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IMPROVING FLOOD FORECAST SKILL USING REMOTE SENSING DATA

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An Australian Government Initiative

CRC AUSTRALIA

MONASH University

MOTIVATION

1) Floods are among the most important natural disasters in Australia.

2) Average annual cost of floods for the last 40 years: $377M/yr.

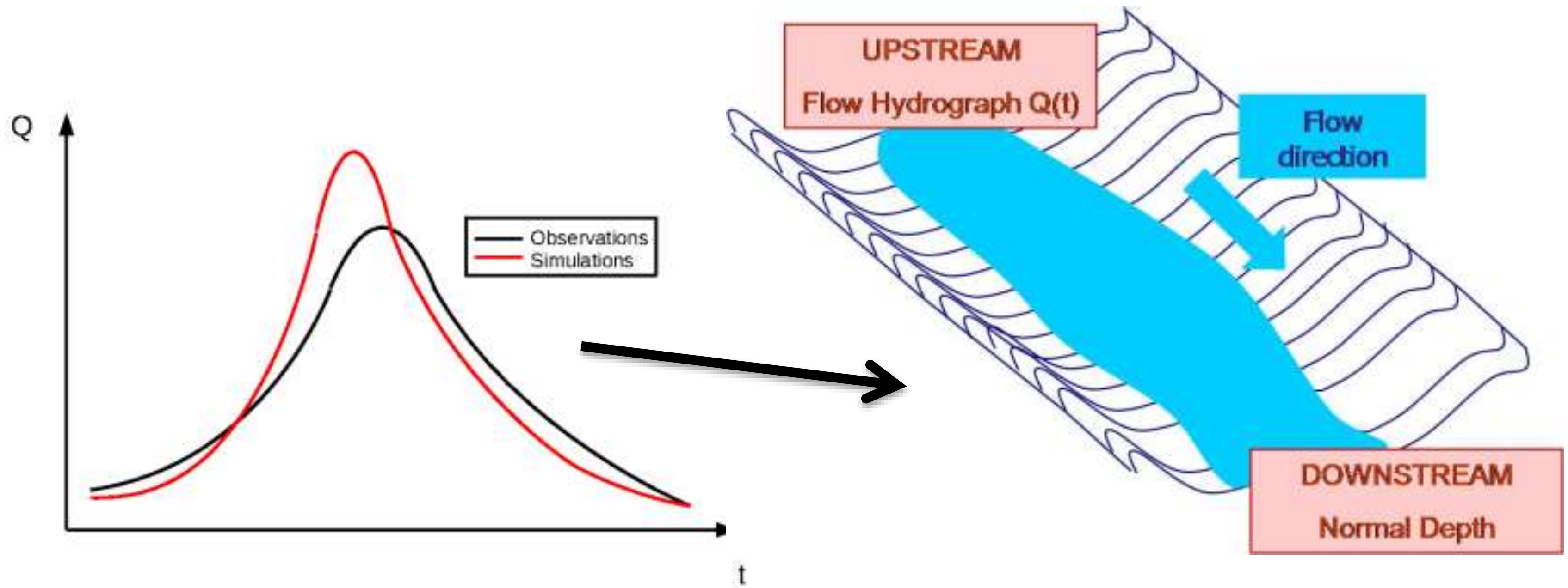
3) 2010-2011 floods in Brisbane and South-East Queensland:
   - 35 confirmed deaths
   - $2.38 billion damage

Examples of airborne radar and visible data

Wagga Wagga Flood 2010

FLOOD FORECASTING SYSTEMS

Flood **volume** and **extent** are predicted by a sequence of models:



Remote sensing data should improve the predictive skill of flood forecast systems.

OBJECTIVES

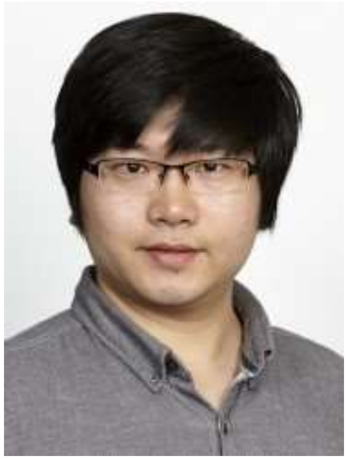
1) Identify two test sites that will form the focus of the study
   - Frequent flooding must have occurred since 2010
   - All data needed to apply the models must be available
2) Calibrate a flood forecasting system using remote sensing data
3) Develop data assimilation methods that work optimally for the hydrologic/hydraulic model sequence and types of data that will be used.
4) Perform a scenario analysis to assess the optimal spatial and temporal resolution of the remote sensing data and hydrologic/hydraulic models.

THE PROJECT TEAM

A/Prof. Valentijn Pauwels

Prof. Jeffrey Walker

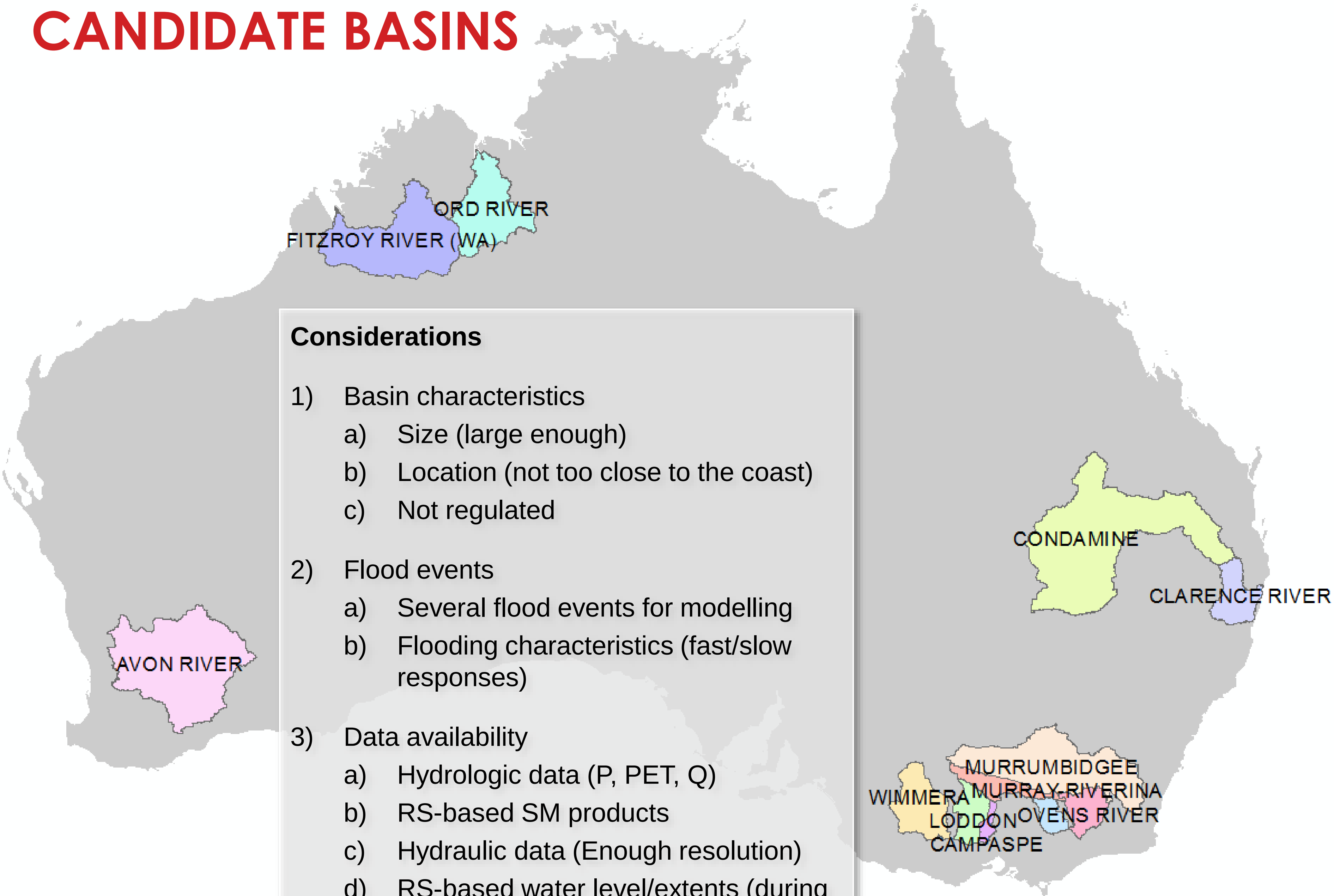
Dr. Stefania Grimaldi



Dr. Yuan Li

Mr. Ashley Wright

CANDIDATE BASINS



Considerations

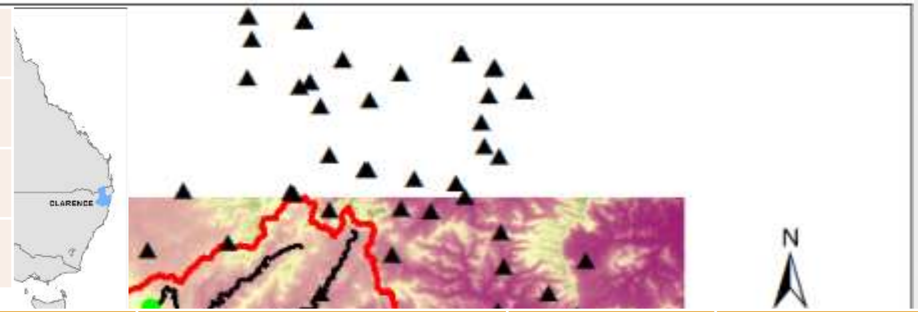
1) Basin characteristics
   a) Size (large enough)
   b) Location (not too close to the coast)
   c) Not regulated

2) Flood events
   a) Several flood events for modelling
   b) Flooding characteristics (fast/slow responses)

3) Data availability
   a) Hydrologic data (P, PET, Q)
   b) RS-based SM products
   c) Hydraulic data (Enough resolution)
   d) RS-based water level/extents (during recent flooding)

TEST BASIN 1: CLARENCE

Area [km²]	20,730
Elevation [masl]	1564-0
Main rivers	Clarence, Mann, Nymboida, Orara
Main urban areas	Lilydale, Grafton, McLean



DATA	Region	Sources	Resolution/number of gauges	Period	Temporal resolution
DEM	Australia	GA	1 sec & 3 sec	/	/
Land cover	Australia	GA	250 m	/	/
Geofabric	Australia	BoM	/	/	/
Water Level and Discharge	Clarence	NSW Office of Water	30 gauges	2000 –	hourly
Rainfall	Clarence	BoM	~130 gauges	**2007 –**	hourly
PET	Clarence	AWAP	5 km	2000 –	monthly
Soil moisture	Australia	SMOS L3	~50 km	2010 –	~daily
Water Level w/o Discharge	Lower Clarence	MHL	13 gauges	Varies	hourly
Land cover	Lower Clarence	CVC	Higher	/	/
Levee and channel surveys	Lower Clarence	CVC	/	/	/
SAR IMAGES	Lower Clarence	GA	60 m	1 images (1 event)	
OPTICAL IMAGES	Lower Clarence	GA	30 m	4 images (3 events)	
AIRBORNE IMAGES	Lower Clarence	LPID-NSW	10-20-30 cm	Images for 2 events	

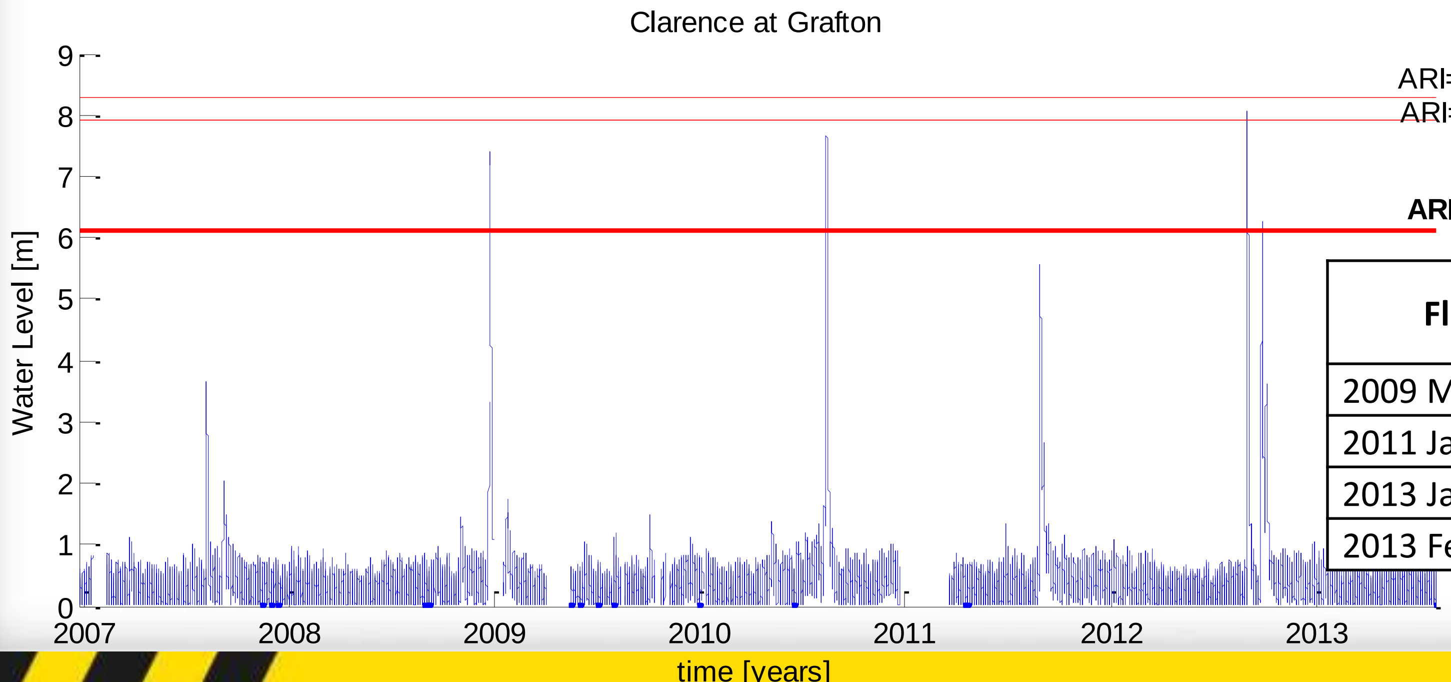
TEST BASIN 1: CLARENCE

Rationale: 1) Large basin without regulation;
2) Fast flow response with recent flood events;
3) Initial soil moisture is important during floods

Previous flood studies:
(GA: Australian Flood Risk Information Portal; BMT WBM Pty Ltd for Clarence Valley Council;
BOM: Water Data Online)

→ Flood frequency analysis: definition of Average Recurrence Interval (ARI) of the flood events

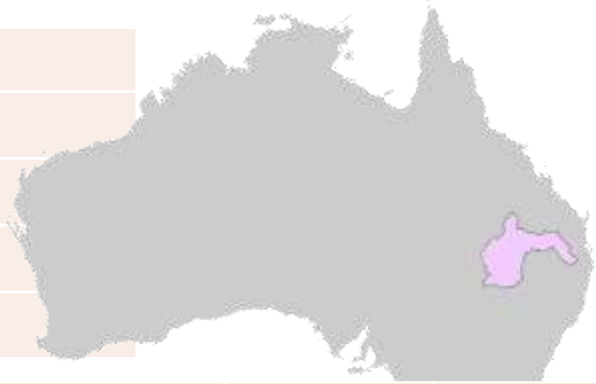
→ Recording of structural interventions:
Grafton and McLean have levees designed against flood events having ARI=5



Flood event	ARI [years]
2009 May 20-29	>5
2011 January 8-16	>5
2013 Jan. 25 – Febr. 2	>20
2013 February 18-27	>5

TEST BASIN 2: CONDAMINE-CULGOA-BALONNE

Area [km^2]	147,817
Elevation [masl]	1300-256
Main rivers	Condamine-Culgoa-Balonne (657km)
Tributaries	Charley Creek, Dogwood Creek, Maranoa River
Main urban areas	Warwick, Dalby, Chinchilla, Surat, StGeorge



DATA	Region	Sources	Resolution/number of gauges	Period	Temporal resolution
DEM	Australia	GA	1 sec & 3 sec	/	/
Land cover	Australia	GA	250 m	/	/
Geofabric	Australia	BoM	/	/	/
Water Level and Discharge	Cond-Cul-Bal	BoM, QLD Department of Natural Resources	13 – Condamine 4 – Balonne 8 - Culgoa	1960/1999 to present	hourly
Rainfall	Cond-Cul-Bal	BoM	About 200	2007 -	hourly
PET	Cond-Cul-Bal	AWAP	5 km	2000 –	monthly
Soil moisture	Australia	SMOS L3	~50 km	2010 –	~daily
Levee and channel surveys	Cond-Cul-Bal	GA, QLD reconstruction Authority, Western Downs Regional Council			
SAR IMAGES	Cond-Cul-Bal	GA	8-50-60 m	8 images (2 events)	
OPTICAL IMAGES	Cond-Cul-Bal	GA	8-10-22-30 m	7 images (3 events)	
AIRBORNE IMAGES	Narran River	GA	50 cm	Images for 1 flood event	

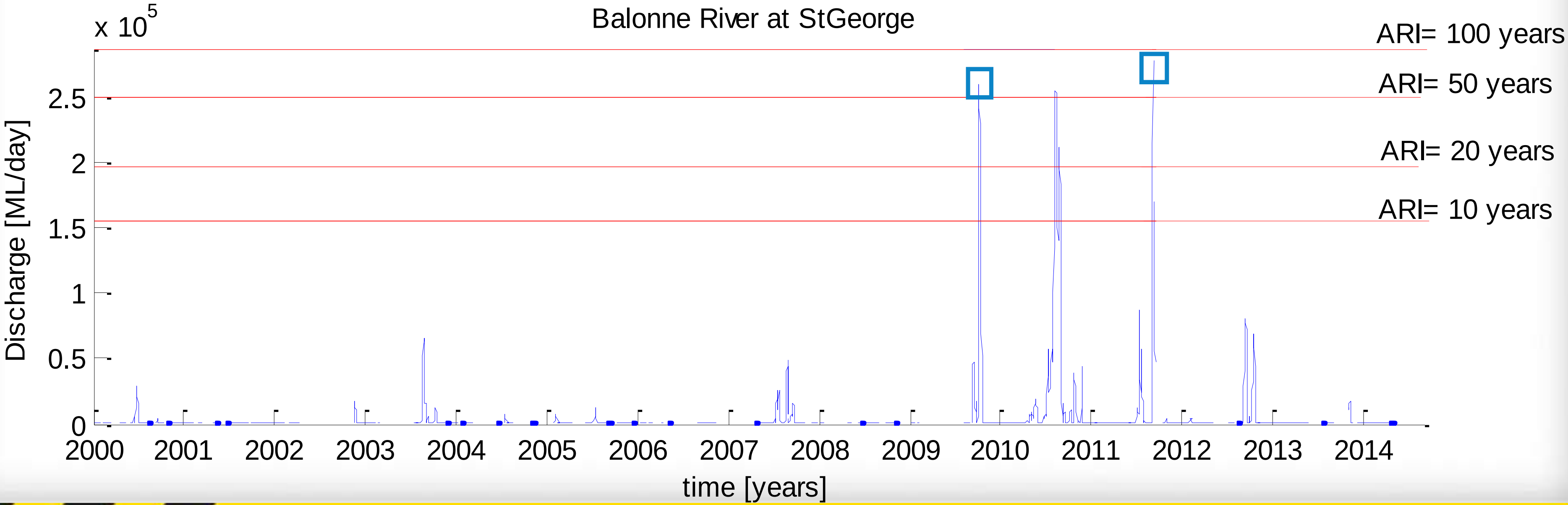
TEST BASIN 2: CONDAMINE-CULGOA-BALONNE

Rationale: 1) slow system;
2) complex network of meandering and braided rivers;
3) good availability of remote sensing data (SAR, OPTICAL, AIRBONE images).

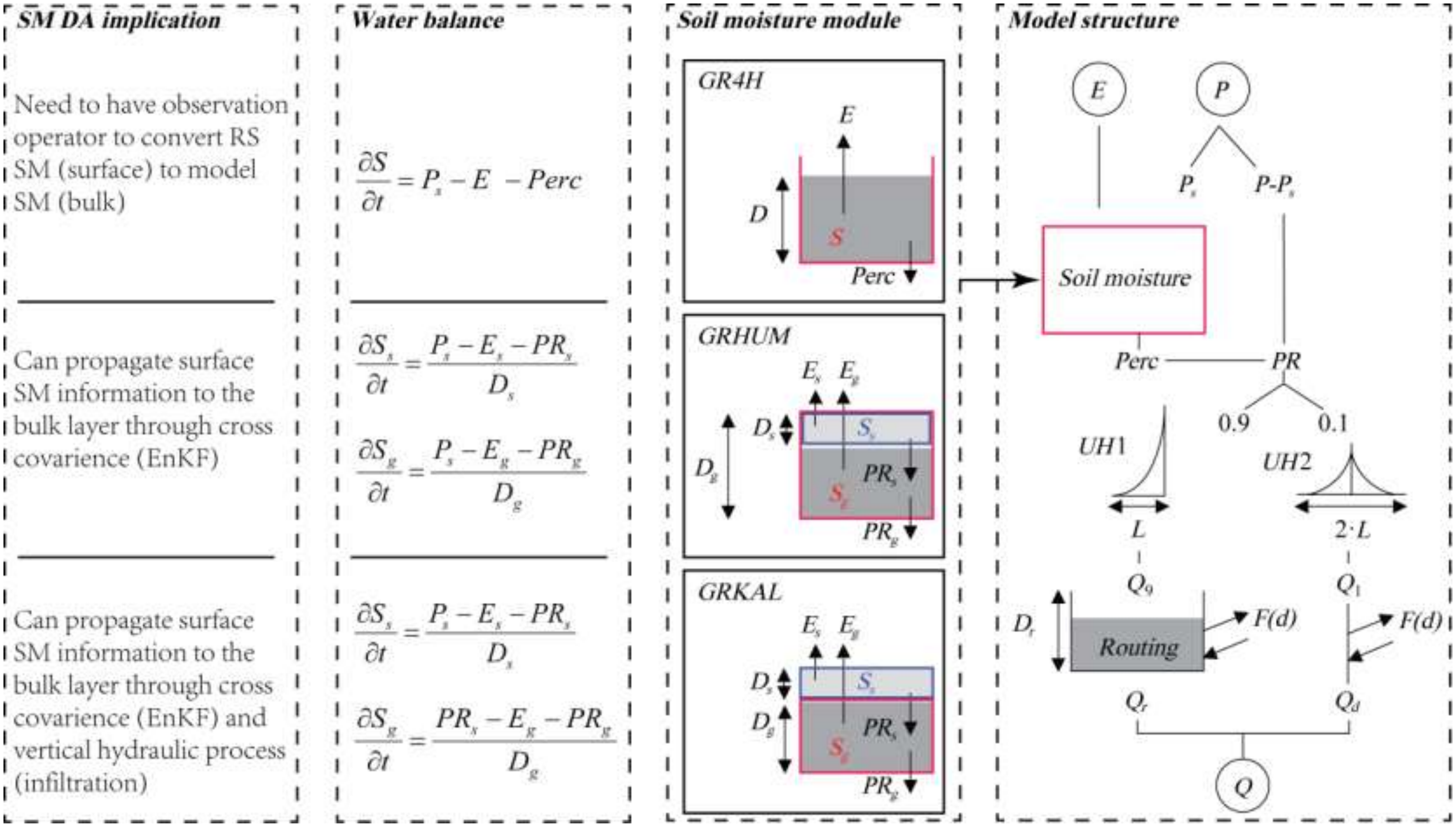
Previous flood studies:

(GA: Australian Flood Risk Information Portal; BOM: Water Data Online)

Year – Month - Days	ARI [years]
2010 March 1-20	>50
2010 Dec 27 - 2011 February 4	>50
2012 February 1-15	>50



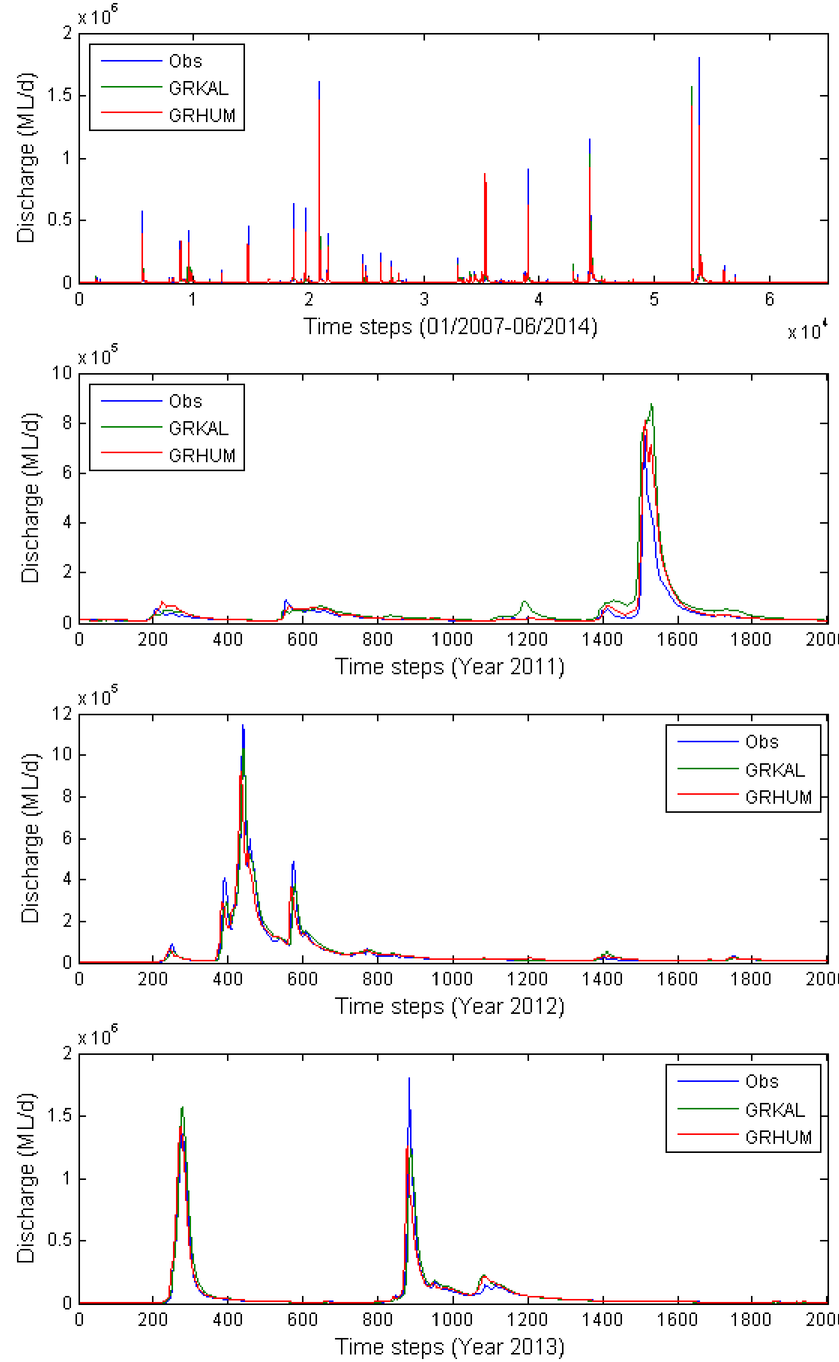
HYDROLOGIC MODEL: GR MODEL



MODEL CALIBRATION AT LILYDALE

- Calibration using discharge data gives similar results for GRHUM and GRKAL.
- Soil moisture predictability needs to be evaluated against ground measurements.
- Recall that GRKAL is more physically based in terms of SM parameterization and can more efficiently propagate surface SM updates into root-zone layer and routing stores

Statistics	NS efficiency	RMSE (m^3/s)	R^2
GRHUM Cal.	0.74	2.9	0.77
GRKAL Cal.	0.78	2.2	0.81
GRHUM Val.	0.70	3.6	0.75
GRKAL Val.	0.71	3.6	0.75



HYDRAULIC MODEL: LISFLOOD*, concepts

Flood waves are described by the shallow water equations (2D)

$$\begin{cases} \dfrac{\partial h}{\partial t} + \dfrac{\partial q_x}{\partial x} + \dfrac{\partial q_y}{\partial y} = 0 \\ \underbrace{\dfrac{\partial q_x}{\partial t}}_{\text{local acceleration}} + \underbrace{\dfrac{\partial}{\partial x}(uq_x) + \dfrac{\partial}{\partial y}(vq_x)}_{\text{convective acceleration}} + \underbrace{gh\dfrac{\partial (h+z)}{\partial x}}_{\text{pressure + bed gradients}} + \underbrace{\dfrac{gn^2\|\mathbf{q}\|q_x}{h^{7/3}}}_{\text{friction}} = 0 \end{cases}$$

Conservation of mass

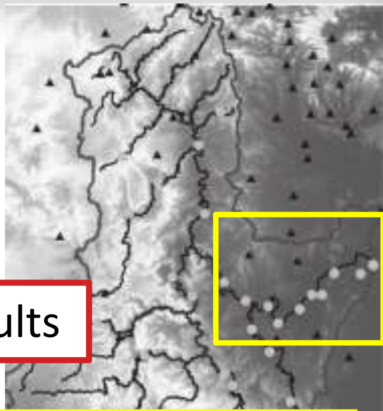
Conservation of momentum

Our model is based on the LISFLOOD-FP model (Bates et al., 2000; *2010*).
It solves the inertial approximation of the Shallow Water Equations using a finite difference scheme based on a rectangular grid. As such, it is suited for the modelling of gradually varied flows in floodplain inundation problems.

In order to optimise both modelling accuracy and computational time, our code (C#) uses an original <u>variable spatial discretization</u>:
- a "coarse" space discretization is used for the modelling of the flood wave in the floodplains;
- a "fine" spatial discretization is used for the modelling of the flood wave in the urban areas.

Information on flood wave velocity and depth are shared between the two spatial domains and the computational time step is based on Courant criterion and it is adjusted accordingly.

HYDRAULIC MODEL: LISFLOOD, first application



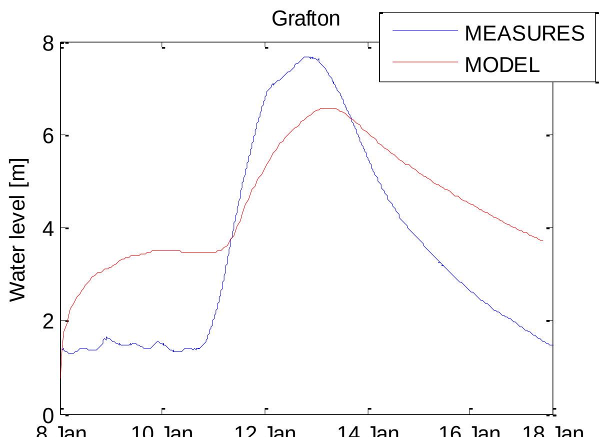
Lower Clarence, flood event January 2011

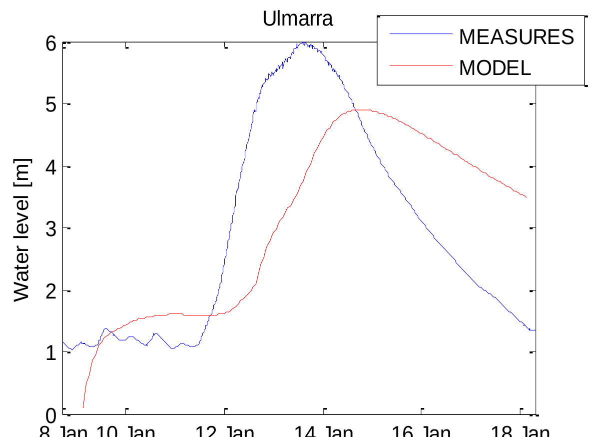
Discharge input hydrograph: Lilydale

Achieved: IMPLEMENTATION OF THE MODEL

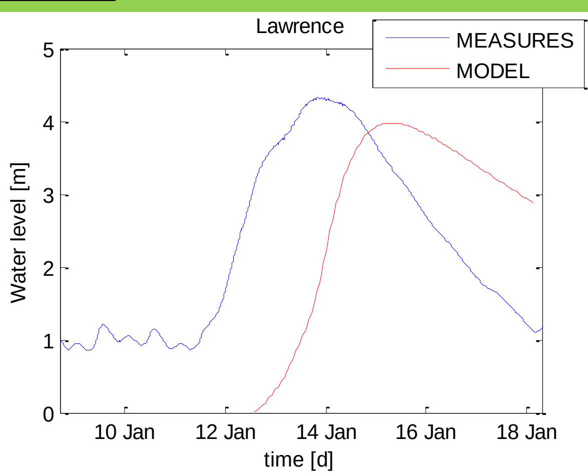
- DEM: GA, Clarence Council
- Roughness and Land Use: GA, Clarence Council

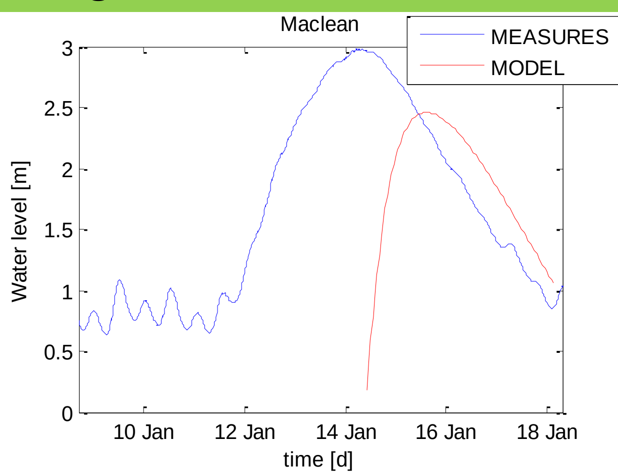
→ First, "RAW" results





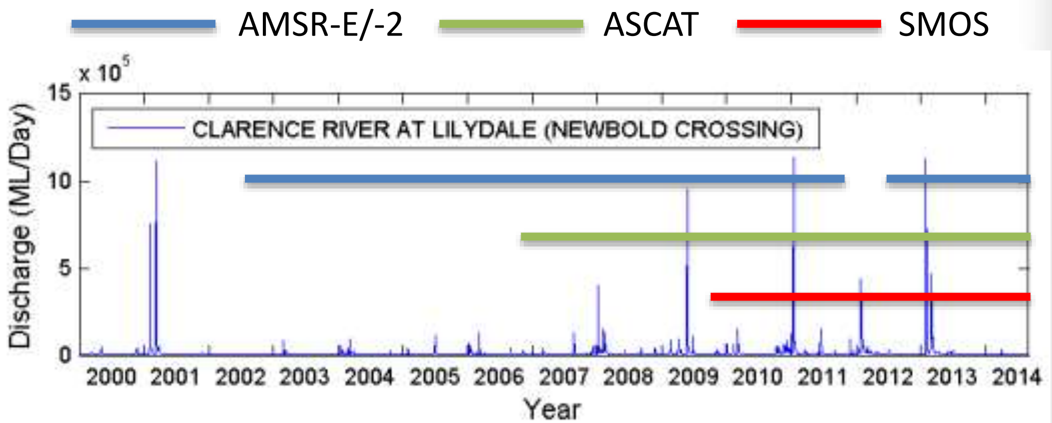
Next step: CALIBRATION, VALIDATION using FIELD and REMOTE SENSING data



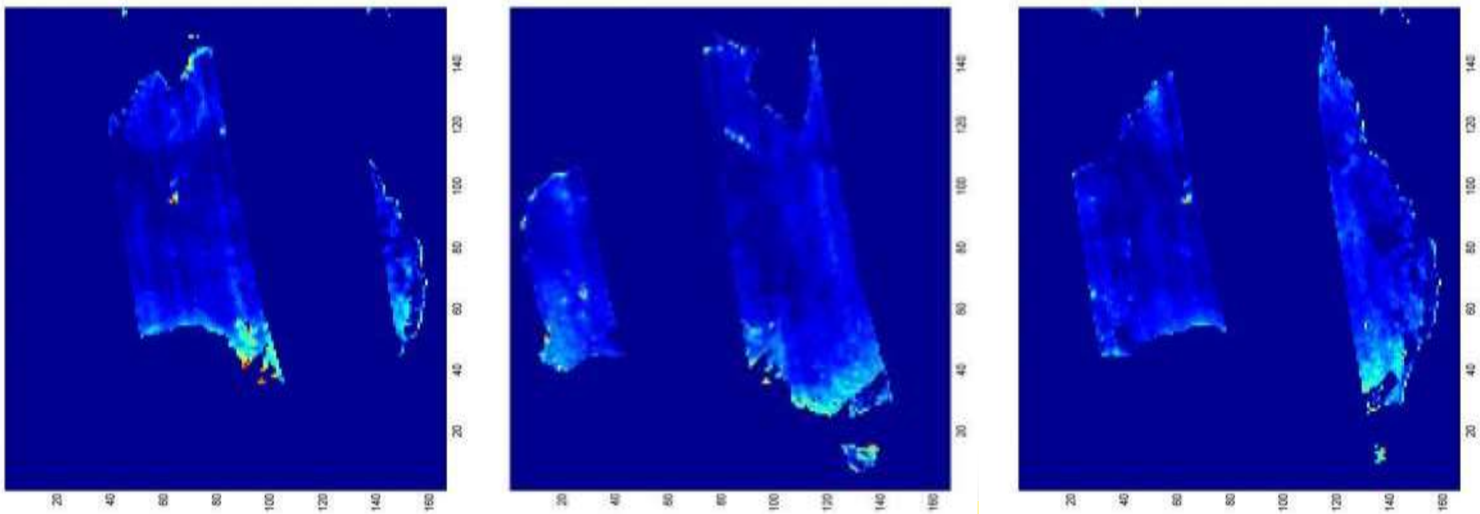


REMOTE SENSING DATA: SOIL MOISTURE

	SMOS	ASCAT	AMSR-E/-2
Period	2/11/2009–	19/10/2006–	18/6/2002– 4/10/2011 & 18/5/2012–
Band	L-band	C-band	C- and X-band
Footprint	~43 km	50 km	50–60 km
Sensor Type	Passive	Active	Passive



Temporal coverage of three SM products



SMOS coverage (morning pass) on 03-05 July 2014

OVERVIEW OF REMOTE SENSING DATA AVAILABILITY FOR THE HYDRAULIC MODEL

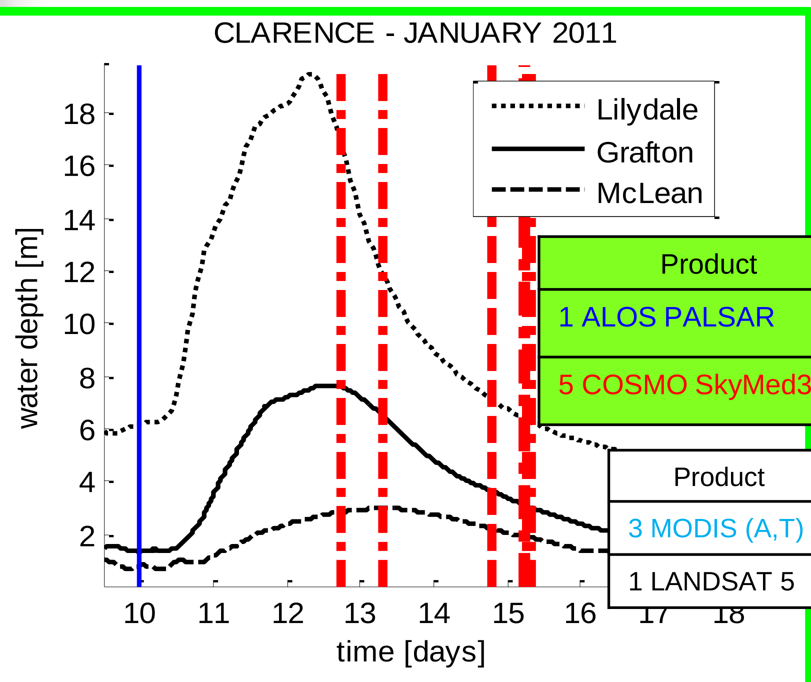
Remote sensing data of **FLOOD EXTENT and WATER DEPTH** are required to calibrate, validate, constrain in real time the hydraulic model.

Satellite or airborne **SAR** are the most suitable source;
optical instruments can sometimes provide information.

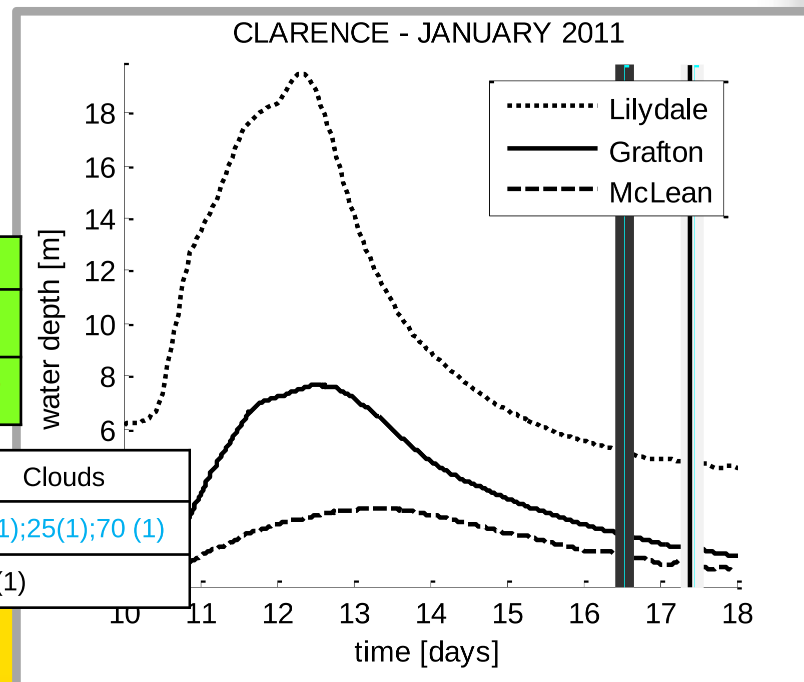
Catalogues of SAR and optical data have been consulted; **GA** provided support and data.

We compiled a list of SAR and optical data availability for each **significant flood event** occurred in the two **selected basins**.

EXAMPLE: CLARENCE, JANUARY 2011



Product	R [m]	Cov.
1 ALOS PALSAR	100	100
5 COSMO SkyMed3	30;5	50;40

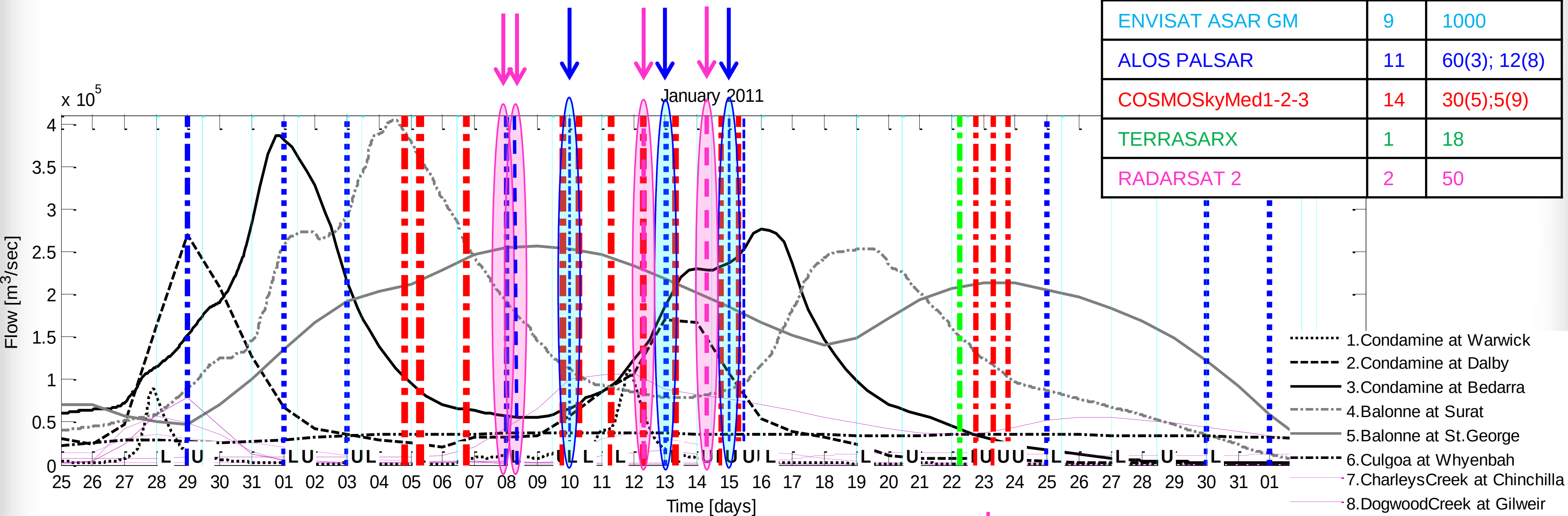


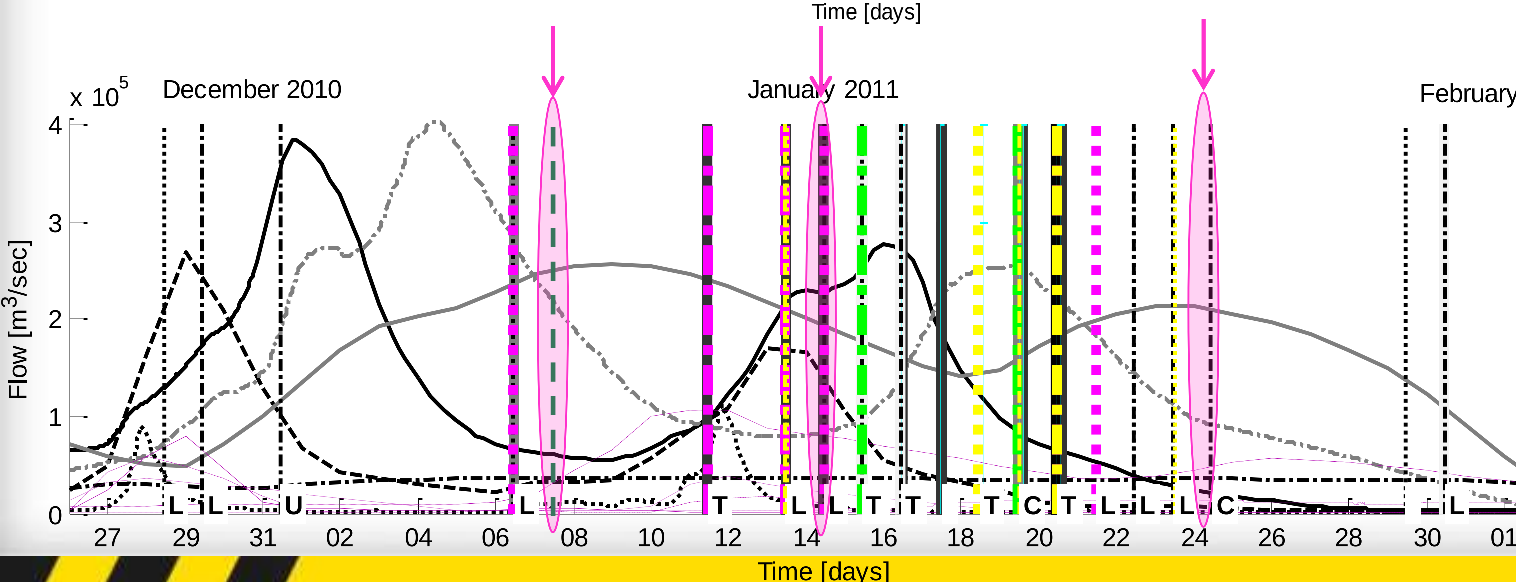
Product	R [m]	Cov.	Clouds
3 MODIS (A,T)	500	100	10(1);25(1);70 (1)
1 LANDSAT 5	30	100	15 (1)

OVERVIEW OF REMOTE SENSING DATA FOR THE HYDRAULIC MODEL

EXAMPLE: CONDAMINE-CULGOA-BALONNE, JANUARY 2011

SAR	n.	Res [m]
ENVISAT ASAR GM	9	1000
ALOS PALSAR	11	60(3); 12(8)
COSMOSkyMed1-2-3	14	30(5);5(9)
TERRASARX	1	18
RADARSAT 2	2	50





OPTICAL	n.	r [m]
MODIS (A,T)	8	500
LANDSAT5,7	10	30
SPOT 5	1	10
UKDMC2	22	22
RAPIDEYE3	4	5
QUICKBIRD2	1	2.4
GEOEYE1	1	1.84
ASTER	2	15

END USER INVOLVEMENT

1) A project kick-off meeting has been held on July 21.
2) Two end-user meetings have been held, on September 24, and December 1.
3) Ashley Wright has spent one month at the BoM for training in operational flood forecasting systems.
4) Yuan Li has spent time in Bureau of Meteorology to extract the hydrological data.
5) Stefania Grimaldi and Yuan Li have spent significant time at Geoscience Australia, to retrieve the required satellite data.
6) Informal contacts are maintained throughout the project.

SUMMARY

1) The modelling activities of the project are now well underway, with the model choice being made.
2) The two test sites have been defined.
3) A remote sensing database is being developed.
4) The end-users are in close contact with the research team.

5) Overall: the project is well on schedule.