Speeding Up CORS Network RTK Ambiguity Resolution

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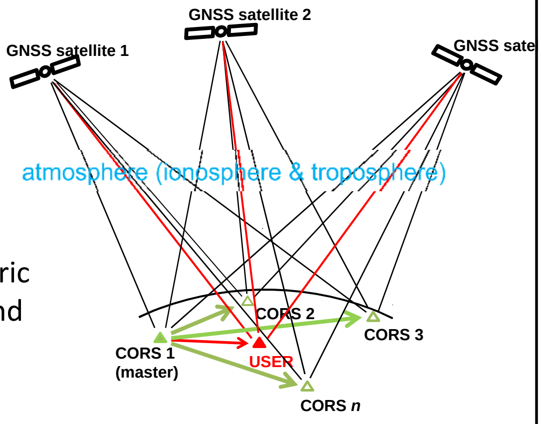
Outline

- Recap CORS Network RTK
- ADOP as diagnostic for network AR
- CORS Network RTK processing model
- CORS Network RTK ADOP closed-form formula
- CORS Network RTK ADOP examples
- Conclusions

Principle of GPS CORS Network RTK

- enabling long-range RTK by receiving **ionospheric corrections** (+ data reference station) from CORS network
- ionospheric corrections are **predicted** from the ionospheric delays from CORS network and disseminated to the user
- precise ionospheric estimation relies on integer **network ambiguity resolution**



CORS Network Ambiguity Resolution

- is **key** to precise CORS Network RTK and should be as fast as possible, preferably **instantaneous (single epoch)** as to generate corrections truly in **real time**
- at present (**dual-frequency GPS**): we have to deal with float ambiguity **convergence times**:
  - **at beginning of operation of CORS network**
  - **when a new satellite rises**
  - **after a long (power) failure**

  before the integer ambiguities can be reliably fixed, since the differential ionospheric delays are unknown

ADOP as diagnostic for network AR

$\boxed{ADOP = |Q_{\hat{a}}|^{1/(2n_a)}}$ ***Ambiguity Dilution Of Precision*** (Teunissen, 1997)

with $Q_{\hat{a}}$ the $n_a \times n_a$ DD **ambiguity variance-covariance matrix**:

$$Q_{\hat{a}} = \begin{pmatrix} \sigma^2_{\hat{a}_1} & \cdots & \sigma_{\hat{a}_1 \hat{a}_{n_a}} \\ \vdots & \ddots & \vdots \\ \sigma_{\hat{a}_{n_a} \hat{a}_1} & \cdots & \sigma^2_{\hat{a}_{n_a}} \end{pmatrix}$$

Properties of ADOP:

- **scalar** measure, expressed in **cycles**
- ambiguity **correlation** is taken into accou
- invariant for **change of reference satellite**
- invariant for **LAMBDA decorrelating transformation**
- **analytical closed-form expressions** possible
- related to **ambiguity success rate**: $ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$

CORS Network AR model assumptions

All *n* CORS stations observe the same *m* satellites during *k* observation epochs

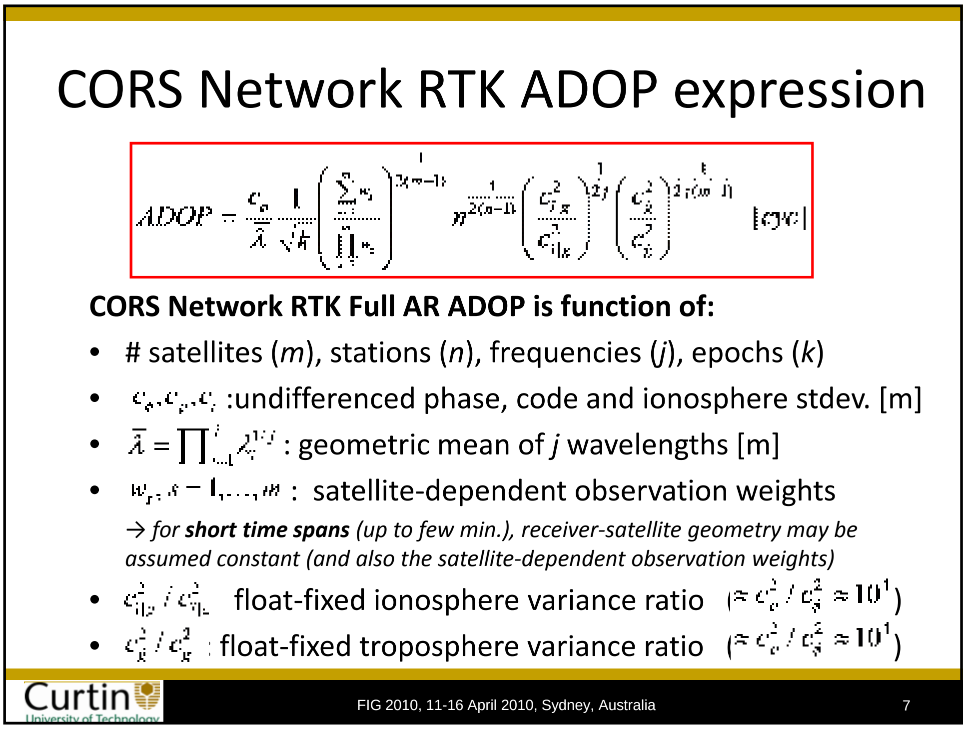
Observations:

- **Carrier-phase** data of *j* frequencies: *jnmk* obs., with a precision of $\sigma_{\phi_j} = c_\phi / \sqrt{w_s}$
- **Code** (pseudorange) data of *j* frequencies: *jnmk* obs., with a precision of $\sigma_{p_j} = c_p / \sqrt{w_s}$
- **Ionospheric** observations: *nmk* obs. (zero or external, e.g. GIM), with a precision of $\sigma_{\iota_s} = c_\iota / \sqrt{w_s}$ and c_ι a function of distance

Parameters:

- ~~**Satellite** coordinates (IGS): 3*mk*~~
- ~~**CORS stations** coordinates: 3*n*~~
- **DD ambiguities**: *j*(*n*-1)(*m*-1)
- **Receiver clock** errors: 2*j*(*n*-1)*k*
- **Satellite clock** errors: 2*jmk*
- **Tropospheric** zenith delays: *n*-1
- **Ionospheric** slant delays: (*n*-1)(*m*-1)*k*

all observations are assumed to be uncorrelated in time



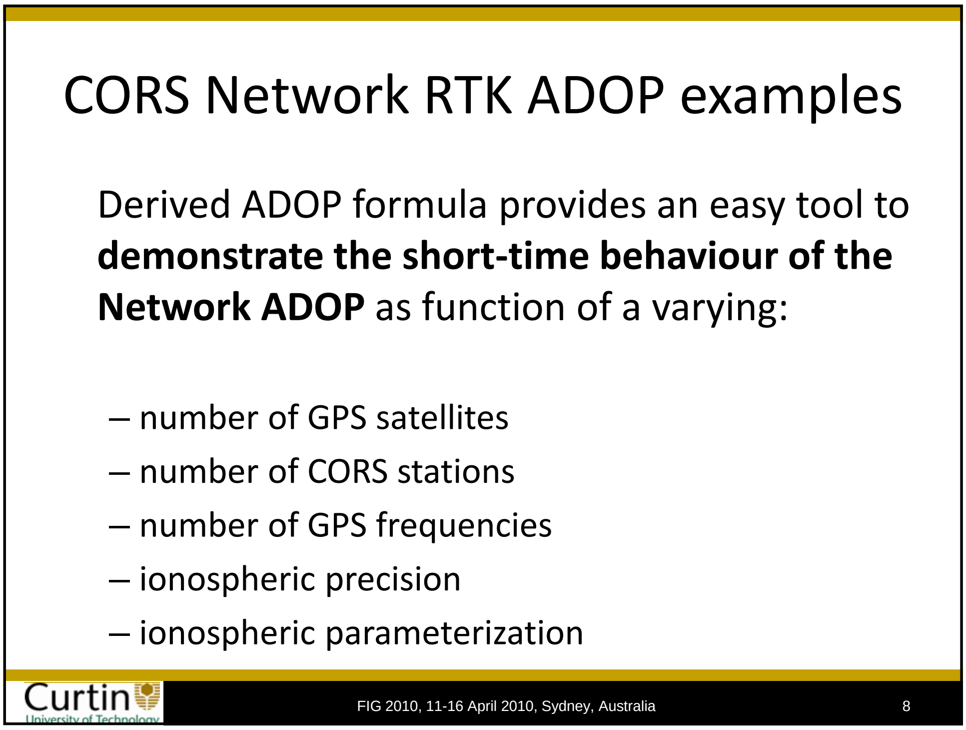
CORS Network RTK ADOP expression

$$ADOP = \frac{c_\phi}{\bar{\lambda}}\frac{1}{\sqrt{k}}\left(\frac{\sum_{s=1}^{m} w_s}{\prod_{s=1}^{m} w_s}\right)^{\frac{1}{2(m-1)}} n^{\frac{1}{2(n-1)}}\left(\frac{c_{\hat{I}|k}^2}{c_{\check{I}|k}^2}\right)^{\frac{1}{2j}}\left(\frac{c_{\hat{T}}^2}{c_{\check{T}}^2}\right)^{\frac{1}{2j(m-1)}} \quad [cyc]$$

CORS Network RTK Full AR ADOP is function of:

- # satellites (*m*), stations (*n*), frequencies (*j*), epochs (*k*)
- c_ϕ, c_p, c_ι :undifferenced phase, code and ionosphere stdev. [m]
- $\bar{\lambda} = \prod_{i=1}^{j} \lambda_i^{1/j}$: geometric mean of *j* wavelengths [m]
- $w_s, s = 1, \ldots, m$: satellite-dependent observation weights

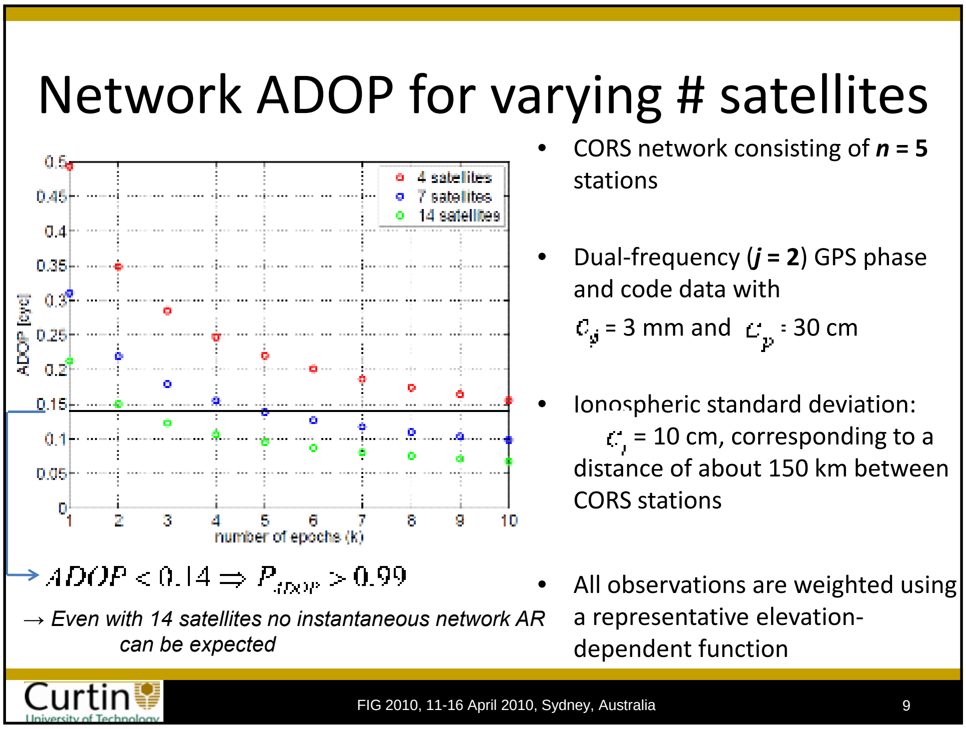
  → *for **short time spans** (up to few min.), receiver-satellite geometry may be assumed constant (and also the satellite-dependent observation weights)*
- $c_{\hat{I}|k}^2 / c_{\check{I}|k}^2$ float-fixed ionosphere variance ratio $(\approx c_\iota^2 / c_\phi^2 \approx 10^1)$
- $c_{\hat{T}}^2 / c_{\check{T}}^2$: float-fixed troposphere variance ratio $(\approx c_\iota^2 / c_\phi^2 \approx 10^1)$



CORS Network RTK ADOP examples

Derived ADOP formula provides an easy tool to **demonstrate the short-time behaviour of the Network ADOP** as function of a varying:

- – number of GPS satellites
- – number of CORS stations
- – number of GPS frequencies
- – ionospheric precision
- – ionospheric parameterization

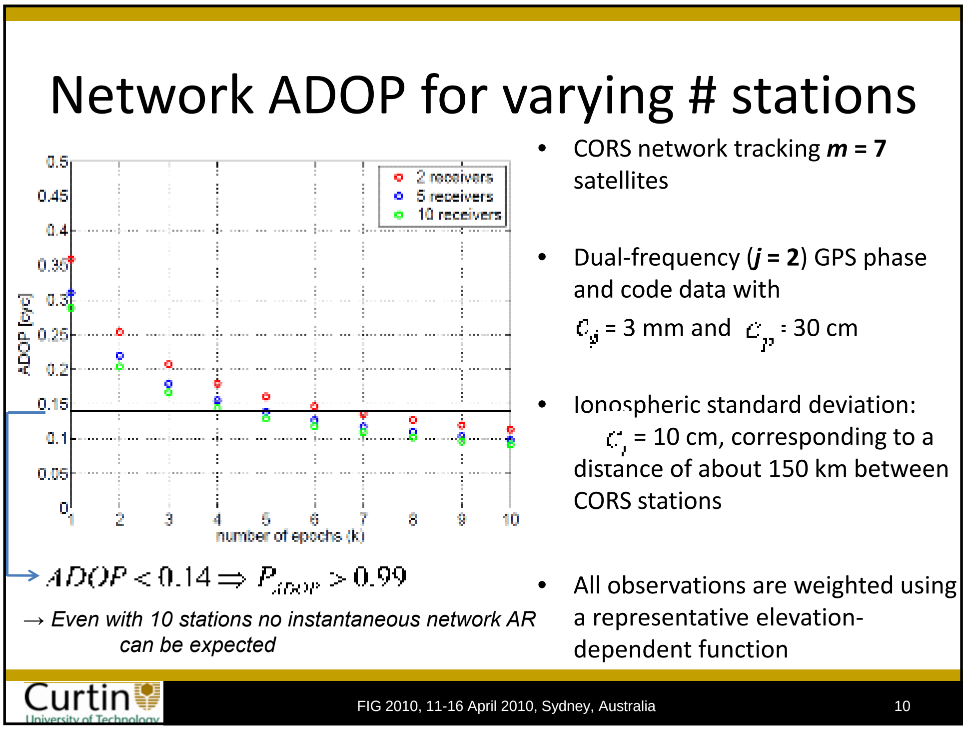


Network ADOP for varying # satellites

- CORS network consisting of ***n* = 5** stations
- Dual-frequency (***j* = 2**) GPS phase and code data with σ_ϕ = 3 mm and σ_p = 30 cm
- Ionospheric standard deviation: σ_I = 10 cm, corresponding to a distance of about 150 km between CORS stations
- All observations are weighted using a representative elevation-dependent function

→ $ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$

→ Even with 14 satellites no instantaneous network AR can be expected

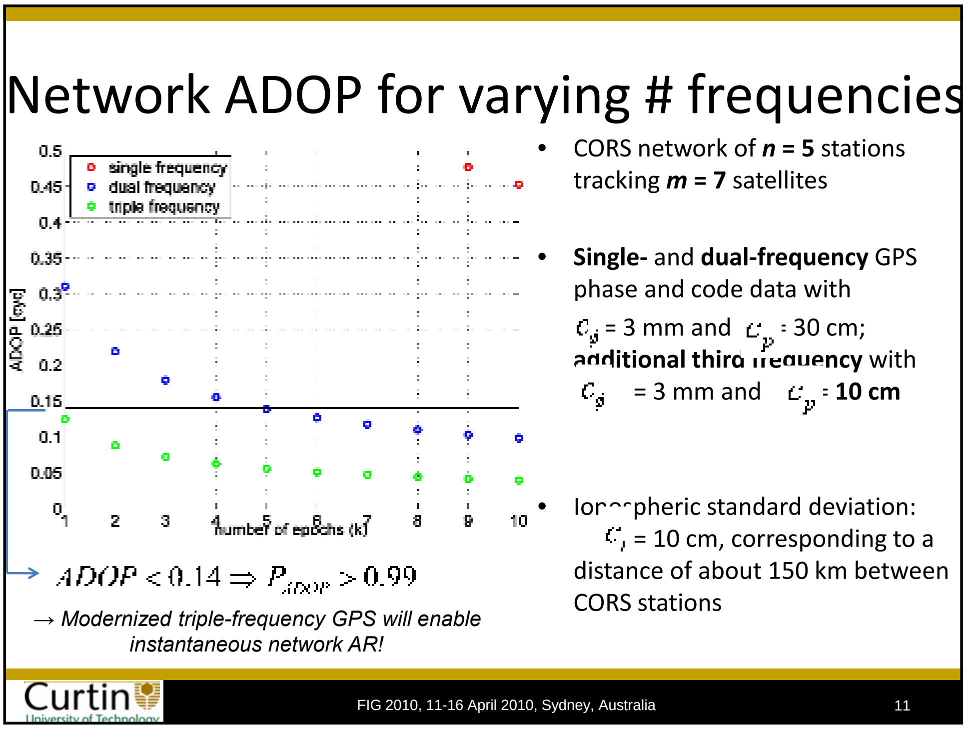


Network ADOP for varying # stations

- CORS network tracking ***m* = 7** satellites
- Dual-frequency (***j* = 2**) GPS phase and code data with σ_ϕ = 3 mm and σ_p = 30 cm
- Ionospheric standard deviation: σ_I = 10 cm, corresponding to a distance of about 150 km between CORS stations
- All observations are weighted using a representative elevation-dependent function

→ $ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$

→ Even with 10 stations no instantaneous network AR can be expected



Network ADOP for varying # frequencies

- CORS network of ***n* = 5** stations tracking ***m* = 7** satellites
- **Single-** and **dual-frequency** GPS phase and code data with σ_ϕ = 3 mm and σ_p = 30 cm; **additional third frequency** with σ_ϕ = 3 mm and σ_p = **10 cm**
- Ionospheric standard deviation: σ_I = 10 cm, corresponding to a distance of about 150 km between CORS stations

$ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$

→ Modernized triple-frequency GPS will enable instantaneous network AR!

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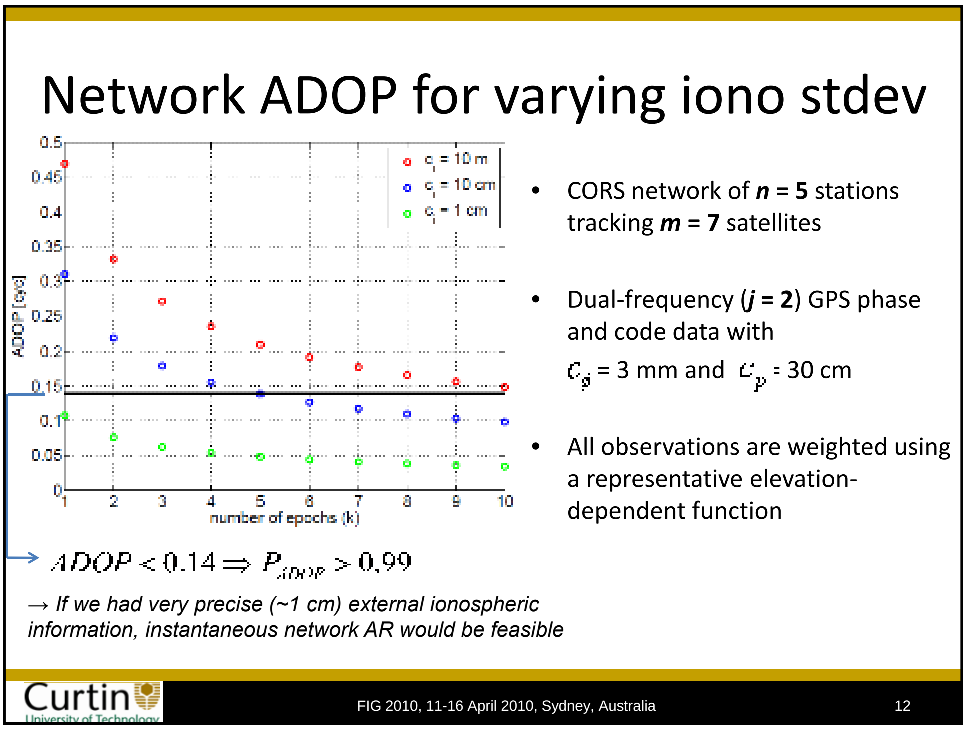

Network ADOP for varying iono stdev

- CORS network of ***n* = 5** stations tracking ***m* = 7** satellites
- Dual-frequency (***j* = 2**) GPS phase and code data with σ_ϕ = 3 mm and σ_p = 30 cm
- All observations are weighted using a representative elevation-dependent function

$ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$

→ If we had very precise (~1 cm) external ionospheric information, instantaneous network AR would be feasible

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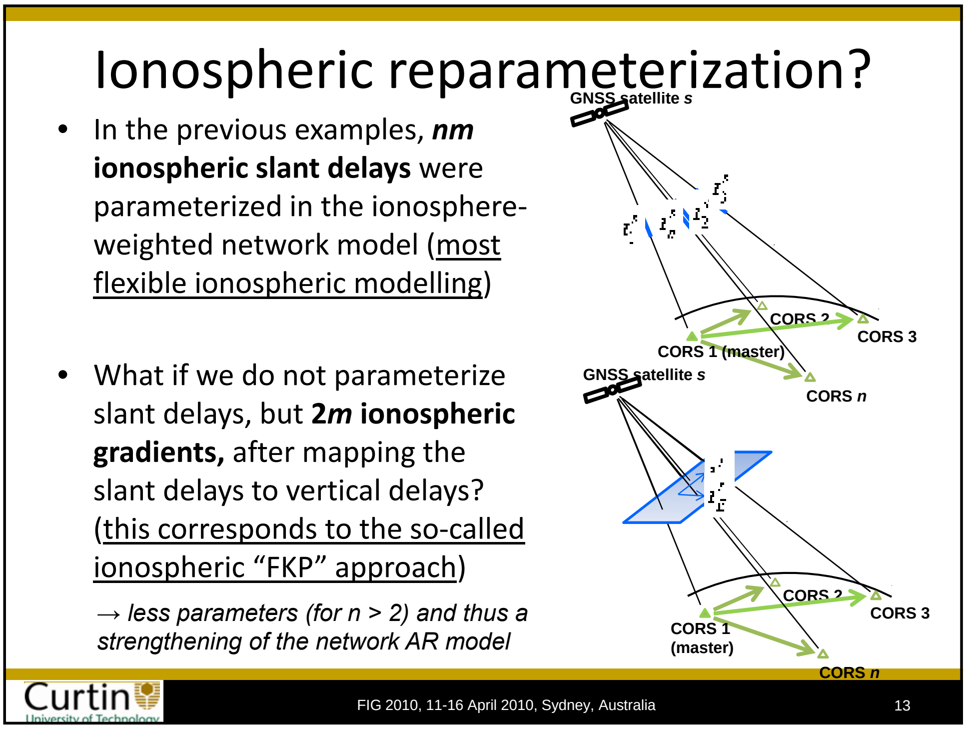

Ionospheric reparameterization?

- In the previous examples, ***nm* ionospheric slant delays** were parameterized in the ionosphere-weighted network model (most flexible ionospheric modelling)

- What if we do not parameterize slant delays, but **2*m* ionospheric gradients,** after mapping the slant delays to vertical delays? (this corresponds to the so-called ionospheric "FKP" approach)

→ *less parameters (for n > 2) and thus a strengthening of the network AR model*

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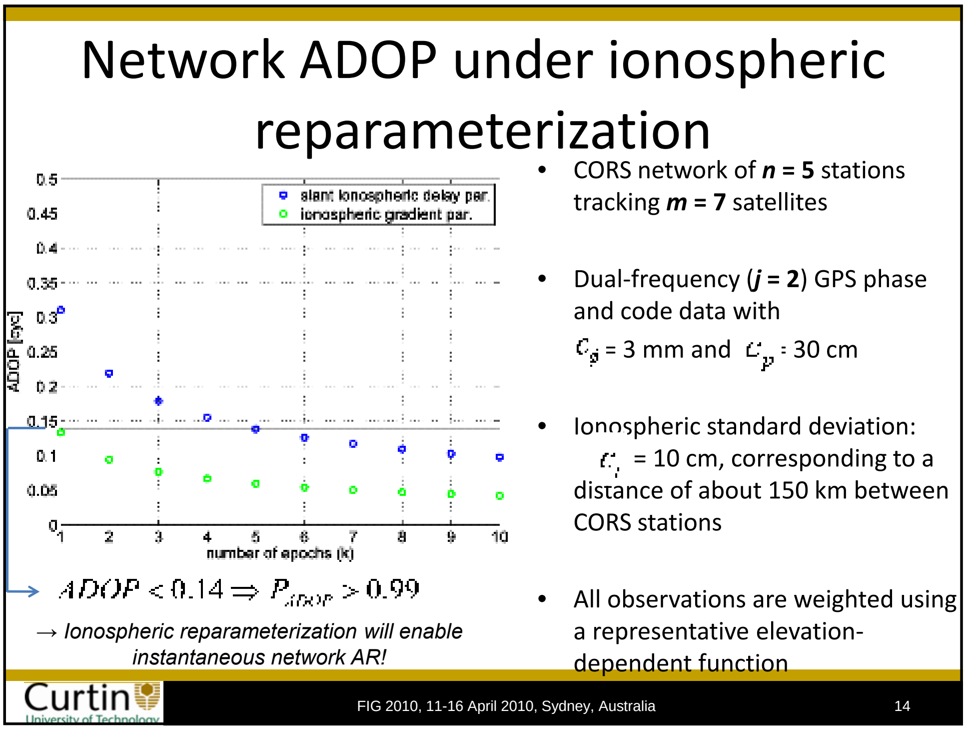

Network ADOP under ionospheric reparameterization

$$ADOP < 0.14 \Rightarrow P_{ADOP} > 0.99$$

→ *Ionospheric reparameterization will enable instantaneous network AR!*

- CORS network of ***n* = 5** stations tracking ***m* = 7** satellites

- Dual-frequency (***j* = 2**) GPS phase and code data with σ_ϕ = 3 mm and σ_p = 30 cm

- Ionospheric standard deviation: σ_ι = 10 cm, corresponding to a distance of about 150 km between CORS stations

- All observations are weighted using a representative elevation-dependent function

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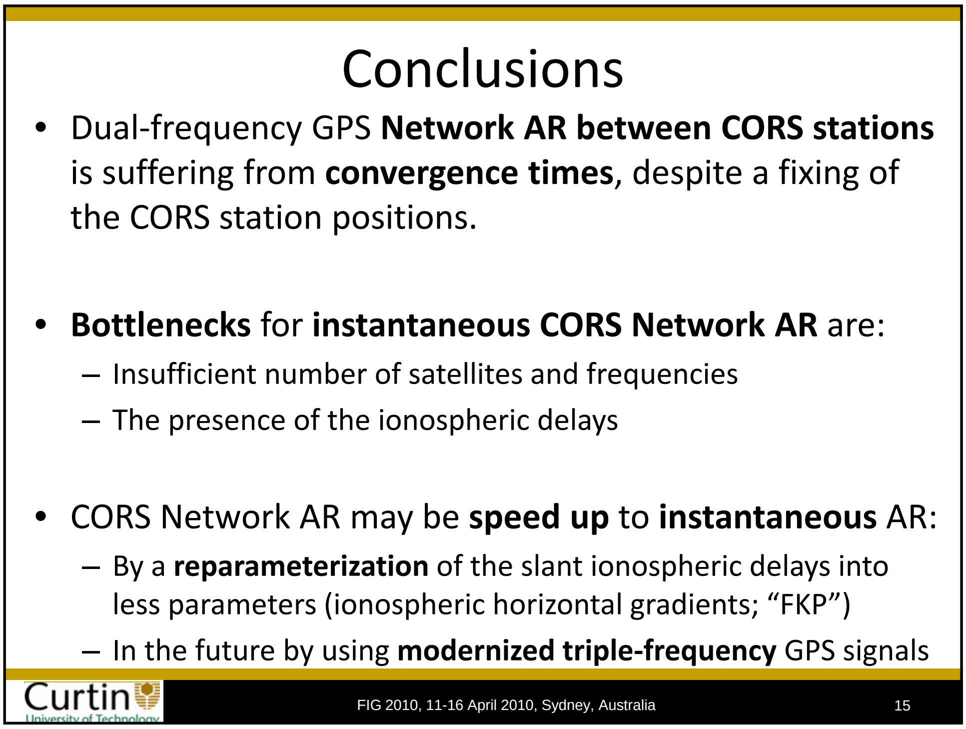

Conclusions

- Dual-frequency GPS **Network AR between CORS stations** is suffering from **convergence times**, despite a fixing of the CORS station positions.

- **Bottlenecks** for **instantaneous CORS Network AR** are:
  - Insufficient number of satellites and frequencies
  - The presence of the ionospheric delays

- CORS Network AR may be **speed up** to **instantaneous** AR:
  - By a **reparameterization** of the slant ionospheric delays into less parameters (ionospheric horizontal gradients; “FKP”)
  - In the future by using **modernized triple-frequency** GPS signals

Questions?

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