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Phase Calibration for Compact Polarimetry: An ALOS-2 Case Study

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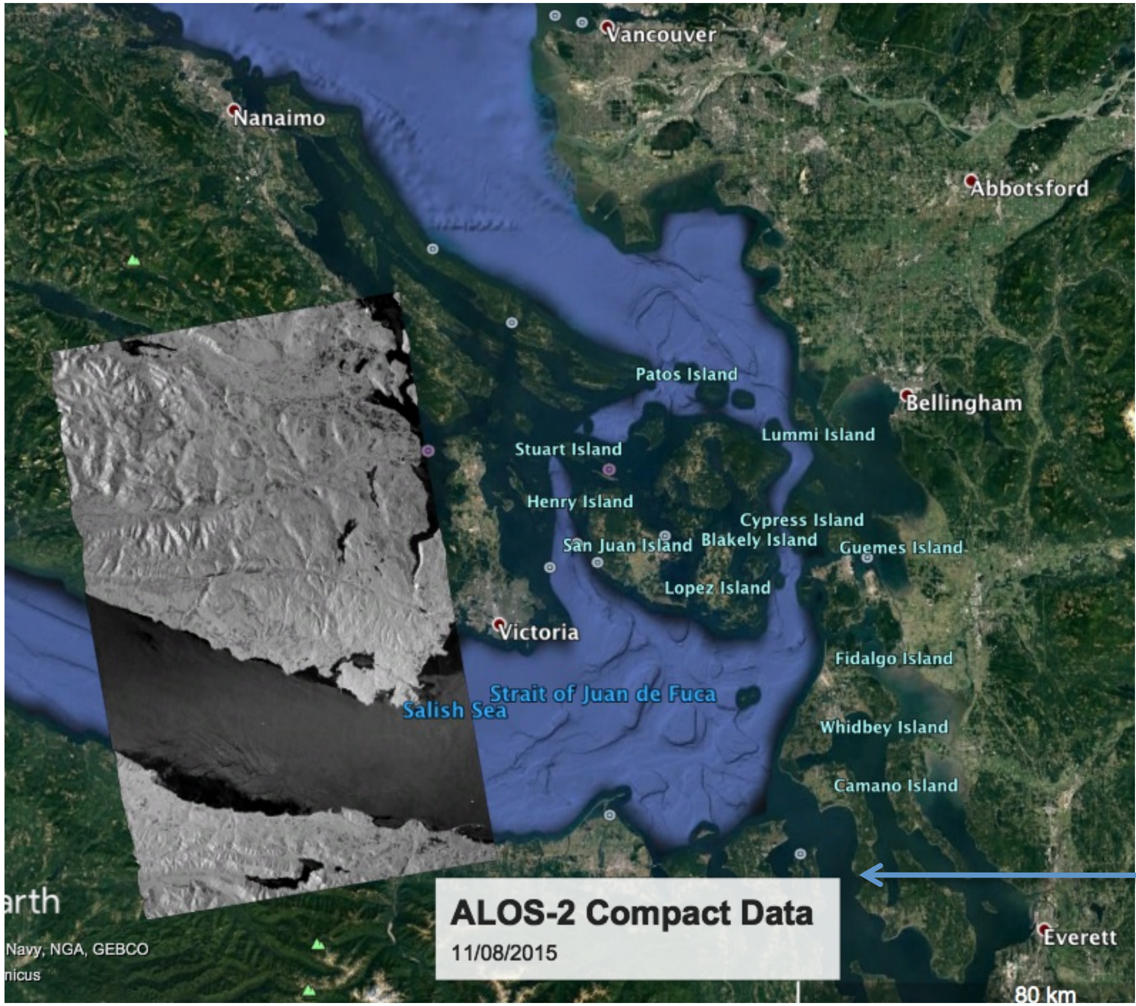
Outline

- Introduction to test site and ALOS-2 data coverage
- Compact SAR modes and the link to polarimetric phase
- ALOS-2 compact data..large phase errors ..why?
  - Calibration issues : Measuring the true TX state
- A model for phase error analysis…

  2 applications:

  - Purity of circular polarization needed for a fixed phase error
  - Compensating error using a scattering model
- Conclusions

ALOS-2 Victoria Calval site:
Trihedral Deployment + Forest Cover for Validation



ALOS-2 launch May 24 2014

LHC or RHC Compact
is an experimental
mode of ALOS-2..

for Calval studies only

We received 3 data sets:

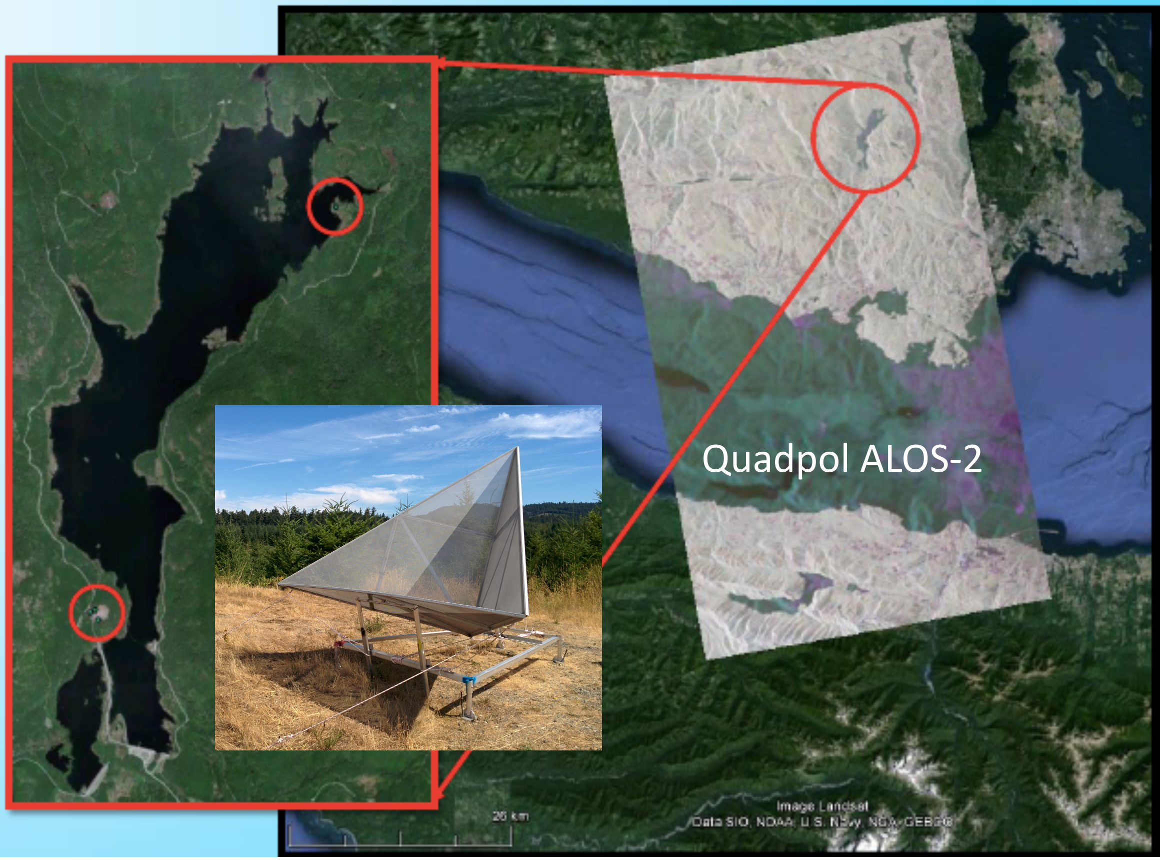
RHC 08/01/2015 (Jan 29^{o} off-nadir)
LHC 06/08/2015 (Aug 29^{o} off-nadir)
LHC 11/08/2015 (Aug 35^{o} off-nadir)

AEL consultants

JAXA-ALOS2- Victoria Corner Reflector Site
x2 2.5m Trihedrals available for Compact Studies

GVWD CORNER REFLECTOR LOCATIONS

- Northeast Shore of Sooke Lake Corner Reflector Location:
  - Latitude: 48.571481°
    Longitude: -123.672023°
  - Grid Northing: 5380039.13m
    Grid Easting: 450426.39m
  - Elevation Height: 184m
- 23 S Quarry (North) Corner Reflector Location:
  - Latitude: 48.530980°
    Longitude: -123.708336°
  - Grid Northing: 5375561.41m
    Grid Easting: 447705.96m
  - Elevation Height: 216m



Natural Resources Canada
Ressources naturelles Canada
Canada

Stokes Vectors and Phase

We are interested in exploiting polarimetric phase for forestry apps….

For a transmit polarisation 't' (nominally circular) the H and V components are received

$$\underline{E} = \begin{bmatrix} E_{th} \\ E_{tv} \end{bmatrix} \Rightarrow \underline{s} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} E_{th}E_{th}^* + E_{tv}E_{tv}^* \\ E_{th}E_{th}^* - E_{tv}E_{tv}^* \\ 2\,\mathrm{Re}(E_{th}E_{tv}^*) \\ 2\,\mathrm{Im}(E_{th}E_{tv}^*) \end{bmatrix}$$

→ Phase of the WAVE
$\arg(s_3+is_4)$

BUT this presentation is about a different phase…a phase from the scattering matrix itself..
…a phase hidden inside the vector $\underline{s}$…

Some notation…
$\underline{s}$ is a scattered wave Stokes vector…$\underline{g}$ is the Stokes vector of the (polarised) transmitter state

Compact Projection : the Perfect Case

source $\quad \underline{g} = \begin{bmatrix} 1 & 0 & 0 & \pm 1 \end{bmatrix}^T \quad \underline{s}$

Scattering matrix .... and its projection

$$T3 = \begin{bmatrix} t_{11} & t_{12} & t_{13} \\ t_{12}^* & t_{22} & t_{23} \\ t_{13}^* & t_{23}^* & t_{33} \end{bmatrix} \xrightarrow{\text{circular TX}} \underline{s} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}(t_{11} + t_{22} + t_{33}) \pm \mathrm{Im}(t_{23}) \\ \mathrm{Re}(t_{12}) \pm \mathrm{Im}(t_{13}) \\ \mathrm{Re}(t_{13}) \mp \mathrm{Im}(t_{12}) \\ \mathrm{Im}(t_{23}) \pm \frac{1}{2}(t_{22} + t_{33} - t_{11}) \end{bmatrix}$$

...a shadow of T3
BUT...

An important special case : Reflection symmetry...when inversion becomes possible (for some terms)

$$T3 = \begin{bmatrix} t_{11} & t_{12} & 0 \\ t_{12}^* & t_{22} & 0 \\ 0 & 0 & t_{33} \end{bmatrix} \xrightarrow{\text{circular TX}} \underline{s} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix} = \begin{bmatrix} \frac{1}{2}(t_{11} + t_{22} + t_{33}) \\ \mathrm{Re}(t_{12}) \\ \mp \mathrm{Im}(t_{12}) \\ \pm \frac{1}{2}(t_{22} + t_{33} - t_{11}) \end{bmatrix} \xrightarrow{Invert} \begin{cases} Span = t_{11} + t_{22} + t_{33} = 2s_1 \\ t_{11} = s_1 \mp s_4 \\ t_{22} + t_{33} = s_1 \pm s_4 \\ t_{12} = s_2 \mp i s_3 \end{cases}$$

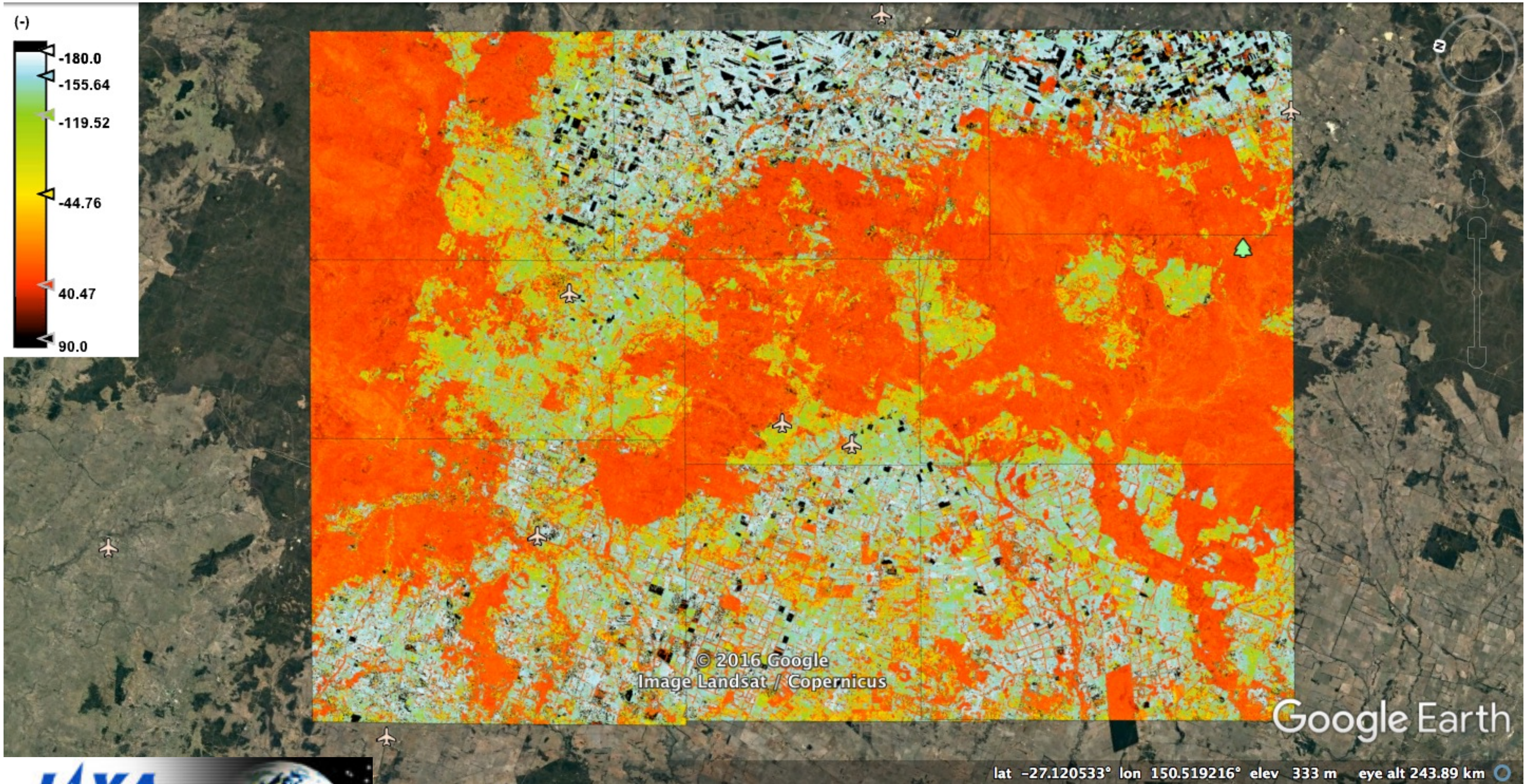
t_{12}_C

the Pauli phase ϕ!

S. R. Cloude, D. Goodenough, H. Chen, "Compact Decomposition Theory", IEEE GRS Letters, Vol. 9 (1), pp 28-32, Jan 2012

Information in Polarimetric Phase?

JAXA Calval site Queensland Australia, April 2016….ALOS-2 Quadpol Data

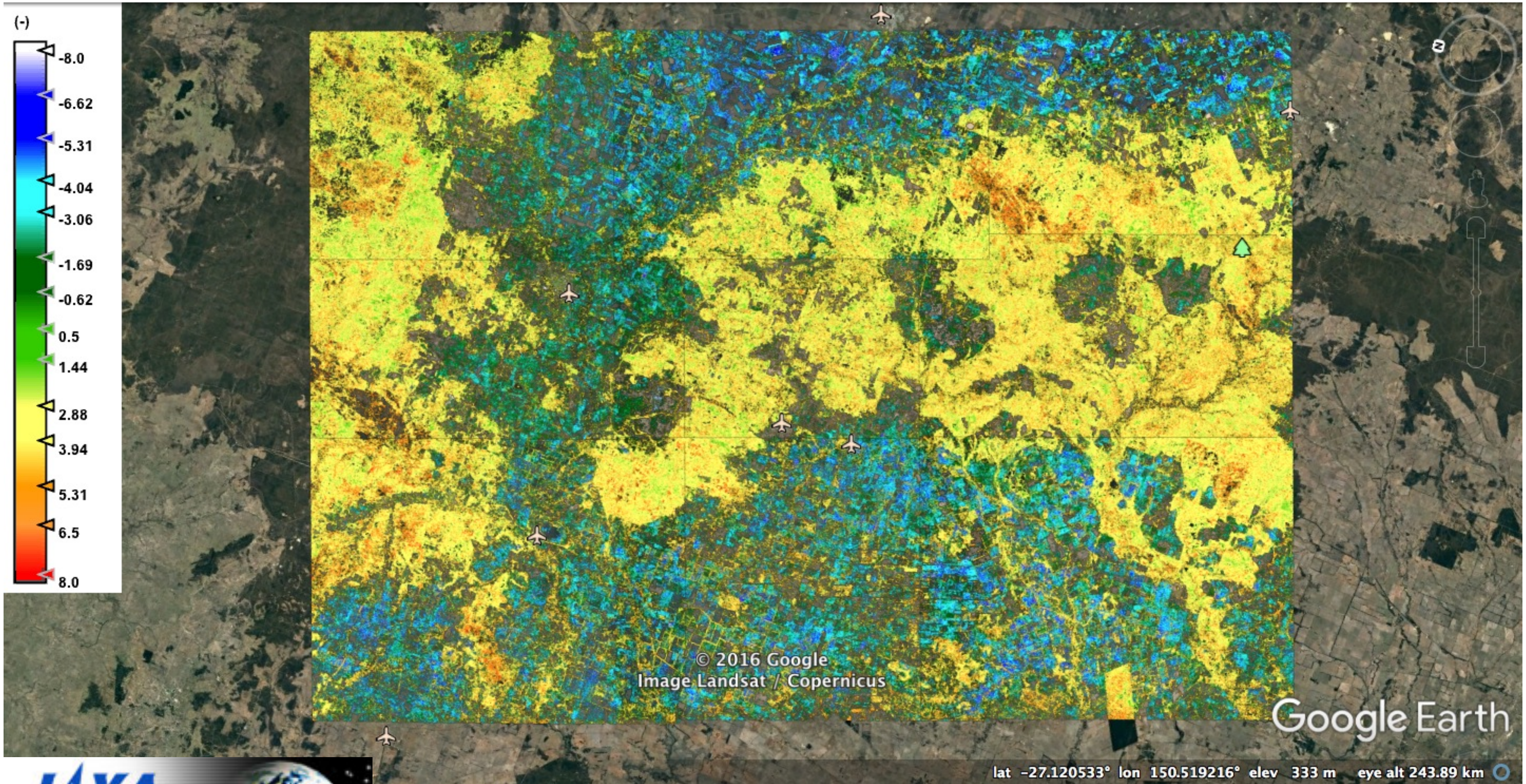


ALOS2 L-band t_{12} phase

Convert Phase –to-Dielectric constant..

Can Compact provide this information?.....let's see

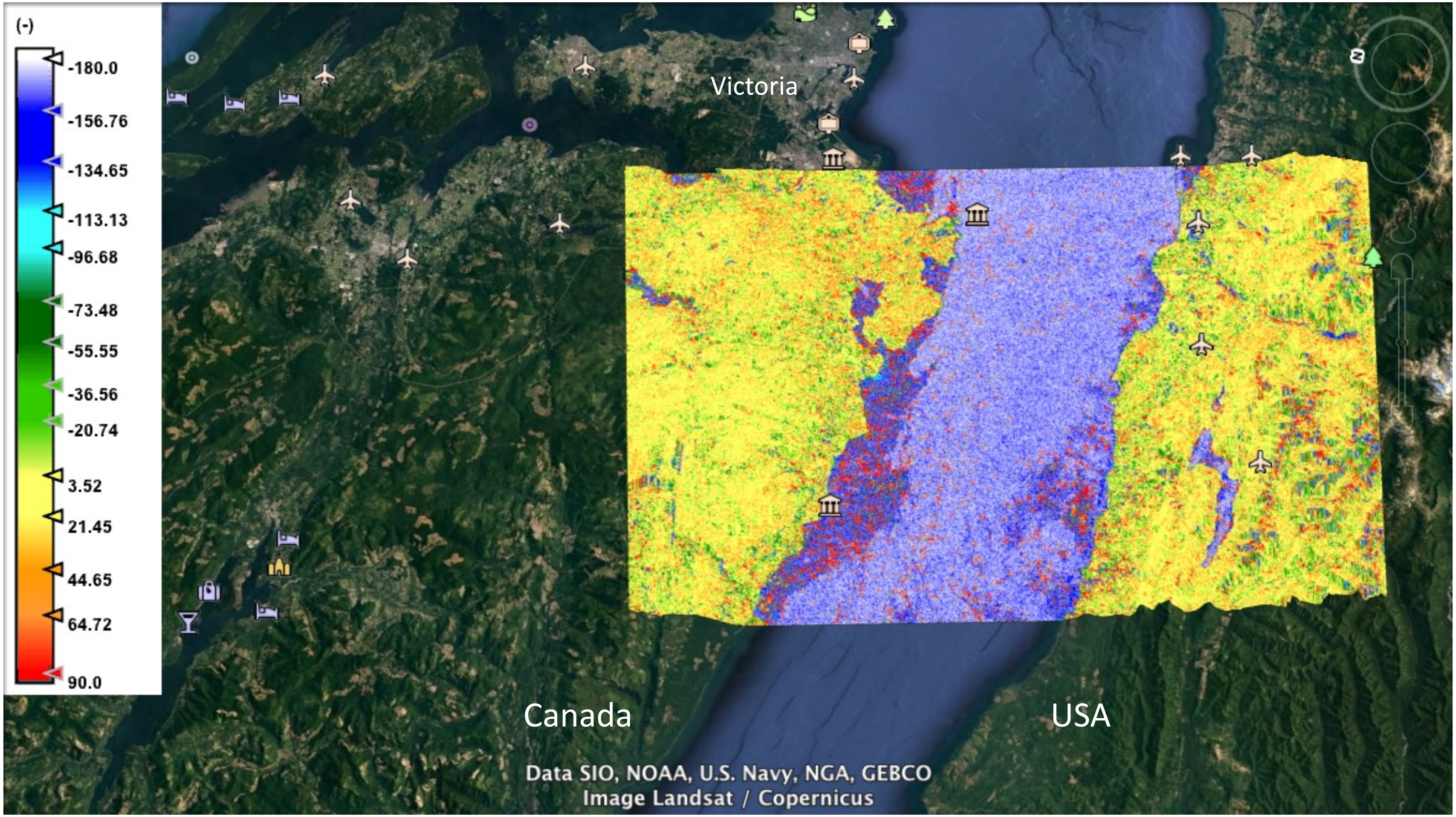
Signed to show 2 classes: Negative values (Crops), Positive values (Forest)…



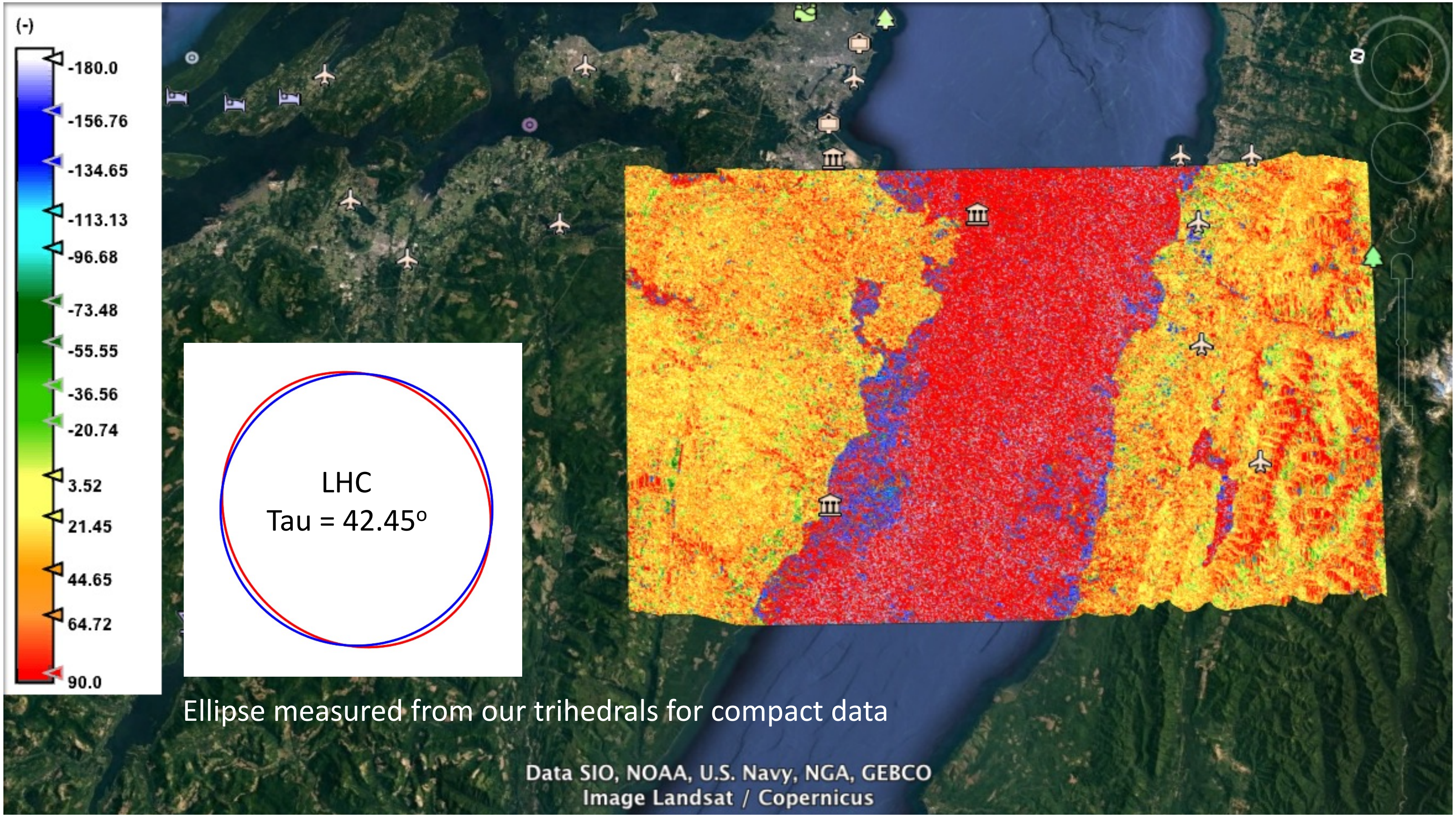
S. R. Cloude, "Zap functions: Phase Information in Quad and Compact Polarimetry",
Proc. 2017 Earth Observation Summit/ASAR workshop, Montreal, Canada, June 2017

Pauli Phase from Calibrated Quadpol ALOS2 Data :
Vancouver Island, BC 04/09/2014

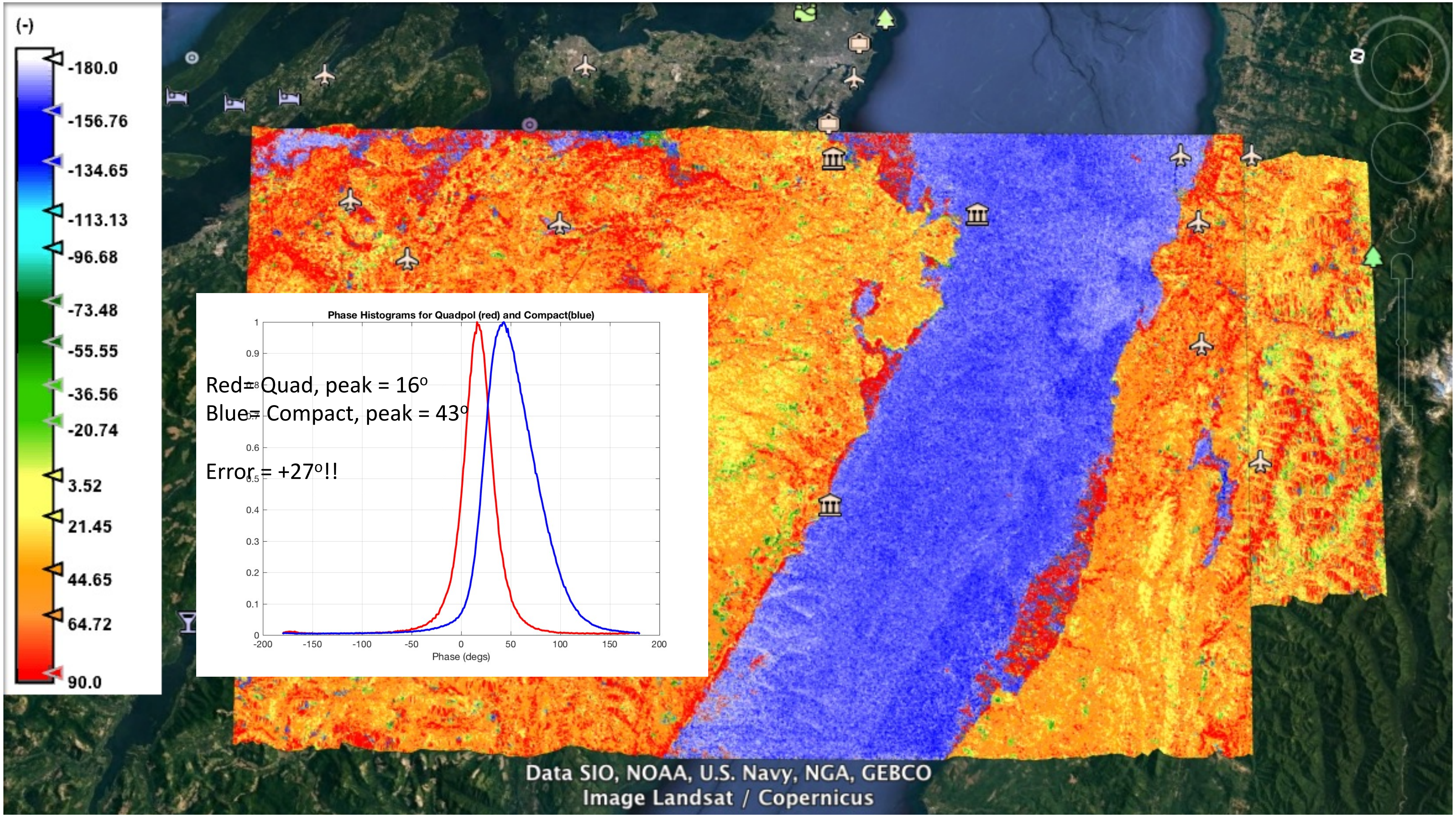
Directly from T3… the 'true' value



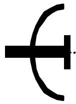
Predicted Compact phase for ‘real’ transmitter state
Synthesized from Quadpol data 04/09/2014



Phase Estimate from ALOS-2 Compact Data : LHC, 11/08/2015



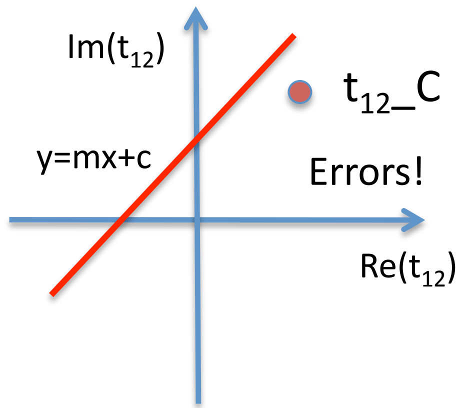
Compact Projection : Imperfections

source  $\underline{g} = \begin{bmatrix} 1 & g_2 & g_3 & g_4 \end{bmatrix}^T$

$g_2^2 + g_3^2 + g_4^2 = 1$

$$[T_V] = \begin{bmatrix} t_{11} & t_{12} & 0 \\ t_{12}^* & t_{22} & 0 \\ 0 & 0 & t_{33} \end{bmatrix} \Rightarrow \begin{cases} s_1 = \frac{1}{2}(t_{11} + t_{22} + t_{33}) + g_2 \operatorname{Re}(t_{12}) \\ s_2 = \operatorname{Re}(t_{12}) + \frac{g_2}{2}(t_{11} + t_{22} - t_{33}) \\ s_3 = \frac{g_3}{2}(t_{11} - t_{22} + t_{33}) - g_4 \operatorname{Im}(t_{12}) \\ s_4 = \frac{g_4}{2}(-t_{11} + t_{22} + t_{33}) - g_3 \operatorname{Im}(t_{12}) \end{cases} \xrightarrow{Inversion?} \frac{1}{2}\begin{bmatrix} 1 & 1 & 1 & 2g_2 & 0 \\ g_2 & g_2 & -g_2 & 2 & 0 \\ g_3 & -g_3 & g_3 & 0 & -2g_4 \\ -g_4 & g_4 & g_4 & 0 & -2g_3 \end{bmatrix} \begin{bmatrix} t_{11} \\ t_{22} \\ t_{33} \\ \operatorname{Re}(t_{12}) \\ \operatorname{Im}(t_{12}) \end{bmatrix} = \underline{s}$$

.. No longer unique…A line of solutions for t_{12}

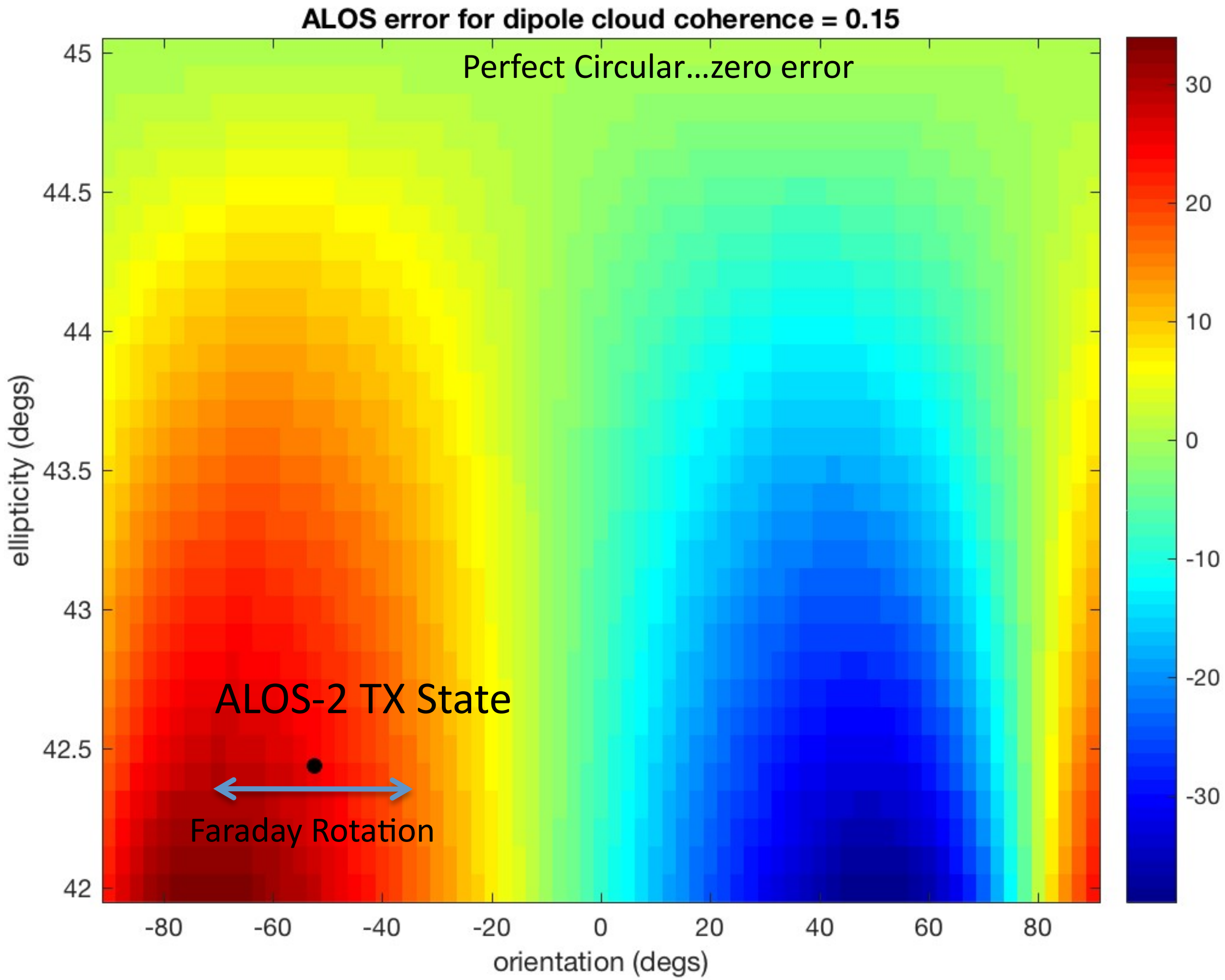


$$\left.\begin{aligned} X &= \begin{pmatrix} 0 & g_3 & g_2 & 0 \end{pmatrix}\underline{s} \\ Y &= \begin{pmatrix} g_4 & 0 & 0 & -1 \end{pmatrix}\underline{s} \end{aligned}\right\} \Rightarrow g_4 X - g_2 g_3 Y = f(t_{12})$$

$$\operatorname{Im}(t_{12}) = m \operatorname{Re}(t_{12}) + c \Rightarrow \begin{cases} m = \dfrac{g_3 g_4 (1 - g_2^2)}{g_2 (g_3^2 + g_4^2)} \\ c = \dfrac{\underline{\mu}.\underline{s}}{g_2 (g_3^2 + g_4^2)} \rightarrow \underline{\mu} = \begin{pmatrix} g_2 g_3 g_4 & -g_3 g_4 & -g_2 g_4 & -g_2 g_3 \end{pmatrix} \end{cases}$$

..how big are the errors?

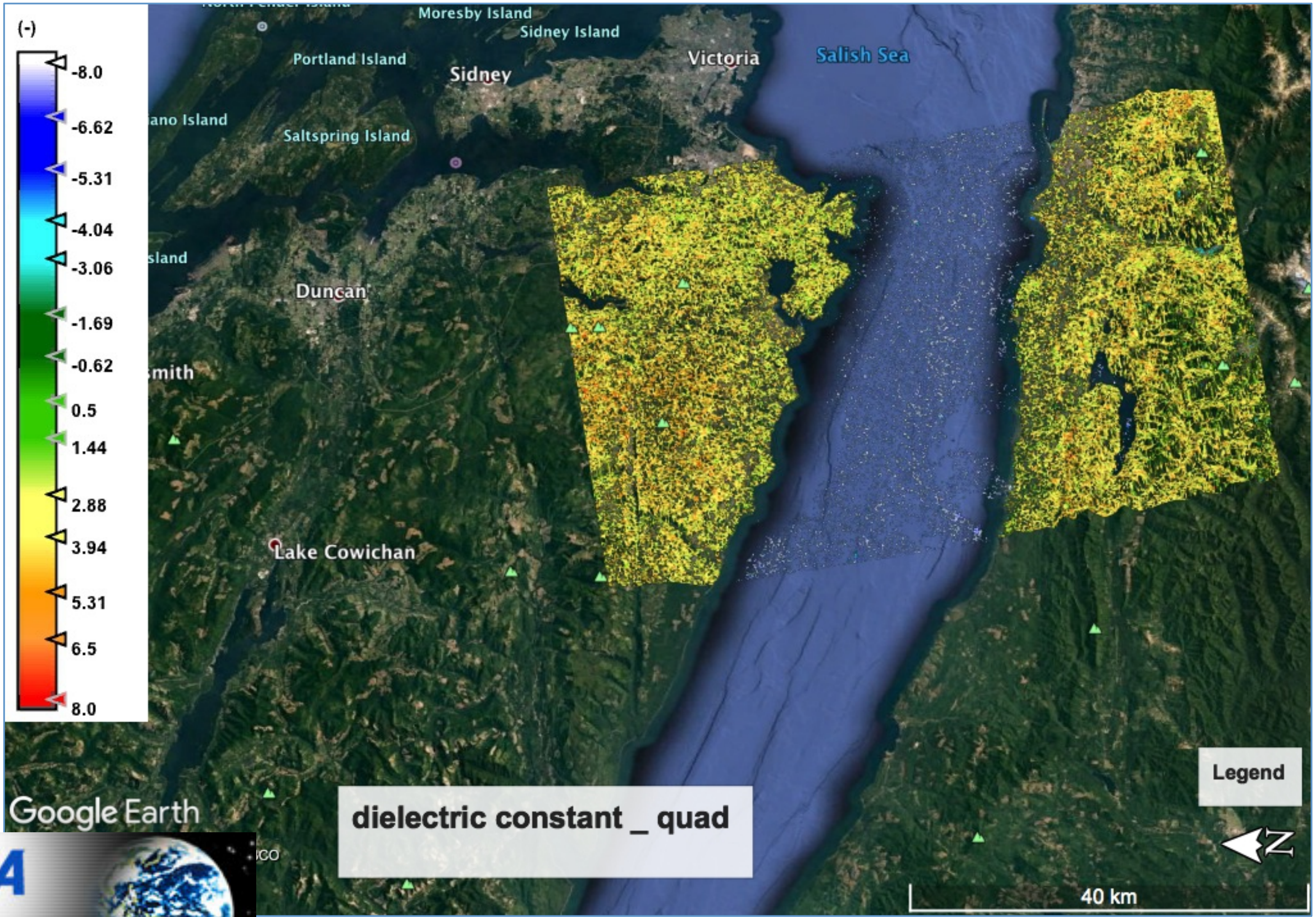
Predicted Phase Error for North Polar Region of Poincaré Sphere



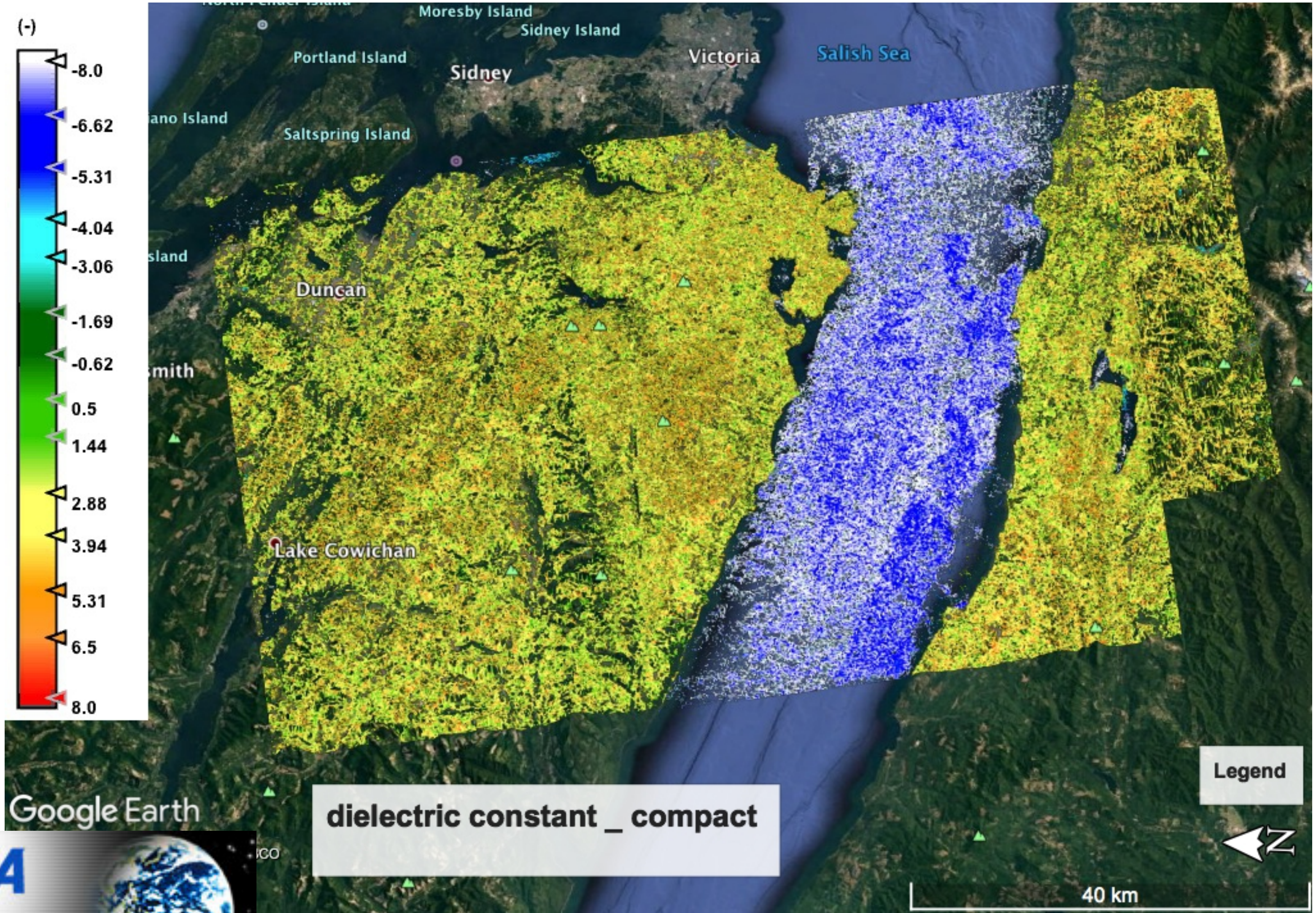
- Use model for T3 from (1)
- Depends on coherence.. obtained from quadpol for same site
- Predicted ALOS-2 error = +26.2°
- We saw earlier that data showed a broad peak of errors around +27°...
- Encouraging that model shows some agreement
- Can use it to correct Phase?

(1) S R. Cloude "**Polarisation: Applications in Remote Sensing**", Oxford University Press, 978-0-19-956973-1, 2009

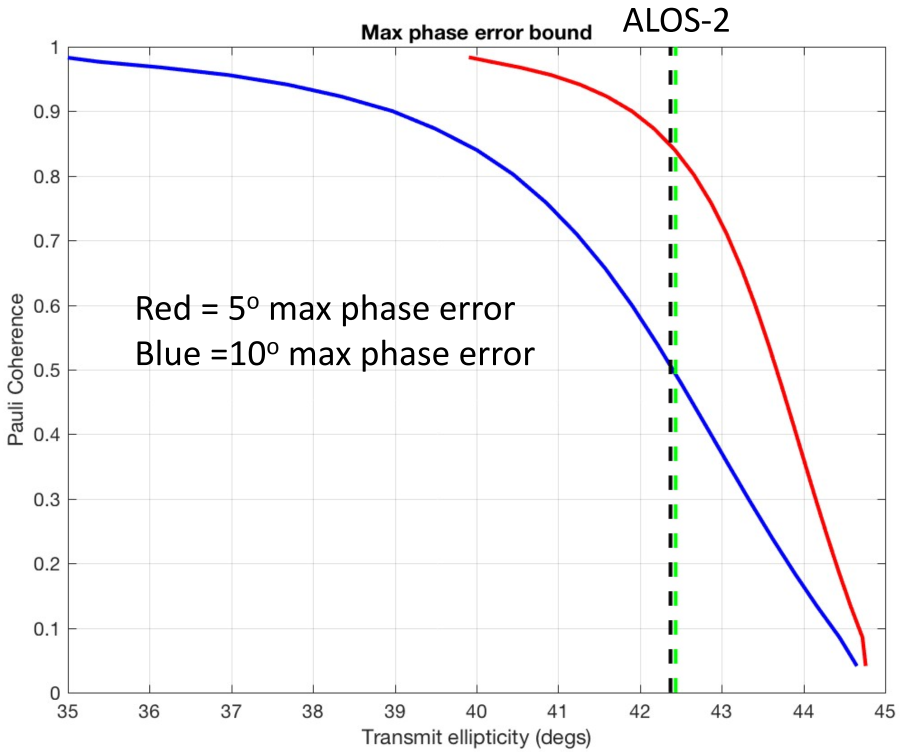
Phase-to-Dielectric : Quadpol Data

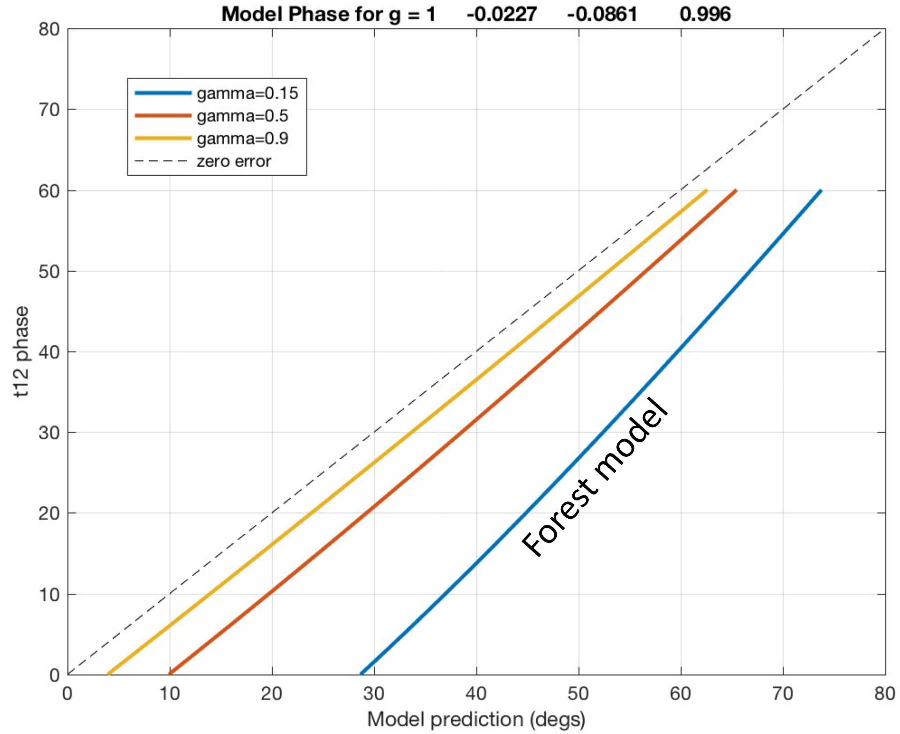


Phase-to-Dielectric : Corrected Compact Data



Summary: How to Deal with Compact Phase Errors





Good antenna design …. or …..model phase compensation (need g and local coherence estimate)

Acknowledgements:

Thanks to

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