STRAIN OVER LANDFAST SEA ICE NEAR JANGBOGO ANT ARCTIC STATION OBSERVED BY INSAR

Hoonyol Lee[1] and Hyangsun Han[2]

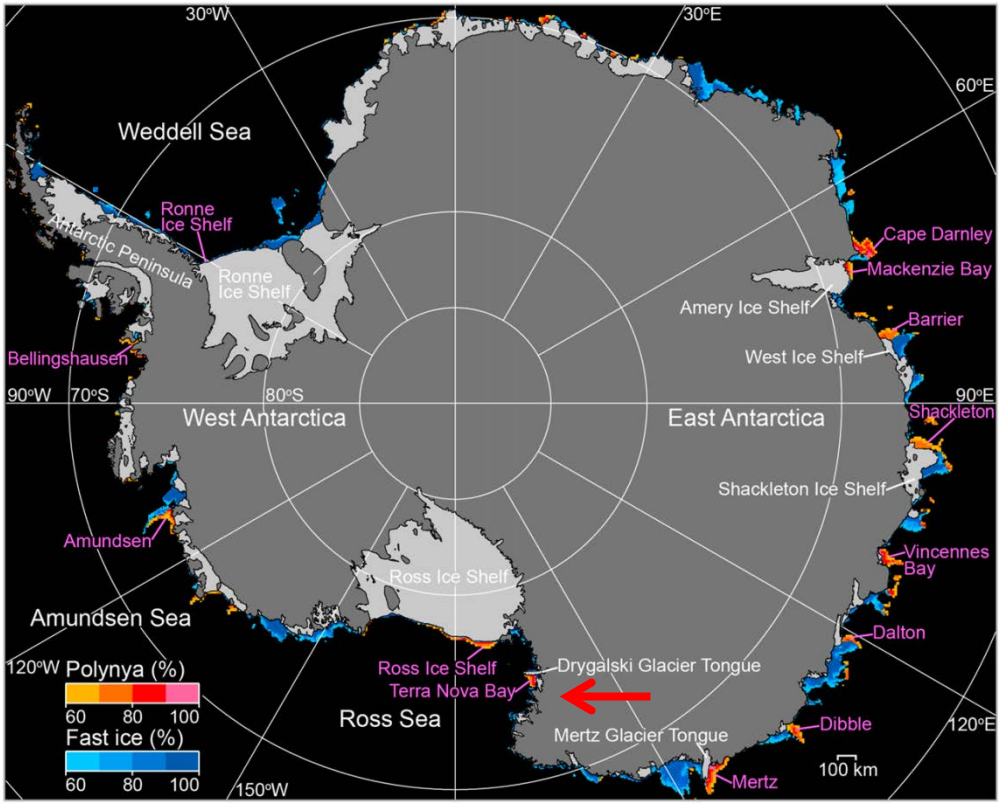
[1] Department of Geophysics, Kangwon National University, Korea
[2] Division of Polar Ocean Environment, Korea Polar Research Institute, Korea

Objectives

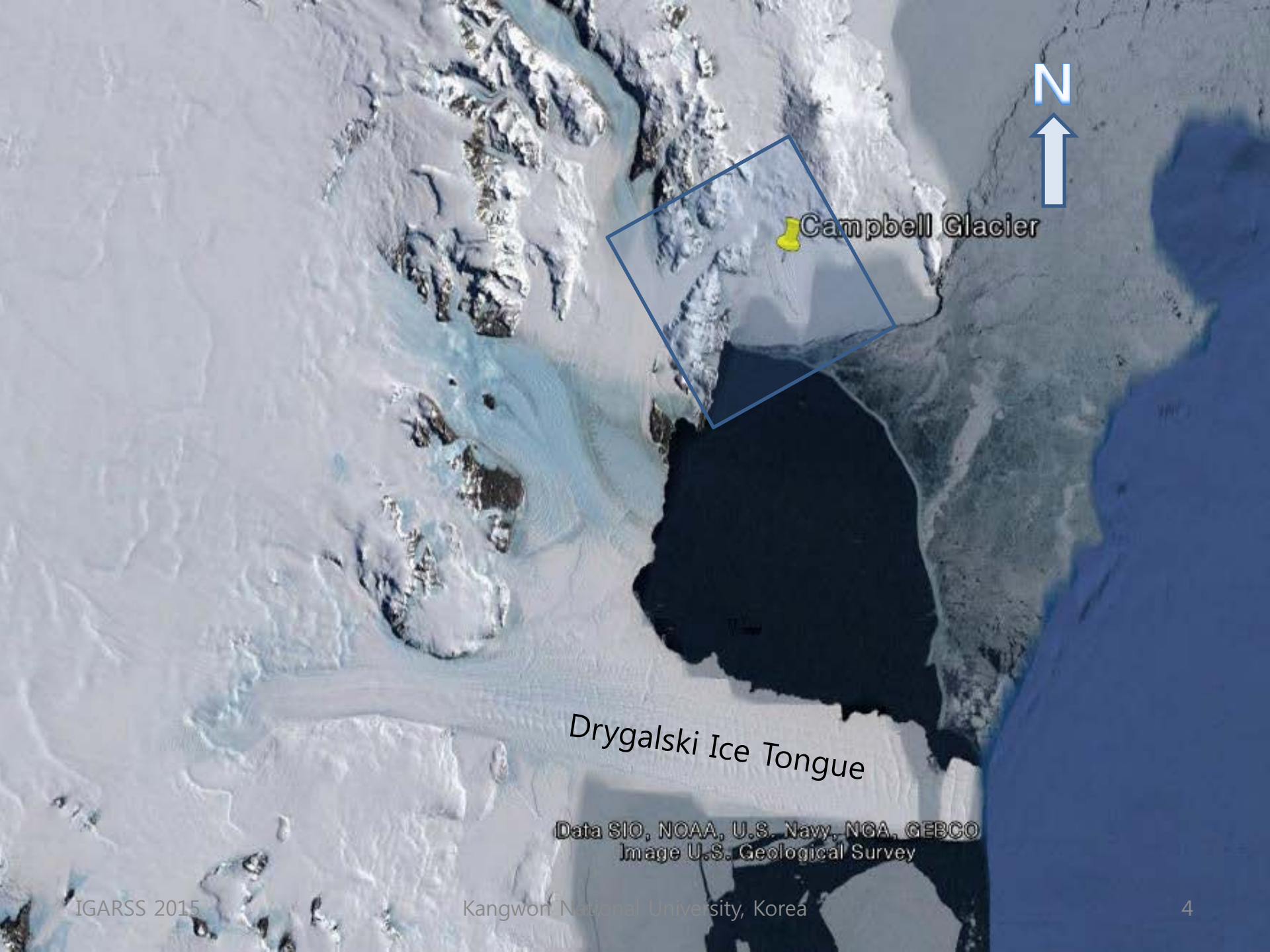
- To map the annual variation of landfast sea ice extent near Jangbogo Research Station
- To understand the strain field on fast ice

Landfast sea ice and Polynyas

- Landfast sea ice (fast ice) is stationary sea ice attached to coastal features such as the shoreline and grounded icebergs (WMO 1970).
- In East Antarctica, polynyas are frequently formed on the western side of fast ice and glacier tongues because they block westward sea ice advection.
- Polyna is factory of sea ice due to severe heat loss of open sea and katabatic wind
- Brine rejection of sea ice leads to formation of dense water which is a major source of Antarctic Bottom Water (AABW) and a driving force of thermohaline circulation

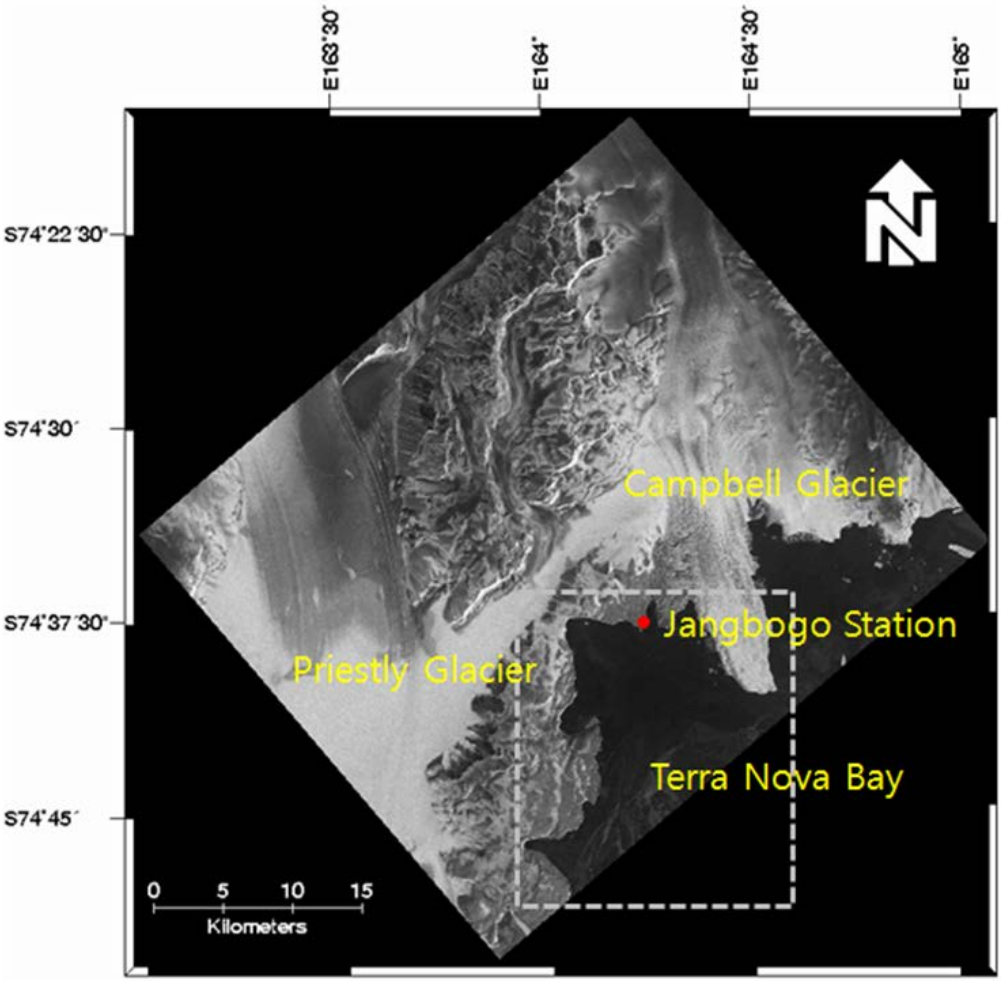


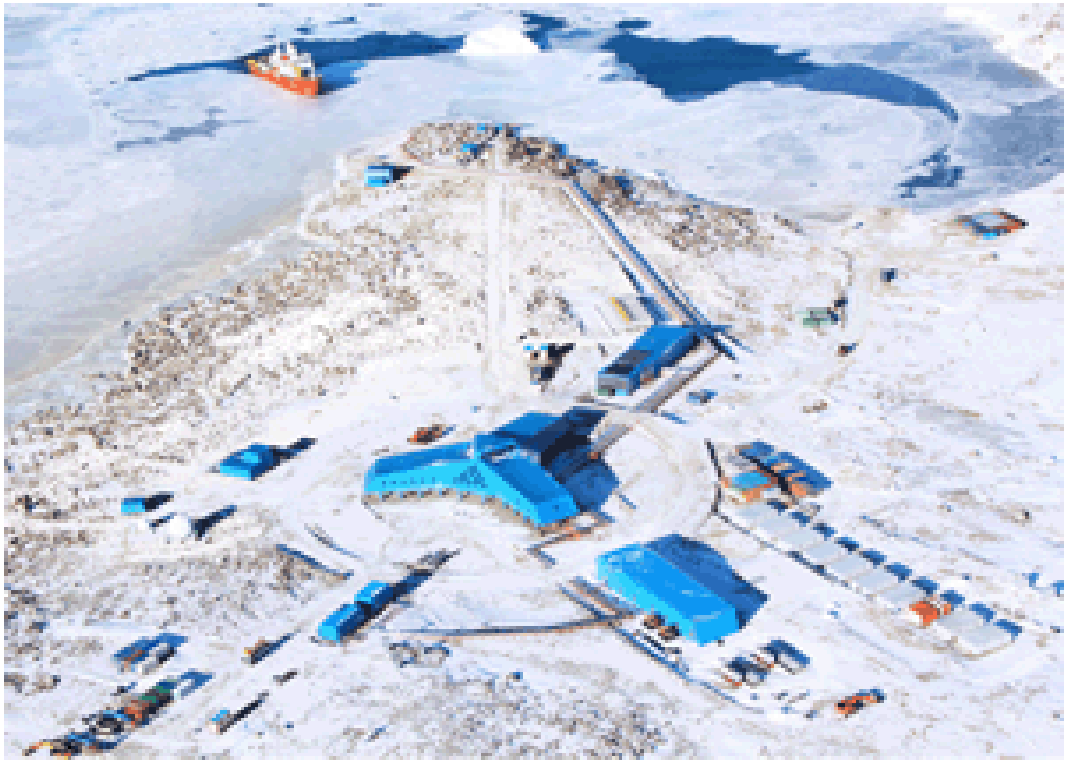
(Nihash and Ohshima, J. Climate, 2015)


N
Campbell Glacier
Drygalski Ice Tongue
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image U.S. Geological Survey

Study Area

- A section of Terra Nova Bay, East Antarctica
- Landfast sea ice near Campbell Glacier Tongue
- Fast ice near TNB affect logistics of research stations
  - Mario Zucchelli Station, Italy, since 1986
  - Jangbogo Station, Korea, since 2013 (74°37′04"S, 164°13′07"E)





Mario Zucchelli Station

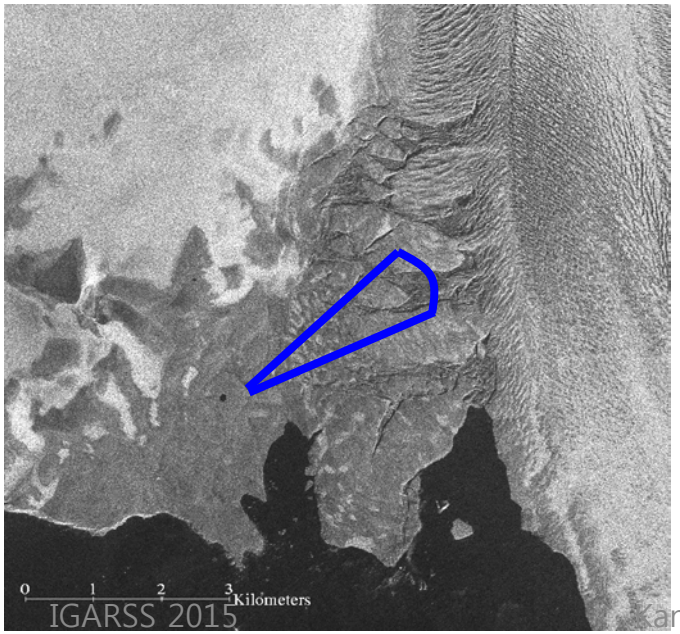
Jangbogo Station

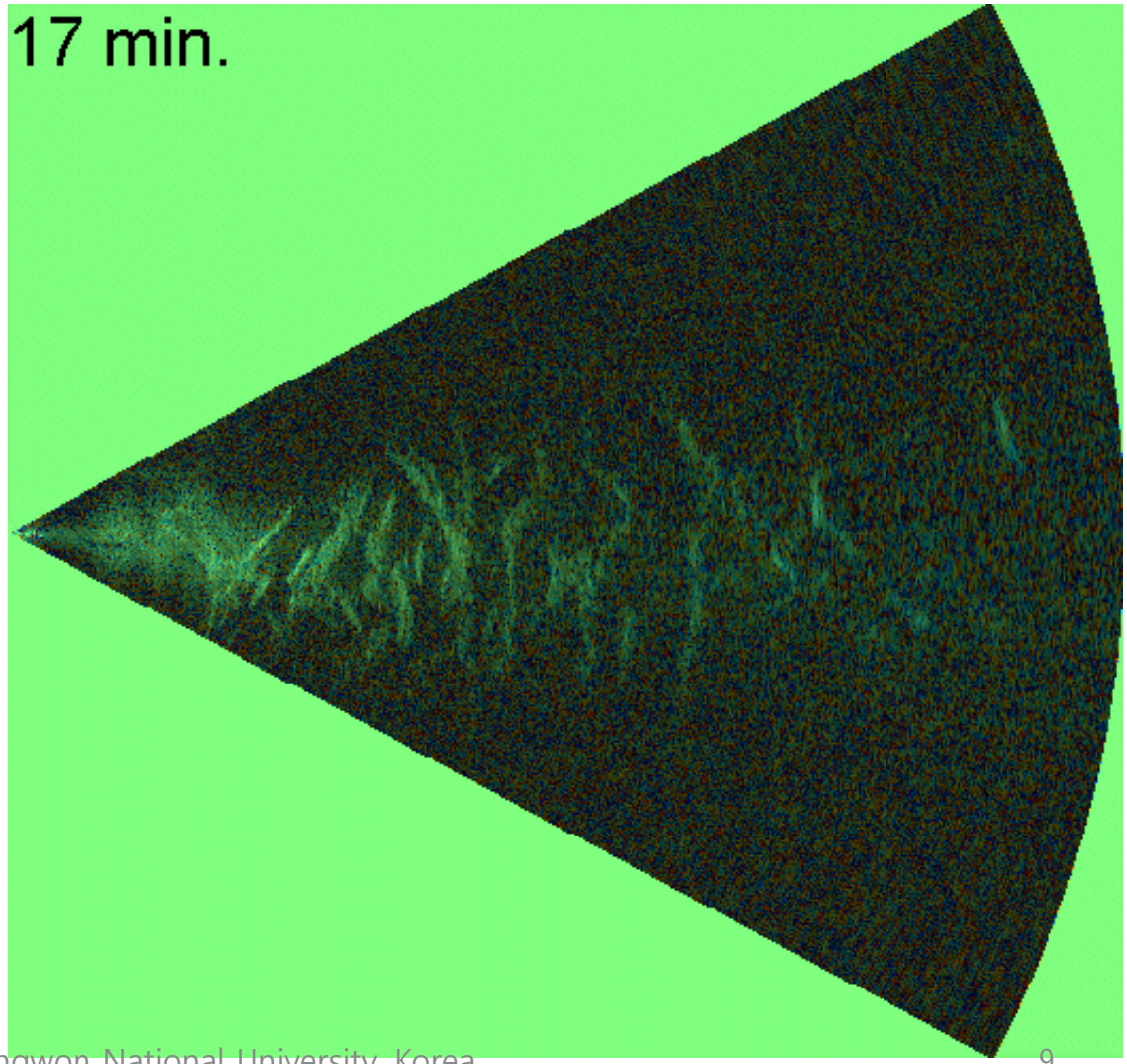
Araon Icebreaker
Research Vessel


Jangbogo Station
Runway on fast ice
Mario Zucchelli Station


Araon Icebreaker, Jan. 2011

GB-SAR on CGT






Araon Icebreaker, Jan. 2012

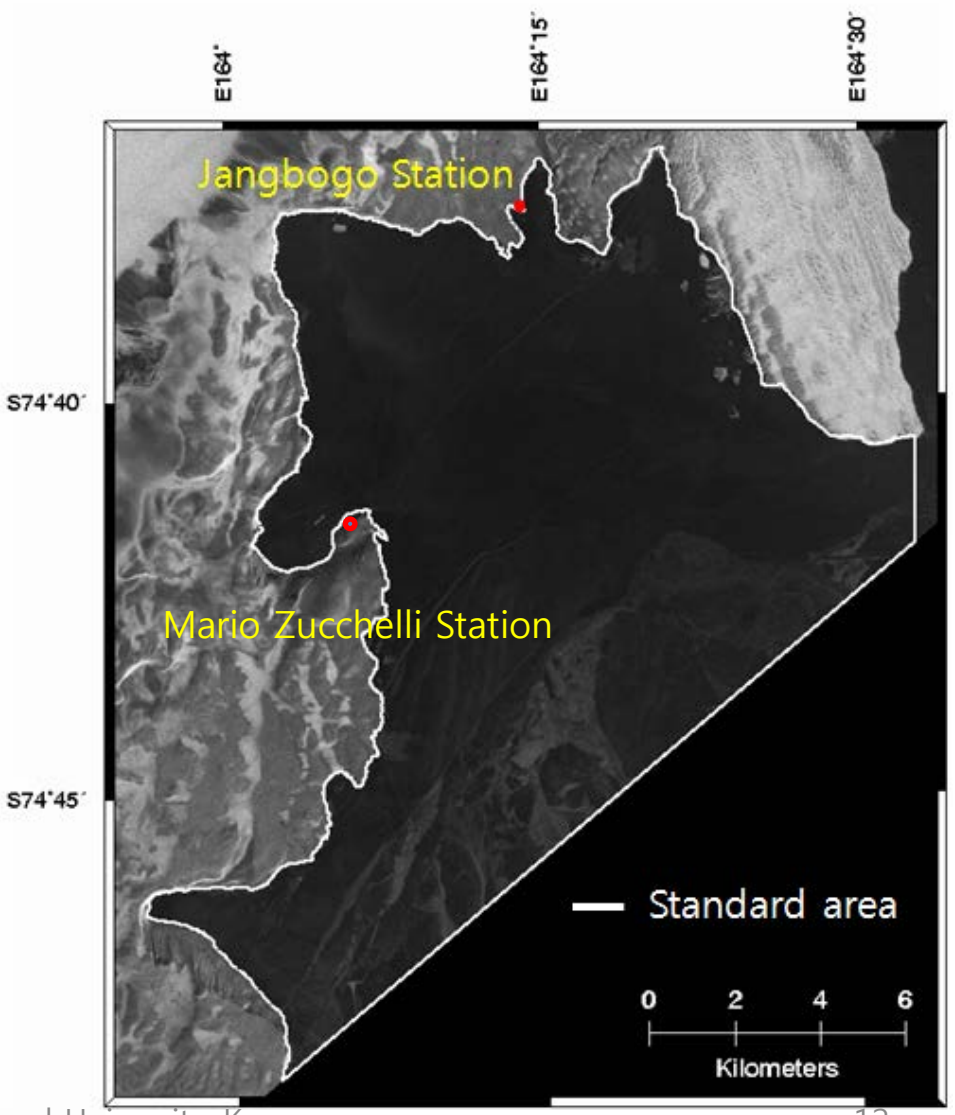
Dataset

- COSMO-SkyMed Constellation (AO 2215)
- X-band, strip map, 3m resolution, VV-pol, descending orbit
- 14 months of observation period from Dec. 2010 to Jan. 2012
- 20 one-day InSAR from CSK1 and CSK2 with 16-day repeat cycle
- 17 weekly InSAR combining CSK3 with 8-day offset
- Automatic Weather Station at Jangbogo Station
- Ross_Inv tide model (Padman et al, 003)

Dates of InSAR pair (yyyy/mm/dd)	Temporal baseline (day)	Dates of InSAR pair (yyyy/mm/dd)	Temporal baseline (day)
2010/12/01, 2010/12/09	8	2011/06/19, 2011/06/27	8
2010/12/09, 2010/12/10	1	2011/07/05, 2011/07/06	1
2010/12/25, 2010/12/26	1	2011/07/22, 2011/07/29	7
2011/01/02, 2011/01/10	8	2011/08/06, 2011/08/07	1
2011/01/10, 2011/01/18	8	2011/08/22, 2011/08/23	1
2011/01/26, 2011/01/27	1	2011/08/30, 2011/09/07	8
2011/02/11, 2011/02/19	8	2011/09/07, 2011/09/08	1
2011/02/27, 2011/02/28	1	2011/09/15, 2011/09/24	9
2011/03/15, 2011/03/16	1	2011/10/01, 2011/10/09	8
2011/03/23, 2011/03/31	8	2011/10/09, 2011/10/10	1
2011/03/31, 2011/04/01	1	2011/10/25, 2011/10/26	1
2011/04/01, 2011/04/08	7	2011/11/02, 2011/11/10	8
2011/04/08, 2011/04/16	8	2011/11/10, 2011/11/11	1
2011/04/16, 2011/04/24	8	2011/11/18, 2011/11/26	8
2011/05/02, 2011/05/03	1	2011/11/26, 2011/11/27	1
2011/05/18, 2011/05/19	1	2011/12/28, 2011/12/29	1
2011/06/03, 2011/06/04	1	2012/01/05, 2012/01/13	8
2011/06/03, 2011/06/11	8	2012/01/13, 2012/01/14	1
2011/06/19, 2011/06/20	1	2012/01/13, 2012/01/21	8

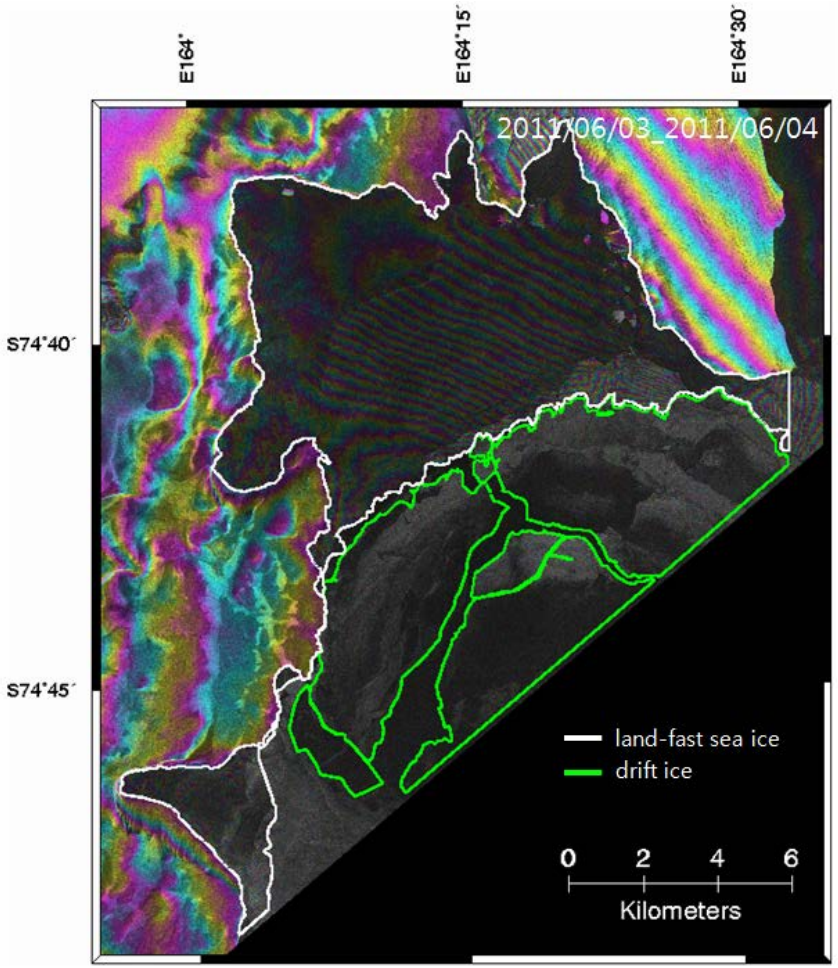
Region of Interest for Sea Ice Extents

- A coastal section of Terra Nova Bay, West of Campbell Glacier Tongue that affects logistics for Jangbogo and Mario Zucchelli Stations
- Image area of common coverage of CSK images

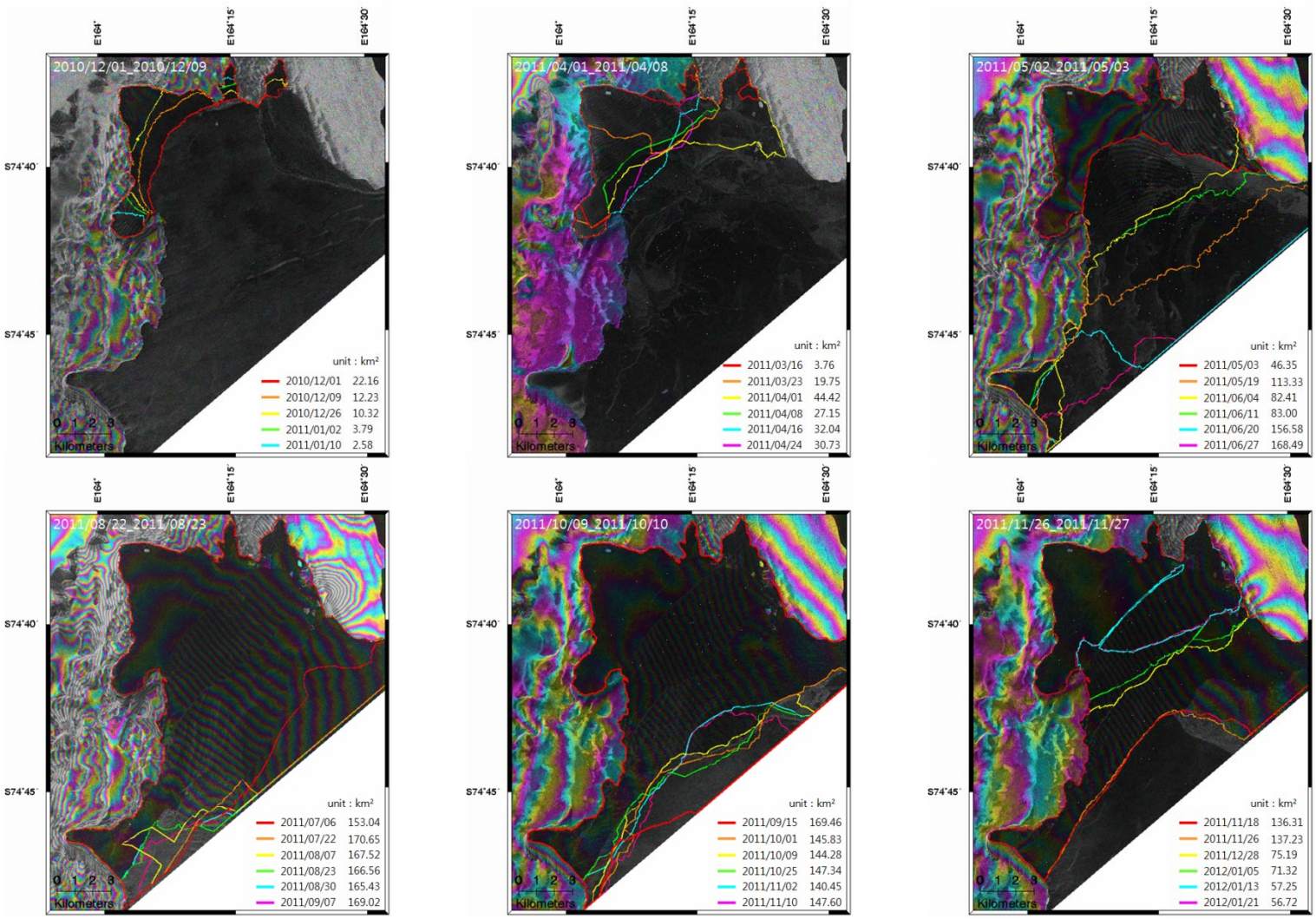


Classification

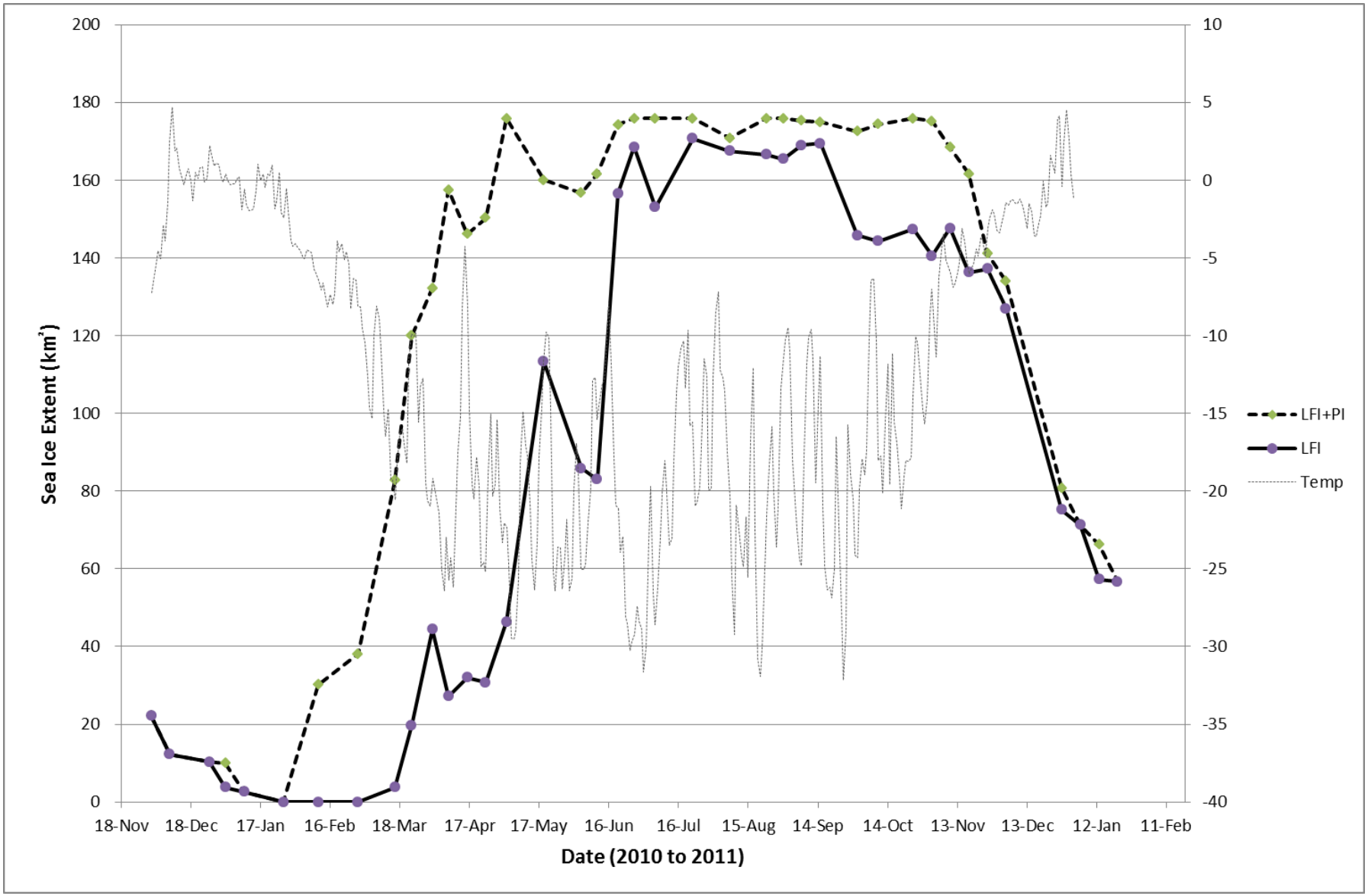
- Fast ice
  - High coherence in one-day InSAR
  - Strain rate less than a quarter of SAR resolution (~ 3/4 m)
- Pack ice
  - Low coherence
  - Cracks and leads
  - Traceable by multi-temporal SAR images
- Ocean
  - Low coherence
  - Dark in calm days (or nilas, frazil ice)
  - Polynya with katabatic winds



Fast Ice Extent

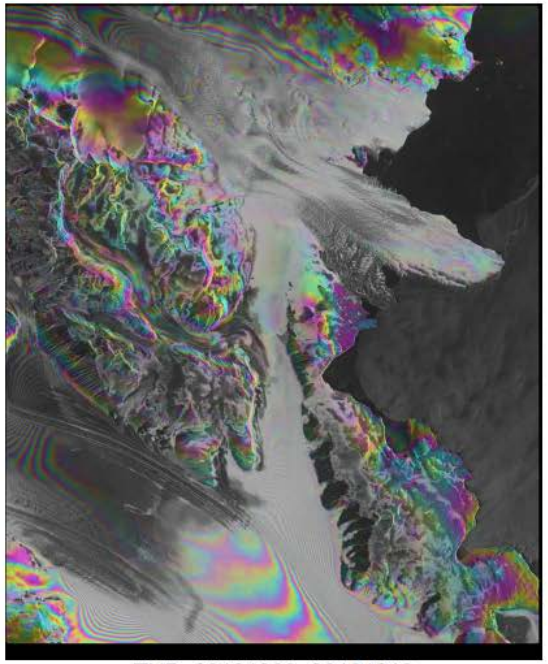


Sea Ice Extent

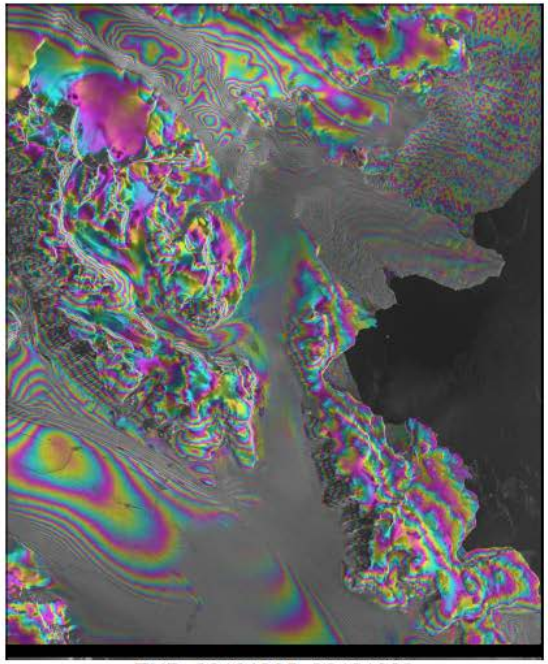


One-day InSAR

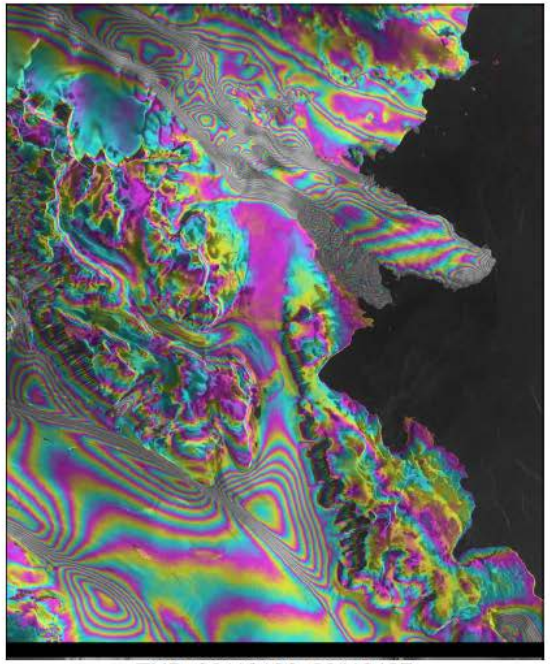
- 20 One-day Cosmo-SkyMed Images
- Repeat cycle of 16 days
- Dec. 2010 ~ Jan 2012
- Earth-flattened



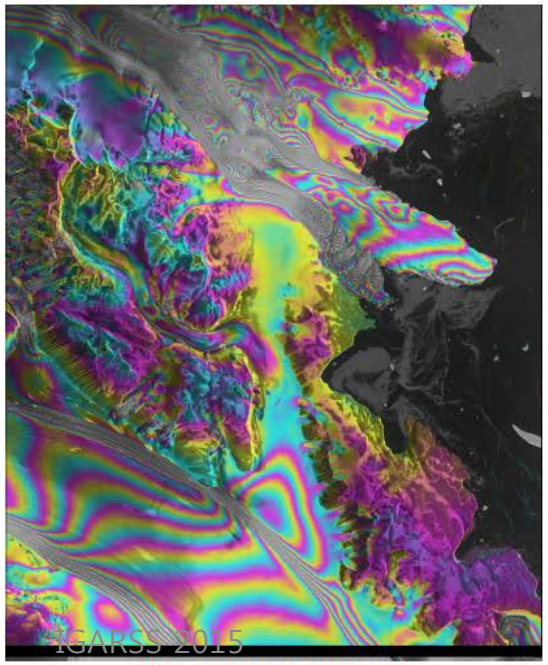
TNB_20101209_20101210



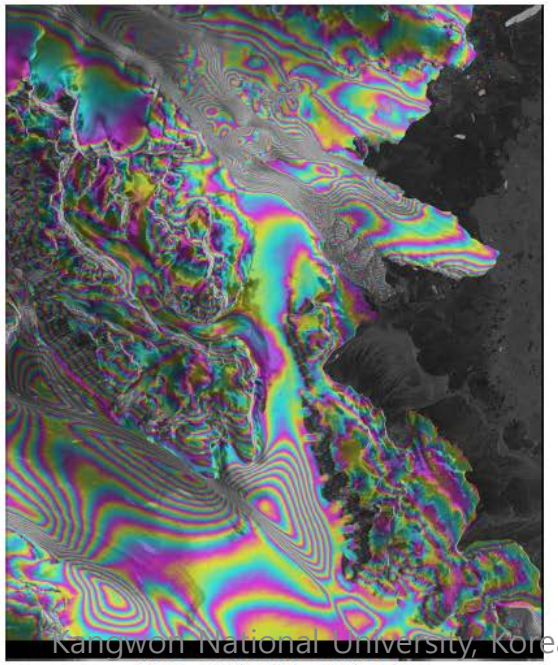
TNB_20101225_20101226



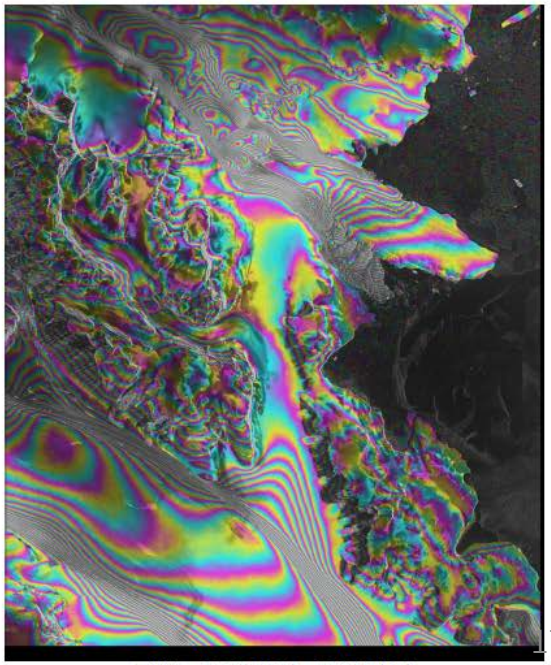
TNB_20110126_20110127



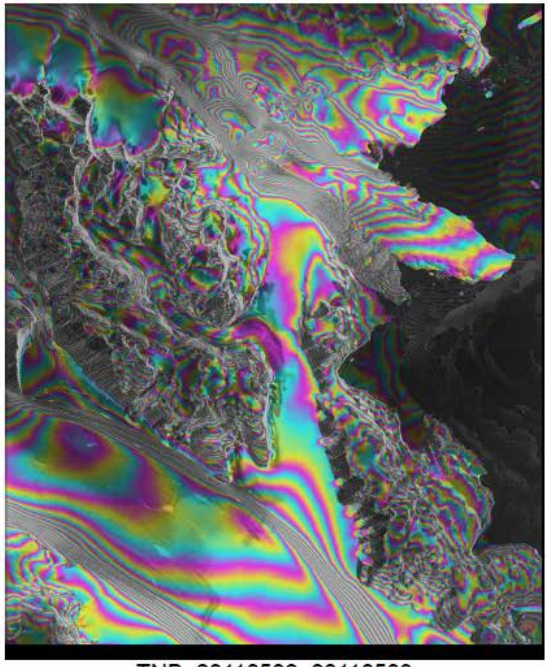
TNB_20110227_20110228



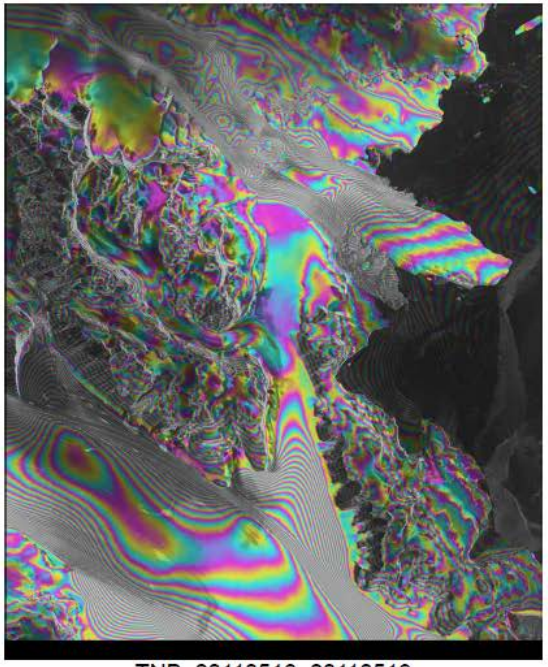
TNB_20110315_20110316



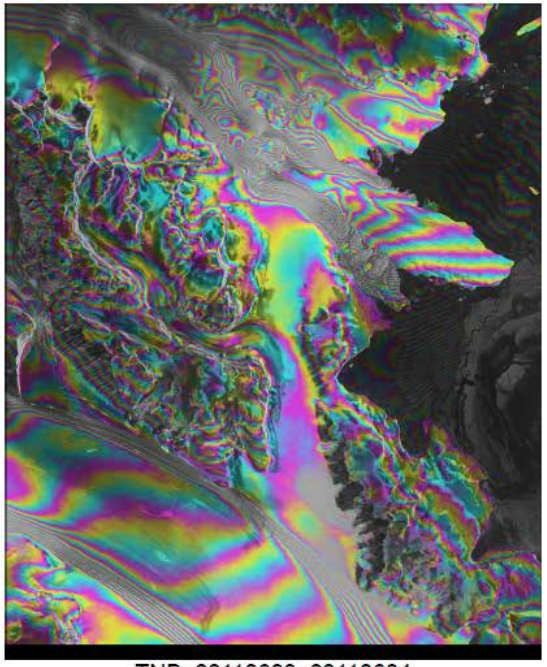
TNB_20110331_20110401



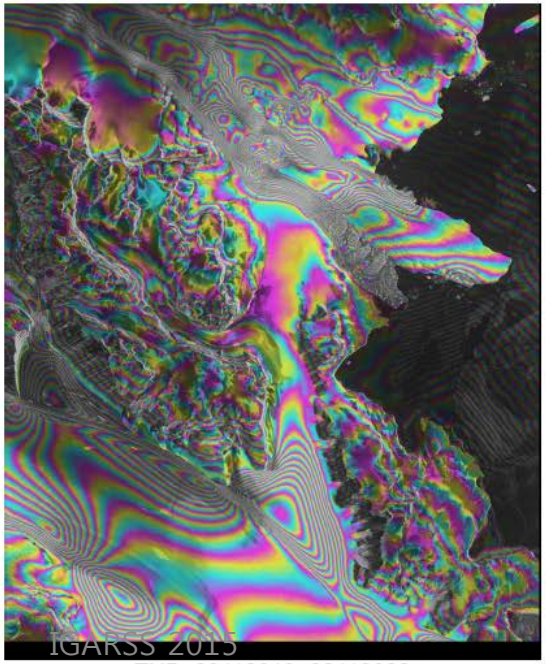
TNB_20110502_20110503



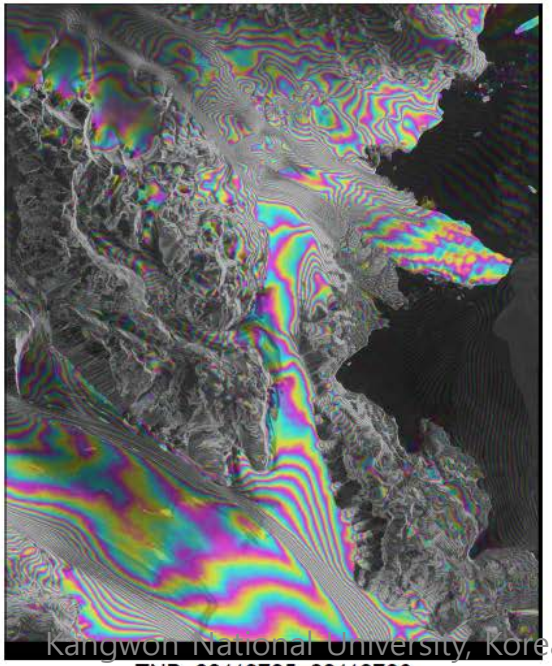
TNB_20110518_20110519



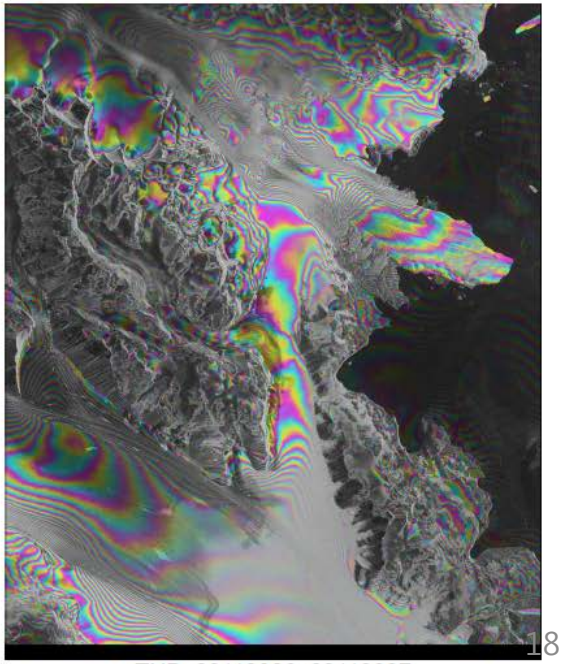
TNB_20110603_20110604



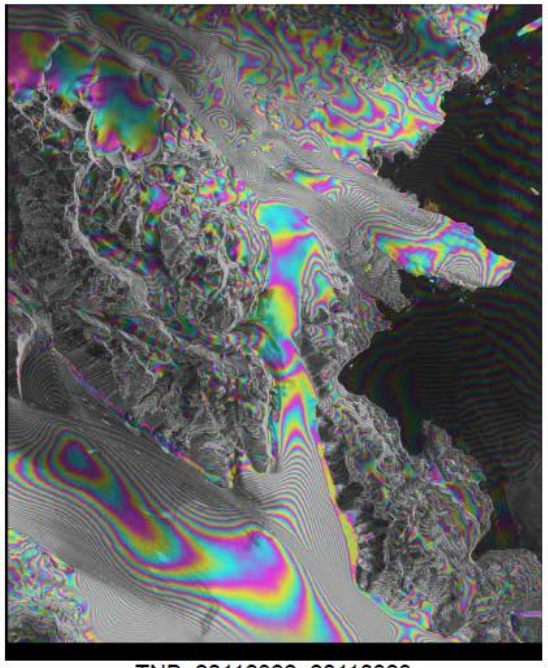
TNB_20110619_20110620



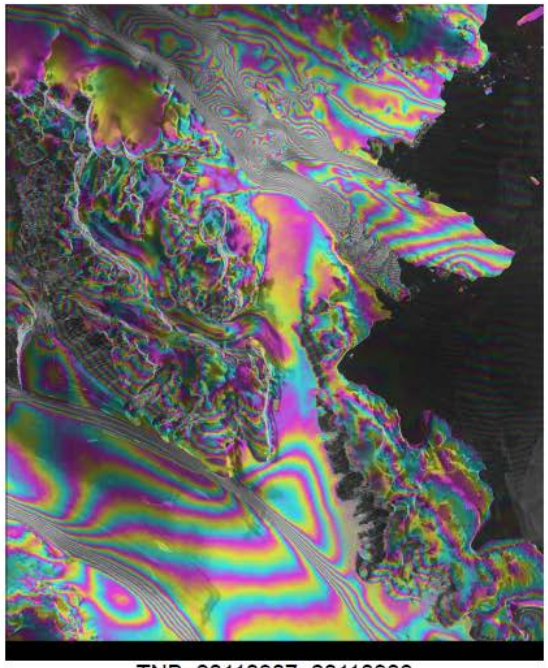
TNB_20110705_20110706



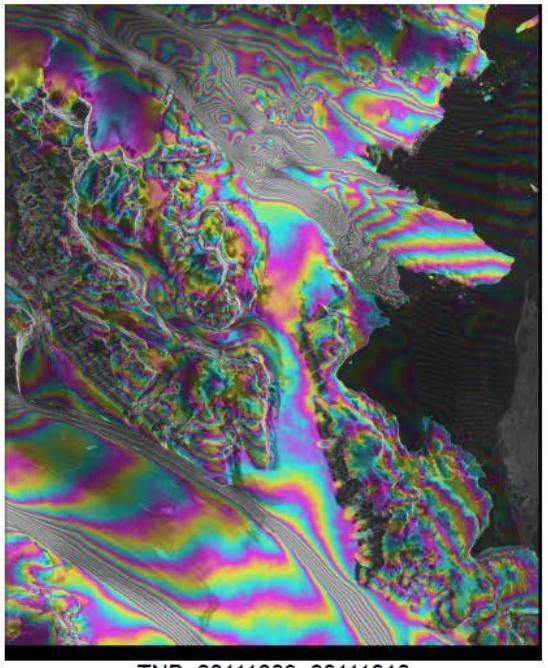
TNB_20110806_20110807



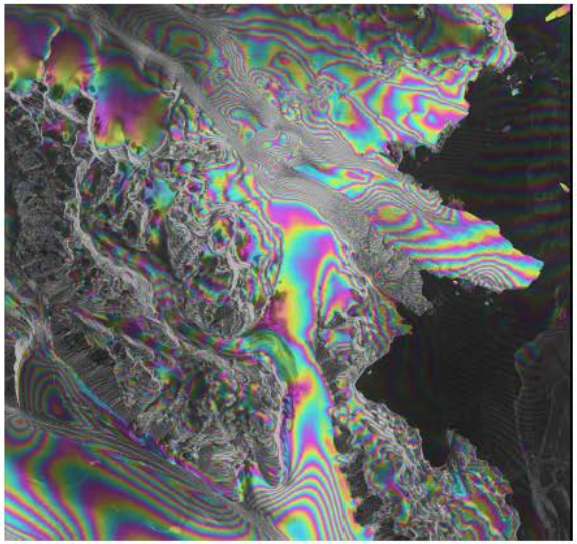
TNB_20110822_20110823



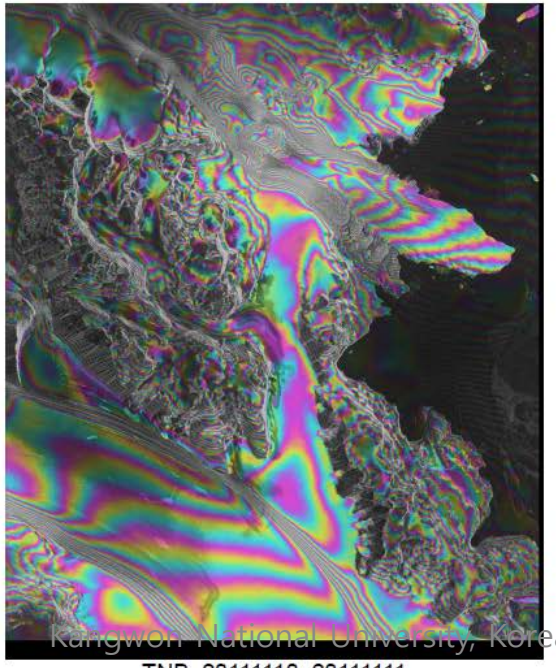
TNB_20110907_20110908



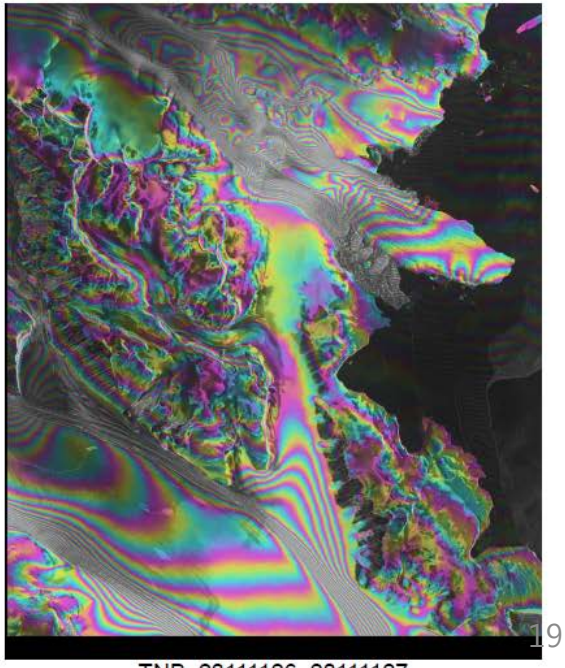
TNB_20111009_20111010



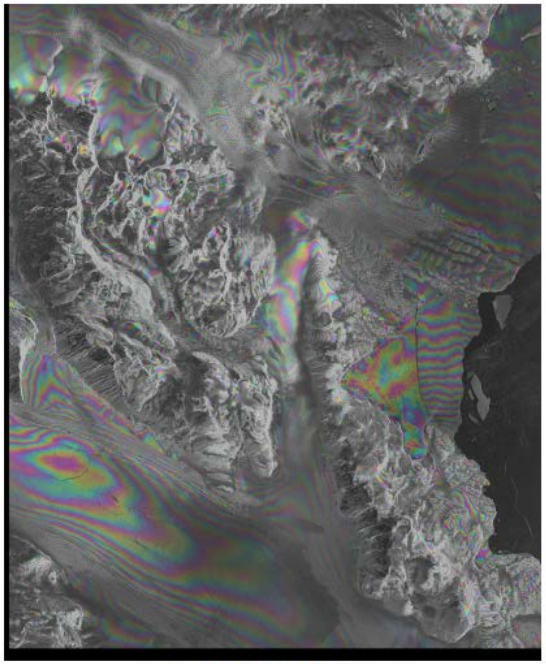
TNB_20111025_20111026



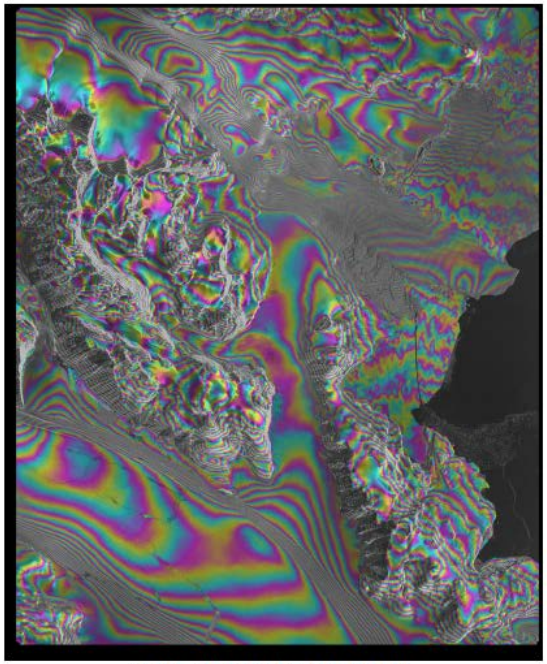
TNB_20111110_20111111



TNB_20111126_20111127



TNB_20111228_20111229



TNB_20120113_20120114

Fast Ice Stress

- Air Stress
  - Katabatic wind is strong but drag coefficient is low
  - Extensional Antarctic sea ice (lead > ridge)*
  - No correlation with fringes
- Water Stress
  - Low drag coefficient due to the absence of keel*
  - No correlations with fringes
- Coriolis Force
  - Strong for heavy icebergs but week for sea ice*
  - fast ice!
- Adjacent sea ice
  - Lead > Ridge
  - Can not explain the year-long consistency in sea ice fringe
- Sea Surface Tilt
  - Induced by tide or current*
  - Some correlations with fringes near sea shore
- Campbell Glacier Tongue
  - Very complex especially in west of CGT
  - Fringe rate and direction varies

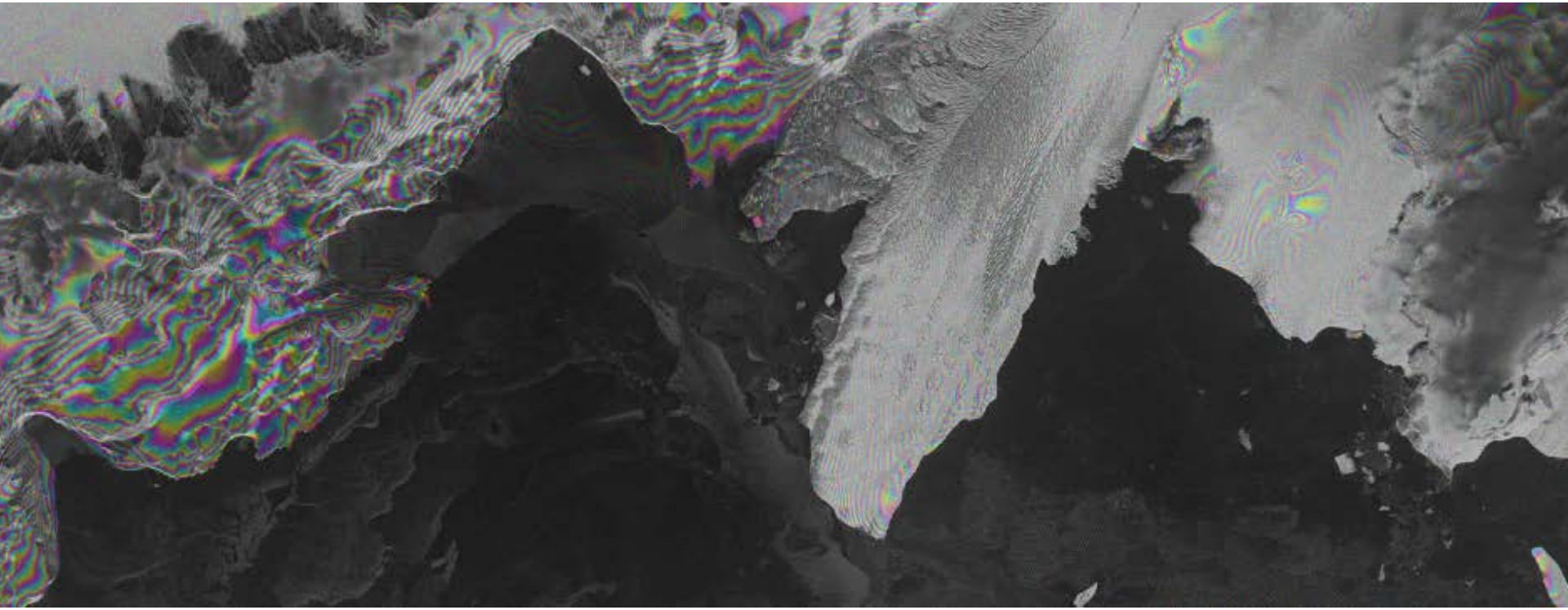
* P. Wadhams, 2000. *Ice in the ocean*, Gordon and Breach Science Publishers

✓ Various multi-dimensional regression have also failed causing year-long intermission in research.
✓ Tidal strain is oscillatory while CGT strain is cumulative -> Weekly InSAR

Weekly InSAR

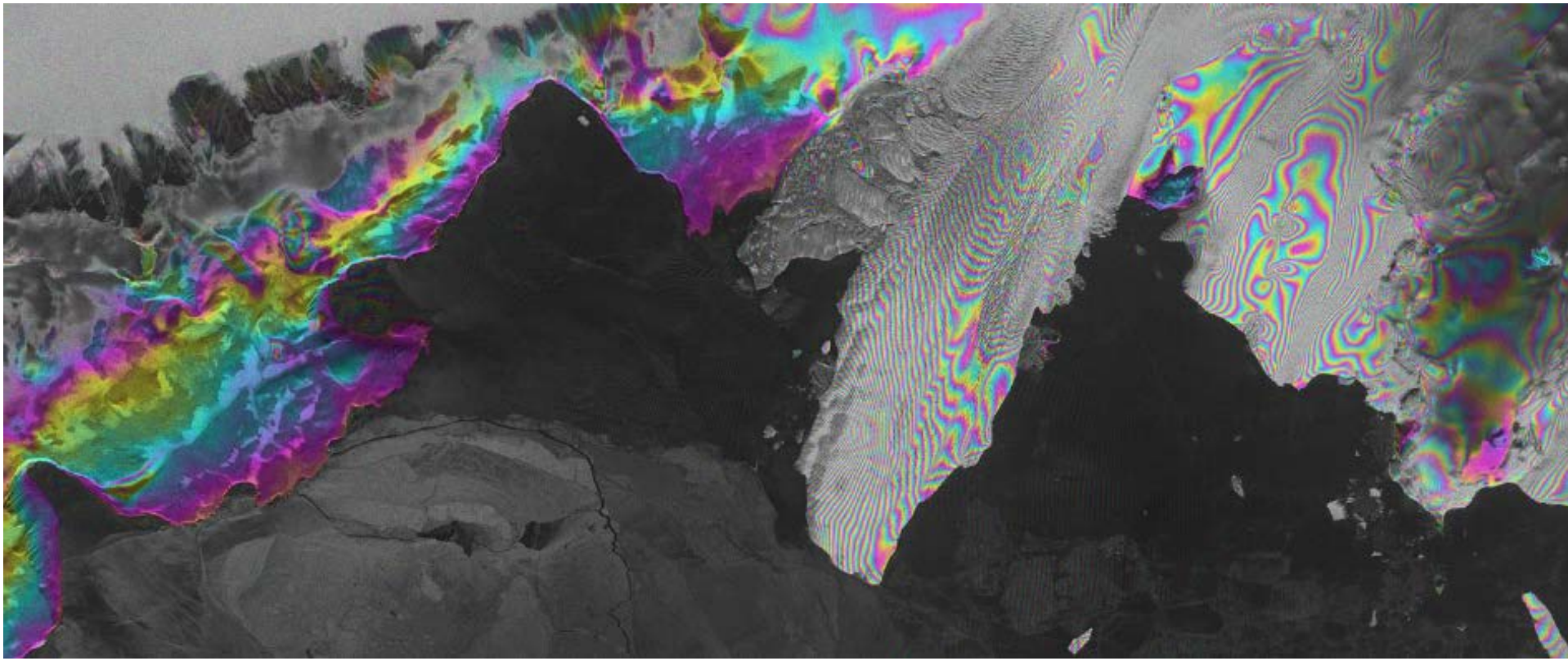
- CSK1-2 one-day tandem is interleaved by CSK3
- 7~9 days of temporal baselines

Weekly InSAR



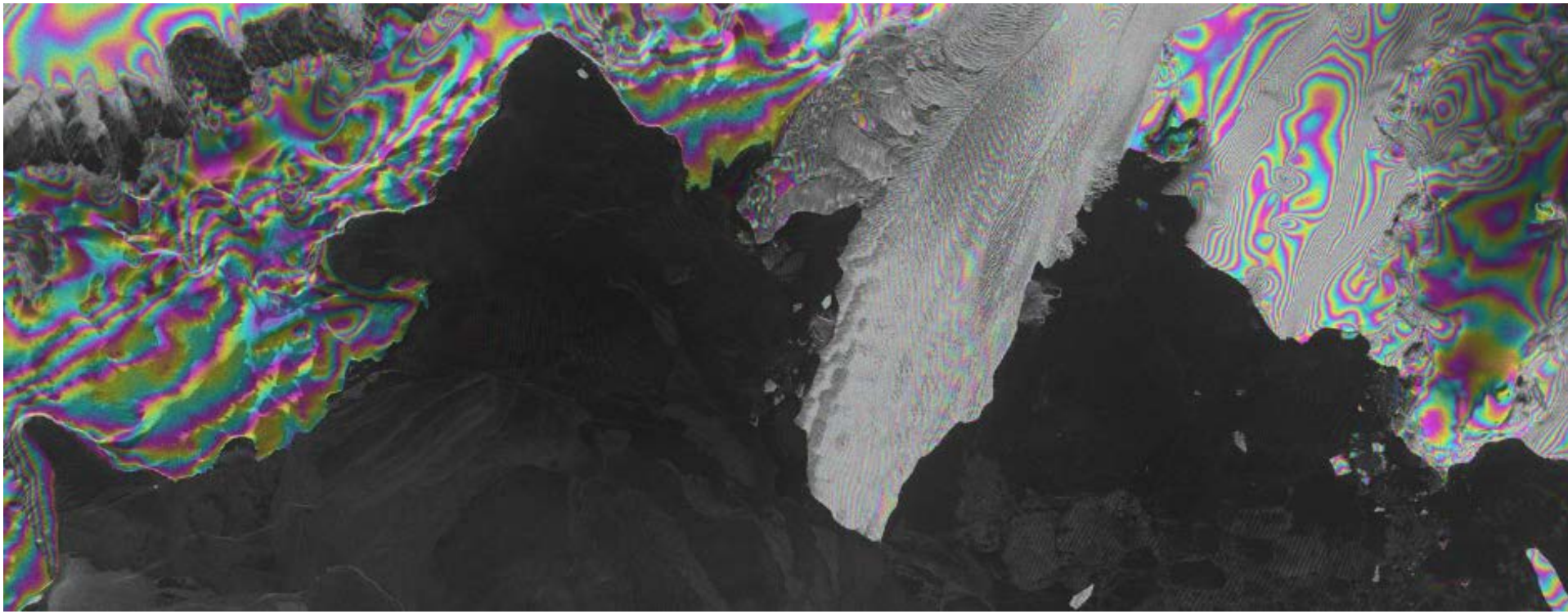
TNB_20110424_20110502

Weekly InSAR



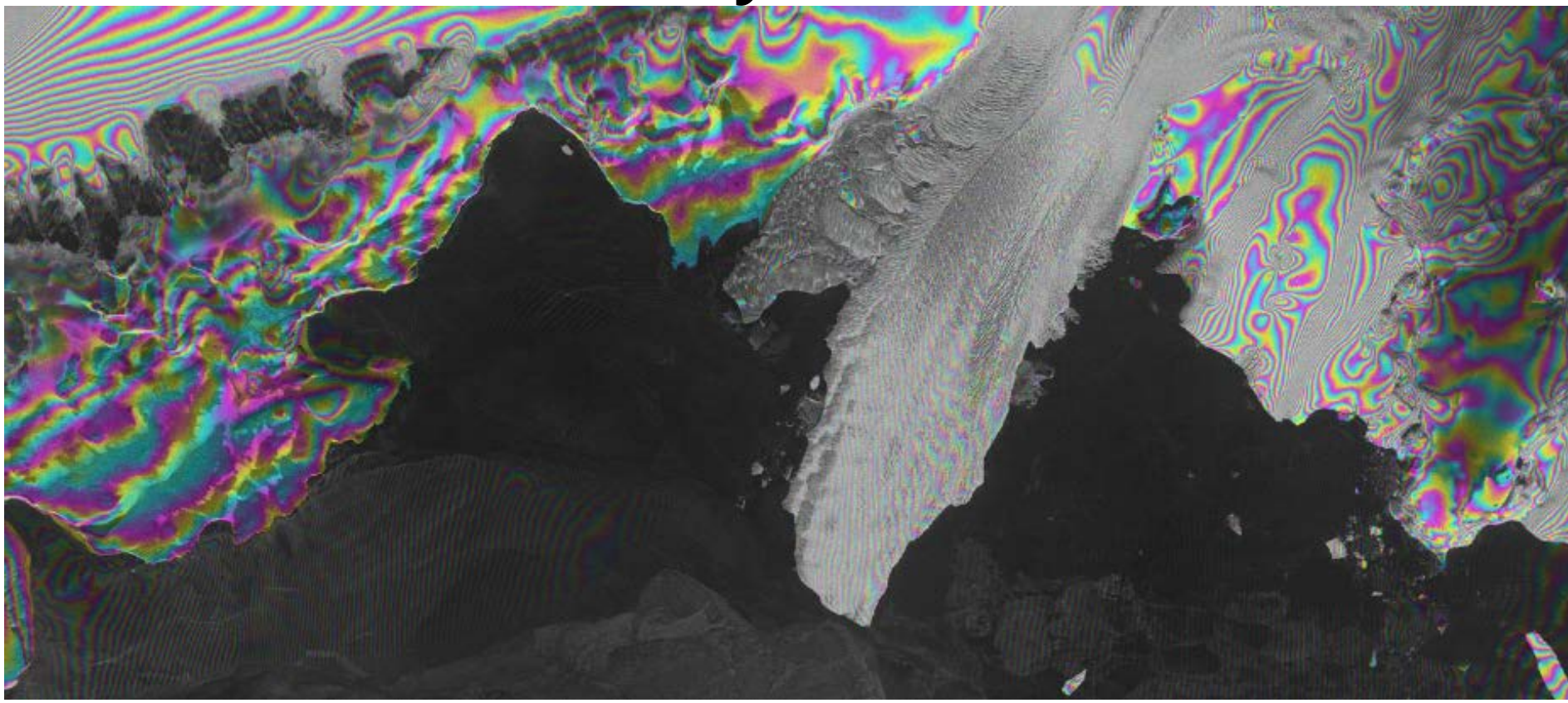
TNB_20110604_20110611

Weekly InSAR



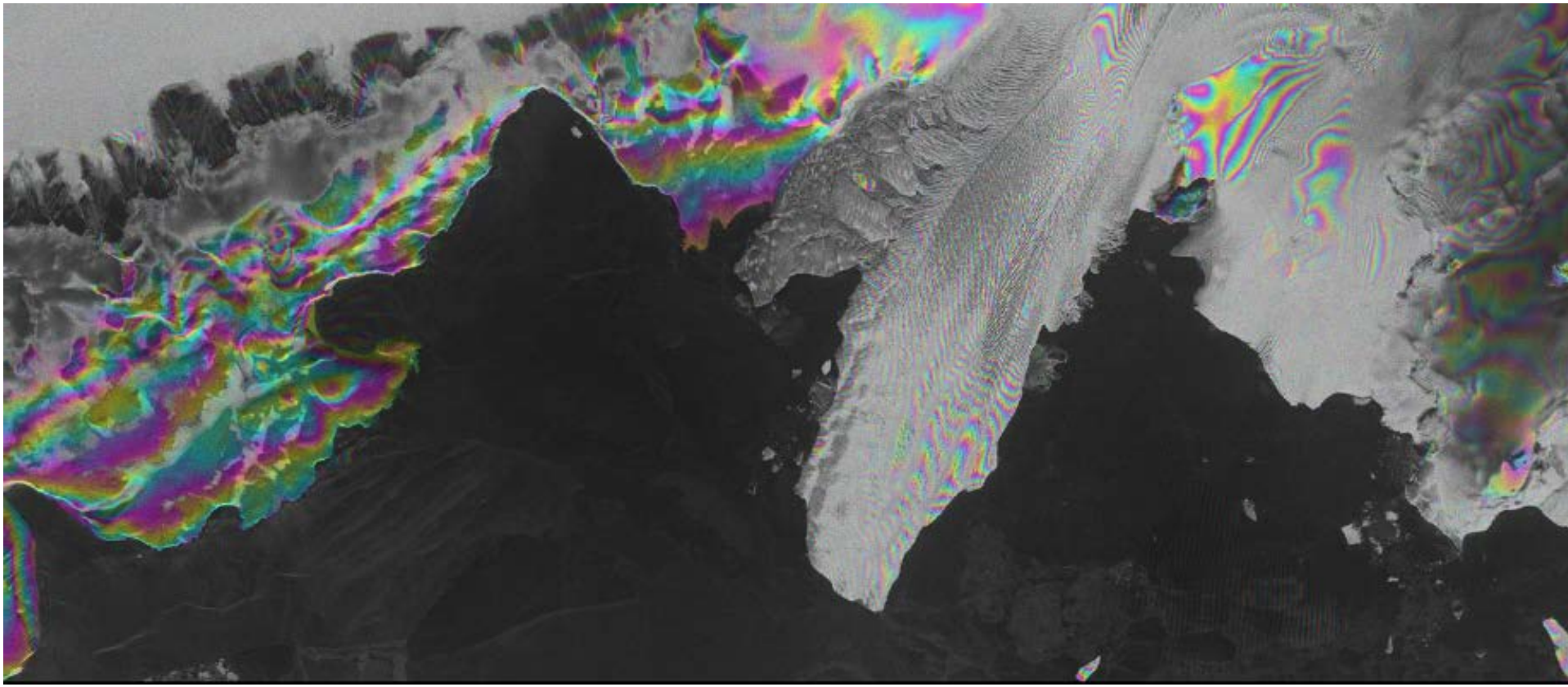
TNB_20110620_20110627

Weekly InSAR



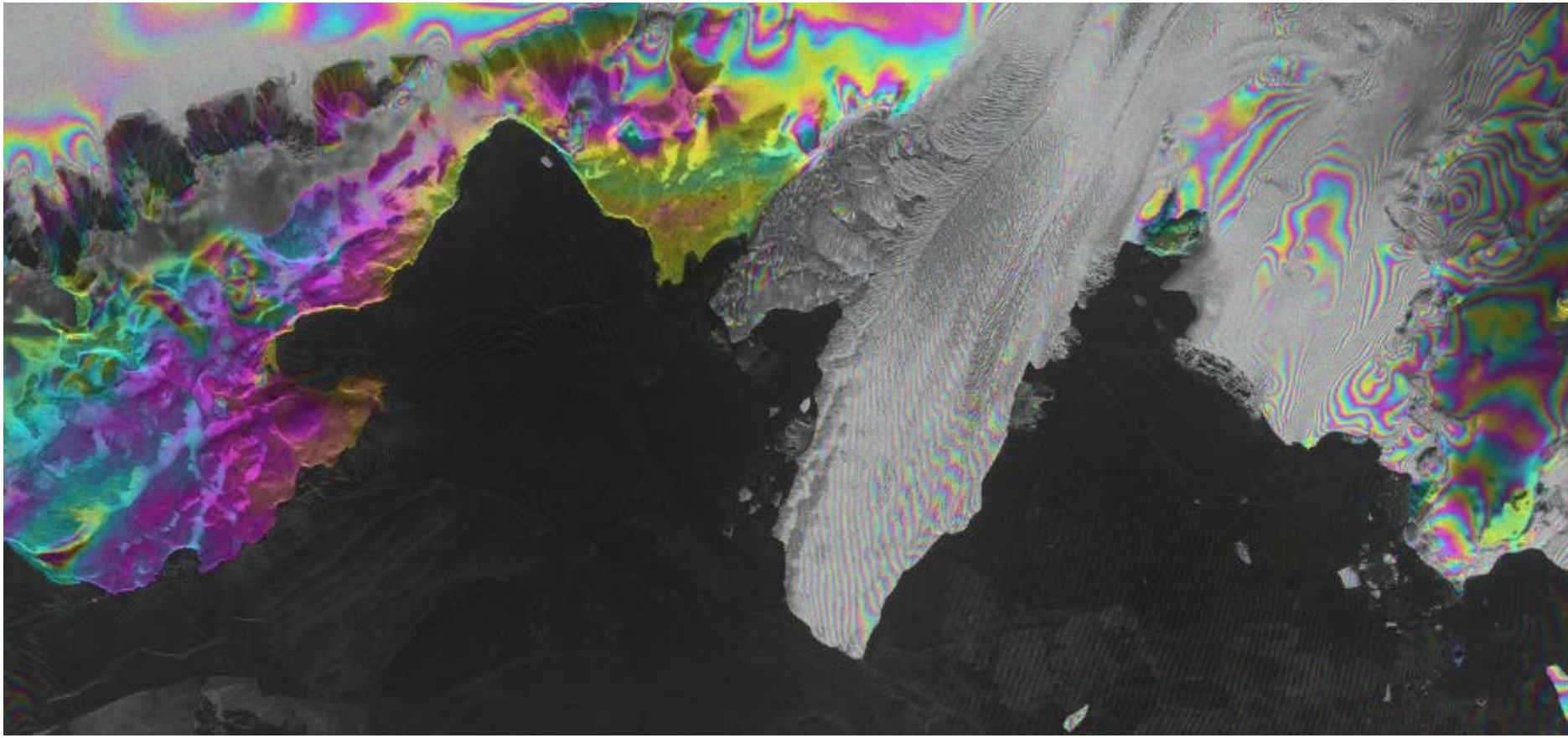
TNB_20110706_20110713

Weekly InSAR



TNB_20110722_20110729

Weekly InSAR



TNB_20110807_20110814

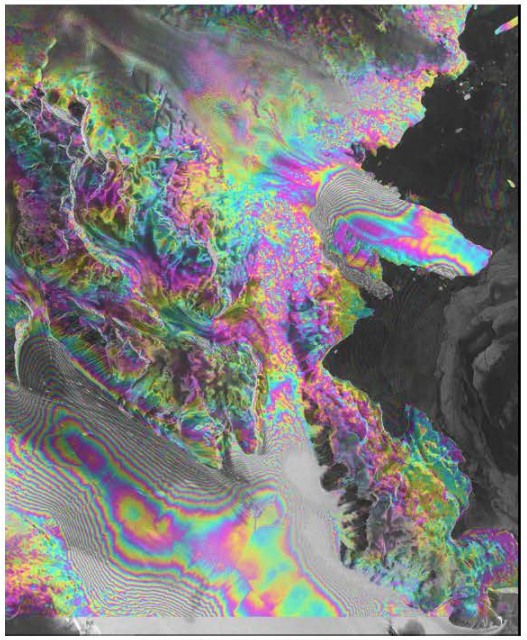
Weekly InSAR

- Weekly InSAR verifies cumulative glacial strain with equi-strain line (fringes) parallel to the glacial contact.
- Fast ice to the east side of CGT is strongly affected by glacial stress
- Some section of fast ice to the west of CGT, in contact with CGT, is also affected by glacial stress with fringes parallel to the ice contact line.
- Fast ice near the shoreline, isolated from CGT by cracks and leads, shows tidal strain only

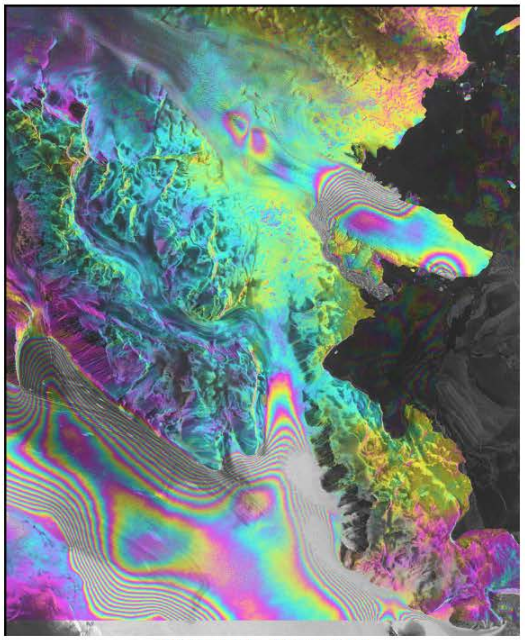
✓ Steady glacial strain can be removed by DDInSAR operation

DDInSAR

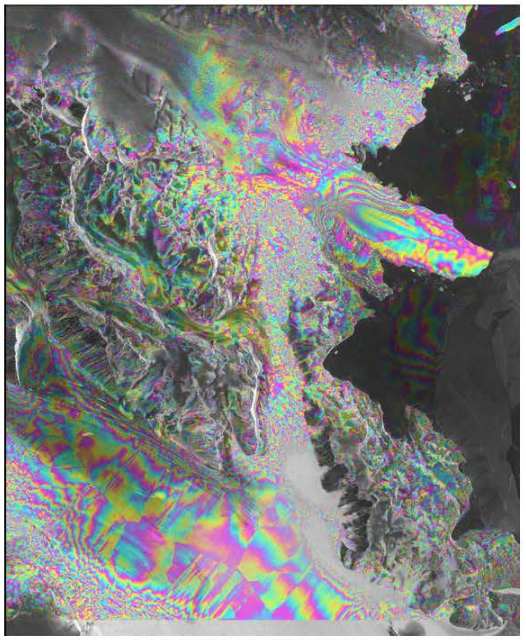
- A technique to remove constant fringes between two InSAR images (Double Differential InSAR)
  - Han and Lee, 2014, Tide deflection of Campbell Glacier Tongue, Antarctica, analyzed by double-differential SAR interferometry and finite element, *RSE*
  - Han and Lee, 2015, Tide-corrected flow velocity and mass balance of Campbell Glacier Tongue, East Antarctica, derived from interferometric SAR, *RSE*
- Valid only when ice surface is stable between two InSAR pairs
- Can remove fringes from consistent glacial stress, if any.



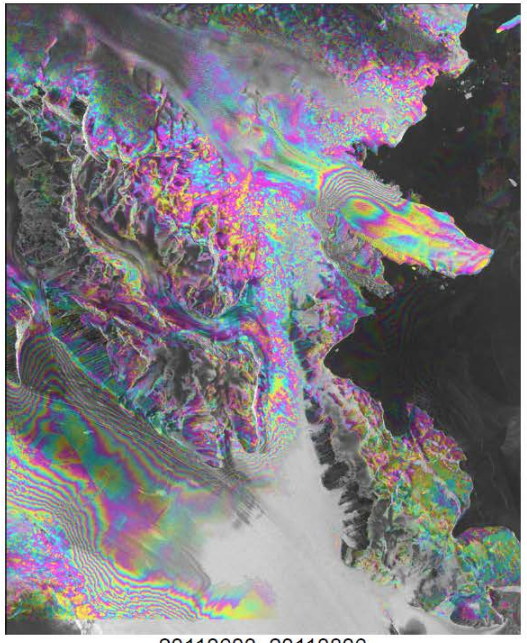
20110518_20110603



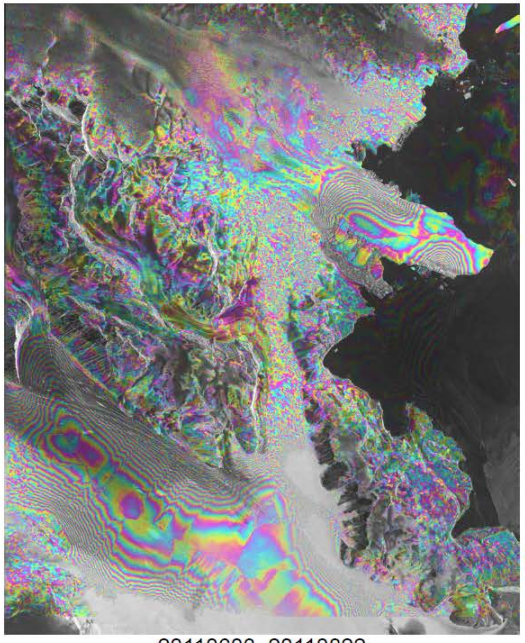
20110603_20110619



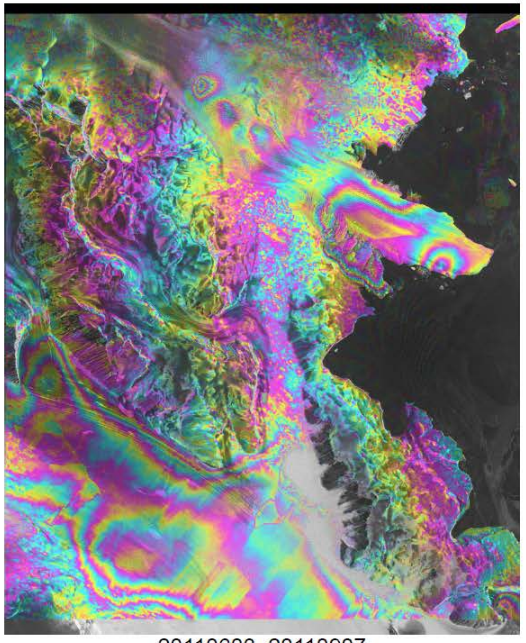
20110603_20110705



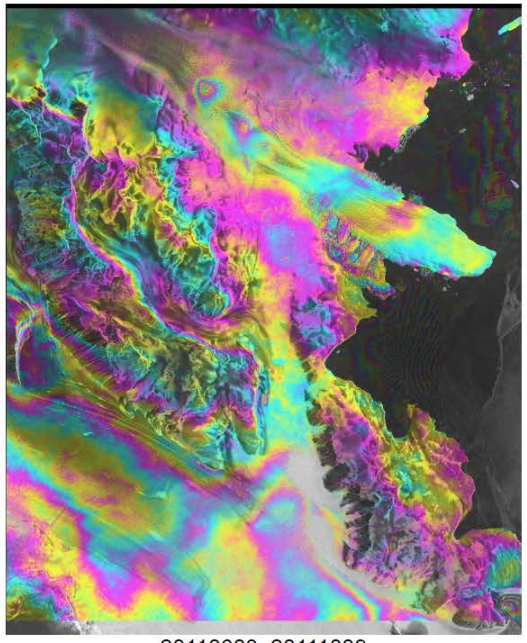
20110603_20110806



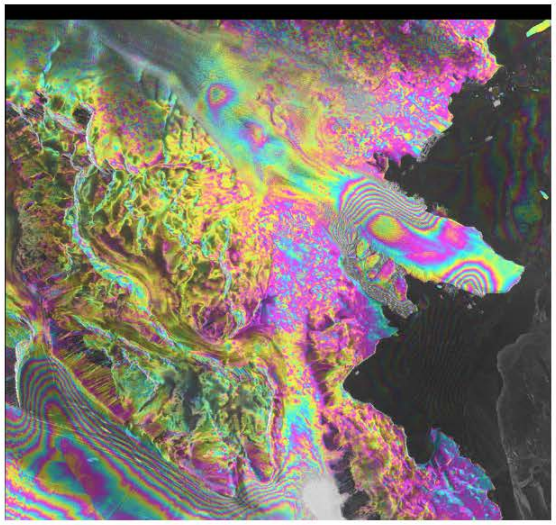
20110603_20110822



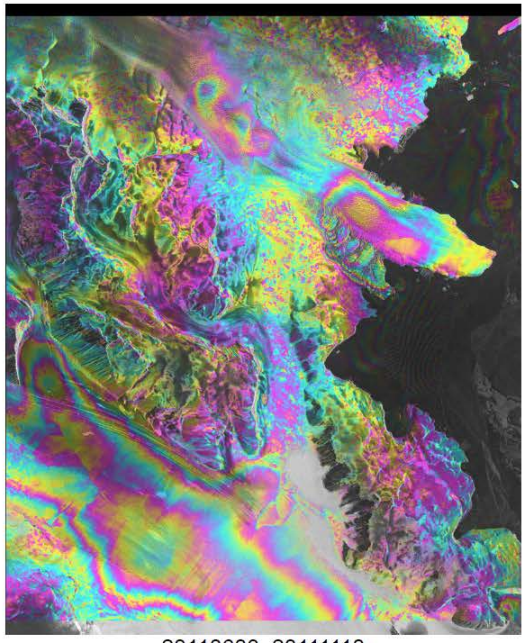
20110603_20110907



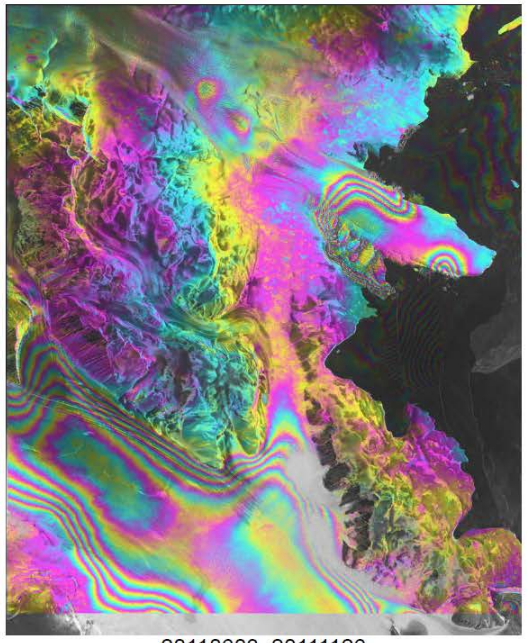
20110603_20111009



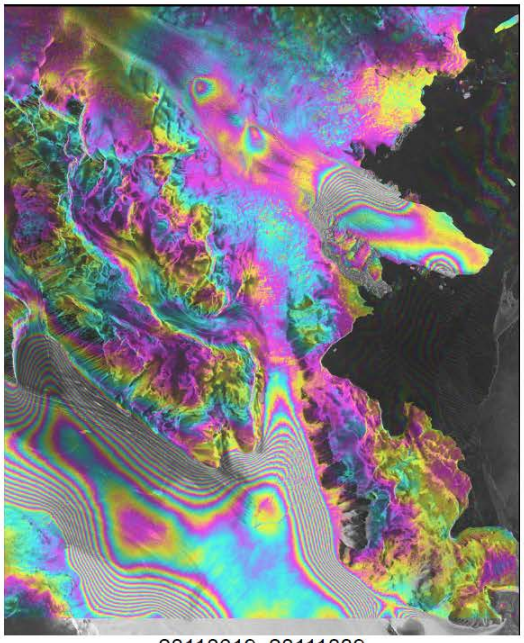
20110603_20111025



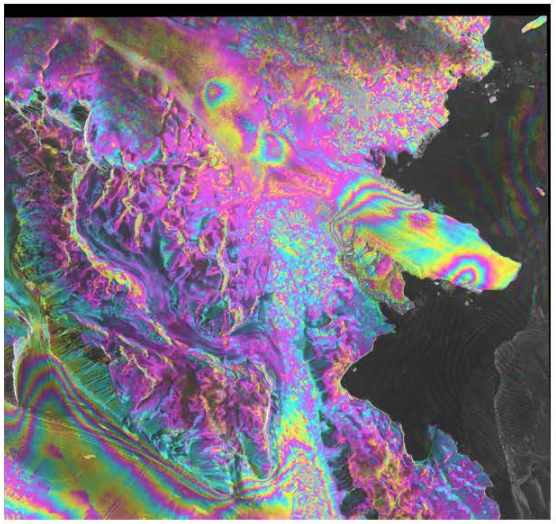
20110603_20111110



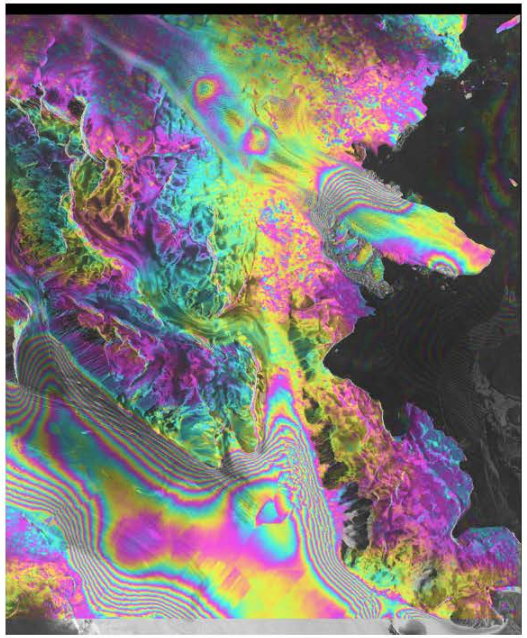
20110603_20111126



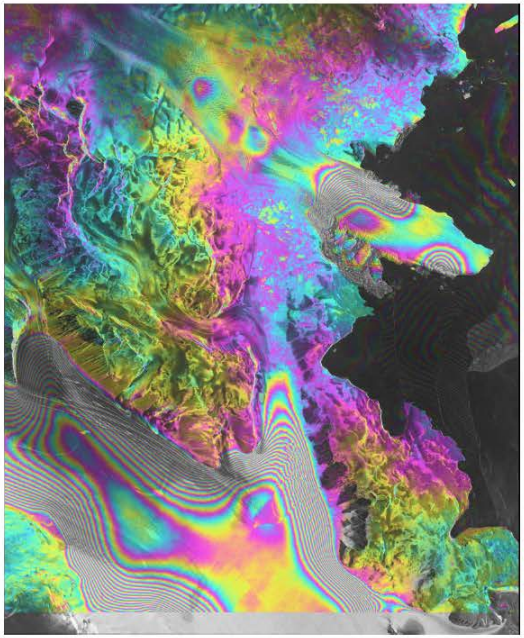
20110619_20111009



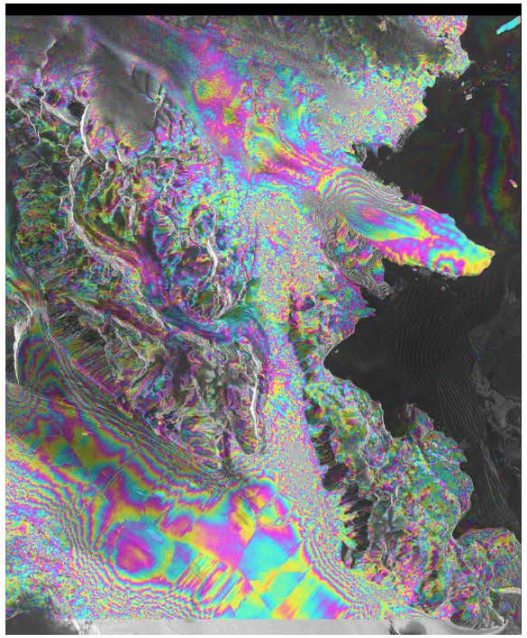
20110619_20111025



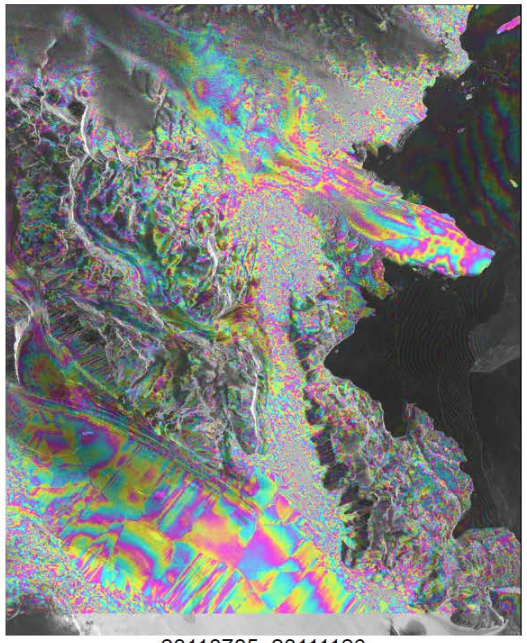
20110619_20111110



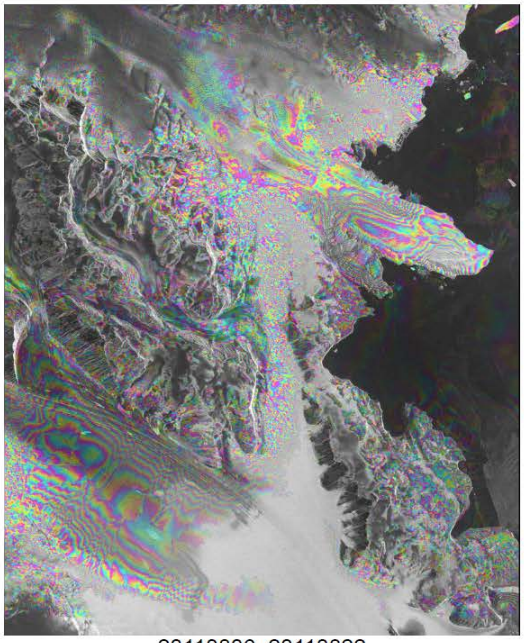
20110619_20111126



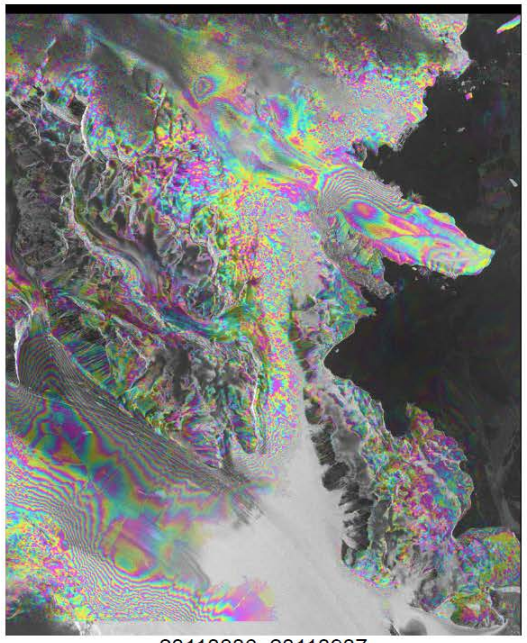
20110705_20111110



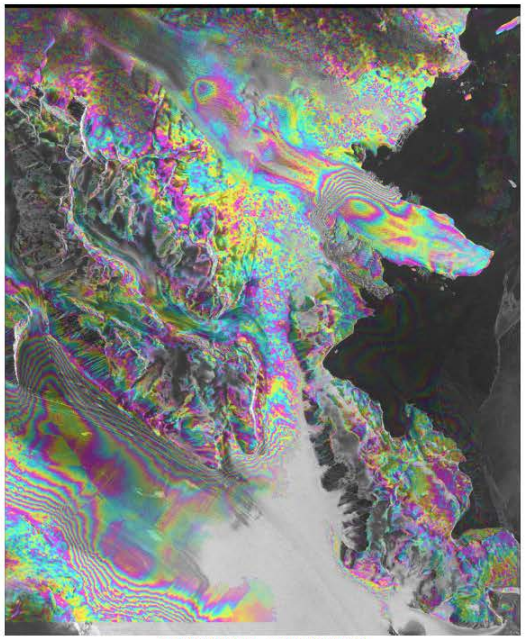
20110705_20111126



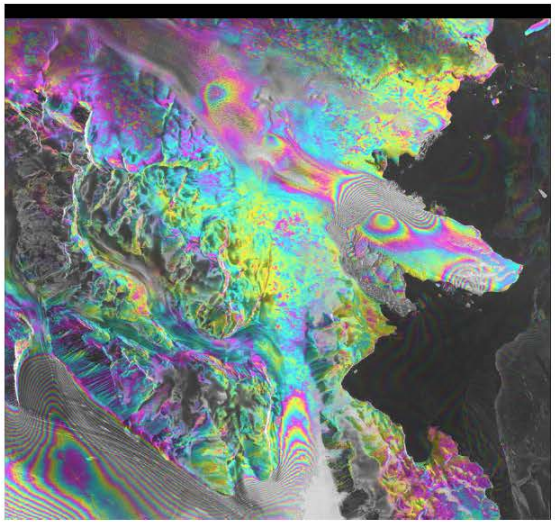
20110806_20110822



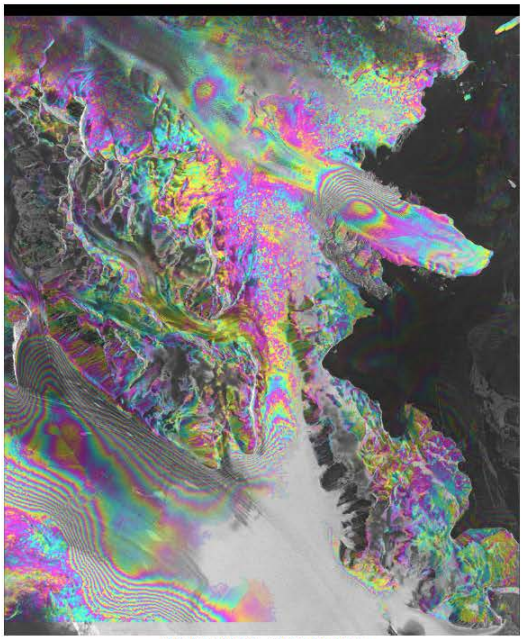
20110806_20110907



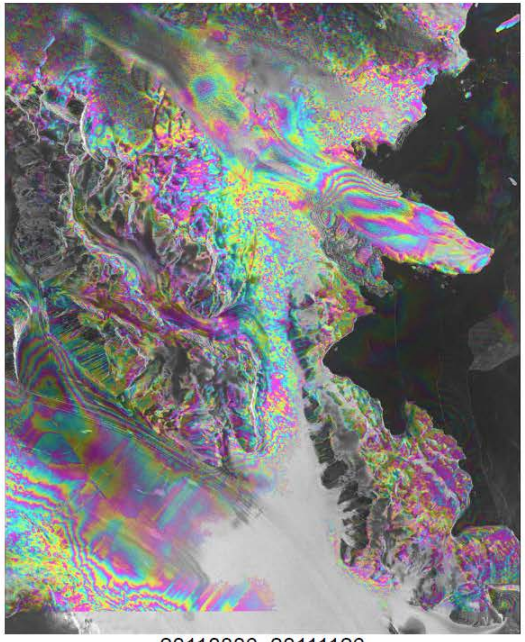
20110806_20111009



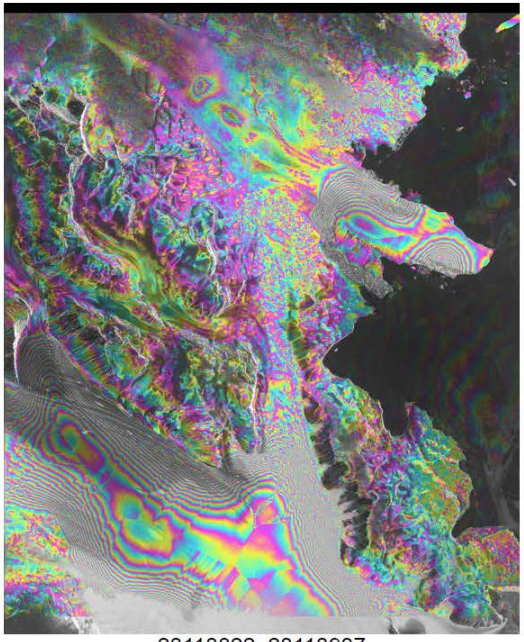
20110806_20111025



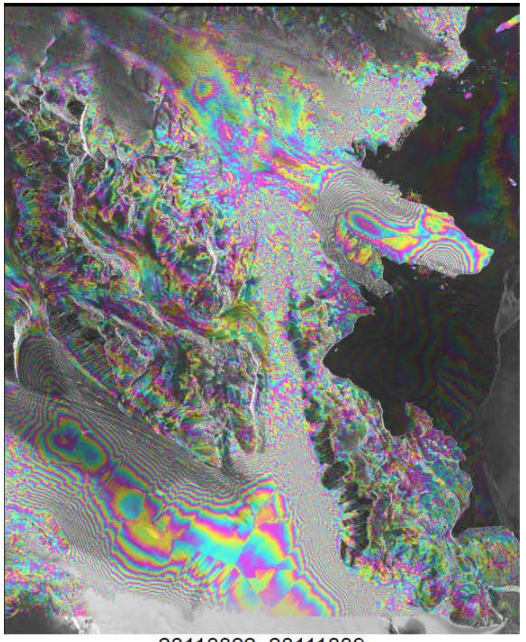
20110806_20111110



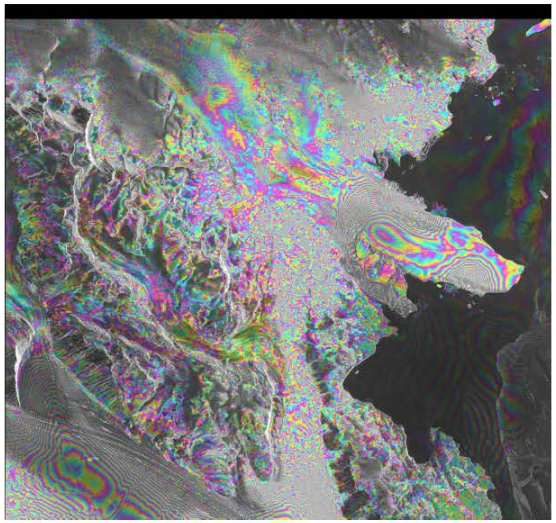
20110806_20111126



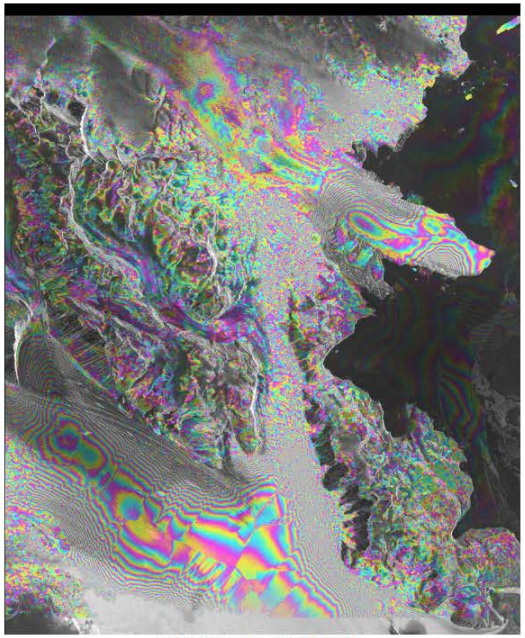
20110822_20110907



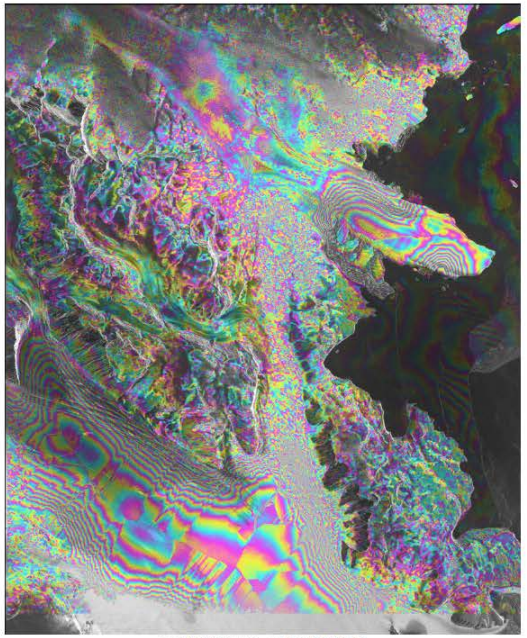
20110822_20111009



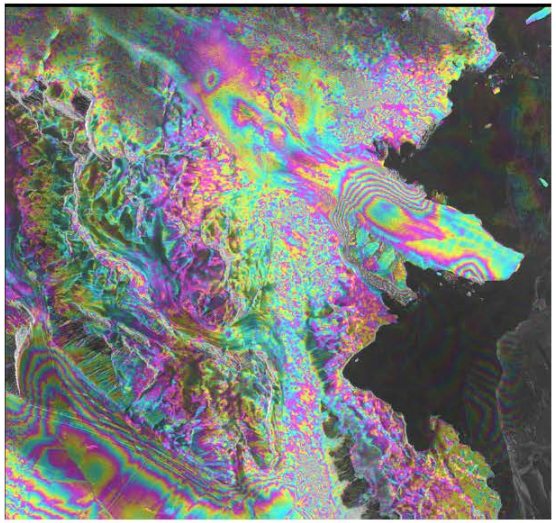
20110822_20111025



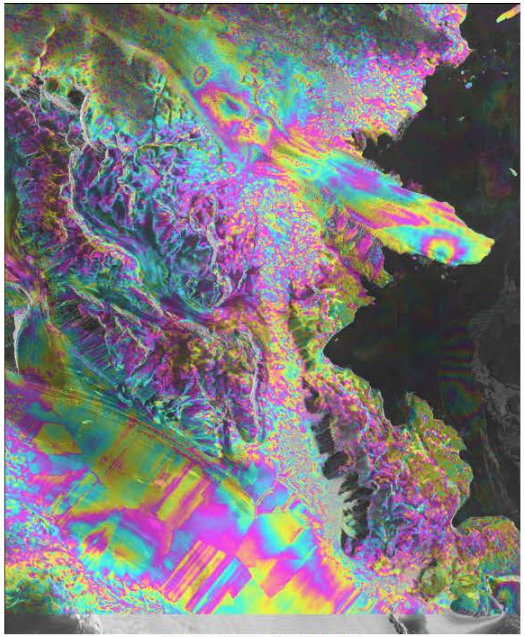
20110822_20111110



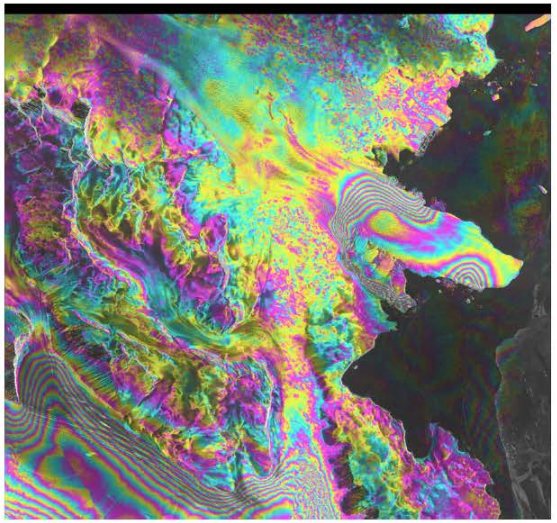
20110822_20111126



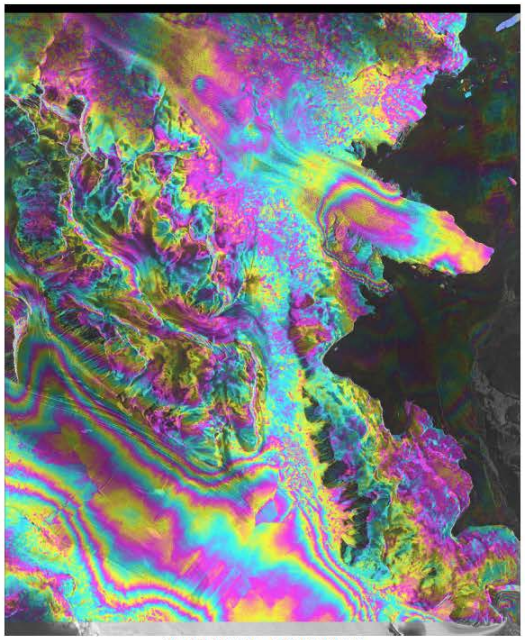
20110907_20111025



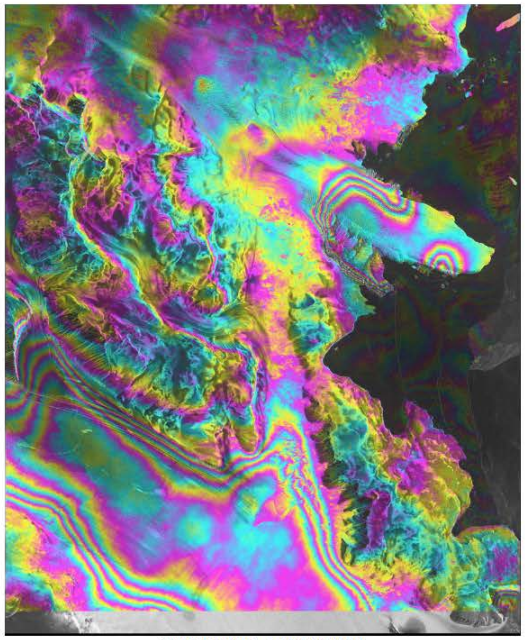
20110907_20111110



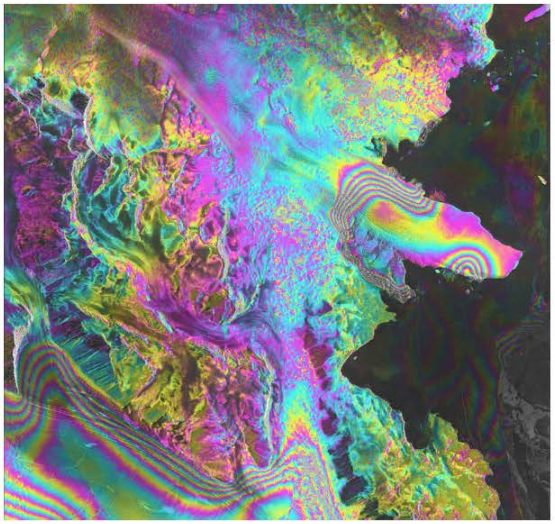
20111009_20111025



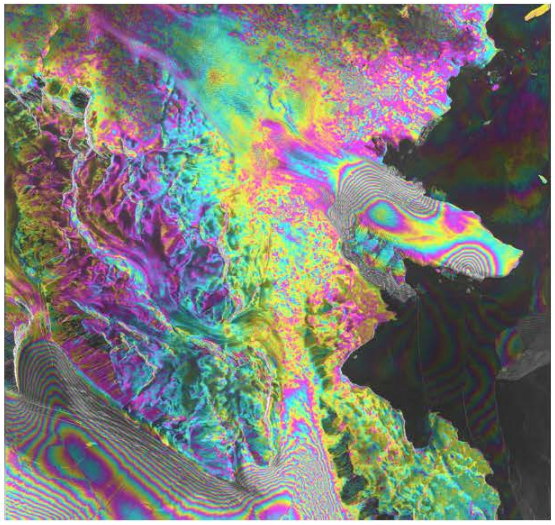
20111009_20111110



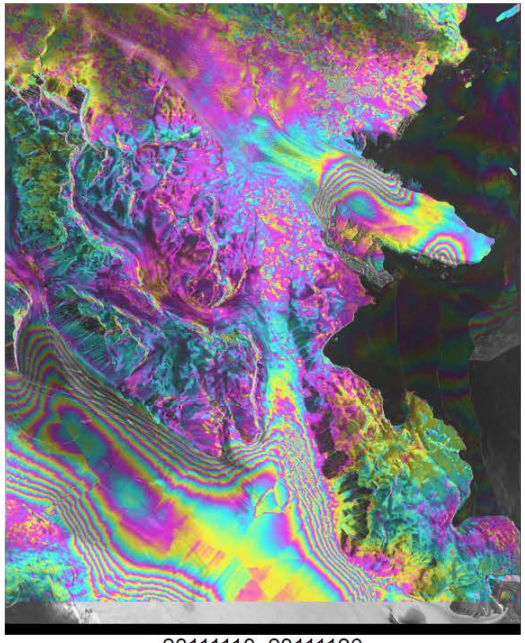
20111009_20111126



20111025_20111110



20111025_20111126



20111110_20111126

Glacial and Tidal Stresses

- Glacial Stress
  - Campbell Glacier Tongue has a year-long steady motion of ~67 cm/day (Han and Lee, 2014, 2015)
  - Equi-strain fringe is parallel to the glacier-fast ice contact
  - Glacier-fast ice contact in the east of CGT is established between mid May and early June

- Tidal Stress
  - Tide generates ocean surface tilt (~ 40 cm)
  - Tidal strain fringe is parallel to the sea shore
  - Affected by tidal current, CGT and ocean bottom topography

- Glacial and tidal strain rates are similar in **one-day InSAR**
- **Glacial strain** is dominant in **weekly InSAR** because CGT gives cumulative stress (~469 cm/week) while tide is oscillatory (~40 cm).
- Consistent glacial strain is removed in **DDInSAR** operation, and only **tidal strain** is visible.

Conclusions

- One day and weekly based InSAR observation enabled the observation of annual variation of landfast sea ice and its dynamics.
- Fast ice lags air temperature by two months in Terra Nova Bay.
- Fast ice fringes in this study area are mainly from glacial stress and tidal stress.
- Weekly InSAR highlights consistent glacial strain (~469 cm/week).
- DDInSAR highlights oscillatory tidal strain (~ 40 cm).

On-going Research

- Tide deflection ratio of fast ice and its seasonal variation can be modeled by DDInSAR.
- Tide-corrected InSAR can reveal the glacial stress-strain relationship and its seasonal variation.
- Quantitative physical properties of fast ice in freezing and thawing season can be deduced by ice modeling.

Thank you