Surface radiation balance, surface layer climate and turbulent exchange in the ablation zone of Pine Island Glacier

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AWS Tower at PIG

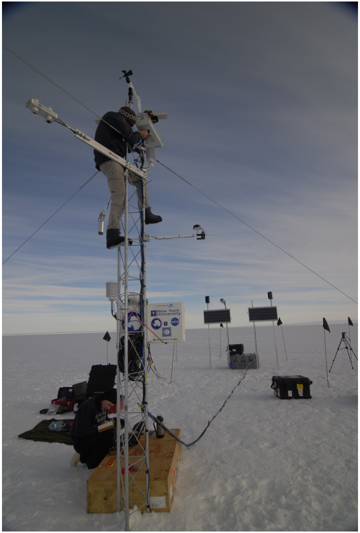
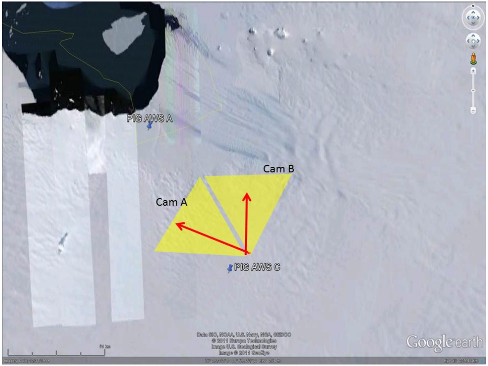


Photo Credit: Cliff Leight

Pine Island Glacier (PIG) AWS Cameras



efdl-ems.cims.nyu.edu/aws-pig

Outline

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Strengthening of the westerlies wind around Antarctica

Westerlies are stronger now than at any time in the past 1000 yrs with a prominent strengthening since the 1970s (Abram et al. 2014).

1- The ozone hole over Antarctica may have cooled the stratosphere while the world is warming faster $\Rightarrow \nabla T$ has increased the winds.

2- Atmospheric influences from the tropics have strengthened winds.

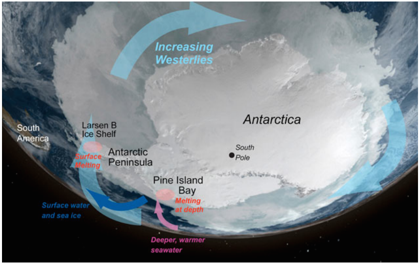


Photo Credit: NASA

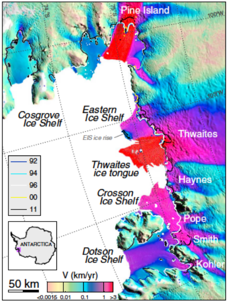


Figure 1. Velocity of the Amundsen Sea (AS) sector of West Antarctica derived using ERS-1/2 radar data in winter 1996 with a color coding on a logarithmic scale and overlaid on a Moderate Resolution Imaging Spectroradiometer mosaic of Antarctica. Interferometrically derived grounding lines of the glaciers are shown in color code for years 1992, 1994, 1996, 2000, and 2011, with glacier and ice shelf names. Note that for Pine Island and Smith/Kohler, the figure merges two independent differential interferograms to show a more complete spatial coverage of grounding lines.

Rignot et al. 2014

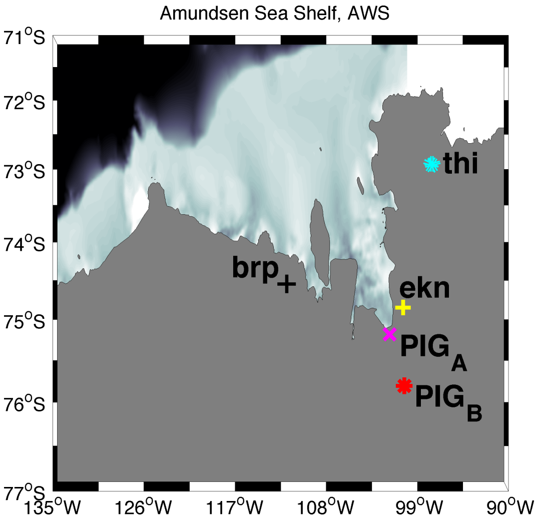
Why AWS on Pine Island Glacier (PIG)?

- PIG ice shelf has thinned nearly continuously since the 1970's.
- Winds in PIG area are related to changes in the tropical Pacific tied to El Nin$\tilde{o}$ events (Ding et al. 2011).
- Westerly winds over the Amundsen Sea can increase the flow of warm ocean water to the base of ice shelves (Thoma et al. 2008).
- The thinning of PIG may reflect changes in surface mass balance.

Climatology mean

- Predominance of westerly winds during the winter-spring, weakly easterly winds in the summer (e.g. Thoma et al. 2008).
- Use of reanalyses: ERA-Interim, NCEP ($\geq$ 3h) resolution.

AWS Locations



- PIG$_A$: 75° 11.02′ **S,** 101° 43.75′ **W**, alt. ∼ 70 m; 2008 – 2009.
- PIG$_B$: 75° 48.40′ **S,** 101° 16.30′ **W**, alt. ∼ 830 m; since 2011.

NYU PIG automatic weather station

Air pressure	CS100
Air temperature	Vaisala HMP45C
Ground temperature	
Relative humidity	Vaisala HMP35C
Wind speed and **Wind direction**	Young 05350
Snow height	Campbell SR50
Cloud fraction	
Short- and **long-wave radiation**	Kipp and Zonen CNR1
2 **cameras**	Campbell CC640
Power	Wind turbine and a solar panel

Temporal resolution

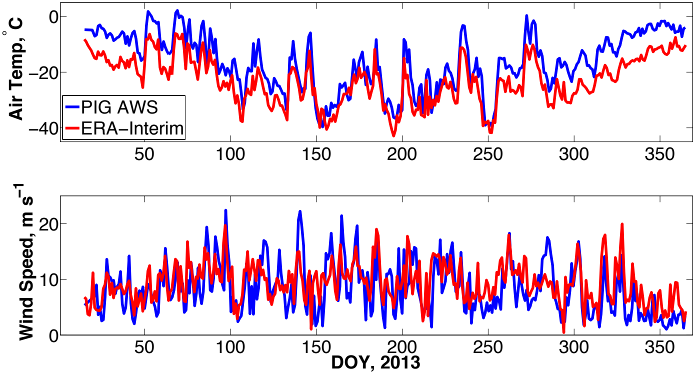
10 min, except for the cloud fraction and camera (1 h) stored on a Campbell CR3000 datalogger and transmitted to the computers of the Environmental Fluid Dynamics Lab. NYU via Iridium communications.

Outline

2 Quality of PIG AWS data

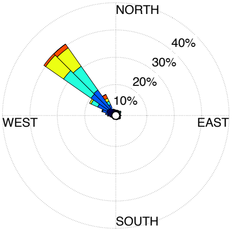
How do we figure out that the ASW data are correct

- Compare to reanalyses product (e.g. ERA-Interim) or neighboring AWS Evan Knoll.

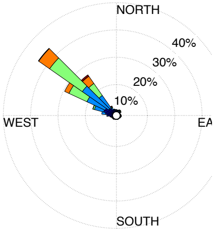


- Westerly winds in the ASE area were easterly from late 2011 to early 2012. Theses changes were related to the 2011 La Ninã event causing less warm water to flow into the ASE.

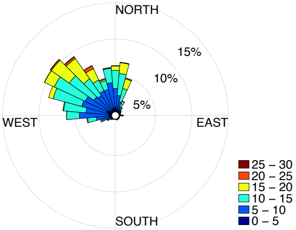
NYU PIG 2008



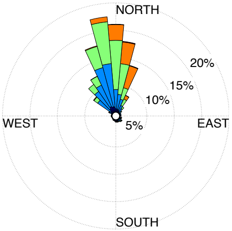
NYU PIG 2009



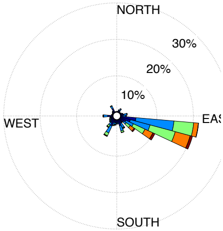
NYU PIG 2011



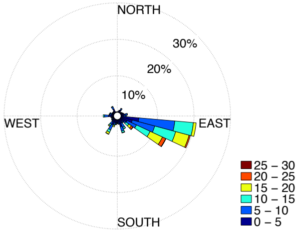
NYU PIG 2012



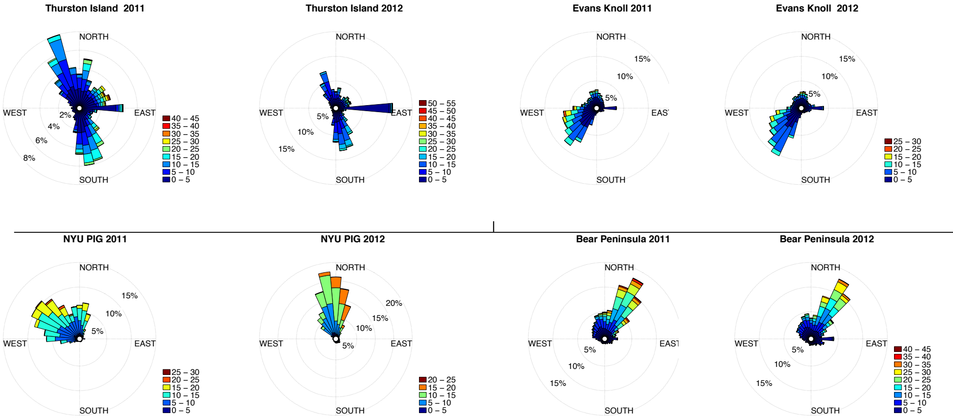
NYU PIG 2013



NYU PIG 2014



Comparison with neighboring AWS



Outline

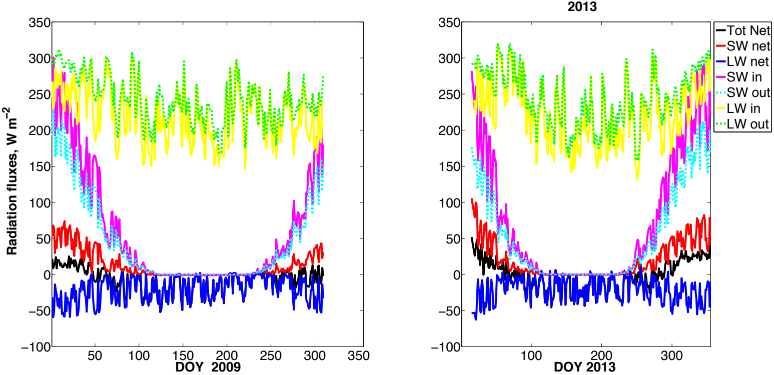
3. Surface radiation balance and turbulent heat fluxes

Energy transfer to the glacier's surface

$$\mathrm{Q_M} = \mathrm{R_{net}} + \mathrm{Q_{sen}} + \mathrm{Q_L} + \mathrm{Q_G}, \quad \mathrm{Q_{sen}} = \rho_a c_p C_H U_a (T_{air} - T_S), \tag{1}$$
$$\mathrm{Q_L} = \rho_a L_f U_a C_E (q_{air} - q_S), \quad \mathrm{R_{net}} = \mathrm{LW_{in}} - \mathrm{LW_{out}} + \mathrm{SW_{in}} - \mathrm{SW_{out}}.$$

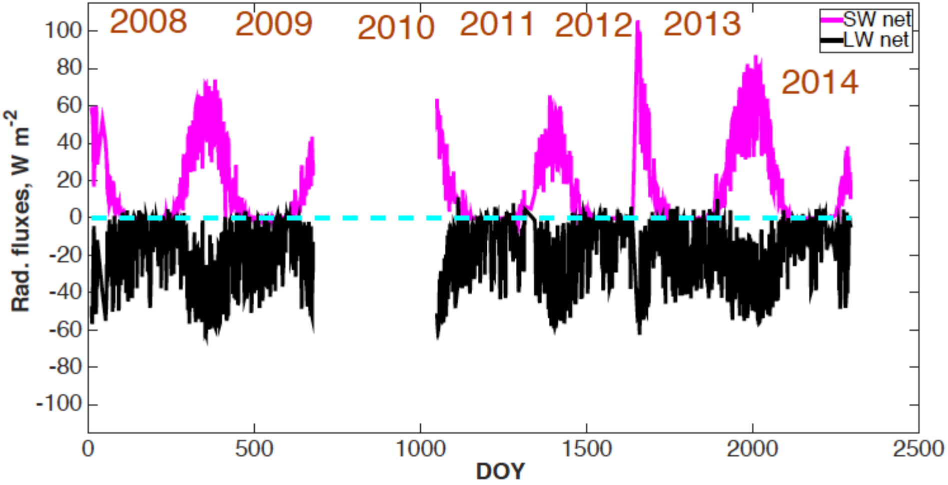
Unknowns: Glacier surface temperature T_S, the glacial heat flux Q_G

$$\rho \mathbf{c_p} \frac{\partial \mathbf{T_S}}{\partial \mathbf{t}} = \frac{\partial}{\partial \mathbf{z}}\left(\kappa_\mathbf{e} \frac{\partial \mathbf{T_S}}{\partial \mathbf{z}}\right) + \frac{\partial \mathbf{Q_a}}{\partial \mathbf{z}} - \frac{\partial}{\partial \mathbf{z}}(\mathbf{ML_f}) + \frac{\partial}{\partial \mathbf{z}}(\mathbf{FL_f}). \tag{2}$$



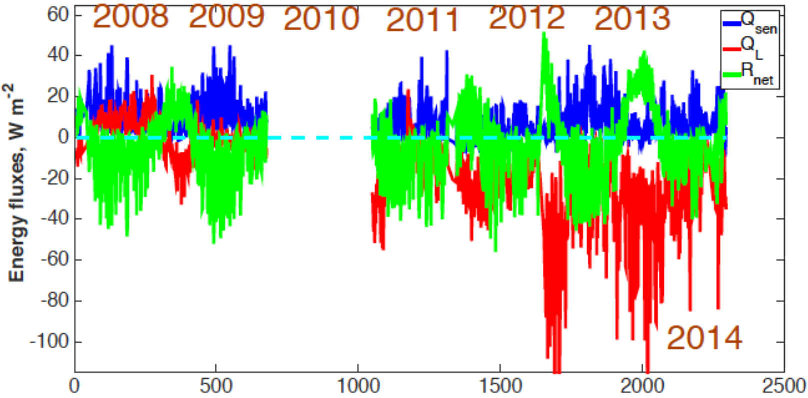
Radiation and turbulent energy

- SW_{net}: the largest energy source, LW_{net}: the largest energy sink.



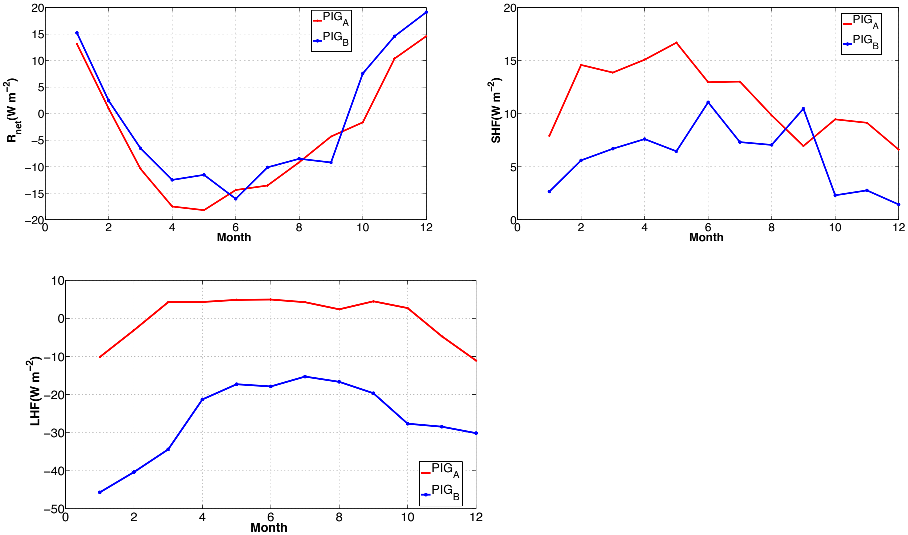
Radiation and turbulent energy (continued)

- The net radiation budget ≤ 0 during most months in Antarctica.



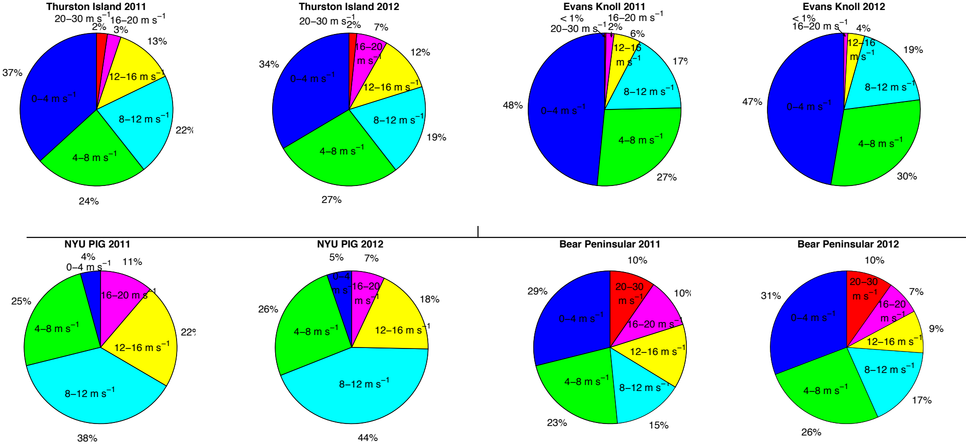
Net radiation %	2008	2009	2011	2012	2013	2014
Positive	43	35	30	25	47	40
Negative	57	65	70	75	53	60

Annual seasonal cycle based on monthly means



Outline

Pie chart of daily mean wind



- WS $< 4\,\mathrm{m\,s^{-1}}$ account for 11% at PIG_A in 2008 – 2009,
- at PIG_B: 5% in 2011 – 2012; 21% in 2013 – 2014.

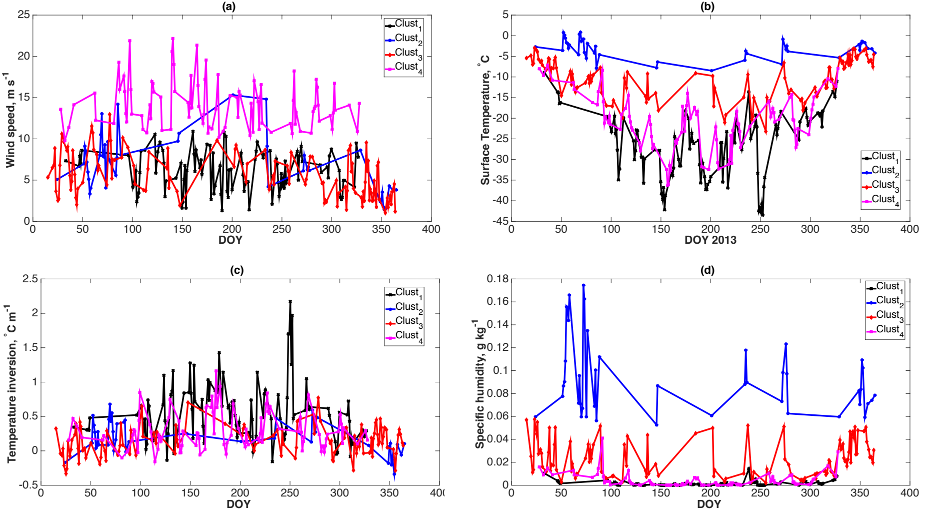
Meteorological regimes at PIG, over Amundsen Sea

- The Antarctic meteo. regimes include the katabatic flow and synoptic-scale disturbances [e.g. Neff, 1999; Bintanja, 2000].
- Surface wind regimes have been study over the
  - Ross Ice Shelf (e.g. Seefeldt et al, 2007, Cohen et al. 2013, Nigro et al. 2014),
  - Dronning Maud Land, East Antarctica (e.g. Bintanja, 2000, Gorodetskaya et al. 2013).

At PIG

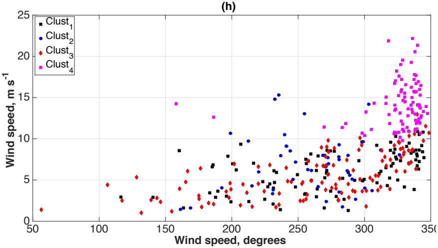
- We want to classify the AWS data in term of meteorological regimes: **cold, intermediate or warm synoptic**.
- Relate AWS data to the Amundsen sea low.
- 5 parameters: **wind speed**, **specific hum.**, $\mathbf{T_{Inv}}$, **Air pres.**, $\mathbf{LW_{down}}$, using *k*-Means Clustering Algorithm.

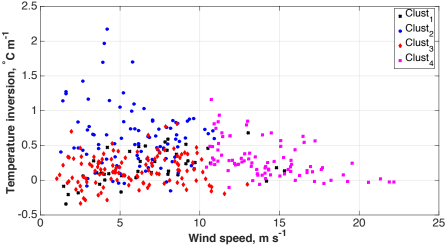
So far four clusters have been identified



Variables	$Clust_1$	$Clust_2$	$Clust_3$	$Clust_4$
Frequency, % of all days **2013**	31%	12%	33%	26%

98% of the wind at PIG AWS in (2013) was restricted to 180° to 360° quadrant.





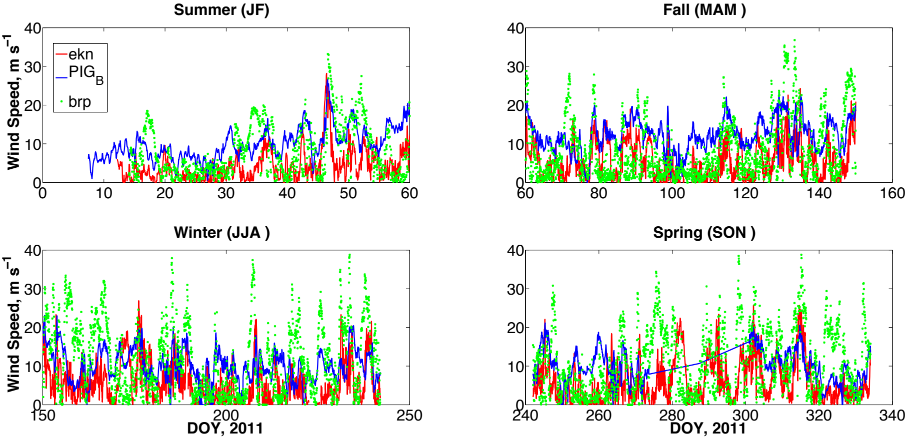
Variables	$Clust_1$	$Clust_2$	$Clust_3$	$Clust_4$
Frequency, % of all days (**2013**)	31%	12%	33%	26%
Air temperature, °C	−2.71	−26.40	−10.29	−20.78
Surface temperature, °C	−3.11	−27.61	−10.6	−21.37
Wind speed, $\mathrm{m\,s^{-1}}$	6.97	6.02	5.8205	14.26

Outline

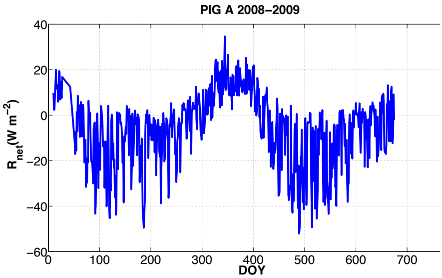
Closing Remarks

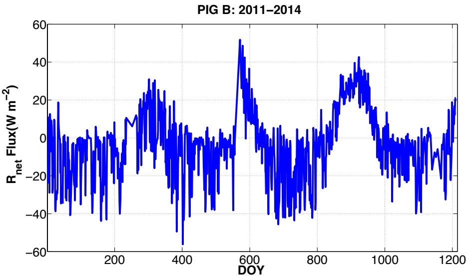
- We have presented the **first ever recorded meteorological data at PIG**. The observed data exhibit strong variability in the wind field. In 2012, the El Ninõ tropical system switched to a La Ninã, reversing the local winds in the ASE region. Our data confirm that.
- In Antarctica, a negative to zero net radiation budget prevails during most months. At PIG AWS, from 2008 – 2009, $\mathbf{R_{net}} > 0 : 43\%, 35\%$; 2011 – 2014, $\mathbf{R_{net}} > 0 : 30\%, 47\%, 40\%$.
- We applied ***k*-means cluster analysis** based of five parameters (wind speed, specific humidity, $\mathrm{T_{Inv}}$, pressure, and $\mathrm{LW_{down}}$) in order to classify daily data into meteorological regimes.
- We now have a good confidence on the AWS measurements, they will serve as input to an energy balance model that searches for the **glacier surface temperature T_S, heat flux Q_G**.

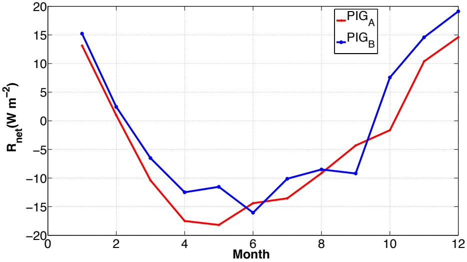
Comparison with neighboring AWS



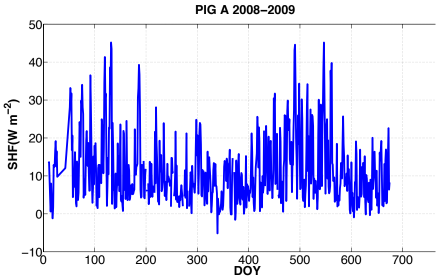
Total net radiation

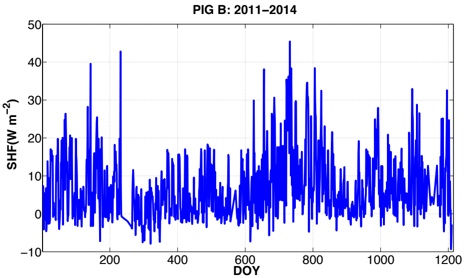


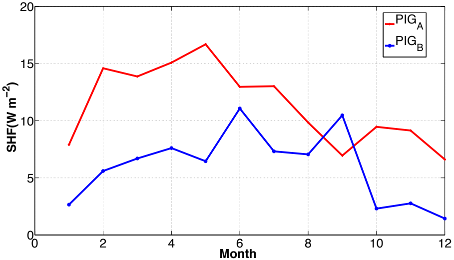




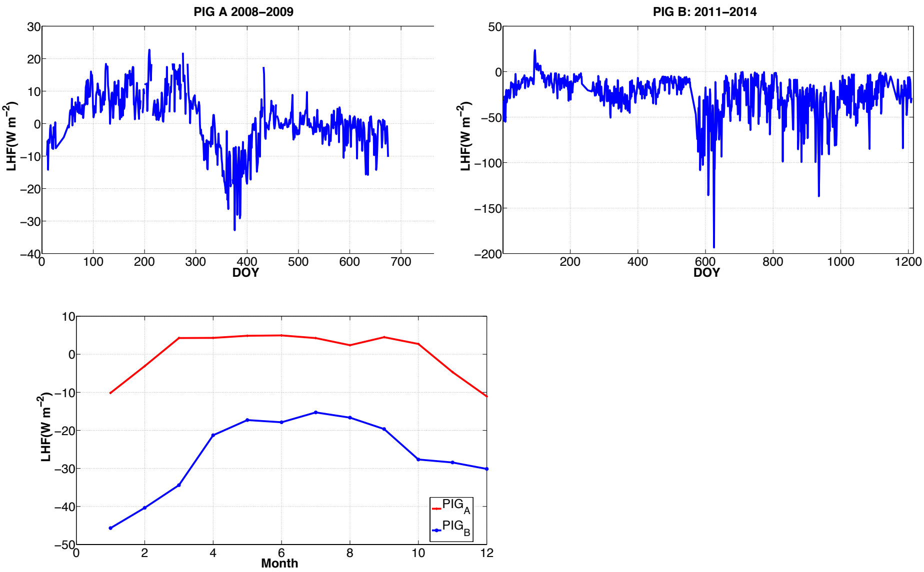
Sensible heat flux







Latent heat flux



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