CNTEC: A regional ionospheric TEC mapping technique over China and adjacent areas

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Outline

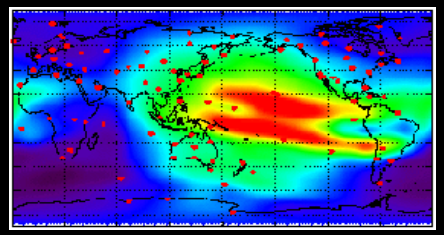
1. TEC Global/Regional Ionospheric Maps
2. GNSS Data Processing and TEC Derivation
3. TEC RIMs Construction: Data Assimilation
4. Results Comparison and Validation

TEC GIM/RIMs

Who provides Global Ionospheric Maps?

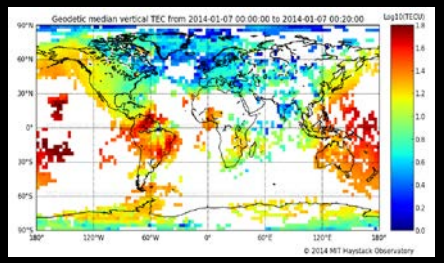
- Center for Orbit Determination of Europe (CODE)
- Jet Propulsion Laboratory (JPL)
- European Space Agency (ESA)
- Polytechnical University of Catalonia (UPC)
- Energy Mines and Resources Canada (EMR)

2.5° *5° *2 hour

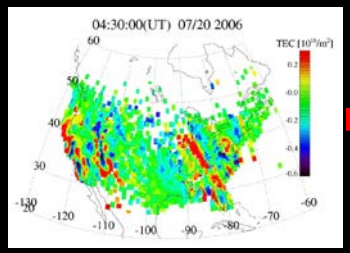


- MIT Automated Processing of GPS (MAPGPS)

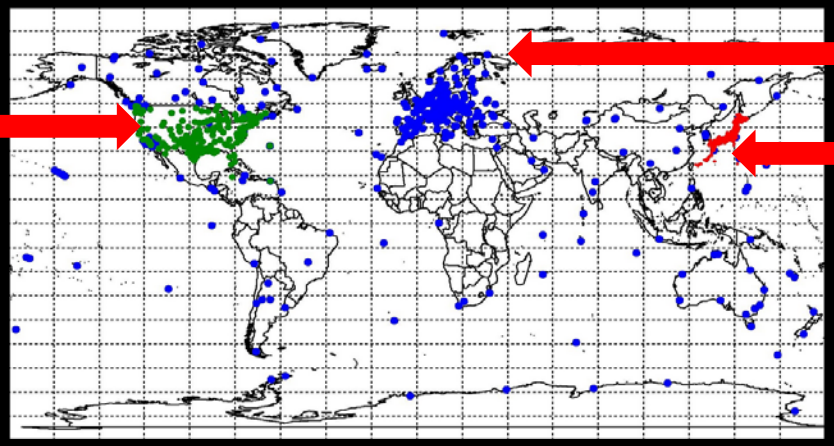
1° *1° *5 min

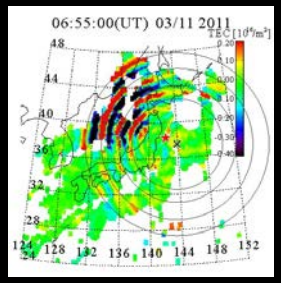


What about typical Regional Ionospheric Maps?

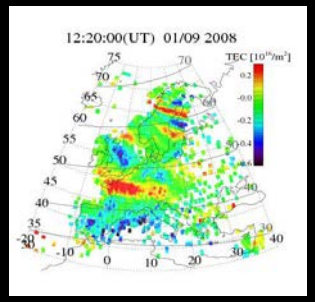


N. America
~2,700 Receivers
[Tsugawa et al., 2007]





Japan
~1,200 Receivers
[Tsugawa et al., 2011]



Europe
~1,200 Receivers
[Otsuka et al., 2012]

What about TEC RIMs over China?

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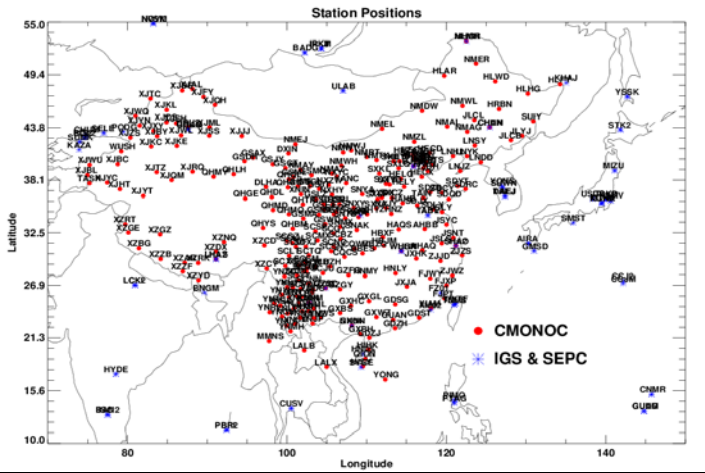
GNSS Data Processing & TEC Derivation

- GNSS Receivers over China and adjacent areas (15°-55°N, 70°-140°E)

~300+ Receivers		
Crust Movement Observation Network of China (**CMONOC**)	International GNSS Service(**IGS**)	Space Environment Prediction Center (**SEPC**)
260+ Receivers	38 Receivers	9 receivers



- TEC can be derived by combining the **Pseudo-range** and **Carrier Phase** measurements of the GPS dual frequency signals

Pseudo-range TEC

$$TEC_P = \frac{(f_{L1} f_{L2})^2}{40.3(f_{L1}^2 - f_{L2}^2)}(PR_{L2} - PR_{L1})$$

Carrier Phase TEC

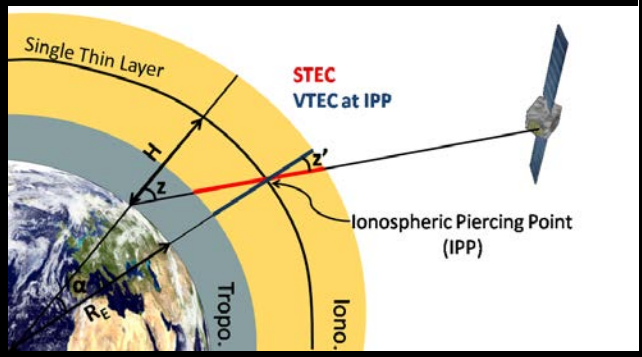
$$TEC_L = \frac{c(f_{L1} f_{L2})^2}{40.3(f_{L1}^2 - f_{L2}^2)}(L_1\lambda_1 - L_2\lambda_2 + b_1\lambda_1 - b_2\lambda_2)$$

$$TEC = TEC_L + B_{rs}$$

$$B_{rs} = \sum_{k=1}^{N}(TEC_k^P - TEC_k^L)\sin^2 el_k \Big/ \sum_{k=1}^{N}\sin^2 el_k$$

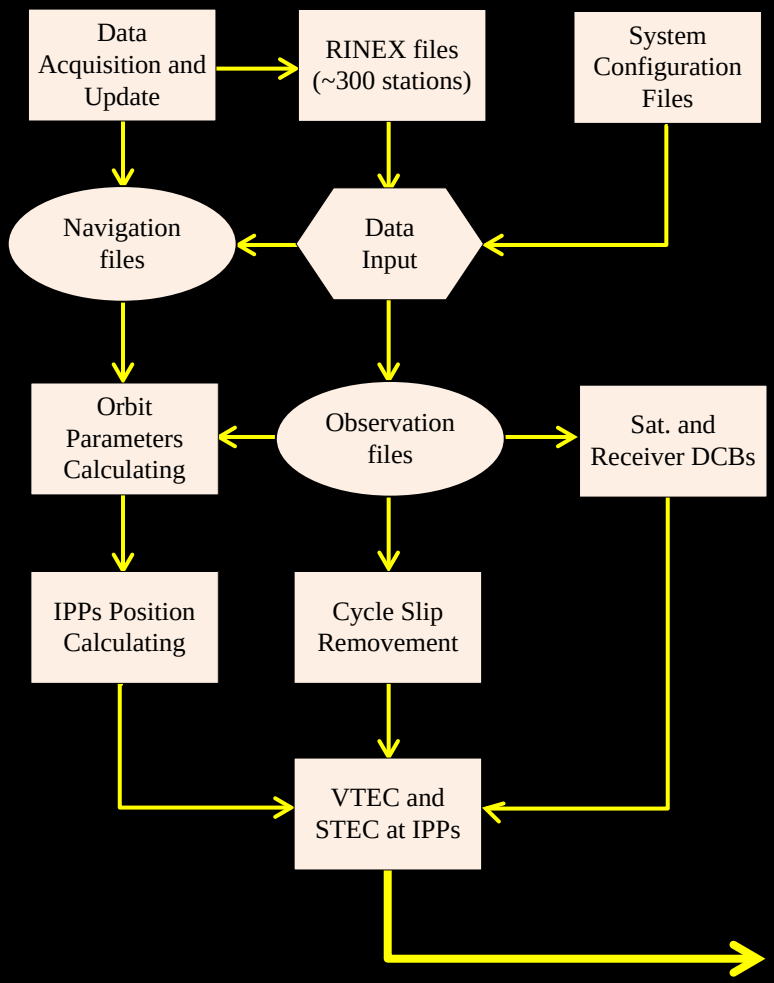
$f_{L1} = 1.575$ GHz

$f_{L2} = 1.227$ GHz



GNSS Data Processing & TEC Derivation

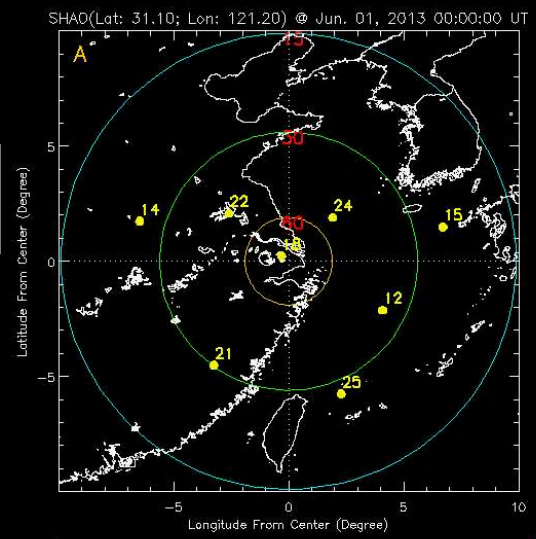
Flow chart of the TEC derivation



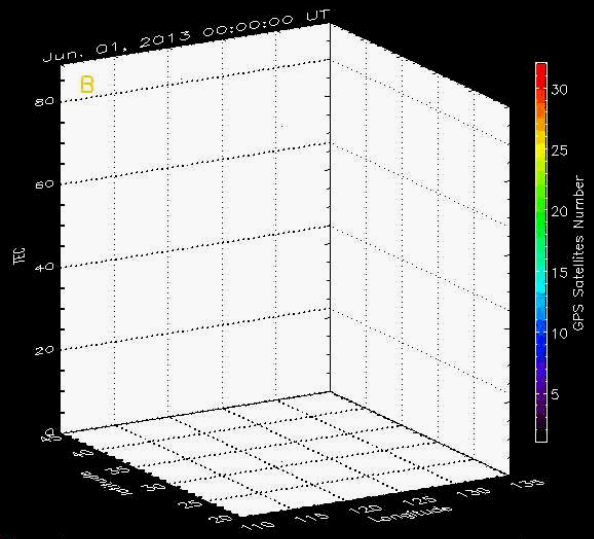
TEC derivation @ Ionospheric Pierce Points

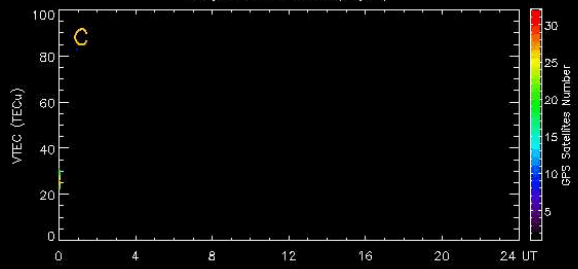
Station	Latitude	Longitude
SHAO	39.62	115.90

2-D Trail of IPPs

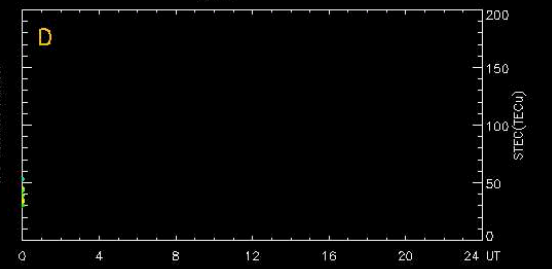


3-D Projection of IPP(TEC)



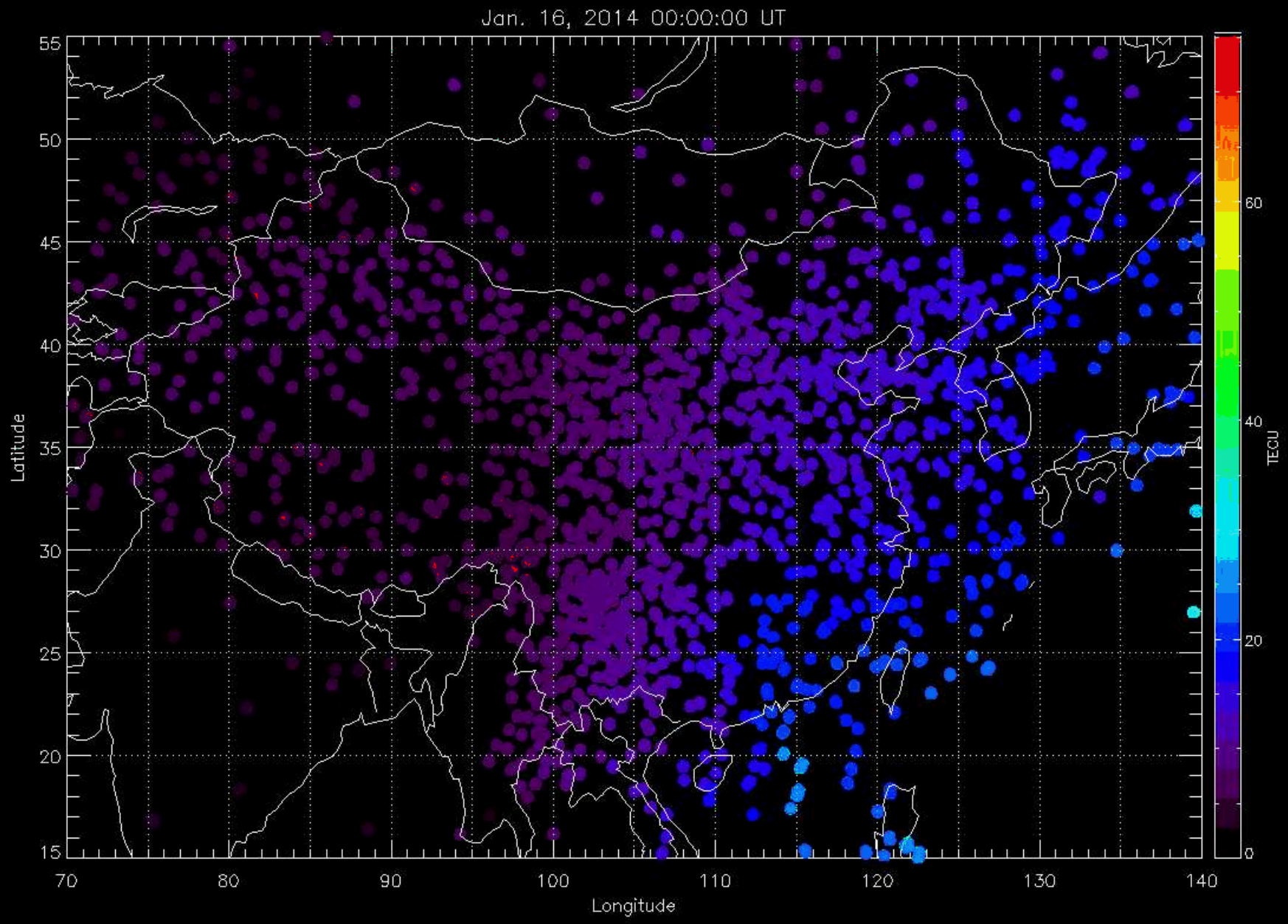


IPPs Vertical TEC



Receiver-Sat Slant TEC

IPPs TEC over China and adjacent areas



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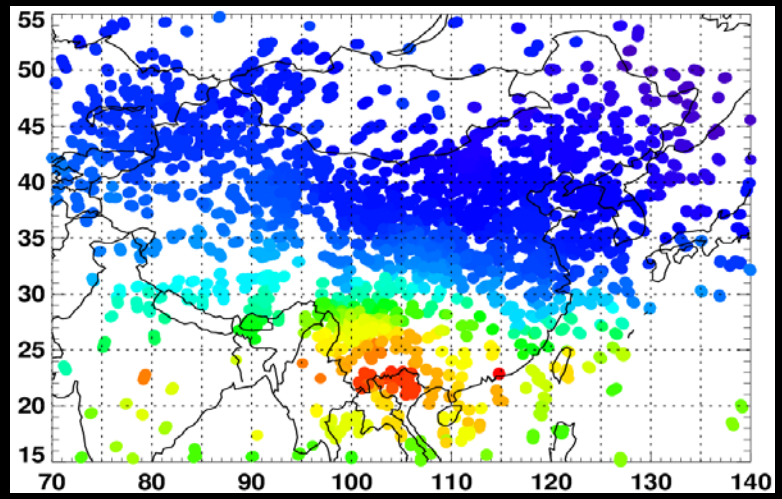
TEC RIMs Construction: Data Assimilation

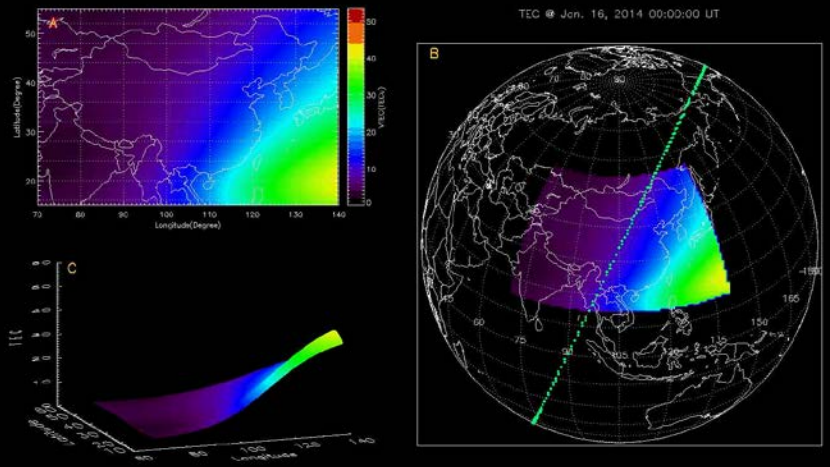
- The aim of DA scheme is to use measured observations in combination with a dynamical system model to derive accurate estimates of the states of the system.

N. K. Nichols (2010)

Observation: TEC Measurements



Model: International Reference Ionosphere



Assimilation technique: Kalman Filter

Initial estimation

X: state variables *Z: observation vectors* *d_{ij}: distance between i and j* *L_{ij}: iono-correlation length* *α¥β: associated coefficients*	$P_{ij} = \alpha X_i^b X_j^b e^{-d_{ij}/L_{ij}}$ $R_{ij} = \beta z^2 \delta_{ij}$ $\frac{1}{L_{ij}^2} = \frac{\cos^2(\alpha)}{L_{\theta i} L_{\theta j}} + \frac{\sin^2(\alpha)}{L_{\varphi i} L_{\varphi j}}$

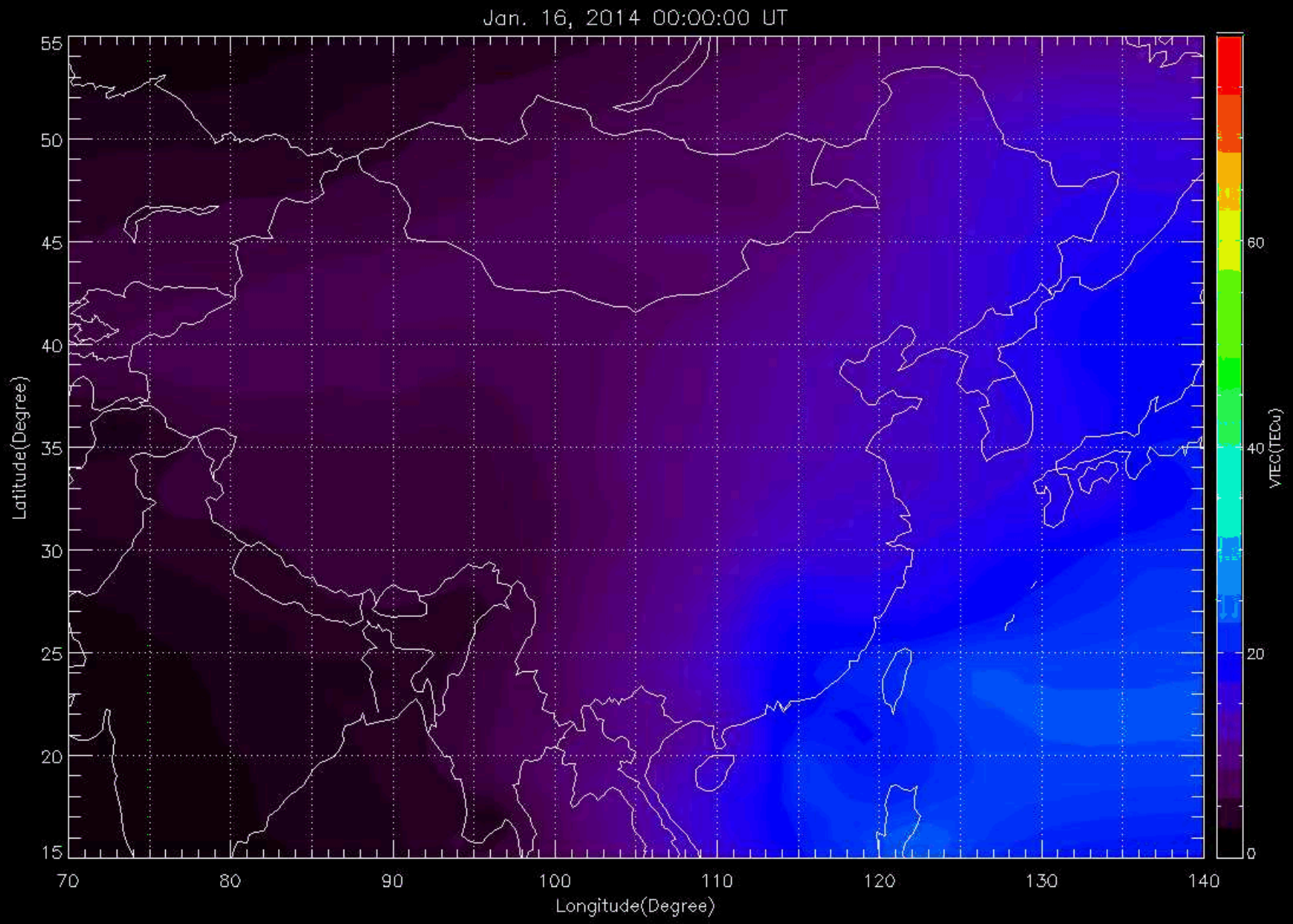
Time Update ("Predict")

1. Project the state ahead	$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1}$
2. Project the error covariance	$P_k^- = AP_{k-1}A^T + Q$

Measurement Update ("Correct")

3. Compute the Kalman gain	$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1}$
4. Update estimate	$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-)$
5. Update the error covariance	$P_k = (I - K_k H)P_k^-$

TEC RIMs over China and Adjacent Areas (1° *1° *5 min)



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Results Comparison and Validation

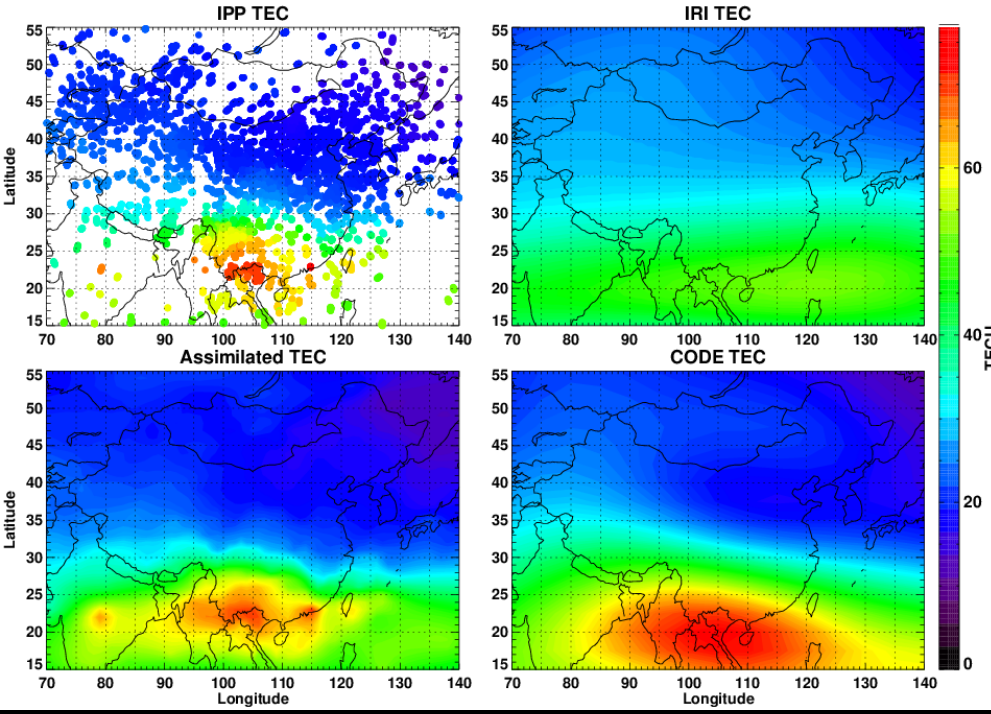
Comparison with IRI and CODE TEC

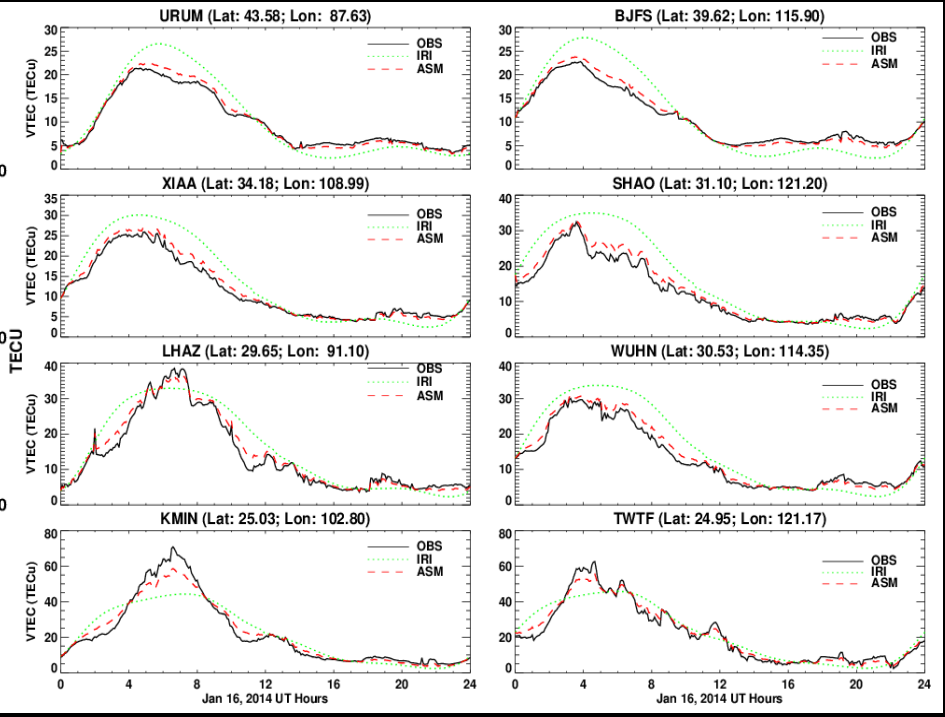
	DA	IRI	CODE
Subtle Structure	√		
Local Variation	√		
Climate Variation		√	√

Cross-Validation with 8 GNSS Stations

	bjfs	shao	wuhn	twtf	urum	xiaa	lhaz	kmin
Lat	39.6	31.1	30.5	24.9	43.6	34.2	29.6	25.0
Lon	115.9	121.2	114.4	121.2	87.6	109.0	91.1	102.8

The TEC data at each one of the 8 stations is excluded from data assimilation process, this makes the chosen data independent for comparison



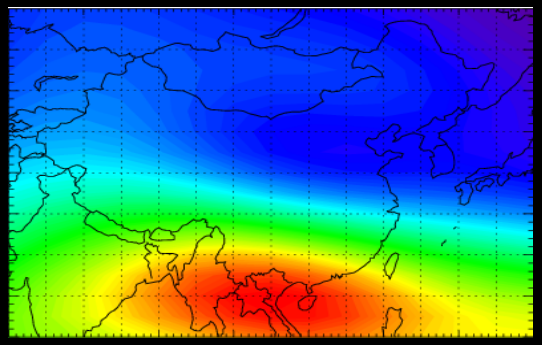


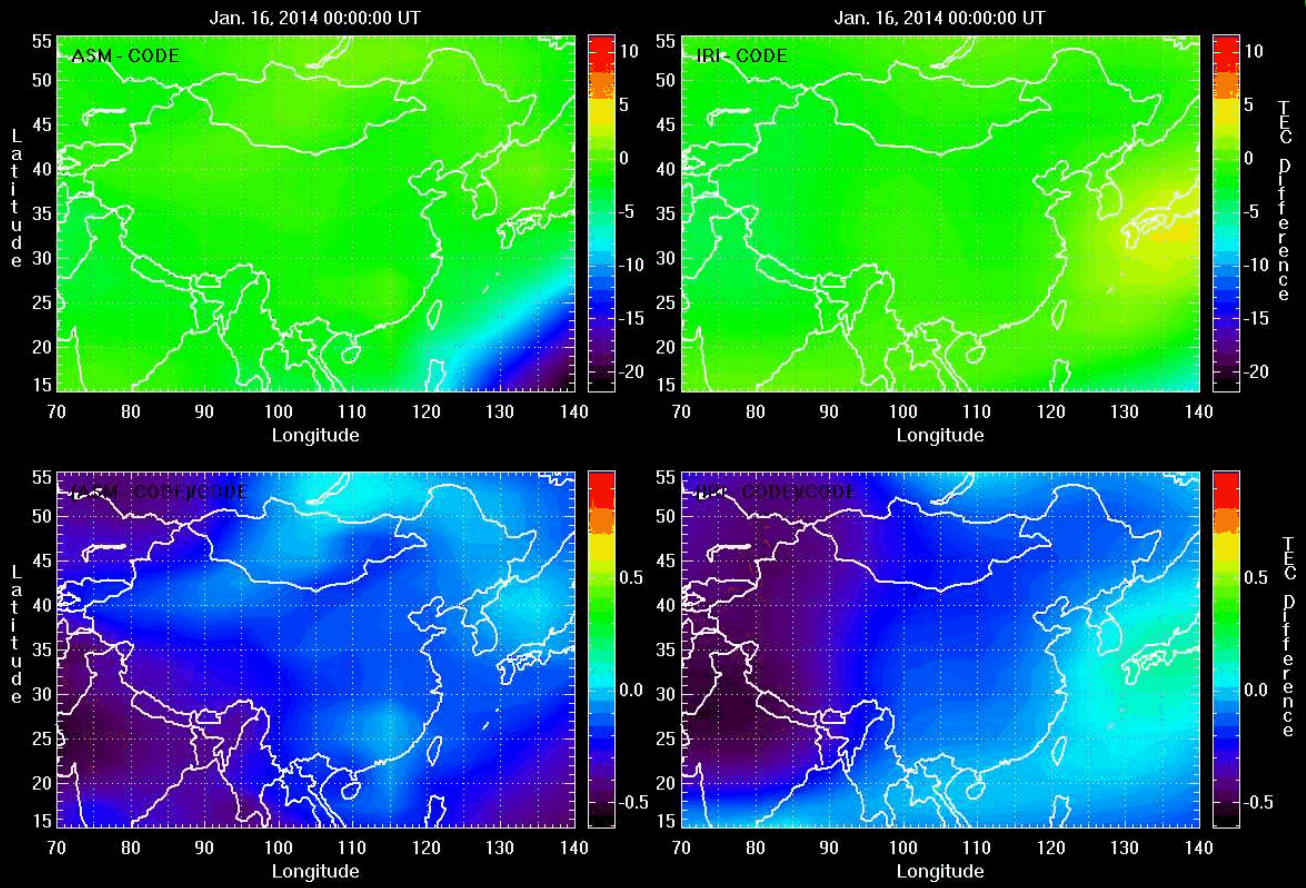
Comparison with CODE GIMs

Analysis centers provide GIMs of TEC

- Center for Orbit Determination of Europe (CODE)
- Jet Propulsion Laboratory (JPL)
- European Space Agency (ESA)
- Poly-technical University of Catalonia (UPC)
- Energy Mines and Resources Canada (EMR)

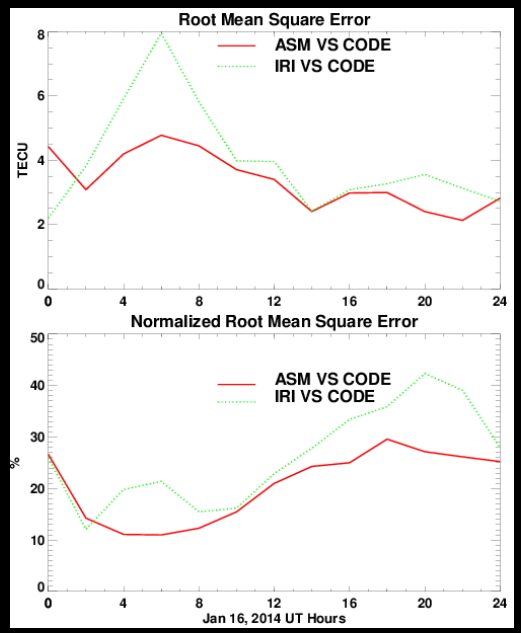
5° *2.5° *120 min



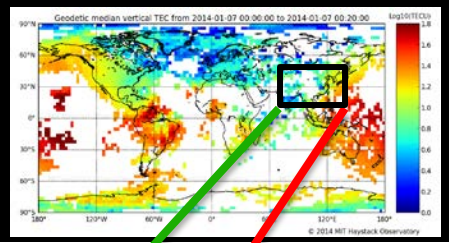


$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(TEC_{mod} - TEC_{ref})^2}$$

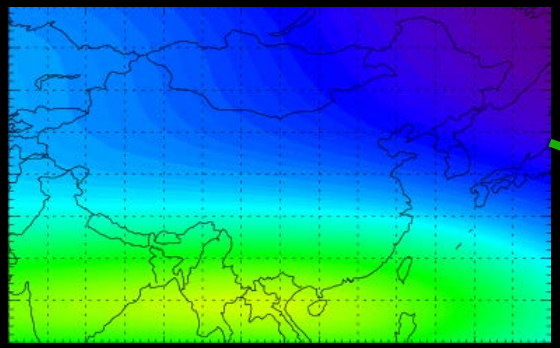
$$NRMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(\frac{TEC_{mod} - TEC_{ref}}{TEC_{ref}}\right)^2}$$



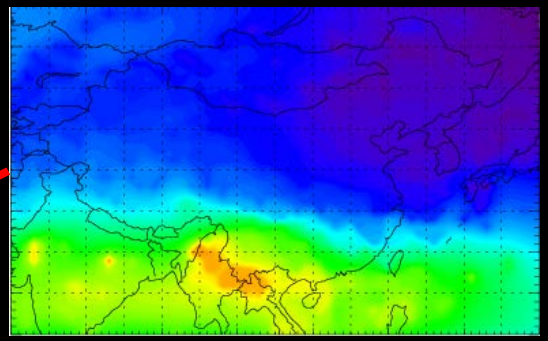
Comparison with Madrigal Database (1° *1° *5 min)

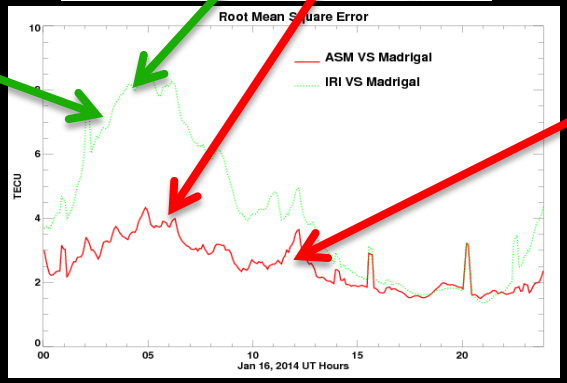


IRI TEC

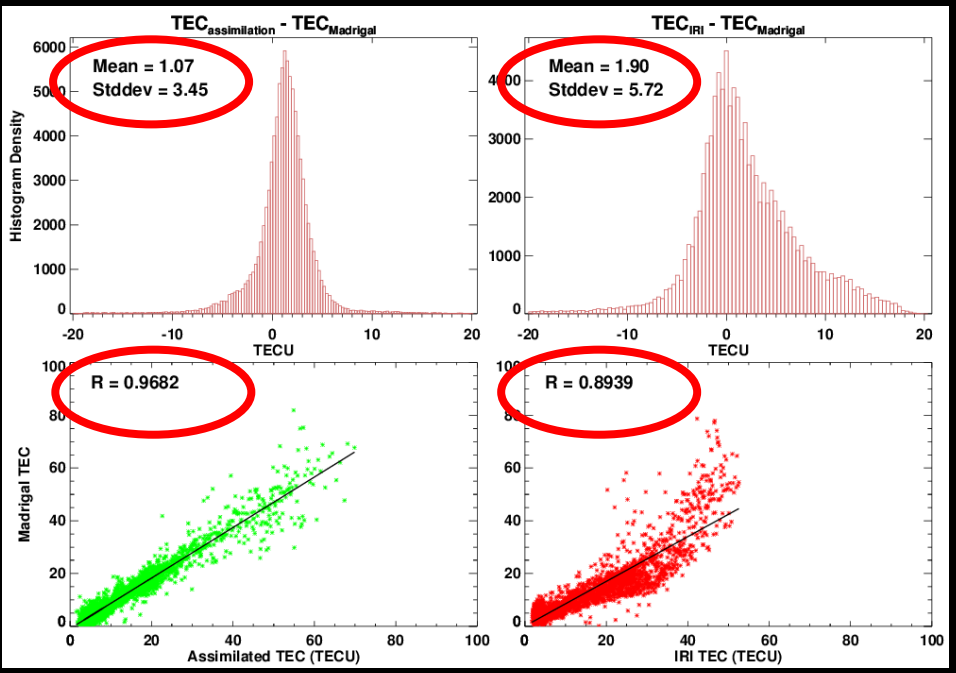


Data Assimilation TEC

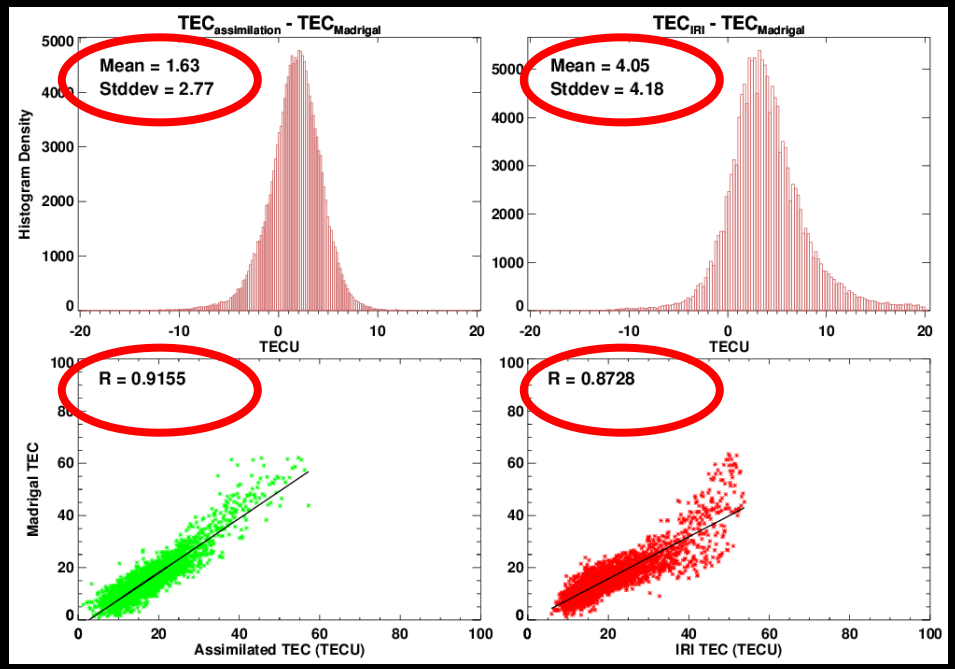




$TEC_{DA\ (IRI\ )} - TEC_{Madrigal}$ @ Jan. 2014



$TEC_{DA\ (IRI\ )} - TEC_{Madrigal}$ @ Jul. 2013



Summary and Conclusion

- A new technique has been developed to derive TEC over China and adjacent areas using CMONOC and IGS data, and a data assimilation method based on Kalman filter scheme is used to assimilate the TEC data into the background IRI model. Regional TEC maps over China and adjacent area (70°E-140°E and 15°N-55°N) are generated accordingly with the resolution being 1°*1° and 5 min respectively.
- The accuracy and validity of data assimilation results have been verified through the comparison with IRI, CODE, and Madrigal TEC data. The data assimilation results are able to capture more subtle local characteristics of TEC variation, and can get a smaller RMSE than those results with no assimilation.
- The histogram and correlation analysis also indicate that considerable systematic improvements can be obtained when GNSS data are assimilated into the background model, which demonstrates the viability and effectiveness of the data assimilation method.

Thank You !