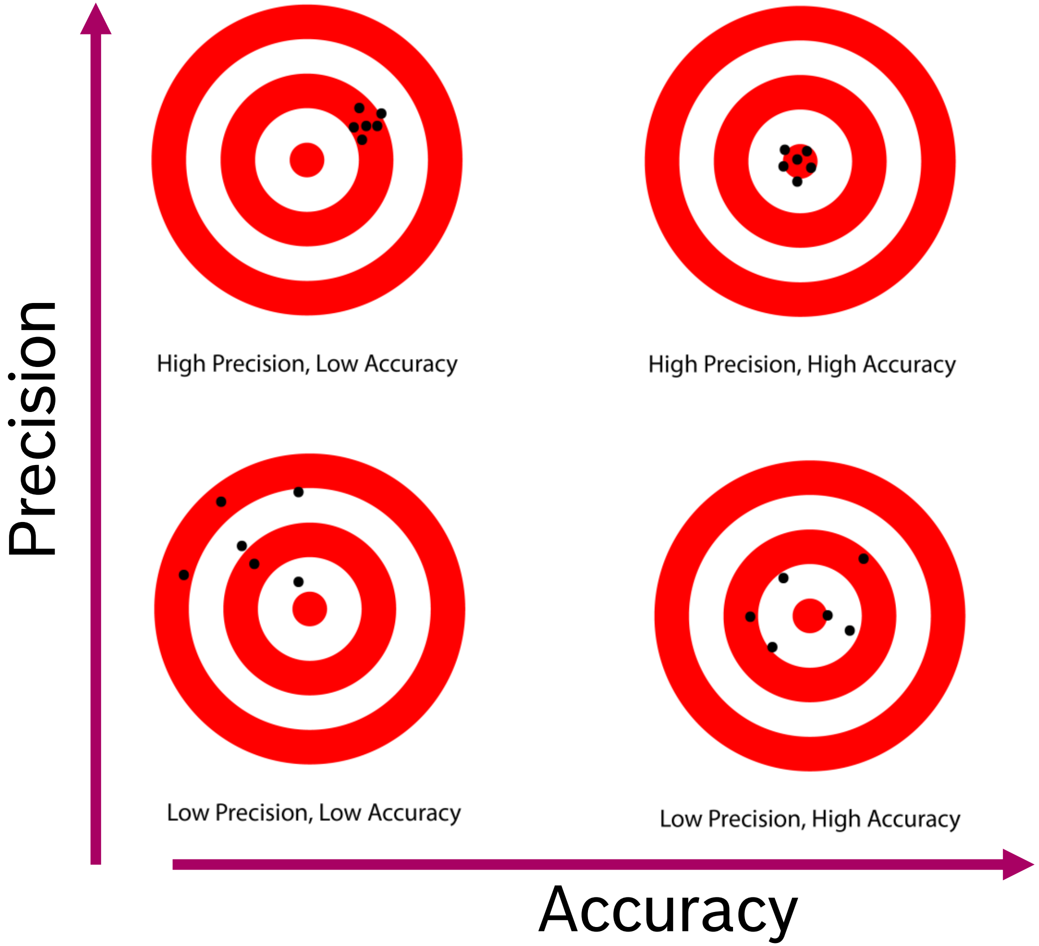
ANALYZIS OF EGNOS IONOSPHERIC MODEL

Introduction to Integrity
Integrity – the aim of the EGNOS analyzis

„Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes the ability of the system to provide timely warnings to users when the system should not be used for navigation”
- *This definition was adapted from the 2008 US Federal Navigation Plan - Navipedia*

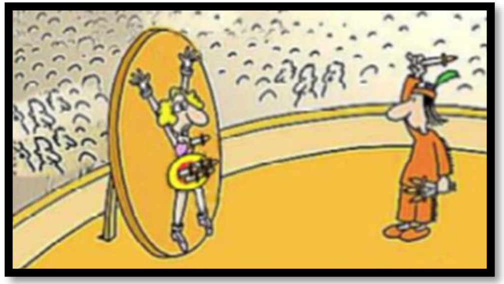
Introduction
Definition of performace key parameter

Accuracy: Measure of navigation output **deviating from truth**.
Integrity: Ability of a system to **provide timely warnings** when the system should not be used for navigation. Integrity risk is the probability of an undetected, threatening navigation system problem.
Availability: Fraction of time navigation system is **usable as determined by compliance with accuracy, integrity and continuity requirements**.
Continuity: Likelihood that the navigation **supports accuracy and integrity requirements for the duration of intended operation**. Continuity risk is the probability of a detected but unscheduled navigation interruption after initiation of an operation.



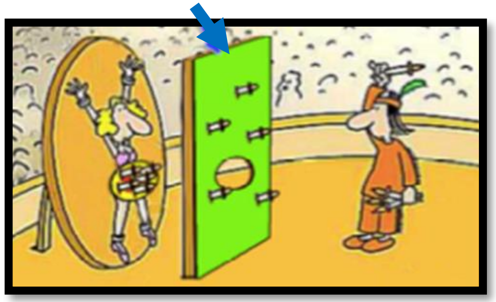
Introduction
System performance

- System performance:
  Accuracy, **Integrity**, **Availability**, **Continuity**

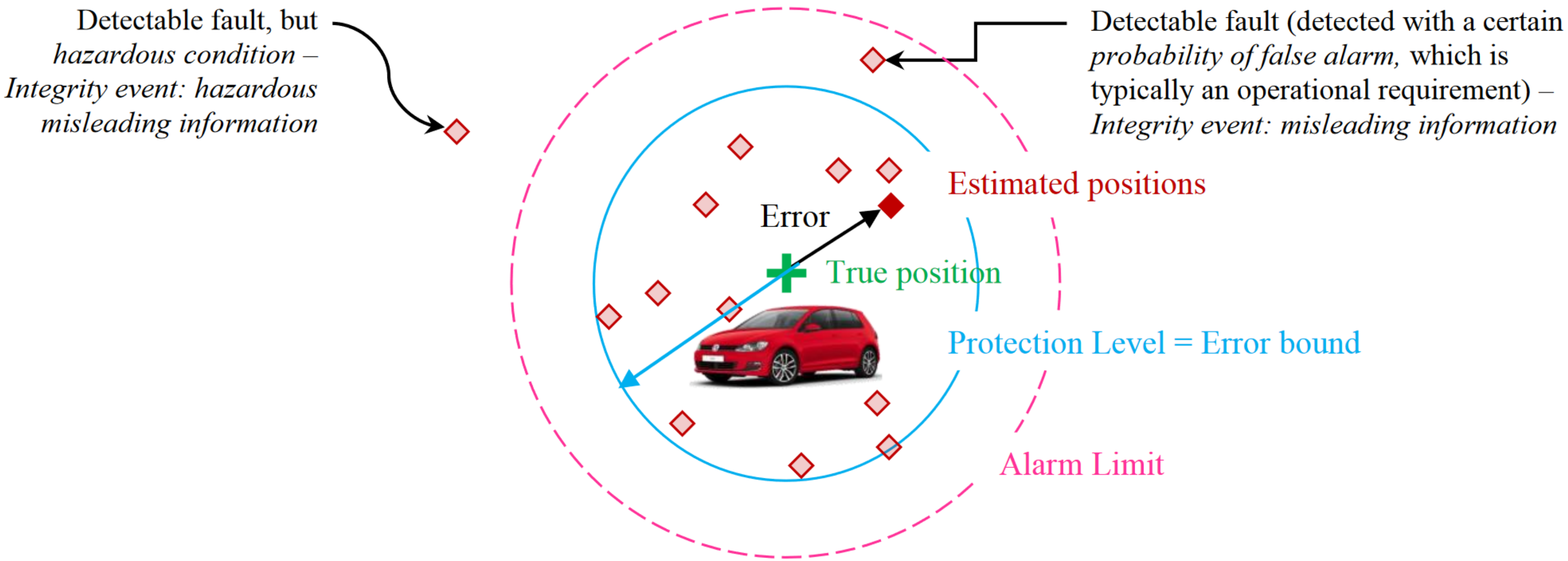


High accuracy, poor integrity

Integrity monitoring/mechanisms



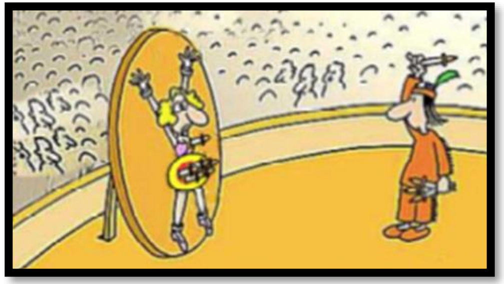
Poor accuracy, high integrity



The concepts of Protection Level, Alarm Limit and integrity events.

Introduction
Stanford diagram

- System performance:
  Accuracy, **Integrity**, **Availability**, **Continuity**



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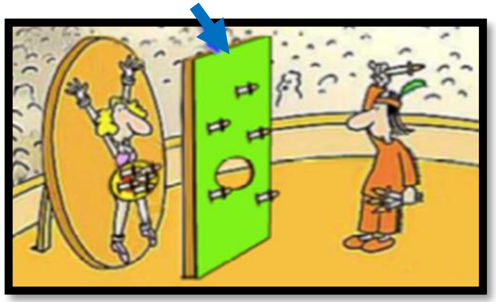

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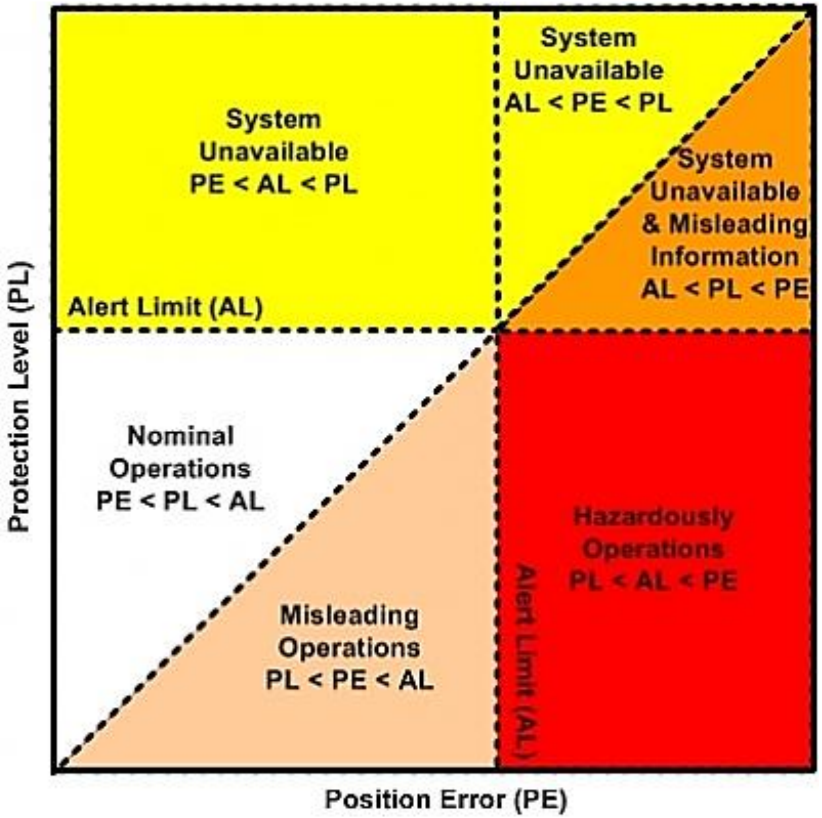

AL: Alert Limit

PL: Protection Level

PE: Position Estimation

HMI: Hazardously Misleading Information

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EGNOS
RTCA's protection level calculation

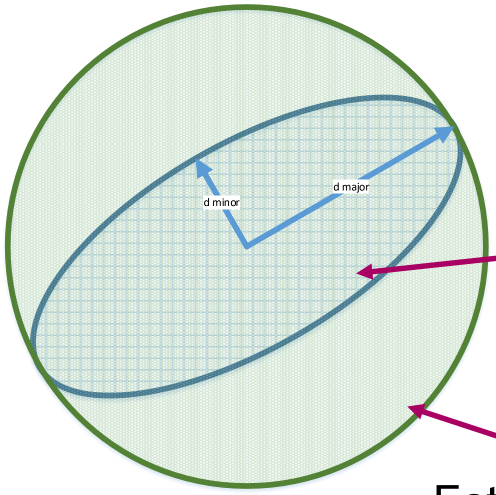
Horizontal protection level

$$HPL = K_H d_{major}$$

$K_H = 6.0 \; - position \; probability \; 10^{-7}$

Variance of the residual after application of ionospehric error

$$\sigma_i^2 = \sigma_{i,flt}^2 + \sigma_{i,UIRE}^2 + \sigma_{i,air}^2 + \sigma_{i,tropo}^2$$



Ellipsoid of projection matrix

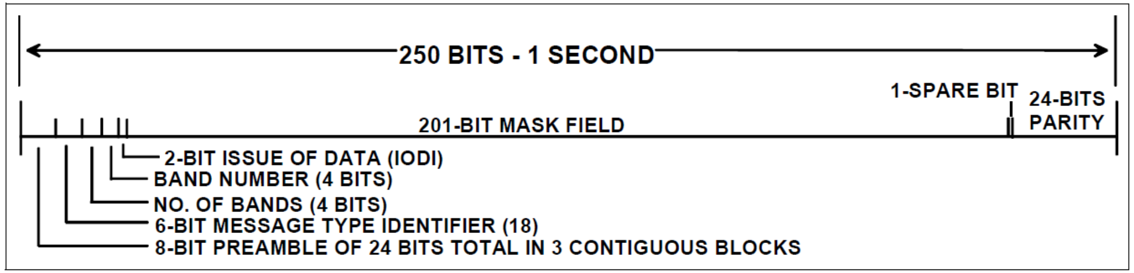
Estimation of protection level

Inverse cummulative function of 2D Gaussian

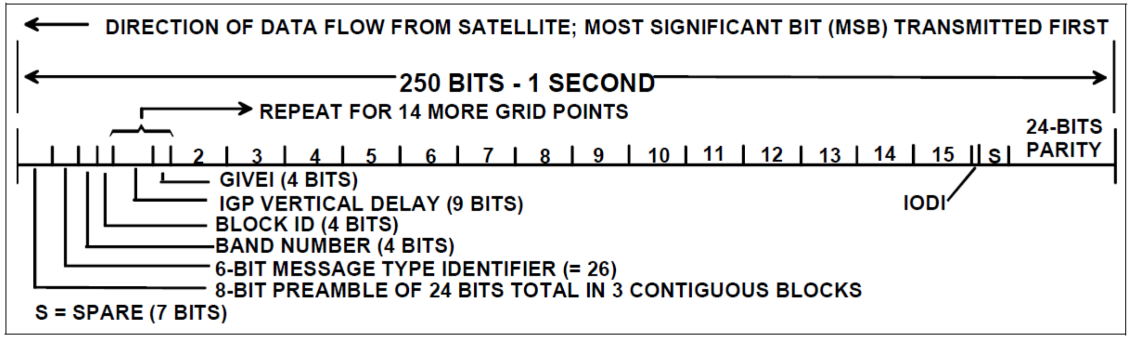
$$r = F^{-1}(p) = \sqrt{-2\ln(1-p)}$$

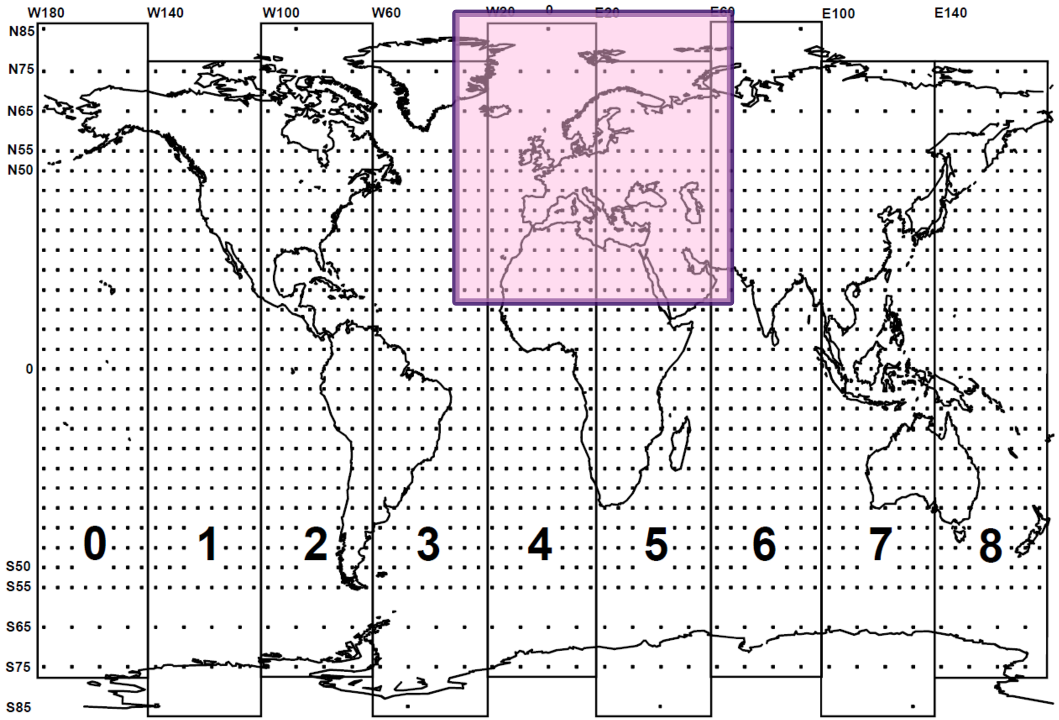
EGNOS
Ionospheric Grid Point and Message Formats

IGP Mask Message Format



Ionospheric Delay Corrections Message Format

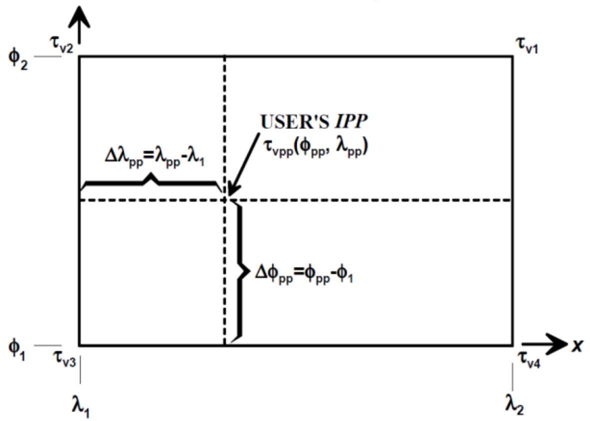


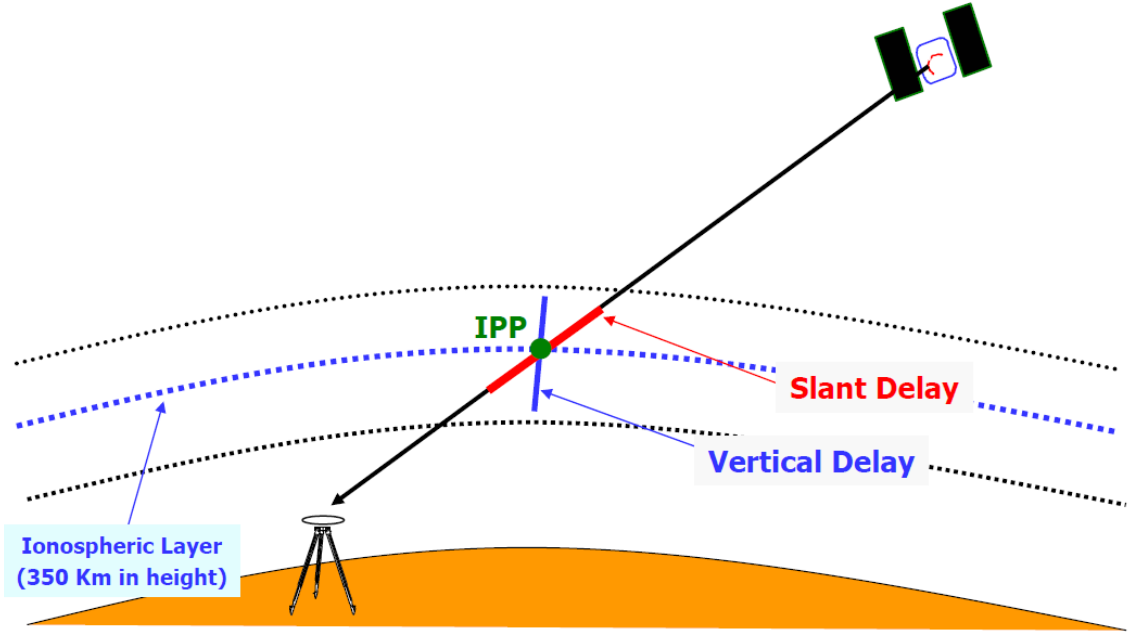


EGNOS
Ionospheric Variance

IONOSPHERIC PIERCE POINTS (IPP)

4 point interpolation algorithm definition





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GINA – Global Integrated Navigation Algorithm
EGNOS

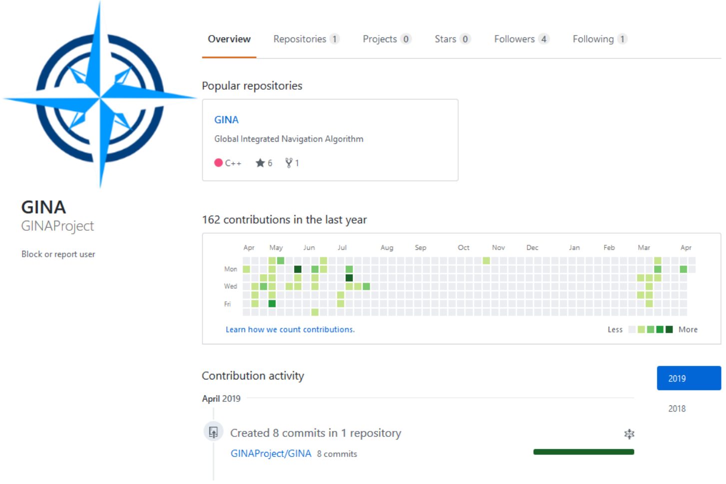
Cmake based C++ project

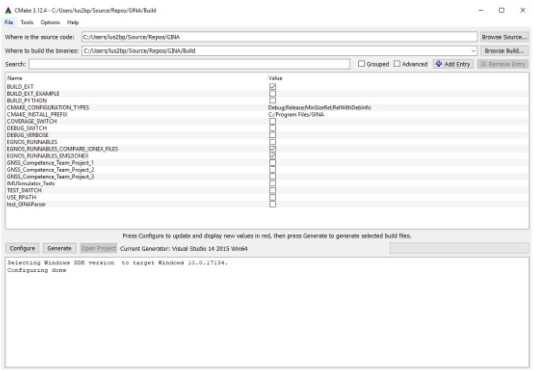
[Github Repo]

Evaulation done by Octova/Matlab

EGNOS is the latest module in GINA

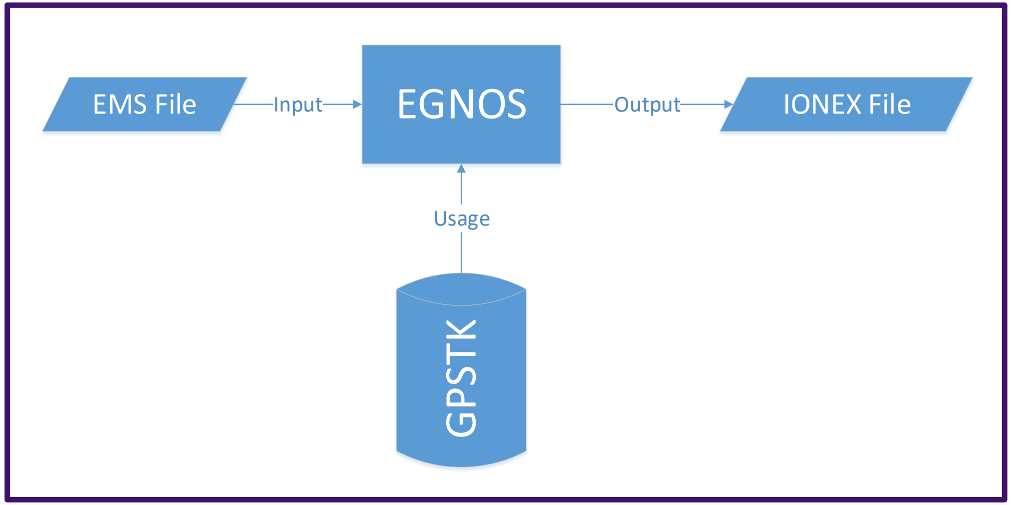
It contains ~4000 Line of Code



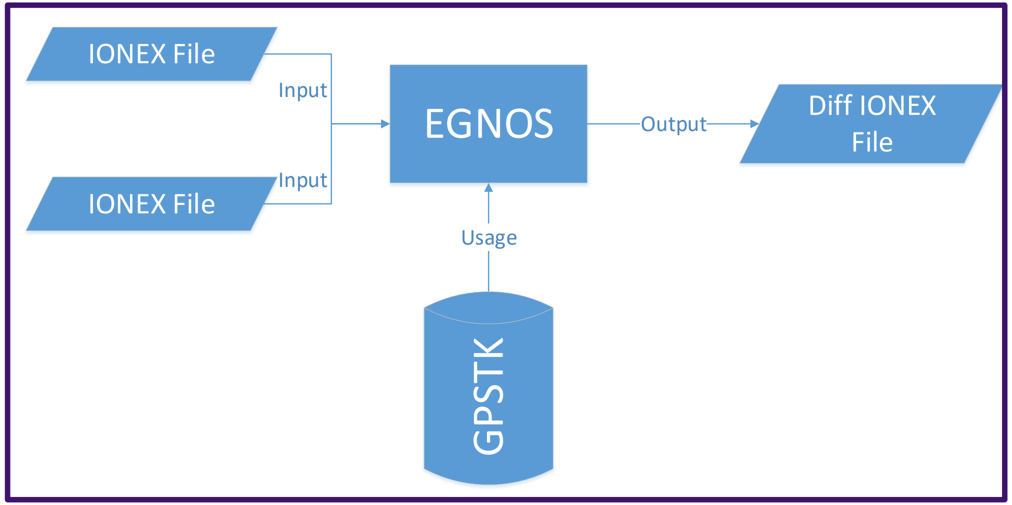


EGNOS - GINA
EGNOS Features – EMS Processing

Create Ionex file from EMS



Difference of Ionex files



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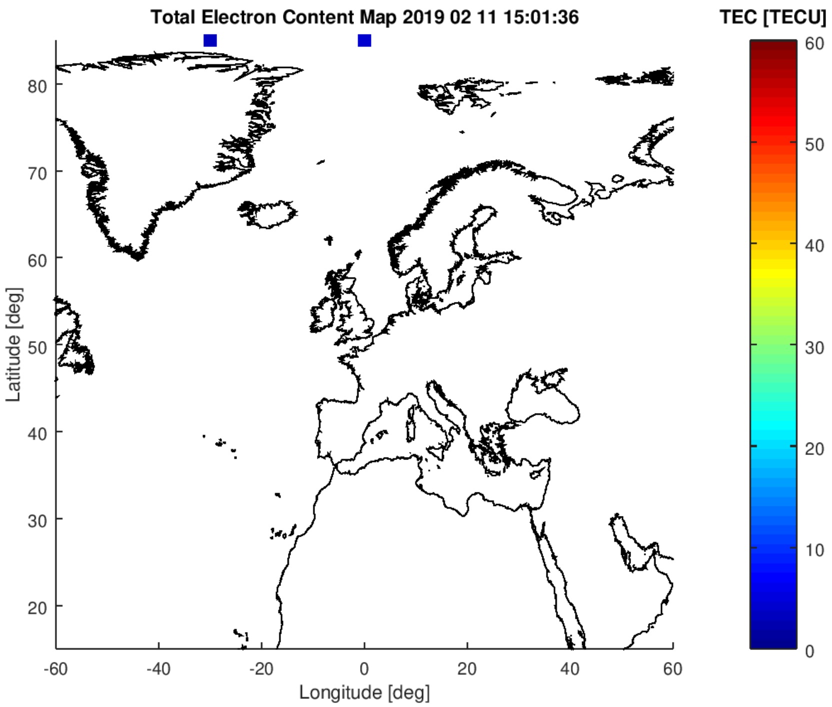
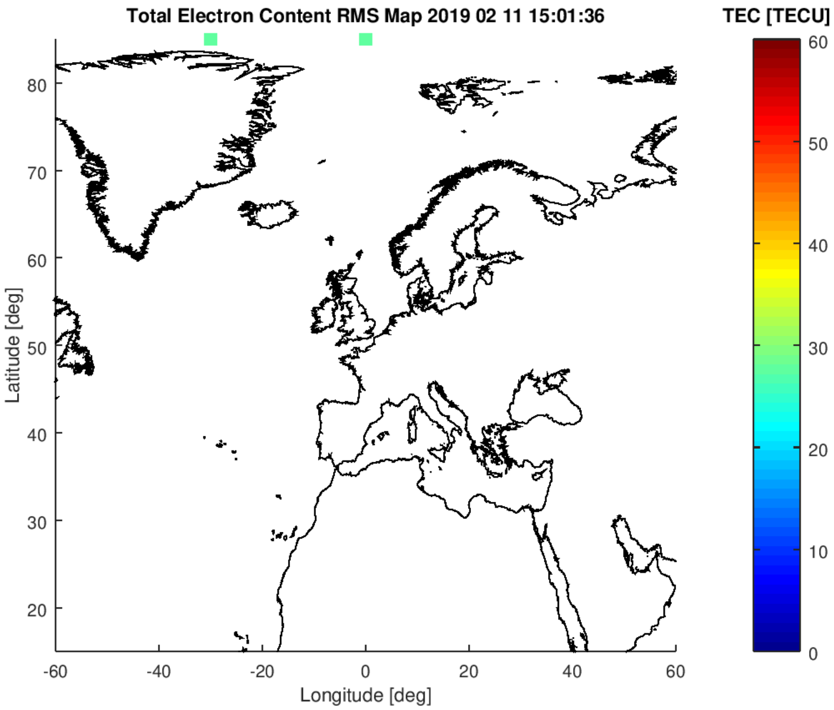
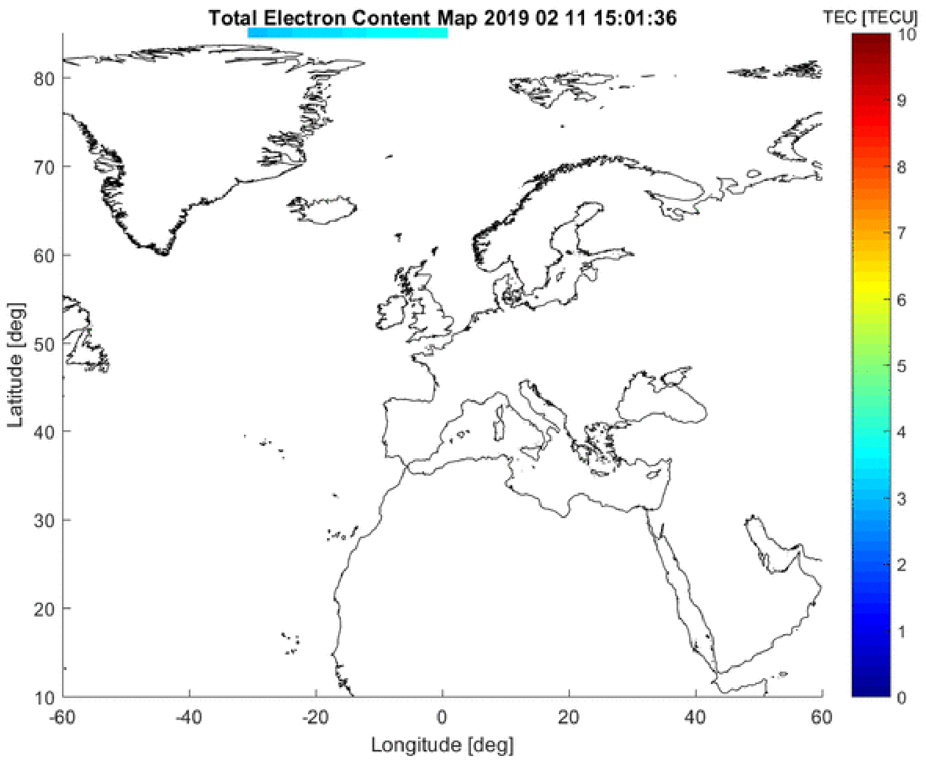
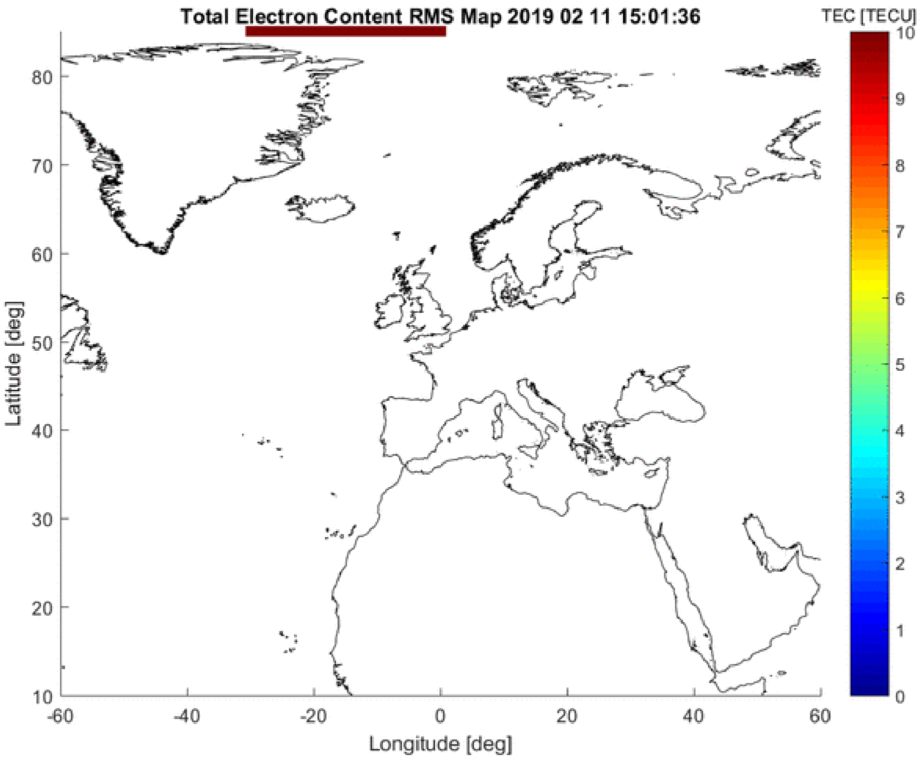
EGNOS - GINA
Raw measurement





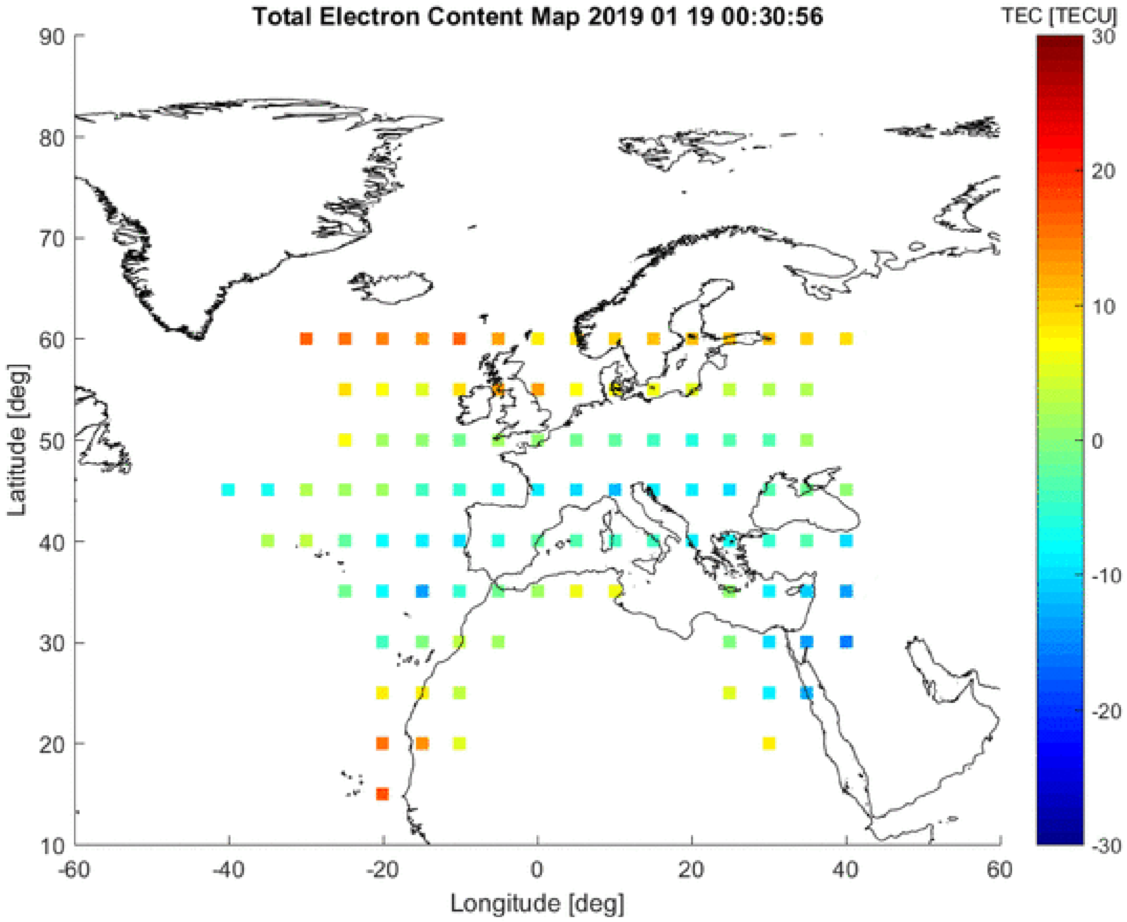
EGNOS - GINA
Interpolated IGPs





EGNOS - GINA
EMS – CODE's GIM

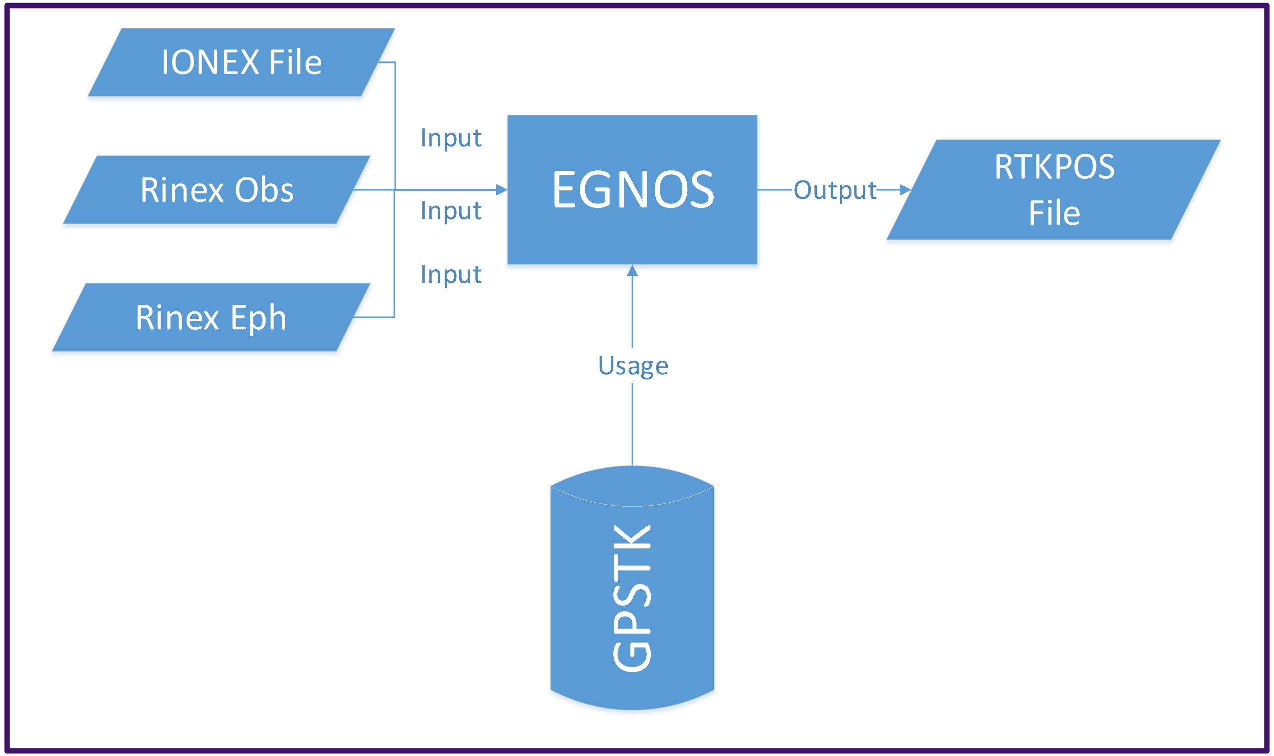
$$dTEC = TEC_1 - TEC_2$$
$$dRMS = \sqrt{RMS_1 + \ RMS_2}$$



EGNOS - GINA

EGNOS Features – Navigation Engine with EGNOS Iono Model

Calculate position with IONEX correction



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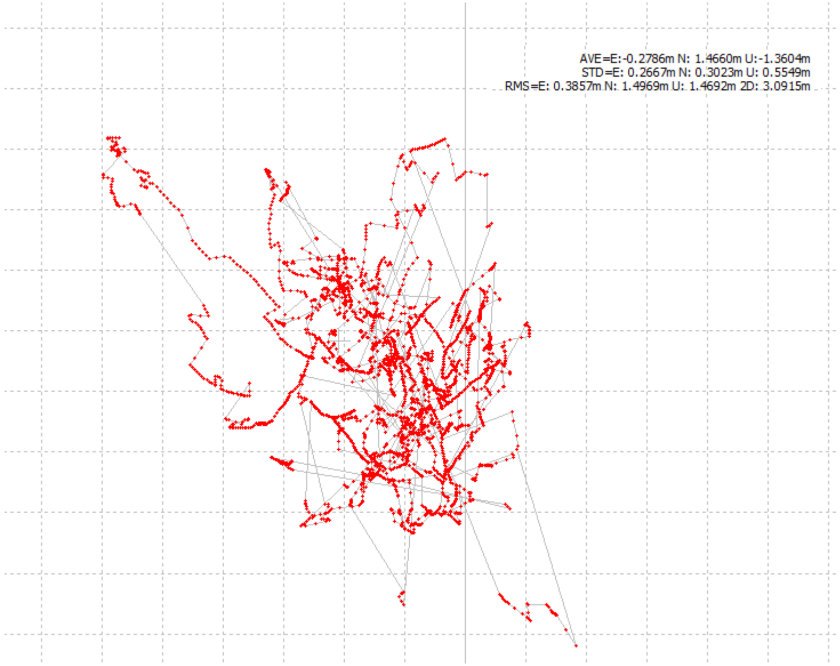
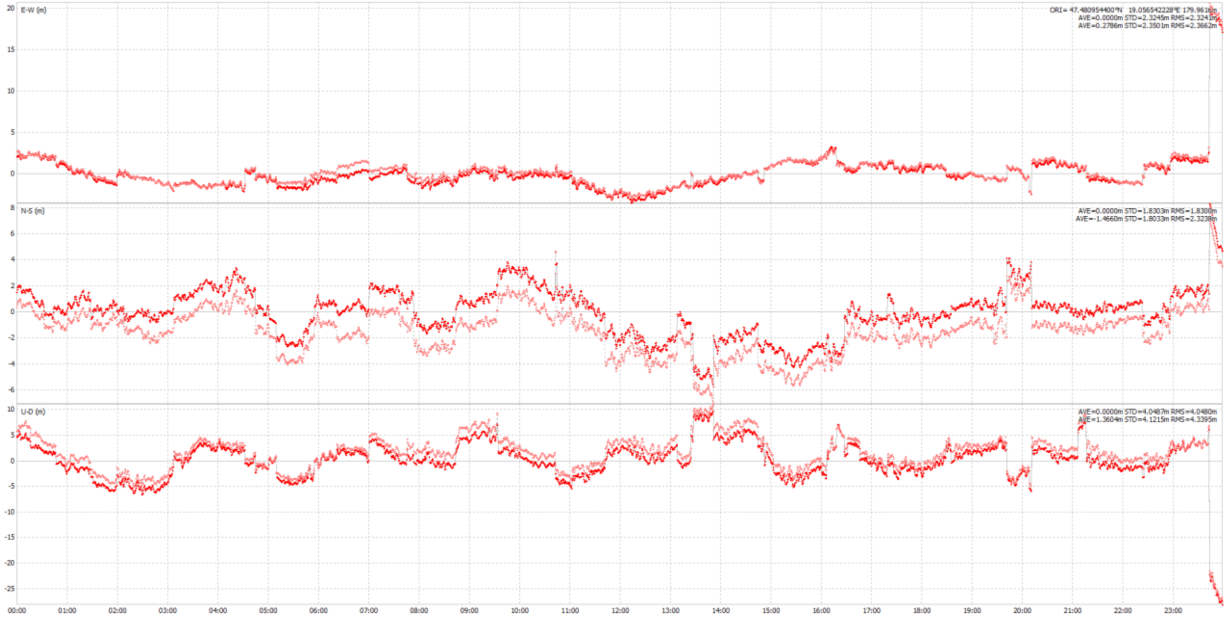
Navigation Engine with EGNOS Iono Model

Position Difference Ground Track

EMS-CODE

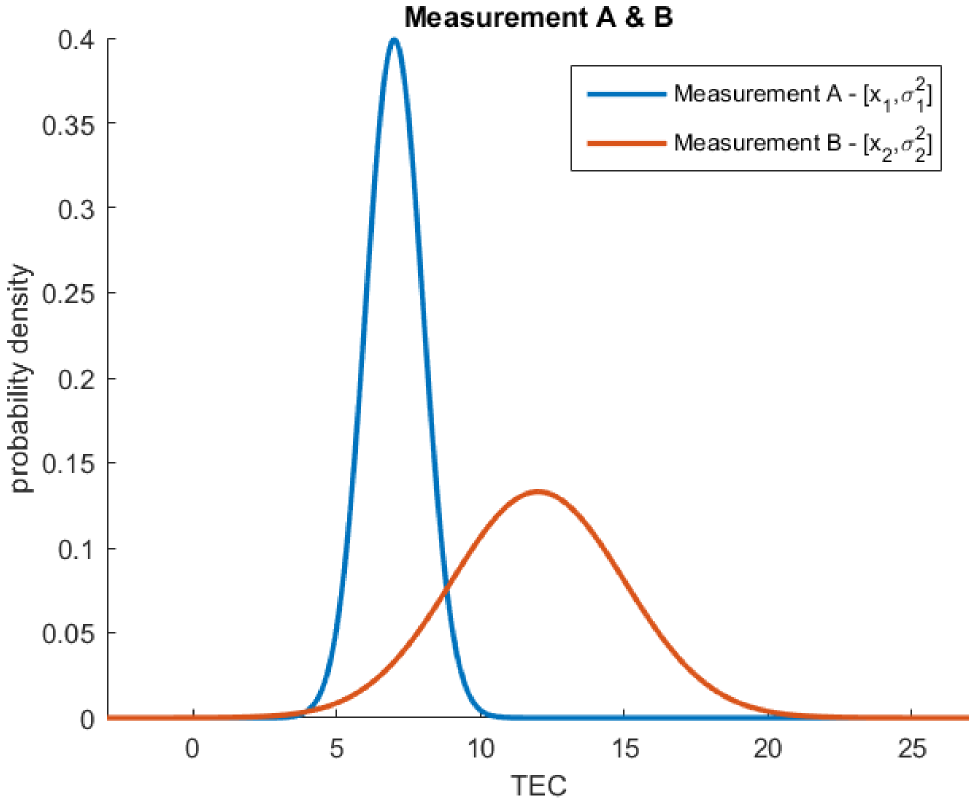


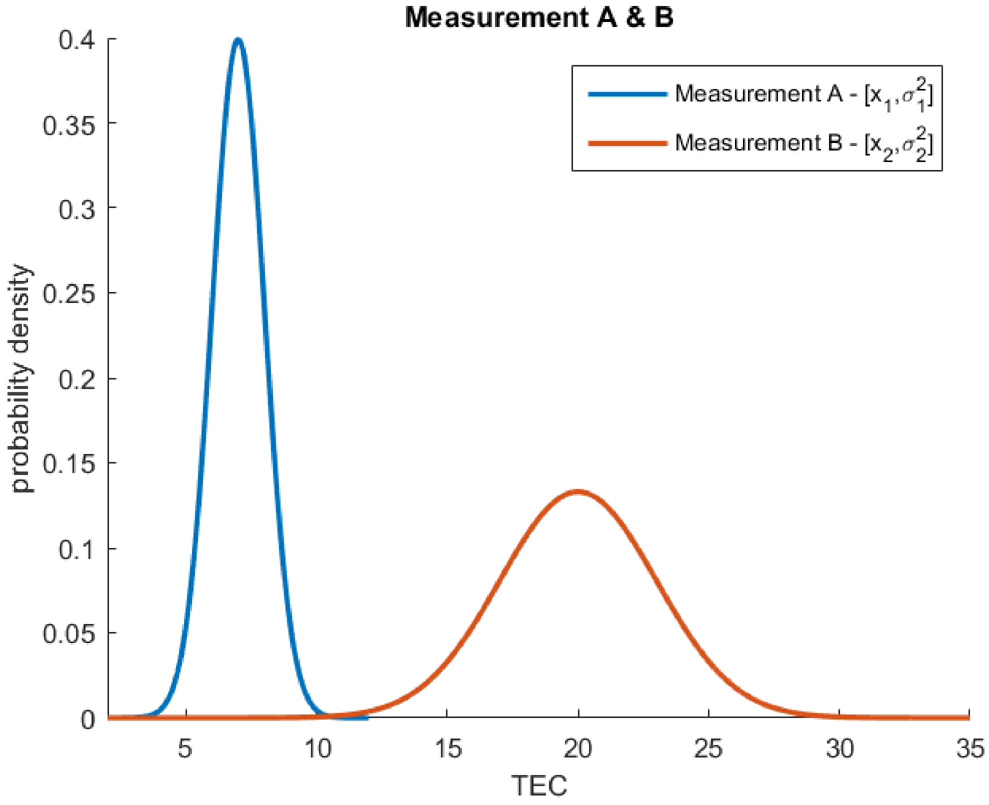
Position with EMS and with CODE



Bayesian statistic

Are the measurements consistent?



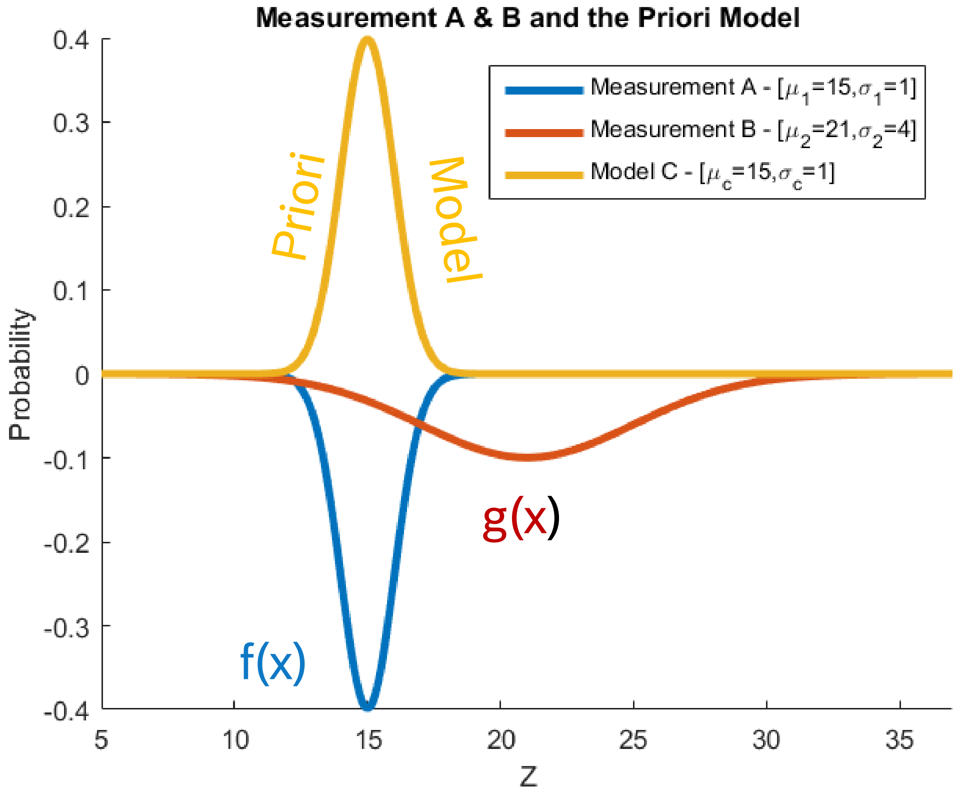


Likelihood of the measurements

Priori beleif is the Measurement A

$$P(A = x_1 \; and \; B = \; x_2 | Priori \; is \; model \; C) =?$$

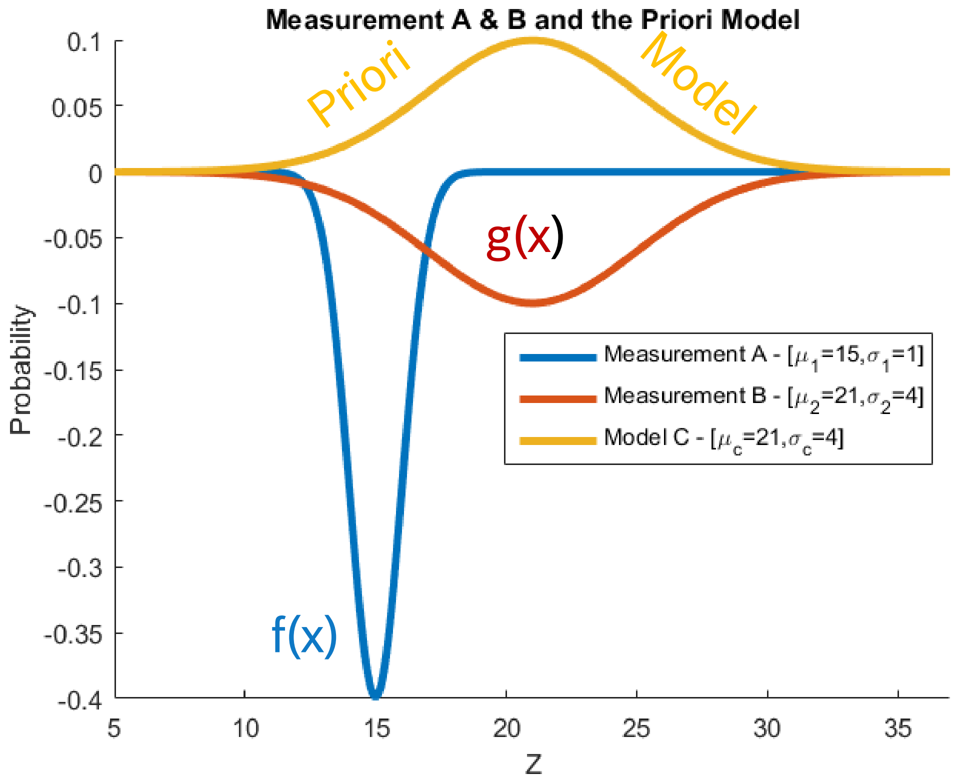
$$P(A = x_1 \; and \; B = \; x_2 | Priori \; is \; model \; A)$$
$$= P(A = x_1 \; | Model \; A) P(B = \; x_2 \; | Model \; A)$$
$$= \sum_i P(A = x_1 | R = x_i) P(R = x_i) \sum_i P(B = x_2 | R$$



Likelihood of the measurements
Priori beleif is the Measurement B

$$P(A = x_1 \; and \; B = \; x_2 | Priori \; is \; model \; C) =?$$

$$P(A = x_1 \; and \; B = \; x_2 | Priori \; is \; model \; B)$$
$$= \; P(A = x_1 \; | Model \; B) P(B = \; x_2 \; | Model \; B)$$
$$= \sum_i P(A = x_1 | R = x_i) P(R = x_i) \sum_i P(B = x_2 | R$$



Likelihood of the measurements
Which Priori Model would give the maximum likelihood?

$P(A = x_1 \; and \; B = \; x_2 | Priori \; is \; model \; C)$ Model C is a Gaussian with mean x_c and σ_c.

$$P(A = x_1 \; and \; B = \; x_2 | Model \; C) = \; P(A = x_1 \; | Model \; C) P(B = \; x_2 \; | Model \; C)$$

$$= \sum_i P(A = x_1 | R = x_i) P(R = x_i) \sum_i P(B = x_2 | R = x_i) P(R = x_i)$$

$$= \int_{-\infty}^{\infty} \Big[x, \sigma_1] |_{x_1} [x_c, \sigma_c] |_x dx \int_{-\infty}^{\infty} [x, \sigma_2] |_{x_2} [x_c, \sigma_c] |_x dx$$

$$= \int_{-\infty}^{\infty} \Big[x_1, \sigma_1] |_x [x_c, \sigma_c] |_x dx \int_{-\infty}^{\infty} [x_2, \sigma_2] |_x [x_c, \sigma_c] |_x dx = \left[x_1, \sqrt{\sigma_1{}^2 + \sigma_c{}^2} \right] |_{x_c} \left[x_2, \sqrt{\sigma_2{}^2 + \sigma_c{}^2} \right] |_{x_c}$$

$$= [\sqrt{\frac{(\sigma_1{}^2 + \sigma_c{}^2)(\sigma_2{}^2 + \sigma_c{}^2)}{(\sigma_1{}^2 + \sigma_c{}^2) + (\sigma_2{}^2 + \sigma_c{}^2)}}, \frac{x_2(\sigma_1{}^2 + \sigma_c{}^2) + x_1(\sigma_2{}^2 + \sigma_c{}^2)}{(\sigma_1{}^2 + \sigma_c{}^2) + (\sigma_2{}^2 + \sigma_c{}^2)}] |_{x_c}$$

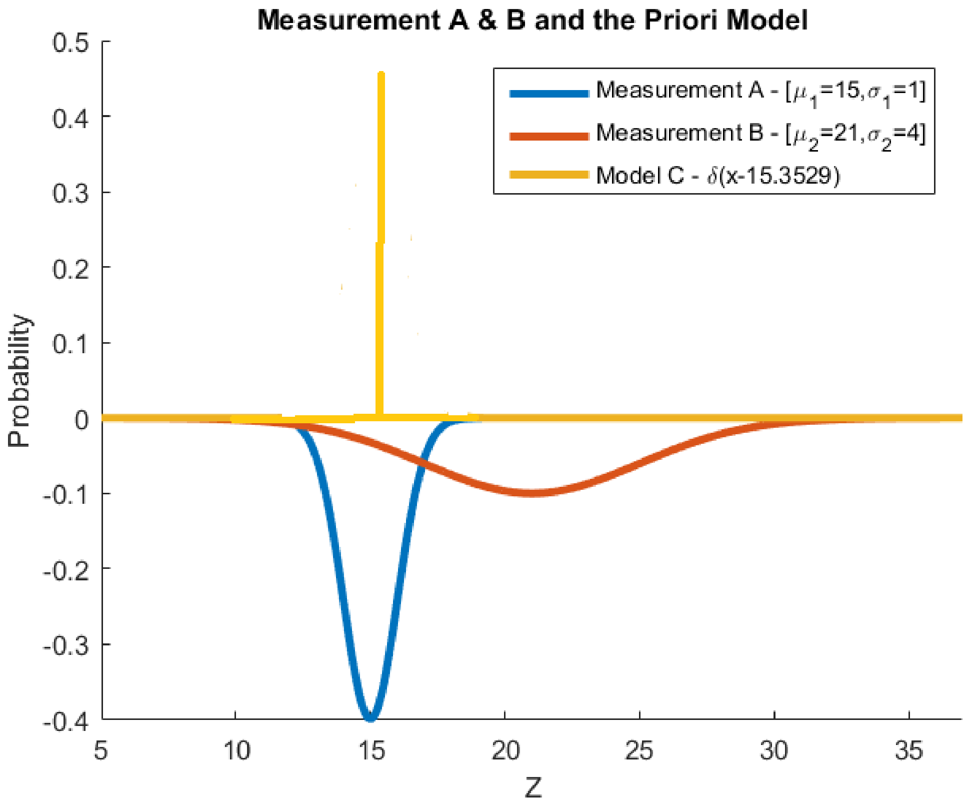
Likelihood of the measurements

Which Priori Model would give the maximum likelihood?

$$\min\left(\frac{(\sigma_1{}^2+\sigma_c{}^2)(\sigma_2{}^2+\sigma_c{}^2)}{(\sigma_1{}^2+\sigma_c{}^2)+(\sigma_2{}^2+\sigma_c{}^2)}\right)\Rightarrow \sigma_c{}^2=0$$

$$\frac{x_2(\sigma_1{}^2+\sigma_c{}^2)+x_1(\sigma_2{}^2+\sigma_c{}^2)}{(\sigma_1{}^2+\sigma_c{}^2)+(\sigma_2{}^2+\sigma_c{}^2)}=\frac{x_2(\sigma_1{}^2)+x_1(\sigma_2{}^2)}{(\sigma_1{}^2)+(\sigma_2{}^2)}=x_c$$

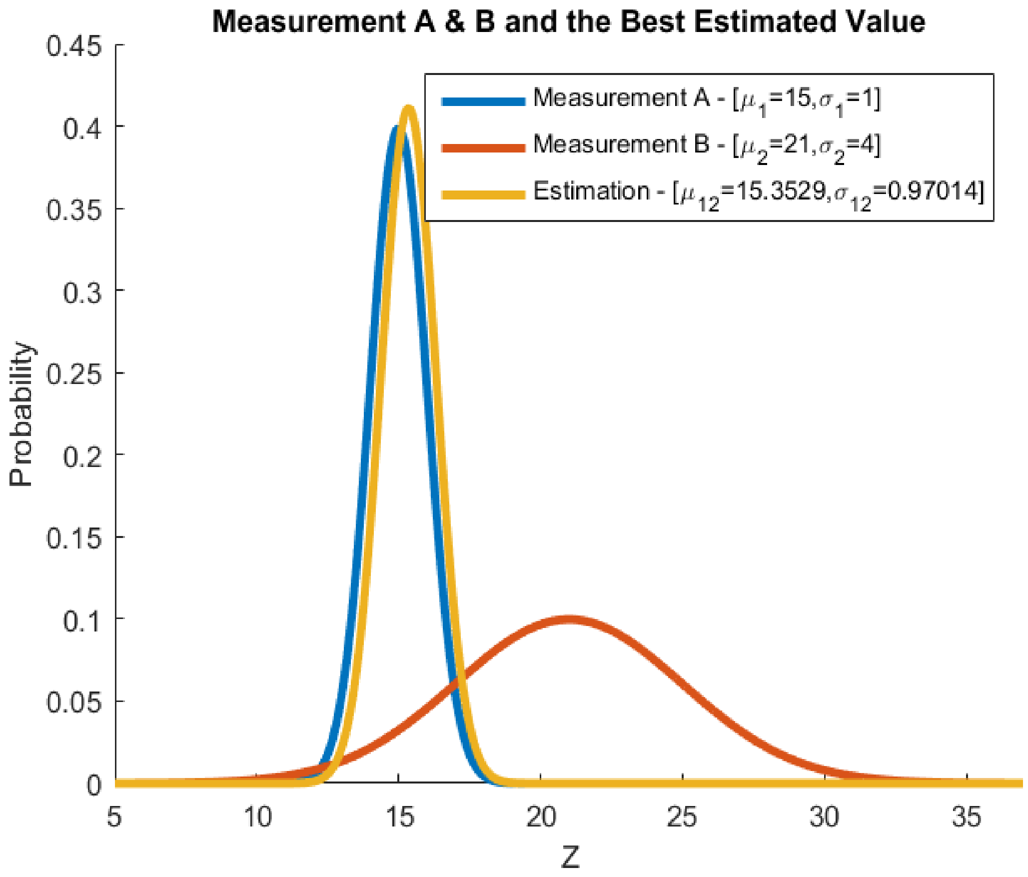
$$\boxed{\lim_{\sigma\to\infty}\frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{1}{2}\frac{(x-\mu)^2}{\sigma^2}}=\delta(x-\mu)}$$



Maximum likelihood

But wouldn’t we get the same result with a Kalman filter or LSQ?

$$P(Priori\ D\ at\ \mu | A = x_1\ and\ B = x_2)$$
$$= \frac{\left[x_1, \sqrt{{\sigma_1}^2 + {\sigma_2}^2}\right] |_{x_2} [x_{12}, \sigma_{12}] |_\mu}{\int_{-\infty}^{\infty} \left[x_1, \sqrt{{\sigma_1}^2 + {\sigma_2}^2}\right] |_{x_2} [x_{12}, \sigma_{12}] |_x dx}$$
$$= \frac{\left[x_1, \sqrt{{\sigma_1}^2 + {\sigma_2}^2}\right] |_{x_2} [x_{12}, \sigma_{12}] |_\mu}{\left[x_1, \sqrt{{\sigma_1}^2 + {\sigma_2}^2}\right] |_{x_2}} = [x_{12}, \sigma_{12}] |_\mu$$



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Next Steps
Think Tank

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THANK YOU