Using Kalman filter to study ocean forcing on Ross Ice Shelf

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Motivation: monitor stability of Antarctic ice shelves

Podolskiy and Walter, 2016

Mass loss from Antarctica (2003-2019)
Smith et al., 2020
SeismoGeodetic Ice Penetrator (SGIP)

GPS receiver: low sampling rate

Seismometer: error propagation when integrating for displacements
Kalman Filter for data fusion

Seismometer data

update

GPS data
Kalman Filter: simulation

Linear dynamical system:

\[ x_{k+1} = A_k x_k + B_k u_k + G_k \alpha_k \]

\[ x_{k+1} = (1)(x_k) \]

Seismometer data

\[ \alpha \sim (0, Q) \]

GPS data

\[ z_k = H_k x_k + \beta_k \]

\[ z_k = (1)(x_k) + \beta_k \]

\[ \beta \sim (0, R) \]
Kalman Filter: simulation

\begin{align*}
P_{k+1}^- &= P_k + Q_k \\
x_{k+1} &= x_k
\end{align*}

Kalman gain

\begin{align*}
P_{k+1}^- &= \frac{P_{k+1}^-}{P_{k+1}^- + R_{k+1}} \\
x_{k+1} &= x_{k+1}^- + \frac{P_{k+1}^-}{P_{k+1}^- + R_{k+1}} (z_{k+1} - x_{k+1}^-)
\end{align*}

Jurić 2015
Kalman Filter: simulation
Kalman Filter: validation

- 2016 MW 7.8 Kaikōura earthquake
- Integrated GPS and accelerometer data
Kalman Filter for data fusion

\[ x_{k+1} = A_k x_k + B_k u_k + G_k \alpha_k \quad \alpha \sim (0, Q) \]

State vector
Accelerometer data

\[ z_k = H_k x_k + \beta_k \quad \beta \sim (0, R) \]

GPS data

\[ u_k \]
Kalman Filter: validation

From Figure 2 in Shu et al., 2018

Displacements (cm)

My result

Displacements (cm)
Kalman Filter: validation

![Graphs showing velocity and displacements over time for different measurements: ACC, GPS/ACC, and GPS. The graphs are plotted against time (in seconds from 11:03:19 UTC, Nov. 13, 2016) for East, North, and Up directions.]
Kalman Filter: Infragravity wave event

- SeismoGeodetic Ice Penetrator will be deployed in RIS in 2021
- 34-station broadband seismographic network (deployed Nov. 2014)
- Co-located GPS receivers (deployed 2015)

Bromirski et al., 2017
Kalman Filter: Infragravity wave event

Displacement (m)

Z-component

Time (seconds from 00:00:00 UTC, Apr. 1, 2016)

4 days
Summary

- Implemented a Kalman filter to fuse GPS and seismometer data
- Validated software using results from 2016 earthquake

Future work

- Use Kalman filter to detect events (e.g. ice fracture, ice quakes, ...)
- Merge Kalman filter software into the SGIP software developed by previous REU students
Questions?