Predictors of High Streamflow Events in the Fraser River Basin of British Columbia, Canada

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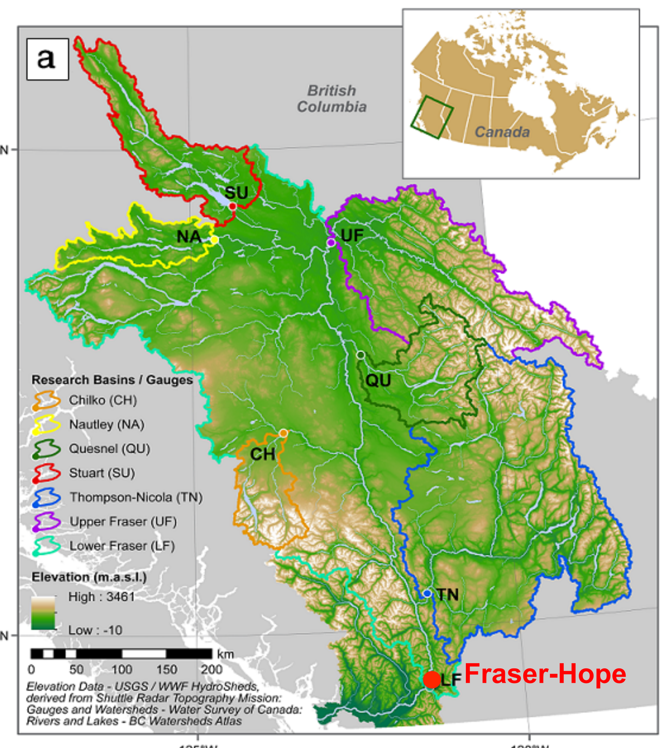
1. Study Region, Observations and Hydrological Model

The ***Fraser River Basin*** **(FRB)** is home to 63% of the population of British Columbia and hosts much of its agricultural and commercial activity. Most of the basin is unregulated and thus the main stem of the Fraser River, with its main outlet at Hope, responds to both long- and short-term climatic variations.

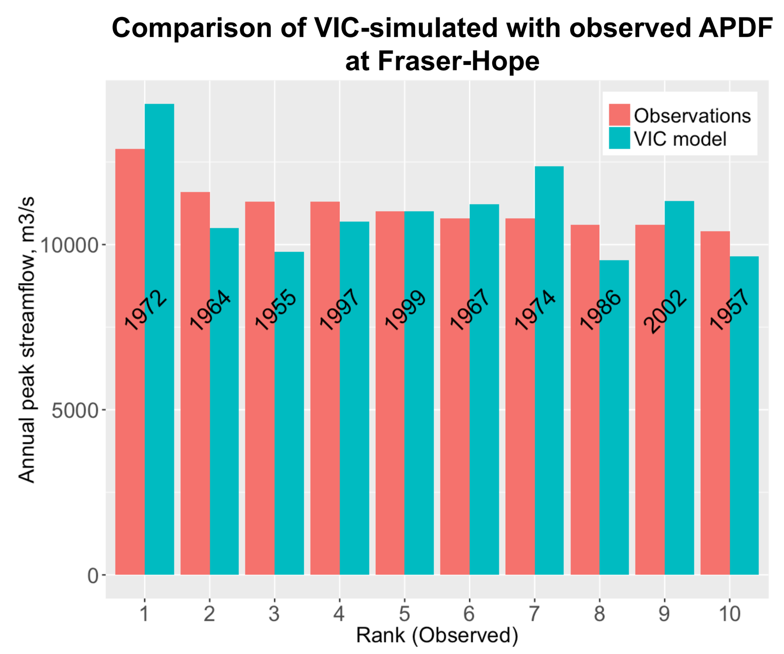


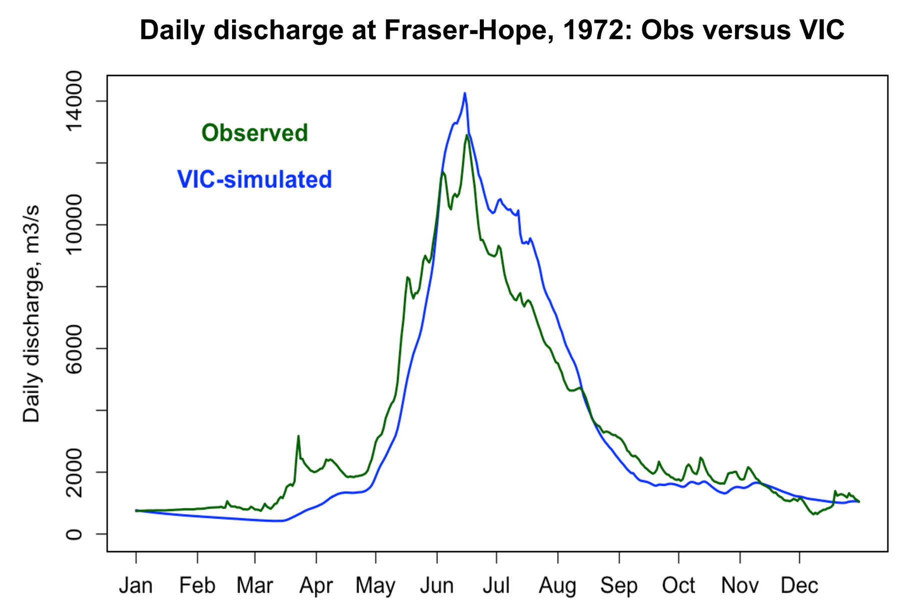
The Fraser River Basin. Courtesy *Islam et al. (2016)*.

FRB hydrology is dominated by snow accumulation & snowmelt processes. **Annual peak daily flow (APDF)** in the FRB invariably occurs during spring freshet → degree & timing of snowmelt govern peak flow characteristics in a given year.

The four upstream sub-basins UF, QU, TN and CH contribute 69% (63%) of observed (VIC-simulated) annual mean discharge at Fraser-Hope.

Hydrological model & driving data: The **Variable Infiltration Capacity (VIC) model** was run at a horizontal resolution of 1/16° (~6 km), driven with gridded meteorological observations (daily minimum & maximum SAT, daily precipitation, derived from ClimateWNA) & daily wind reanalysis (NCEP-I) over the period 1955-2004. Calibration and validation of VIC on the FRB was carried out by *Shrestha et al. (2012)*. **The Figures below** show that VIC simulates both the APDF (**left**) and daily intra-annual flow (**right**) with reasonable skill.

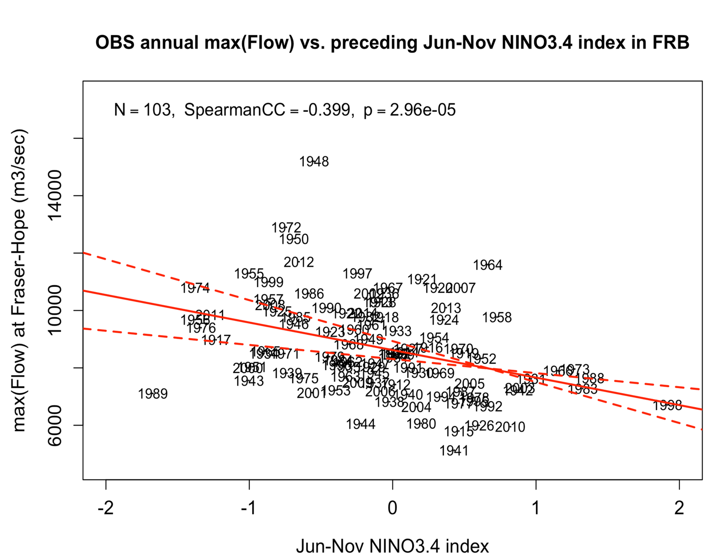


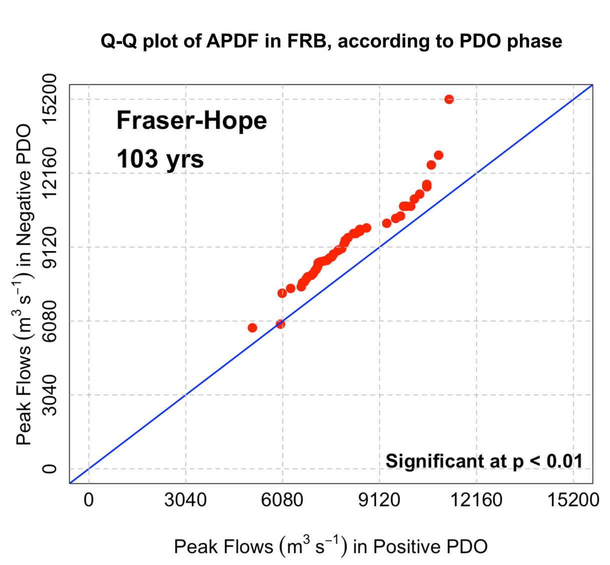


2. Teleconnections and Peak Flows in the FRB

The Pacific Decadal Oscillation (PDO) and El Niño-Southern Oscillation (ENSO) are known to influence hydroclimate in western Canada and the U.S. Pacific Northwest (*Stewart et al., 2005; Gurrapu et al., 2016*). **The Figures below** show that higher streamflow is associated with the La Niña and negative PDO phases.

Note, however, that the four largest APDFs in the record occurred during weak-neutral La Niña conditions (left panel). Other studies have demonstrated only weak predictability of APDFs based on such climate indices alone (*McCabe et al. 2014*). This suggests that the magnitude of the largest APDFs are more influenced by local factors.

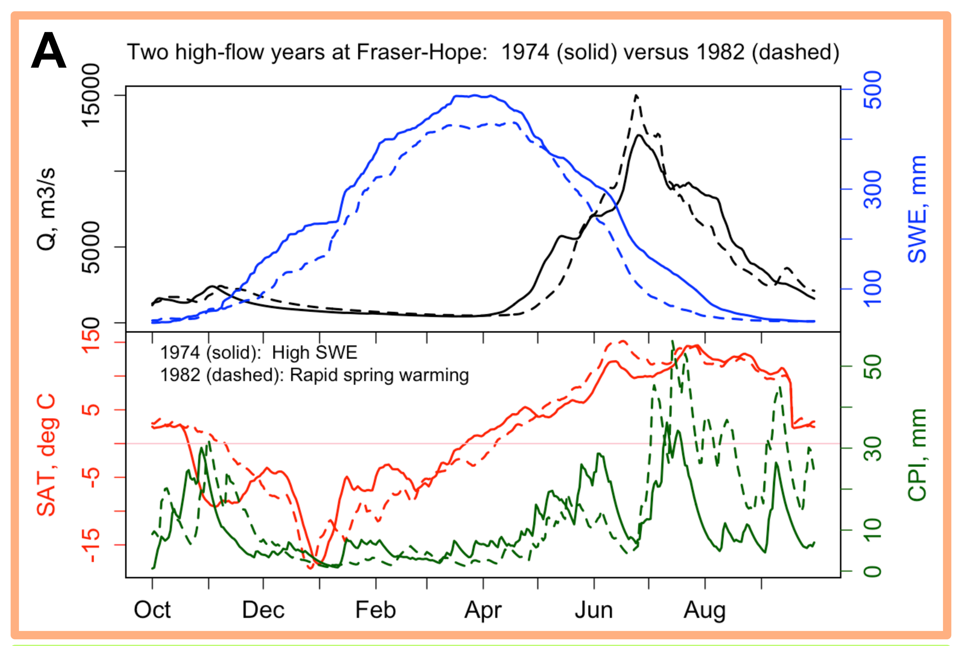


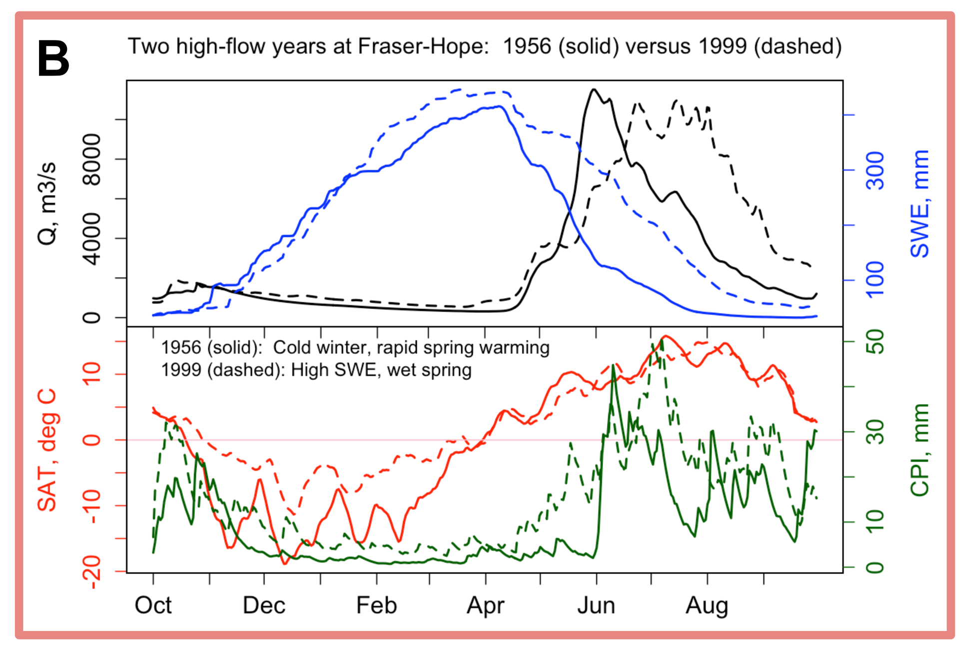


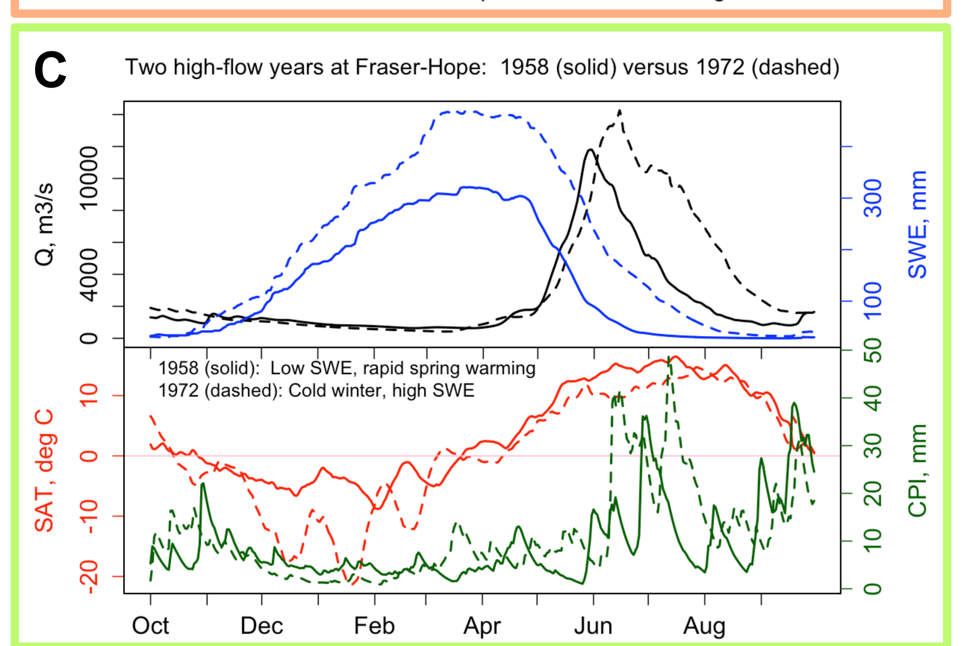
3. Interannual Variations in Peak Flow: Local Drivers

Panels A & B below: In years with similar SWE accumulation, differences in spring warming rate and/or rainfall timing & duration can result in very different hydrographs.

Panel C: In years with disparate SWE accumulation, APDF can be of comparable magnitude under rapid warming, although total runoff is still dictated by max(SWE).







Top 10 annual peak flow years in VIC, 1955-2004

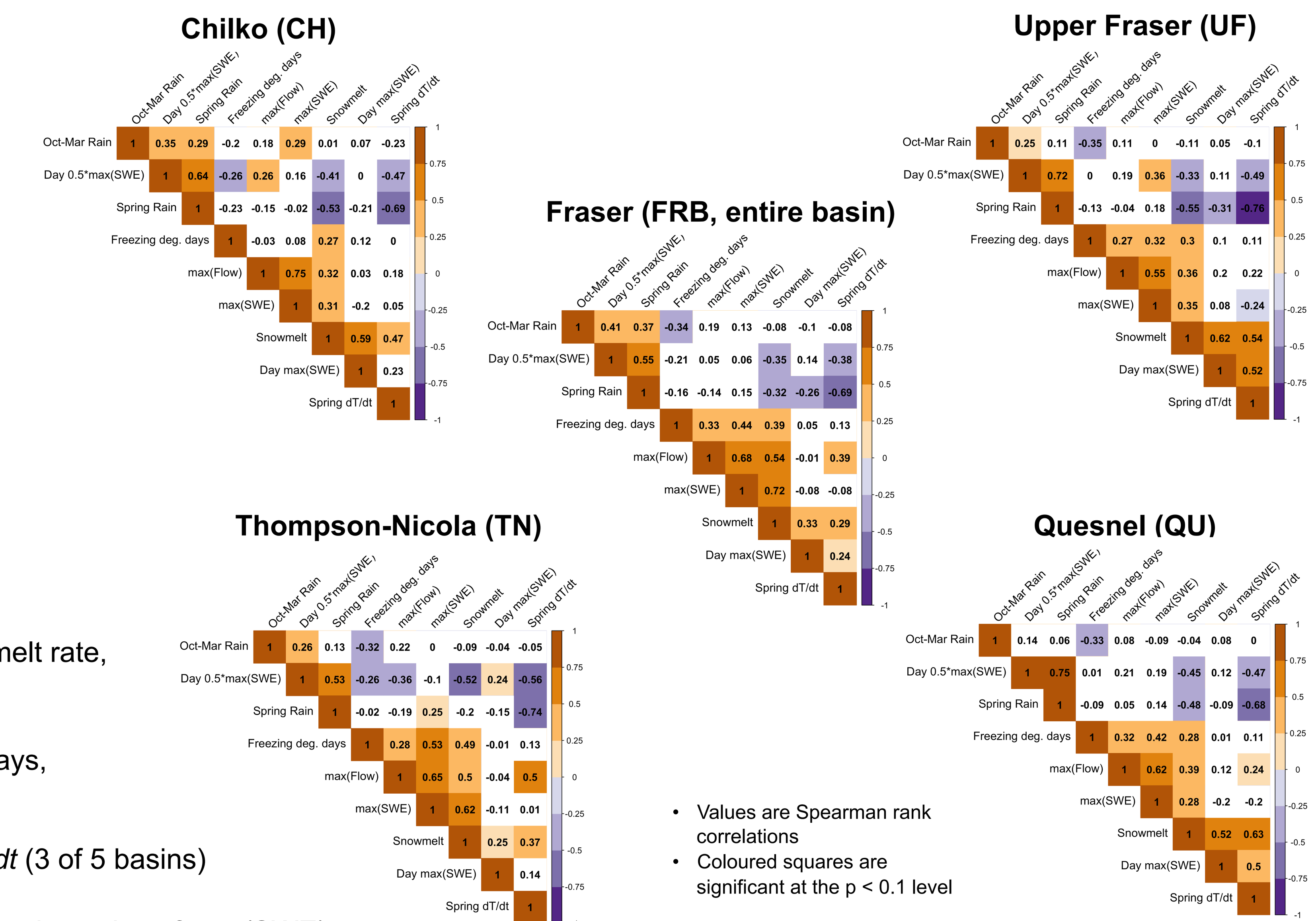
Rank [max (Flow)]	Year [max (Flow)]	Rank [max (SWE)]	Rank (T < 0 deg days)	Rank (Spring Warming)	Rank (Spring Rainfall)
1	1982	6	14	1	47
2	1972	2	4	21	26
3	1974	1	17	39	22
4	1958	25	46	5	49
5	1956	10	1	11	50
6	2002	15	26	8	23
7	1967	7	28	7	39
8	1999	4	44	45	1
9	1997	5	9	22	13
10	1964	18	33	26	15

4. Local Drivers of Extreme Streamflow Events

We performed an extensive linear regression analysis on an array of possible correlates of max(Flow). **The Figure below** shows the results for the FRB and its sub-basins as correlograms, including cross-correlations between all variables

Variable	Description
max(Flow)	Annual maximum 3-day average streamflow, *m^3/sec*
max(SWE)	Annual maximum SWE, *mm*
Day max(SWE)	Calendar day of max(SWE)
Day 50% max(SWE)	Subsequent day of 0.5*max(SWE)
Snowmelt	Rate of snowmelt in P1*, *mm/day*
Freezing degree days	Integral of SAT over days with SAT > 0, Oct-Mar, °C days
Spring dT/dt	Rate of SAT change in P1, degrees °C day^{-1}
Oct-Mar Rain	October-March rainfall prior to max(Flow), *mm*
Spring Rain	Rainfall during P1, *mm*

* P1 defined as the period between max(SWE) and max(Flow) for each year.



- Values are Spearman rank correlations
- Coloured squares are significant at the p < 0.1 level

Regression results

- Max(Flow) positively correlated with max(SWE), snowmelt rate, freezing degree days and spring *dT/dt*
- Max(SWE) positively correlated with freezing degree days, snowmelt rate
- Day of max(SWE) positively correlated with spring *dT/dt* (3 of 5 basins)
- Snowmelt rate positively correlated with freezing degree days, day of max(SWE), spring *dT/dt*; negatively correlated with spring rain, day of 0.5*max(SWE)

5. Conclusions and Ongoing Work

- Regression analysis identified several predictors of annual peak daily streamflow in the FRB and its major sub-basins over the period 1955-2004
- While the most influential predictor of APDF is annual max(SWE), it alone does not account for the largest APDFs found in VIC simulations. Additional important predictors are antecedent freezing degree days, snowmelt rate and spring warming rate
- The phase of the PDO and ENSO large scale climate modes also have a detectable influence on streamflow variability in the FRB. However, PDO/ENSO state alone is not a good predictor of the largest historical events

Event attribution study: We are now conducting an event attribution study for the largest recorded APDFs at Fraser-Hope (1948, 1972) using VIC simulations driven by downscaled CMIP5 GCM output. The knowledge gained from the work summarized here will be useful in assessing the antecedent conditions for these extreme floods in recent decades and into the future.

Acknowledgements

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