A-Train and Reanalysis Data: An Evaluation of the Arctic Energy budget

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Goal: Describe the COMPrehensive ARctic Energy budget DataSet (COMPARES) and use it for product evaluation and scientific inquiry.

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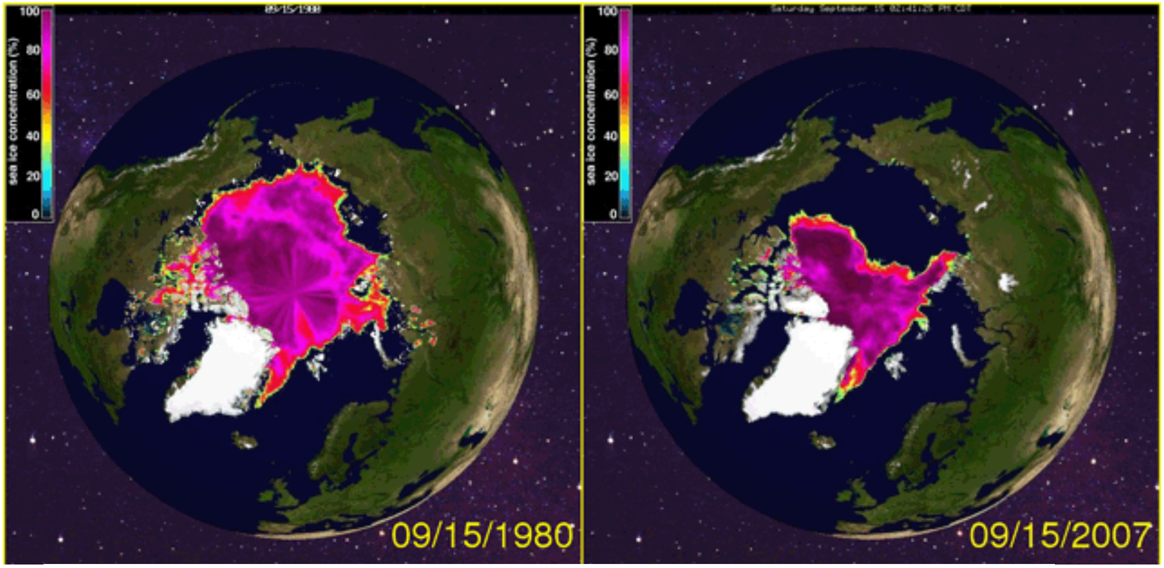
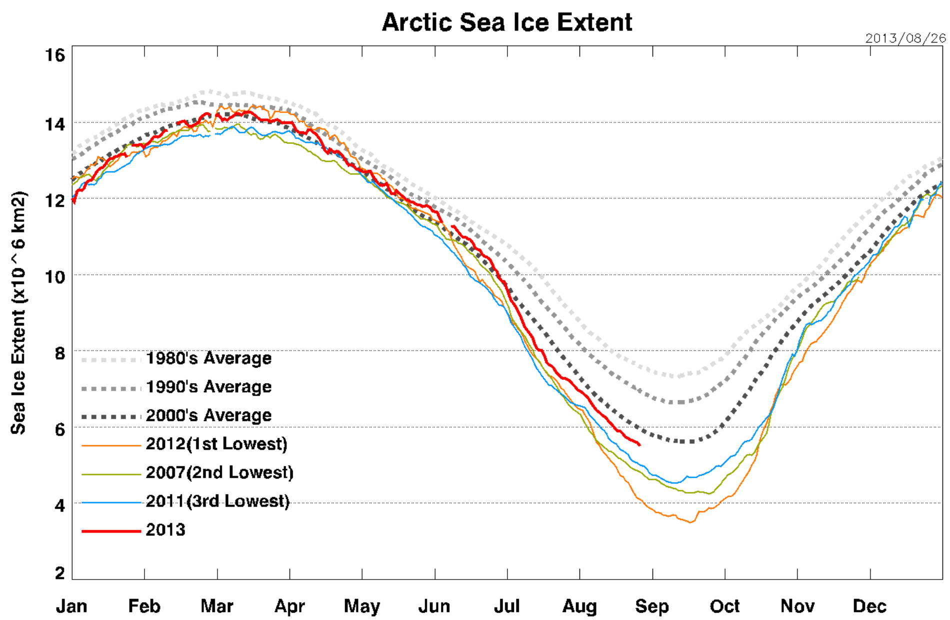
Arctic Melting



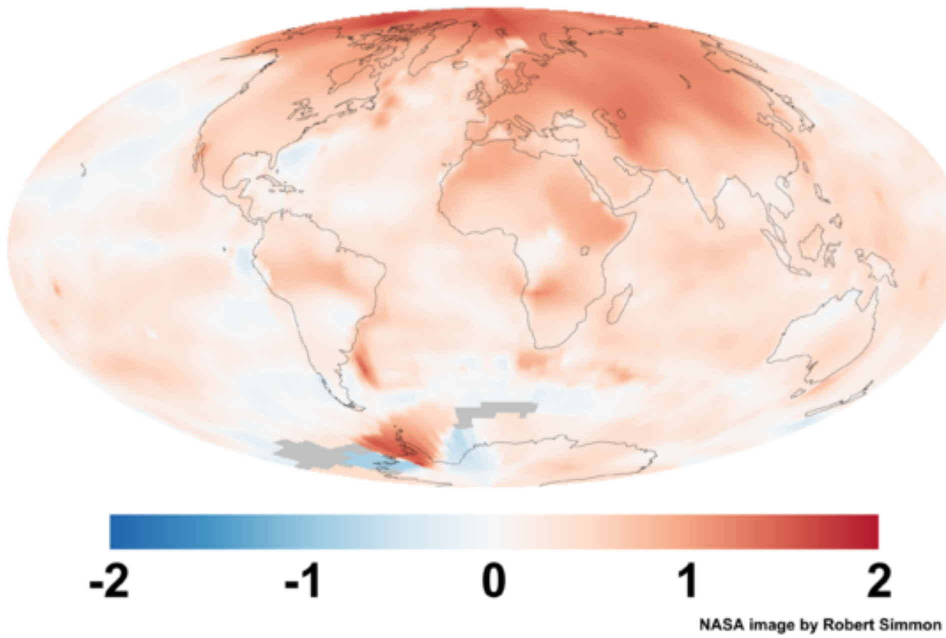


National Snow and Ice Data Center (NSIDC) Sea Ice Extent Product

- IPCC 5th Assessment report stated that it is *very likely* that the rise of CO_2 and other greenhouse gases has led to the dramatic decline of sea ice and snow extent across the Arctic.
- Sea ice extent has a substantial seasonal cycle with a minimum occurring in September.
- September 2012 had the lowest sea ice extent on record.

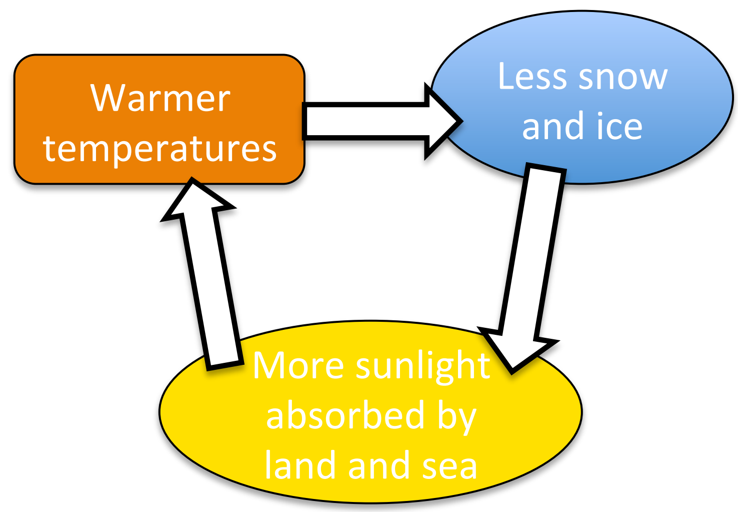
Arctic Amplification

2000 – 2009 GISS Surface Temperature Anomaly

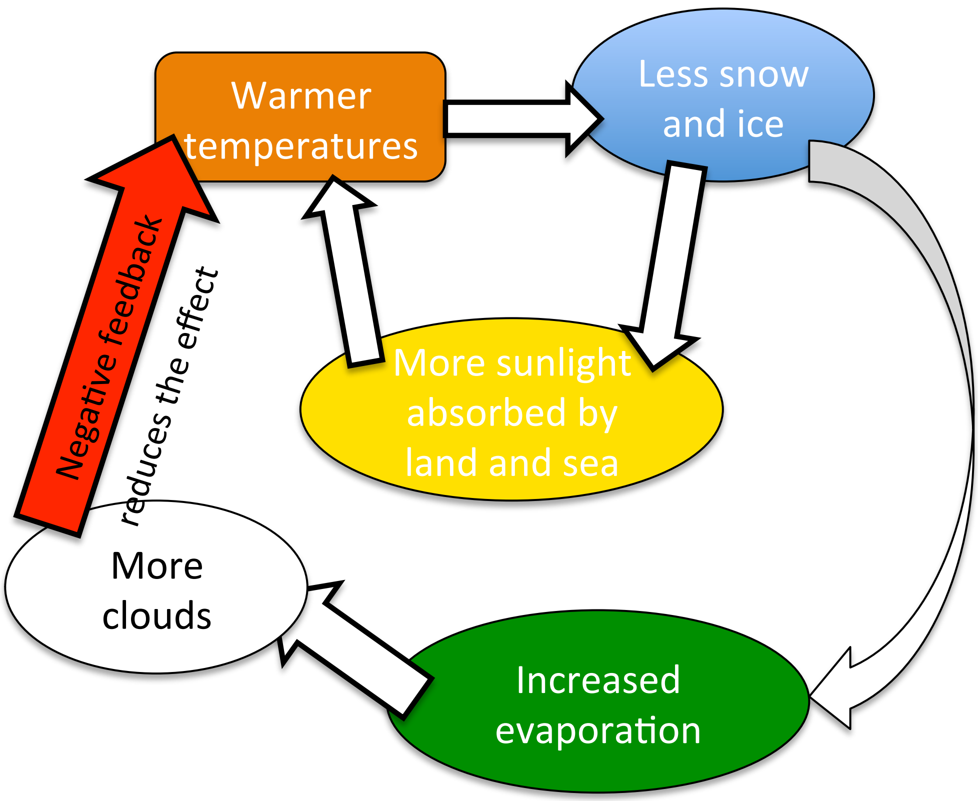


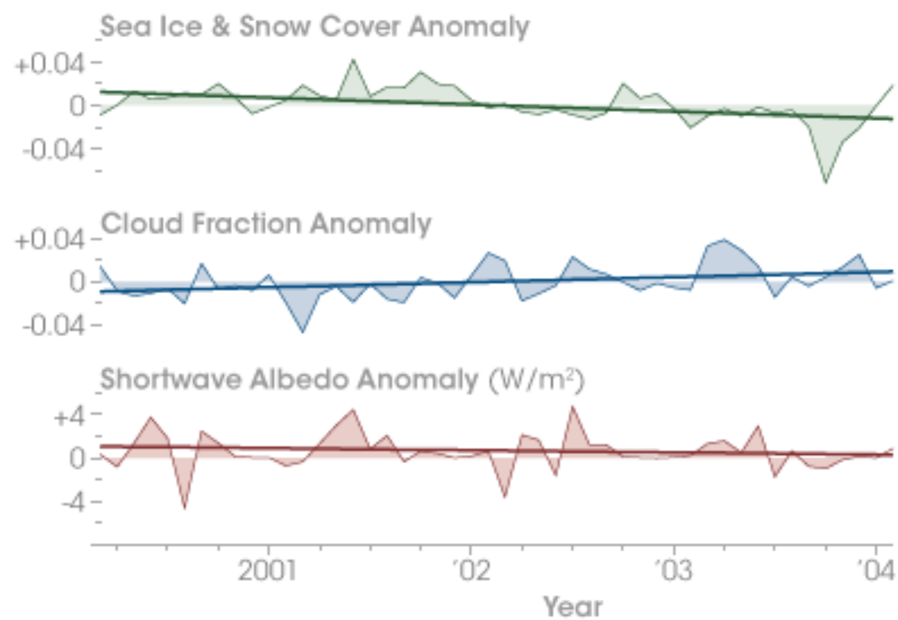
- Greater temperature increases in the Arctic compared to the earth as a whole.

- *Ice-albedo feedback:* Bright snow and sea ice melt giving way to darker ocean which absorb more solar radiation causing greater heating.



The ice-albedo feedback has a competitor: *clouds*





Source: Kato et al. 2006, GRL

- MODIS Cloud coverage increased between 2000 and 2004.
- Increase in clouds cancel out the impact of melting snow and ice on polar albedo.

Questions

1) Do these trends hold up using a longer record?
2) Are these trends identified in other datasets?

Overview of Products

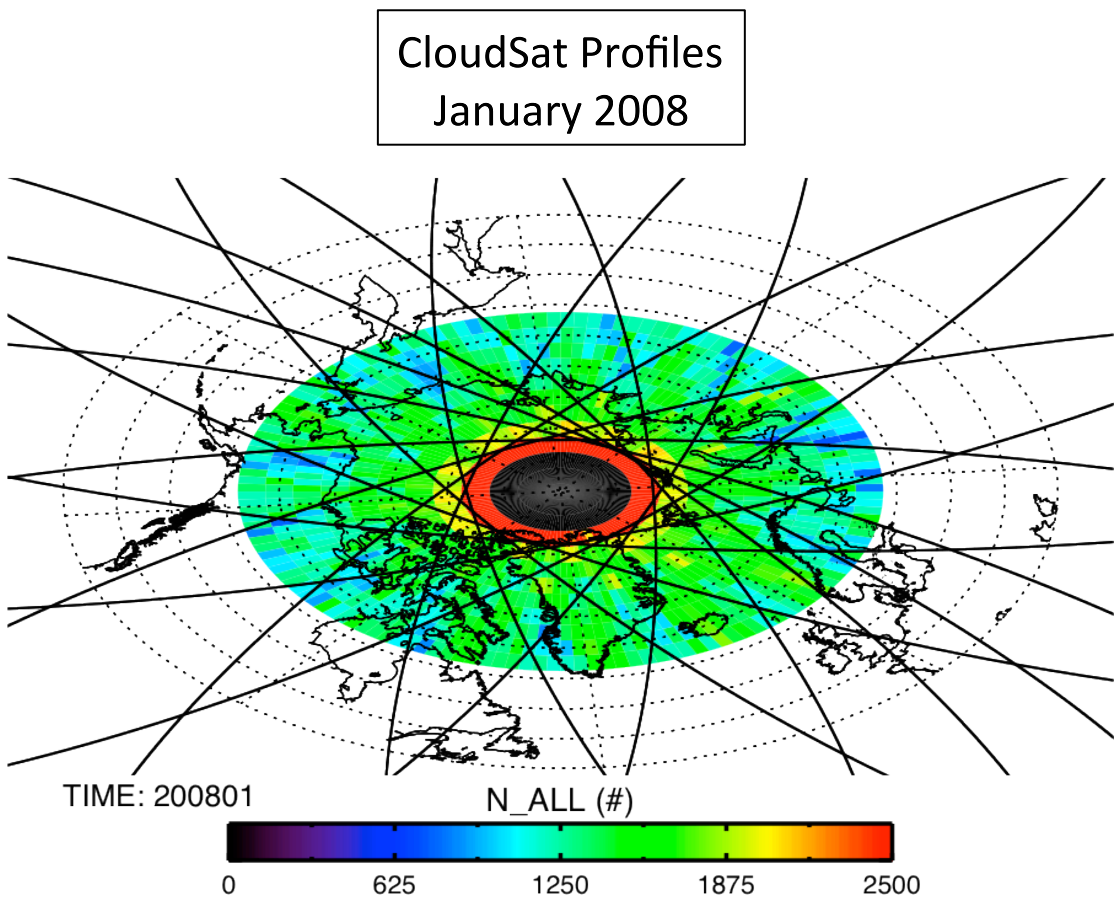
Satellite Observations

Dataset	Primary Variables	Product	Period	Resolution spatial & temporal	Note
AIRS	meteorology & cloud	AIRX3STM	2002 – 2013	14km→1°; month	high spectral resolution spectrometer
CERES	radiation	EBAF V2.7	2002 – 2013	20km→1°;month	broadband scanning radiometer
CloudSat	cloud, radiation, & precipitation	geoprof, flxhr, cldclass, rain & snowprofile	2006 – 2011	1.4km→2.5°×2.5°; instantaneous	radar & lidar (CALIPSO)
CloudSat-L3	radiation	FLXHR-LIDAR	2006 – 2011	1.4km→2.5°;month	radar & Lidar (CALIPSO)
MODIS	cloud	MYD08_M3	2002 – 2013	1km→1°×1°; month	scanning spectroradiometer
GEWEX-SRB	radiation	REL3.1 LW REL3.0 SW	1983-2008	1°; month	ISCCP cloud and GMAO input to radiation algorithm.
GRACE	water storage	CSR, JPL, GFZ	2003 – 2013	1°; month	ranging polar orbiting twin-satellites
NSIDC	snow & ice	EASE-Grid	2002 – 2013	25 km; week	passive microwave: Nimbus-7, SMMR, and SSM/I
CMAP	precipitation	standard	1979-2011	2.5°; month	GPI,OPI,SSM/I scattering, SSM/I emission and MSU
GPCP	precipitation	V2.2	1979-2010	2.5°; month	gauge + GPI,OPI,SSM/I, & MSU

Overview of Products

Dataset	Product	Period	Resolution	Note
		Reanalysis Products		
MERRA	Interim	1979-2013	1.25°; 6xdaily	
NCEP	DOE-Reanalysis 2	1979– 2013	1.25°; 6xdaily	
ECMWF	IAU 2D_rad_Nx	2002-2013	1.25°;6xdaily	
ASR	Interim	2000-2010	30 km; 3hr	WRF-VAR & PWRF
		Assimilated (satellite + reanalysis) Products		
MACC	ECMWF	2006-2013	1.25°; 6xdaily	For *aerosol data*
GLDAS	NOAH025_M.020	2002-2013	0.25°×0.25°;month	NOAH model + Obs [CMAP, GDAS, MODIS, & AGRMET]
		Ground Observations		
ARM	ARMBE ARSCL	1998-2011	hour	Barrow, AK
GPCC	Full V6	1901-2010	0.5°; month	network of gauges
AMVER	ship inventory	2006-2010	0.25°; day	ship vessel density

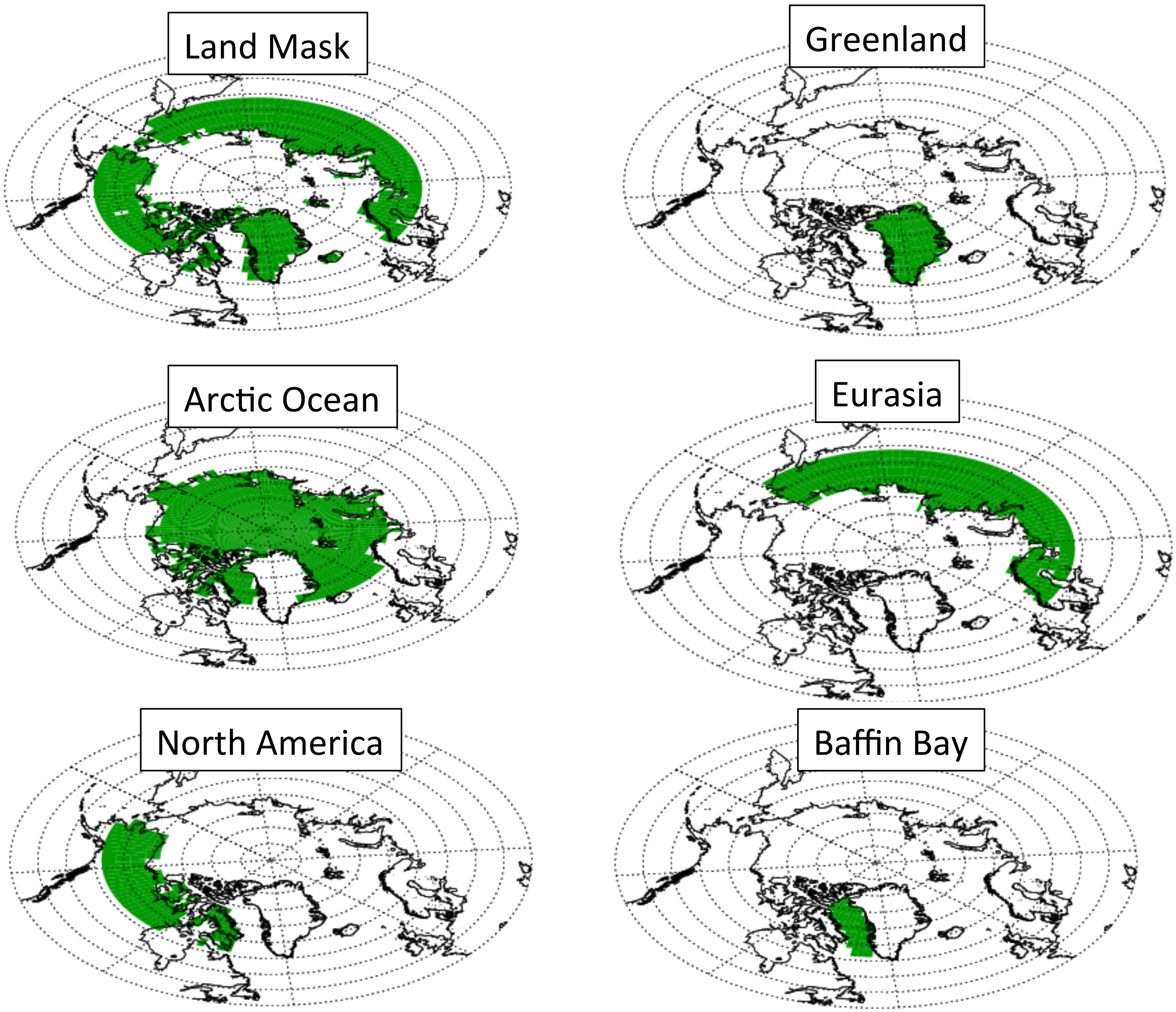
Geolocation and Grid



Orbit: CloudSat is in a sun synchronous orbit with latitude range 82degS/N. Consecutive swaths are 2752 km apart at the equator. Return cycle is every 16 days. Makes 14 – 15 orbits per day.

- Temporal Resolution: Monthly average data
- Spatial Resolution: 2.5°×2.5°
- Range: 60 N to 90 N
- Each region contains a minimum of 700 CloudSat profiles.
- Boxes at higher latitudes are smaller but get more satellite passes per area.

Region Mask

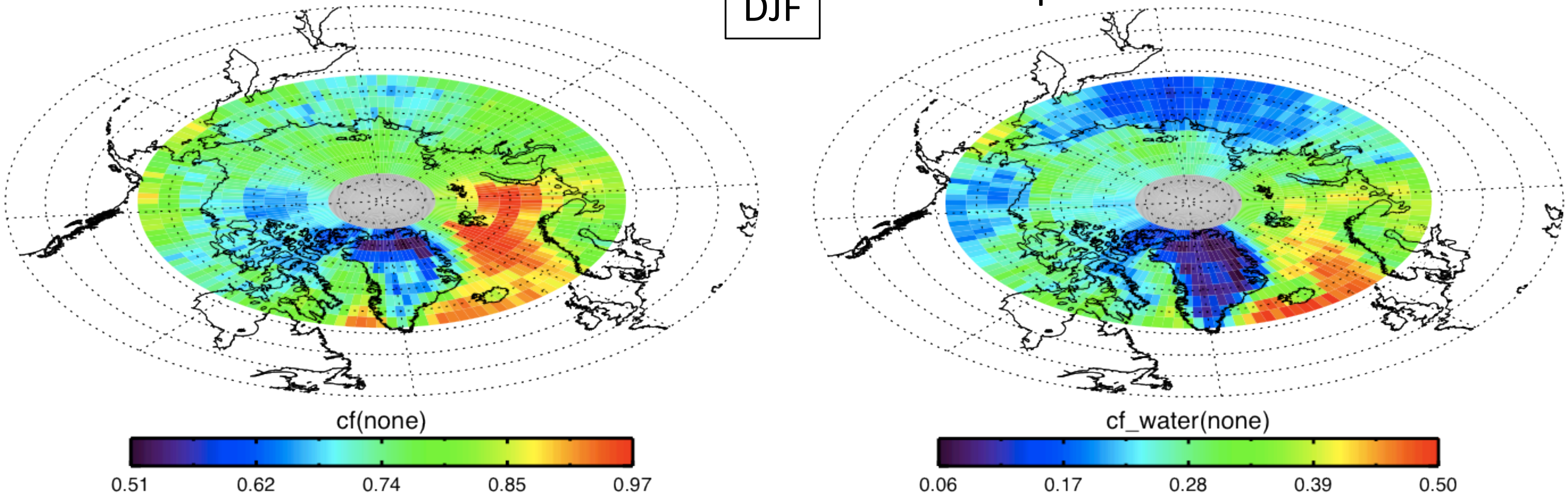


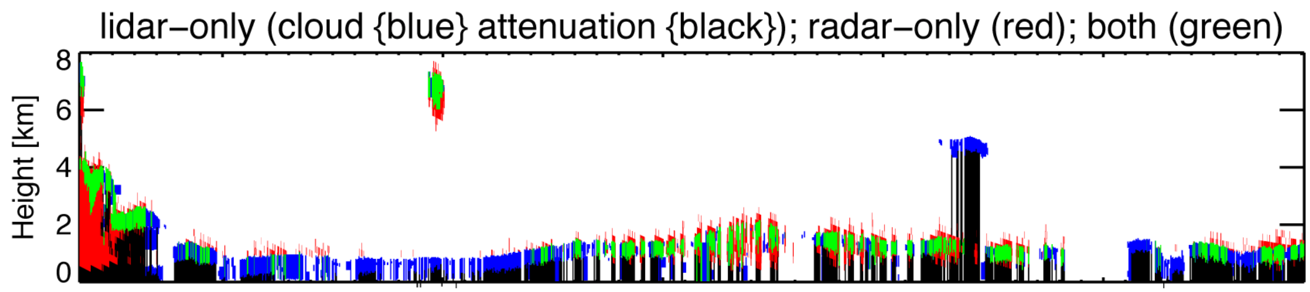
Land Mask
Greenland
Arctic Ocean
Eurasia
North America
Baffin Bay

Cloud Cover Fraction

Cloudsat/CALIPSO: 2B-Geoprof-Lidar

total cloud fraction | DJF | liquid cloud fraction

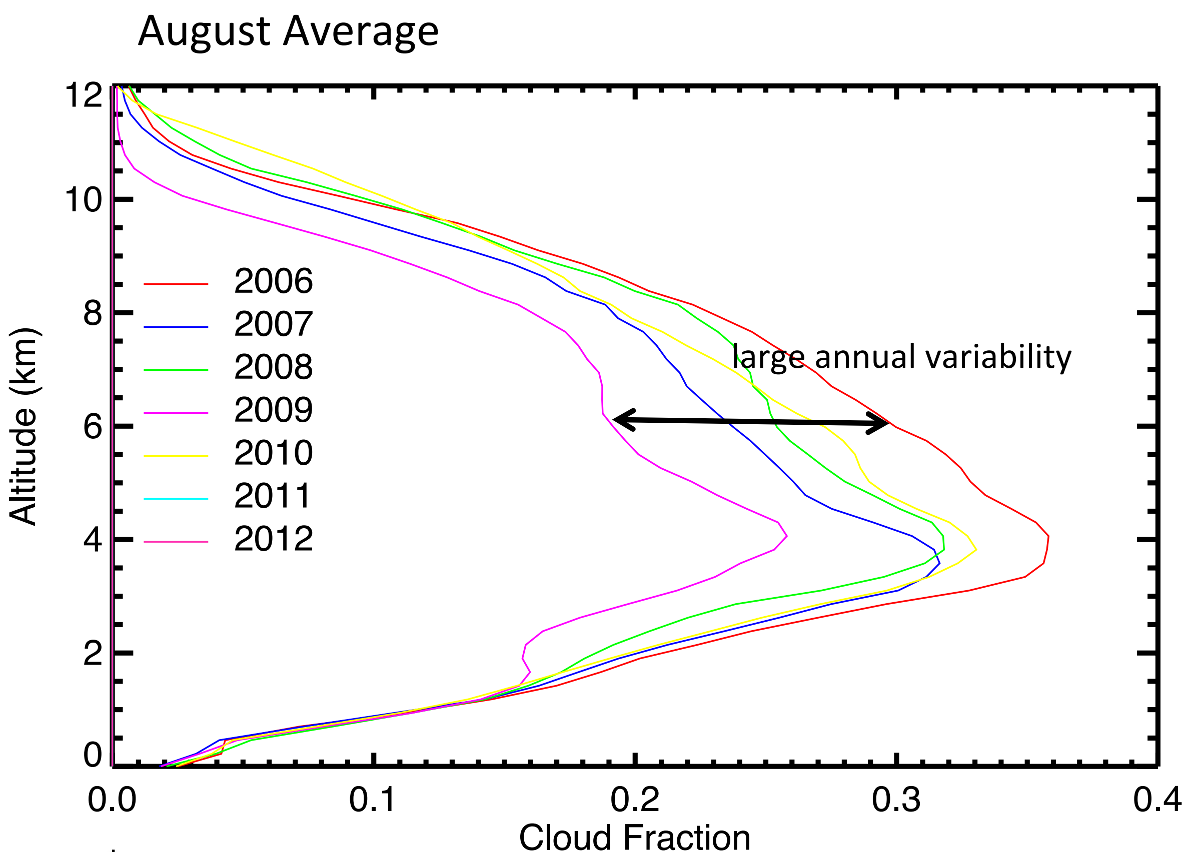




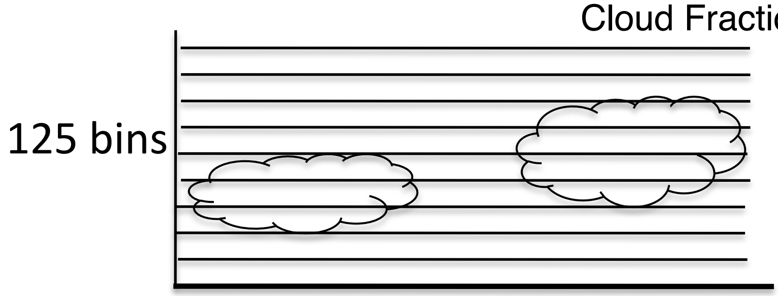
- 2B-Geoprof-Lidar merges cloud layer detection from CloudSat and CALIPSO to produce the most accurate quantitative description of hydrometeor layers in the atmosphere that is possible.

Vertical Cloud Fraction

Greenland

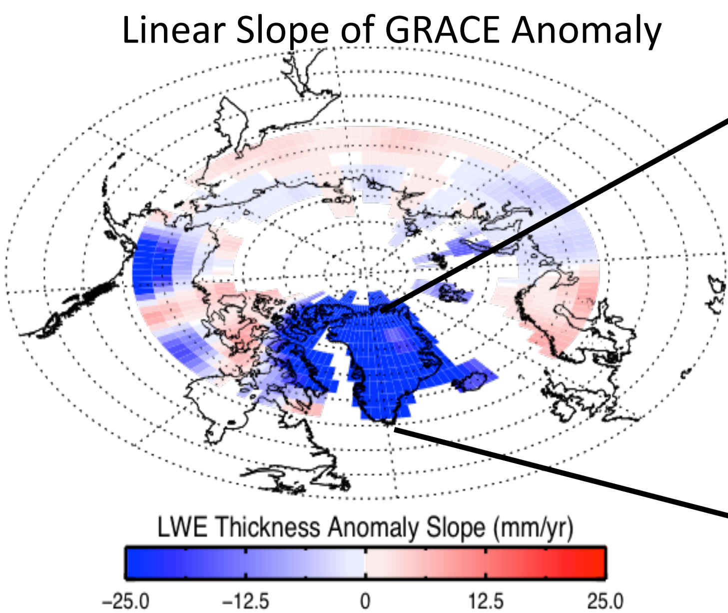


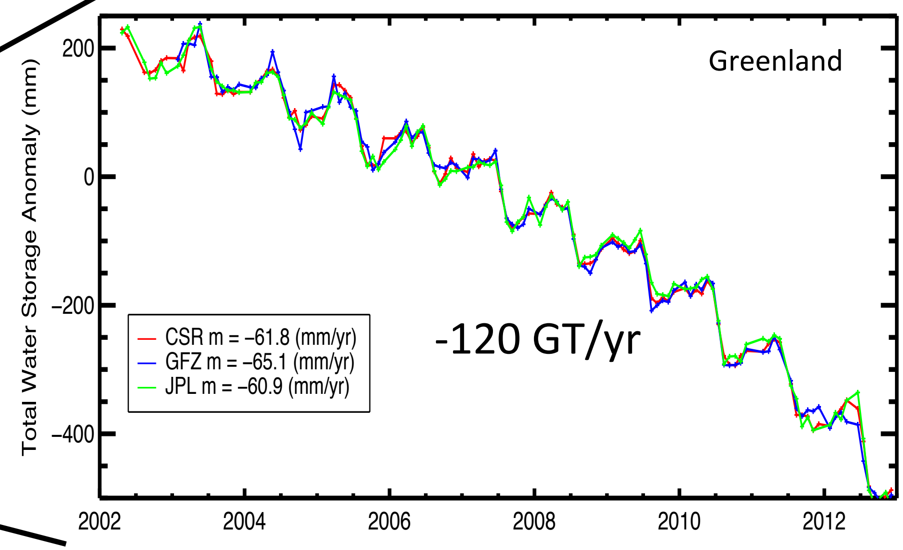
- 125 vertical levels at 240 m resolution.
- Clouds are included if they span the depth of the vertical bin.
- Cloud fraction was greatest in 2006. Largest variability occurs at 4 km.

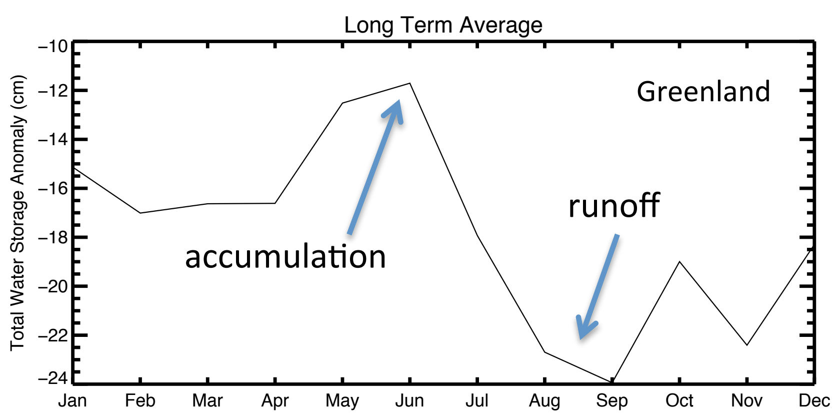


*Count number of clouds that fall into each vertical bin to obtain vertical cloud fraction.

Total Water Storage Anomaly (GRACE)



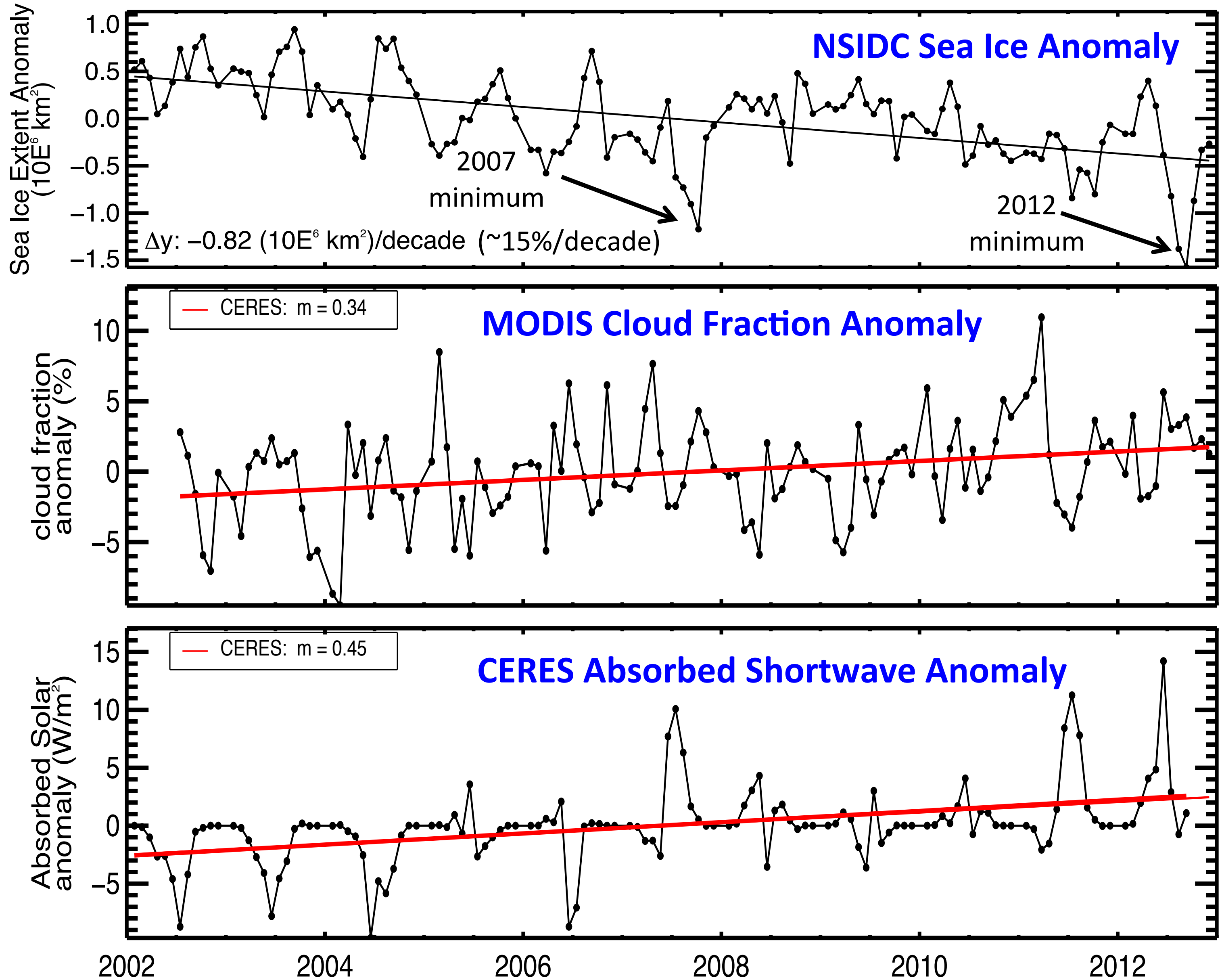




Products: CSR.LAND University of Texas, GFZ Helmholtz Center, & JPL Pasadena.

- 1°x1° averaged monthly
- Total water storage can only be inferred over land.
- Total water storage decreases over Greenland during the CloudSat period.

Polar Region Anomaly (70° – 82° N)

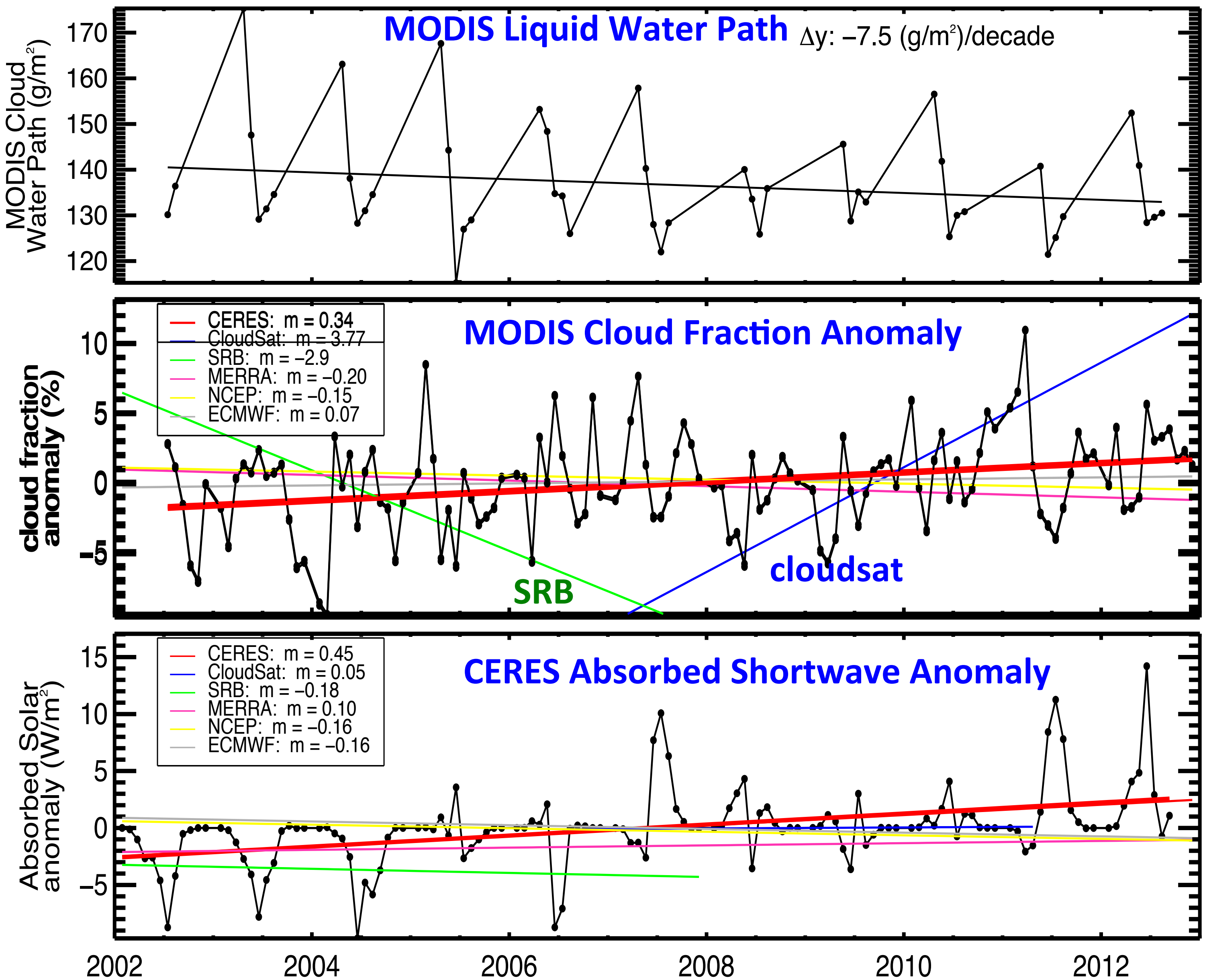


Negative trend: snow & sea-ice melt caused by rising temperature over the arctic.

Positive trend: more clouds tend to occur as stronger evaporation rates over more open water become available as sea-ice melts (Wang and Key, 2005).

Warming trend: despite increase in cloudiness, less sea-ice is likely having the dominant effect on the top of atmosphere shortwave albedo anomaly.

Polar Anomalies: Comparison with Reanalysis



Cloud thinning: Mean cloud water paths are decreasing.
→ Weaker shortwave cloud radiative effect.

Inconsistent trends: MODIS, CloudSat, & ECMWF show a positive trend while SRB, MERRA, and NCEP show a negative trend. (SRB may be prone to substantial biases caused by snow/ice and steep viewing angles).

Next question: How well do these products compare with ARM surface observations?

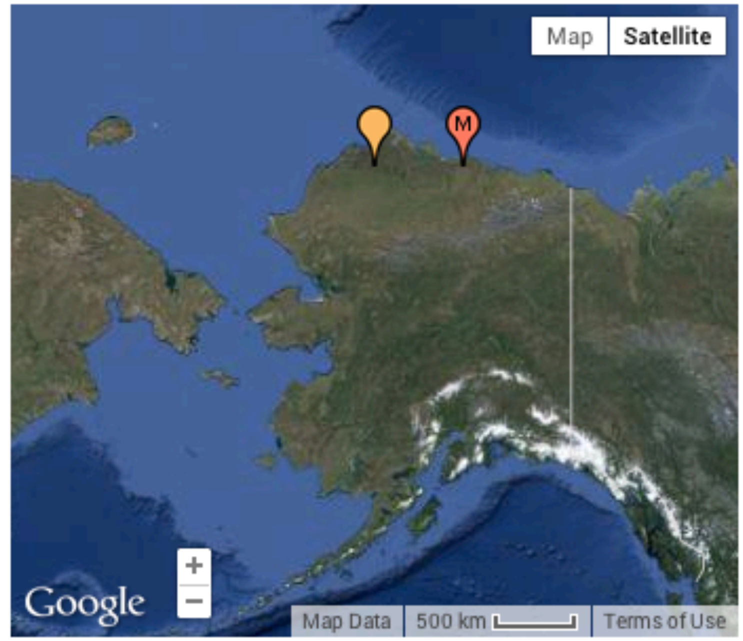
ARM

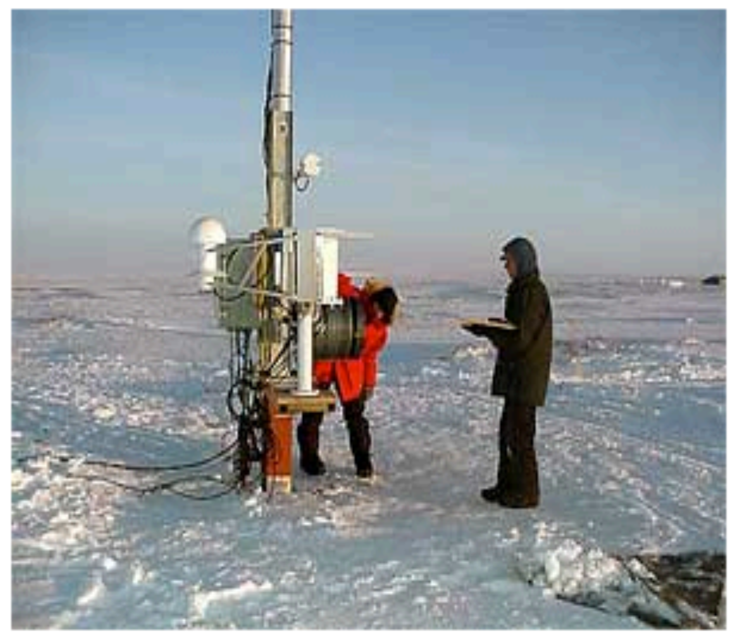
North Slope of Alaska
Barrow: 71° 19’ 23.73” N, 156° 36’ 56.7” W

- BOA Radiative fluxes
  - ARM Best Estimate data products (ARMBE)
  - Pyranometer (shortwave)
  - Pyrgeometer (longwave)

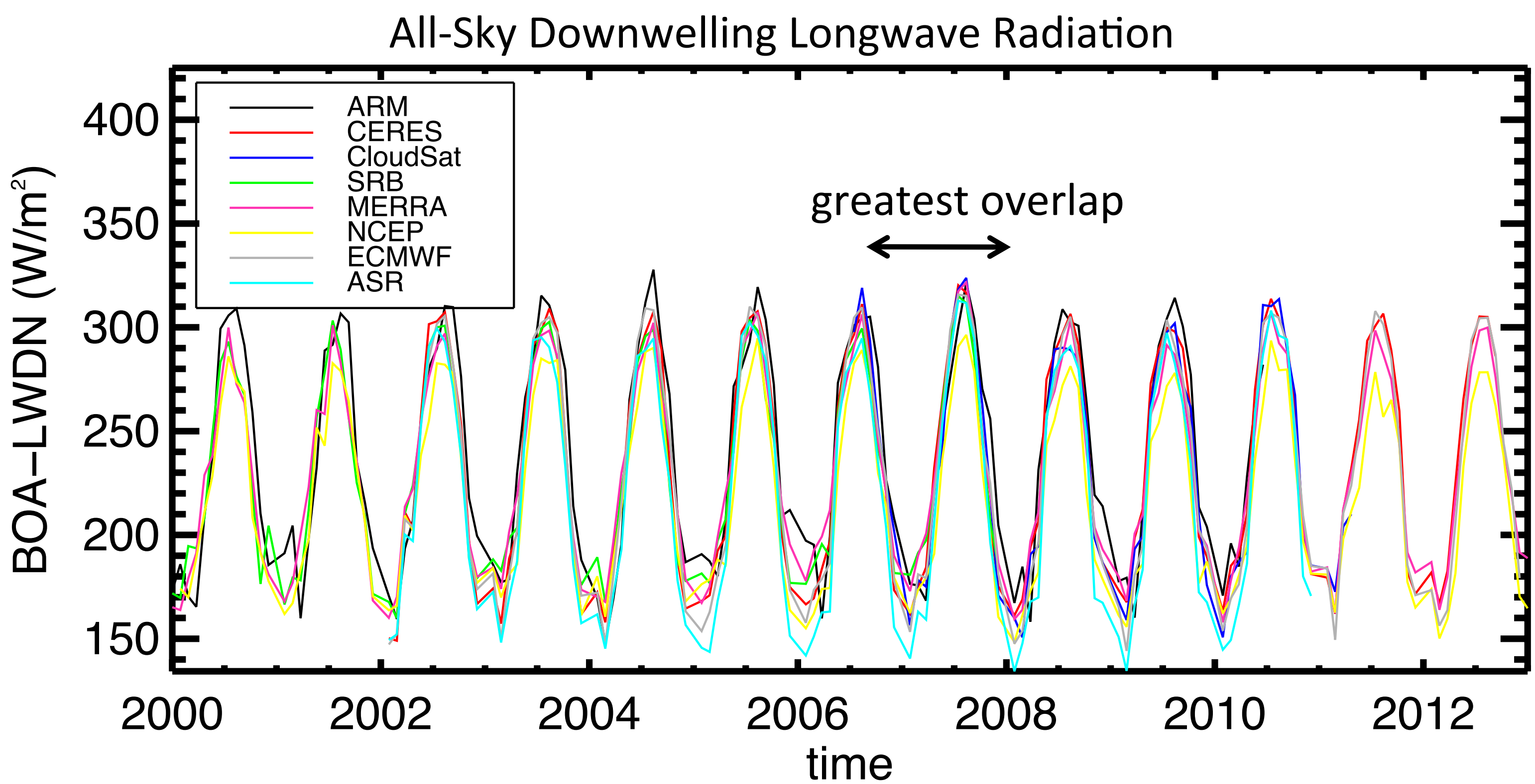
- Cloud properties
  - Actively Remoteley-Sensed Cloud Locations (ARSCL)
  - Ceilometer
  - micropulse lidar
  - cloud radar (35 GHz)
  - Cloud base height, precipitation, fall velocity, reflectivity.

- Meteorology
  - Radiosondes
  - ARM standard meteorological instrumentation at surface.





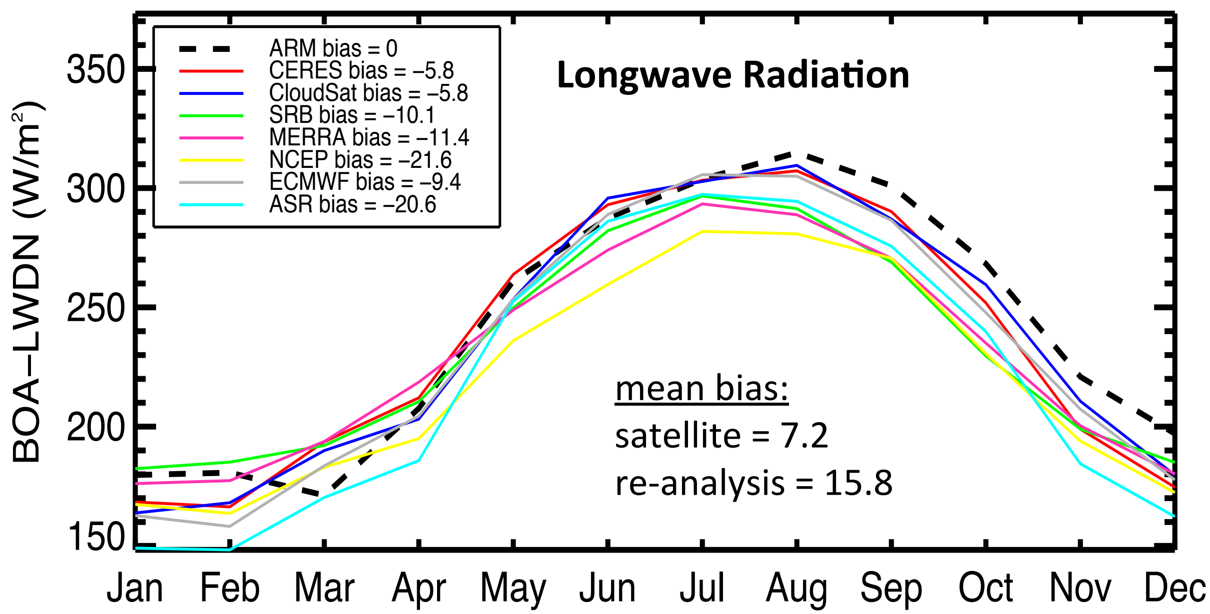
ARM Comparisons

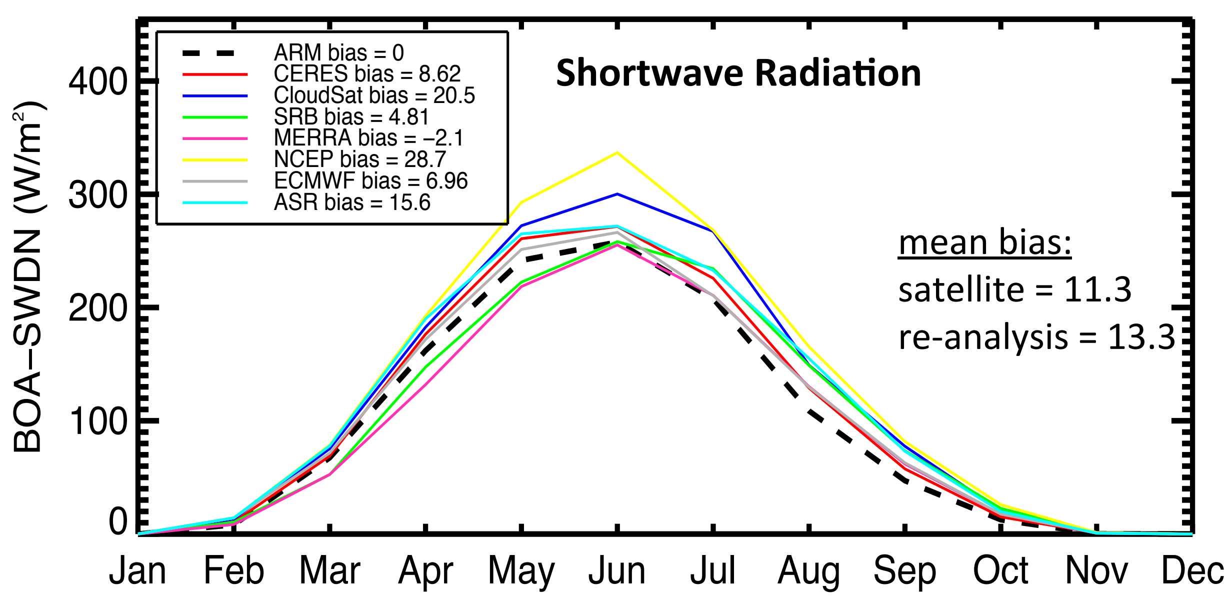


Greatest overlap of data occurs between 2007 – 2010.

Largest variation in surface downwelling longwave radiation occurs during winter.

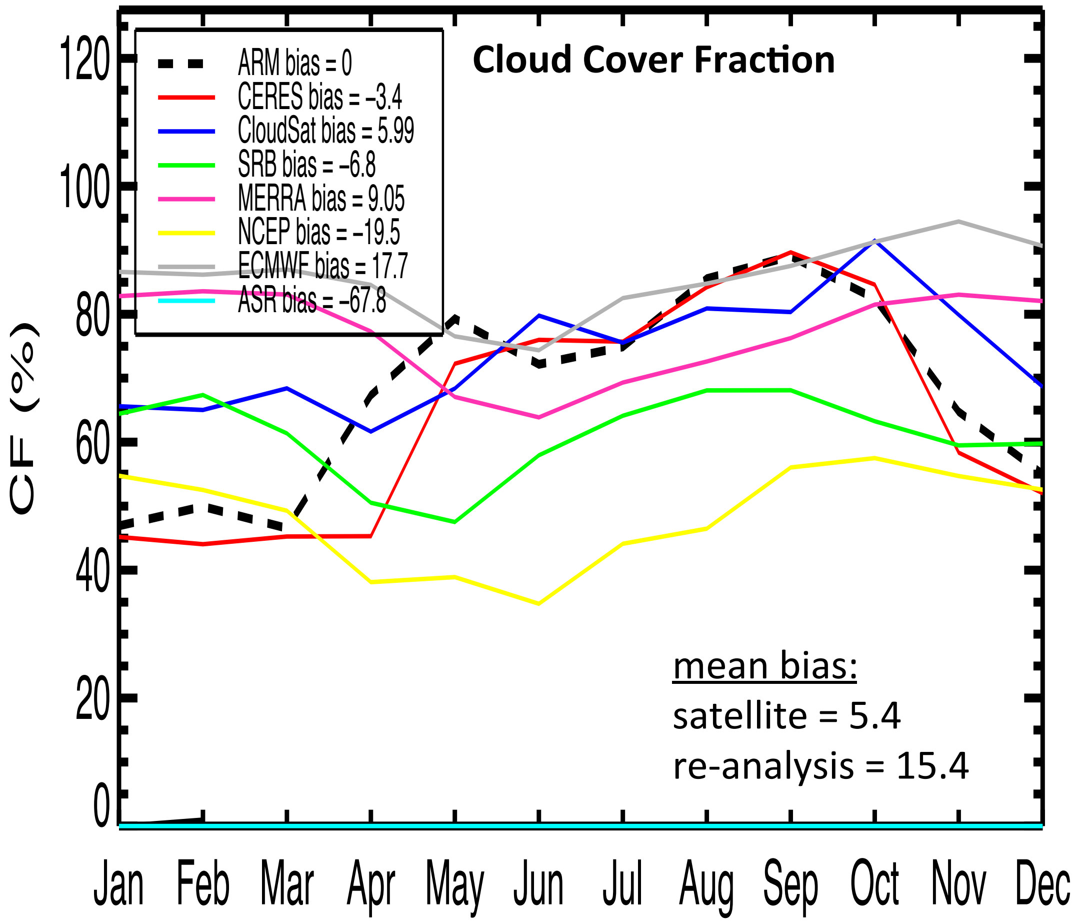
ARM Comparison





- Longwave bias is two times larger using *reanalysis* data.
- Shortwave bias is large for both satellite observations and reanalysis data.
- CloudSat significantly overestimates absorbed solar radiation.
  - Cloud microphysical properties (water and particle size) and cloud thickness are the largest contributors to uncertainty [Kay and L'Ecuyer, 2013, JGR].

ARM Comparisons



- Cloud cover fraction bias is three times larger using *reanalysis* data.
- Cloud cover fraction significantly varies amongst reanalysis products.
- Best agreement amongst satellite observations in summer.
  - MODIS product incorporates optical retrievals during polar summer.
- CloudSat/CALIPSO systematically detects more clouds than MODIS.
  - Lidar is sensitive to thin clouds.

Arctic Radiation Budget

70° – 82° N

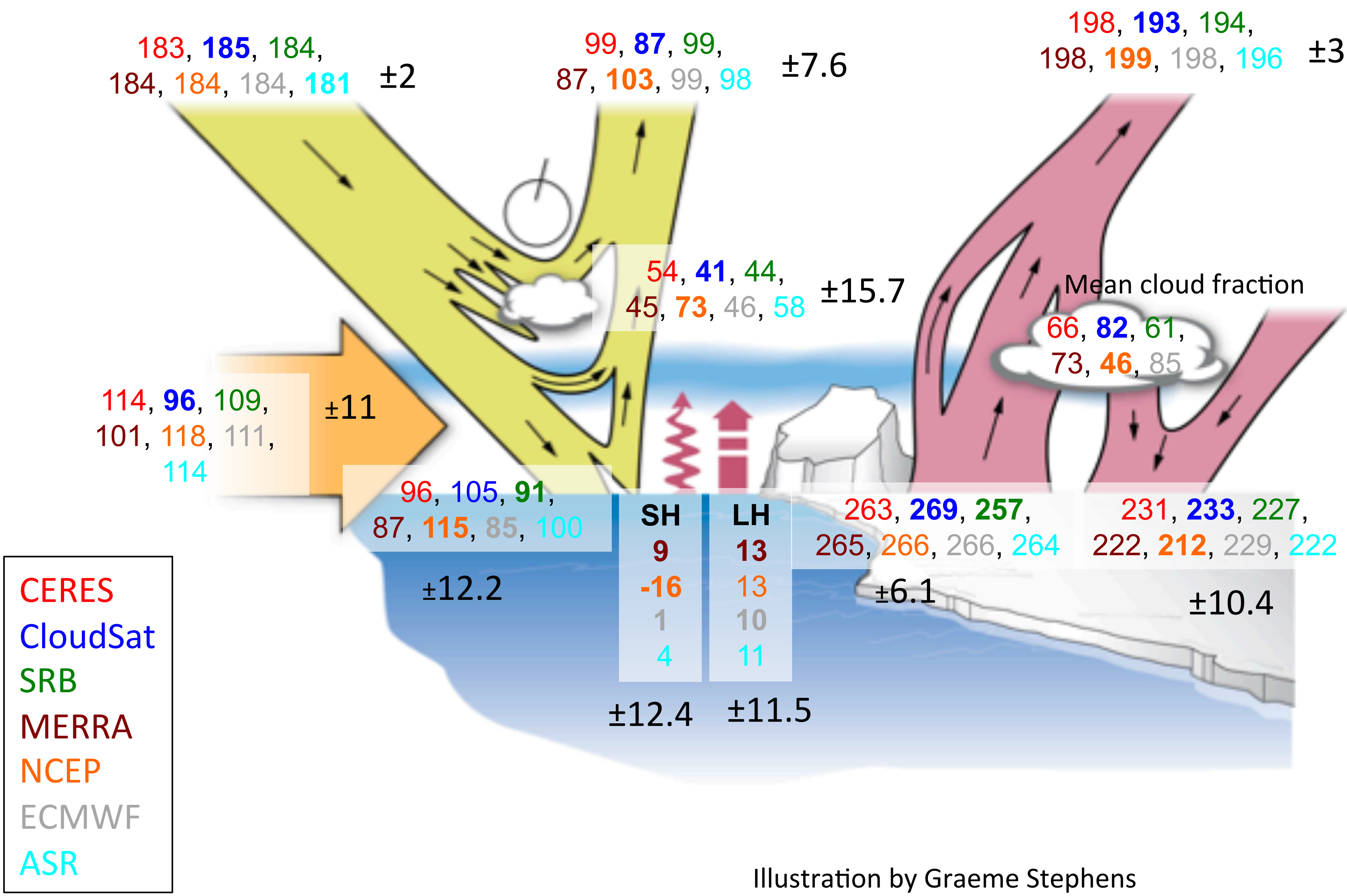


Illustration by Graeme Stephens

Conclusions

- The COMPrehensive Arcitc Energy budget dataSet (COMPARES) combines multiple datasets into one easy-to-use framework.
  - Can be used for inter-comparison, validation, and evaluation studies as well as for scientific inquiry.
- ARM Comparisons (Barrow, AK)
  - Satellite estimated surface radiation fluxes are within 7, 11 W/m^2.
  - The bias is 2 – 3 times larger using reanalysis data.
  - CloudSat derived shortwave flux are in poor agreement with CERES because the a priori value used as inputs where the lidar fails to retrieve optically thick clouds is probably too small.
- Polar cloud coverage has increased according to MODIS & CloudSat in recent years presumably due to the loss of sea ice. However, absorbed solar radiation continues to increase and the loss of sea ice dominates the change in reflected radiation
  - These relationships are generally not supported by reanalysis data.
- Dataset is currently available online via Colorado State University http://reef.atmos.colostate.edu/~chrismat/arctic_html/arctic.html