Polarimetric Response of Rice Fields at C-band: Analysis and Applications

Juan M. Lopez-Sanchez
Fernando Vicente
J. David Ballester-Berman

Shane R. Cloude

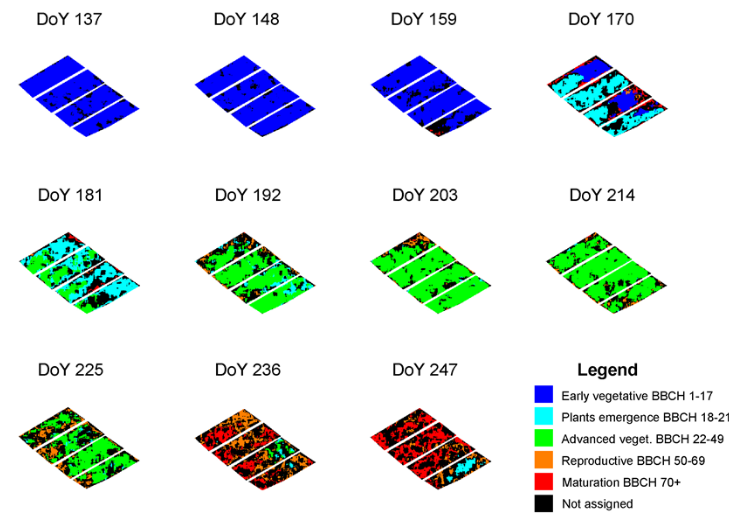
Universitat d'Alacant
Universidad de Alicante

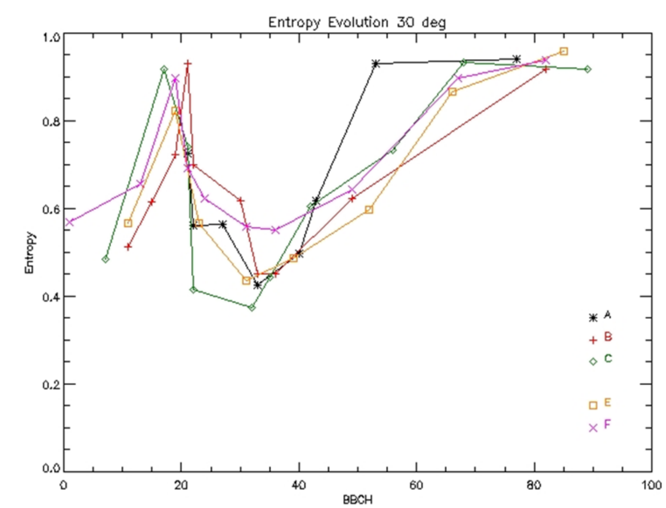
AEL consultants

Previously...

Lopez-Sanchez et al. [IEEETGRS'12, POLinSAR2011]

- Coherent dual-pol HHVV images acquired by TerraSAR-X showed the sensitivity of polarimetry to track and retrieve phenology of rice fields
  - Results:
    - Five phenological intervals can be identified
    - Phenology estimated from just one acquisition
    - Usefulness:
      - At pixel level: different growth rates within a parcel and cultivation problems
      - At parcel level: overall development rate for planning and triggering of cultivation practises
  - Limitations:
    - Ambiguity: Start of tillering (stages 18-21) and maturation (stages 70+) present high entropies and cannot be distinguished in many cases
    - Small swath (low spatial coverage)
    - Low SNR at some stages (NESZ ~ -19 dB)





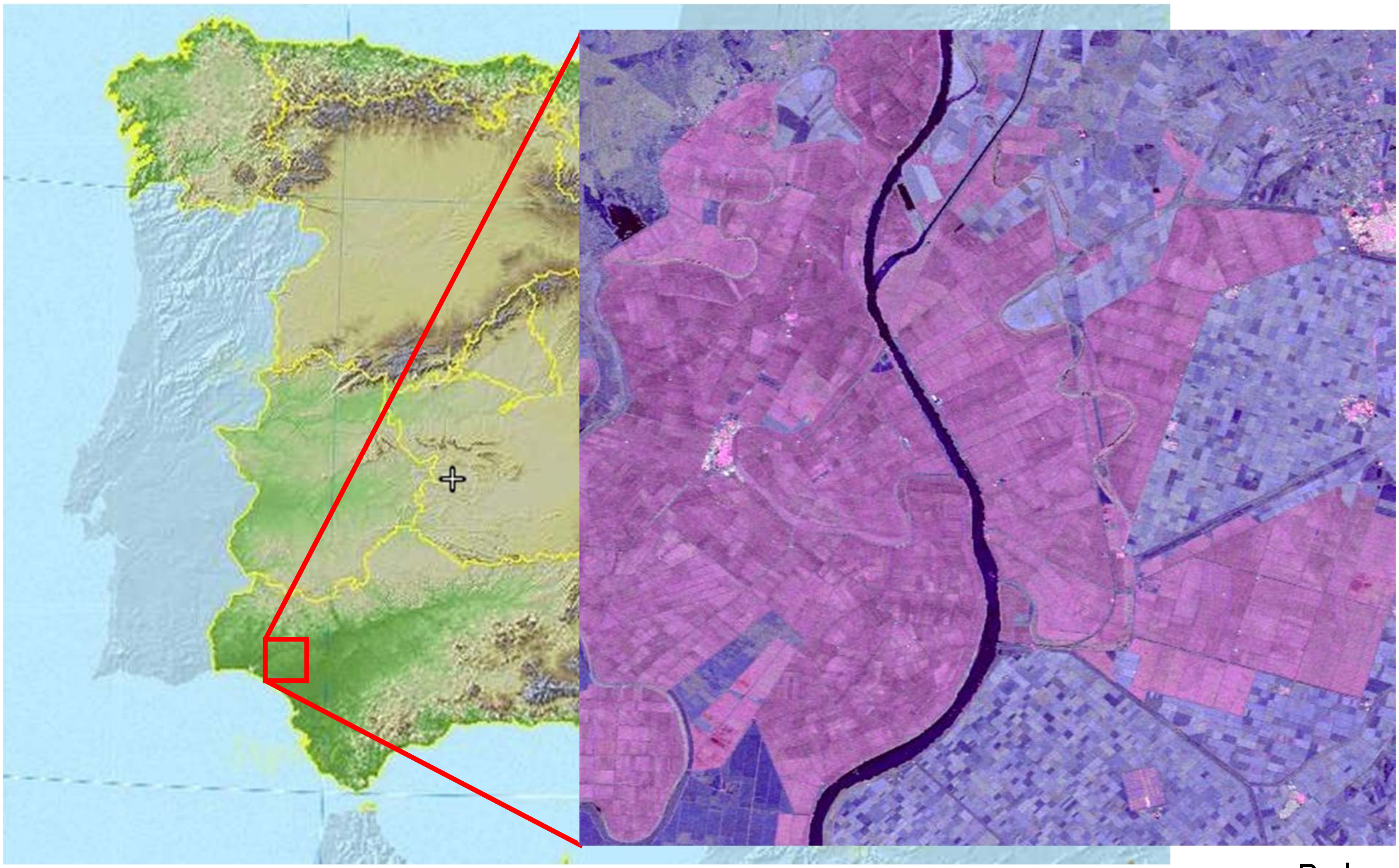
Pending questions

- Could the ambiguities found with HHVV images be solved by full polarimetry?
  - Test it with Radarsat-2…
  - But acquisitions during 2009 were restricted to the first half of the campaign Lopez-Sanchez et al. [POLinSAR2011]

- What is the influence of frequency band (C vs X) on the polarimetric observables as a function of phenology?
- Can phenology be retrieved with a single Radarsat-2 image?
- Is full polarimetry strictly required for such an application? What about compact-pol or conventional dual-pol?
  - Interest for RCM, Sentinel-1, etc.
  - Increased spatial coverage

Test site

Mouth of the Guadalquivir river, Seville, Spain



Radarsat-2, 6-Aug-2010
Pauli RGB composite

Ground campaign: 2009 and 2010

- Ground data provided at 5 and 6 parcels
  - Weekly update
  - Phenological stages in BBCH scale
  - + Additional info:

2009

Label	Surface (ha)	Sowing date (DoY)	Plants/m^2	Panicles/m^2	Harvest date (DoY)	Yield (kg/ha)
A	13.14	17-may (137)	315	530	07-oct (280)	8.949
B	12.47	15-may (135)	350	600	29-sep (272)	8.729
C	40.5	07-may (127)	850	1300	25-sep (268)	10.400
D	4.34	24-may (144)	400	512	08-oct (281)	10.060
E	17.26	15-may (135)	450	580	14-oct (287)	9.000

2010

Label	Surface (ha)	Sowing date (DoY)	Plants/m^2	Panicles/m^2	Harvest date (DoY)	Yield (kg/ha)
A	13.14	22-may (142)	469	620	19-oct (292)	9.493
B	12.47	22-may (142)	464	510	18-oct (291)	8.400
C	40.5	17-may (137)	425	560	02-oct (275)	10.057
D	4.34	23-may (143)	350	640	13-oct (286)	10.495
E	17.26	02-jun (153)	183	549	04-nov (307)	9.500
F	9.68	27-may (147)	380	540	27-oct (300)	9.403

Ground data acquired by the
Federación de Arroceros de Sevilla

Available radar data

- 10 Radarsat-2 images

Mode	Fine Quad-Pol.
Beam	FQ13
Avg. Incidence angle	33 degrees
Pass	Descending
Acquisition time	6:30 a.m.
Pixel spacing	4.7 x 4.7 m

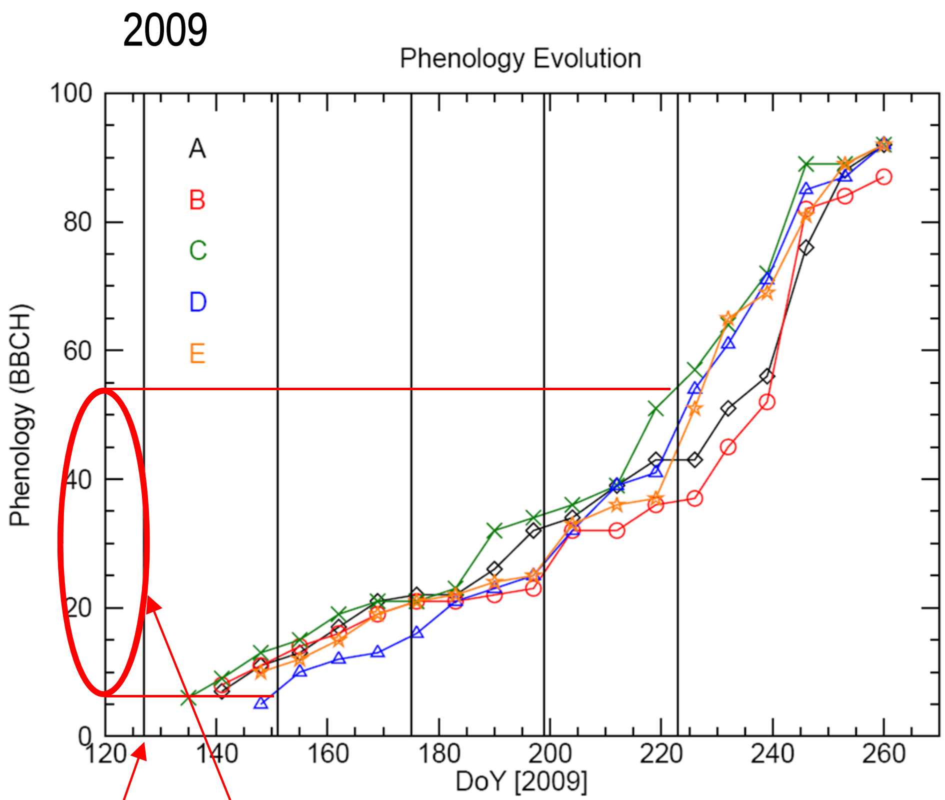
Date	DoY
07-May-2009	127
31-May-2009	151
24-Jun-2009	175
18-Jul-2009	199
11-Aug-2009	223
26-May-2010	146
19-Jun-2010	170
06-Aug-2010	218
23-Sep-2010	266
17-Oct-2010	290

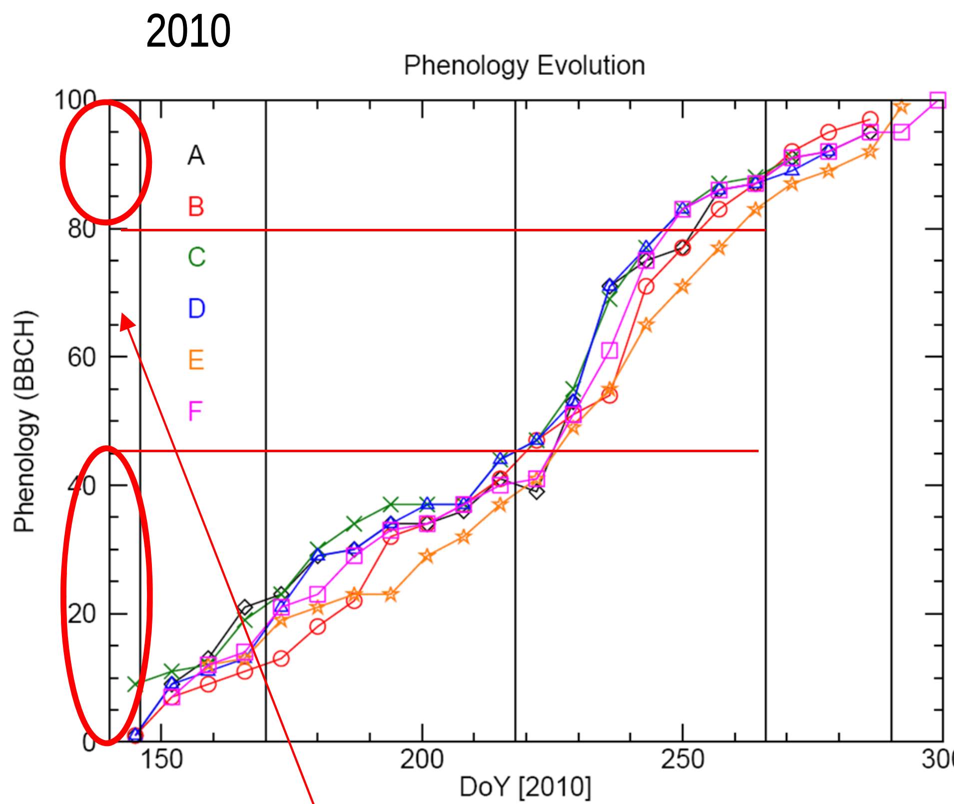
Every 24 days

Gaps (missed acquisitions)

Images provided by MDA and CSA under the SOAR project 2125

Phenology at radar acquisition dates



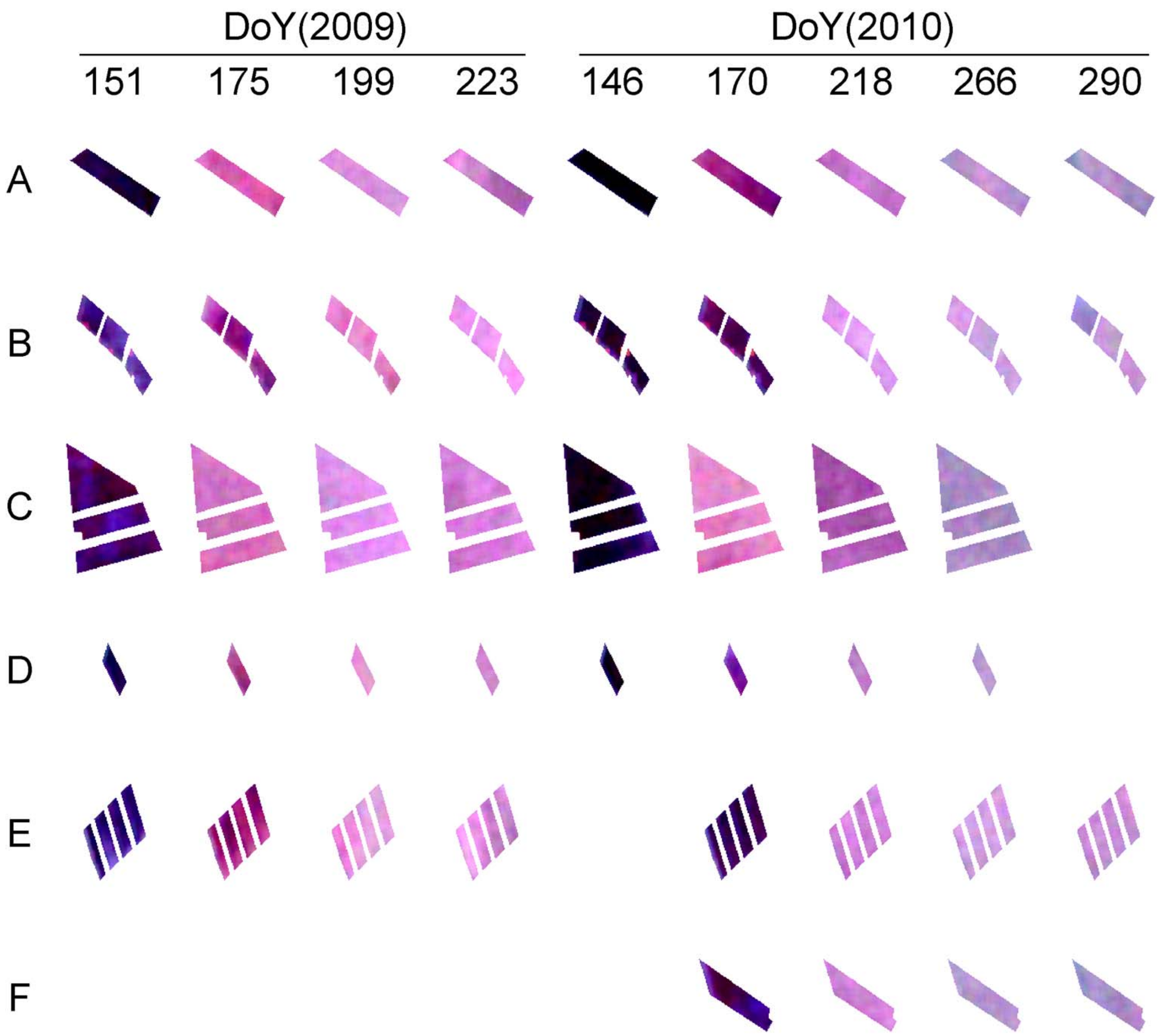


Observation in 2009 is restricted to stages below 55

The first image in 2009 was acquired before sowing any field: discarded

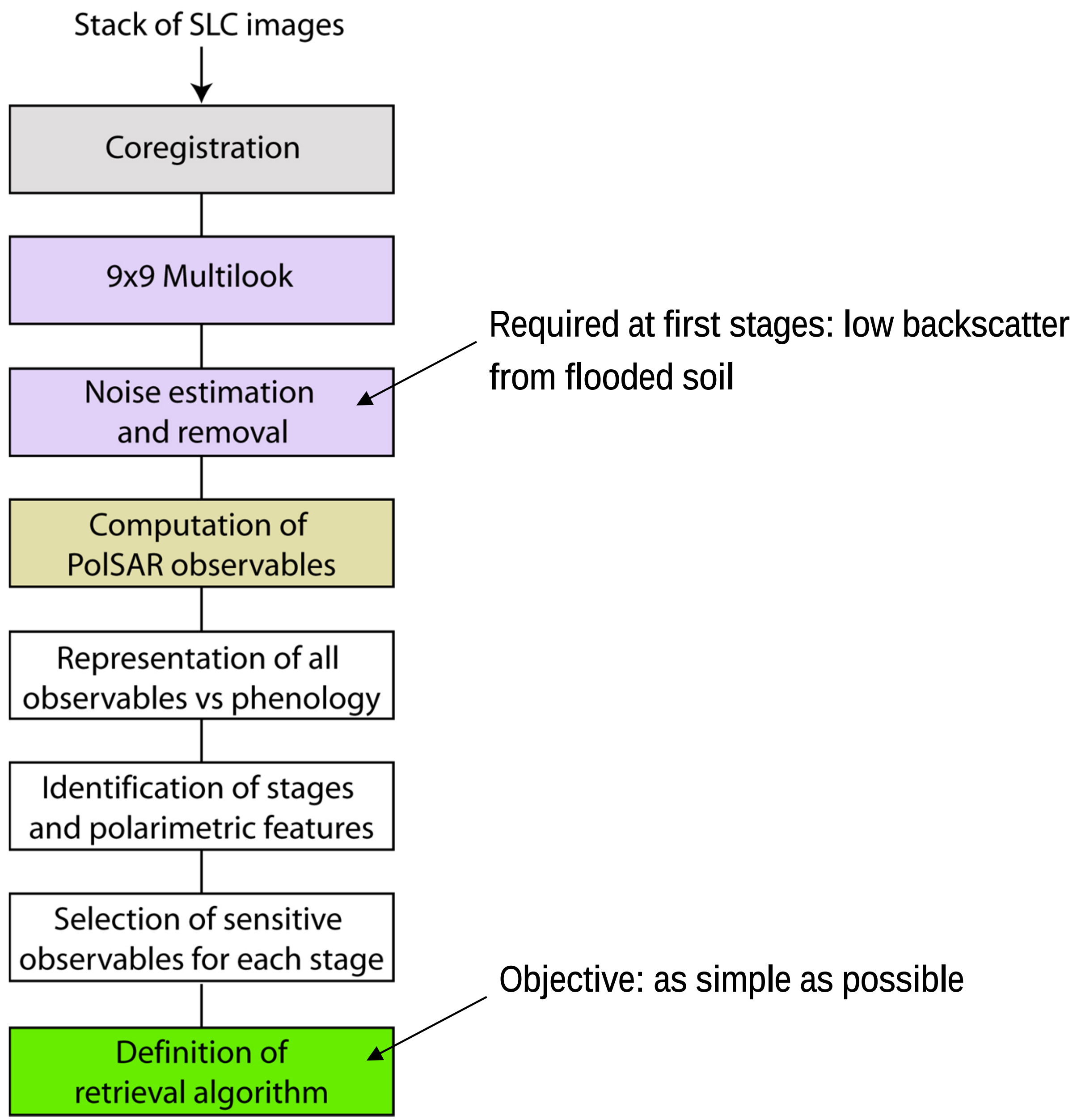
There are not observations during the reproductive phase and early maturation: stages 55-80

Observations at every parcel and date



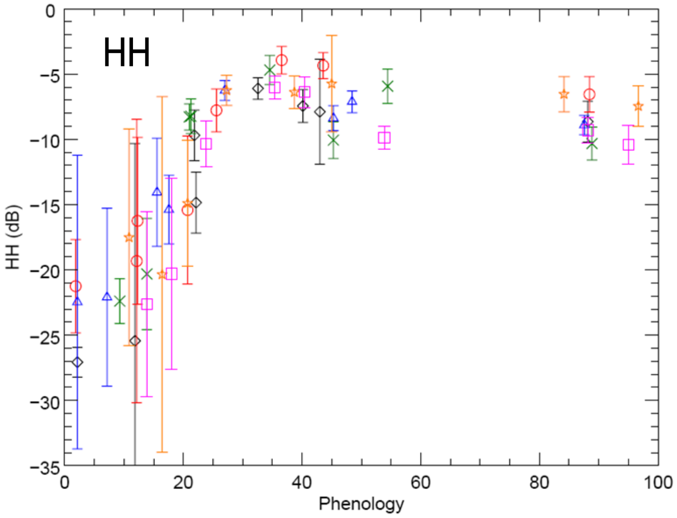
Pauli RGB composite

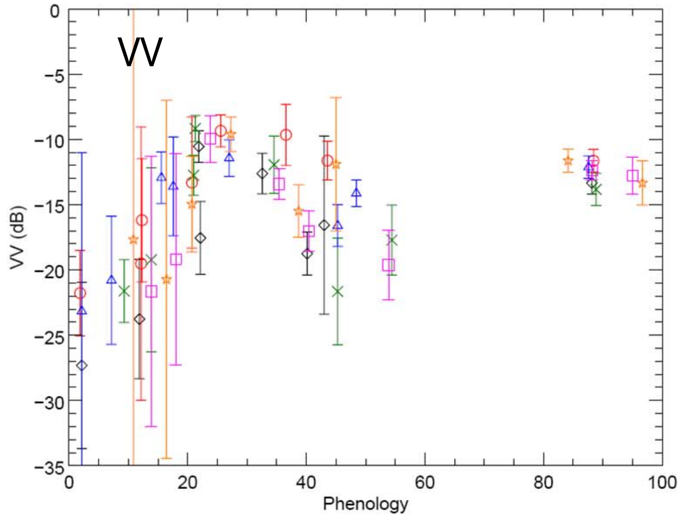
Data analysis

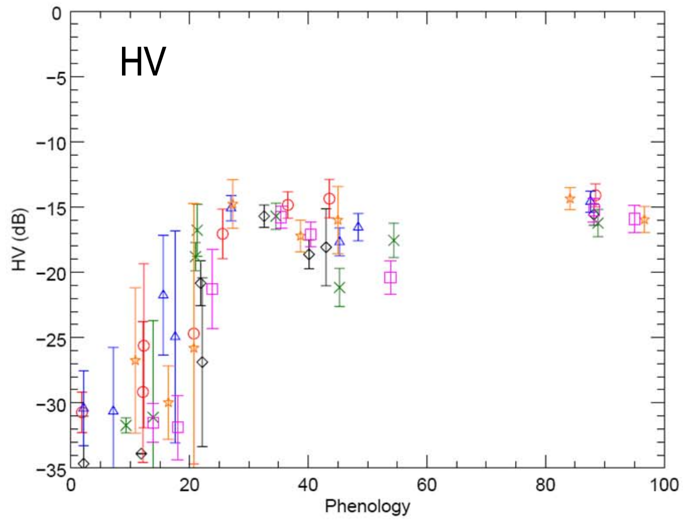


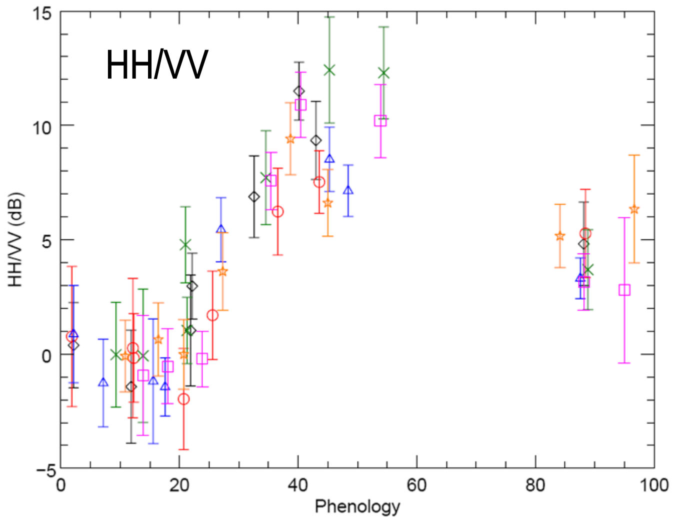
Observables vs phenology

Backscattering coefficients







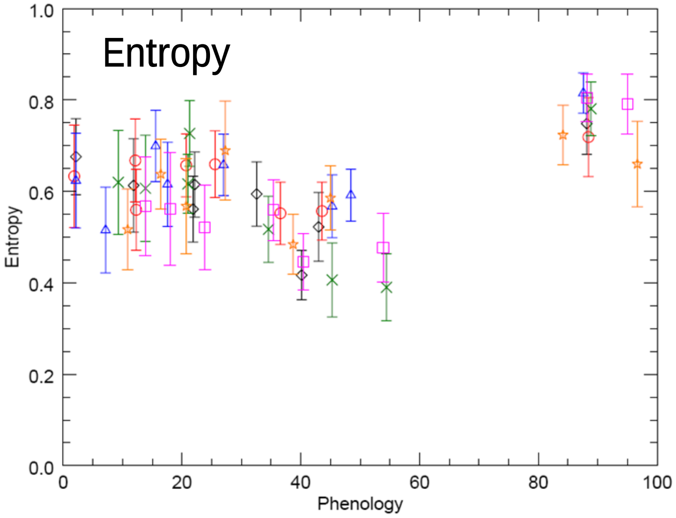


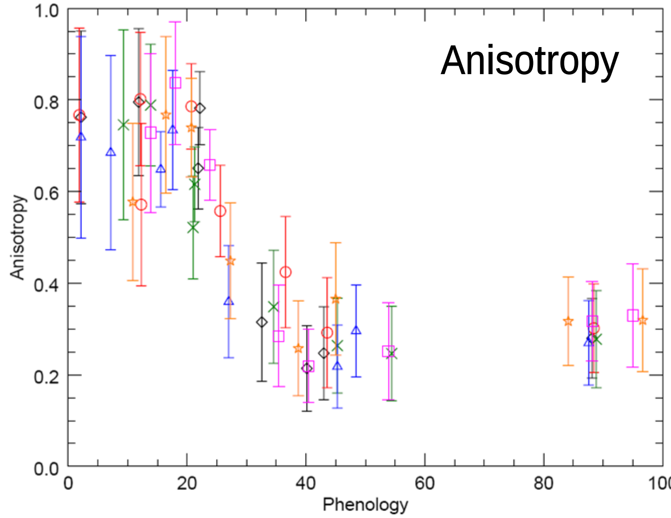
Overall response coincident with published results

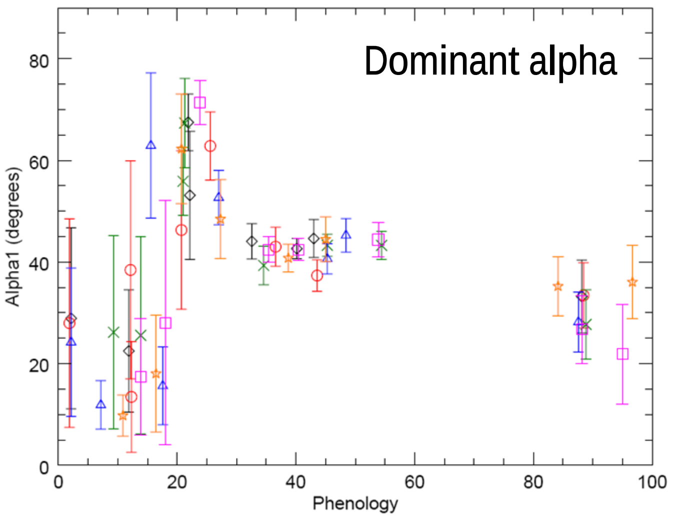
Ratio used for rice-planted area mapping with Envisat
Bouvet et al. [IEEETGRS'09]

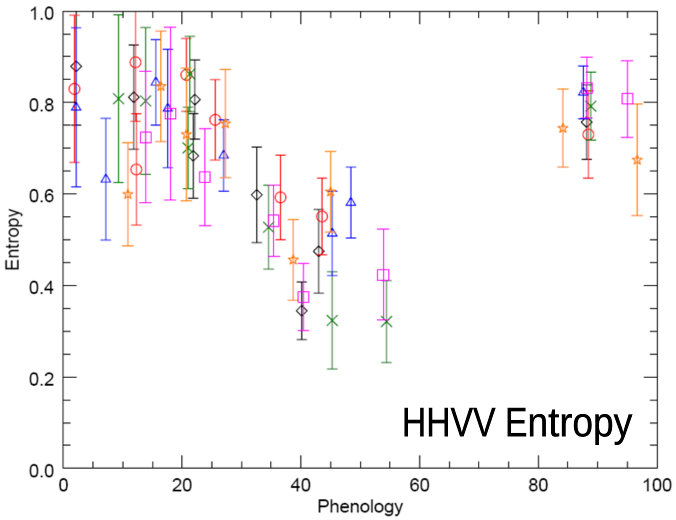
Observables vs phenology

Eigenvalue/vector decomposition



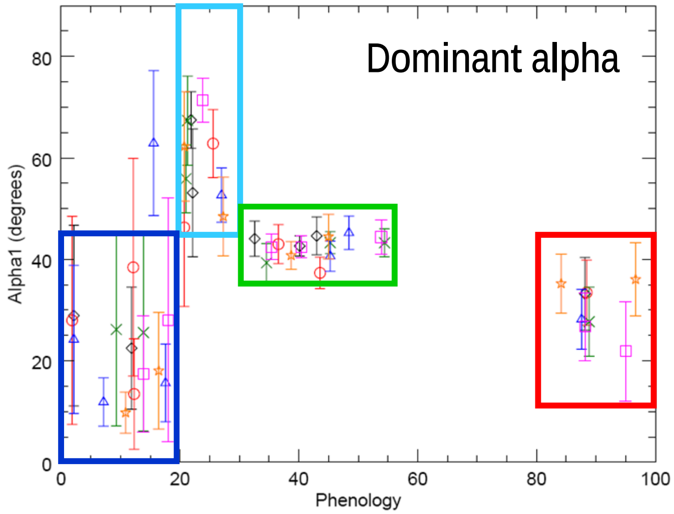






Physical interpretation

- **Early vegetative (0-20)**
  - Dominated by surface scattering (flooded ground) with short vegetation
  - Only two scattering mechanisms: surface and double-bounce
- **Tillering (20-30)**
  - Dominated by double-bounce: interaction between stems/tillers and flooded ground
- **Advanced vegetative (30-55)**
  - Linearly polarised backscatter (horizontal), due to double-bounce and differential extinction
- **Maturation (80-100)**
  - Approaching a random volume: high entropy and low anisotropy

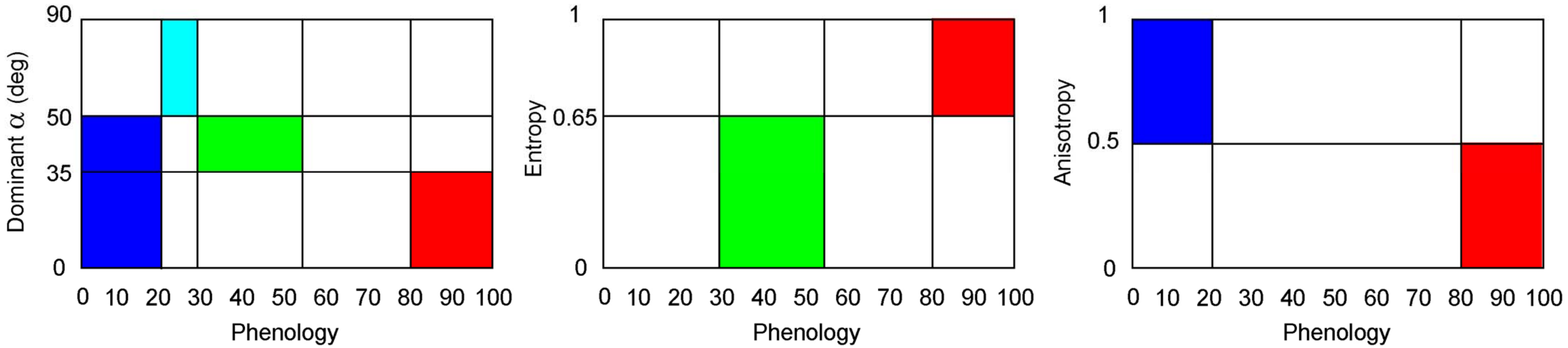


C-band vs X-band

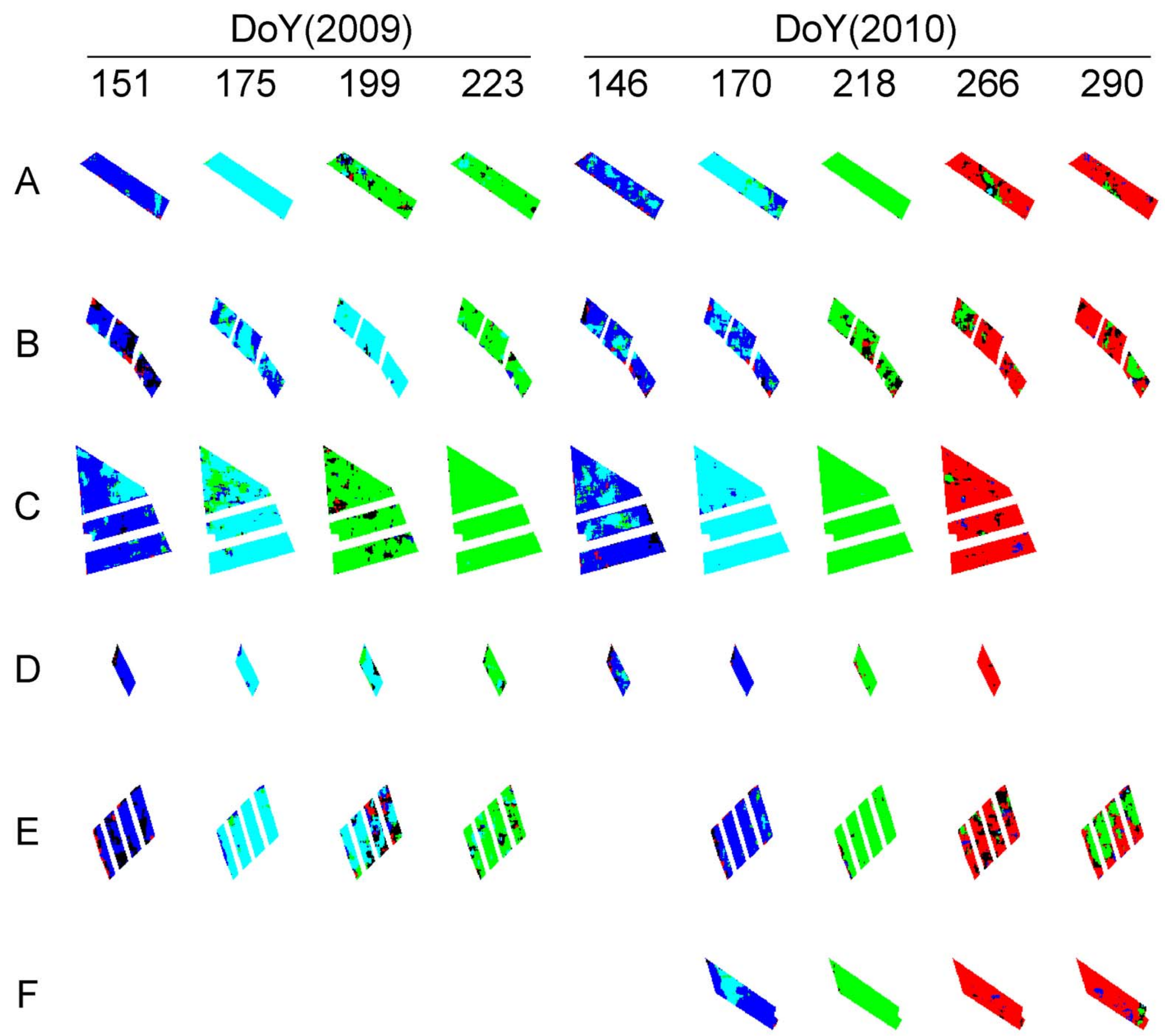
- Overall response similar to X-band
- One main difference:
  - At X-band the dominance of the double bounce around tillering phase starts before and ends quickly: stages 18-21
  - At C-band, however, it lasts from stage 20 to 30
  - Justification: size of the tillers in terms of the wavelength

Phenology retrieval: algorithm with quad-pol

- Identification of radar response for 4 phenological intervals:
  - **Early vegetative (0-20)**
  - **Tillering (20-30)**
  - **Advanced vegetative (30-55)**
  - **Maturation (80-100)**
- Reproductive and early maturation (55-80) are not available
- First proposal with 3 parameters: α_1, H, A
- Rules based on physical interpretation



Phenology retrieval: results with quad-pol



Phenology retrieval: results with quad-pol

- Validation at parcel level:
  - The most retrieved value (mode) within each parcel is compared with ground campaign
  - Example for a parcel:

PARCEL A

RETRIEVAL RESULT: NUMBER OF PIXELS

DoY – Acquisition	Not assigned	1	2	3	5	Total pixels
151 (2009)	8	1891	109	35	44	2087
175 (2009)	0	1	2078	8	0	2087
199 (2009)	297	76	104	1566	44	2087
223 (2009)	85	0	126	1874	2	2087
146 (2010)	66	1496	364	96	65	2087
170 (2010)	1	294	1587	205	0	2087
218 (2010)	2	0	2	2083	0	2087
266 (2010)	264	11	29	154	1629	2087
290 (2010)	133	59	2	72	1821	2087

PERCENTAGE OVER ASSIGNED PIXELS

1	2	3	5
91,0	5,2	1,7	2,1
0,0	99,6	0,4	0,0
4,2	5,8	87,5	2,5
0,0	6,3	93,6	0,1
74,0	18,0	4,8	3,2
14,1	76,1	9,8	0,0
0,0	0,1	99,9	0,0
0,6	1,6	8,4	89,4
3,0	0,1	3,7	93,2

GROUND DATA

Phenology
12
22
32
43
2
22
40
88
92+

  - Complete statistics:
    - 44 right estimates of 46 cases: **96% coincidence**

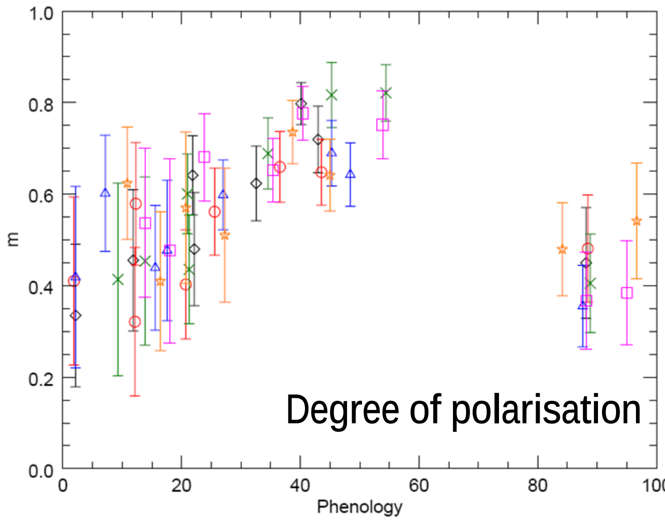
Alternative observables

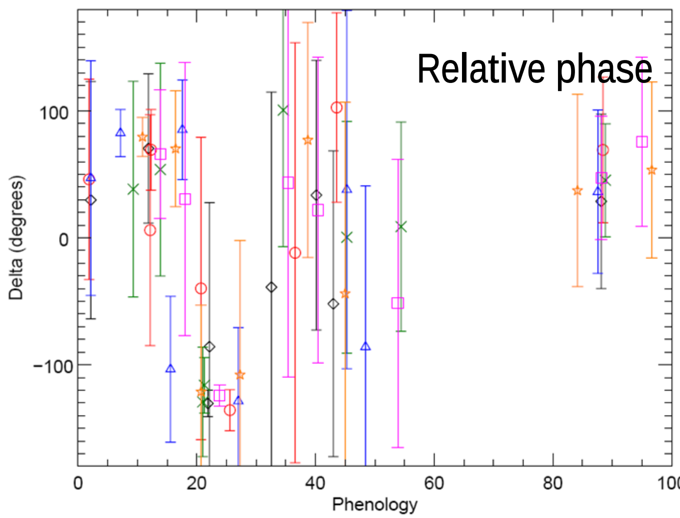
Early vegetative (0-20)	HH/VV ≈ 0 dB
	Moderate to high correlation between HH and VV
	Phase difference between HH and VV ≈ 0
	Freeman-Durden: Ratio of volume-to-ground scattering ≈ -5 dB
	Freeman-Durden: Odd-bounce > double-bounce (above 5 dB)
Tillering (20-30)	Phase difference between HH and VV below -90 degrees
	Freeman-Durden: Double-bounce > odd-bounce (above 5 dB)
Advanced veg. (30-55)	HH/VV > 6 dB
	High correlation between the first two Pauli channels
Maturation (80-100)	Freeman-Durden: Ratio of volume-to-ground scattering around or above 0 dB

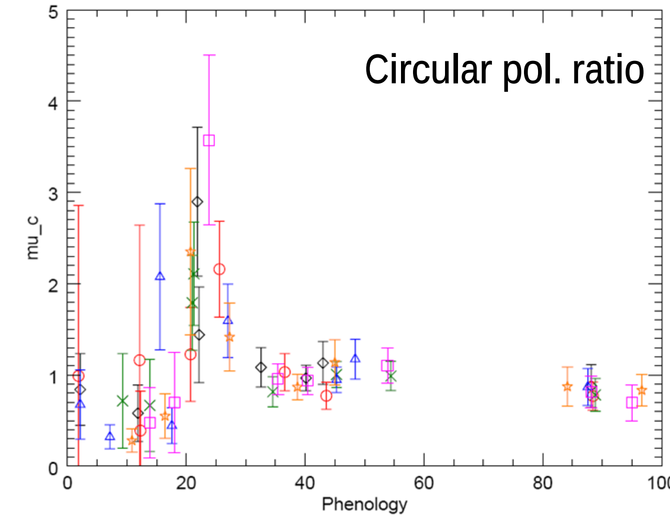
… and others with circular polarisation basis

Compact-pol observables

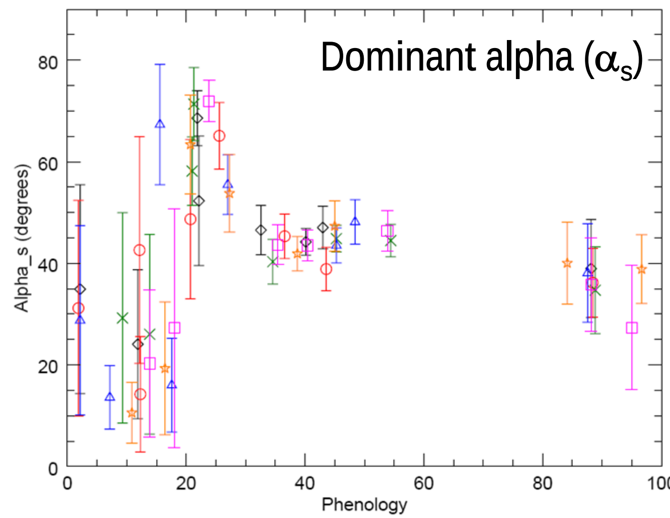
Conventional hybrid-pol parameters







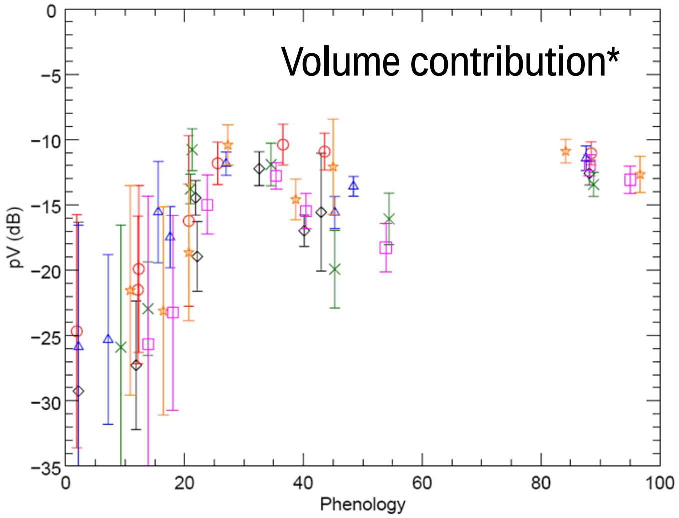
- Equivalent information provided by:
  - Degree of polarisation – entropy
  - Circular pol. ratio – dominant alpha
- But anisotropy cannot be measured equivalently



Cloude et al. [IEEEGRSL'12]

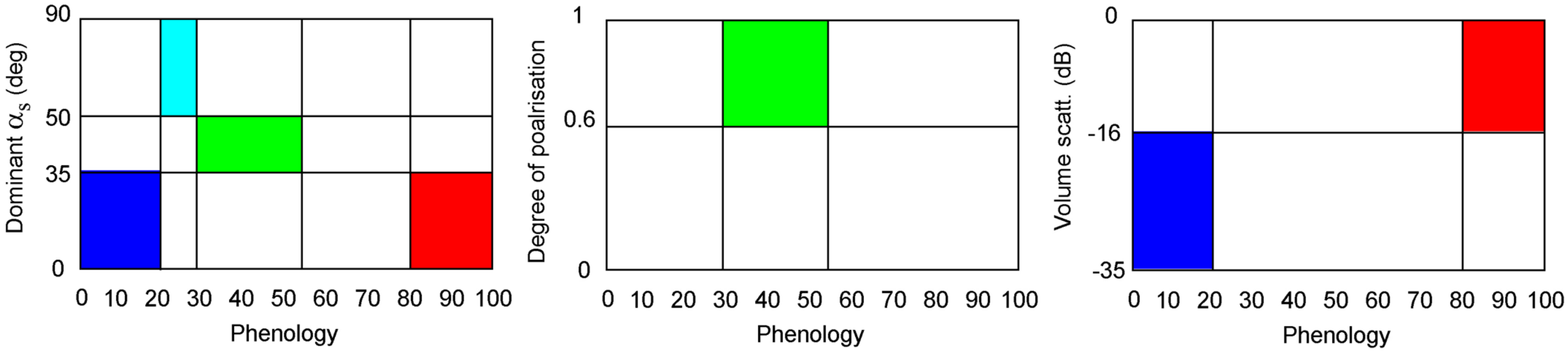
Phenology retrieval: algorithm with compact-pol

- In quad-pol, anisotropy was used to discriminate the first and the last intervals. The same can be done with other parameters. For instance:

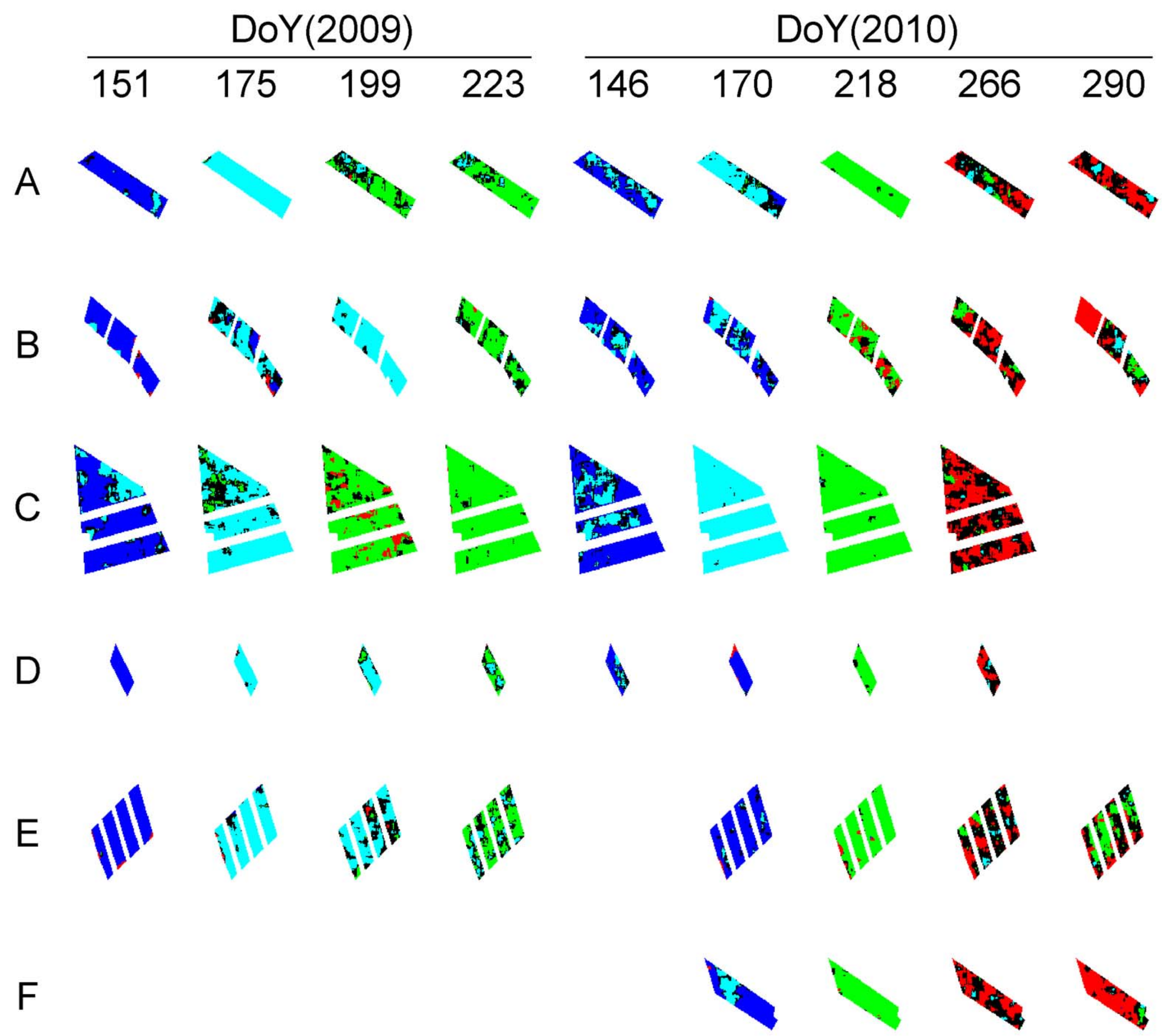


*Model-based decompostion proposed in Cloude et al. [IEEEGRSL'12]

- First proposal with 3 parameters: α_s, m, p_V



Phenology retrieval: results with compact-pol



Phenology retrieval: results with compact-pol

- Validation at parcel level:
  - Example for a parcel:

PARCEL A — RETRIEVAL RESULT: NUMBER OF PIXELS

DoY – Acquisition	Not assigned	1	2	3	5	Total pixels
151 (2009)	179	1761	142	5	0	2087
175 (2009)	15	0	2068	4	0	2087
199 (2009)	787	0	181	1105	14	2087
223 (2009)	454	6	158	1469	0	2087
146 (2010)	548	1013	525	1	0	2087
170 (2010)	537	146	1368	34	2	2087
218 (2010)	38	0	2	2045	2	2087
266 (2010)	1137	0	147	157	646	2087
290 (2010)	932	2	146	10	997	2087

PERCENTAGE OVER ASSIGNED PIXELS

1	2	3	5
92,3	7,4	0,3	0,0
0,0	**99,8**	0,2	0,0
0,0	13,9	**85,0**	1,1
0,4	9,7	**90,0**	0,0
65,8	34,1	0,1	0,0
9,4	**88,3**	2,2	0,1
0,0	0,1	**99,8**	0,1
0,0	15,5	16,5	**68,0**
0,2	12,6	0,9	**86,3**

GROUND DATA

Phenology
12
22
32
43
2
22
40
88
92+

  - Complete statistics:
    - 44 right estimates of 46 cases: **96% coincidence**
    - Same performance as quad-pol at parcel level, but “noisier” results at pixel level

Conclusions: answers to initial questions

- Could the ambiguities found with HHVV images be solved by full polarimetry? **Yes**
- What is the influence of frequency band (C vs X) on the polarimetric observables as a function of phenology?
  - **Similar** overall response for all observables
  - Some stages (e.g. tillering) are shifted due to wavelength sensitivity
- Can phenology be retrieved with a single Radarsat-2 image? **Yes**
- Is full polarimetry strictly required for such an application? What about compact-pol or conventional dual-pol?
  - **Compact-pol is enough** for this application
  - HHVH and VVHV provide two real observables (reflection symmetry):
    - Limited applicability:
      - Low backscatter at early vegetative
      - Saturation and reduced ranges afterwards

Outlook for rice

- More experiments including images at the **reproductive phase** should be conducted. Expected results:
  - Stage characterised by a smooth transition between vegetative and maturation at all observables Li et al. [CJRS'12] , Lopez-Sanchez et al. [IEEETGRS'12]
  - Phenology retrieval at the two borders may result complicated
- From the **application** point of view:
  - 24 days revisit time is too large:
    - Different passes (asc/desc) and beams should be combined to provide a shorter refresh rate
  - The success with compact-pol envisages the exploitation of RCM for this application

… but NESZ = -17 dB will complicate its performance.

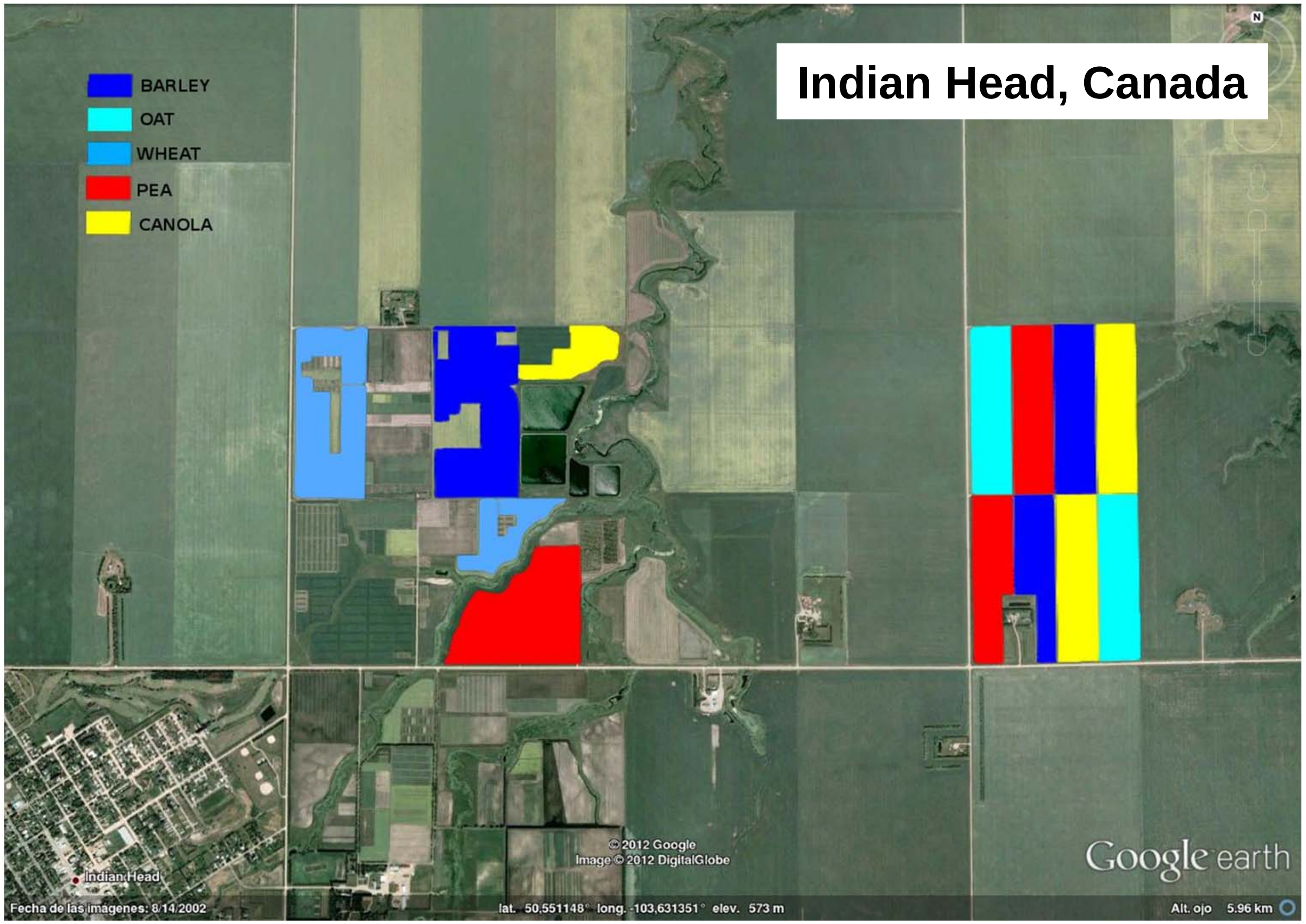
Phenology retrieval for other crop types?

An equivalent experiment has been carried out in the framework of the ESA-funded **PolSAR-Ap project** (AO 1-6707/11/I/NB), using the **AgriSAR2009** campaign dataset

5 crop types:
- Cereals: barley, oat & wheat
- Canola
- Field pea

Phenology information:
- 1st June – 31 August
- Numerical scales
- Updated every 7-10 days
- Records: [min,max]

Radarsat-2 images:
- 57 in total
- 20 used:
    - Restricted to 3 months
    - ***All beams (22-39 deg)***



Phenology retrieval for other crop types?

- First conclusion: Polarimetry is relevant when phenological development entails morphological changes in the plants… *it depends on the crop type*
  - Cereals: OK for barley and wheat, not enough for oat
    - Compact-pol presents slightly lower performance than quad-pol
    - Conventional dual-pol (HHVH, VVHV) identifies less stages
  - Canola: HV is enough
    - Constant random structure but increasing amount (height) of vegetation volume
  - Pea: Polarimetry is not enough
    - Auxiliary information is required