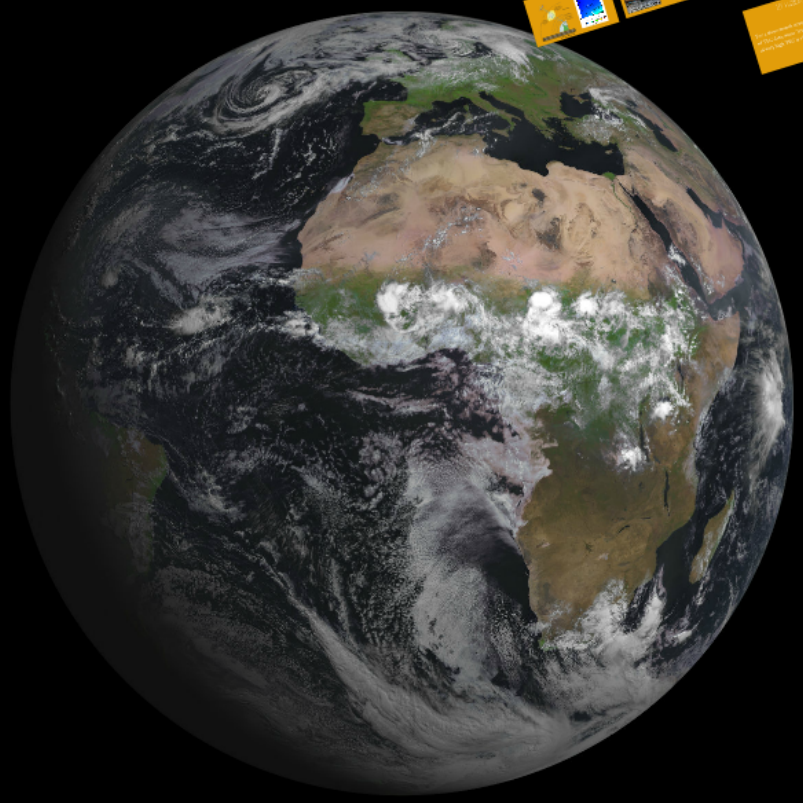
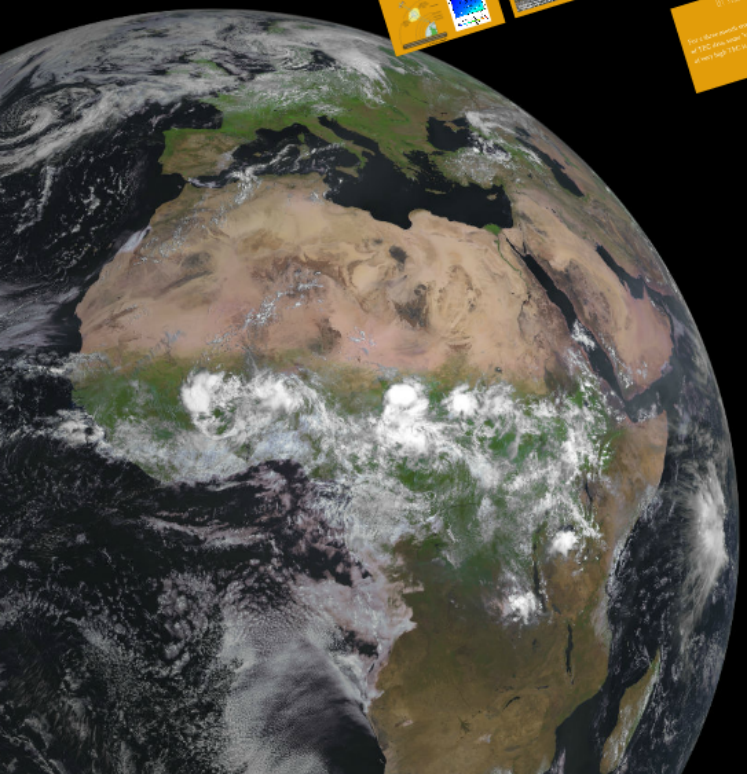
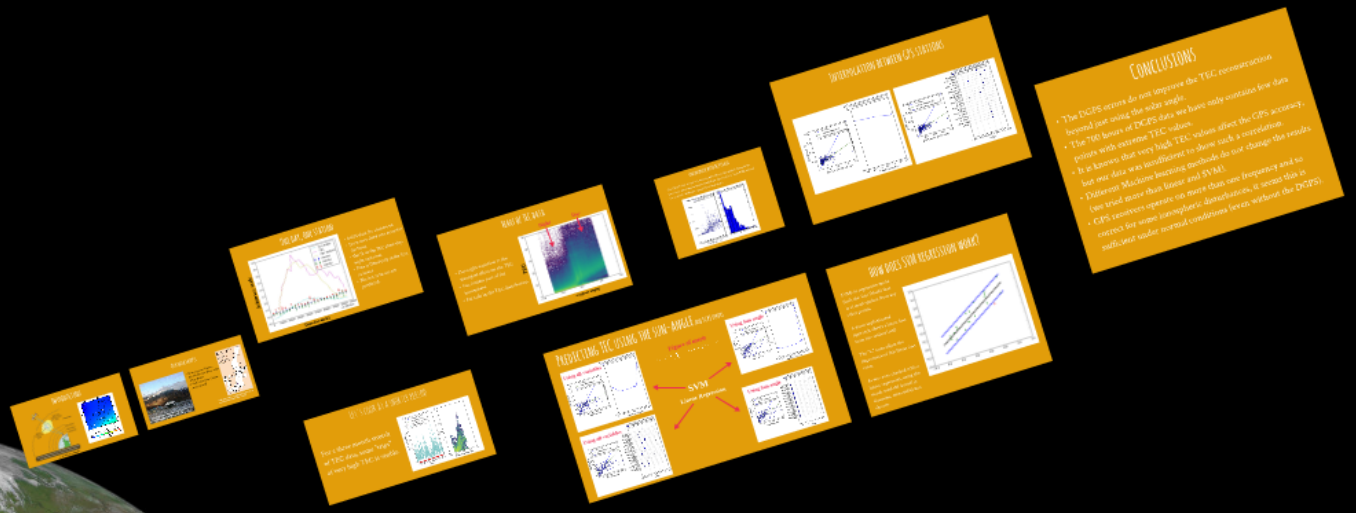


Predicting the ionosphere

Knut Morå & Seméli Papadogiannakis

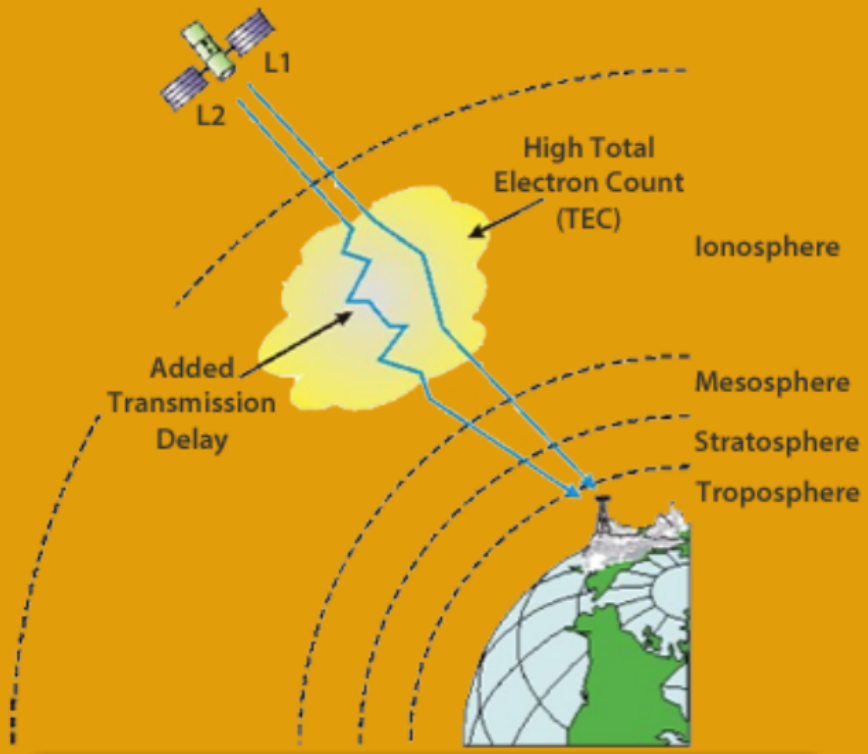




Predicting the ionosphere

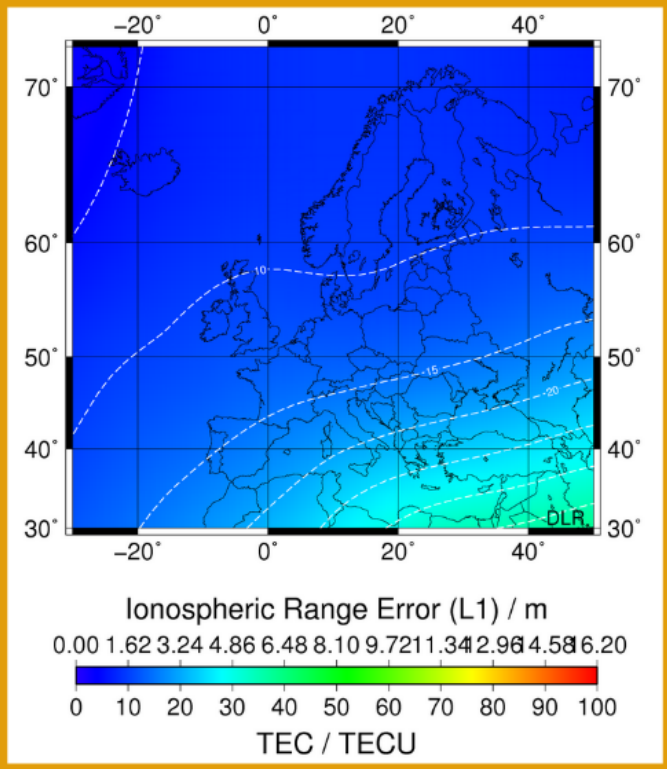
Knut Morå & Seméli Papadogiannakis

Introduction

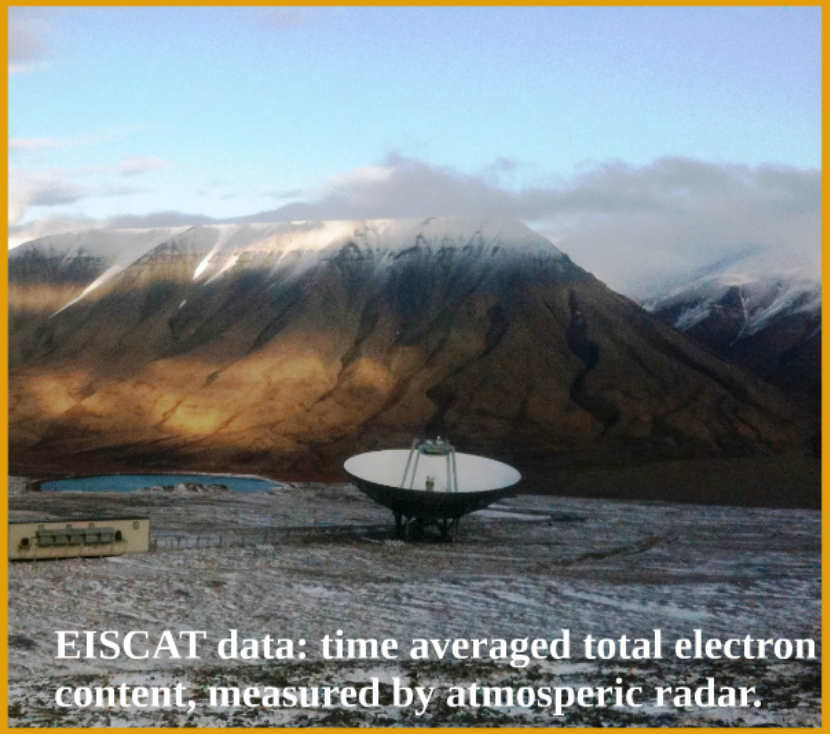


Effect of ionospheric refraction. The GPS signal are affected in different ways, depending on whether it is a question of codes or phases.

credit:reflexions.ulg.ac.be

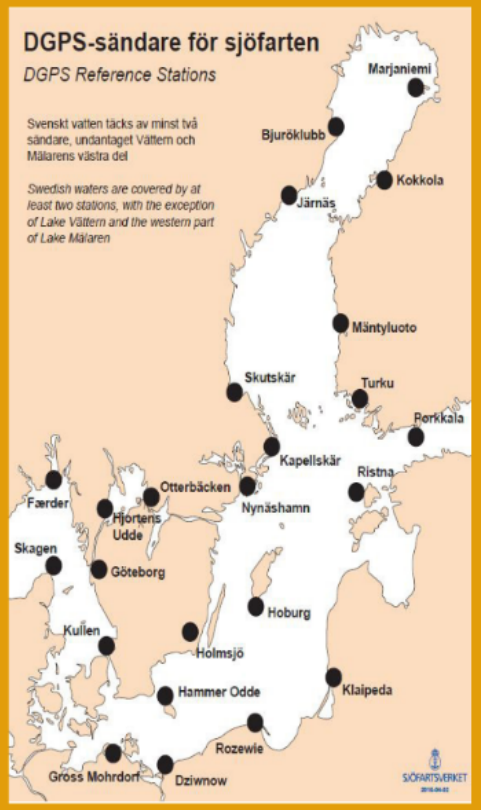


Our data sample



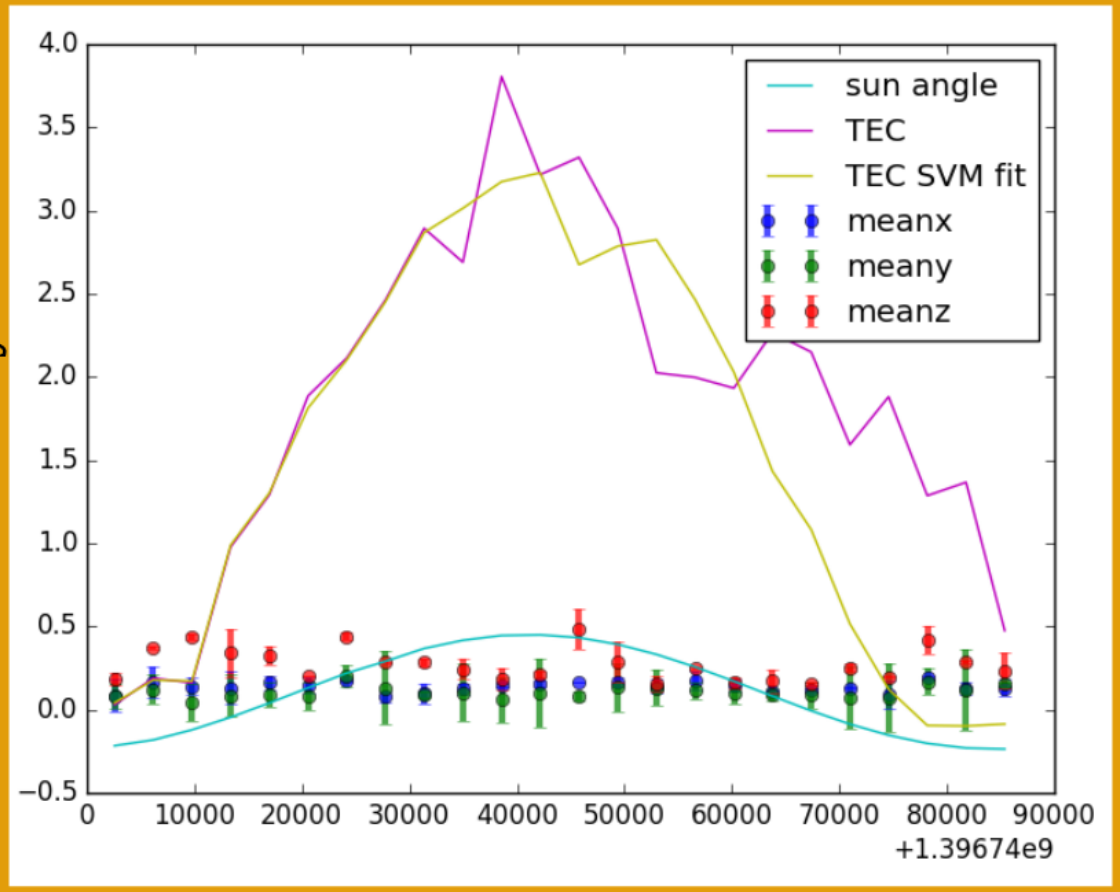
EISCAT data: time averaged total electron content, measured by atmosperic radar.

- 700 data points GPS data (Bjoröklubb, Göteborg, Järnäs & Kapellskär).
- EISCAT data from Tromsø (every minute).



GPS data: time averaged position error in lat. long and altitude (for 1 hour)

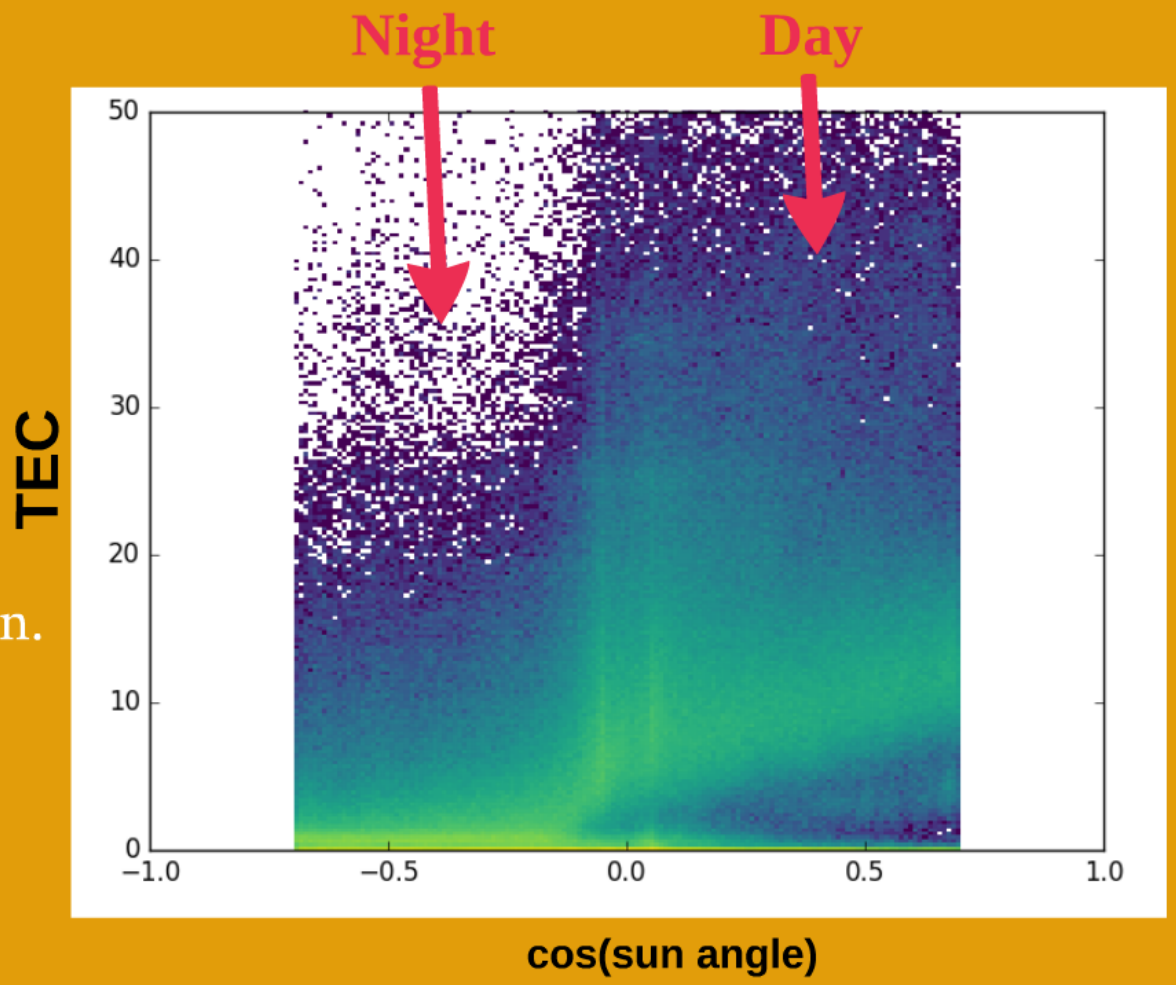
One day, one station



- DGPS data for 2016-04-06
- Error bars show rms error for the hour.
- The fit to the TEC show day-night variation.
- Data is fitted only to the first 12 hours.
- The last 12 hours are predicted.

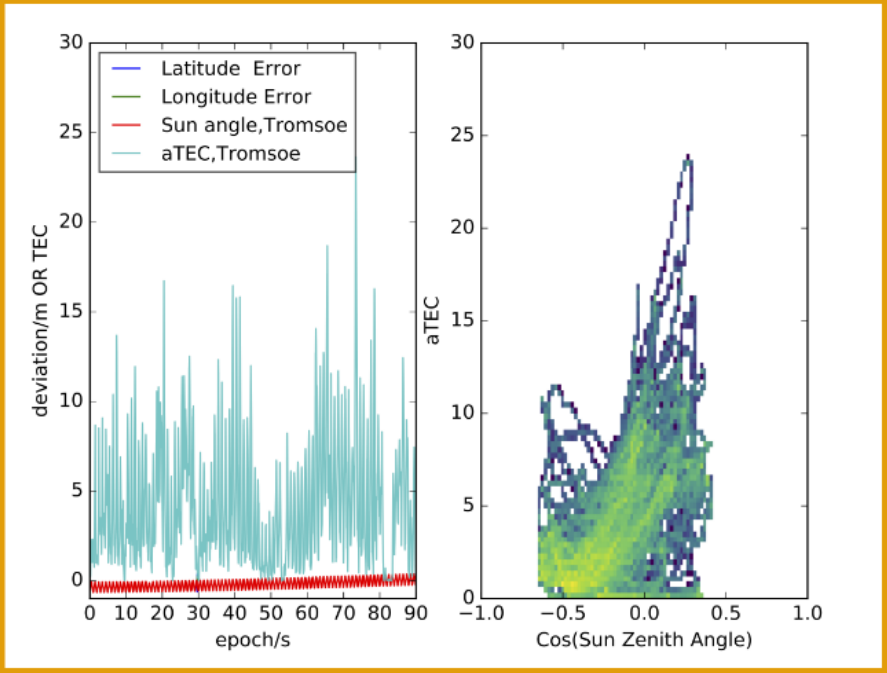
Years of TEC data

- Day night variation is the strongest effect on the TEC
- Sun ionizes part of the ionosphere.
- Fat tails in the TEC distribution.



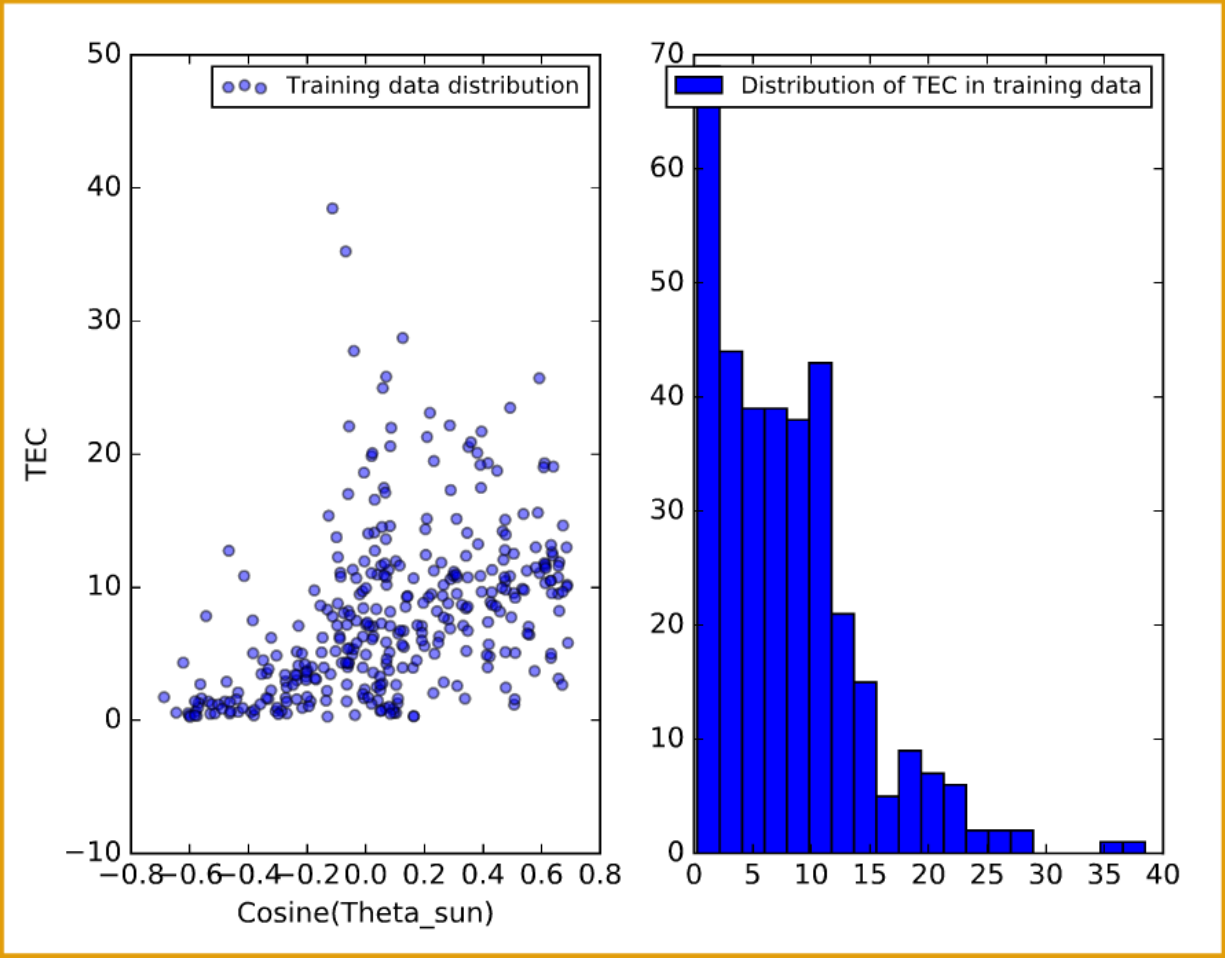
Let's look at a shorter period

For a three month stretch of TEC data, some "trips" of very high TEC is visible.



Synchronize with DGPS data

The DGPS data we have does not cover this entire period. Instead, we have hour-averaged measurements from four stations (and RMS values) for in total 700 hours, spread over four years.



Predicting TEC using the Sun-angle and DGPS errors

Using all variables

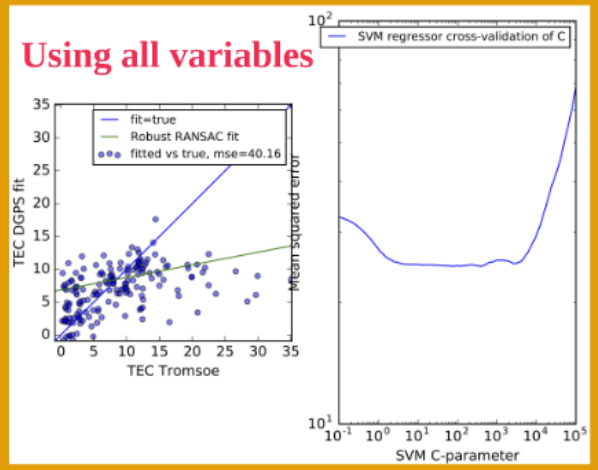
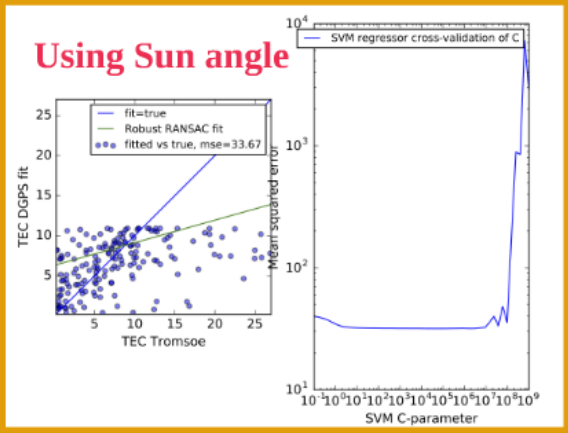


Figure of merit

$$C_{\text{score}} \equiv (1/N) \sum_{\text{validation}} (x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (z_i - \hat{z}_i)^2$$

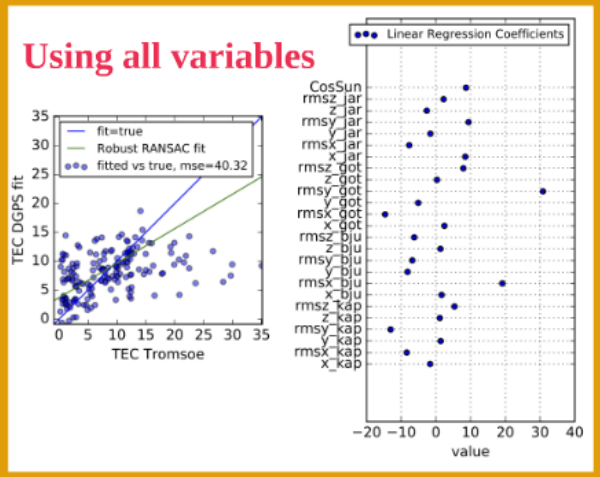
Using Sun angle



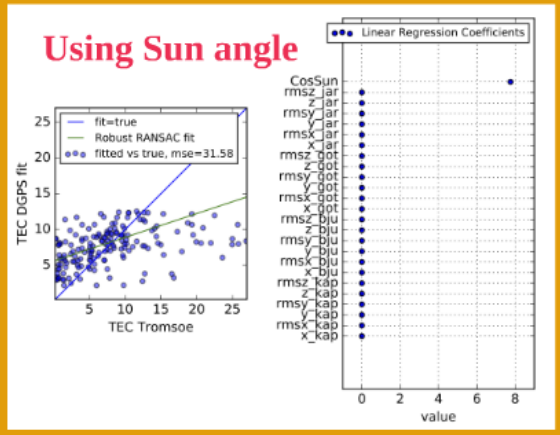
SVM

Linear Regression

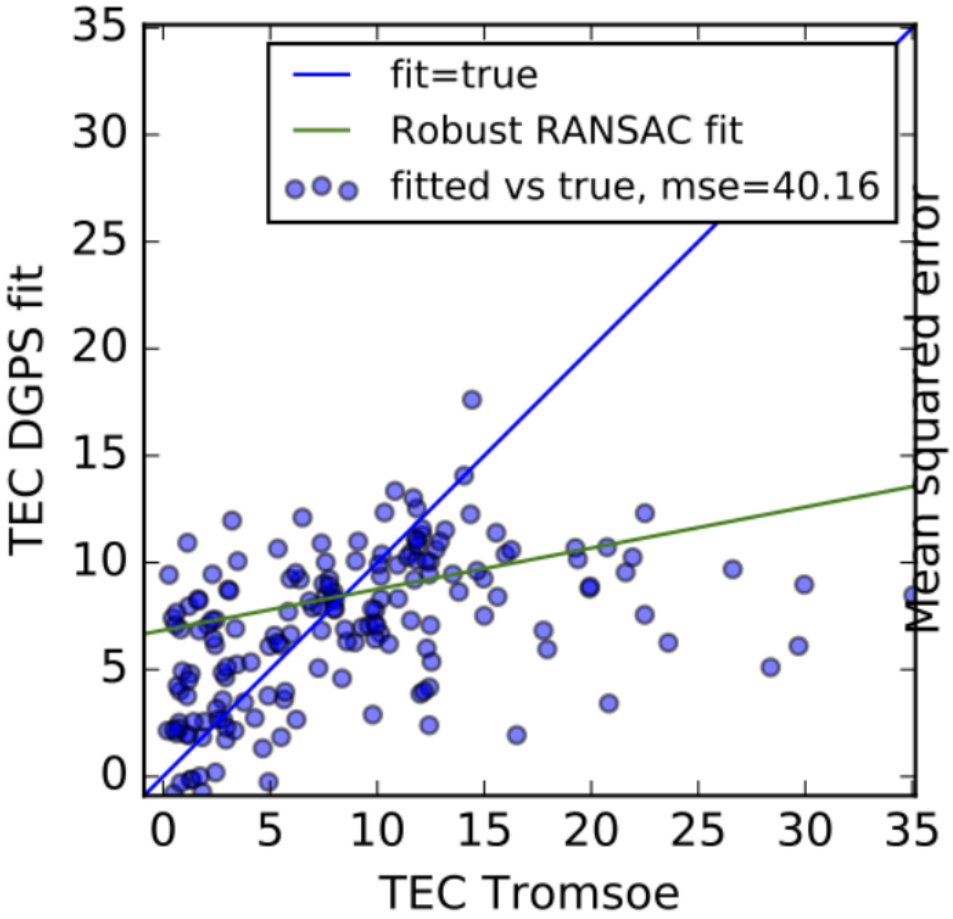
Using all variables

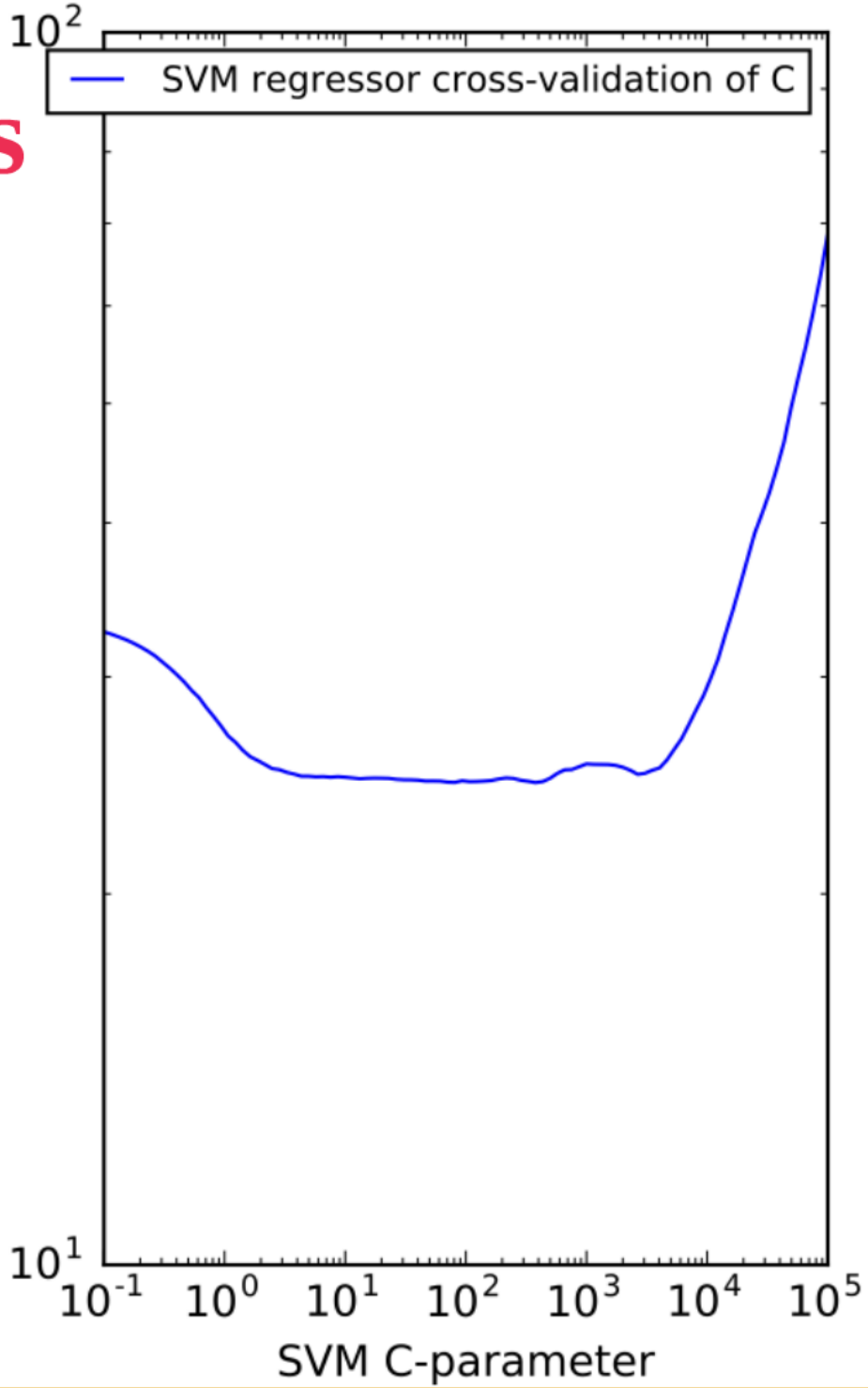


Using Sun angle

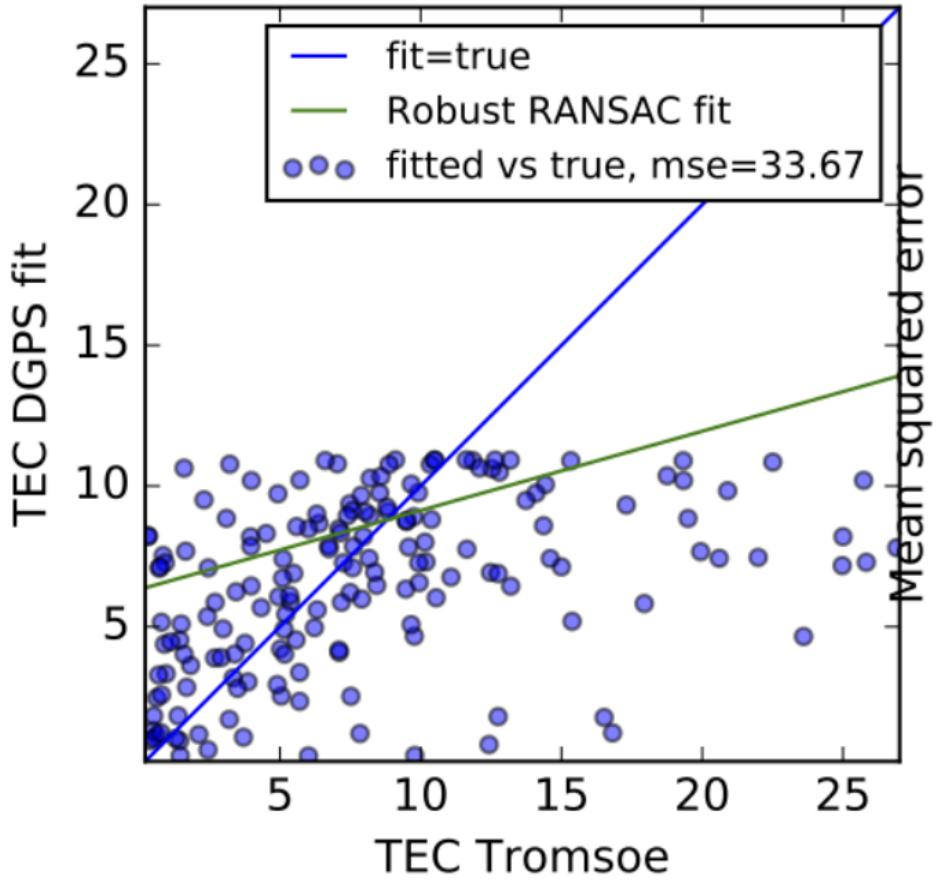


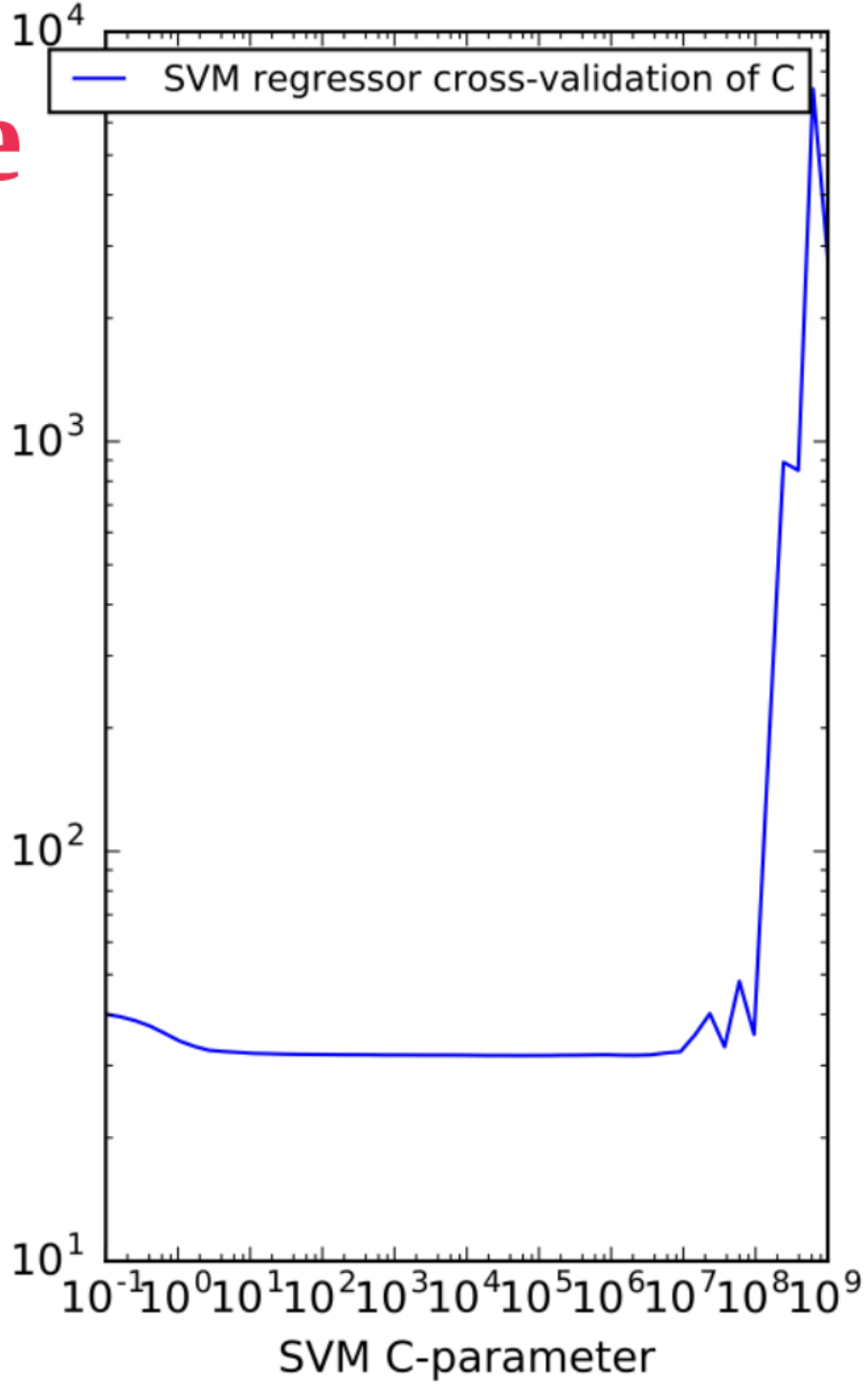
Using all variables





Using Sun angle



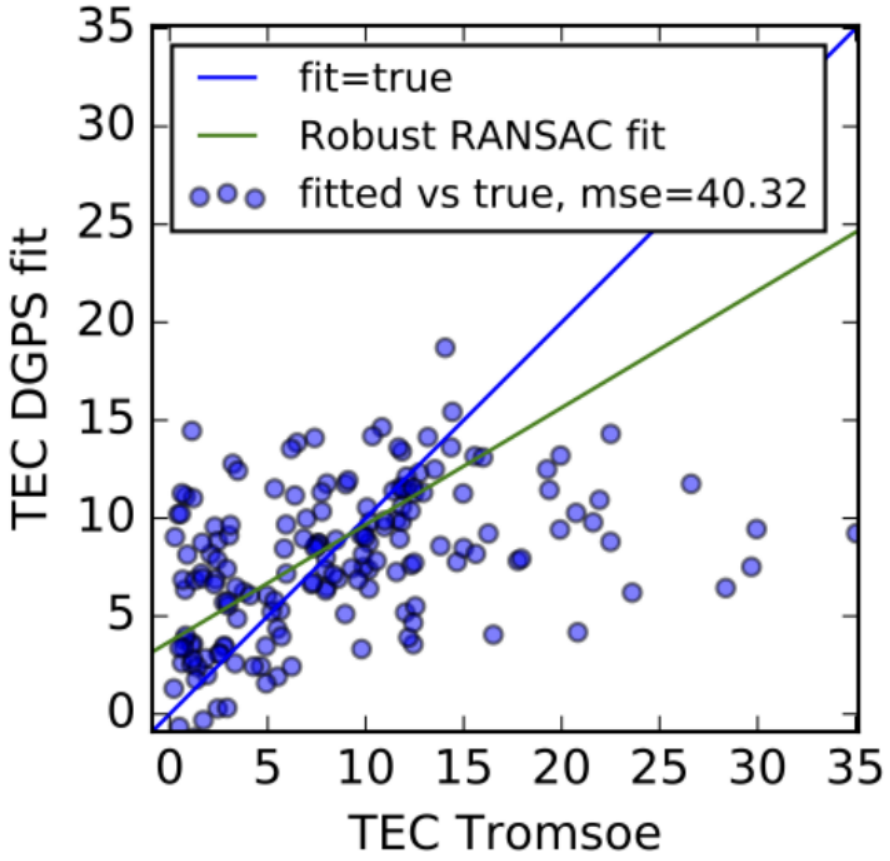


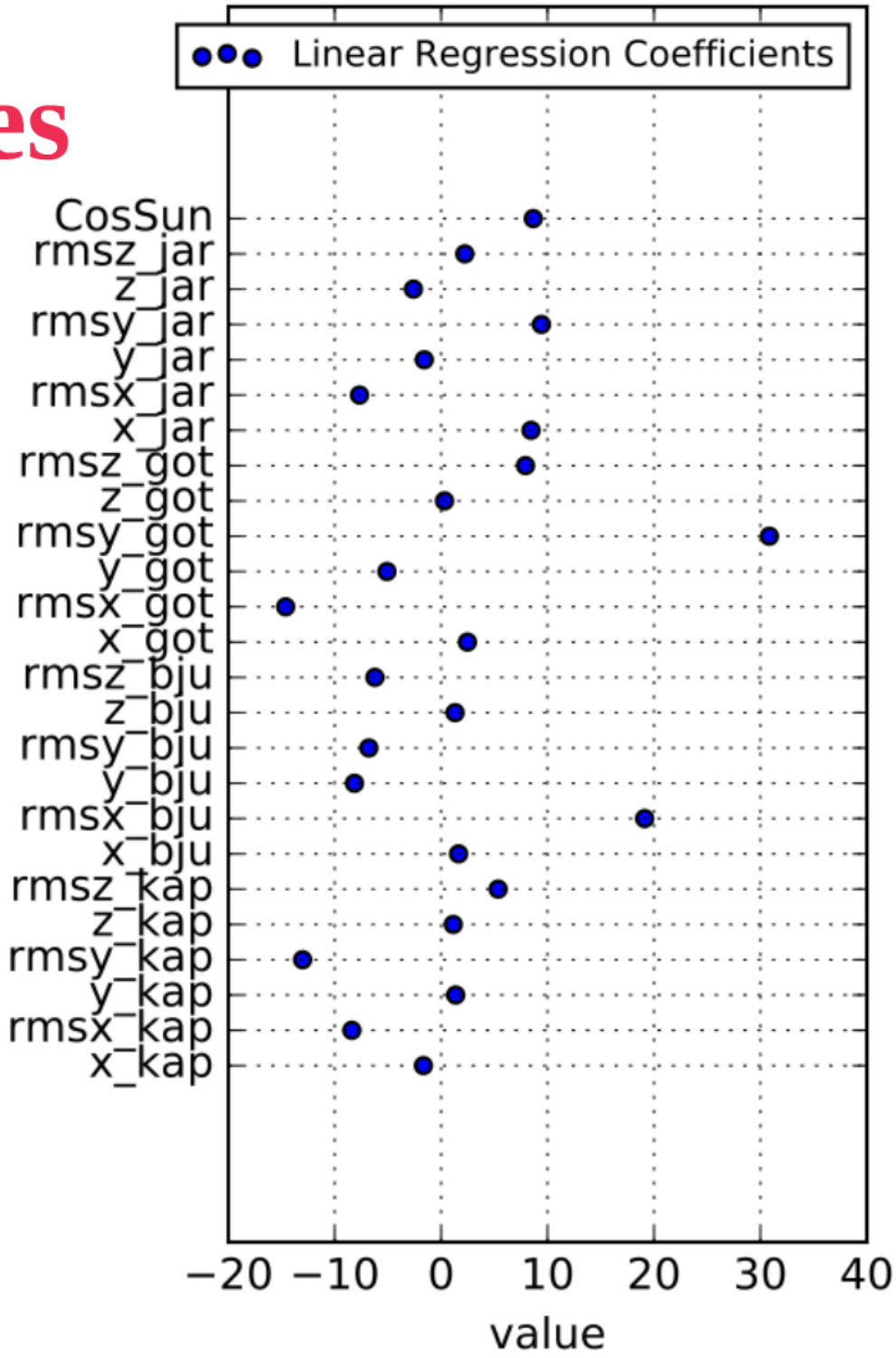
HE SUN-ANGLE AND DGPS ER

Figure of merit

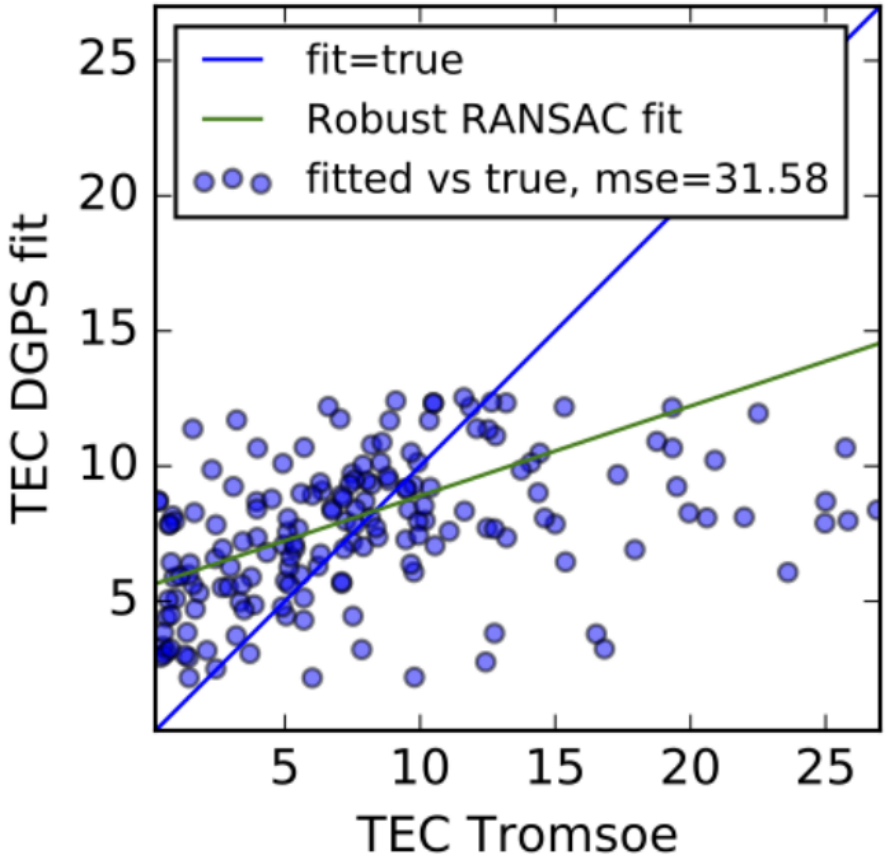
$$C_{\text{score}} \equiv (1/N) \sum_{\text{validation}} (x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2 + (z_i - \hat{z}_i)^2$$

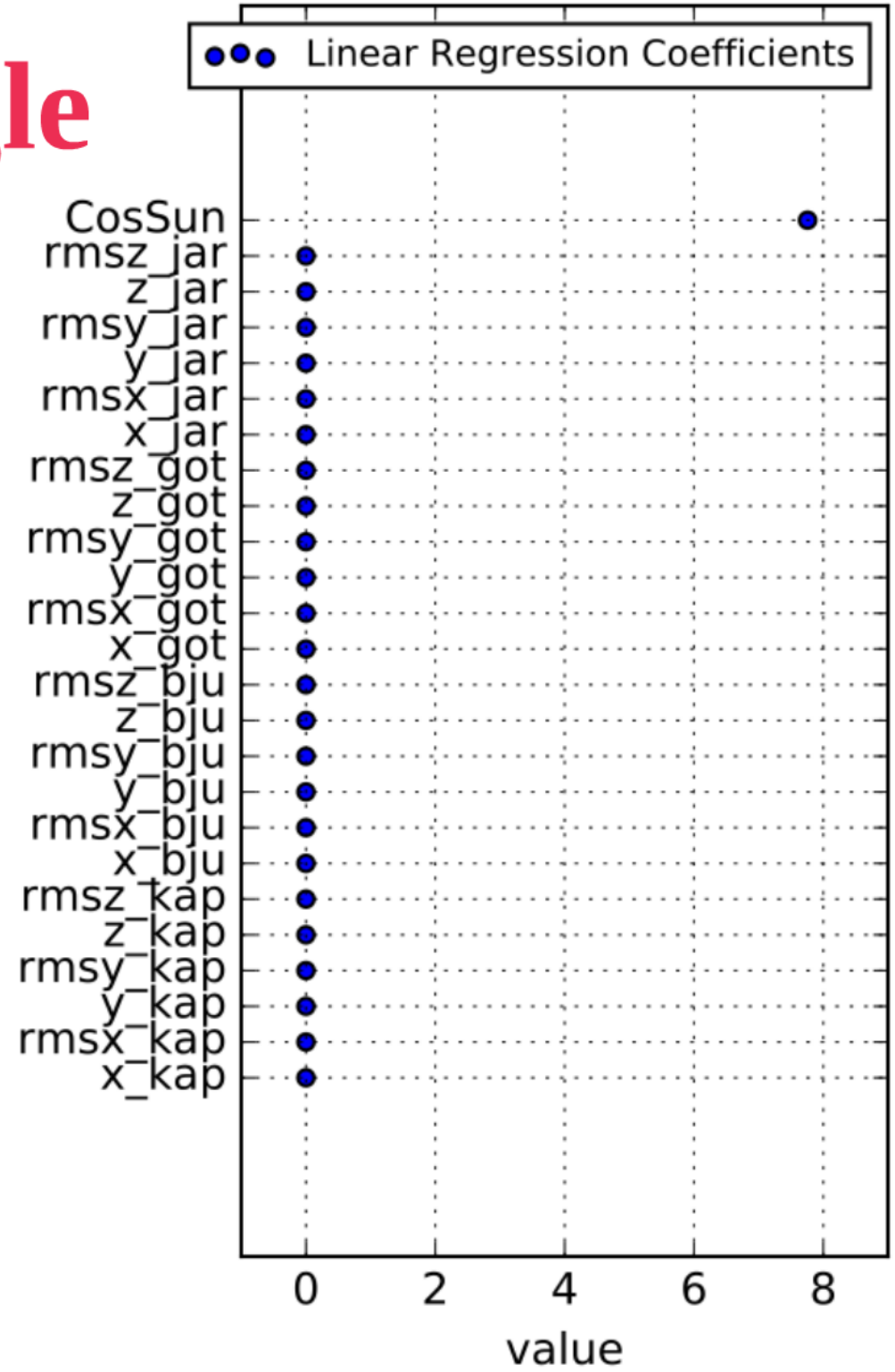
Using all variables





Using Sun angle





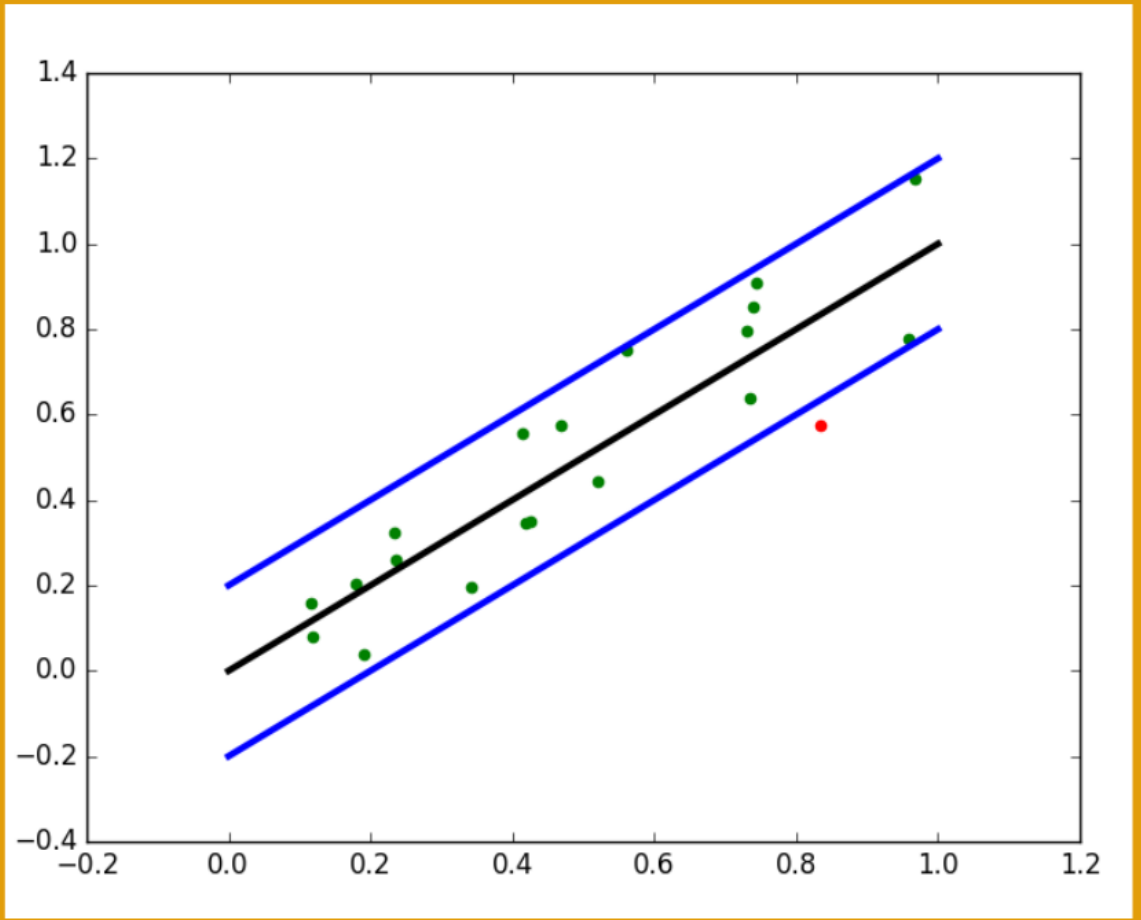
How does SVM regression work?

SVMs in regression mode finds the line (black) that is at most epsilon from any other points.

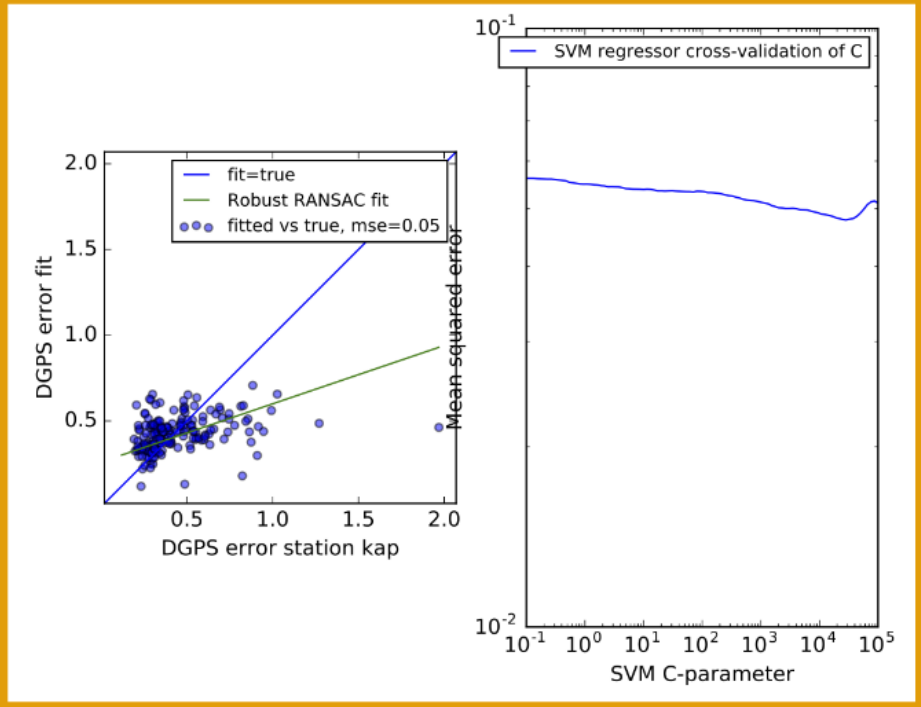
A more sophisticated approach allows a linear loss term for outliers (red).

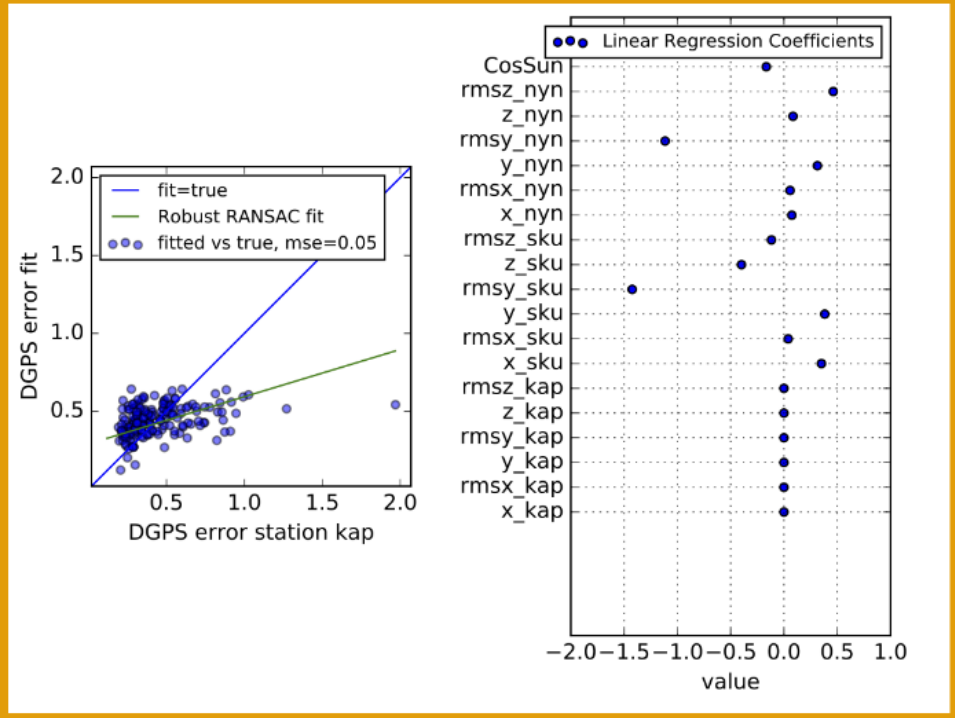
The "C" term adjust the importance of this linear loss term.

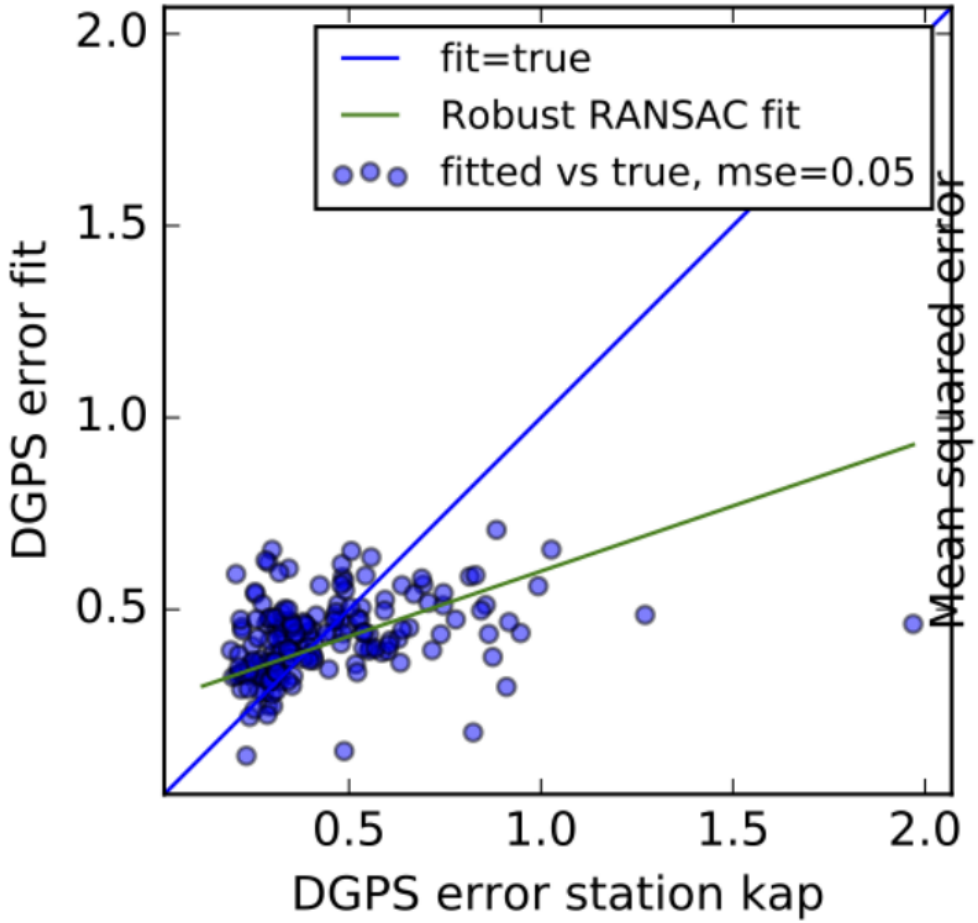
As we cross-checked with a linear regression, using the much-used rbf-kernel (a Gaussian, essentially) was chosen.

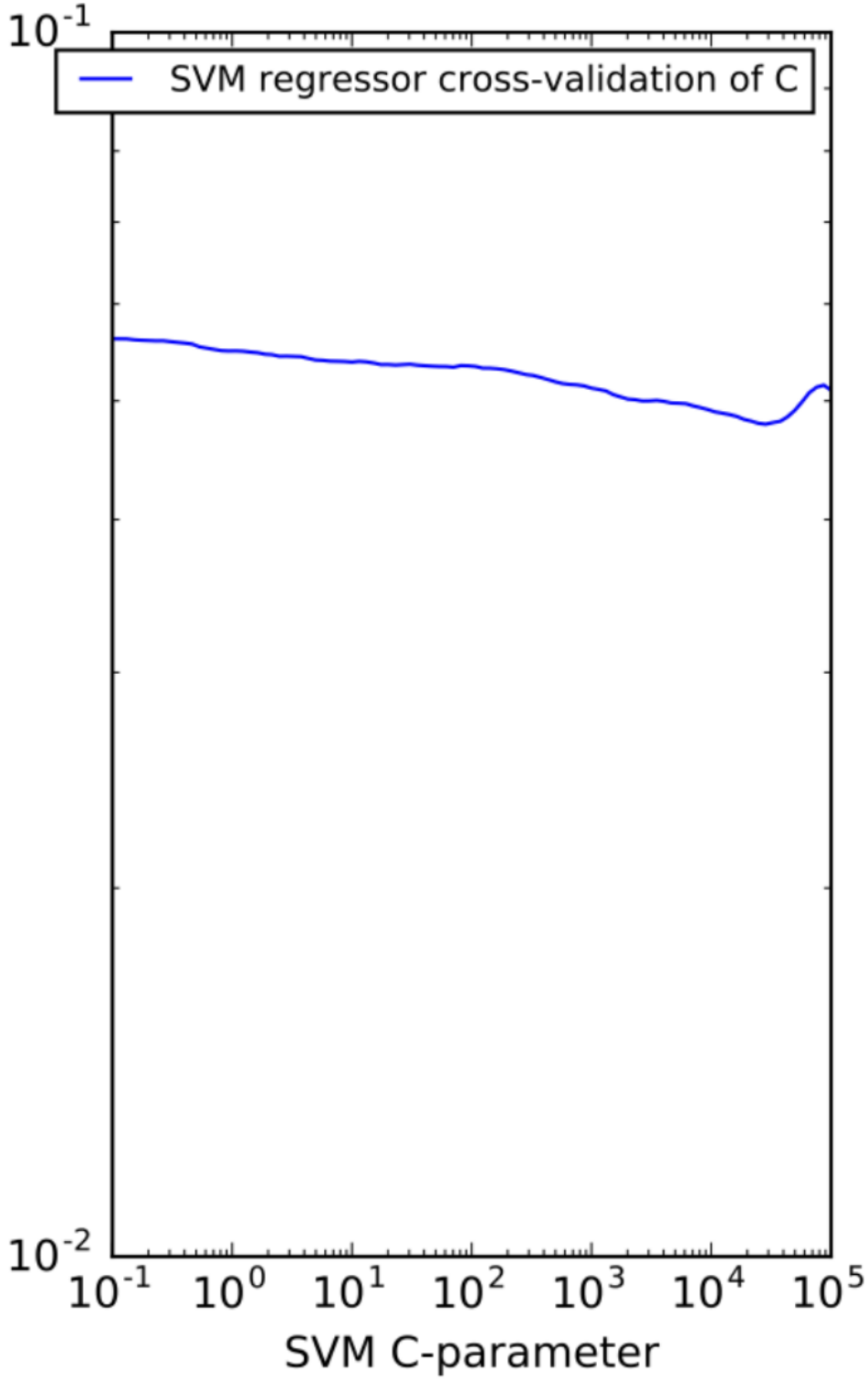


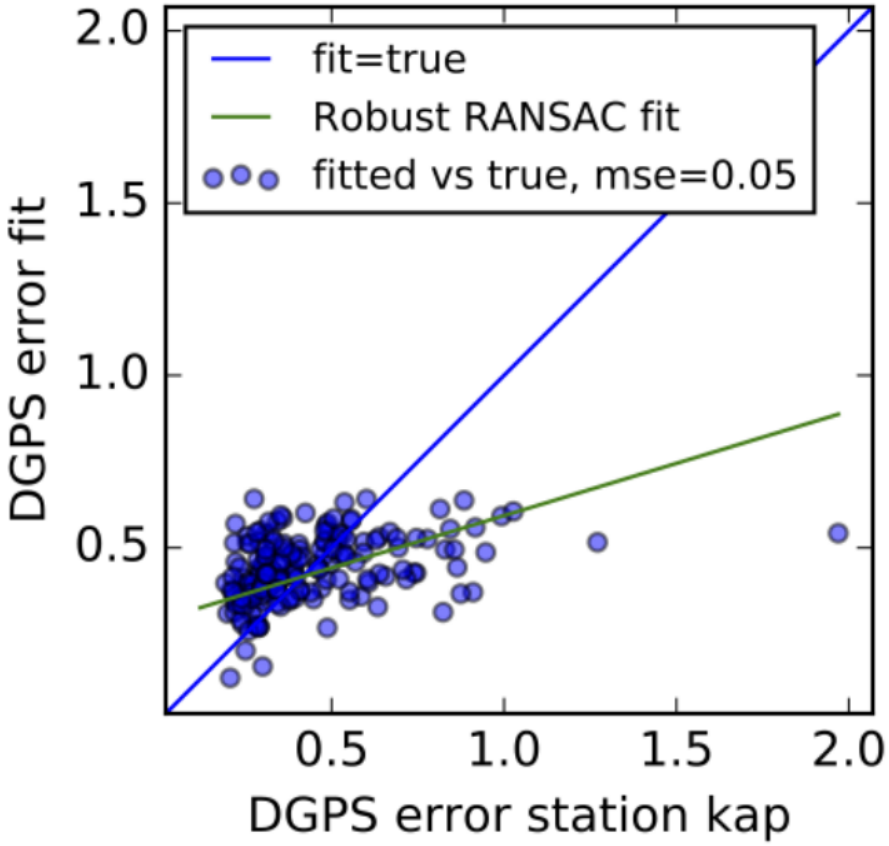
Interpolation between GPS stations






fit=true
Robust RANSAC fit
fitted vs true, mse=0.05
DGPS error fit
DGPS error station kap
2.0
1.5
1.0
0.5
0.5
1.0
1.5
2.0


SVM regressor cross-validation of C
Mean squared error
SVM C-parameter
10^{-1}
10^{-2}
10^{-1} 10^{0} 10^{1} 10^{2} 10^{3} 10^{4} 10^{5}


fit=true
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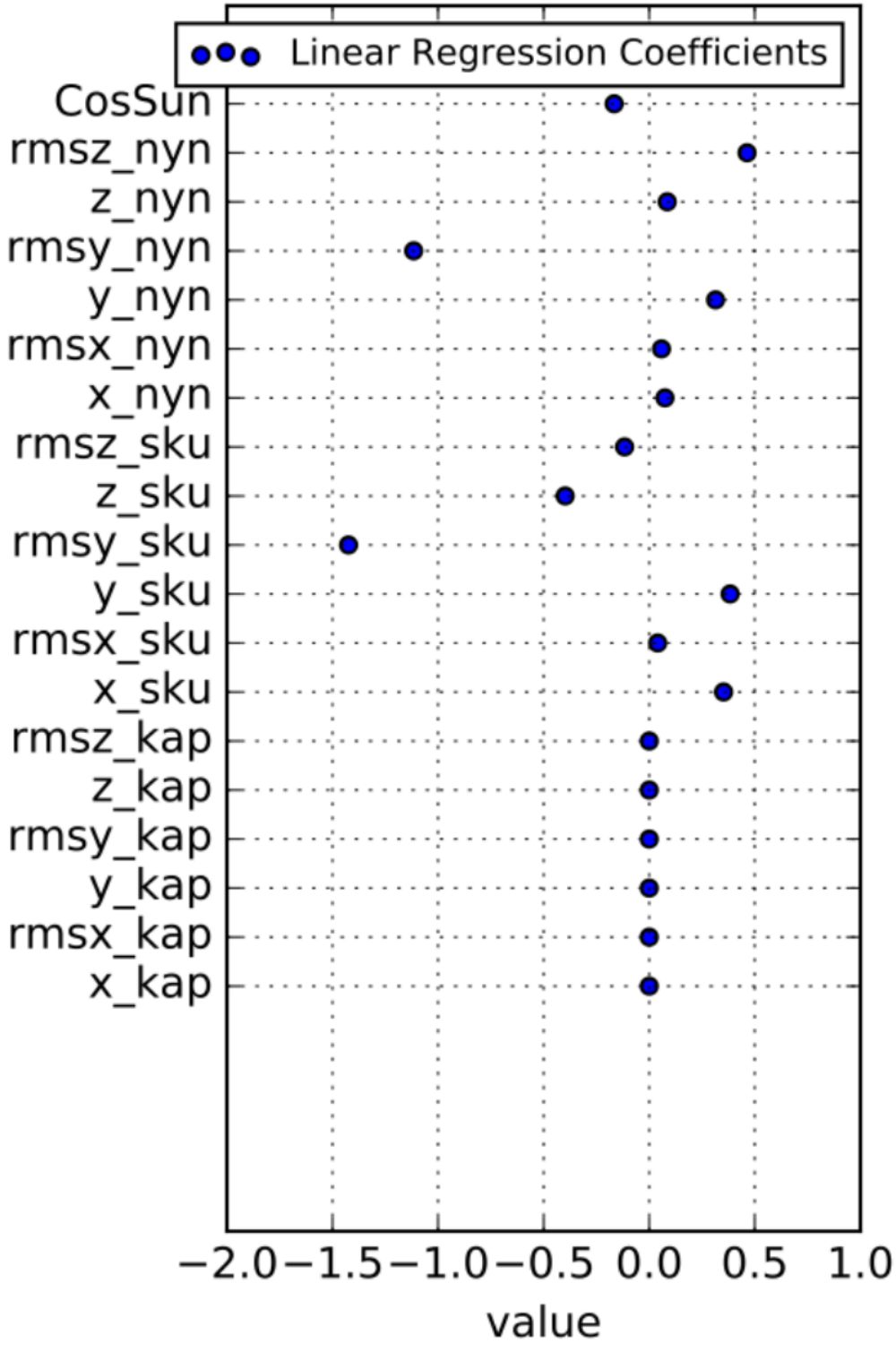
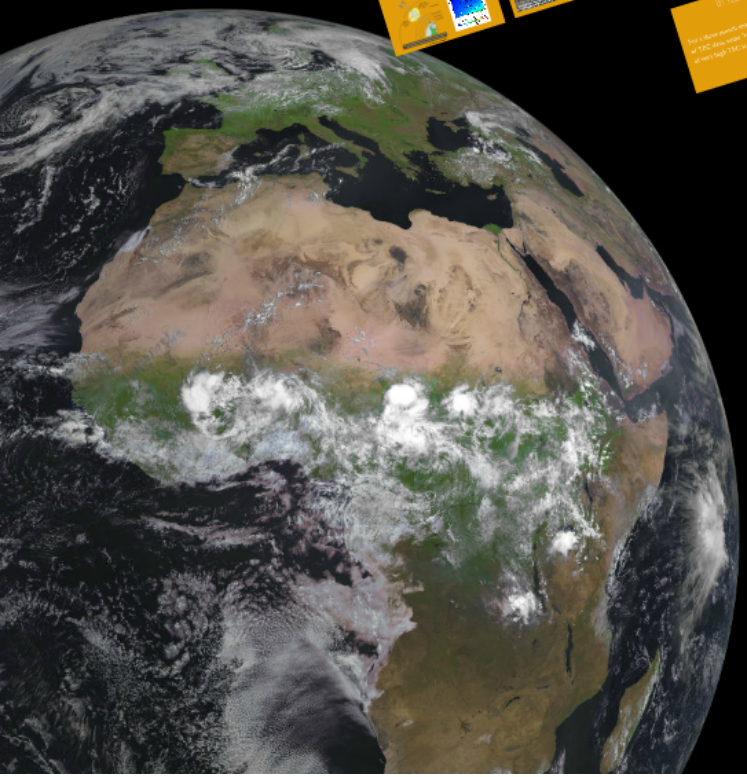
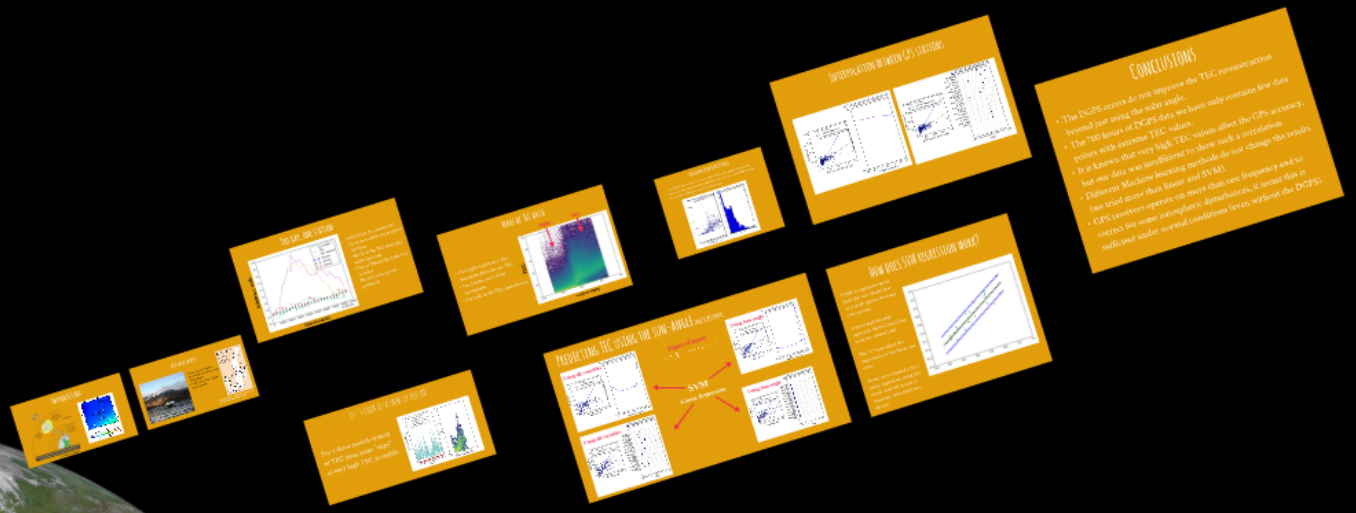
1.0
0.5
0.5
1.0
1.5
2.0


Linear Regression Coefficients
CosSun
rmsz_nyn
z_nyn
rmsy_nyn
y_nyn
rmsx_nyn
x_nyn
rmsz_sku
z_sku
rmsy_sku
y_sku
rmsx_sku
x_sku
rmsz_kap
z_kap
rmsy_kap
y_kap
rmsx_kap
x_kap
−2.0 −1.5 −1.0 −0.5 0.0 0.5 1.0
value

Conclusions

- The DGPS errors do not improve the TEC reconstruction beyond just using the solar angle.
- The 700 hours of DGPS data we have only contains few data points with extreme TEC values.
- It is known that very high TEC values affect the GPS accuracy, but our data was insufficient to show such a correlation.
- Different Machine learning methods do not change the results (we tried more than linear and SVM).
- GPS receivers operate on more than one frequency and so correct for some ionospheric disturbances, it seems this is sufficient under normal conditions (even without the DGPS).





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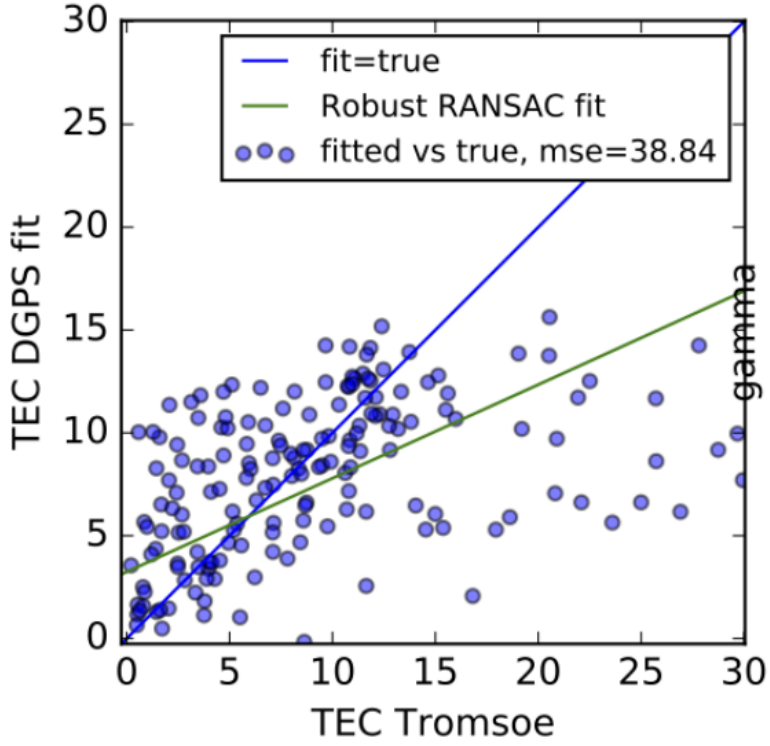
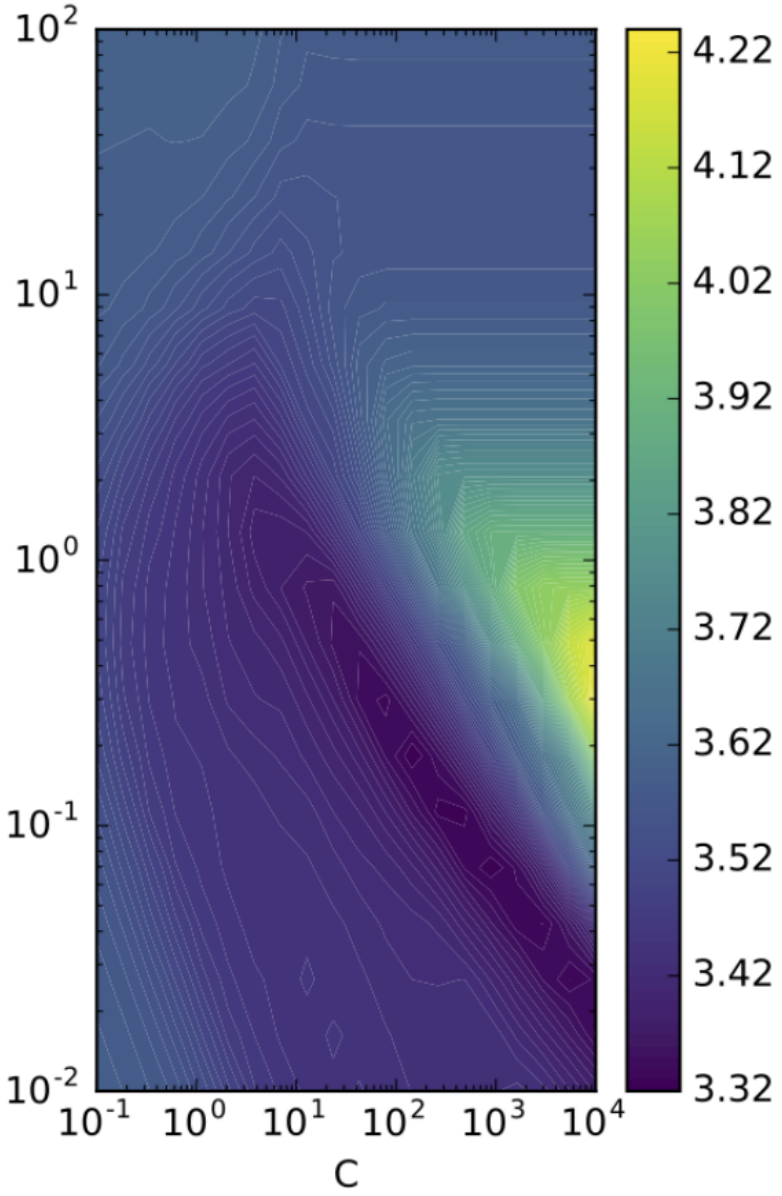
More X-validation





Higher resolution