Identification and Prediction of Flux Tower Latent Heat Data and Their Source Variables (Time Series Imputation)

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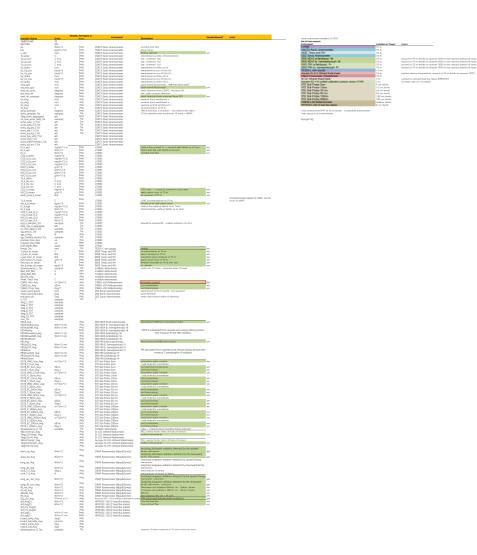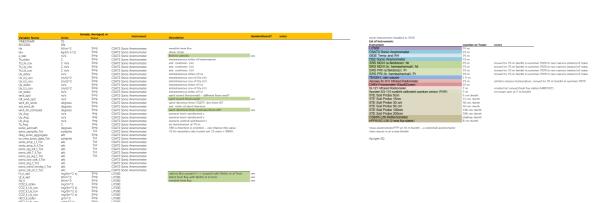
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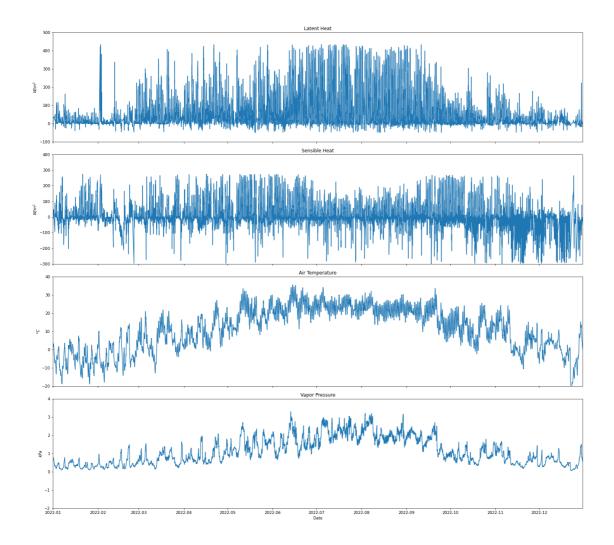
Dataset Description

We propose to use Goose Creek Eddy Covariance Flux Tower Sensor Data[**kumar2024?**]. The data is collected from the Eddy Covariance Flux Tower in Goose Creek, Piatt County. The dataset consists of time series data spanning from Spring 2016 to Spring 2023 with 15 minutes time interval. Dataset involves 167 variables shown in Figure [**fig?**]: Data including latent heat, sensible heat, wind speed, temperature, and changes in the ecosystem with respect to water, carbon, and temperature. Figure 2 illustrates part of variables in 2022. The data collected by flux tower provides a foundation for further investigation into hydrological, meteorological, and environmental phenomena. The format of dataset is CSV file (generated from raw PICKLE file). The dataset can be found through link: https://www.hydroshare.org/resource/c276c71e8d1246e29d8502f5b2054668/

most instruments installed in 2016

List of Instruments

Instrument	Location on Tower	notes
LI7500	75 m	
CSAT3 Sonic Anemometer	75 m	
083E Temp and RH	75 m	
DS2 Sonic Anemometer	10 m	
SRS NDVI (a: fieldstop): Nr	75 m	moved to 75 m height in summer 2020 to see canopy instead of grass
SRS NDVI (b: hemispherical): Ni	75 m	moved to 75 m height in summer 2020 to see canopy instead of grass
SRS PRI (a:fieldstop): Pr	75 m	moved to 75 m height in summer 2020 to see canopy instead of grass
SRS PRI (b: hemispherical): Pi	75 m	moved to 75 m height in summer 2020 to see canopy instead of grass
TE525-L rain gauge	1.5 m	
Apogee SI-1H1 Infrared Radiometer	75 m	getting canopy temperature, moved to 75 m height in summer 2020
CNR4 Pyranometer (Kipp&Zonen)	10 m	
SI-121 Infrared Radiometer	7 m	pointed at/around heat flux plates (HFP01SC)
Apogee SQ-110 sunlit calibrated quantum sensor (PAR)	7 m	on tower arm at 7 m height
STE Soil Probe 5cm	5 cm depth	
STE Soil Probe 15cm	15 cm depth	
STE Soil Probe 30 cm	30 cm depth	
STE Soil Probe 50 cm	50 cm depth	
STE Soil Probe 100cm	100 cm depth	
STE Soil Probe 200cm	200 cm depth	
CS655-L50 Reflectometer	shallow depth	
HFP01SC-L50 (2 heat flux plates)	8 cm depth	

new anemometer???? at 10 m height - a campbell anemometer
main source is at a new height

Apogee SQ

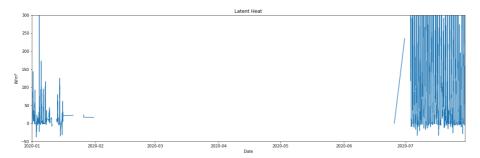| Variable	Units	Agg	Instrument	Description	Flag
H2O_li_Ux_cov	g/(m^2 s)	Smp	Li7500		
H2O_li_Uz_cov	g/(m^2 s)	Smp	Li7500		
Tc_li_stdev	C	Smp	Li7500		
Tc_li_Ux_cov	C m/s	Smp	Li7500		
Tc_li_Uy_cov	C m/s	Smp	Li7500		
Tc_li_Uz_cov	C m/s	Smp	Li7500		
CO2_li_mean	mg/m^3	Smp	Li7500	CO2 conc --> need to convert to ppm units	yes
H2O_li_mean	g/m^3	Smp	Li7500	water vapor conc at 75 m	yes
amb_press_li_mean	kPa	Smp	Li7500	air pressure at 75 m	yes
					corrected temp based on CSAT, not as good as 083E
Tc_li_mean	C	Smp	Li7500	CSAT air temperature at 75 m	
rho_a_li_mean	kg/m^3	Smp	Li7500	density of air with water vapor	yes
Fc_li_irga	mg/(m^2 s)	Smp	Li7500	carbon flux without Webb et al. Term	
LE_li_irga	W/m^2	Smp	Li7500	latent heat flux without Webb et al. Term	
CO2_li_wpl_LE_li	mg/(m^2 s)	Smp	Li7500		
CO2_li_wpl_H_li	mg/(m^2 s)	Smp	Li7500		
H2O_li_wpl_LE_li	W/m^2	Smp	Li7500		
H2O_li_wpl_H_li	W/m^2	Smp	Li7500		
irga_li_samples_Tot	samples	Tot	Li7500	should be around 60 - quality indicator of LiCor	
diag_irga_li_aggregate	arb	Tot	Li7500		
no_new_data_li_Tot	samples	Tot	Li7500		
sig_error_li_Tot	samples	Tot	Li7500		
agc_li_Avg	%	Avg	Li7500		
agc_thrshld_exced_Tot	samples	Tot	Li7500		
process_time_Avg	us	Avg	Li7500		
process_time_Max	us	Max	Li7500		
buff_depth_Max	scans	Max	Li7500		
Precip_Tot	mm	Tot	TE525-L rain gauge	rainfall	
T_tmpr_rh_mean	C	Smp	083E Temp and RH	air temperature at 75 m	yes
e_tmpr_rh_mean	kPa	Smp	083E Temp and RH	vapor pressure at 75 m	yes
e_sat_tmpr_rh_mean	kPa	Smp	083E Temp and RH	saturated vapor pressure at 75 m	yes
H2O_tmpr_rh_mean	g/m^3	Smp	083E Temp and RH	water vapor conc at 75 m	yes
RH_tmpr_rh_mean	%	Smp	083E Temp and RH	Relative Humidity at 75 m (e/e_sat)	yes
rho_a_tmpr_rh_mean	kg/m^3	Smp	083E Temp and RH	air density	yes
slowsequence_1_Tot	samples	Tot	multiple instruments	cycles per 15 mins - scanning every 10 secs	
Batt_Volt_Min	V	Min	multiple instruments		
Solar_Batt_Min	V	Min	multiple instruments		
Box_Rh_Avg		Avg	multiple instruments		
Panel_Tmpr_Avg	C	Avg	multiple instruments		
CS655_Wcr_Avg	m^3/m^3	Avg	CS655-L50 Reflectometer	soil water content	yes
CS655_Ec_Avg	dS/m	Avg	CS655-L50 Reflectometer	soil conductivity	
CS655_Tmpr_Avg	Deg C	Avg	CS655-L50 Reflectometer	soil temperature	
mean_wind_speed	m/s	Avg	DS2 Sonic Anemometer	wind speed at 10 m height- not average?	
mean_wind_direction	Deg	Avg	DS2 Sonic Anemometer	wind direction	
std_wind_dir	Deg	Avg	DS2 Sonic Anemometer	mean wind vector stdev of direction	
n_TOT	samples	Tot		?	
diag_1_TOT	samples				
diag_2_TOT	samples				
diag_4_TOT	samples				
diag_8_TOT	samples				
diag_9_TOT	samples				
diag_10_TOT	samples				
one_Tot	samples				
NDVI_Avg		Avg	SRS NDVI (both instruments)	Normalized Difference Vegetation Index	yes
NDVIUpRed_Avg	W/m^2 nm	Avg	SRS NDVI (b: hemispherical) Ni		
NDVIUpNIR_Avg	W/m^2 nm	Avg	SRS NDVI (b: hemispherical) Ni	NDVI is calculated from upward and canopy facing sensors	
NDVIIndUp		Smp	SRS NDVI (b: hemispherical) Ni	that measure IR an NIR radiation	
NDVIDownRed_Avg	W/m^2 nm	Avg	SRS NDVI (a:fieldstop): Nr		
NDVIDownNIR_Avg	W/m^2 nm	Avg	SRS NDVI (a:fieldstop): Nr		
NDVIIndDown		Avg	SRS NDVI (a:fieldstop): Nr		
PRI_Avg		Avg	SRS PRI (both instruments)	Photochemical Reflectance Index	yes
PRIUp531_Avg	W/m^2 nm	Avg	SRS PRI (b: hemispherical): Pi		
PRIUp570_Avg	W/m^2 nm	Avg	SRS PRI (b: hemispherical): Pi	PRI calculated from upward and canopy facing sensors that	
PRIIndUp		Smp	SRS PRI (b: hemispherical): Pi	measure 2 wavelengths of radiation	
PRIDown531_Avg	W/m^2 nm	Avg	SRS PRI (a:fieldstop): Pr		
PRIDown570_Avg	W/m^2 nm	Avg	SRS PRI (a:fieldstop): Pr		
PRIIndDown		Avg	SRS PRI (a:fieldstop): Pr		
DSTE_VWC_5cm_Avg	m^3/m^3	Avg	5TE Soil Probe 5cm	volumetric water content	yes
DSTE_P_5cm_Avg		Avg	5TE Soil Probe 5cm	bulk dielectric permittivity	
DSTE_EC_5cm_Avg	dS/m	Avg	5TE Soil Probe 5cm	soil electrical conductivity	yes
DSTE_T_5cm_Avg	Deg C	Avg	5TE Soil Probe 5cm	soil temperature	yes
DSTE_VWC_15cm_Avg	m^3/m^3	Avg	5TE Soil Probe 15cm	volumetric water content	yes
DSTE_P_15cm_Avg		Avg	5TE Soil Probe 15cm	bulk dielectric permittivity	
DSTE_EC_15cm_Avg	dS/m	Avg	5TE Soil Probe 15cm	soil conductivity	yes
DSTE_T_15cm_Avg	Deg C	Avg	5TE Soil Probe 15cm	soil temperature	yes
DSTE_VWC_30cm_Avg	m^3/m^3	Avg	5TE Soil Probe 30 cm	volumetric water content	yes
DSTE_P_30cm_Avg		Avg	5TE Soil Probe 30 cm	bulk dielectric permittivity	
DSTE_EC_30cm_Avg	dS/m	Avg	5TE Soil Probe 30 cm	soil conductivity	yes
DSTE_T_30cm_Avg	Deg C	Avg	5TE Soil Probe 30 cm	soil temperature	yes
DSTE_VWC_50cm_Avg	m^3/m^3	Avg	5TE Soil Probe 50 cm	volumetric water content	yes
DSTE_P_50cm_Avg		Avg	5TE Soil Probe 50 cm	bulk dielectric permittivity	
DSTE_EC_50cm_Avg	dS/m	Avg	5TE Soil Probe 50 cm	soil conductivity	yes
DSTE_T_50cm_Avg	Deg C	Avg	5TE Soil Probe 50 cm	soil temperature	yes
DSTE_VWC_100cm_Avg	m^3/m^3	Avg	5TE Soil Probe 100cm	volumetric water content	yes
DSTE_P_100cm_Avg		Avg	5TE Soil Probe 100cm	bulk dielectric permittivity	
DSTE_EC_100cm_Avg	dS/m	Avg	5TE Soil Probe 100cm	soil conductivity	yes
DSTE_T_100cm_Avg	Deg C	Avg	5TE Soil Probe 100cm	soil temperature	yes
DSTE_VWC_200cm_Avg	m^3/m^3	Avg	5TE Soil Probe 200cm	volumetric water content	yes
DSTE_P_200cm_Avg		Avg	5TE Soil Probe 200cm	bulk dielectric permittivity	
DSTE_EC_200cm_Avg	dS/m	Avg	5TE Soil Probe 200cm	soil conductivity	yes
DSTE_T_200cm_Avg	Deg C	Avg	5TE Soil Probe 200cm	soil temperature	yes
slowsequence_2_Tot	samples	Tot	multiple instruments	rules - 1 minute loops (number times scanned)	
SBI21TempC_Avg		Avg	SI-121 Infrared Radiometer	SR = sensor body temp of body of sensor	
Targ121TempC_Avg		Avg	SI-121 Infrared Radiometer	surface temperature	yes
Targ121mV_Avg		Avg	SI-121 Infrared Radiometer		
SBIH1TempC_Avg		Avg	Apogee SI-1H1 Infrared Radiometer	SR = sensor body temp of body of sensor	
Targ1H1TempC_Avg		Avg	Apogee SI-1H1 Infrared Radiometer	surface temperature	yes
Targ1H1mV_Avg		Avg	Apogee SI-1H1 Infrared Radiometer		
short_up_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Incoming shortwave radiation detected by the upward facing instrument	yes
short_dn_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Outgoing shortwave radiation detected by the downward facing instrument	yes
long_up_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	incoming longwave radiation detected by upward facing instrument	
long_dn_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	outgoing longwave radiation detected by downward facing instrument	
cnr4_T_C_Avg	deg_C	Avg	CNR4 Pyranometer (Kipp&Zonen)	temperature of sensor	
cnr4_T_K_Avg	K	Avg	CNR4 Pyranometer (Kipp&Zonen)	temperature of sensor in Kelvin	
long_up_corr_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Incoming longwave radiation detected by the upward instrument_corrected	yes
long_dn_corr_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Outgoing longwave radiation detected by the downward facing instrument_corrected	yes
Rs_net_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Shortwave net radiation (Rshort_up – Rshort_down)	yes
Rl_net_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Longwave net radiation (Rlong_up – Rlong_down)	yes
albedo_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Albedo	yes
Rn_Avg	W/m^2	Avg	CNR4 Pyranometer (Kipp&Zonen)	Net radiation (Rs_net + Rl_net)	yes
SQ_110_Avg	(??mol m_-2	Avg	Apogee SQ-110 sunlight calibrated quant	PAR (photosynthetically active radiation)	yes
shf_Avg[1]	W/m^2	Avg	HFP01SC-L50 (2 heat flux plates)	Ground heat flux	yes
shf_Avg[2]	W/m^2	Avg	HFP01SC-L50 (2 heat flux plates)	Ground heat flux	yes
shf_mV_Avg[1]		Avg	HFP01SC-L50 (2 heat flux plates)		
shf_mV_Avg[2]		Avg	HFP01SC-L50 (2 heat flux plates)		
shf_cal[1]	W/m^2 mV	Smp	HFP01SC-L50 (2 heat flux plates)		
shf_cal[2]	W/m^2 mV	Smp	HFP01SC-L50 (2 heat flux plates)		
board_temp_Avg	degC	Avg			
board_humidity_Avg	percent	Avg			
incline_pitch_Avg	deg	Avg			
incline_roll_Avg	deg	Avg			
slowsequence_3_Tot	samples	Tot		number of times scanned in 15 mins (once per min)	

Proposal

Background

Evapotranspiration (ET) is the process of water transferring from land to the atmosphere, accompanying the phase change of water from liquid to gas. This process plays a critical role in the ecohydrological system and profoundly affects the hydrological cycle. The processes of evapotranspiration and energy exchange are interdependent. Both latent heat (LE) and evapotranspiration (ET), from the perspective of energy and water flux, are key terms for anticipating weather conditions, simulating climate, and diagnosing climate change. However, the measurement of evapotranspiration is challenging because the process itself is invisible and complex.

Figure 3 shows the latent heat data gap in 2020 due to covid-19 and overhaul of equipment. Our project goal is to fill in these missing data. The ground truth data is collected from satelite sensors (https://etdata.org/). Despite the existence of numerous classical evapotranspiration simulation models, such as Bowen Ratio, Priestley-Taylor and Penman-Monteith models, the predictive accuracy of these models is inferior to that of deep learning models. Therefore, we plan to use RNN and LSTM

deep learning models to predict latent heat and fill the gap.

Step 1: Regression analysis

We have 167 variables in the dataset. Although we can filter some ET related variables based on empirical models, these variables may not accurate and AI models tend to obtain adequate information. Therefore, we propose to conduct regression analysis to find out variables highly correlated to latent heat. These variables will be input variables in deep learning model.

Step 2: Deep Learning Time Series Forecast (Time Series Imputation)

Once we confirm the input variables, we plan to use RNN or LSTM forecast models to predict latent heat in 2020. All the input are divided into training datasets and the validation datasets. After the RNN model is trained, the validation datasets are used to verify the model. At last, the missing data are generated by the model.

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Basic formatting

Bold text

Semi-bold text

<div align="center">Centered text</div>

<div align="right">Right-aligned text</div>

Italic text

Combined *italics and **bold***

~~Strikethrough~~

1. Ordered list item
2. Ordered list item
   a. Sub-item
   b. Sub-item
      i. Sub-sub-item
3. Ordered list item
   a. Sub-item

- List item
- List item
- List item

subscript: H_2O is a liquid

superscript: 2^{10} is 1024.

[unicode superscripts](#)^{0123456789}

[unicode subscripts](#)$_{0123456789}$

A long paragraph of text. Lorem ipsum dolor sit amet, consectetur adipiscing elit, sed do eiusmod tempor incididunt ut labore et dolore magna aliqua. Ut enim ad minim veniam, quis nostrud exercitation ullamco laboris nisi ut aliquip ex ea commodo consequat. Duis aute irure dolor in reprehenderit in voluptate velit esse cillum dolore eu fugiat nulla pariatur. Excepteur sint occaecat cupidatat non proident, sunt in culpa qui officia deserunt mollit anim id est laborum.

Putting each sentence on its own line has numerous benefits with regard to [editing](#) and [version control](#).

Line break without starting a new paragraph by putting
two spaces at end of line.

Document organization

Document section headings:

Heading 1

Heading 2

Heading 3

Heading 4

Heading 5

Heading 6

A heading centered on its own printed page

Horizontal rule:

`Heading 1`'s are recommended to be reserved for the title of the manuscript.

`Heading 2`'s are recommended for broad sections such as *Abstract*, *Methods*, *Conclusion*, etc.

`Heading 3`'s and `Heading 4`'s are recommended for sub-sections.

Links

Bare URL link: https://manubot.org

Long link with lots of words and stuff and junk and bleep and blah and stuff and other stuff and more stuff yeah

Link with text

Link with hover text

Link by reference

Citations

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Citation by PubMed Central ID [2].

Citation by PubMed ID [3].

Citation by Wikidata ID [4].

Citation by ISBN [5].

Citation by URL [6].

Citation by alias [7].

Multiple citations can be put inside the same set of brackets [1,5,7]. Manubot plugins provide easier, more convenient visualization of and navigation between citations [2,3,7,8].

Citation tags (i.e. aliases) can be defined in their own paragraphs using Markdown's reference link syntax:

Referencing figures, tables, equations

Figure 1

Figure 2

Quotes and code

> Quoted text

> Quoted block of text
>
> Two roads diverged in a wood, and I—
> I took the one less traveled by,
> And that has made all the difference.

Code `in the middle` of normal text, aka `inline code`.

Code block with Python syntax highlighting:

```python
from manubot.cite.doi import expand_short_doi

def test_expand_short_doi():
    doi = expand_short_doi("10/c3bp")
    # a string too long to fit within page:
    assert doi == "10.25313/2524-2695-2018-3-vliyanie-enhansera-copia-i-
        insulyatora-gypsy-na-sintez-ernk-modifikatsii-hromatina-i-
        svyazyvanie-insulyatornyh-belkov-vtransfetsirovannyh-geneticheskih-
        konstruktsiyah"
```

Code block with no syntax highlighting:

```
Exporting HTML manuscript
Exporting DOCX manuscript
Exporting PDF manuscript
```

Figures

Figure 1: A square image at actual size and with a bottom caption. Loaded from the latest version of image on GitHub.

Figure 2: An image too wide to fit within page at full size. Loaded from a specific (hashed) version of the image on GitHub.

Figure 3: A tall image with a specified height. Loaded from a specific (hashed) version of the image on GitHub.

Figure 4: A vector `.svg` image loaded from GitHub. The parameter `sanitize=true` is necessary to properly load SVGs hosted via GitHub URLs. White background specified to serve as a backdrop for transparent sections of the image. Note that if you want to export to Word (`.docx`), you need to download the image and reference it locally (e.g. `content/images/vector.svg`) instead of using a URL.

Tables

Table 1: A table with a top caption and specified relative column widths.

Bowling Scores	Jane	John	Alice	Bob
Game 1	150	187	210	105
Game 2	98	202	197	102
Game 3	123	180	238	134

Table 2: A table too wide to fit within page.

	Digits 1-33	Digits 34-66	Digits 67-99	Ref.
pi	3.14159265358979323 846264338327950	28841971693993751 0582097494459230	78164062862089986 2803482534211706	`piday.org`
e	2.71828182845904523 536028747135266	24977572470936999 5957496696762772	40766303535475945 7138217852516642	`nasa.gov`

Table 3: A table with merged cells using the `attributes` plugin.

Size	Text Color	Background Color
Colors		
big	blue	orange
small	black	white

Equations

A LaTeX equation:

$$\int_0^\infty e^{-x^2}dx = \frac{\sqrt{\pi}}{2} \tag{1}$$

An equation too long to fit within page:

$$x = a + b + c + d + e + f + g + h + i + j + k + l + m + n + o + p + q + r + s + t$$
$$+ u + v + w + x + y + z + 1 + 2 + 3 + 4 + 5 + 6 + 7 + 8 + 9 \tag{2}$$

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> LINK STYLED AS A BUTTON

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> Manubot Manubot Manubot Manubot Manubot. Manubot Manubot Manubot Manubot. Manubot Manubot Manubot. Manubot Manubot. Manubot.

Adding arbitrary HTML attributes to an element with the Manubot `attributes` plugin (more flexible than Pandoc's method in terms of which elements you can add attributes to):

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useful for *general information* - <u>manubot.org</u>

ℹ️ Blue Banner

useful for *important information* - <u>manubot.org</u>

🚫 Light Red Banner

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References

1. **Sci-Hub provides access to nearly all scholarly literature**
   Daniel S Himmelstein, Ariel Rodriguez Romero, Jacob G Levernier, Thomas Anthony Munro, Stephen Reid McLaughlin, Bastian Greshake Tzovaras, Casey S Greene
   eLife (2018-03-01) https://doi.org/ckcj
   DOI: 10.7554/elife.32822 · PMID: 29424689 · PMCID: PMC5832410

2. **Reproducibility of computational workflows is automated using continuous analysis**
   Brett K Beaulieu-Jones, Casey S Greene
   Nature biotechnology (2017-04) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6103790/
   DOI: 10.1038/nbt.3780 · PMID: 28288103 · PMCID: PMC6103790

3. **Bitcoin for the biological literature.**
   Douglas Heaven
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4. **Plan S: Accelerating the transition to full and immediate Open Access to scientific publications**
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   (2018-09-04) https://www.wikidata.org/wiki/Q56458321

5. **Open access**
   Peter Suber
   MIT Press (2012)
   ISBN: 9780262517638

6. **Open collaborative writing with Manubot**
   Daniel S Himmelstein, Vincent Rubinetti, David R Slochower, Dongbo Hu, Venkat S Malladi, Casey S Greene, Anthony Gitter
   Manubot (2020-05-25) https://greenelab.github.io/meta-review/

7. **Opportunities and obstacles for deep learning in biology and medicine**
   Travers Ching, Daniel S Himmelstein, Brett K Beaulieu-Jones, Alexandr A Kalinin, Brian T Do, Gregory P Way, Enrico Ferrero, Paul-Michael Agapow, Michael Zietz, Michael M Hoffman, … Casey S Greene
   Journal of The Royal Society Interface (2018-04) https://doi.org/gddkhn
   DOI: 10.1098/rsif.2017.0387 · PMID: 29618526 · PMCID: PMC5938574

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   Daniel S Himmelstein, Vincent Rubinetti, David R Slochower, Dongbo Hu, Venkat S Malladi, Casey S Greene, Anthony Gitter
   PLOS Computational Biology (2019-06-24) https://doi.org/c7np
   DOI: 10.1371/journal.pcbi.1007128 · PMID: 31233491 · PMCID: PMC6611653