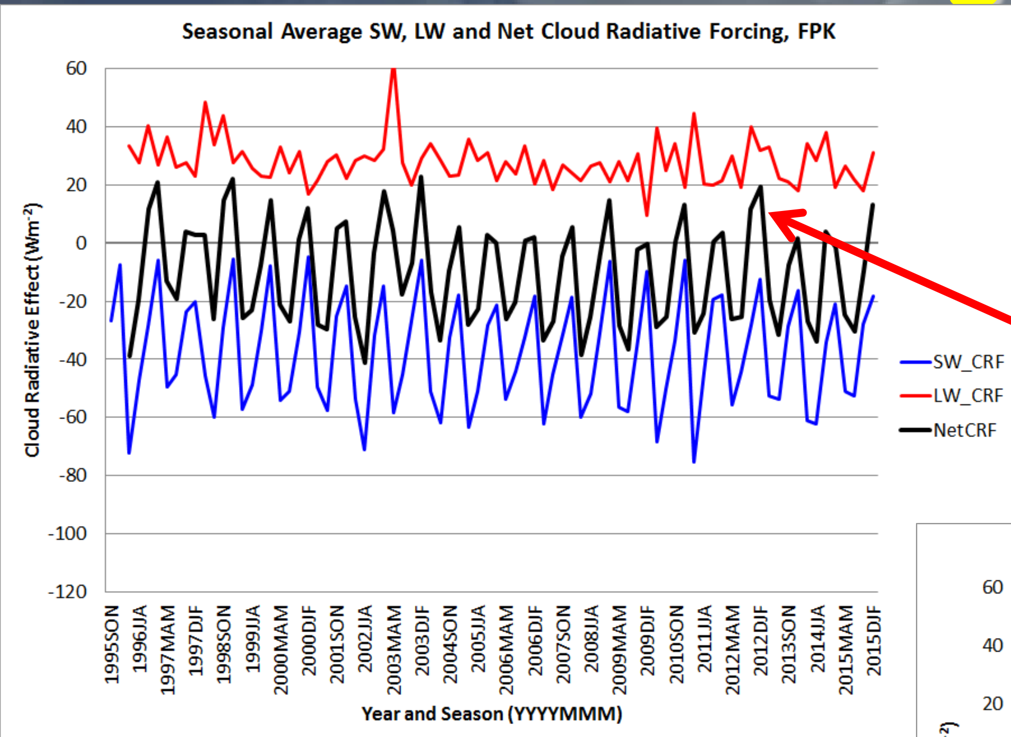
- <u>Overall</u> LW CRE magnitude is less than SW CRE magnitude
- Goodwin Creek SW CRE always greater magnitude than LW CRE
- But for Fort Peck, winter SW CRE is smaller magnitude than LW CRE



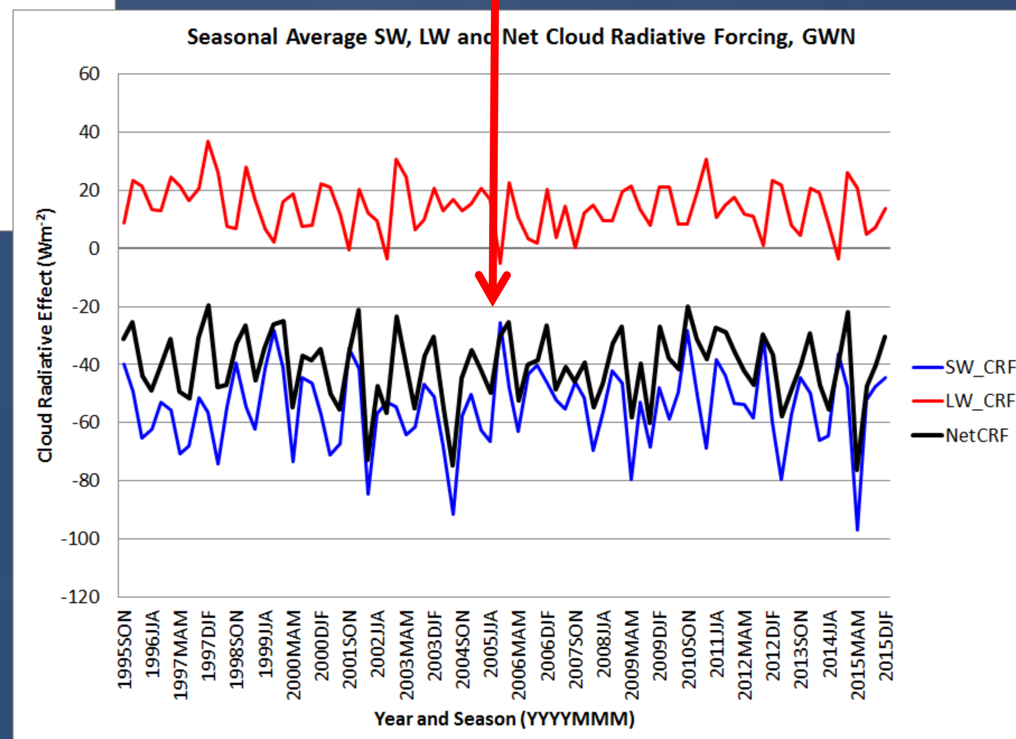
LW

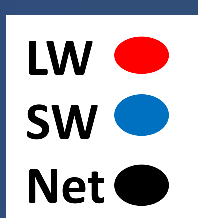
SW

Seasonal Average CRF Example

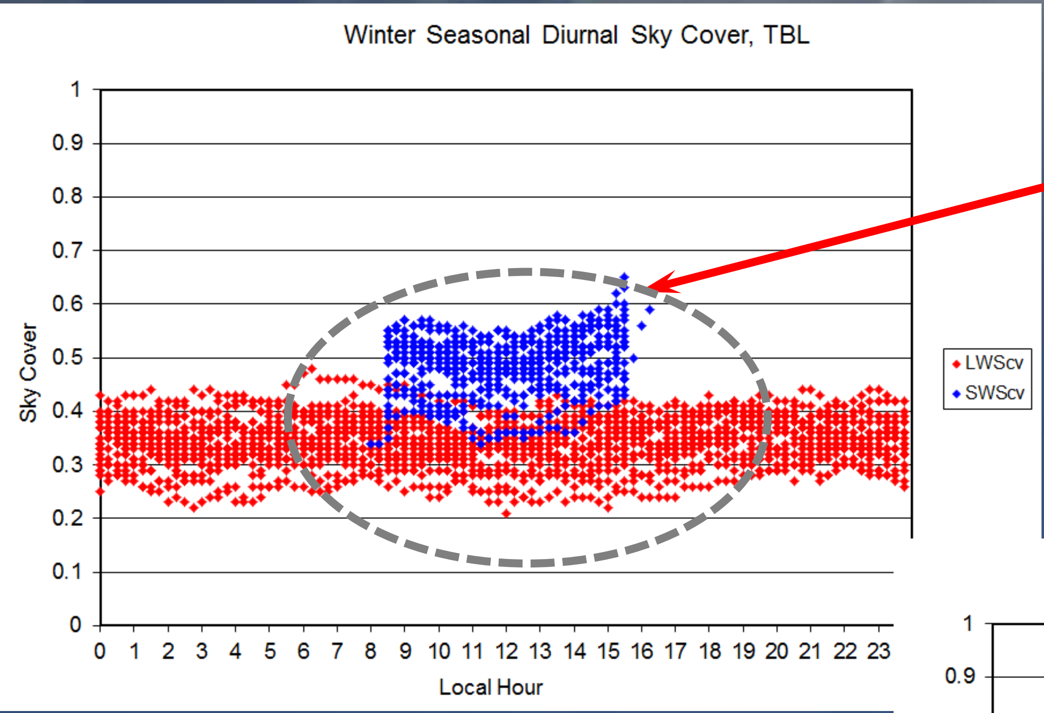


- Adding the upwelling CRE gives the Cloud Radiative Forcing
- Southern-most Goodwin Creek Net CRF always remains negative: SW dominates budget and cloud forcing
- But for northern-most Fort Peck, winter net CRF is most often positive

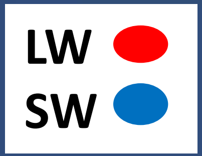


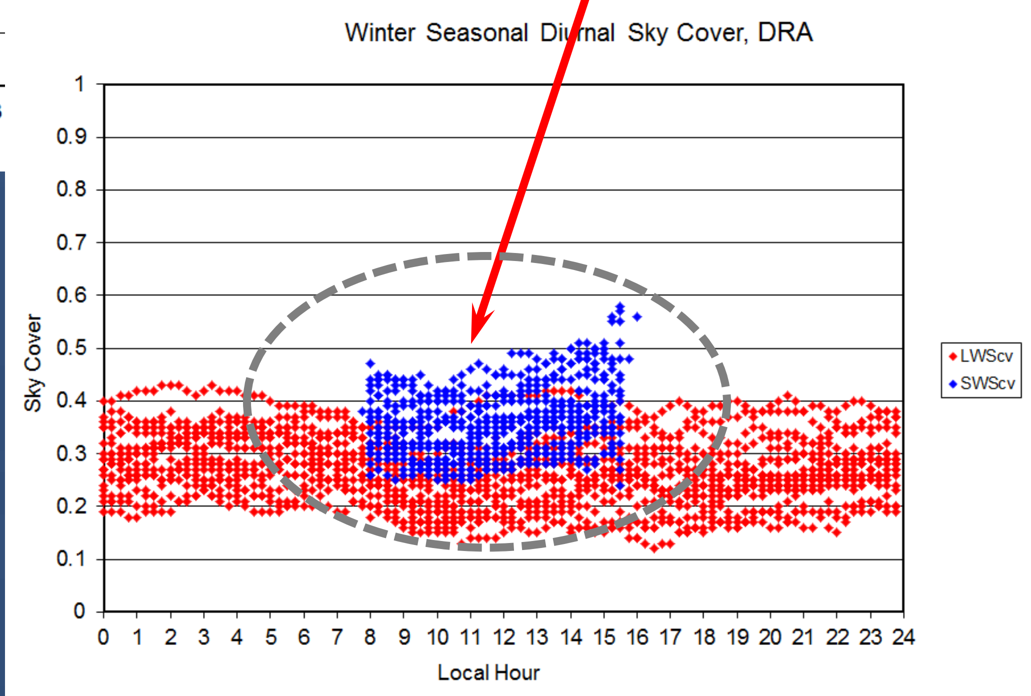


Yearly Seasonal Diurnal Examples



- Winter cloud amounts are slightly greater at Table Mountain than Desert Rock
- Amounts do not exhibit any significant diurnal signature
- LW cloud amount less than SW, is indication of the amount of high cloudiness





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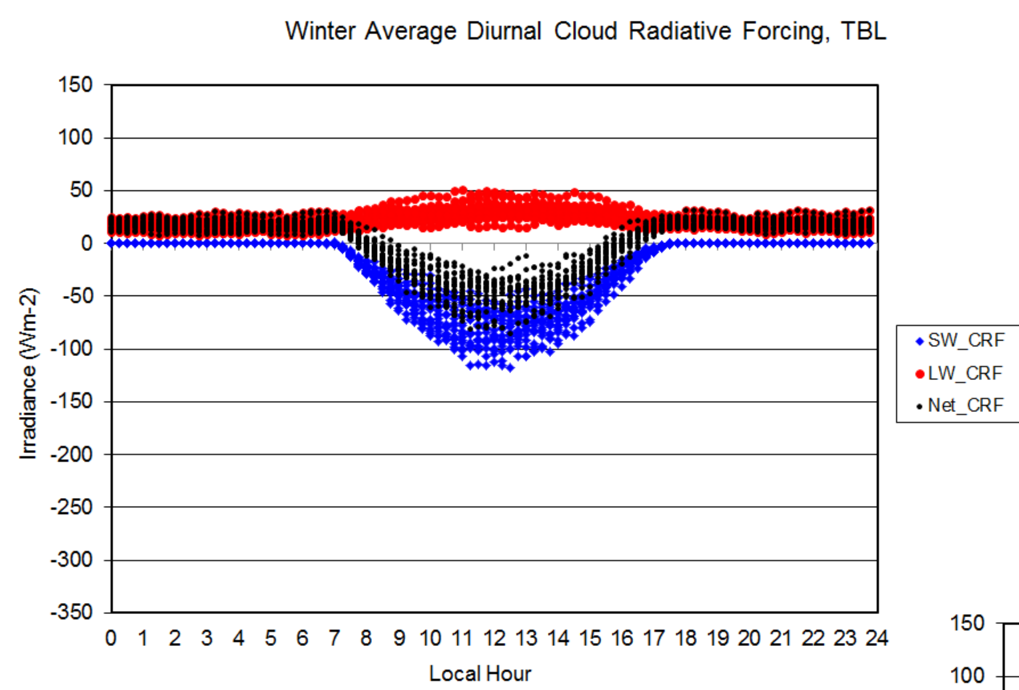
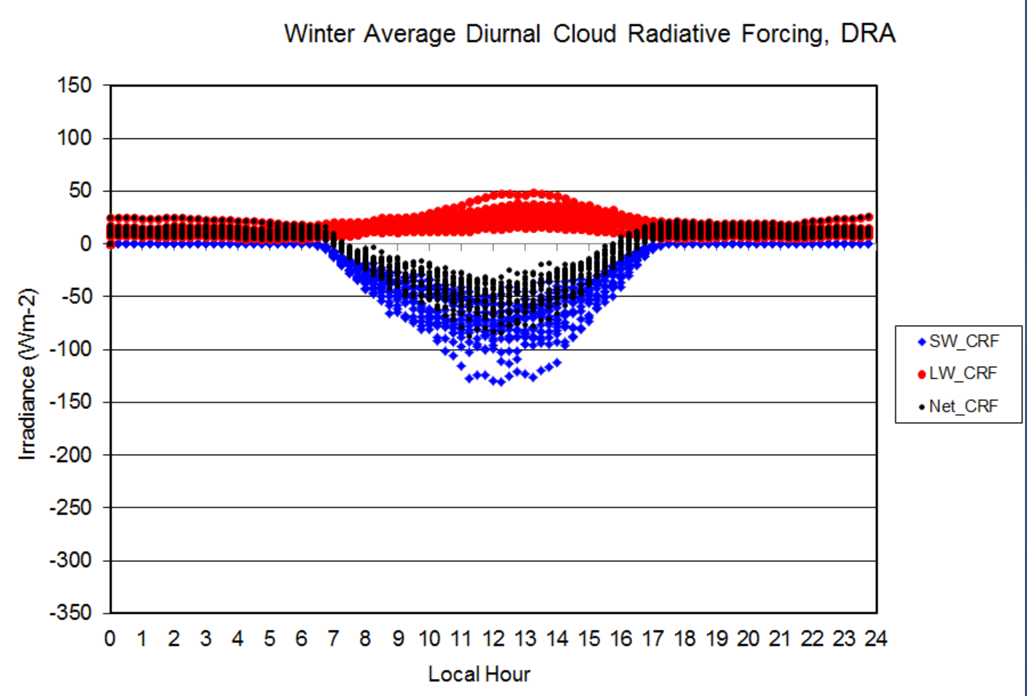


- Winter cloud amounts produce similar CRF at Table Mountain and Desert Rock
- Net CRF is positive during night, but then negative during day when SW dominates

LW
SW
Net



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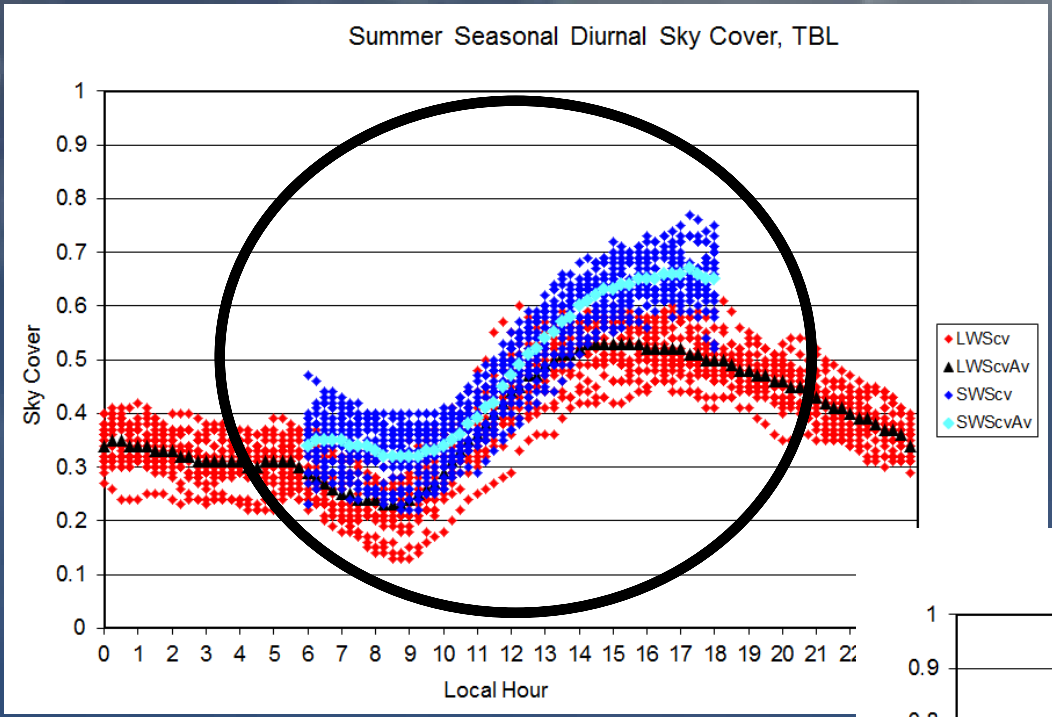
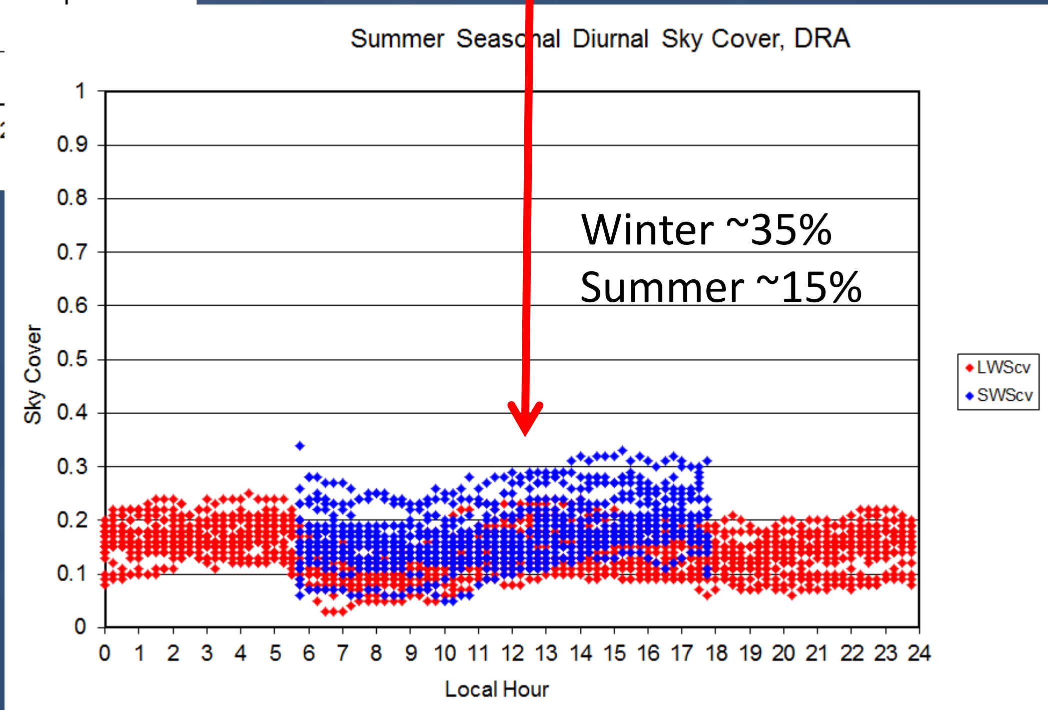
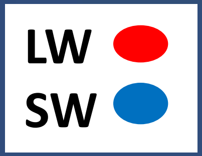
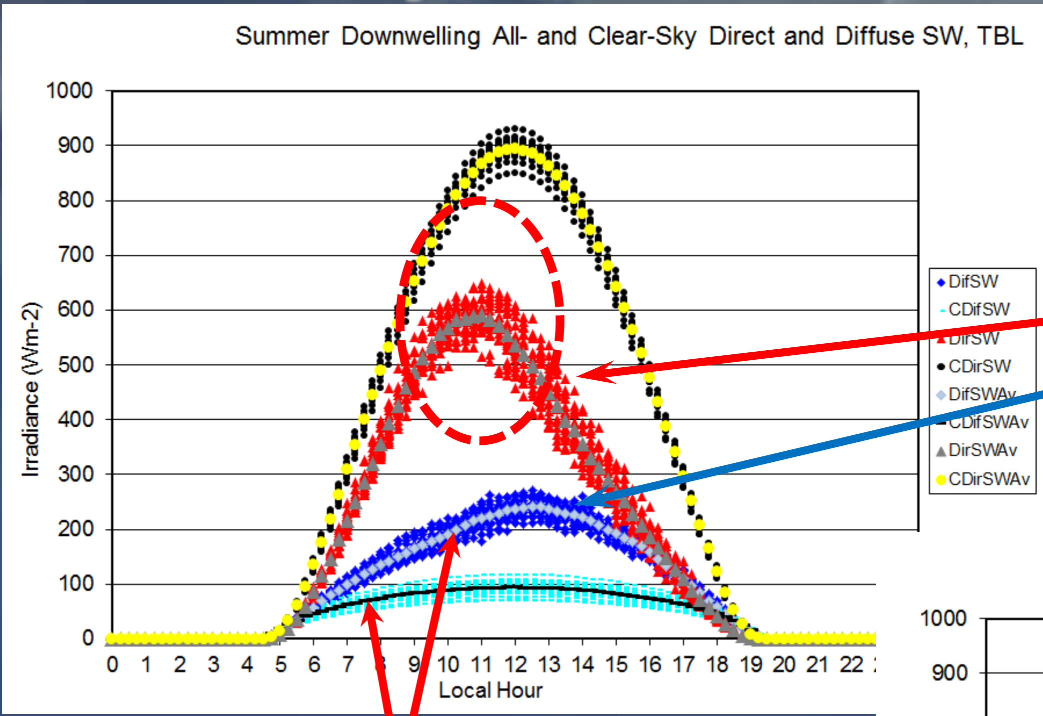


- Summer cloud amounts at Desert Rock are less than Winter amounts
- Still no significant diurnal signature at Desert Rock
- Table Mountain shows much greater cloudiness in afternoon



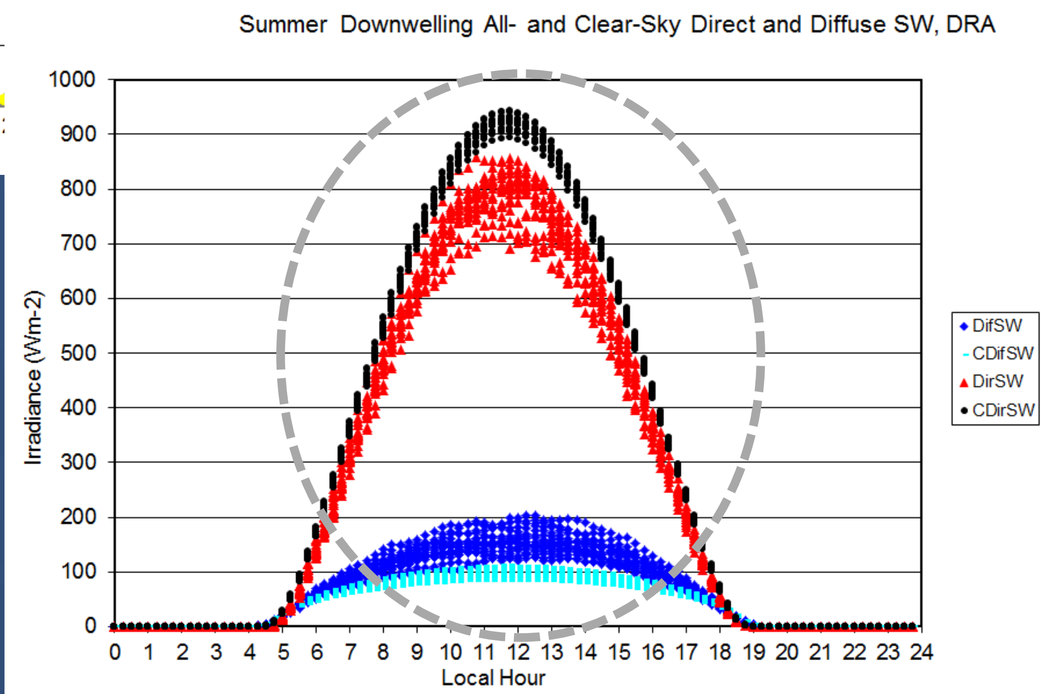


Yearly Seasonal Diurnal Examples

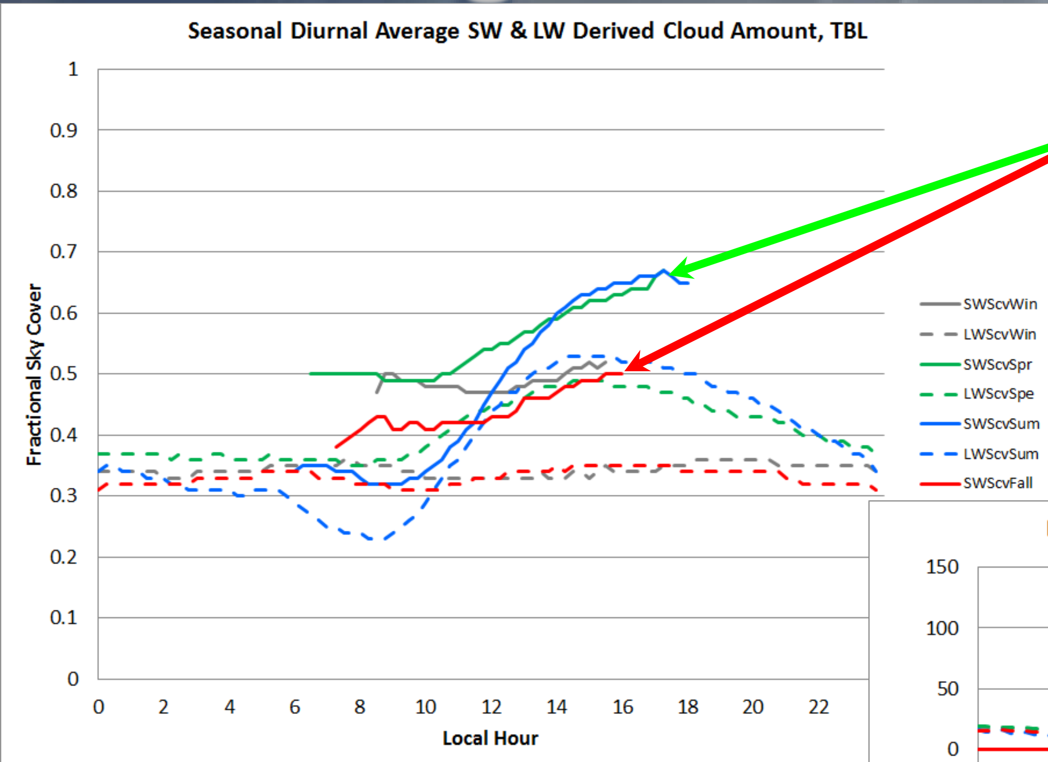


- Desert Rock summer direct and diffuse SW show only modest differences from clear-sky
- Table Mountain shows decreased all-sky direct SW and increased diffuse SW in afternoon
- Peak all-sky SW occurs at 10:30 am local

Average Seasonal Diurnal Cycle: take the average of all the yearly average diurnal cycles.

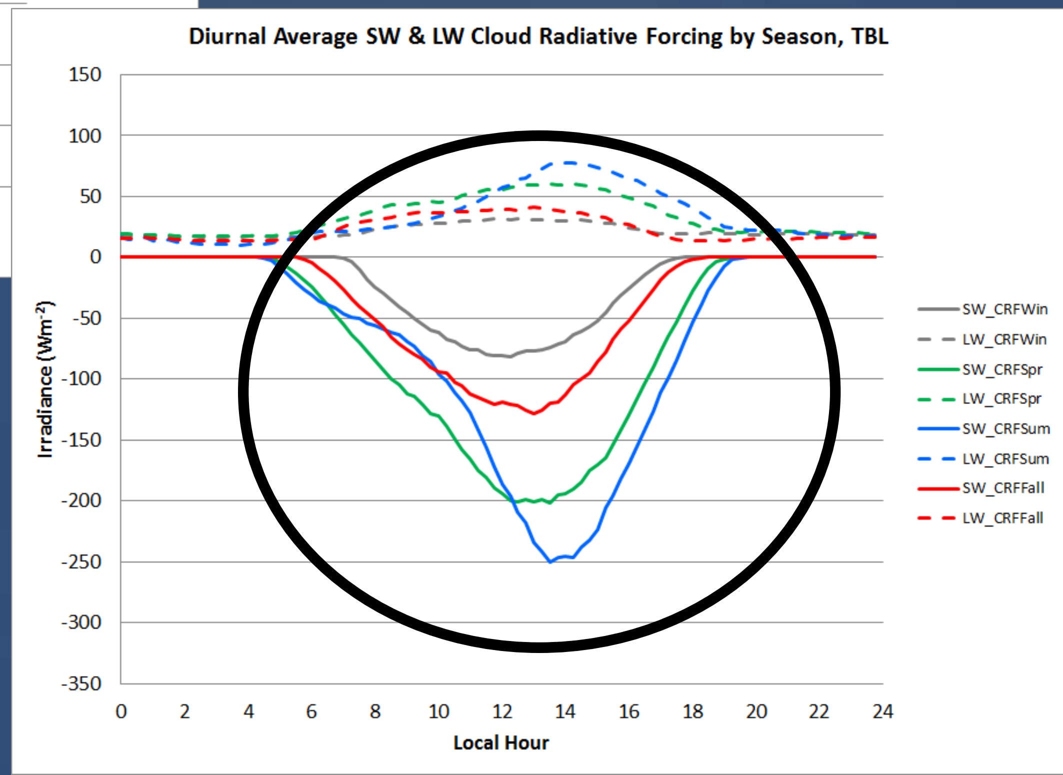


Average Seasonal Diurnal Cycles

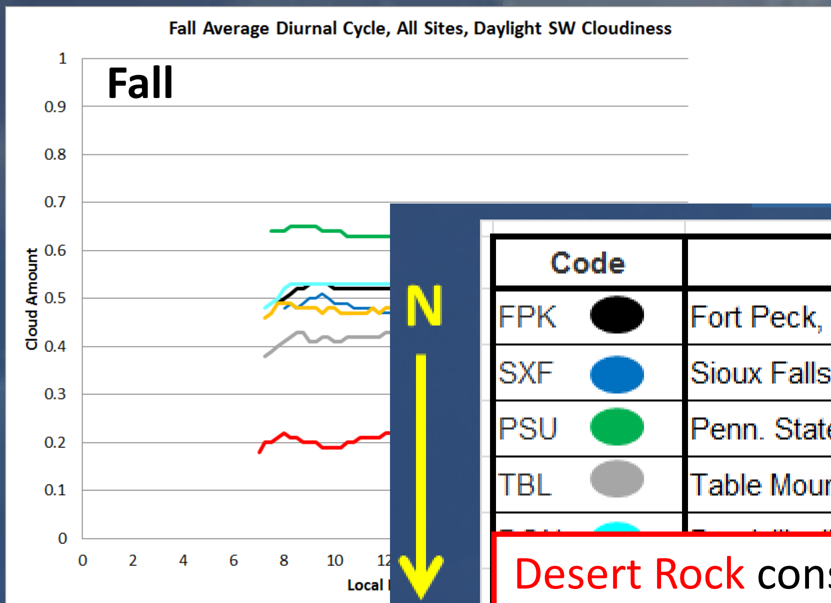


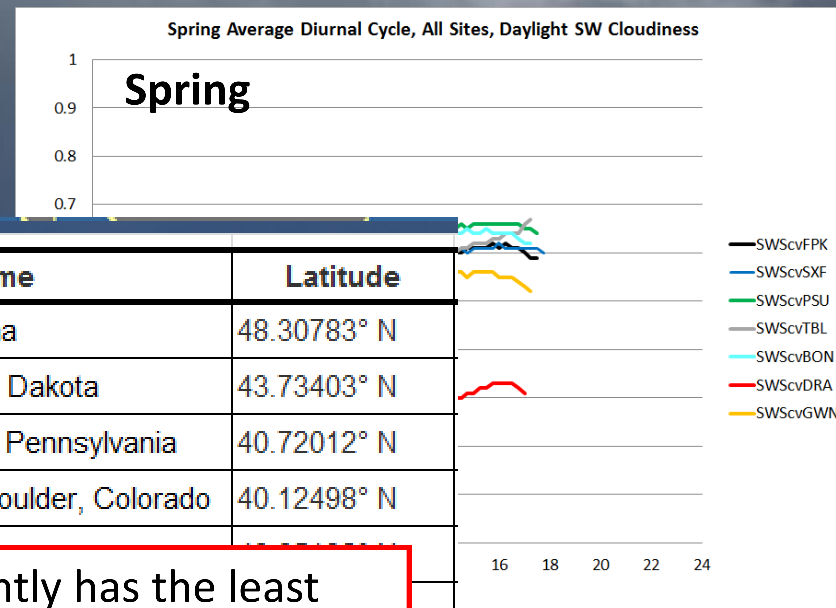
- Table Mountain afternoon cloudiness increase also exhibited a little in fall and a bit more in spring
- The cloud radiative forcing reflects this seasonal diurnal cloudiness signature

Winter
Spring
Summer
Fall



Average Seasonal Diurnal Cycles All Sites
Cloud Amount





N

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SXF	Sioux Falls, South Dakota	43.73403° N
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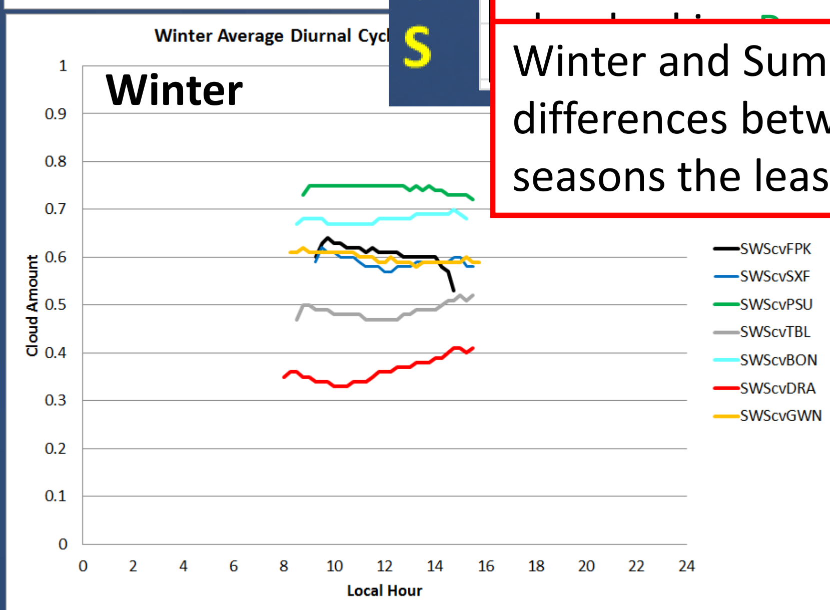
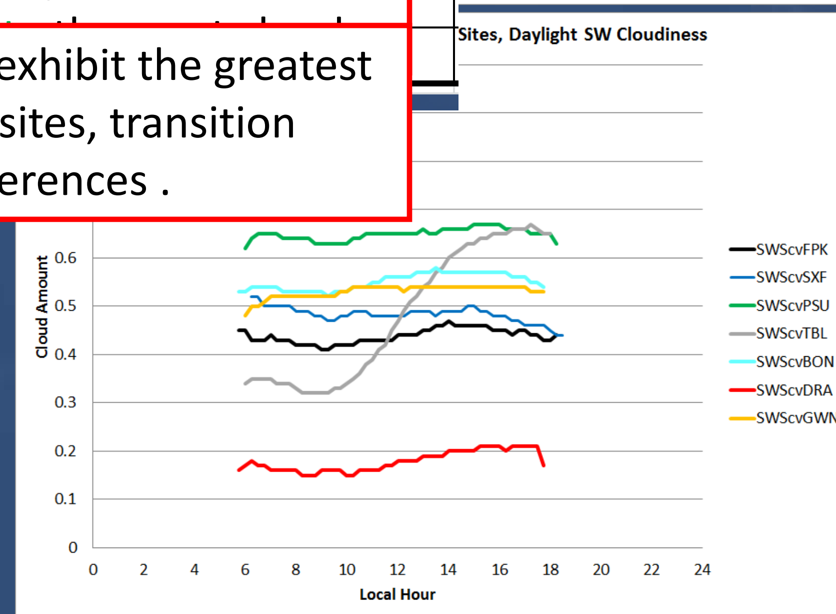
TBL	Table Mountain, Boulder, Colorado	40.12498° N

Desert Rock consistently has the least

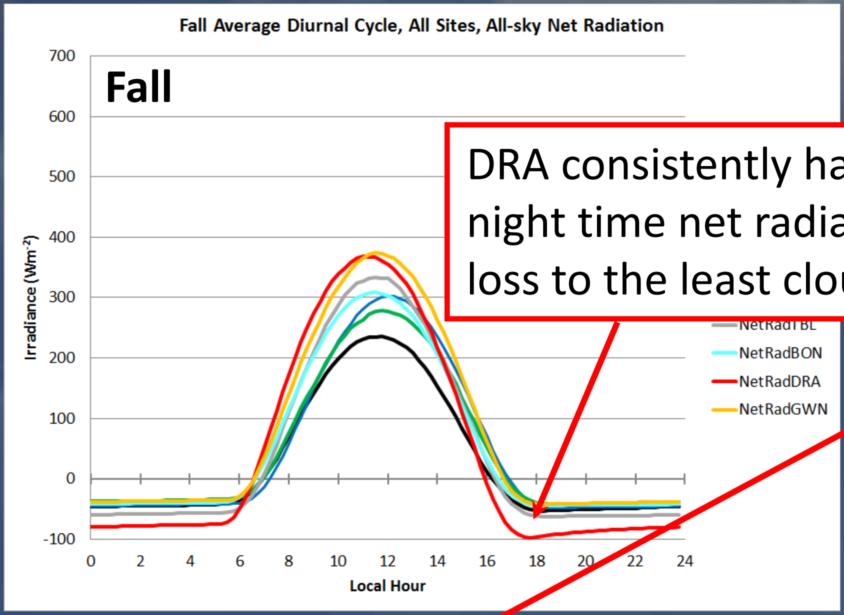
Winter and Summer exhibit the greatest differences between sites, transition seasons the least differences .

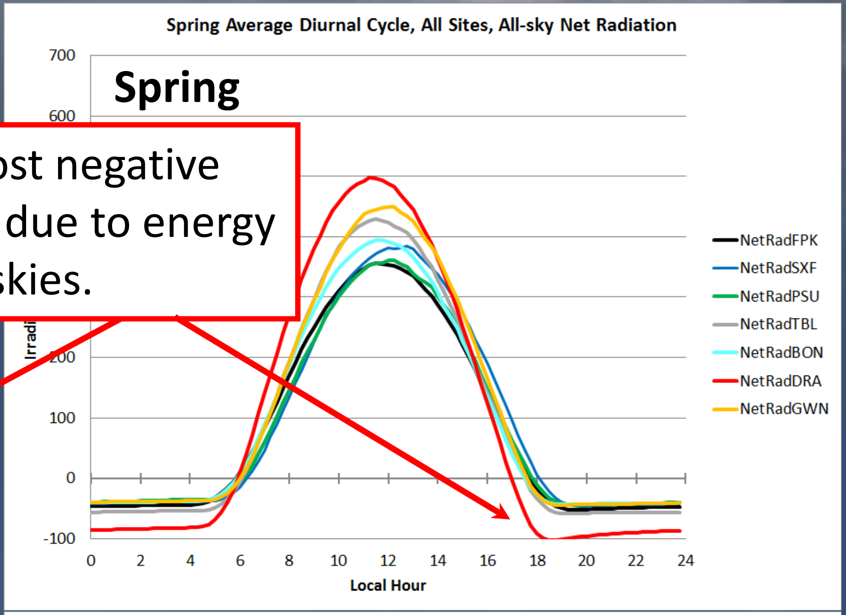


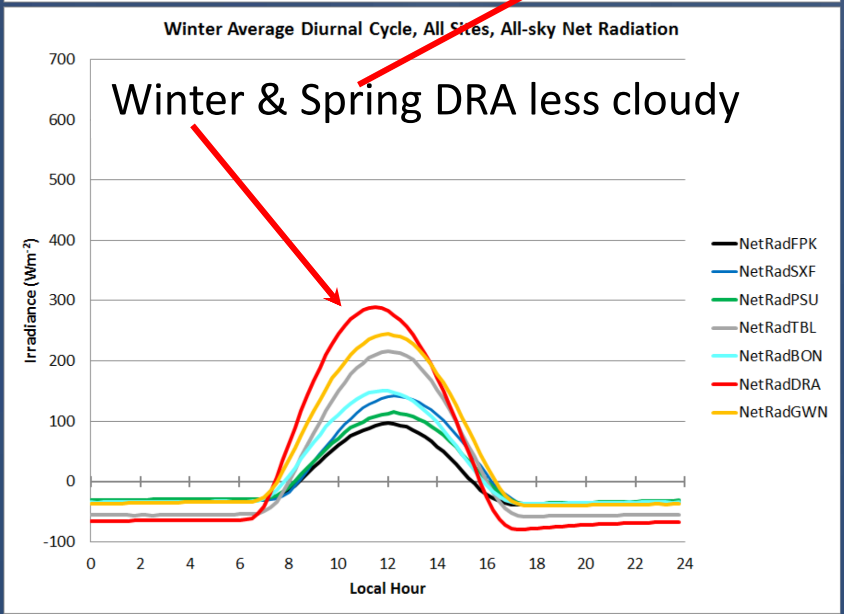


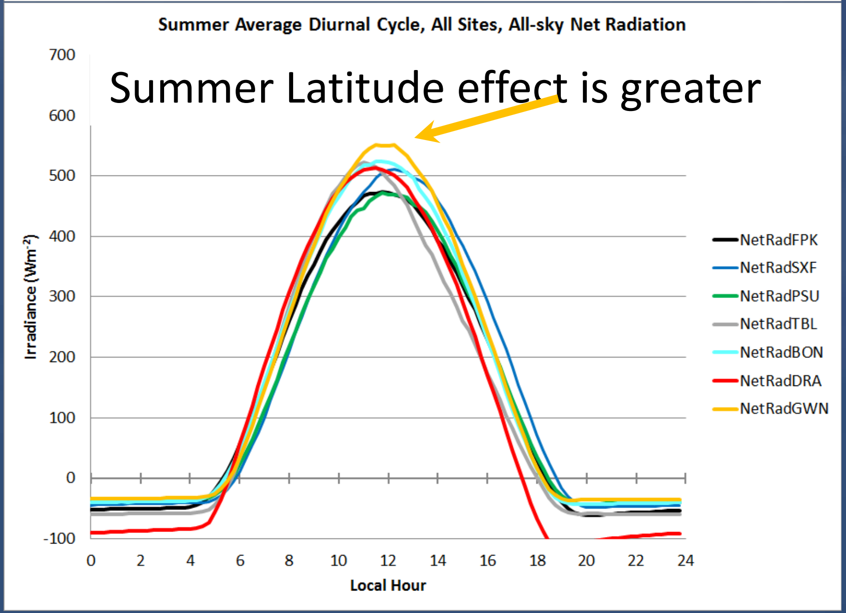
Average Seasonal Diurnal Cycles All Sites

Net Radiation Budget



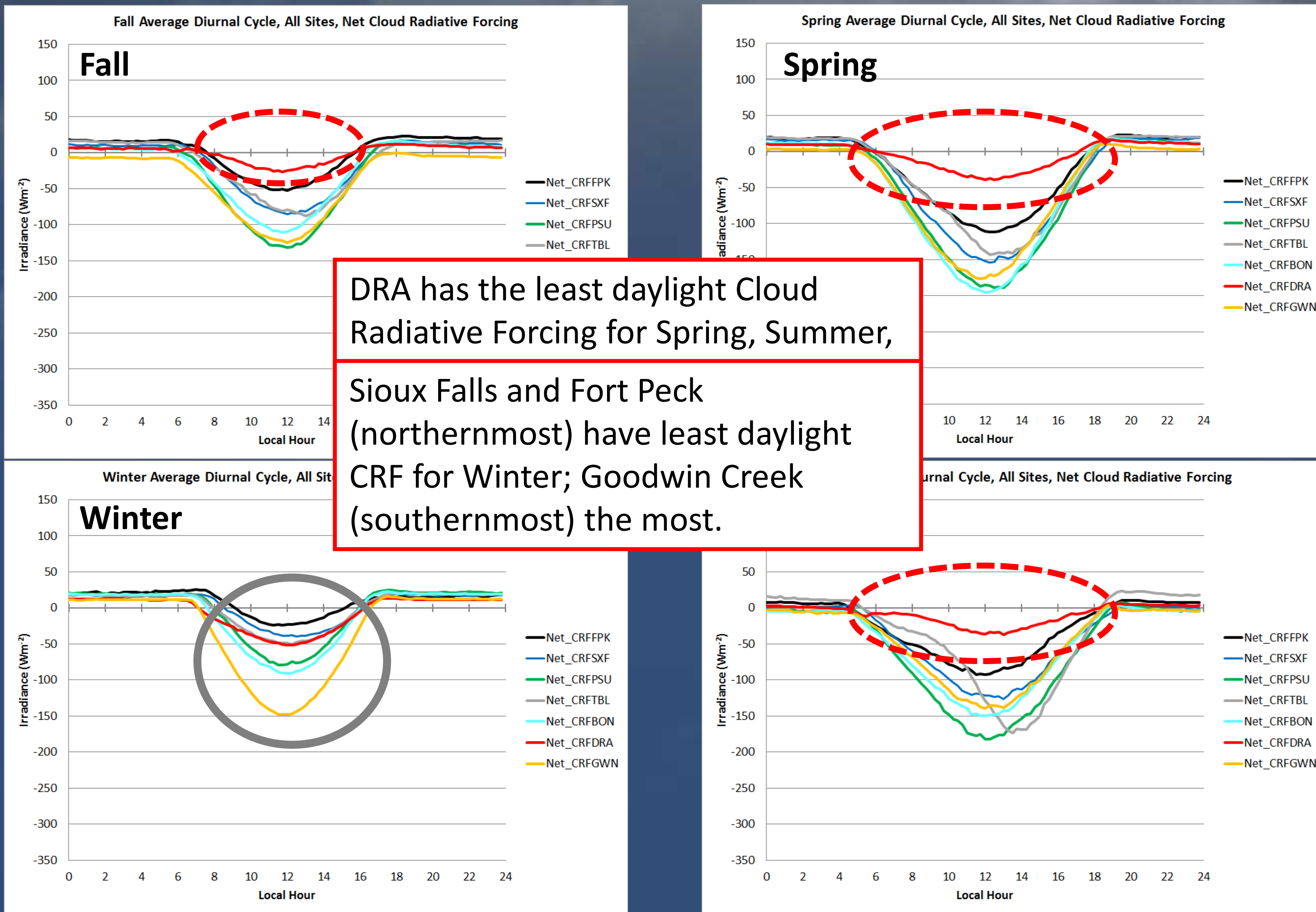






Average Seasonal Diurnal Cycles All Sites

Cloud Radiative Forcing



DRA has the least daylight Cloud Radiative Forcing for Spring, Summer,

Sioux Falls and Fort Peck (northernmost) have least daylight CRF for Winter; Goodwin Creek (southernmost) the most.

Summary

- SURFRAD sites sample the complete surface radiative energy budget for 7 major US climate regimes
- Data are processed through the RadFlux methodology to produce value added products for all sites
  - http://www.esrl.noaa.gov/gmd/grad/surfrad/index.html
- We have produced analyses of the seasonal average diurnal cycles
  - Sites exhibit differences in surface radiation budget, cloudiness, and cloud radiative effects as an interplay of various factors
- Next:
  - Investigate seasonal & diurnal trends across the years
  - GMD Baseline Observatories

Thanks for listening…

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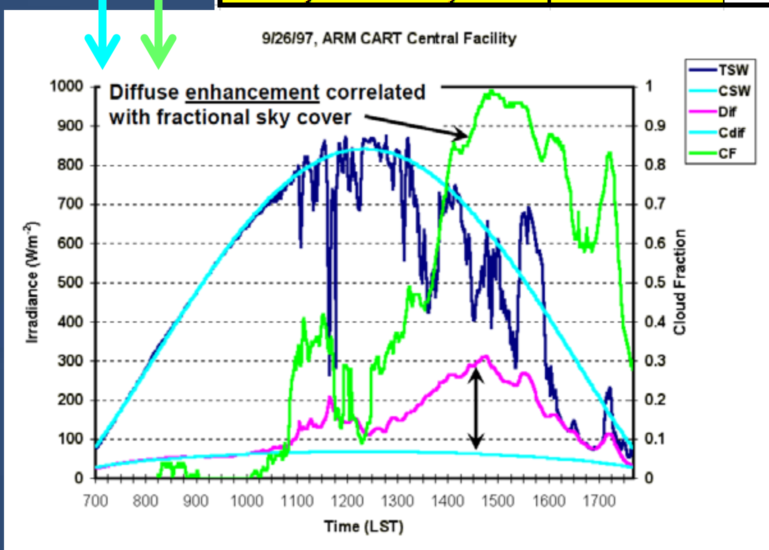
Following is extra

Radiative Flux Analysis

Parameter	Meas./Retr.	Comments
Downwelling Total SW	Measured	Unshaded Pyranometer
Clear-sky Total SW	Retrieved	Long and Ackerman, 2000, JGR
Diffuse SW	Measured	Shaded Pyranometer
Clear-sky diffuse SW	Retrieved	Long and Ackerman, 2000, JGR
Direct SW	Measured	Sun Tracking Perheliometer
Clear-sky direct SW	Retrieved	Long and Ackerman, 2000, JGR
Upwelling SW	Measured	Pyranometer
Clear-sky Upwelling SW	Retrieved	Long, 2005, ARM
Downwelling LW	Measured	Pyrgeometer
Clear-sky Downwelling LW	Retrieved	Long and Turner, 2008, JGR
Upwelling LW	Measured	Pyrgeometer
Clear-sky Upwelling LW	Retrieved	Long, 2005, ARM
Clear-sky periods	Retrieved	Long and Ackerman, 2000, JGR [daylight only]
LW Effective Clear-sky periods	Retrieved	Long and Turner, 2008, JGR [24-hour, may be high clouds present that do not affect LW]
Air Temperature	Measured	Temperature sensor
Relative Humidity	Measured	Humidity sensor
Total Sky Cover	Retrieved	Long et al., 2006, JGR [daylight only]
LW Effective Sky Cover	Retrieved	Long and Turner, 2008, JGR; Durr and Philipona, 2004, JGR [low/mid cloud only]
Cloud Vis optical depth	Retrieved	Barnard and Long, 2004, JAM; Barnard et al., 2008, TOASJ [Skycover>90% only]
Cloud SW transmissivity	Retrieved	Long and Ackerman, 2000, JGR [daylight only]
Sky brightness temperature	Retrieved	Long, 2004, ARM
Cloud radiating temperature	Retrieved	Long, 2004, ARM [LW Scv>50% only]
Clear-sky LW emissivity	Retrieved	Marty and Philipona, 2000, GRL; Long, 2004, ARM



Estimated Clear-Sky LW