中国水利水电科学研究院
China Institute of Water Resources and Hydropower Research

Webinar No.4 *"Managing Risks from Ice-jam Floods"* ICFM

Progress and some trends in the study of river ice hydraulics

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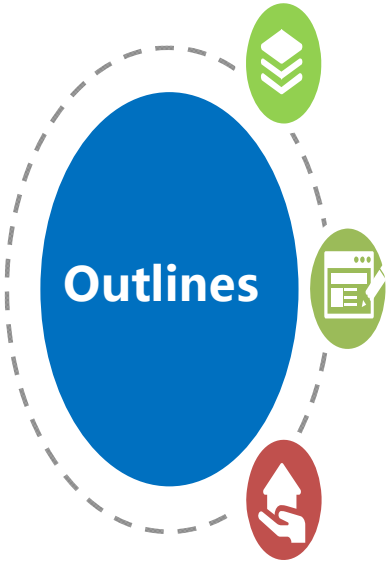


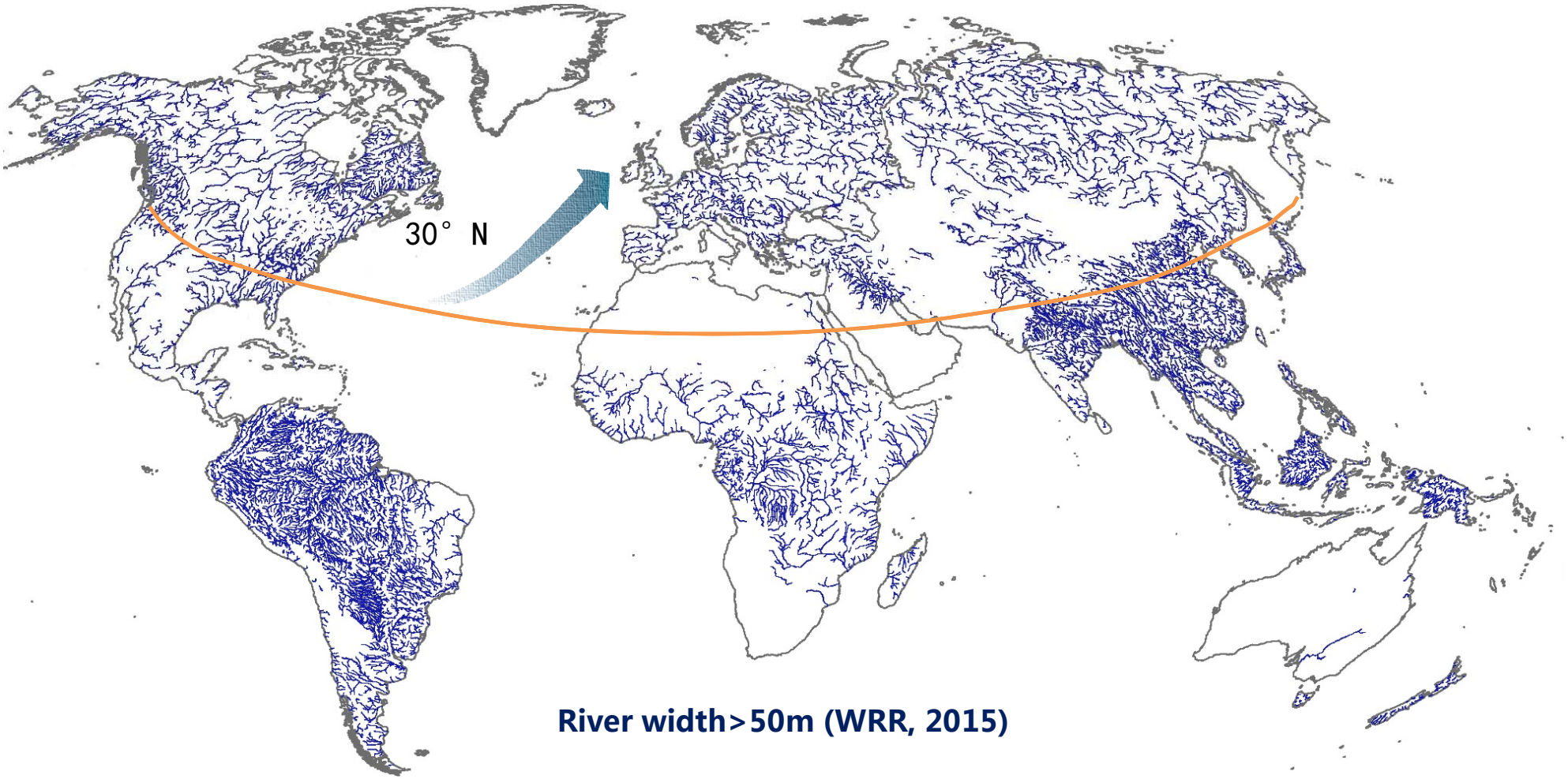
Background

Review of

1) Theories of river ice hydraulics ;
2) Ice condition forecast and numerical models;
3) Observation and mitigation: equipment and technology

Recent works of our group

1、Background

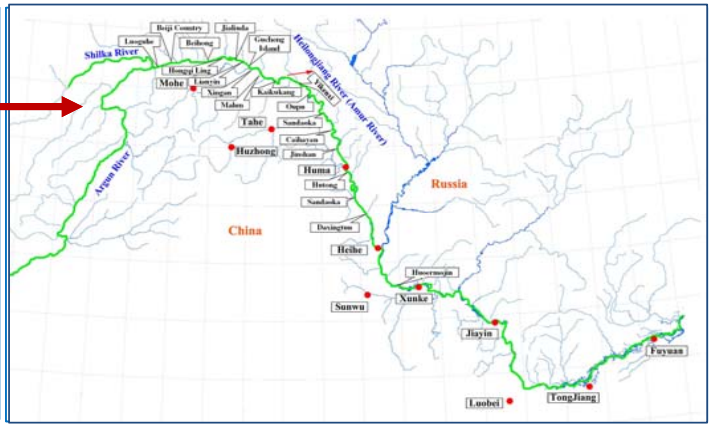


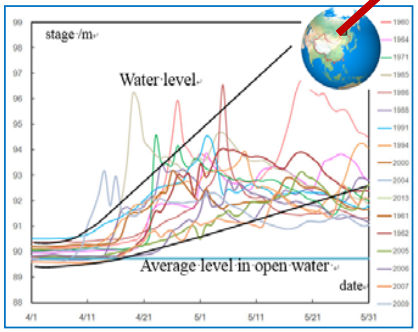
River width>50m (WRR, 2015)

1、Background

Heilong (or Amur) River and the Inner Mongolia region in China;

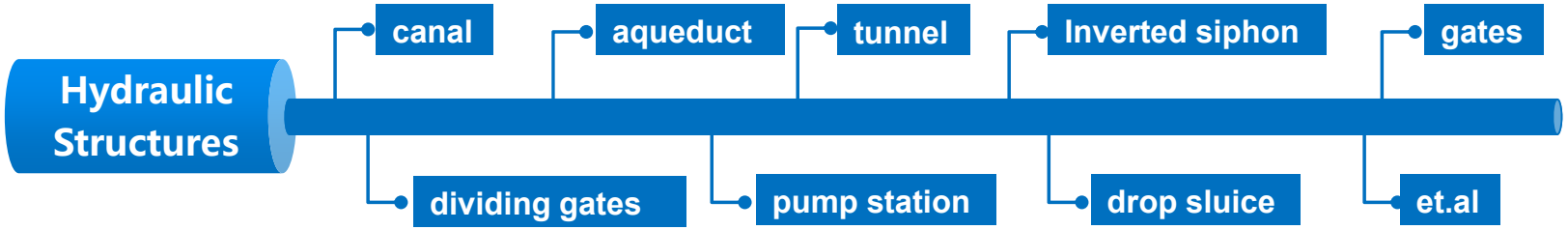
From lower latitude to higher latitude , resulting in reversed breakup conditions that can lead to frequent ice jam formation during breakup in certain reaches. Significant ice jam events occur every 3 years





Water level rising **Ice jams** **Ice flood**

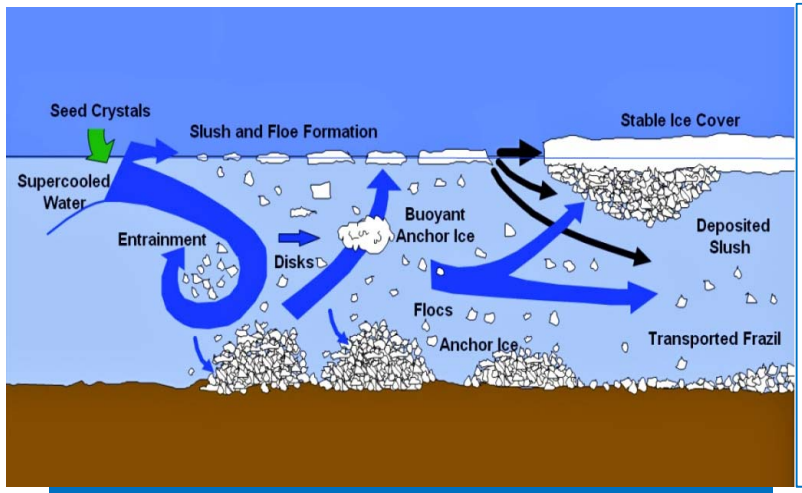
1、Background



Long Distance Water Diversion Project

1、Background

Key difficulties



River ice formation process (White, 1999)

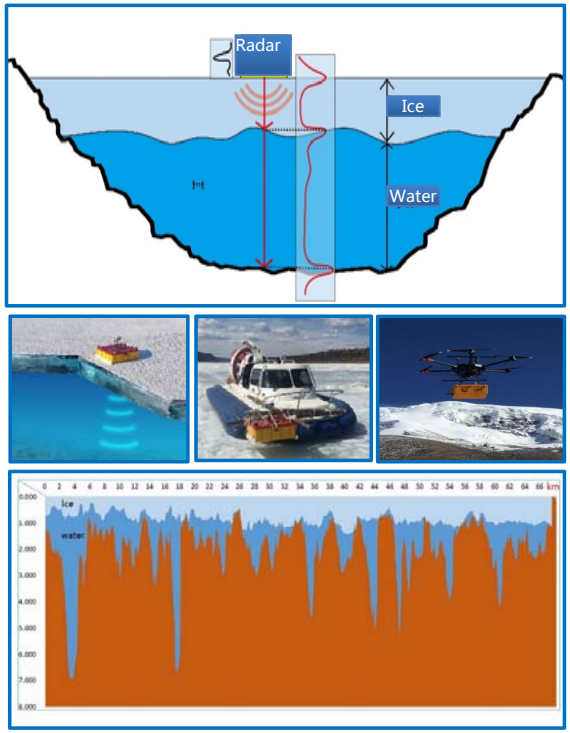
Ice process during winter and spring (from internet)

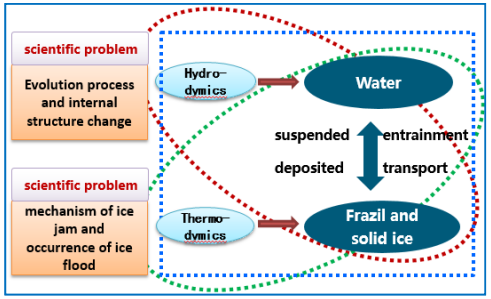
Not only involves the process of hydraulics and thermodynamics, but also accompanied by internal structure change in ice, such as density, porosity, etc and mechanical movement.

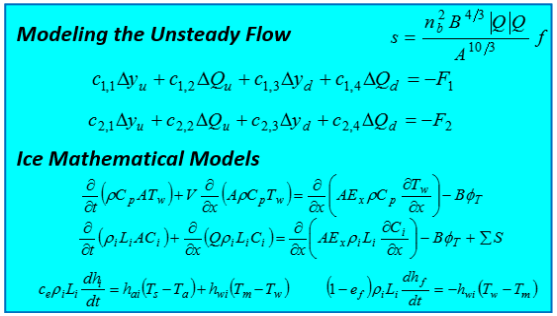
1、Background

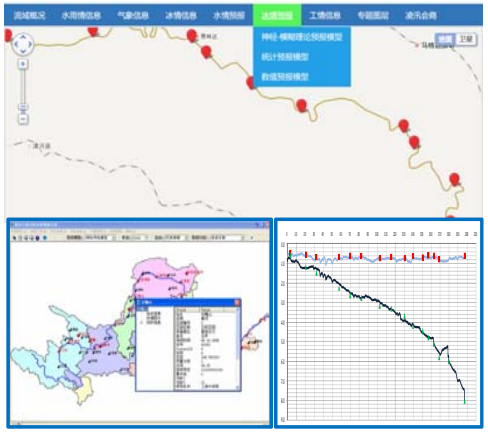
Ice process forecast, simulation and ice flood prevention

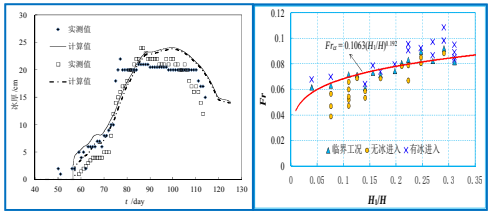
Monitoring | **Mechanics of river ice** | **Forecast and modeling** | **Prevention and control**

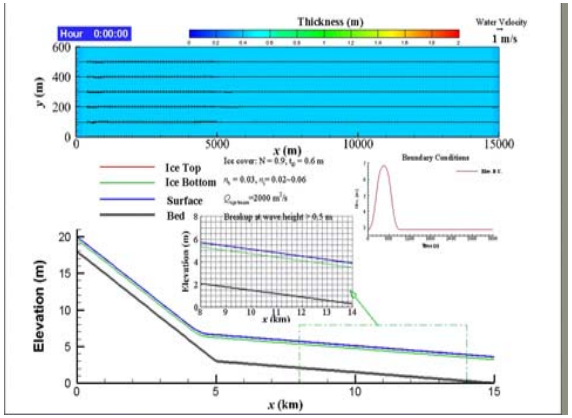


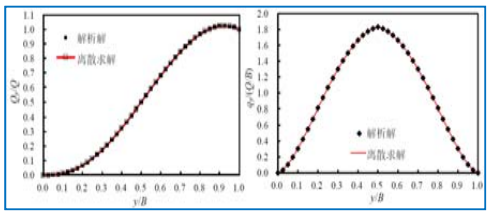






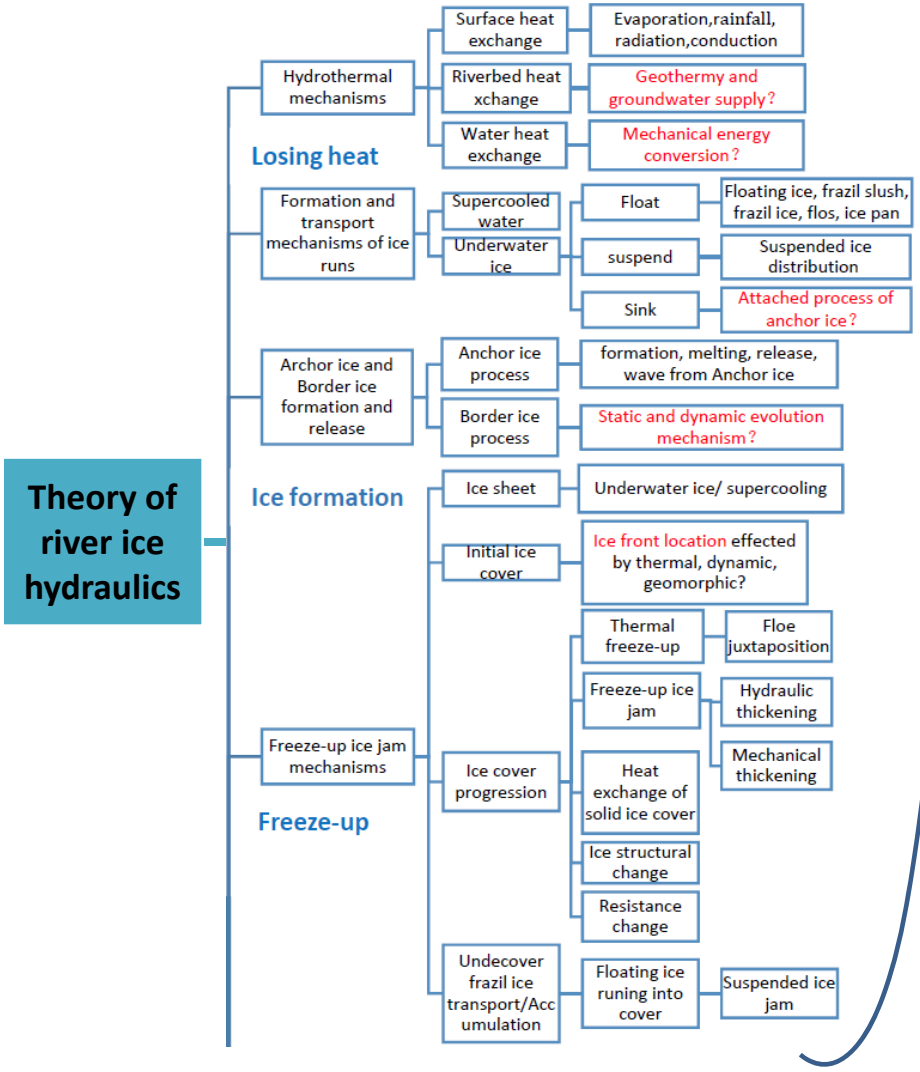


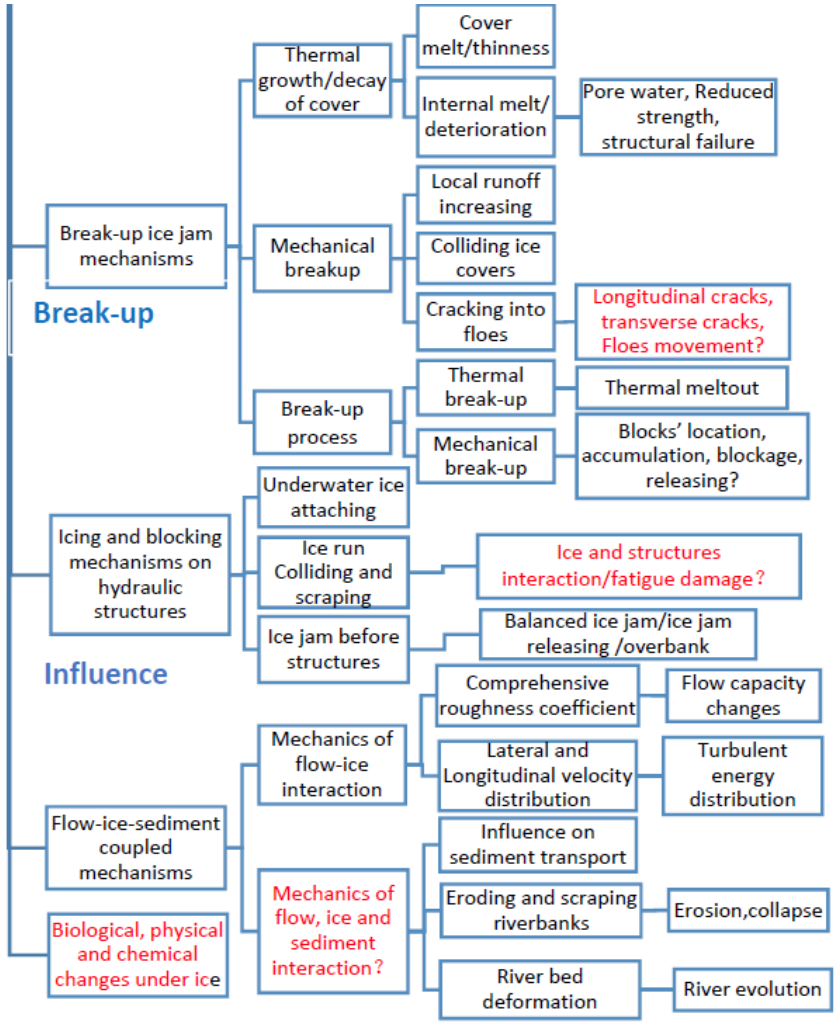




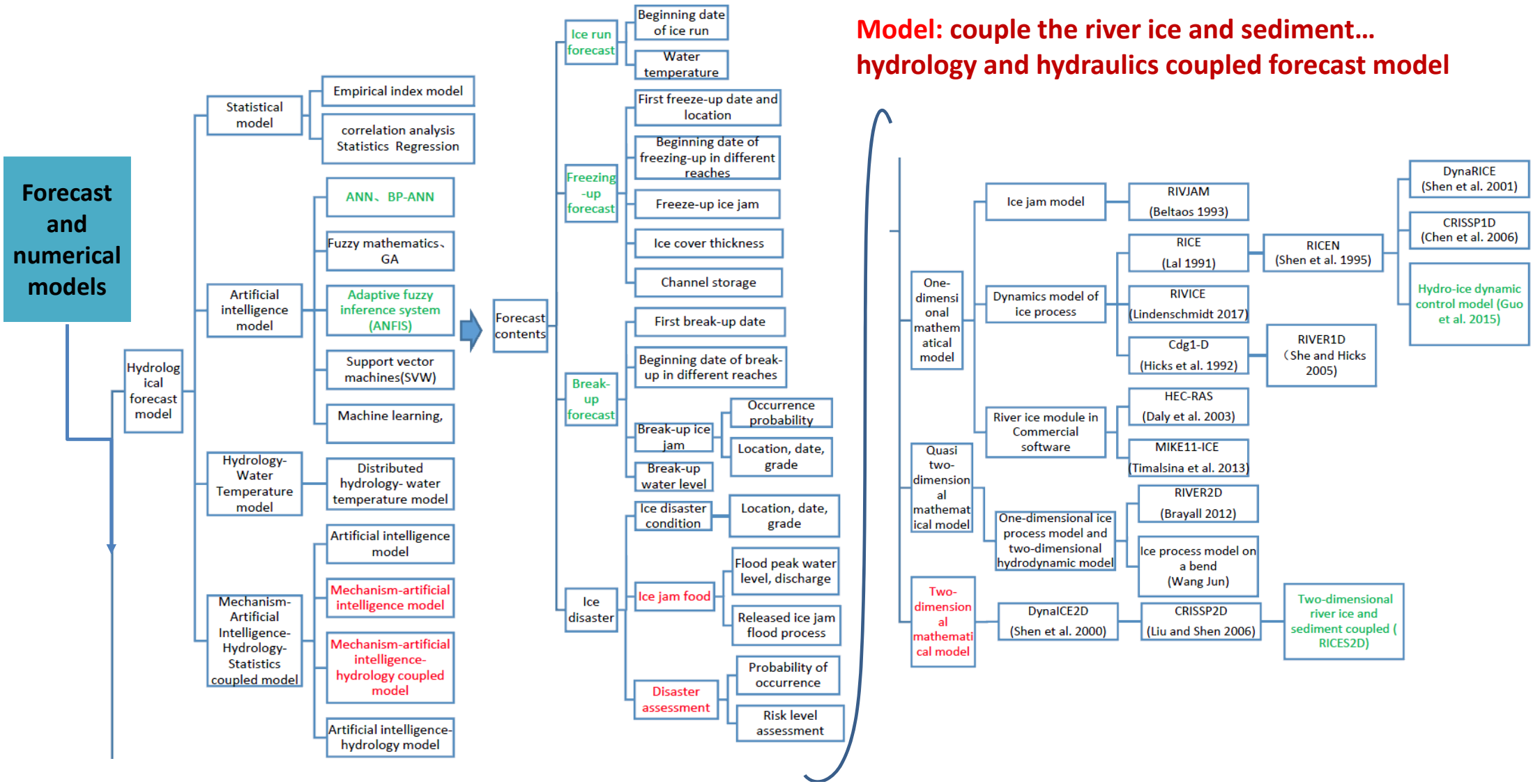
2、Review of theories of river ice hydraulics

Red font: Current research challenges

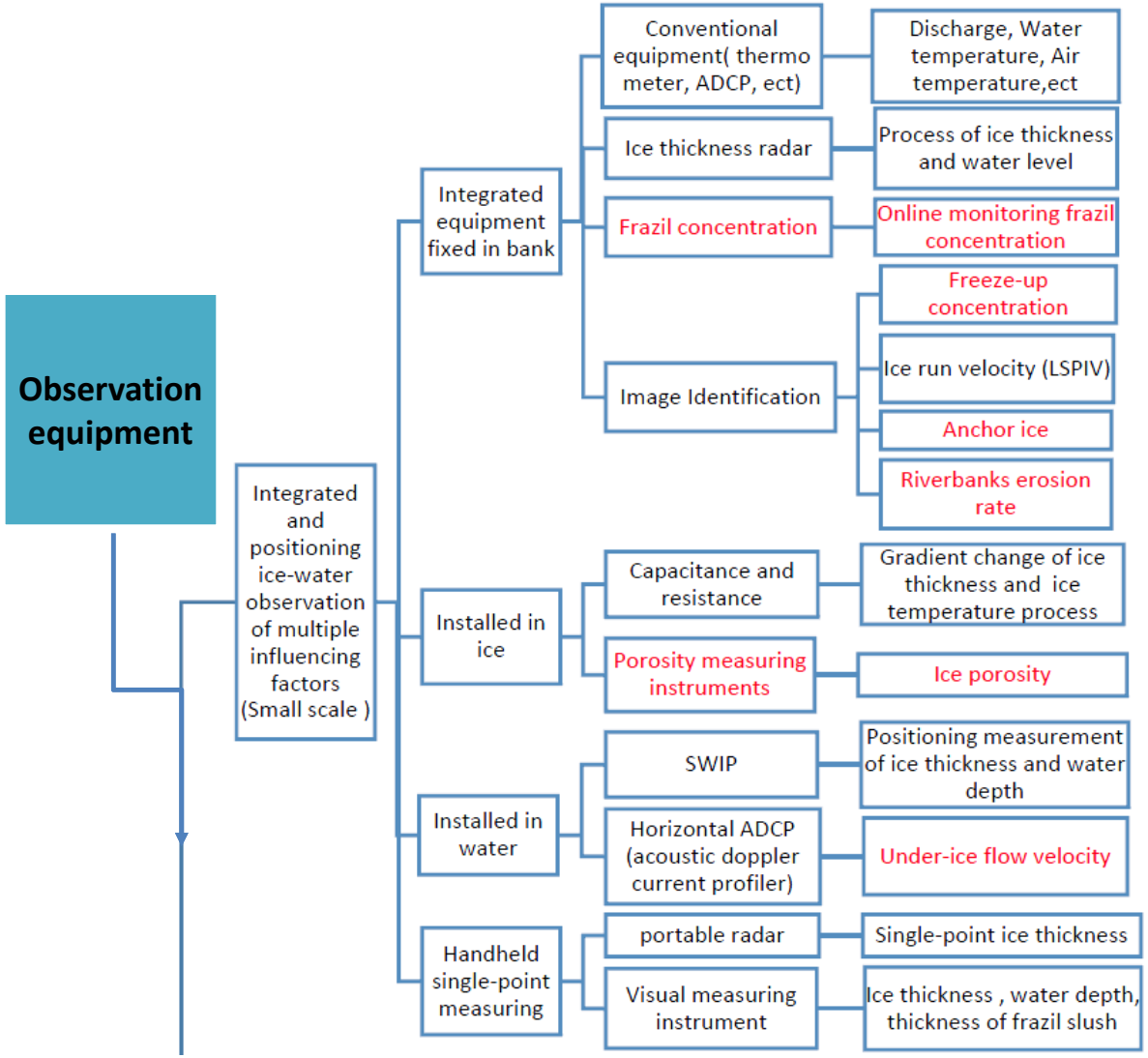




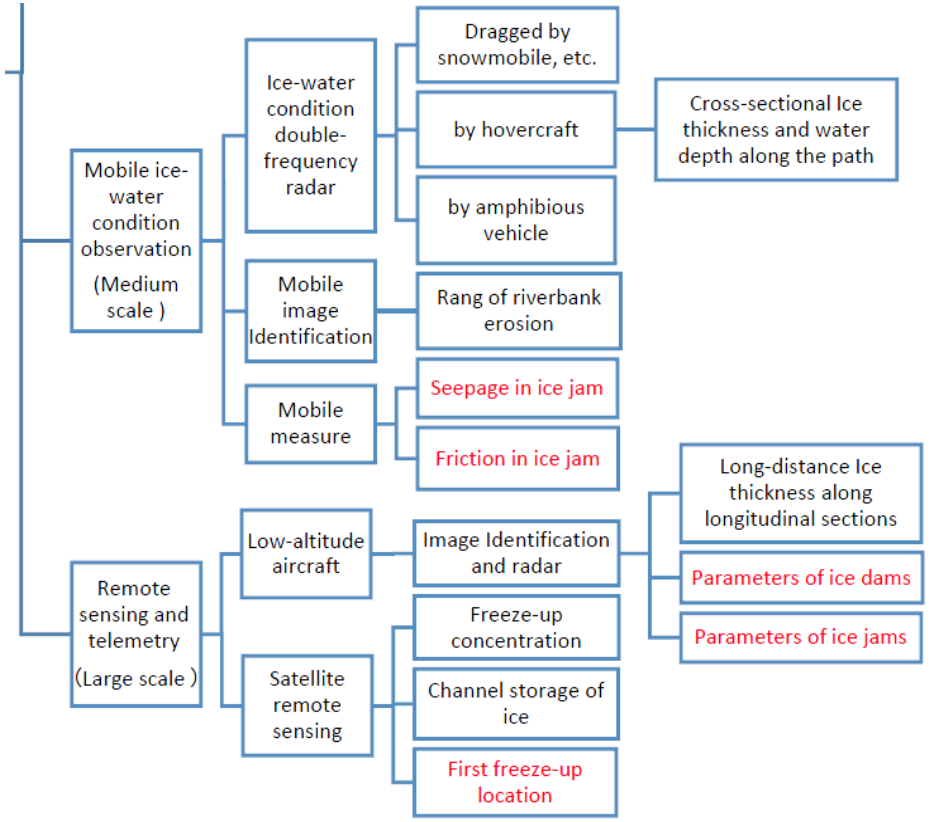
2、Review of Ice condition forecast and numerical models



2、Review of Observation and mitigation: equipment and technology



Monitoring: seepage flow in ice jam
internal ice resistance
physical structure evolution in ice jam



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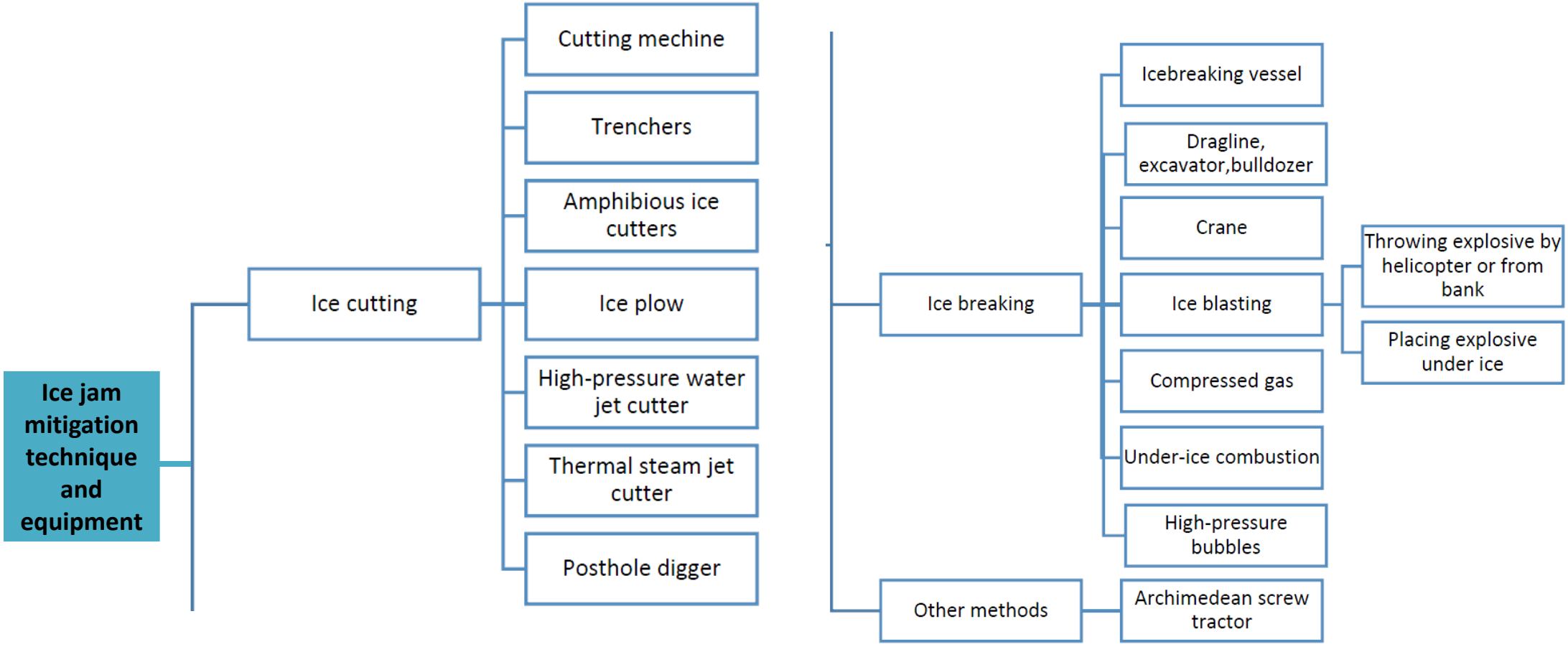
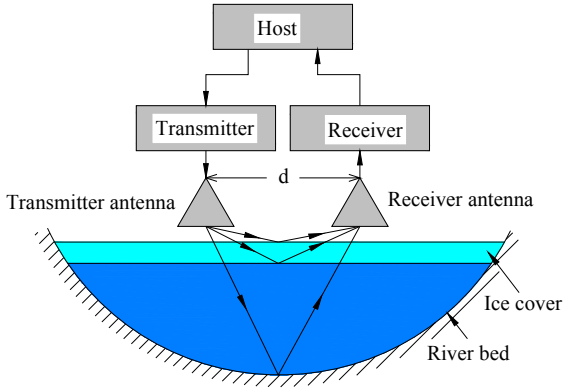
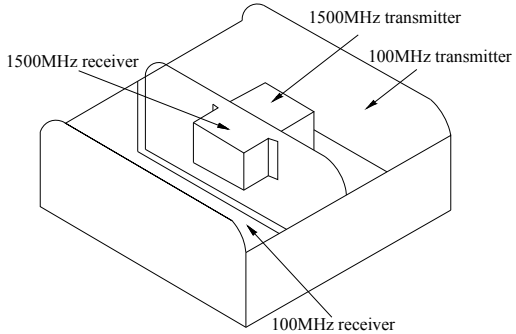


3、Recent works of our group ◆Instrument

■ **A new dual frequency ground penetrating radar(GPR) was developed to measure the ice thickness and water depth.**



Different dielectric constant is the base of GPR measurement

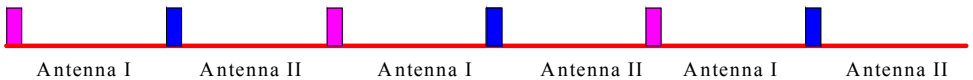


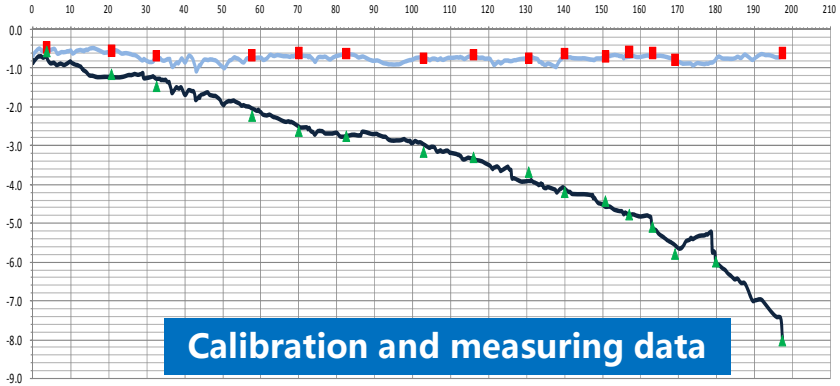
New design structure

$$H_w = \frac{c(t_w - t_i)}{2\sqrt{\varepsilon_w}}$$

$$H_i = \frac{ct_i}{2\sqrt{\varepsilon_i}}$$

$$\hat{R}_{xy}(m) = \frac{1}{N}\sum_{k=0}^{N-|m|-1} x(k)y(k+m) \qquad n = 0,1,.....,N-1$$





Calibration and measuring data

3、Recent works of our group ◆Instrument

Type	integrated	by UAV	portable type	fixed type
Dimensions	80×79×24cm	105×105×50 cm	27×12×70 cm	105×105×50 cm
Water depth	<16 m	-	-	-
Ice thickness	<6 m	<6 m	<6 m	<6 m
Resolution	mm	mm	mm	mm
GPS	cm	cm	cm	cm
Temperature	-40~+60℃	-40~+60℃	-40~+60℃	-40~+60℃

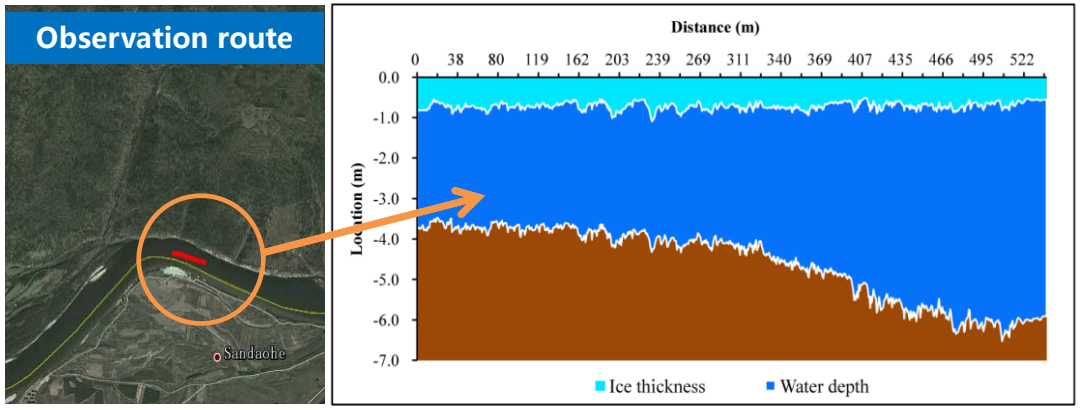
integrated type

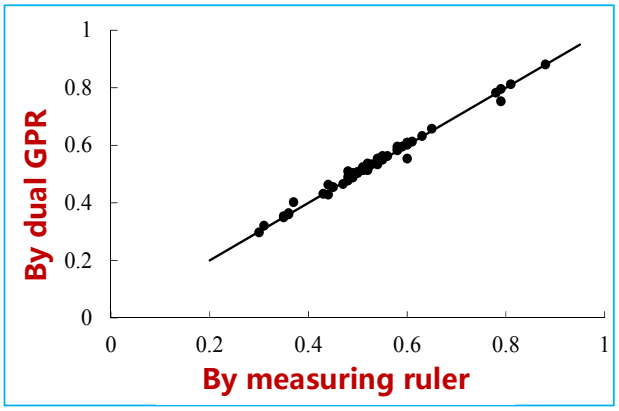
by UAV

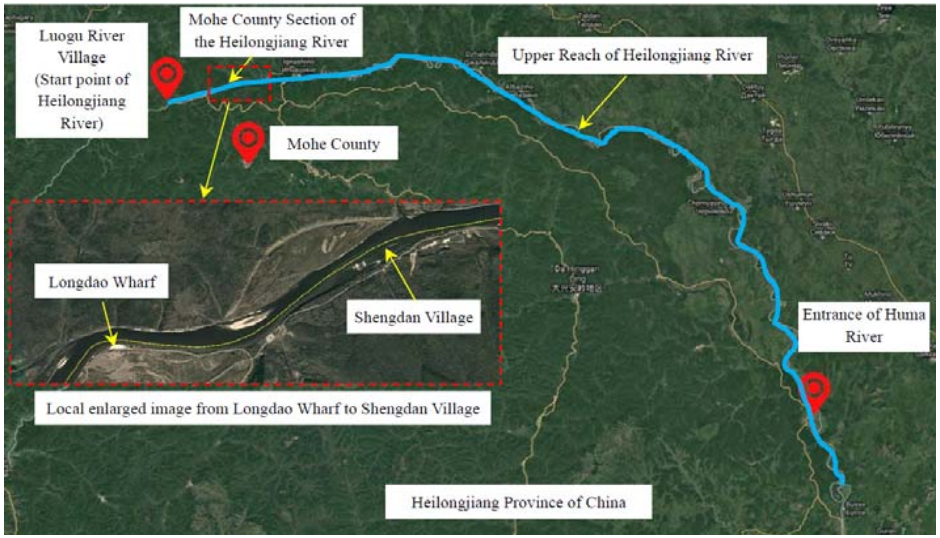
portable type

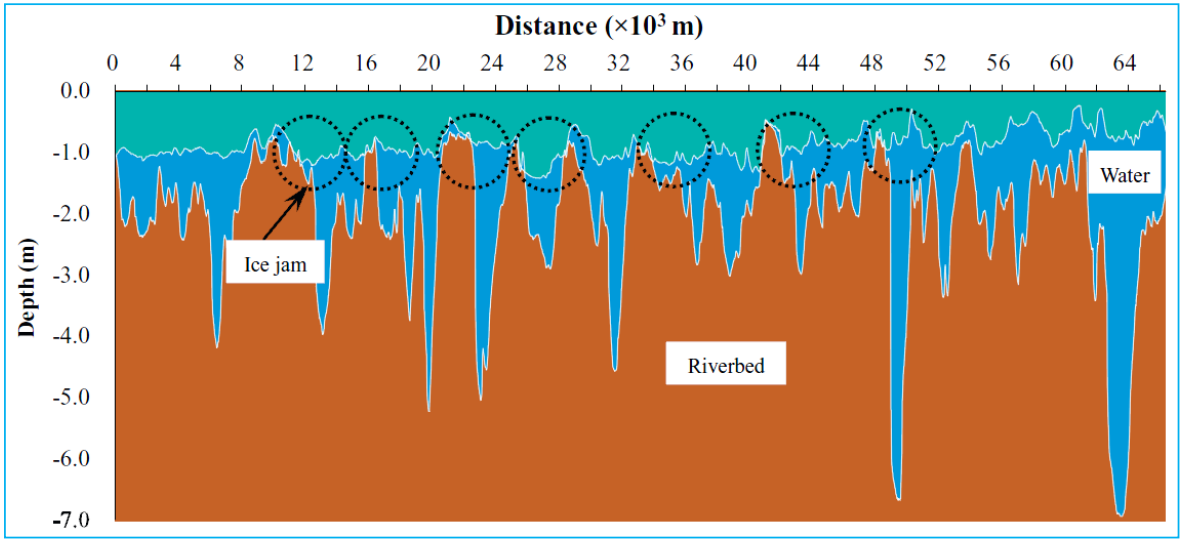
fixed type

3、Recent works of our group ◆Instrument









3、Recent works of our group ◆Ice condition forecast

Forecast procedure of NN

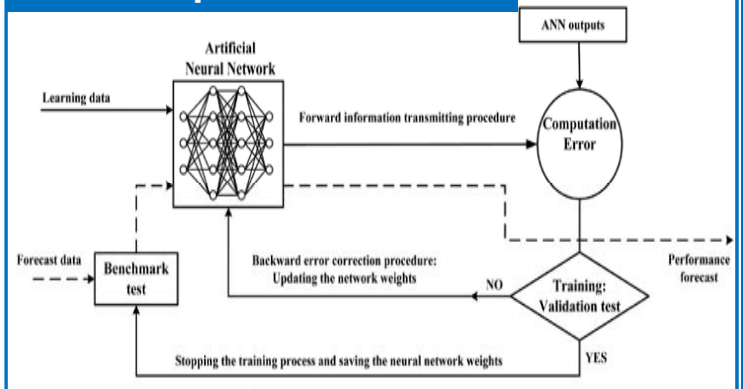
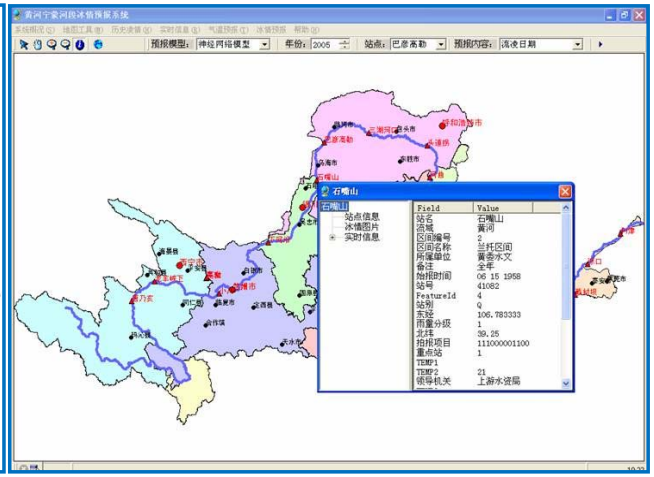


Fig. 1. Forecast procedure of the neural network.



Year	Measured date	Forecast date	Error	Forecast period	Pass (Y or N)
2004	4/28	4/27	-1	8	Y
2005	5/2	4/30	-2	12	Y
2006	5/1	5/1	0	11	Y
2008	5/2	5/2	0	12	Y
2010	5/2	5/2	0	12	Y
2011	4/25	4/25	0	5	Y
2012	4/30	5/1	1	10	Y
2013	5/1	4/30	-1	11	Y
2014	4/29	4/29	0	9	Y
2015	4/27	4/27	0	7	Y
2017	4/28	4/28	0	27	Y

3、Recent works of our group ◆Modeling

■ **A two-dimensional flow-ice-sand coupling model for northern rivers was established**

Two-dimensional River Ice and Sediment Coupled Model (RICES2D)

Hydrodynamic and Sediment Transport Module

- Two Layer Flow

$$\frac{\partial H}{\partial t}+\frac{\partial q_{tx}}{\partial x}+\frac{\partial q_{ty}}{\partial y}=\frac{\partial}{\partial t}(Nt_i')$$

$$\frac{\partial}{\partial t}(q_{tx})+\frac{\partial}{\partial x}\left(\frac{q_{tx}^2}{H_t}\right)+\frac{\partial}{\partial y}\left(\frac{q_{tx}q_{ty}}{H_t}\right)=\frac{1}{\rho}\left[\frac{\partial T_{xx}}{\partial x}+\frac{\partial T_{yx}}{\partial y}+\tau_{sx}-\tau_{bx}\right]-gH_t\frac{\partial \eta}{\partial x}$$

$$\frac{\partial}{\partial t}(q_{ty})+\frac{\partial}{\partial y}\left(\frac{q_{ty}^2}{H_t}\right)+\frac{\partial}{\partial x}\left(\frac{q_{tx}q_{ty}}{H_t}\right)=\frac{1}{\rho}\left[\frac{\partial T_{yy}}{\partial y}+\frac{\partial T_{xy}}{\partial x}+\tau_{sy}-\tau_{by}\right]-gH_t\frac{\partial \eta}{\partial y}$$

- Ice Effects on Conservation of Flow Mass and Momentum

$$\frac{\partial\left(\frac{q_{bk}}{u_{bk}}\right)}{\partial t}+\frac{\partial(\alpha'_{bx}q_{bk})}{\partial x}+\frac{\partial\left(\alpha'_{by}q_{bk}\right)}{\partial y}+(1-p'_m)\left(\frac{\partial z_b}{\partial t}\right)_k=0$$

- Upwind Petrov-Galerkin FES

$$\frac{\partial\left(\frac{q_{bk}}{u_{bk}}\right)}{\partial t}+\frac{\partial(\alpha'_{bx}q_{bk})}{\partial x}+\frac{\partial\left(\alpha'_{by}q_{bk}\right)}{\partial y}+\frac{1}{L_{bk}}(q_{bk}-q_{*bk})=0$$

Ice Dynamic Module

- Ice Momentum and Mass Conservation

$$M\frac{d\vec{V}}{dt}=\vec{R}+\vec{F_a}+\vec{F_w}+\vec{G}$$

- Viscoelastic-plastic Constitutive Law for Ice Internal Stress

$$\frac{dM}{dt}+M\nabla\cdot\vec{V}=E_m$$

- SPH

$$\frac{dN}{dt}+N\nabla\cdot\vec{V}+R_a-E_a=0$$

Bank Stability Module

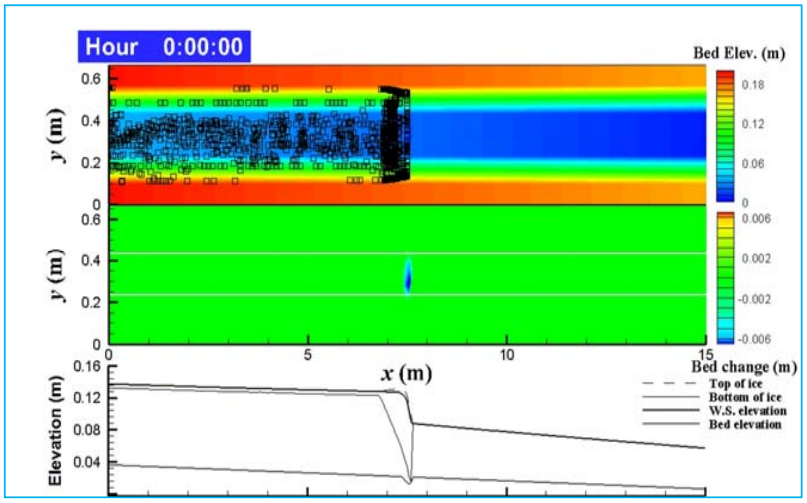
- Flow Erosion, Riverbank Collapses, Re-stabilizing

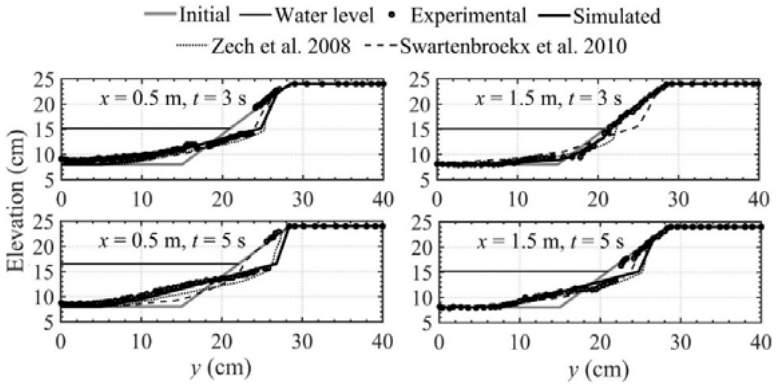
$$A_s=A_f$$

- Ice Gouging and Abrasion on Streambank

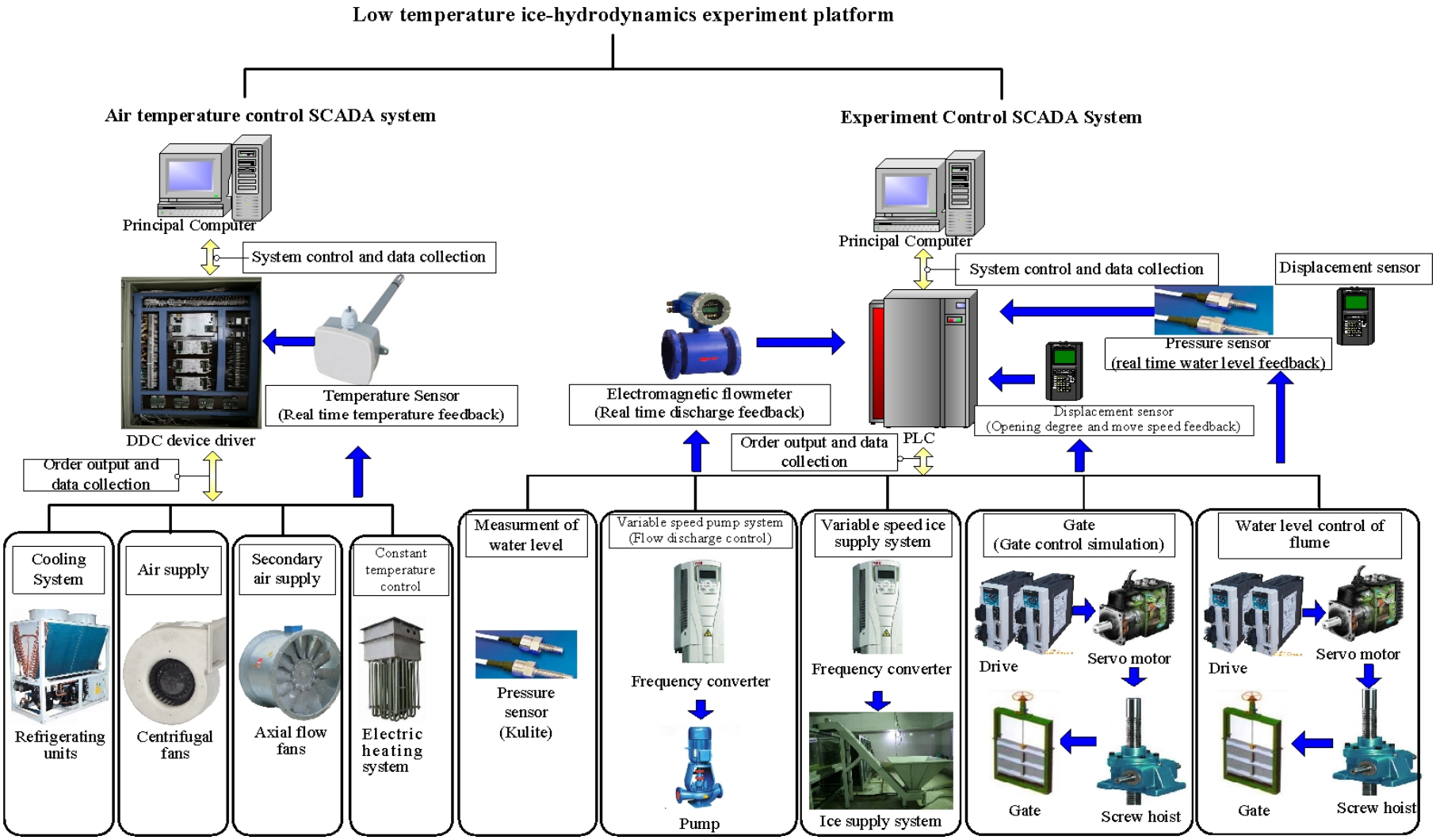
$$A_s=\sum_{i=N_s+1}^{N_c}\frac{(y_i-y_{i-1})(\Delta z_{bi}+\Delta z_{bi-1})}{2}$$

- Two Sets of Repose Angles for Bank





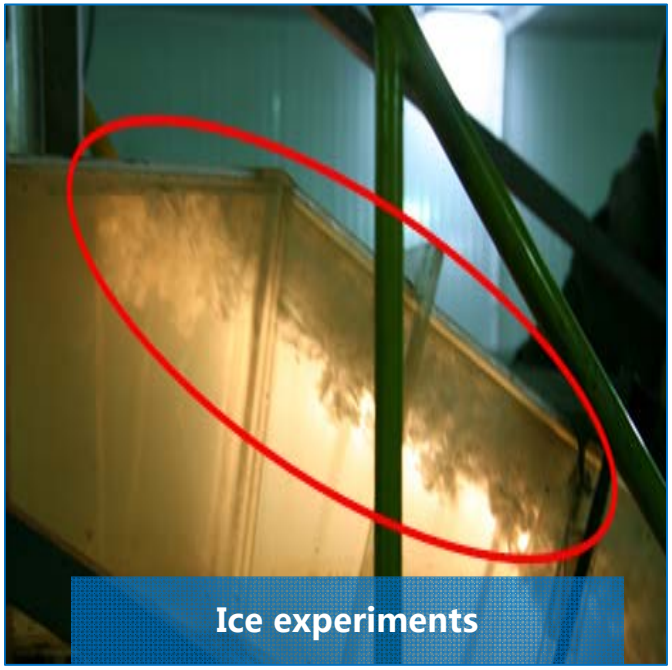
3、Recent works of our group ◆Lab and experiments



3、Recent works of our group ◆Lab and experiments

Ice-hydrodynamics Lab

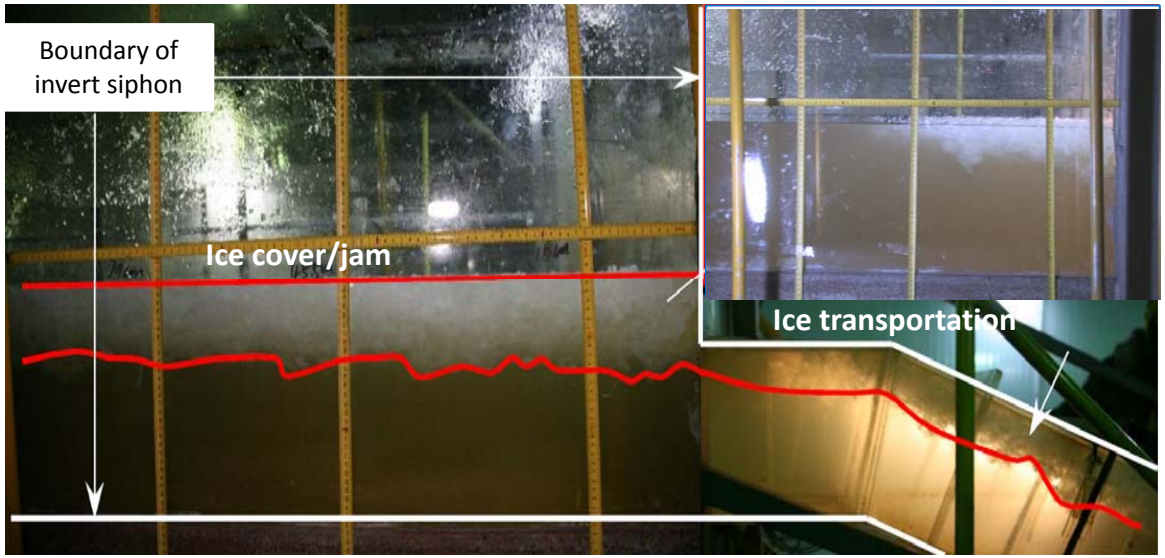
Inverted siphon

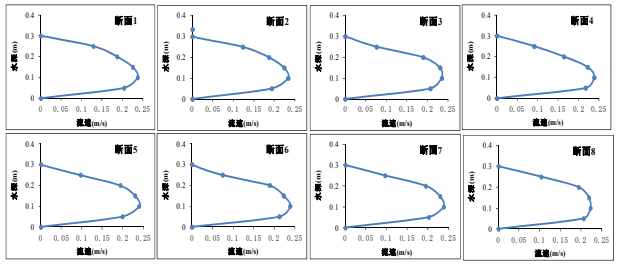


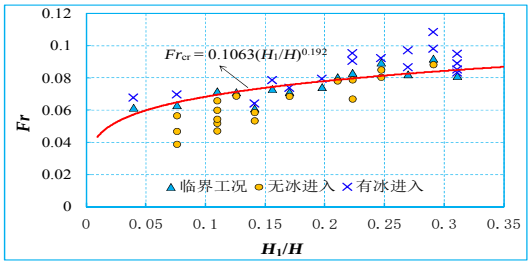
Ice experiments

3、Recent works of our group ◆Lab and experiments

■Some critical relationship for safe operation of water diversion project during ice period was presented







Velocity distribution before siphon

$$u=\left(\frac{y}{0.82H_2}\right)^{ab\left(\frac{H-H_2}{H}\right)}\left[\frac{u_*}{k}\ln\left(\frac{yu_*}{v}\right)+B\right]$$

Ice jam thickness before inverted siphon

$$\frac{t_i}{H}=k\left(Fr_i\right)+b$$

$$Froude_{cr}=\frac{Q}{A\sqrt{gH}}=0.1063\left(H_1/H\right)^{0.192}$$

Composite roughness coefficient

$$n_c=\frac{\left(n_i^{3/2}+\beta a^{3/2}n^{3/2}\right)^{5/3}}{\left(1+\beta\right)^{2/3}\left(n_i^{3/2}+\beta a^{5/2}n^{3/2}\right)}$$

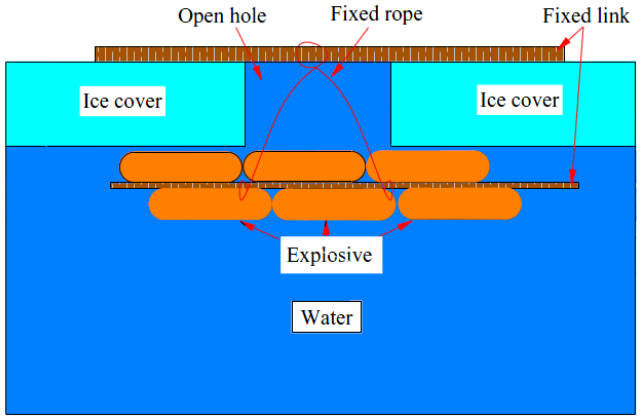
3、Recent works of our group ◆Measures and application

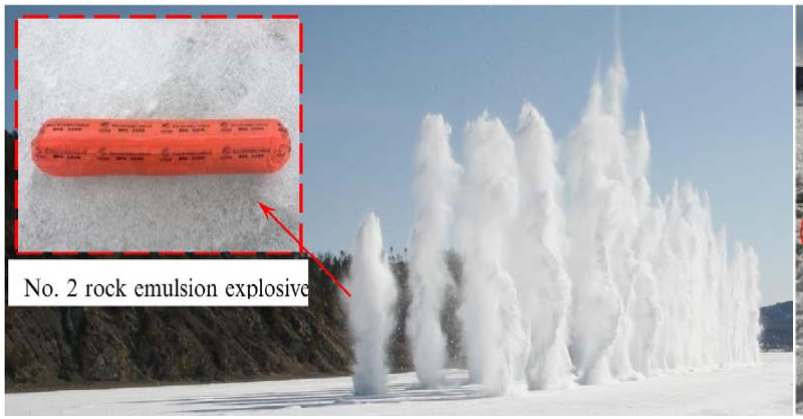
■Ice jam risk (Why), jam location(Where), time for prevention(When), effect measures(How)

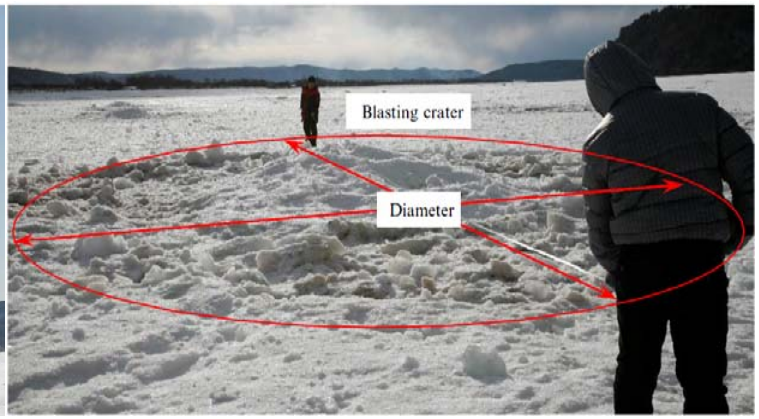
2019.4.6-10:30 Mohe section(Heilongjiang River)

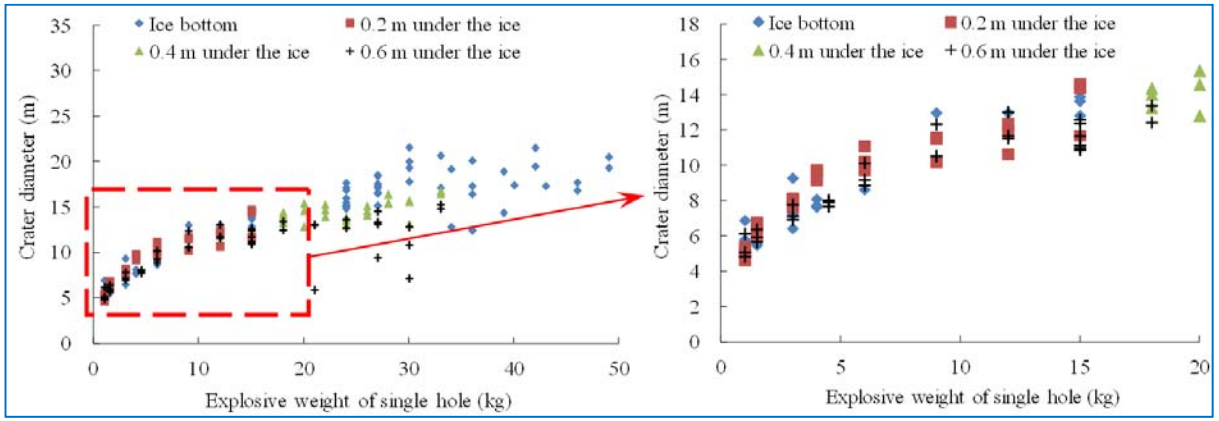
3、Recent works of our group ◆Measures and application

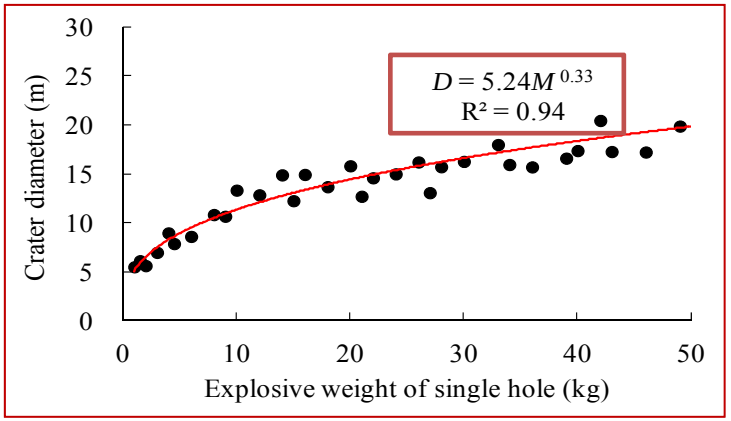
■Ice jam risk (Why), jam location(Where), time for prevention(When), effect measures(How)





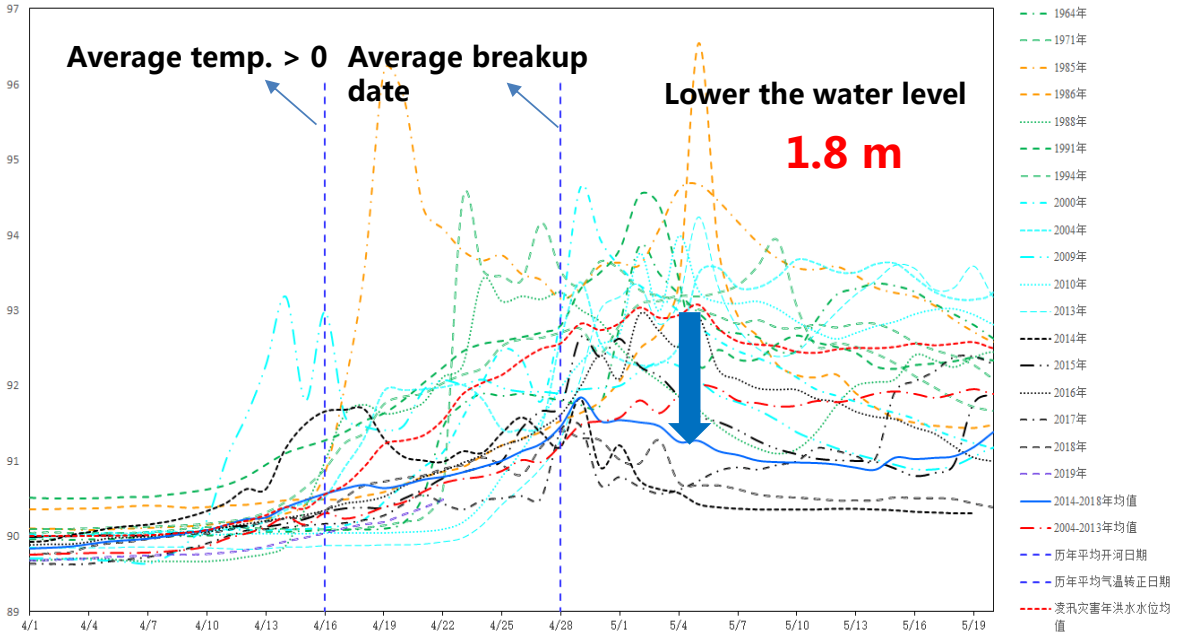






3、Recent works of our group ◆Measures and application

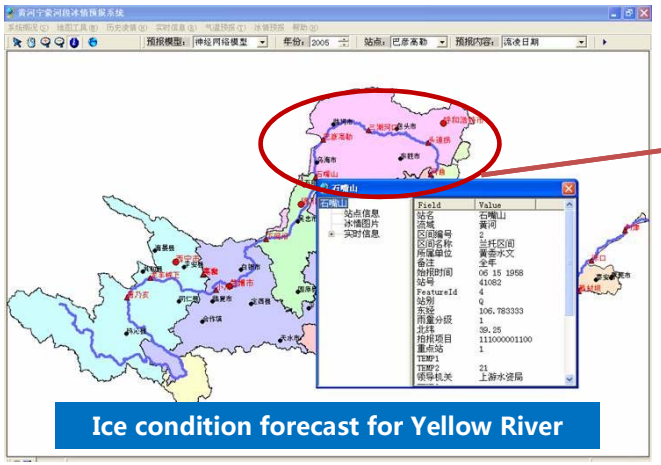
■Ice jam risk (Why), jam location(Where), time for prevention(When), effect measures(How)



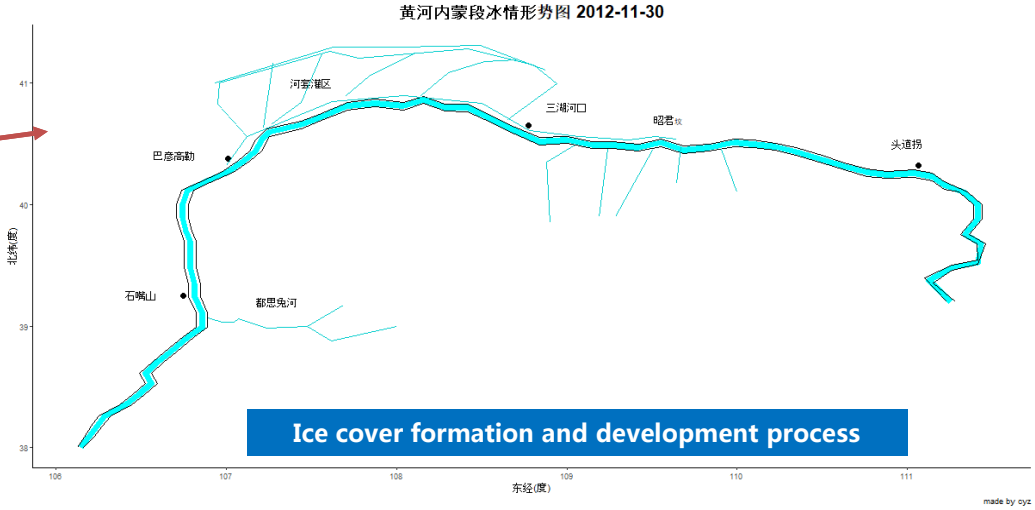
2015-2019 drilling the explosive placement hole 20938，with amounts of explosives 33912kg

3、Recent works of our group ◆Measures and application

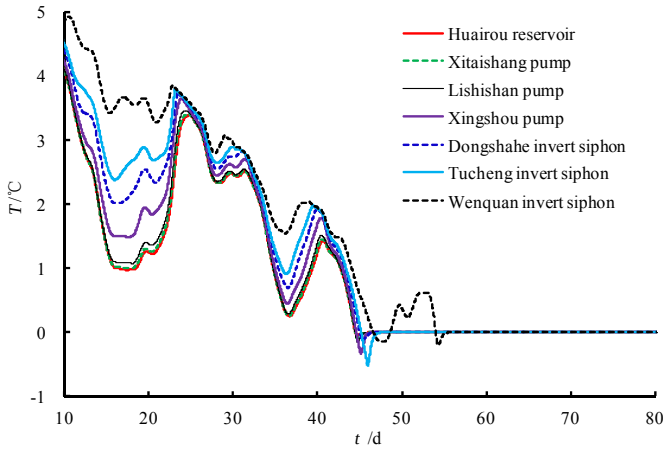
■Other applications



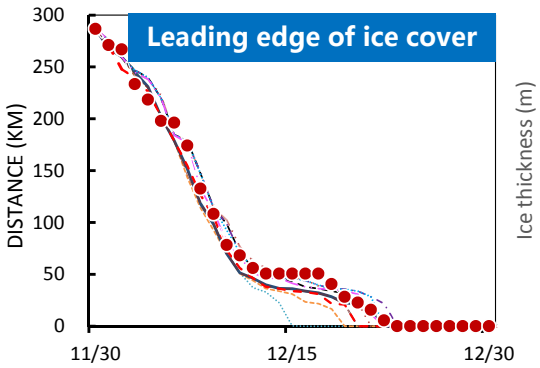
Ice condition forecast for Yellow River

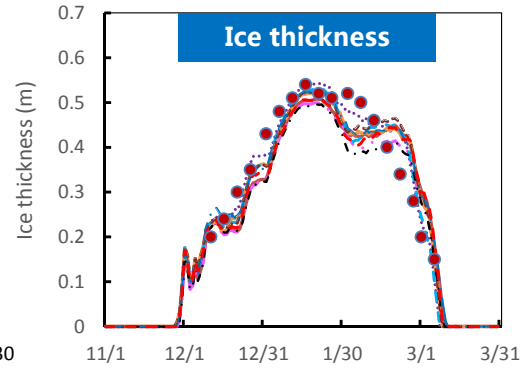


Ice cover formation and development process



Water temperature simulation for SNWDP, China





Thank you

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