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Autoscaled MUF assimilation in RATIM

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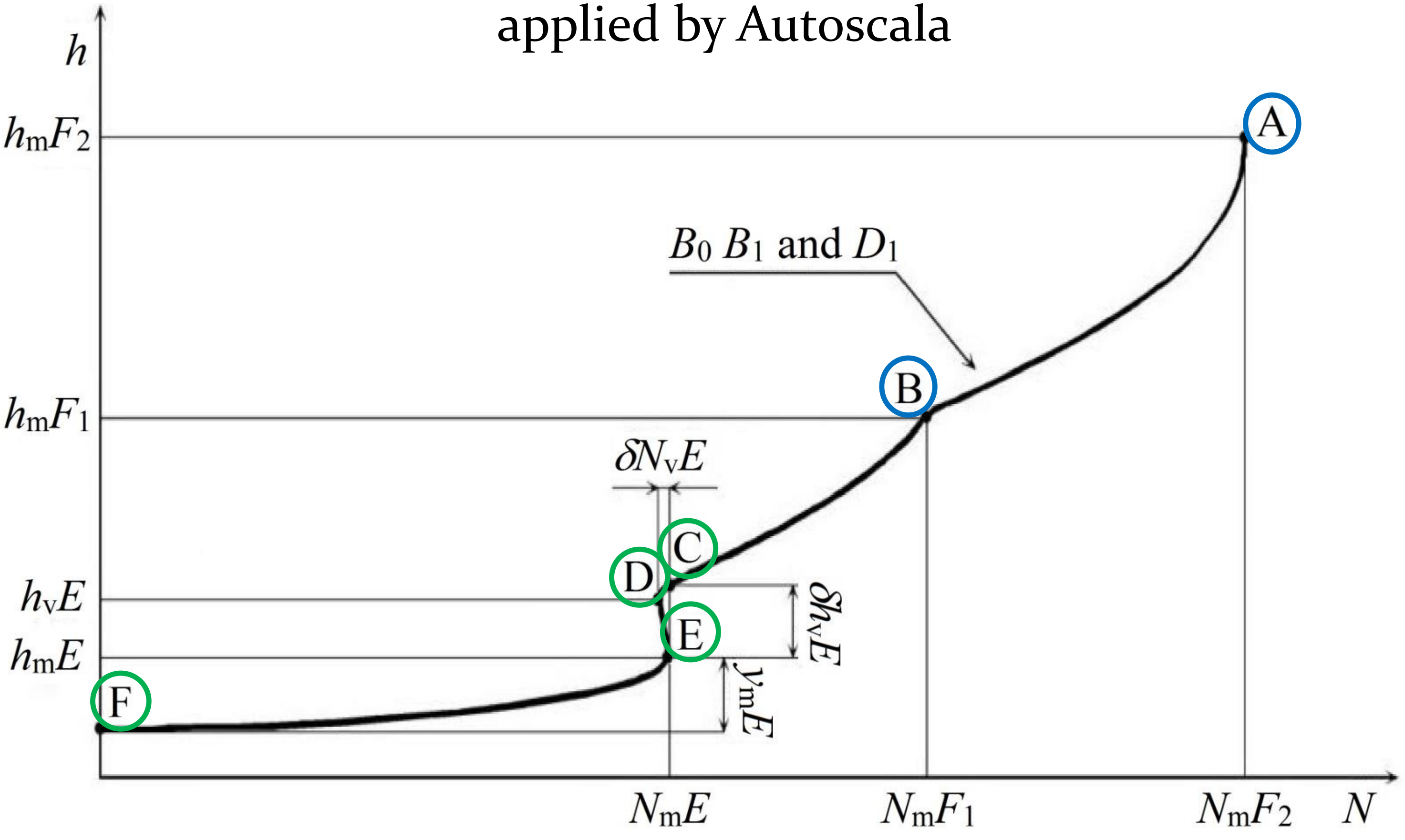
Outline

- ✓ The Regional Assimilative Three-dimensional Ionospheric Model (**RATIM**)*
- ✓ Vertical HF radio-sounding data ingestion
- ✓ Oblique HF radio-sounding data ingestion (new)
- ✓ Preliminary results over the Japanese-South Korean region

* Sabbagh, D., Scotto, C., Sgrigna, V., 2016.
A regional adaptive and assimilative three-dimensional ionospheric model.
Adv. Space Res. 57 (5), 1241-1257, doi:10.1016/j.asr.2015.12.038.

The adaptive *N*(*h*) model

- ✓ Adaptive Ionospheric Profiler (**AIP**)* applied by Autoscala
- ✓ 12 free parameters



F region

1) N_mF_2
2) h_mF_2
3) N_mF_1
4) B_0
5) B_1
6) D_1

7) N_mE
8) h_mE
9) h_vE
10) δh_vE
11) δN_vE
12) y_mE

E region

* Scotto, C., 2009. Electron density profile calculation technique for Autoscala ionogram analysis. Adv. Space Res. 44, 756-766.

Climatological 3D model

1) $N_m F_2$	$f_o F_2$ (IRI) → Jones et al. (1962, 1969)
2) $h_m F_2$	Bradley and Dudeney (1973)
3) $N_m F_1$	$f_o F_1$ (IRI) → DuCharme et al. (1971, 1973)
4) B_0	Scotto (2009)
5) B_1	$B_1=3$
6) D_1	χ dependent variation
7) $N_m E$	$f_o E$ (IRI) → Davies (1990)
8) $h_m E$	$h_m E=110$ km (IRI)
9) $h_v E$	Mahajan et al. (1997)
10) $\delta h_v E$	
11) $\delta N_v E$	
12) $y_m E$	$y_m E=15$ km

(t,φ,λ)
dependence:

3D description of a monthly median ionosphere at specified

- time
- region

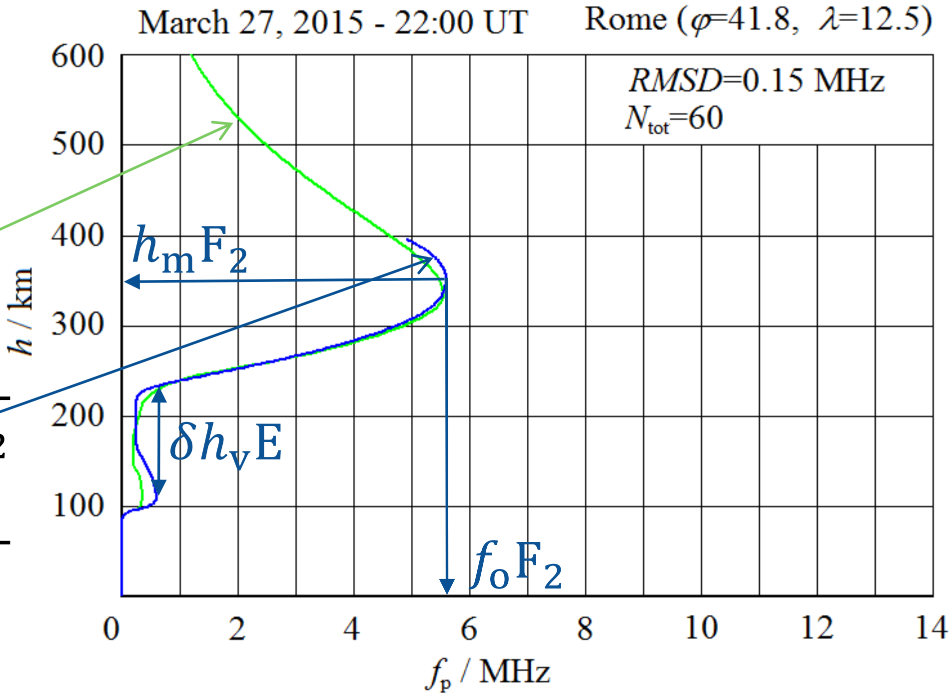
Vertical plasma frequency profiles ingestion

- ✓ Climatological parameter $P_{\mathrm{i[base]}}(\varphi,\lambda)$ $\xrightarrow[\text{variation } \Delta P_{\mathrm{i}}]{}$ Actual value $P_{\mathrm{i}}(\varphi,\lambda) = P_{\mathrm{i[base]}}(\varphi,\lambda) + \Delta P_{\mathrm{i}}$

- ✓ Parameters varied
  - $f_o F_2$
  - $h_m F_2$
  - $\delta h_v E$

- ✓ *RMSD* minimization ⇨
  - $\Delta f_o F_2$
  - $\Delta h_m F_2$
  - $\Delta \delta h_v E$

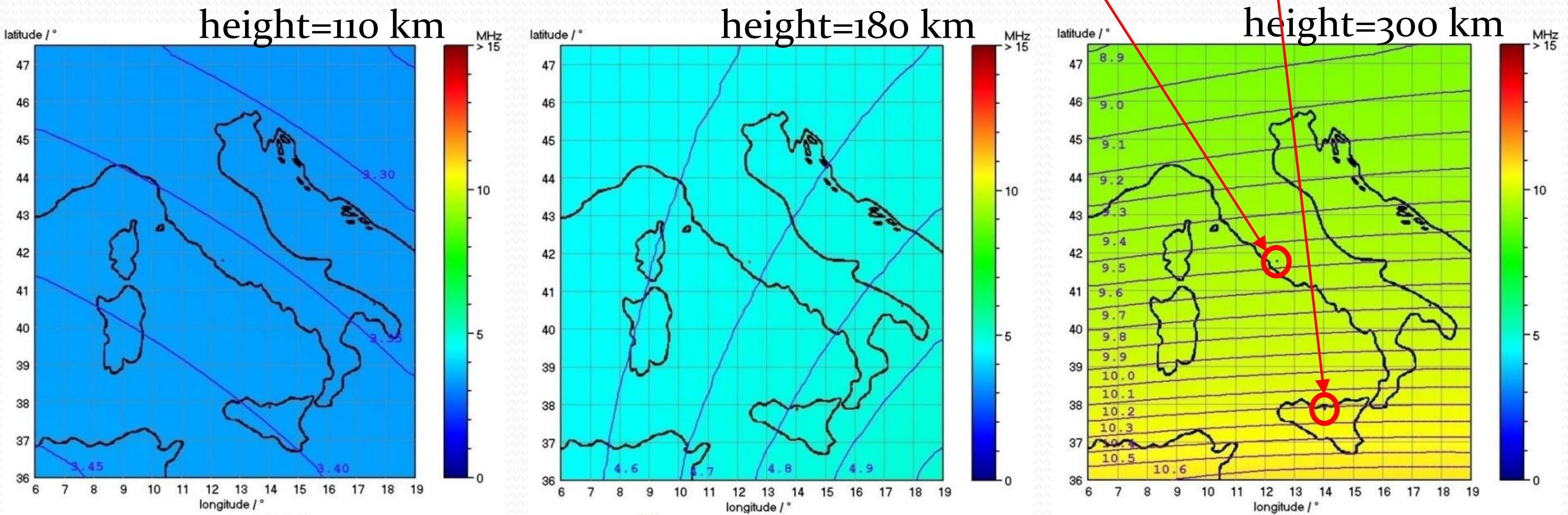
$$\sqrt{\frac{\sum_{i=1}^{N_{\mathrm{tot}}}\left(f_{\mathrm{p[ionos]}}(h^{[i]}) - f_{\mathrm{p[model]}}(h^{[i]})\right)^2}{N_{\mathrm{tot}}}}$$



Products

- March 27, 2015, 12:45 UT
- from Rome (41.8° N, 12.5° E) and Gibilmanna (40.6° N, 18.0° E) data

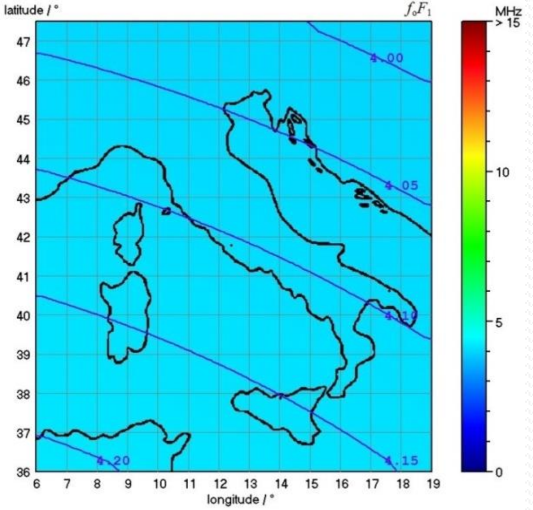
✓ f_p at fixed altitude


height=110 km

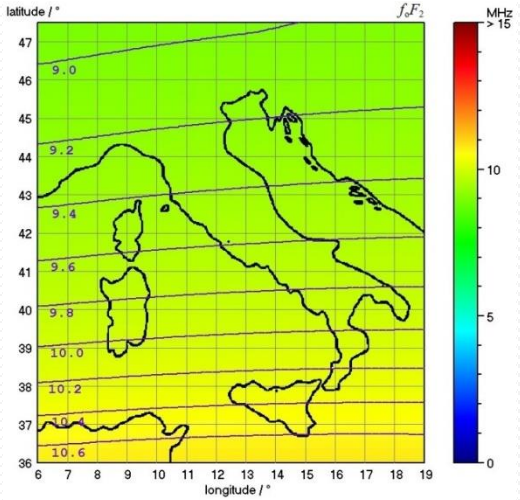
height=180 km

height=300 km

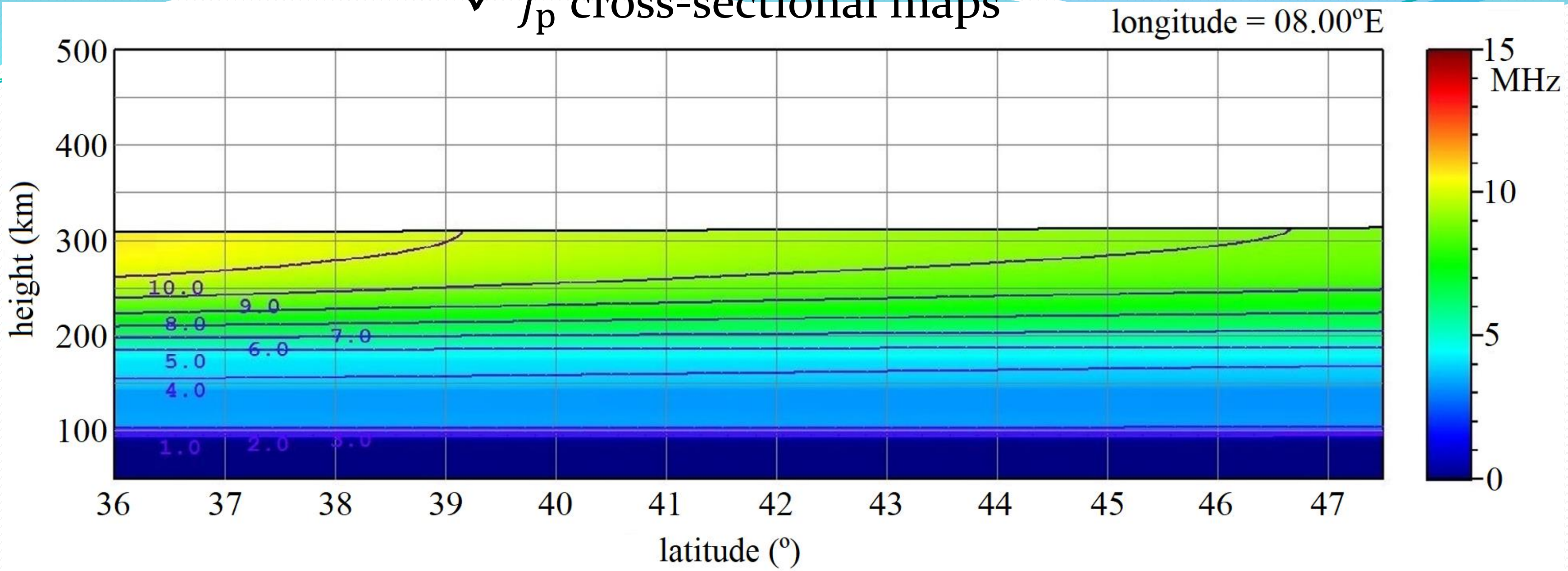
✓ f_oF_1



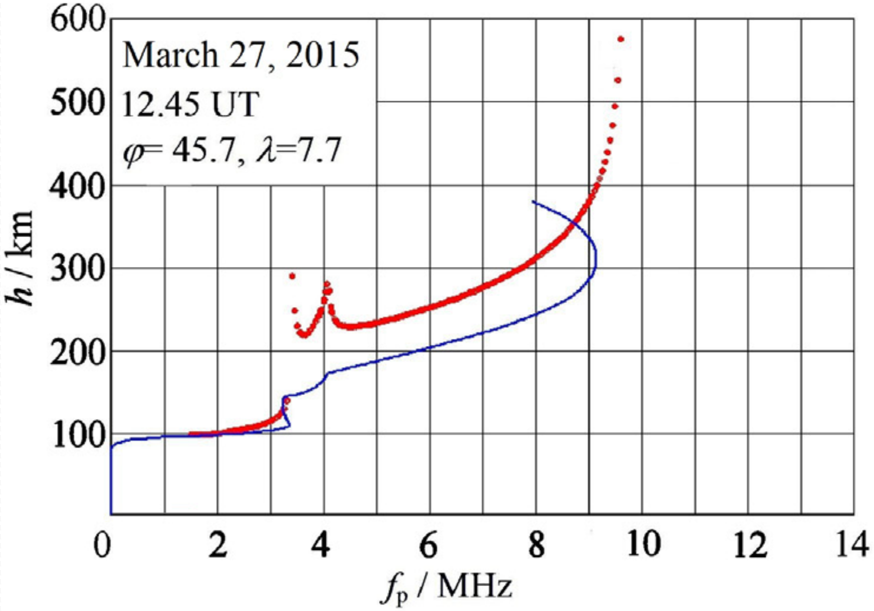
✓ f_oF_2

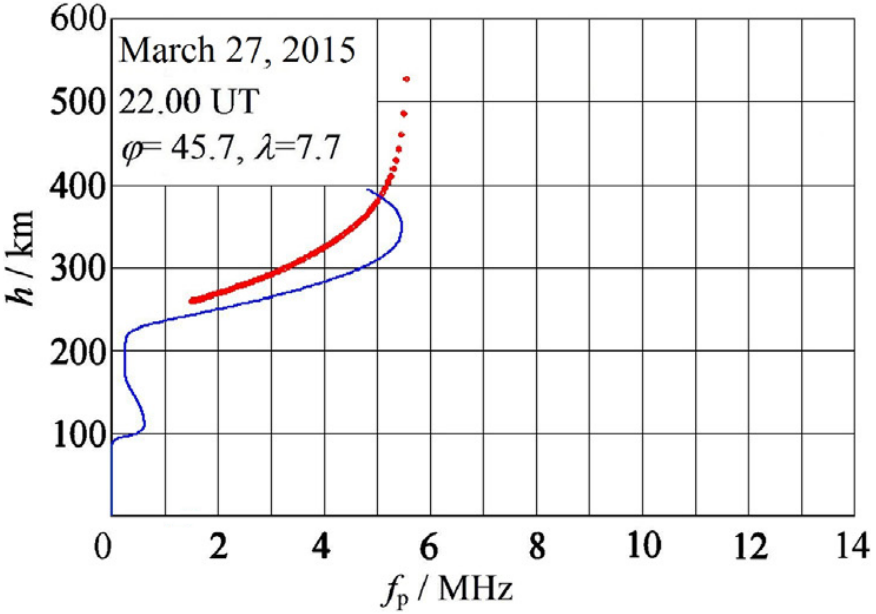


- ✓ f_p cross-sectional maps

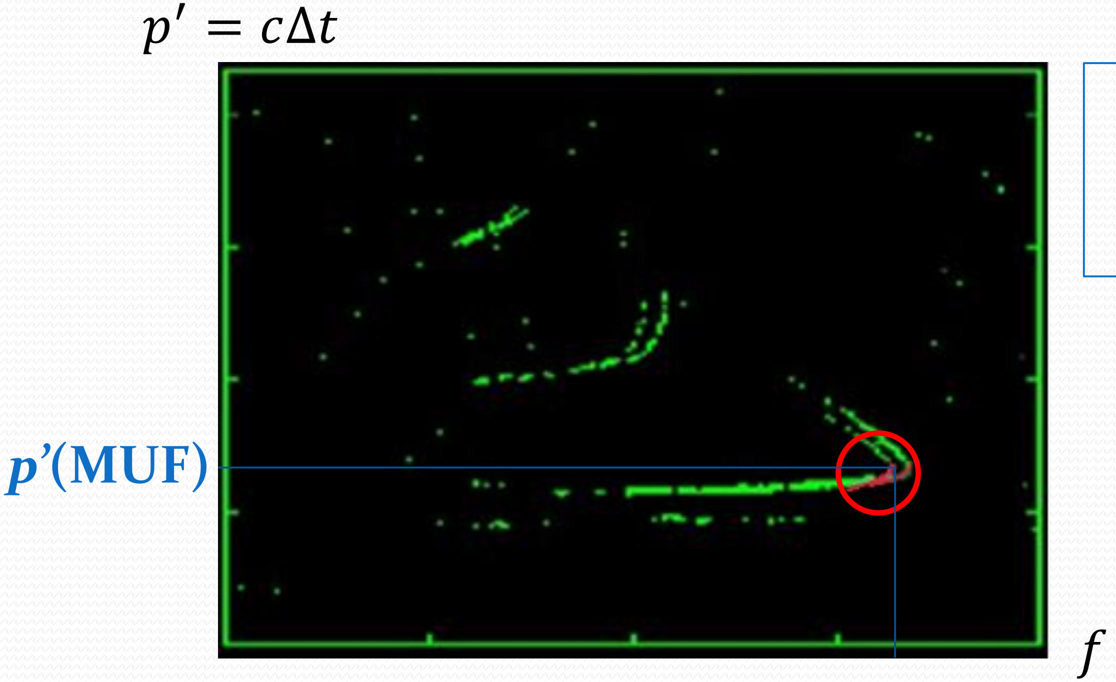


- ✓ $f_p(h)$ profiles and corresponding simulated ionograms





MUF from oblique radio-soundings



Maximum Usable Frequency (MUF)

Oblique Ionogram
Automatic Scaling Algorithm
(**OIASA**)*

image recognition technique: determination of the MUF through the **maximum contrast method**

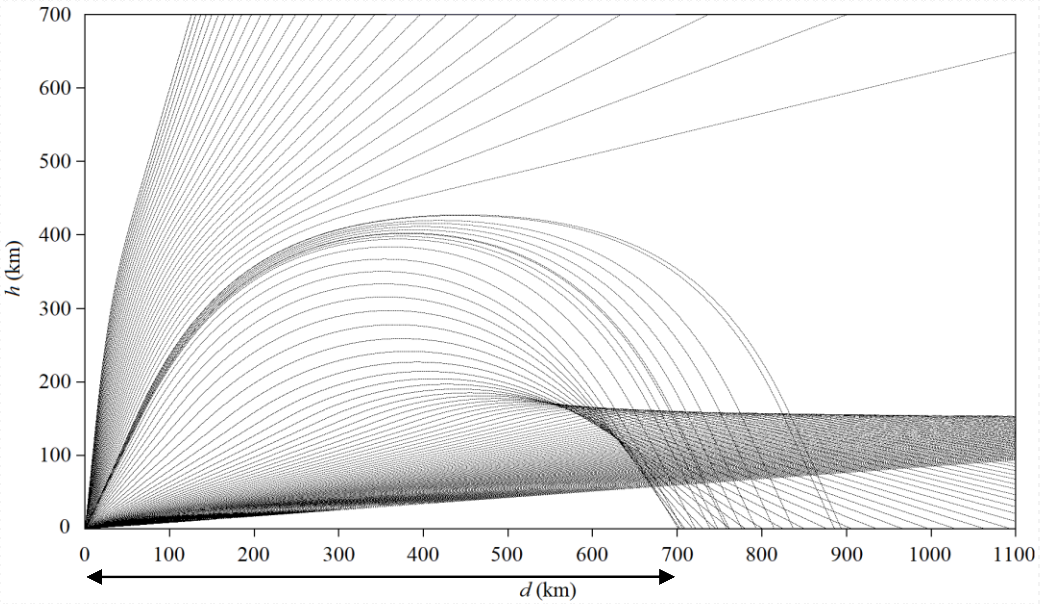
[1] Ippolito, A., Scotto, C., Francis, M., Settimi, A., Cesaroni, C., 2015. Automatic interpretation of oblique ionograms, Adv. Space Res., 55, 1624–1629.

[2] Ippolito, A., Scotto, C., Sabbagh, D., Sgrigna, V., Maher, P., 2016. A procedure for the reliability improvement of the oblique ionograms automatic scaling algorithm. Radio Sci. 51, doi:10.1002/2015RS005919.

Eikonal based ray-tracing technique

- ✓ differential ray equation $$\frac{d}{ds}\left(n(s)\,\frac{d\vec{r}(s)}{ds}\right) = \nabla n(s)$$
- ✓ phase refraction index $$n(\vec{r}) = \left(1 - \left(\frac{f_{\mathrm{p}}(\vec{r})}{f}\right)^{2}\right)^{1/2}$$

neglecting:
- Earth's Magnetic Field
- collisions



skip distance

≡ ground range D, when f = MUF

skip distance simulation associated to fixed frequencies

simulation of the ground range between the end points of an oblique radio-sounding from the corresponding MUF

RATIM MUF ingestion procedure

✓ simplified ionosphere between the transmitter and the receiver ➡ same parabolic vertical profile:

$$\left.\begin{array}{l}\boxed{\begin{array}{l}\bullet\ N_{\mathrm{max}} = N_{\mathrm{m}}\mathrm{F}_{2[\mathrm{midpoint}]} \\ \bullet\ h_{\mathrm{max}} = h_{\mathrm{m}}\mathrm{F}_{2[\mathrm{midpoint}]}\end{array}} \\ \bullet\ \text{thickness} \propto B_{0[\mathrm{midpoint}]}\end{array}\right\}\ \text{modelled by RATIM}$$

✓ Combined $f_{\mathrm{p}}(h)$ and MUF ingestion procedure

- $f_{\mathrm{p}}(h)$ ingestion ⟶ *RMSD* minimization testing a number of combination of $\Delta f_{\mathrm{o}}\mathrm{F}_2$, $\Delta h_{\mathrm{m}}\mathrm{F}_2$, $\Delta\delta h_{\mathrm{v}}\mathrm{E}$ values
- MUF ingestion ⟶ for each iteration:
  - $RMSD < RMSD_{\text{current min}}$
  - $\boxed{\Delta D < \Delta D_{\mathrm{t}}}$ further adapting condition

where $\Delta D = |D_{[\mathrm{real}]} - D_{[\mathrm{MUF}]}|$

Data set

- ✓ Japanese-South Korean region

vertical ionograms recorded at

Jeju (33.4° N, 126.3° E), South Korea
Icheon (37.1° N, 127.5° E), South Korea

oblique ionograms recorded between

Kokubunji (35.7° N, 139.5° E), Japan
Icheon (37.1° N, 127.5° E), South Korea

140 cases ↔ measurements

every 30 min.

October 5, 2016
November 3, 2016
November 19, 2016

Preliminary results

✓ all available input data

Tab. 1	# cases	# adapted	% adapted	⟨*RMSD*⟩ (MHz)	⟨Δ*D*⟩ (km)
Only $f_p(h)$ adapting	140	118	84.29	0.36	-
$f_p(h)$ and MUF adapting, $\Delta D_t = 50$ km	140	93	66.43	0.36	32
$f_p(h)$ and MUF adapting, $\Delta D_t = 20$ km	140	89	63.57	0.37	11

poor-quality data rejection ability

good degree of adaptability (~0.1 MHz)

better adaptability for low ΔD_t

✓ only validated input data

Tab. 2	# cases	# adapted	% adapted	⟨*RMSD*⟩ (MHz)	⟨Δ*D*⟩ (km)
Only $f_p(h)$ adapting	65	62	95.38	0.31	-
$f_p(h)$ and MUF adapting, $\Delta D_t = 50$ km	65	58	89.23	0.32	31
$f_p(h)$ and MUF adapting, $\Delta D_t = 20$ km	65	56	86.15	0.33	12

Conclusions

- ✓ Improvement of the RATIM ionosonde data assimilation capability, including oblique radio-sounding data (MUF)
- ✓ Introduction of ionospheric radio-propagation modelling capabilities
- ✓ Preliminary results in agreement with previous results
  - adaptability (better for low ΔD_t)
  - incorrect input data rejection ability (better)
  - promising for automatically retrieving *N* from oblique ionograms

- ✓ Too long computational times for the data ingestion
- ✓ Different parts of the system not yet automatically interconnected

➡ need to faster algorithms, and automatic procedures for the real-time application

Thank you
for your attention

Acknowledgments:

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National Institute of Information and Communications Technology (NICT),
Kokobunji, Japan.

	Δf_oF_2 [MHz]	Δh_mF_2 [km]	$\Delta\delta h_vE$ (night) [km]	$\Delta\delta h_vE$ (day) [km]
min	-4.0	-150	10	-7.5
max	4.0	150	105	40.0
step	0.1	15	5	2.5
# values	81	21	20	20
# combinations			34020	34020

$$\Delta B_o = \Delta B_o^{[N]}$$

$$\Delta B_o^{[n]} = (-1)^{n+1} \cdot n \cdot 0.05\% \cdot B_{o[\mathrm{base}]} \qquad n = 0, \ldots N$$

(until the algorithm is able to link the profile consistently with the Reinisch and Huang formulation)