International Workshop on Geological CO_2 Sequestration

Simulation Study of Pilot CO_2 Injection in Iwanohara, Nagaoka City, Japan

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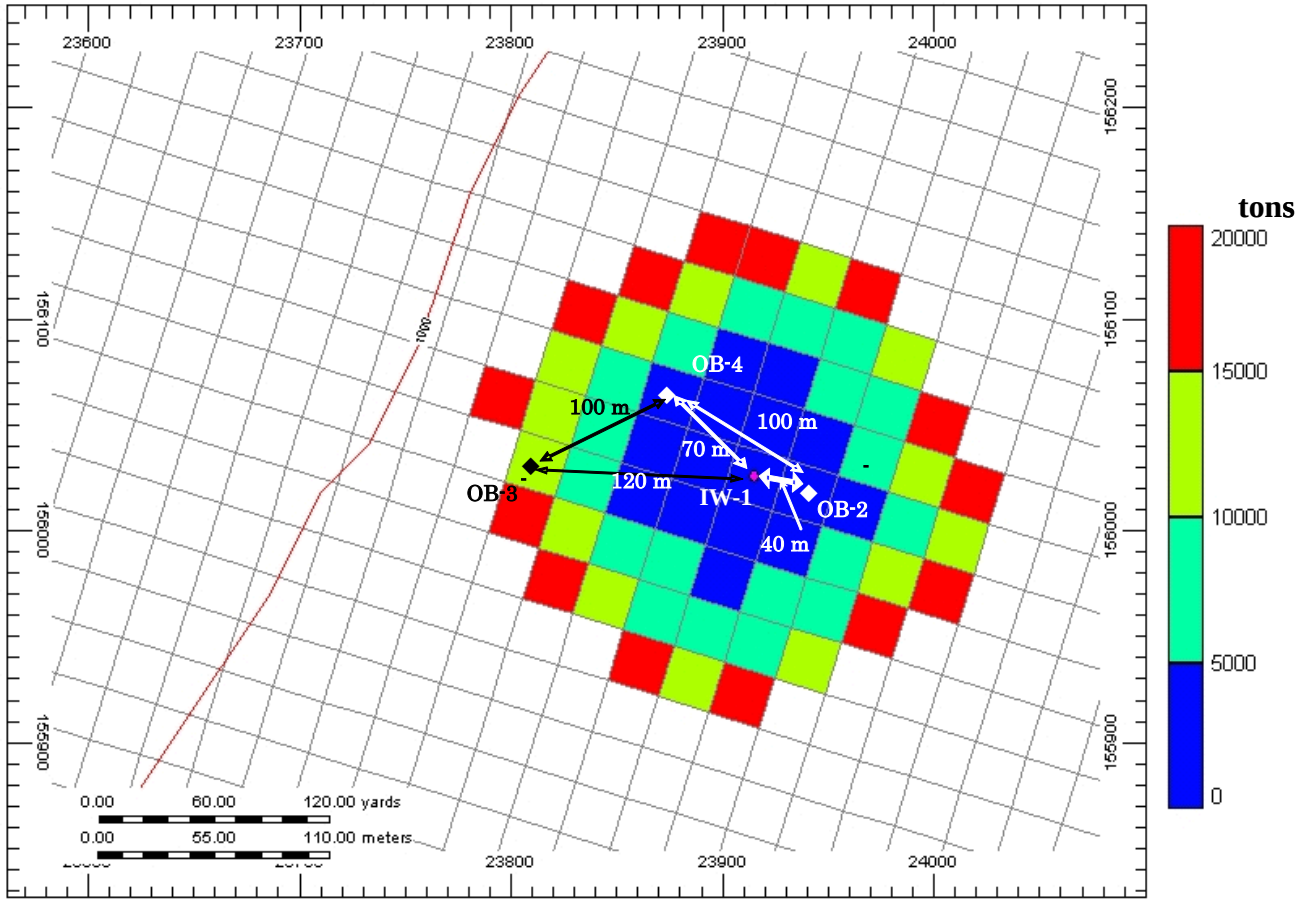
Chronicles of Pilot Test and Simulation

Japanese Fiscal Year	Events	Available Data	Simulation Study
2000	* Geological study	* Structure map & isopach map	* Preliminary sensitivity study
	* IW-1 drilled	* IW-1 well logs	* Determination of observation well locations
2001	* OB-2 & 3 drilled	* IW-1 core data * OB-2 & 3 well logs	* Adjustment of well locations & examination of technical feasibility of the test plan
2002	* Pumping test at IW-1	* Pumping test results	* Same as 2001
2003	* Acidization at IW-1 * OB-4 drilled	* Pumping test results after acid * OB-4 well logs	* Same as 2001 & 2002
	* CO_2 injection started * CO_2 breakthrough at OB-2	* Injection rate * IW-1 & OB-4 BHP * Logs at OB-2,3, & 4	* History matching
2004	* CO_2 injection continued * CO2 breakthrough at OB-4 * CO_2 injection completed	* Injection rate * IW-1 & OB-4 BHP * Logs at OB-2,3, & 4	* History matching * Long-term prediction of CO_2 fate

Determination of Observation Well Locations (3/3): Area Extent of CO_2 as Function of Cumulative Injection



IW-1 Pumping Test Data

- **Pumping test at IW-1 showed only top 12m (Zone-2) has sufficient injectivity with average k of only 6.7 md and the well damage was severe (skin factor s=6.88).The simulation model incorporating these data implied:**
  - **Well damage should be removed**
  - **For safe injection the injection rate should be half of the initial plan (i.e., 40 tons/day →20 tons/day)**
  - **Injection should be limited over Zone-2 to observe CO_2 breakthrough at two observation wells at least during the test period (approximately 500 days)**
- **Acidization at IW-1 was successfully carried out prior to the injection, resulting in s=-2.9. The model with this negative skin suggested the injection at 40 tons/day would be possible but it was decided to inject at 20 tons /day during JFY2004.**

History Matching Parameters

- **Parameters to be matched:**
  - **IW-1 BHP at -1,018.90 m (Jul. 7, 2003 – Jan. 11, 2005)**
  - **OB-4 BHP at -1,034.96 m (Jul. 7, 2003 – Jan. 11, 2005)**
  - **Breakthrough of gaseous CO_2 at OB-2 between Feb. 12 and Mar. 10, 2004; Cumulative injection = 4,000 tons)**
  - **Breakthrough of gaseous CO_2 at OB-4 between May 12 and Jun. 14, 2004; Cumulative injection = 5,300 tons)**
- **Varied Parameters:**
  - **Relative permeability curves and end points (S_{wir}, S_{gc}, k_{rg} @ S_{wir})**
  - **Zone-2 permeability and its areal heterogeneity**
  - **Vertical permeability**
  - **Well damage at OB-2**
  - **Rock compressibility**

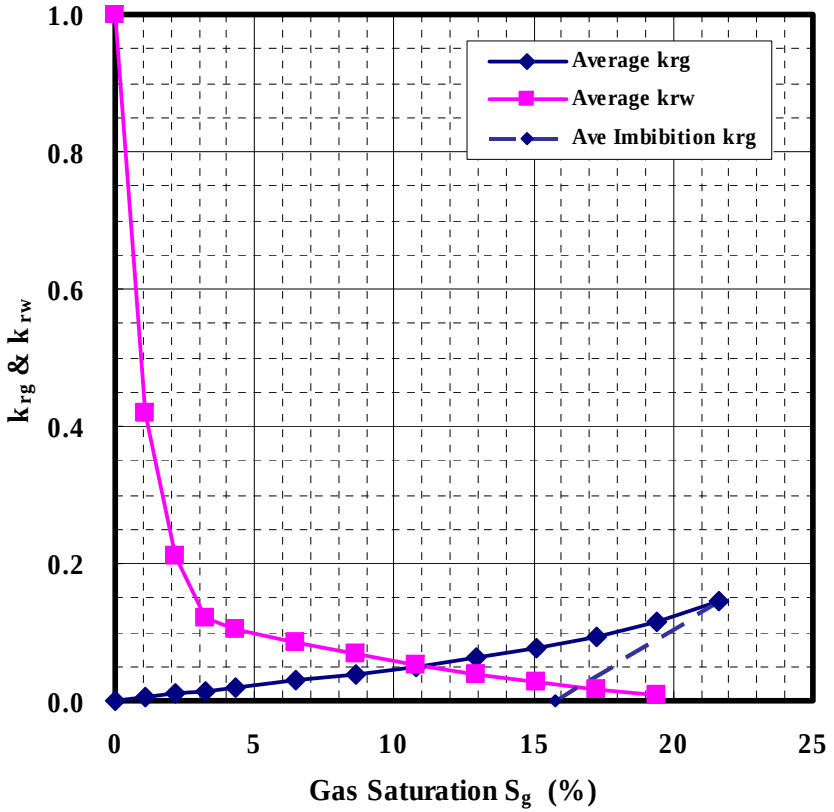
Evolution of Simulation Studies

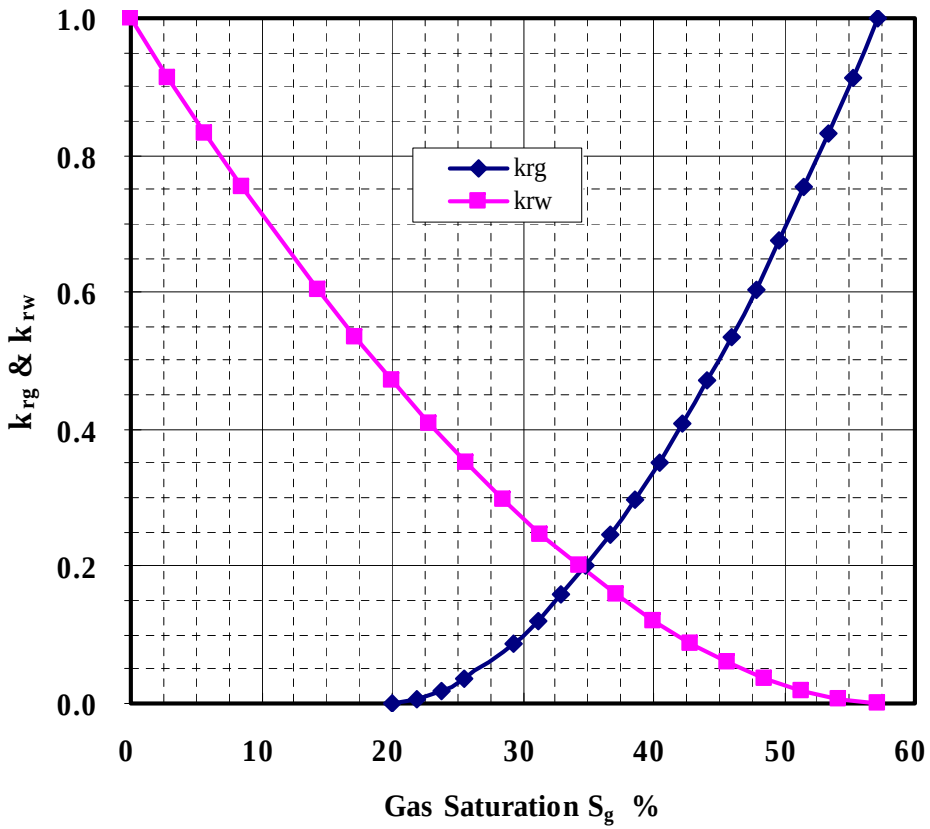
		Injection Rate t-CO_2/day	Skin Factor	Data Pertaining to Relative Permeabilities				Injection Well BHP (kgf/cm^2)
				Swir (fraction)	Sgc (fraction)	k_{rg} @ S_{wir} (fraction)	Curves	
2002 Study		20	0	0.82-0.84	0	0.060-0.065	SCAL Data	169→175
2003 Study	Prior to Injection	20	-2.9	0.82-0.84	0	0.061-0.065	SCAL Data	137
Actual Injection Behavior	2003	20	-2.9	-	-	-	-	119→123
	2004	40	-2.9	-	-	-	-	124→129
2005 History Matching			-2.9	0.43-0.67	0.20	1.0	$(S_g^*)^{1.75}$	Good Match

* BHP is the bottom-hole pressure at the gauge depth (-1018.90 m).

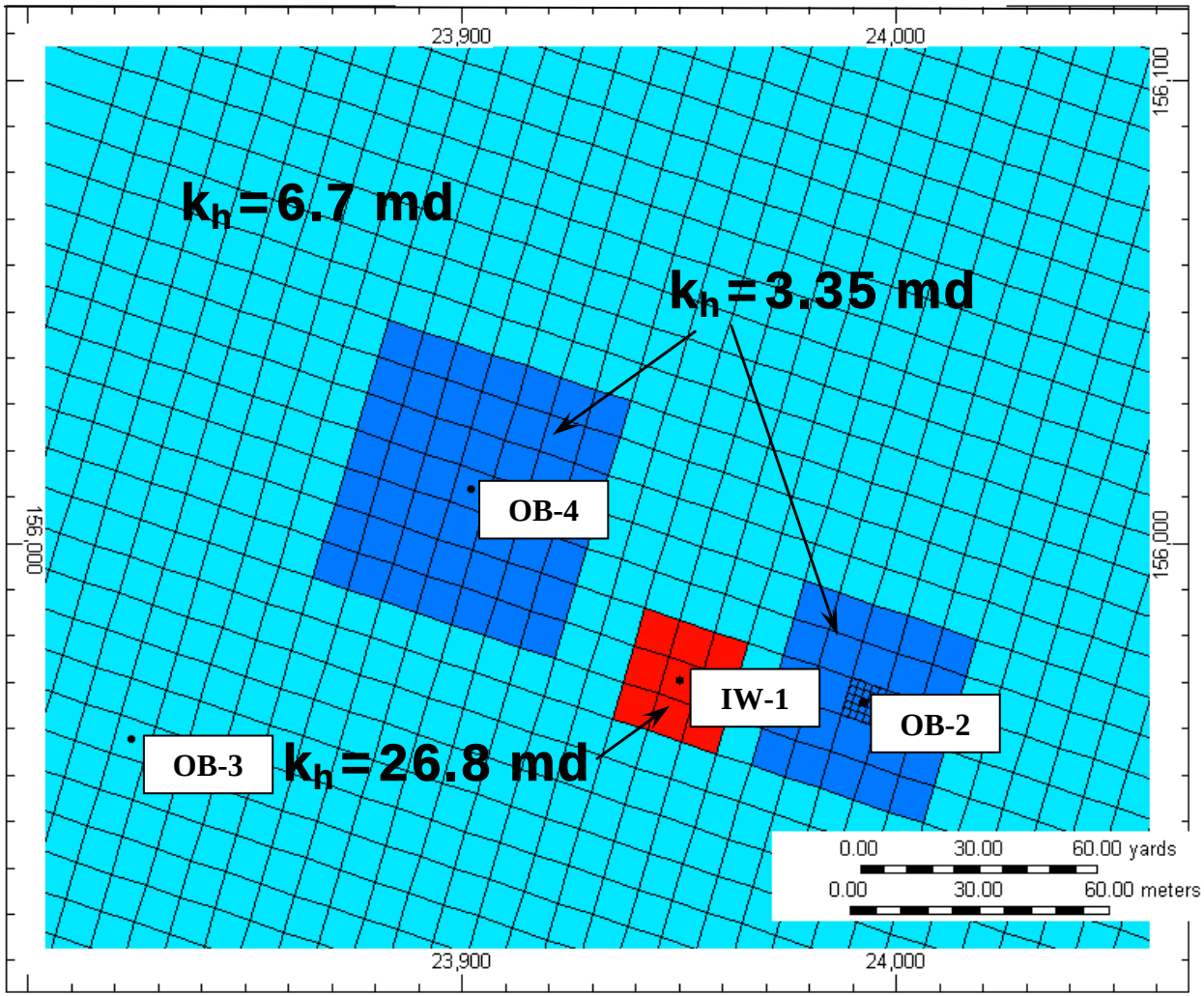
** Initial pressure at the gauge depth was 110 kgf/cm^2. Maximum injection BHP was set at 190 kgf/cm^2.

Relative Permeability Data

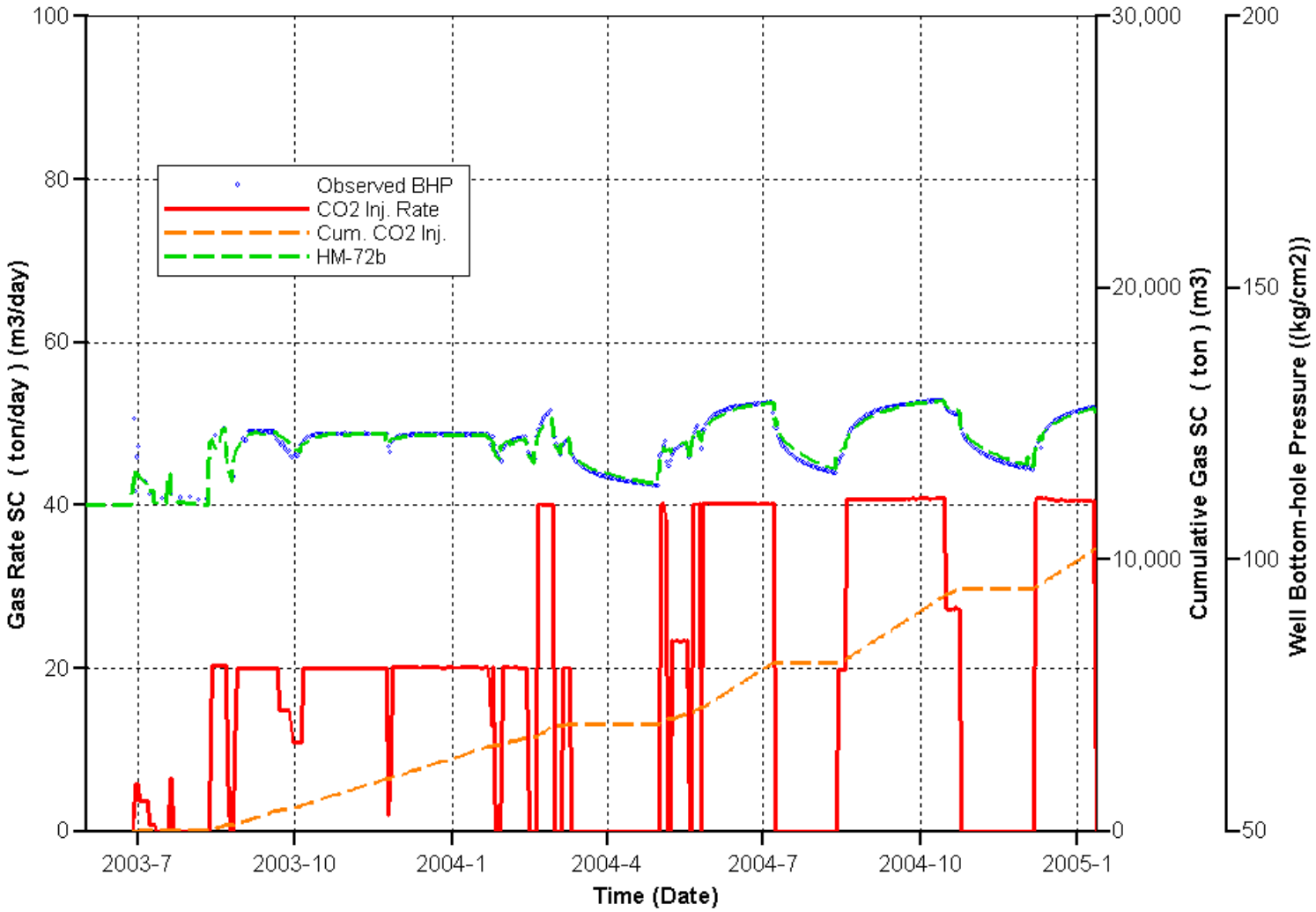




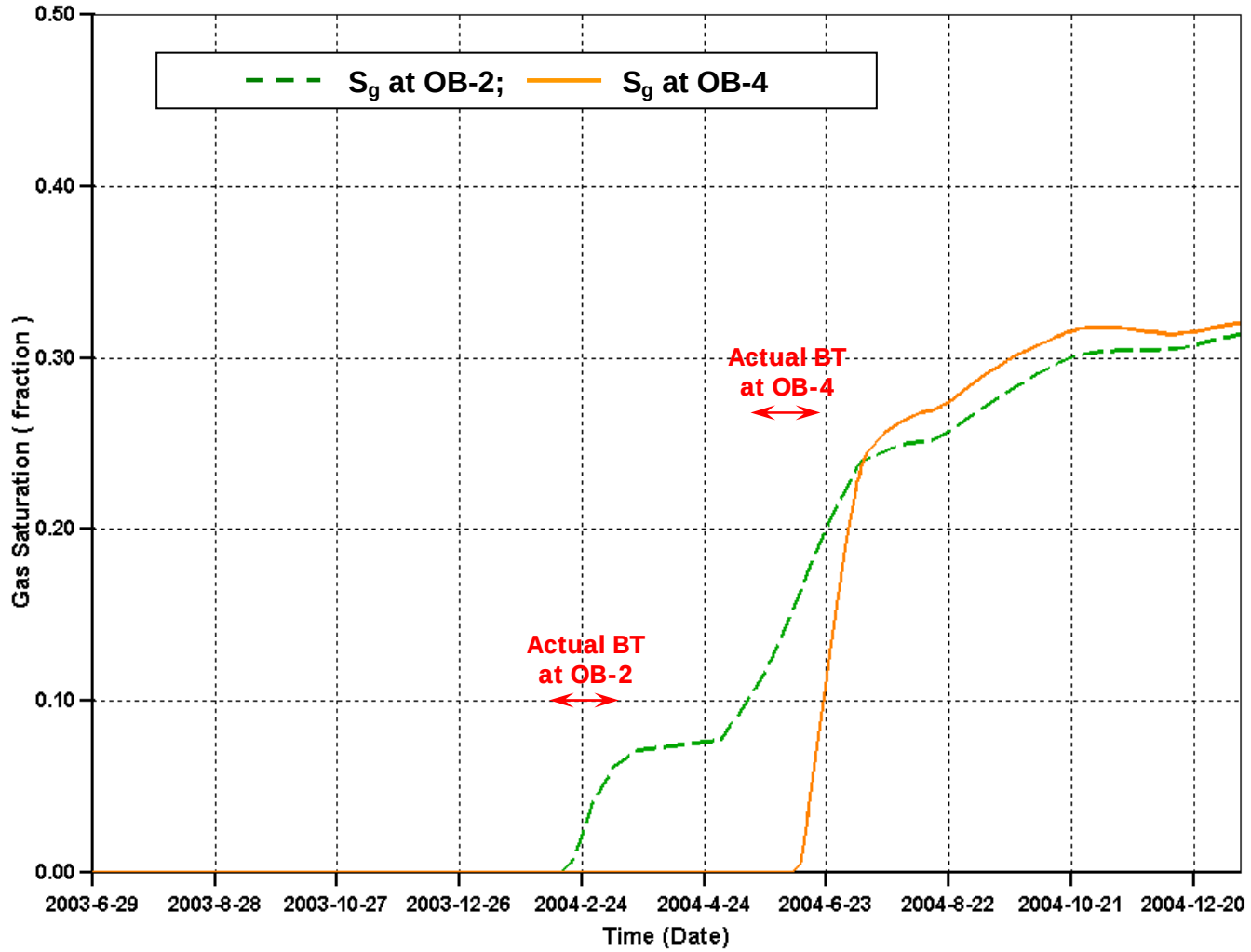
Areal Permeability Change (Zone-2 Average k)



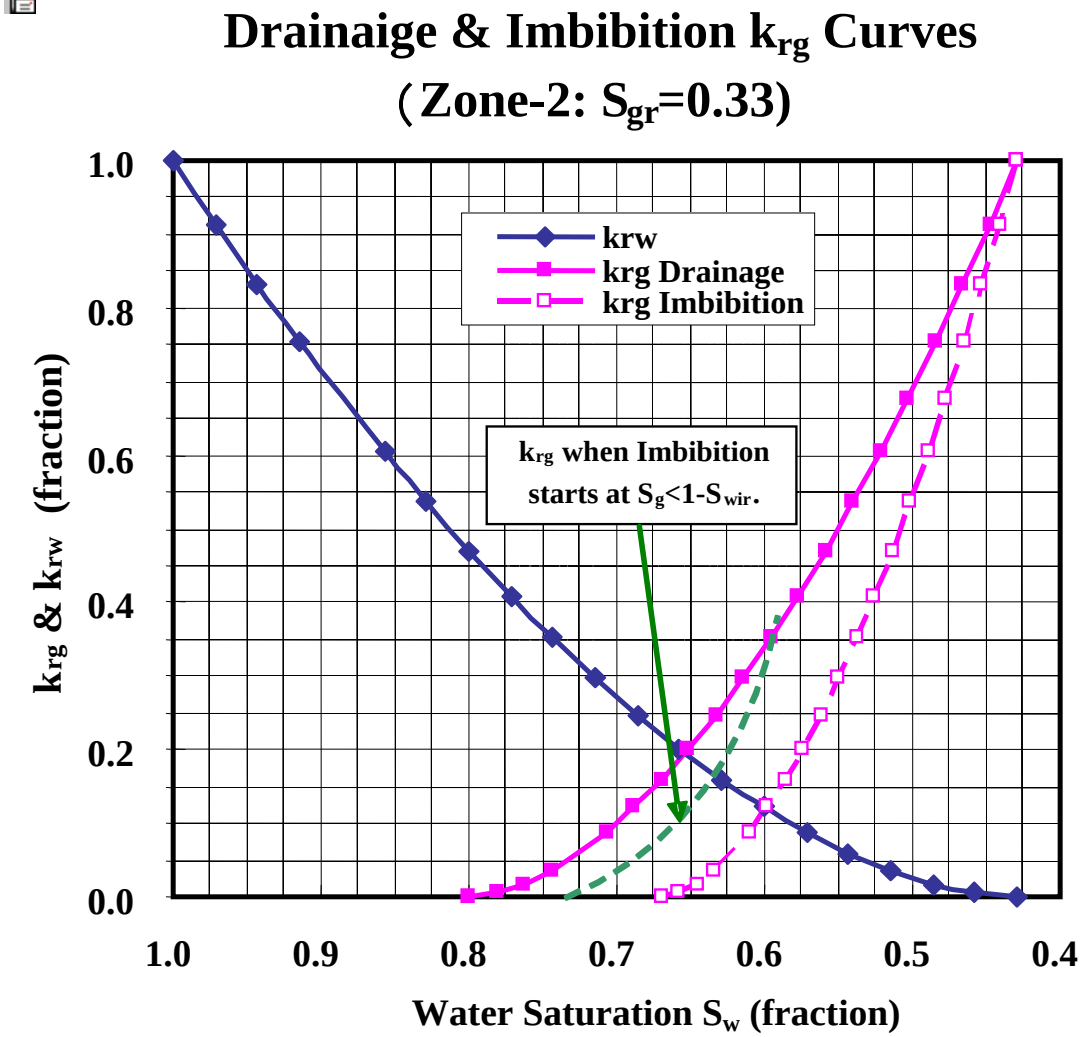
Matching of Injector IW-1 BHP



Matching of CO_2 Breakthrough at OB-2 & OB-4



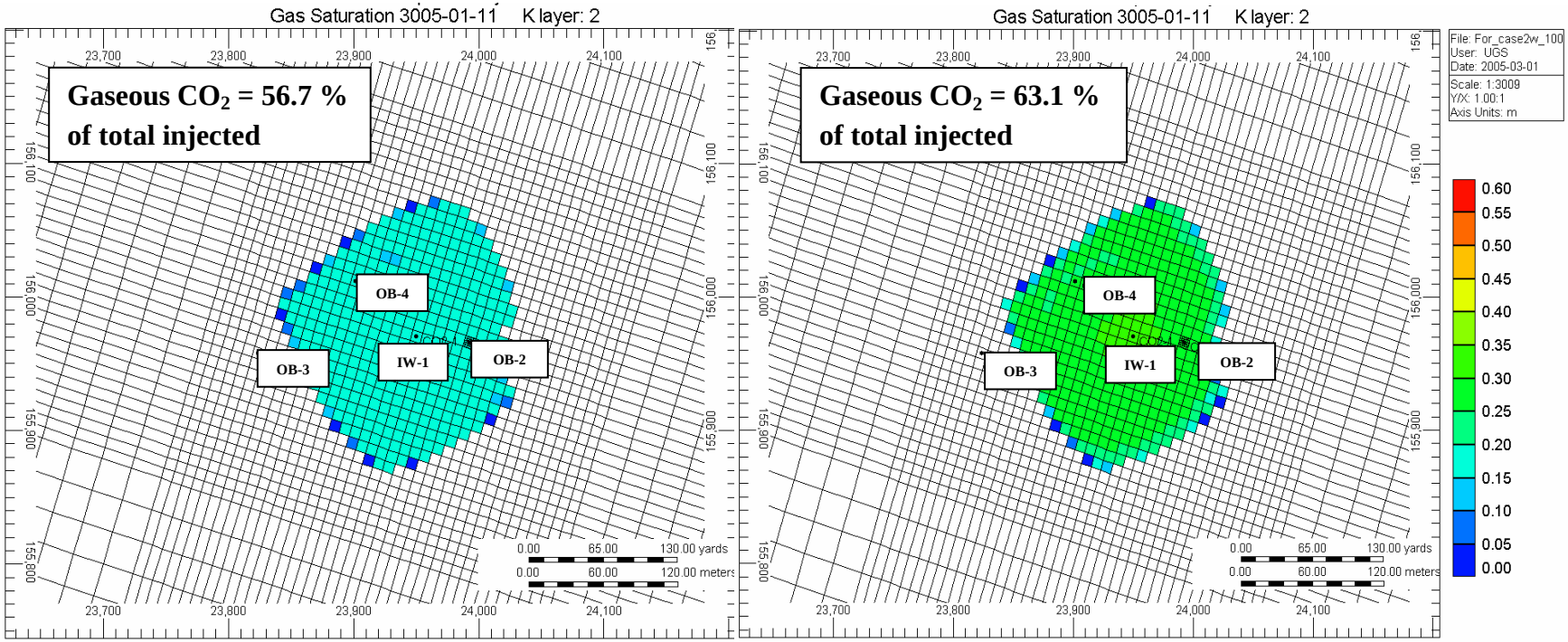
Relative Permeability Hysteresis



S_g Distribution in Zone-2 Middle after 1000 years

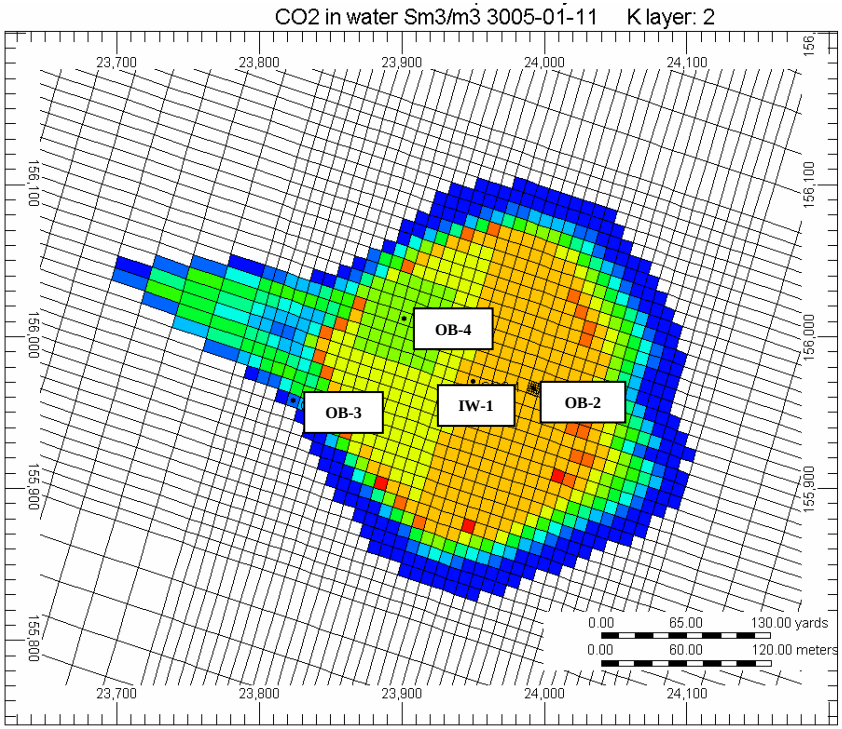
Case P-1: $S_{grmax}=S_{gc}=0.2$

Case P-2: $S_{grmax}=0.33$



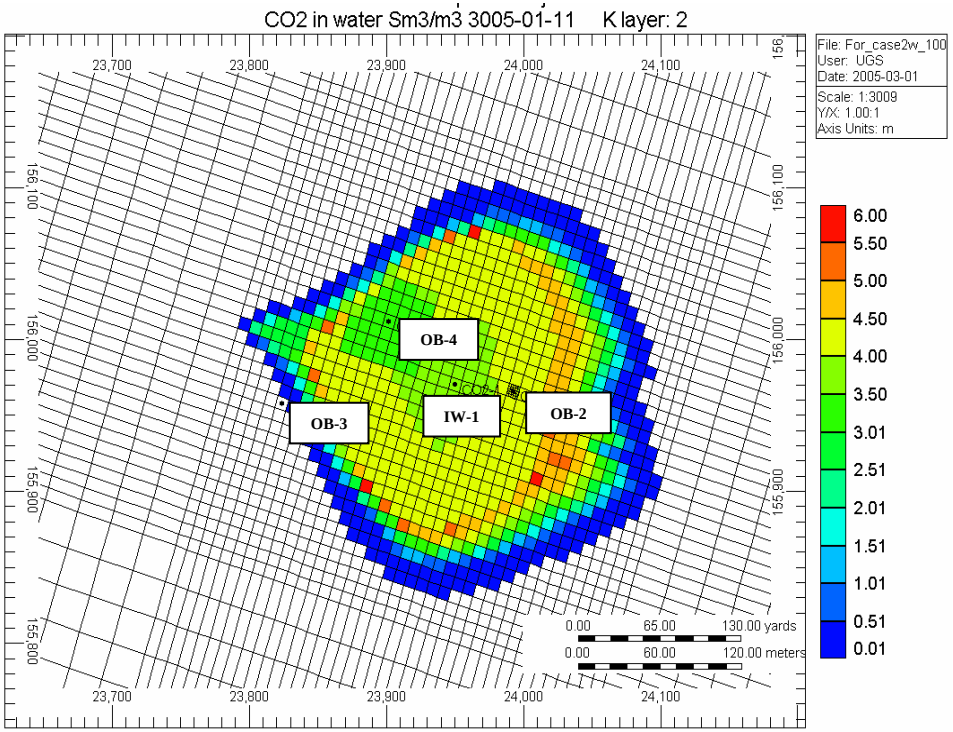
Distribution of Solution CO_2 in Zone-2 Middle after 1000 years

Case P-1: $S_{grmax}=S_{gc}=0.2$



CO_2 in Solution = 43.3 % of total injected

Case P-2: $S_{grmax}=0.33$



CO_2 in Solution = 36.9 % of total injected

Conclusions from Simulation Studies

- **Reasonable history match was attained with the following factors:**
  - **Areal heterogeneity of permeability**
  - **High critical gas saturation: S_{gc}=20 %**
  - **Significantly higher k_{rg} at S_{wir} than SCAL data**
  - **Large formation damage around OB-2**
- **Due to small k, gaseous CO_2 movement by buoyancy is limited and remains for long time (1000 years) essentially in the same area as that at the end of injection. Breakthrough to OB-3 is predicted not to occur in 1000 years.**
- **Some CO_2 is expected to move in the up-dip direction after injection ended but dissolves into formation water. Formation water containing dissolved CO_2 moves downward very slowly.**