Real-time ionosphere monitoring by three-dimensional tomography over Japan

[1*]Susumu Saito, [2,†]Shota Suzuki, [2]Mamoru Yamamoto, [3]Chia-Hun Chen, and [4]Akinori Saito

[1]Electronic Navigation Research Institute, Japan

[2]Research Institute of Sustainable Humanosphere, Kyoto University, Japan

[3]National Cheng Kung University, Taiwan

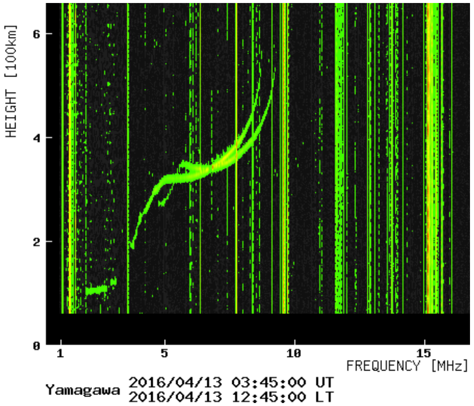
[4]Department of Science, Kyoto University, Japan

[†]Now at SQUARE ENIX Co. Ltd.

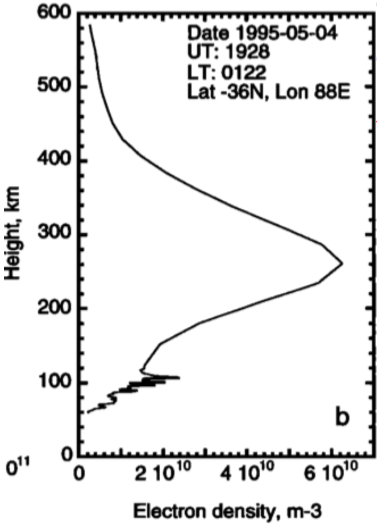
Ionospheric density profile measurements

* 3-D ionospheric density profiles are very useful for radio applications (such as communications or GNSS augmentation) as well as ionospheric sciences.

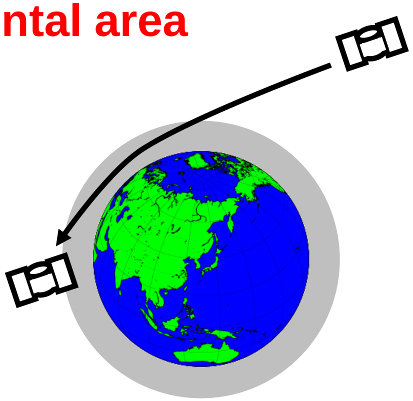
Ionosonde:
Classic simple device
Bottomside profiles only

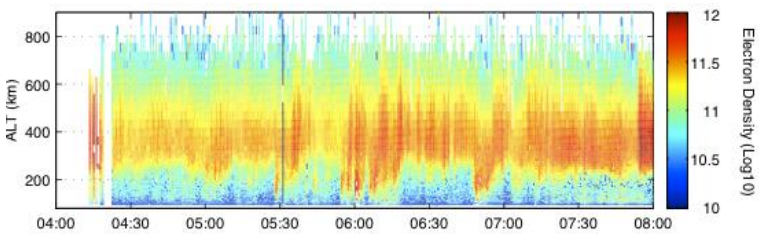


GNSS radio occultation:
Globally observable
Smoothed in a wide horizontal area



[Haji and Romans, 1997]

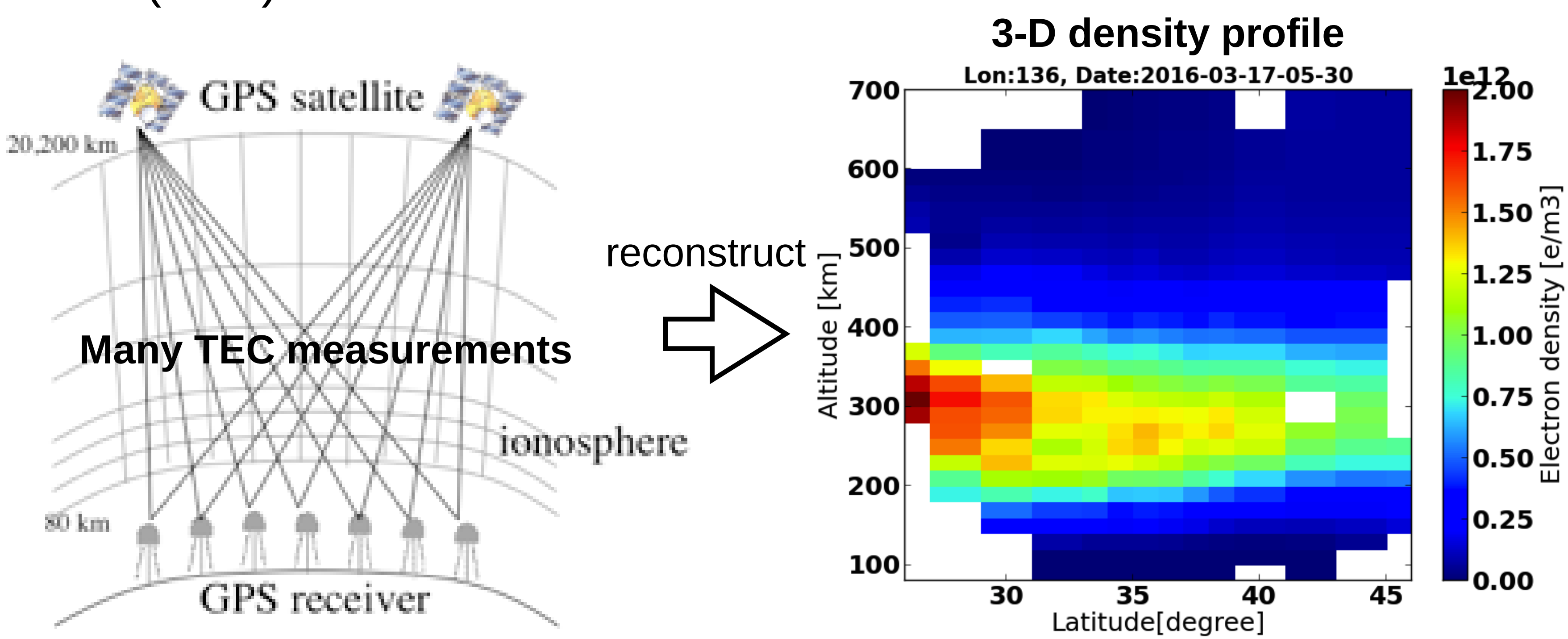




Incoherent scatter radar:
Very powerful, various parameters can be derived.
Extremely expensive

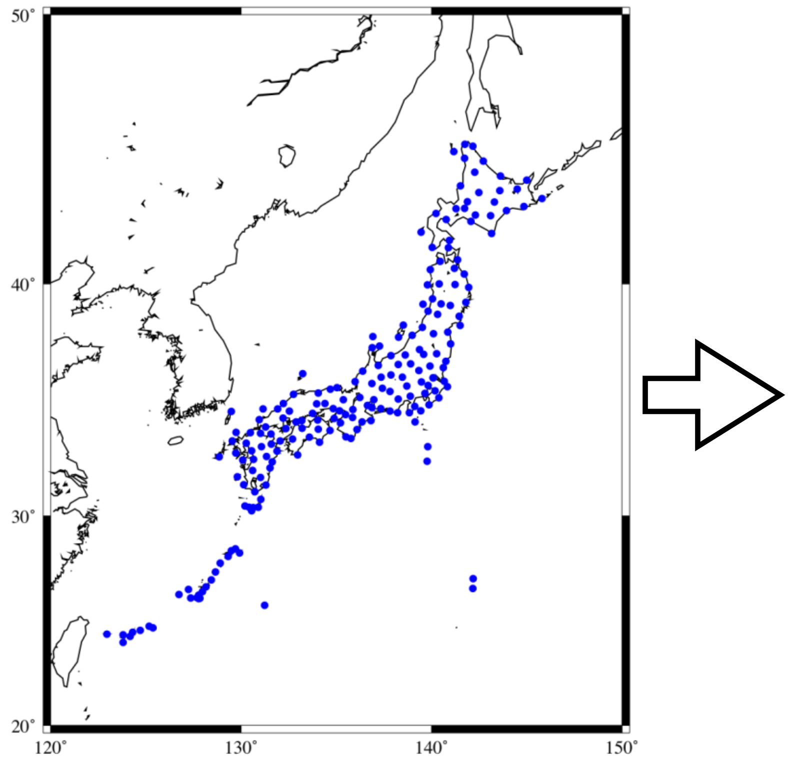
GNSS tomography

- GNSS tomography is a powerful technique to reconstruct 3-D ionospheric density profiles from total electron content (TEC)measurements.

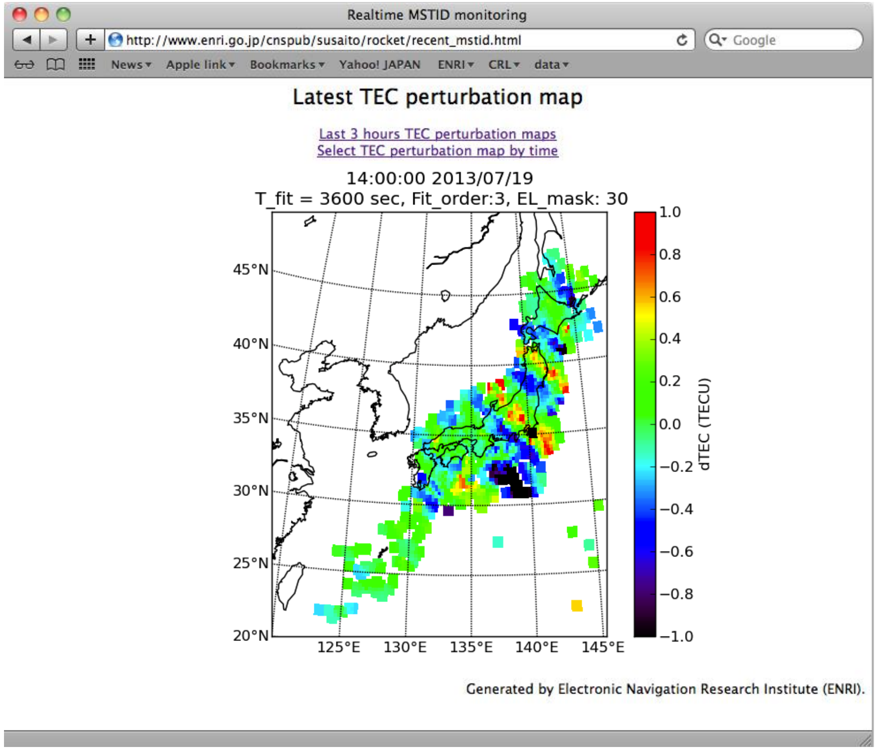


- Objectives: Make 3-D ionospheric density profiles available by tomography in real-time

Real-time ionosphere monitoring



Real-time GNSS measurements from 200 selected GEONET stations



Real-time 2-D ionosphere disturbance monitoring [Saito et al., ION ITM 2014]

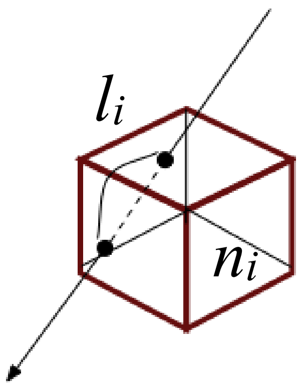
- ENRI has developed a real-time 2-D ionospheric disturbance monitoring system using real-time data from 200 selected GEONET stations. [Saito et al., ION ITM 2014]
  - can be expanded to a real-time 3-D ionospheric tomography system

3-D tomography

TEC of i-th satellite

$$TEC_i = \sum_{s=1}^{N_i} l_i n_i$$

$$= \sum_{j=1}^{N} l_{i,j} n_{i,j}$$



TEC vector

$$\vec{T} = A\vec{n}$$

Electron density vector

Geometry Matrix

Cost function

Hyper parameter

$$J(\vec{n}) = ||\vec{T} - A\vec{n}||^2 + \lambda||W\vec{n}||^2$$

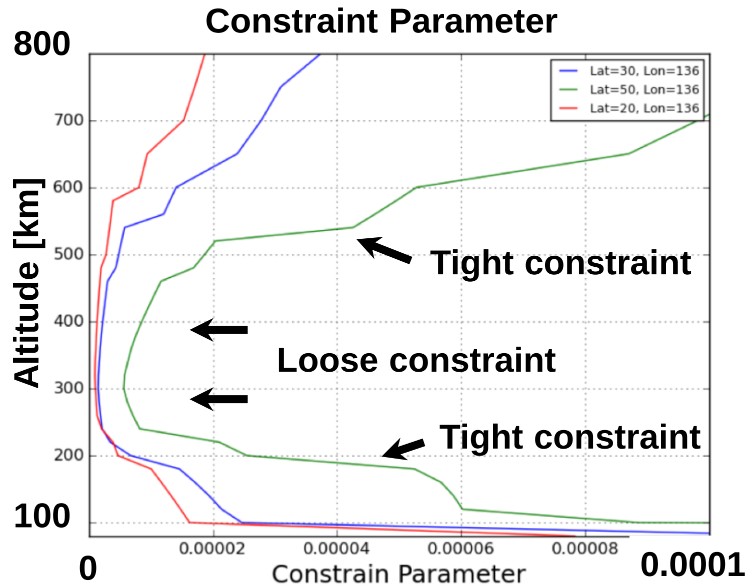
Least-square term   Constraint term

Constrained least-square solution

$$\vec{n} = \left(A^T A + \lambda W^T W\right)^{-1} A^T \vec{T}$$

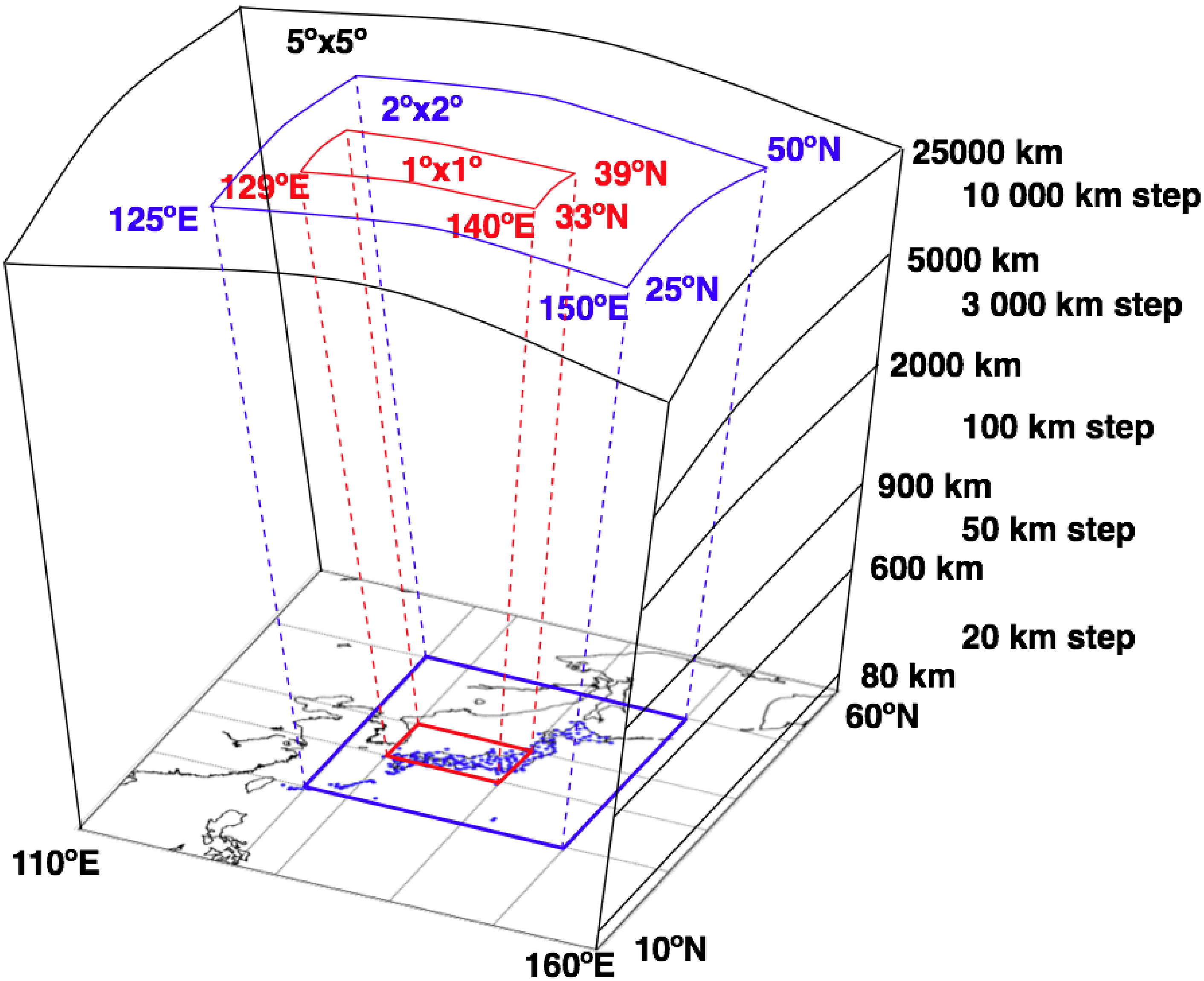
Constraint term

$$\vec{W}\vec{n} = \sum_{i=1}^{N} \sum_{j=1}^{6} C_{i,j}(n_i - n_{i,j})$$



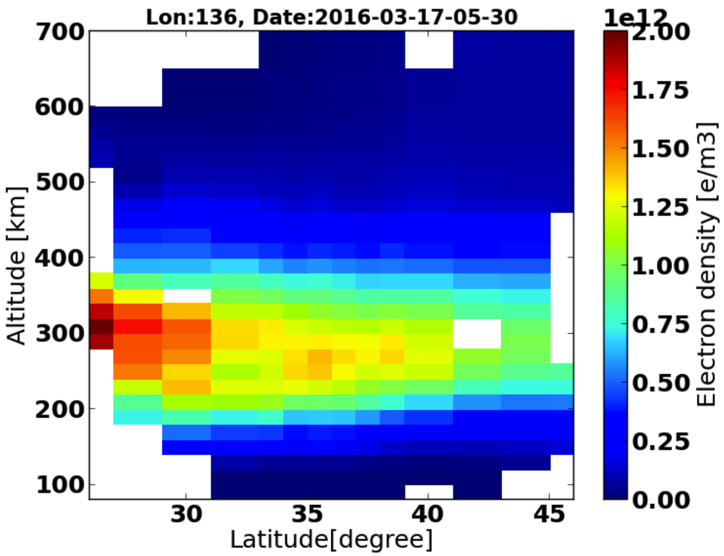
Constraint parameter depends on locations (calculated based on NeQuick model)

Tomographic reconstruction volume

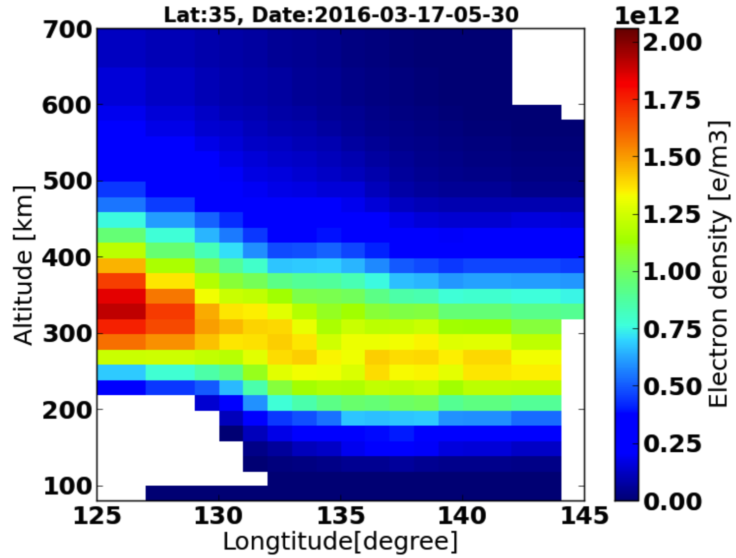


Realtime tomography results

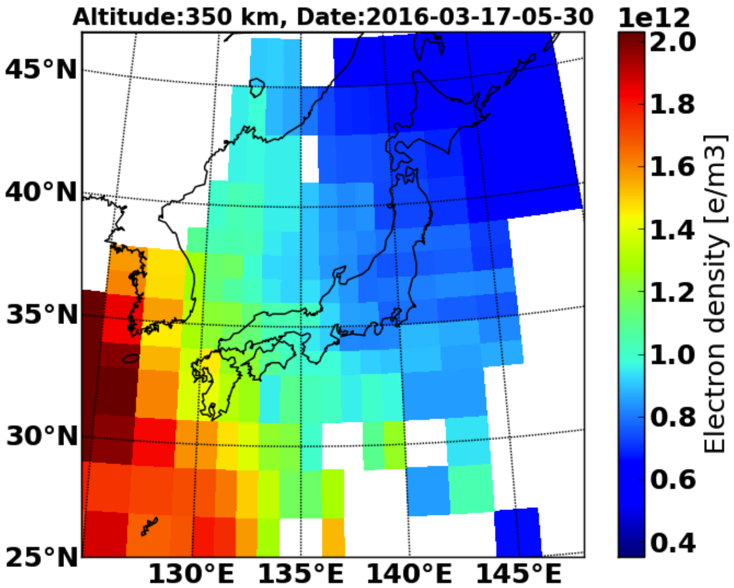
(a) Meridional cross-section (136ºE)



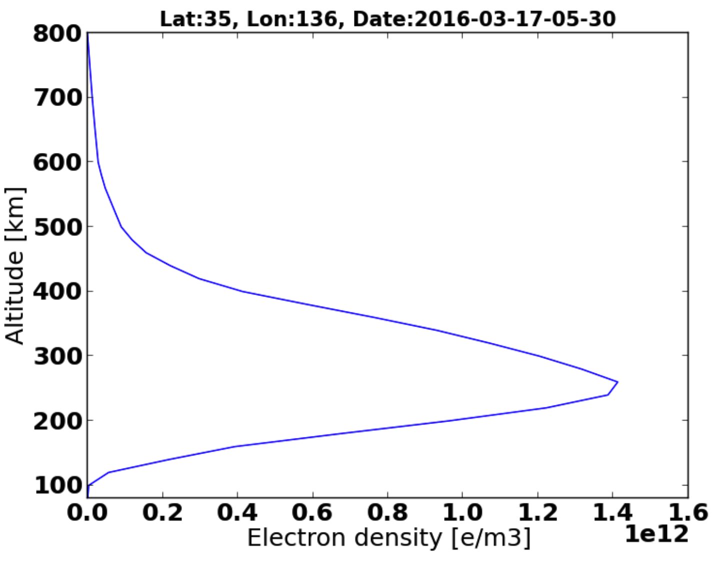
(b) Latitudinal cross-section (35ºN)



(c) Horizontal distribution (Altitude: 350 km)

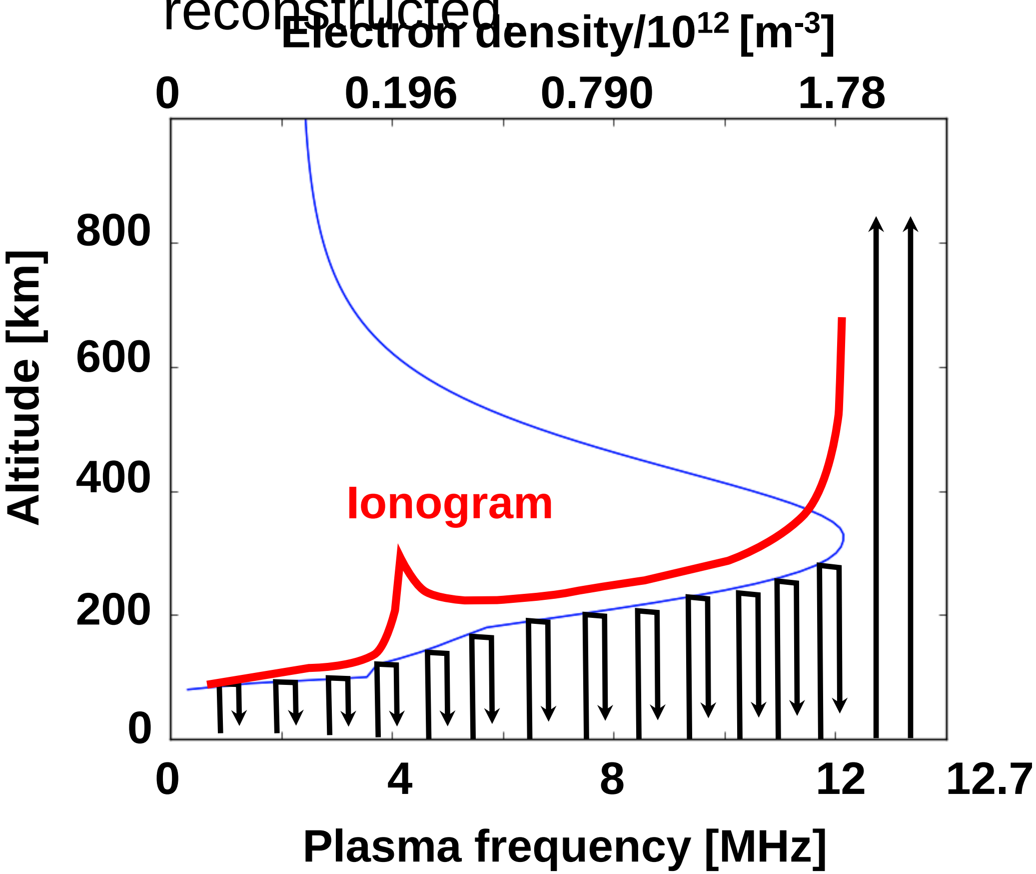


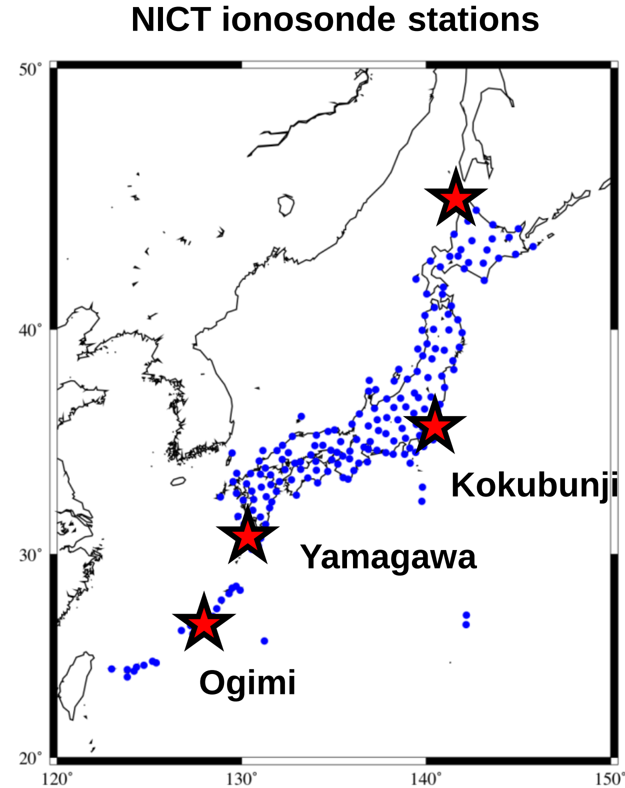
(d) Vertical profile (35ºN, 136ºE)

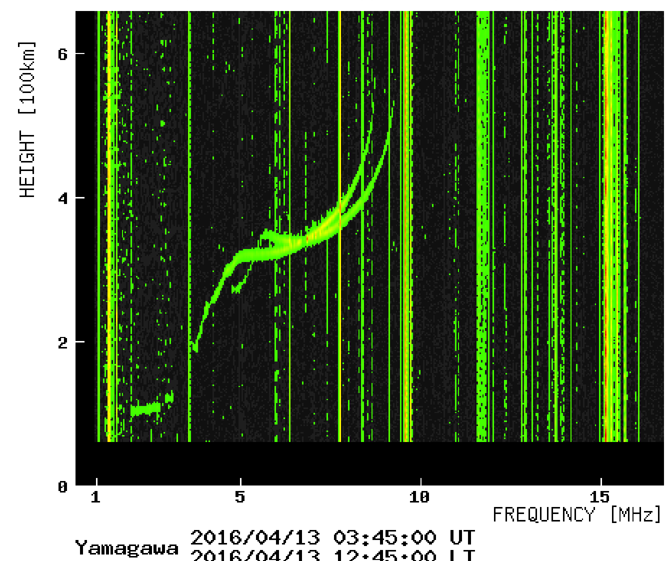


Validation

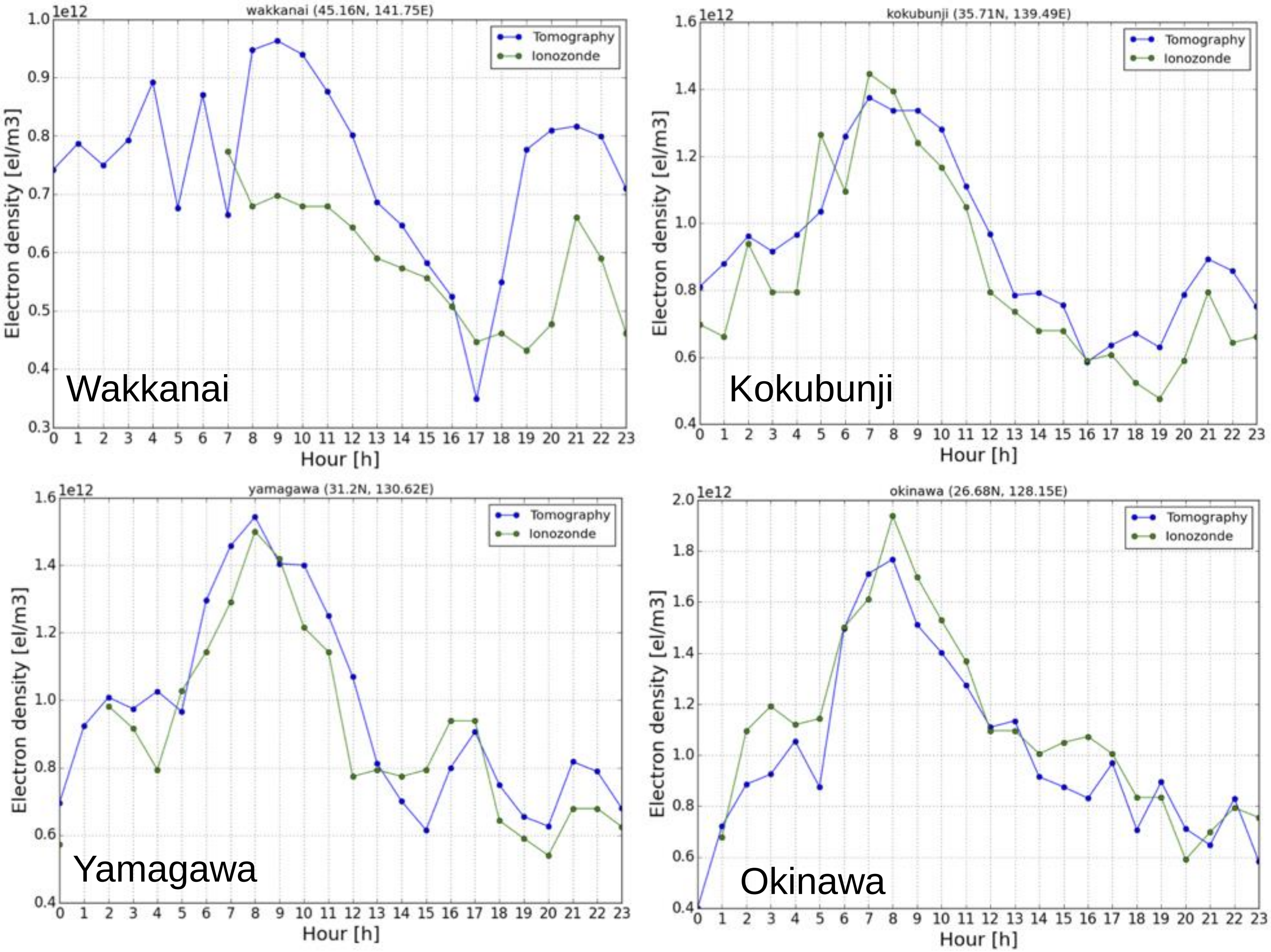
Ionosonde
- Vertical HF sounder
- Peak density can be precisely determined.
- Bottom-side profile can be reconstructed.



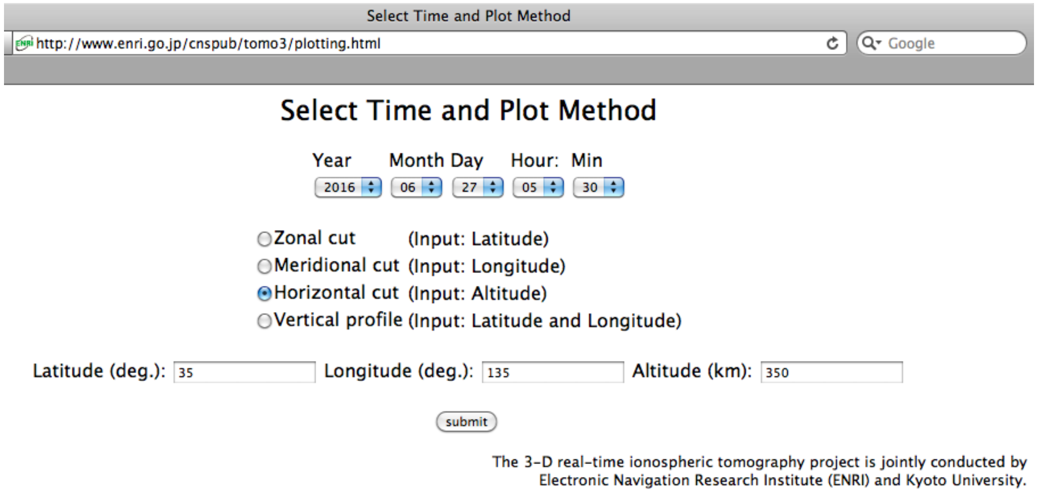


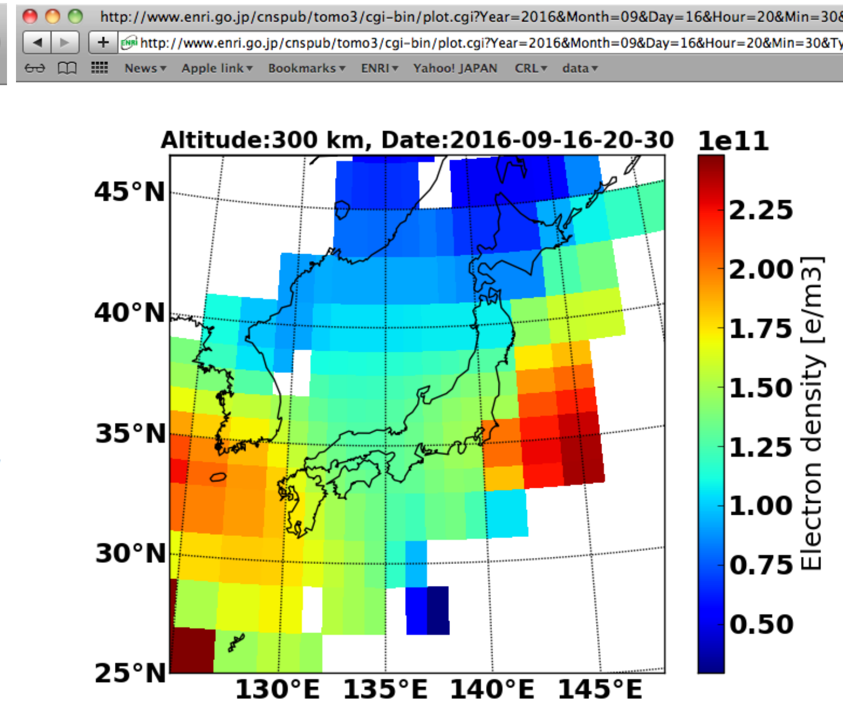


Validation results



Real-time web interface





- Preliminary real-time web interface
  - On-demand plotting of zonal, meridional, and horizontal cross sections and vertical profile

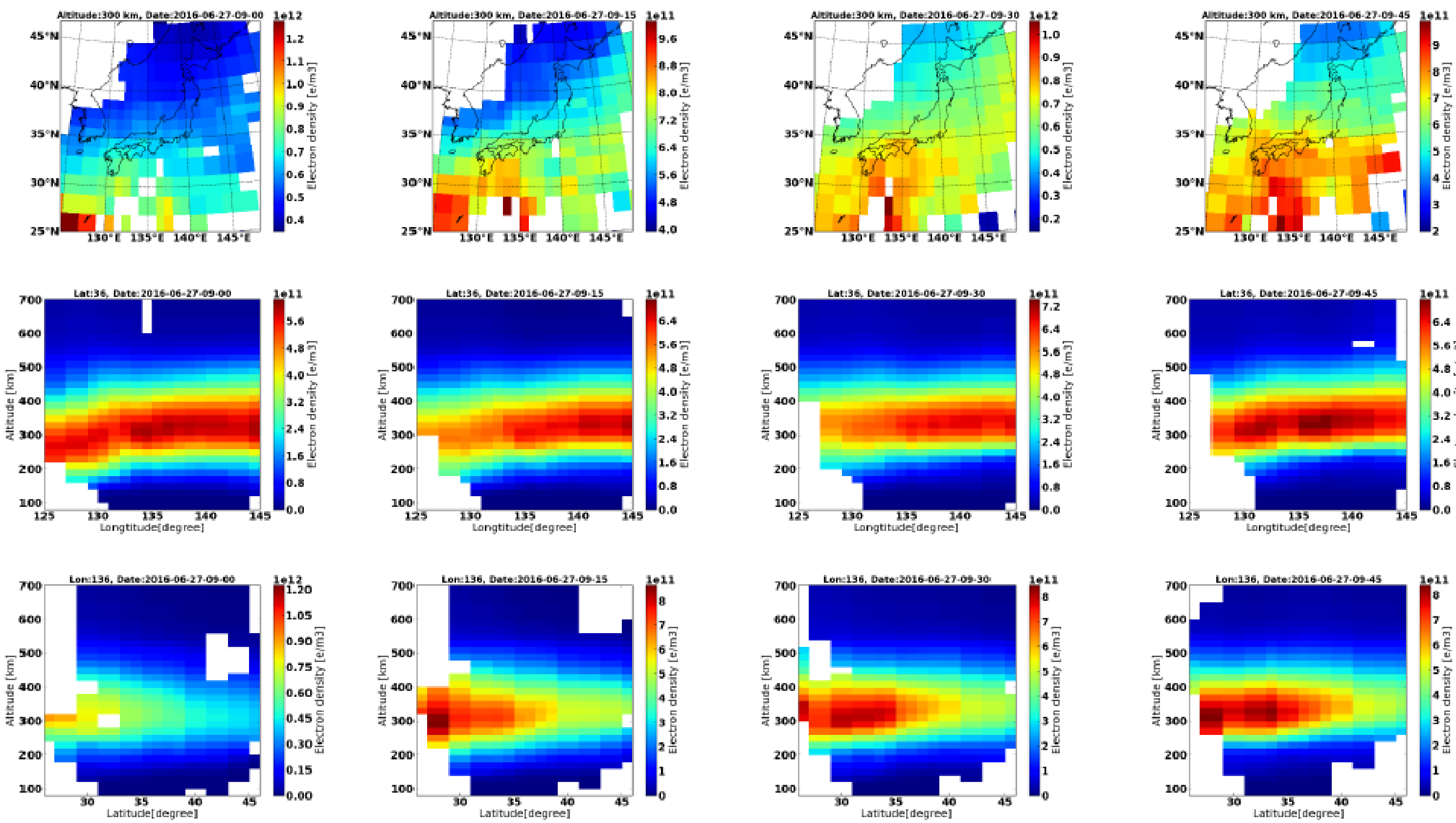
http://www.enri.go.jp/cnspub/tomo3/plotting.html

2016年4月からリアルタイムサービスを開始

http://www.enri.go.jp/cnspub/tomo3/

2016年6月27日の例

	09:00UT 18:00LT	09:15UT 18:15LT	09:30UT 18:30LT	09:45UT 18:45LT
水平分布 300km ALT				
東西-高度 36N LAT				
南北-高度 136E LON				



Potential use of tomography

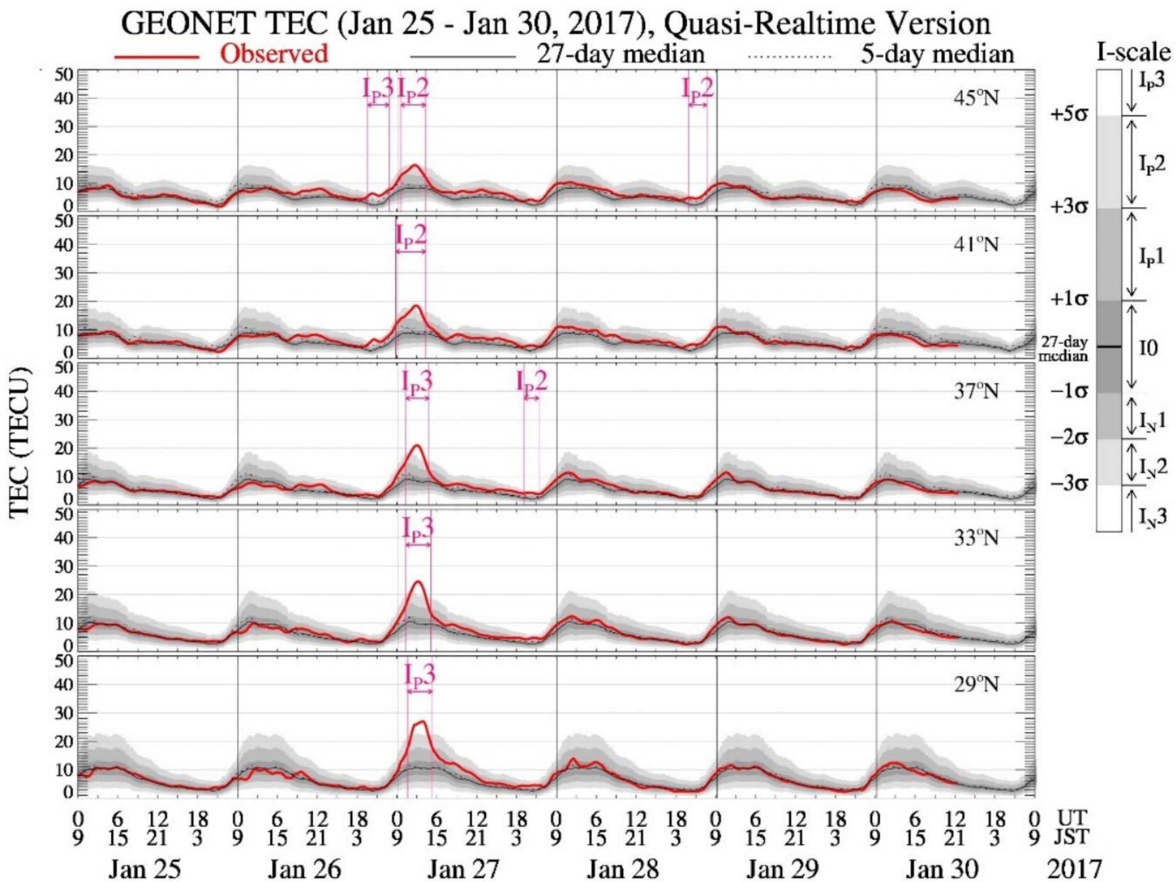
- Ionospheric science
  - 3-D structure of traveling ionospheric disturbances (TIDs)
  - Ionospheric climatology with tomography of archived GEONET data
- Engineering application
  - Better ionospheric correction for single-frequency GNSS
  - HF radio wave propagation prediction

Summary

- Real-time 3-D ionospheric tomography system over Japan has been developed.
  - Every 15min with about 10min latency
- Tomography results are validated with independent measurements
  - In good agreement
  - More validation works planned
- Scientific and engineering applications are provisioned.

Acknowledgment: This work is supported by JSPS Grant-in-Aid for Challenging Exploratory Research JP2663018

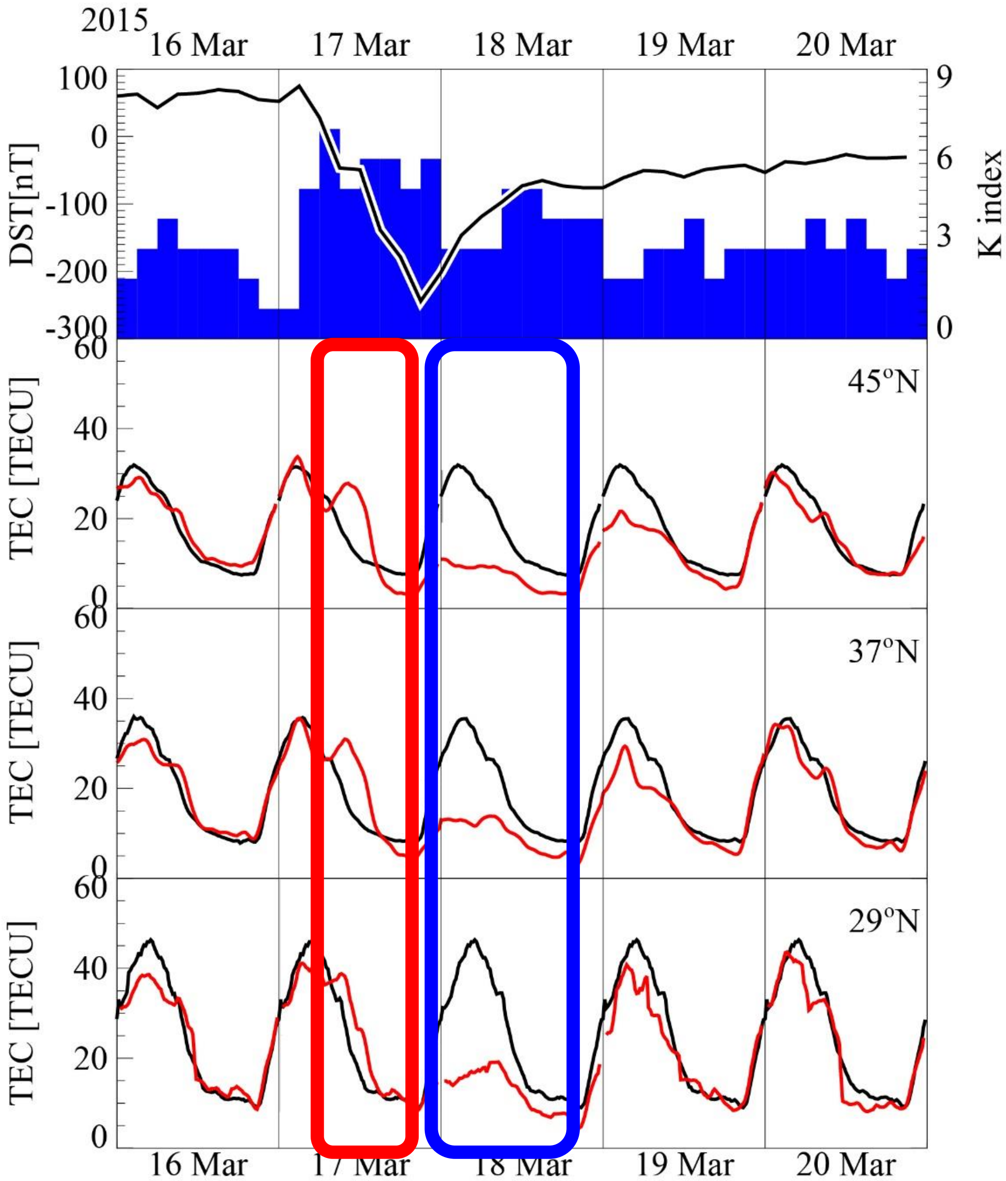
A new ionospheric storm scale (I-scale)



TEC monitoring system in NICT
[http://seg-web.nict.go.jp/GPS/FC_GEONET/LAT-TEC/]

“A new ionospheric storm scale based on TEC and foF2 statistics”, M. Nishioka, T. Tsugawa, H. Jin and M. Ishii, accepted to *Space Weather*

Motivation



Positive storm

Negative storm

TEC in the Japanese sector during the St Patrick's day storm

- Observation
- median of 27 days

- Ionospheric storms have no clear definition.
- Ionospheric parameters largely depend on local time, season, and latitude.
- It is necessary to investigate the ionospheric parameters statistically in order to define an universal ionospheric scale.

Data set and methodology

【Data Set】

- 15-minute TEC for 18 years from 1997 to 2014 (TEC_{obs}).

【Methodology】

- Percentage deviation of TEC from the reference, P_{TEC}, is used to describe ionospheric state.

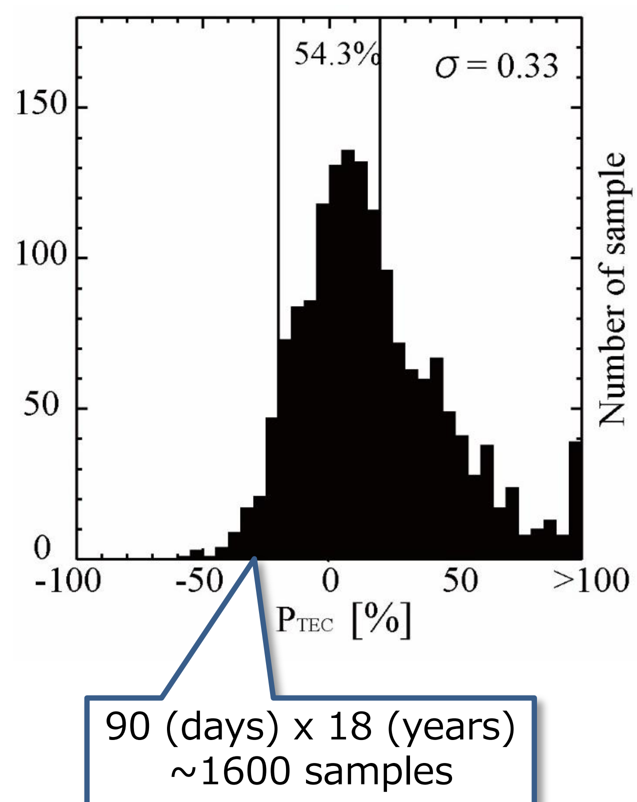
$$P_{TEC} = \frac{TEC_{obs} - TEC_{ref}}{TEC_{ref}}$$

- The reference value, TEC_{ref} is defined as a median of TEC_{obs} at the same local time and latitude in the past 27 days.

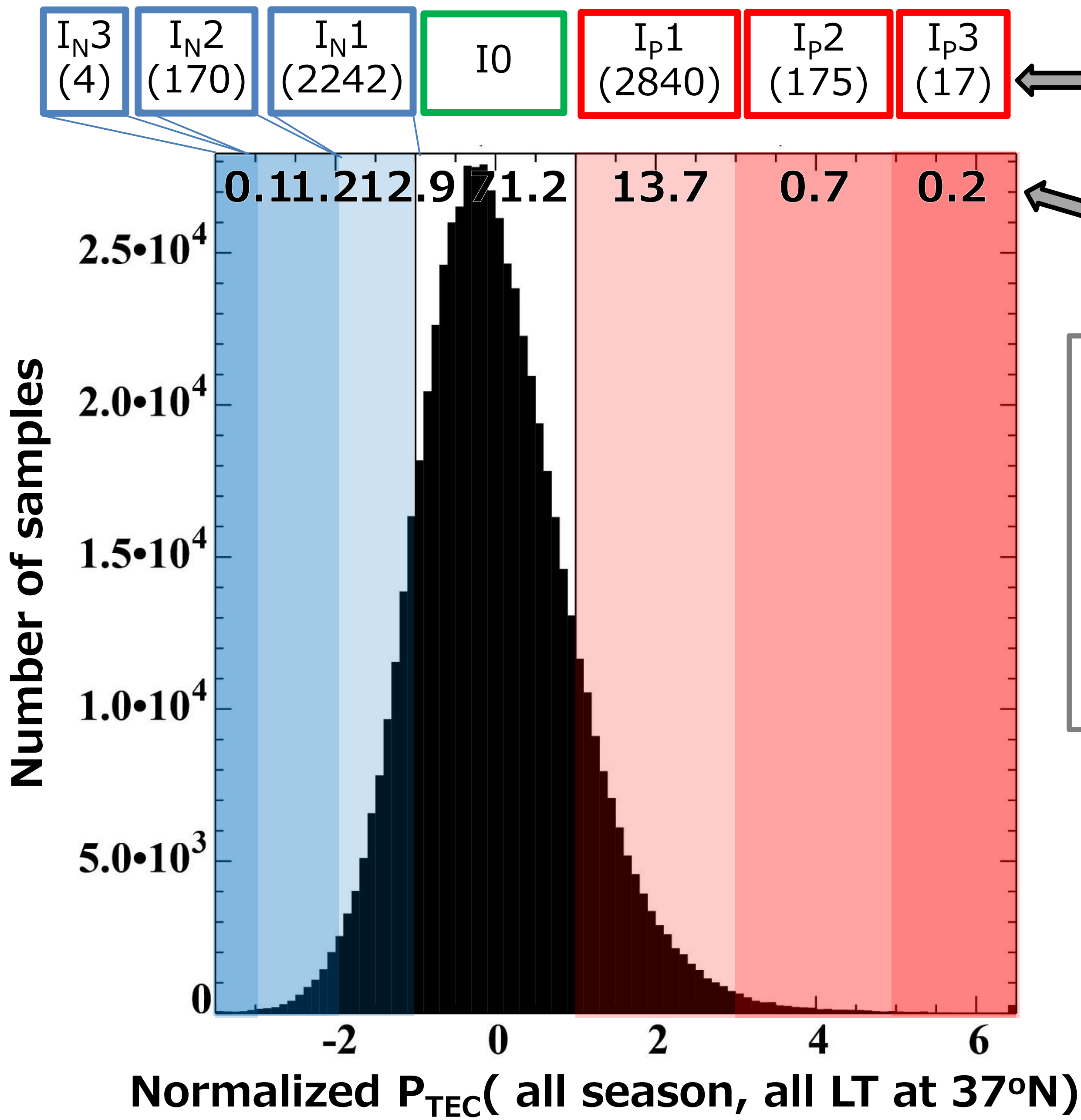
- Since distributions of P_{TEC} are different among different seasons, local-times, and latitudes, P_{TEC} is normalized by σ. The normalized P_{TEC} is used to determine an I-scale. It is defined by setting thresholds to the normalized numbers to seven categories:

I0: Quiet state
I_P1, I_P2, I_P3: moderate, strong, severe positive storms
I_N1, I_N2, I_N3: moderate, strong, and severe negative storms

Distribution of P_{TEC}
(29° N, Feb-Apr, 20JST)



I-scale



Ionospheric scale (Number of events with a duration of 2h or more)

Occurrence rates (every 15min) (%)

Positive storm scale

- I_P1: 1σ~3σ
- I_P2: 3σ~5σ
- I_P3: 5σ>

Negative storm scale

- I_N1: -1σ~-2σ
- I_N2: -2σ~-3σ
- I_N3: -3σ<

- This ionospheric scale does not depend on season/LT/latitude.
- Positive and negative storms during St. Patrick's day storm were I_P2 and I_N3, respectively.

JpGU@Makuhari, Chiba, 22 May 2016
P-EM04 Space Weather, Space Climate, and VarSITI, 09:30-09:45

Solar Flare Prediction with Vector Magnetogram and Chromospheric Brightening using Machine-learning

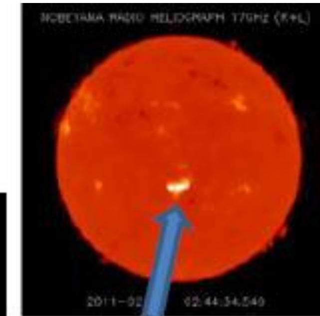
○ N. Nishizuka[1], Y. Kubo[1], K. Sugiura[2] , M. Den[1],S. Watari[1], M. Ishii[1]

出典 www.google.co.jp

AlphaGo
Deep-learning

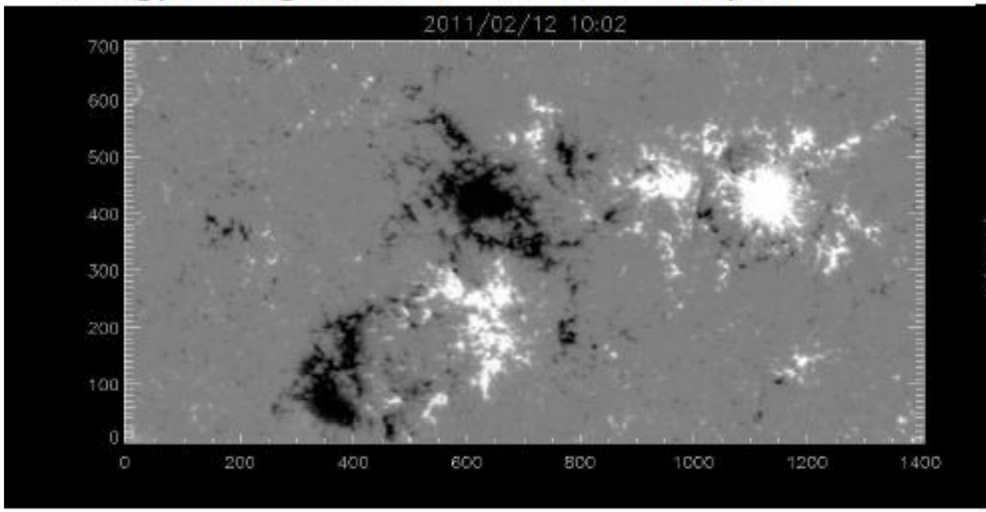
National Institute of Information and Communications Tech. (NICT)
[1]Applied Electromagnetic Research Institute, Space Environment Lab.
[2]Advanced Speech Translation Research and Development Promotion Center (ASTREC), Advanced Translation Tech. Lab.

Active Region Evolution and Solar Flares



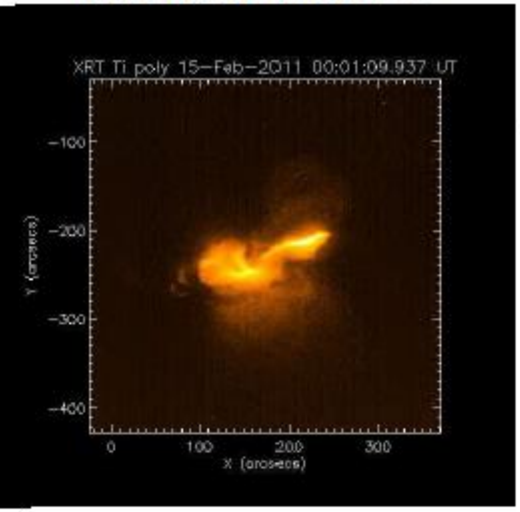
Solar flare
(NoRH data)

Energy storage and evolution of sunspot



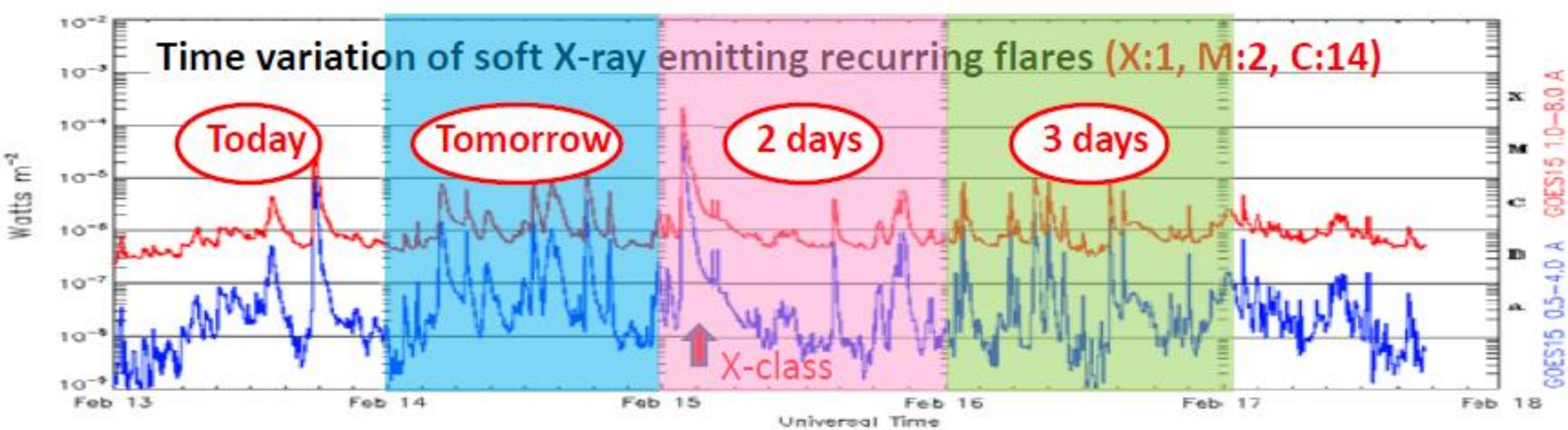
(Hinode/SOT)

Intermittent Flares



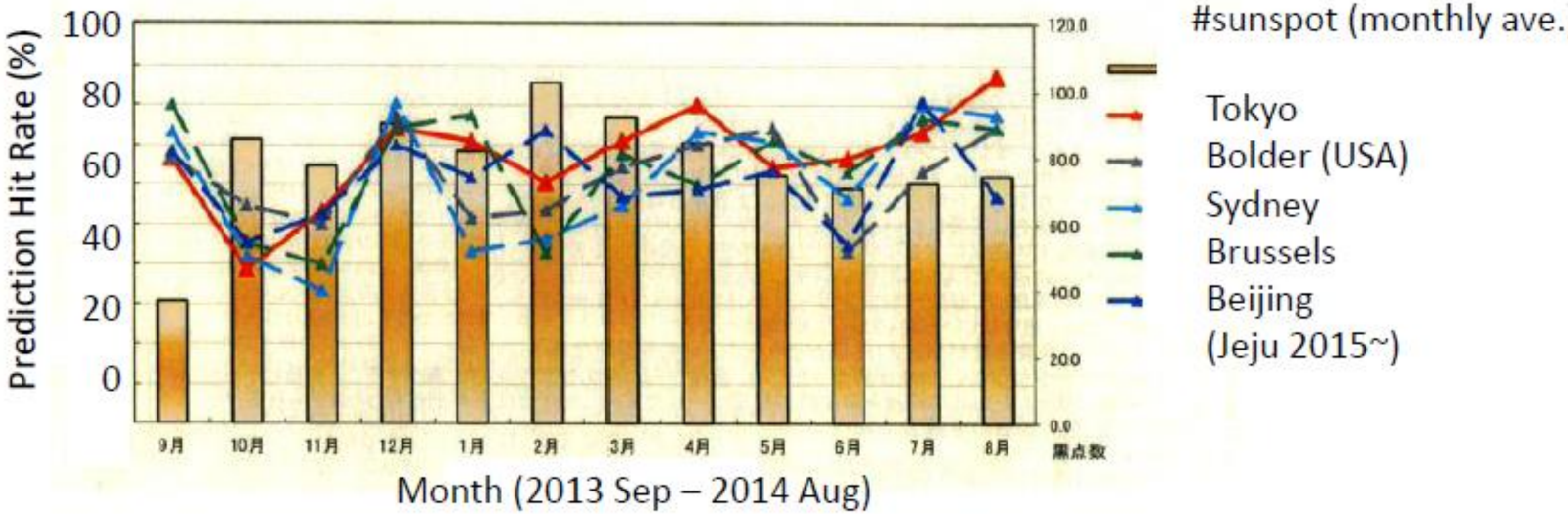
(Hinode/XRT)

To predict the maximum class of flares within the next 24 hours !!



Daily Space Weather Forecasts

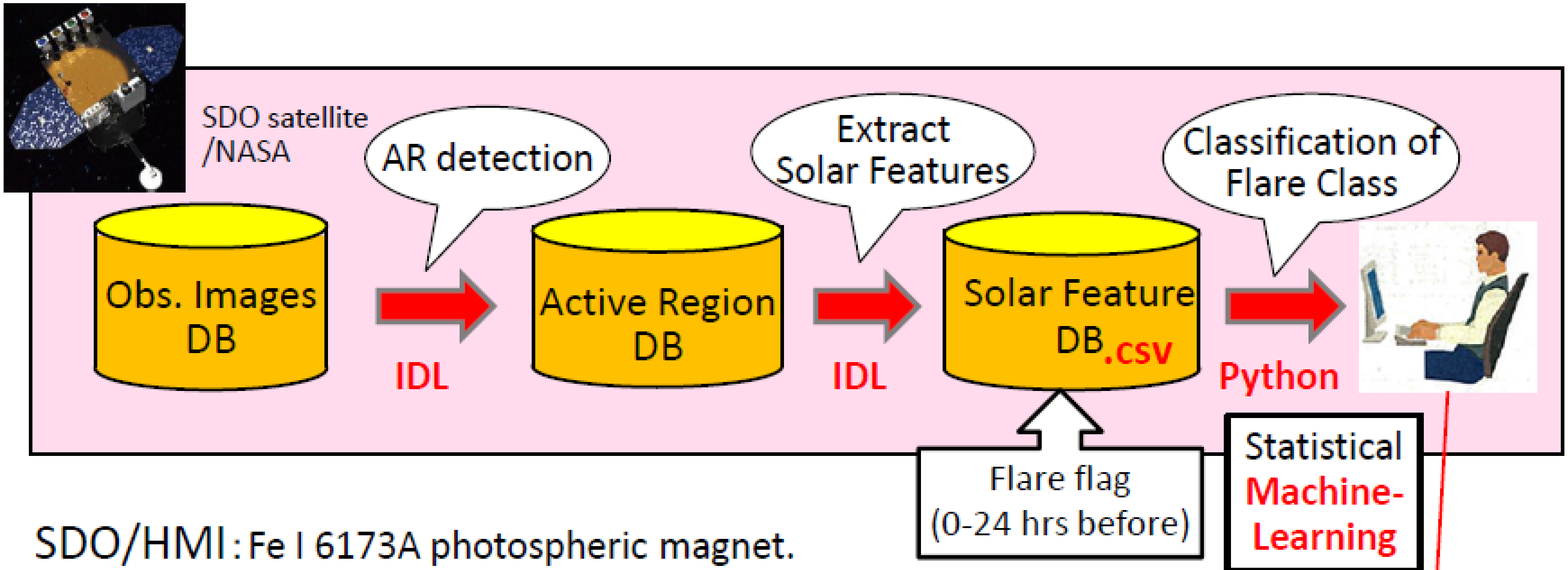
Sunspot Num. & Hit rate of flare predictions in 2013~2014



Manual Prediction:
Hit rate~60-80%

True Skill Score:
TSS~0.5
(-1.0 < TSS < 1.0)

Flow chart of Flare Prediction System



SDO/HMI : Fe I 6173A photospheric magnet.
SDO/AIA : 1600A UV cont. (full disc)

Period: 2010~ 2015
X class ~40 event
M class ~460 event

(limb event 10%)

Reduction to 1 image/hour.

- Magnetogram (B_{LOS}) 3TB, 10^5 images
- Vector magnetogram (Bx, By, Bz) 12TB
- Photospheric BP (UV 1600 Å) 3TB

Flare occurrence
Prob. In each AR

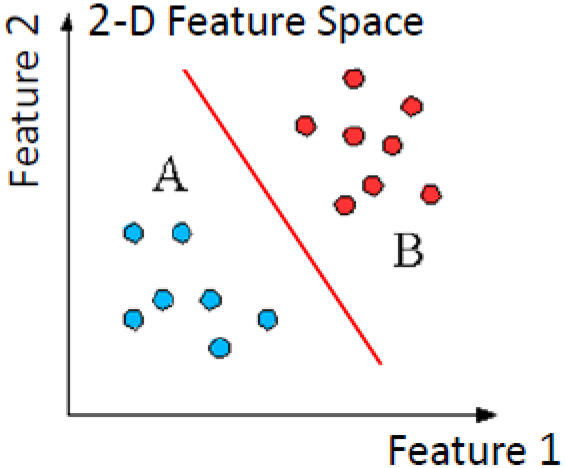
X ○%
M ○%
C ○%
none

Machine-Learning

(1) To construct algorithms that can learn from and automatically make classification or prediction on known/unknown data.

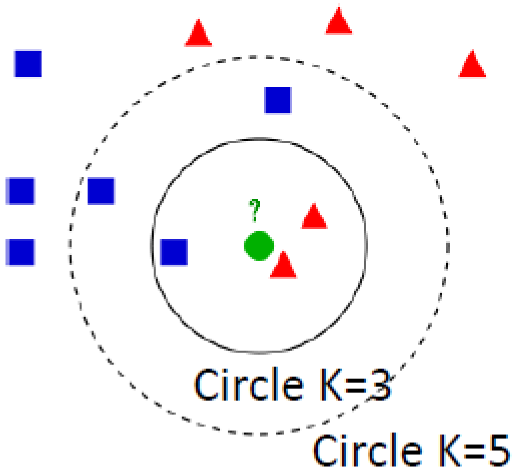
(2) To classify and predict the complex data, beyond the human processing capacity.

① Support Vector Machine (SVM)



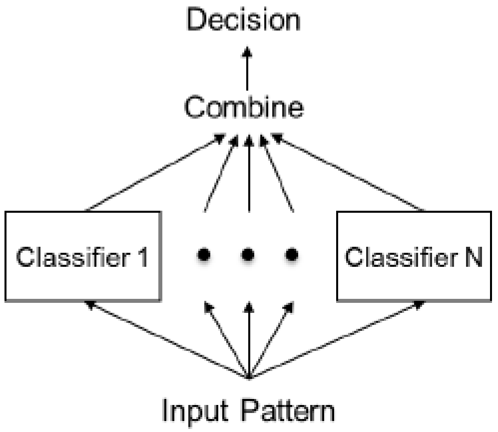
Division by straight line

② k-Nearest Neighbor (k-NN)



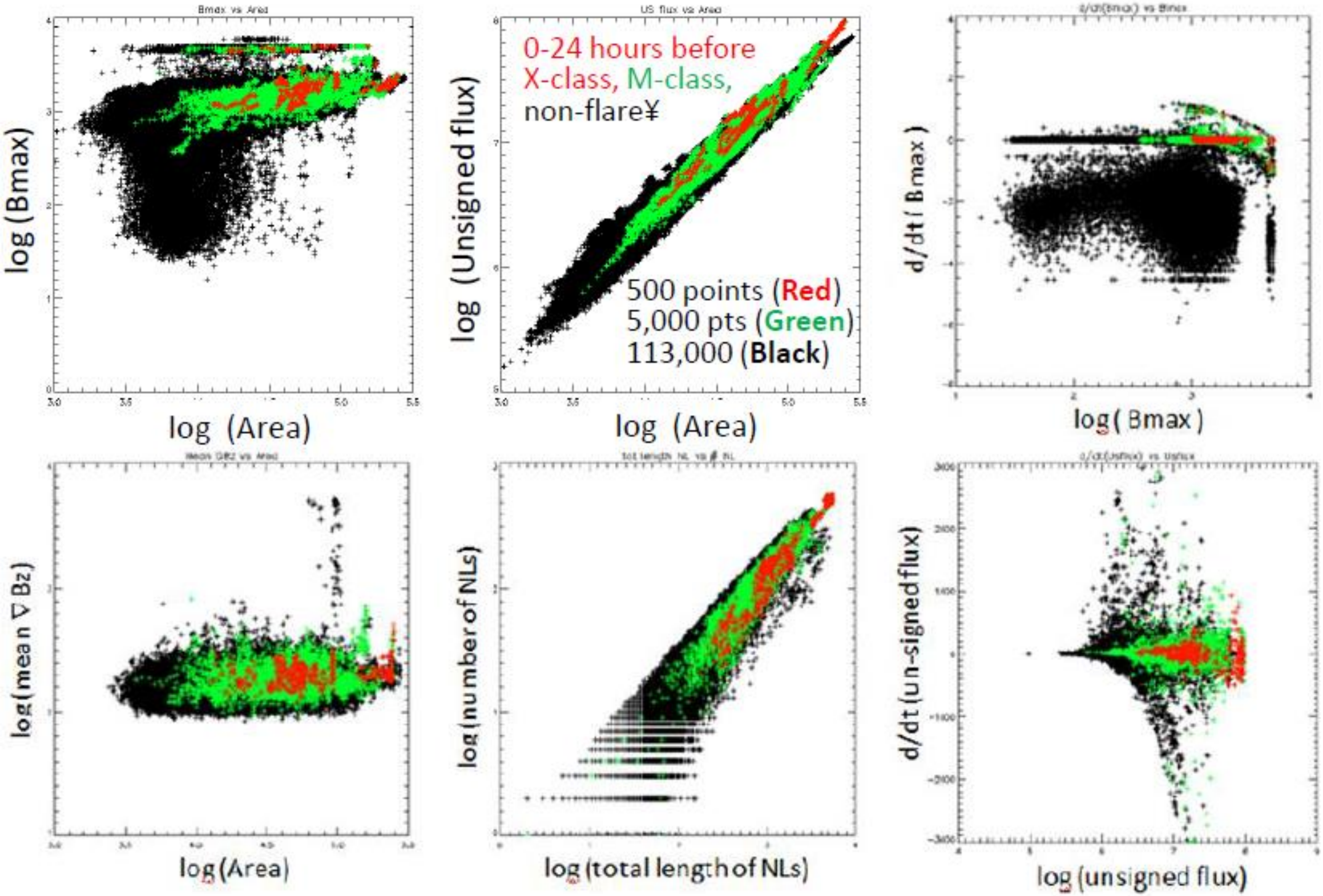
Majority rule in a circle of the radius k

③ Ensemble Learning (ERT: extra random trees)



Combination of weak classifiers

Statistical map of Solar features before Flares



Prediction Results & Evaluation

- We divided the database of features randomly into training/test datasets with the ratio of 70 : 30. We evaluated the prediction results with TSS.

		Observation: flare	Observation: no
Prediction	flare	TP	FP
Prediction	no	FN	TN

● True Skill Statistic
[by Hanseen & Kuipers '65]

$$TSS = \frac{TP}{TP + FN} - \frac{FP}{FP + TN}$$

TSS = 1 means 100% Hit prediction

full shuffle (1 hr)

SVM		Observation: flare	Observation: no
Prediction	flare	144	15
Prediction	no	18	54439

TSS= 0.889

kNN		Observation: flare	Observation: no
Prediction	flare	146	6
Prediction	no	16	54448

X flare TSS= **0.927**

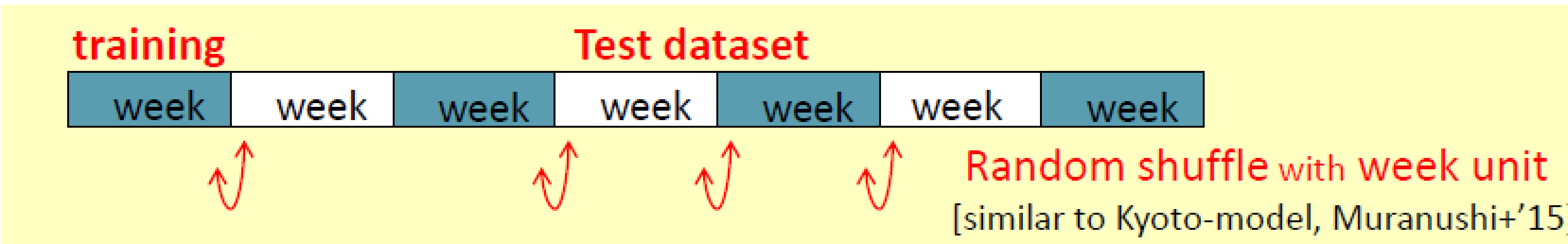
ERT		Observation: flare	Observation: no
Prediction	flare	130	**1**
Prediction	no	32	54453

TSS= 0.802

- We achieved TSS = 0.927 → world top-class score.
- In our model, kNN showed better score than SVM, ERT.

Operational Prediction (week shuffle)

Magnetic filed of sunspots does not change so much within 24 hours, so it's not good to divide the data just before a flare into training/test data sets. Therefore, we adopted the week shuffle for operation evaluation.



SVM

		Observation: flare	Observation: no
Prediction	flare	39	10
	no	26	26335

TSS= 0.600

kNN

		Observation: flare	Observation: no
Prediction	flare	59	15
	no	6	26330

TSS= 0.907

ERT

		Observation: flare	Observation: no
Prediction	flare	34	2
	no	31	26343

TSS= 0.523

- In operational model, we achieved TSS = 0.907 → world top-class !
  cf) Bobra & Couvidat'15 TSS=0.76, Muranushi+'15 TSS=0.75
- kNN is the best, among the three machine-learning methods.

Importance Ranking of Features (from ERT)

Ranking	Features	Importance
1.	Xhis	0.0519
2.	Xmax1d	0.0495
3.	Mhis	0.0365
4.	TotNL	0.0351
5.	Mhis1d	0.0342
6.	NumNL	0.0341
7.	Usflux	0.0332
8.	CHArea	0.0235
9.	Bave	0.0230
10.	Xhis1d	0.0224
11.	TotBSQ	0.0199
12.	VUSflux	0.0196
13.	Bmax	0.0193
14.	MeanGAM	0.0179
15.	dt24SavNCPP	0.0171

Total 50 features

- Flare history (total, 1day),
- Max X-ray intensity 1 day before

- Total length of Neutral Lines
- Number of NLs
- Unsigned magnetic flux,
- averaged/max Bz

Chromospheric Bright Area

- Total magnitude of Lorentz force
- Mean angle of field from radial
- Sum of the modules of the net current per polarity