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Monitoring Waste Heat Rejection to the Environment via Remote Sensing

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INTRODUCTION

Nuclear power plants typically use waste heat rejection systems such as cooling lakes and natural draft cooling towers. These systems are designed to reduce cooling water temperatures sufficiently to allow full power operation even during adverse meteorological conditions. After the power plant is operational, the performance of the cooling system is assessed. These assessments usually rely on measured temperatures of the cooling water after it has lost heat to the environment and is being pumped back into the power plant (cooling water inlet temperature). If the cooling system performance is not perceived to be optimal, the utility will collect additional data to determine why. This paper discusses the use of thermal imagery collected from aircraft and satellites combined with numerical simulation to better understand the dynamics and thermodynamics of nuclear power plant waste heat dissipation systems. The ANS meeting presentation will discuss analyses of several power plant cooling systems based on a combination of remote sensing data and hydrodynamic modeling.

REMOTE SENSING AND WASTE HEAT REJECTION TO THE ENVIRONMENT

The Department of Energy (DOE) funded the development and testing of a high-resolution demonstration satellite project called Multi-spectral Thermal Imager (MTI)[1,2,3]. MTI takes images in 15 wavebands in the visible, near, mid-wave and thermal infrared (IR) parts of the spectrum. MTI's resolution (pixel size) is 5 m in the visible and near IR wavebands and 20 m in the mid-wave and thermal IR bands. One of the objectives of the MTI Project was to determine what information a high-resolution multi-spectral satellite could provide about power plant heat dissipation systems. As a part of the DOE MTI team, the Savannah River National Laboratory (SRNL) collected ground truth data at several nuclear power plants, with the permission and support of those organizations. These 5 power plants used different types of waste heat dissipation systems:

- Pilgrim (ocean discharge)
- Comanche Peak (cooling lake)
- Turkey Point (cooling canals)
- H. B. Robinson (cooling lake with long discharge canal)
- Vogtle (natural draft cooling towers)

MTI imaged these cooling systems over a period of about two years at the end of which 10 to 33 high-quality images (clear skies) were available for analysis. During the two-year collection period, SRNL measured water temperatures in the aqueous systems and air temperature and humidity in the cooling tower, along with ambient meteorological data. SRNL used the ground truth data and an algorithm developed by Los Alamos National Laboratory (LANL) to calibrate the MTI images.

SRNL used hydrodynamic simulation codes[4, 5, 6] as tools to interpret the MTI imagery. SRNL primarily used imagery in the thermal wavebands because when calibrated those images provide a temperature map of the entire cooling system and its environment. Three-dimensional, time-dependent hydrodynamic simulations of these cooling systems allow the flow fields to be derived from the thermal imagery by exploiting the coupling of the thermodynamics and dynamics by the buoyancy force.

After completion of the MTI Project, SRNL continued research on power plant waste heat rejection systems. In one project, SRNL investigated mechanical draft cooling towers in normal (fans on) and off-normal (fans off but cooling water circulating) operating conditions. In another current project, SRNL is assessing the performance of a cooling lake in extremely cold conditions, when much of the lake is frozen and the ice and snow inhibit heat transfer to the atmosphere.

RESULTS

Figure 1 compares a calibrated MTI image of the Pilgrim thermal discharge plume to a hydrodynamic simulation when wind-driven currents carried the plume straight offshore. This flow pattern ensures that none of the heated discharge returns to the cooling water inlet. In contrast, Figure 2 compares MTI image and simulation when the current carried the thermal plume past the cooling water intake. This flow configuration does imply that there is potential for recirculation of the heated discharge and some degree of a "hydraulic short-circuit". However, the cooling water inlet is well below the surface, so unless there is significant vertical mixing of that part of the heated discharge that enters the cooling water inlet's protected embayment, little recirculation would be expected. Any significant short-circuiting would probably be limited to cases when flow convergence in the immediate vicinity of the cooling water inlet is strong enough to overcome the thermal stratification of the water in the embayment.

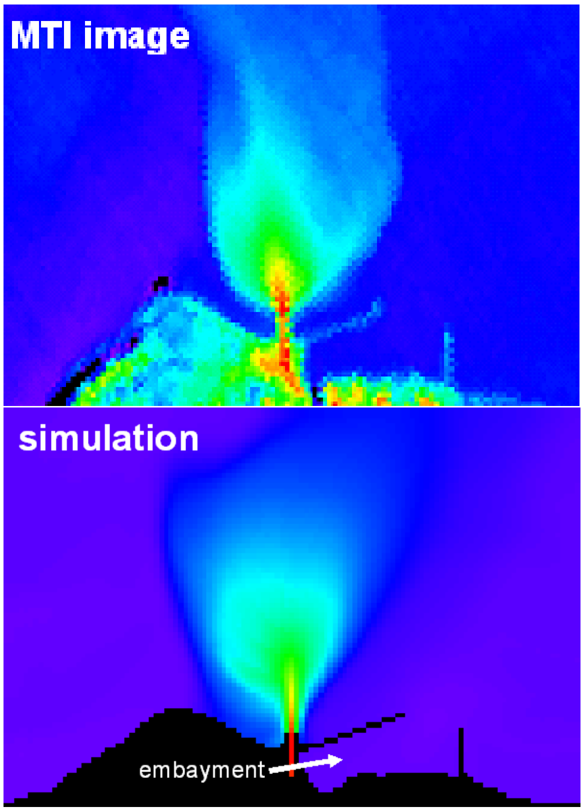

Fig. 1. MTI image and simulation of Pilgrim power plant thermal discharge when offshore winds carry thermal discharge away from cooling water inlet located within embayment.

High-resolution thermal images of power plant thermal discharges such as those shown in Figs. 1 and 2 can be collected from aircraft or by satellite. But it is not feasible to monitor a power plant cooling system by continuously collecting thermal imagery from either platform. However, Figs. 1 and 2 imply that numerical simulation can fill in the gaps between actual thermal images and enable the power plant personnel to determine the frequency that undesirable flow configurations occur.

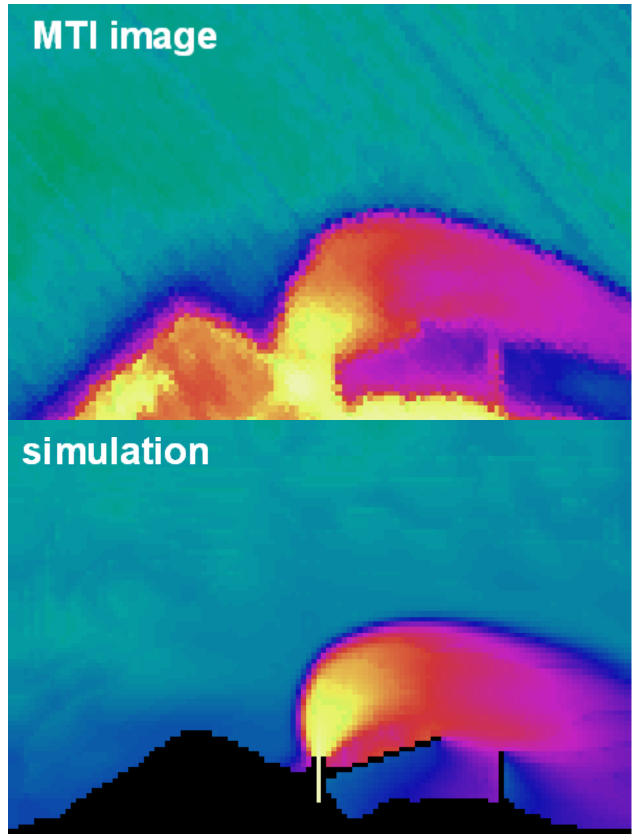

Fig. 2. MTI image and simulation of Pilgrim power plant thermal discharge when along-shore winds carry thermal discharge toward embayment and cooling water inlet.

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